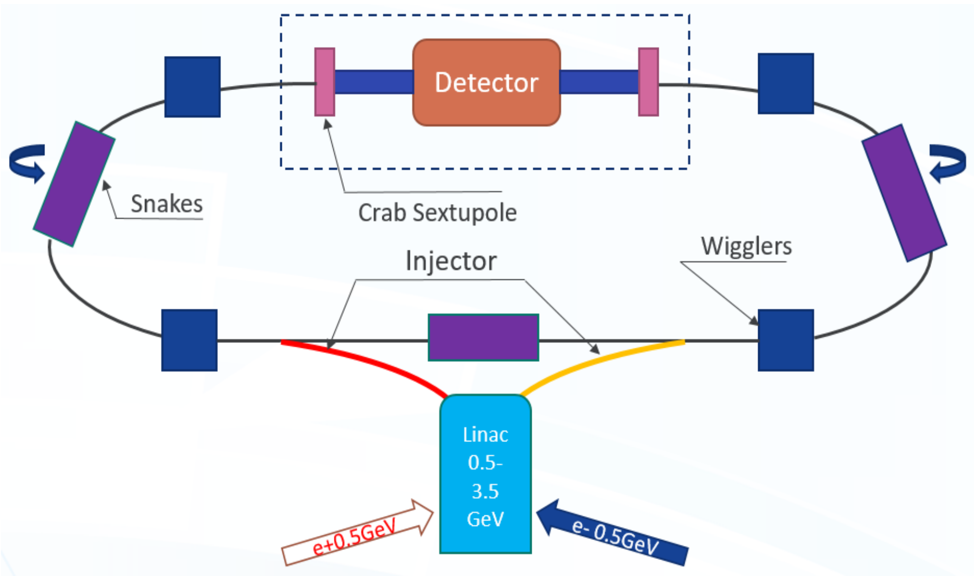
STCF Detector Concept

Jianbei Liu
For the STCF detector team
State Key Laboratory of Particle Detection and Electronics
University of Science and Technology of China

EicC-STCF Joint Meeting
February 22, 2020

Super Tau-Charm Facility in China

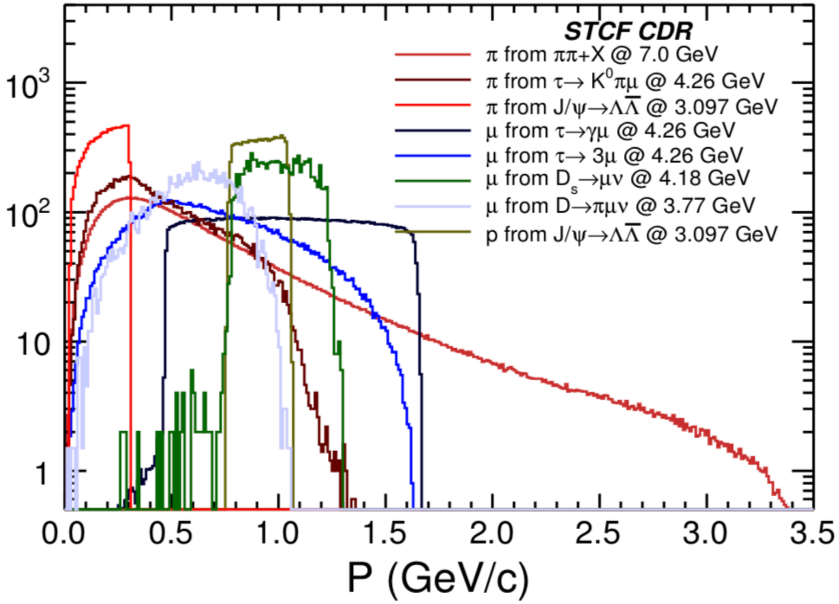
- **STCF** : a natural extension of BEPCII and a viable option for a post-BEPCII HEP project in China.



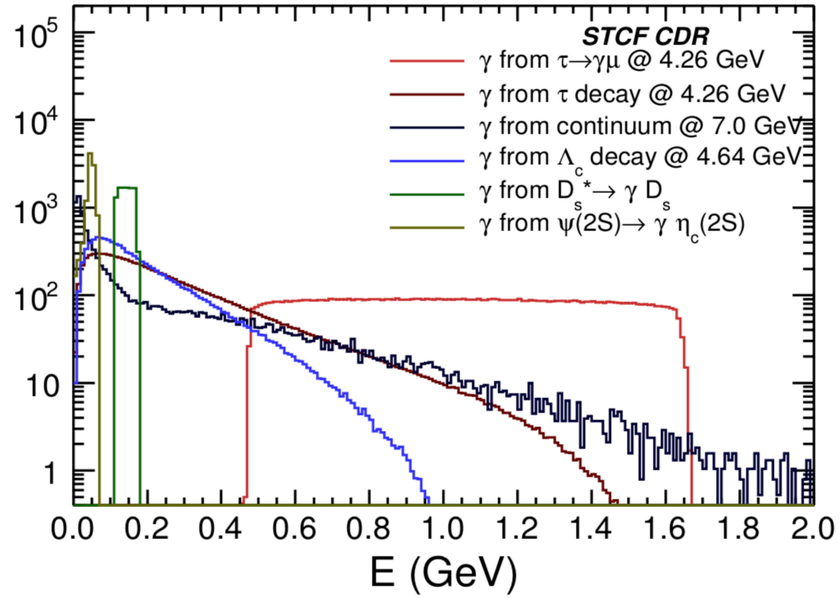
- E_{cm} = 2-7 GeV, L ~ 0.5×10^{35} $cm^{-2}s^{-1}$ @4 GeV
- Symmetrical collision
- double-ring, 600-800 m
- Large Piwinski angle & Crab waist
- Upgradable for polarized electron beam

An super τ-c machine far beyond BEPCII

Feature of Final States at STCF



Charged particles



Photons

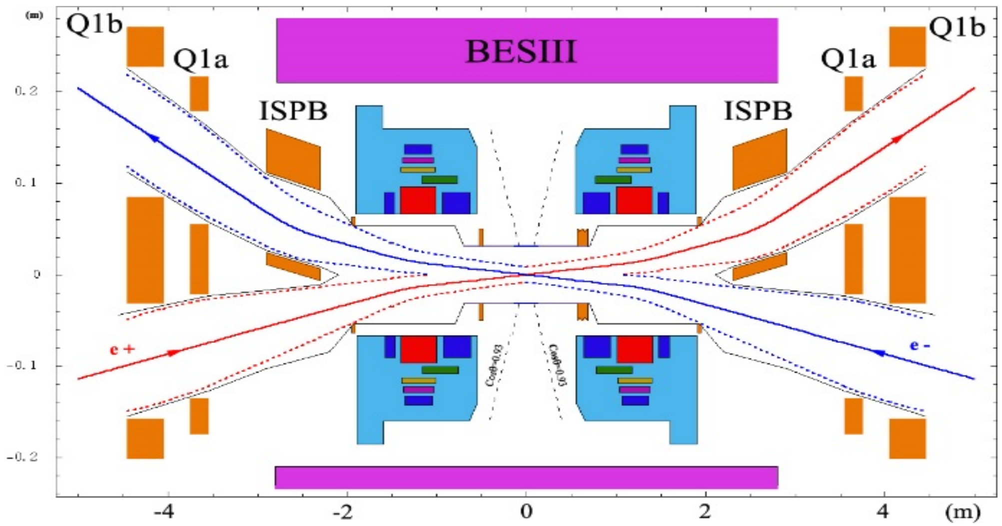
- Final-state particles are largely of low momentum /energy .
- Design of the STCF detector has to match this important feature of final states.

Physics Requirements

- The centerpiece
  - Efficient and precise reconstruction of exclusive final states produced in e^+e^- collisions of 2-7 GeV.
- Large solid angle coverage
- High efficiency and good resolution for both charged and neutral particles of low momentum/energy (<~ 1 GeV).
- E_{cm} being up to 7 GeV calls for PID in a large momentum range (up to 2 GeV)
- Measurement of and search for rare processes demands superior pi/K and μ identification capability.

Experimental Conditions

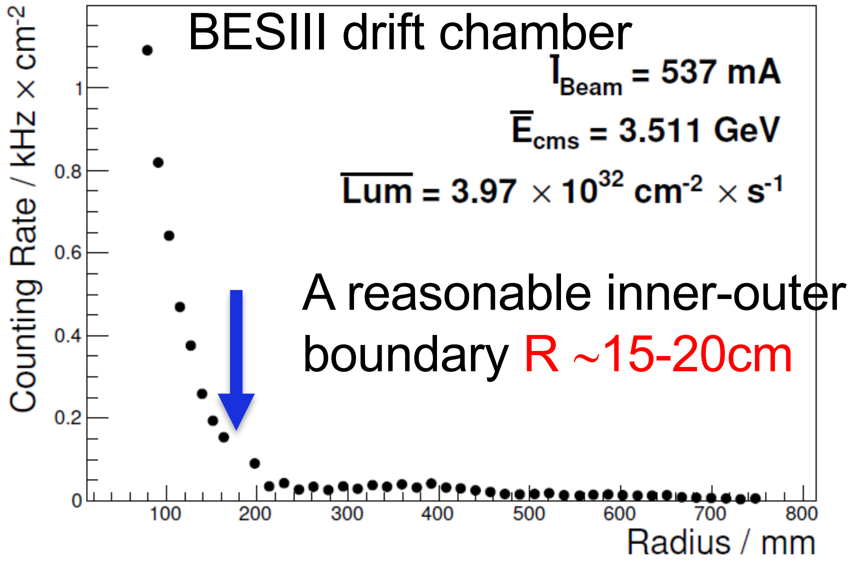
- High luminosity of ~10^{35} $cm^{-2}s^{-1}$ at STCF
  - High counting rate and high radiation level
- Constrains from the interaction region (IR), particularly on trackers.
- Detailed MDI studies are required (and ongoing)



IR of BEPCII

Extrapolation from BESIII ($\times$100)

- Counting rates
  - Tracker: >> 100 kHz/cm^2@R<5cm, < 5 kHz/cm^2 @ R > 20cm

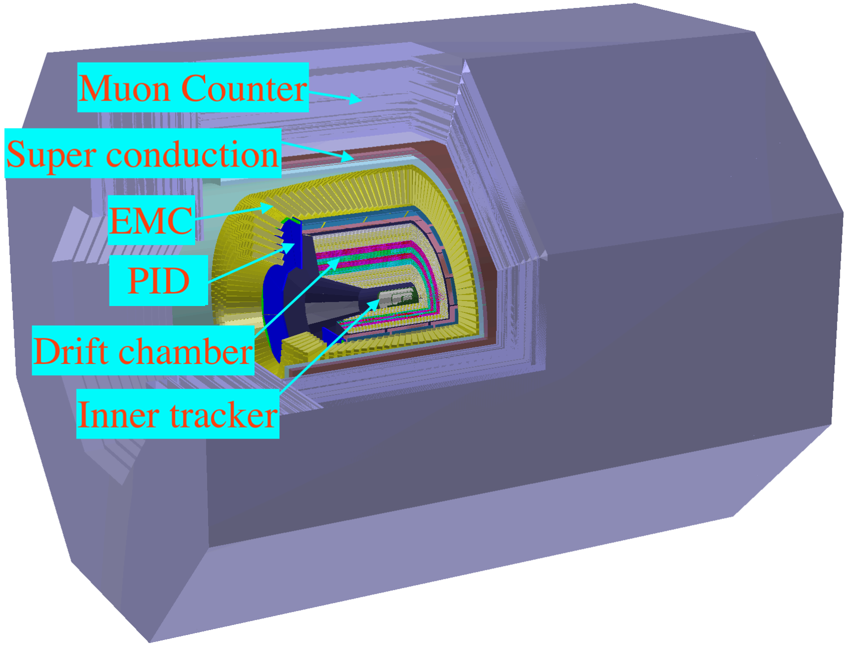


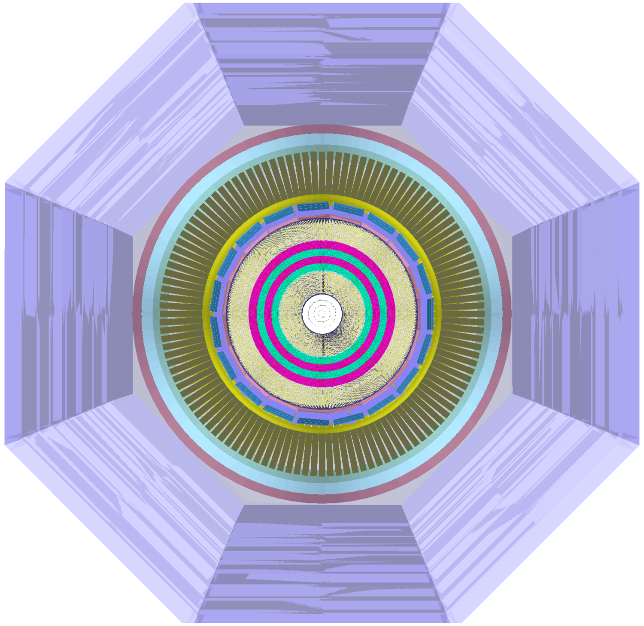
  - PID: 400 Hz/cm^2 (Barrel), 4 kHz/cm^2 (Endcaps)
  - ECAL: 400 kHz/crystal (Barrel), 3 MHz/crystal (Endcaps)
- Radiation dose
  - ECAL: 10 krad/year (Barrel), 20 krad/year (Endcap)

Important Aspects for STCF Detector

- Large and well-defined acceptance $\rightarrow$ cone-shaped endplate of the tracker
- High rate capability and radiation tolerance
- Fast response and high resolution
- Mis-measurement/identification well under control
- Low detection threshold (tracking, γ, μ-ID …)
- Everything inside ECAL needs to be as light as possible
- Vertexing not critical. Inner-outer separate design for tracking system, and the inner part has to stand very high levels of radiation $\rightarrow$ challenging part.
- Technology beyond dE/dx+TOF is required for PID up to 2GeV .

STCF Detector Concept

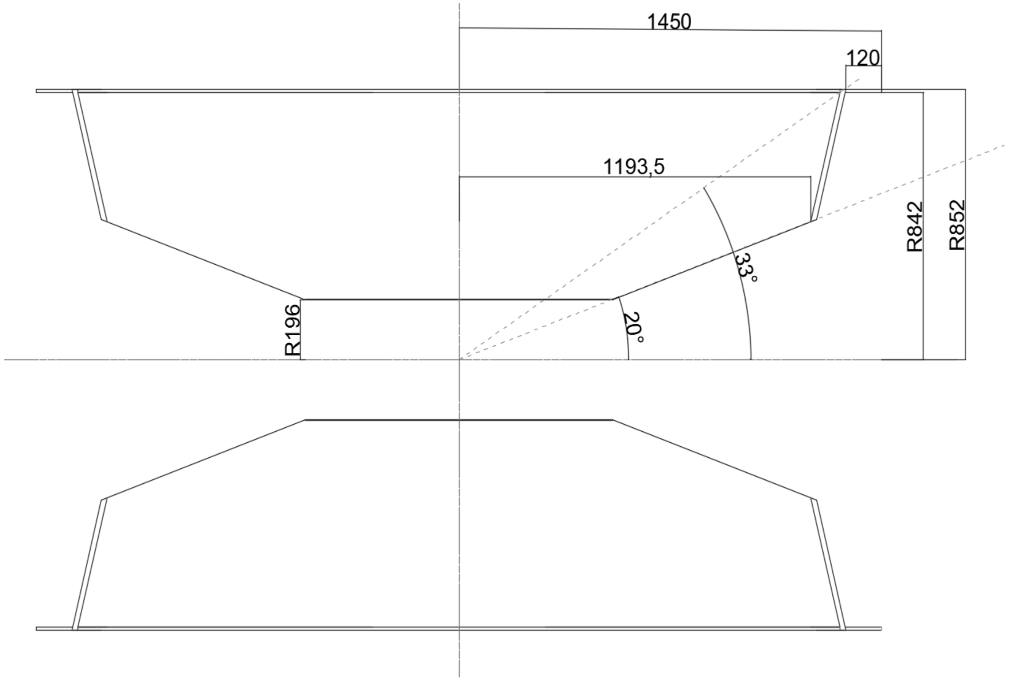


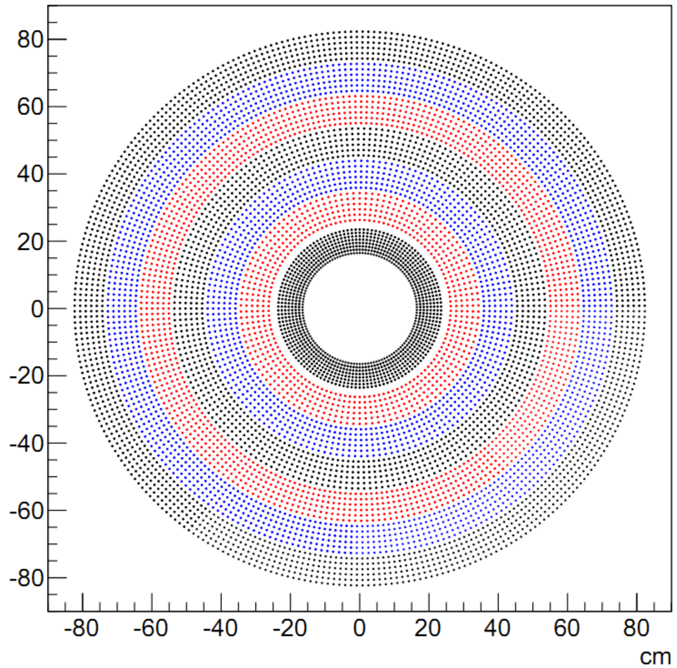


Tracking System

- Fully efficient tracking is needed for particles down to 100 MeV, and it is highly desirable to have good tracking performance even down to 50 MeV : tracking in low p
- Dominant factors in low p tracking: multiple scattering and energy loss
- So driving force in design of tracking system: low mass.
- Separate designs for the inner and outer trackers.
- A low-mass drift chamber could serve as the outer tracker.
- But new technology is needed for inner tracking
  - Low mass + high rate
- Magnetic field: 1 T (adjustable for lower fields).

