ATLAS ITK STRIP SENSOR QUALITY ASSURANCE

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On behalf of ATLAS ITk group in China

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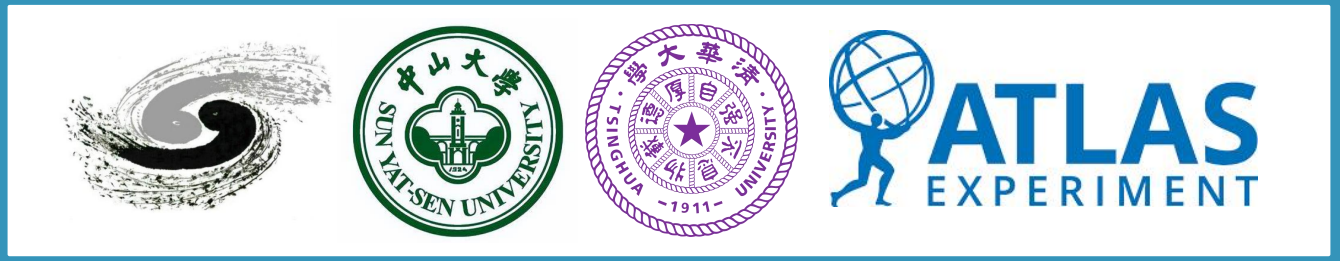

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- CSNS Irradiation Site Qualification
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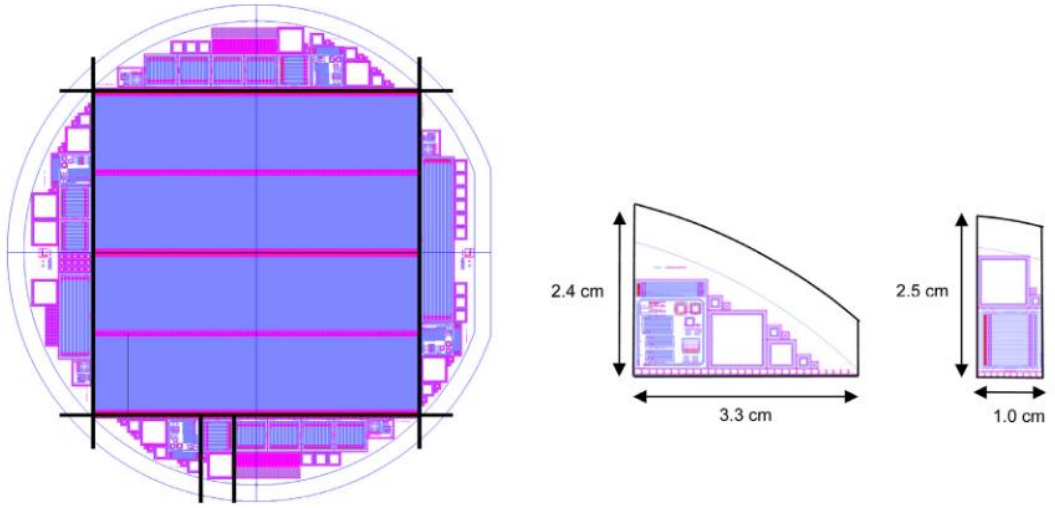
ATLAS ITk Strip Sensor Quality Assurance

- To upgrade ATLAS inner detector, nearly 22,000 large area sensors will be produced over about five years by Hamamatsu Photonics K.K. (HPK).
- To monitor the production of ATLAS ITk sensor, the strategy of sensor quality assurance (QA) has been carried out.
- ATLAS ITk collaboration has prepared a detailed irradiation and test plan.

ITk sensor QA strategy

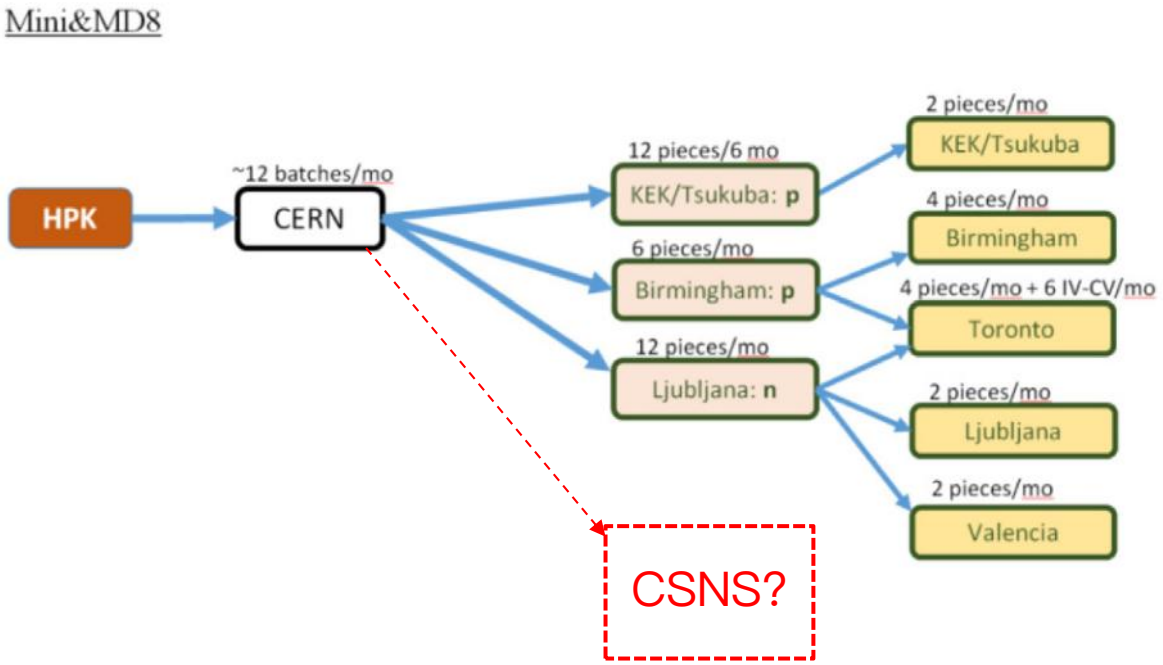
- Wafer:
  - Large–area MAIN sensor
  - The periphery remaining (the ‘‘halfmoons’’) – test devices used for QA:
    - 1×1 cm^2 miniature strip detectors (‘‘Mini’’)
    - large area (8×8 mm^2) diodes (‘‘MD8’’)
    - ATLAS test chip
- Mini used for CCE test, under 1.6 × 10^{15} $\mathrm{neq/cm}^2$ dose
- MD8 used for IV and CV test, focused on V_{FD}



Dicing scheme for the wafers (left), and detail of the QA–pieces design and size, “Testchip & MD8” (center) and “Mini & MD8” (right).

Planned irradiations

- All QA-pieces will be received at CERN first, then distributed to different irradiation sites.
- ITK strip sensors need to tolerate around an integrated total ionizing dose (TID) of 66 Mrad and a neutron-equivalent fluence of 1.6×10^{15} neq/cm^2
- After irradiation, the QA pieces are sent to test sites for measurement.
- Could CSNS become an irradiation site?



