中科大探测器技术研究现状

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中国科学技术大学

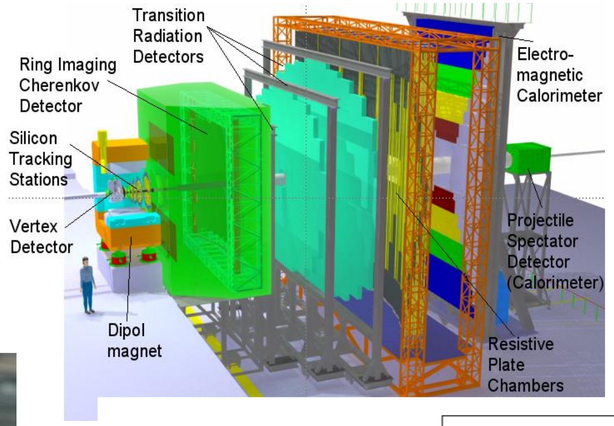
测试束流与先进探测技术研讨会
郑州 登封
2025年8月15日

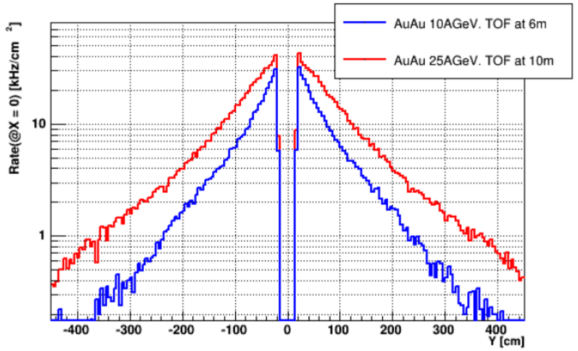
目前在开展的研究工作

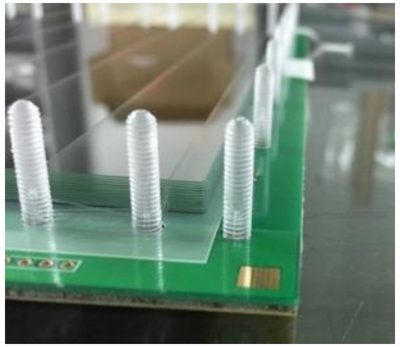
- 气体探测器
  - MRPC、RPC：高时间分辨、高计数率
  - MPGD： 大面积、高计数率、其他特殊需求
  - 超快气体探测器
- 半导体探测器
  - LGAD超快探测器
  - MAPS像素探测器
- 量能器
  - 晶体量能器
  - 成像型量能器
- 契伦科夫探测器
  - RICH探测器
  - DIRC探测器
- 光电探测
  - 大动态范围光电探测
  - 半导体、真空型光电器件
  - 气体光电探测器
- 低本底探测器
  - 液氙TPC
  - 高气压TPC
  - 深冷低温量热器
- 新兴探测器（融合量子精密测量技术）
- 应用与交叉
  - 射线成像、放射医疗、超低本底αβ检测
  - 粒子束交叉应用

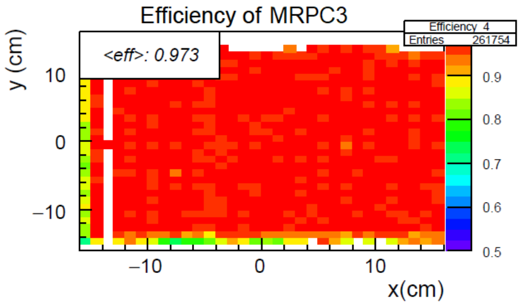
CBM-TOF：薄浮法玻璃MRPC

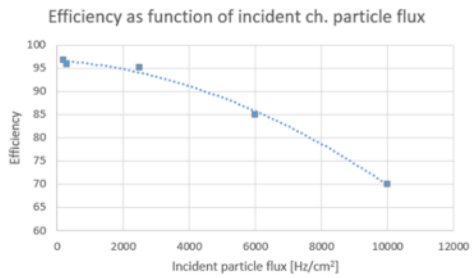
- High rate @CBM TOF as a fixed target heavy iron experiment
  - Coverage: ~ 120 m^2
  - Rate: 1-25 kHz/cm^2
- Thin float glass MRPC is a cost-effective solution for the TOF wall outer region (rate ~ 1 kHz/cm^2)
- challenges
  - Glass thickness: 0.23 mm
  - Detector size: 377x324mm (MRPC3), 377x588mm (MRPC3)
  - Rate capability: 2 kHz/cm^2
- 80 MRPC3 produced and installed for STAR e-TOF as pre-production

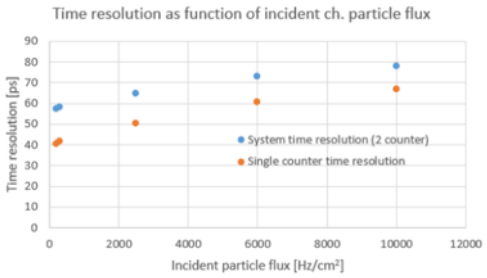


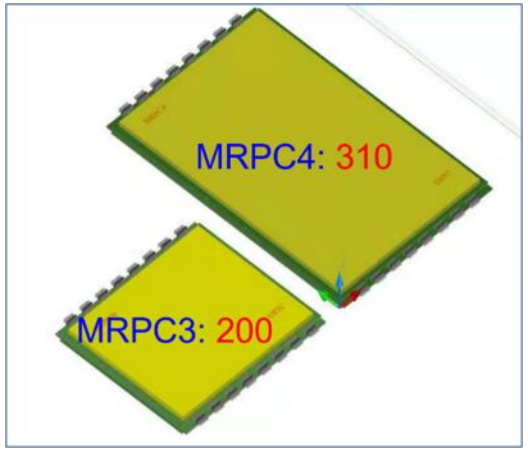








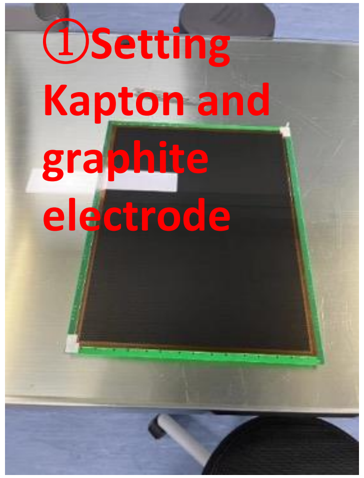


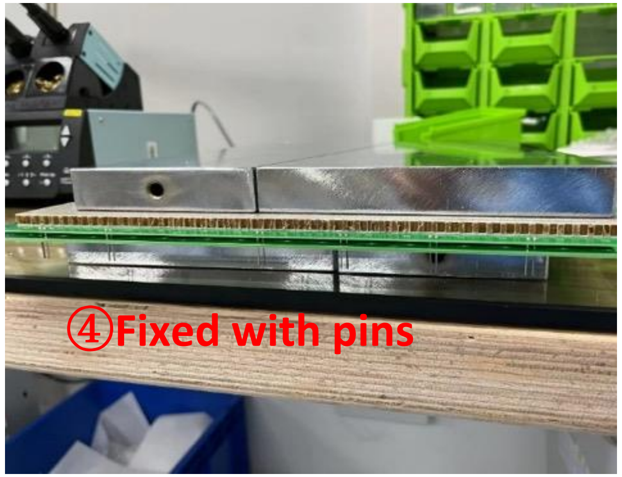


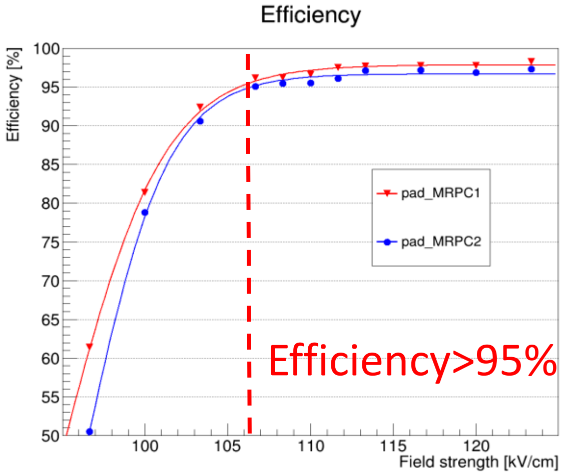
		MRPC 3	MRPC 4
Glass	Type	ultra-thin float	
	Size	353 x 276 x 0.23 mm	353 x 540 x 0.23 mm
Gaps	Size	0.230 mm	
	Number	5 x 2	
Readout strips		(0.7 cm + 0.3 cm) x 32, double-end strip	
Impedance		50 Ω differential signal to PADI	
Active area		320 mm × 270 mm	320 mm × 540 mm
Detector size		377 ×324 mm	377 × 588 mm
Total Amount		200	310

MRPC：鱼线->垫片

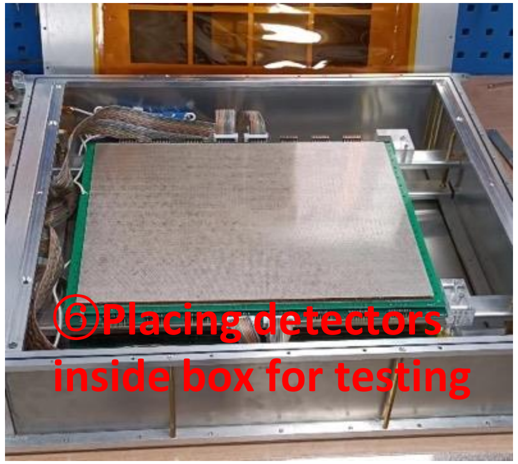
- Good candidate for CBM TOF
- Have a better anti-aging effect under high flux.

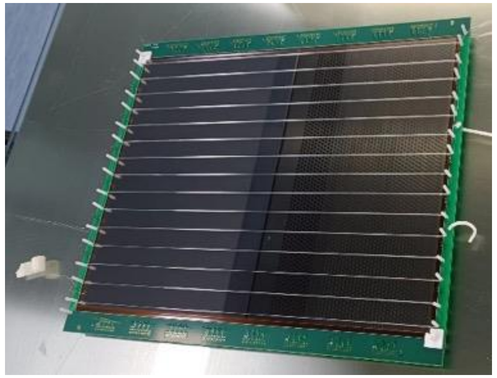




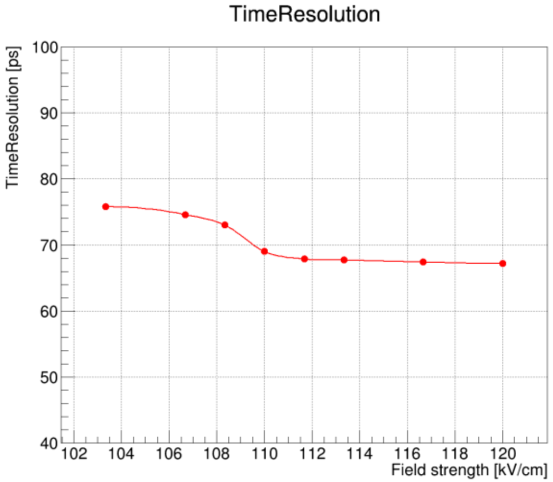


⑤Upper stack with 5 layers spacers





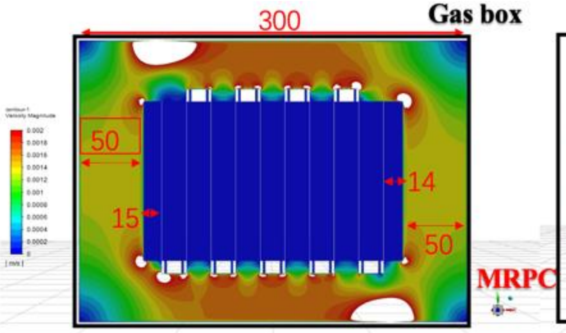
Fishline spacer MRPC



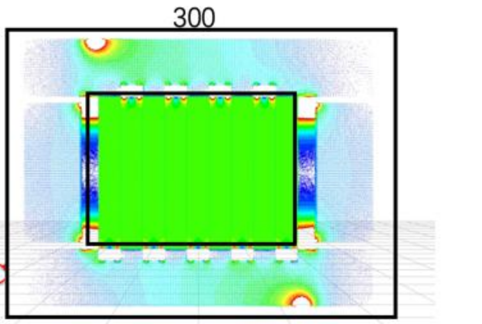
CEE：高时间分辨MRPC

- Reduce gap thickness
- More gaps
- Improve the time resolution of electronics
- Choose a good working gas

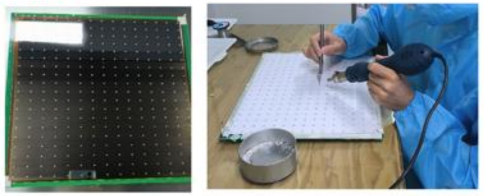
- 4×6 gaps
- 0.16mm gap width
- NINO FEE + FPGA TDC
- 30 ps time resolution achieved (20 ps reported, with Waveform sampling readout)



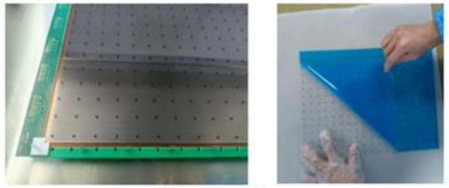
Fraction of gas flux inside MRPC gas gaps: 0.48%



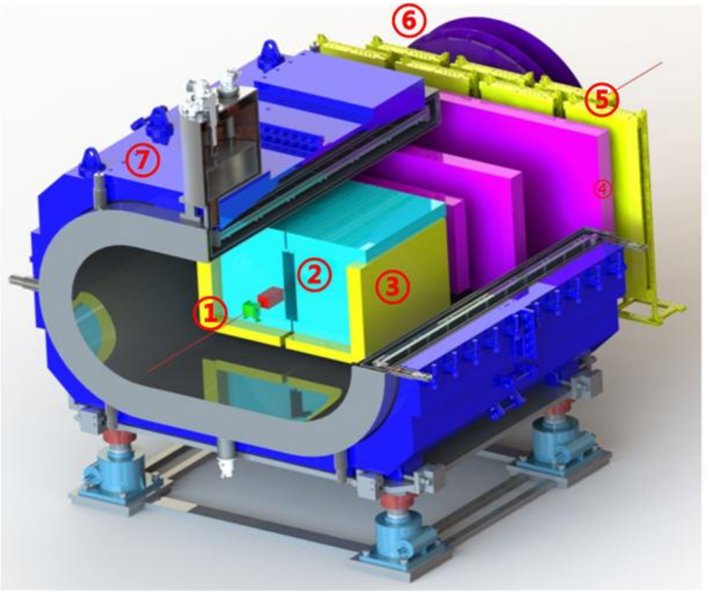
Fraction of gas flux inside MRPC gas gaps: 42.5% Can be further improved



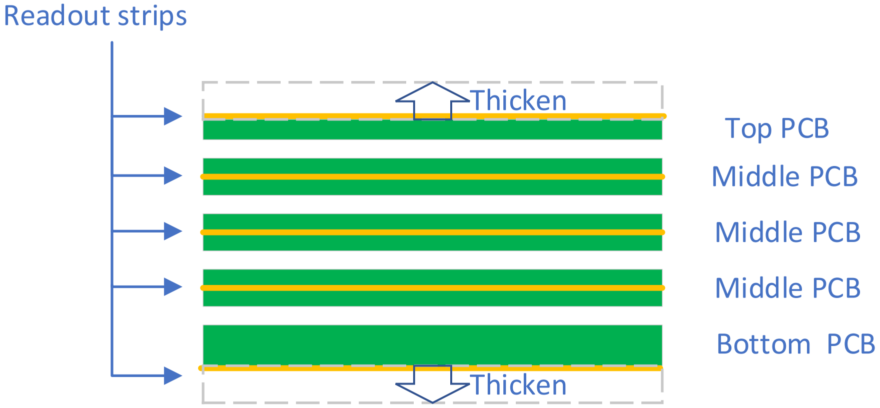
Thermal bonding spacer (TBS)



Mylar pad spacer

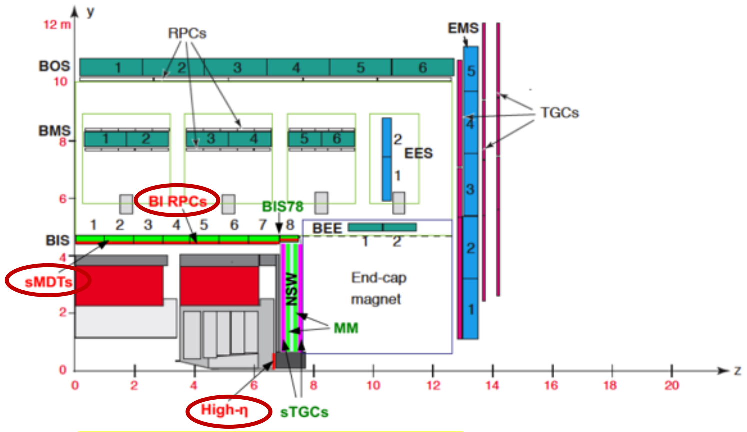


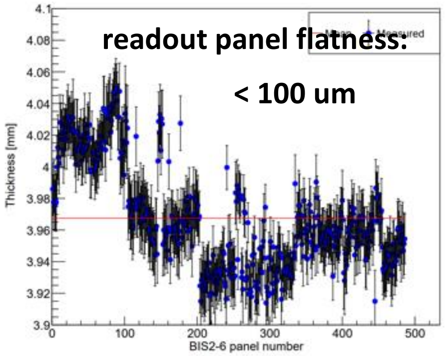
1. T0
2. TPC
3. iTOF
4. MWDC
5. eTOF
6. ZDC
7. Dipole magnet

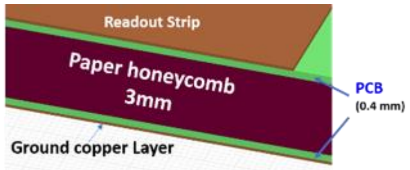


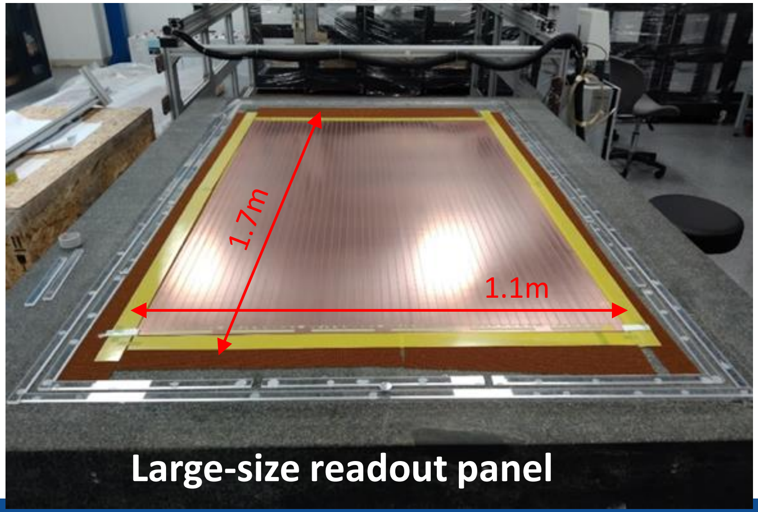
ATLAS二期升级：窄气隙电木RPC

- 3 layers of thin-gap RPC to be installed in ATLAS Barrel Inner region during LS3 with rate capability up to 1 kHz/cm^2
- Tasks undertaken by ATLAS Chinese cluster
  - ~ 900 BIS/BIL/BOM/BOR read-out panels will be produced and qualified
  - ~70 gas gap will be produced and qualified
  - ~360 singlets assembly carried out in China
  - Full production chain of thin-gap RPC

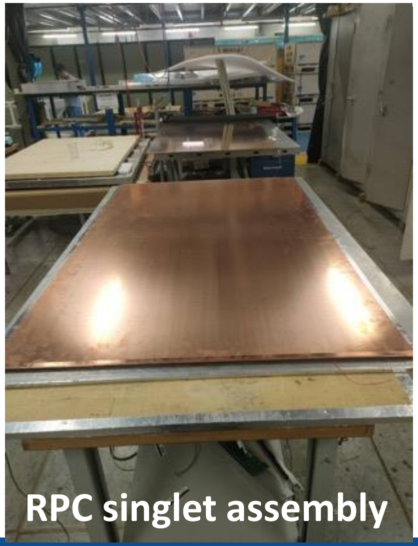


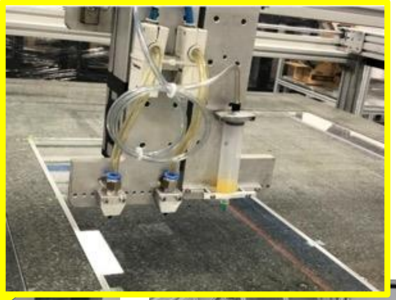


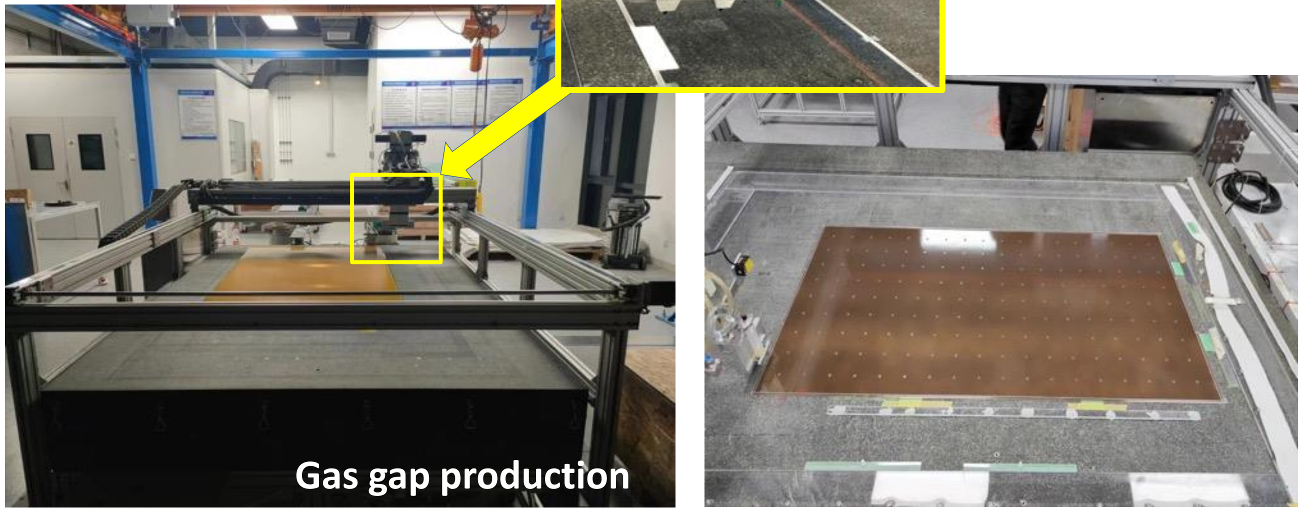




Large-size readout panel

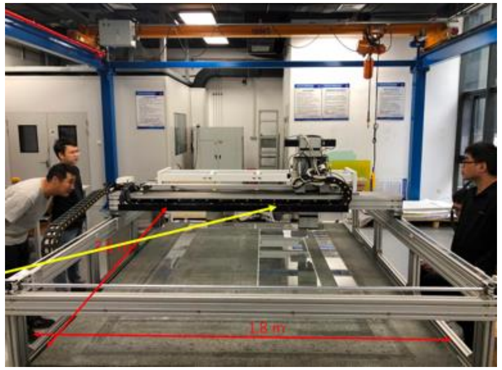

RPC singlet assembly




Gas gap production

STCF谬子探测器：高计数率玻璃RPC

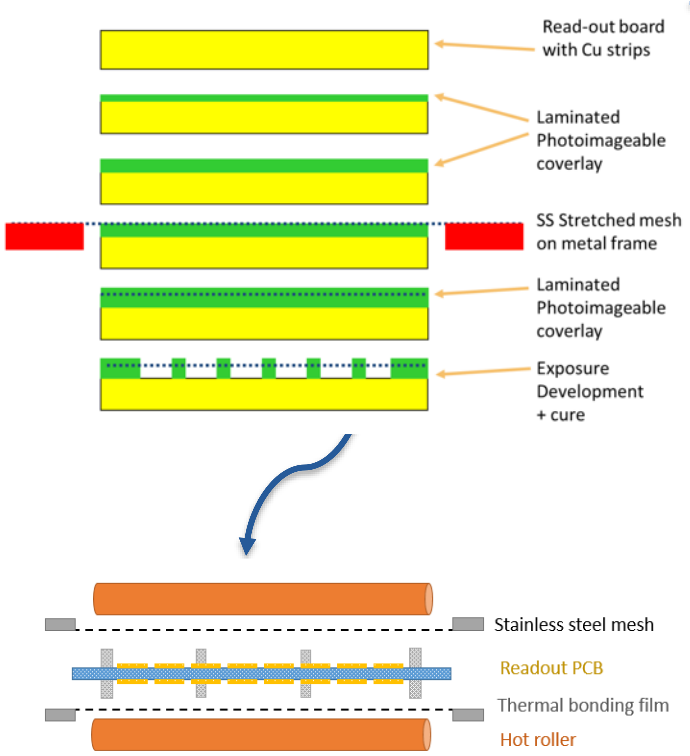
- 与郑大共同研制高计数率玻璃RPC



热压接Micromegas探测器

热压接Micromegas方法

1：一体化压接替代多重压合蚀刻



- ✓ 材料灵活
- ✓ 参数可控
- ✓ 面积易扩展

Jianxin Feng et al,. NIM-A 989 (2021) 164958.

