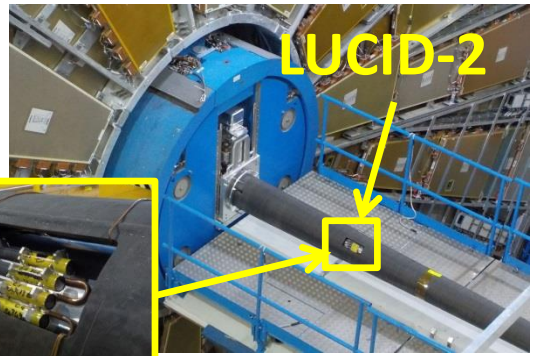
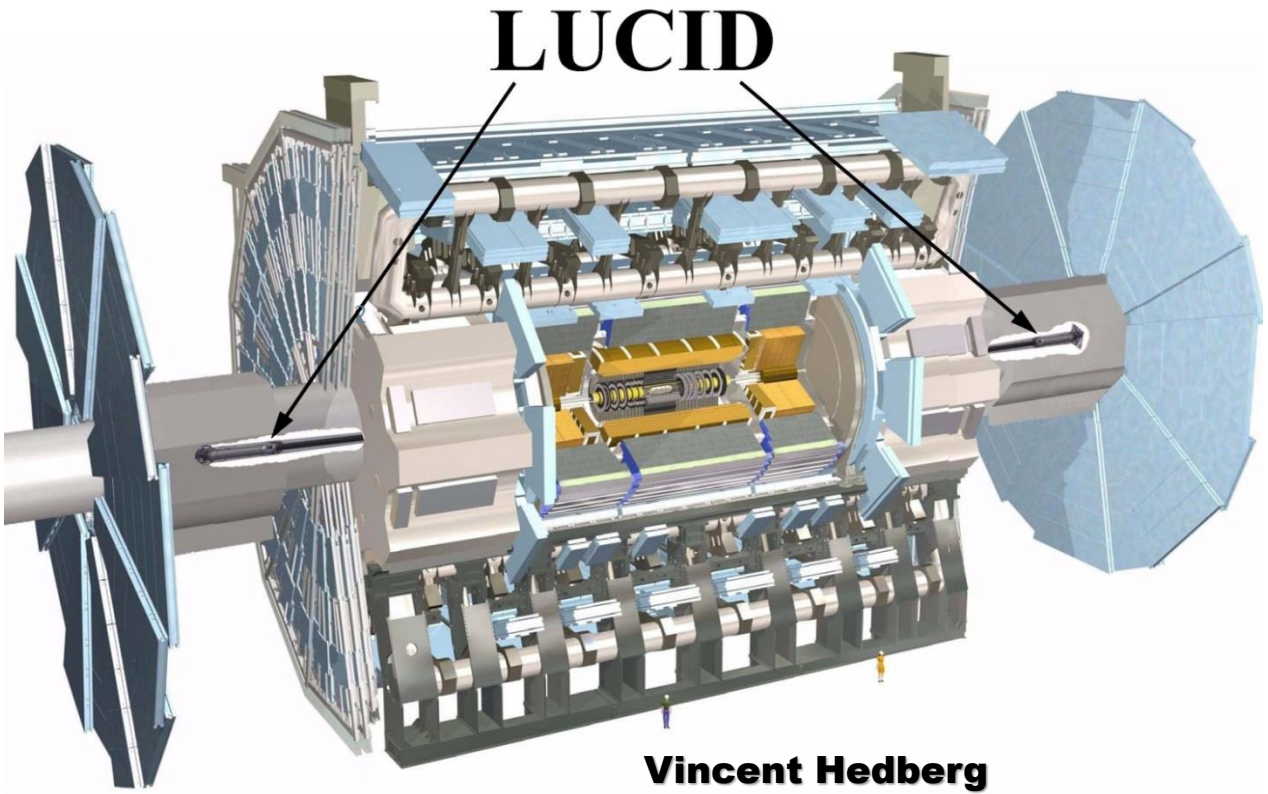
LUCID-3: the upgrade of the ATLAS luminosity detector for High Luminosity LHC

