ATLAS ITk 硅微条束流测试研究

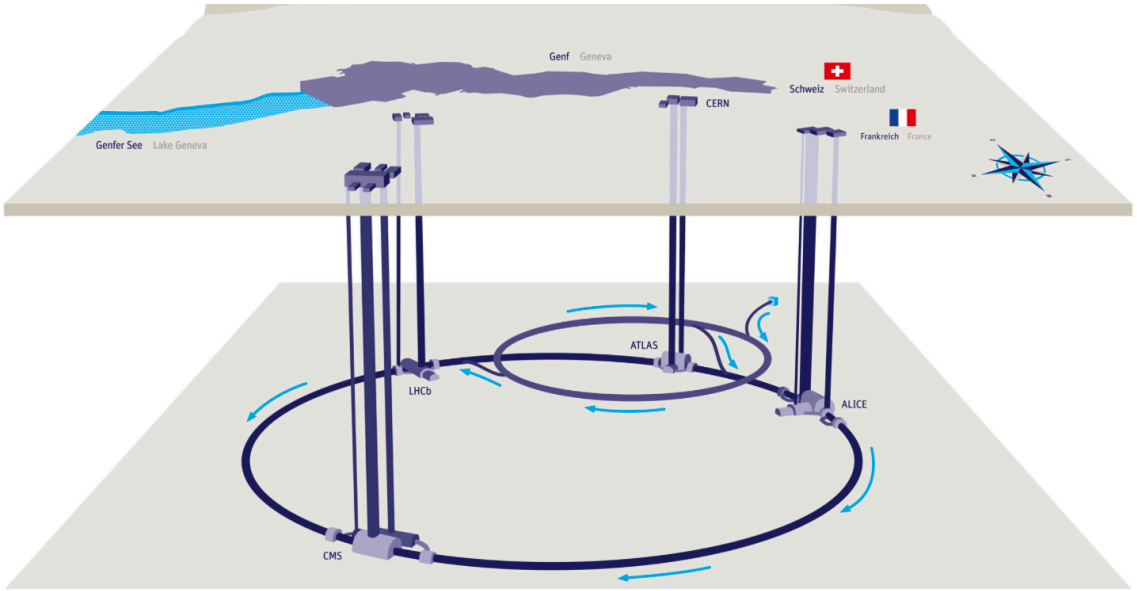
何亚君
中科院近代物理研究所
第二届测试束流与先进探测技术研讨会
2026年10月11日@长沙

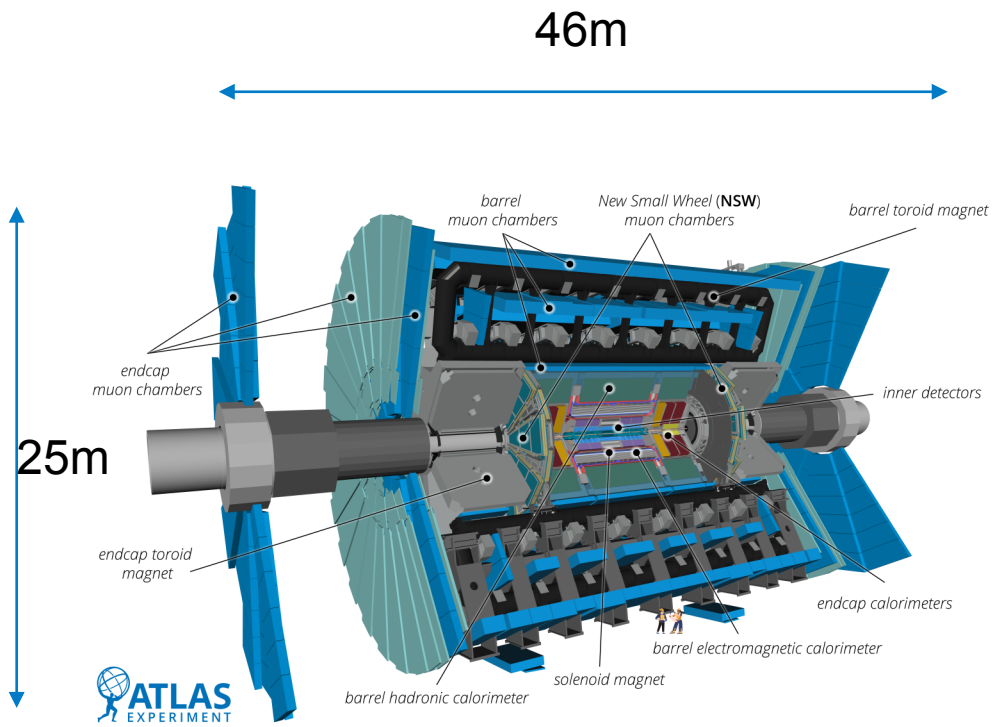
Most of the work presented in this talk was carried out at DESY, where I was previously affiliated.

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- ATLAS ITk 硅微条探测器介绍
- ITk硅微条束流测试及分析系统
- 模块性能测试及设计问题评估
- ITk 硅微条DAQ系统束流测试进展
- 总结