2：非晶锗薄膜替代电子浆料阻性阳极

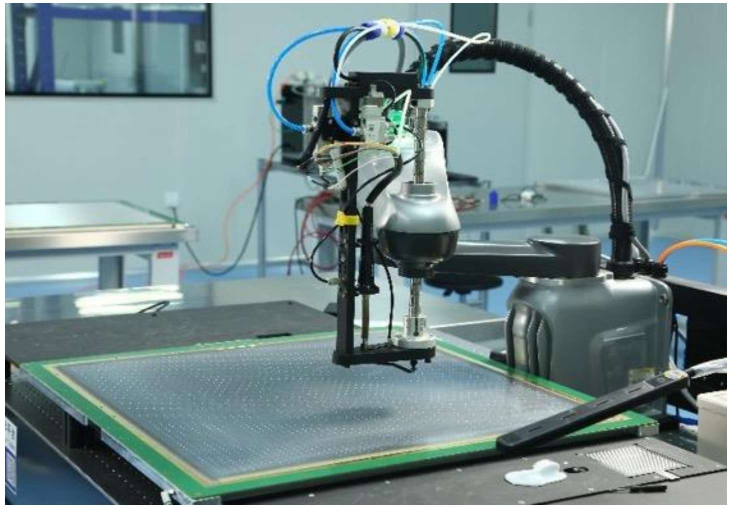
丝网印刷阻性浆料 → 热蒸发制备锗薄膜

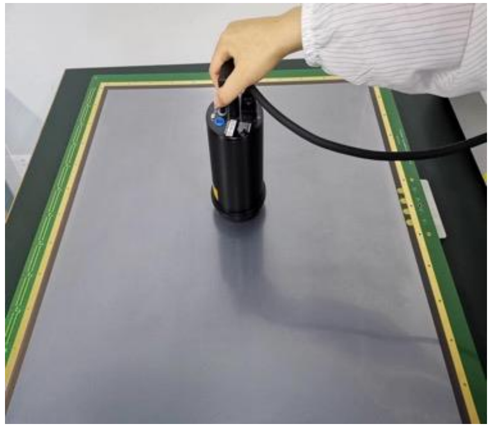
- ✓ 电阻率可控
- ✓ 低放射性本底
- ✓ 大面积制作

Jianxin Feng et al,. NIM-A 1031 (2022) 166595

热压接Micromegas探测器

专用设备和场地：大面积高性能Micromegas全流程开发





热压接Micromegas探测器

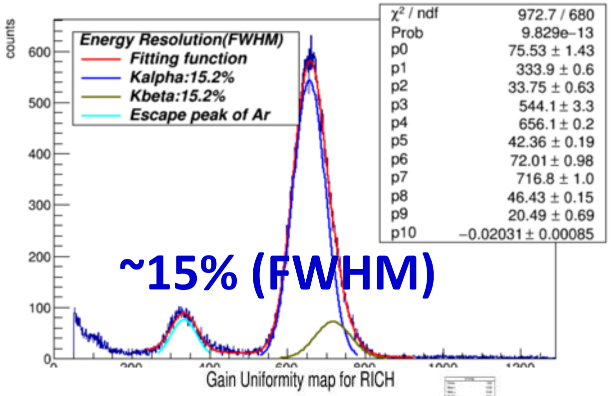
主要性能指标

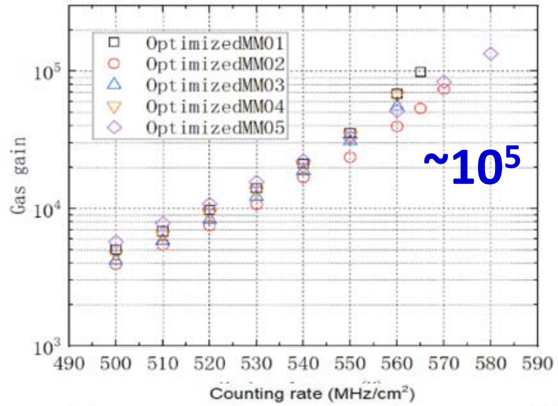
X射线测试（5.9 keV）

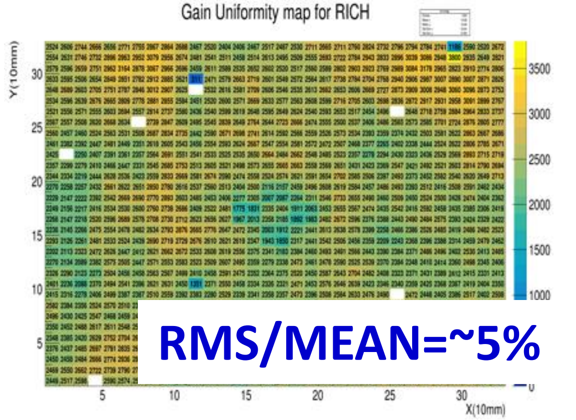
- 增益：~10^5 (Ar+7%CO2)
- 能量分辨：~15% (FWHM)
- 增益均匀性: ~5% for 30×30 cm^2
- 高计数率：> MHz/cm^2

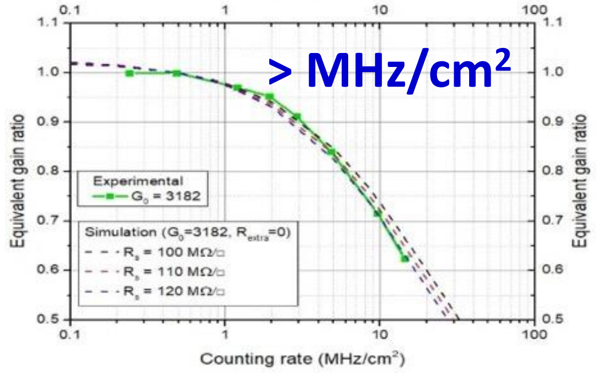
电子束流（5GeV）

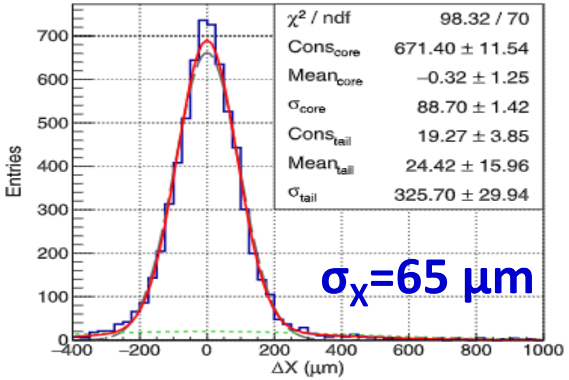
- 探测器效率：>98%
- 位置分辨：65μm

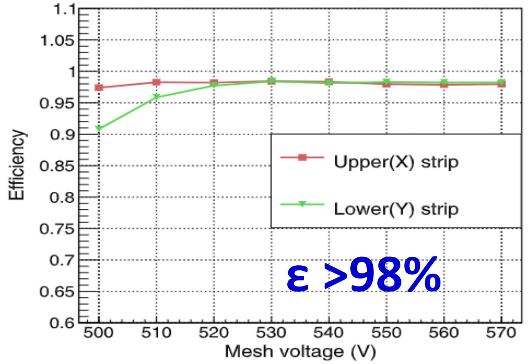






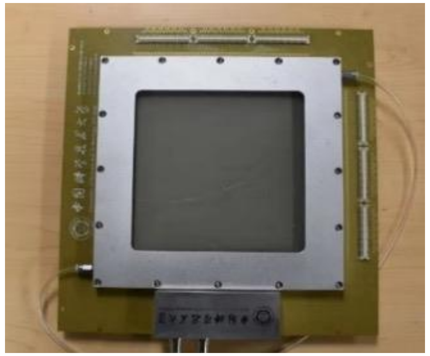






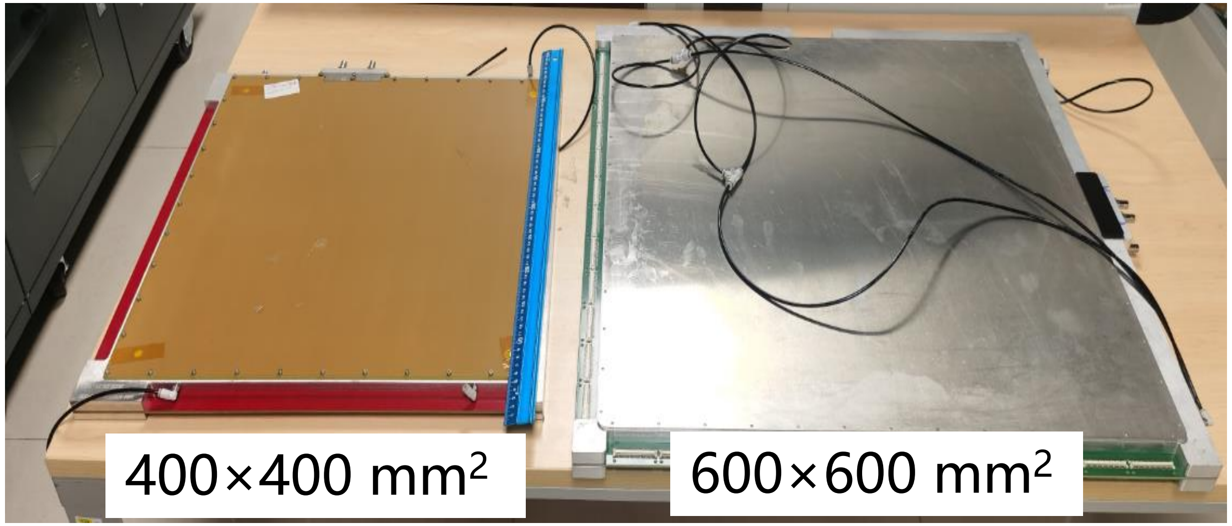
热压接Micromegas探测器

大面积高分辨径迹探测器

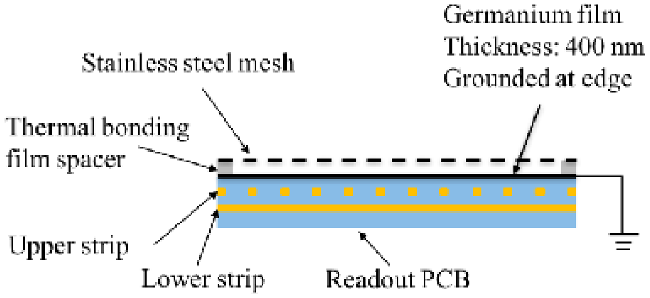


150×150 mm²

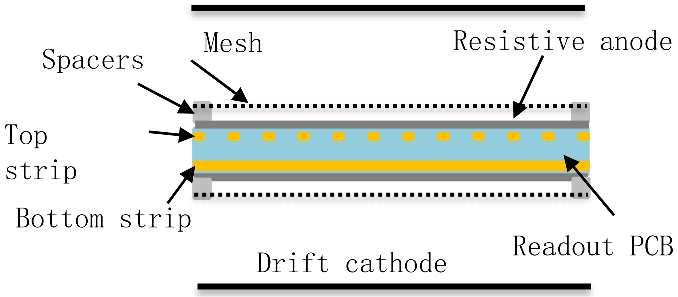
400μm 条间距



单面读出



背靠背读出

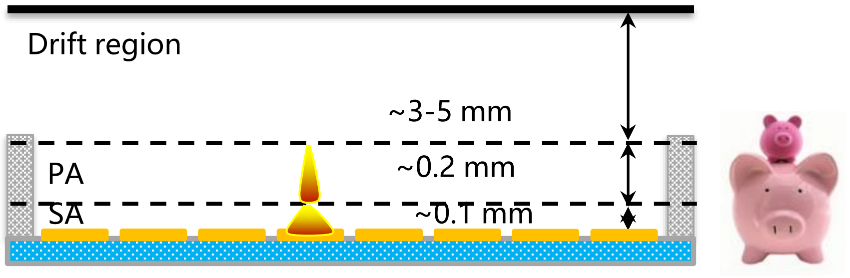


尺寸 (mm²)	读出方式	位置分辨	MIP探测效率
150×150	单面	**< 100μm**	**>95%**
400×400	单面	**~130μm**	**>95%**
600×600	背靠背	**~150μm**	**>95%**

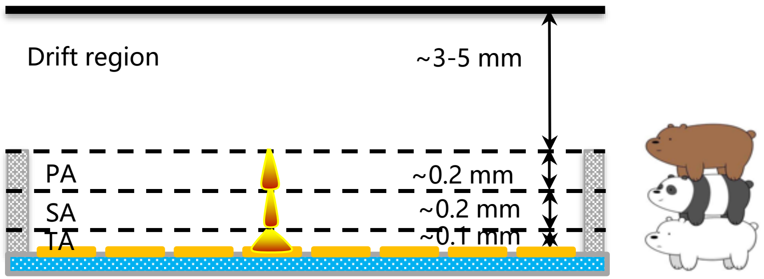
超低离子反馈多层微网探测器

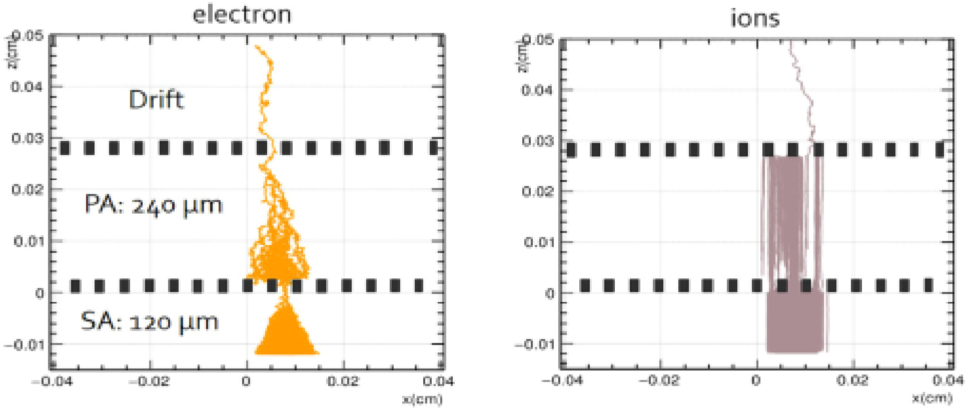
面向高技术率TPC和气体光电探测需求

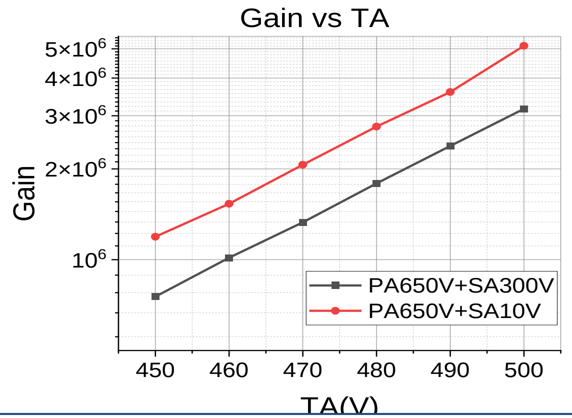
DMM: Double Micro-Mesh gaseous structure

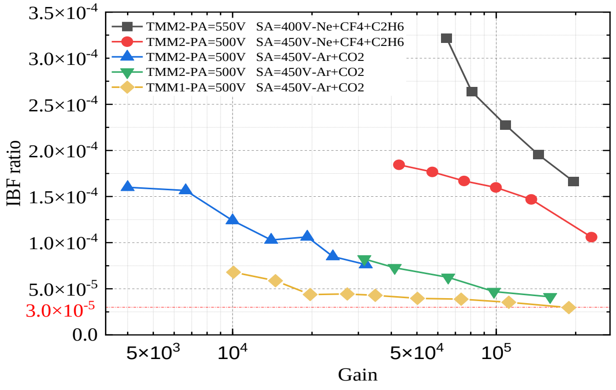


TMM: Triple Micro-Mesh gaseous structure





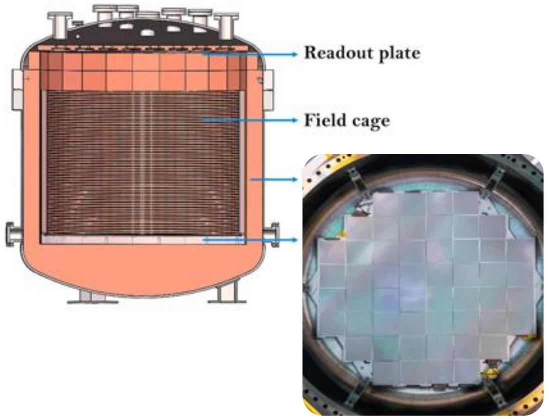




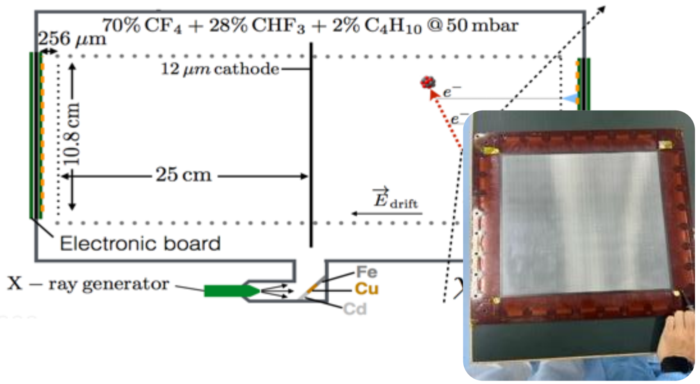
优化电子收集效率条件下：实现>10^6高增益和<3×10^{-5}超低离子反馈率。

Zhiyong Zhang et al., NIM-A 889 (2018) 78–82；Binbin Qi et al., NIM-A 976 (2020) 164282；
Kunyu Liang, et al., NIM-A,1070 (2025) 170033.

