# Detector for the Super Tau-Charm Facility


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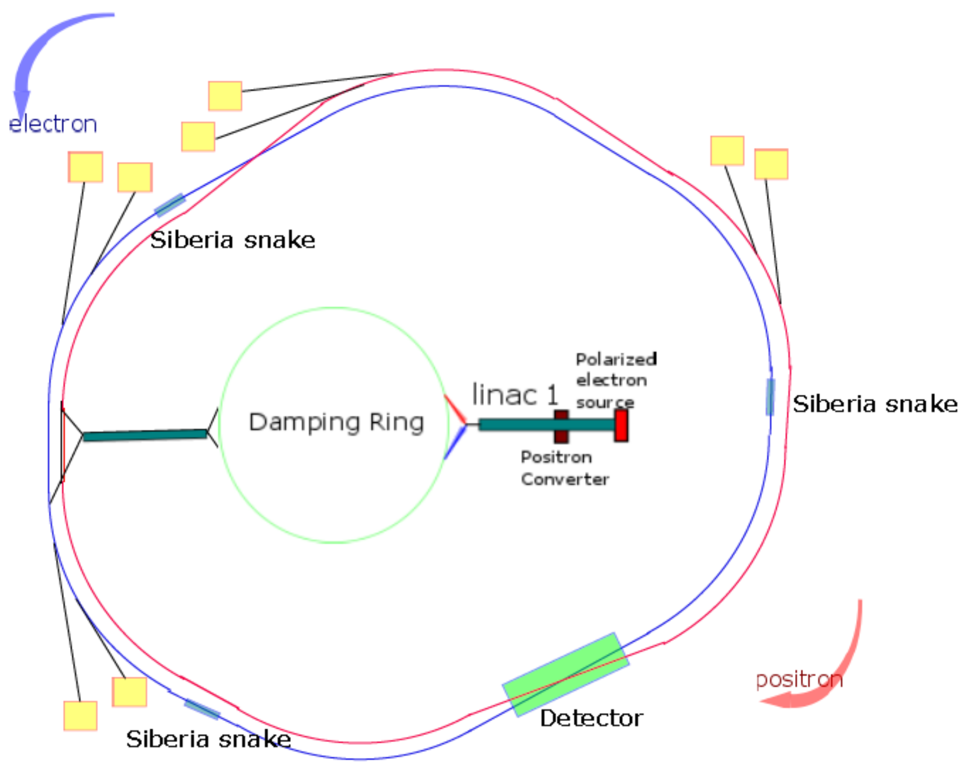
# Super Tau Charm Facility

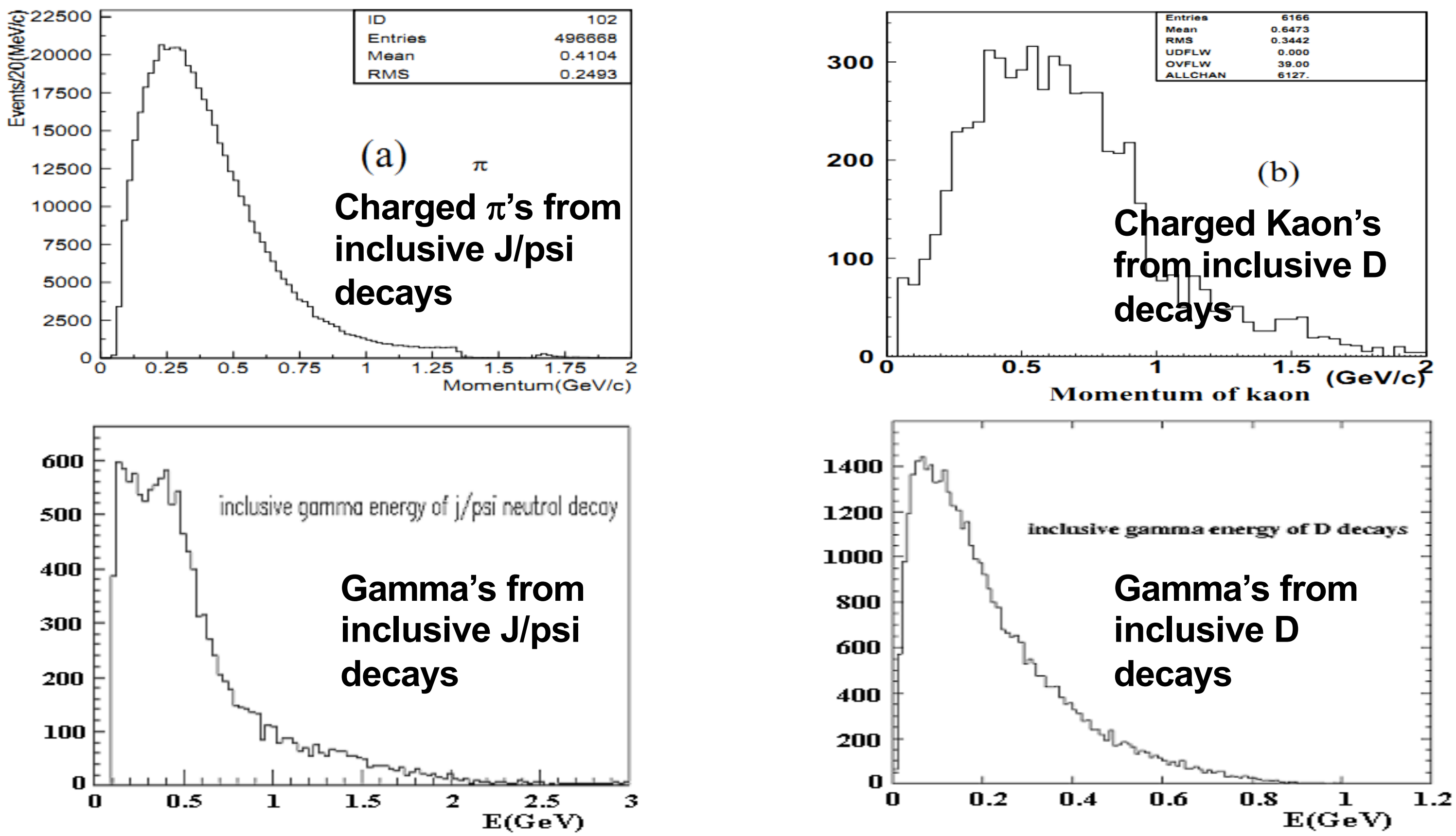
- **STCF** : a natural extension of BEPCII and a viable option for a post-BEPCII HEP project in China.




- $E_{cm}$ = 2-7 GeV, L=1×10$^{35}$ cm$^{-2}$s$^{-1}$ @4 GeV
- Symmetrical collision
- double-ring, 600-1000m
- Crab waist scheme
- Single beam polarized

**An super τ-c machine far beyond BEPCII**

# Feature of Final States at STCF



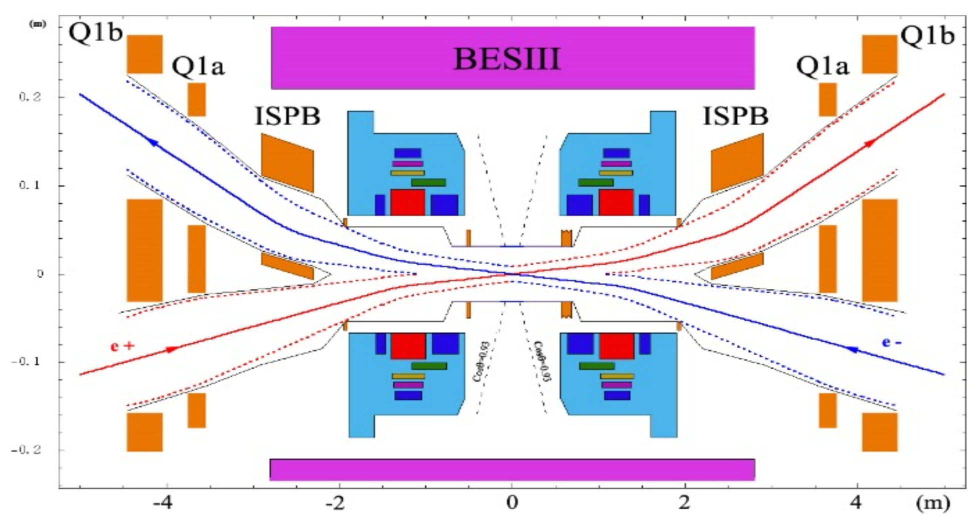

- Final-state particles are largely of low momentum /energy (< 1GeV/c )
- Designs of the HIEPA detector have to match this important feature of final states.

# Other Physics Requirements

- $E_{cm}$ of up to 7 GeV demands PID in a large momentum range.
- $D^0D^{0bar}$ mixing studies requires superior PID (pi/K) capability.
- Measurement with semi-leptonic decays of D mesons and search for cLFV (tau->**γμ**) call for muon identification with low threshold, high efficiency and purity.
- ……

# Requirements from Accelerator

- High luminosity ~$10^{35}$ $cm^{-2}s^{-1}$
  - High rate and high radiation level
- Constrains from IR design
- Detailed MDI studies are required




**IR of BEPCII**

# Detector Requirements for STCF

- **General considerations and overall requirements**
  - Large and well defined acceptance
  - Efficient and fast triggering
  - High efficiency and resolution for both charged and neutral particles
  - Mis-measurement well under control
  - Efficient and precise reconstruction of exclusive final states
  - High rate capability and radiation tolerance, particularly around IP and in forward regions
  - Precise luminosity measurement

# Continued

- **Vertexing (or inner tracking)**
  - Vertexing not very critical for HIEPA, more to combine with a central tracker for tracking, particularly low p tracking (down to ~50 MeV)
- **Central tracking**
  - large acceptance, low mass, high efficiency (p down to ~0.1 GeV) and high resolution (p <~ 1GeV)
- **PID**
  - $\pi$/K separation up to 2GeV, compact and low mass

# Continued

- **e/γ measurement**
  - Good energy and position resolution in 0.02-3 GeV
- **μ detection**
  - Low momentum threshold (p <~0.4GeV)
  - high μ efficiency and π suppression power ( > 10 )
- **Magnet**
  - adjustable from 0.5- 1.0 T

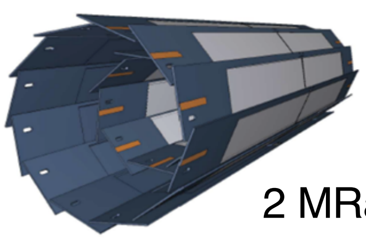
# Inner & Outer Trackers

- Dominant factors in low p tracking: multiple scattering and energy loss
- So driving force in design of tracking system: low mass.
- Special design is required for inner tracking to cope with the very high level of radiation close to IP
  - An inner-outer separate design is optimal.
- Detector technology options
  - Inner tracker
    - Low mass, fast and radiation hard silicon detectors: DMAPS
    - MPGD: cylindrical GEM/MicroMegas/uRWELL
  - Outer tracker: a low mass drift chamber

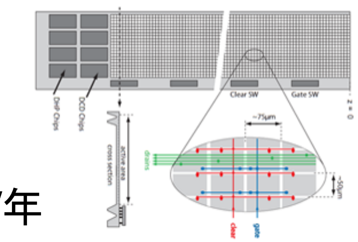
# Inner Tracker Technologies

## 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.

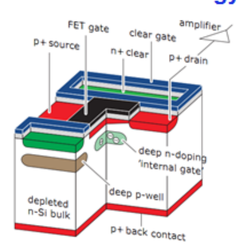


2 MRad/年

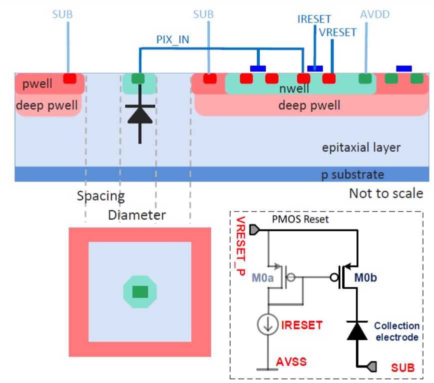


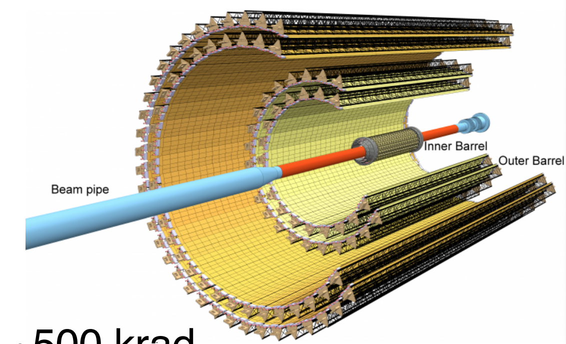
| | |
|---|---|
| Number of pixels per module | 250 x 1536 |
| Pixel size (r-phi, z) | 50μm x (60-75) μm |
| Frame time | 20 μs |
| Material budget per layer | 0.15% $X_0$ |
| Resolution (r-phi, z) | <10μm, < 20μm |
| Occupancy at 1.8 cm radius | 0.2 hits $\mu m^{-2}s^{-1}$ |
| Radiation environment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

