Vinicius Franco Lima, on Behalf of the ATLAS Collaboration

Operational Experience and Performance with the ATLAS Pixel detector at the Large Hadron Collider at CERN

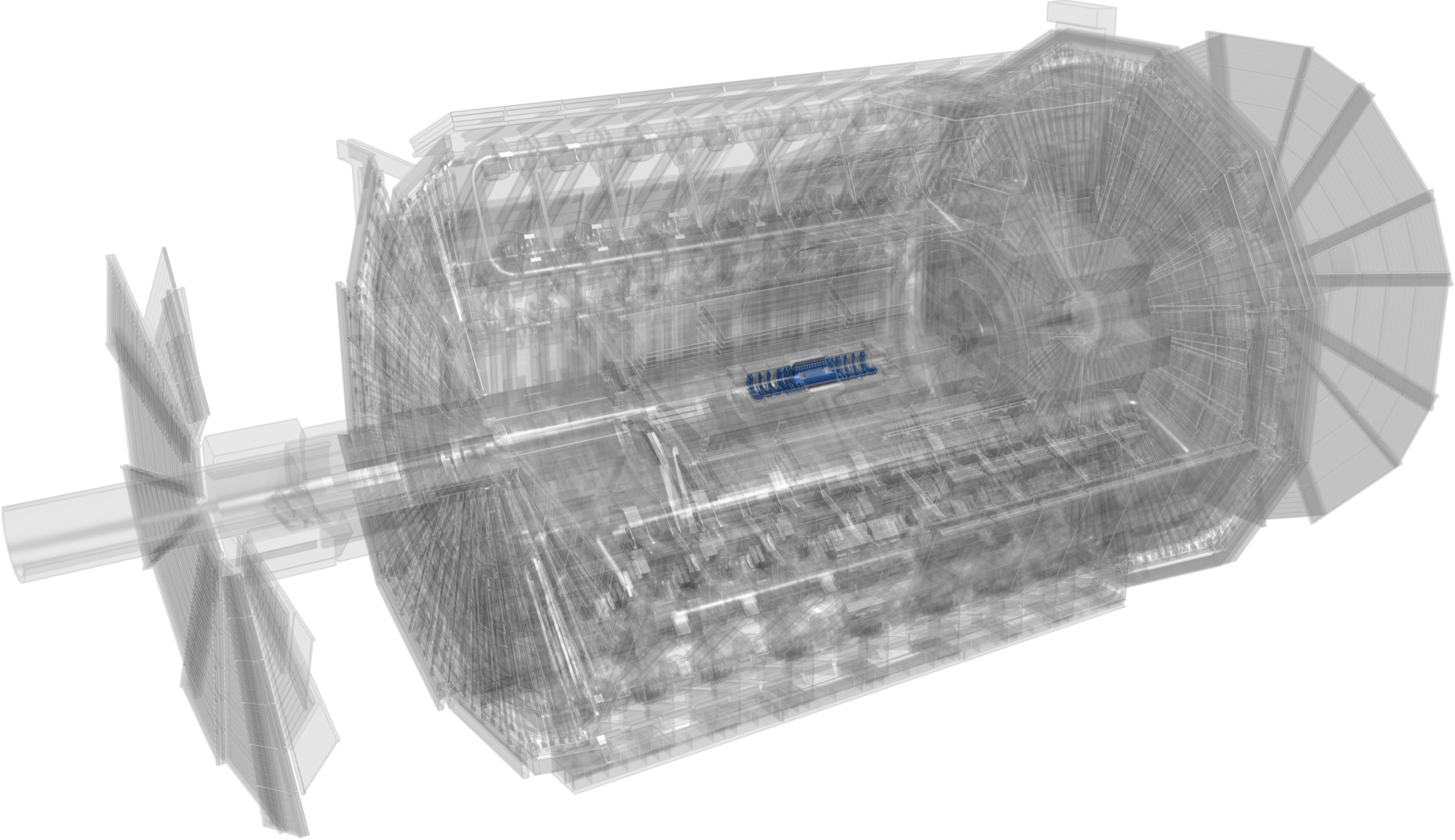
ATLAS Pixel Detector

Inner silicon layers

4 Layers of hybrid pixel detectors in the barrel region, 3 disks in the forward region.

Central part of the ATLAS inner detector, inside a solenoidal field of 2 T.

Fundamental for particle - primary vertex association, tracking.



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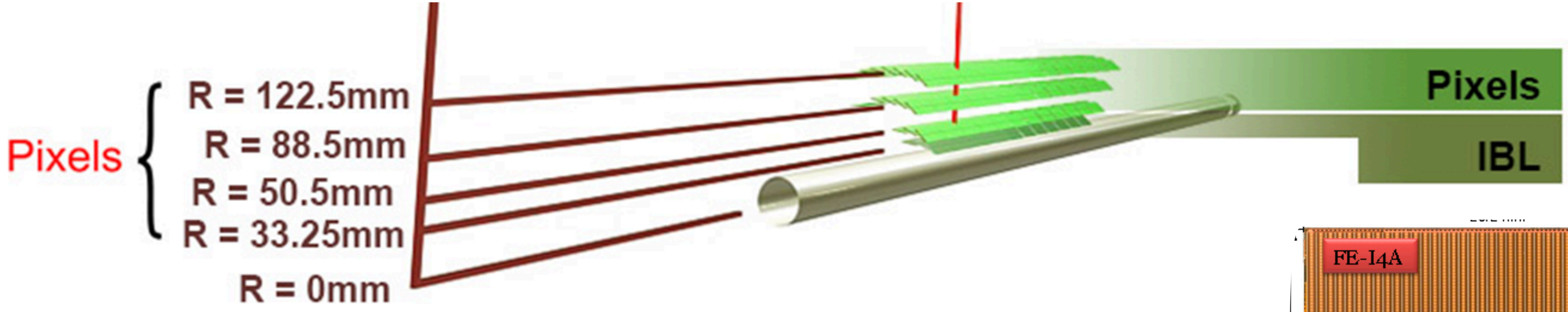
ATLAS Pixel Detector

