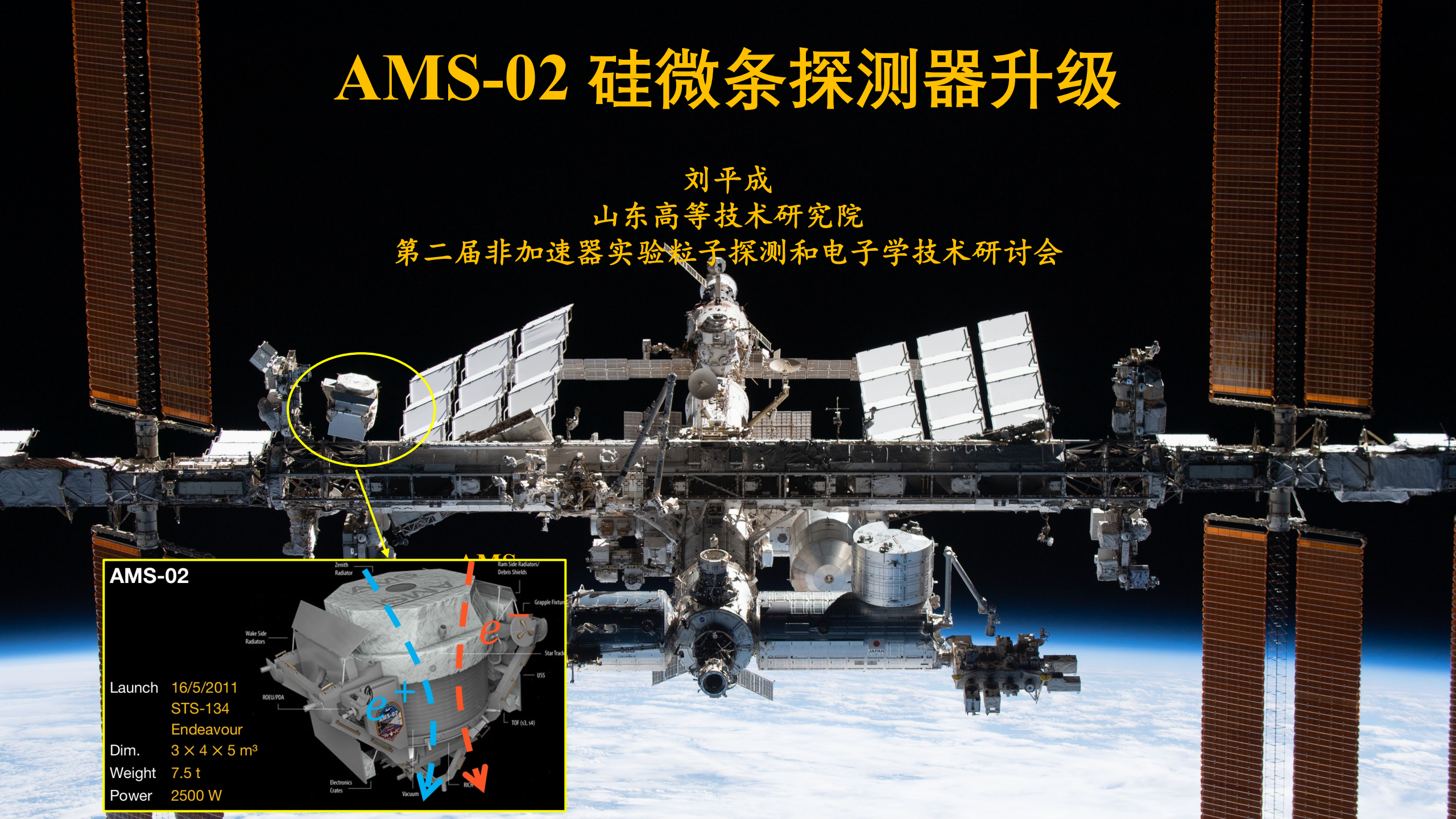
AMS-02 硅微条探测器升级

刘平成
山东高等技术研究院
第二届非加速器实验粒子探测和电子学技术研讨会

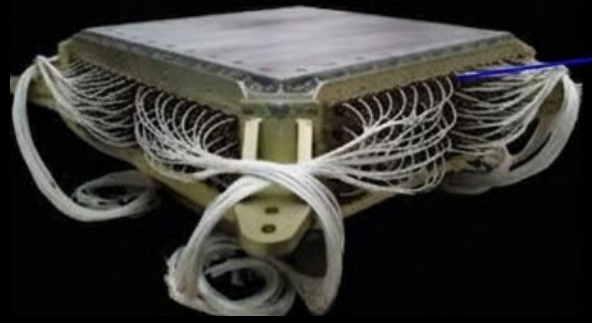


阿尔法磁谱仪AMS

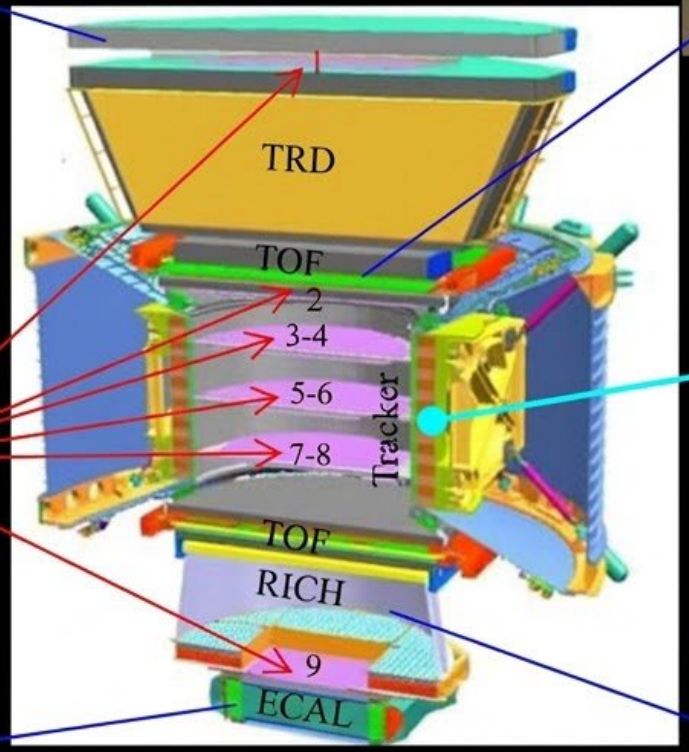
TRD: 识别 e^+, e^-, 测量Z

Tracker: 测量 Z, P

ECAL: 识别e^+, e^-，测量E



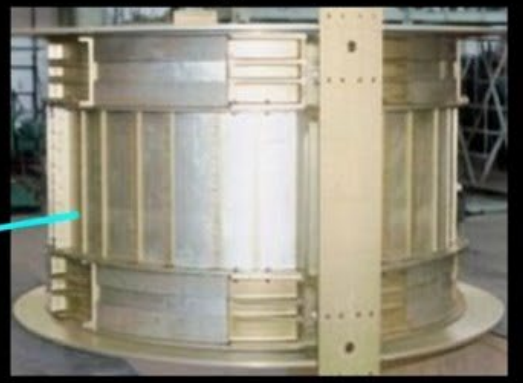
电荷Z、能量E（或动量P）
是粒子和原子核的基本物理量



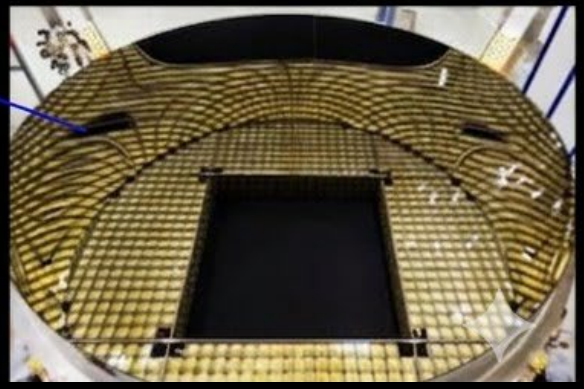
Tracker, RICH, TOF 和 ECAL
对Z 和 P（E）进行多次精确测量

TOF: Z, E

Magnet: ±Z

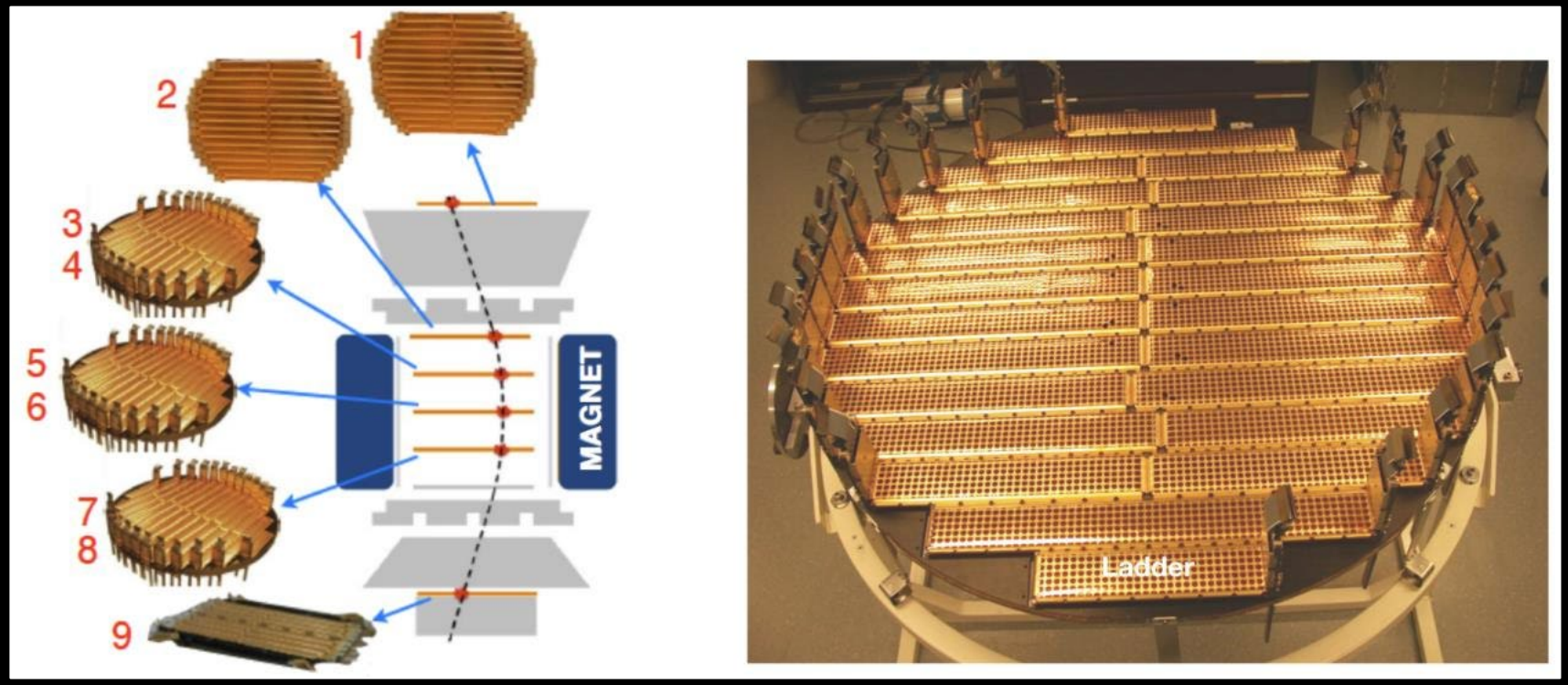


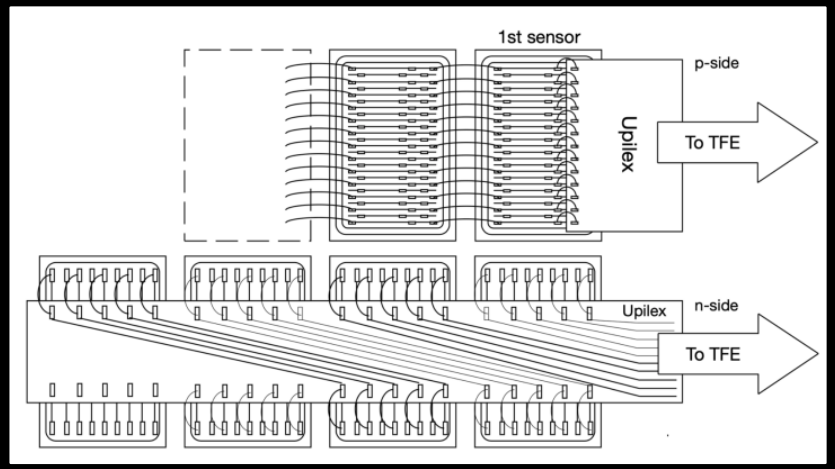
RICH: Z, E

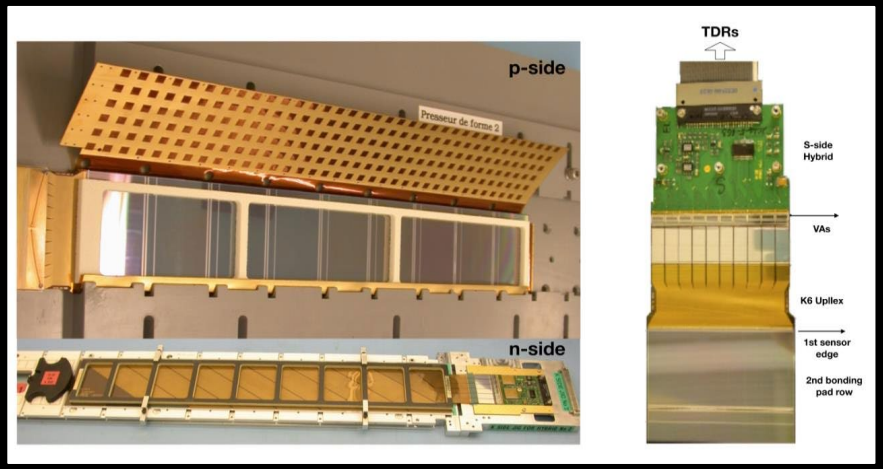


AMS-02 硅微条探测器

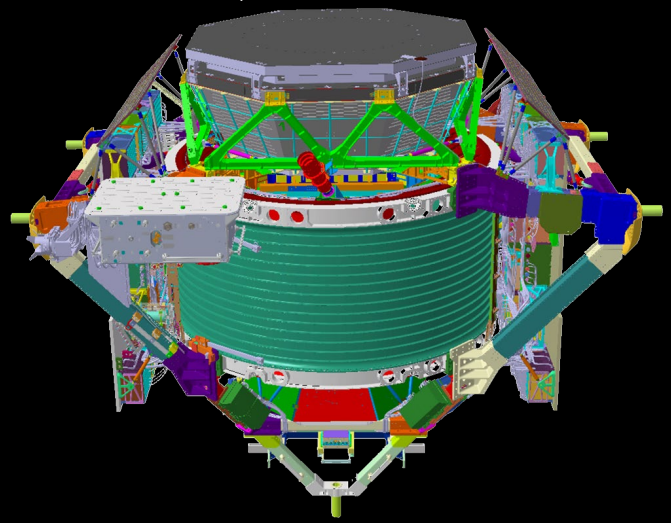
- 9层双面读出硅微条探测器
- L1至L9：~3m lever arm
- 192条Ladder
  - 2264片硅微条传感器
  - 读出间距110 μm（X方向），208 μm（Y方向）
  - ~20万道读出
- 单层位置测量精度
  - 10 μm for Z=1