**DEPFET Technology**




## MAPS (ALPIDE)

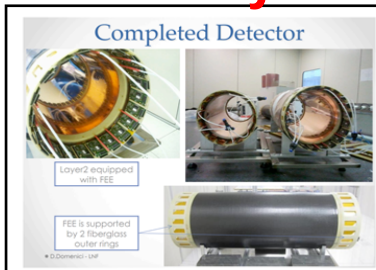


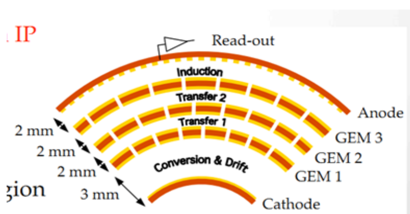




~ 500 krad

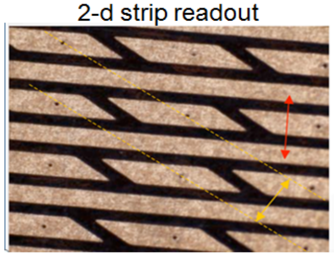
Pixel size: 29*27μm, high resistivity epitaxial, deep PWELL, reverse bias, global shutter (<10 μs), triggered or continuous readout, resolution < 5um, material budget <0.3%$X_o$

## Cylindrical GEM




2-d strip readout

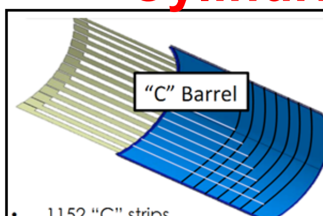


X pitch 650μm → X res 190 μm
V pitch 650μm → Y res 350 μm

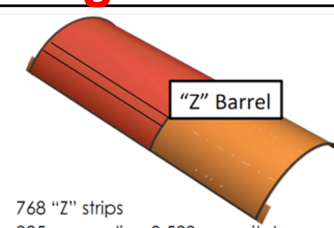
| Material Budget | |
|---|---|
| Total 1 layer | 0.49% |
| Total 4 layers | 1.95% |

Pixel readout would be required for the innermost layers at HIEPA

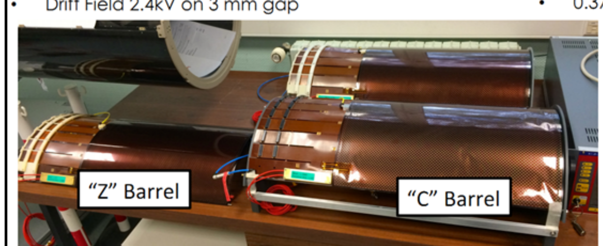
## Cylindrical MicroMegas

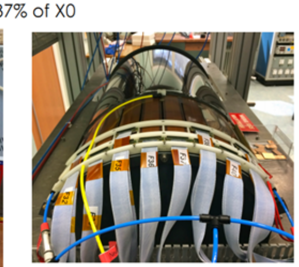



- 1152 "C" strips
- Pitch from 0.67 to 0.33 mm
- 221 mm radius
- PCB thickness 100 μm
- Drift thickness 250 μm
- Drift Field 2.4kV on 3 mm gap

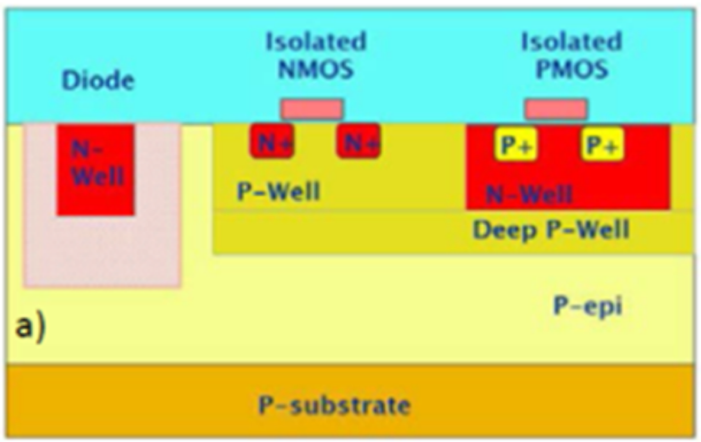


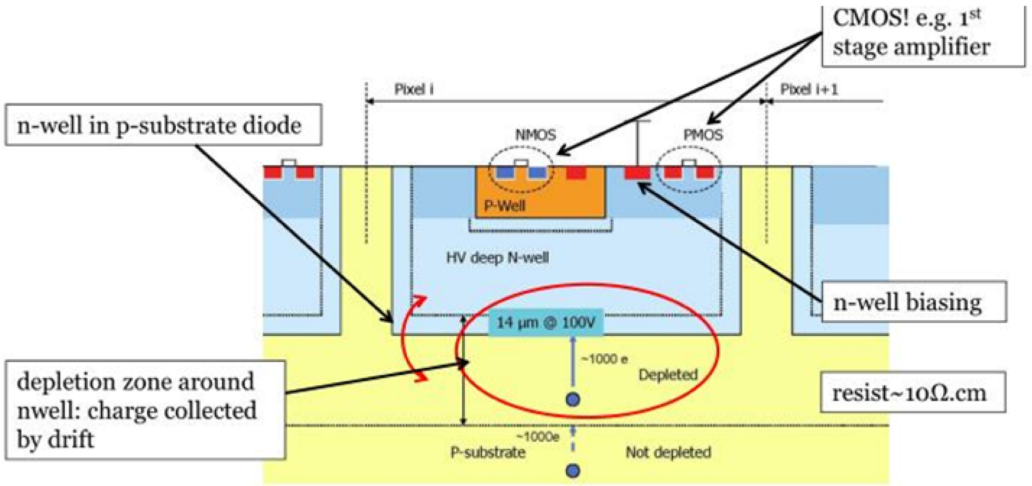

- 768 "Z" strips
- 225 mm radius, 0.529 mm pitch
- PCB thickness 200 μm
- Drift thickness 250 μm
- Drift Field 2.4kV on 3 mm gap
- 0.37% of X0



# CMOS MAPS




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

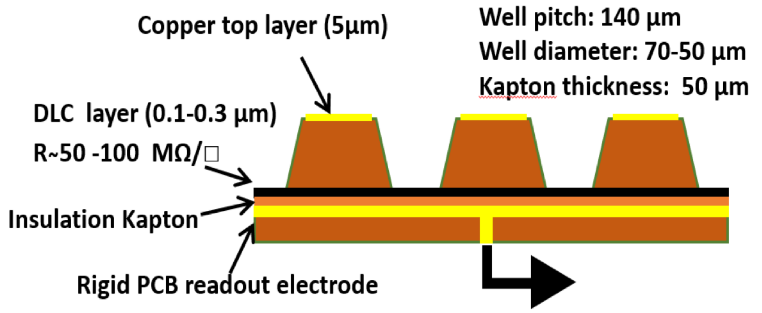
Novel on-chip readout schemes also under development for high rate application

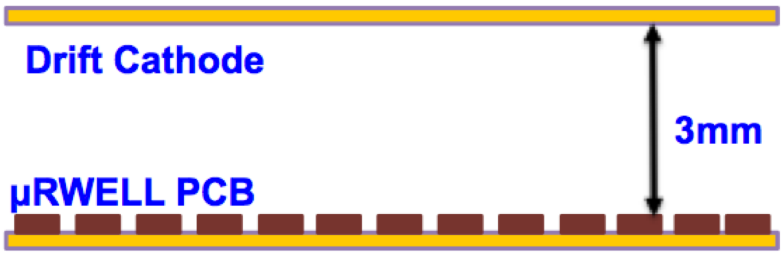
**Depleted CMOS MAPS** → low mass, high rate, radiation hard

→ A promising inner tracking technology for STCF

# A new MPGD : uRWELL

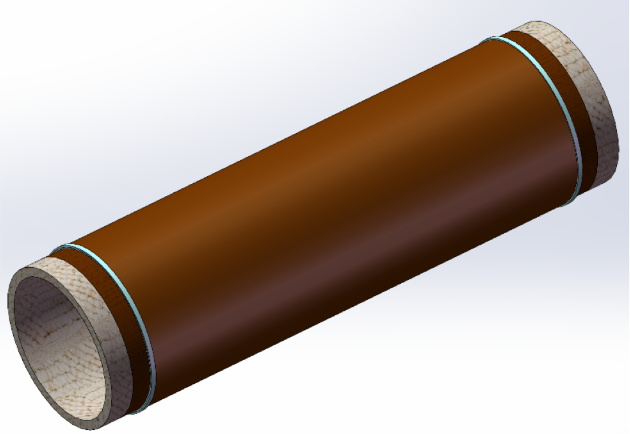
- Very compact, spark protected, simple to assemble, flexible in shapes, low cost.



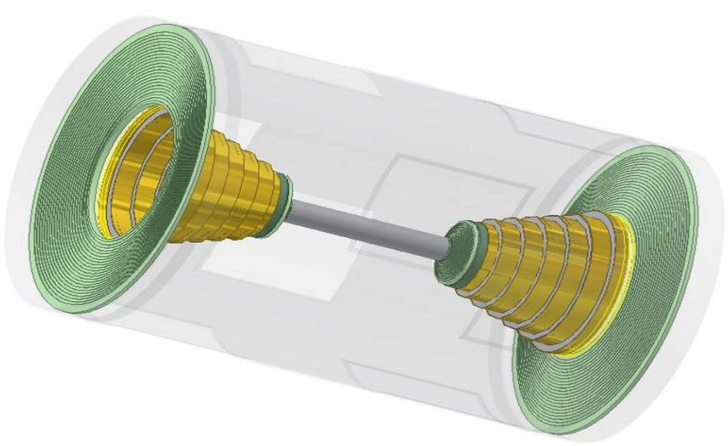

- More importantly, a very promising approach to making a cylindrical MPGD detector

- Another option for the STCF inner tracker



# Outer Tracker: A Drift Chamber

- Possible modifications to the BESIII drift chamber
  - $R_{in}$ has to be enlarged to avoid the very high rate region at HIEPA
  - Smaller cell size for inner layers to accommodate a higher count rate
  - No Au coating on Al wires and thinner W wires to reduce material
  - A lighter working gas to reduce material
  - Sharing field wire layers at the axial-stereo boundaries to reduce material



$$\sigma_x \sim 130\,\mu m$$

$$\frac{\sigma_P}{P} \sim 0.5\%@1\mathrm{GeV/C}$$

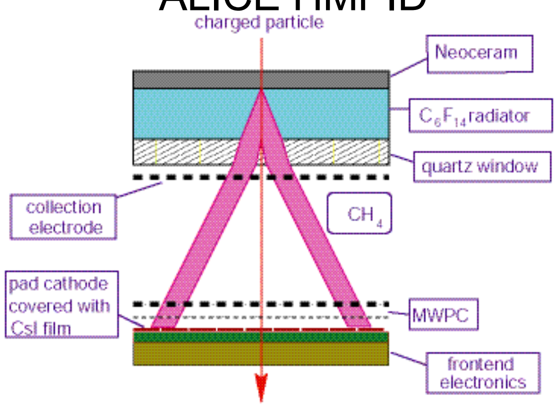
$$\frac{\sigma_{\frac{dE}{dx}}}{\frac{dE}{dx}} \sim 6\%$$

