COLLISION RATE MONITORS FOR LHC

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Abstract

Collision rate monitors are essential in bringing particle beams into collision and optimizing the performances of a collider. In the case of LHC the relative luminosity will be monitored by measuring the flux of small angle neutral particles produced in the collisions. Due to the very different luminosity levels at the four interaction regions (IR) of LHC two different types of monitors have been developed. At the high luminosity IR (ATLAS and CMS) fast ionization chambers will be installed while at the other two (ALICE and LHC-b) solid state polycrystalline Cadmium Telluride (CdTe) detectors will be used. The ionization chambers are being developed by LBNL while the CdTe monitors are being developed by CERN and CEA-LETI.

INTRODUCTION

The ultimate aim of LHC is producing collisions inside the four experimental detectors: ATLAS, CMS, ALICE and LHC-b. This will allow the further understanding of the nature of matter and of the forces holding it together.

The four detectors are quite different and so are the optimal conditions for their data acquisition. ATLAS and CMS will profit from the highest collision rate possible while ALICE and LHCb require the collision rate to be set and controlled at optimal levels. In the case of ALICE the radiation damage sustained by the sub-detectors in case of long terms p-p luminosities above $10^{30}\,cm^{-2}s^{-1}$ is dangerous. For LHC-b the upper limit is defined by the requirement of avoiding pile-up of p-p interactions during the same bunch crossing, which corresponds to a maximum “bunch” luminosity of $1.8\ 10^{29}\ cm^{-2}s^{-1}$ and thus a maximum luminosity of $5\ 10^{32}\ cm^{-2}s^{-1}$ for 2808 bunches.

LUMINOSITY

In order to express the collision rate in a univocal way the concept of “Luminosity” is normally used as collisions can be of many different kinds and shades.

Luminosity is defined as the ratio between the collision rate of any particular process and the respective cross section. Cross sections of known processes have been calculated, measured or estimated and are available.

$$L=\frac{\dot{N}_x}{\sigma_x} \quad (1)$$

Luminosity can also be expressed as a relation between the parameters of the colliding beams. As explained before the luminosity of the machine at all four interaction points must be known with adequate accuracy [1]. If all beam parameters were precisely known these could be used to calculate the luminosity. Unfortunately this is not the case, especially for the separation between the two beams (assuming, equal, round beams, a separation of one beam sigma reduces the luminosity by 20%). With the nominal LHC optics the incertitude on the beams position at the interaction point (IP) will be of the order of several beam sigma.

For this reason the luminosity must be monitored using a dedicated device not affected by the incertitude on the beam parameters and optics.

COLLISION RATE MONITORS (“LUMINOSITY MONITORS”)

During the tuning of LHC a very important information will be the relative impact of the different trims on the luminosity. Devices that measure the rate of a particular group of events are sufficient for this task, even if the exact value of the cross section for these events is not known; this will in fact be constant and not influenced by the trims. Such devices will of course not allow measuring directly the absolute value of the luminosity. It is however possible to periodically calibrate the readings of the monitors with the values accurately measured by the experiments.

In the p-p collisions at LHC many particles will be generated including neutral particles like neutrons and photons (either directly or as decay of unstable neutral particles). These neutrals will in general follow the trajectories of the interacting protons. Tacking advantage of the geometry of the IRs it is possible to intercept these particles at a location where the two proton beams are sufficiently deviated by the bending magnets D1 and D2. At about 140 m from the IP the two proton beams are separated by about 160 mm. This leaves a space of about 100mm between the two vacuum chambers where a detector can be placed. The neutral particles are unaffected by the magnets and will thus intercept the detector in its centre. In fact this flux of neutrals would be sufficient to damage the magnet D2 at the high luminosity IRs (1 and 5). For this reason absorbers made of copper several meters long, the TANs, are installed just in front of the D2 magnets [2][3]. These absorbers allow a detector to be inserted inside them, and precisely at the location where the shower generated by the neutral particles reaches the maximum. A layout of the IR can be seen in Fig. 1.

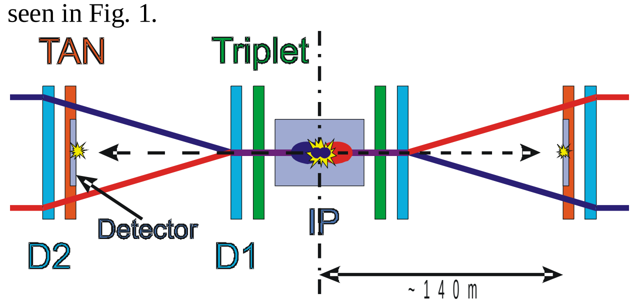

Figure 1: Typical layout of a luminous IR in LHC.

