Workshop on Experimental Conditions and Beam-Induced Detector Backgrounds

CERN, Geneva, Switzerland

INTRODUCTION

As a follow-on from the 21st LHCMAC meeting, the LHCMAC executive is pleased to initiate a workshop on Experimental Conditions and Beam-Induced Detector Backgrounds. This workshop is to be seen as an important activity and is carried out as a joint Detector-Accelerator concern.

Given the wide experience with these matters at other cryogenic hadron colliders such as the Tevatron, HERA and RHIC, the LHCMAC suggests that such a workshop involving the detector and accelerator experts from the corresponding laboratories would be very beneficial in highlighting the various effects and their cures. Beam induced detector backgrounds have been a challenge at all colliders.

Catalog of questions

Questions to the external machine experts:

- Are / were machine backgrounds an issue ?
- Which type ?
- How was it solved ?
- Halo : what are the sources.
- Scraping halo : needed, useful ?

Request made by the LHC machine to the experiments:

It is foreseen to receive detailed signals from the experimentswhich should allow us to monitor backgrounds. In addition to many, detailed signals, we request few (say two, BKG1, BKG2) normalised figure of merit background signals from each detector. Ideally, they should be representative of backgrounds in the detectors, the running and data quality, and be somewhat complementary. They should be available before stable collisions are declared. Invalid or missing information should be clearly flagged (i.e. flagged with a negative number).

If some detector components are reduced in sensitivity or turned off during injection/ramp/squeeze: when will they be turned on based on which information? Consider to use LHC machine mode and BKG1/2 ?

Possible issues, things to be kept in mind :

- Non-uniformity in the distribution of the backgrounds around the ring depending on positions of collimators and optics phase advance.
- Scaling of backgrounds with intensity. Increased relative backgrounds for lower luminosity interaction regions.
- Out off bucket particles, off momentum background.

SIMULATION OF MACHINE BACKGROUNDS

V. Talanov*
Institute for High Energy Physics, Protvino, Russia and TS/LEA Group, CERN

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.

* Vadim.Talanov@ihep.ru, Vadim.Talanov@cern.ch

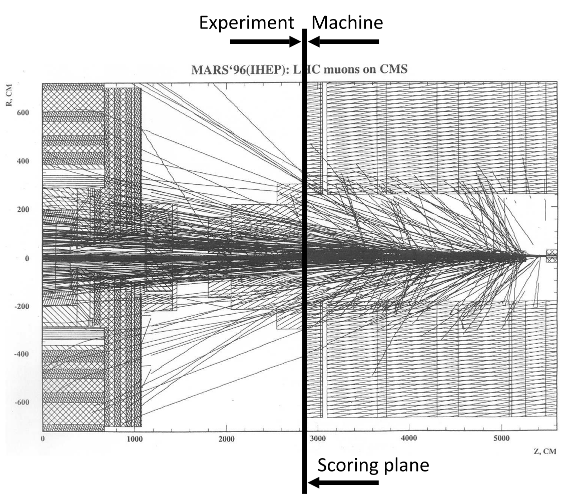

Figure 1: An illustration to the concept of the background "scoring plane" for the background analysis at the boundary between machine and experiment.

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):

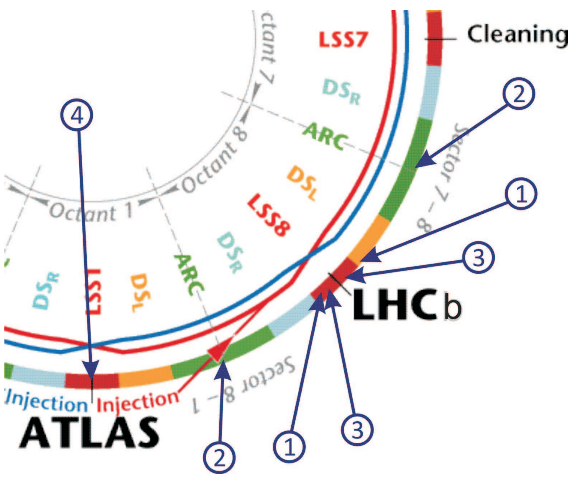

Figure 4: A part of the LHC scheme with the LHCb experiment at IP8 between the betatron cleaning insertion at IP7 and the ATLAS experiment at IP1 (the labels are explained in the text).

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

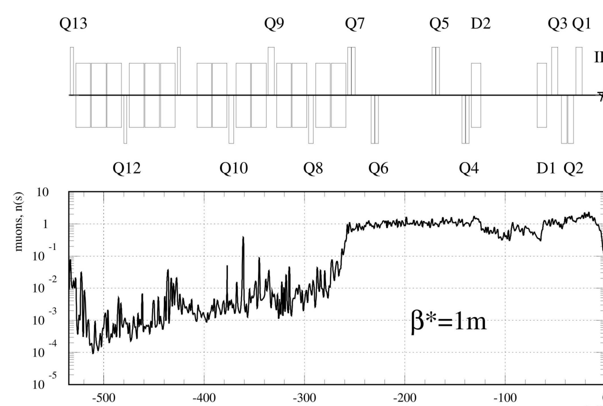

Figure 5: Number of the background muons at the IP7 side of IP8 as a function of the primary loss distance to the interaction point, given per unit of the linear density of the beam-gas loss rate in LSS8.

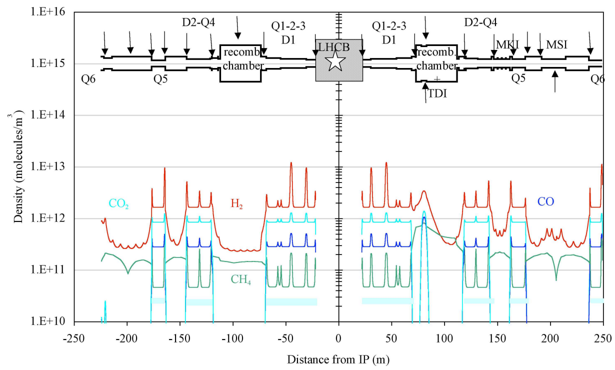

Figure 6: Density profiles for the different components of the residual gas in LSS8 (courtesy of A.Rossi).

