LUCID Upgrade for ATLAS Luminosity Measurement in Run II.

A precise measurement of *luminosity* is a key component of the ATLAS program: its uncertainty is one of the dominant systematics for many cross-section measurements, from Standard Model processes to new discoveries.

1) Reasons for the upgrade

1) increased number of interactions per bunch crossing;
2) change of the beam pipe material;
3) 25 ns bunch-spacing.

New LUCID has reduced granularity as well as new electronics: PMTs' quartz window are used as Cherenkov radiator and signals are immediately digitized.

3) New read-out electronics

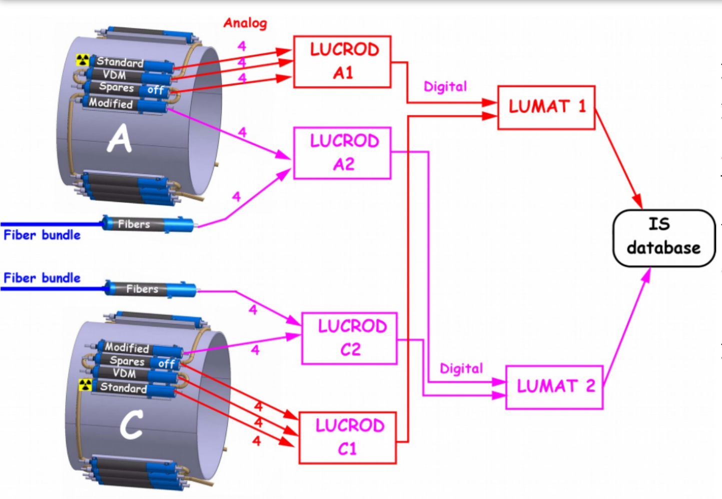


Fig. 2: Diagram of the electronics

Four custom-made VME boards (LUCROD), installed only 15 m away from the sensors, provide not only *hit counting* but also a new *charge measurement* at each bunch crossing. Two other boards (LUMAT) correlate hits coming from the two sides of the detector. A scheme of the electronics is illustrated in Fig. 2. The main advantage of charge measurement (direct pulse integration) is its insensitivity to *pile-up*.

In addition, total charge is directly proportional to luminosity. New electronics allows also signal shape monitoring (Fig. 3). Redundancy of measurements is the key to control the systematics: the new electronics allow to implement about 100 different algorithms.

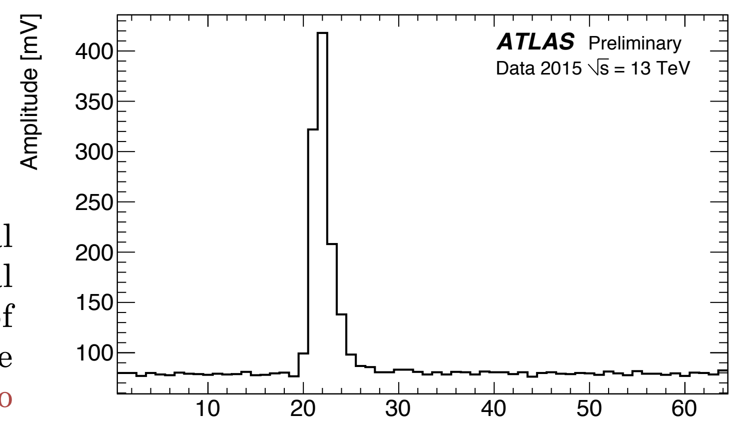
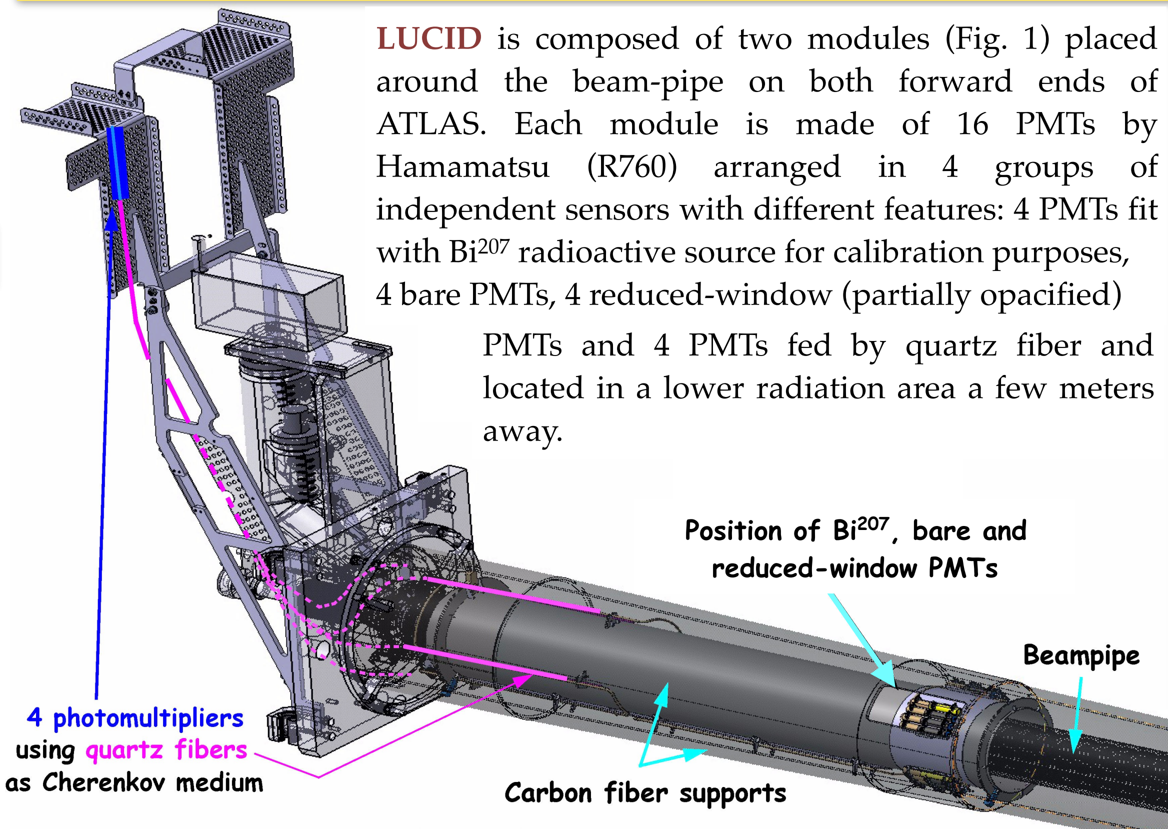


