Probe for Luminosity Measurement at LHCb

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PLUME detector

It is installed upstream the LHCb collision area. The elementary module is a PMT (1% occupancy) with a *quartz* entrance window able to detect photons from *Cherenkov light* emission. An optically connected quartz tablet is positioned in front of the photocathode to increase the light yield (~factor 5). The overall layout counts *48 PMTs* arranged in *two-layers* hodoscope, around the beam, forming a cross (see Fig. 1-2). Each PMT pair points to the interaction point (IP) at a different angle, between 5.4° and 9.4° (Fig. 3). This structure enables to require coincidences between 2 PMTS on the same pair, reducing background, and to count the coincides that are required as input to the LogZero method for luminosity determination $\mathcal{L}$. The probability to receive a contribution from two particles within one bunch crossing (BX) is negligible due to the small size of the unit.

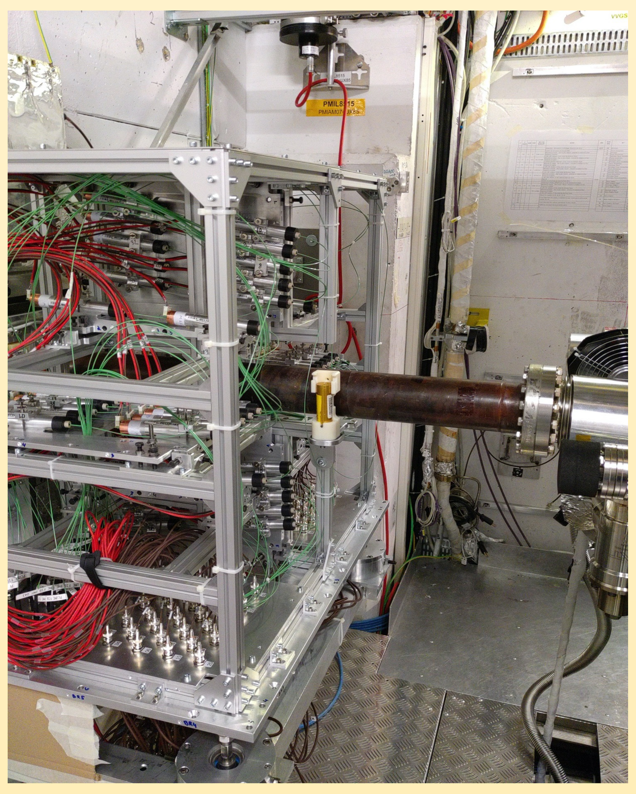


Figure 1: PLUME box in the LHCb experiment

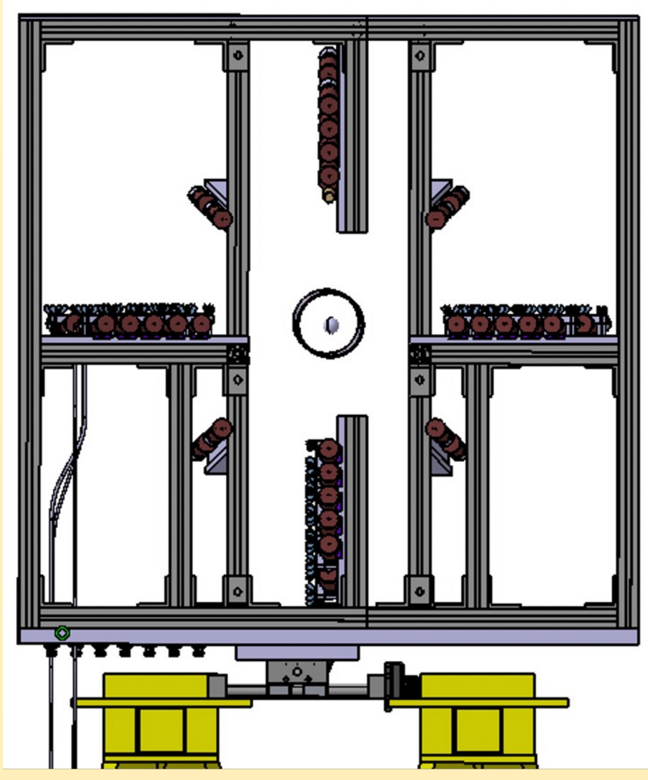


Figure 2: PMTs cross arrangement, beam view

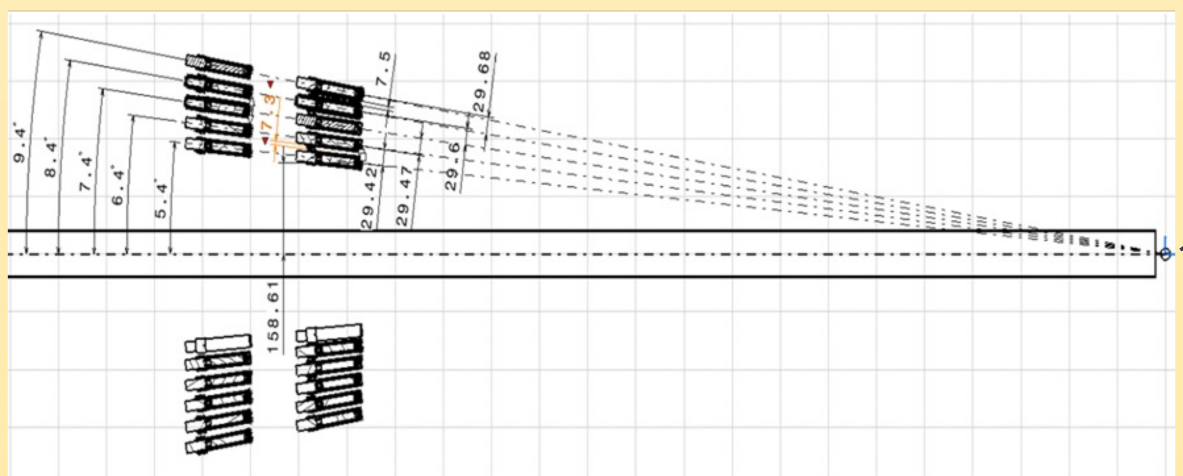


Figure 3: Angular positions of PLUME elementary detectors with respect to the Interaction Point.

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.

4 FE boards (FEB) + 1 control unit (CU):

- 2 for channels *readout*;
- 1 for *monitoring* system reading out data from PIN diodes (see calibration);
- 1 for precise *timing* measurements;
- 1 CU *transmits* clocks, commands, configurations from global LHCb to FEB.

FE amplifies, shapes, integrates from PMTs → Signal digitalized from ADC chip → Digital output processed in FPGAs → Formatted data sent to BE

2 BE boards (PCIe40):

- 1 (TELL40) for two main functions: 1. *Compute* online instantaneous luminosity 2. *Format data* for HLT and offline storage
- 1 (SOL40) for *handling* configuration, timing and control commands

In the end, *software tools* integrate data in the global LHCb DAQ and Real Time Anlysis framework. The main item of DAQ is the PLUME RAW event decoder which transforms data into usable objects for analysis software (HLT or offline analysis). PLUME information should be available ***both*** online and offline and should be running even when the other detectors are not. In particular, during the adjustment phase of LHC cycle, the value of $\mathcal{L}_{inst}$ at the LHCb IP is necessary for the LHC operator *to prepare and optimize* LHCb collisions.

