The Super Tau Charm Factory Plan in China

Guangshun Huang

State Key Laboratory of Particle Detection and Electronics

University of Science and Technology of China (USTC)

15th Tau Workshop

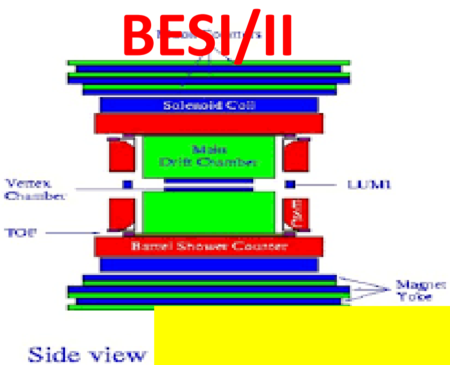
Sep. 24-28, Amsterdam, Netherlands

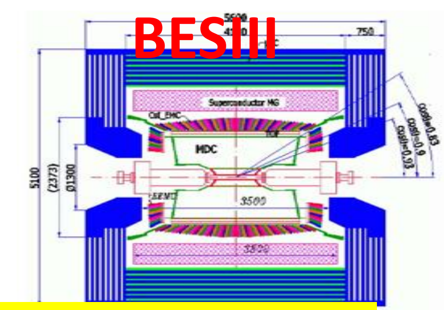
30 Years of τ-c factory in China

BEPCI (1988–2005)

$10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1} \Rightarrow 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

BEPCII (2006–now)





Fruitful Physics results

BEPCII/BESIII will end her mission in 5-10 years

STCF in China

Super Tau-Charm Factory (STCF)

- Peak luminosity 0.5-1×10^{35} $cm^{-2}s^{-1}$ at 4 GeV
- Energy range E_{cm} = 2–7 GeV
- Polarization available on beam (Phase II)
- A dedicated machine for HEP, no synchrotron radiation mode considered

A STCF, far beyond BEPCII, is a natural extension and a viable option for a post-BEPCII HEP project in China.

Integrated Luminosity of STCF

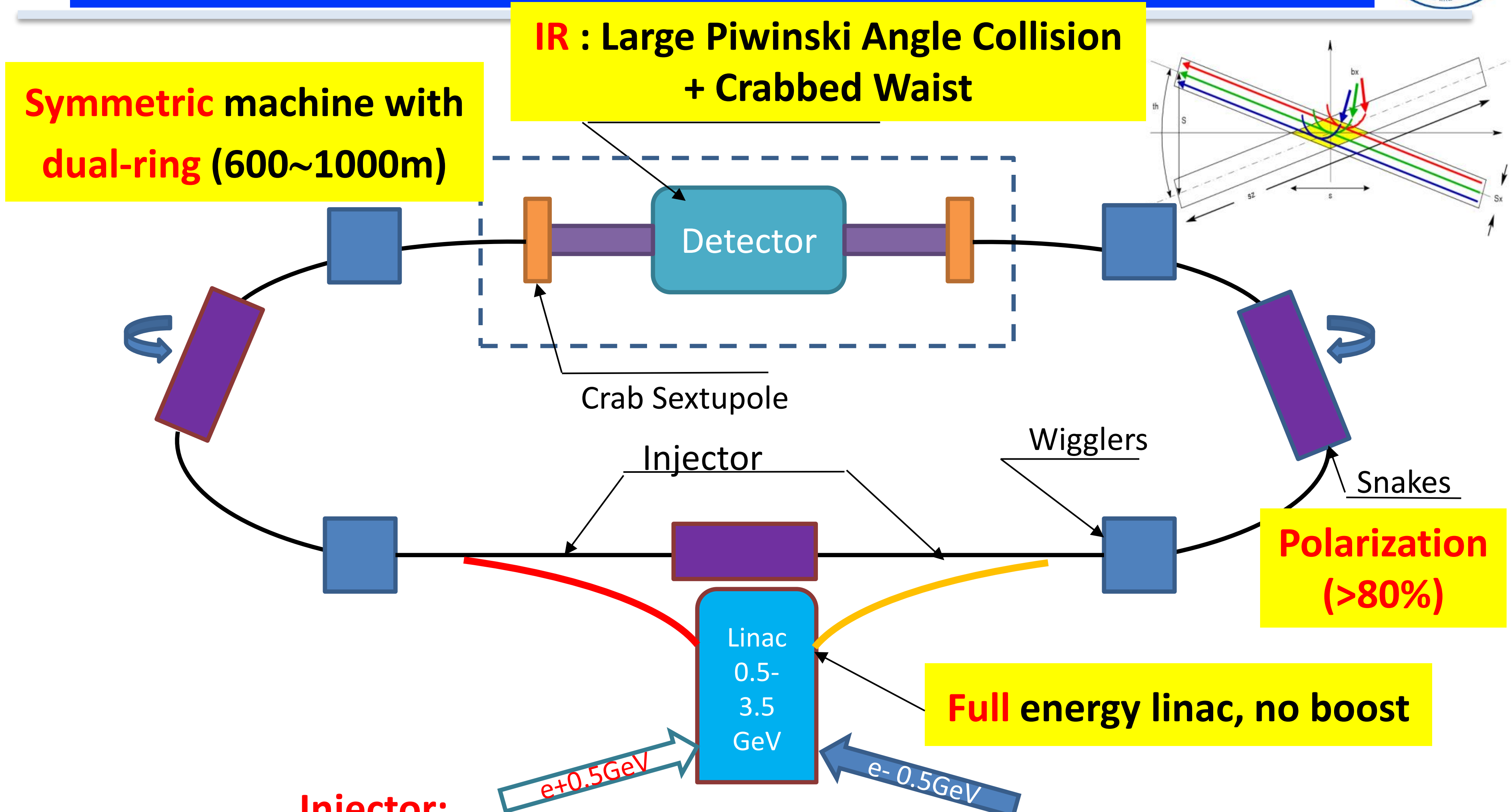
- **No synchrotron radiation mode, assume running time 9 months/year,**
- **Assume data taking efficiency 90%:**

$$10^{35}cm^{-2}s^{-1} \times 86400s \times 270days \times 90\% \sim \mathbf{2.0\ ab^{-1}/year}$$

10 years data taking, total 10~20 ab^{-1} conservatively

- **One of the crucial precision frontier :**
  - rich physics program
  - unique for physics with c quark and τ leptons,
  - great opportunity for study of QCD, exotic hadrons and search for new physics.

Layout of Machine



Injector:

- **e^+, a convertor, a linac and a damping ring, 0.5 GeV**
- **e^-, a polarized e^- source, accelerated to 0.5 GeV**

Parameters of Machine

Parameters	1	2
Circumference/m	~600	~600
Beam Energy/GeV	2	2
Current/A	1.5	2
Emittance$(\varepsilon_x/\varepsilon_y)$/nm·rad	5/0.05	5/0.05
β Function @ IP (β_x^*/β_y^*)/mm	100/0.9	67/0.6
Collision Angle(full θ)/mrad	60	60
Tune Shift ξ_y	0.06	0.08
Hour-glass Factor	0.8	0.8
Luminosity/$\times 10^{35}$cm^{-2}s^{-1}	~0.5	~1.0

Luminosity :

$$L = \frac{\gamma n_b I_b}{2 e r_e \beta_y^*} \xi_y H$$

- Increase beam current
- Minimize β Function β_y^*
- Optimize ξ_y and H

Strategy :

- (Phase 0) Pilot: 0.5×10^{35}
- (Phase I) Nominal: 1.0×10^{35}
- (Phase II) Polarized beam
- .....

Accelerator Physics

- **Lattice Design:**
  - Ring and Interaction Region Lattice: β↓↓ ξ_y↑
- **Non-linearity**
  - Focus↑↑ ☞ Dynamic Aperture ↓ etc.
- **Collective Effect**
  - Current↑ Bunch Size↓↓ ☞ Beam Instability↑ ↑ ↑

Key Technologies

Polarization

- Spin Polarized Electron Source
- Polarization Rotation and Maintenance for Rings and Final Focus

RF

- Superconducting Cavities, Deflecting Cavities, Higher Harmonic Cavities, etc.

Magnets

- High Quality Magnets with high strength, Superconducting Magnets and Solenoids

Diagnostics and Control

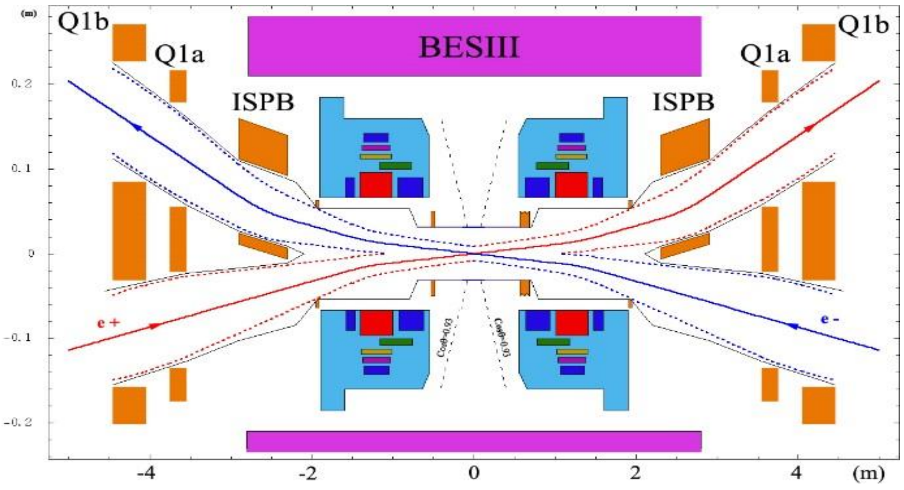
- Low Emittance Measurement, Transverse and Longitudinal Feedback, etc.