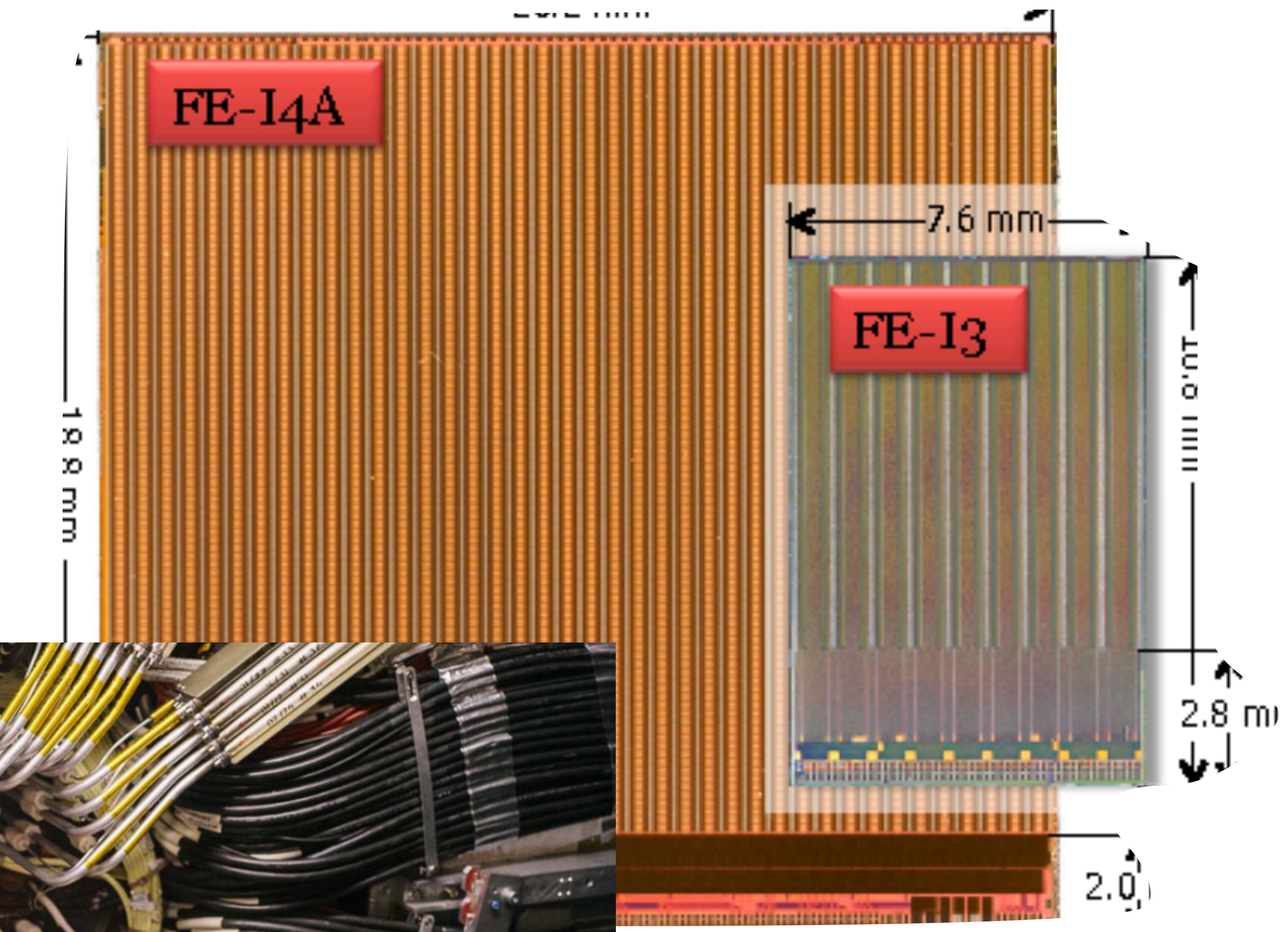
Pixels and IBL

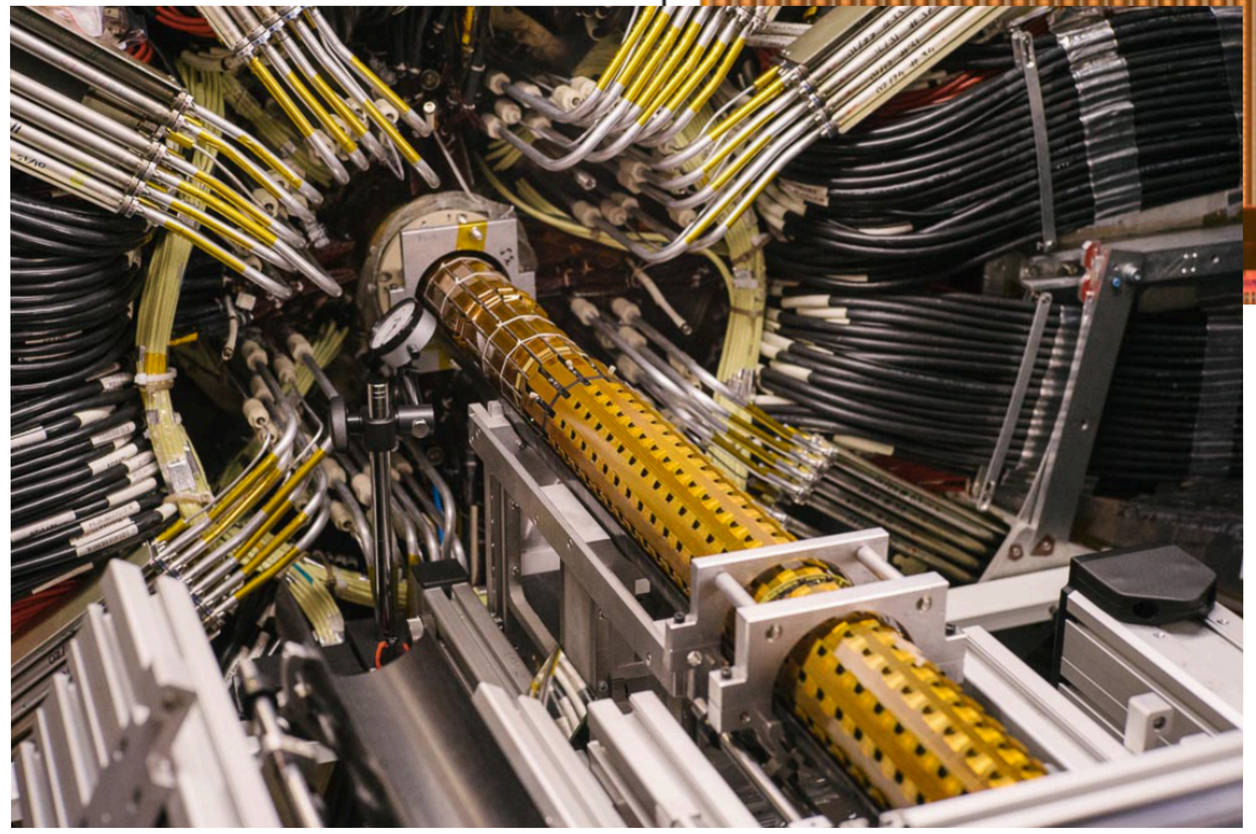


Hybrid pixel detectors using silicon sensors bump-bonded to FEI3 (original 3 layers), FEI4 (IBL*) ASICS.

IBL uses a combination of n-in-n planar sensors and n-in-p 3D sensors with a 50µm by 250µm pitch.

FEI4 is a 130 nm CMOS ASIC containing 336x80 pixels





*IBL : Insertable B Layer

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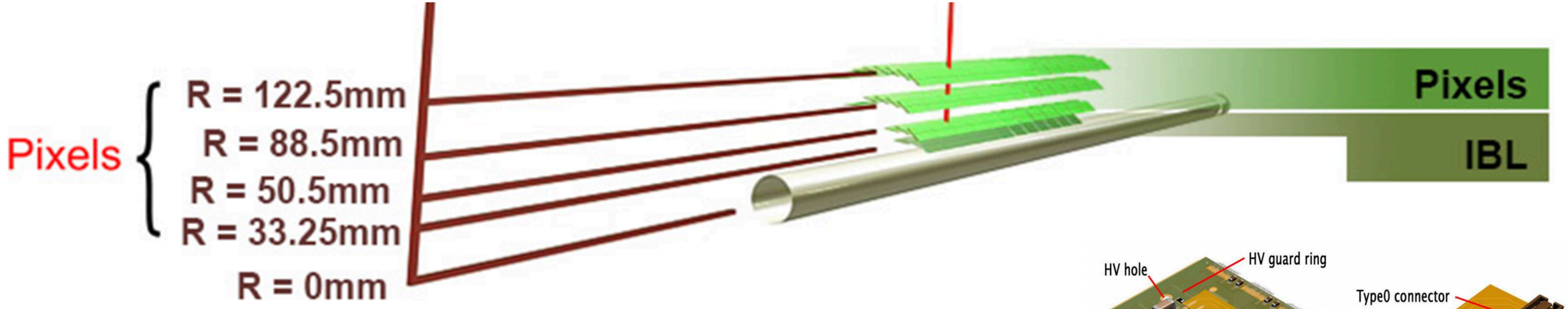
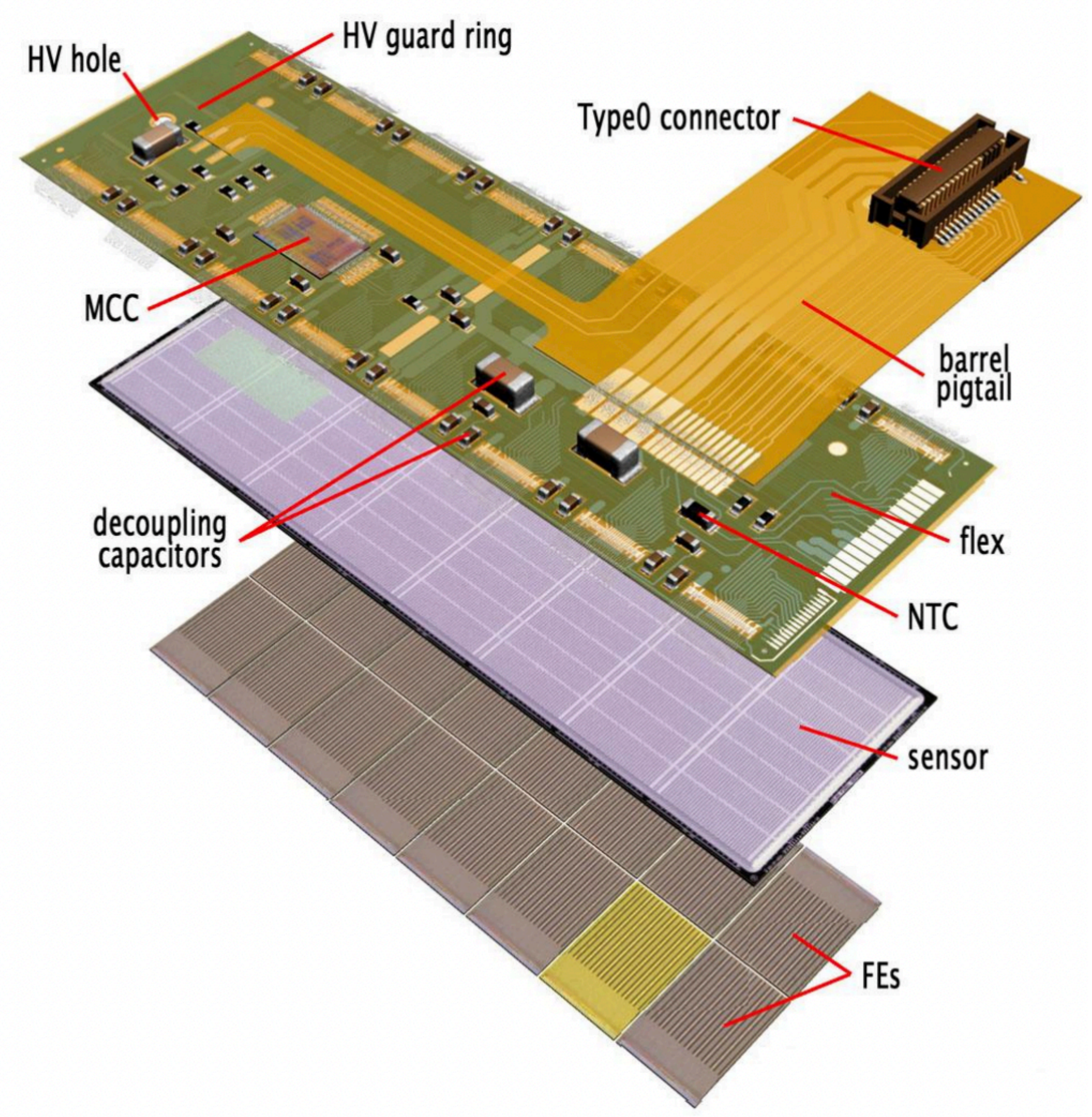
ATLAS Pixel Detector

Pixels and IBL





All other pixel layers use n-in-n planar sensors with 50µm by 400µm pitch. They are readout using the FEI3 ASIC, a 250nm CMOS ASIC containing 160 x 18 pixels.

Each readout module is composed of 16 FEI3s and an ASIC (MCC) responsible for communication between FEs and the DAQ

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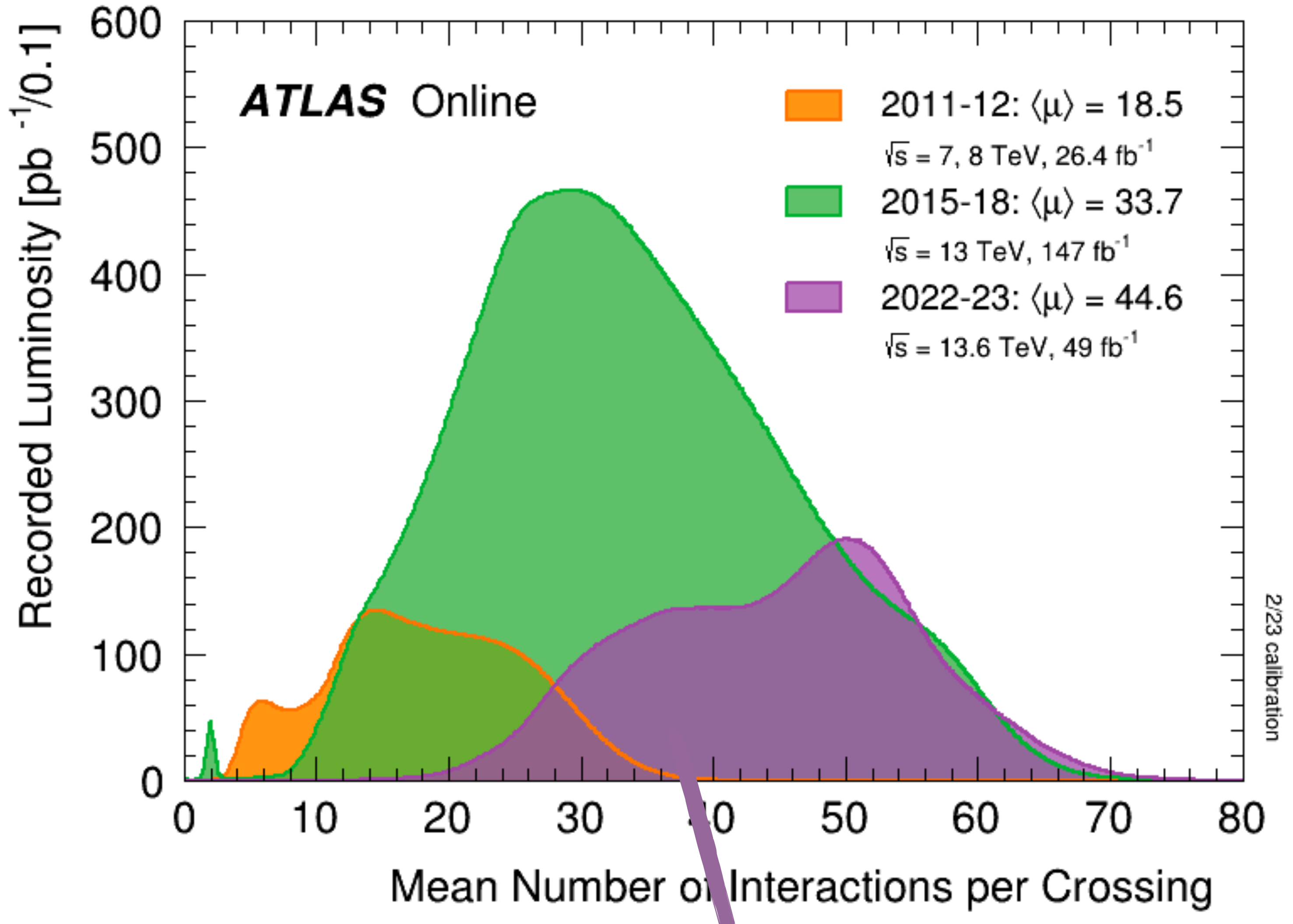
Outlook for Run 3