ATLAS 探测器





TOPIC: Accelerators

CERN bids farewell to the LHC and enters Long Shutdown 3

The Large Hadron Collider is embarking on its most ambitious upgrade yet

—

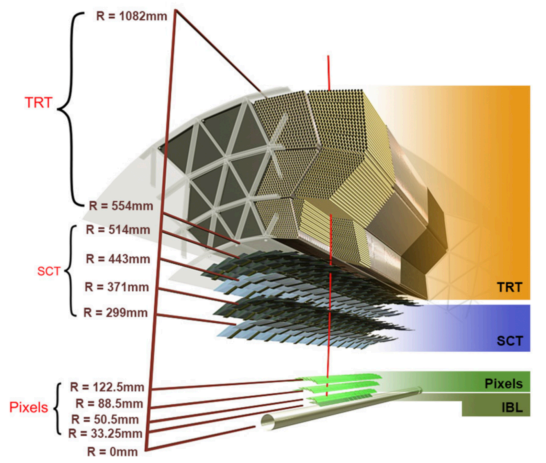
29 June, 2026

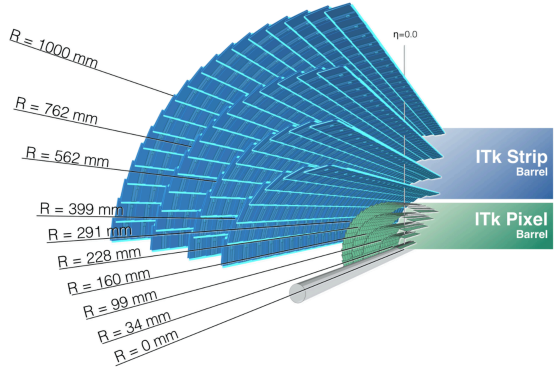
26 June, 2026

ATLAS phase II 升级

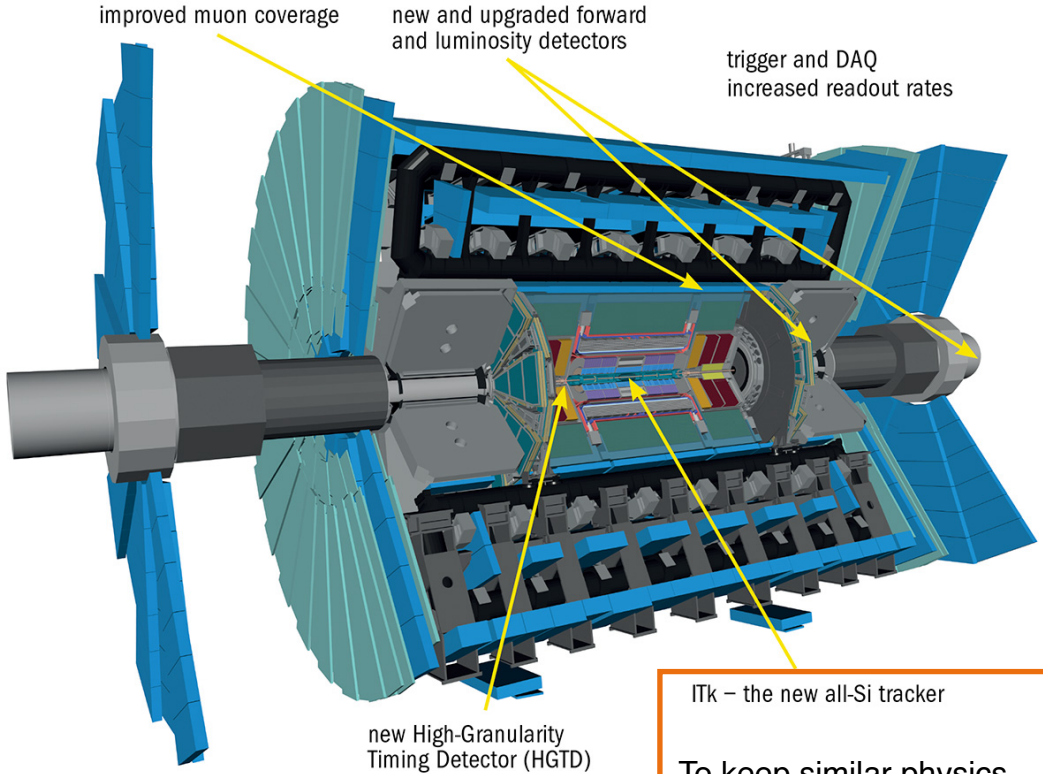
- **LHC → High-luminosity LHC from 2026**
  - More interactions of interest: 50 →200 per BX
  - More pile-up events: 60 →200 per BX

- **Key requirements change for tracking:**
  - Trigger rate
    - 100 kHz → 1 MHz
  - Worse radiation damage
    - up to 2×10^{16} n_{eq}/cm^2





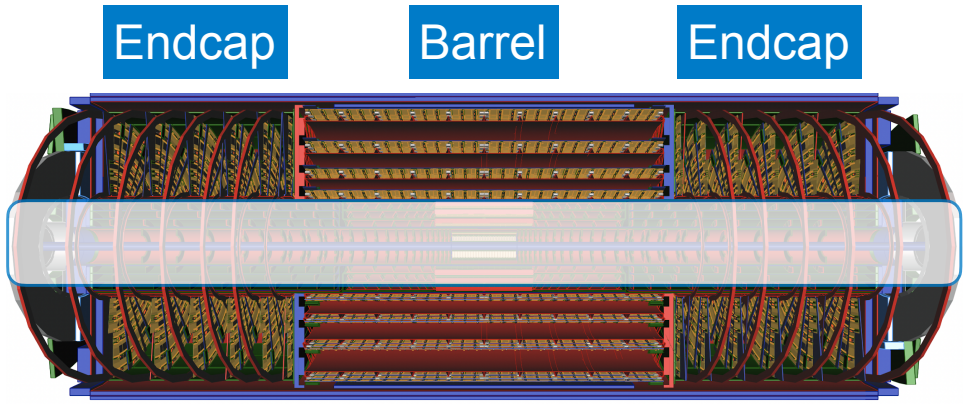
Old: Si+gas New： all silicon **Inner Tracker (ITk)**



ITk – the new all-Si tracker

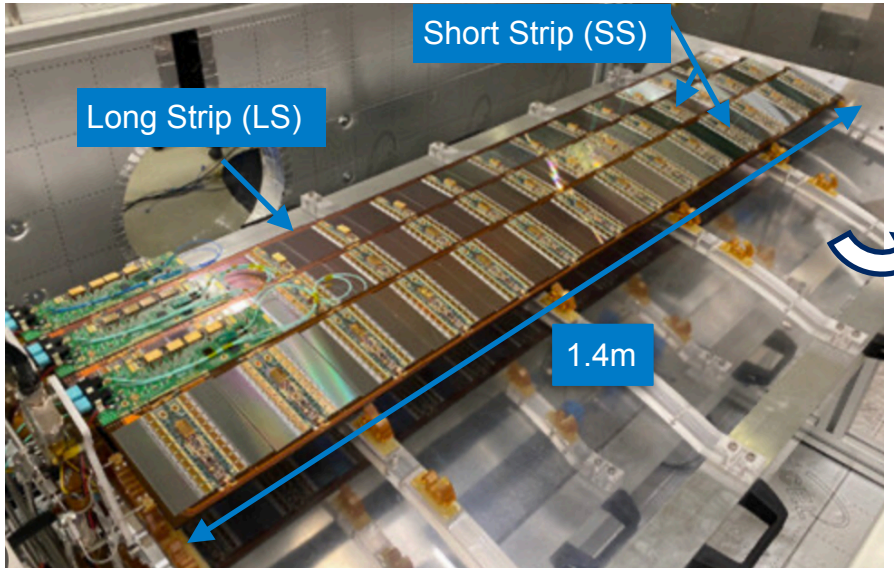
To keep similar physics performance during high luminosity phase

ITk 硅微条探测器



Barrel

- **2** inner SS layers, **2** outer LS layers



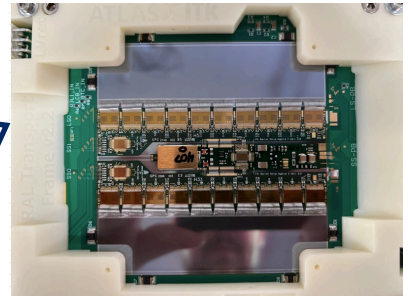
Endcap

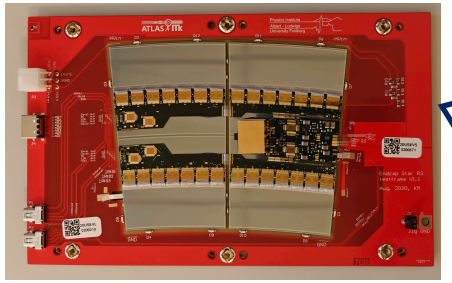
- **6** disks, **192** double-sided petals



