# Upgrade of the ATLAS Luminosity Monitor for HL-LHC

## "The LUCID 3 detector for the ATLAS Phase-II Upgrade" CERN-LHCC-2021-016 [1]

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## LUCID: ATLAS' Main Luminometer

### LUCID-2

LUCID-2 [2] installed on beampipe: 32 PMTs with quartz windows (& previously 8 bundles of quartz fibres) monitored by $^{207}$Bi sources. Provides precise measurements of $\mathcal{L}$ via Cherenkov light in quartz & is the main ATLAS luminometer.

- Achieved precision of 0.8% in offline $\mathcal{L}$ in Run-2.
- Only Run-2 detector providing measurement per bunch for all number of collisions per bunch crossing ($\mu$).

Figure 1: LUCID-2 PMTs - yellow cylinders

- Provides $\mathcal{L}$ online in all beam modes in 2 second intervals.

### Limitations

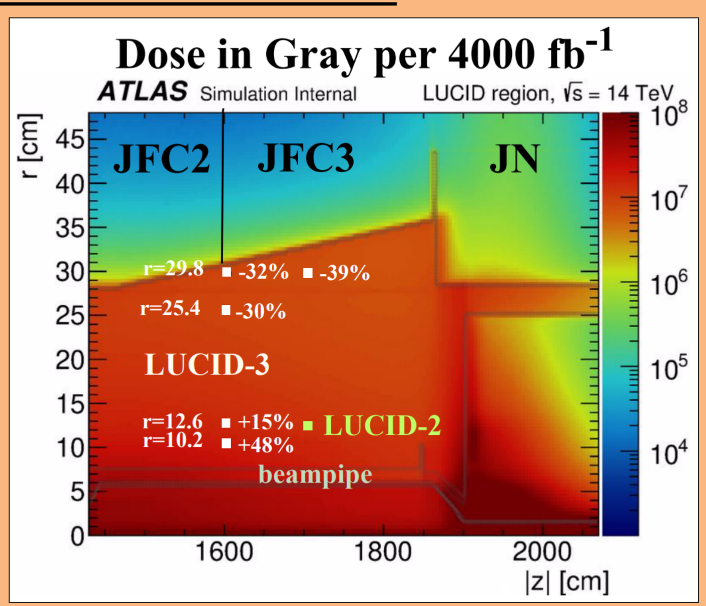


Figure 2: HL-LHC - Dose around beampipe

Two main limitations with LUCID-2 due to high $\mathcal{L}$ in HL-LHC, requiring LUCID-3.

- $\mathcal{L}$ cannot be measured if hit in every bunch crossing (hit-saturation).
- Saturated at $\mu \approx 110 - 120$.
- PMTs operate up to 1 MGy, yearly dose in HL-LHC - current fibres fail. Testing new radiation hard fibres.

### Requirements for HL-LHC

- Survive 326 fb$^{-1}$ per year [3].
- Operate up to $\mu$=200.
- Precision measurements require uncertainty in offline $\mathcal{L}$ <1%.
- Maintain current online $\mathcal{L}$ performance - so $\mathcal{L}$ leveling can be performed well.

| | Baseline | Ultimate |
|---|---|---|
| Number of colliding bunches in ATLAS | 2748 | 2748 |
| Peak Luminosity [cm$^{-2}s^{-1}$] | $5\times10^{34}$ | $7.5\times10^{34}$ |
| Peak pile-up [collisions/crossing] | 131 | 197 |
| Luminosity leveling time [hours] | 7.4 | 3.6 |
| End-of-fill luminosity [cm$^{-2}s^{-1}$] | $3\times10^{34}$ | $4.5\times10^{34}$ |
| Peak pile-up line-density [events/mm] | 1.3 | 1.95 |
| Average pile-up line-density [events/mm] | 0.8 | 1.2 |
| RMS time spread of the luminous region [ps] | 178 | 178 |
| Integrated luminosity [fb$-1$/year] | 262 | 326 |