Collaboration Needed

- **Accelerator Physics**
  - IR Design
  - Polarization: Spin Rotation and Maintenance
  - Collective Effects: Simulation and Bench Measurements
  - Advanced Computational Accelerator Physics
- **Accelerator Technologies**
  - Superconducting Cavities and Magnets
  - Polarized Beam Sources
  - Ultrahigh Vacuum Chamber with Small Aperture, Optimized Impedance and Low SEE

Detector : Requirement from Accelerator

- **High luminosity : 10^{35} cm^{-2}s^{-1} :**
  - High radiation tolerance, especially at IP and forward region
    - ✓ Constrains from IR design, detail MDI studies is necessary

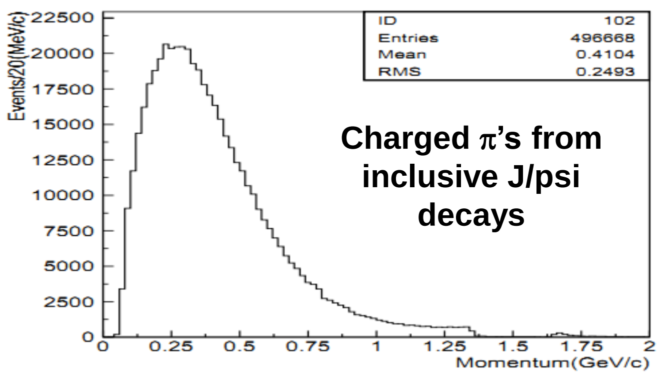


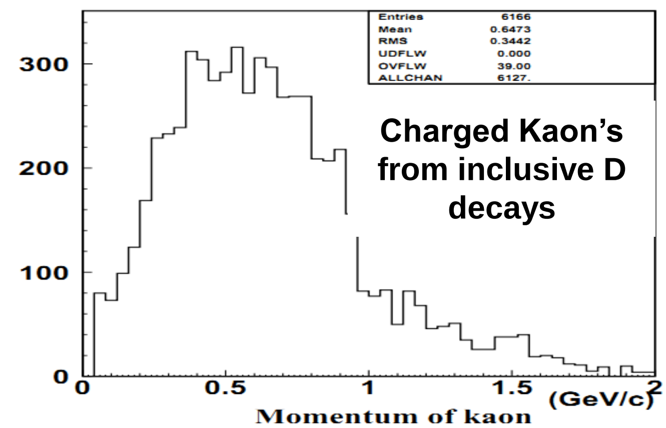
IR of BEPCII

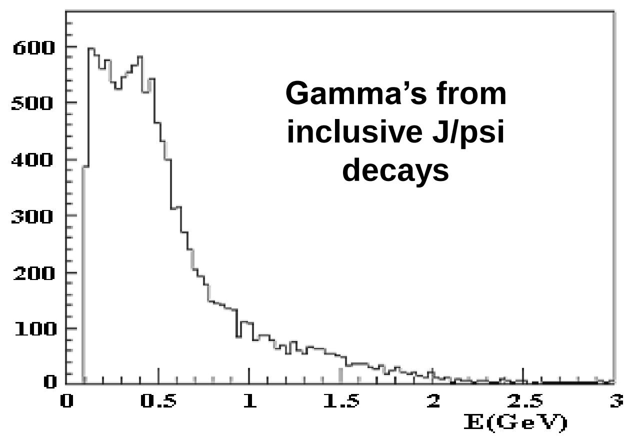
  - High event rate

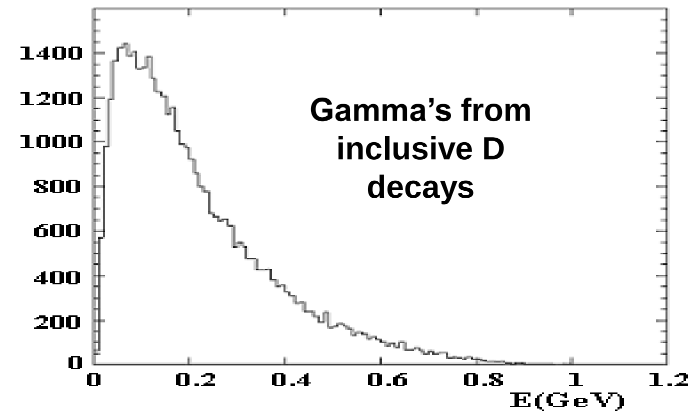
Detector/electronics should withstand the expected does and be fast enough.

Detector : Requirement from Physics



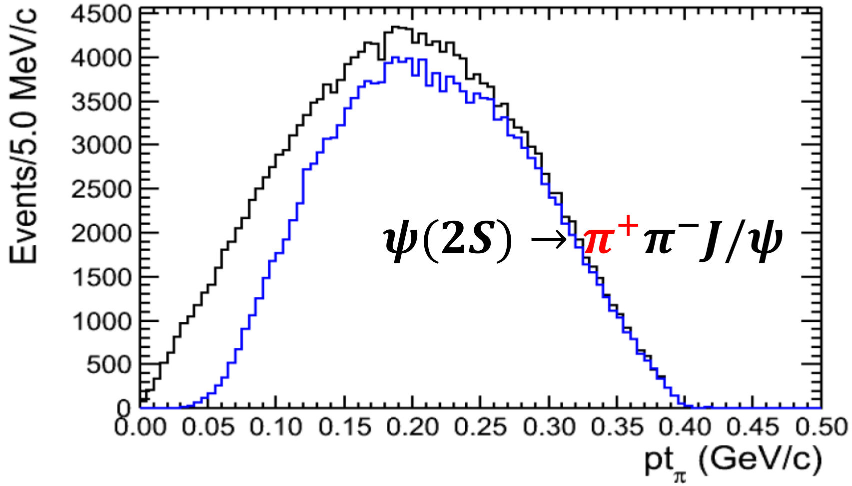


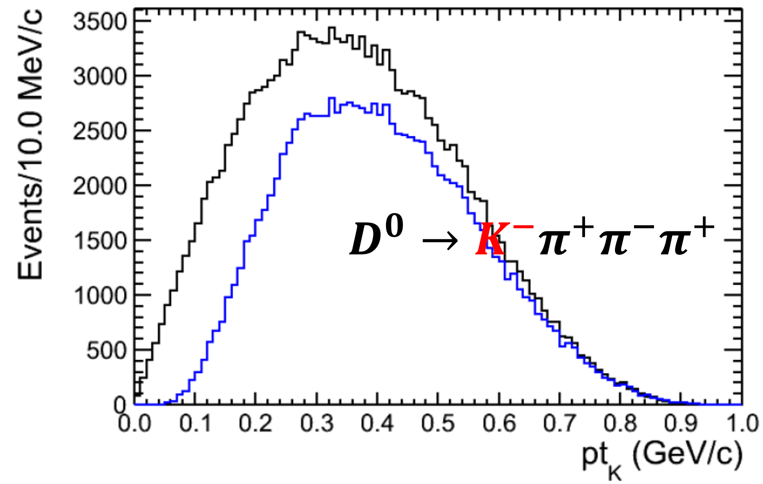


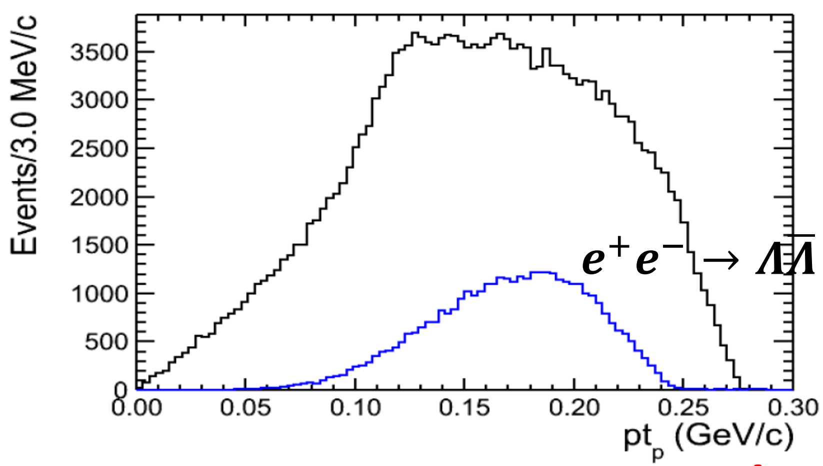


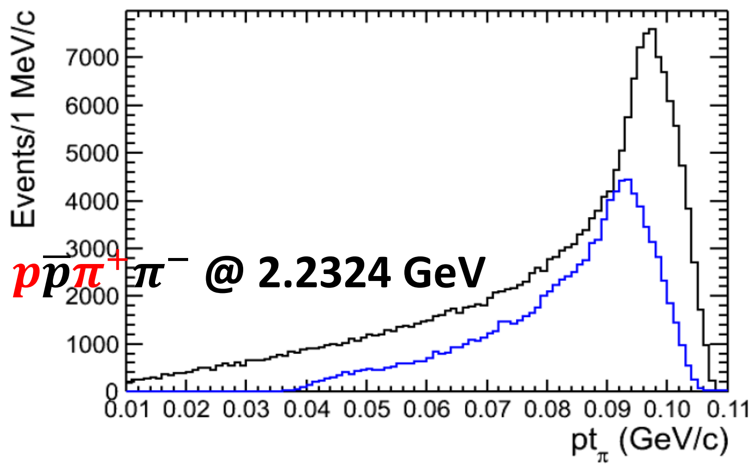
A mount of final state particle are of momentum/energy lower than 1 GeV