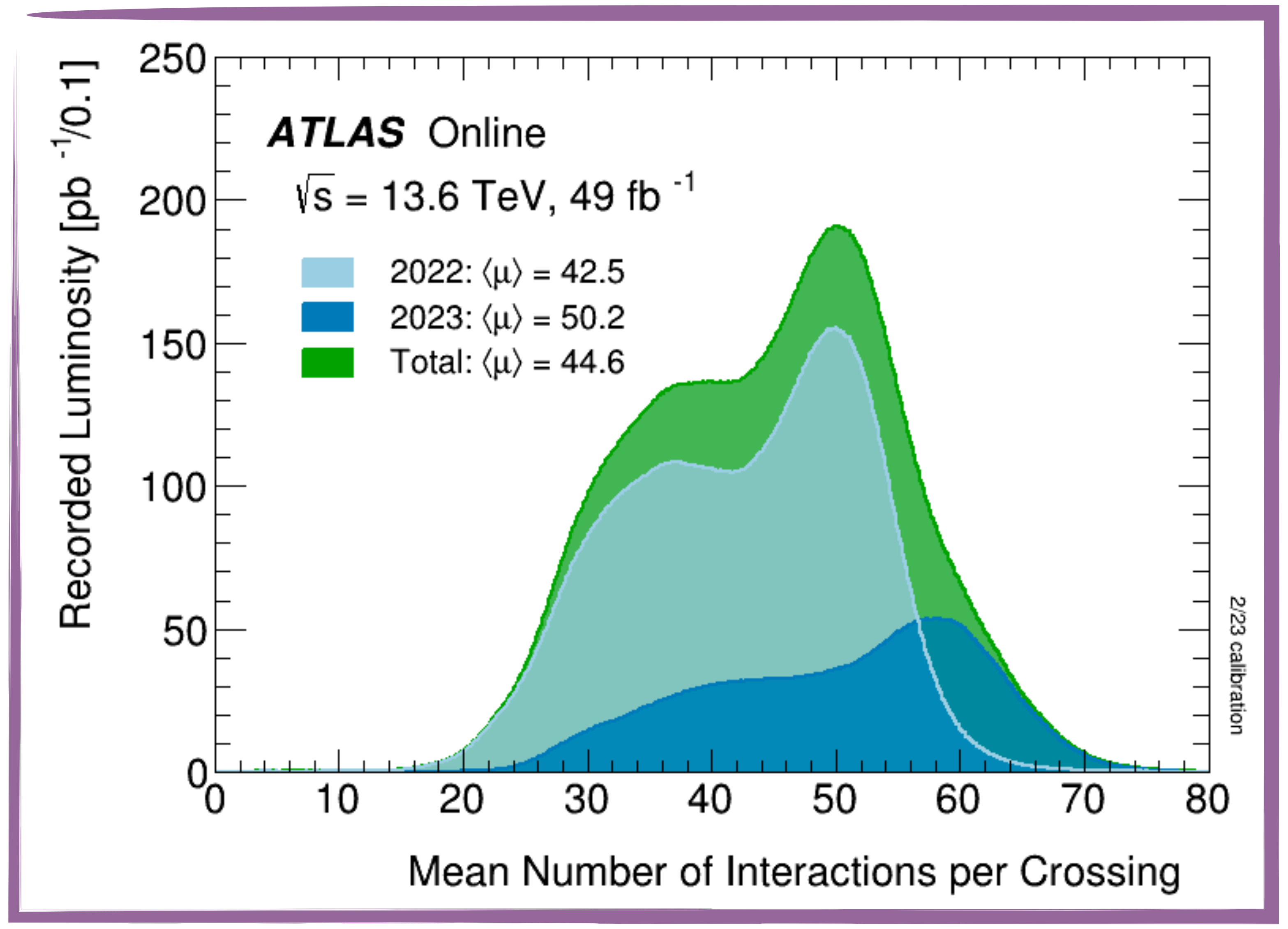
Last run before HiLumi

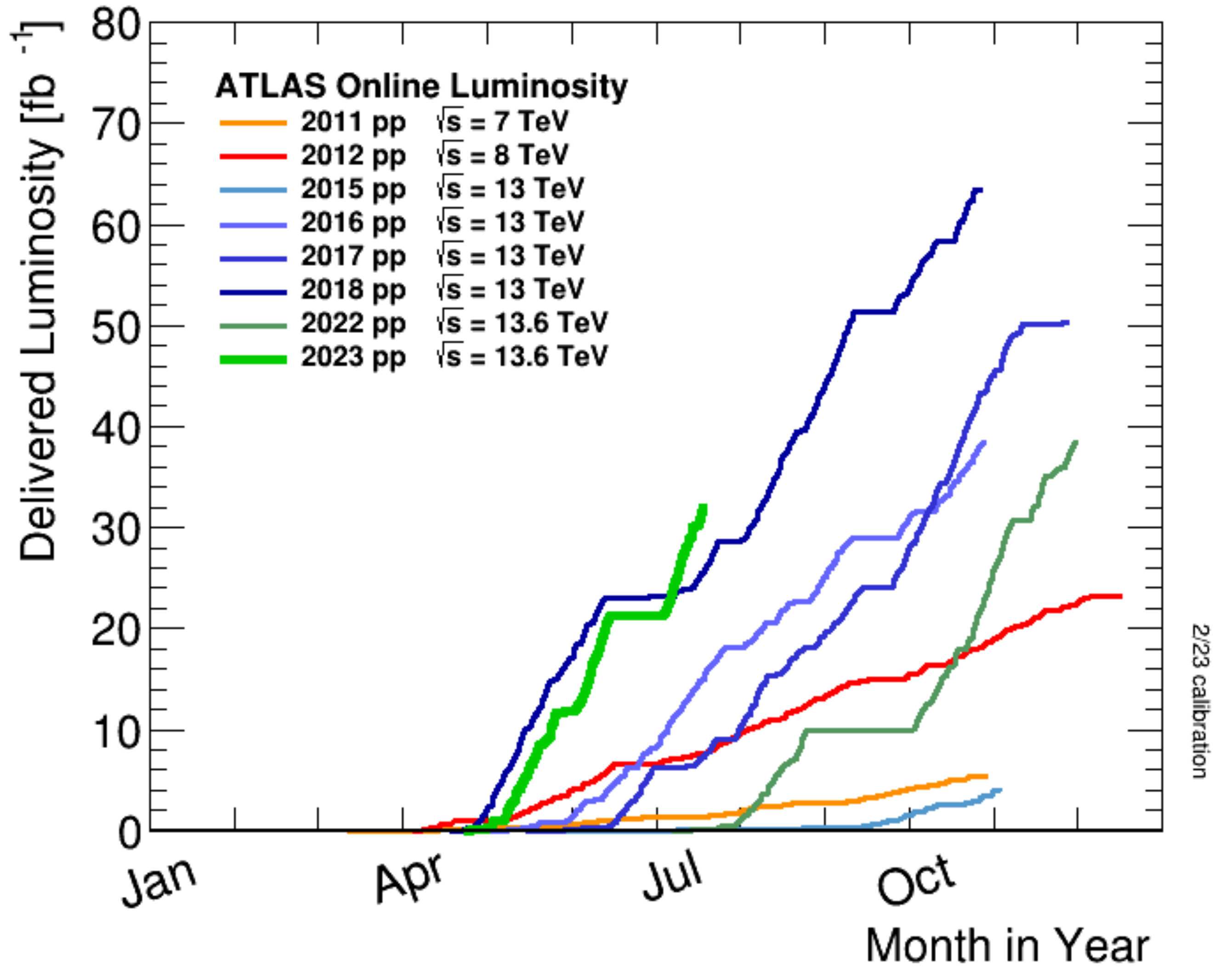
ATLAS Phase I upgrade items: (NSW, LAr Digital trigger, etc..), allow for higher inst. luminosity whilst keeping dead time low.

LHC luminosity levelling; Long fills with significant fraction of luminosity at a relatively high and “constant” <μ>*.

Goal is to roughly double previous Run I + Run II dataset; ~250 fb^{-1}.







*mean number of interactions per bunch crossing

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Outlook for Run 3

Radiation Damage

The increased accumulated luminosity also implies increased radiation damage.

Lower charge collection efficiency might degrade physics performance, has to be recouped by increasing bias. Potentially decreasing thresholds.

Fluence in IBL at the en of Run 3 is expected to be 2.1×10^{15} 1MeV n_{eq}/cm^2. BLayer is further away from the IP and is expected to be exposed to ~1.5×10^{15} 1 MeV n_{eq}/cm^2

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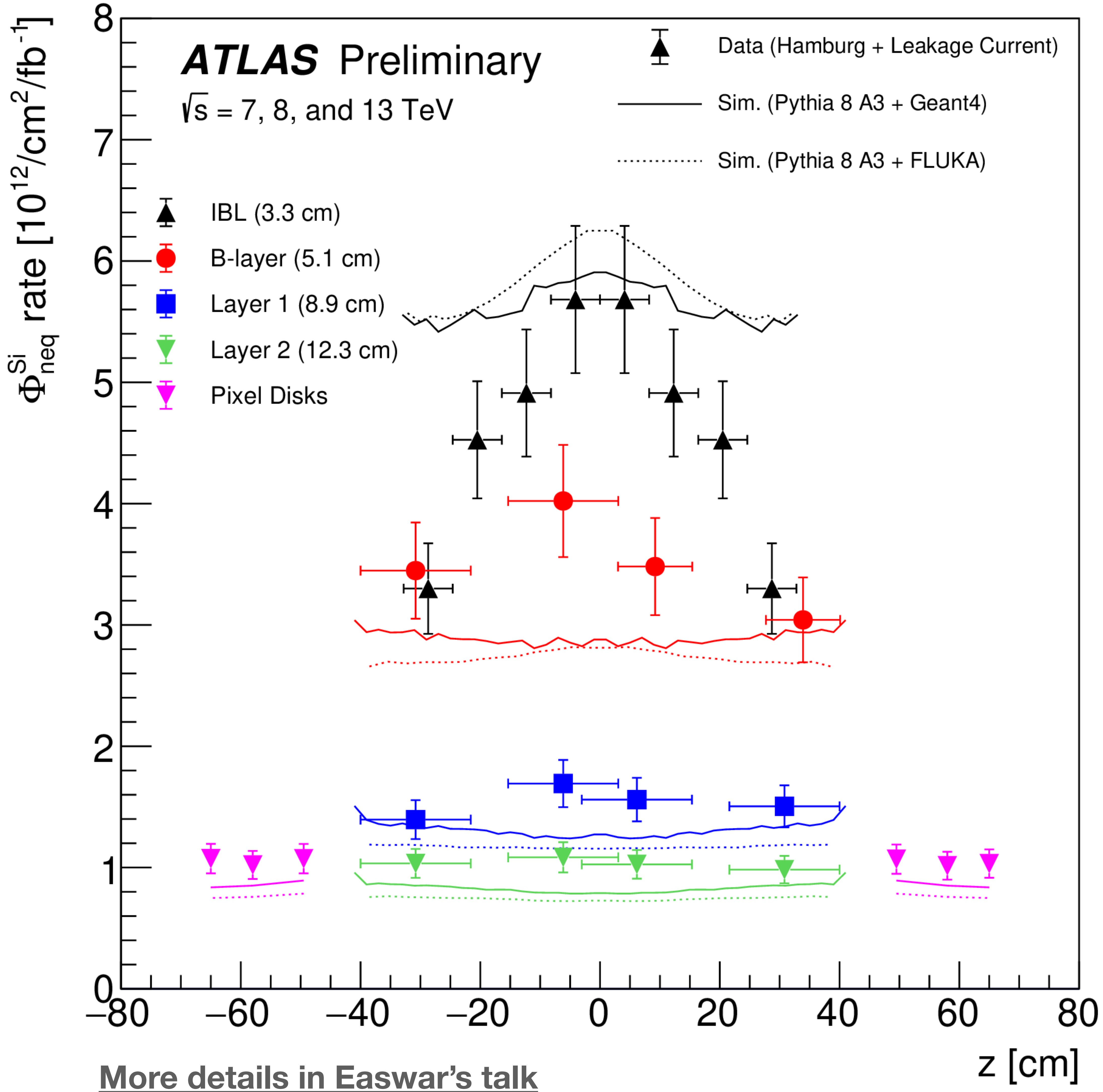