BESIII Drift Chamber

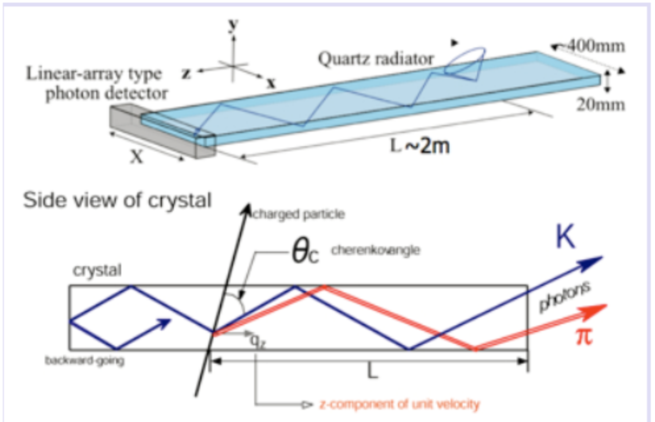
# PID Detector

- $\pi$/K separation up to 2GeV.
  - Cherenkov-based technology is favorable.
  - Very low p region (<~0.6GeV) covered by trackers through dE/dx
- Compact (<20cm) and low mass (<$0.5X_0$)
- Detector options
  - RICH, DIRC-like, …

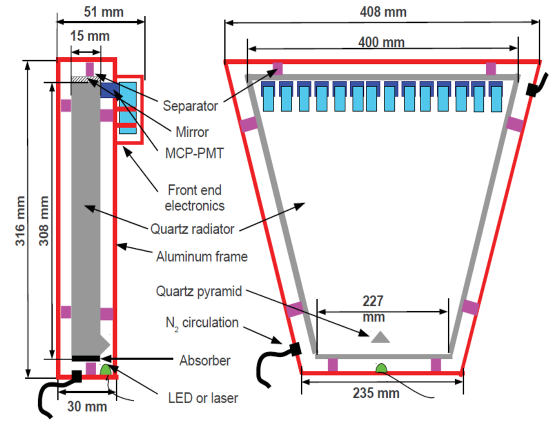
ALICE HMPID




iTOP for BELLE2

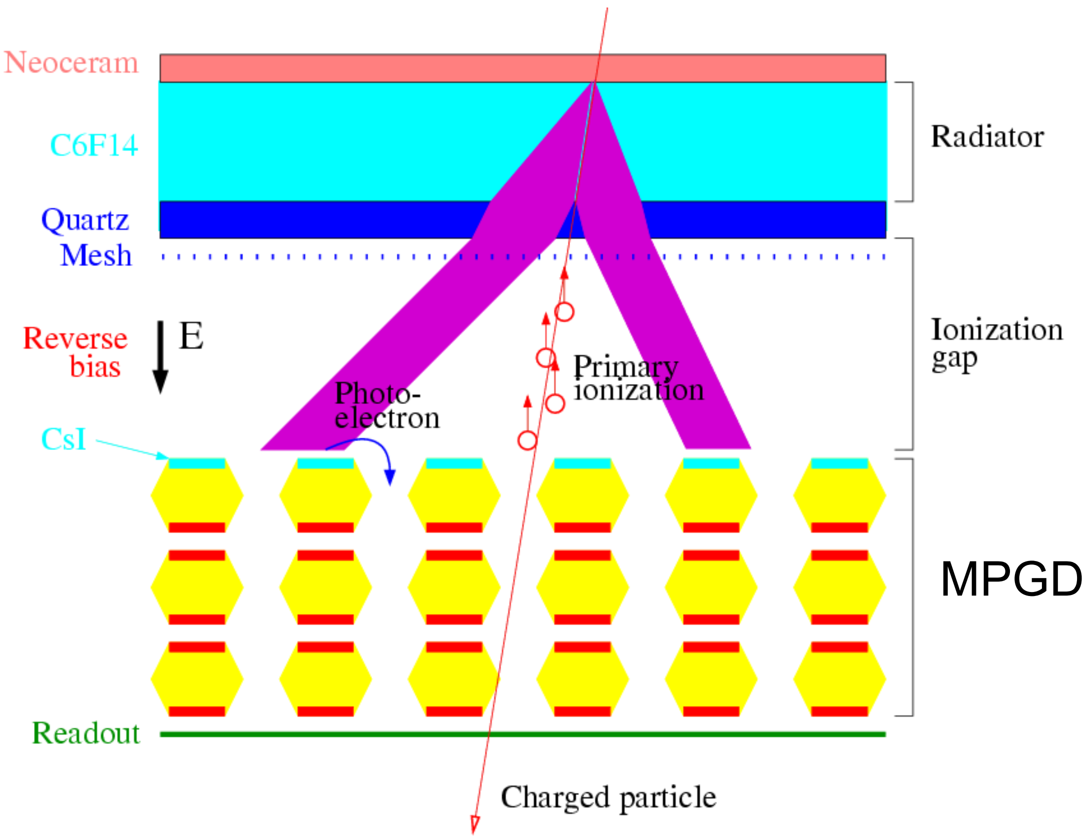



FTOF for superB



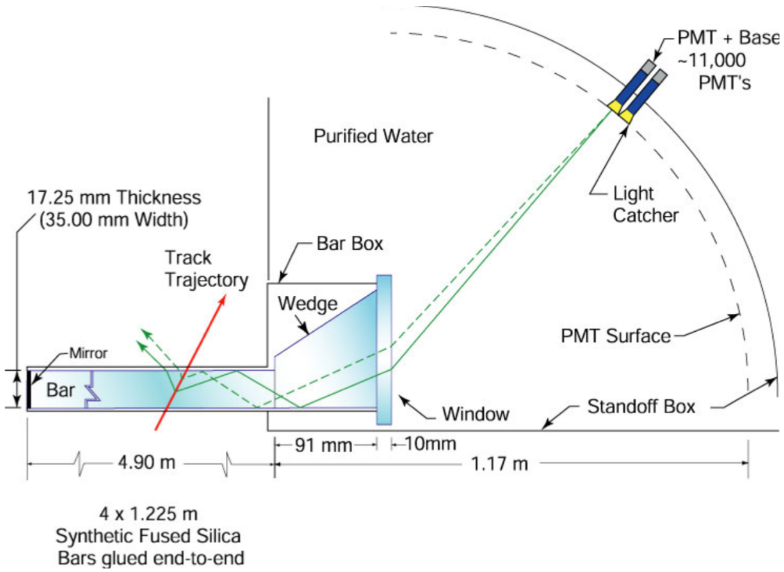
# A RICH Design for STCF

- Proximity focusing RICH, similar to ALICE HMPID design, but 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, UV detection

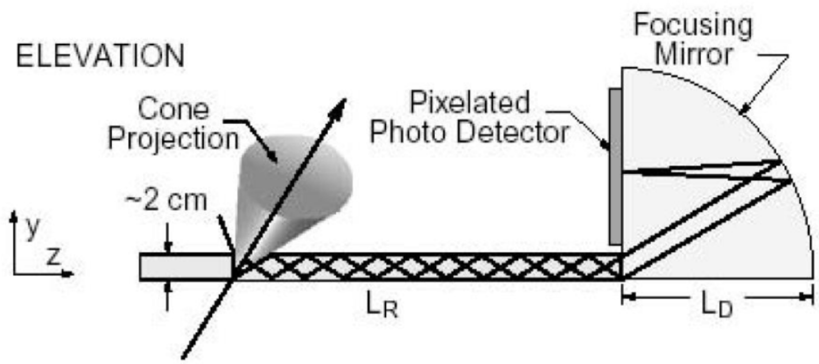


# DIRC Detectors

First DIRC at a HEP experiment (Babar)

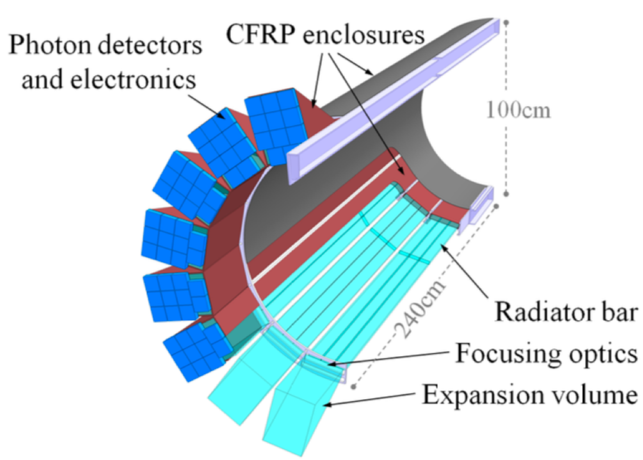


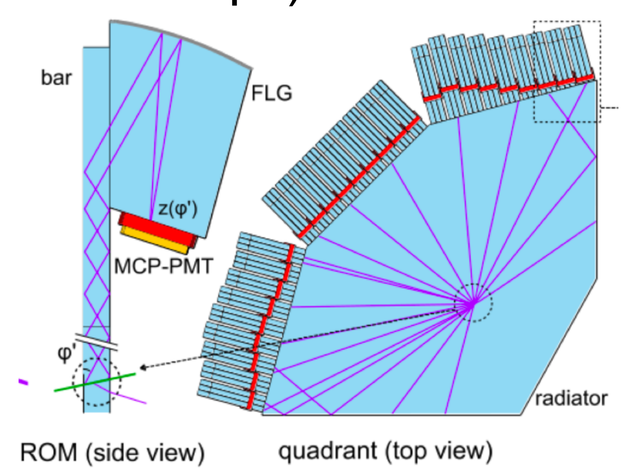

Advent of high performance silicon photon sensors (magnetic field resistant, high-gain, fine granularity, compact, high time resolution) makes a compact DIRC possible




A focused DIRC concept

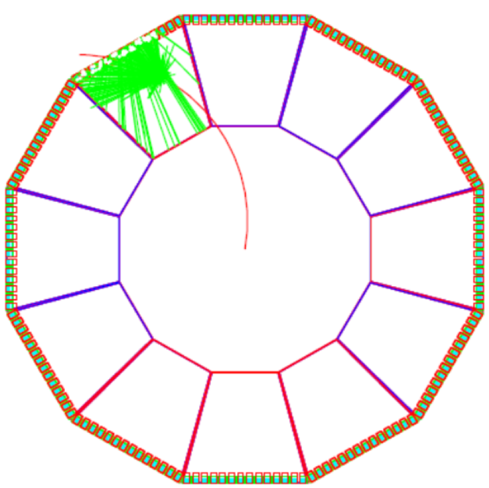
Panda DIRCs ( barrel and endcaps)

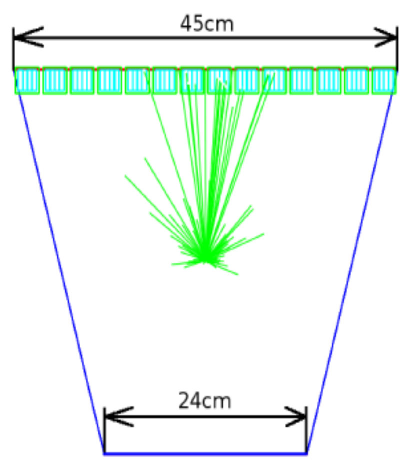


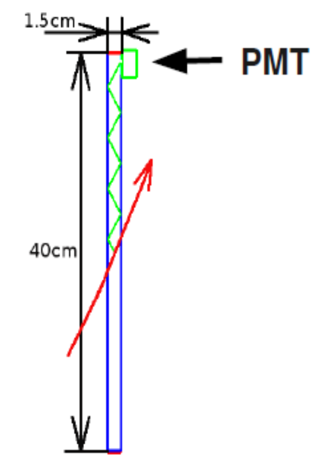



# DIRC-like TOF for Endcaps

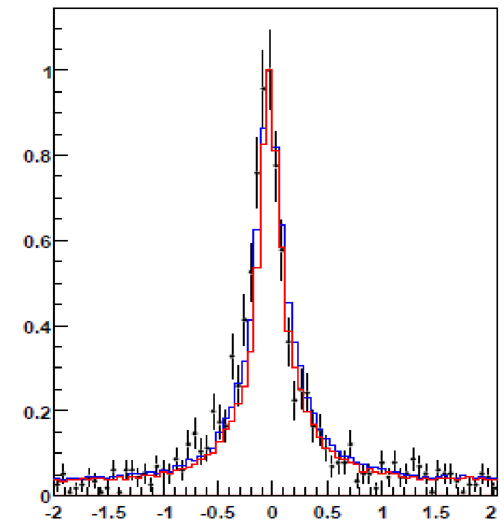
- DIRC-like forward TOF detector (FTOF:  quartz + MCP-PMT ) was developed at LAL for the SuperB factory project.
- Also an endcap PID option for STCF.
  - Flight length ~ 1.4 m for endcaps. ~30ps time resolution is required for pi/K separation to reach 2GeV.






