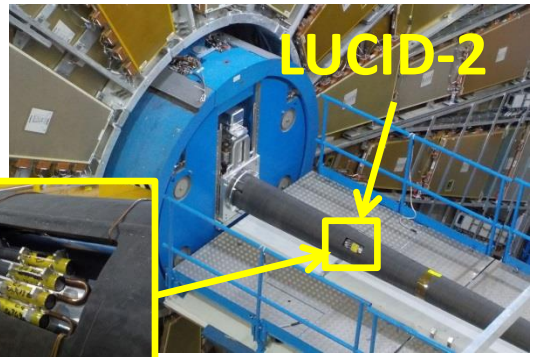
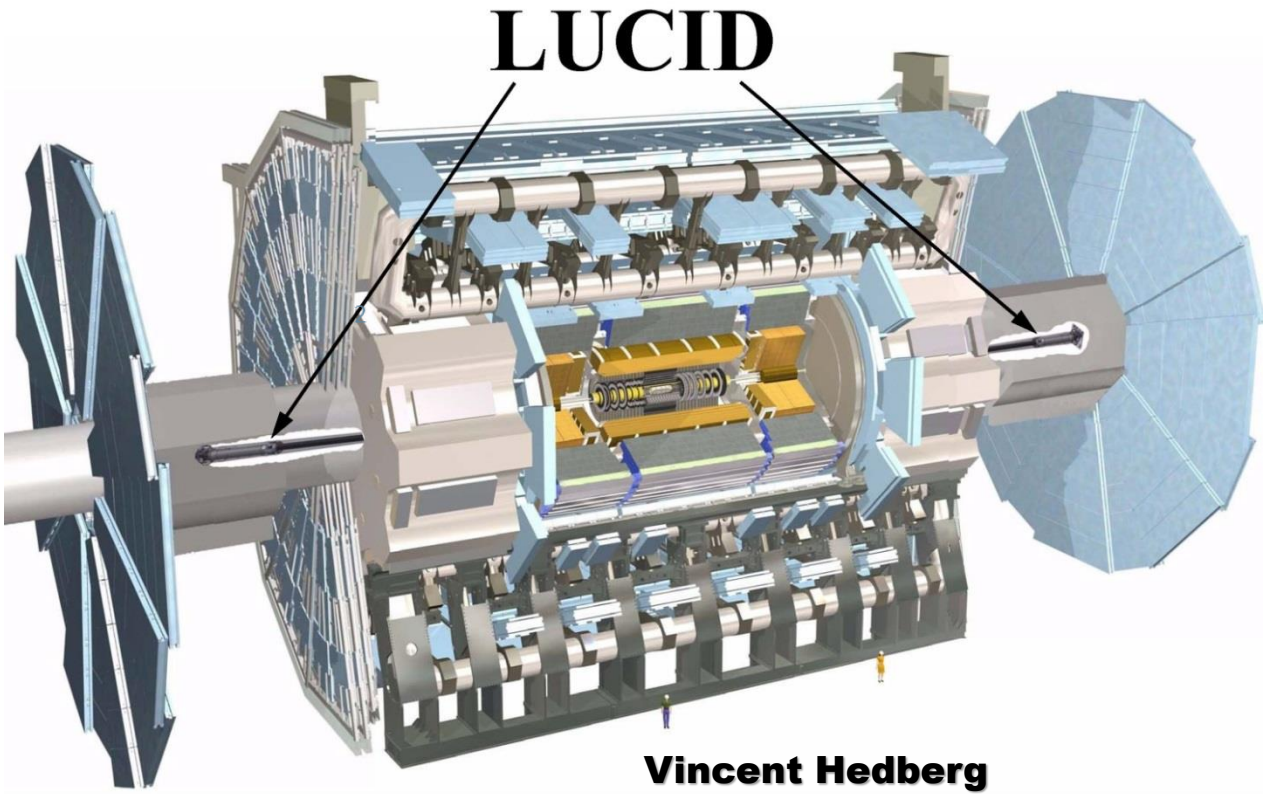
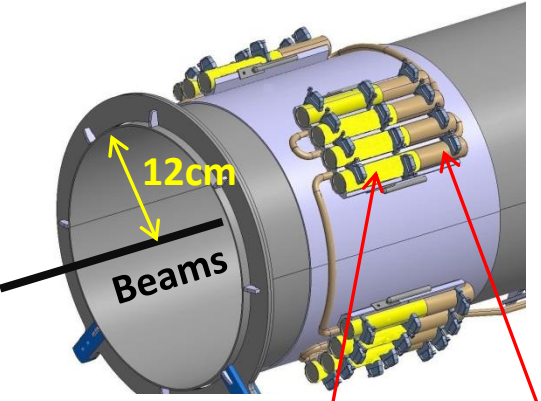
# The upgrade of the ATLAS luminosity detector LUCID for High Luminosity LHC






