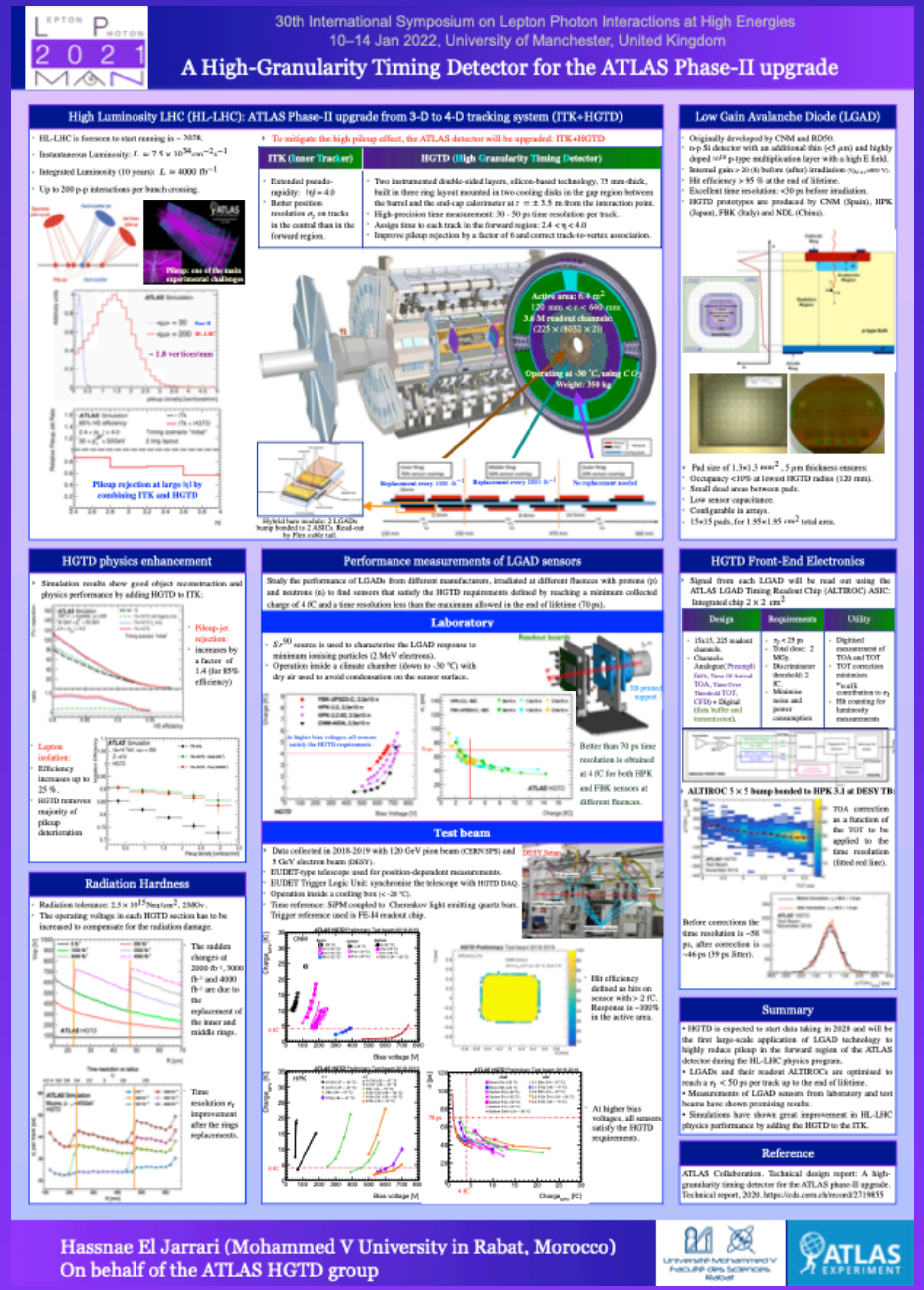
A High-Granularity Timing Detector for the ATLAS Phase-II upgrade

Poster prize talk 1



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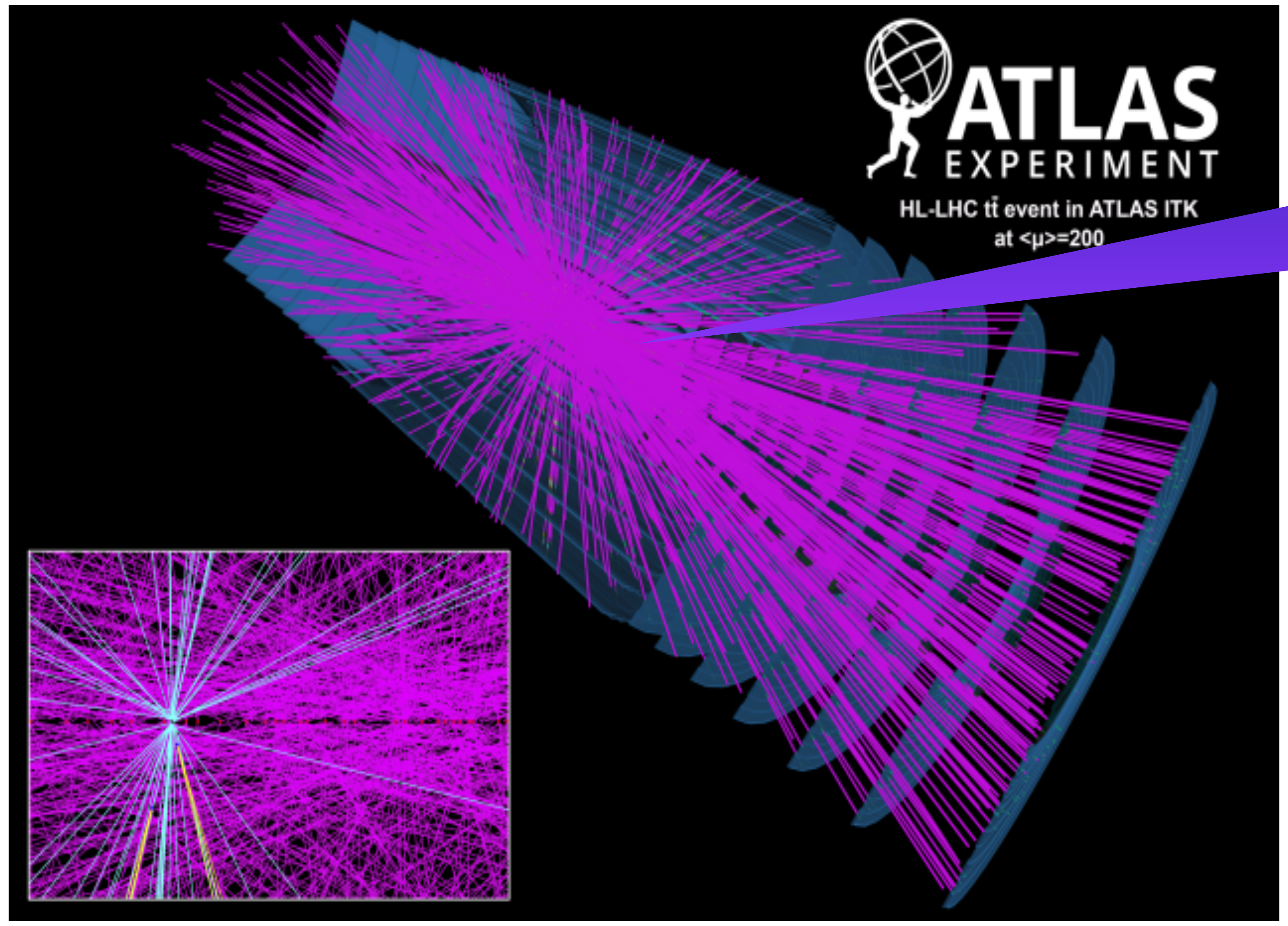
30th International Symposium on Lepton Photon Interactions at High Energies
10–14 Jan 2022, University of Manchester, United Kingdom.

