Test Beam performance of ALTIROC3 hybrid assemblies with LGAD sensors for the ATLAS HGTD Upgrade

Speaker: Salah El Dine HAMMOUD

On Behalf of ATLAS HGTD Group

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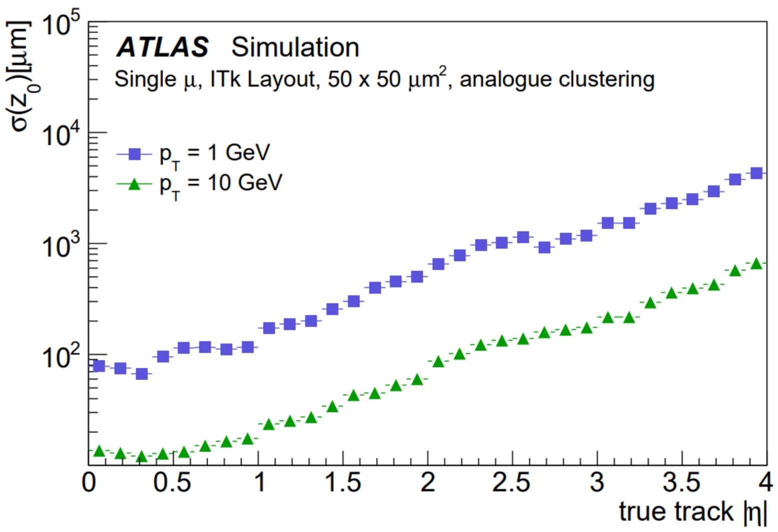
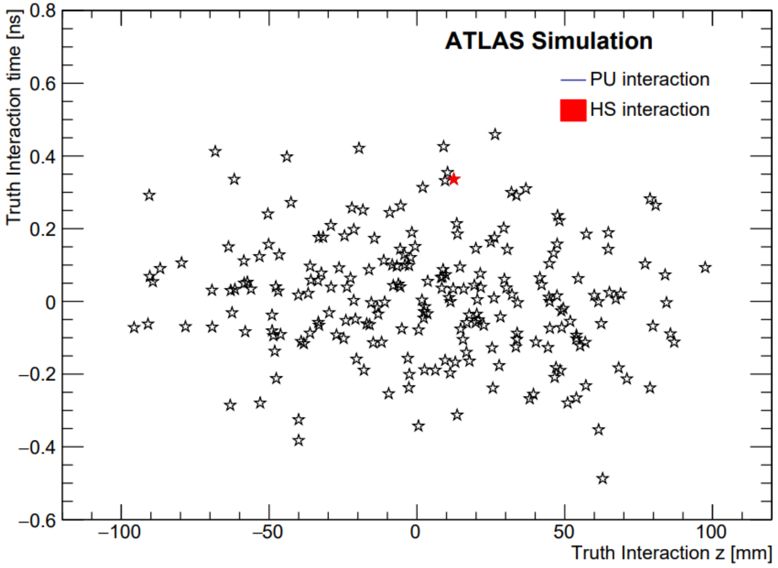
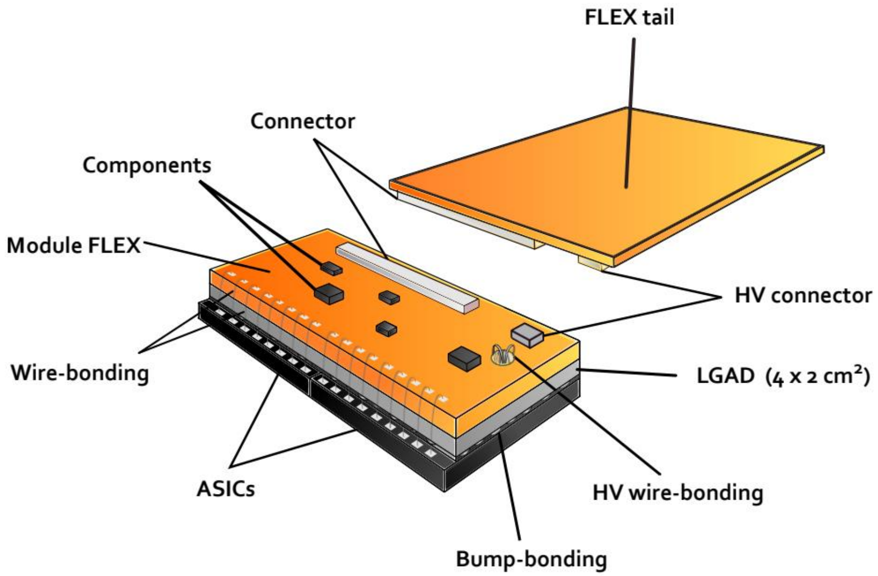
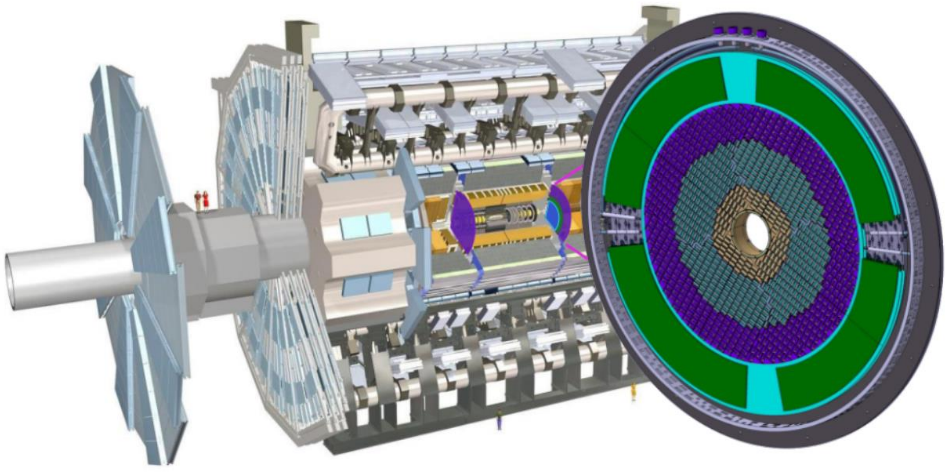
The ATLAS High Granularity Timing Detector "HGTD"









Requirements:
- 35 - 70 ps per hit up to 4000 fb^{-1}
- 30 - 50 ps per track
- Fluence Max 2.5×10^{15} n_{eq}/cm^2

Luminosity measurement:
- Bunch by Bunch

Position and Active area:
- Outside ITK
- $2.4 < |\eta| < 4$
- Radial Extention: 12 to 64 cm

Module View:
- 2 ASICs + 2 LGADs / Module
- In total: 8032 Modules
- 15×15 pads for 1 ASIC + 1 LGAD

Front-End Readout System ASIC

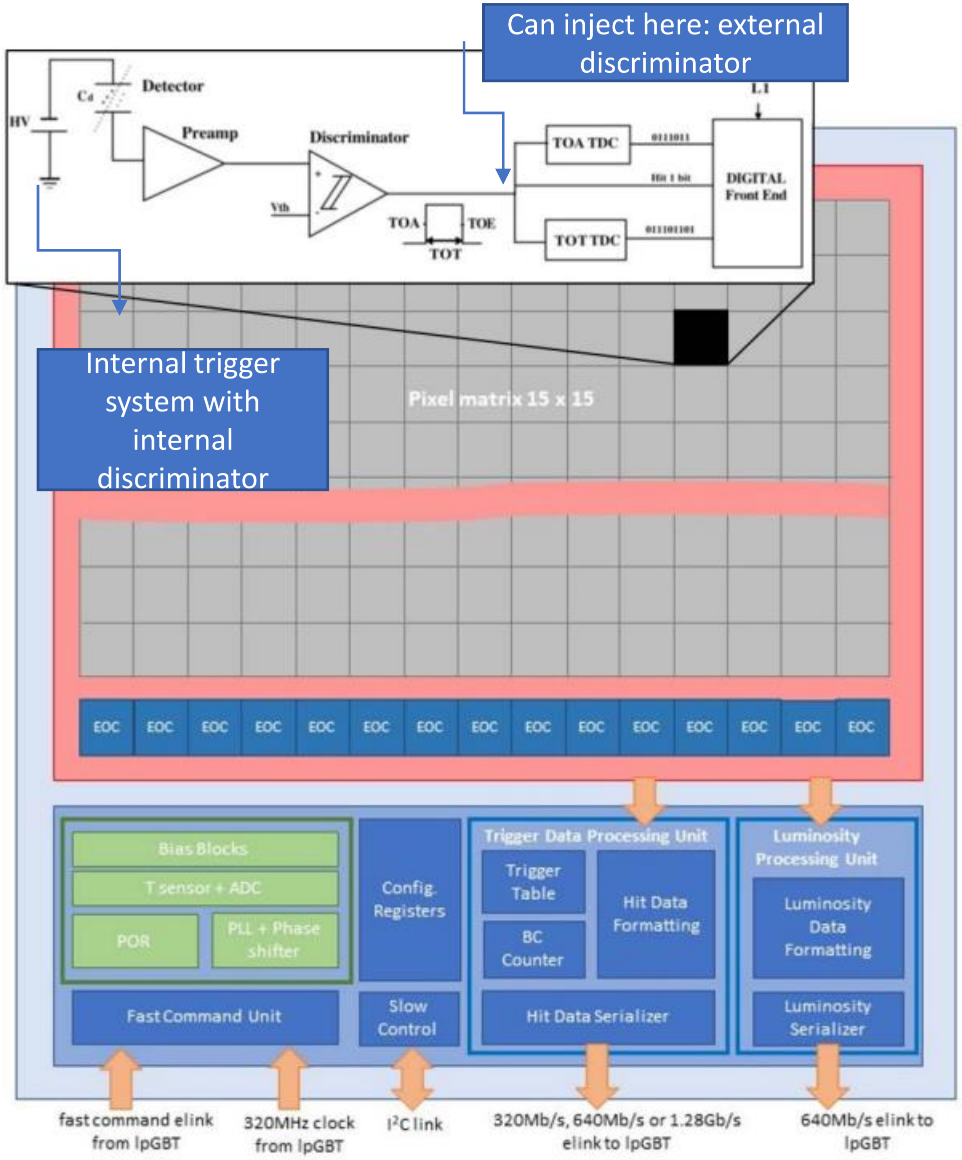
- **1 ASIC will be bump bonded to 1 LGAD**
- **One ASIC chip: 15×15 pixels | 1.3 mm $\times$ 1.3 mm per pixel**
- **2 parts: analog + digital**

- **Time Of Arrival** (TOA) measurement: delay of the signal w.r.t 40MHz Clock
- **Time Over Threshold** (TOT) measurement: Width of the signal

$$\sigma_t^2 = \sigma_{Landau}^2 + (\sigma_{jitter}^2 + \sigma_{TimeWalk}^2 + \sigma_{clock}^2 + \sigma_{TDC}^2)$$

specifications: ~ 25 ps | $\sim 25 - 65$ ps | ~ 25 ps | < 10 ps | < 10 ps

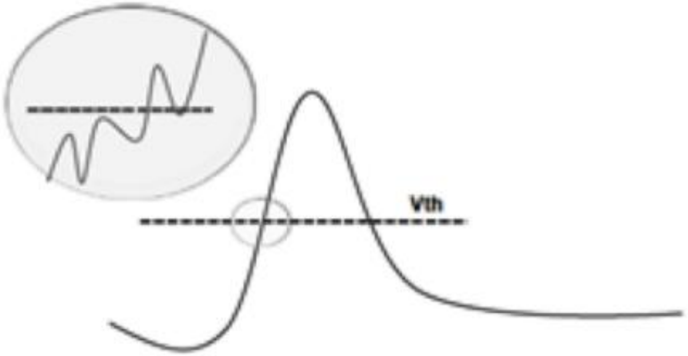
Before-After irradiation



Some of the Resolution Terms

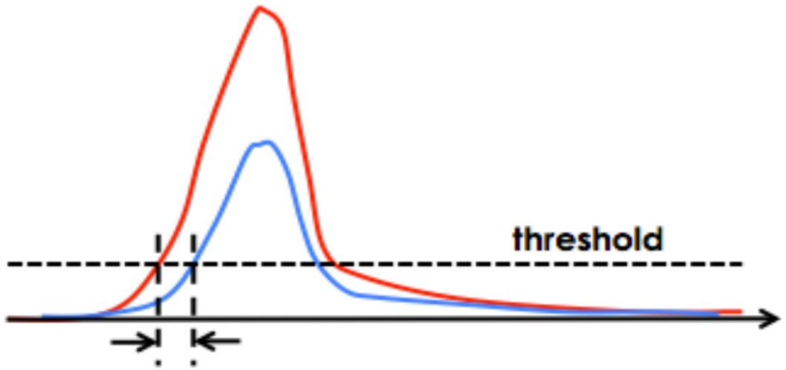
- $\sigma_{jitter} \approx 25 - 65$ ps
- Due to electronic noise in the signal shape
- Smaller slope leads to more noise
- Find a compromise between collected charge and settled threshold

$$\sigma_{Jitter} = \frac{N}{dV/dt} \approx trise/(\frac{S}{N})$$

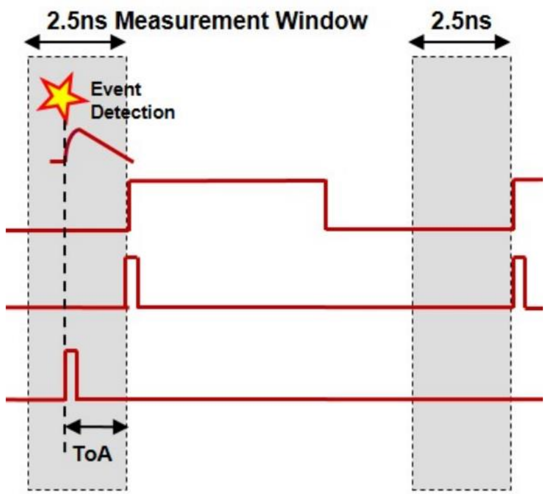


- $\sigma_{TimeWalk} \approx 25$ ps
- Same TOA in theory but different collected charges
- Different measured TOA
- We use TOT to correct this effect

$$\sigma_{TimeWalk} = [t_d]_{RMS} = [\frac{V_{th}}{S/t_{rise}}]_{RMS} \propto [\frac{N}{dV/dt}]_{RMS}$$