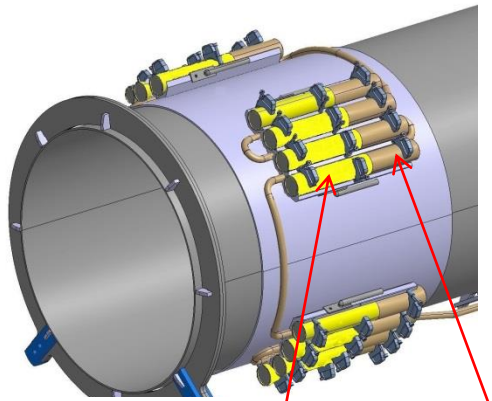


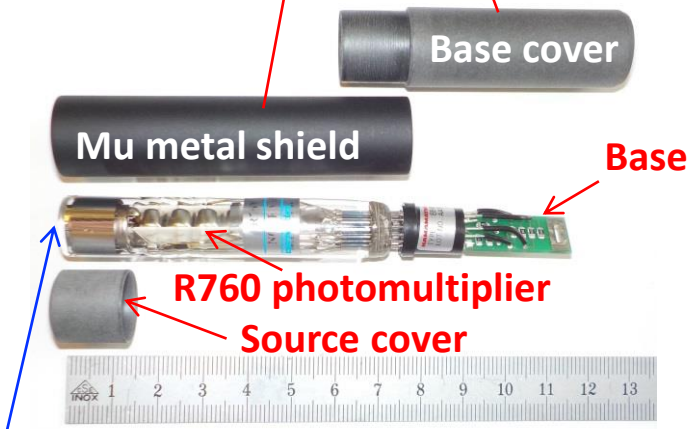


Vincent Hedberg
on behalf of the ATLAS collaboration

The present LUCID-2 detector

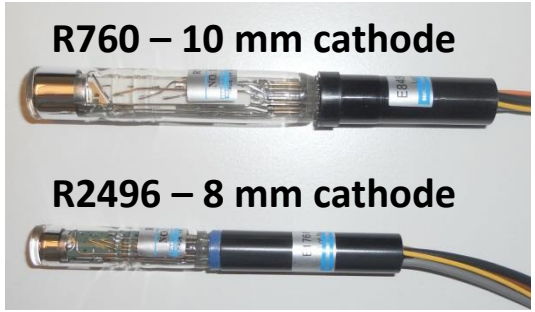
- Sixteen photomultipliers (PMTs) are installed around the beampipe on each side of ATLAS.
- Each PMT is an independent luminosity detector.
- The radiation-hard quartz windows in the PMTs act as a Cherenkov medium.
- Purpose built electronics measures the amplitude of the PMT signals, independent of ATLAS DAQ, every 3.125 ns.
- Signals above a threshold are called hits and these are counted during 2s and 60s periods for online and offline measurements.
- Low-activity Bi-207 sources applied on the windows also produce Cherenkov light that is used for gain monitoring.





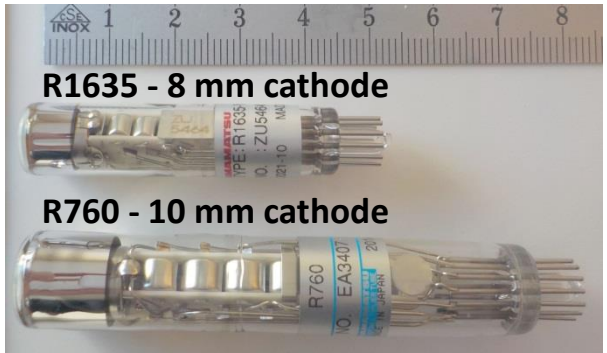
The search for the perfect photomultiplier

- A high acceptance is important for a detector that aims to measure luminosity for single bunch crossings in the tails of the van-der-Meer scans.
- However, a too large acceptance gives hit-saturation (hits in every bunch crossing) which kills the measurement during high luminosity physics running.
- LUCID can only use PMTs with quartz windows, i.e., pure SiO_2 windows, in order to avoid radiation damage.
- The Hamamatsu company has provided ATLAS with specially built small PMTs with quartz windows. The latest is the R1635 which will be evaluated during 2022.