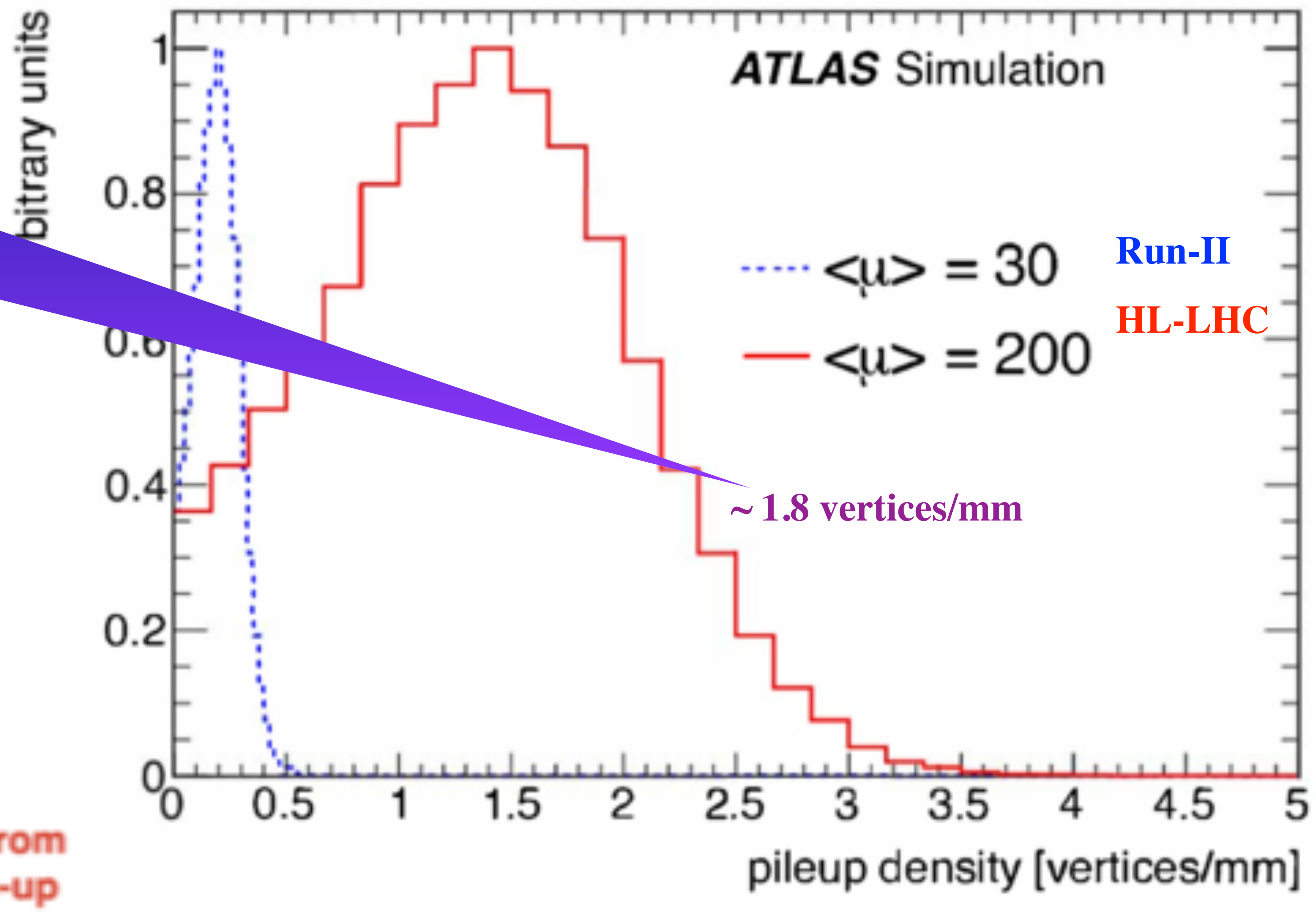
14 Jan 2022

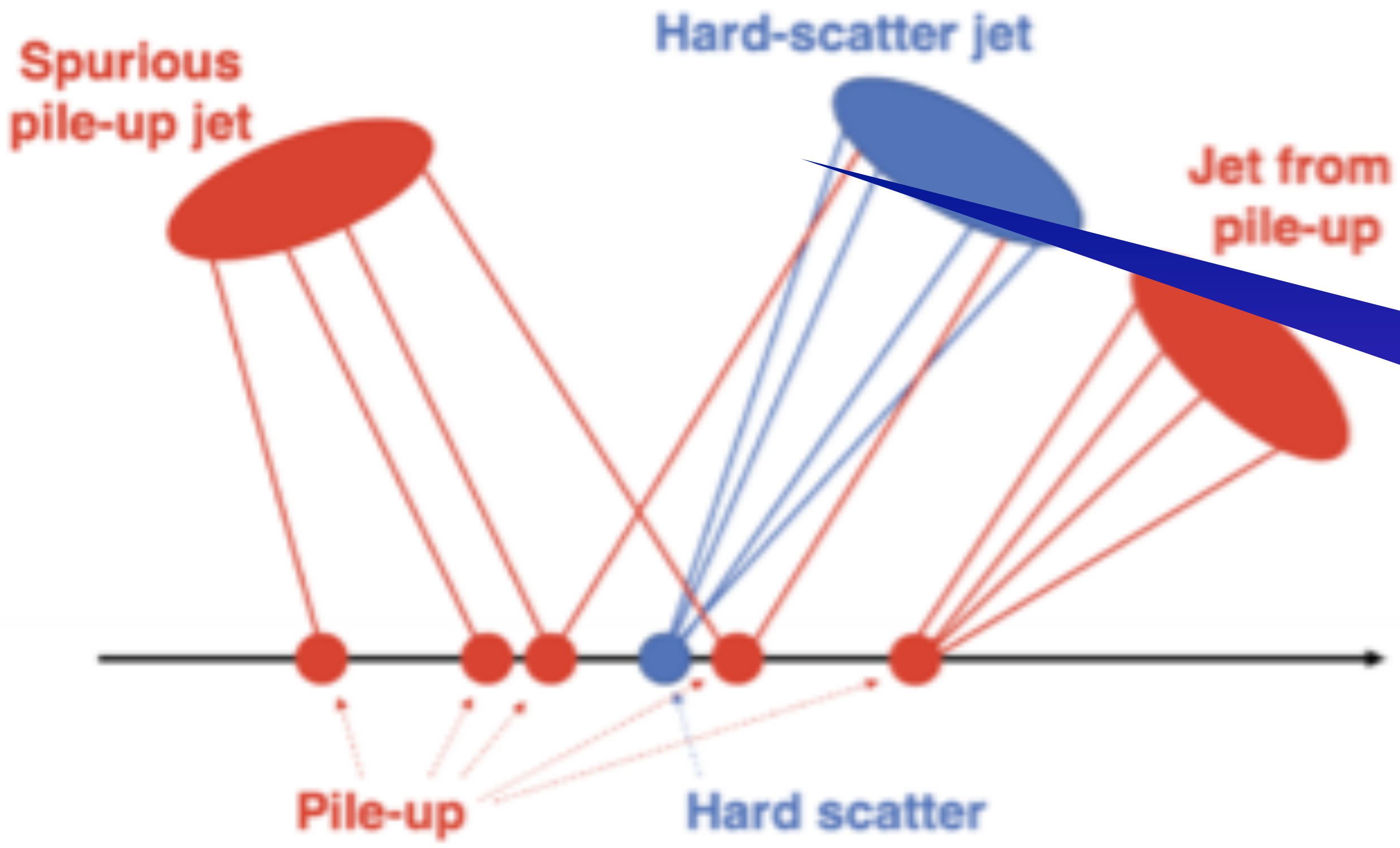
High Luminosity LHC (HL-LHC)

