STCF 探测谱仪研究进展

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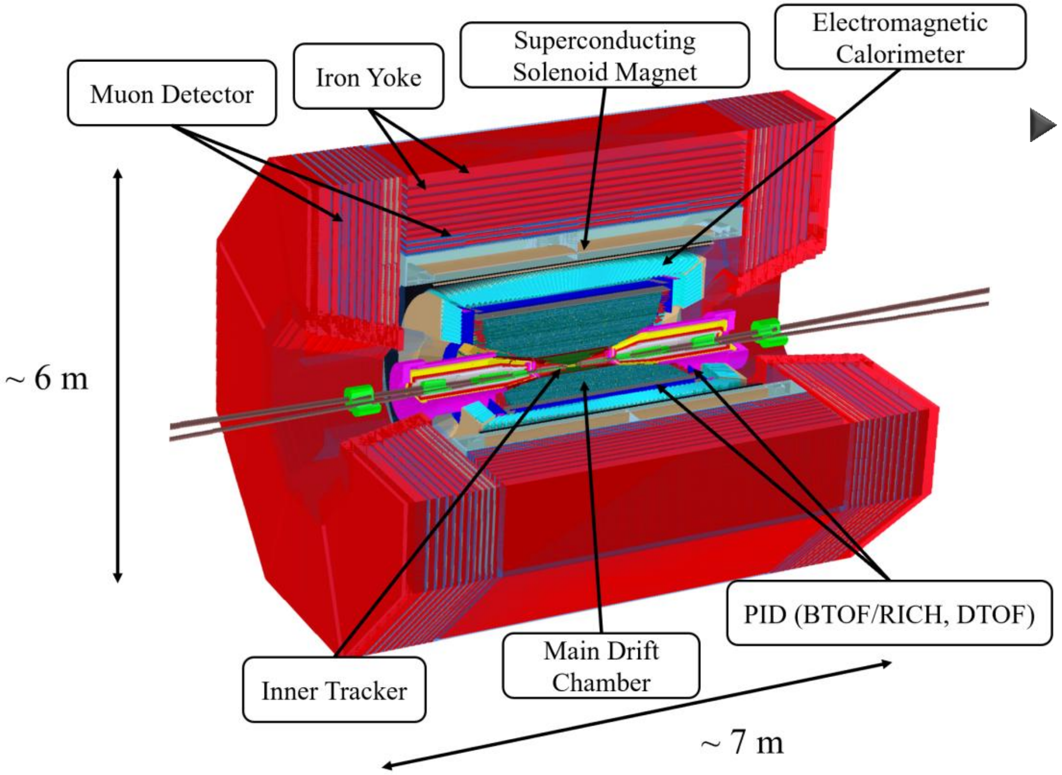
(On behalf of the STCF Detector Working Group)
University of Chinese Academy of Sciences

超级陶粲装置研讨会, 西安, 2026

07/01, 2026

STCF 探测器物理指标要求



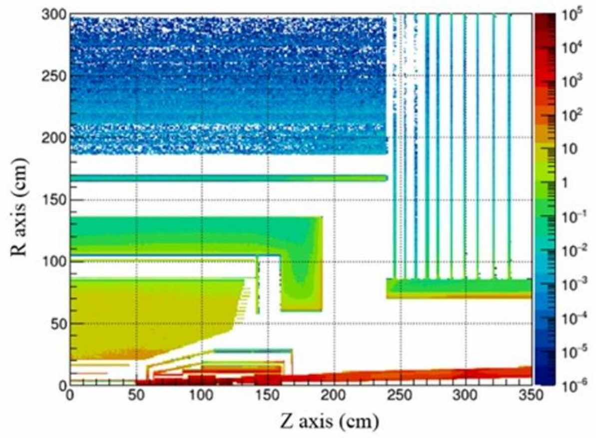
❖ **Highly efficient and precise reconstruction of exclusive final states produced in 2-7 GeV e⁺e⁻ collisions**

- Precise measurement of low-p (~>1GeV/c) particles → low mass tracking and PID detectors
- Excellent PID: π/K and μ/π separation up to 2 GeV and beyond

Process	Physics Interest	Optimized Subdetector	Requirements
$\tau \to K_s \pi \nu_\tau$, $J/\psi \to \Lambda\bar{\Lambda}$, $D_{(s)}$ tag	CPV in the τ sector, CPV in the hyperon sector, Charm physics	ITK+MDC	acceptance: 93% of 4π; trk. effi.: $> 99\%$ at $p_T > 0.3$ GeV/c; $> 90\%$ at $p_T = 0.1$ GeV/c $\sigma_p/p = 0.5\%$, $\sigma_{\gamma\phi} = 130\ \mu$m at 1 GeV/c
$e^+e^- \to KK + X$, $D_{(s)}$ decays	Fragmentation function, CKM matrix, LQCD etc.	PID	π/K and K/π misidentification rate $< 2\%$ PID efficiency of hadrons $> 97\%$ at $p < 2$ GeV/c
$\tau \to \mu\mu\mu$, $\tau \to \gamma\mu$, $D_s \to \mu\nu$	cLFV decay of τ, CKM matrix, LQCD etc.	PID+MUD	μ/π suppression power over 30 at $p < 2$ GeV/c, μ efficiency over 95% at $p = 1$ GeV/c
$\tau \to \gamma\mu$, $\psi(3686) \to \gamma\eta(2S)$	cLFV decay of τ, Charmonium transition	EMC	$\sigma_E/E \approx 2.5\%$ at $E = 1$ GeV $\sigma_{\rm pos} \approx 5$ mm at $E = 1$ GeV
$e^+e^- \to n\bar{n}$, $D_0 \to K_L \pi^+\pi^-$	Nucleon structure Unity of CKM triangle	EMC+MUD	$\sigma_T = \frac{300}{\sqrt{p^3({\rm GeV}^3)}}$ ps

束流相关本底

TID



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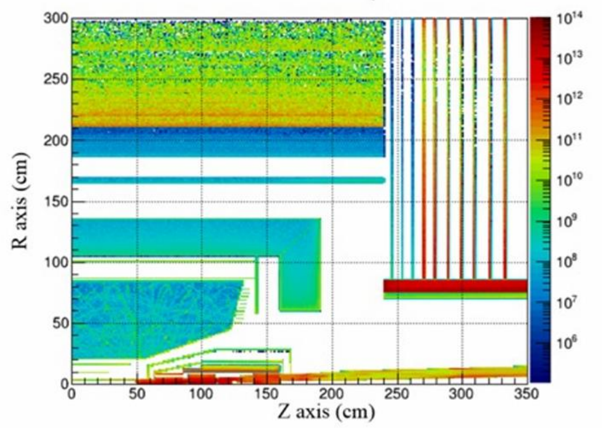
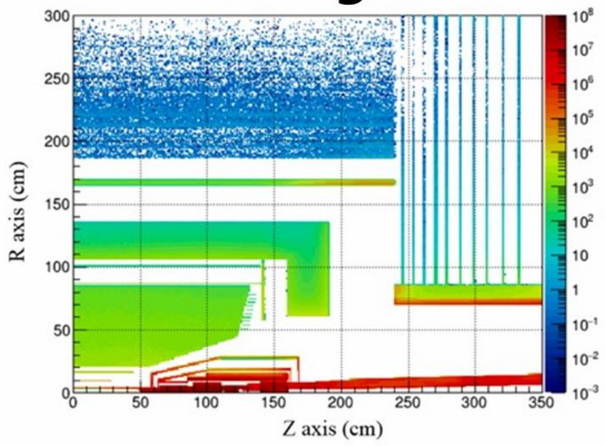
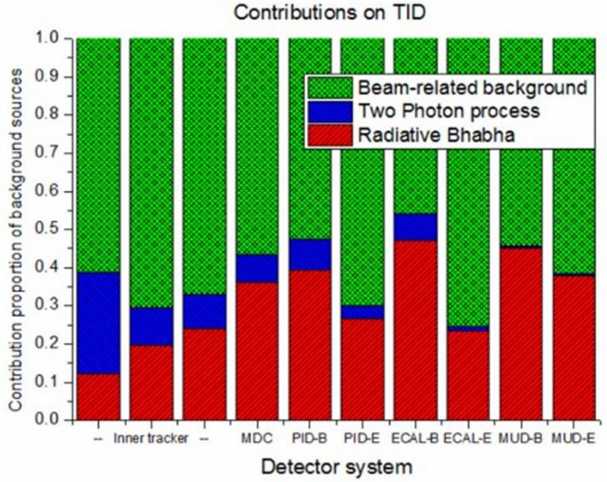
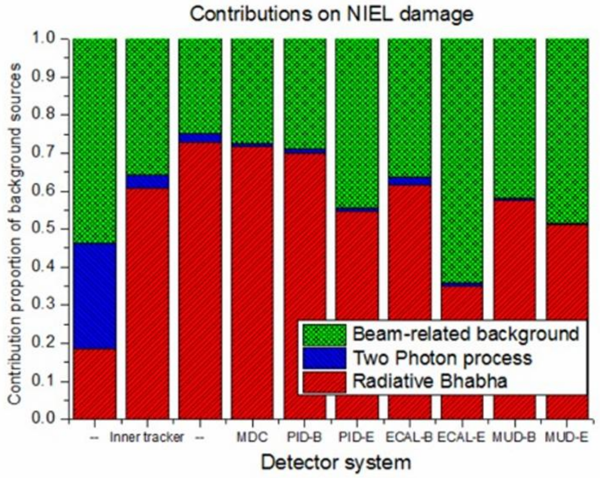
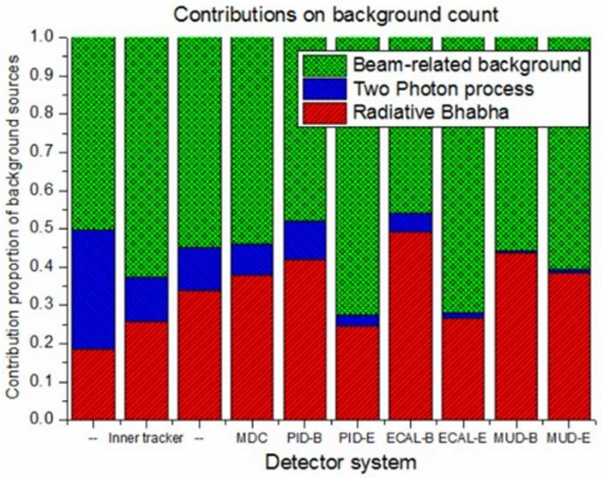


Counting rate





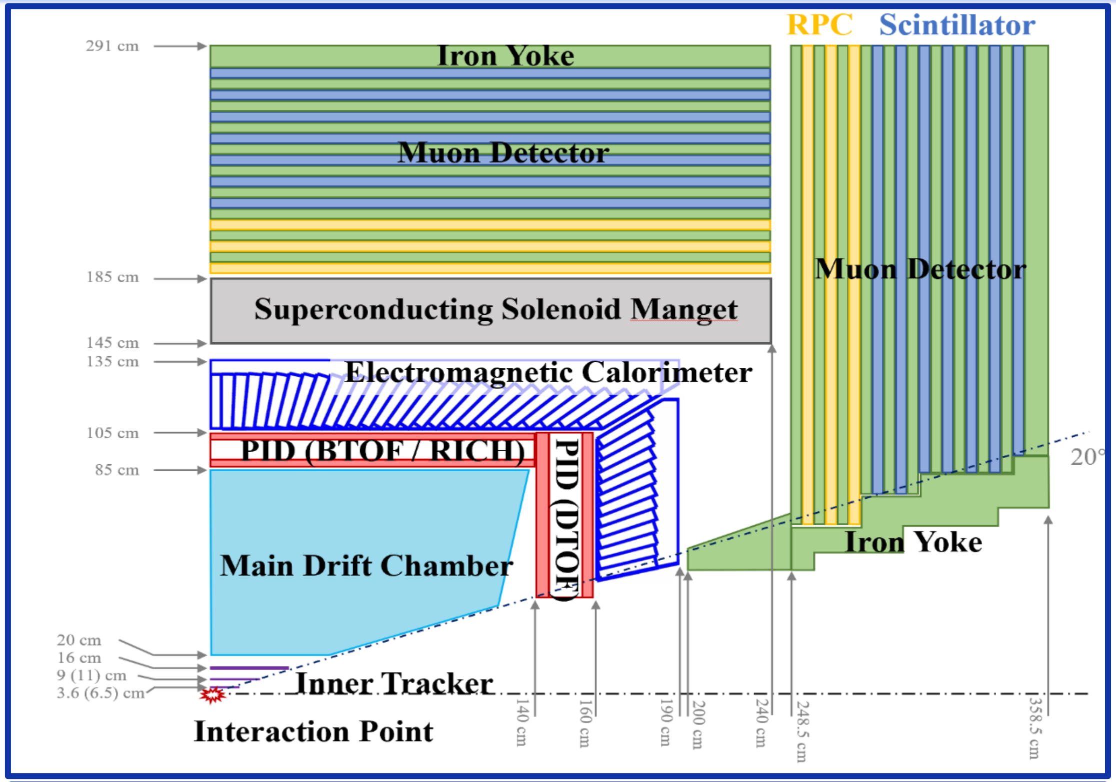




◇ 最内层Maps： ~12 kGy/y, ~2×10^{10} 1MeV n-eq/cm^2/y, ~1 MHz/cm^2

核心难点在于：实验环境工况大幅恶化的前提下，维持甚至进一步提升各类探测器的顶尖性能水平。

Detector Design and Key Technologies



Major Performance Requirements

Acceptance: 94%×4π

Momentum res.: $\sigma_p/p \sim 0.5\%$ @ 1 GeV

Energy res. : $\sigma_E/E \sim 2.5\%$ @ 1 GeV

Hadron ID: π/K ~4σ @ 2 GeV

Muon ID: eff. >95%, misrate <3.3% @1 GeV

- Inner Tracker
  - MPGD: cylindrical uRGroove, σ_x ~100 μm
  - Silicon: low-mass MAPS, <0.3%X_0/layer
- Central Tracker (σ_p/p~0.5% @ 1GeV)
  - Drift chamber with super-small cells, σ_x <130 μm
- PID System (π/K ~4σ @ 2GeV)
  - Barrel: DIRC-like TOF (σ_t~30 ps)
  - Endcap: RICH (<4mrad) or ASHIPH
- EMC
  - pCsI + APD: (σ_E/E~2.5%, σ_x~5 mm, σ_t~300 ps @ 1GeV)
- Solenoid： 1 T
- Muon Detector (eff. >95%, mis-rate <3% @1GeV)
  - inner layers : glass RPC， > 300 Hz/cm^2
  - outer layers : scintillator strip + SiPM, ~ 2.4 m
- Trigger, DAQ, Clock and Data Transmission

Beam background at the inner most layer

~1 Mrad/y, ~1×10^{11} 1MeV n-eq/cm^2/y, ~1 MHz/cm^2

工作组例会与专题研讨会

- 各细分工作组实行每周或每两周例会制度；探测器全体大会每月召开一次；针对专项研发课题不定期举办小型专题研讨会。

January 2024
- Jan 23 Detector Division Technical Discussion Meeting

November 2023
- Nov 30 Detector Division Technical Discussion Meeting

October 2023
- Oct 27 Detector Division Progress Review Meeting

September 2023
- Sep 27 Detector Division Technical Discussion Meeting
- Sep 08 Detector Division Progress Review Meeting

MAPS-ITK Working Group	85 events
MPGD-ITK & MDC Working Group	31 events
PID Working Group	39 events
EMC Working Group	32 events
MUD Working Group	35 events
Trigger & DAQ Working Group	37 events
Clock and Data Transmission Working Group	7 events
Detector Control System Working Group	1 event
Mechanical Working Group	13 events
Forward Region Working Group	19 events
Magnet Working Group	3 events
General Meetings	21 events

2:00 PM → 2:10 PM **Introduction** 10m
Speakers: Jianbei Liu (University of Science and Technology of China), Qian Liu (University of Chinese Academy of Sciences), Yi Qian (Institute of Modern Physics, Chinese Academy of Sciences), Lei Zhao (University of Science and Technology of China), Dongdong Hu (University of Science and Technology of China)
进度和质量...

2:10 PM → 2:30 PM **MAPS Inner Tracker（ITKM）** 20m
Speakers: Jiajun Qin (University of Science and Technology of China), Lailin Xu (University of Science and Technology of China)
STCF_MAP...

2:30 PM → 2:50 PM **uRWELL Inner Tracker（ITKW）** 20m
Speakers: Yi Qian (Institute of Modern Physics, Chinese Academy of Sciences), Yi Zhou (University of Science and Technology of China)
STCF分总...

2:50 PM → 3:10 PM **Main Drift Chamber（MDCH）** 20m
Speakers: Limin Duan (Institute of Modern Physics, Chinese Academy of Sciences), Zhe Cao (University of Science and Technology of China)
MDC9月总... MDC读出...

3:10 PM → 3:30 PM **Barrel Particle Identification Detector（PIDB）** 20m
Speakers: Lei Zhao (University of Science and Technology of China), Qian Liu (University of Chinese Academy of Sciences)
20230907 ...

3:30 PM → 3:50 PM **Endcap Particle Identification Detector（PIDE）** 20m
Speakers: Ming Shao (University of Science and Technology of China), Yonggang Wang (Univeristy of Science and Technology of China)
STCF谱仪...

3:50 PM → 4:10 PM **Electromagnetic Calorimeter（ECAL）** 20m
Speakers: Yunlong Zhang (University of Science and Technology of China), Zhongtao Shen (University of Science and Technology of China)
STCF EMC ...

4:10 PM

4:30 PM

2:40 PM → 3:10 PM **MAPS Inner Tracker ASIC**
Speakers: Jiajun Qin (University of Science and Technology of China), Lailin Xu (University of Science and Technology of China)
STCF ASIC讨论会...

3:10 PM → 3:50 PM **uRWELL Inner Tracker & PIDB ASIC**
Speaker: jiaming li (University of Science and Technology of China)
STCF RICH μRWELL...

3:50 PM → 4:20 PM **Endcap Particle Identification Detector ASIC**
Speakers: Yonggang Wang (Univeristy of Science and Technology of China), 然 王
2023-09-27_DTOFA...

4:20 PM → 4:50 PM **Muon Detector ASIC**
Speaker: Feng Li (University of Science and Technology of China)
MUD ASIC进展2023...

4:50 PM → 5:20 PM **Data Transmission ASIC**
Speakers: Jinhong Wang (University of Science and Technology of China), 迪 郭
时钟与高速数据传...

高亮度实验触发和数据获取系统设计研发讨论会
会议通知

高亮度实验触发和数据获取系统设计研发讨论会定于 2023 年 2 月 17 日在合肥中国科学技术大学举行。本次会议由核探测与核电子学...

高亮度实验MAPS研发讨论会

Saturday, 1 April 2023 from **08:00** to **20:00** (Asia/Shanghai)
at **物质科研楼 (A608)**
中国科大东校区

Manage

Description 高亮度实验MAPS内径迹探测器研发讨论会定于2023年4月1日(3.31报道，4.1全天开会，4.2离会）在合肥中国科学技术大学举行。本次会议由核探测与核电子学国家重点实验室中国科学技术大学部主办。

高亮度前沿是高能物理实验目前三大前沿研究方向之一，对研究稀有事例，探索新物理有重大推动作用。在高亮度环境中低动量带电粒子的径迹重建具有重大挑战。本次会议将针对高精度、低物质量、低功耗的MAPS内径迹探测器的研发展开相关讨论，并针对国产MAPS工艺的关键技术攻关进行研讨。

STCF探测谱仪机械设计研讨会

Monday Aug 19, 2024, 9:00 AM → 6:05 PM Asia/Shanghai
物质科研楼三楼会议室 (中国科学技术大学)

Description 本次会议将针对STCF实验谱仪机械结构的设计研发问题进行深入讨论，议题包括：谱仪整体的支撑移动系统设计、各探测器系统的内部与谱仪层级机械连接装配设计、电子学芯片散热设计等。

腾讯会议：456-104-342

https://meeting.tencent.com/dm/3arobCI1DURC

STCF HLT 计算存储专题研讨会

Thursday Nov 21, 2024, 2:00 PM → 11:05 PM Asia/Shanghai
物质科研楼三楼会议室 (中国科学技术大学)

Description 高层级触发（HLT）设计是决定STCF实验数据量的关键环节，计算存储方案则影响了后续的长期数据存储、分析、利用的规划，都是工程化阶段需要慎重考虑的系统。目前粗估输入给HLT的数据量约10 GB/s，每年数据存盘量在200 PB水平，需要详细讨论两个系统的设计与实现方案以获得更好的综合性能，保障STCF的长期稳定运行。

https://cern.zoom.us/j/67548157547?pwd=S0B7TYHk4M6hcDtEuy5qjNzPFv2aBJ.1

ZOOM ID: 675 4815 7547

Password: 325525

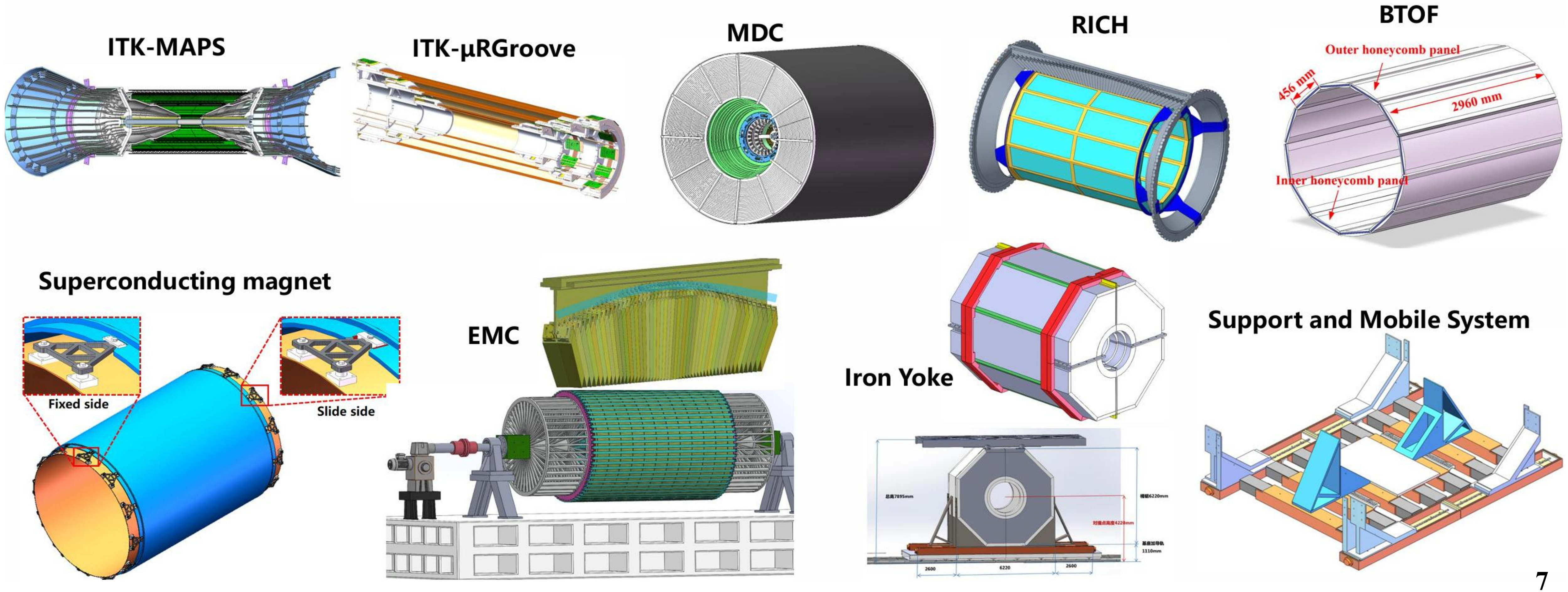
2:00 PM → 2:20 PM **STCF初步采数规则说明**
Speaker: Xiaorong Zhou (University of Science and Te...
STCF_data_taking_...

2:20 PM → 3:10 PM **STCF HLT研究进展与计算资源估算**
Speaker: Zhujun Fang (USTC)
20241118 STCF HL...

3:10 PM → 4:10 PM **从DAQ角度看STCF计算中心需求_FTCF2024**
Speaker: Junfeng Yang (USTC)
从DAQ角度看STCF...

