ATLAS ITk strip sensor quality assurance tests and results of ATLAS18 pre-production sensors

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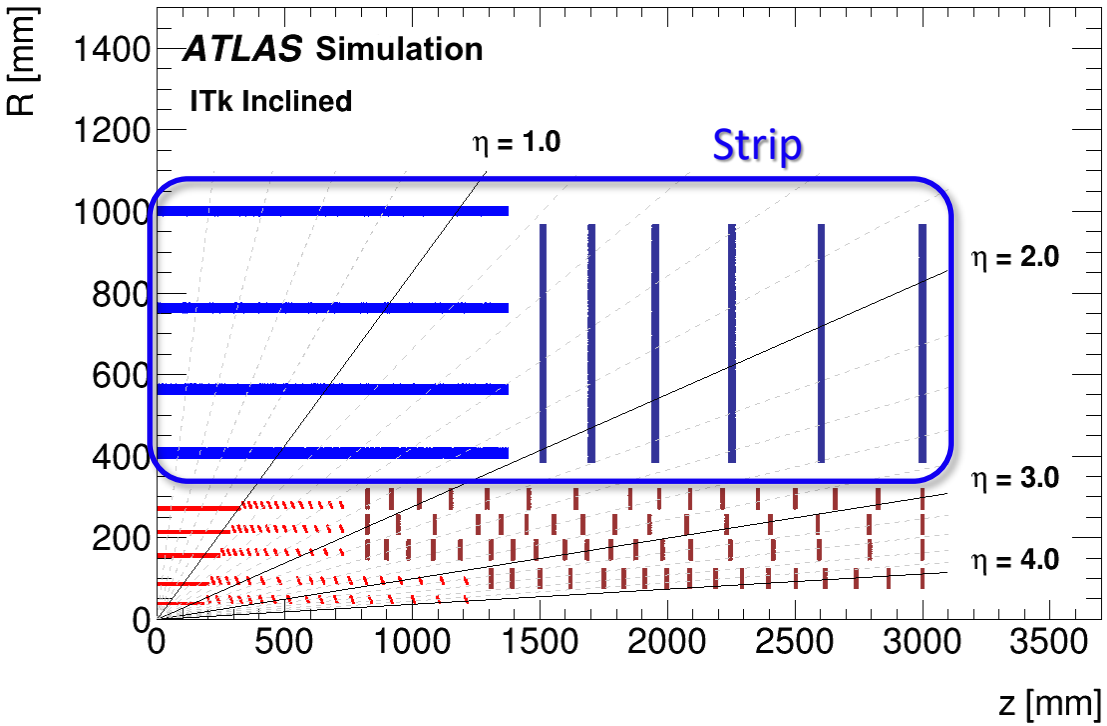
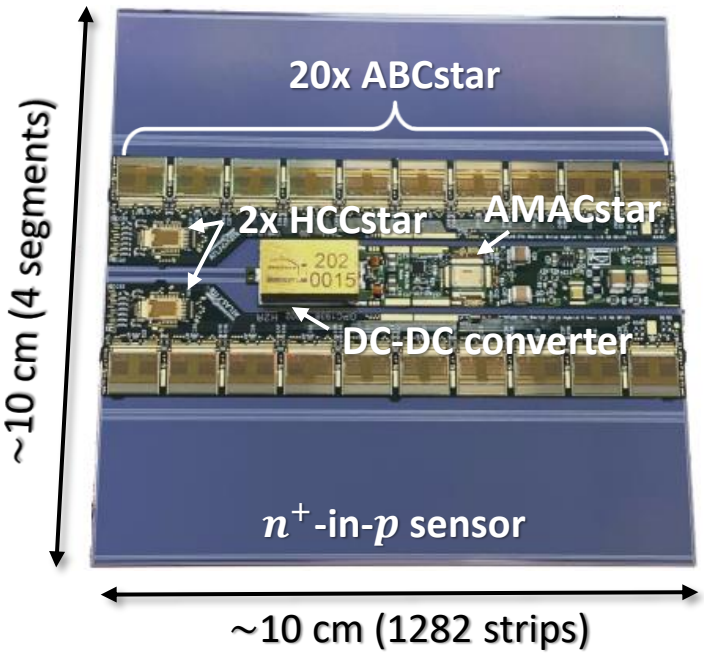
On behalf of the ATLAS ITk Strip Sensor Collaboration

ITk Strips



Short-strip module
(Inner two barrel layers)

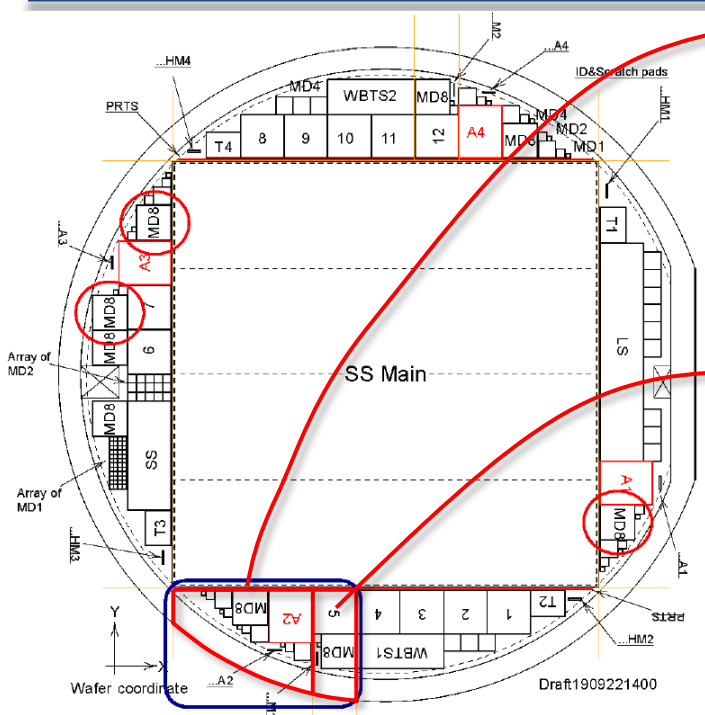


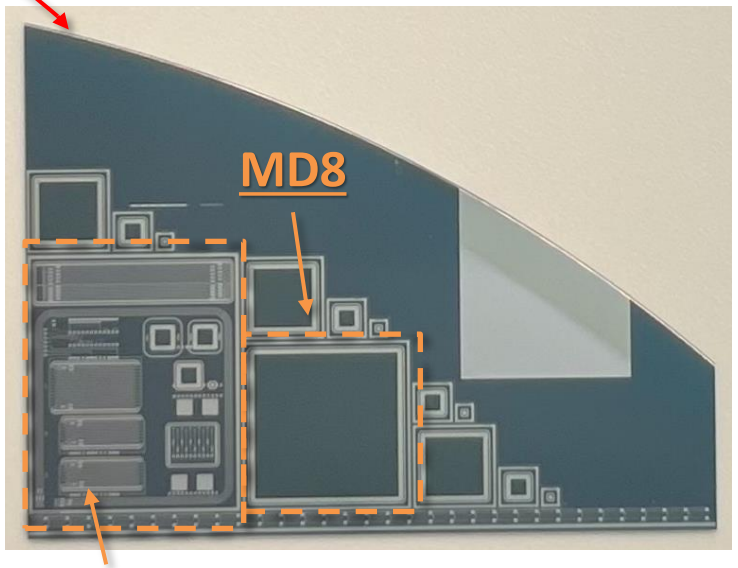
- ~18,000 sensors are needed to cover the entire volume
- Expected to receive ~10^{15} n_{eq}/cm^2 during HL-LHC operation

