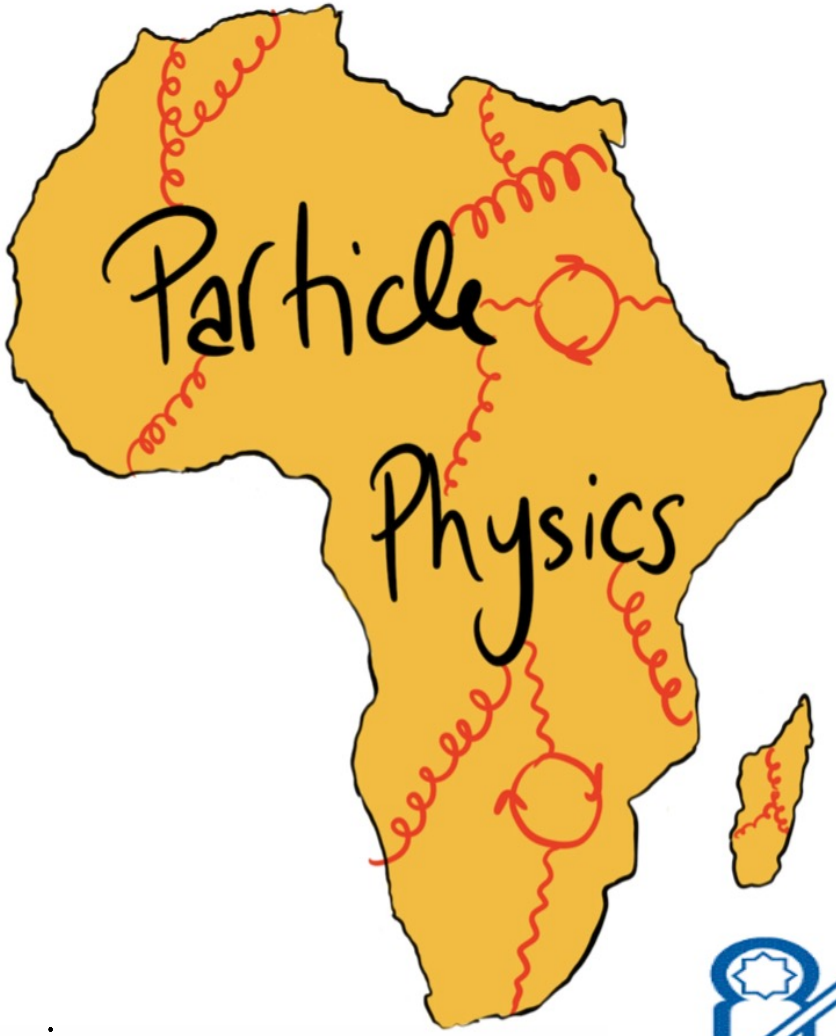
ASFAP-Particle Physics Day- PhD and Postdocs

Jet energy scale and resolution in the forward region using High-Granularity Timing Detector in ATLAS upgrades at HL-LHC



Asmaa Aboulhorma, Farida Fassi,

Mohammed V University in Rabat,Morocco

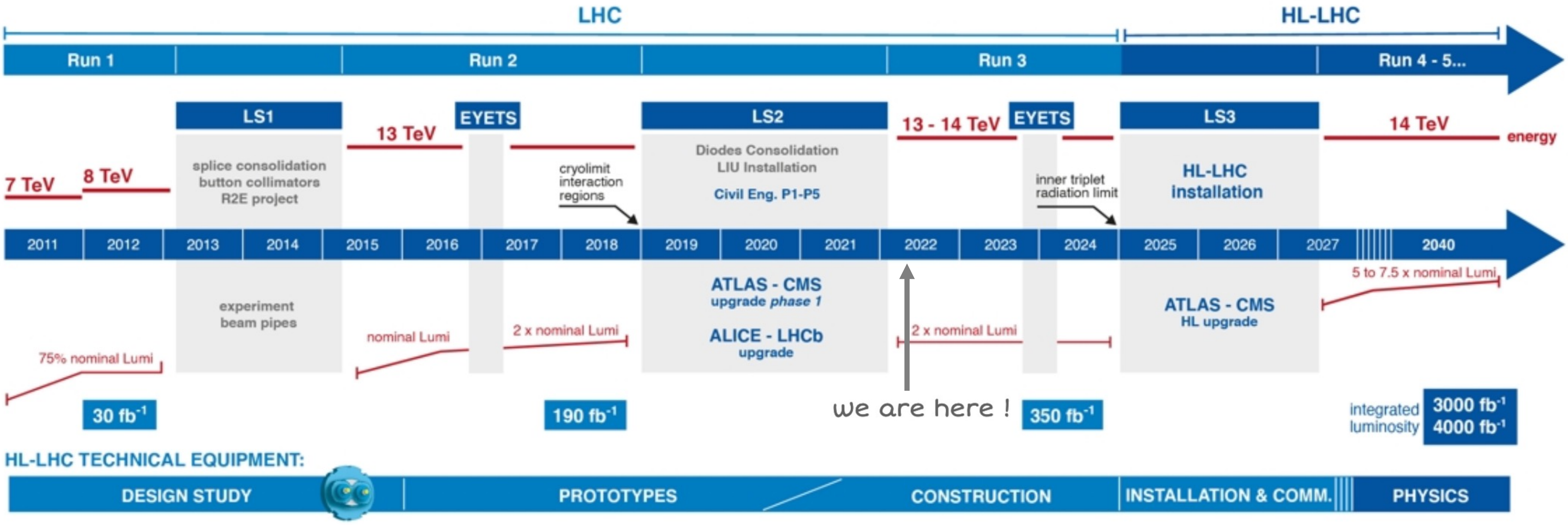
ATLAS EXPERIMENT

Université Mohammed V de Rabat
Mohammed V University of Rabat

Overview

- The ATLAS detector phase II upgrade
- The case for the ATLAS High Granularity Timing Detector
- Description of the HGTD system
- *Suppression of Pileup Jets*
- *Jet Energy Response & Resolution in Forward region*
- *Jet Correction*

The High Luminosity At Large Hadron Collider



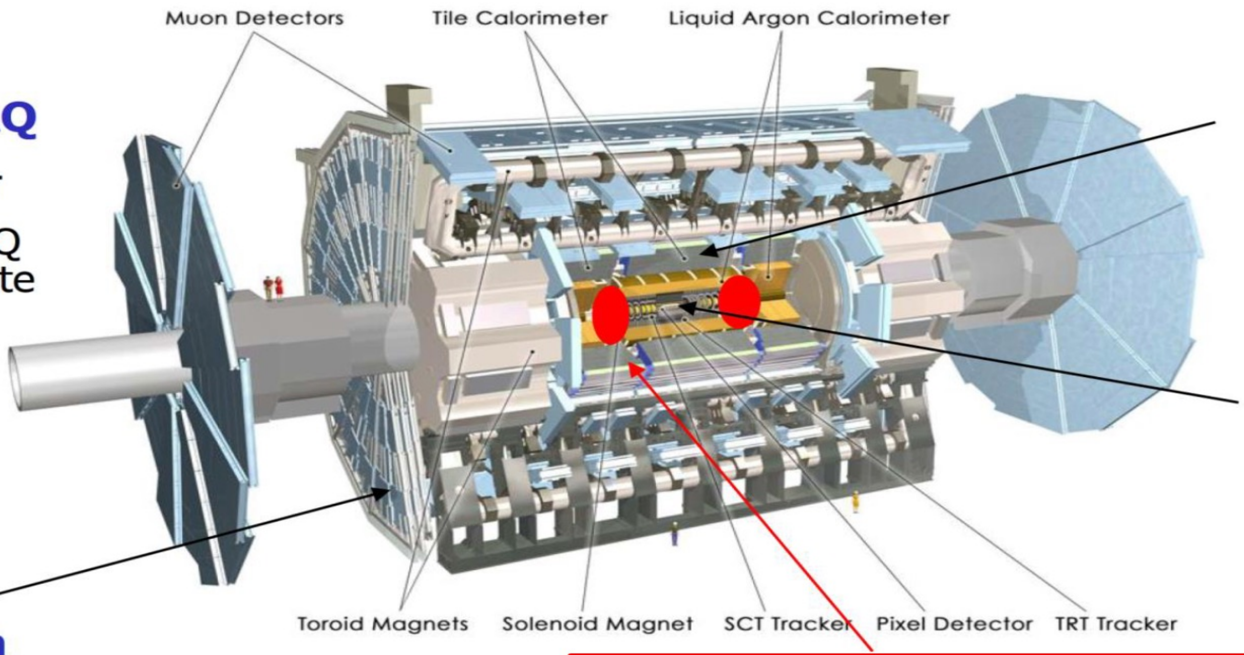
- To extend the discovery potential, the LHC scheduled for an upgrade.
- The HL phase is expected to start in 2027 reaching 5-7.5 x 10^{34} the design luminosity.