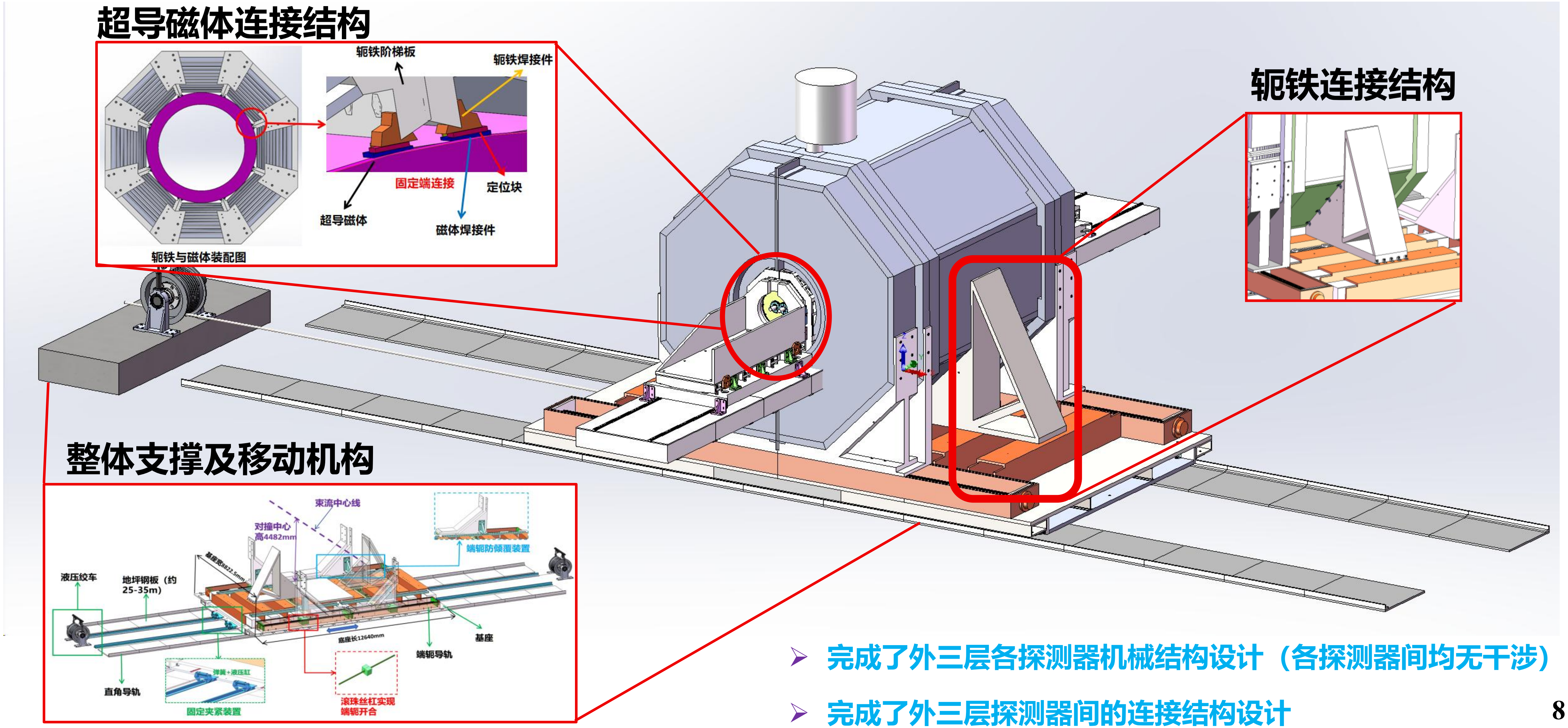
谱仪探测器机械设计

- 探测器概念设计已完成工程图纸转化；
- 各子探测器与配套系统均已出具工程设计方案；
- 同步开展探测器整机装配、现场安装相关设计论证工作。



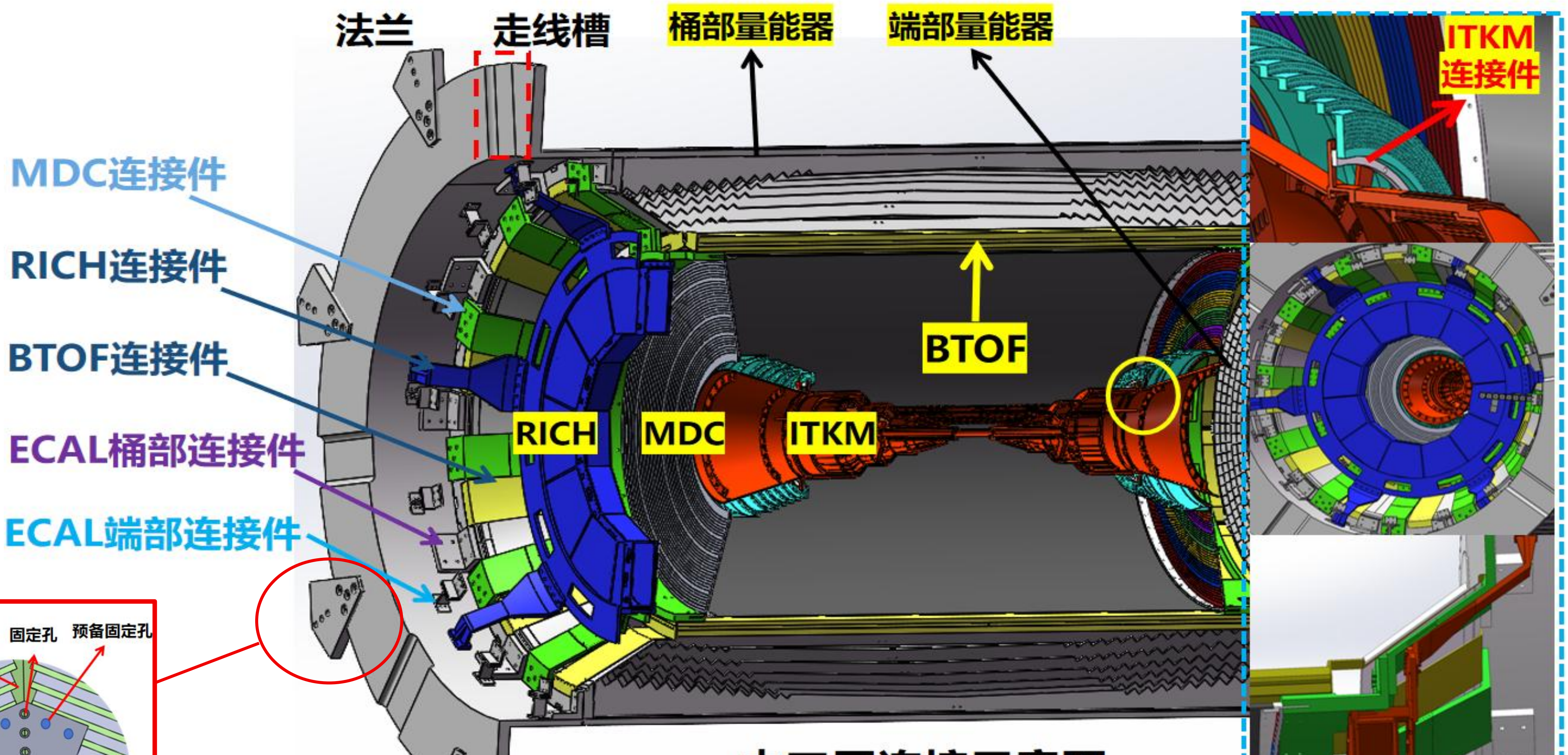
谱仪探测器机械设计：外三层总装图

谱仪机械结构及连接总图

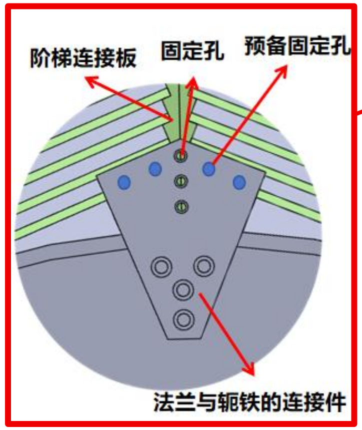


- 完成了外三层各探测器机械结构设计（各探测器间均无干涉）
- 完成了外三层探测器间的连接结构设计

谱仪探测器机械设计：内三层总装图



内三层连接示意图

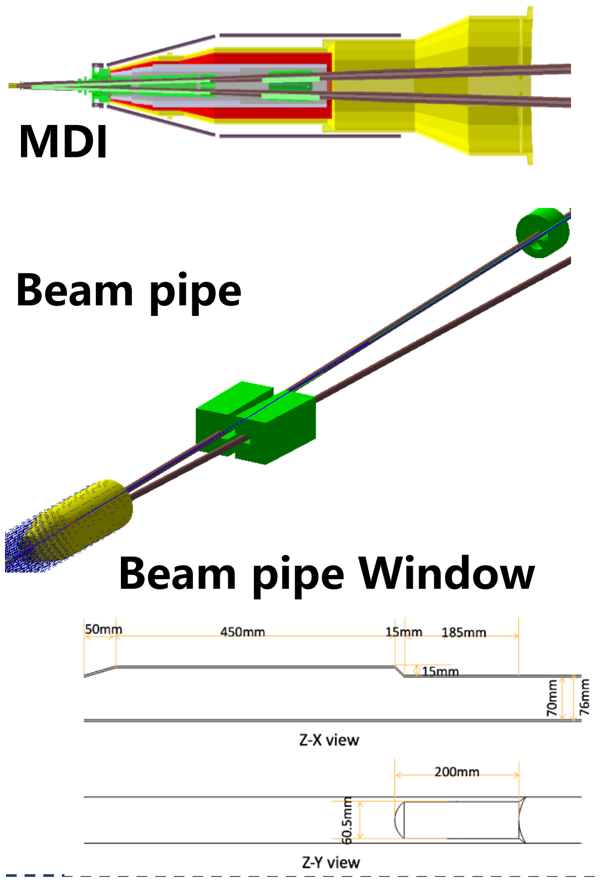


- 完成了内三层各探测器机械结构设计（各探测器间均无干涉）
- 完成了内三层探测器间的连接结构设计（各探测器间连接件均无干涉）

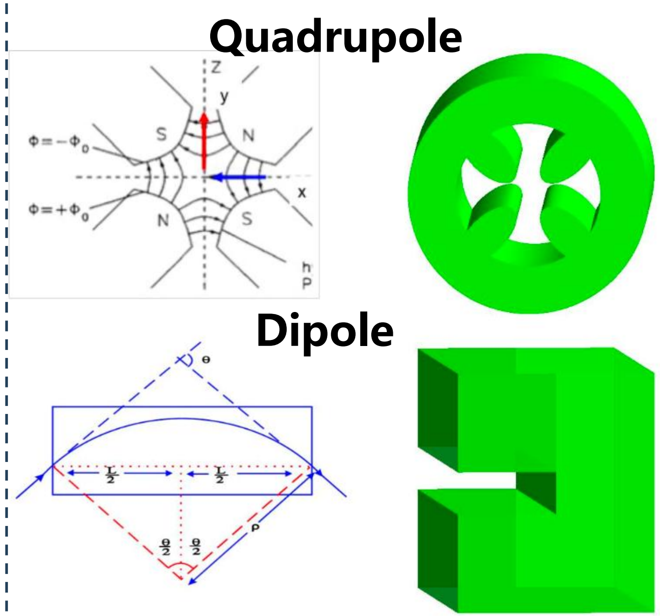
前向探测器模拟框架

❑ 构建了针对 STCF 前向探测器设计的完整全模拟（Full Simulation）框架。

Geometry



Magnetic Field



Event Generator

➢ Several specialized event generators focus on specific processes at STCF, including:

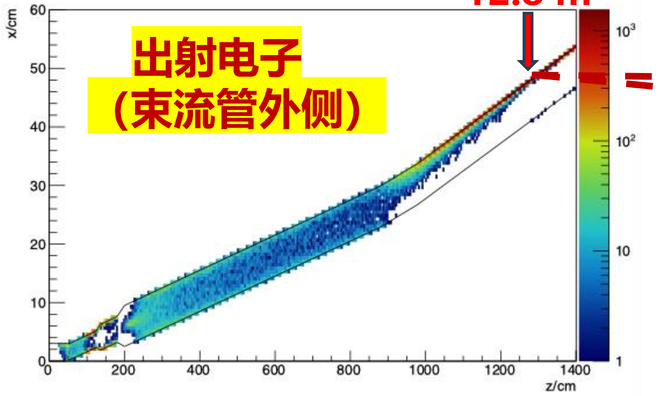
BBBREM: radiative Bhabha
DOI: 10.1016/0010-4655(94)90085-X

EKHARA: hadrons with tagged photons
DOI: 10.1016/j.cpc.2018.07.021

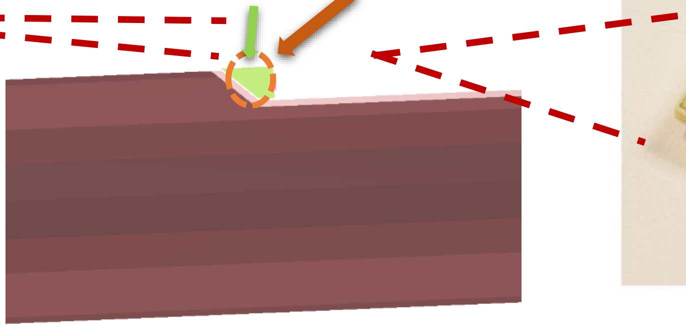
BHWIDE: small angle Bhabha scattering
DOI:10.1016/S0370-2693(96)01382-2

前向探测器快模拟结果

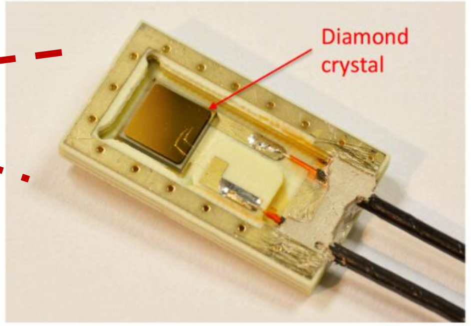
- 针对当前束流管设计，确定了两个通道的亮度监测安装位置：12.8米处针对正负电子在的金刚石探测器，以及11.8米处针对光子的PbF_2切伦科夫探测器，并且对两种探测方案完成了模拟仿真及其本底评估。

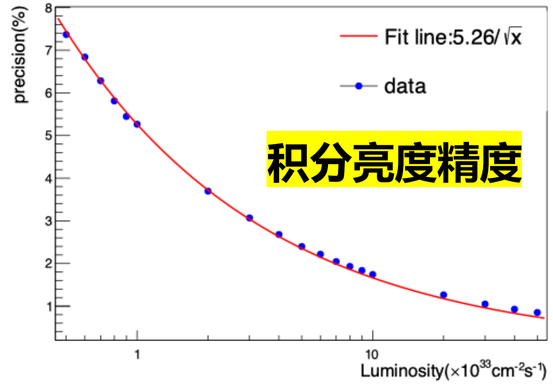


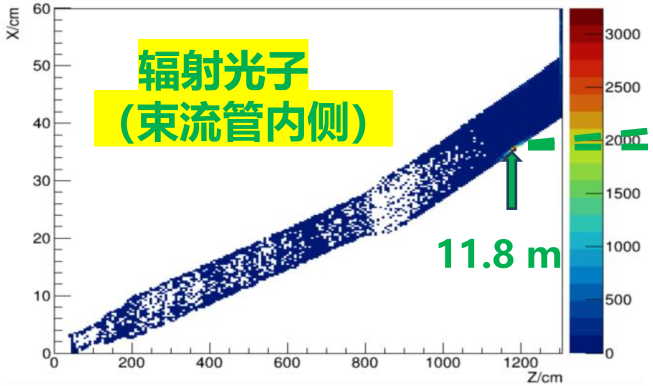
Tungsten Converter

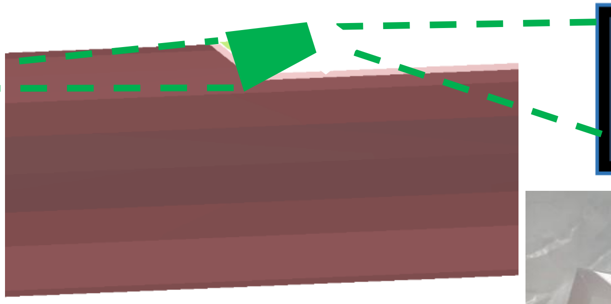


Diamond Detector

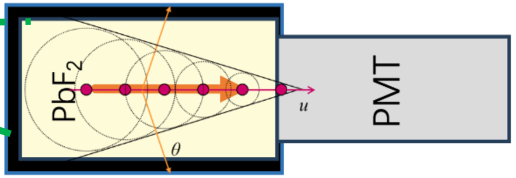


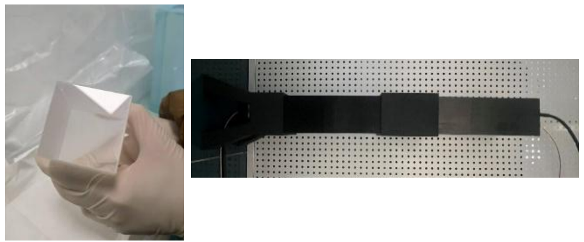


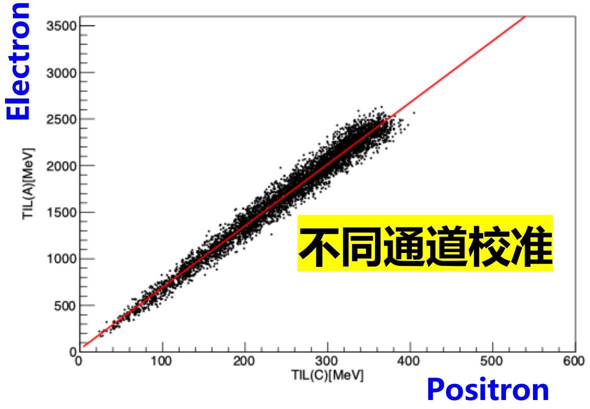




Cherenkov Detector



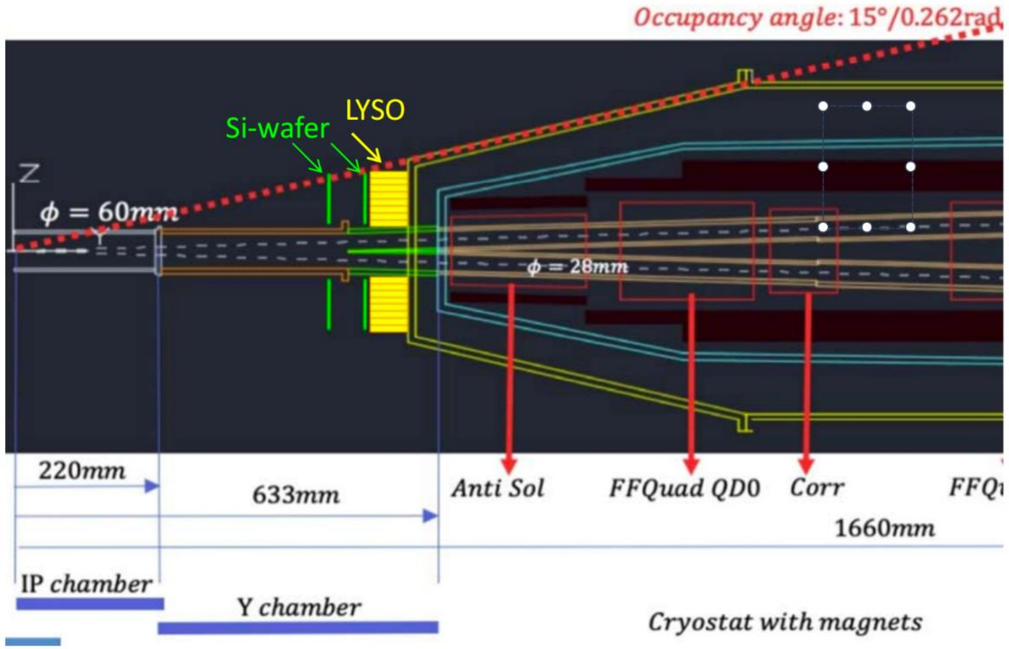




前向探测器&零角度探测器

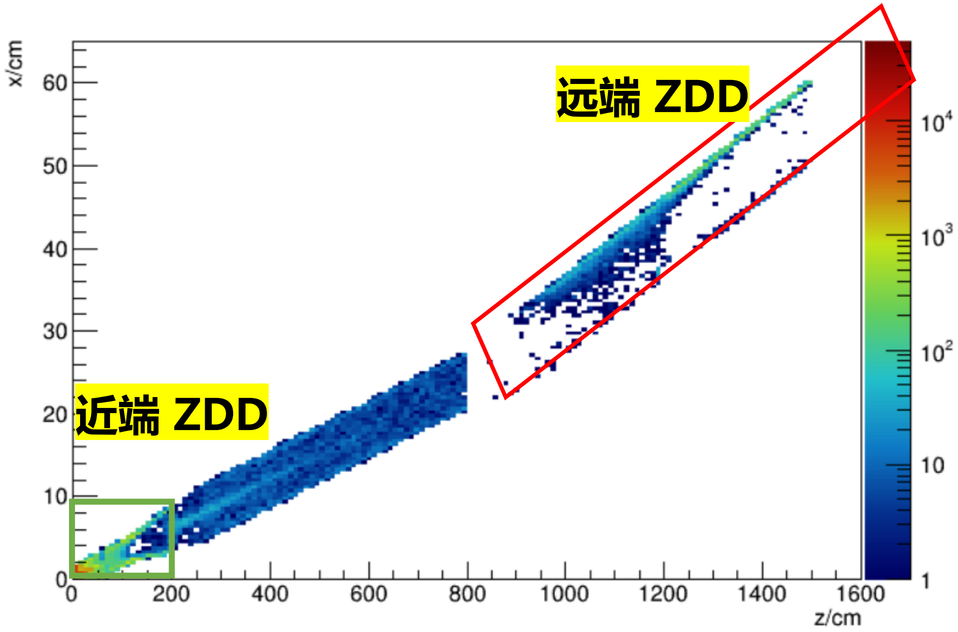
前向量能器（Forward Calo）

- 小角度 Bhabha 精确测量来检验QED和绝对亮度测量
- 完成了基于硅探测器 + 10 X_0 LYSO 晶体阵列的模拟
- 存在挑战：提前簇射+空间限制+位置校准精度



零角度探测器（Zero Degree Detector)

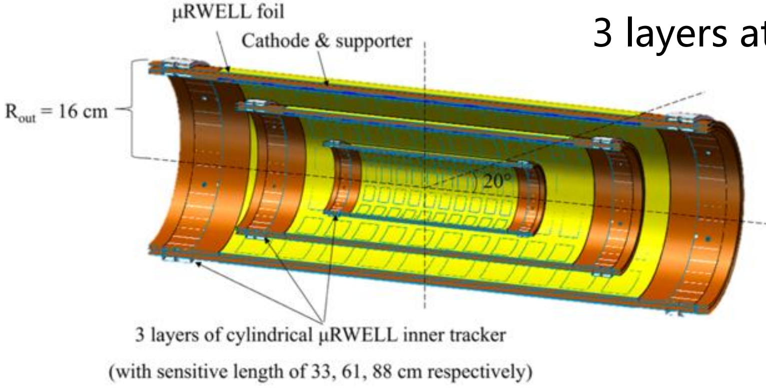
- 双光子过程精确标记和测量光子-光子强散射（HLbL）过程，以降低缪子g-2的理论不确定性
- 类似的硅探测器 + LYSO 晶体阵列方案模拟，同时也存在近端ZDD的空间限制和本底问题