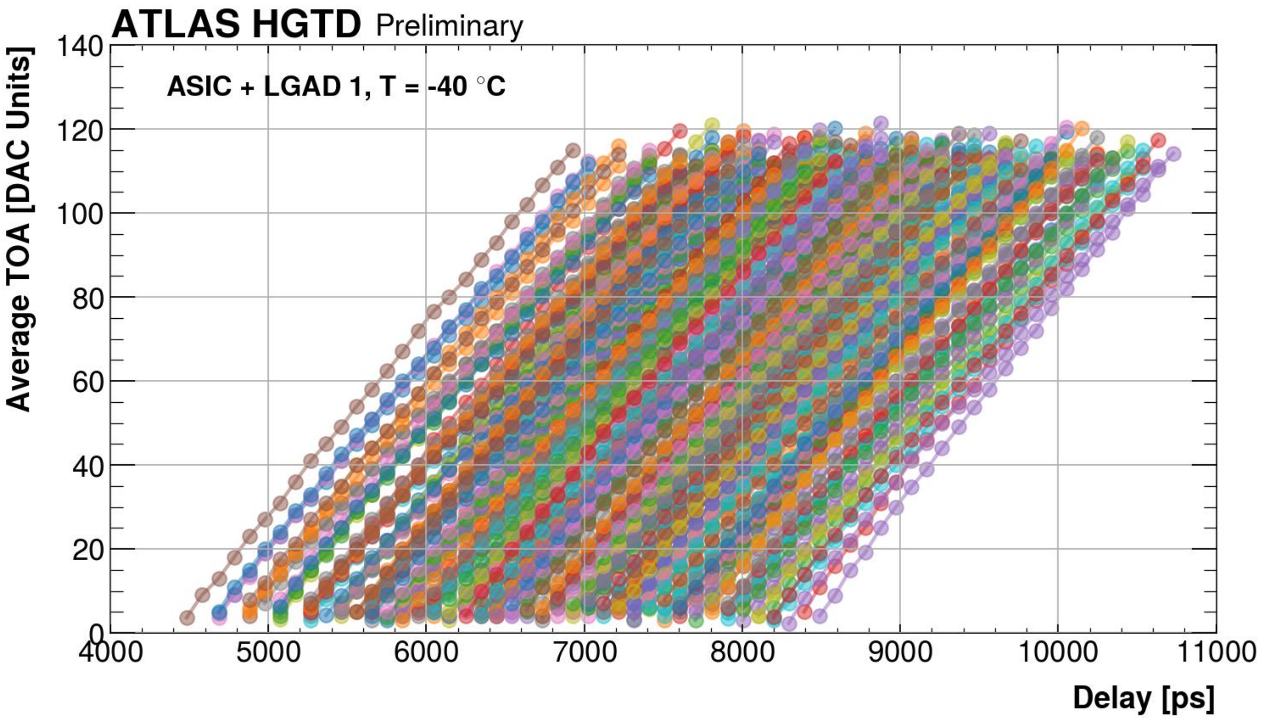
- $\sigma_{clock} < 10$ ps
- In theory the frequency of the clock should be 40 MHz
- In practice we expect a small shift



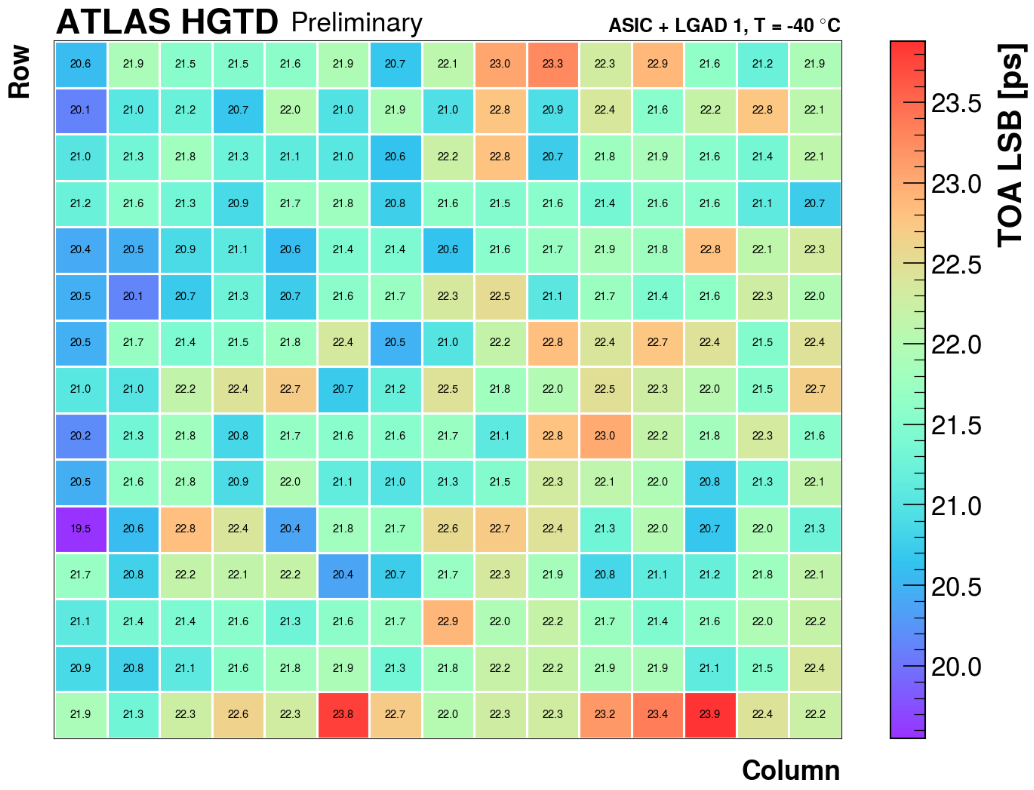
arXiv:1704.08666v4 **[physics.ins-det]**

TOA TDC Calibration

- TOA measurement with the TDC.
- We use an external discriminator
- The temperature shown in the figure is the temperature inside the climate chamber.
- The TOA TDC'S binning quantization (LSB) is given by LSB=1/slope



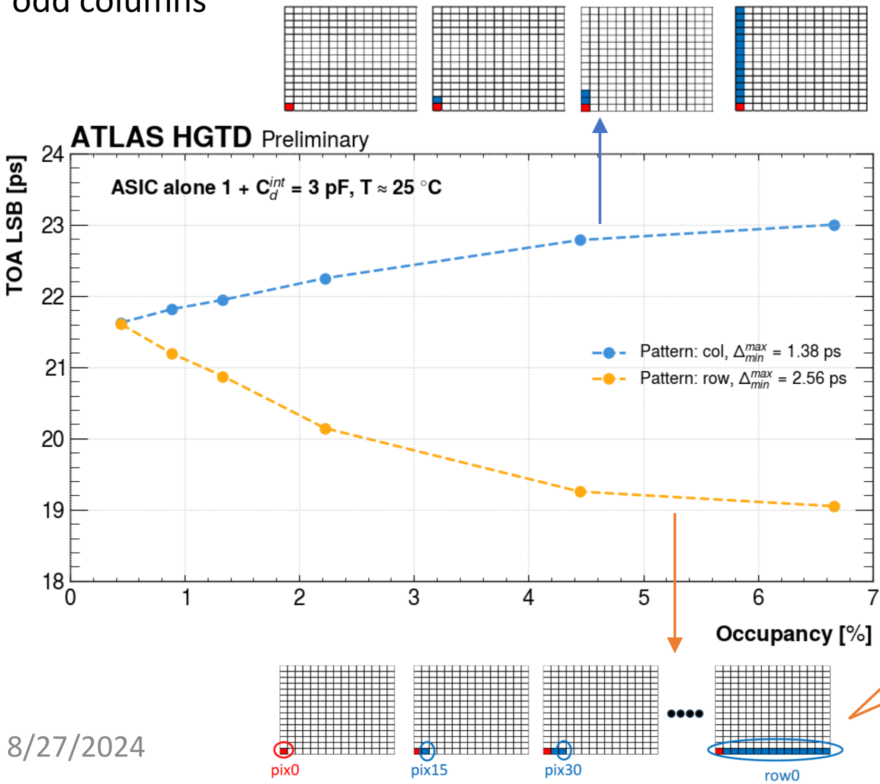
- We show the LSB map after computation
- It shows a reasonable homogeneity over pixels
- No clear dependency over columns or rows



TOA LSB VS Occupancy

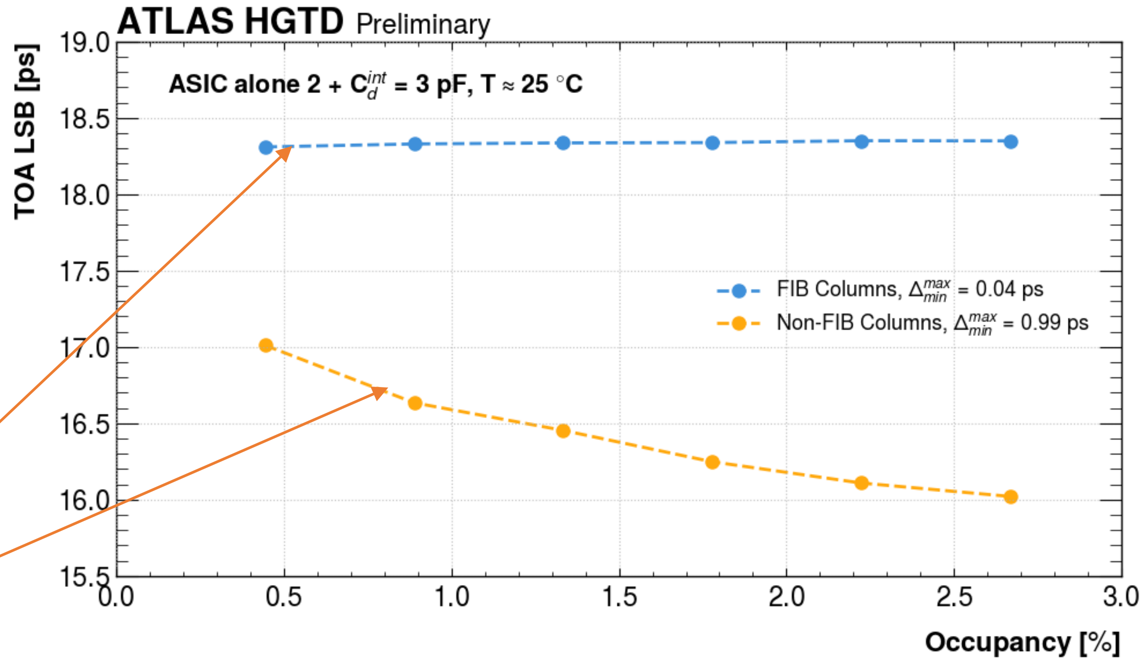
- **Injection in the same column:**
  1. Each column is powered separately – Voltage drop can happens at the level of one column only.
  2. Voltage drop due to resistance of wire bonds between ASIC and PCB