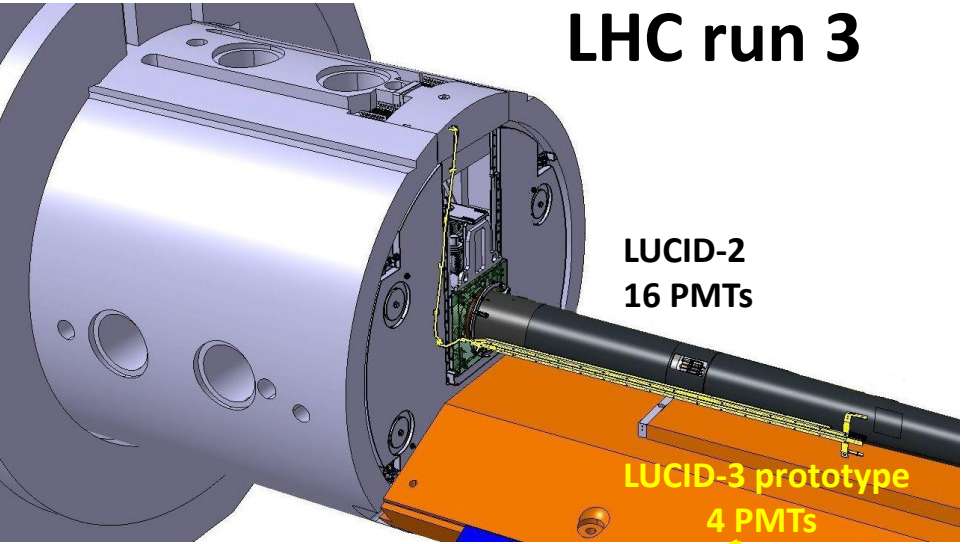
The R2496 has a concave window that creates many small signals and a non-linear luminosity measurement.

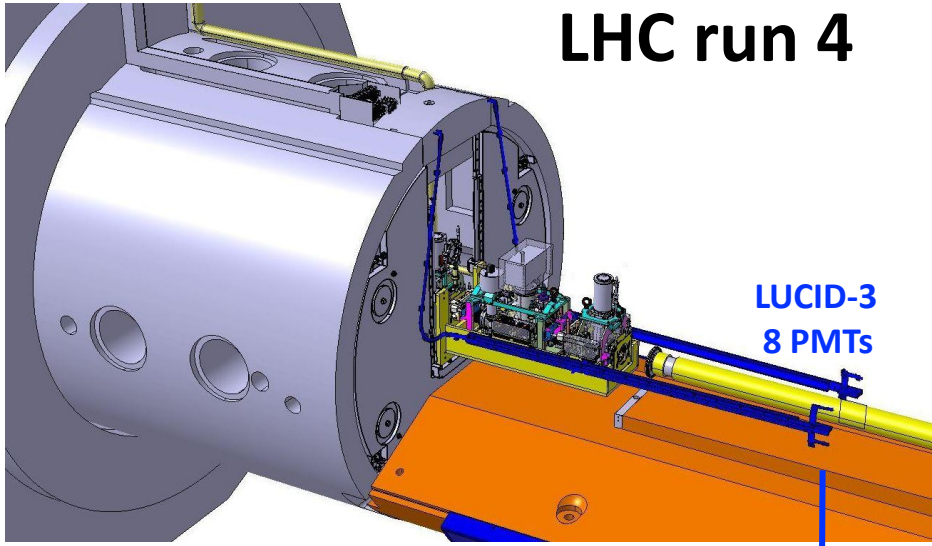
The R760 MOD also has a larger non-linearity than R760 since the Al ring creates many small signal.