Monitoring performance of irradiated sensors during production is essential! (→Quality Assurance)

- Pre-production was carried out in 2020 to ensure final sensor quality as well as to establish QC/QA procedures

Strip sensor QA





[M. Ullán et al., NIM A 981 (2020) 164521]

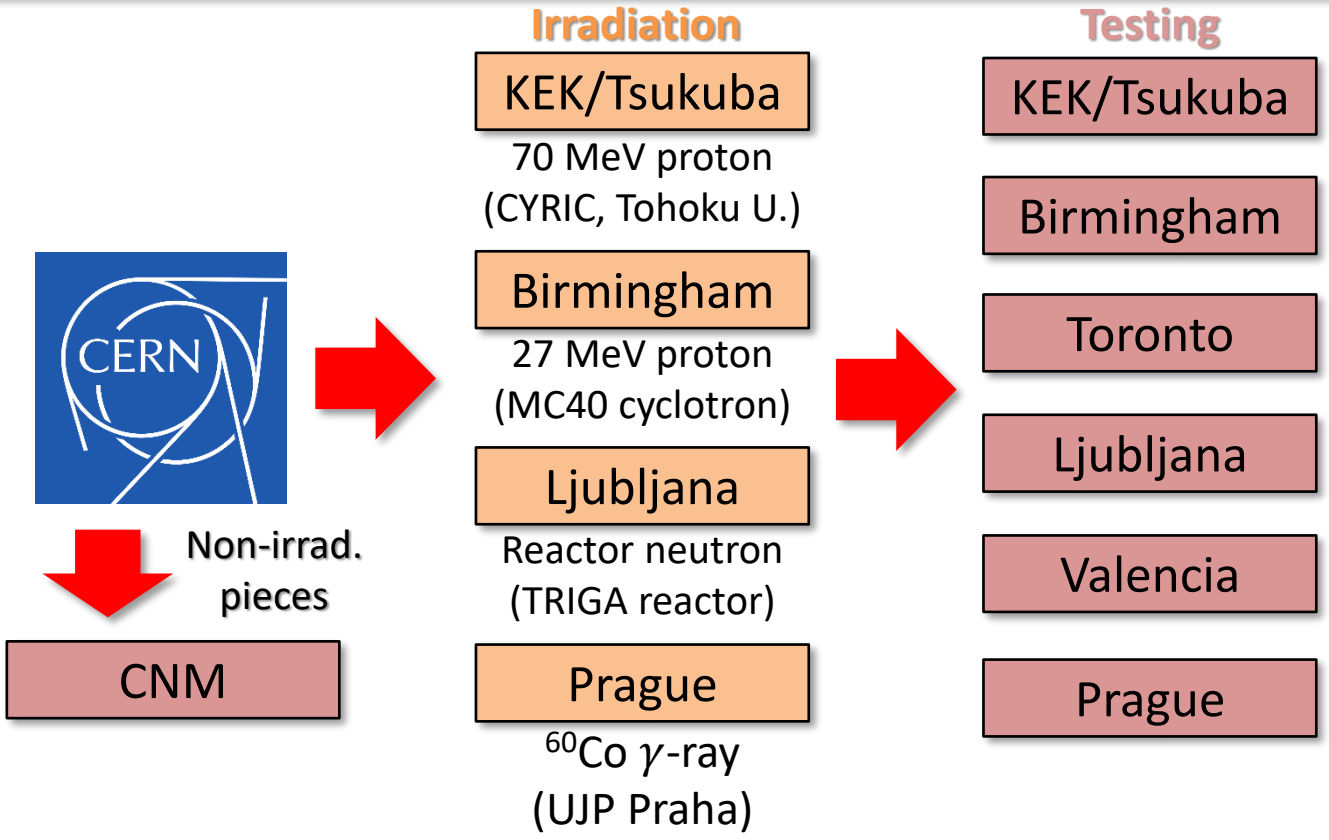
Mini sensor

Test chip

- Evaluate basic technological properties using dedicated pieces
  - **Mini sensor** is a 10x10 mm^2 strip sensor with the same structure as the main sensor; for CCE measurement
  - **MD8** is a simple 8x8 mm^2 diode for IV/CV measurements
  - **Test chip** has various structures to measure fundamental parameters
- 127 QA pieces were irradiated / measured during pre-production
  - Update of presentation at PSD12

[E. Bach, presented at PSD 12] (Proceedings accepted by JINST)

Flow of QA evaluation

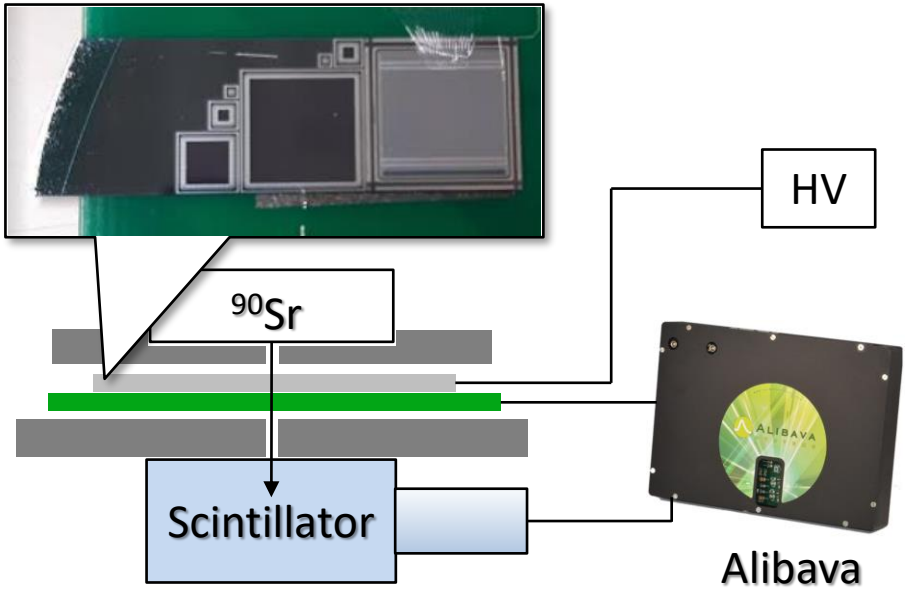


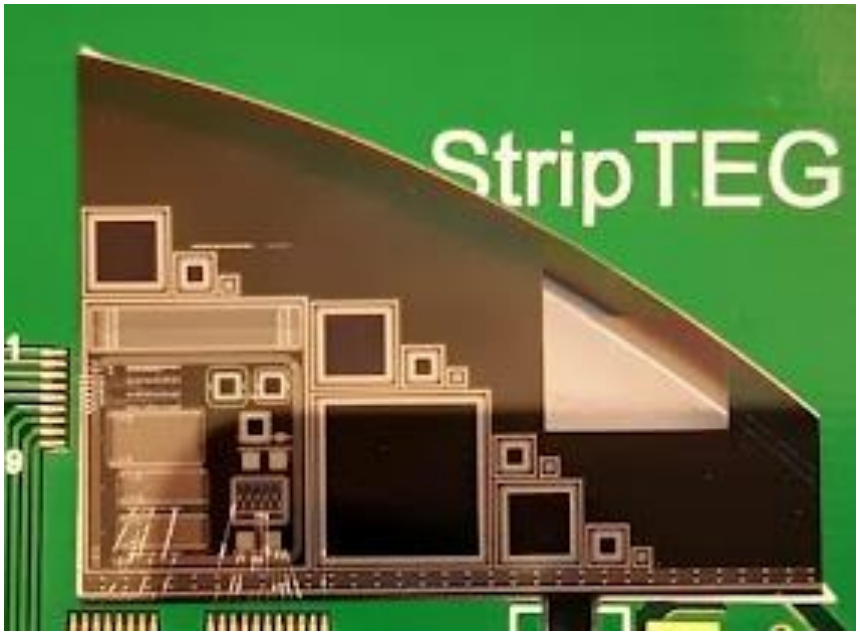
- Irradiation for QA pieces at four facilities
  - Protons/neutrons up to 1.6×10^{15} n_{eq}/cm^2
  - γ-rays up to 660 kGy

