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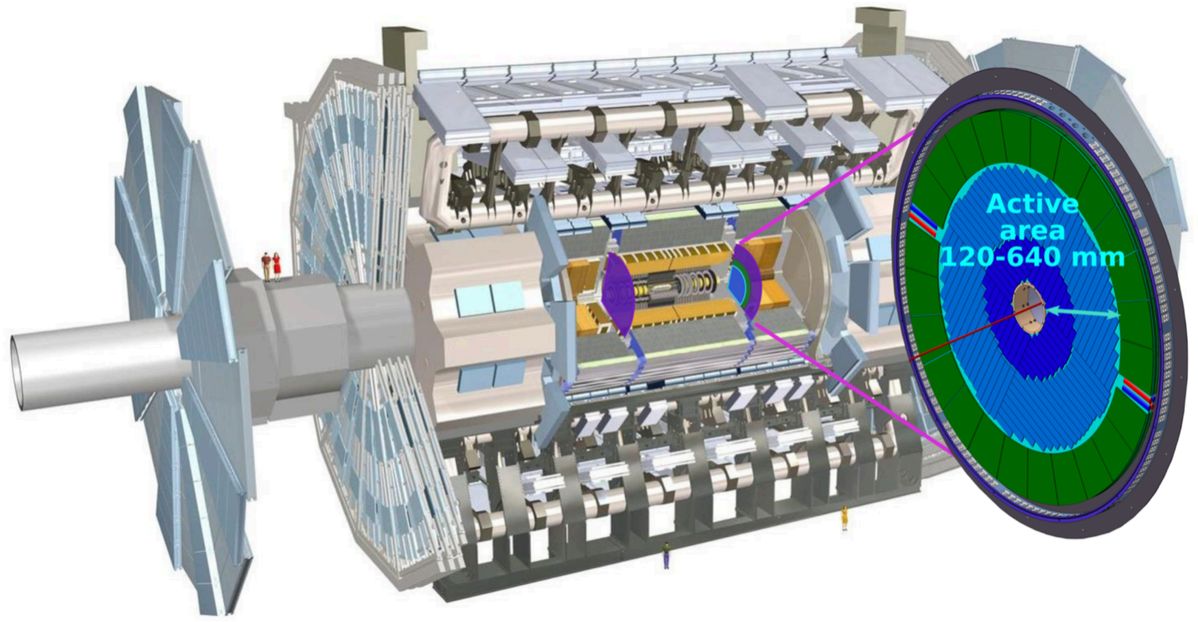

Performance studies of the Low Gain Avalanche Detectors for the ATLAS High Granularity Timing Detector in beam tests

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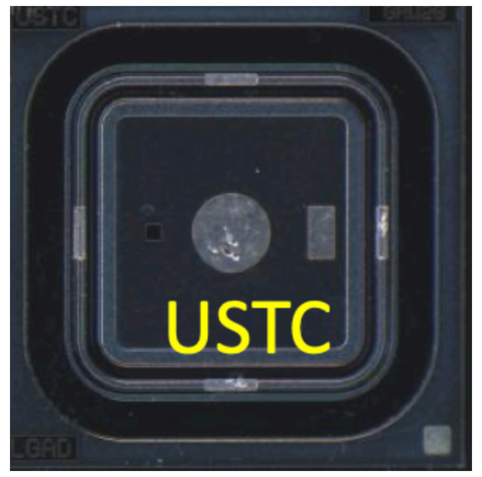
Outline

- Low Gain Avalanche Detectors (LGAD)
- Single Event Burnout
- Sensors list
- Test Beam setups: DESY, CERN SPS
- Results
- Conclusion

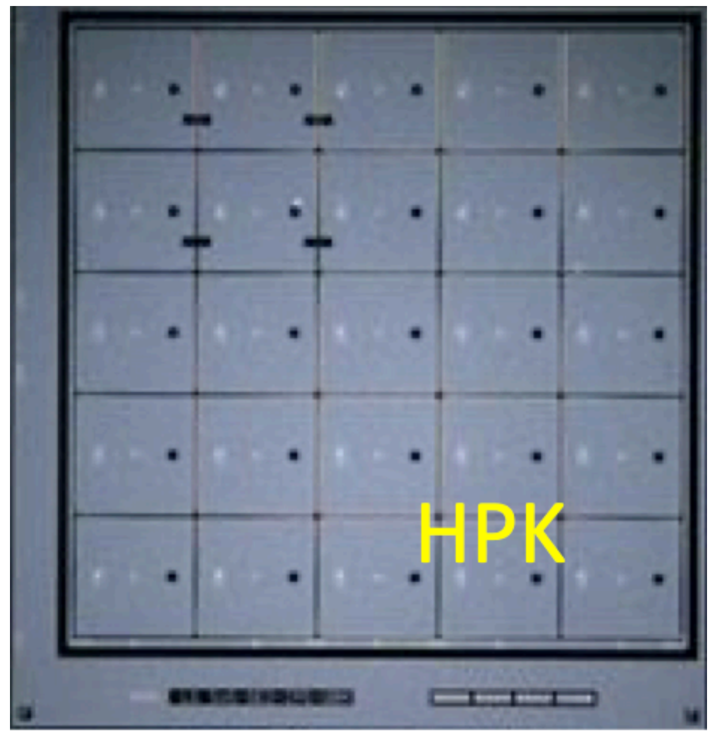
Low Gain Avalanche Detector (LGAD)

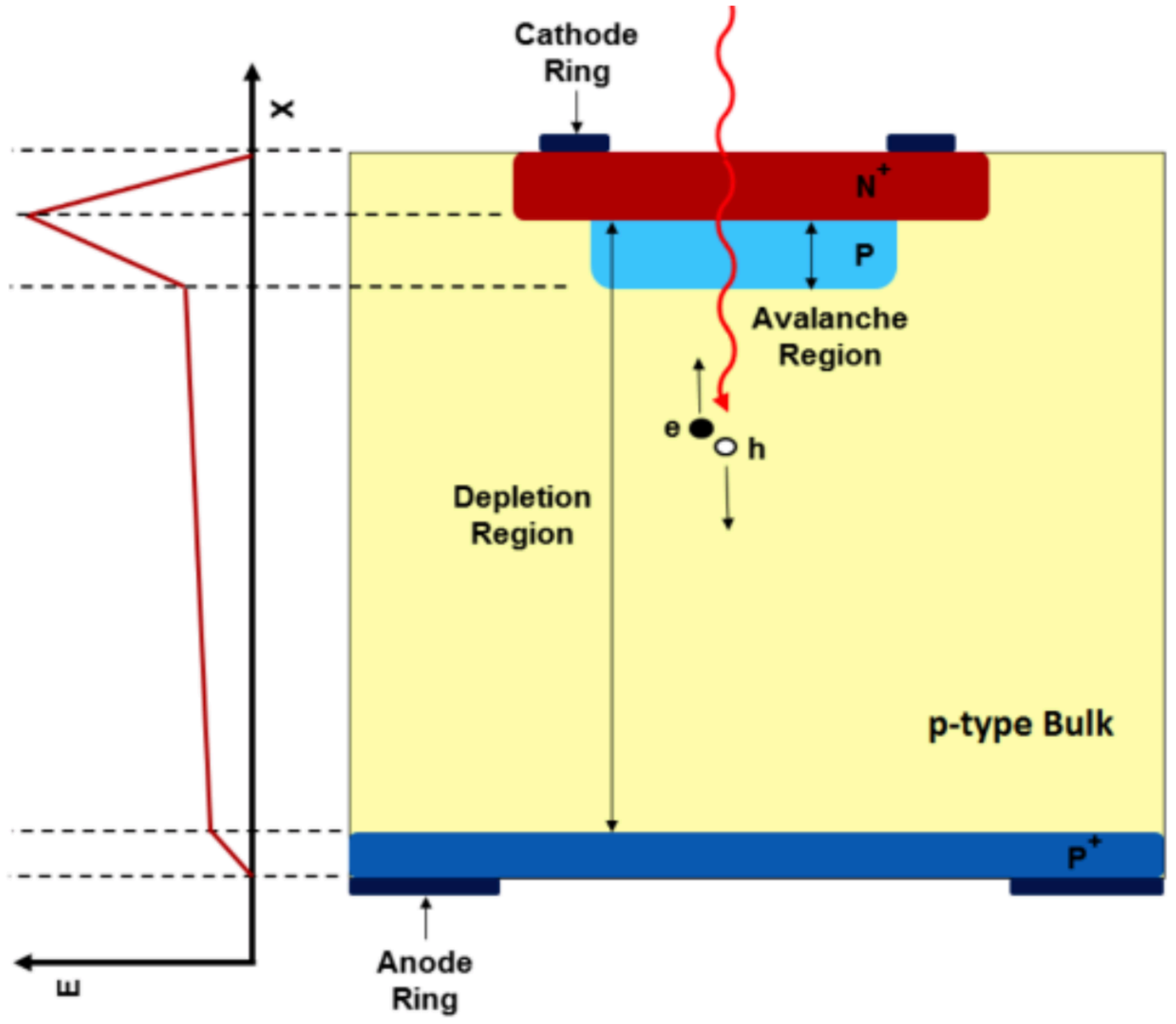
- n on p sensor with a p-type multiplication layer of thickness ~50μm
- Moderate internal gain (8-50)
- The higher the Bias Voltage applied, the higher the gain
- Fast rise time (0.5-0.8 ns)
- Time resolution before irradiation ~ 30ps
- 15 x 15 pads of size 1.3 x 1.3mm^2