More details in Easwar's talk

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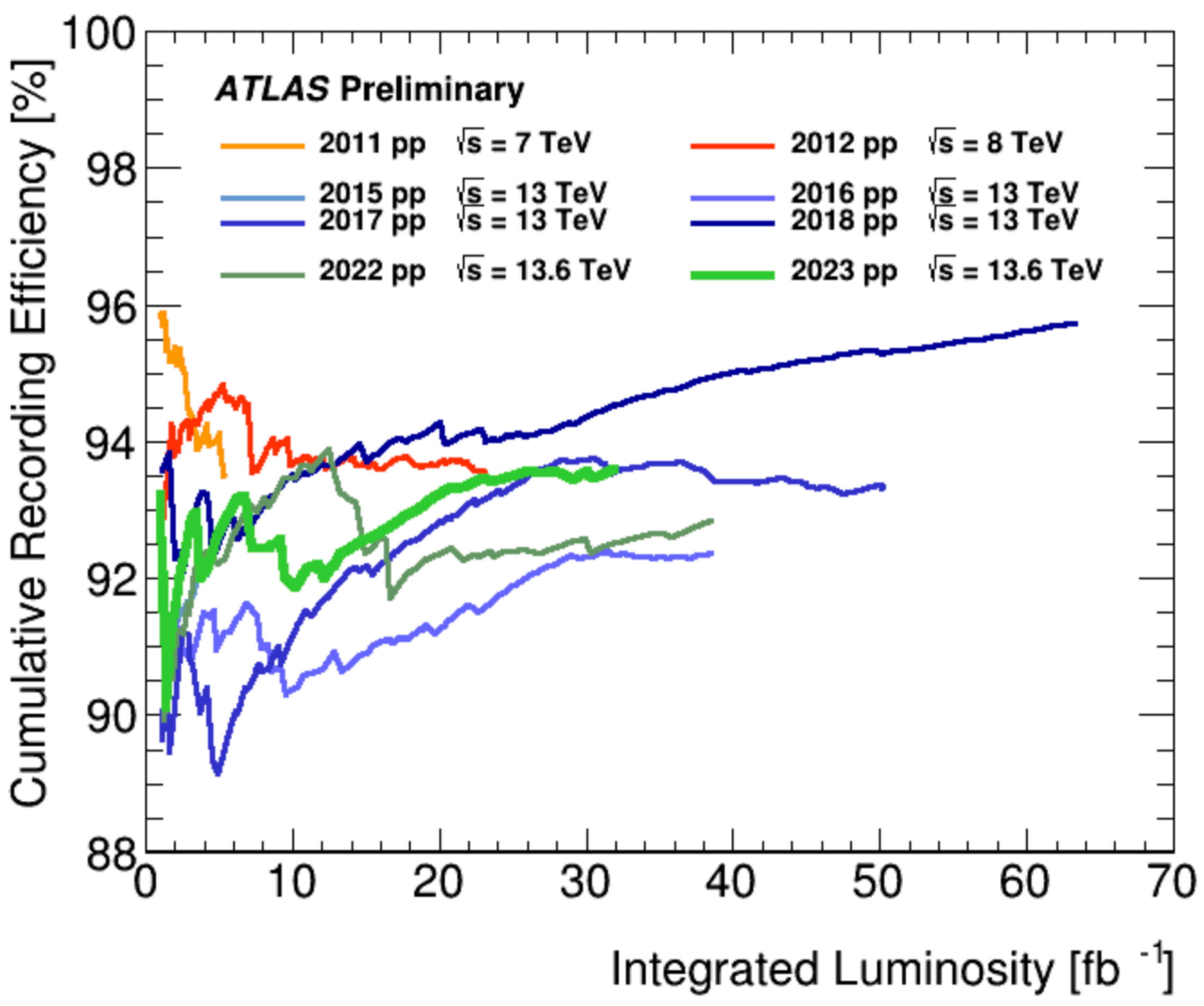
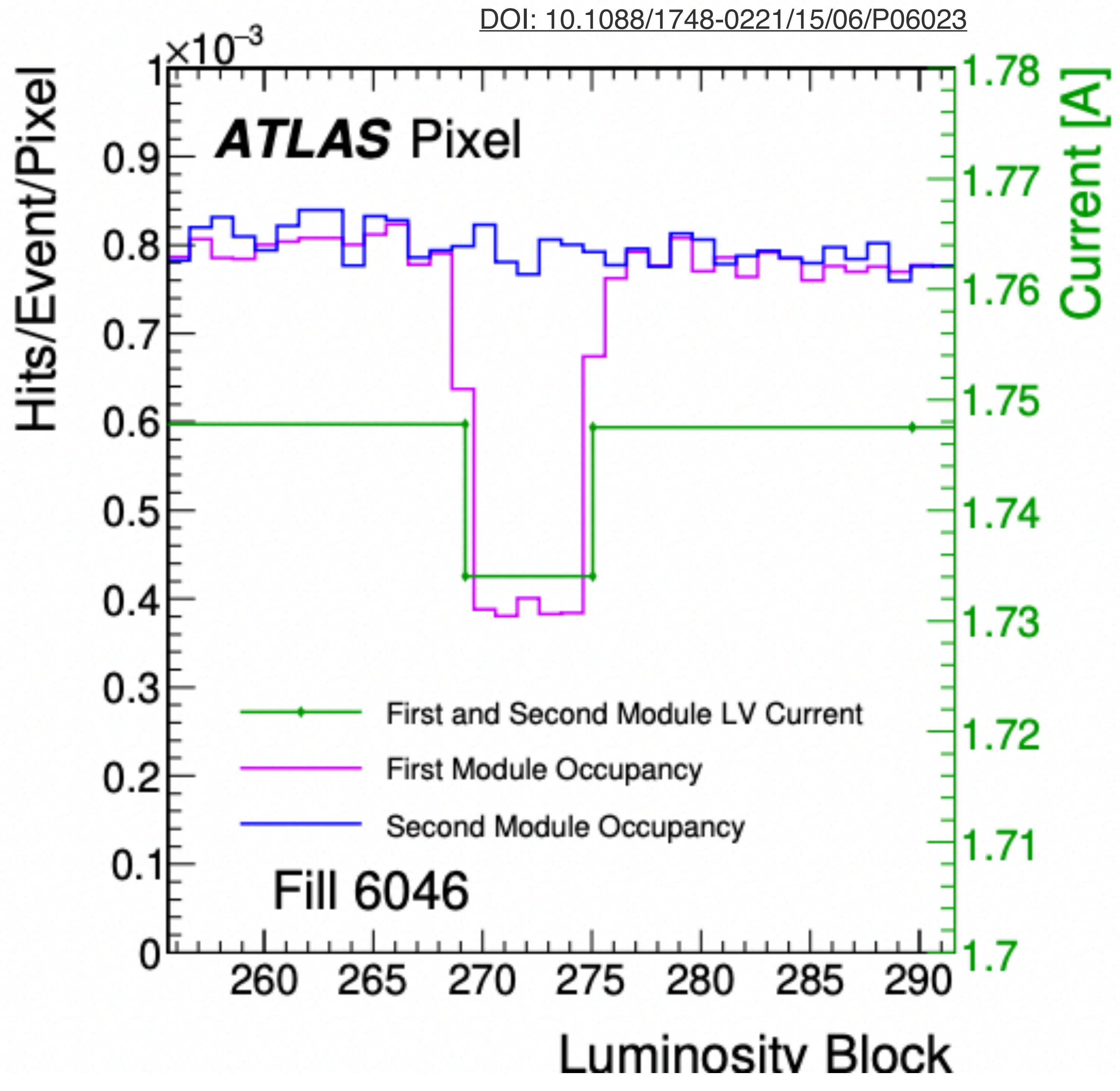
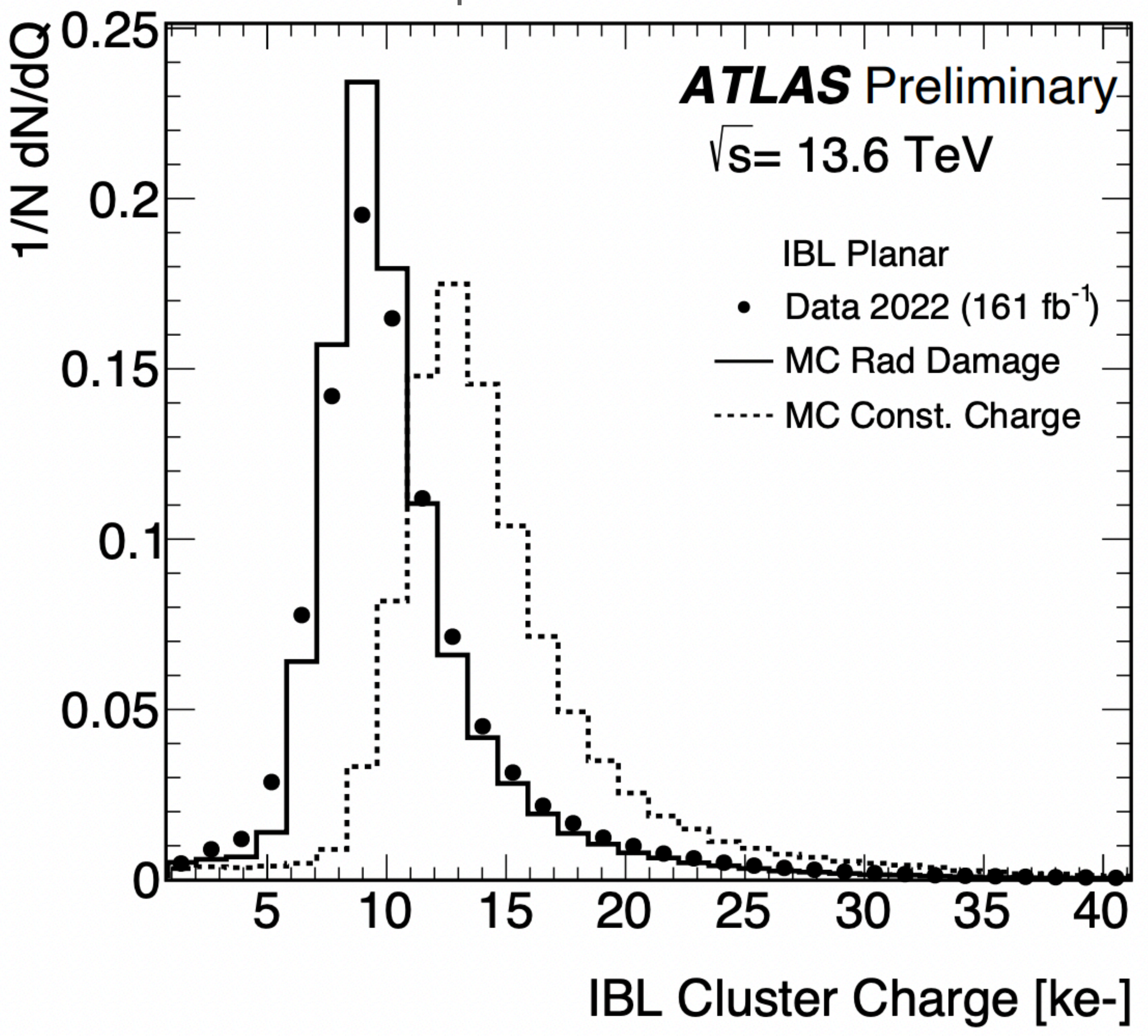
Pixel Overview







Pixel contributes well below 1% of the the total ATLAS dead time in 2022.

