ATLAS硅微条探测器升级进展

陆卫国
On behalf of the ATLAS ITk China group

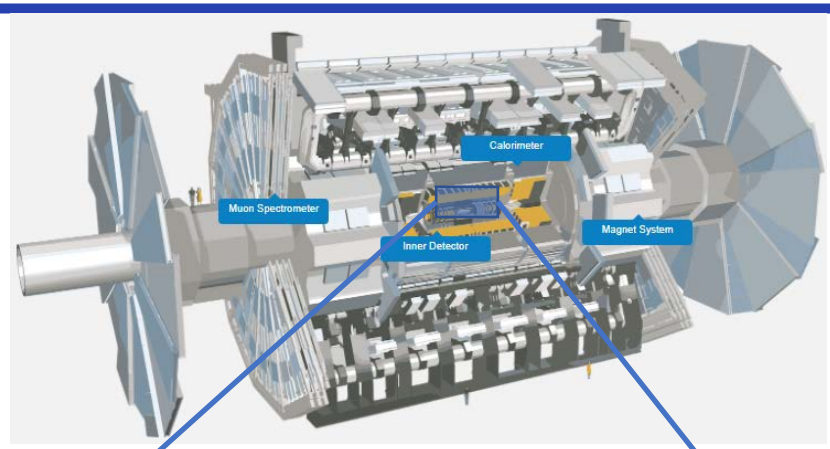
第四届半导体辐射探测器研讨会
5月23-26日，2024
青岛

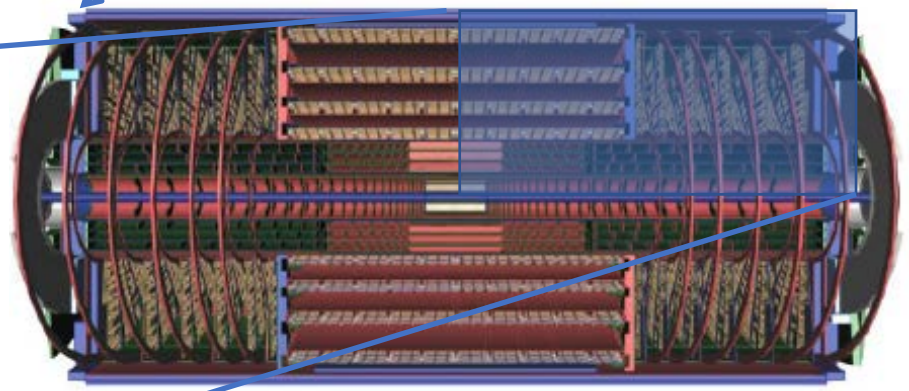
报告内容

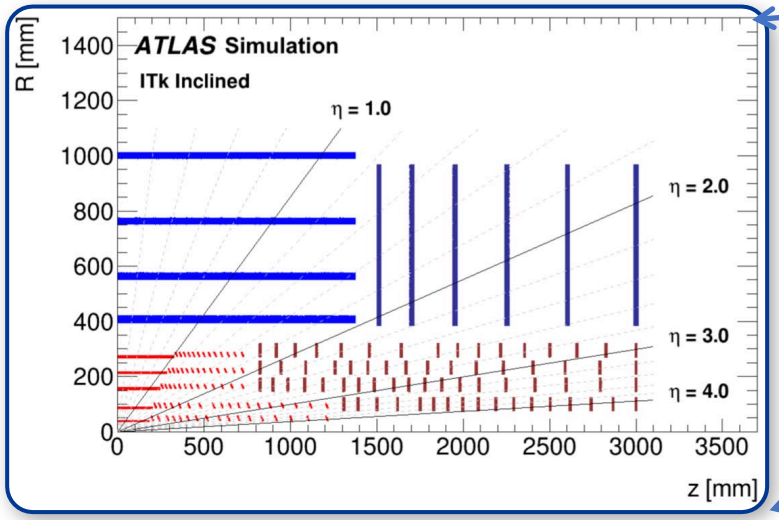
- 项目背景及状态
- 项目问题及解决
- 高能所站点生产准备
- 传感器和芯片辐照效应研究
- 总结

项目背景

- ATLAS ITk二期升级，内径迹系统全部由硅探测器构成
- 磁场2T，长约6米，半径约1米
- 硅微条探测器包括4层桶部和6层(x2)端盖
  - 约18000 个模块
  - 约6千万道读出
  - 硅微条覆盖面积165m2
  - 由16个不同的资助机构的50个单位共同承担



