UNIVERSIDAD SIMÓN BOLÍVAR

ATLAS EXPERIMENT

LPNHE PARIS

Summer Student Project

Test Beam Analysis for HGTD Sensors

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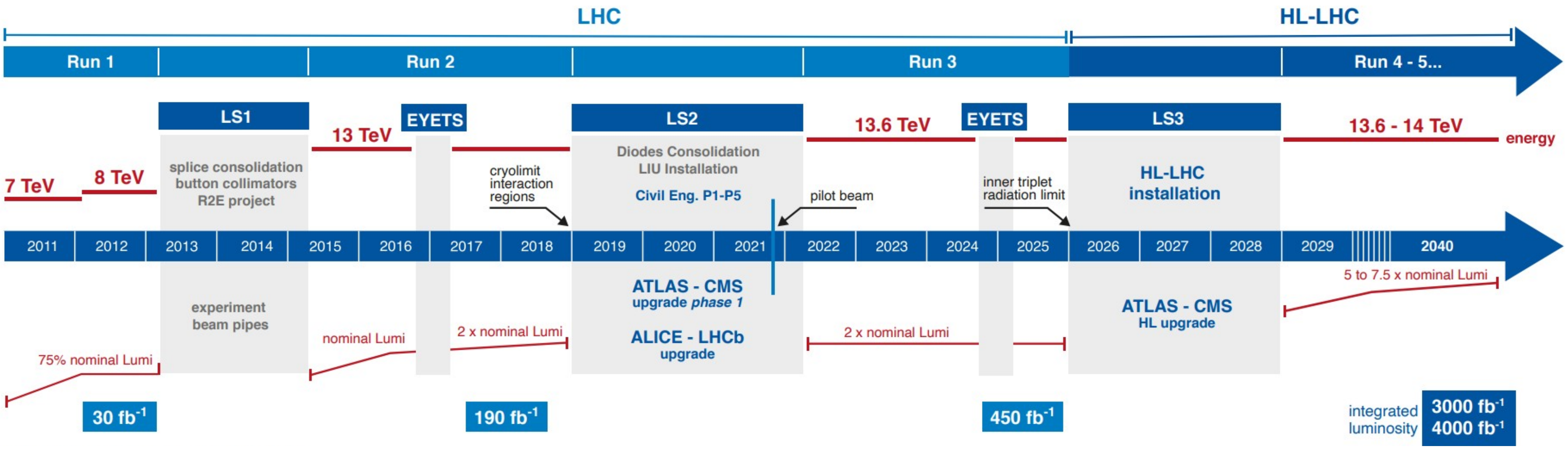
1. **Introduction:**
   - The High Luminosity LHC,
   - HGTD,
   - LGAD.
2. **Setup:**
   - Test-Beam
3. **Analysis and Results:**
   - Sensors Characterization
4. **Conclusions**

From 2026, LHC will be upgraded and in 2029, LHC will run in “High Luminosity" (HL-LHC)

- Instantaneous **luminosity** will be approximately a factor of **~5-7.5** higher than the LHC nominal values.
- Average number of interactions per bunch crossing (**pileup events**) reaches **200**.
- Harsh radiation environment.
- **ATLAS experiment** also needs to be upgraded to meet the new requirements.



Introduction: The High Granularity Timing Detector (HGTD)

- Two instrumented double-sided layers mounted in two cooling/support disks per end-cap.
- Placed at **$z \approx \pm 3.5$ m** from the nominal interaction point.
- Total radius **$110 < r < 1000$ mm.**
- Active detector region: **$2.4 < |\eta| < 4$, 120 mm $< r <$ 640 mm. η is the pseudorapidity.**
- Time resolution ~30-50 ps per track (start-finish).

$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

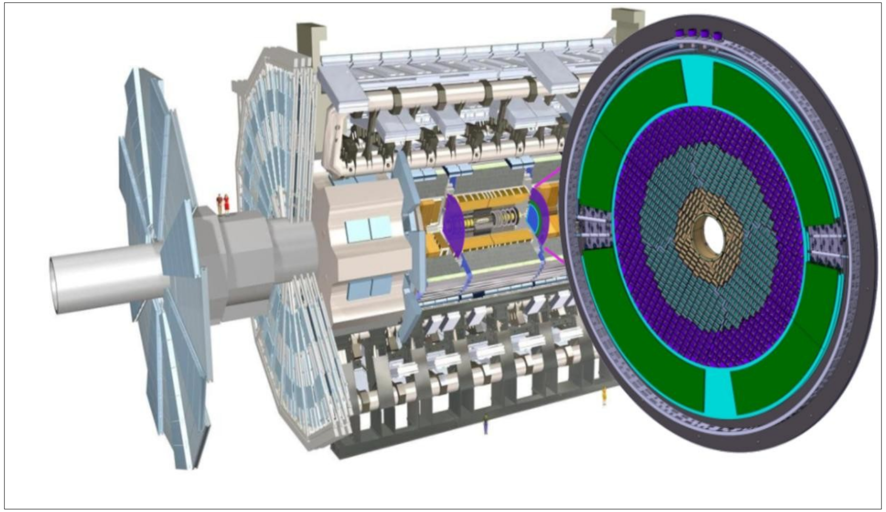


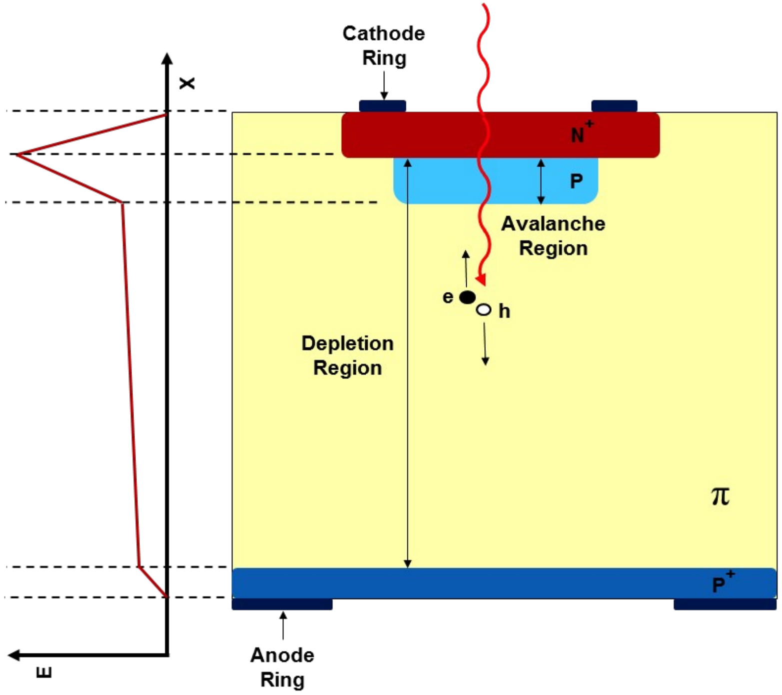
Figure 3: HGTD inserted in ATLAS.

- Although a track may appear to align spatially with a particular vertex, differences in the track's time and the selected vertex's time can be used to identify and discard pile-up tracks.

A good time resolution of HGTD will be achieved by using the ***Low Gain Avalanche Detectors*** (LGAD), the new semiconductor sensors technology meant for precise timing measurements.

Sensor technology: Low Detector (LGAD)

- **n-p Si** detector with an additional **p-type doped layer.**
- Excellent time resolution **< 40 (50) ps** pre-irradiation (after-irradiation) .
- Expected charged collected larger than **15 (4) fC** pre-irradiation (after-irradiation).
- Hit efficiency **> 95%** at the end of lifetime.



- **General Objective:**

Characterization of the LGAD performance using Test Beam Data.

- Measuring Time Resolution
- Measuring Collected Charge

- **Test Beam Description:**

For this work were used the data obtained by 8 LGAD sensors for different design and fluency.