The ATLAS Detector Phase-II upgrade for HL-LHC

The ATLAS detector is undergoing a significant upgrade program for all subsystems to operate in challenging HL-LHC conditions

Luminosity up to 7.5×10^{34} $cm^{-2}s^{-1}$, pileup <μ> ~200, irradiation level TID ~2MGy

L1 trigger rate of 1 MHz. Additional 15 years of operation and maintenance



Trigger + DAQ
- Track trigger
- Upgrade DAQ for higher rate

Calorimeters
- Upgrade electronics

Inner Tracker
- Full replacement: all-S extended to |η|=4

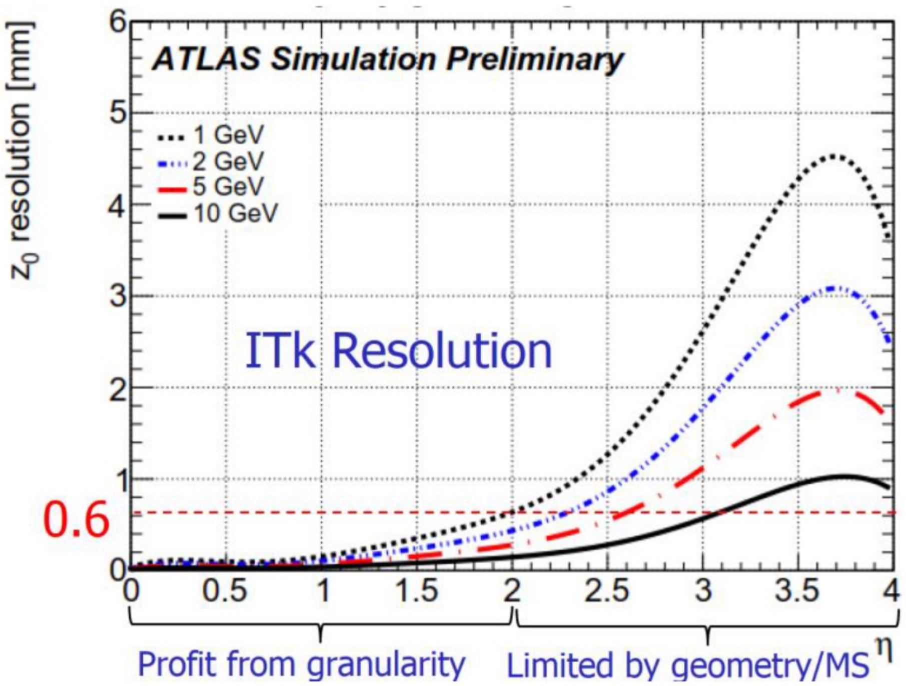
Muon System
- New trigger chambers in barrel

- High Granularity Timing Detector
- Silicon-based novel detector

The case for the HGTD : Pile-up challenge

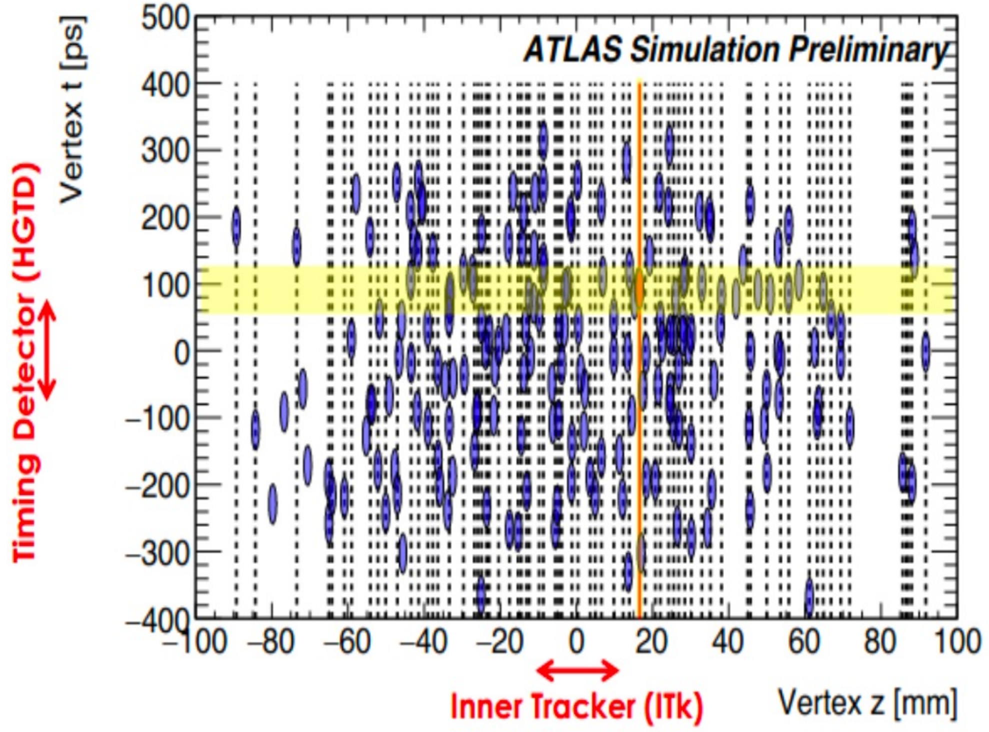
- Main challenge for detectors at the HL-LHC is pile-up
- Need to identify if particles or jets come form hard scattering vertex
- Time spread of vertices ~ 175 ps :
  - With 1.6 vertices/mm -> <0.6 mm ITk resolution

	Energy	Instantaneous $\mathcal{L}$	Integrated $\mathcal{L}$	Pileup
Run 2 LHC	13 TeV	2×10^{34} cm^{-2}s^{-1}	300 fb^{-1}	37
HL-LHC (Nominal)	14 TeV	5×10^{34} cm^{-2}s^{-1}	3000 fb^{-1}	140
HL-LHC (Ultimate)	14 TeV	7.5×10^{34} cm^{-2}s^{-1}	4000 fb^{-1}	200



ITk performs well only up to $|\eta| \sim$ 2-2.7
Assign time to each track in 2.7<$|\eta|$<4.0

30-50 ps time resolution per track would give ~x6 pile-up rejection



The HGTD System

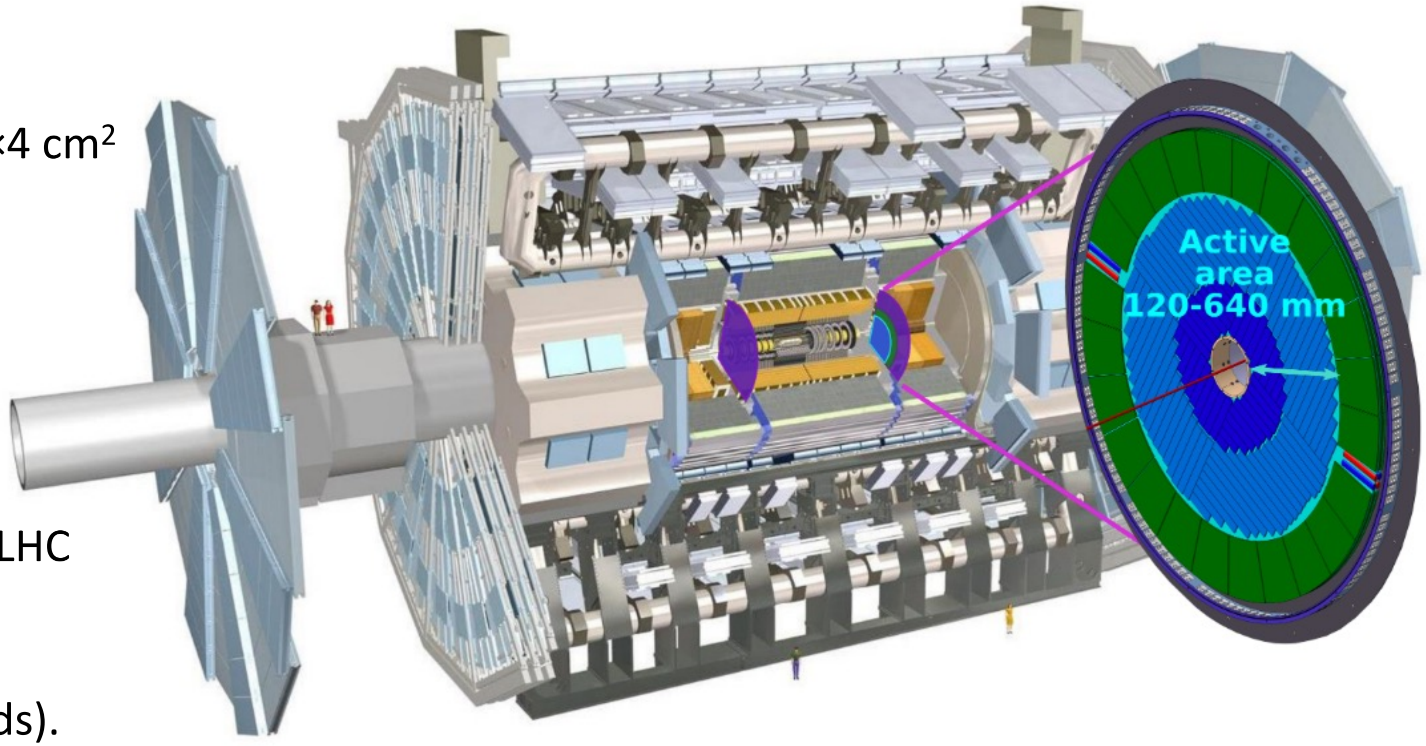
The HGTD will provide time measurements for objects in the forward regions of the ATLAS detector