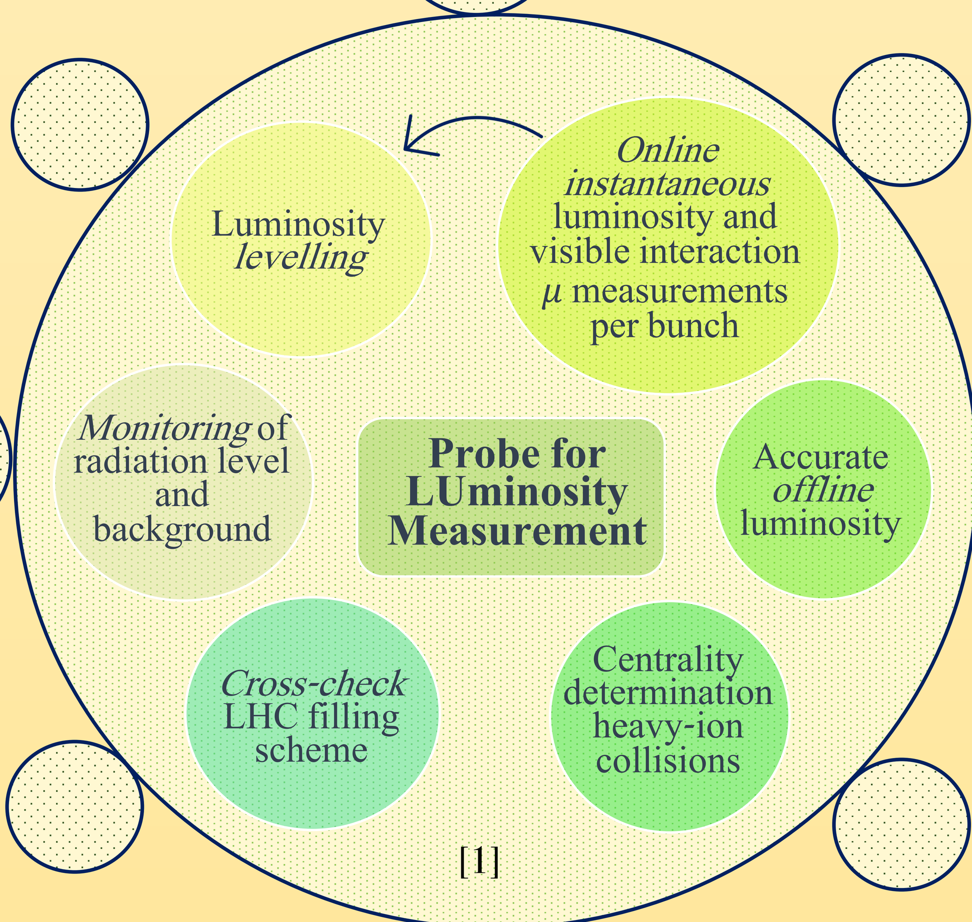
Statistical error ~3% achievable in 0.01 *s* with 1000 bunches

Calibration and monitoring

The accuracy on $\mathcal{L}$ measurements is limited by *systematics*. The largest effect is given by PMT gain stability (gain ~ 1.5×10^5), which depends on detector occupancy, temperature and radiation dose. Thus the *monitoring* of PMT stability is a key point. It is based on two *strategies*:

1. LED calibration system: it pulses light to the PMT during gaps in LHC filling scheme. Based on PMTs response, their HV is adjusted. *PIN photodiodes* are used to monitor LED stability;
2. Use VELO tracks directed in PLUME acceptance: it is requested simultaneously a reconstructed track and a coincidence signal in 2 PMTs.

It was checked that *gain change* is *not* negligible, but in these ways it can be *controlled* and the response in the number of photons can be *corrected* and kept *constant*.