Detector : Requirement from Physics









Extreme low momentum,

suffer severely from material effects – multiple scattering

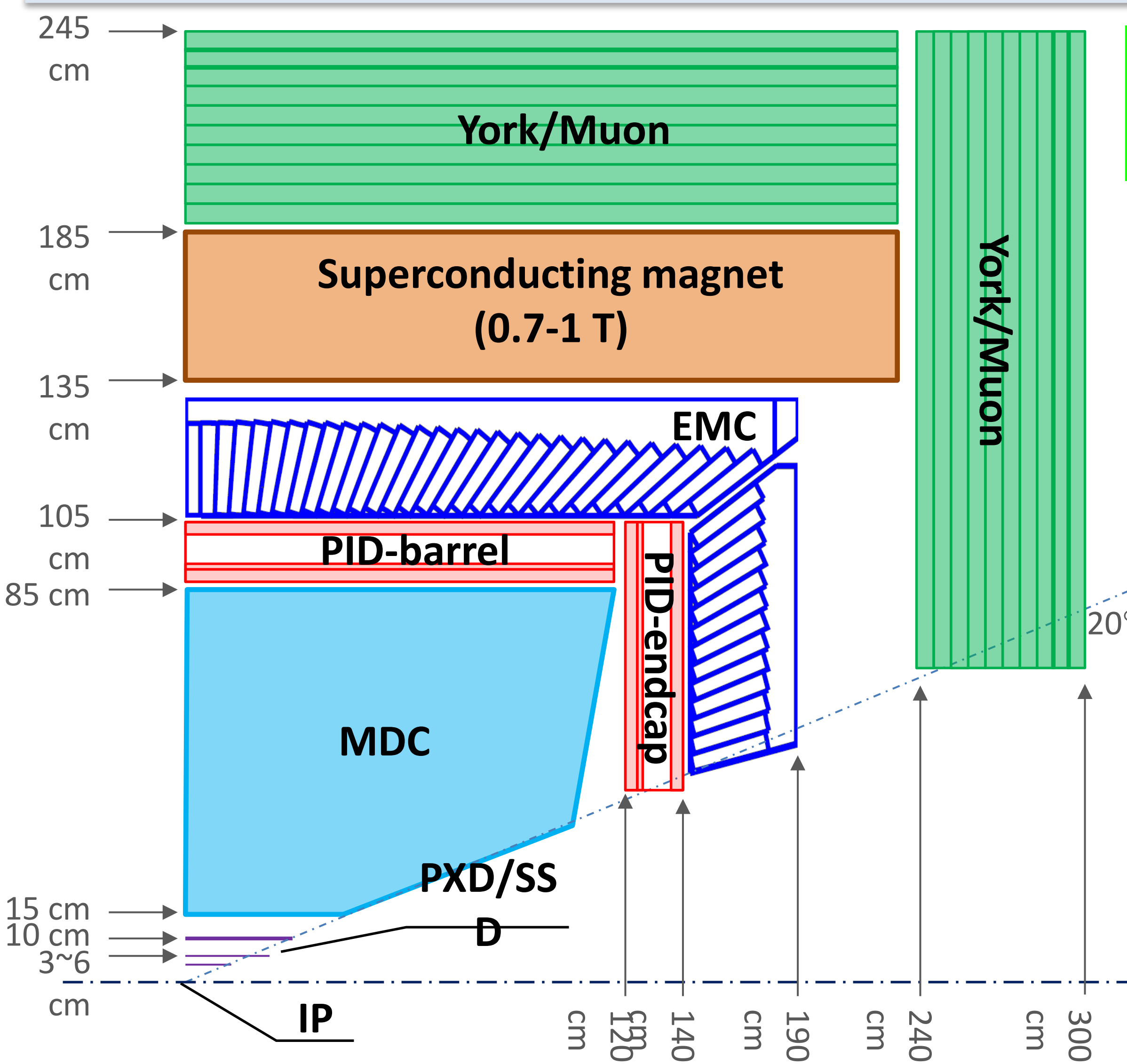
Detector : Requirement from Physics

- **PID system :**
  - A large momentum range : E_{cm} of up to 7 GeV
  - Superior PID (π/K) capability : $D^0\overline{D^0}$ mixing studies
- **μ ID :**
  - with lower momentum threshold, higher efficiency and μ/π separation capability
    - ✓ Measurement of D mesons semi-leptonic decays of D mesons
    - ✓ search for cLFV process ($\tau\to\gamma\mu$)
- ……

General Consideration of Detector

- **Much larger radiation tolerance, especially at IP and forward regions**
  - The detector and electronics should withstand the expected does
- **Efficient event triggering, exclusive state reconstruction and tagging**
  - High efficiency and resolutions for charged and neutral particles
  - Fast response, low noise and high rate capability
- **The Systematic uncertainty control**
  - Detector acceptance : geometrical acceptance or detector response
  - Mis-measurement : mis-tracking, fake photon, particle mis-ID, noise
  - Luminosity measurement
- **Reasonable cost**

Detector Layout



MUD
- μ/π suppression power >10/30

EMC
- Energy range: 0.02-2.5 GeV
- At 1 GeV σ_E (%)
  - Barrel(Cs(I): 2
  - Endcap (Cs): 4

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

MDC (Low mass)
- σ_{xy}=130 mm
- dE/dx<7%, σ_p/p =0.5% at 1 GeV

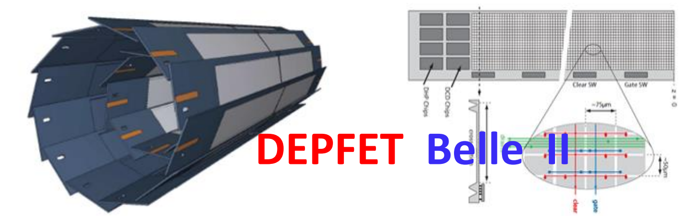
PXD
- Material budget ~0.15%X_0/layer
- σ_{xy}=50 mm

Inner tracks –Vertexing

- To combine with a central tracker to improve the tracking efficiency for low momentum track and resolution
- Dominant factor in low p tracks : multiple scattering and energy loss
- Driving force in design : low mass and high precision
- Special design to cope with the large radiation close to IP
- Technologies options :
  - ✓ A low mass silicon detectors: DEPFET, MAPS …
  - ✓ MPGD : Cylindrical GEM/MicroMegas/uRWELL

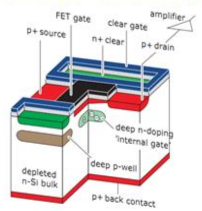
Inner Tracker Technologies

- 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.

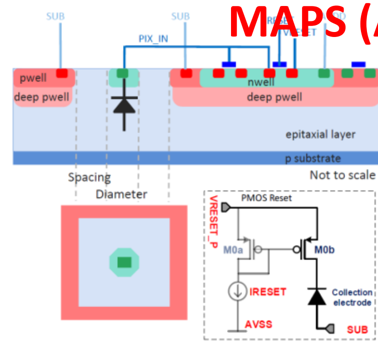


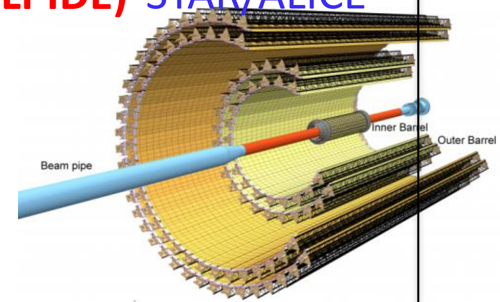
Number of pixels per module	250 x 1536
Pixel size (r-phi, z)	50μm x (60-75) μm
Frame time	20 μs
Material budget per layer	0.15% X_0
Resolution (r-phi, z)	<10μm, < 20μm
Occupancy at 1.8 cm radius	0.2 hits $\mu m^{-2} s^{-1}$
Radiation environment	~1 Mrad/year