Radiation also impacts operation of the detector, effects of SEUs* are visible in the detector.

Physics performance matches well with MC simulation.

*SEU: Single Event Upset

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FE Reconfiguration @ECR

New DAQ features

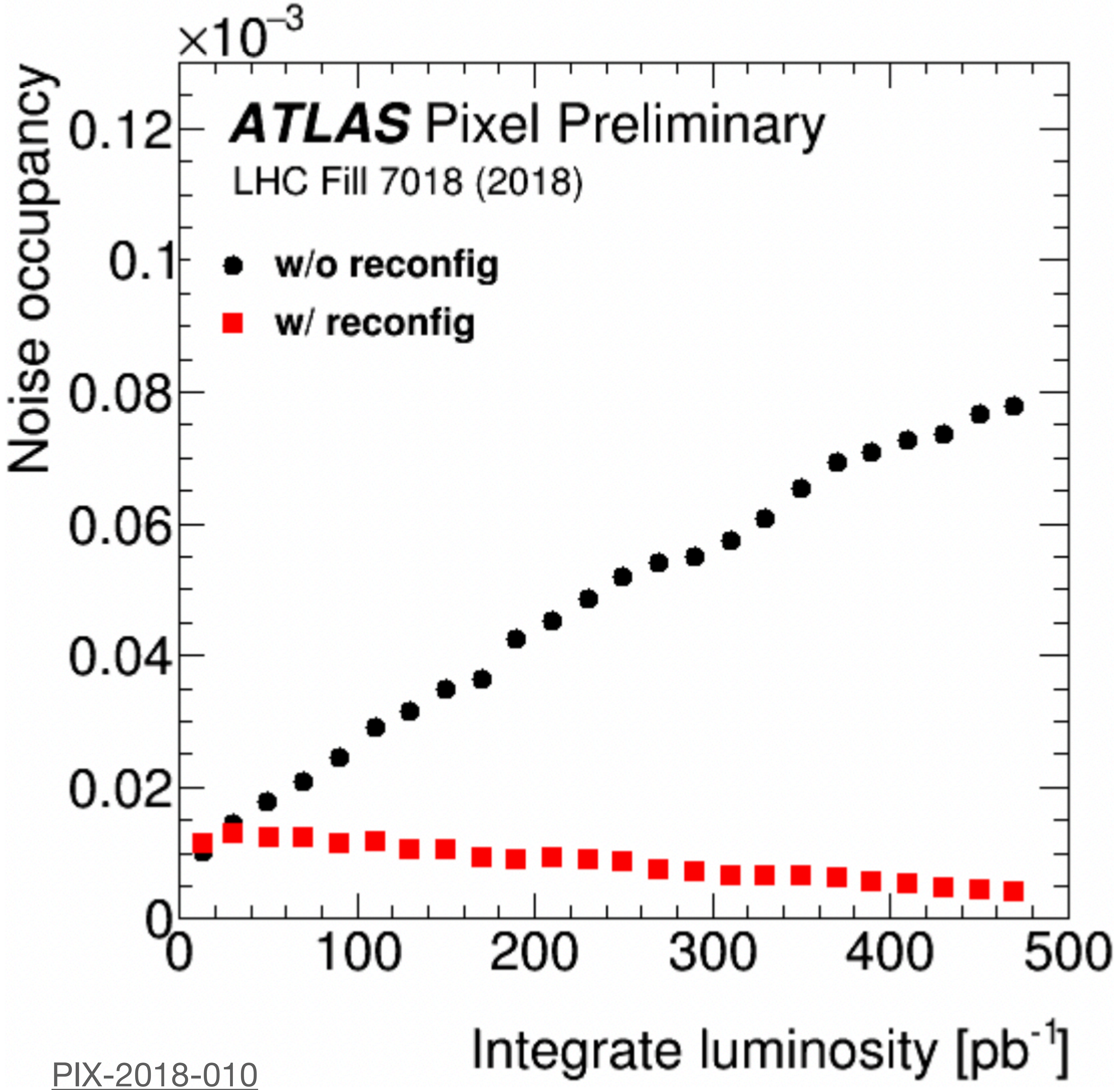
During operation the detector suffers from SEUs due to radiation effects on the ASICs

Every 5 seconds ATLAS sends a global Event Counter Reset (ECR) signal.

Guaranteed no triggers for 2ms. Since Run 2, we have used this to reconfigure global registers of IBL.

We have expanded this feature such that all pixels in IBL also have their pixel-level registers reconfigured every 11 minutes.

Global level reconfiguration was also deployed in all other layers this year.



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Smart L1 Forwarding

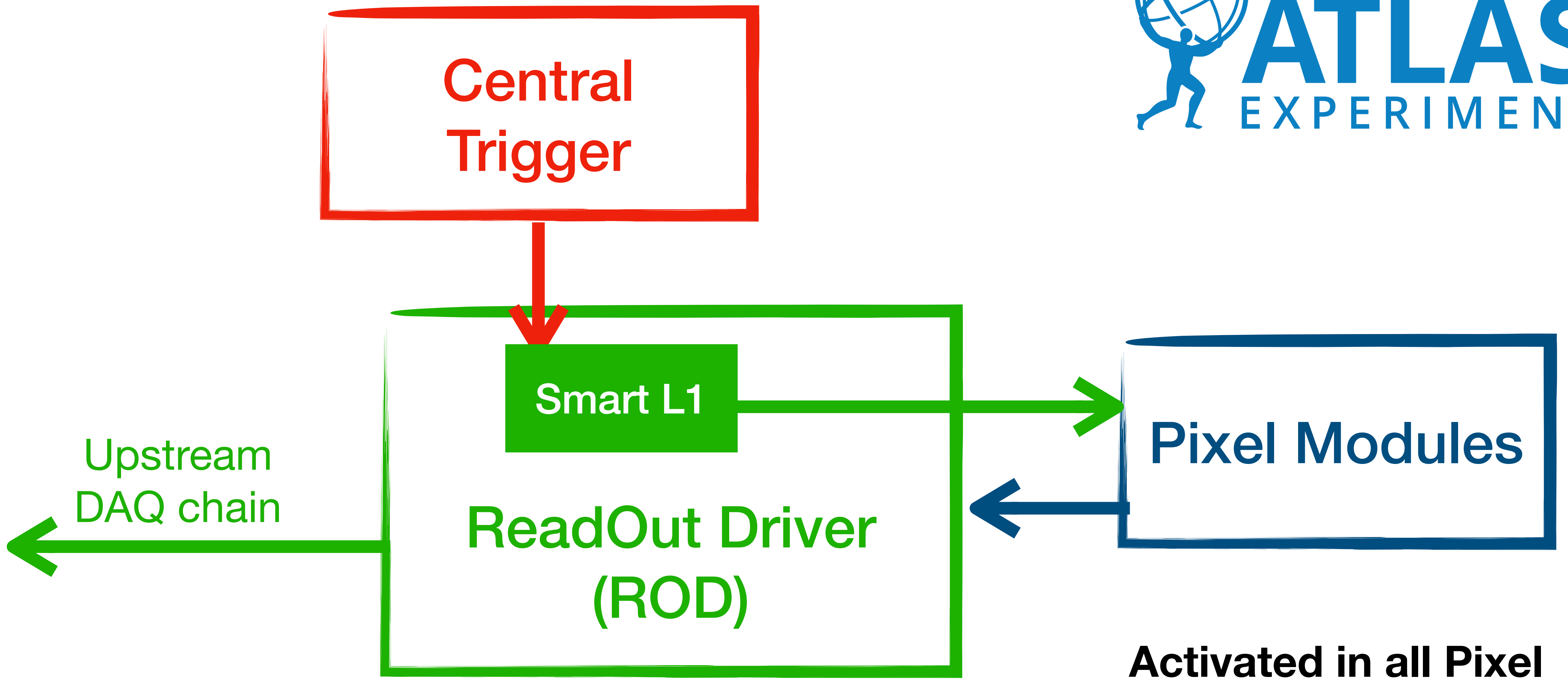
New DAQ features

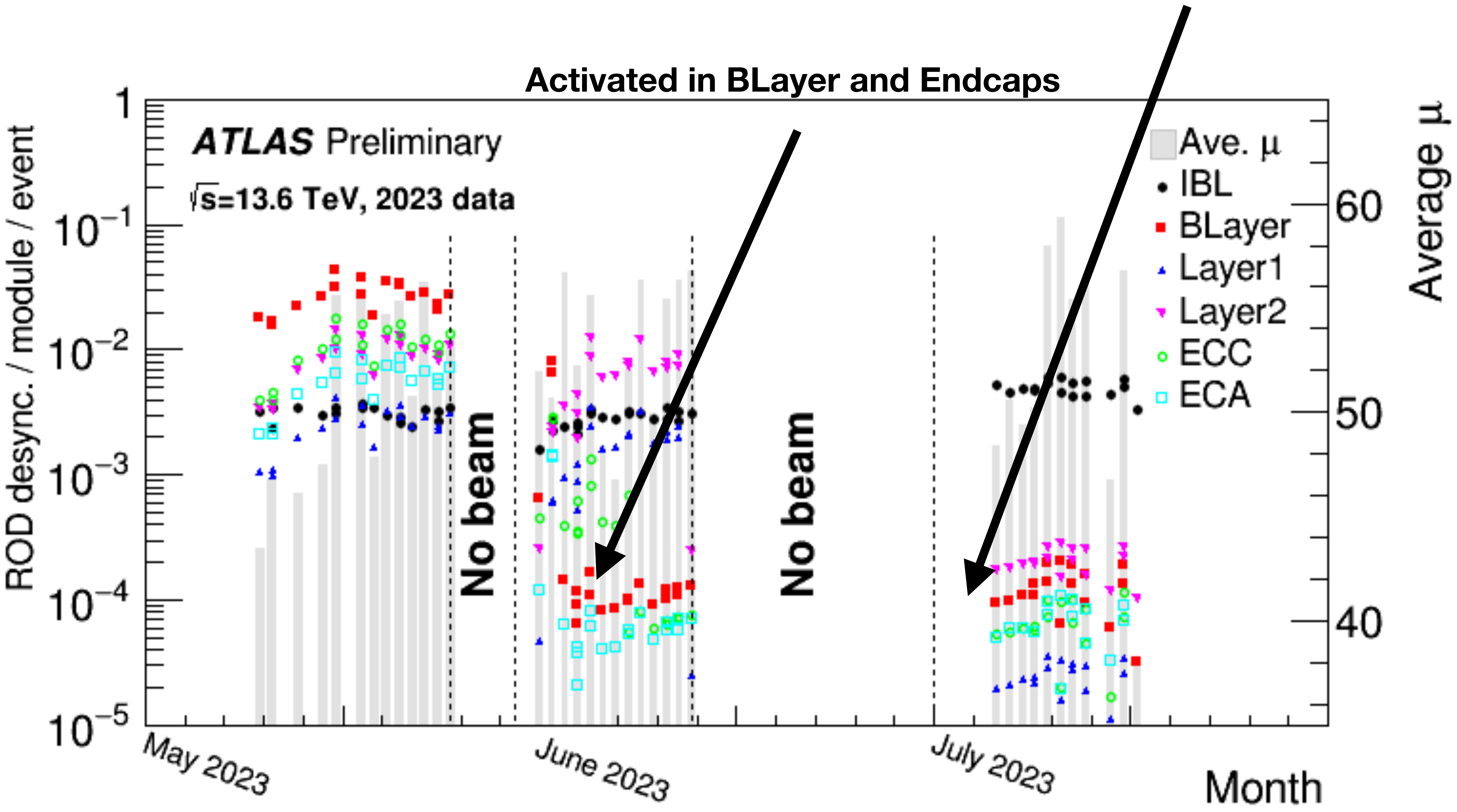
ROD builds an event, waits for all modules to reply with their data for a particular trigger.