Production flow for Mini&MD8 QA-pieces including irradiation and tests

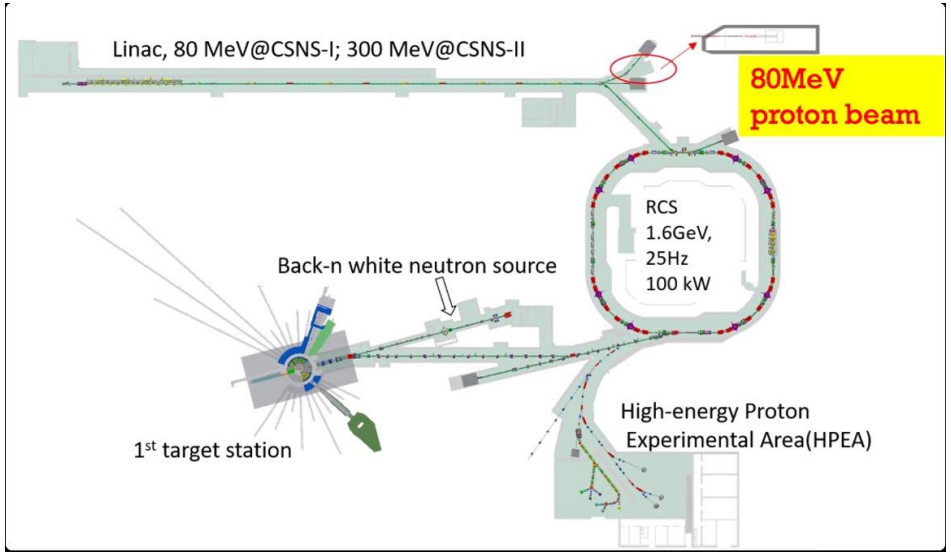
China Spallation Neutron Source (CSNS)

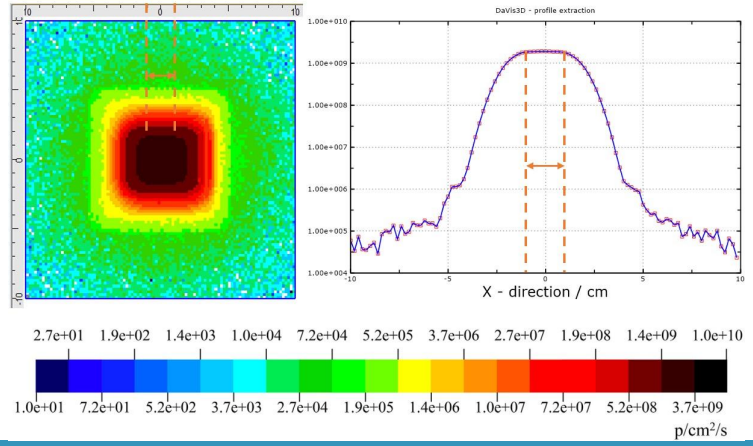
- Located in Dongguan.
- First pulsed neutron source facility in China.
- It now includes:
  - a powerful linear accelerator and a rapid circling synchrotron
  - a target station and three Phase I neutron instruments

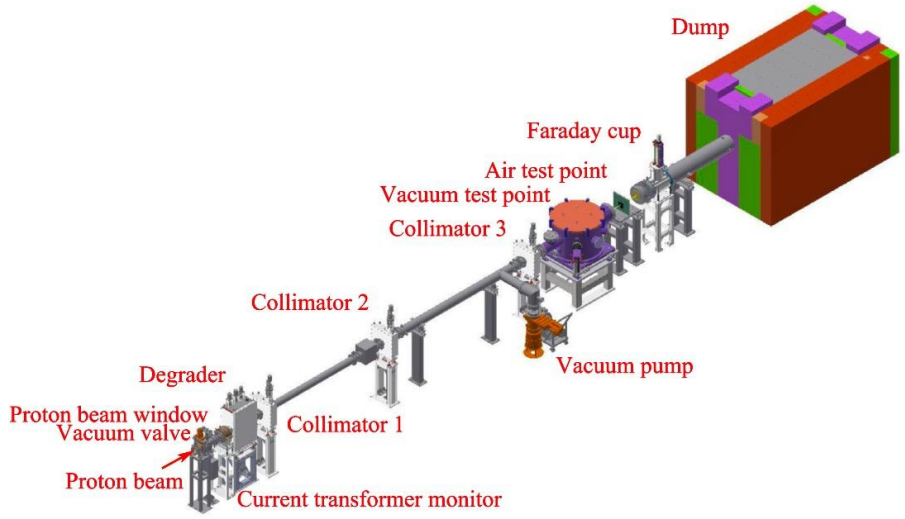
Aerial View of CSNS

Associated Proton Experiment Platform (APEP)

- Located at the end of the CSNS linear accelerator
- Proton beam energy 80 MeV
- 20 mm × 20 mm (flat top of flux) beam spot
- The simulated flux intensity at the sample location for a beam spot of this size is 3.04 × 10^9 p/ cm^2 /s
- Take around 102.3 hours to reach 1.6 × 10^{15} neq/cm^2

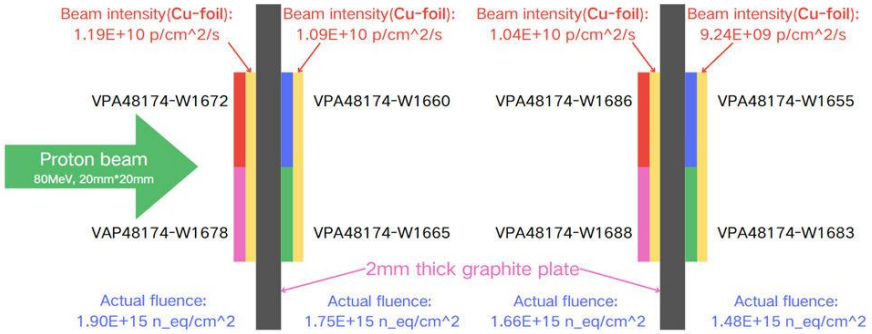


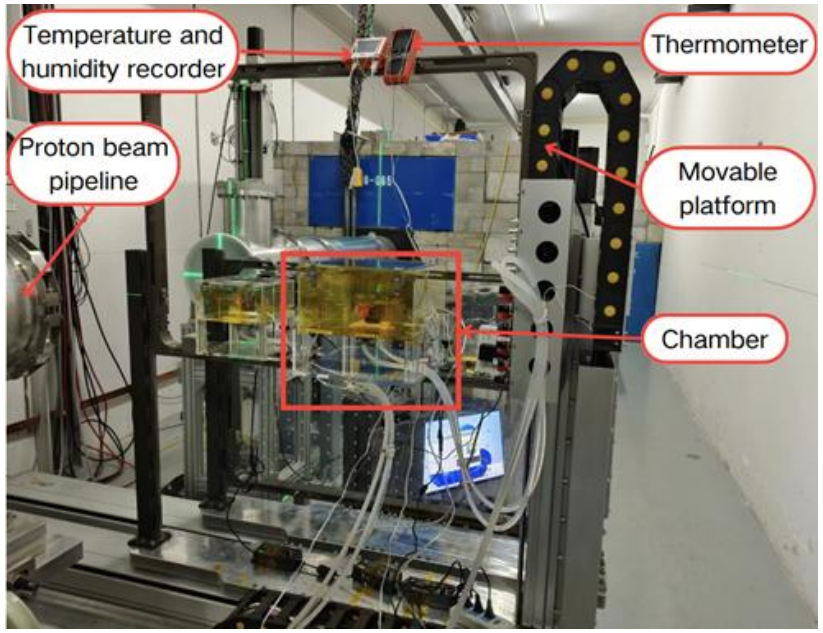




CSNS irradiation site qualification

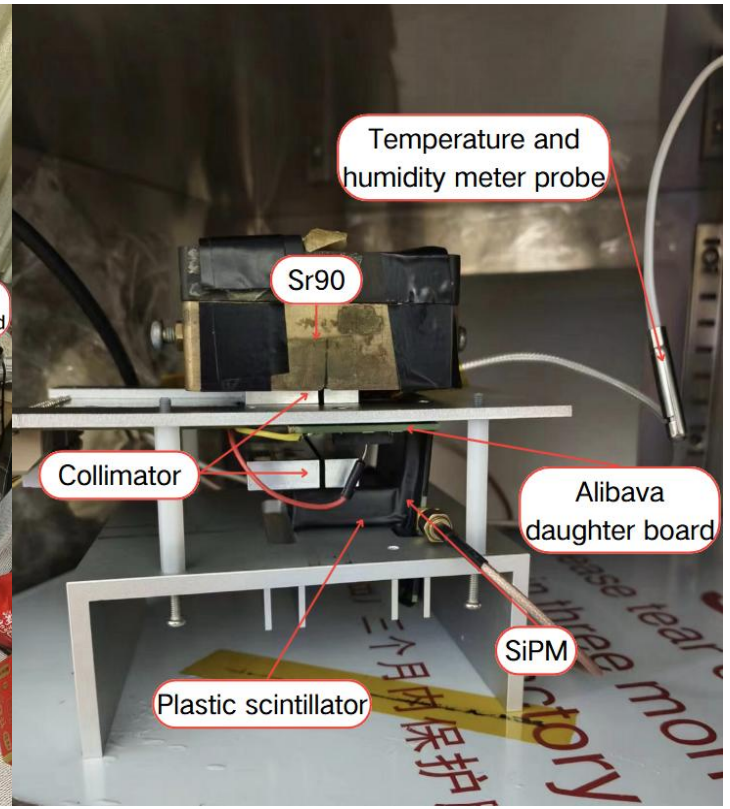
- QA irradiation should be conducted at less than –15°C to avoid the sample annealing and simulate the ATLAS ITk at the the normal run time. To meet this requirement:
  - Temperature and Humidity: –20℃ (Peltier + water cooling), <5%RH
  - Irradiation fluence: using foil activation technique

