R&D for the STCF PID detector

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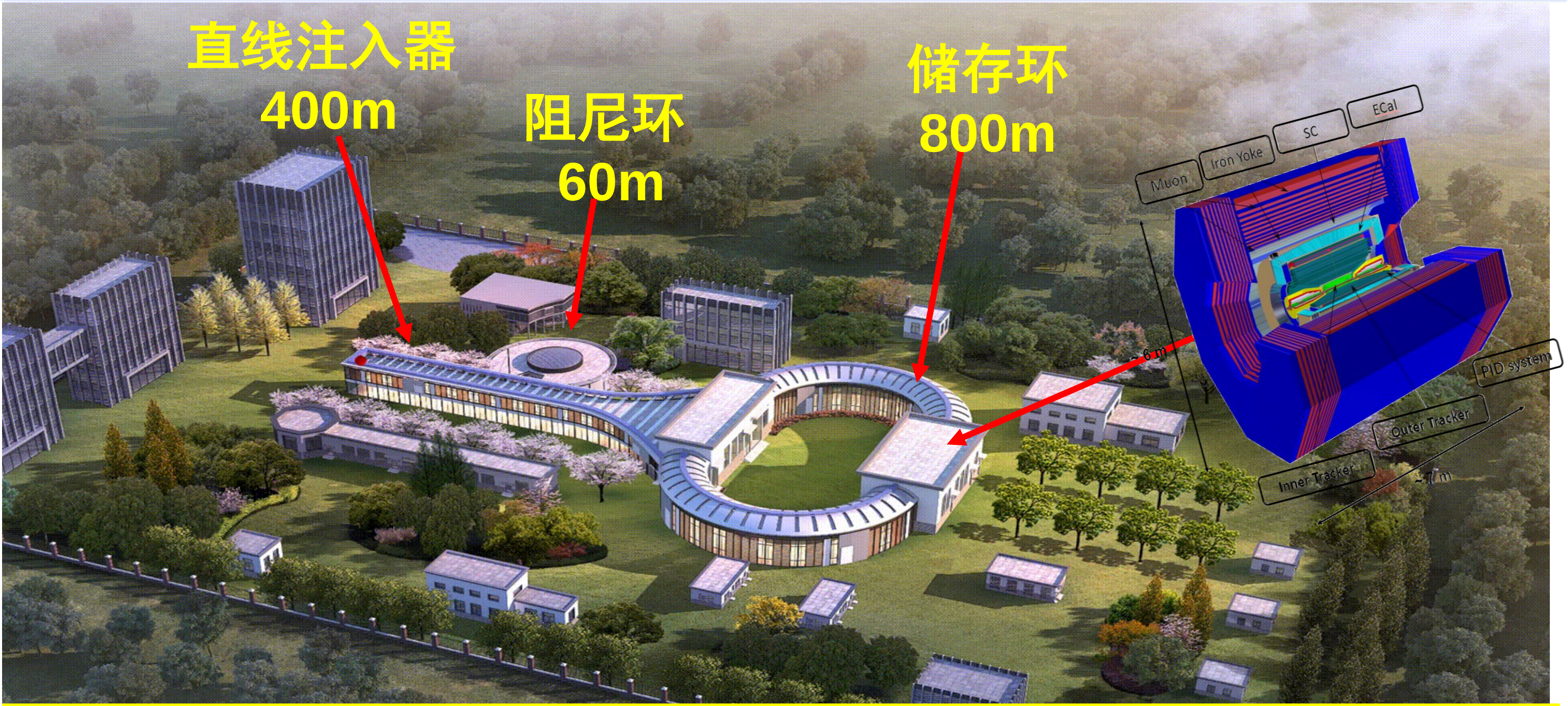
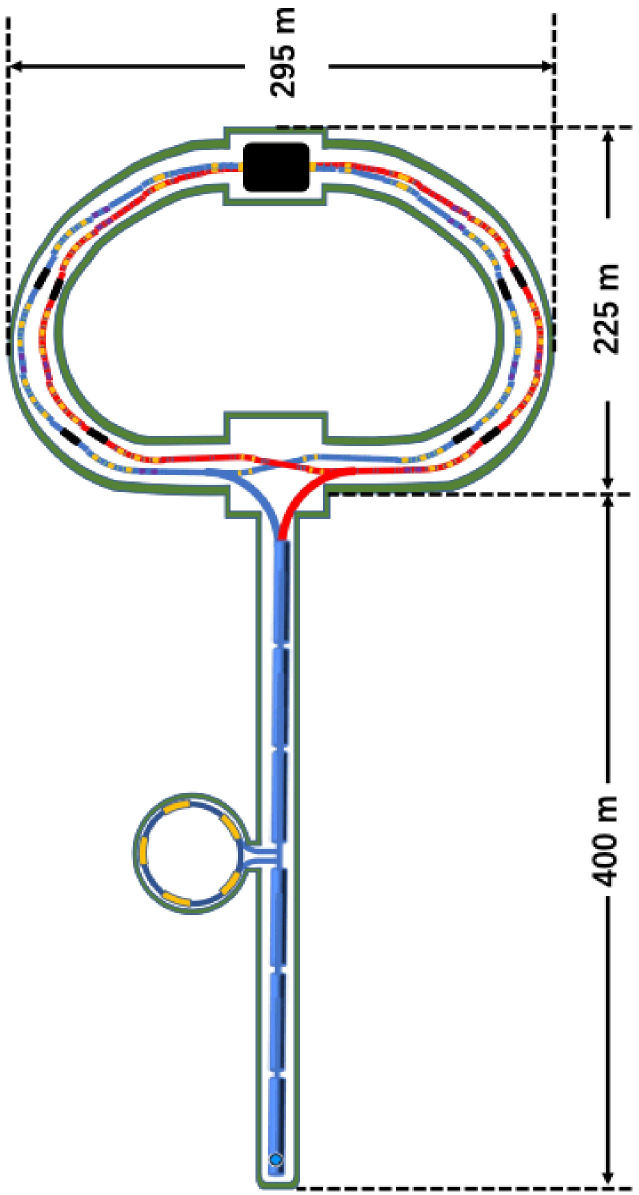
The CEPC Workshop on Flavor Physics, New Physics and Detector Technologies
Fudan university, ShangHai
Aug 15, 2023

STCF project



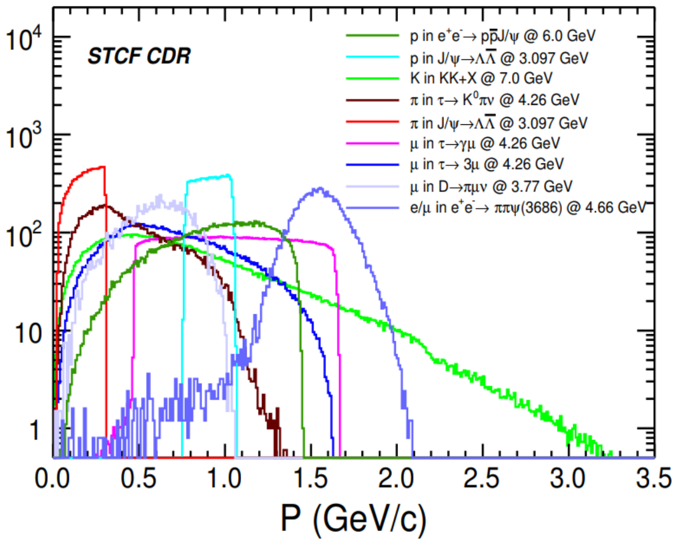


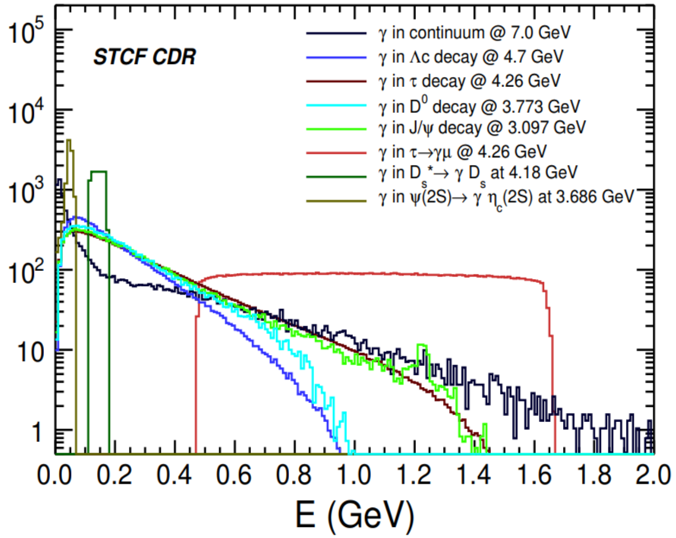
- 质心能量=2-7GeV，峰值亮度 =5×10^{34} cm^{-2} s^{-1} @ 4GeV
- 具备进一步提升峰值亮度和实现束流极化的潜力
- 十四五规划(2021-2025)：关键技术攻关， 4.2亿.
- 十五五规划(2026-2030)： 建设，6-7年，45亿.
- 运行15年