  } ~HL-LHC (4000 fb^{-1})

- ~3 pieces are irradiated for every batch (~40 wafers)

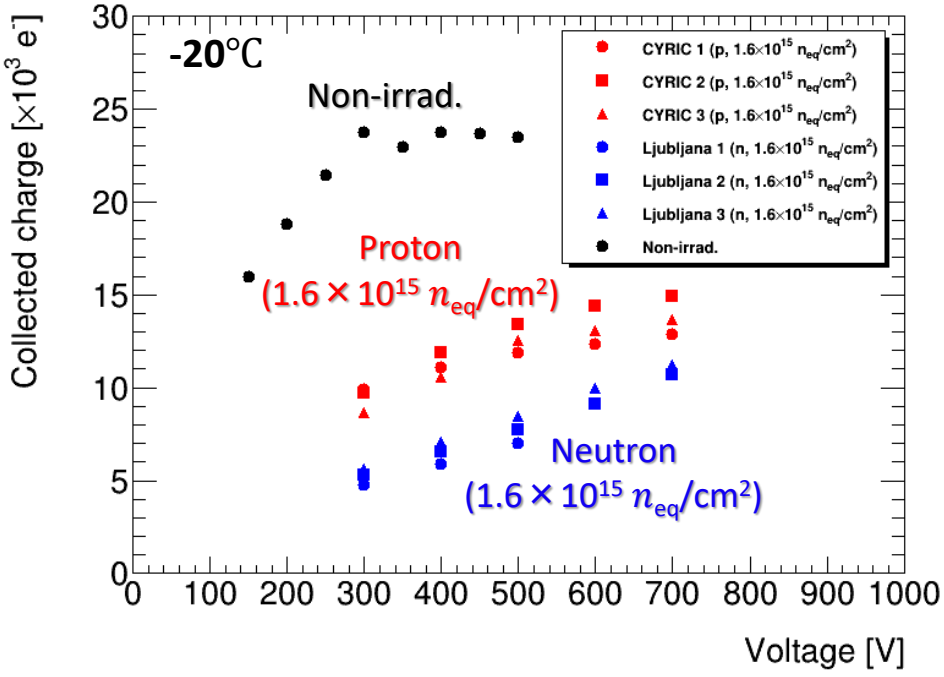
QA testing setup

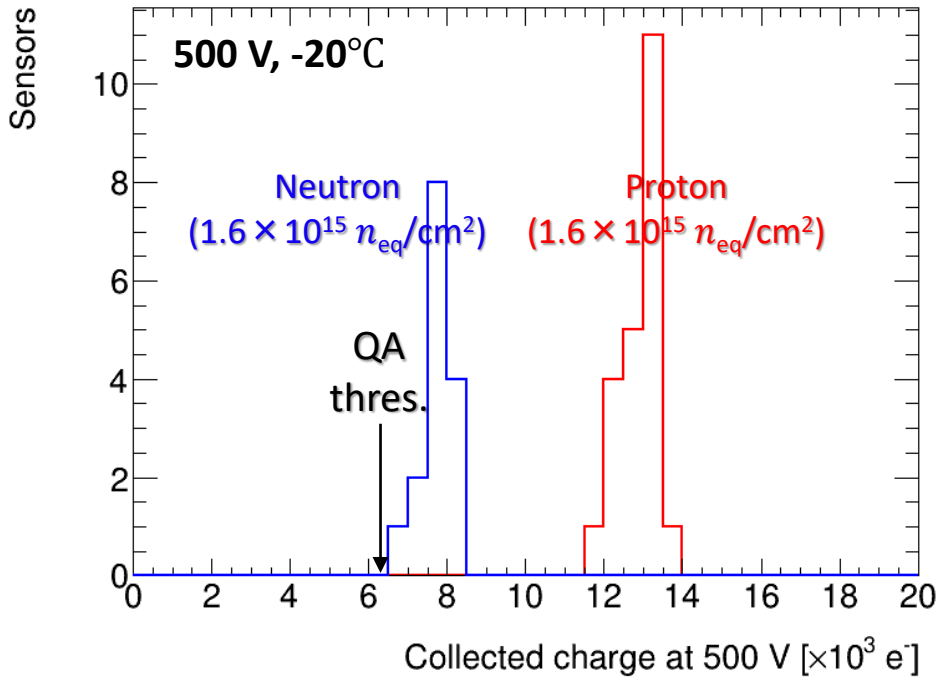




- **Mini sensor**: measure charge created by electrons from ^{90}Sr
  - Use Alibava board for DAQ *R. M.-Hernandez et al., IEEE Trans. on Nucl. Sci. 56, 1642 (2009)*
- **MD8/test chip**: measurements can be performed via pads
  - Either a PCB with wire-bonding or a probe station
- Measurements at -20℃ after annealing at 60℃ for 80 mins.

