ATLAS EXPERIMENT

Operational Experience and Performance with the ATLAS PIXEL DETECTOR in Run 3 at the LHC

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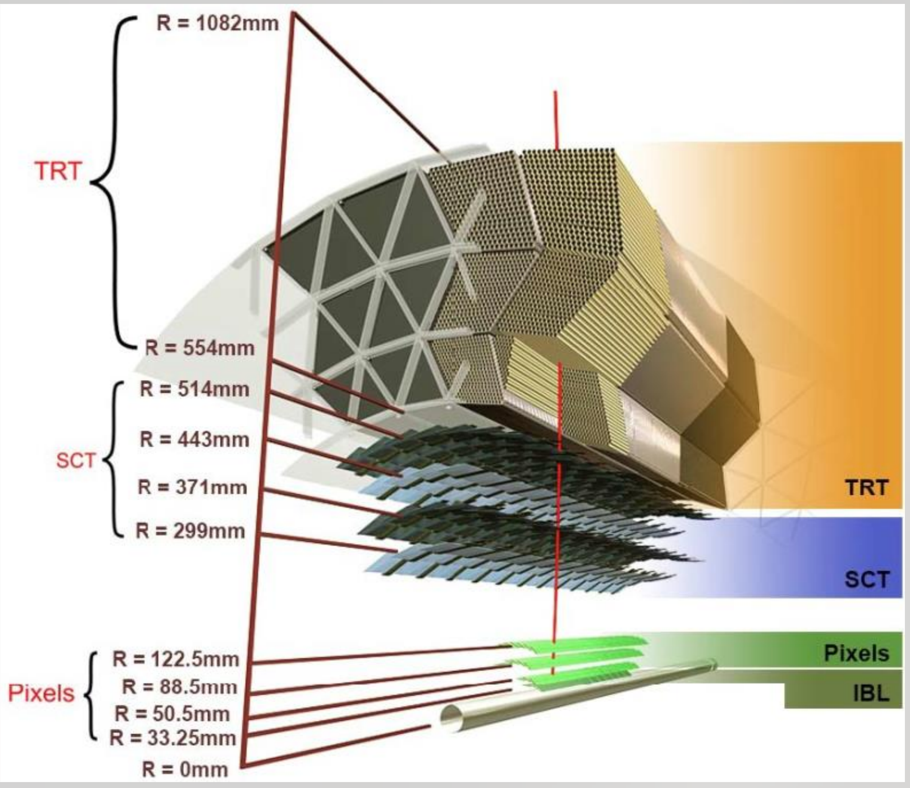
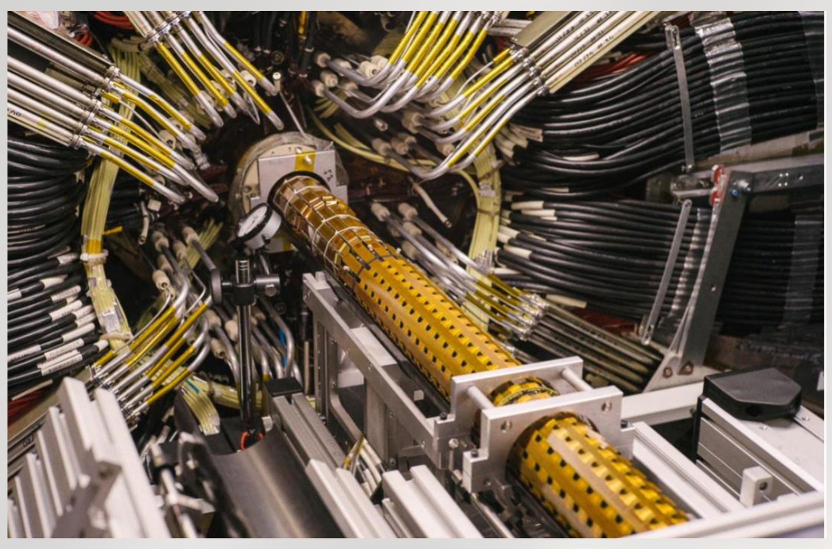
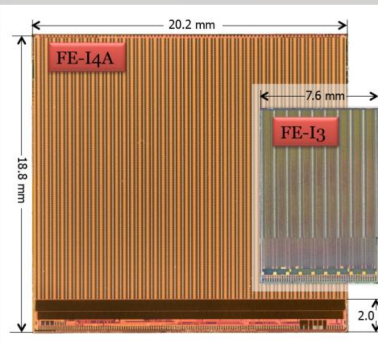
The ATLAS Pixel Detector





