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LHC WORKSHOP ON EXPERIMENTAL CONDITIONS AND BEAM-INDUCED DETECTOR BACKGROUNDS

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Workshop Website

http://indico.cern.ch/conferenceDisplay.py?confId=25768

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Abstract

This report contains the proceedings of the LHC Workshop on Experimental Conditions and Beam-Induced Detector Backgrounds held at CERN from 3 to 5 April 2008. The meeting was organized as a joint LHC machine and experiments workshop. The main aims were to review the experience gained at the Tevatron, HERA, and RHIC in these matters; to see what beam conditions can be expected for the LHC, and what actions can be taken on the machine side; and to see what data exchange is required between the LHC and the experiments in order to allow the machine to efficiently optimize the backgrounds and experimental conditions. The workshop was organized in three open sessions and followed by a closed summary session to agree on the main conclusions of the workshop and to specify the issues to be followed up. Whilst it was clear that not all speakers would be able to provide written versions of their presentations, the decision was made to produce formal proceedings, and all written contributions that were received are contained in these proceedings. These proceedings also include the summaries of the session discussions, the summaries of the sessions, and the conclusions from the executive session. All presentations are available from the workshop web page.

Contents

[1] A paper was not submitted to the proceedings. However, the slides presented are available in electronic form at http://indico.cern.ch/conferenceDisplay.py?confId=25768

Workshop Summary

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INTRODUCTION

The subject of this joint machine–experiments workshop was to prepare for making good experimental conditions and in particular for being able to keep any machine-induced background at tolerable levels. The LHC is a unique machine with its massive use of cryogenic magnets and unprecedented stored beam energy. Taking this new machine under control, including establishing optimal conditions for physics, will require much expertise and the ability to solve problems as they emerge. The aim of this workshop was to help in anticipating issues related to beam conditions and to elaborate a framework to attack such problems.

The workshop was divided into three half-day sessions. The first session was a review of the experience from other laboratories, namely from the Tevatron, RHIC, and HERA machines and experiments. The second session focused on general considerations and expectations for the LHC, including simulation studies for the generation of background particles and their transport to the experimental areas, and their main effects on the experiments. The foreseen infrastructure for beam interlocks and for exchanging data between the machine and the experiments was introduced. The third session was devoted to the strategy of the experiments for monitoring background, disentangling the various types, and exchanging background-related information with the machine. The workshop finished with a closed summary session with participation of the organizers, speakers, and representatives from LHC machine operations and experiments.

The format of these workshop proceedings is as follows. The outcome of the closed session is summarized below. A summary of each session and of the discussions is presented in separate contributions at the end of each session. In addition, individual contributions to the workshop by the speakers have been collected. For contributions where written versions were not received, the first slide of the presentation is shown. All presentations a re available from the workshop website [1].

SUMMARY OF DECISIONS

We summarize here the main points that emerged from the discussion in the closed session and that need to be followed up.

For future work, a clear need and a request emerged for rationalization of machine-induced background studies. The various contributors must agree first on a set of configurations and a systematic strategy. This implies

1. Definition of a few benchmark running scenarios, i.e., optics, bunch filling patterns, intensities, crossing schemes and ramped energy;
2. Definition of collimator settings for each running scenario;
3. IP-generated protons:
   a. Generation and transport of scattered protons from IPs to first restriction,
   b. Shower generation by those protons and transport of particles;
4. Production of vacuum profiles for the relevant sections based on best knowledge. Here, the only missing input identified is possible pressure bumps due to elements that warm up because of beam losses, for example. Future knowledge based on actual measurements with beams should be included at a later stage;
5. Production of collimator-induced halo particles, including quartic halo;
6. Production of distant beam-gas particles and transport to the experimental interface plane;
7. Simulation of backgrounds within the experiments.

Special requests specific to forward detectors should be expressed by the interested experiments. Effort from the machine side will be invested in the specific interests of each experiment in proportion to their needs, while taking into account the general physics priorities. Many LHC simulation results shown in this workshop were fostered by the Machine-Induced Background Working Group (MIBWG) organized by TSLEA, which has offered an excellent forum for background-related issues since February 2005 [2]. A natural evolution of this working group would be to include more players from the experiments and the LHC machine, to address the questions raised in this workshop, and to prepare for the first LHC collisions. This working group should be prepared to interpret background data as measured by the machine diagnostics and detectors in the experiments, perfect understanding of the data with the help of simulation tools, compare results between experiments, adjust definitions of the beam conditions signals, suggest improvements, etc., as soon as first protons circulate in the LHC. The actors of the MIBWG are strongly encouraged to continue their work in this new domain. It is also desirable that each experiment maintains (or strengthens) a small group of people to continuously address beam-induced background issues. It was also pointed out that an increased participation from the machine side would be very beneficial.

It was agreed that a few figure-of-merit signals (2 to 4) would be provided by each experiment for the operators to tune the beam conditions in an efficient way. The meaning of the signals should be clearly defined and the sensitivity to types of backgrounds (e.g., beam 1 or beam 2, if applicable) clearly stated. The experiments and machine people should agree on a common scale definition for these signals, with a universal meaning. The implementation of this scale and the algorithmic of the signals involved should be discussed among the experiments to ensure that a similar interpretation is indeed implemented by each experiment. For instance, will the signals be approximately linear with the current-normalized rates? Or is a logarithmic scale more appropriate?

In addition to these few figure-of-merit signals, each experiment will provide a (possibly interactive) summary page about the status of their experiment that machine operators will use when discussions specific to that experiment are going on in the CERN Control Centre (CCC). This should also be discussed among the experiments in order to promote a minimum coherence among the experiments. For instance, it was suggested to include a pictorial view of the experiment around which the measured signals are displayed.

It was agreed that, in order not to create unnecessary background in the experiments (especially ALICE), the tertiary collimators should be put as far out as possible, such that the triplet magnets remain in the their shadow. This depends on the beam configuration (energy, optics, ß*).

It was agreed that the collimation group would provide AT-VAC with a list of elements that are expected to warm up significantly due to beam losses (which can change the local vacuum conditions due to outgassing).

ACKNOWLEDGEMENTS

The organizing committee wishes to thank all the speakers once again for their high quality presentations and written contributions. We express our gratitude to the scientific secretaries and session conveners for their help in collecting and writing down the main points of the discussions. We are particularly grateful to Lauriane Bueno and Marie Colin who very efficiently helped to organize this workshop. We thank as well the CERN Director-General, Robert Aymar, for his welcome speech, and the CERN management in general (AB and PH Departments) for supporting this workshop.

REFERENCES

[1] Workshop web site:
http://indico.cern.ch/conferenceDisplay.py?confId=25768

[2] Background working group and Session V of the LHC Chamonix Workshop 2006.

Beam Induced Backgrounds: CDF Experience

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Abstract

We summarize the experiences of the Collider Detector at Fermilab (CDF) experiment in the presence of backgrounds originating from the counter circulating beams in the Fermilab Tevatron. These backgrounds are measured and their sources identified. Finally, we outline the strategies employed to reduce the effects of these backgrounds on the experiment.

EFFECTS OF ACCELERATOR BACKGROUNDS AT CDF

Since the beginning of the Tevatron run II, CDF has experienced a number of operational issues related to accelerator induced backgrounds. Among these issues are: chronic radiation damage to detectors, which we define as damage induced by long term exposure to radiation, single event effects (SEE) in electronics and signals in detectors which mimic expected physics signatures. Each of these issues will be addressed in turn in the following paragraphs.

Chronic radiation damage, particularly to the innermost silicon detectors is expected at CDF. While the damage mechanisms are well known, the lifetime of detectors typically can only be estimated from either from simulations with large uncertainties (typically 50% to 100% uncertainty) or from projections of measured damage profiles. In these lifetime estimate, one of the largest uncertainties involves details of the radiation environment near the detectors. Measurements of the observed radiation damage to the CDF silicon detector have been reported elsewhere [1] and are beyond the scope of this paper. However, the observed radiation damage is as expected from projections based on radiation field measurements summarized in the following sections [2].

In addition to chronic radiation damage, sensitive electronics may exhibit a change of state (bit flip, transistor state change, etc.) due to the passage of a single particle. These phenomena, collectively, are known as single event effects (SEE) in the literature. How these processes affect the operation of a complex detector range from reasonably benign such as single bit errors in the data, through annoying occurrences where electronics in the readout chain freezes and needs to be reset, to catastrophic where the electronics fails completely and must be replaced. As part of the run II upgrades, much of the CDF detector infrastructure and readout electronics is now located on the detector. Figure 1 shows a photograph of the face of the CDF detector showing locations of sensitive electronics.

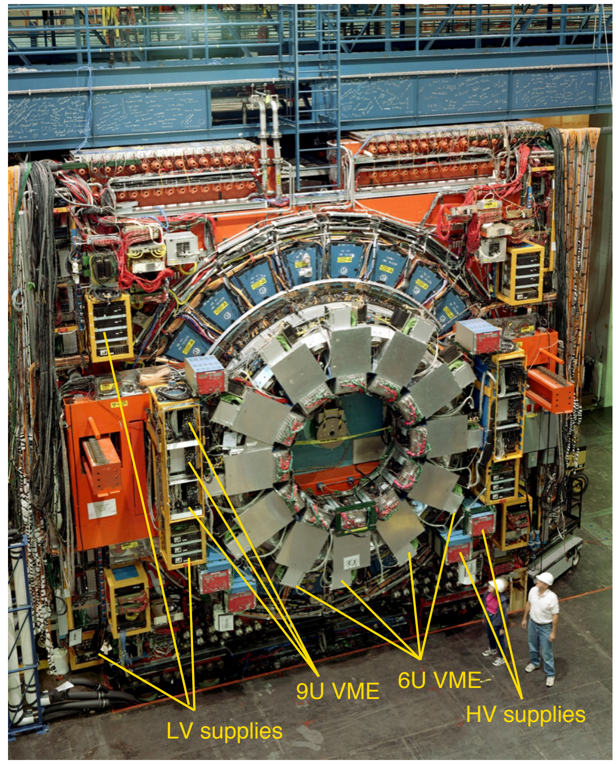

Figure 1: Photograph of the CDF detector. Some of the electronics found to be sensitive to radiation are indicated. For reference, protons are incident into the page.

Since 2001, CDF has observed multiple types of SEE in sensitive electronics. Single event burnout (SEB), a catastrophic failure of a power MOSFET was observed in high power (5kW) low voltage, switching power supplies during commissioning phase of the experiment. Subsequently, single event upsets (SEU) and single event latch-up (SEL) were observed in commercial high voltage, switching power supplies and in custom detector readout electronics.

Typical SEB rates in these power supplies were approximately three failures per week. Epidemiology of the failures indicated more on the incoming proton side with nearly all failures occurring in locations where the power supply had an uninterrupted (line-of-site) view of the final focus quadrupole triplet. The SEU and SEL events are in regions where the electronics have a line-of-site view of the final focus magnets or near the beam line, in regions where radiation is expected to be more intense. Additional details regarding the above SEE may be found in references [3, 4].

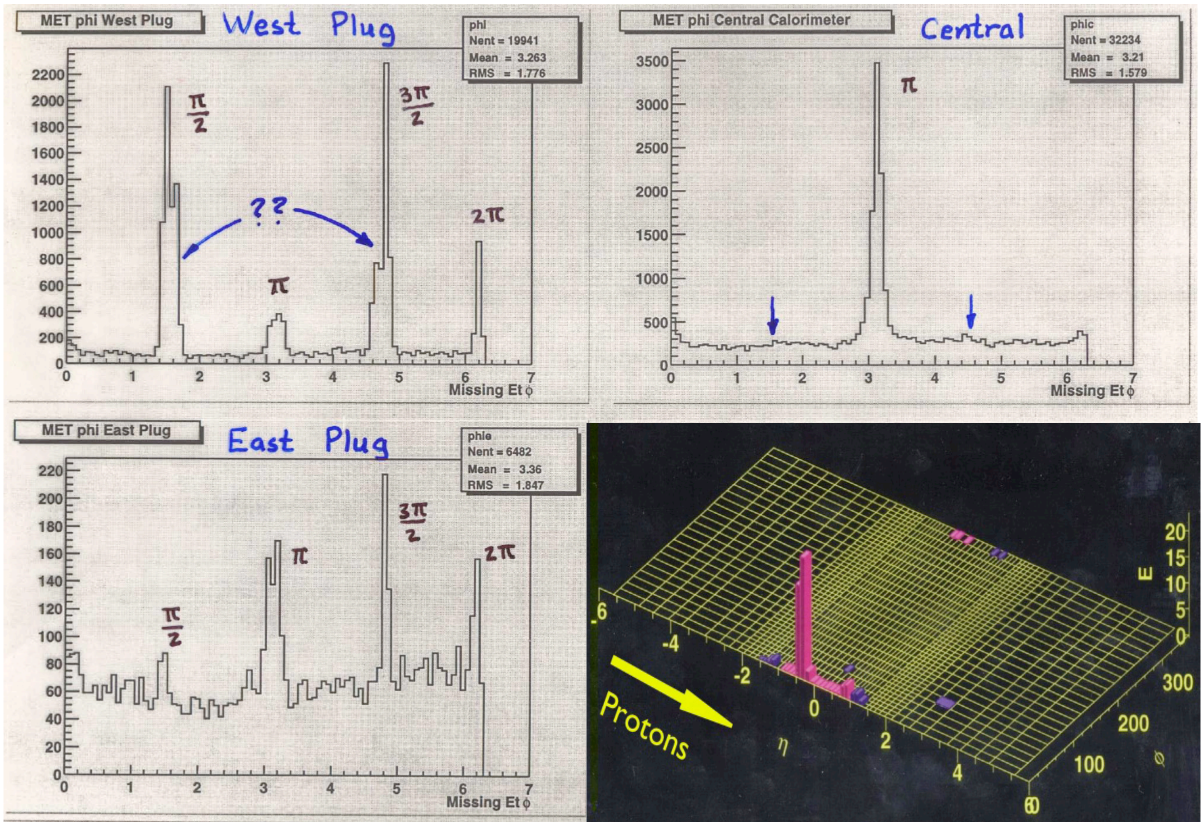

Figure 2: Missing transverse energy (MET)ϕ distributions for events with at least 25 GeV of MET by detector region. Distributions are shown for the forward calorimeters on the incoming proton (upper left) and incoming antiproton (lower left) and central calorimeter (upper right). The direction $\phi = 0$ corresponds to the plane of the accelerator pointing radially outward from the center of the accelerator, the z axis is defined by the proton direction. In the lower right is an event display showing energy deposits in the electromagnetic calorimeters (pink or light color) and hadronic calorimeters (blue or dark color) as a function of $\eta = -\log\left(\tan\frac{\theta}{2}\right)$ and ϕ for a beam halo muon.

In addition to the operational issues outlined in the above paragraphs, beam related particles are observed to produce signals in the CDF calorimeters which mimic certain kinds of physics signals requiring energy imbalance in the detector (missing transverse energy or MET). Because MET is "missing" or unbalanced energy, the energy deposited in the calorimeter is opposite the direction of MET. Figure 2 shows the ϕ distribution of the MET for triggers with MET larger than 25 GeV in the two forward calorimeters and the central calorimeters. Peaks in the MET distributions occur at multiples of $\pi/2$ in the calorimeters.

The sources of the peaking background in the MET ϕ distributions are different for the central and forward (plug) calorimeters. In the central calorimeters, the source was tracked down to beam particles outside the core of the beam hitting an aperture restriction, the CDF Roman pots, approximately 60 m upstream (on the incoming proton side) and producing muons. The relative size of the peaks at $\pi/2$ and $3\pi/2$ between the two forward calorimeters is approximately the same ratio as the incoming proton and antiproton beam currents (losses). The peaks are consistent with beam losses hitting the far forward (miniplug) calorimeters. The resulting secondaries then pass through a 5 cm crack in the shielding surrounding the miniplug calorimeters and shower in the plug calorimeters. Detailed information about these backgrounds is found in ref [5, 6].

BEAM LOSSES AND HALO

All the effects outlined above have been traced to particles lost from one or both beams. Identifying sources of those losses and the subsequent radiation requires detailed knowledge of both the accelerator and the experiment. While a detailed discussion of the Tevatron and CDF are beyond scope of this paper, Relevant components or geometry are discussed when appropriate. Table 1 summarizes some of the basic accelerator parameters for the Tevatron collider which are relevant for subsequent discussions.

Accelerator performance and quantifying the beam losses mentioned earlier is accomplished by making measurements near the CDF detector. Luminosity is measured at CDF using a gaseous Cherenkov counter system located on the CDF detector. Measurements of beam losses and beam halo are made using sets gated scintillation counters

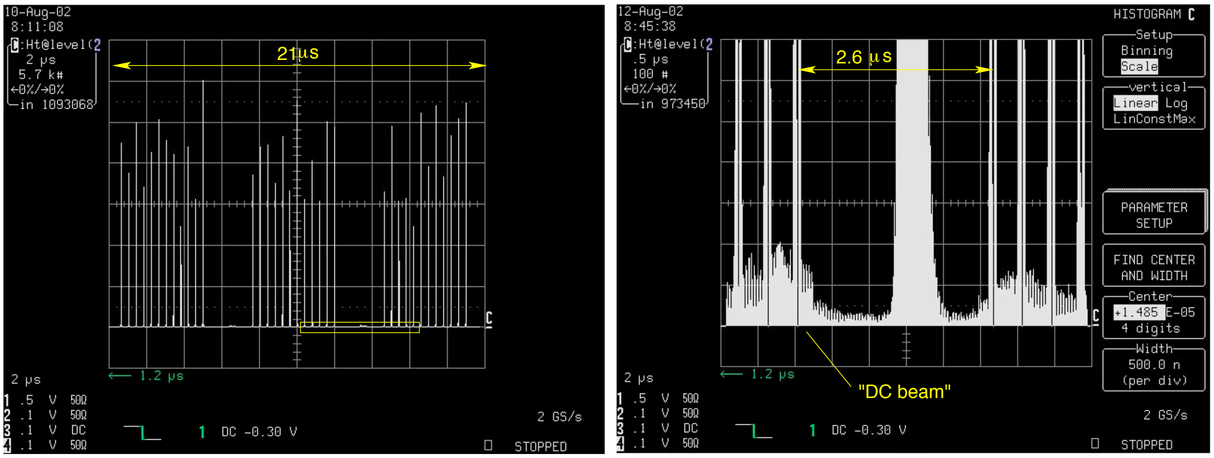

Figure 3: Distribution of beam losses as a function of time during a revolution. The left figure expands the vertical and horizontal scales to view the abort gap. The comb-like structures is due to the accelerator RF.

Table 1: Summary of Tevatron accelerator parameters.

Parameter	Value	Units
interaction regions	2	
beam energy	980	GeV
# bunches[1]	36	
bunch length	1-2	ns
bunch spacing	396	ns
abort gap[2]	2.6	μs
protons/bunch	30×10^{10}	particles
pbars/bunch	8×10^{10}	particles
luminosity	2.8×10^{32}	$\mathrm{cm}^{-2}\mathrm{s}^{-1}$
RF frequency	53	MHz

[1] 3 trains of 12 bunches
[2] 3 abort gaps

to provide some discrimination between protons and antiprotons. Details of the luminosity, beam loss and beam halo systems may be found elsewhere [7, 8, 9]. For the loss and halo measurements, discriminated counter signals are in coincidence with the time beam particles pass the plane of the counter on their way into CDF. Beam losses are measured using coincidences with a bunch signal and measured within a few centimeters of the beam. Halo is measured using the same technique, but with larger counters approximately a half meter from the beam. All these monitors provide real time feedback on beam conditions at CDF to the accelerator control room. While the beam loss and halo counters typically measure rates integrated over one second, because the counter signals are extremely fast, one may use these devices to understand beam structure. An example of such a measurement is shown in Figure 3. The same Figure also shows losses measured in the abort gaps and between bunches: "DC beam" or un-captured beam."

BACKGROUND RADIATION

To understand radiation effects in various CDF instruments, a number of measurements were made of the spatial distribution of ionizing radiation and low energy neutrons using thermoluminescent dosimeters(TLDs). Details of the individual measurements taken inside the CDF tracking volume are reported elsewhere [10, 11, 12, 13, 14]. Similar measurements were made external to the CDF detector in the collision hall [15].

In the CDF tracking volume measurements were made under differing beam conditions. The left side of Figure 4 shows the ionizing radiation measurements for three periods under differing beam conditions. In the Figure, protons are incident from the left and antiprotons are incident from the right. Assuming that the measurements represent a linear superpositon of contributions from beam losses and proton-antiproton collisions, we can separate out the effects from the two sources. The right side of Figure 4 shows the spatial distribution of ionizing radiation in the CDF tracking volume due to collisions and proton losses. From these data the radiation dose inside the CDF tracking volume may be estimated for any combination of integrated luminosity and integrated proton losses and is publically available [16].

Multiple measurements of the radiation field external to the CDF detector do not include periods which were dominated by beam losses. Consequently, a separation of components from losses and collisions was not made. However, measurements were made for different configurations of the collision hall. Results of these measurements are presented later in this paper.

In addition to TLD measurements, a series of experiments using telescopes of scintillation counters were also performed to isolate sources of charged particles. Details of those measurements are described elsewhere [17, 18]. From the counter experiments, we learn that the final focus triplet forms a line source of charged particles. These parti-

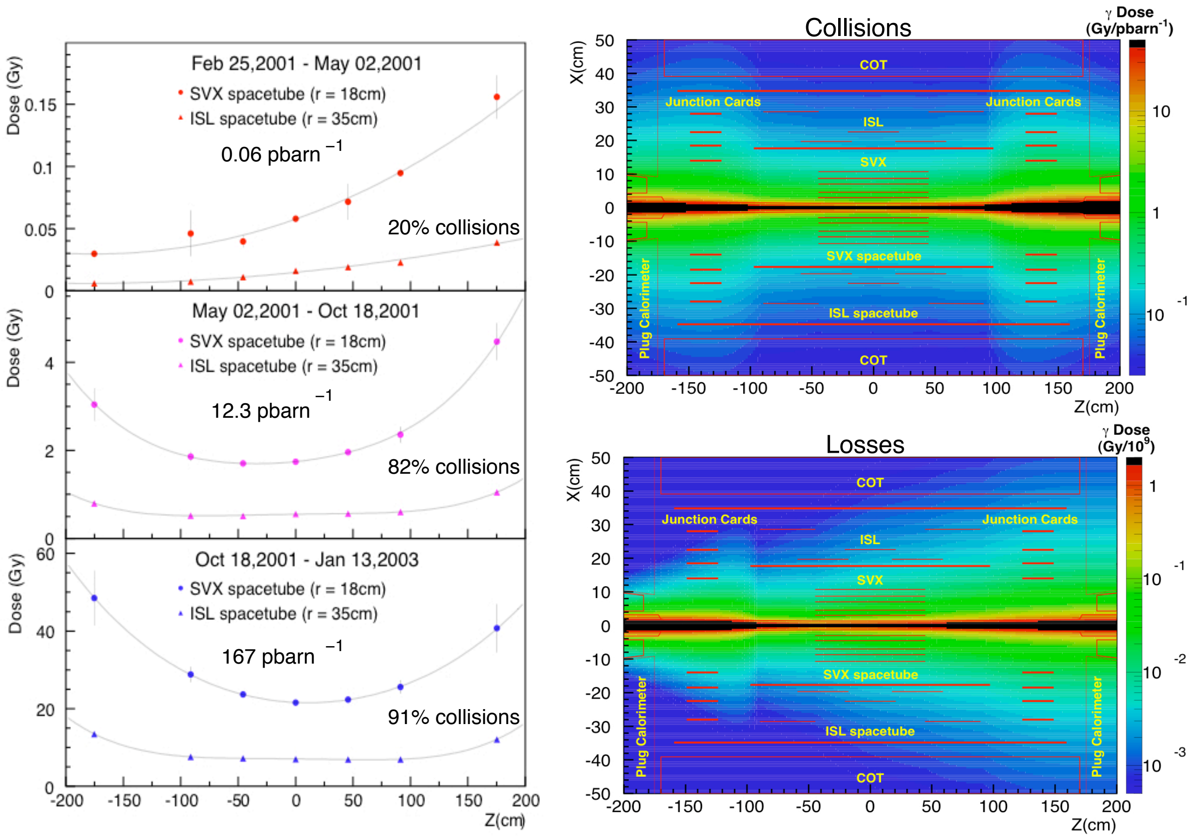

Figure 4: Ionizing radiation field in the CDF tracking volume. The left figures represent separate measurements using thermal luminescent dosimeters for three exposure periods. The right plots show the radiation field maps for collisions(upper right) and losses (lower right) based on the measurements. In all plots, protons are incident from the left, antiprotons from the right.

cles originating from beam protons and antiprotons hitting the walls of the vacuum pipe inside the quadrupole magnets.

BACKGROUND REDUCTION

The previous sections summarize the effects of accelerator induced backgrounds at CDF. The effects of these backgrounds are addressed in a collaborative effort between CDF and accelerator personnel. This effort has resulted in a number of steps taken to minimize the imact of beam induced backgrounds including:

- Reduction of beam losses at CDF by improving the beam quality in the Tevatron.
- Installation of additional shielding at CDF to reduce backgrounds.
- Modification of operating conditions to eliminate catastrophic failures.
- Modification of operational procedures to reduce the amount of down time for resetting electronics.
- Development of analysis selection criteria to remove beam background events.

The following paragraphs will briefly describe each of the steps noted above.

Reduction in beam losses near CDF represent the single largest improvement to accelerator backgrounds. Early studies found that vacuum in warm sections of the Tevatron was higher than expected [19, 20, 21]. Improvements to the vacuum quality,commissioning of a multiple stage collimation system [22] and routine re-alignment of magnets have all contributed to a reduction of beam losses at CDF [23]. Typical proton losses in 2004 were 2–15 kHz. By 2008, proton losses have been reduced to the range of 0.05–15 kHz[3]. An improvement of nearly two orders of magnitude.

In addition to reducing particles lost from the accelerator, additional shielding was added surrounding part of the final focus quadrupole magnets. The effectiveness of this shielding was subsequently evaluated using TLDs as described previously. Figure 5 shows the ratio of radiation dose rates before/after installation of the shielding on the incoming proton side of the CDF collision hall. The reduction near sensitive electronics is observed to be approximatley 25%, consistent with reduction of solid angle sub-

[3] Loss rates for a typical store start out at the higher value, but quickly reduce to a steady state value near the lower value after approximately 2 hours.

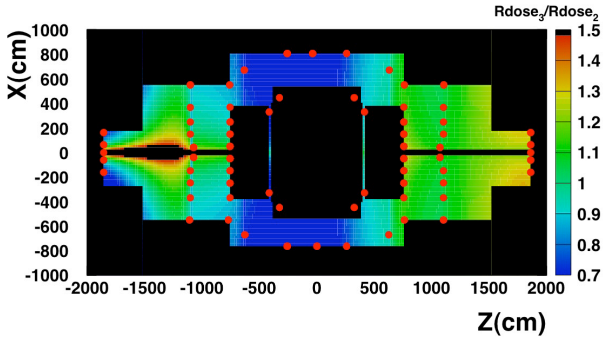

Figure 5: Ratio of ionizing radiation dose rates before/after installation of shielding surrounding the incoming proton focusing quadrupole magnets. Protons are incident from the left. The red spots indicate locations of TLDs used in the measurements. Sensitive electronics are located in the "central corners" of the collision hall. near $z = \pm 700$ cm.

tented by the quadrupole magnets at the electronics. Details of the shielding and evaluation may be found in references [15, 18].

The catestrophic SEB events observed earlier have been eliminated by changing the operating point of the sensitive MOSFET. However, despite the overall reduction in beam losses, SEU and SEL events continue to occur in CDF. These effects were responsible for 16% of the non-accelerator related downtime for CDF. Operating efficiency was improved by modifying recovery procedures from these faults. Additional details of the effects and recovery procedures are given in references [3, 4].

Physics backgrounds were reduced by as much as 40% in some triggers by the reducing beam losses by approximately a factor of 10. However, analysis selection using calorimeter timing and event topology has further reduced these backgrounds to negligible levels and has resulted in several physics results [24, 25].

SUMMARY

The Tevatron beam has been shown to be an important source of backgrounds for CDF. Particles escaping the beam contribute to degradation in detector performance due to radiation damage, compromise detector reliability from SEE and contribute to backgrounds to physics processes. Many sources of these backgrounds have been identified. Improved the quality of the Tevatron beam, addied shielding around background sources, improved operational procedures and event selection have all contributed to reduction of the above effects.. Close collaboration between experiment and accelerator physicists was instrumental in this effort.

REFERENCES

[1] I.Redondo-Fernandez, *Proceedings:ICATPP Conference* Villa Olmo, Como, Italy 8–12 October 2007. A.Mitra, *Proceedings: IEEE/NSS-MIC,* San Diego, California, 29 October – 4 November 2006.

[2] S.Worm, *Proceedings: Vertex03 Conference,* Lake Windermere, Cumbria, United Kingdom, 14–19 September 2003.

[3] R.J.Tesarek, *et al., Proceedings: IEEE/NSS-MIC* Wyndham, El conquistador Resort, Fajardo, Puerto Rico 23–29 October 2005.

[4] R.J.Tesarek, *et al., CDF internal note:* **CDF5903** 6 May 2002.

[5] R.J.Tesarek, *et al.,* Presentation, CDF Joint Physics meeting, Batavia, Illinois, 3 May 2002.

[6] M.Albrow, *et al., CDF internal note:* **CDF5926** 16 April 2002.

[7] D.Acosta, *et al.,* Nucl. Instrum. and Meth. **A494**(2002)57–62.

[8] A.Bhatti, *et al., CDF internal note:* **CDF5247** 10 October 2000.

[9] M.Karagoz-Unel, R.J.Tesarek, Nucl. Instrum. and Meth. **A506** (2003) 7–19.

[10] R.J. Tesarek, *et al., Proceedings: IEEE/NSS-MIC,* Portland, Oregon, 19–25 October 2003.

[11] R.J.Tesarek, *et al.,* Nucl. Instrum. and Meth. **A414** (2003) 188–193.

[12] S.Dauria, *et al.,* Nucl. Instrum. and Meth. **A413** (2003) 89–93.

[13] K. Kordas, *et al., Proceedings: IEEE/NSS-MIC,* Norfolk, Virginia, 10–16 November 2002.

[14] R.J.Tesarek, *et al., CDF internal note:* **CDF5723,** 31 August 2001.

[15] K.Kordas, *et al., Proceedings: IEEE/NSS-MIC,* Portland, Oregon, 19–25 October 2003.

[16] `http://ncdf67.fnal.gov/~tesarek/radiation/iondose.html`

[17] R.J. Tesarek, *CDF internal note:* **CDF5973**, 23 March 2002.

[18] M. Lindgren, *et al., CDF internal note:* **CDF5960**, 2 June 2002.

[19] R.Moore, V.Shiltsev *Beams Document:* **Beams-doc-240-v1** May-June 2002.

[20] A.Drozhdin, *et al., Proceedings: Particle Accelerator Conference (PAC03),* Portland, Oregon, 12–16 May 2003.

[21] A.Drozhdin,*et al., Fermilab Technical Memo:* **FERMILAB-FN-0734**, April 2003.

[22] D.A.Still, *Talk given to CERN LHC Collimator Working Group*, *Beams Document:* **Beams-doc-1792-v1**, 15 April, 2005.

[23] D.A.Still, G.Annala, Fermi National Accelerator Laboratory, Batavia, IL, *Private Communication.*

[24] A.Abulencia, *et al.,* (CDF Collaboration) Phys. Rev. Lett. **99**, (2007) 121801.

[25] D.Acosta, *et al.,* (CDF Collaboration) Phys. Rev. Lett. **92** (2004) 121802.

[26] Many references are available online at:

`http://ncdf67.fnal.gov/~tesarek/`
`http://ncdf67.fnal.gov/~tesarek/radiation`

HERA: Sources & Cures of Background - Machine Perspective

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Abstract

This report gives an overview about the background sources, measurements and optimisation procedures in the HERA storage ring. After a short introduction into the basic parameters of the machine, the tools are presented that were used to guarantee the beam quality and minimise the particle losses during luminosity runs. Different typical background problems are presented, including their signature and their influence on the data taking of the high energy physics detectors.

THE HERA STORAGE RING

The HERA machine [1] was a double ring collider for the collision of protons and electrons/positrons at DESY (Deutsches Elektronen Synchrotron) in Hamburg. The 920 GeV protons and the 27.5 GeV leptons were accelerated and stored in two independent rings and brought into collision at the two interaction points “South & North” where the high energy detectors ZEUS and H1 were installed.

Figure 1: The HERA storage ring in Hamburg

According to the nature of the two particle beams in HERA the background characteristics were twofold: Synchrotron light and electromagnetic showers on one side, and hadronic showers related to the proton beam on the other. While the synchrotron light related topics are covered in a dedicated contribution to this workshop [2] the purpose of this document is to concentrate on the details of the HERA proton beam and the related hadronic backgrounds. Detailed analysis of the HERA background situation and its improvement over the past years, as seen by the experiments, can be found in [3,4].

In HERA typical beam intensities for the protons of I_p=100mA and for the electrons of I_e=45mA have been achieved, distributed in routine luminosity runs over 180 bunches.

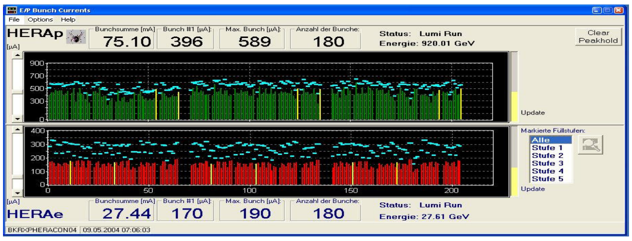

Figure 2: 180 bunches form the HERA standard bunch train for luminosity runs

The resulting single proton bunch population $N_p=7*10^{10}$ therefore differs not much from the foreseen design value for the LHC ($1*10^{11}$). Figure 2 shows the 180 bunches of a standard HERA fill during luminosity operation (upper part for the protons, lower for the lepton beam). As can be deduced from the plot, the intensity distribution of the bunches was constant within approximately 10%. The main parameters of the HERA machine are listed in the table below [5].

	protons	*electrons*
β_x	*2.45m*	*0.6 m*
β_y	*0.18m*	*0.26m*
ε_x	*5.1 nm*	*21nm*
ε_y	*"*	*3.5nm*
σ_x	*112 μm*	*112μm*
σ_y	*30 μm*	*30 μm*
$\Delta\nu_x$	*1.1*10 -3*	*3.0*10 -2*
$\Delta\nu_y$	*3.1*10 -4*	*4.9*10 -2*

Table 1: HERA optical parameters

The two beams, differing by the nature of the particles in emittance and coupling, were matched in a dedicated way to obtain the same beam size at the interaction points. The beta-function and the tune shift parameter Δν refer to the IP North or South.

Machine Aperture:

For luminosity operation an overall aperture in the proton machine of at least 12 sigma of a transverse Gaussian beam distribution has been considered as sufficient. In other words the beta function has been matched in any part of the storage ring according to that requirement. In the super conducting sections of the machine beam losses are much more critical than in the straight sections where conventional magnets are installed. Therefore an aperture of at least 20 σ was guaranteed in the sc. arc. However, unlike to the LHC definition, no additional safety margins has been added for dispersion trajectories and orbit distortions. The luminosity optics of HERA proton ring is plotted in the figure 3.

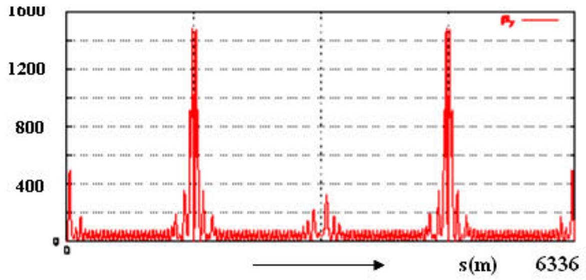

Figure 3: Beta function of the HERA proton ring

According to the mini beta insertions, the highest values of the beta function occur close to the interaction points South and North, where the detectors of the collider experiments are located. At these locations (i.e. inside the mini beta quadrupoles) the free aperture is limited to 12 sigma and - with the exception of the collimators that are put at approximately 7...8 sigma - these regions defined the smallest aperture in the ring. This situation is again reflected in the two plots below: The 12 sigma beam profile for standard luminosity operation is plotted in the cold section of the arc and compared to the free aperture that is obtained inside the horizontal mini beta quadrupole. To enlarge the free space for the beam a special shape of the vacuum chamber has been chosen. The figures show 12 σ of a 920 GeV proton beam inside the cold section (left) and inside the shamrock type vacuum chamber of the warm mini beta quadrupole magnets.