Petal

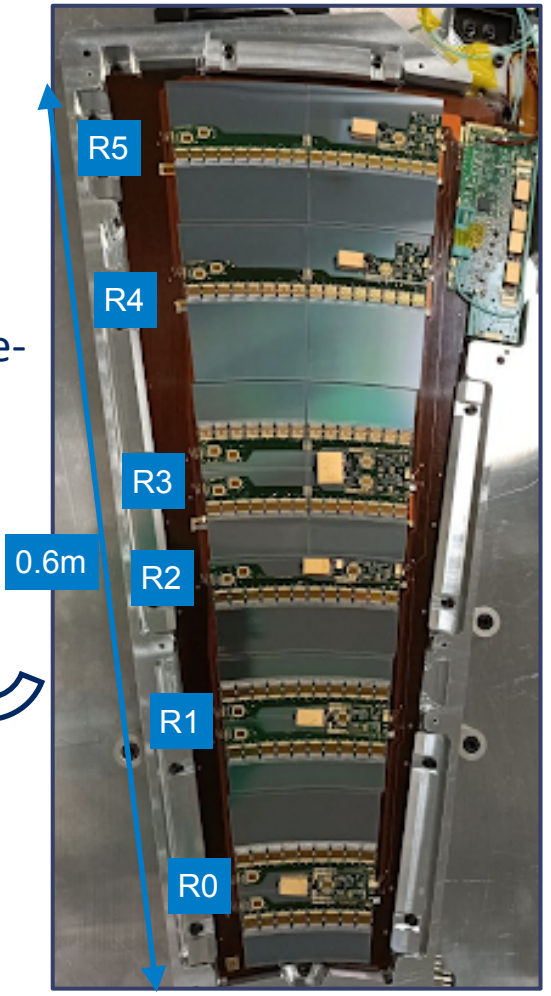
- **6** module-types



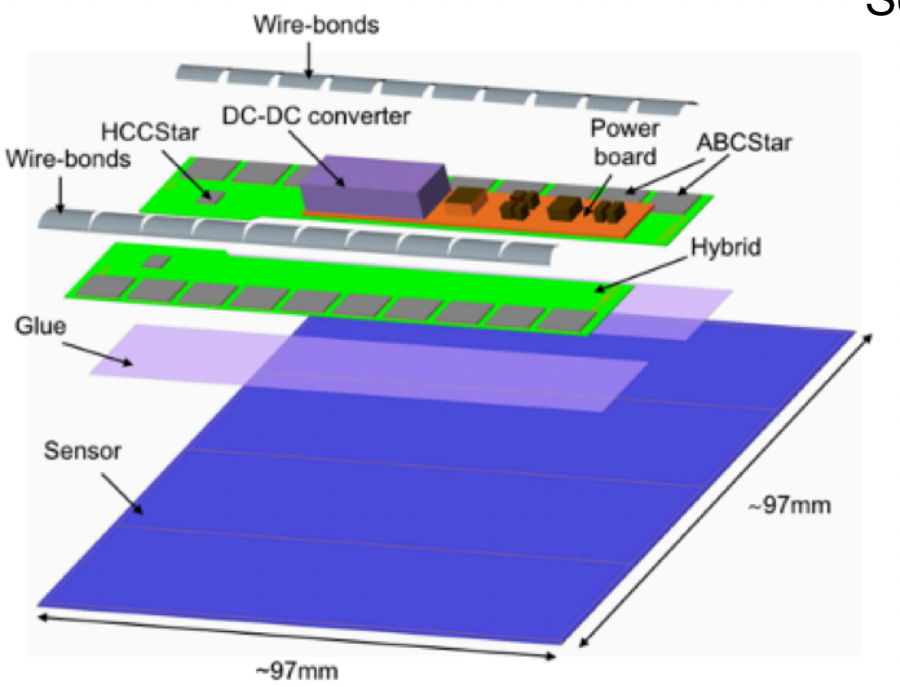


Modules

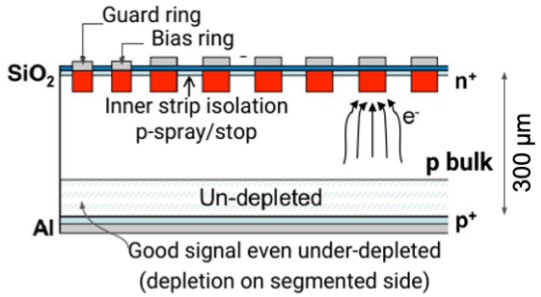
165 m² active detection area



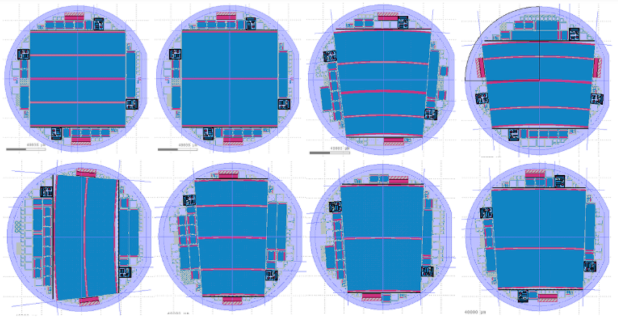
硅微条探测器模块



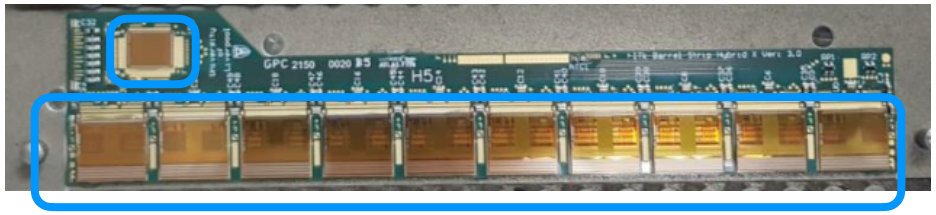
Sensor



6-inch float-zone silicon wafer
8 geometries

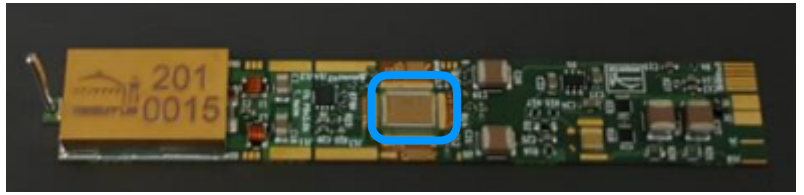


Hybrid HCCStar

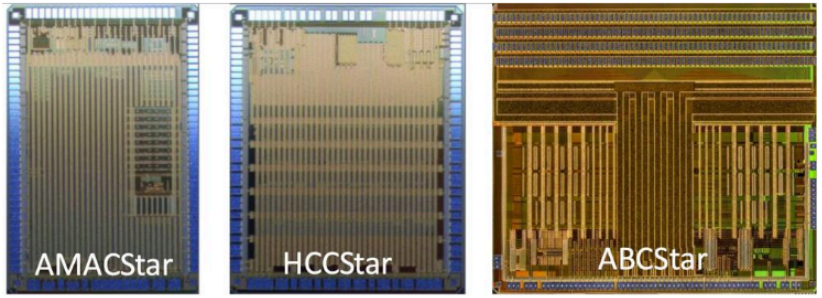


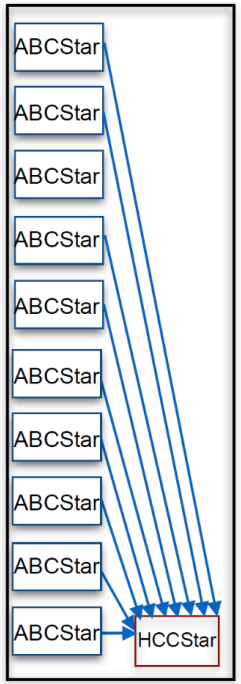
ABCStar

Power board



AMACStar

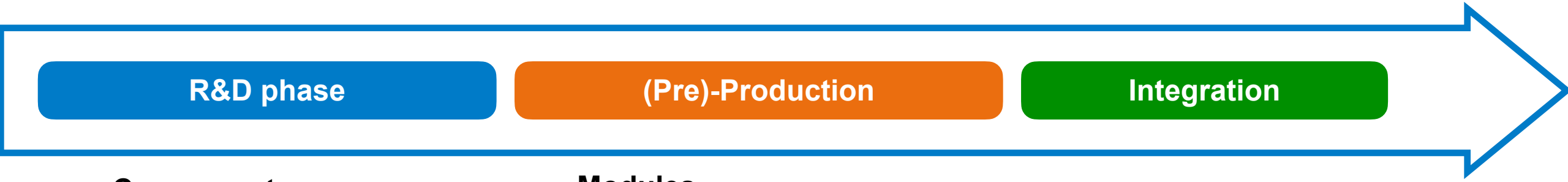




