The LUCID-2 detector

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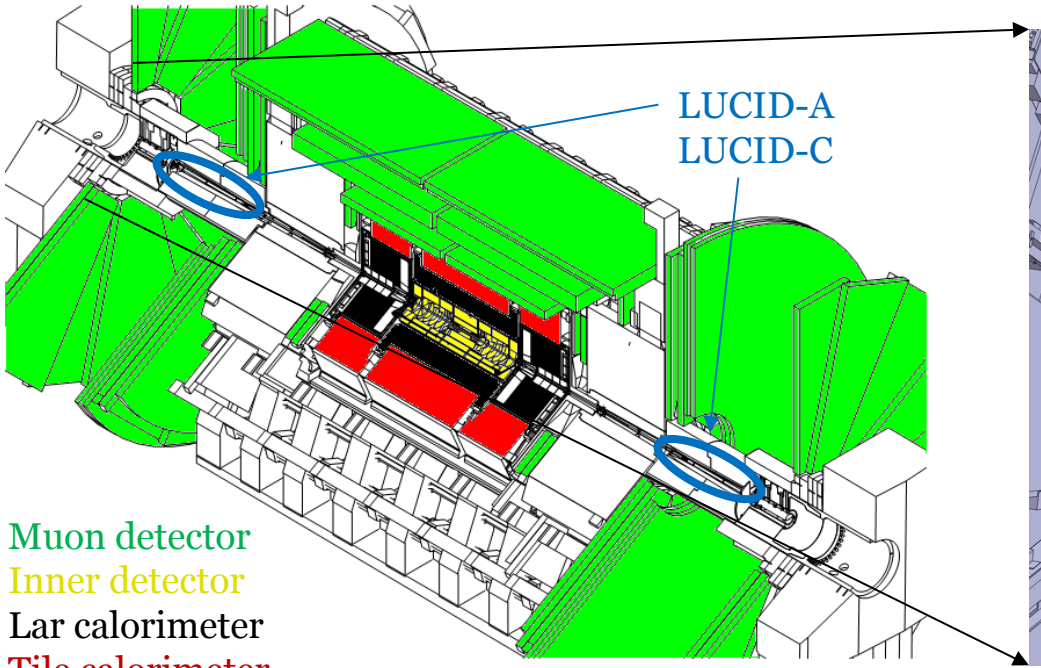
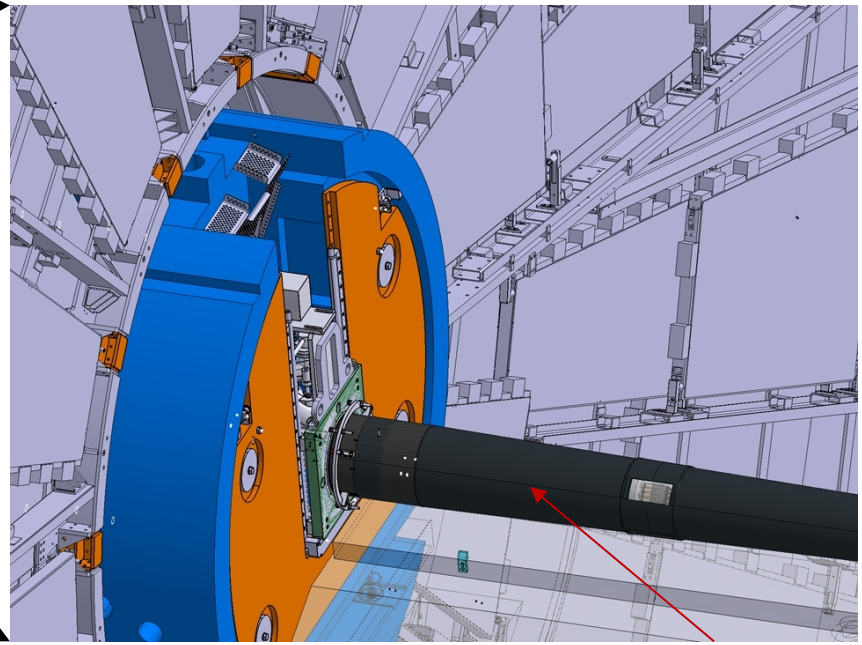
ATLAS

LUCID in ATLAS

- LUCID (LUminosity Cherenkov Integrating Detector) is the main ATLAS luminometer for online and offline luminosity.