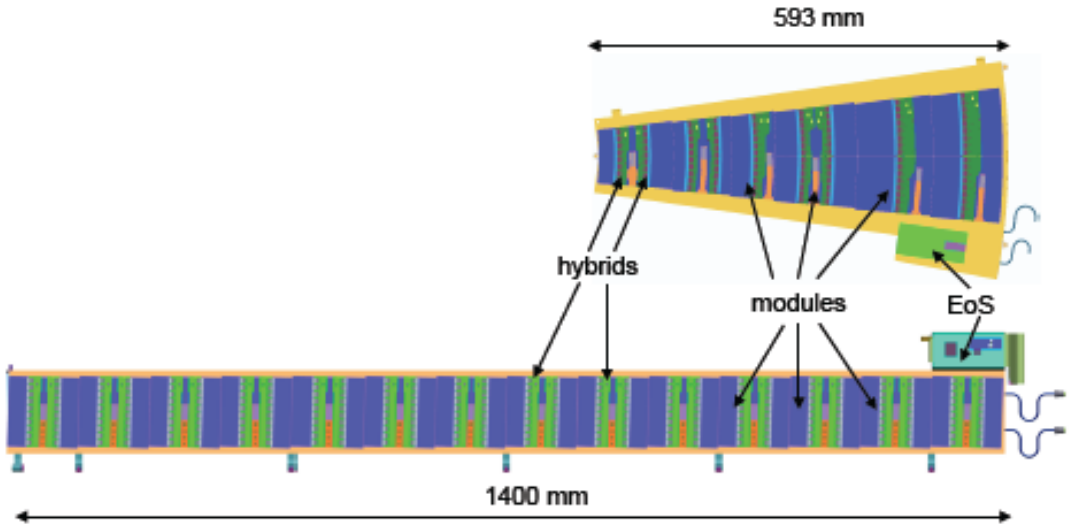


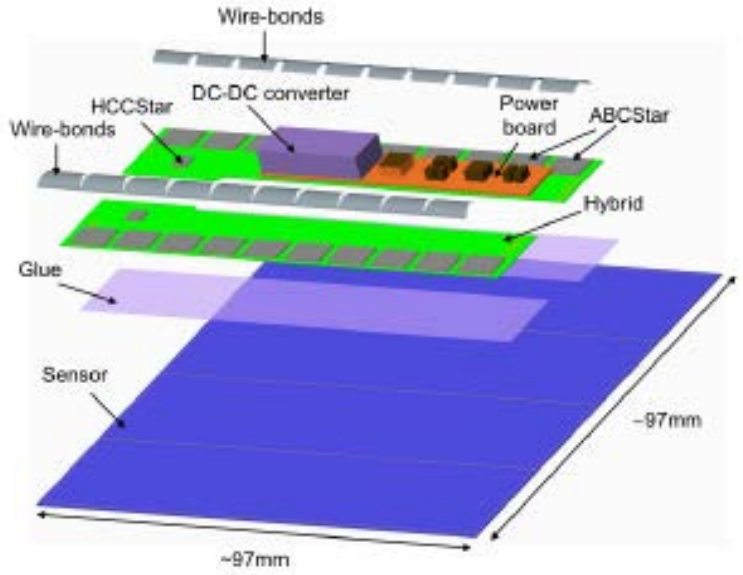


探测器结构及升级状态

- 探测器系统结构复杂，规模大
- 价格贵，性能要求高
- 工程进度滞后
  - 传感器和芯片生产过半
  - 模块预生产阶段即将结束
  - 预计下半年开始生产

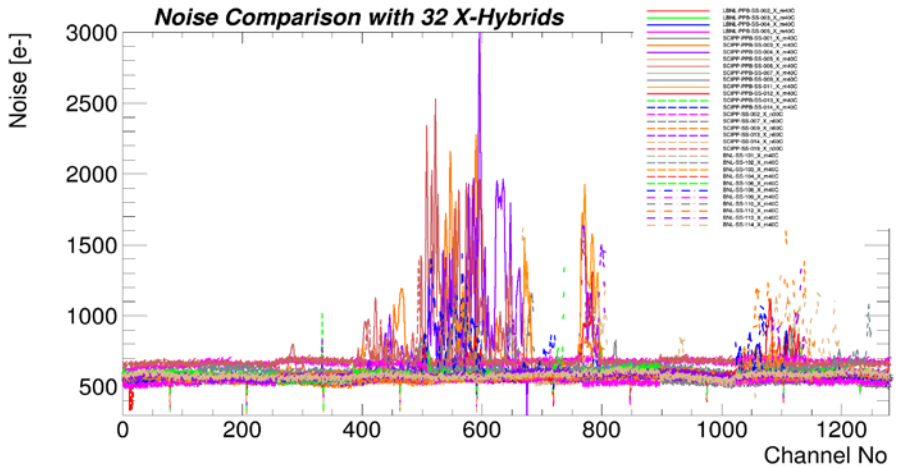
Barrel Layer:	Radius [mm]	# of staves	# of modules	# of hybrids	# of of ABCStar	# of channels	Area [m^2]
L0	405	28	784	1568	15680	4.01M	7.49
L1	562	40	1120	2240	22400	5.73M	10.7
L2	762	56	1568	1568	15680	4.01M	14.98
L3	1000	72	2016	2016	20160	5.16M	19.26
Total half barrel		196	5488	7392	73920	18.92M	52.43
Total barrel		392	10976	14784	147840	37.85M	104.86