- **Injection in the same row:**
  1. Due to internal coupling issue the TOA LSB decreases with occupancy
  2. This issue is due to the presence of TOA busy signal (Debugging signal)
  3. We cut TOA busy signal using Focused Ion Beam (FIB) from ASIC 2 board's odd columns

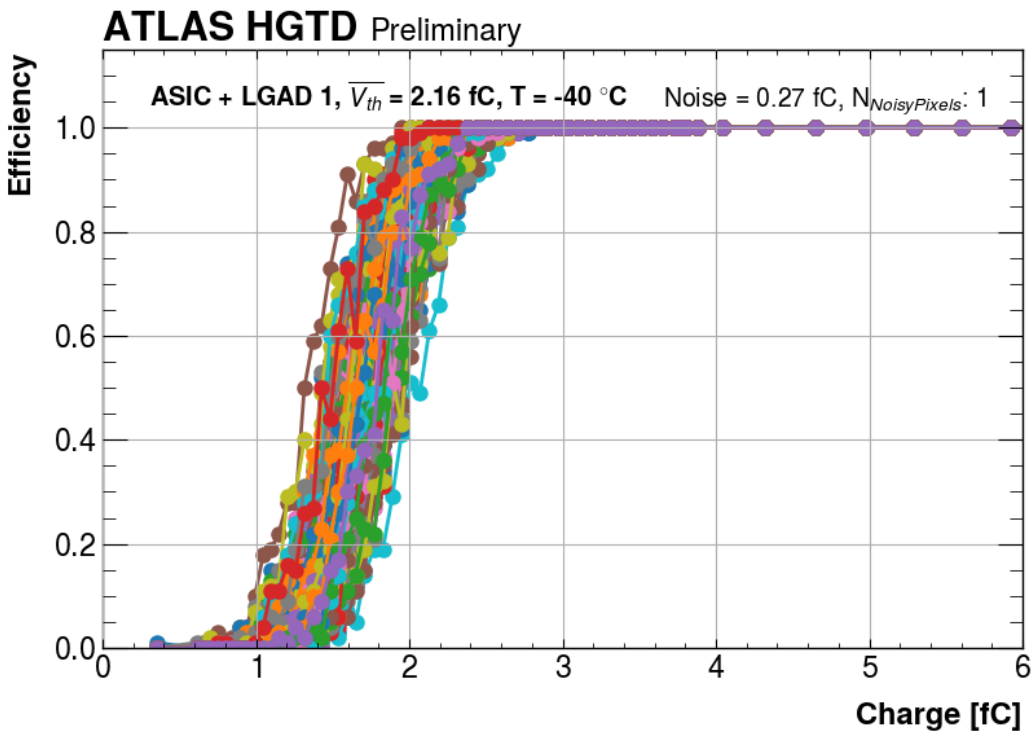


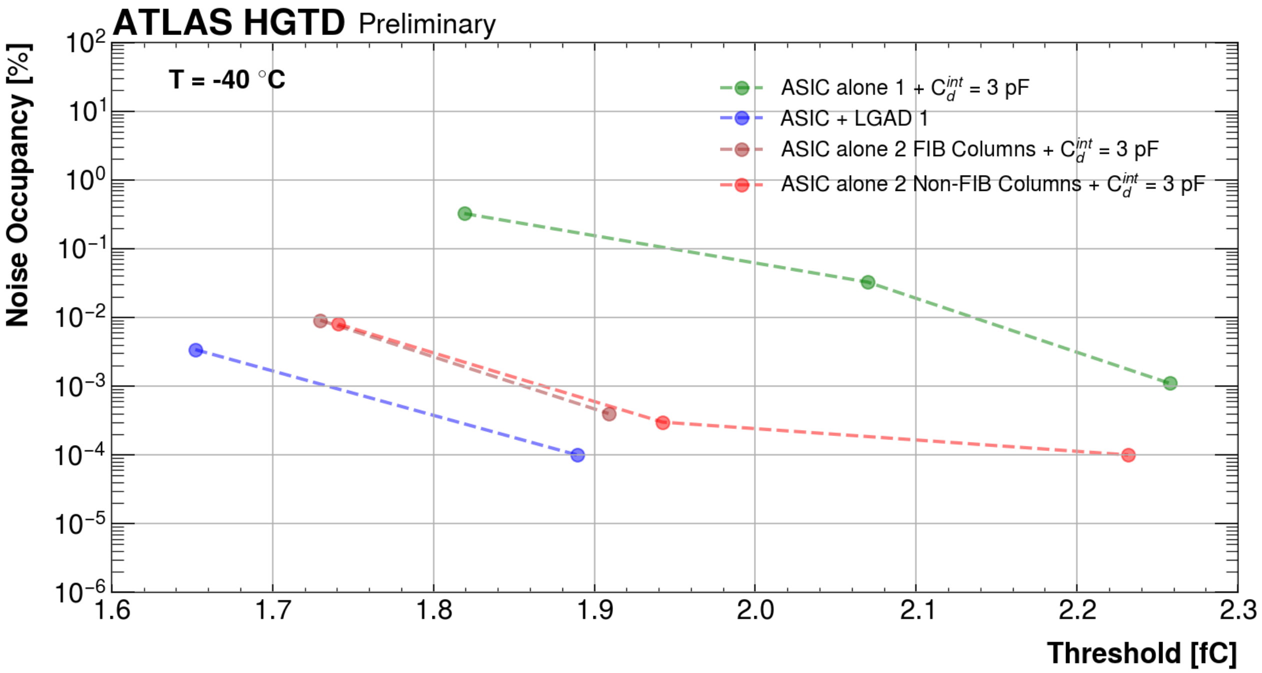
- **Adding pixels from FIB columns:**
  No dependency anymore
- **Adding pixels from Non-FIB columns:**
  Decrease with occupancy

- **In ALTIROCA the TOA busy signal will be removed.**
- **However we notice that those test are useful to understand the electronics but it is quite unlikely that several adjacent pixel from same col/row will fire during data taking.**
- **So we do not expect big effect**



Efficiency, Q_{min} and Noise





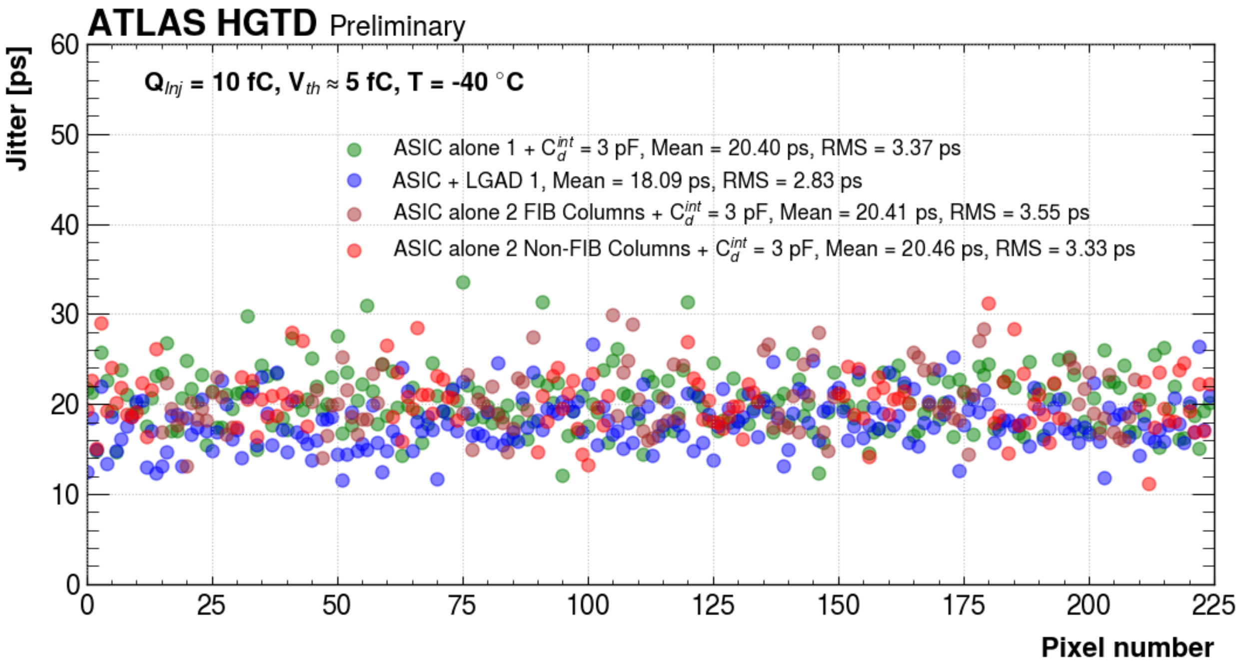
- We show the 225 channels S-curve obtained from a charge scan
- The curve is fitted with an error function, where the sigma of the fit is defined as the noise
- The threshold is defined as the charge value at 95 % efficiency
- Usually the minimal detectable charge Q_{min} is close to 2.5 fC in average

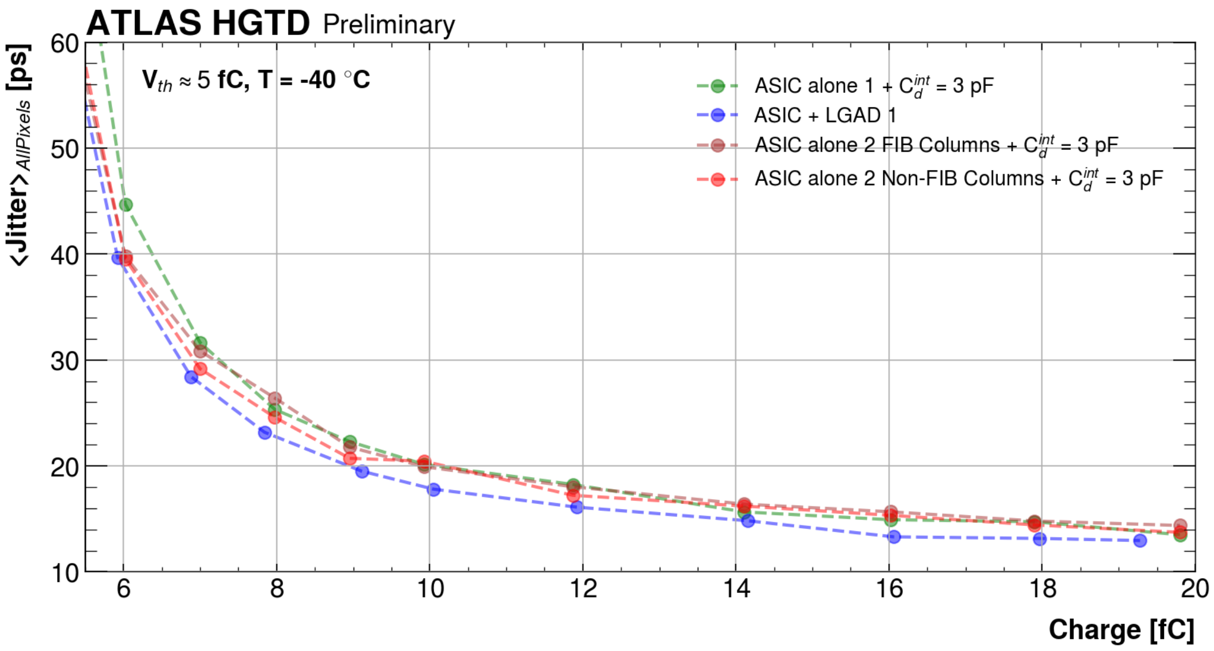
- Noise occupancy as a function of the threshold
- We use an internal trigger system
- We trigger 500k signal of charge = 0 DAC unit
- We count registered hits
- The noise is not dominant: Q_{min} meets the requirements $Q_{min} \gtrsim 2$ fC

Jitter

Homogeneity over pixels:
This Plot shows a good homogeneity over all pixels of multiple boards

Dependence over collected charge:
This plot shows that the jitter saturates after 10 fC
The saturation value is close to 14ps



