Production status report: Wafer irradiation tests (JSI)

HGTD SENSOR MEETING, 2025

Overview IHEP-IME

	Previous status	Change	New status
Wafers received	0	17	17
Wafers irradiated			
Wafers tested			
Wafers accepted			
Wafers rejected			

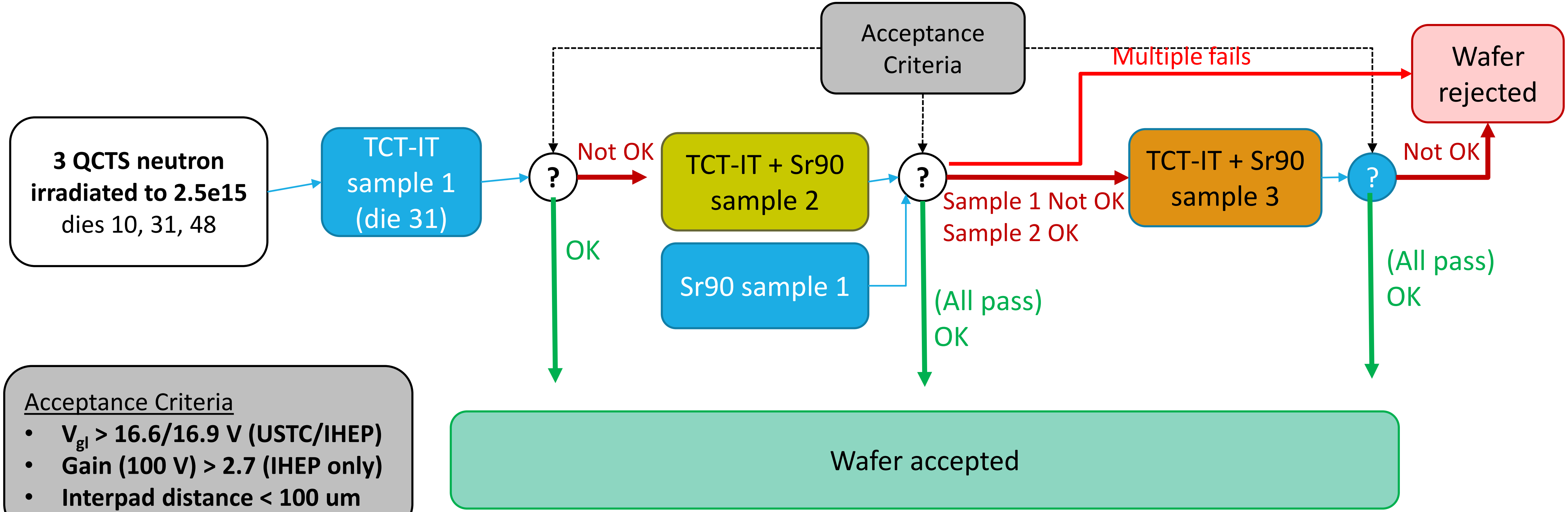
- Received IHEP QCTS from production pilot batch !
  - Batch no. 4
- Example QCTS ATLAS ID (wafer 2, die 5):
  - **20WS2104000205**
  - ATLAS ID generation tool in internal database

Overview USTC-IME

	Previous status	Change	New status
Wafers received			
Wafers irradiated			
Wafers tested			
Wafers accepted			
Wafers rejected			

BACKUP

Wafer Acceptance/Rejection process



3 QCTS neutron irradiated to 2.5e15
dies 10, 31, 48

TCT-IT sample 1 (die 31)

?

Not OK

OK

TCT-IT + Sr90 sample 2

Sr90 sample 1

Acceptance Criteria

?

Multiple fails

Sample 1 Not OK
Sample 2 OK

(All pass) OK

TCT-IT + Sr90 sample 3

?

Not OK

(All pass) OK

Wafer rejected

Wafer accepted

<u>Acceptance Criteria</u>

- **V_{gl} > 16.6/16.9 V (USTC/IHEP)**
- **Gain (100 V) > 2.7 (IHEP only)**
- **Interpad distance < 100 um**

Sensor IT specifications

From HGTD Invitation to Tender – Technical Specification:

