LEPTON PHOTON 2021 MAN

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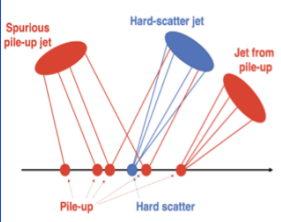
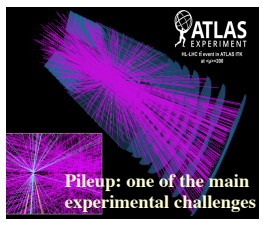
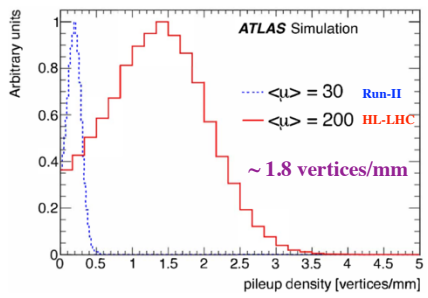
A High-Granularity Timing Detector for the ATLAS Phase-II upgrade

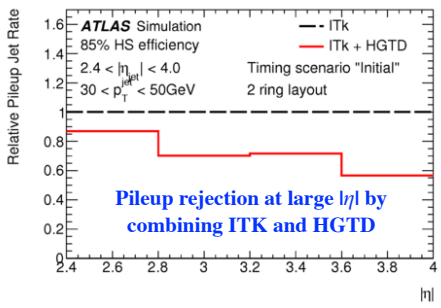
High Luminosity LHC (HL-LHC): ATLAS Phase-II upgrade from 3-D to 4-D tracking system (ITK+HGTD)

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



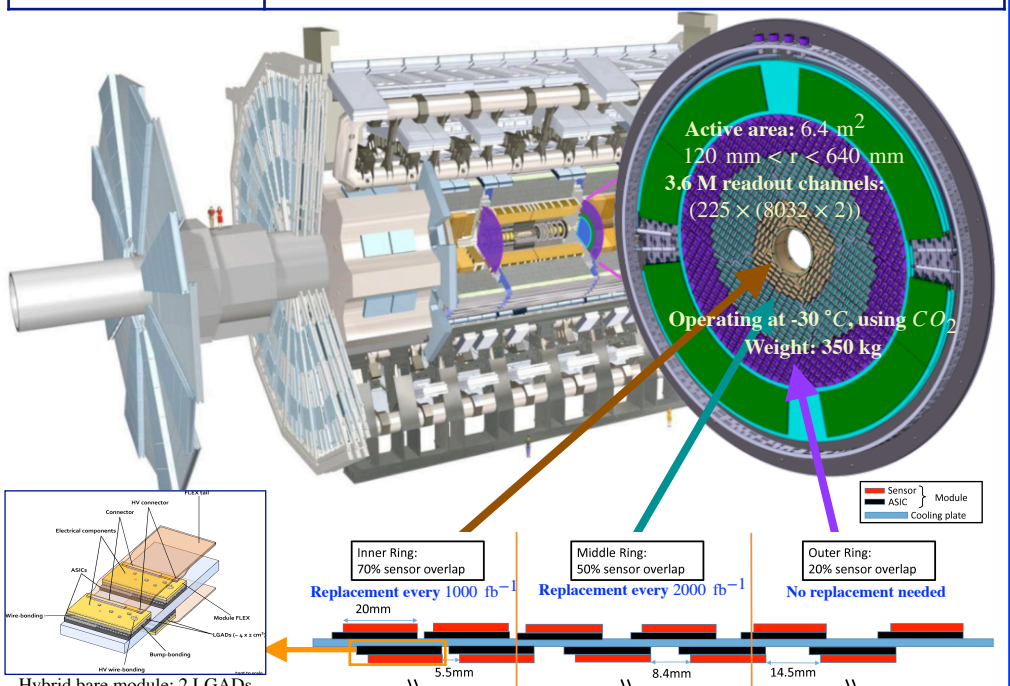






- To mitigate the high pileup effect, the ATLAS detector will be upgraded: ITK+HGTD