Fig. 3: PMT signal shape

2) The LUCID II detector



LUCID is composed of two modules (Fig. 1) placed around the beam-pipe on both forward ends of ATLAS. Each module is made of 16 PMTs by Hamamatsu (R760) arranged in 4 groups of independent sensors with different features: 4 PMTs fit with Bi^{207} radioactive source for calibration purposes, 4 bare PMTs, 4 reduced-window (partially opacified) PMTs and 4 PMTs fed by quartz fiber and located in a lower radiation area a few meters away.

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

4) Calibration system

The LUCID upgrade includes a new calibration system based on Bi^{207} sources.

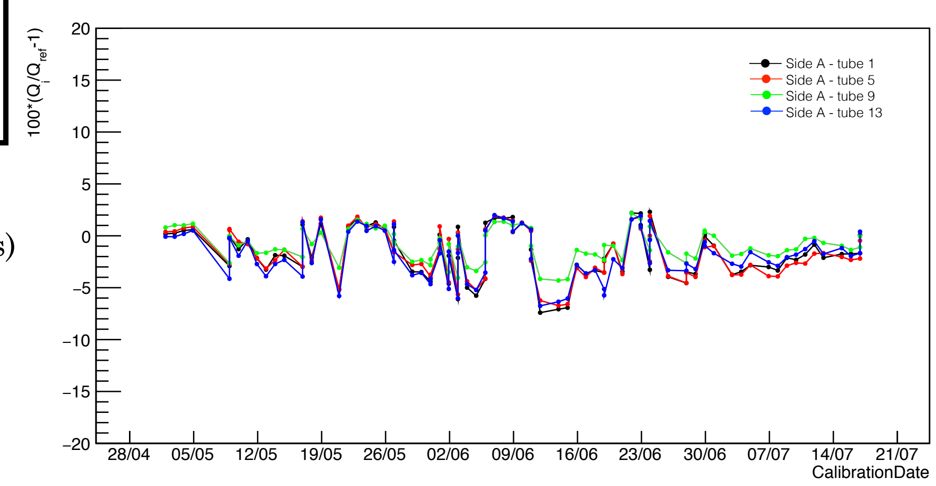
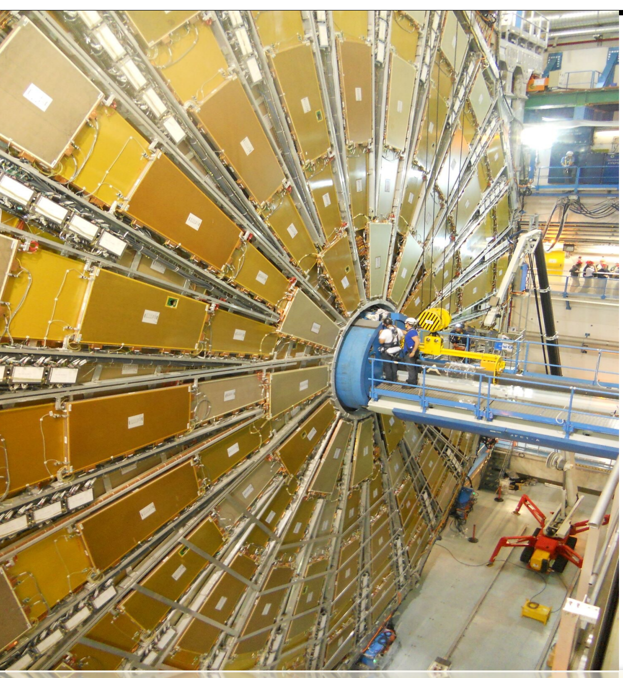