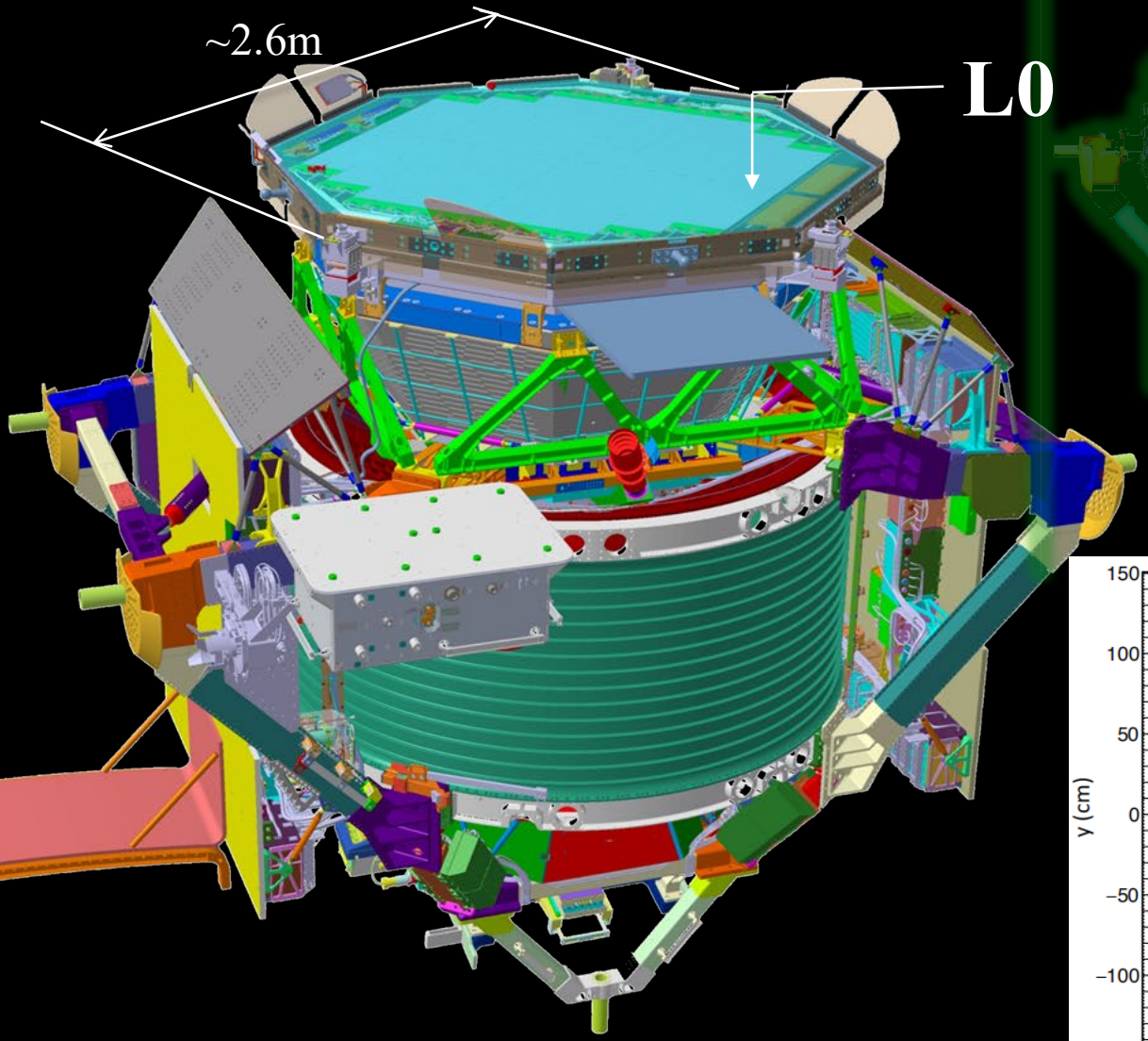


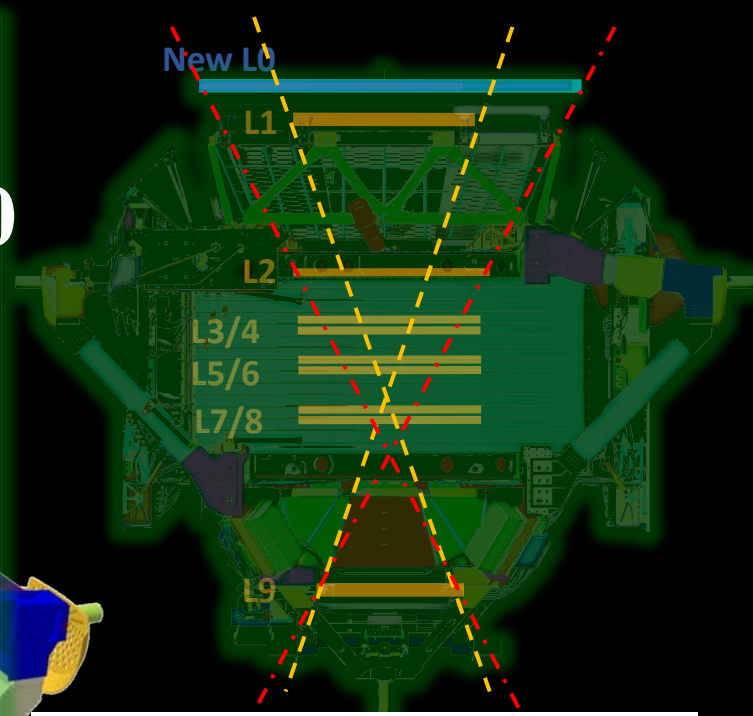


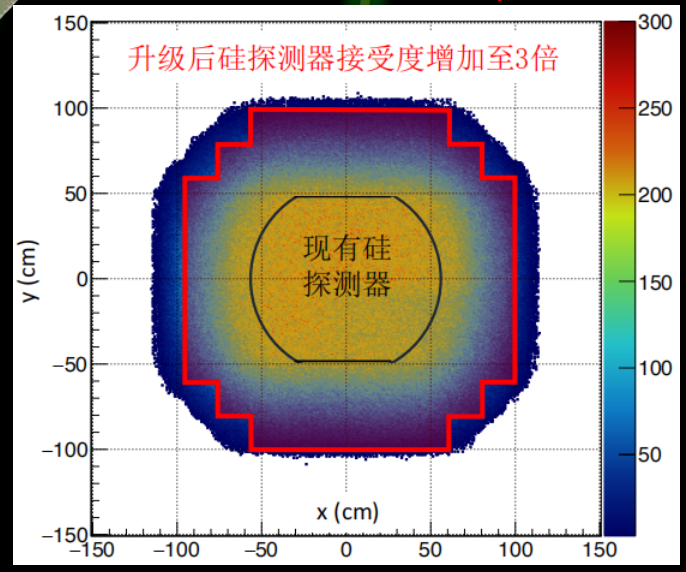


AMS-02 硅微条探测器升级

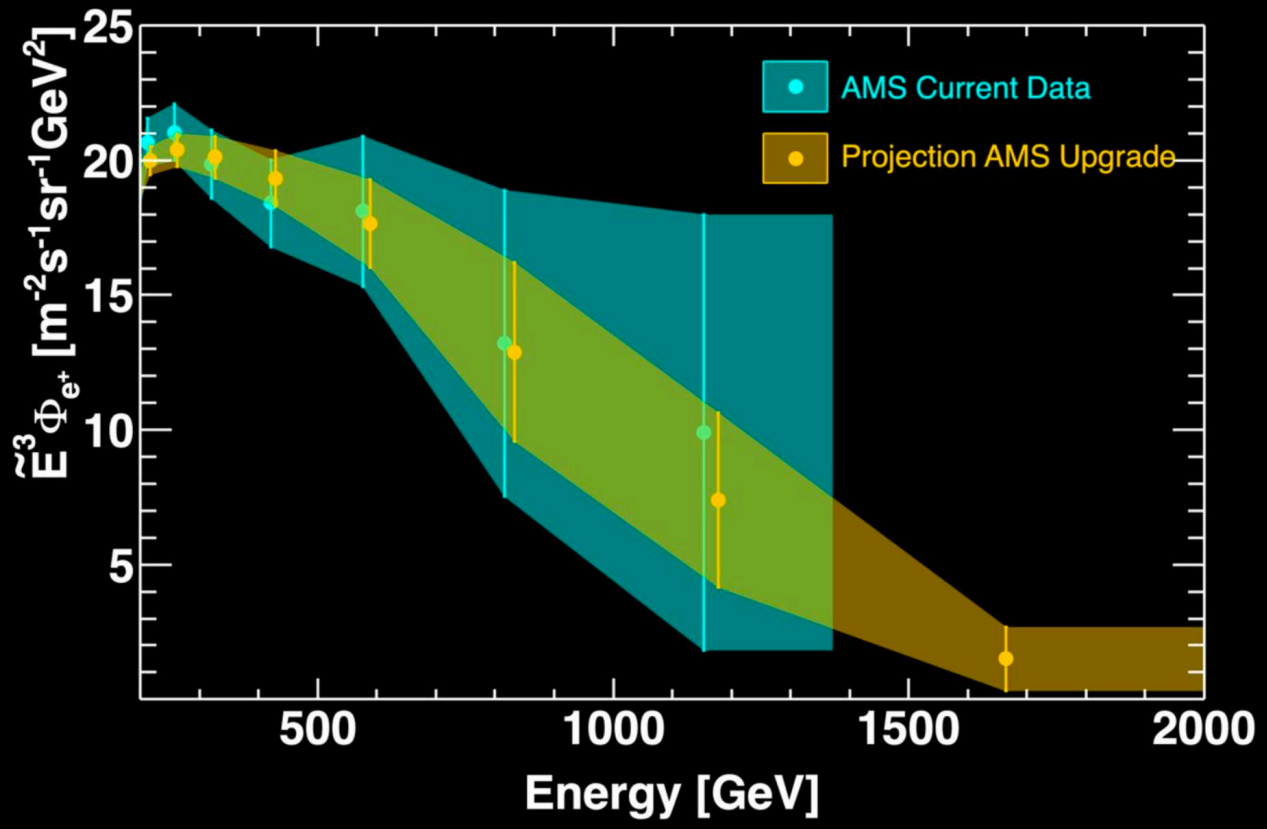


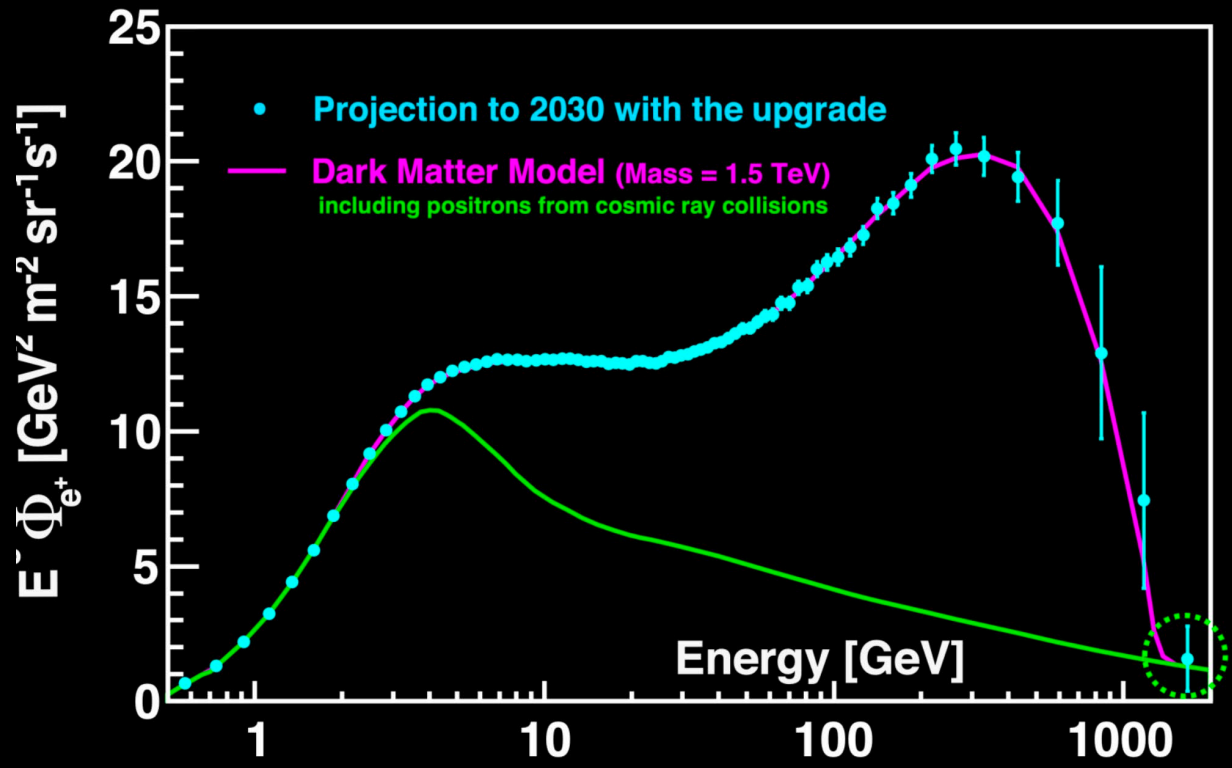






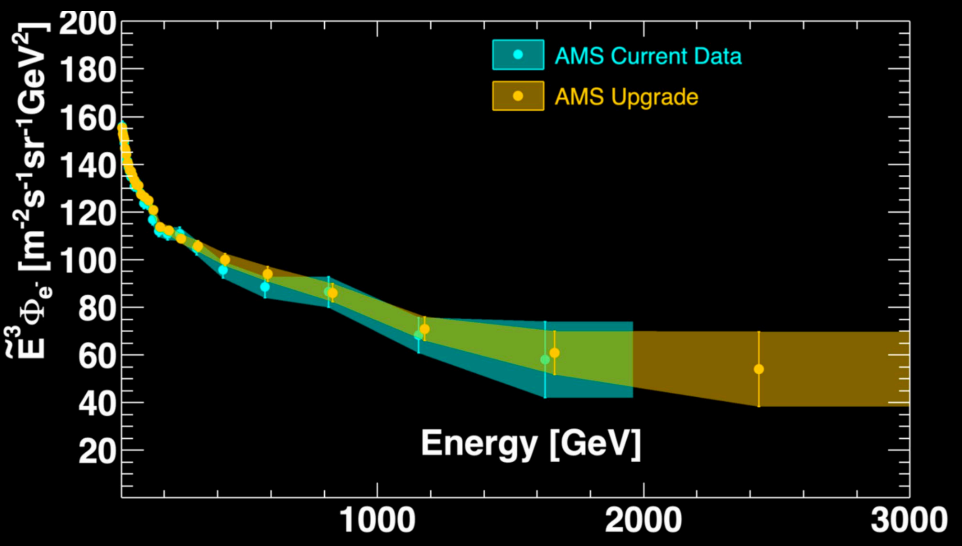
物理动机





将正电子通量测量的能量范围扩展到约2 TeV（2019年公布了1 TeV的数据）。
升级后的AMS-02中的最终数据点对于理解 TeV 能标下暗物质的贡献至关重要。

物理动机

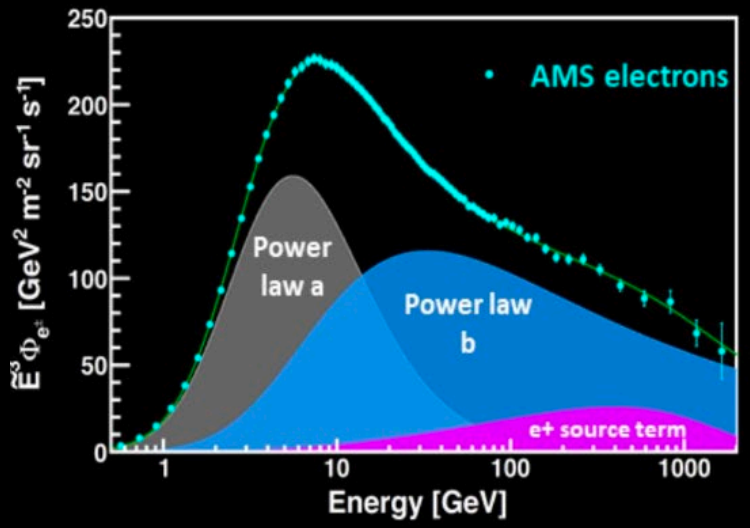


New sources like Dark Matter will produce equal amounts of positrons and electrons

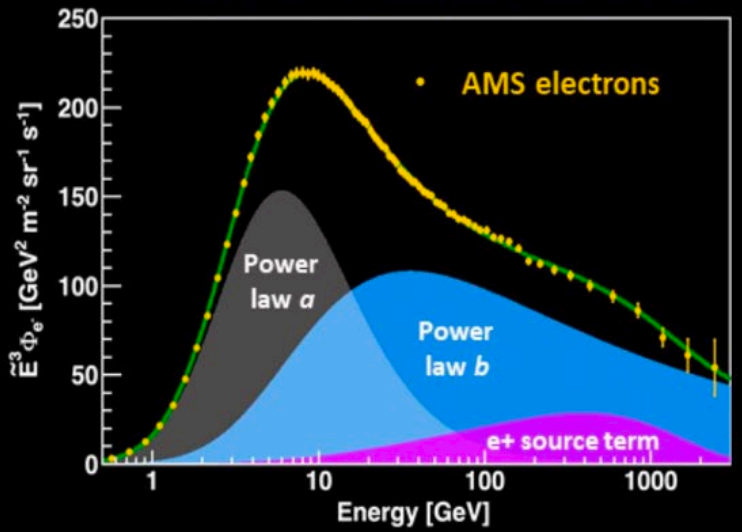
$$\Phi_{e^-}(E) = C_a E^{\gamma a} + C_b E^{\gamma b} + C_s E^{\gamma s}\exp(-E/E_s)$$

Power law *a* Power law *b* Positron source term

Current Data
95% C.L. detection of source term

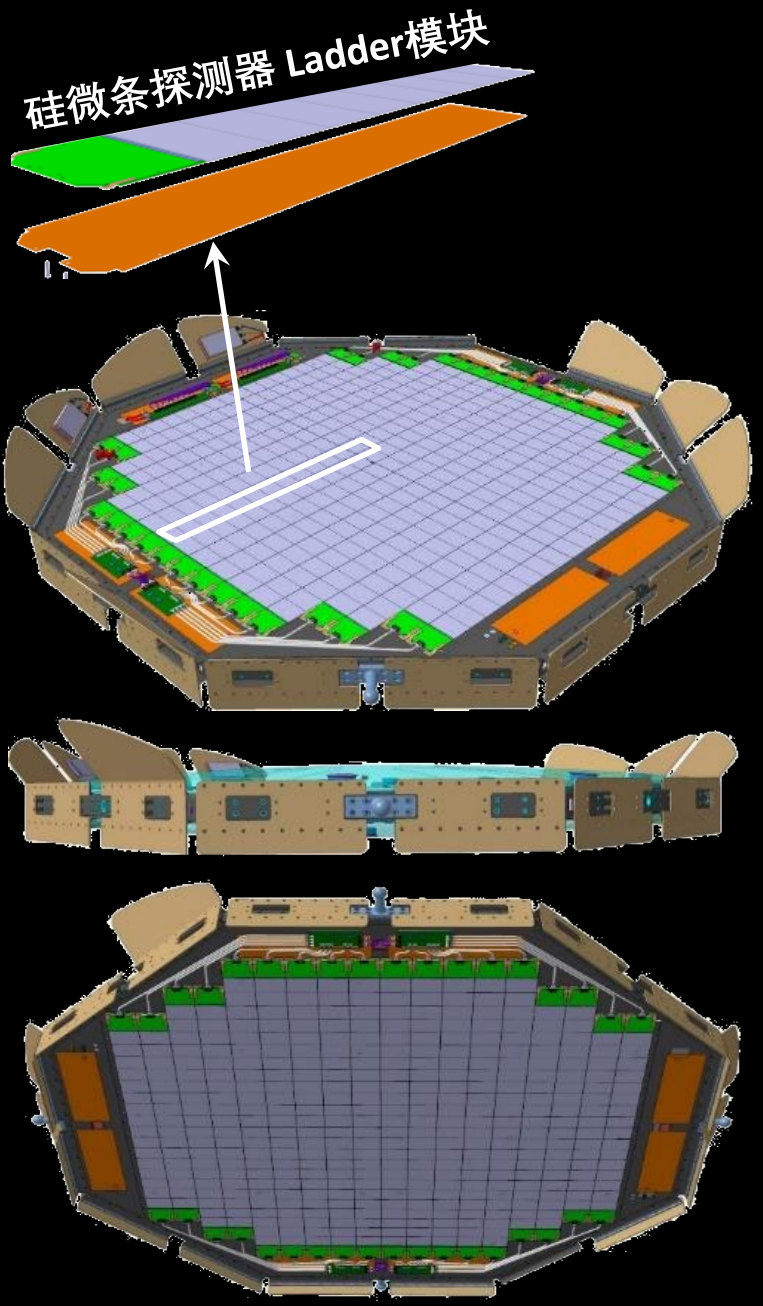


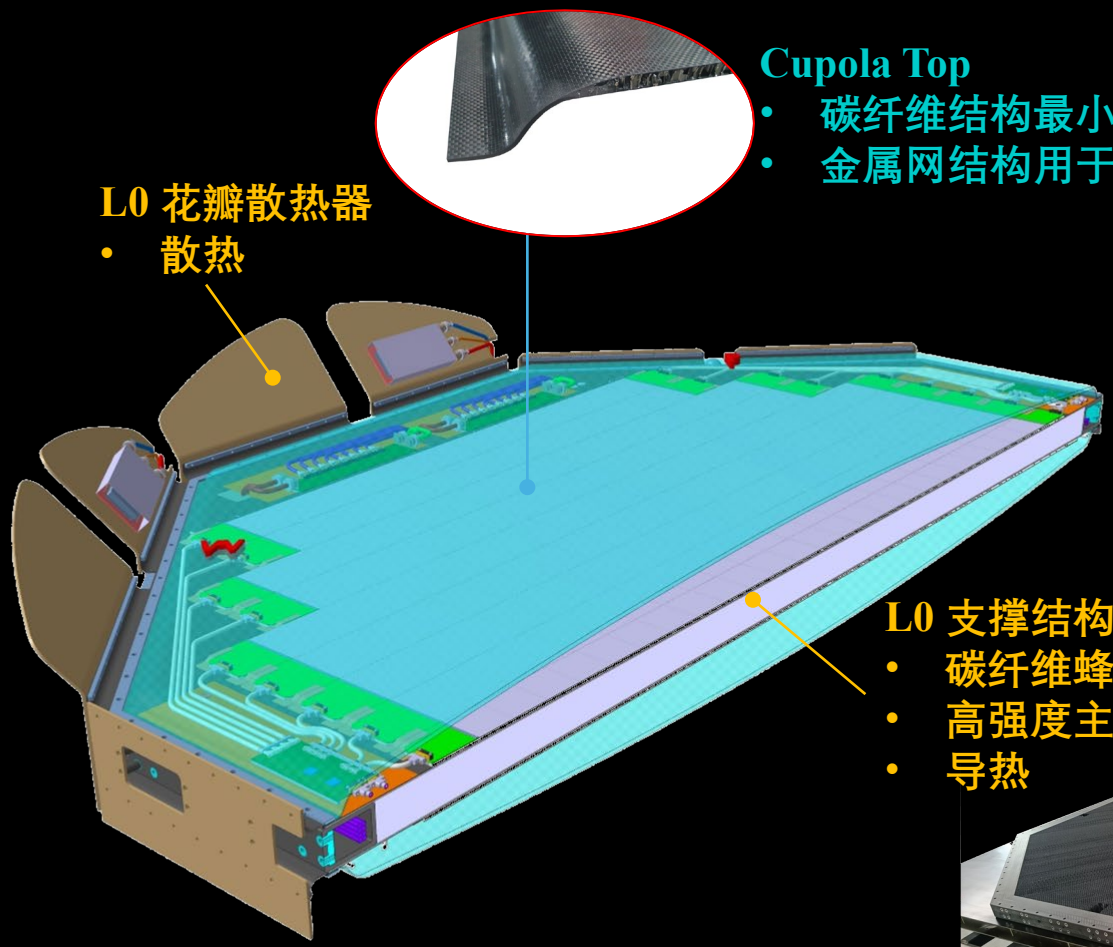
With Upgrade
99.994% C.L. detection of source term

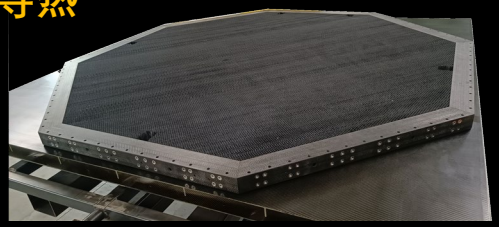


将电子通量测量的能量范围从目前的约2 TeV（2019年公布的为1.4 TeV）扩展到3 TeV。
通过AMS升级，能够以更高的置信度更好地将正常的宇宙射线与可能的新信号（如暗物质）区分开来。

L0结构





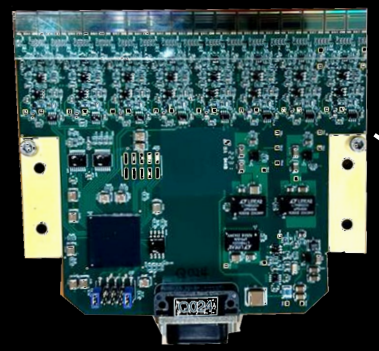


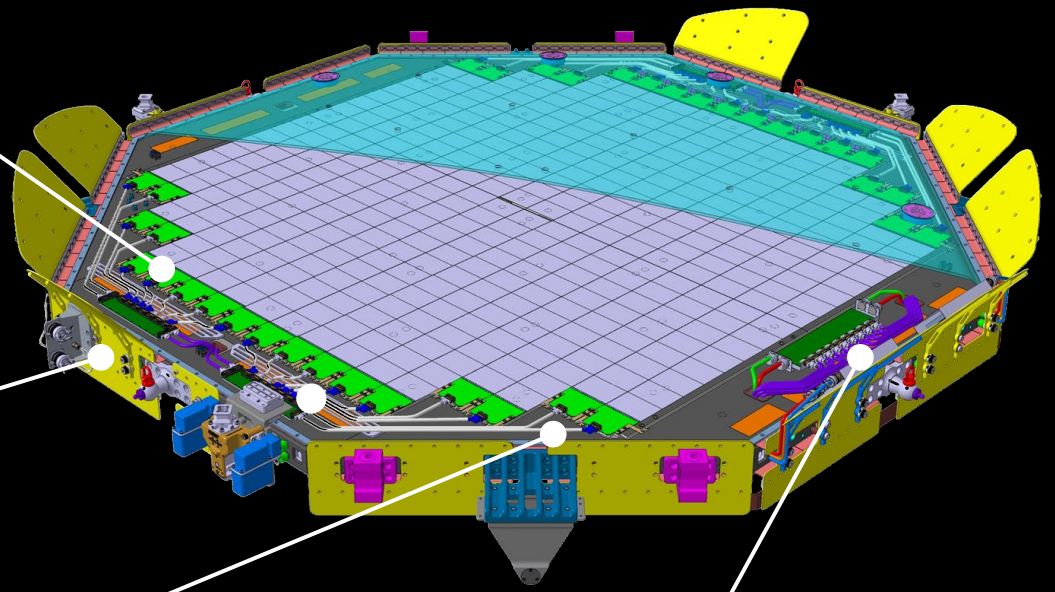
- ~8m^2 探测面积
- 72条Ladder
- ~7.4万道读出
- L0整体直径~2.6m，厚度~0.5m，总重量~350kg

电子学

72 × Front End Board （LEF）

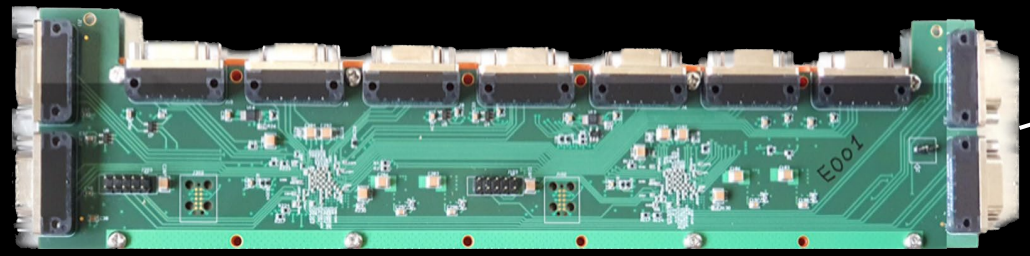
- 16个IDE1140芯片数据采集
- 8路读出（信号放大与整形
- 模数转换）
- SSD偏置电压
- 数据压缩