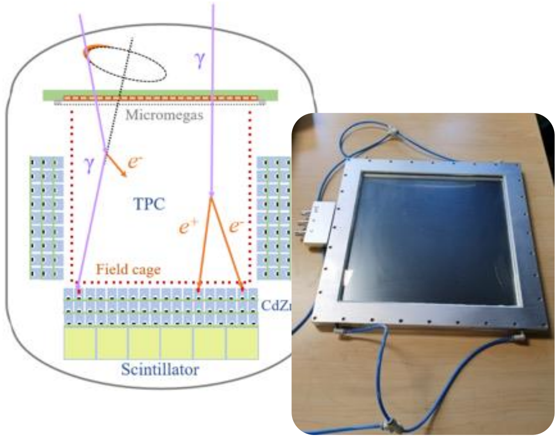
热压MM技术支撑科学前沿研究



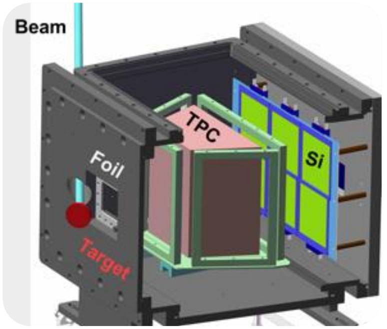
PandaX-III（上海交大）
无中微子双贝塔衰变稀有事例搜寻

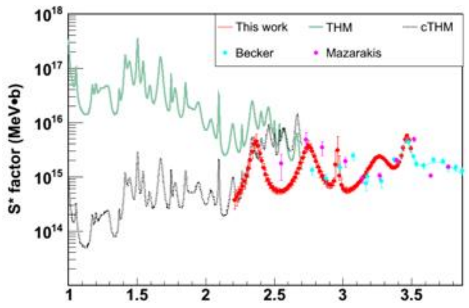


MIMAC（法国）
方向性暗物质探测

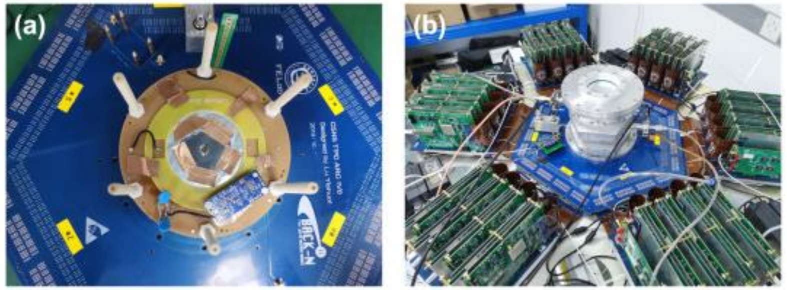


MeGaT（中科大&深空实验室）
新一代伽马天文望远镜

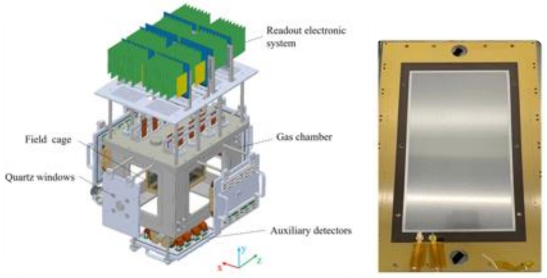




Mate-TPC (近物所)
核天体物理能区关键核数据测量

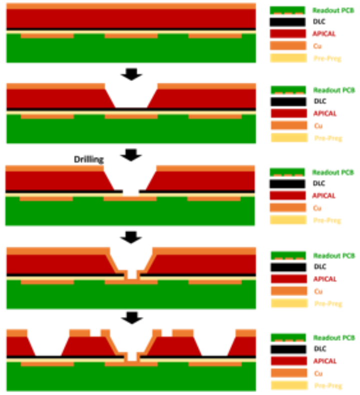


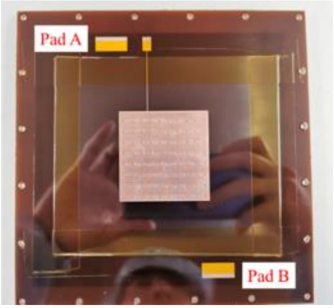
MTPC (散裂中子源)
中子核数据测量

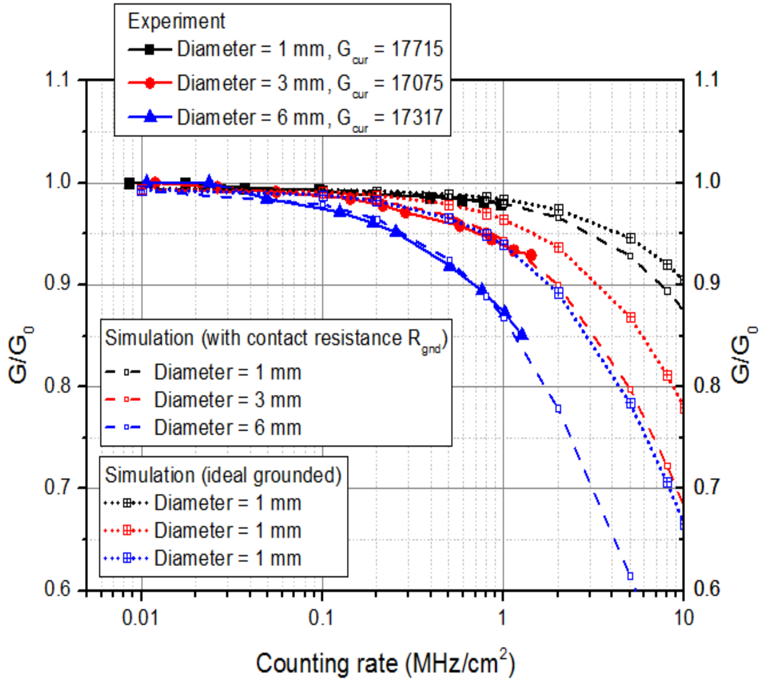


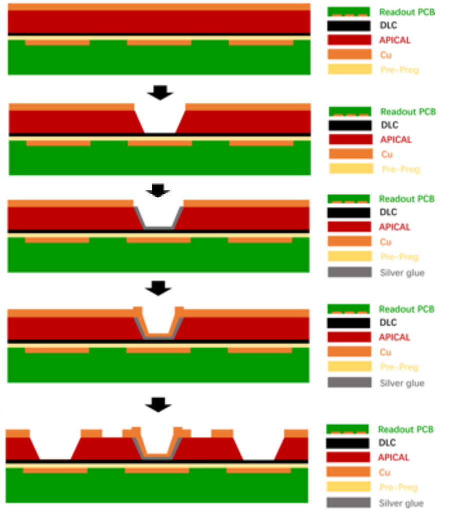
fMeta-TPC (复旦大学)
光核相互作用测量

μ RWELL探测器



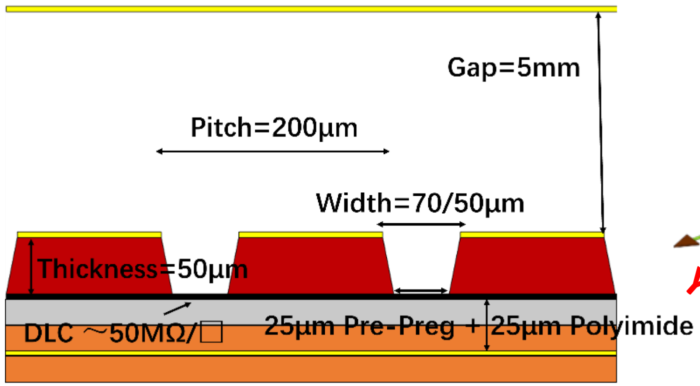


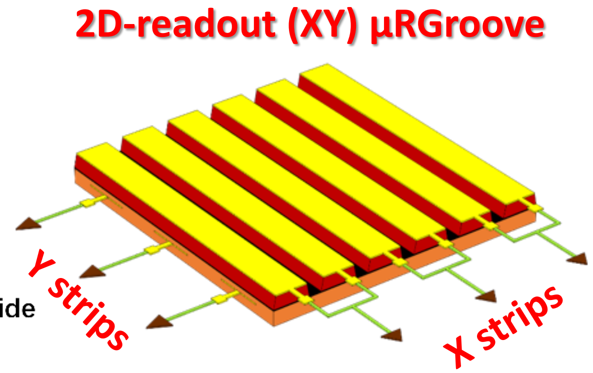


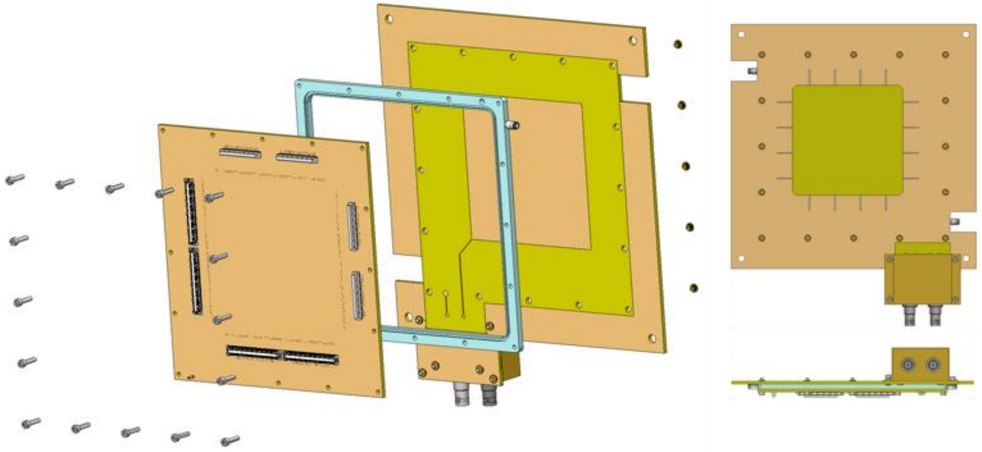


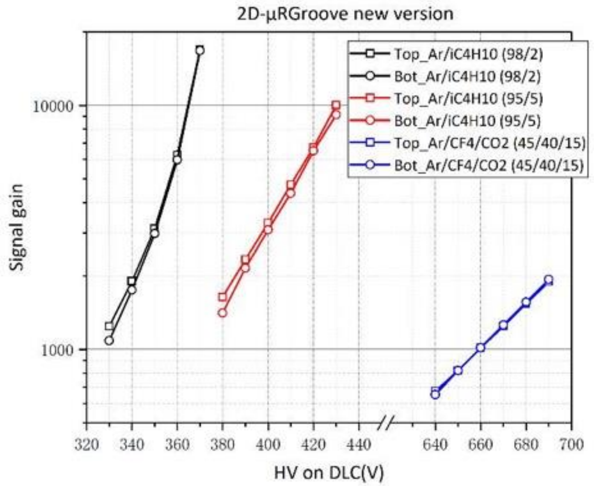
- 开发PEDP工艺，研制了点阵列快速接地μRWELL，8.1keV X射线照射下计数率能力达百kHz/cm²。
- 研究并模拟快速接地机制和阻性电极电荷泄放过程，模拟结果与实验结果高度吻合。
- 开发更适合大面积探测器的PEP工艺，研制了线阵列快速接的50cm×50cm μRWELL
- 探测器正常工作、测试正在进行中

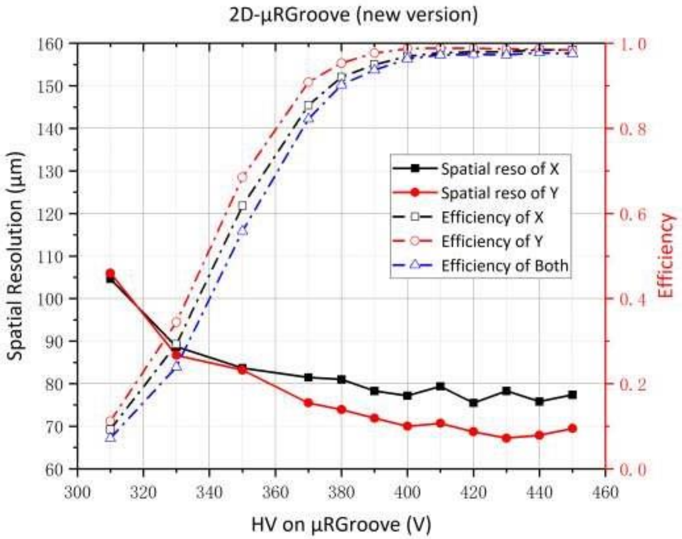
μ RGroove探测器





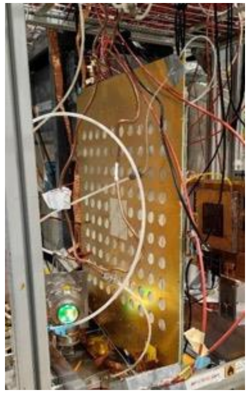


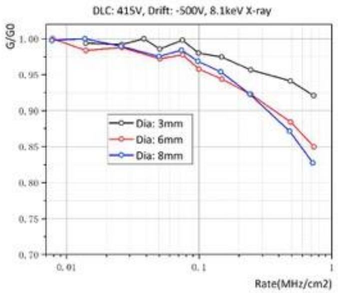


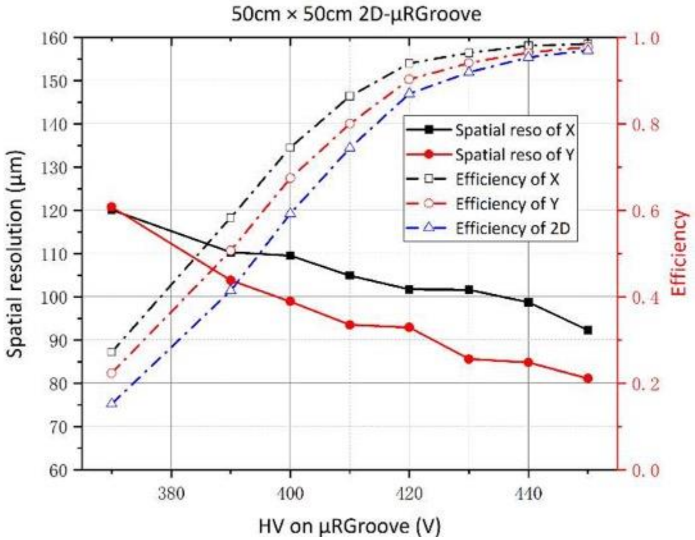


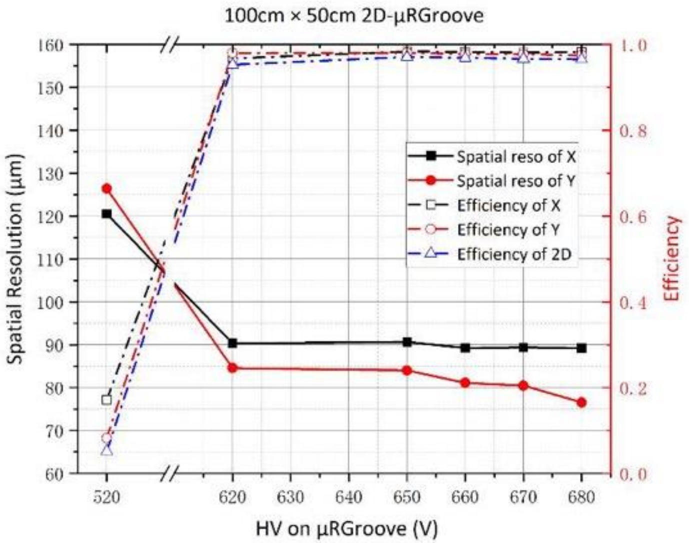
- 研究新型MPGD：μRGroove：
- 避免电荷分享效应，信号幅度大
- 机械结构简单、容易清理、物质量更低
- 完成10cm×10cm原型研制，探测效率接近98%，位置分辨好于80μm，扣除径迹误差后好于60μm

大面积 μ RGroove





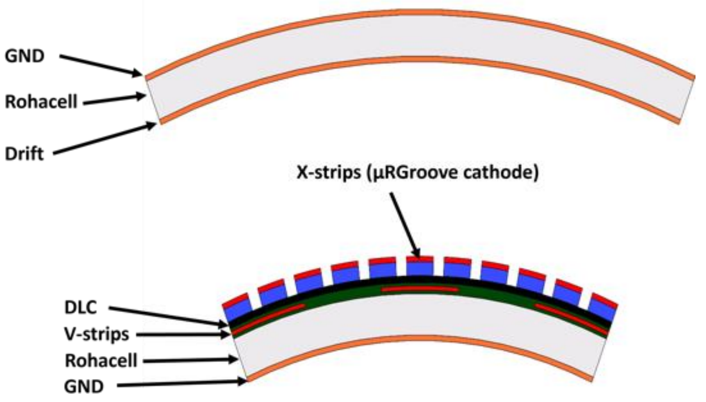


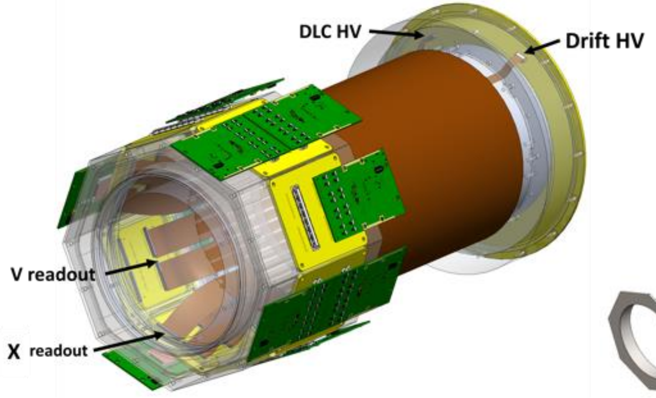


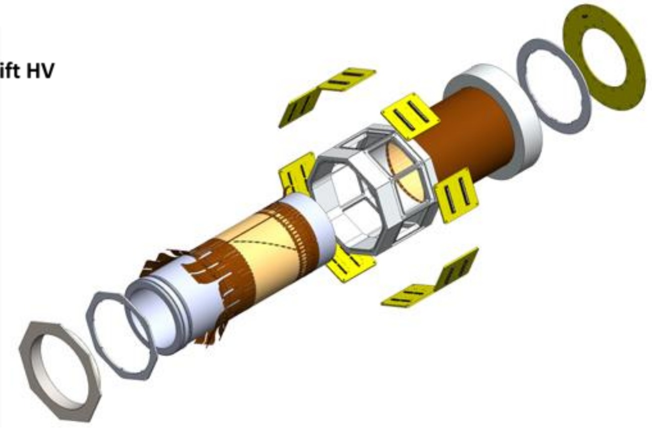
- 50cm × 50cm μRGroove:
  - 基于PEP工艺的快速接地线阵列，死区<1.6%
  - 8.1keV X射线照射下计数率能力~300kHz/cm^2
  - 探测效率约97%，位置分辨好于100μm，扣除径迹误差后好于80μm

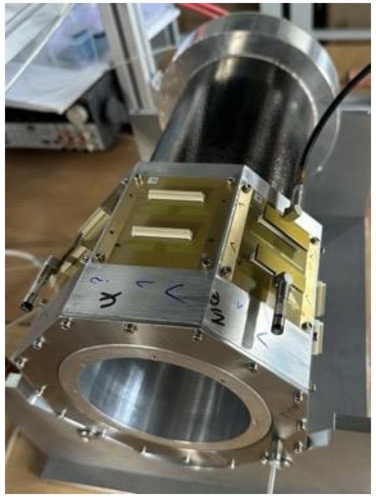
- 100cm × 50cm μRGroove:
  - 基于PEP工艺的快速接地线阵列，死区<1.6%
  - 探测效率约97%，位置分辨好于90μm，扣除径迹误差后好于70μm
  - 详细的测试正在展开

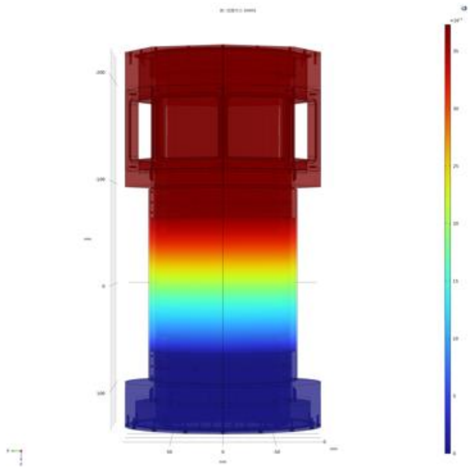
圆柱形 μ RGroove







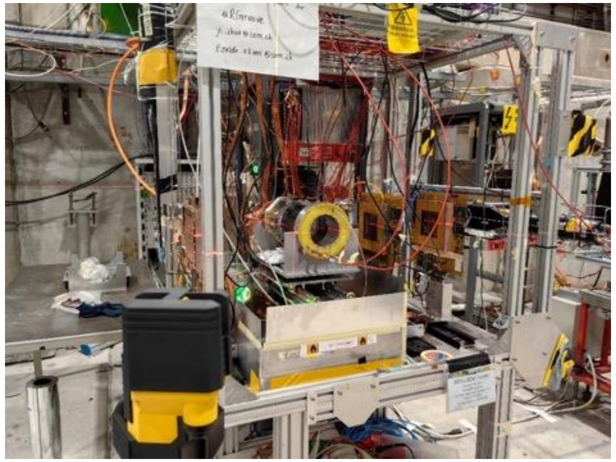


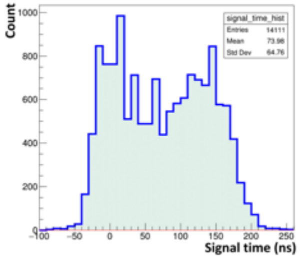


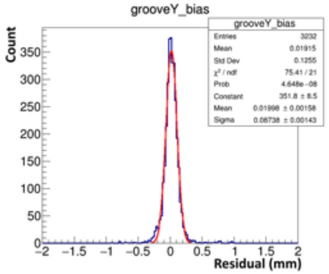
Structure	Material	Thickness (cm)	Material budget (X0)
Drift electrode	LMB-GND	---	2*0.001138%
	Polyimide (X0=28.57cm)	0.0025*2	0.0175%
	Glue (X=20cm)	0.001*2	0.01%
	Rohacell (X0≈689cm)	0.2	0.029%
Gas volume	Argon-based gas mixture (X0=11760cm)	0.5	0.00425%
Inner cylinder (μRGroove foil)	Cu (X0=1.43cm)	0.0015*65%	0.0682%
	Cr (X0=2.077cm)	0.000001*65%	0.0000313%
	Apical (X0=28.57cm)	0.005*70%	0.01225%
	Glue (X0=20cm)	0.001*5	0.025%
	Kapton (X0=28.57cm)	0.0025*2	0.0175%
	Al (X0=8.892cm)	0.0012*(1*32.5%)	0.00439%
	DLC (X0=12.13cm)	0.0001	0.00082%
	Polyimide (X0=28.57cm)	0.0025	0.00875%
	Rohacell (X0≈689cm)	0.2	0.029%
	LMB-GND	---	0.001138%
Total			0.2301%

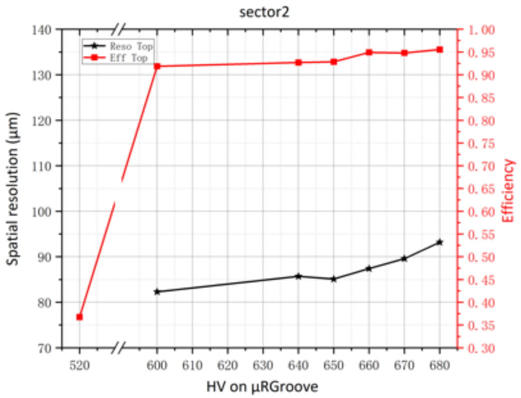
- 可拆卸式机械设计，机械强度高
- 外筒漂移级、内筒放大结构，便于清理维护
- 灵敏区域尺寸：直径131mm，长度100mm
- 极低物质量：0.23%X_0

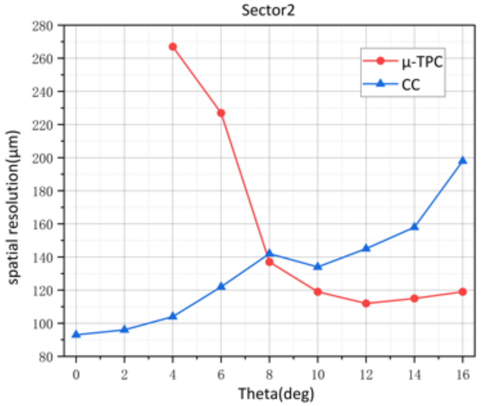
圆柱形 μ RGroove



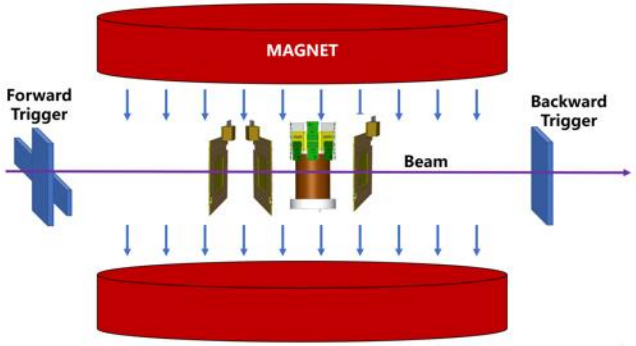


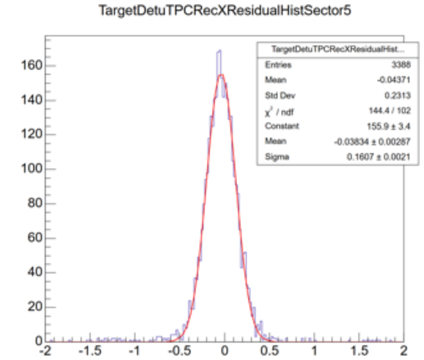


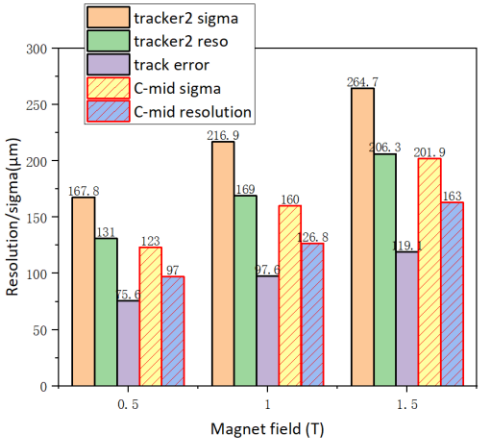




- 无磁环境中的束流测试
  - 探测效率大于95%
  - 位置分辨：CC好于100μm，μTPC好于120μm，扣除径迹误差后分辨好于80μm和110μm

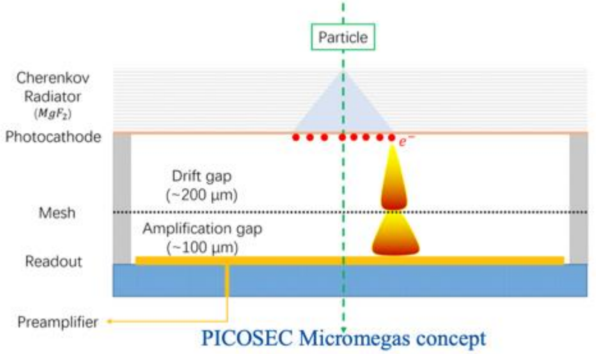


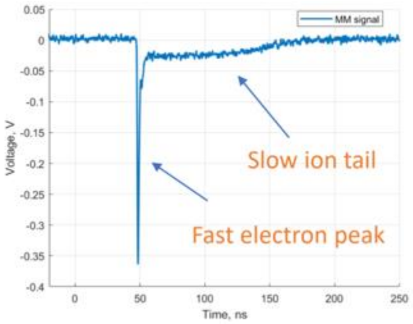


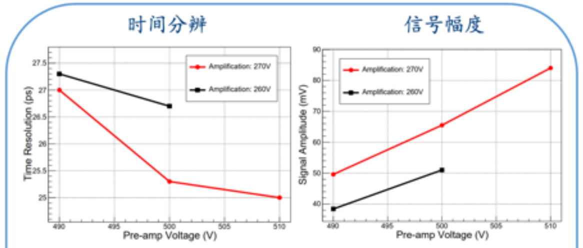


- 1T强磁场中的束流测试
  - 洛伦兹角约24°
  - 对垂直入射粒子，扣除径迹误差后μTPC分辨130μm

超快定时Micromegas探测器

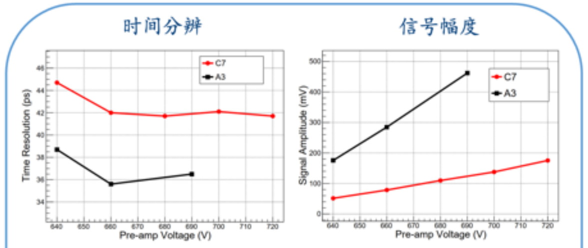






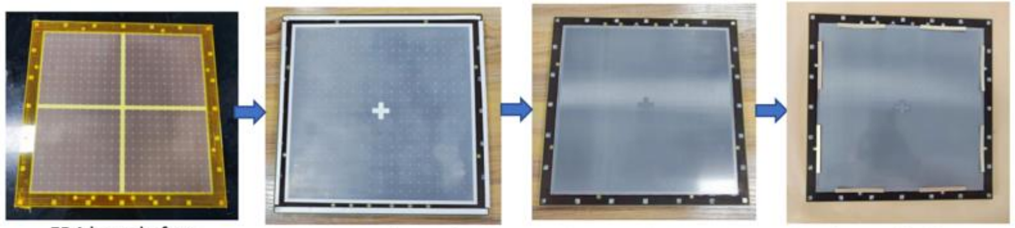
- **CsI 光阴极：**
  - 量子效率高，可达 10 个光电子 (效率>99%)
  - 单通道最佳时间分辨可达~ 25 ps
  - 局限性：易老化，影响长期稳定性