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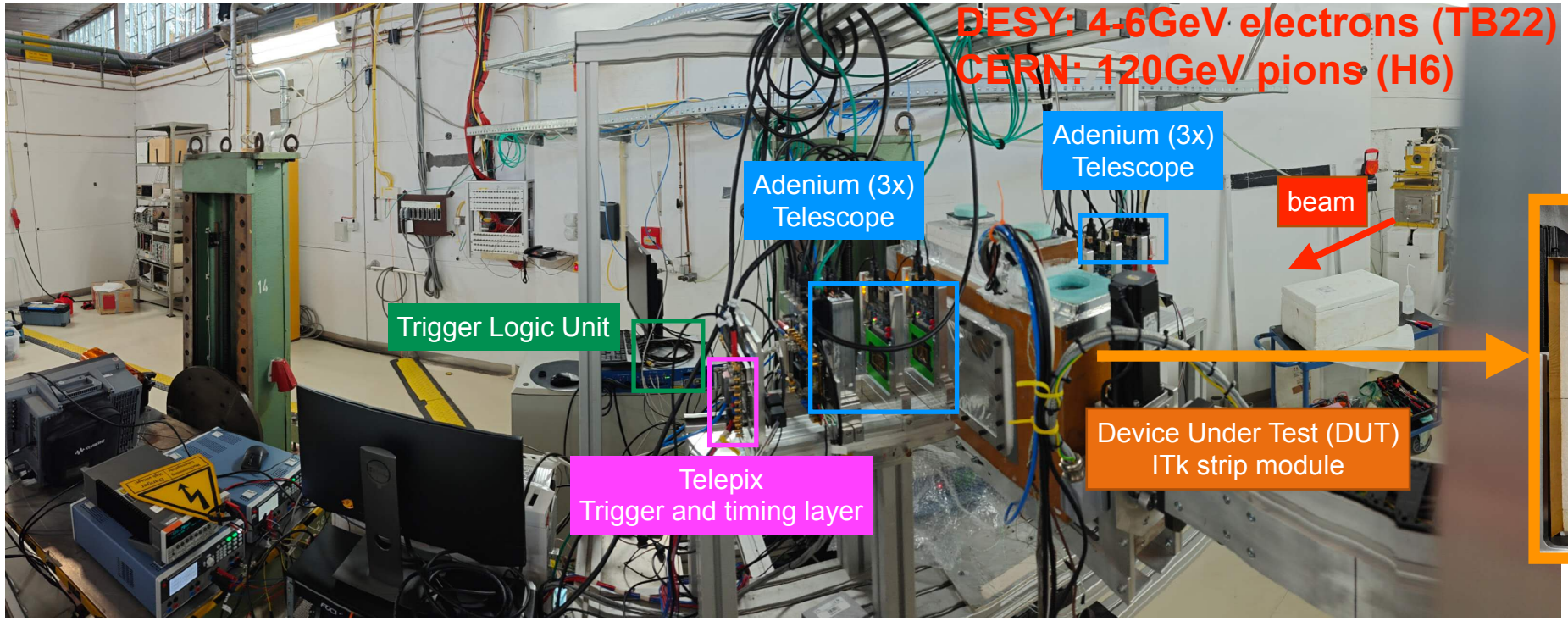
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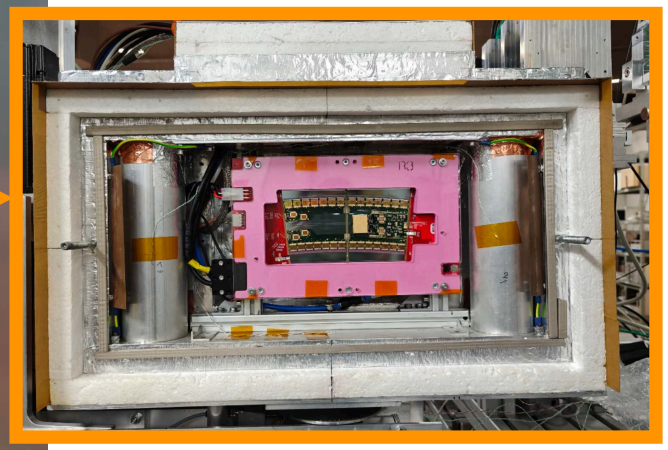
硅微条探测器束流测试（和辐照）活动



- **Components**
  - Sensor, ASICs
- **Modules**
  - Performance verification
  - Study on production issues and their solutions
- **Large scale readout**

束流测试（辐照）装置系统

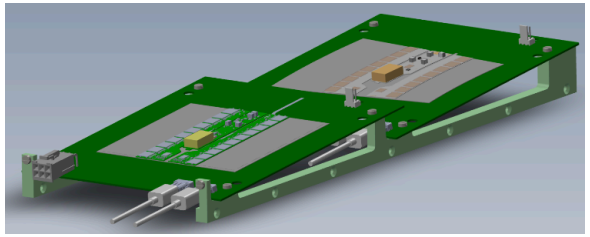








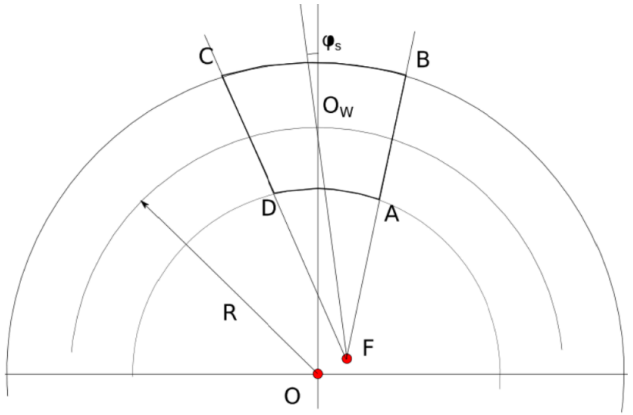
辐照(10^{14}-10^{16} n_{eq}/cm^2):
24GeV protons@IRRAD
400MeV protons@FNAL
Neutrons@TRIGA