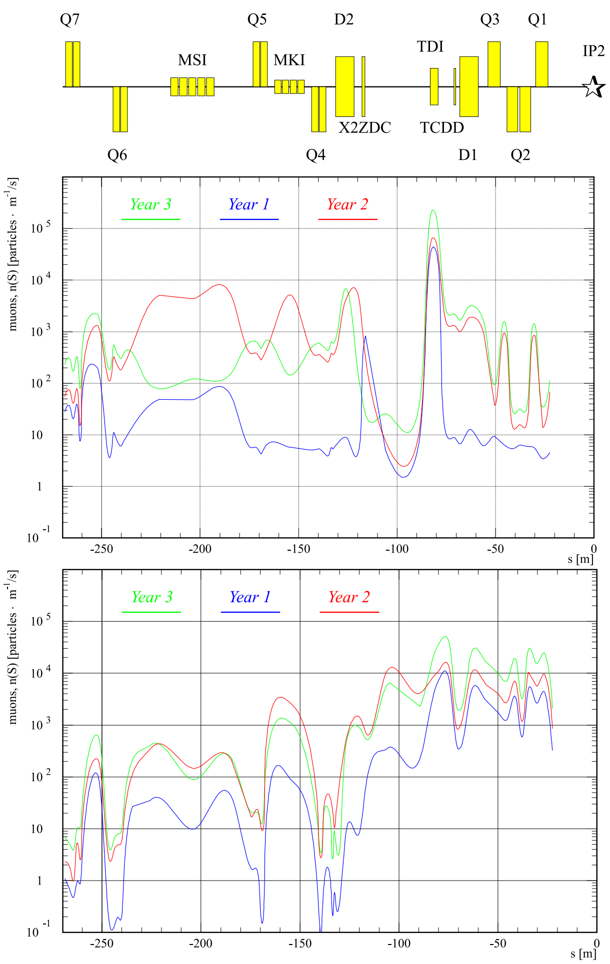

Figure 7: Number of the background muons as a function of the primary (top) and last (bottom) hadron-nucleus interaction distance to IP2, for three different scenarios of the machine operation.

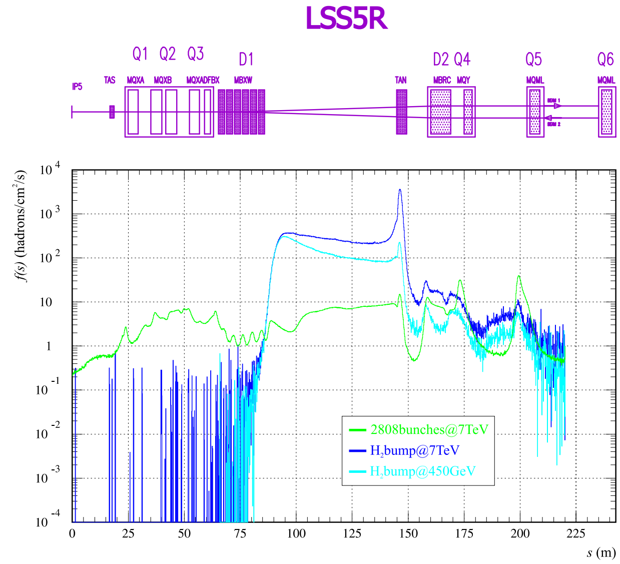

Figure 8: Hadron flux density $f(s)$ as a function of the distance to IP5, for three cases of the beam-gas losses in LSS5R considered.

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

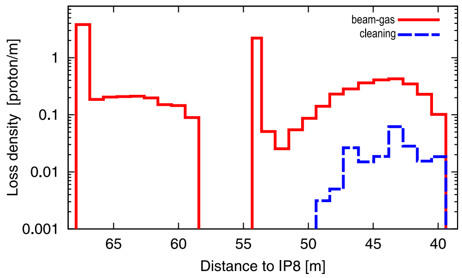

Figure 9: Loss density near the D1–Q1 low-beta section of LSS8L, for the beam-gas scattering in the section 78 (solid histogram) and the betatron cleaning inefficiency (dashed) (courtesy of I.Bayshev).

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

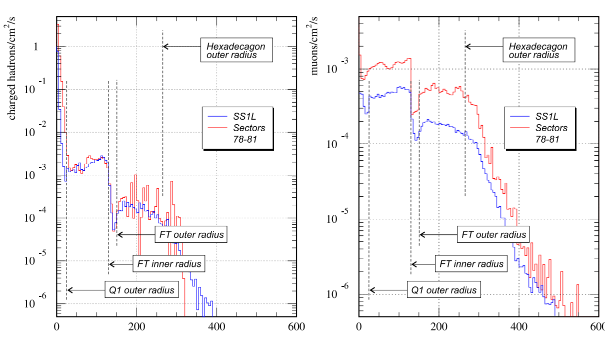

Figure 10: Charged hadron and muon flux density [particles/cm^2/s] at the UX15 entrance due to the beam-gas losses in LSS1L (blue) and sectors 78-81 (red).

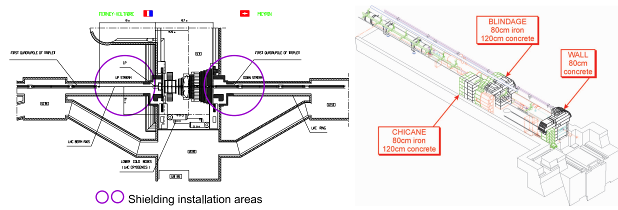

Figure 11: Top view of the UX85 cavern with the layout of the machine elements and the proposed locations of the background shielding (left) and layout of the shielding at the IR7 side of IR8 (right).

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.

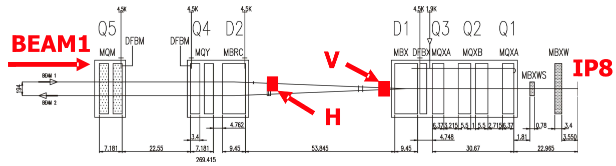

Figure 13: Positions of vertical and horizontal TCT collimator in LSS8L.

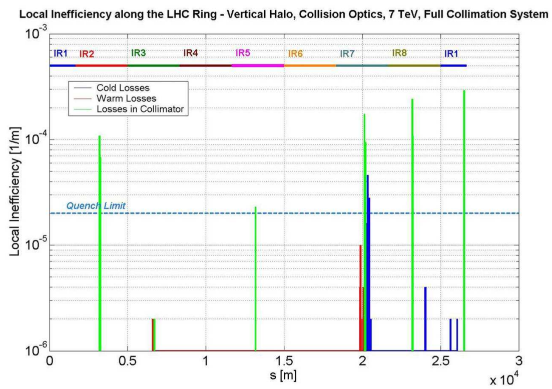

Figure 14: Loss distribution around the LHC Ring 1 for the primary losses at the betatron cleaning in IR7.