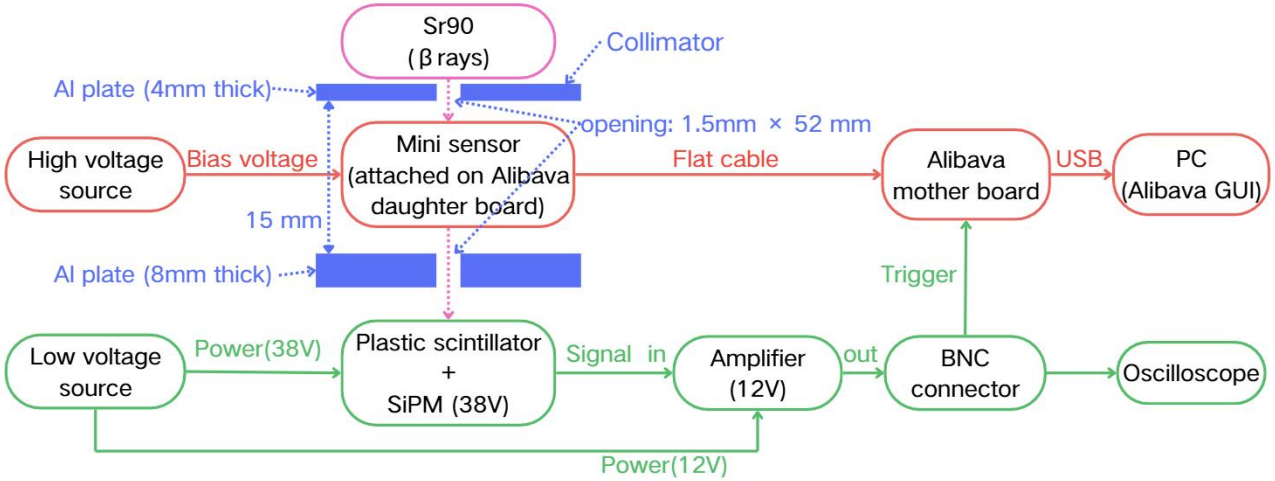




IHEP: QA site – CCE

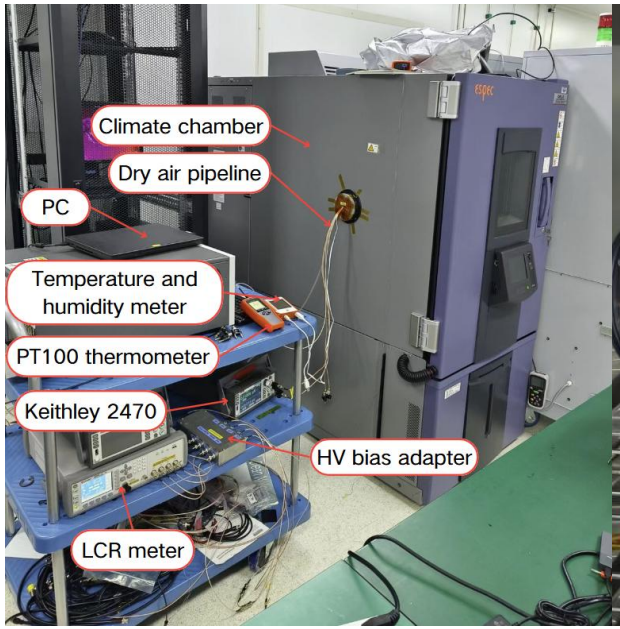
- β–ray penetrating mini sensor detected by scintillator
- Output charge measured by the ALiBaVa system.
- Collected charge is defined as the Most Probable Value of Landau function obtained from the fit of Landau convoluted with Gaussian to distribution of measured cluster charges.
- Temperature and Humidity: –20℃ (controlled by the refrigerator), <10%RH (Dry air flowed into the refrigerator)

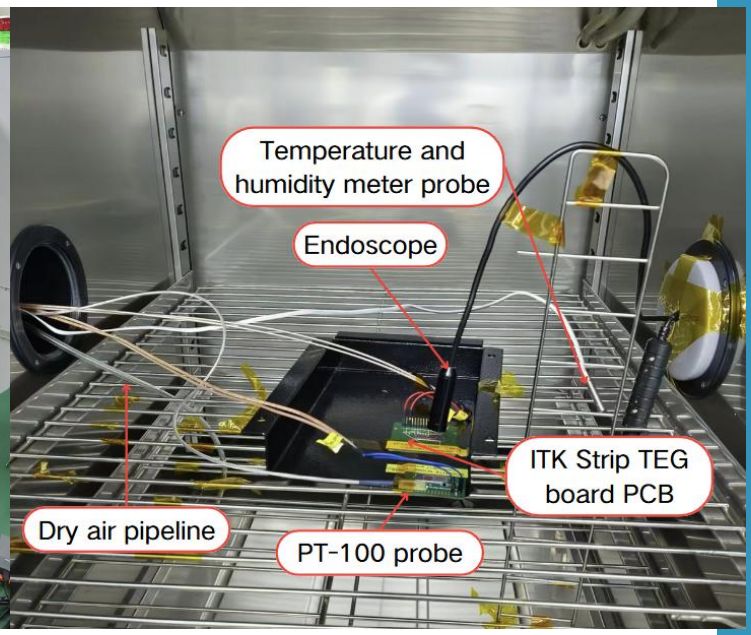


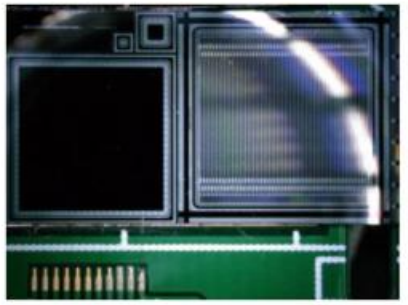


IHEP: QA site – IV, CV

- To estimate the IV and CV characteristics of the sensors, the MD8 was attached to the ITK Strip TEG board PCB and placed in the chamber .
- Temperature and Humidity: 20℃ (unirradiated), –+20℃ (irradiated), controlled by the chamber , <10%RH (Dry air flowed into the climate chamber)





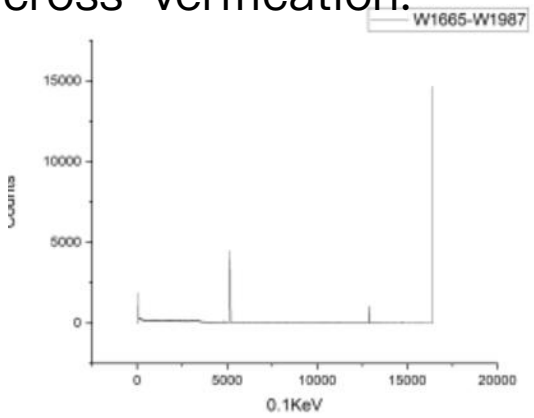


The MD8 was mounted on the PCB for IV and CV measurements

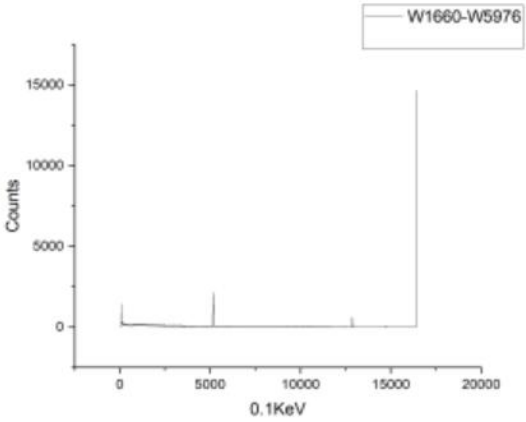
IV/CV/CCE Site Qualification

- Samples irradiated at the CSNS, with subsequent IV, CV, and CCE measurements completed at IHEP.
- Do the gamma spectroscopy and ship them to Birmingham and Ljubljana site for independent cross-verification.