- HL-LHC is foreseen to start running in ~ 2028.
- Instantaneous Luminosity: $L \approx 7.5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$
- Integrated Luminosity (10 years): $L \approx 4000 \text{ fb}^{-1}$
- Up to 200 p-p interactions per bunch crossing.



Pileup: one of the main experimental challenges during HL-LHC



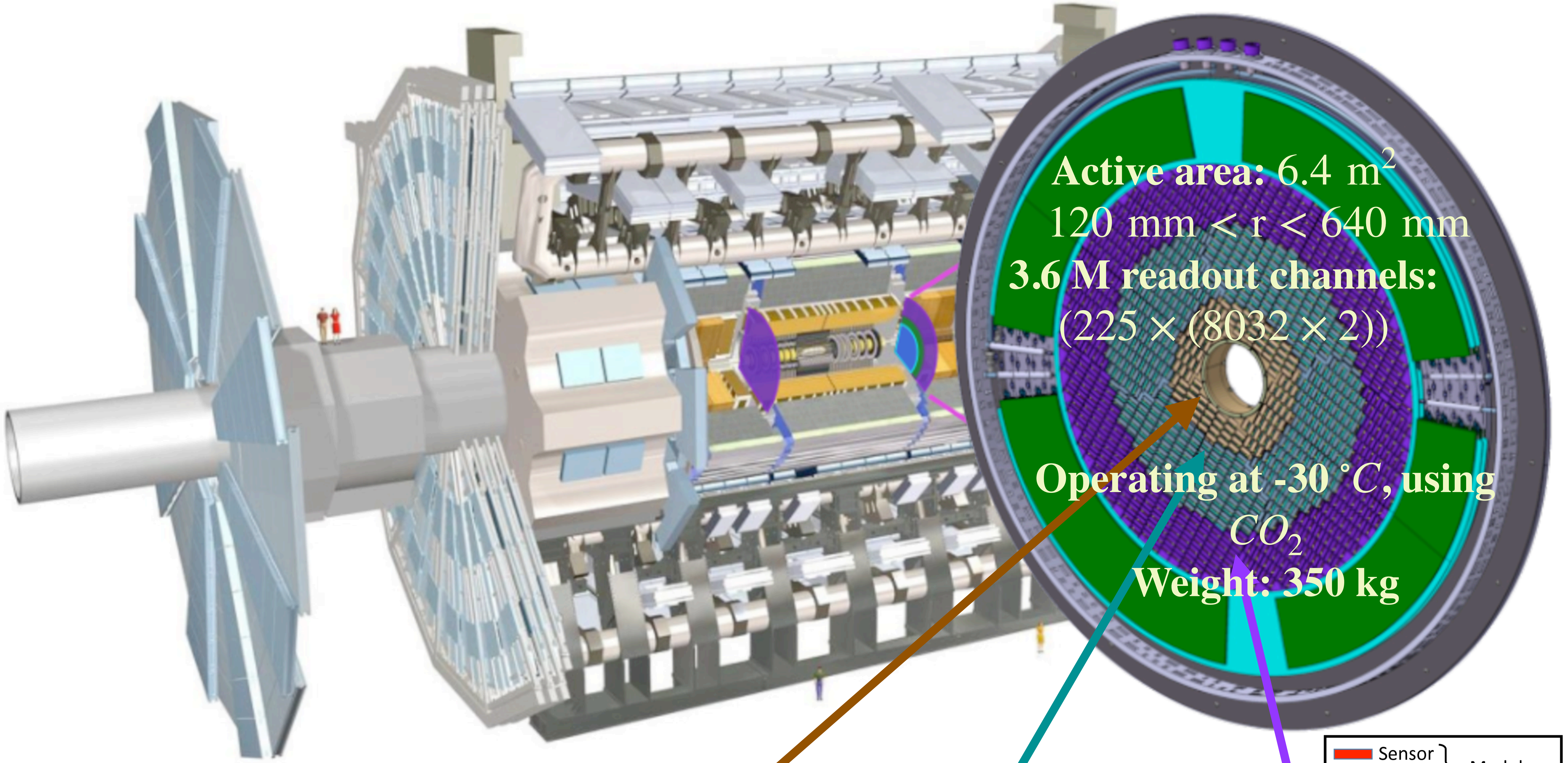


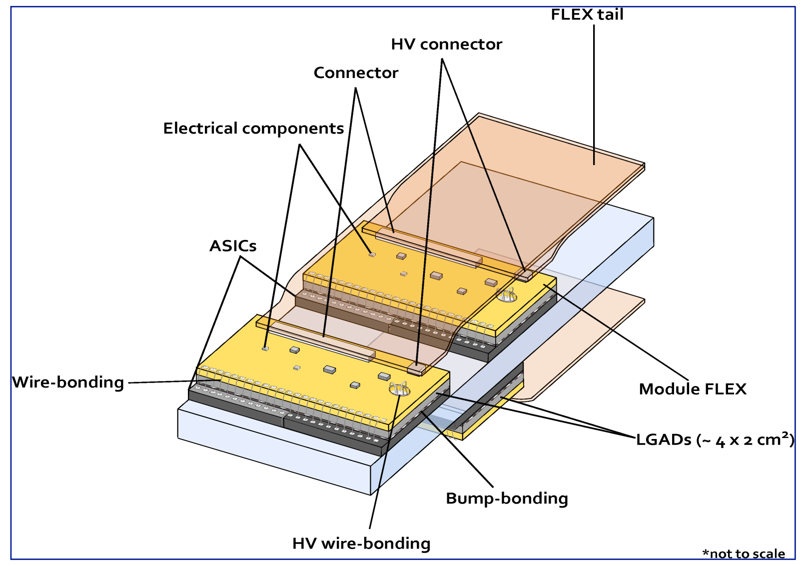
Difficult to well separate pile-up jets from Hard scatter jet

ATLAS Phase-II upgrade from 3-D to 4-D tracking system (ITK+HGTD)