General parameters:

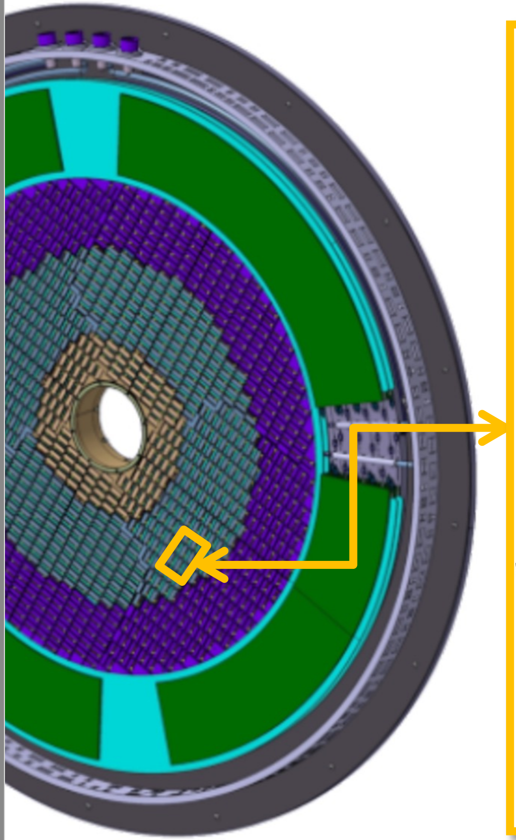
- $2.4 < |\eta| < 4.0$
- Active area 6.3 m^2 (total)
- Design based on 1.3×1.3 mm^2 silicon pixels ($2{\times}4$ cm^2 sensors)
  → optimised for < 10% occupancy and small capacitance
- Number of hits per track:
  - 2 in $2.4 < |\eta| < 3.1$
  - 3 in $3.1 < |\eta| < 4.0$
- Inner ring to be replaced at half life-time of HL-LHC

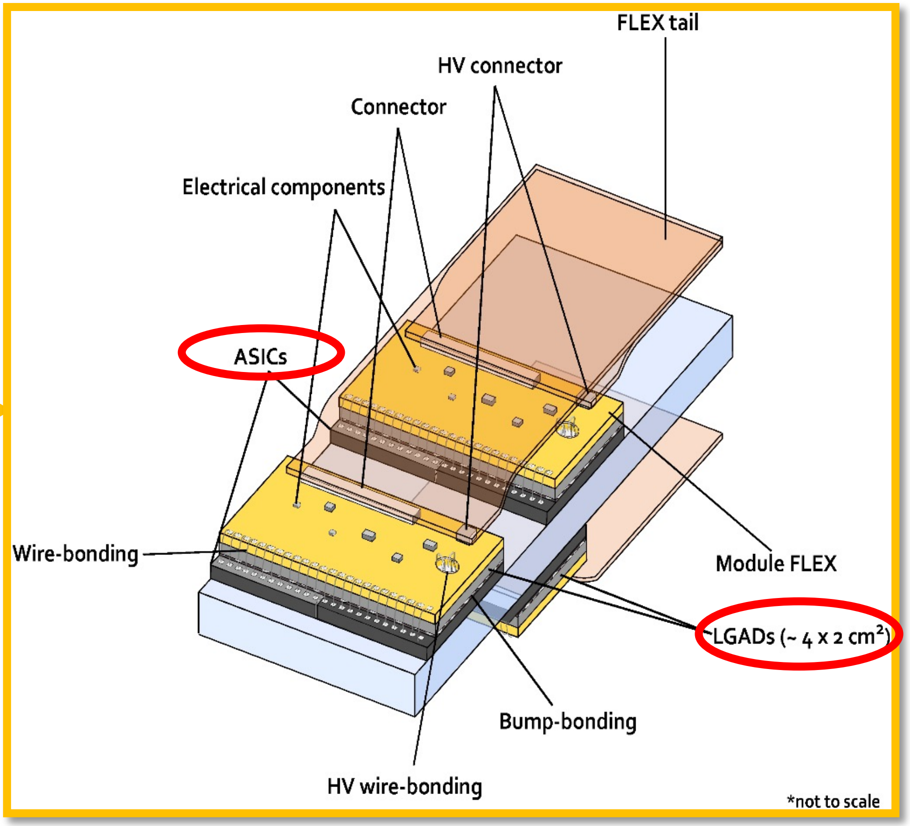
Goal:

- Resolve close-by vertices
- small timing resolution (~few 10s of picoseconds).
- Provide minimum bias trigger
- Instantaneous and unbiased luminosity measurement



HGTD Modules



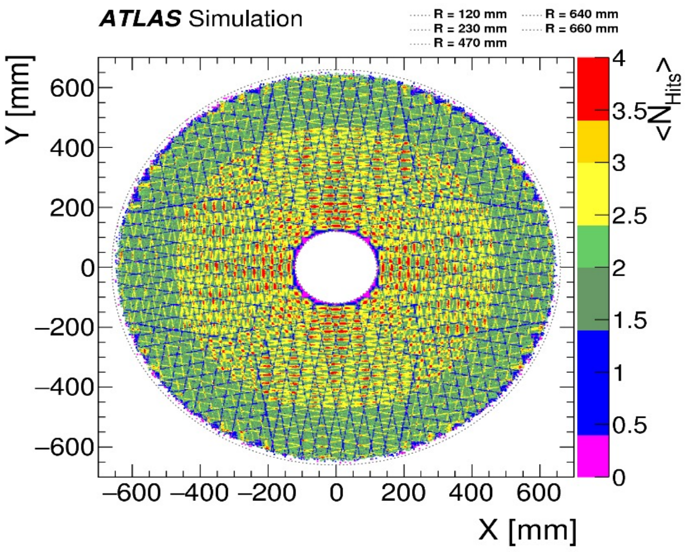


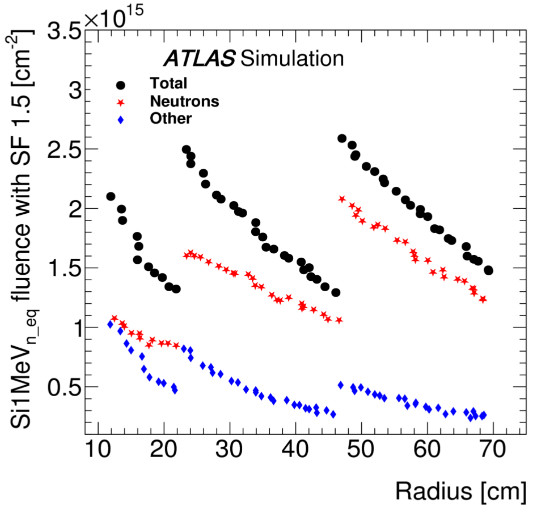
- 8032 modules to be installed in HGTD
- Bare module: 2 LGADs + 2 ASICs
  - LGAD: two 15x15 pads of 1.3x1.3mm^2
  - Each LGAD pad is bump-bonded to ALTIROC chip
- Bare module glued to flexible PCB (FLEX cable)
  - Readout and distribute power to each individual module