~ 80ps per PE



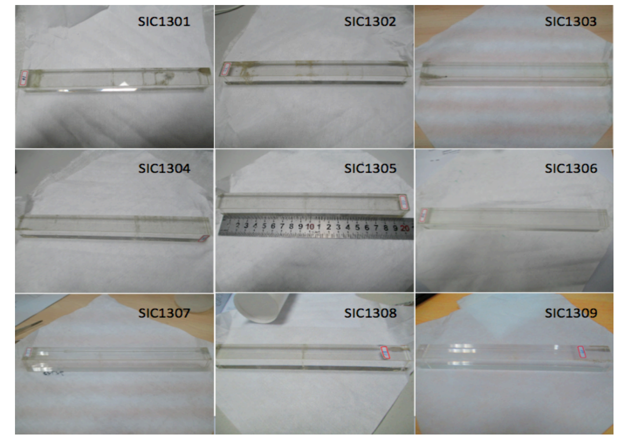
# EMC

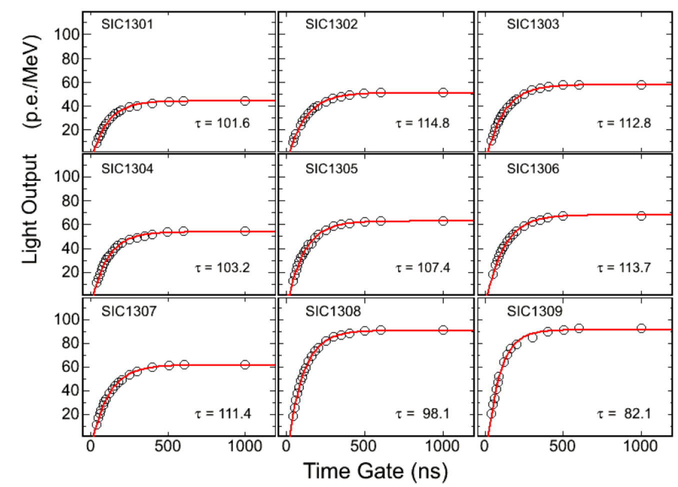
- Main performance requirements
  - High efficiency for low energy γ
  - Good energy resolution in low energy region
  - Good position resolution (for γ)
  - Fast response
  - Radiation hardened
- Technology option
  - Crystal + Silicon photon detector (e.g. PD, APD, SiPM)

# Crystal Options

| Crystal | CsI(Tl) | CsI | BSO | $PbWO_4$ | LYSO(Ce) |
|---|---|---|---|---|---|
| Density ($g/cm^3$) | 4.51 | 4.51 | 6.8 | 8.3 | 7.40 |
| Melting Point (°C) | 621 | 621 | 1030 | 1123 | 2050 |
| Radiation Length (cm) | 1.86 | 1.86 | 1.15 | 0.89 | 1.14 |
| Molière Radius (cm) | 3.57 | 3.57 | 2.2 | 2.0 | 2.07 |
| Interaction Len. (cm) | 39.3 | 39.3 | 23.1 | 20.7 | 20.9 |
| Hygroscopicity | Slight | Slight | No | No | No |
| Peak Luminescence (nm) | 550 | 310 | 480 | 425/420 | 420 |
| Decay Time $^b$ (ns) | 1220 | 30<br>6 | 100<br>26,2.4 | 30<br>10 | 40 |
| Light Yield $^{b,c}$ (%) | 165 | 3.6<br>1.1 | 3.4<br>0.5/0.25 | 0.30<br>0.077 | 85 |
| LY in 100 ns | 13 | 4.6 | 2.9 | 0.37 *(2-3x↑)* | 78 |
| LY in 30 ns | 4 | 3.3 | 1.5 | 0.26 (2-3x↑) | 45 |
| d(LY)/dT $^b$ (%/ °C) | 0.4 | -1.4 | -2.0 | -2.5 | -0.2 |
| Radiation hardness (rad) | $10^3$ | $10^{4-5}$ | $10^{6-7}$ | $10^{6-7}$ | $10^8$ |
| Dose rate dependent | no | no | yes | yes | |
| Experiment | CLEO, BABAR, Belle, BES III | KTeV,E787<br>Belle2 1st<br>SuperB 2nd | Belle2 3rd | CMS, ALICE<br>PANDA<br>Belle2 2nd | SuperB 1st (Hybrid) |

## R&D on BSO



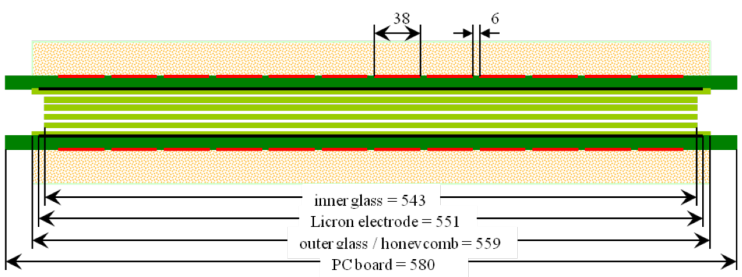




Different options for barrel and endcaps

# Muon Detector

- Idea to lower muon detection threshold: measuring time of flight at entrance to iron yoke — a timing muon detector.
- Can be realized with MRPC technology

Long-Strip MRPC @ STAR

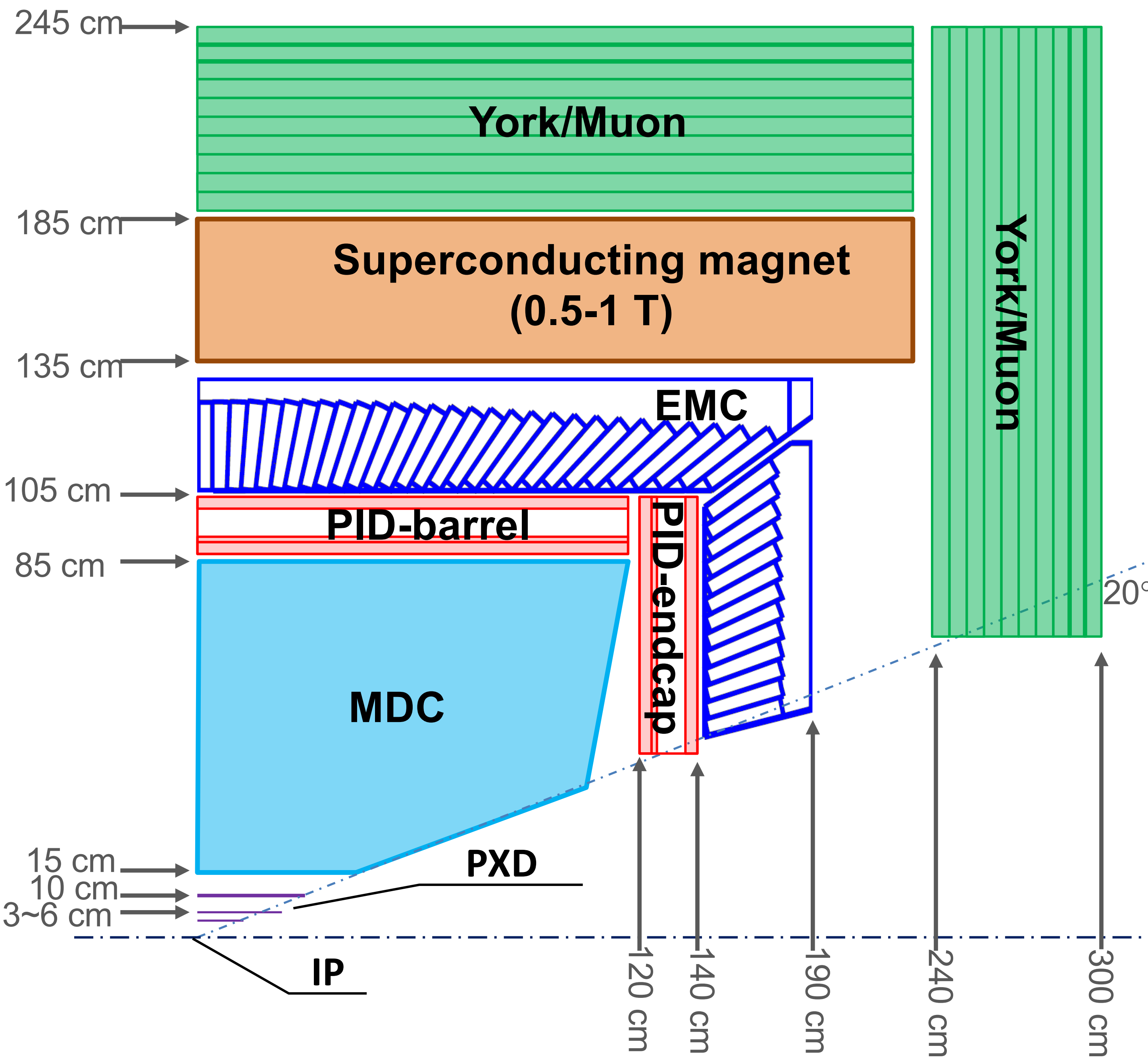



Performance:

- Efficiency: > 98%
- Time resolution: < 80 ps
- Spatial resolution: 0.6 cm

- A possible muon detector configuration
  - 2-3 inner layers with MRPC for precise timing
  - ~8 outer layers with RPC

# Pre-Conceptual Detector Layout




PXD
- $\sim 0.15\% X_0$ / layer
- $\sigma_{xy} \sim 50\ \mu m$

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

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

EMC

Energy range: 0.02-3GeV

| At 1 GeV | $\sigma_E$ (%) |
|---|---|
| Barrel: | 2 |
| Endcap: | 4 |

MUD
- Down to <~0.4GeV
- π suppression >10

# Advance R&D for STCF Detector

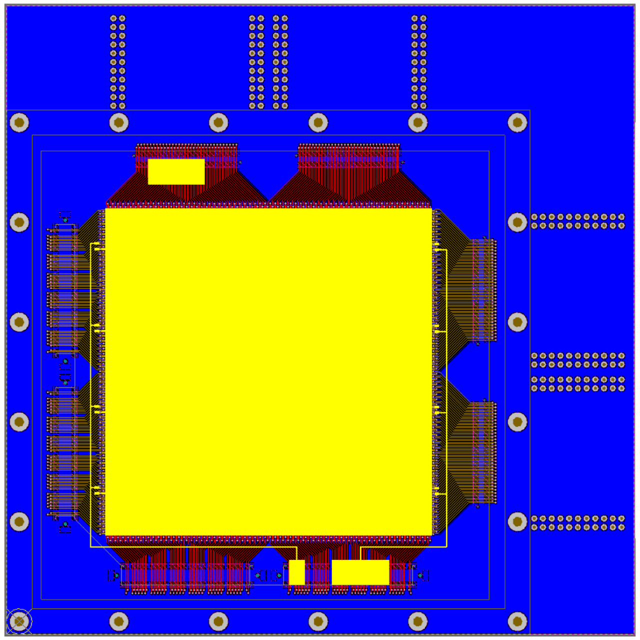
- Supported by an initial fund from USTC and started this June.
- Seek synergies with other R&D projects as much as possible
- Physics simulation
- Detector design and simulation
- Technology R&D is focusing on PID and EMC at present, and will expand to other areas as appropriate.

