Upgraded LUCID and Zero Degree Calorimeter Detectors for ATLAS at the High Luminosity LHC

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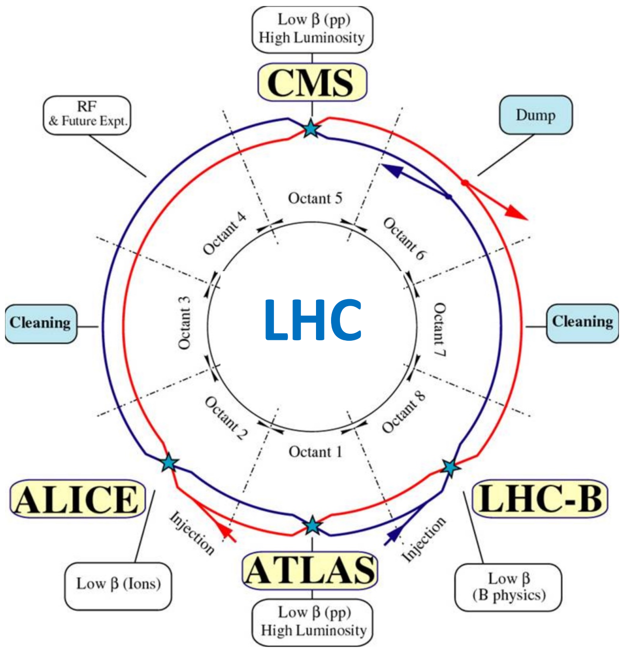
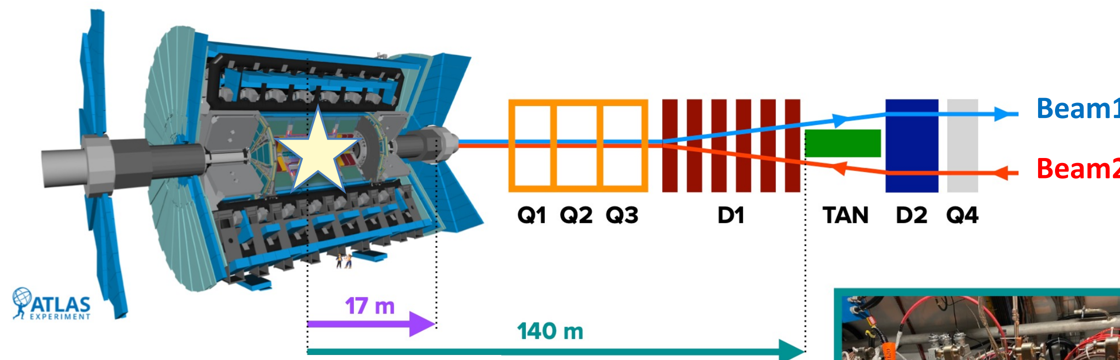
On behalf of the ATLAS collaboration

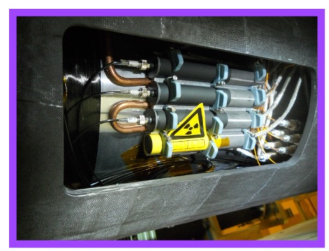
Istituto Nazionale di Fisica Nucleare

LUCID and ZDC at LHC

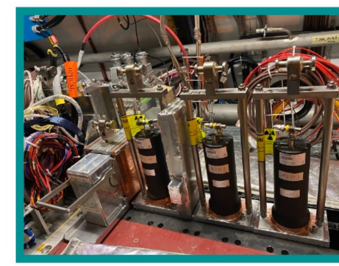
LUCID and ZDC are two ATLAS sub-systems with completely different goals and technologies







LUCID-2



ZDC

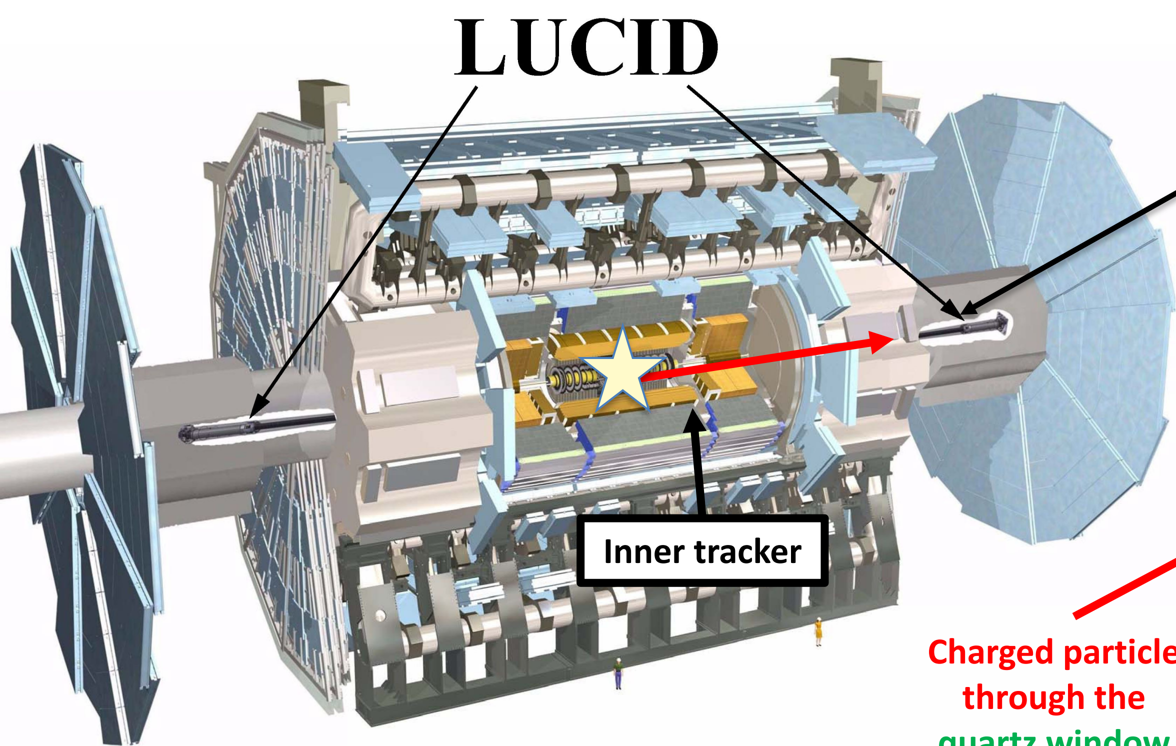
LUCID goal

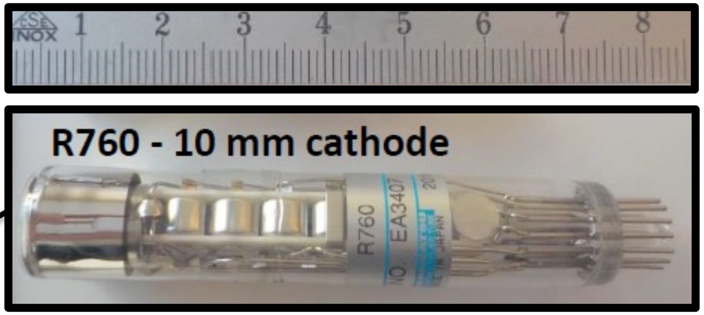
Measure luminosity in the ATLAS interaction point