Vincent Hedberg
on behalf of the ATLAS collaboration

# The present LUCID-2 luminosity detector




Instantaneous Luminosity

$$\mathcal{L}_{\text{inst}} = \frac{R}{\sigma_{pp}} \sim \mu = \frac{\mu_{meas}}{\varepsilon_{hit}} = -\frac{\ln(1-P_{hit})}{\varepsilon_{hit}} = \frac{C}{\varepsilon_{charge}}$$

pp interaction rate

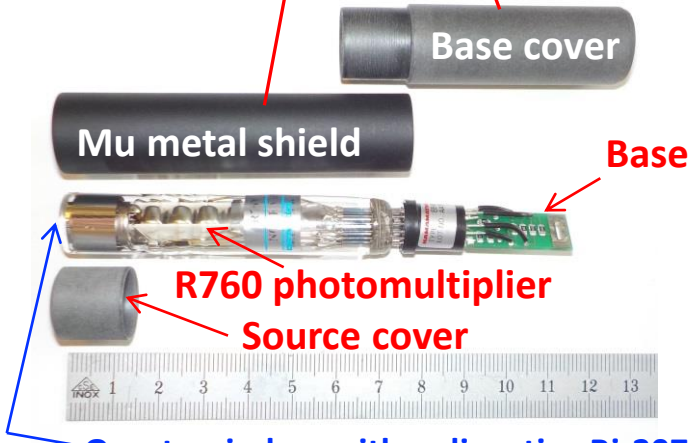
Number of pp collisions per 25 ns

Charge per colliding bunch

pp cross-section

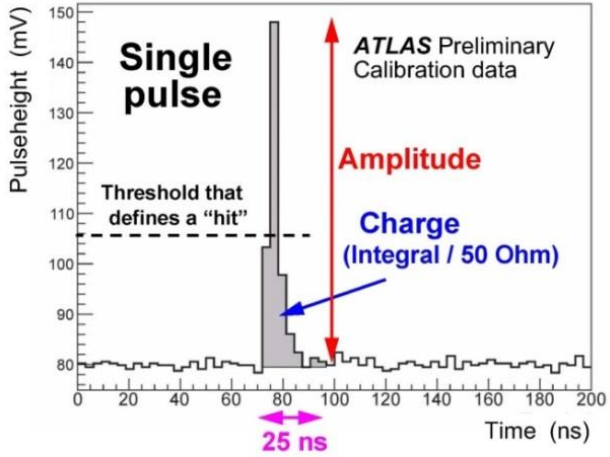
Acceptance (calibration constant)

Hit probability per colliding bunch




LUCID-2 is a Cherenkov detector that uses the quartz window in photomultipliers as the Cherenkov medium.

The number of signals (hits) above a threshold is counted as well as the integral of the pulses (charge) every 25ns during 2s timeperiods (online) and 10-60s timeperiods (offline).



# Challenges at the high luminosity LHC

| | | |
|---|---|---|
| **Hit saturation** | ➡ | **Use smaller photomultipliers;**<br>**Change location of the photomultipliers;**<br>**Increase threshold that defines a hit.** |
| **Dynamic range** | ➡ | **A μ-range of $10^{-3}$ to 200 might require several detectors.** |
| **Pile-up** | ➡ | **Correct the LUCID measurement using measurement by other detector.** |
| **PMT gain stability** | ➡ | **Frequent gain measurements and corrections using radioactive Bi-207.** |

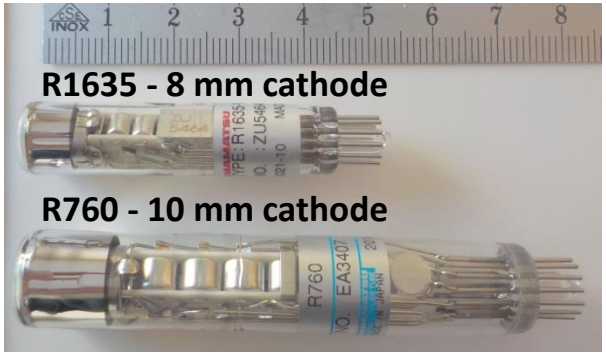
Average number of pp collisions — Hit probability

$$\mu = \frac{\mu_{meas}}{\varepsilon_{hit}} = -\frac{\ln(1 - P_{hit})}{\varepsilon_{hit}}$$