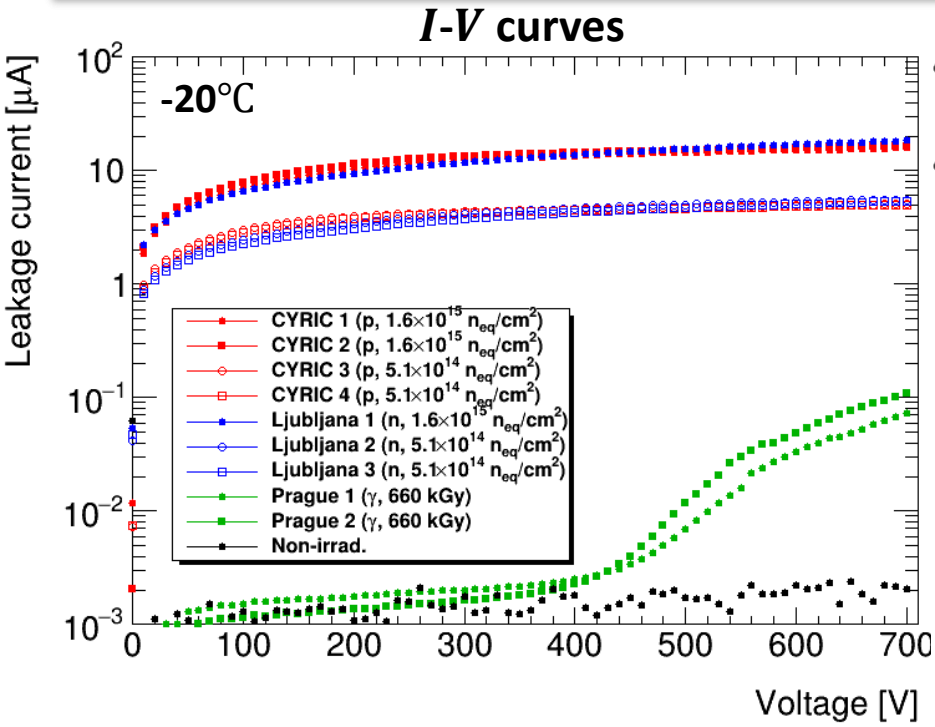
Collected charge with mini sensors

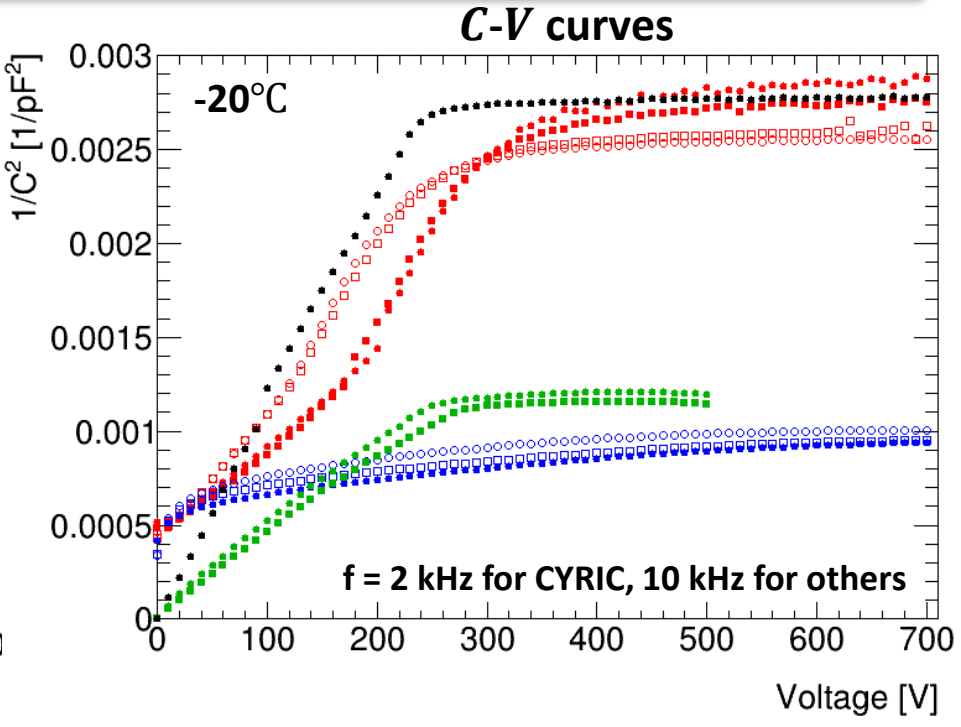




- Normalise the plateau charge from non-irrad. sensors to 23k e^-
- Neutron-irradiated sensors tend to have lower collected charge
  - Different damage states from proton irradiation [K. Hara et al., NIM A 983 (2020) 164422]
- Acceptance threshold: 6350 e^- at 500 V
  - All sensors have passed; n-irrad. samples also have sufficient headroom as significantly more than expectation is irradiated

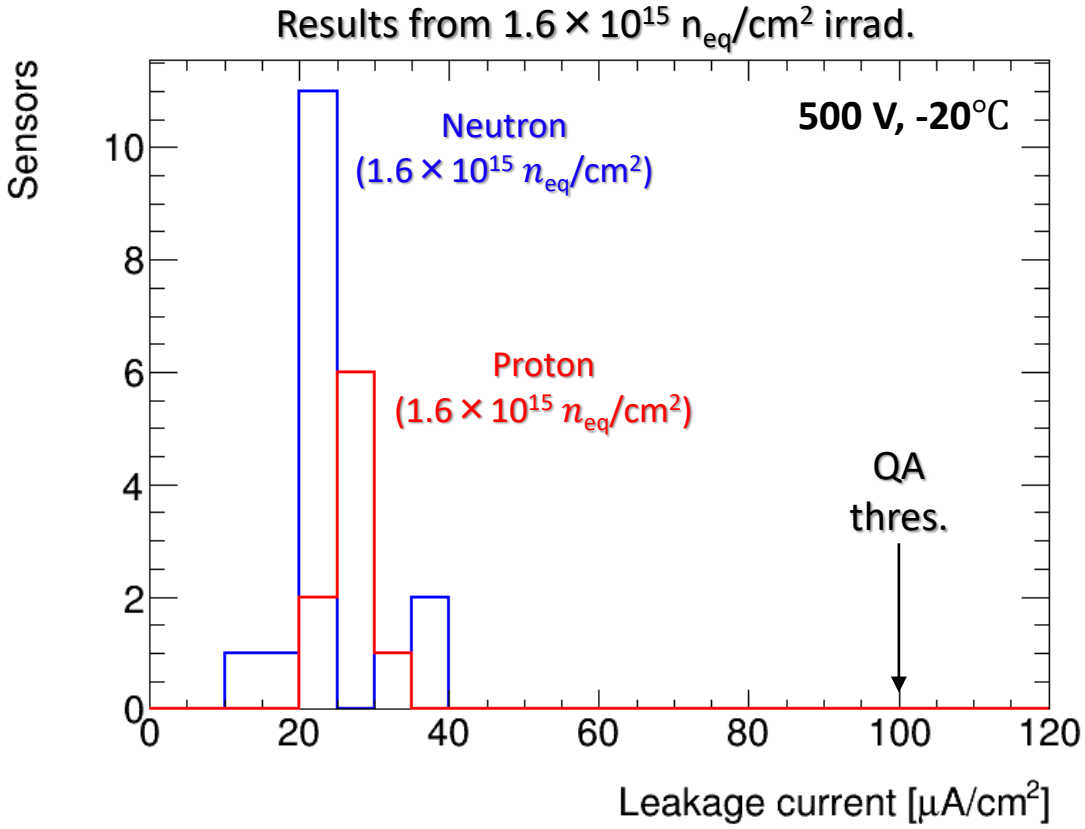
I–V/C–V characteristics with MD8





- I-V/C-V curves are measured using MD8
  - Very consistent I-V are obtained between p and n
  - Significant increase of C is observed in n-irradiation
  - Earlier breakdowns and increase of C in γ-irrad. samples seemed to be attributed to surface currents due to measurement setup