DEPFET Technology



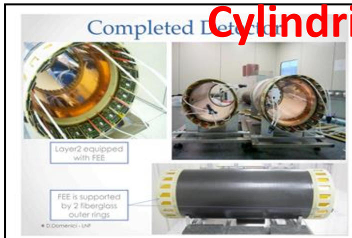
MAPS (ALPIDE) STAR/ALICE

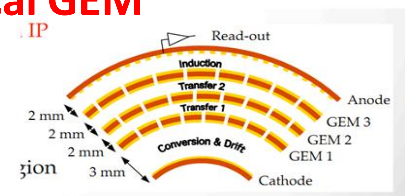




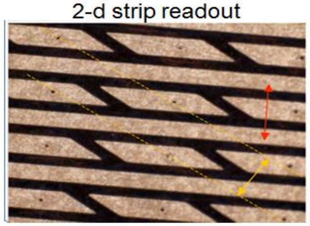
Pixel size: 29*27μm, high resistivity epitaxial, deep PWELL, reverse bias, global shutter (<10 μs), triggered or continuous readout, resolution < 5um, material budget <0.3%X_0

Cylindrical GEM





2-d strip readout

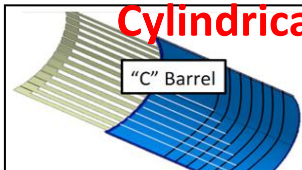


X pitch 650μm → X res 190 μm
V pitch 650μm → Y res 350 μm

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

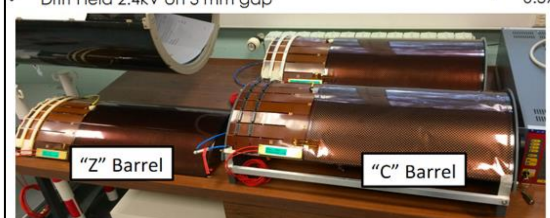
Pixel readout would be required for the innermost layers at HIEPA

Cylindrical MicroMegas CLAS12



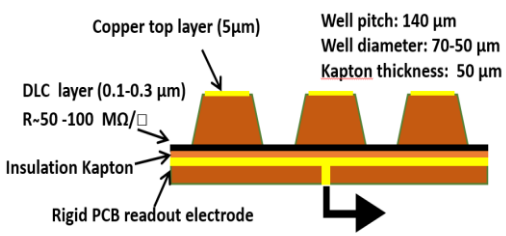
- 1152 "C" strips
- Pitch from 0.67 to 0.33 mm
- 221 mm radius
- PCB thickness 100 μm
- Drift thickness 250 μm
- Drift Field 2.4kV on 3 mm gap

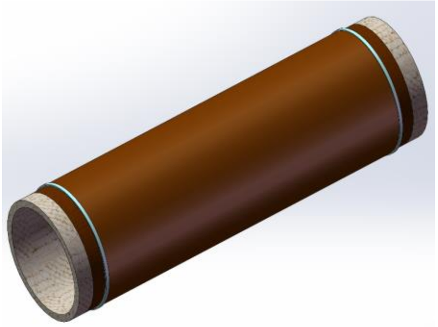
- 768 "Z" strips
- 225 mm radius, 0.529 mm pitch
- PCB thickness 200 μm
- Drift thickness 250 μm
- Drift Field 2.4kV on 3 mm gap
- 0.37% of X0



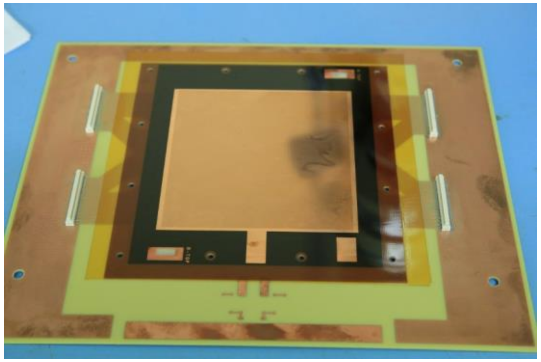
A new MPGD : uRWELL

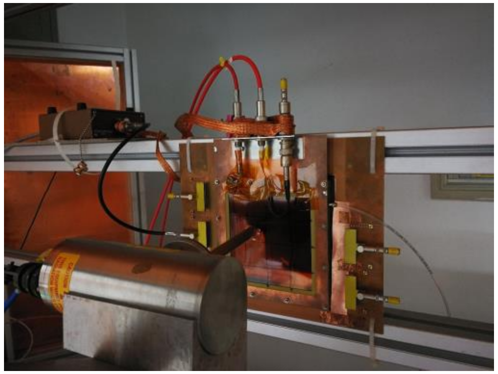
- Very compact, spark protected, simple to assemble, flexible in shapes (rather easy to make a cylindrical detector)

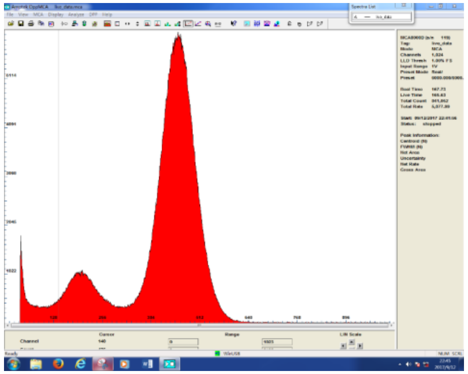




- A possible solution to be inner tracking, R&D underway at USTC.







Out Tracker : A Drift Chamber

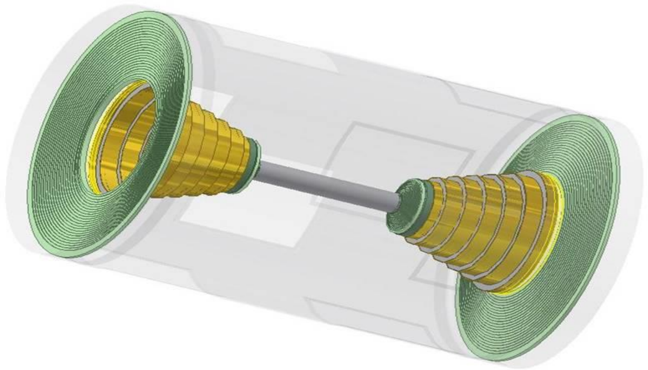
Large acceptance, low mass, high efficiency and high resolution

- **BESIII drift chamber serve as a good starting point, some refinement**
  - R_{in} has to be enlarged to avoid the very high rate region
  - 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

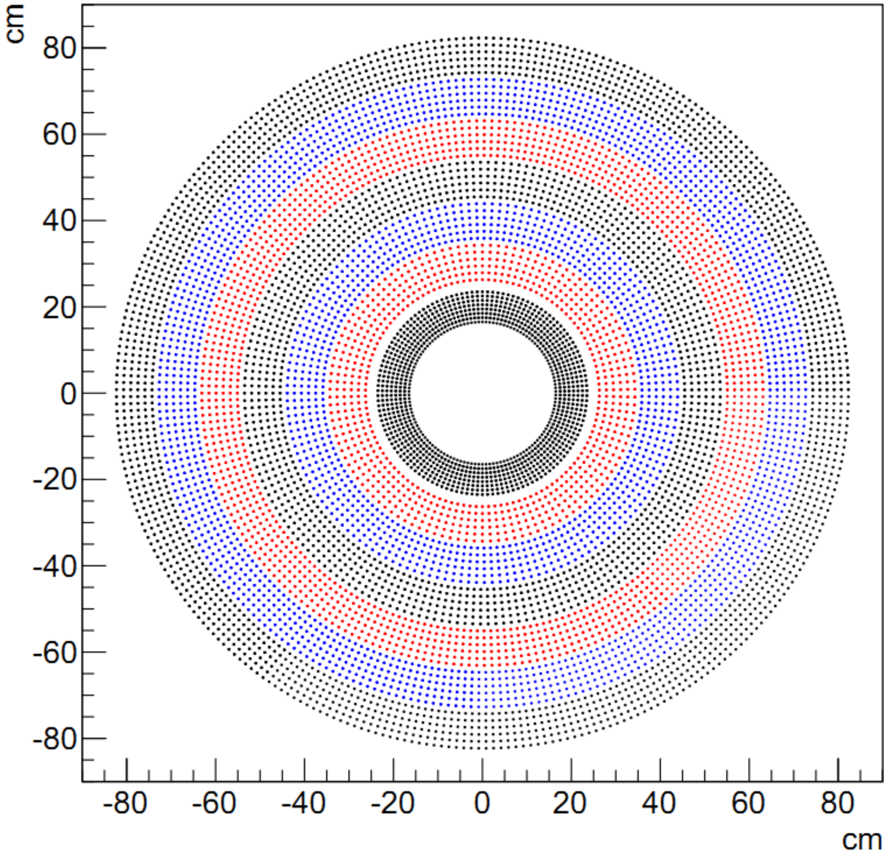
$$\sigma_x \sim 130\mu m$$

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

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



A Drift Chamber for STCF



- Rin = 15 cm, Rout = 85 cm, L = 2.4 m
- B = 1 T
- He/C_2H_6 (60/40)
- Cell size =1.0cm(inner),1.6cm(outer)
- Sense wire: 20 um W
- Field wire: 110 um Al
- # of layers = 44
- Layer configuration: 8A-6U-6V-6A-6U-6V-6A
- Carbon fiber for both inner and outer walls
- Expected spatial resolution: <130μm
- Expected dE/dx resolution: <7%

