ATLAS High Granularity Timing Detector
Test beam performance of LGAD sensors

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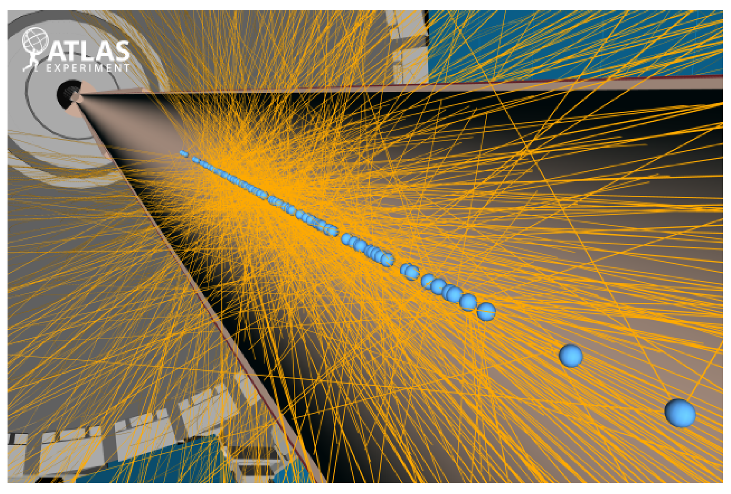
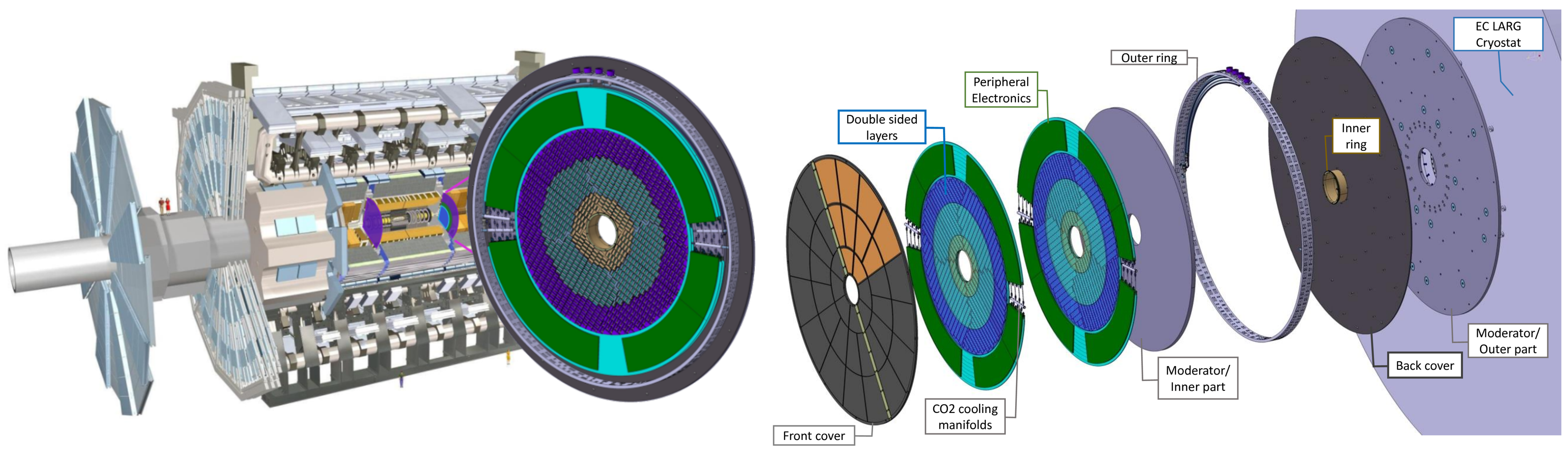
Introduction