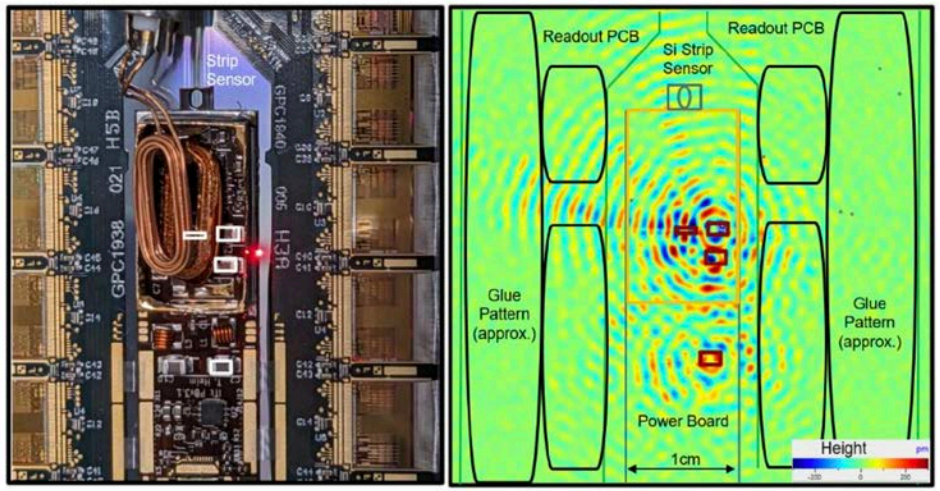




模块低温噪声

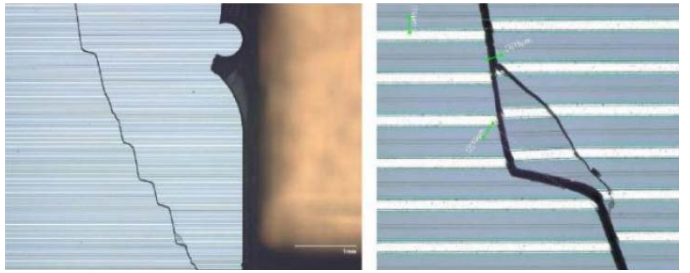
- 模块在热循环至低温（-35℃）部分通道噪声增大
  - 温度回升后依然存在
- 电源板上的电容振动通过传感器引起电子学噪声
- 短微条模块问题更显著
  - 端盖和长微条（TB胶水）未见
- 跟胶水类型和点胶方法相关
  - 磁场对低温噪声的影响
  - 辐照对低温噪声的影响
  - 振动对焊点可靠性的影响

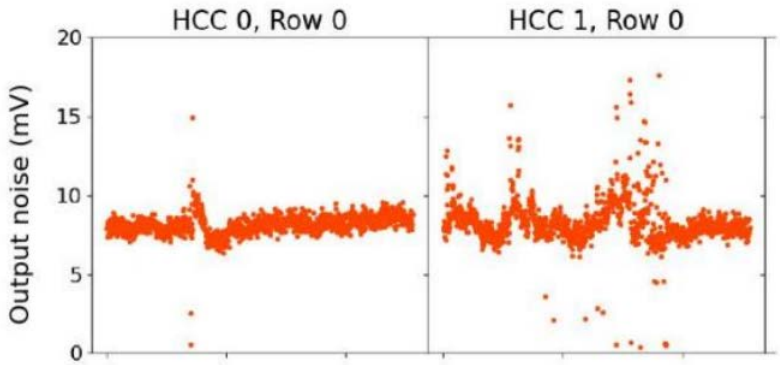


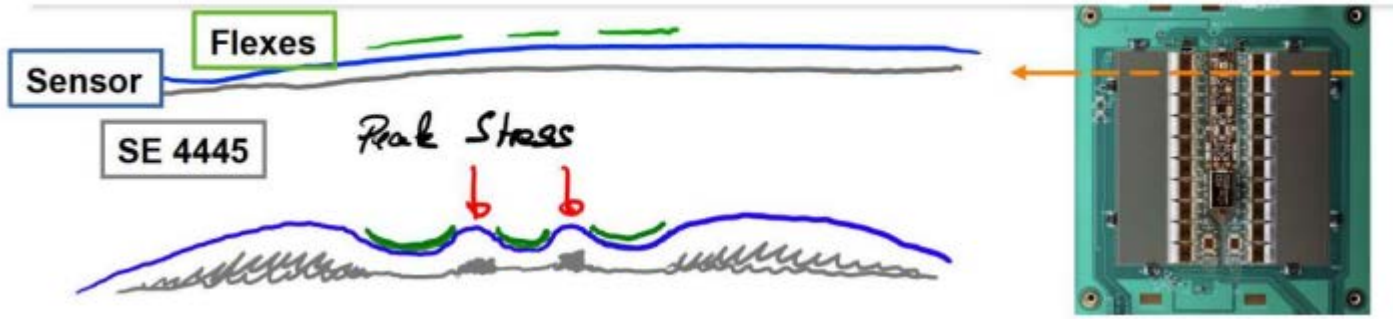


传感器开裂

- 预生产桶板在热循环测试中部分模块表现出<100V的击穿电压
  - 发现由于传感器裂开导致
  - 在裂开位置的通道表现为很高或者很低的噪声
- 复合板和传感器的热导系数不同
  - 压力峰值在电路板之间的小间隙
- 缓解办法
  - 模块和桶板之间改用Hysol胶水
  - 增大电路板之间的间隙
  - 电路板和传感器之间用垫片机械隔离
  - 更薄的复合电路板

