PROCEEDINGS OF SCIENCE

Probe for LUminosity MEeasurement

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A new detector capable of measuring the LHC luminosity has been installed at the LHCb interaction point. It is named Probe for LUminosity MEasurement - PLUME. This detector is undergoing commissioning and will operate throughout LHC Run 3. It will enable real time monitoring of beam condition parameters such as luminosity, number of visible interactions per bunch crossing and LHCb background. It will also cross-check the LHC filling scheme in real time, and contribute to the centrality determination for the LHCb fixed-target program. The detector is based on the detection of Cherenkov light produced in quartz material by charged particles moving upstream from the LHCb collision region. PLUME needs to provide both online and offline luminosity measurements. PLUME will provide both fast real-time luminosity feedback, and offline counters for measurements of integrated luminosity, and it will ensure the vital luminosity-levelling procedure at LHCb and act as real-time alarm for LHC.

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1. Introduction

The Probe for LUminosity Measurement (PLUME) [1] is a new detector for the LHC luminosity measurement installed at the LHCb interaction point. Luminosity is a fundamental parameter which needs to be known precisely in order to ensure the detector safety and to measure the cross section of any processes. For that reason, its instantaneous value needs to be measured and stored. The LHCb detector has been designed as a single arm forward spectrometer with very good tracking performances which can be degraded by high occupancy. Hence, the instantaneous luminosity (L_{inst}) of LHCb is lower with respect to that of other experiments and it is kept constant through a procedure called *luminosity levelling*. Modifying the distance between the two colliding beams, it is possible to keep L_{inst} stable within ±5%. During Run 3, some degrading effects are expected, thus, measuring L_{inst} in real time is essential for the operation of the LHC machine and in particular for the levelling procedure. The PLUME detector needs to fulfil several tasks: measure L_{inst} and the number of visible interactions (μ) per bunch to allow the LHC to perform the luminosity levelling, monitor the radiation level and machine background, cross-check the LHC filling scheme, determine the centrality of heavy ions collisions, and collect data to measure offline luminosity. It is installed upstream of the LHCb collision area. The elementary detector is a photomultiplier (PMT) with a quartz window able to detect photons from Cherenkov light emission. In order to increase the light yield, a small quartz tablet is optically connected to the PMT window. The overall layout counts 48 PMTs arranged in a two-layers hodoscope, forming a cross around the beam pipe, as shown in Fig.(1). Each PMT pair points to the interaction point (IP) at a different angle, between 5.4° and 9.4°.The probability to receive a contribution from two particles within one bunch crossing (BX) is negligible due to the small size of the unit.

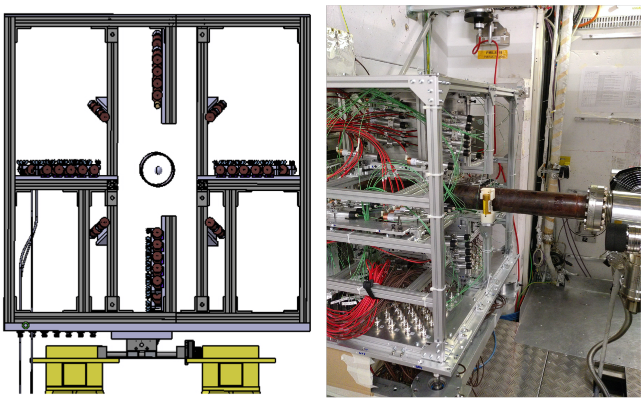

Figure 1: Left: Scheme of the PLUME projective pairs. Right: Photo of the detector around the beam pipe.

2. Electronics and readout

The LHCb ECAL electronics are used for PLUME readout [2] and consist in a front-end (FE) and back-end (BE) part. The system will provide both the online and offline luminosity information. The FE part is composed by four front-end boards (FEB) and one control unit (CU). Each component has a specific role: two FEBs for readout channels, one for the monitoring system reading out data from PIN diodes (see calibration and monitoring section) and the second one for precise timing measurements. The CU task is to transmit clocks, commands and configurations from the global LHCb system to the FEBs. The FE system amplifies, shapes and integrates the signal arrived from PMTs and then sends it to and integrates the signals from the PMTs and then sends them to the

ADC chip. The FPGAs process the digital output and the formatted data are sent to the BE system. The latter is composed by 2 PCIe40 boards: one (TELL40) will compute online the instantaneous luminosity will compute online instantaneous luminosity and format the data for the high level trigger (HLT) and the offline storage, while the second (SOL40) will handle the configuration, the timing and the control commands. In the end, software tools integrate the data in the global LHCb DAQ and the Real Time Analysis framework. The main item of the DAQ is the PLUME RAW event decoder which transforms data into usable objects for the analysis software (HLT or offline analysis). PLUME information should be available both online and offline and PLUME detector should be running even when the other detectors are not. In particular, during the adjustment phase of the LHC cycle, the value of L_{inst} at the LHCb IP is necessary for the LHC operator to prepare and optimize LHCb collisions.