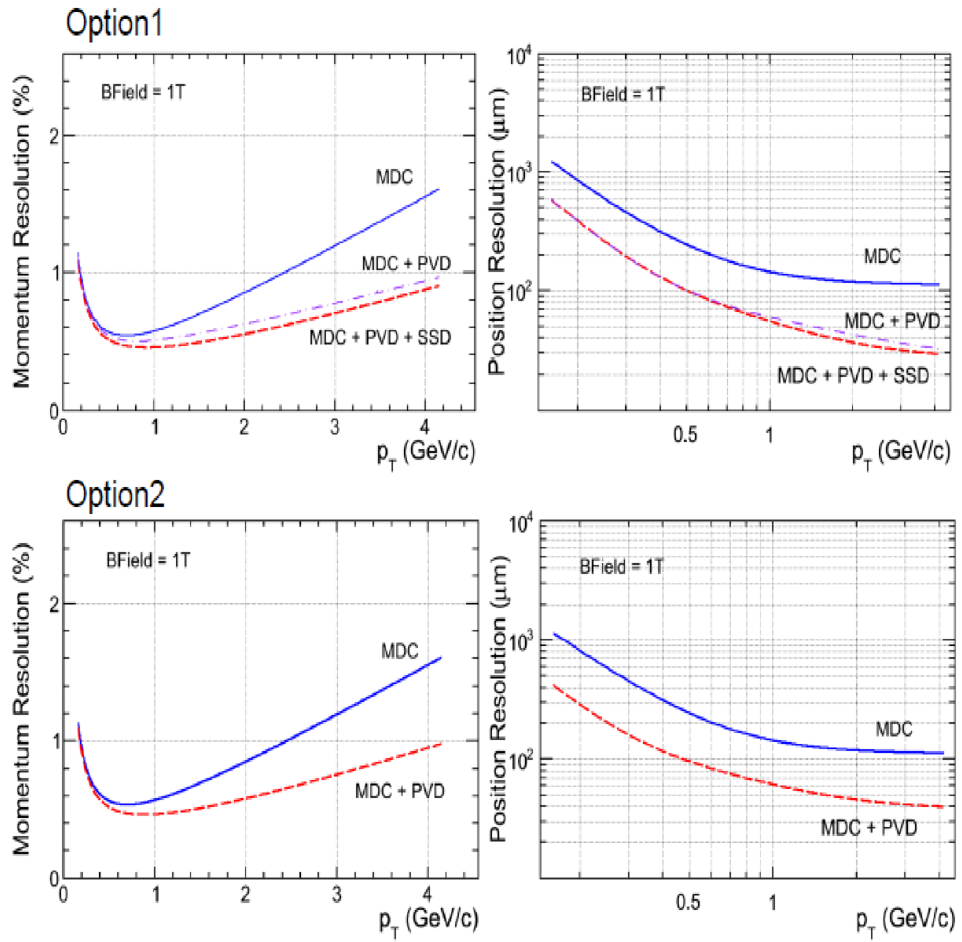
Performance of inner/outer trackers

Option I: MDC + STAR HFT (geometry is not optimized)

Detector	radius (cm)	material (%X_0)	resolution (μm)
MDC Outer 9-48	23.5-82	0.0045 /layer	130
MDC Inner 1-8	15-22	0.0051 /layer	130
SSD	10	1.5	250
PXD 2 layers	3/6	0.37 /layer	30
Beam pipe	2	0.15	-

Option II: MDC + Belle-II PXD (geometry is not optimized)

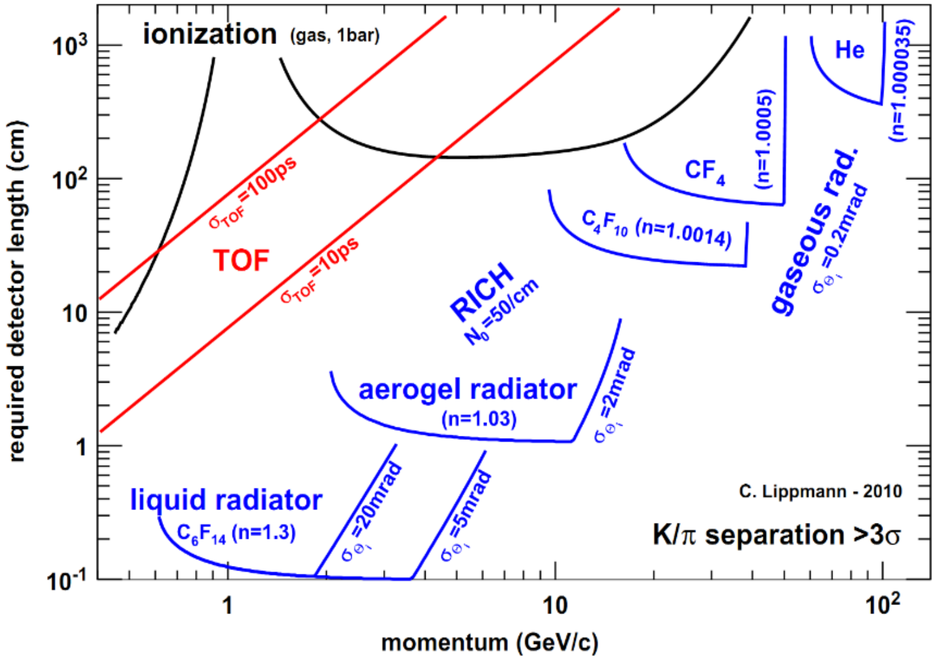
Detector	radius (cm)	material (%X_0)	resolution (μm)
MDC Outer 9-48	23.5-82	0.0045 /layer	130
MDC Inner 1-8	15-22	0.0051 /layer	130
PXD 3rd layer	10	0.15	50
PXD 2 layers	3/6	0.15 /layer	50
Beam pipe	2	0.15	-



$$\frac{\sigma_{P_t}}{P_t}pos. = \frac{3.3\times 100\times \sigma_x}{BL^2}P_t\sqrt{\frac{720}{N+5}} \qquad \frac{\sigma_{P_t}}{P_t}_{MS} = \frac{5.7}{BL}\times\frac{1}{\beta}\times\sqrt{\frac{LP}{X_0 P_t}}$$

PID System

- $\pi/K/p$ **separation** up to 2.0 GeV/c (3-4σ)
- **Fast timing, High radiation resistance for high lumi., especially in the endcap**
- **Compact – reduce costs of the outer detectors**
- **Modest material budget(<0.5X_0) – resolution of following up detector**



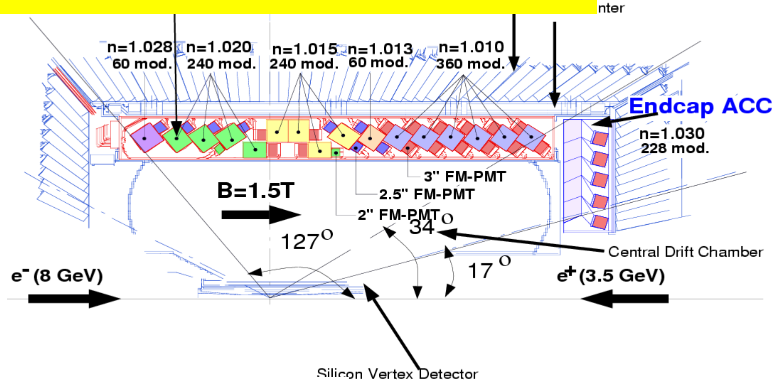
- **dE/dx in the tracking detector**
  - ~6% resolution,
  - track length ~0.7 m,
  - π/K ID for p<0.8 GeV/c
- **π/K separation at 0.8~2.0 GeV/c,**
  - Cherenkov detector and TOF .