$I-V/C-V$ characteristics with MD8

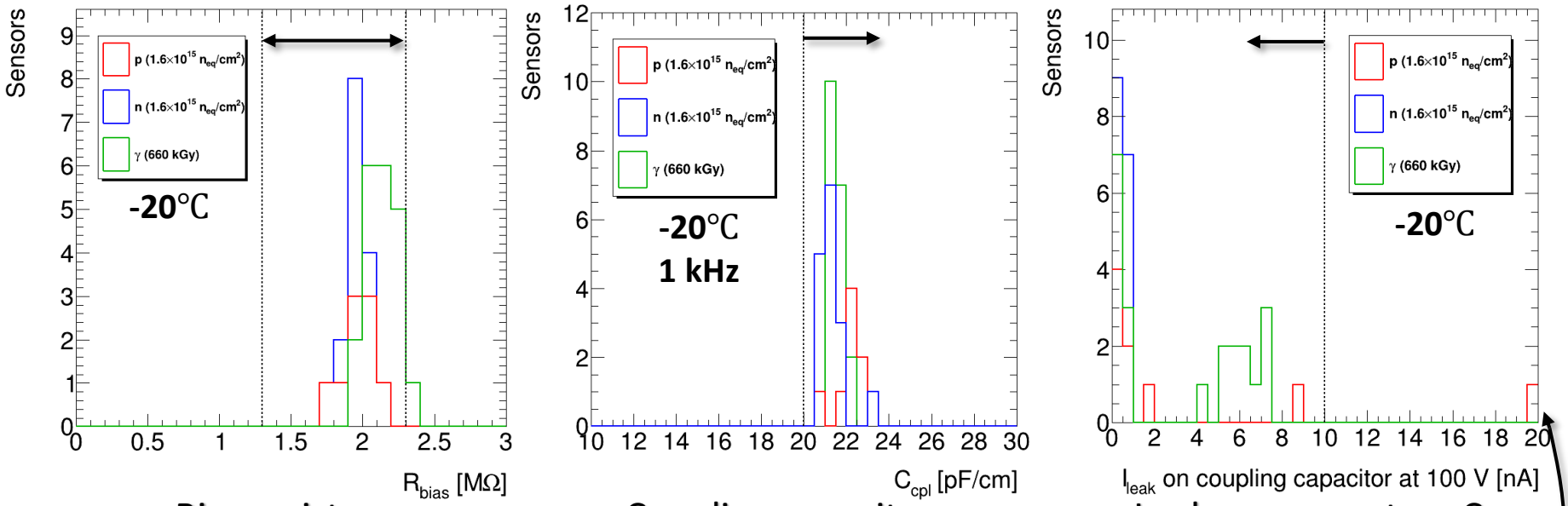


- Acceptance thresholds
  - 100 μA/cm^2 at 500 V and breakdown voltage above 500 V
- All sensors passed the thresholds
  - No early breakdown was observed except for some γ-irrad. samples

Results from test chips

Results from 1.6×10^{15} n_{eq}/cm^2 irrad.

Arrows indicate acceptance ranges



Bias resistance | Coupling capacitance | Leakage current on C_{cpl}

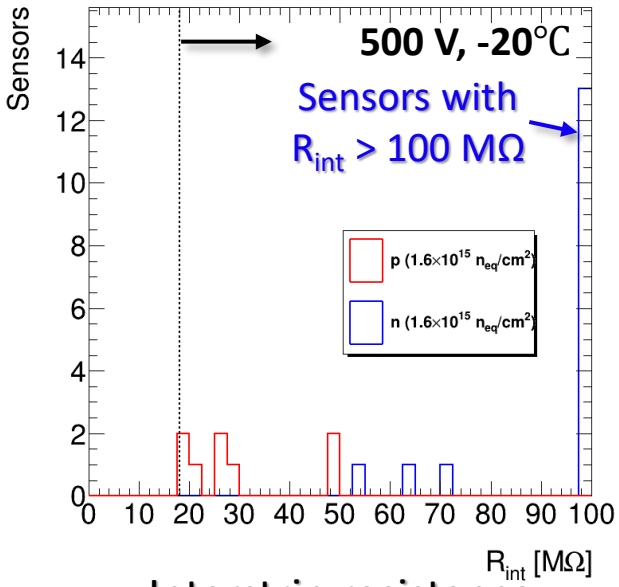
- Bias resistances are to be within [1.3, 2.3] MΩ at -20°C
- Coupling capacitance should be >20 pF/cm
  - All sensors passed the requirement
- Leakage current on the coupling should be < 10 nA @ 100 V
  - A few samples showed breakdown likely due to mis-handling
    → Cross-checked with other sensors from the same batches

Allow +0.2 MΩ for γ-irrad. samples

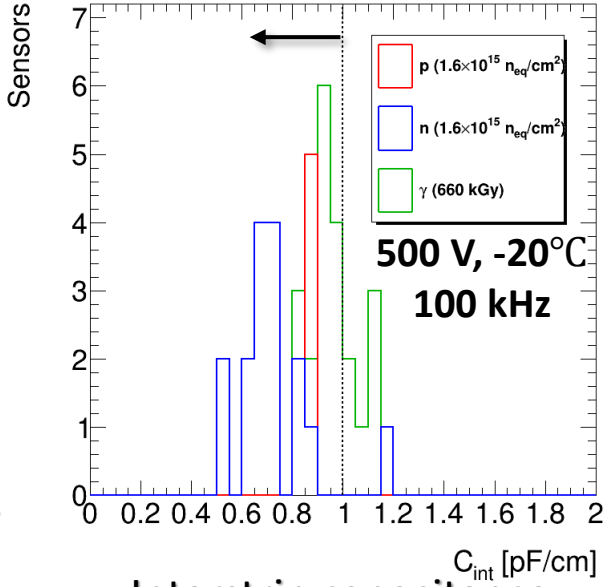
Results from test chips

Results from 1.6×10^{15} n_{eq}/cm^2 irrad.

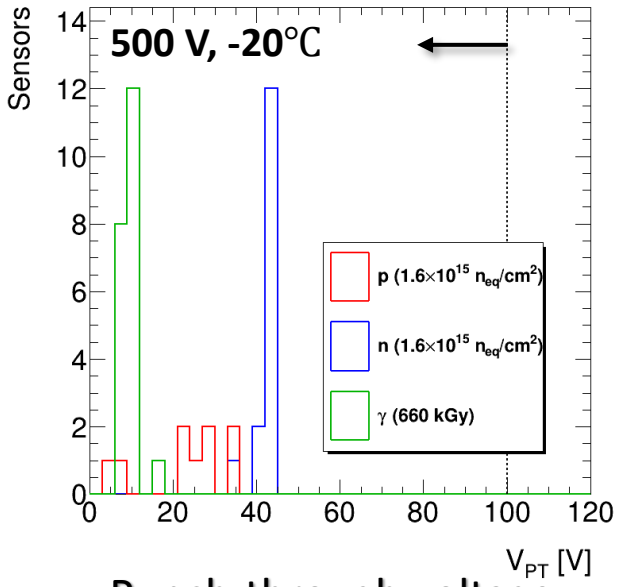
Arrows indicate acceptance ranges



Interstrip resistance



Interstrip capacitance



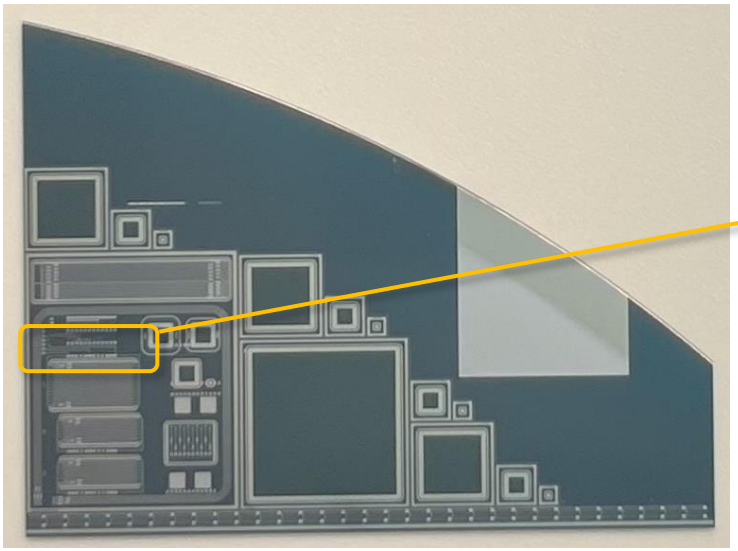
Punch-through voltage

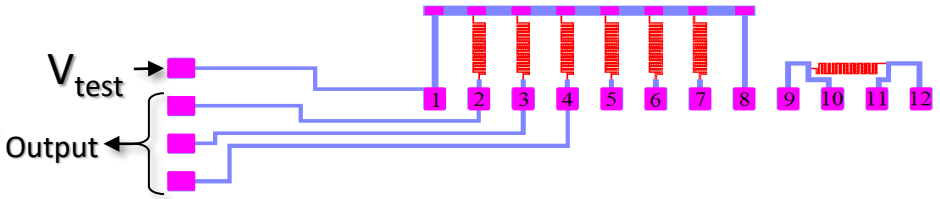
- R_{int} should be $R_{\mathrm{int}} > 10R_{\mathrm{bias}}$ (~18 MΩ)
  - p-irrad. sensors marginally passed due to excessive TID (~1.3 MGy); decided to reduce the fluence of p-irrad. to correspond to 660 kGy
- C_{int} of some samples exceeded 1 pF/cm
  - Larger spread after irradiation; the threshold is being revisited
- V_{PT} should be < 100 V to protect strips from over currents