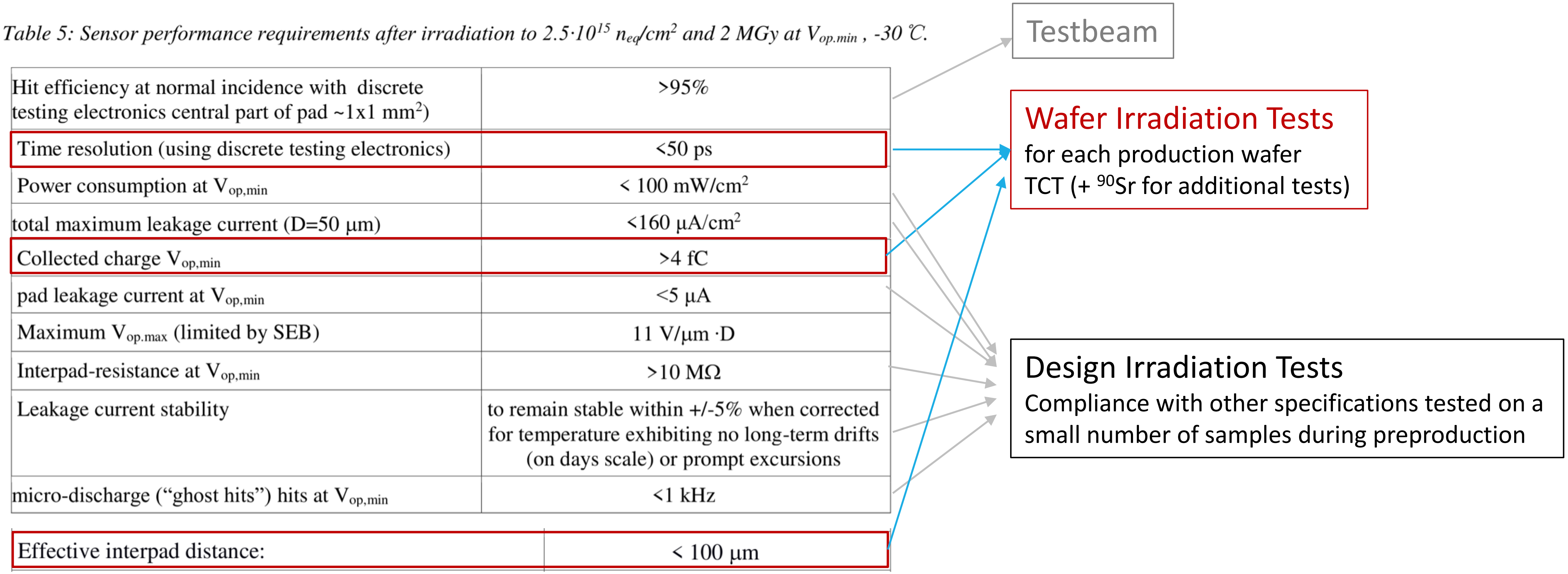


Table 5: Sensor performance requirements after irradiation to $2.5{\cdot}10^{15}$ n_{eq}/cm^2 and 2 MGy at $V_{op.min}$, -30 ℃.

Hit efficiency at normal incidence with discrete testing electronics central part of pad ~1x1 mm^2)	>95%
Time resolution (using discrete testing electronics)	<50 ps
Power consumption at $V_{op,min}$	< 100 mW/cm^2
total maximum leakage current (D=50 μm)	<160 $\mu A/cm^2$
Collected charge $V_{op,min}$	>4 fC
pad leakage current at $V_{op,min}$	<5 μA
Maximum $V_{op.max}$ (limited by SEB)	11 V/μm ·D
Interpad-resistance at $V_{op,min}$	>10 MΩ
Leakage current stability	to remain stable within +/-5% when corrected for temperature exhibiting no long-term drifts (on days scale) or prompt excursions
micro-discharge ("ghost hits") hits at $V_{op,min}$	<1 kHz

Effective interpad distance:	< 100 μm

Testbeam

Wafer Irradiation Tests

for each production wafer

TCT (+ ^{90}Sr for additional tests)

Design Irradiation Tests

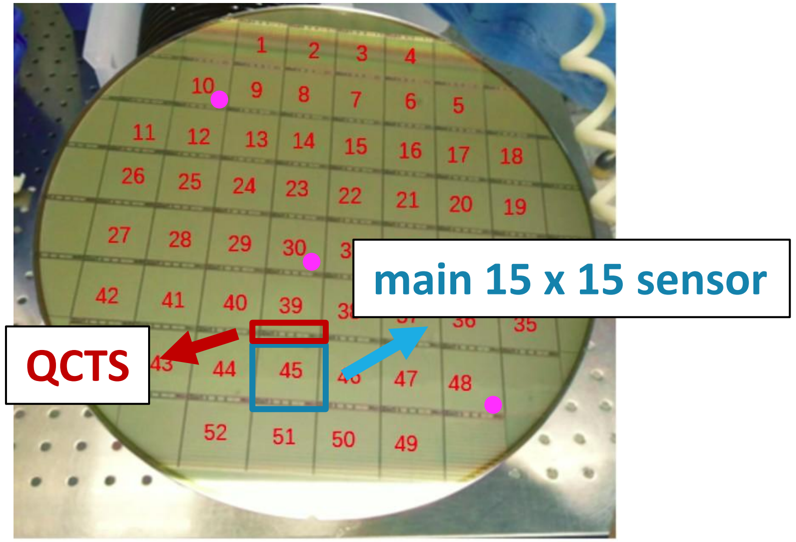
Compliance with other specifications tested on a small number of samples during preproduction

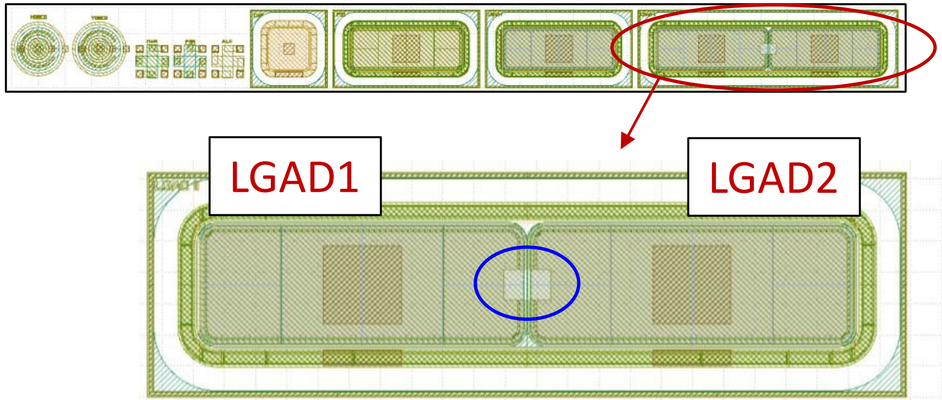
Sensor End of Life (EoL) fluence **2.5e15 n_{eq}/cm^2** and TID **1.3 MGy**

IT test structure and studied samples

- Irradiation Tests done on Quality Control Test Structure (QCTS) using 1 × 2 LGAD
  - QCTS adjacent to each main sensor on wafer
  - Channel size 2.1 mm × 0.8 mm (geometric capacitance same as pad on the main sensor)
  - Same device measured with different methods to minimize systematics
  - In production irradiate dies 10, 30 and 48 [•]
    - Fluence 2.5e15 neq/cm2, annealing 80 min at 60 °C

- Electrical connections of 1 × 2 LGAD :
  - **CV/IV:** one channel to Signal, one channel + guard ring to Guard
  - **Sr90:** one channel to Signal, one channel + guard ring to Guard
  - **TCT:** both channels to Signal, guard ring floating

