ATLAS ITk Strip Detector Radiation Hardness Study and Integration

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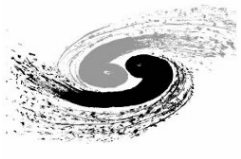
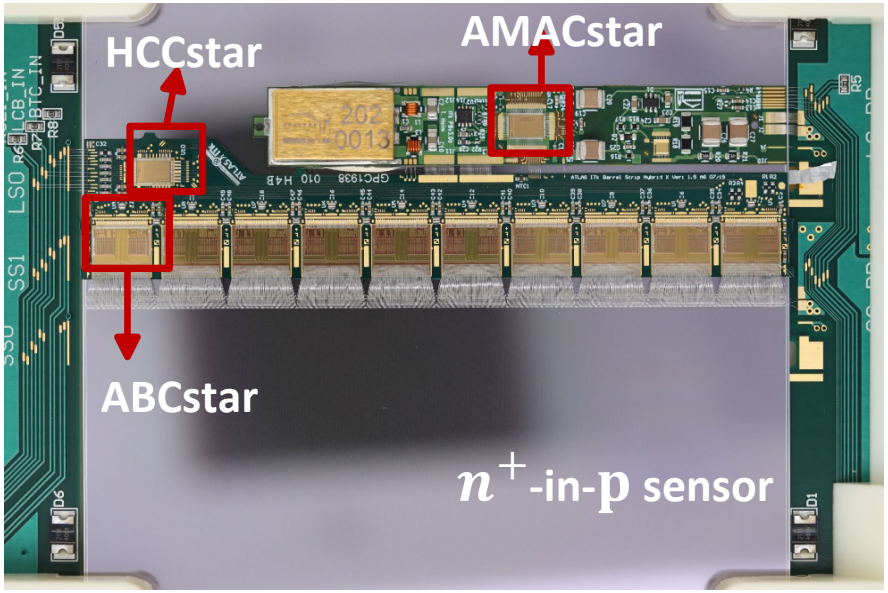
On behalf of the ATLAS ITk Chinese Group



MOST ATLAS Detector Upgrade Project Annual Meeting, 2025.6.6

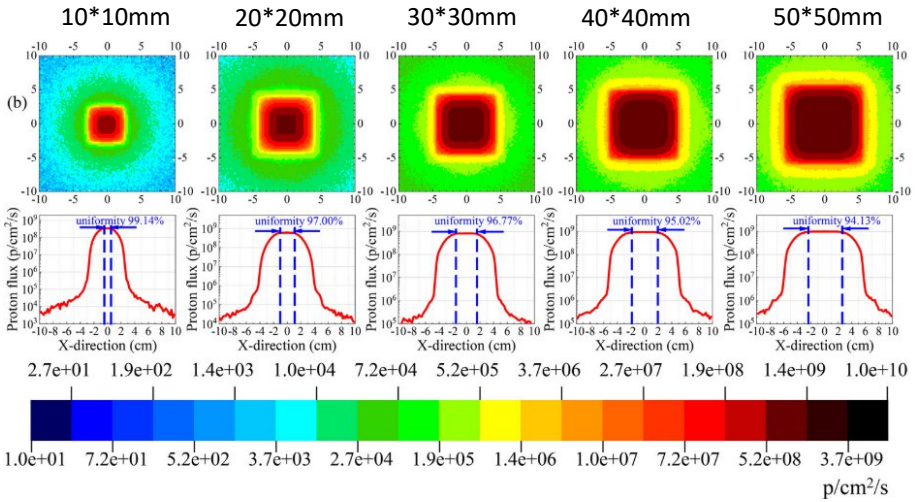
Radiation Effects

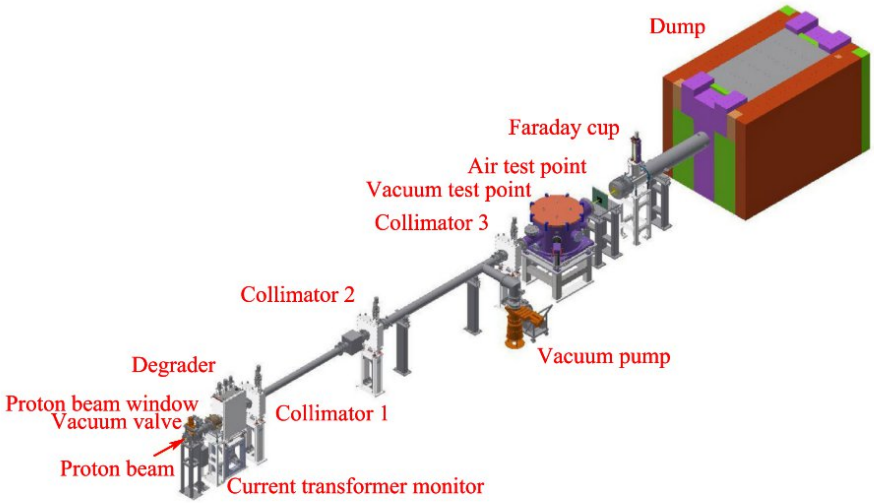
- Three main groups of radiation effects
  - **DDD**(Displacement Damage Dose): damage the atomic structure,not ionize the medium—>**Sensor:charge capture**
  - **TID**(Total Ionizing Dose): Ionize the medium, not has enough energy to structually damage it —> **Chip:significant increase of current**
  - **SEE**(Single Event Effects):Release enough energy to produce malfunction—>**Chip:memory bits flipped and data stream destroyed**
- Radiation damage study carried out on sensors and ABC/HCC/AMACstar



Proton Irradiation at CSNS

- Irradiation with the proton beam at China Spallation Neutron Source(CSNS)
- Beam Energy range: $10-80MeV$
- Beam spot size: $10 \times 10mm^2-50 \times 50mm^2$
- Beam spot uniformity: >90%





Sensor Radiation Study

- **Sensors Quality Assurance (QA):** aims at monitoring of radiation tolerance
- Dedicated radiation samples: 1cm× 1cm mini sensor, 0.8cm×0.8 cm MD8 , with the same layout as main sensors
- Radiation damage depends on particle type and energy