Layout & Radiation Hardness

- Modules are arranged in an overlapping manner
- Ring structure: easy replacement of sensors (radiation damage)
  - Outer ring, 470 < r < 640 mm : 20% overlap ➔ never replaced
  - Middle ring, 230 < r < 470 mm : 54% overlap ➔ replaced each 2000 fb^{-1}
  - Inner ring, 120 < r < 230 mm : 70% overlap ➔ replaced each 1000 fb^{-1}

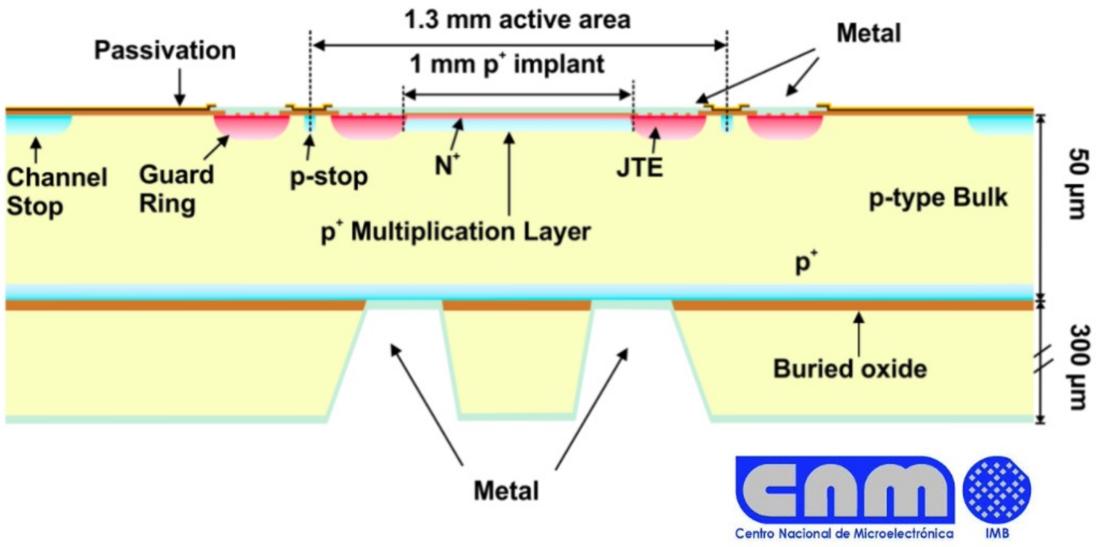
- In order to get at least 4 fC of charge the radiation should not exceed:
  - Total Ionizing Dose (TID): 2 MGy
  - Neutron fluence: $2.5\times10^{15} n_{eq} cm^{-2}$





HGTD Sensor Technology and Time Resolution

HGTD needs to achieve about 60 ps/mip/layer resolution: technology **beyond silicon** devices



Time resolution:

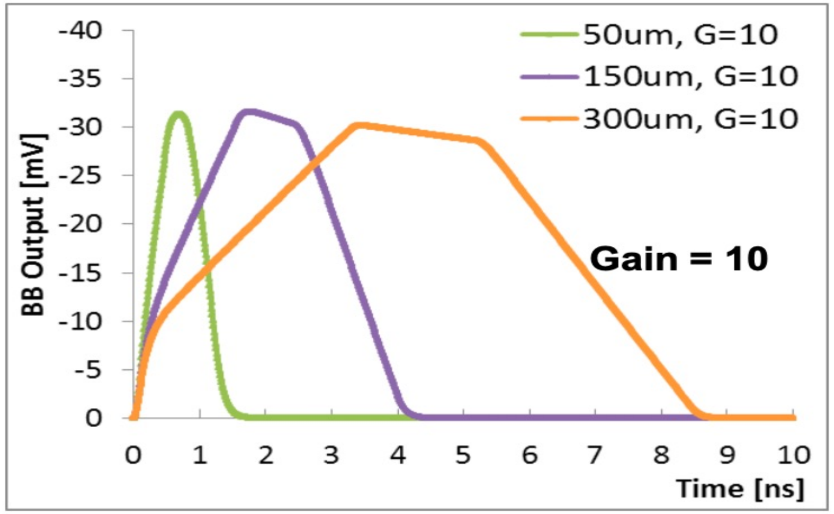
$$\sigma_{tot}^2 = \sigma_{Landau}^2 + \left(\frac{t_{rise}}{S/N}\right)^2 + \left(\left[\frac{V_{thr}}{S/t_{rise}}\right]_{RMS}\right)^2 + \left(\frac{TDC_{bin}}{\sqrt{12}}\right)^2 + \sigma_{clock}^2$$

Jitter Time-walk (negligible)

Need fast signal and excellent S/N

- A multiplication layer increases signal slope
- Time walk contribution negligible with CFD

Thin sensors (50 µm) to reduce intrinsic Landau contribution to resolution



ATLAS LGAD Timing Integrated ReadOut Chip

Each LGAD will be readout using the ALTIROC chip

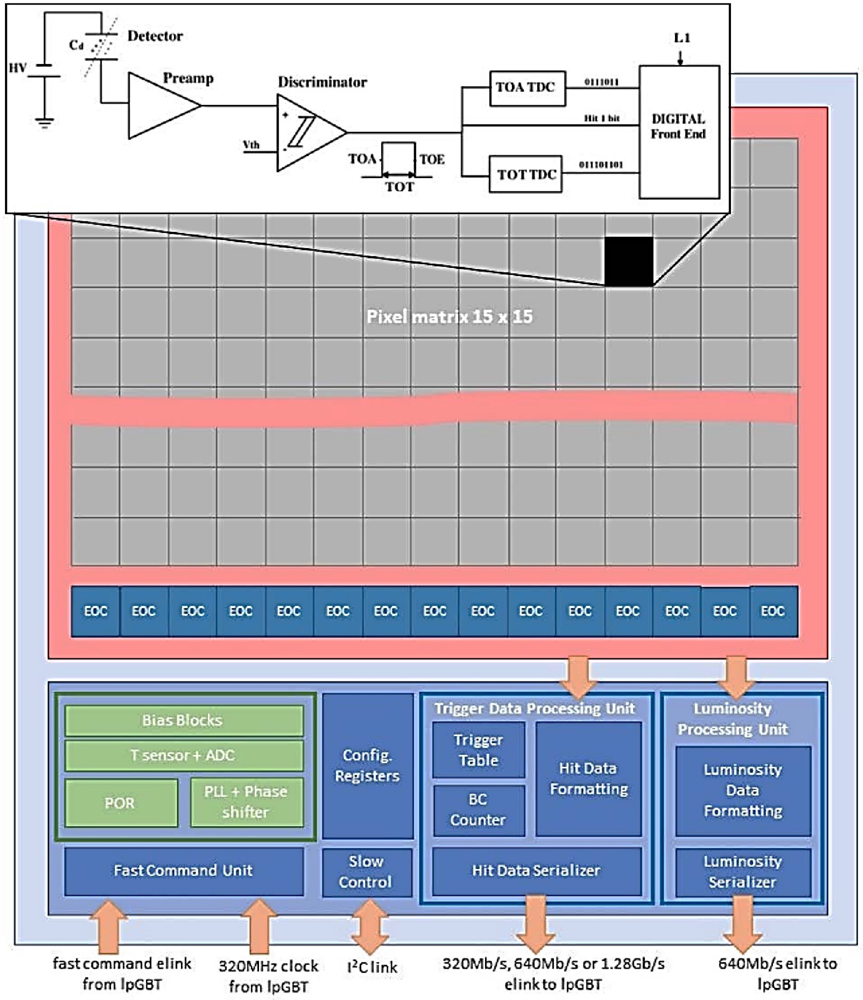
- Final size: 225 readout channels

Two generation of ALTIROC chips produced and tested:

- ALTIROC0: 2016
  - four channels in a 2 x 2 array
  - Each channel (200 µm x 100 µm) = Preamplifiers + TOT and CFD
- ALTIROC1: 2018
  - 25 channels in 5 x 5 array
  - Each channel = Preamplifiers + TOT and CFD + digital components

Other generations of ALTIROC:

- ALTIROC2: 2020
  - Full size: 225 channels
  - Integrate all functionality of final ASIC
- ALTIROC3
  - The radiation hard version of ALTIROC2