The cleaning inefficiency for the TCT(V,H) at the IR7 side of IR8 was estimated equal to (0.84, 0.22)$\times10^{-3}$ for the vertical halo and (0.003, 0.3)$\times10^{-3}$ 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.

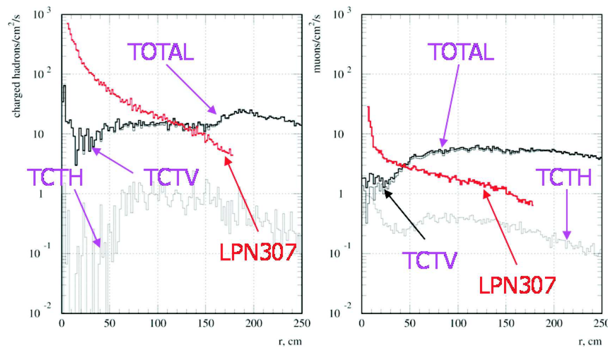

Figure 15: Particle flux density, [particles/cm^2/s] at 1 m from IP8, calculated for the losses at the TCTV/H, compared to the background from the beam-gas losses in LSS8L.

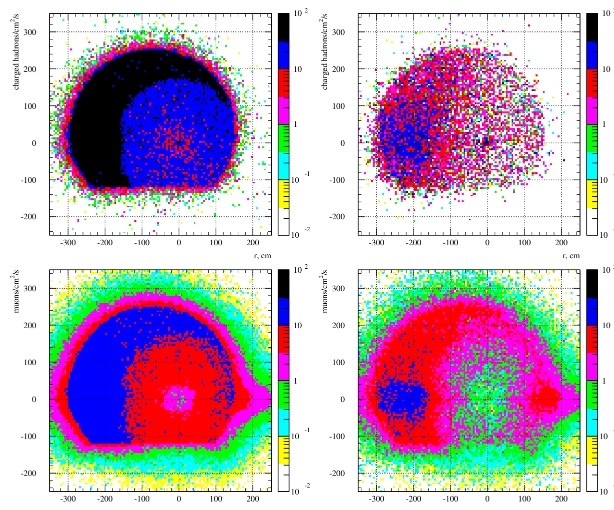

Figure 16: Particle flux density for charged hadrons (top) and muons (bottom), without (left) and with staged shielding (right).

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

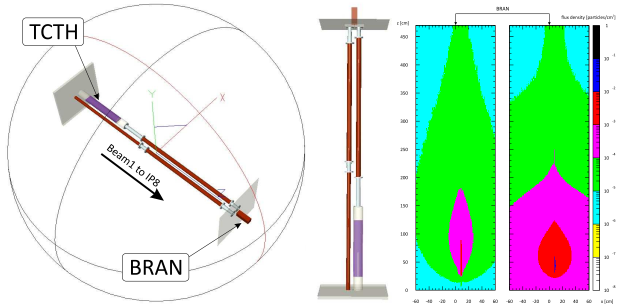

Figure 17: BRAN monitor position in the LSS8 (left) and the maps of charged and neutral components of the collimation background (right).

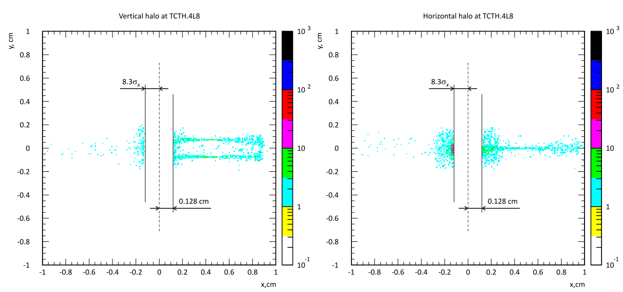

Figure 18: Vertical (left) and horizontal (right) tertiary halo losses at the TCTH in IR8.

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

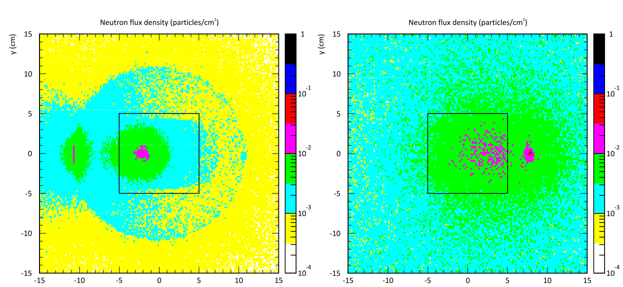

Figure 19: Neutron flux density per 1 p-p event in the IP (left) and per 1 proton lost at the TCTH (right).

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

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

N.V. Mokhov#, FNAL, Batavia, IL 60510, U.S.A.
T. Weiler, CERN, Geneva, Switzerland

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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#mokhov@fnal.gov

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 β^* = 0.55m, 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).

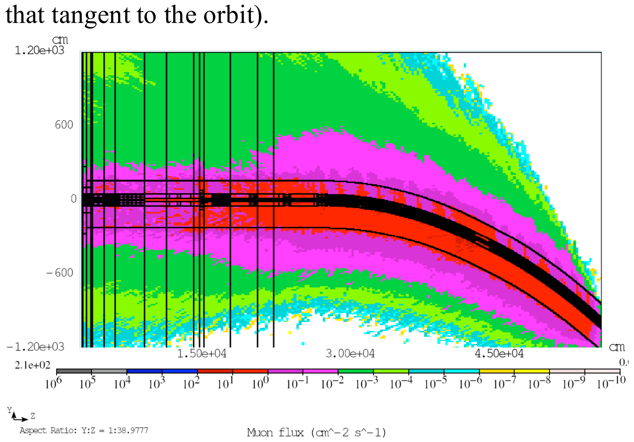


Figure 1: Muon flux isocontours in the orbit plane at 22<z<550m upstream IP1 and IP5.

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).

