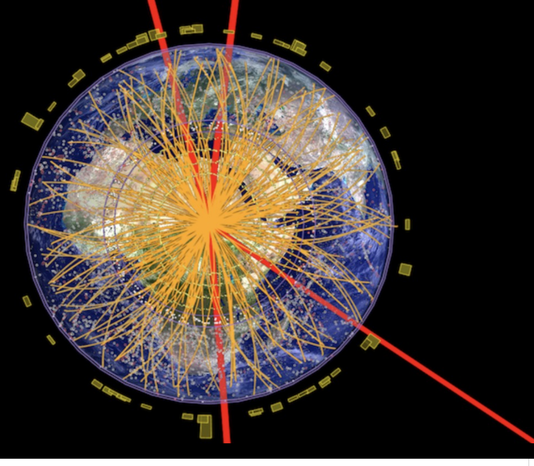
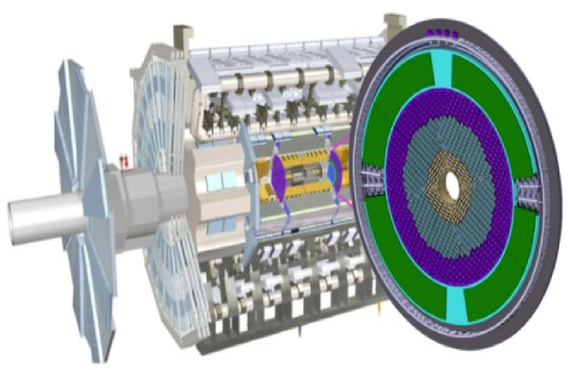
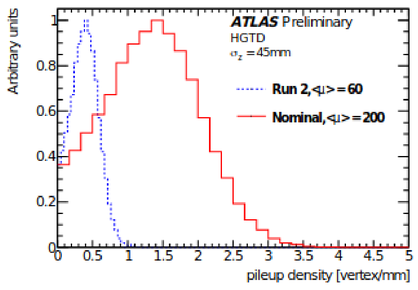
A High-Granularity Timing Detector (HGTD) for the Phase-II upgrade of the ATLAS detector





The High Granularity Timing Detector (HGTD)[1] is a proposed silicon detector for the forward region of the ATLAS detector in the High Luminosity LHC. It's high granularity and excellent timing resolution open new possibilities in the particle reconstruction, physics analysis and luminosity measurement at the HL-LHC

Motivation

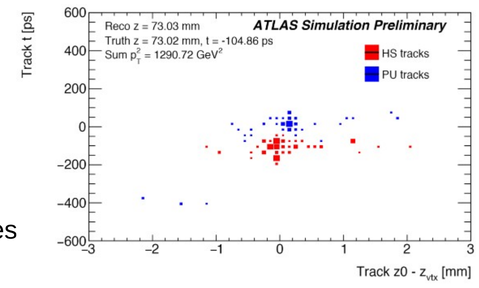


HL-LHC

- 200 interactions/bunch crossing
- σ_z= 45 mm (150 ps)
- σ_t= 175 ps
- on average: 1.6 vertices/mm
- ITk:z_0>1 mm for η >3 ,p_T<1.5 GeV

HGTD

- Coverage: 2.4<|η|<4.0z
- position = 3.5m
- σ_t=30ps/MIP(preirrad.)
- Resolve merged-in spacevertices

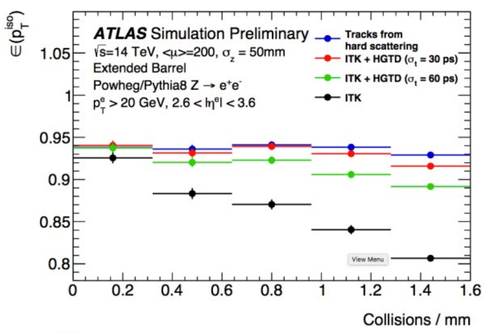


The HGTD has to maintain an excellent timing resolution under very high radiation doses

Pileup Mitigation With Timing

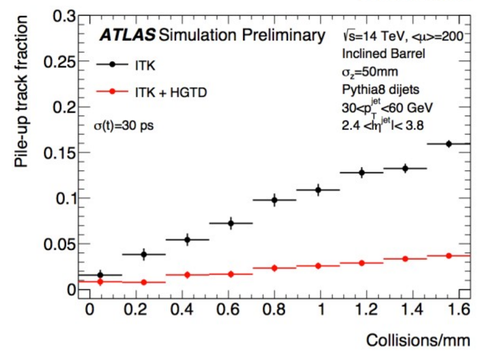
Including a timing detector in the forward region improves reconstruction performances:

- improves efficiency in selecting hard scatter isolated objects (electron, photon, τ): recovery of ~12% of electrons
- improves pileup-jet tagging



Dedicated combined reconstructions developed:

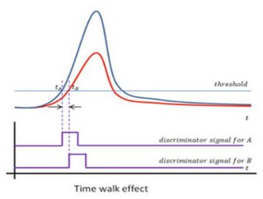
- Vertex time reconstruction
- Hit to track association

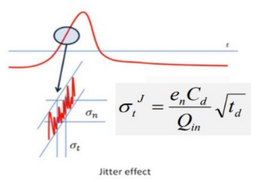


Electronics contributions to the time resolution

$$\sigma^2_{det} = \sigma^2_{Landau} + \sigma^2_{jitter} + \sigma^2_{TW} + \sigma^2_{TDC}$$

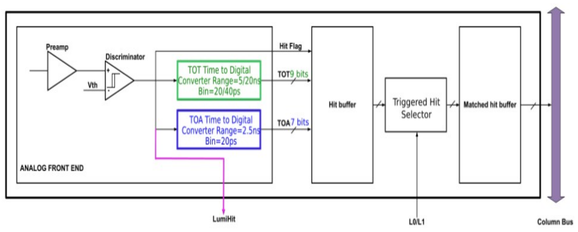
- **Jitter**: Noise contribution to the signal -**fast signals**, **small detector capacitance**
- **Time Walk**: large signals cross a constant threshold faster than small ones -**Time-Over-Threshold measurement**
- Binning of the**Time-to-Digital Converter** (TDC) -**fine binning**
- **Clock** contribution → online calibration





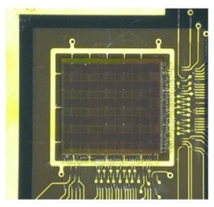
HGTD Front-End Electronics

ALTIROC: 225 channels - 2x2cm2ASIC for measurement and digitization ofLGAD signal



Requirements

- Excellent time resolution
- radiation hardness
- trigger rates of HL-LHC



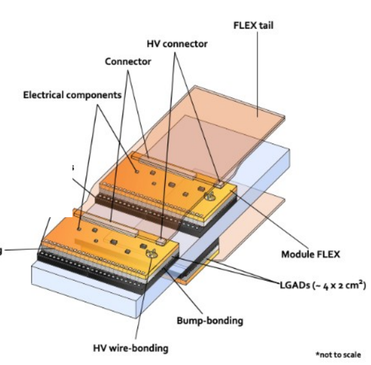
In each channel:

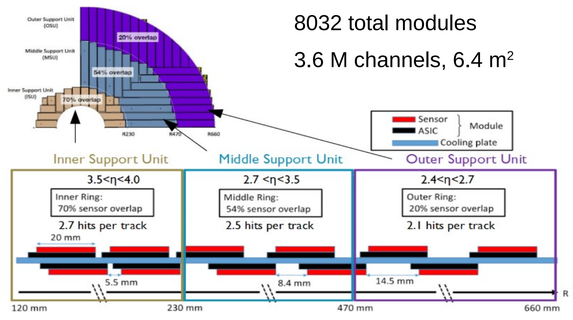
- Preamplifier
- TOT Discriminator - time walk correction
- 2 TDCs - digitization of time measurements
- Memory - information storage until trigger

HGTD Modules

Module

- Sensor: 15x30 pads of 1.3x1.3 mm^2
- Bump-bonded to two readout ASICs
- Flex-PCB glued on top
- Flexible tail to outer radius electronics



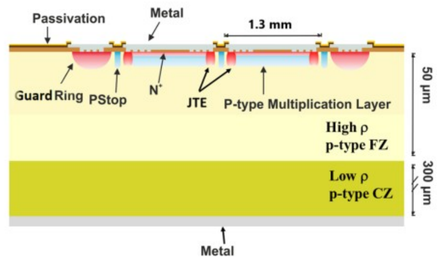


8032 total modules

3.6 M channels, 6.4 m^2

- Modules on both sides of layer
- Overlap decreases with radius to maintain average N hits per track 2

Sensor Technology: Low Gain Avalanche Detector



LGAD

- n on p sensor with p-type multiplication layer
- Low gain (G~10): to improve signal slope but control noise
- Expected time resolutionbefore irradiation = 30 ps