Single pad



5x5 array





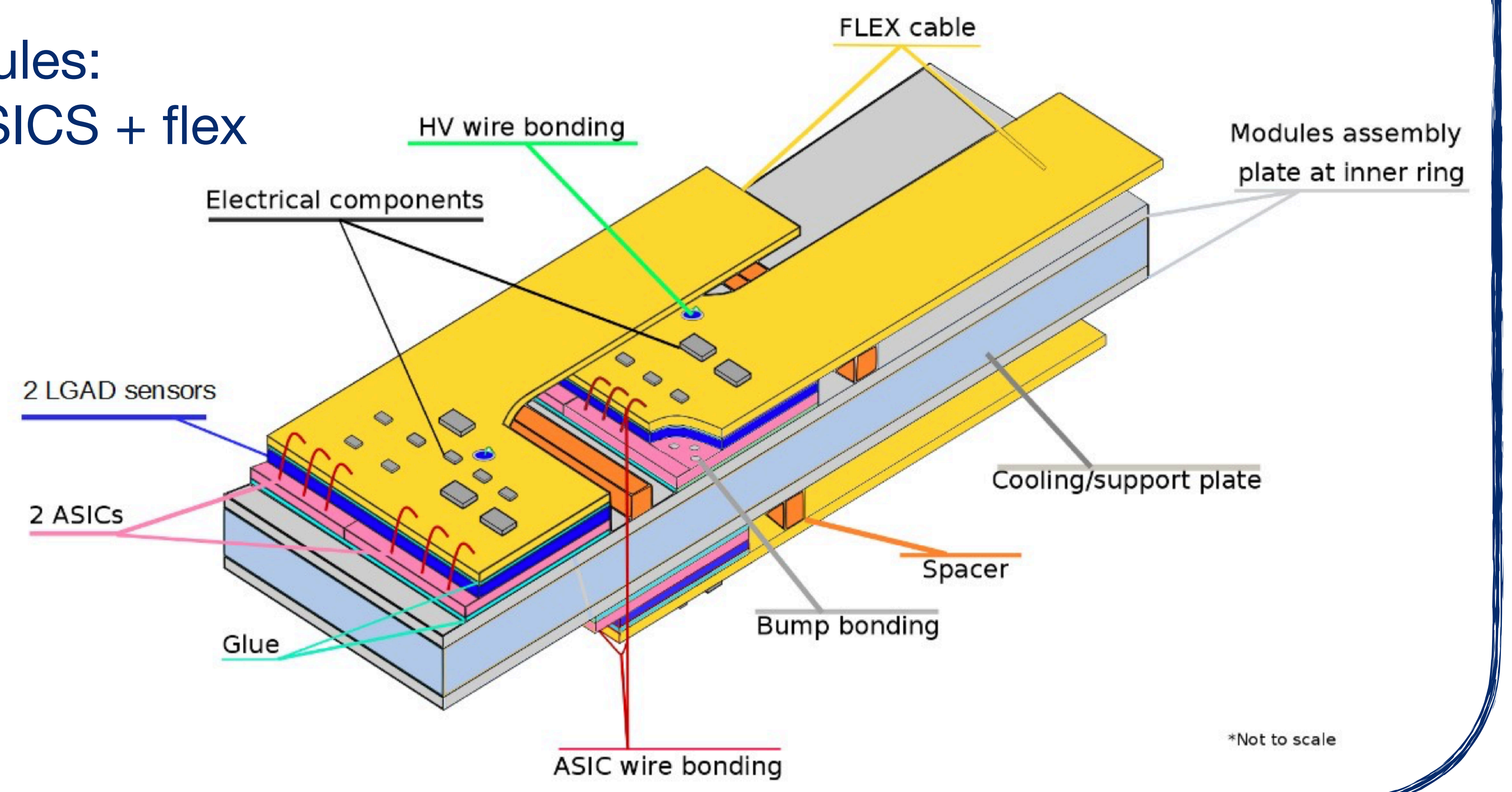
Key design requirements:

- Radiation hardness
- Minimum required charge collection of 4fC
- < 70ps time resolution
- > 95% efficiency

} at maximum irradiation of 2.5x10^{15} n_{eq} /cm^2

Read out : ASICS integrated circuits ALTIROC

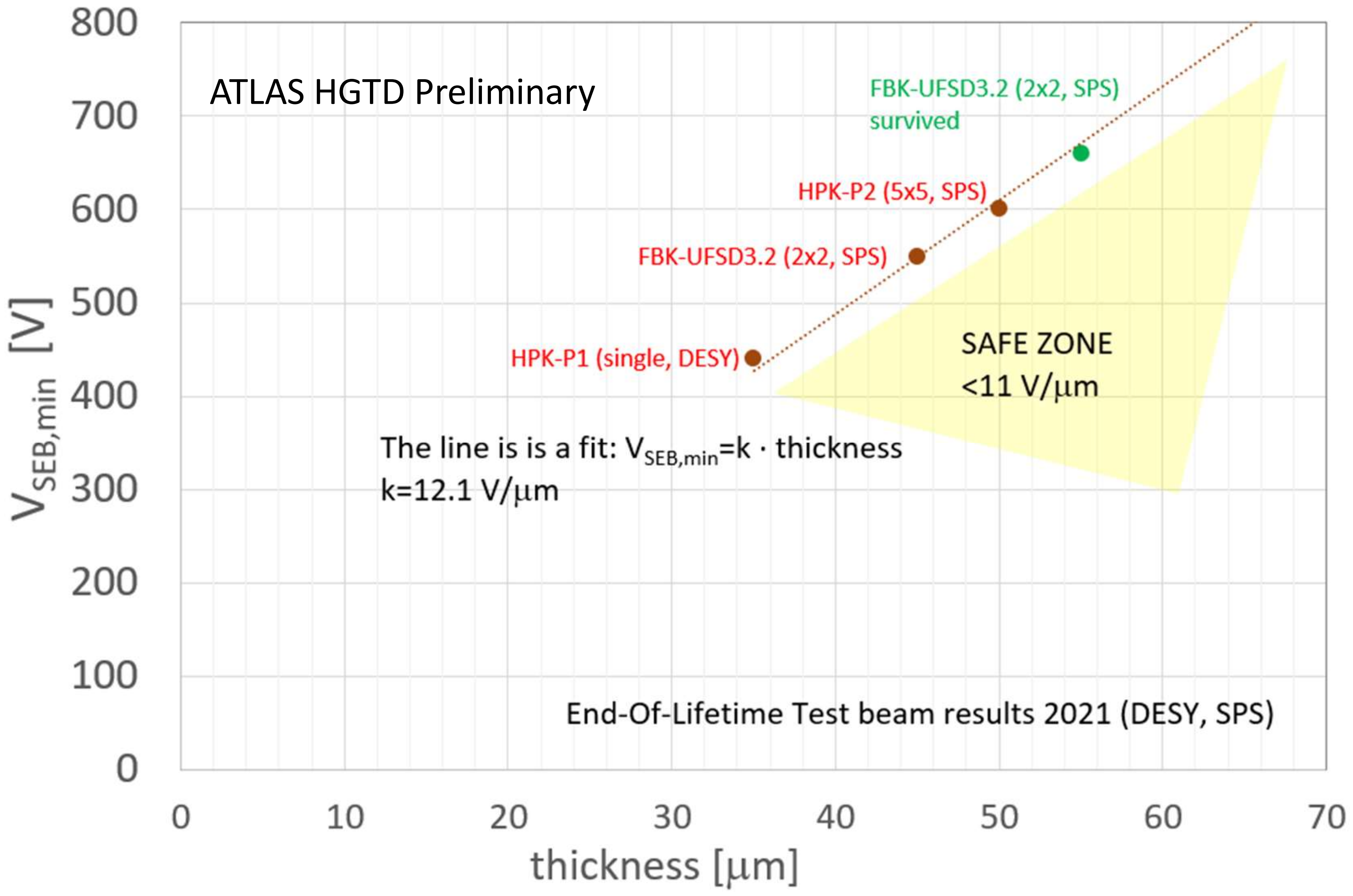
8032 modules:
2 sensors + 2 ASICS + flex



Single Event Burnout

The process of large current in narrow path is called "Single Event Burnout"

- The field collapse in the presence of high concentration of free carriers is the probable cause
- Need to be ensured that sensors can meet project requirements without risk of SEB
- Electric field (V_{bias}/thickness) is the key parameter determining the fatality