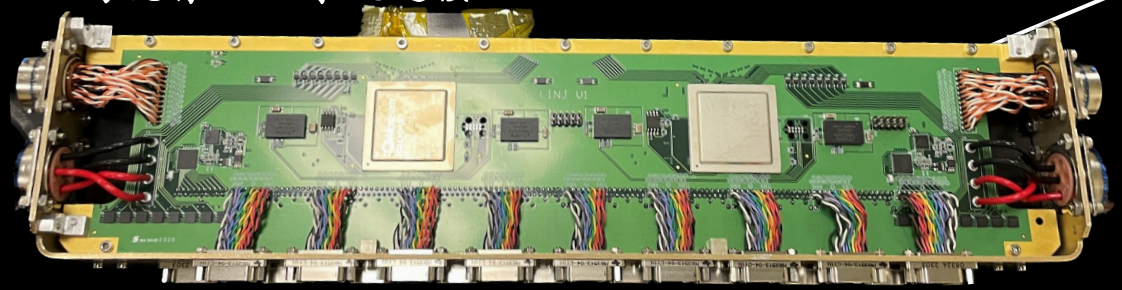
8 ×Intermediate Board （LINF）

每个LINF负责9个LEF信号串行传输



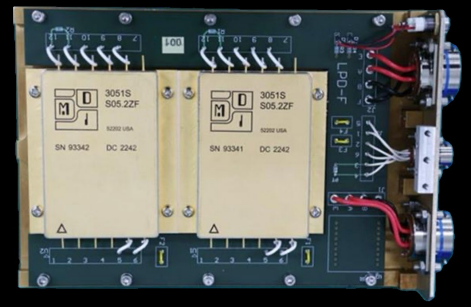
1 ×Interface Board （LINJ）

与现有AMS系统连接



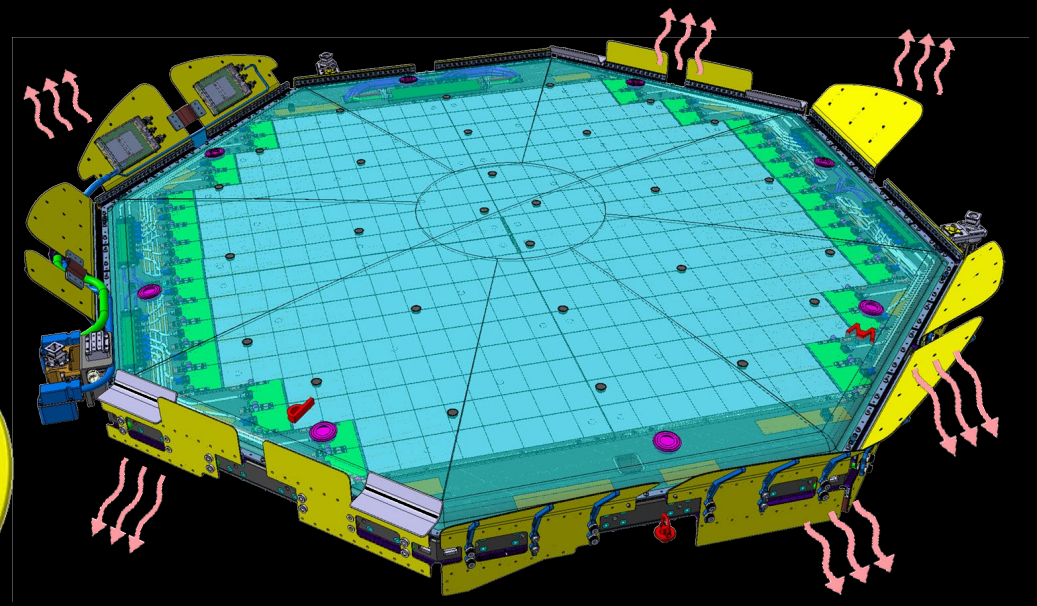
2×Power conversion and distribution，LPD

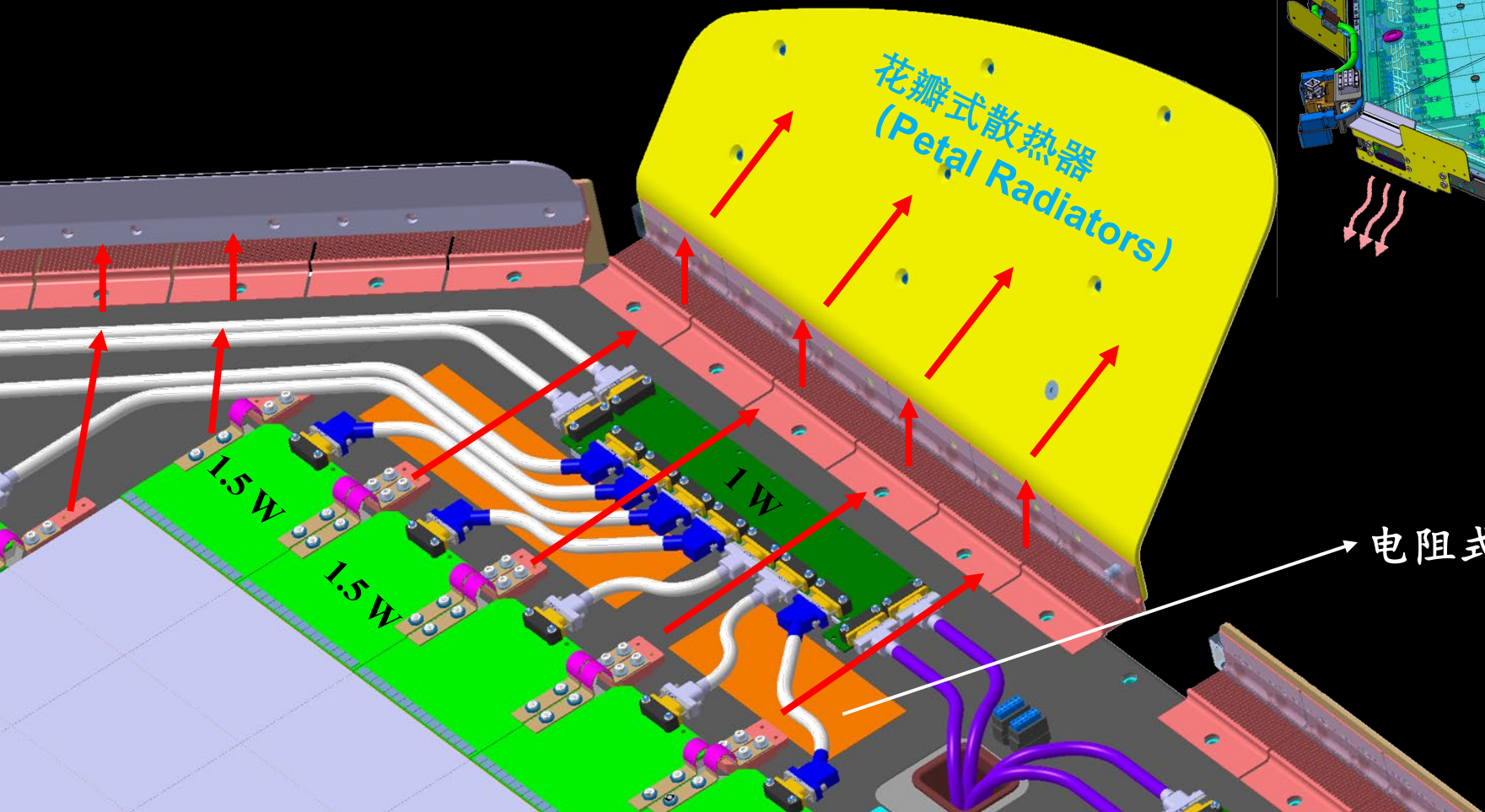
- 5V探测器供电
- 120V加热系统供电



热管理系统

电子设备产生的热量通过导热路径传导至花瓣式散热器，再由散热器将热量散发到太空中。



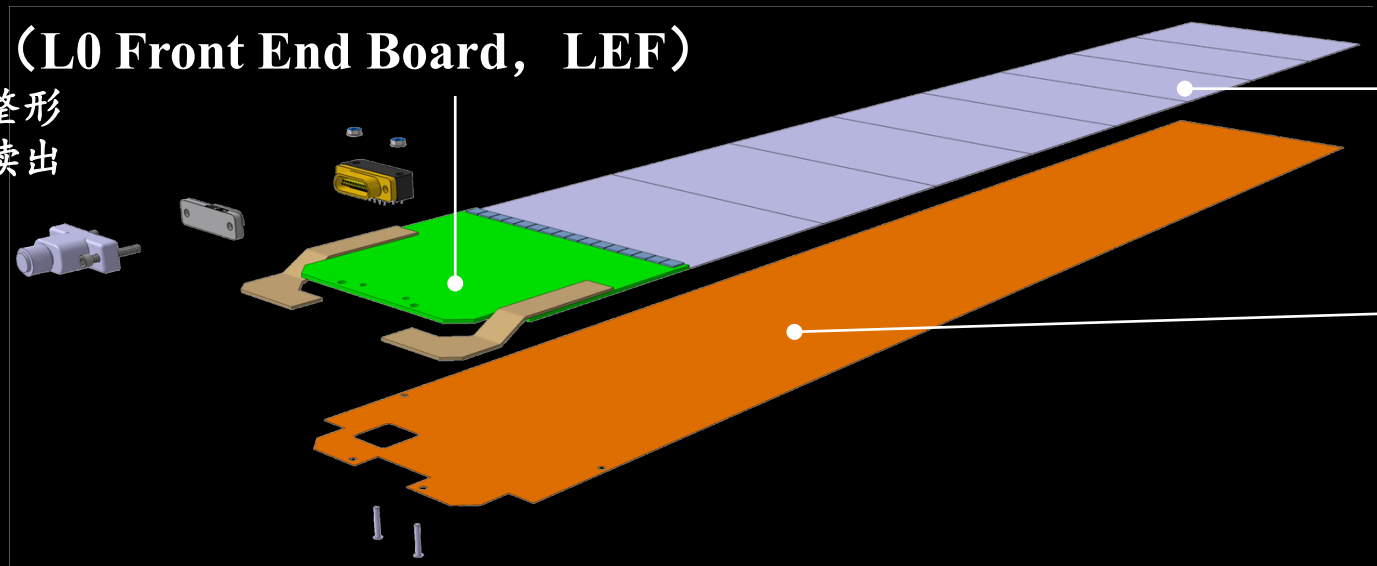


电阻式加热器（Heater）稳定温度。

Ladder

前端电子学（L0 Front End Board，LEF）

- 信号放大与整形
- 电荷收集与读出
- 模数转换

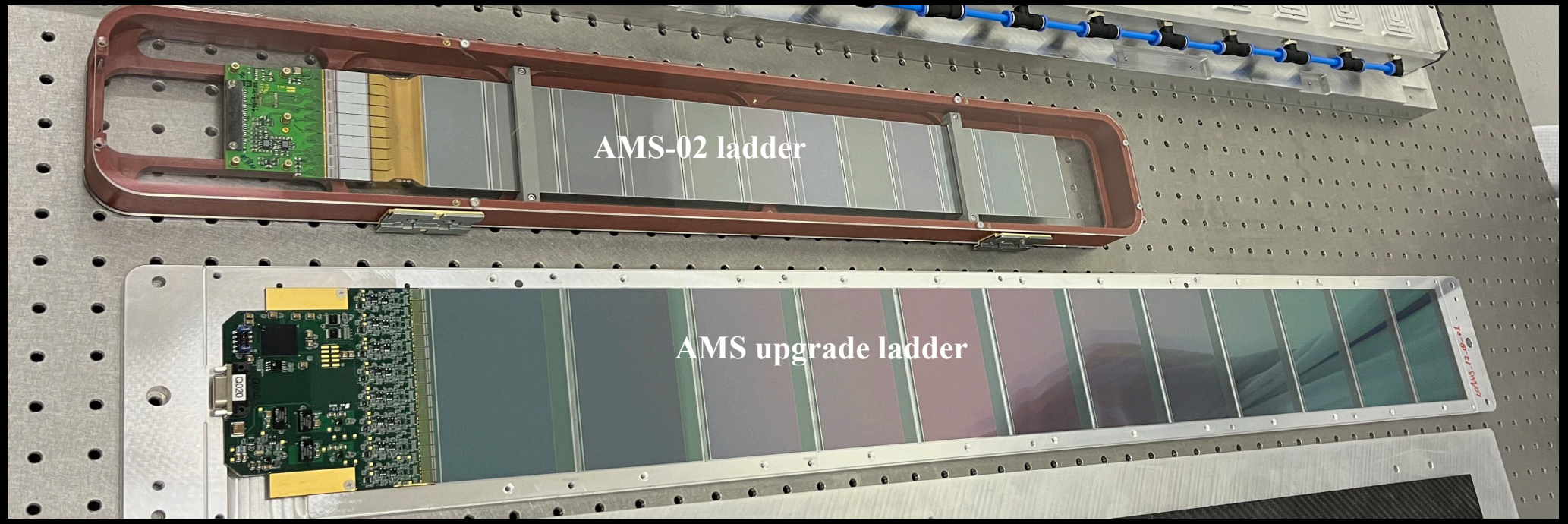


硅微条传感器芯片（SSD）

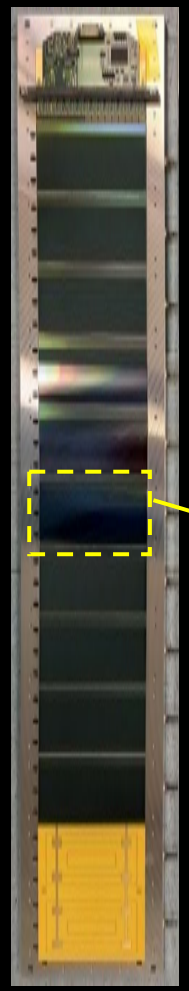
- 8，10，12 SSD

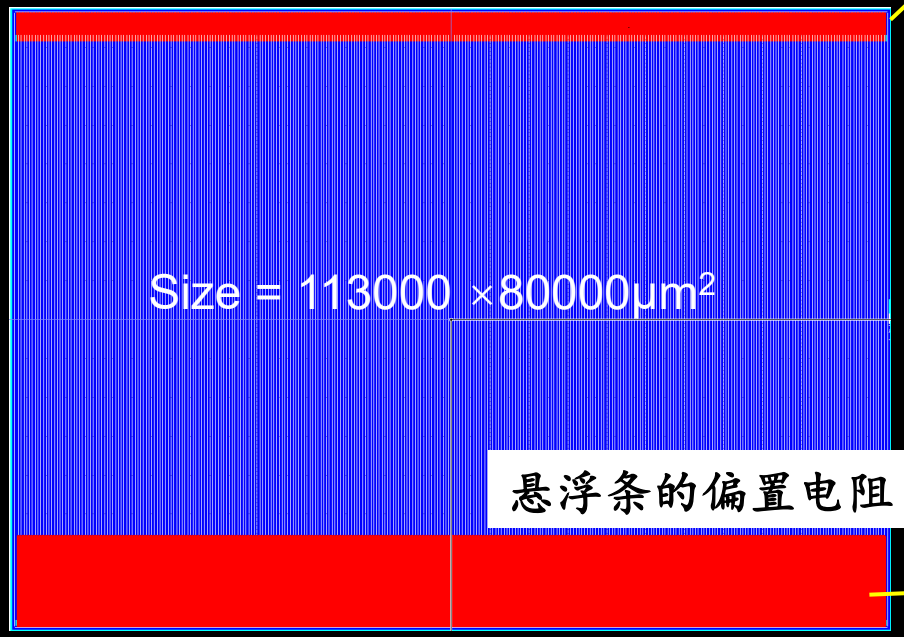
L0 Back Board，LBB

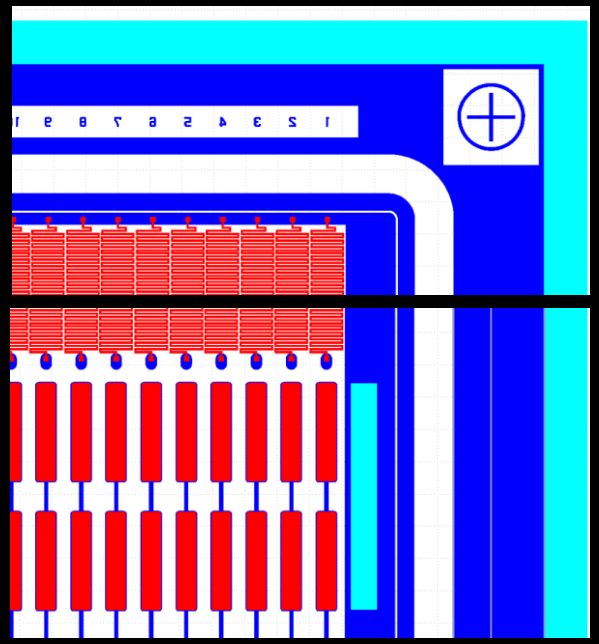
- 支撑
- 偏压

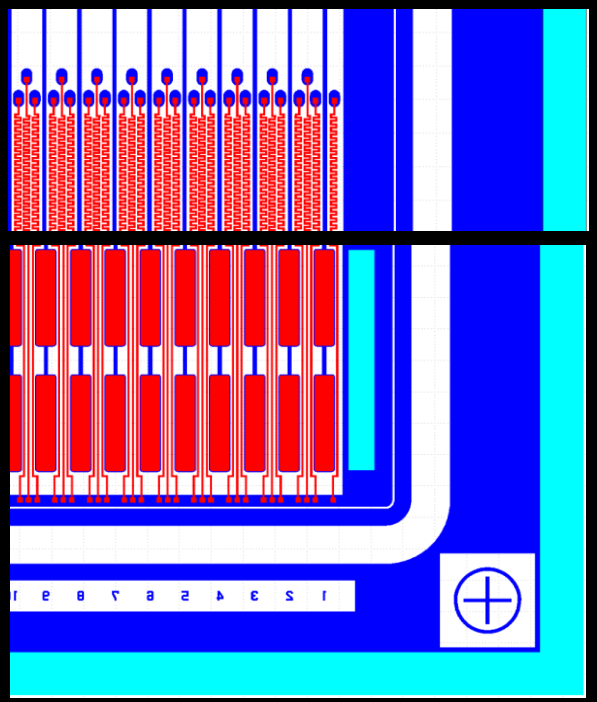


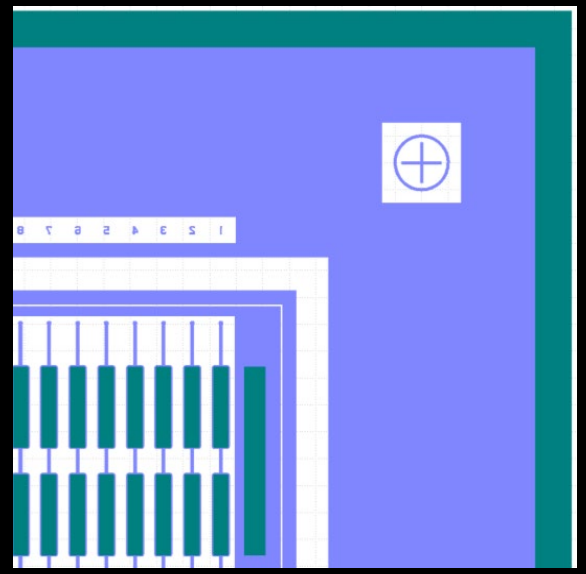
硅微条传感器

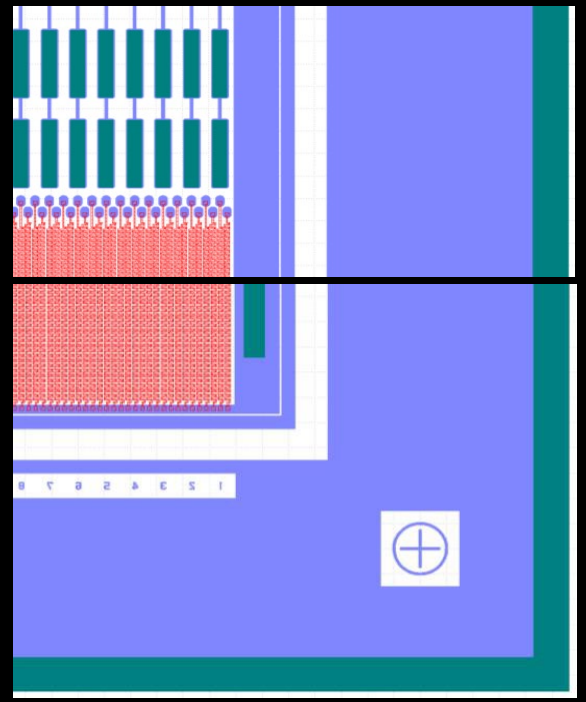








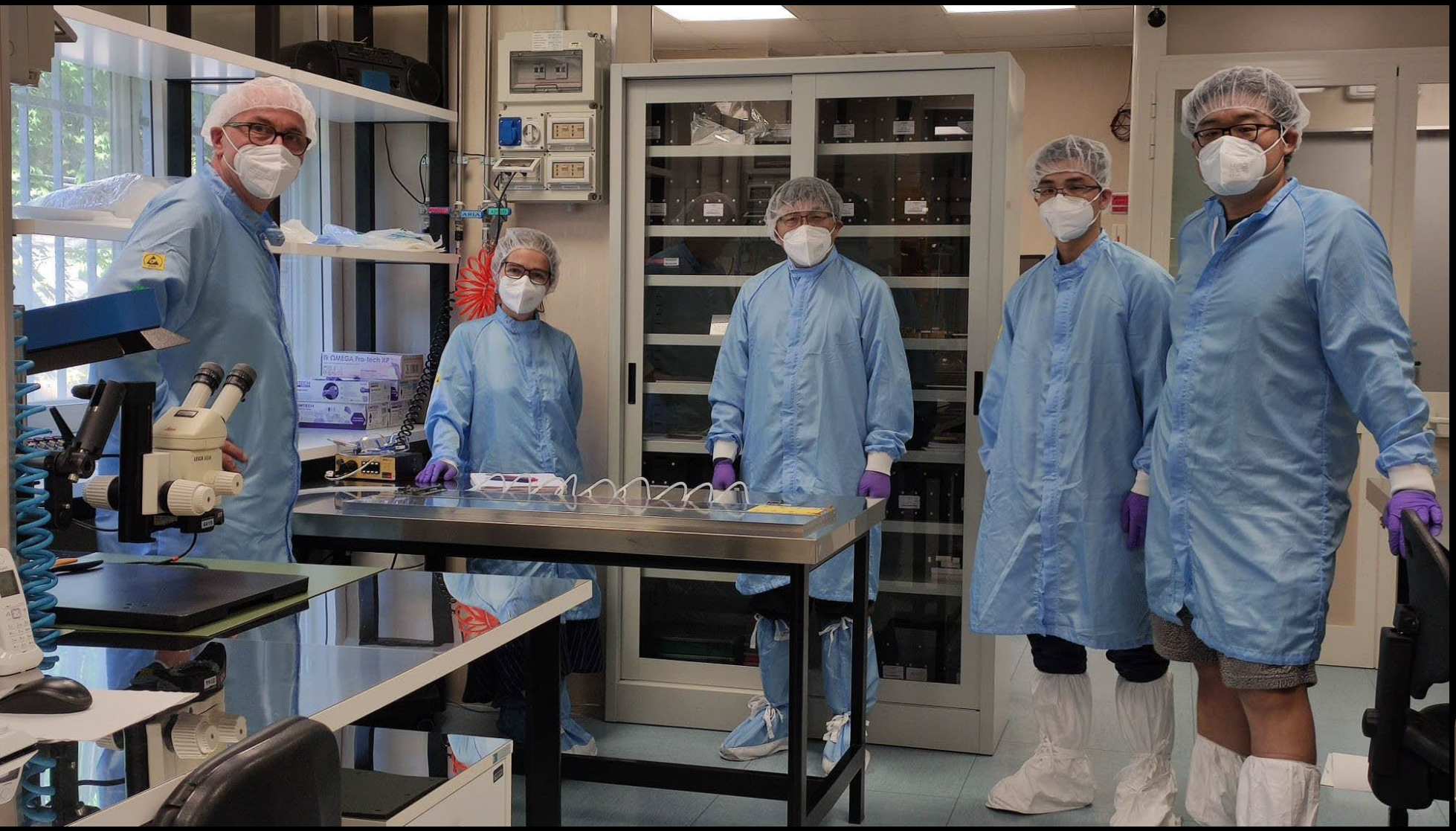




偏置电阻两侧分布，悬浮条的偏置电阻置于读出条间

- 增大有效面积
- 减少Bonding的长度

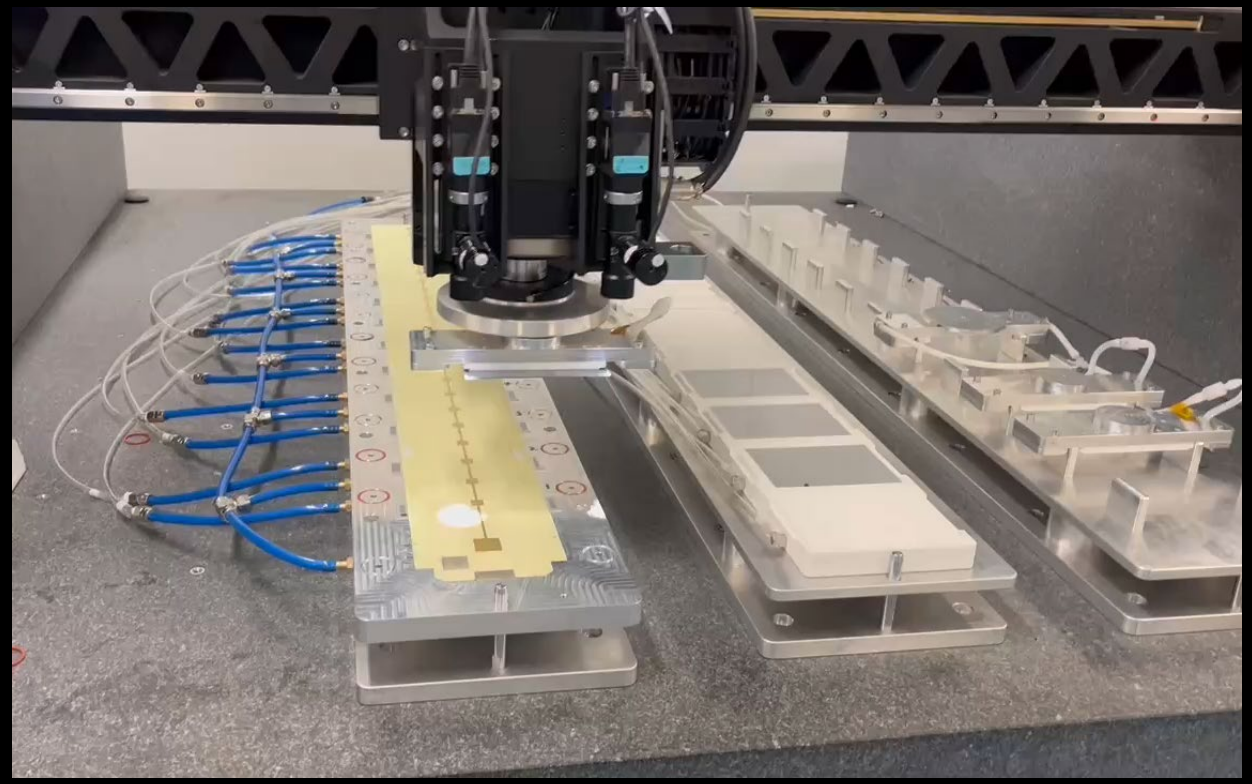
原型机的研制——INFN，Perugia，2022年

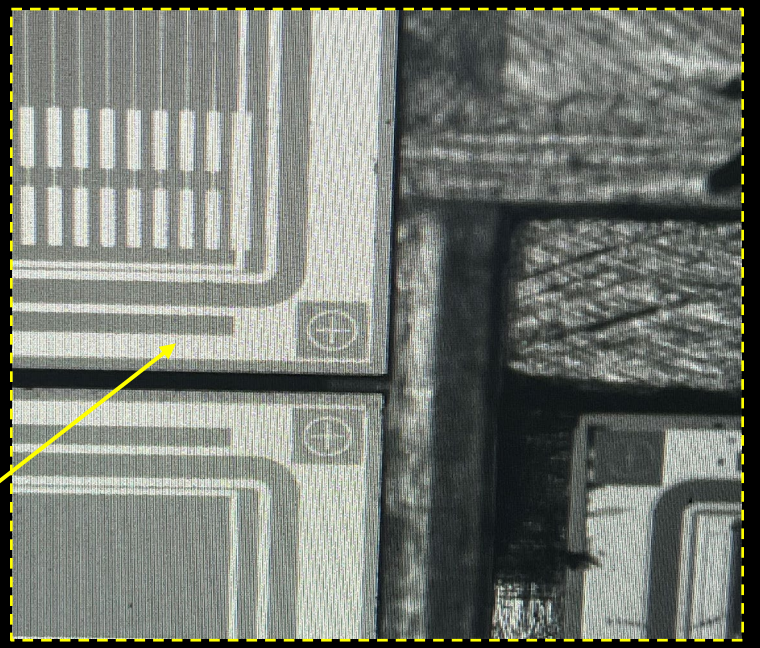


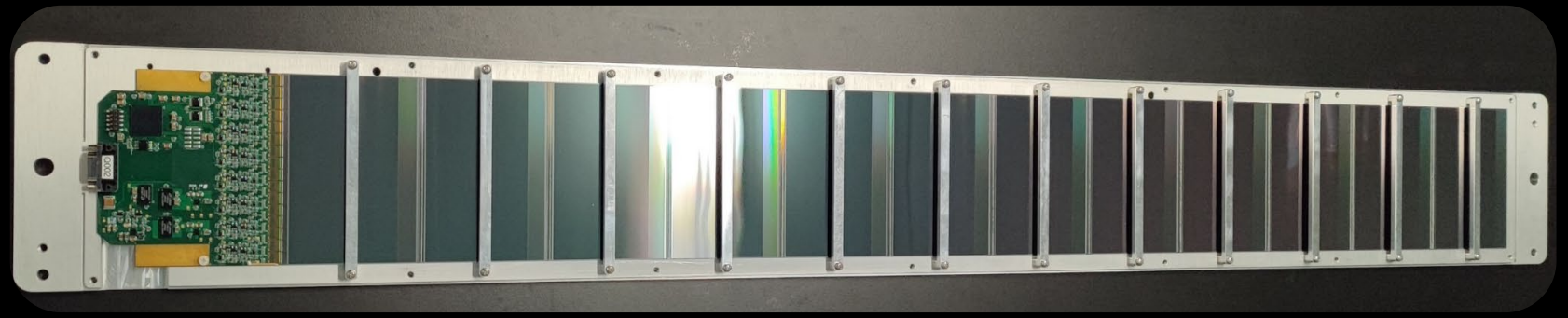
来自INFN—Perugia , IHEP and SDIAT的研究人员.

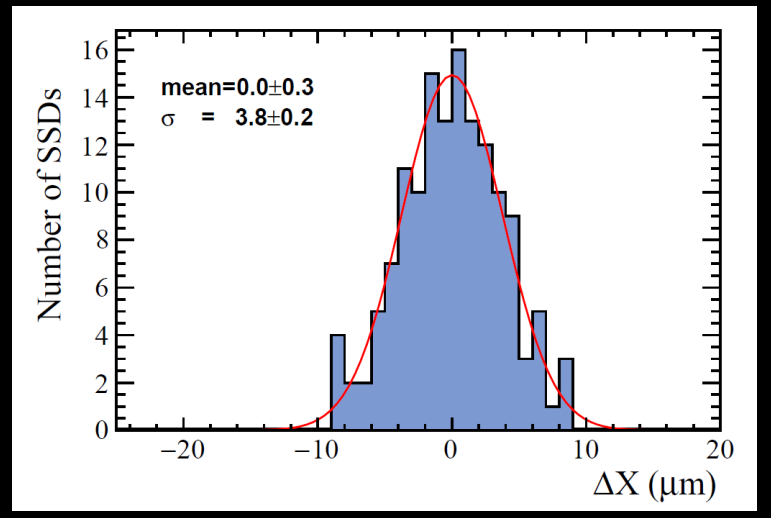
2024 年，IHEP和SDIAT的研究人员合作，以极高的精度组装了 72 + 5 个Ladder模块