3. Calibration and monitoring

While the statistical error is of the order of $\sim$ 3% (achievable in 0.01 s with 1000 bunches), the accuracy on L measurements is limited by systematics. The largest effect is given by PMT gain stability (gain $\sim 1.5 \times 10^5$), which depends on the detector occupancy, temperature and radiation dose. Thus, monitoring the PMT stability is a key point and is based on two strategies. The first exploits the LED calibration system which pulses light to the PMTs during gaps in LHC filling schemes. The voltage of the PMTs is adjusted depending on their response. Also LED stability is crucial, thus PIN photodiodes are used to monitor it. The second strategy utilizes the LHCb vertex locator (VELO) to select tracks directed towards the PLUME acceptance, requiring simultaneously a reconstructed track in the VELO and a coincidence signal in 2 PMTs. This will allow to tune the PMT response in a reduced background environment, by selecting real particles coming from the IP.

4. Luminosity measurement

The instantaneous luminosity can be computed as

$$L_{inst} = \frac{\nu_{rev} \epsilon \langle \mu_{vis} \rangle}{\epsilon \langle \sigma_{vis} \rangle}, \tag{1}$$

and it depends on the revolution frequency of the collider (for LHC: $\nu_{rev} = 11.45$ kHz), the average number of visible interactions μ_{vis}, the visible cross-section averaged over BXs σ_{vis} and the detector acceptance and efficiency ϵ. For the computation of the online luminosity, two histograms are stored for every PMT per BX: one for the number of events below and above a given threshold and another for the number of coincidences in projective PMT pairs. These numbers are needed as inputs for the LogZero method, used to evaluate μ_{vis}. It exploits the fraction of events without visible interactions N_0/N, where N is the total number of BXs, such that:

$$\mu_{vis} = -\log(\frac{N_0}{N}). \tag{2}$$

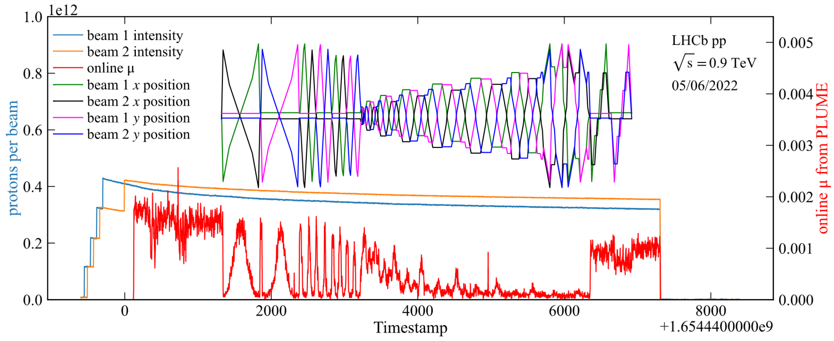

Figure 2: Upper part of the plot: x and y positions of the beams during a VdM scan. Bottom part of the plot: protons per beam are shown, while the number of interactions (per BX) seen by PLUME is reported in red. The larger the beam overlap, the higher the luminosity.

σ_{vis} in Eq.1 can be measured through a Van der Meer scan, where the beam position is moved by horizontal and vertical steps [3]:

$$\sigma_{vis} = \int \frac{\mu(\Delta x \Delta y)}{N_1 N_2} d\Delta x \Delta y, \tag{3}$$

where N_1 and N_2 are beam 1 and 2 bunch populations. The first VdM scan of Run 3 has been performed in 2022. During that, the PLUME detector was calibrated and now it can provide luminosity measurements for pp at $\sqrt{s}$ = 900 GeV (Fig.2) [4]. Histograms are read and cleared at a rate of 1 Hz by a script, its output L_{inst} is transmitted to the LHC control system and to the LHCb monitoring panel. [1]. For offline measurements a dedicated selection for PLUME data will be implemented in the LHCb high-level trigger system. Data are stored in nano-events taken with a random trigger. The analysis proceeds as for the online but with some advantages: cross-calibration with other luminometers is possible and the usage of different methods to evaluate μ_{vis} could be employed. Offline luminosity will be calibrated per run by the dedicated LHCb Luminosity working group.

5. Conclusion

PLUME has been projected after Run 2 and built in just two years. It is currently installed and started to take data at the beginning of Run 3. All the system is under commissioning, including the monitoring and the implementation of the counters for the luminosity measurements. In June, background data were taken and the luminosity calibration at physics energies of PLUME was achieved with a full VdM scan.

References

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