Required Precision on $\mathcal{L}$:
- Online: < 10%
- Offline: for pp ≤ 2%, for PbPb ~ 4%

Luminosity measurements

$$\mathcal{L}_{inst} = \frac{\nu_{rev}\epsilon\langle\mu_{vis}\rangle}{\epsilon\langle\sigma_{vis}\rangle}$$

Revolution frequency
Visible interactions
Visible cross section
ϵ: acceptance × efficiency

Online: for every PMT **two** histograms are stored per BX:

1. Number of events below and above ***threshold***;
2. Number of hits in ***coincidence*** with projective PMT.

Fraction of events (BXs) without visible interactions N_0/N is used to compute (Total number of BXs)

$$\mu_{vis} = -\log\left(\frac{N_0}{N}\right) \quad \text{logZero method}$$

σ_{vis} can be computed through *Van der Meer scan* where beam position is moved by steps $\Delta x, \Delta y$ [3]:

$$\sigma_{vis} = \int \frac{\mu(\Delta x, \Delta y)}{N1N2} d\Delta x d\Delta y$$

Beams population from beam monitor

First 2022 VdM has been made in Run 3. During that, the PLUME detector was calibrated and now it can provide luminosity measurement for *pp* at $\sqrt{s} = 900\ GeV$ (Fig. 4 a-b).

Histograms are read and cleared at a rate of 1 Hz by a script, its output $\mathcal{L}_{inst}$ is transmitted to *the LHC control system* and to the *LHCb monitoring panel*. To the latter is reported also the Luminosity per BX [1].

Offline: A PLUME Lumi line will be implemented in *High Level Trigger 1*. Data are stored in *nano-events* taken with a random trigger. The analysis will proceed as for the online but with some advantages:

1. Coincidences with *other luminometers*;
2. Use *different methods* to evaluate μ_{vis};
3. Adjusting PMTs gain, signal will be constant, but *small corrections* on top of that might be required offline and deviations may reveal detector effects or systematics.

Offline luminosity will be calibrated per run by Lumi group .

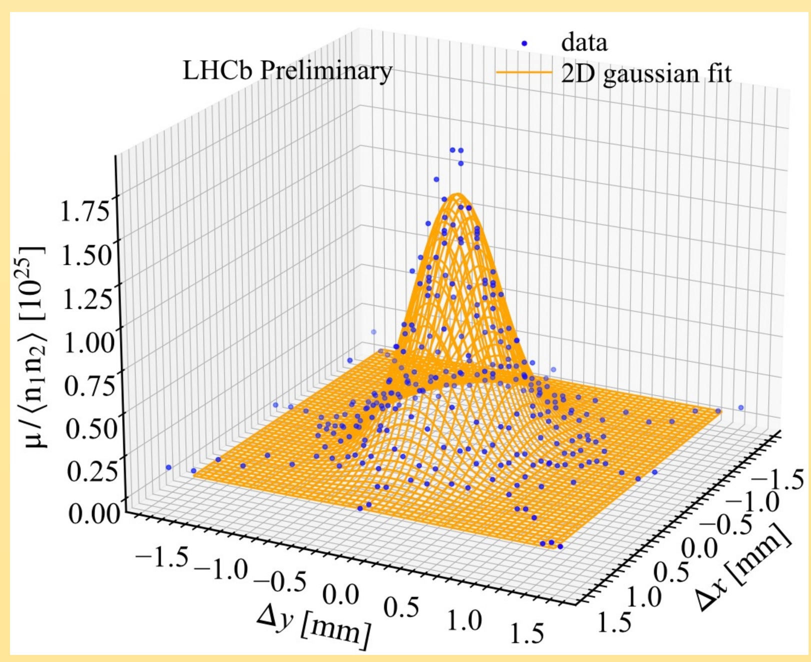


Figure 4a: Values of PLUME μ normalized by average product of numbers of protons in colliding bunch pairs from 2-D scan.