Ladder批量生产——高精度组装

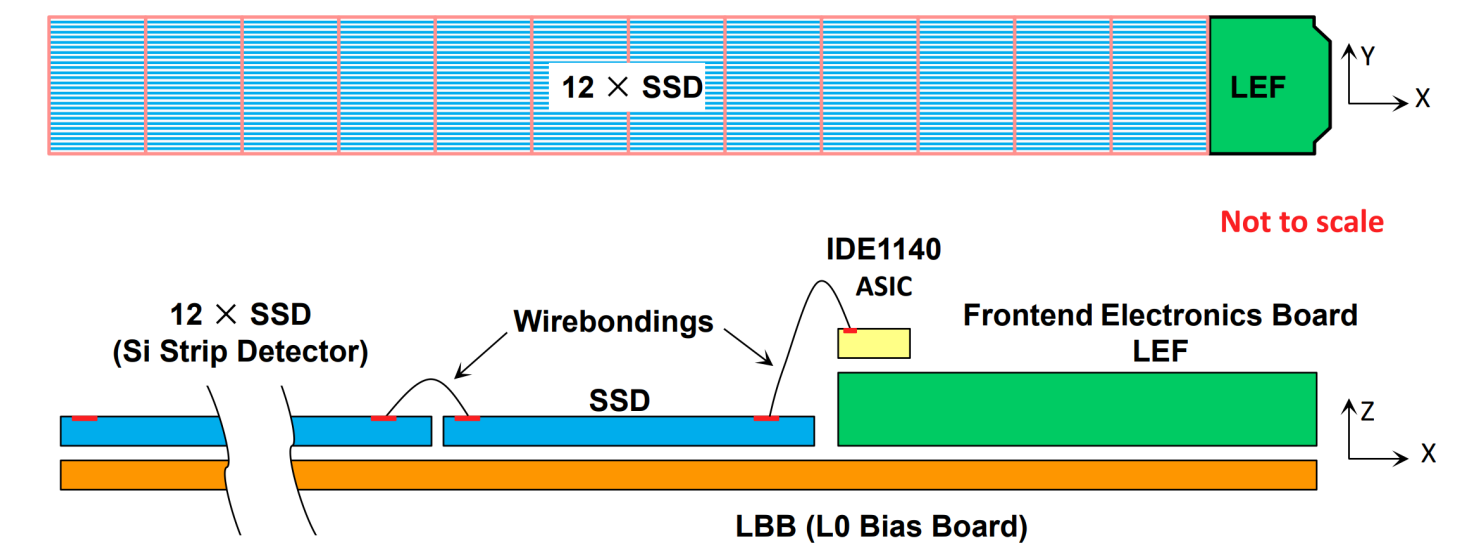


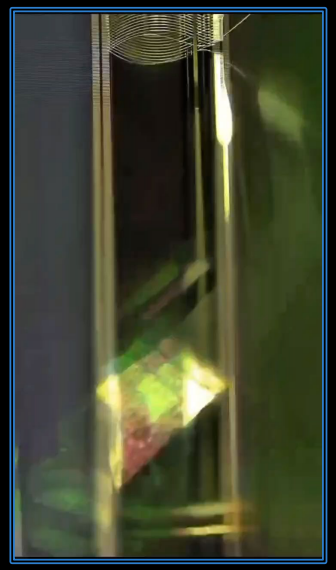


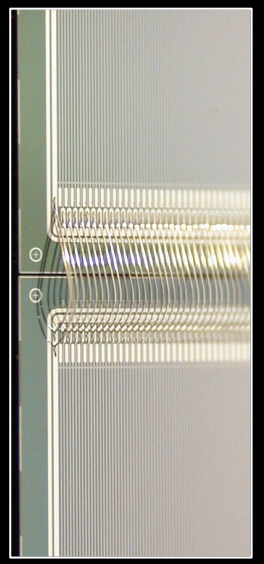


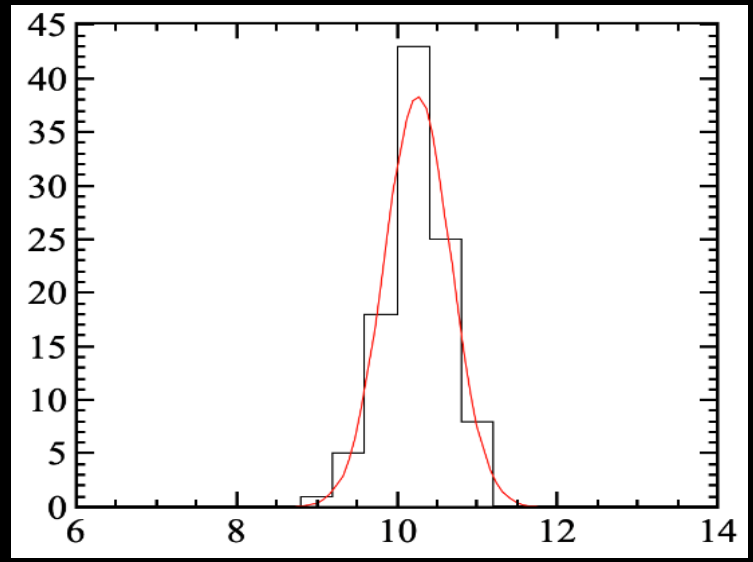


Ladder批量生产——Wire bonding







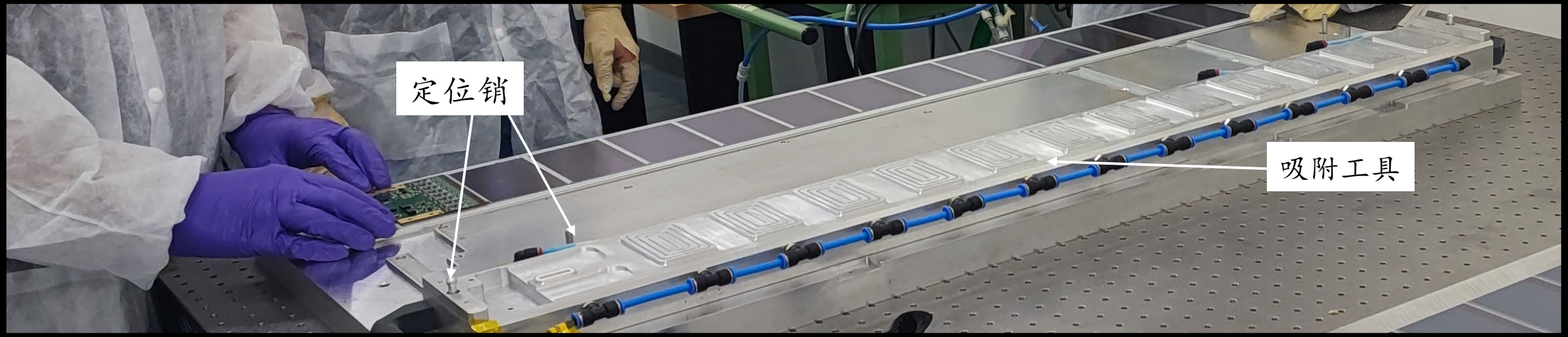


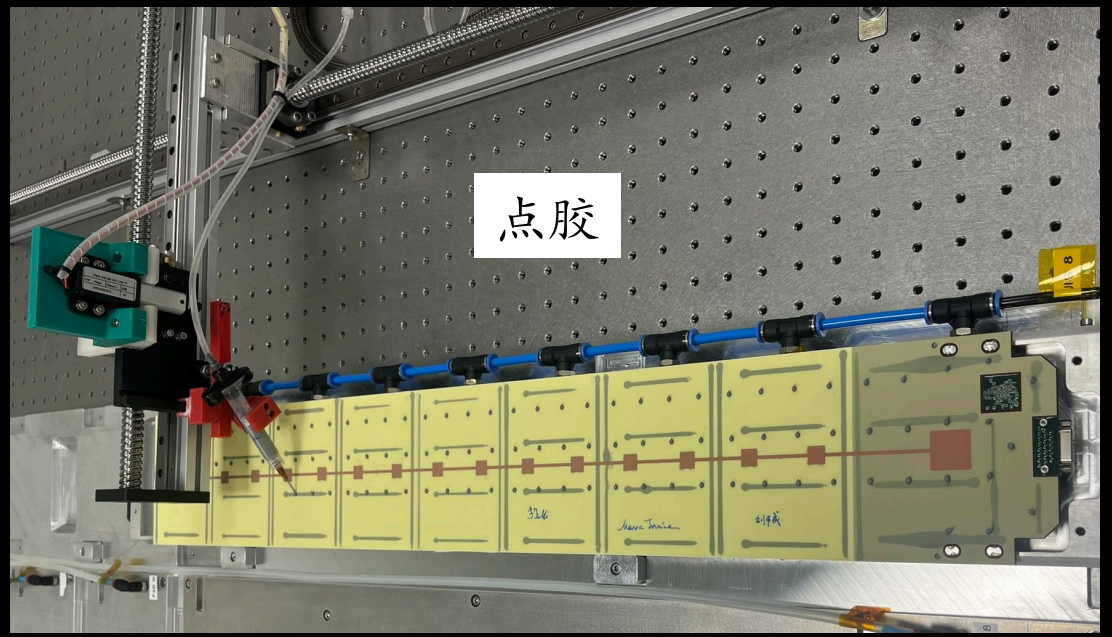
Ladder批量生产——测量和电子学测试

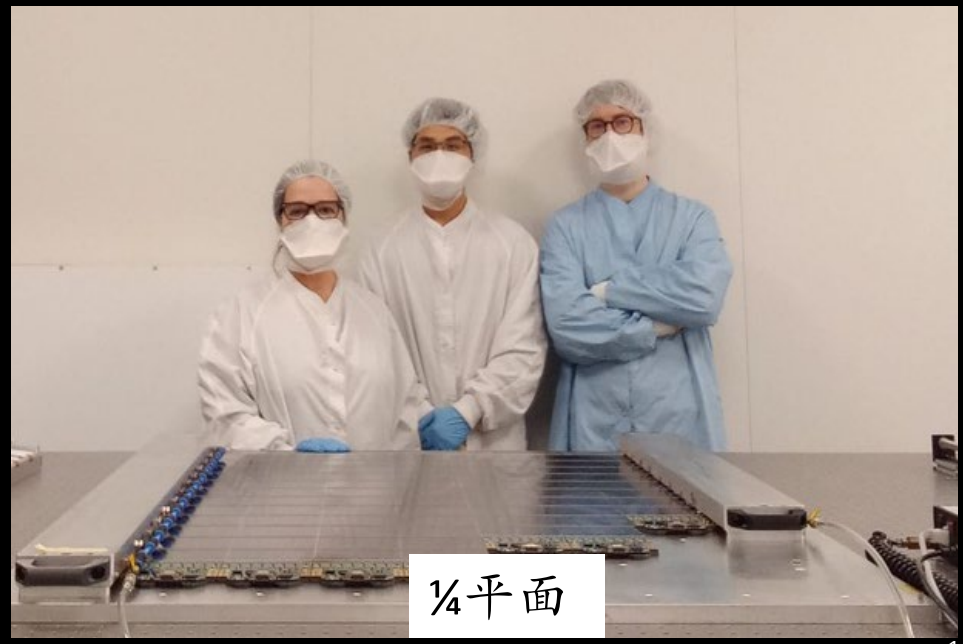
三坐标精密测量系统的测量
精确测量所有SSD的相对位置。

电子学测试
暗电流、噪声水平、通道连接……

探测器平面集成——意大利

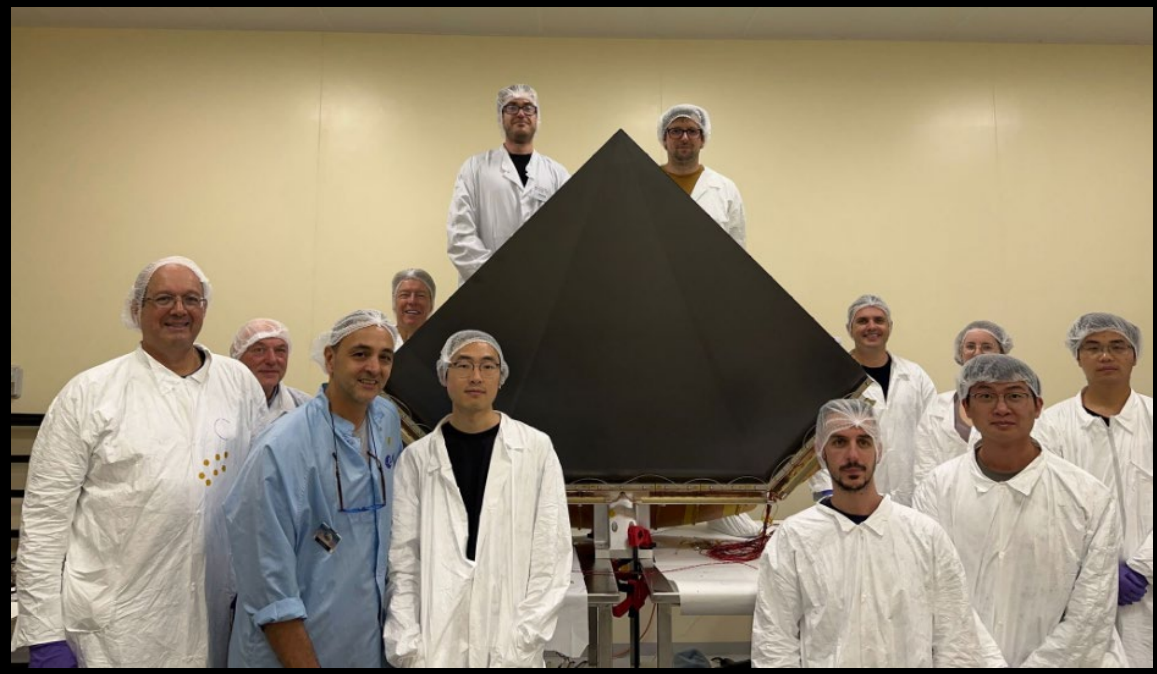






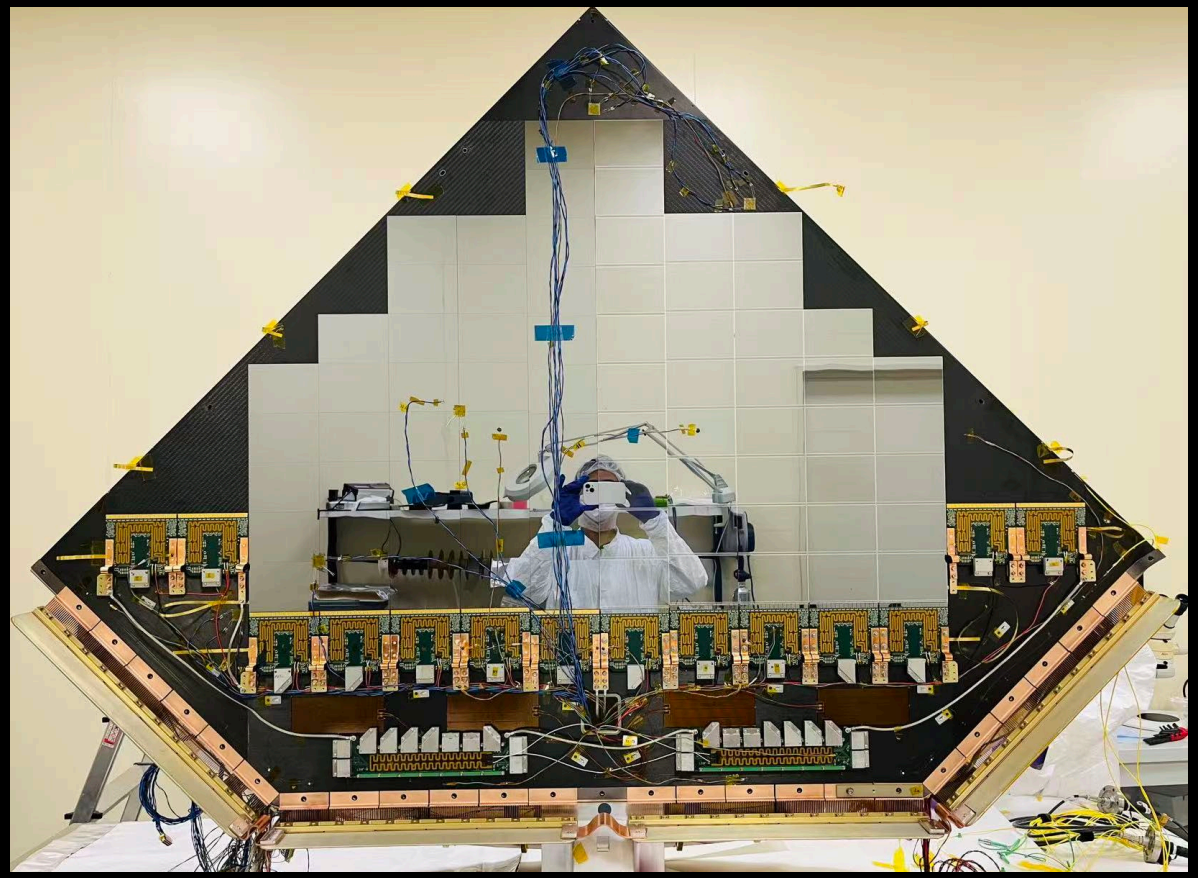
质量验证1/4模型的集成和空间资格测试

用于验证探测器的集成过程和空间资格测试。



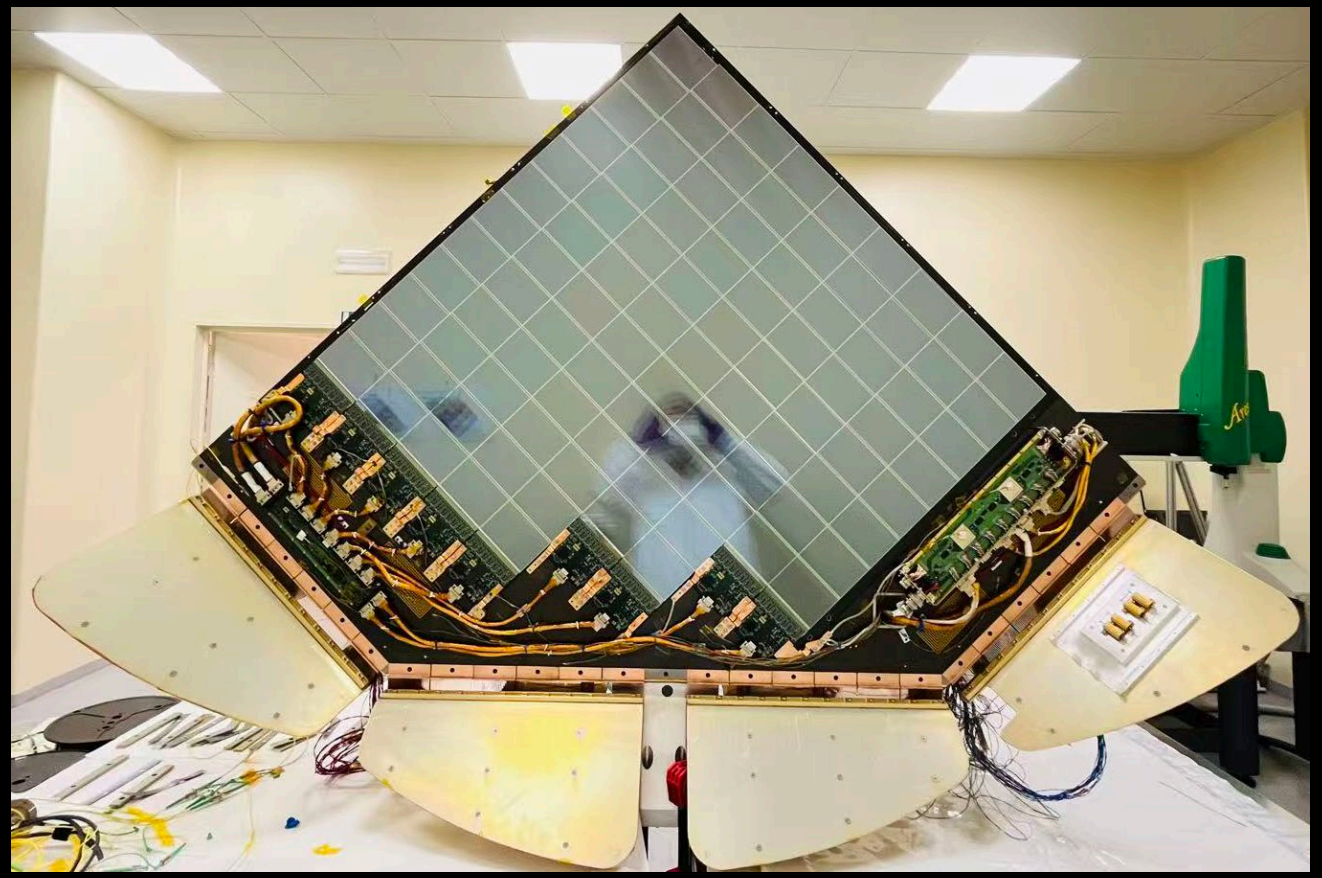
来自美国国家航空航天局（NASA）、麻省理工学院（MIT）、欧洲核子研究中心（CERN）、中国科学院高能物理研究所（IHEP）、意大利国家核物理研究所（INFN）和山东高等技术研究院（SDIAT）的科学家与工程师们

