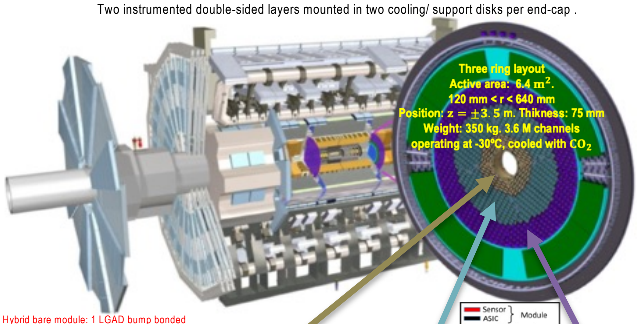
LHCC Poster Session - CERN, 18th November 2021

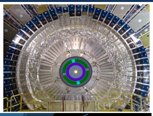
PERFORMANCE OF LGAD SENSORS FOR THE ATLAS HIGH-GRANULARITY TIMING DETECTOR HGTD

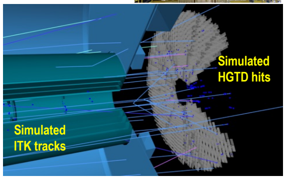
HL-LHC: upgrade of ATLAS from 3-D to 4-D tracking system (ITK+**HGTD**)

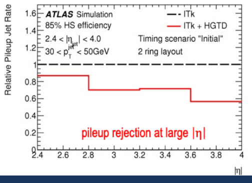
Two instrumented double-sided layers mounted in two cooling/ support disks per end-cap .



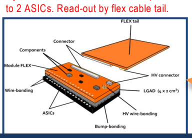
Located in the gap region between the barrel and the end-cap calorimeters.

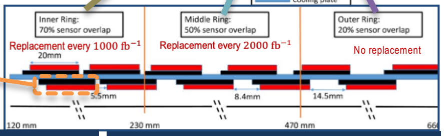






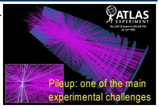
Hybrid bare module: 1 LGAD bump bonded to 2 ASICs. Read-out by flex cable tail.

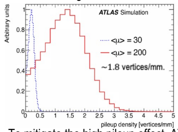


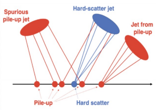


High Luminosity LHC (HL-LHC)

- Foreseen to start running in ~2027.
- Instantaneous Luminosity: $L \approx 7.5\times10^{34} cm^{-2} s^{-1}$
- Integrated Luminosity (10 years): $L \approx 4000 fb^{-1}$
- Up to 200 p-p interactions per bunch crossing.





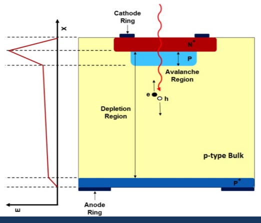


To mitigate the high pileup effect, ATLAS detector will be upgraded:

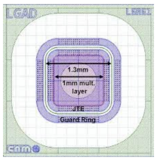
ITK (Inner Tracker)	HGTD (High Granularity Timing Detector)
• Extended pseudo-rapidity (|η|=4.0). • Better position resolution (σ_z) on tracks in the central than in the forward region.	• Silicon-based detector technology. • High-precision time measurement: 30-50 ps time resolution per track. • Assign time to each track in the forward region: 2.4<η<4.0 • Improve pileup rejection by a factor of 6. • Correct track-to-vertex association.

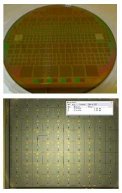
Low Gain Avalanche Diode (LGAD)

- Developed by CNM and RD50.
- n-p Si detector with an additional thin (<5 µm) and highly dopped (10^{16}) p-type multiplication layer with a high E field.
- Internal gain (V_{bias}<800 V) >20 and >8 after irradiation.
- Hit efficiency >95 % at the end of lifetime.
- Excellent time resolution σ_t<30 ps before irradiation.



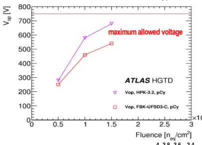
- Pad size of 1.3×1.3 mm^2, 5 µm thickness ensures:
- Occupancy <10% at lowest HGTD radius (120 mm).
- Small dead areas between pads.
- Low sensor capacitance.
- Configurable in arrays.
- 15×15 pads, for a total area of 1.95×1.95 cm^2





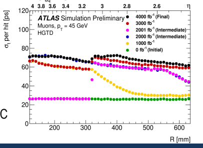
Radiation hardness

- Several studies have been performed on the LGADs radiation hardness using proton and neutron irradiations.
- Radiation tolerance: $2.5\times10^{15} Neq/cm^2$, $2\ MGy$.



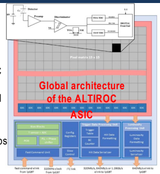
The applied bias voltage in each HGTD section has to be increased accordingly to compensate for the radiation damage.