Outer Tracker: A Drift Chamber



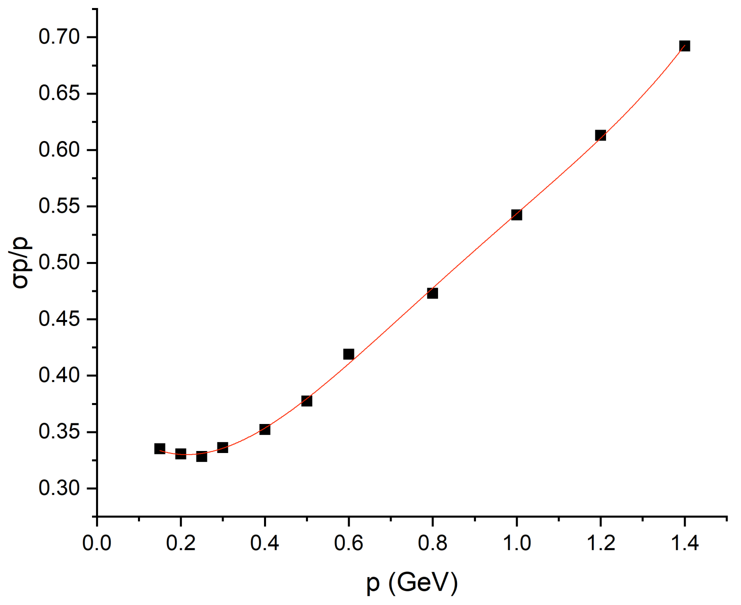


- Helium-based gas: He/C_2H_6 (60/40)
- Small square cells
- Sense wire: 20 um W, Field wire: 100 um Al
- Carbon fiber for both inner and outer walls

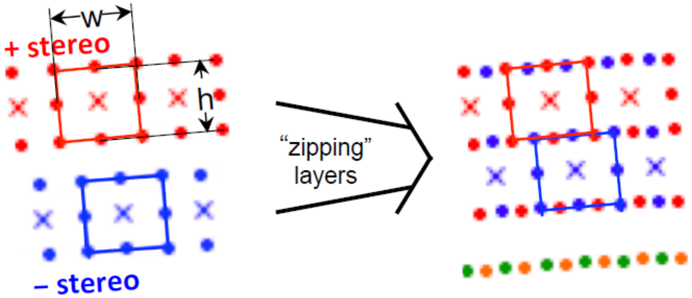
Continued

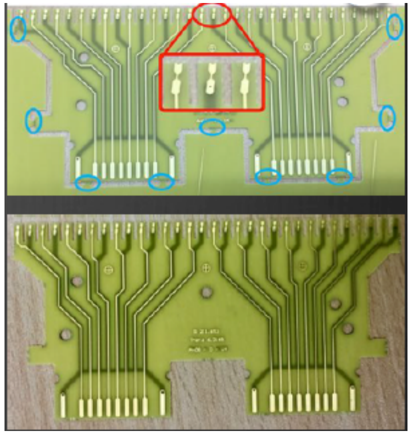
Layer	No.of cells	Start radius(mm)	Cell size(mm)	Stereo angle(degree)
Axial 1	128	200.0	9.8	0
Axial 2	128	209.8	10.3	0
Axial 3	128	220.1	10.8	0
Axial 4	128	230.9	11.3	0
Axial 5	128	242.2	11.9	0
Axial 6	128	254.1	12.5	0
Stereo U 7	160	272.6	10.7	2.49
Stereo U 8	160	283.3	11.1	2.59
Stereo U 9	160	294.4	11.6	2.69
Stereo U 10	160	306.0	12.0	2.79
Stereo U 11	160	318.0	12.5	2.90
Stereo U 12	160	330.5	13.0	3.02
Stereo V 13	192	343.5	11.2	-2.61
Stereo V 14	192	354.7	11.6	-2.69
Stereo V 15	192	366.3	12.0	-2.78
Stereo V 16	192	378.3	12.4	-2.87
Stereo V 17	192	390.7	12.8	-2.97
Stereo V 18	192	403.5	13.2	-3.06
Axial 19	224	422.7	11.9	0
Axial 20	224	434.6	12.2	0
Axial 21	224	446.8	12.5	0
Axial 22	224	459.3	12.9	0
Axial 23	224	472.2	13.2	0
Axial 24	224	485.4	13.6	0
Stereo U 25	256	505.0	12.4	2.87
Stereo U 26	256	517.4	12.7	2.94
Stereo U 27	256	530.1	13.0	3.01
Stereo U 28	256	543.1	13.3	3.08
Stereo U 29	256	556.4	13.7	3.16
Stereo U 30	256	570.1	14.0	3.24
Stereo V 31	288	584.1	12.7	-2.95
Stereo V 32	288	596.8	13.1	-3.01
Stereo V 33	288	609.9	13.3	-3.08
Stereo V 34	288	623.2	13.6	-3.14
Stereo V 35	288	636.8	13.9	-3.21
Stereo V 36	288	650.7	14.1	-3.28
Axial 37	320	670.8	13.2	0
Axial 38	320	684.0	13.4	0
Axial 39	320	697.4	13.7	0
Axial 40	320	711.1	14.0	0
Axial 41	320	725.1	14.2	0
Axial 42	320	739.3	14.5	0
Axial 43	352	753.8	13.5	0
Axial 44	352	767.3	13.7	0
Axial 45	352	781.0	13.9	0
Axial 46	352	794.9	14.2	0
Axial 47	352	809.1	14.5	0
Axial 48	352	823.6	14.7	0

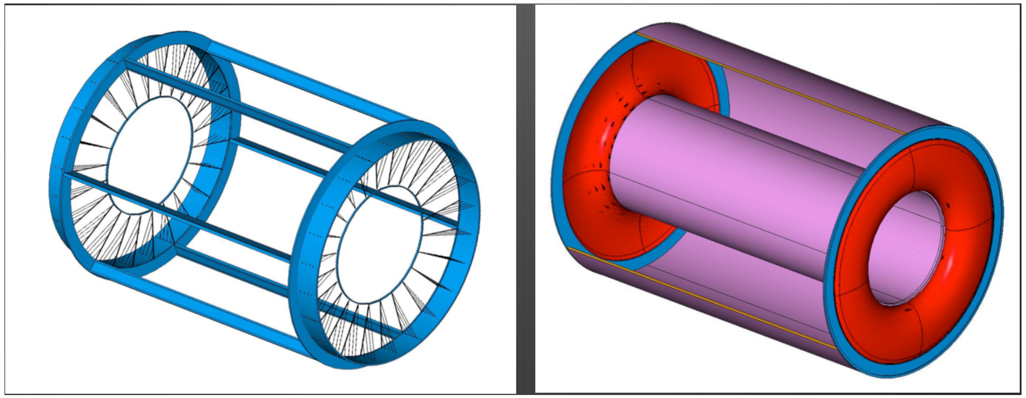
Expected momentum resolution

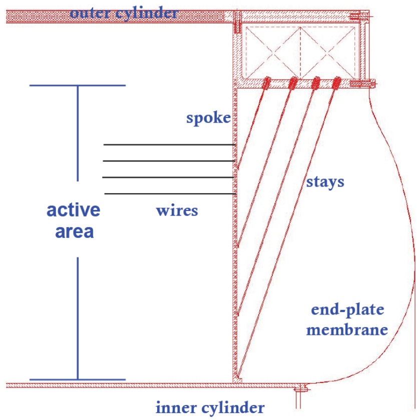


Pushing a drift chamber to the limit









把漂移室的物质量推低到极限

By Francesco GRANCAGNOLO from INFN

A STCF Drift Chamber with extremely low mass

$R_{in} – R_{out}$ [mm]		200 – 800
active L – service area [mm]		1800 – 200
inner cylindrical wall		
C-fiber/C-foam sandwich	2×80 μm / 5 mm	0.036 g/cm^2 – 8×10^{-4} X/X_0
outer cylindrical wall		
C-fiber/C-foam sandwich	2×5 mm / 10 mm	0.512 g/cm^2 – 1.2×10^{-2} X/X_0
end plate		
gas envelope	160 μm C-fiber	0.021 g/cm^2 – 6×10^{-4} X/X_0
instrumented wire cage	wire PCB, spacers, HV distr. and cables, limiting R, decoupling C and signal cables	0.833 g/cm^2 – 3.0×10^{-2} X/X_0

cell	
shape	square
size [mm]	7.265 – 9.135
layer	
8 super-layers	8 layer each
64 layer total	
stereo angles	66 – 220 mrad
n. sense wires [20μm W]	23,040
n. field wires [40/50μm Al]	116,640
n. total (incl. guard)	141,120
gas + wires [600 mm]	
90%He – 10%iC_4H_{10}	4.6×10^{-4}
W + 5 Al → Ti + 5 C	(13.1 → 2.5)×10^{-4}

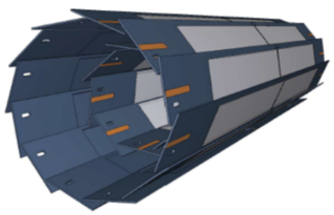
$$\sigma_{pt}/pt = 0.1\%\ pt \oplus 0.2\%$$

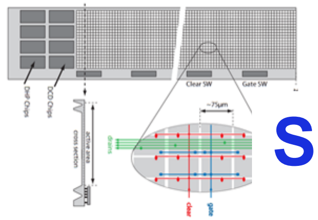
by Francesco GRANCAGNOLO from INFN

Existent Inner Tracker Technologies

DEPFET

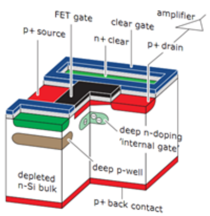
- Two layers of PXD: 1.8 cm and 2.2 cm in radius, consisting of 8 and 12 modules for innermost layer and the second, respectively.





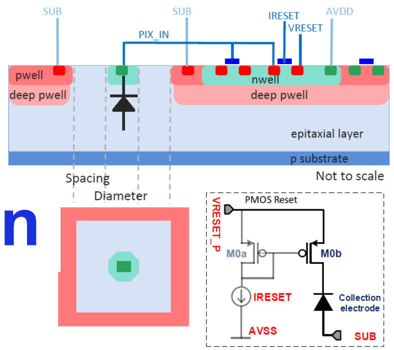
Number of pixels per module	250 x 1536
Pixel size (r-phi, z)	50μm x (60-75) μm
Frame time	20 μs
Material budget per layer	0.15% X_0
Resolution (r-phi, z)	<10μm, < 20μm
Occupancy at 1.8 cm radius	0.2 hits $\mu m^{-2} s^{-1}$
Radiation environment	~1 Mrad/year

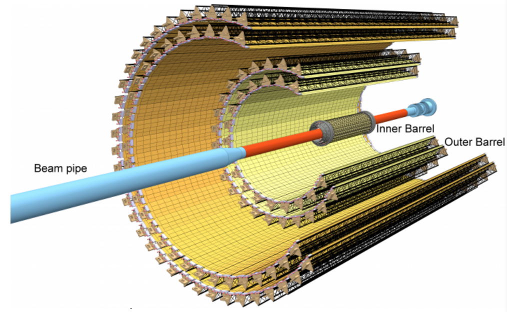
DEPFET Technology



Silicon

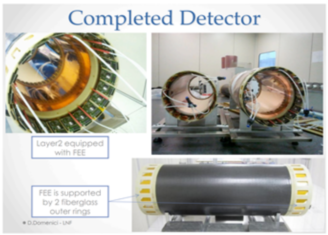
MAPS (ALPIDE)

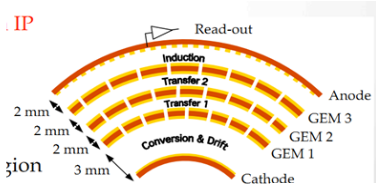




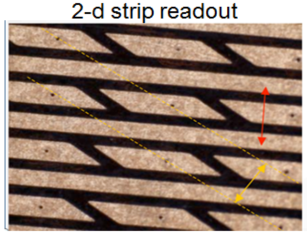
Pixel size: 29*27μm, high resistivity epitaxial, deep PWELL, reverse bias, global shutter (<10 μs), triggered or continuous readout, resolution < 5um, material budget <0.3%X_o

Cylindrical GEM





2-d strip readout



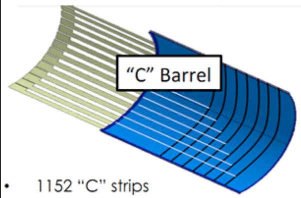
X pitch 650μm → X res 190 μm
V pitch 650μm → Y res 350 μm

Material Budget	
Total 1 layer	0.49%
Total 4 layers	1.95%

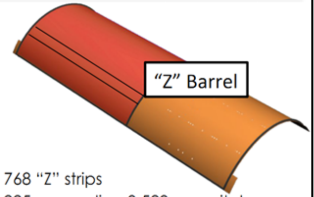
Pixel readout would be required for the innermost layers at HIEPA

MPGD

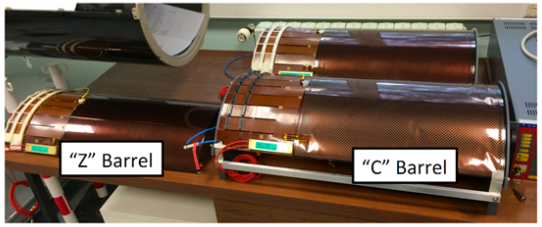
Cylindrical MicroMegas

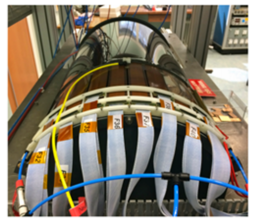


- 1152 "C" strips
- Pitch from 0.67 to 0.33 mm
- 221 mm radius
- PCB thickness 100 μm
- Drift thickness 250 μm
- Drift Field 2.4kV on 3 mm gap