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Required Performances

Table 1 shows the luminosity values for the different machine conditions. In particular the values expected at the start up of LHC where two un-squeezed pilot bunches will be collided first.

Table 1: Different p-p luminosity scenarios

N_b	k_b	IP		L
Collision studies with single pilot bunch **(Initial condition)**				
5×10^9	1	IP1, IP5	β=18 m	2.5×10^{26}
		IP1, IP5	β=1.2 m	3.7×10^{27}
		IP2, IP8	β=10 m	4.4×10^{26}
Collision studies with single bunch				
2.75×10^{10}	1	IP1, IP5	β=1.2 m	1.1×10^{29}
1.15×10^{11}		IP1, IP5	β=0.55 m	4.3×10^{30}
		IP2	β=10 m	2.4×10^{29}
		IP8	β=35 m	6.7×10^{28}
Early p-p luminosity run				
2.75×10^{10}	43	IP1, IP5	β=1.2 m	4.8×10^{30}
1.15×10^{11}				8.4×10^{31}
4.0×10^{10}	2808			6.5×10^{32}
1.15×10^{11}	936			1.8×10^{33}
Nominal p-p luminosity run				
1.15×10^{11}	2808	IP1, IP5	β=1.2 m	1.0×10^{34}
		IP8	β=35 m	1.9×10^{32}
		IP2	β=10 m	3.0×10^{30}

Table 2: Requirements for the luminosity monitors

Luminosity [$cm^{-2} s^{-1}$]	**resolution**	**Integration time [s]**
$10^{26} \rightarrow 10^{28}$	±10% (beam)	~ 60
$10^{28} \rightarrow 10^{34}$	±1% (beam)	~ 1
$10^{33} \rightarrow 10^{34}$	±10% (bunch) (machine)	~ 10
	±1% (bunch) (experiment)	~ 100

The performances required for the luminosity monitors are presented in Table 2. The absolute accuracy of the measurement is not specified, it has already been mentioned that the main aim of these detectors is to monitor variations of the luminosity in a fast and reliable way [1] and not the absolute value.

Table 3: Estimated integration times

Luminosity [$cm^{-2} s^{-1}$]	**Rate of p-p events [s^{-1}]**	**Int. time [s]** (10% error)	**Int. time [s]** (1% error)
1.0×10^{26}	8.0	50	5.0×10^{3}
1.0×10^{28}	800	0.5	50
1.0×10^{30}	8.0×10^{4}	5.0×10^{-3}	0.5
1.0×10^{32}	8.0×10^{6}	5.0×10^{-5}	5.0×10^{-3}
1.0×10^{34}	8.0×10^{8}	5.0×10^{-7}	5.0×10^{-5}

Table 3 indicates the expected integration times for different luminosity levels and different resolutions (1% and 10%). These values are calculated solely from the statistical point of view, not considering the effects of an eventual background field.

THE MONITORS

There are two different types of detectors being developed for the luminosity monitors of LHC. On one side LBNL, in the framework of the US-LARP collaboration [4], is developing four fast ionization chambers (IC) to be installed inside the TANs around IP1 and IP5 . On the other side CERN will install solid state (CdTe) detectors [5][6] developed by CEA-LETI [7] around the other two points; IP2 and IP8. The reasons for having two different types of monitors reflects the two main challenges of the detectors. The most difficult requirement is to stand a very high radiation dose, of the order of ~1 GGy for IP1 and IP5 [2], considerably lower for IP2 and IP8 (~100 times less). The second requirement is to be capable of resolving p-p events bunch by bunch (40 MHz), or in other words to have a response time shorter than 25 ns. The two adopted technologies are each very good with either one or the other of these requirements. The IC is very resistant to radiations (only ceramic and metal parts), but has a response time of the order of 25 ns, leaving very little margin. The CdTe on the other hand can easily comply with the 40 MHz requirement, but can only stand the lower radiation dose of IR2 and IR8.

Energy Deposition

In order to develop the monitors the characteristics of the neutral particle flux and the consequent showers must be known. The energy deposition in the detectors translates directly in radiation doses and detector signals; both fundamental parameters for the design of the detectors and of the read-out system. For this reason computer simulations of the p-p interactions have been carried out using several simulation codes. Initially MARS had been used to calculate the radiation dose inside the TANs. More recently a simulation based on DPMJET3 (event generator) and FLUKA (transport, decay and interactions) has been used to estimate the signals induced in the detectors by the p-p collisions. These studies have been done for two different energies: 450 GeV (injection) and 7 TeV (top). Among other results this simulation allows the calculation of the signal spectrum. which is necessary for the development of the acquisition system.