- LUCID is located at ~17 m from the IP, at ~12 cm to the beamline (η ~ 5.6).





zoomed view

Carbon fiber cone supporting LUCID

The LUCID challenge

Detector requirements for an accurate luminosity monitoring @ LHC

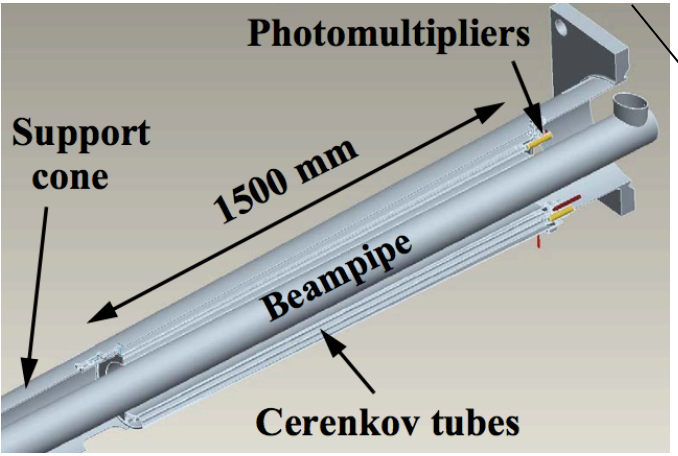
- Fast
  - Time between colliding bunches is only 25 ns.
- Stable in time
  - Only one calibration fill per year is highly demanding in terms of stability which must be continuously monitored.
- Stable over a wide luminosity range
  - The average number of pp-interactions (μ) is calibrated at very low values (10^{-3}) and is accurately extracted to more than 60.
- Stable for different pile-up conditions
  - Particles from overlapping pp-interactions might affect the accuracy of the luminosity determination.
- Radiation hard
  - High level of radiation in the proximity of the LHC beam-pipe.

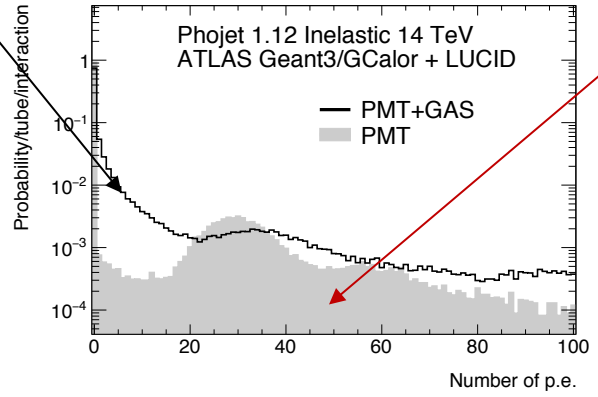
The LUCID evolution

- LUCID-1 was a Cherenkov tube detector with a gaseous radiator.

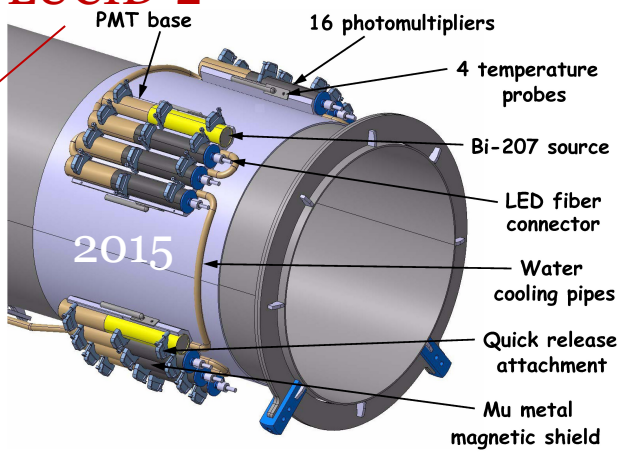
- LUCID-2 is designed to cope with an increased number of interactions (μ) per LHC bunch crossing and a reduced bunch spacing (from 50 to 25 ns):
  - Remove the gas detector to reduce systematics.
  - Use PMTs with smaller windows to reduce acceptance.
  - Read-out electronics has been redesigned to cope with 25 ns bunch spacing.