Physics Requirements

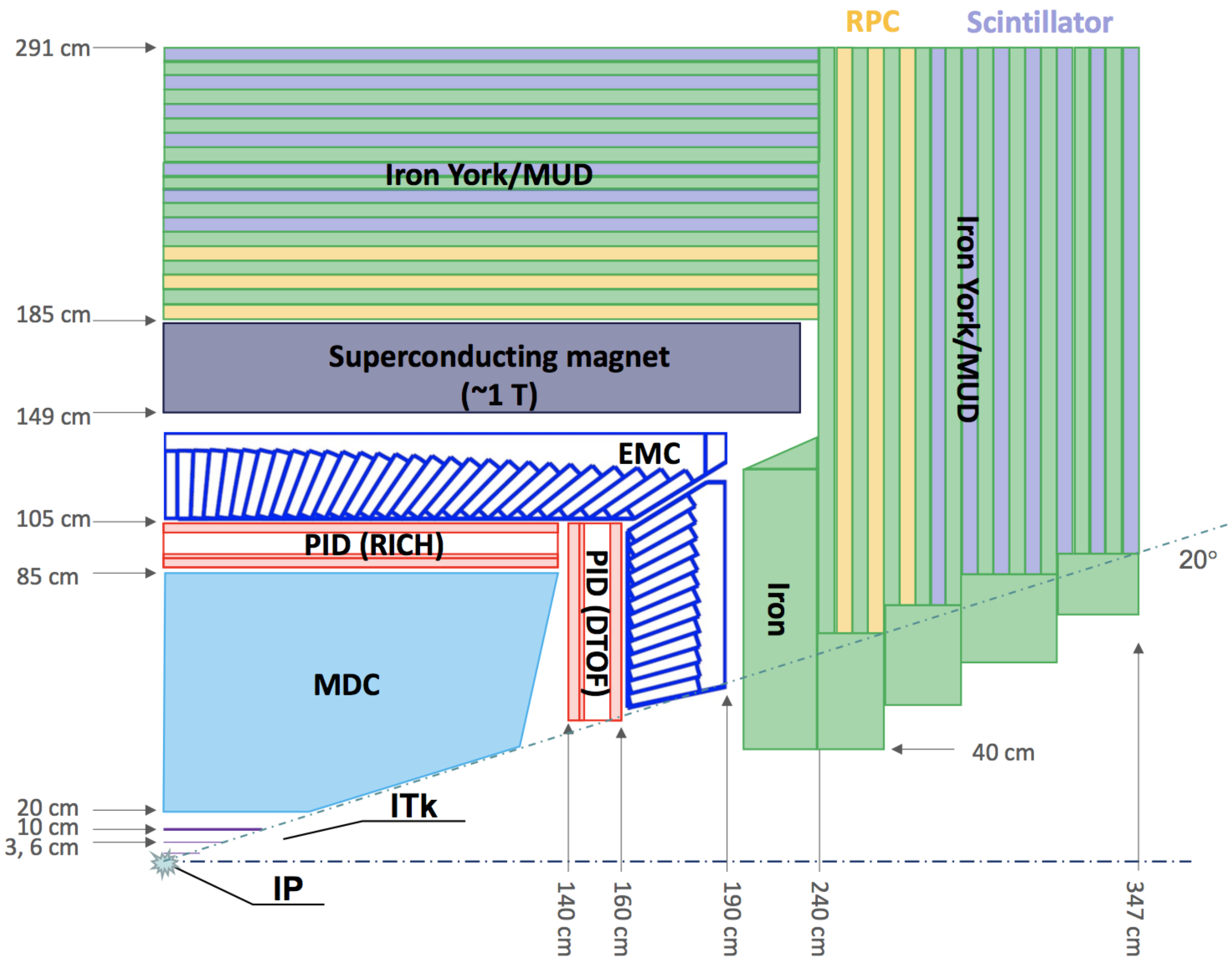
- **Highly efficient and precise reconstruction of exclusive final states produced in 2-7 GeV e+e- collisions**
  - Precise measurement of low-p particles → low mass
  - Excellent PID: π/K and μ/π separation up to 2 GeV

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 $\sigma_{\text{pos}} \approx 5$ 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	$\sigma_T = \frac{300}{\sqrt{p^3(\text{GeV}^3)}}$ ps





The STCF Detector Conceptual Design

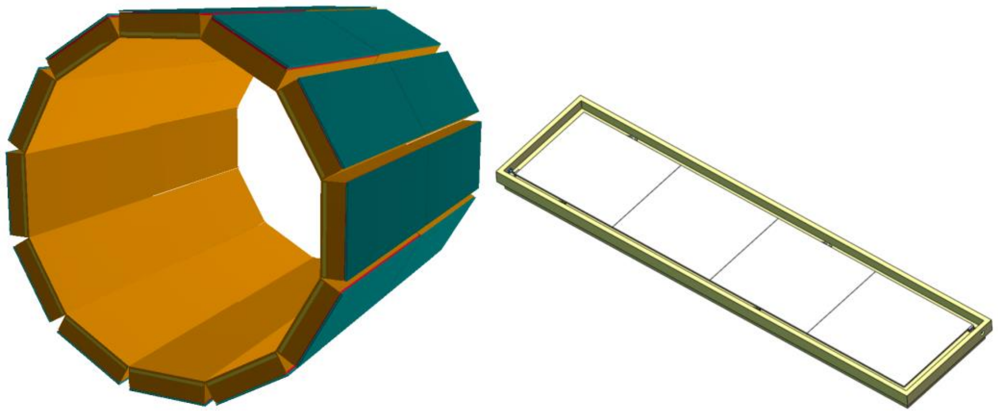


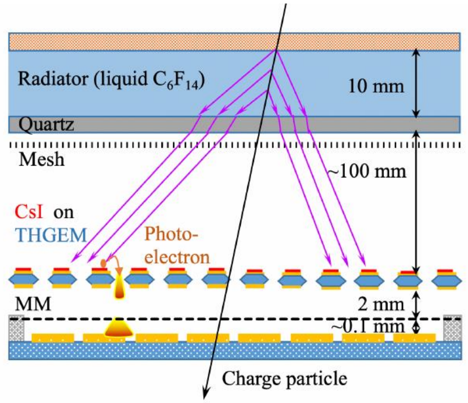
Solid Angle Coverage : 94%•4π (θ~20⁰)

ITk • $< 0.25\% X_0$ / layer • $\sigma_{xy} < 100\ \mu m$	Cylindrical μRWELL CMOS MAPS
MDC • $\sigma_{xy} < 130\ \mu m$ • $\sigma_p/p \sim 0.5\%$ @ 1 GeV • dE/dx~6%	Cylindrical Drift chamber
PID • π/K (and K/p) 3-4σ separation up to 2GeV/c	RICH with MPGD DIRC-like TOF
EMC E range: 0.025-3.5GeV σ_E (%) @ 1 GeV Barrel: 2 .5 Endcap: 4 Pos. Res. : 5 mm	pCsI + APD
MUD • 0.4 - 2 GeV • π suppression >30	RPC + scintillator

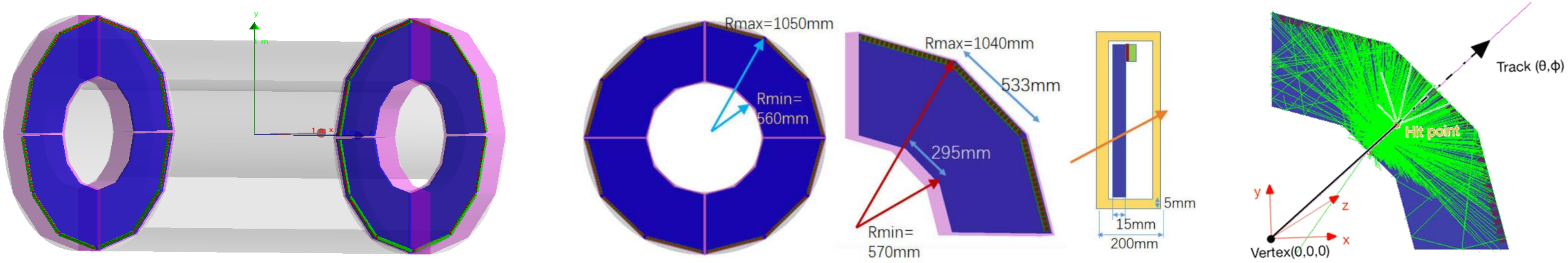
Particle Identification

❖ **Barrel : RICH detector utilizes MPGD for photon detection (TOF technology is no longer feasible for PID up to 2 GeV due to the short distance of flight)**





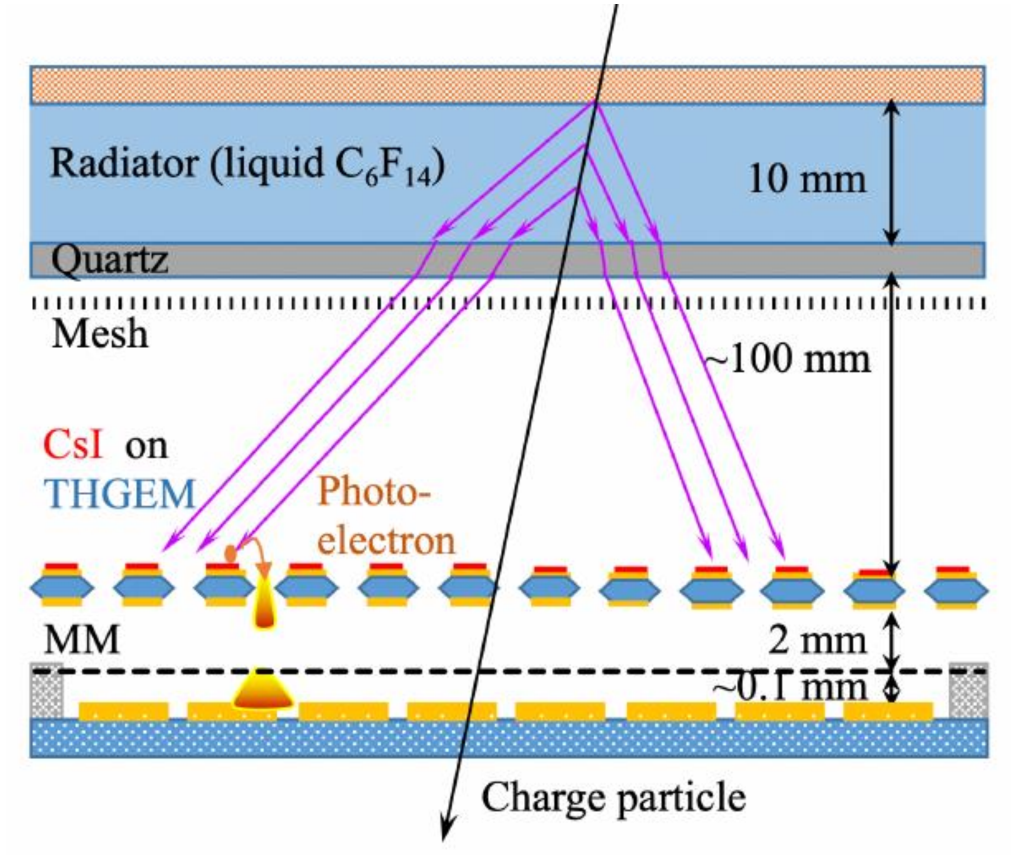
❖ **Endcaps : DIRC-like high-resolution TOF detector is proposed (TOF option is possible thanks to the longer distance of flight) .**



