BACKGROUND ISSUES FOR CMS

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Abstract

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

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

INTRODUCTION

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

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

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

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

BACKGROUND ISSUES

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

1. Tracker safety

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

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

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

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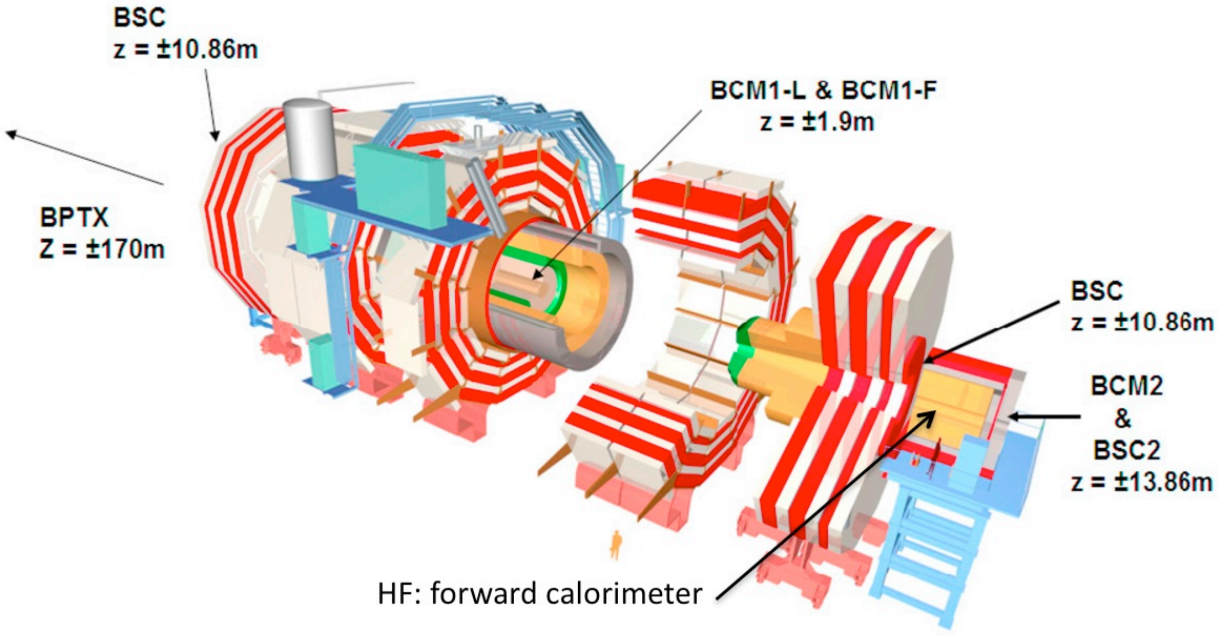

Figure 1: The CMS detector showing positions of the dedicated sub-detectors for monitoring beam conditions. The position of HF used for luminosity determination is shown and the extensive coverage of muon chambers, between the iron (shown in red).

2. Efficient Operation and Long Term Health of the Detector

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

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

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

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

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

3. Backgrounds in Triggers and Luminosity Measurement

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

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

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

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

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

MEASUREMENT OF BEAM CONDITIONS AT CMS

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

BRM Detectors

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

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

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

HF-Luminosity

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

Location and Shape of the Luminous Region

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

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

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

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

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

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

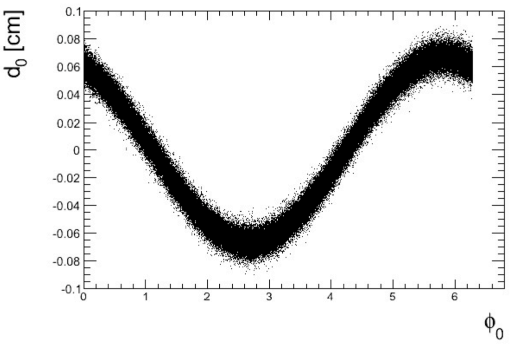

Figure 2.a: The impact parameter versus ϕ for tracks with p_T>2 GeV.

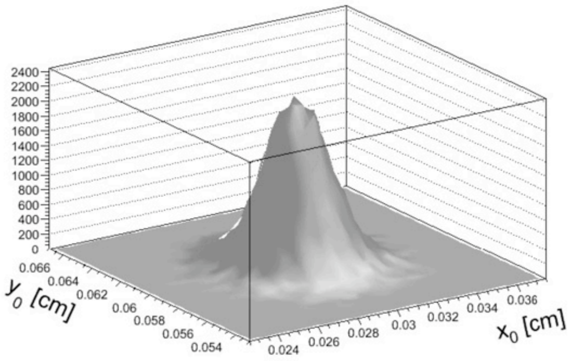

Figure 2.b: The luminous region in the transverse plane for the same tracks.

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

SUMMARY

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

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

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

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

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

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

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

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

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

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

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

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

[10] Section 11.6 in Ref [1]

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

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