质量验证1/4平面



Dummy Sensor Side

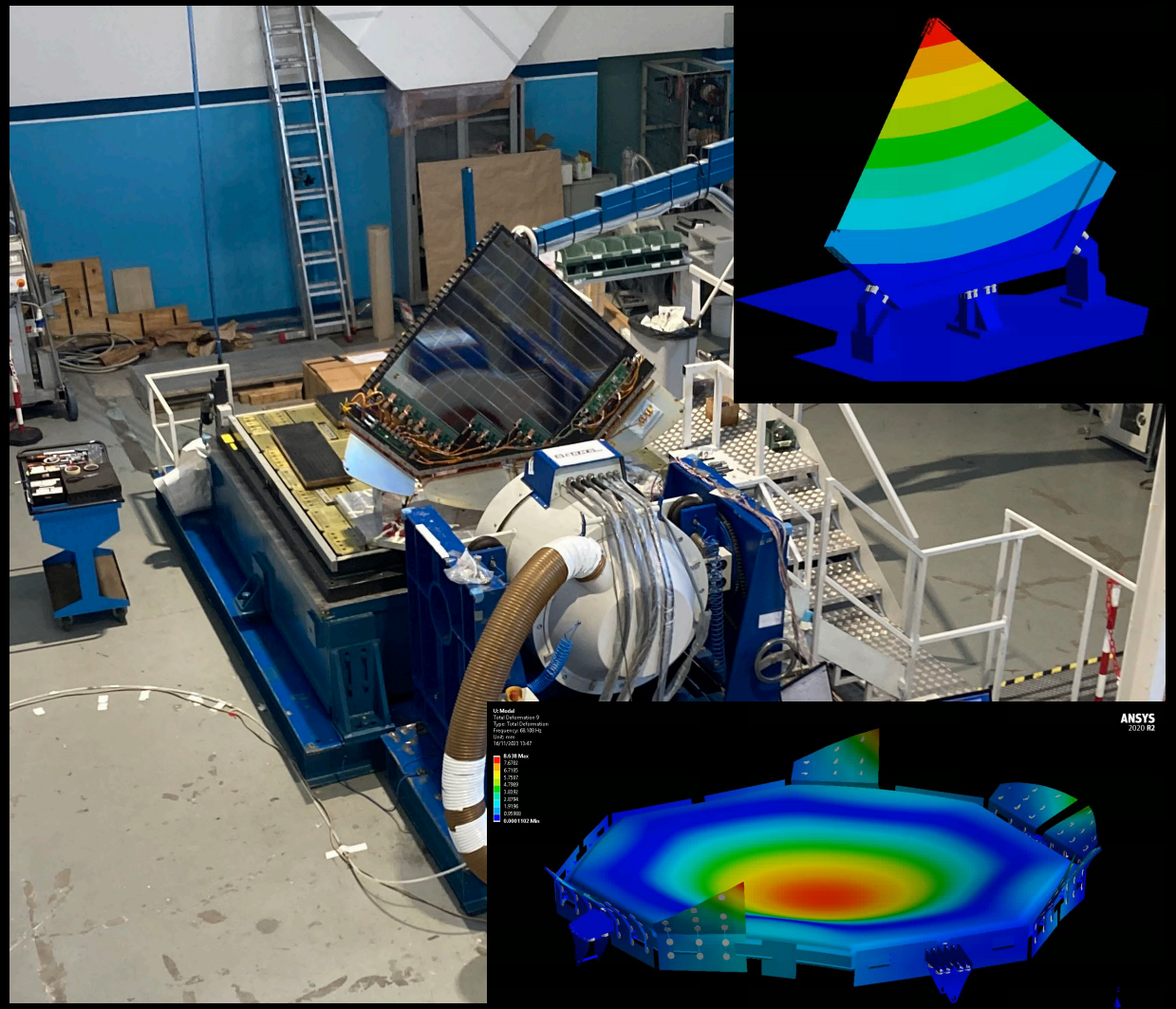
粘贴加速度传感器和温度传感器，研究机械性能（共振，传热等）。



Real Sensor Side

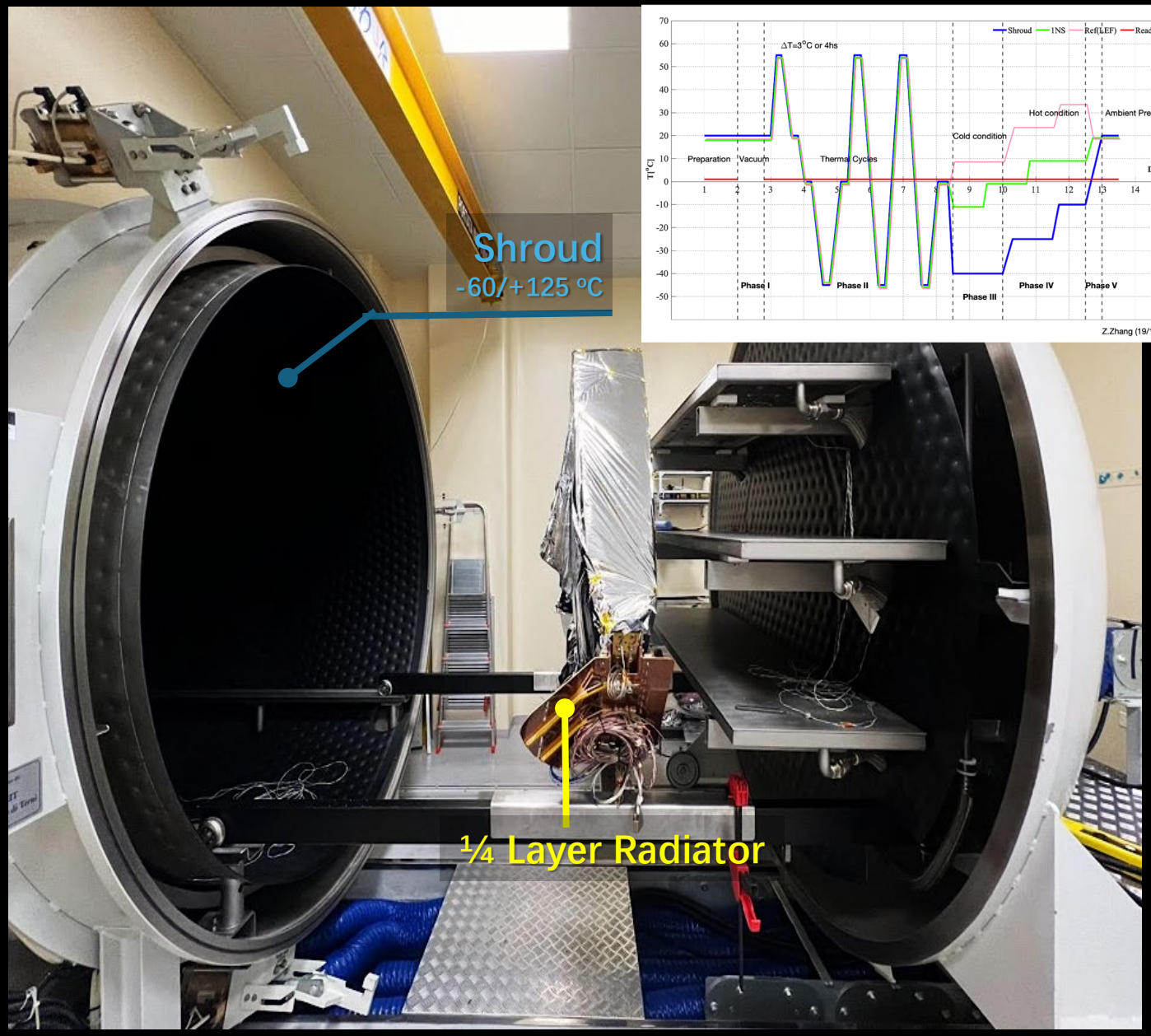
与飞行件相同的探测器和电子学，研究在极端环境下（发射和在轨运期间）的探测器性能。

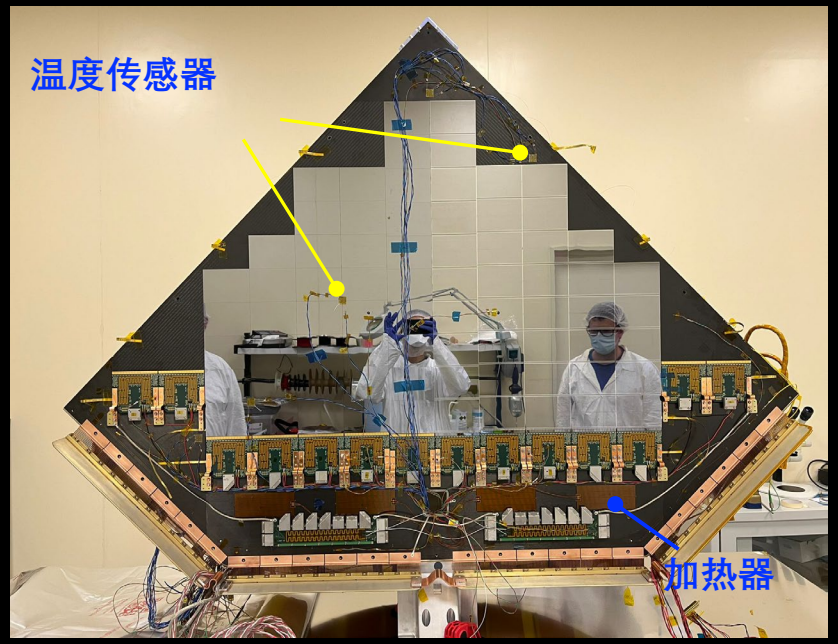
振动测试



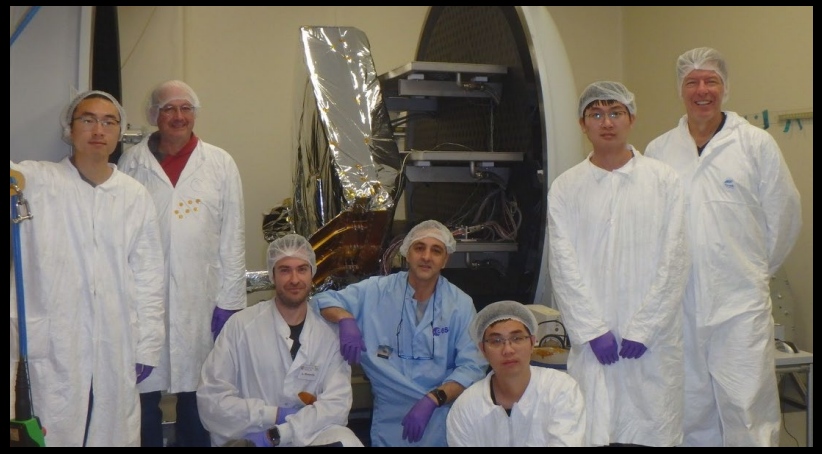
- ✓ 共振符合火箭发射的要求
- ✓ 发射过程中的振动不会对探测器造成损坏

热真空测试

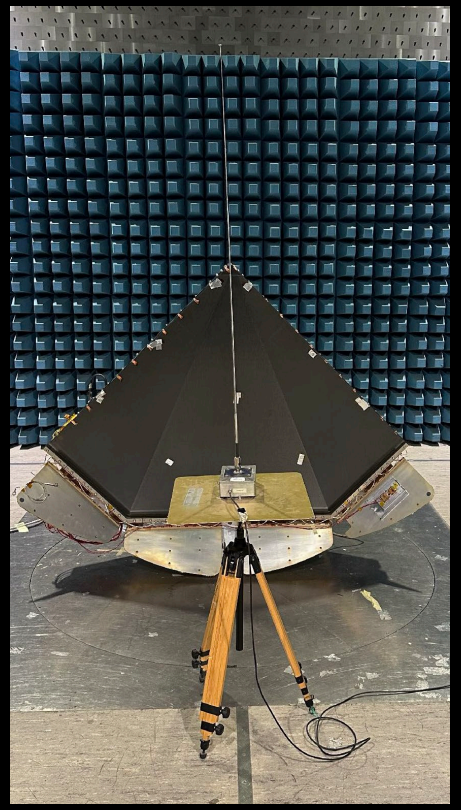




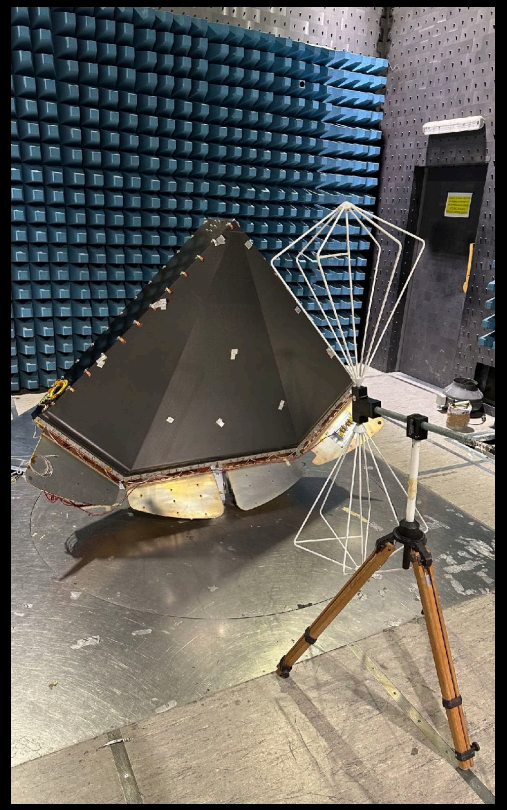
- ✓ 温度控制系统验证
- ✓ 探测器工作状态检查



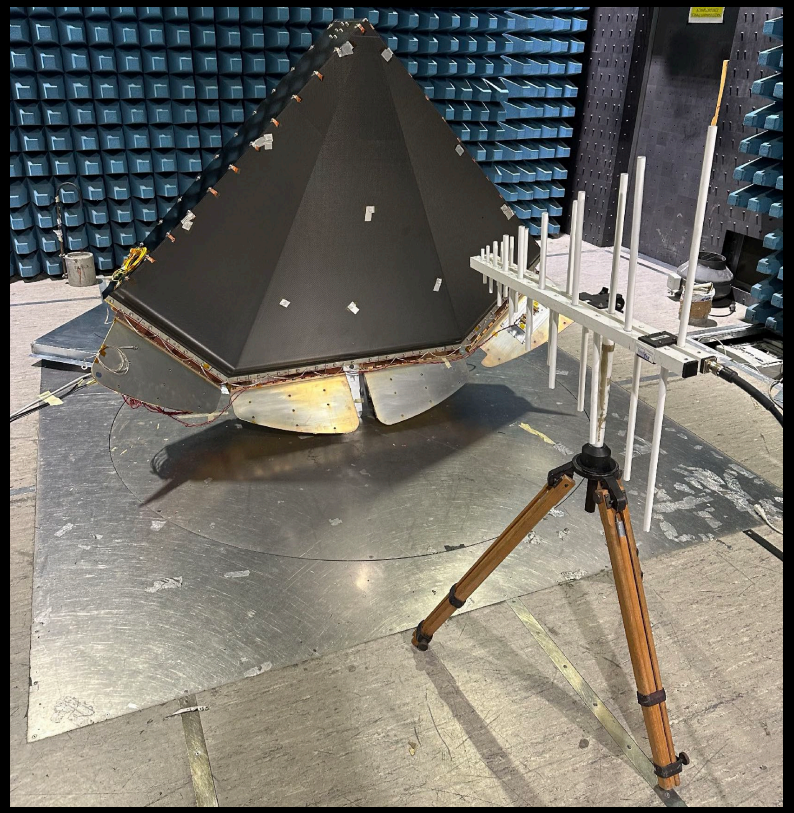
电磁兼容测试



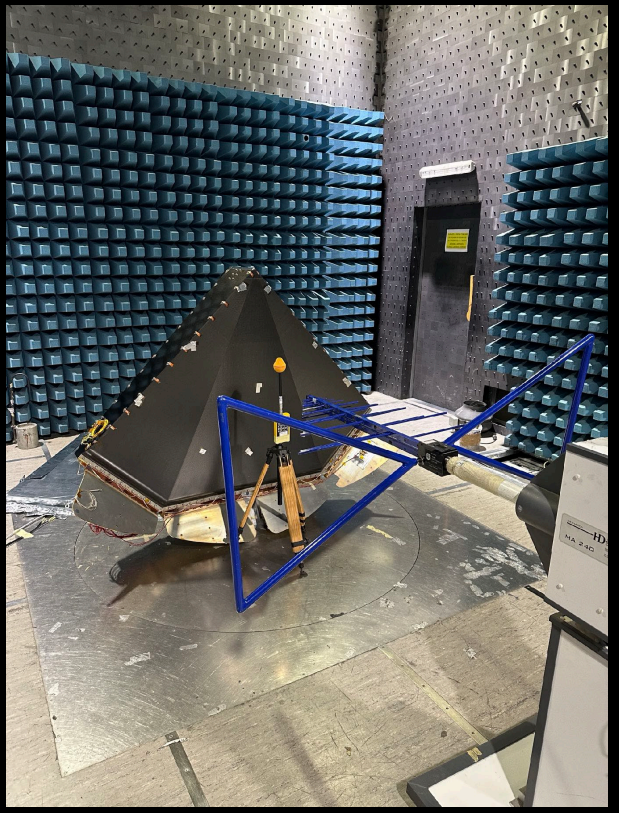
杆式单极天线
(14 kHz – 30 MHz)



双锥形天线
(30 MHz - 300 MHz)

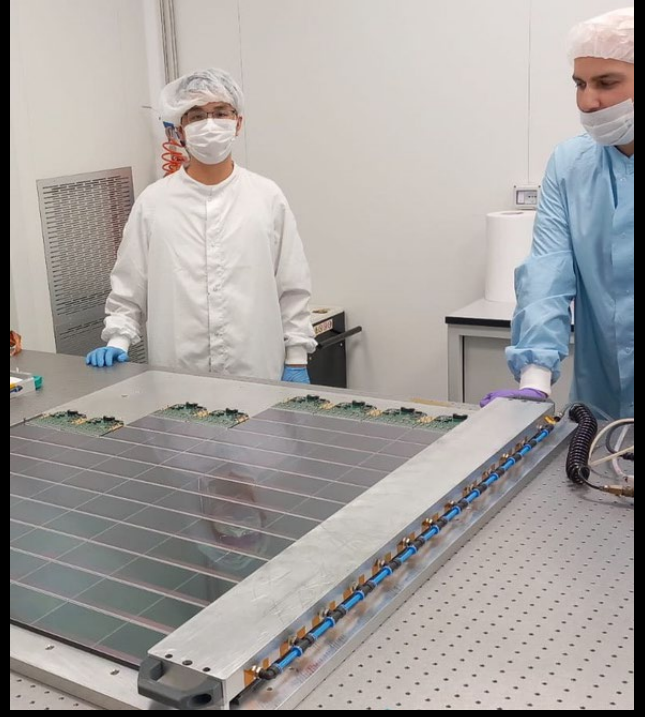
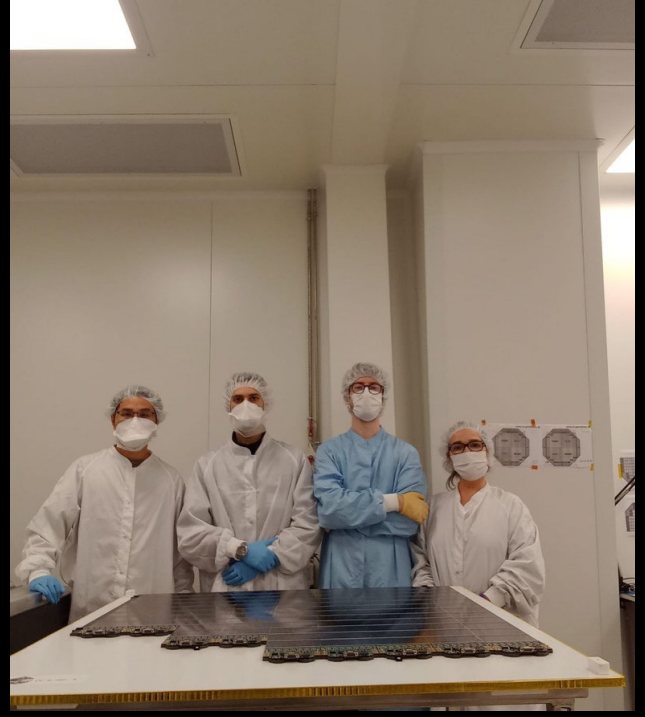