Summary

- Pre-production was carried out in 2020
  - >100 QA pieces were irradiated and tested
- Overall, good performance was obtained from pre-pro. QA
  - Most of the pieces passed the QA criteria; bad results were all understood, such as bad handling before QA testing
  - QA flow was well established in terms both of quality and speed
  - Acceptance criteria were optimised towards main production
    - E.g. n (1.6×10^{15} $n_{\mathrm{eq}}/\mathrm{cm}^2$) + γ (660 kGy) irradiation to a single sensor is chosen to be a nominal irradiation to have more realistic damages
- Based on the outcomes from pre-production, ATLAS18 sensor main production was started in July 2021
  - 3.8 year programme to produce >20,000 sensors; >5,000 sensors have been produced so far

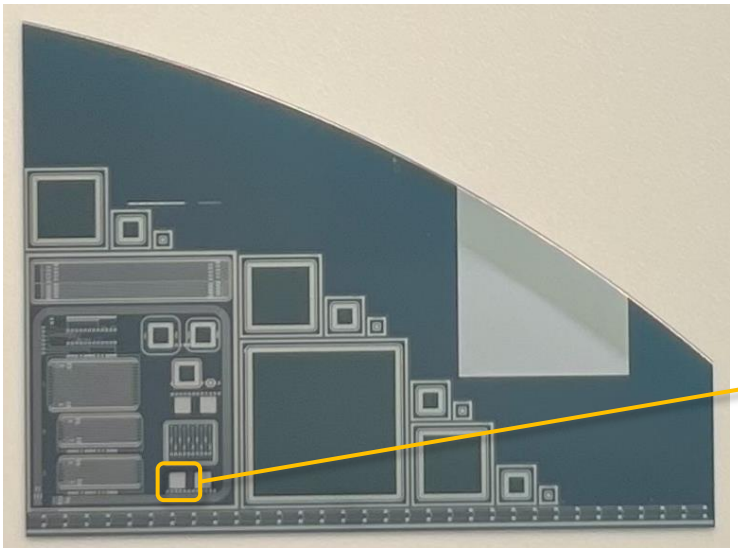
Rbias measurement

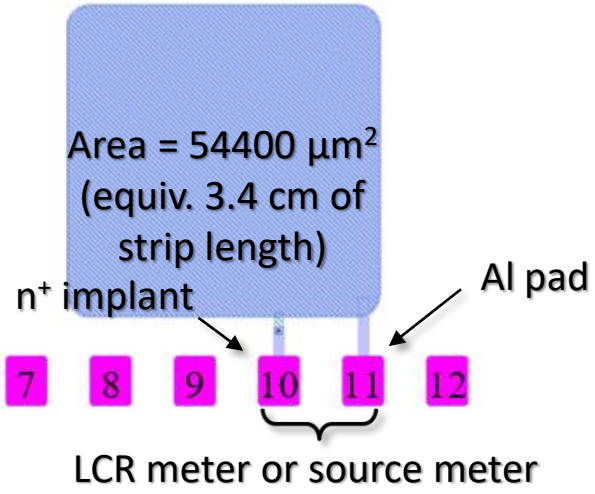




- Use a structure with several poly-Si resistances
  - Sweep V_{test} from -5 V to +5V and measure I
    →Determine R_{bias} from a slope of the I-V
- Requirements
  - 1.5±0.5 MΩ at 20℃ (irradiated measurements at -20℃ is normalised to 20℃)
  - γ-irradiated samples are allowed to be up to 2.2 MΩ at 20℃

Coupling capacitance

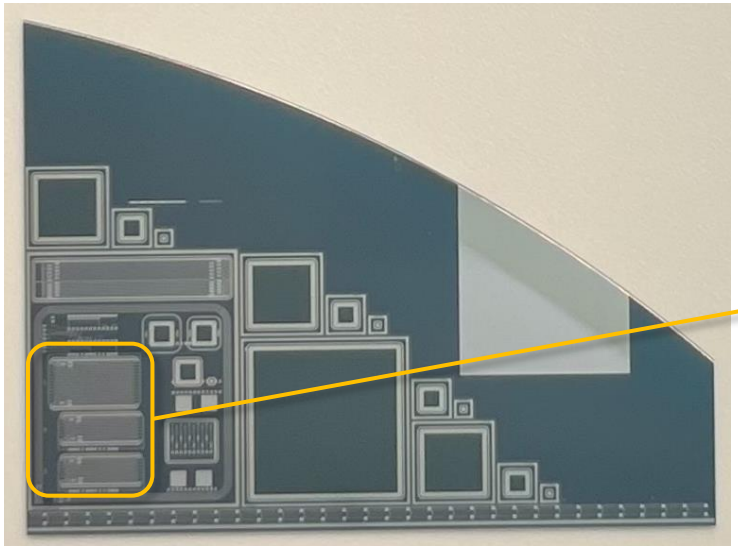


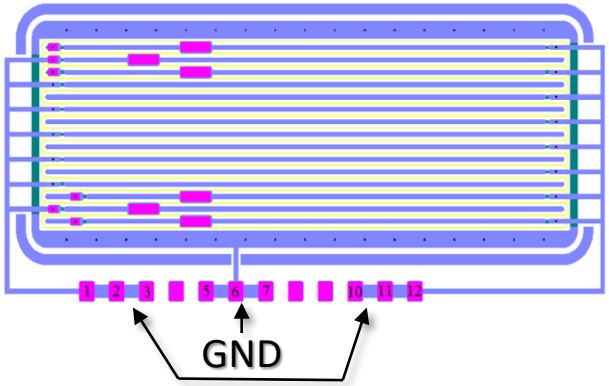


- C_{cpl} measurement
  - Use a square-shape capacitor with an area = 54400 µm²

    → Equivalent to a strip length of 3.4 cm; square shape reduces an 'edge' effect
  - Ccpl measurement with an LCR meter (f = 1 kHz); divided by 3.4 cm
  - Ccpl leak measurement with IV up to 100 V