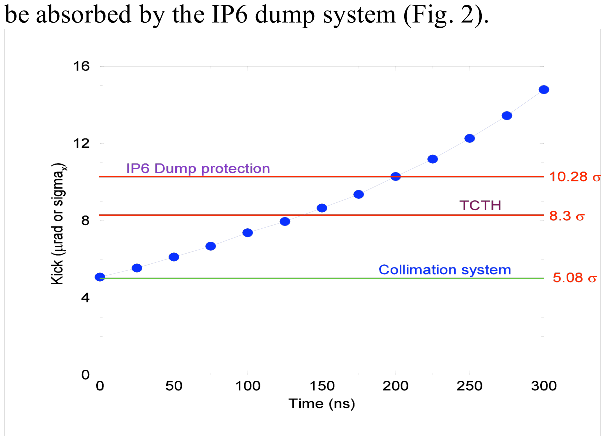


Figure 2: Angular kick for 13 bunches at prefire of the MKD.OR6.B2 beam dump kicker module.

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.

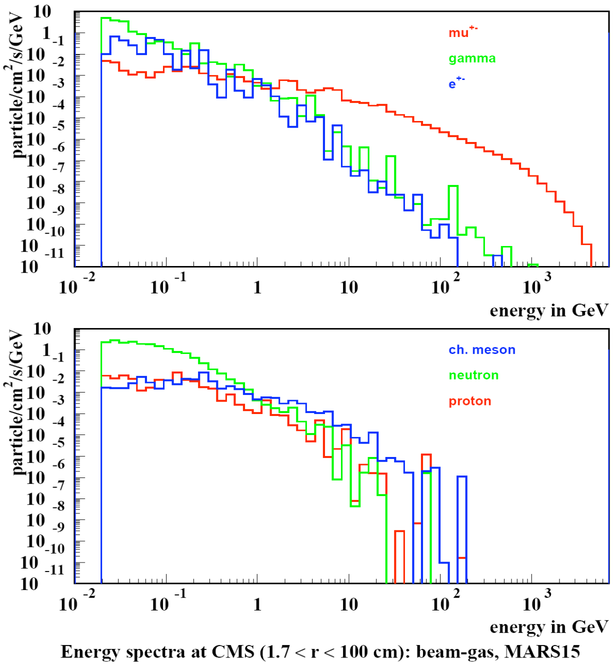


Figure 3: Particle energy spectra at z=22.6 m from IP5 in the 1.7 < r < 100cm region for beam-gas.

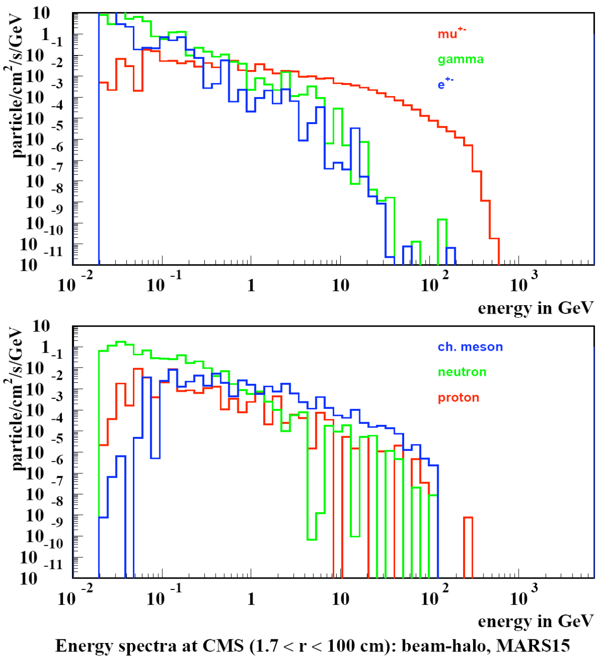


Figure 4: Same as in Fig. 3, for tertiary halo.

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.

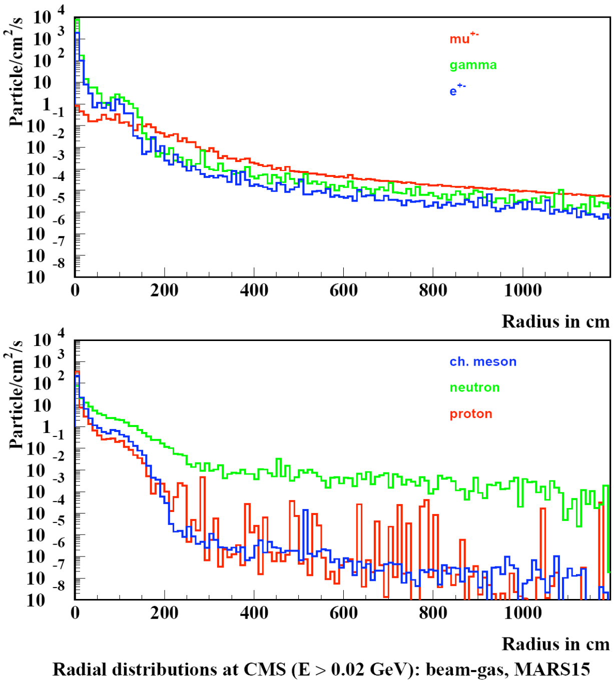
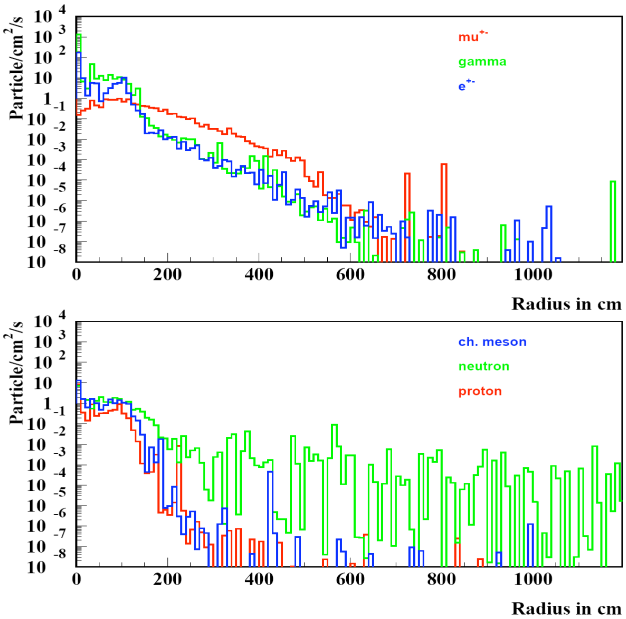