Original Pixel Detector consists of 3 barrel layers and 2x3 endcap disks. IBL (Insertable B-Layer) was installed during the first long LHC shutdown [1,2,3].



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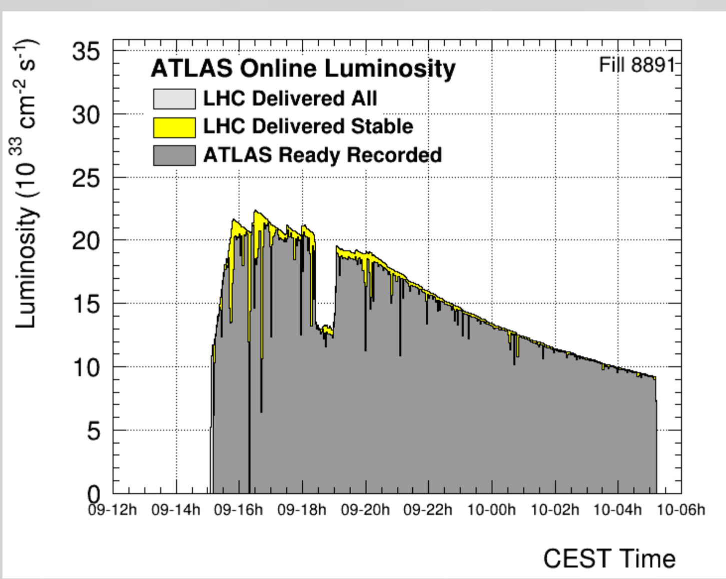
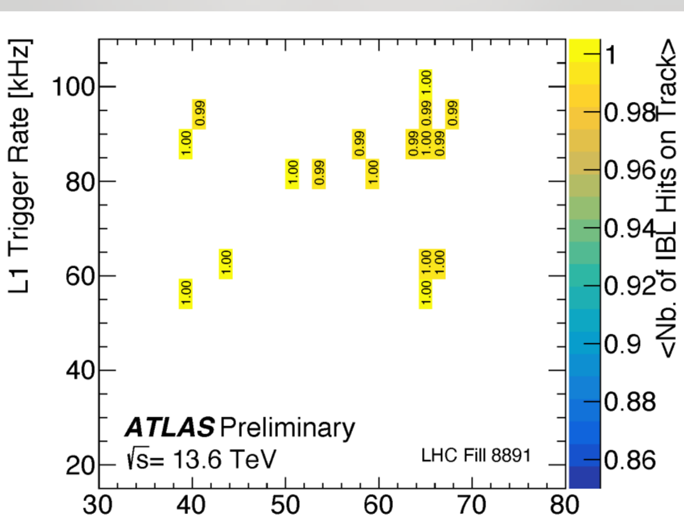
	Pixel	IBL
Channels	80x10^6	12x10^6
Pixel implants	n+-in-n	n+-in-n (planar) n+-in-p (3D)
Pixel size [µm x µm]	50x400	50x250
Design fluence [1 MeV n_{eq} cm^{-2}]	1x10^{15}	5x10^{15}
CMOS technology	250 nm	130 nm
FE ASICs per sensor	16 (+1MCC)	2 (planar) 1 (3D)
ToT information	8 bit	4 bit

Performance of the Pixel Detector

- Special fill in the beginning of 2023 to probe the limits of the Pixel Detector in terms of pile-up and trigger rate
- Scanned trigger rates at different values of <µ>, reaching up to 68.5.
- IBL, which has biggest impact in reconstruction, has a stable performance through the tested ranges.
- Big impact on performance of B-layer comparing original 2022 conditions with 2023. Possible thanks to improvements in the readout and adjustment of threshold settings. B-Layer was designed for <µ> = 23.