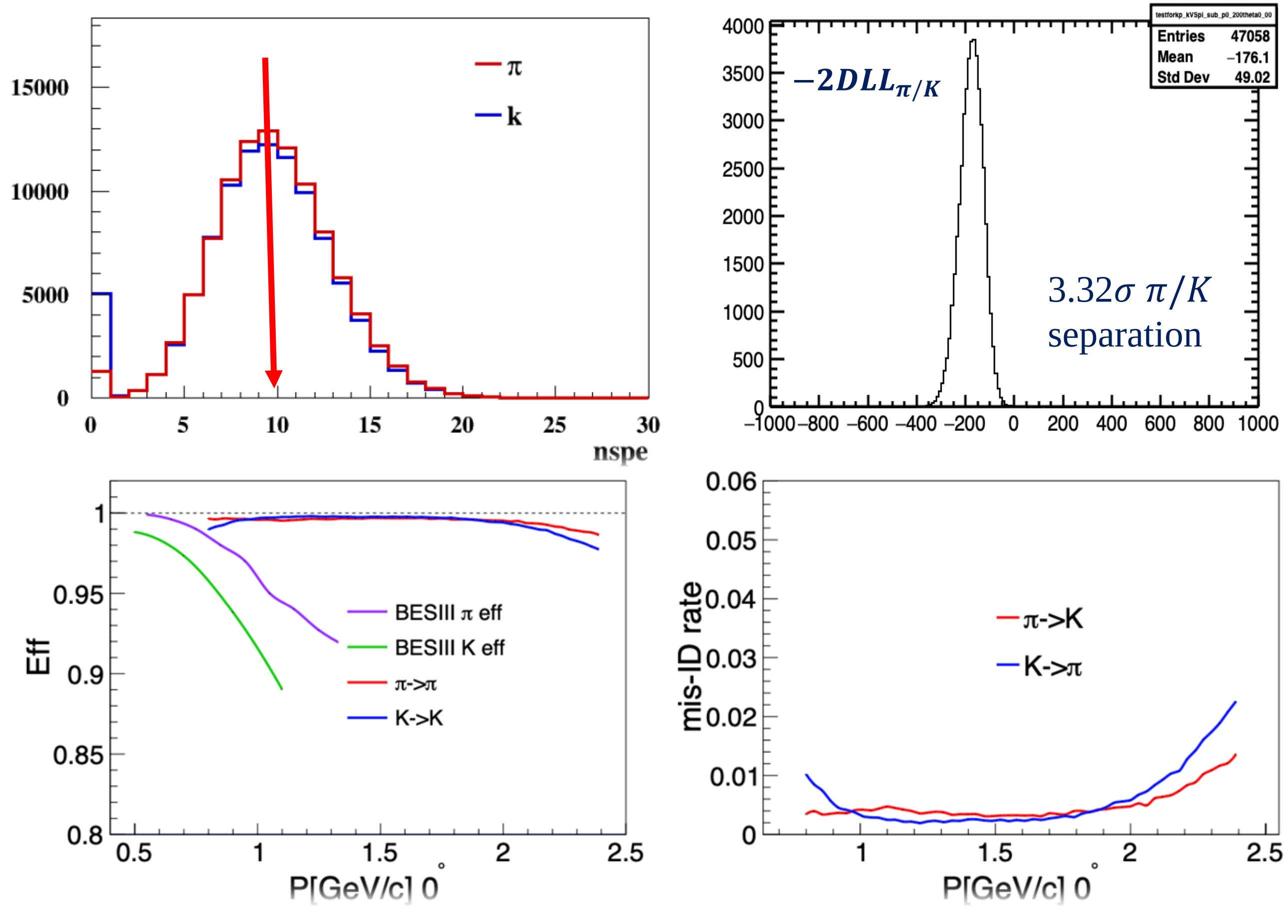
The RICH Detector

大面积单光电子探测
挑战：大面积气体探测器、紫外单光电子探测、读出电子学等

- Radiator: liquid C6F14 with n ~ 1.3
- THGEM+MM with CsI photo cathode
- Simulated number of photon electrons ~ 10
- Total material budget < $0.3X_0$

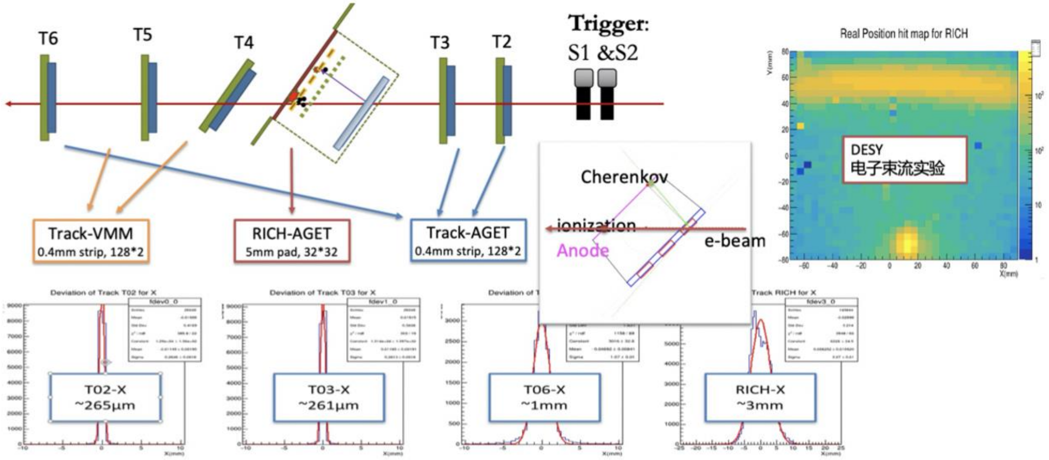


- Likelihood method adopted



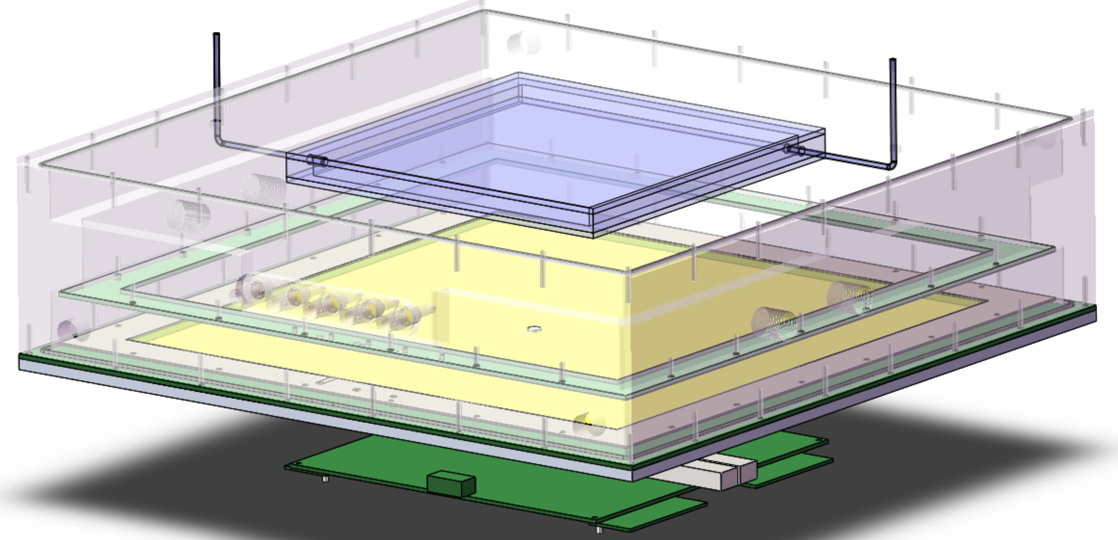
The RICH Detector R&D

A RICH prototype with quartz radiator
Performance study @ DESY in 2019
THGEM(CsI) + MM