ZDC goal

Measure forward spectator neutrons in heavy-ion collisions

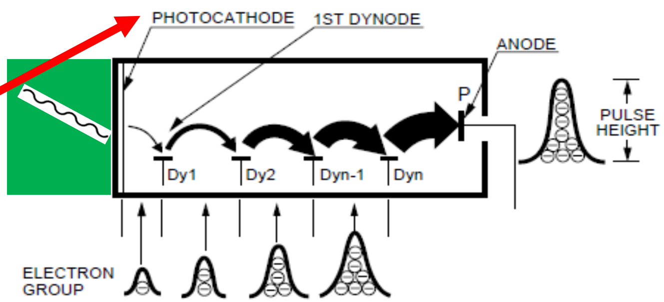
The LUCID-2 detector in ALTAS





The 1.2 mm photomultiplier entrance quartz window acts as Cherenkov radiator

Charged particle through the quartz window



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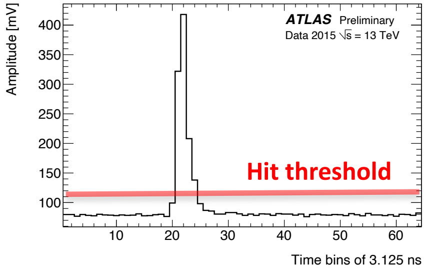
Luminosity determination in *pp* collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC

ATLAS Collaboration*

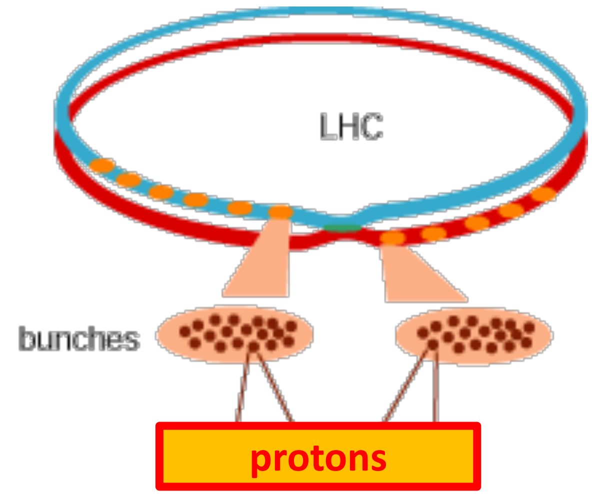
CERN, 1211 Geneva 23, Switzerland

Accuracy in Run-2: 0.83%



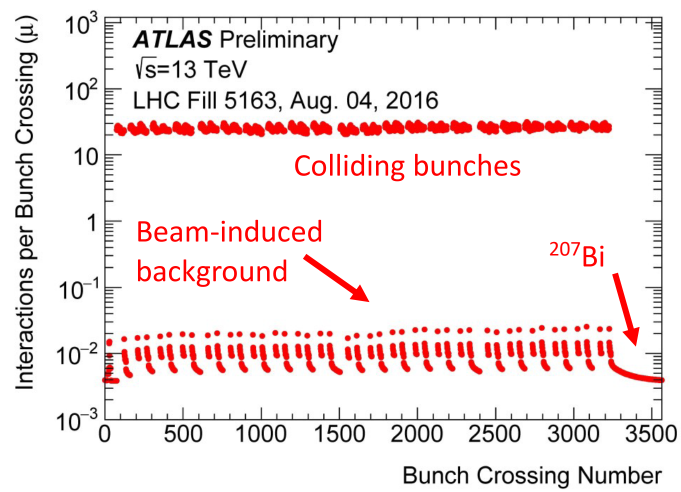
Luminosity measurement in pp colliders

- The LHC collide protons bunches every 25 ns.
- Luminosity is measured by counting the average number of pp collisions per bunch crossing (μ).
- Typical value at LHC: μ **= 60**.

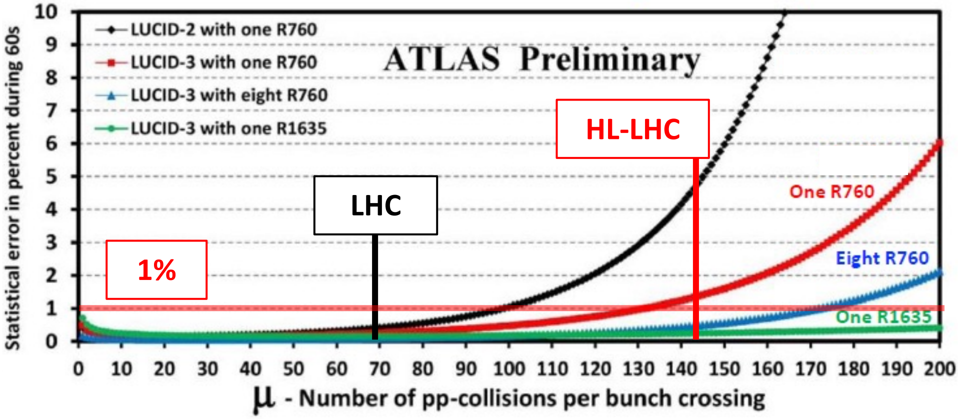


- **Hit-counting method (LUCID)**: count the fraction of bunch crossings with hits in the photomultipliers (PMTs).
- **Tracking algorithm (Inner Tracker)**: complementary method counting the number of reconstructed tracks.

- PMT gain is kept constant by **monitoring the response to a radioactive source** (^{207}Bi) deposited on the PMT.
- The intensity of the source is such that ^{207}Bi signals do not interfere with the luminosity measurement.



Going from LHC to HL-LHC



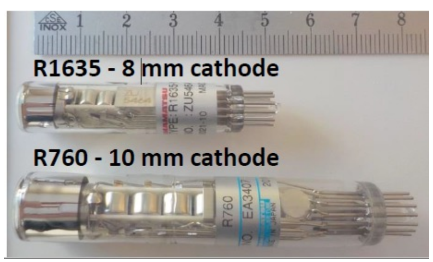
LUCID goal

Measure luminosity with the same accuracy (**1%**) despite the larger pileup (**μ = 60 → 140**) and the larger integrated luminosity (**300 → 4000 fb^{-1}**)

LUCID-2 will not work at the HL-LHC since it will have hits in every bunch crossing (**hit-saturation**) and potentially larger radiation damage effects.

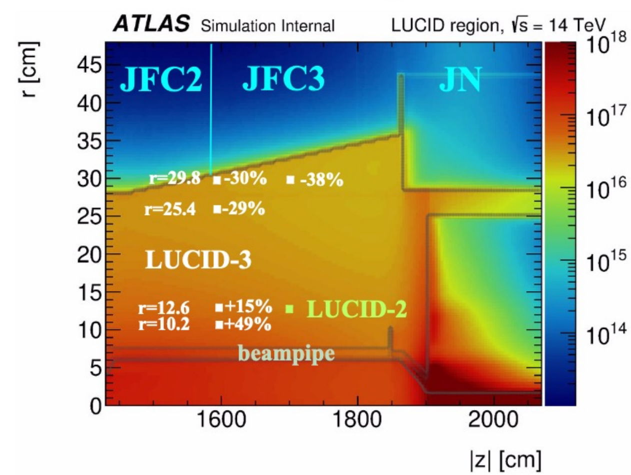
LUCID-3 strategy for HL-LHC

Decrease acceptance and radiation damages by installing smaller PMTs (-30% acceptance) at a larger radial distance from the beampipe (-30% particle flux)