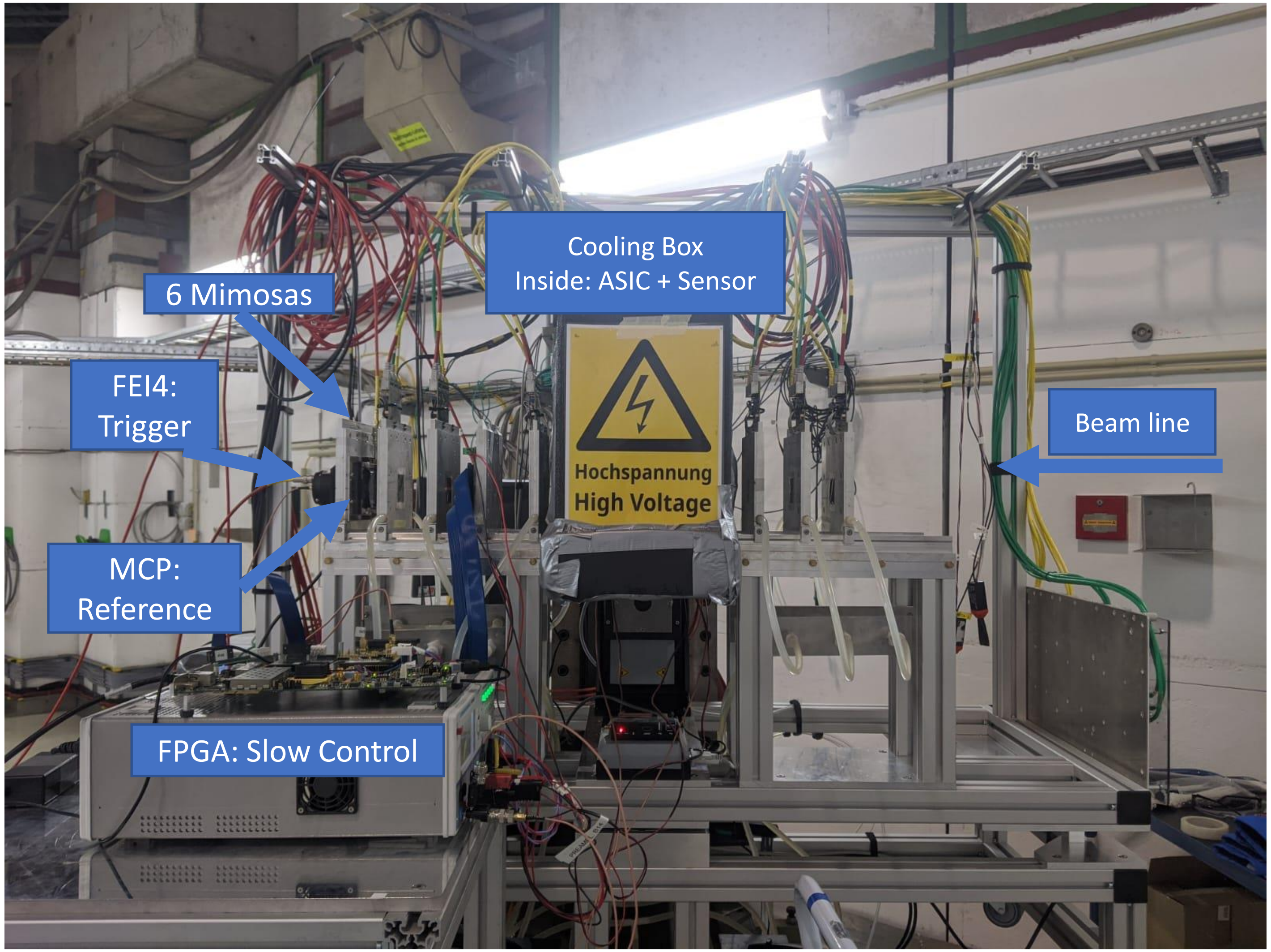


Test Beam Setup

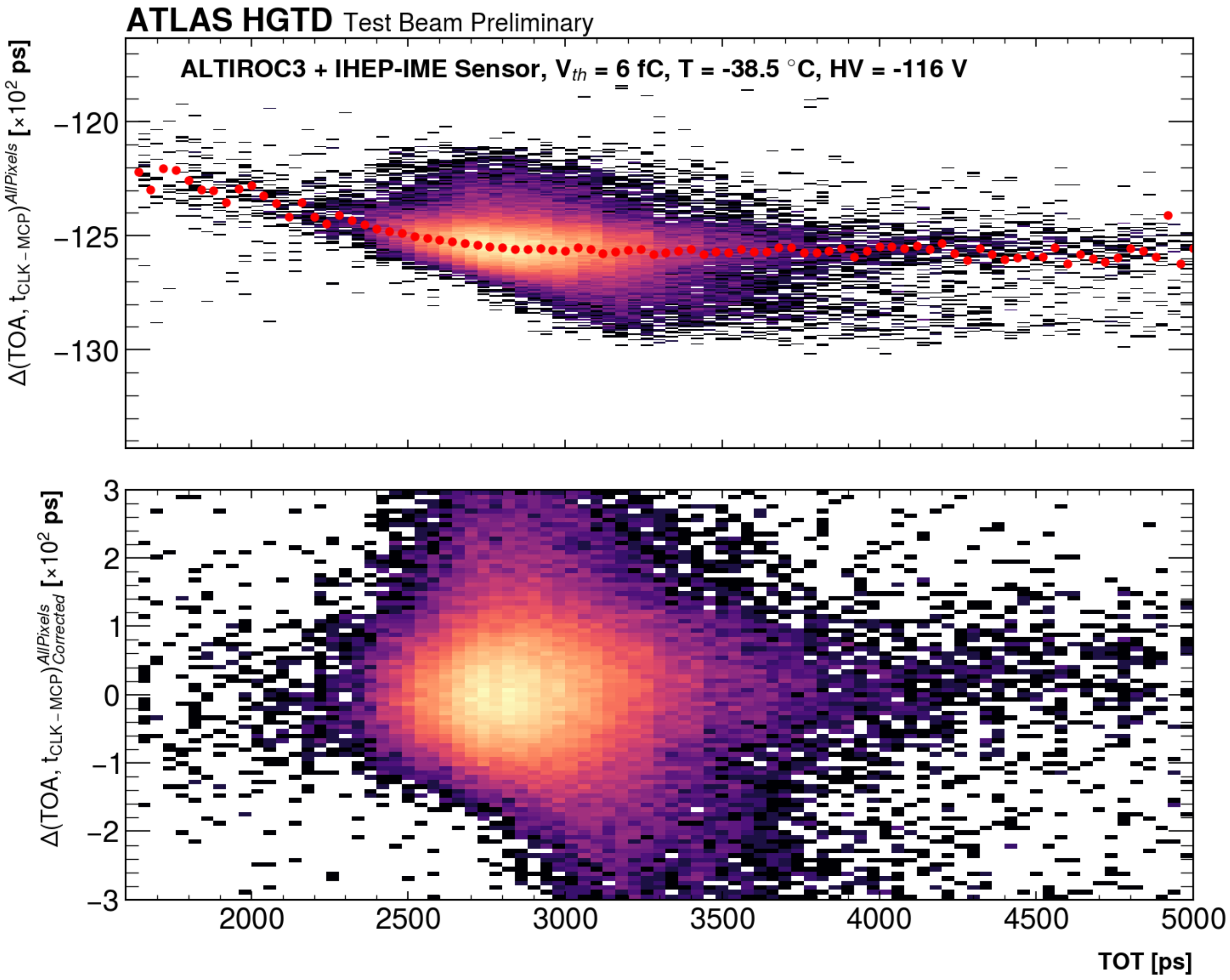
- Mimosas are used for tracking with pixel size of ~18.5 µm
- The hybrid is put within a cooling box
- The resolution of the Micro Channel Plate (MCP) is negligible: Good for timing reference
- The MCP pulse shape is recorded with a digitizer
- The FEI4 is used to trigger event that cross the hybrid and the MCP simultaneously
- The time resolution is the sigma of a gaussian fit of ASIC timing w.r.t. MCP timing:

$$\Delta t = -LSB \times TOA - (CLK - MCP)$$

- We use pre-production sensors

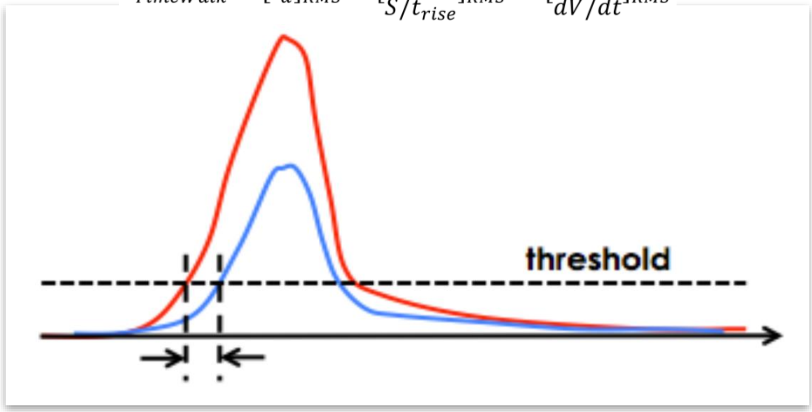


Time-Walk correction



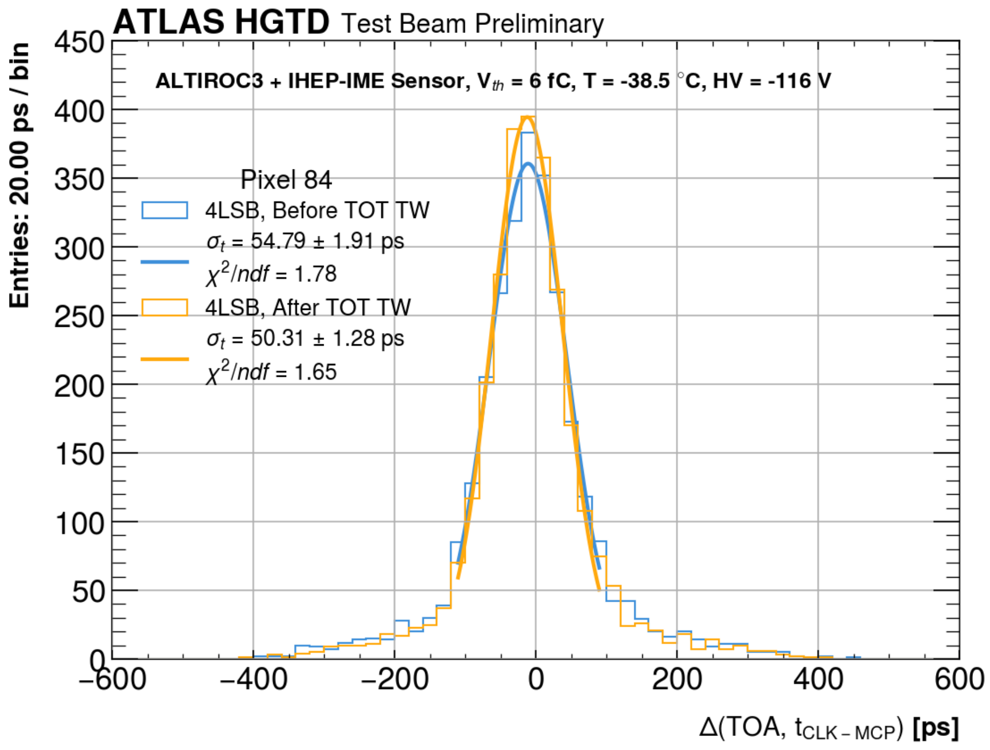
- TOA depends on the collected charge
- Removing this dependency is what we call Time-Walk correction
- Since the TOT is a proxy to collected charge we use this variable for correction
- For each TOT bin: fit Δt distribution with gaussian and extract mean
- We subtract the fit
- The residual is the corrected Δt distribution

$$\sigma_{TimeWalk} = [t_d]_{RMS} = [\frac{V_{th}}{S/t_{rise}}]_{RMS} \propto [\frac{N}{dV/dt}]_{RMS}$$