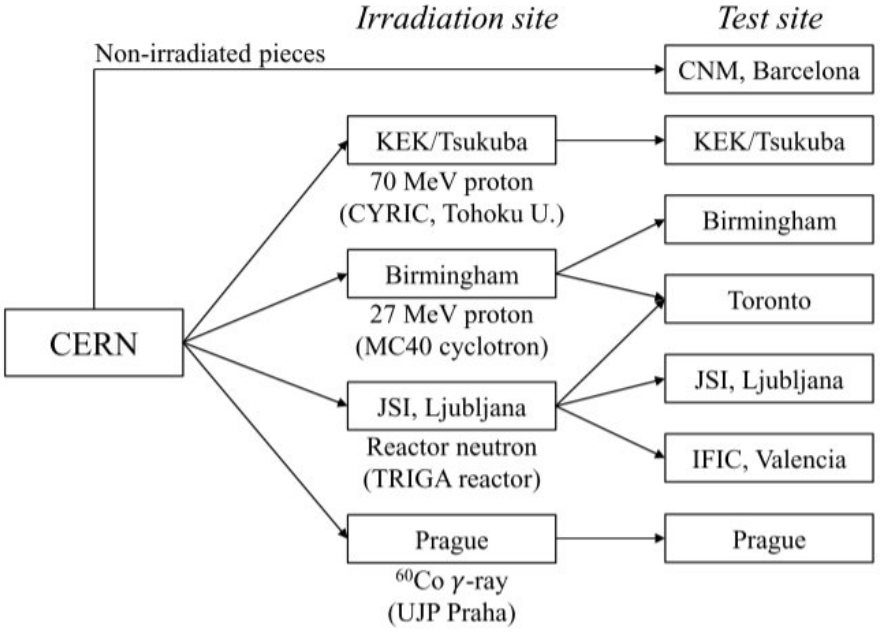


Fig. 2. Flow chart of the strip sensor QA test pieces for the pre-production QA.

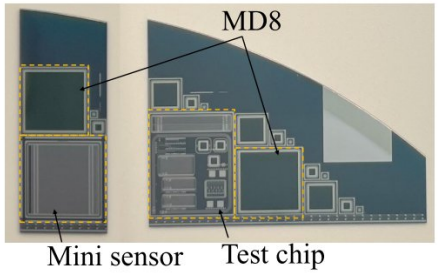
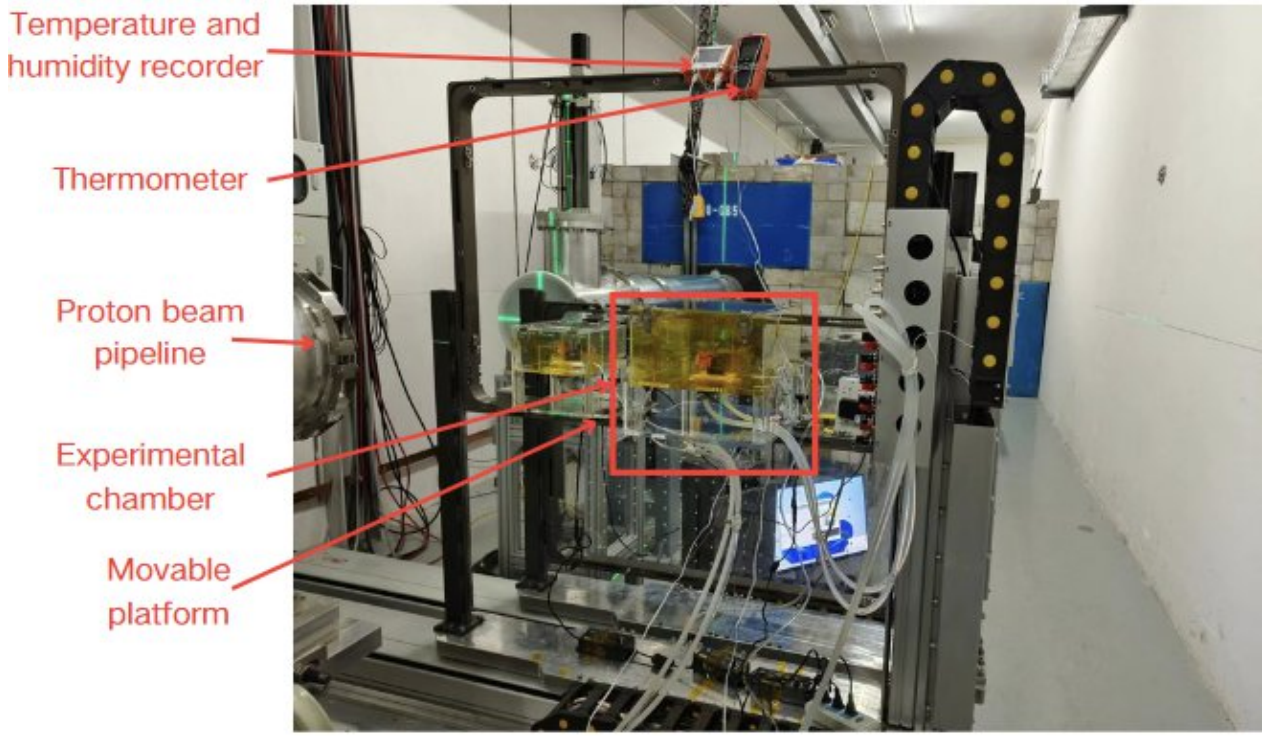


Fig. 1. Photos of the QA test pieces. The left structure holds a mini sensor and an MD8 while the right one a test chip and an MD8.