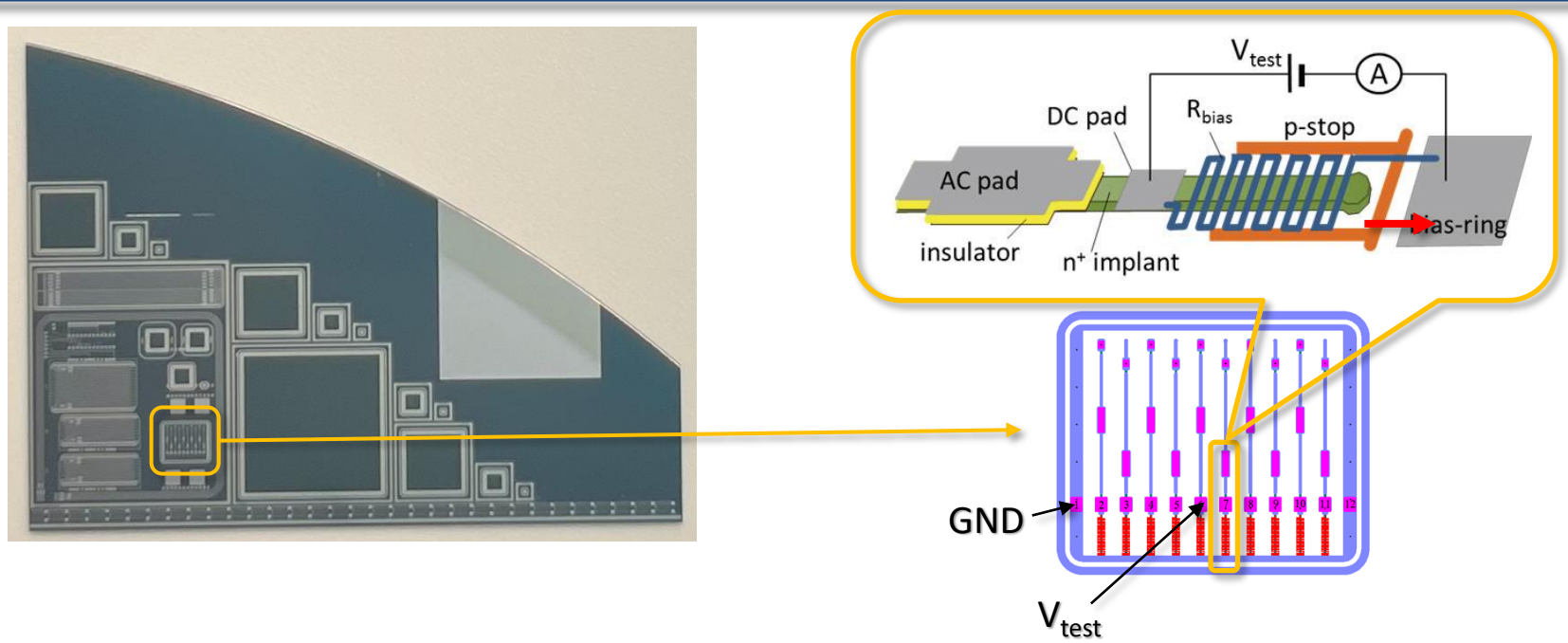
Interstrip properties





- Use interdigitated structure
  - 14 inter-strips in total
  - Three different structures
    - 'LOW' has l = 2.401 cm → Use it for R_{int} measurement
    - 'MID' and 'UP' have length dependent on the sensor type → For C_{int} measurement
- Apply a bias voltage of 500 V

PTP measurement



- Punch-through protection voltage
  - Apply a bias voltage of 500 V
  - Sweep V_{test} from 0 V to -40 V and evaluate R_{eff} = V/I at each point
    → Define V_{PTP} by $R_{eff} = R_{bias}/2$
- V_{PTP} should be less than 100 V

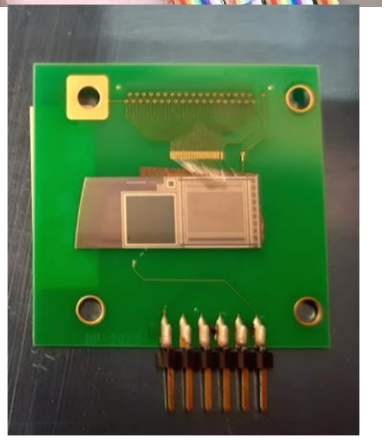
QA testing method

- Each site has their own preferred testing method
  - Consistency was checked with reference samples at site-Q