# Design of the 2-D μRWELL PCB

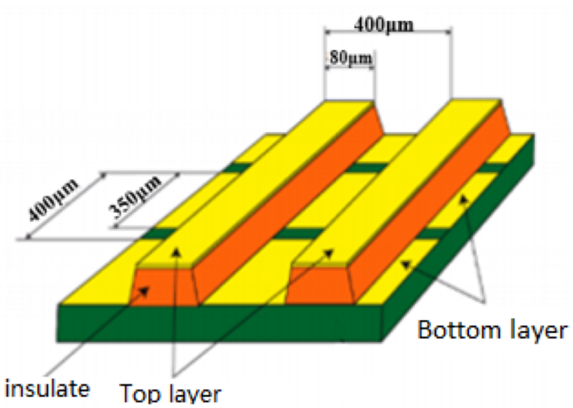
- μRWELL PCB
  - Sensitive area was divided into 4 sectors
  - Well pitch: 140 μm
  - Pre_preg(50 μm) isolate the DLC electrode from readout strip

- 2-D readout strip

  Pitch: 400 μm
  Top layer: 350 μm
  Bottom layer: 80 μm
  Insulate thickness: 50 μm



μRWELL PCB




2-D readout strip

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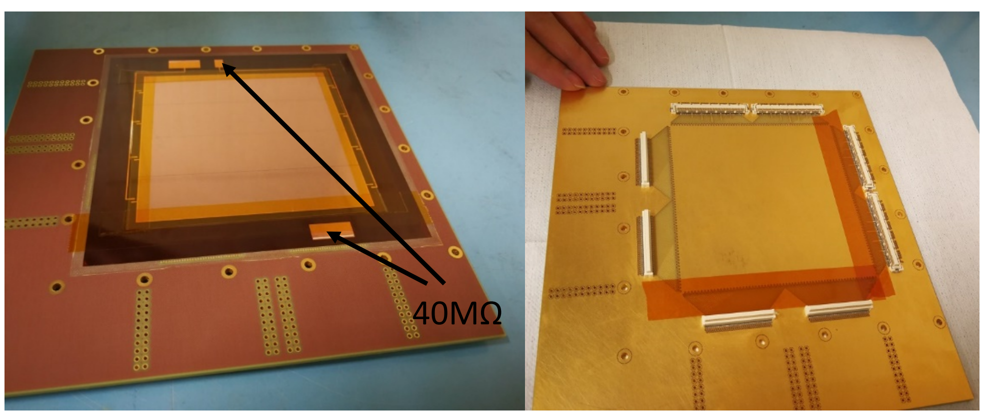
# Continued

## Fabrication of µRWELL detector

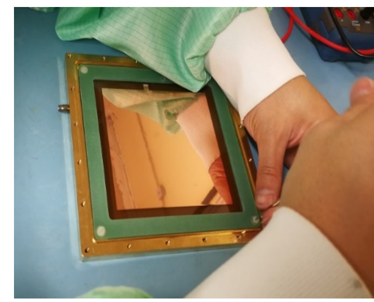
➢ µRWELL detector

- DLC Electrode resistivity: 40MΩ
- 10cm×10cm active area
- 3mm drift region
- Hirose connector + Panasonic connector

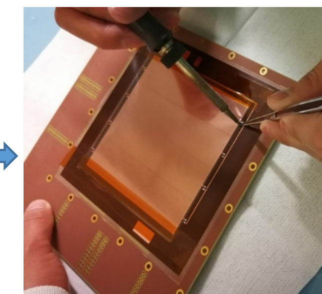
Special thanks to Antonio Teixeira, Rui De Oliveira for the technical support



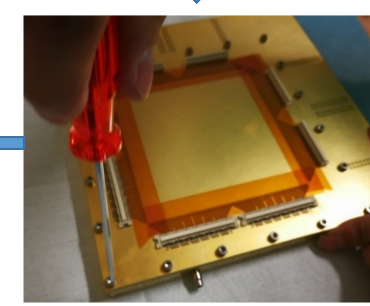

µrwell_PCB



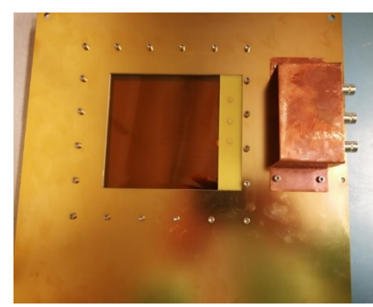
Fix drift electrode



Solder HV Connector



Fix µRWELL PCB



µRWELL Detector

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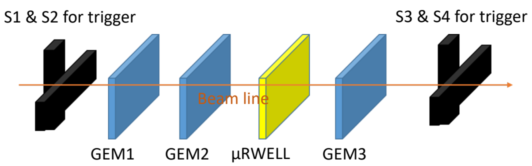
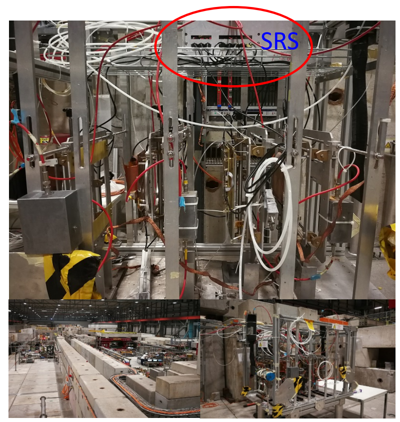
## Beam Test Setup

- Scintillator for trigger
- RD51 GEM Tracker
- RD51 SRS DAQ
- APV25 readout chip
- 150GeV muon




Detector Position:
(GEM1,GEM2,uRWELL,GEM3)=(0,270,546,729)

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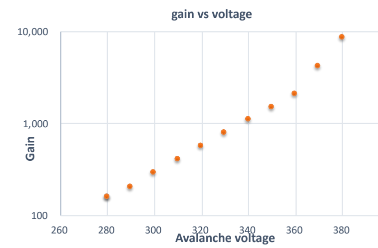
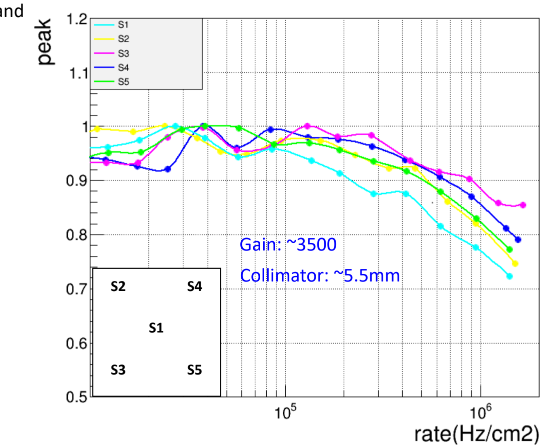
## µRWELL Rate Capability

µRWELL detector worked more stable in argon and C4H10 mixture gas

- Argon:C4H10=95:5
- Source: 8keV Copper x-ray
- Rate capability: >100kHz/cm2




Gain VS avalanche voltages

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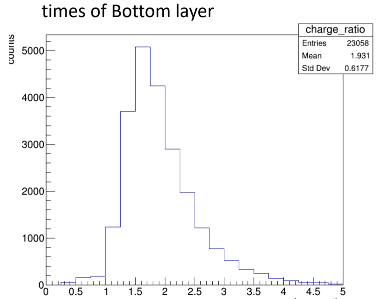
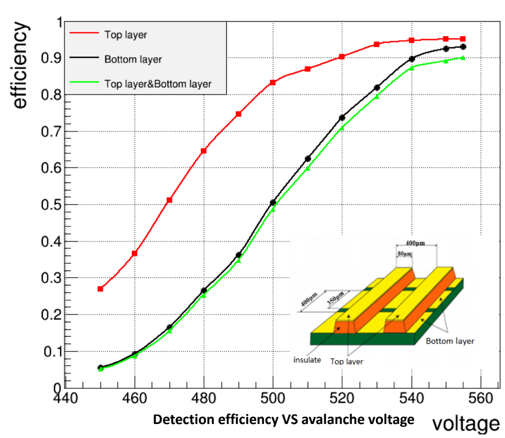
## µRWELL detection efficiency

- Top layer(Y) efficiency : ~95%
- Bottom layer(X) efficiency: ~92%
- Top & Bottom efficiency: ~90%
- The signal amplitude of Top layer is 1.9 times of Bottom layer




Top layer Charge/Bottom layer charge

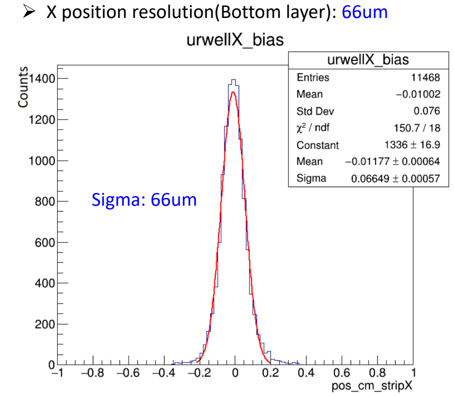


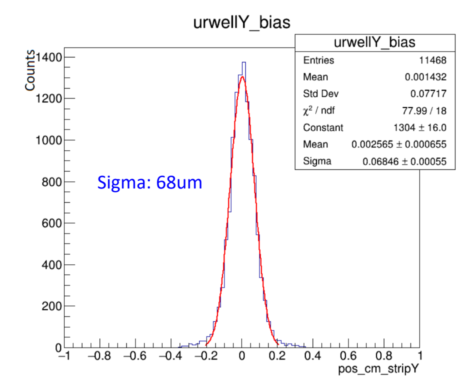

Detection efficiency VS avalanche voltage

12

## uRWELL position resolution

- Avalanche voltage: 555V
- Y position resolution(Top layer): 68um
- X position resolution(Bottom layer): 66um

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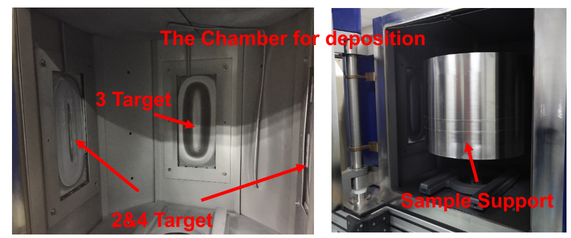
# DLC R&D

## DLC deposition procedure and devices

Sample Baking → Sample Clamping → Vacuum Pumping → Sample Pre-treating → Deposition → Cooling in Vacuum → Sample taking down


1. **Baking base material at 70 degrees for 12 hours.**
2. **Vacuum pumping to remove the air from the chamber.**
3. **Start procedure to coat DLC on the pre-treated sample.**
4. **Cooling in vacuum to release the inner stress uniformly of the sample.**

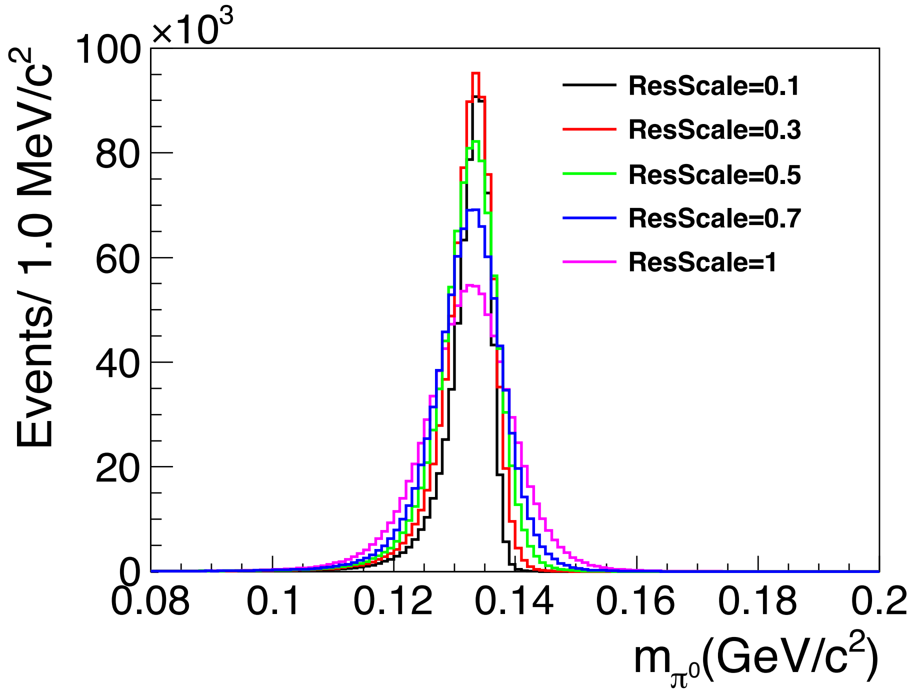




**State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences** 5

| | | | | |
|---|---|---|---|---|
| 210 | 200 | 178 | 176 | 200 |
| 105 | 93 | 96 | 82 | 102 |
| 68 | 70 | 72 | 71 | 68 |
| 78 | 77 | 78 | 81 | 77 |
| 135 | 130 | 120 | 135 | 126 |

| Size | Initial vacuum degree | Deposition Time | Current |
|---|---|---|---|
| 30cm×30cm | $1.2\times10^{-5}$Torr | 40 min | 1.0 A |

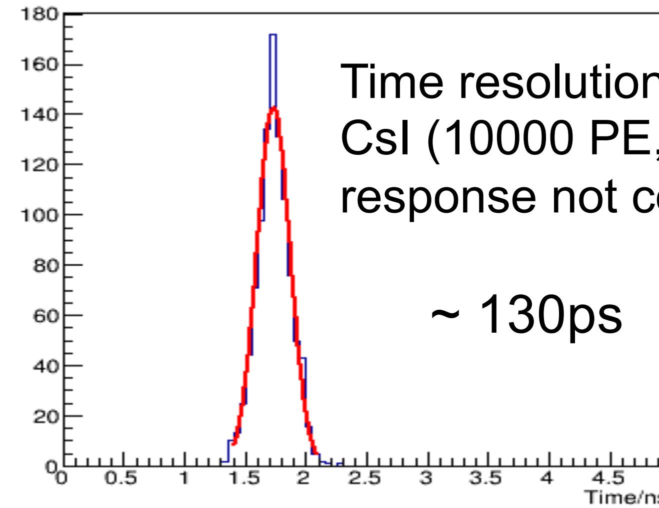
# EMC Optimization




The position resolution of ECAL has a significant impact on object/event reconstruction involving **γ** .