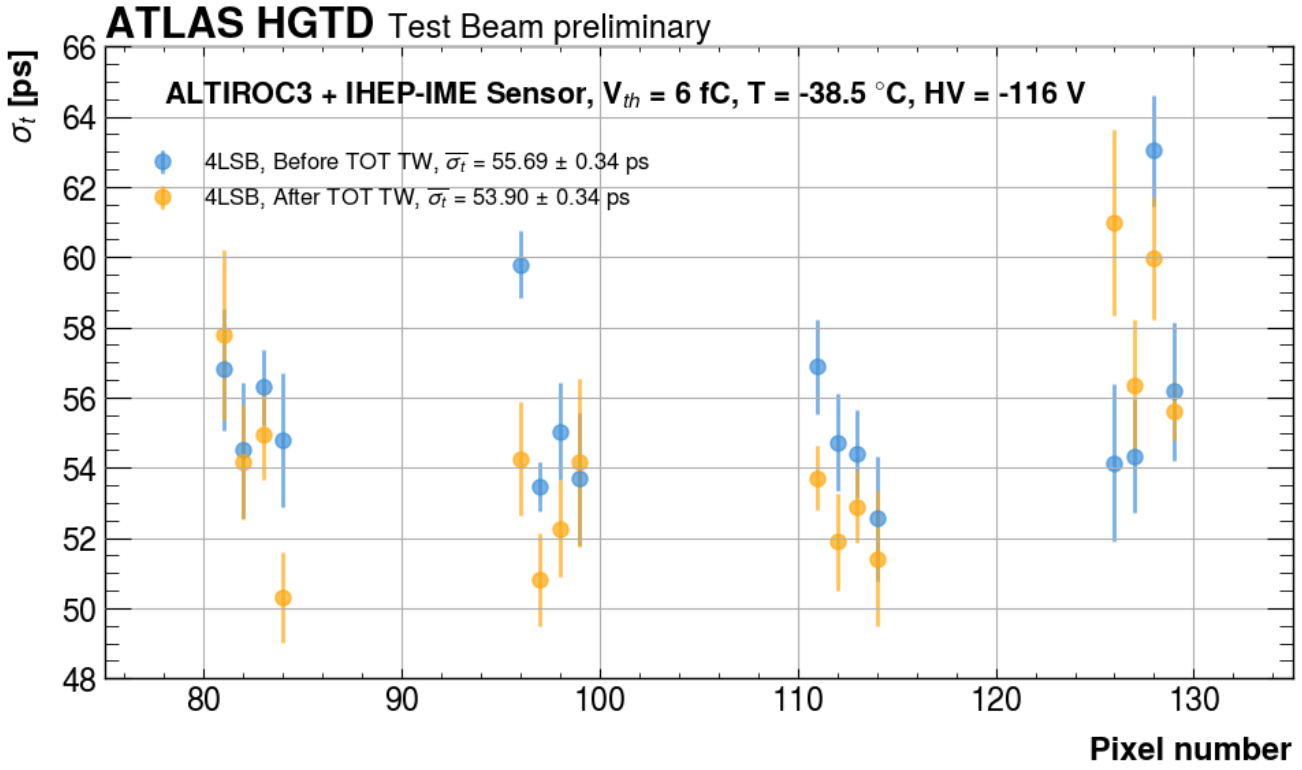


Time Resolution

- Δt distribution before (blue) and after (orange) Time-Walk correction
- The conditions of data taking are shown in the title



- Measured time resolution before (blue) and after (orange) Time-Walk correction for multiple tested channels.
- The conditions of data taking are shown in the title.
- For some pixels the TW is not giving any gain because of multiple issues (expect better performance with ALTIROCA)
- HV = -116 V is around 85 % of the $V_{breakdown}$
- Close to $V_{breakdown}$ we can achieve ~48 ps



Conclusion

- HGTD is a new timing detector aiming to mitigate pile-up during HL-LHC phase
- Each module consists of 2 LGADs + 2 ASICs
- The readout system of HGTD (ASIC) is called ALTIROC

- Test Bench tests show good performance in term of efficiency, noise, jitter …
- We obtain $\sigma_t \approx 50$ ps in average: higher than the specification value (35 ps)
- Multiple effects degrading the resolution are understood and some other effects are under investigation

- Next:
    1. We started testing the pre-prod type of ALTIROC: ALTIROCA
    2. The measurements of ALTIROCA showed that we obtained better performance
    3. We expect that with ALTIROCA the TW correction and LSB computation will be better

Backup

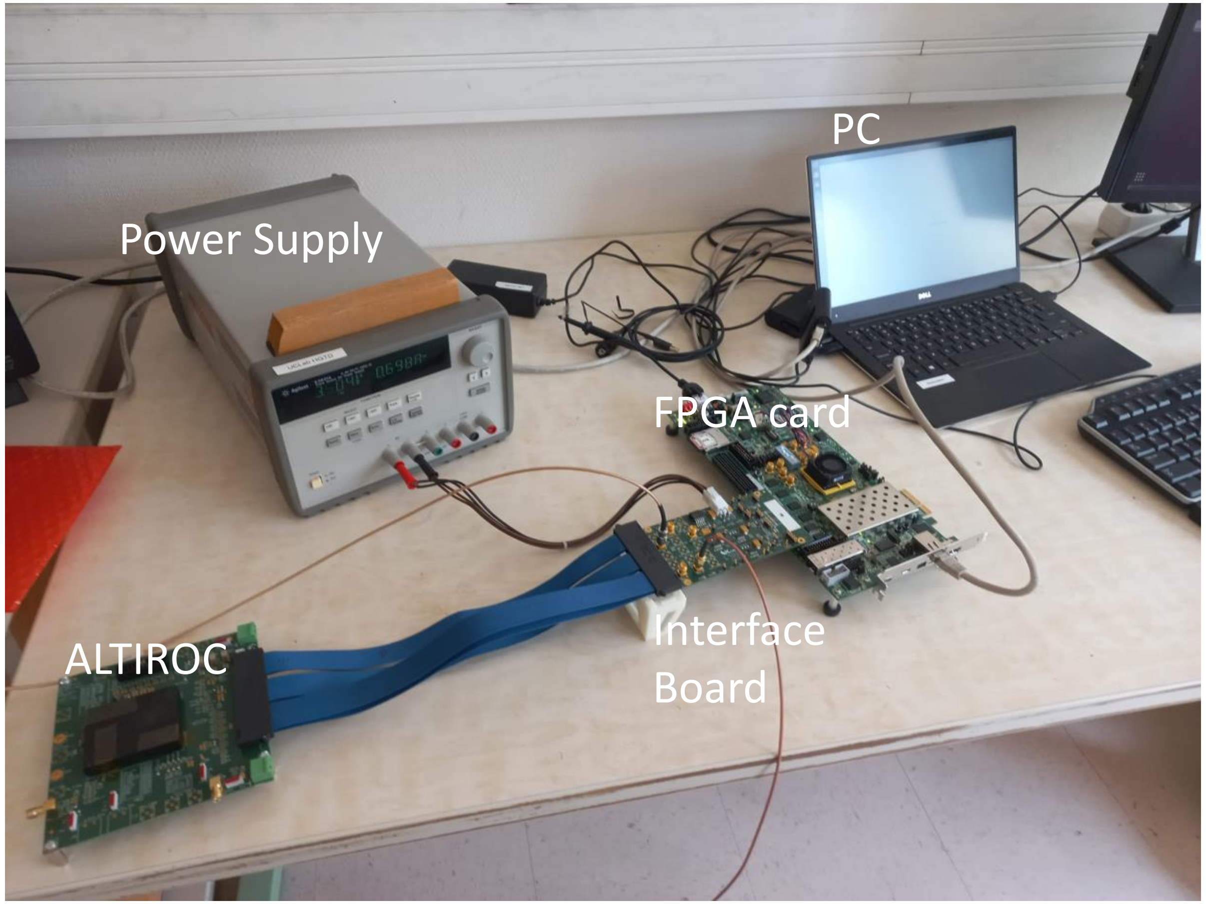
Test Bench Setup

- The **ASIC** is mounted in a dedicated central region of a specific board

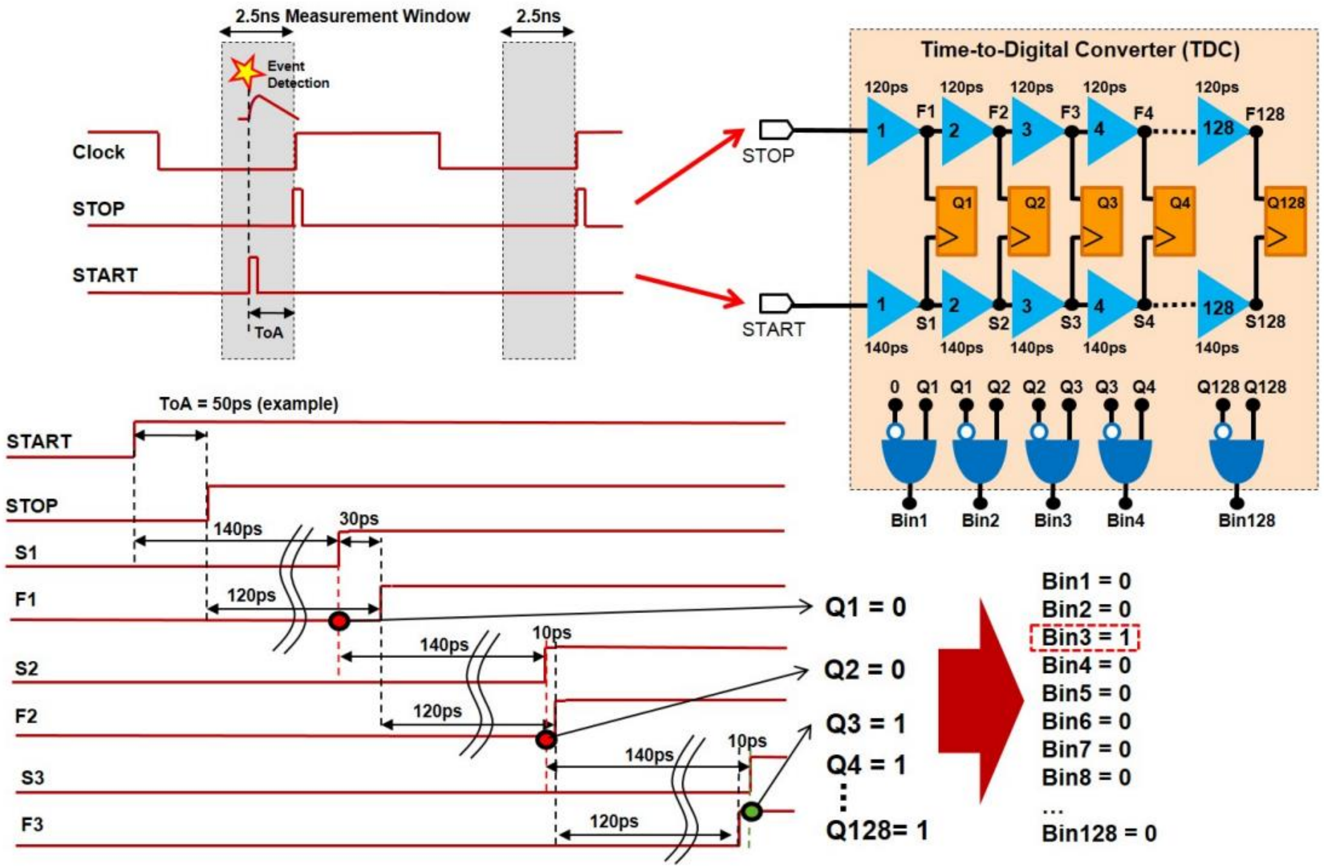
- The **FPGA card**: provides control of the ALTIROC