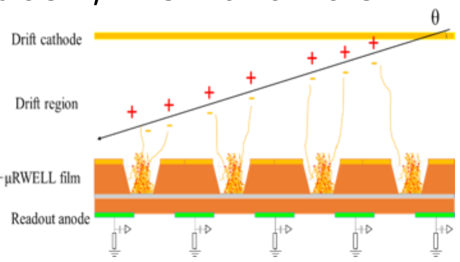


径迹系统：内径迹室+漂移室

ITK Gaseous option : MPGD

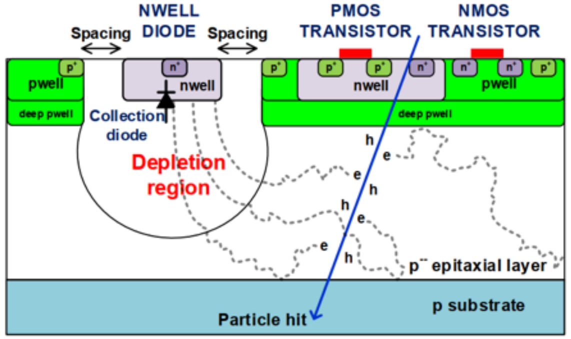
3 layers at 6cm, 11cm and 16 cm





Material budget ~ 0.3%X_0/layer

ITK Silicon option: CMOS MAPS

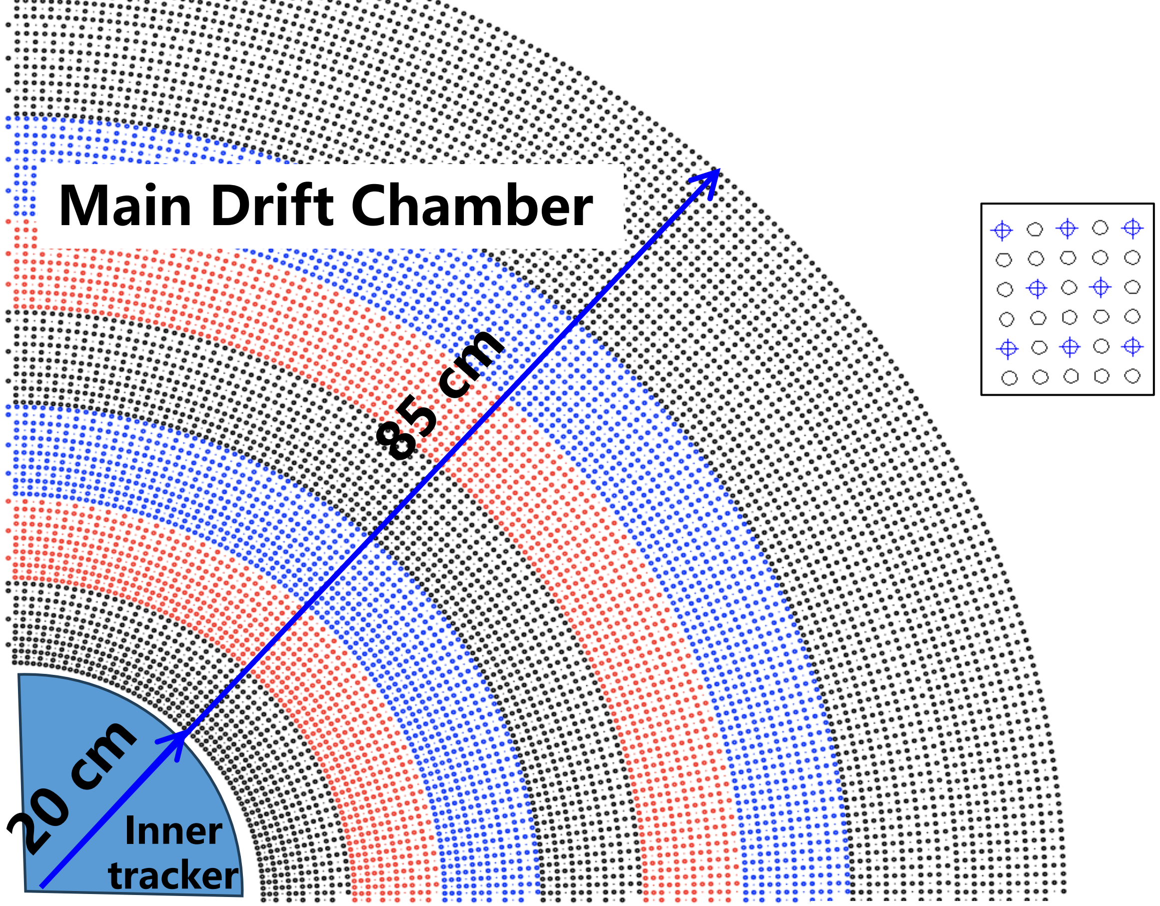


3 layers at

3.6cm, 9.8cm and 16 cm

总物质量 ~ 4%X_0

(inner and outer walls included)

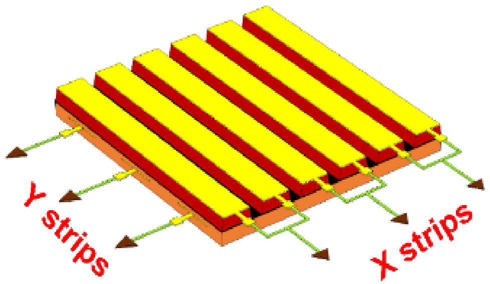


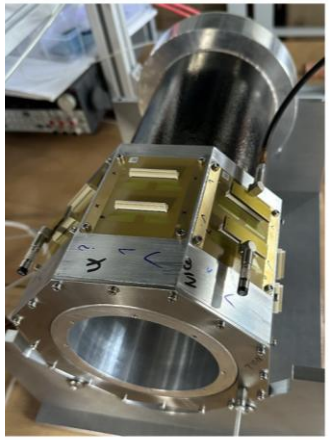
~400 kHz/ch

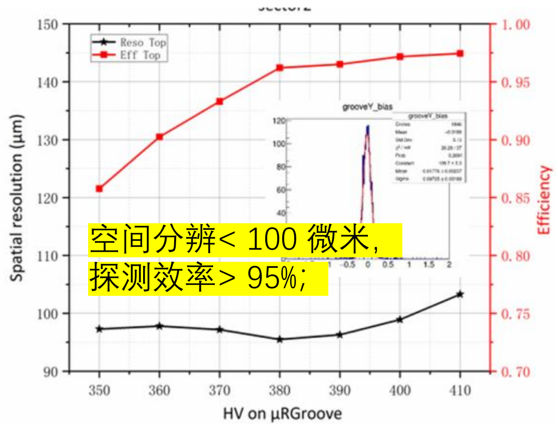
~30 kHz/ch

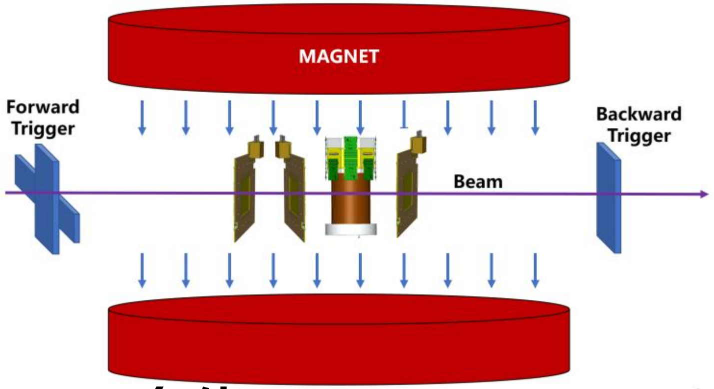
◆ **采用内外分区独立设计，以适配不同强度的辐射本底环境**

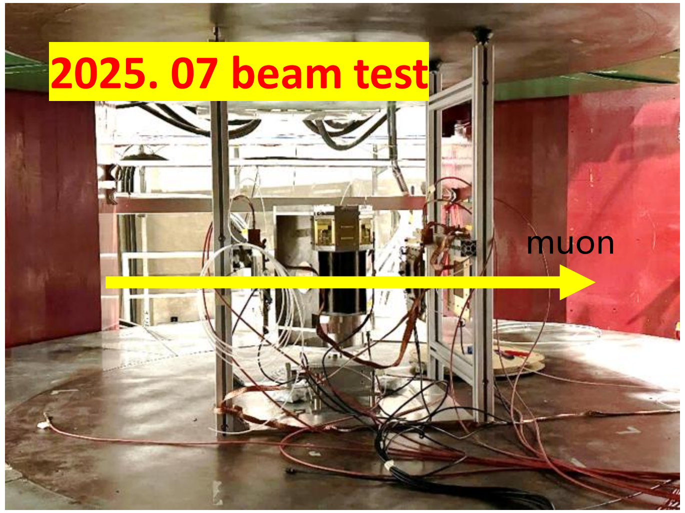
MPGD ITK: µRGroove Detector



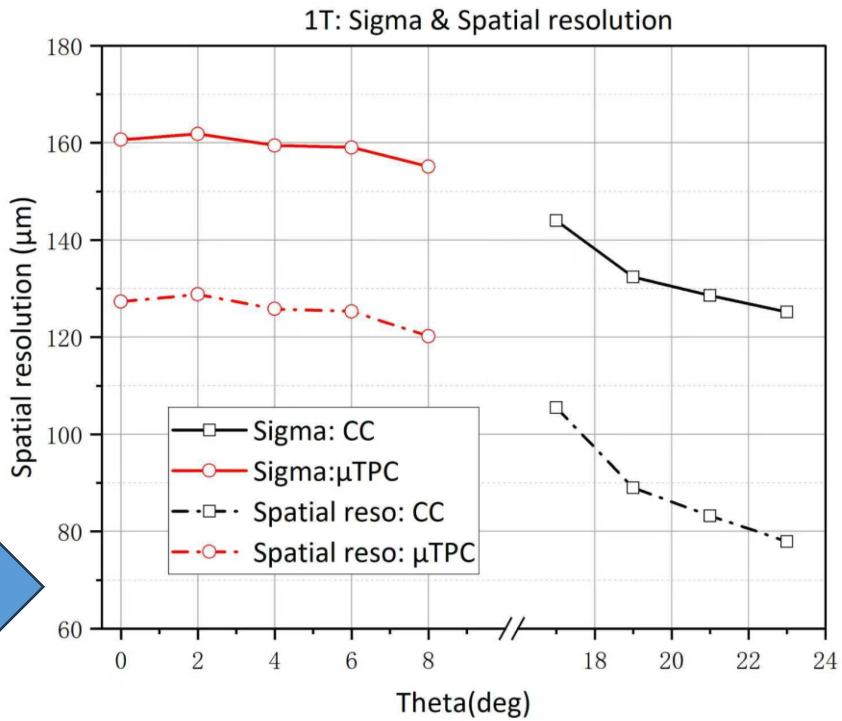








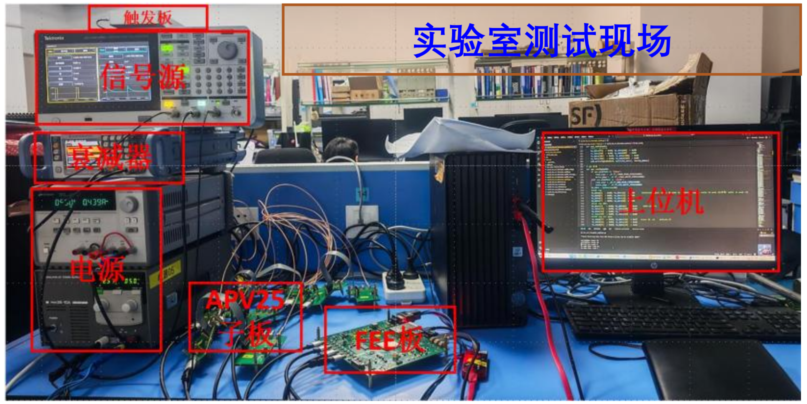
- 气体: Ar:CF_4:CO_2/45:40:15
- 1 Tesla 磁场

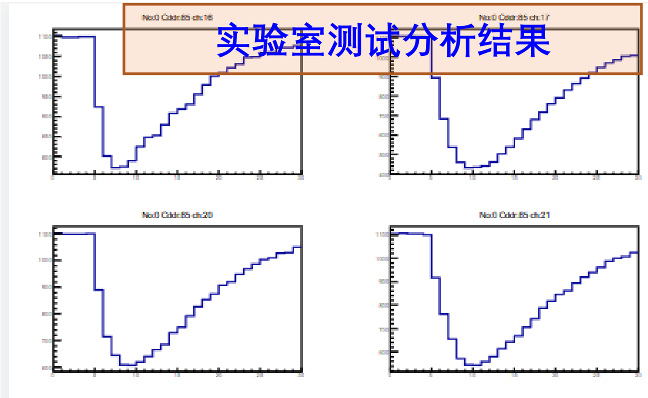


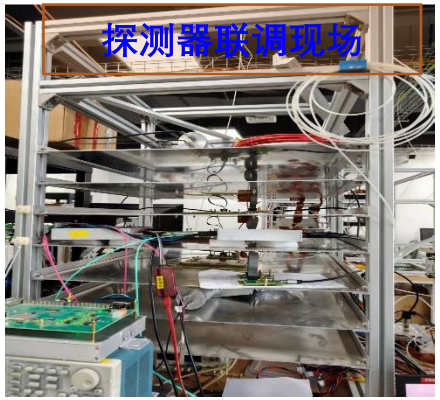
- 洛伦兹角：~24°
- 当入射角度= 0°时，µTPC位置分辨 ~160µm；扣除径迹误差后~126µm
- 当入射角度和洛伦兹角抵消时，CC位置分辨 ~125µm；扣除径迹误差后~78µm

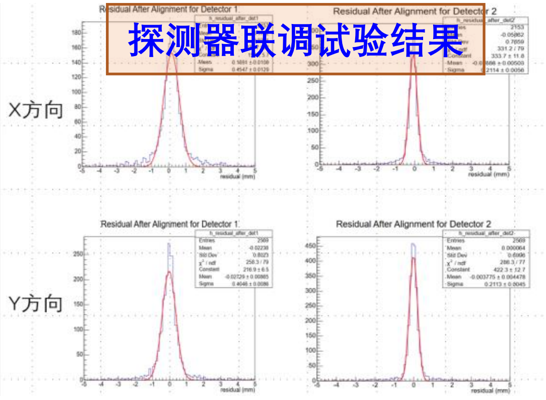
MPGD ITK : Electronics

➢ **基于APV25的前端电子学系统：** 完成实验室1024路测试和探测器宇宙射线2048路联调测试。

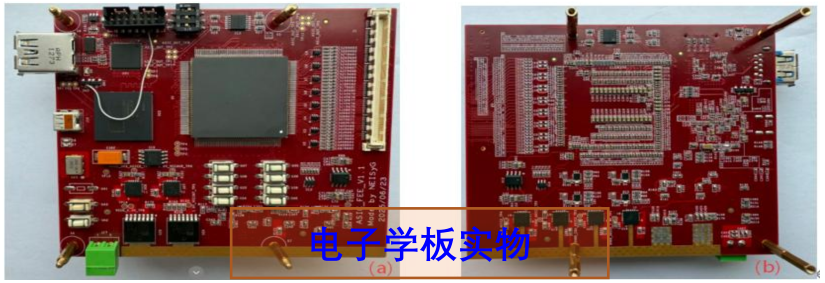


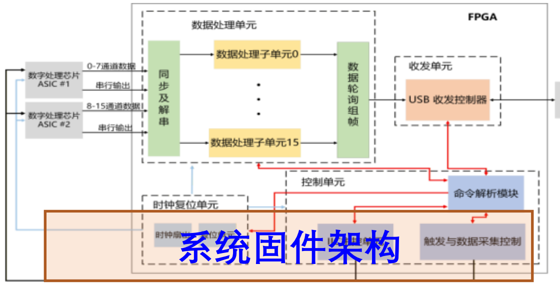


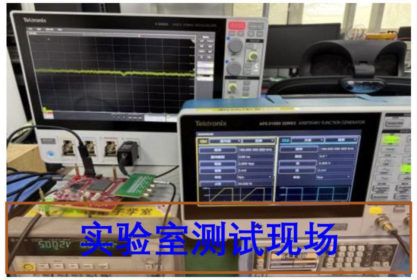


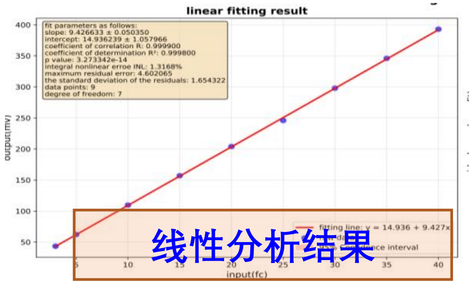


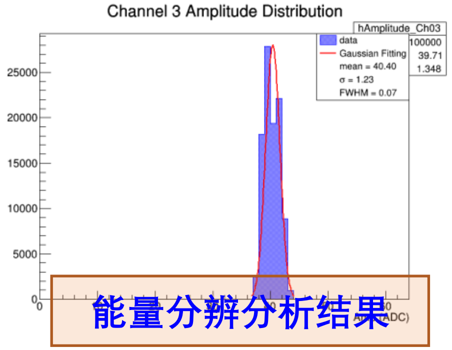
➢ **基于自研ASIC的前端电子学系统**

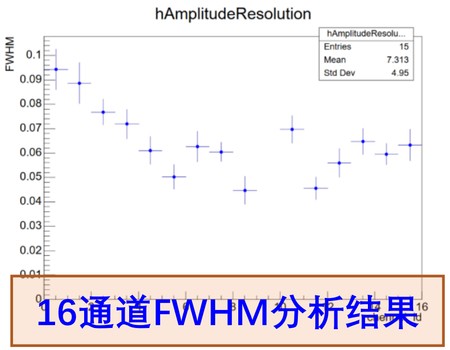


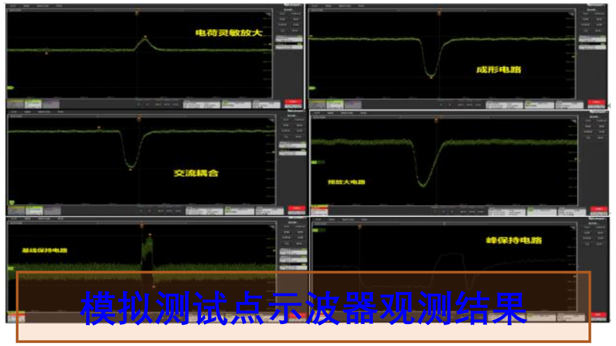








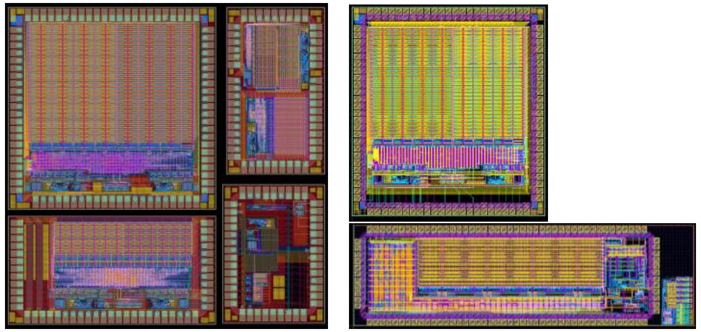




✓ 完成实验室测试，部分结果展示如图所示，模拟调理电路的积分非线性误差**小于1.5%**；在输入电荷量为40 fC时，单个通道的能量分辨**均小于10%@40fC**。