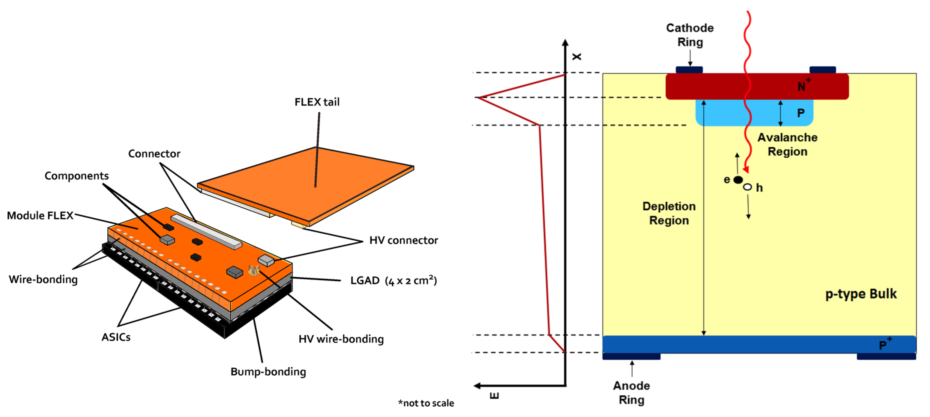
The High-Luminosity LHC (HL-LHC), currently foreseen to start towards 2029, will operate at an instantaneous luminosity of up to $7.5 \times 10^{34} cm^{-2} s^{-1}$ corresponding to an unprecedented average number of proton proton collisions per bunch crossing of up to 200. Efficient techniques to identify and suppress jets originating from pile-up interactions are critical to achieve the physics potential of the HL-LHC. The High-Granularity Timing Detector (HGTD) that will be installed in the forward region for Run 4, will improve the pile-up suppression through timing information at the 30-50 ps level. The design of the HGTD is based on the use of Low Gain Avalanche Detectors (LGADs). Performances of several LGAD sensors from different vendors, before and after irradiation with high fluences (ϕ) of 1.5x$10^{15} n_{eq}/cm^2$ and 2.5x$10^{15} n_{eq}/cm^2$, have been measured in beam test campaign at CERN SPS. Results for collected charge, time resolution and hit efficiency are presented.



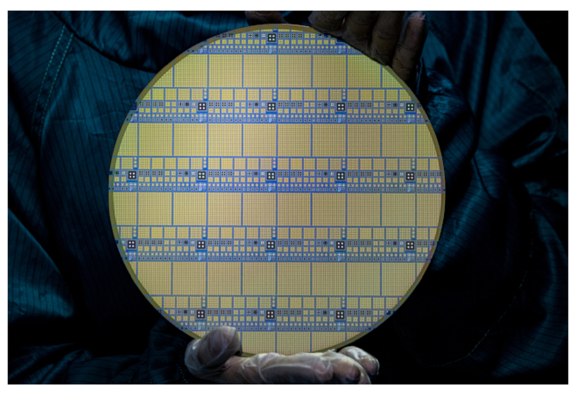


The HGTD Sensor

HGTD module consists of 2 LGAD sensors + 2 ALTIROC. ASICs bump-bonded and glued to a module flex. HGTD will have 8032 modules => 3.6 M channels. Modules mounted on cooling plate, connected to the surrounding Peripheral Electronics Boards via FLEX cables.