Fast Ionization Chambers

The detector developed by LBNL consists of a pressurized ionization chamber, depicted in Fig. 2, whose parameters are summarized in Table 4. The gas mixture is Ar + 6%N_2 at 6 bar (10 bar max). It is composed of 4 independent square quadrants in order to measure the centre of gravity of the impinging neutral flux, this will allow the calculation of the crossing angle at the IP (angle between the two beams). Each quadrant has 6 gaps connected in parallel with a gap width of 1mm [4].

Fig. 2 shows the detector: the left picture shows the ionization chamber (white rectangular object) installed on its copper filler bar and sitting next to the stainless steel pressure housing. The other pictures in Fig. 2 show models and details of the IC. The IC is made entirely of copper and MACOR®.

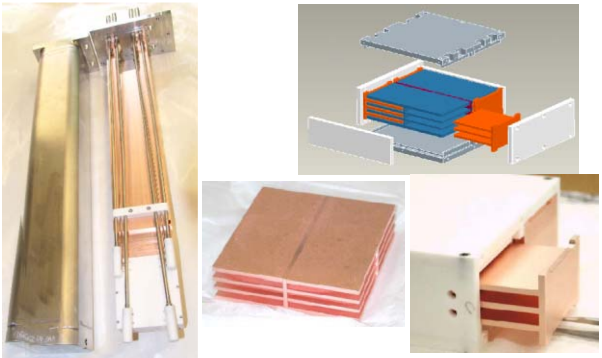

Figure 2: Pictures and model of the Ionization chamber parts.

Table 4: Nominal parameters of the Ionization Chamber

Quadrant area	1600 mm^2
Gap between electrodes	1 mm
No. of gaps in parallel	6
Gas mixture	Ar + 6%N_2
Gas pressure	6 bar (abs)
Ioniz. Pairs / MIP mm	58
E / P	200 V/mm bar
Gap voltage	1200
e^- drift velocity	45 mm/µs
Amplifier gain	0.16 $\mu V/e^-$
Noise (RMS)	1.24 mV

Read-out of the IC

The front-end electronics consists of a very low noise pre-amplifier based on the “cold resistor” scheme [8] followed by a rather complicated shaper. The first component has been initially developed by the University of Pavia (Italy) and is now being refined in Berkeley. The second is entirely developed at LBNL. Both components are keystones to this project as their performances will influence the ultimate speed of the detectors.

Test performed on an X-ray test beam at ALS indicate that the 40 MHz feature is right at the edge of what the system can do. The rest of the acquisition system is based on the DAB-IV card developed by TRIUMF and CERN for the BPM project [9] and the integrators mezzanine developed for the fast beam transformers [10].

CdTe Detectors

The Cadmium Telluride detectors (Fig. 3) are the result of a collaboration between CERN and LETI. In order to validate the technology, sample CdTe disks were irradiated in nuclear reactors up to equivalent doses of 10^{17} n/cm^2 [5][6]. This showed that the maximum dose they could stand was ~10^{16} n/cm^2 (NIEL), which is sufficient for IR2 and IR8 but not for IR1 and IR5. The detectors consists of an aluminium housing of about 10cm width containing 10 polycrystalline CdTe disk of 17 mm diameter and 300 µm thickness. The CdTe disks are polarized to 300 V, when an ionizing particle traverses them e^-/holes pairs are created and drifted to the collection electrodes. The resulting signal is then fed to a linear pre-amplifier (the S/N ratio is not as vital here as for the IC).

At IR2 and IR8 the p-p event probability per bunch crossing is smaller than 1 due to the lower luminosity. This allows to use a counting based acquisition system. A dedicated analogue processing/counting VME board has been designed for this purpose. The amplitudes of each CdTe disk separately will also be acquired for the determination of the crossing angle (at low speed though).

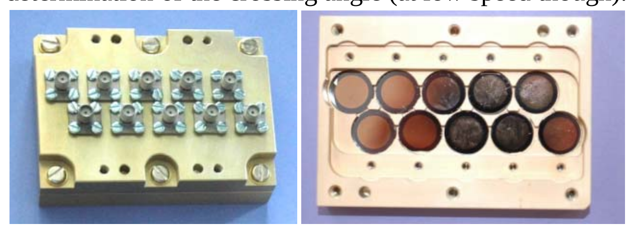

Figure 3: Pictures of the CdTe detectors.

These detectors are very simple in terms of mechanics and read-out electronics. This is one of the reasons that lead to the adoption of this technology.

CONCLUSIONS

Measuring the collision rates at the four IPs will be fundamental for the LHC setting up and operation. Therefore reliable and fast monitors, capable of measuring small variations in luminosity, are needed. Two different technologies will be used: a fast ionization chamber developed by LBNL for IP1 and IP5 and solid state CdTe detectors developed by CERN and LETI for IP2 and IP8.

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