A module that doesn't reply immediately might end up desynchronised if triggers keep arriving.

Smart L1 forwarding: tool implemented in the Pixel ROD firmware that holds sending triggers to **individual** modules with too many pending triggers.

Big impact in module desynchronisation.





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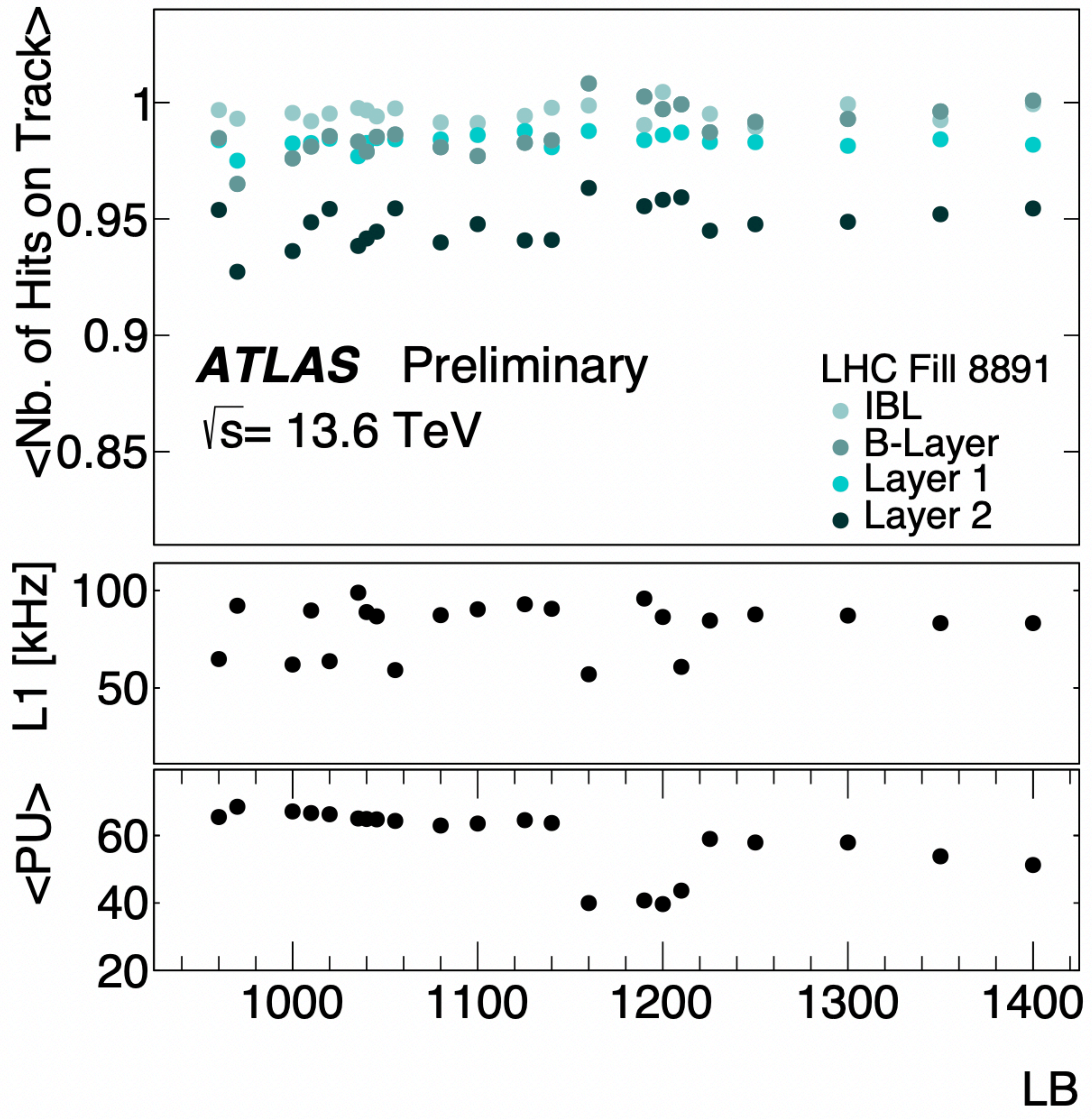
Probing the Limits

Pixel tracking efficiency in extreme environments

LHC not the limiting factor in luminosity delivery to the experiments.

In 2023 we showed we could operate at a <μ> 65 and 90 kHz trigger rate.

Try to push further, and see how physics performance is impacted under such conditions.



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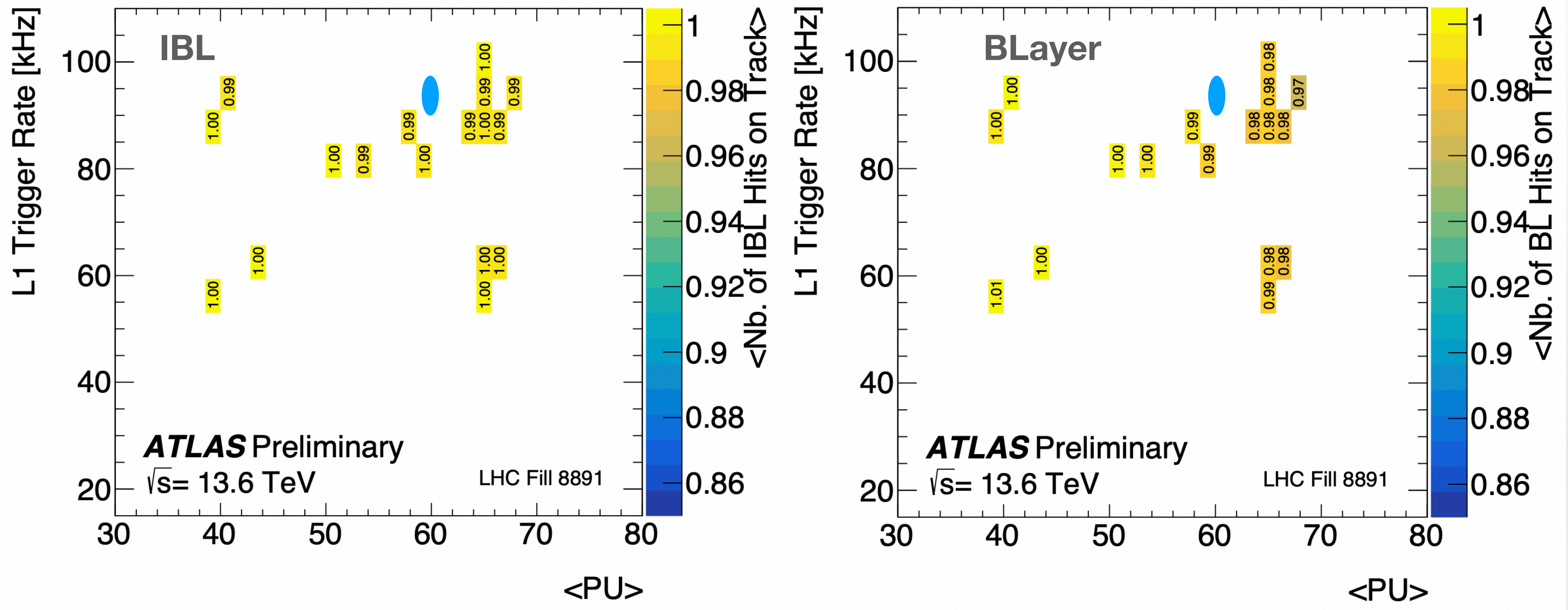
Probing the Limits

Pixel tracking efficiency in extreme environments

Scanned trigger rates at different values of <μ>, reaching up to 68.5.



Both IBL and Blayer kept up tracking performance !

: Original target for 2023

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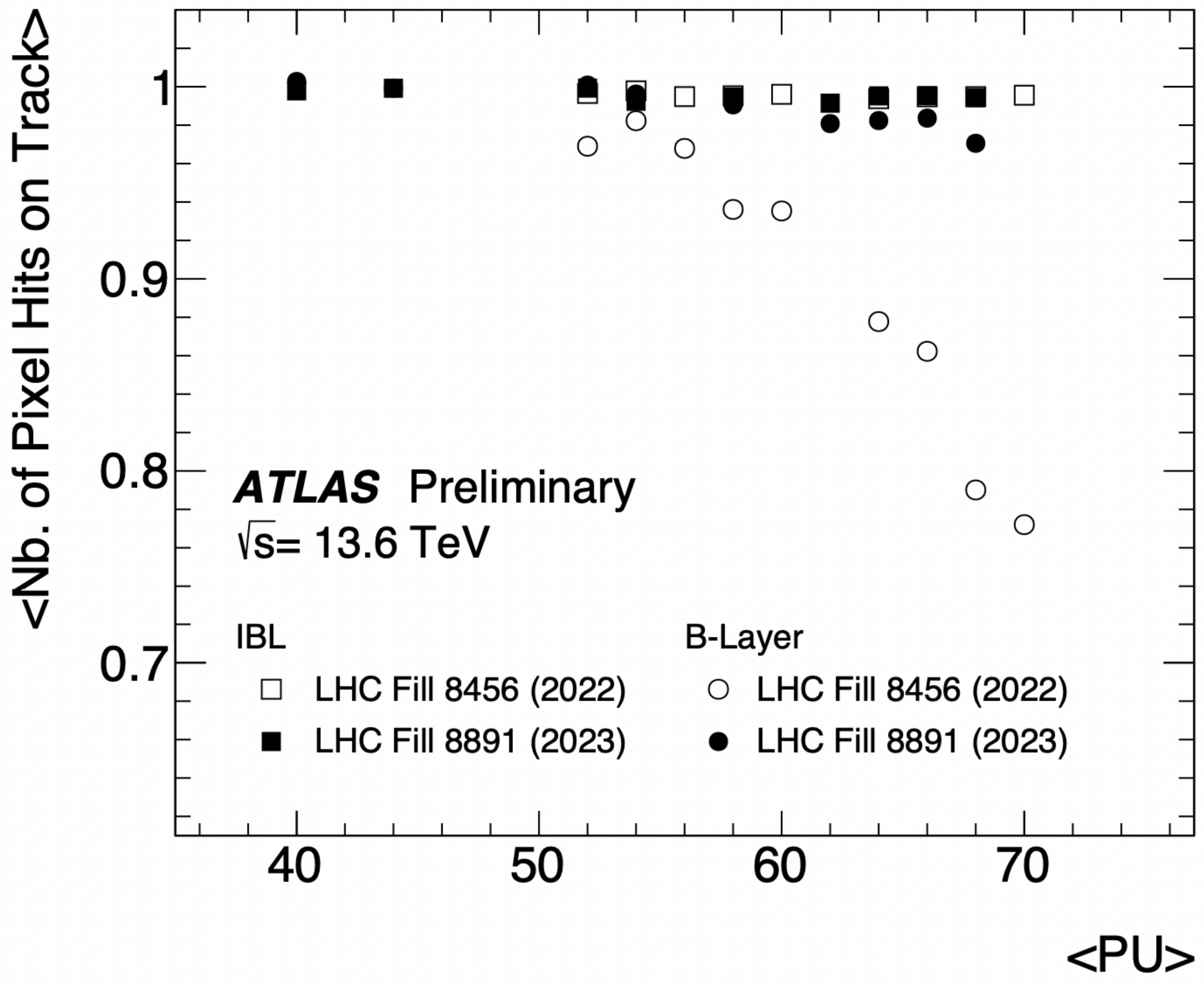
Probing the Limits

Pixel tracking efficiency in extreme environments

IBL, which has biggest impact in reconstruction, has stable performance through the ranges tested.