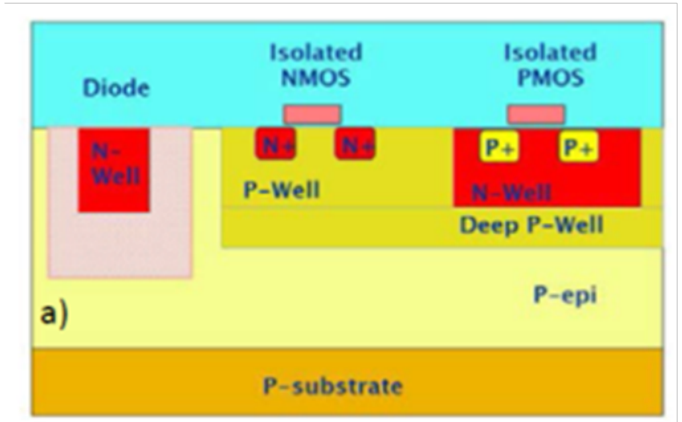


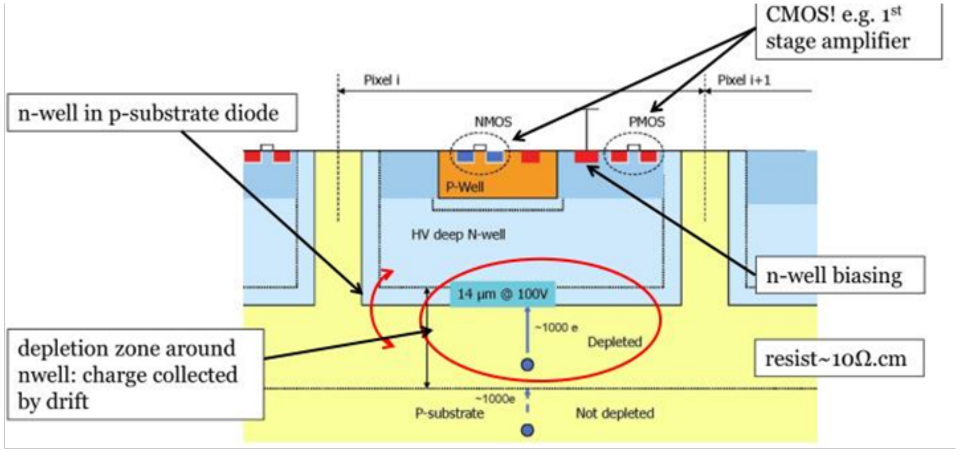
- 768 "Z" strips
- 225 mm radius, 0.529 mm pitch
- PCB thickness 200 μm
- Drift thickness 250 μm
- Drift Field 2.4kV on 3 mm gap
- 0.37% of X0





A New Silicon Detector: DMAPS





Electronics outside the charge collection diode, small capacitance → low noise. Long drift distance, low field

Electronics inside the large charge collection diode, large capacitance → high noise, high power consumption. short drift distance, high field

Depletion is needed for radiation hardness $\sqrt{\rho V_{bias}}$ → HR or HV: two approaches to depletion

R&D ongoing for HL-LHC

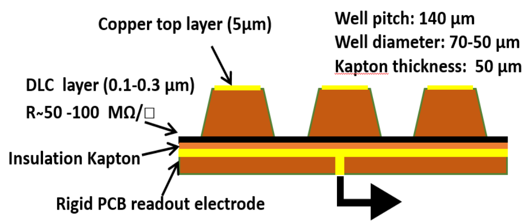
Novel on-chip readout schemes also under development for high rate application

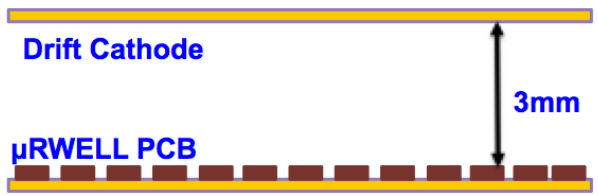
Depleted CMOS MAPS → low mass, high rate, radiation hard

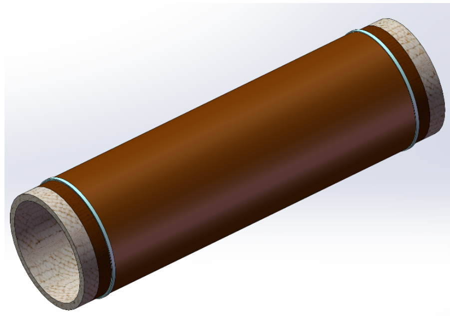
→ An interesting technology for inner tracking at STCF

A New MPGD : uRWELL

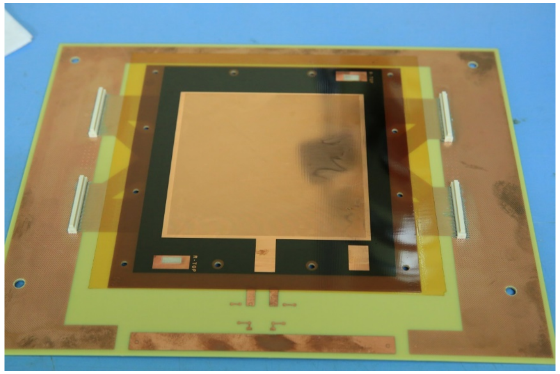
- Very compact, spark protected, simple to assemble, flexible in shapes (rather easy to make a cylindrical detector)

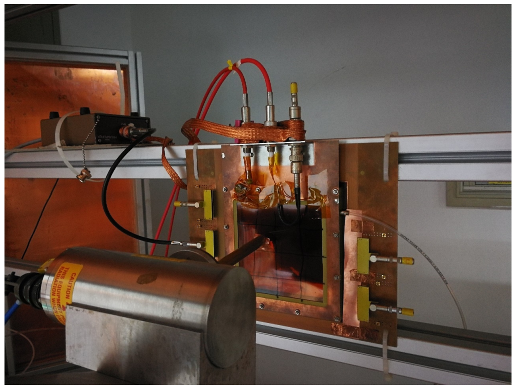


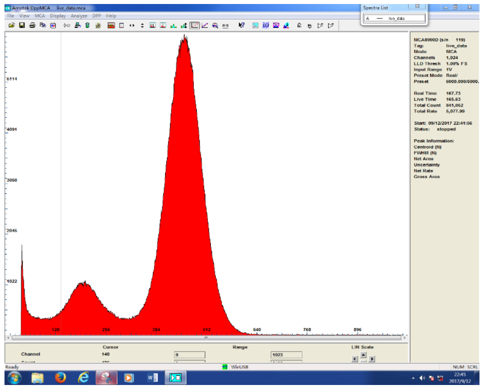




- Another promising solution to STCF inner tracking. R&D underway in collaboration with INFN and CERN.







Inner Tracker Baseline

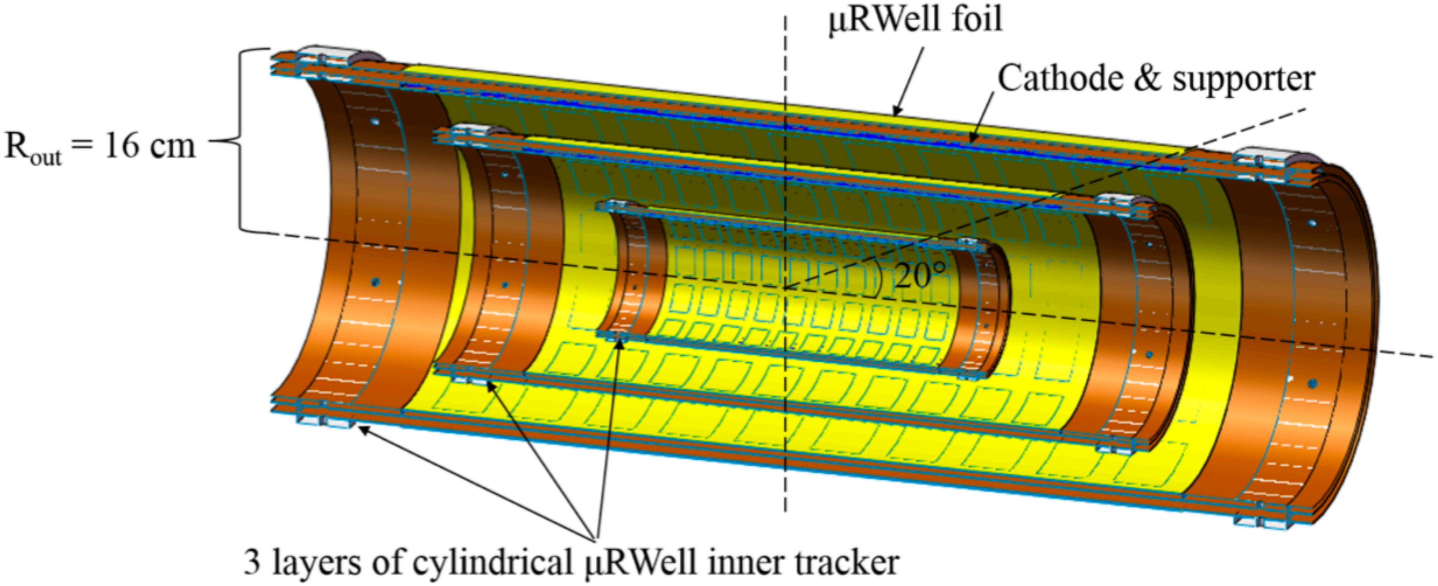


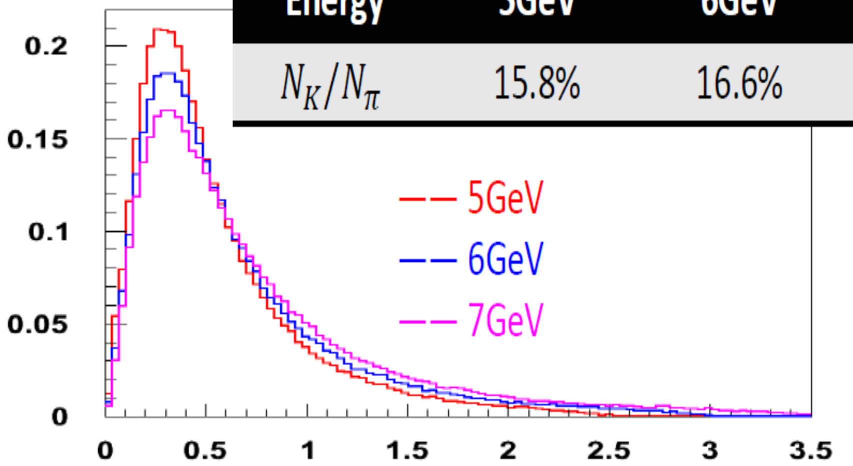
Table 4.1.1: The material budget of the μRWell-based inner tracker design.

Structure	Material	Thickness (cm)	Material budget (X/X_0)
Inner tube	Copper (X_0=1.436 cm)	0.001	0.069%
	Polyimide (X_0=28.57 cm)	0.01	0.035%
	Aramid honeycomb/Rohacell ($X_0\simeq$800 cm)	0.2	0.025%
Gas Volume	Helium-based gas mixture (X_0=56710 cm)	0.3	0.00053%
Outer tube (μRWell foil)	Copper (X_0=1.436 cm)	0.001	0.069%
	Polyimide (X_0=28.57 cm)	0.015	0.053%
	DLC (X_0=12.13 cm)	0.0001	0.00082%
Total			0.252%

PID Detector

- π/K separation up to 2 GeV.
  – Cherenkov-based technology is favorable.
  – Very low p region (<~0.6GeV) is covered by trackers through dE/dx measurement
- Compact (<20cm) and low mass (<$0.5X_0$)

Energy	5GeV	6GeV	7GeV
N_K/N_π	15.8%	16.6%	16.7%

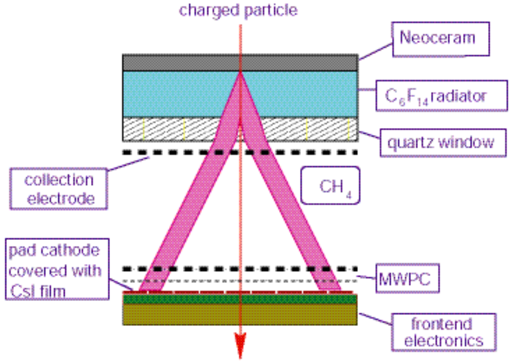


Collins效应测量要求高动量π/K分辨

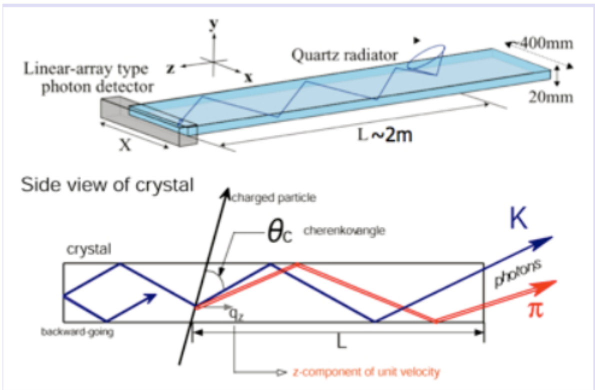
Detector Options

- RICH
  - Very powerful over a wide range of momentum
  - Reconstruction straightforward
  - Additional space for Cherenkov cone expansion: less compact
  - A large number of readout channels : cost, cooling …
- DIRC-like: iTOP, FTOF, DIRC …
  - Very compact, operation convenient
  - Reconstruction complicated
  - Quartz manufacturing and processing very challenging

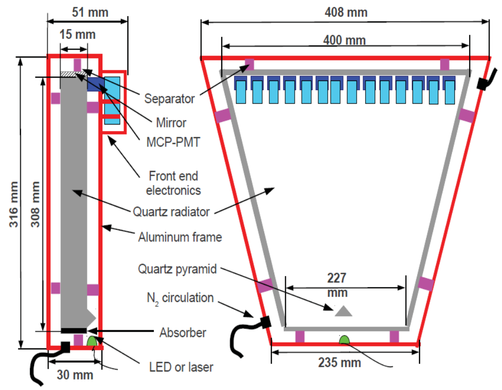
ALICE HMPID



iTOP for BELLE2

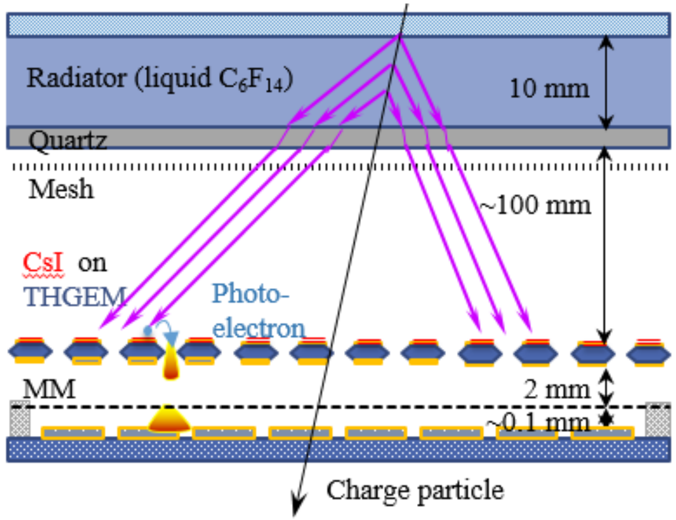


FTOF for superB

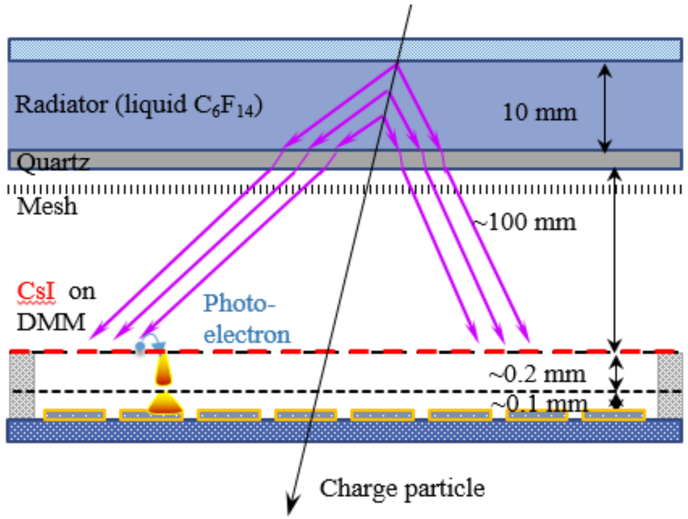


STCF-RICH Design

- Proximity focusing RICH with CsI-coated MPGD readout
  - avoid photon feedback
  - less ion backflow to CsI
  - Fast response, high rate capacity
  - Radiation hard
- Proximity gap ~10cm
- Radiator: liquid C_6F_{14}, n~1.3
- CsI光阴极：紫外光收集和探测（很多问题的根源）