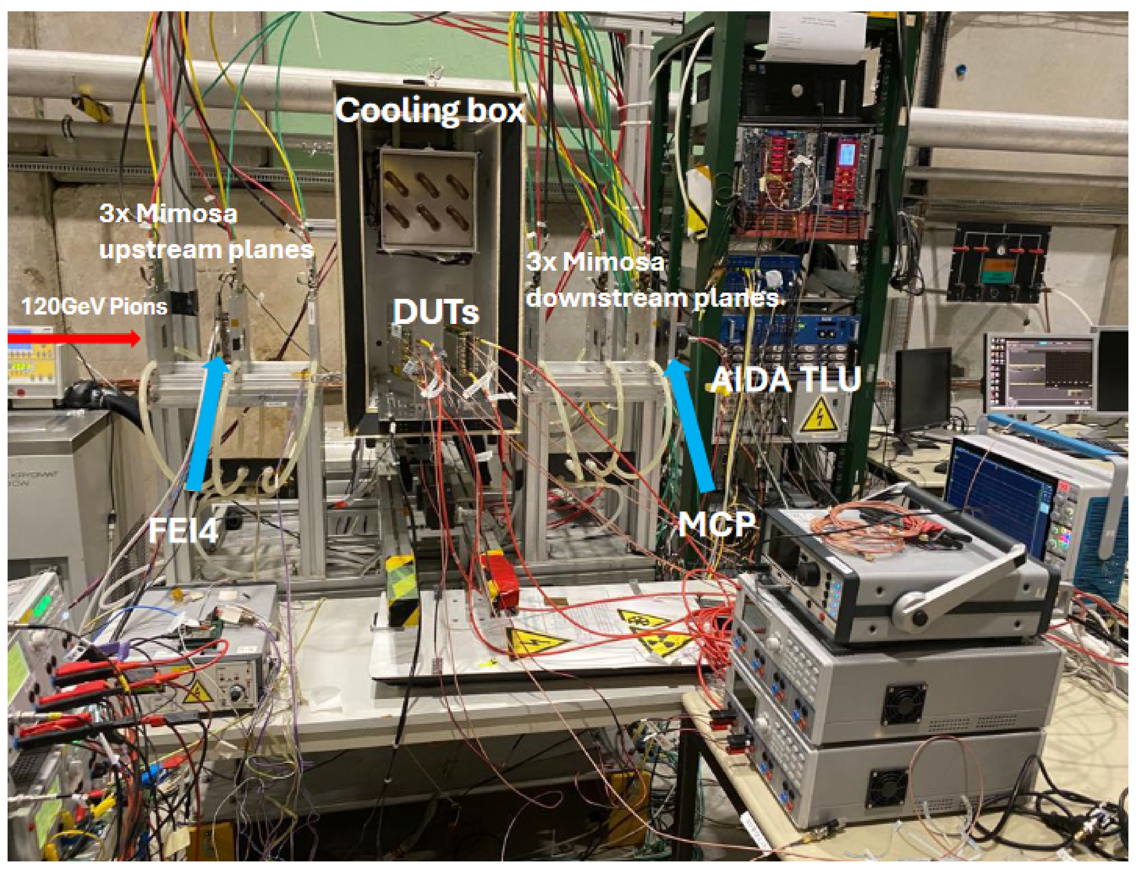


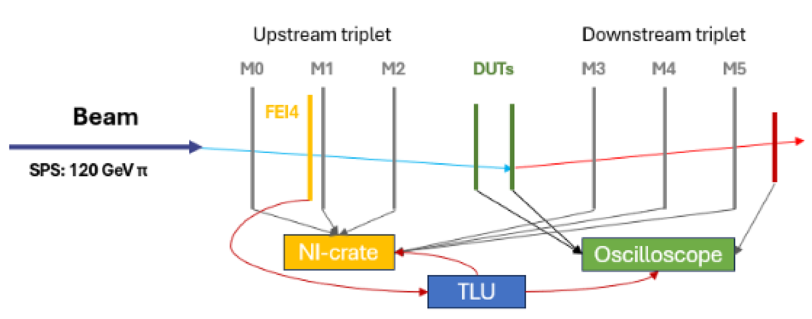
LGAD Technology: N-in-P diode structure with additional p-type gain-layer having, moderate gain 10 to 20. Fast rise time and larger signal-to-noise ratio and excellent time resolution. Each sensor is an array of 15 x 15 pads. The Pad size: 1.3 mm x 1.3 mm, active thickness: 50 micro μm. Vendors: IHEP-IME and USTC-IME



Test beam setup

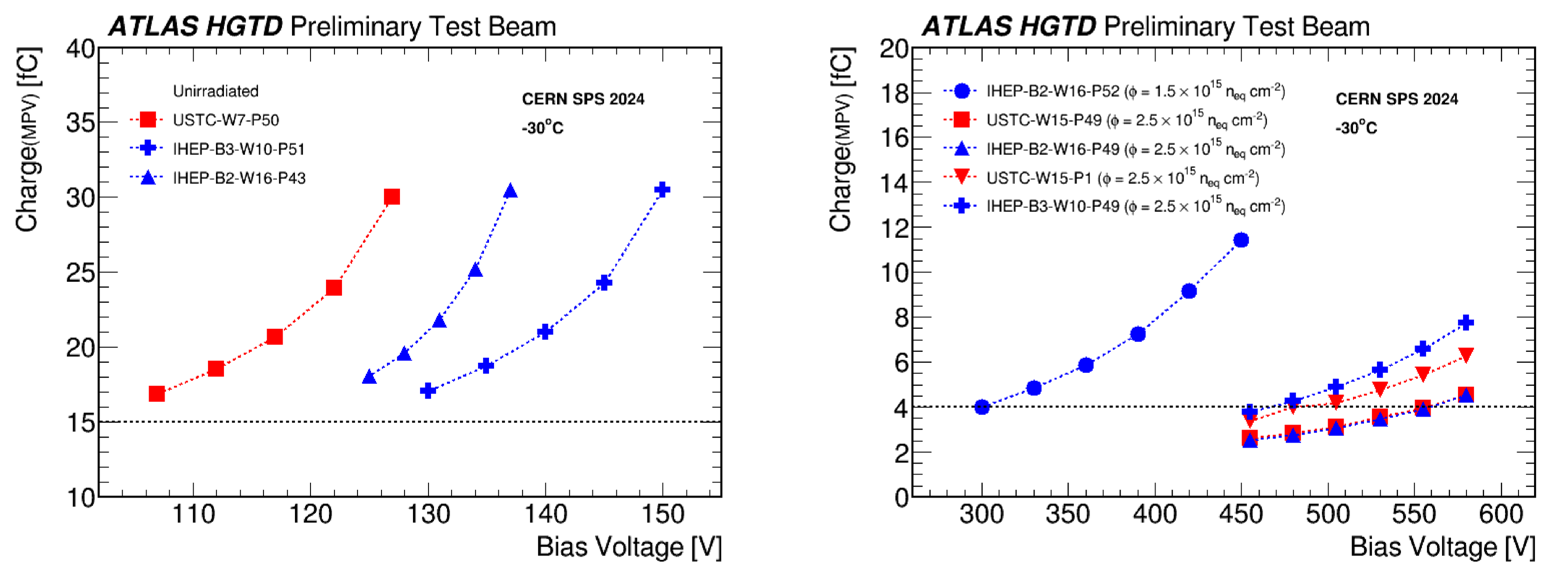
The test beam campaign was conducted at CERN SPS (H6A line) using a high momentum 120 GeV pion beam. A beam telescope with six MIMOSA planes were used to track the incident charged particles. An FEI4 detector was used to utilize the ROI for triggering the readout. An AIDA-Trigger Logic Unit (TLU) was used for distribute the synchronized triggers to DUT and Telescope with pre-defined logic. MCP was used for timing reference. Corryvreckan framework was used for a test beam data reconstruction. The data were collected at -30^oC.