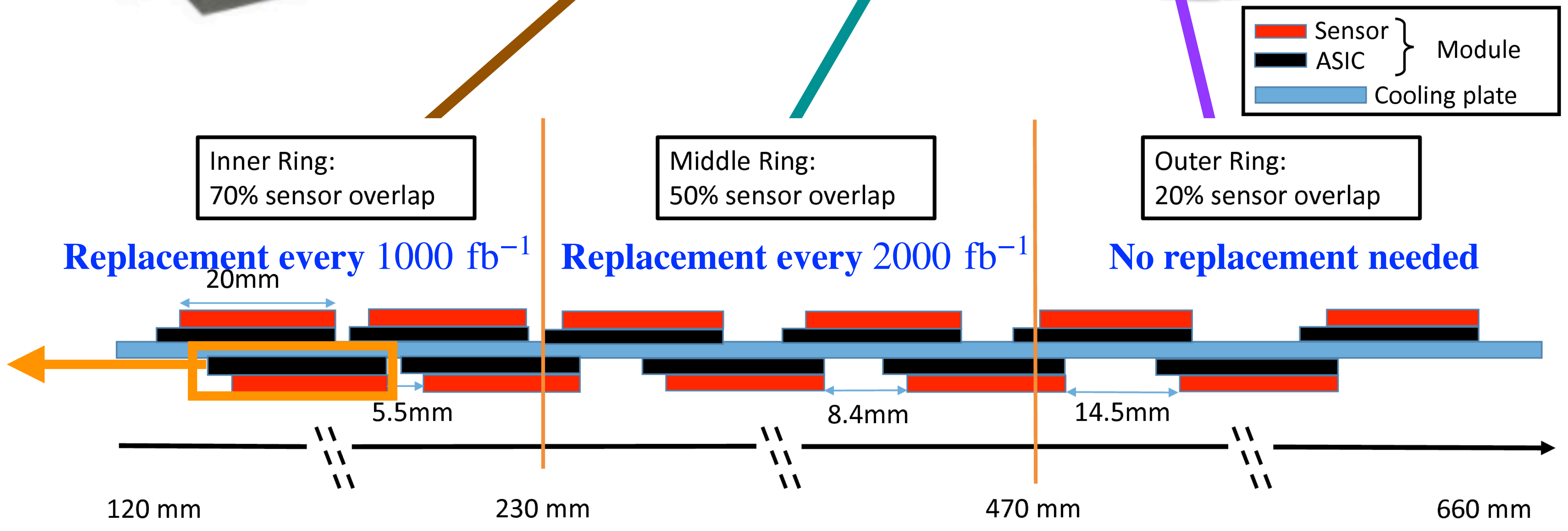
- To mitigate the high pileup effect, the ATLAS detector will be upgraded: ITK+HGTD

ITK (Inner Tracker)	HGTD (High Granularity Timing Detector)
• Extended pseudo-rapidity: $\|\eta\| = 4.0$ • Better position resolution on tracks in the central than in the forward region.	• Two instrumented double-sided layers, silicon-based technology, 75 mm-thick, built in three ring layout mounted in two cooling disks in the gap region between the barrel and the end-cap calorimeter. • High-precision time measurement: 30 - 50 ps time resolution per track. • Assign time to each track in the forward region: $2.4 < \eta < 4.0$ • Improve pileup rejection and correct track-to-vertex association.



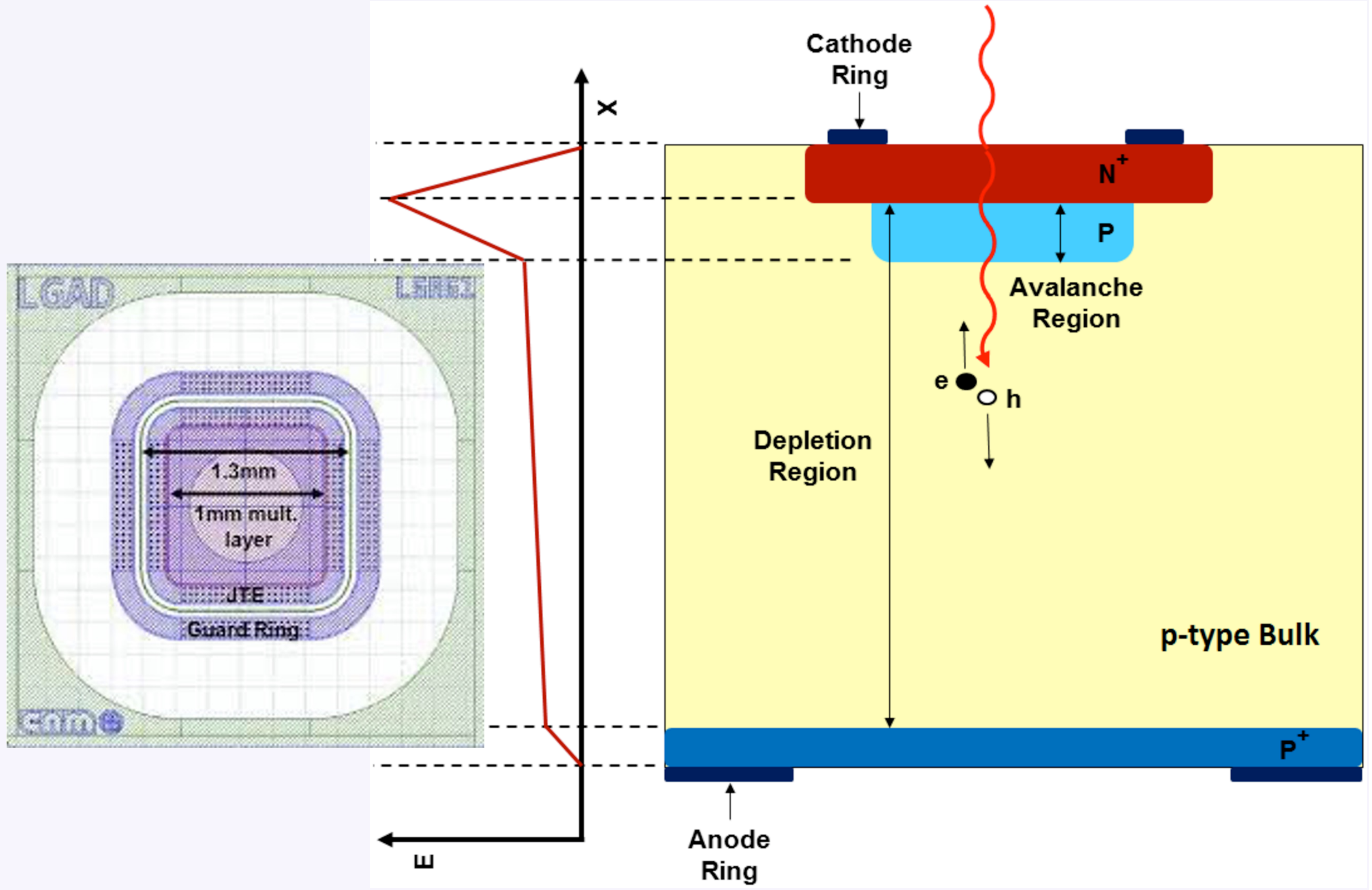


Hybrid bare module: 2 LGADs bump bonded to 2 ASICs.



Low Gain Avalanche Diode (LGAD)

- n-p Si detector with an additional thin (<5 μm) and highly doped 10^{16} p-type multiplication layer with a high E field providing an excellent time resolution: <30 ps before irradiation.
- HGTD prototypes are produced by CNM (Spain), HPK (Japan), FBK (Italy) and NDL (China).