    电压耐受性差，易产生反馈电流



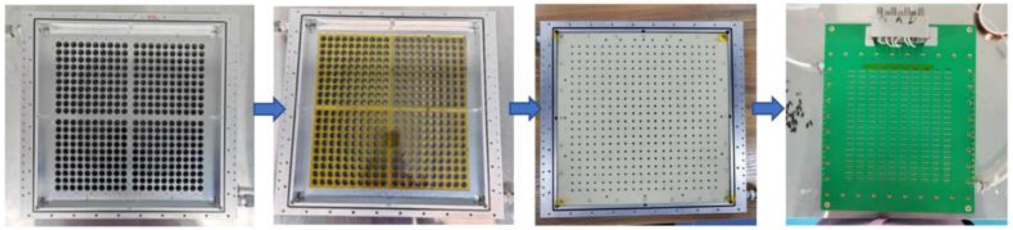
- **DLC光阴极：**
  - 束流中产生约 2~3 个光电子 (效率~90%)
  - 单通道最佳时间分辨~35.6 ps
  - 具有良好化学稳定性，抗老化

- Thermal Bonding Method to make Micromegas



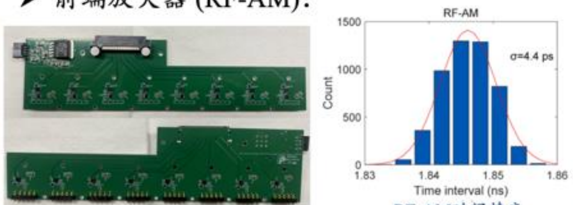
FR4 board after bonding ceramic board | Resistive Electrode | Adhesion of the mesh | Putting on the Spacers

- Assembling into PICOSEC mode



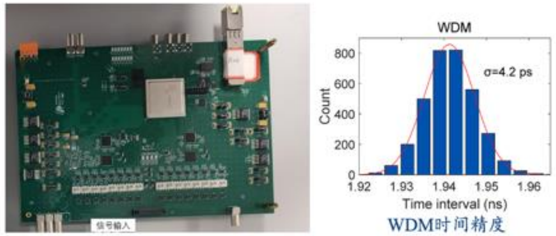
Gas Frame | Kapton film & Photocathodes | MM board | Outer PCB

- 前端放大器 (RF-AM):

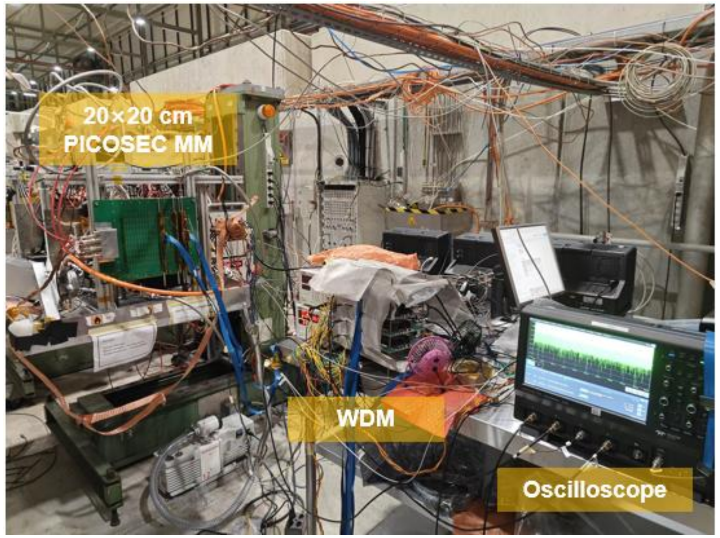


RF-AM时间精度

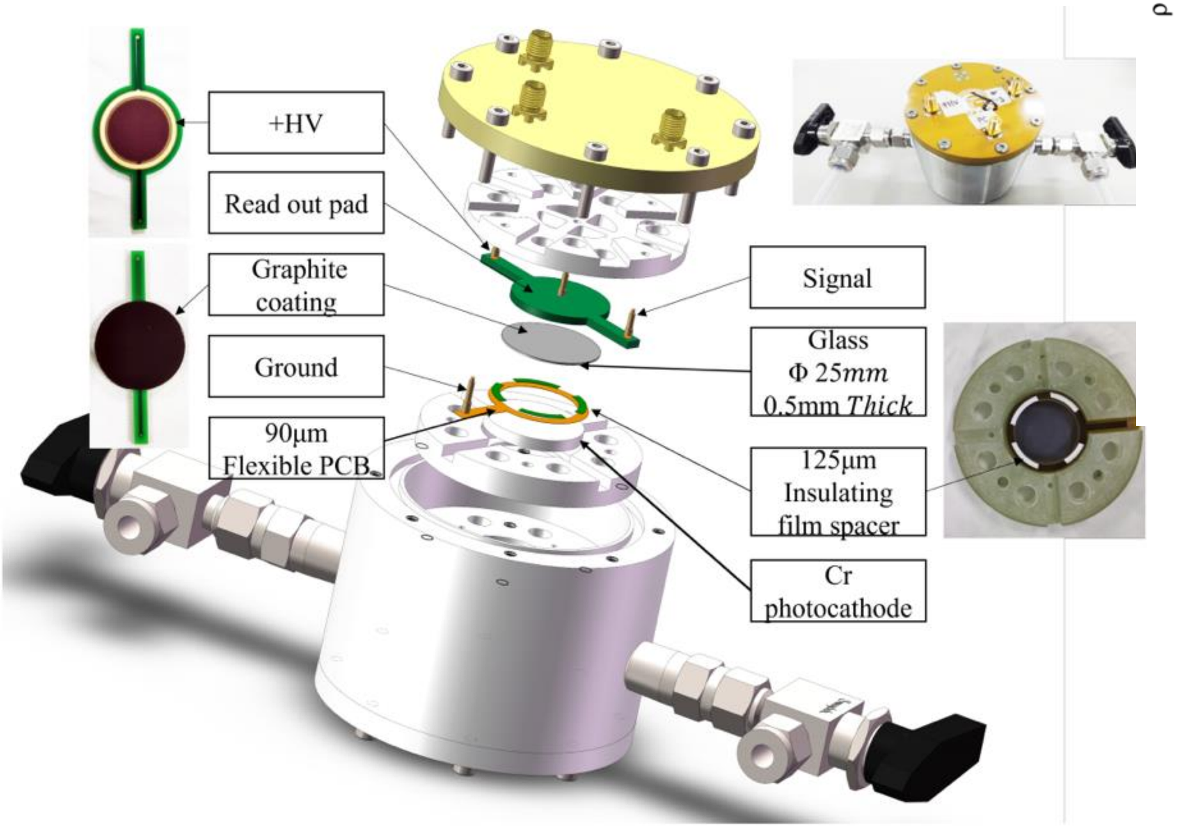
- 波形数字化板(WDM):

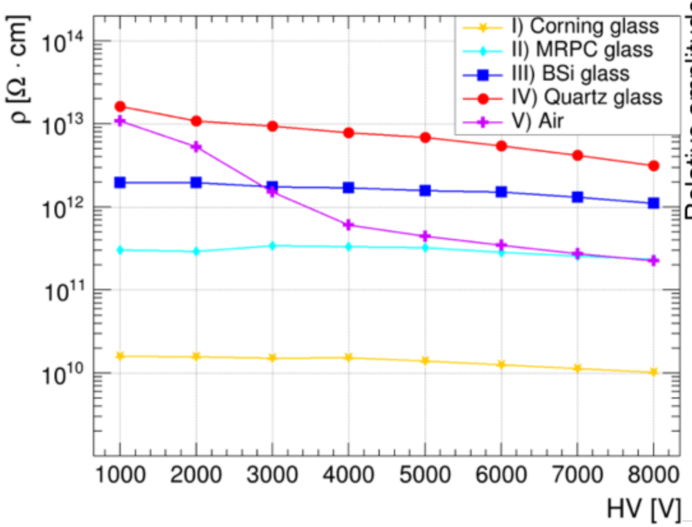


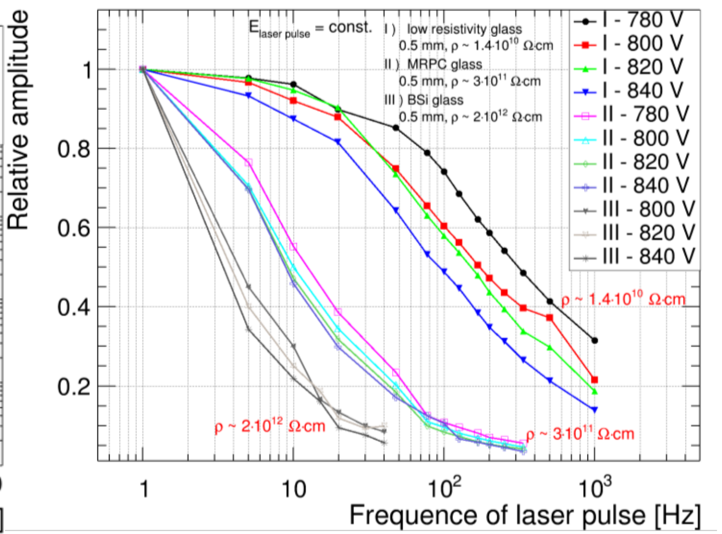
WDM时间精度

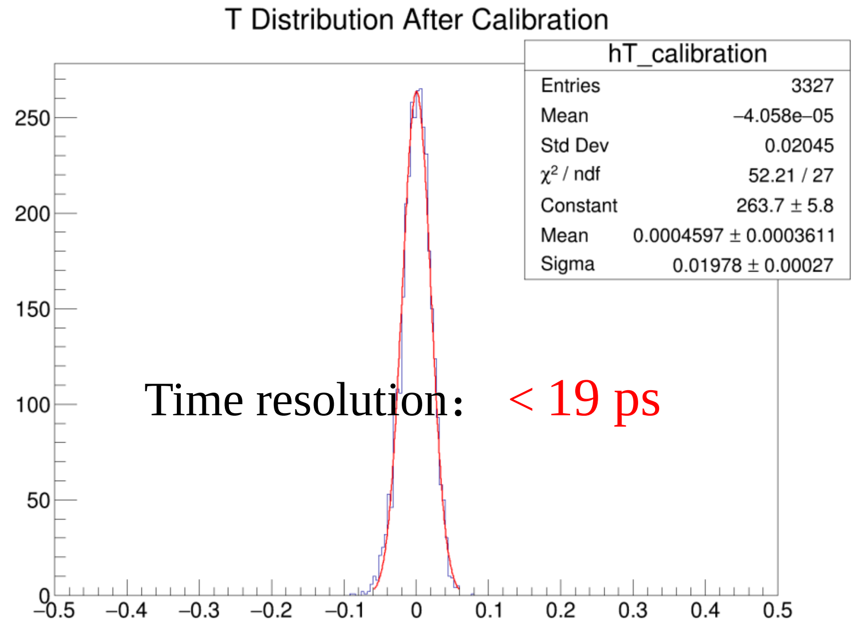


高计数率光电RPC









计数率能力使用低阻浮法玻璃：> 100 kHz/cm^2

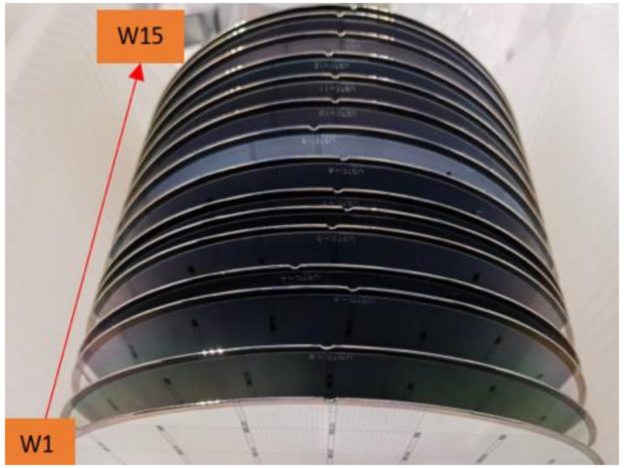
$\sigma_{NPE=1}$ Time resolution： ~ 19 ps

signal： 2e5 ~ 6e6 Qe

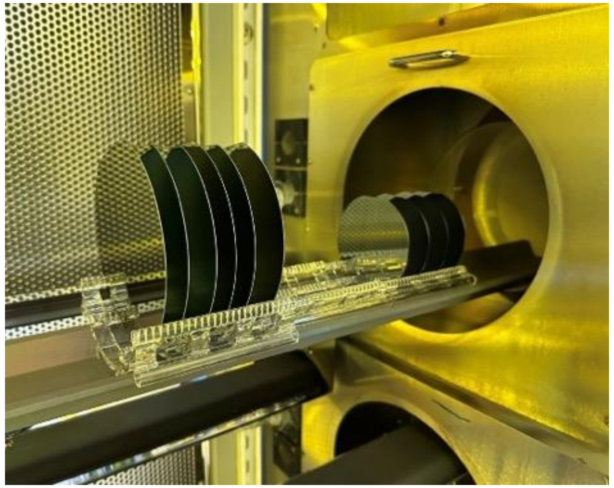
$\sigma_{NPE>5}$ Time resolution： ~ 8 ps

DC- and AC-LGAD R&D at USTC

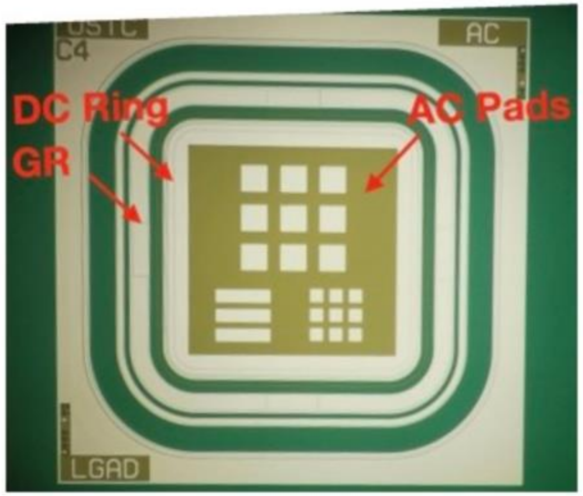
- AC-LGAD is an enabling technology for 4D tracking at future colliders
  - time resolution of ~20 ps and potential spatial resolution of ~10 μm
  - Currently considered for TOF at Electron-Ion Collider and LHC(ALICE)
- USTC team mastered the LGAD design
  - ❑ USTC-IME DC-LGAD sensor in production for ATLAS phase 2 upgrade
    time resolution: 30 ps (unirradiated), 40 ps after 2.5×10^{15} cm^{-2} n$_{eq}$
- USTC Center for Micro- and Nanoscale Research and Fabrication(NRFC) supports in-house prototyping: ideal for R&D



USTC-IME DC-LGAD wafers for ATLAS



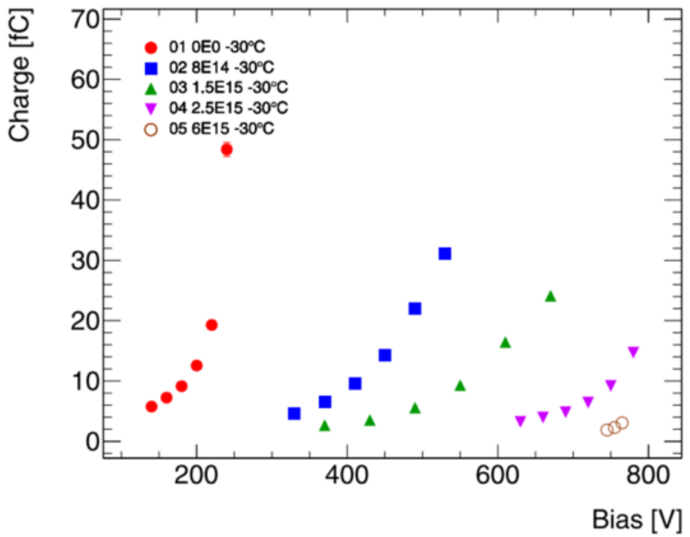
AC-LGAD fabrication at USTC NRFC



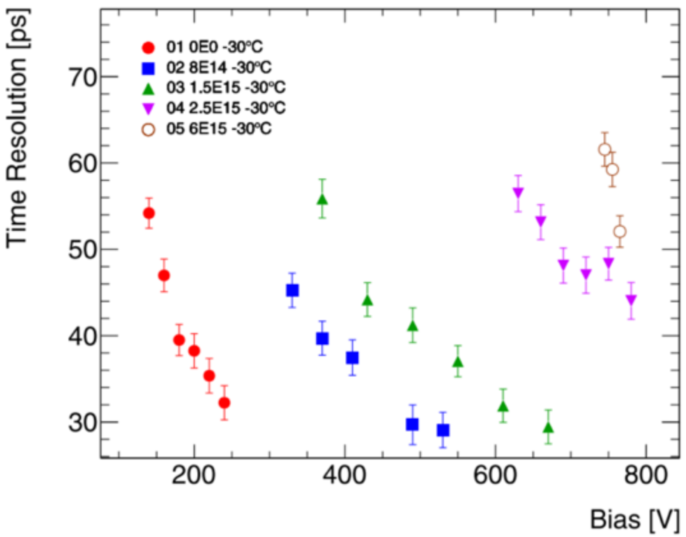
USTC AC-LGAD (v0)

Some test results of USTC LGAD

DC-LGAD measured with Sr-90 at -30 deg C

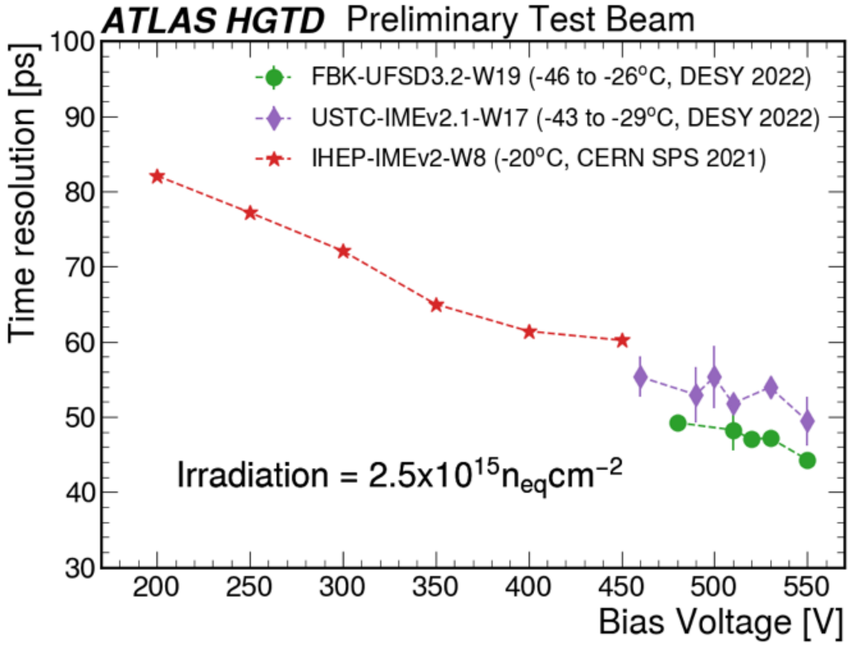


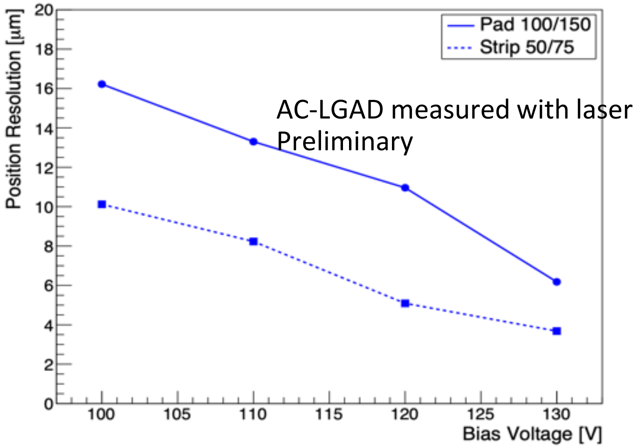
(a) Collected charge

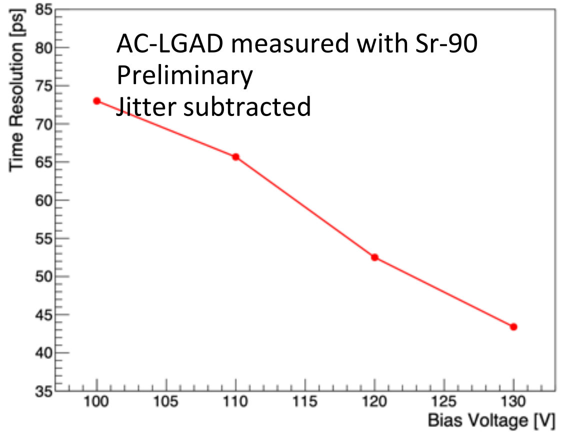


(b) Time resolution

DC-LGAD measured at test beam

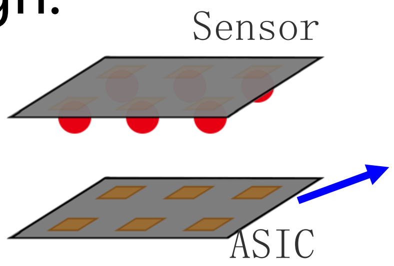


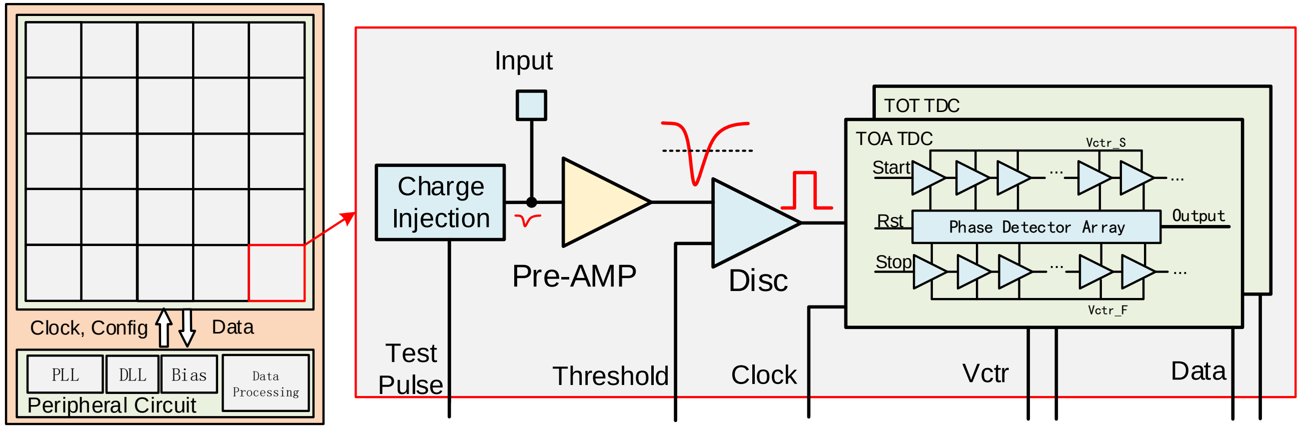




LGAD ASIC

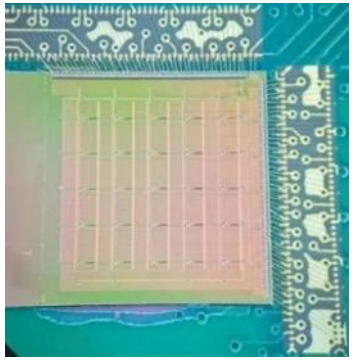
- High-performance ASIC is very important for high-granularity AC-LGAD readout.
- Challenges on ASIC design:
  - ◇ weak signal: < 10 fC
  - ◇ high-precision: 10～15 ps
  - ◇ high channel density
  - ◇ low noise and low power