LUCID-1

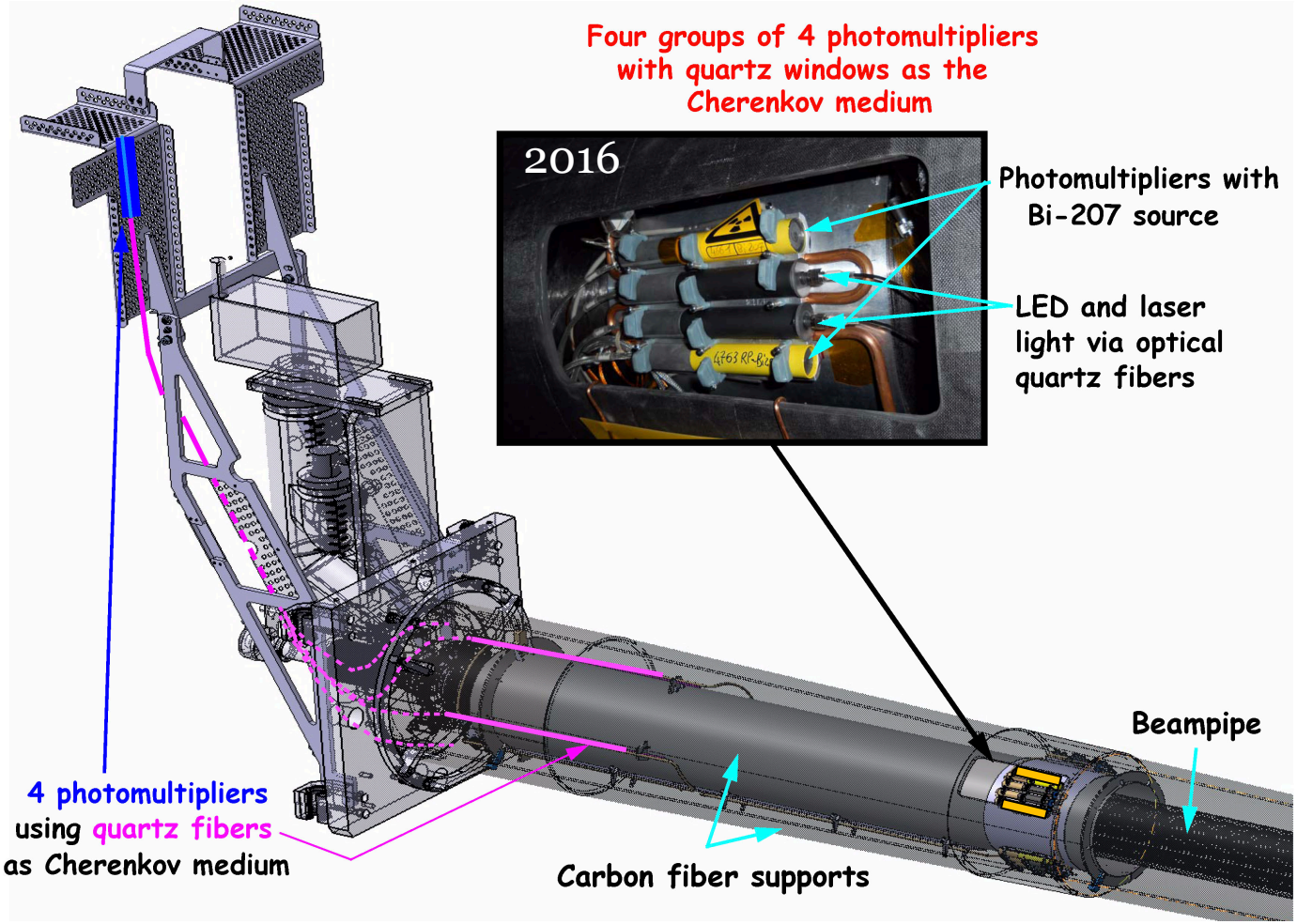




LUCID-2



The LUCID-2 detector

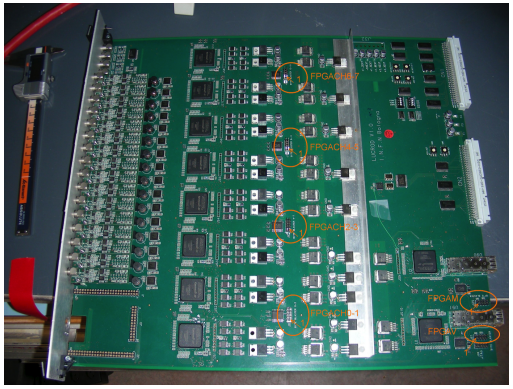


From 2017 all PMTs are monitored with Bi-207, except those for fiber read-out.