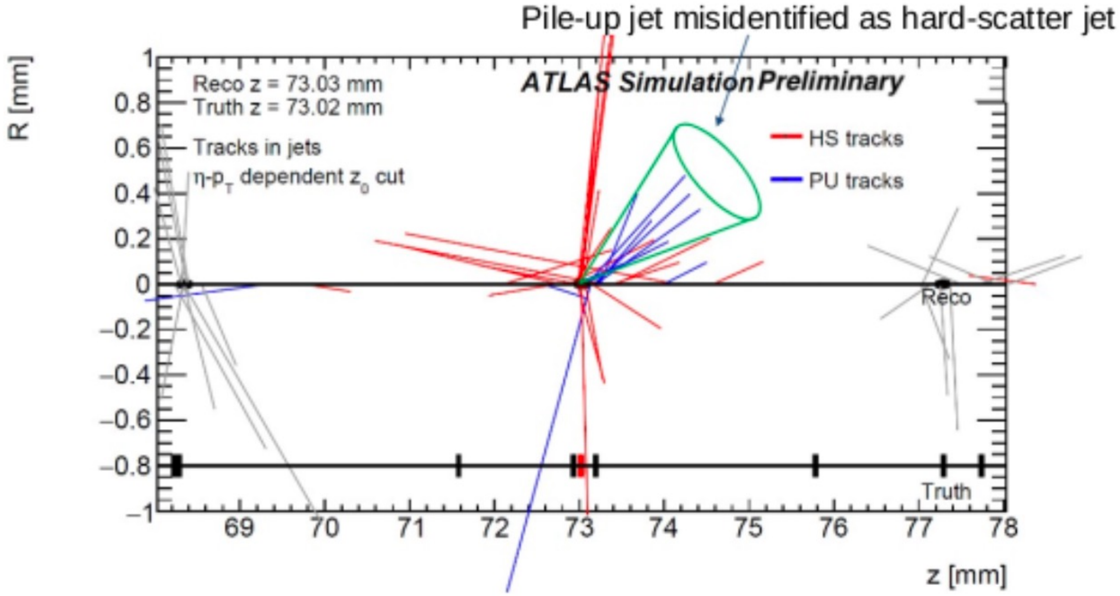
Suppression of Pileup Jets

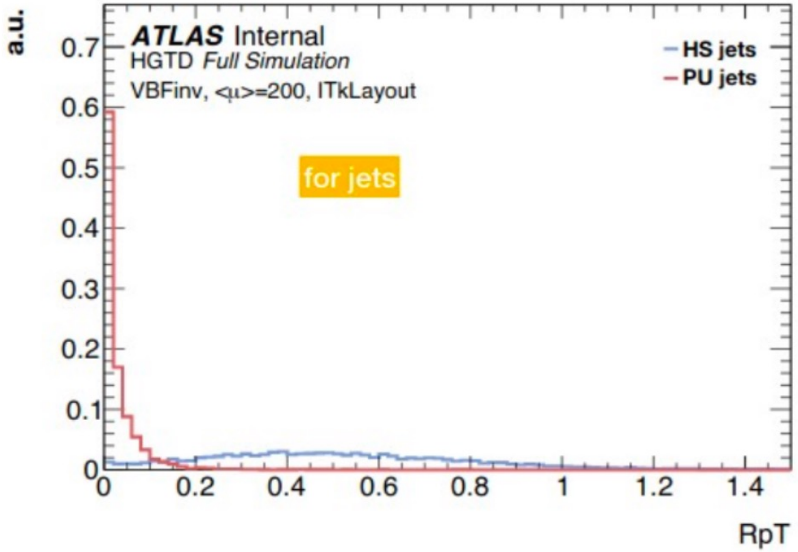
- Pile-up local fluctuations within a same event can lead to fake pile-up jets:
  - Uniform distribution of particles from multiple interactions
  - Anomalous jet structure with no high pT jet core

- The key element to suppress pileup jets is the accurate association of jets with tracks and primary vertices.

$$RpT = \frac{\sum_k P_T^{Track_k}(PV_0)}{P_T^{Jet}}$$

- increase the separation power between HS and PU jets for the RpT variable





Jet Energy Response & Resolution in Forward region

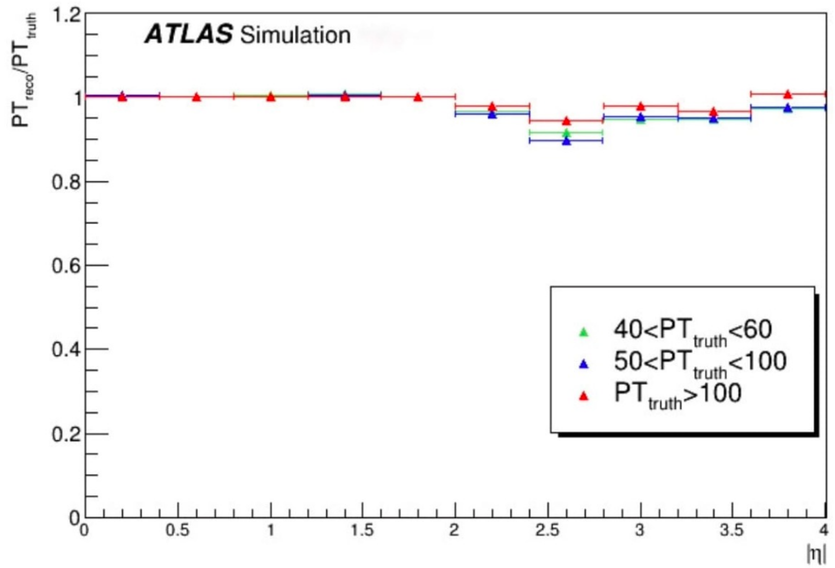
The VBF process ($H \rightarrow ZZ \rightarrow$ 4 neutrinos plus 2 jets) has been used to perform this study.

The jet energy response and resolution has been studied as a function of jet-eta and jet-pt.

Pt-jet correction:

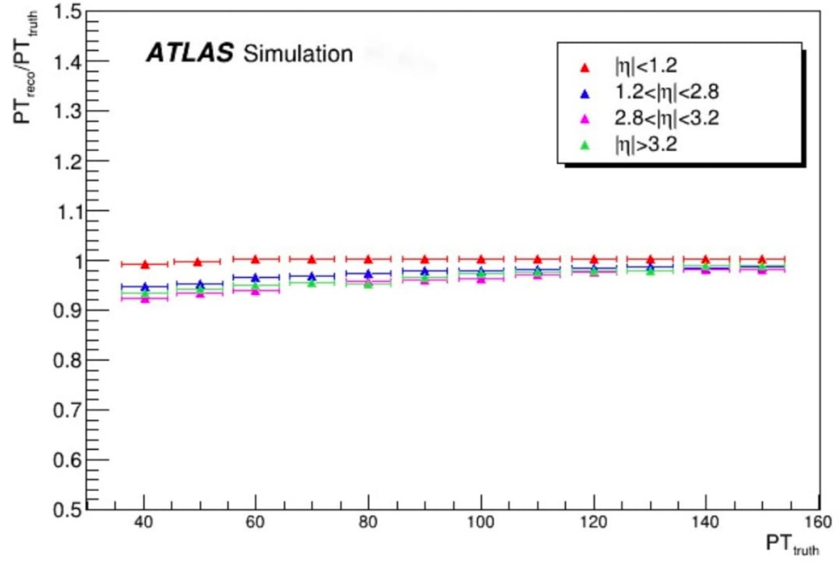
- timing information is applied.
- to drop the PU track, the association between the track and the vertex is performed based on the truth information

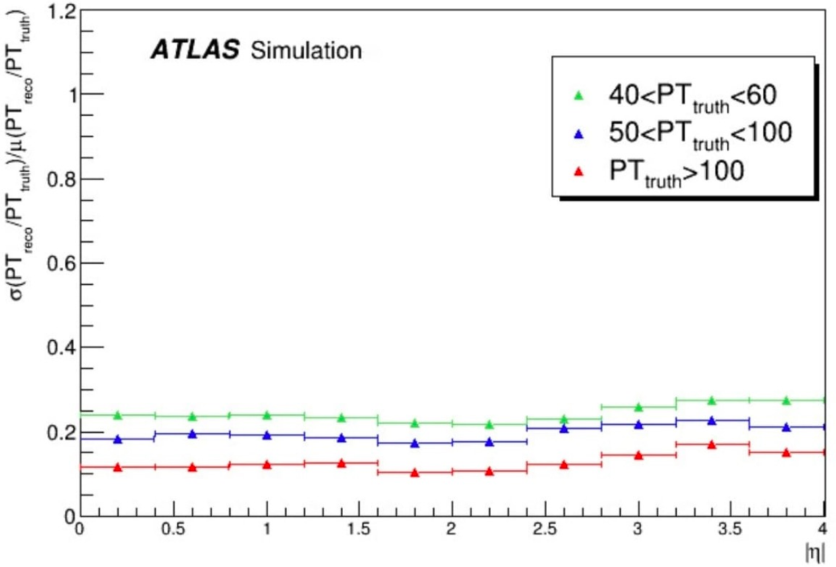
Jet Energy Response & Resolution



Jet energy response

The ratio of the reco-jet over the truth jet energy.It is evaluated as the mean value μ of the Gaussian fit of the distribution $\frac{p_{T\ reco}}{p_{T\ truth}}$