Cherenkov PID system

- **Threshold Cherenkov**
- **Imaging Cherenkov:**
  - Ring Imaging Cherenkov detector (RICH)
  - Detection of Internally Reflected Cherenkov light(DIRC)

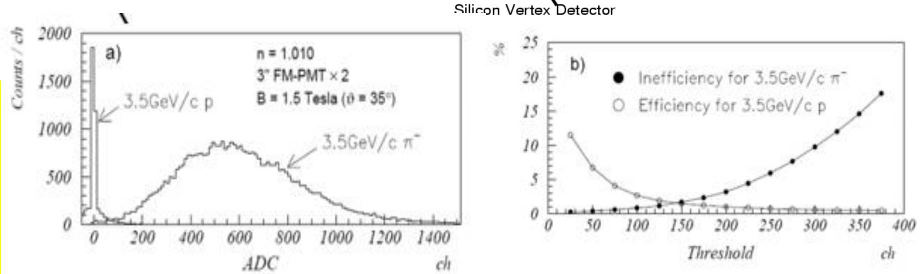
BELLE Aerogel Cherenkov Counter (ACC) – threshold

- **TOF resolution ~90 ps,**
  - for K/p separation 0.8-2.5 GeV/c
- **n = 1.030, π /K separation 0.6-2.0 GeV/c**
- **n = 1.010, π /K separation 1.0-3.5 GeV/c**



Structure simple

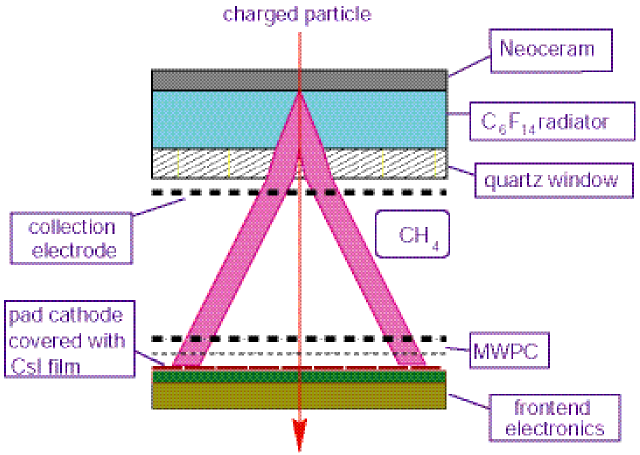
but require large space to install



Cherenkov PID system - RICH

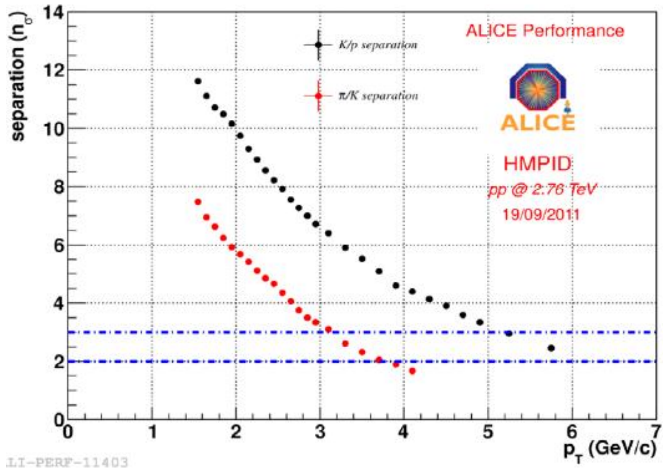
ALICE HMPID : High Momentum PID

- Liquid C_6F_{14} radiator n~1.3 @ 175 nm
- Proximity gap = 80 mm
- Readout pad size 8 mmX8.4 mm
- >3 σ π /K separation at 3 GeV/c



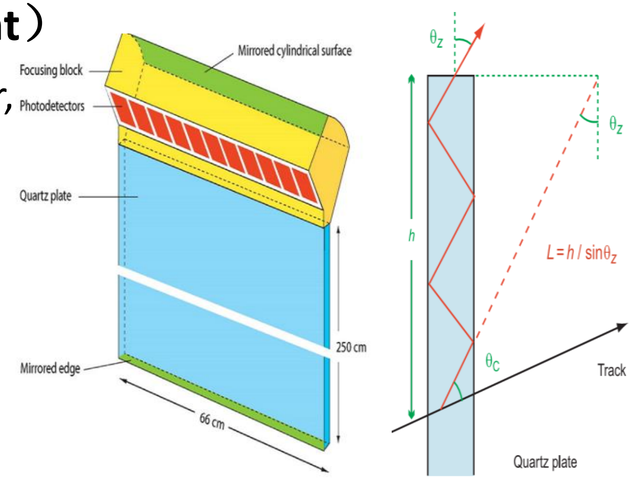
Already proven:

- Large momentum range
- System complicated

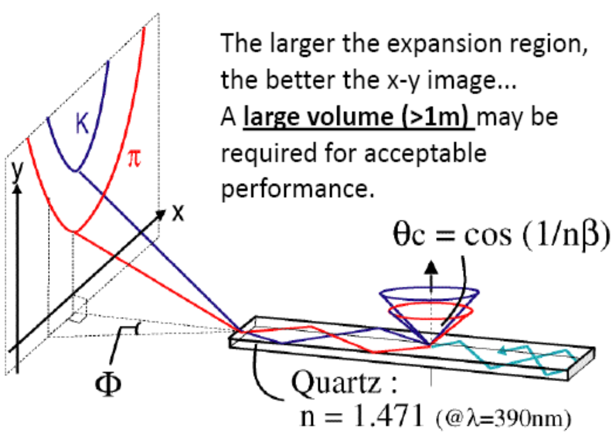


Cherenkov PID system — DIRC

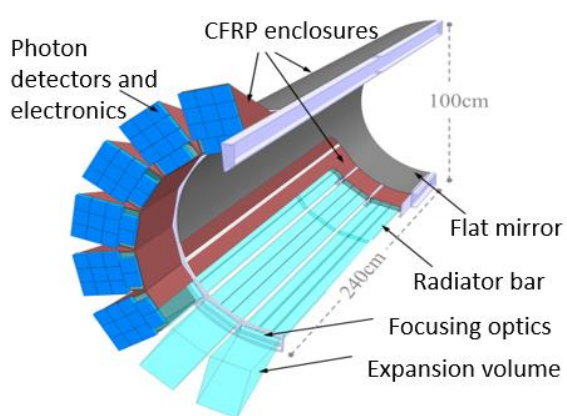
- **LHCb : TORCH (Time Of internally Reflected Cherenkov light）**
  - Large-area Quatz radiator + Light reflecting and focusing mirror,
  - MCP-PMT readout
- **BELLE-II : TOP (Time of Propagation)**
  - Quatz radiator + MCP-PMT readout
- **PANDA： DIRC**
  - Silicon radiator + MCP-PMTs readout
- **SuperB : DIRC-Like TOF in Forward Region**
  - Large-area Quatz radiator + MCP-PMT/SiPM readout