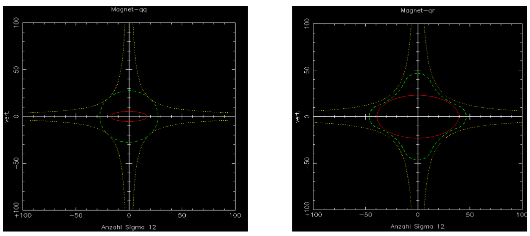

Figure 4: Beam size and aperture in the cold section (left) and in the conventional mini beta quadrupole lens (right). The aperture limitation by design corresponds to 12 σ.

Communication between experiments and machine:
In each big collaboration there is a fundamental problem of how to define and establish the communication flow.

Figure 5: Some members of the ZEUS collaboration

At HERA four high energy detectors had been installed and the number of collaborators easily exceeded 400 per experiment. Very soon therefore it turned out that a well defined information structure and communication flow was needed to avoid misunderstandings and guarantee that the relevant running parameters are known by those to whom they concern. We defined one contact person per experiment and in addition a spokes person that coordinated the wishes and needs of the four different experiments among each other. The basic running conditions were discussed in a weekly meeting. For special problems e.g. commissioning of new detector parts or background tuning a number of experts from the experiment was joining the machine studies in the control room and it turned out to be a very efficient procedure. Direct communication with the experts from the detector and the ability to run specific detector signals in the control room to tune the storage ring turned out to be an ideal solution.

BEAM QUALITY

Proton Injection
It can be considered as a part of the special character of the super conducting HERA ring, that its basic parameters - at low fields - were neither very stable nor reproducible [6]. Instead, they depended on the history of the magnets, i.e. the time and niveau of the preceding run and the way the magnets had been cycled before. Due to eddy / persistent currents [7] the magnetic field at injection was differing from run to run and drifting at the injection plateau. Accordingly a high quality beam in HERA could only be obtained if these fields and the corresponding beam parameters had been measured and corrected properly.
Fig. 6 shows an example of an injection of a pilot bunch train that was routinely used to set up the machine before a complete luminosity fill had been injected. The figure on the left part shows the longitudinal injection oscillations that had typically been observed at the first injection after a magnet cycle. Dipole field mismatches of up to 1 Gauß had been obtained in extreme situations; typical values were measured to be around +/- 0.5 Gauß.
Fitting these longitudinal oscillations and compensating the injection field accordingly led to the situation shown in the right part of the figure, where essentially no further oscillations are observed.

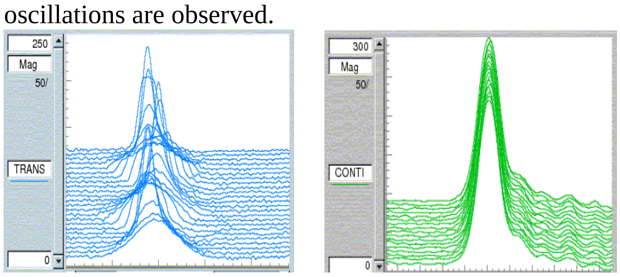

Figure 6: Longitudinal beam oscillations at injection; before and after correction

In a similar way the 10 bunch pilot train was used to measure and optimise the injection energy and phase, the tunes, the coupling and the transverse injection oscillations, the latter with respect to the closed orbit. The key issue of this procedure was to obtain and sustain routinely a high quality beam, i.e. a transverse beam emittance that corresponded to the design values of 20 π mm mrad (normalised and referring to 2 sigma).

Therefore the emittance in both transverse planes had been measured and checked before the start of each acceleration ramp. A typical example is shown in the next figure: The emittance of all 180 bunches is plotted after injection. Values between 15 and 20 π mm mrad were considered as acceptable and the fluctuation between bunches was usually small.

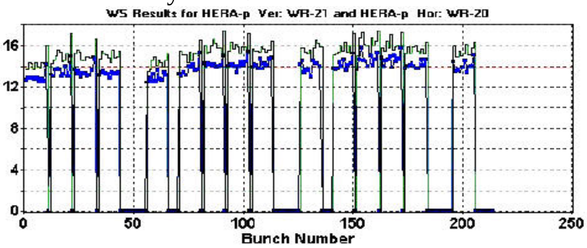

Figure 7: Beam emittance of the 180 HERA proton bunches, measured after injection to check the beam quality before starting the ramp

Proton Ramp:

Problems affecting the beam quality during the acceleration were rare but possible. It turned out that uncompensated coupling of the two transverse planes, orbit distortions and lifetime problems due to aperture or even tune steering had no or only negligible influence on the beam quality. However quite opposite to that chromaticity changes could severely affect the beam quality. Namely the snapback effect in HERA [8], if not compensated accurately, could lead to small or even slightly negative chromaticities and the head tail instability could spoil the beam quality on the first steps of the ramp. For the operators it was visible as a short but strong excitation of the beam in the tune spectrum. A beam quality check at the end of the ramp therefore was indispensable. Fig 8 shows such a measurement at 920 GeV after a head tail instability occurred at the lower part of the ramp. Some bunches in the 180 bunch train show an emittance blow up of nearly a factor of two. Consequently such beams could not been brought into collision and had to be aborted.

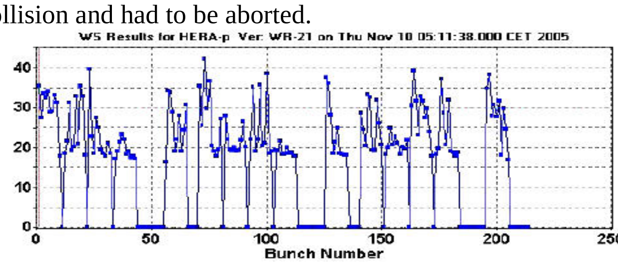

Figure 8: An event that could happen from time to time:
A strong beam excitation on the ramp spoiled the bunch quality: some bunches have nearly doubled their transverse emittance; better throw them away.

Luminosity Run:

Once collisions had been established and the ideal machine parameters could be set up, smooth machine running was obtained in general. Similar to the situation at injection however, drifts in tune, coupling, orbit and chromaticity have been observed and had to be compensated. This was usually not a big problem; however a general trend of decaying specific luminosity due to a slow increase of the beam emittance could not be counteracted. After a luminosity run of typically 12 hours duration the emittance increased up to values of 25 ... 30 π mm mrad (fig.9) - limiting in the end the length of a luminosity run.

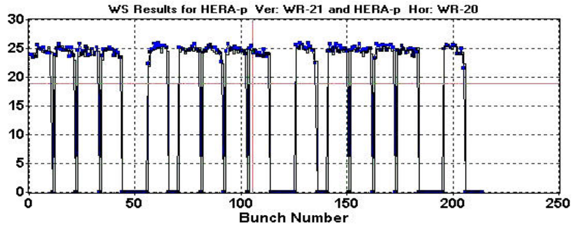

Figure 9: Beam emittance of the 180 bunches after a long luminosity run: still smooth but quite larger than in the beginning of the run (see Fig. 7)

BACKGROUND TUNING

Machine:

In the end this is the topic of the workshop. Once the beams had been brought into collision the main task for the operations group was to optimise the machine parameters, keep them stable and establish reasonable background levels at the high energy detectors. In principle three parameters had been used for that purpose: The beam lifetime, the loss rates at the collimators and signals from different parts of the high energy detectors. In practise it turned out that the HERA lifetime measurement was to slow and not precise enough to be used for fine tuning of the machine.

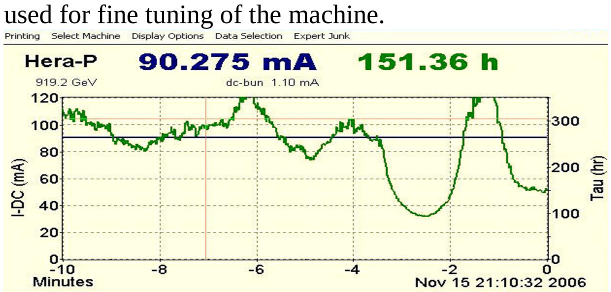

Figure 10: Beam lifetime measurement: Used mainly for “long term” measurements. For fast and efficient background tuning the significance was limited.

At least it was not trivial to disentangle the fluctuations of the lifetime measurement from real tuning effects, as the indicated lifetime oscillated between 50 and 150 hours (fig. 10). A much better tool for background tuning was the beam loss monitor (BLM) system [9,10]. Originally installed to detect local beam losses and in case of problems dump the proton beam to prevent the machine from quenching, the BLM’s also had been installed at the collimator system [11]. And these turned out to be an ideal tool for machine tuning. The BLM diodes measured the beam losses with a period of 5ms and for the display in the control room these values were averaged over one second. Figure 11 shows the BLM signals for each collimator stations: They were used to define the collimator positions with respect to the beam and the relative positions of main and secondary collimators with respect to each other.

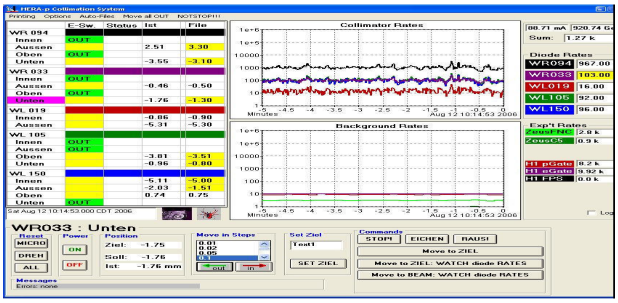

Figure 11: HERA proton collimators: left positions, right loss rates measured at the corresponding collimator jaws.

For machine optimisation and background tuning the sum signal of these single BLMs turned out to be the ideal tool, and in the following figures (Fig 12 a,b,c) I have plotted the sum signal of theses devices, as used by the operators for three different situations:

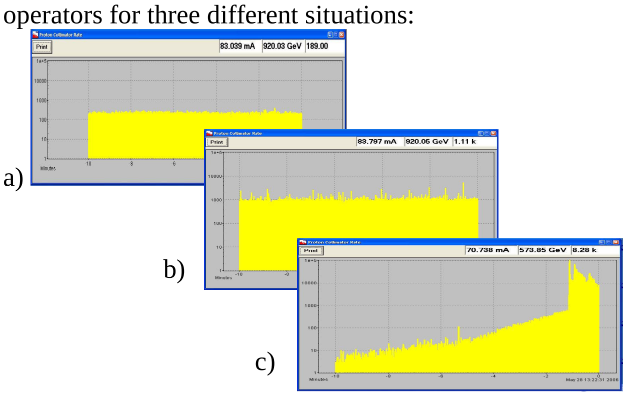

Figure 12: A standard tool for background and machine tuning: the sum of the collimator loss rates displayed as a function of time. The three plots correspond to three different machine situations (see text).

a) The beginning of a luminosity run: All parameters had been optimised, the collimators were closed and the data taking of the experiments started. The loss rates as seen in the plot are low and even more important they are smooth.

b) Typical situation towards the end of a luminosity run: The background rates increased, mainly due to the larger beam emittance. Corresponding to that the lifetime is reduced and from time to time spikes occur. The general beam situation however is still acceptable and data taking was possible.

c) The third example shows in contradiction to the smooth behaviour during a routine luminosity run, a problematic situation: The diffusion rate of the beam is much larger than the previous examples and the beam loss rates increase dramatically over several minutes (note the logarithmic scale). At the right part of the plot even a sharp increase of the BLM rates is detected, indicating a sudden change of a beam or machine parameter, such as orbit or tune jumps. Clearly in such a situation data taking by the particle detectors was nor possible and, if after a short while the situation could not be improved, the beam had to be aborted by the operators or by the machine/experiment protection system.

A less dramatic example that demonstrates the way of how the HERA proton beam was tuned is given in the next figure 13: It shows a routine procedure (compensation of the coupling and fine tuning of the chromaticity) during a luminosity run and the corresponding reduction of the beam loss rates as measured by the BLM's.

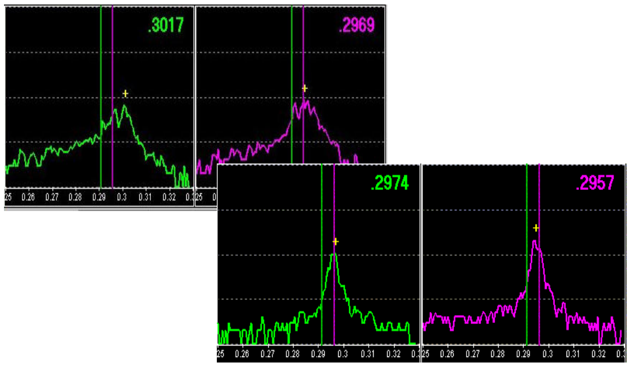

Figure 13: Tune spectrum during fine tuning of the chromaticity and coupling in a luminosity run: The resulting beam loss reduction is displayed in Fig 14.

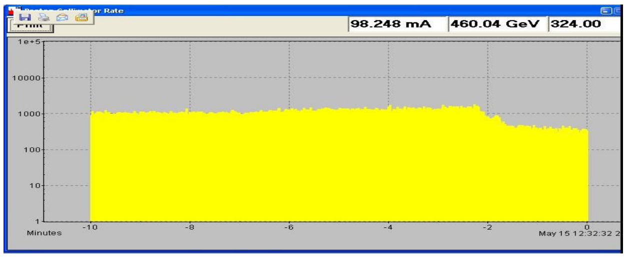

Figure 14: Reduction of the beam loss rates after optimisation of coupling and chromaticity during a luminosity run.

During luminosity runs these fine tuning procedures were repeated several times to keep the beam parameters at optimum values at any time.

Experiment signals

In addition to the global background level, indicated by the beam loss monitor diodes, a successful data taking of the particle detectors required also local beam steering in the straight sections of the machine. Therefore in HERA further background signals were taking into account to get the optimum machine setting and data taking efficiency for the detectors. For this purpose a large number of signals from the high energy detectors could be displayed in the control room.

In the end, for background tuning at the collider experiments H1 and ZEUS, the drift chamber currents turned out to be the most significant devices. Figure 15 shows a typical example from a HERA luminosity run. Out of 9 detector chambers in the experiment H1 we could choose the most appropriate one to tune the machine and get the lowest possible background situation. Background tuning included in this case also the optimisation of the vertex position and the crossing angle of the two beams.

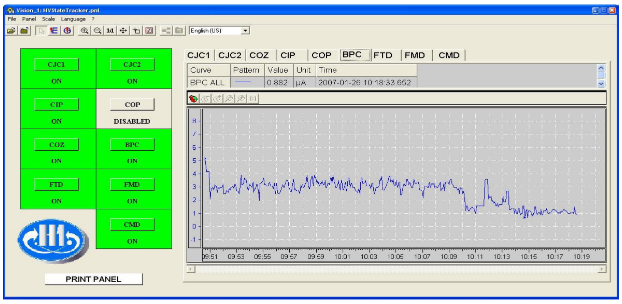

Figure 15: Drift chamber currents from the H1 detector during a HERA luminosity run. The currents were used to perform the fine (and best) background tuning of the machine.

PROBLEMS AND SURPRISES

Sources of Background:

It has already been mentioned that in general once the beams had been prepared carefully, no major background problems occurred. Put in a bit sloppy words: If the proton beam quality is good just leave the beam alone.

With the exception of a slow increase of beam emittance there was no major source of backgrounds. However among the years a number of technical problems occurred that either increased the diffusion rate on the particles or caused spikes in the otherwise smooth back ground level. Examples for typical problems that could cause quite some trouble for the operations crew were: power supply (chopper-) frequencies running on or close to the tune frequency could spoile in a short time the beam emittance, broken power supply electronics leading to ringing or jumping magnet currents, broken filter circuits (that are used to damp jitter), broken (or even burned) magnet coils, bad connections between the rf preamplifier and the main driver tube (causing noise in the rf system) and driving a large dc contribution in the bunch train, faulty power supply electronics etc. Figure 16 shows just one example out of many.

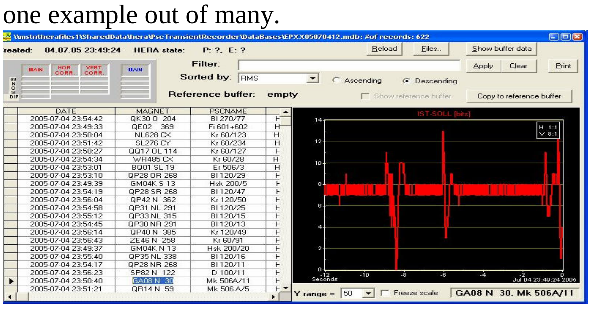

Figure 16: Survey and control of power supply currents.

The example shows the fluctuating current of a mini beta quadrupole as a function of time.

Due to a broken trim potentiometer in the power supply electronics sudden jumps in the magnet current are observed and according to that, strong spikes in the background.

Unfortunately background spikes of that magnitude could not be filtered out by the HERA collimator system. Severe background problems in all experiments therefore led to unacceptable dead-times or even endangered detector components. To overcome the problem a system had been installed to survey the actual magnet current produced by any power supply in the machine [12, 13]. The data were running through a circular buffer and could be stored and analysed at any moment.

The data of any power supply could be plotted and analysed according to the magnitude of the current fluctuations or alternatively according to the rms of the current entries, to localise the problematic device.

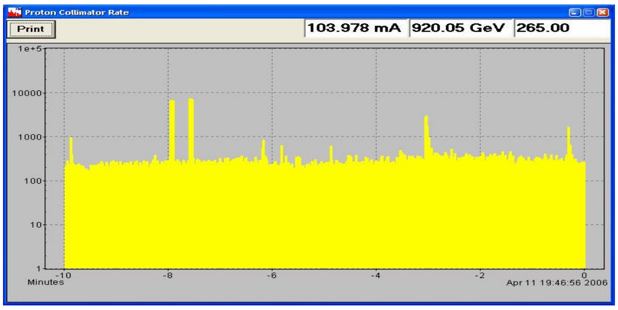

Figure 17: Spikes observed in the proton background due to unstable power supply currents.

In quite a similar way noise of the rf system could lead to problematic running conditions: Faulty connections or broken electronic parts in a tuner loop could eventually lead to a strong increase of the dc contribution in the beam. There is not much to say about that: The problem had to be detected and repaired.

Just for completeness I would like to present the ideal case (which is in the end our goal): The magnet current generated by a well behaving power supply, as a function of time (fig. 18).

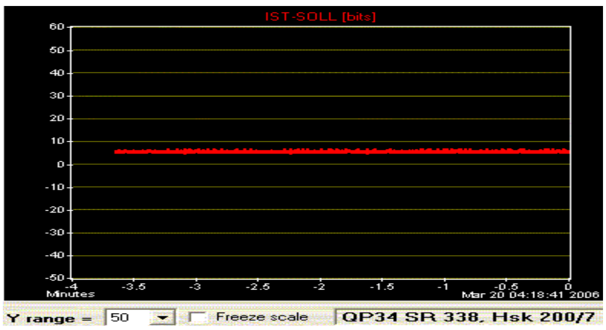

Figure 18: The ideal case: stable and smooth behaviour of the magnet current - to be compared to Fig. 16 where a problematic situation is displayed.

Beam sensitivity:

By far the most surprising fact was the sensitivity of the proton beam while in collision. Small diffusion rates and good background situation only could be obtained in HERA if the main machine parameters, namely tune, the coupling and the chromaticity had been set to their optimum values and kept constant during the complete luminosity run within a narrow tolerance window. Optimum values in this context means values that had been established empirically during the machine running including the background data from the four experiments. The sensitivity to even small changes in the tune for example was remarkable: The optimum value for the transverse working point was $Q_x = 0.292$, $Q_y = 0.297$. These values are located close to the coupling resonance in a small triangle and it turned out that the free space available for machine tuning was as small as 95 Hz (fig 19). Crossing the resonance lines (of 13th order in the figure) could easily increase the beam background by more than an order of magnitude. Even more: to get the real optimum tuning, the trim quadrupoles used for tune control had been changed in bit wise manner, corresponding to a tune variation of $\Delta Q \approx 0.00004$.

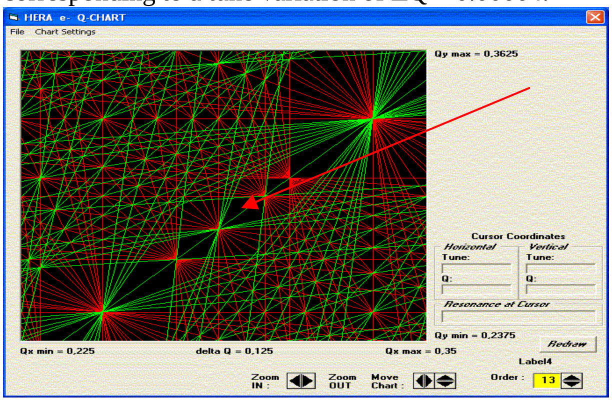

Figure 19: HERA tune in the working diagram

CONCLUSIONS

Helmuts Questions

- Are / were machine backgrounds and issue ?

The answer is clearly yes. Background problems were always an issue and it took for each of the high energy detectors quite a while (e.g. weeks to find the ideal setting for the vertex, the crossing angle, the up stream and downstream orbit and the collimators.

- Which types of background were most severe?

DC current contributions of the proton beam and hadronic spikes due to (even small) technical problems caused the main trouble.

- How has the problem been solved?

Practically in all cases the ideal solution was to detect and localise the origin of the problem and repair or exchange the technical device responsible for it. A big step forward was to survey and control power supply currents, including the use of transient recorders to detect fast and irregular fluctuations of the magnet currents. These recorders were an ideal tool to analyse and localise broken hardware. No solution has been found to avoid external distortions - or "cultural noise" as it is sometimes called. In this sense weekend shifts and mainly night shifts were the ideal conditions to achieve good beam backgrounds.

- The main sources of halo were mostly noise or ripple due to technical problems.
- Is scraping useful ?

It had been tried several times in HERA to overcome background problems by scraping. Especially in the presence of spikes the idea was to take away the halo population and retain luminosity conditions afterwards. In some cases it worked; the better choice however in our case was to localise the problem and fix the technical component that was creating the trouble. And scraping could even in HERA easily damage the collimator jaws ... and did!

All in all tuning the background in HERA was a tedious, time consuming, never ending story. I may even say that it was also an art of its own as in the end you had to know and take into account the complete machine. And so it was fun for those who liked the beast.

REFERENCES

[1] B.H.Wiik et al, "HERA, A Proposal for a Large Electron Proton Colliding Beam Facility at DESY", DESY HERA 81/10, Hamburg, 1981.

[2] C.Niebuhr, "Background at HERA, Experiments perspective", these proceedings.

[3] "Study of Beam-Induced Backgrounds in the ZEUS Detector from 2002 HERA Running", ZEUS note 02-018, 02-020, 02-027, 2002/2003

[4] "Technical Report on the Beam Induced Background in the H1 Detector",H1-10/02-606,H1-01/03-607, 2002/2003

[5] U. Schneekloth (editor), "The HERA Luminosity Upgrade", DESY 98/05, Hamburg, 1998.

[6] B.Holzer and C.Montag, "Reproducibility and Predictability of Persistent Current Effects in the HERA Proton Storage Ring", EPAC Wien, 2000.

[7] K.H.Mess, P.Schmüser, S.Wolf, "Super Conducting Accelerator Magnets", World Scientific, 1996

[8] B.Holzer, "Impact of Persistent Currents on Accelerator Performance", Part. Acc. 1995.

9] K.Wittenburg,, "Preservation of Beam Loss Induced Quenches, Beam Lifetime and Beam Loss Measurements with the HERA-P Beam Loss Monitor System", DESY 94/003, Hamburg, 1994.

[10] K.Wittenburg,, "The PIN-Diode Beam Loss Monitor System at HERA", DESY-HERA 00/03, Hamburg, 2000.

[11] M.Seidel, "The Proton Collimation System of HERA",DESY 94 -103,Hamburg,1994.

[12] S.Herb, P.Bartkiewicz, DESY, priv. com.

[13] M.Werner, "A Fast Magnet Current Change Monitor for Machine Protection in HERA and LHC", ICALEPCS, Geneva, 2005.

Background at HERA: Perspective of the Experiments

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Abstract

Machine induced background of various kinds has played an important role in the four experiments at the ep collider HERA which has been in operation from 1992 to 2007 at DESY in Hamburg. The largest impact on the operation was seen during the initial phase of HERA II after the HERA luminosity upgrade in 2000-2001 when backgrounds were found to be intolerably high in the colliding beam experiments H1 and ZEUS and machine currents had to be limited for some time in order to avoid damage to the sensitive detector components. In this article the main sources of this background and the measures taken to mitigate them are described. More specific background issues like those related to the operation of Roman pot devices or the wire target of the HERA-b experiment are not discussed here. The background related HERA machine aspects are desribed elsewhere in these proceedings [1].

INTRODUCTION

The most sensitive components of the colliding beam experiments H1 and ZEUS are the tracking devices. They consist of silicon strip detectors with their associated readout electronics which are mounted close to the beam pipe and of conventional gas detectors. Already before the luminosity upgrade of HERA (1992-2000, HERA I) some radiation damage was observed in the H1 silicon detector after periods of machine studies [2] and in the gas detectors which are only operated during luminosity runs [3]. While over the years the readout electronics for the vertex detectors was replaced with more radiation tolerant versions the basic operational parameters of the gas detectors could not be altered. As a consequence rather stringent background limits had to be respected for safe operation of both detector systems. Bad background conditions after the luminosity upgrade unexpectedly enforced to set limits on the maximum beam currents for several months in order to avoid damage. Many experiments and simulations very carried out to study the different background sources in detail and to devise counter measures. External expertise from other laboratories was involved within the framework of an international workshop and two external reviews between July 2002 and January 2003. The results of the studies are documented in several reports [4, 5] and most of the measures were implemented in a shutdown in the year 2003. Although several different background mechanisms contributed to the problem the interaction of the proton beam with residual rest gas atoms in the vacuum system was identified as the major source of background. This type of background is particularly severe at the ep collider HERA because of the unique combination of vacuum degradation in the beam pipe close to the experiments caused by photo desorption resulting from the intense synchrotron radiation and the large hadronic cross section for the interaction of protons with the released rest gas atoms.

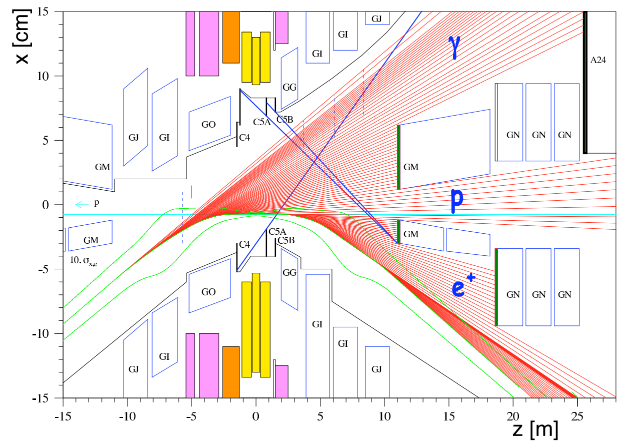

Figure 1: Schematic view of the H1 interaction region after the luminosity upgrade. Note the different scales in x and z. The shaded boxes indicate the position of the detector elements close to the beam pipe. Starting from absorber 4 at a distance of 11 m from the IP the common beam pipe splits into three separate beam pipes for electrons, protons and for the synchrotron radiation fan.

HERA LUMINOSITY UPGRADE

In the year 2000 HERA regularly surpassed its design luminosity of $\mathcal{L} = 1.5 \times 10^{31}$ cm^{-2}s^{-1} at the beginning of a luminosity fill and a major upgrade of the machine was needed to substantially increase luminosity for the experiments further. In order to reach a reduction of the beam cross sections in the transverse plane by roughly a factor of 3 a more compact design of the magnet lattice for bending and focussing of the two beams close to the interaction points was required [6]. As a result the interactions regions of the colliding beam experiments H1 and ZEUS were completely rebuilt in the years 2000-2001. One of the challenges of the new machine layout was the handling of the intense synchrotron radiation generated by the newly designed superconducting separation magnets inside the detectors (GO and GG in Fig. 1). A total synchrotron radiation power of 15-20 kW with critical energy in the range 100-150 keV had to be transported through the ex-

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periments. At a distance of 11 m from the IP a septum absorber (absorber 4) is installed which separates the electron[1] and proton vacuum systems and which has to absorb a power of 4-6 kW. The major part of the radiation is absorbed further downstream at a distance of 25 m from the IP. In order to leave space for the synchrotron radiation fan the shape of the beam pipe inside the experiments is elliptical. Integrated tungsten collimators (C4, C5 in Fig. 1) shield the inner detector elements and the beam pipe from radiation which is backscattered from the absorbers.

BACKGROUND SOURCES

The following types of background mechanisms were observed in the experiments: (i) synchrotron radiation, (ii) electron-gas, (iii) proton-gas and (iv) proton beam-halo losses. Under normal conditions the last type of background (iv) did not represent a major problem for the experiments. Exceptions were periods when malfunctioning machine components like faulty magnet power supplies or noisy RF-systems caused background spikes or led to a to buildup of coasting beam. The contribution of the sources (i)-(iii) to the total current observed in the central track detector (CTD) can be parametrized as follows:

$$I_{CTD} = I_0 + \alpha_{SR} I_e + \alpha_e I_e^2 + (\alpha_p I_e + \alpha_{p_0}) \cdot I_p \quad (1)$$

This parameterization reflects the fact that the direct and backscattered synchrotron radiation, which is proportional to the electron beam current not only directly contributes to the chamber current $\propto I_e$, but in addition causes a dynamic pressure increase on top of the base pressure p_0 around the experiments by photo desorption.

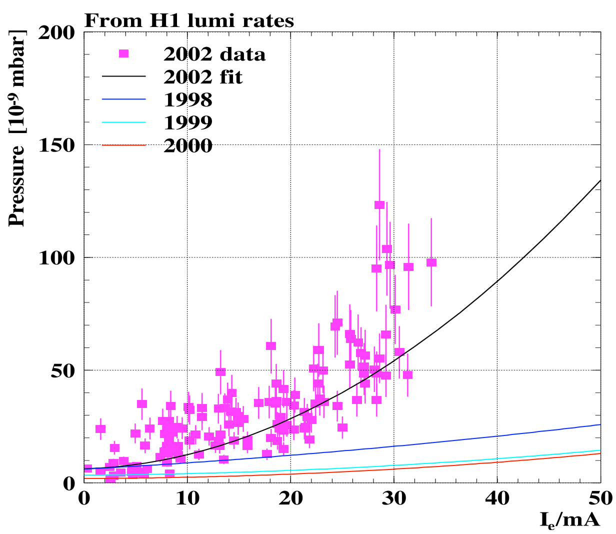


Figure 2: Pressure in the H1 interaction region as deduced from the observed rate in the luminosity system as a function of the electron beam current. The 2002 data are compared to parameterizations obtained at HERA I.

[1]HERA was operated with electrons or positrons. For simplicity the term electrons is used for both particle types throughout this text.

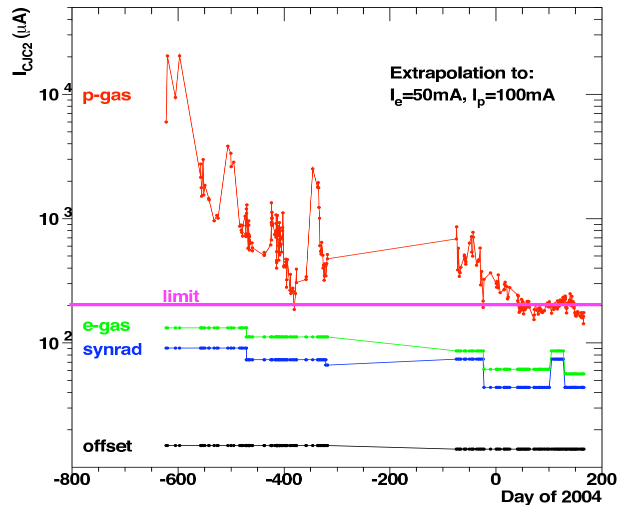


Figure 3: Evolution of the sum of the different contributions to the chamber current in the H1 central tracker from 2002-2004. The data are extrapolated to the design beam currents using the parameterization given in Eq. 1. The limit for safe operation of the chamber at 200 μA is indicated.

In Fig. 2 the pressure in the H1 interaction region as determined from the rate of electron-gas events in the H1 luminosity system is shown as a function of the electron beam current. The observed dynamic pressure increase has contributions from outgassing due to higher order mode (HOM) heating at injection energy (12 GeV) and of photo desorption due to synchrotron radiation. Comparing the dynamic pressure increase in the early period of 2002 with the situation before the luminosity upgrade shows that the conditions in HERA II were worse by about a factor of 5.

Off-momentum electrons resulting from upstream electron-gas interactions are deflected into the detector by the bending magnets inside the experiments leading to a term $\propto I_e^2$ in Eq. 1. Similarly proton interactions with the rest gas inside and proton upstream of the detectors result in secondary scatters at aperture limitations in the vicinity of the sensitive detector components (e.g. synchrotron radiation masks) and thus to a contribution $\propto I_e I_p$. The coefficients α_{SR}, α_e, α_p and α_{p_0} have been determined using special runs and were used to extrapolate the expected chamber currents to the design currents of the machine of $I_e = 50$ mA and $I_p = 100$ mA. Fig. 3 shows the development of the sum of the three background contributions to the chamber current in the central drift chamber of H1. All components are seen to go down with time. Since the coefficients for electron gas and synchrotron background could only be determined in dedicated runs the corresponding background contribution exhibit a rather coarse time dependence in the plot. The structures visible in the proton gas contribution however result from various vacuum incidents followed by reconditioning of the vacuum (see below). In spring 2004 the machine currents for the first time were no longer limited by background in the chamber.

A very similar improvement of the chamber current with time was seen in the ZEUS central tracker. Fig. 4 shows the chamber current as a function of the electron beam current for various runs in the period from October 2003 to July 2004.

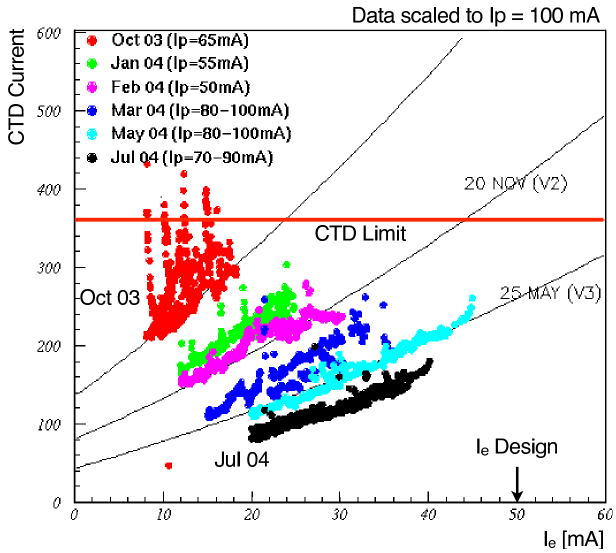


Figure 4: Dependence of the chamber current in the ZEUS CTD as a function of the electron beam current for different runs from October 2003 to July 2004. For comparison the data have been scaled to $I_p = 100$ mA using the parameterization given in Eq. 1. Around March 2004 the chamber currents for the first time did not limit the machine currents.

Synchrotron Radiation Background

The design of the new interaction region was made such that synchrotron radiation should only reach the beam pipe inside the experiments after at least two scatters and therefore should not lead to a significant background contribution in the detectors. However, first attempts to switch on the electron machine at HERA II immediately showed that this was not the case. By a combination of detailed Monte Carlo simulations and dedicated measurements it was found that initial misalignment of beam elements beyond the tolerances of 0.3 mm, oversight of an additional source of synchrotron radiation at a distance of -90 m far electron upstream of the IP and wrongly designed internal synchrotron radiation masks inside one of the experiments could explain the observed problems.