- Two design: USTC and IHEP.
- Different Fluencies: 0, 1.5×10^{15}, 2.5×10^{15} neq/cm^2

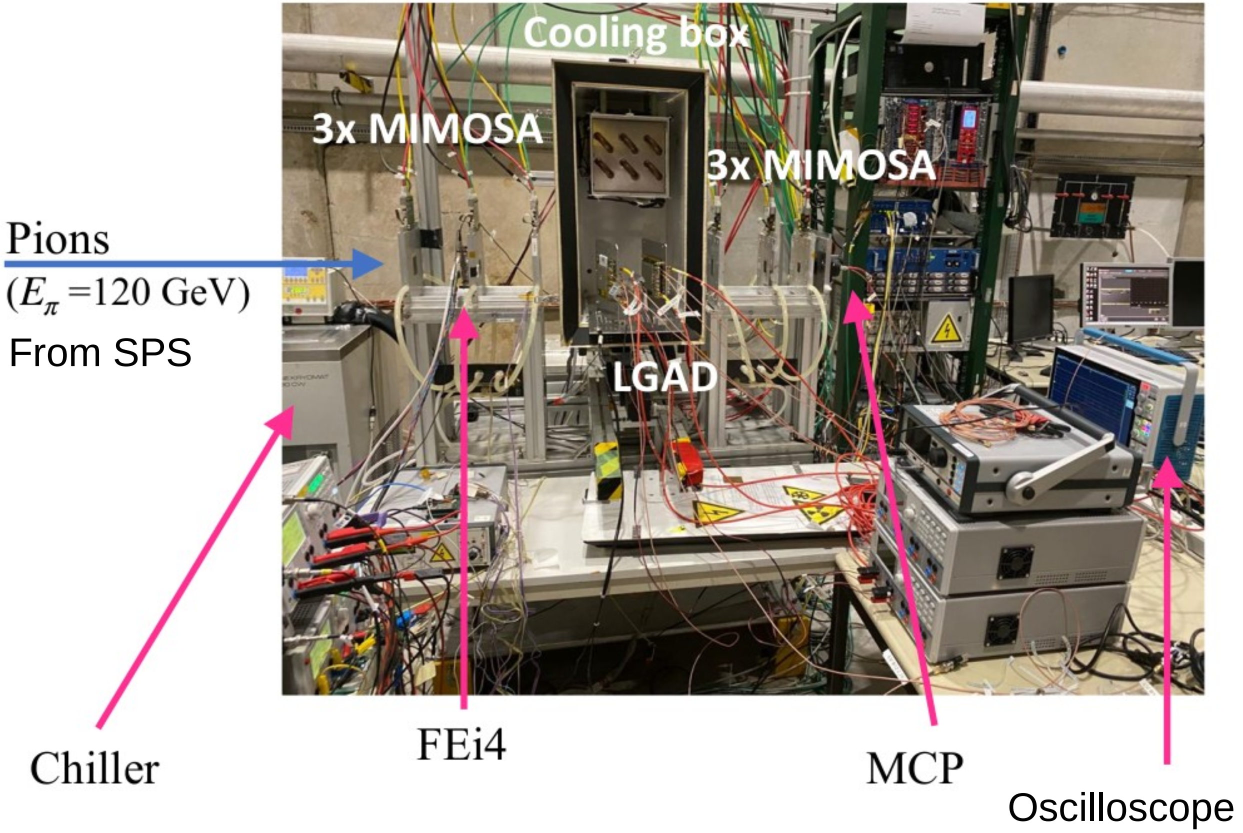


Figure 4: Test-Beam SetUp at CERN.

MCP: Micro Chamber Plate

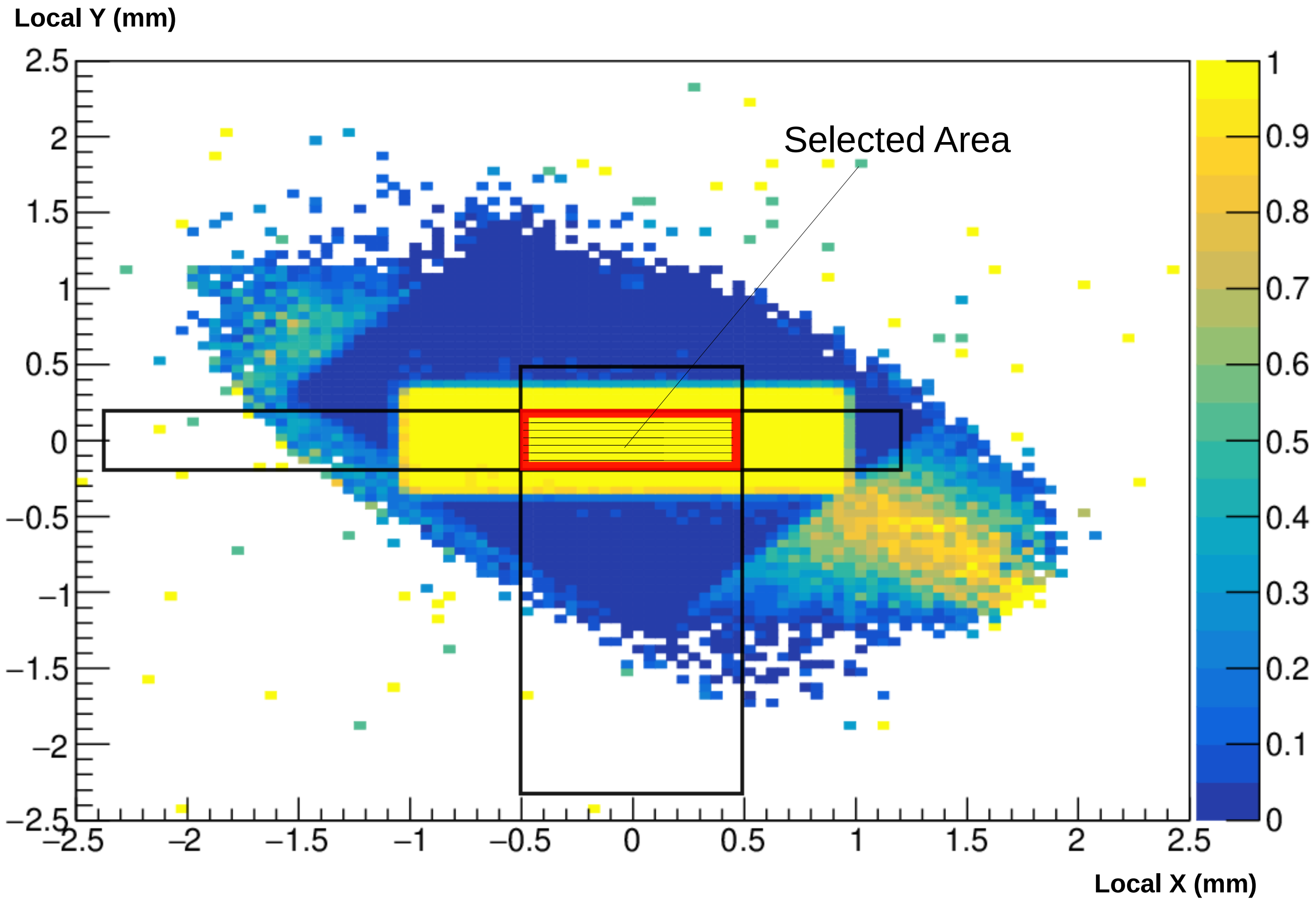


Figure 7: Charge Efficiency Plot for a irradiated sensor with a High Voltage of 150 V

Explanation:

- In order to reduce the contribution of noise, events that pass through the center of the sensor are used for analysis.
- For each sensor **a cut in the Local X and Local Y** variables were applied.
- This same analysis was done with all of the sensors.