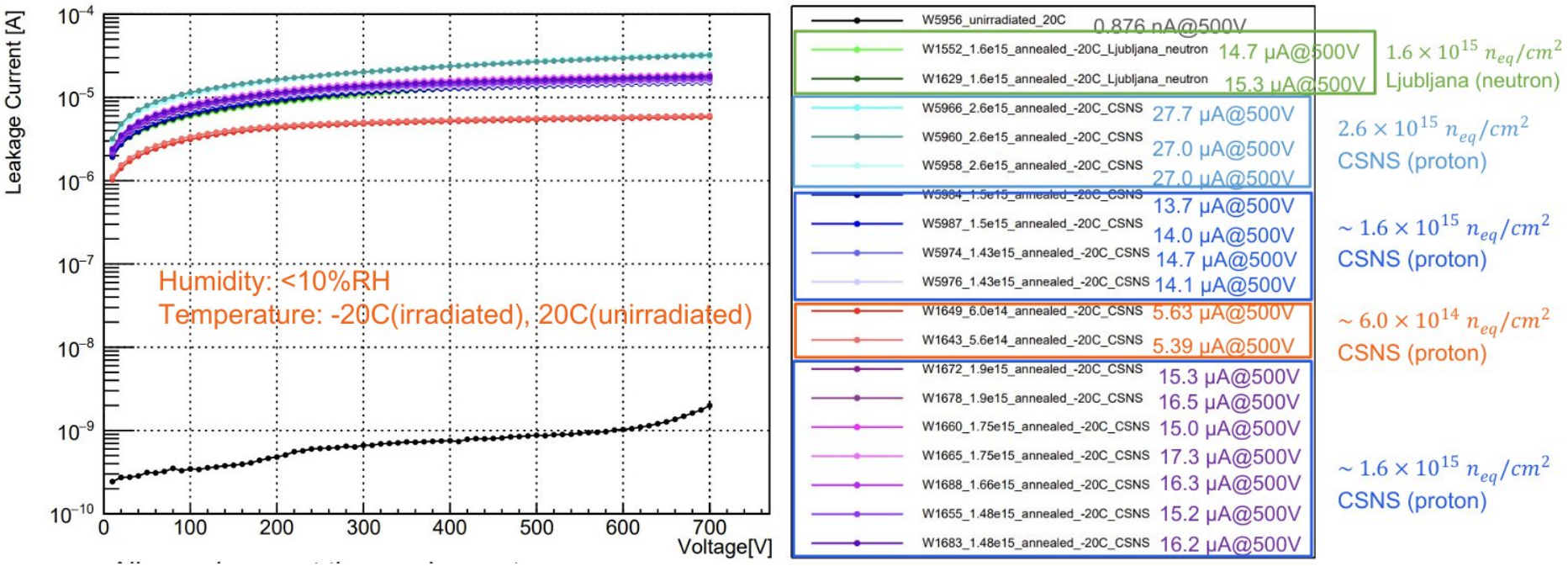
- After irradiation at the irradiation sites, all QA pieces are distributed to test sites, to characterize: I-V, C-V, Charge Collection Eff.(CCE)
- **A good opportunity to step in: 70MeV proton beam at KEK is gone in 2025**

Setup for Sensor Irradiation

- Custom made chamber to reach good cooling and humidity control: **-20℃, <10%RH**
- Latest setup: up to 16 samples in two chambers can be irradiated in one week
- Three irradiation were carried out
- **18 sensor samples have been irradiated with proton beam at CSNS**
- 5 irradiated samples from Ljubljana and Birmingham to cross check