Timing resolution

$$\sigma^2_{det} = \sigma^2_{Landau} + \sigma^2_{elec}$$

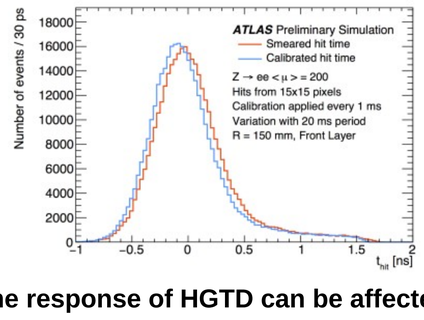
$$\sigma^2_{elec} = \left(\frac{t_{rise}}{S/N}\right)^2 + \left(\left[\frac{V_{thr}}{S/t_{rise}}\right]_{RMS}\right)^2 + \left(\frac{TDC_{bin}}{\sqrt{12}}\right)^2$$

Jitter **Time walk**

HGTD requirements after 2.5E15 n_{eq} /cm^2

- Good and uniform electrical behavior
- 4fC collected charge (for front-end functionality)
- Time resolution better than 70ps (~50 ps/track)
- Hit efficiency better than 95%

Time Calibration



Time response of HGTD can be affected by:

- LHC Clock bias
- Clock distribution
- Delays per Flex, per peripheral board (Felix,LpGBT)
- Time dependent variations of the clock

Calibration based on equalisation of the hit time response using collision data

Target precision of Time calibration 10 ps. To be performed: frequently (online), per ASIC

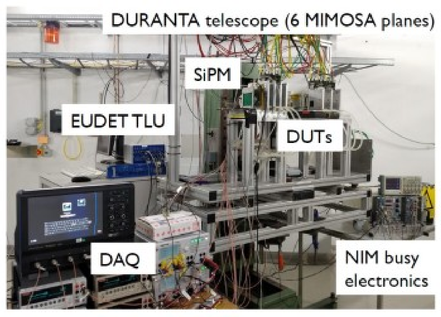
Test beam measurements with ALTIROC prototype

ALTIROC0:

- 8-channel prototype
- only analog (preamp + discri)
- 4-pad unirradiated sensorbump-bonded

Testbeam with ALTIROC0:

- Test beam with pion/electron beams (CERN/DESY)
- Telescope planes to provide track reconstruction
- Record wave-forms to perform analysis
- Tested single diodes and 2x2 arrays



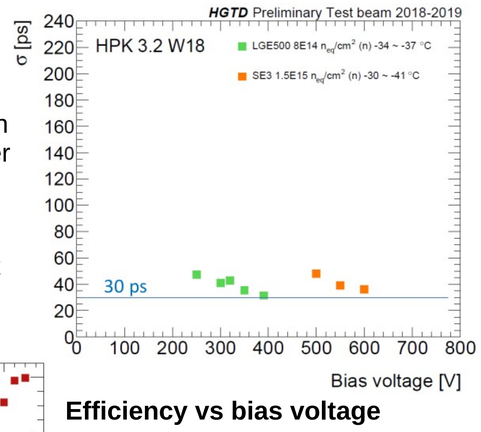
Results

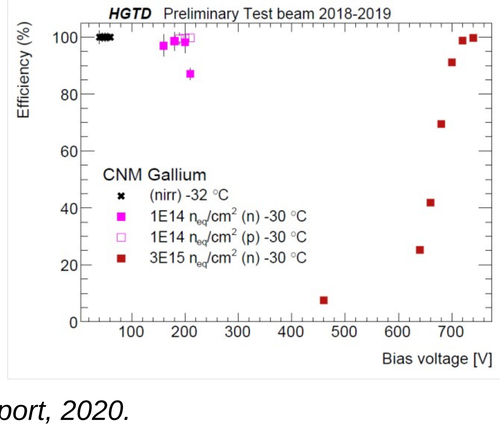
TIME CALIBRATION

- Time resolution is computed from time difference distribution between the sensor and the SiPM or another Sensor

$$\sigma^2(\Delta t) = \sigma^2(t_{sensor\ i}) + \sigma^2(t_{sensor\ j})$$

- time resolution better than 40 ps at higher bias voltage





Efficiency vs bias voltage

- For each bias voltage point, efficiency is defined as :

$$\varepsilon = \frac{\textit{Tracks in the sensor center (0.5x0.5 mm}^2\textit{) with Q>2fC}}{\textit{Tracks in the sensor center}}$$

- For CNM sensor, efficiency reaches 99.7% for a bias voltage of 740 V and a collected charge of 5.3 fC

[1] ATLAS Collaboration. Technical design report: A high-granularity timing detector for the atlas phase-ii upgrade. Technical report, 2020.

Asmaa Aboulhorma, Farida Fassi
Mohammed V University in Rabat, Morocco

جامعة محمد الخامس بالرباط
Université Mohammed V de Rabat
Mohammed V University of Rabat