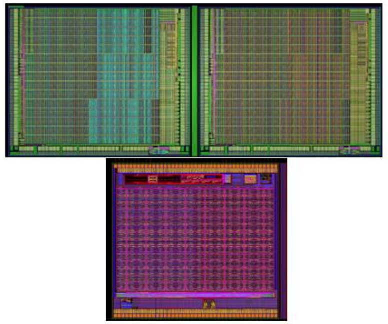
MAPS ITK

◈ 多种工艺原型芯片



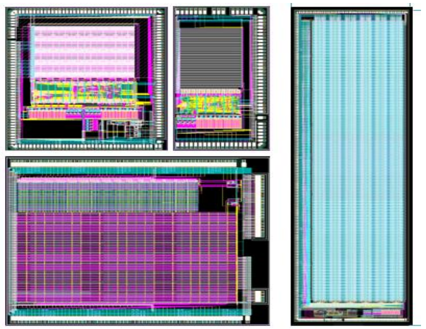
CharTPix-TJ-v0.1/v0.2

- 国外成熟180nm工艺，四阱，高阻外延层，2024.12回片
- 第二版预计七月回片



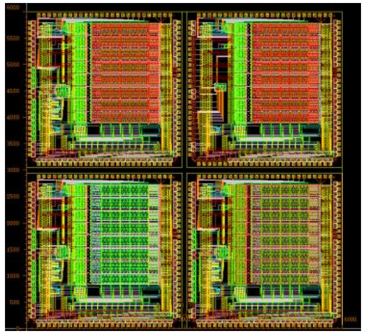
CharTPix-BCIS-v0.1

- 国内90nm CIS工艺，三阱，低阻外延层，2025.6回片



CharTPix-GSMC-v0.1

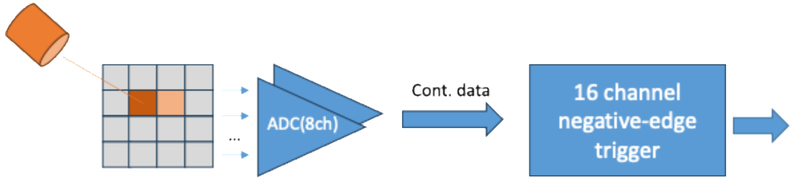
- 国内130nm工艺，四阱，高阻衬底，2025.6回片

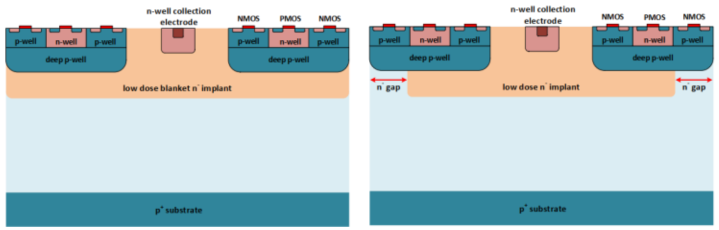


CharTPix-IRAY-v0.1

- 国内180nm工艺，预期可以实现四阱，高阻外延，2025.9回片

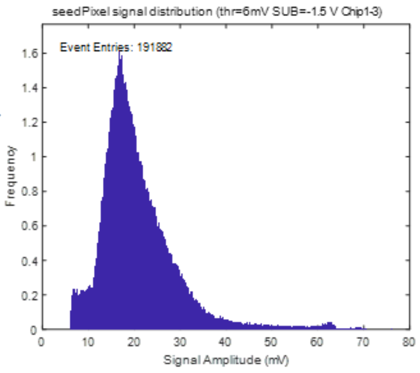
◈ IRAY180测试，^{55}Fe全能峰清晰可见



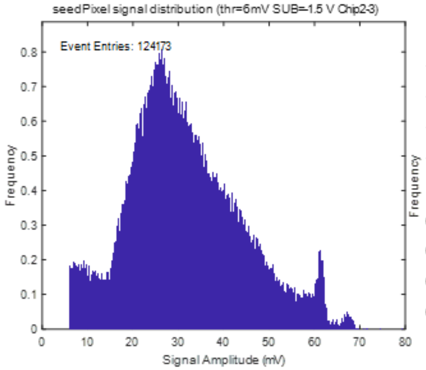


Modified

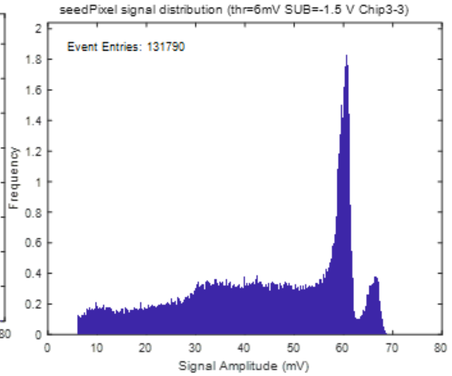
Modified with gap



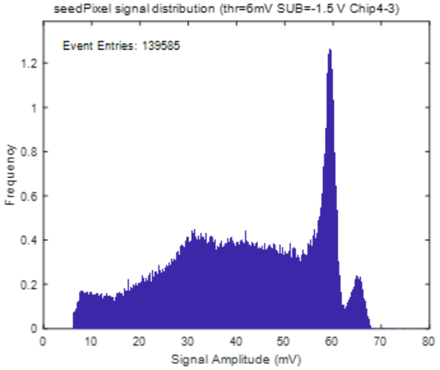
Standard



Modified



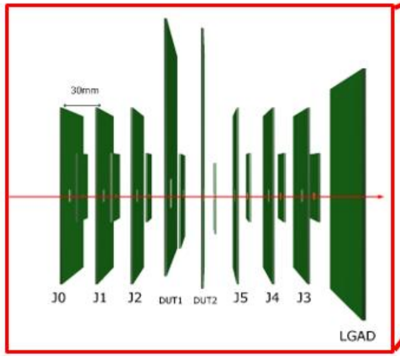
Modified
N-gap=2.5 μm

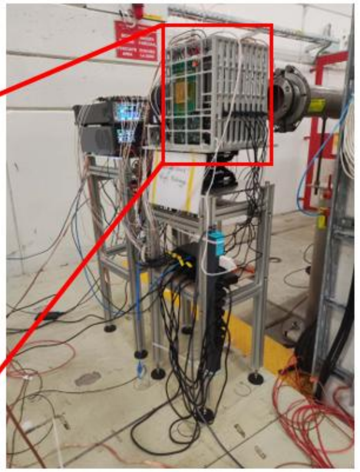


Modified
N-gap=4 μm

MAPS ITK

CERN束流实验

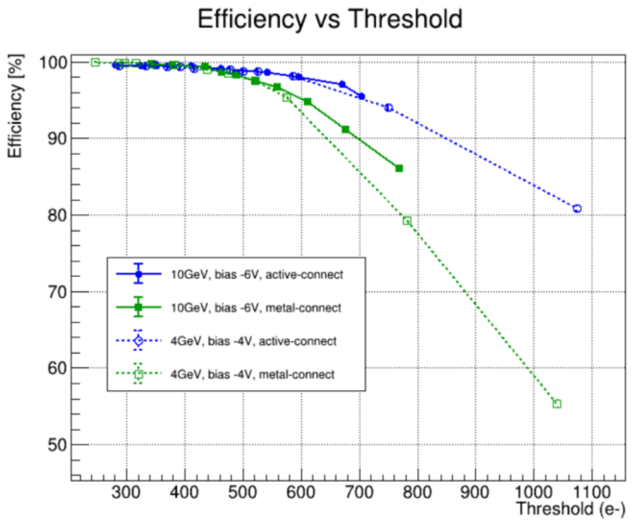


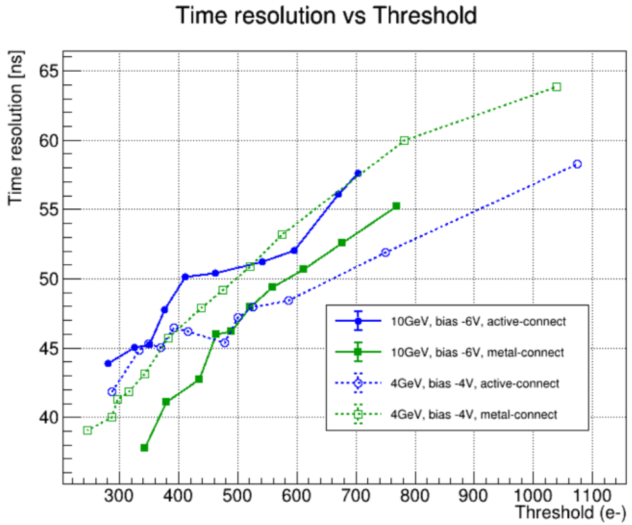


束流望远镜：

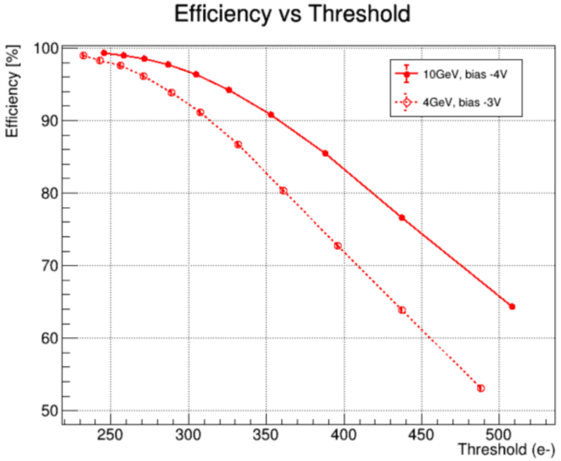
- 6层Jadepix-3芯片作为径迹参考探测器（J0-J6）
- 1层LGAD作为时间参考探测器
- 2层DUT：CharTPix-TJ和CharTPix-GSMC

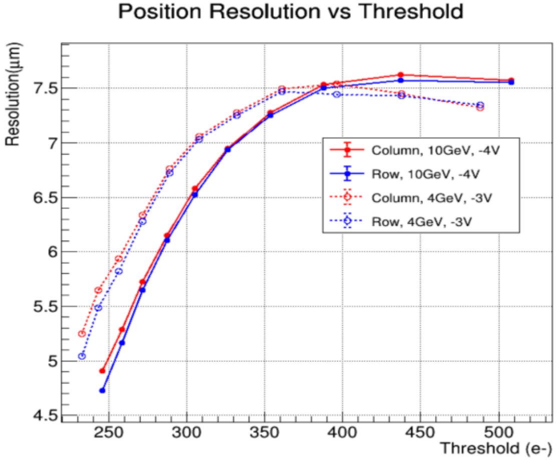
CharTPix-TJ-v0.1

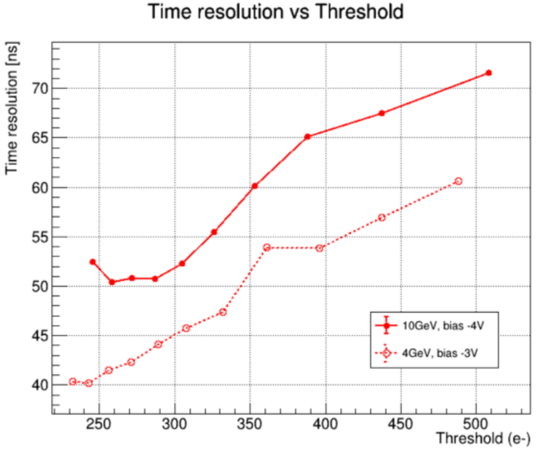




CharTPix-GSMC-v0.1



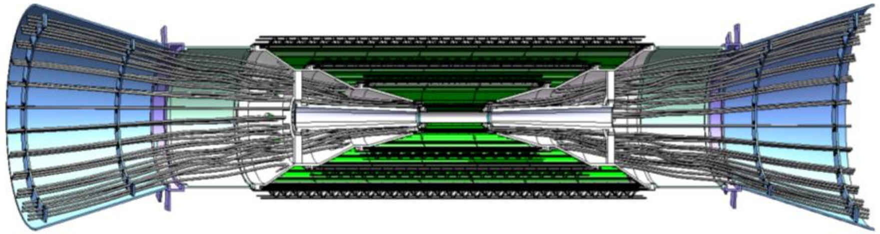


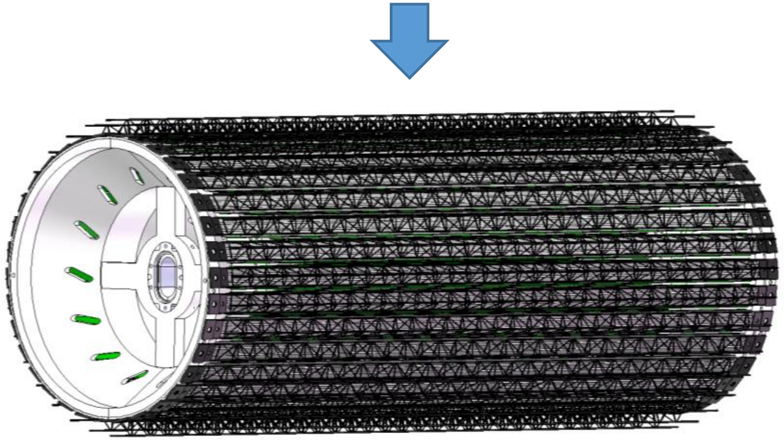


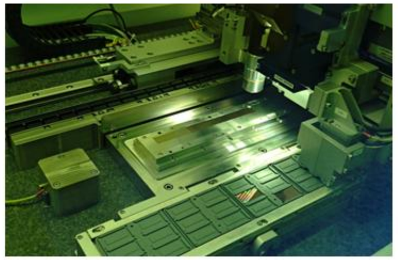
MAPS ITK

◈ 模块和机械设计

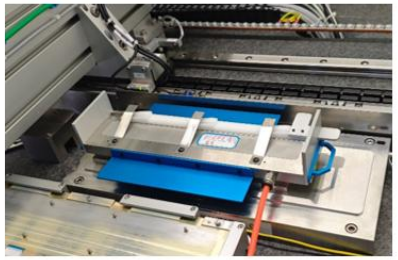
- ❖ ITKM是由MAPS芯片拼成的四层桶状结构，基本结构单元是Stave模块
- ❖ 机械结构提供支持和制冷、走线



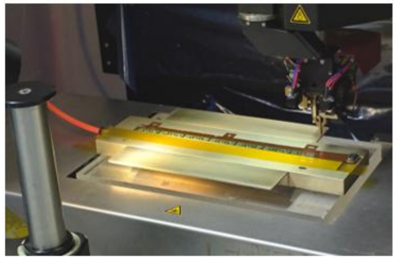




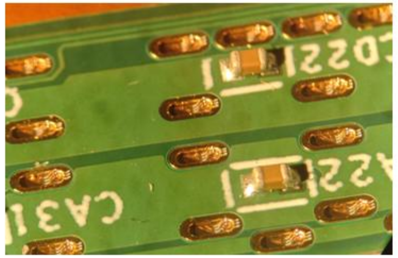
芯片摆放对齐



芯片-PFC粘合固化



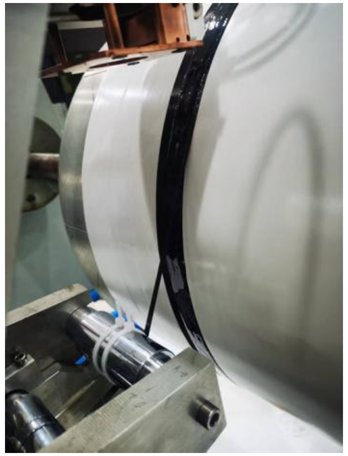
芯片-PFC绑线



完成绑线的FPC焊盘

- ❖ Stave生产工艺已验证可行
- ❖ 与中科院宁波材料所达成合作，第一批stave碳纤维部件样品已完成制作，正在迭代优化中

- 基于Dummy ALPIDE芯片 + 铜基1*7FPC完成了两个混合集成电路（HIC）模块的制作
- 集成精度优于5um，绑线质量合格



预浸料加工

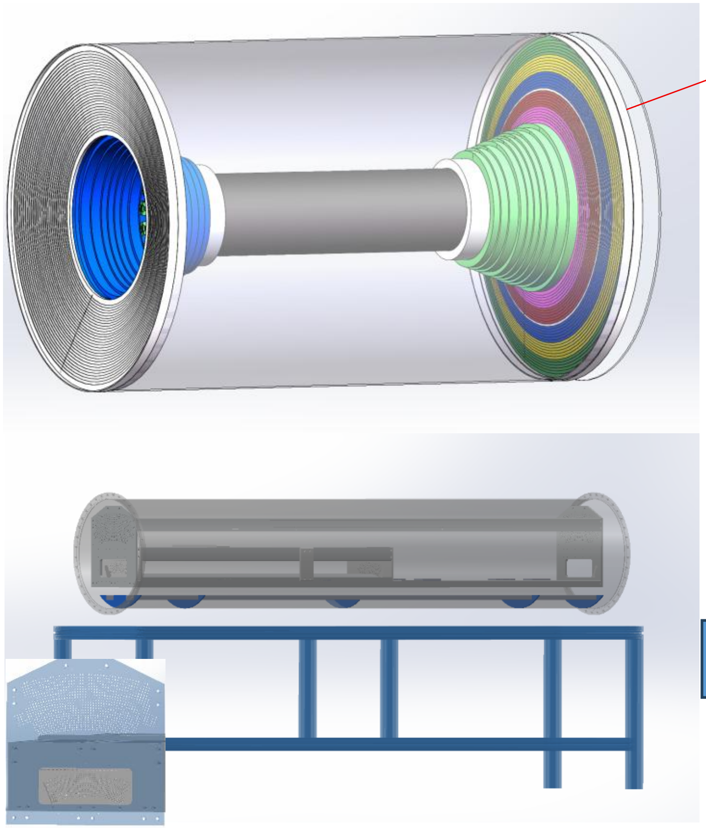
冷却板固化

冷却板

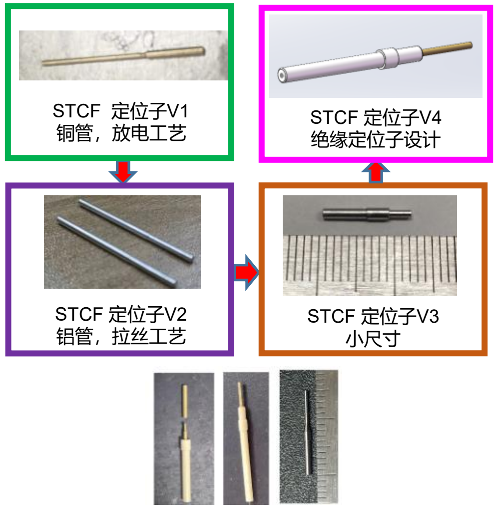
M55J缠绕成型

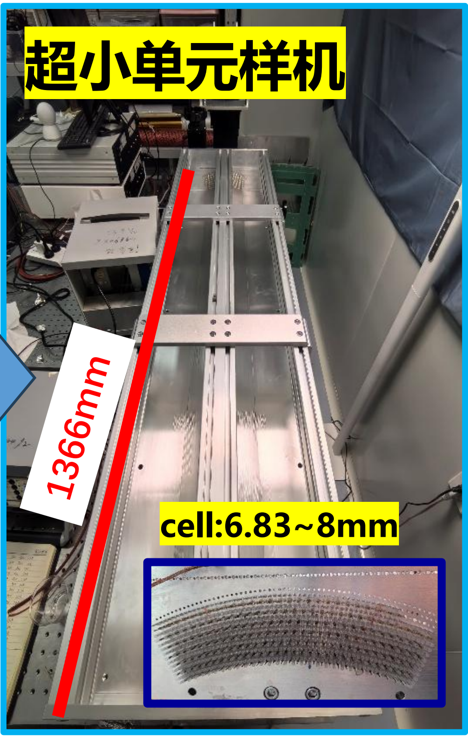
MDC：探测器

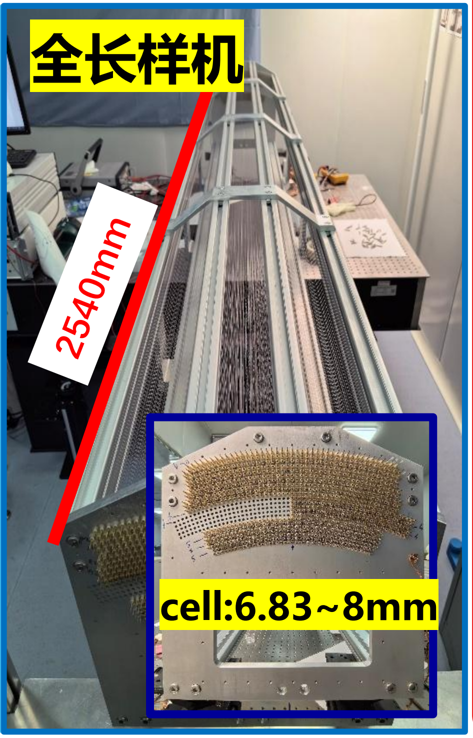
完成MDC端板和单元优化及样机设计

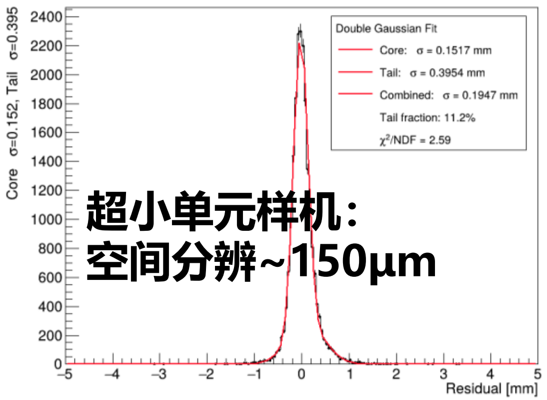


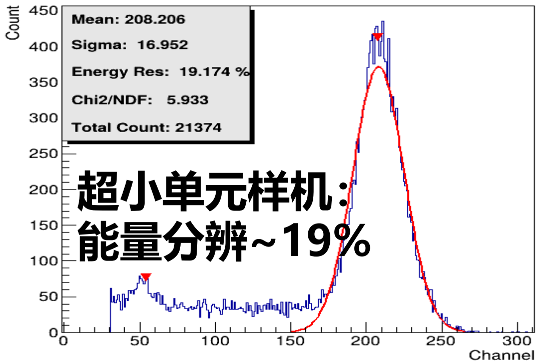
多版本定位子优化设计

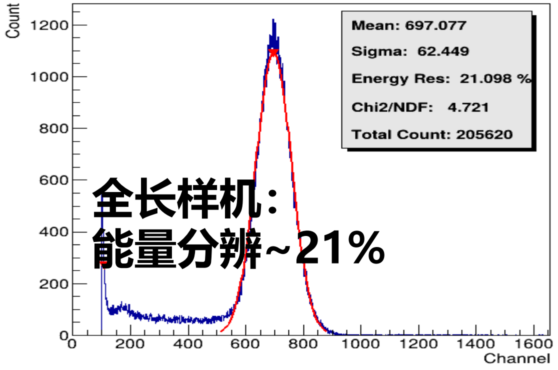






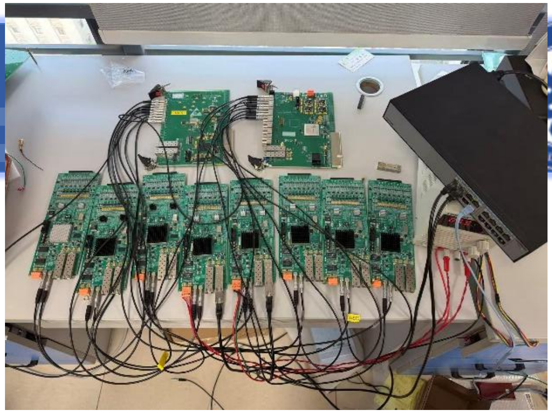




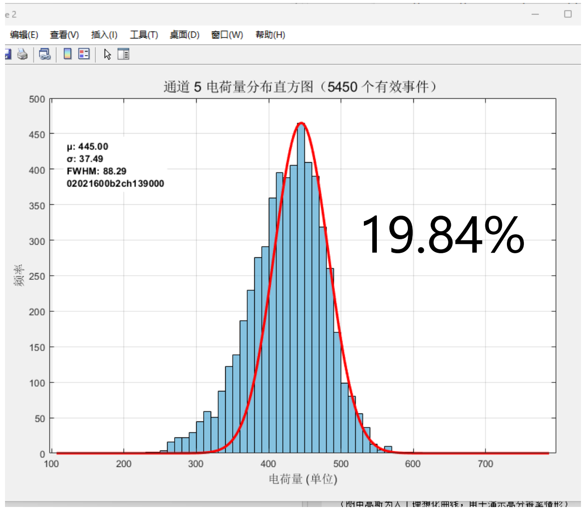


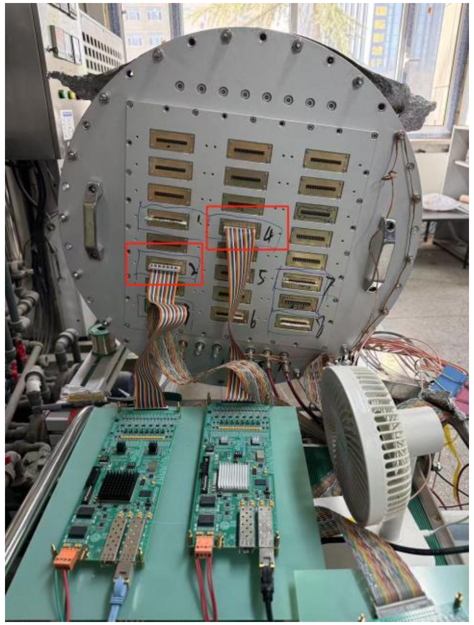
◇ **下一步将开展宇宙线测试**

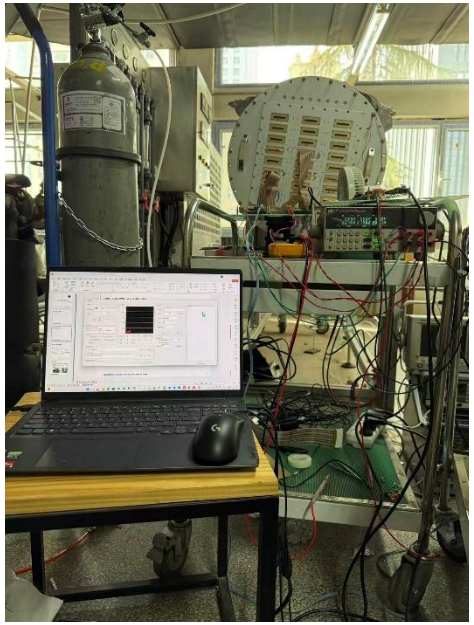
MDC：电子学

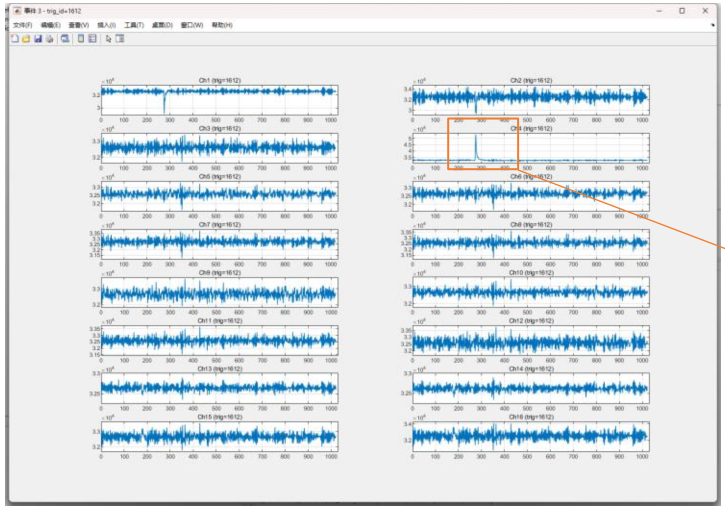


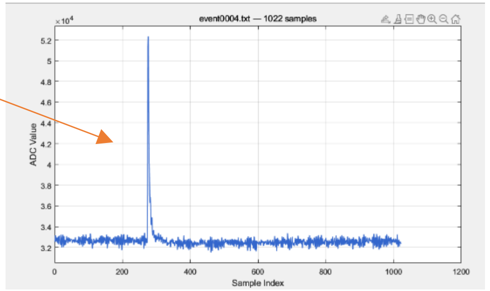
- 已完成多通道读出电子学原理样机研制，共144个读出电子学通道
- 已完成性能测试，时间分辨≤1 ns，电荷测量噪声≤8 fC，事例率≥100 kHz
- 已完成探测器联调铁源测试，能量分辨半宽均约20%左右
- 初步进行超小单元宇宙射线联调测试，电子学系统可以正确进行数据获取
- 即将配合MDC探测器完成宇宙射线测试（双样机）