Analysis and Results: ΔT (MCP and Sensor Time Difference)

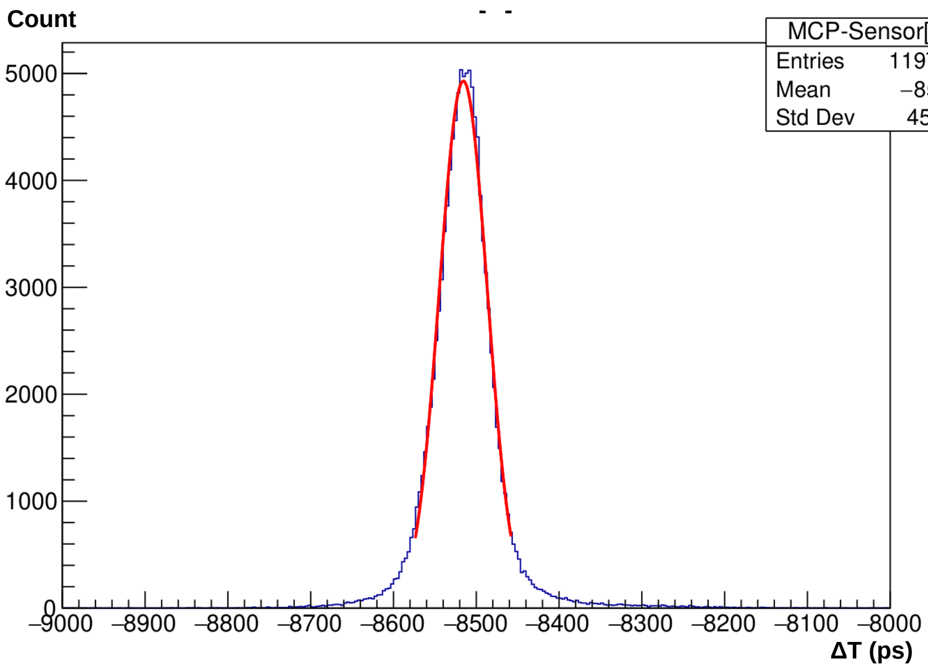


Figure 8: ΔT Distribution for a sensor with a high voltage of 127 V

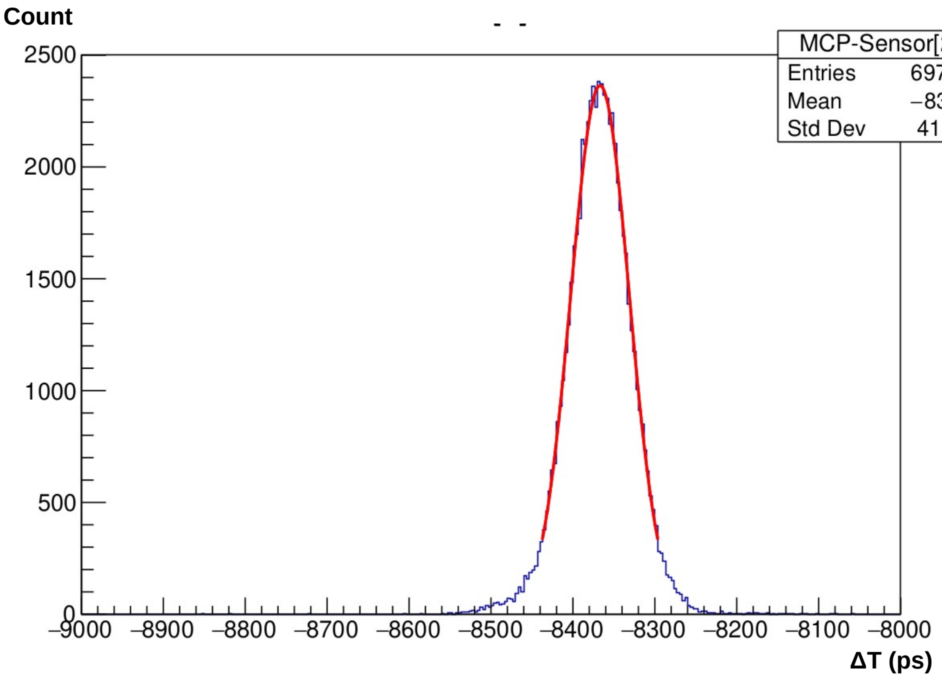


Figure 9: ΔT Distribution for a sensor with a high voltage of 555 V

- $\Delta T = tCFD_{MCP} - tCDFD_{sensor}$
- Gaussian Fit

MCP resolution = σ_{MCP} = 10.6 ps

$$\sigma = \sqrt{\sigma_{MCP}^2 + \sigma_{LGAD}^2}$$

σ_{LGAD}

Analysis and Results: ΔT vs High Voltage (HV)

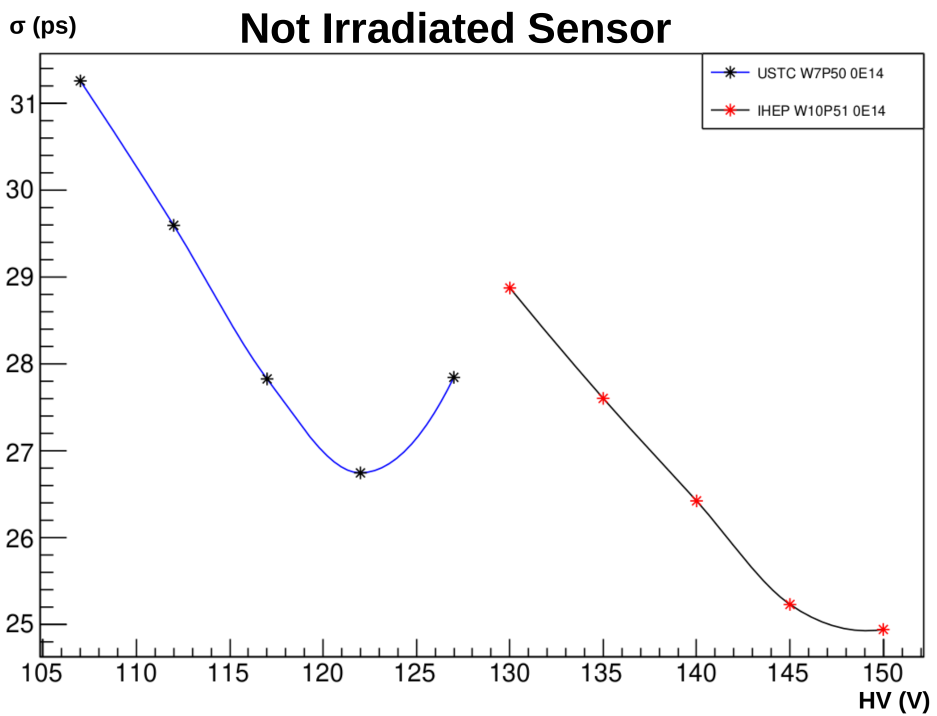


Figure 10: σ vs High Voltage for not irradiated sensors

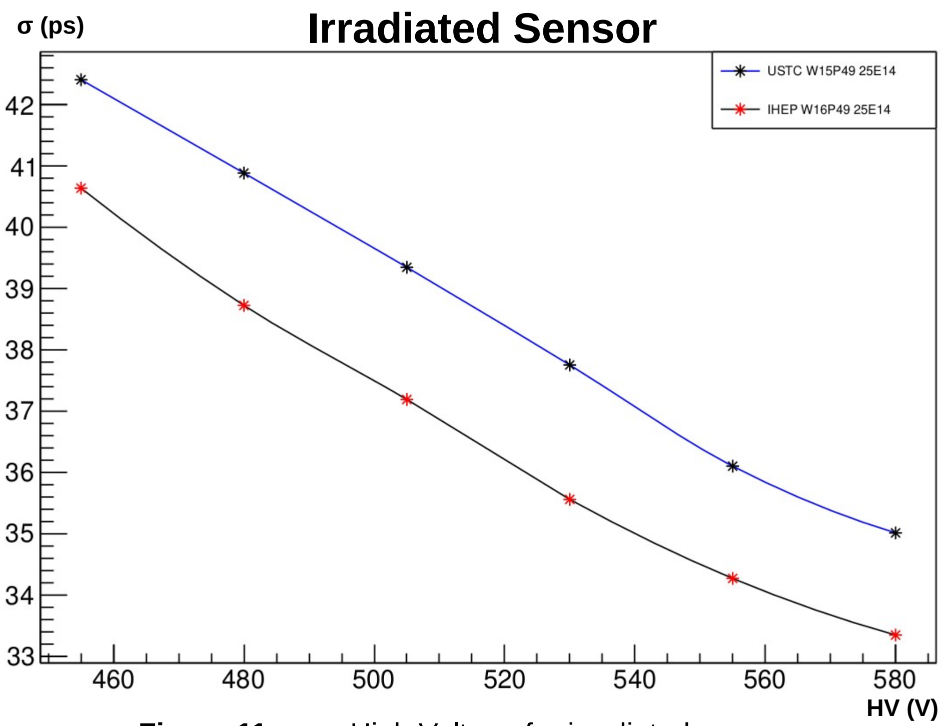


Figure 11: σ vs High Voltage for irradiated sensors

- As the voltage increase, the resolution improves.
- At some point, the HV is so high that the resolution gets worse.
- The irradiated and not irradiated sensors behave as expected.