To Birmingham

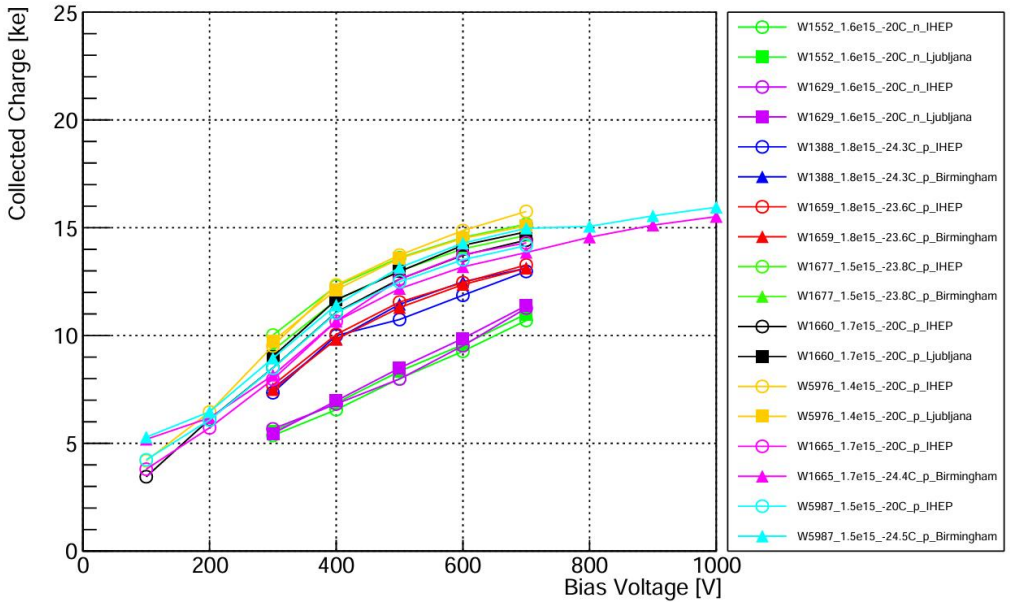


To Ljubljana



- The total α dose for all samples is 0 < 11.5(cps), and the β/γ dose is 104.1 < 115(cps), both meeting the standard.
- The sample is in line with expectations and has basically only Na^{22} radioactive source, with peaks of 0.511MeV and 1.27MeV observed as expected.

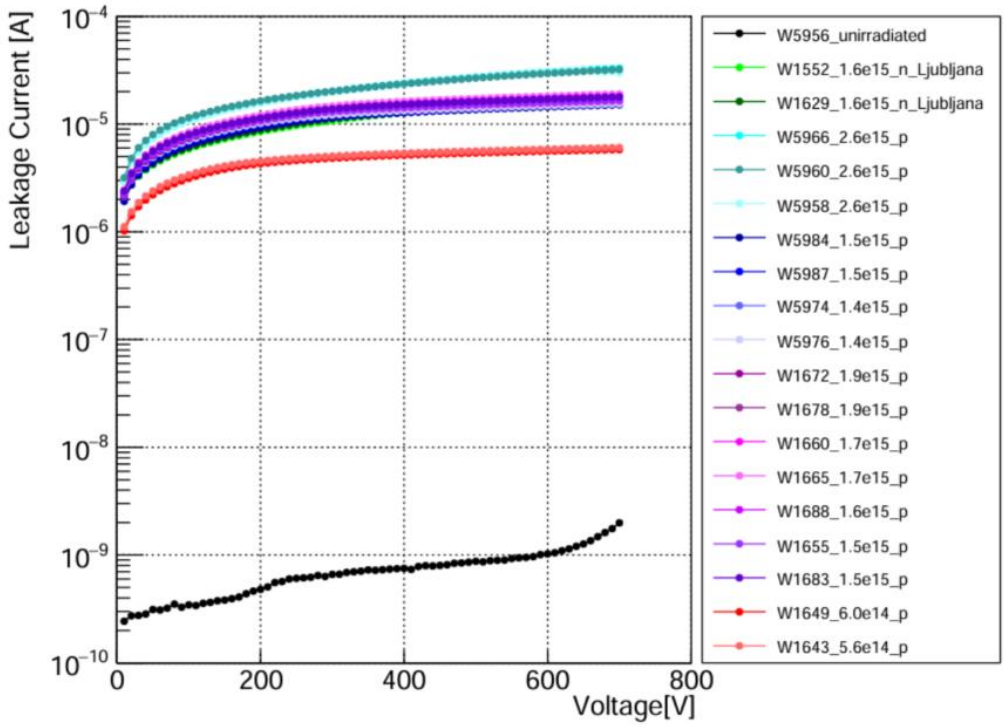
CCE test site qualification



- CCE results measured at IHEP showed good consistency with results from Ljubljana and Birmingham(difference: <10%) .

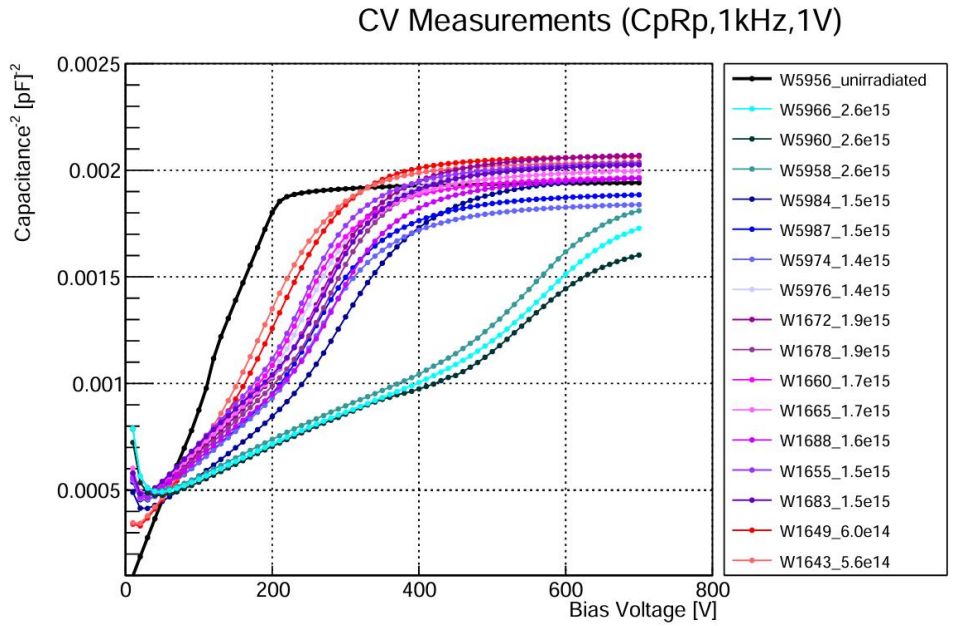
IV test site qualification

- The same dose of 1.6 × 10^{15}, the IVs at both sites are about 22 μA.
- The damage constant α is evaluated as (3.83 ± 0.22) × 10^{-17} A/cm, consistent with the value of $\alpha_{80/60}$ = (4.06 ± 0.04) × 10^{-17} A/cm from the literature(ATL–ITK–PROC–2023–001)



CV test site qualification

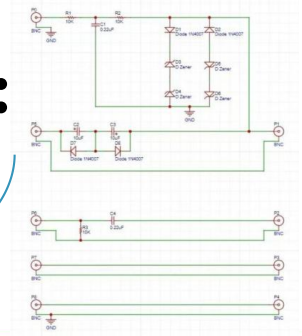
- The full depletion voltage was around 220 V for un-irradiated MD8, meeting the QA requirement (no more than 350 V).
- Samples with similar fluence have close full depletion voltages.
- The curves of W5966 and W5958 are inconsistent.