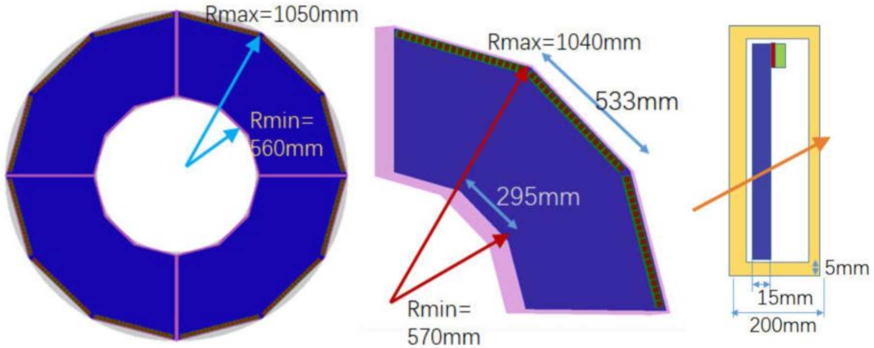


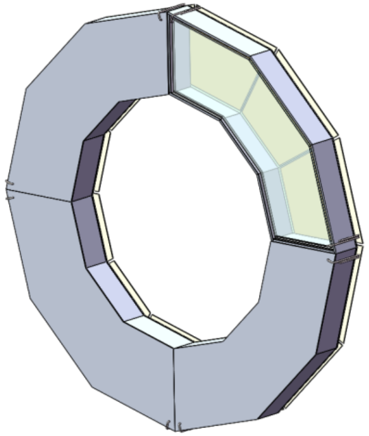


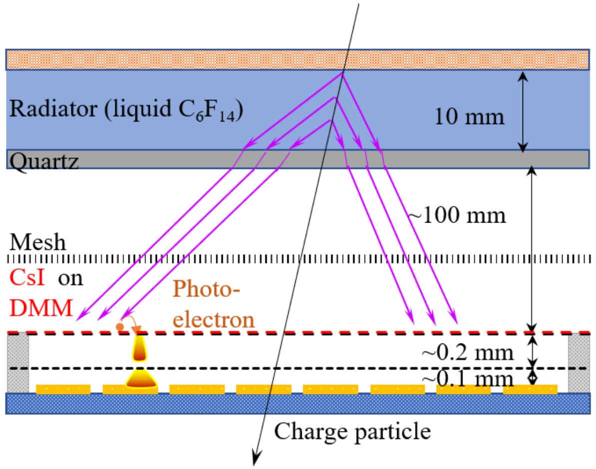


PID System

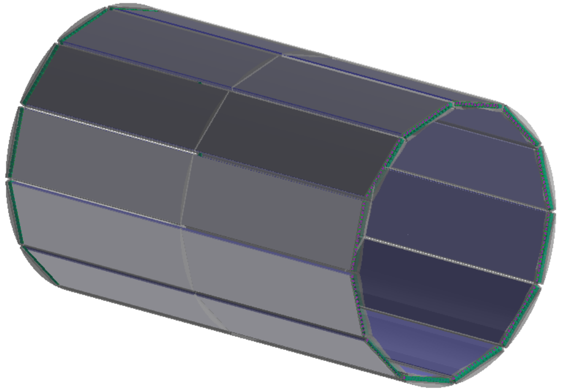
- **PID system: thickness < 20cm, material budget < $0.3X_0$, π/K ~4σ @ 2GeV**
- **Endcap PID:**
  - A DIRC-like TOF detector, DTOF, quartz plate + MCP-maPMT
  - A RICH detector using MPGD with CsI for photon detection

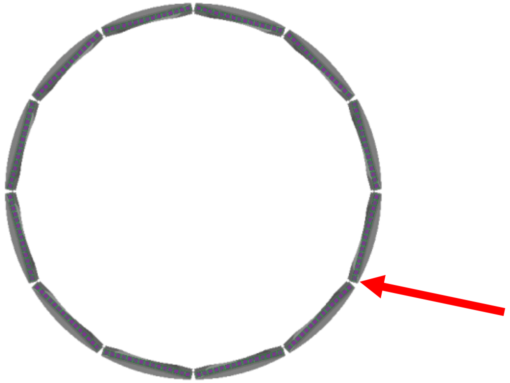


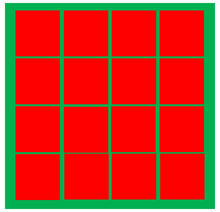


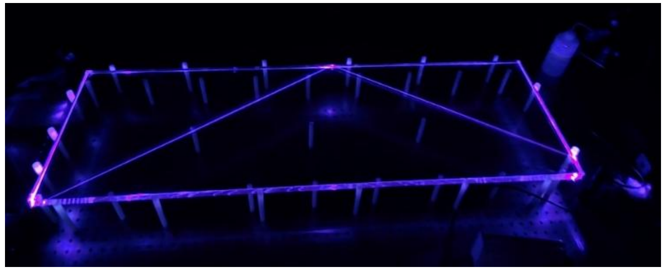


- **Barrel PID: A Barrel DIRC-like TOF detector, BTOF**





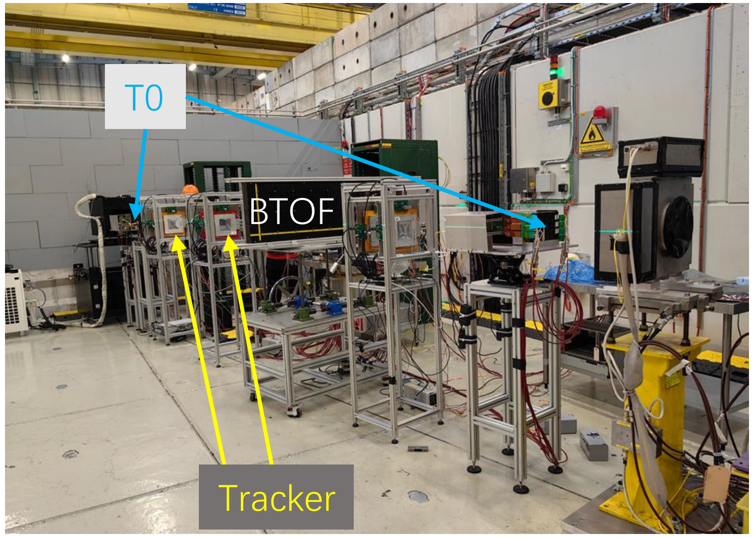


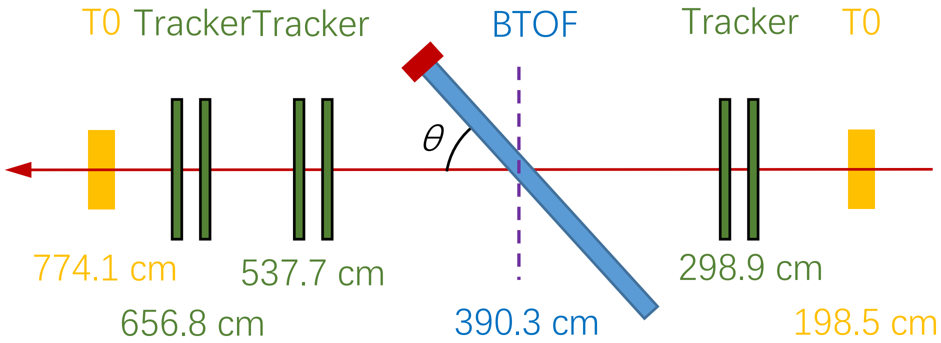


PID-BTOF

◈ 束流实验

现场摆放：



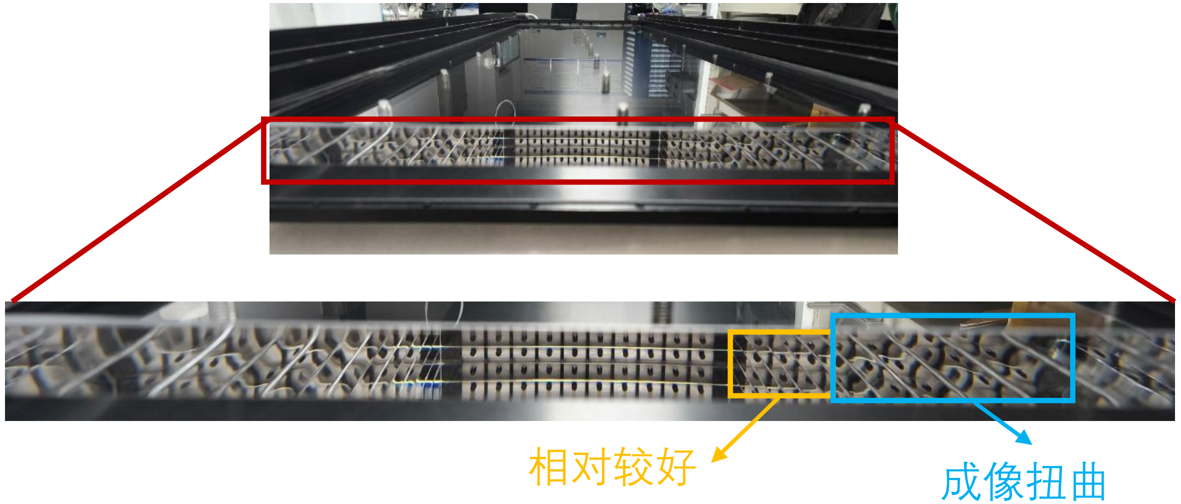


鉴别性能(Data Driven)：

入射角度θ	40°	53°	74°
性能	4.2σ	3.6σ	2.5σ

大角度下性能不佳，是因为辐射体侧边平整度严重不足

侧边反射次数较多的大角度光路畸变严重



更进一步的分析需要量化描述辐射体侧表面情况

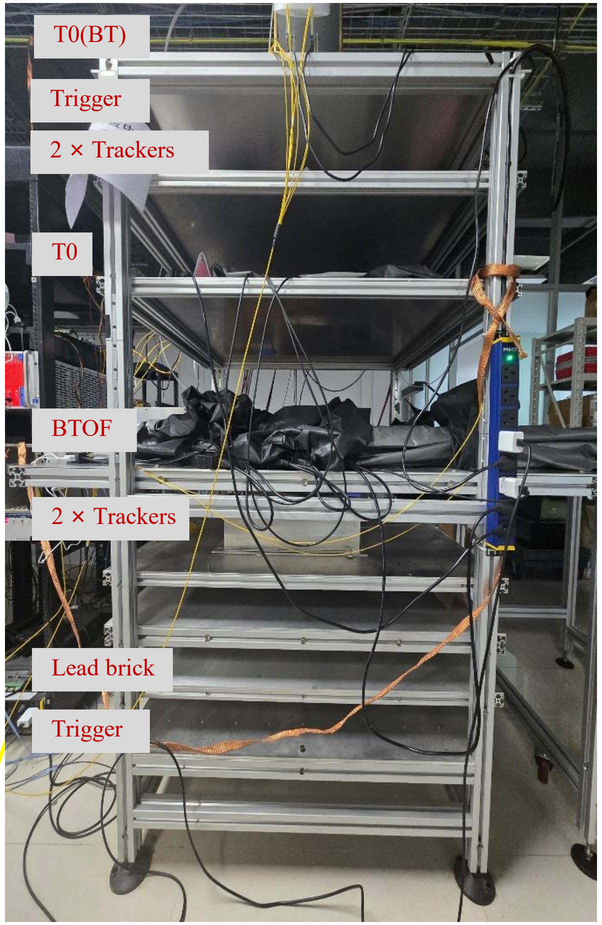
PID-BTOF

◇ 探测器其他进展

◆ 国产光电倍增管研制：

西光所研制的光电倍增管（多阳极10支，单阳极5支）已通过验收

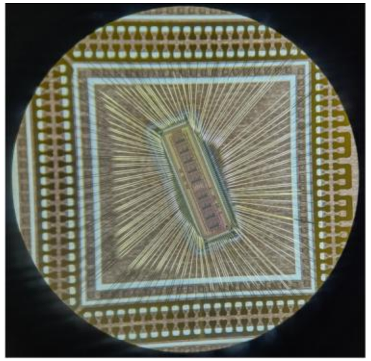
◆ 宇宙线测试：



宇宙线实验已稳定运行两个月，分析进行中

◇ 电子学相关进展

◆ 完成第二版ASIC FET设计以及封测

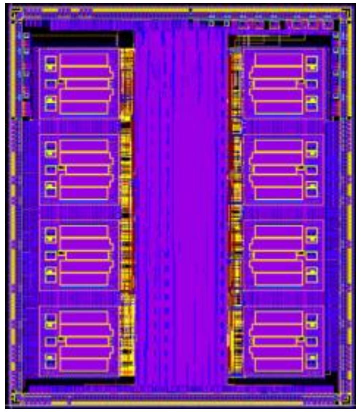


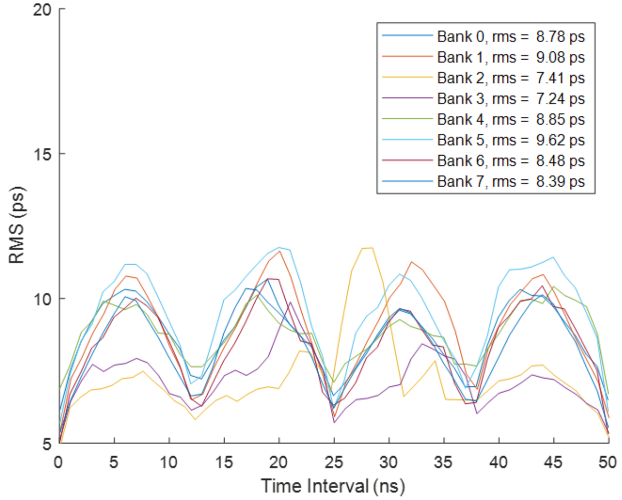
	FET v1	FET v2
前沿定时精度	4 ~ 11 ps	3 ~ 10 ps
TOT分辨率	> 50 ps	3 ~ 15 ps
单光子时间分辨	37 ~ 42 ps	38 ~ 43 ps

新版放大电路整形后有效压制后沿振铃，TOT测量精度大幅提升

◆ 完成第二版ASIC DSTA-TDC的设计测试

TOT Bank	RMS Precision
0	8.78 ps
1	9.08 ps
2	7.41 ps
3	7.24 ps
4	8.85 ps
5	9.62 ps
6	8.48 ps
7	8.39 ps

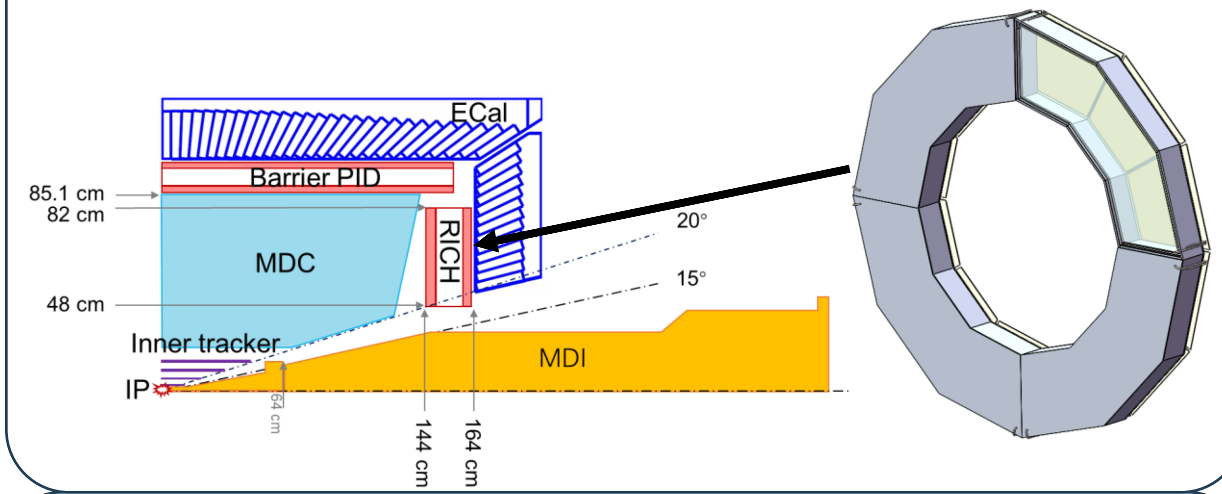




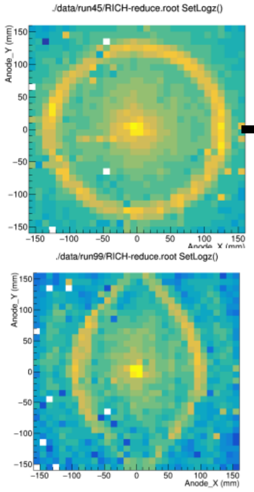
TDC v2定时精度随延迟时间变化

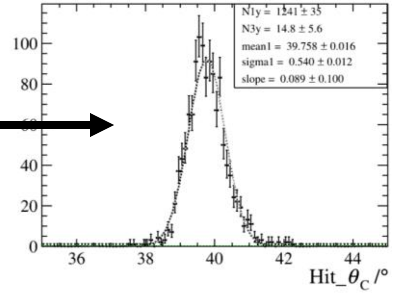
PID-RICH

RICH探测器更换到端盖部分
覆盖动量范围0.7~2GeV/c，角度20°~28°



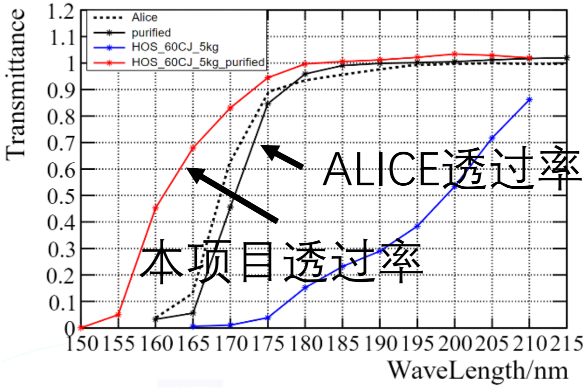
在CERN开展了束流实验，使用液体与棱柱型固体辐射体，都探测到切伦科夫光环

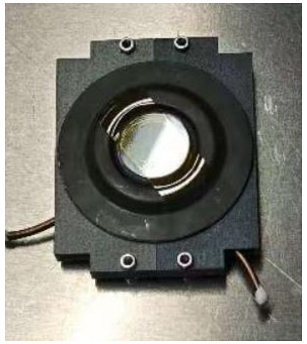




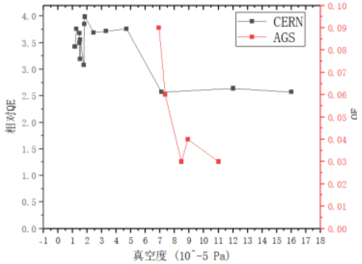
单光电子角分辨符合设计指标，平均光电子数还不足。

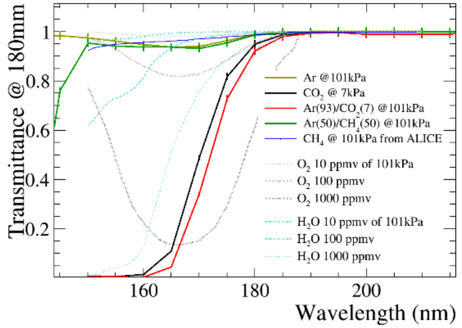
与国内厂家合作，稳定获得优于国际水平的辐射体。制作密闭辐射体容器用于束流实验，性质稳定。





根据实验结果继续优化：确定了光阴极QE与真空度之间的关系，QE达到8%@180nm。测量气体透过率，换用了甲烷基工作气体

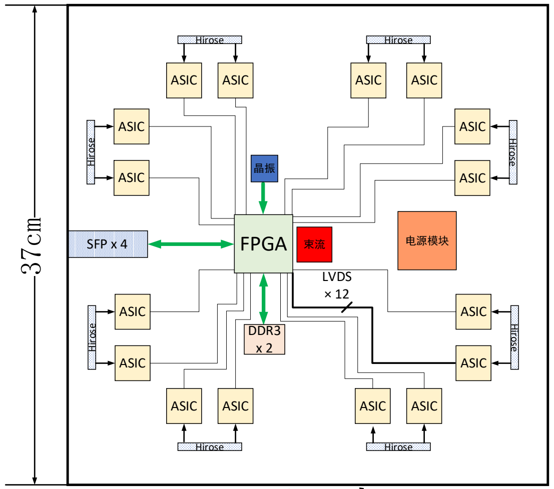


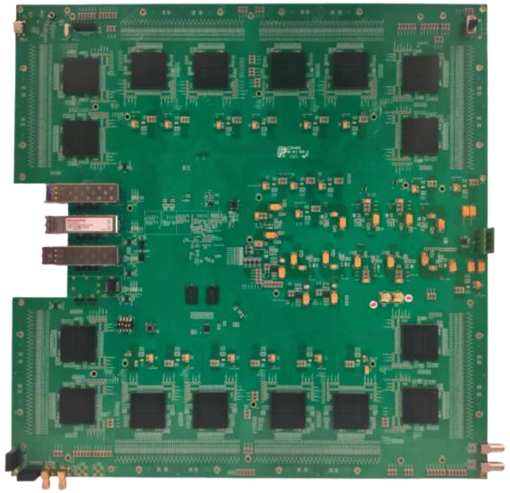


QE随真空度变化的关系　不同气体对紫外光的透过率

PID-RICH：Electronics

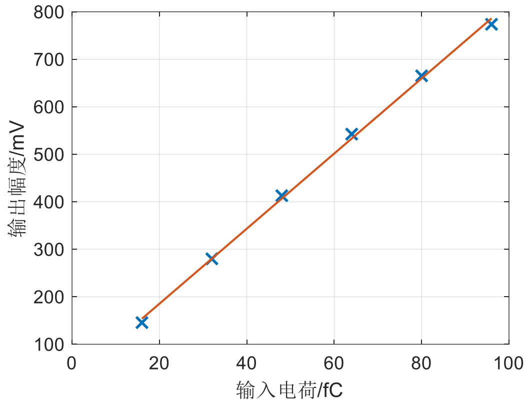
基于ASIC芯片设计制作了1024通道前端电子学



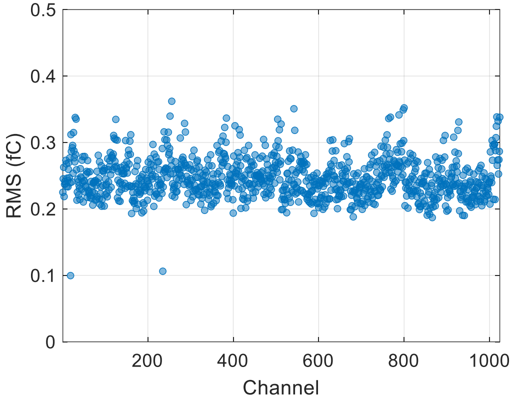


FEE设计

单通道测试与多通道测试，各项指标均满足设计要求

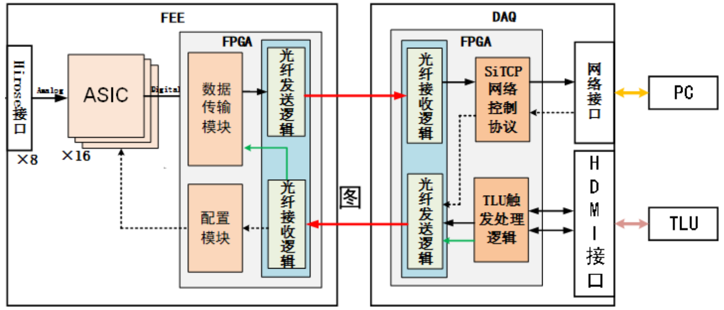


单通道响应曲线

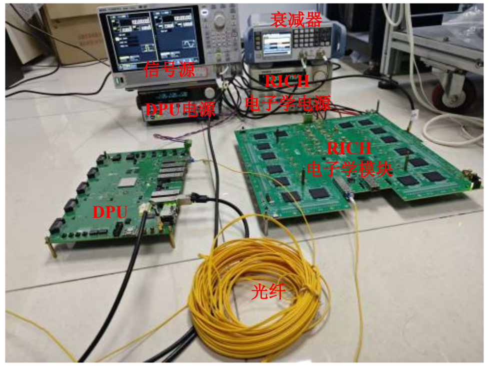


多通道噪声水平

配套后端电子学：使用一块DAQ板处理触发、命令、数据的传输。搭建测试平台

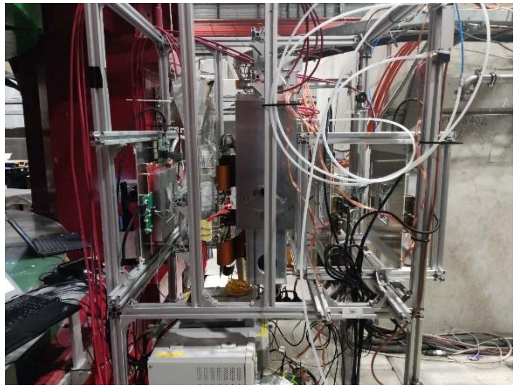


数据传输链路

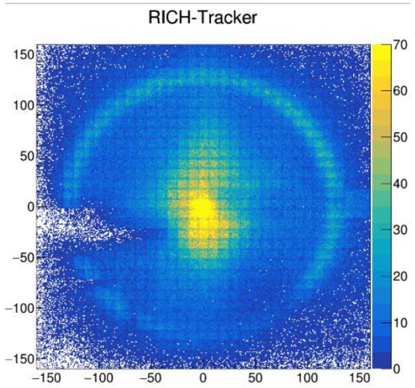


测试平台

参与了与STCF-DAQ系统的联调。与探测器联调并开展了束流实验。发现了问题，后续优化完成。



束流实验中的电子学

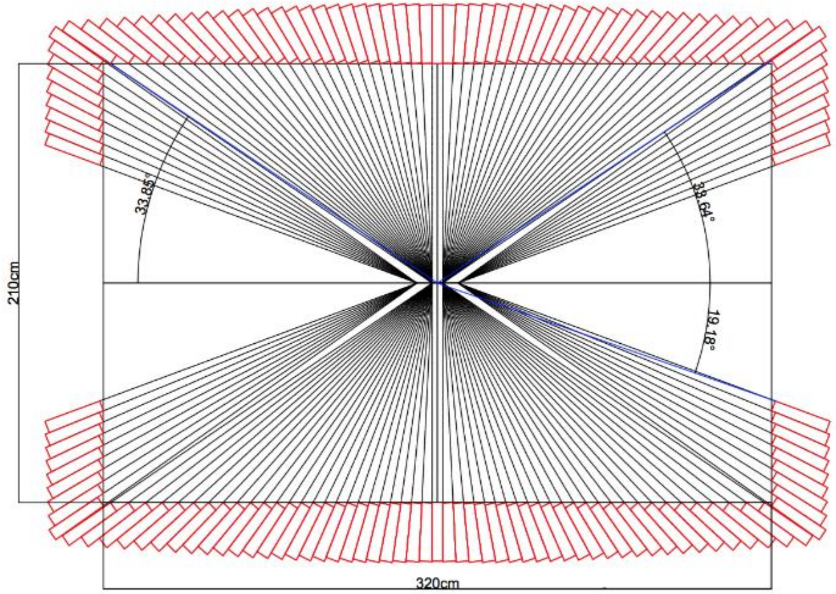


ASIC-FEE束流实验数据

电磁量能器

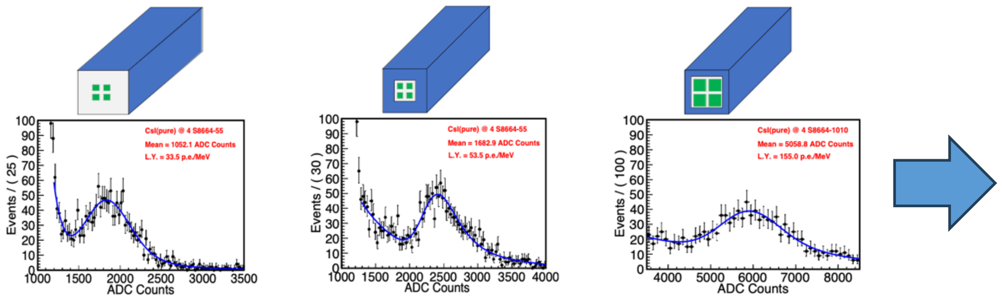
特点：快时间响应，高能量分辨
挑战： CsI光产额，事例堆积及时间提取等

- 采用碘化铯钐晶体（pCsI，发光衰减时间~ 30 ns）搭建晶体量能器，以应对极高本底计数率工况（~ 1 MHz/crystal）
  - 晶体尺寸：28cm ($15X_0$), $5\times5cm^2$
  - 散焦排布方案：桶部晶体 6732 块，端盖晶体 1938 块
  - 配置 4 片雪崩光电二极管（APD）以弥补晶体低光产额短板: $4\times(1\times1cm^2)$