对数周期天线
(300 MHz - 1 GHz)



对数周期天线
(200 MHz - 1 GHz)

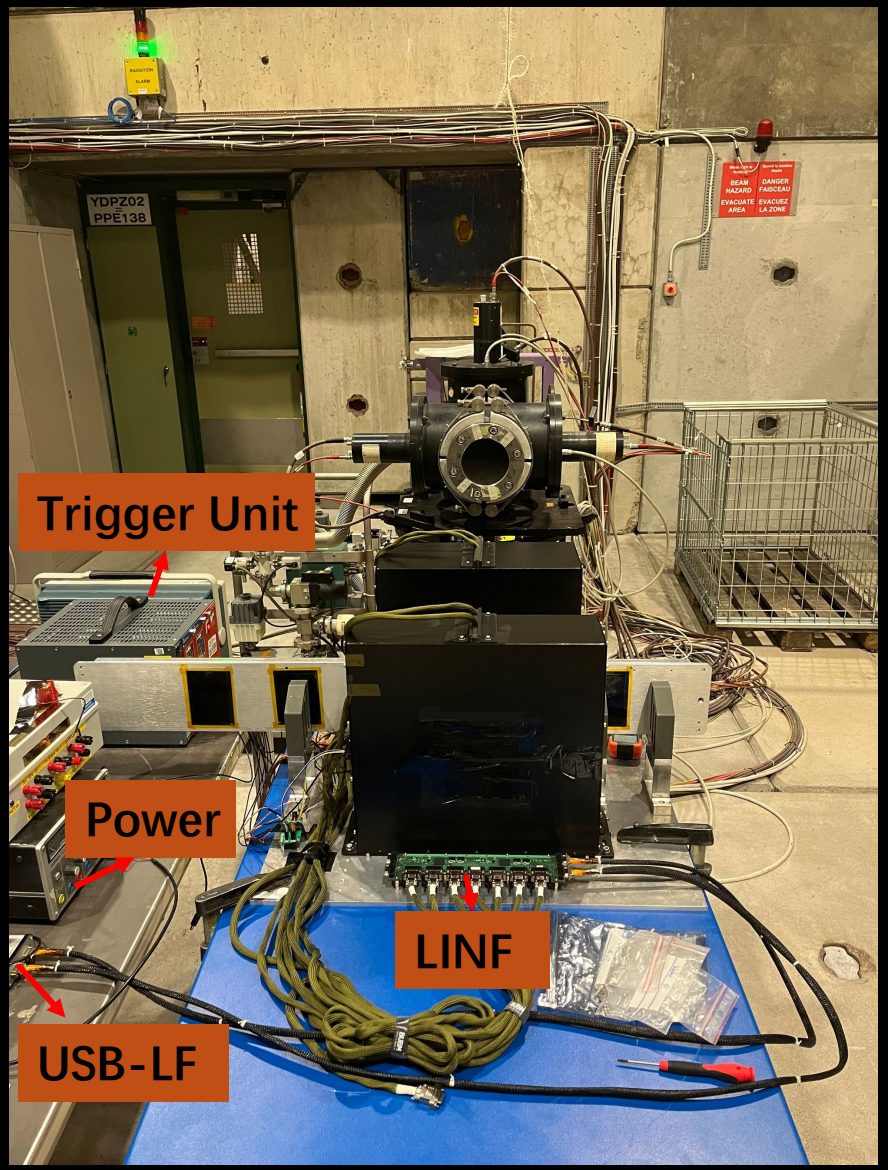
✓ 国际空间站（ISS）发出的电磁脉冲不会影响探测器的电子设备。

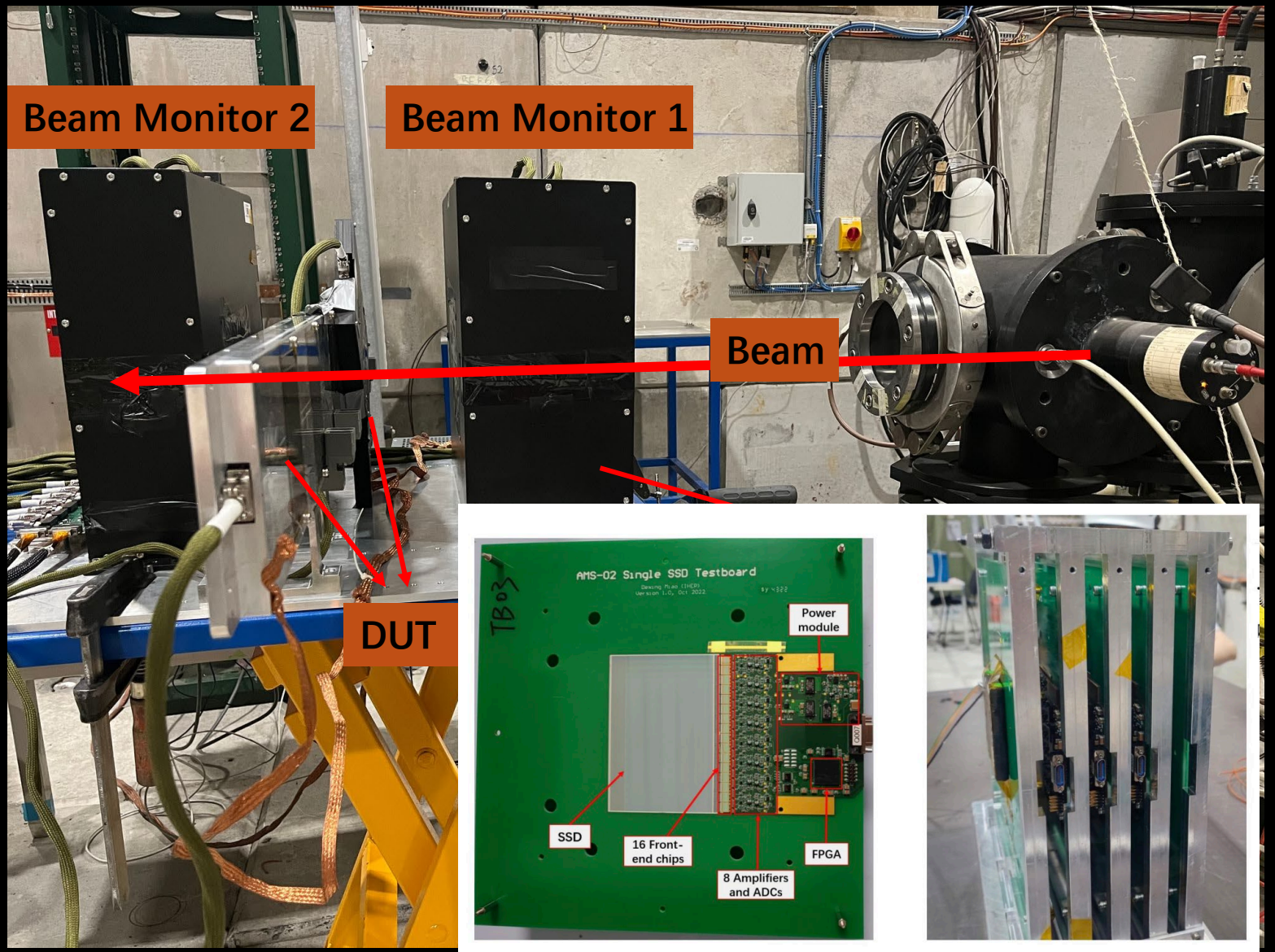





¼平面飞行件（Flight Model，FM) 在INFN-Perugia完成

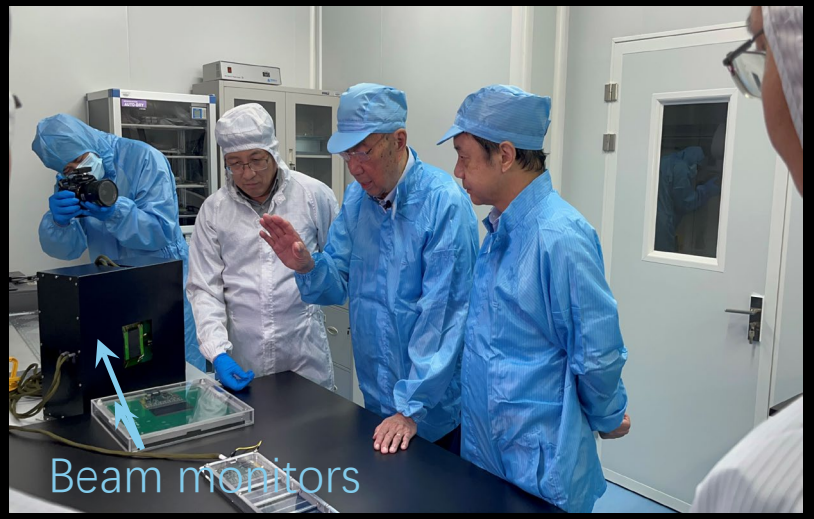
- 共8个FM QL于2025年5月完成。
- 由意大利国家核物理研究所（INFN）、高能物理研究所（IHEP）和山东高等技术研究院（SDIAT）的研究人员合作完成。

束流测试——欧洲核子研究中心CERN，SPS





束流测试——欧洲核子研究中心CERN，SPS



2024.05 Muon Beam Test

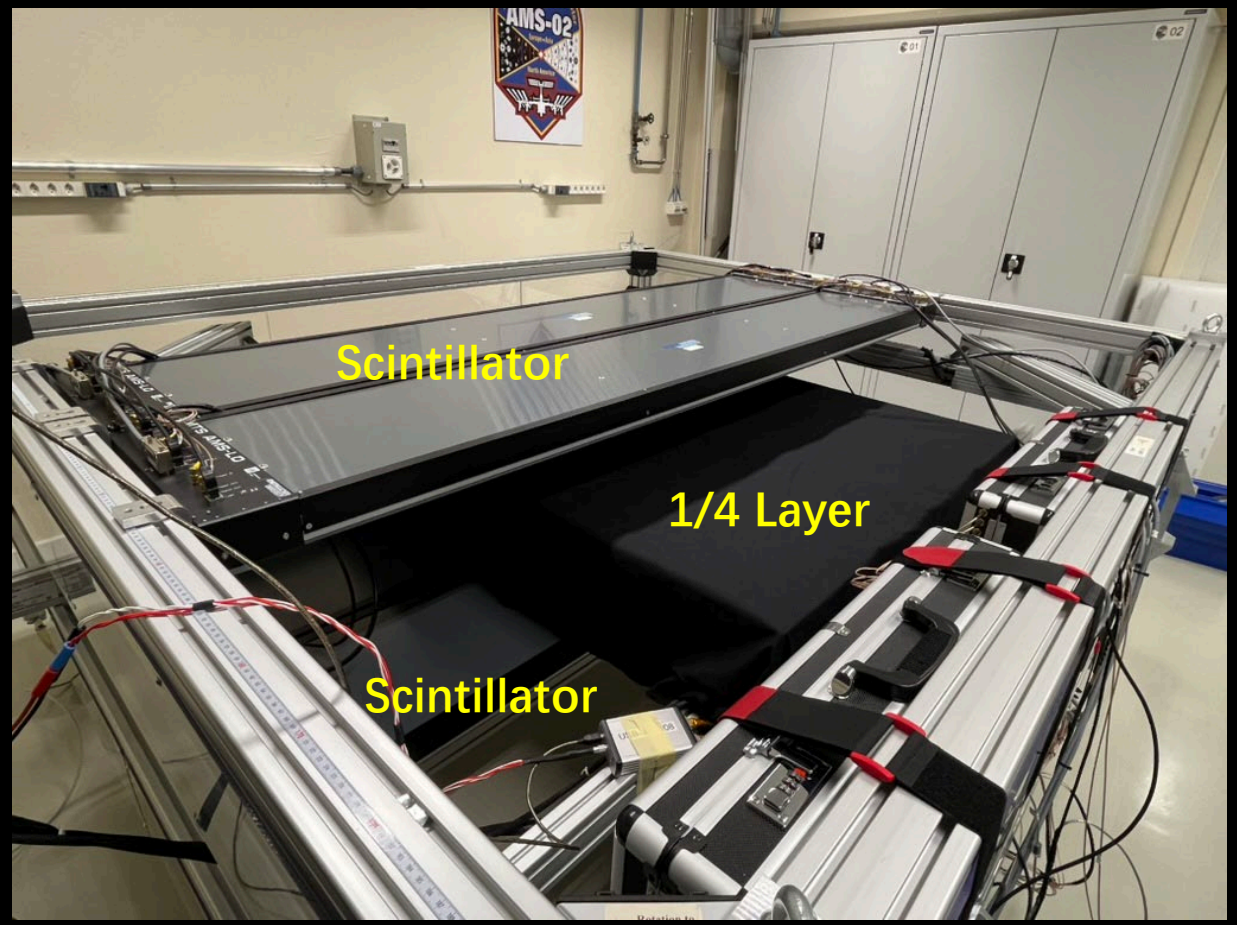
2024.11 ion Beam Test

2023.10 Ion Beam Test

2023.08 Proton Beam Test

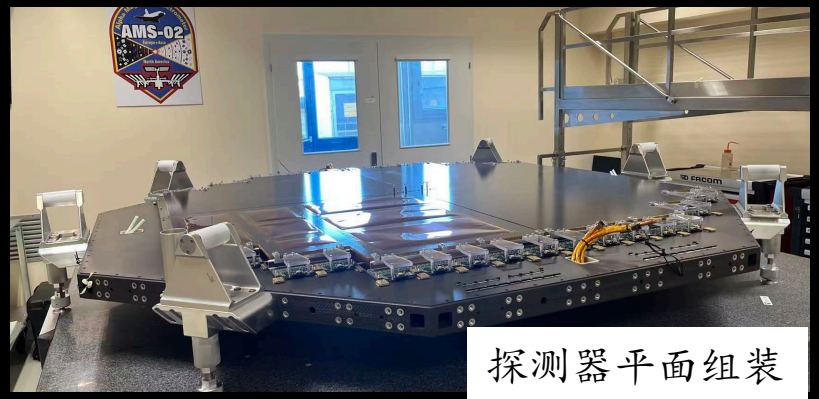
- 空间分辨率
- 能量分辨率
- 重核碎裂
- 探测器效率
- 动态范围研究
- 感应电荷重心
- 电子学与数据获取系统调试

宇宙线测试——欧洲核子研究中心

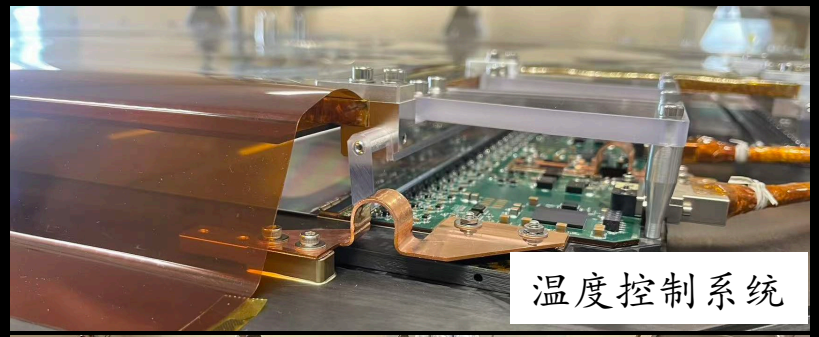


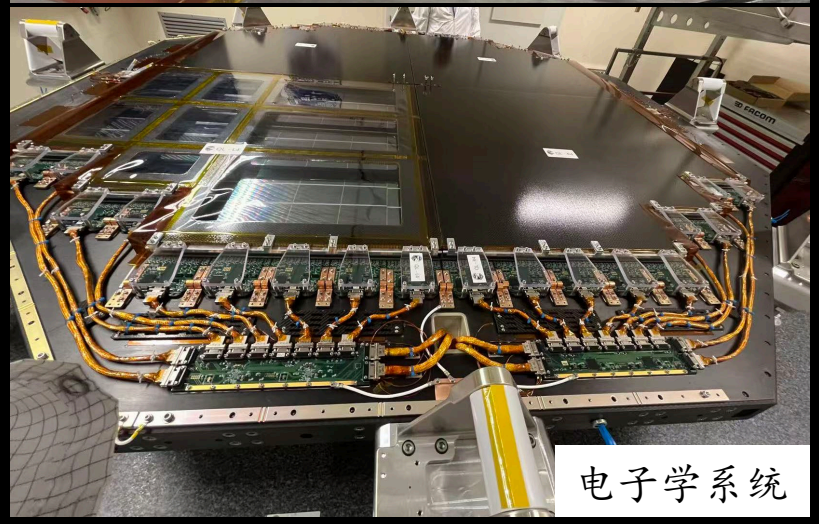
CMTS（宇宙μ子测试系统）由亚琛工业大学设计开发，
日内瓦大学和山东高等技术研究院参与了其调试和运行工作。