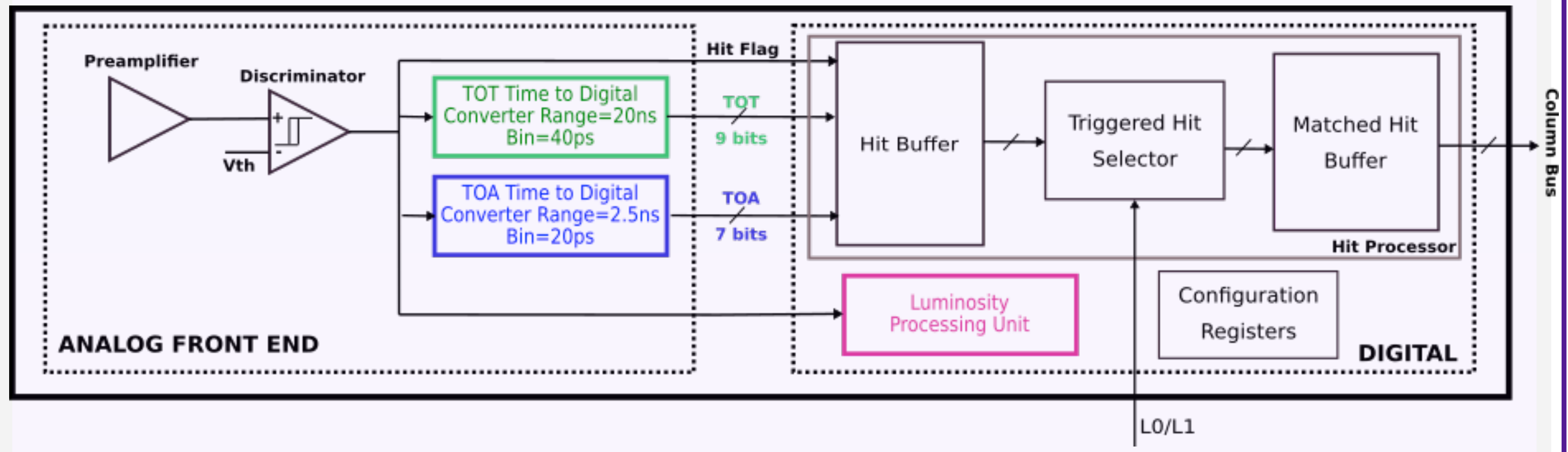


- Pad size of 1.3×1.3 mm^2, 5 μm thickness ensures:
- Small dead areas between pads.
- Low sensor capacitance.
- Configurable in arrays.

HGTD Front-End Electronics

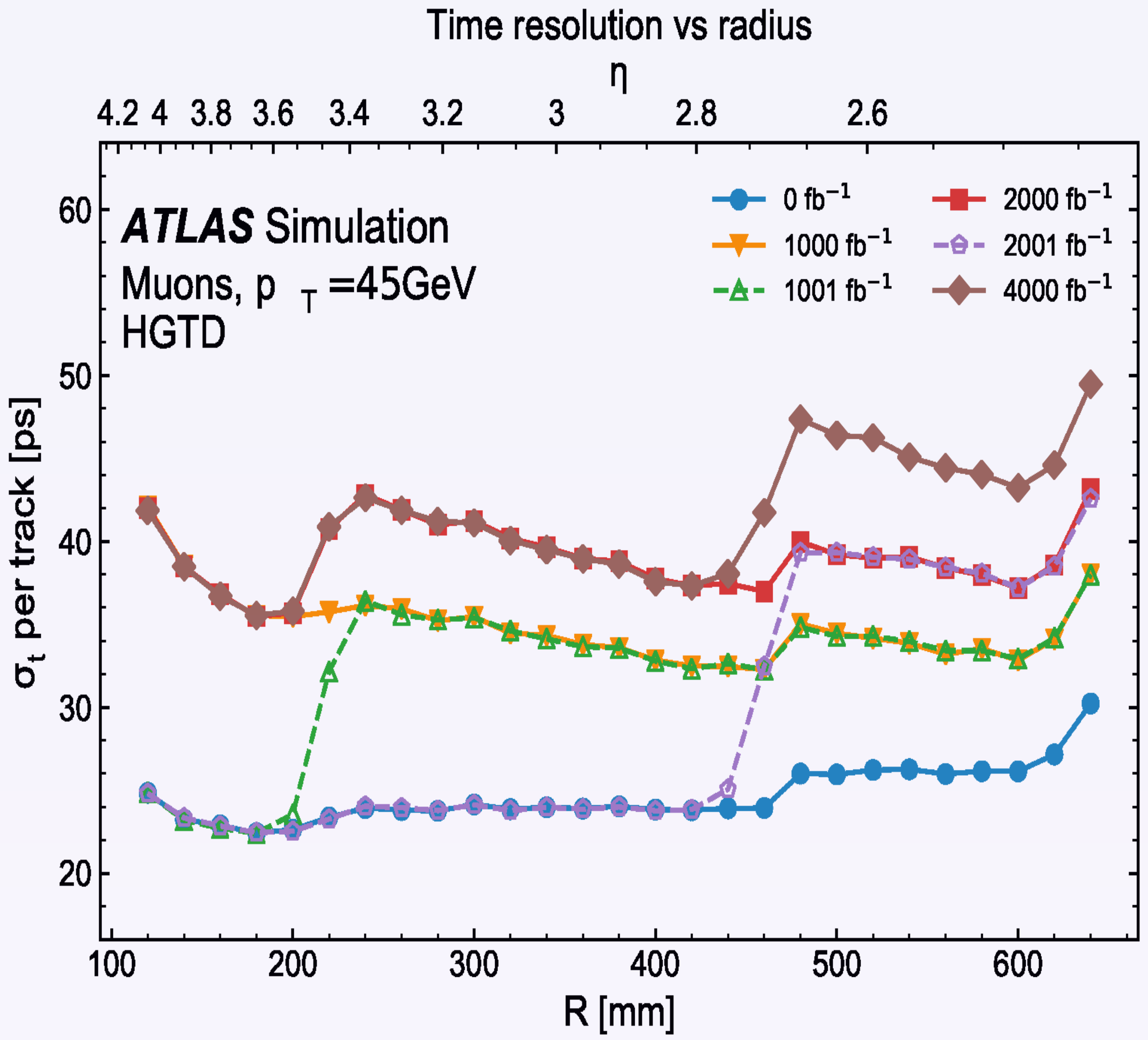
- Signal from each LGAD will be read out using the ATLAS LGAD Timing Readout Chip (ALTIROC) ASIC: Integrated chip 2×2 cm^2

Design	Requirements	Utility
• Readout Channel= Analogue(Preamplifiers, Time Of Arrival TOA, Time Over Threshold TOT CFD) + Digital (data buffer and transmission).	• $\sigma_t < 25$ ps • Threshold: 2 fC. • Minimise noise and power consumption	• Digitised measurement of TOA and TOT • TOT correction minimises σ_{walk} contribution to σ_t • Hit counting for luminosity measurements



Radiation Hardness

- Radiation tolerance: 2.5×10^{15}Neq/cm^2, 2MGy
- The operating voltage in each HGTD section has to be increased to compensate for the radiation damage.