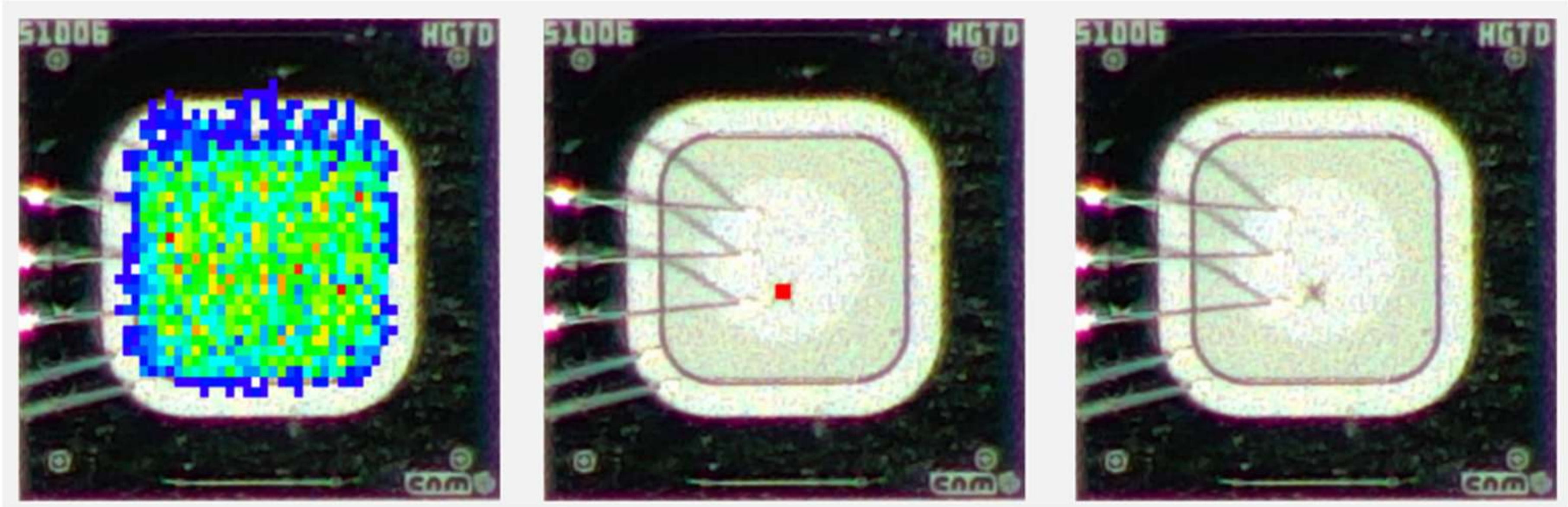


In 2019-2021 Test beam campaigns, the sensors mortality was observed

Mortality test beams were organised at DESY in June 2021 (3 GeV electrons) and CERN SPS in November 2021 (120 GeV pions)

- 74 sensors tested, 55 survived to voltages expected to meet HGTD specs
- Defined safe zone < 11V/μm

ATLAS HGTD Preliminary



Typical Single Event Burnout mark is shown in the right plot (2019 DESY test-beam with 5 GeV e). The reconstructed track in the SEB event pointed to the location of the burn mark (middle and right plot). All the reconstructed tracks distribution across the detector before SEB is shown in the left plot.

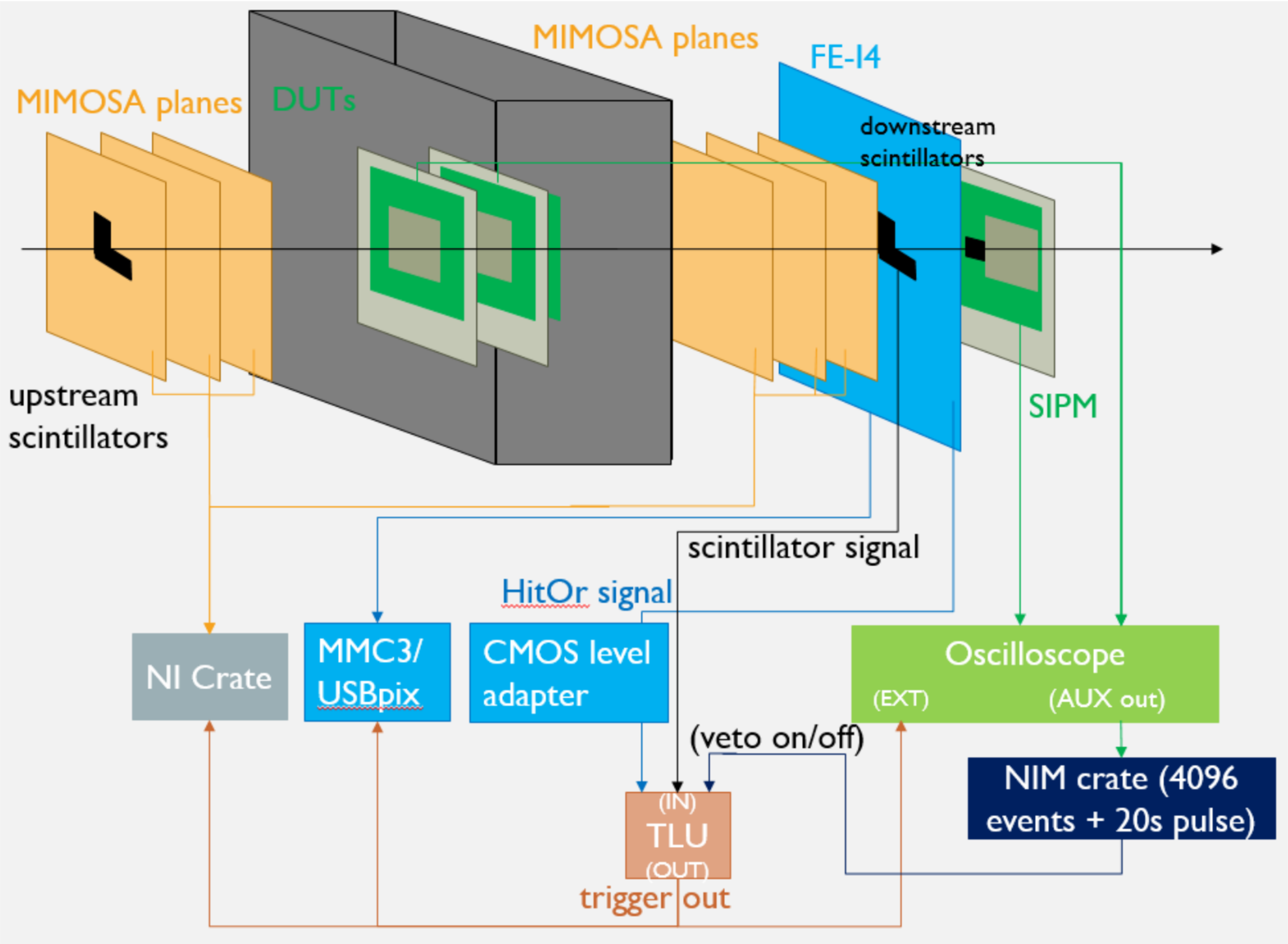
Sensors presented in this talk

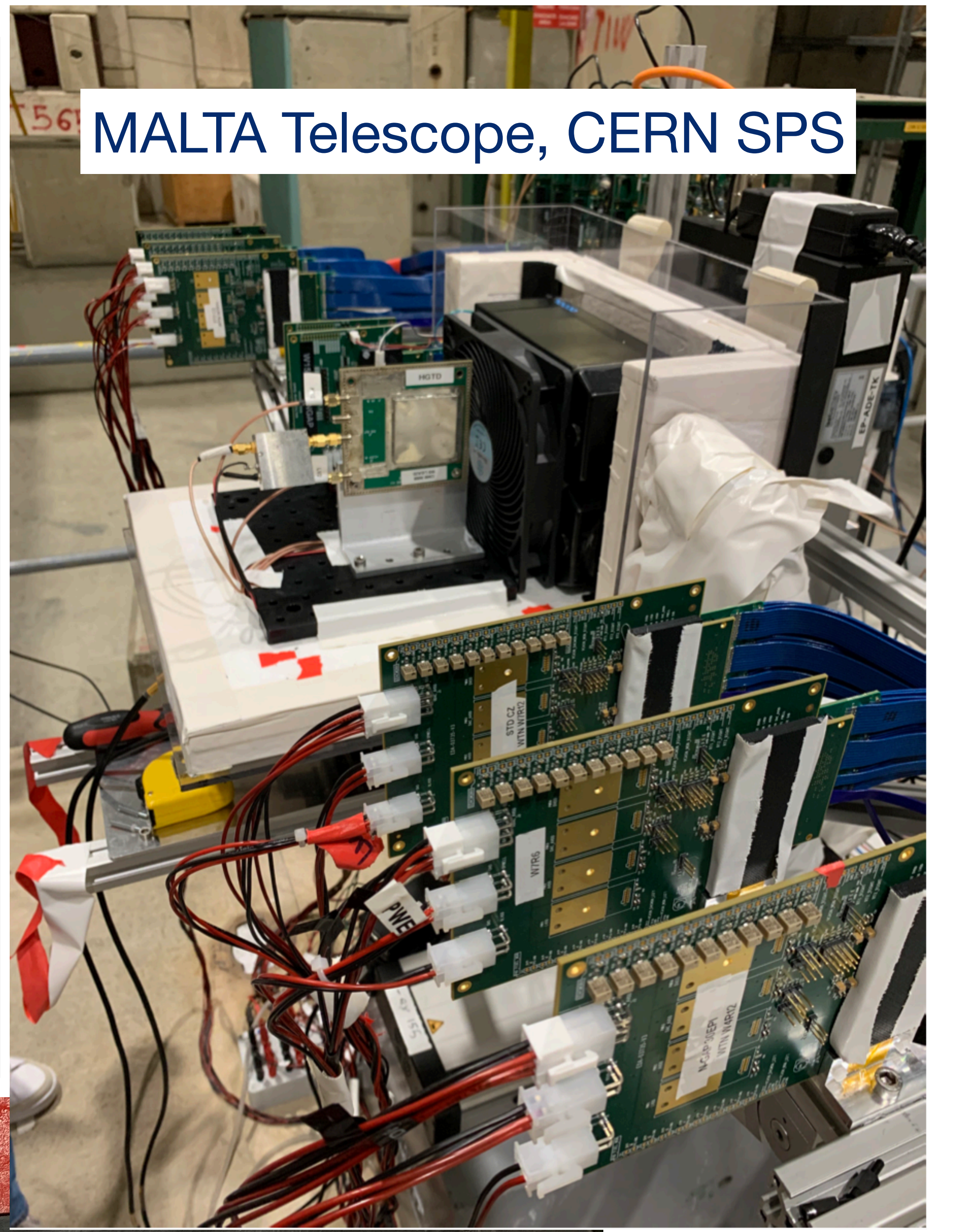
Device name	Manufacturer	Implant	Fluence [n_{eq}/cm^2]	Test Beam	Temperatures [^oC]
FBK-UFSD3.2 W19	FBK	Boron + C diffused	1.5×10^{15} 2.5×10^{15}	DESY DESY/CERN	-40 to -30 -46 to -26 / -20
USTC-IMEv2.1 W17	USTC-IME	Boron + C diffused	1.5×10^{15} 2.5×10^{15}	DESY DESY	-39 to -24 -43 to -29
IHEP-IMEv2 W7Q2	IHEP-IME	Boron + C diffused	1.5×10^{15} 2.5×10^{15}	DESY CERN	-43 to -30 -20