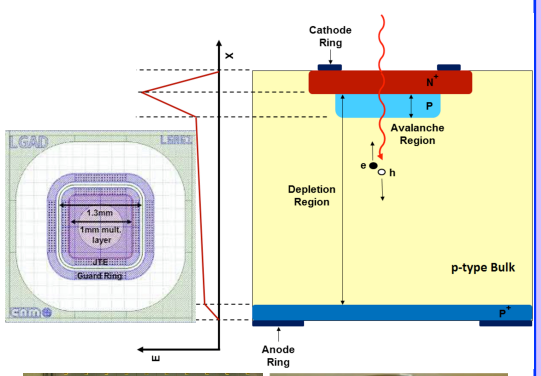
ITK (Inner Tracker)	HGTD (High Granularity Timing Detector)
• Extended pseudo-rapidity: $\lvert\eta\rvert = 4.0$ • Better position resolution σ_z on tracks in the central than in the forward region.	• Two instrumented double-sided layers, silicon-based technology, 75 mm-thick, built in three ring layout mounted in two cooling disks in the gap region between the barrel and the end-cap calorimeter at $z = \pm 3.5$ m from the interaction point. • 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 by a factor of 6 and correct track-to-vertex association.

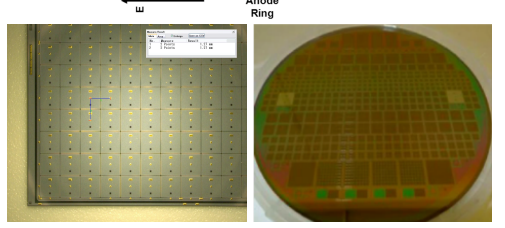


Hybrid bare module: 2 LGADs bump bonded to 2 ASICs. Read-out by Flex cable tail.

Low Gain Avalanche Diode (LGAD)

- Originally developed by CNM and RD50.
- n-p Si detector with an additional thin (<5 μm) and highly doped 10^{16} p-type multiplication layer with a high E field.
- Internal gain > 20 (8) before (after) irradiation (V_{bias}<800 V).
- Hit efficiency > 95 % at the end of lifetime.
- Excellent time resolution: <30 ps before irradiation.
- HGTD prototypes are produced by CNM (Spain), HPK (Japan), FBK (Italy) and NDL (China).

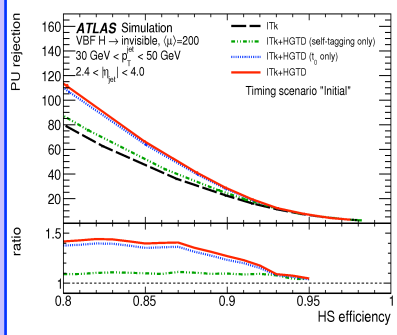




- Pad size of 1.3×1.3 mm^2 , 5 μm thickness ensures:
- Occupancy <10% at lowest HGTD radius (120 mm).
- Small dead areas between pads.
- Low sensor capacitance.
- Configurable in arrays.
- 15×15 pads, for 1.95×1.95 cm^2 total area.

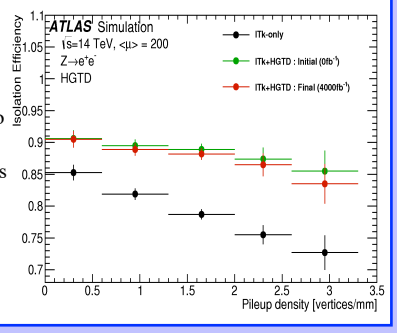
HGTD physics enhancement

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



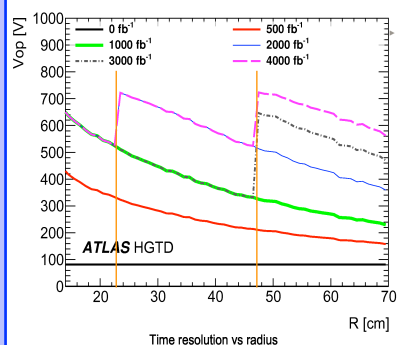
Pileup-jet rejection:
- increases by a factor of 1.4 (for 85% efficiency)