Analysis and Results: Collected Charge

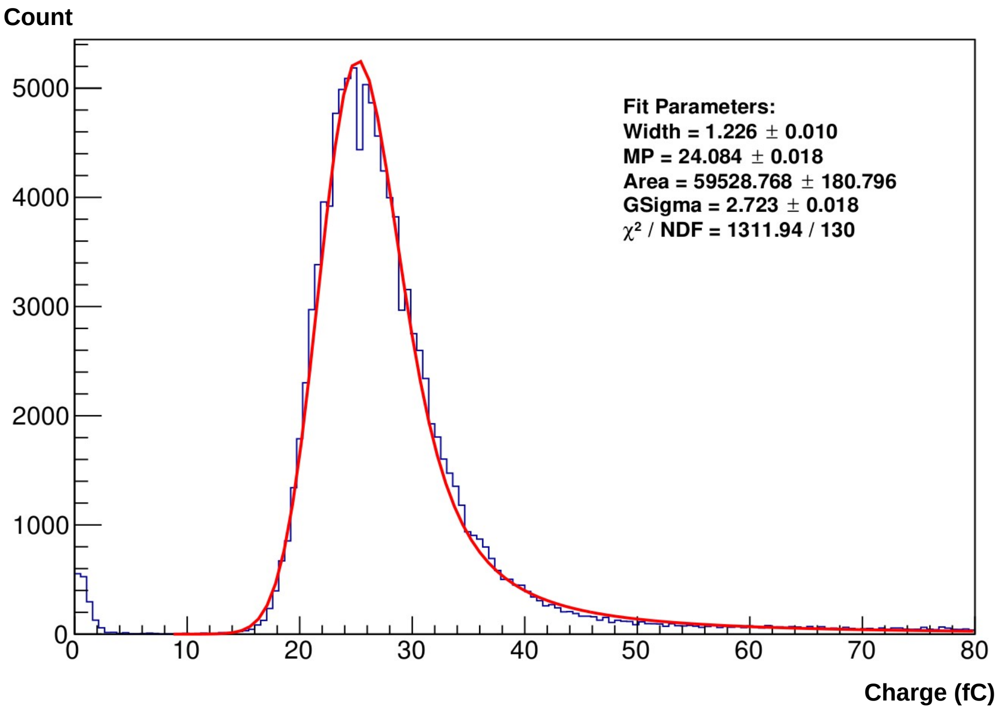


Figure 12: Charge distribution for a sensor with a high voltage of 122 V

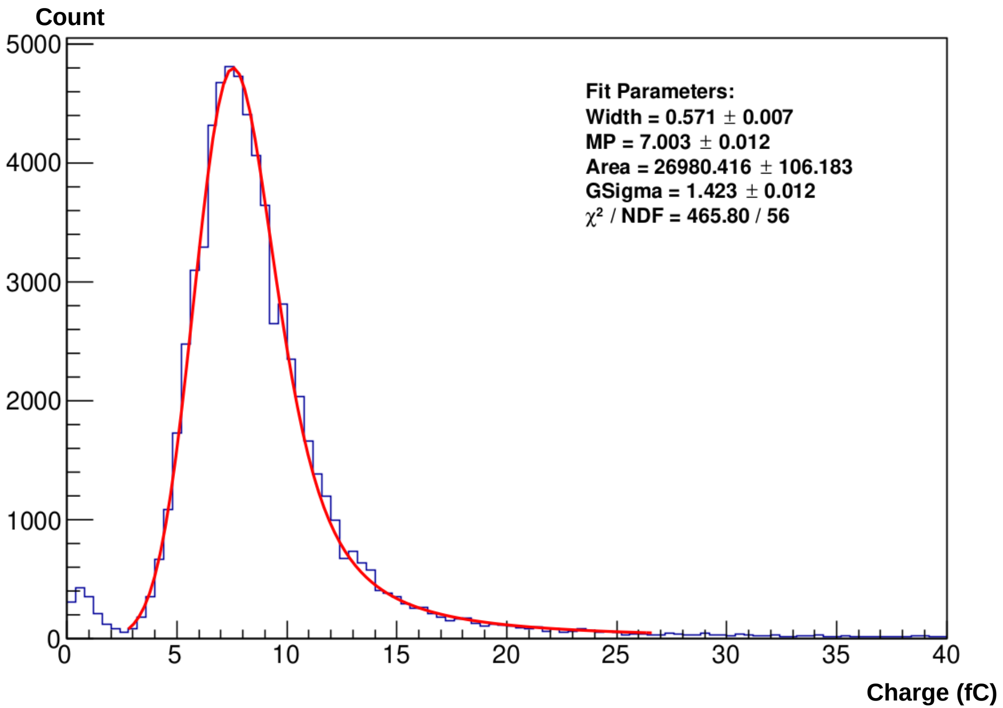


Figure 13: Charge distribution for a sensor with a high voltage of 555 V

- Fit with Landau-Gaussian convolution Distribution.
- From the fit Parameters was taken the Most Probable value (MP).
- This plots were repeated with all the sensors.

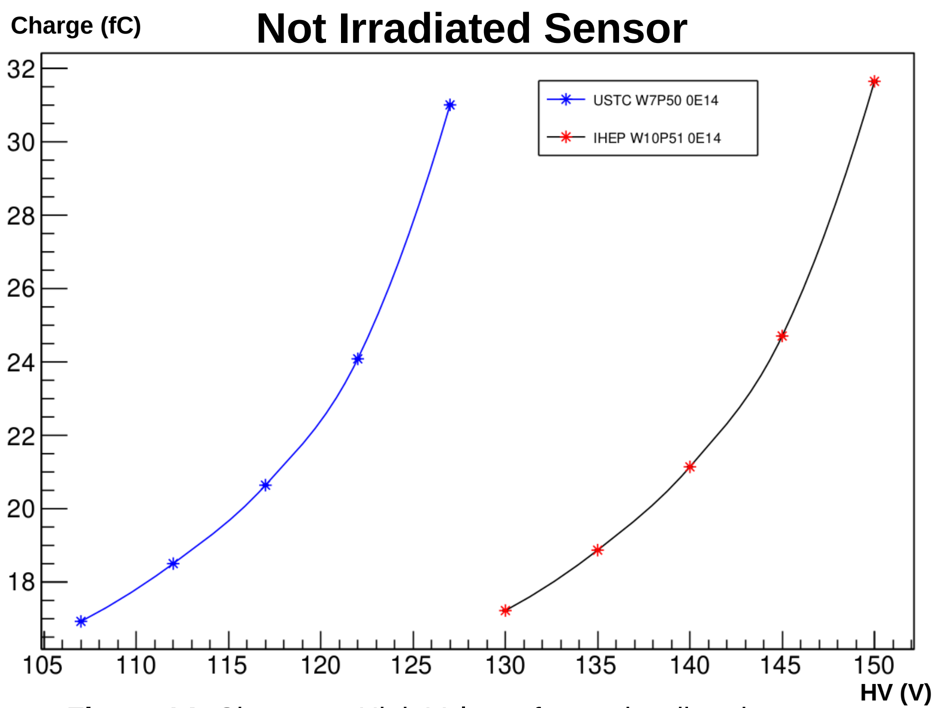


Figure 14: Charge vs High Voltage for not irradiated sensors

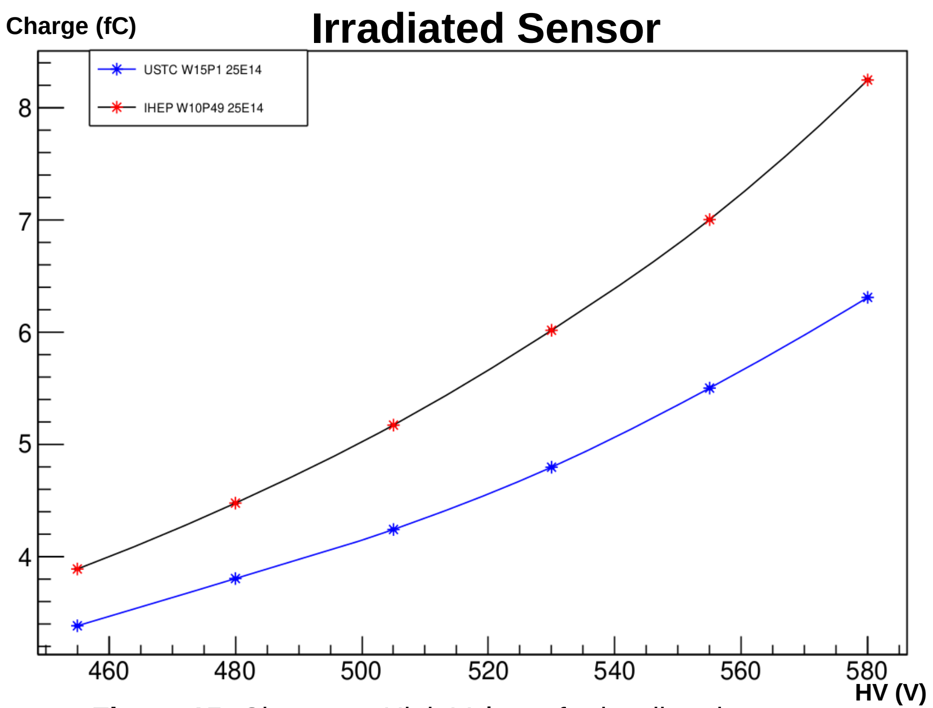


Figure 15: Charge vs High Voltage for irradiated sensors

- As the HV increase, the collected charge also increase for irradiated and not irradiated sensors.
- This behavior is expected for all the cases.