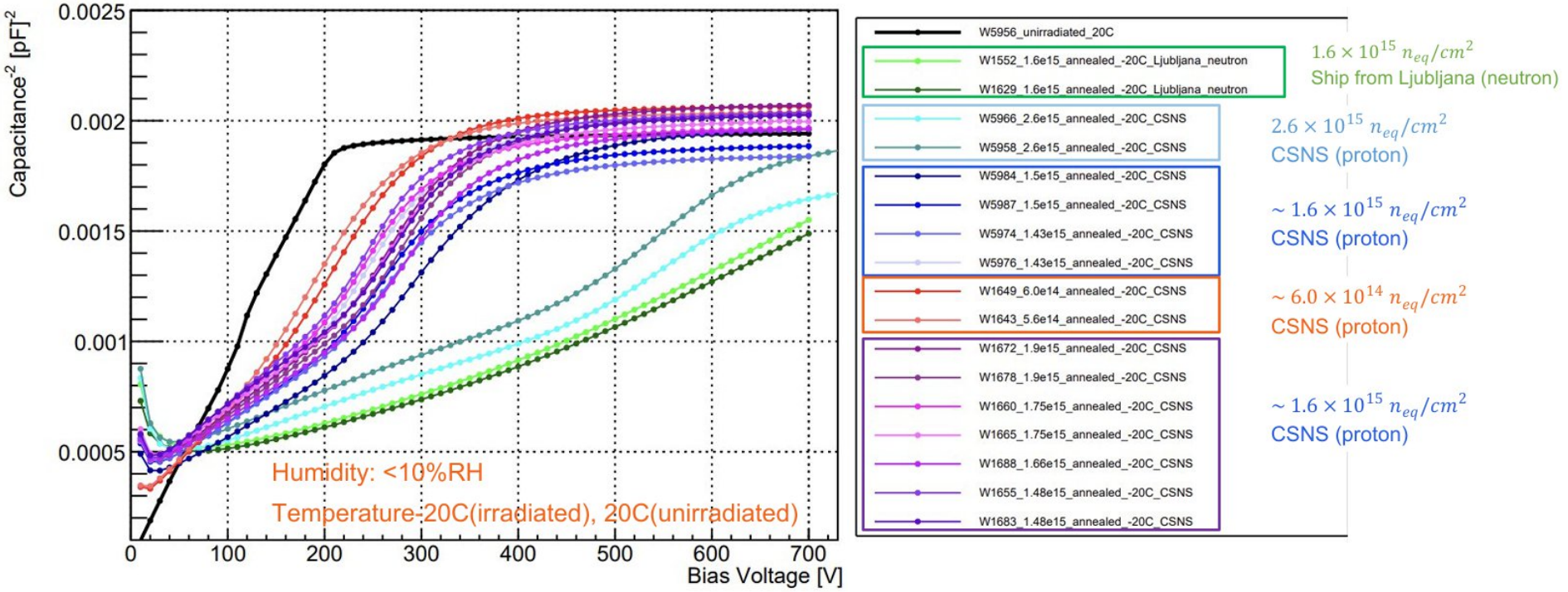


I-V



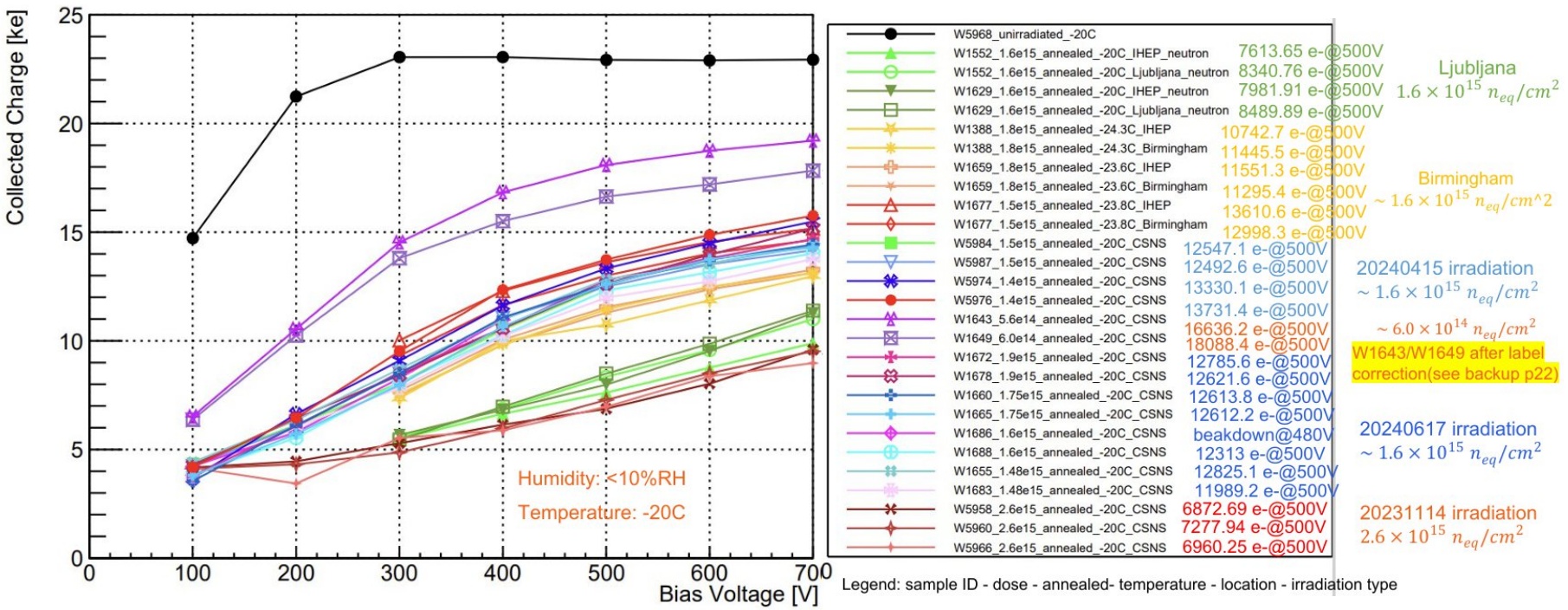
- **All samples meet the QA requirements:**
  - <0.1μA/cm^2 at 500V for unirradiated samples
  - <0.1mA/cm^2 at 500V for samples irradates with fluence $1.6 \times 10^{15}\ n_{eq}/cm^2$
- **Samples irradiated with the same fluence have the same behavior**
- The higher the fluence, the greater the leakage current

C-V



- QA requirement on fully depletion voltage V_{FD}: **no more than 350V for unirradiated sample**
- Irradiation samples hard to fully deplete