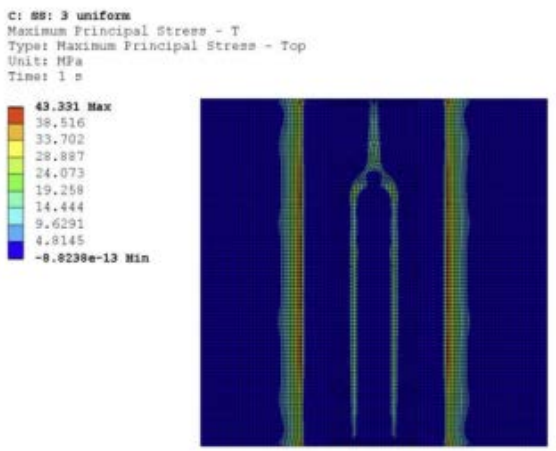


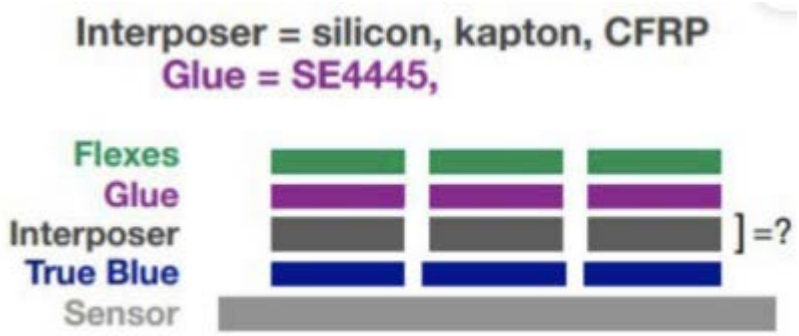




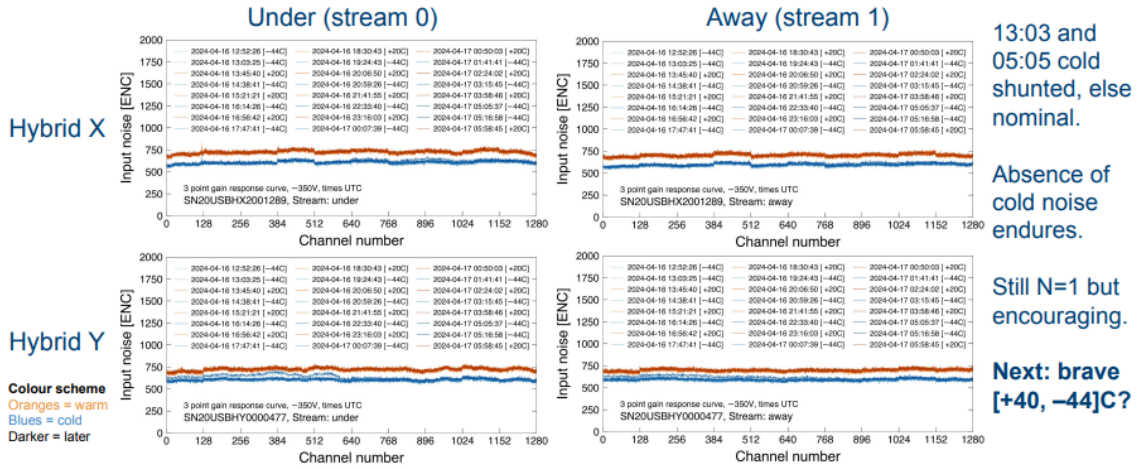
模块加垫片

- 缓解电子学板和传感器之间的应力
  - 材料选择
  - 厚度选择
  - 安装方法
- 有望同时解决低温噪声和传感器裂开问题
  - 仿真显示可以减小~90%的应力
  - 已有的垫片模块测试未见低温噪声
    - 50um kapton
  - 桶板热循环测试计划中