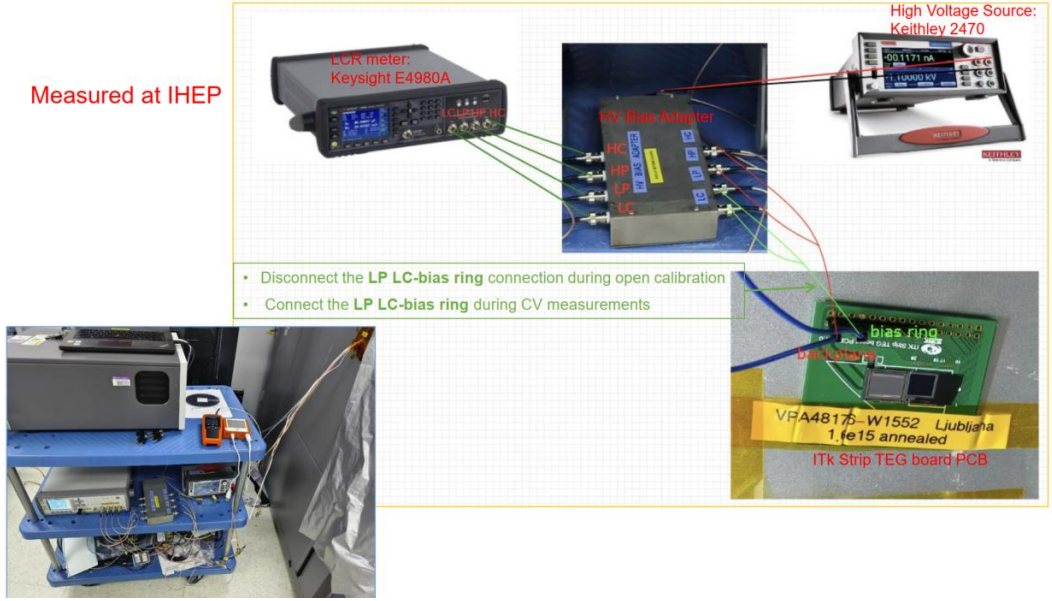


Further investigation on CV

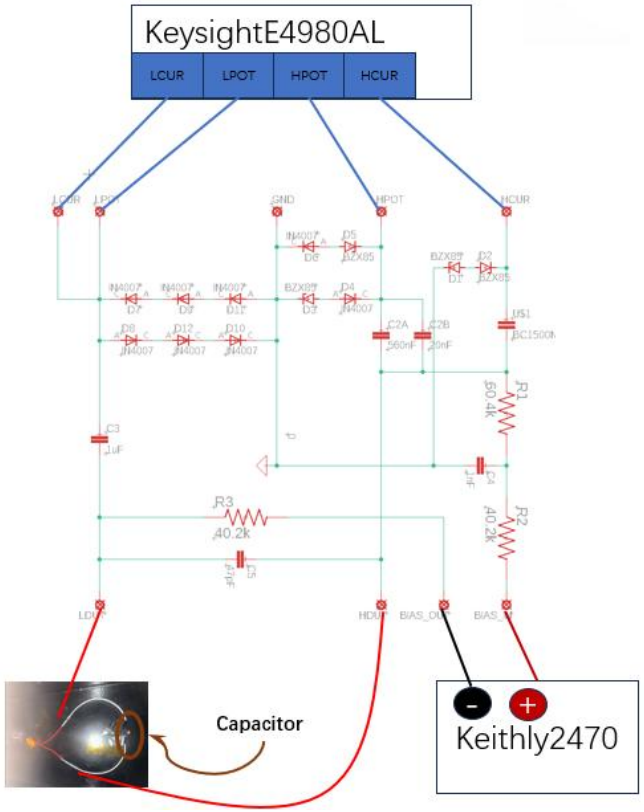
- In order to understand the reasons for these differences, we customized a new box according to the community's opinion to achieve the same test setup as other sites.

- **Circuit connection:**





New box layout and connection



Further investigation on CV

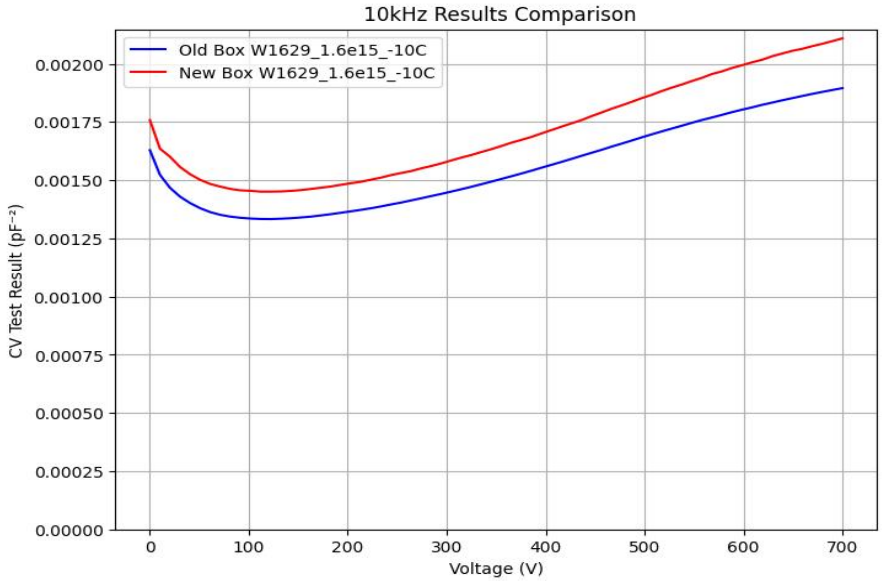
- **We did some tests to check whether it was caused by the different designs of decoupling.**

Standard Capacitance

Capacitor	1	2	3
			
Old box(pF)	97.47	96.66	97.63
New box(pF)	98.19	97.5	97.93

- We have verified through experiments with standard capacitors that both the old and new boxes can measure correct results.

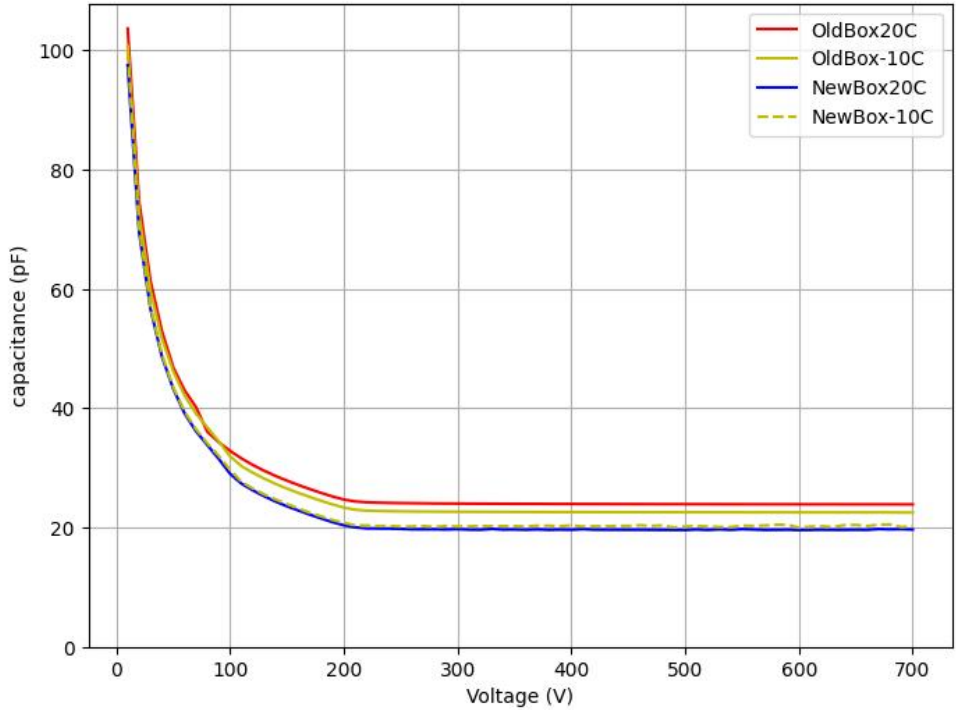
CV comparison on irradiated samples (10kHz)