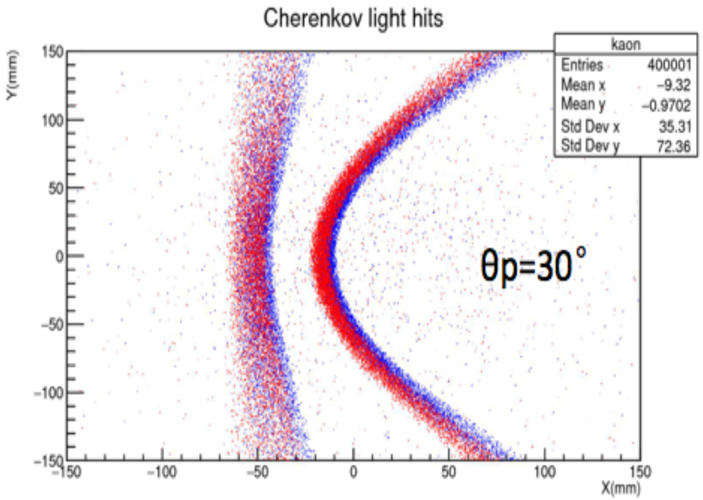


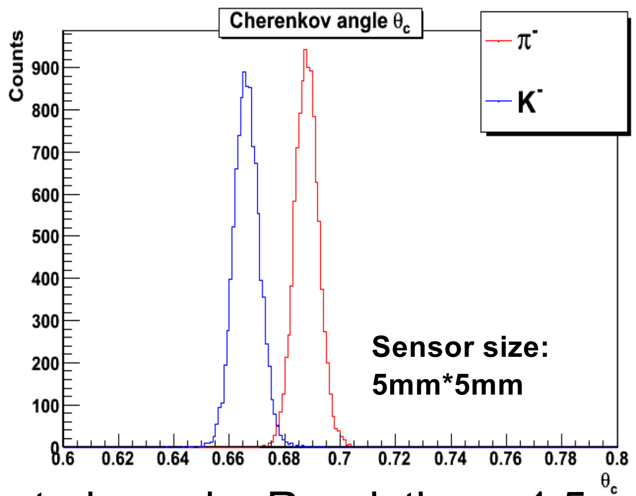
THGEM + MM



DMM

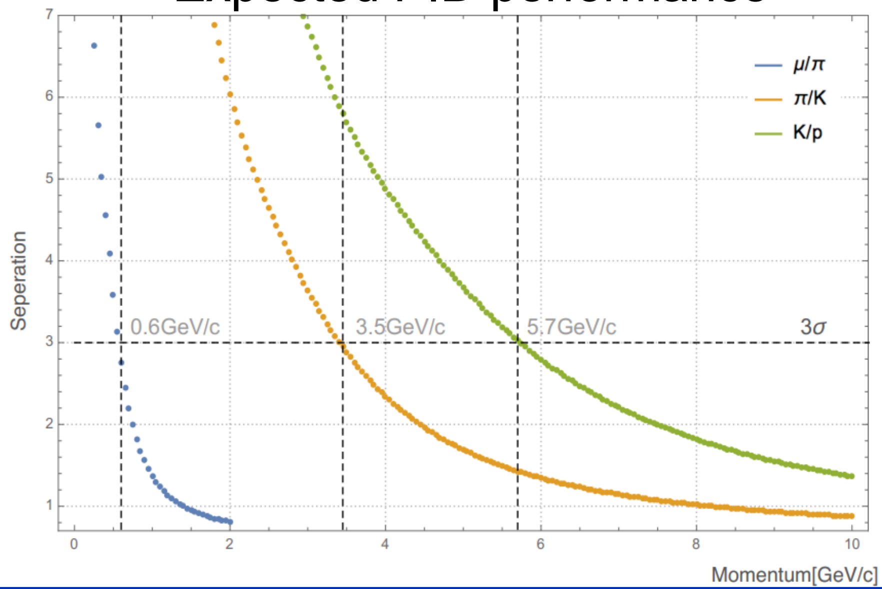
Performance Simulation





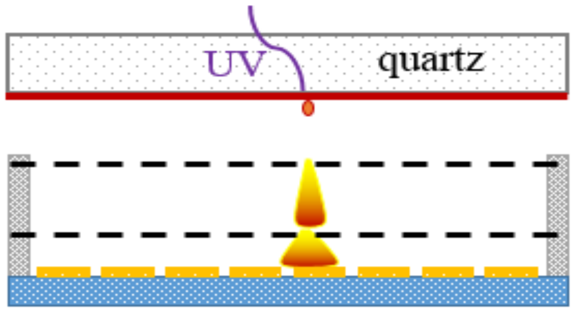
Optimum pad size: $0.5 \times 0.5\text{cm}^2$, expected angular Resolution: ~1.5 mrad

Expected PID performance

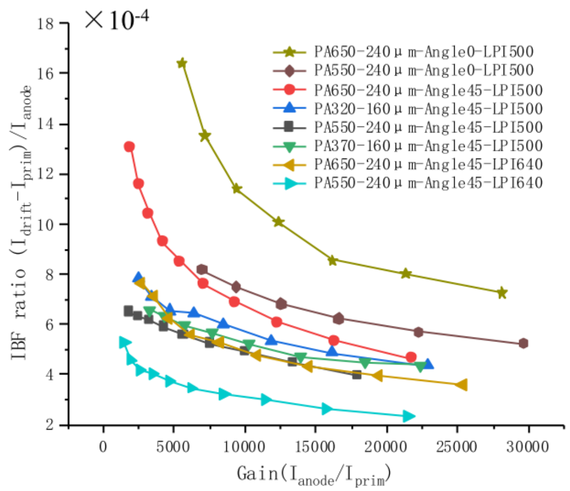


DMM: A Promising MPGD Photon Detector

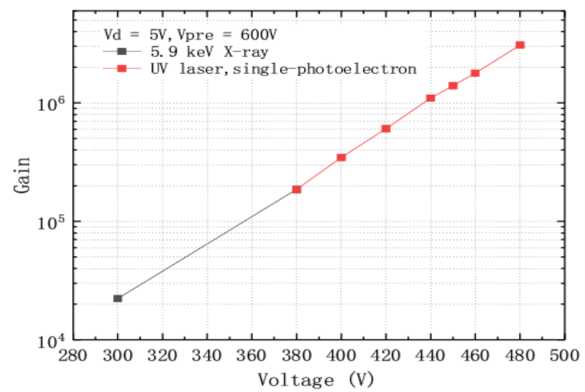
- DMM: Double-mesh Mircromegas detector, which is being developed at USTC
  - High gain and very low ion backflow
  - Very suitable for single photon detection (with a proper photon-electron converter)
  - An promising photon detector option for STCF-RICH



IBF ~ 0.03%

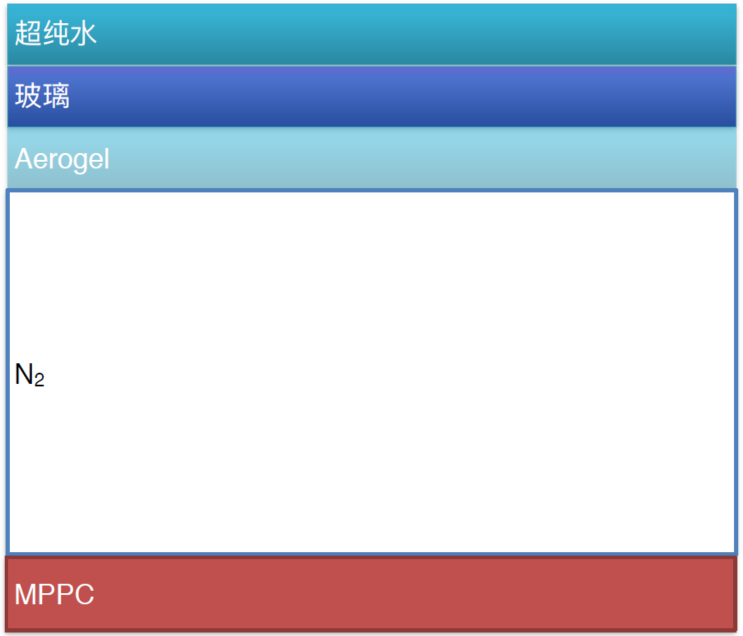


Gain ~ 3×10^6



使用可见光波段?

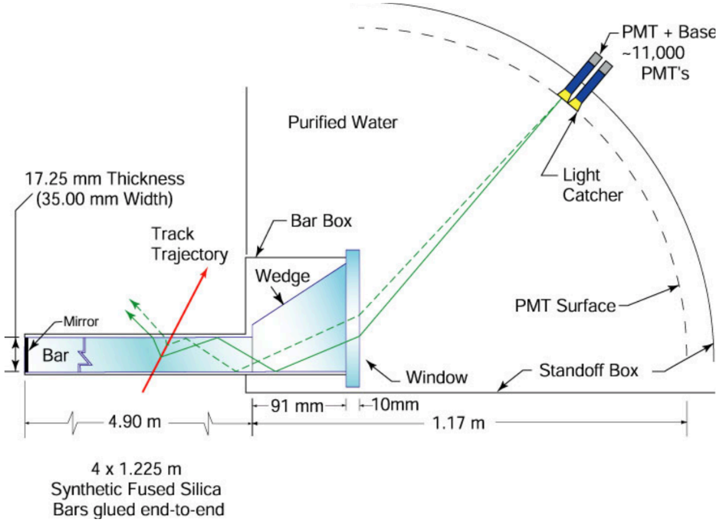
- 如果使用对可见光敏感的光探测器，则可极大简化RICH探测器的设计、制作和运行。
- 半导体光电器件的迅速发展为此提供了可能?



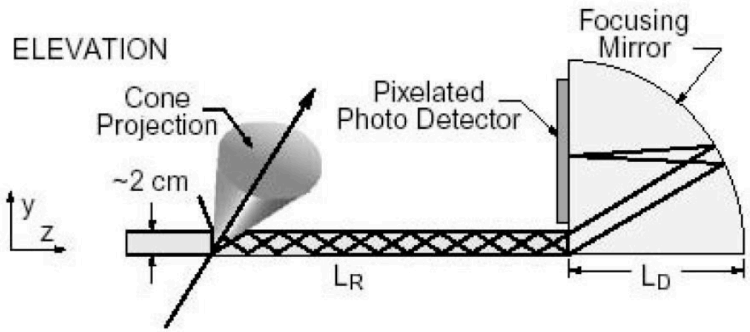
- 双辐射体RICH探测器概念
- 水、普通玻璃和Aeorgel对可见光均透明!
- 可以很好的兼顾π/K和π/μ 鉴别。
- SiPM：造价、噪声 ?

DIRC Detectors

First DIRC at a HEP experiment (Babar)

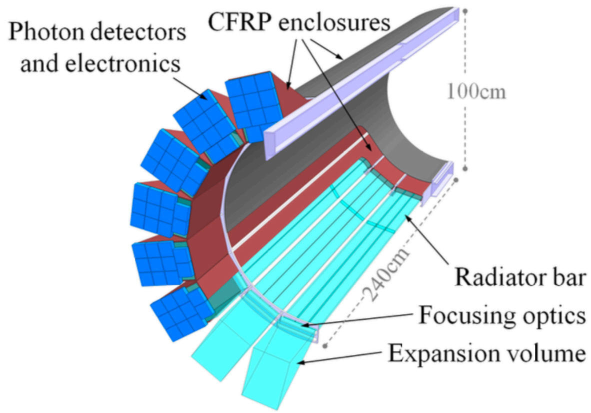


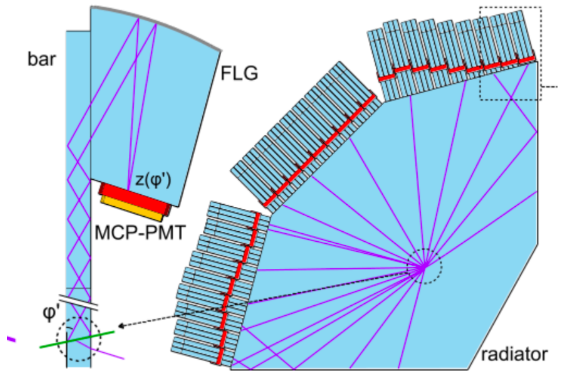
Advent of high performance silicon photon sensors (magnetic field resistant, high-gain, fine granularity, compact, high time resolution) makes a compact DIRC possible



A focused DIRC concept

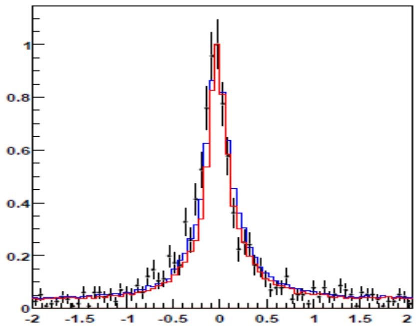
Panda DIRCs (barrel and endcaps)





DIRC-like TOF for Endcaps

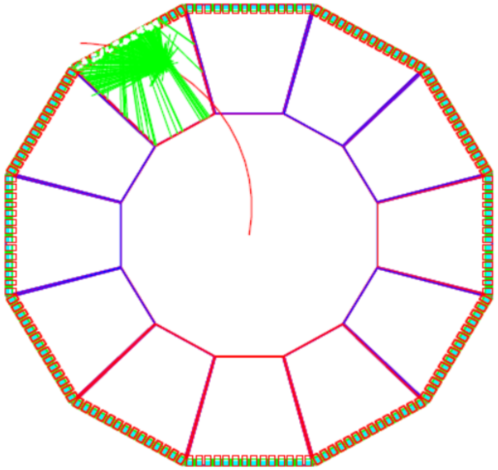
- DIRC-like forward TOF detector (FTOF: quartz + MCP-PMT) was developed at LAL for the SuperB factory project.
  - No Cherenkov angle reconstruction, simple and no need for space for optical expansion → very compact!
- Flight length to STCF endcaps ~ 1.4 m, making FTOF a feasible PID detector option for STCF endcaps.
  - A time resolution of ~40 ps is required for pi/K separation to reach 2GeV.