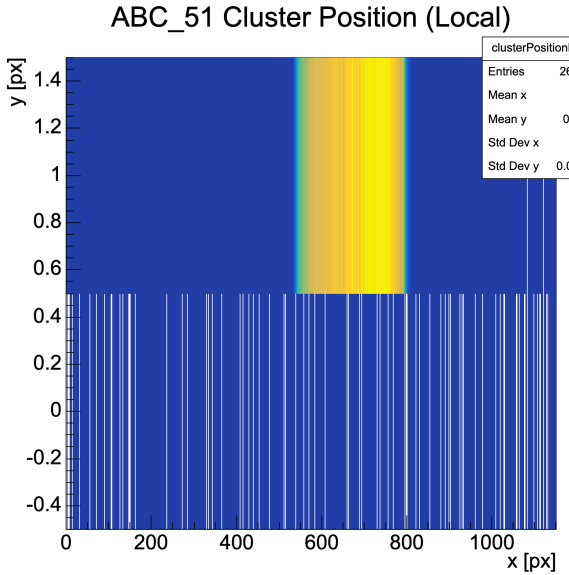


数据分析

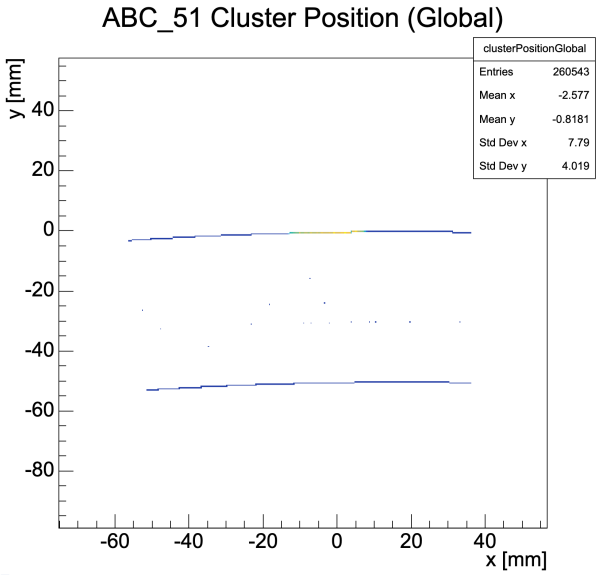
Corryvreckan

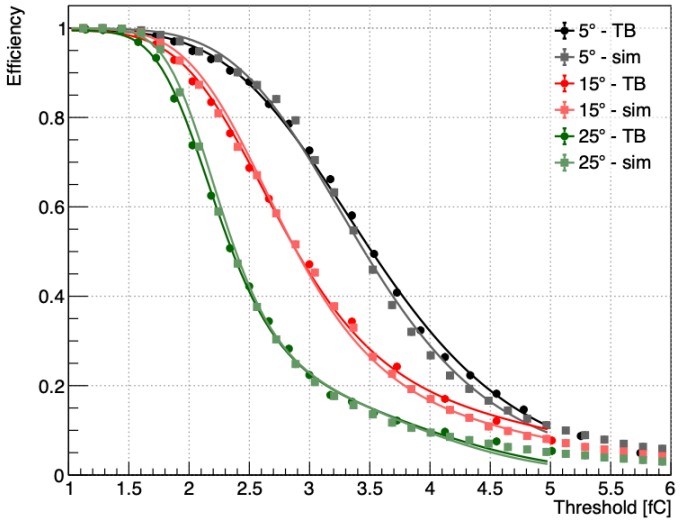
Radial strips with stereo angle

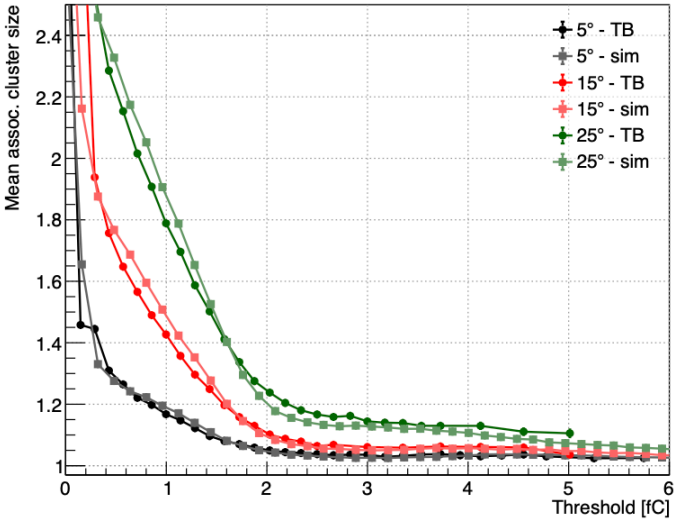




Polar geometry







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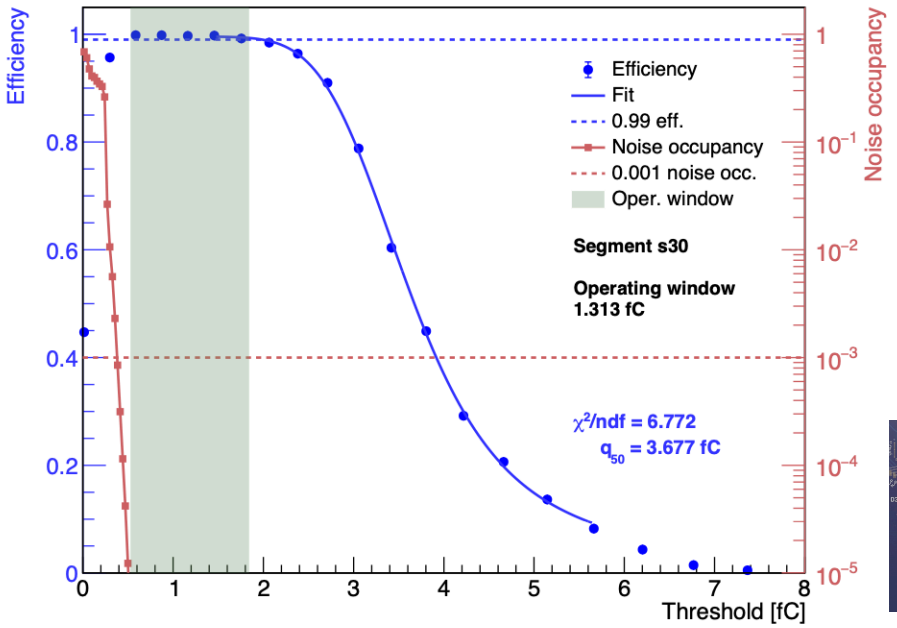
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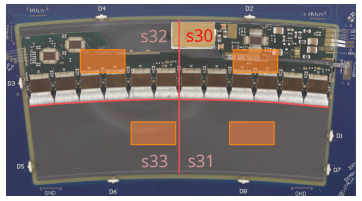
探测器模块性能验证

- ITk requirement:
  - Efficiency $> 99\,\%$ to maintain physics performance
  - Noise occupancy $< 0.1\,\%$ to see pile-up events
- **All module types have been validated**

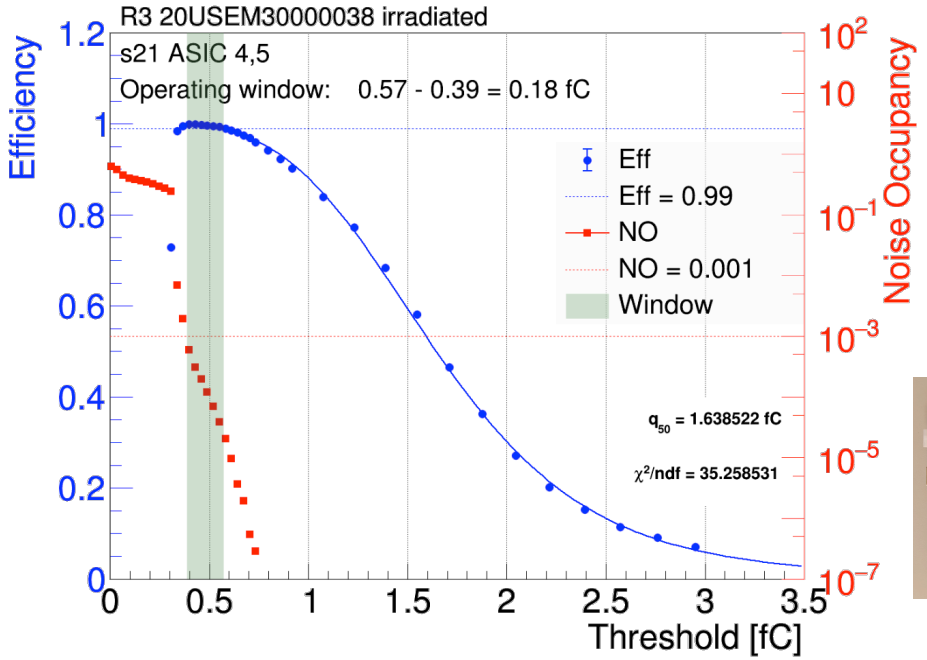
	Median collected charge	Operating window
Before irradiation	~3.5fC	1-1.5fC
After irradiation	~1.5fC	<0.3fC