Fig. 5: Bi^{207} calibration trending plot



Calibration systems:

- electrons from Bi^{207} internal conversion
- LED pulses (whose stability is monitored by PIN diodes)
- Laser signals from the Tile Calorimeter

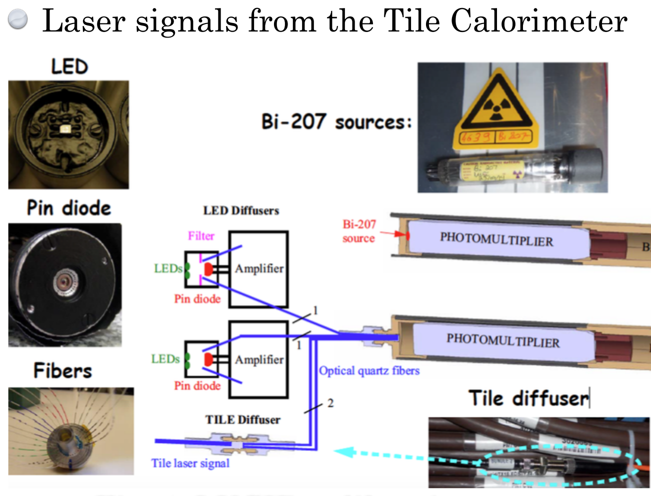


Fig. 4: LUCID calibration system

Bi^{207} emission permits 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. Fig. 5 shows the PMTs' charge variation, as a function of time, with respect to the reference one. Dedicated calibration sessions are performed at the end of each LHC fill. Possible gain losses are automatically compensated by increase of HV. The success of Bi^{207} calibrations led to the installation of 4 new Bi^{207} PMTs per side during the 2016 winter shutdown.

5) vdM scans

The absolute calibration constant is measured for each algorithm and sensor type during dedicated LHC fills and are called vdM scans. As shown in Fig. 6, background from Bi^{207} sources is low enough not to spoil the precision of such method. The total systematic error on σ^{vis} is ~ 1.66%.

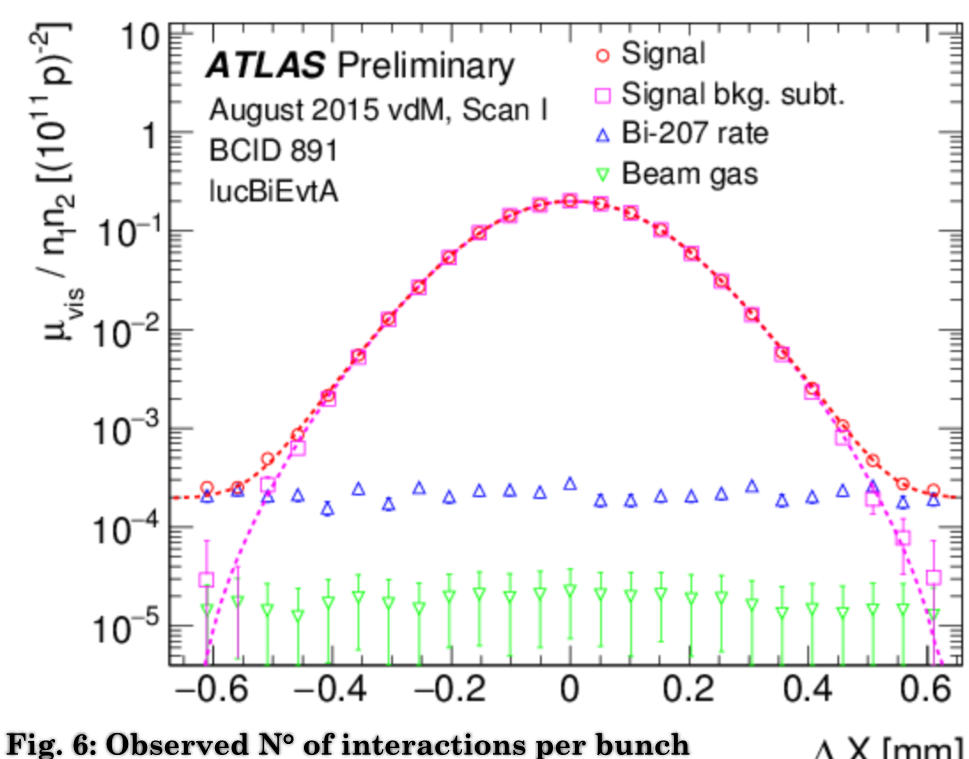


Fig. 6: Observed N° of interactions per bunch crossing normalized to the measured p current.