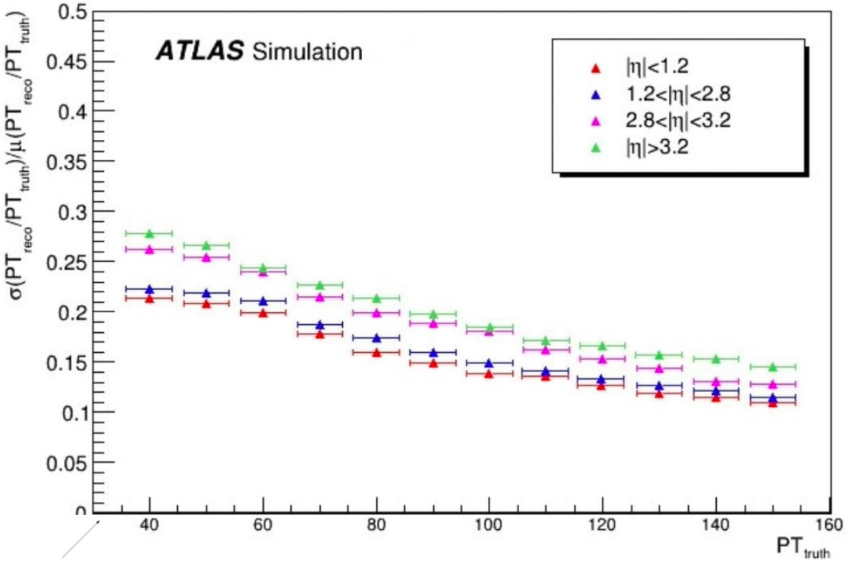




Jet energy resolution

It is defined as The ratio :

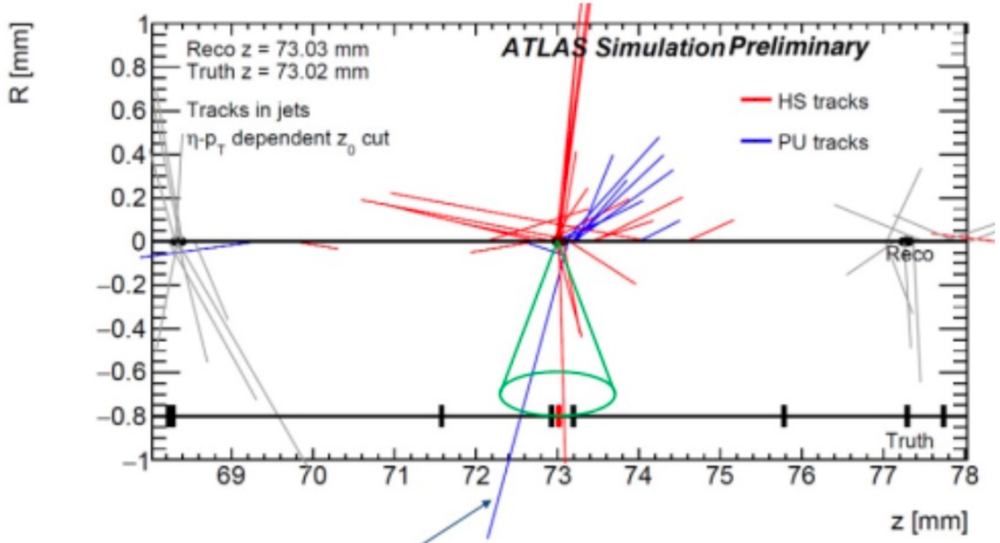
$$\frac{\sigma(p_{T\ trut}/pT_{\ truth})}{\mu(p_{T\ trut}/pT_{\ truth})}$$



Jet Correction

The association of tracks to vertices relies on assigning tracks that are geometrically compatible in z with the vertex position

$$\frac{Z_0 - Z_{vtx}}{\sigma} < 2$$



Pile-up track contamination in hard-scatter jets

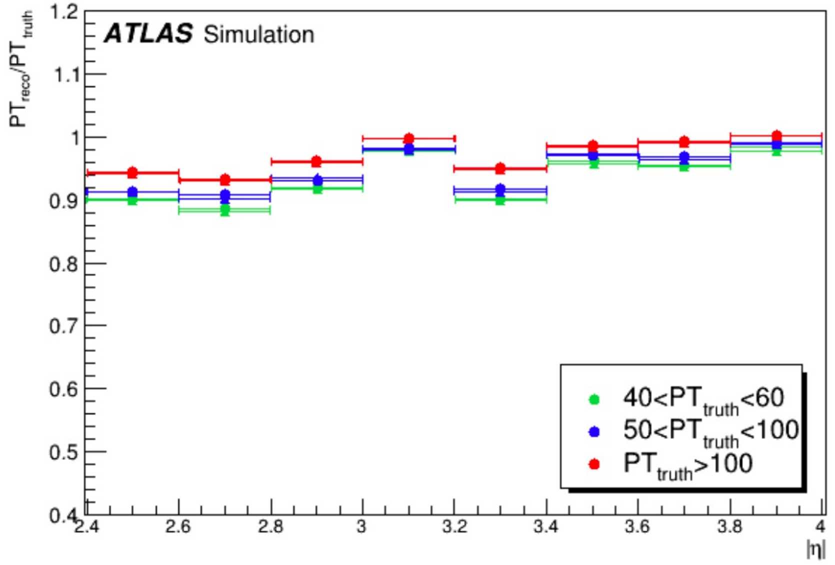
Timing information is an additional handle to reject pile-up

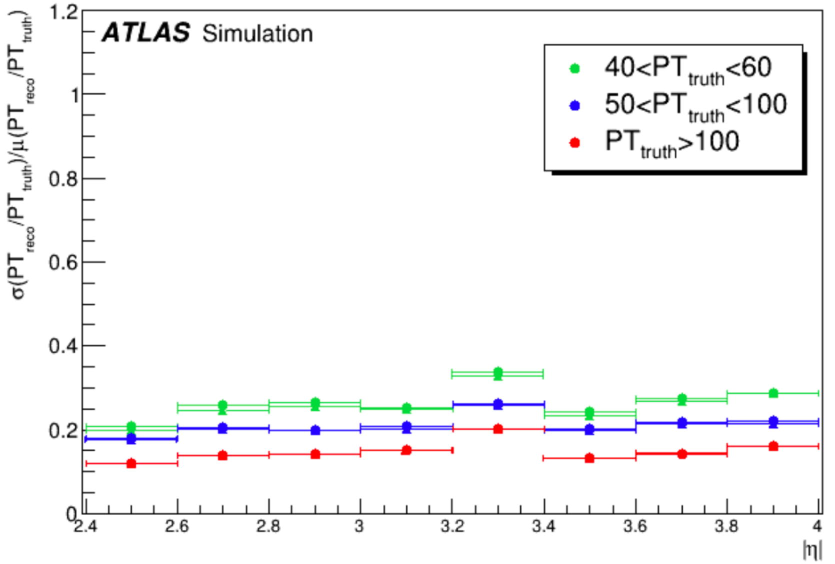
Looking at how to incorporate HGTD to reduce pileup contributions and improve the jet energy resolution.