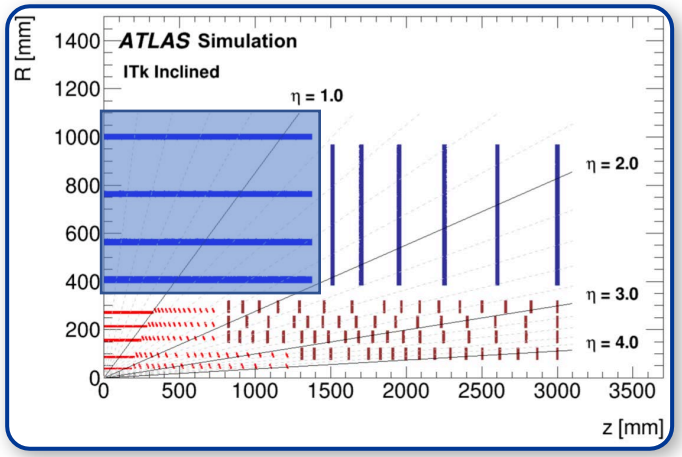


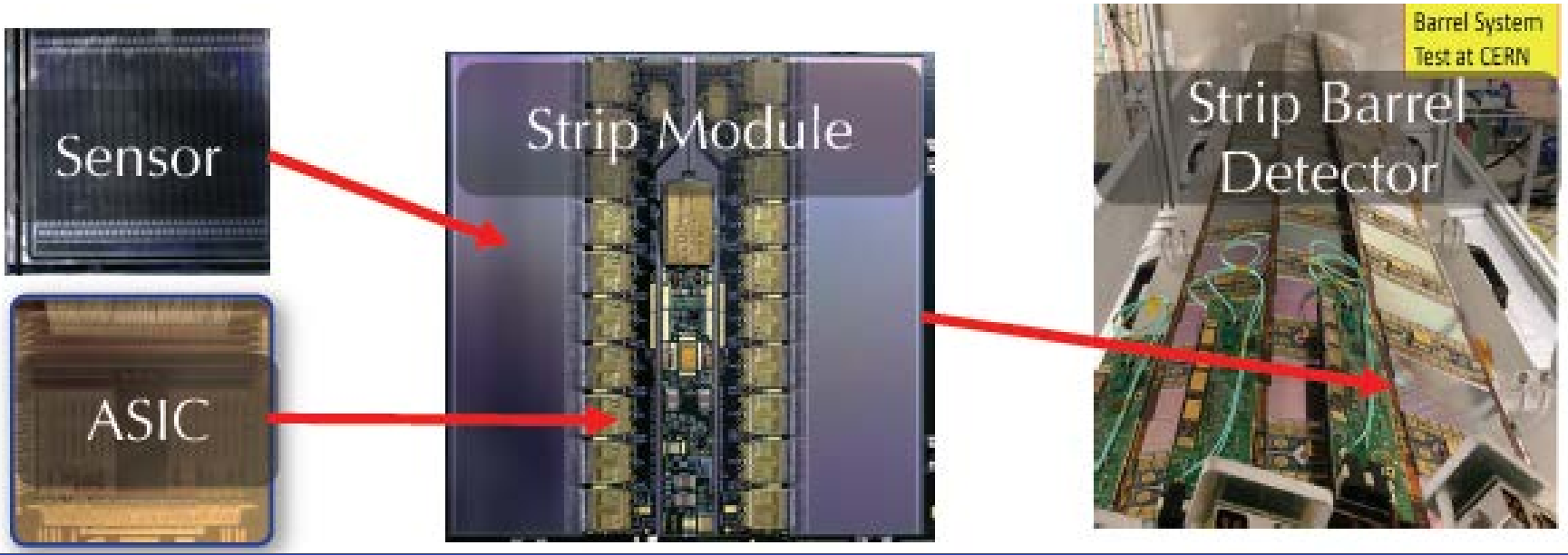
10x [20, –44]C: no news is good news



中国组任务

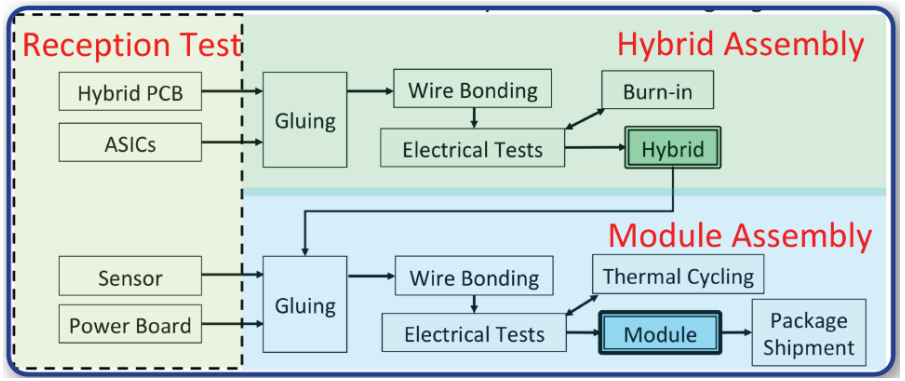
- 中国组承担10%的硅微条桶部模块建造任务
  - >1000个模块, ~10m²探测面积
- 主要任务
  - 抗辐射传感器和读出芯片研究
  - 高性能硅微条探测器模块生产
  - 硅微条探测器系统集成