To disentangle the different background contributions dedicated electron-only runs with isolated bunches were taken. Observing the dependence of the chamber current as a function of the electron beam current allowed the separation of synchrotron radiation contribution ($\propto I_e$) from electron gas contribution ($\propto I_e^2$). By measuring the leading edge of the drift time distribution of hits from the isolated bunch in the drift chambers (see Fig. 5) the absorber 4 at 11 m was confirmed as the main source of backscattered radiation. By installation of an additional movable collimator 65 m electron upstream of the experiments and after a redesign of the internal synchrotron masks in ZEUS which was implemented during the 2003 shutdown to avoid sneak-through of back scattered photons the synchrotron radiation background was brought to an acceptable level for both experiments.

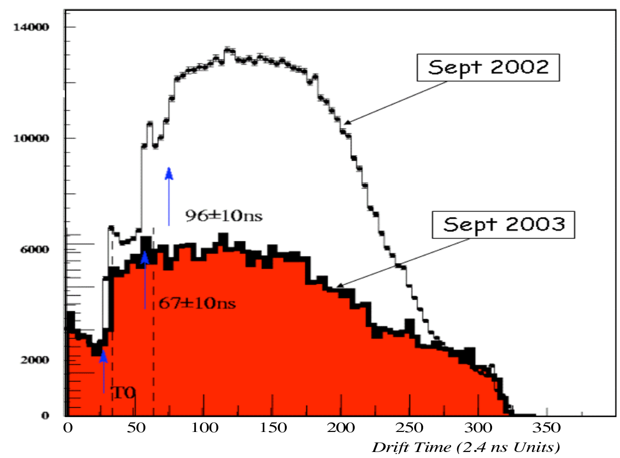


Figure 5: Drift time distribution of hits from an isolated electron bunch in the ZEUS CTD before and after the modification of the synchrotron radiation masks. The delayed component which is compatible with backscattering from the synchrotron radiation absorbers was successfully suppressed after the shutdown in 2003.

To improve the overall alignment of the machine the method of beam based alignment [7] was found to be very useful especially for the superconducting combined function magnets GO and GG inside the experiments. Furthermore time-dependent orbit fluctuations, partially arising from magnet movements due to changing magnetic forces, were reduced using an automatic orbit stabilizer [8]. Despite these efforts some residual misalignment of the machine elements and the experimental beam pipe in the H1 interaction region could not be fully resolved. Possibly as a consequence two major vacuum incidents occurred in 2004 and 2006 when the common stainless beam pipe around $6 - 8$ m proton upstream was hit by direct synchrotron radiation for several minutes, probably during electron injection or during a period of dedicated HOM-heating at 12 GeV (see below). The large temperatures following from the incident radiation led to gas outburst which then resulted in huge background from proton-gas interactions. Moreover the beam pipe was locally deformed by several millimeters which further restricted the available aperture also for luminosity operation thus constraining the available parameter space for the machine considerably. As a consequence this section of the beam pipe had to be replaced. In the subsequent period machine currents had to be limited again until the original vacuum conditions were restored. In order to prevent further damage a multitude of temperature sensors mounted on beam pipe and absorbers and vacuum pressure monitors were added as input to the electron beam-dump trigger system which otherwise was based on several independent radiation monitor systems.

Electron Gas Background

Off-momentum electrons which have lost part of their energy by Bremsstrahlung in an interaction with the residual gas atoms upstream of the experiment are deflected by the superconducting dipoles and quadrupoles and hit the beam pipe inside the detectors. This kind of background events can be distinguished from proton-gas events by the lower track multiplicity and the non-uniform spatial distribution of the showers the off-momentum electrons produce in the detectors. According to detailed simulations the sensitivity of the experiments to this type of background extended beyond -60 m electron upstream. In contrast to the rest of the straight section of the machine a 5 m long section of beam pipe inside one of the focusing quadrupoles (GA) for the proton beam originally was not equipped with NEG pumps because of limited space in the transverse direction and therefore was suspected to produce a pressure bump within the sensitive region. By piecewise modification of the iron yoke of this magnet it was possible to connect this section of the beam pipe to ion getter pumps during the shutdown 2003. After this modification and due to further vacuum conditioning the contribution of electron gas background was brought to an acceptable level.

Proton Gas Background

As explained in the previous sections the proton-gas background was the dominant contribution to the background problem for H1 and ZEUS after the initial problems with the synchrotron radiation had been solved. It became clear that the dynamic pressure increase had to be drastically reduced in order to be able to stand design machine currents. A particular challenge was to disentangle

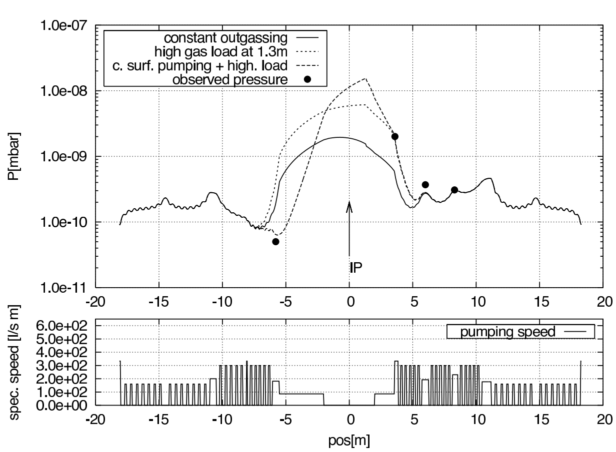


Figure 6: Pressure profile simulations for the inner interaction region at H1, for different outgassing and pumping scenarios in comparison with observed pressure readings.

the impact of higher order mode (HOM) losses, which are strongest during electron injection at 12 GeV, of photo desorption due to direct or reflected synchrotron radiation and of the vicinity of the cold inner surfaces (T$\sim$55K) of the superconducting magnets on the proton-gas background. In order to gain a better understanding of the vacuum behavior around the IPs and its contribution to the detector background many experiments and simulations were carried out. This included the simulation of the vacuum profile under different boundary conditions (an example is shown in Fig. 6), operating the superconducting magnets at elevated temperatures, trying to thermally bake out the interaction region by operating the electron ring for about a week at injection energy (HOM heating), the creation of artificial pressure bumps by heating individual pumps and comparing with simulation (see Fig. 7), laboratory experiments with NEG-pumps, Titanium sublimation pumps (TSP) and installation of a dedicated residual gas analyzer to monitor the gas decomposition close to the IP.

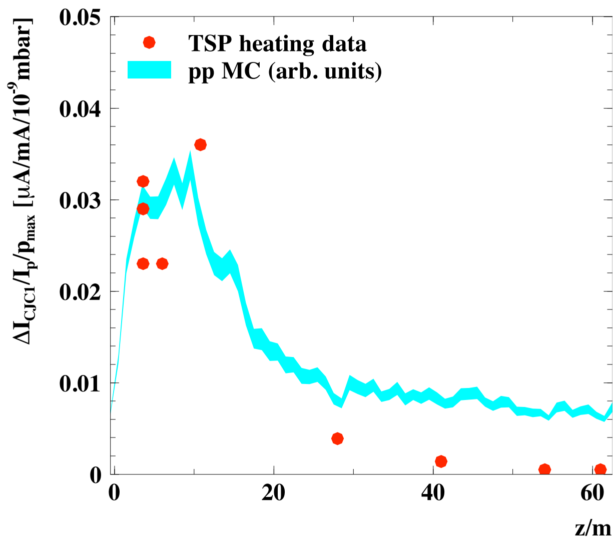


Figure 7: Comparison of observed and simulated increase of chamber current in the H1 central track detector normalized to the proton current and to the magnitude of the pressure bump after TSP heating as a function of the distance to the pump.

It turned out that the most critical area concerning bad vacuum was the region 2-11 m proton upstream. As a result of these studies [4, 5] the following modifications to the vacuum system [9] and to the region of the experimental beam pipes were introduced in the shutdown 2003:

- doubling the pumping speed of the ion getter pumps between 3.6 and 11 m
- improving conductance of pumping ports by increasing width of pumping slits
- reducing the thickness of over-designed synchrotron radiation mask C5B by a factor of 4 in order to reduce the interaction probability for secondaries from proton-gas events

- reducing HOM losses in the interaction region at injection energy by tapering the C5B synchrotron mask and by improving its cooling

- installing a new integrated ion getter pump inside the H1 experiment at 1.5 m from the IP

Fig. 8 shows the long term evolution of the proton gas background contribution in the H1 interaction region as derived from the normalized track trigger rate. The normalization

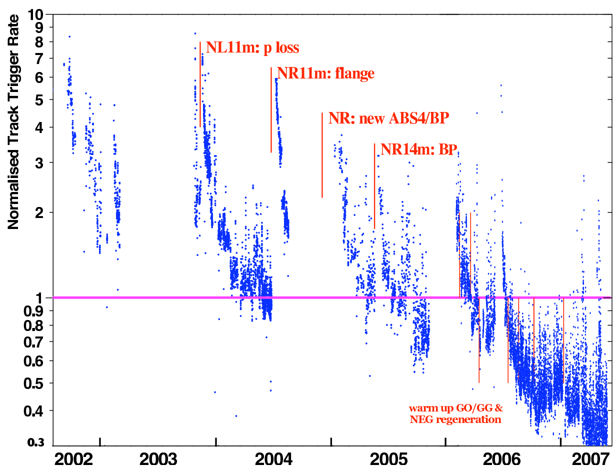


Figure 8: Long term history of normalized track trigger rate in H1, which is proportional to the proton gas background contribution to the chamber current.

is chosen such, that at values of 1 the chamber current due to proton background at design beam currents is roughly equal to the limit of 200 μA. The long-term trend of vacuum improvement has a time constant of approximately 600 days. As can be seen this overall trend was repeatedly interrupted by vacuum leaks which in most cases occurred in the region close to absorber 4. This region turned out to be the weak point in the design of the area around the IP after the luminosity upgrade where three vacuum flanges share a very crowded space. Slight misalignments of machine components in this constrained area in combination with the large heat load of absorber 4 caused large mechanical and thermal stresses on the flanges. In several occasions one of the flanges opened at H1 or ZEUS due to the fast temperature change which followed an electron beam loss at high intensity. The average time constant for restoring the previous vacuum conditions after such incidents was observed to be in the range $20 - 30$ days.

After many tests the most effective strategy for long term improvements of the vacuum was found to be a combination of vacuum conditioning during luminosity operation interleaved with regularly warming up of the superconducting magnets in order to release the gas which had accumulated on the cold surfaces and subsequent activation of Ti- and NEG pumps.

SUMMARY

Machine induced background severely affected the start-up after the luminosity upgrade of HERA. Until spring of 2004 machine currents had to be limited in order to prevent damage to sensitive detector components thus reducing the available luminosity for the experiments. Several background mechanisms were identified to contribute to the overall problem but a background component specific to the ep collider HERA and resulting from dynamic pressure increase due to synchrotron radiation in combination with the large hadronic cross section for the interaction of protons with the rest gas upstream of the experiments was found to be the dominating source. In a very fruitful collaboration between experiments and the machine group very detailed experiments and simulations were carried out to study possible counter measures. Besides the effect of several such improvements that were implemented in the area around the IPs in the shutdown 2003 the conditioning of the vacuum system by regular luminosity operation in combination with regular warming up of the superconducting magnets and subsequent pump activation was found to be most effective for long-term improvements.

REFERENCES

[1] B. Holzer, “HERA: Sources and cures of background - machine perspective”, These proceedings.

[2] B. List, “The H1 silicon tracker”, Nucl. Instrum. Meth. A **549** (2005) 33.

[3] C. Niebuhr, “Aging in the Central Jet Chamber of the H1 experiment”, Nucl. Instrum. Meth. A **515** (2003) 43.

[4] D. Bailey *et al.*, “Study of beam-induced backgrounds in the ZEUS detector from 2002 HERA running”, ZEUS-02-018, ZEUS-02-020, ZEUS-02-027: `www-zeus.desy.de/~kuze/zeusbg/`.

[5] V. Andreev *et al.*, “Technical report on the beam induced backgrounds in the H1 detector”, H1-10/02-606: `www-h1.desy.de/publications/bgrep.pdf`;
V. Andreev *et al.*, ‘Further report on beam-induced backgrounds in the H1 detector”, H1-01/03-607: `www-h1.desy.de/publications/bgrep2.pdf`.

[6] U. Schneekloth (ed.), “The HERA luminosity upgrade”, DESY-HERA-98-05;
M. Seidel and F. Willeke, “Layout of the upgraded HERA interaction regions”, DESY-M-00-04ZP, (EPAC 2000), Vienna, Austria, 26-30 Jun 2000.

[7] F. Brinker *et al.*, “Beam based alignment of combined function magnets in the upgraded HERA interaction regions”, DESY-M-02-01I, (EPAC 2002), Paris, France, 3-7 Jun 2002.

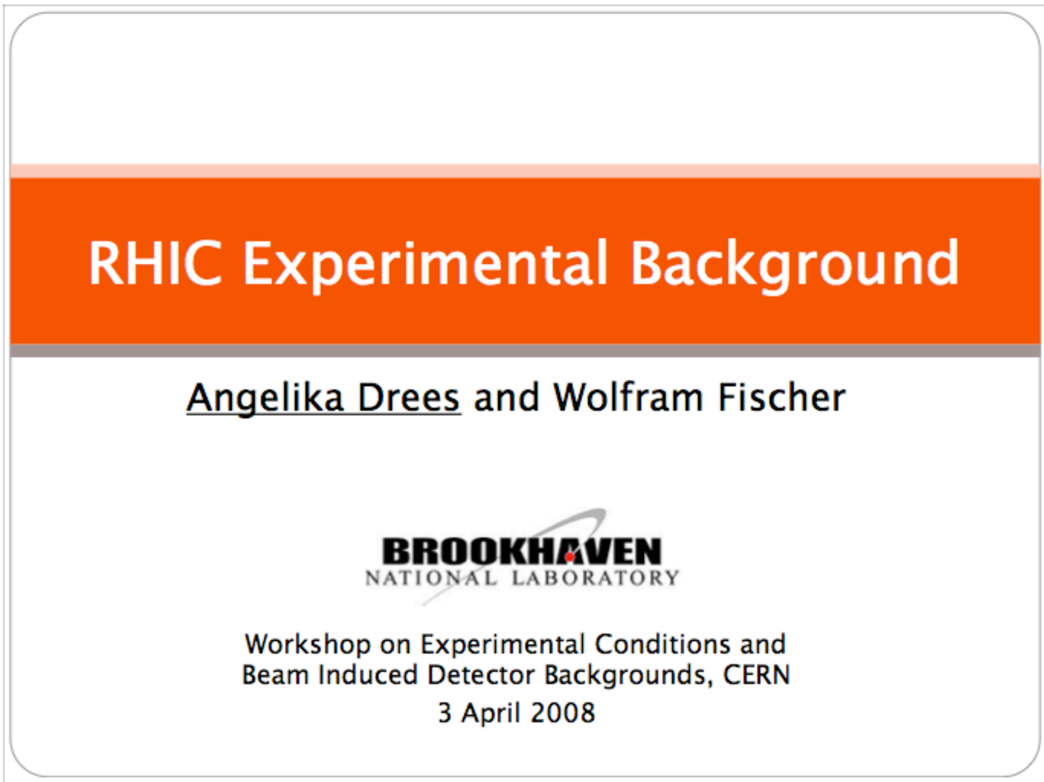
[8] P. K. Bartkiewicz, F. Brinker, S. W. Herb and J. M. Maass, “Automated Orbit Control for the HERA ep Collider”, (EPAC 2004), Lucerne, Switzerland, 5-9 Jul 2004.

[9] M. Seidel, J. Kouptsidis, G. Nawrath, U. Schneekloth and K. Zapfe, “The vacuum system for the upgraded HERA interaction regions”, Vacuum **60** (2001) 267.

RHIC Experimental Background

A. Drees and W.Fischer
Brookhaven National Laboratory, USA.

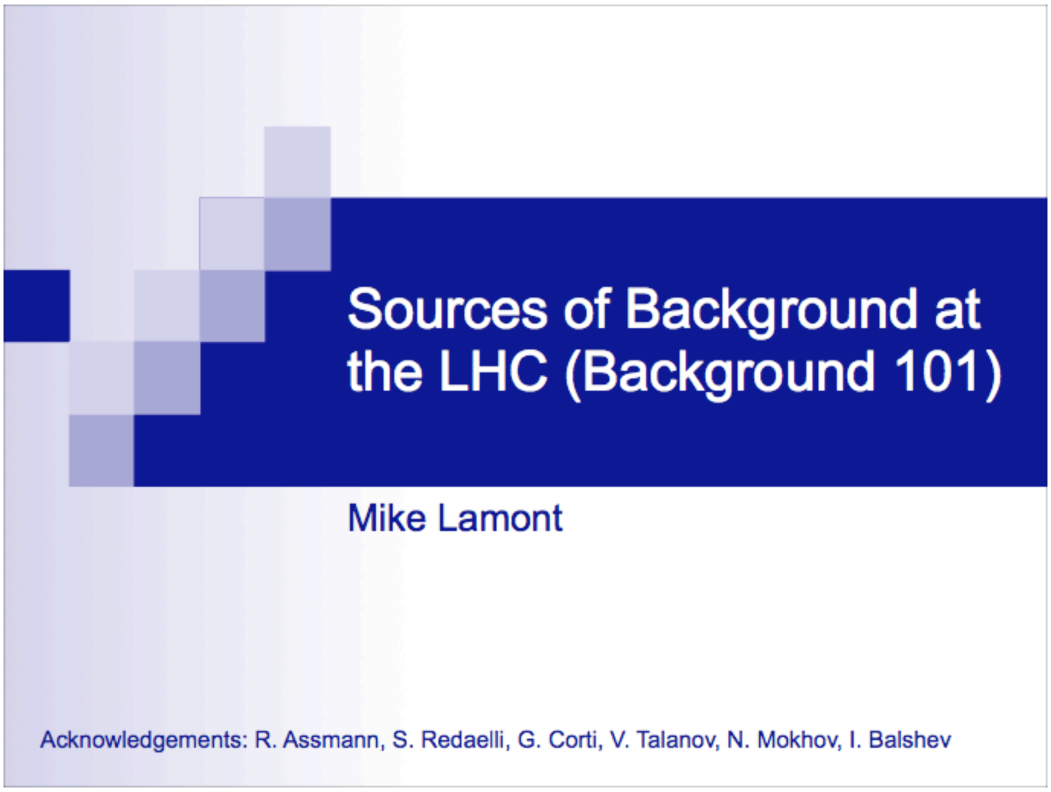
A paper was not submitted to the proceedings. However, the slides presented are available in electronic form at http://indico.cern.ch/conferenceDisplay.py?confId=25768. The cover slide from this talk is given as reference.



Sources of Background at the LHC

M. Lamont
CERN, Switzerland.

A paper was not submitted to the proceedings. However, the slides presented are available in electronic form at http://indico.cern.ch/conferenceDisplay.py?confId=25768. The cover slide from this talk is given as reference.



Session 1 Discussion Summary

R. Alemany-Fernández, CERN, Geneva, Switzerland

Mike Lamont chaired this session devoted to review the experience from TEVATRON, HERA and RHIC, both from machine perspective and detectors point of view, in order to get an idea about what we could expect and optimise from the machine side and from the LHC experiments side. The session consisted of five talks and a series of discussions after each one. The main points raised during the discussions are collected in this document.

TEVATRON SOURCES AND CURES OF BACKGROUND – MACHINE AND EXPERIMENTS PERSPECTIVE (SPEAKER: R. TESAREK)

Abort Gap: DC beams in the abort gap are observed since Run II. There was some discussion about the nature of this abort gap beam. R. Tesarek explained that this beam was originated from RF noise. The beam was diffusing to neighbouring RF buckets. Elena Chapochnikova said that there are two types of beam in the Tevatron abort gap:

1. uncaptured, which moves along the abort gap staying longer between buckets due to small velocity at this place;
2. captured, most probably created in the main injector (MR), injected into Tevatron and then captured at the beginning of the acceleration. This beam doesn't move with time.

Another remark was made about the origin of uncaptured beam during the coast. Elena said that publications (e.g. V. Lebedev EPAC'03) exist which show from comparison of simulations with measurements that Intra Beam Scattering (IBS) is the main source for this beam loss. However, the speaker said that he doesn't fully agree with this explanation.

Is uneven bunch intensity distribution within a bunch train a source of background? (Answer from J. Annala) The uneven bunch intensities can be a source of high background for the opposite beam. Unequal bunches were common in the Tevatron back when the Protons were much stronger than the Pbars. Although nowadays the Proton beam sees very strong effects from the Pbar beam since the Pbars are more intense and can have very small emittances, Tevatron gets a fairly even intensity distribution in the Pbar bunches and, therefore, there are no Proton background problems anymore

What are the Lifetimes during Collider Run II?: Below there is the answer from J. Annala:

If we go back several years (2004), when Tevatron top Luminosity was $100x10^{30}$ we had particle and luminosity lifetimes at the beginning of the stores in the range of:

	Real (hours)	Optimum* (hours)
Protons	30-200	200
Pbars	15-30	40
Luminosity	6-15	30

(*every particle ends up in a collision, i.e. no particle loss and no emittance growth)

These lifetimes depended not only on how well we had everything tuned up to reduce backgrounds, but also on the initial luminosity. We could have a large variation in the number of Pbars available, so the initial luminosity could vary a lot as well.

If we look at our best store recently (initial luminosity of $315x10^{30}$) we had lifetimes of:

	Real (hours)	Optimum* (hours)
Protons	15	70
Pbars	15	23
Luminosity	4	17

(*every particle ends up in a collision, i.e. no particle loss and no emittance growth)

At the present time, our Pbar lifetime is very close to the optimum (luminous) lifetime because we have very small emittances. Also, the backgrounds are now very close to where they were in 2004, although the instrumentation ages. We actually lose more Protons now that in 2004, but we do a better job of keeping the background down. We do this with better placement of collimators, careful tuning, and positioning the beam within the aperture better.

Background rejection: during the discussion R. Tesarek made clear that the track reconstruction in the Tevatron experiments is very demanding and, therefore, the physics background rejection is very efficient. The experiments have also put in place a three dimensional track reconstruction technique to improve off-line background rejection. At the on-line level, Tevatron is able to reduce the amount of triggered backgrounds by reducing the diffused halo of particles surrounding the core of the beam. This reduction came about by:

- improving the vacuum;
- commissioning collimators and routinely using them to scrape the halo surrounding the beam core away.

According to R. Tesarek these two improvements were mostly responsible for the 40% reduction in trigger rates that he reports in his talk, but he does not completely rule out that:

- magnet unrolls (quadrupole unrolls)

- Tevatron dipole coil shimming to reduce skew quadrupole component of the field

helped to reduce horizontal/vertical coupling of the beam and allowed for better understanding of orbits.

HERA SOURCES AND CURES OF BACKGROUND – MACHINE PERSPECTIVE (SPEAKER: B. HOLZER)

Collimators: B. Holzer clarified that the ratio secondary/primary collimator positions had to be calibrated from time to time.

What was the orbit stability at HERA? ½ mm in the arcs; at HERA there was not a feedback system to help with the orbit correction. At the experiments the correction was local. Global corrections were considered too dangerous.

Tune: at HERA the tune optimization was done at the level of single bits at the power supply controller, because the available phase space was very small, just 600 Hz. The optimal tune was placed within a very small triangle. This triggered the question if HERA operators ever tried to jump into a bigger triangle. B. Holzer answered that yes but that was not successful.

How did experiments protect against background? the experiments were protected by the BLM system; high losses dumped the beam. The experiments themselves did not have a direct input into the beam dump system.

Is uneven bunch intensity distribution within a bunch train a source of background? B. Holzer answered that strong differences in the bunch intensity can indeed make problems with background as it will not be easy to find a place in the tune working diagram that is good for every bunch. Therefore one should always try to fill all bunches equally. At HERA they always checked the equal density distribution over the bunches for every fill and before the ramp.

Chromaticity measurement during luminosity runs: B. Holzer explained that chromaticity measurements were done shifting the momentum with the RF system and observing the tune change. Nevertheless, looking at the tune working diagram one can see there is basically just enough space in the working diagram to survive. Any tune change will, therefore, cause a lot of lifetime breakdowns, background events and drift chamber trips in the detectors. So he advised not to modify the tune during luminosity runs.

HERA SOURCES AND CURES OF BACKGROUND – EXPERIMENTS PERSPECTIVE (SPEAKER: C. NIEBUHR)

Vacuum quality inside the detectors: The beam pipe at the insertion regions of the HERA machine is quite complex since it has to accommodate three different beam types: electrons, protons and photons (see slide 9). This triggered the question how one can guarantee a good vacuum inside the detectors given the complex topology of the beam pipe. C. Niebuhr answered that there is a pump inside the detector, but on the other hand, the vacuum quality in this region was never an issue. What was an issue is the vacuum quality in the regions before and after the detectors. Many efforts were conducted to solve the problems in those regions. R. Tesarek commented that in Tevatron the warm sections were a source of pressure problems and as a consequence the beam was scattered and after ten revolutions, on average, went into the detector.

BACKGROUND IN RHIC (SPEAKER: W. FISCHER)

Does background quench the inner triplets?: W. Fischer answered that at the beginning it happened from time to time. To cure this they installed shielding and now it happens very rarely.

EXPECTED SOURCES OF BACKGROUND IN LHC OPERATION (SPEAKER: M. LAMONT)

What is the cleaning efficiency of the momentum collimators at the start of the ramp?: R. Assman did not provide with a concrete number for the cleaning efficiency but replied that we believe that the system will be able to cope with the expected loss rates.

Is there background cross-talk between experiments?: according to simulations background cross-talk between CMS and ATLAS may exist. B. Holzer added that in HERA they also had this problem.

SESSION 1 SUMMARY

M. Lamont, CERN, Geneva, Switzerland

Abstract

A summary is given of the first session of the workshop on experimental conditions and machine induced background held at CERN in April 2008. The first session concentrated mainly on experience from other machines.

TEVATRON - MACHINE

Abort Gap

The abort gap systematically fills every shot. Why this is is still not clear: RF noise is a possible candidate (although it is noted with the use of Tetrodes rather than klystrons (LHC) things might be expected to be quieter). The contents of abort gap is seen as an important machine health indicator.

Cleaning the abort gap is possible. It is monitored using synchtron light by the accelerator team. The loss rate from the abort gap is also monitored by CDF. Beam in the abort gap makes the experiments very nervous because they get hit by some of the contents on an abort. Note that it is the small amplitude kick on the rising edge of the abort kickers that pushes beam into experiments.

Some debate between machine and CDF about the usefulness of measuring losses from abort gap rather than the contents.

Halo

- Each experiment has different problems. CDF don't worry about halo so much any more after addition of extra shielding. D0 still suffer.
- Prompt losses from halo – here assume protons lost upstream of experiments causing showers.
- Use of nearby (tertiary in LHC parlance) collimators is not obvious. Pushing them in produces background. Presumably they bite into the tertiary halo and generate showers. Balance between protection and cleanliness to be anticipated.

Halo character

Not totally clear what is populating halo. Beam is breathing: magnet vibrations, quad movements, insertion quad movements with temperature variations "breathing the beam against the collimators".

Anything slow, such as beam-beam, can be mopped up with collimators.

Spikes look common. Fast diagnostics (60 Hz fast time plots) are crucial. The spikes are not fully understood.

Orbit

Originally there were definite orbit control shortcomings at Tevatron. Clear that properly optimized orbit (position and angle) though the detector is important. Things like:

- Big angle through D0 - eating aperture. Beam not centred in detector. Ideally centre beam with zero angle.
- D0 (and CDF have subsided). Important to track this.
- Importance of detector-accelerator alignment noted.
- Importance of Quad alignment noted.

Beam loss

Experiments worry about radiation field in tracking volume, in collision hall. Concerns include radiation damage to silicon, and effect of radiation field on electronics. Note that the experiments didn't properly vet for radiation hardness. Typical SEU effects: lock-up necessitating power cycles.

Worries include:

- Losses during the injection cycle.
- Losses during squeeze. Because of helix manipulations, beam separation drops to three sigma - beam-beam causes beam blow-up, multi-turn effect and beam losses in IR (D0 at the moment).
- NB: collimators are not in during ramp and squeeze. Aperture limit is separators either side of IP.
- Sudden beam loss incidents over a very short time span - leading to silicon damage. Such events include: pre-fires, messy aborts (NB Tevatron aborts on quenches not losses).

Vacuum

Vacuum is definitely an issue. Locally bad vacuum clearly can cause problems. E.g. F sector graphite and halo induced heating.

TEVATRON - EXPERIMENTS

Instrumentation

Clear that experiments have done well to

1. Protect themselves;
2. Provide additional diagnostics.

CDF have fast scintillators in front of triplets, which give data on the abort gap, the halo and proton losses. These have proved very useful. They answer important questions: What particles? Where are they coming from?

Also:

- Dedicated BLMs feeding to abort channel

- Diamond BCMs using new BLM electronics feeding abort loop (1 legitimate dump since installation).

Other measures include appropriate interlocks (if roman pots not where they should be - switch off silicon).

Other monitoring introduced includes seismometers, these have picked up on quad vibrations due to traffic.

Monitoring

Experiments feed machine with a lot of data including: transverse beam position, real-time calculation of shape of luminous region - including hourglass.

CDF pulls in a lot of stuff: BLMs, RF (klystrons, modulators), abort gap, vacuum, and separators. Take an active participation in accelerator monitoring. Try to avoid knock-on in sudden MP events.

Culture

It is very important to build up relationship between machine and experiments. Foster cross-domain problem solving. (Note existence of fixed target culture at Fermilab before the Tevatron.)

CDF specific

- Shielding, the canonical example: muons - hard brem - into EM calorimeter – 30 to 80% of triggers. Low angle elastic scattering from gas - bad vacuum - adjacent roman pots acting as collimators. Gap in shielding.
- Scattering from collimators
- Cleaning up vacuum had a huge effect.

Improved control of accelerator beam parameters (coupling etc.) has had a big effect. (Backgrounds are an order of magnitude lower - although not sure why).

- St. Catherine's day massacre: sagging bellows plus bad orbit - showering into ff hadron cal - glowed like the sun - lots of dead electronics.
- A few years into the run a collimator was added before the low betas on the proton (higher intensity) side of CDF. It was beefed up a year later. This definitely helped in cases of kicker pre-fires or messy aborts, though Rick thinks there were still some damaging incidents after it was put in.

HERA - MACHINE

- Advice for good beam conditions in physics - leave the beam alone.
- Beam quality at injection is very important – some beam emittance growth during the ramp.
- Display beam loss sum signal.
- Spikiness again an issue.
- Orbit at the experiments important for BG – tune on angle/position and global beam parameters.
- Currents of all experiment's sub-detectors available on request
- The exquisite sensitivity of the beam and thus beam conditions to the tune was noted.
- Orbit bumps used to minimize non-linear offsets.

HERA - EXPERIMENTS

In general, the BG at HERA was dominated by synchrotron radiation from leptons, particularly after the IR upgrades. Of relevance to the LHC:

- Importance of possible out-gassing, gas hit by protons – secondary showers etc. Related is HOM losses and local heating.
- Importance of dynamic vacuum increase and vacuum conditioning and scrubbing runs.
- Single beam calibration runs.
- Got a handle of beam gas composition by looking at multiplicity of beam-gas events.
- High sensitivity to vacuum conditions 2 -12 m from the IP.
- Careful beam steering and beam based alignment.
- Monitoring emphasised as being very important.

See Carsten's conclusions.

RHIC

- Collimators used for BG and abort gap cleaning. Setting of collimator done empirically. Reload settings and the re-optimise to take account of drifts in orbit.
- H & V BLMs on triplet – directionality
- Time structure of losses from scintillators.
- IR steering useful.
- IR quad vibrations clearly visible – nice plots.
- Collision contamination of BLM signals.
- BG signals include in separation scans.
- Electron cloud leads to dynamic pressure rise – serious enough to prevent data taking and to limit bunch intensity.

LHC – BG SOURCES

Main sources of background enumerated. Briefly

Beam Gas

IP +/- 23 m	Inelastic	beam loss rate in the detector regions depends linearly on the gas pressure
LSS 23 to 270 m	Inelastic	Hadron & Muons Only particles outside outer shielding radius reach IR1 directly
Adjacent arcs	Elastic	Scattered protons caught on tertiary collimators. Depends on residual gas pressure in cold ares – potentially large contribution.

Tertiary collimators

- Tungsten, 1 meter long, on incoming beam,
- Stops protons dead,

- Resulting cascades – additional sources of decay into muons in downstream drift (see V. Talanov),
- Nominal setting: 8.4 sigma in 1 & 5 fully squeezed, crossing angle on. Further out 2 & 8. Going to have to watch these very carefully.

Beam-gas in LSS	BG pushed up somewhat by presence of tertiary collimators
Tertiary halo from collimation system	Direct source of background
Elastically scattered beam-gas from upstream adjacent arc	"The losses on the tertiary collimators from beam-gas scattering in the arcs are potentially the main source of background"
Elastically scattered from collisions	From IP1 to IPs 2 & 8

Other issues

Other issues related to experiments' background conditions include:

- Satellite bunches
- Pressure bumps
- Roman pots
- Optics dependency
- Commissioning and evolution (increasing intensity, crossing angles, squeeze etc.)
- Optimization
- Ions

ESTIMATES OF RESIDUAL GAS DENSITY IN THE LHC

A. Rossi, CERN, Geneva, Switzerland.

Abstract

A short review on estimates of residual gas density in the LHC is presented. Results, presented for stable beam, are strongly dependent assumptions surface properties and beam operating configuration (beam current, energy, etc.) and represent only a 'snapshot' in time for the machine. Constant particle losses are not included at present and constitute a future study.

INTRODUCTION

Beam-gas interactions along the experimental insertion regions (i.e. between two arcs) have been indentified as one of the main sources of background noise to the experiments in the LHC [1], [2] during physics runs.

In the LHC the main gas species are expected to be hydrogen (largely dominant in the cold arcs), methane, carbon monoxide and dioxide. The presence of water should be negligible, given that room temperature sections are conditioned (baking and NEG activation), and that the water will have an extremely low vapour pressure in the cold sections.

In this paper estimates of residual gas density in the LHC are presented. Depending on the specific period of operation, the residual gas density varies with gas sources – mainly ion, electron and photon-induced gas desorption – which depend on the surface properties and on the operating configuration. On the one hand beam vacuum chamber preparation i.e. ex-situ cleaning, in-situ baking (or activation in the case of NEG surfaces), and particle bombardment, influence the gas induced desorption yields. On the other hand the beam current and energy will determine the total ionisation rate, the photon (synchrotron radiation) energy spectrum and flux to the wall, and, the electron flux and energy to the wall.

This paper details some of these dependences and present estimates made for stable proton beam (negligible beam losses) in the ATLAS interaction region, for initial beam operations and including thermal outgassing of the tertiary collimators before the Inner Triplets. The expected density in the arcs and during ion operations is also discussed.

It should be noted that if regular beam losses are expected during physics operation, their effect should be studied and added to the present calculations. Moreover, any other operating configuration should be analysed case by case, depending on the history of the machine at that moment in time.

VACUUM CALCULATIONS

The gas sources included in the simulations code (VASCO [3]) are thermal outgassing and dynamic effects, i.e. beam induced desorption phenomena: ion, electron and photon induced molecular desorption. In the case considered, the vacuum is "stable" (no pressure run away is expected due to the very high distributed pumping and low desorption), and electron cloud build up is neglected.