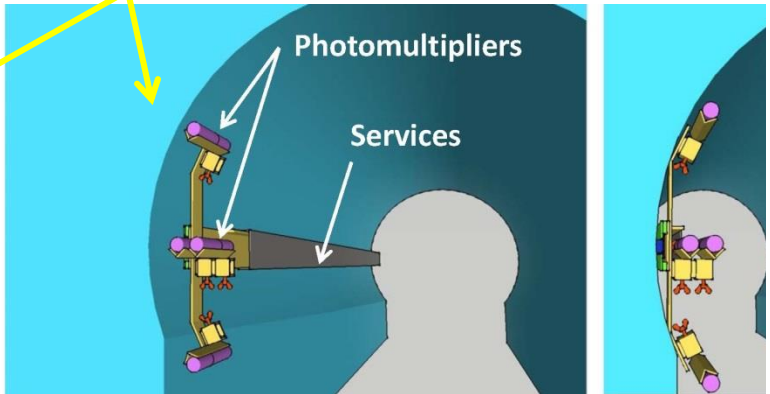


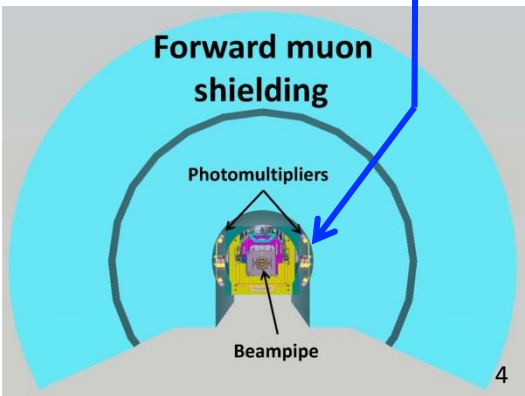
The R1635 has now been specially made for LUCID with a flat quartz window. The window is thinner than for R760 and the non-linearity is expected to be smaller.

The LUCID-3 detector

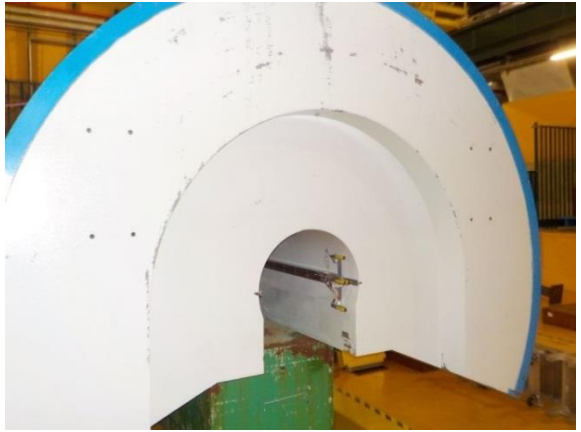








LUCID-3 prototypes attached to the shielding

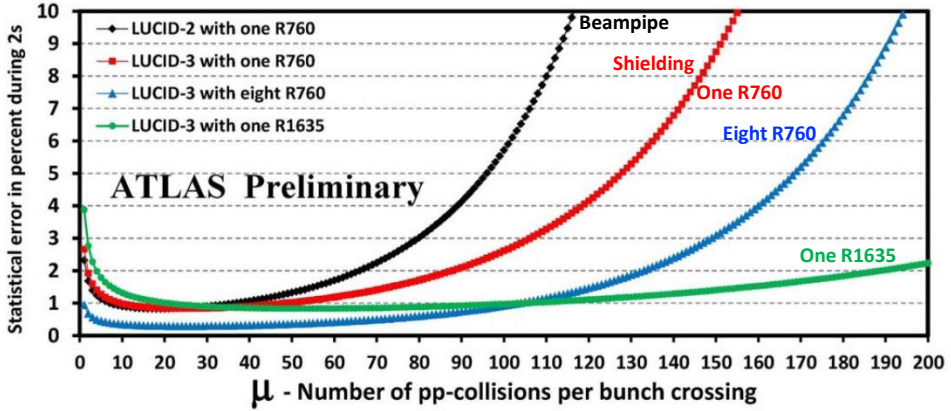


- Prototype detectors have been attached to the shielding on both sides of ATLAS.
- One detector consists of four R760 PMTs with 10 mm diameter.
- The other detector consists of one R1635 PMT with 8 mm diameter and one R760 PMT.