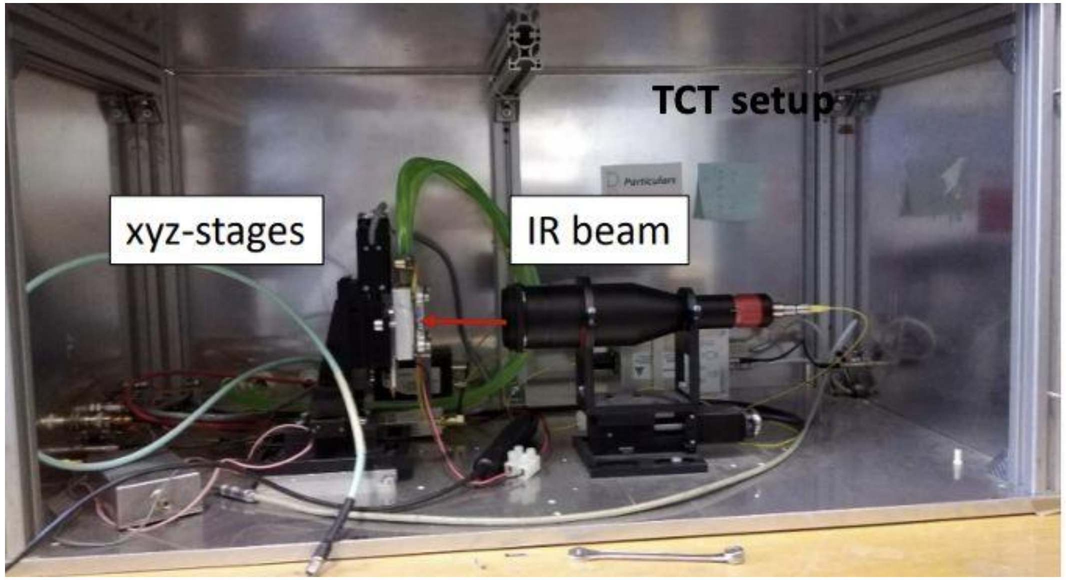


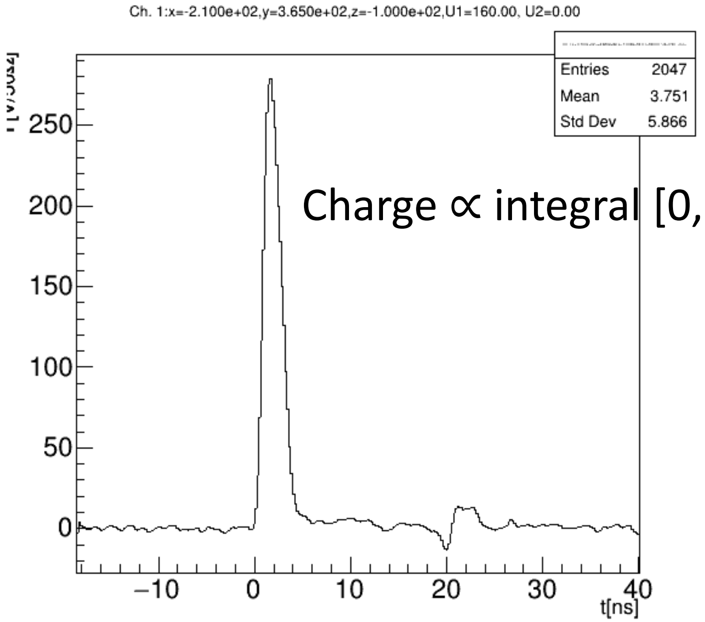


Optical window in the interpad region

Irradiation Test – TCT setup

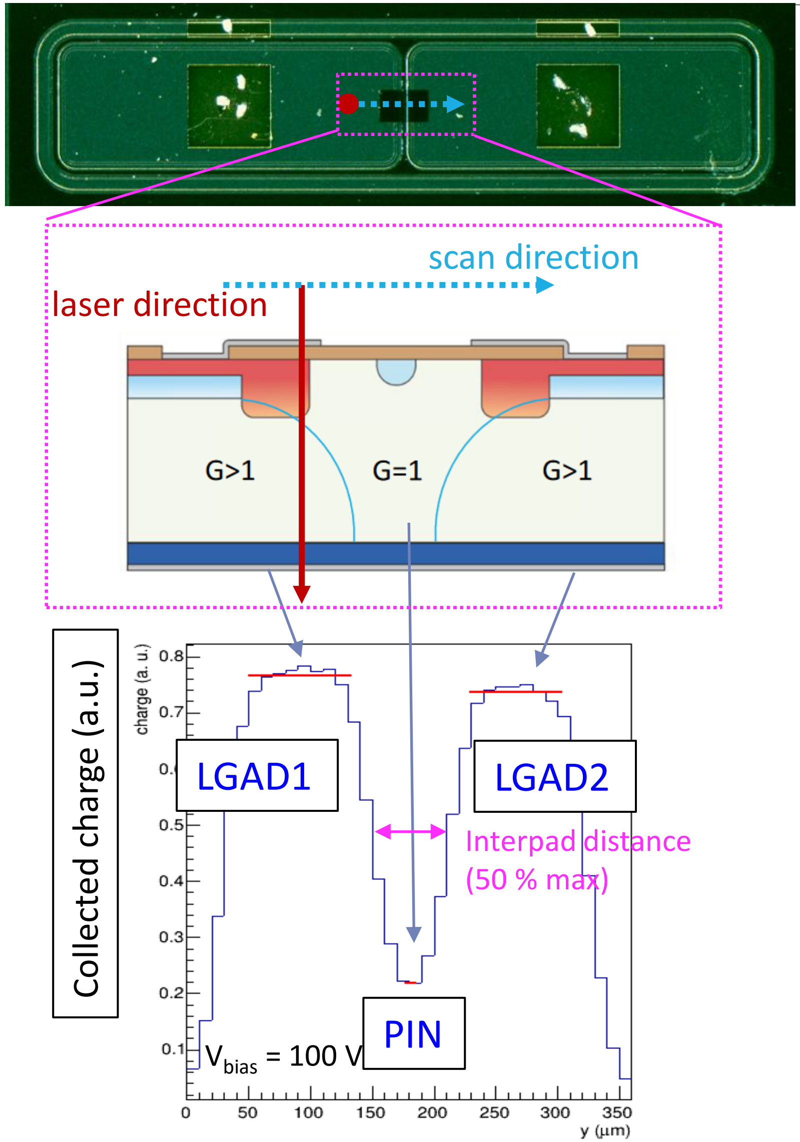
- Particulars TCT setup (**infrared light 1064 nm** – MIP-like charge distribution, pulse duration 600 ps, repetition rate 1 kHz)
- Beam spot FWHM 10 µm, positioning stages wit sub-µm resolution
- 2.5 GHz Particulars amplifier and DRS4 readout
- Beam energy monitor to normalize injected charge within individual run
- Active temperature control to **+20 °C**
- Collected charge proportional to signal integral [0, 3 ns]