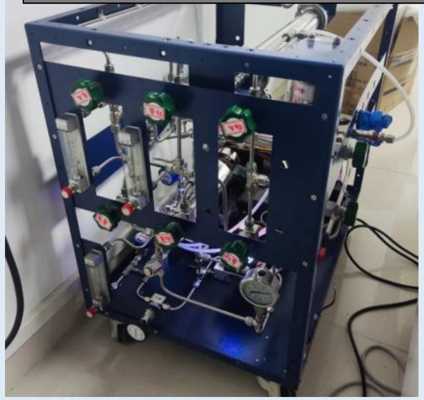
Towards to prototype with C6F14

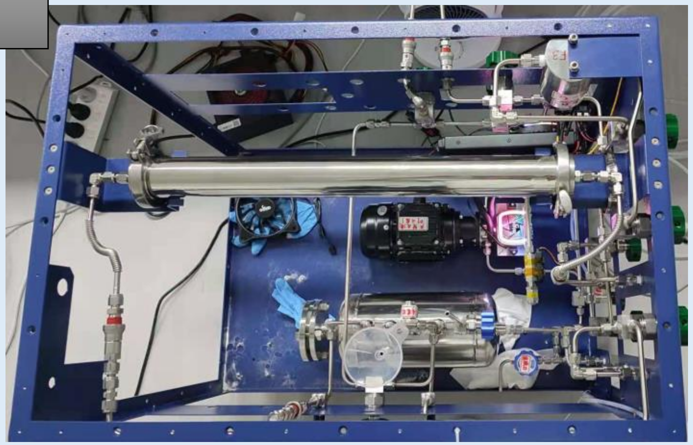
工程尺寸样机：2023年

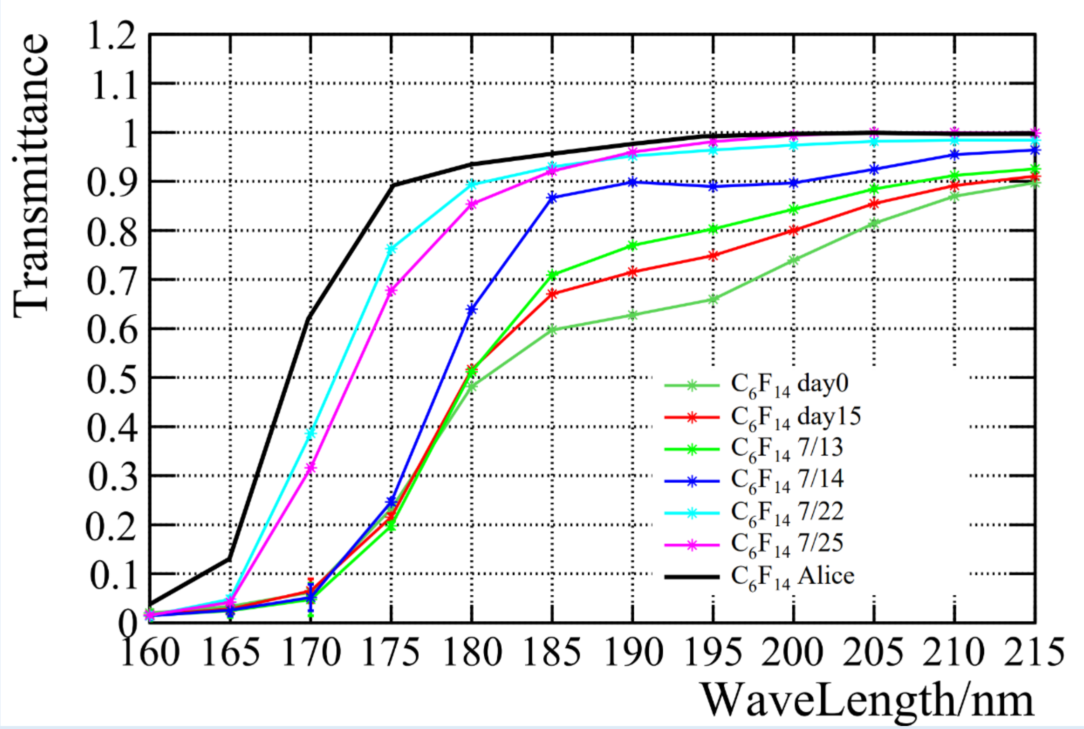


Development of a RICH Prototype with C6F14

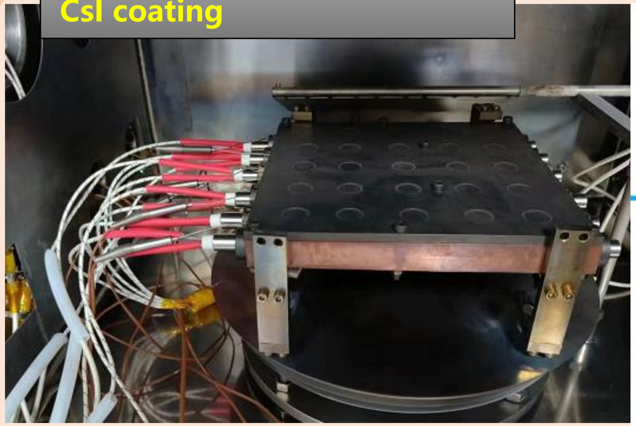
C6F14 purification

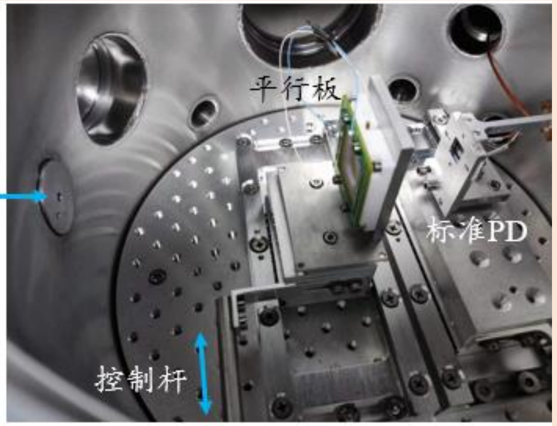


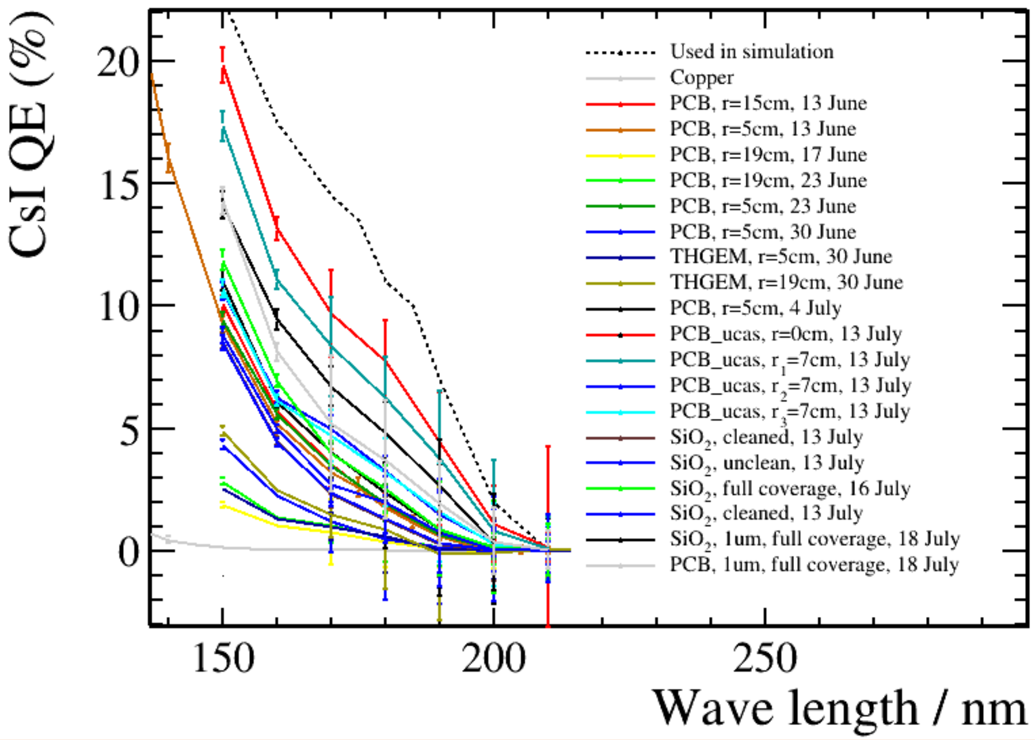




CsI coating

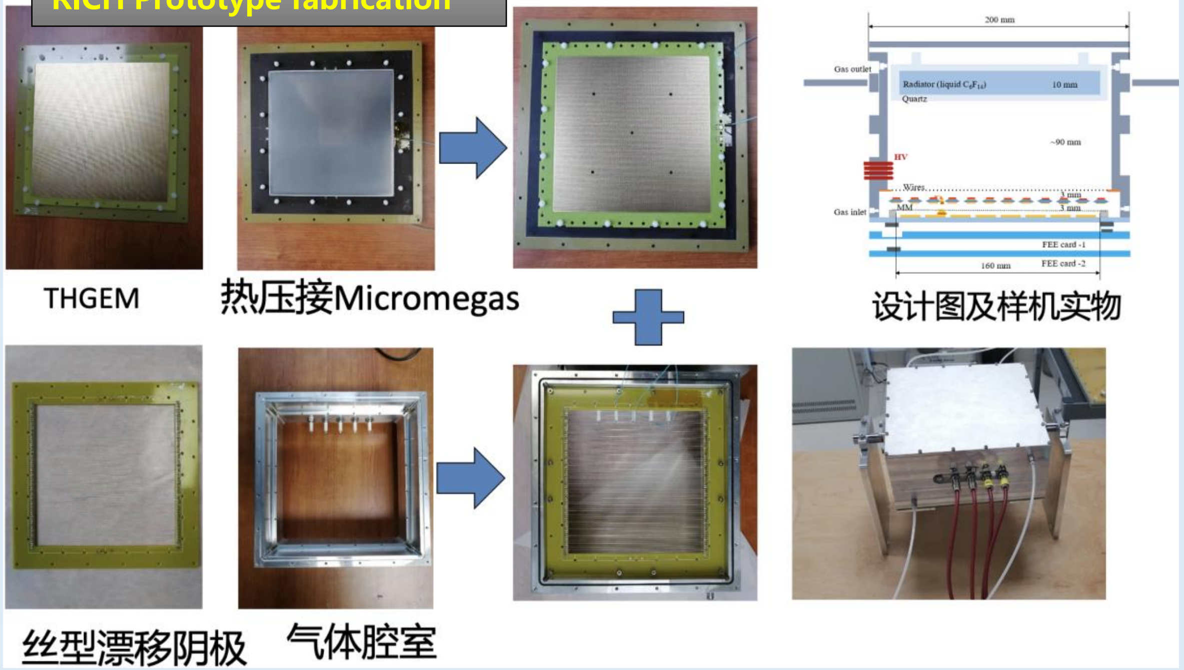


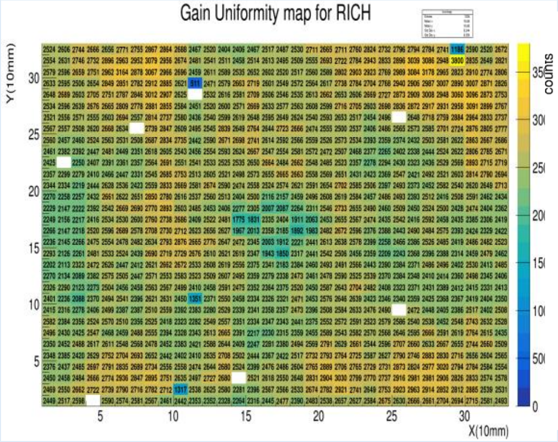


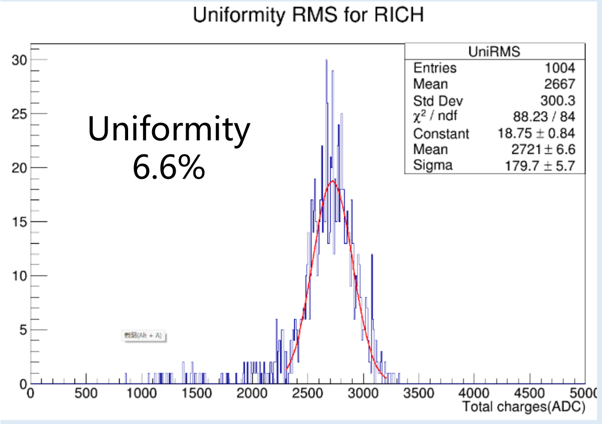


Development of a RICH Prototype with C6F14

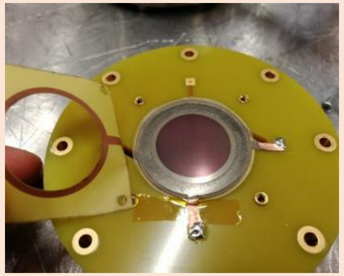