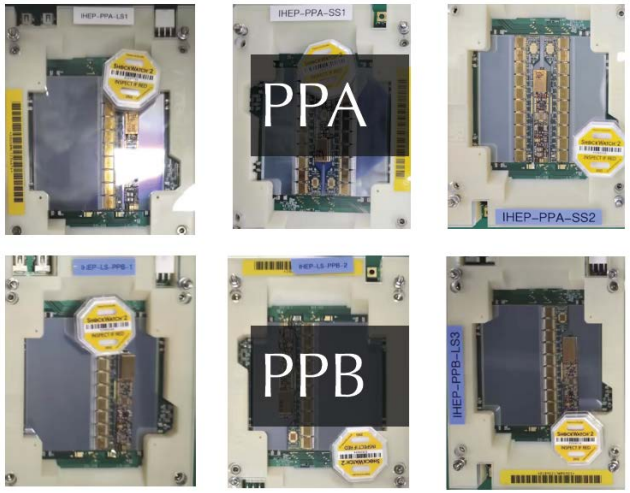


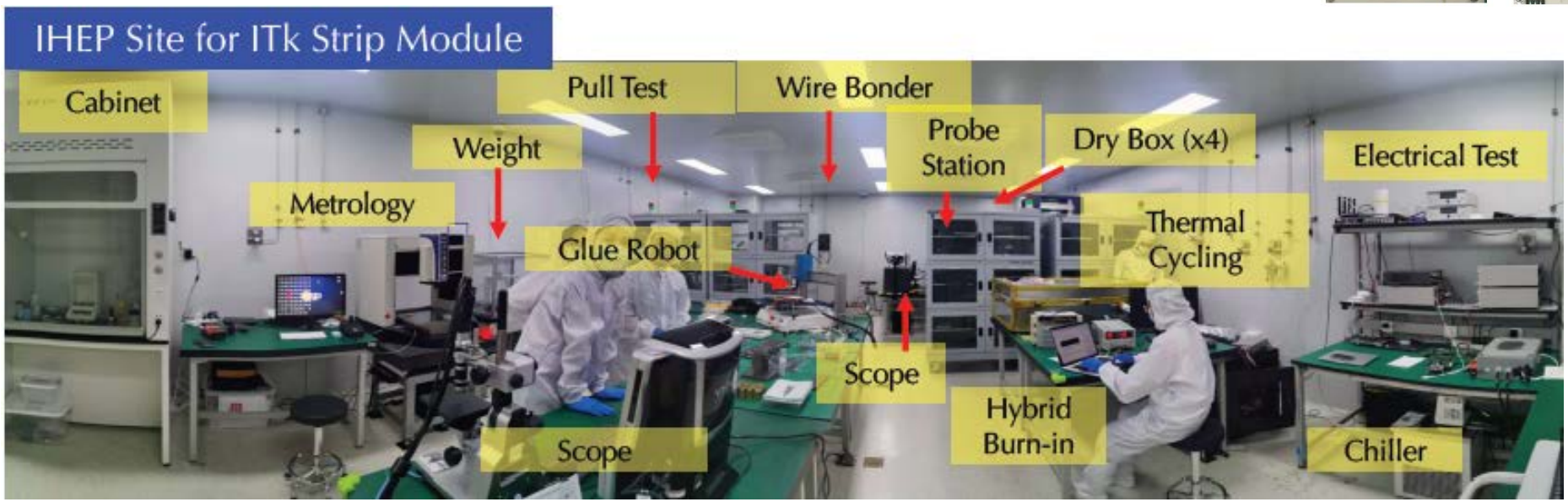


站点评估

- 搭建了完备的洁净间实验环境
- 已经生产了多个长硅微条和短硅微条模块
- 完成了复合板和模块生产的所有步骤评估

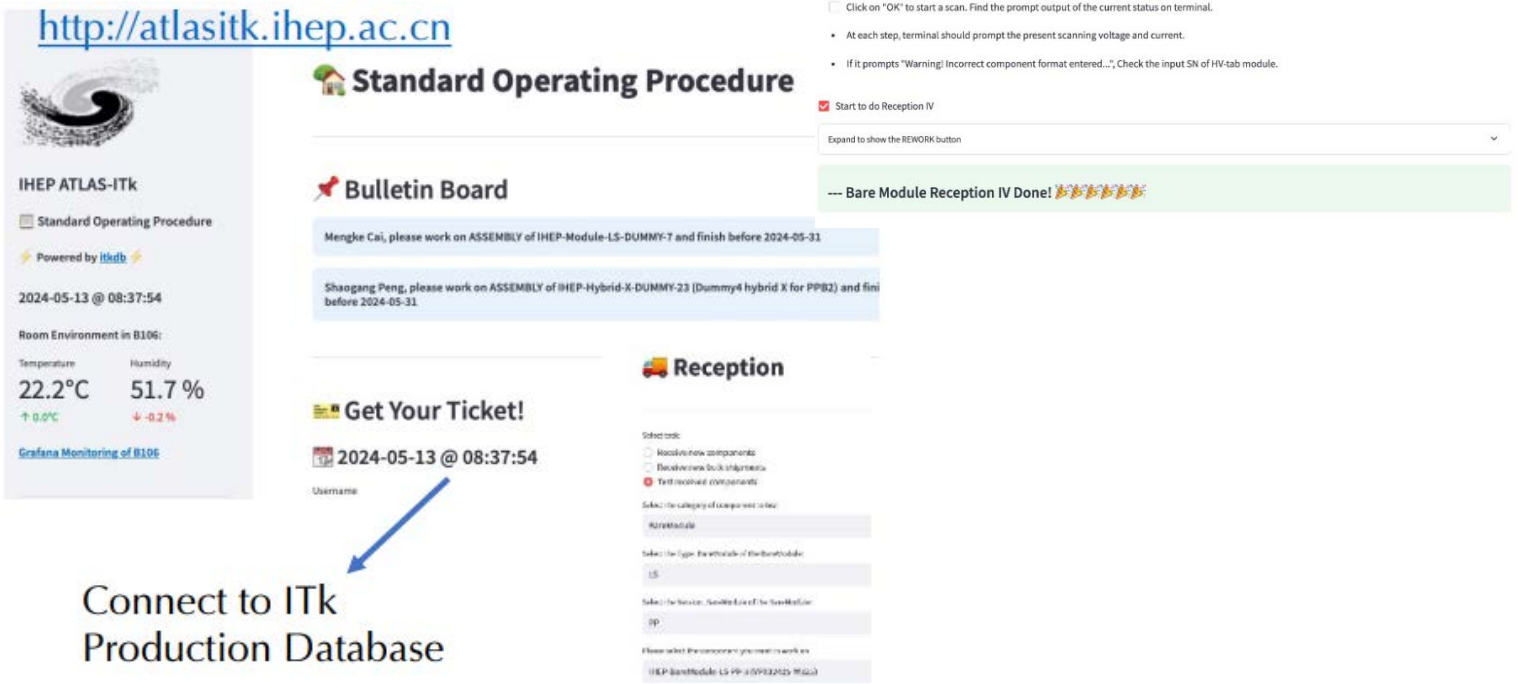






生产准备

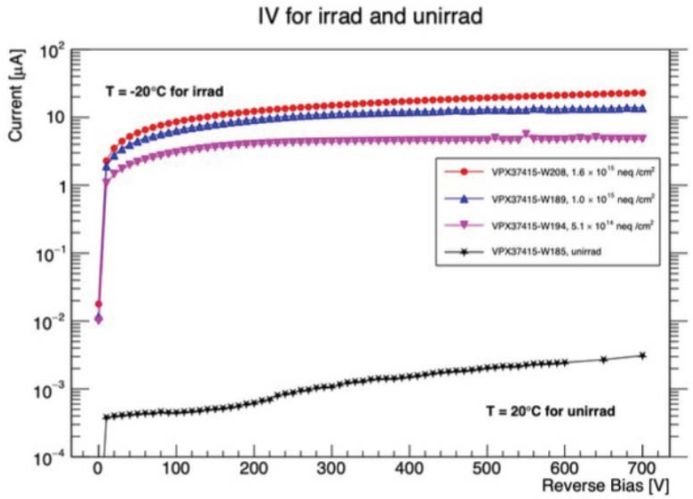
- 标准操作流程
  - 发展了Standard Operation Procedure系统用于本地模块生产
  - 全部29步集成到SOP系统
  - 可与数据库直接交互