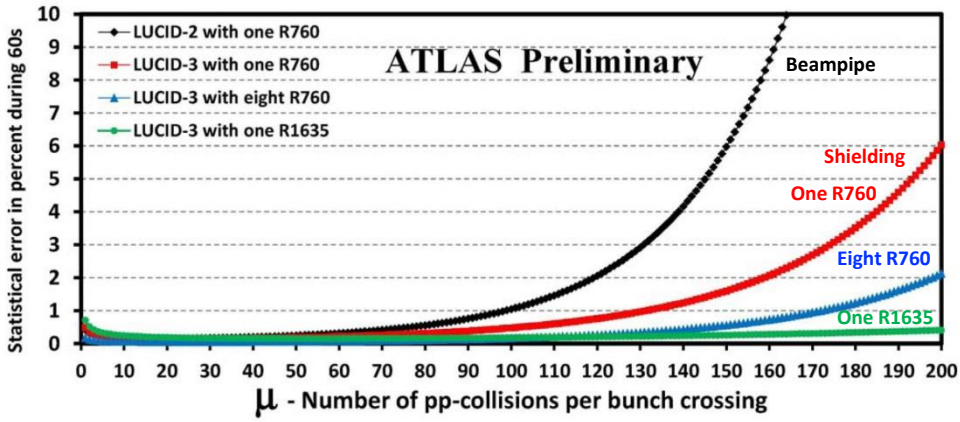
Hit-saturation of LUCID-3

Measurements of the hit-rate in a 13.6 TeV run with VDM optic in 2022 has made it possible to predict the saturation.

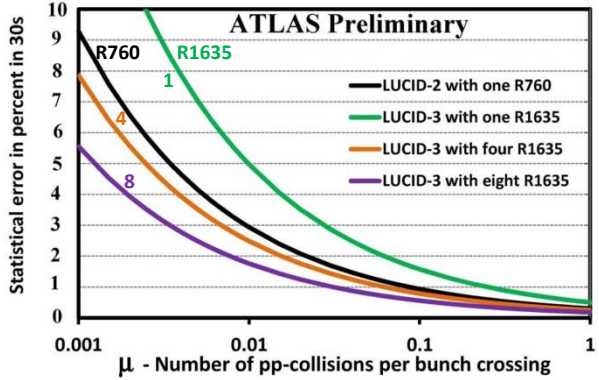
Online measurements of single bunch-pairs.



Offline measurements of single bunch-pairs.