RICH Prototype fabrication

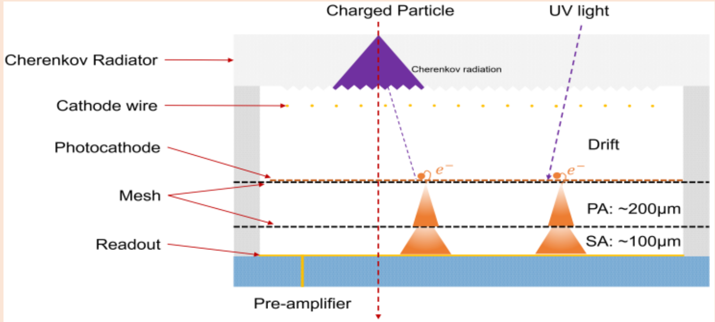


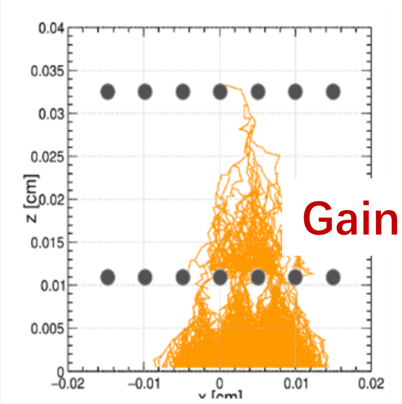




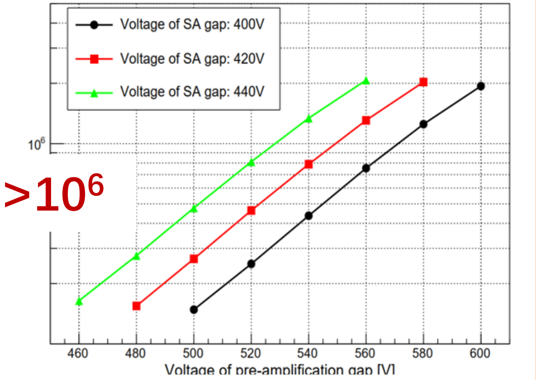
Fast Timing-DMM



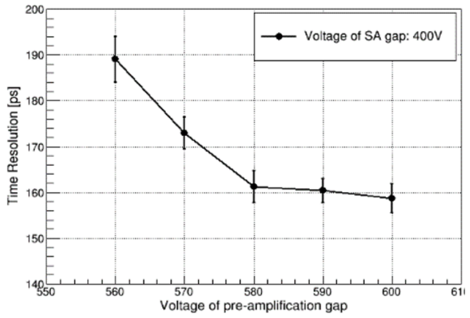


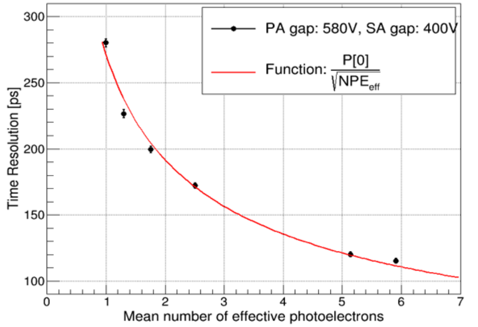


Gain>10^6



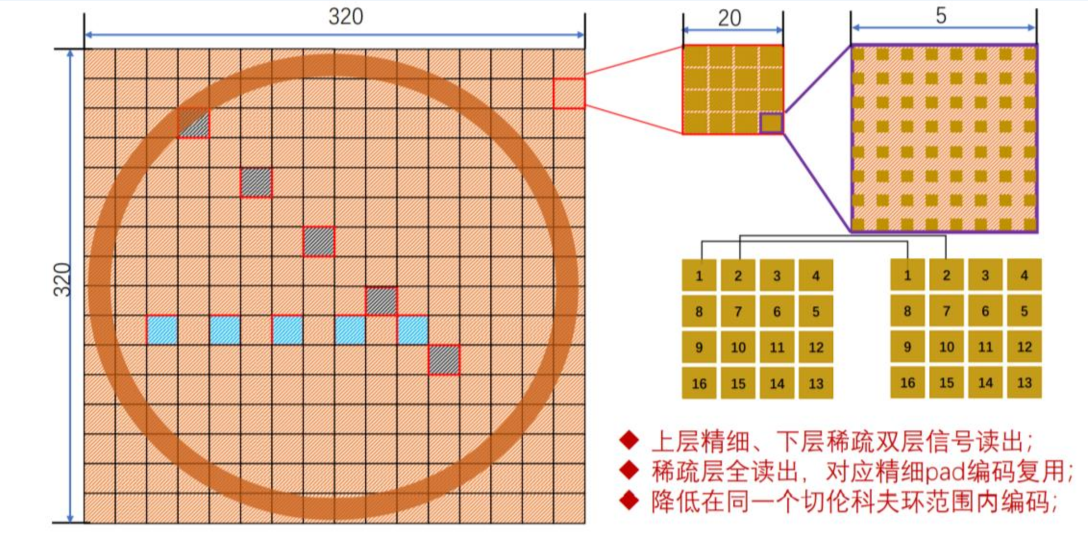
S.P.E. Time resolution < 250 ps

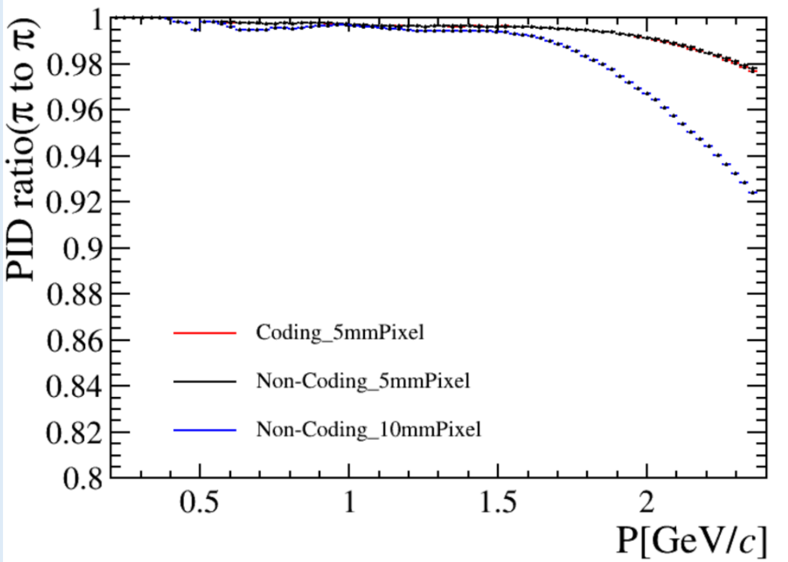




Development of a RICH Prototype with C6F14

Anode coding

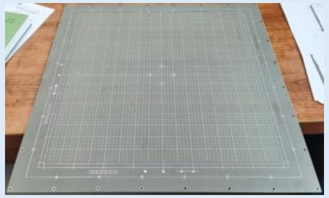




Reduce to

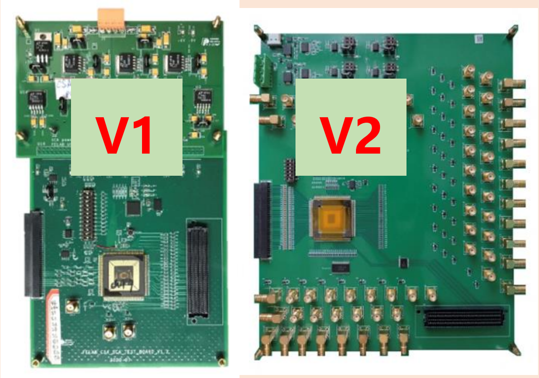
(from 0.52M to 0.13M)

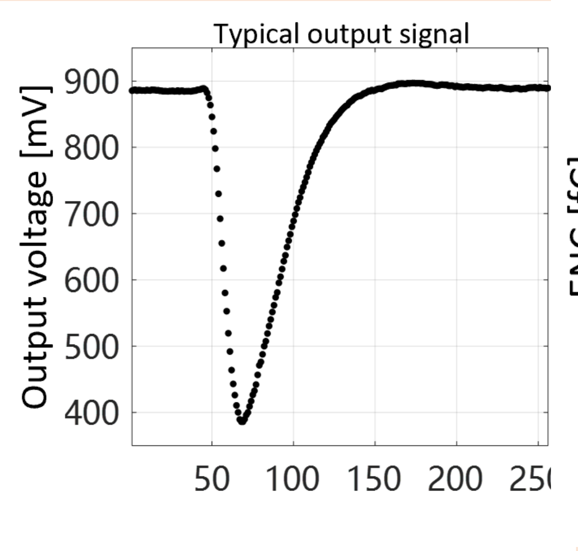
1/4!