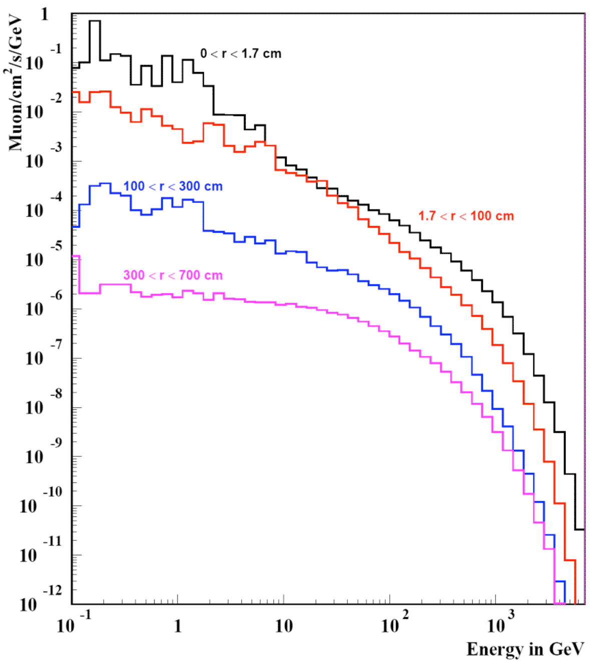
Figure 5: Radial distributions of particle fluxes (E>20 MeV) at z=22.6 m from IP5 for beam-gas.



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

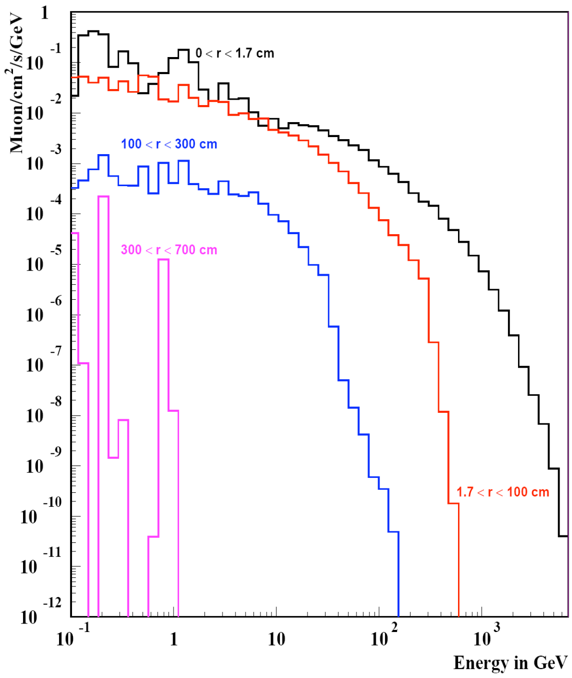
Figure 6: Same as in Fig. 5, for tertiary halo.

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 $cm^{-2}s^{-1}$.



Muon energy spectra at CMS: beam-gas, MARS15

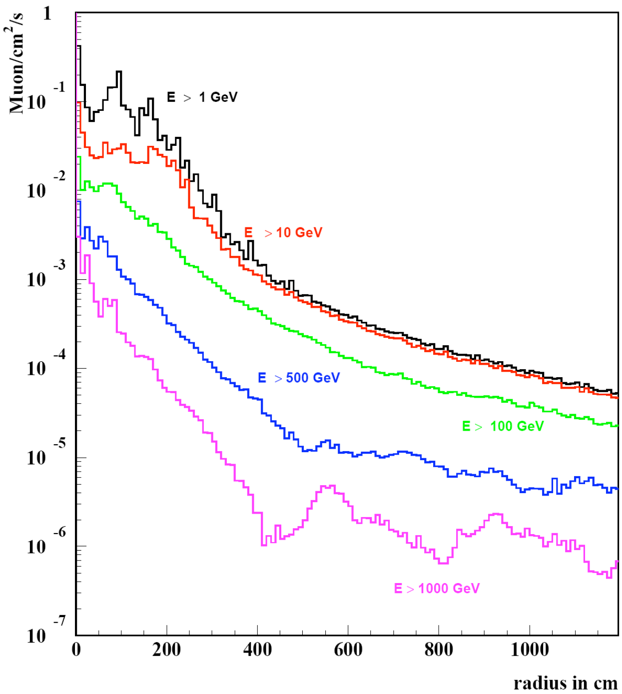
Figure 7: Muon energy spectra at z=22.6 m from IP5 in 4 radial regions for beam-gas.



Muon energy spectra at CMS: beam-halo, MARS15

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.



Muon radial distributions at CMS: beam-gas, MARS15

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

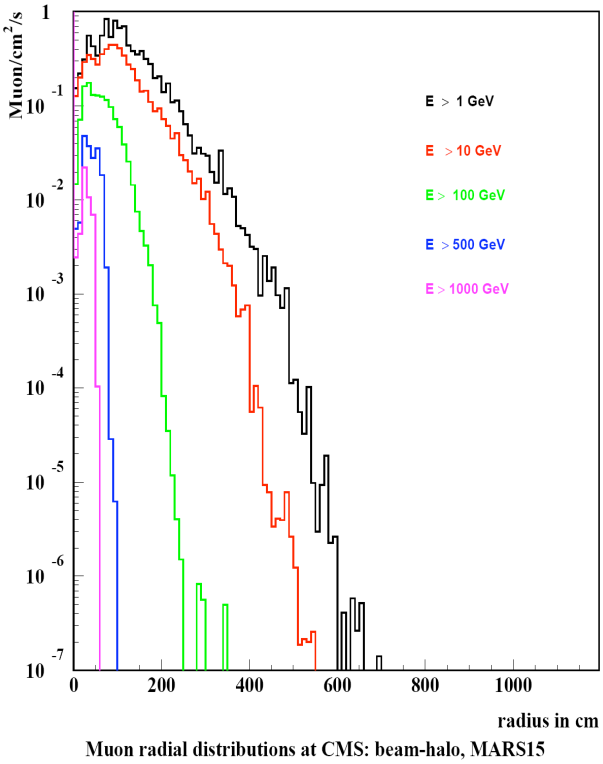


Figure 10: Same as in Fig. 9, for tertiary halo.

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.