### Luminosity Algorithms

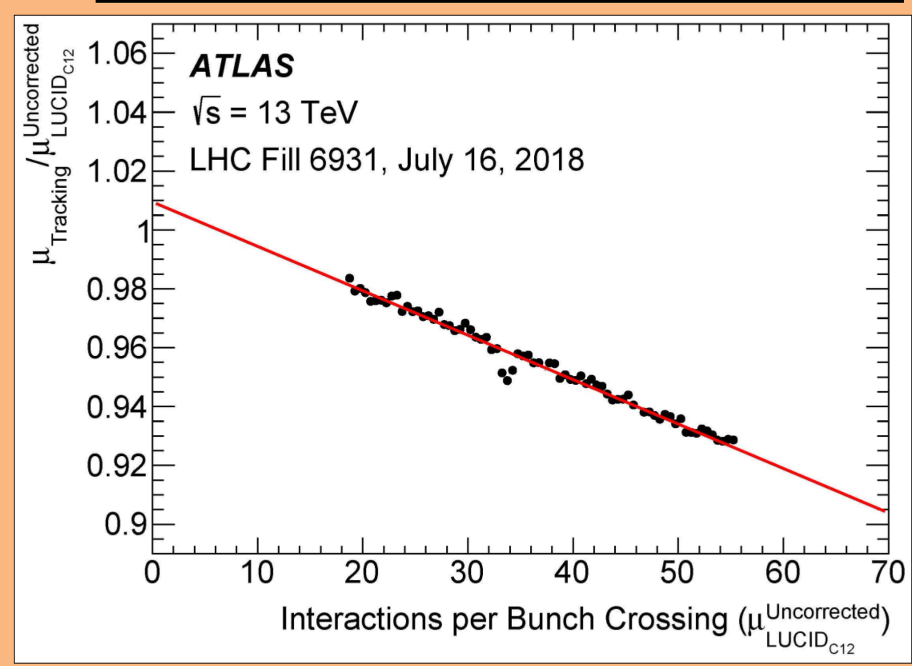


Figure 3: $\mu$-dependence of LUCID PMT-C12.

Many complementary algorithms are used in LUCID to calculate $\mathcal{L}$, broke down into three classes:

- Event counting - Robust against PMT issues, low saturation limit.
- Hit counting - Sensitive to single PMT issues, high saturation limit.
- Particle counting - e.g. charge - Sensitive to PMT gain variations, but directly $\propto \mathcal{L}$.

Event & hit counting corrected for $\mu$ dependence. Charge counting & others kept stable against varying gain by monitoring with $^{207}$Bi on PMT window.

## Location: Baseline LUCID-3 JF (Attached to Forward Shielding)

- Less radiation: Use similar PMTs.
- Larger radius - lower acceptance - greater $\mu$ hit-saturation limit.
- Accessible: Replace PMTs during End Of Year Shutdowns (EOYS).
- Disconnected every EOYS: Location may change slightly.
- Additional machining needed.

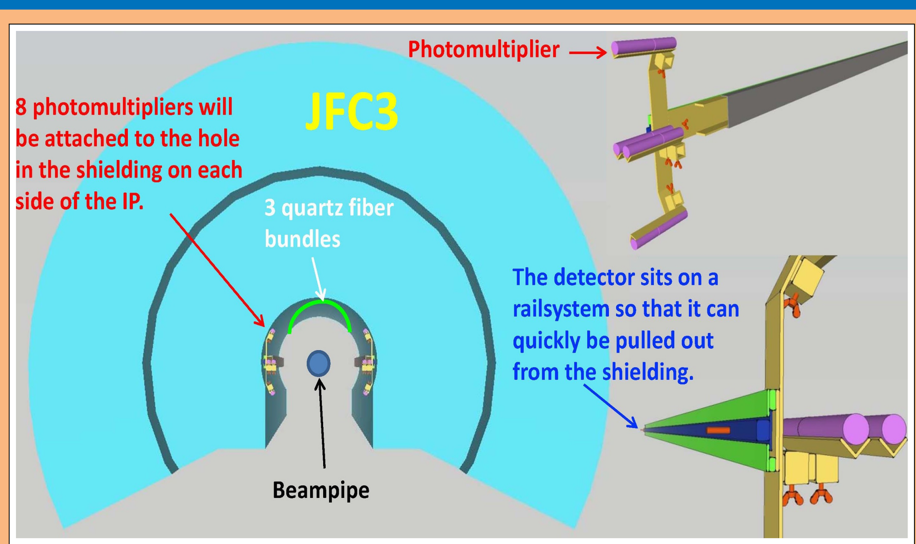


Figure 4: LUCID-3 attached to forward shielding.

## Location: Alternative LUCID-3 JN (Behind Upper Forward Shielding)

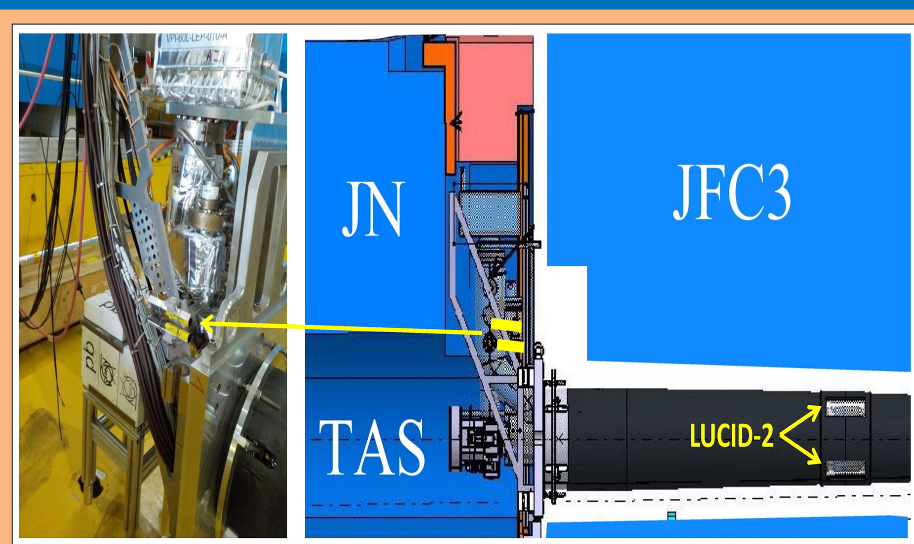


Figure 5: LUCID-3 attached behind JFC3.