- **Interface board**: ensures the interconnection of the FPGA and the ALTIROC

- Characterization of ALTIROC: Software and Firmware

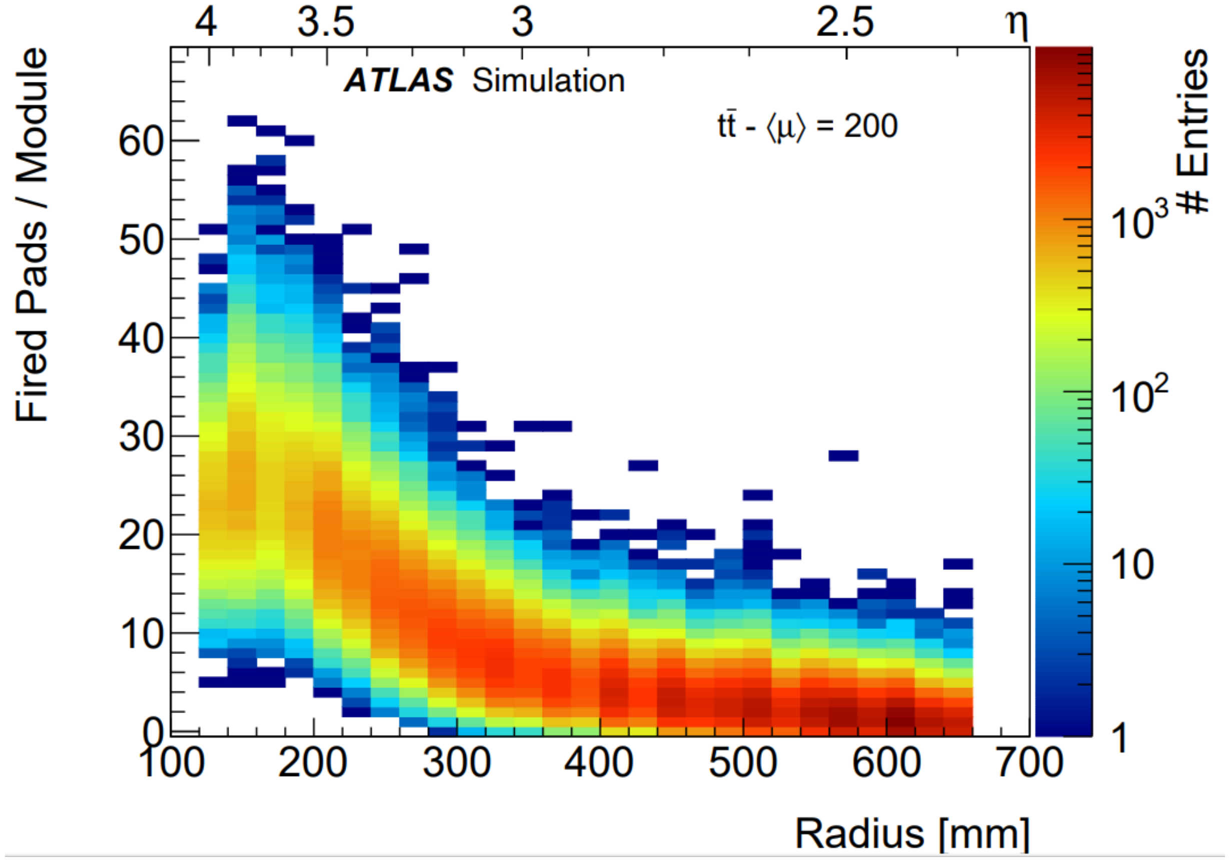


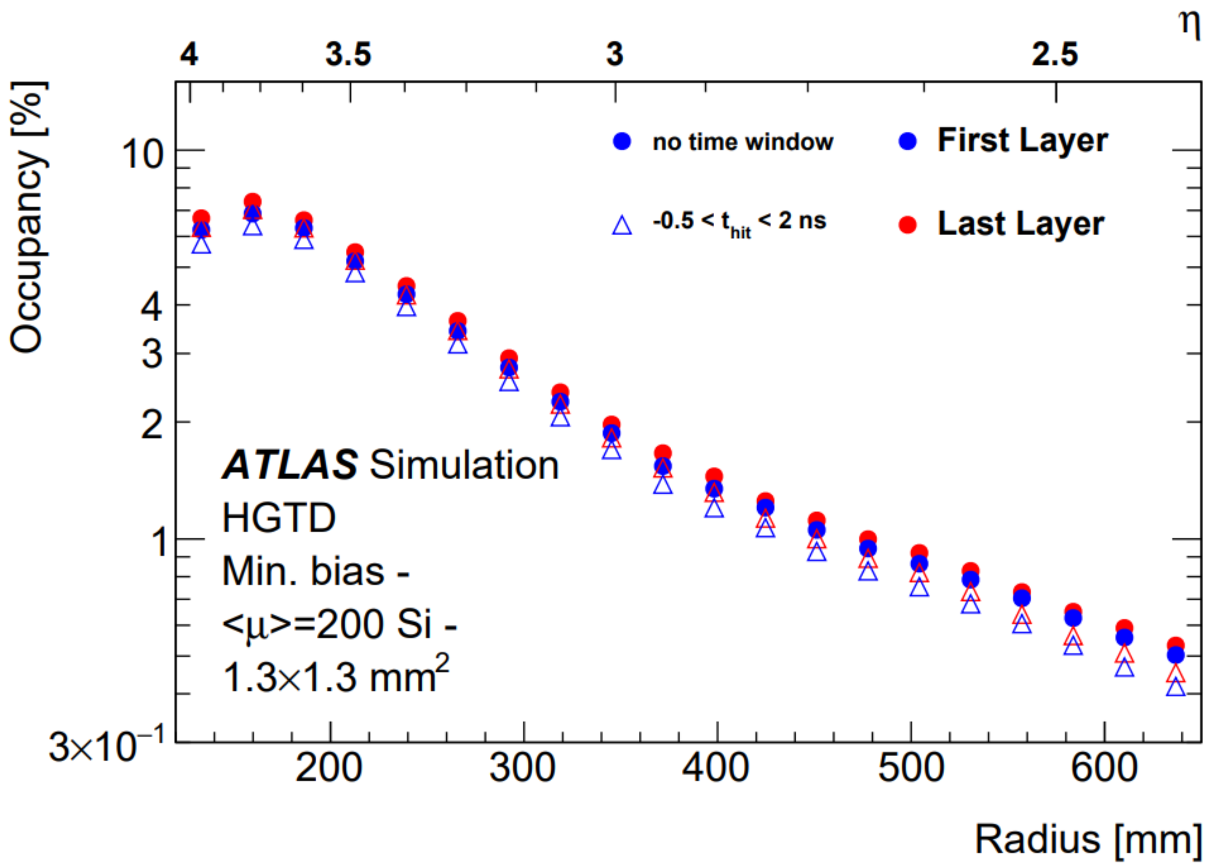
Time to Digital Converter TDC



- Dynamic range of TOA : 127 DAC Units – 2560 ps
- We do cyclic configuration: over 4 cycles of 32 DAC Units each
- The TOA is determined by the number of cells needed so that the fast 140ps line surpasses the slow 120ps

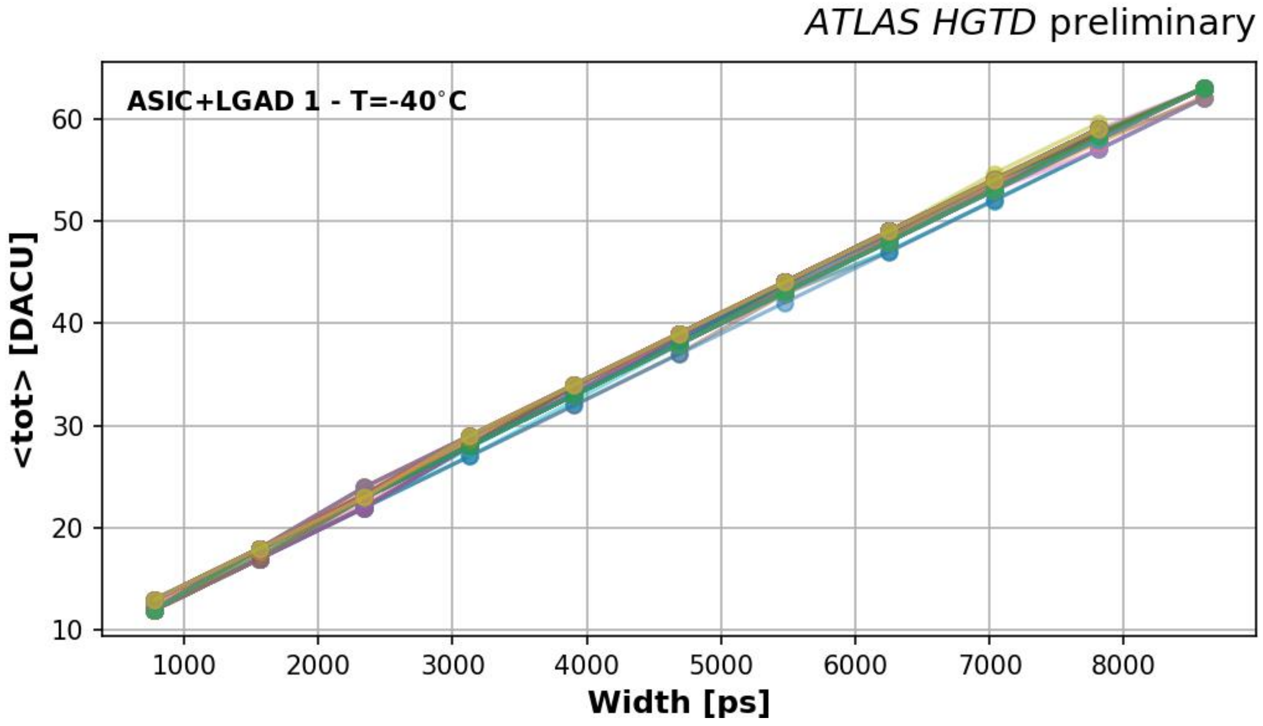
Occupancy HL-LHC phase

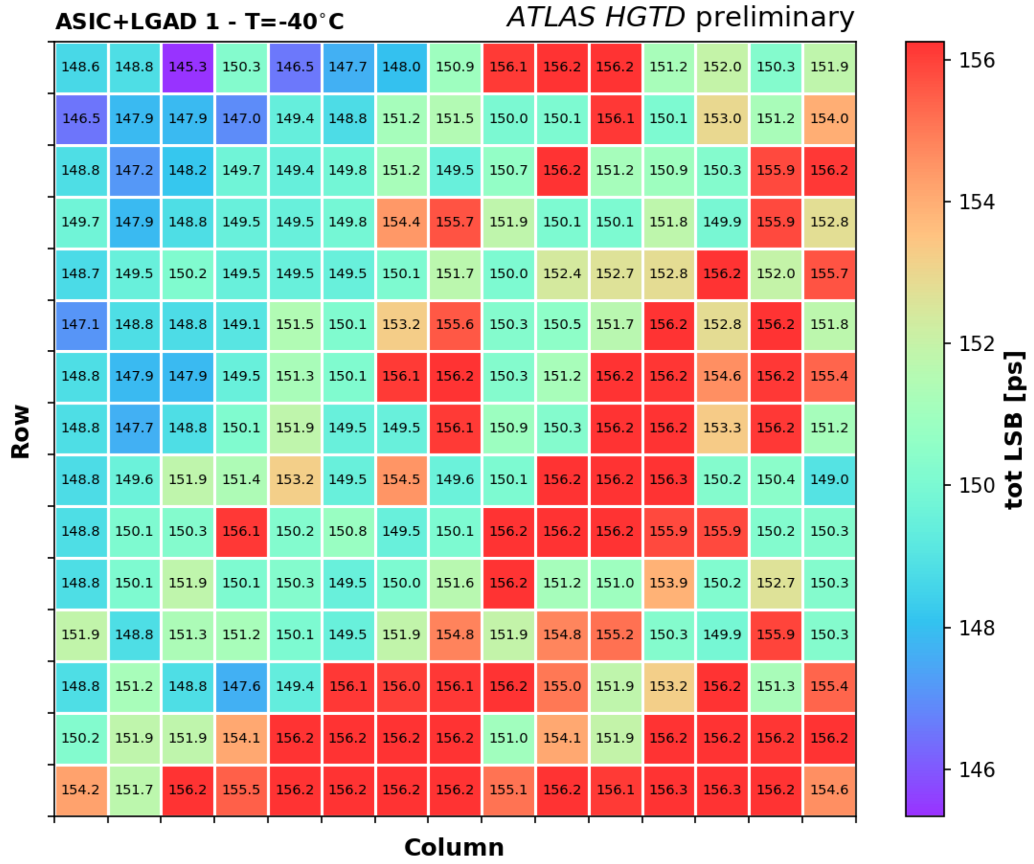




TOT TDC Calibration

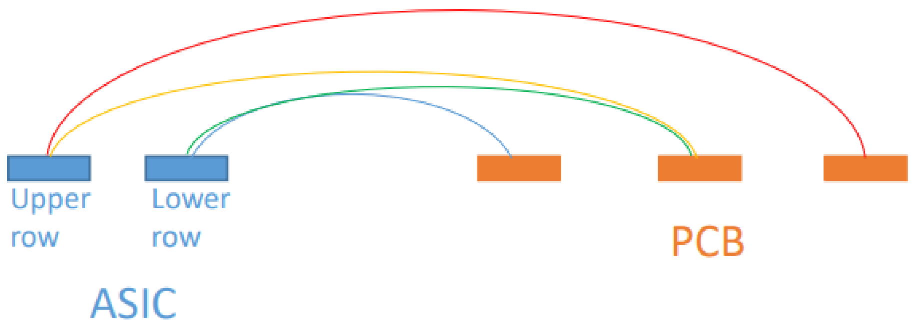
- Time Over Threshold (TOT) scan using external discriminator
- Good homogeneity over pixels of the matrix