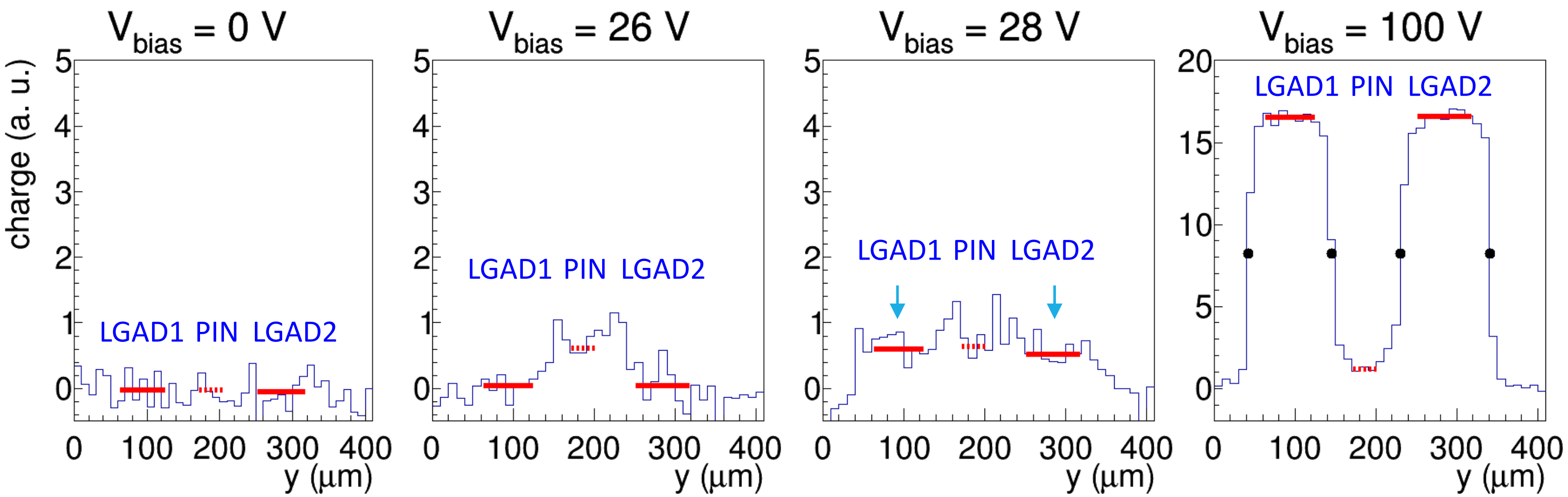


Charge ∝ integral [0, 3 ns]

