# LUCID-3: the upgrade of the ATLAS Luminosity detector for High Luminosity LHC

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## LUCID in Run 2 (and 3)

LUCID is and has been the main ATLAS Luminosity monitor: the only detector able to measure luminosity both integrated and bunch by bunch, online and offline, in any LHC L range.

- *Total Run 2 offline luminosity measured with a 0.83% uncertainty and a better than 0.1% stability over time.*
- *Main systematic:* ***van der Meer (VdM) calibration****(0.65%)****.***

Design strategies:

- A fast, low-background and rad-hard PMT-based Cherenkov detector (Hamamatsu R760).
- Quartz fiber coupled with PMTs to reduce radiation damage to PMTs.
- Fast electronics handling hit and charge algorithms.
- Stable, flexible and redundant operation thanks to gain calibration system and layout

## New PMT detector

Main strategy: reduction of acceptance

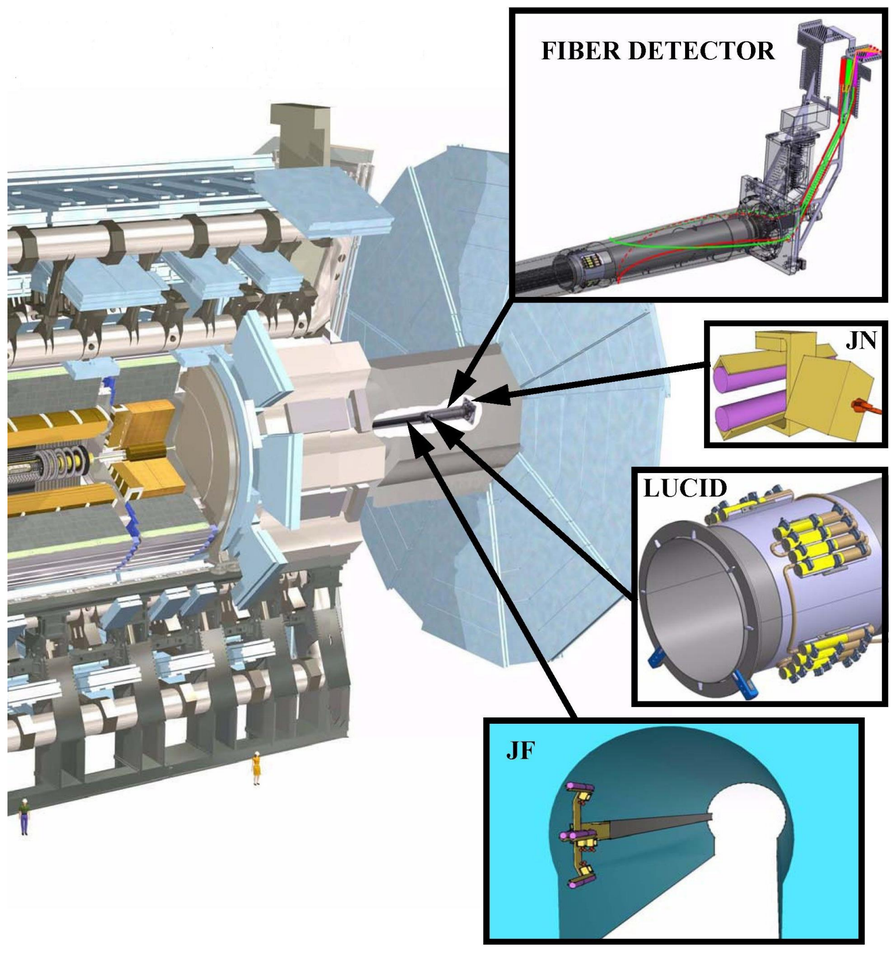
- Smaller PMTs (Hamamtsu R1635)
- New location further away from beampipe

LUCID JF (main detector):

- PMTs attached to forward shielding via a rail system -> easy to replace and lower radiation exposition during maintenance
- Smaller acceptance wrt LUCID-2

LUCID JN (auxiliary detector)

- PMT behind forward shielding -> very low acceptance
- Improved linearity wrt μ




## LUCID-3 prototypes

Prototypes of PMT and fiber detector under study to validate LUCID-3 possible design:

- Statistical error
- Linearity with respect to μ
- Long term stability

## HL-LHC challenges

Luminosity requirements:

- Offline precision ~ 1%.
- Online stability and precision (~3%) in 2s-long periods.
- Working point far from saturation.