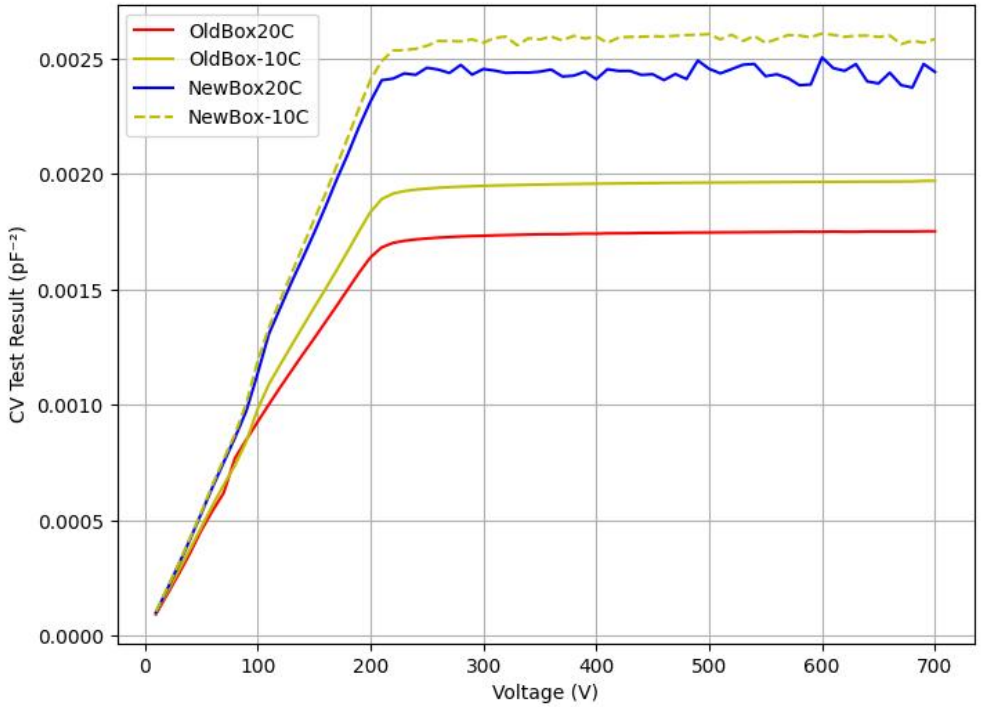


- The results of new and old boxes are basically the same, with only 10% different in 1/C^−2

Further investigation on CV

Unirradiated Capacitance result
(1kHz)



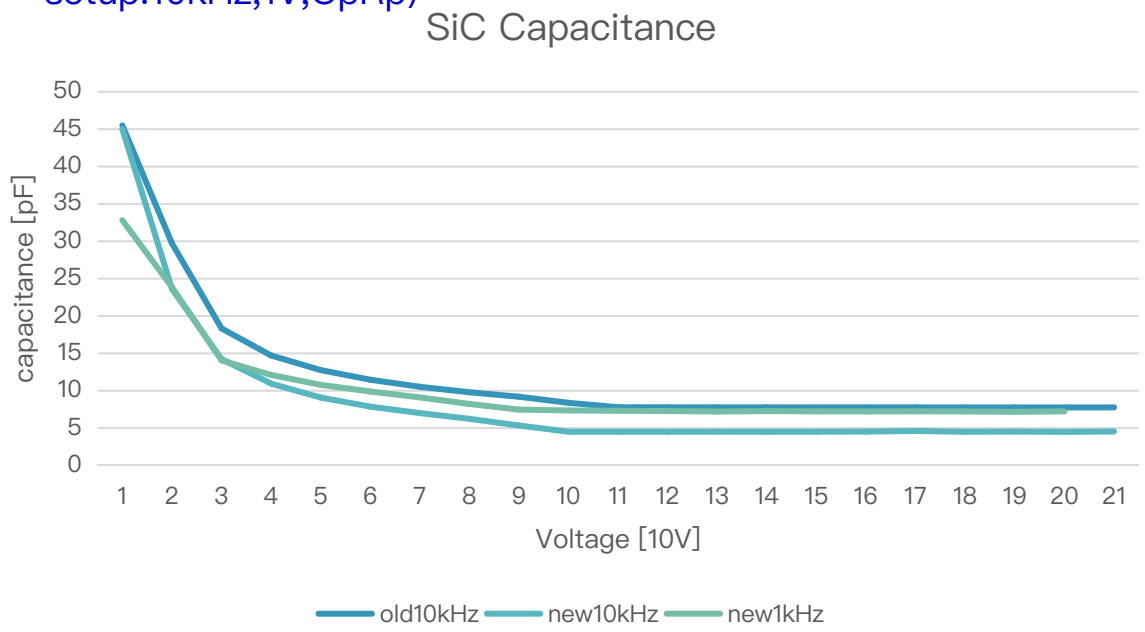


- At 20˚C, the capacitance at full depletion for the old box (23.8 pF) is consistently about 4 pF higher than that of the new box (19.6 pF).
- At –10˚C, the capacitance at full depletion for the old box (22.5 pF) is consistently about 4 pF higher than that of the new box (20.2 pF).

Further investigation on CV

Test comparison using SiC samples

- We borrowed a SiC sample from another group for a comparison test between the new and old boxes. This sample is designed with a full depletion depth of 50 μm, corresponding to a full depletion voltage of around 100V and a capacitance of approximately 7–8 pF. This sample has undergone cross-checking.(their official setup:10kHz,1V,CpRp)



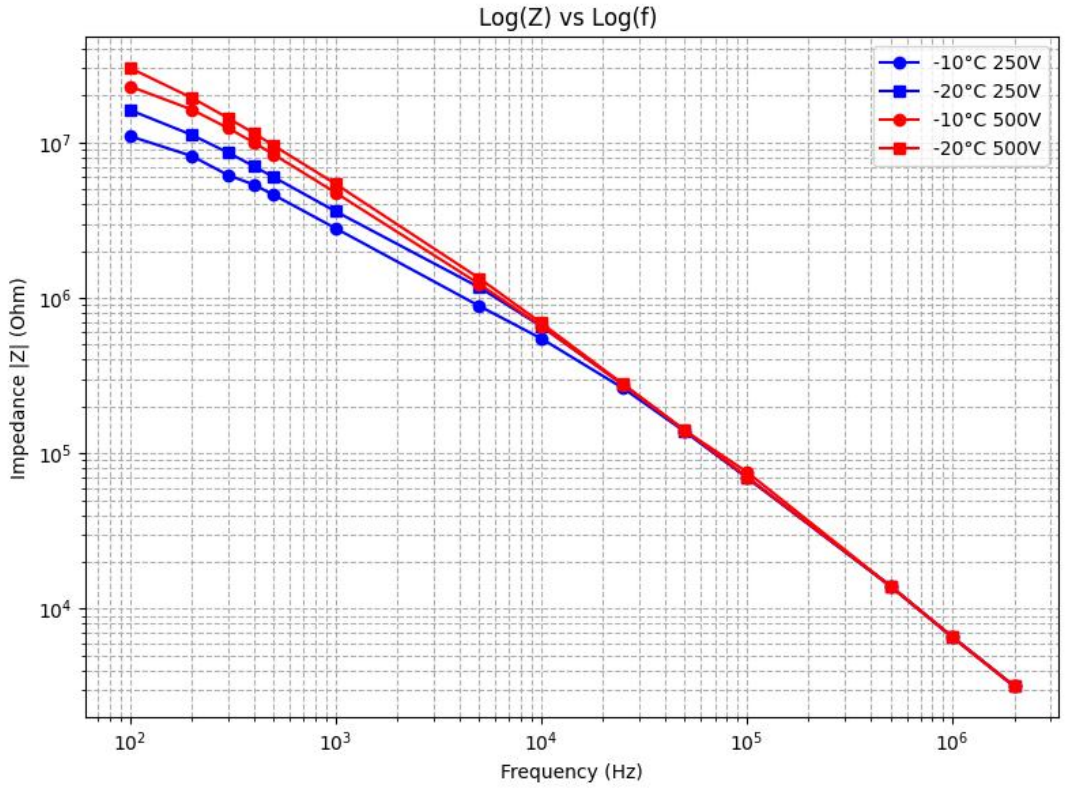
- The old box measurement is consistent with results from other frequency stations, showing a capacitance of approximately 7.7 pF after full depletion.
- In contrast, the new box measures around 4.5 pF at full depletion, resulting in an absolute discrepancy of about 3 pF compared to the old box.