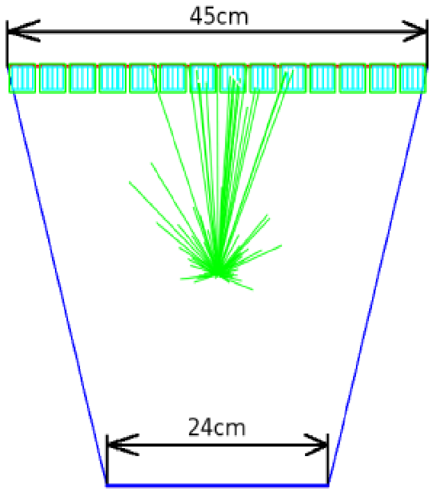


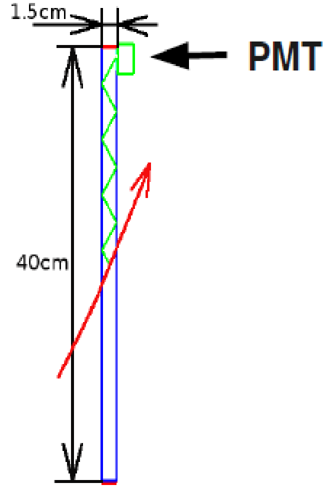
From SuperB R&D

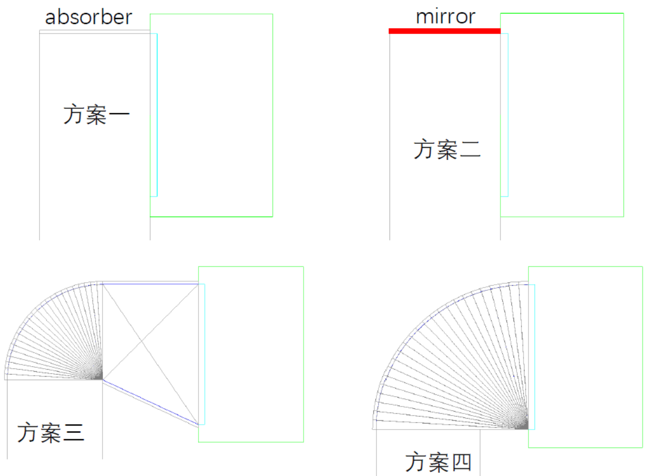
~ 80ps per PE

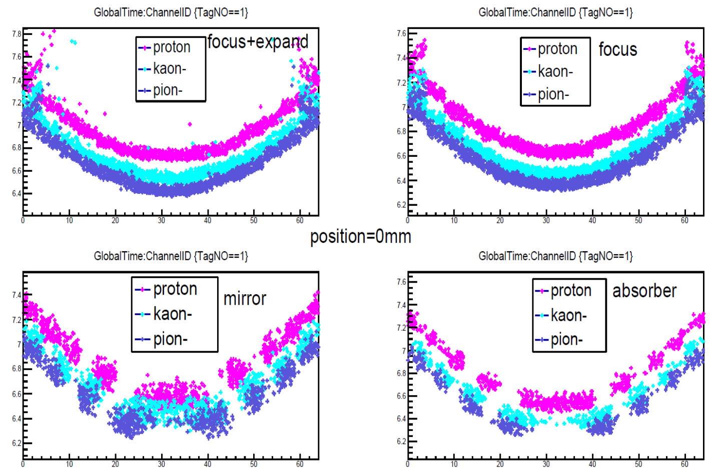
STCF-FTOF Design











使用圆柱形透镜耦合石英辐射体与MCP-PMT（方案四）

STCF-FTOF Performance

FTOF K/π separation (endcap)

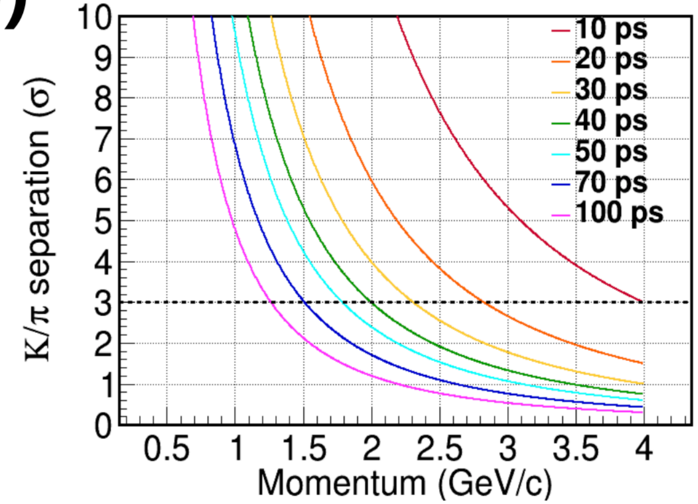
$$\Delta t = \frac{Lc}{2p^2}\left(m_1^2 - m_2^2\right) \qquad L_{\min}=1.28\ \mathrm{m}$$

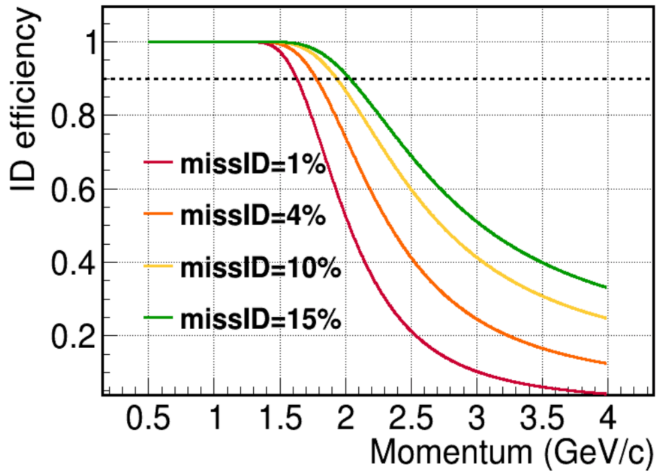
$$\text{separation power} = \frac{|\Delta t|}{\sigma}$$

$$\sigma_{\text{tot}}^2 \sim \left(\frac{\sigma_{\text{electronics}}}{\sqrt{N_{\text{p.e.}}}}\right)^2 + \left(\frac{\sigma_{\text{detector}}}{\sqrt{N_{\text{p.e.}}}}\right)^2 + \left(\frac{\sigma_{\text{TTS}}}{\sqrt{N_{\text{p.e.}}}}\right)^2 + \sigma_{\text{trk}}^2 + \sigma_{t0}^2$$

$\sigma_{electronics} = 10ps$
$\sigma_{TTS} = 70ps$
$\sigma_{detector} = 80\text{ps}$
$\sigma_{trk} = 10ps$
$\sigma_{T0} = 40ps$
$NPE > 10$

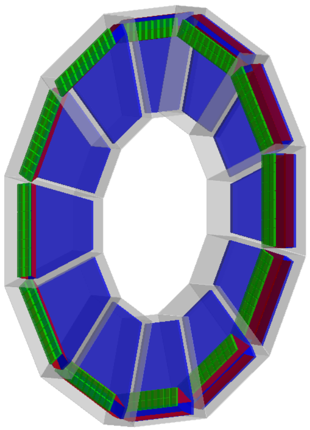
Total time resolution <50ps

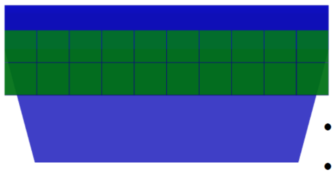




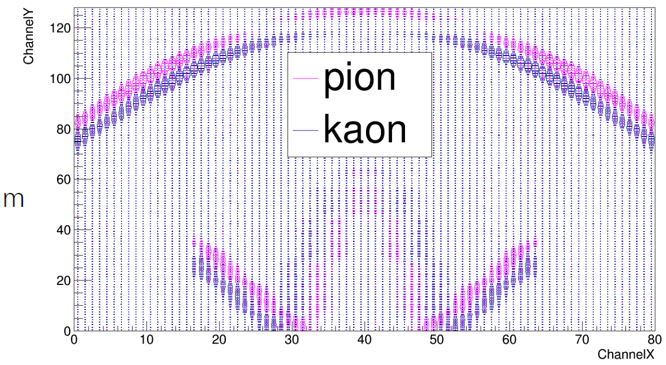
Endcap PID Alternative: DIRC

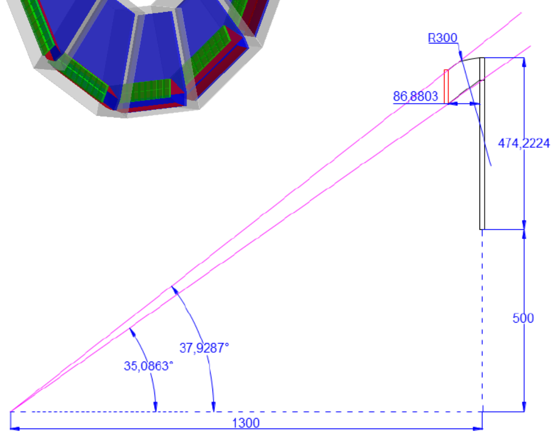
成像型DIRC探测器设计

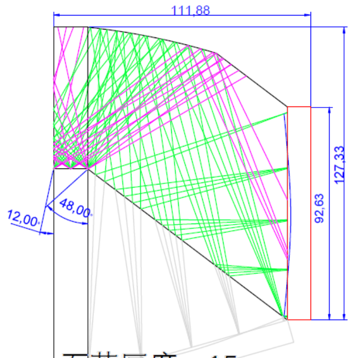




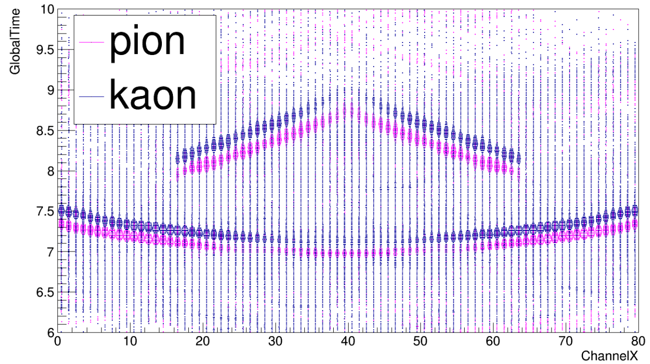
- MCP-PMT：2×10个
- MCP-PMT尺寸：45mm×45mm
- 阳极划分：8×64个
- 阳极尺寸：0.7mm×5.6mm



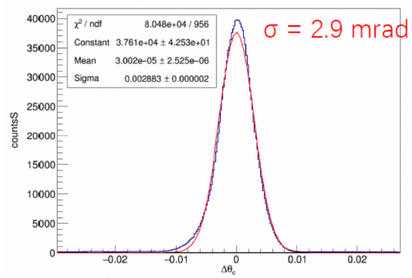




- 石英厚度：15mm
- 聚焦镜厚度：86.8803mm
- 聚焦镜半径：300mm



性能模拟

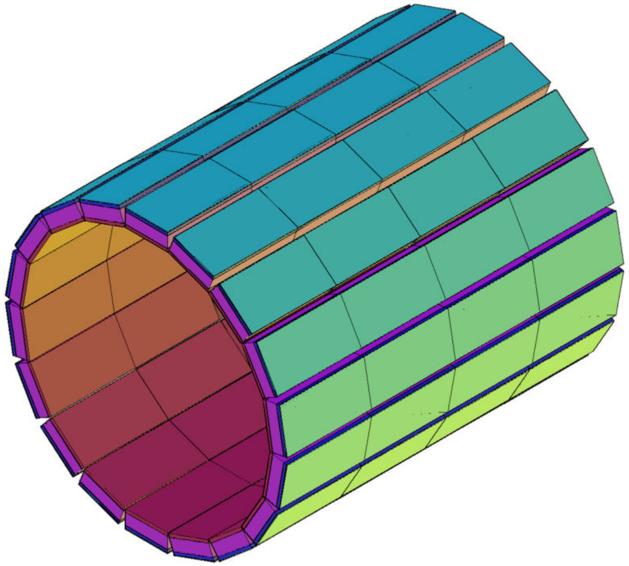


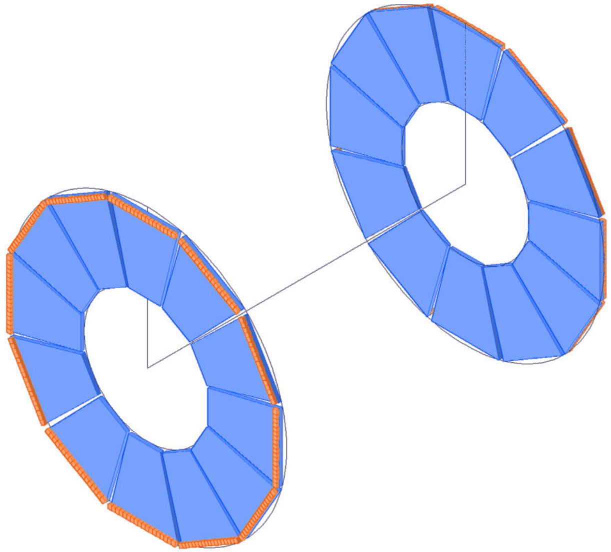
$\sigma_{\theta c}$ = 2.9mrad,
σ_{LOP} = 4.2mm,
σ_{TOF} = 33ps
(single pe)

具有更强大的粒子鉴别能力

Baseline STCF PID Detector System

- RICH in Barrel + FTOF in Endcaps



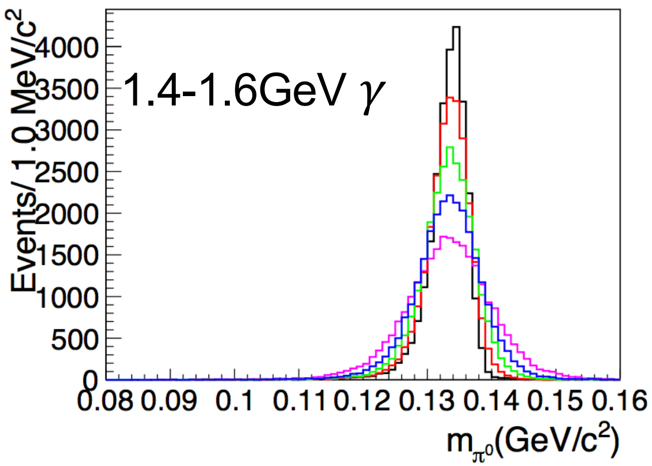


Issues to be clarified:

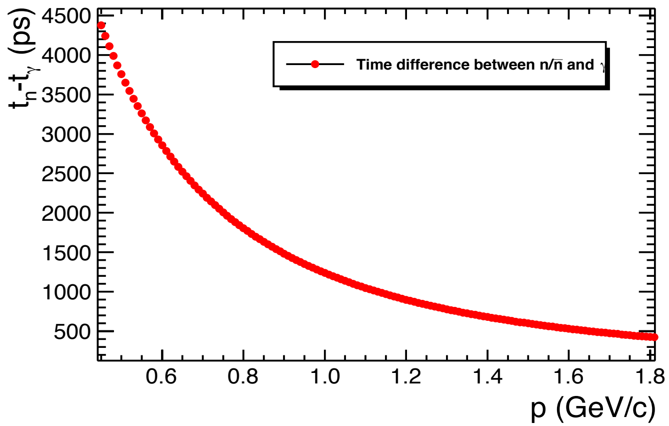
- Size of dead area between detector sectors (particularly in the case of RICH)
- RICH performance degradation at large incident angles
- Timing uncertainty due to longitudinal beam size
- Impact of background radiation on FTOF performance

电磁量能器

- 核心是能在高本底计数下精确测量能量 (20 MeV - 2 GeV)
  - 探测器方案：快发光晶体 + 半导体光电器件
- 此外，位置测量和时间测量也很重要。量能器设计应同时充分考虑这两方面的要求。



Invariant mass of high energy π^0 vs. γ position resolution



Difference in TOF of n and γ

Precise ECAL timing is very useful in suppressing γ background and measuring TOF of neutrons to infer their momenta.

