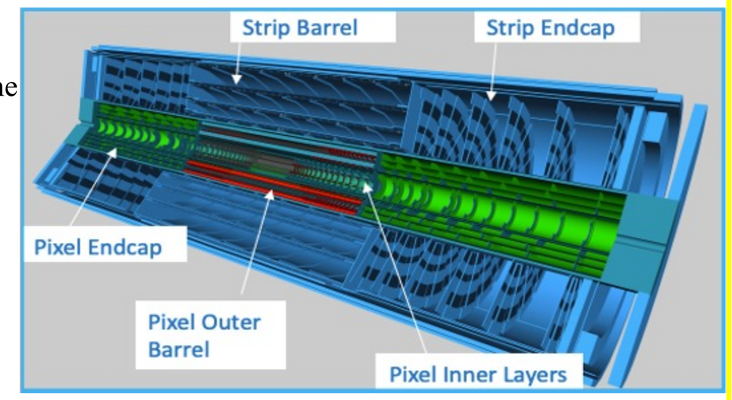
A study on the feasibility of CSNS becoming an ATLAS ITk sensor QA irradiation site

H. Li[a,b,*], Z. Li[b], S. Wang[b], Z. Xu[b], X. Chen[a], M. Xia[a], Y. Huang[c], Y. Liu[c], Z.Tan[d,b], H. Jing[d,b], S. Xiao[e,f], V. Fadeyev[g], M. Ullan[h], Y. Unno[i], X. Shi[b,*]

[a] Physics Department, Tsinghua University, Beijing, China
[b] Institute of High Energy Physics (IHEP), Chinese Academy of Sciences, Beijing, China
[c] School of Science, Shenzhen Campus of Sun Yat-sen University, Shenzhen, China
[d] Spallation Neutron Source Science Center, Dongguan, China
[e] Shandong Institute of Advanced Technology, Jinan, China
[f] Shandong University, Jinan, China
[g] Santa Cruz Institute for Particle Physics (SCIPP), University of California, Santa Cruz, USA
[h] Centro Nacional de Microelectrónica (IMB-CNM, CSIC), Barcelona, Spain
[i] Institute of Particle and Nuclear Study, KEK, 1-1 Oho, Tsukuba, Japan
[*] hui-li20@mails.tsinghua.edu.cn, shixin@ihep.ac.cn

Introduction

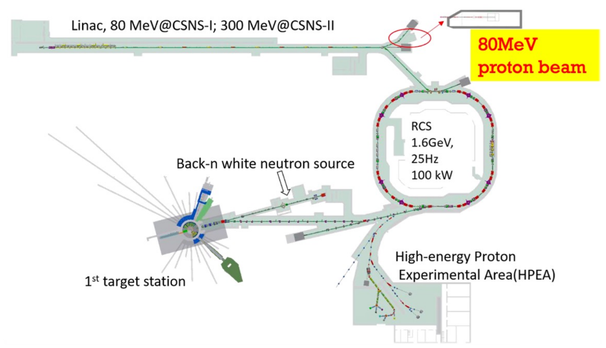
- The current ATLAS Inner Detector will undergo a complete upgrade in order to meet the requirements of the High Luminosity Large Hadron Collider (HL-LHC).
- In order to monitor nearly 22,000 large area silicon strip sensors production for the ATLAS Inner Tracker, a Quality Assurance (QA) strategy has been prepared to be carried out during the whole production period.
  - ➢ QA aims to flag the issues due to the fabrication process.
  - ➢ A detailed irradiation and testing plan has been prepared by the ATLAS-ITk Collaboration.

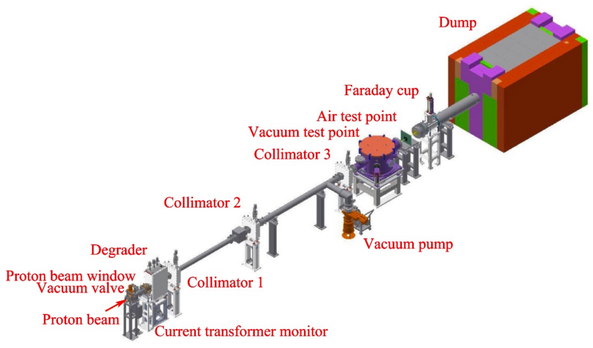


CSNS irradiation

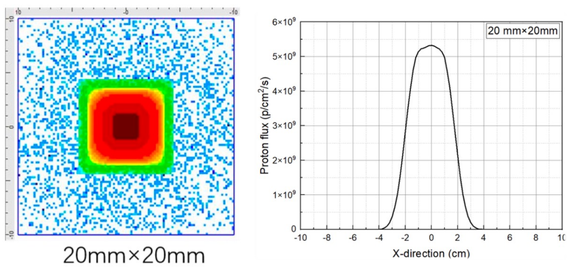
China Spallation Neutron Source (CSNS)

- Located in Dongguan city.
- It is the 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
- We use the Associated Proton Experiment Platform (APEP) in CSNS to irradiate the test samples. APEP locates at the end of the CSNS linear accelerator.