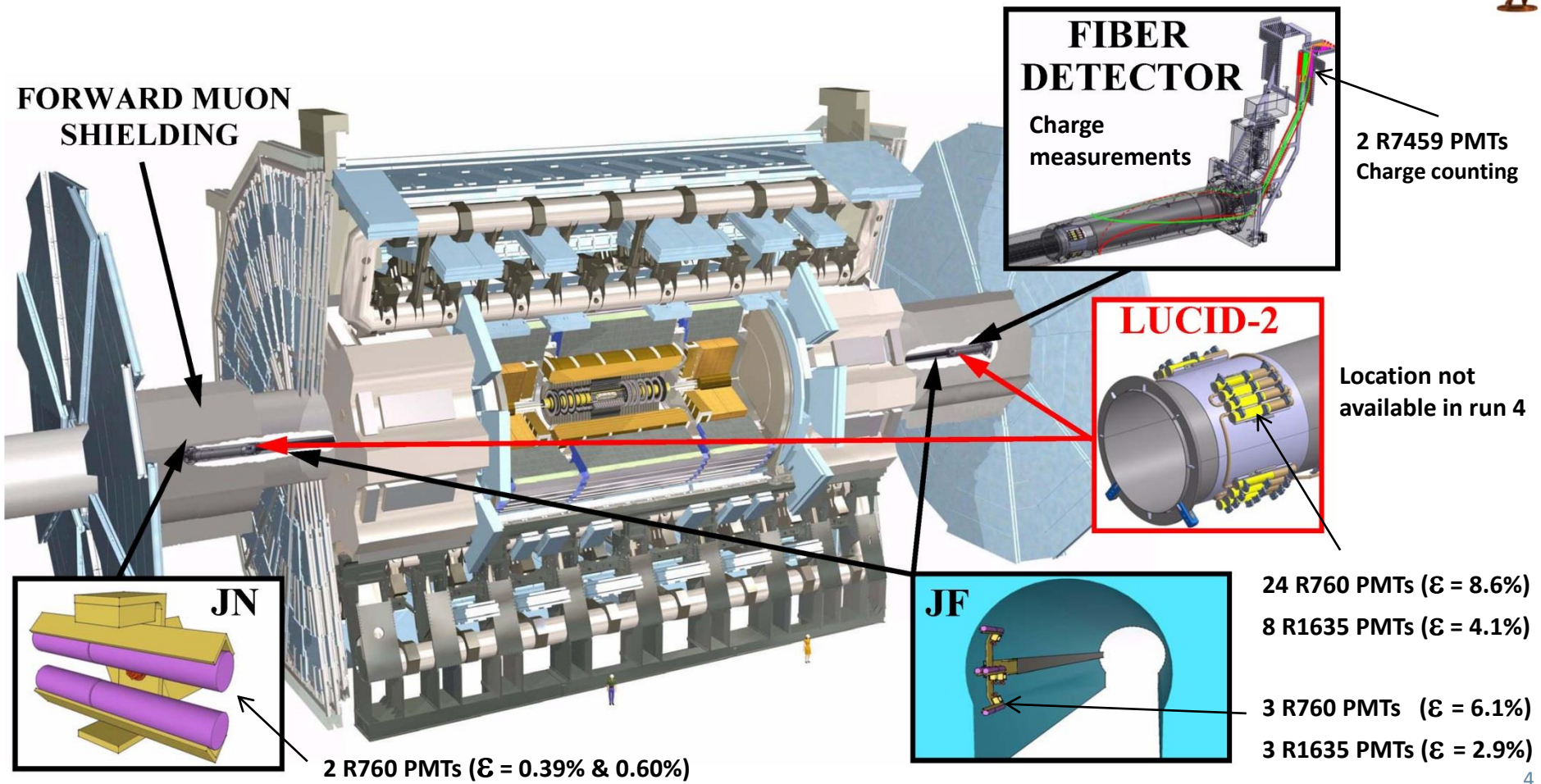
Acceptance (calibration constant)

**The R1635 PMT has been specially made for LUCID with a flat quartz window.**

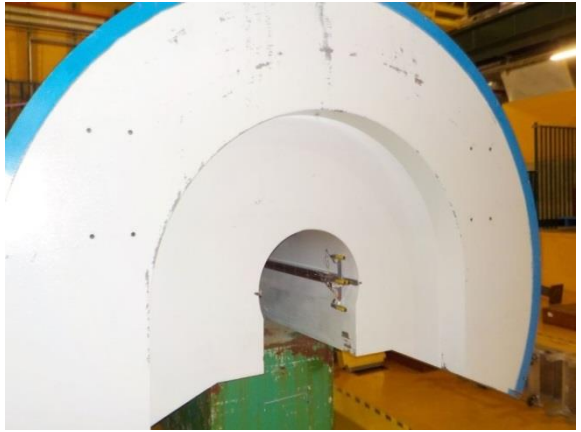
**The smaller cathode results in 52% smaller acceptance and less hit-saturation.**



# LUCID-3 prototype detectors



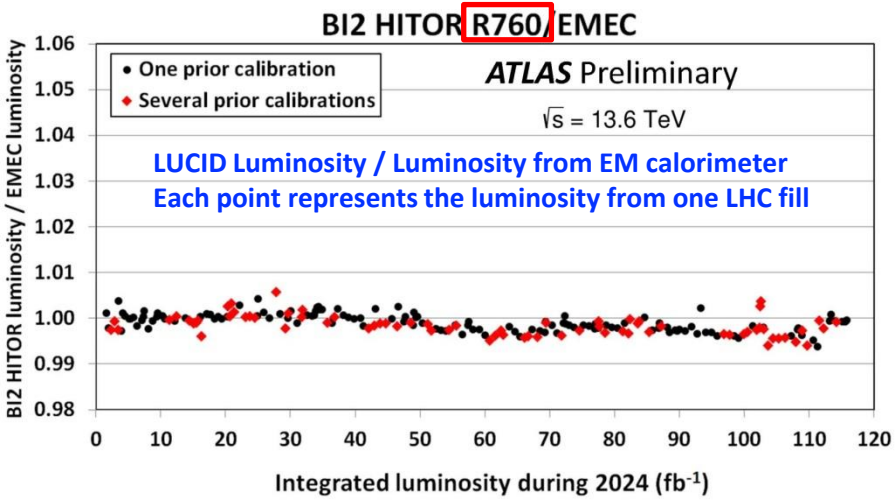
# The JF detector attached to the shielding