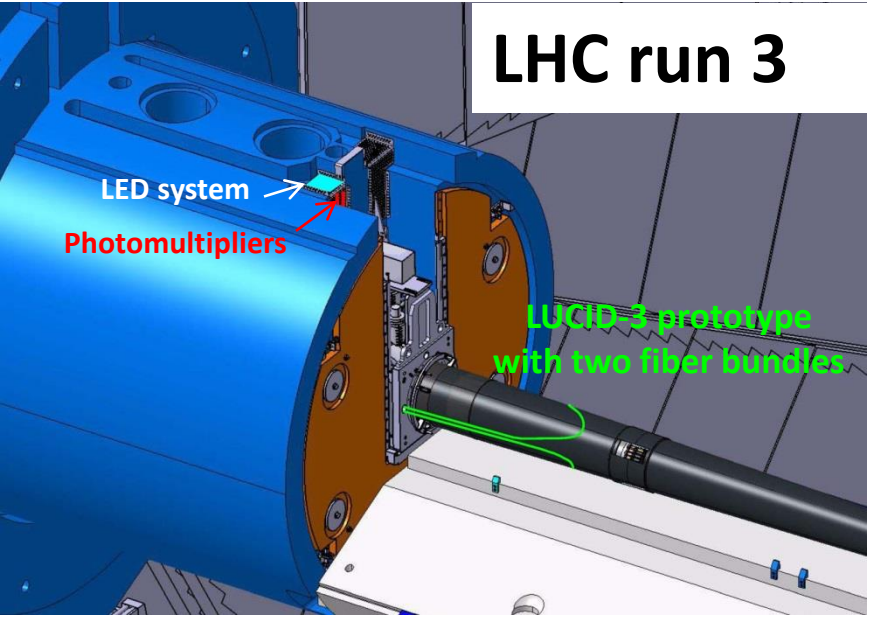


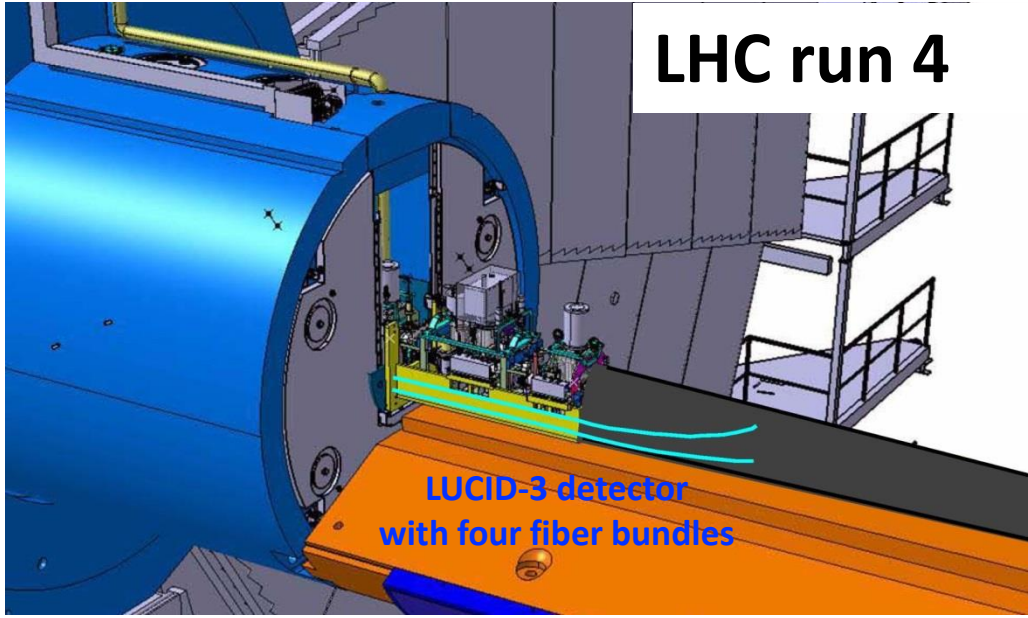
- An algorithm that uses eight R760 PMTs will work online to a μ of about 150 and at higher μ a detector using R1635 PMTs will be needed.
- Offline it will be necessary to use eight R760 PMTs. A single R1635 PMT will work offline without any problem to a μ > 200.
- A single R1635 PMT will, however, lack statistics in VDM calibrations using single bunches. Algorithms using 4 or 8 R1635 PMTs will be better for VDM calibrations.