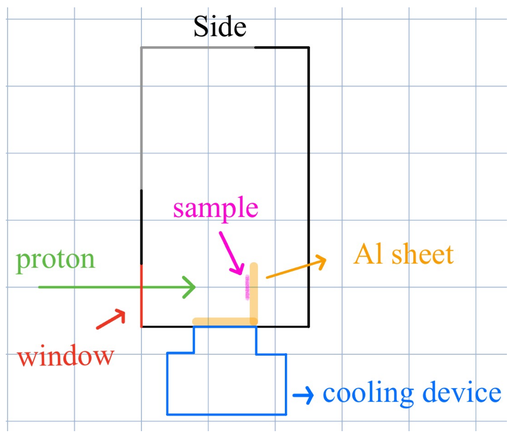
- We use a 20 mm × 20 mm (flat top of flux) beam spot.
- The proton beam energy is 80 MeV.
- The simulated flux intensity at the sample location for a beam spot of this size is 3.04 × 10^9 p/cm^2/s.
- It would take around 102.3 hours to reach 1.6 × 10^{15} neq/cm^2.



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



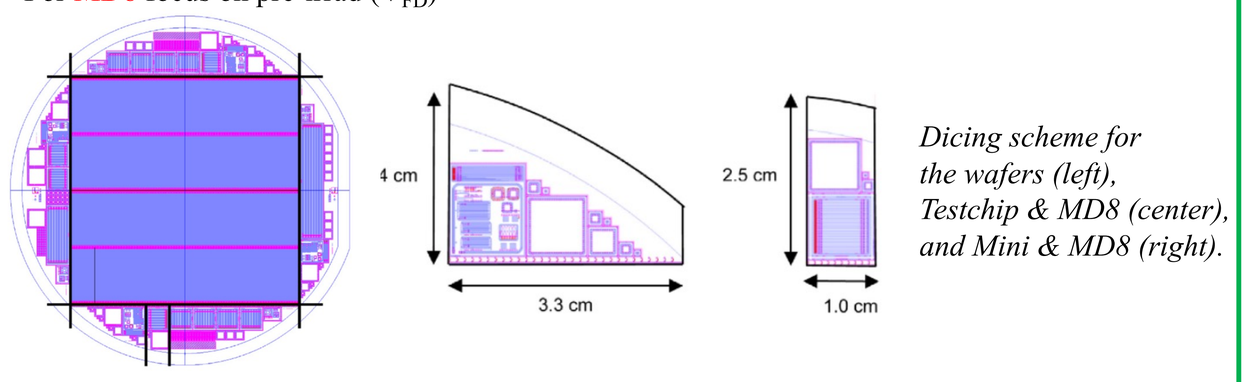
ITk Quality Assurance strategy

1. Test samples

The main devices that are used by the collaboration for QA purposes are the miniature strip sensors, with the same design as the MAIN (large format) sensor but with 1×1 cm^2 dimensions; the monitor diodes of 8×8 mm^2 size with contactable guard ring; and the ATLAS test chip.

Principles:

- For Mini sensor, focus on CCE (@1.6x10^{15} neq/cm^2)
- For Test Chip focus on pre-irrad and TID (@66 Mrad[Si])
- For MD8 focus on pre-irrad (V_{FD})



Dicing scheme for the wafers (left), Testchip & MD8 (center), and Mini & MD8 (right).