The Jet has been corrected as following:

$$p_{T\ jet\ \_\ corr} = p_{T\ \text{jet}} - \text{E/p} \times \sum p_{T\ \text{Track}}$$

Jet Energy Response & Resolution After Correction



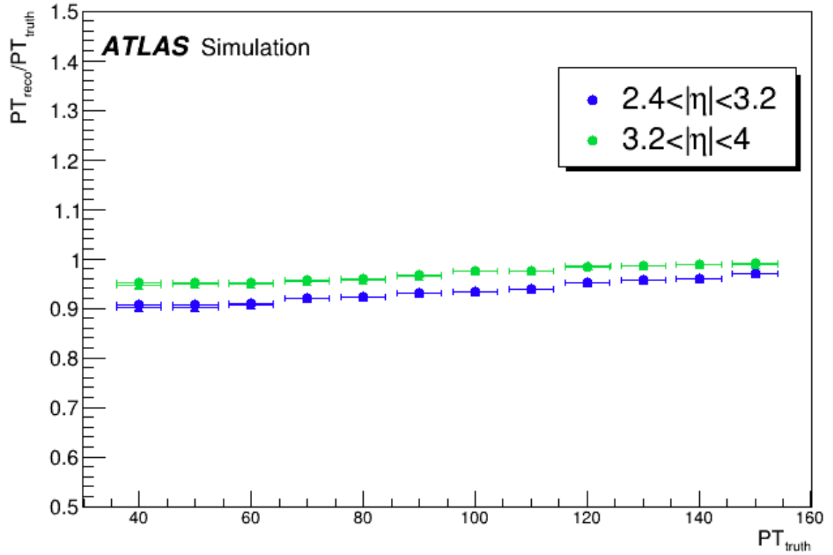


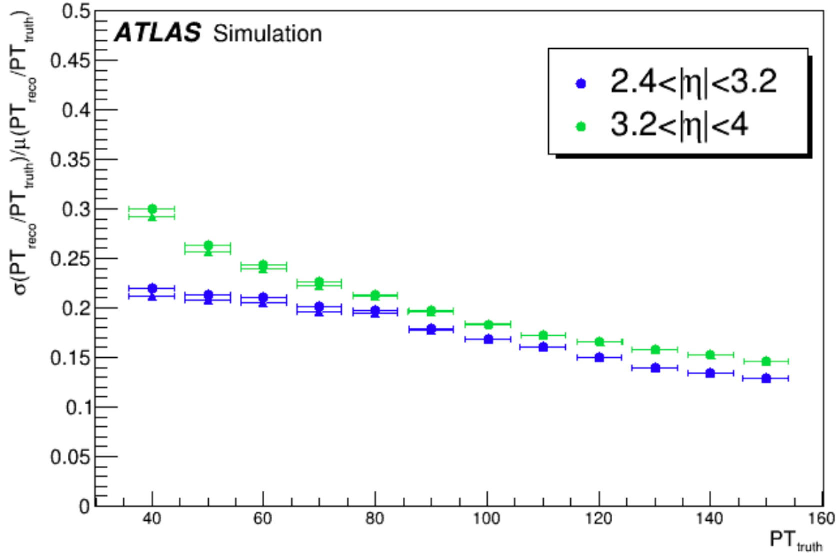
Jet energy response

The response is decreased, as expected, after applying the correction as a function of η_{jet} and $p_{T\text{-}jet}$

Jet energy resolution

- For 2.4 < |η| < 3.2 The resolution has been improved ruffly 3.5%, and 1.78% Respectively for 40 < *PT* < 60 and 50<*PT* <100
- For 3.2 < |η| < 4 The resolution has been improved ruffly 3.1% and 1.37%, Respectively for 40 < *PT* < 60 and 50<*PT* <100.





Summary

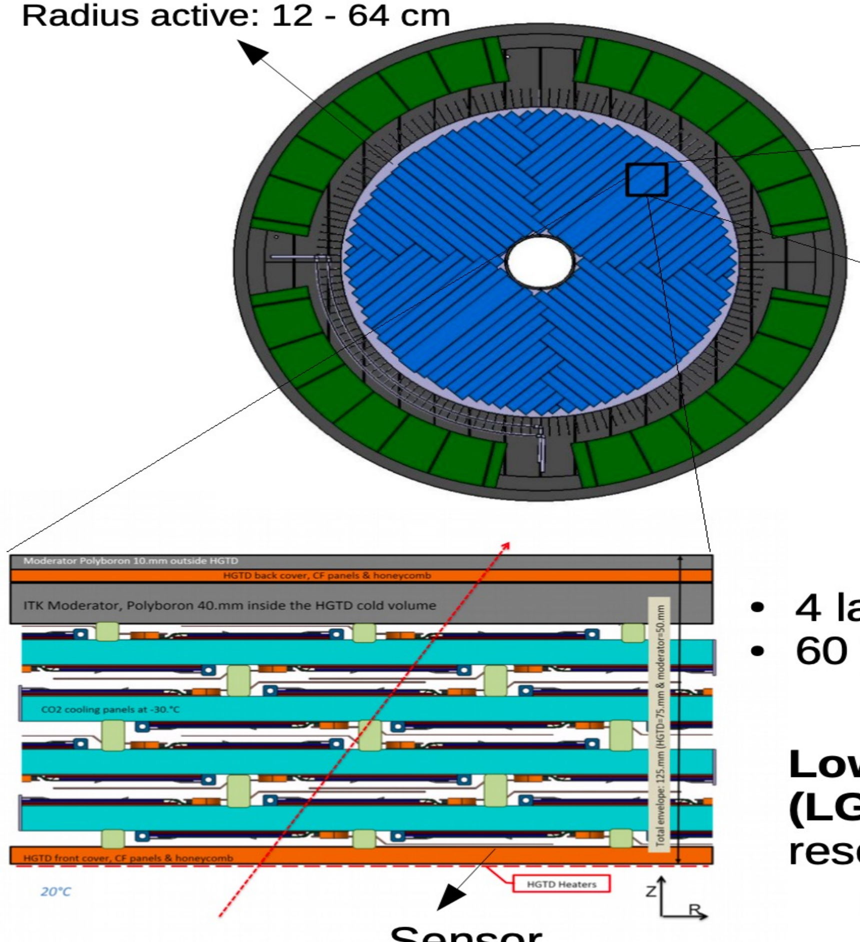
At the HL-LHC, the pile-up will present an unprecedented challenge and the HGTD is expected to play a key role in ATLAS by adding timing information in the forward region.

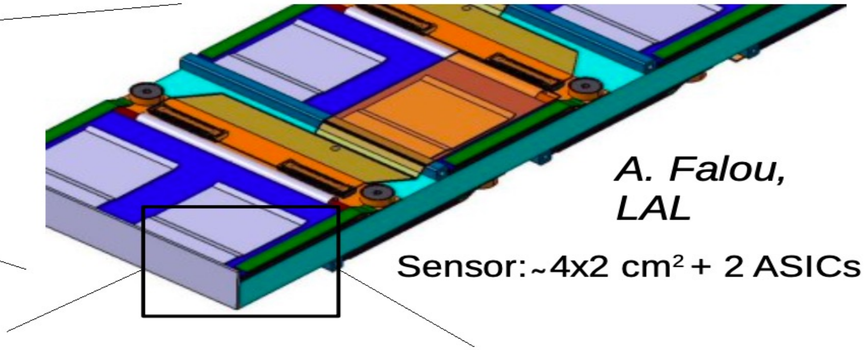
Promising results for pileup rejection in the high region for object reconstruction performance VBF and exotics will benefit, high purity for invisible searches.


ARCHIVE
BACKUP

HGTD Detector

HGTD requirements of **radiation hardness** and **compactness** well met with **silicon sensors**