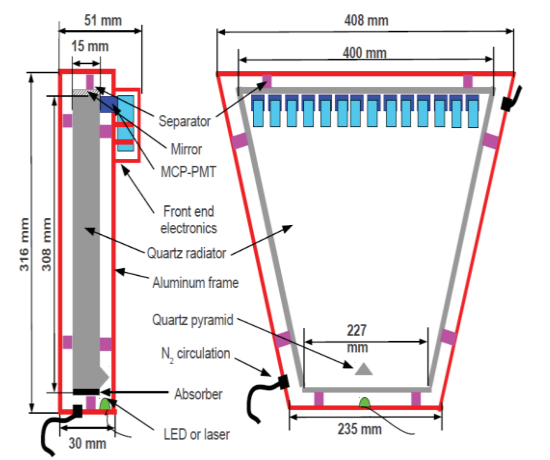
LHCb : TORCH



BELLE-II : TOP



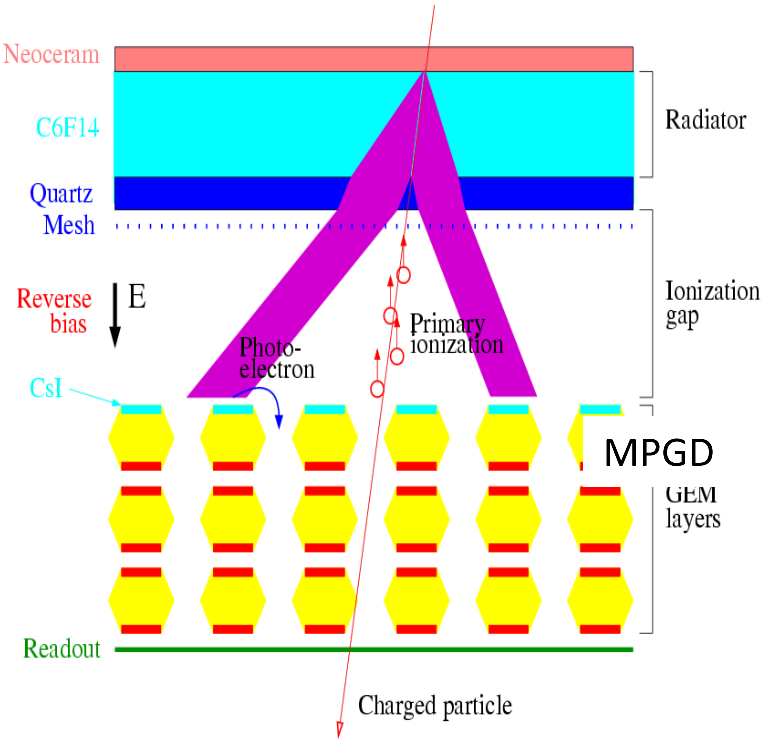
PANDA : DIRC



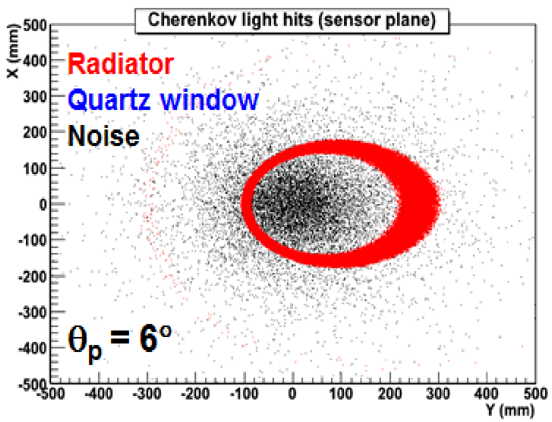
BELLE-II : TOP

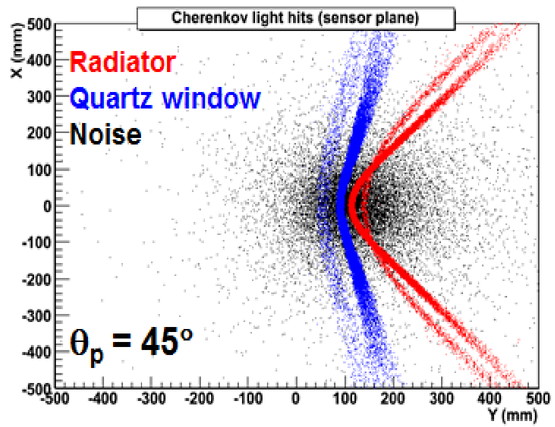
A RICH Design for STCF

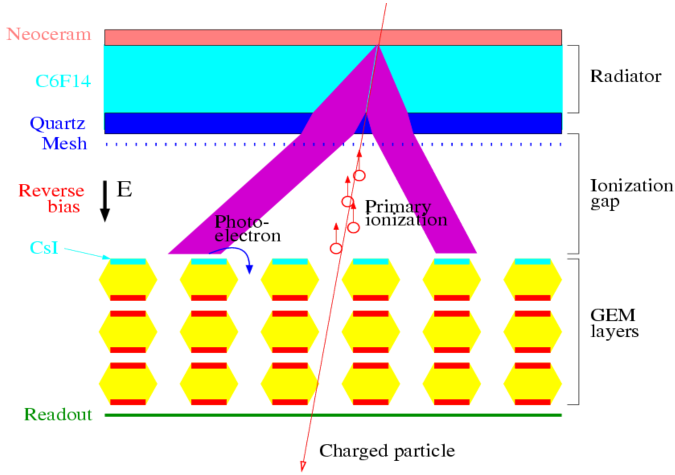
- **Proximity focusing RICH, similar to ALICE HMPID design, but with CsI-coated MPGD readout**
  - avoid photon feedback
  - less ion backflow to CsI
  - Fast response, high rate capacity
  - Radiation hard
- **Proximity gap ~10 cm**
- **Radiator: liquid C_6F_{14}, n~1.3, UV detection**

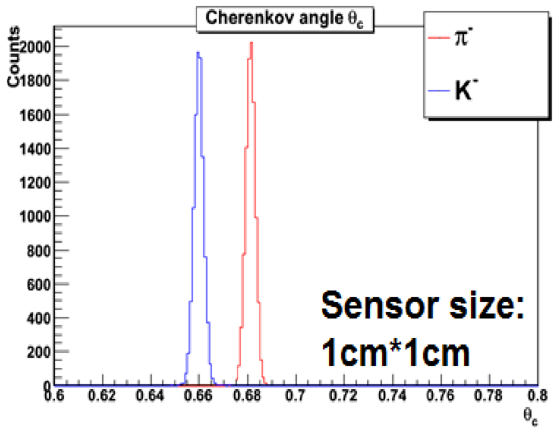


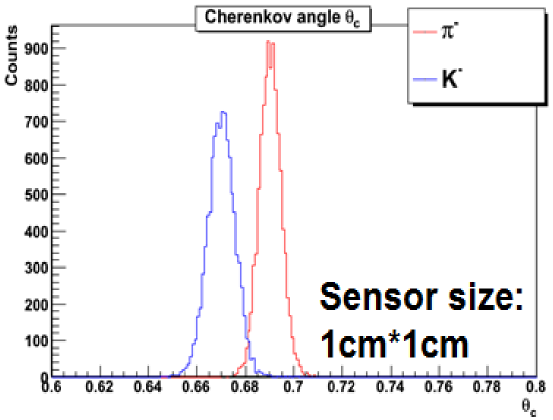
Performance Simulation

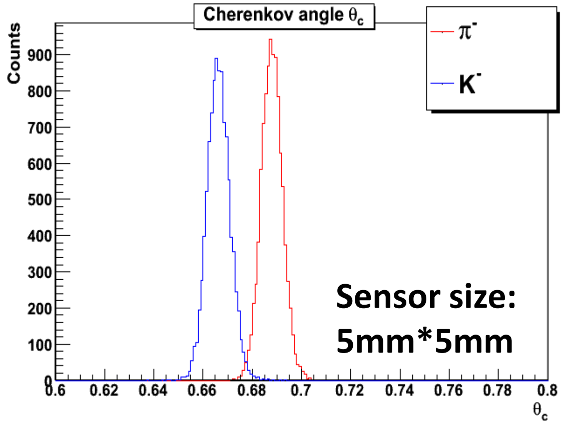










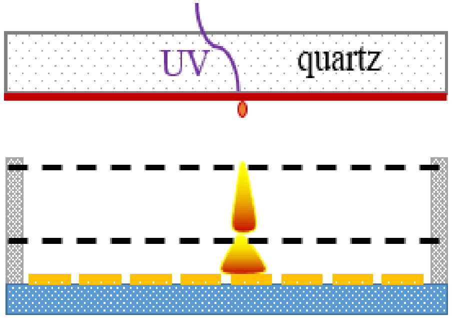


The π/K separation requirement can be met with a RICH detector.

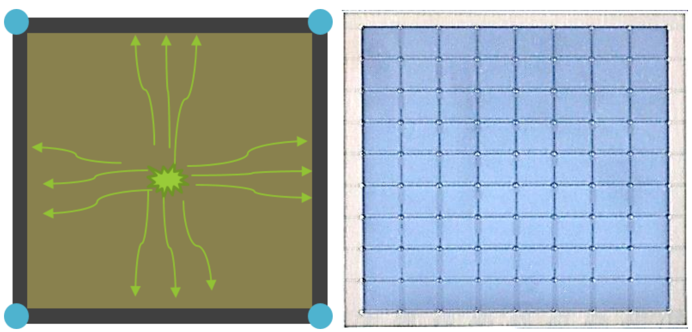
MPGD Photon Detector R&D

Double-Mesh Micromegas (DMM), a promising photon detector for RICH

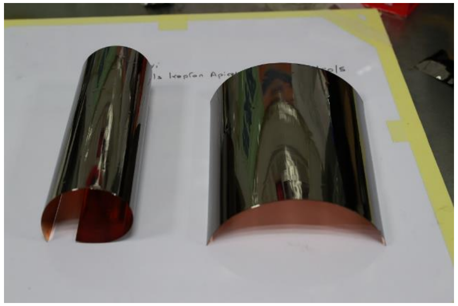
- **Single photoelectron detection:**
  - achieve $>10^6$ high gas gain and ~ 0.05% excellently low ion backflow ratio;
- **2D high spatial resolution :**
  - A four-corner resistive array anode readout to reduce the amount of electronics channels;
- **Photoelectron convertor :**
  - A Diamond-like Carbon (DLC) photocathode replace the fragile CsI.