The results are presented in form of gas density per gas species and hydrogen equivalent gas density, i.e. weighted by the nuclear scattering cross sections as follows:

$$n_{H_2 equiv.} = n_{H_2} + \frac{\sigma_{CH_4}}{\sigma_{H_2}} n_{CH_4} + \frac{\sigma_{CO}}{\sigma_{H_2}} n_{CO} + \frac{\sigma_{CO_2}}{\sigma_{H_2}} n_{CO_2}$$

$$\frac{\sigma_{CH_4}}{\sigma_{H_2}} = 5.4; \ \frac{\sigma_{CO}}{\sigma_{H_2}} 7.8; \ \frac{\sigma_{CO_2}}{\sigma_{H_2}} = 12$$

Variation of input parameters with surface conditions and beam operations configuration

As highlighted before, the parameters determining the residual gas density strongly depends on surface conditions and beam operations. Both thermal outgassing and induced desorption yields may vary by several order of magnitudes depending on surface conditions, i.e. whether the surfaces was in situ baked/activated or if it has been bombarded by particles. Particle flux to the wall, and their incident energy, change with machine operating configuration (mainly beam intensity and energy) and history. Some examples, amongst many others, are given in the following (see talk transparencies for more data)

- NEG properties as a function of activation/venting cycle (aging), and of amount of gas pumped [4].
- Evolution of photon induced gas desorption with accumulated dose - total number of photon impinging on the surface [5].
- Evolution of electron induced gas desorption with accumulated dose - total number of electron impinging on the surface [6].
- Dependence of photon induced gas desorption with photon critical energy [7].

- Dependence of electron induced gas desorption with electron incidence energy [8].

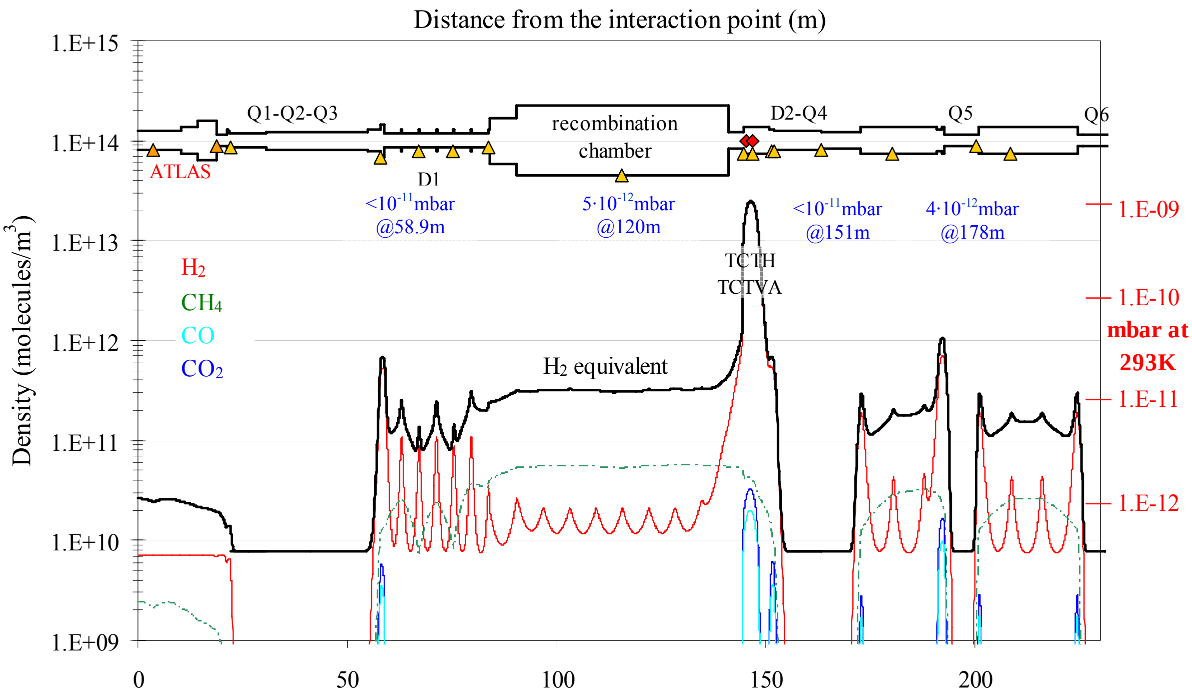


Figure 1: Residual gas density for the main gas species in the ATLAS interaction region as a function of distance from the interaction point for beginning of LHC operations. The region being symmetric, only the right hand side is shown. On the right hand side of the plot, a vertical scale for pressure (mbar) is given for 293K (room temperature). The values given in blue print are the pressure reading at the specified location at the beginning of April 2008.
Conversion factors: 1.E11 molec/m^3 ~ 4.5.E-12 mbar at 293K; ~ 2.7 E-14 mbar at 2K

Machine layout and assumptions

The layout considered [9] includes cold magnets (working at 1.9K or 4.5K) and room temperature sections. The cold magnets are equipped with a beam screen (cooled at 5 to 20K), which intercepts synchrotron radiation, thereby reducing heat load on the cold bore, and pumps gas thus avoiding ion induced pressure instability and guaranteeing a low background pressure. The beam screen distributed pumping works both via cryo-sorption on its own surface and via perforated holes onto the cold bore surface. In the calculations, cryo-sorption on the beam screen is neglected. The room temperature sections are, for most of their length, coated with Non Evaporable Getter. NEG coating is employed to prevent electron multipacting, given the low secondary electron yield after activation at a temperature between 160 and 200ºC for 2 hours, and to ensure low desorption and the gas pumping necessary for ion induced desorption stability and low background pressure. All room temperature sections are being baked-activated. In the calculations presented, NEG pumping is assumed to be 1/10 of a “freshly” activated NEG, i.e. of a NEG surfaced activated for the first time and never exposed to air.

RESULTS

Insertion regions

Residual gas density estimates presented so far [9, 10], are for stable beam, i.e. assuming no particle losses. Furthermore, they do not include the effect of collimators, introduced in the experimental interaction regions only at a later stage. Thermal outgassing has been fully characterised for each collimator installed in the machine [11]. After baking, it is dominated (by 90% or more) by hydrogen. Dynamic effects have been measured in the SPS with an unbaked graphite collimator In that case, as it was presented during the workshop [12], the pressure at the collimator varied from about 1. to 5.E-09 mbar, with hydrogen being the main gas. In the case of the experimental regions, the TCTH and TCTVA tertiary collimators, installed to protect the Inner Triplets from quenching, are made out of tungsten and are baked. The experience accumulated in the HERA operation show no effect due to proton losses on tungsten collimator, when the base pressure is in the order of 1.E-8 mbar [13]. A similar behaviour is expected in the LHC experimental interaction regions. The residual gas density for the ATLAS insertion region is plotted in Figure 1, for the beginning of LHC operations, including collimator outgassing. In 2008, the proton beam will be composed by 43 bunches of few E10 proton per bunch at 5 TeV. With respect to earlier scenarios (Figure 2 for the CMS interaction region, 44 bunches, 1.5.E11 p/b at 7 TeV, as calculated in [9]), the photon flux is reduced by about a factor of 50. In the first case (as shown in

Figure 1), dynamic effects can be neglected, and the major contribution to density will be given by thermal outgassing.

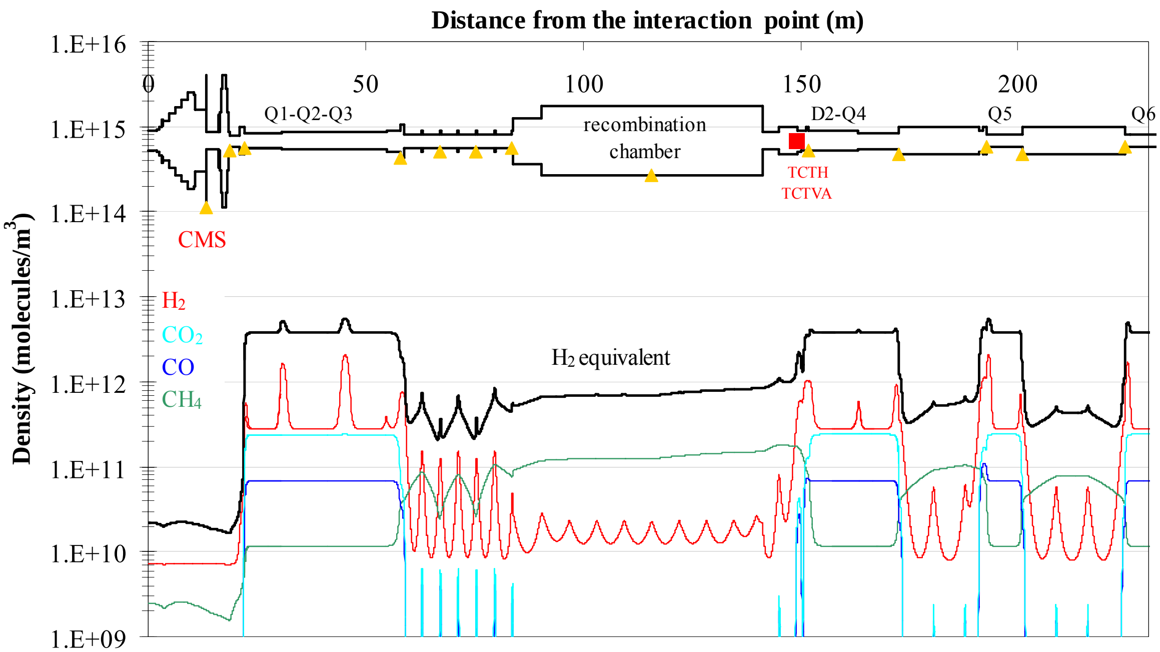


Figure 2: Residual gas density for the main gas species in the CMS interaction region as a function of distance from the interaction point for beginning of LHC operations. 44 bunches – 1.5.E11 proton/bunch at 7 TeV

The results presented in Figure 2, show the effect of beam operating configuration, in this case increasing synchrotron radiation, which cause the gas density to increase. The results, though, did not include the effect of the tertiary collimators, which should be comparable, as discussed before, to the contribution given by thermal outgassing, as calculated in

Figure 1.

Arcs

The gas density in the arcs can be estimated assuming, as for the cold magnets in the experimental insertion regions, the beam screen pumping only via holes (very conservative). In this case, for the same beam parameters, the photon critical energy will be about 3 times as in the experimental insertion regions, and the photon (and photoelectrons) flux about 10 times as much. The induced gas desorption yields for photon and photo-electron can be taken about the same values for similar history. With these hypotheses, the density expected in the arcs will be $\leq$ 20 times the one estimated in the cold sections of the insertion regions. The value given for the LHC design of 1.E15 hydrogen molecules/m^3 (corresponding to 100h beam lifetime) will nevertheless be the upper limit for background calculations.

Ion operations

Estimates for ion operations were presented in [14] and are expected to be in all operating configuration very close to the density calculated for thermal outgassing only. In this case in fact, gas sources other than thermal outgassing can originate only from beam losses, given the fact that

- Residual gas ionisation can be neglected and at ion estimated energy ~ 2eV no gas desorption is expected;

- Synchrotron radiation desorption can be neglected at critical energy ~ 2.8eV;
- No photoelectron or electron multipacting is expected due to low beam current and long bunch spacing.

In the case of ion beam losses, desorption yields are expected to be in the range of ~ 1.E5 molecules/ion [15] for each gas species considered (H_2, CH_4, CO and CO_2). Assuming beam screen holes pumping only (as done before), the continuous ion loss rate leading to the maximum density for 100h beam lifetime would be about 2.E6 ions/turn, which in reality corresponds to a beam lifetime < 2s. Furthermore, even in the case of localised losses as high as quench limit (estimated to 200x100 beam lifetime if lost over one second), pressure recovery would take < 1s. In conclusion, vacuum not expected to be limiting factor to beam lifetime for ion operations.

DISCUSSION AND CONCLUSIONS

Estimates of residual gas density for LHC operations were presented, given emphasis to their dependence on beam operating configuration and surface conditioning (i.e. machine history), and to how they represent only a 'snapshot' in time. Contribution of collimator outgassing in the insertion regions of ATLAS and CMS was calculated. Similar values are to be evaluated for the other experimental insertion regions, even if values are not expected to be very different.

The estimates where carried out for stable beam, assuming no continuous losses. If this assumption is to be reviewed, the effect of such losses should be analysed and added to present values.

Further comments:

- The vacuum group will be working close to the operation to learn how to use information on beam lifetime to renormalise the pressure estimates.
- In the event of a He leak in the arcs, it is expected to have a magnet quench before any effect of pressure can be seen [16]. BLM will be likely to give some useful information, and one should learn if beam lifetime can give an early warning on leaks in general.
- Possible cause of accident in the vacuum system would be fast temperature gradients opening leaks (in LEP, with beam at 80GeV due to synchrotron radiation hitting aperture restrictions), or damage caused by loss of beam.
- HOM are not expected, at present, to give temperature rise in the experimental regions, according to estimates (L. Vos) made at time of design and to measure introduced to prevent it : Cu coating, conical transition, RF contact, RF screen for pumps. This matter under investigation.
- Residual gas density can be computed case by case, working in close collaboration with operations, to establish machine history, and to study machine behaviour with particle losses.

REFERENCES

[1] A.I. Drozhdin et al./Nucl. Insfr. and Met/t. in Phys. Rex A 381 (1996) 531-544.
[2] G.Corti and V.Talanov, Proc. to the 3rd LHC Project Workshop - Divonne-les-Bains, France, 23 - 27 Jan 2006, pp.178-184.
[3] A. Rossi, LHC Project Note 371.
[4] P. Chiggiato, JVC-Gratz-06-2002
[5] O. Gröbner et al. Vacuum, Vol 37, 8-9, 1987
[6] G. Vorlaufer et al., Vac. Techn. Note. 00-32
Copper Unbaked
[7] J. Gómez-Goñi et al., JVST 12(4), 1994 J.
[8] J. Gómez-Goñi et al., JVST A 15(6), 1997
Copper baked at 150ºC
[9] A. Rossi, LHC Project Report 783, CERN Sept. 2004
[10] A. Rossi et al., LHC Project Report 674, CERN Sept. 2003.
[11] N. Hilleret, CERN private communication.
[12] A. Rossi, unpublished.
[13] B. Holzer and B. Nagorny, DESY, mail on April 23, 2008.
[14] A. Rossi, presented at I-LHC meeting on December 9, 2004.
[15] E. Mahner, LHC Project Report 798, CERN
[16] V. Baglin XXX

SIMULATION OF MACHINE BACKGROUNDS

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Abstract

The results of the numerical simulations of the machine background in the low luminosity experimental insertion regions IR2 and IR8 of the LHC are reviewed. The background sources considered include the beam-gas losses in the long straight sections, elastic scattering in the LHC cold sectors and the halo losses at the tertiary collimators. The scheme of the background shielding is also presented and the shielding efficiency for the collimation background is estimated as well.

INTRODUCTION

One of the possible definitions of the machine background describes it as the products of the secondary cascades, initiated by proton losses upstream and downstream of the beam interaction points (IPs), that reach the zones of the experiments from the machine tunnel [1]. Concerning the LHC Project, the first comprehensive review of this subject was done in the Workshop on LHC Backgrounds at CERN in 1996 [2]. There was introduced a concept of the background "scoring plane" (see Fig. 1) as a fictitious boundary between the machine and the experiment, where the simulated background tracks are recorded for the further analysis in the experimental detectors. Splitting the background calculations into two stages appeared to be absolutely critical for the background analysis, taking into account the unprecedented complexity of the Monte-Carlo calculations in both LHC and LHC experiments.

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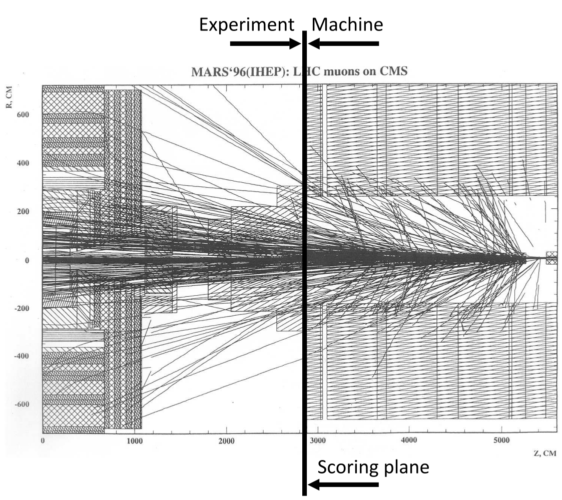

Figure 1: An illustration to the concept of the background "scoring plane" for the background analysis at the boundary between machine and experiment.

Figure 2: Installation of a part of the the ATLAS shielding in the UX15 cavern (a photo from the CERN Multimedia and Outreach Collection).

One of the purposes of the present review is an attempt to demonstrate a dramatic progress, achieved in understanding of this phenomenon during the past decade.

Because the machine background depends on the rate of the proton losses, this component of the secondary radiation in the experimental zones becomes visible with the very first bunch of the particles in the machine. Due to the same reason, the background rate scales with the intensity of the beam and not with the luminosity at the particular interaction point (apart from the component that is deter-

Figure 3: The frame of the blockhouse for the CMS forward shielding at the IHEP workshop (a photo from the IHEP Photo Gallery).

mined by the collision rate in the neighboring IPs). In detail, the background formation depends on practically every machine parameter — optics, apertures, filling scheme, residual gas density in the vacuum chamber, cleaning efficiency etc. — and their combination.

One of the passive measures to protect the experiments from the machine background is the installation of the background shielding at the entrance of the machine tunnel into the experimental zone. Due to the high luminosity in the IPs the LHC experiments at IP1 and IP5 were protected by such shielding from the machine background "by default" (see Fig. 2 and 3) while the shielding at IP2 and IP8 was missing and its configuration was proposed as a result of the presented background analysis.

BACKGROUND SOURCES

For a particular interaction point, the sources and origins of the machine induced background can be grouped as following (see Fig. 4):

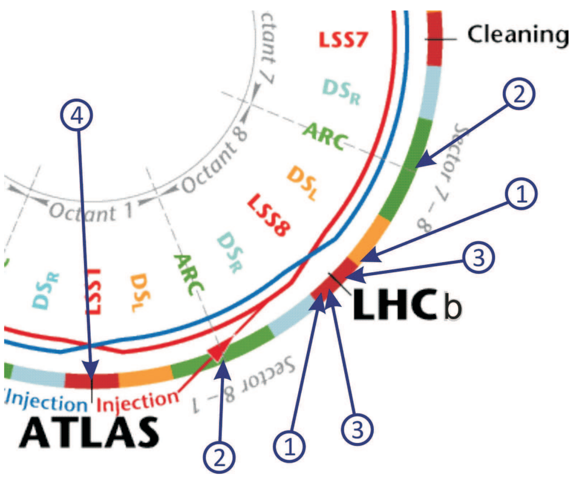

Figure 4: A part of the LHC scheme with the LHCb experiment at IP8 between the betatron cleaning insertion at IP7 and the ATLAS experiment at IP1 (the labels are explained in the text).

1. Beam-gas interactions in the Long Straight Sections (LSSs) that define a background component that strongly depends on the residual gas composition and density, and on the configuration of the limiting apertures in the LSS. An important feature is that the resulting products have a direct line of sight into the IP.

2. Elastic scattering of the beam particles on the residual gas in the cold sectors of the machine, which, depending on the scattering angle, may result in a proton loss at the next aperture limitation and thus strongly depends on the optics in the LSS.

3. Tertiary halo (also called "tails from collimation") that is comprised of the out-scattered protons not absorbed in the cleaning insertions and hence depends on the configuration of the collimation for a particular scenario of the machine operation. What is important is that the formation of the tertiary halo is different for LHC Beams 1 and 2 and for each IP a clear asymmetry of the tertiary losses is predicted.

4. Collisions in the neighboring IPs that can give a product lost in the next LSS upstream or downstream. This is the only background source that directly depends on the luminosity at some IP and so most probably can be considered relevant only for the case of the IP1 influence on the background at IP2 and IP8.

These background sources are evaluated below for the insertion regions IR2 and IR8, basing on the best available background estimates.

BEAM-GAS LOSSES IN THE LSSS

Simulation of the secondary cascades in the model of the LSS assuming the uniform distribution of the residual gas pressure gives the profile of the particle flux at the scoring plane depending on the layout of the insertion (see Fig. 5). As it was found, the dependence of the background flux from the beam-gas losses in the LSS on the machine optics was rather weak in the studied range of the β^* values at IP8 [3]. The absolute values for the background flux are obtained by the introduction of the residual gas density profile [4] for some period of the machine operation (see Fig. 6). The resulting distributions allow to study the formation of the background on the length of the LSS and to identify the background origins, as shown in Fig. 7.

In the nominal machine operation, the average H_2 equivalent density of 6.5×10^{12} mol/m^3 in the LSS results in the background muon flux of $\sim 10^6$ particles/s at the entrance to the IP2 experimental zone [5]. Apart from the fact that at the machine start-up period the predicted residual gas density can be factor 20 higher [4], one of the reasons to care

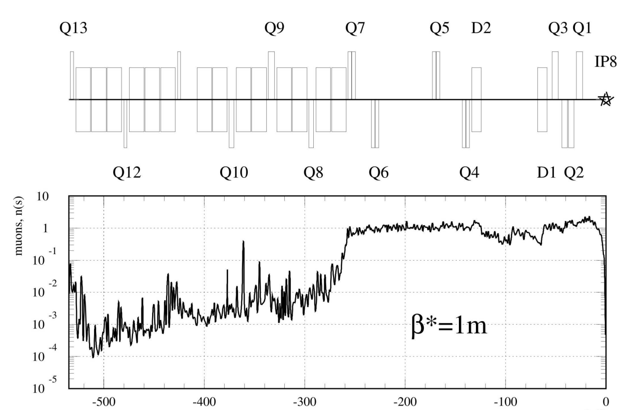

Figure 5: Number of the background muons at the IP7 side of IP8 as a function of the primary loss distance to the interaction point, given per unit of the linear density of the beam-gas loss rate in LSS8.

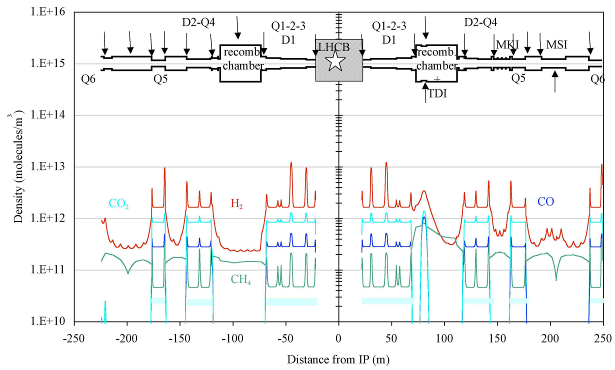

Figure 6: Density profiles for the different components of the residual gas in LSS8 (courtesy of A.Rossi).

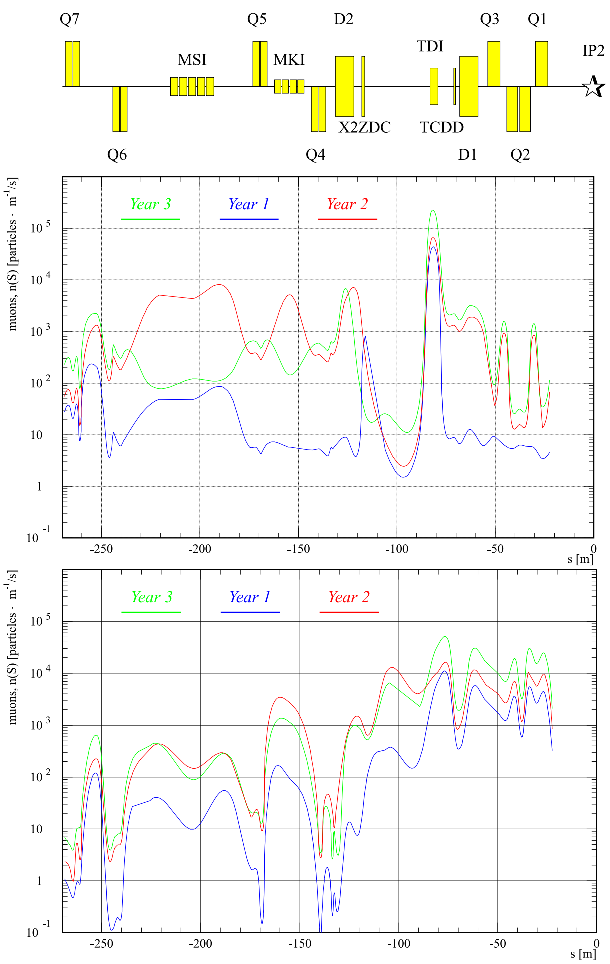

Figure 7: Number of the background muons as a function of the primary (top) and last (bottom) hadron-nucleus interaction distance to IP2, for three different scenarios of the machine operation.

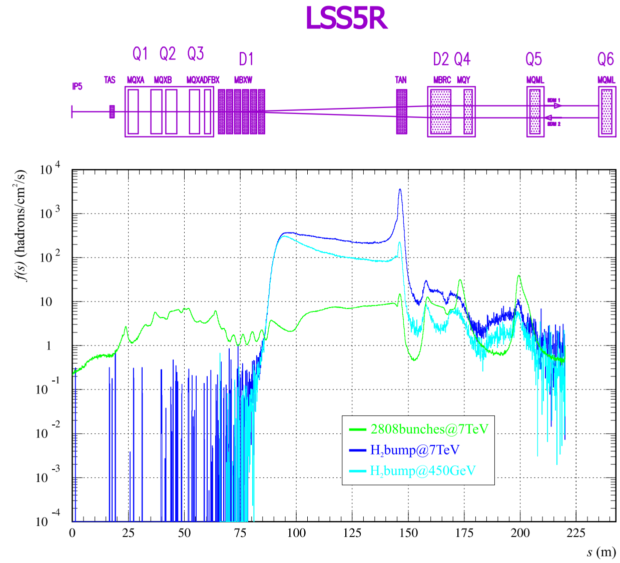

Figure 8: Hadron flux density $f(s)$ as a function of the distance to IP5, for three cases of the beam-gas losses in LSS5R considered.

about the beam-gas losses in the LSSs was studied in [6], considering the possible use of the radiation monitors as a vacuum diagnostic. It was taken as an input that a pressure bump 10. . .100 higher than the average gas density can exist locally for more than 100 hours due to the high NEG pumping capacity. The results of the calculations showed that in this case a few meter bump can produce the rate of the background compared to the whole LSS (see Fig. 8) and this increase in the background will most probably be the only way to detect the abnormal gas pressure.

SCATTERING IN THE COLD ARCS

Depending on the resulting angle the elastic scattering on the residual gas components may contribute to the primary beam halo, giving a proton that will be lost at the next aperture limitation, even before reaching the cleaning insertion. In the experimental insertion IR8, the losses in the low-β region between D1 dipole and Q1 quadrupole were found to be the most critical [7] (see Fig. 9). The sum of the background rates from the beam-gas losses in LSS8 and from the elastic scattering in the cold arcs, estimated using a very approximative value of 5×10^{14} mol/m^3 for H_2 equivalent gas density in the cryogenic vacuum chamber, is given in Table 1 for IR8, for several background components and different operation scenarios. As can be seen, the background rates at IP8 may vary from few MHz to few dozens of MHz, depending on the LHC Ring number and assumed vacuum conditions.

These estimates have been obtained without tertiary collimators (TCTs) that are by design a new aperture limitation in the LSSs. An attempt to evaluate the effect of the TCTs on the protons elastically scattered in the LHC cold sectors has been already done for the TCTs in IR1 at the

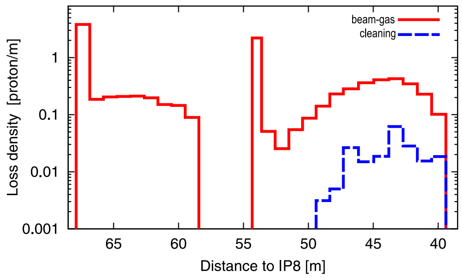

Figure 9: Loss density near the D1–Q1 low-beta section of LSS8L, for the beam-gas scattering in the section 78 (solid histogram) and the betatron cleaning inefficiency (dashed) (courtesy of I.Bayshev).

Type of particle	Particles per bunch (a) β^* = 1 m, I = 0.3 I_n			(b) β^* = 10 m, I = I_n		
	Ring 1 at -1 m from IP8			**Ring 2** at 19.9 m from IP8		
	Year 2 Beginning (a)	Year 2 +10 days (a)	Year 3 +90 days (b)	Year 2 Beginning (a)	Year 2 +10 days (a)	Year 3 +90 days (b)
muons	1.07	0.015	0.008	1.42	0.026	0.030
neutrons	3.43	0.065	0.059	5.09	0.185	0.423
p + π + K	7.68	0.133	0.104	8.54	0.194	0.304
Total	12.18	0.213	0.171	15.05	0.405	0.756

Table 1: Rates of the background components at the IP8, [particles/bunch] for the LHC Ring 1 and 2, two options of β^* in the IR8 and three cases of the residual gas pressure at different stages of the machine operation.

13.5 σ distance from the beam [8]. It was found that up to 90 % of the halo protons that were previously lost on the apertures in IR1 are now intercepted by the TCTs, but the resulting flux of the background muons at the cavern entrance in this case is $\sim$ 4 times higher than from the beam-gas losses in the LSS itself (see Fig. 10).

BACKGROUND SHIELDING

Heavy shielding that protects the experiments at IP1 and IP5 from the secondary radiation from the collimator in front of the Q1 quadrupole also suppresses the machine background at the tunnel entrance into the experimental zones. Due to the low luminosity, initially there was no

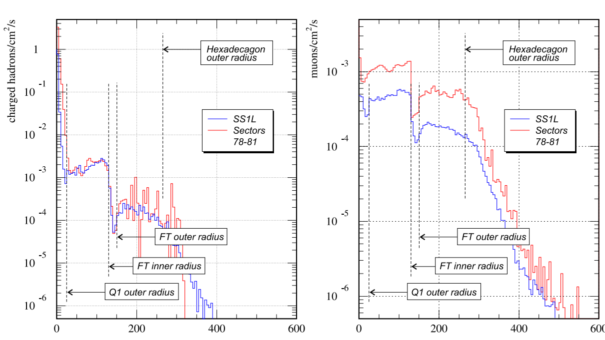

Figure 10: Charged hadron and muon flux density [particles/cm^2/s] at the UX15 entrance due to the beam-gas losses in LSS1L (blue) and sectors 78-81 (red).

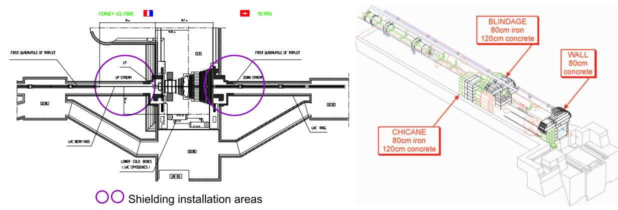

Figure 11: Top view of the UX85 cavern with the layout of the machine elements and the proposed locations of the background shielding (left) and layout of the shielding at the IR7 side of IR8 (right).

Figure 12: Machine background shielding in IR8, as installed at the IR1 side around the Q1 quadrupole (courtesy of D.Lacarrère).

such shielding at IP2 and IP8 until its position and configuration was proposed (see Fig. 11) basing on the background calculations and various mechanical constraints [9].

Full configuration of the shielding on both sides of IR8 includes 120 cm of concrete and 80 cm of iron, divided into blindage and chicane (an additional 80 cm concrete wall is installed at the IR7 side). Already installed (see Fig. 12) in IR8 ”staged” configuration of the shielding has the reduced number of iron blocks. The effect of the shielding has been estimated for the background from the beam-gas losses in LSS8 and it was found that the full shielding reduces the charged hadron flux by a factor of 1.6–1.9 (and by a factor of $\sim$ 50 above the radius of 25 cm) and muon flux by a factor of 2.4–2.6, for the IR1 and IR7 sides of LSS8.

COLLIMATION BACKGROUND

Machine background from the tertiary losses in the LSS has been estimated for the case of the losses at two tertiary collimators installed in LSS8L (see Fig. 13). The distribution of the losses along the LHC Beam 1 has been calculated by the Collimation Project (see Fig. 14) for the full collimation and ideal machine, nominal settings of all collimators (TCTs in the IR8 at 8.3σ), nominal beam parameters and optics with the β^* of 10 m at IP8.

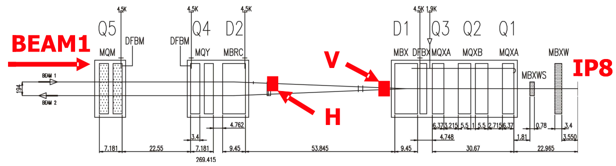

Figure 13: Positions of vertical and horizontal TCT collimator in LSS8L.

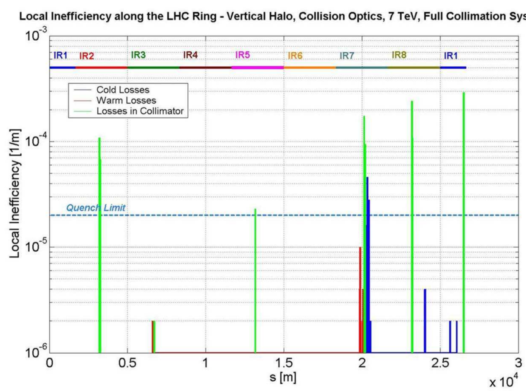

Figure 14: Loss distribution around the LHC Ring 1 for the primary losses at the betatron cleaning in IR7.

The cleaning inefficiency for the TCT(V,H) at the IR7 side of IR8 was estimated equal to (0.84, 0.22)$\times 10^{-3}$ for the vertical halo and (0.003, 0.3)$\times 10^{-3}$ for the horizontal one. To get the absolute values of the background particle fluxes, the value of 2.8×10^{9} protons/s for the losses on the primary collimators in IR7 was used that corresponds to the 30 h beam lifetime [10]. Under these conditions, the background from the losses at the TCTV is dominating, resulting in the flux of 5.7×10^{6} charged hadrons/s and 1.8×10^{6} muons/s at 1 m from the IP8 at the IR7 side [11]. These numbers are of the same order as the estimates for the background flux from both types of the beam-gas losses. The radial distribution of the collimation background is absolutely different — the particles from the beam-gas losses are the main contribution to the background around the beam line, while the collimation background clearly dominates at the large radii (see Fig. 15).

The efficiency of the staged shielding configuration was evaluated also for the collimation background in LSS8. Figure 16 gives the transverse distributions of the background flux within the tunnel entrance at the IR7 side of IP8, for the vertical halo losses at the TCTV. The full shielding at the IR7 side removes completely the charged hadron background and $\sim$ 2/3 of the background muons [11]. The efficiency of the staged shielding is less: $\sim$ 14 % of the charged hadrons and 45 % of muons are still visible after the shielding, mainly distributed in the areas where the iron shield is not installed.

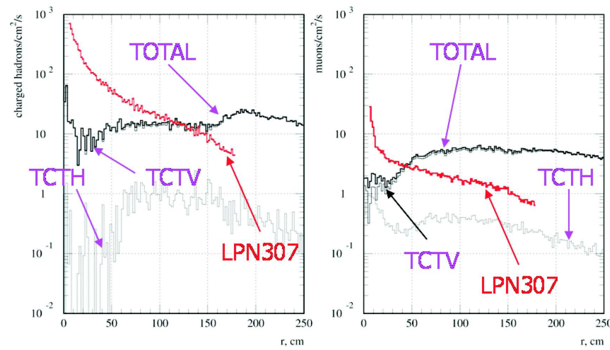

Figure 15: Particle flux density, [particles/cm^2/s] at 1 m from IP8, calculated for the losses at the TCTV/H, compared to the background from the beam-gas losses in LSS8L.

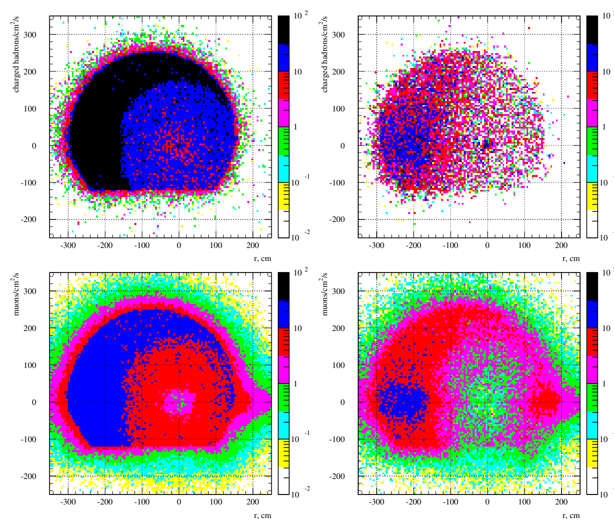

Figure 16: Particle flux density for charged hadrons (top) and muons (bottom), without (left) and with staged shielding (right).