→ Energy resolution is not everything, position resolution also important.

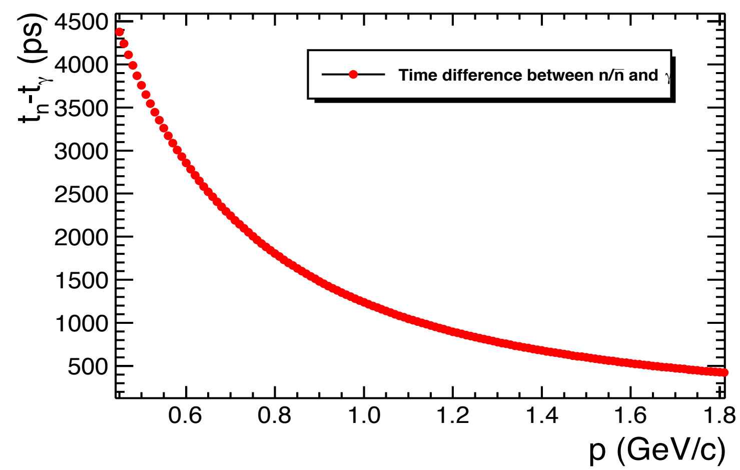
A timing ECAL !




Time resolution of pure CsI (10000 PE, PMT response not considered)

~ 130ps

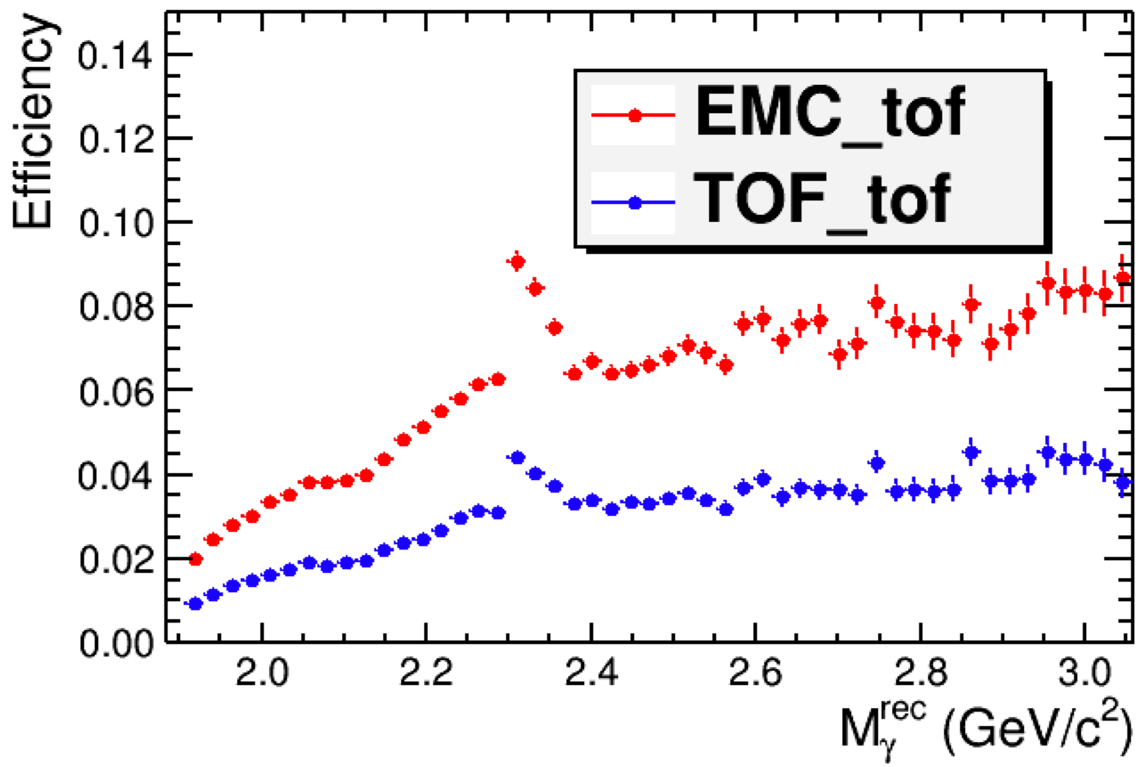
Difference in TOF of n and **γ**




Precise ECAL timing is very useful in suppressing **γ** background

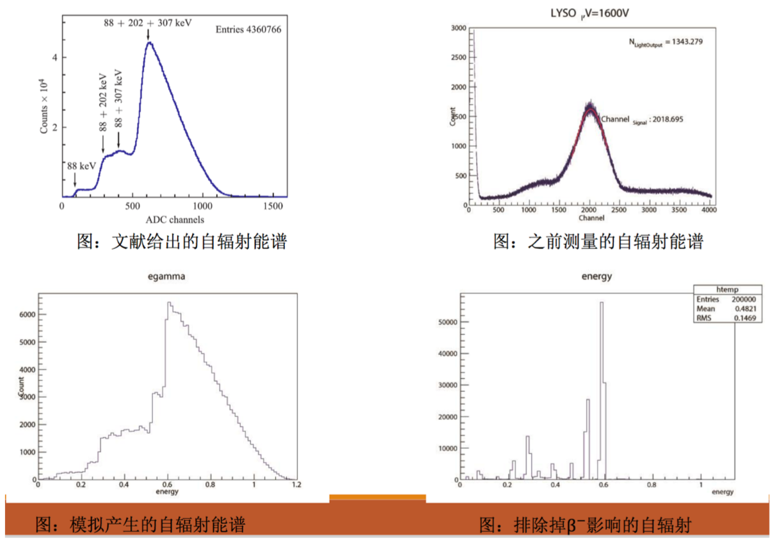
# EMC Timing on Physics

- ISR n nbar process
- Use ECAL timing to determine nbar beta
- Efficiency significantly enhanced

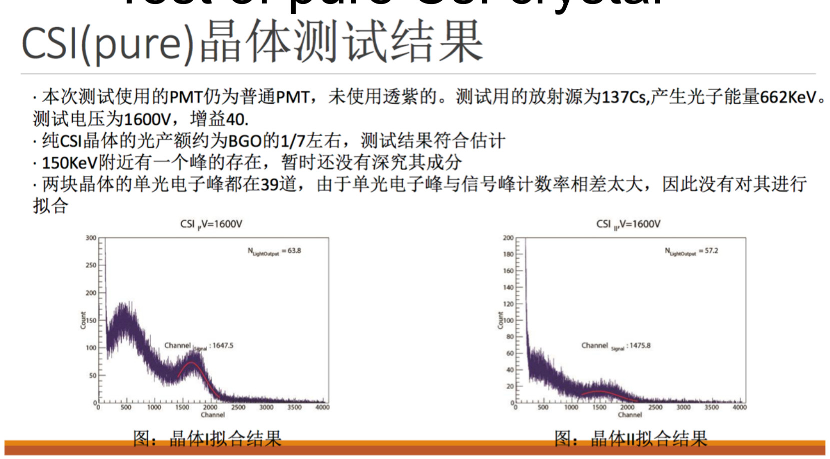


# ECAL R&D

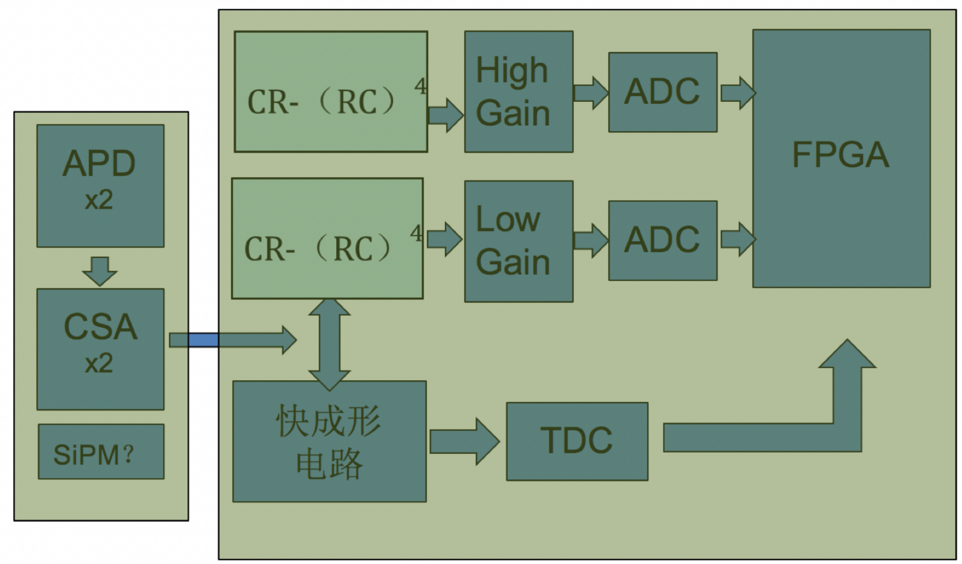
## Test of LYSO crystal




## Test of pure CsI crystal

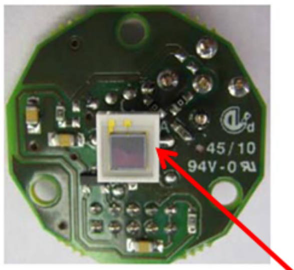


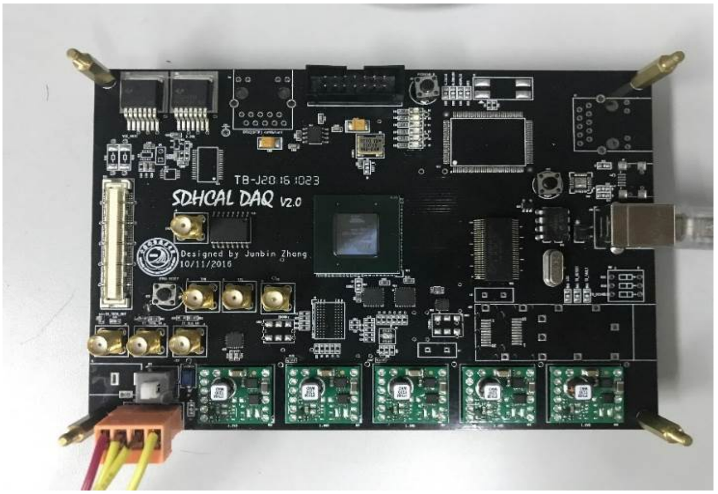

## Readout electronics design



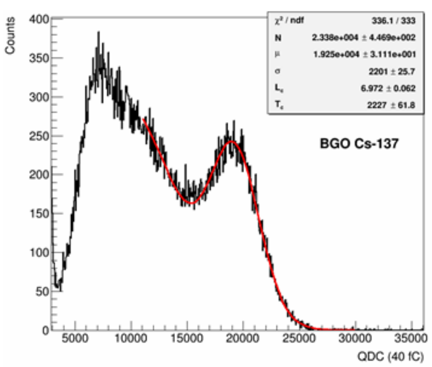
# SiPM Technology

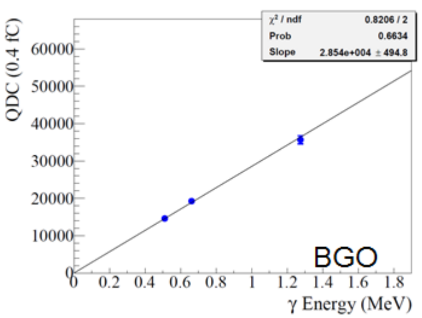
- SiPM: a novel and rapidly-developing photo-sensor technology
  - High gain, low equivalent noise, B-field resistant, good time resolution
- R&D at USTC