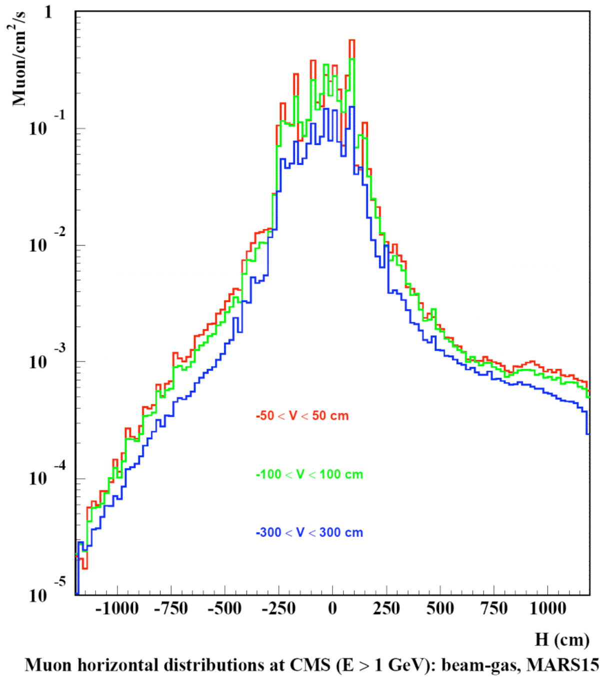


Figure 11: Horizontal distributions of muon fluxes in 3 vertical slices at z=22.6 m from IP5 for beam-gas.

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).

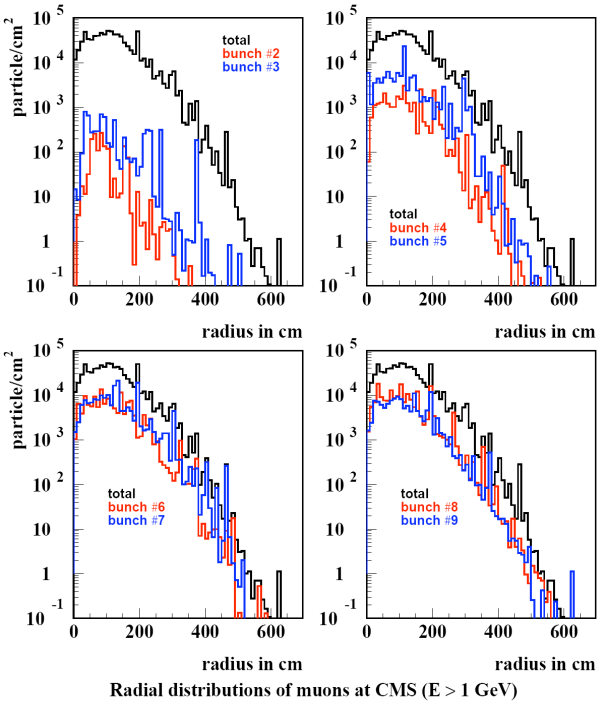


Figure 12: Radial distributions of muon fluxes above 1 GeV at z=22.6 m from IP5 for a kicker prefire event: total and for bunches 2 through 9.

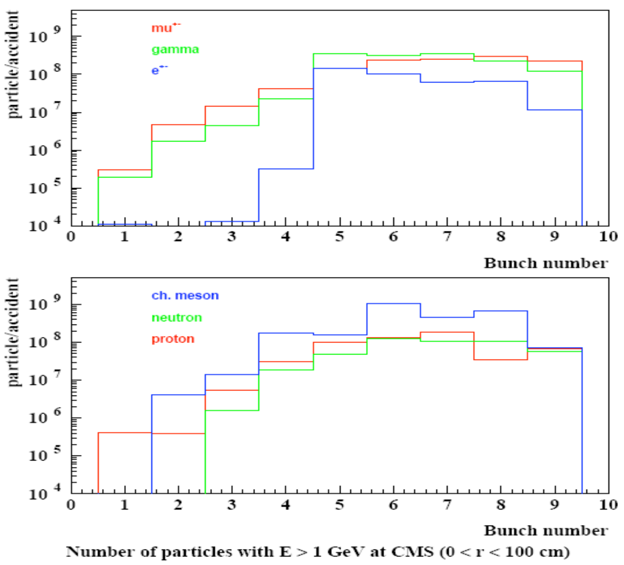


Figure 13: Bunch distribution for particle load on CMS (E> 1 GeV, r < 100 cm).

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.

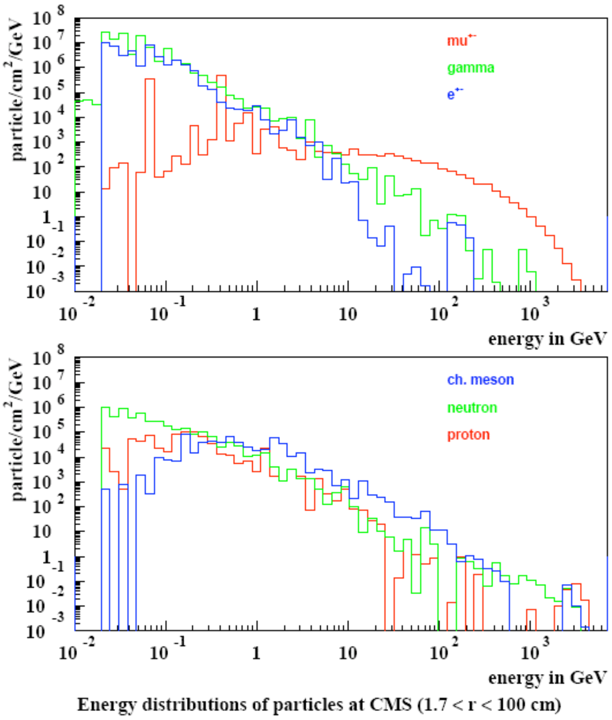


Figure 14: Particle energy spectra at z=22.6 m from IP5 in the 1.7 < r < 100cm region for kicker prefire.

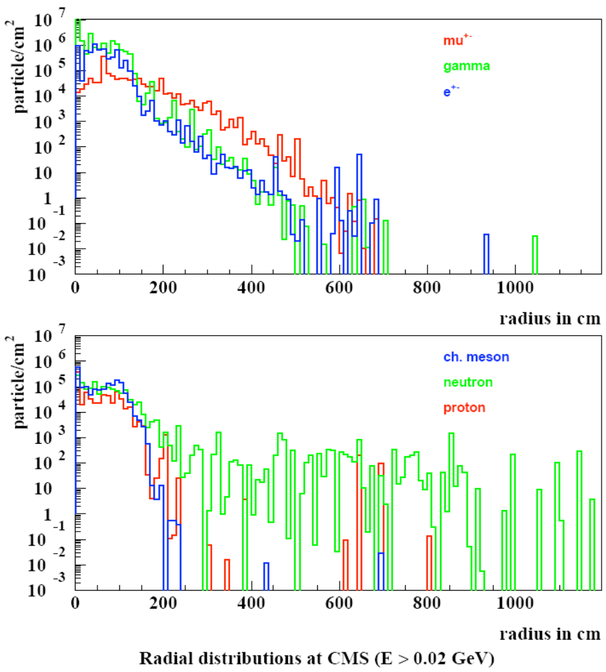


Figure 15: Radial distributions of particle fluxes (E>20 MeV) at z=22.6 m from IP5 for kicker prefire.