- **8 LGAD sensors** with **different fluence** and from different vendors were Characterized.
  -Events passing at the center of the LGAD were selected in the analysis to reduce the noise contribution.
  -Time resolution and collected charge as a function high voltage were studied.

- Time resolution and collected charge as a function high voltage was studied. **All sensors meet the requirements:**
  -Collected charge > 15 fC (4fC) for not irradiated (irradiated) sensor
  -Time resolution > 40 ps (50 ps) for not irradiated (irradiated) sensor

- **Next steps:**
  -Study other sensor characteristics, i.e. efficiency, size of the sensor
  -Actively participate to test-beam.

Thank You!

The Pile-up will be caused by the increase of the instantaneous luminosity

- Pile-up <> = 200 interactions per bunch crossing, spread in **~45 mm** along the beam axis.
- **The Inner Tracker (ITk)** mostly mitigates the pile-up effect but is still challenging in the forward region.
- To discriminate between pile-up and hard scattering interaction, the HGTD will be added in the forward region with the goal to have **30-50 ps** per track time resolution (beginning-end).
- By utilizing both spatial and timing information, we can confidently link tracks to vertices in the forward region.

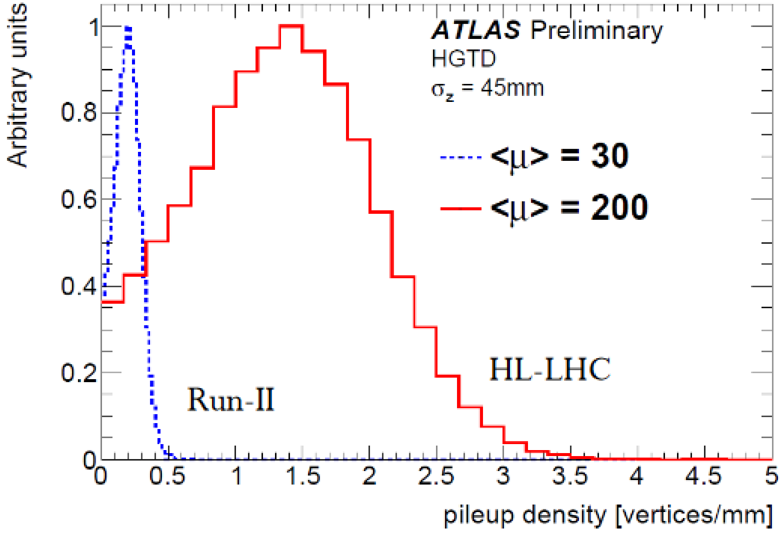
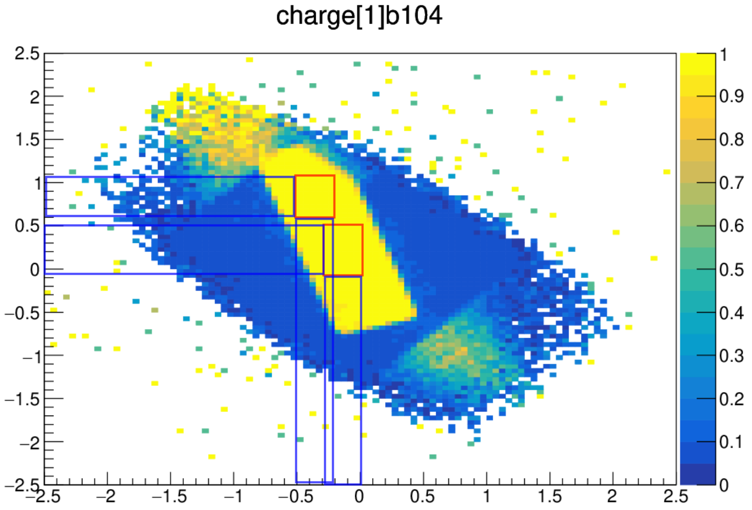


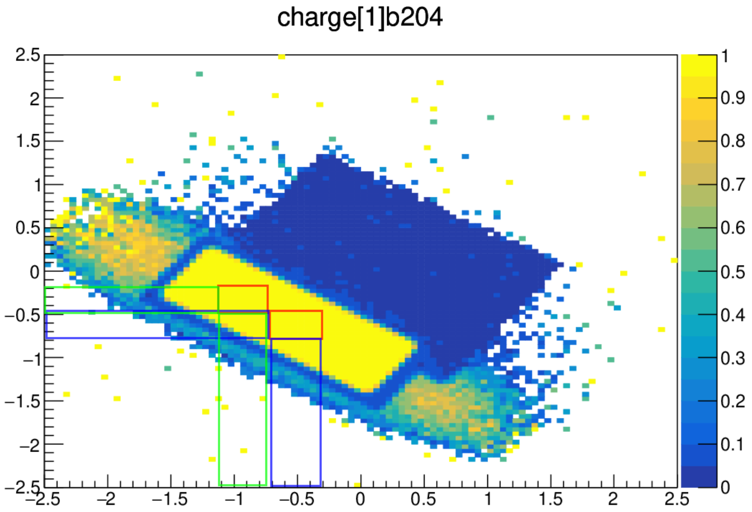
Figure 2: Pile-up differences.

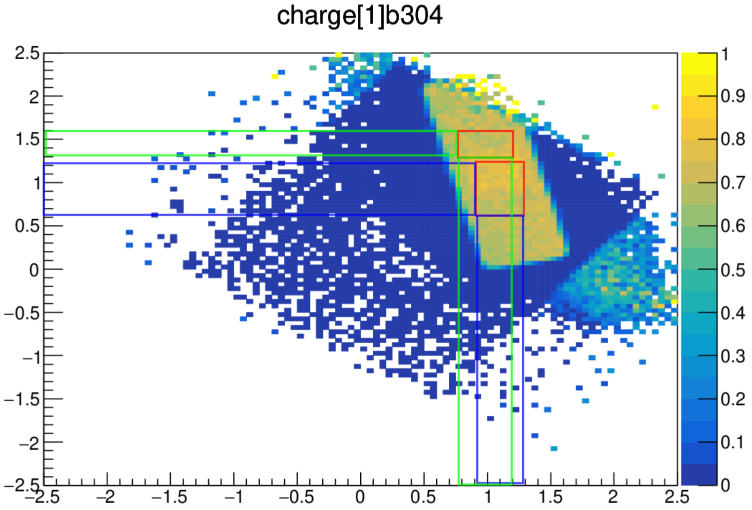
Back-Up: Table of used Sensors

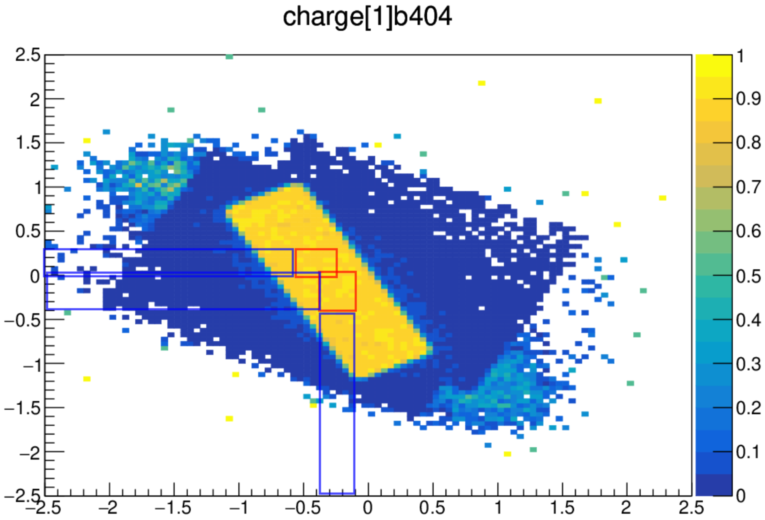
Table of Sensors		
Batch	**Sensor 1**	**Sensor 2**
1	USTC W7P50 0E14	IHEP W16P52 15E14
2	IHEP W16p43 0E14	IHEP W16P52 15E14
3	USTC W15P49 25E14	IHEP W16P49 25E14
4	USTC W15P1 25E14	IHEP W10P49 25E14