Further investigation on CV

- We used test setup to scan range from 100Hz to 2MHz
- –20℃/–10 ℃ ， 250V/500V humidity < 10%
- Not observe any clear region where the inductive behavior (i.e., impedance increasing with frequency) dominates, even up to the maximum frequency supported by the KEYSIGHT E4980A (2 MHz).
- There is a slight difference due to temperature in the capacitance–dominated region, and all four datasets show very good overlap in the high–frequency region (100k – 1M Hz).

$$Z = R + j\omega L + \frac{1}{j\omega C}$$

$$|Z| = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$



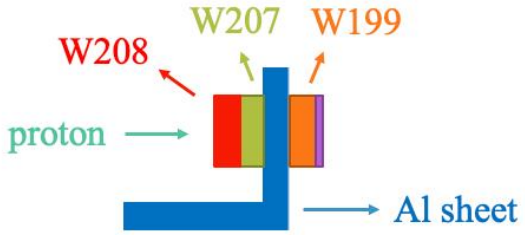
Summary

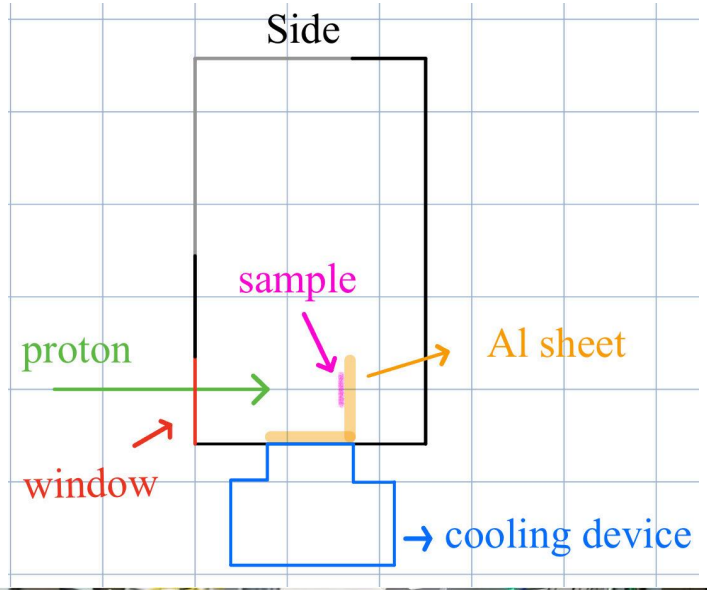
- IHEP has passed the CCE/IV/CV site qualification and CSNS pass the irradiation site qualification.
- China ATLAS ITk group has fully prepared all materials and devices required for irradiation, and now only awaits experimental approval from the irradiation sites to commence operations.
- With the assistance of the community, we conducted extensive CV–related inspections, which have significantly enhanced our understanding of the post–irradiation CV results.

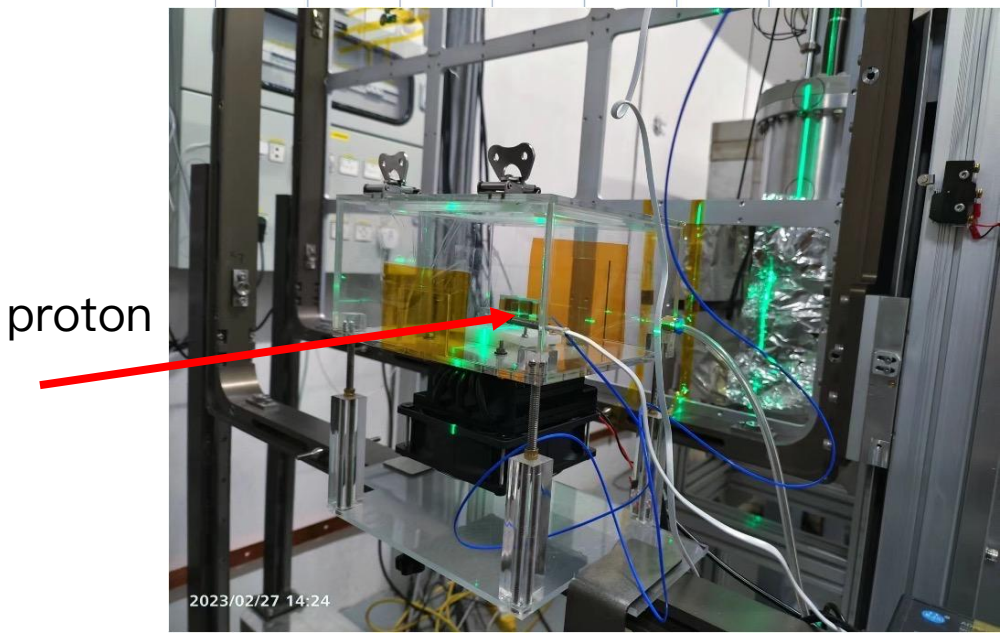
Thank you!

Low temperature irradiation setup

- QA irradiation should be conducted at less than –15°C to avoid the sample annealing and simulate the ATLAS ITk at the the normal run time. To meet this requirement:
- Temperature (T ~ –15°C) control: Semiconductor refrigeration sheet + aluminum sheet
- Humidity (RH ~ 5%) control: Air compressor + dryer
- Temperature monitoring: Thermocouple + Thermometer
- Humidity monitoring：Electronic hygrometer