A very low light yield of 3.6% for pCsI

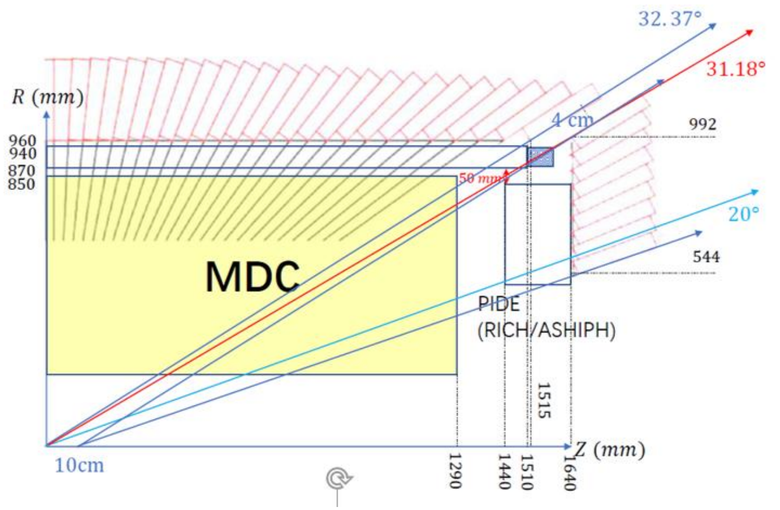
核心研发任务：提升 pCsI 探测单元的光产额。



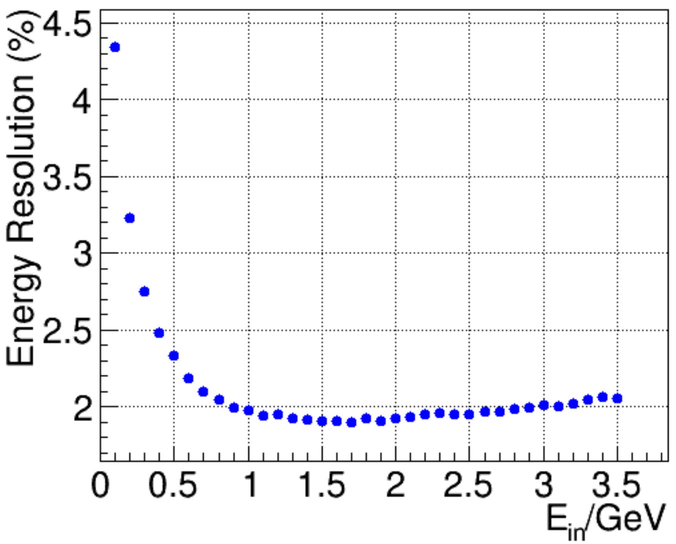
Light yield : 50 p.e./MeV → 300 p.e./MeV

EMC-几何更新

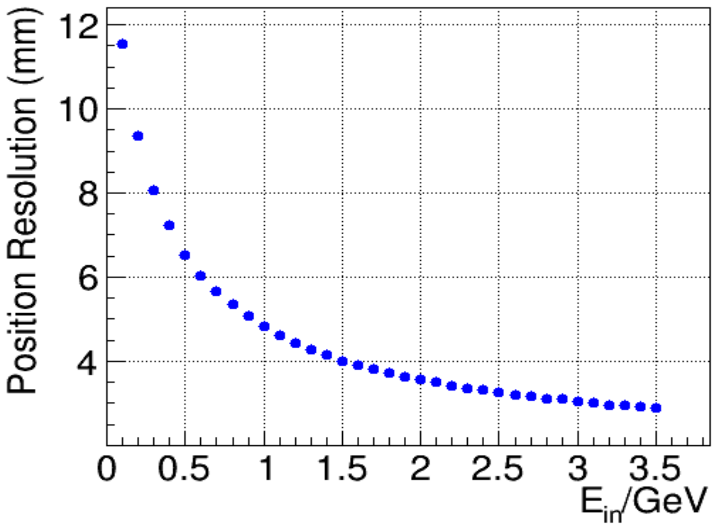
- 几何结构更新汇总
  - 桶部位置：1050 毫米调整为 960 毫米
  - 端盖位置：1600 毫米调整为 1640 毫米
  - 桶部与端盖衔接处预留 4 厘米线缆布线空间
  - 桶部晶体环：新增 2 环，总计 53 环，共 6996 块晶体
  - 端盖：结构无改动，维持 9 环，共 1920 块晶体
  - 整体体积：6.47 立方米，较原设计缩减约 11%



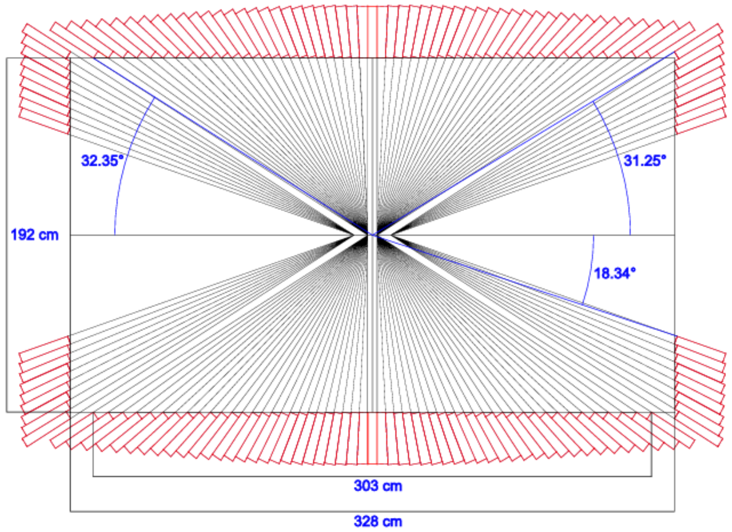
- Simulation performance with the updated geometry
  - Energy resolution: ~2% @ 1 GeV
  - Position resolution: ~5 mm @ 1 GeV



Energy Resolution

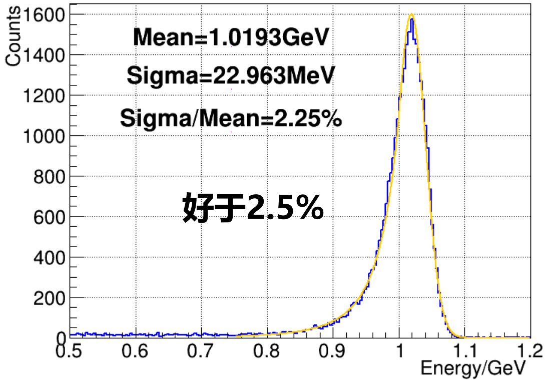


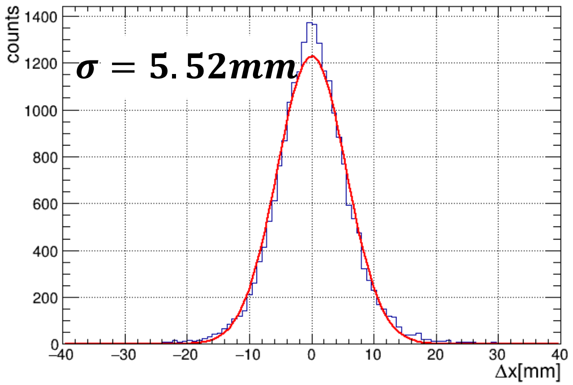
Position Resolution

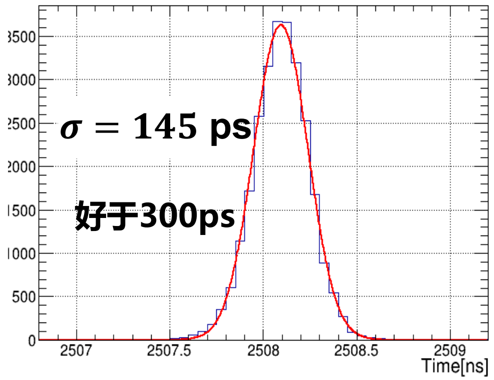


5 × 5 pCsI EMC 束流实验 (2025)

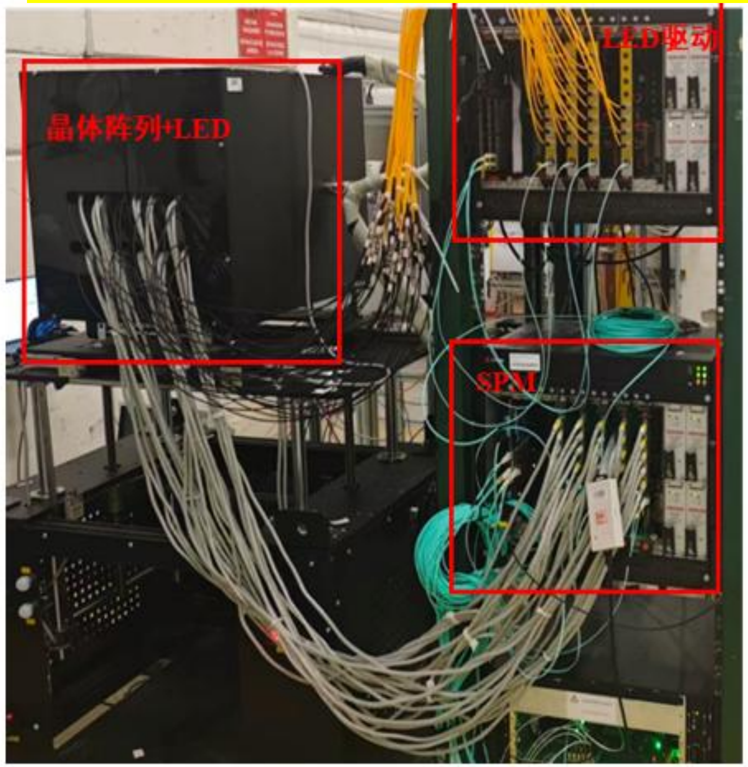
- 相较于 2024 年束流测试:
  - 拓宽电子束能量覆盖区间：0.2–3.5 GeV
  - 采用前沿波形拟合算法，时间分辨率优化至约 150 ps
  - 上线能量、时间实时提取功能，在线计算结果与离线分析结果吻合度良好
  - 开展 LED 光源标定试验，用于模拟束流相关本底噪声



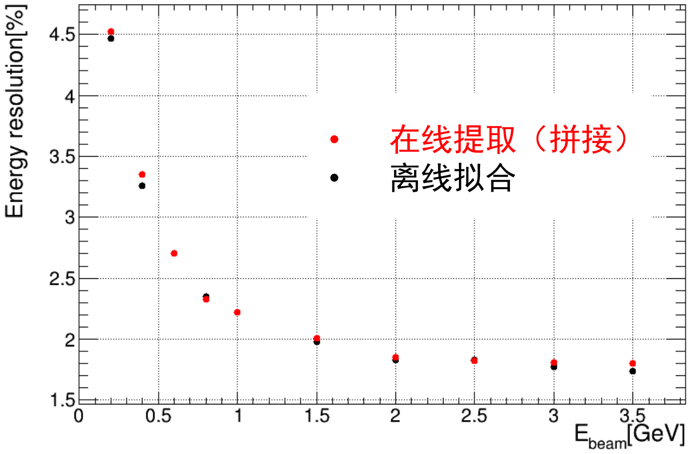


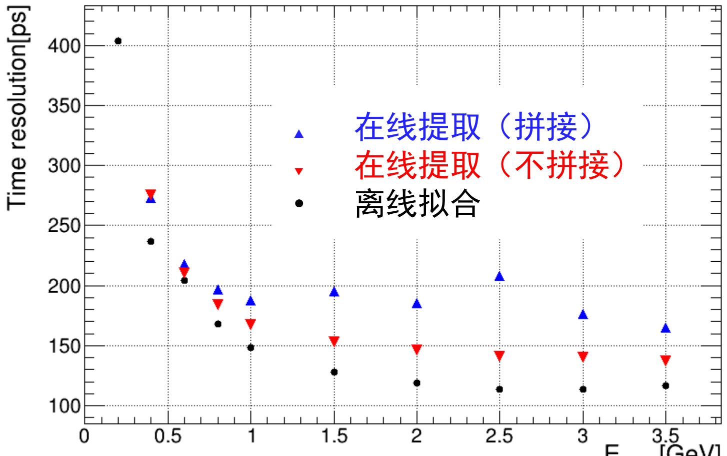


Beam test at CERN PS



Performance form the beam test with 1 GeV/c electrons





MUON 塑闪探测器

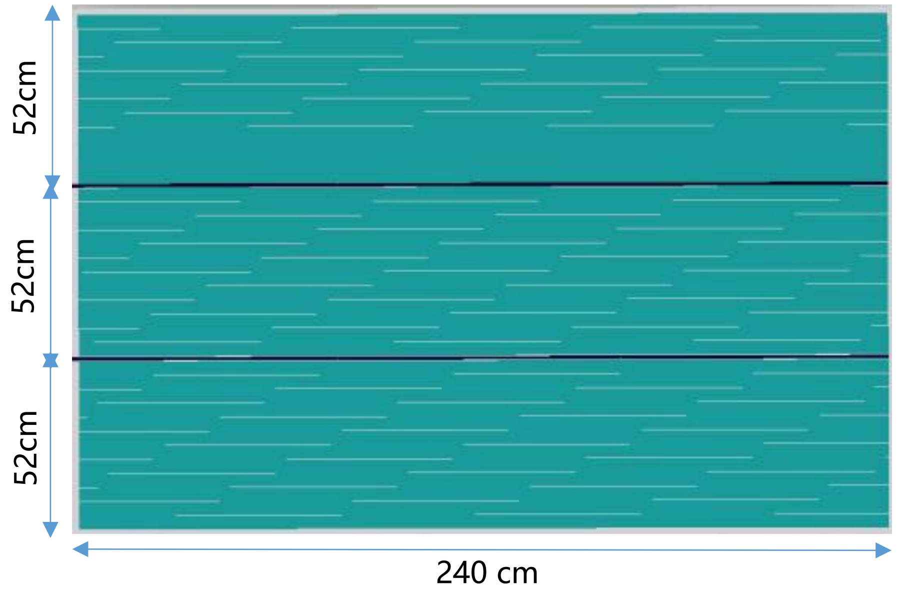
◈ 样机研制和测试：

- ◈ 2.4米 * 0.5米， 双层塑闪条十字交叉
- ◈ 重点验证长塑闪性能、整体封装和机械工艺等

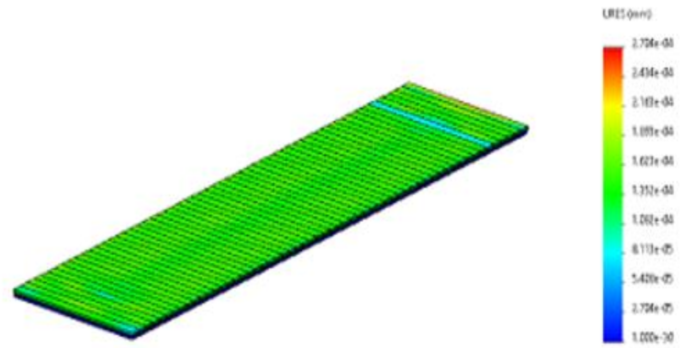
◈ 正在研制

- ◈ 1:1的全尺寸桶部模块，2.4米 * 1.5米
- ◈ 迭代优化模块封装工艺、机械受力等方面设计
- ◈ 开发调试：基于数据库的质量控制系统

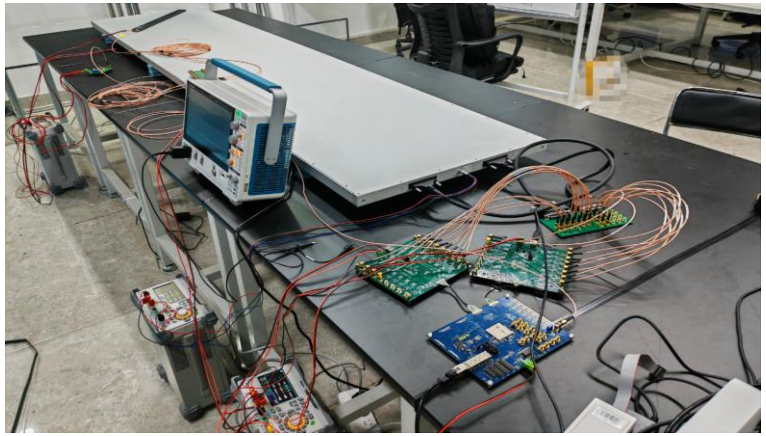
  → 对大批量塑闪条、各元器件品控和质量追踪



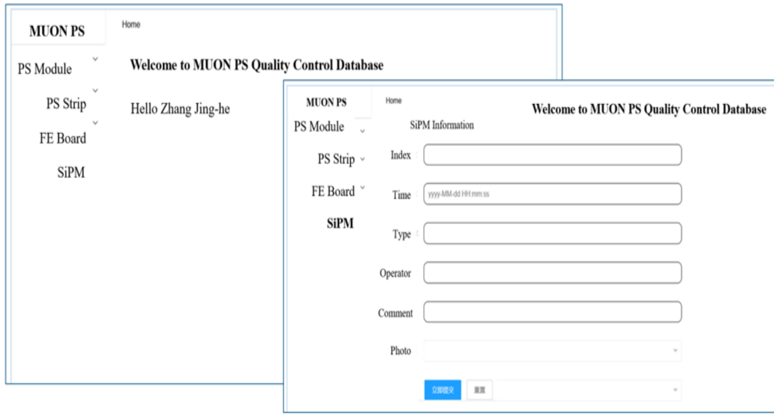
桶部全尺寸模块建模



样机机械受力形变的仿真分析



样机宇宙线实验进行数据采集

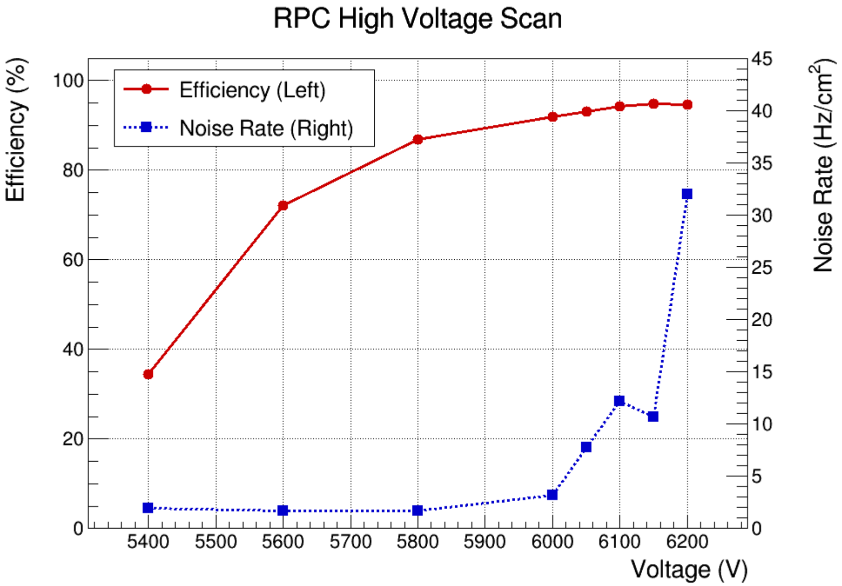


基于数据库的质量控制系统开发

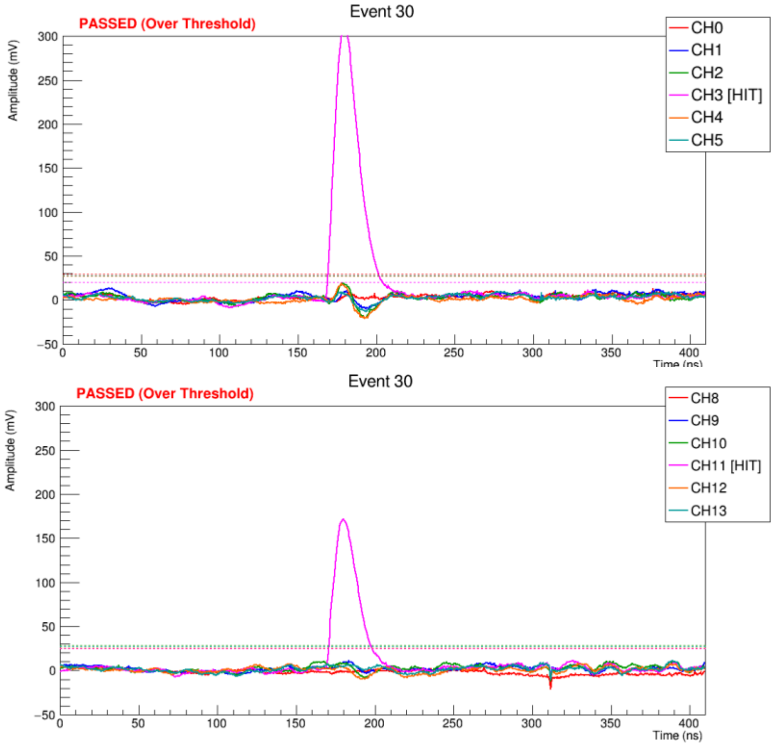
MUON RPC探测器

RPC缪子探测器采用商业低阻玻璃：大面积探测器覆盖的成本
机械稳定、耐空气湿度
高计数率 (>300Hz/cm2)

