LUCID: the ATLAS Luminosity Detector

A precise measurement of luminosity is a key component of the ATLAS program: its uncertainty is a systematics for all cross-section measurements, from Standard Model processes to new discoveries, and for some precise measurements it can be dominant. To be predictive a precision compatible with PDF uncertainty (1-2%) is desired. LUCID (LUminosity Cherenkov Integrating Detector) is sensitive to charged particles generated by the pp collisions. It is the only ATLAS dedicated detector for this purpose and the referred one during LHC RUN 2.

LUCID-2: Reason for upgrade

The increased energy of the proton beams and the higher luminosity of RUN 2 of the LHC accelerator required a redesign to cope with the more demanding conditions. The novelties of the LUCID-2 detector are the thin quartz windows of photomultipliers used as Cherenkov medium and a small amounts of radioactive 207 Bi sources deposited on to these windows to monitor the gain stability of the photomultipliers. Thanks to new electronics, luminosity can be accurately measured online for each of the up to 2808 colliding bunch pairs, 25 ns spaced.

Detector

LUCID is composed of two modules (Fig. 1) symmetrically positioned around the beam-pipe on both forward ends of ATLAS at ±17 m from the Interaction Point (IP).

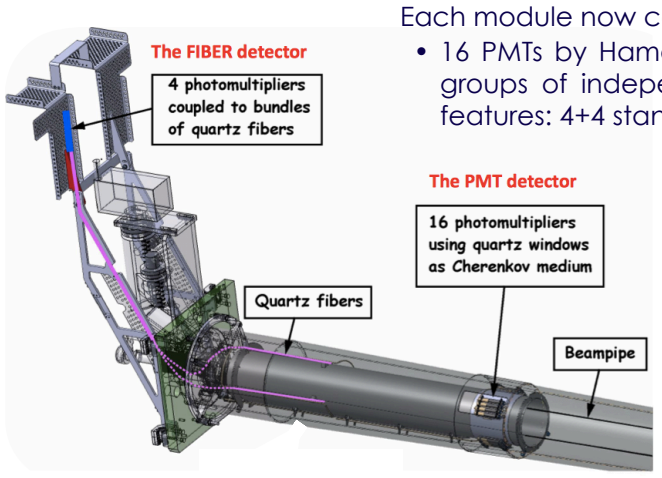


Fig. 1: View of one of the two detector modules.

Each module now consists of:

- 16 PMTs by Hamamatsu (R760) arranged in 4 groups of independent sensors with different features: 4+4 standard PMTs, 4 spare PMTs, and 4 PMTs with reduced acceptance, all of them fit with Bi^{207} radioactive source for calibration purposes
- 4 PMTs fed by quartz fibers and located in a lower radiation area a few meters away. These sensors are calibrated via LED pulses (stability monitored by Pin Diode).

Electronics

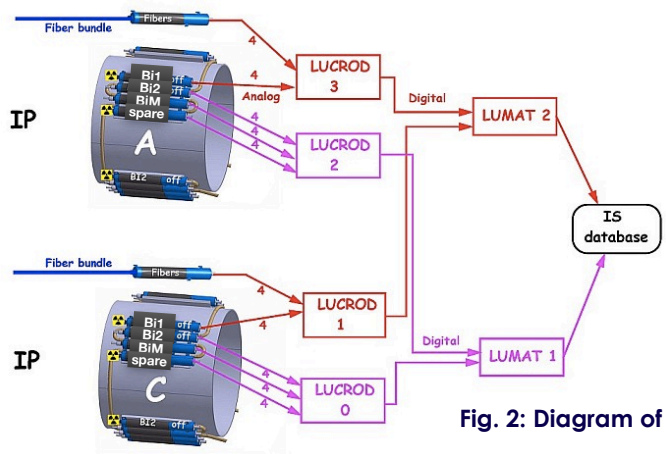


Fig. 2: Diagram of the electronics

- 4 custom-made VME boards (LUCROD) placed 17 m from the PMTs provide hit counting and charge measurement (insensitive to pile-up and proportional to luminosity) at each bunch crossing.
- 2 LUMAT boards correlate hits coming from the two sides of LUCID.

Calibration

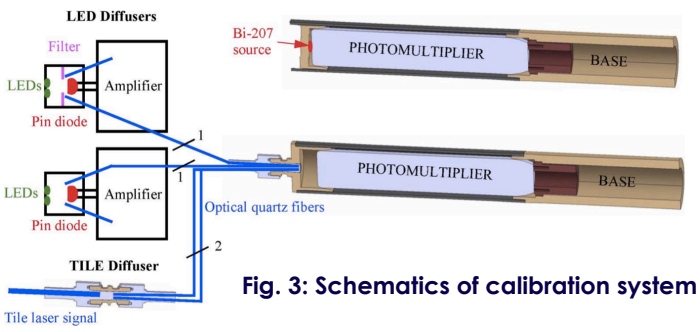


Fig. 3: Schematics of calibration system

"PMT detector" → **electrons from Bi^{207} internal conversion**

Bi^{207} emissions allows accurate calibration of the PMTs since the energy of the emitted electrons (around 1 MeV) mimics the signal of high energy charged particles crossing the same quartz window.

"FIBER detector"

→ **LED pulses (whose stability is monitored by PIN diodes)**

→ **Laser signals from the Tile Calorimeter**

For redundancy, two fibers come from two different LED diffusers and two fibers come from one laser diffuser.

Dedicated calibration sessions are performed at the end of each LHC fill (Fig 4). Possible gain losses are automatically compensated for an increase of High Voltage (Fig 5).