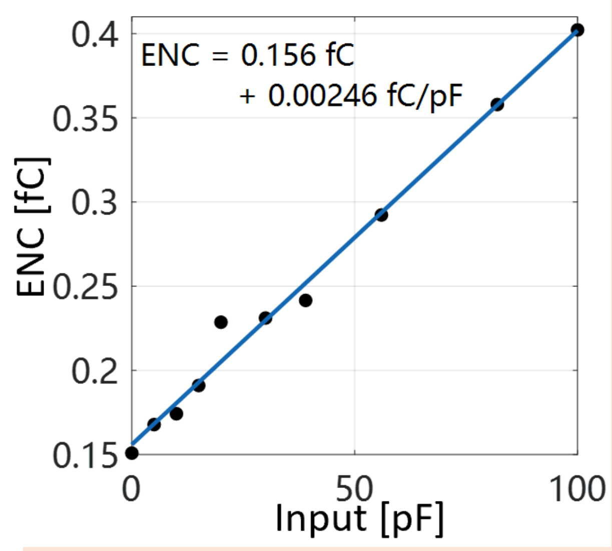


Readout ASIC

读出电子学指标	需求
电荷测量范围	48 fC
电荷测量噪声(ENC)	0.5 fC@48 fC@20 pF
时间测量精度	≤1 ns @ 48 fC @ 20 pF
单通道平均事例率	~ 1.6 kHz



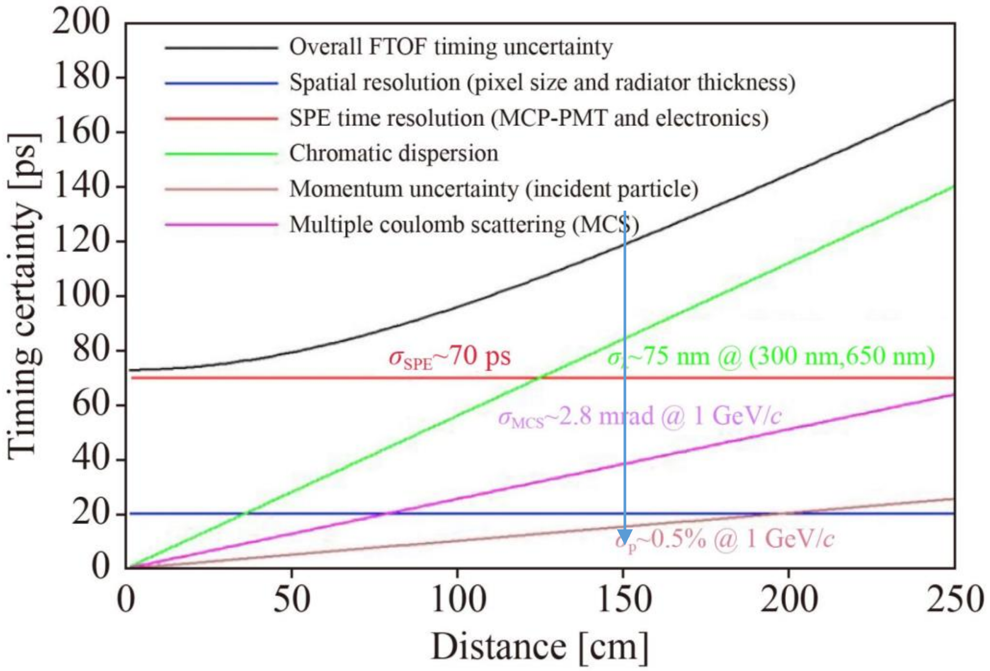


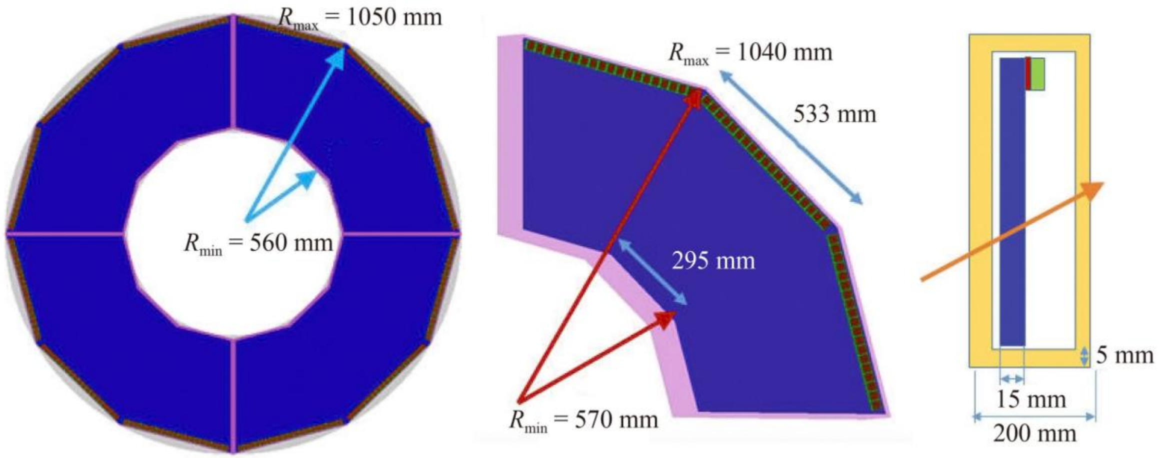


The DTOF Detector

高精度时间探测
挑战：大面积石英辐射体加工、多阳极光电倍增管等

- Radiator: fused silica
- Multi-anode MCP-PMT
- 1400mm to the collision point
- Time resolution < ~30 ps
- No focusing component





$$\sigma_{t0}^2 \sim \sigma_{tr}^2 + \sigma_{T_0}^2 + \left(\frac{\sigma_{elec}}{\sqrt{N_{p.e}}}\right)^2 + \left(\frac{\sigma_{TTS}}{\sqrt{N_{p.e}}}\right)^2 + \left(\frac{\sigma_{det}}{\sqrt{N_{p.e}}}\right)^2$$

~40 ps

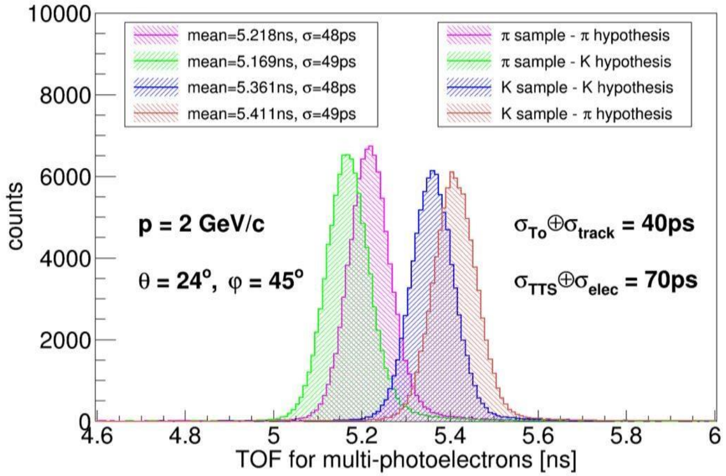
Requirement: 4σ π/K@2 GeV/c
➔系统总时间分辨σ_{tot} < 50 ps
➔DTOF本征时间分辨σ_{DT} < 30 ps

The DTOF Detector expected performance

Timing method

- PDF based on the reconstructed time of flight

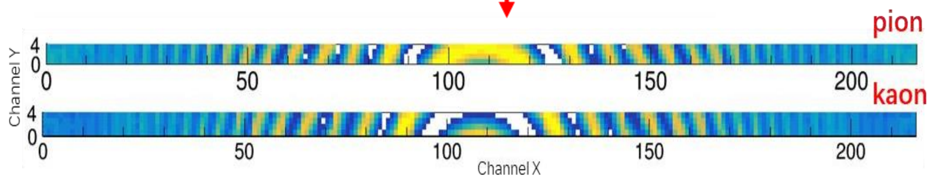
$$\mathcal{L}_h = p_h(N_{p.e.}) \prod_{i=0}^{N_{p.e.}} f_h(TOF_i)$$