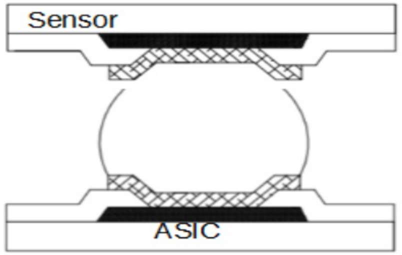




Core of HGTD: hybrid silicon sensors with 1.3 x 1.3 mm² pixels

- 4 layers in about 7 cm
- 60 ps/mip/layer resolution

Low gain avalanche detectors (LGAD) to achieve target resolution



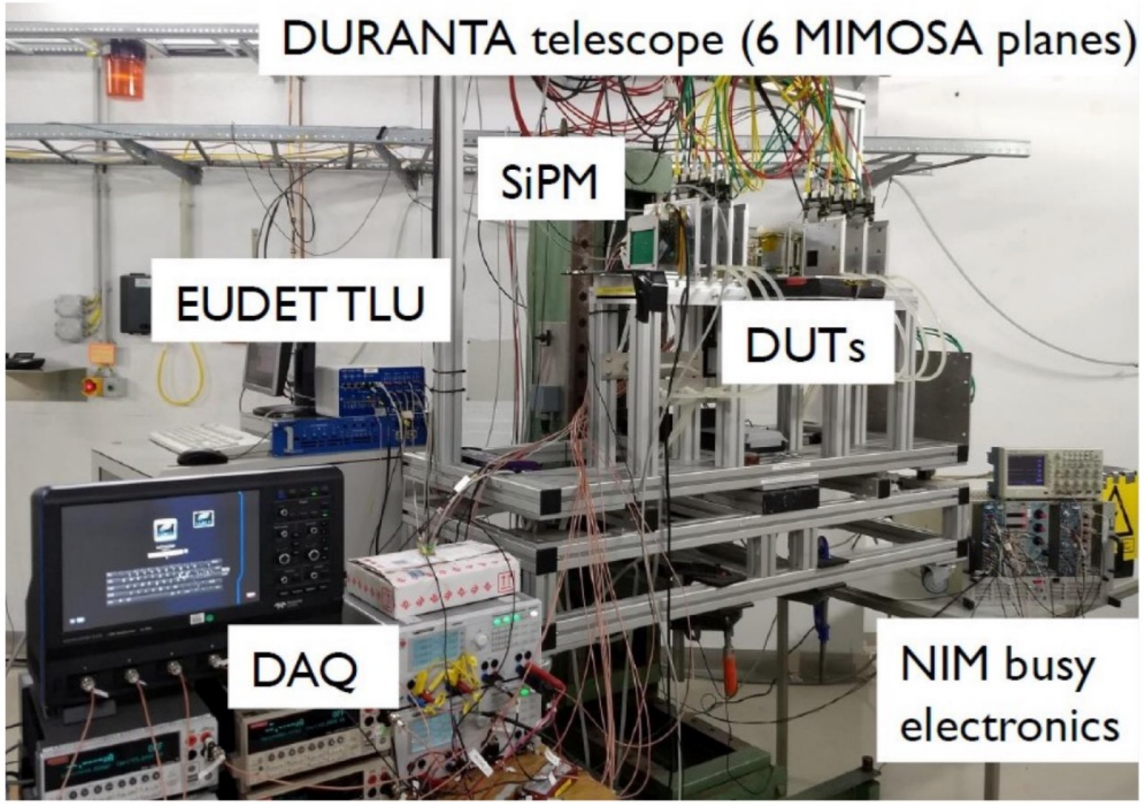
S. Grinstein - PSD11 2017

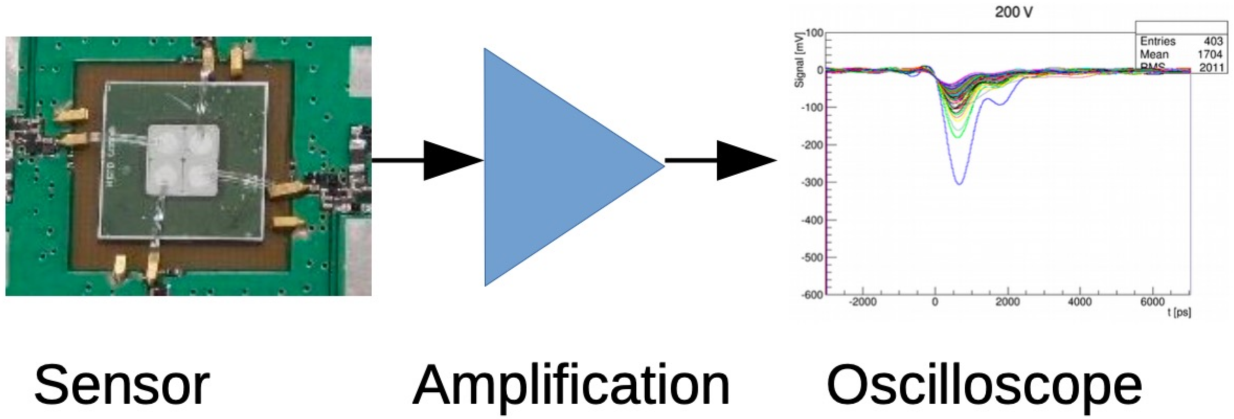
Main HGTD parameters

Pseudo-rapidity coverage	$2.4 < \|\eta\| < 4.0$
Thickness in z	75 mm (+50 mm moderator)
Position of active layers in z	$z = \pm 3.5$ m
Weight per end-cap	350 kg
Radial extension:	
Total	$110\,\text{mm} < r < 1000\,\text{mm}$
Active area	$120\,\text{mm} < r < 640\,\text{mm}$
Pad size	$1.3\,\text{mm} \times 1.3\,\text{mm}$
Active sensor thickness	50 µm
Number of channels	3.6 M
Active area	$6.4\,\text{m}^2$
Module size	30 x 15 pads ($4\,\text{cm} \times 2\,\text{cm}$)
Modules	8032
Collected charge per hit	> 4.0 fC
Average number of hits per track	
$2.4 < \|\eta\| < 2.7$ ($640\,\text{mm} > r > 470\,\text{mm}$)	≈ 2.1
$2.7 < \|\eta\| < 3.5$ ($470\,\text{mm} > r > 230\,\text{mm}$)	≈ 2.5
$3.5 < \|\eta\| < 4.0$ ($230\,\text{mm} > r > 120\,\text{mm}$)	≈ 2.7
Average time resolution per hit (start and end of operational lifetime)	
$2.4 < \|\eta\| < 4.0$	≈ 35 ps (start) ≈ 70 ps (end)
Average time resolution per track (start and end of operational lifetime)	≈ 30 ps (start) ≈ 50 ps (end)

HGTD LGAD Sensors Test Beam Setup

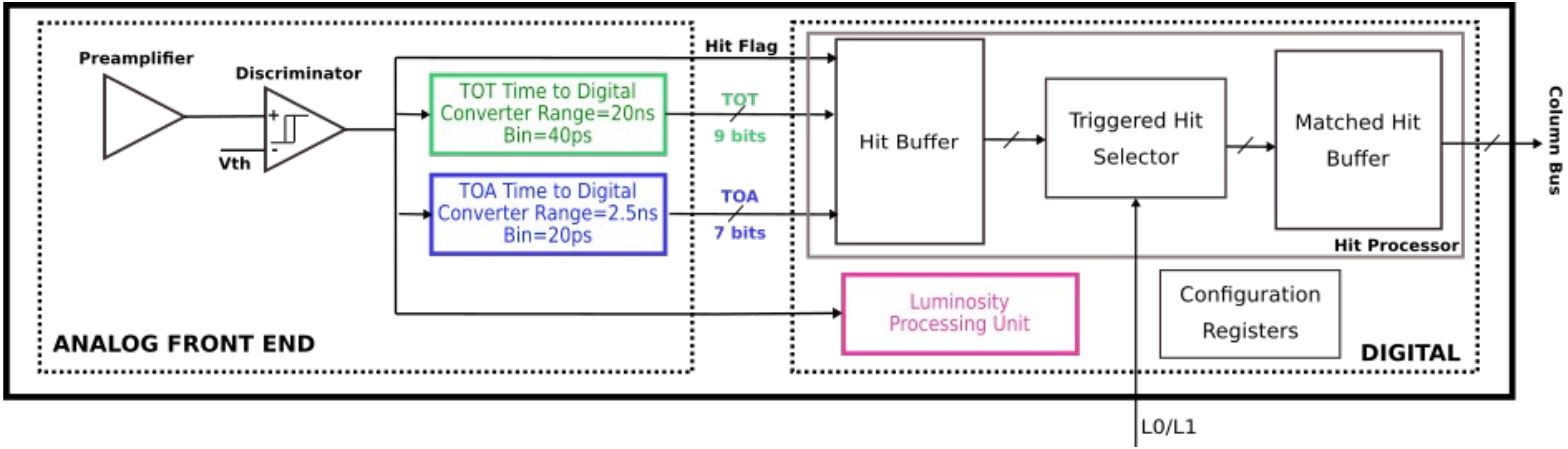
Test beam with pion/electron beams at CERN and DESY.





- Multiple LGAD sensors mounted on beam
- Also SiPM (10 ps) used for timing reference
- Particle tracking available
- Waveforms stored and analyzed offline (CFD)
- Extract various measurements from waveforms

HGTD Electronics



- Signal from each LGAD read out using the ATLAS LGAD Timing Readout Chip (ALTIROC)
- Bump-bonded to LGAD module
- 15x15 = 225 readout channels

- Channel= Analogue(Preampli fiers, Time Of Arrival TOA, Time Over Threshold TOT, CFD) + Digital data transmission
- Time resolution of 58 ps before corrections

Time-Line and Milestones for the implimentation of the HGTD