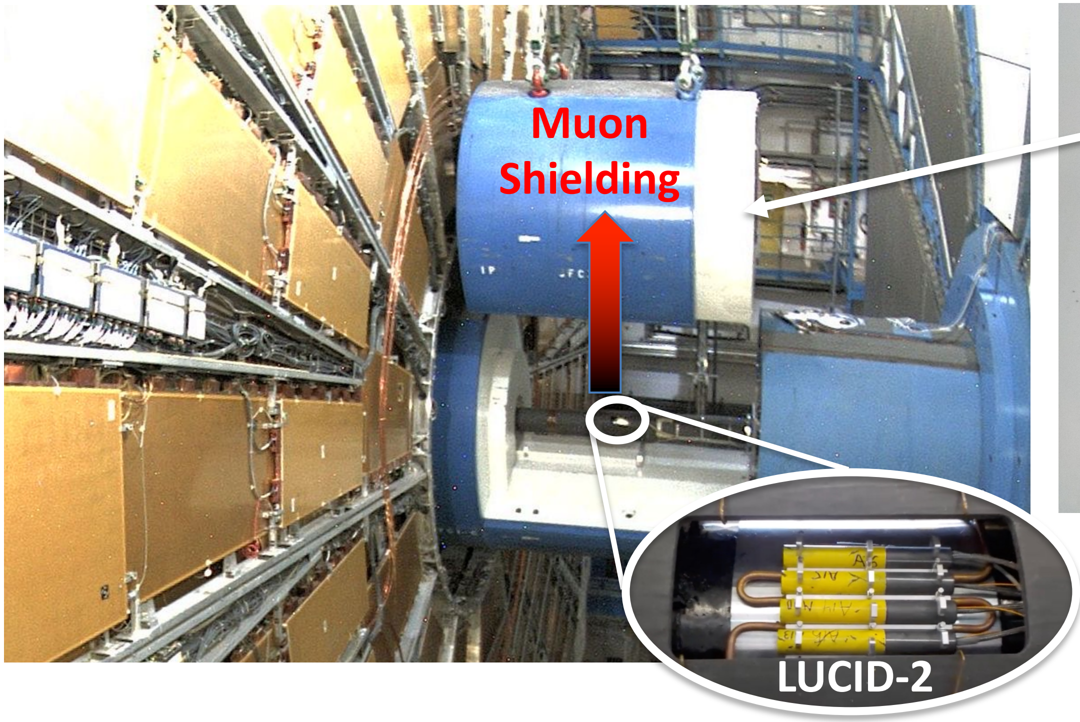
The **Hamamatsu R1635 PMT** has been produced with a **flat quartz window** (radiation-hard).

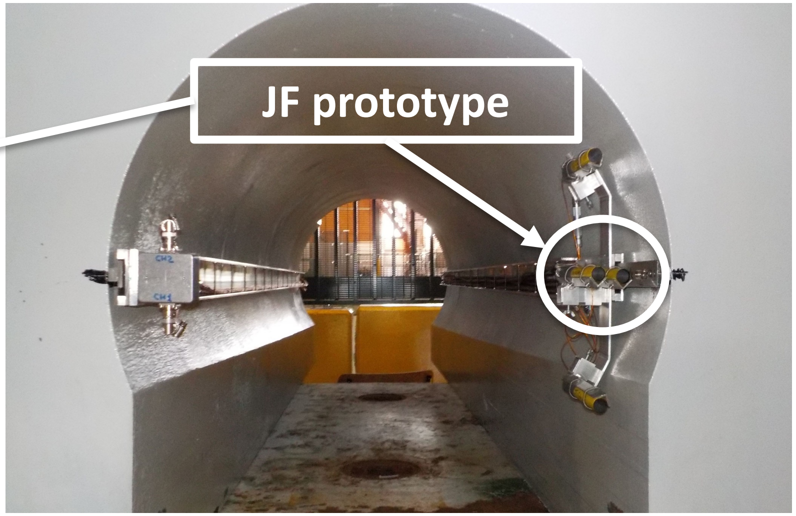
Electron flux per cm^2



CERN-LHCC-2021-016 / LHCC-P-018
16/10/2021

The LUCID-3 prototype in the Muon Shielding

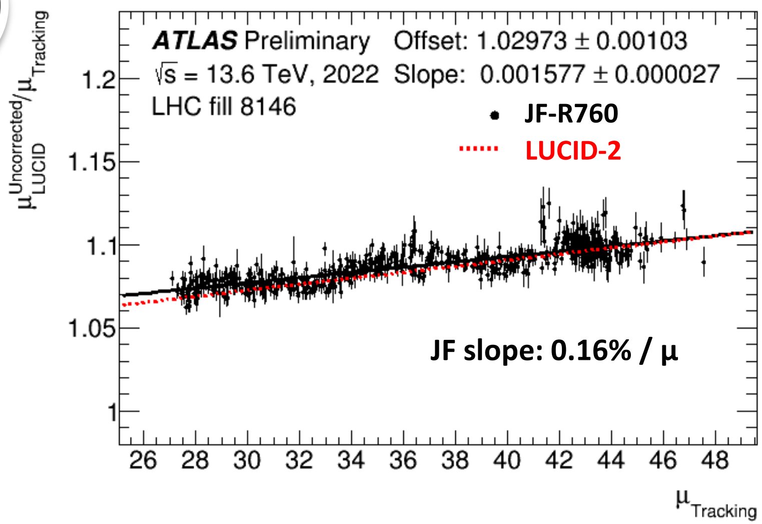




LUCID-3 JF prototypes have been attached to the Muon Shielding: easy to replace.

Run-3 experience: despite the smaller acceptance, same performance*.

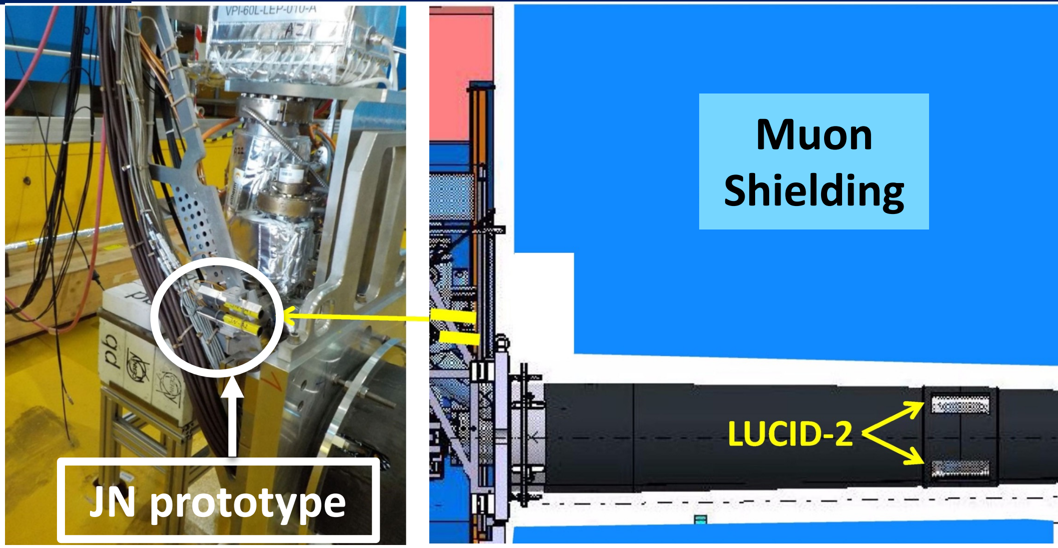
*Non-linearities are corrected with Track-Counting algorithms.