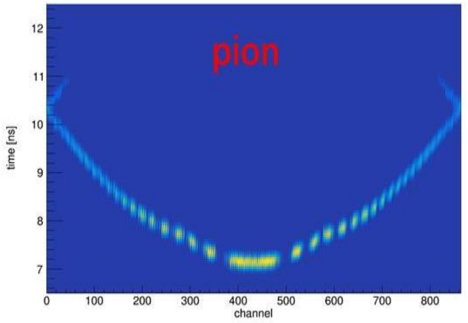


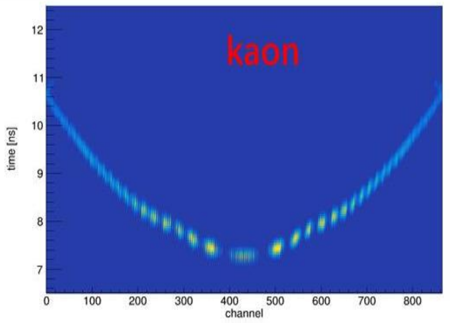
Imaging method

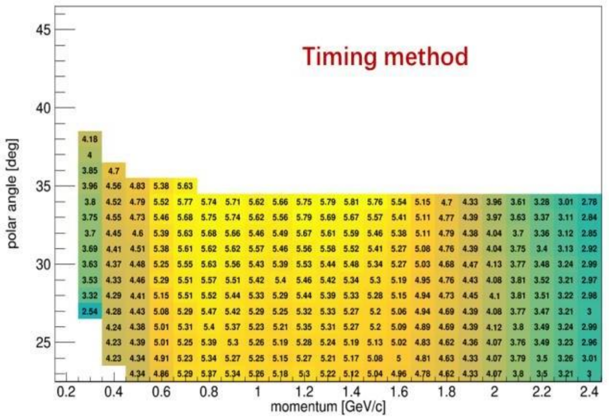
- PDF based on the timing info. From each readout channel

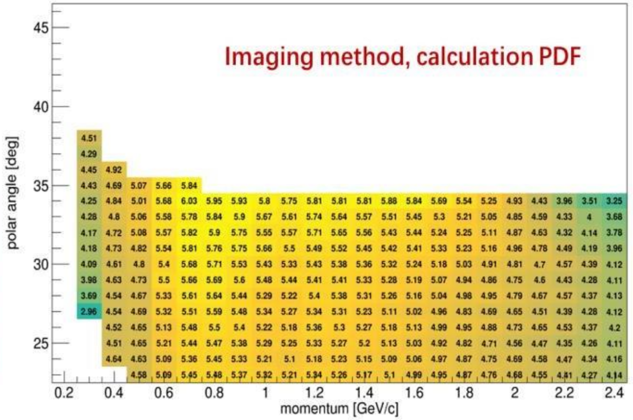
$$\mathcal{L}_h = p_h(N_{p.e.}) \prod_{i=0}^{N_{p.e.}} f_h(ch_i, t_i)$$







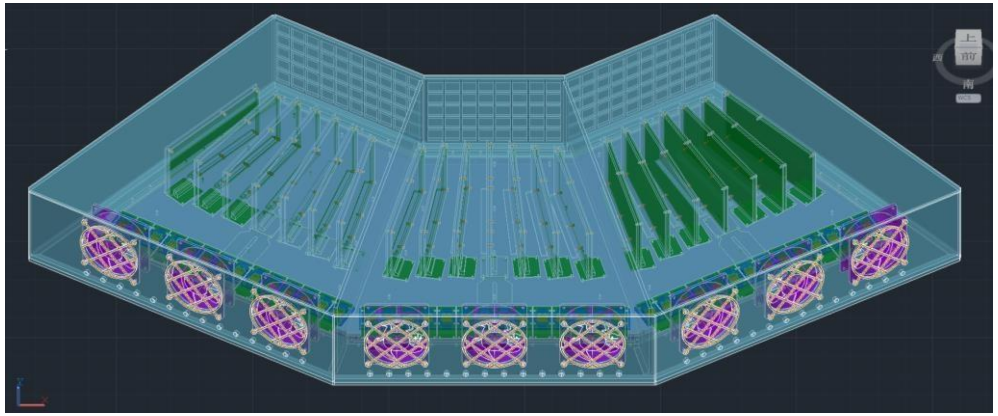


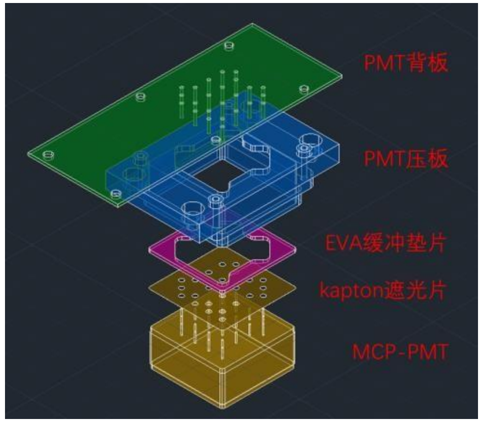


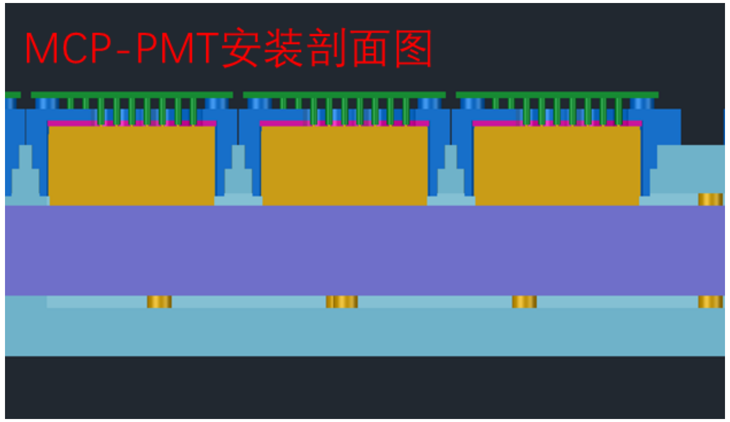
π/K separation

- ✓ Both satisfied: 4σ π/K@2 GeV/c
- ✓ Imaging method significant improvement in >2 GeV/c

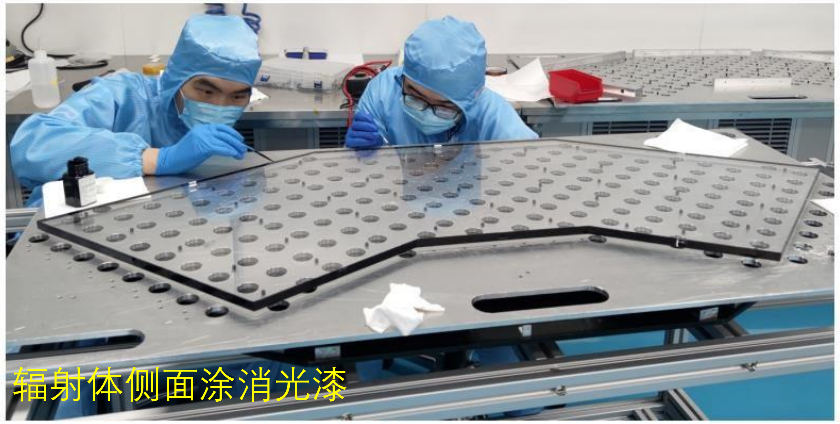
The DTOF full size prototype R&D





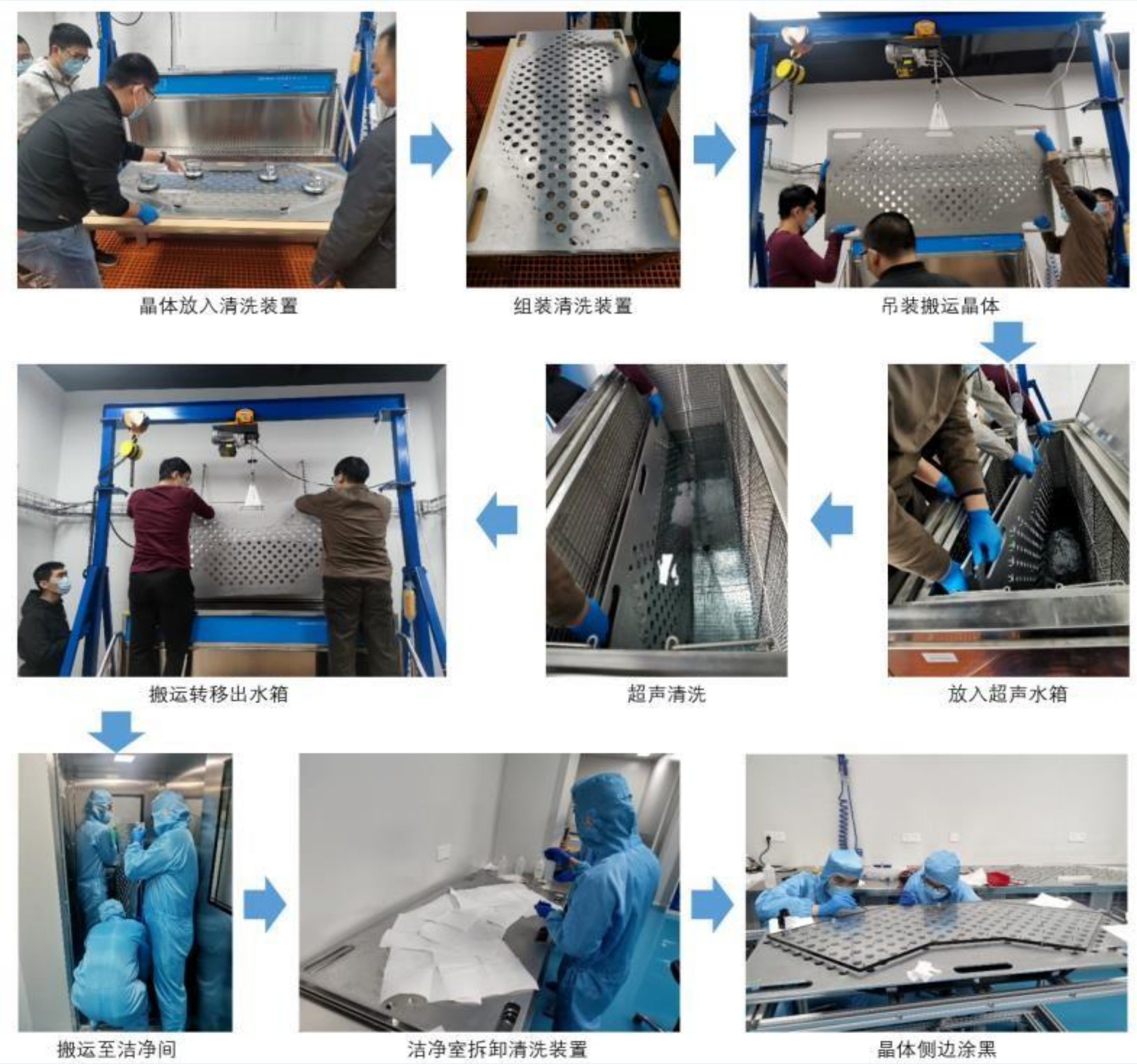


- 大面积高纯度熔融石英辐射体
  - 厚度=15 mm, 灵敏面积~0.56 m^2
  - 表面粗糙度<1 nm(0.75 nm, 😊)
  - 上下侧边涂黑
  - 厚度±0.1 mm, 厚度max-min<25 μm
- 42个微通道光电倍增管(MCP-PMT)
  - 4×4 阳极，像素面积5.5 mm×5.5 mm
  - 灵敏面积 23 mm×23 mm
- 高精度定时电子学
  - 21块前端读出板，2块数据控制板，1块时钟 扇出板
  - 672读出通道TOT定时电路，时间晃动<10 ps
- 高机械强度光密盒，兼顾散热设计