CNM: probe station

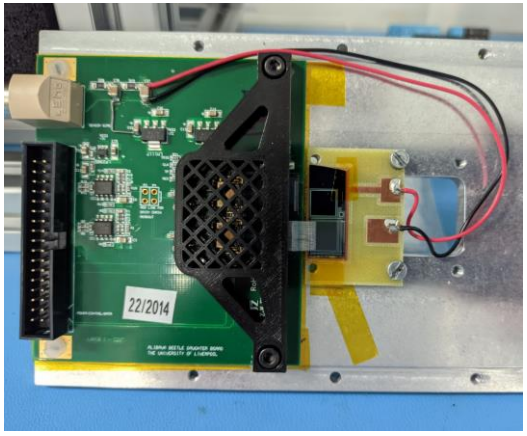
Toronto: PCB

KEK/Tsukuba: PCB

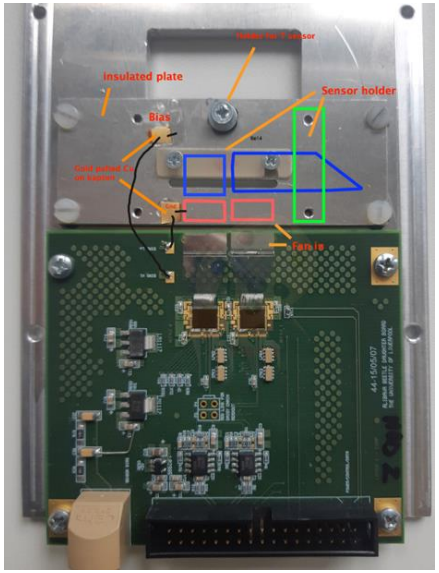


Birmingham: PCB

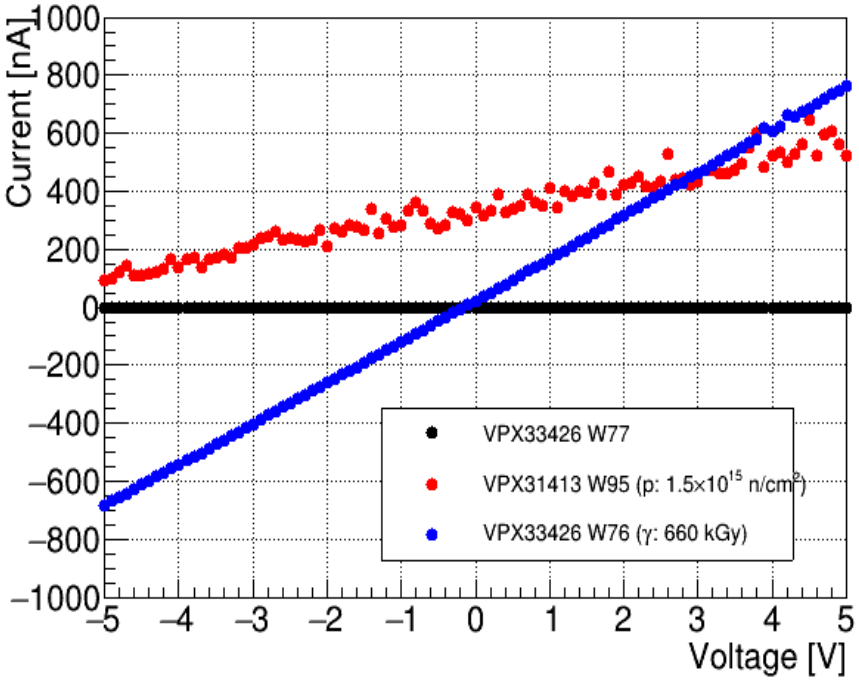
Valencia: PCB

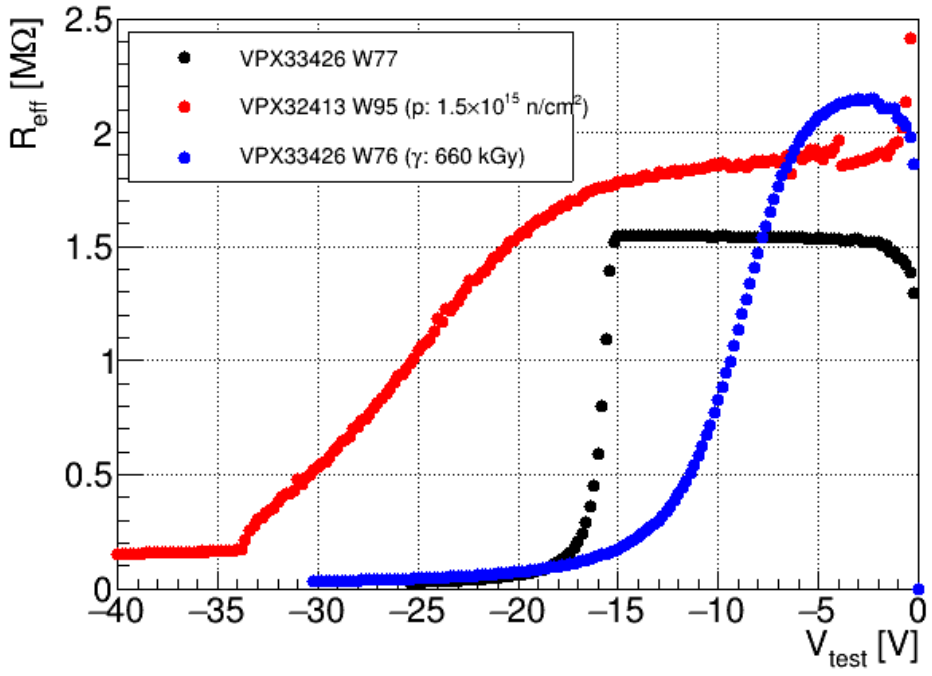


Ljubljana: PCB



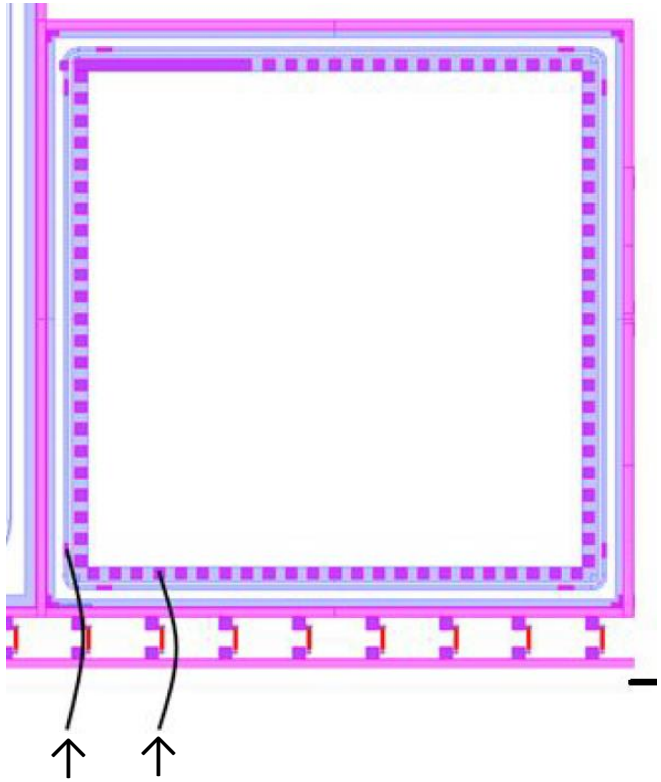
IV in R_{int} and V_{PT}





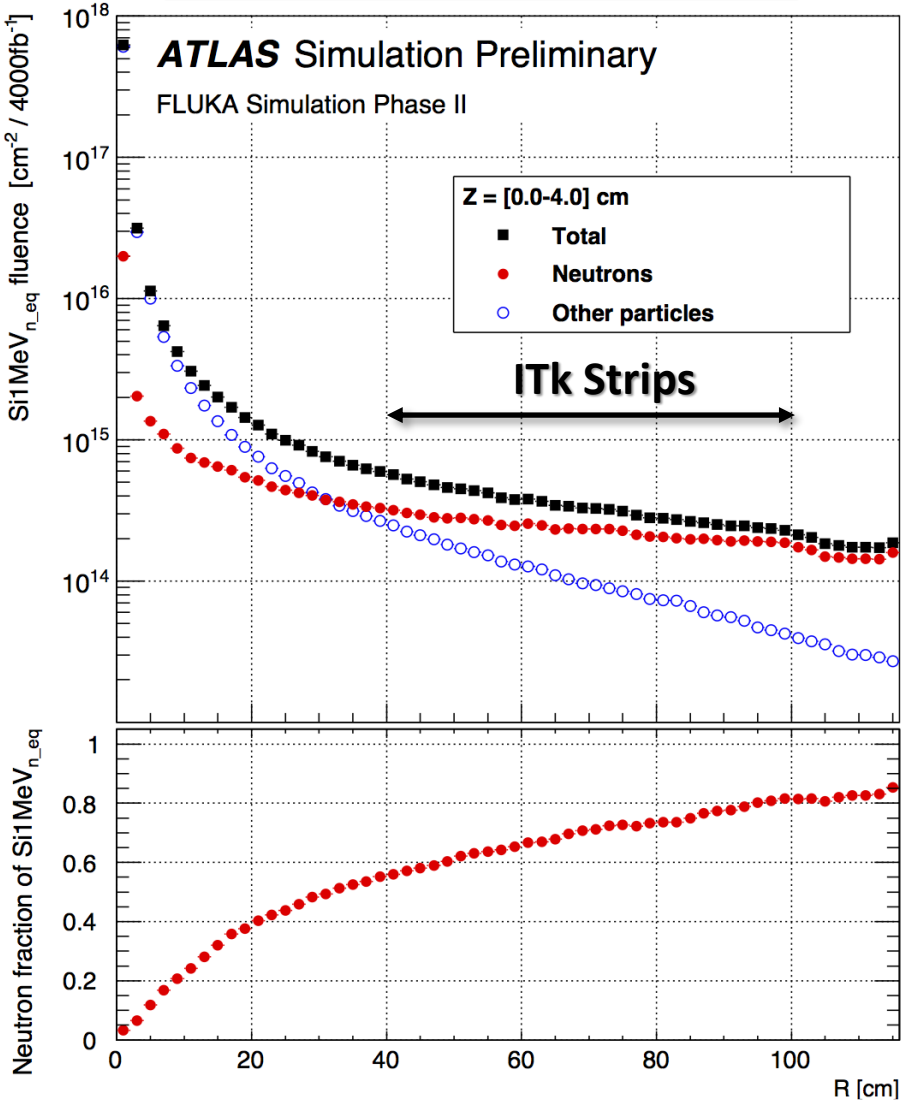
MD8

- Simple 8x8 mm^2 diode
  - Possible to measure IV/CV with avoiding various effects from sensor structures
- Keep the bias ring to GND and apply



Fluence around ITk Strips

ATLAS Radiation Simulation Public Results



Split of QA irradiation

- Since it is very challenging to irradiate all radiation types to all QA pieces, batches are split as following table.

Prod plan		QA-piece	
		Mini&MD8	Testchip&MD8
Batch	odd	Ljubljana (1.6e15) Ljubljana (5.1e14)	Birmingham (66 Mrad)
	even	Birmingham (1.6e15)	Ljubljana (1.6e15) Prague (66 Mrad)
	all	1/6 CYRIC (1.6e15)	CNM (pre-irrad) 1/6 CYRIC (66 Mrad)

γ+n