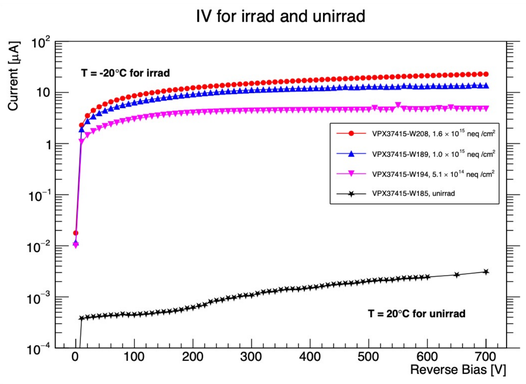
2. Planned irradiation and test

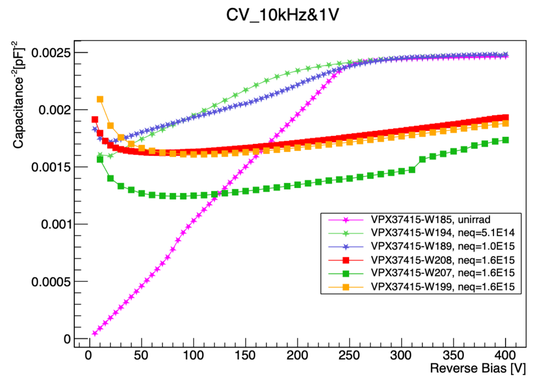
- All QA pieces are first delivered to CERN and then distributed to each irradiation site.
- The ITk strip sensors need to endure a high level of radiation. With the standard safety factors on projected particle fluences, they're designed to handle around an integrated total ionizing dose (TID) of 660 kGy (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.

Measurements

- At high temperatures, the diffusion of defects will happen. This process is called annealing.
- α is the current-related damage rate.
- The average α after a standard annealing scenario of 80 minutes at 60°C is 4 × 10^{-17} A/cm.
- The collaboration uses the parameter above for annealing, to get to the minimum of the non ionizing energy loss (NIEL) damage in the bulk.

IV and CV test on MD8 diodes

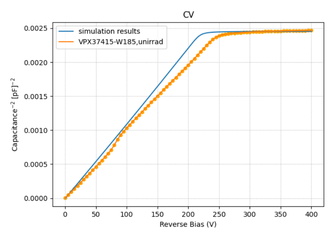




- ✓ For unirradiated diodes, the current should not exceed 0.1 μA/cm^2 at 500V (RH<20%).
- ✓ The diodes should show a leakage current of less than 0.1 mA/cm^2 at 500V (-20°C) after irradiation to 1.6×10^{15} neq/cm^2.
- ✓ Onset of micro-discharge should be at V_{MD}>500V for both unirradiated and irradiated diodes.
- ✓ For unirradiated diodes, the depletion voltage (V_{FD}) should be less than 350V.

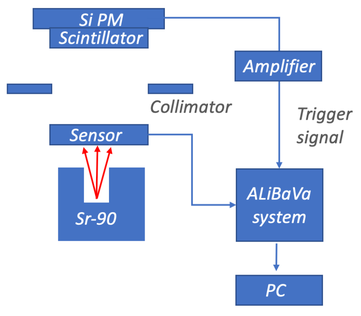
TCAD simulation

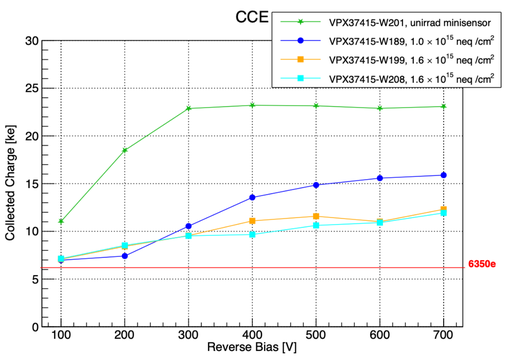
- Area of MD8: 8×8 mm^2
- Sample thickness: 305 μm
- n^+ implants in p-type bulk
- Bulk doping concentration: 3.2×10^{12} cm^{-3}



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 ~23 ke, for 1.0×10^{15} neq/cm^2 ~15 ke, for 1.6×10^{15} neq/cm^2 ~11 ke. The collaboration has established a minimum threshold of 6.35 ke.

Conclusion

- Several proton irradiations have been performed at the Associated Proton Experiment Platform (APEP) in China Spallation Neutron Source (CSNS).
- We tested ITk strip Mini and MD8 sensors with controlled temperature (-15.4°C) and humidity (5%) during irradiation.
- The fluence points used are from 5.1×10^{14}, 1.0×10^{15}, and 1.6×10^{15} neq/cm^2.
- The post-irradiation measurements (IV, CV, and CCE) are done, under the cold temperature (-8°C), after annealing for 80 minutes at 60°C.
- Test results are consistent with other sites, which means CSNS could be a proton irradiation site for ATLAS ITk sensor QA, after formal site qualification.

Acknowledgement: This work was supported by Tsinghua University Initiative Scientific Research Program and National Natural Science Foundation of China (No. 11961141014). It is part of the Spanish R&D grant PID2021-126327OB-C22, funded by MCIN/ AEI/10.13039/501100011033 / FEDER, UE. The work at SCIPP was supported by the US Department of Energy, grant DE-SC0010107.