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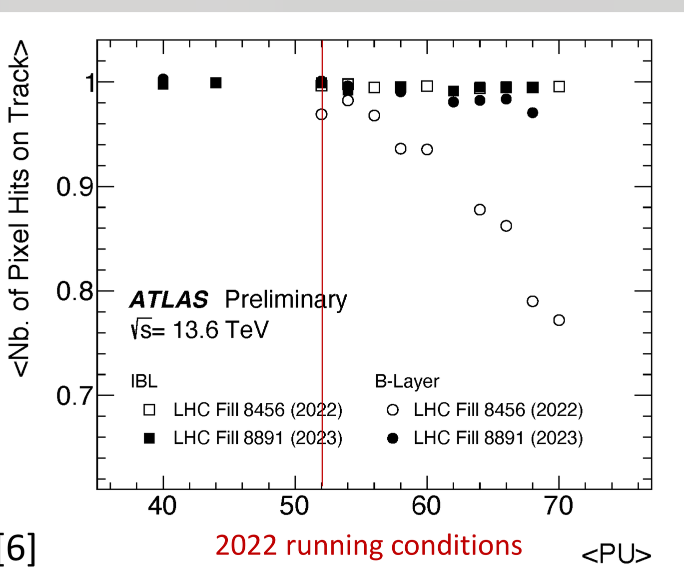

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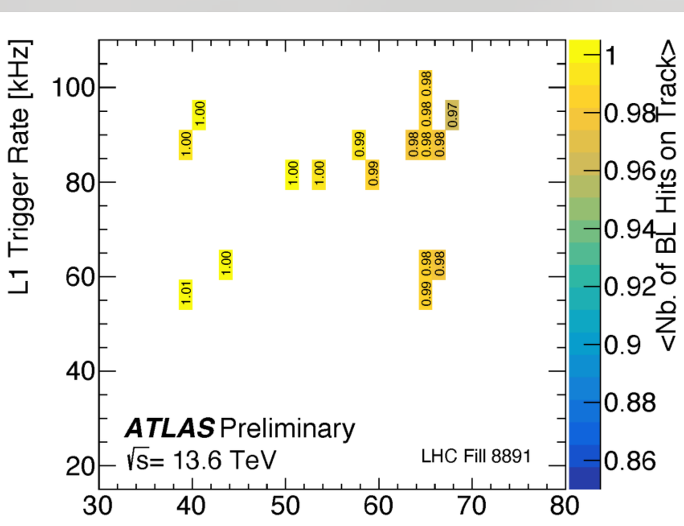

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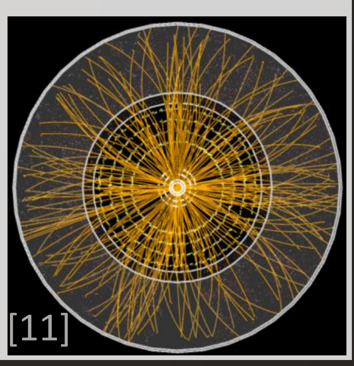
- *All Pixel layers can deliver high efficiency tracking performance beyond the ATLAS target conditions.*