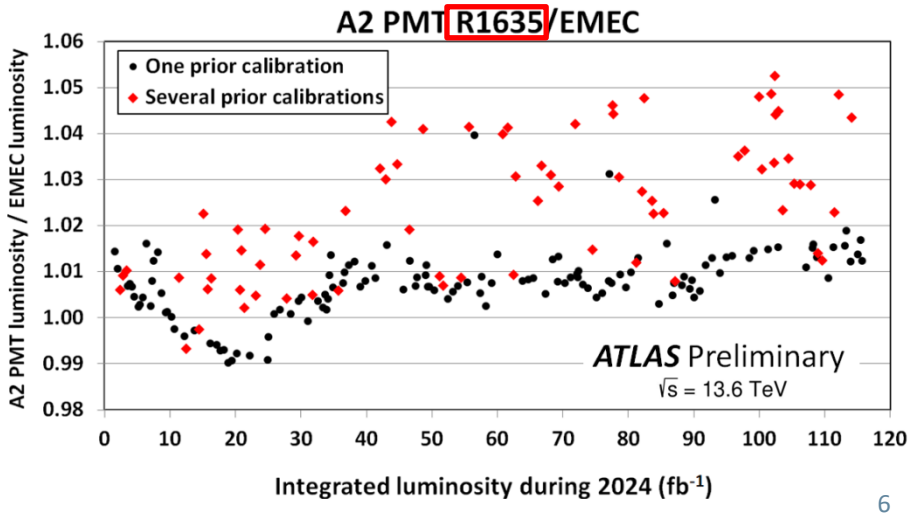


- Prototype detectors have been attached to the shielding on both sides of ATLAS.
- The new location (R = 12.6 -> 29.1 cm) reduced the measured efficiency by 29%.
- The two detectors have R760 PMTs with 10 mm diameter and R1635 PMTs with 8 mm cathodes.
- The detector sits on rails and can be pulled out of the shielding.

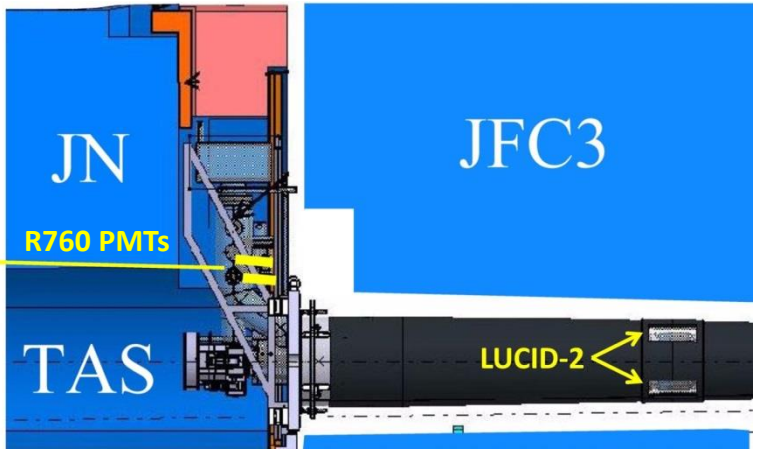
# Gain monitoring with Bi-207 sources

- The photomultiplier gain is monitored with Bi-207 calibrations in the interfill periods and the PMT high voltage is automatically adjusted.
- The stability of the luminosity measurements with the smaller R1635 PMTs in LUCID-2 shows a much worse result compared to the larger R760 PMTs due to problems with the Bi-207 calibrations.
- If one divides the physics runs into one group with exactly one prior Bi-207 calibration and another group with several prior calibrations then one can see a clear difference between the two groups.
- Studies in the lab has shown that the gain of the R1635 PMTs are not stable after a luminosity measurement.