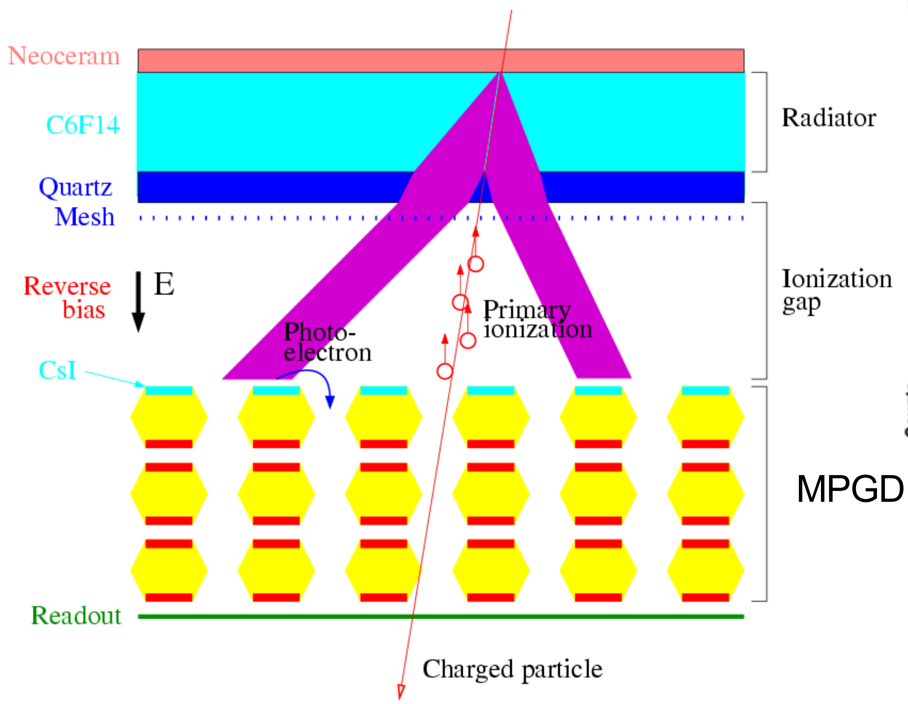



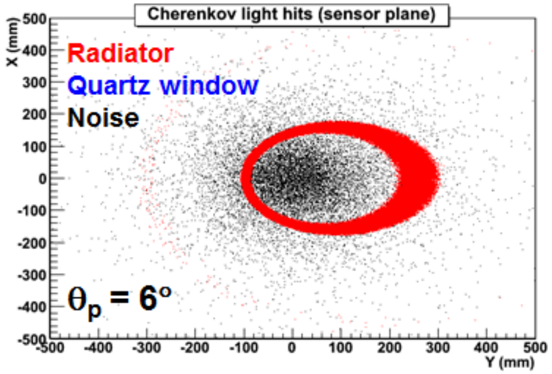

Hamamatsu S10362-33-050C, 3x3 mm$^2$

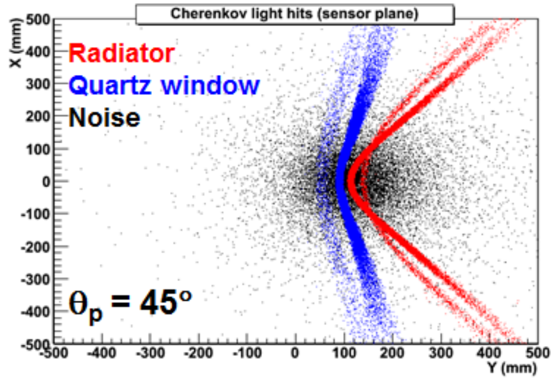


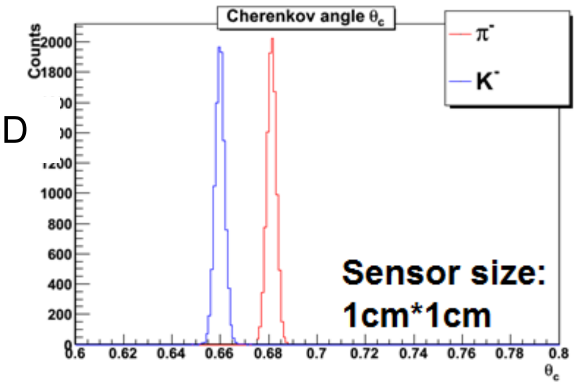


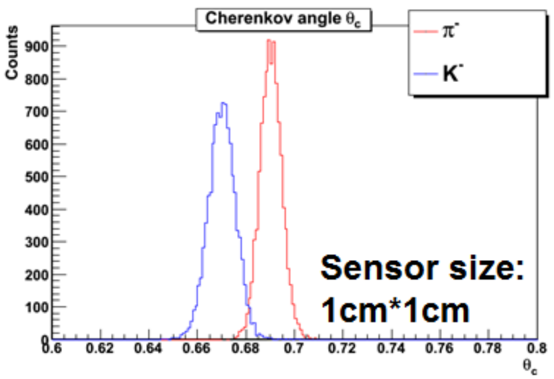
# RICH Simulation



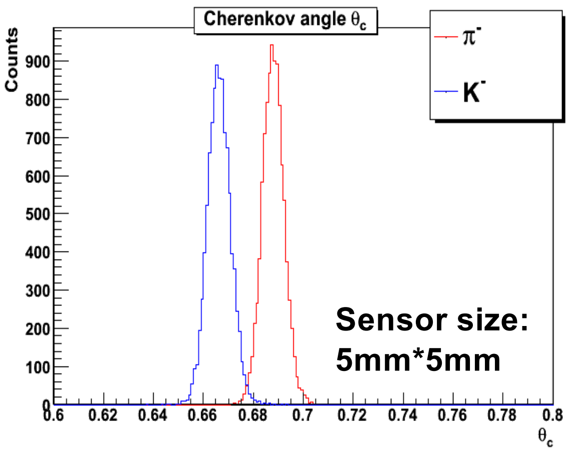



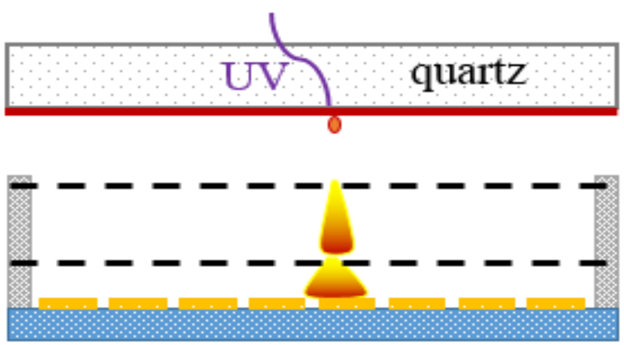




The π/K separation requirement can be met with a RICH detector.

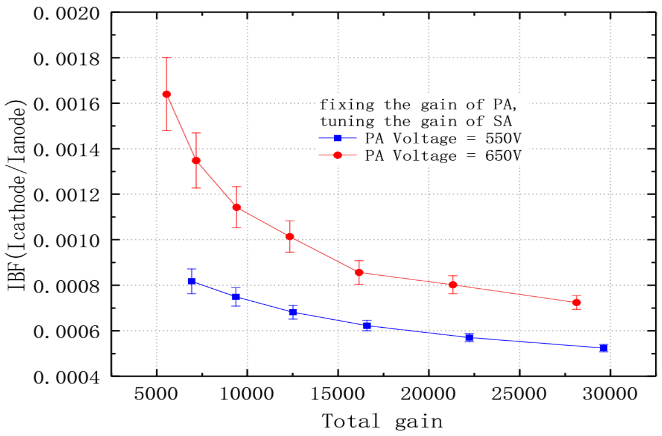


# MPGD Photon Detector R&D

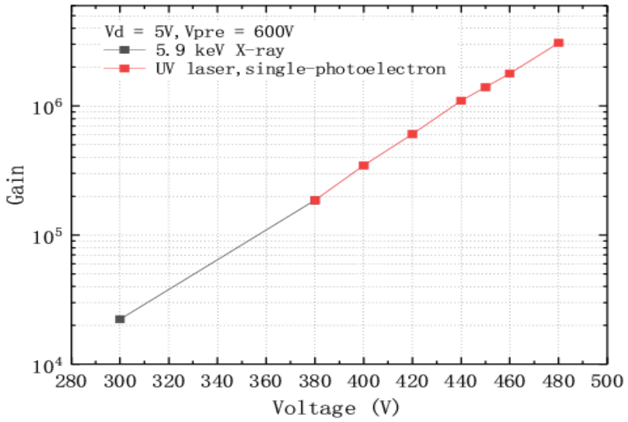
- A double-mesh Mircromegas detector is under development
  - High gain and very low ion backflow
  - Very suitable for single photon detection (with a proper photon-electron converter)
  - A promising photon detector option for RICH




IBF ~ 0.05%

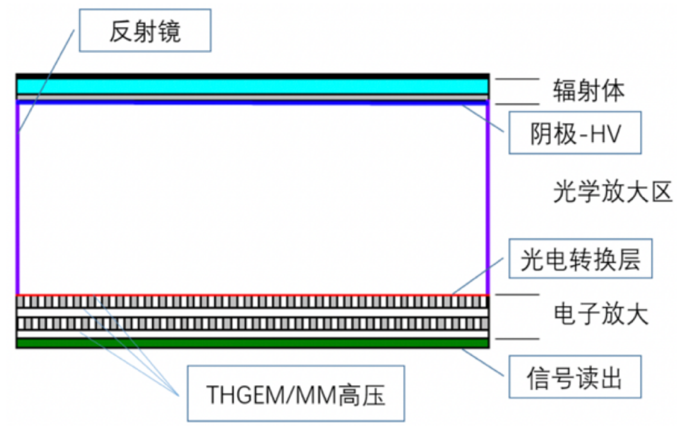



Gain ~ 3×10$^6$



# RICH Prototype Design

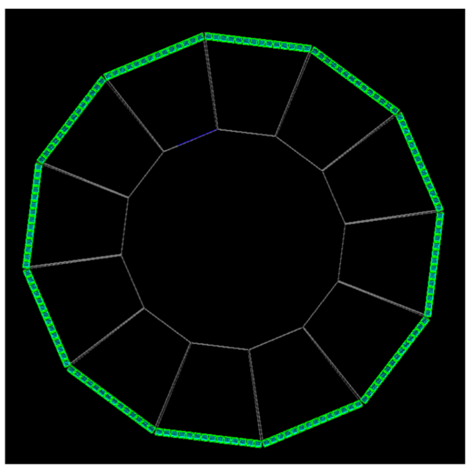
研制一个如右图的RICH原型样机，并通过该样机对多项技术环节进行检验。该样机可实现多种结构、辐射体和读出方案的实验测试，可方便调换不同部位的设计。



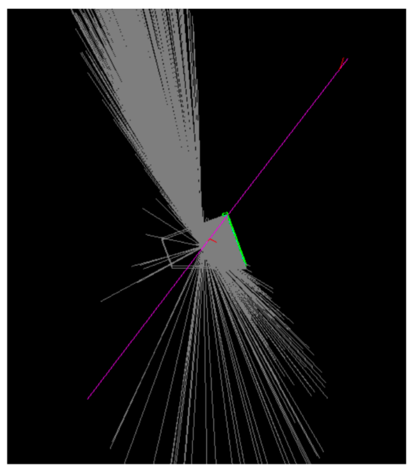

主要参数：
辐射体：高纯熔融石英（厚度1cm/0.5cm），高纯全氟己烷（厚度1.5cm）+0.2cm石英窗
光学放大区：8-12cm
灵敏区面积：16cm*16cm
读出通道数：512（四角读出，每单元1cm$^2$，双读出），或1024（pixel读出，每单元0.25cm$^2$)
读出要求：四角读出需分别测量信号电荷和时间；点阵读出需测量Hit和时间
读出方式：THGEM+MM/DMM，或DMM，反射式光阴极
工作气体：Ar+CH4(+CF4)等；