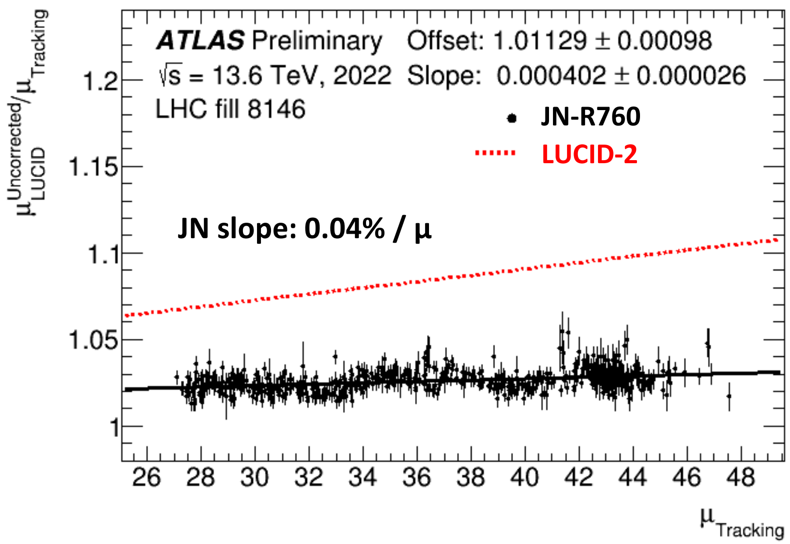


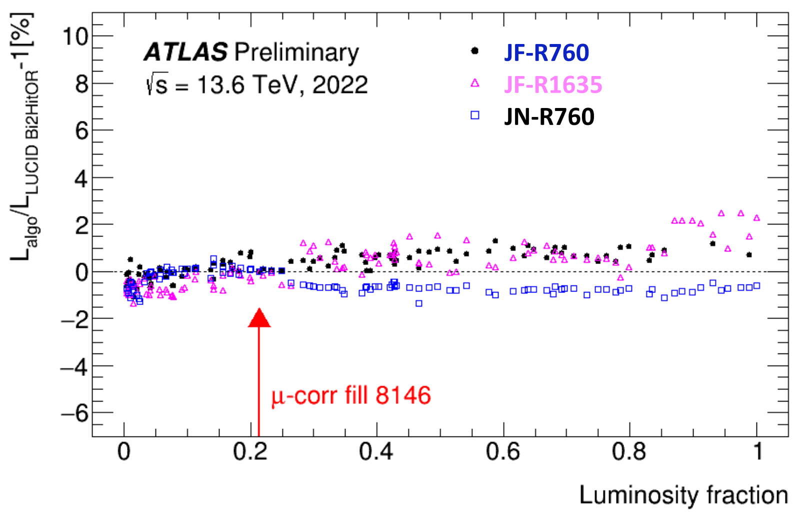
The LUCID-3 prototype behind the Muon Shielding

LUCID-3 JN prototypes have been installed in the shadow of the Muon Shielding.

Run-3 experience: significantly smaller non-linearities due to the smaller acceptance.



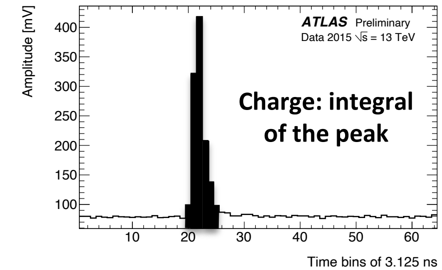




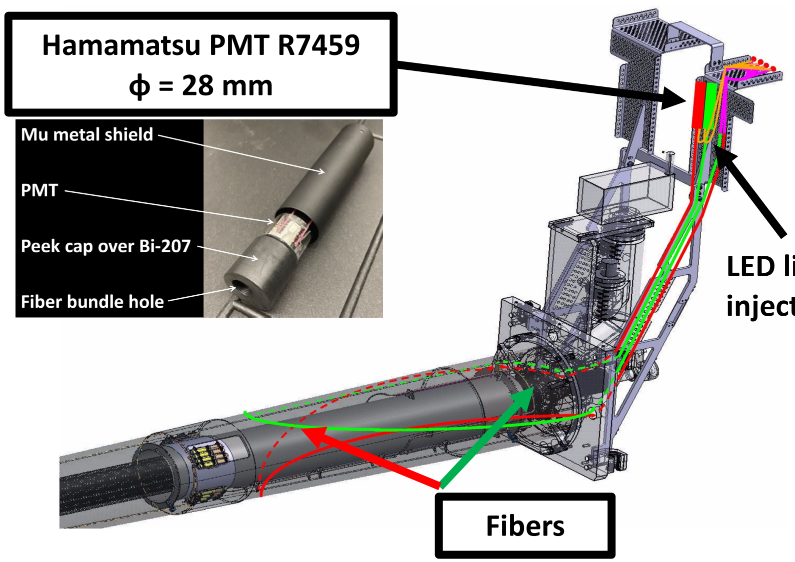
Good long-term stability of LUCID-3 prototypes
(R1635 readout will be modified to further improve its long-term stability)

The LUCID-3 fiber prototype

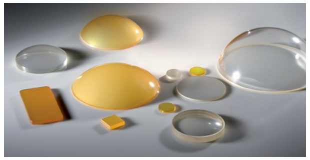
Two bundles of **radiation hard quartz fibers** around the beampipe, acting as Cherenkov radiator (**charge counting algoritm**)



- **PMTs are located in low radiation area** (^{207}Bi gain monitoring system).
- One bundle equipped with a **CLEARTRAN UV filter** (ϕ = 12 mm, d = 5 mm) to reduce the impact of radiation damage effects (mostly in the UV range).

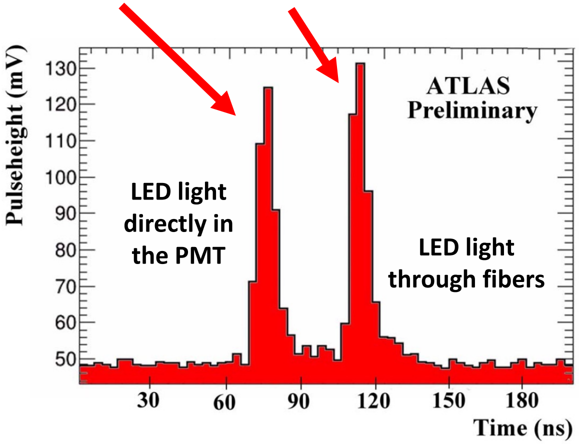


Ceramoptec OPTRAN® UV200/240A, 400um jacket, NA=0.22
F-doped fused silica, acrylate jacket



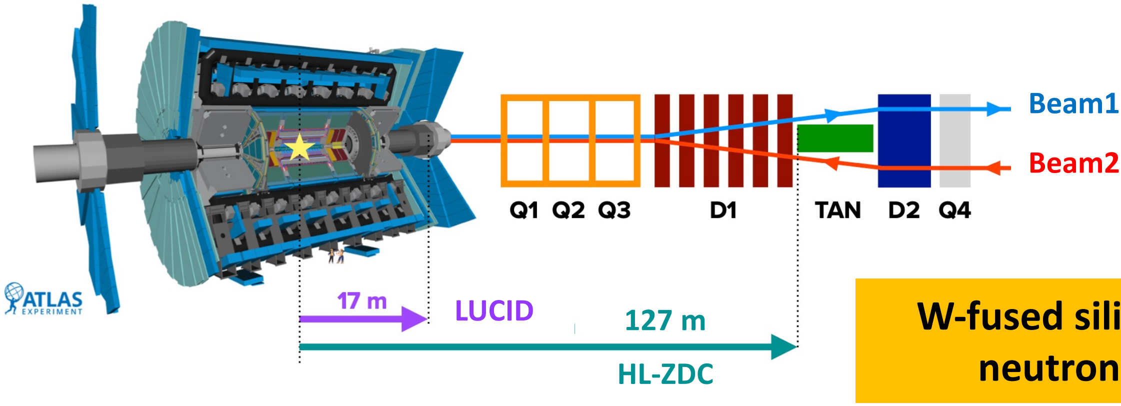
CLEARTRAN UV filter

Fiber degradation is monitored through the ratio between **prompt** and **delayed** LED signals