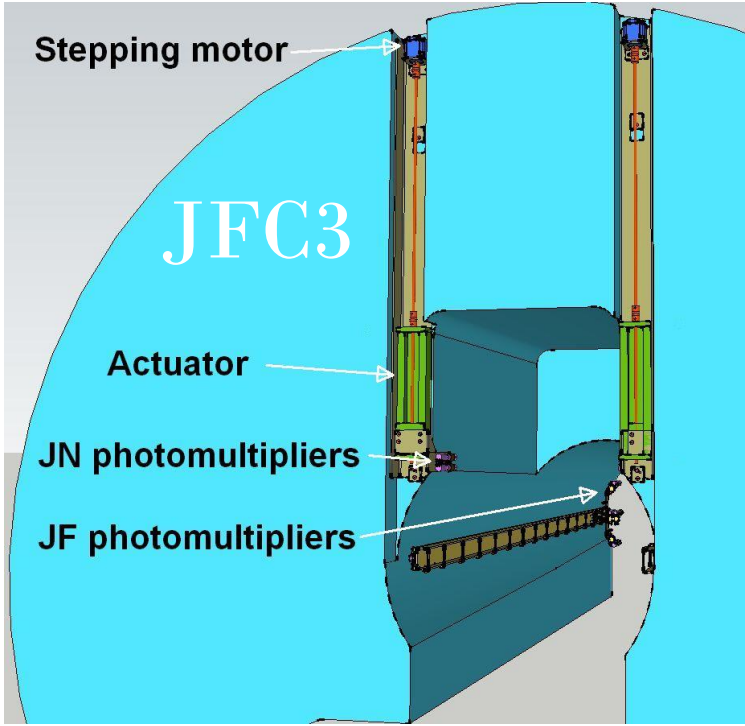



# The JN low-rate detector



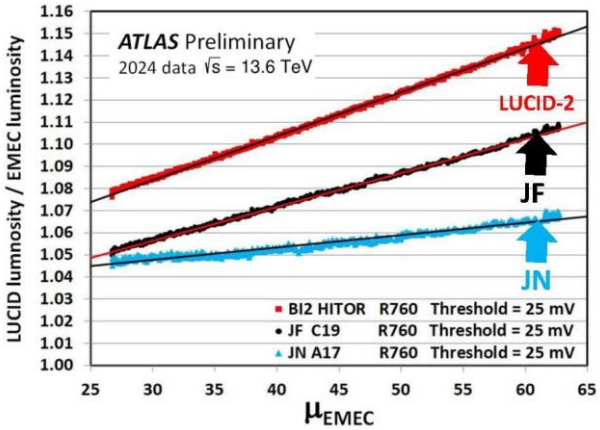

- The present JN detector consists of two R760 PMTs that sits behind and in the shadow of the JFC3 forward muon shielding.
- The two photomultipliers have an efficiency of only 0.4% and 0.6% compared to 8.6% for the LUCID-2 PMTs.
- For the HL-LHC it is suggested to build a detector with four R760 PMTs on each side that can be moved remotely by actuators and stepping motors.
- The detector would be attached to the back of the JFC3 forward shielding.