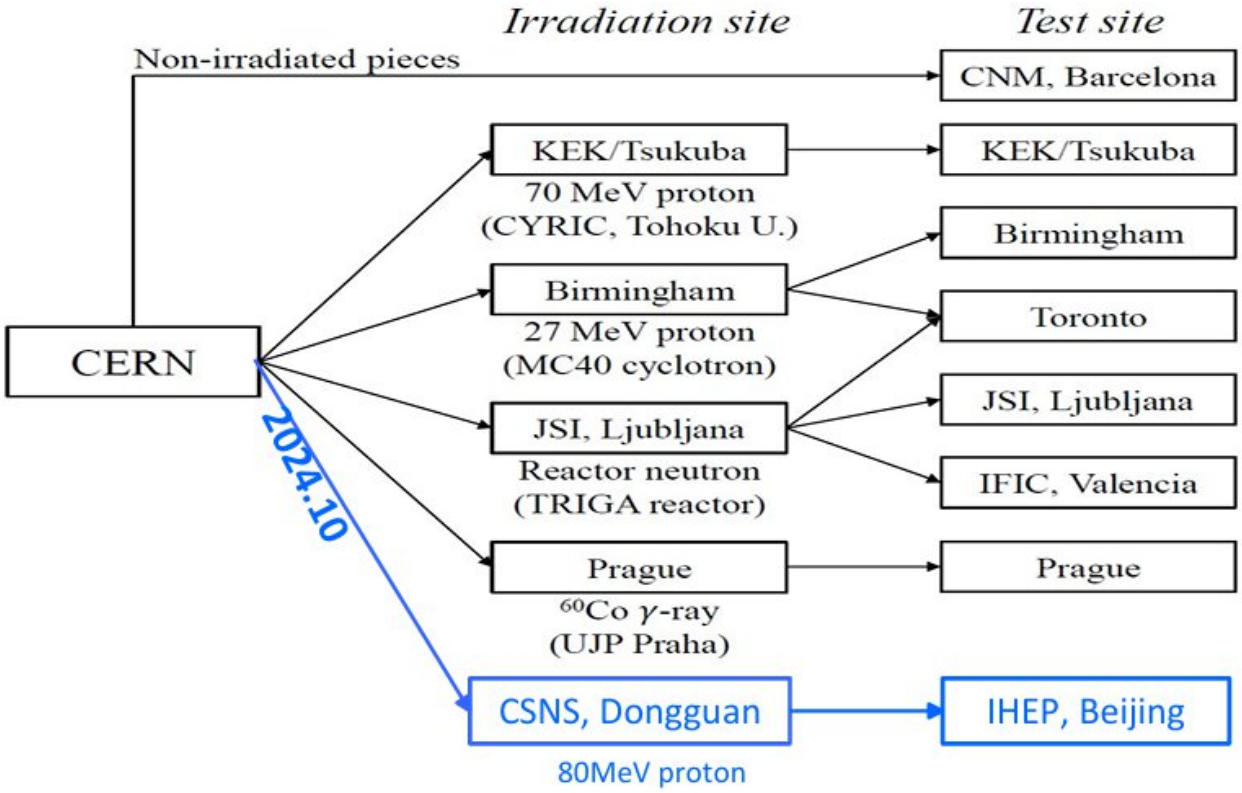
Charge Collection Efficiency



- **Lower charge collection**
  - **Sensor not fully depleted**
  - **Charge trapped by defects in sensor**
- **QA requirement: more than 6350 e- at 500V when the fluence reach $\mathbf{1.6 \times 10^{15}}\ n_{eq}/cm^2$** (10 years operation x 1.5)

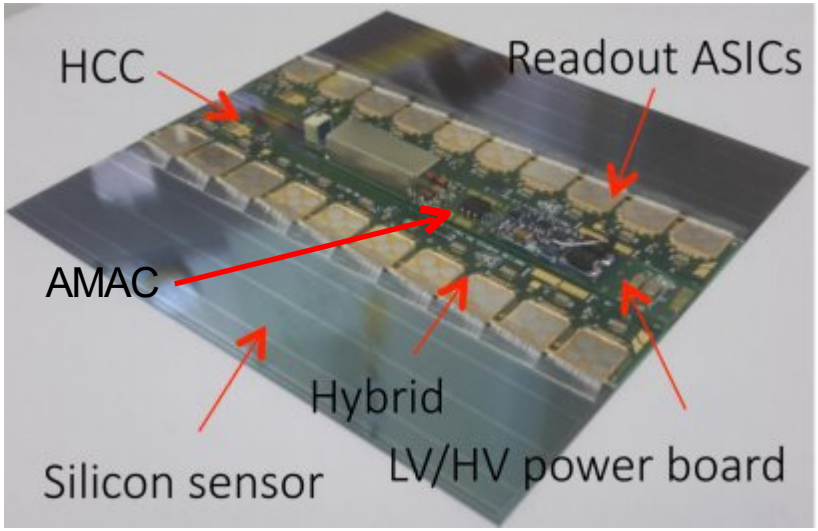
CSNS/IHEP Qualified as Sensor Irradiation/Testing Site

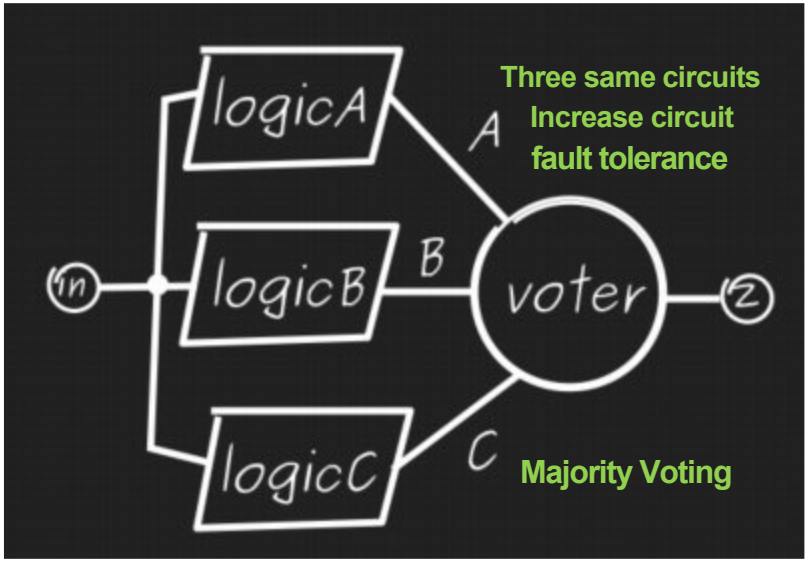
- **Key properties of sensor (I-V, C-V and CCE) we measured are in good agreement with those from Ljubljana and Birmingham**
- **Both the irradiation and testing setup and the measurements are solid**
- **CSNS/IHEP are qualified as a QA irradiation/testing site for sensors**

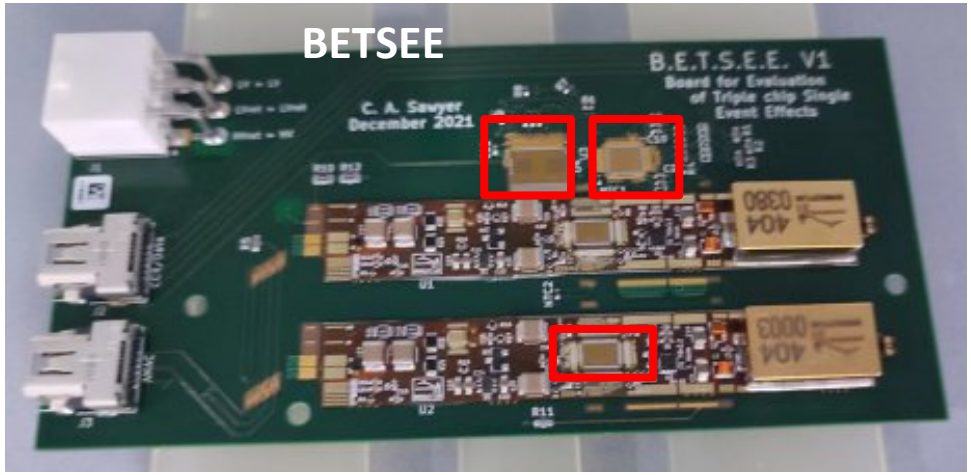


Irradiation Study of ASICs

- ITk modules include 3 kinds of ASICs
- **SEE flips logic state and destroy data**
- **All ASICs were designed with triple redundancy to protect against SEE**
- SEE study
  - **Single chip board** carrying ABC/HCCstar
  - **BETSEE board** carring four chips