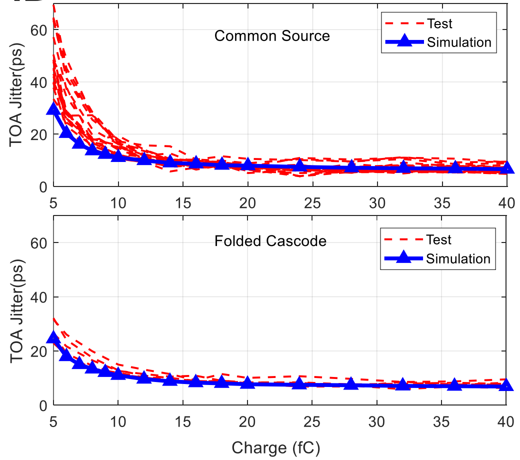




- Key techniques:
  - ✓ Low-noise low-power high-bandwidth pre-amplifier
  - ✓ High-speed discriminator
  - ✓ High-precision time-to-digital converter
  - ✓ Build-in test circuit
  - ✓ On chip data collection and transfer

- Research experience:
  - ✓ 20 ps @ 10 fC is achieved in the prototype ASIC for DC-LGAD

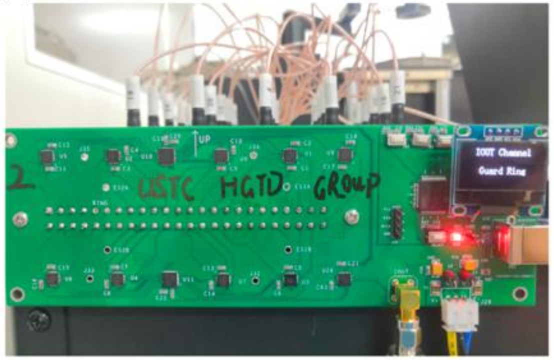


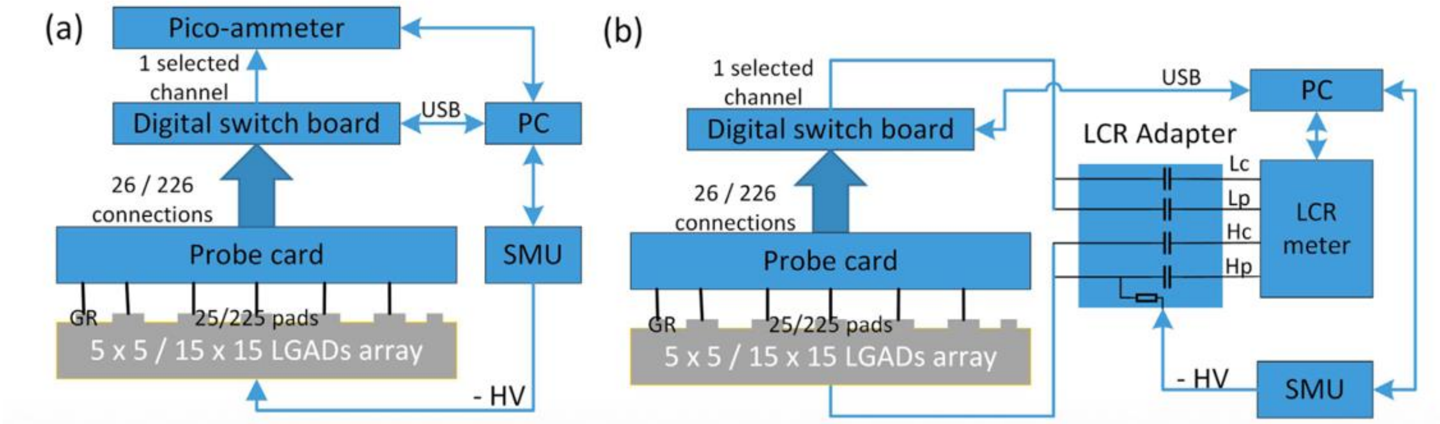


- R&D of the readout electronics based on the ASIC is also an important task for the AC-LGAD system

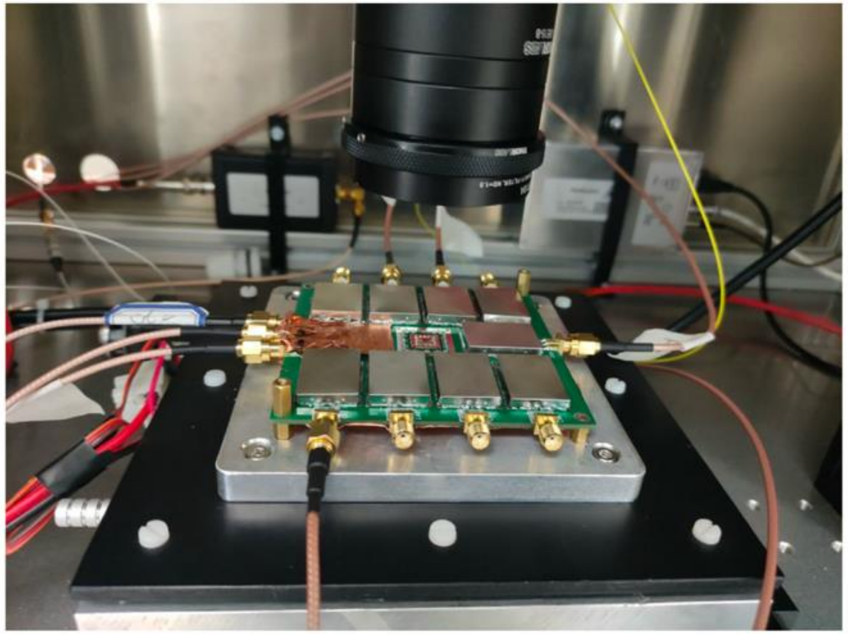
Some tools for sensor measurements

Digital Switch board for IV/CV measurements
with probe card





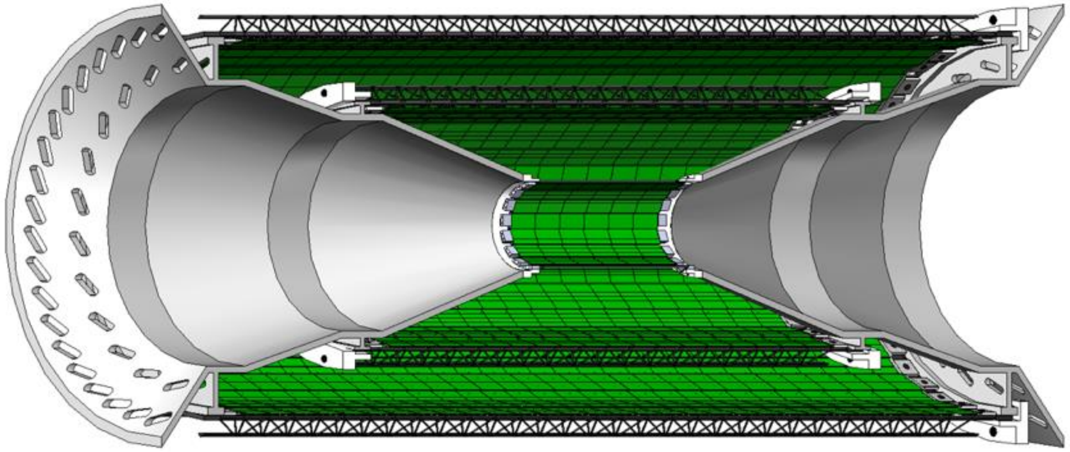
9-channel ampifier board for DC-LGAD



Both boards designed by Jiajin Ge

R&D of Monolithic Active Pixel Sensors (MAPS)

- Motivation: to meet the physics requirements of the STCF Inner Tracker:
  - Tracking efficiency: >99% @ $p_T > 0.3\ GeV$; >90% @ $p_T > 0.1\ GeV$
- A preliminary design of the MAPS based Inner Tracker (ITKM)
  - Three layers of silicon pixel detectors, with radii of 36mm, 98mm, 160mm (beam pipe: 30mm)
  - Acceptance: polar angle of 20º~160º
- Total area: 1.3m^2

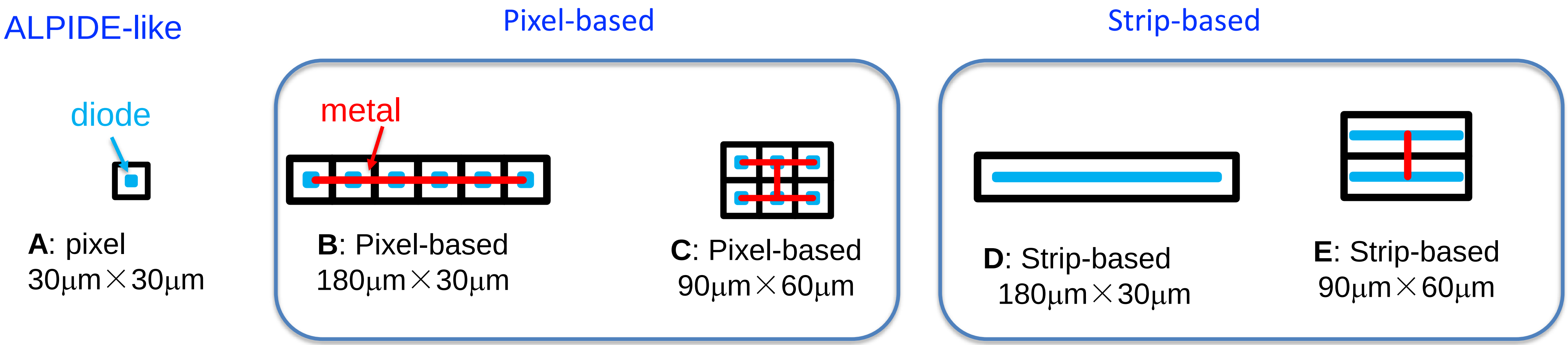


Requirements on the STCF MAPS: CharTPix

- Power consumption： $\leq 100mW/cm^2$
- Material budget per layer： $\leq 0.35\%\ X_0$
- Spatial resolution： $\leq 30\mu m$
- Time resolution： $\leq 20\mathrm{ns}$ (to deal with the pileup issue at high luminosity)
- Hit rate capability: $\geq 1\mathrm{MHz}/cm^2$
- Time-over-threshold (TOT) measurement:
  - Time-walk correction
  - Correction of multi-coulomb scattering in track finding

CharTPix Sensor design

- Pixel size considerations
  - Higher priority on the power consumption than the spatial resolution → larger pixel size to reduce the power consumption density
  - Three different designs
    - Pixel-based: analog connected small pixels ($1 \times 6 \rightarrow 1, 2 \times 3 \rightarrow 1$) using metal lines
    - Strip-based: extended diode size in one direction
    - Superpixel based: digital connected small pixels



Design technologies

- Three different CIS technologies are being explored
  - Default: 180nm CIS with high-resistivity epitaxial wafers
    - Resistivity: $\gtrsim 1\text{k}\Omega \cdot cm$; epi thickness: ~20 μm
    - Eg: Tower 180nm(ALPIDE)

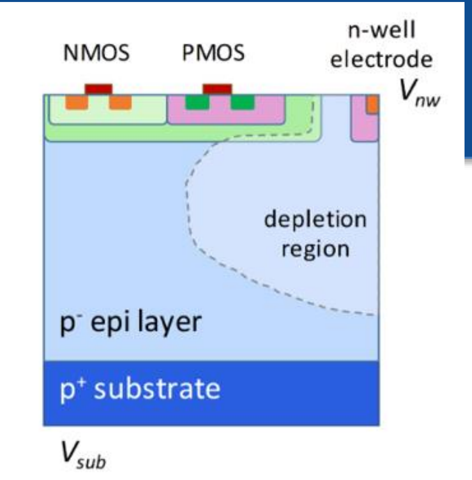
- Mature technology, well validated
- Foreign technologies

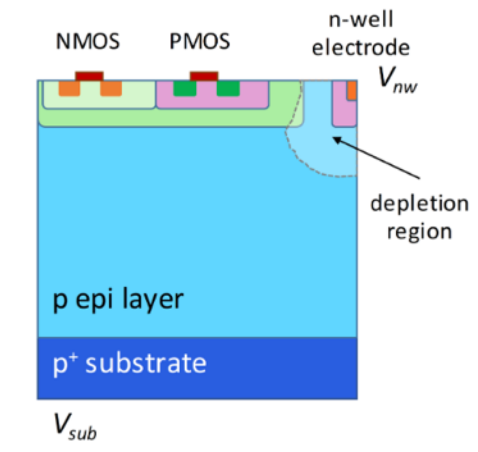
  - 90nm CIS with low-resistivity epi wafers:
    - Resistivity: $\gtrsim 10\Omega \cdot cm$; epi thickness: 10~20 μm

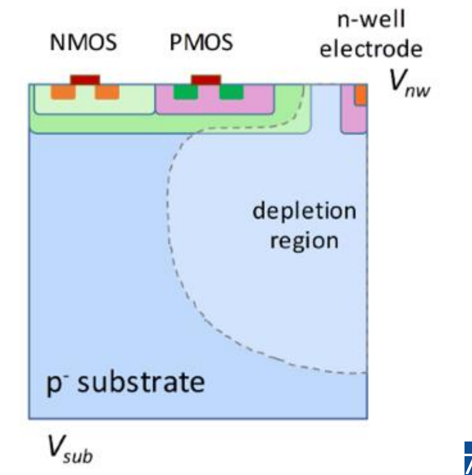
- Domestic technology under development
- Performance limited by the low resistivity
- Advantage of smaller process node

  - 130nm CIS with high resistivity substrates:
    - Resistivity: $\gtrsim 1\text{k}\Omega \cdot cm$, no epi layers

- Domestic technology under development
- Advantage of smaller process node
- High voltage beneficial to improve the timing performance (eg. MALTA2)





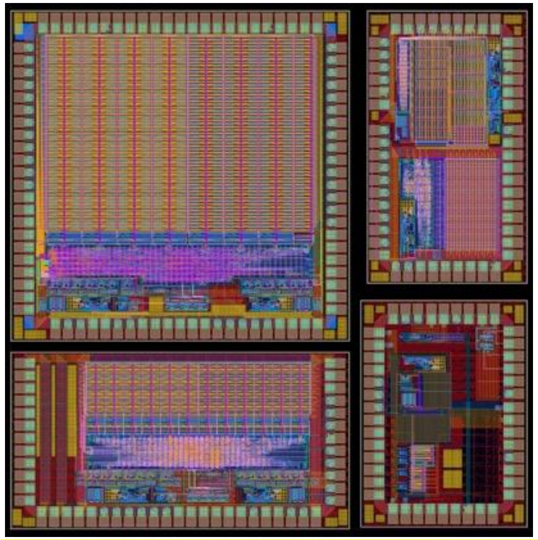


CharTPix protypes

Prototype MAPS design under three different technologies

TowerJazz180nm

- Mature process in HEP (ALPIDE, TJ-Monopix)
- **Baseline techno**
- Low res substrate + high res ($>1\mathrm{k}\Omega \cdot \mathrm{cm}$) EPI



Submitted in March 2024
Chip returned in Dec 2024

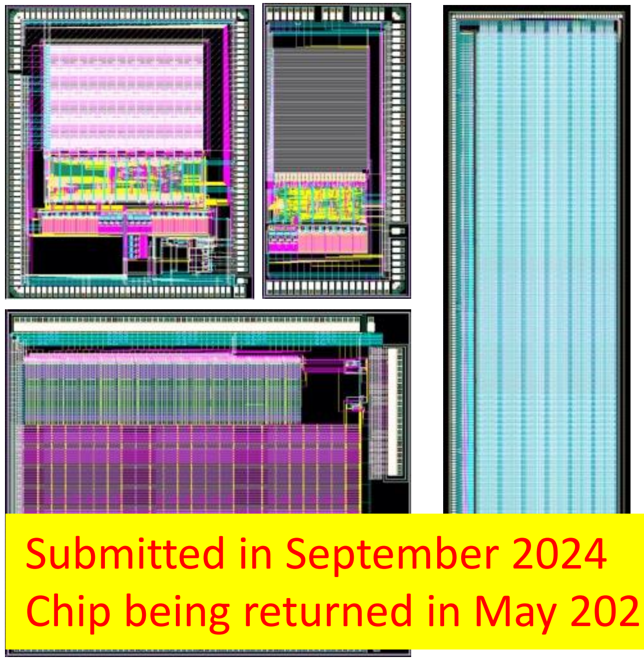
NexChip BCIS90nm

- **Local techno**
- Low res EPI ($10\Omega \cdot \mathrm{cm}$)

Submission in Jan 2025

GSMC130nm

- **Local techno**
- High res substrate, no EPI



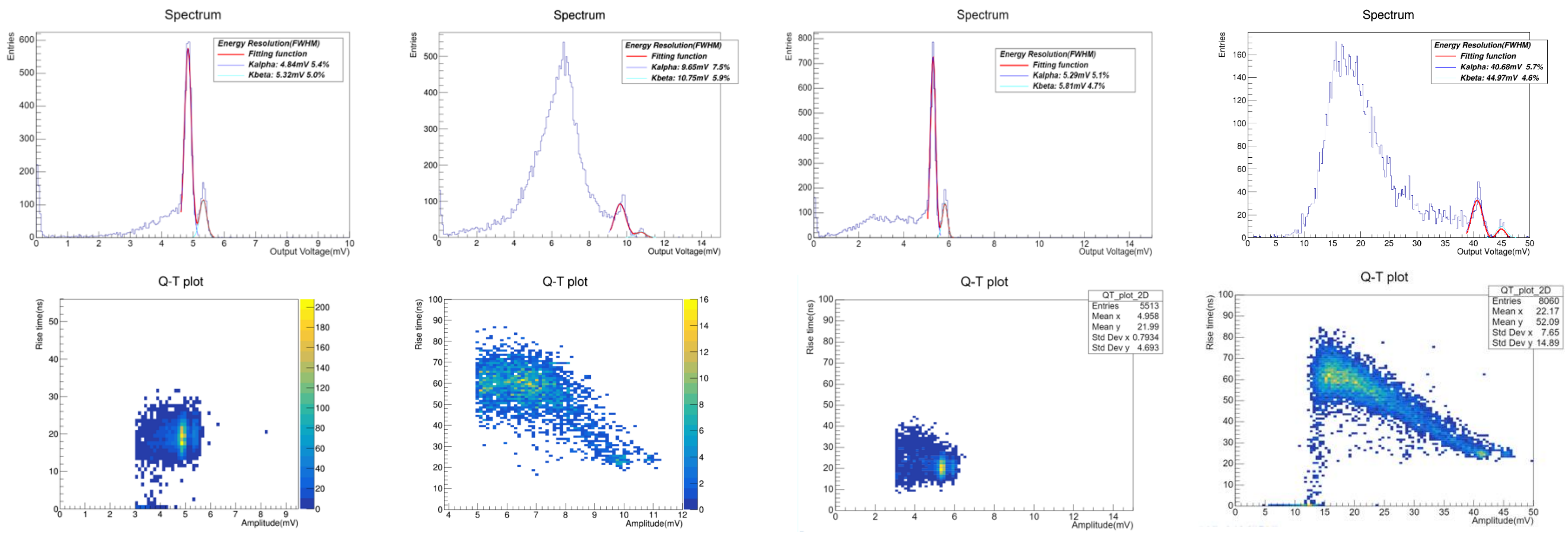
Submitted in September 2024
Chip being returned in May 2025

CharTPix-TJ 芯片测试：Fe55放射源测试

- 3T读出芯片测试

能谱

上升时间

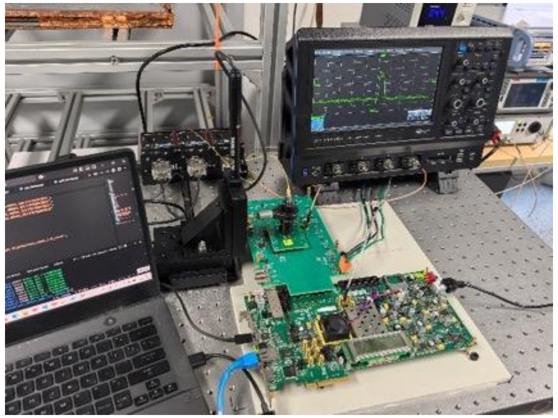


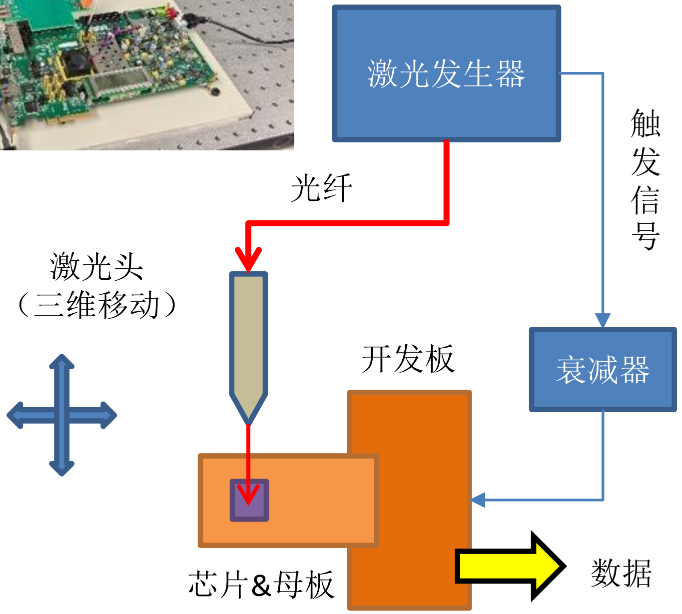
1×6 strip-based | 1×6 pixel-based | 2×3 strip-based | 1×1 ALPIDE-like