Operations Summary

- The Pixel Detector performs well!
- No major hardware failures after replacement of the on-detector opto-electrical conversion boards in early 2021 because of dying VCSELs.
- Average deadtime of 0.03 % during stable beams on the entire 2023 dataset.
- 99.8 % data quality efficiency („Good for Physics") in Pixel in 2023.
- Retaining expertise is essential. For succesful data taking, and to react to challenging conditions.
- Even at this stage, still improvements possible and needed.
- Strive for streamlining operations and for automation.
- Radiation damage:
  - Stable cooling conditions, minimize downtime.
  - Regular, careful monitoring
  - Good modelling of the effects to minimize impact on physics objects



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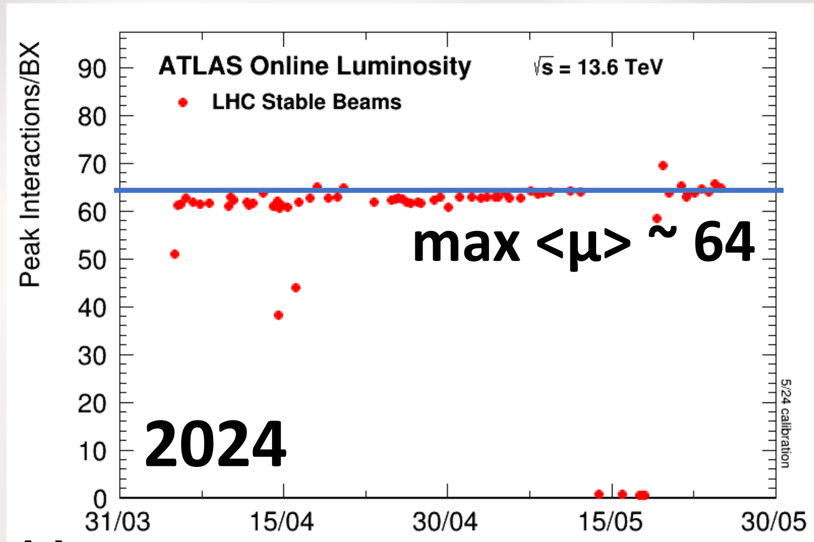
LHC Run 3



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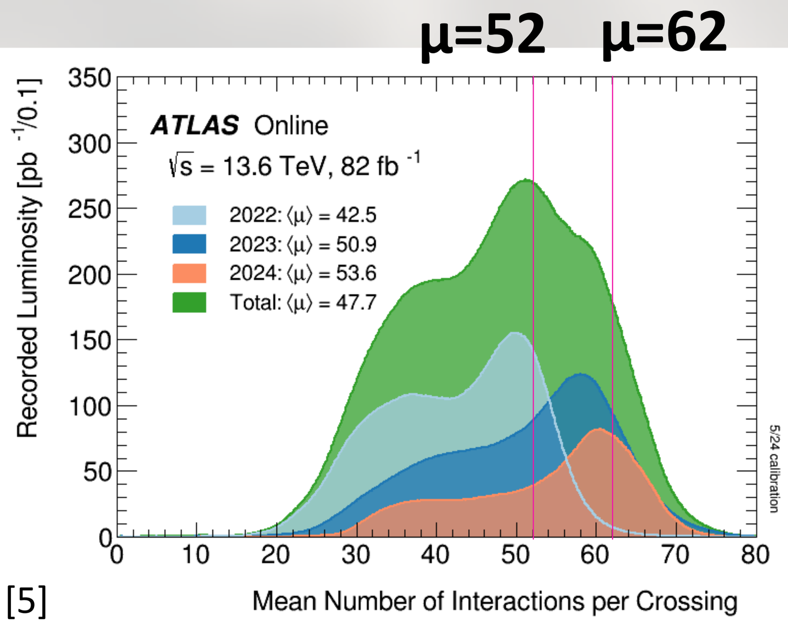