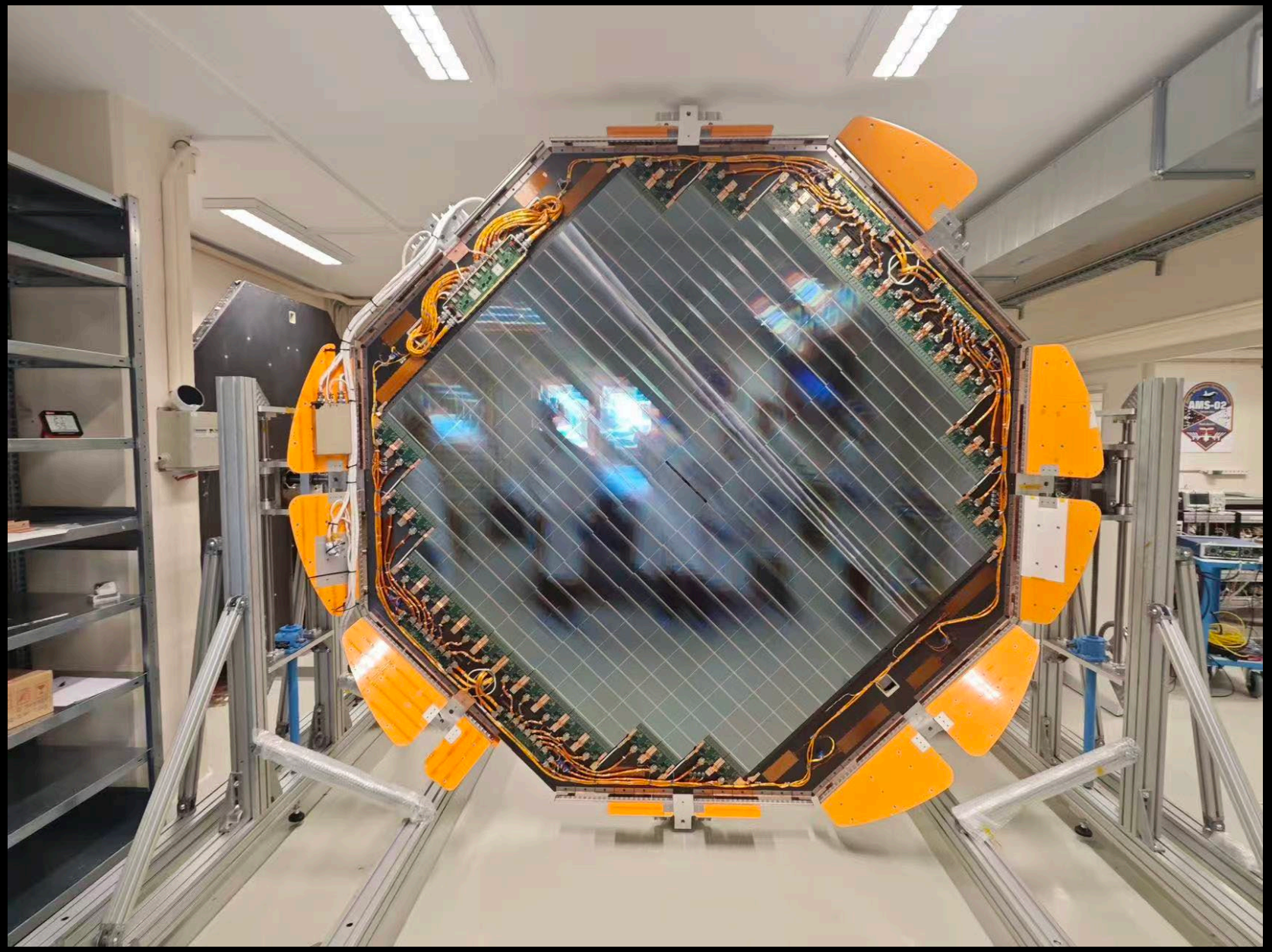
L0整体集成



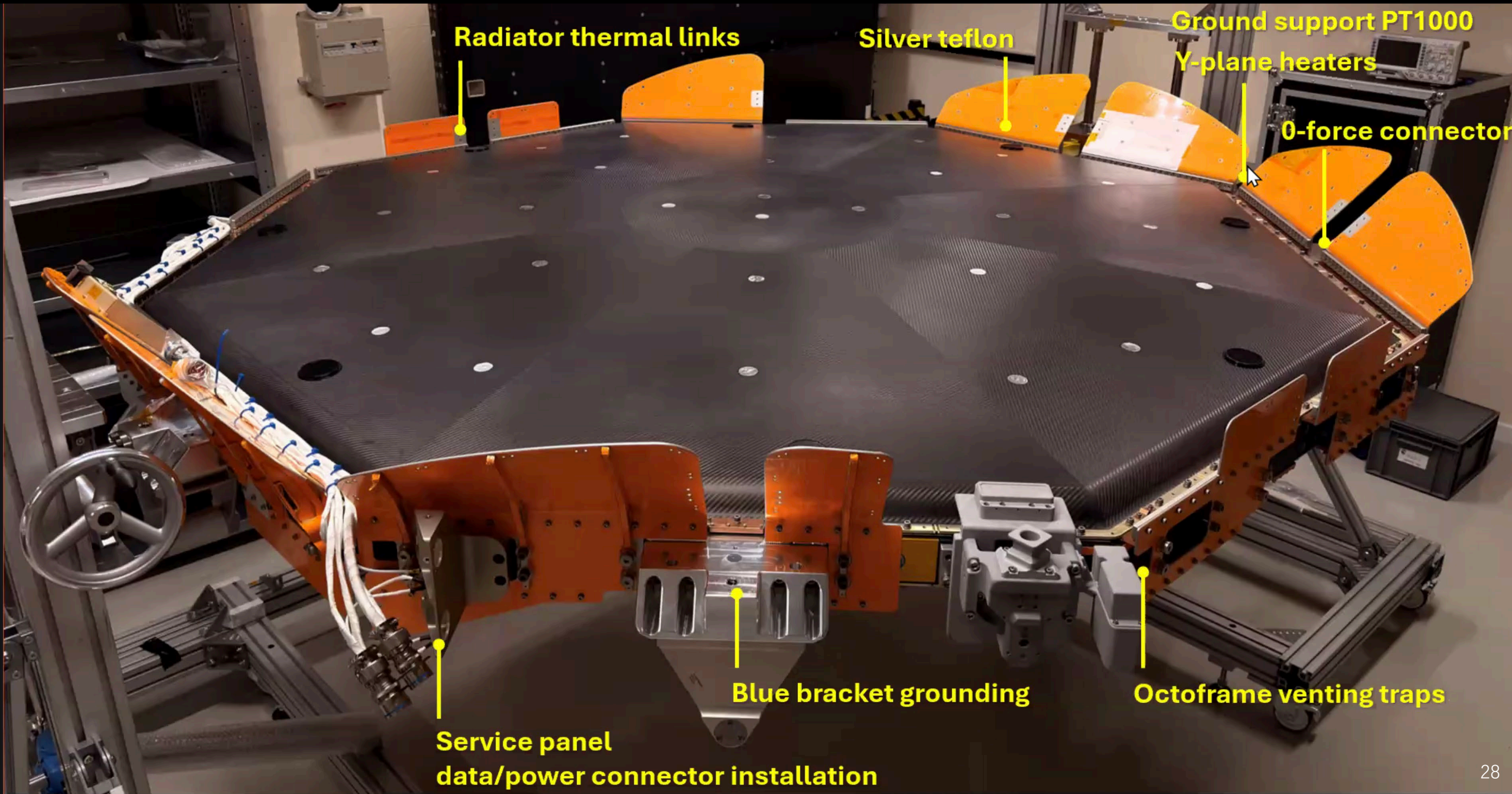
探测器平面组装

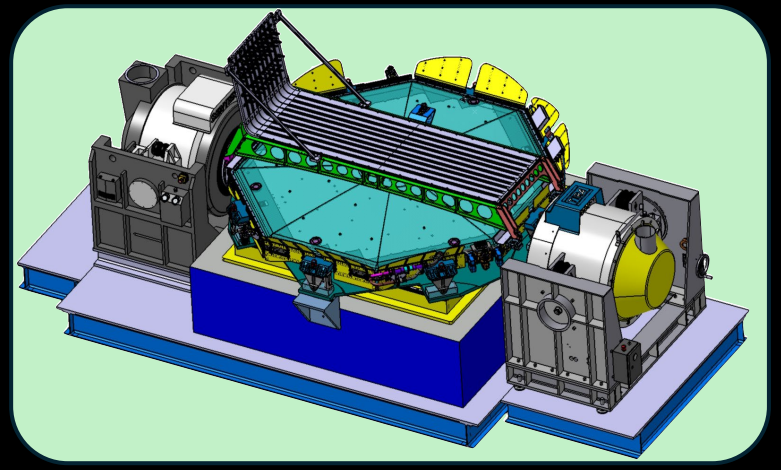

温度控制系统


电子学系统

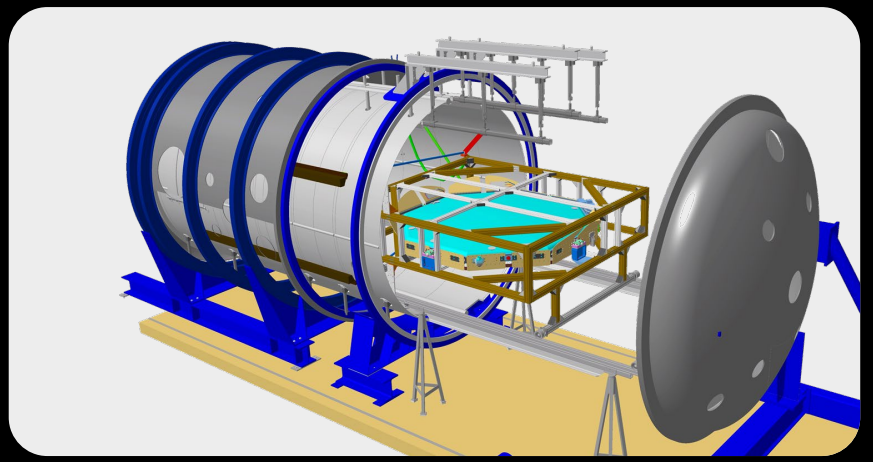


L0整体集成

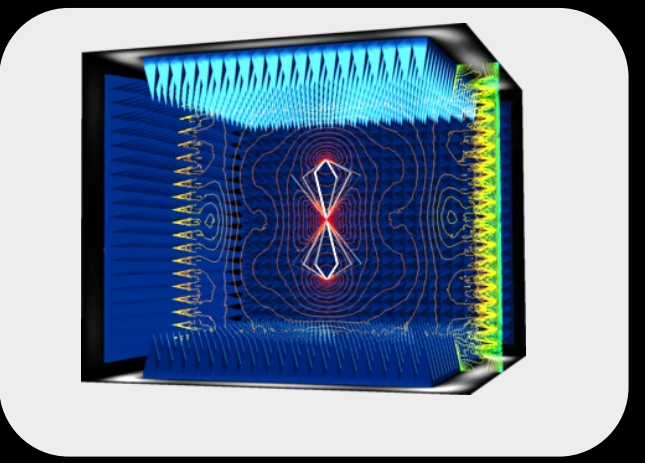

Radiator thermal links
Silver teflon
Ground support PT1000
Y-plane heaters
0-force connector
Blue bracket grounding
Octoframe venting traps
Service panel
data/power connector installation



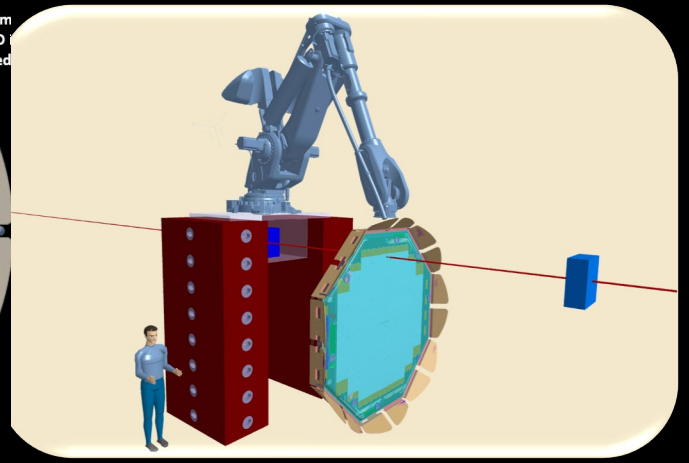
振动测试，2026年4月



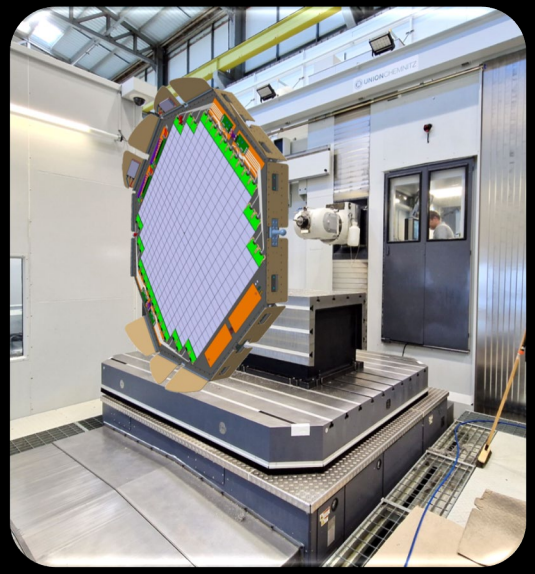
热真空测试，2026年5月



电磁兼容测试，2026年6月

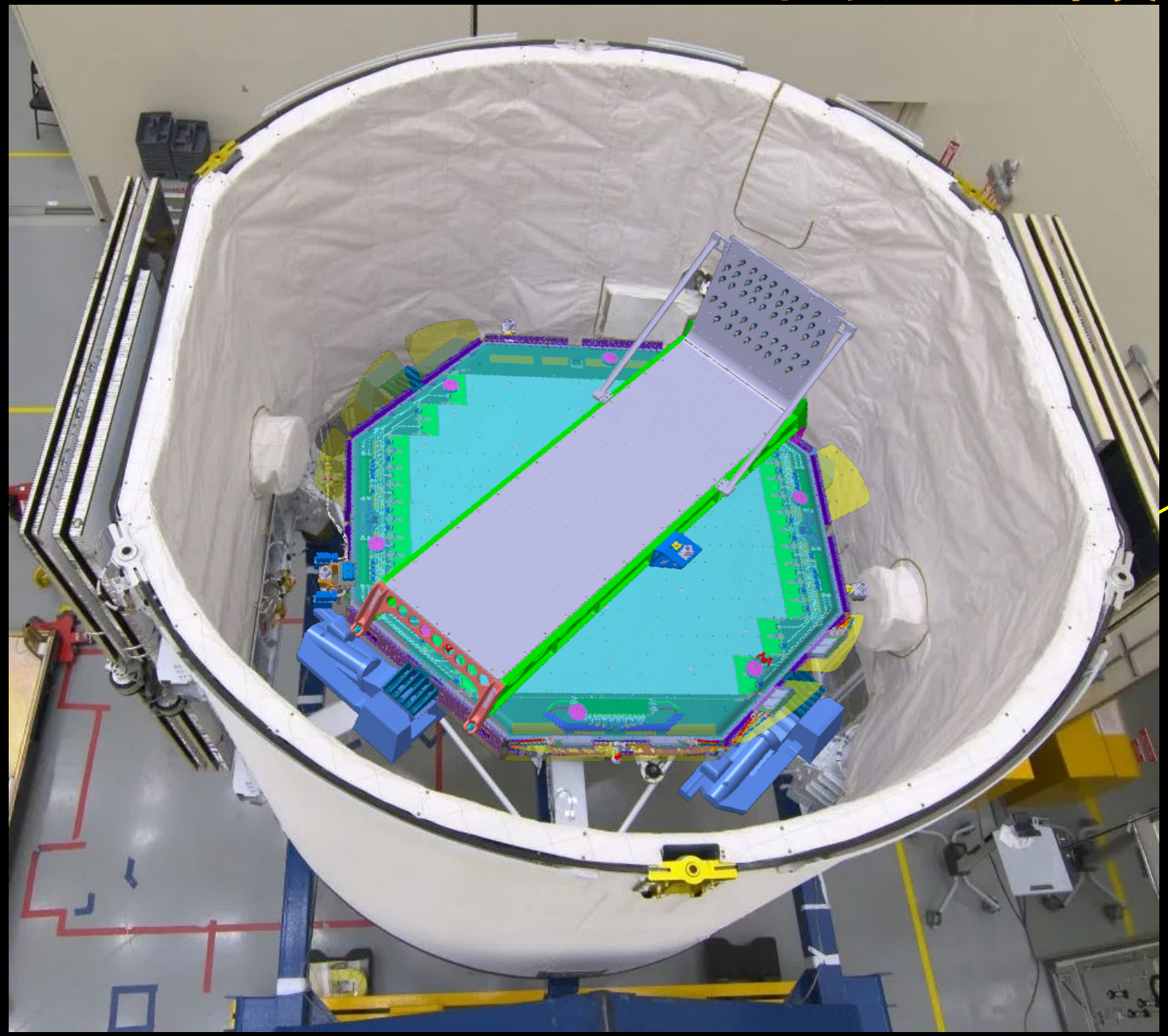


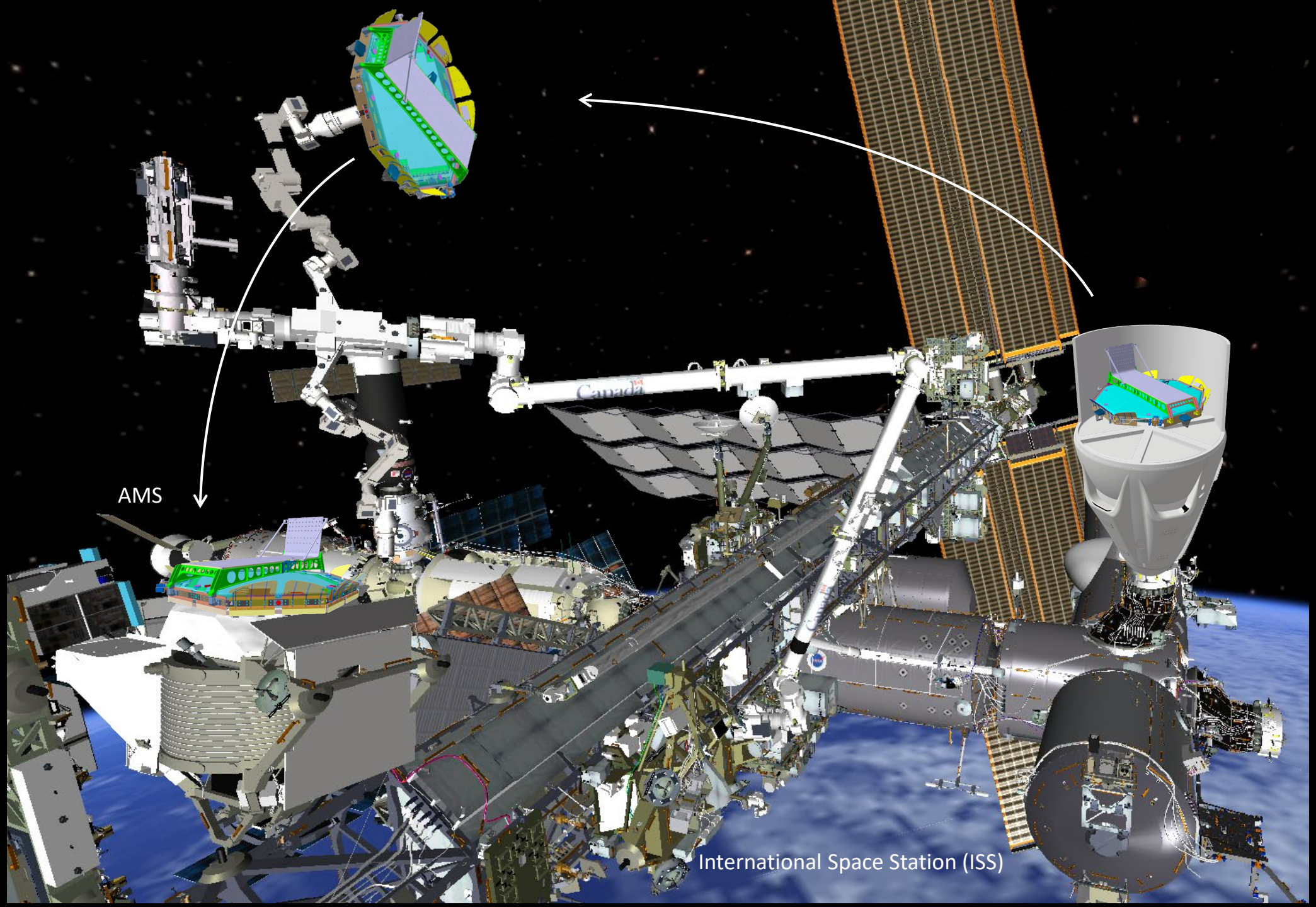
束流测试，2026年7月



Metrology，2026年8月

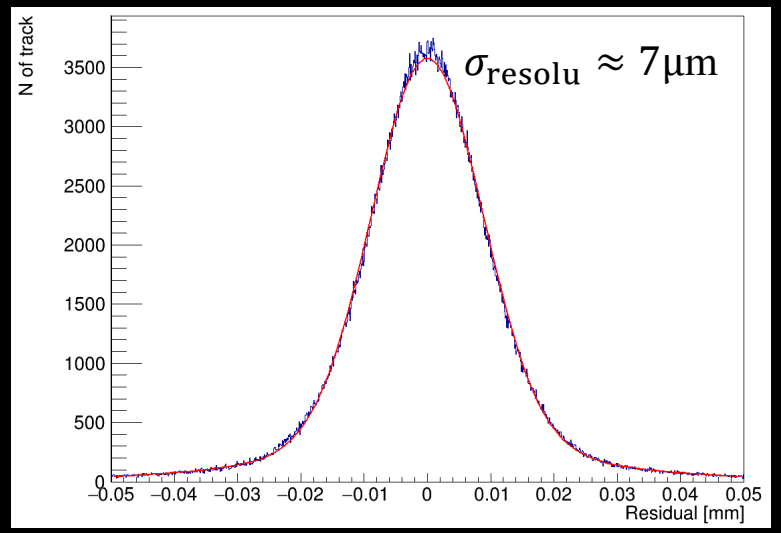
计划于2027年发射



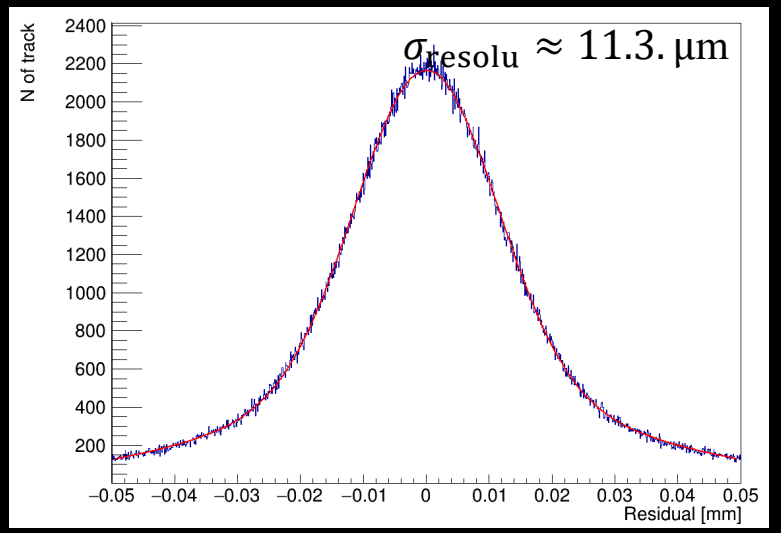

AMS
International Space Station (ISS)