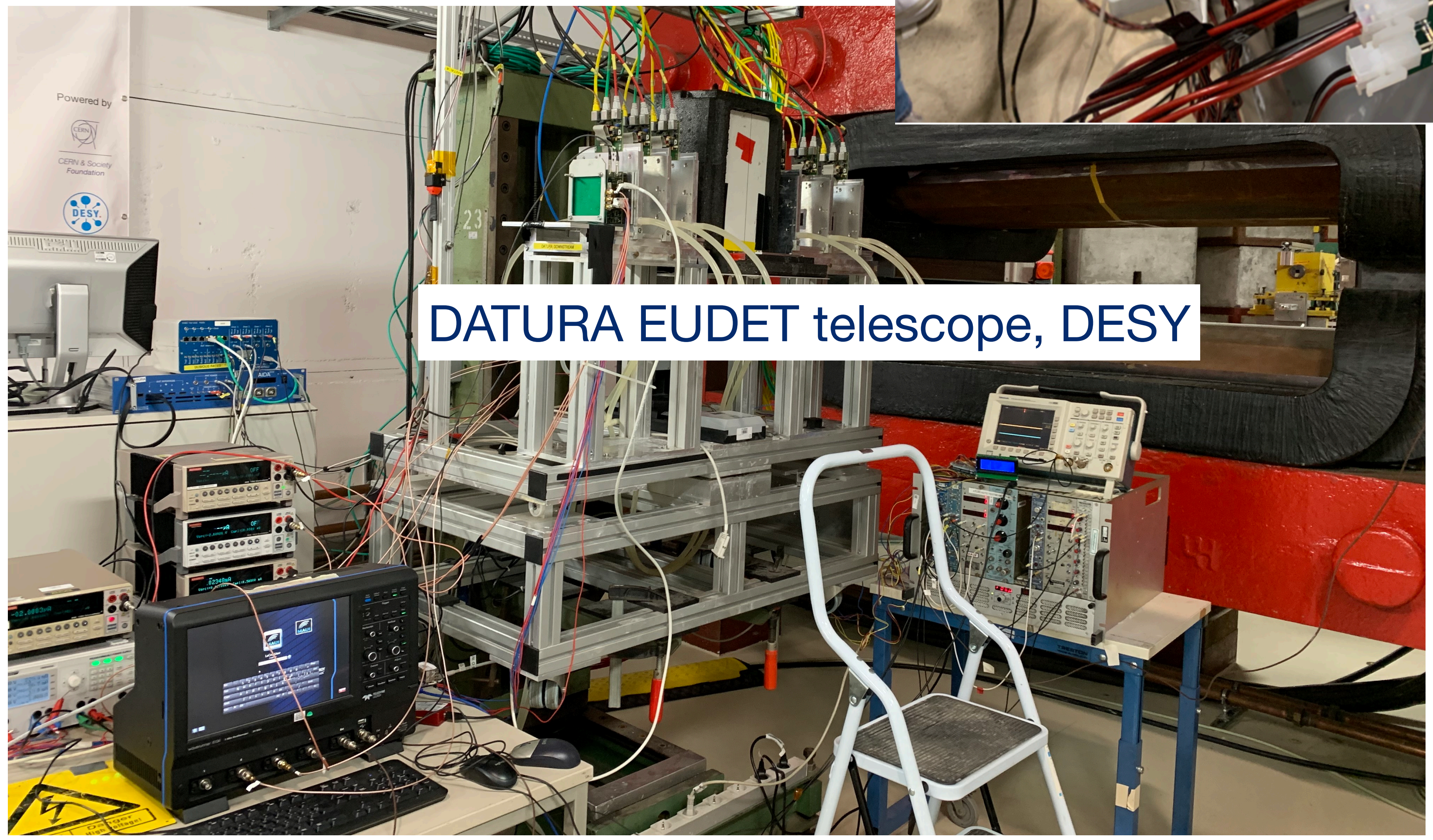
All sensors irradiated with reactor neutrons at JSI and annealed for 80 mins @ 60°C

Test Beam setup

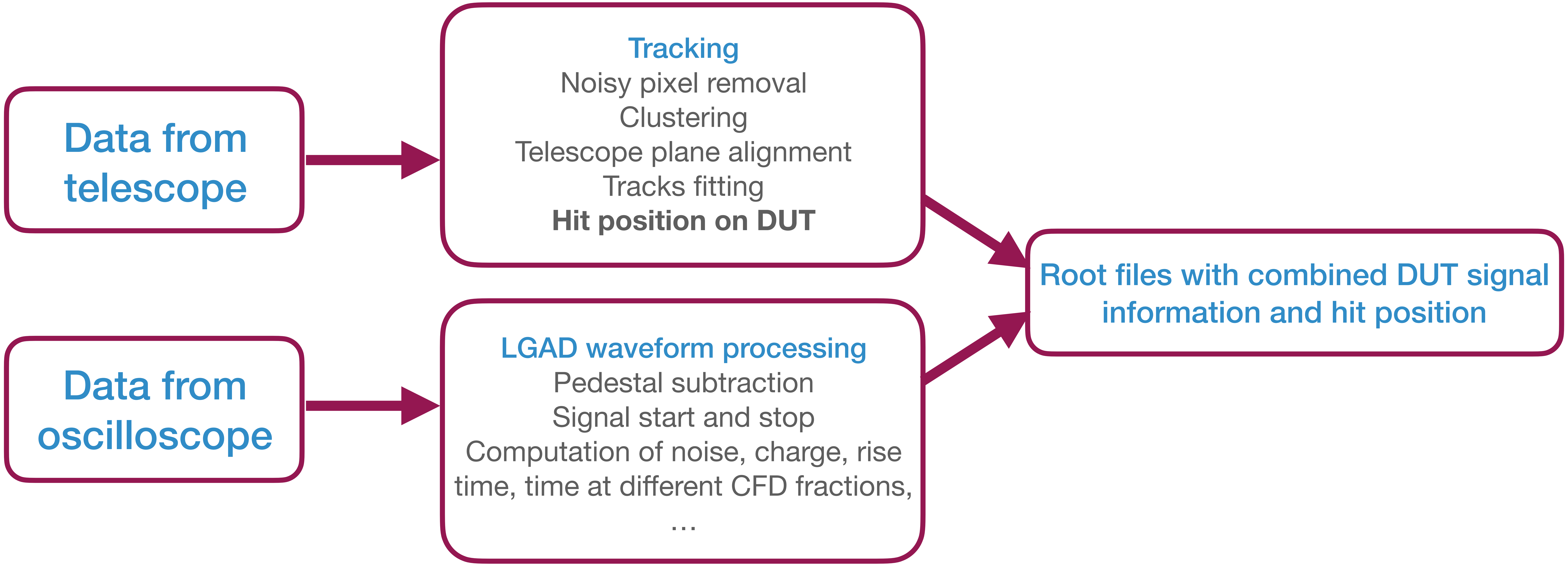
- Sensors:
  DESY: 12 sensors tested (5 GeV electrons)
  CERN: 10 sensors tested (120 GeV pions)
  Oscilloscope for waveform readout
- Tracking with 6 telescope planes:
  DESY: DATURA EUDET telescope with MIMOSA chips
  + FEi4 (trigger/ROI)
  CERN: MALTA telescope with MALTA chips
- Time reference:
  DESY: SiPM (resolution of ~66ps)
  CERN: Unirradiated LGAD (resolution of ~35ps)
- Cooling:
  DESY: Cold box with dry ice, 2 PT100 sensors for temperature monitoring
  CERN: Cold box with climate chamber keeps temperature at -20 C^{o}
- 2 Devices Under Tests (DUT) simultaneously
- Sensors were studied at the safe from SEB voltages