BACKGROUND AT BRAN MONITORS

The issue of the machine background in IR2/8 is also extremely important for the operation of the collision rate monitors (BRANs) [12]. BRANs are installed in LSS2/8 in front of the D2 dipole, in the same region as the horizontal collimator TCTH. Contrary to the insertion regions IR1 and IR5, the detectors at this location are not shielded from the background from the tertiary collimator since there is no TAN absorber in the low luminosity insertions. In the case of the tertiary halo losses at the TCTH the BRANs in IR2/8 fall inside a peak of both charged and neutral background particle flux (see Fig. 17).

To estimate the background at the BRANs, the same set of the maps of the tertiary losses were used as in the evaluation of the background shielding in LSS8 (see Fig. 18). An example of the calculated background flux map at the BRAN is given in Fig. 19, compared to the distribution of

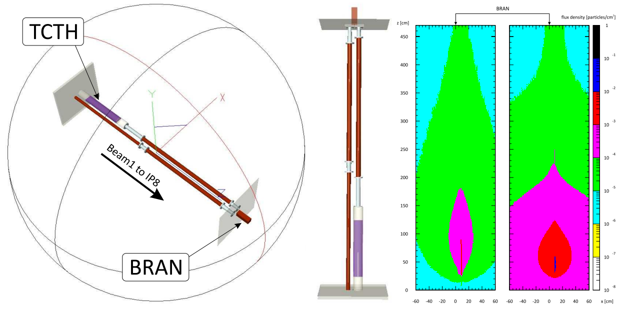

Figure 17: BRAN monitor position in the LSS8 (left) and the maps of charged and neutral components of the collimation background (right).

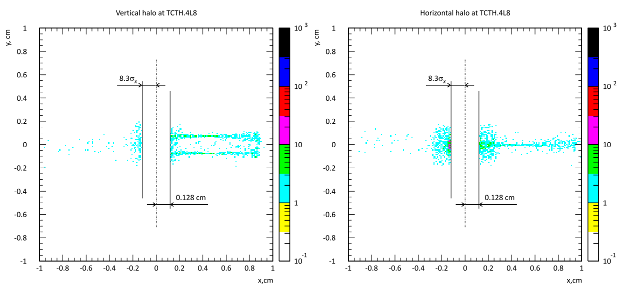

Figure 18: Vertical (left) and horizontal (right) tertiary halo losses at the TCTH in IR8.

the particles from the p-p collisions at the IP [13]. As can be seen, for the neutron flux density the estimated values are of the order of magnitude and equal to few 10^{-2} particles per primary event. For few 10^6 protons/s lost at the TCTH and 16 MHz event rate at IP8 this gives $\sim$ 10:1 signal to background ratio at the BRAN, for the neutron flux at the nominal machine operation.

However, if the rate of the losses at the TCTH will increase due to some abnormal spike of the halo, this ratio may change to the opposite one. The same is true for the BRAN operation at IP2 where the collisions are foreseen at the luminosity much lower than at IP8. Examining the loss distributions in Fig. 18, it may be proposed to put the collimators in IR2/8 in a more "relaxed" position since opening the TCT jaws just twice comparing to the assumed

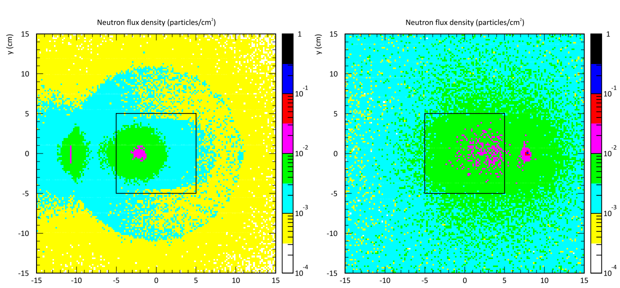

Figure 19: Neutron flux density per 1 p-p event in the IP (left) and per 1 proton lost at the TCTH (right).

settings would allow to decrease significantly the rate of the tertiary losses and the rates of the produced collimation background in the low luminosity insertions.

CONCLUSION AND OUTLOOK

Beam-gas losses in LSS2/8 and elastic scattering in the cold sectors of the machine between IP2/8 and the closest cleaning insertion in total result in the background flux at the entrance into the experimental zones of few 10^6 muons/s (hadron flux in a general case is an order of magnitude larger). For both sources of the beam-gas losses, a fresh set of the residual gas density estimates exist and the numbers above should be updated with these new estimates and the realistic model of the installed shielding in IR2/8.

Tertiary losses at the collimators in the experimental insertions, calculated for the nominal operation, add another few 10^6 muons/s to the background flux. The efficiency of the installed staged shielding for this background source is 86 % for charged hadrons and 55 % for muons, for the maximum of the tertiary losses at the IR7 side of IR8.

As it was shown, the rate of the collimation background (including the contribution from the primary halo losses at the TCTs due to the elastic beam-gas scattering) depends on the optimal settings of the collimators during nominal operation and start-up, and may be critical not only for the experiments at IP2 and IP8, but also for the luminosity measurement with the BRAN monitors.

ACKNOWLEDGMENTS

The author is grateful to K.M. Potter and E. Tsesmelis for the continuous support of this work in the TS/LEA Group.

REFERENCES

[1] G. Corti and V. Talanov, "Aspects of Machine Induced Background In The LHC Experiments", In: Proc. of the LHC Project Workshop — Chamonix XV, 2006, p.179–185.

[2] K.M. Potter (editor). Proc. of the Workshop on LHC Backgrounds, CERN, Geneva, March 22, 1996.

[3] I. Azhgirey, I. Baishev, K.M. Potter *et al.*, "Methodical Study of the Machine Induced Background Formation in the IR8 of LHC", LHC Project Note 258, CERN, Geneva, 2001.

[4] A. Rossi and N. Hilleret, "Residual Gas Density Estimations in the LHC Experimental Interaction Regions", LHC Project Report 674, CERN, Geneva, 2003.

[5] I. Azhgirey, I. Baishev, K.M. Potter *et al.*, "Machine Induced Background in the Low Luminosity Insertions of the LHC", LHC Project Report 567, CERN, Geneva, 2002.

[6] V. Baglin, V. Talanov, T. Wijnands, "Radiation monitors as a Vacuum Diagnostic for the Room Temperature Part of the LSS", LHC Project Note 378, CERN, Geneva, 2006.

[7] I. Baichev, J.B. Jeanneret, K.M. Potter, "Proton Losses Upstream of IP8 in LHC", LHC Project Report 500, CERN, Geneva, 2001.

[8] V. Talanov, "Estimation of the Machine Induced Background for the Commissioning Period with Tertiary Collimators in the IR1 of the LHC", LHC Project Note 371, CERN, Geneva, 2005.

[9] I. Azhgirey, I. Baishev, K.M. Potter *et al.*, "Evaluation of Some Options for Shielding from Machine Induced Background in the IR8", LHC Project Note 307, CERN, Geneva, 2002.

[10] R. Assmann, "Collimators and Cleaning: Could This Limit The LHC Performance ?", In: Proc. of the LHC Performance Workshop — Chamonix XII, 2003, p.163–170.

[11] R. Assmann, D. Macina, K.M. Potter *et al.*, "Tertiary Halo and Tertiary Background in the Low Luminosity Experimental Insertion IR8 of the LHC", In: Proc. of EPAC 2006, Edinburgh, p.532-534; LHC Project Report 953, CERN, Geneva, 2006.

[12] E. Bravin, S. Burger, C. Dutriat *et al.*, "Collision Rate Monitors for LHC", In: Proc. of PAC 2007, Albuquerque, p.4171-4173; LHC Project Report 1024, CERN, Geneva, 2007.

[13] H. Burkhardt, D. Macina, V. Talanov *et al.*, "Numerical Study of the Very Forward Background from the Proton-Proton Collisions in the Experimental Insertions of the LHC", In: Proc. of PAC 2007, Albuquerque, p.1619-1621; LHC Project Report 1049, CERN, Geneva, 2007.

MACHINE-INDUCED BACKGROUNDS: THEIR ORIGIN AND LOADS ON ATLAS/CMS*

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Abstract

A detailed analysis of machine-induced backgrounds (MIB) in the LHC collider detectors is performed with focus on origin and rates for three sources: tertiary beam halo, beam-gas interactions and kicker prefire. Particle fluxes originating from these operational and accidental beam losses are carefully calculated with the MARS15 code and presented at the entrance to the ATLAS and CMS experimental halls. It is shown that background rates in detector subsystems strongly depend on the origin of MIB, particle energy and type. Using this source term, instantaneous and integrated loads on the detectors and impact on the detector performance can be derived.

INTRODUCTION

The overall detector performance at the LHC is strongly dependent on the background particle rates in detector components. Particles originating from the interaction point (IP) are thought to be the major source (>99%) of background and radiation damage in the ATLAS and CMS detectors at nominal parameters and with a well tuned machine. Beam loss in the IP vicinity is the second source of background, but minor at nominal conditions [1, 2]. Particle fluxes generated by such beam interactions are called machine-induced backgrounds (MIB). As shown in [2], the relative importance of this component can be comparable to the first one at early operation of the LHC because MIB is mostly related to beam intensity and not luminosity, and tuning of the LHC will require substantial time and efforts. These facts are confirmed by the Tevatron experience.

Even in good operational conditions in an accelerator, some particles leave the beam core – due to various reasons [3] - producing a beam halo. Particle fluxes, generated in showers developed at halo interactions with limiting apertures, are responsible for MIB rates and radiation loads in accelerator and detector components. A multi-stage collimation system reduces these rates at critical locations by orders of magnitude; e.g., a factor of 10^3 at the Tevatron [3]. In addition to these slow losses, there is a probability of fast single-pass losses, caused, e.g., by an abort kicker prefire, when a certain number of bunches can make it through an unprotected section of the ring and be lost in front of the detector. Impact on the machine and collider detectors can be quite severe [4]. Tertiary collimators - as the last line of defense for slow and fast beam losses in the IP vicinity - are mandatory in the LHC, as proven at the Tevatron.

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In this paper, a description of three terms of MIB is given. The proton losses on the IP1 and IP5 tertiary collimators are calculated using a collimation version of SixTrack [5]. Beam-gas interaction modeling as well as comprehensive simulation of hadronic and electromagnetic showers induced in the LHC components are performed with the 2008 version of the MARS15 code [6]. All essential details of the machine, interface, detectors and conventional constructions in ±550-m regions of IP1 and IP5 are taken into account: 3-D geometry, materials, magnetic fields, tunnel and rock outside (up to 12-m radially). Note that the code and approach were successfully benchmarked over 15 years at the Tevatron and DØ and CDF collider detectors. Particle fluxes above 20 MeV at the interface scoring plane at z=22.6m from the IP are calculated for further tracking in the ATLAS and CMS detectors. Representative distributions are shown, with respective source term files available to the detector collaborations.

MIB SOURCES IN IP1 AND IP5

1. Collimation Tails ("tertiary beam halo")

The first term of MIB for the experiments are protons escaping the betatron and momentum cleaning insertions (IP7 and IP3, respectively) and being intercepted by the tertiary collimators TCT. This term, related to the inefficiency of the main collimation system, is called "tails from collimators" or "tertiary beam halo". The TCTs are situated between the neutral beam absorber (TAN) and D2 separation dipole at about 148m on each side of IP1 and IP5. It is noted that most of protons coming from IP3 and IP7 would be lost in the triplet (closer to the experiment) if they were not intercepted by the TCTs. Assuming an ideal machine (no alignment and magnet errors) at 7 TeV and the high-luminosity insertions (IP1 and IP5) squeezed to $\beta^* = 0.55$m, we only take into account the contribution from the betatron cleaning in IP7 at the rate of 8.3×10^9 p/s for a 10-hr beam lifetime and nominal intensity. The collimators were set to the nominal settings, in this case 8.3σ for the tertiary collimators, to fully protect the triplet magnets. The resulting loss rates on the TCTs are 2.61×10^6 p/s and 4.28×10^6 p/s for Beam-2 approaching IP5 and Beam-1 approaching IP1, respectively. Corresponding loss rates on the other sides of these insertions are about 10% of those. 95% of muons illuminating ATLAS and CMS in a radius of 3m are generated at 50<z<148m from the IP. Note that the above rates are ~45 times higher for the transient 0.22-hr beam lifetime. Contributions from the momentum cleaning are thought to be substantially lower.

2. Beam-Gas Interactions

Beam-gas interactions [7, 8] comprise the second term of MIB. Products of beam-gas interactions in straight sections and arcs upstream of the experiments and not intercepted by the collimation system have a good chance to be lost on limiting apertures in front of the collider detectors. As described in [7, 8], the main process of beam-gas interaction, multiple Coulomb scattering, results in slow diffusion of protons from the beam core causing emittance growth. These particles increase their betatron amplitudes gradually during many turns and are intercepted by the main collimators before they reach other limiting apertures. Similar behaviour takes place for small-angle elastic nuclear scattering. In inelastic nuclear interactions, leading nucleons and other secondaries are generated at angles large enough for them to be lost within tens or hundreds of meters of the LHC lattice after such interactions.

The rate of beam-gas interactions is proportional to the beam intensity and residual gas pressure in the beam pipe. Longitudinally it follows the pressure maps of [9]. The points of beam interactions with residual gas nuclei can be sampled from these maps for the given operational conditions [10], using corresponding lattice functions. At the nominal beam current, the expected rates of inelastic nuclear interactions (m^{-1} s^{-1}) in IP1 and IP5 are about 10 in the UX detector region, 400 in the inner triplet and cold segments of the matching section, 20-30 in the warm sections in-between, and 8×10^{3} in the arcs [11]. Detailed studies since the first papers on MIB in LHC [1, 2] have shown that inelastic and large-angle elastic nuclear interactions in the 550-m regions upstream of IP1 and IP5 are mostly responsible for the beam-gas component of MIB Fig. 1). The total number of elastic and inelastic nuclear interactions in these regions for each of the beams coming to IP1 and IP5 is 3.07×10^{6} p/s which is used for normalization in this paper. Despite a high gas pressure – and beam-gas interaction rate – in the arcs, most muons coming to ATLAS and CMS are generated in ±400-m regions around IP1 and IP5. The others are absorbed/scattered in the magnets and rock (especially that tangent to the orbit).

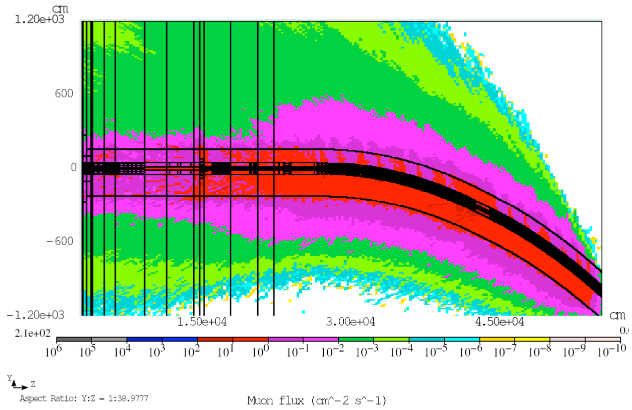


Figure 1: Muon flux isocontours in the orbit plane at 22<z<550m upstream IP1 and IP5.

At certain conditions, an additional contribution can come from medium-angle elastic scattering [8]. Such a process can result in a substantial increase of the betatron amplitude and, if not intercepted by the main collimators, the scattered protons can be lost in the vicinity of the experimental insertions. This single-pass process, taking place between the cleaning insertions and 550-m regions around IP1 and IP5, can give some rise to the "scraping" rate on the TCTs adding to MIB.

3. Kicker Prefire

The third term of MIB is generated by remnants of a mis-steered beam uncaptured in the IP6 beam dump system. These irregular fast losses are caused by machine failures, such as irregular dumps. As was first shown in [4], the impact on the machine and collider detectors – without a multi-component protection system in IP6 [12] - can be disastrous. The worst design case is a dump kicker module prefire. If such an event is detected, the remaining 14 modules will be fired within 700ns to dump the beam [13]. Since the dump kicker modules need a certain time to reach their nominal strength (~3μs), a certain number of bunches will be deflected before they are extracted at the end of one turn.

The scenario considers a kicker prefire, assuming a $\pi/2$ phase advance between the pre-firing kicker magnet and the TCT tertiary horizontal collimator in front of IP5 (worst case). This results in maximum deflection of the beam at the location of the TCT [14]. Furthermore it is assumed that the dump protection is misaligned so that protons with a betatron amplitude between 8.3σ (nominal setting of the collimator at 7TeV and β^* = 0.55m in IP5) and 10σ will hit the TCTs.

Our calculations have shown that some protons of 8 mis-steered bunches of Beam 2, separated by 25 ns and each of 1.15×10^{11} protons, can hit the IP5's TCT. The total amount of protons deposited on the TCT is of the order of 2 to 2.5 full bunches. Particles with a deflection below 5.08σ (μrad) pass through IP5 and may hit the IP7 collimators or are extracted after one turn, while those with a deflection above 10.28σ (μrad) are all assumed to be absorbed by the IP6 dump system (Fig. 2).

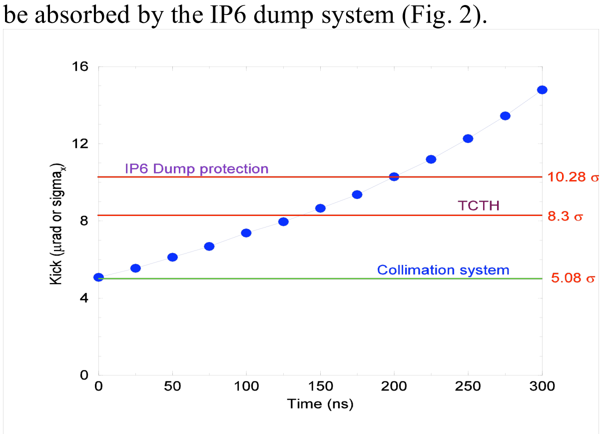
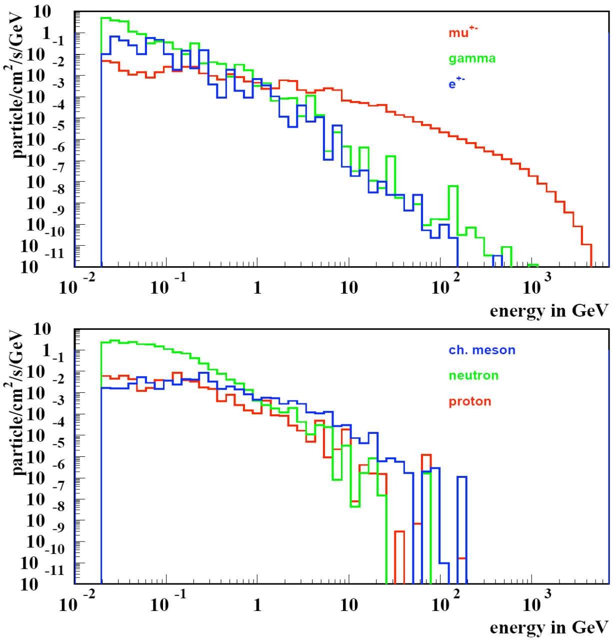


Figure 2: Angular kick for 13 bunches at prefire of the MKD.OR6.B2 beam dump kicker module.

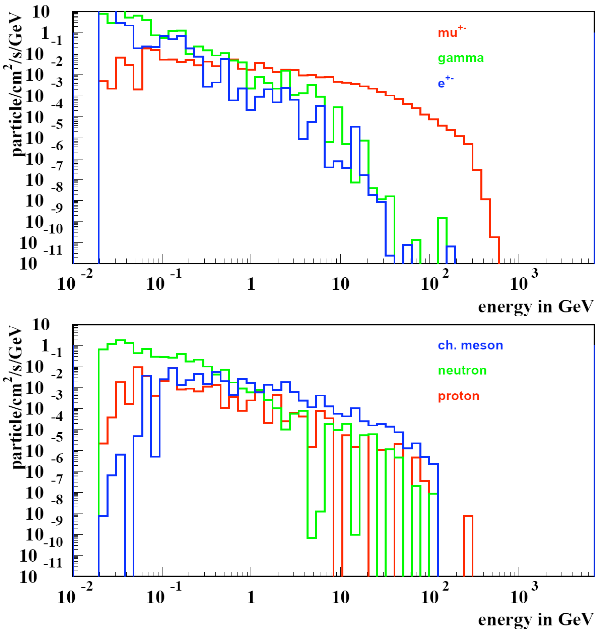
BEAM 2 MIB ON CMS

In this section, side-by-side comparison is given for various distributions of particles crossing the z=22.6m plane and approaching the IP5 with Beam 2 towards CMS, i.e., counter-clockwise. MARS15 results for hadrons, muons, photons and electrons above 20 MeV are presented for the nominal conditions and are normalized to cm^{-2} s^{-1} for the tertiary halo and beam-gas cases, and to cm^{-2} per accident for kicker prefire. The distributions cover laterally the entire detector: inner tracker, forward and barrel calorimeters, and muon chambers.



Energy spectra at CMS (1.7 < r < 100 cm): beam-gas, MARS15

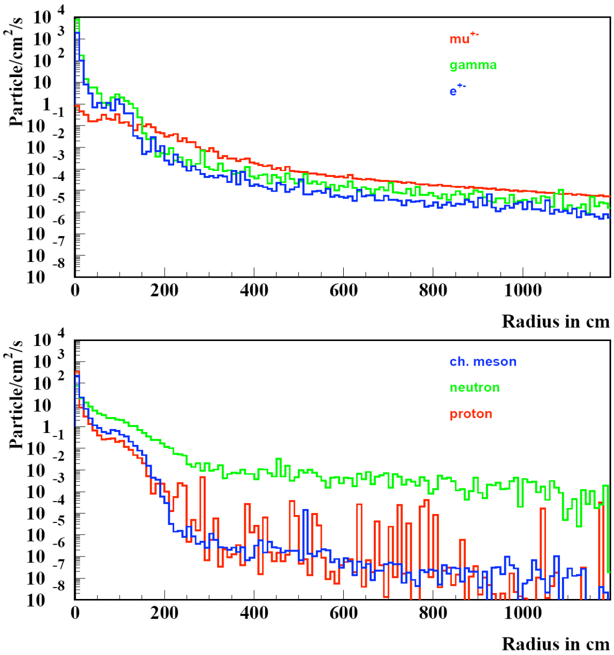
Figure 3: Particle energy spectra at z=22.6 m from IP5 in the 1.7 < r < 100cm region for beam-gas.



Energy spectra at CMS (1.7 < r < 100 cm): beam-halo, MARS15

Figure 4: Same as in Fig. 3, for tertiary halo.

Figs. 3 and 4 show particle energy spectra at 1.7<r<100cm for beam-gas and tertiary halo, respectively. The spectra are not very different for the two sources, but muons up to 5 TeV are present for beam-gas while there are no muons above 0.6 TeV induced by beam losses on the TCT collimators (much shorter decay path in the later case). At energies below 1 GeV, particles other than muon dominate. Radial distributions are shown in Figs. 5 and 6. The distributions are not that different for the two sources at r < 3 m, but at larger radii they are pretty flat for beam-gas and drop rapidly (except neutrons) for tertiary halo.



Radial distributions at CMS (E > 0.02 GeV): beam-gas, MARS15

Figure 5: Radial distributions of particle fluxes (E>20 MeV) at z=22.6 m from IP5 for beam-gas.

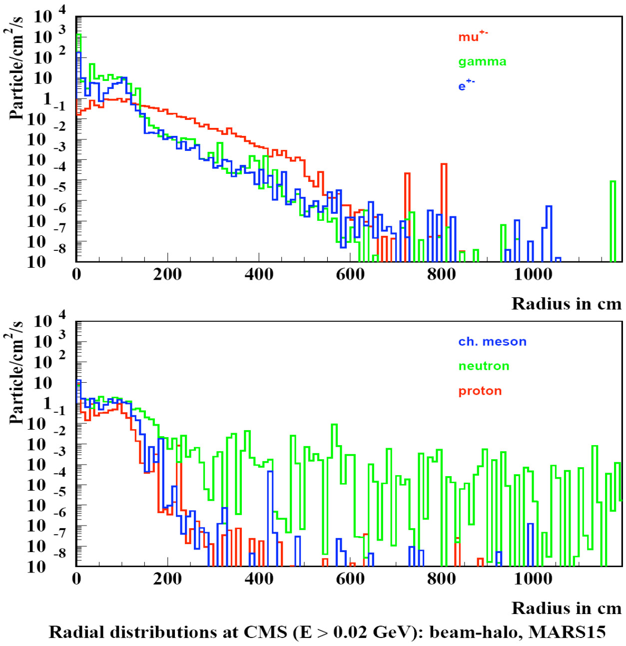


Figure 6: Same as in Fig. 5, for tertiary halo.

Muon energy spectra in four radial regions are shown in Figs. 7 and 8 for beam-gas and tertiary halo, respectively. As noted above, spectra for beam-gas outside of the beam pipe are much harder compared to those for tertiary halo and kicker prefire (as will be shown later). There are almost no charged particles at r>6m for the latter two sources. The peak muon flux at the ATLAS and CMS detectors for beam-gas and tertiary halo is about 1 cm^{-2}s^{-1}.

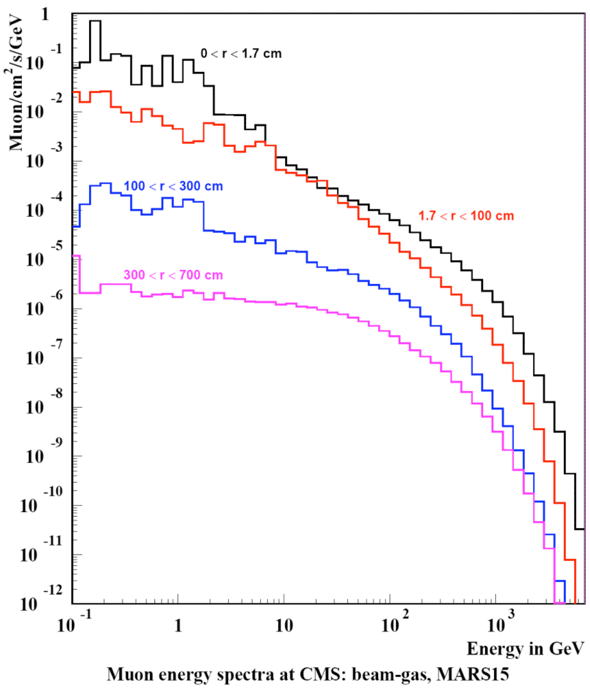


Figure 7: Muon energy spectra at z=22.6 m from IP5 in 4 radial regions for beam-gas.

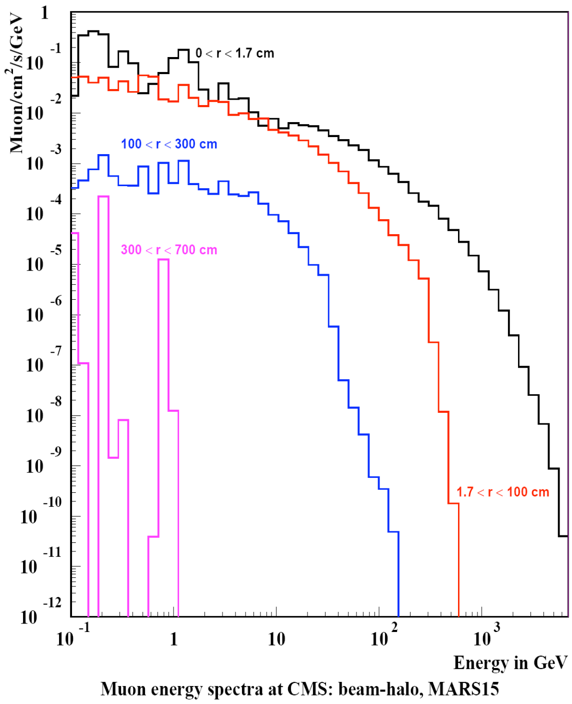


Figure 8: Same as in Fig. 7, for tertiary halo.

The difference between the two sources is further illustrated in Figs. 9 and 10. Beam-gas interactions – contributing to muon fluxes on ATLAS and CMS – take place up to 500m upstream of the IP1 and IP5, respectively, which results in the presence of very energetic muons through the entire detector cross-section.

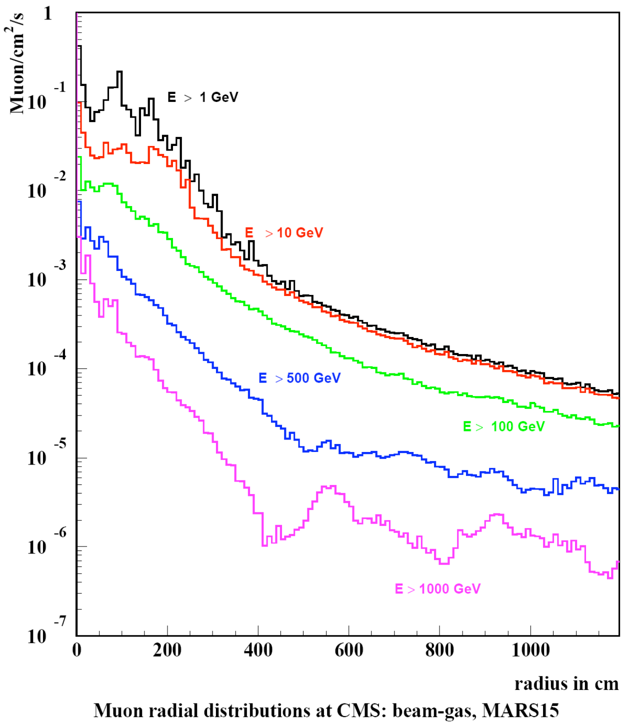


Figure 9: Radial distributions of muon fluxes above 5 cut-off energies at z=22.6 m from IP5 for beam-gas.

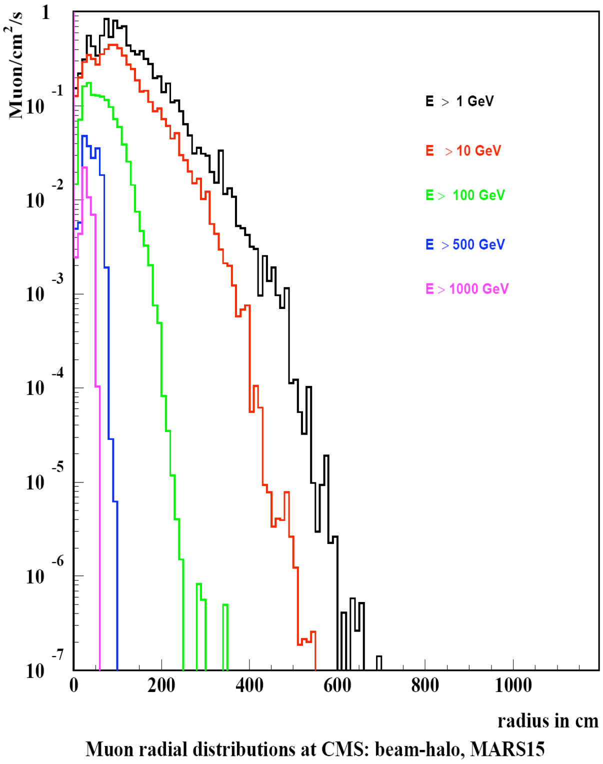


Figure 10: Same as in Fig. 9, for tertiary halo.

Muon fluxes, resulting from beam-gas interactions, exhibit rather strong vertical/horizontal and left/right asymmetry (see Fig. 1), certainly at distances greater than 2 meters from the beam axis, as shown in Fig. 11. This is also true for other particles – photons and electrons first of all – accompanying the muons. Contrary, particle flux distributions at the detectors (outside the beam pipe) from tertiary halo and kicker prefire are pretty symmetric around the beam axis at IP1 and IP5. This is because of the point-like nature of the source (TCT) and just a straight section between that source and the detector.

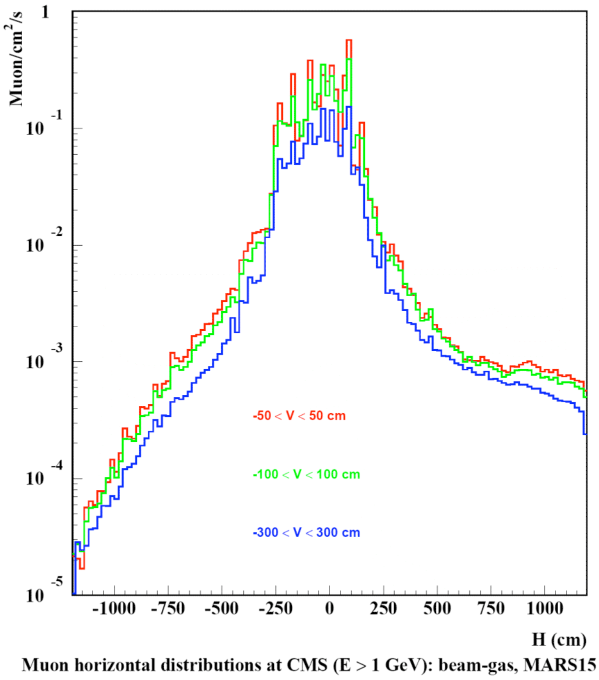


Figure 11: Horizontal distributions of muon fluxes in 3 vertical slices at z=22.6 m from IP5 for beam-gas.

SUM RULES FOR MIB IN ATLAS/CMS

The previous section gives detailed information on beam-gas and tertiary halo contributions to the MIB in CMS for the counter-clockwise Beam 2. The MARS15 results presented can be used with a good – from a practical standpoint – accuracy for estimation of the total MIB loads on ATLAS and CMS. The sum rules are especially accurate for the energetic muon component.

Let's define the beam-gas results presented above as BG, and tertiary halo results for the betatron cleaning of Beam 2 in IP5 as BH. Proton losses for the betatron cleaning have been calculated with SixTrack and their rate on the IP1 and IP5 tertiary collimators gives us corresponding weighting factors for the total loss. Thus, the total MIB stationary load on ATLAS is estimated as (BG+0.12 BH) on the right side (Beam 1) and (BG+1.64BH) on the left side (Beam 2). For CMS, the corresponding rules are (BG+BH) on the right side (Beam 2) and (BG+0.085BH) on the left side (Beam 1), which gives about 3 muons/cm^2/s for the maximum total muon flux at the detector center.

KICKER PREFIRE

This section gives results for the third component of MIB, generated by remnants of a mis-steered beam uncaptured in the IP6 beam dump system. As with the first two sources, particle fluxes above 20 MeV are calculated with MARS15 at the interface plane z=22.6 m for the counter-clockwise Beam 2 approaching CMS. It was found in our calculations that mainly protons from bunch 4 through 9 hit the TCT to the load on CMS in the case considered (Figs. 12 and 13).

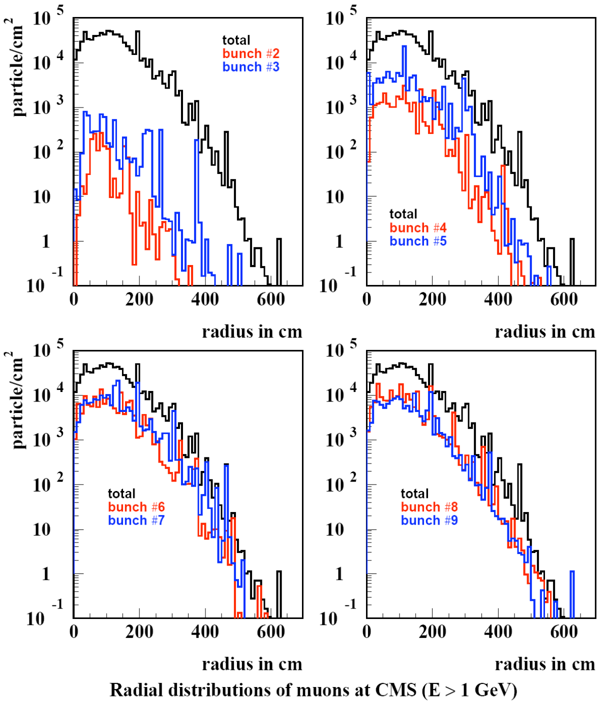


Figure 12: Radial distributions of muon fluxes above 1 GeV at z=22.6 m from IP5 for a kicker prefire event: total and for bunches 2 through 9.