Back-Up: 2D Plots of Local X vs Local Y for Sensors 1

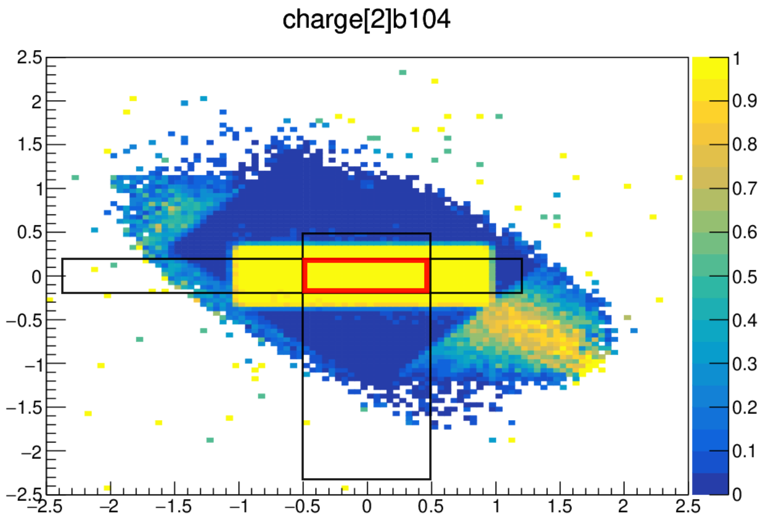


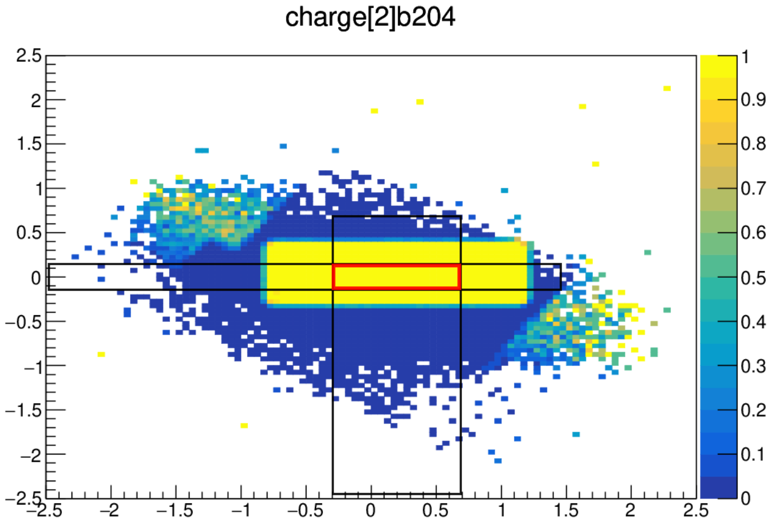


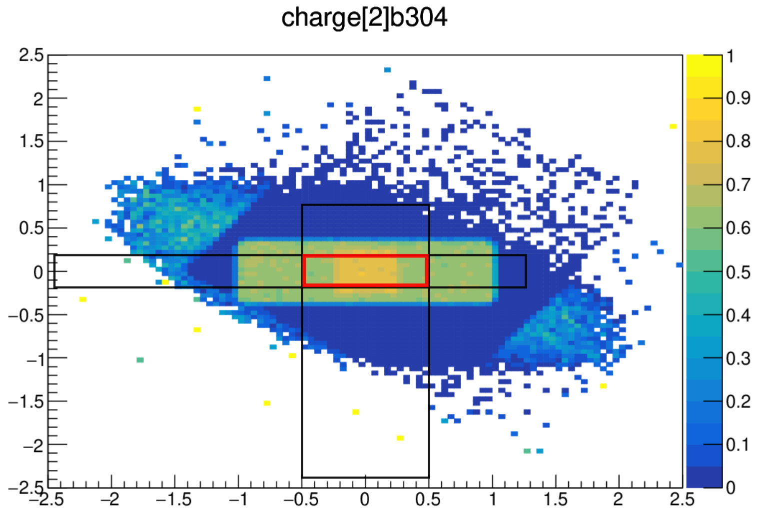


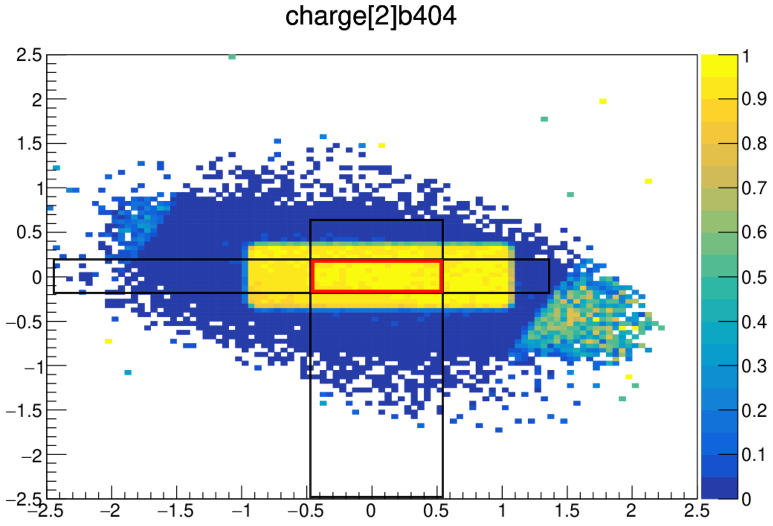