Ongoing Run-3 data-analysis

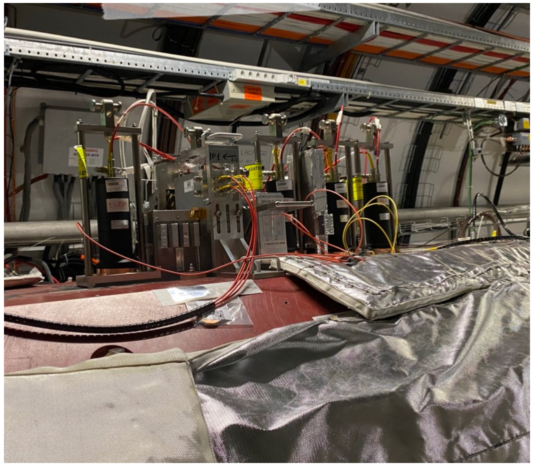
The ZDC upgrade for HL-LHC



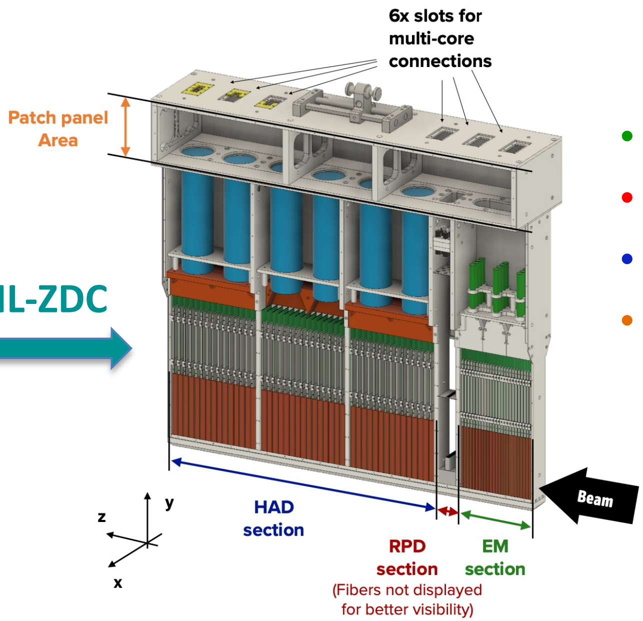
Same detection principle of ZDC

W-fused silica sampling calorimeter for forward neutron detection in heavy ion collisions

ZDC detector in Run-3

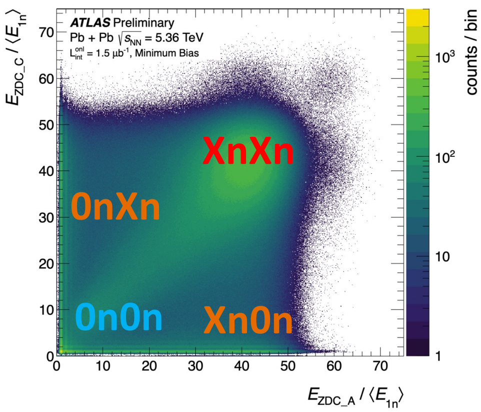


HL-ZDC



- Electromagnetic section (EM)
- Reaction Plane detector (RPD)
- Hadronic section (HAD)
- Detector patch panel design minimizes dose to workers during installation.

Physics with ZDC



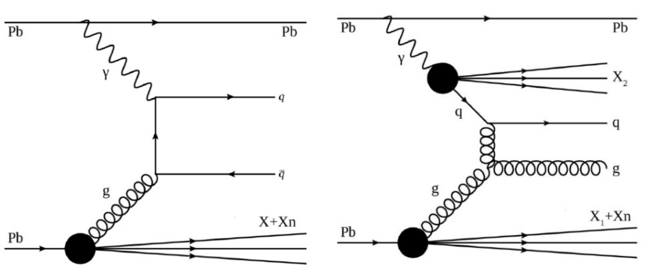
Measure the number of forward neutrons in heavy ion collisions to distinguish between different classes of physics processes.

- "0n0n": no neutrons on either side ($\gamma\gamma$ **processes**).
- **"0nXn":** neutrons only on one side (**photo-nuclear processes**).
- **"XnXn":** neutrons on both sides (**hadronic processes**).

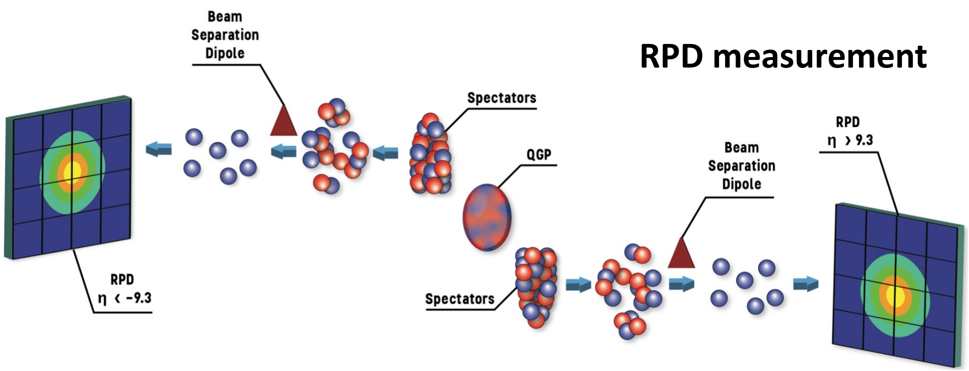
ZDC has a key role for **trigger** and **offline selection** of **Ultra Peripheral Pb-Pb Collisions** (UPC).

RPD estimates the **reaction plane angle** by measuring correlated deflections of spectator neutrons (2D mapping of the shower after the electromagnetic module).

Photo-nuclear processes ("0nXn" topology)



RPD measurement

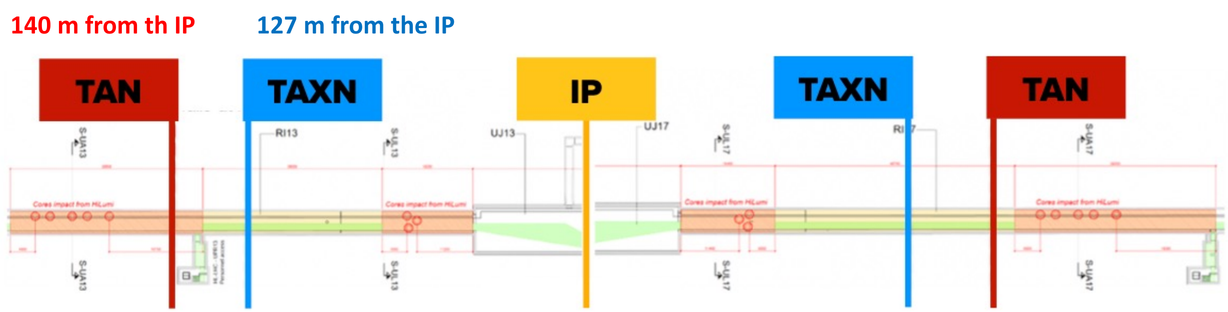


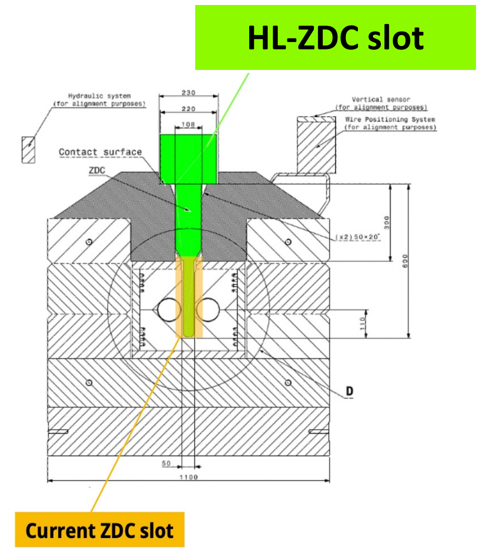
The HL-ZDC project

Joint project between ATLAS and CMS (proposal submitted in July 2022).

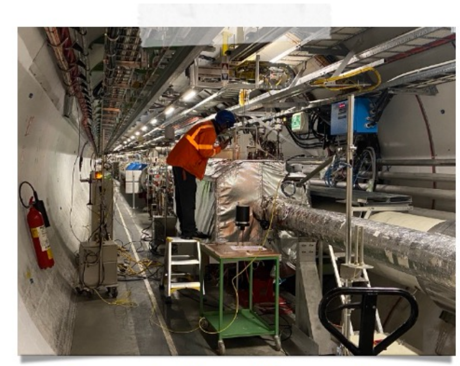
The Target Absorber for Neutral (**TAN**) hosting the ZDC has been redesigned for HL-LHC (**TAXN**). Common design ATLAS-CMS.