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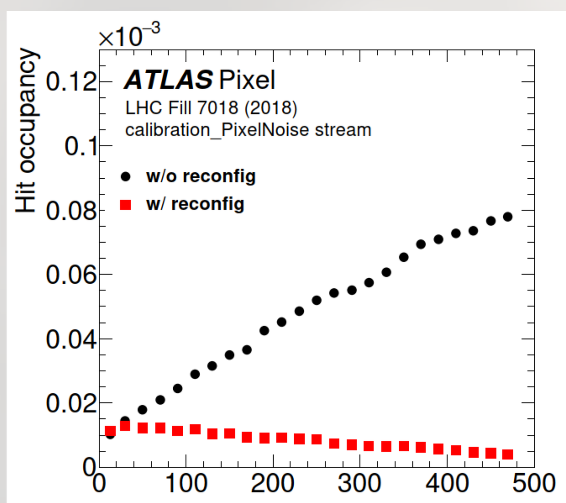
- LHC Run 3: 2022 – 2025
- End of 2022: Running at a significantly higher instantaneous luminosity is possible. This was previously limited by the heatload in the arcs. → ATLAS was levelling in 2023 at a <µ> of 62 and even higher in 2024.

µ = number of interactions per bunch crossing, pile-up

New DAQ features

- Deadtimeless reconfiguration is essential to mitigate the effect of Single Event Effects in IBL. A guaranteed 2 ms window without triggers every five seconds (when ATLAS sends the „Event Counter Reset") is used to reconfigure the global registers. This mechanism was expanded, so that each pixel register gets reconfigured every 11 minutes.
- Significant reduction in noisy and quiet pixels
- A new firmware has been deployed that keeps track of the number of pending triggers for each module. In this way it can be prevented that a module receives more triggers that it can handle without desynchronizing due to buffer sizes.
- Instead of sending a trigger, a dummy fragment is inserted into the data stream. With this mechanism only single events are lost per module, instead of all events up to the next reset.
- Improves Pixel desynchronization by several orders of magnitude.



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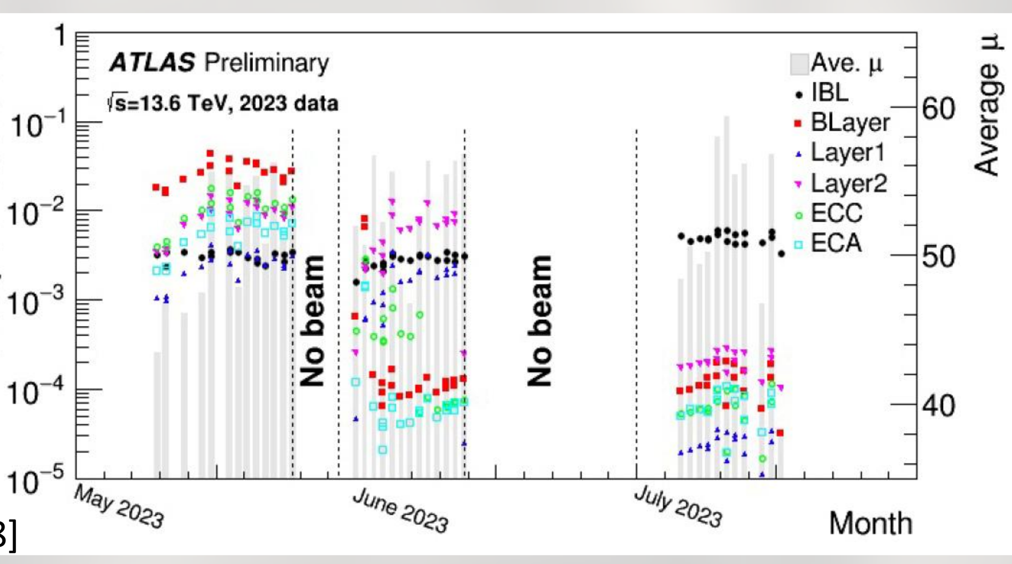