- Low rate: allows larger PMTs and high $\mu$ hit-saturation limit.
- Improved linearity and smaller $\mu$ corrections.
- Low radiation.
- Easy to access and install.
- Low sensitivity in very low $\mathcal{L}$ special runs, e.g. vdM scans.

## Technology: Baseline PMTs

- Smaller diameter Hamamatsu PMTs custom made for LUCID-3.
- Cherenkov light produced in quartz window.
- HIT & CHARGE counting.
- Gain monitoring well understood.
- High radiation dose, but PMTs can be changed every year.


Figure 6: LUCID-3 specially made PMTs.

## Technology: Alternative Fibre optics

Figure 7: LUCID-3 quartz fibre bundle.

- Cherenkov light produced in bundles of quartz optical fibres from detector to shielded PMTs.
- No radiation damage to PMTs.
- Only charge measurements.
- Challenging gain monitoring system with LEDs.
- Unlikely to be possible to change fibres near VAX in EOYS.

## Luminosity Uncertainty

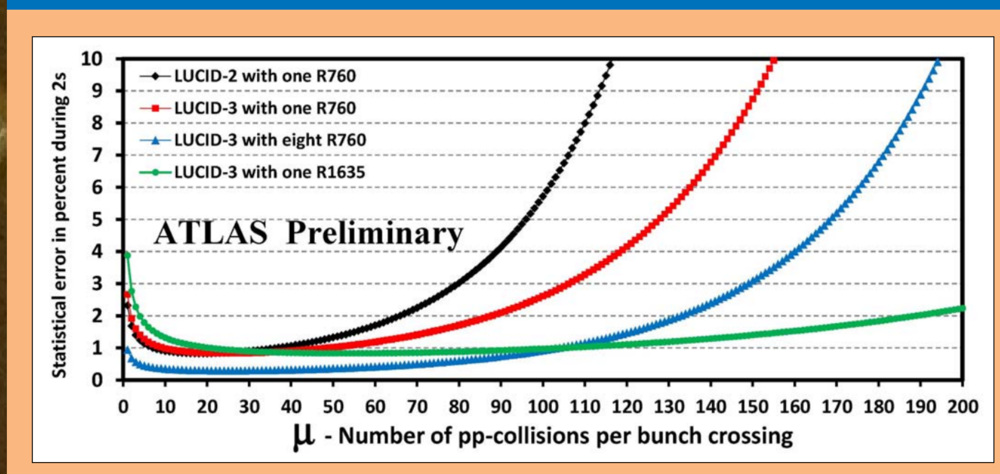


Figure 8: Luminosity Uncertainty.

Performance of LUCID-3 configurations.

- LUCID-2 - vdM calibrations in 2018.
- LUCID-3 - hit rates between LUCID-3 & -2 in 2022 vDM.
- $\mu > 30$ any LUCID-3 configuration outperforms -2.

## PMT long term stability

Fill-by-fill prototype long term $\mathcal{L}$ stability compared to LUCID-2.

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

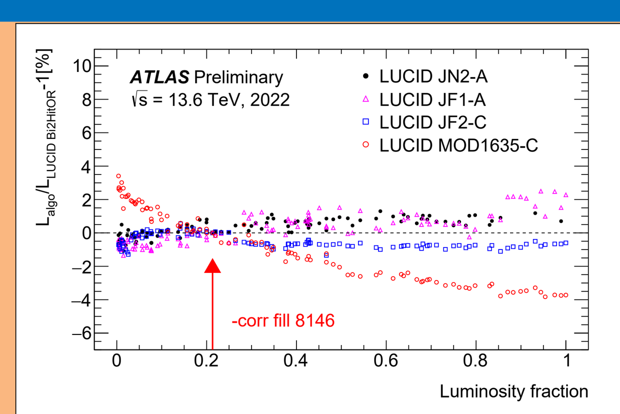


Figure 9: Stability of all PMT prototypes

## References


[1] "*The LUCID 3 detector for the ATLAS Phase-II Upgrade*" CERN-LHCC-2021-016
[2] "*The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS*" 2018 JINST 13 P07017
[3] "*Assessment of the performance of HL-LHC operational scenarios: integrated luminosity & effective pile-up density*" Can. J. Physics. 97 (2019) 498
[4] "*Photographs of LUCID at: https://hedberg.web.cern.ch/hedberg/home/lucid3/lucid3.html*"
[5] "*LUCID Plots at: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsForwardDetectorsLUCID_figures*"
[6] "*Luminosity Plots at: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/LUMI-2023-11/*"


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