Back-Up: 2D Plots of Local X vs Local Y for Sensors 2

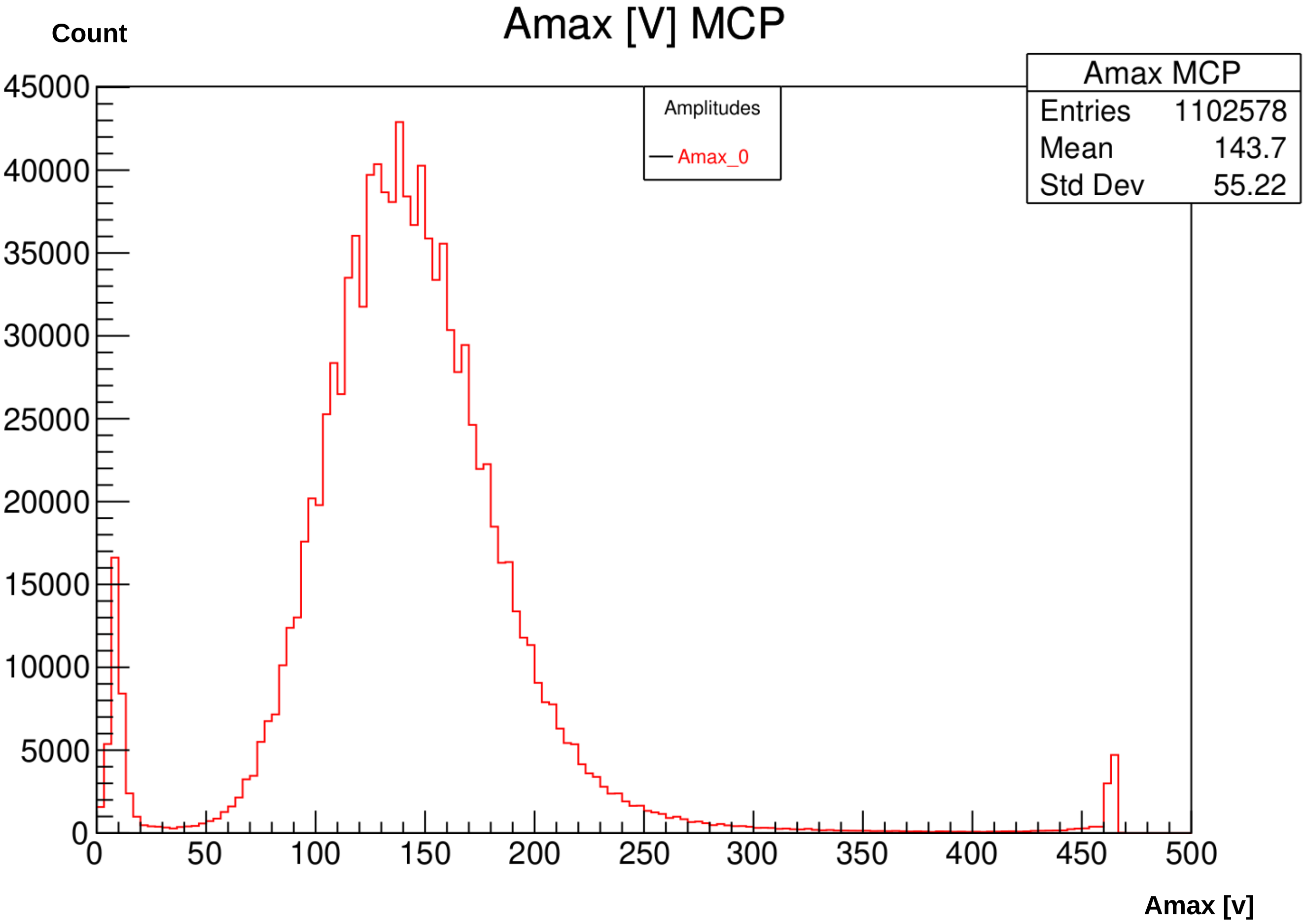




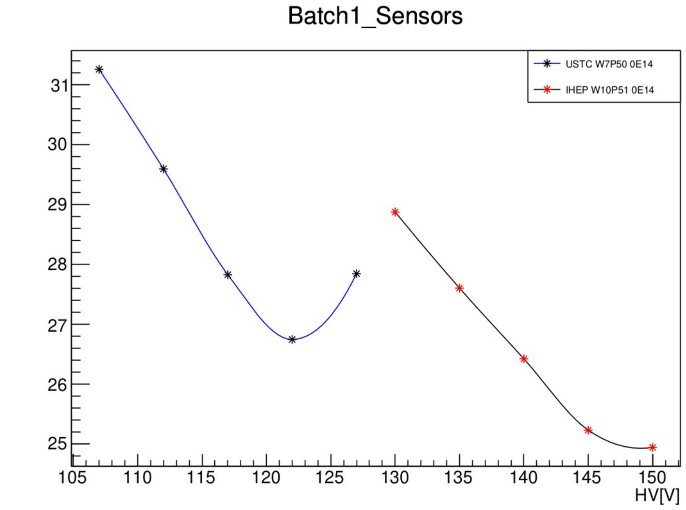


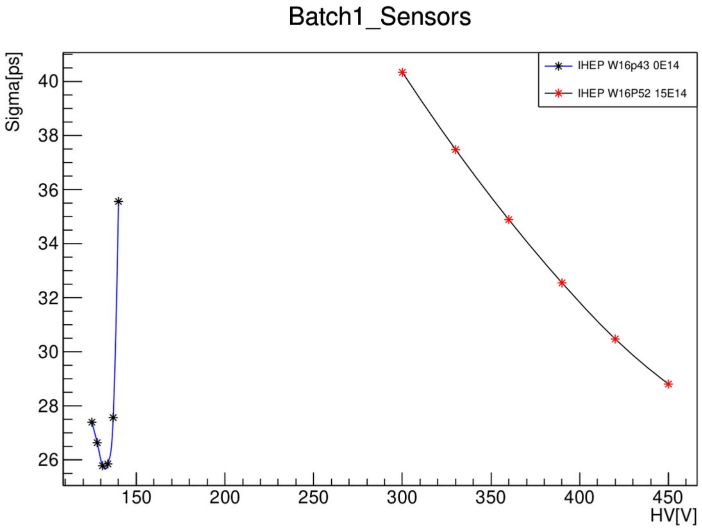


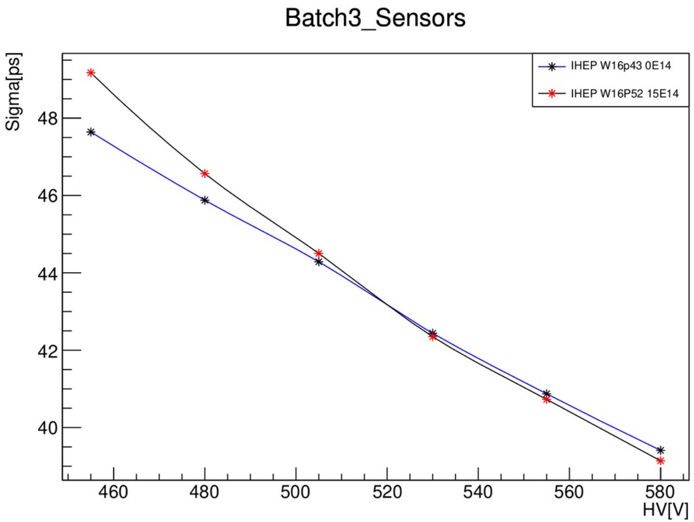
Back-Up: Maximum Amplitude for MCP [V]