Challenging conditions: pile-up (μ) <= 200 and L = 4000 $fb^{-1}$

- Leading to potential saturation of the PMT acceptance and high total dose and current.
- Large (and not-predictable) non-linearity in the larger μ-range.

Different ATLAS TDAQ infrastructure:

- New electronic infrastructure required.

## New Fiber detector

Fiber detector introduced in Run 1, improved in Run 2, upgraded prototype in Run 3:

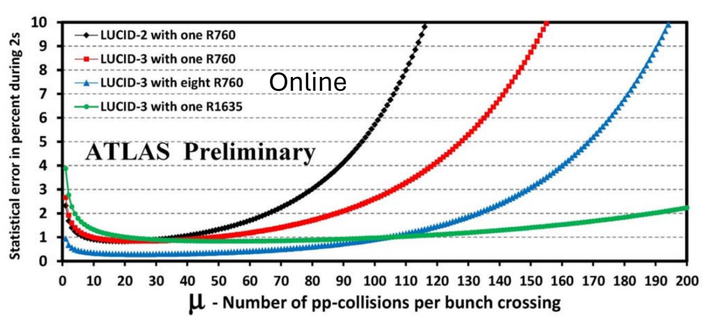
- New calibration system
- New quartz fiber with better radiation hardness
- UV filter in one of the detector to improve long term stability

Improved calibration system wrt LUCID-2

- PMT gain monitored with the $^{207}Bi$ (like all PMTs),
- LEDs to monitor fiber ageing,
- Possibility to correct offline for fiber ageing.

Main advantage:

- Very good linearity wrt μ
- PMT placed in a less radioactive area




## Statistical error

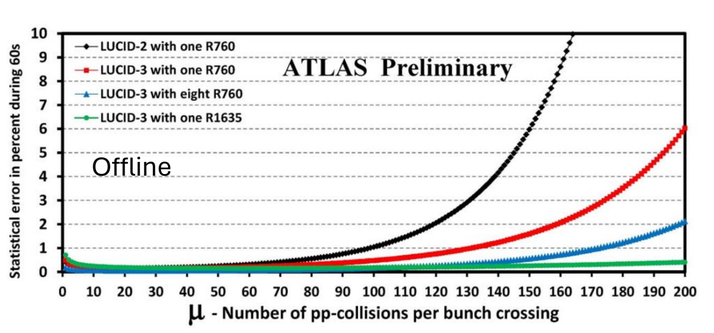
2s time window (online lumi):

- Goal: <2/3%
- LUCID-2 reaches only μ = 80
- Just 1 R1635 reaches μ = 200

60s time window (offline lumi):