Error	50 ns	25 ns
Calibration error	1.66%	
Error in the calibration transfer correction	0.8%	0.9%
Run to run stability uncertainty	1.0%	
Total systematic error	**2.1%**	

Table 1: Summary of syst. errors in 2015

6) Luminosity measurement

Luminosity algorithms are based on **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. In addition, **charge**, as measured in each sensor at each bunch crossing, is directly proportional to the luminosity. Currently, LUCID event counting provides measurements of **a) the ATLAS luminosity for physics analysis, b) the instantaneous luminosity to LHC**, for beam stability monitoring.

$$\mathscr{L}_{LB} = \frac{f_{LHC}}{\sigma_{inel}} \sum_{j=1}^{n_b} \mu_j = \frac{f_{LHC}}{\sigma^{vis}} \sum_{j=1}^{n_b} \mu_j^{vis}$$

Experimental quantity:
- ✤ following Poisson statistics for **Hit and Event counting**;
- ✤ directly proportional to **charge**;

A robust measurement of luminosity, and an accurate control of systematic uncertainties, is ensured by the redundancy of the measurement performed by different detectors: LUCID luminosity is monitored by the **Inner detector (TRACKS)** and the **Electromagnetic/Tile/ calorimeters (EMEC, TILE).**

The fractional difference (Fig. 7) between LUCID and other detectors shows the consistency between luminosity measurements as a function of time. The TILE, EMEC and TRACKS algorithms are cross-calibrated to LUCID in a group of physics runs close to a vdM scan. A run to run stability of 1% is ensured as can be seen in Fig. 7.

The main source of uncertainties arise from the absolute calibration and from long term stability (Table 1).
A final uncertainty of 2.1% has been achieved both for the 50 ns and 25 ns bunch spacing configurations in 2015.

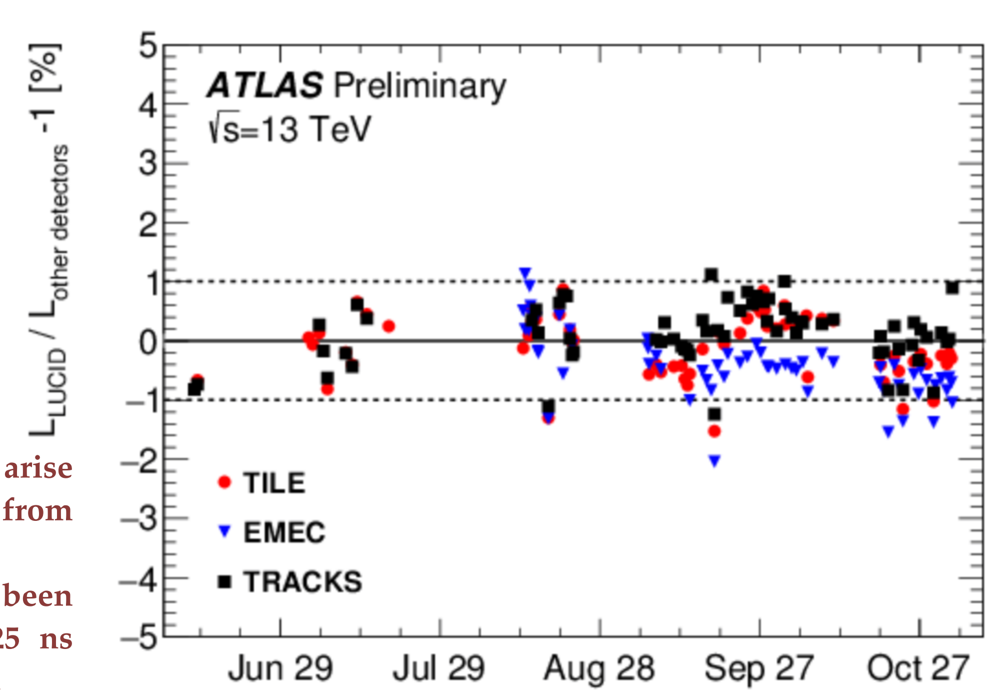


Fig. 7: Run to run stability

Giulia Ucchielli, University of Bologna and INFN

Chicago, ICHEP 2016