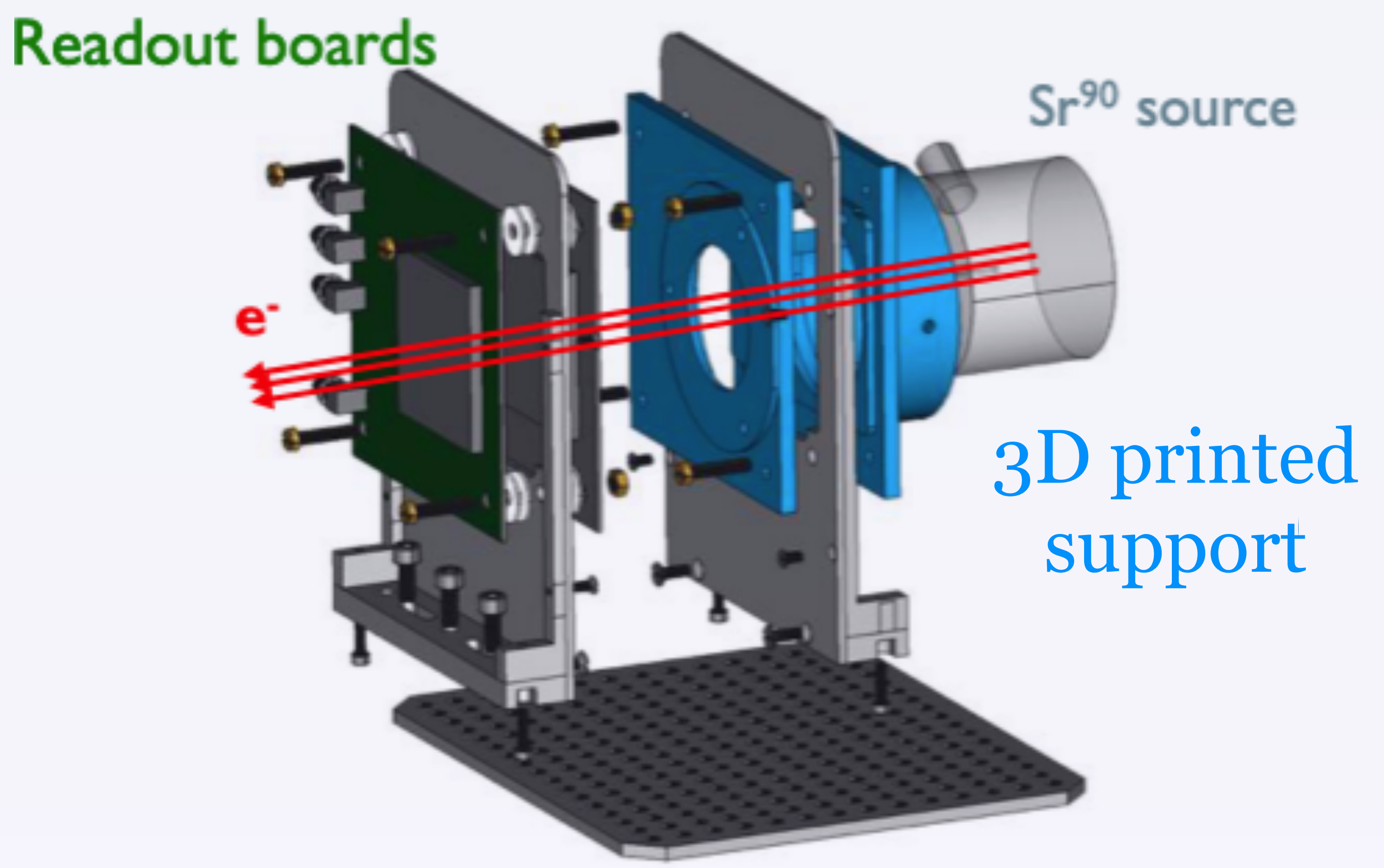


- The sudden changes at 2000 fb^{-1}, 3000 fb^{-1} and 4000 fb^{-1} are due to the replacement of the inner and middle rings.
- Time resolution σ_t improves after the rings replacements.

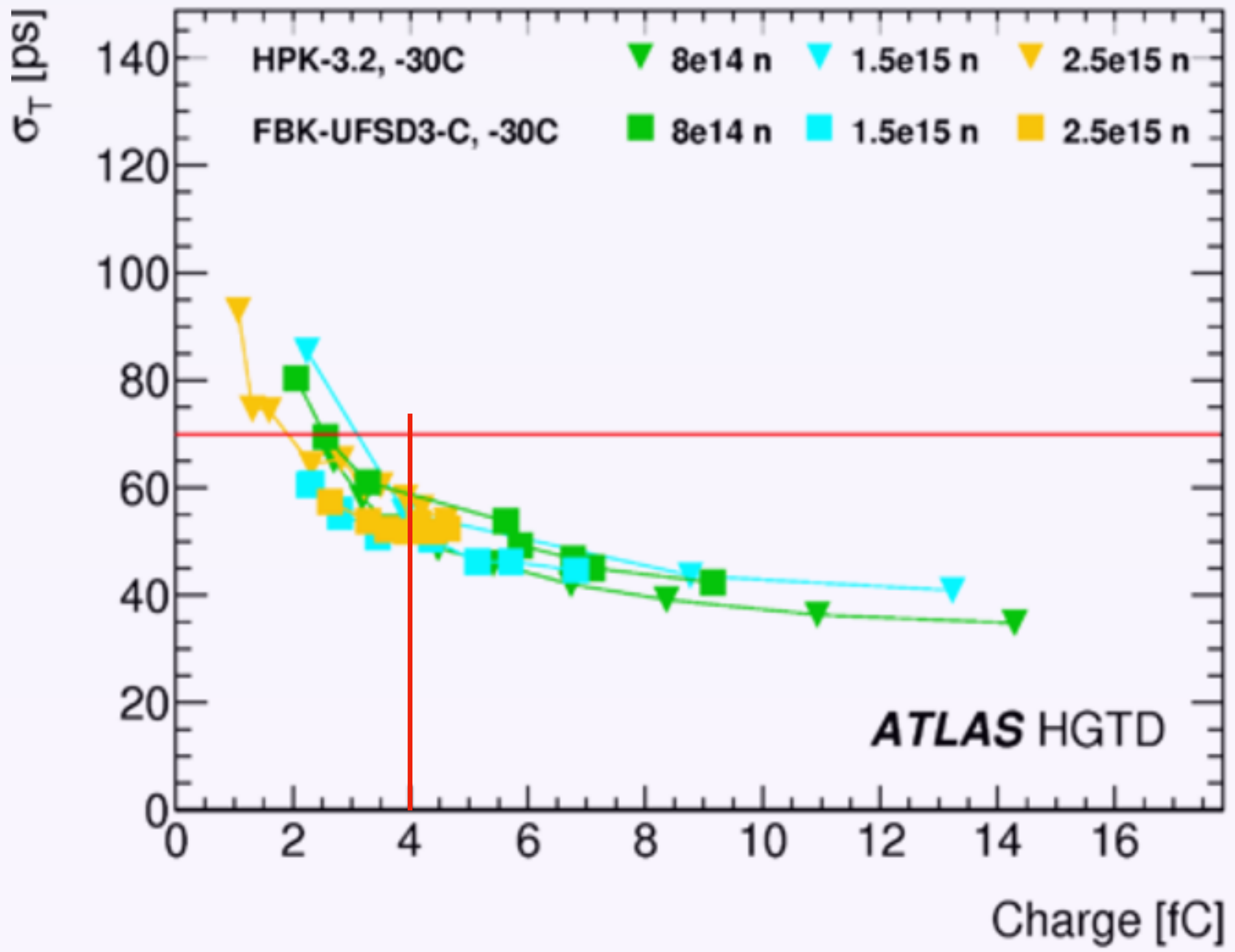
Performance measurements of LGAD sensors

Laboratory

Sr^{90} is used to characterise the LGAD response to minimum ionising particles (2 MeV electrons).