# FTOF Simulation

Geant4 建模

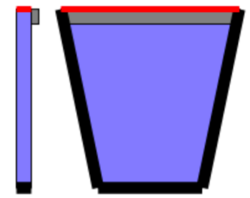


12个扇区

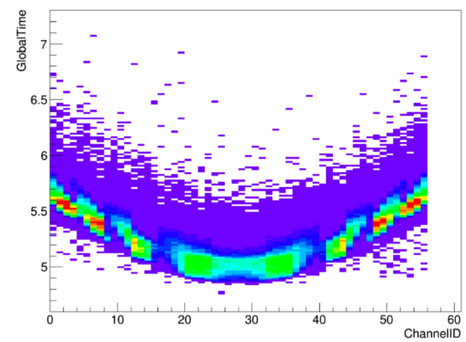


2 GeV pi-

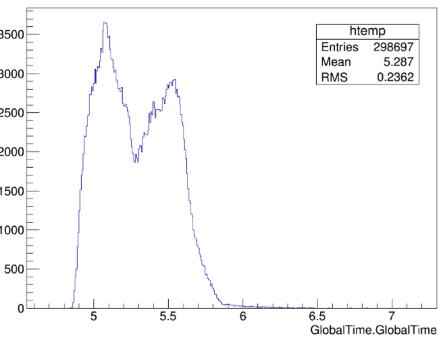
## 初步结果



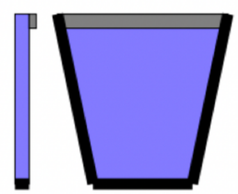
- 侧面和底部：吸收体
- 顶部：镜面
- 1000 pi-（2GeV）
- 未设置石英光吸收长度，即光子在石英中不会衰减



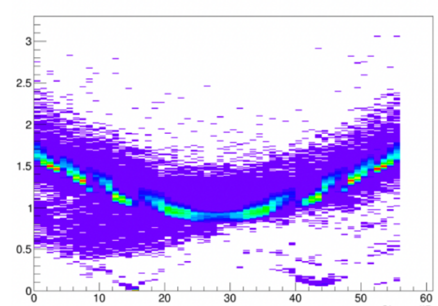

时间 VS channel



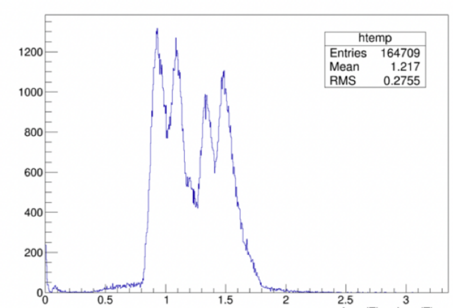

光子产生传输到MCP-PMT时间分布



- 侧面、顶部和底部：吸收体
- 1000 pi-（2GeV）
- 未设置石英光吸收长度，即光子在石英中不会衰减




时间 VS channel




光子产生传输到MCP-PMT时间分布

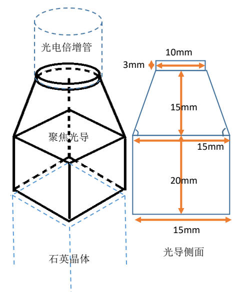
# FTOF R&D

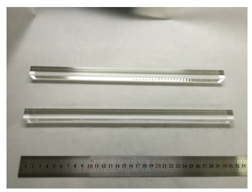
## 实验方案

MCP-PMT（R3809U）+ 不同尺寸熔融石英晶体

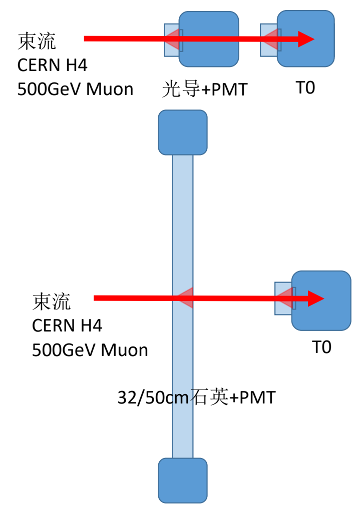
- 15mm x 15mm x 50cm + 光导
- 15mm x 15mm x 32cm + 光导
- 光导（38mm长）
- 5mm x 5mm x 5mm（T0）

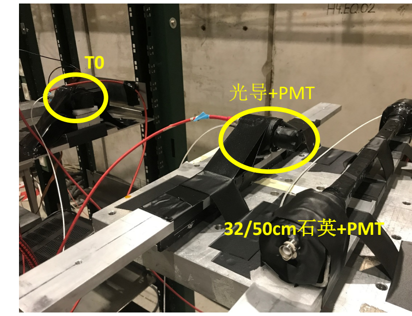
前沿定时：
测试FTOF在不同工作电压和阈值下的本征时间分辨



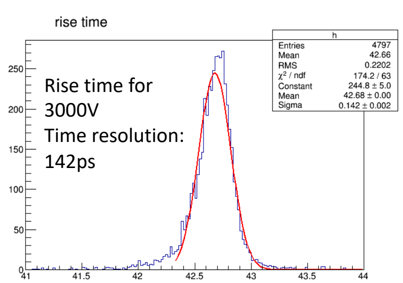



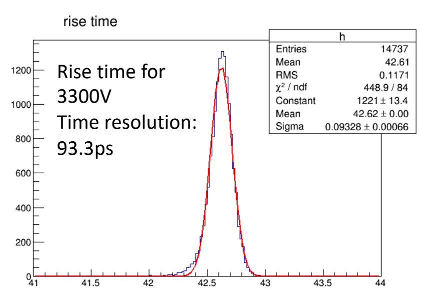
## 实验方案

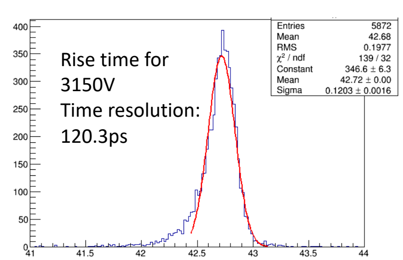



## 32cm石英+PMT的时间分辨（示波器读出）



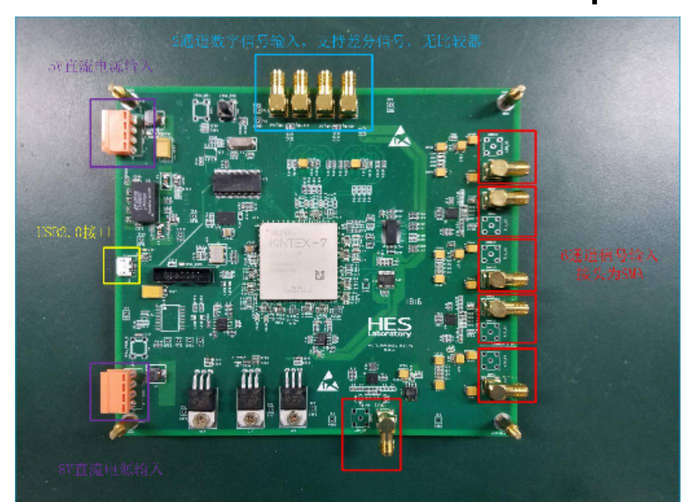




2 x PMT + T0 符合（10ns内）

定阈定时：80 mV

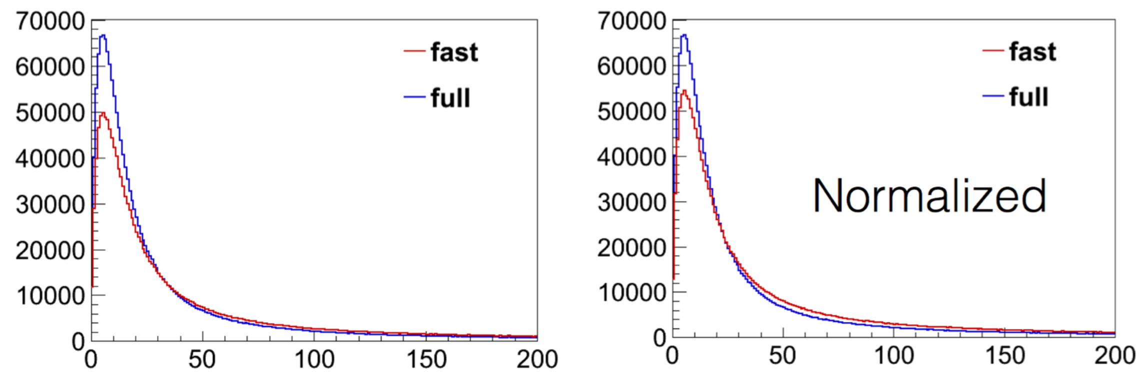
## Readout electronics development



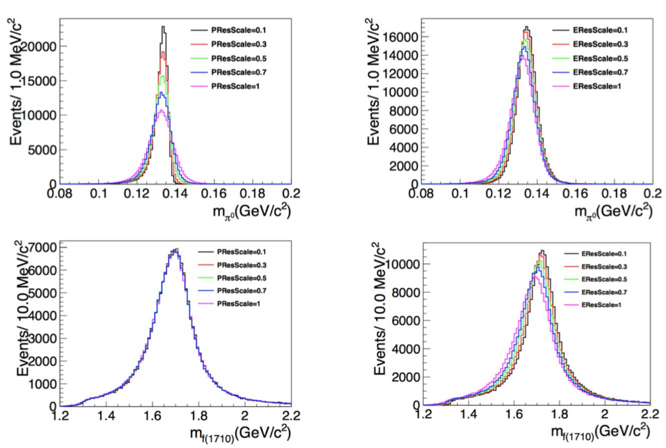
# Fast Simulation

- A simple physics simulation framework is under development.

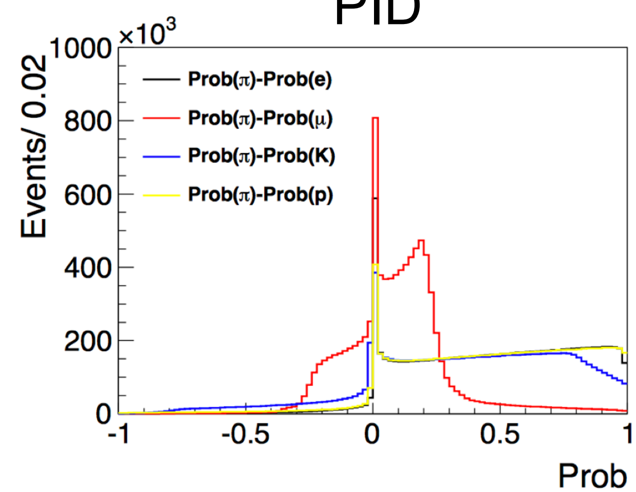
Charged tracks




ECAL




PID



# Organization

- Working groups and regular meetings

## STCF ECAL Working Group

### September 2018

- 12 Sep STCF ECAL (protected) New!

### August 2018

- 29 Aug STCF ECAL (protected)
- 15 Aug STCF ECAL (protected)

## STCF Physics/MC Working Group

### July 2018

- 25 Jul STCF Physics/MC Working Group Meeting (protected)

## STCF PID Working Group

STCF PID system design and technology development

### September 2018

- 19 Sep STCF PID Working Group Meeting (protected)
- 05 Sep STCF PID Working Group Meeting (protected)

### August 2018

- 22 Aug STCF PID Working Group Meeting (protected)
- 08 Aug STCF PID Working Group Meeting (protected)

### July 2018

- 25 Jul STCF PID Working Group Meeting (protected)
- 11 Jul STCF PID Working Group Meeting (protected)
- 04 Jul STCF PID Working Group Meeting (protected)

### June 2018

- 06 Jun STCF PID Working Group Meeting (protected)

### May 2018

# Final Remarks

- STCF is definitely NOT a project of some one's or some institute's. It's a project for ALL of us!
- And only so will the project be a success.
- It really belongs with our young (or not that young) generation.
- So please join us and let's work together hard to make it happen.