PHYSICAL REVIEW ACCELERATORS AND BEAMS **25,** 053001 (2022)





- New detector design due to **narrower slot** in the TAXN (**10 cm → 5 cm**).
- **Higher radiation levels** compared to Run-3 (**4.5 Mgy** full physics program).
- **Radiation hard** and **stable detector** with a good energy resolution.
- **Limit exposure of workers** (easy cable connection and **remote handling**).

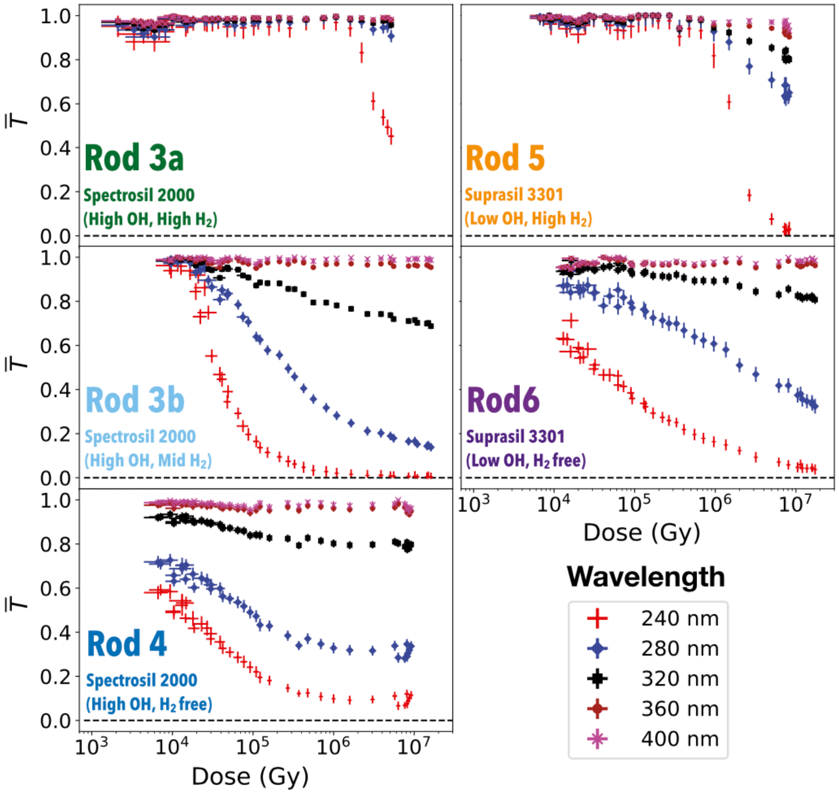


Remote handling setup

Radiation hardness of the ZDC rods

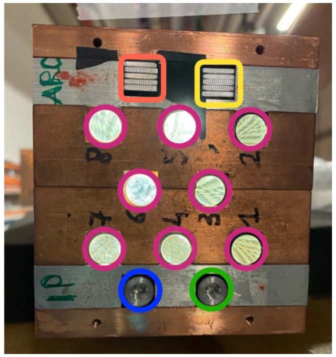
Results of the Run-2 irradiation campaign done in collaboration with the BRAN luminosity detector of LHC

Transmittance Vs Dose* in the UV region



*The dose delivered to the rods was estimated using Monte Carlo simulations performed by the CERN FLUKA team.

https://doi.org/10.1016/j.nima.2023.168523



Rods inserted in the BRAN detector

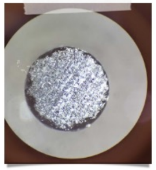
- **Rod 3a: No relevant losses** in the irradiation range expected on the ZDC in Run 3 (**1.4 MGy**).
- Run-3 irradiation campaign will extend the irradiation range of 1 order of magnitude.

Run-3 experience

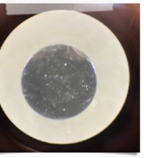
ZDC operation in Run-3 will provide relevant input for the HL-ZDC upgrade

- Performance of the new **fused silica core** rods (**Spectrosil 2000, High OH, High H_2**).
- Effect of the **improved polishing** on the surface facing the PMT (x5 transmission).
- Performance of the **ZDC-LUCROD readout board** (adapted from the LUCID-LUCROD): waveform sampling at 320 MHz and digital trigger based on lookup tables (3 bits).
- Performance of the **air core cables** transmitting signals over 220 m.

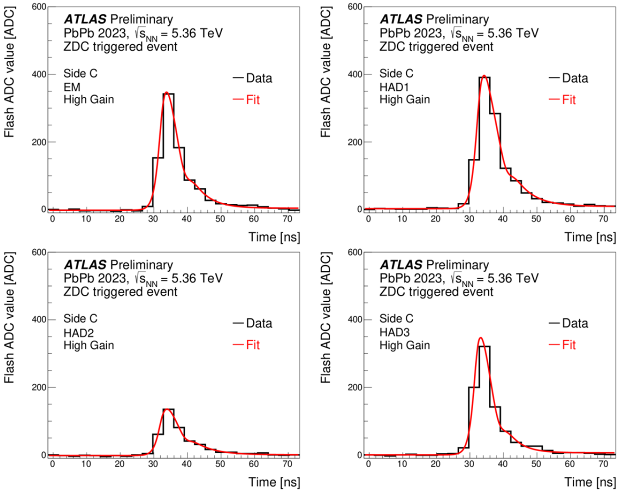
Unpolished Rod



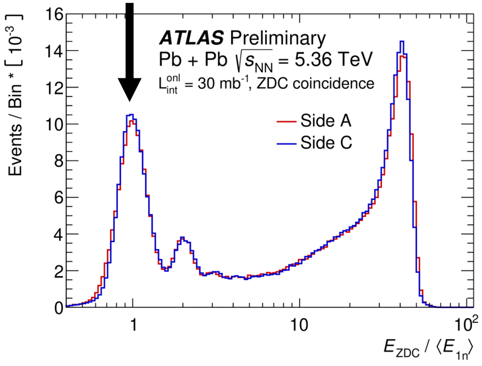
Polished Rod



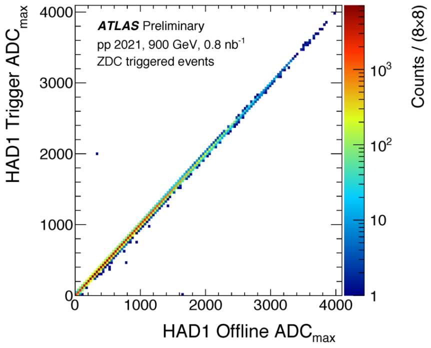
Examples of ZDC digitized pulses



1n peak



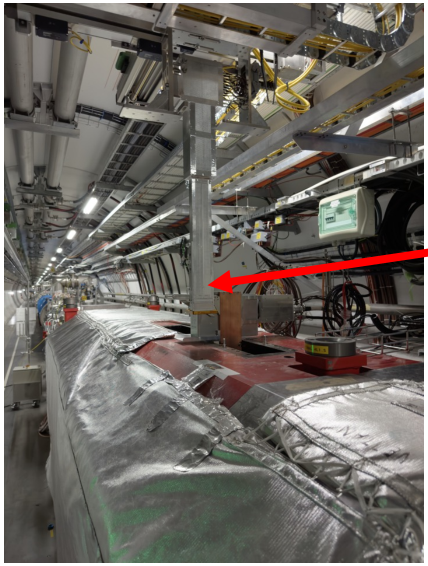
Digital Trigger performance



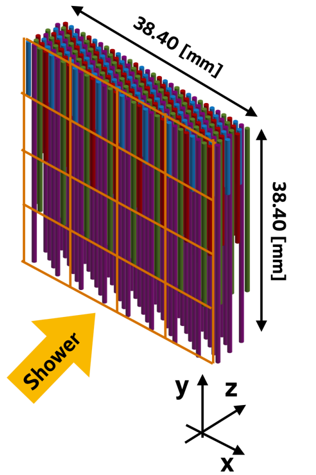
A new LUCROD board is being designed for HL-LHC (in collaboration between LUCID and ZDC groups).