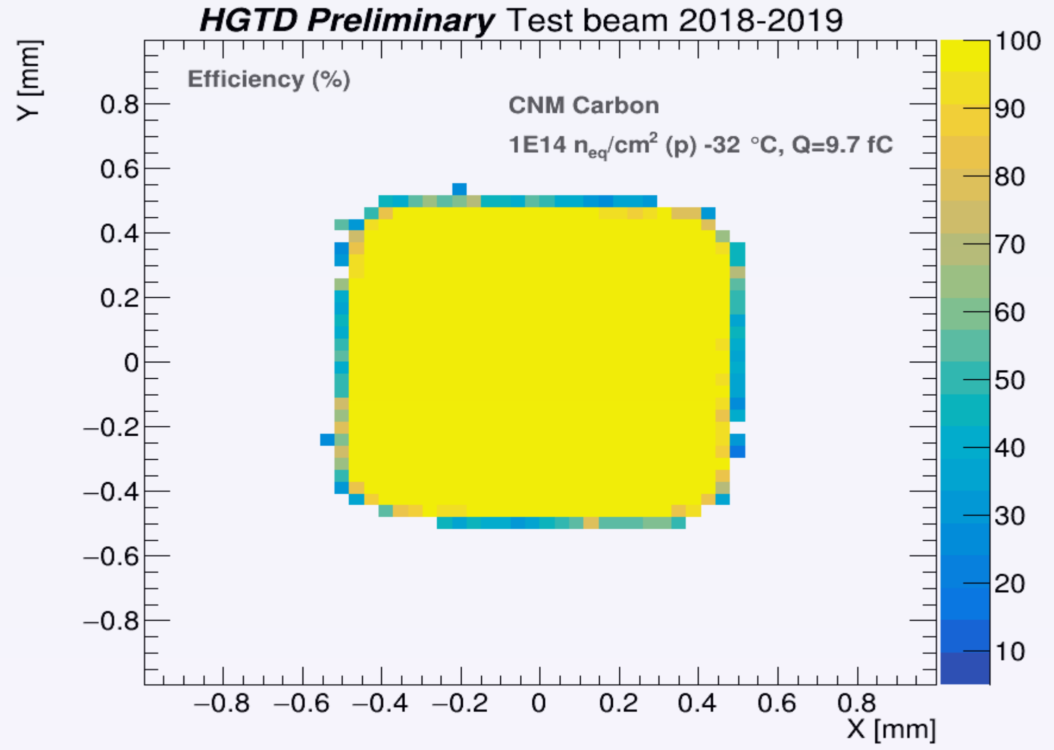
- Better than 70 ps time resolution is obtained at 4 fC for all the sensors at different fluences.



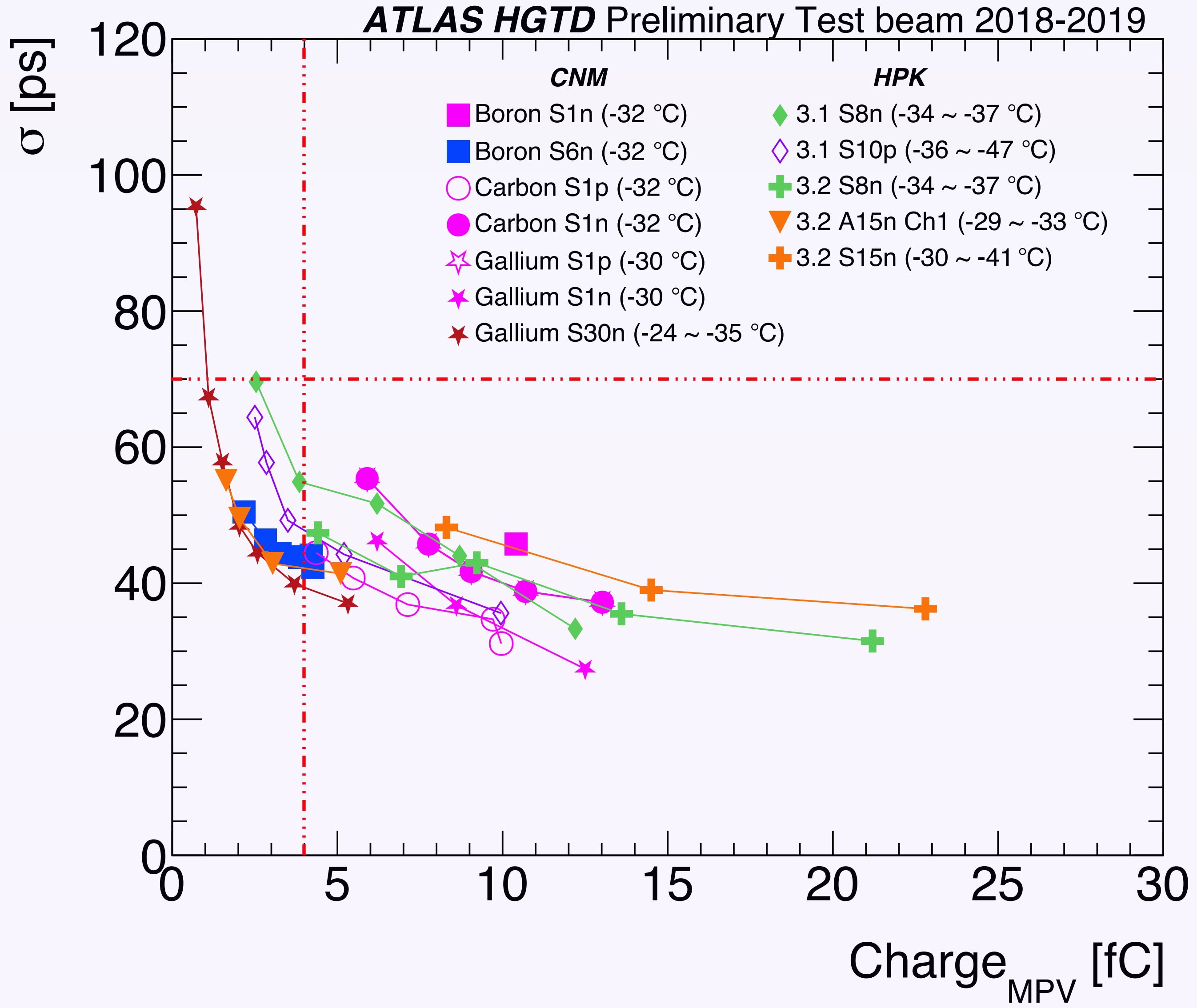
Test Beam

Data collected with 120 GeV pion beam (CERN SPS) and 5 GeV electron beam (DESY).

- Hit efficiency defined as hits on sensor with > 2 fC. Response is ~100% in the active area.