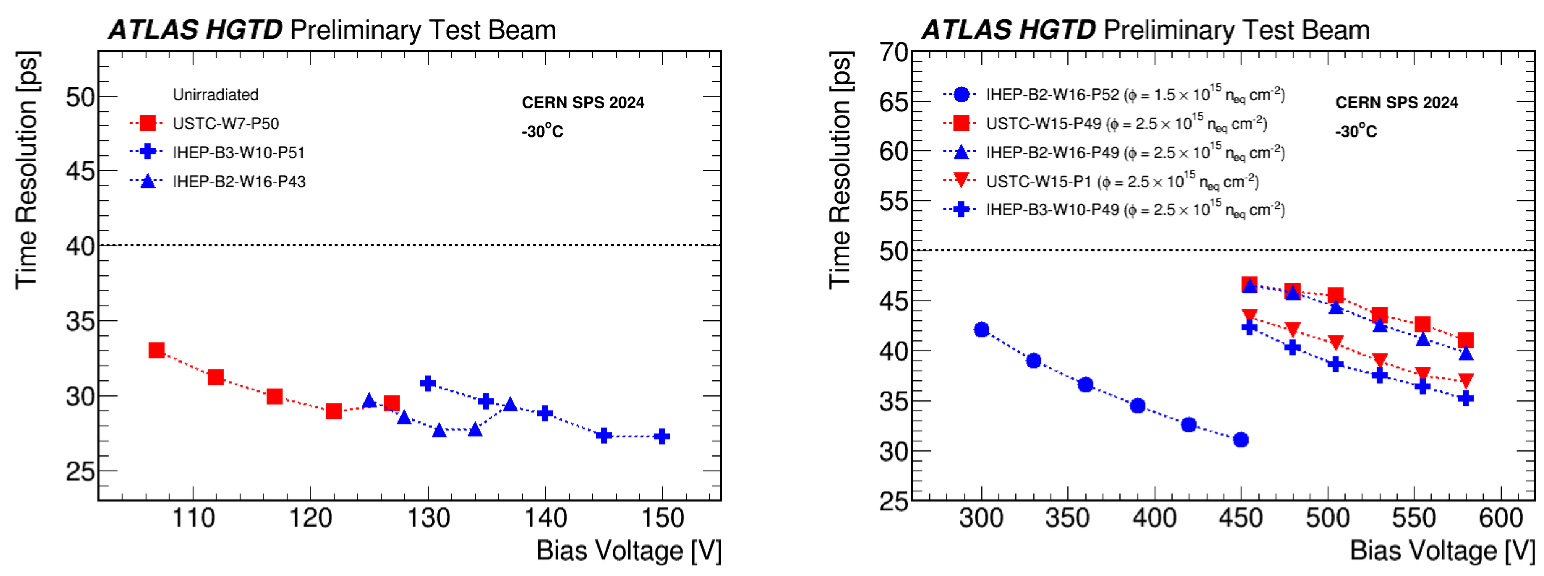
Charge collection

Collected charge as a function of the bias voltage for different HGTD preproduction single-pad sensors. MPV of the collected charge distribution is determined using a Landau convoluted to Gaussian fit. The dashed line at 15(4) fC indicates the requirement as minimum collected charge for unirradiated(irradiated) sensors.