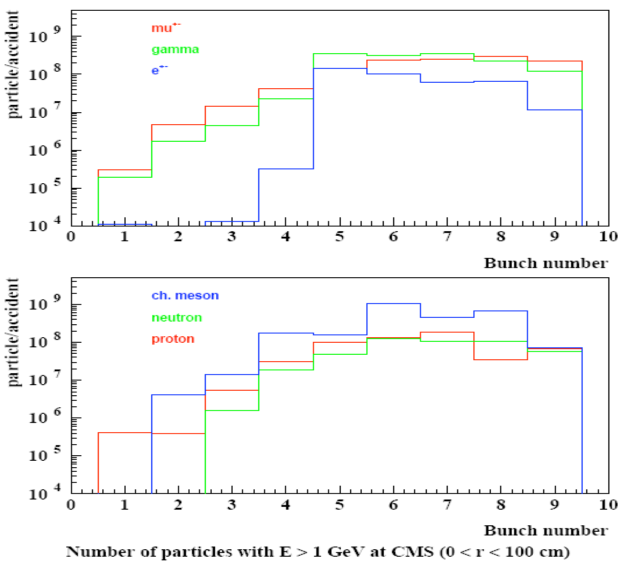


Figure 13: Bunch distribution for particle load on CMS (E> 1 GeV, r < 100 cm).

Fig. 14 shows energy spectra of particles approaching the CMS detector in the first meter radially outside the TAS aperture of 1.7 cm. General features of the spectra are similar to those with two other sources. It is interesting to note the presence of rather energetic tails for hadrons and muons more energetic than for tertiary halo because of more grazing-angle events on the TCTs.

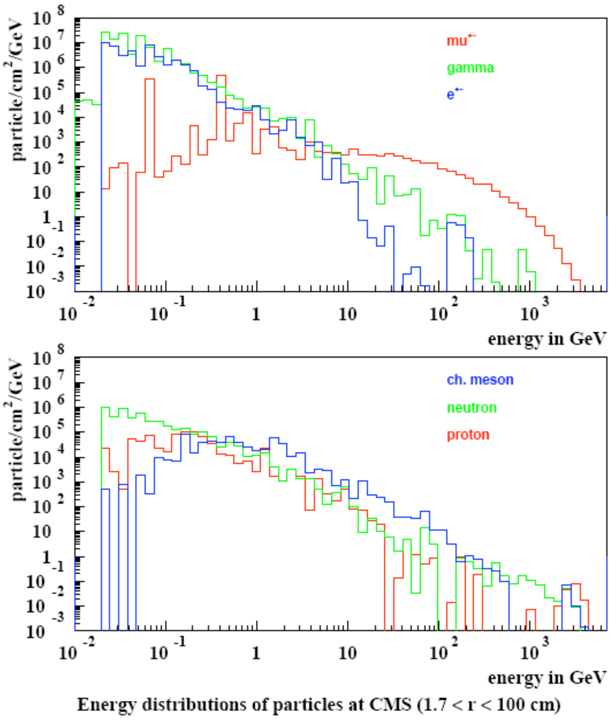


Figure 14: Particle energy spectra at z=22.6 m from IP5 in the 1.7 < r < 100cm region for kicker prefire.

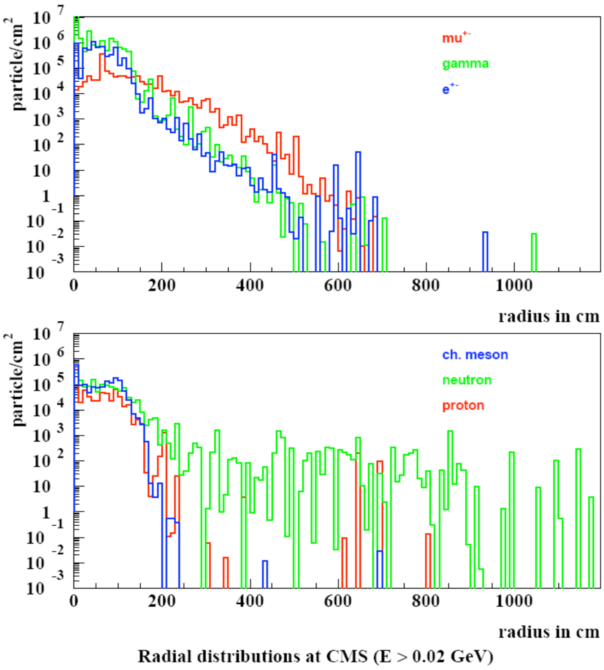


Figure 15: Radial distributions of particle fluxes (E>20 MeV) at z=22.6 m from IP5 for kicker prefire.

Radial distributions of particle fluxes above 20 MeV and muon fluxes for 5 cut-off energies from 1 GeV to 1 TeV are shown in Figs. 15 and 16, respectively. Again, they are not that different from the tertiary halo case. Temporal considerations though are quite different: a continuous steady state for the beam-gas and tertiary halo cases, and a very short 125-150 ns pulse for the case of kicker prefire. As a result, the integral loads from a kicker prefire event are very small compared to all other sources, while large instantaneous ionization over all the detector volume can cause irreversible damage by creating breakdown in some components [4]. Estimated peak dose and MIP flux for the innermost CMS pixel are about 0.02 Gy and 10^8 cm^{-2} per such an event. Note that the loads induced by a kicker prefire are much lower for Beam 1 at CMS and for both beams on ATLAS compared to those considered here for Beam 2.

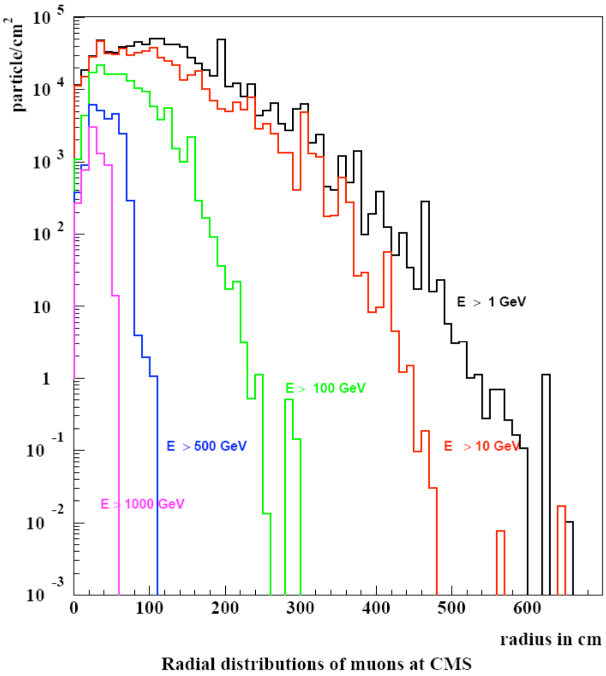


Figure 16: Radial distributions of muon fluxes above 5 cut-off energies at z=22.6 m from IP5 for kicker prefire.

CONCLUSIONS

Detailed MARS15 calculations of machine-induced backgrounds have been performed for the current models of the LHC high-luminosity insertions, gas pressure, steady state and fast beam losses in the vicinity of IP1/IP5. Results presented are consistent with our earlier results of the mid-90s. Tertiary collimators protect critical detector components at beam accidents, and reduce steady state machine backgrounds at small radii. The sum rules for calculation of total MIB loads have been derived for the ATLAS and CMS detectors. The files of particles at the interface plane z=22.6m are available to the detector community; several groups have already started corresponding detector modeling.

Thanks to A. Rossi and M. Huhtinen for crucial input to a gas pressure model and S. Striganov for help with enhancement of the analysis tools.

REFERENCES

[1] N.V. Mokhov, Nucl. Physics B, 51A (1996) 210.
[2] A.I. Drozhdin, M. Huhtinen, N.V. Mokhov, Nucl. Instr. And Meth. A381 (1996) 531.
[3] N.V. Mokhov, "Beam Collimation at Hadron Colliders", AIP Conf. Proc. 693, p. 14 (2003).
[4] A.I. Drozhdin, N.V. Mokhov, M. Huhtinen, "Impact of the LHC Beam Abort Kicker Prefire on High Luminosity Insertion and CMS Detector Performance", Proc. PAC'99, p. 1231, New York, 1999; Fermilab-Conf-99/060 (1999).
[5] G. Robert-Demolaize, et al., "A New Version of SIXTRACK with Collimation and Aperture Interface", PAC'05, Knoxville, Tennessee, 2005.
[6] N.V. Mokhov, "The Mars Code System User's Guide", Fermilab-FN-628 (1995); N.V. Mokhov, S.I. Striganov, "MARS15 Overview", in *Proc. of Hadronic Shower Simulation Workshop*, Fermilab, September 2006, AIP Conf. Proc. 896, p. 50 (2007); Fermilab-Conf-07/008-AD (2007); http://www-ap.fnal.gov/MARS/
[7] N.V. Mokhov, V.I. Balbekov, "Beam and Luminosity Lifetime", in *Handbook of Accelerator Physics and Engineering, 2nd Printing*, Ed. A.W. Chao, M. Tigner, P. 218, World Scientific (2002).
[8] A.I. Drozhdin, V.A. Lebedev, N.V. Mokhov et al., "Beam Loss and Backgrounds in the CDF and D0 Detectors due to Nuclear Elastic Beam-Gas Scattering", PAC'03, Portland, Oregon, 2003; also Fermilab-FN-734 (2003). http://www.JACoW.org.
[9] A. Rossi, CERN-LHC-Project-Report 783 (2004).
[10] M. Huhtinen, private communication.
[11] M. Huhtinen, these proceedings.
[12] N.V. Mokhov, A.I. Drozhdin, I.L. Rakhno, M. Gyr, E. Weisse, "Protecting LHC Components against Radiation Resulting from an Unsynchronized Beam Abort", Proc. PAC'01, p. 3168, Chicago, 2001; Fermilab-Conf-01/133 (2001).
[13] The LHC Collaboration, "LHC Design Report, Volume1", CERN-2004-003-V1, 2004.
[14] R. Assmann, et. al., "The Consequences of Abnormal Beam Dump Action on the LHC Collimation System", LHC-Project-Note-293, 2002.

EFFECTS OF MACHINE INDUCED BACKGROUND ON EXPERIMENTS

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Abstract

This paper discusses the possible effects which background from the LHC machine (MIB) could have on the four main experiments: ALICE, ATLAS, CMS and LHCb. The possible effects are discussed and the needs of further simulation work are indicated. Some unclear issues in the input assumptions to these simulations, as well as other open issues are emphasized. In conclusion, the high-luminosity LHC experiments appear to be quite insensitive to MIB even if it were considerably above presently predicted levels. ALICE and LHCb will be more sensitive, but even for them MIB appears to be an issue only if rates exceed available estimates by an order of magnitude.

INTRODUCTION

By Machine Induced Background (MIB) in the LHC experiments, we refer to particle fluxes caused by interactions of the LHC beam protons, except beam-beam collisions at the IP of the experiment itself.

Broadly MIB can be divided to come from 2 sources, although these are not totally independent:

1. beam-gas interactions and
2. proton halo[1] lost at limiting apertures.

The rate of beam-gas interactions depends on the beam intensity and the residual pressure in the vacuum system[2].

The loss rate of proton halo has a more complicated dependence on beam intensity, efficiency of IR3 and IR7 cleaning insertions and machine optics. But it also has contributions from the luminosity in the experiments and beam-gas rate around the ring.

These sources – more or less distributed around the ring – give rise to hadronic and electromagnetic cascades, but also to formation of high-energy (up to the TeV-range) muons. The latter can penetrate large distances in the surrounding soil and reach the experiments even if their source is far upstream. No shielding in the experimental areas can suppress such muons. Their rate can only be reduced by local absorbers that limit the decay-path for high-energy pions and kaons.

The main purpose of this paper is to review what we know about MIB today, what we do not know and what adverse effects MIB could have on the performance and lifetime of the experiments.

[1] Unless otherwise specified, in this paper the term ‘proton halo’ will be used for any off-beam protons of 7 TeV. This is a wider definition than used by the machine, where halo is always a multi-turn, slowly evolving component.

[2] This statement applies mainly to muon background. Especially elastic and diffractive protons from beam-gas events will be influenced also by the optics and collimator settings - and thus might fall into item 2 above.

BEAM-GAS INTERACTIONS

For simulation-technical reasons the beam-gas contribution to MIB is often divided into two contributions: events within the UX-areas and events elsewhere in the machine. While the first part can be handled entirely by the simulation software of the collaborations, the second needs specific machine simulations, where the lattice and optics of the LHC are properly reproduced. These simulations then must be interfaced by a suitable way with the detector software. As proposed in Ref, [1], this is best done by defining a virtual plane at the UX/machine boundary, where detector specific simulation software takes over. Distributions on such a plane, shown in this talk, are based on simulation results [2] obtained with the MARS15 simulation package [3].

Beam-gas in UX-areas

According to the most recent LHC pressure maps [4] the NEG-coating of the warm experimental chambers will provide an extremely good vacuum. As shown in Fig. 1 we expect about 10 interactions per meter per second at nominal beam current.

During possible single-beam operation at LHC-startup beam-gas events taking place in the region of the IP might be useful for initial alignment. However, the p_T-spectrum of the secondaries is so soft, that only a few useful tracks per hour can be expected in the tracker acceptance for $I = 3.1\,\mathrm{mA}$.

Beam-gas in LHC-machine

In the Long Straight Section (LSS), adjacent to the interaction points, the residual pressure and hence, the beam-gas interaction rate, varies according to the temperature, being higher in the cold sections, as shown in Fig. 2. In the arc it is assumed that synchrotron radiation increases the pressure to 20 times that of the cold LSS section [5]. Beam-gas interaction points are sampled from the residual pressure map and events are generated with a suitable generator, e.g. DPMJET-III [6]. The produced secondaries then have to be transported through the soil, tunnel or machine optics until they arrive at the interface plane defined at 23 m from the experimental IP.

The residual pressure variations are reflected in Fig. 3, where for high-energy muons observed at the interface plane, the coordinates of the initial proton-gas scattering are shown, weighted by the observed muon weight. The

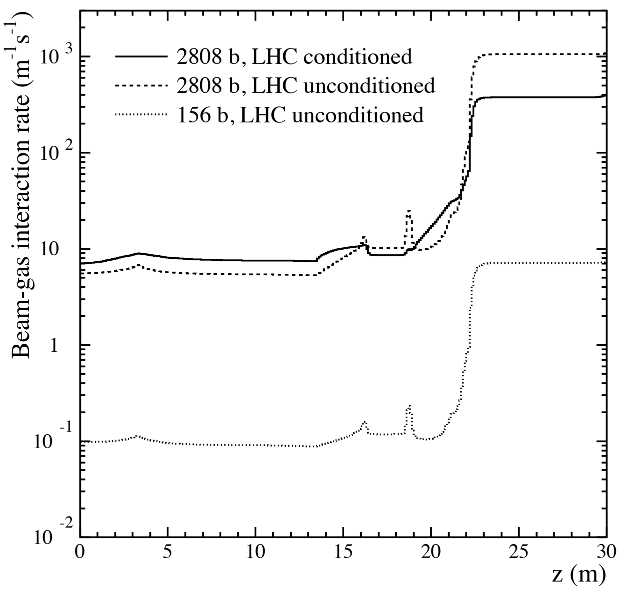

Figure 1: Beam-gas interaction density in the CMS experimental beam-pipe.

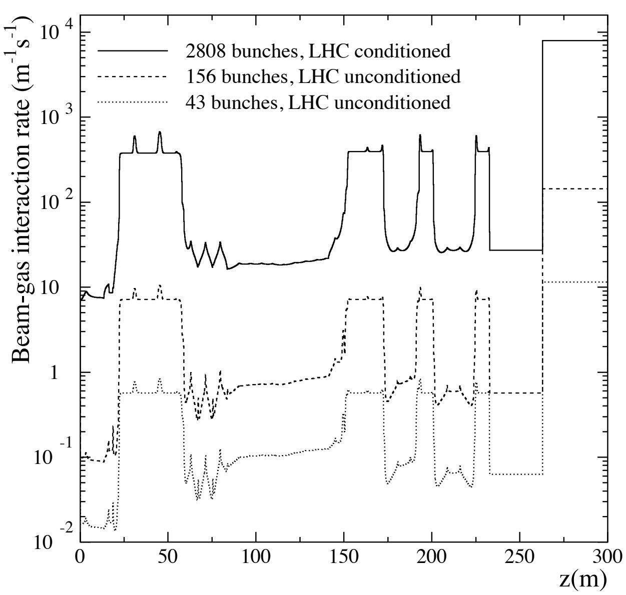

Figure 2: Beam-gas interaction density in LSS and LHC arc.

figure illustrates that the muon flux entering the cavern has non-negligible large-distance contributions from the arc.

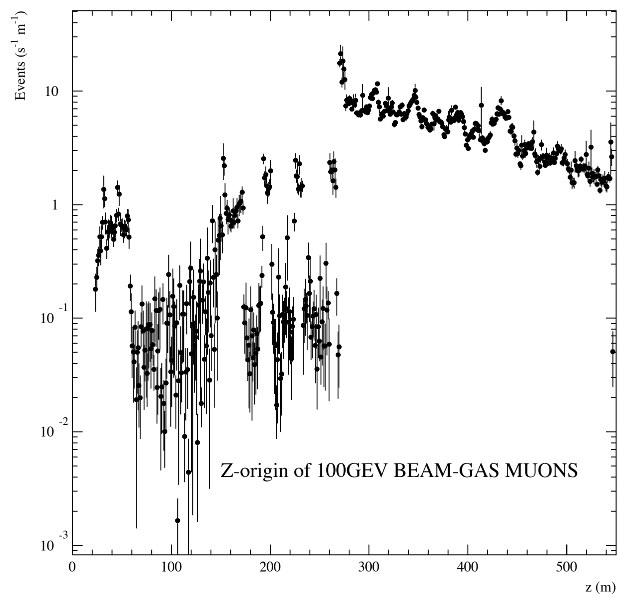

Figure 3: Coordinates of intial proton-gas collisions for E>100 GeV muons observed at the z=23 m interface plane [2].

INTERACTIONS OF PROTON HALO

With its intense high-energy proton beams the LHC requires an extremely efficient cleaning system in order to prevent quenches of the superconducting magnets. This will be provided by two separate cleaning insertions: betatron cleaning at IR7 and momentum cleaning at IR3. The efficiency in the nominal machine has to be $>99.9\%$. In order to protect the inner triplets of the experimental insertions additional tertiary collimators (TCT) have been introduced. These are set such that they remove the tertiary proton halo[3] that would otherwise impinge on the triplet. The main role of the TCT, however, is to protect the triplet in case of accidental beam losses.

Sitting at 150 m from the IP the TCT is an important source of MIB for the experiments. Ideally – from the point of view of the experiments – it should intercept only protons that would otherwise be lost on the triplet. If the presence of the TCT increases losses in the LSS significantly with respect to the unprotected triplet, it will have adverse consequences on the experimental conditions. In available simulations [2] all halo-losses take place on the TCT. Thus a plot similar to Fig. 3 just shows a single sharp peak at the TCT location.

It is predicted [7] that in the nominal machine with a 20 h beam-lifetime about 2×10^6 protons per second are lost on the 'worst side' TCT[4].

[3] Primary and secondary halo will be intercepted in IR7.

[4] The losses on the TCT are highly asymmetric depending on the location with respect to the cleaning insertions.

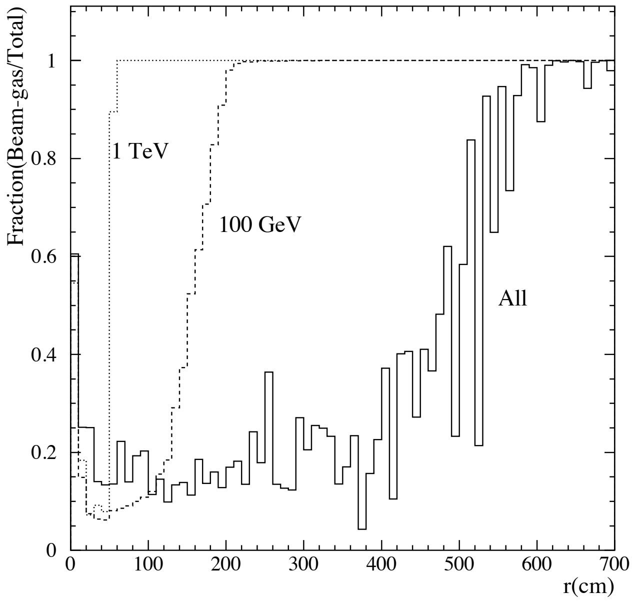

Figure 4: Relative importance of beam-gas scattering to muon background with different energy cuts. The complement to unity comes from proton-halo losses on the TCT.

However, there have been studies [8] predicting that secondaries from elastic beam-gas scattering in the LHC can impinge on the TCT before reaching the IR7 collimators. The rates have been estimated to be about one order of magnitude higher than the losses of normal halo, i.e. in the 10^7 p/s range.

While the muons from beam-gas events, being emitted tangentially from the arc, reach to large radii with an asymmetric distribution those from the halo-interactions on the TCT stay closer to the beam line and are rather symmetrically distributed in azimuth. The relative importance of the two components as a function of radius and muon energy is shown in Fig. 4. It can be seen that close to the beam-line the halo-losses dominate by about an order of magnitude. The radial region of this dominance, however, decreases with increasing muon energy.

CUMULATIVE RADIATION LOAD

The high-luminosity detectors, ATLAS and CMS, have been designed to operate in the hostile radiation environment created by the pp-interactions at LHC. In order to achieve this, the experiments are heavily shielded and radiation hardness of detector technologies has been a central design criterion. In particular, it should be pointed out, that in both high-luminosity experiments the whole beam-line between the detecor and the end-wall of the cavern is hermetically enclosed in massive shielding which also seals the tunnel entry.

The TAS, initially introduced to protect the triplet from collision products, also serves the purpose to stop MIB close to the beamline and to provide a last defense against accidental beam losses. In fact there is no viable way to steer a 7 TeV beam past the TAS such that it could hit the experimental vacuum chamber.

This does not apply to the two low-luminosity experiments. These do not have a TAS and also the forward shielding of both ALICE and LHCb is significantly thinner and less hermetic than of the high-luminosity experiments.

In CMS the attenuation provided by the shielding, together with the large distance, cause that the radiation load on the inner pixel detector, due to one proton lost on the TCT, is about 5 orders of magnitude lower than that from one pp-collision at the IP. Assuming that each of the high-luminosity experiments would integrate $500\,\mathrm{fb}^{-1}$ in 10 years (5×10^{16} pp-interactions), there would be some 2×10^{14} protons lost on the TCT over the same time. Thus the radiation load of 10 years worth of TCT losses would be equivalent to roughly 10 s of normal high-luminosity operation. Similar arguments show that the losses from beam gas in the machine and the UX are of the same order of magnitude. Thus MIB is totally negligible for cumulative damage in the high-luminosity experiments.

LHCb is also designed for high radiation doses and despite weaker shielding around the beamline, MIB is not expected to be an issue for cumulative radiation damage.

ALICE, however, will take data only at very low luminosities, not exceeding $3 \times 10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ in pp-mode. Together with weak forward shielding this implies that MIB contributes a significant fraction of the total radiation exposure.

It should be remarked, however, that hot spots, either spatially (MIB focused by quadrupole fields) or in time (accidents of significant spikes in background) could lead to local damage or instantaneous single failures that might accumulate over time to reach levels that compromise detector performance.

EFFECTS OF MIB ON TRIGGER

ATLAS and CMS

The total predicted rate of MIB muons – radial distributions are shown in Fig. 5 – entering the experimental caverns is comparable to the L1 trigger rate of the order of 100 kHz. However, both high-luminosity experiments require already at L1 that a triggered muon points to the IP. Even if this pointing is done with fairly wide tolerances, it still reduces the geometric acceptance for MIN-muons dramatically. Therefore the rate is negligible compared to the L1 bandwidth. Random hits by the MIB might in theory lead to accidental IP-pointing, but at full luminosity the rate of such hits will be dominated by the pp-created neutron background in the UX areas [1], which is well understood.

At the High Level Trigger (HLT) level information from the Tracker is included in the muon reconstruction, ensur-

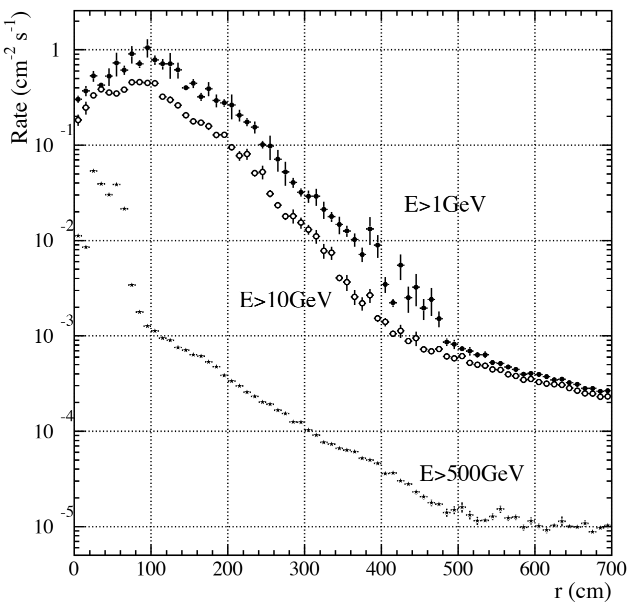

Figure 5: Radial distribution of muons at the z=23 m interface plane. Beam-gas and proton-halo losses (on TCT) are included [2].

ing that all triggered muons originate form the IP.

A high-energy (E $>$100 GeV) muon traversing calorimeter material can undergo a radiative energy loss, which results in local deposition of a significant fraction of the muon energy. Such losses might lead to fake missing E_T (MET) triggers. The rate of such events can be roughly estimated to be of the order of 1 Hz, which is many orders of magnitude below the L1 bandwidth. However, it is not clear to what extent HLT is able to filter out such events, especially if they happen to overlap with a real event at the IP. Given about 2 orders of magnitude with respect to the HLT bandwidth this is unlikely to become a problem, but it should not be completely ignored as a potential issue.

In both cases, however, timing might help to reduce the rate. Most often the fake MIB-induced trigger will lie outside the expected time window for a particular detector. For instance the possible fake-MET triggers are likely to be in-time only in the downstream endcap calorimeters.

LHCb

In the L0μ trigger of LHCb MIB overlapping with a Minimum Bias event can occupy few percent of the bandwidth [9]. This value is based on losses at the TCT at the 10^6-level. This trigger rate can be reduced by shielding in the tunnel close to the VELO detector. At present part of this shielding has been staged.

ALICE

The ALICE triggers have very small rejection rates, of the order of 1000 and are based on event characteristics (high multiplicity) that are not expected to be sensitive to MIB. In addition the L0 interaction trigger will efficienctly discriminate beam-background.

BACKGROUND TO PHYSICS

SUSY searches

SUSY events will typically be characterized by jet activity associated with missing E_T (MET). As discussed in the context of the trigger, an energetic muon has a small chance to deposit a very large energy in a calorimeter. If such a fake energy deposition happens to overlap with a hard QCD event at the IP, it can resemble a SUSY event with large MET. Although such an overlap will be very rare, the rate might still be comparable to the rate of real SUSY events. Offline handles probably can be devised to recognize such cases, but depending on the rate, it is a potentially significant pollution of the data sample.

Luminosity measurement

Several techniques have been studied and implemented by the collaborations to perform the luminosity measurement. Except for TOTEM, which is specially designed for this purpose, most luminosity monitors do not have pointing capability and therefore will not be able to tell if a track originates from the IP-region. For all such systems the accuracy of the luminosity determination will be influenced by the uncertainty in the MIB-contribution to the measurement.

In particular, collisions of satellite bunches with the nominal bunch might be an issue in this respect. Such collisions will not happen at nominal crossing angle, but in early running, with head-on collisions, satellite bunches could collide at 37.5 cm from the IP with normal bunches. The relative luminosity would correspond to the relative population of the satellite bunch. Thus, if the latter is too high, it could introduce a bias in the early luminosity determination.

Forward physics

Forward physics studies looking at rapidity gaps can obviously suffer from MIB filling the gap. Without tracking and IP-pointing capability these effects are irrecoverable. In addition MIB is likely to influence the studies of forward energy flow, but exclusive MIB simulation samples are needed to quantify these effects.

EARLY OPERATION

When LHC starts up the experiments will use the initial low luminosity to explore the behaviour of their triggers. Therefore, the trigger thresholds will be much lower at start-up than at the nominal LHC. This will make them significantly more sensitive to background, including MIB.

While the LHC, from the point of view of not quenching magnets, could operate with less efficient cleaning at low beam intensity, it should be remembered that this could compromise the early trigger studies of the experiments by introducing an excess background trigger rate.

It should be emphasized that essentially all simulations so far have considered only the nominal machine. At lower luminosity the relative importance of MIB – even for same cleaning efficiency and vacuum quality – will be higher alone by the fact that MIB is mostly related to beam intensity and not luminosity.

DETECTOR ALIGNMENT

All experiments recognize that MIB-muons could be useful for alignment of the detectors. In particular, energetic muons, being parallel to the beam-line, could be a useful means to inter-align the endcap detectors on each side of the detector. However, a prerequisite of using MIB for this purpose is a capability to trigger on it. Studies in this direction with existing hardware are in progress in both ATLAS and CMS.

Should the LHC start up with a prolonged period of single beam, then MIB (and cosmic muons) will be the only means to align the detectors. MIB will arrive at the IP in time with the bunches and thus will be a suitable reference to time-in detectors and triggers. Despite these possibilities to use MIB beneficially, it is clear that the experiments would prefer to get background-free collisions from the start on.

MEASURING THE BACKGROUND

In order to control its effects, even if small, the experiments need to measure the MIB.

Ideally this should be done in conditions as similar as possible to the normal collider operation. Especially at higher luminosities it is possible that due to the absence of beam-beam effects a measurement performed during single-beam operation would not be representative.

ALICE and LHCb will always have some periods of non-colliding beam since the abort and injection gaps in the LHC beams meet only at the two high-luminosity insertions. The latter, therefore, will never see single beam in normal operation.

One proposal to accomplish the MIB measurements is to have some non-colliding bunches in the beam structure. In order to ensure that only MIB gets measured, enough time must be allowed for products of the last pp-collisions to disappear and detectors to terminate signal collection. The exact times for this still need to be specified, but are likely to be of the order of a few hundred ns. If bunches would be removed from a bunch following an injection gap[5], the detector would be 'clean' already when the next bunch-train arrives and the non-colliding time could be halved, thus saving some luminosity.

Such special conditions will not be required in every fill, but only from time to time to monitor the conditions and initially to establish the first background measurement.

Obviously it is up to the LHC experts to decide what is technically the best possibility to provide the most representative non-colliding conditions with a minimal price in luminosity for physics.

SIMULATION NEEDS

The first complete studies of MIB in the experiments date back to 1996 [1]. Since then further studies have been performed by various groups for all experiments. Unfortunately the present picture is rather confusing, probably mostly due to different assumptions used in the simulations over the years, but also because most simulations have considered only one source of MIB at a time. Thus, no up-to-date, complete and commonly agreed simulations are available at the moment.

By now a fairly consistent picture of the loss sources is available from the vacuum and collimation groups. It would be highly desirable to repeat the MIB simulations for all experiments using consistent and agreed input. However, past experience has shown that these MIB simulations are very complex and sensitive to small variations. Therefore independent simulations by more than one group would be appreciated in order to be able to cross-check the results and to estimate uncertainties.

A special issue is that up to now all MIB estimates have been based on biased Monte Carlo[6]. The biasing has been mandatory in order to obtain even close to sufficient statistics in reasonable CPU time. The biasing, however, results in a spread of statistical weights of the particles arriving at the interface plane. While this makes their use in non-biased MC codes (e.g. Geant4) difficult, even more problematic is that a biased simulation is intrinsically incapable of reproducing any correlations. The latter would be needed to reliably study the effects on trigger and physics. It is probably not possible to do all forthcoming simulations in non-biased mode, but some smaller non-weighted sample files would be useful in order to get an idea of the correlations.

OPEN ISSUES & QUESTIONS

While the contributions from inelastic beam-gas scattering and from proton-halo losses on the TCT appear to be rather well understood, there remain several issues that need further clarification or call for detailed simulation studies:

[5]The abort gap is used for detector timing and its length should not be modified.

[6]Biasing in this context does not mean that the results would be biased. The biasing applies only to the statistics, i.e. the particle population is artificially increased in regions of phase space that are of interest - and correspondingly reduced elsewhere.

- The effect of elastic scattering in the arcs appears contradictory. Can the scattered protons be lost on the TCT before they are intercepted by the cleaning insertions. If so, what would be the rate? A related specific issue is, if diffractive or elastic protons from ATLAS – operating at 4 orders of magnitude higher luminosity than neighboring ALICE – might have an influence on the latter.
- It has been predicted [7] that the losses on the TCT can momentarily increase by about 2 orders of magnitude. It remains to be clarified what the origin of these spikes is, how often they occur and under which conditions.
- While no mechanism has been identified that could steer 7 TeV protons past the TAS on the ATLAS/CMS experiments, it has been pointed out that for protons with energies $E < 5$ TeV it is possible to impinge on the experimental beam pipe. The rate of these should be quantified since their effect might be significant with respect to other background.
- The present pressure maps do not include the TCT or other elements with potentially increased outgasing due to the radiation-load [10]. In these the pressure could be significantly higher than elsewhere. This calls for some quantification.

The issue of total losses on the TCT, e.g. item 1 above, appears to be of crucial importance and at the moment the the spread of values is an order of magnitude. A consistent (e.g. wrt beam-lifetimes) and commonly agreed number should be worked out urgently.

In general, it would be important to agree on a consistent set of assumptions to be used as input values for all forthcoming MIB-simulations.

SUMMARY

Both high-luminosity experiments, ATLAS and CMS, are designed for such high radiation loads that MIB – at predicted levels – appears totally negligible in this respect. The same is true, albeit to a slightly lesser extent, for LHCb. ALICE, however, is designed for much lower radiation exposure and is not as heavily shielded. If MIB increases above presently predicted levels, its first adverse consequence most likely will be excess radiation damage in ALICE.

Concerning effects on the trigger, the only potential issue identified so far in ATLAS/CMS is the possibility of fake missing E_T due to radiative losses of very energetic muons. However, present estimates do not indicate that this would reach rates that could come close to constituting a real problem. In LHCb MIB, overlapping with a MinBias event, can fill a non-negligible fraction of the L0 bandwidth according to present estimates (order of 10^6 protons lost on TCT per second). A significant increase of this loss rate might severely compromise LHCb trigger efficiency.

It should be noted that the experiments will start data-taking with triggers wide open, i.e. with very low thresholds. Thus they will be initially much more sensitive to background effects. In view of this, it is desirable that MIB is minimized as much as reasonably possible already from the beginning of LHC operation, even if machine protection considerations would not yet impose full cleaning efficiency.

All experiments will utilize MIB to some degree for their detector alignment. It will certainly be a useful tool to inter-align endcap detectors. Should LHC start up with a prolonged period of single beam, MIB can be used to time in trigger and detectors already prior to collisions.

ACKNOWLEDGEMENTS

Numerous people from all four big experiments have provided essential input for this talk. Out of the many, I would like to mention in particular G. Corti, A. Morsch, W. Smith, J. Spalding, W. Kozanecki (& ATLAS Background WG), D. Macina and N. Mokhov.

REFERENCES

[1] A.I. Drozhdin, M. Huhtinen and V.N. Mokhov, Nucl. Instr. and Meth. A381 (1996) 531.

[2] Based on files provided by N.V. Mokhov in Aug 2007. Preliminary comparisons indicate that these agree with the presentation of N.V. Mokhov at this workshop. Private communication.

[3] N.V. Mokhov, "The MARS Code System User's Guide", Fermilab-FN-628 (1995).
N.V. Mokhov, S.I. Striganov, "Mars15 Overview", Fermilab-Conf-07/008-AD (2007).

[4] A. Rossi, CERN-LHC-Project-Report-783 (2004).