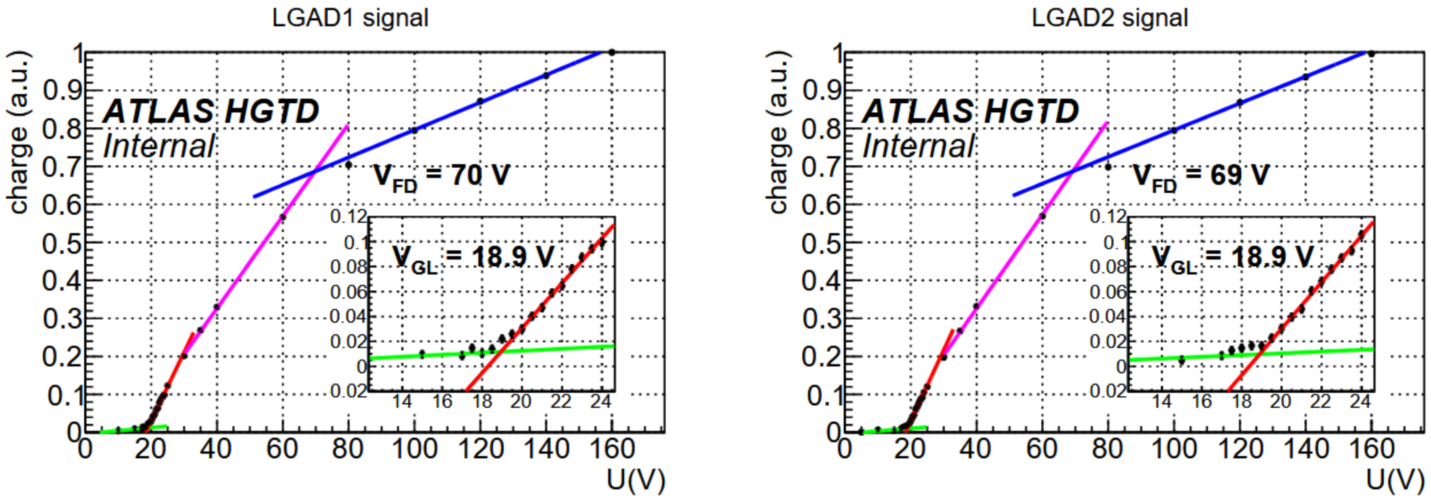
IT-QC: TCT test method



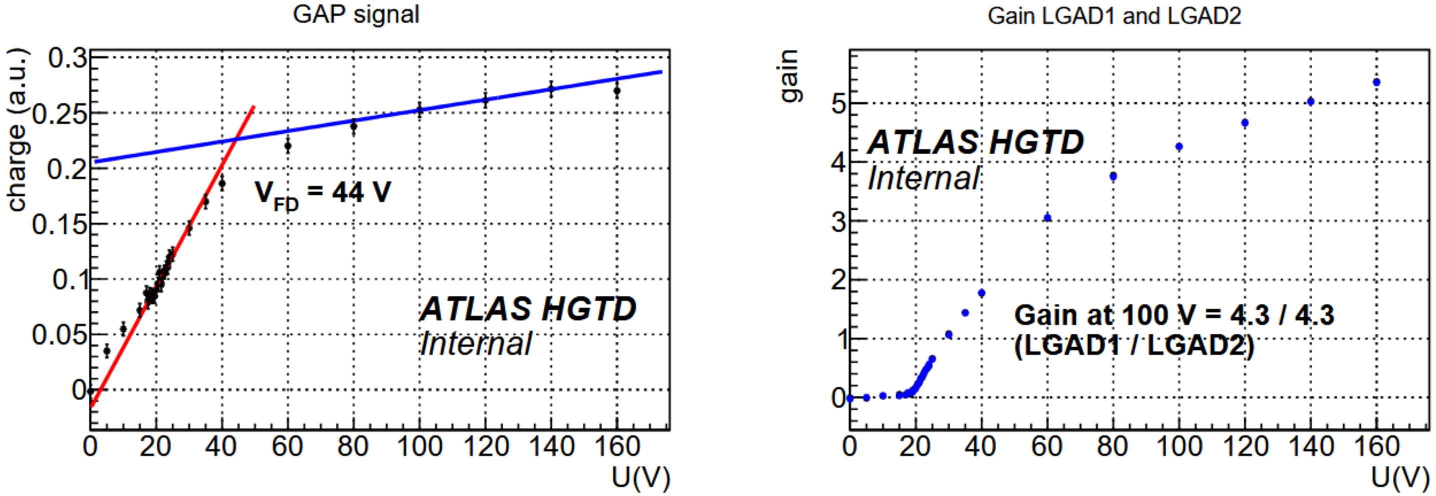
- Top-TCT in the interpad window using focused infrared laser (MIP-like charge distribution)
  - Access the region with gain (LGAD) and region without gain (“PIN”)
- Collected charge as a function of voltage in LGADs and PIN
  - **V_{gl}** is at the onset of LGAD signals
  - **Gain (V)** = Charge (LGAD) / Charge (PIN) … Gain (100 V) as figure of merit
  - **Interpad distance**
- Semi-automated upload of analyzed data to database (Grafana)
- Qualification Task Iskra Velkovska (JSI Ljubljana) – Report 1, Report 2



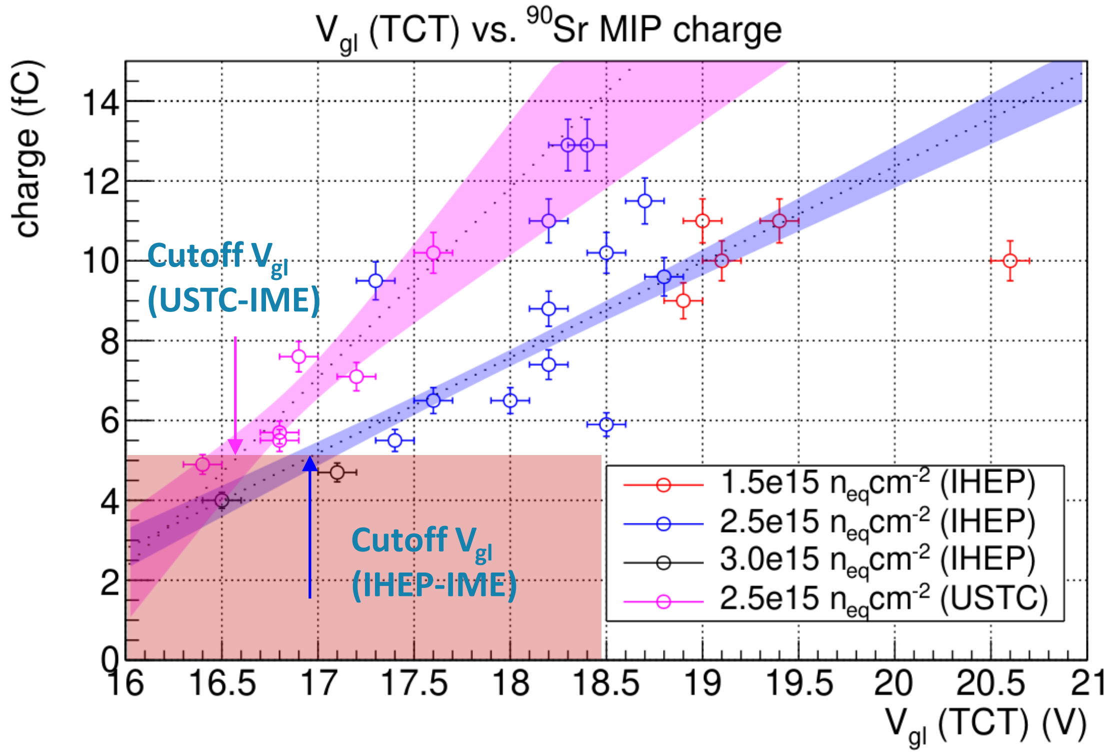
IT-QC: TCT parameter extraction



(a)