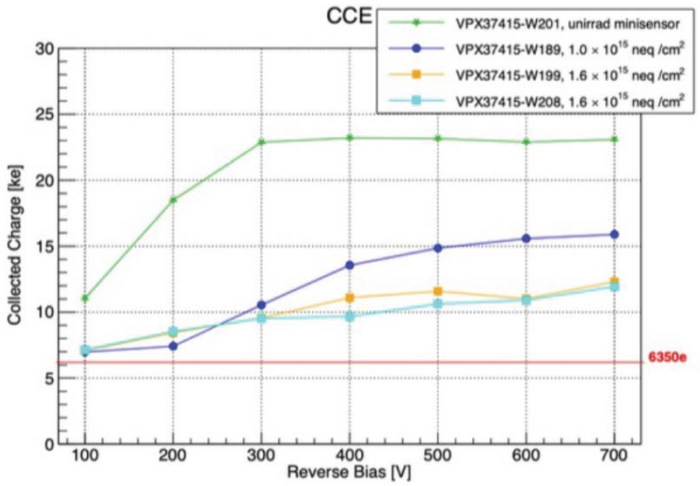


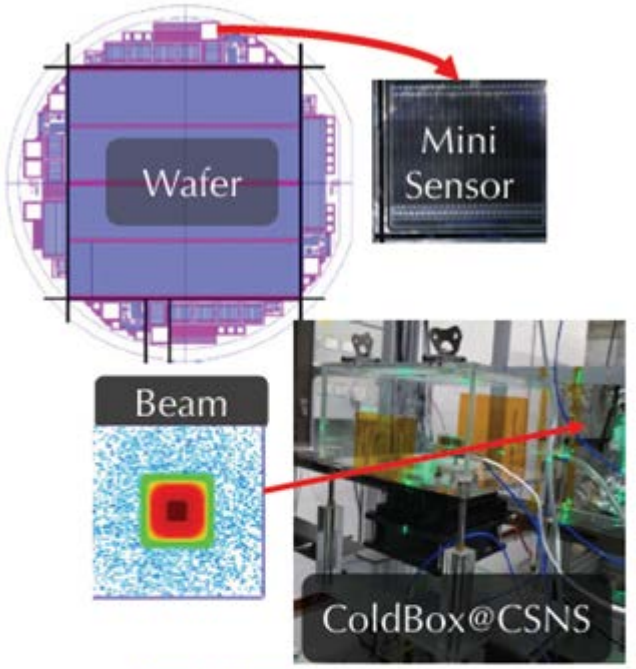
Step Number	Qualification Step	Review End Date
3.2	Sensor Storage	finished: 2021-06-17
6.1	PB Reception	finished: 2022-01-11
6.2	PB E tests	finished: 2022-07-14
6.3	PB Vis Insp	finished: 2021-12-16
6.4	PB Storage	finished: 2021-06-17
8.2	Storage + shipping of glue	finished: 2021-08-26
8.3	Assembling hybrids	finished: 2021-11-20
8.4	Glue weight measurements	finished: 2021-11-21
8.5	Bonding procedures: hybrids	finished: 2022-05-31
8.6	Metrology: hybrids	finished: 2023-03-07
8.7	Visual inspection: hybrids	finished: 2021-08-06
8.8	Hybrid Burn-In	finished: 2023-05-25
8.10	Hybrid Storage	finished: 2021-06-17
8.11	hybrid QC: single panel testing	finished: 2022-08-25
11.1	Storage of modules	finished: 2021-06-17
11.2	Cleaning module jigs	finished: 2021-06-16
11.4	Storage + shipping of glue	finished: 2021-11-29
11.5	Removing hybrids from panel	finished: 2021-12-09?
11.6	Module Assembly	finished: 2022-02-25
11.7	Metrology: modules	finished: 2023-07-10
11.8	Bonding procedures: modules	finished: 2022-05-25
11.9	Visual inspection: modules	finished: 2021-07-19
11.10	Module Thermal Cycling	finished: 2023-10-29
11.11	Single Module Electrical Test	finished: 2022-10-23
12.1	Shipping modules	finished: 2022-04-25
13.1	Cleanroom standards	finished: 2021-11-25
13.2	ASIC Compliance & Handling	finished: 2021-06-03
13.3	Bond Pulling Procedures	finished: 2021-12-03
14.1	Module Reception	Finished: 2022-01-25

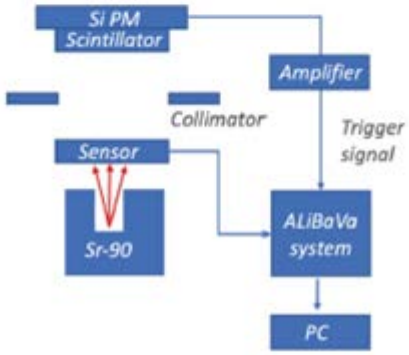
传感器辐照研究

- 硅微条mini sensor质子辐照
  - 80MeV质子，注量1.6×$10^{15}n_{eq}/cm^2$
  - 温湿度控制实验装置
- 传感器特性研究
  - I-V，C-V性能测试
  - 电荷收集效率CCE测试
- 推动散裂中子源作为QA站点