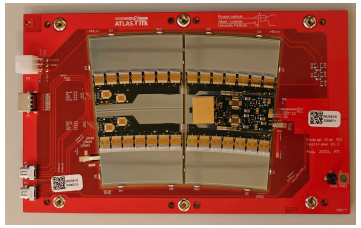
R2 unirradiated





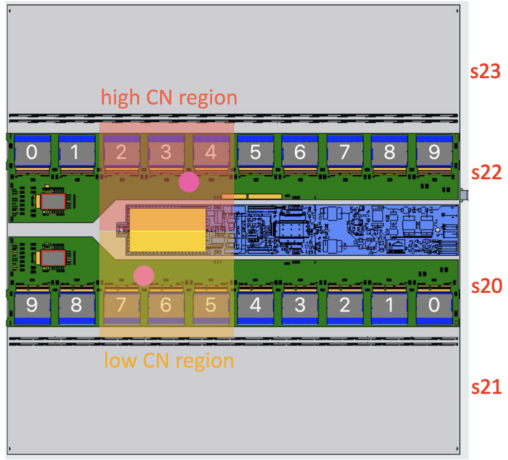
R3 irradiated

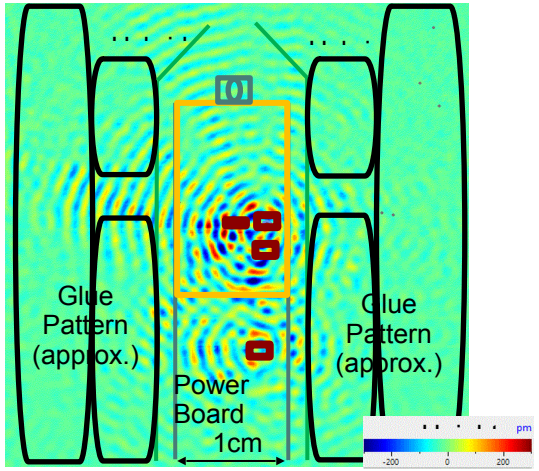


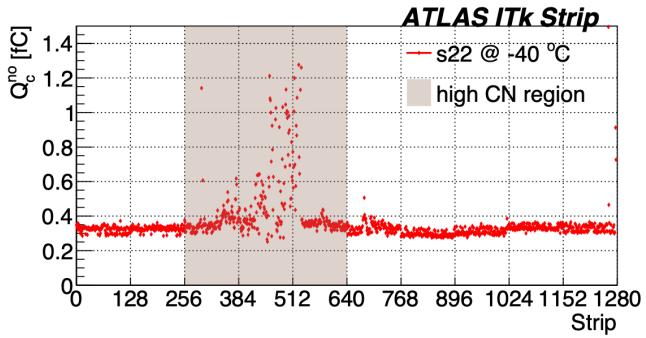


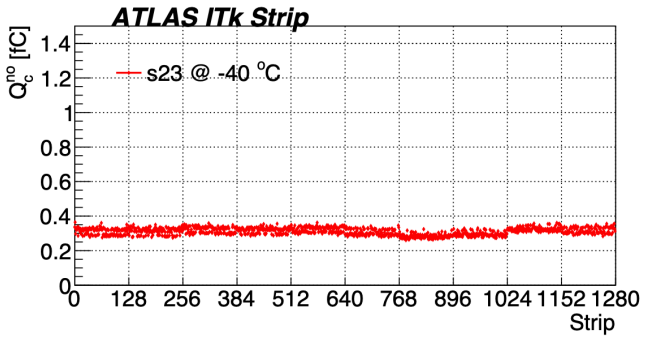
冷噪声（Cold Noise）问题评估

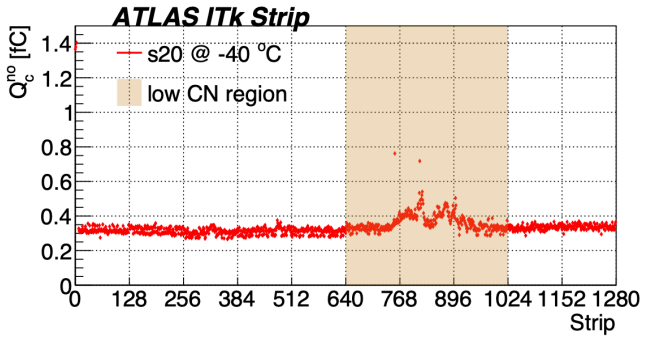
Crazy noise at low temperature

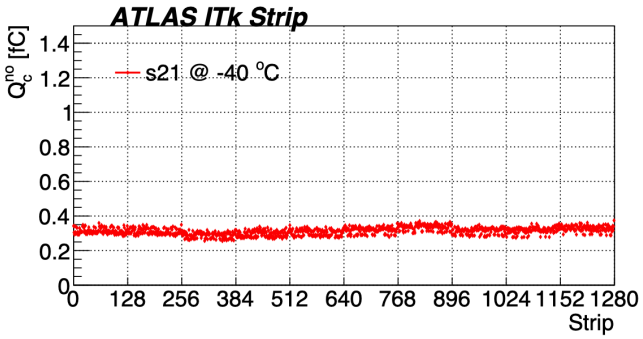






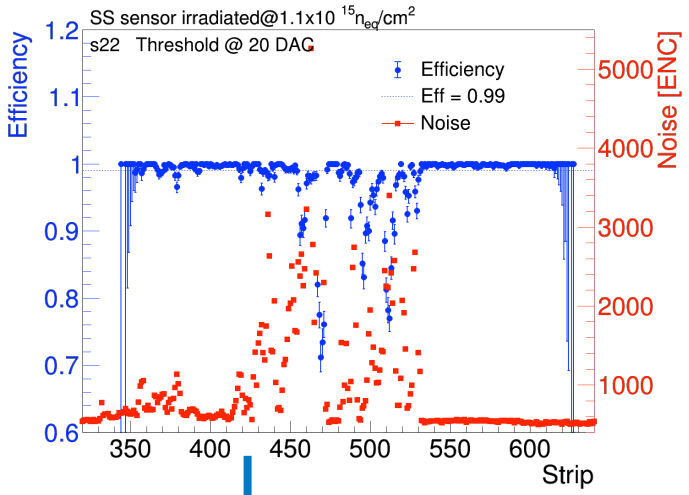






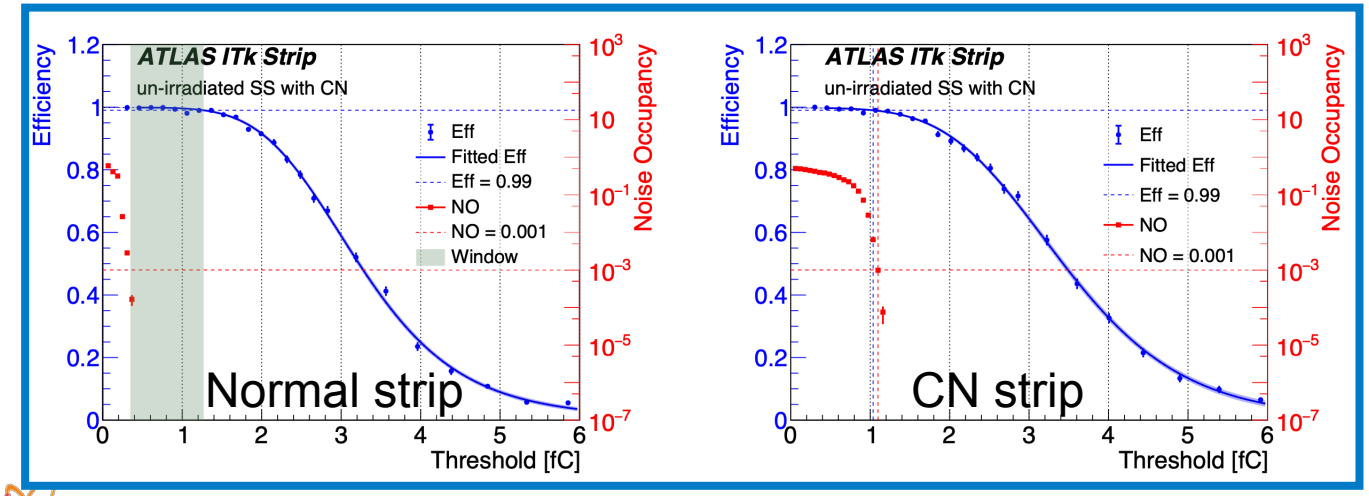
- Correlated to the DC-DC converter: switching @ 2MHz
- Mechanical wave from the DC-DC converter couples into sensor (via glue) & travels
- Project delayed by ~1 year