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

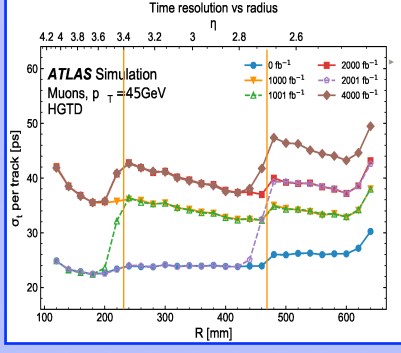


Radiation Hardness

- 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.



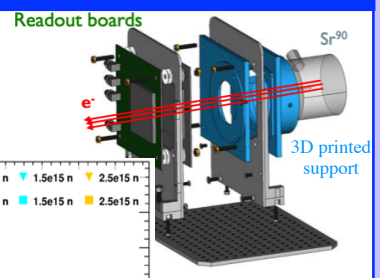
Time resolution σ_t improvement after the rings replacements.

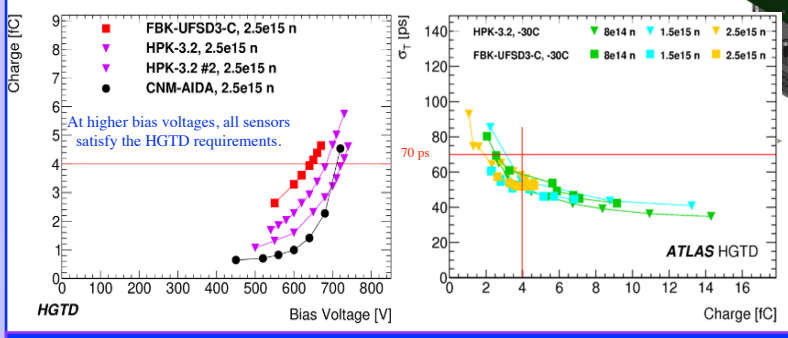
Performance measurements of LGAD sensors

Study the performance of LGADs from different manufacturers, irradiated at different fluences with protons (p) and neutrons (n) to find sensors that satisfy the HGTD requirements defined by reaching a minimum collected charge of 4 fC and a time resolution less than the maximum allowed in the end of lifetime (70 ps).

Laboratory

- Sr^{90} source is used to characterise the LGAD response to minimum ionising particles (2 MeV electrons).
- Operation inside a climate chamber (down to -30 ºC) with dry air used to avoid condensation on the sensor surface.

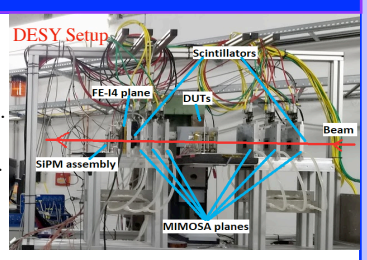


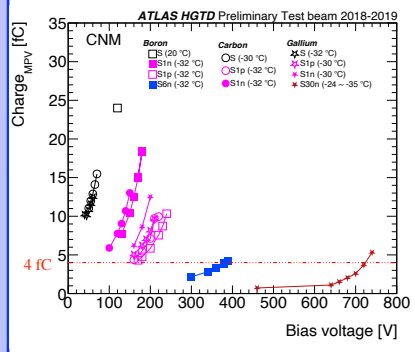


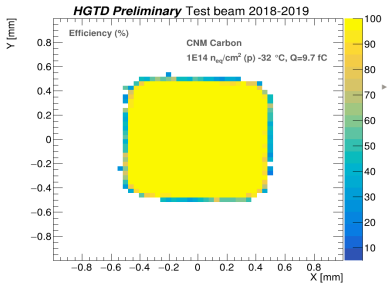
Better than 70 ps time resolution is obtained at 4 fC for both HPK and FBK sensors at different fluences.