- Strip型能观测到明显的全能峰 →更好的电荷收集效率
- Sensor上升时间可以好于20ns

CharTPix-TJ芯片测试：激光测试

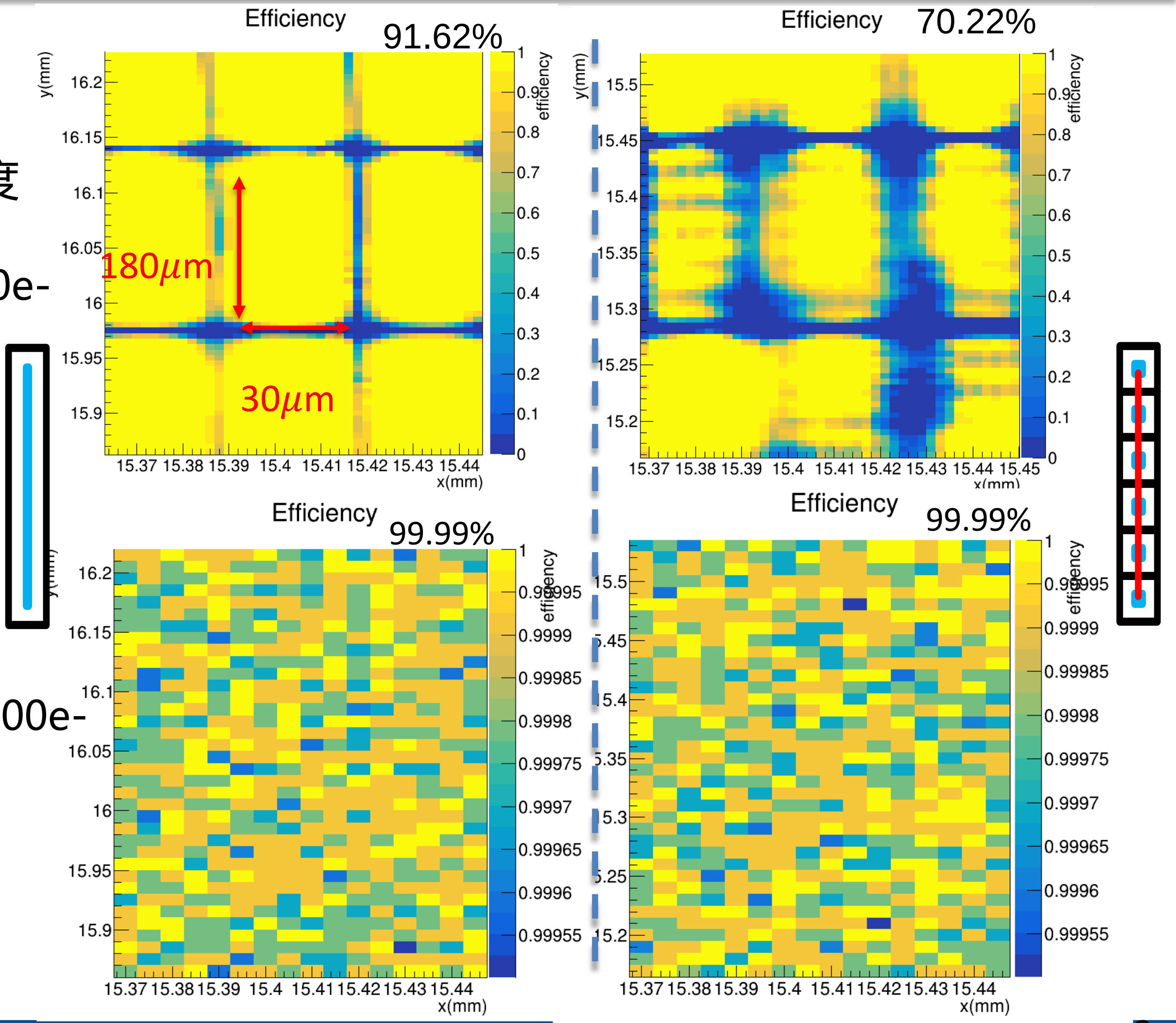
- 红外皮秒激光测试
  - 高精度三维移动平台（1μm精度）
  - 激光强度可调，利用S-curve标定激光强度





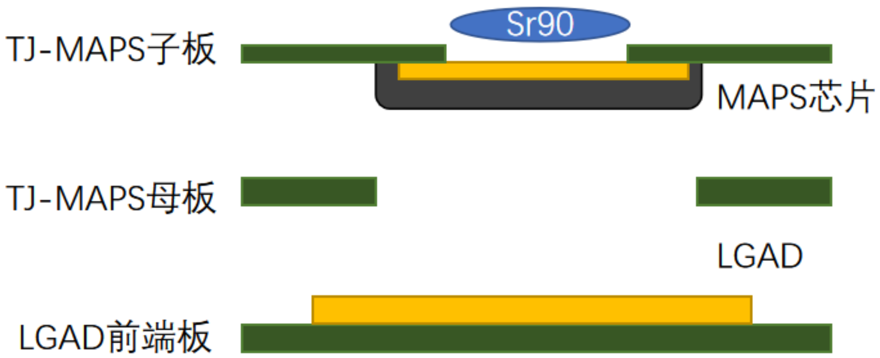
约为600e-

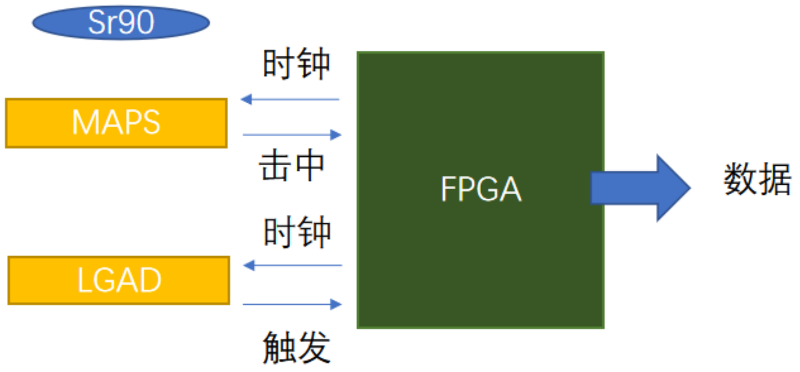
约为1600e-

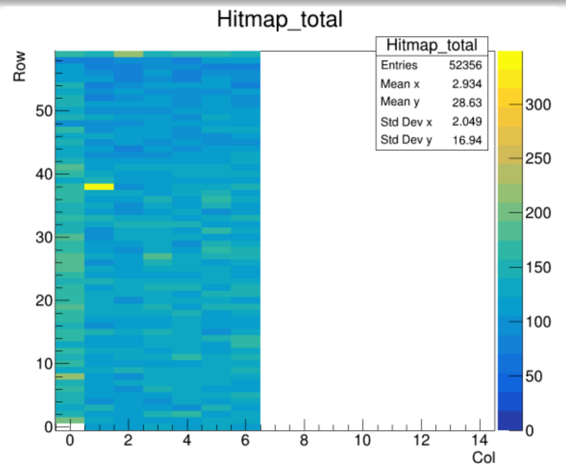


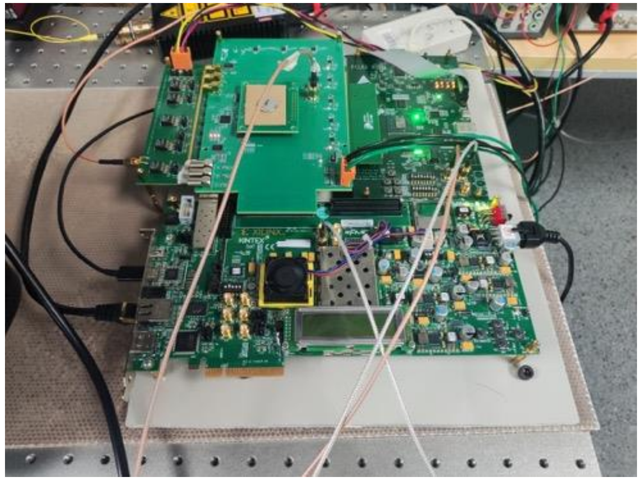
CharTPix-TJ芯片测试：Sr90放射源测试

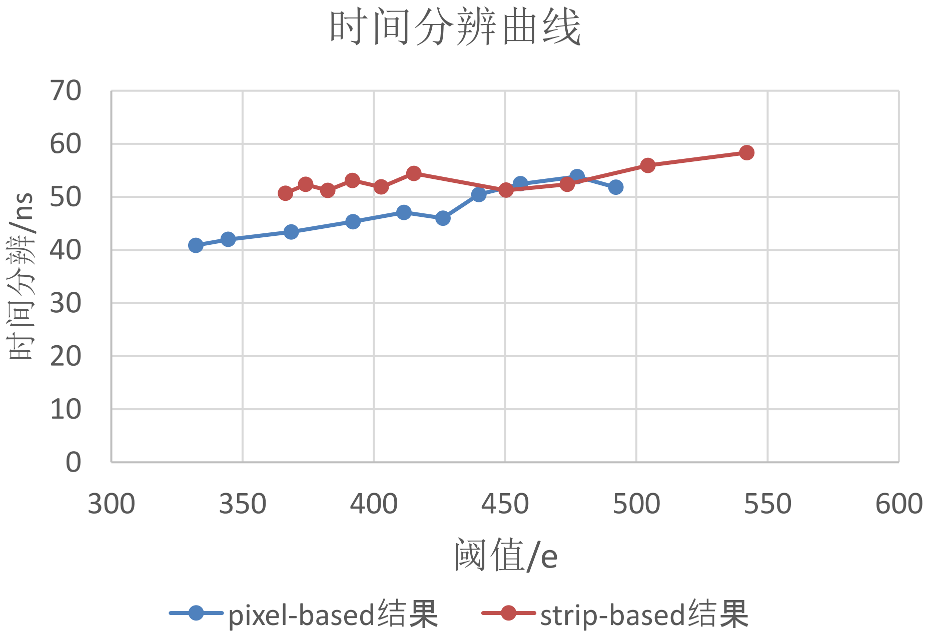
- 时间分辨性能测试
  - LGAD提供触发和参考时间

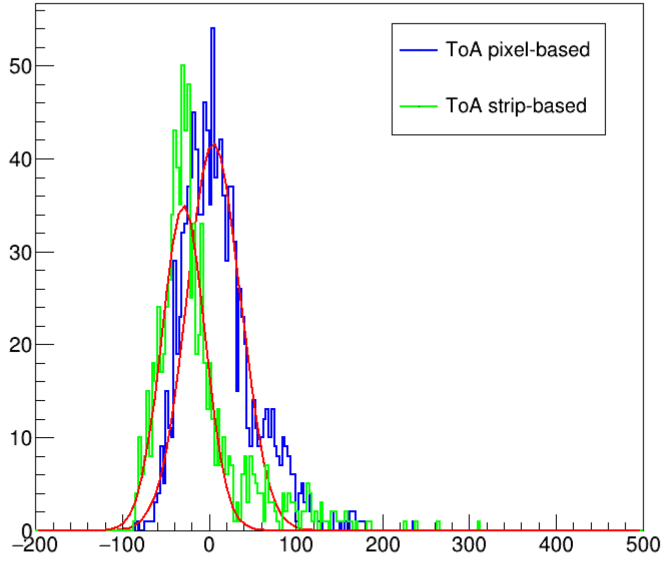










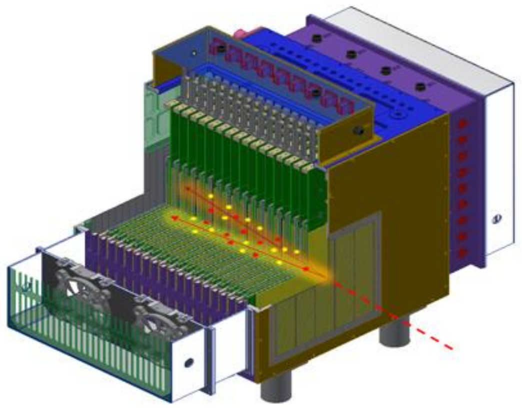


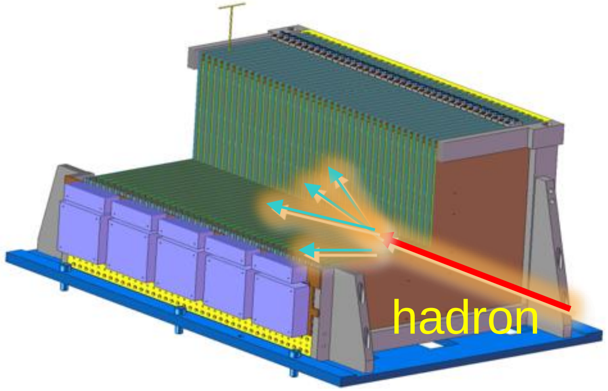
- 时间分辨能好于50ns →基本实现了预期设计指标

高颗粒度量能器

- 瞄准下一代高能量实验前沿需求，研制了高颗粒度量能器样机

Calo	Sampling No.	Sensitive detector	Absorber	Granularity	Electronics	Absorb length	Energy Resolution	weight
Sci-W ECAL	32	PSD+SiPM	W-Cu	5mm×5mm	SP-2E	22 X_0	16%@ 1 GeV	0.3 T
AHCAL	40	PSD+SiPM	Fe	40mm×40mm	SP-2E	4.7 NIL	60%@ 1 GeV	5.0 T



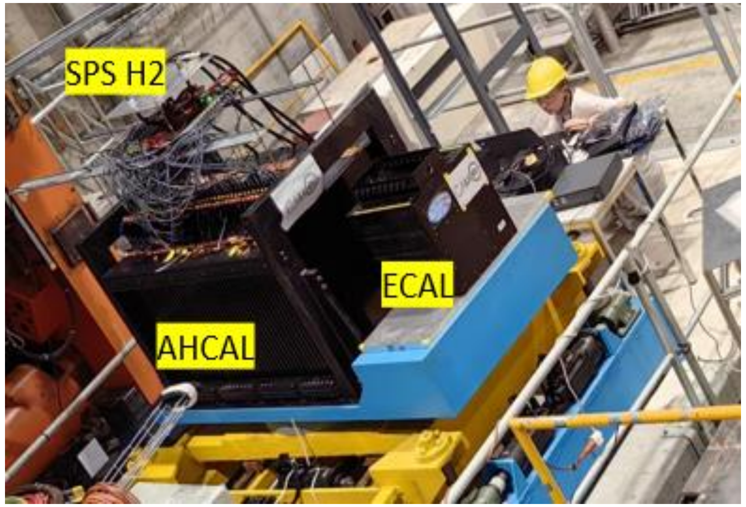


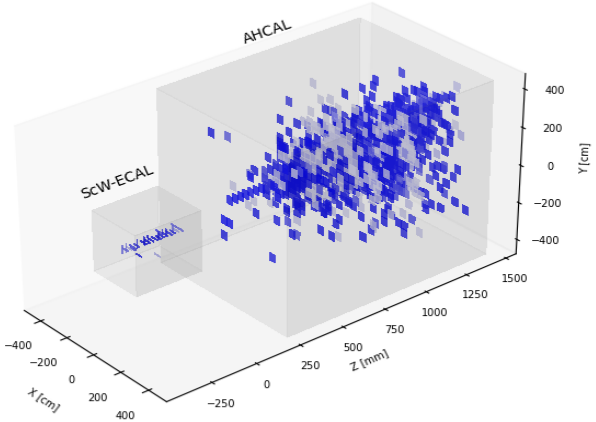
电磁量能器

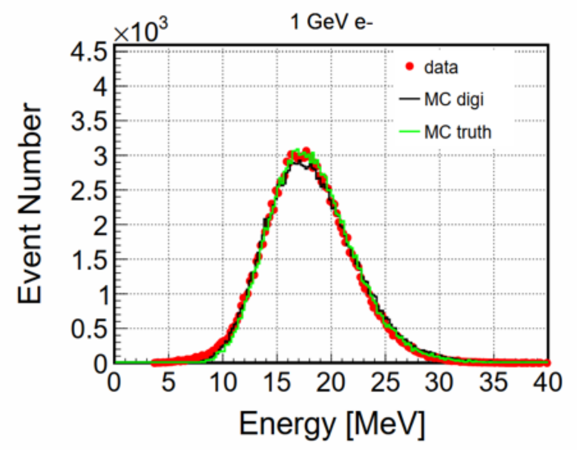
强子量能器

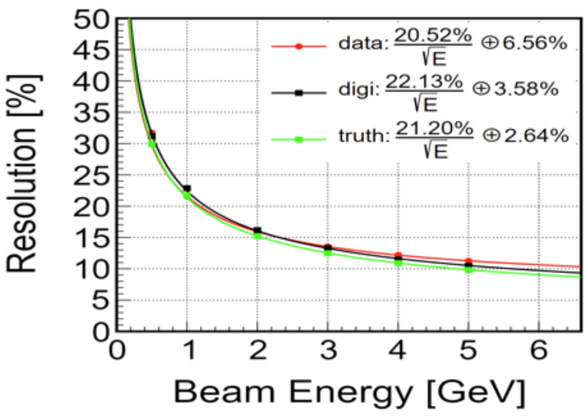
高颗粒度量能器

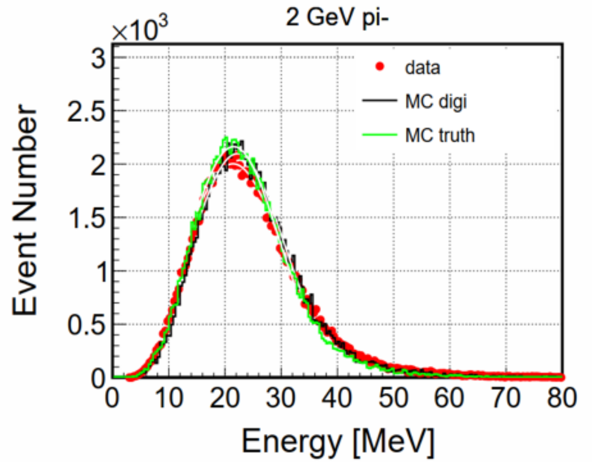
- 在CERN开展了束流测试
- AHCAL能量分辨率
  - 22% @ 1 GeV e-
  - 55%@ 1 GeV pi-

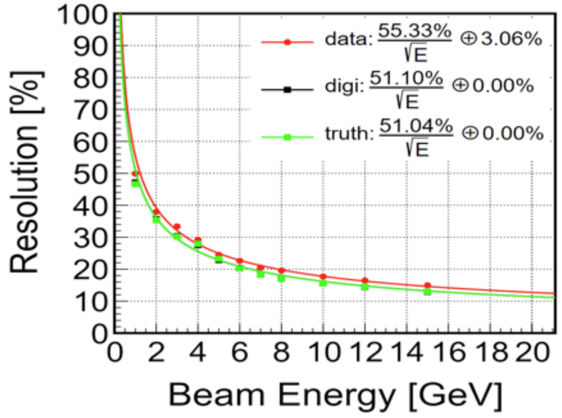










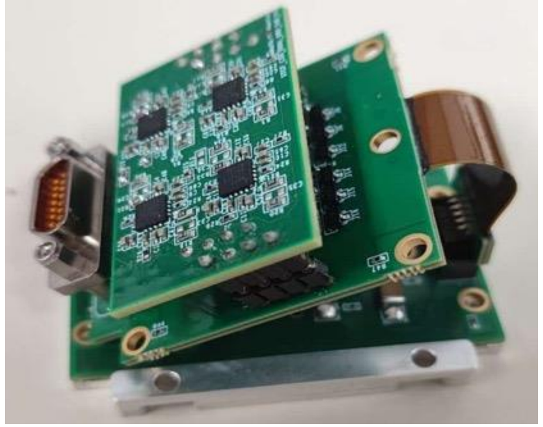


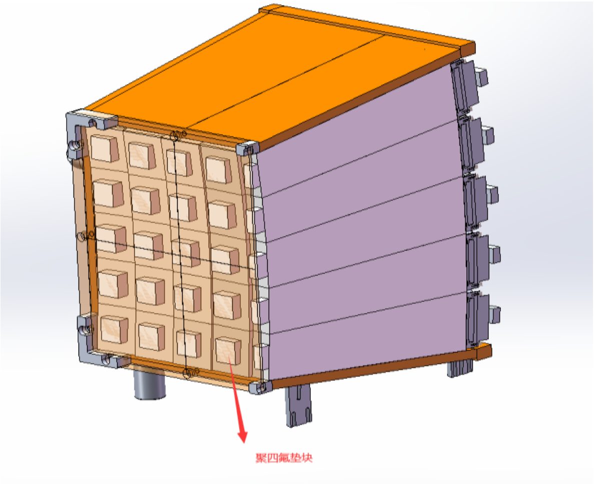
AHCAL对电子的能量响应

AHCAL对强子的能量响应

晶体型快时间响应量能器

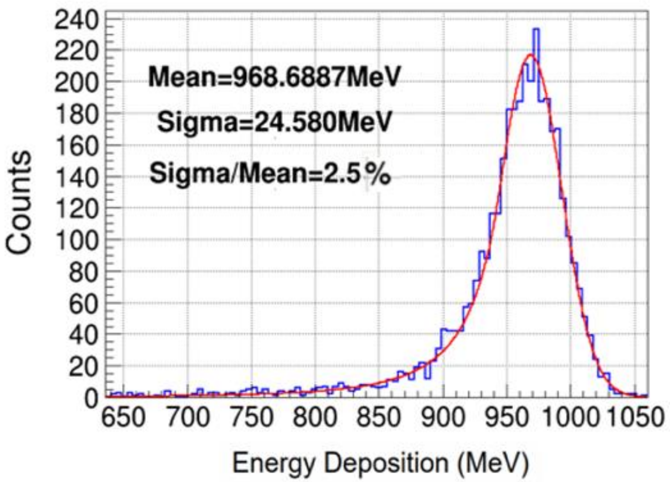
- 瞄准下一代高亮度实验前沿需求
- 基于pCsI+APD开展了新型高精度快响应量能器的研究
  - 优化了pCsI晶体光输出
    - LY ＞ 200 pe/MeV
  - 设计了高精度、大动态范围读出电子学
    - 噪声 ＜ 2 fC，动态范围>1000倍