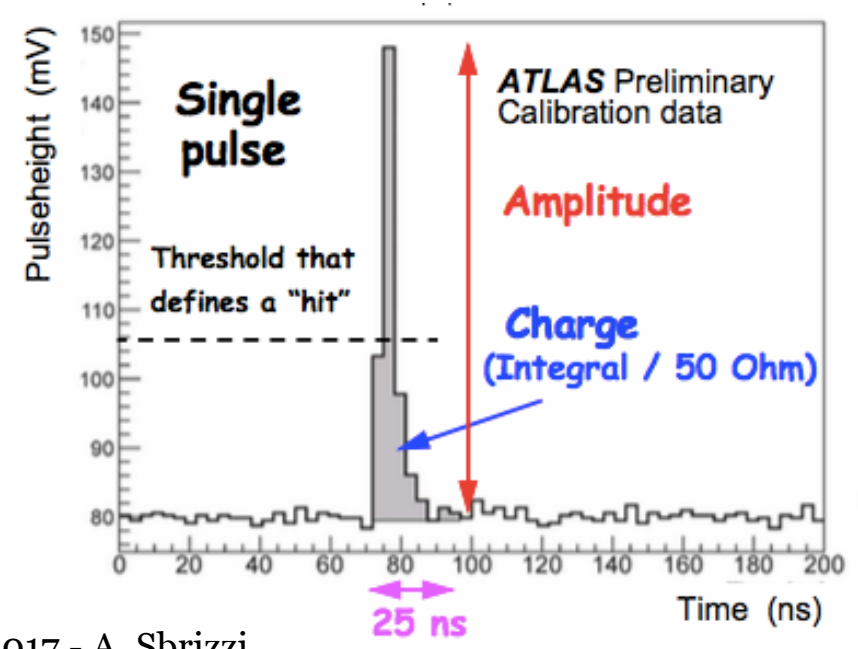
The LUCID-2 readout

- Four custom VME boards ("LUCROD") hosting 16 FADCs.
  - Boards are placed at ~15 m from the detector to cope with 25 ns bunch spacing.

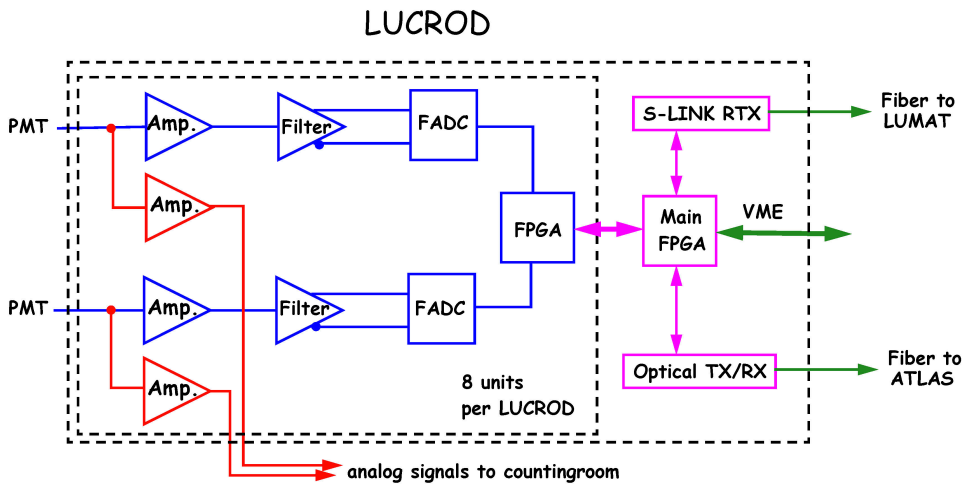
- The FADC performs digital samplings of analogic signals with 12 bits precision and stores them in FIFOs.
  - FADC sampling rate: 320 MS/s (one every 3.125 ns).
  - Number of sampling: 64 but it can be changed.
  - Range of input signals: 1.5 V.
  - Optical data transfer: 1.3 Gb/s.
  - Max transfer rate: 100 k events/s.