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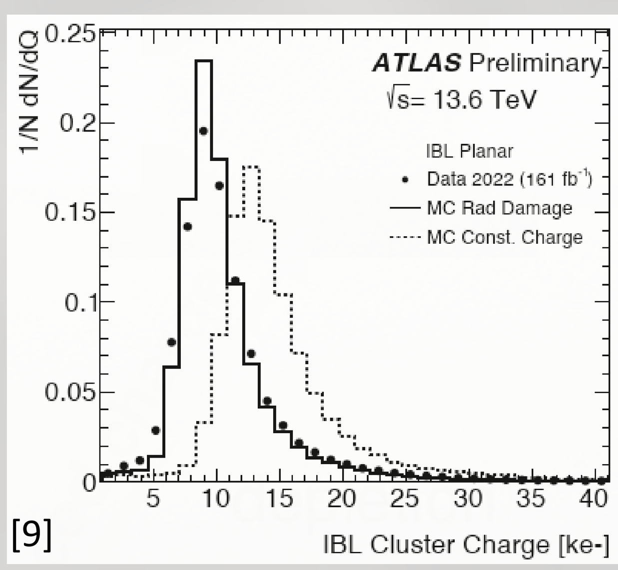
Radiation Damage

- Increased integrated luminosity and fluence means more radiation damage effects
- Two aspects for mitigation: optimize detector conditions on the one side and on the other side monitoring and modelling/simulation of radiation damage to minimize the effects on physics objects.
- Keep periods without cooling (e.g. maintenance) as short as possible to avoid reverse annealing.
- Regular monitoring of depletion voltage at least twice a year, and adjustment of operational voltage for each data taking period.
- Threshold adjustments are constrained by readout efficiency considerations.
- Using leakage current measurement to determine fluence
- Dedicated radiation damage simulation based on realistic Si bulk E-field maps at different fluences and bias voltages. Adopted in official ATLAS MC.



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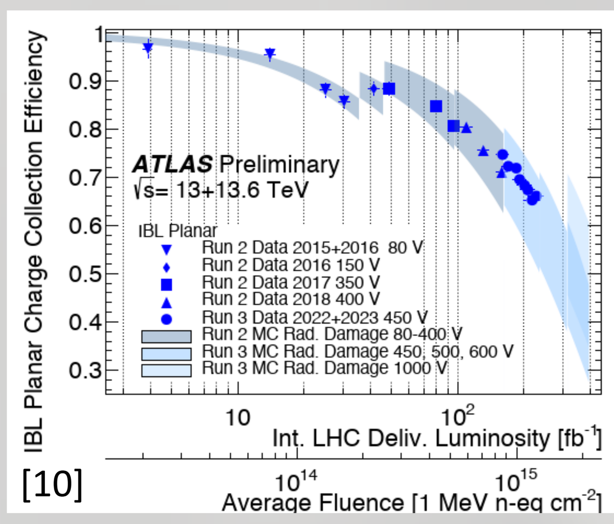

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References

[1] G. Aad et al., ATLAS pixel detector electronics and sensors, 2008 JINST 3 (P07007)

[2] B. Abbott et al., Production and Integration of the ATLAS Insertable B-Layer, 2018 JINST 13 (T05008)

[3] ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider: A Description of the Detector Configuration for Run 3, JINST 19 (2024) P05063

[4] ATLAS IBL Collaboration, Prototype ATLAS IBL Modules using the FE-I4A Front-End Readout Chip, 2012 JINST 7 P11010

[5] ATLAS Collaboration, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun3

[6] ATLAS Collaboration, https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/PIX-2023-003

[7] G. Balbi et al., Measurements of Single Event Upset in ATLAS IBL, 2020 JINST 15 (P06023)

[8] ATLAS Collaboration, https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/PIX-2023-004

[9] ATLAS Collaboration, ATL-PHYS-PUB-2022-033

[10] ATLAS Collaboration, https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/PIX-2023-001

[11] From https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayRun3Collisions