- Goal: <1%
- LUCID-2 reaches only μ = 100
- Just 1 R1635 reaches μ = 200

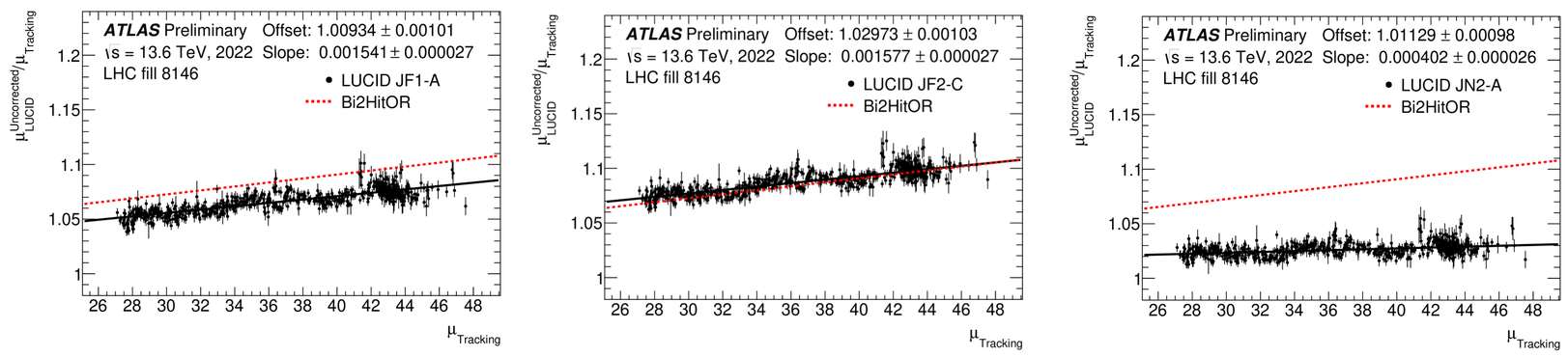
Drawback: 8 R1635 in VdM




## Linearity

Comparison of various LUCID algorithm with track vs μ

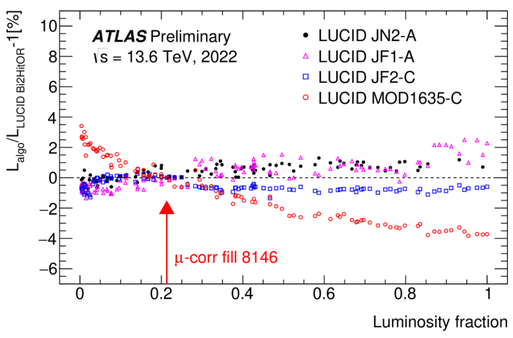
- JF1-A (R1635): slightly better linearity wrt LUCID-2
- JF2-C (R760): slightly better linearity wrt LUCID-2
- JN2-A (R760): linearity 3/4 times better wrt LUCID-2




## PMT long term stability

Compare fill-by-fill prototype lumi measurement wrt to LUCID-2:

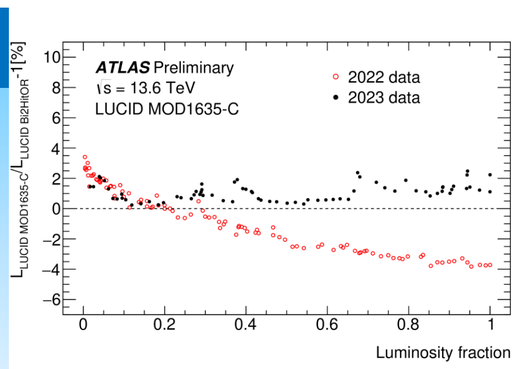
- JF1-A and JF2-C similar to LUCID-2
- JN2-A larger fluctuation compared to LUCID-2




## LUCID MOD1635

Test: use new R1635 in LUCID-2 position

- Large drift in 2022: this PMT produce shorter pulses that current electronics cannot digitize perfectly
- Pulse widened in 2023: improved stability
- electronics under redesign to cope with R1635 signals and new ATLAS-TDAQ scheme



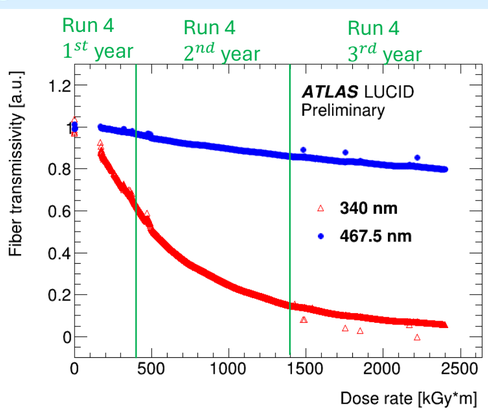

## Fiber long term stability

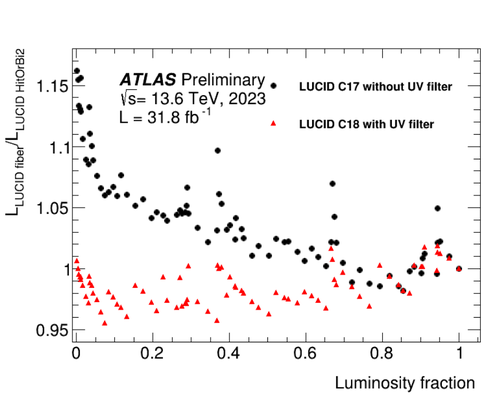
Long term stability strongly influenced by fiber ageing

- Large loss of light in UV region -> UV filter in one of the prototype

Comparison between L measured by LUCID-2 and fiber

- Large loss without filter
- Sawtooth shape problem with gain monitoring
  - Indication of mitigation in 2024




## Conclusions

LUCID-3 prototypes are currently under study:

- JN: very low μ correction but large run-to-run fluctuations
- JF: very good run-to-run stability but modest improvement in linearity wrt LUCID-2
- New R1635 PMT needs a new readout board with higher sampling rate
- UV filter inserted in one fiber prototype improves long term stability

## References

"The LUCID 3 detector for the ATLAS Phase-II Upgrade" CERN-LHCC-2021-016
"The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS" 2018 JINST 13 P07017
"Choice and characterization of photomultipliers for the new ATLAS LUCID detector" 2016 JINST 11 P05014