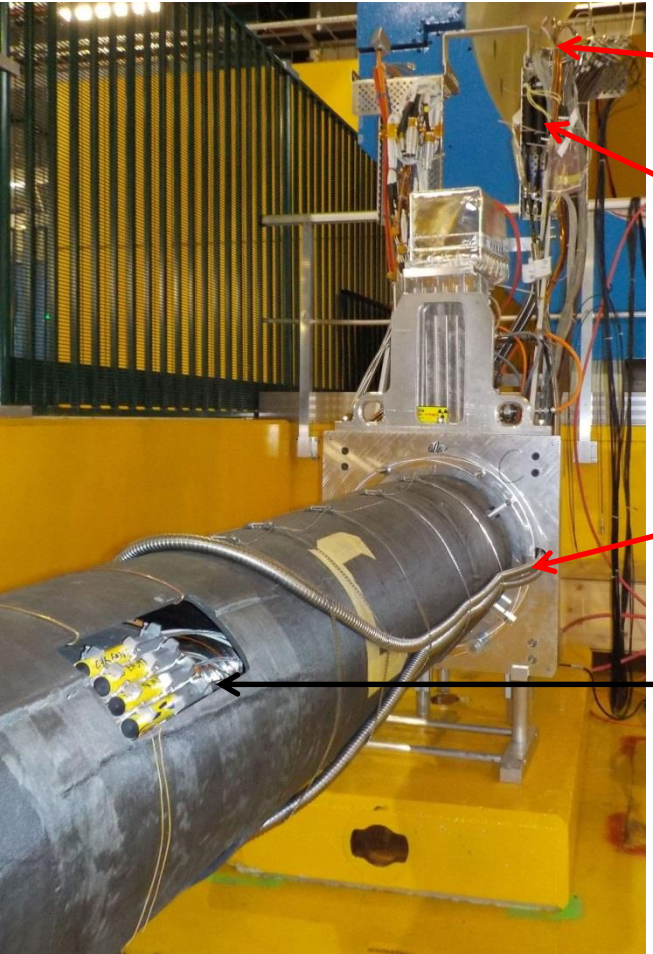
The LUCID-3 FIBER detector

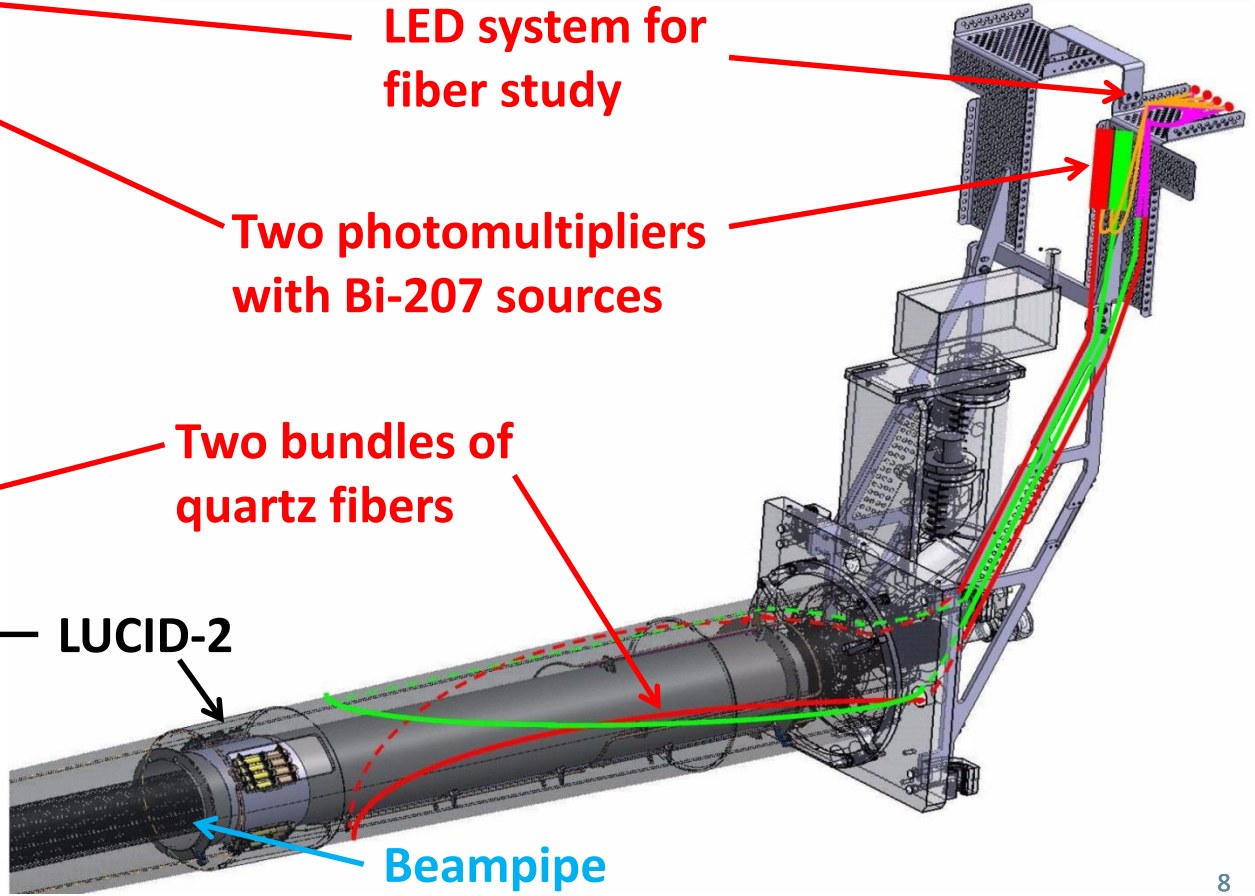
- A fiber detector is studied as an alternative or an addition to a PMT detector.
- Bundles of radiation-hard quartz fibers would provide the Cherenkov medium.
- Photomultipliers could be placed in a shielded location and would see 100 times less radiation than the photomultipliers in the PMT detector.