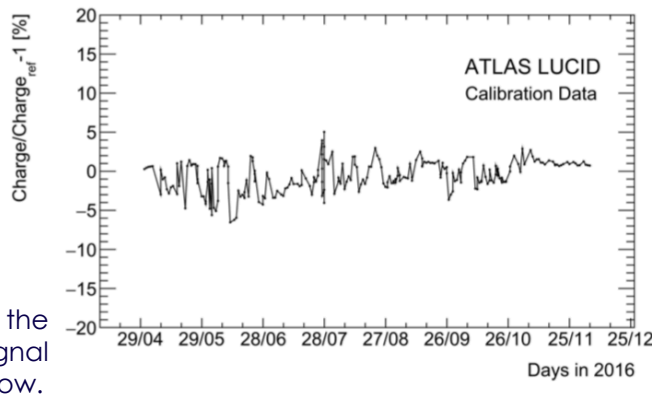
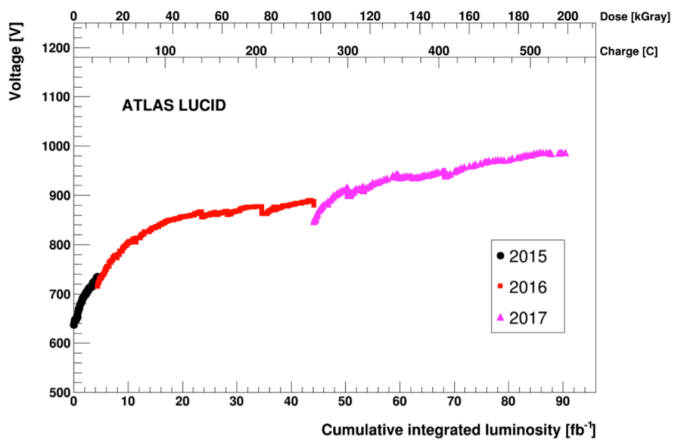


Fig. 4: Percentage deviation of the measured mean charge relative a reference run for one of the Bi-calibrated photomultipliers, as function of time.

Fig. 5: HV applied to the PMTs as a function of cumulative luminosity delivered to the LHC, of dose and charge, in the last three years.



Luminosity measurement

$$L = \frac{R}{\sigma}$$

R: rate of a process

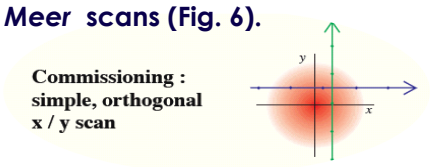
σ: cross section of the same process

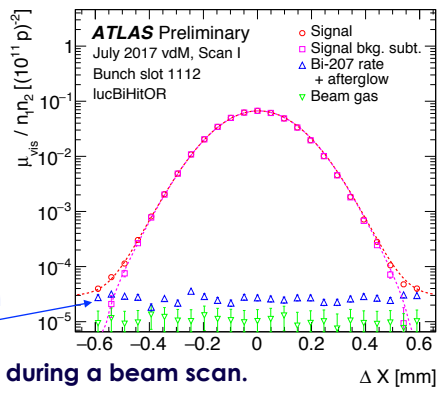
LUCID estimates the rate of inelastic pp interactions in each bunch crossing using various algorithms:

Hit and Event counting: a "hit" is defined as a pulse above a given threshold, and an "event" is defined as a particular hit configuration. Hits and events can be related to the average number of interactions per bunch crossing (μ) via Poisson statistics. Both methods are affected by pileup of several below-threshold signals which combine resulting in a spurious hit over threshold.

Charge integration as measured by each sensor at each bunch crossing, is directly proportional to the luminosity.

The absolute calibration constant is measured for each algorithm and sensor type during dedicated LHC fills, called *Van der Meer* scans (Fig. 6).





Background from Bi-207 sources is low enough not to spoil the precision of such method.

Fig. 6: Visible interaction rate per bunch crossing during a beam scan.

Results

Since 2015, LUCID provides measurements of the ATLAS luminosity for physics analysis, and the instantaneous luminosity to LHC, for on-line beam stability monitoring, luminosity levelling and ATLAS trigger pre-scales adjustments.

The redundancy of the measurement performed by different detectors and methods ensure a robust measurement of luminosity and an accurate control of systematic uncertainties.

LUCID luminosity is corrected by the Inner detector (**TRACKS**), and is monitored by the calorimeters (**EMEC**, **TILE**, **FCAL**), and the detector for neutrons (**TPX**). A run to run stability of 1.3% is ensured in 2017 as can be seen in Fig. 7.

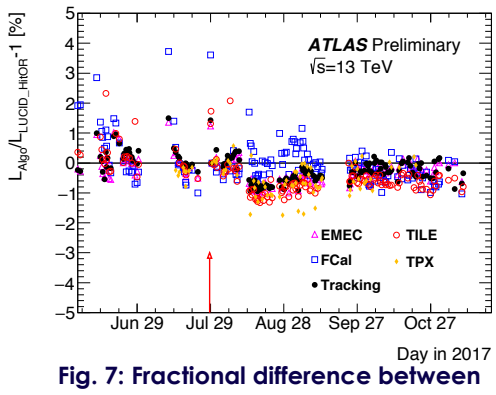


Fig. 7: Fractional difference between LUCID and different detectors vs time.

The final precision on integrated luminosity is dominated by uncertainties in the absolute calibration, long term stability and linearity.

Systematics used for pp data analysis are shown in Table 1 per each year of running.

Year	Precision (%)
2015	2.1
2016	2.2
2017	2.4*

* preliminary

Table 1: systematic uncertainties on pp integrated luminosity

Laura Fabbri, University of Bologna and INFN, on behalf of the ATLAS - LUCID Group