[5] A. Rossi, private communication.

[6] S. Roesler, R. Engel, J. Ranft: "The Monte Carlo Event Generator DPMJET-III", Proc. Monte Carlo 2000, Lisbon, October 23-26, 2000, A. Kling, *et al* eds., Springer-Verlag Berlin, 1033-1038 (2001).

[7] R. Assmann, presentation at Machine Induced Background Working Group, 15 June 2007.

[8] I. Bayshev, presentation at Machine Induced Background Working Group, 29 September 2006.

[9] G. Corti and V. Talanov, Proc. of the LHC Project Workshop – 'Chamonix XV' (2006).

[10] A. Rossi, presentation at this workshop.

Collimation Issues

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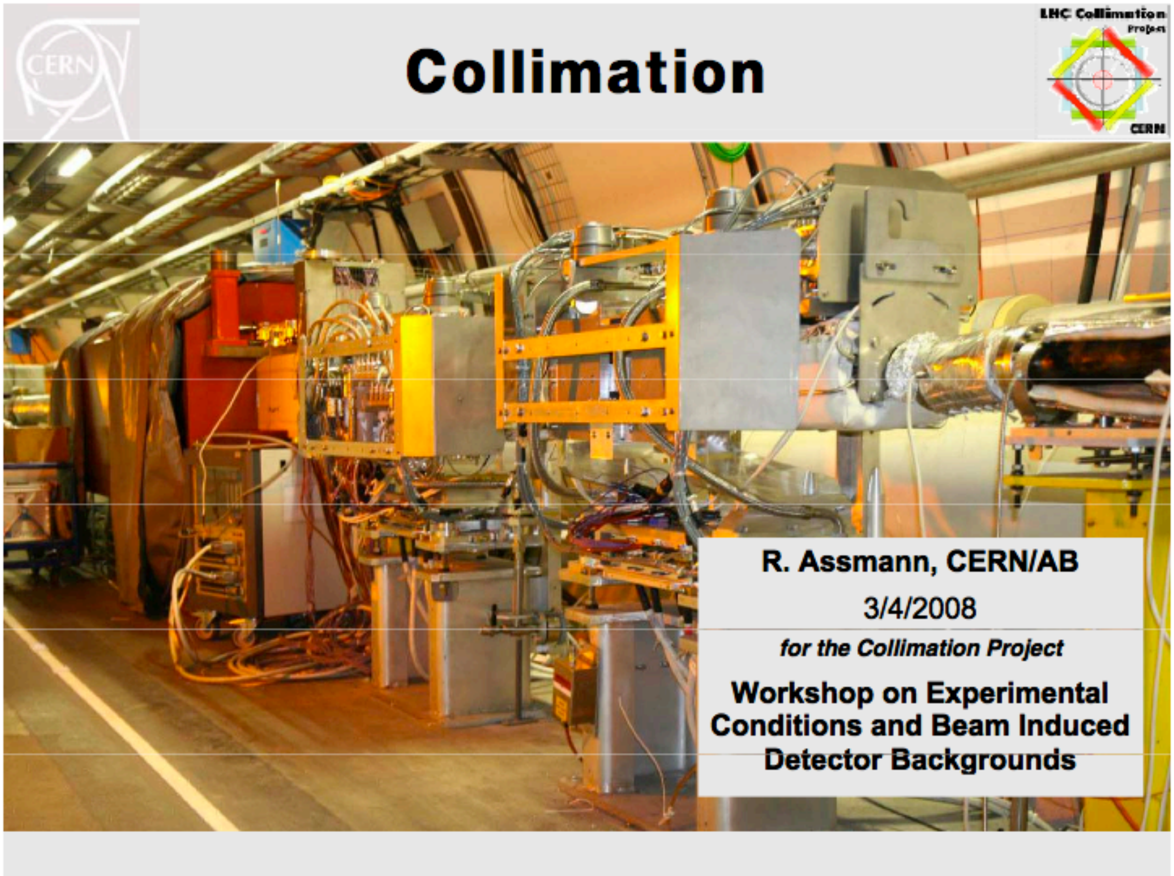
CERN, Switzerland.

Representing the LHC CollimationProject

A paper was not submitted to the proceedings. However, the slides presented are available in electronic form at http://indico.cern.ch/conferenceDisplay.py?confId=25768. The cover slide from this talk is given as reference.



EXPERIMENT PROTECTION FROM BEAM FAILURES AND EXPERIMENT-MACHINE SIGNAL EXCHANGE

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Abstract

This paper briefly reviews the LHC experiment's protection from beam failures and the signal exchange that will be implemented for the LHC start-up.

BEAM FAILURE SCENARIOS DIRECTLY INVOLVING THE EXPERIMENTAL AREAS

The LHC protection from beam failures is described in several papers [1,2]. A dedicated workshop has been organized in June 2007 in order to address in detail scenarios which could involve directly the experimental areas. Talks and outcome of the workshop can be found in [3].

Unlike HERA, TEVATRON and RHIC, the LHC cannot be operated without collimators (except at injection with low intensity). In fact, the protons lost along the ring must be intercepted with very high efficiency before they can quench a superconducting magnet. This is done via the collimation system which defines the aperture limitation in the LHC. Collimators are located mainly in the cleaning insertions (IR3, IR7). A few additional collimators are located in the dump insertion (IR6) and in the experimental insertions. This has an important impact on the Machine Protection since, for most of the multi-turn failures, the beam will hit the collimator first. Hence, for most of the multi-turn failures, the experiments are protected by the collimators mainly located in the LHC beam cleaning insertions. However, a few scenarios (both multi-turn and single-turn) potentially dangerous for the experiments have been identified and listed in the following.

Failures at injection and extraction:

Wrong settings at injection

This failure is due to the wrong setting of one or more magnets located in the experimental insertion (in particular, the orbit correctors and the D1/D2 separation dipoles). This failure concerns all experimental insertions. A dedicated study for ATLAS [4] has shown that, depending on the type of error, the injected beam may hit/scrape the TAS and shower into the experimental regions, or directly impact the beam pipe. ALICE and LHCb are more exposed due to the fact that no TAS is foreseen in IP2 and IP8 and to the fact that these IPs have the added complication of a dipole magnet (associated with corrector magnets). Protection from these kinds of failures relies on the software interlock of the magnet settings, on the "probe beam flag" which will interlock the maximum beam intensity which can be injected into an empty LHC and the "pilot beam" procedure which foresees the injection of a pilot bunch ($5{\cdot}10^9$ protons) prior to the normal batch injection if the LHC is empty.

Error failures at injection (IR2 & IR8)

This failure is due to the wrong setting of the transfer line magnets or of the injection septum, a fast trip of the power supplies, failure of the SPS extraction kicker during extraction, etc. Protection from these failures is based on the response to magnet current surveillance and fast current change monitors and on passive protection from absorbers and collimators. In particular, the injection kicker failures in the LHC ring are caught by dedicated moveable absorbers like the TDI and the TCLI. These failures affect directly either IR2 (beam1) or IR8 (beam2). However, the injection failure can in principle affect the whole machine depending on the phase advances and the absorber/collimator settings.

Error at extraction (IR6)

This failure is related to the loss of synchronisation with the abort gap, an over-populated abort gap, the pre-firing of one of the 15 kicker modules or a failure in the energy tracking system. It is difficult to quantify the frequency of the pre-fire failure but it looks like once per year is possible. The downstream magnets and the adjacent Insertion Regions (IR5 and IR7) should be protected by dedicated passive absorbers (movable TCDQ and TCS, fixed TCDS and TCDQM). However, in case of problems during extraction coupled with TCDQ settings and/or orbit/optics errors, some beam loss may occur at the tertiary collimators (TCT) or triplets in IR5. The loss is difficult to quantify but a detailed analysis is ongoing (existing studies were done without taking into account the TCT/TCDQ, since introduced at a later stage). The abort gap (re)population is monitored via a dedicated instrument which could be connected to the interlock system (under discussion). This failure directly affects only IR5/CMS. However, there is the possibility that the mis-kicked beam passes through IR5 and IR3 and hits IR2 and/or IR1. In fact, the momentum cleaning collimators have a rather large aperture compared to the ones in the betatron cleaning insertion (aperture ~ 15 sigma in IR3 compared to ~ 6 sigma in IR7) and, therefore, the protection due to IR3 is less effective compared to IR7. This probability is expected to be low and it should be checked by simulation looking at the mis-kicked beam phase advance. The protection from this failure relies on the correct positioning of the above absorbers.

Failures during circulating beam

This concerns magnet failures including operational mistakes. It is usually slow and detected first in the aperture restrictions of the machine. The potential danger for the experiments (in particular the near-beam detectors like Roman Pots and VELO) is due to uncontrolled closed bumps since they could affect only the experimental areas. However, they build up slowly (BLM should trigger a beam dump early enough), they are extremely difficult to create at 7 TeV (less difficult at 450 GeV) and only critical if combined with a fast failure of one of the insertion elements. Therefore, the probability of this failure is considered very low. Protection from these failures relies on the tertiary collimators, on the fast current change monitors, on the Beam Loss Monitors (BLM) and on the experiment Beam Condition Monitors (BCM). If particularly dangerous bump scenarios will be identified by future simulations, ad-hoc software interlocks on the settings of the magnets may be envisaged.

COMMUNICATION CHANNELS BETWEEN THE EXPERIMENTS AND THE MACHINE

The communication between the machine and the experiments relies on the five communication channels which are described below.

Timing, Trigger and Control (TTC)

The overall TTC system architecture [5] provides for the distribution of synchronous timing, level-1 trigger, and broadcast and individually-addressed control signals, to electronics controllers with the appropriate phase relative to the LHC bunch structure, taking account of the different delays due to particle time-of-flight and signal propagation. Within each trigger distribution zone, the signals can be broadcast from a single laser source to several hundred destinations over a passive network composed of a hierarchy of optical tree couplers. For what concerns the machine interface, it transmits the LHC fast timing signals from the RF generators, i.e. the 40.08 MHz bunch clock frequency and the 11.246 kHz revolution frequency. In the experiments, this system is used by the Trigger Community.

Machine Beam Synchronous Timing (BST)

It is developed using the TTC technology to provide the LHC beam instrumentation with the 40.08 MHz bunch clock frequency, the 11.246 kHz revolution frequency and an encoded message that can be updated on every LHC turn and that is mainly used by the LHC Beam Instrumentation Group to trigger and correlate acquisitions [6]. The message also contains the current machine status and values of various beam parameters. The message is sent to the experiments [7] and used to provide the TTC with the "Machine Status" information to define the type of clock delivered (rising, stable, not guaranteed). Some experiments use it also to get the GPS absolute time and the beam parameters.

Beam Interlock System (BIS)

The Beam Interlock System (BIS) of the LHC provides a hardware link from a user system to the LHC Beam Dumping System, to the LHC Injection Interlock System and to the SPS Extraction Interlock System [2]. The LHC BIS is split into a system for beam1 and a system for beam2 and carries the two independent BEAM_PERMIT signals, one for each beam. The BEAM_PERMIT is a logical signal that is transmitted over hardware links and that can be either TRUE (i.e. injection of beam is allowed and, with circulating beam, beam operation continues) or FALSE (i.e. injection is blocked and, if a beam is circulating, the beam will be dumped by the Beam Dumping System).

The individual user systems must provide USER_PERMIT signals for beam1 and/or beam2 that are collected by the BIS through the Beam Interlock Controller (BIC) modules. The USER_PERMIT is a logical signal that is transmitted over a hardware link and that can be either TRUE (i.e. the user is ready and beam operation is allowed according to the user) or FALSE (i.e. beam operation is not allowed according to the user). To obtain permission for beam operation, i.e. BEAM_PERMIT=TRUE, all the connected USER_PERMIT signals must be TRUE. This condition is somewhat relaxed for the maskable user signals, where the USER_PERMIT signal may be masked only if the beam intensity is safe, i.e. below the machine damage threshold. The delay between reception of an interlock (USER_PERMIT to FALSE) and the moment where the last proton is extracted on the dump block varies between 100 and 270 μs depending on the location of the USER and the precise timing with respect to the beam abort gap position in the ring.

The BIS for the experiments is described in [8]. Special attention is paid to the interlocking of the movable devices since they are supposed to be positioned between 10-70 σ from the beam axis. Therefore, a wrong operation of these devices may lead to significant damage to both the devices themselves and the machine. In general, the movable devices are authorized to leave their garage position only during collisions.

It should be noted that the experiments will use the actual BIS only to dump the beam. In order to inhibit injection, they have asked to get an independent system which would not dump the beam at the same time. In fact, the injection inhibit will be based on the state of the detectors and it will not depend on the data from the experiment's protection system. New hardware has been developed for the extraction systems and it allows for a direct link via optical fibers to the Injection BICs in SR2 and SR8. The new hardware will be used by the experiments to inhibit injection without dumping the beam [9].

Finally, a number of hand-shaking signals have been agreed between the machine and the experiments aiming at improving the communication during the LHC operation [8]. This should ensure a more efficient and safer beam operation. The hand-shaking signals will be sent through the DIP system.

General Machine Time (GMT)

This system synchronizes all CERN accelerators [10]. In particular, it distributes:

- The UTC time of the day.
- The LHC telegram: it represents a snap shot of the machine state and it is updated each second. Among the various parameters, it sends out the Safe Beam Parameters which are essential for building the interlock signals.
- LHC Machine events: an event is sent punctually when something happens that affects the machine state. Some are asynchronous that come from external processes, e.g. post-mortems, while others are produced from timing tables corresponding to running machine processes. The Safe Beam Parameters are also sent as events and supplied to the experiments via hardware. Part of the telegram information relevant to the experiments (like the beam modes, the machine modes etc) are also distributed via DIP.

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CERN Data Interchange Protocol (DIP)

This system allows relatively small amounts of soft real-time data to be exchanged between very loosely coupled heterogeneous systems [11]. All signals regarding the quality of beam collisions, data from beam instrumentation, and the operation status (mode) of the LHC are exchanged via this system. It should be noted that this system is highly flexible and data and signals to be exchanged may be added as the experience with the experiments and accelerator operation develops. The data already agreed between the machine and the experiments can be found in [12,13,14].

What else?

The transmission of additional relevant parameters is actually being discussed. In particular:

- The actual value of the SPS Probe Beam Flag [15] (default 10^{10} protons, maximum value 10^{11} protons). The experiments have requested the information to be provided as a Safe Beam Parameter even though it would be acceptable to get it via DIP for the start-up run in 2008.
- The background levels: the experiments should send to the machine two complementary normalized signals to help the operators in reducing the background levels whenever it is necessary. The information should be independent from data taking and sent at a rate of about 1 Hz.
- Information about the collimator settings, the filling scheme and the beam life-time is under discussion.

CONCLUSIONS

A number of communication channels between the machine and the experiments have been defined in order to protect the experiments from beam failures and to optimize the data taking and, therefore, the physics results. The commissioning of these channels is presently ongoing. Experience in the operation of the LHC may lead to an optimization of the present scheme.

REFERENCES

[1] “Machine protection for the LHC: architecture of the beam and powering interlock systems”, F. Bordry et al., LHC Project Report 521

[2] “The beam interlock system for the LHC”, B. Puccio et al., CERN EDMS Document 567256

[3] “Joint LHC-experiments meeting on experiments protection from beam failures”, http://ts-dep.web.cern.ch/ts-dep/groups/lea/int/workshops/workshop_protection_june_2007.htm

[4] “Accidental beam losses during Injection in the in the Interaction region IR1". Bocian D., January 30, 2004, Note 335

[5] “TTC Web Site”: http://ttc.web.cern.ch/TTC/

[6] “The BST Home Page”, http://ab-dep-bdi-em.web.cern.ch/ab-dep-bdi-em/index.php?n=Lhc.BST

[7] “The interface and structure of the Machine Beam Synchronous Timing message for the LHC experiments”, R Jones, CERN EDMS Document 638899

[8] “LHC experiments Beam Interlocking”, D. Macina et al., CERN EDMS Document 653932

[9] “40th and 41st LEADE Meeting”, http://indico.cern.ch/categoryDisplay.py?categId=592

[10] http://ab-dep-co-ht.web.cern.ch/ab-dep-co-ht/timing/index.htm

[11] “DIP Web Site”: http://itcofe.web.cern.ch/itcofe/Services/DIP/welcome.html

[12] “Data and signals to be exchanged between the LHC machine and experiments”, E. Tsesmelis, CERN EDMS Document 701510

[13] “LHC Machine and experiment data exchange systems implementation”, D. Swoboda, CERN EDMS Document 772011

[14] https://twiki.cern.ch/twiki/bin/view/Leade/WebHome

[15] “85th LTC Meeting”, https://ab-div.web.cern.ch/ab-div/Meetings/ltc/2007/ltc_2007-18.html

Session 2 Discussion Summary

S. Redaelli, CERN, Geneva, Switzerland

INTRODUCTION

The second session of the workshop addressed the prediction of known background sources at the LHC, the available knobs to optimize the machine-induced background and the experiment protection.

ESTIMATES OF RESIDUAL GAS PRESSURE IN THE LHC (A. ROSSI)

M. Huhtinen expressed concerns about the vacuum measurements shown for SPS collimator tests with beam that took place in 2004. Should we expect the same levels for the Tertiary collimators (TCT's) close to the detectors? *S .Redaelli* replied that this is not the case because the materials are different (Carbon instead of Tungsten). Tungsten collimators have not yet been tested with beam. *R. Assmann* warned that the out-gassing will manly take place at the collimators in the dedicated cleaning regions, which are exposed to large losses. The TCT's close to the experiments act as triplet protection and are not supposed to get high beam loads during standard operation. *M. Huhtinen* stressed that we then urgently need vacuum estimates for the TCT's with realistic loss rates.

H. Burkhardt commented that it will be important to monitor the vacuum levels at the machine start-up to feed this experience back into the simulations. In particular, it will be useful to determine basic scaling laws of the vacuum level against basic beam parameters in order to be prepared for the following commissioning stages.

W. Kozanechi asked about the estimates shown of collimator flange heating and corresponding out-gassing. The presented value of about 10^{-9} bar would be too large even for the vacuum of the cleaning insertions. *R. Assmann* replied what was shown by A. Rossi is not the typical case during beam operation but refers to a worst case scenario used as a criterion for the system design. The out-gassing in this case will not be steady but will last at most for 10 seconds. This was considered by AT-VAC to be acceptable.

M. Ferro-Luzzi asked if vacuum leaks can be detected with beam loss monitors (BLM's). In particular, if we encounter a beam-gas background problem due to a possible Helium leak in a cold section, could the BLM's give information for localizing the leak and with what longitudinal accuracy? This is not clear because with the present system the spacing between the monitors might not be optimized to detect leaks. *H. Burkhardt* suggested that we could envisage dedicated beam time to address this issue, for example by creating on purpose controlled vacuum bumps. *W. Kozanechi* also liked this idea and stated this should be followed up.

SIMULATION OF MACHINE BACKGROUND (V. TALANOV)

A. Morsch commented that the tertiary collimators are not needed in IP2 with un-squeezed optics because the triplet aperture is not critical. He is strongly against the possibility of closing them and using the IP2 as a cleaning insertion. This topics was addresses in detail in R. Assmann's talk, where it was clarified that the TCT in IP2 are only supposed to be used for the early commissioning phase with reduced β^*.

A. Morsch also stated that IP2 has been treated less well than other interaction regions as far as detailed loss studies are concerned. He expressed the request that, as an outcome of this workshop, the inputs for background studies shall be provided for the relevant machine configurations.

MACHINE-RELATED BACKGROUNDS: THEIR ORIGIN AND LOADS ON ATLAS/CMS (N. MOKHOV)

W. Kozanechi expressed concerns about the plot in page 10 of N. Mokhov's slides, where muon fluxes up to 10^{11} are quoted. Indeed, after the meeting N. Mokhov clarified that there was a typo in the vertical scale of the plot: given number have to be reduced by a factor 10^6. The slides on the workshop web site have been updated accordingly.

M. Huhtinen commented that the sharp reduction of muons that occurs at about 500 meters from the IP (see slide 8 of N. Mokhov's talk) is actually an artifact of the simulations because the model does not includes the arc further downstream. N. Mokhov agreed however commented that the sources of muons in the machine regions that are not modelled do not contribute significantly to the background and therefore they can be safely neglected.

W. Kozanechi asked if the output of N. Mokhov's simulations can be used as an input both for ATLAS and CMS background studies. Nikolai replied that this is indeed the case.

EFFECTS OF BACKGROUNDS ON EXPERIMENTS (M. HUHTINEN)

K. Eggert asked if the diffractive protons that leave the interaction point are expected to be a source of background for the other experiments. For example, this can clearly become an issue for ALICE that could collect the ATLAS physics debris in beam 1 direction.

Responding to a question brought up by M. Huhtinen about the statistical weight and data biasing in the background simulations, *N. Mokhov* stated that a new version the `MARS` code is being prepared which will address these issues.

A. Morsch pointed out that the statement about ALICE, that beam-gas rates are predicted to contribute 10% of the absorbed dose, was based on conservative assumptions. In the light of the actual pressure achieved, this could be an order of magnitude less.

COLLIMATION (R. ASSMANN)

M. Lamont asked about the settings of the beam dump collimators (TCDQ elements). There is only a margin of half betatron sigma between the settings of the TCDQ and of the secondary collimators in the betatron cleaning insertions. Clearly this is difficult to control operationally. R. Assmann replied that this is a known concern. The scale for collimator settings is set by the aperture of the machine. The presented settings were agreed with the injection and beam dump teams and we cannot easily relax them if we want to protect the machine aperture while ensuring the required cleaning performance.

M. Lamont also asked what is the damage limit for the tertiary collimators. R. Assmann replied that one nominal bunch at 7 TeV can potentially destroy them.

H. Burkhardt suggested that with reduced beam emittance we could relax the collimator settings. On the other hand, R. Assmann warned that beam with smaller emittance will also be more dangerous because the energy density will be larger.

J. Spalding asked some details about the working assumptions for the asynchronous beam dump failure scenarios. R. Assmann clarified that the TCT's will be set such that the triplets are always in the TCT shadow. More detailes about the simulation assumptions were provide to J. Spalding after the workshop.

EXPERIMENT PROTECTION (D. MACINA)

A. MacPherson asked if the protection of the level 2 trigger relies only on data communication with DIP and if this is considered to be safe enough. D. Macina replied that of the experiment protection interlocks, only (and temporarily) the threshold value of the SPS Probe Beam Flag is transmitted by DIP. The rest is via the BIS or GMT. Therefore, what relies on DIP is not the full detector protection but rather the protection against scenarios that are not considered as catastrophic. An example is the switching off of high voltages, which is recommended in case of injection failure but is not expected to put in danger the detector in case of failure of DIP signals.

SESSION 2 SUMMARY

H. Burkhardt, CERN, Geneva, Switzerland

LHC CONDITIONS : WHAT CAN BE EXPECTED AND OPTIMIZED

Vacuum

A. Rossi presented the expected vacuum conditions. All warm LHC sections will be backed out. Vacuum conditions are generally expected to be good and the resulting beam gas backgrounds of no major concern to the experiments under nominal conditions.

The vacuum model predicts the static pressure distributions and the dynamic pressure rise in the presence of beams resulting in desorption by synchrotron radiation or induced by ion or electron cloud effects. Uncertainties were considered and the estimates given generally represent the upper limits. The effects of local heating by beam loss on aperture restrictions (collimators) is currently not included in the vacuum model.

It will be important to verify, check and benchmark the vacuum predictions by observations with beam. It will also be important to help to diagnose and regularly follow up on observations in operation which could indicate potential vacuum problems, like locally increased beam loss rates or detector backgrounds.

Background simulations

Even if much has been done on simulations for the LHC [1], it already became clear during the preparation of this workshop, that the LHC experiments require further work and clarification on this subject. A good fraction of the second session of this workshop was therefore scheduled for presentations and discussions on simulations of backgrounds and their effects on experiments.

In principle, signatures and effects of machine induced backgrounds are well predictable. Operation of the TEVATRON with measurements of backgrounds in the CDF and D0 detectors constitute over 15 years of experience and allowed for benchmarking and calibration of background simulations.

Quantitative background predictions crucially depend on the knowledge of the input parameters to the models. Ideally a complete set of input parameters would include

- a realistic description of the physical aperture
- an accurate machine-lattice description with magnet imperfections, misalignment, noise and ripple and beam-beam effects
- the actual values of adjustable optics parameters like tune and chromaticity
- rf voltage and phase stability
- knowledge of the vacuum conditions for beam-gas background predictions.

A complete simulation would also require a full description of the beams with bunch intensities and profiles with halo in all dimensions. Beam profiles and in particular the halo are generally not a priory known and the evolution with time will be very sensitive to tuning of the machine and maybe rather different from fill to fill.

Practical simulations rely on simplifying assumptions. LHC simulations for collimation and background generally assume the nominal machine with no or few imperfections and do not actually model the beam but rather use loss rates as input parameter. Cross talk between experiments due to pp-scattering close to the machine acceptance were not included until very recently : a first estimate of losses around the ring originating in pp collisions in IR5 was presented by R. Assmann at this workshop.

The high luminosity experiments ATLAS and CMS have been designed to be able to cope with very high collision rates. Machine induced backgrounds are normally expected to add little in energy and extra tracks to the signals from collisions.

Machine induced backgrounds mostly scale linearly with beam intensity, while the luminosity scales with the sum of the square of the bunch intensities. Signal to background ratios are expected to be worse in earlier LHC operation. In addition, the triggers for the experiments will be less selective and the LHC machine less well known and corrected. Machine induced backgrounds may be rather important for all experiments in the earlier operation of the LHC and in high luminosity operation for the lower luminosity experiments ALICE and LHCb.

Collimation

The LHC has a three stage collimation system. Collimation systems in most machines are designed to minimize backgrounds to the experiments. The LHC system was designed for high collimation efficiency, or essentially to minimize beam losses in the cold parts of the machine. The LHC has no collimators dedicated to background control and reduction to the experiments.

Tertiary collimators are installed around all experiments, to shadow the triplet magnets and reduce tertiary halo losses on the triplet magnets. They reduce the loss of halo particles in the detector region and are at the same time source of secondary particles and in particular secondary muons reaching the detectors. The LHC collimation system is rather tightly constraint. To minimize beam induced quenches and exclude damage, a hierarchy between primary, secondary and tertiary collimators will have to be respected with safety margins on tolerances, orbit and optics errors. This will leave little freedom for safe tuning of tertiary collimators under nominal conditions. More margin will be available for less squeezed beams, i.e. $\beta^* \gtrsim 2\,\mathrm{m}$ rather than the nominal 0.55 m.

Secondary collimators should remain in the shadow of the primaries, and tertiary collimators in the shadow of the secondary collimators.

Scraping into the halo using primary collimators is expected to be useful for diagnostics purposes in machine studies to allow to distinguish between halo and other sources of background. Optional scraping before the ramp or squeeze could be useful to anticipate later uncontrolled losses. It is at present not clear if halo scraping will also be needed or helpful in regular physics operation in the LHC. The functionality to be able to perform automatic scraping with primary collimators will be implemented such that scraping can be tested and applied if required.

The collimators for the betatron cleaning are located in a single straight section (IR 7). Depending on the distance and phase advances from the collimators to the experiments, the induced backgrounds for the experiments from beam 1 and beam 2 can be rather different.

The same collimation system will also be used for heavy ion operation in the LHC. Beam intensities will be much reduced compared to proton operation. Cross sections instead will be much larger and loss distributions quite different from proton operation. The optimisation of the running conditions for heavy ion operation in the LHC will require extra time and efforts.

Experiments protection

Session 2 ended with a review about protection of experiments in case of failures and exchange of signals. These subjects are followed up in working groups [2, 3]. Protection in case of beam failures were also the subject of a previous dedicated workshop [4]. The experiments all have fast beam condition monitors and can quickly dump the beam. The infrastructure for the signal exchange between the machine and experiments is set up and will soon be tested. Some details of the contents and meaning of the data will still have to be worked out and will require follow up during the commissioning. This includes the definition of a small number of normalized figure of merit background numbers from each experiment.

REFERENCES

[1] LHC Machine Induced Background Group Working MIBWG and Session V of the LHC Chamonix XV Workshop 2006

[2] SPS and LHC Machine Protection Working Group LHC-MPWG

[3] LHC Experiment Accelerator Data Exchange Working Group LEADE

[4] Joint LHC Machine-Experiments Meeting on experiment protection from beam failures

Beam Induced Backgrounds in ATLAS: Issues and Plans

W. Kozanecki
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Representing the ATLAS Background Working Group

A paper was not submitted to the proceedings. However, the slides presented are available in electronic form at http://indico.cern.ch/conferenceDisplay.py?confId=25768. The cover slide from this talk is given as reference.

BIB's in ATLAS: Issues & Plans

W. Kozanecki (CEA-Saclay)

for the ATLAS Background Working Group

- Introduction: scope & scale
- Expected impact of Beam-Induced Backgrounds on ATLAS performance
- Overview of background-monitoring instrumentation
- What feedback could ATLAS provide?
- What accelerator information might prove valuable?
- Special beam conditions
- Summary

W. Kozanecki *Workshop on Experimental Conditions & Beam-Induced Backgrounds, 3-4 Apr 07*

BACKGROUND ISSUES FOR CMS

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Abstract

This paper discusses the issues anticipated for radiation background and accidental beam loss for the CMS experiment at LHC. It includes a brief description of the extensive set of dedicated detectors for monitoring beam conditions and initiating corrective action. The information from these detectors will be available in the LHC control room to assist in optimizing LHC performance and beam conditions at CMS.

The CMS detector, including the subsystems discussed in this paper is described in Ref [1].

INTRODUCTION

The primary goal for CMS in initial data-taking will be to commission the sub-detectors and triggers, and to understand and optimize detector performance. The first steps will be to commission the safety systems and procedures that will protect the experiment, and in particular the pixel and silicon tracking system, from damage due to radiation and beam accidents, and to develop monitoring tools for beam conditions.

It is likely that beam background issues will become a concern in early physics running when backgrounds may be high relative to luminosity, and CMS operates with initial triggers that are "open" and more susceptible to background effects. In general, steady state backgrounds are not expected to be a serious problem once LHC is operating well. However, anomalous or "spiky" beam losses that can arise from a variety of sources, may well be a long-term concern both for operation of the detector and for data quality.

CMS places a high emphasis on beam conditions monitoring. This monitoring is important for safe and efficient operation of the detector, and to ensure high data-quality. Both the LHC machine state and the rates of machine backgrounds will be incorporated into the CMS interlocks and detector control system (DCS) state machine. The primary goal will be to avoid having the tracker bias voltage and muon chamber high voltage ON when there is a heightened potential for unsafe beam conditions. When conditions become worrisome, or when the LHC state is such that high losses are expected, DCS will set CMS into STANDBY, with these high-voltages set low. Protection from a rapid deterioration of conditions will be provided by the Beam Condition Monitor (BCM) which provides an input to the LHC abort system, and of course all sub-detectors are protected at some level by interlocks on over current. The second role for this monitoring is to warn when conditions may adversely affect triggers or data quality, and to provide information to assist in tracking and correcting such effects. Corrective action may involve configuration changes for both the detector and the accelerator.

CMS will provide the data from a series of beam condition detectors to the LHC control room to facilitate optimization of beam conditions at IP5.

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BACKGROUND ISSUES

Issues associated with high beam backgrounds can be considered in the following three categories.

1. Tracker safety

Protection from multi-turn accidents with circulating beam is provided by the BCM input to the abort. However, no protection can be provided for very fast accidents, occurring within a single turn. These can occur due to incorrect setting of magnets during beam injection, or when an abort kicker fires at the wrong time relative to the beam, or at the right time but when beam is present in the abort gap.

Fast beam accidents can produce an extremely high flux of charged particles in the CMS pixel and silicon trackers, which have the potential to cause permanent damage to the front-end electronics. The inner pixel layers will experience a charged particle flux of order 10^8 cm^{-2} s^{-1} from collisions at 10^{34} cm^{-2} s^{-1}, whereas fast beam accidents can result in a fluence of around 10^8 cm^{-2} on a time scale of order 100 nsec [2]. The resulting flood of charge in the detector can effectively short the bias voltage across the front-end electronics. Beam tests have exposed a small number of detector elements to accident conditions in excess of the expected fluence, without causing permanent damage [3]. Nevertheless, the situation can be different with an extensive exposure of the full detector and it is prudent to assume that a fast accident presents a serious risk [4].

The limiting aperture for such fast accidents is typically in the low-beta quads near the experiment interaction point. The mitigation of risk is provided by (a) monitoring conditions to ensure that CMS is in STANDBY when the risk is deemed to be high, and (b) positioning collimators to shadow the low-beta quads. In this regard, CMS is dependent on the use of beam flags to indicate the state of the accelerator, on software monitoring of magnet settings at injection and critically on the alignment of the TCDQ, TCS and TCT collimators. Recent simulation results show that the collimator shadowing can be very effective in protecting CMS, but does require precise positioning [2].

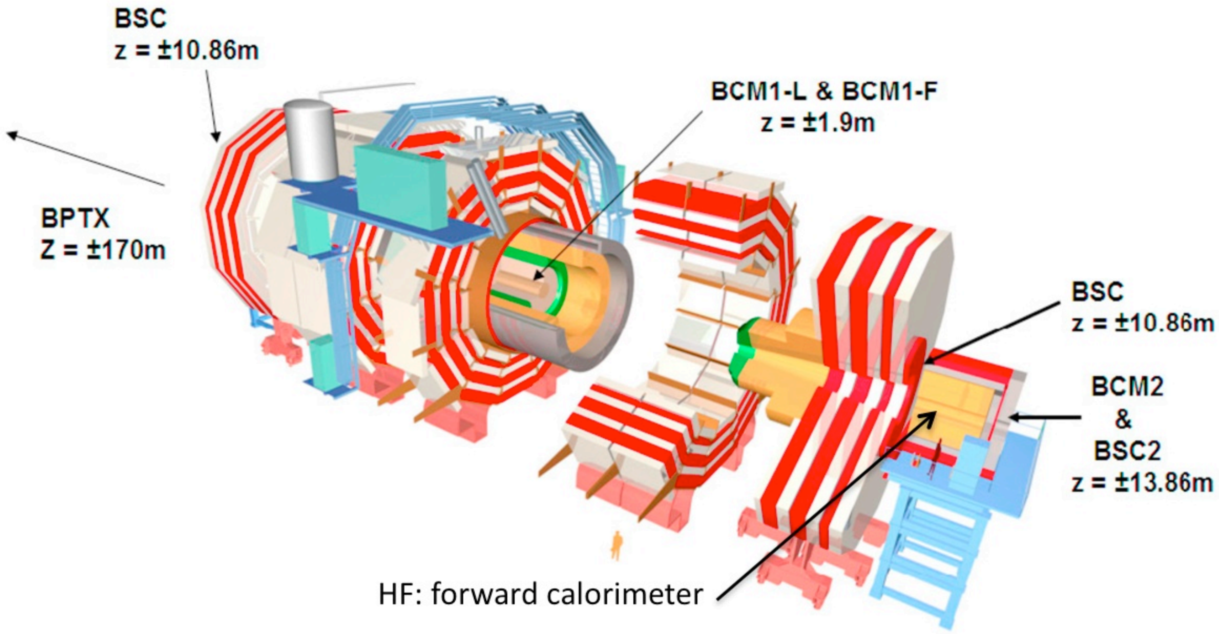

Figure 1: The CMS detector showing positions of the dedicated sub-detectors for monitoring beam conditions. The position of HF used for luminosity determination is shown and the extensive coverage of muon chambers, between the iron (shown in red).

2. Efficient Operation and Long Term Health of the Detector

The second category of issue covers high wire chamber currents and single-event effects in front-end electronics, and long-term health of the detectors. In general these are not expected to be an issue for CMS unless loss conditions are truly anomalous – but there can always be surprises. Typically protection is provided by current interlocks which trip the power supplies, causing operational difficulties and inefficiency in the short-term, and by monitoring conditions and re-tuning or making procedural adjustments if conditions persist.

CMS is designed for years of operation at a luminosity of 10^{34} cm^{-2} s^{-1}. Sustained periods of high radiation from machine backgrounds will age the detector prematurely. The dose will be monitored on an on-going basis to ensure that the dose due to backgrounds is small (less than 10% or so) compared to that from collisions. If the background fraction is high for a sustained period CMS will request that machine conditions be adjusted.