Time resolution deterioration due to radiation exposure after different amounts of delivered integrated luminosity at the HL-LHC

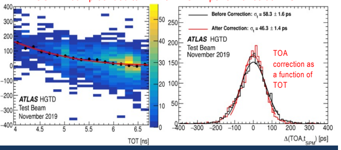


ATLIROC

- ATLAS LGADs Timing Readout Chip: Signal from each LGAD will be read out using ALTIROC ASIC, an integrated chip (15x15 channels), based on 2 parts:
  1. Analogue: amplifier, discriminator, TDC
  2. Digital: data buffer and transmission
- Pre-amplifier followed by Time Of Arrival (TOA) and Time Over Threshold (TOT).
- Minimize noise and power consumption
- Target time resolution contribution <25 ps
- Discriminator threshold of about 2 fC.



- ALTIROC 1v2 bump bonded to HPK 3.1 LGAD performance at DESY TB:

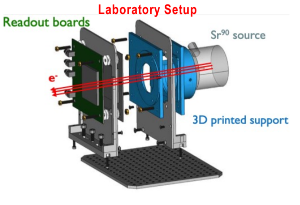


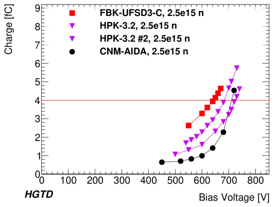
Performance measurements of LGAD sensors

- Goal: Study the performance of LGADs from different manufacturers, with different fluences (protons (p), neutrons (n)) up to $3\times10^{15} Neq/cm^2$ in laboratory and test beam.
- In both setups: The output analogue signal from the read-out board is recorded with an oscilloscope for different bias voltages and data is saved for offline waveform processing.
- Q: the most probable value of the fitted charge (the integral of the signal area for each waveform) using a Landau-Gaussian convoluted function.
- σ_t : Time difference between the DUT(CFD= 50%) and reference sensor (CFD= 20%) as the Gaussian sigma of the distribution.
- HGTD requirements: defined by reaching the minimum collected charge required of 4 fC and a time resolution less than the maximum allowed in the end of lifetime (70 ps). [Q>4 fC , σ_t<70 ps]

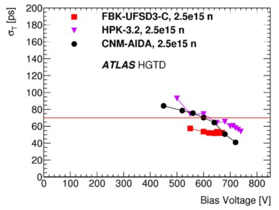
Laboratory

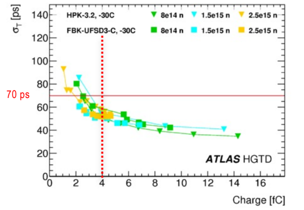
- Sr^{90} source is used to characterize the LGAD response to minimum ionizing particles (2 MeV electrons).
- Operation inside a climate chamber (down to -30 °C).
- Dry air used to avoid condensation on the sensor surface.
- Time reference: using a non-irradiated LGAD with well known performance and previously calibrated.





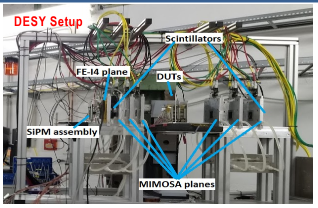
- At higher bias voltages, FBK, HPK and CNM sensors satisfy the HGTD requirements.
- At lower bias voltages and at the same irradiation fluence (2.5×10^{15} n), the FBK sensor shows a better performance.
- Better than 70 ps time resolution is obtained at 4 fC for both HPK and FBK sensors at different fluences.

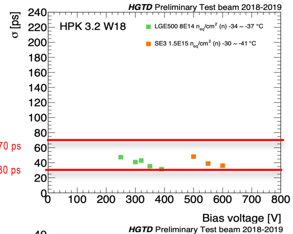




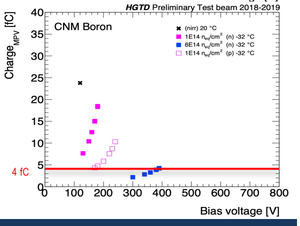
Test Beam

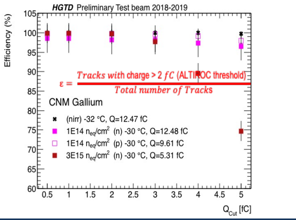
- Data collected at DESY in 2018-2019 with 5 GeV electrons.
- DURANTA telescope: position-dependent measurements.
- EUDET Trigger Logic Unit: synchronize the telescope with DAQ system.
- Operation inside a cooling box with dry ice (< -20 °C).
- Time reference: SiPM and Cherenkov light emitting quartz bars.
- Trigger reference: FE-I4 readout chip.





- At different fluences, CNM B-dopped and HPK sensors were proven to satisfy HGTD requirements under beam tests.
- Good efficiency (ε) was obtained for n and p irradiation CNM Ga-dopped sensors at the same fluence of $1\times10^{14} Neq/cm^2$.
- At higher n fluence of $3\times10^{15} Neq/cm^2$, Q=5.31 fC, a minimum bias voltage of 740 V and a $Q_{Cut} \leq 3$ fC are required to get a good efficiency.





Summary

- HGTD is expected to start data taking in 2027 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 optimized to reach a σ_t<50 ps per track up to the end of lifetime.
- Measurements from laboratory and test beams have shown promising results in terms of Q, σ_t and ε.
- More test beam campaigns have been performed at DESY and CERN during 2020-2021 will provide more information about the performance of LGAD sensors and ALTIROC for the ATLAS HGTD.

References

ATLAS Collaboration. Technical design report: A high-granularity timing detector for the ATLAS phase-II upgrade. Technical report, 2020.

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ATLAS EXPERIMENT