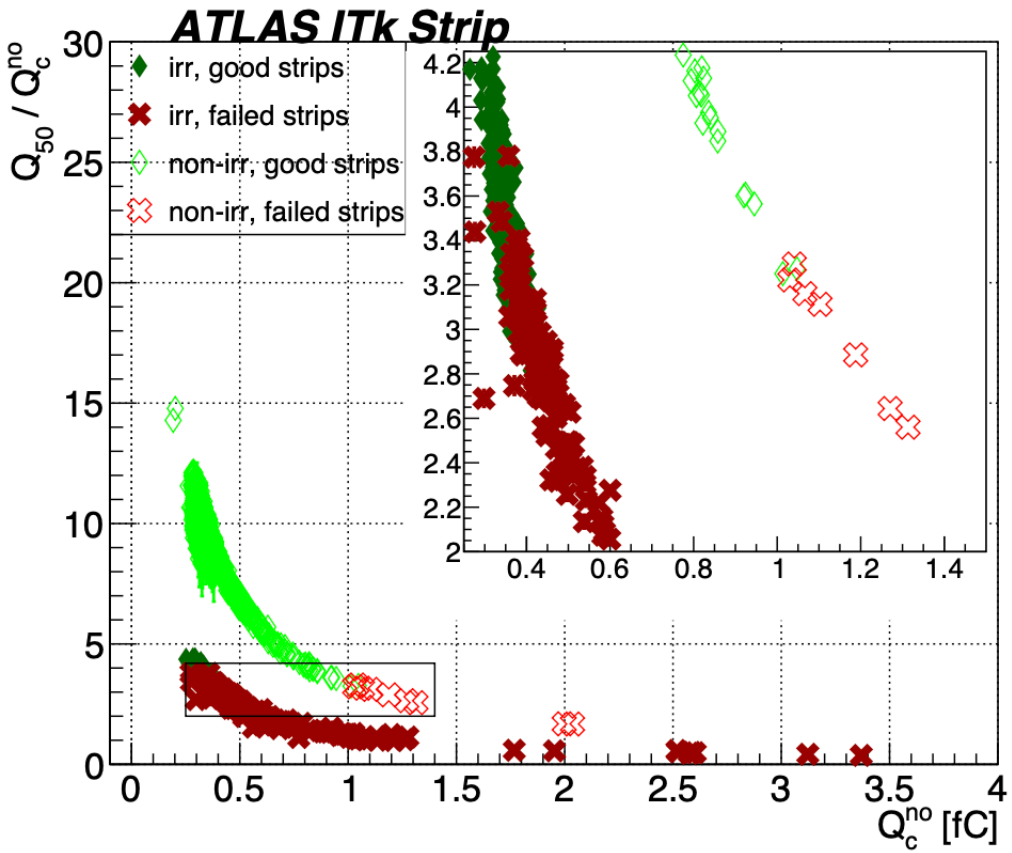
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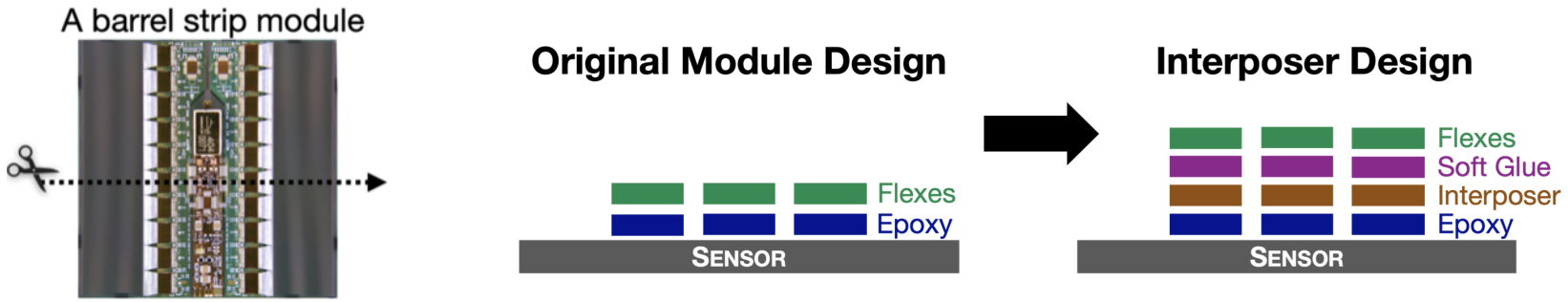
strip-by-strip studies

- S/N cut-off at ~3 to meet the operational requirement
- Modules with CN can NOT meet the detector requirement after irradiation

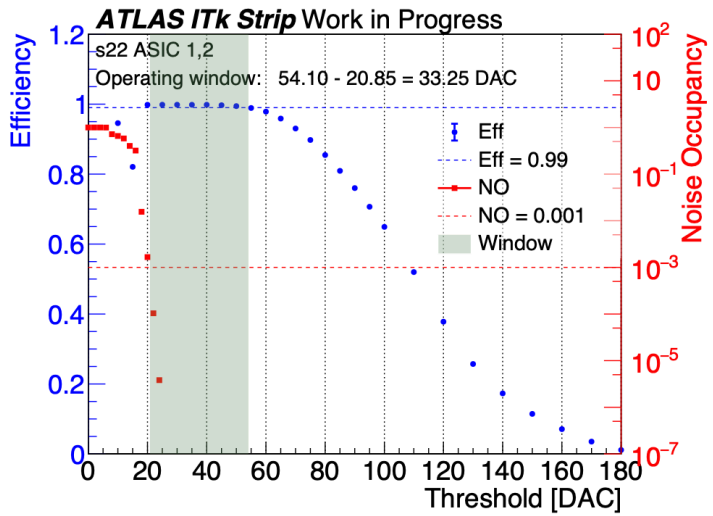




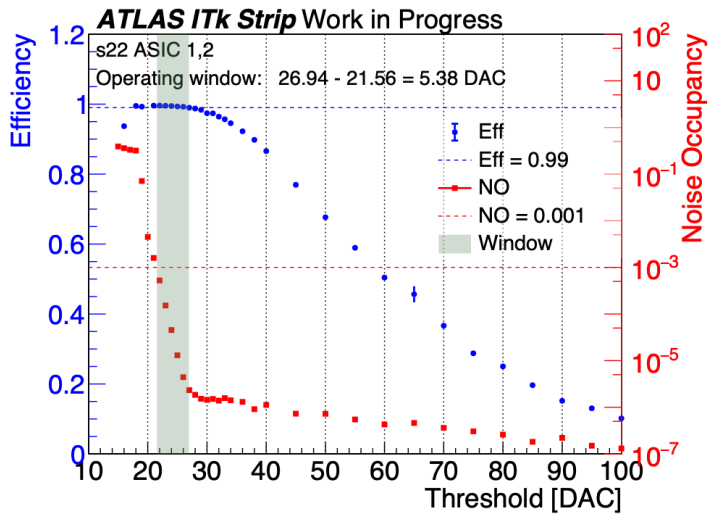
冷噪声问题解决方案评估



Before irradiation



After irradiation



- The interposed solution can fix the CN issue
- The radiation-tolerance has been verified