MALTA Telescope, CERN SPS


DATURA EUDET telescope, DESY

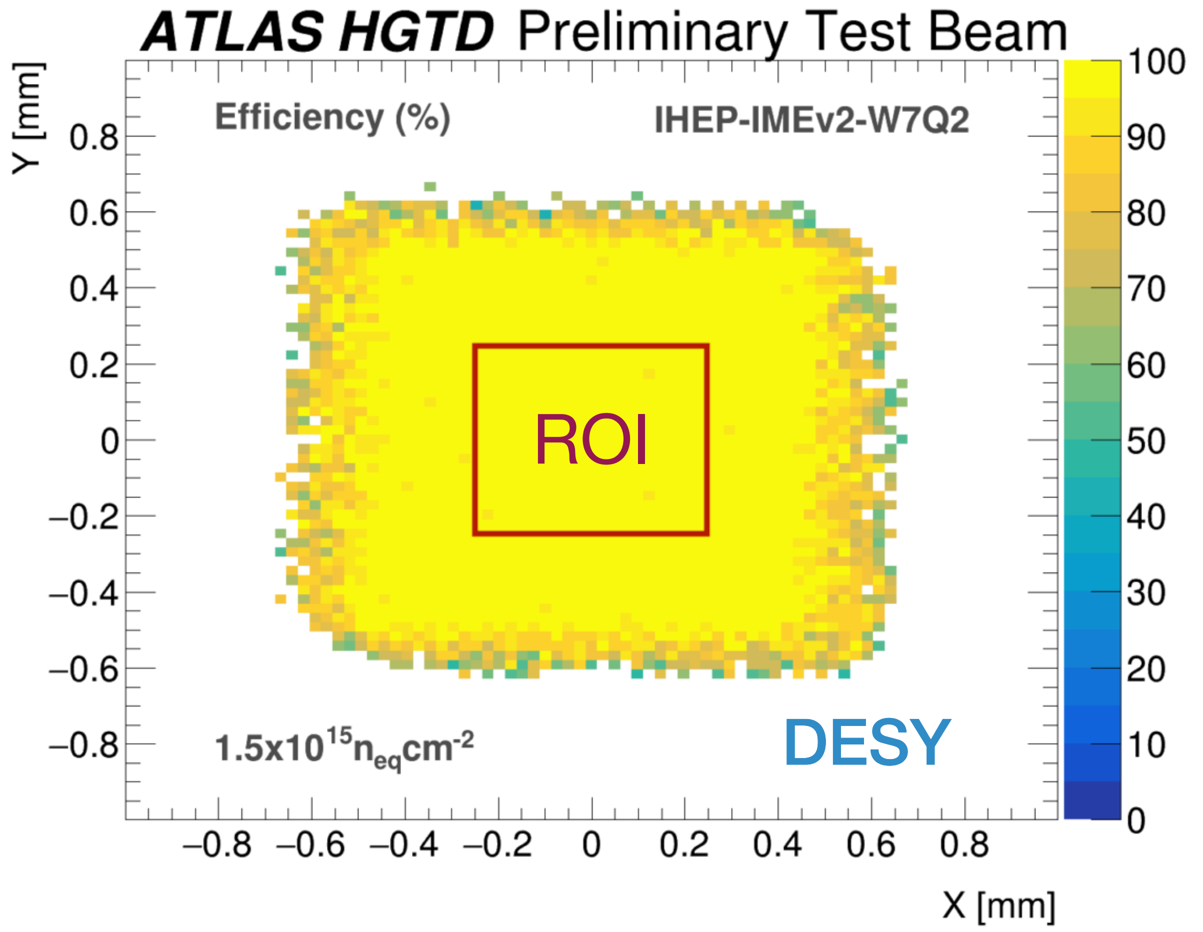
Data processing workflow

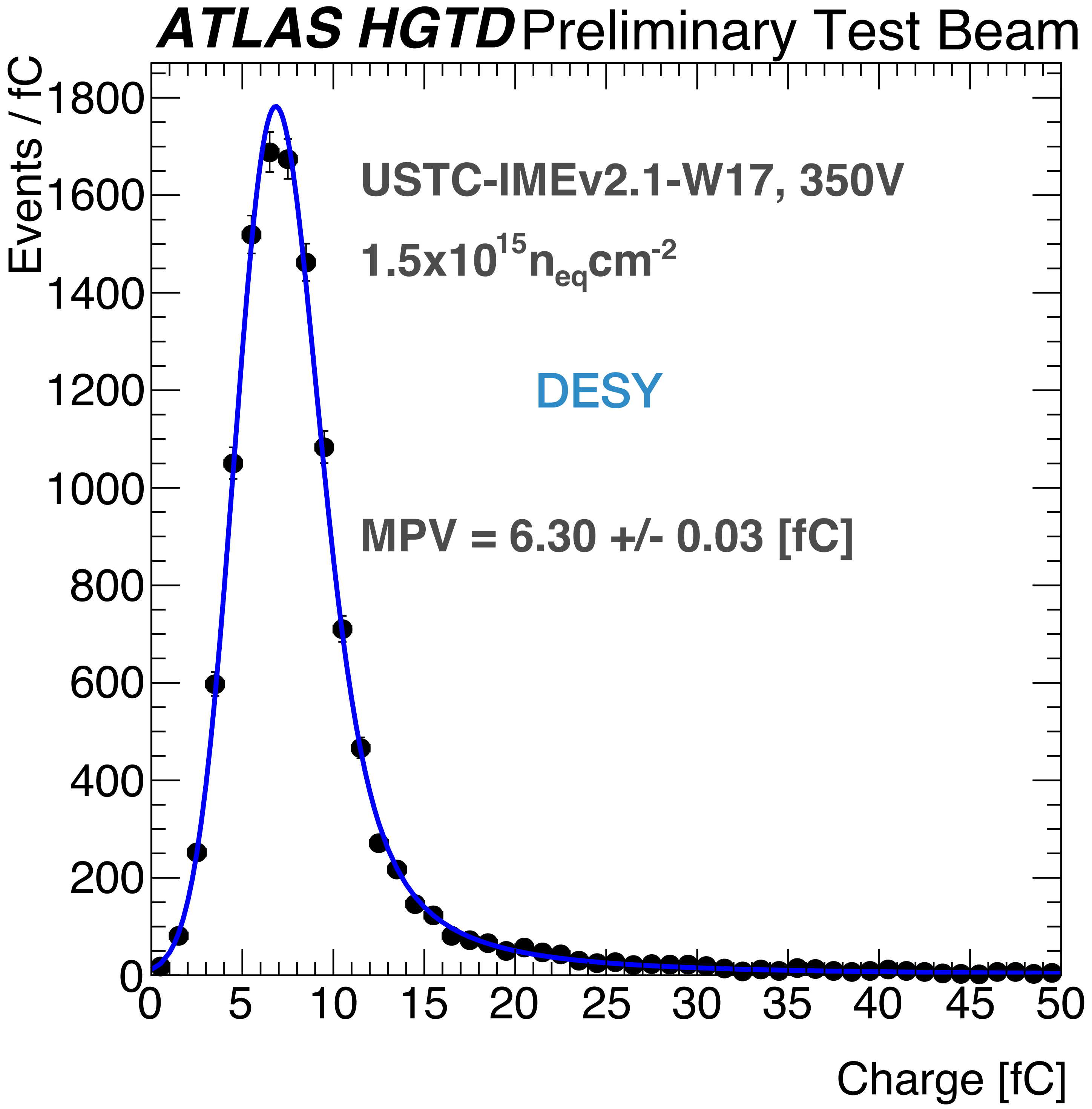


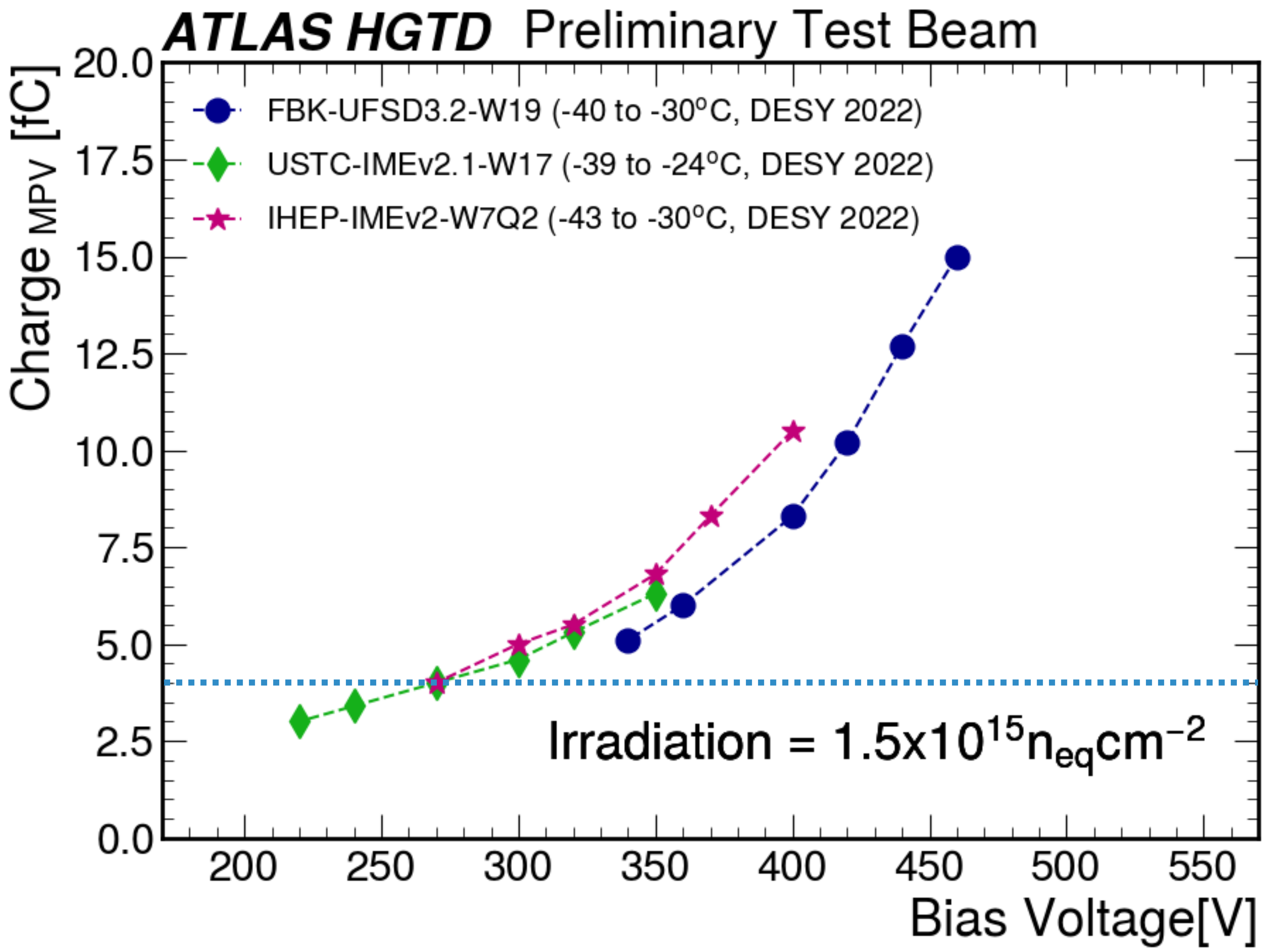
Results: charge collection

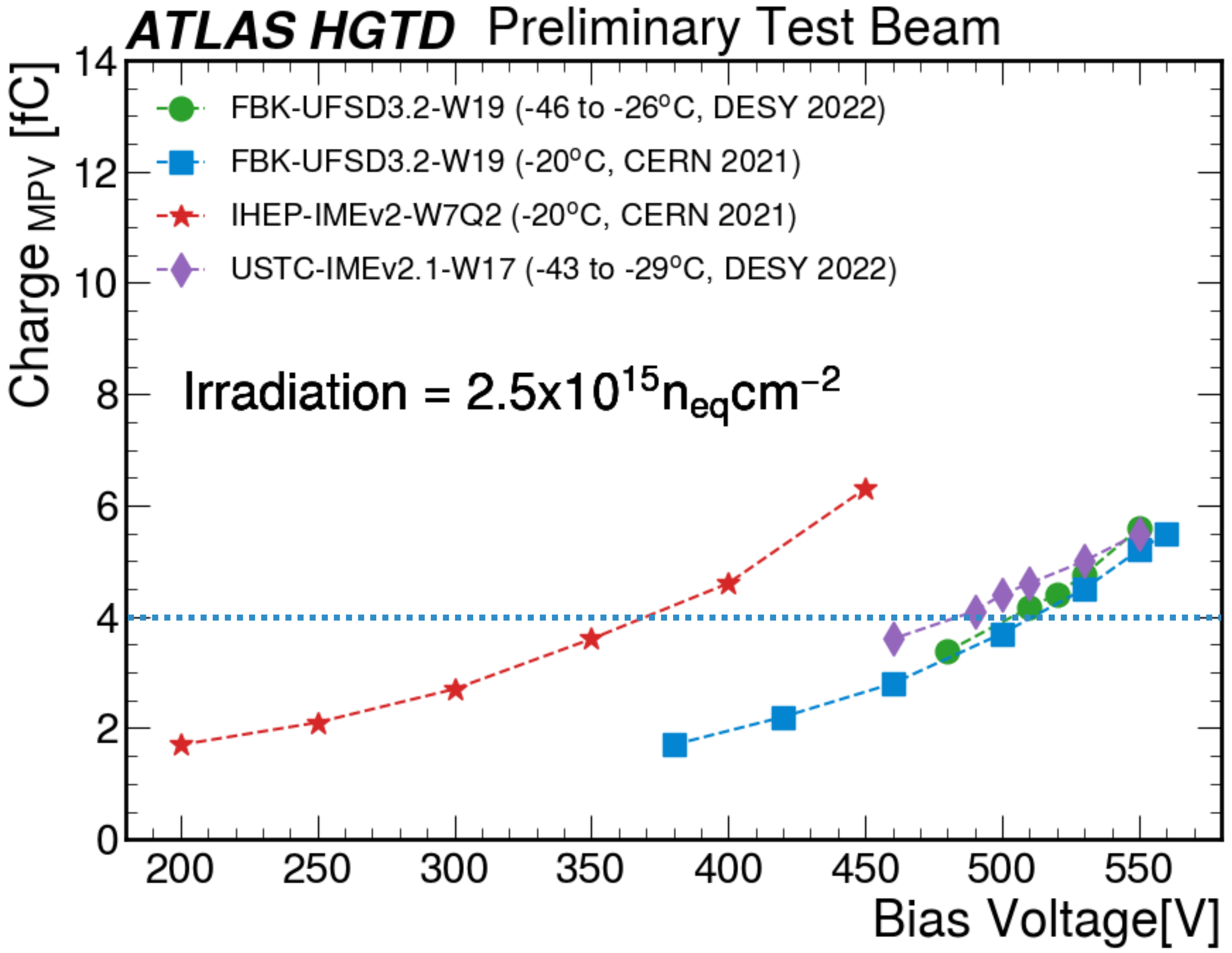
Charge

- Fit charge distribution in the ROI with convolution of Landau & Gaus
- Extract the MPV to get the Charge value