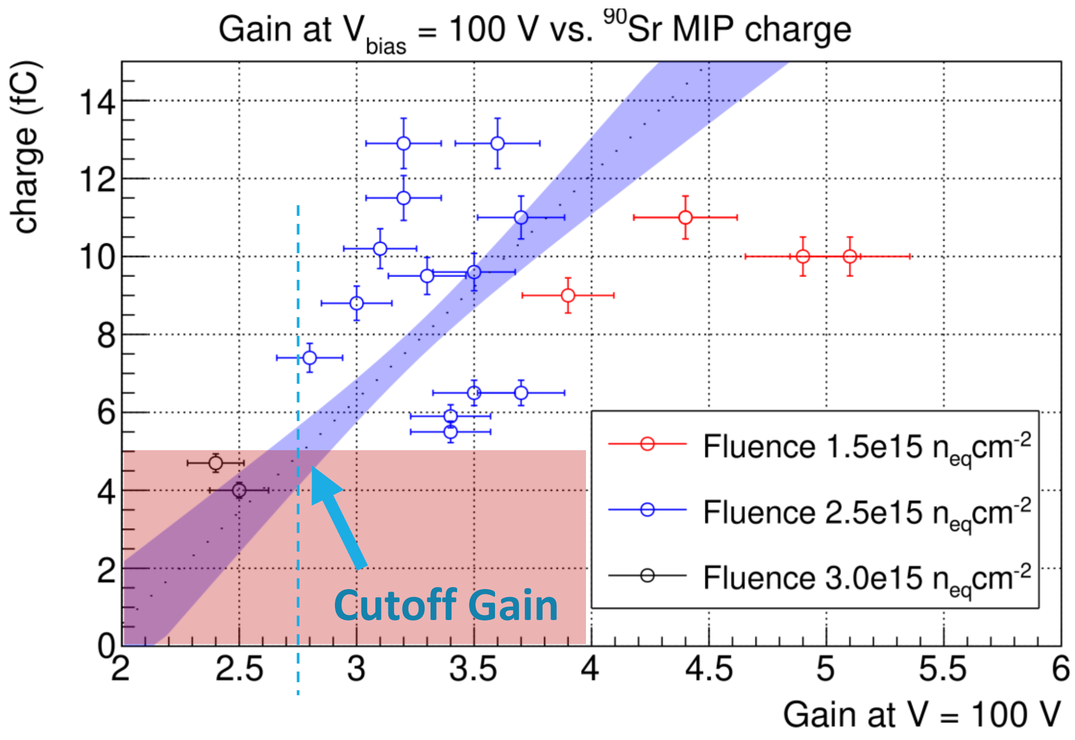


Correlation V_{gl}(TCT) vs. Sr90 charge (preproduction)



- Correlation between V_{gl} **from TCT** and **collected charge with ^{90}Sr** used to derive **Acceptance Criteria**
- **Cutoff V_{gl} corresponding to 5 fC (HGTD spec) is**
  - **USTC-IME: 16.6 V**
  - **IHEP-IME: 16.9 V**

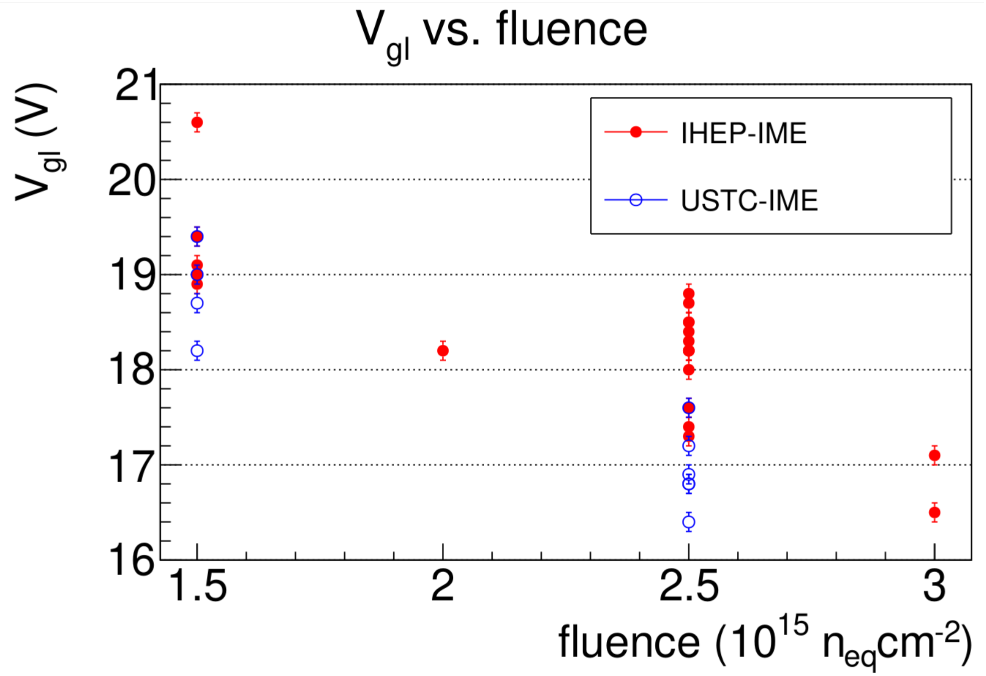
Correlation Gain(TCT) vs. Sr90 charge (IHEP-IME only)