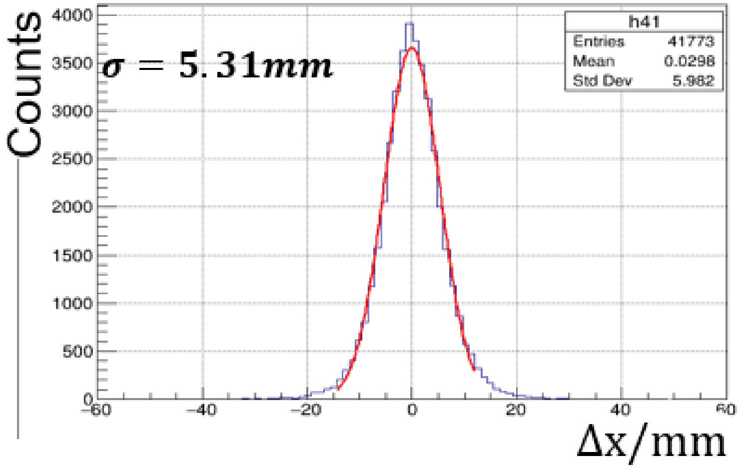


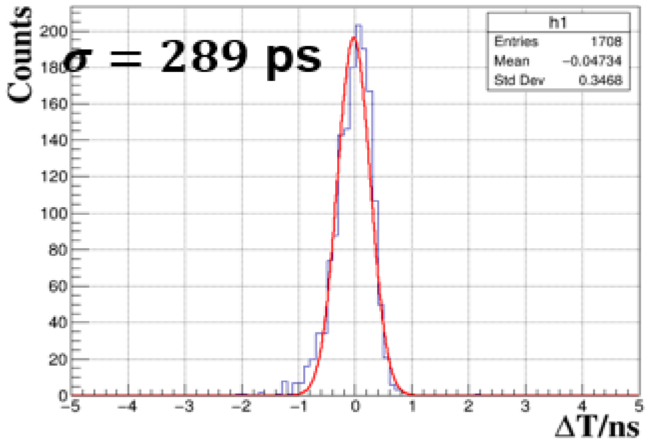


晶体型快时间响应量能器

- 2024年，在CERN PS束线开展了束流测试，对1 GeV电子的响应：
  - 能量分辨率：2.5 % @ 1GeV
  - 位置分辨：好于 6 mm
  - 时间分辨：好于300 ps

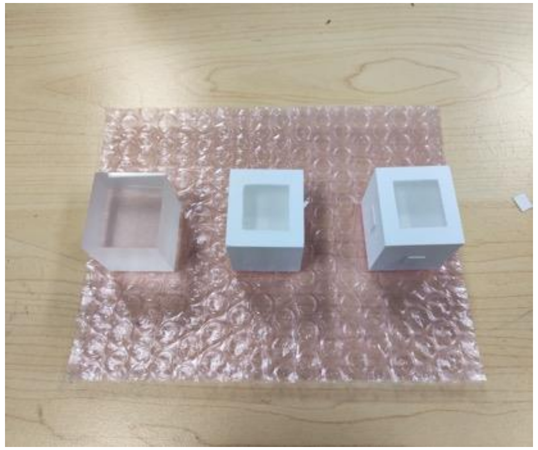




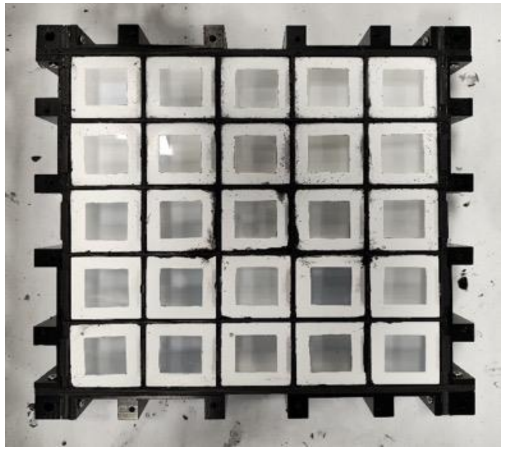


基于晶体的高颗粒度量能器

- 瞄准下一代空间大型高能宇宙线实验，开展晶体型高颗粒度量能器的研究
  - 没有额外的吸收体，可以兼顾能量分辨和位置分辨两个方面，且扩展性好
- 基于BGO立方晶体+APD读出开展了相关工作
  - 两个APD读出实现了10^6倍读出动态范围

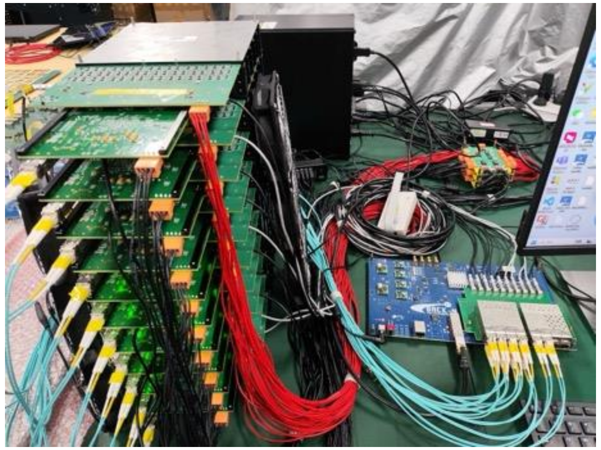


BGO晶体单元



BGO晶体阵列

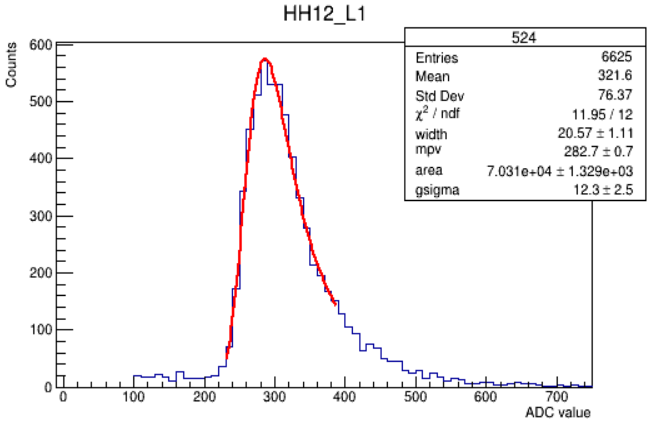
读出电子学板



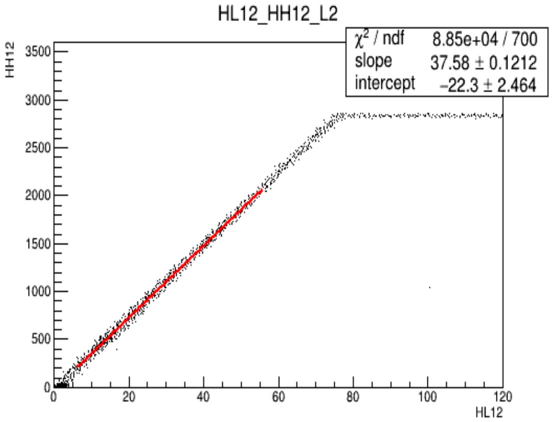
样机

基于晶体的高颗粒度量能器

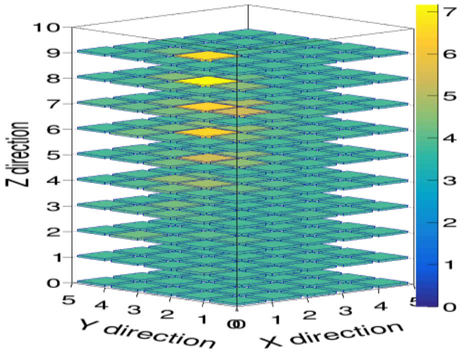
- 2024年， 在CERN开展了高能粒子束测试
- 能量分辨 5% @5 GeV e-
  - 高颗粒度引入的支撑材料较多
  - 晶体自身光收集均匀性问题



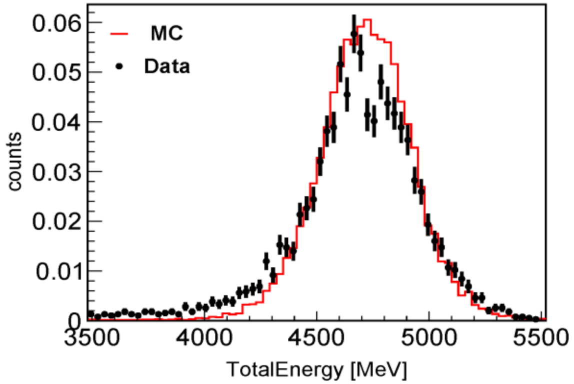
单元 MIPs响应



高低增益关系

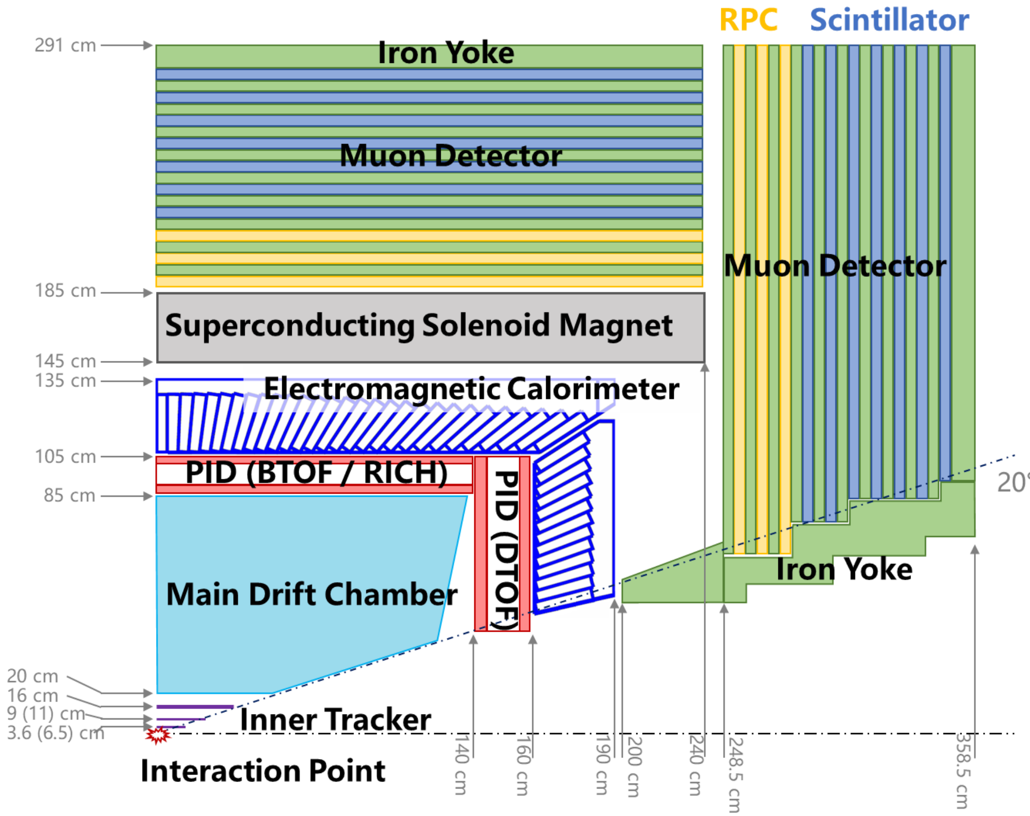


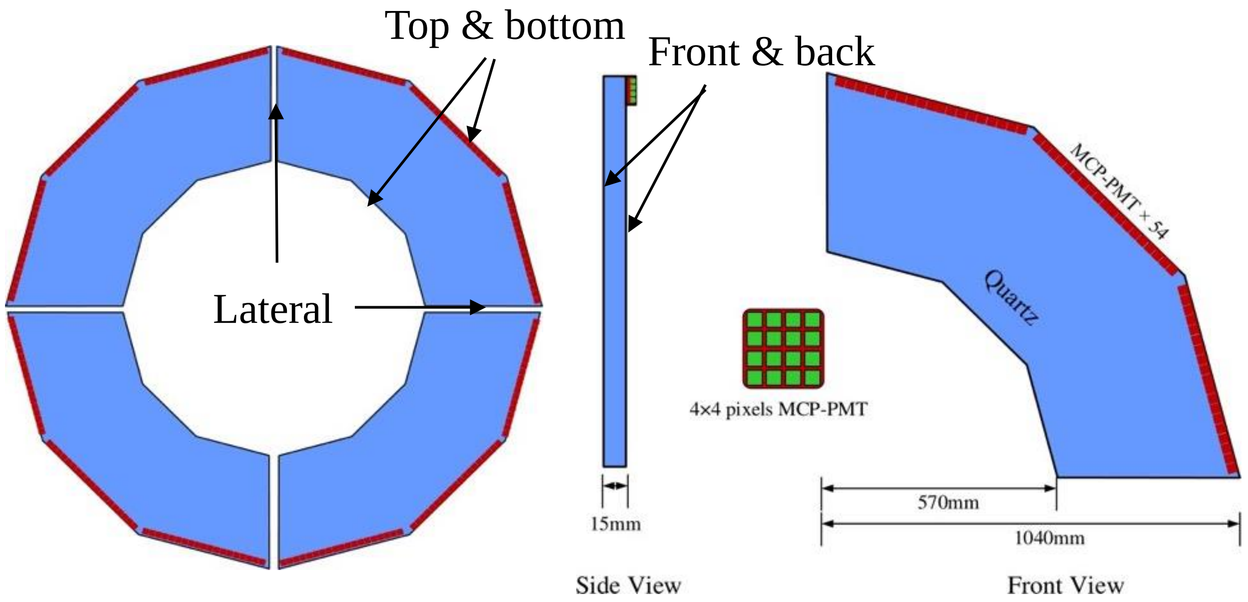
簇射发展



5 GeV e-能量沉积

DIRC探测器：DTOF粒子鉴别器





$$\sigma_{tot}^2 \sim \boxed{\sigma_{trk}^2 + \sigma_{T_0}^2} + \boxed{\left(\frac{\sigma_{elec}}{\sqrt{N_{p.e.}}}\right)^2 + \left(\frac{\sigma_{TTS}}{\sqrt{N_{p.e.}}}\right)^2 + \left(\frac{\sigma_{det}}{\sqrt{N_{p.e.}}}\right)^2}$$

~40 ps

DTOF：DIRC-like TOF，类全反射契伦科夫光探测的飞行时间探测器

- STCF物理需求：4σ π/K 鉴别 @p≤2 GeV/c

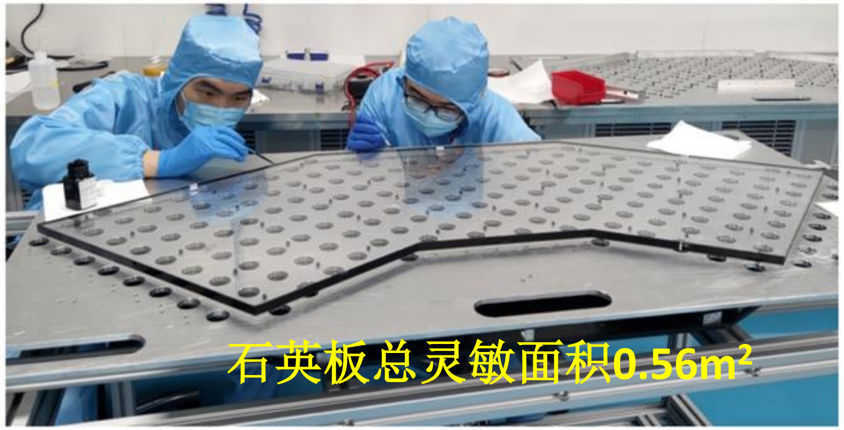
➔总时间分辨$\sigma_{tot} < 50$ ps

➔DTOF 本征定时分辨$\sigma_{DT} < 30$ ps

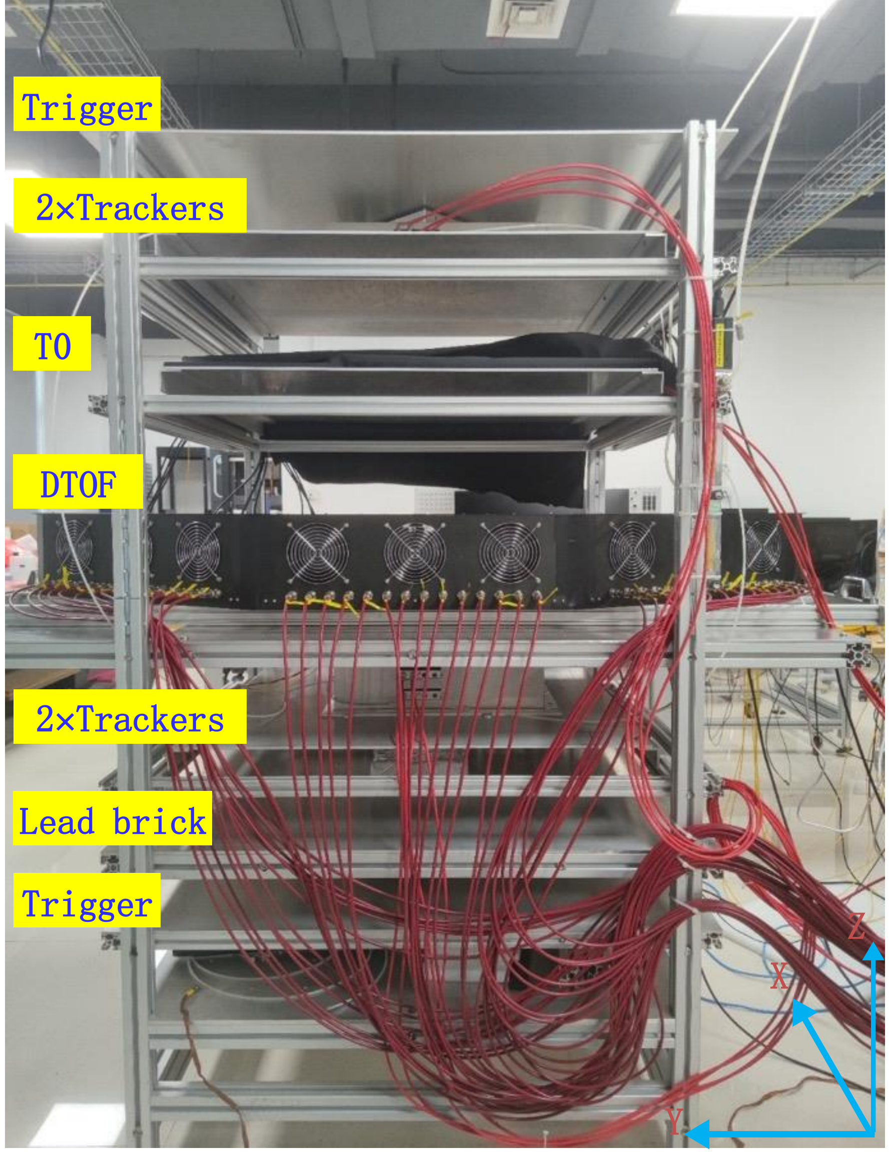
DTOF全尺寸样机和宇宙线测试平台

贺利氏 Suprasil 312 高纯熔融石英辐射体

- 表面粗糙度<1nm
- 厚度(平行度)<±25um
- 保持契伦科夫光方向性，重建每个光子的传播路径



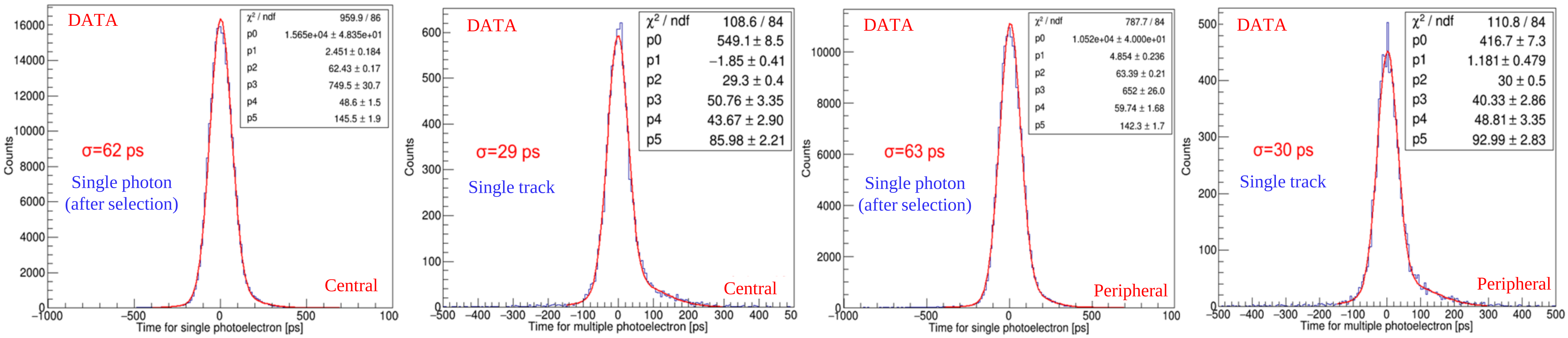
- 微通道板光电倍增管（MCP-PMT）探测契伦科夫光，TTS~30ps
- 高精度电子学，系统时间分辨<15ps
- 宇宙线测试系统径迹测量误差<200um，定时误差~20ps，运行稳定（>2月）



宇宙线测试结果

- 探测效率 ~99%
- 单光子时间分辨：~60*ps*
- 单径迹时间分辨：~22*ps*
- 实验结果与GEANT4模拟符合

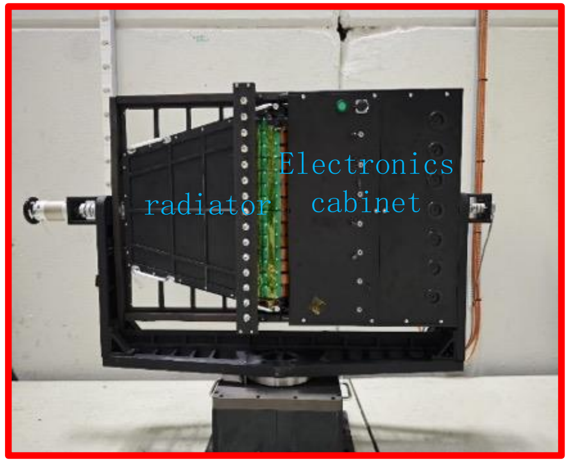
Test areas			Central area	Peripheral area
Number of photon electrons		DATA	20.6	17.8
		MC	20.3	17.6
Time resolution of the DTOF prototype	DATA	Single photon	59 ps	60 ps
		Single track	21 ps	22 ps
	MC	Single photon	54 ps	57 ps
		Single track	18 ps	22 ps