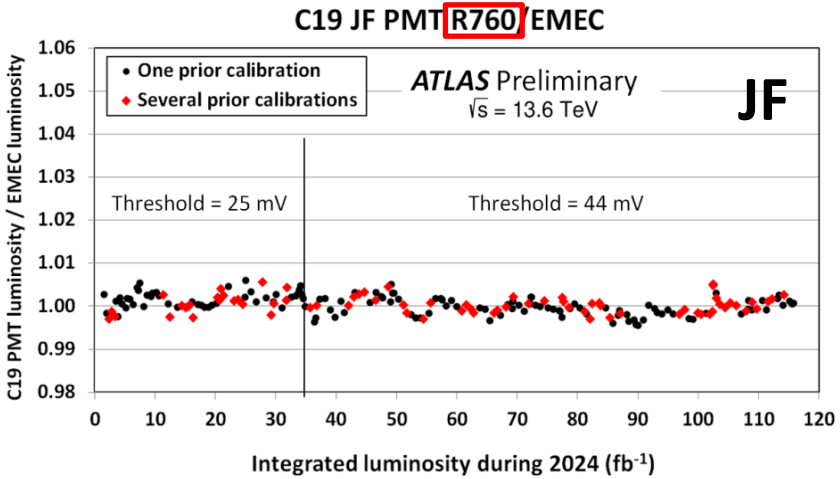
## Proposal for the HL-LHC

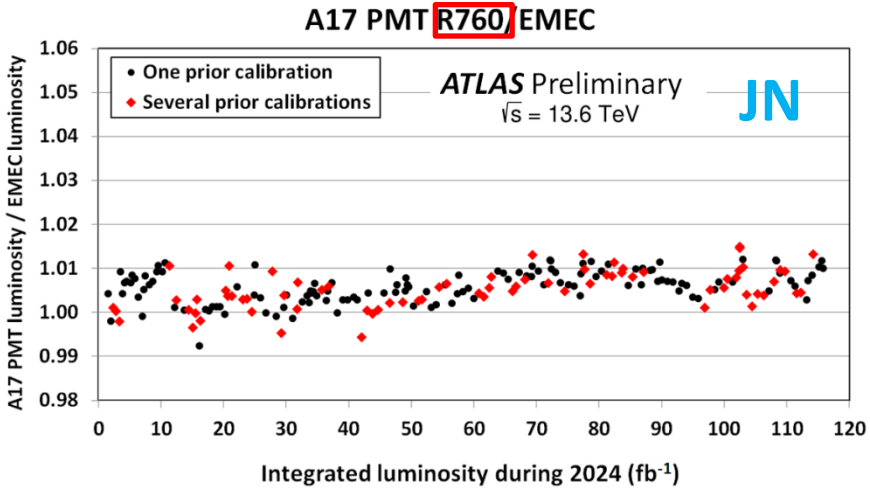


# Measurements with the JF and JN detectors

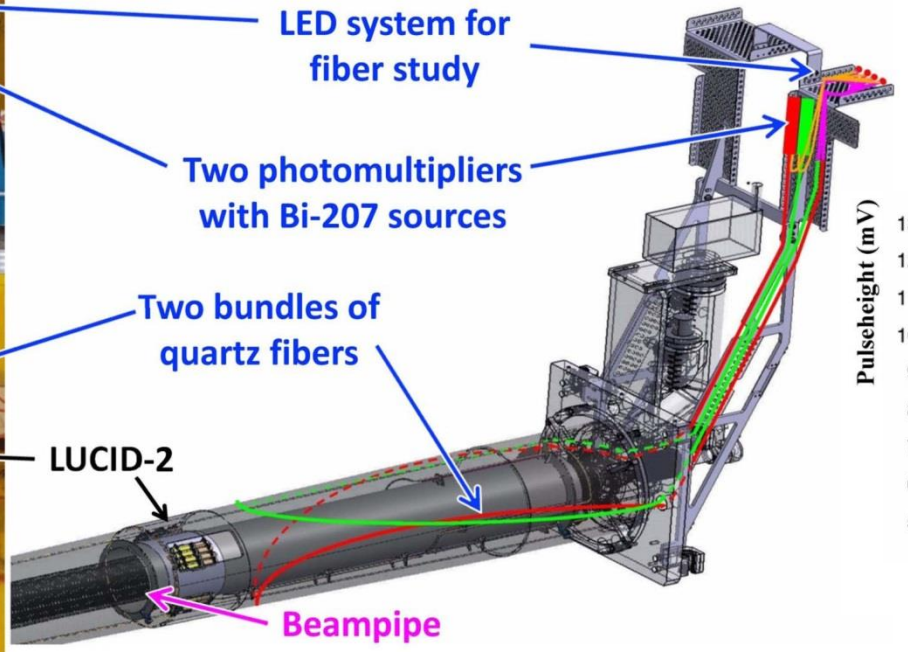
- The JF R760 PMTs attached to the inside of the shielding has a 29% lower efficiency than the same PMTs attached to the beampipe.
- An increase of the hit threshold from 25 to 44 mV decreases the efficiency by another 14%. The μ-dependence is linear also with a larger threshold but it has a larger slope.
- A study of a high-μ special run showed that the JF R760 PMT did not saturate at a μ of 150 with the higher threshold.
- The low efficiency of the JN detector results in smaller pile-up and smaller μ-dependence than LUCID-2 and the JF detector.