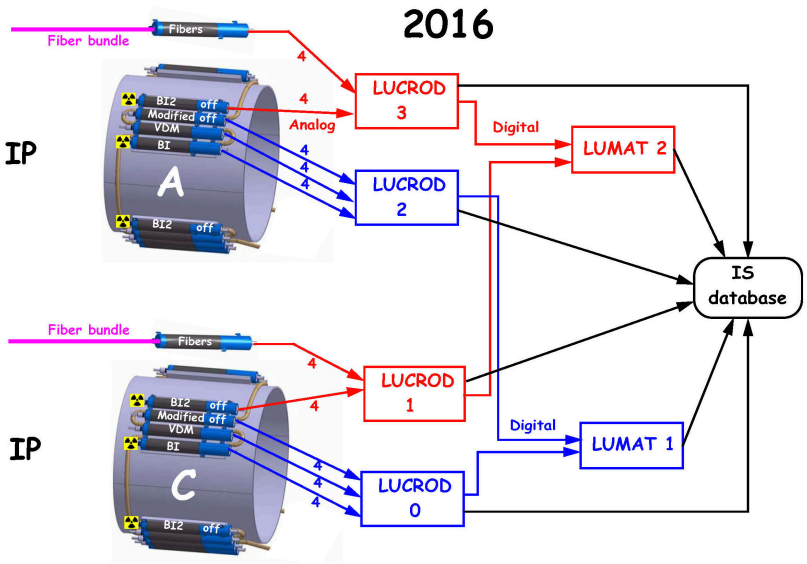


LUCROD



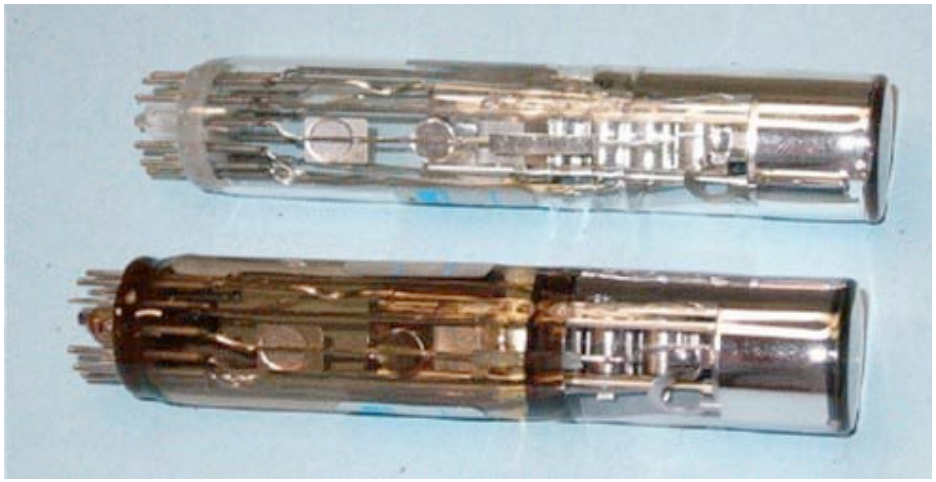
The LUCID-2 readout





- The LUCROD amplifies, digitizes, discriminates and integrates signals to measure the charge in every 25 ns bunch crossing periods.
- Hit patterns in 25 ns time slots are transmitted to two LUMAT boards located about 100 m away from the detector via optical links.
- The LUMAT correlates hits of the two LUCID detectors and produce online and offline luminosity measurements with several independent algorithms.

Radiation hardness



Before irradiation

After γ irradiation

- PMTs with fused silica (100% SiO2) windows are radiation hard.
- PMTs have been exposed to γ (200 kGray) at the CALLIOPE facility and to neutrons (2.6 10^{14} n/cm^2) at the TAPIRO facility.
  - An increase of the dark current was observed but no change of signal size or gain.
  - The measured dose delivered to PMTs in 2015 was 9.4 kGray.

The luminosity measurement

LUCID measures the average instantaneous luminosity for each pair of colliding LHC bunches during time periods of about 1 minute.

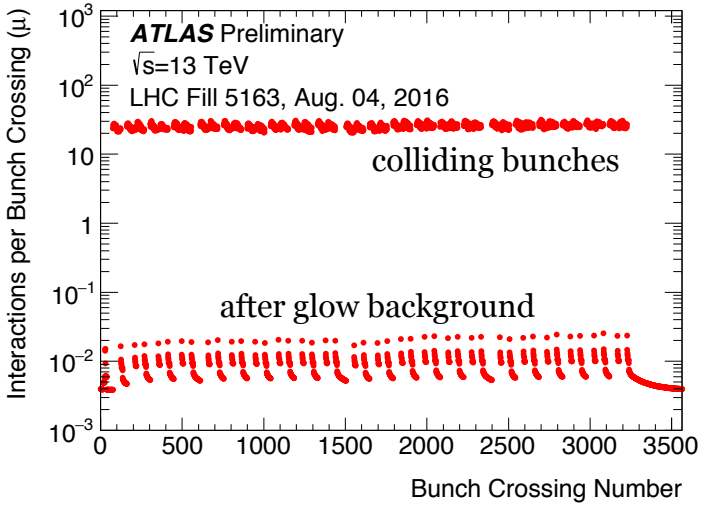
$$L = f_{LHC} \frac{\mu_{VIS}}{\sigma_{VIS}}$$

f_{LHC}: LHC revolution frequency 11.245 kHz.

μ_{VIS}: "visible" average number of pp interactions per bunch crossing measured by LUCID.

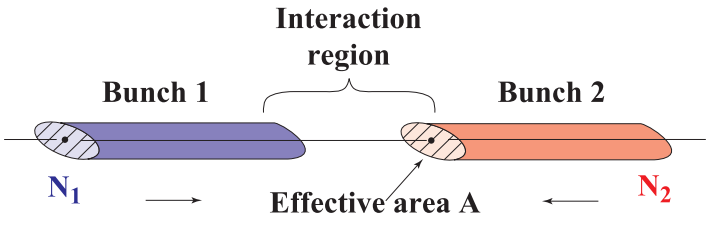
σ_{VIS}: "visible" cross section measured in beam separation scans, typically once per year.