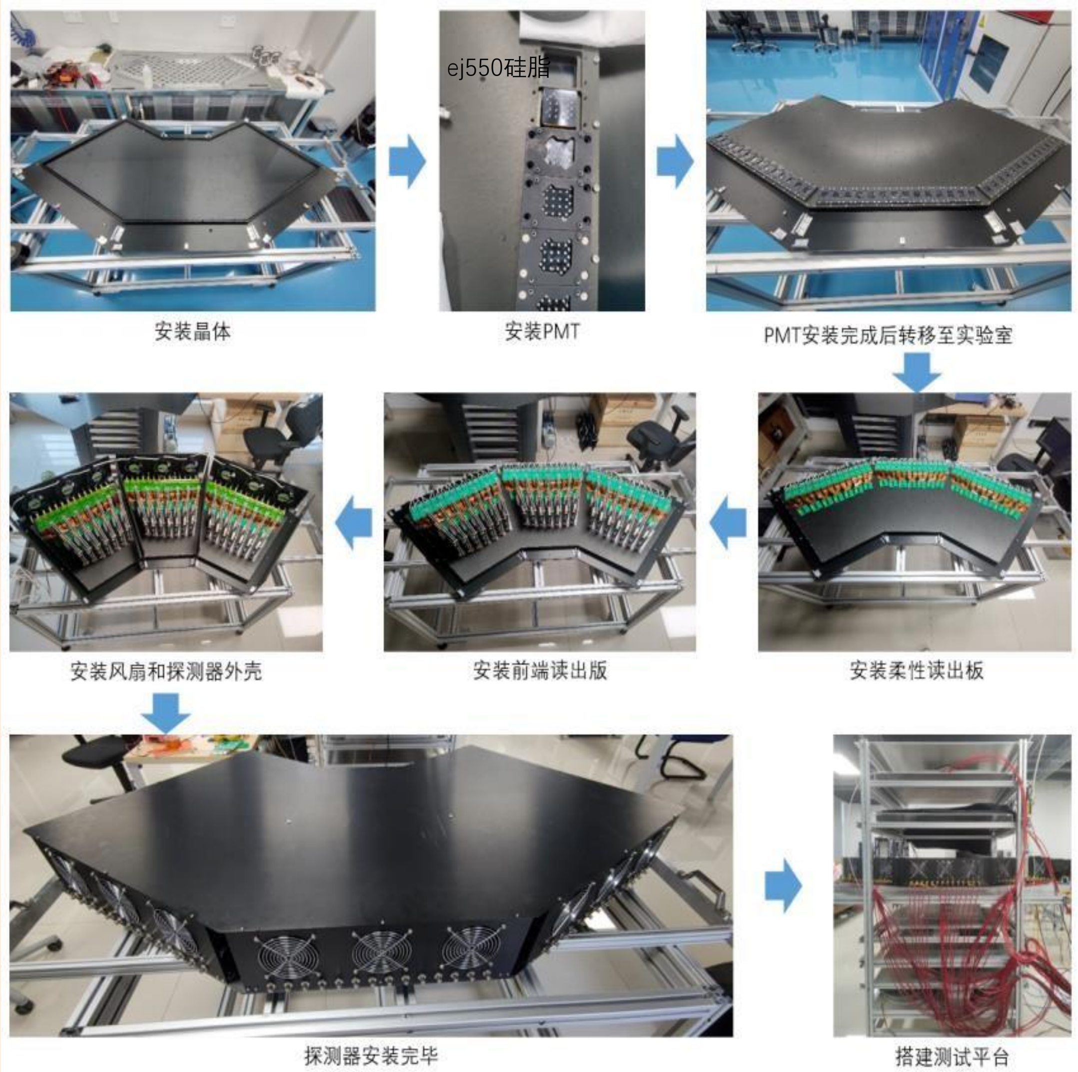


The DTOF full size prototype assembly

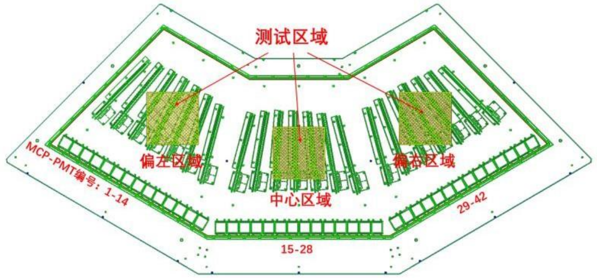
Quartz radiator cleaning and mounting



Detector assembling

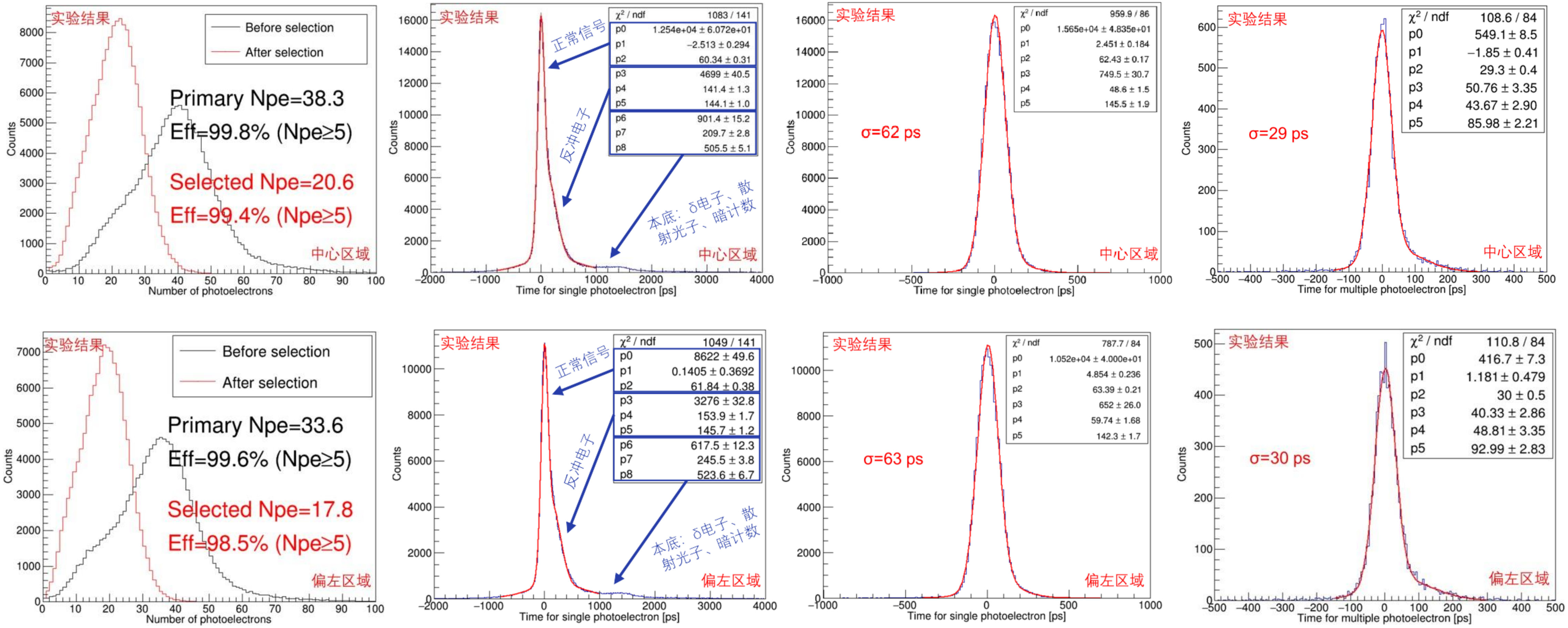


Cosmic-ray test for the full size DTOF prototype



中心区域

偏左区域



- ✓ 中心区域：单光子σ=sqrt(62²-20²)≈59 ps，多光子σ=sqrt(29²-20²)≈21 ps
- ✓ 偏左区域：单光子σ=sqrt(63²-20²)≈60 ps，多光子σ=sqrt(30²-20²)≈22 ps

$\sigma_{T_0} \approx 20$ ps

Summary

- **STCF is a super tau-charm facility proposed by the Chinese HEP community as one of the post-BEPCII HEP projects in China.**
  - E_{cm} = 2 – 7 GeV, L > 0.5×10^{35} $cm^{-2}s^{-1}$@4 GeV
- **A lot of progress on PID detector R&D in various aspects.**
  - RICH for PIDB, key technology research and development is currently underway.
  - DTOF for PIDE, Completed full-scale prototype, performance meets requirements.
- **Many new R&D efforts have launched, significantly changing the R&D landscape.**

Thanks!