Big impact on performance of Blayer comparing original 2022 conditions with 2023.

All DAQ improvements previously discussed together with increase in the Blayer analog threshold play a role.



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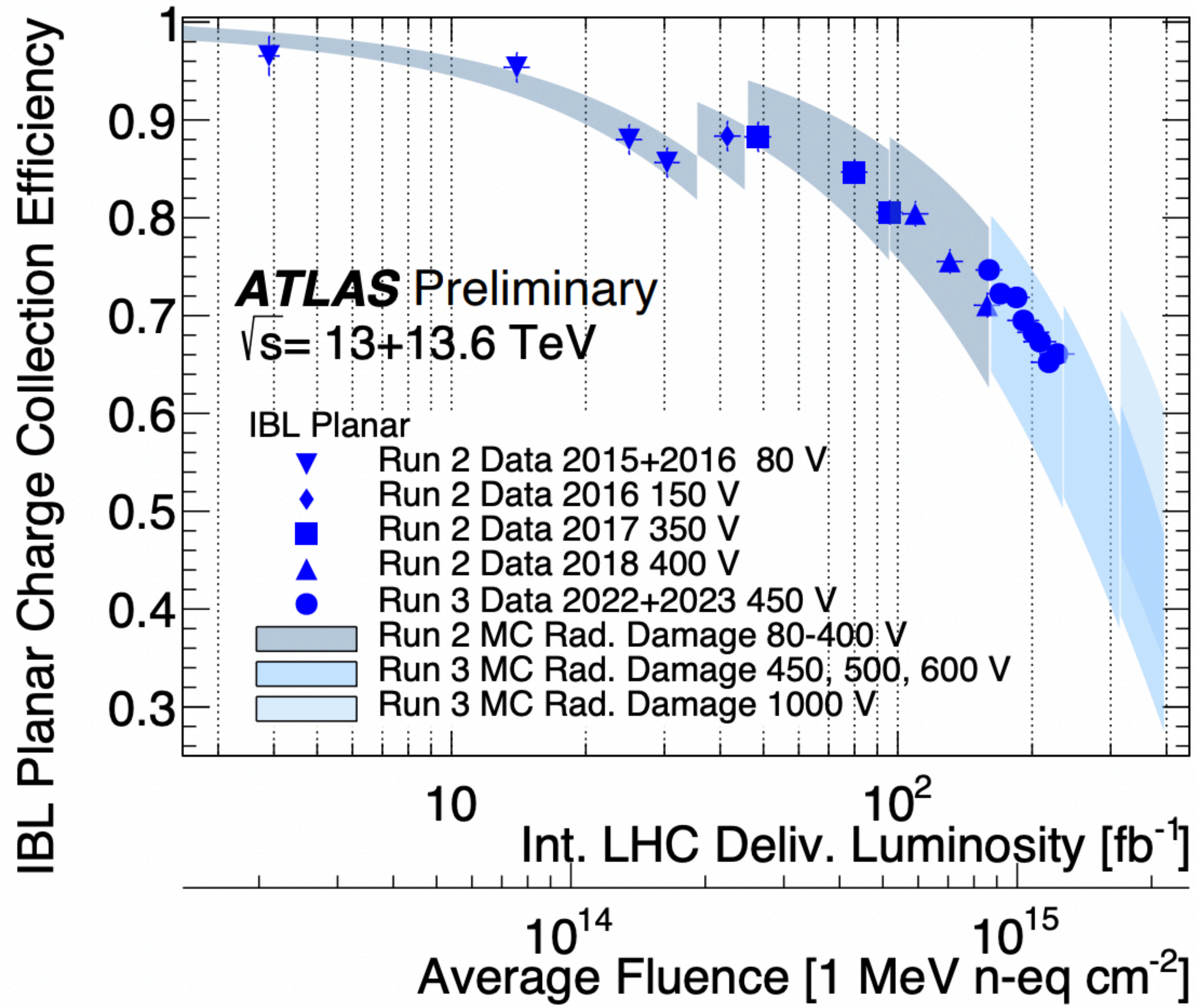
Future Performance

Radiation Damage



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With good modelling of radiation damage we can have a good idea of future charge collection efficiency.

Use HV scans twice a year to check CCE as a function of bias voltage.

IBL planar sensors can be biased up to 1000V, detector settings still at 450 V; plenty of margin for the next 2 years.

More details in Easwar's talk

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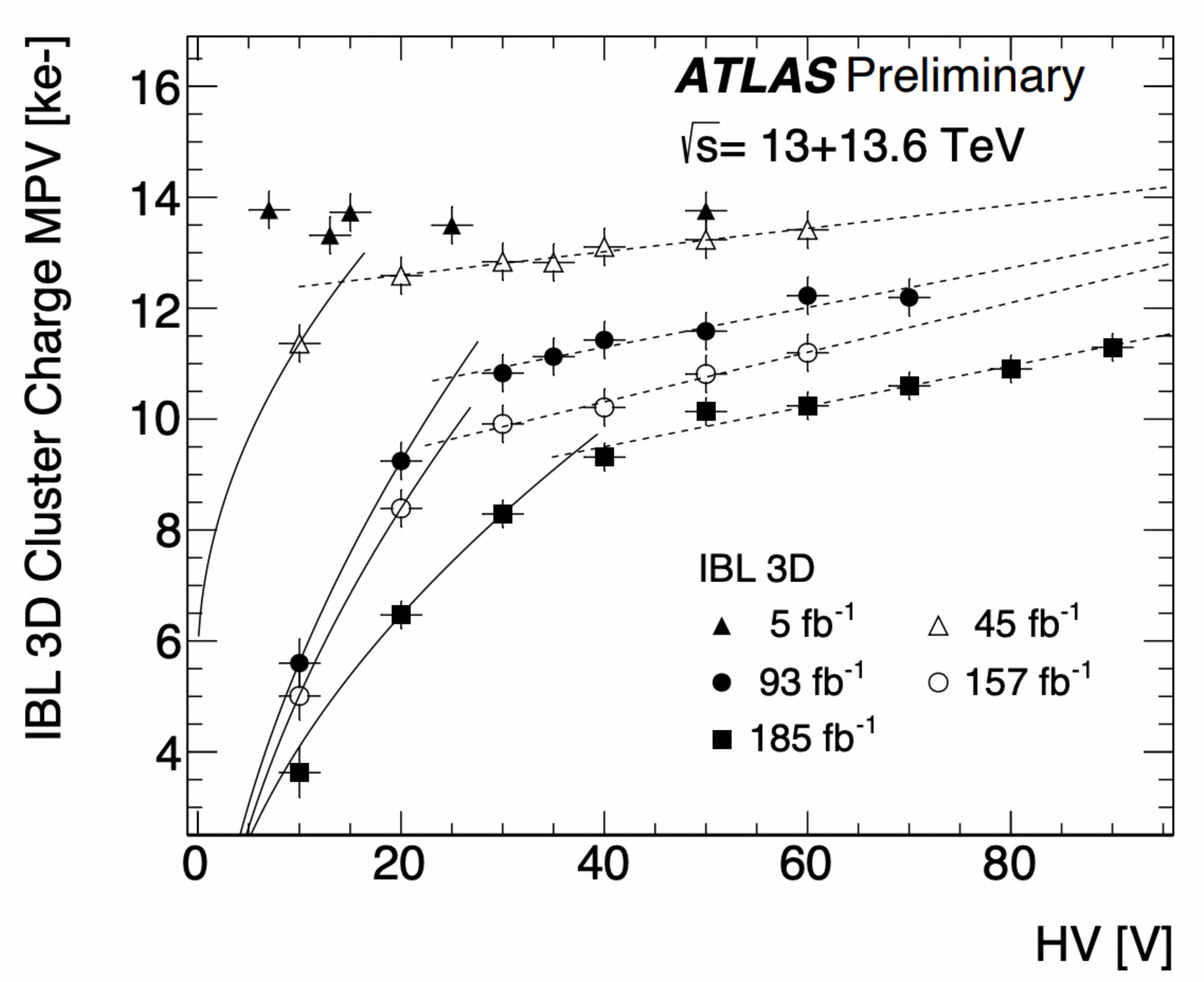
Future Performance

Radiation Damage



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Future Performance

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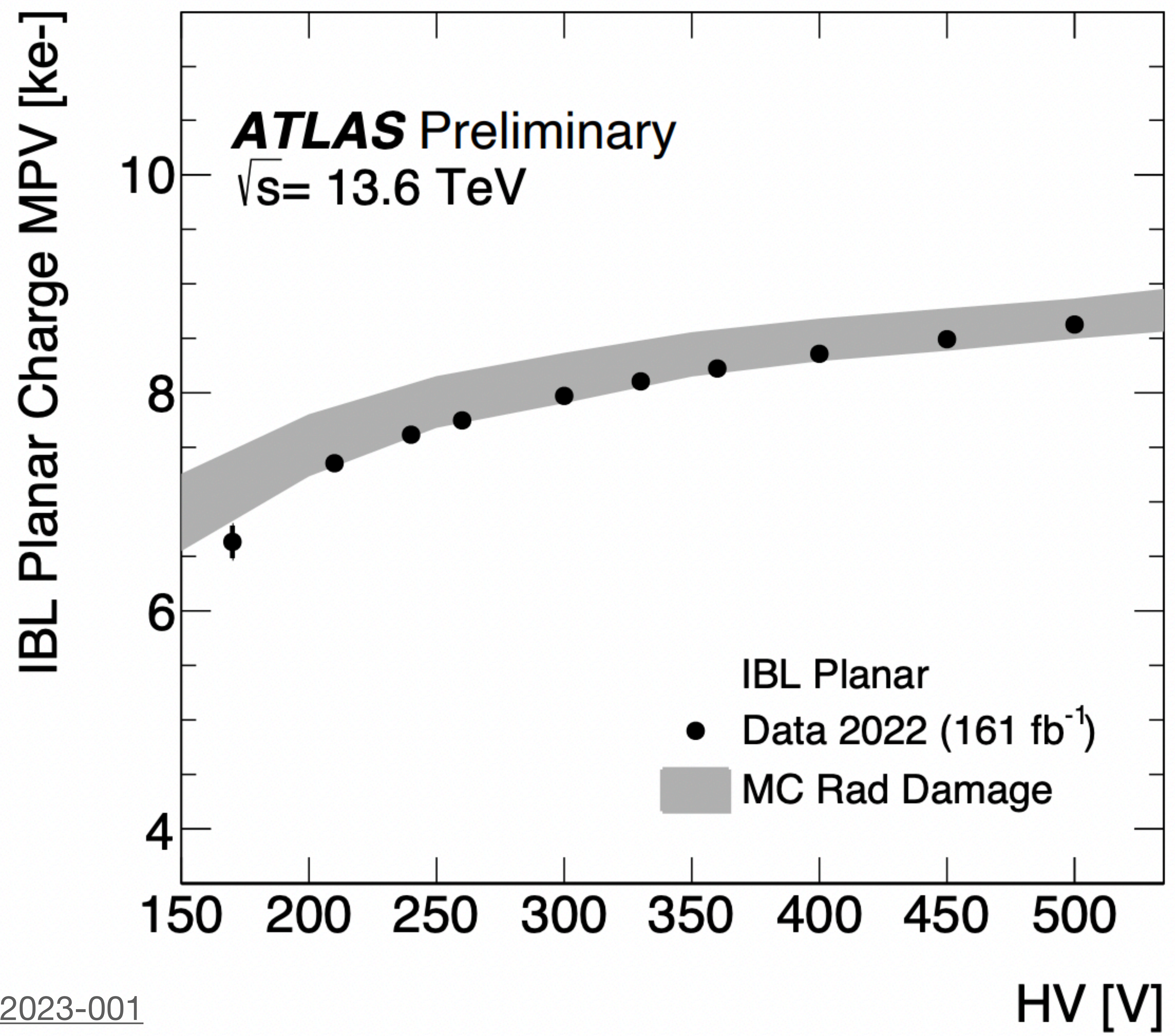