- μ_{VIS} is measured with algorithms based on events/hits counting and on charge integration.
- Each PMT can be used as an independent luminosity detector.

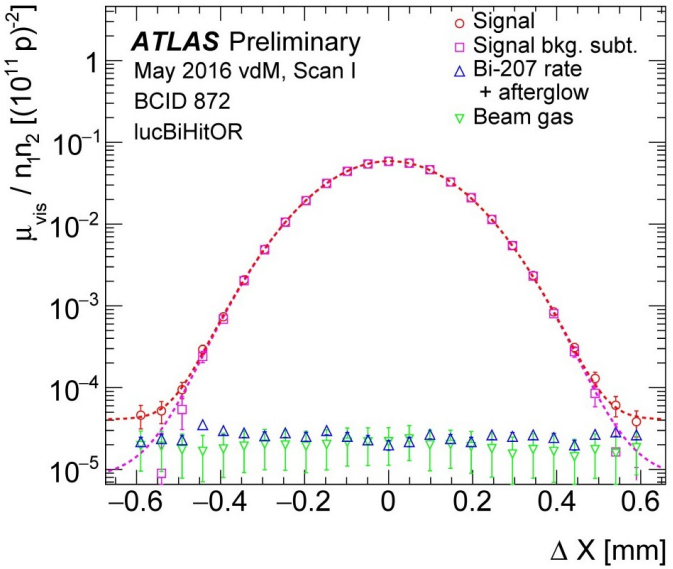


Beam separation scan

”Low intensity” runs ($\mu \sim 10^{-3}$) in which luminosity detectors measure the interaction rate for several beam separations to extract σ_{VIS}.