Cross section from 1D scans in X and Y-axis:
$\sigma_{1D} = 1.17 \pm 0.12$ mb

Cross section from 2D scans:
$\sigma_{2D} = 1.22 \pm 0.10$ mb

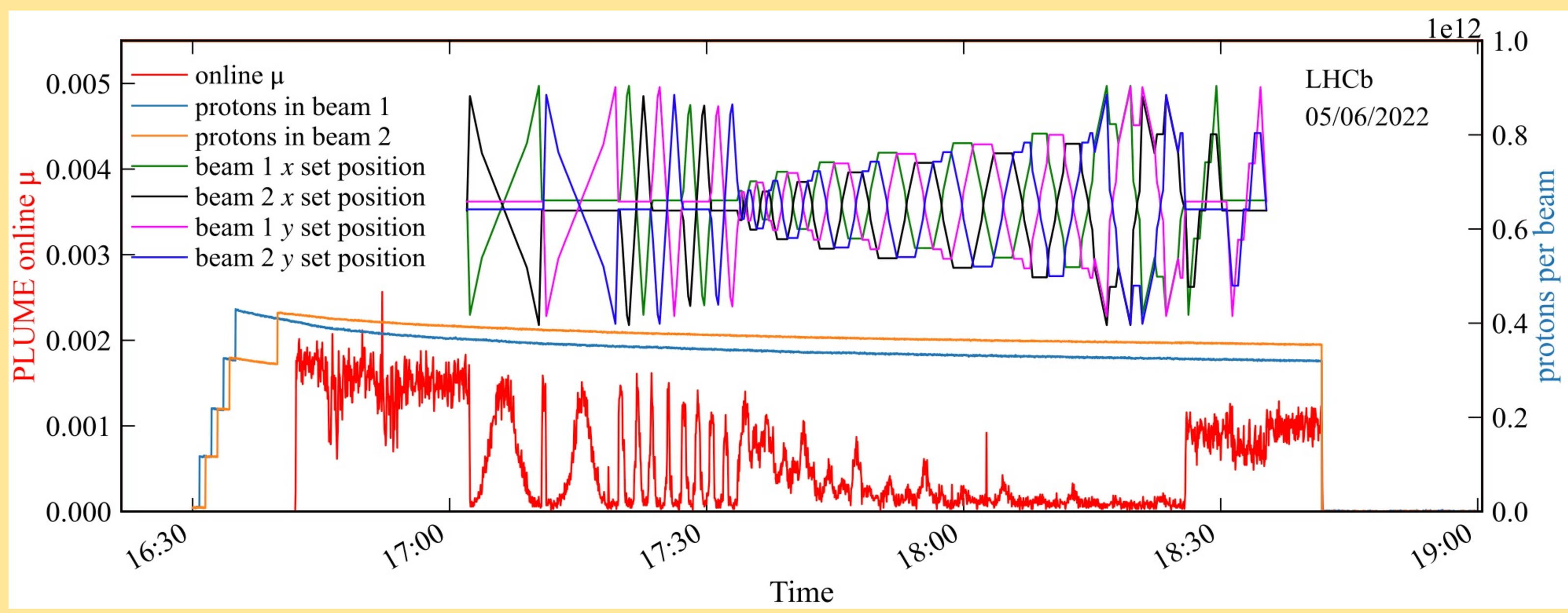


Figure 4b: In the upper plot the positions of the beams on the x and y direction during the VdM scan are reported. In blue and orange the protons per beam are shown, while in red the visible interactions seen by PLUME. As expected, the more the two are overlapped, the higher the luminosity is.

State of the art

Now PLUME is currently installed on its upstream position. From the beginning of Run 3, it has begun to take data and all the system is under test, including the monitoring.
In June:

- ✓ Background data taking;
- ✓ The luminosity calibration at 450 GeV of PLUME was achieved with a full VdM scan for cross calibration of ECAL, HCAL, MUON and RHIC;
- ✓ High-rate (30 − 40 MHz) tests with TELL40s have been succesfully done.

References:
[1] The LHCb collaboration, *LHCb PLUME: Probe for LUminosity MEasurement*, CERN-LHCC-2021-002, LHCB-TDR-022 (2021), 2750034
[2] Y. Guz, *The LHCb Calorimeter System: Design, Performance and Upgrade*, LHCb-TALK-2017-032 (2017), 2255089
[3] V. Balagura, *Van der Meer scan luminosity measurement and beam–beam correction*, EPJ C 81 26 (2021), s10052