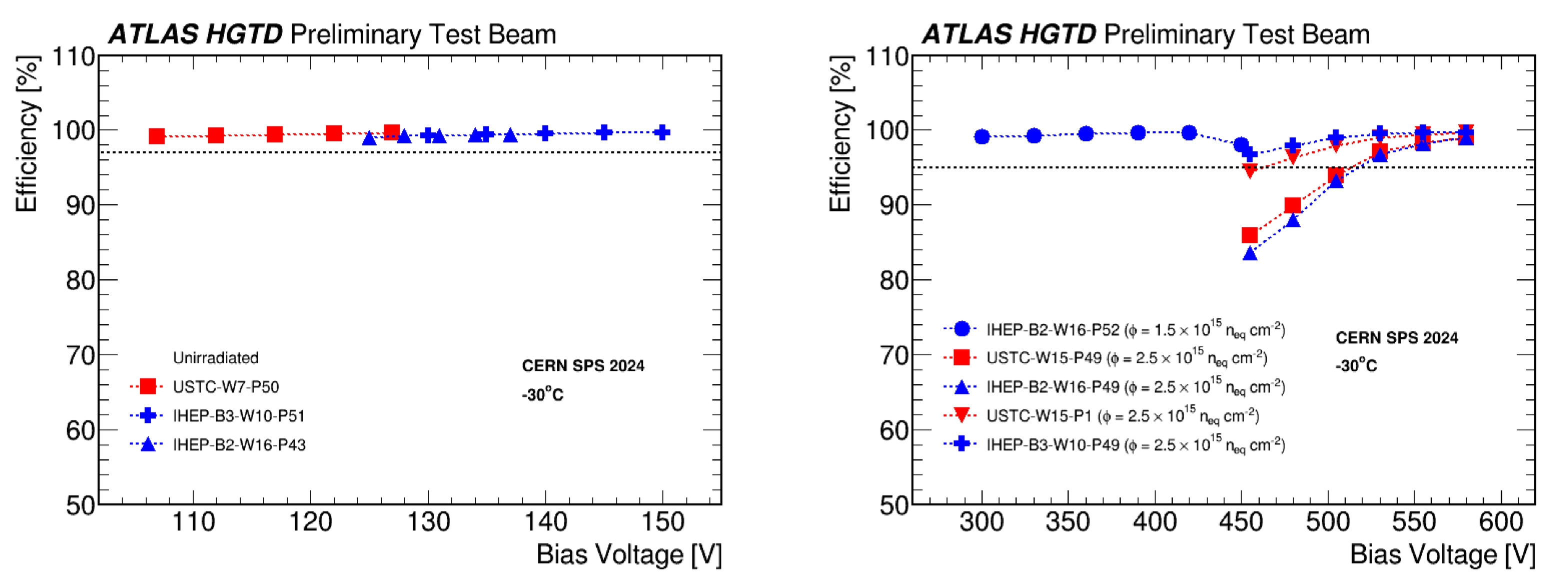
Time resolution

Time resolution as a function of the bias voltage for different HGTD preproduction single-pad sensors. Time resolution defined as the standard deviation of the Gaussian fit on the distribution of the Time Of Arrival (TOA) differences between the Device Under Test (DUT) and the Micro Channel Plate (MCP) used a reference detector. The TOA is evaluated using the Constant Fraction Discriminator (CFD) method with fCDF = 50%. A charge threshold at 2fC was applied. The time resolution of HGTD sensors meet the required thresholds, achieving below 40 ps for unirradiated sensors(left) and below 50 ps for irradiated sensors(right).



Hit efficiency

Efficiency as a function of the bias voltage for different HGTD preproduction single-pad sensors. The efficiency is defined as the ratio of the reconstructed tracks passing the 2fC threshold on the charge collection over all the reconstructed tracks penetrating the central sensor area. The dashed line at 97(95)% indicates the efficiency requirement for unirradiated(irradiated) sensors.



Conclusion

The HGTD sensors have demonstrated strong performance in test beam studies, even under radiation conditions as high as 2.5x$10^{15} n_{eq}/cm^2$, which corresponds to the maximum expected fluence in the forward regions of ATLAS at the HL-LHC. The HGTD sensors achieved the objectives of a collected charge of more than 4 fC while guaranteeing an optimum time resolution below 50 ps. An efficiency larger than 95% uniformly over the sensor's surface is obtained with a charge threshold of 2 fC. These results confirm the capability of HGTD LGAD sensors to meet the stringent performance requirements of HL-LHC.