低阻玻璃RPC原型模块在进行宇宙线测试



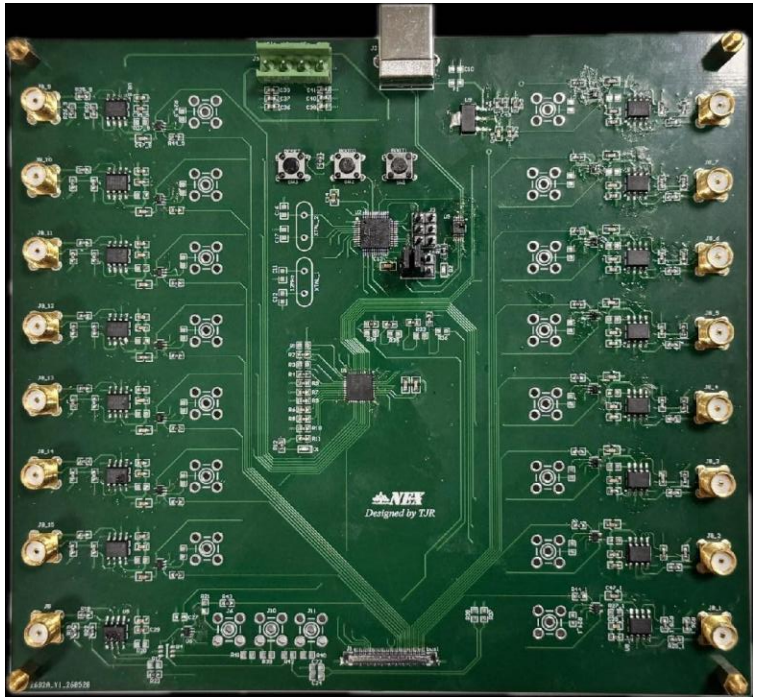
效率和噪声的偏压扫描（优化探测器工作偏压）

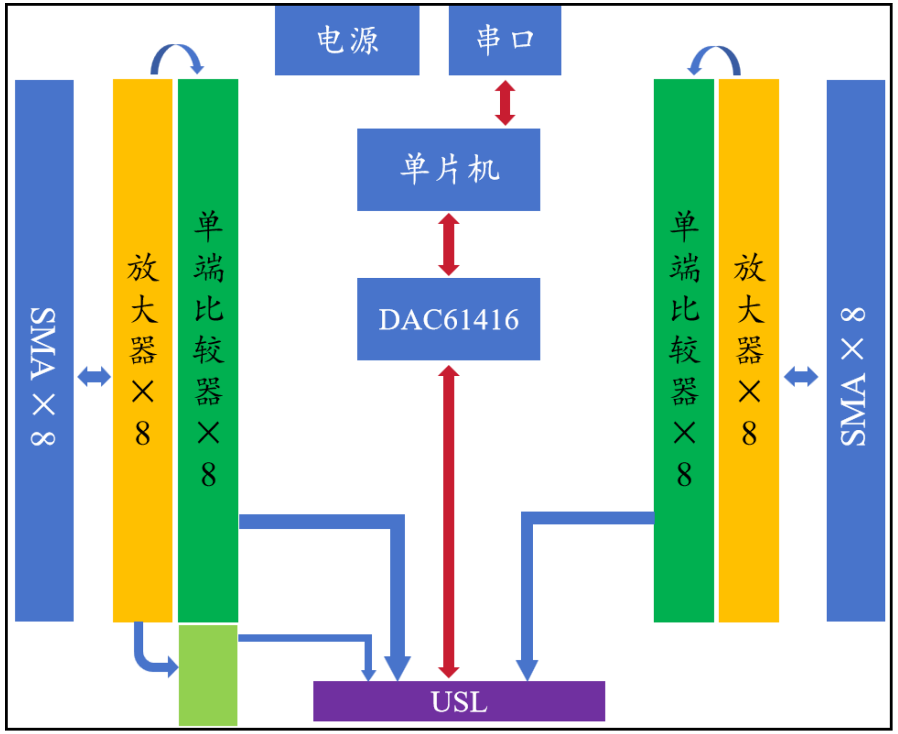


同一触发在上下两个RPC平面上的击中响应

进行中：双端读出电子学的适配
X射线辐照背景下的计数率测试

MUON 板级电子学



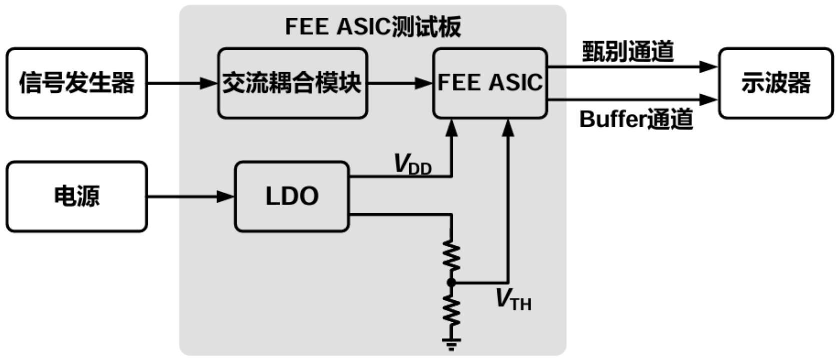


8通道前端板　　16通道前端板　　16通道前端板原理图

板级电子学持续优化设计，提升性能

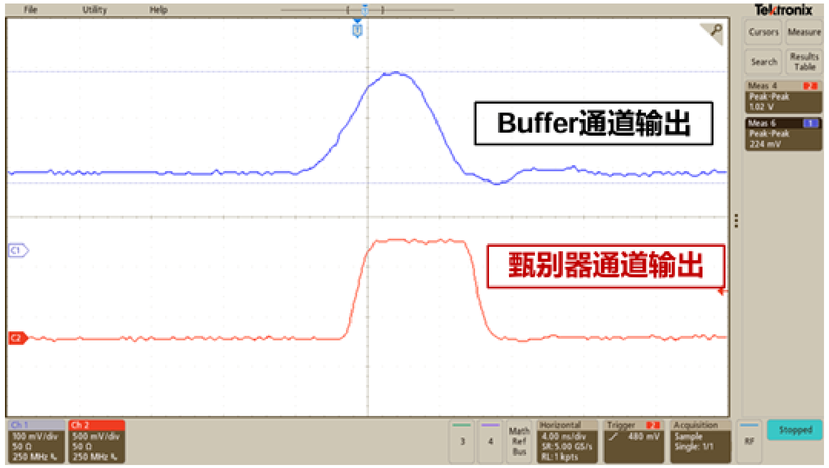
- 使用16通道DAC61416，可以配置负阈值，解决基础阈值过高的问题
- 使用信号发生器测量时，时间分辨率从20多ps提升到10多ps

MUON ASIC测试

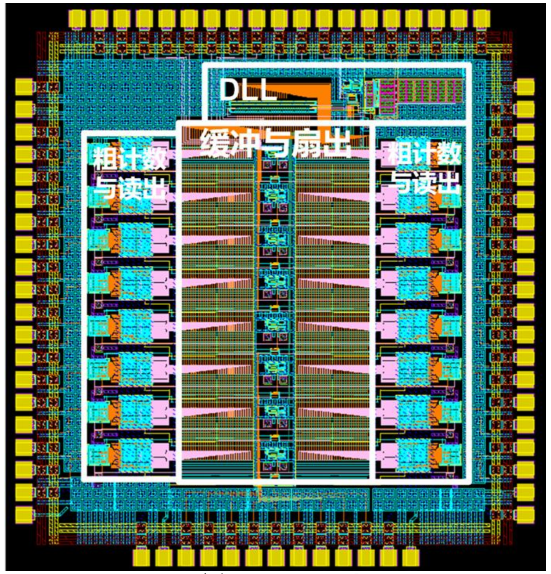


前端ASIC测试系统框图

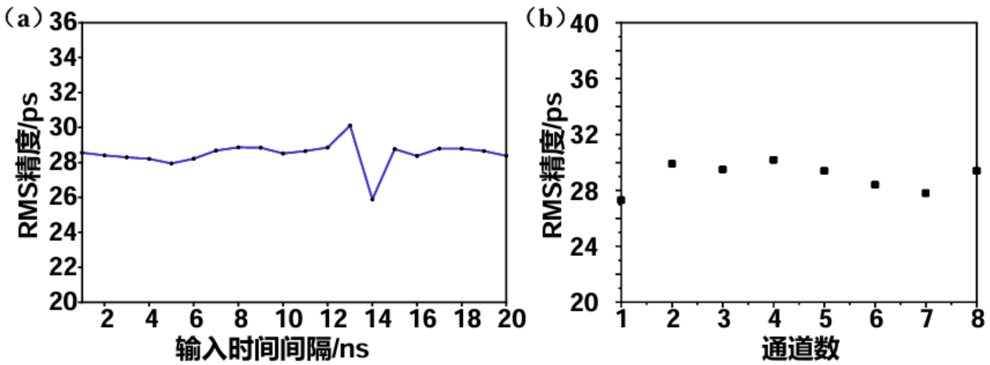
前端ASIC测试板实物图



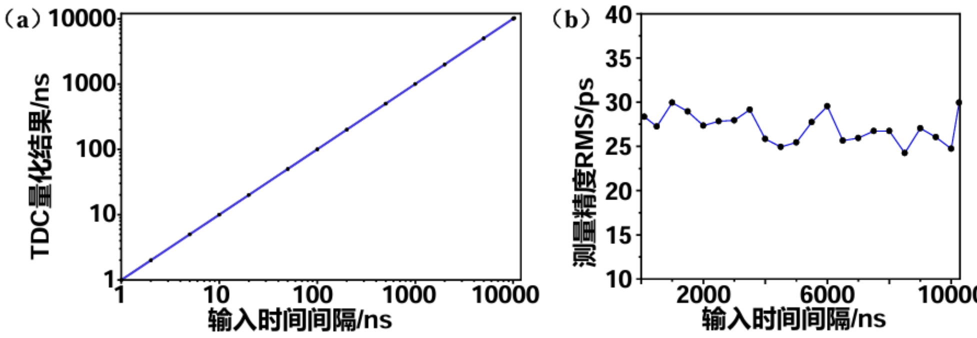
前端ASIC典型测试结果



8通道TDC版图

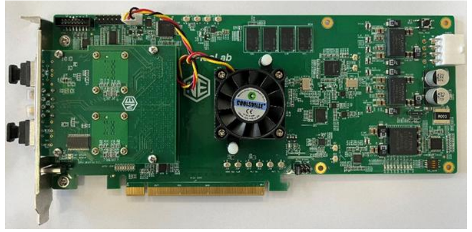


多通道精度RMS测试（约30ps）

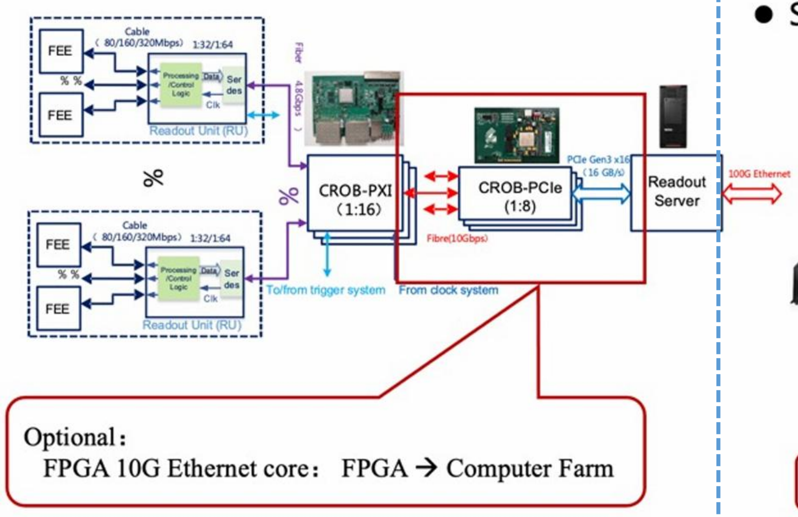


全量程测试(10us)

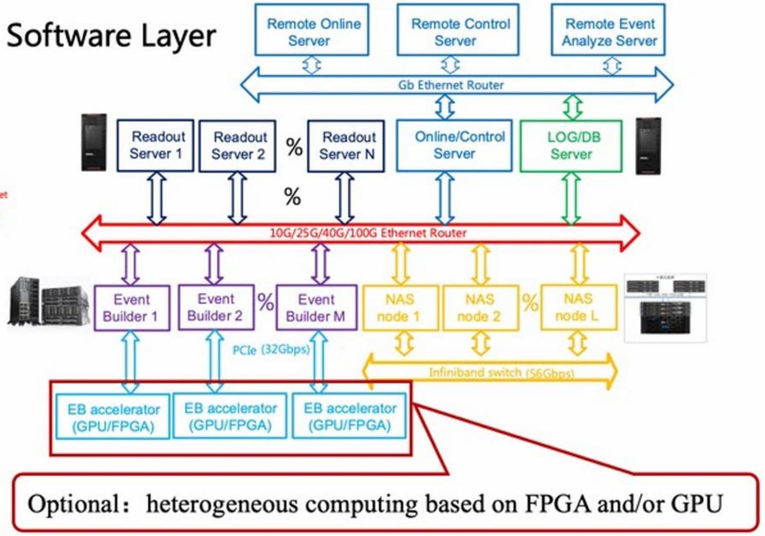
数据获取系统



- FPGA Layer

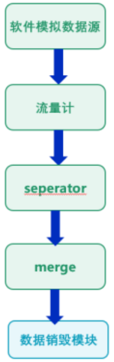


- Software Layer



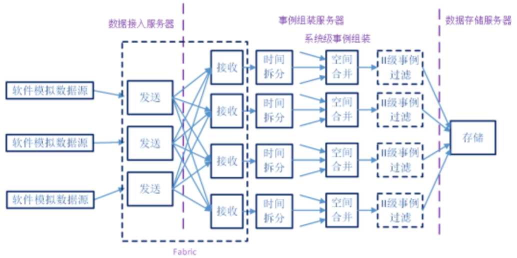
- **所需硬件已经全部就位**
  - **所有CROB板完成批量复制**
  - **CROB-PCIe卡完成机架服务器的安装和电源适配**
  - **完成了操作系统、驱动程序适配和5个服务器规模的测试集群安装**

- **完成链路传输速度测试和软件模拟数据测试**
- **正在进行全系统模拟数据测试**



单节点软件模拟数据测试

链路传输速度测试

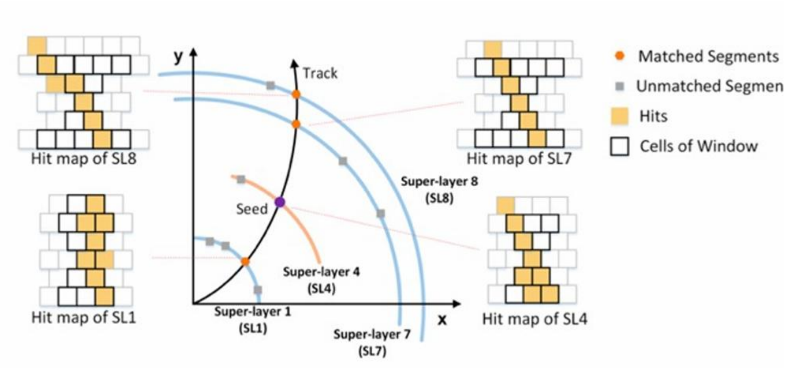


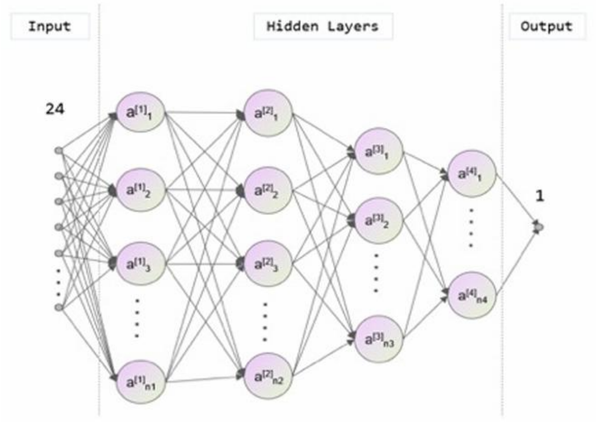
多节点软件模拟数据测试

*详细测试结果参见DACQ部分报告

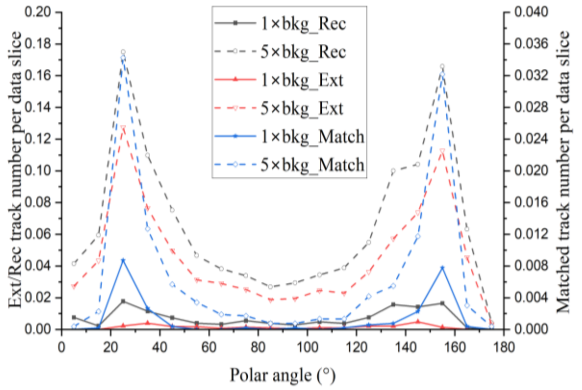
Trigger：触发算法研究

- STCF触发架构：一级触发 L1 (MDC, ECAL and global trigger) +高层触发 HLT；
- L1-MDC 触发架构: 基于模式匹配实现二维径迹重建(寻迹参数pt, θ, φ, t), 依托神经网络完成二维短径迹重建及估算碰撞顶点Z；
- L1-ECAL触发架构: 重叠事例分离、能量簇团重建与簇团拆分，输出簇团物理参数(E, θ, φ, t)
- L1 全局触发:完成径迹-能量簇团匹配、事例初始时刻T0估计, 提供带电道、中性道两类触发
- HLT高层触发: 正在开展漂移室高层触发，目标剔除噪声击中信号、压缩事例数据量。



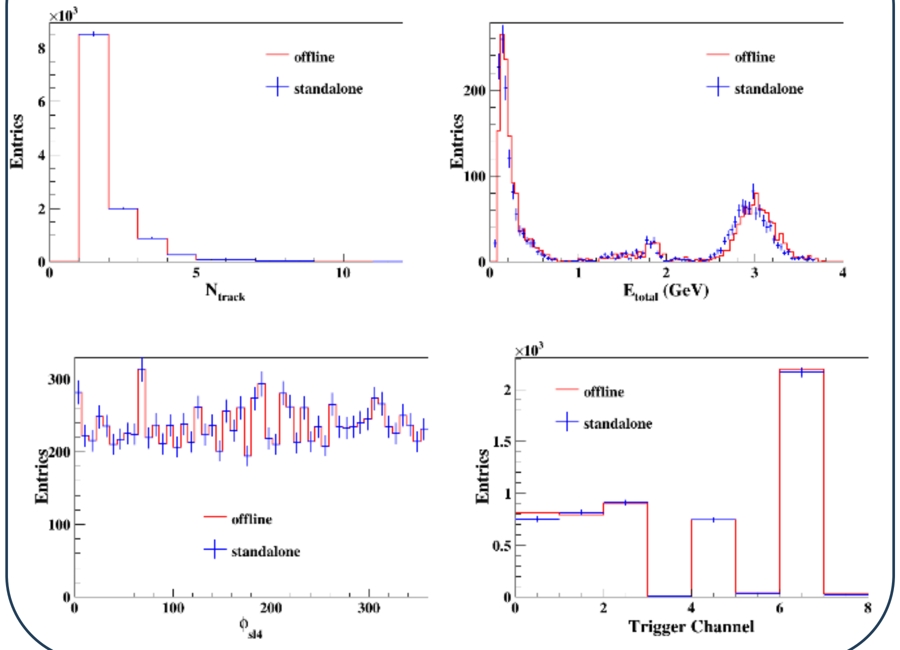


L1 GTL 优化



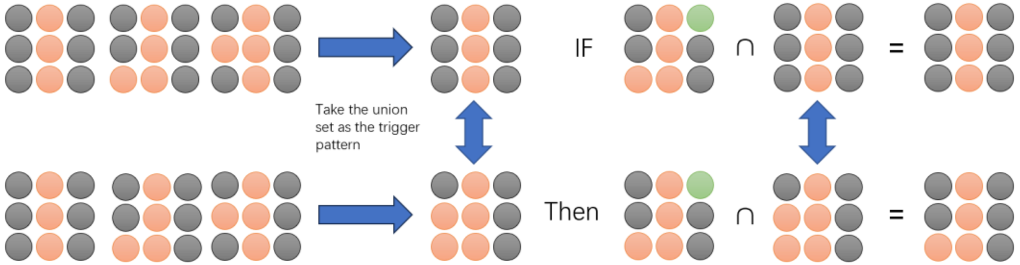
- Charged channels: ~20% reduction
- Neutral channels: ~30% reduction
- Total: ~25% reduction at 1–5×bkg

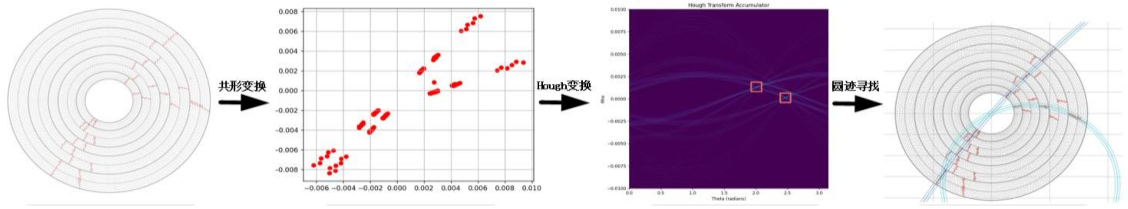
触发算法植入OSCAR框架



Trigger: HLT 基于MDC的算法开发

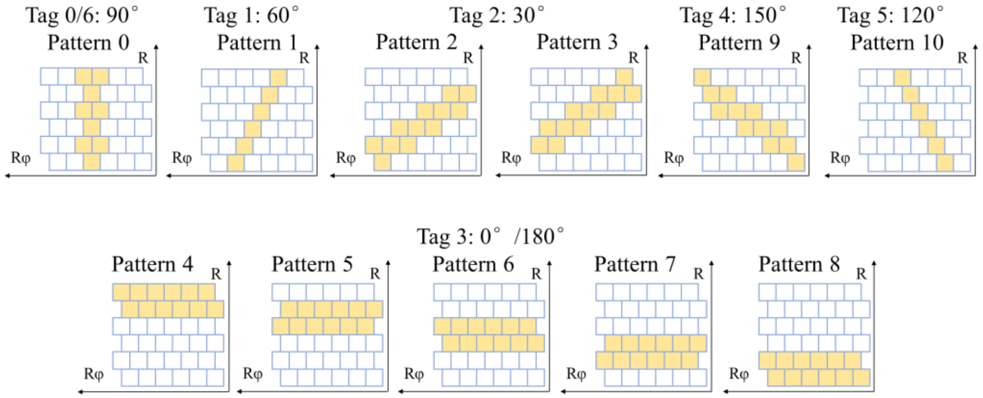
◇ Route 1:混合模式匹配 - 霍夫变换算法

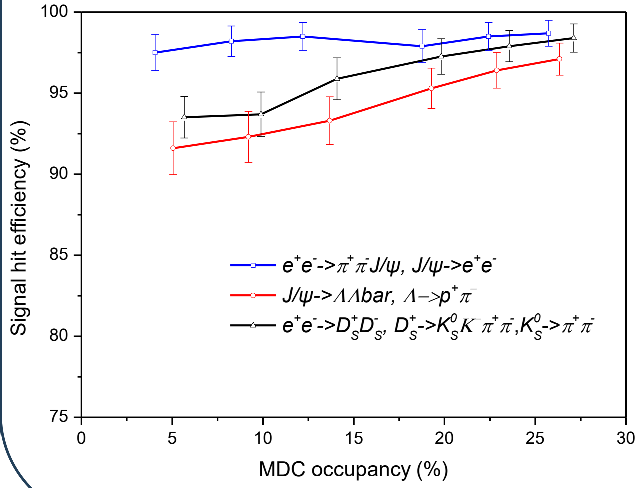


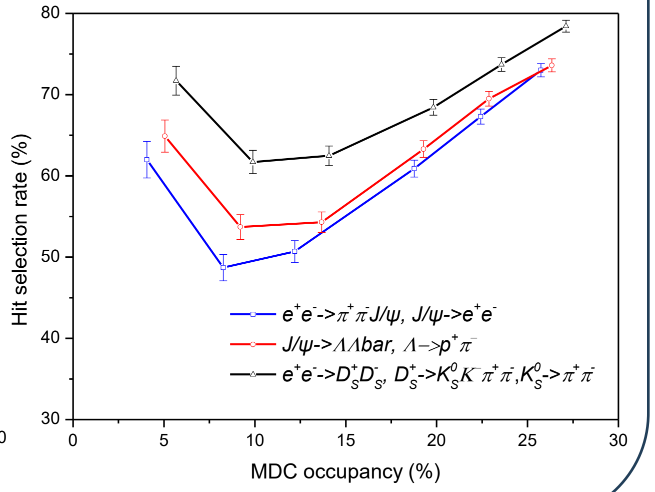


通道编号	物理分析道	数据压缩率	信号留存率
Channel 1	$e^+e^- \to K^+K^-J/\psi$ $J/\psi \to l^+l^-$	0.494	0.912
Channel 2	$J/\psi \to \Lambda\bar{\Lambda}$	0.469	0.831
Channel 3	$e^+e^- \to \tau^+\tau^-$	0.387	0.966
Channel 4	$e^+e^- \to \pi^+\pi^-J/\psi$ $J/\psi \to e^+e^-$	0.495	0.960
Channel 5	$e^+e^- \to \pi^+\pi^-J/\psi$ $J/\psi \to \mu^+\mu^-$	0.496	0.967