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.

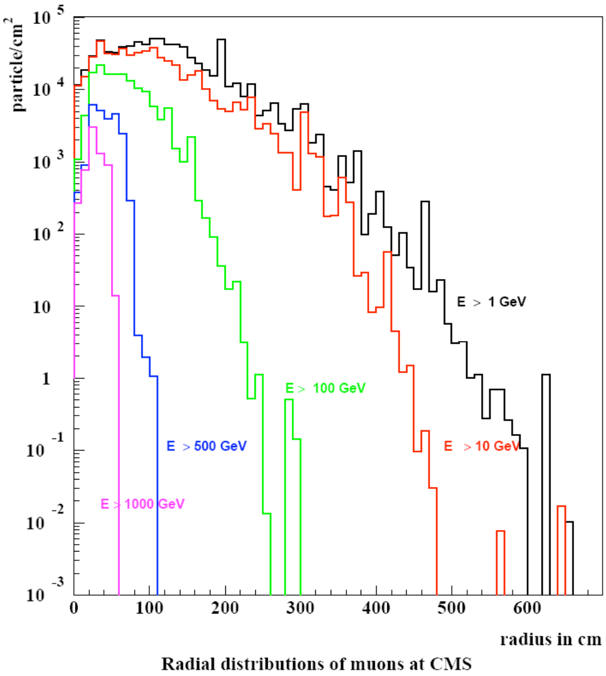


Figure 16: Radial distributions of muon fluxes above 5 cut-off energies at z=22.6 m from IP5 for kicker prefire.

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.

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EFFECTS OF MACHINE INDUCED BACKGROUND ON EXPERIMENTS

M. Huhtinen, CERN, Geneva, Switzerland

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

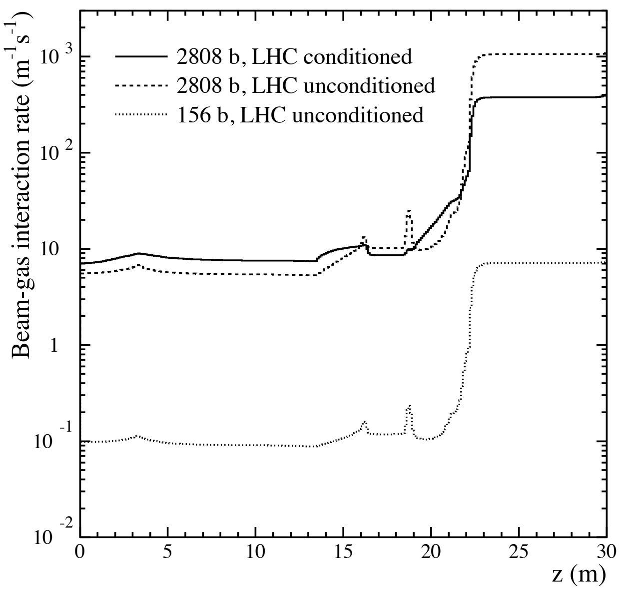

Figure 1: Beam-gas interaction density in the CMS experimental beam-pipe.

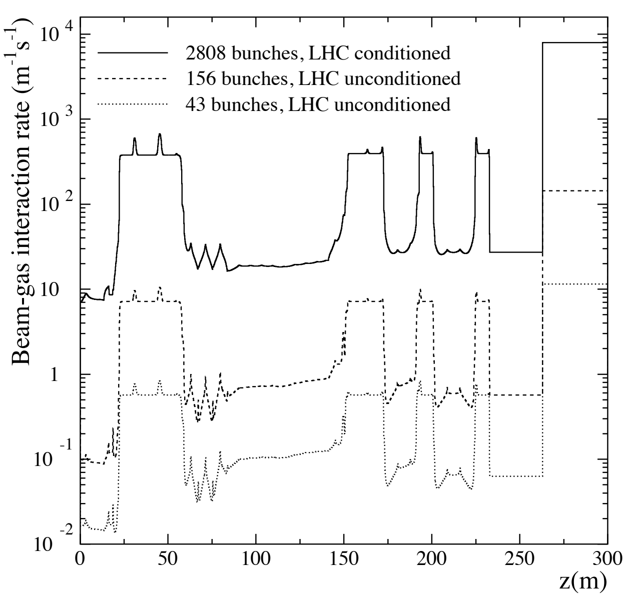

Figure 2: Beam-gas interaction density in LSS and LHC arc.

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

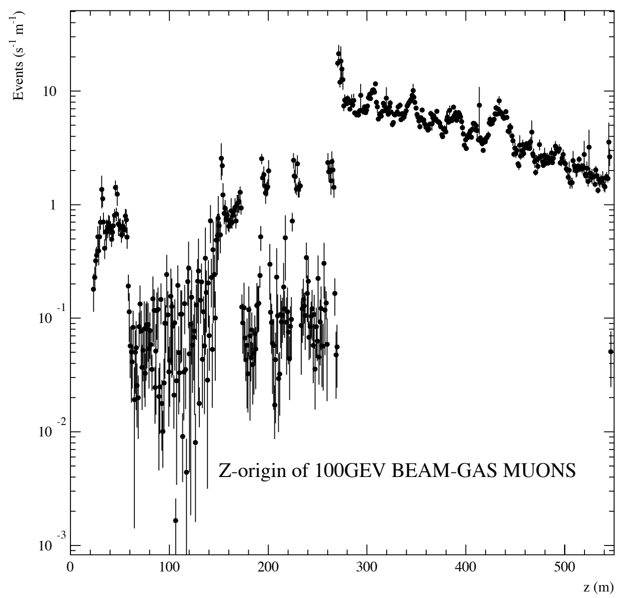

Figure 3: Coordinates of intial proton-gas collisions for E>100 GeV muons observed at the z=23 m interface plane [2].