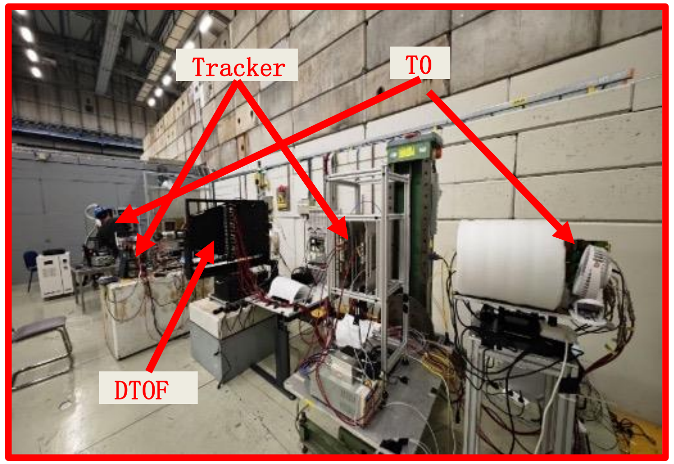


图中时间分辨均包含系统时间晃动贡献（20ps）

CERN PS-T9 束流测试

- 利用最大似然法，实现4.4σ的π/p分辨@4GeV/c（等效π/K分辨@2GeV/c ）
- 模拟结果4.6σ的π/p分辨@4GeV/c，实验与模拟吻合

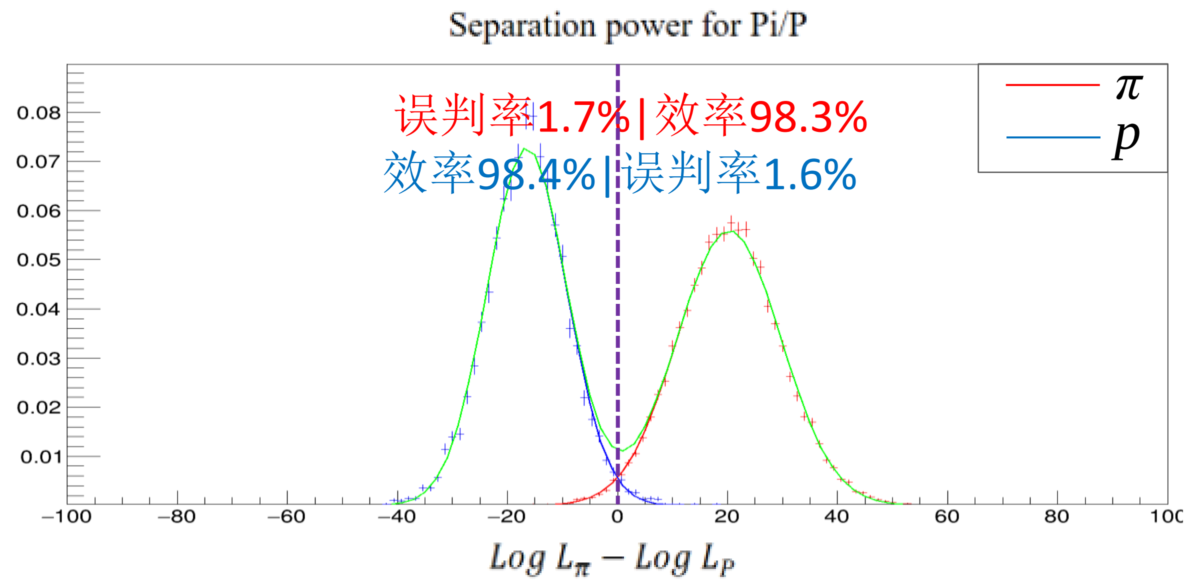


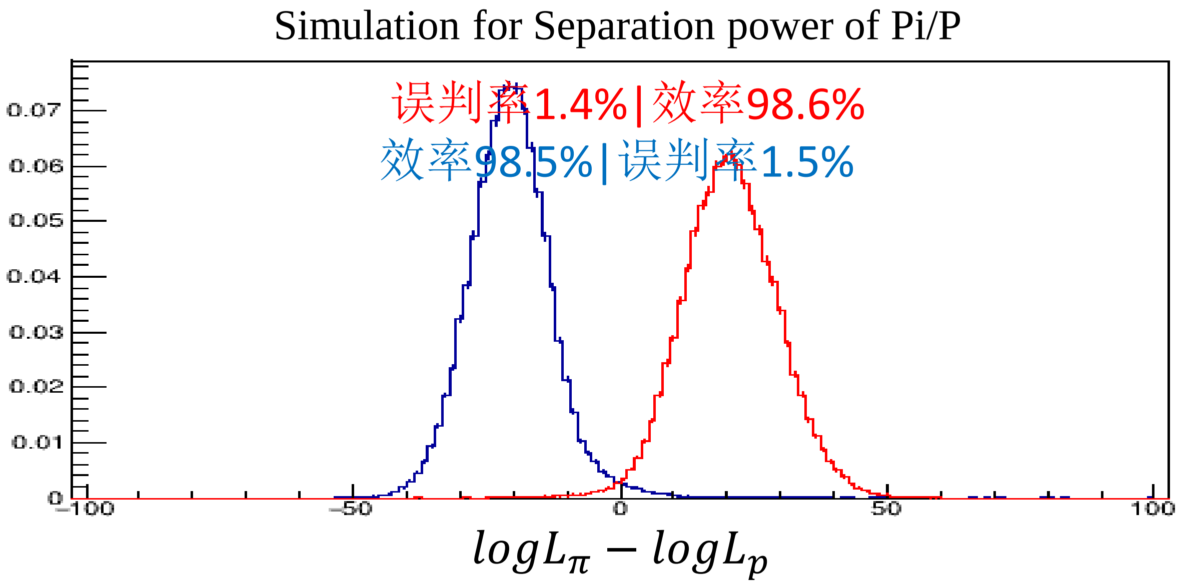


DTOF 1/3尺寸样机(辐射体、MCP-PMT、电子学、机械)

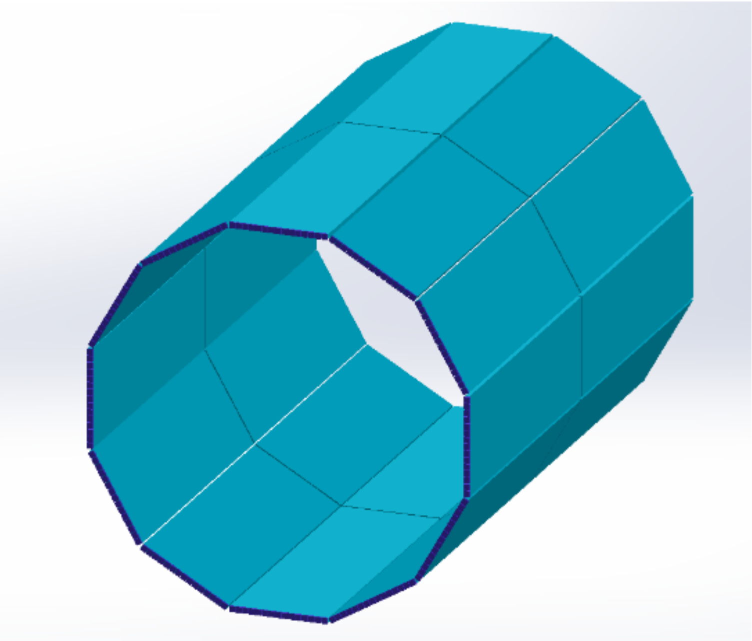
DTOF @ PS-T9

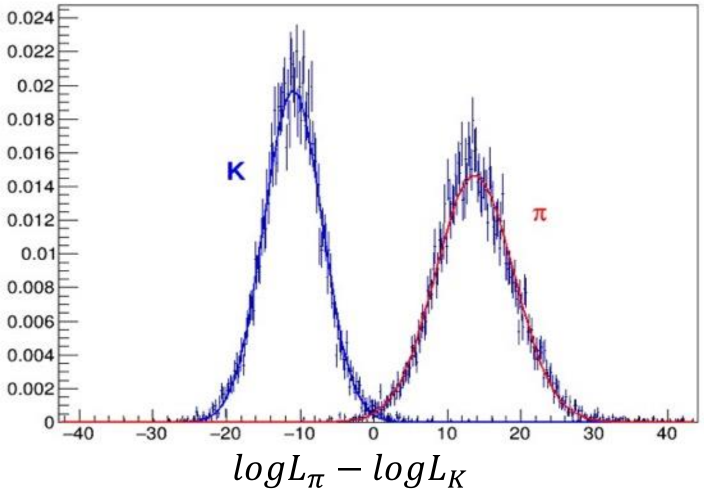
4.4σ的π/p分辨@4GeV/c

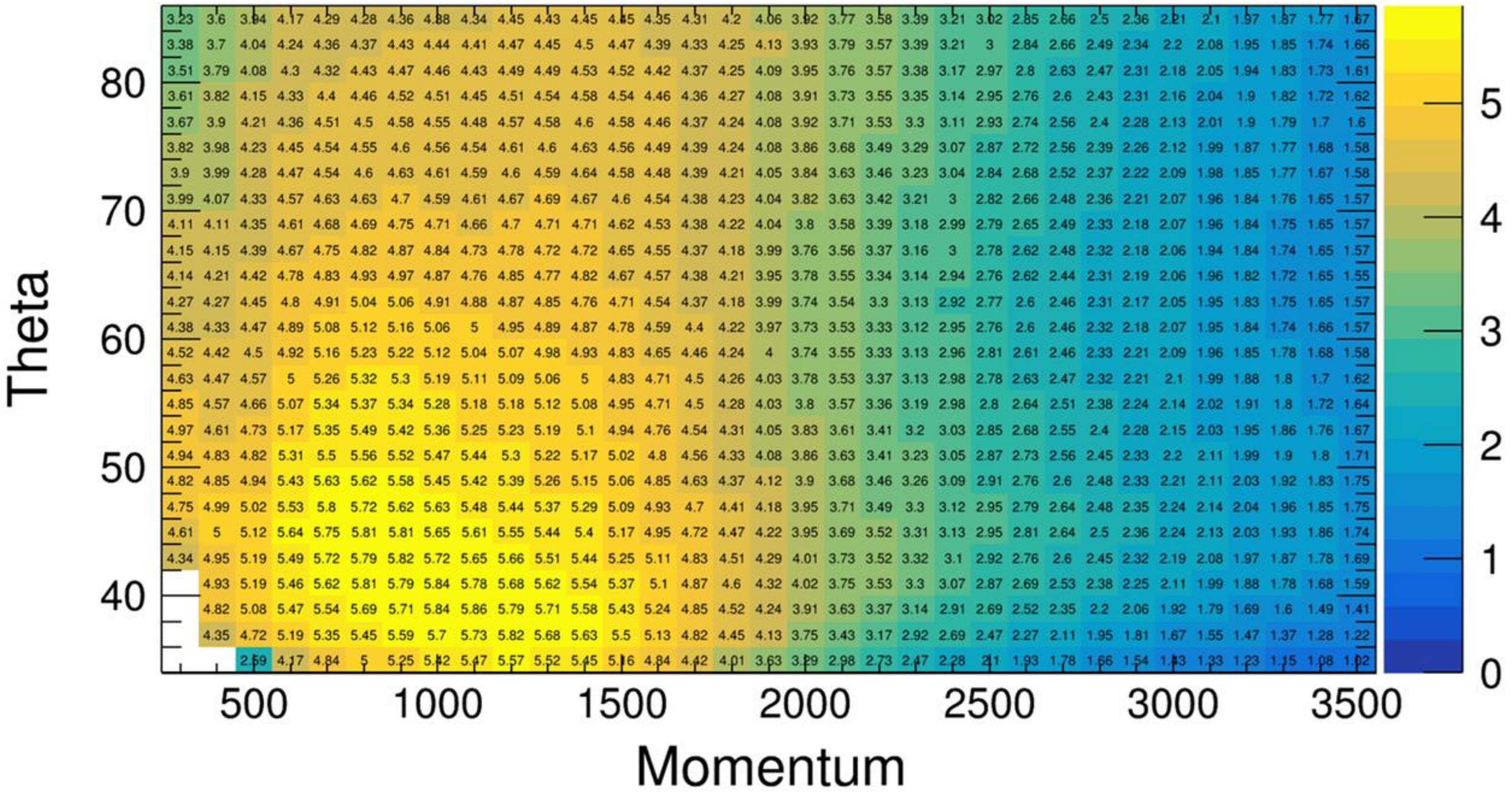




DTOF用于STCF谱仪桶部粒子鉴别





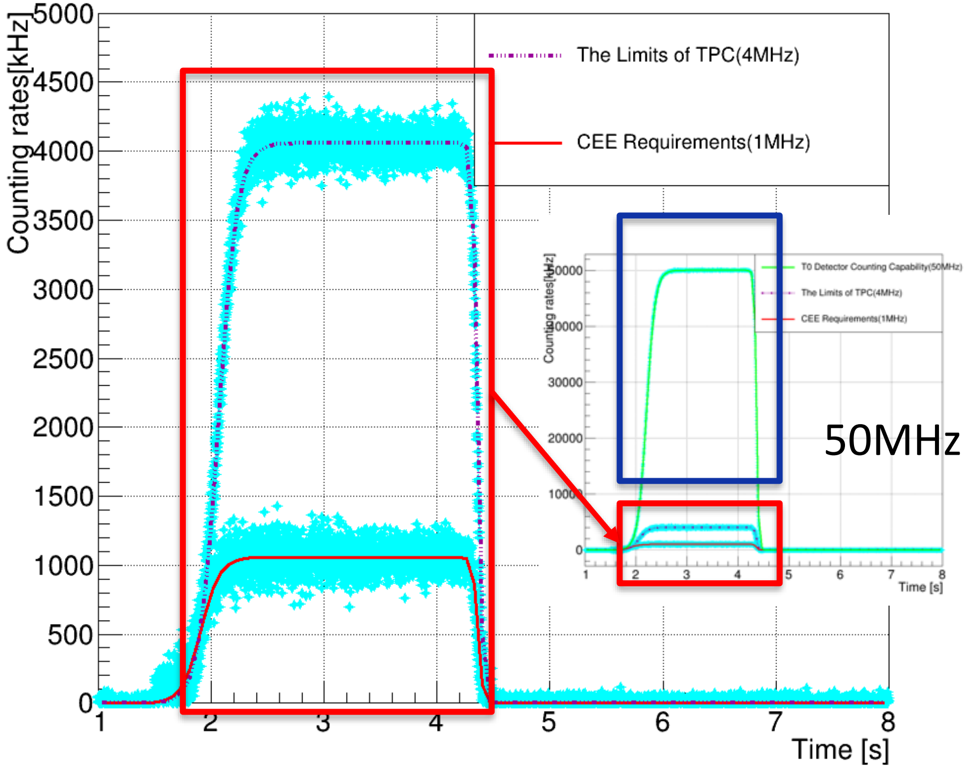


桶部DTOF结构紧凑、PID性能基本满足STCF实验需求

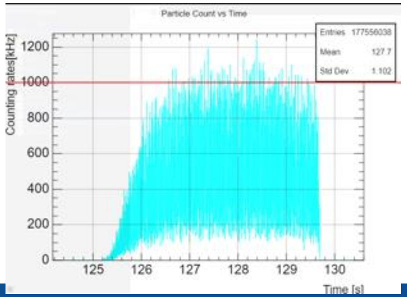
桶部DTOF模拟：在2GeV/c处对Pi/K鉴别水平~4σ

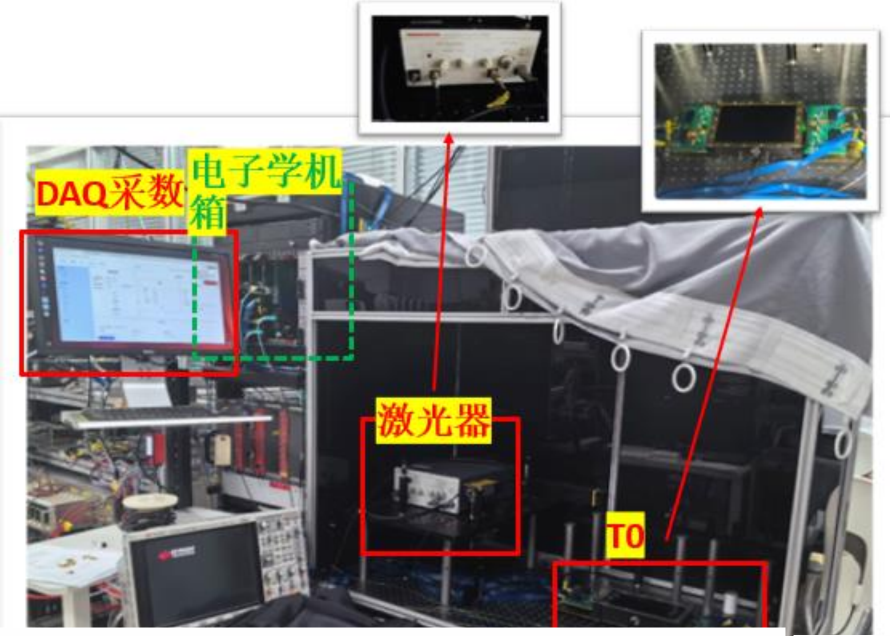
优化方向：添加光导、增长扩展区、调整滤波范围等

使用SiPM的超快定时



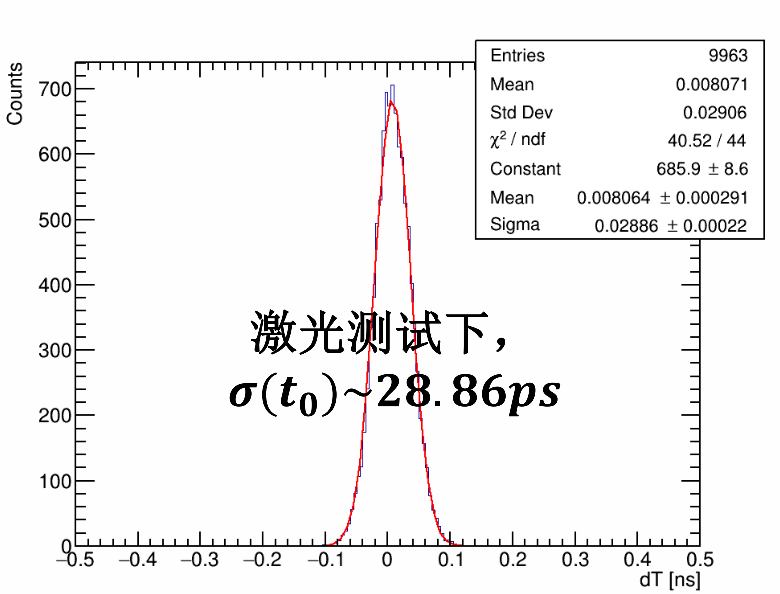
T0 探测器的计数率能力和束流诊断能力

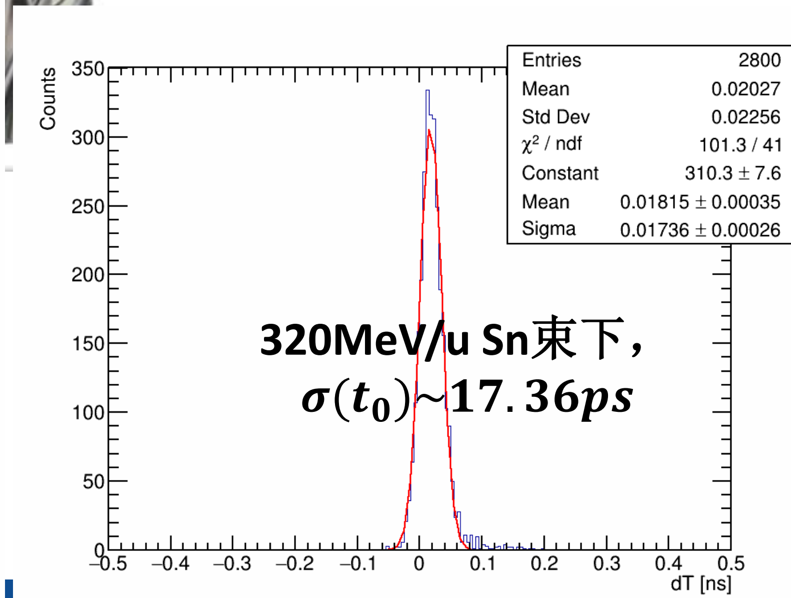




T0探测器激光测试条件：

- $TOT \sim 22ns$，$NPE \sim 400$
- SiPM电压58V





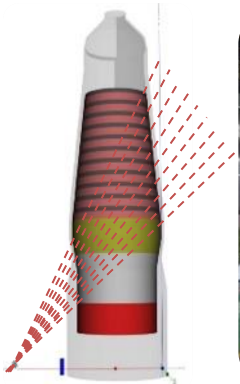
缪子成像装置及应用

工业生产安全、轨道交通、地质勘探等

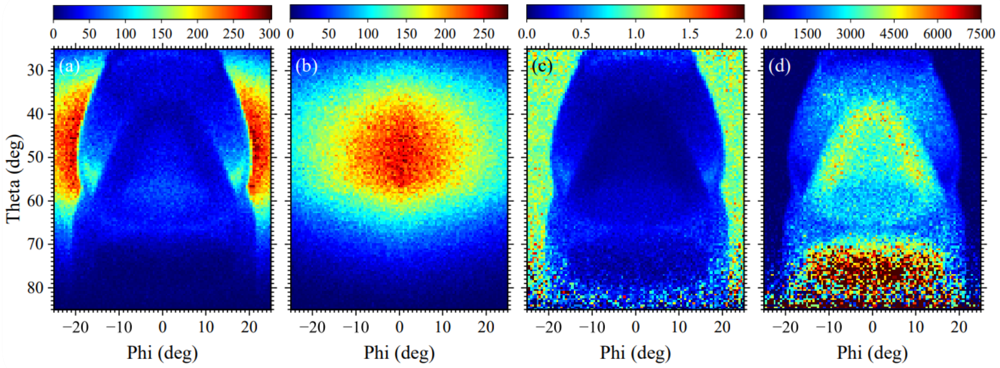
高分辨缪子“CT”成像装置

隧道施工与运行中安全预警（与深圳地铁合作）

河南钢铁公司2号高炉三维成像



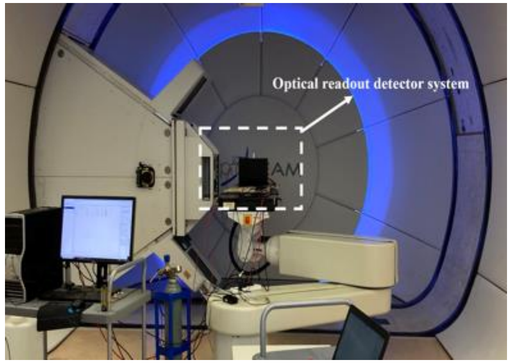

完成4套μSTC装置部署

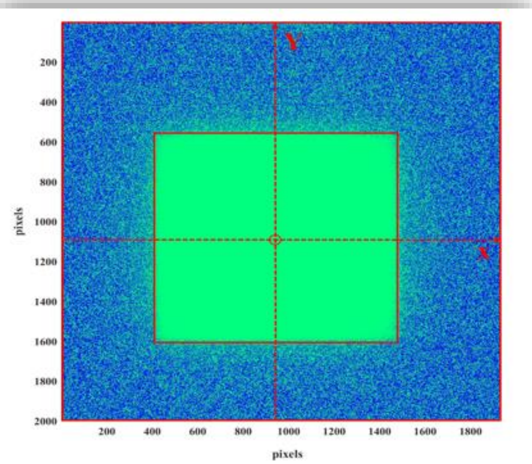


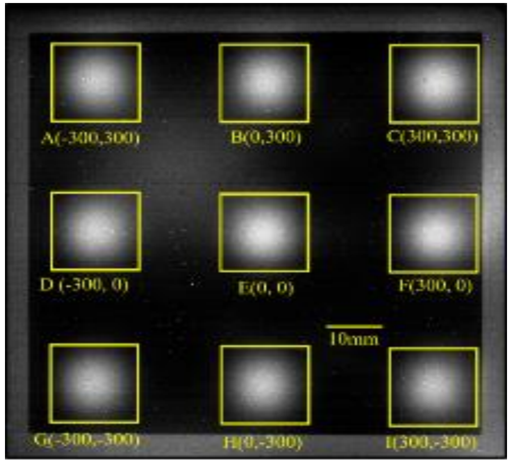
模拟预期结果

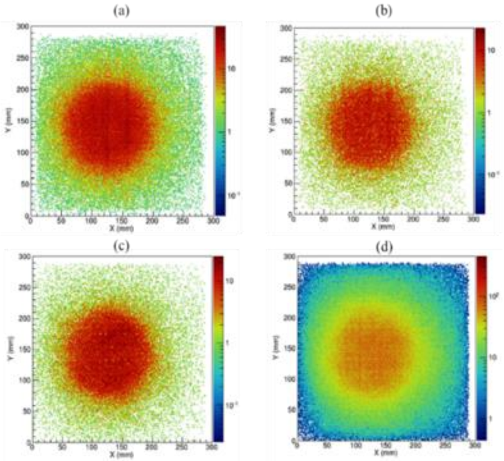
放射医疗射束质量保证（QA）

硼中子俘获、质子/重离子、以及伽马治疗射束QA









光子放疗QA

质子医疗QA

硼中子束QA

Cong Liu et al., NIM-A 1072 (2025) 170120.

Zhujun Fang et al., NIM-A1053 (2023) 168361