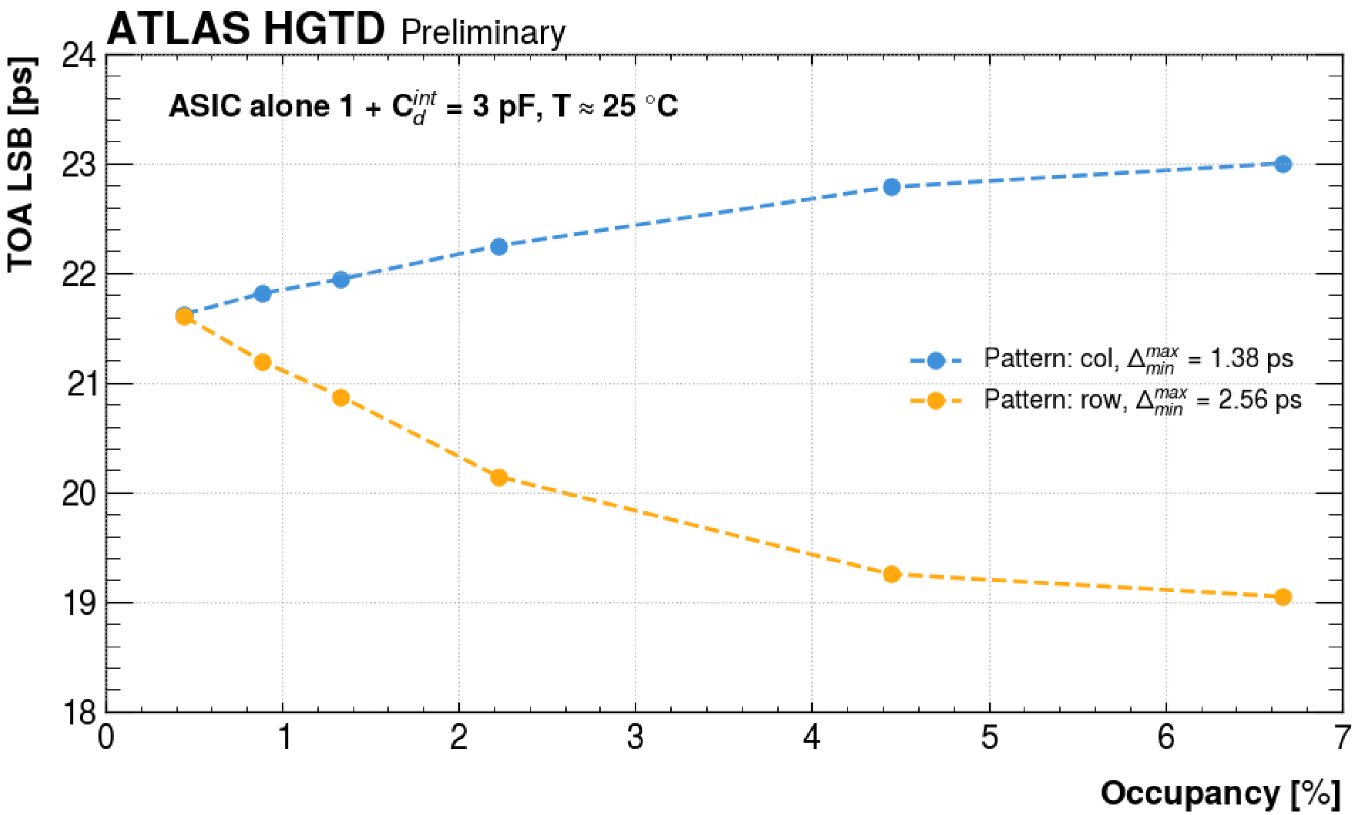


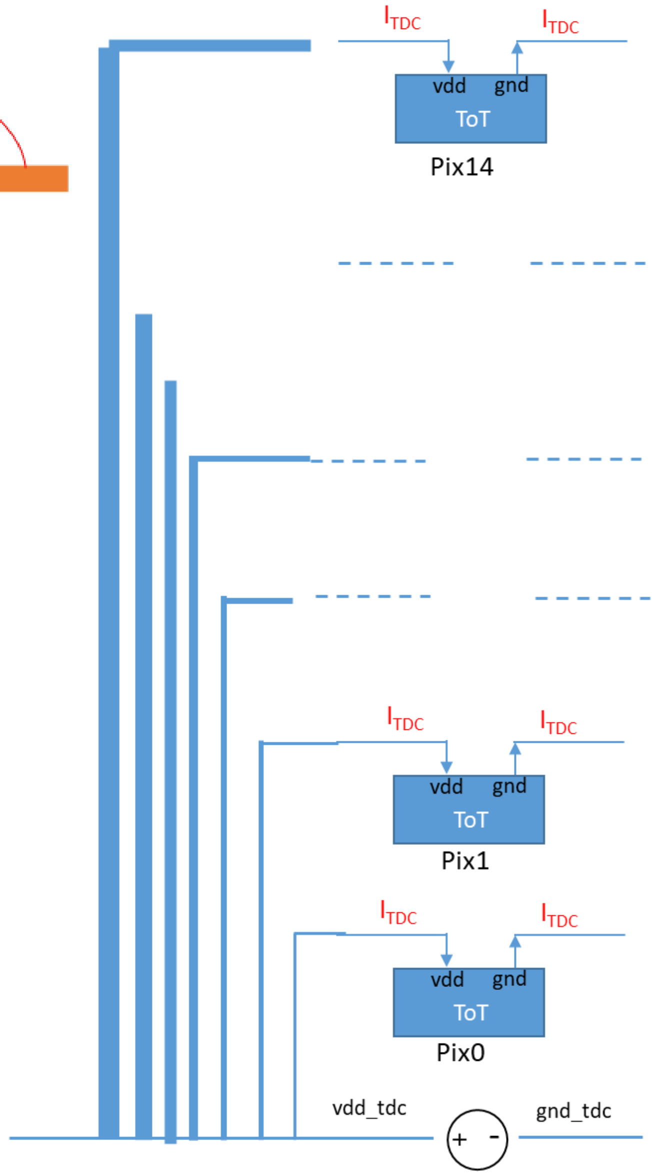


TOA LSB VS Occupancy: Col VS Row patterns

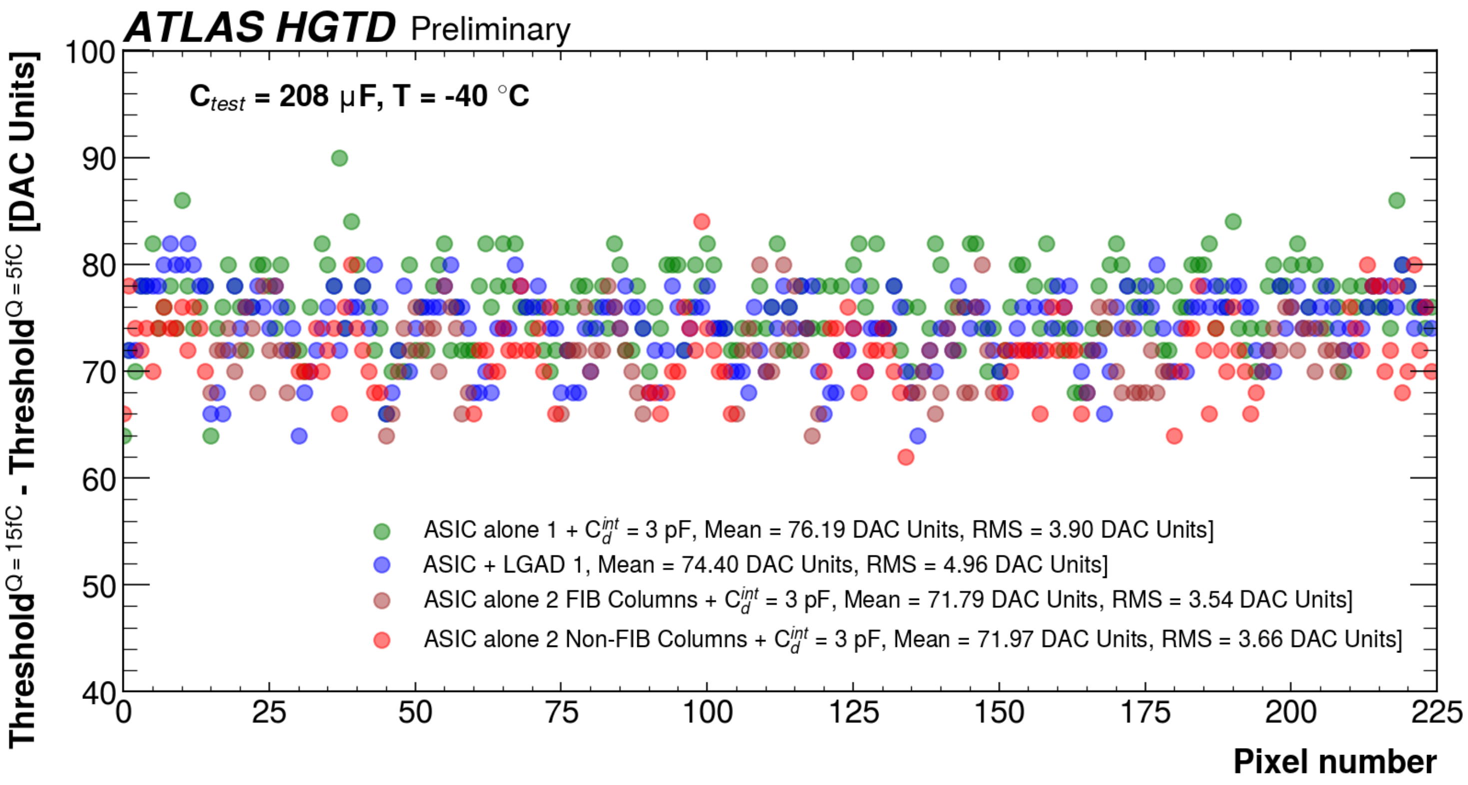
ALTIROC3: Each column is powered separately – Voltage drop can happens at the level of one column only