CMS has an extensive array of muon chambers, with drift tubes, resistive pad chambers and cathode strip chambers. In general current draw in these chambers is not expected to be an issue for nominal steady-state running. The expected values for operational current limits correspond to a halo flux of about 2 KHz cm^{-2}s^{-1} (~1000x the simulated steady state at a luminosity of 10^{34} cm^{-2} s^{-1} [5]). Similarly, the calorimeters are not expected to have problems with muon halo up to 10^2–10^3 cm^{-2} s^{-1}. At higher flux, muon interactions in the photo-multipliers will produce noticeable trigger contamination.

During injection and ramp, when losses are expected to be high, those sub-detectors which are sensitive to beam conditions (certainly the tracker and muon chambers) will be in STANDBY. For silicon detectors this state has the bias voltage OFF, and for wire chambers the high-voltage is reduced by ~200 volts, resulting in the chamber gain being down from nominal by a factor of 1000. The transition from STANDBY to ON, after stable beam is established, will take a few minutes.

Single event effects in the front-end electronics can be very disruptive to operations, but the rate should not be a problem unless conditions are abnormal. CMS electronics which will be exposed to radiation has been tested to ensure that the rate of single-events is acceptable - see for example Ref [6] for the silicon tracker amplifier chips. However, there may be surprises [7]. RADMON detectors [8] are located in strategic locations to monitor the radiation fields near sensitive electronics.

3. Backgrounds in Triggers and Luminosity Measurement

The third category of concern is background contamination of the triggers and data, typically from the interaction of halo muons in the detector. In general the signature of background halo interactions can be easily recognized and removed offline. Two areas are of particular concern.

The interaction of halo muons in electromagnetic and hadron calorimeters can contaminate low level physics triggers, in particular those based on missing energy. It may also be a problem for rapidity-gap triggers for forward physics. This contamination is however quite easy to identify and remove offline or in higher level triggering, since it has particular directional signature and contribution of electromagnetic or hadronic energy depending on the location of the halo interaction.

The determination of luminosity in the forward hadronic calorimeter (HF) uses an algorithm that counts zero-occupancy in calorimeter towers [9]. The location of HF is indicated in Figure 1. The measurement is linear for luminosities between 10^{28} and 10^{34} $cm^{-2}s^{-1}$, but may be susceptible to background contamination if the beam halo is higher than expected. Simulations of these effects are underway and will be compared to initial data. A full simulation requires event-by-event Monte Carlo generation to account for all correlations, which is extremely CPU intensive [5]. Once both the luminosity calculation and the LHC are commissioned, dedicated special fills with specific bunches missing will allow a more detailed understanding of background effects, and allow the development of correction algorithms. The luminosity determination will be cross-calibrated with Van der Meer scans in the LHC, and with the W and Z cross-sections. The accuracy is expected to be of the order of 10% for early physics running.

The missing-bunch running will similarly allow detailed studies of halo-induced background in the triggers. The bunch structure for these special fills will be discussed between LHC and all experiments. A bunch-gap of three empty bunches in the middle of a bunch train, not adjacent to the abort gap will allow a measurement of background-only effects under conditions very similar to normal running.

Background effects will be studied and corrected in time periods that can be less than the duration of an LHC fill, so fill-by-fill variations will be taken into account. Variation in intensity and loss conditions bunch-by-bunch will be much harder to study and correct. But variations of order 30% or so between bunches would not present a problem.

MEASUREMENT OF BEAM CONDITIONS AT CMS

The CMS detector includes an extensive set of instrumentation dedicated to monitoring beam conditions. This instrumentation will provide information at the IR for optimizing the accelerator, including bunch-by-bunch loss and halo measurements, and precision beam spot information.

BRM Detectors

The Beam Radiation Monitoring project in CMS provides a series of detectors dedicated to monitoring beam conditions [10]. These include (1) the Beam Condition Monitor (BCM) diamond detectors BCM1 and BCM2, which measure radiation rates close to the beam pipe near the IP, (2) the Beam Scintillation Counters (BSC) which are mounted in the HF region and measure beam halo, and (3) The Button Beam Pickup (BPTX), which provide information on bunch timing and intensity. The location of these detectors is indicated in Figure 1. These detectors are always "live" when beam is in LHC, and operate independent of the CMS control and data-acquisition systems.

The data from these detectors will be provided to the LHC control room using the Data Interchange Protocol (DIP), along with summary parameters which will provide the figure-of-merit for background conditions at the IP. These "pseudo-devices" will include a relative measure of the halo associated with each beam, and a general background level, corrected for luminosity. More detailed information will be available with slower accumulation of per-bunch values, radial/phi segmentation in halo rates, and pseudo-devices measuring loss spikiness.

The BCM detectors are read via standard LHC BLM electronics. The BCM2 diamonds have been cross calibrated to a standard LHC BLM in test beams [10]. BCM1 readout will be calibrated relative to BCM2 in situ, and together they will provide continuity of the loss measurements through the IP with the BLMs on the low β quadrupoles on either side. The response of the diamond sensors is linear over six orders of magnitude, with sensitivity to ~ 10^4 MIPs cm^{-2} s^{-1}, corresponding to a luminosity of about 10^{30} cm^{-2} s^{-1}.

HF-Luminosity

The luminosity measurement is necessary to interpret background information at the IP. The information will be sent to the LHC control room via DIP, on a timescale of ~minutes initially and finally ~seconds. The data will include an absolute measure of luminosity averaged over all bunches, and relative luminosity per crossing. The intent is to have the luminosity data available immediately after ramping, when LHC is in adjust state.

Location and Shape of the Luminous Region

The position and shape of the luminous region ("beam-spot") will be determined on-line using the tracking detector [12]. This information will be available in real-time only after stable beam has been established for several minutes, and of course only after the detector, the alignment, and the reconstruction algorithms are fully commissioned (probably by mid-2009). The information will be updated every few minutes and can be sent to the LHC control room via DIP.

A simulation of this analysis is illustrated in Figure 2. The algorithm determines the impact parameter for tracks with p_T>2 GeV and reconstructs the beam spot. Using the notation defined in Ref [12], the impact parameter is defined by

$$d_0 = x_0 \cdot \sin\phi_0 + dx/dz \cdot \sin\phi_0 \cdot z_p - y_0 \cdot \cos\phi_0 - dy/dz \cdot \cos\phi_0 \cdot z_p$$

where d_0 is the signed impact parameter distance between helix and origin at minimum approach, ϕ_0 is the azimuthal angle in the x-y plane at minimum approach, and z_p is the z position

In this example the transverse beam position is offset relative to the tracker by 300 μm in x and 600 μm in y, producing the characteristic sine wave in Figure 2.a. The two-dimensional shape of the luminous region is shown in Figure 2.b.

Several thousand tracks can be used to determine the transverse position to a few μm and the z-position to a few 10's of μm every few minutes. With a few hours of data-taking, several million tracks can be used to determine the β* and emittance.

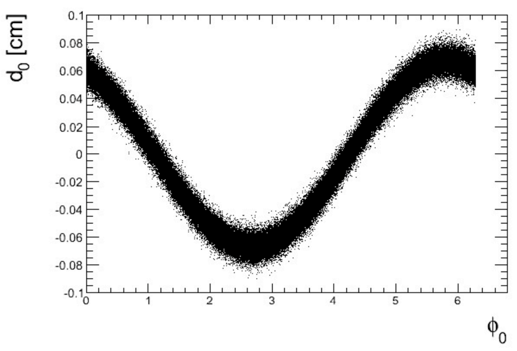

Figure 2.a: The impact parameter versus ϕ for tracks with p_T>2 GeV.

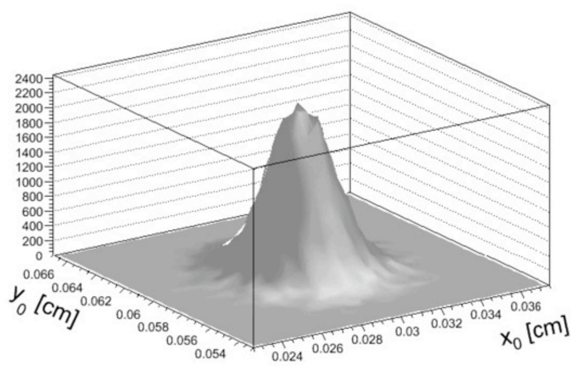

Figure 2.b: The luminous region in the transverse plane for the same tracks.

The z-distribution of the luminous region will provide a measure of near satellite crossings, which are separated in time by only 2.5 or 5 nsec. These satellites will have the effect of stretching the luminous region and may have different trigger acceptance due to their position and timing.

SUMMARY

The CMS detector has been designed to operate in the high radiation environment at the LHC at full LHC design luminosity, and under nominal background conditions. However, loss spikes will cause problems for detector operation and contamination of triggers, and beam accidents pose a danger to the detector.

Hardware protection is in place to limit the risk from high currents and high radiation dose. However this cannot act fast enough to protect the pixel and silicon tracking detectors from fast beam accidents. Beam tests and simulations indicate that there is a safety margin in such cases, nevertheless CMS relies on the collimation system in the LHC to limit exposure to such accidents.

In general, corrections for trigger contamination can be accomplished offline once background signatures are well understood and algorithms developed. This will require further simulation studies and comparison to data taken under special conditions with specific bunches missing in the bunch train. These special fills will be important. A specific program should be agreed once CMS and LHC are commissioned and after a first analysis of conditions is in hand.

CMS places a high emphasis on monitoring beam and background conditions for equipment protection and data correction, and to assist in optimizing LHC performance at IP5. Measurement of losses, beam halo and precision measurement of the luminous region will be sent to the LHC control room.

Acknowledgements

The following people provided input for this talk/paper: Pushpa Bhat, Monica Grothe, Richard Hall-Wilton, Valerie Haylo, Mika Huhtinen, Christos Leonidopoulos, Nikolai Mokhov, Wesley Smith, Joao Varela. Any mistakes and omissions however are the author's.

REFERENCES

[1] CMS Detector Paper. To be published in the Journal of Instrumentation (JINST).
http://cmsdoc.cern.ch/cms/Publications/detpaper/finaldraft.pdf

[2] Private communication from Pushpa Bhat, Nikolai Mokhov and Thomas Weiler.

[3] For silicon tracker see: NIM A518 (2004) 328: Weiler, Dirkes, Fahrer, Hartmann, Heier, Macpherson, Müller. For pixel detector: private communication from Mauro Dinardo.

[4] CDF exposed test parts to instantaneous fluences well above an accident scenario, yet experienced permanent damage to the detector in real kicker pre-fire incidents. See the talk of Rick Tesarek at this workshop.

[5] See the talk of Mika Huhtenin at this workshop.

[6] E. Noah et al, Single Event Upset Studies on the CMS Tracker APV25 Readout Chip, Nucl. Instr. & Meths A. 492 (2002) 434-450

[7] CDF suffered from single-event burn-out in VME power supplies. See the talk of Rick Tesarak at this work shop. The solution was (a) to reduce the operating voltage of these switching supplies, and (b) to add shielding at the exit of the low-β quadrupoles.

[8] See http://lhc-expt-radmon.web.cern.ch/

[9] Section 8.3.1, CMS Physics TDR: Volume I. http://cmsdoc.cern.ch/cms/cpt/tdr/ptdr1_final_colour.pdf

[10] Section 11.6 in Ref [1]

[11] Private communication from Steffen Mueller, see also talk given to AB/BI group on Dec 17, 2007 “CMS Beam Condition Monitor – testbeams and calibration”

[12] CMS NOTE-2007/021 -- Beam Position Determination using Tracks. T. Miao, H. Wenzel, F. Yumiceva, N. Leioatts

What ALICE Requires and Provides for Background Optimisation

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Abstract

This paper briefly discusses the ALICE machine background concerns and the background monitoring system.

ALICE RUNNING STRATEGY

ALICE (A Large Ion Collider Experiment) [1] is a general purpose detector designed to address the physics of strongly interacting matter and the quark-gluon plasma in nucleus-nucleus collisions at the LHC. It will allow a comprehensive study of particles produced in Pb–Pb collisions, up to the highest multiplicities anticipated at the LHC. The physics program also includes collisions with lighter ions as well as dedicated proton-nucleus runs. Regular data taking during pp runs will provide reference data for the heavy ion program and address a number of specific pp topics.

The pp runs will be in parallel with the other experiments but at a reduced luminosity in IP2. In order to keep the pile-up in the Time Projection Chamber (TPC) and Silicon Drift Detectors (SDD) at an acceptable level, the luminosity during pp runs has to be limited to $3 \times 10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, corresponding to an interaction rate of $200\,\mathrm{kHz}$. At this rate we record on average 20 overlapping events. The optimal detector operation and physics performance with the TPC, i.e. no pile-up, is at $10^{29}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

IMPACT OF MACHINE BACKGROUND

General considerations

Due to the running at reduced luminosity ALICE has the most unfavorable interaction rate over background rate ratio (at least a factor of 10^3 less than the high luminosity experiments). Machine background effects are alleviated by the fact that ALICE has been designed to perform tracking for up to 1000 times the pp multiplicity and the trigger reduction factors are relatively small (typically 10^3). So far the expected effects of the background are mainly of cumulative nature, such as radiation damage (integral dose and neutron fluences). Also the increase of the data volume has obvious negative consequences in terms of data storage and offline computing requirements.

To simulate these effects ALICE has so far considered beam gas events in the experimental region IP $\pm 20\,\mathrm{m}$ and beam-halo from beam-gas scattering outside the experimental regions. Input for the quartiary background caused by tertiary collimators (TCT) close to the experimental region is not yet available for IP2. In case the collimators are at the nominal settings this contribution could well be the dominant source of machine background. However, since at full beam intensity ALICE will run at high β^* ($10\,\mathrm{m}$), the inner triplet will not limit the aperture of the machine. ALICE requires that for stable beams the TCTs will be put at a position at which they protect the inner triplets against accidental losses but do not produce extra losses for stable beams.

Dose in central detectors

The radiation environment in the experimental cavern has been simulated for the planned running scenario of the ALICE experiment (Table 1) [2]. Running with p-p, low and high mass ion–ion collisions over a ten year period has been assumed. Beam-beam and beam-gas interactions have been considered as potential radiation sources. The highest doses, up to 2.8 kGy, are expected at the location of the inner tracking system (ITS) (Table 2). The contribution from beam halo [3] amounts to $\approx 20\%$ of the total dose. The contribution from beam-gas collisions within the experimental region has been calculated assuming a very conservative residual gas pressure of $2 \times 10^{13}\,\mathrm{molecules/m}^3$. Only under these conditions a sizeable contribution of about 10% of the total dose is expected.

Charged particle rates on RPCs

Among the ALICE detectors, the muon trigger system is one of the most sensitive to the machine induced background. As a matter of fact, the Resistive Plate Chambers (RPC) rate capability ($50 - 100\,\mathrm{Hz/cm}^2$) might be saturated by a too high background level, which might also have an impact on the detector lifetime. The fluxes of secondary charged particles through muon trigger system originating from machine induced background has been simulated [4]. The trigger background consists mainly of electrons from hadronic showers resulting in a hot spot of $\approx 60\,\mathrm{Hz/cm}^2$ located at $x = 1.5\,\mathrm{m}$ and $|y| < 1.5\,\mathrm{m}$.

BACKGROUND MONITORING

For machine background monitoring during injection ALICE will use the beam condition monitor (BCM) and the V0 forward scintillator detectors at safe photomultiplier settings. Due to the different acceptance of the two detectors an OR of the two signals will be used. With circulating stable beams a combination of signals from BCM, V0, SPD, TPC and forward muon spectrometer will be used to obtain a normalized machine background signal.

Beam condition monitors

The purpose of the Beam Condition Monitor (BCM) is to detect adverse beam conditions within the ALICE exper-

Table 1: Operation scenario for a ten-year run period, where $\langle \mathcal{L} \rangle$ is mean luminosity, and $\sigma_{\rm inel}$ is the inelastic cross section. One year of pp run corresponds to 10^7 s and one year of heavy-ion run corresponds to 10^6 s.

	pp	Ar–Ar	Ar–Ar	Pb–Pb	dPb
$\langle \mathcal{L} \rangle$ ($\mathrm{cm^{-2}s^{-1}}$)	3×10^{30}	3×10^{27}	10^{29}	10^{27}	8×10^{28}
$\sigma_{\rm inel}$ (mb)	70	3000	3000	8000	2600
Rate ($\mathrm{s^{-1}}$)	2×10^5	9×10^3	3×10^5	8×10^3	2×10^5
Runtime (s)	10^8	1.0×10^6	2.0×10^6	5×10^6	2×10^6
Events	2×10^{13}	9×10^9	6×10^{11}	4×10^{10}	4×10^{11}
Particles per event	100	2400	2400	14 200	500
$N_{\rm tot}$	2.1×10^{15}	2.2×10^{13}	1.4×10^{15}	5.7×10^{14}	2×10^{14}

Table 2: Doses in inner tracking system

Detector	Dose [Gy] IP Collisions	Dose [Gy] Beam-Gas	Dose [Gy] Halo	Dose [Gy] Total
SPD1	2000	250	500	2750
SPD2	510	48	120	680
SDD1	190	12	45	250
SDD2	100	2.4	13	120
SSD1	40	1.2	7	50
SSD2	26	0.6	2.5	30

imental region. It provides active protection, in particular of the ITS, against multi-turn beam failures. The detector is based on pCVD diamond sensors ($1\mathrm{cm}^2 \times 500\,\mu\mathrm{m}$) and its design is a copy of the LHCb BCM [5].

BCM sensors have been installed at three different location, 4 sensors $z = 15.5\,\mathrm{m}$ (BCMA2), 4 sensors at $z = 4.5\,\mathrm{m}$ (BCMA1) and 8 sensors at $z = -19\,\mathrm{m}$ behind the small angle absorber. These loactions have been chosen since no other space is available on the muon spectrometer side. The advantage of the location is that the expected signals due to pp collisions and due to background events (beam-gas collisions in the experimental region, machine induced background) are of comparable intensity. Closer to the IP pp collisions are dominating.

V0 Detector

The V0 detector consists of two arrays of 64 scintillator tiles read out via fibers. V0A is located $340\,\mathrm{cm}$ from the IP on the side opposite to the muon spectrometer and the V0C is fixed at the face of the fron absorber, $90\,\mathrm{cm}$ from the vertex. The covered pseudo-rapidity ranges are $2.8 < \eta < 5.1$ (V0A) and $-3.7 < \eta < -1.7$ (V0C). The detector is used as a minimum bias trigger and for rejection of beam-gas background. A large background trigger rate is is expected in the muon spectrometer trigger chambers. The absence of a Minimum Bias Trigger (MB) from V0C alone, will be a good signal to reject a large part of thes false muon triggers [6].

SUMMARY

ALICE will participate in standard pp runs at reduced luminosity ($3 \times 10^{30}\ \mathrm{cm^{-2}s^{-1}}$). Quartiary halo from the TCTs is a concern since it might represent the largest background source. At full intensity ALICE will run at $\beta* = 10\,\mathrm{m}$. ALICE requires that for stable beams the TCTs will be put at a position at which it protects the inner triplet against accidental losses but does not produce extra losses for stable beams. Special beam condtion detectors and ALICE forward detectors are used for background monitoring.

REFERENCES

[1] F. Carminati *et al.* [ALICE Collaboration], J. Phys. G **30** (2004) 1517.

[2] A. Morsch and B. Pastircak, ALICE Internal Note 2002-28.

[3] I. Azhgirey *et al.*, LHC Project Note 273 (2001).

[4] R. Guernane *et al.*, ALICE Internal Note 2003-41.

[5] C.J. Ilgner, Nuclear Science Symposium Conference Record, 2007. NSS ’07. IEEE (2007) 1700.

[6] B. Rapp, Thesis, Lyon University, (2004).

LHCb: What the Experiment Provides and Requires for Optimization

G. Corti
CERN, Switzerland.

A paper was not submitted to the proceedings. However, the slides presented are available in electronic form at http://indico.cern.ch/conferenceDisplay.py?confId=25768. The cover slide from this talk is given as reference.

LHC Workshop on

Experimental Conditions and Beam Induced Background

What the experiment provide and require for optimization

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CERN/PH

4 April 2008

Acknowledgments: M.Ferro-Luzzi, C.Ilgner, R.Jacobsson, K.Hennessey, M.Lieng, V.Pugatch, A.Schopper, D.Wiedner

Machine Induced Backgrounds in the Forward Experiments

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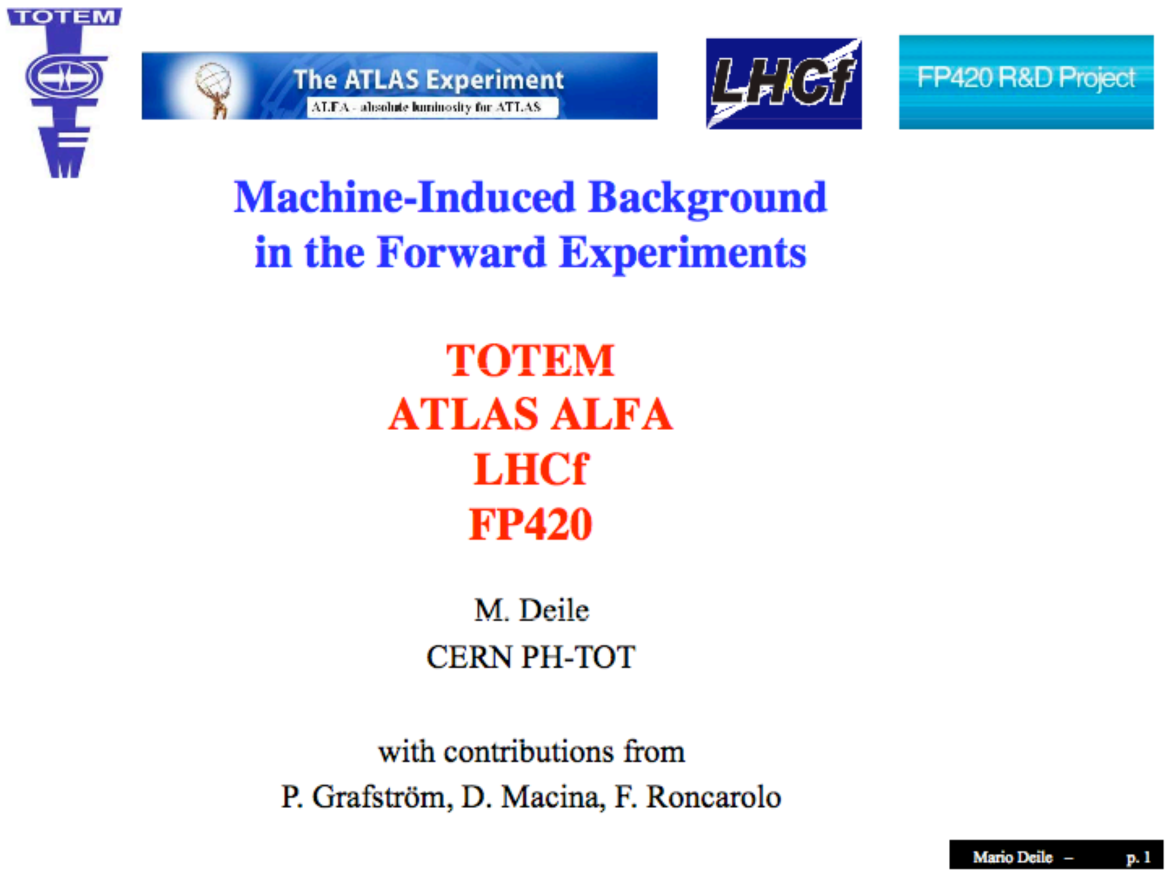

Session 3 Discussion Summary

A. Macpherson, CERN, Geneva, Switzerland

INTRODUCTION

The third session of the workshop addressed the issue of what the experiments require and provide for optimization of known background sources at the LHC, and the discussion generated by the presentations is summarised herein.

ATLAS (W. KOZANECKI)

The speaker was asked to discuss the role of LUCID in the ATLAS background monitoring. It was explained that LUCID was a conical Cerenkov Counter detector placed around the beam pipe close to the interaction point. Its primary function is to provide online luminosity measurements, but in addition the time resolution of LUCID could provide information on out of time hits, and so could potentially be used to identify background. It was stated that in principle LUCID could provide such information. However, it was stressed that the sensitivity of LUCID as a background monitor has not yet been studied.

R. Tesarek asked if there were any BLM monitors in direct line of sight with the IP. It was stated that the all the ATLAS BLMs are mounted on the endplate of the inner detector, and so are not in line of sight with the IP. It was further mentioned that the signal expected from these BLMs is to be predominantly proportional to luminosity/ collision products, but *M. Mikuz* commented that these devices had been added to ATLAS primarily for the purpose of protection.

P. Grafstrom also commented that a re-evaluation of the simulation of scattering of primary particles off the TCT is needed, as the present level of detail is insufficient for a realistic detector level response to backgrounds. Further, this simulation should also include the response of the endcap muon chambers.

The issue of when to turn on the various ATLAS monitors that could provide background information was also mentioned, but was left as an open issue that is to be followed up. In particular *P. Grafstrom* commented that the danger levels for the various sub-detectors and monitors needs to be defined and calibrated before a turn-on policy can be specified. However it should be noted that the ATLAS BCM monitors are implemented for the purpose of experiment protection, and are to always on when there is the possibility of beam in the machine.

CMS (J. SPALDING)

O. Bruning asked about the details of the "St Catherine's Day Massacre event in CDF, and it was explained that this was an incident where Tevatron beam grazed the CDF beam pipe when exiting CDF. *J. Spalding* and *R. Tesarek* pointed out that this was an exceptional situation, and was related to a beam pipe misalignment due to fault installation. This mis-alignments situation resulted in a steady state source of SEU events until it was identified and corrected.

O. Bruning also asked about the expected performance of the CMS beam spot measurements reported by *J. Spalding*. It was explained that bunch by bunch monitoring measurements are to be to maintained as running sums. For beam spot measurements, the expected time scale is of order of a few minutes, and should give a transverse position resolution to O(~ few μm) and a z-position resolution to O(~few 10's μm). For precision measurements of β^* and emittance, it is expected to take several hours for reasonable values to be obtained, as several million tracks are needed for the measurement.

Regarding the Beam Scintillator Counters (BSC) *M. Ferro-Luzzi* asked about the hit occupancies and readout, and it was stated that the readout is by standard TDC with a hit rate of ~1 Hz/cm^2. *K. Eggert* questioned this for the BSC tiles installed in the forward region close to the beampipe, as the density of tracks in the TOTEM region is expected to be large.

ALICE (A. MORSCH ON BEHALF OF T. NAYAK AND A. DI MAURO)

It was noted by the speaker that ALICE has the most unfavourable Luminosity/Background ratio (at least factor of 1000 less than high luminosity experiments) and that the ALICE has been designed to perform tracking for 1000 times the pp multiplicity. This prompted *A Rossi* to ask if the forward detectors of ALICE could be used to reject beam gas events.

It was stated that this is to be done at the trigger level as such events can be identified as out of time events. *H Burkhardt* commented that for pp collisions and with background problems from beam gas the effectiveness of such an approach would be diminished at higher luminosities. *K. Eggert* further commented that in order for a beam-gas rejection method to be established, you would need good minimum bias runs at low luminosities. *K. Eggert* also stated that this was the reason behind the request by ALICE and TOTEM for special low luminosity runs.

In regard to the question of assessing the beam gas background contribution *R. Assmann* noted that single beam running is planned, and that this may be useful to ALICE

The speaker was also asked if ALICE (and LHCb) could receive very high luminosities by accident. The answer is believed to be yes, and the speaker explained that BCM units are to be used, in part, to protect ALICE against such accidents

LHCb (G. CORTI)

As it was noted that the BCM is based on 16 1cm^2 diamond sensors (8 on each side of IP), *R. Tesarek* asked if LHCb was planning to have large area monitors (eg scintillators ala BSC) to measure beam losses. The speaker replied that at this stage no such monitors were foreseen. R Tesarek also commented that for CDF the change in the signal to background ratio for changing conditions is of order 0.005, and is rather insensitive due to the slowness of controls system implementation. He pointed out that it would be to LHCb's benefit if there radiation monitoring could be done so that such insensitivity could be avoided.

In relation to the effect of beam gas on trigger efficiency, the speaker pointed out that previous studies indicated that if the vacuum pressure increases by a factor of 10 above the target value (ie to a pressure of 10^7 millibar), the trigger efficiency loss rises to ~10%, due to beam gas events. The speaker was then asked to give an estimate on the maximum allowed pressure in the VELO, and she stated that this could be ~1000 times the nominal ie the maximum pressure allowed is of order 10^{-6} millibar. This raised the issue of what should be done to set and monitor acceptable operational limits on the vacuum pressure. This was left as an open issue.

In regard to the RADMON monitors deployed around LHCb the speaker was asked to comment on what they would measure and on their availability. It was then noted that the RADMON monitors installed around LHCb were standard RAMON monitors, and so could provide total dose measurements as well as dose rate, flux, flux rate, and SEU rates, and that these monitors were already installed.

FORWARD DETECTORS (M. DEILE)

After a review of the various forward detector systems, *B. Holzer* asked if it was foreseen to have an alarm system that can react on a fast timescale, especially for the forward detectors that involve or are near movable devices. The speaker replied that in the case of the Roman Pots, BLMs are mounted next to them, so that the protection mechanism of the BLMs, which is integrated into the Beam Interlock system, should give sufficient protection. In addition, there is an interlock based on the Roman Pot position as determined by contact switches.

For the forward detectors it was also indicated that if rates in either the detectors themselves, or the neighbouring BLMs were too high, the detectors would simply be turned off. However this raised a question from *K. Eggert*, as to whether the various forward detectors discussed here can survive if hit directly either by the beam or by significant beam halo. This question was left as an open issue, as the answer is not clear and cannot be generalized to all the forward detectors discussed in the presentation.

In regard to LHCf, the speaker was asked why a double arm cut on the extreme forward p-p production is foreseen to be applied as a means to reduce the effect from beam-gas background contributions: The physics motivation of such a cut was questioned, but was not clarified.

The speaker was also asked why the presentation did not include RP220 and the ZDC experiments, and it was stated that the focus of the presentation was on the forward detectors foreseen for the early running but that given the information received, some experiments were not covered.

SESSION 3 SUMMARY

M. Ferro-Luzzi, CERN, Geneva, Switzerland

WHAT DO THE EXPERIMENTS REQUIRE AND PROVIDE FOR OPTIMIZATION

In this session the experiments (ALICE, ATLAS, CMS and LHCb) presented their strategy for monitoring background, disentangling the various types (when applicable) and exchanging background-related information with the machine. The last presentation was dedicated to Roman Pots (TOTEM, ALFA), LHCf and FP420.

It appeared that experiments have so far focused their attention to beam losses on severe failure scenari and protection of the experiment. Beam-induced background has (naturally) been given less priority. In this respect, the preparation for and realisation of this workshop have favored the creation (or consolidation) in each collaboration of a group of physicists to work on these issues. Understanding backgrounds at start-up should benefit from this increased momentum.

It was generally agreed that background is rarely disastrous, but can often be quite a nuisance and difficult to tackle. The example of an excess at high values of missing transverse energy ($\not{E}_T$) observed in CDF was given to illustrate that these background-contaminated data were not lost and could be cleaned up offline, with extra work. Slow-varying backgrounds are generally thought to be less problematic than sudden bursts ("spikes").

Given the different running conditions and detector configurations, the experiments will have different sensitivities to background rates. For example, ATLAS and CMS have been designed for high luminosity ($10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$) and therefore one expects no substantial contribution to the integrated dose by steady state beam-induced background. ALICE and LHCb will run at lower luminosity and without TAS/TAN absorbers around the experiment. Thus, they are potentially more exposed to degraded beam conditions. ALICE in particular will normally run at $10^{29}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (and generally at $< 3\times10^{30}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$) and, being designed for such luminosity, is likely to be (of the four large experiments) the most sensitive to beam-induced background. In fact, for ALICE, nominal backgrounds are expected to contribute a few percent to the total dose.

Furthermore, it was pointed out that, because of the lower luminosity and the fact that the machine will be less well understood, beam-induced background are likely to be a bigger issue during the initial runs.

It was also reminded that all electronics of the experiments around the detectors have been carefully designed or chosen such as to be compatible with the expected particle flux at nominal luminosity. Therefore single event effects are not expected be an issue.

Some of the experiments may have the capability to distinguish, by timing, the backgrounds induced by the two beams. For example, ATLAS will use time correlations within the Beam Conditions Monitor, Minimum Bias Trigger Scintillators halo trigger and Forward Muon trigger to disentangle backgrounds from the two beams. The first two should always be on, the third only when beams are stable. Several other detectors (Forward Muon Chambers, Transition Radiation Tracker, Pixel and Semiconductor Tracker, Luminosity Cerenkov Integrating Detector) will be used to monitor occupancies per bunch crossing. However, these detectors are mostly off when beams ar not declared stable (except LUCID).

A number of signals to be exchanged beteween the experiments and the CERN control room (CCC) were proposed and discussed. In particular, it was proposed to add the following to the list of parameters transmitted by the CCC via DIP:

1. the beam life times,
2. BRAN rates and luminosity,
3. the extrapolated positions and angles at the IP,
4. vacuum pressure readings in the vicinity of the experiments,
5. the positions of collimators and beam losses.

The questions addressed to the experiments concerning special beam conditions were partially answered. Negative effects due to bunch-to-bunch luminosity variations, luminosity and background variations during a fill, and fill-to-fill variations are difficult to quantify and will require first real data to be properly assessed. ATLAS mentioned that 20% bunch-to-bunch luminosity variations may be tolerable, though this would need further studies.

Concerning vacuum in the IR, it seems that actual or expected vacuum conditions give large margins (more than one order of magnitude) to what could cause a nuisance to the experiments. The effect of the tertiary collimator vacuum and other elements that may cause local pressure bumps (such as elements that warm up due to beam losses) was not yet included in simulations and needs to be looked at.

The effect of satellite bunches is also difficult to quantify. Interestingly, it was pointed out by ATLAS and LHCb that the experiments may be able to actually measure the relative charge in some satellite bunches (at ±2.5 ns from the main bunch) by reconstructing collisions at IP±37.5 cm. This may prove useful for understanding the machine. It was also said that such displaced collisions may be useful for alignment (in particular, to constrain so-called 'weak modes') and a small amount of beam time with such collisions might be requested by the experiments.

Locally non-colliding bunches may also prove useful for understanding backgrounds from each beam and might be requested by the experiments in special fills. Though, it is not clear to what extent such bunches will be representative of the other bunches.

In general, it is thought that several signals will be combined by the experiments to create a few (2 to 4?) 'background figure of merit values' (sometimes termed BKG1, BKG2, ...). The details of this combination are yet to be worked out and may well need to evolve with time, especially during the first run. The experiments might start with simple one-to-one relations between BKG values and the normalised rates measured by selected background-monitoring detectors.

ALICE expressed worries about quartic halo background which may be the largest source for them. They request that the tertiary collimators be not put more inward than required by protection of the triplet magnets. It was also pointed out that background conditions between experiments should be compared with care, as for example the impact of a given absolute background rate may be much worse for a low-luminosity experiment as it is for a high-luminosity experiment.

All experiments have dedicated detectors to monitor luminosity and backgrounds, such as the Beam Conditions Monitor (BCM). The primary role of the BCM is to protect the experiment against beam-induced damage. They are therefore designed for detecting abnormally large background rates that could lead to destruction of equipment. Such rates are generally orders of magnitude higher than the rates of backgrounds which may already affect data quality. Therefore, the sensitivity of the BCM may not be optimal for monitoring ordinary backgrounds.

In general the subtraction of the luminosity signal from background-monitoring signals appeared not to be thoroughly addressed.

For forward detectors, current simulation results indicate that halo from distant beam-gas scattering is expected to be the dominant background source at low luminosity (around $10^{29}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$), while background from secondary interactions due to IP collisions may become dominant as one approaches high luminosity ($\sim 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$).

Concerning simulation studies, several signs were given indicating that future work should be coordinated such as to promote a more coherent approach among machine and experiments.