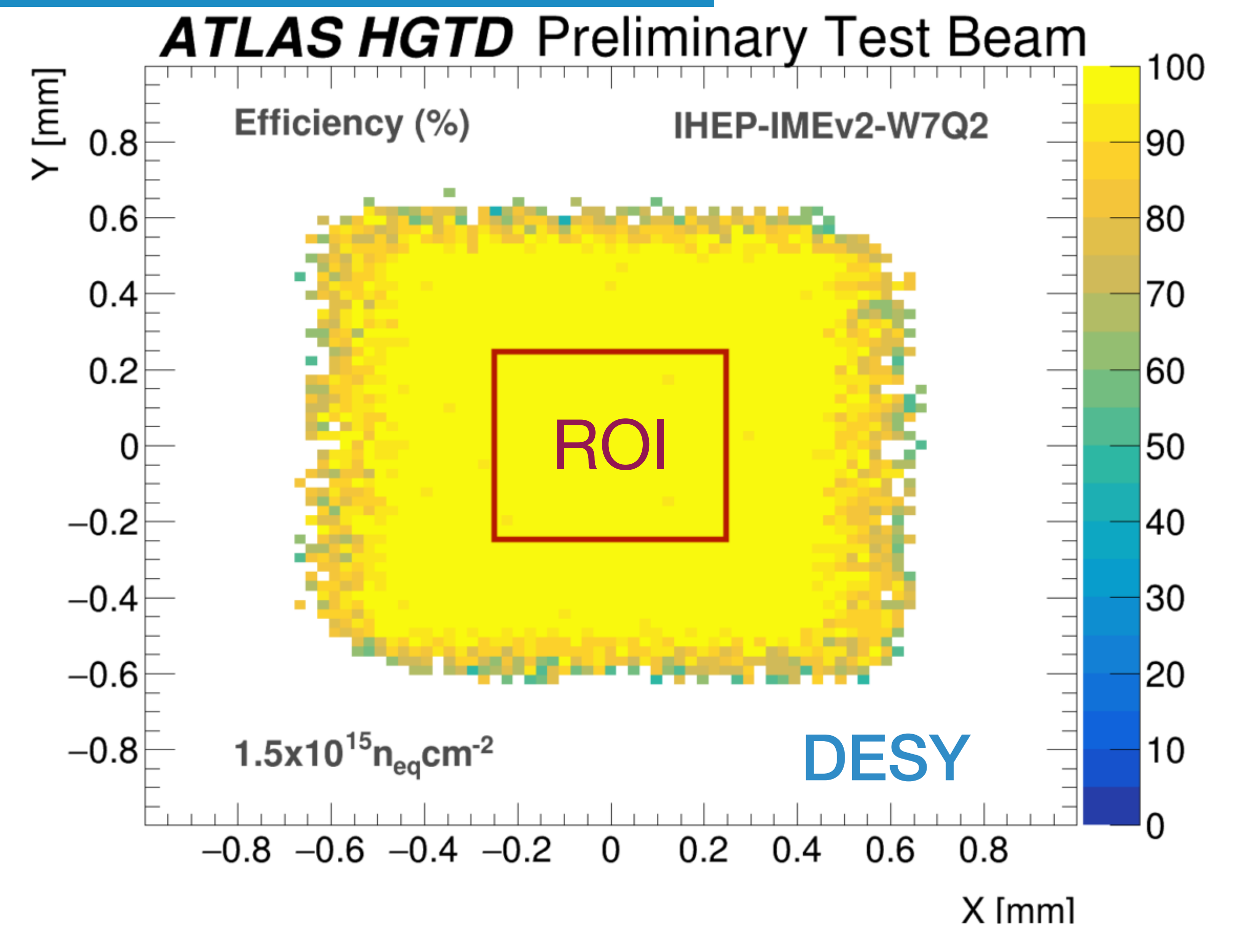


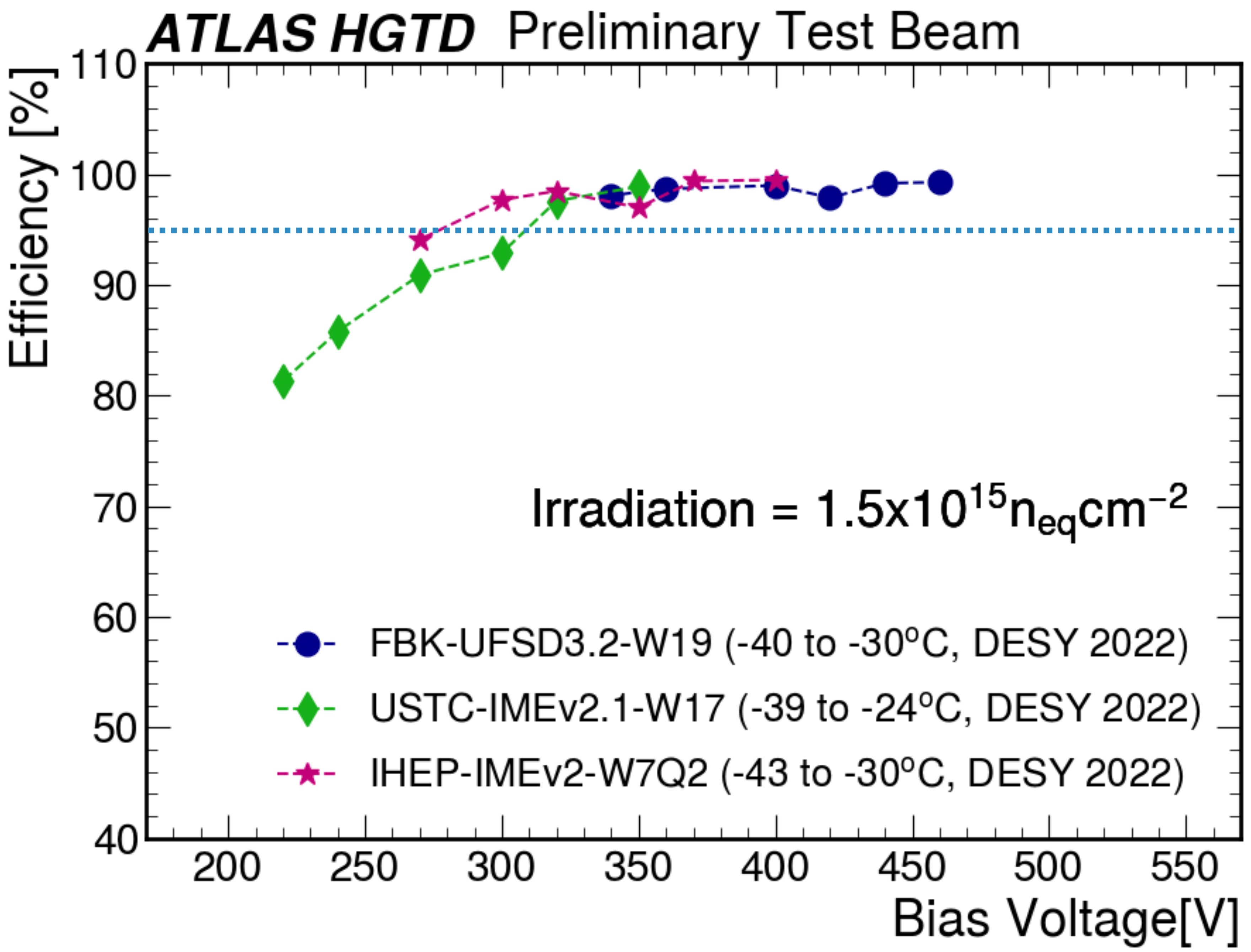


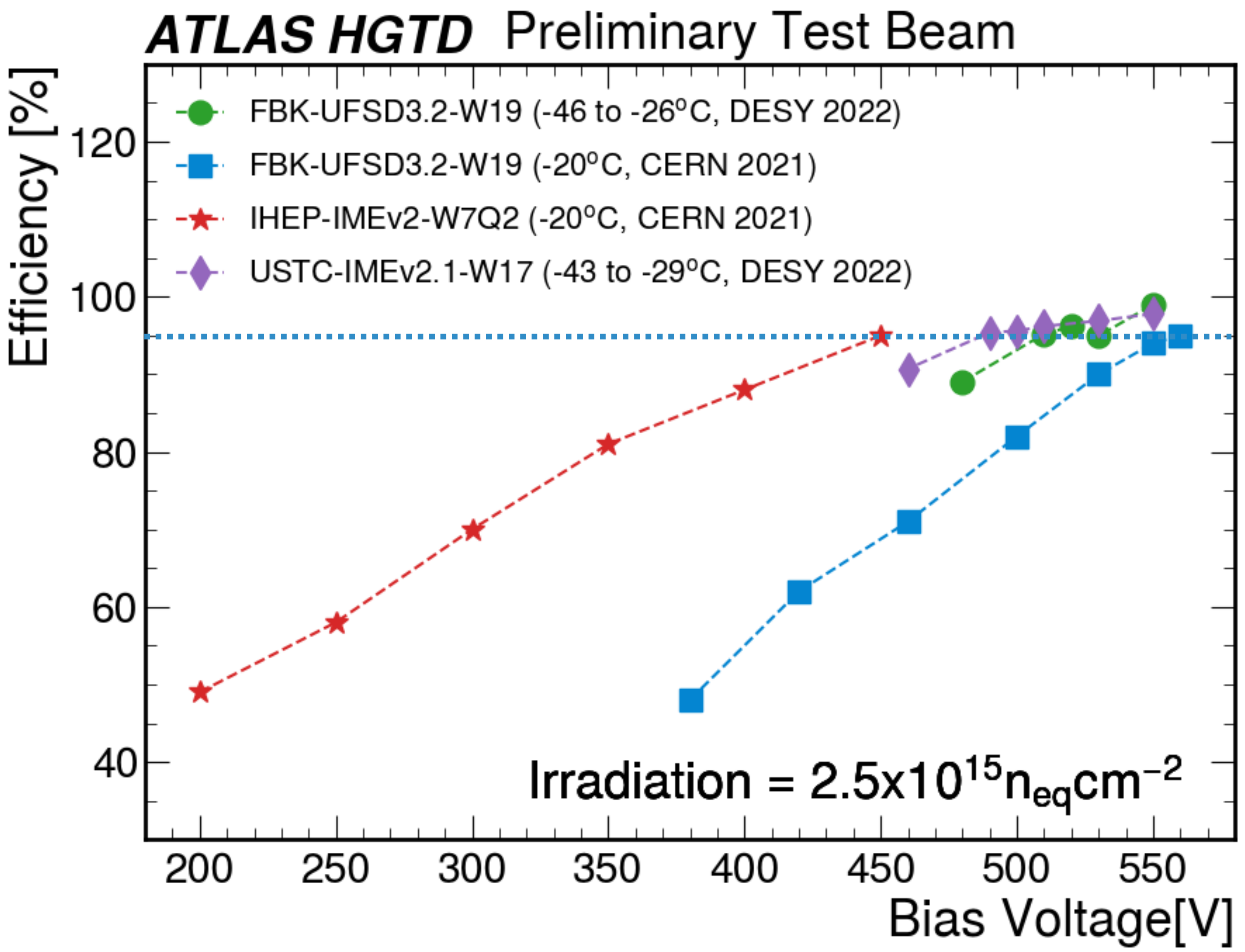


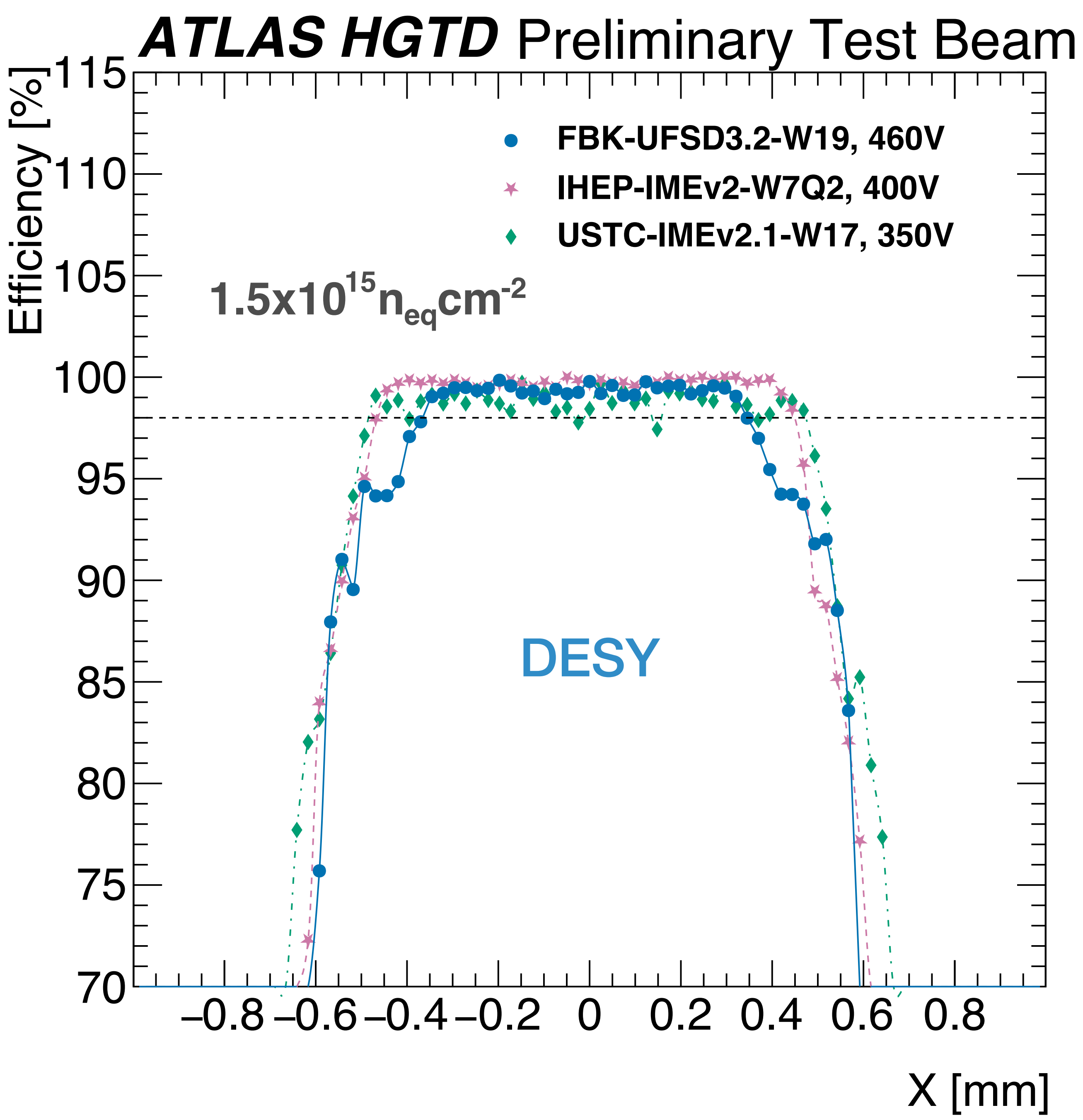
Results: efficiency

Efficiency $\varepsilon = \dfrac{\#\text{hits in DUT passing the charge threshold } (Q > 2fC)}{\#\text{projected tracks in the DUT}}$