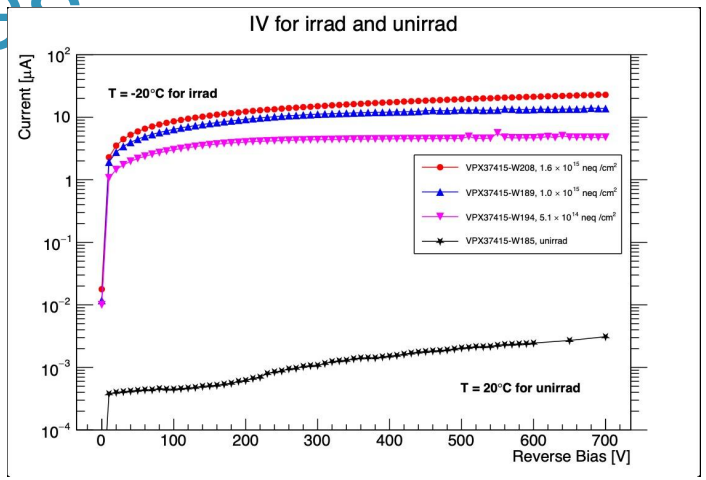


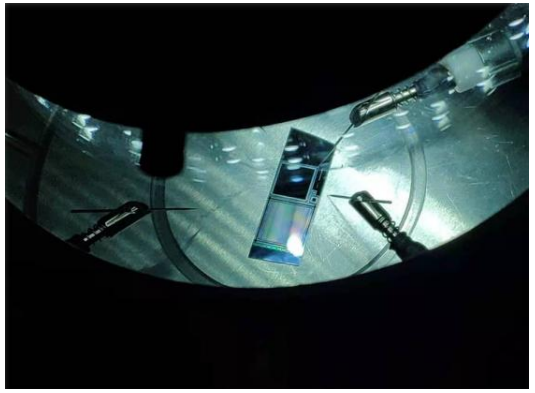


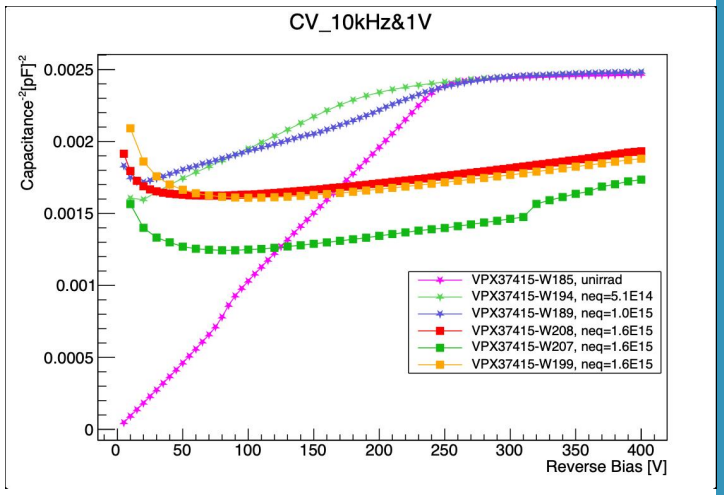


IV and cv test on md8 diodes

- For unirradiated diodes, the current should not exceed 0.1 μA/cm2 at 500V (RH
- The diodes should show a leakage current of less than 0.1 mA/cm2 at 500V (–20°C) after irradiation to 1.6× 10^{15} neq/cm2.
- Onset of micro–discharge should be at VMD>500V for both unirradiated and irradiated diodes.
- For unirradiated diodes, the depletion voltage (VFD) should be less than 350V.

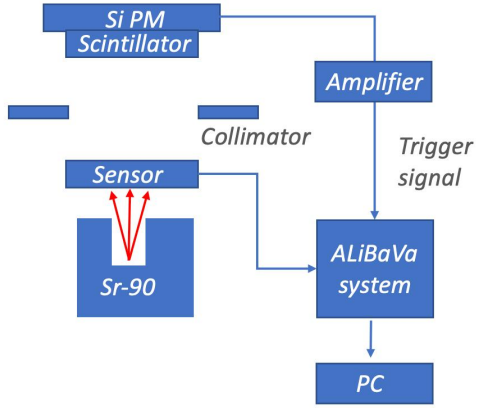


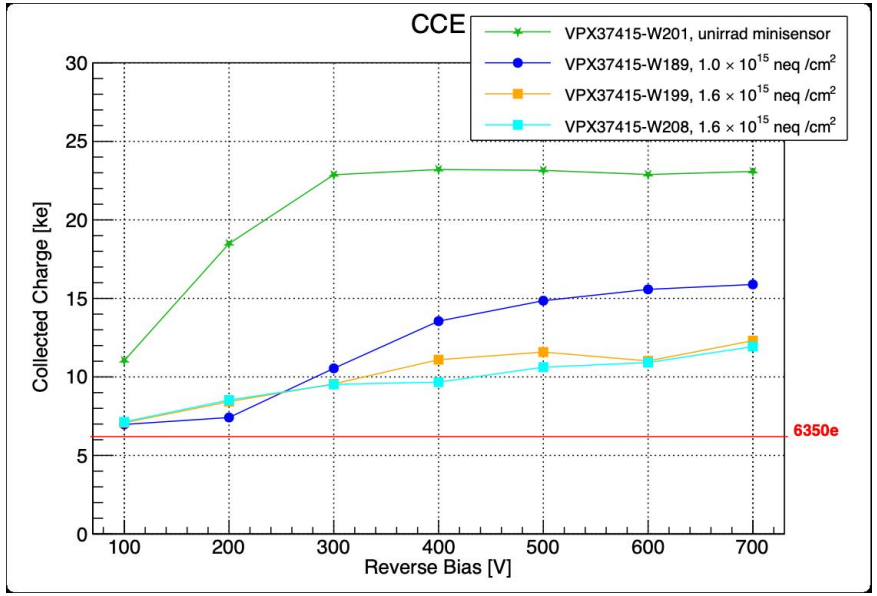




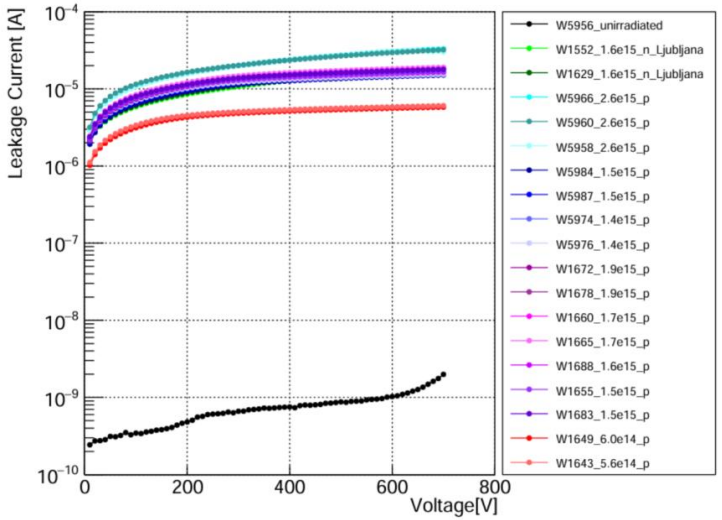
CCE test on mini sensors

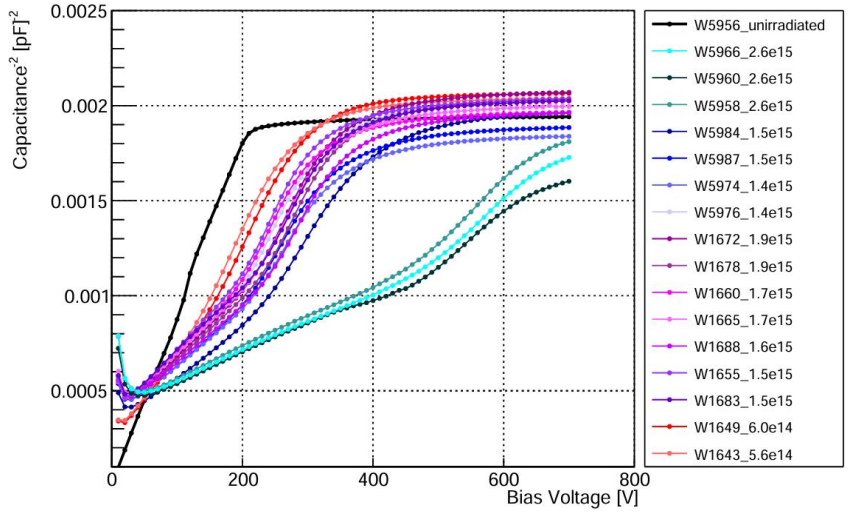
- ALiBaVa Setup
- Landau convolutional Gaussian distribution of signal spectrum
- Obtain the ADC value of the Landau peak
- Combined with the calibration to get the collected charge
- At 500 V, the CCE of data points for unirradiated mini sensor ~ 23ke− , for 1.0×10^{15} neq/cm2 ~ 15ke− , for 1.6×10^{15} neq/cm2 ~11ke− . The collaboration has established a minimum threshold of 7.5 ke− .





IV/CV test site qualification





1kHz

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