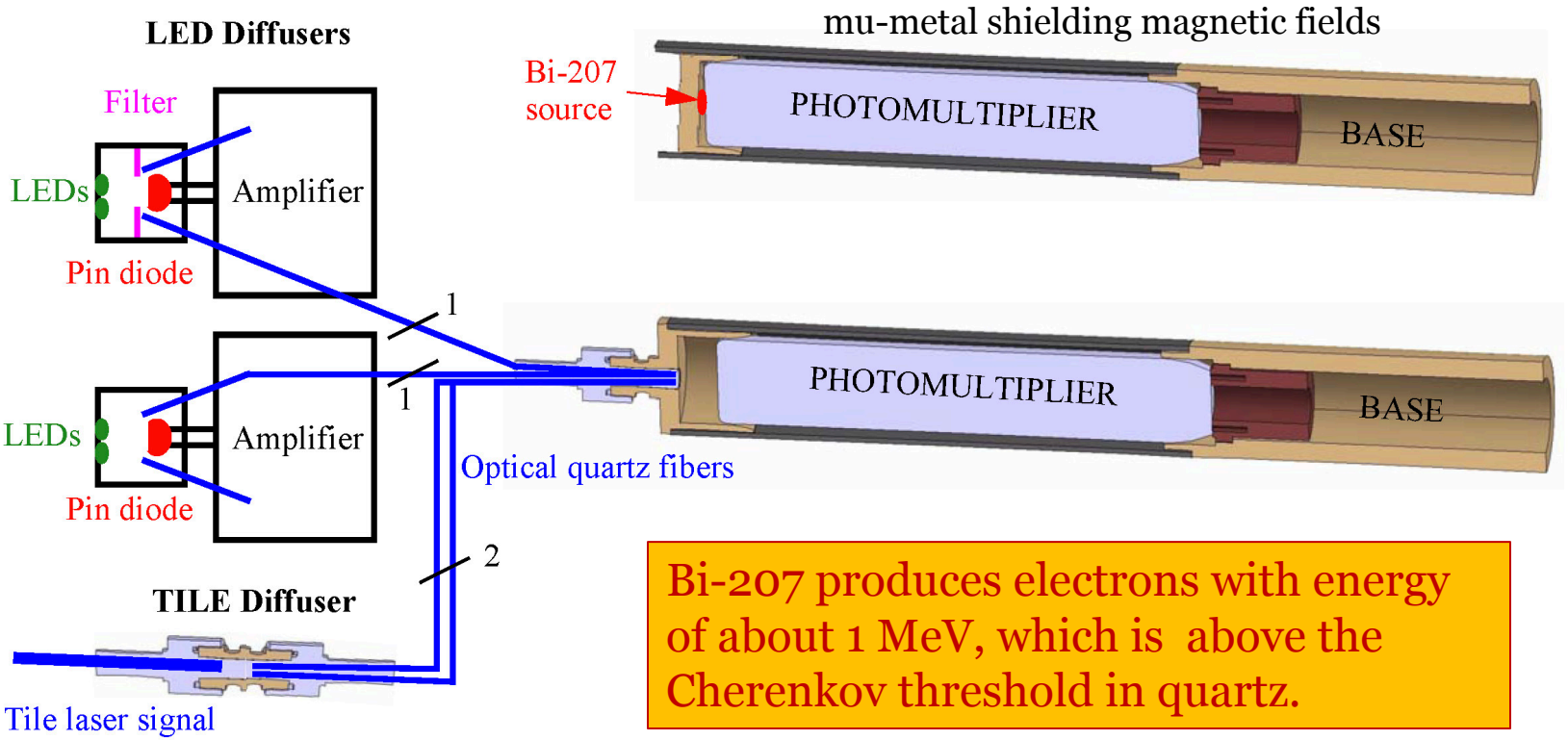


$$\sigma_{VIS} = \mu_{VIS}^{MAX} \frac{2\pi\Sigma_X\Sigma_Y}{n_1 n_2}$$



- $n_1 n_2$: beam population product from beam current measurement.
- μ_{VIS}^{MAX}: maximum interaction rate.
- $\Sigma_X\Sigma_Y$: product of the widths of the interaction rates.

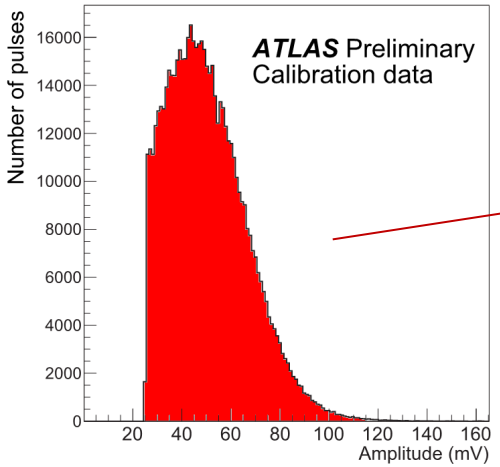
PMT stability monitors

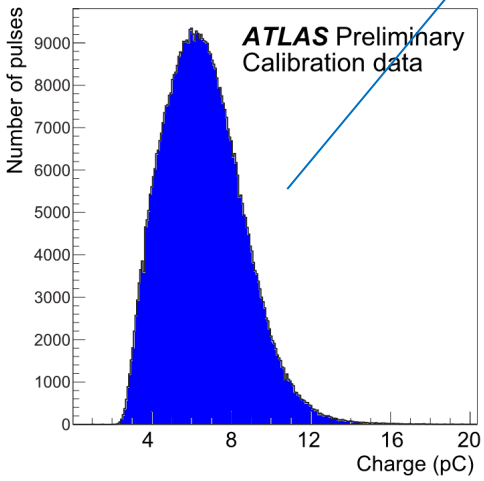


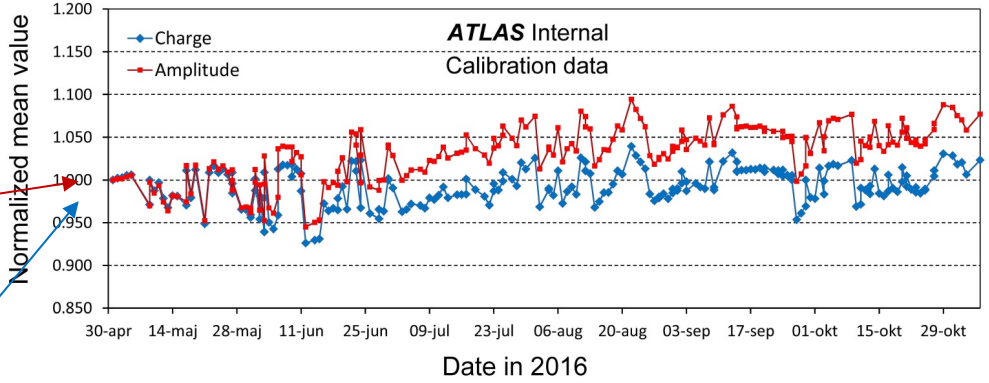
Bi-207 produces electrons with energy of about 1 MeV, which is above the Cherenkov threshold in quartz.