定时量能器

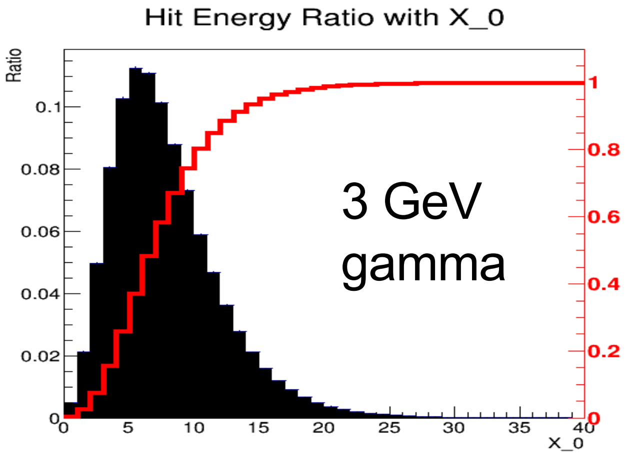
候选晶体

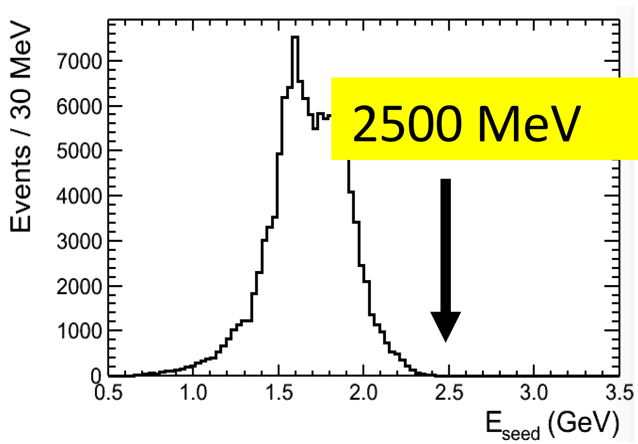
Crystal	Pure CsI	LYSO	GSO	YAP	PWO	BGO	CsI (Tl)
Density (g/cm^3)	4.51	7.40	6.71	5.37	8.30	7.13	4.51
Melting Point (°C)	621	2050	1950	1872	1123	1050	621
Radiation Length (cm)	1.86	1.14	1.38	2.7	0.89	1.12	1.86
Moliere Radius (cm)	3.57	2.07	2.23	4.50	2.00	2.23	3.57
Refractive index	1.95	1.82	1.85	1.95	2.20	1.82	1.95
Hygroscopicity	Slight	No	No	No	No	No	Slight
Luminescence (nm)	310	402	430	370	425 420	480	550
Decay time (ns)	30 6	40	60	30	30 10	300	1220
Light yield (%)	3.6 1.1	85	20	65	0.3 0.1	20	165
Dose rate dependent	No	No	TBA	TBA	Yes	Yes	No
d(LY)/dT (%/°C)	-1.4	-0.2	-0.4	TBA	-2.5	-1.0	0.4
Experiment	KTeV Mu2e				CMS ALICE PANDA	L3	BESIII BELLE(II) BaBar

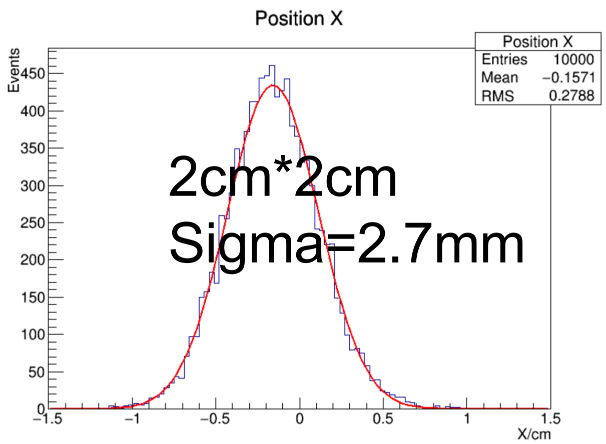
STCF-EMC选用纯CsI(pCsI)晶体

单元设计

- 长度：15 X_0
- 横截面： 5cm*5cm
- 动态范围：1 MeV ~2000 MeV
  - APD是比较合适的光探测器
- 时间分辨： 几百ps

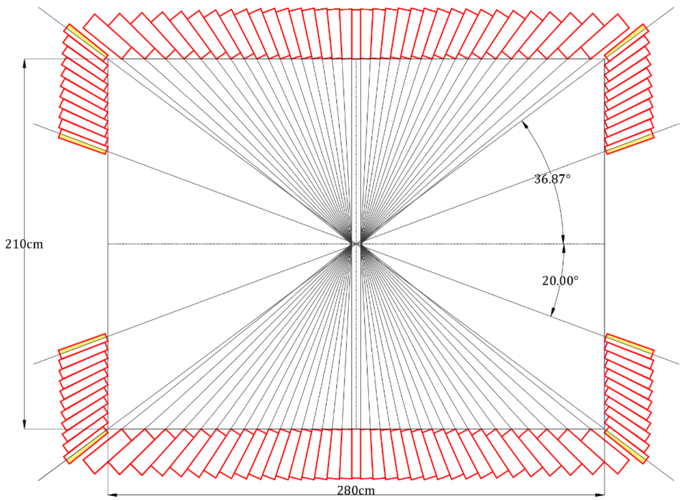


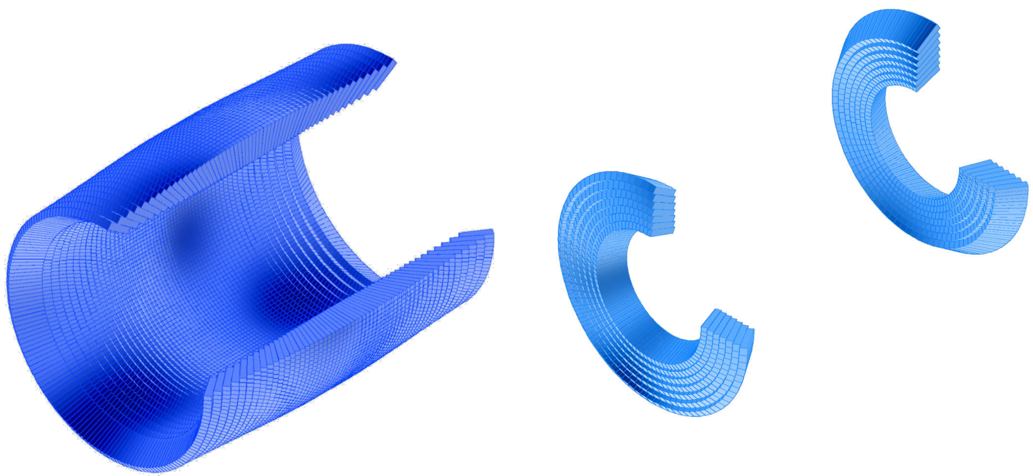




Layout of Crystals

- Barrel includes 4200 pCsI crystals arranged in 35 rings (along Z) of 120 crystals each.
- Endcap is composed of 1256 pCsI crystals.
- ～15 X_0





能量分辨研究

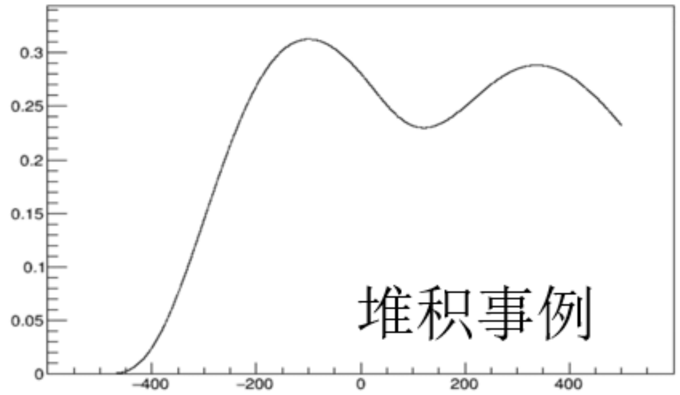
1. 本征分辨（只考虑能量沉积）
2. 引入光电子涨落
3. 引入晶体荧光收集非均匀性
4. 引入APD对次级带电粒子的响应
5. …

	无包装	有包装	光电子涨落			不均匀性（100 pe/MeV）		
			20	50	100	0%	5%	10%
桶部	0.85%	0.96%	1.58%	1.30%	1.14%	1.07%	1.02%	1.12%
端盖	1.05%	1.25%	1.62%	1.37%	1.22%	1.21%	1.37%	1.48%

1 GeV 光子

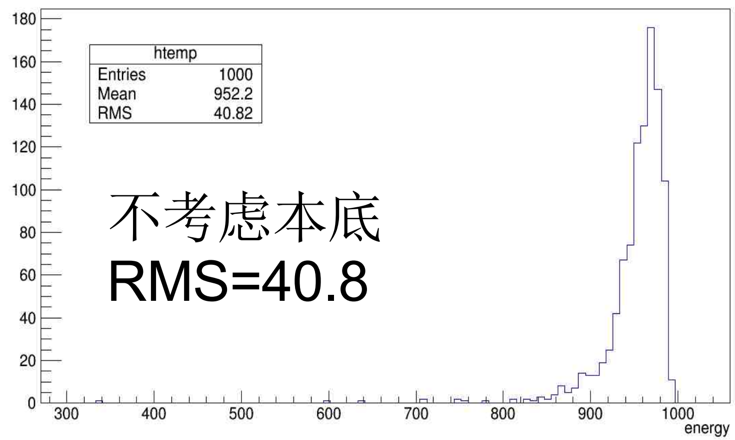
本底的影响

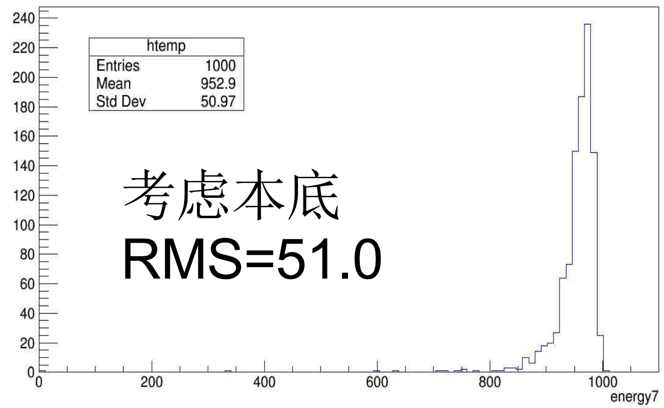
$$v_0(t) = L^{-1}[V_o(s)] = \frac{Q}{C_f} \cdot \frac{1}{m!}\left(\frac{t}{\tau}\right)^m e^{-t/\tau} \cdot u(t)$$



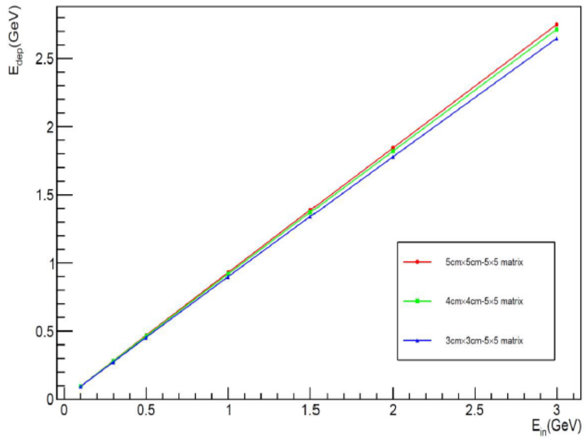
- 采用 BES3-ECAL本底计数率×100
- 考虑完整电子学响应
- 模拟堆积效应

对低能光子能量分辨影响极大！ 本底计数率估计太高?

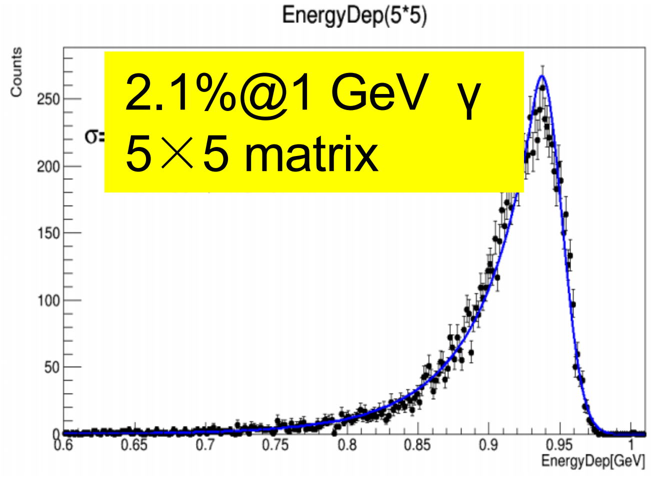




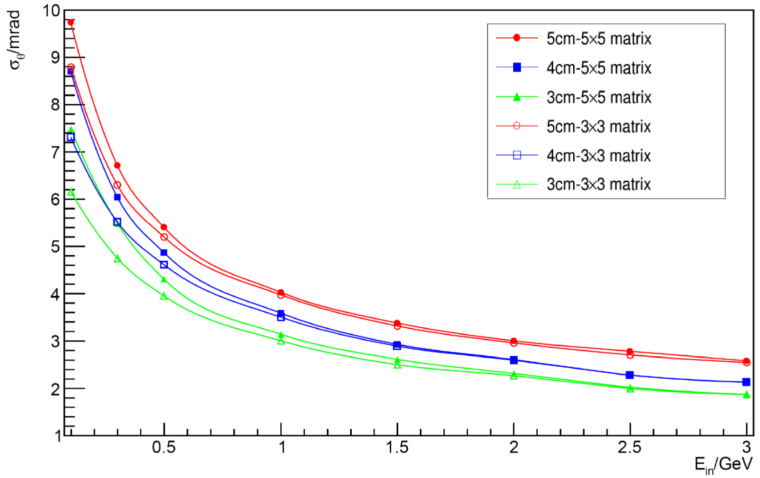
EMC Performance



能量线性



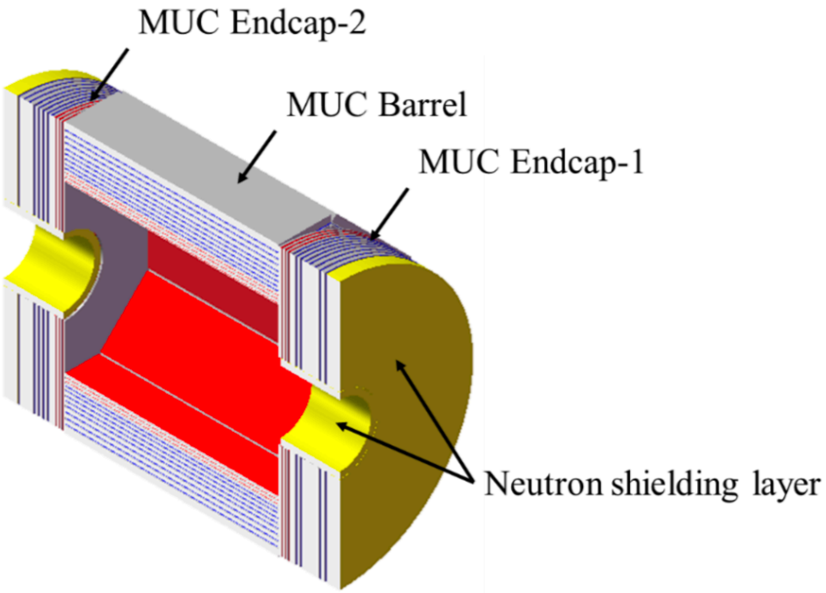
能量分辨率



位置分辨率

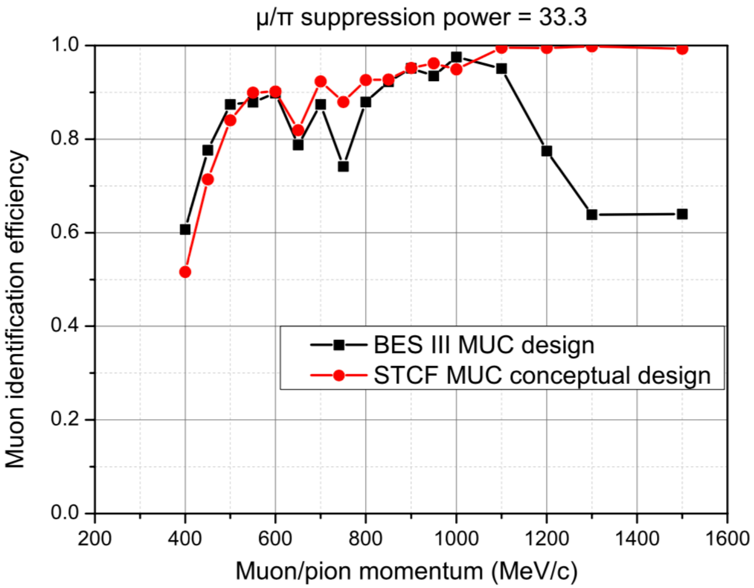
谬子探测器

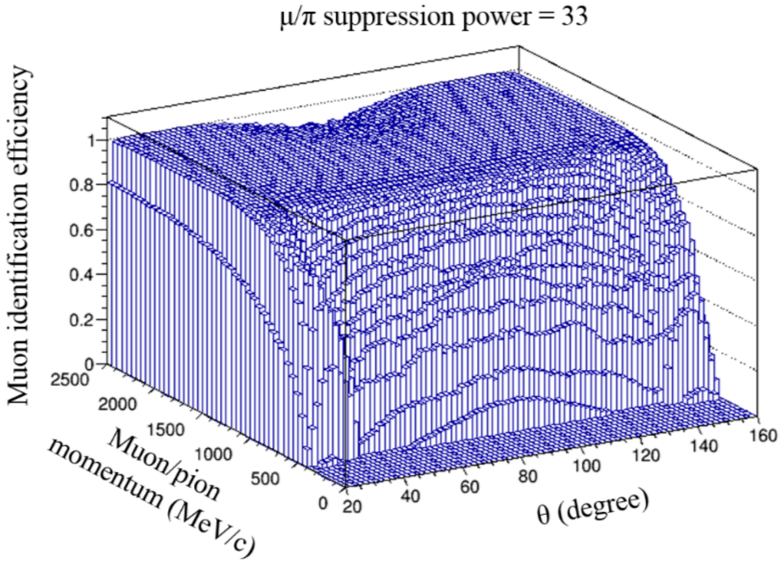
- 探测器技术选项：RPC、塑闪+SiPM
- 采用RPC-塑闪混合式设计（3层RPC + 8层塑闪）可以有较好的中性强子识别能力。