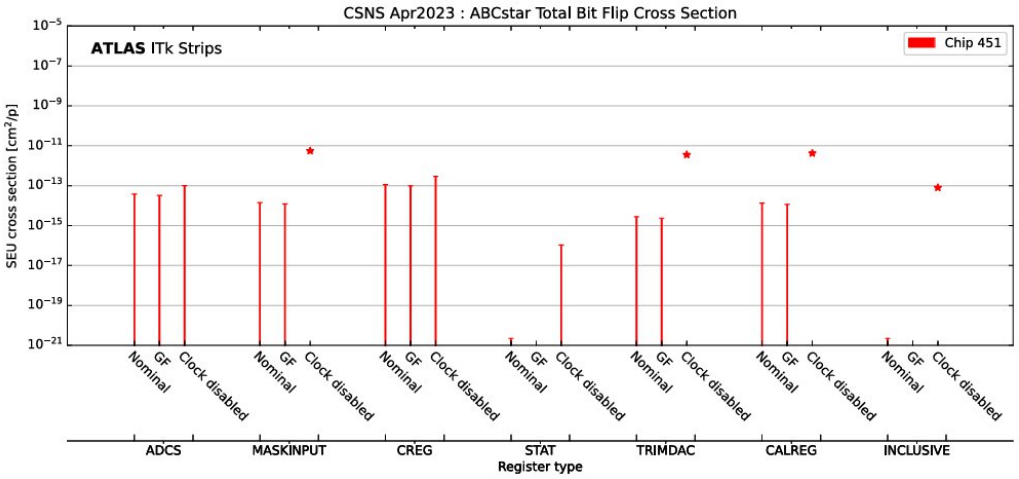


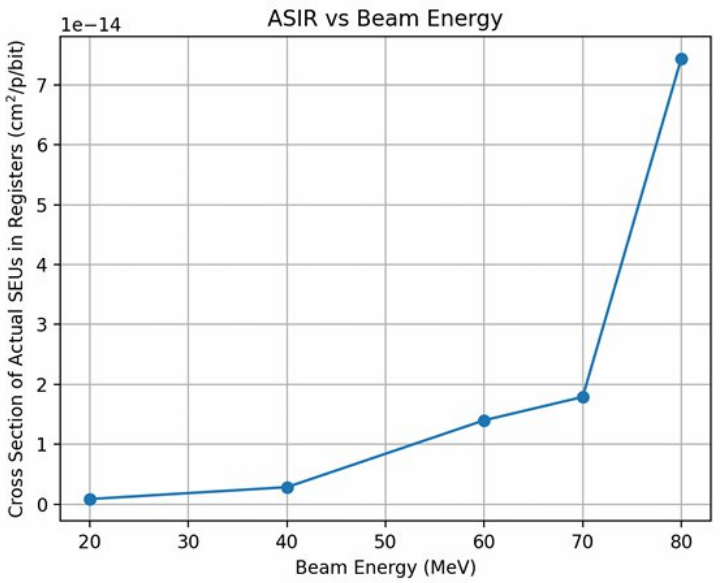


Cross-sections of SEE

- SEE cross-sections for bit-flips in registers at fixed patterns

$$\sigma_{SEE} = \left(\frac{1}{N_{bits}}\right)\frac{N_{flips}}{\Phi_{total}}$$





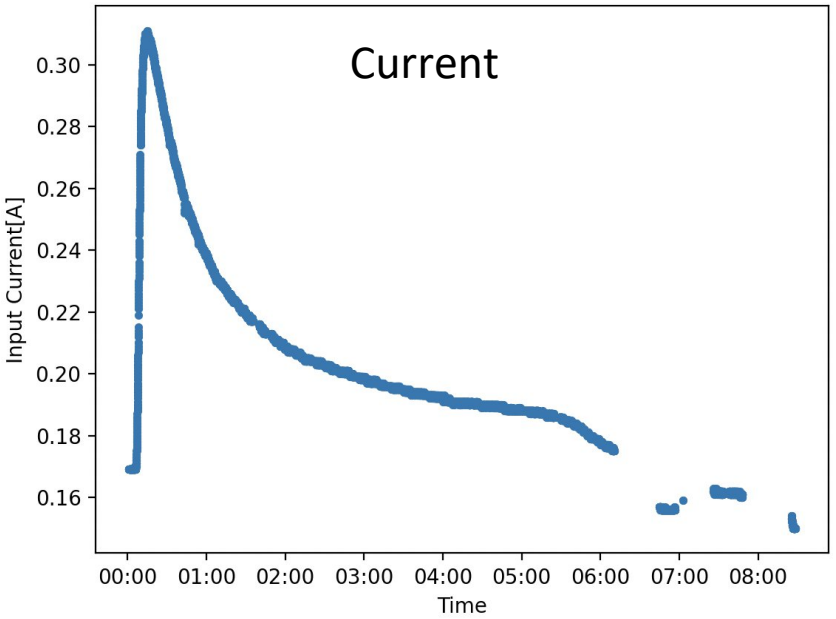
error rate during normal operation is $\mathcal{O}(10^{-9})$ errors/event/ABC