Run-3 experience with the RPD

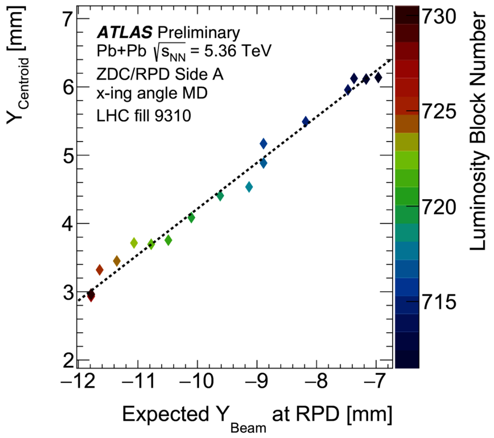
RPD being inserted in Run-3



Pan Flute design
4x4 tile segmentation



Correlation between the beam position measured with LHC beam position monitors and RPD during LHC Machine Development



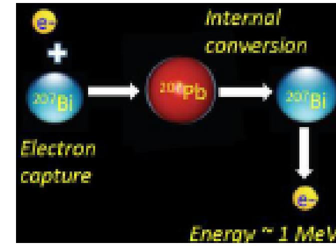
- Signal from 8 layers of **staggered fibers of 4 different lengths** collected by 16 PMTs.
- **Rad-hard fused silica fibers** (polymicro, ϕ = 710 µm) as Cherenkov radiator and readout fibers.

The RPD was successfully operated in ATLAS during the 2023 heavy ion run.
Ongoing development of Machine Learning algorithms to reconstruct the reaction plane angle.

THANKS
for your attention

Backup slides

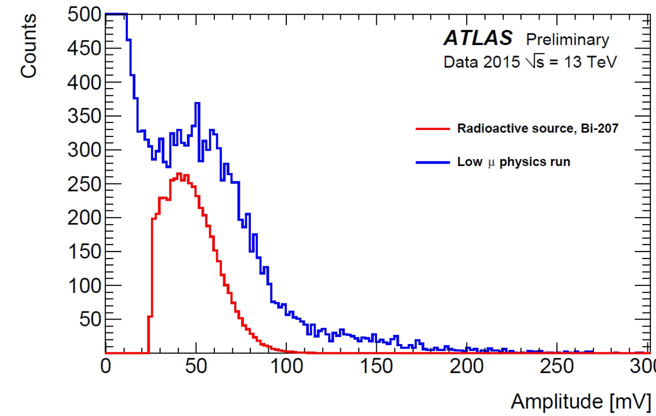
The LUCID ^{207}Bi monitoring system

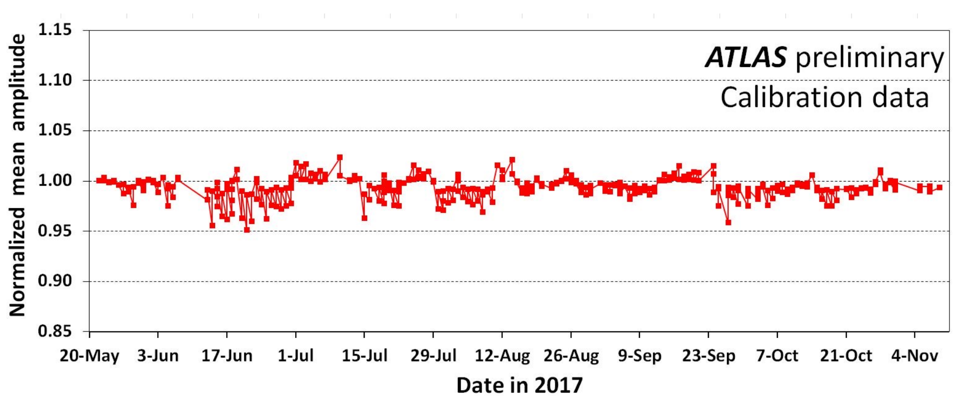


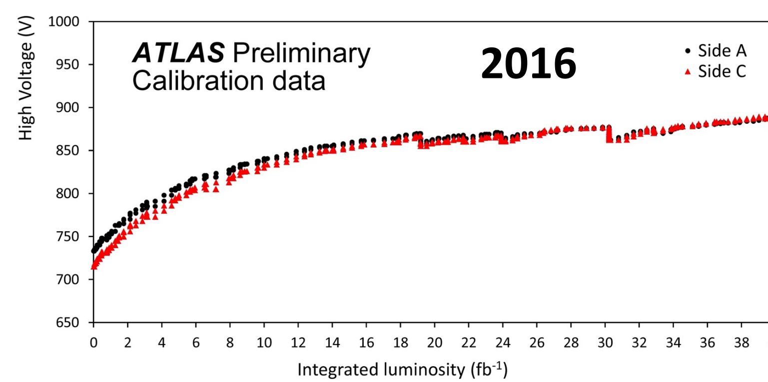
- During high-luminosity operation (large number of colliding bunches at $\mu = 60$), the PMT gain decreases due to a combination of radiation damages and large anodic currents.

- At each LHC interfill, phtomultipliers are calibrated and the **high-voltage is adjusted to compensate for gain losses**.

- Calibration signals are provided by a ^{207}Bi source deposited on the PMT window (providing internal conversion electrons).

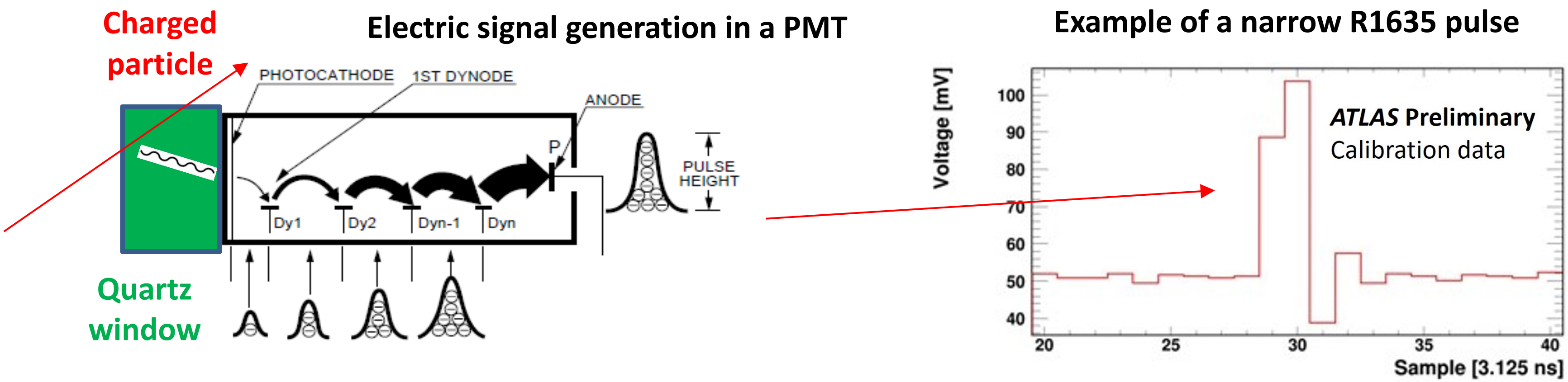






LUCID-3: the Hamamatsu R1635 PMT signal

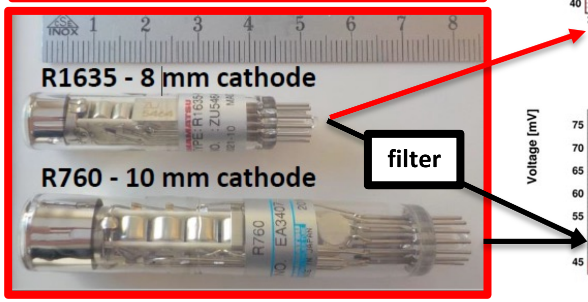
- The narrow pulses produced by **R1635** PMTs are not optimal in terms of long-term stability of the **luminosity measurement with hit-counting**.
- The **HV adjustments** required to keep the **gain stable** during a year produce a **variation of the electron transit-time** in the dynode chain affecting the timing of the signal.