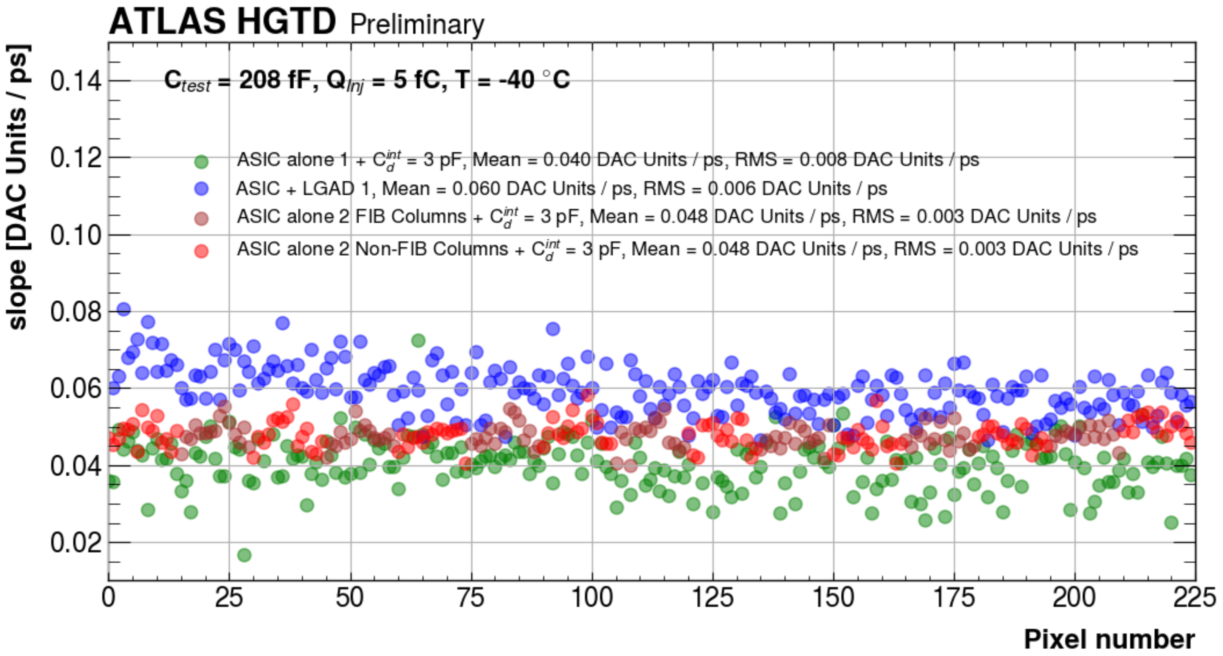


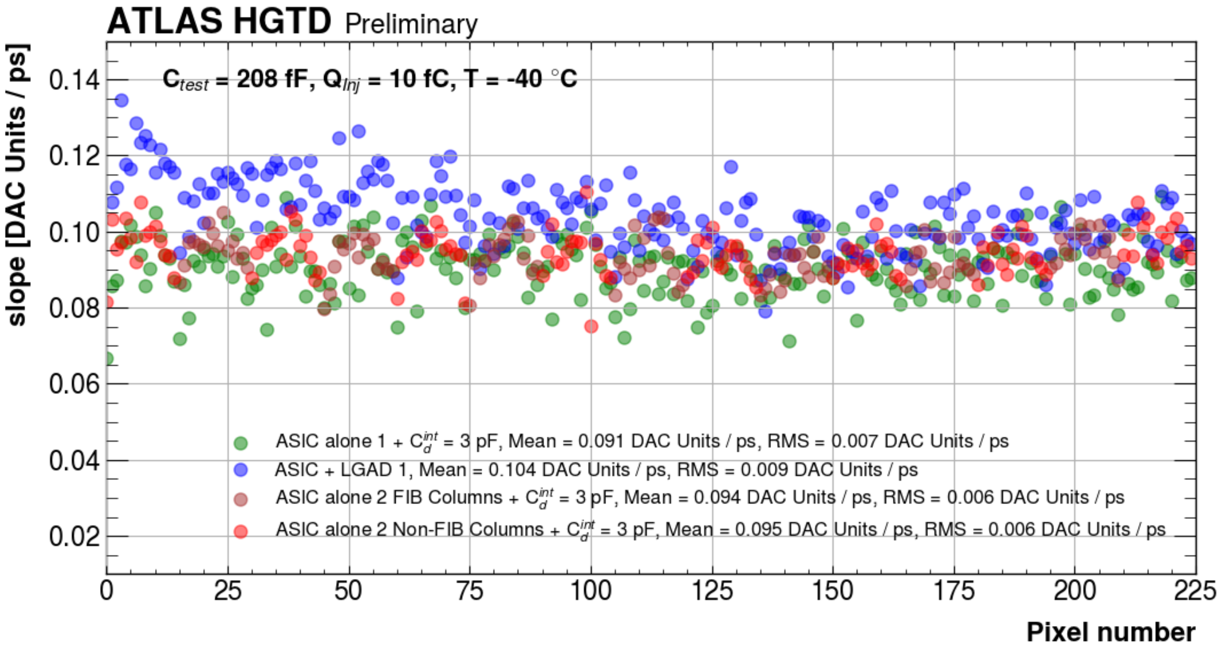
ΔV_{th} VS Pixel



- Measured threshold difference between $Q \approx 15$ fC and $Q \approx 5$ fC as a function of pixel numbers
- Good homogeneity over pixels

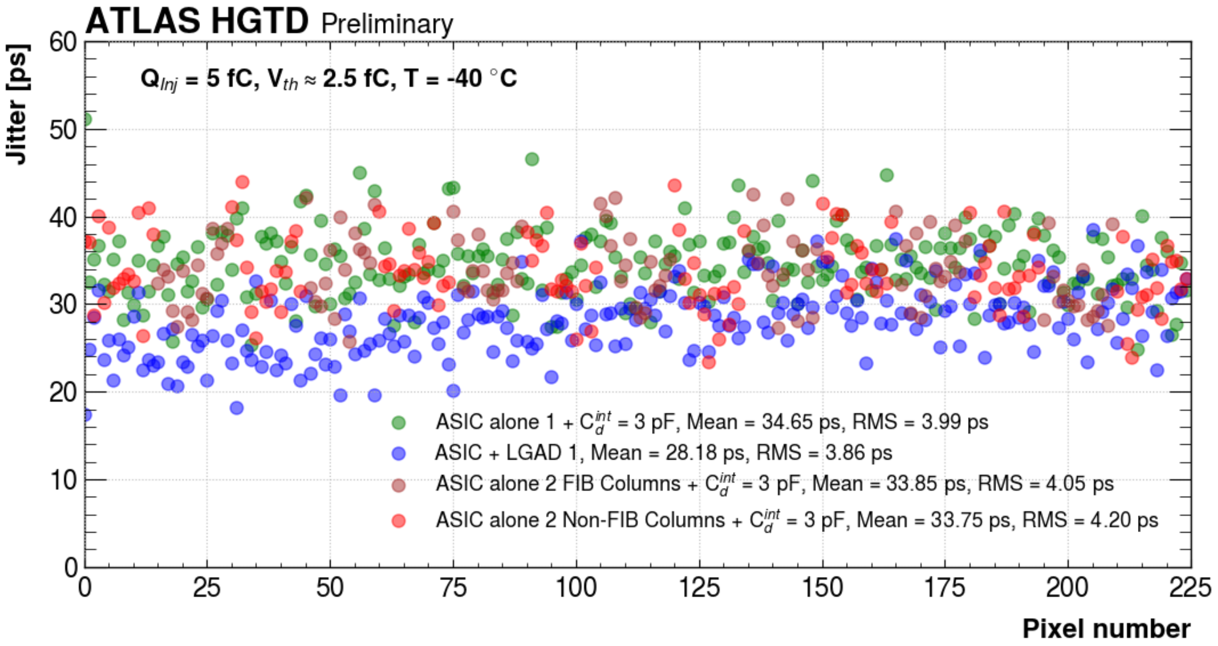
Slope VS Pixel

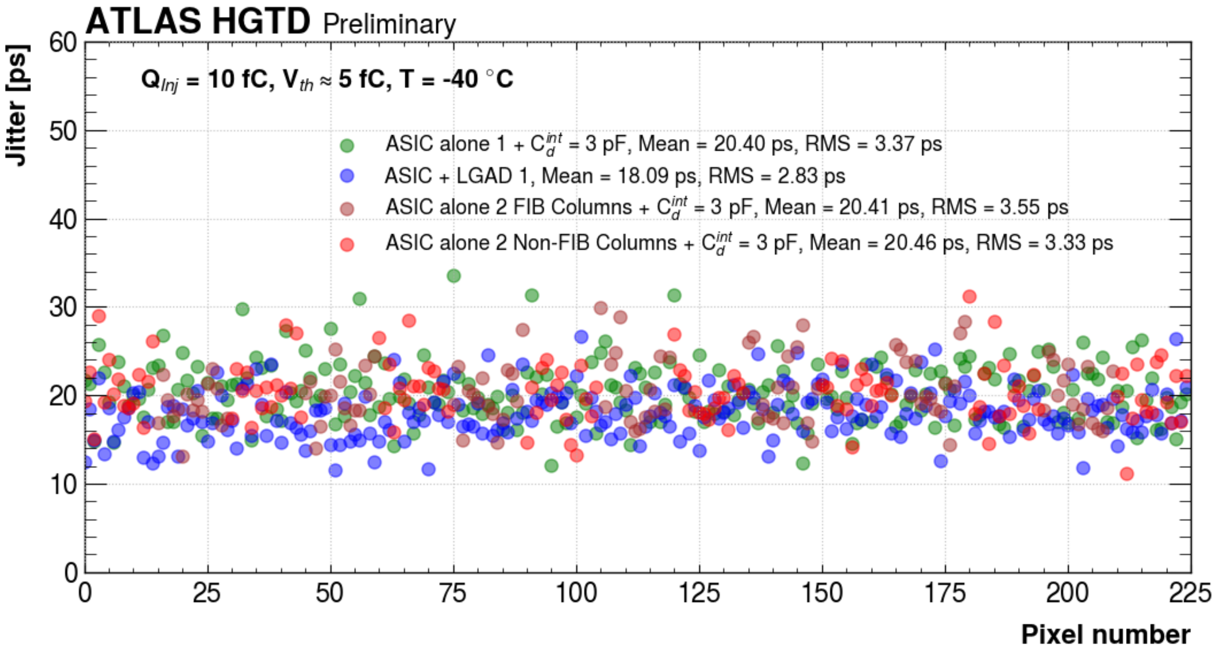




- Measured slope difference at Q = 10 fC (right) and Q = 5 fC (left) and as a function of pixel numbers.
- Good homogeneity over pixels
- When the collected charge increase the slope gets better (higher) because the signal rise increases at higher charge values

Jitter VS Pixel

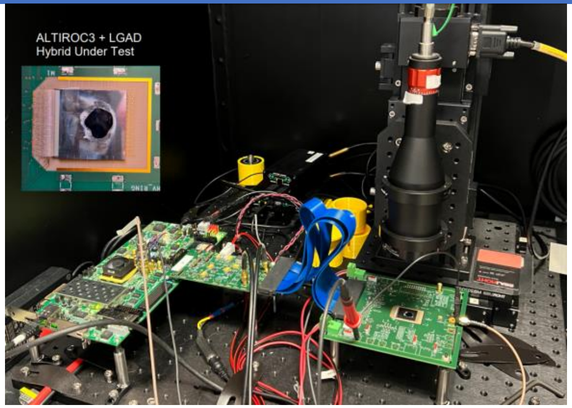




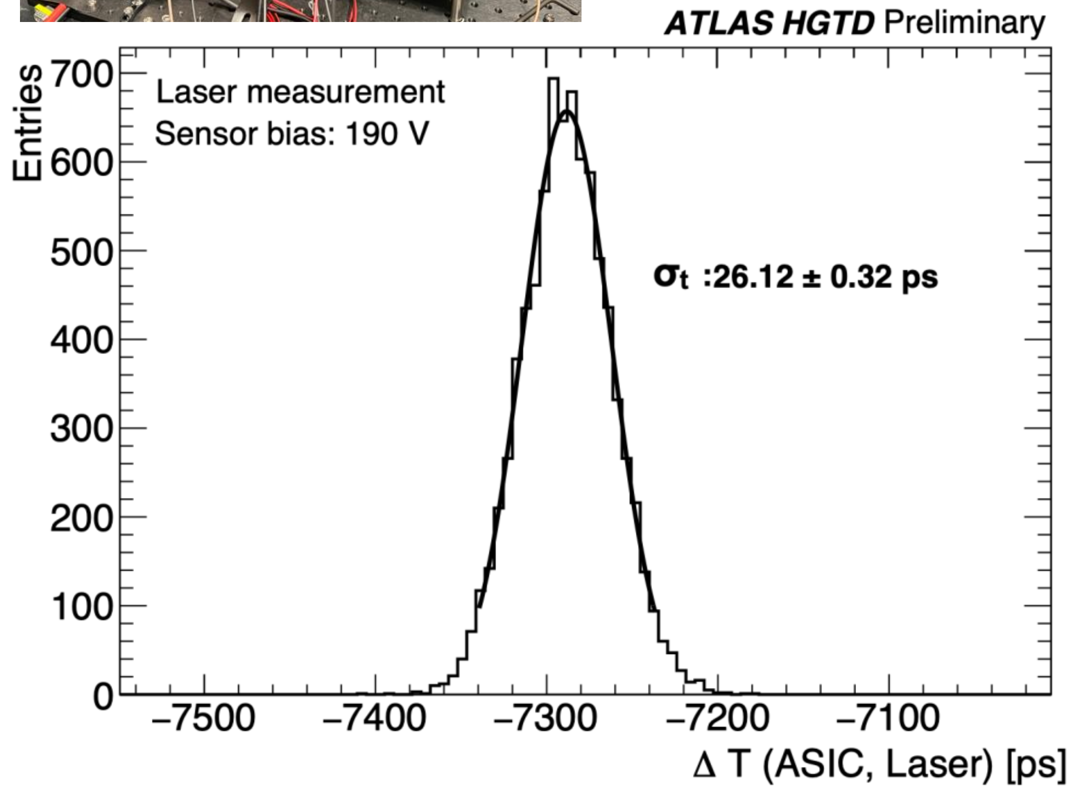
- Measured slope difference at Q = 10 fC and $V_{th} = 5$ fC (right) and Q = 5 fC and $V_{th} = 2.5$ fC (left) and as a function of pixel numbers.

- The homogeneity gets a little bit better with injected charge and threshold

Laser



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HGTDPublicPlots



- In general with Laser we obtained a resolution of 26 ps after TDC's Non-Linearity correction.
- Given that Landau contribution and TW are negligible
- Removing Landau (Measured During TB ~30 ps) and TW residuals (Measured with Prob ~25 ps) and assuming a Total corrected Test Beam resolution of ~25 ps
- We get 31 ps close from Laser 26 ps. (25.5 ps assuming Landau contribution of 35 ps)
- Removing also NL we get 21 ps