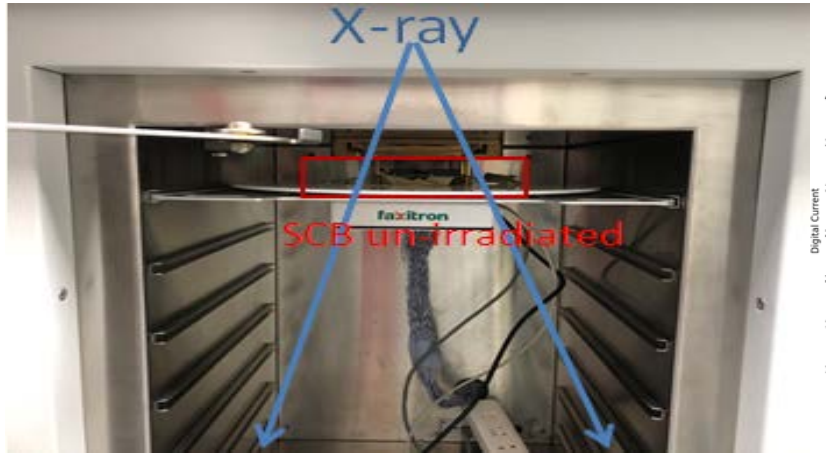


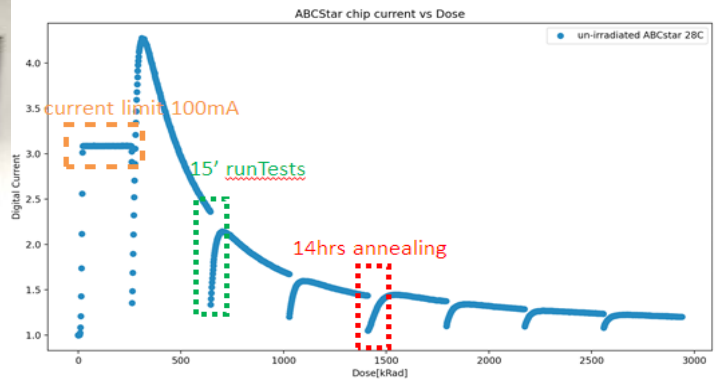


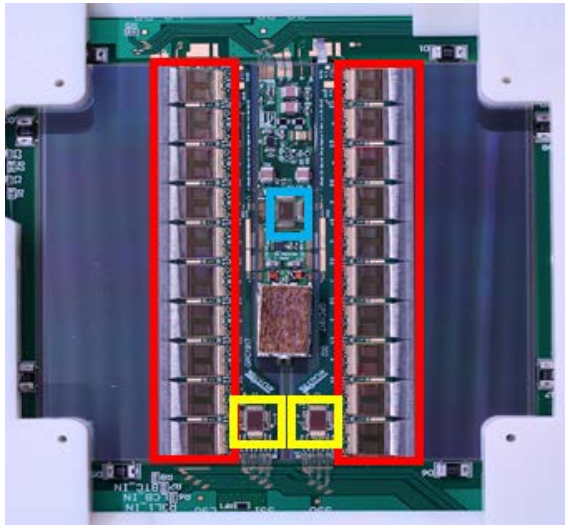


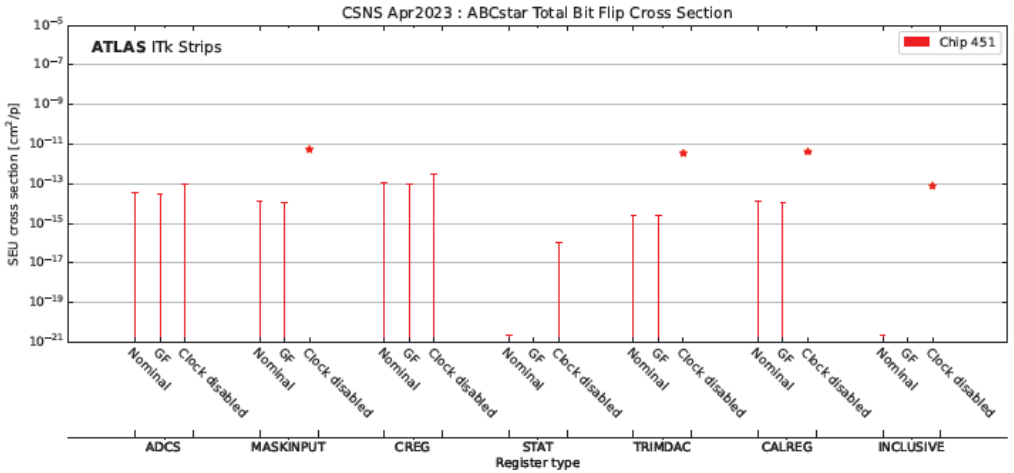
芯片辐射效应

- 总剂量效应研究
  - X光机辐照
  - Current bump效应
- 单粒子效应
  - ABCStar和HCCStar单芯片
  - 模块级芯片组









总结

- ITk升级是ATLAS升级的重要组成部分，决定着升级的成败
  - 暂时遇到了低温噪声和传感器裂开等技术问题
  - 已经找到了问题原因并提出了加垫片的方法

- 高能所承担了桶部模块的生产建造任务
  - 完成了站点评估
  - 发展标准操作流程，为生产做好了准备

- 开展了传感器和芯片的辐照效应研究
  - 传感器辐射效应研究有望成为QA站点
  - 完成了芯片总剂量和单粒子效应研究

谢谢

请批评指正！