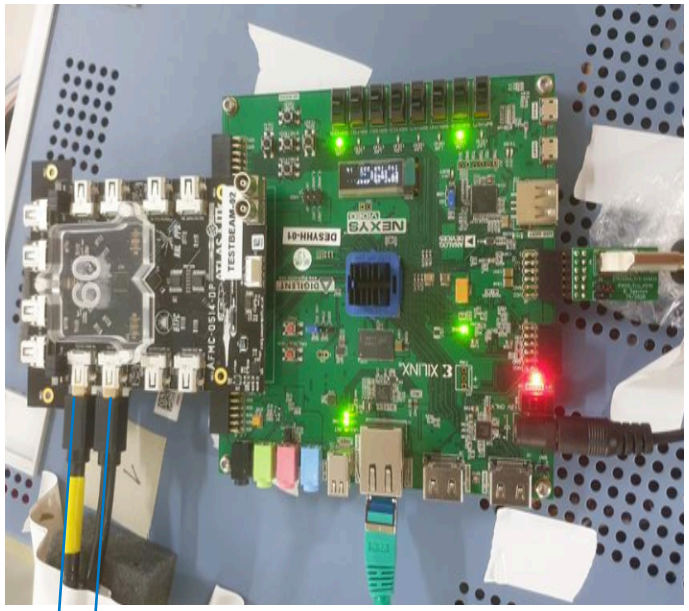
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从单模块测试到petal测试

Test beam DAQ system

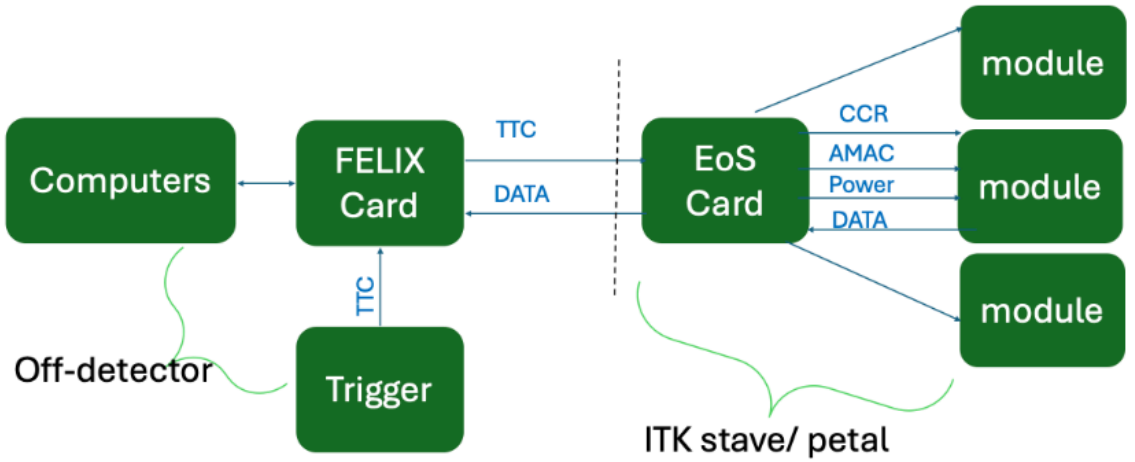
Nexys + FMC-DP + ITSDAQ SW



Module

ITk DAQ system

FELIX + EoS + YARR SW



End of Structure card



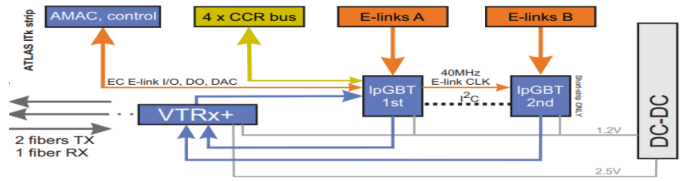
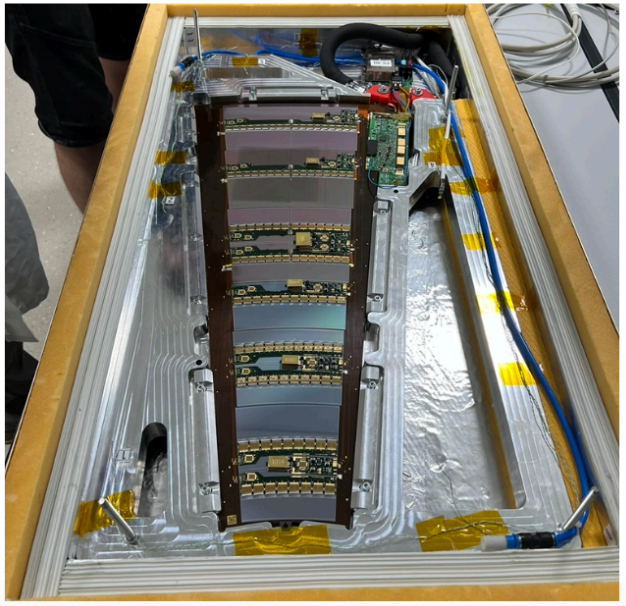


Figure 3: The EoS card block diagram.

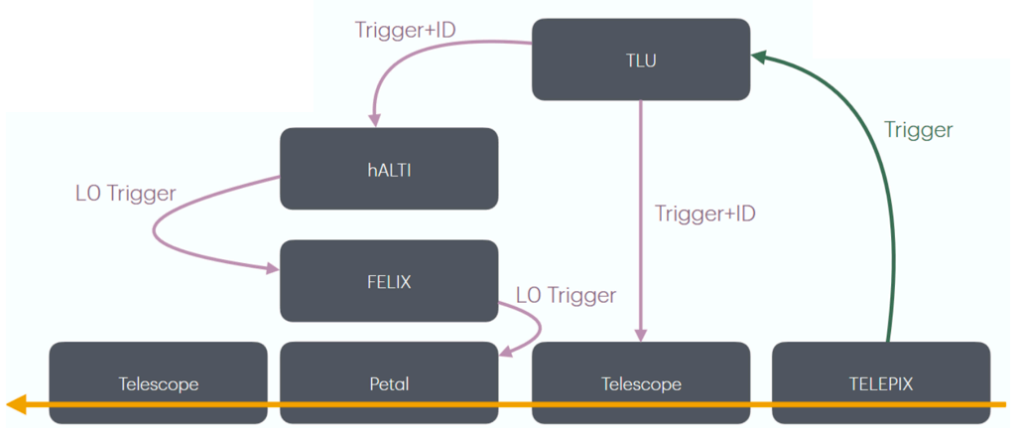
从单模块测试到petal测试

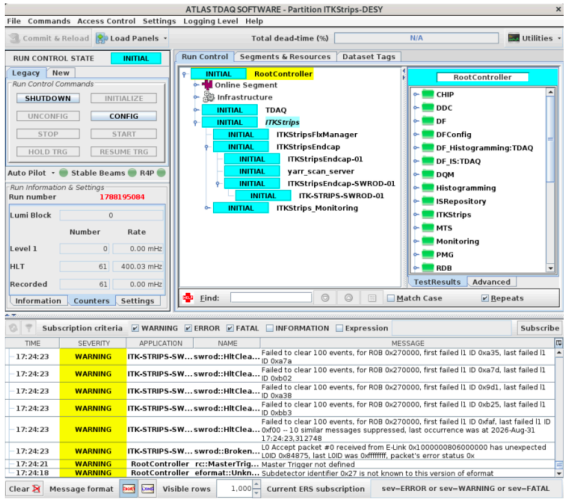
- Full analysis of data to be done.

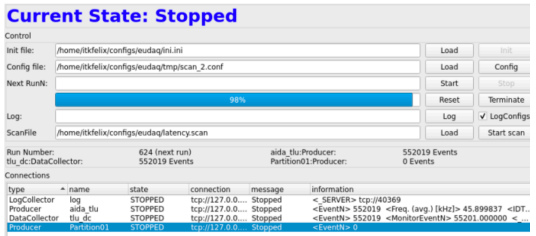
Photos from K. Mauer











总结

- 束流测试服务于ITk项目的全周期，满足项目不同阶段的交付需求，ITk现已平稳进入批量生产阶段
- 束流测试不仅能对探测器进行性能测试，而且为探测器运行操作提供了大量经验及数据
- 如果有可能的话，避免在一个探测器系统上设计八种不同的探测器模块

Thank you

联系方式

中国科学院近代物理研究所
何亚君
heyajun@impcas.ac.cn