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.

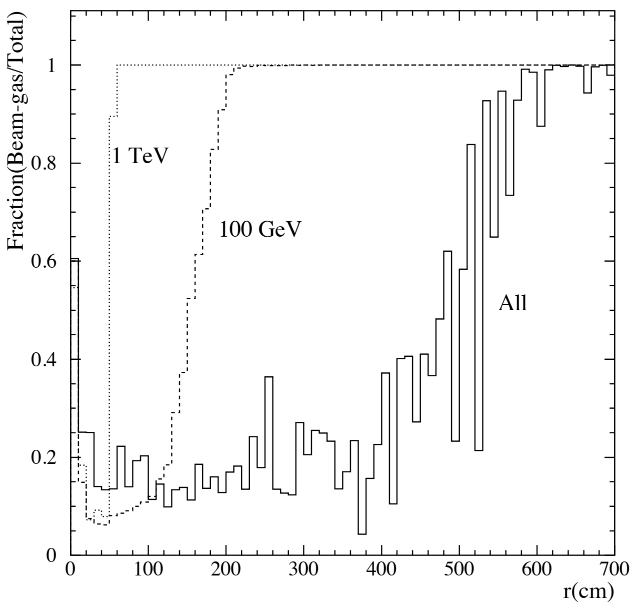

Figure 4: Relative importance of beam-gas scattering to muon background with different energy cuts. The complement to unity comes from proton-halo losses on the TCT.

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-

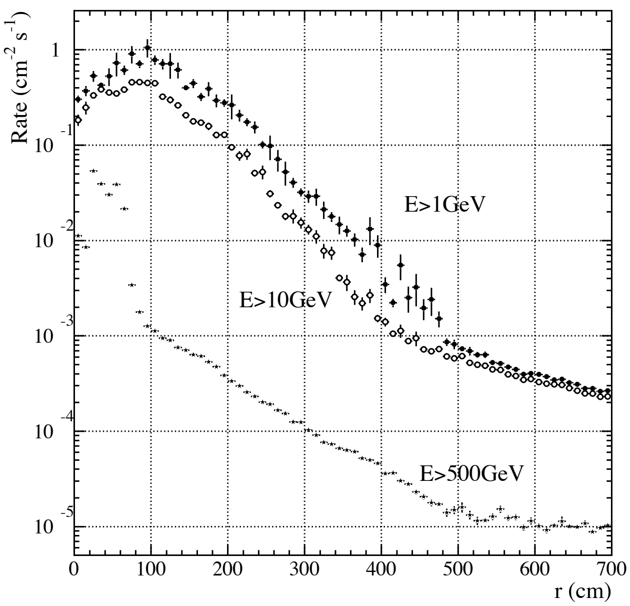

Figure 5: Radial distribution of muons at the z=23 m interface plane. Beam-gas and proton-halo losses (on TCT) are included [2].

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 intime 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.

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

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:

[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.

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EXPERIMENT PROTECTION FROM BEAM FAILURES AND EXPERIMENT-MACHINE SIGNAL EXCHANGE

D. Macina, CERN, Geneva, Switzerland

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 ($5\cdot10^9$ 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.

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Workshop on Experimental Conditions and Beam-Induced Detector Background
Summary of Session 2 discussions

Chairmen: H. Burkhardt, M. Ferro-Luzzi - Scientific secretary: 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 II 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.

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[3] LHC Experiment Accelerator Data Exchange Working Group LEADE

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

What ALICE Requires and Provides for Background Optimisation

A. di Mauro and A. Morsch
CERN, Geneva, Switzerland

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 $3 \times 10^{30}\,\mathrm{cm^{-2}s^{-1}}$, 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 $10^{29}\,\mathrm{cm^{-2}s^{-1}}$.

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
$\langle \mathcal{L} \rangle$ ($\rm cm^{-2}s^{-1}$)	3×10^{30}	3×10^{27}	10^{29}	10^{27}	8×10^{28}
$\sigma_{\rm inel}$ (mb)	70	3000	3000	8000	2600
Rate ($\rm s^{-1}$)	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 ($1 \rm cm^2 \times 500\,\mu m$) and its design is a copy of the LHCb BCM [5].

BCM sensors have been installed at three different location, 4 sensors $z = 15.5\,\rm m$ (BCMA2), 4 sensors at $z = 4.5\,\rm m$ (BCMA1) and 8 sensors at $z = -19\,\rm m$ 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 $340\,\rm cm$ from the IP on the side opposite to the muon spectrometer and the V0C is fixed at the face of the fron absorber, $90\,\rm cm$ 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 ($3 \times 10^{30}\ \rm cm^{-2}s^{-1}$). Quartiary halo from the TCTs is a concern since it might represent the largest background source. At full intensity ALICE will run at $\beta* = 10\,\rm m$. 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.

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Workshop on Experimental Conditions and Beam-Induced Detector Backgrounds
Summary of Session 3 Discussions

Chairman: M. Ferro-Luzzi - Scientific secretary: 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.

SESSION3 SUMMARY

Chairman: M. Ferro-Luzzi* - Scientific secretary: A. Macpherson, CERN, Geneva, Switzerland
Reported by M. Ferro-Luzzi

SESSION III

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 (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.

* massimiliano.ferro-luzzi@cern.ch

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.

WORKSHOP SUMMARY

H. Burkhardt, M. Ferro-Luzzi, CERN, Geneva, Switzerland

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 usage 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 anticipating issues related to beam conditions and elaborate a framework to attack such problems.

The workshop was divided in 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, 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 of the LHC machine 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. In addition, individual contributions to the workshop by the speakers have been collected.

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 rationalisation of machine-induced background studies. It was demanded that the various contributors agree first on a set of configurations and a systematic strategy. This implies:

1. definition of a few benchmark running scenari, 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 are possible pressure bumps due to elements that warm up because of e.g. beam losses. 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 organized by TS-LEA, which offered an excellent forum for background-related issues since February 2005. 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, perfection understanding of the data with the help of simulation tools, compare results between experiments, adjust definitions of 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 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-normalised rates ? Or is a logarithmic scale more approriate ?

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 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 shadow of the TCTs. This depends on the beam configuration (energy, optics β^*).

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 again for their high quality presentations and written contributions. We express our gratefulness 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 organising 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] Background working group and Session V of the LHC Chamonix Workshop 2006.