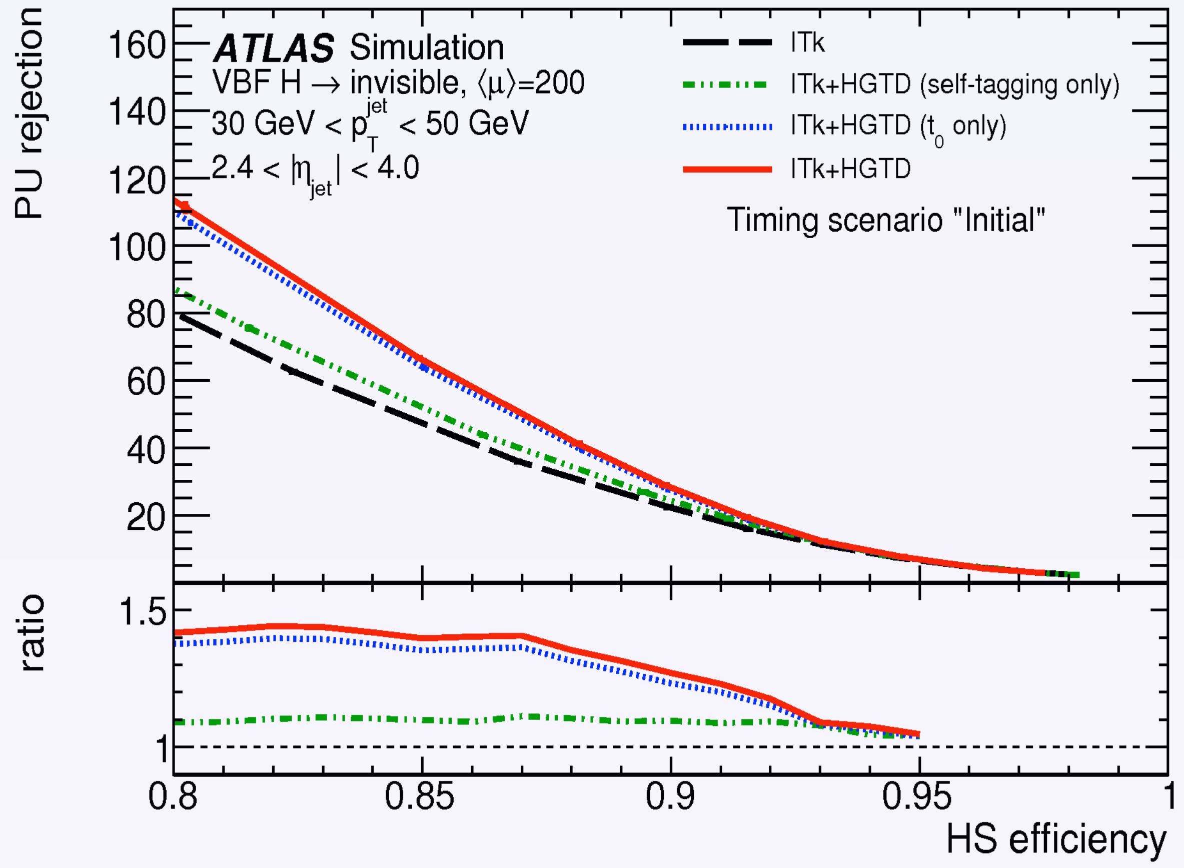
- At higher bias voltages, all sensors satisfy the HGTD requirements.



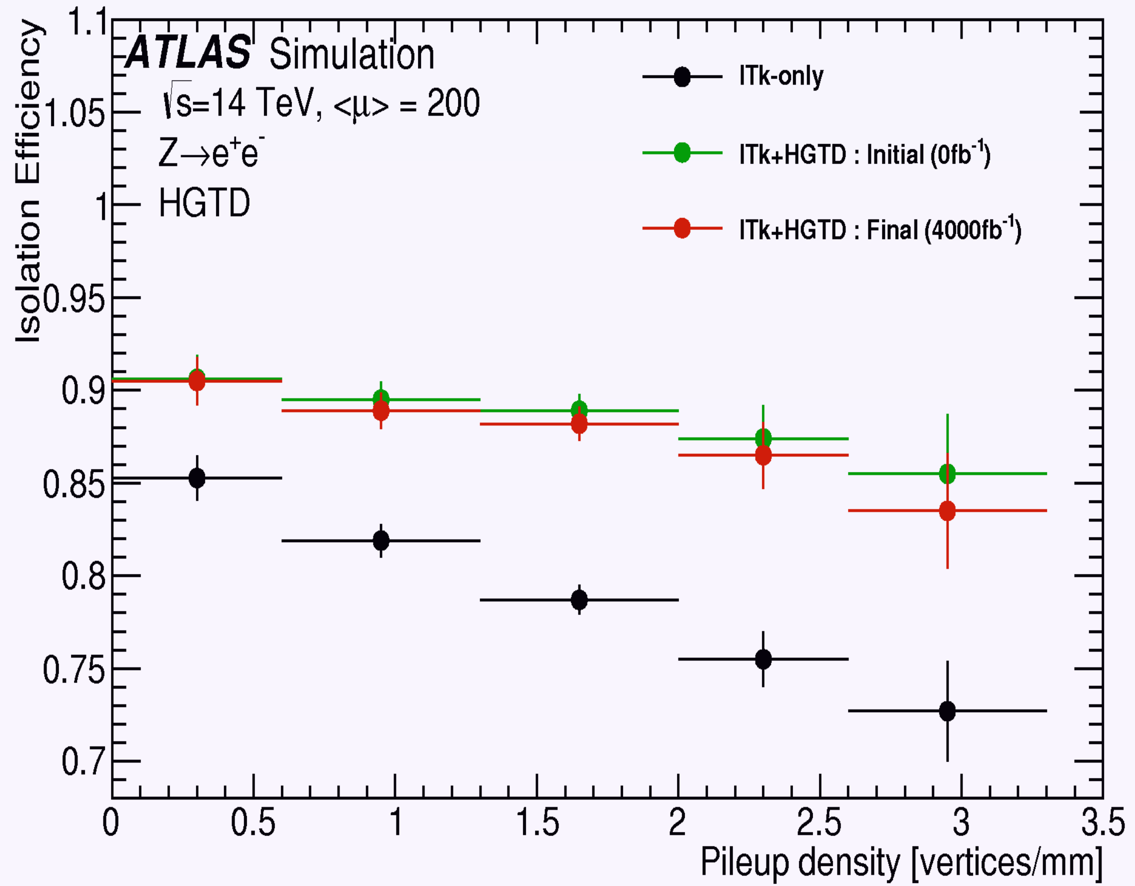
HGTD physics enhancement

- Simulation results have shown good object reconstruction and physics performance by adding HGTD to ITK:

- Pileup-jet rejection:
- increases by a factor of 1.4 (for 85% efficiency)



- Lepton isolation:
- Efficiency increases up to 25 %.
- HGTD removes majority of pileup deterioration



Summary

- HGTD is expected to start data taking in 2028 and will be the first large-scale application of LGAD technology to highly reduce pileup in the forward region of the ATLAS detector during the HL-LHC physics program.
- LGADs and their readout ALTIROCs are optimised to reach a $\sigma_t < 50$ ps per track up to the end of lifetime.
- Measurements of LGAD sensors from laboratory and test beams have shown promising results.
- Simulations have shown great improvement in HL-LHC physics performance by adding the HGTD to the ITK.

Reference

ATLAS Collaboration. Technical design report: A high-granularity timing detector for the ATLAS phase-II upgrade. Technical report, 2020. https://cds.cern.ch/record/2719855