Test beam

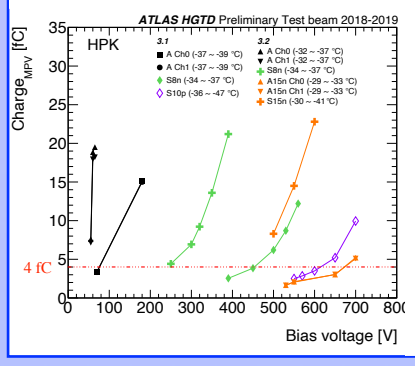
- Data collected in 2018-2019 with 120 GeV pion beam (CERN SPS) and 5 GeV electron beam (DESY).
- EUDET-type telescope used for position-dependent measurements.
- EUDET Trigger Logic Unit: synchronise the telescope with HGTD DAQ.
- Operation inside a cooling box (< -20 ºC).
- Time reference: SiPM coupled to Cherenkov light emitting quartz bars. Trigger reference used is FE-I4 readout chip.

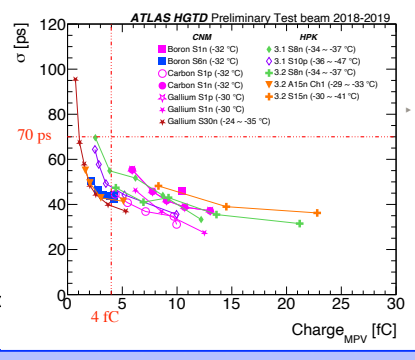






Hit efficiency defined as hits on sensor with > 2 fC. Response is ~100% in the active area.



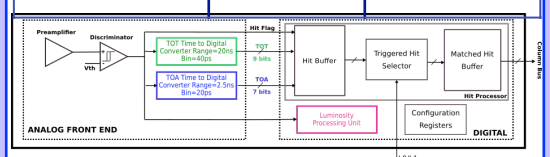


At higher bias voltages, all sensors satisfy the HGTD requirements.

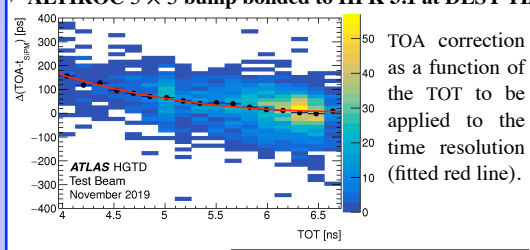
HGTD Front-End Electronics

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

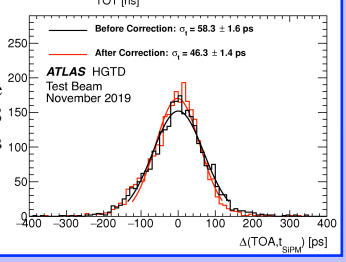
Design	Requirements	Utility
• 15x15, 225 readout channels. • Channel= Analogue(Preamplifiers, Time Of Arrival TOA, Time Over Threshold TOT, CFD) + Digital (data buffer and transmission).	• σ_t < 25 ps • Total dose: 2 MGy. • Discriminator threshold: 2 fC. • Minimise noise and power consumption	• Digitised measurement of TOA and TOT • TOT correction minimises σ_{walk} contribution to σ_t • Hit counting for luminosity measurements



ALTIROC 5 × 5 bump bonded to HPK 3.1 at DESY TB:



TOA correction as a function of the TOT to be applied to the time resolution (fitted red line).



Before corrections the time resolution is ~58 ps, after correction is ~46 ps (39 ps Jitter).

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 σ_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

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