Parameter	Baseline design
R_{in} [m]	185
R_{out} [m]	303
R_e [m]	85
L_{Barrel} [m]	480
T_{Endcap} [m]	107
Segmentation in ϕ	8
Number of detector layers	11
Iron yoke thickness [cm]	4/4/4.5/4.5/6/6/6/8/8/8 cm
(λ=16.77 cm)	Total: 59 cm, 3.52λ
Solid angle	79.2%×4π in Barrel 14.8%×4π in Endcap 94%×4π in total
Total area [m^2]	Barrel ~821 Endcap ~572 Total ~1393

MUD Performance





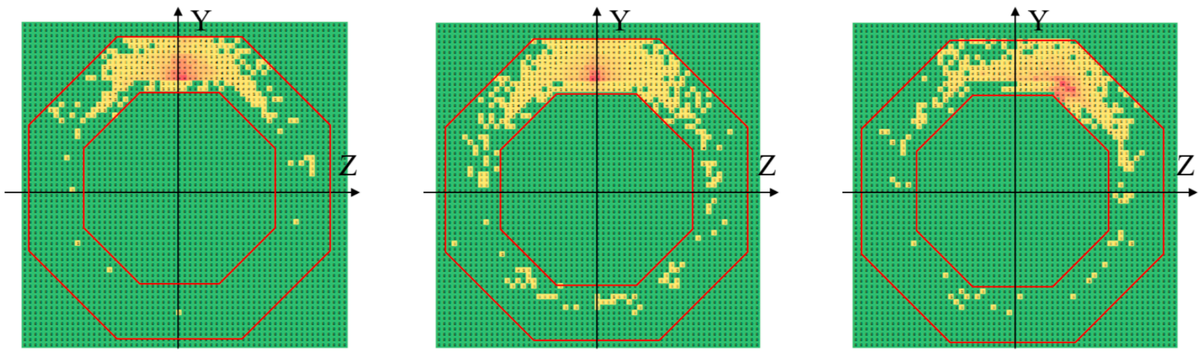
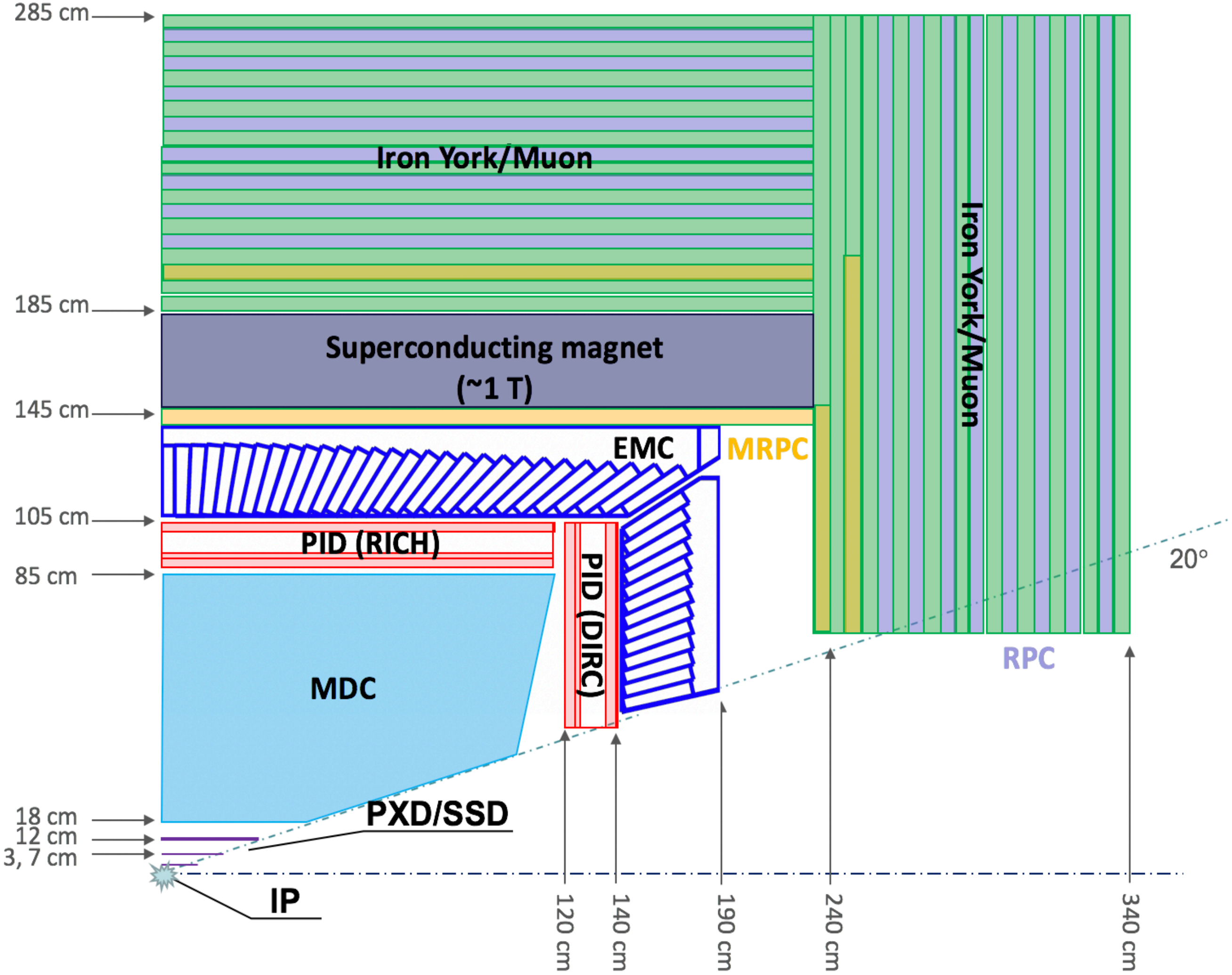


Figure 4.5.5: The cluster distribution in MUC: 1000 600 MeV/c neutron (left), 1000 600 MeV/c KL (middle), 1000 600 MeV/c pi$^+$ (right).

Summary



PXD
- $\sim<0.25\% X_0$ / layer
- $\sigma_{xy} < 130$ μm

MDC
- $\sigma_{xy} < 130$ μm
- $\sigma_p/p \sim 0.5\%$ @ 1 GeV
- dE/dx~6%

PID
- π/K (and K/p) 3-4σ separation up to 2GeV/c

EMC
E range: 0.02-2GeV
σ_E (%) @ 1 GeV
Barrel: 2 .5
Endcap: 4
Pos. Res. : ~ 5 mm

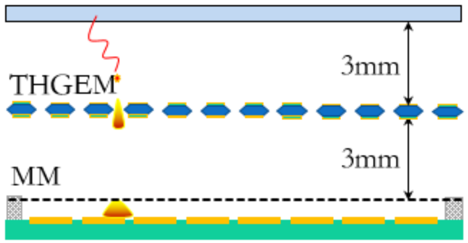
MUD
- 0.4 - 1.8 GeV
- π suppression >30

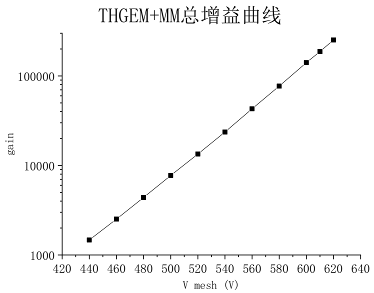
Highlights of STCF detector R&D

探测器原理样机束流测试@DESY

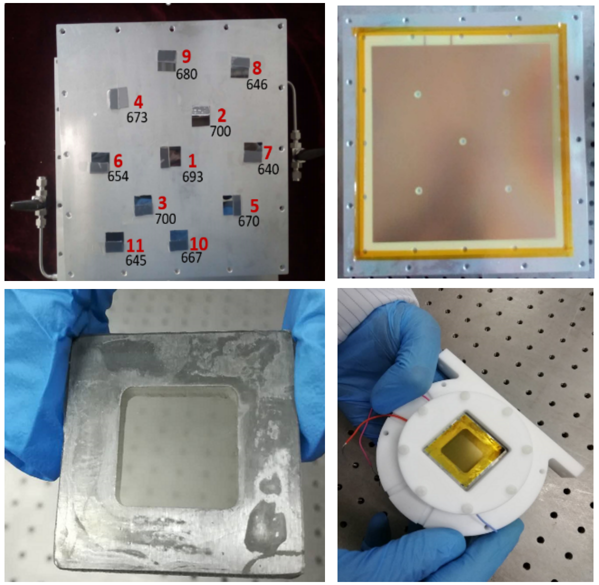
RICH样机研制

- CsI光电阴极
- MPGD光电探测器
  - 基于THGEM+MM基准方案

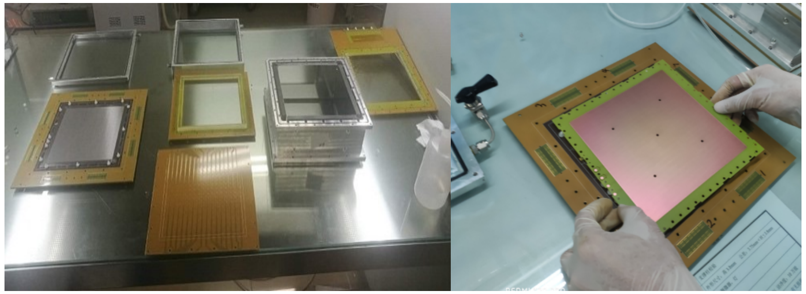




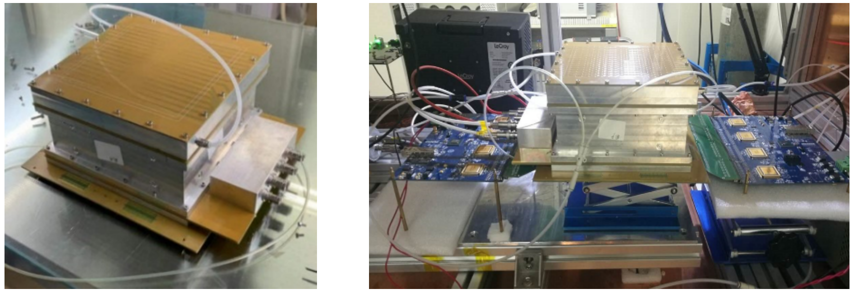
光电探测器性能测试



CsI 光电阴极的制备

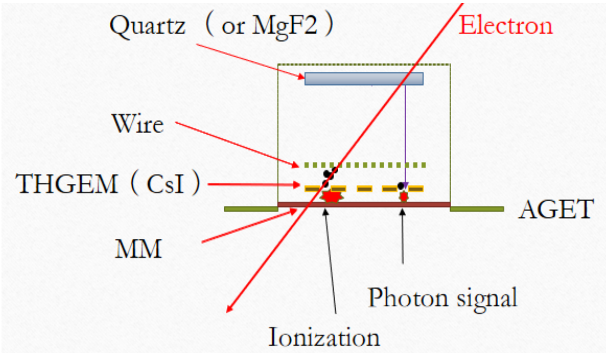


RICH样机组建

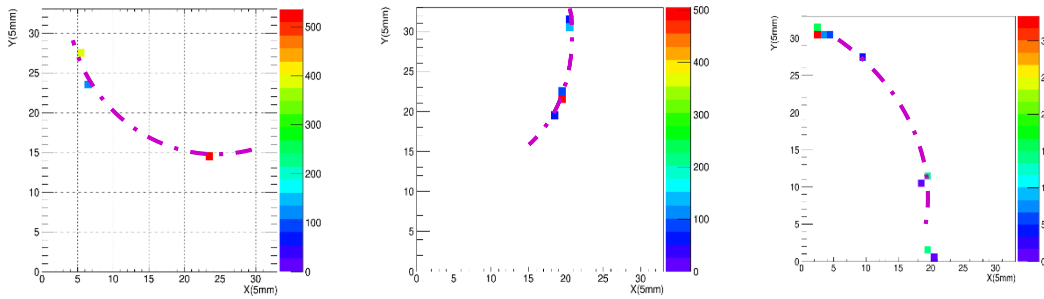


连接电子学读出联调

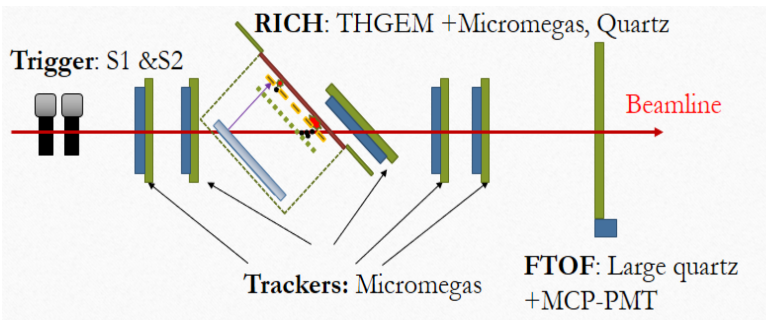
RICH样机宇宙线及束流测试



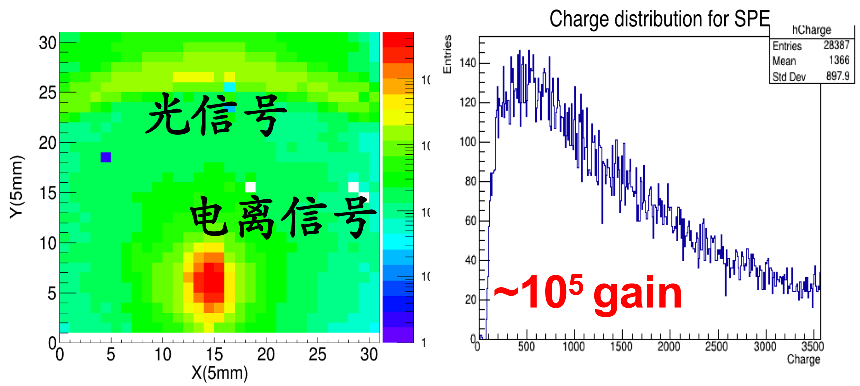
宇宙线μ子及高能电子束
流测试示意图



宇宙线μ子产生的切伦科夫光信号候选事例



高能电子束流测试实验设置

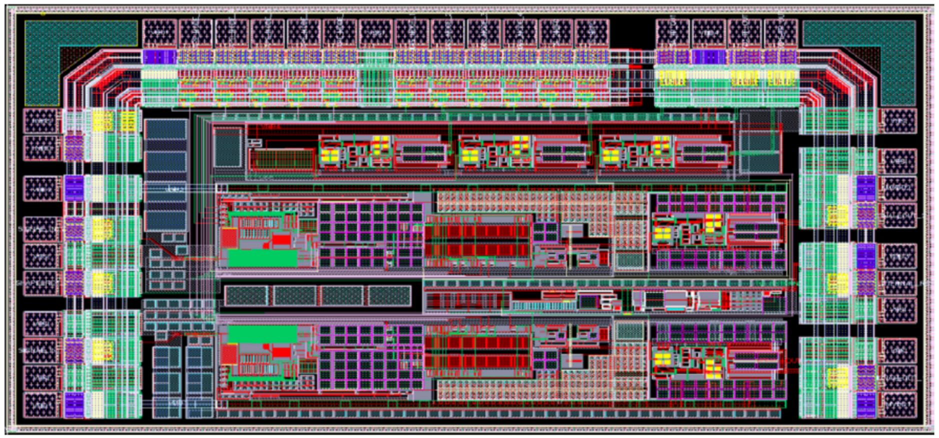


束流测试切伦科夫光信号

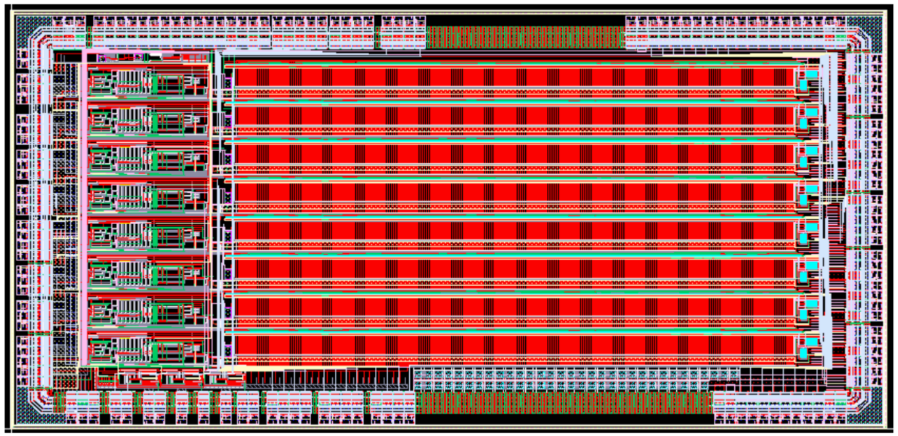
RICH Readout ASIC

STCF RICH 前端读出ASIC设计

- 近期，STCF RICH的ASIC设计完成，并已进行了投片，目前芯片正在制作中。此次投片的原理验证ASIC共包含两种：
  - 纯模拟前端双通道芯片：仅包含电荷灵敏前置放大器、极零相消及成形电路，用于评估模拟部分的电路性能；
  - 模数混合8通道芯片： 包含模拟前端电路、开关电容采样阵列及片内ADC，降低后端电路复杂性。