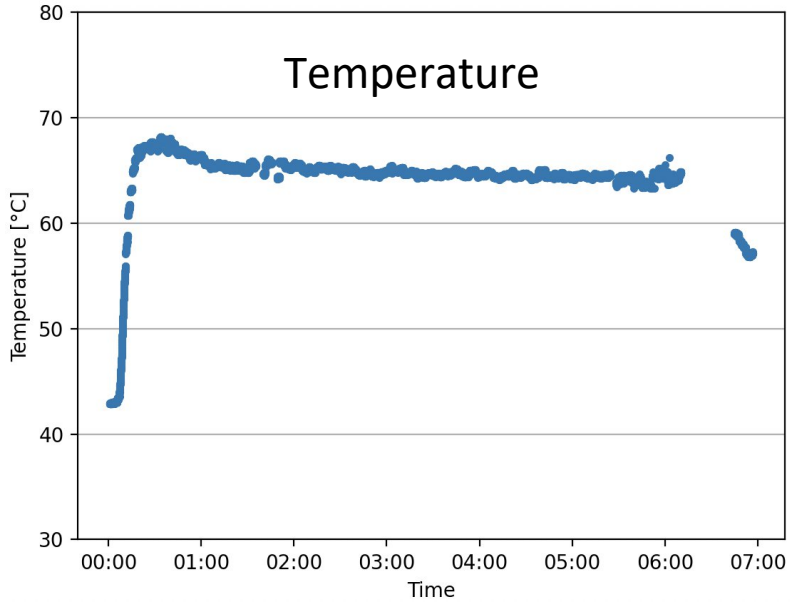
more bits flip as the energy of the beam paritlcles increase, higher LET

- **The triple redundancy of crucial logic designed in ASICs really does the work**

ASICs - TID Bump

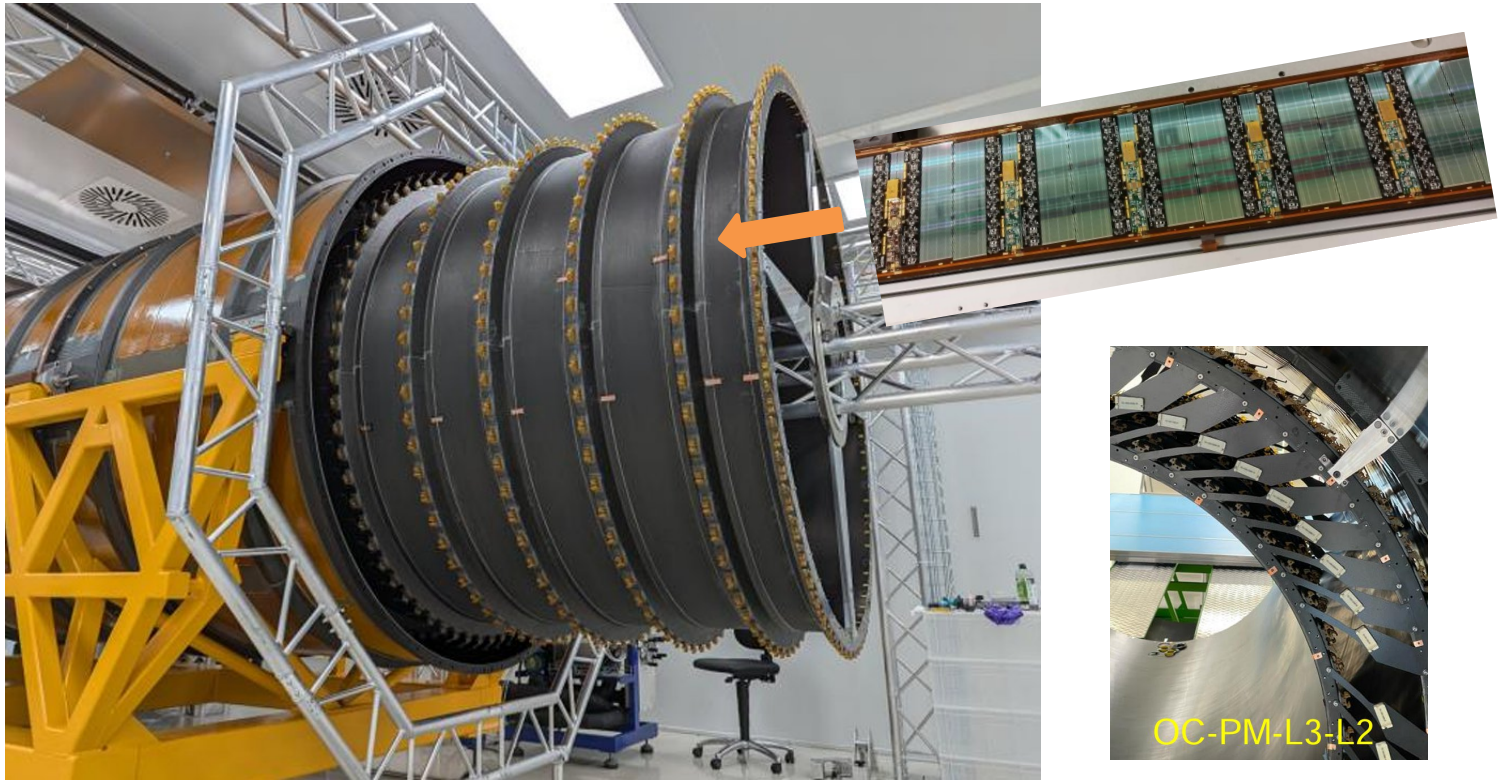
- All 3 ASICs made in 130nm CMOS technology at Global Foundries (GF)
- **TID bump is a well known feature of 130nm GF chips**
  - Under irradiation, the current rapidly increases and then drops
- **Pre-irradiating the ASICs to 5Mrad, to avoid the peak in operation**





Detector Integration

- ITk barrel integration is to happen at CERN
- Staves loaded with 28 modules will be inserted in four concentric Carbon cylinders (L0-L3)
- The global structure, Outer Cylinder (OC) hosts the ITk, already at CERN in the integration hall
- **L3 and L2 already assembled into OC, and the stave insertion tool installed and tested**