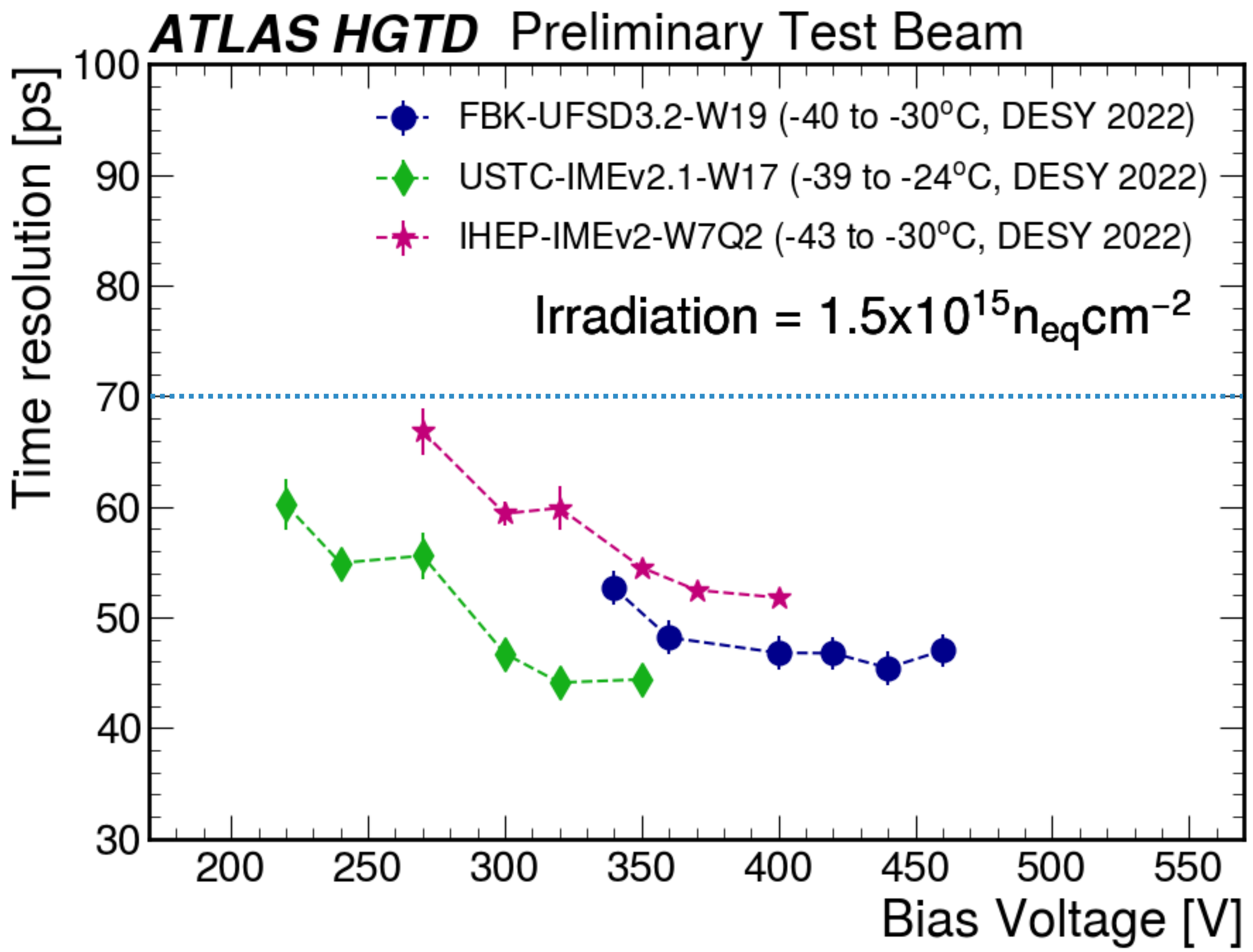


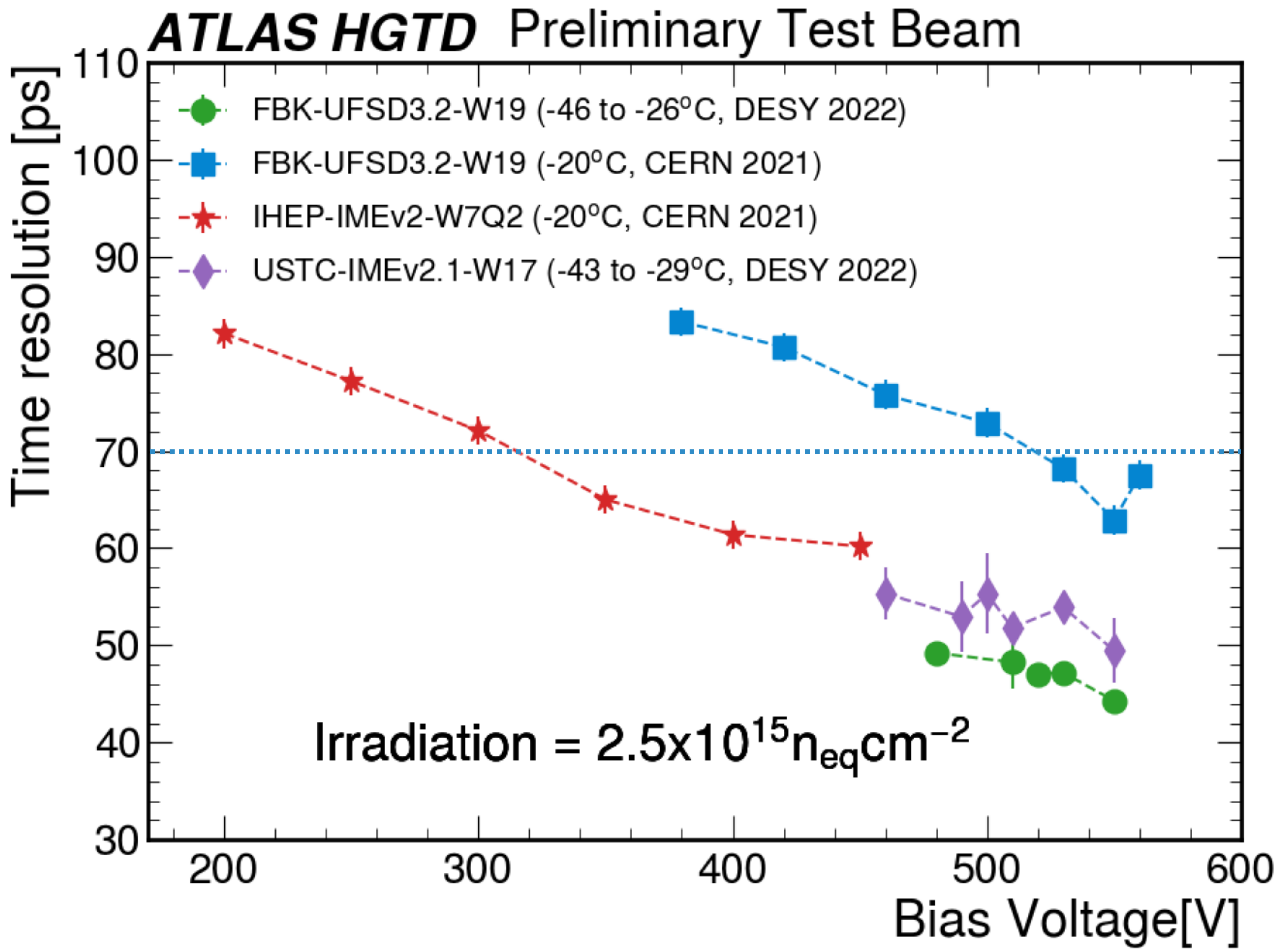


Results: time resolution

Time resolution is computed from time difference distribution between the sensor and/or the SiPM or another sensor σ_{ij}

Having 3 devices, the resolution of each one is calculated as $\sigma_i = \sqrt{\frac{\sigma_{ij}^2 + \sigma_{ik}^2 - \sigma_{jk}^2}{2}}$





Summary

Presented results have been essential to validate various sensor designs:

- Single Event Burnout resolved at voltages required to meet HGTD specifications
- Qualified performance of latest generation of Carbon diffused LGADs at the highest irradiation:
    - Efficiency of all presented sensors is > 98% at $1.5\text{x}10^{15} n_{eq}$ / cm^2 and is > 95% at $2.5\text{x}10^{15} n_{eq}$ / cm^2 going up to ~99% for some sensors
    - Charge of all presented sensors is > 5 fC at $1.5\text{x}10^{15} n_{eq}$ / cm^2 and $2.5\text{x}10^{15} n_{eq}$ / cm^2
    - Time resolution is lower than 60 ps for all the tested sensors at $1.5\text{x}10^{15} n_{eq}$ / cm^2 and $2.5\text{x}10^{15} n_{eq}$ / cm^2 and can get < 50 ps for some sensors

Test Beam campaigns studying the combined performance of LGAD + ALTIROC have started this summer

Thank you for your attention!