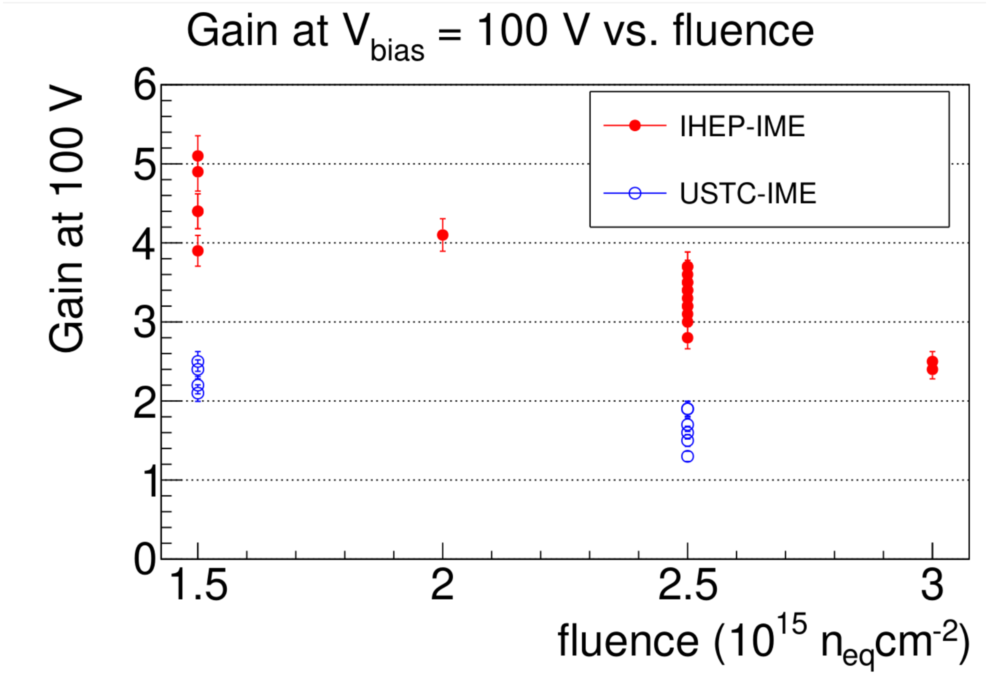


IHEP-IME only

- **Cutoff Gain(100 V) corresponding to 5 fC (HGTD spec) is 2.7 (IHEP-IME)**
- Not applicable for USTC-IME, since gain is smaller and uncertainty is large

IT-QC: TCT results (preproduction)

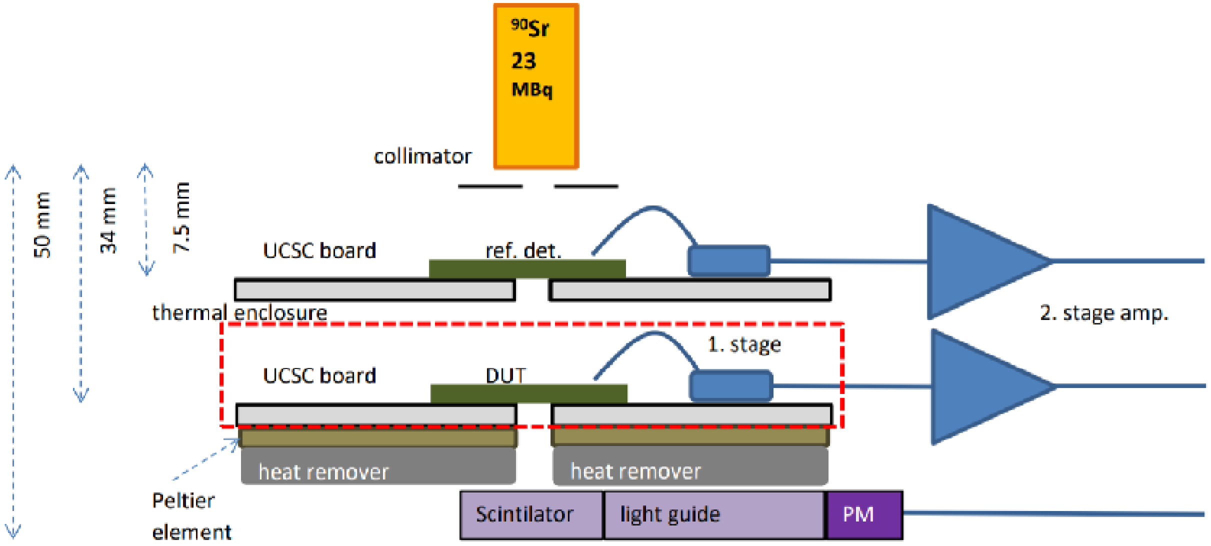




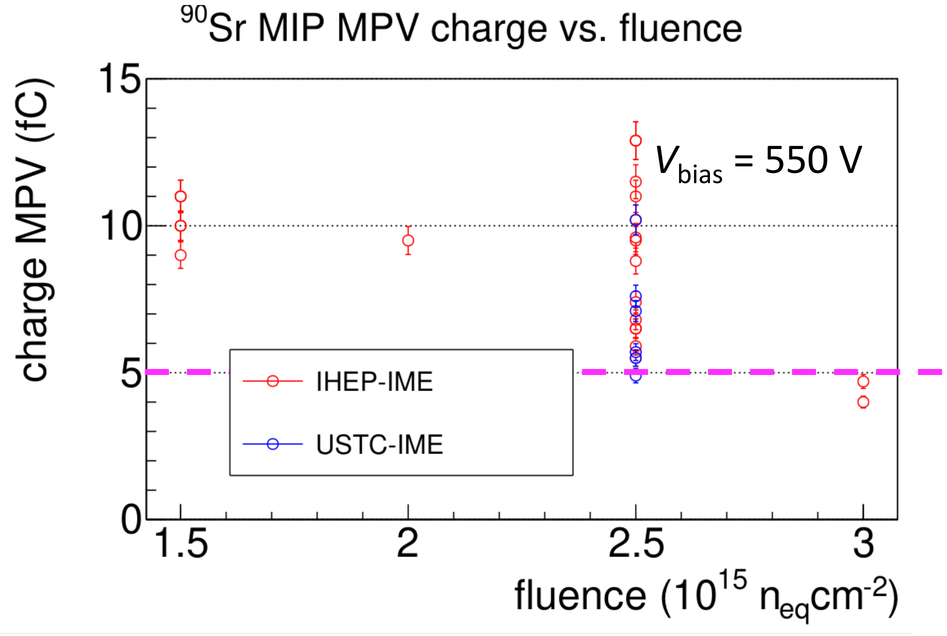
- Preproduction TCT results (V_{gl} and Gain (100 V)) as a function of fluence
  - 29 IHEP-IME wafers, 5 USTC-IME wafers
  - Results slightly different between two designs (Gain (100 V)) not very sensitive on fluence in USTC-IME)
- These results were correlated with ^{90}Sr measurements to derive **Acceptance Criteria**