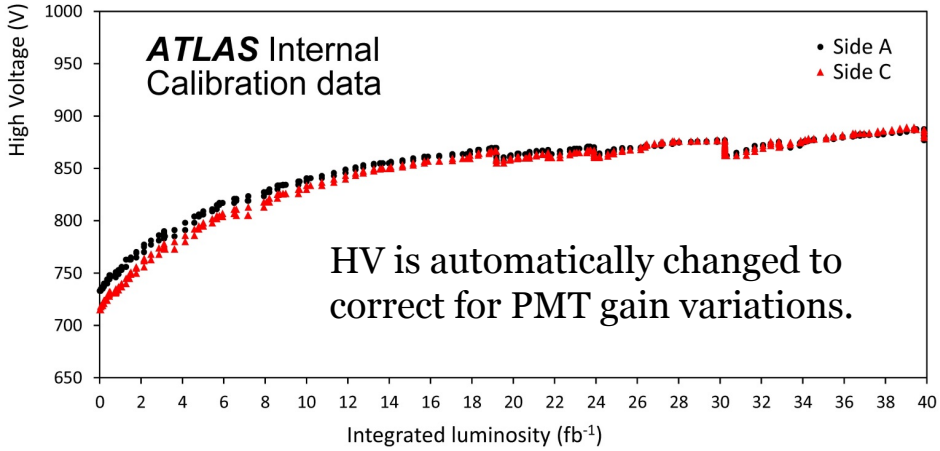
- Three systems to monitor the PMT stability between LHC fill.
- The monitoring system based on Bi-207 has performed better than the system based on LED light.

The Bi-207 monitoring system



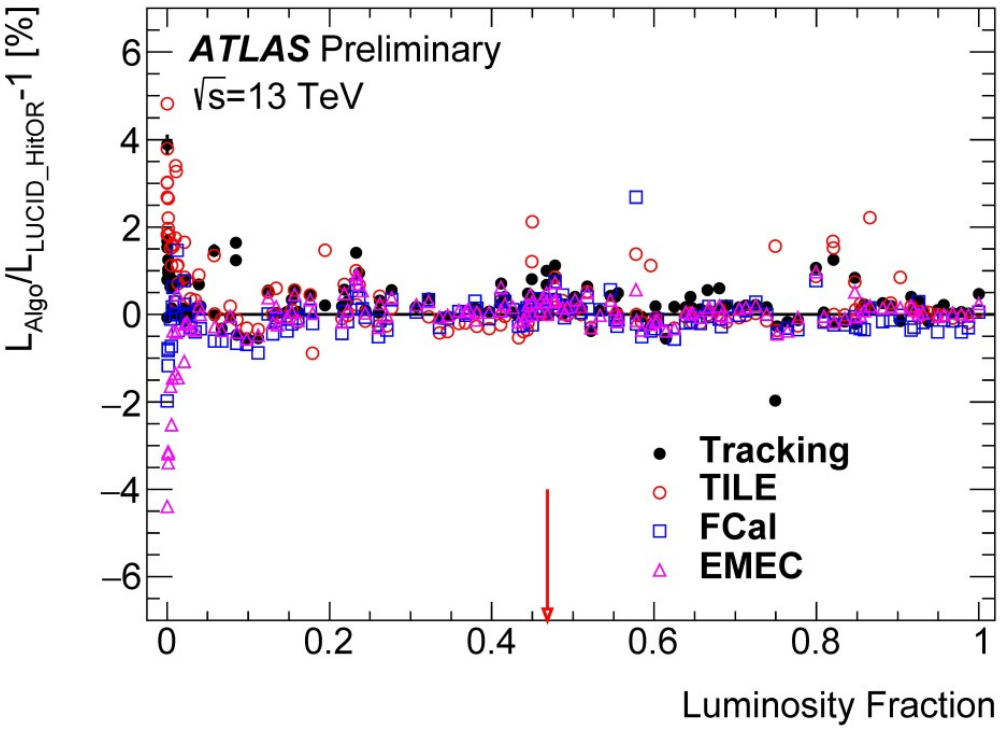






The mean amplitude and charge are also used for online and offline luminosity corrections.

Accuracy of luminosity measurement



Statistical uncertainty is negligible.

Systematic uncertainty is obtained by comparing to other detectors.

The red arrow indicates the run used to normalize LUCID to all other detectors.

$$\sigma_{sys}^{2015} = 2.1\%$$
$$\sigma_{sys}^{2016} = 2.2\%$$

- LUCID luminosity is corrected for:
  - PMT gain changes using the Bi-207 monitoring system.
  - PMT gain drift using other detectors (0.7%).
  - μ-dependence using track counting in one run.

Conclusions

- The LUCID-2 detector is the main ATLAS luminosity detector.
- It is a Cherenkov detector made of radiation hard PMTs
  - The Cherenkov radiator is the 1.2 mm thick quartz window.
- Thanks to fast PMT signals (1 ns rise-time), LUCID-2 can measure the luminosity of individual LHC bunch crossings (25 ns).
- High stability is necessary for an accurate luminosity measurement.
  - Novel monitoring system: small drops of radioactive Bi-207 deposited on the PMT quartz windows provides a flux of ~1 MeV monitoring electrons.
- Despite more than 60 pp-interactions per bunch crossing, the systematic uncertainty reached in 2016 was slightly higher than 2%.