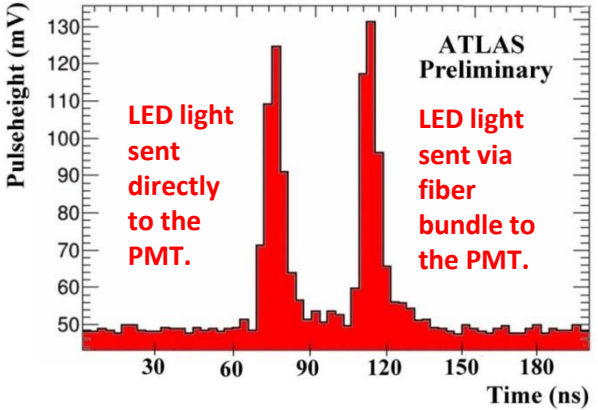



# The prototype fiber detector




FADC measurements of LED calibration signals

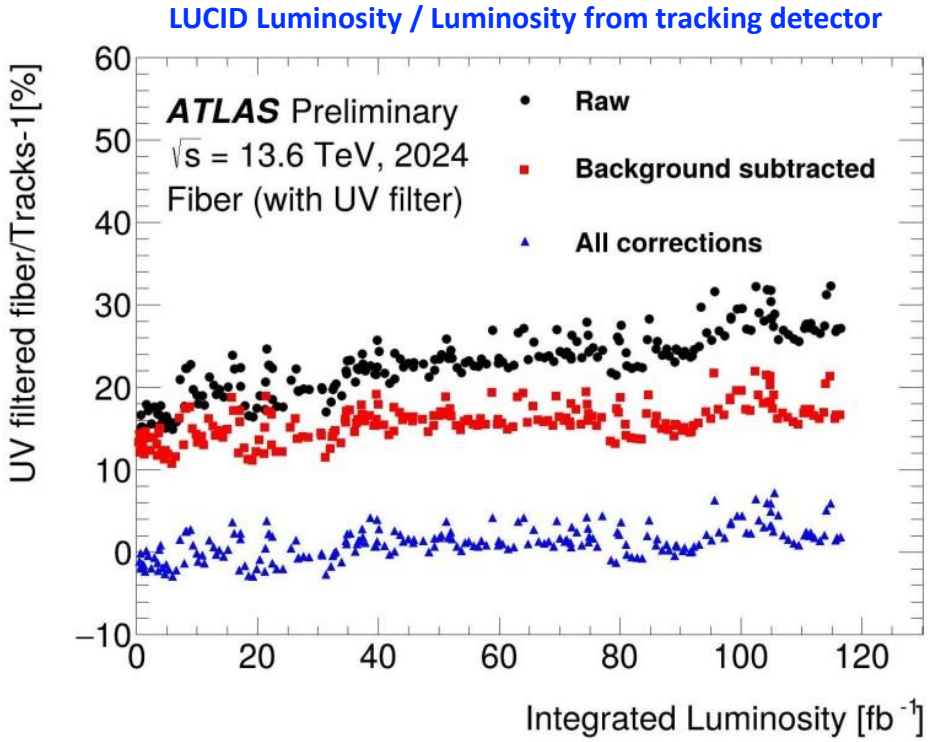



- Two bundles of radiation-hard quartz fibers provide the Cherenkov medium.
- The lower fiber bundle has a UV filter.
- R7459 photomultipliers (25 mm diameter) are placed in a shielded location and see 200 times less radiation than the photomultipliers in the PMT detector.

# Measurements with the fiber detector

- The measurement with a UV filter shows a much better long-term stability than those without a UV filter.
- The LED monitoring system is therefore not needed.
- Subtraction of background and bunch-to-bunch leakage has provided a measurement without pile-up and the need of a correction by another detector.
- The fiber detector is using charge measurements and not hit measurements and this makes it more sensitive to gain variations that creates fill-to-fill variations.

## Charge measurement with UV filter



# SUMMARY

- **JF R760 detector:**
  No hit saturation up to a $\mu$ of 150 but large pile-up corrections needed.

- **JF R1635 detector:**
  Stability in interfill periods perhaps not good enough for Bi-207 calibrations.

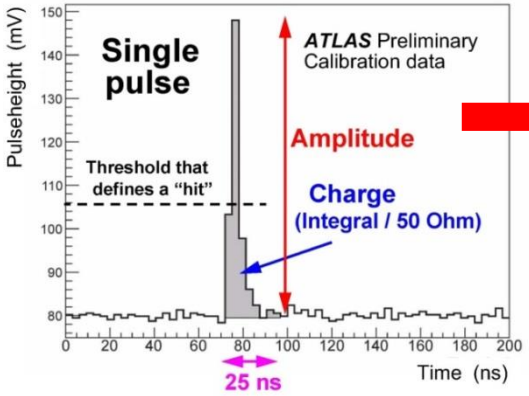
- **JN R760 detector:**
  No hit saturation up to a $\mu$ of 200 and only small pile-up corrections needed.
  The present acceptance is too low for beam-separation (VDM) calibrations.

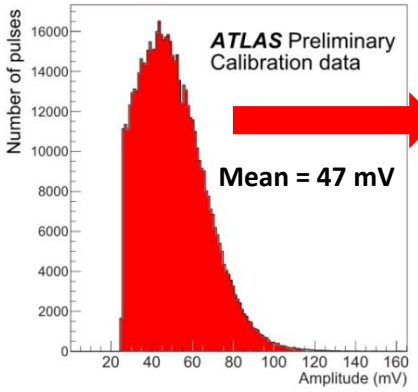
- **FIBER detector:**
  UV filter improves long-term stability.
  Measurements without pile-up can be achieved.
  Charge measurements results in larger gain variations and larger fill-to-fill variations.

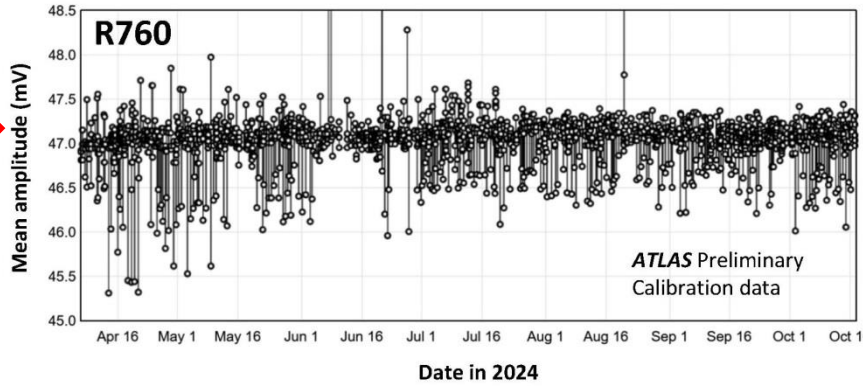
# BACK-UP

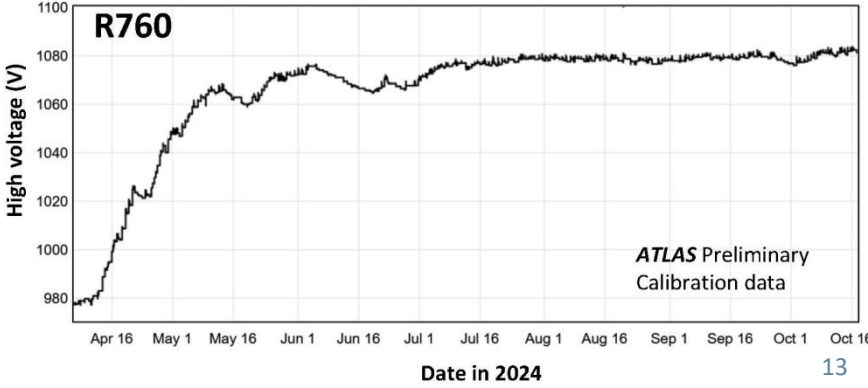
# Gain monitoring of R760 PMTs with Bi-207 sources