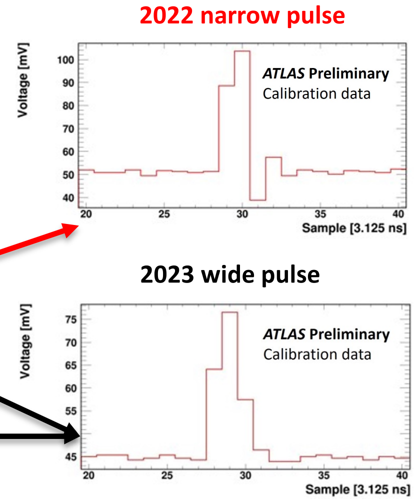


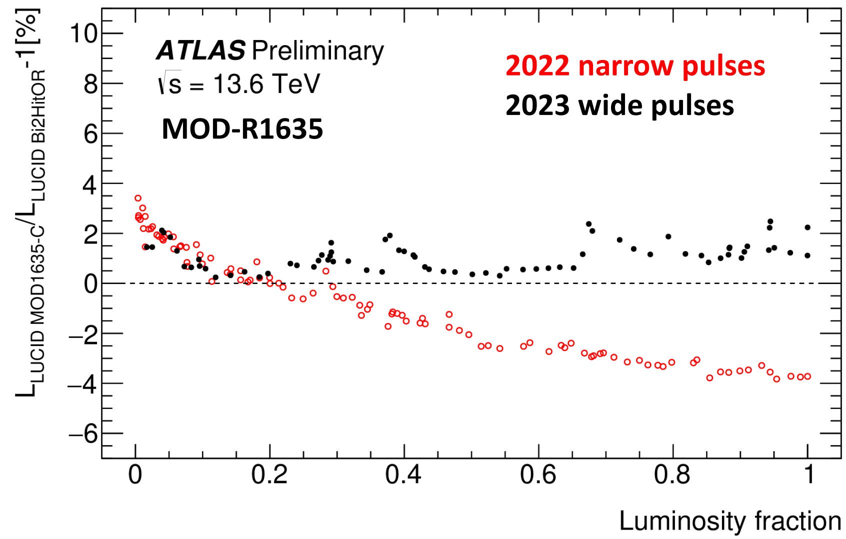
Timing shifts smaller than the signal sampling (3.125 ns) can introduce systematic effects in the signal amplitude determination, affecting the luminosity measurement with hit-counting.

LUCID-3: improved long-term stability

R1635 - fewer dynodes, smaller anodic current, narrower pulses.



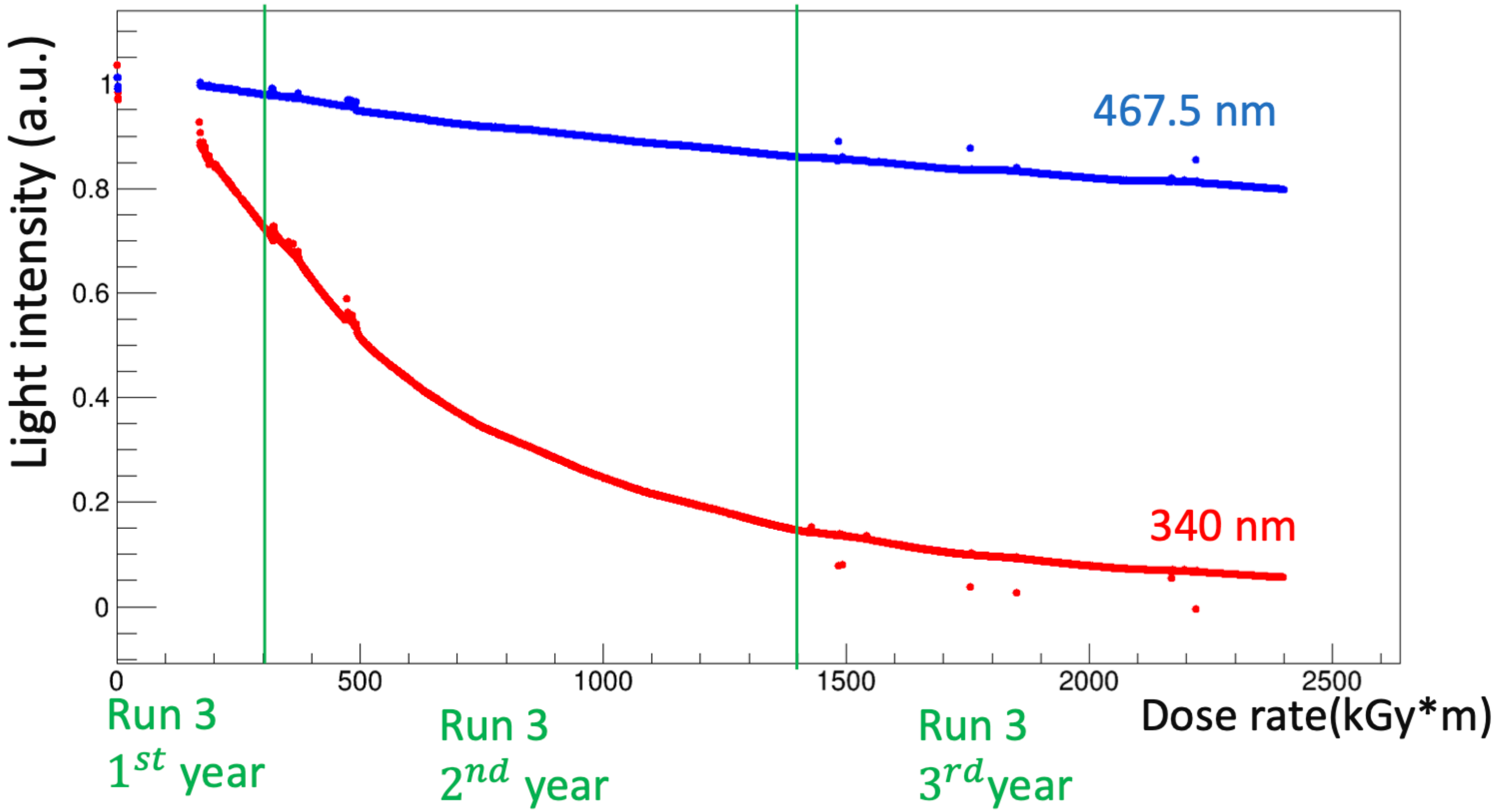




- In order to **mitigate the effect of transit-time variations**, we have installed an **analog filter** along the read-out of a R1635 detector located in the proximity of the beampipe where the radiation effects are larger compared to LUCID-3 (**MOD-R1635**).
- The effect of the filter was to **increase the width of R1635 signals** to make them similar to R670 signals (that are not affected by amplitude measurements issues).

Long-term stability improves significantly by increasing the width of R1635 signals.

LUCID-3 fiber degradation



- Fibers irradiated with γ's at ENEA with total dose corresponding to 3 years of Run-3.
- **Large losses observed in UV range.**