纯模拟前端双通道电路版图

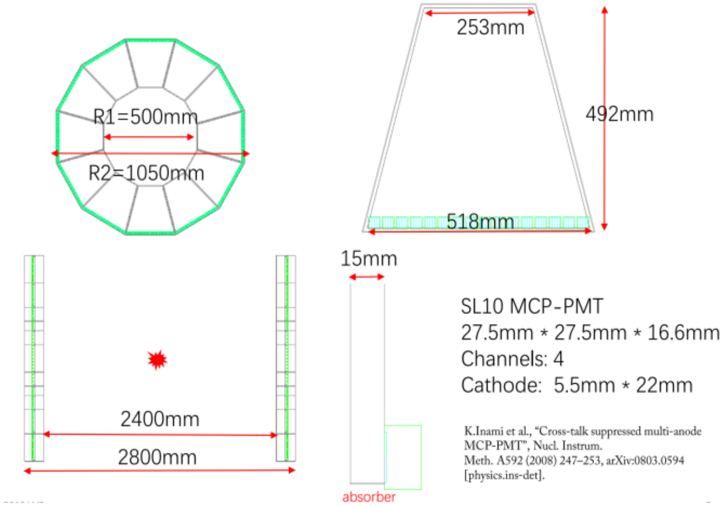


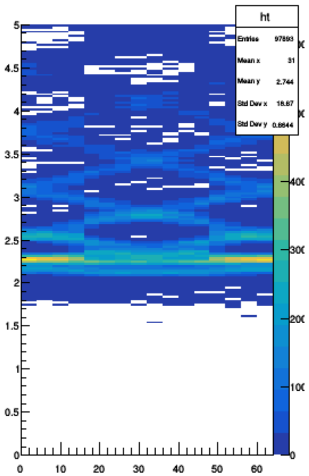
模数混合8通道芯片版图

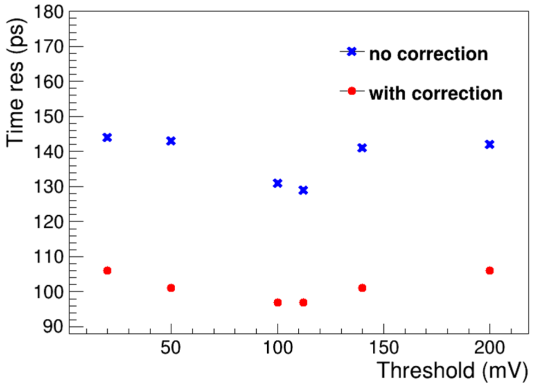
粒子鉴别器 - FTOF

FTOF探测器概念

探测器结构







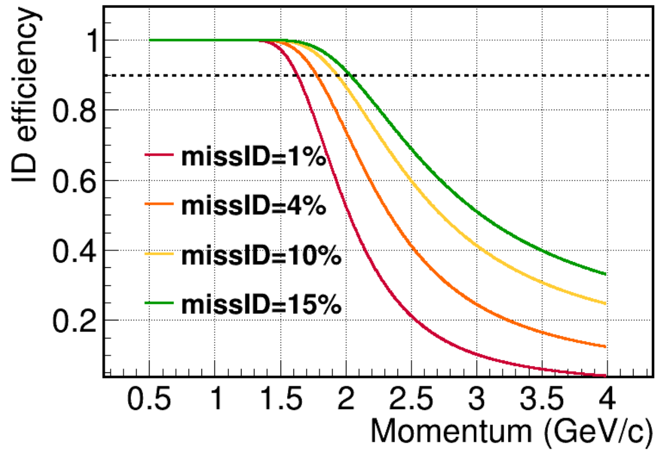
初步分析单光电子时间分辨～**100ps**

FTOF原理样机及束流测试

50cm x 12cm x 1.5cm 熔融石英晶体（全光谱透过率~ 90%@波长>190nm），表面及侧面抛光质量分别达到100Å RMS。

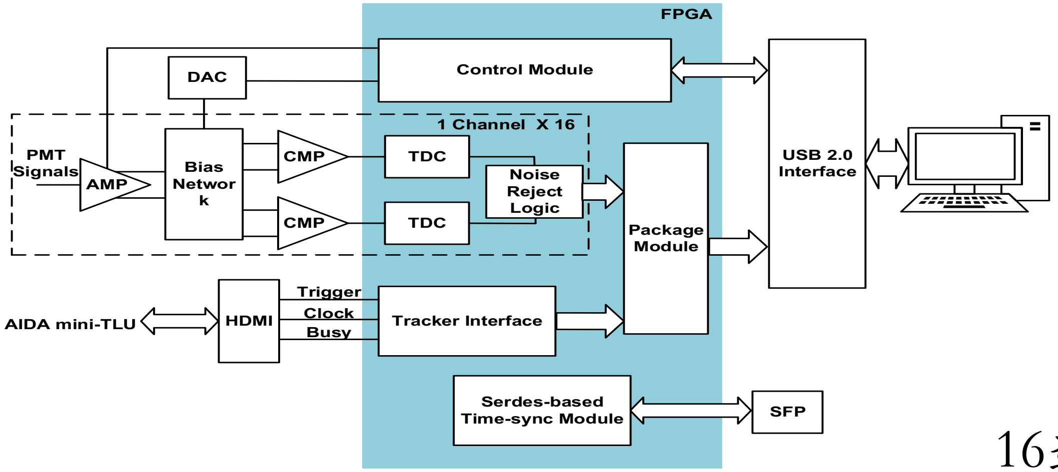
$$\sigma_{\text{tot}}^2 \sim \left(\frac{\sigma_{\text{electronics}}}{\sqrt{N_{\text{p.e.}}}}\right)^2 + \left(\frac{\sigma_{\text{detector}}}{\sqrt{N_{\text{p.e.}}}}\right)^2 + \left(\frac{\sigma_{\text{TTS}}}{\sqrt{N_{\text{p.e.}}}}\right)^2 + \sigma_{\text{trk}}^2 + \sigma_{t0}^2$$

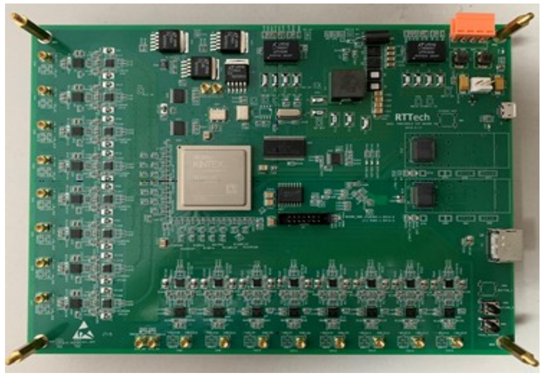
50ps 总体时间分辨下FTOF粒子鉴别能力



粒子鉴别器 - FTOF

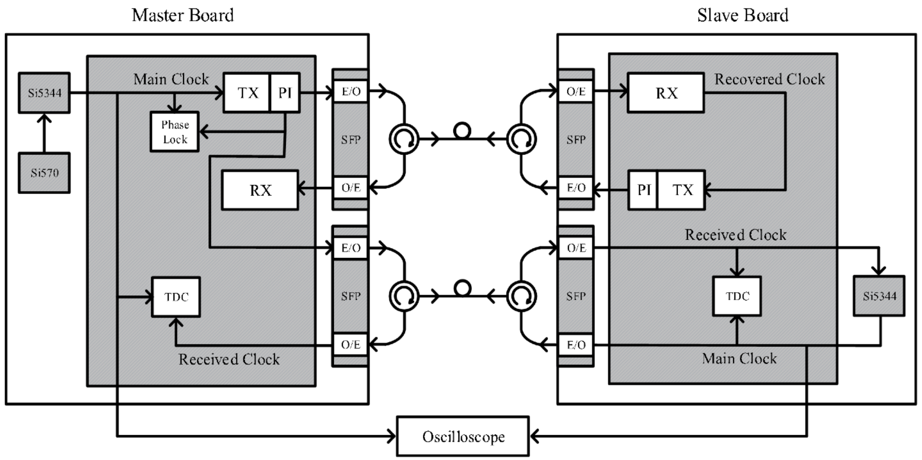
FTOF双阈值定时电路

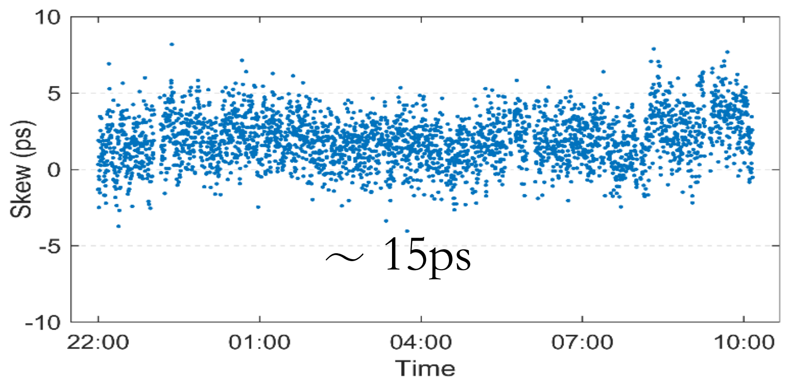




16通道，TOT修正，定时精度~8ps

高精度时钟分发电路

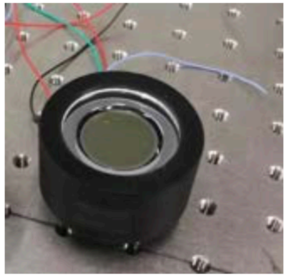
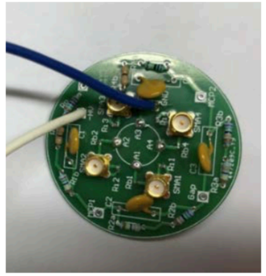
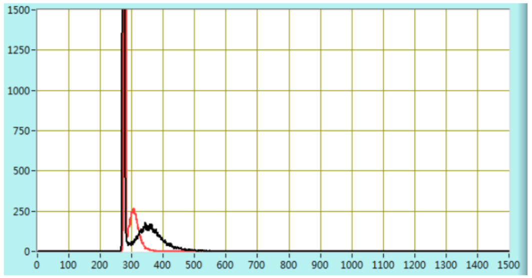
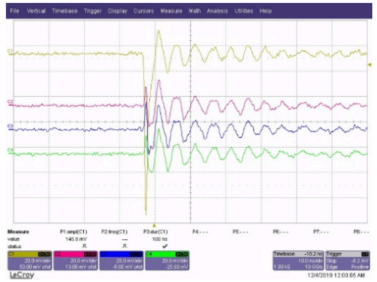
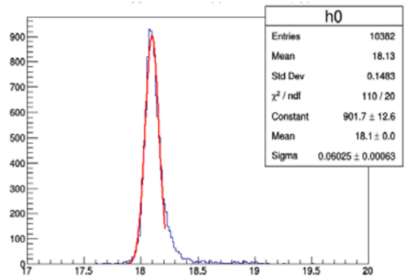


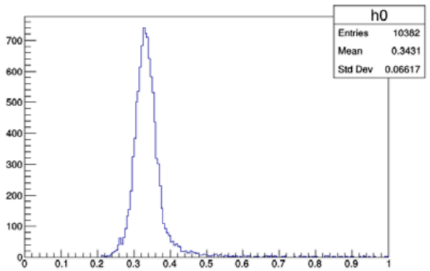


MCP-PMT Development

中科大-西光所MCP-PMT联合研制

- 西光所-中科大研究人员组成了联合研究组，在STCF项目的支持下先后完成了单阳极和多阳极MCP-PMT的研发和测试，主要性能接近或达到国际同型号产品的先进水平。

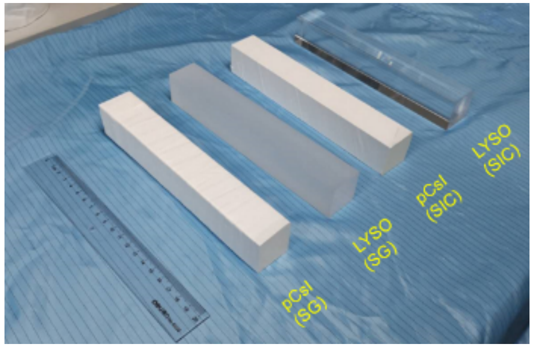









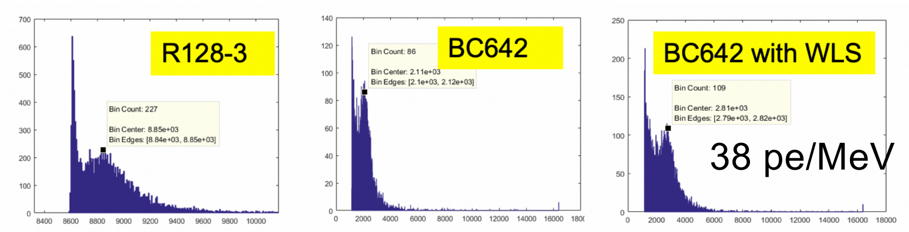
PMT编号	量子效率	增益	峰谷比	时间分辨(ps)	上升时间 (ps)	串扰信号幅度比
1#	22%@400nm	1.5×10^{7}@2100V	3.4	~70 (σ)	340	~13%
2#	24%@400nm	1.3×10^{7}@1900V	4.0	~55 (σ)	350	~16%
Photonis M16	22%@~400nm	$>10^{6}$	>2	35-50 (σ)	500	~10-20%
Hamamatsu M16	24%@~400nm	$>10^{6}$	>2	70-100 (FWHM)	180	~10-20%

ECAL关键技术研究

ECAL探测单元（晶体+APD）

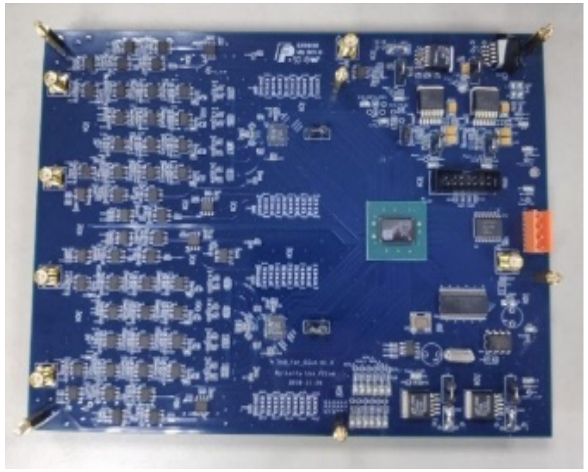


ECAL探测单元光产额



目前研究重点：提高pCsI荧光产额

ECAL读出电子学
电荷灵敏前放+成形放大



噪声水平