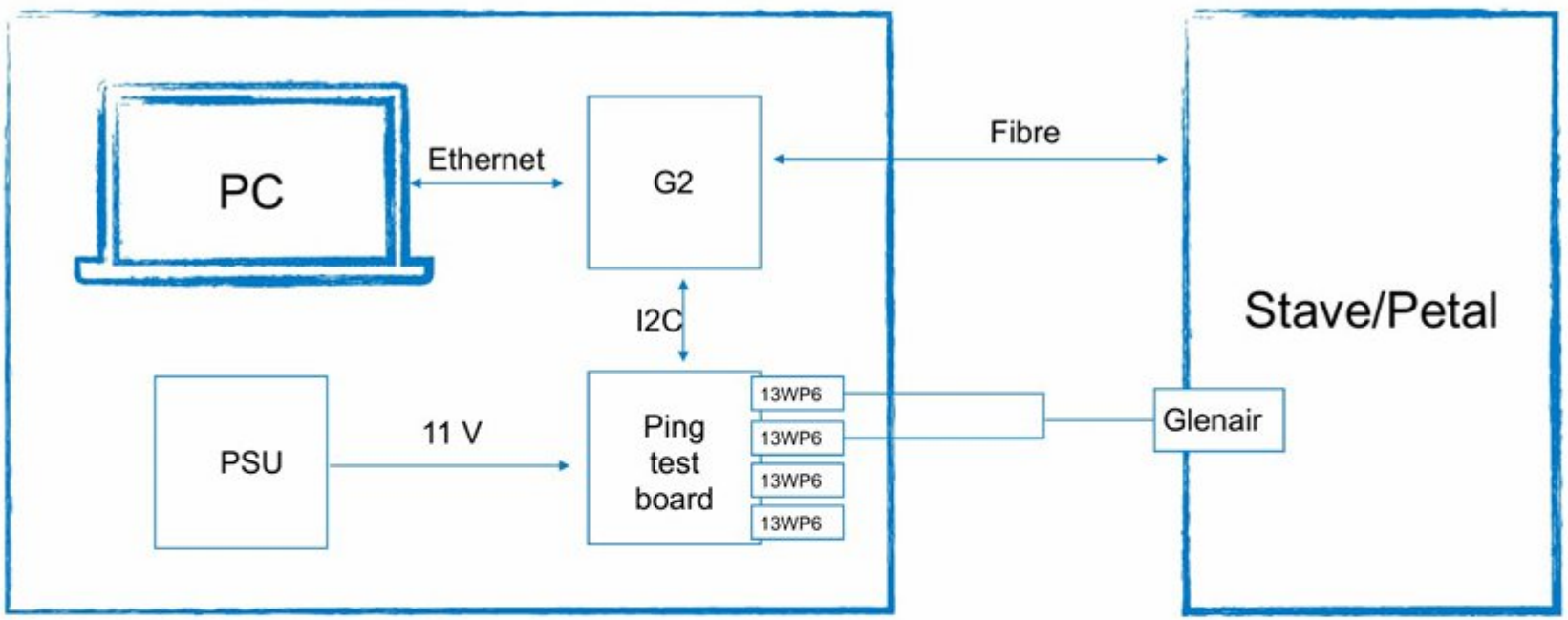
Ping Test

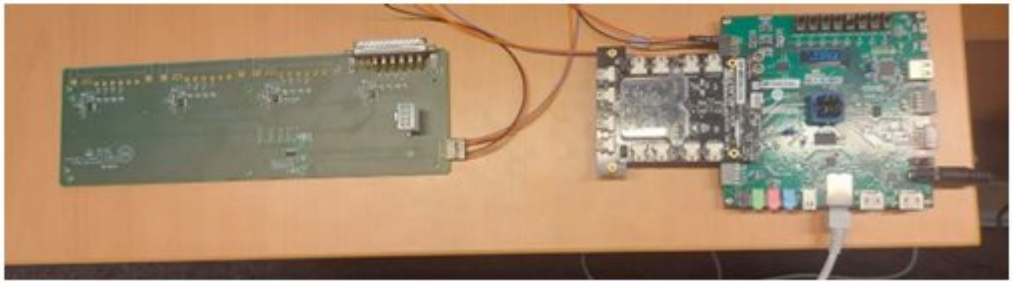
- One crucial testing performed once the stave in inserted to the cylindrical structure.
- The test in done in one minute, ensuring all electronics parts are functional and the sensor being active.

Step	Duration [s]	Comments
Switch on Stave/Petal Side	2	
Configure lpGBT (master)	1	
Configure VTRX+	5	Turn off redundant laser drivers, will save about 1/3 of power
Configure lpGBT (slave)	10	Slower configuration than first as via I2C (only short-strip staves)
Configure AMACs	14	
Measure HV lines	10	DVM/ADC measurement of light voltage (w/ HV switch)
Switch on DCDC	2	
Release HCC LP mode	2	HCC reset released here too
Configure HCC	2	Configuration includes a check of HPR packets
Release ABC LP mode	2	
Configure and test ABC	5	Configuration includes a check of HPR packets, burst of triggers to see FE connections
Switch off DCDC	2	
Switch off Stave Side	2	
TOTAL TIME	**59**	**Should be able to do full ping test of one side in estimated 1 minute**

Ping Test Setup

- Ping test setup ready at CERN
- Contribution to staves reception test and ping test





Summary

- **Irradiation study**
  - Committed in the program

    在硅微条传感器和读出电子学方面，拟采用高能质子束方法分别对硅微条传感器和读出电子学专用芯片进行辐照，测试辐照后硅微条传感器的电流电压特性、电荷收集效率的变化；读出芯片在的辐照下的单粒子效应、异常逻辑状态的及时恢复等性能。

  - **How is it going?**
    - Proton irradiation study of both sensor and ASICs have been carried out
    - (Un-)irradiated sensors are well characterized
    - The triple redundancy of crucial logic designed in ASICs really does the work

- **Detector integration**
  - Committed in the program

    在径迹探测器系统方面，拟通过高精度的龙门吊将 28 个硅微条探测器模块安装在碳纤维板条上组装成硅微条探测器桶板，并进行高低温环境下的电子学测试；通过机械精准定位将桶板集成到径迹探测器的支撑结构上，实现系统供电、冷却、数据传输，并进行系统联调测试。

  - **How is it going?**
    - Starting soon
    - We contribute to stave reception and ping test