**Frequent gain monitoring calibrations using the Bi-207 sources are crucials to maintaining stability in the luminosity measurements. The high voltage is automatically changed if a calibration shows a change of the mean amplitude.**

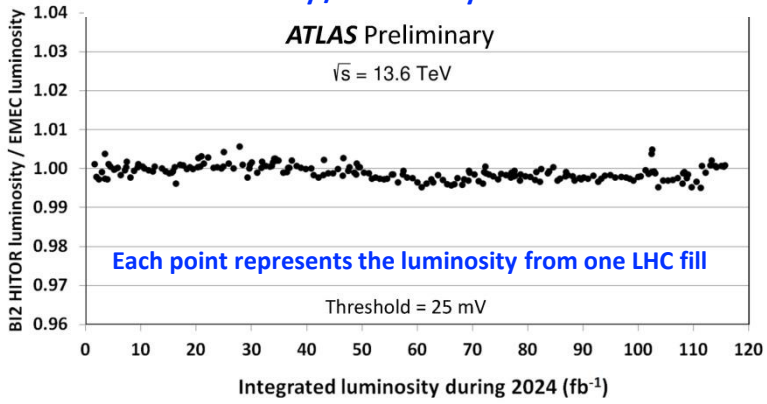


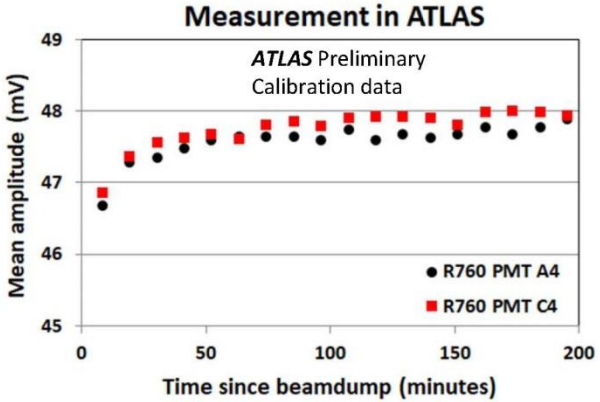
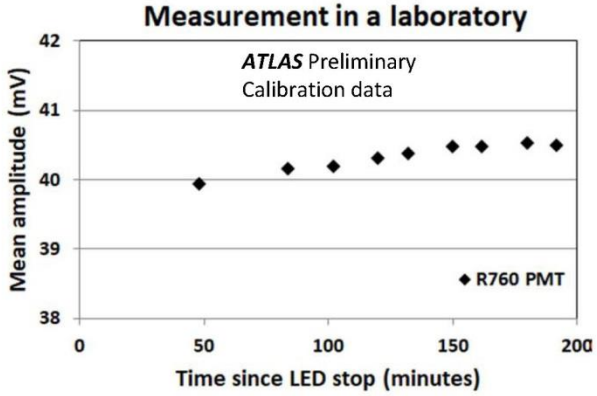
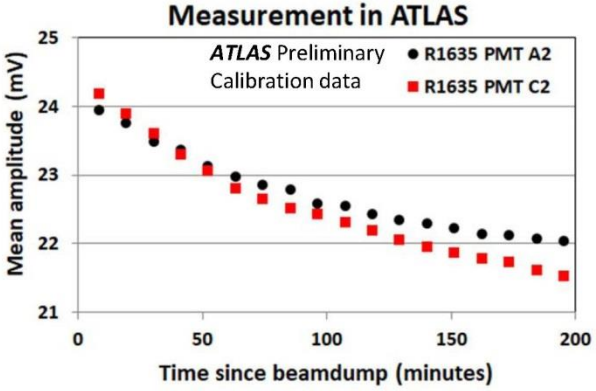
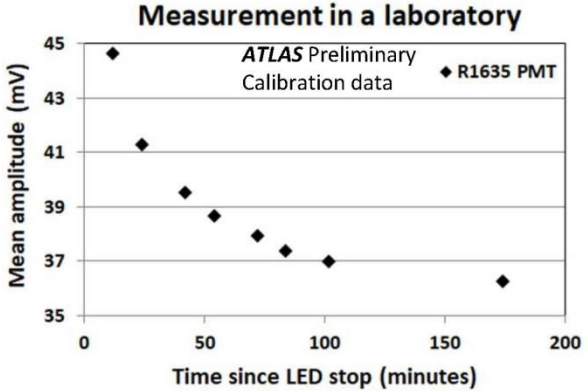




**LUCID Luminosity / Luminosity from EM calorimeter**



# Repeated Bi calibrations after using a PMT

- Repeated Bi calibrations have been made in ATLAS during interfill periods and in the lab after exposure to LED signals that imitate physics running.
- The time dependence of the measured mean amplitude is very different both for R760 and R1635 PMTs. Both in ATLAS and in the lab.