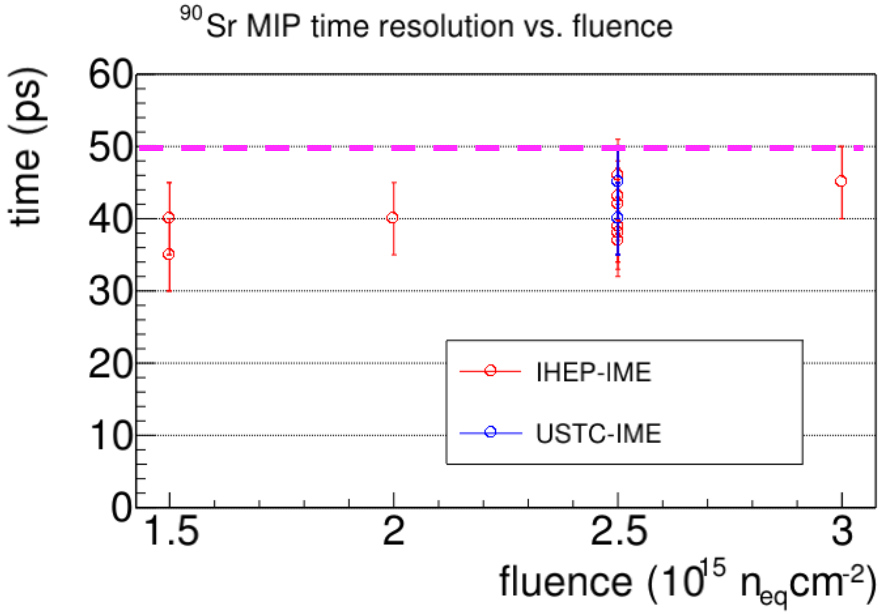
Sr90 measurements

- Sr90 Charge collection/Time resolution measurement setup
  - Setup based on UCSC boards
  - Trigger on reference LGAD + PMT
  - DUT cooled to –30°C, not part of the trigger
  - Up to 2 measurements per day, relatively time consuming
  - In production will only be used for diagnostics of problematic wafers / occasional calibration
  - 5000 events per setting, geometric acceptance 10 %
- Deposited charge from 2 MeV beta electron is 20 % more than a MIP (conservative estimate)
  - 10 % more ionization
  - 10 % comes from more multiple scattering → wider charge cloud → less gain loss due to smaller E-field screening
  - **4 fC MIP specification corresponds to 5 fC charge in Sr90 measurements**



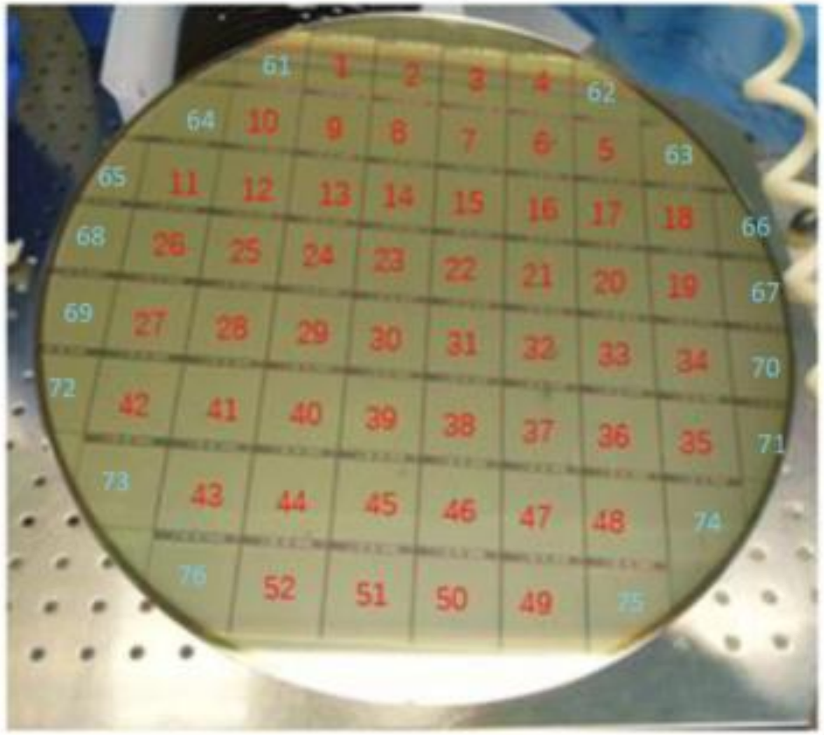
^{90}Sr charge collection results (preproduction)





- Preproduction samples characterized also with ^{90}Sr (MIP charge MPV and time resolution)
  - Beta electrons generate 20 % more charge than MIP, hence charge **threshold 5 fC**
- Significant scattering of results at EoL fluence – wafer to wafer and fluence (10 %) variations
- All samples after EoL fluence within the charge and time resolution specifications

Database sensor serial numbers



Wafers:

20WS 0 M P BB O NNNN

M=0 IHEP-IME, M=1 USTC-IME

P=0 preproduction P=1 production

BB=batch number

O=wafer orientation

NNNN = wafer number

Sensors:

20WS M T BB NNNN XY

M=1 IHEP-IME preproduction , M=2 IHEP-IME production, M=3 USTC-IME preproduction , M=4 USTC-IME production

T=0 Main Sensor ; T=1 QC-TS ; T=2 main partial sensor ; T=3 QC-TS of the partial sensor

BB=batch number (1 digit for batch number 0-Z – same as for wafer)

XY= position of the sensor on wafer (see plot in the left) – partial sensor should get XY>60

NNNN = wafer number