To be continued…

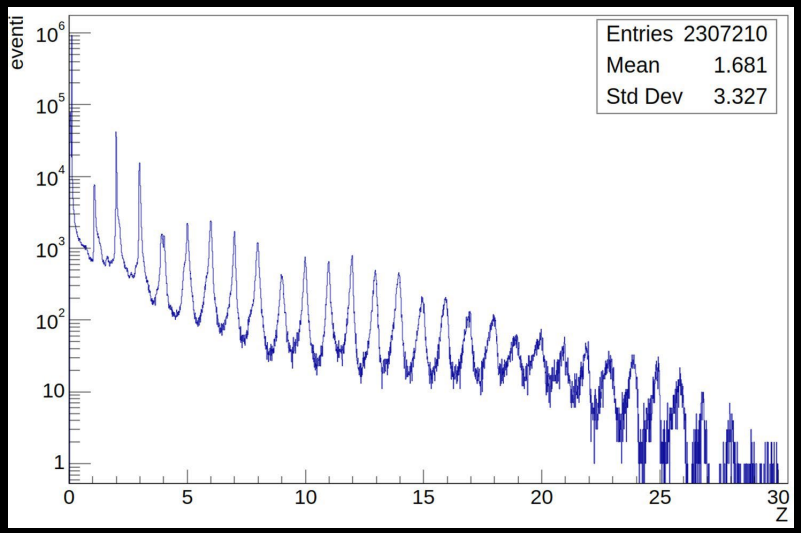
Thank you



单SSD的位置分辨



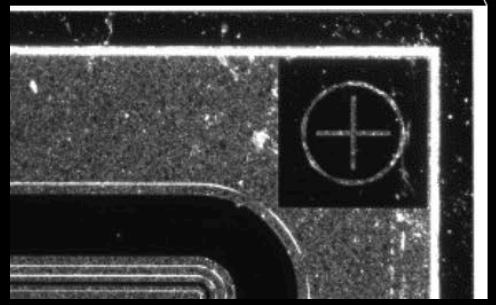
10-SSD Ladder的位置分辨

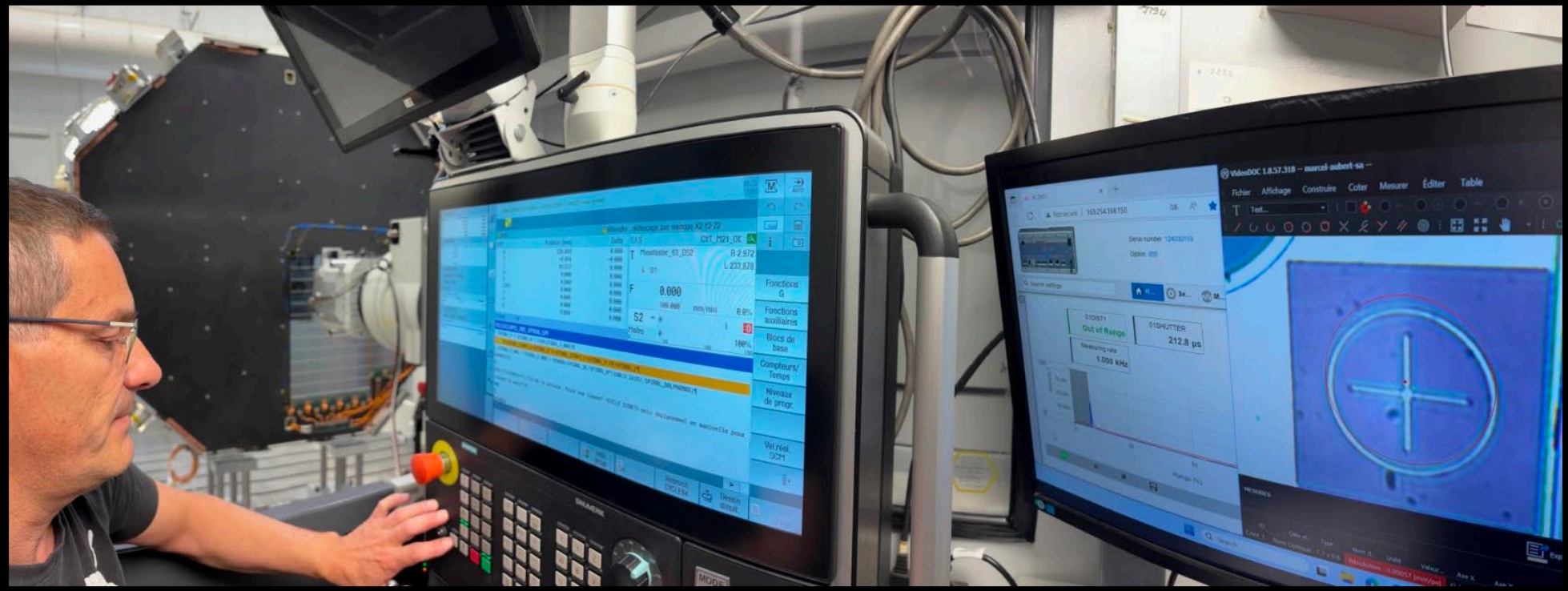


电荷分辨

Metrology

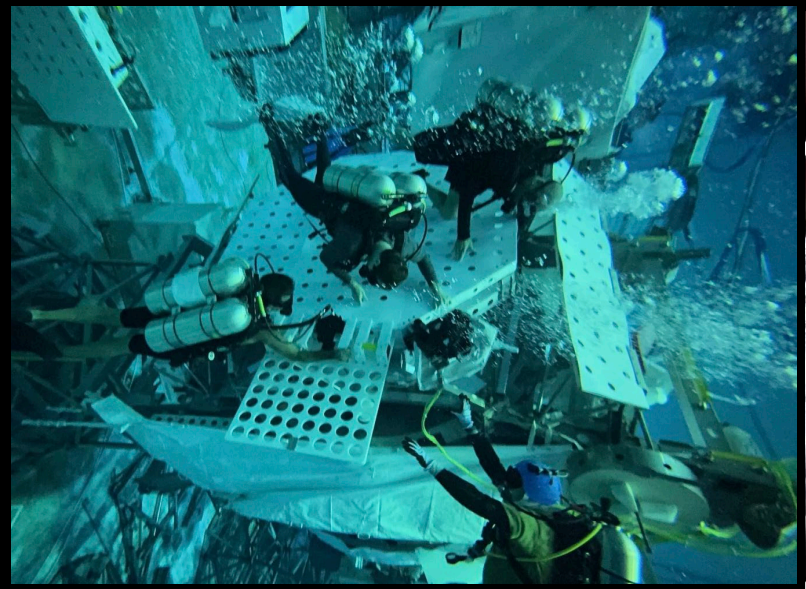
4 crosses

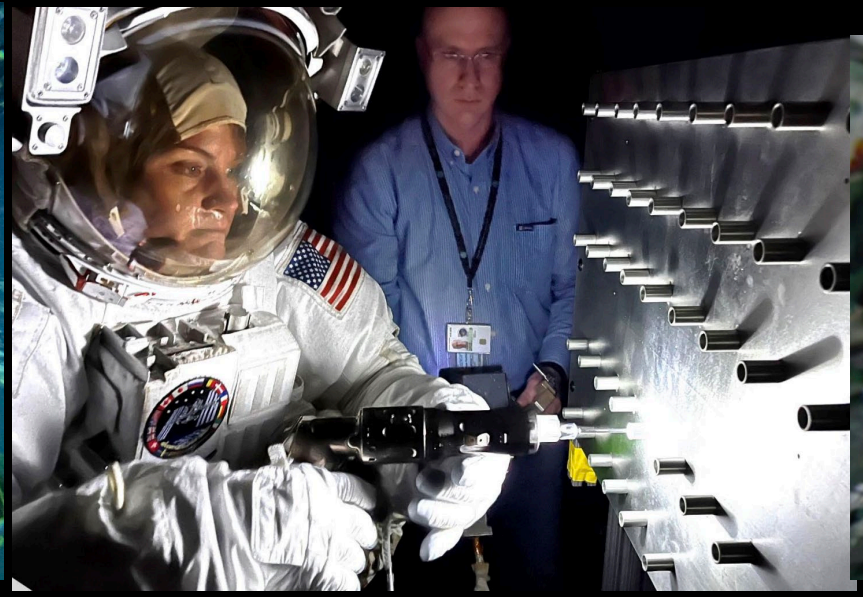


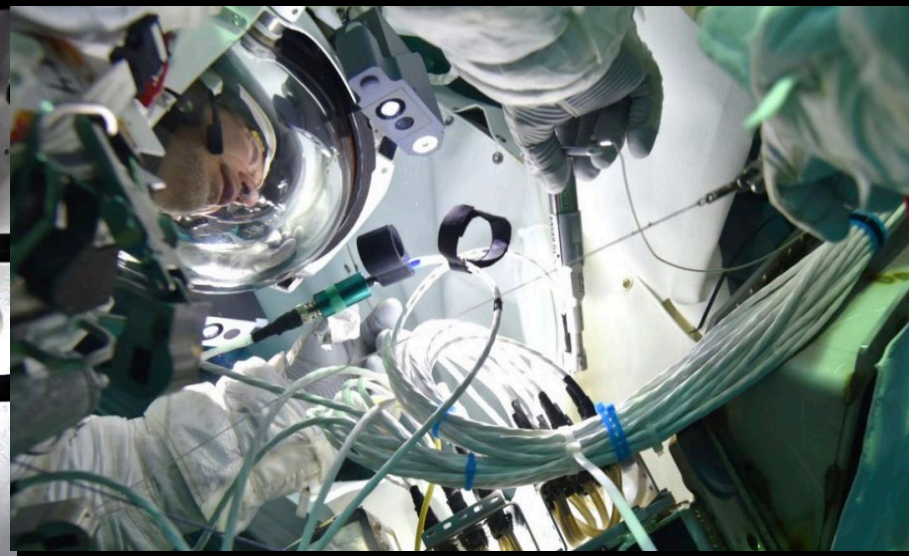


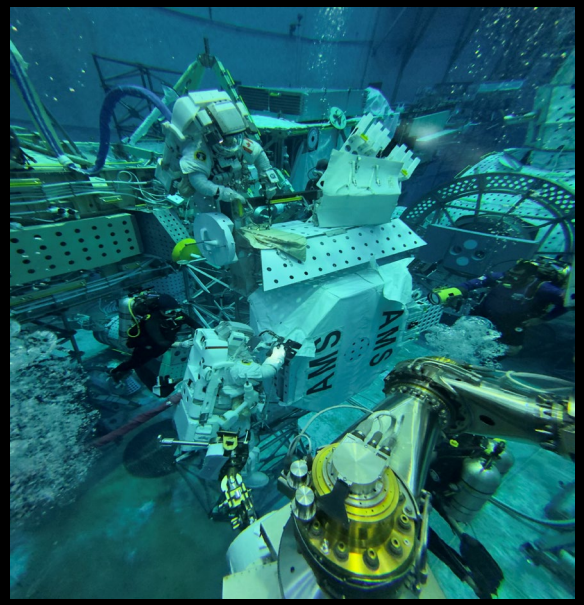
Detector mapping is performed at several steps during integration and a final one after all the tests and before test beam

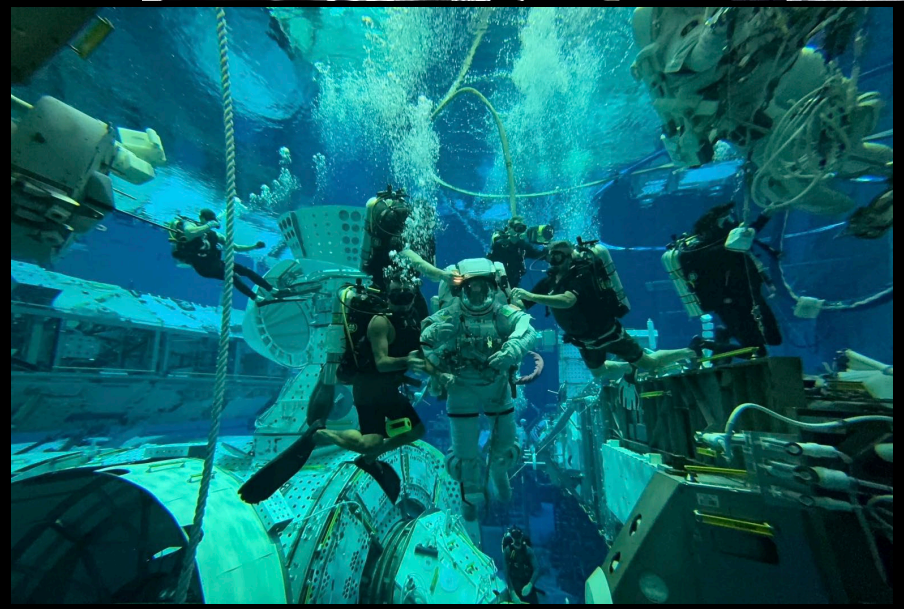
NASA Activities

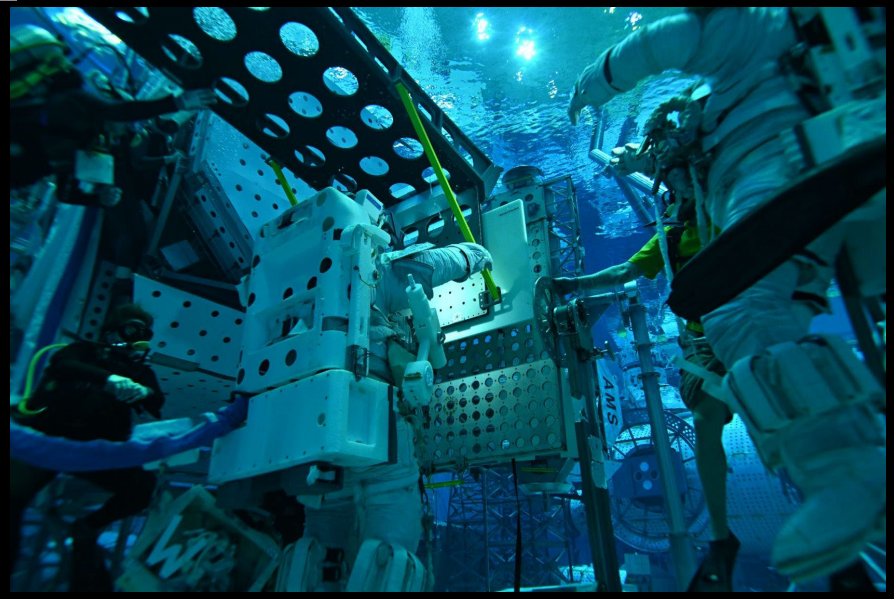


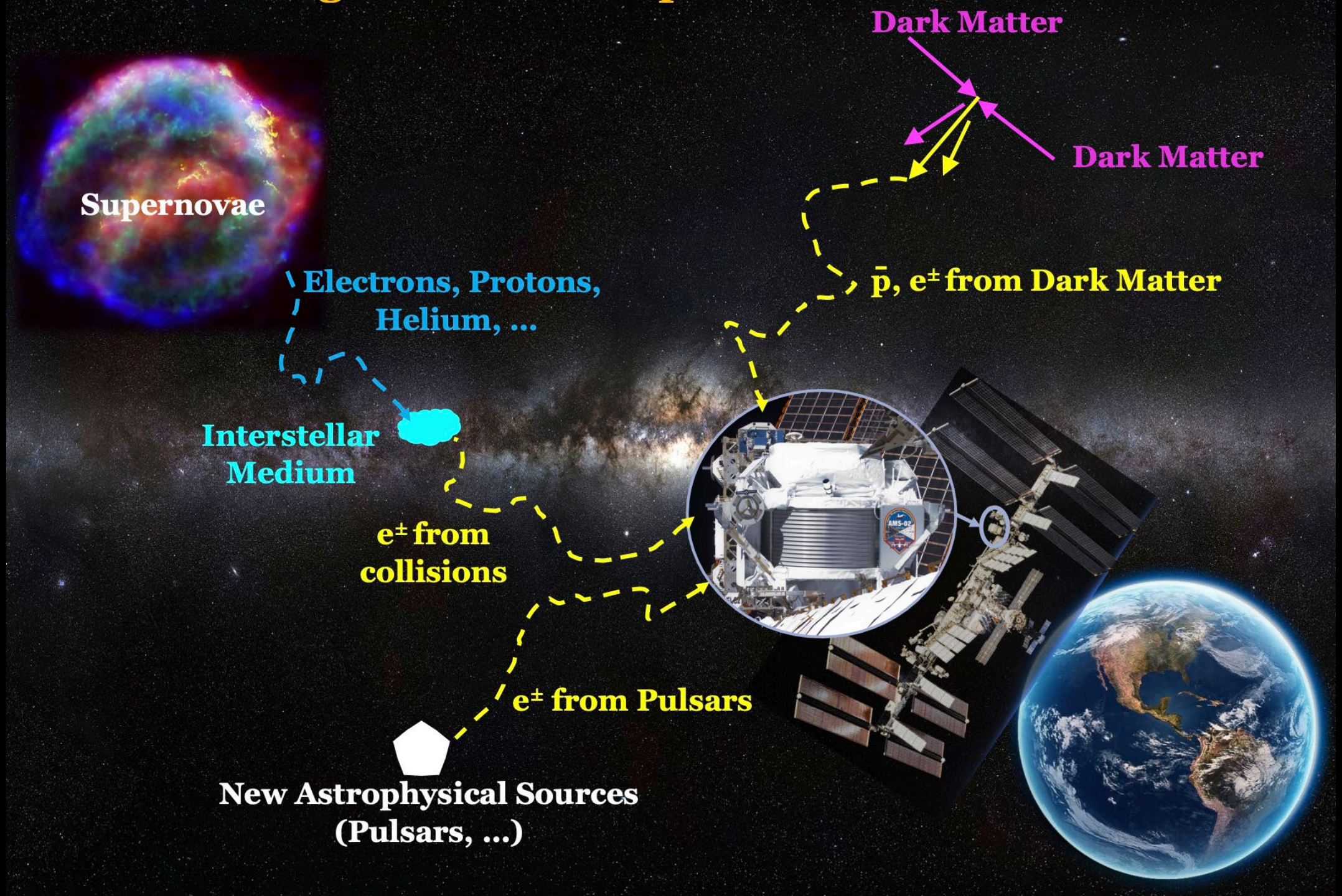


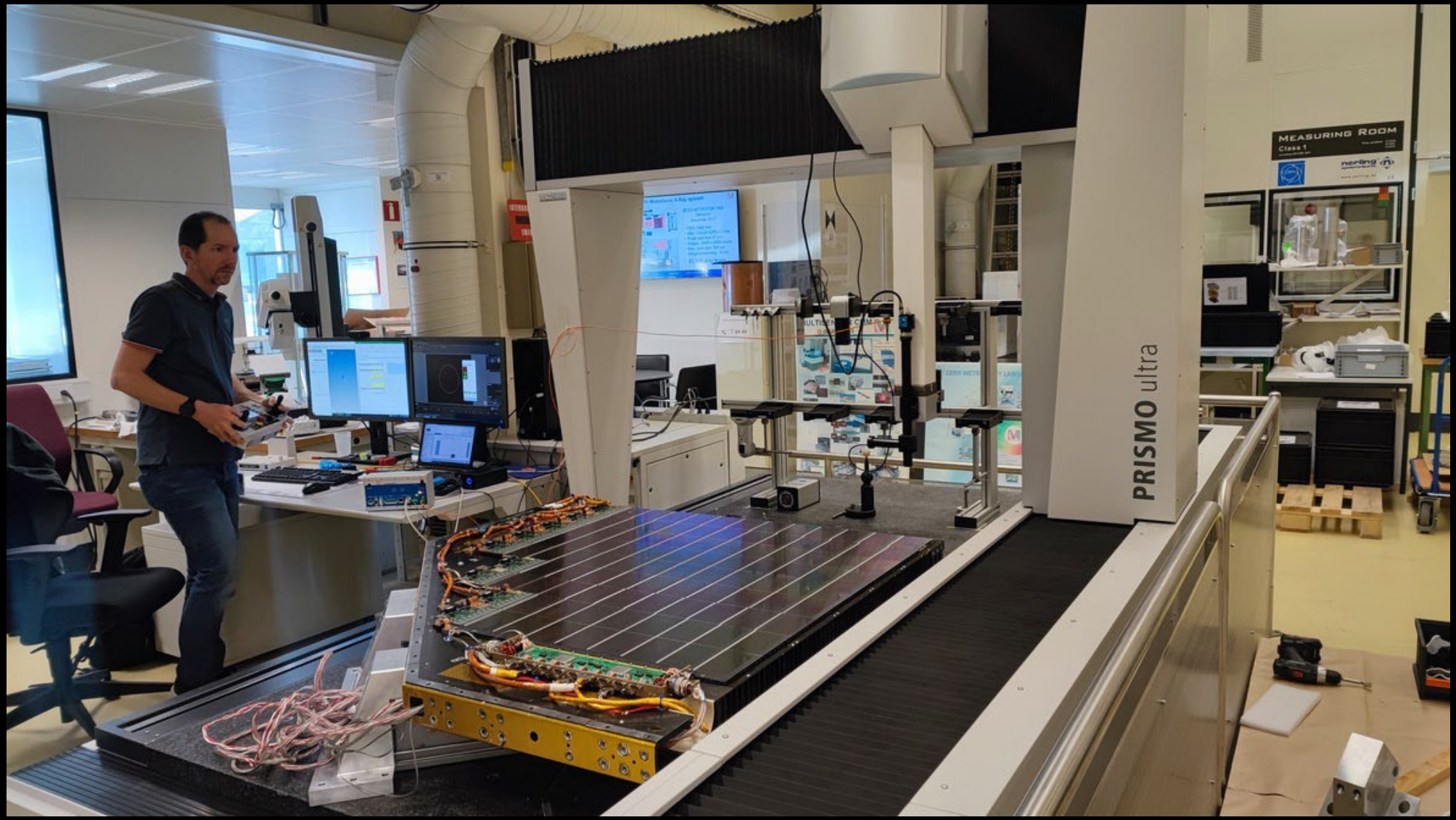









Dark Matter
Dark Matter
Supernovae
Electrons, Protons,
Helium, ...
p̄, e± from Dark Matter
Interstellar
Medium
e± from
collisions
e± from Pulsars
New Astrophysical Sources
(Pulsars, ...)


MEASURING ROOM
Class 1
PRISMO ultra

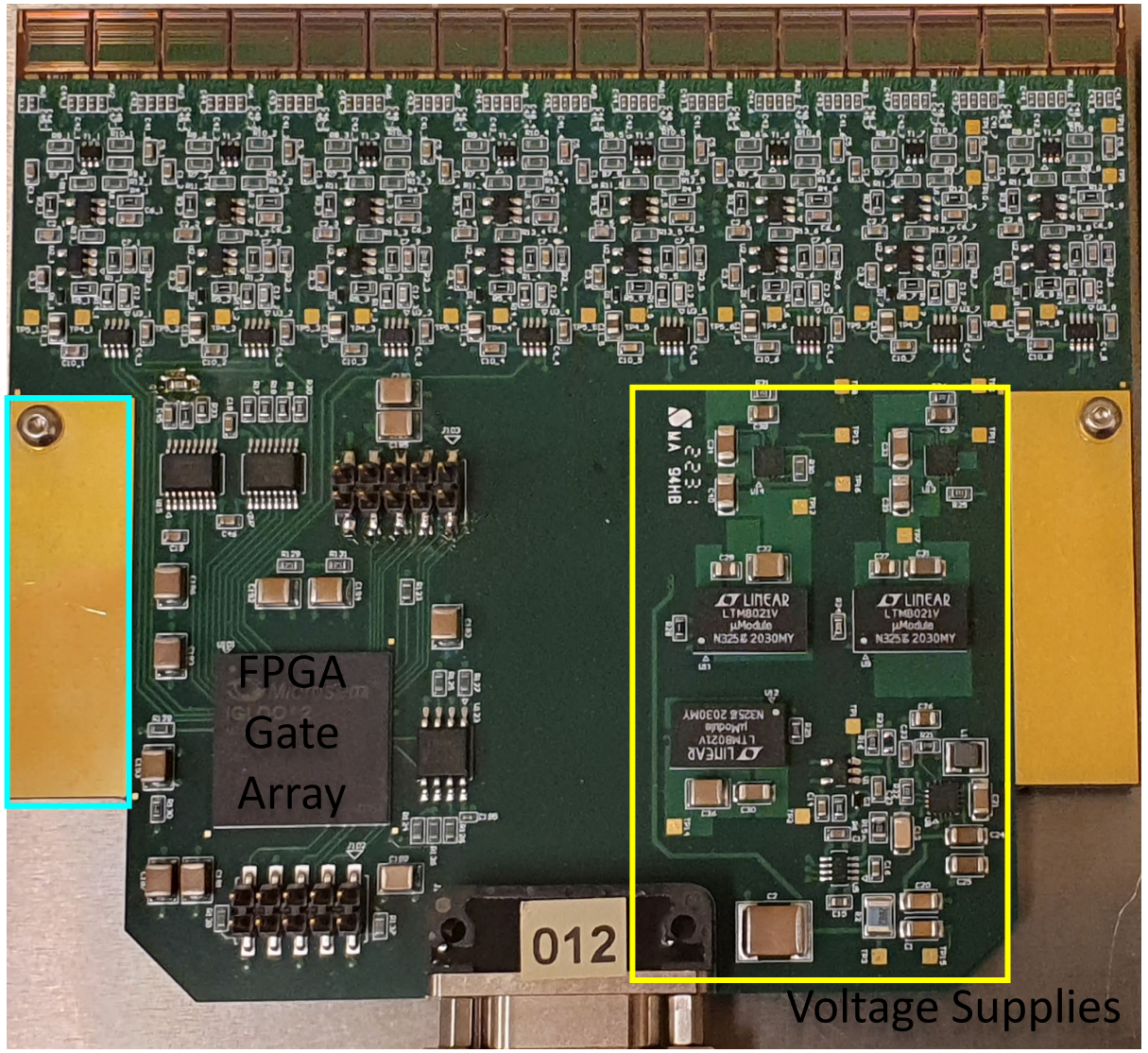
LEF

Version 2.0

Thermal Strips

1. Heat path to radiators.

2. Ground path to chassis



Component side

16 IDE1140, 1024 strips

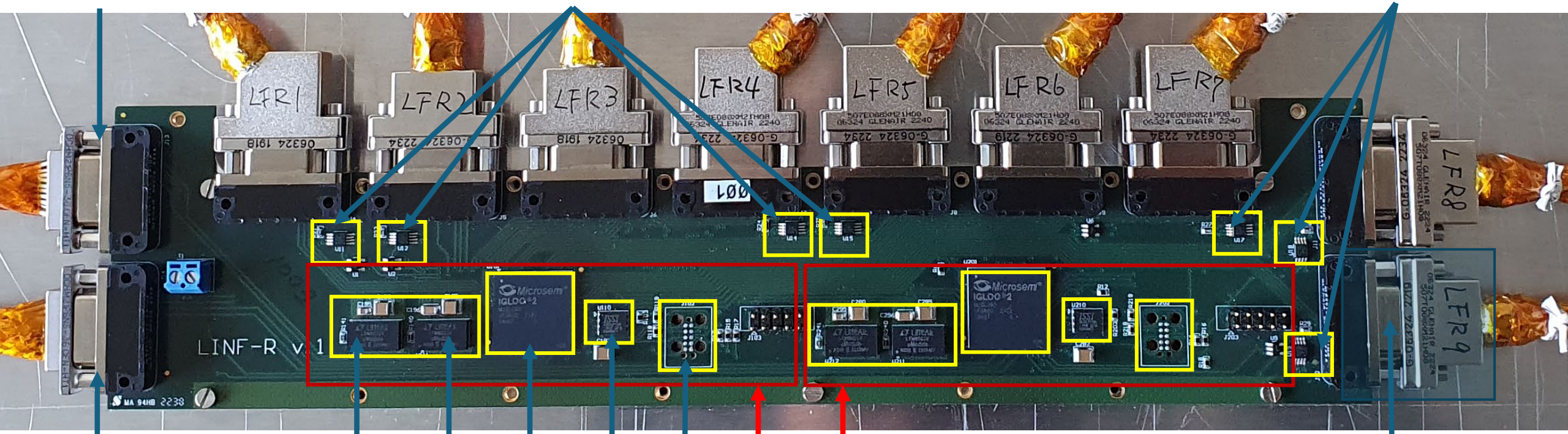
8 Amplifiers 6.97 mV / uA

8 14-Bit, 2.5Msps, Serial Sampling ADCs, 4096mV

Each IDE1140 (“VA”)

- 64 channels charge amplifiers / shapers.
- Sample and hold.
- 64 channels analog multiplexor.
- 2.6 uA per 1 fC differential current output

LINF-R


LINJ-A Cable
LEF Power Switch
LEF Power Switch
LINF-R v.1
LINJ-B Cable
1.2V DCDC
2.5V DCDC
FPGA
Flash Memory
JTAG for FPGA programming
LINF-A
LINF-B
9 LEF Cables

Repair of the detector at the University of Geneva