◇ Route 2:面向高本底环境、基于11种模板的深度优先搜索径迹重建算法







Trigger: 硬件开发

◈ **Trigger Board Design Finalization & Replication**

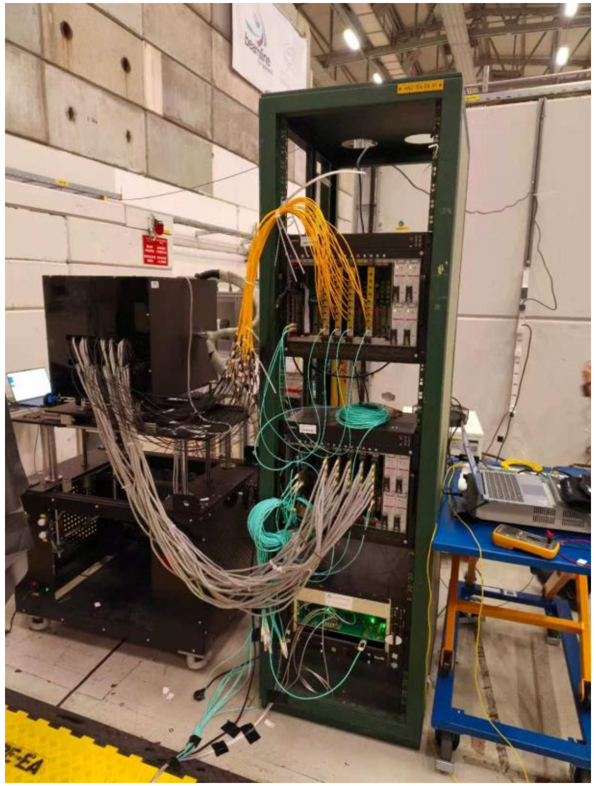
CROB-LTU board

DAQ board

FMC+ sub board

CTM board

◈ **L1-Trig in CERN Beam Test**

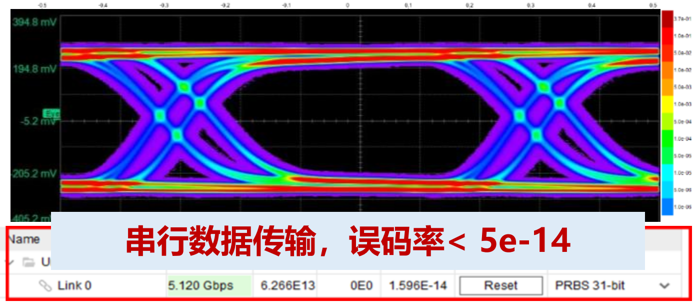


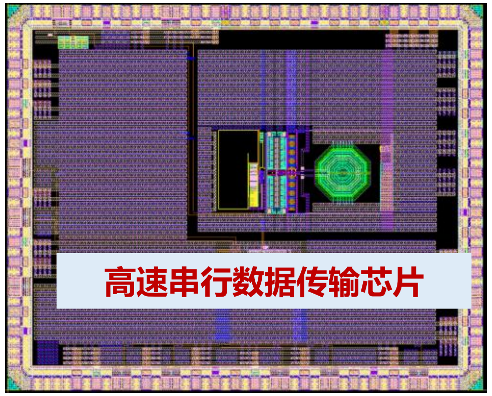
◈ **Hardware Algorithm Test on the L1-Trig Prototype**

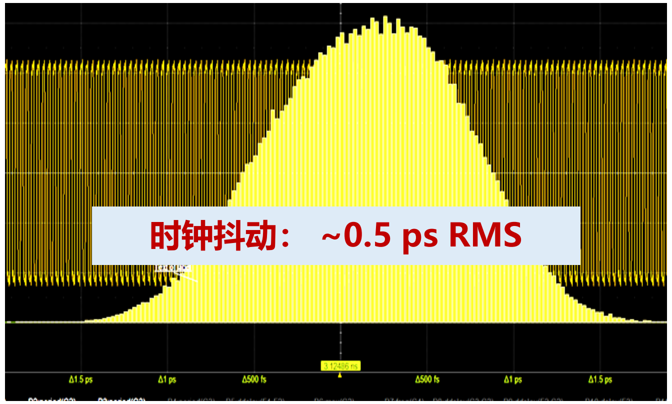
时钟分发系统 CLDT

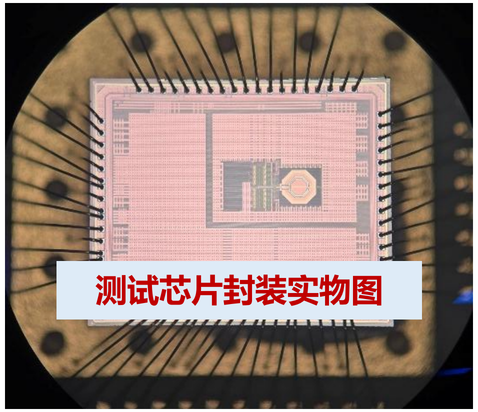
高速串行数据传输ASIC

- 完成第一版关键电路模块的设计、性能测试
- 误码率： < 5e-14（指标要求 < 1e-12）
- 时钟抖动：~0.5 ps RMS (<1 ps RMS)
- 抗辐照性能测试，TID耐受 > 100 Mrad



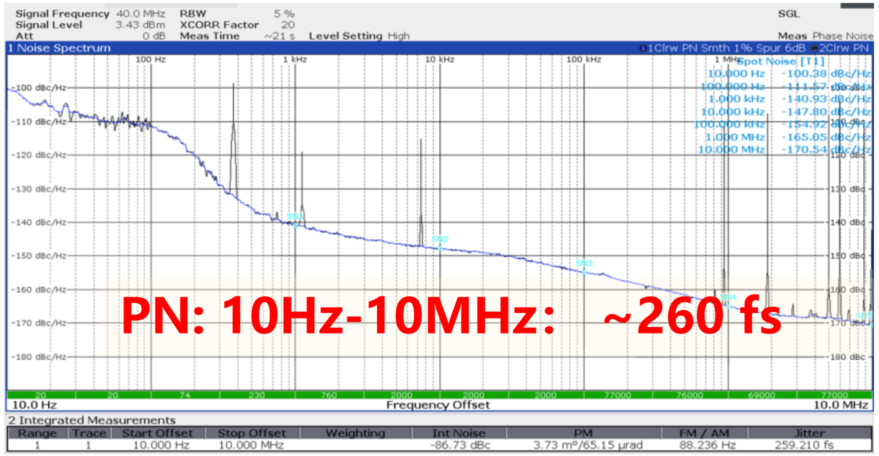






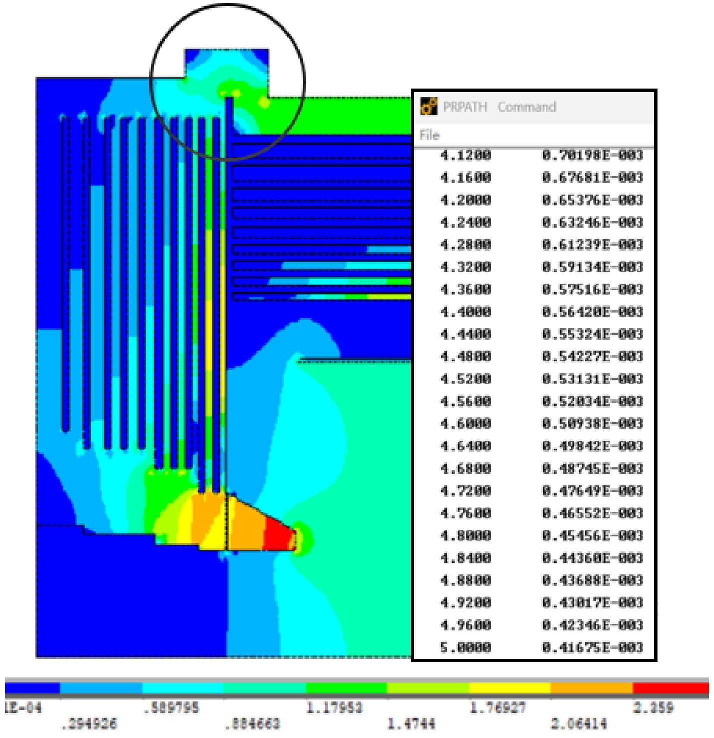
时钟分发系统

- 完成第一版时钟分发系统硬件设计、测试、性能评估
- 时钟周期抖动好于设计指标260fs（< 5 ps RMS）
- 已完成2025年CERN束流实验



磁铁系统

超导磁体的漏磁仿真

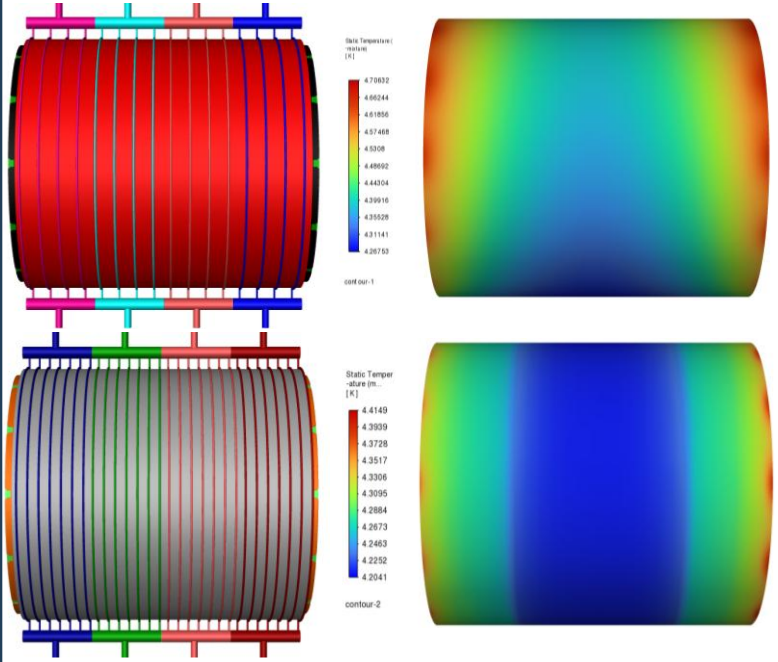


4.1200	0.70198E-003
4.1600	0.67681E-003
4.2000	0.65376E-003
4.2400	0.63246E-003
4.2800	0.61239E-003
4.3200	0.59134E-003
4.3600	0.57516E-003
4.4000	0.56420E-003
4.4400	0.55324E-003
4.4800	0.54227E-003
4.5200	0.53131E-003
4.5600	0.52034E-003
4.6000	0.50938E-003
4.6400	0.49842E-003
4.6800	0.48745E-003
4.7200	0.47649E-003
4.7600	0.46552E-003
4.8000	0.45456E-003
4.8400	0.44360E-003
4.8800	0.43688E-003
4.9200	0.43017E-003
4.9600	0.42346E-003
5.0000	0.41675E-003

轭铁全封闭桥式连接结构的仿真结果

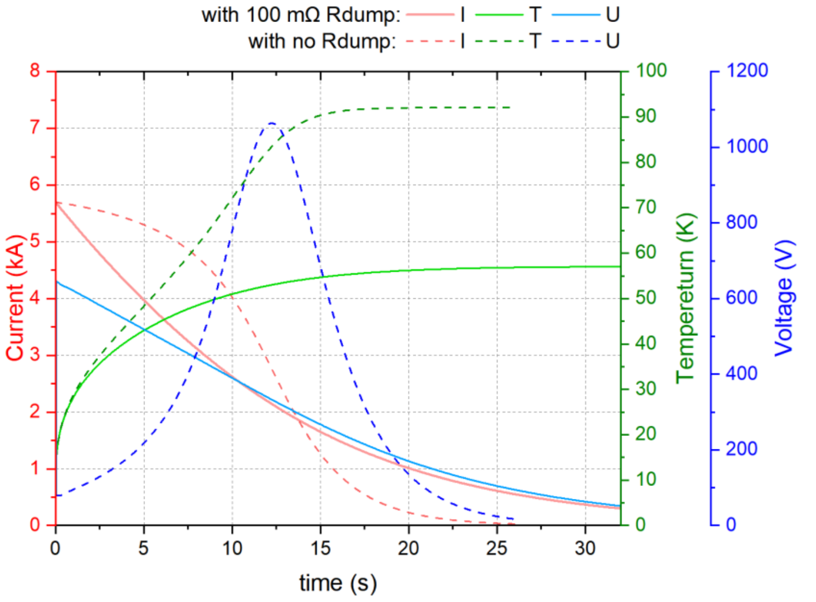
- 满足加速器对漏磁场的要求
- 8 Gs @距离 IP 4.5 m处(<10 Gs)

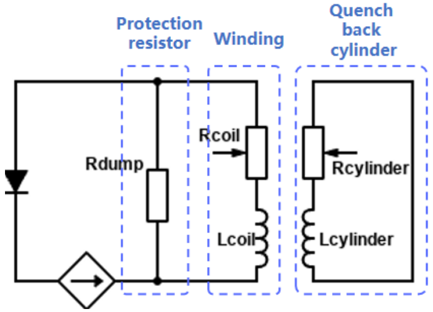
液氦冷却超导磁体仿真



- 满足超导磁体低温的要求
- 热虹吸管之间的最佳间距为100~150mm

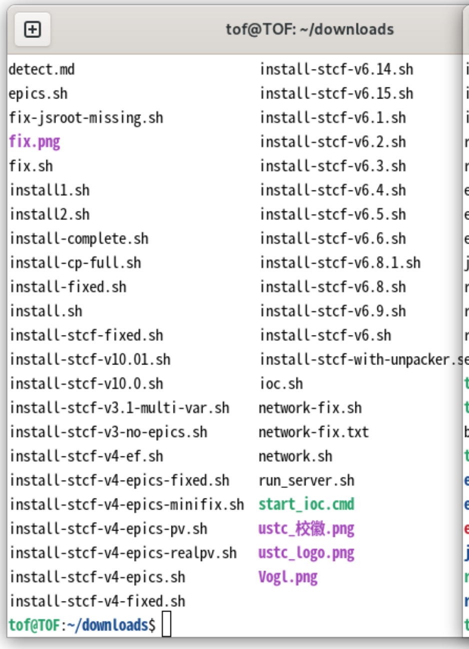
失超保护回路设计



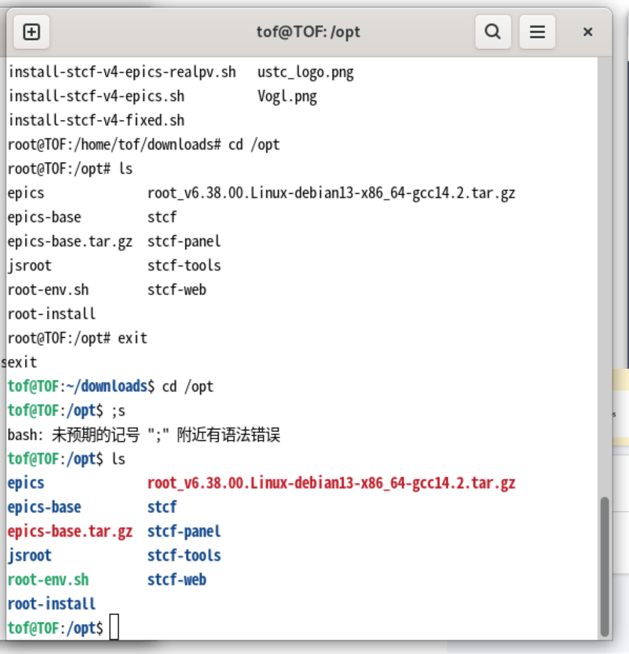


- 失超后的内部电压和温升合理可控

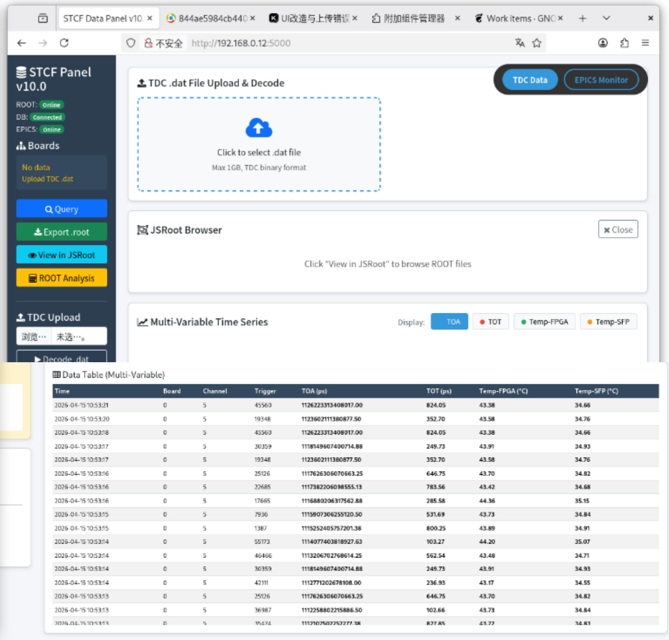
DCSS-全自动安装与一键启动、DAQ&DCS联测



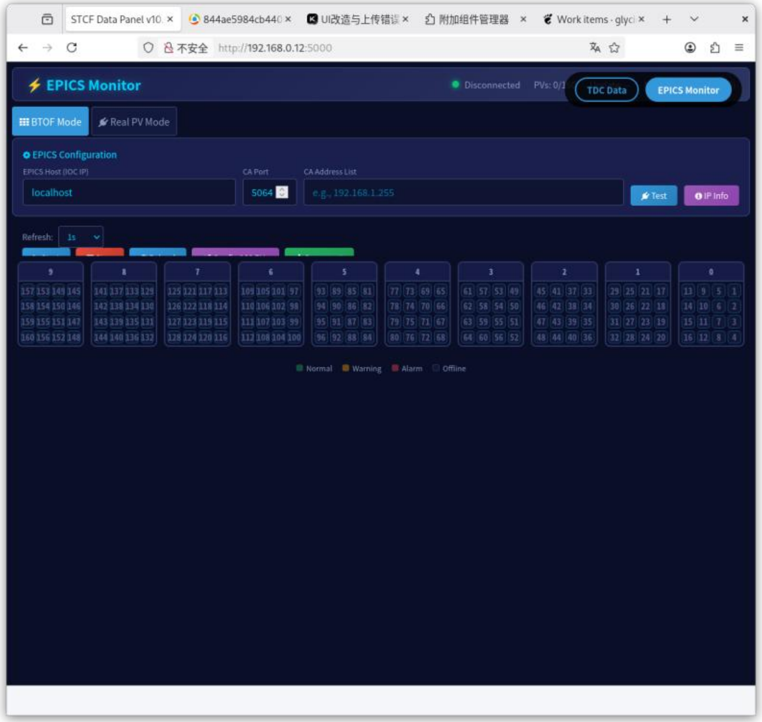
安装脚本



安装目录



可视化启动\过往数据展示界面

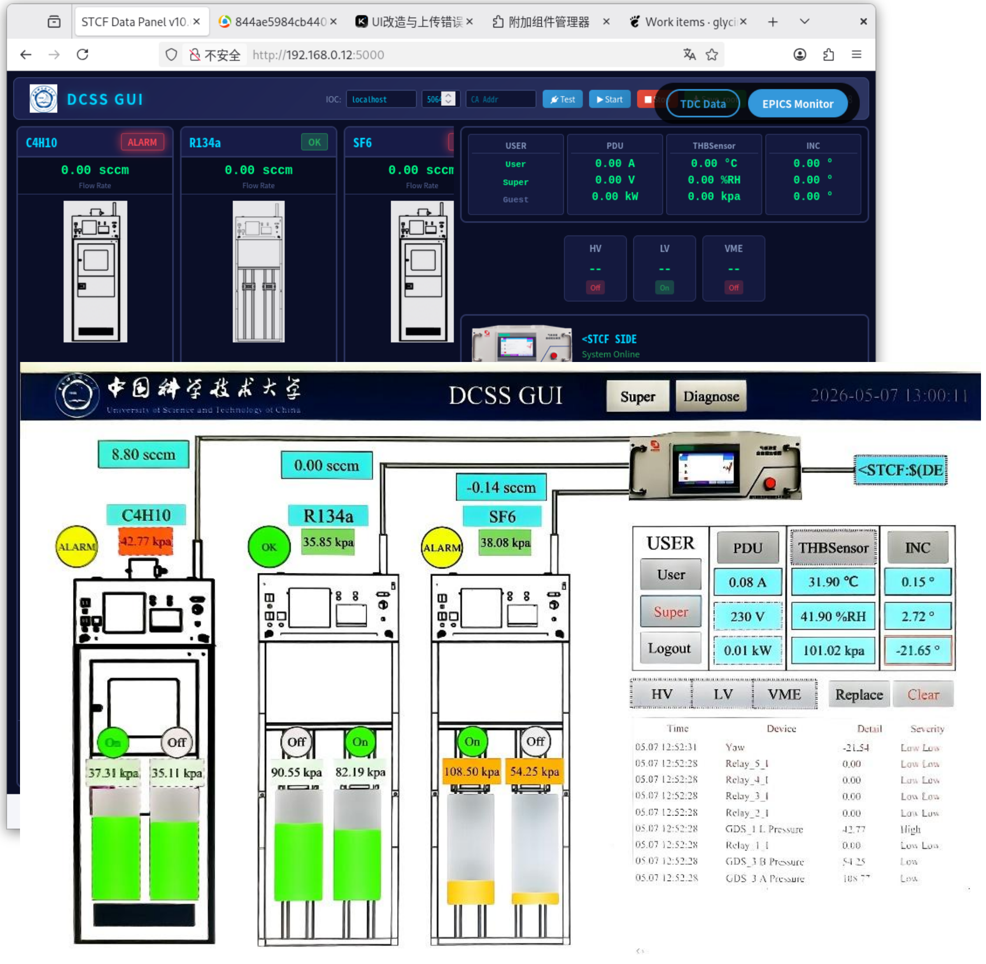


DTOF DAQ与DCS联控界面

- **实现了控制系统软件一件安装的多个版本的迭代**
- **借助DTOF实现了DCS与DAQ的联调测试**

机械控制与集成供气系统优化

实现了EPICS对三菱、西门子PLC的运动控制



实现集成供气系统从phobus到web界面的升级

总结

- 项目整体及各子探测器、配套系统均取得大量阶段性成果，部分子探测器已完成大型工程样机研制。
- 去年 10 月已在欧洲核子中心完成电磁量能器 (EMC)+ 桶形飞行时间探测器 (BTOF)+ 环成像切伦科夫探测器 (RICH)+ 时钟系统 + 触发系统 + 数据获取系统 (DAQ) 一体化集成系统束流测试。
- 基于全流程仿真完成了探测器性能评估，各项指标均可满足物理设计需求；
- 多个子探测器依托仿真完成迭代优化，其余探测器的仿真优化工作仍在持续开展，以进一步提升整机探测性能。
- STCF 探测器技术设计报告（TDR）编制工作正在推进。