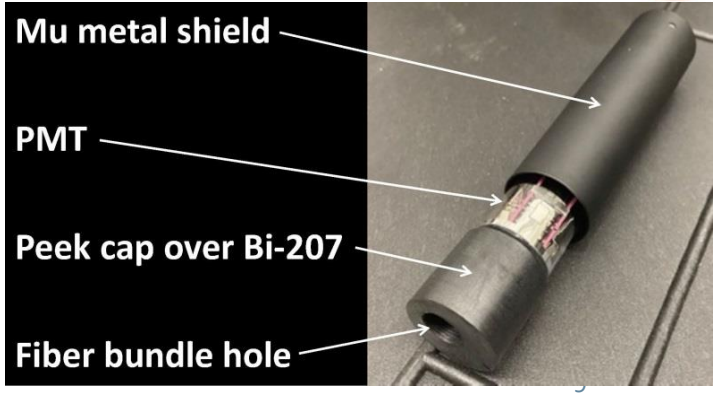
The fiber prototype detector for run 3



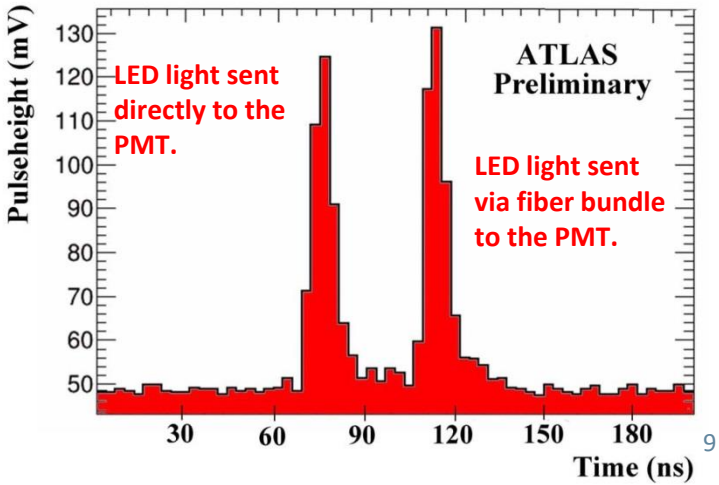


Status of LUCID-3 fiber prototype

- The two bundles of fibers contain 46 and 56 fibers that are 5.6 m long. The fiber has a 600 μm diameter quartz core and a fluorine-doped quartz cladding.
- The PMT gain is monitored with Bi-207 sources on the PMT windows. The high voltage is automatically adjusted so that the measured mean amplitude, and thereby the gain, is kept constant.
- The fibers are monitored with LED signals with 6 different wavelengths sent both directly to the PMTs and via the fiber bundles. The ratio of the LED peaks will be used to monitor the fiber degradation.
- Studies of the radiation hardness of the quartz fibers show that the transmission of UV light is mostly affected by radiation. One fiber bundle is therefore equipped with a UV filter that blocks UV light.



FADC measurements



Summary

- The LUCID-2 detector has been the main online and offline luminosity detector in ATLAS during LHC run 2 and will continue to be it during run 3. It consists of photomultipliers with quartz windows that are equipped with Bi-207 sources for gain monitoring.
- At the High Luminosity LHC in run 4 the present detector will saturate and it cannot remain in its present location.
- The collaboration is therefore investigating the possibility of attaching a detector, based on the same principles, on the forward muon shielding which is further away from the beam and where the particle density is therefore lower.
- New smaller photomultipliers with quartz windows have been manufactured and installed in an attempt to reduce the hit-rate even further.
- Two prototype detectors have been built and installed in ATLAS to test the performance during LHC run 3.
- A detector using optical quartz fibers has also been built and installed in ATLAS for tests during run 3.
- It has a novel calibration system with Bi-207 used to keep the photomultiplier gain constant and LED signals that are used to monitor any degradation of the fibers due to radiation.