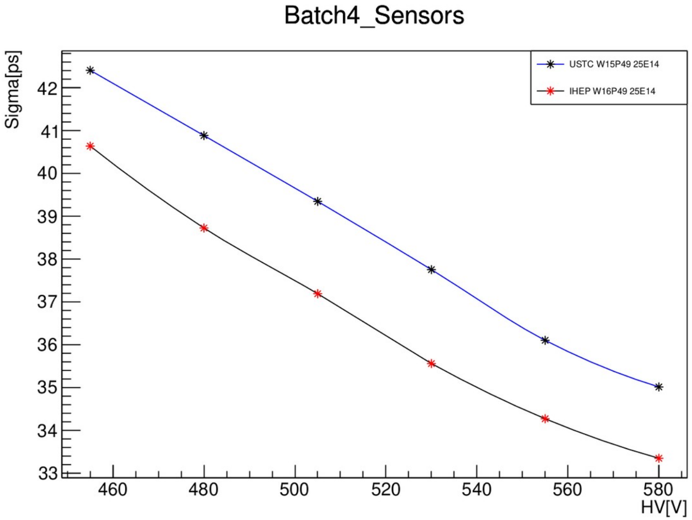


Back-Up: ΔT vs High Voltage

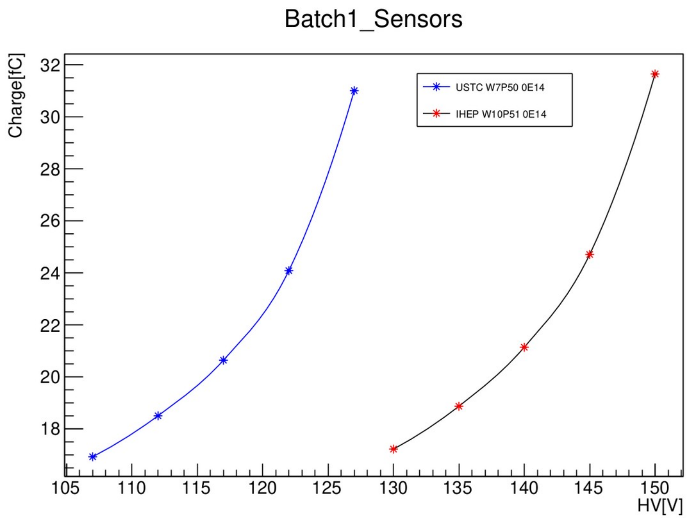


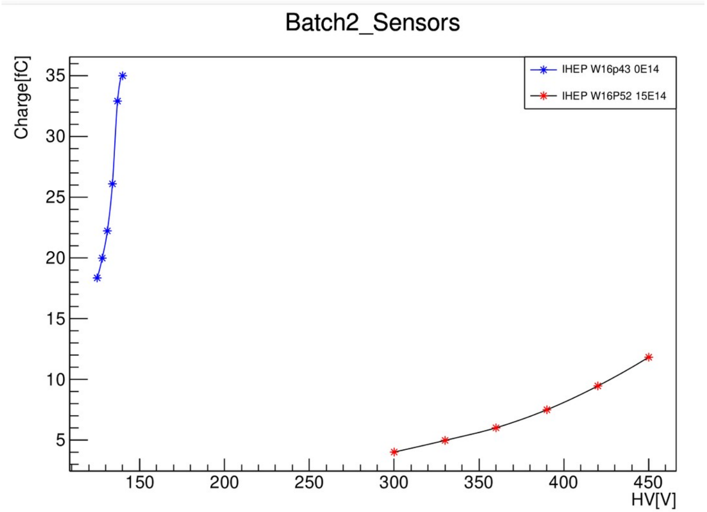


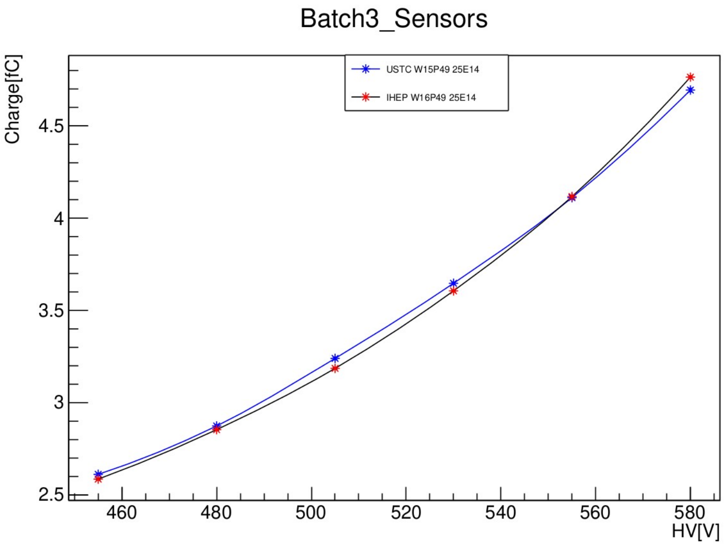


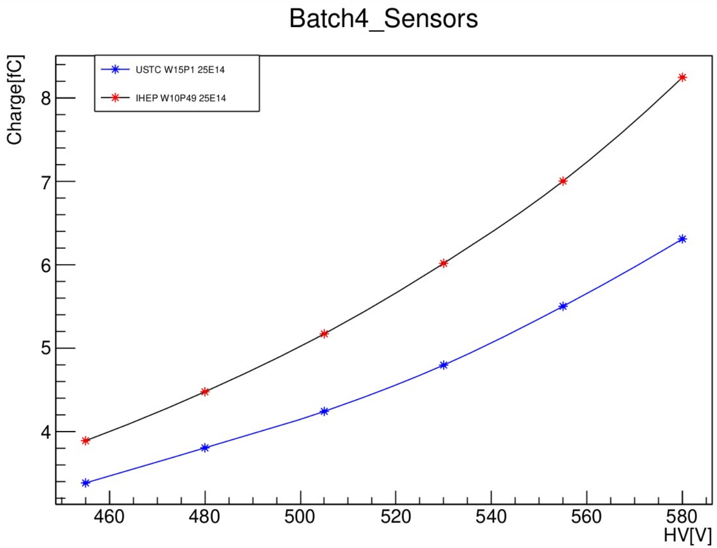


Back-Up: Charge vs High Voltage









Back-Up: Voltage Maximum Amplitude (Amax)

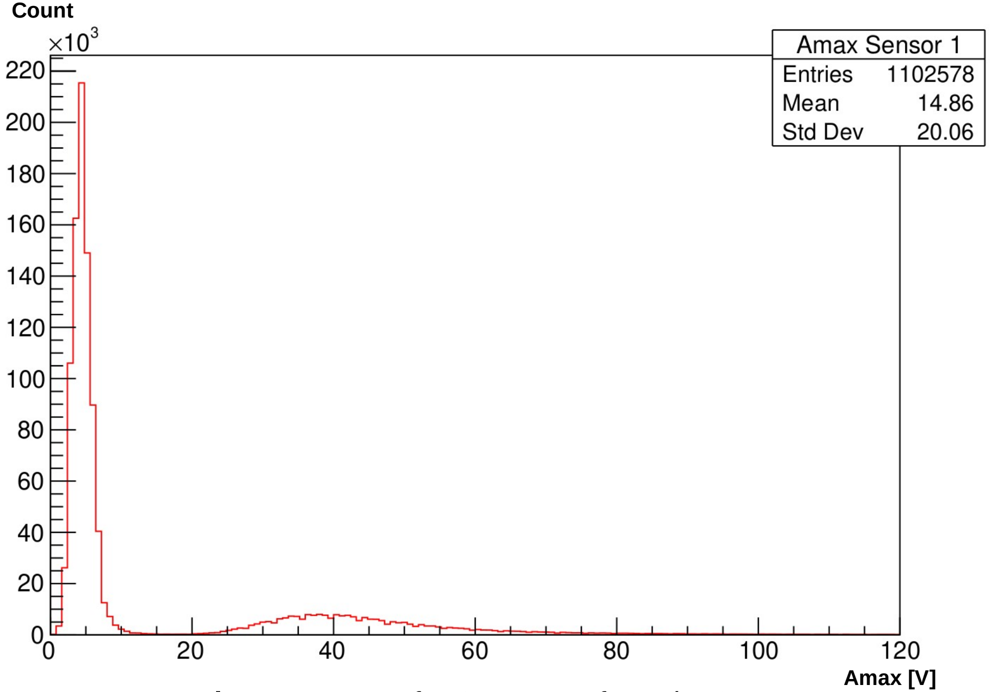


Figure 5: Amax for Sensor 1 of Batch 404

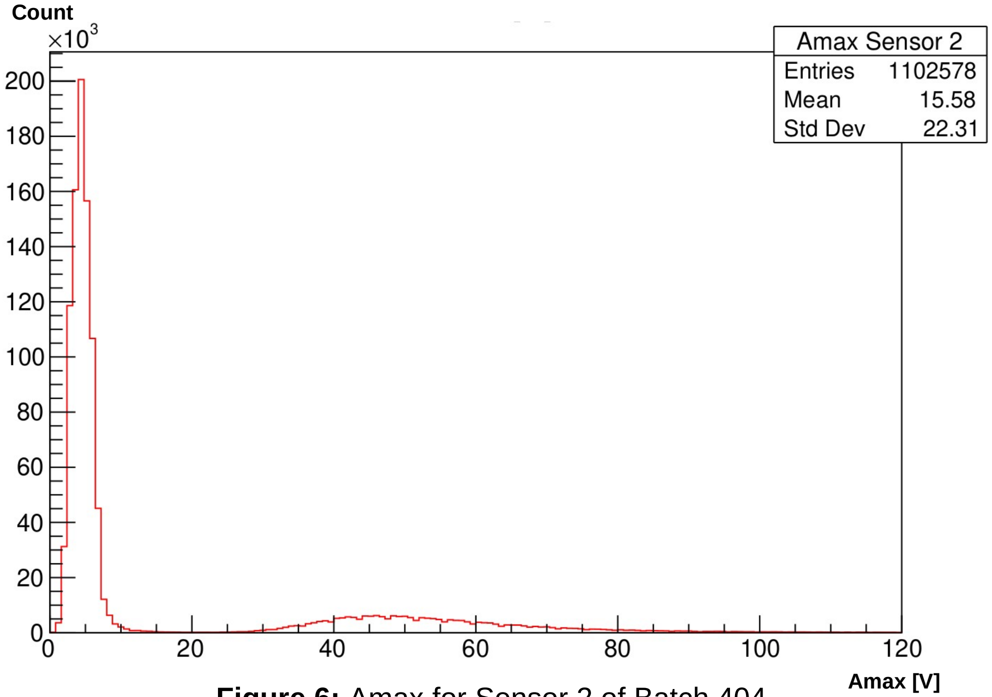


Figure 6: Amax for Sensor 2 of Batch 404

- The plots shows that there's always a big contribution in Amax due to noise.
- The higher the radiation damage, the smaller the Amax.
- For Highest fluence sensor the cut on Amax cannot separate signal from noise.

Introduction: HGTD Performance Example