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Conclusion

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Conclusions

The reconfiguration @ ECR procedure was expanded into re-configuration of the global and pixel level registers in IBL and global level registers for Pixel detectors.

A new firmware feature of Smart L1 forwarding greatly improves the desynchronisation levels in Pixel modules.

We tested the operation of the detector under challenging conditions by testing the physics performance of the system under different combinations of $\langle \mu \rangle$ and trigger rate.

Radiation damage to the silicon sensor bulk and its impact on charge collection efficiency is well modelled and closely monitored.

The ATLAS Pixel detector has been operating very well with >99.9% data quality efficiency in physics data under challenging Run 3 conditions.

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Backup

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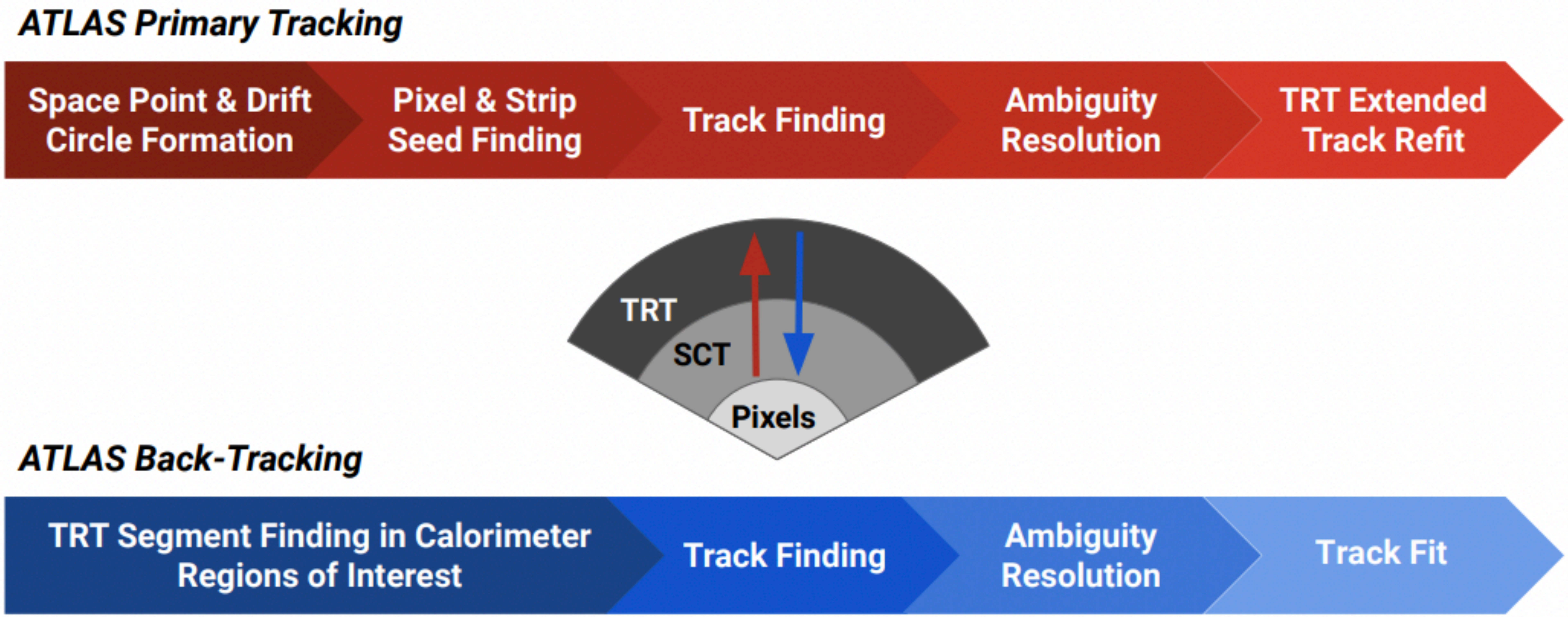

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Pixel-level Reconfiguration @ECR

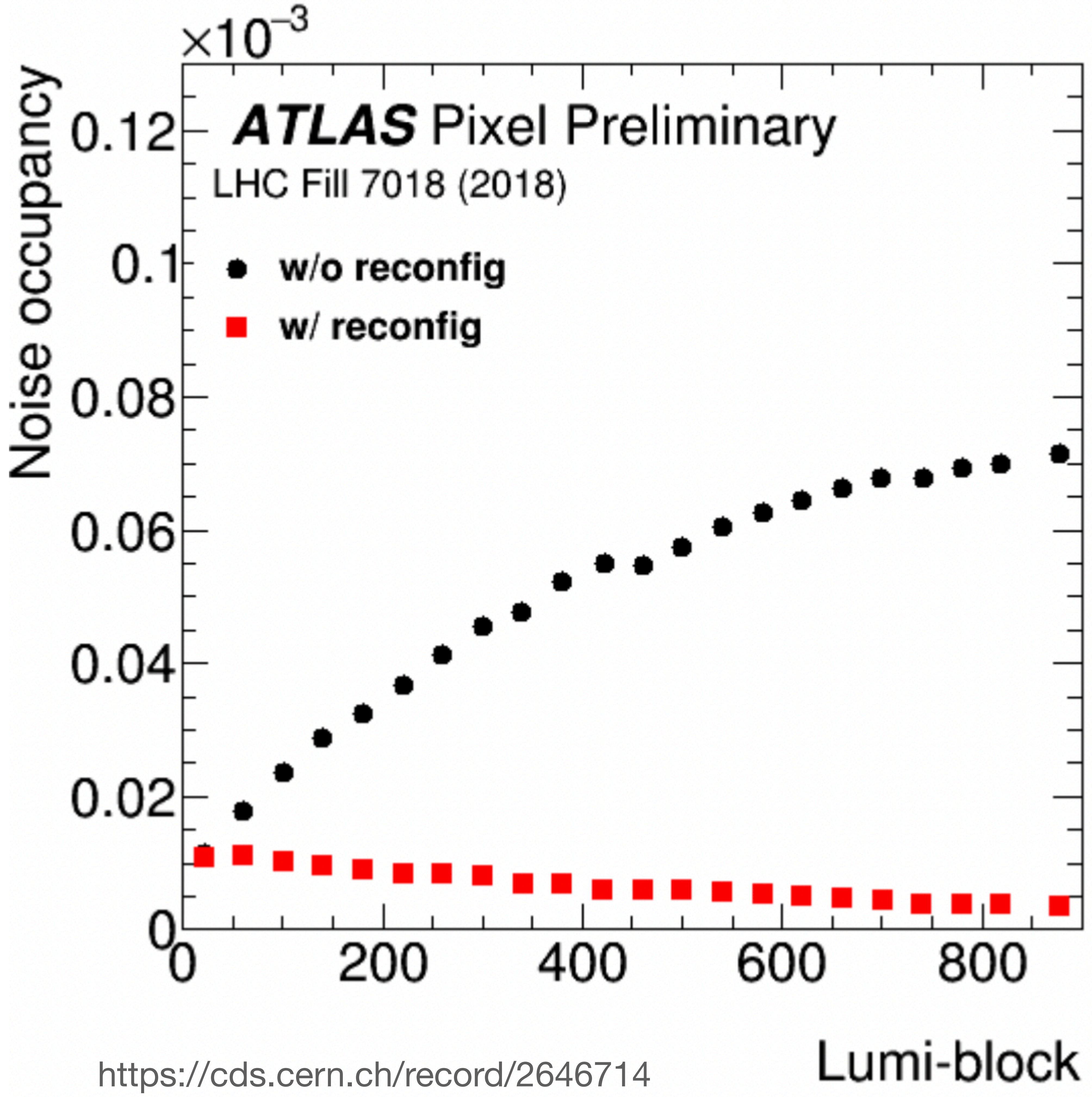
New DAQ features

Every 5 seconds ATLAS sends a global Event Counter Reset (ECR) signal.

Guaranteed no triggers for 2ms. Since Run 2, we have used this to reconfigure global registers of IBL and empty trigger FIFOs in pixel.

We have expanded this feature such that of all pixels in IBL also have their pixel-level registers reconfigured every 11 minutes.

Global level reconfiguration was also deployed in all other layers.



https://cds.cern.ch/record/2646714

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Backup

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/RunStatsPublicResults2010

ATLAS EXPERIMENT

ATLAS pp Run-3: 2022

Trigger	Inner Tracker			Calorimeters		Muon Spectrometer			Magnets	
L1	Pixel	SCT	TRT	LAr	Tile	MDT	RPC	TGC	Solenoid	Toroid
98.82	99.95	99.85	99.89	98.98	99.67	99.99	97.95	99.72	100	100

Good for physics: 93.1% (31 fb^{-1})

Luminosity weighted relative detector uptime and good data quality efficiencies (in %) during stable beam in pp collision physics runs with 25 ns bunch-spacing at $\sqrt{s}$=13.6 TeV for the 2022 Run-3 period, corresponding to a delivered integrated luminosity of 36 fb^{-1} and a recorded integrated luminosity of 34 fb^{-1}. Runs with specialized physics goals or non-standard running conditions, amounting to 1.7 fb^{-1}, are not considered and thus not included in the denominator of the efficiency calculation. Dedicated luminosity calibration activities during LHC fills used 0.6% of recorded data in 2022 and are included in the inefficiency. Inefficiencies related to object reconstruction, which amount to 1.3%, are currently included in the overall inefficiency but will be recovered in future reprocessings of the data, as will approximately 0.4% of the data lost from the LAr inefficiency. When the stable beam flag is raised, the tracking detectors undergo a so-called "warm start", which includes a ramp of the high-voltage and turning on the pre-amplifiers for the Pixel system. The inefficiency due to this, as well as the DAQ inefficiency, are not included in the table above, but accounted for in the ATLAS recording efficiency. The luminosity good for physics is 31 fb^{-1}. It is reduced to 29 fb^{-1} (26 fb^{-1}) for analyses relying on muon-based (jet- and missing-transverse-momentum-based) triggers due to incorrect detector conditions deployed in early 2022.

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