Schematic of DMM

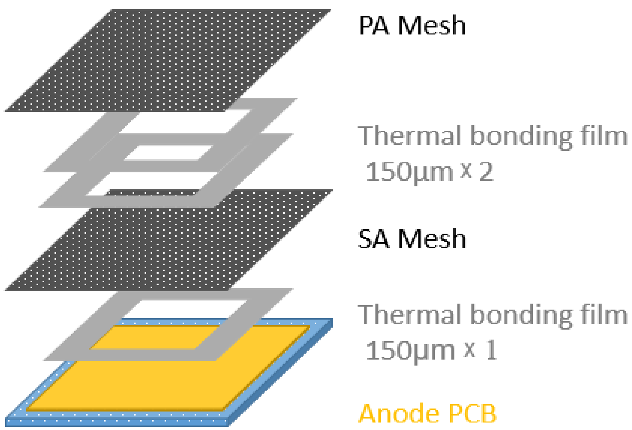


Four-corner readout

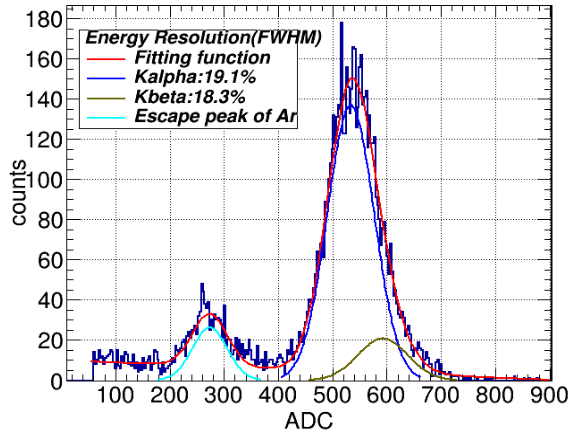


DLC coating on a KAPTON foil

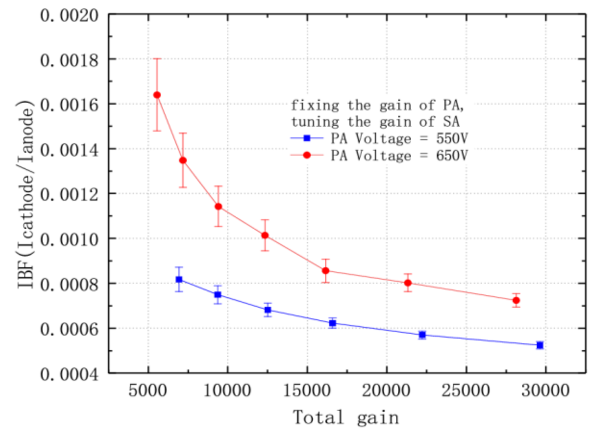
DMM prototype and Performance



A 5.9 keV x-ray spectrum

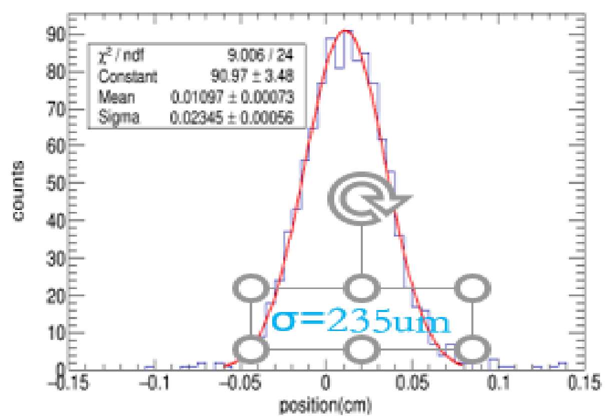


~0.0005 IBF ratio

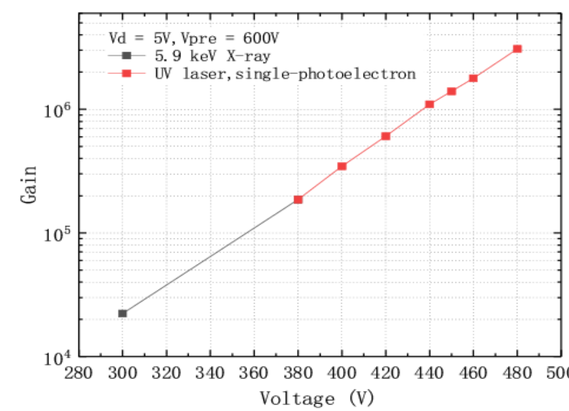


Fabricated with a thermal bonding technique, developed by USTC MPGD group.

Spatial resolution in size 10x10 mm^2



3 $\times 10^6$ high gain for single photoelectron



NIMA, 889 (2018) 78-82

DIRC-Like TOF for Endcaps

The 3σ separation of TOF : $\sigma_t < \frac{1}{3}\frac{x}{c}\frac{1}{2p^2}[m_K^2 - m_\pi^2].$

- For K/p at p=2 GeV/c, ΔT ~ 0.27ns*X(m) = 270 ps at X~1 m.

  3σ K/p separation for overall TOF time resolution is 90 ps
- For π/K at p=2 GeV/c, ΔT ~ 0.1ns*X(m) = 100ps at X~1 m.

  3σ π/K separation for overall TOF time resolution is ~30 ps.

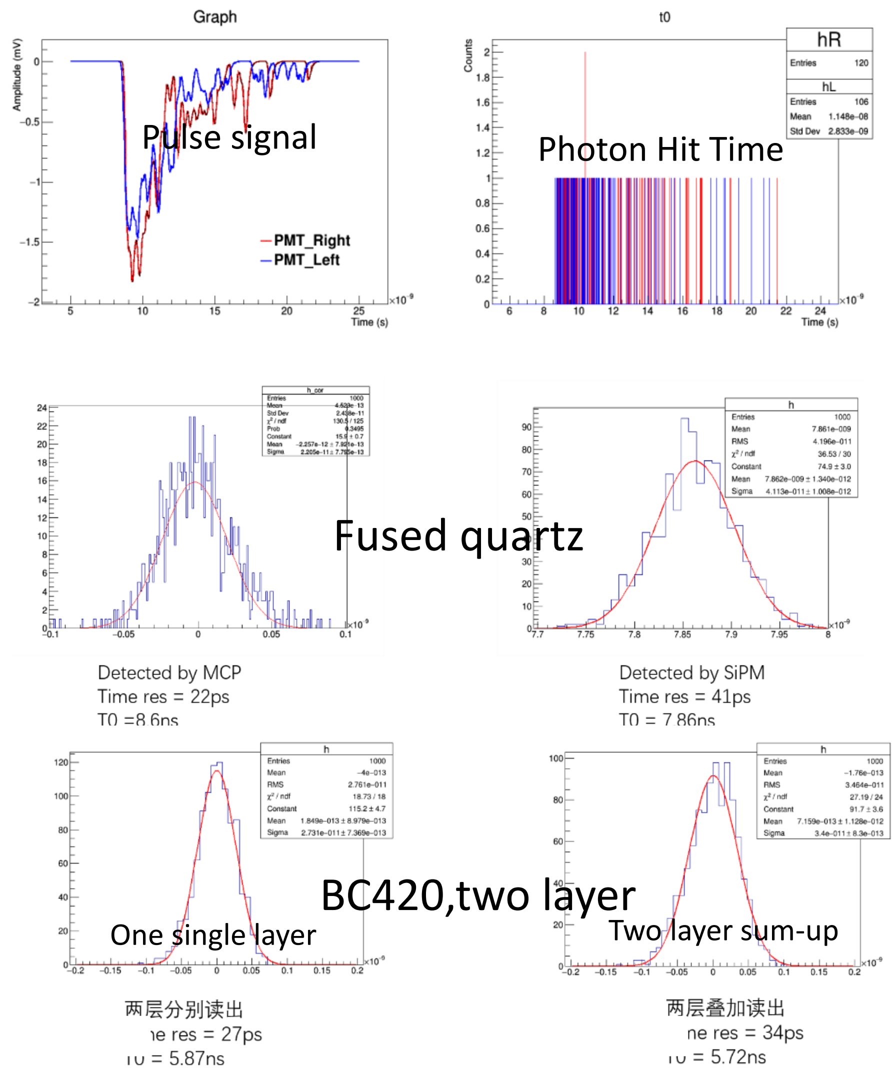
Very challenge for TOF technology

- Fast Timing TOF(<30 ps) based on new pico-second timing technology (TOF combined with DIRC method) is an endcap PID option for STCF
- DIRC-Like forward TOF detector (FTOF: quartz + MCP-PMT) was developed at LAL in Orsay for the SuperB project.

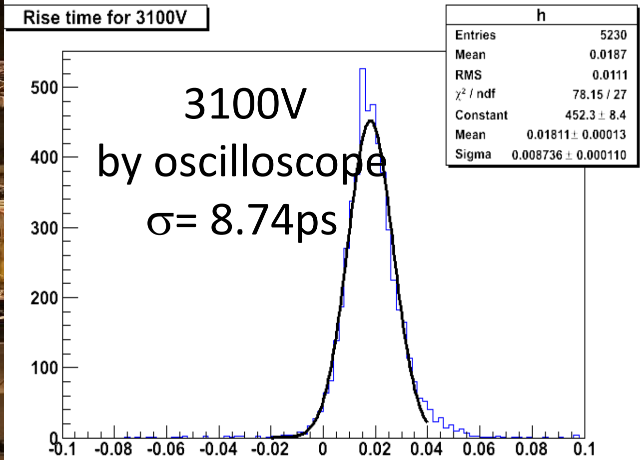
Simulation on Fast Timing TOF

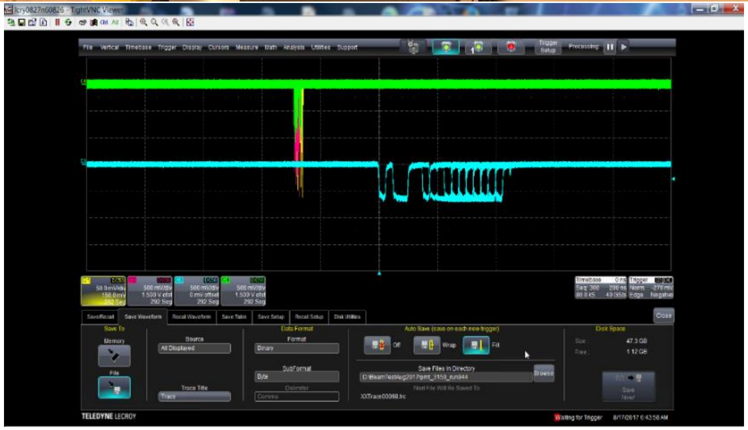
- Fused quartz + MCP-MPT readout
- Scintillator (BC420, double layer) with SiPM (or MCP) readout
- Threshold: 1 pe

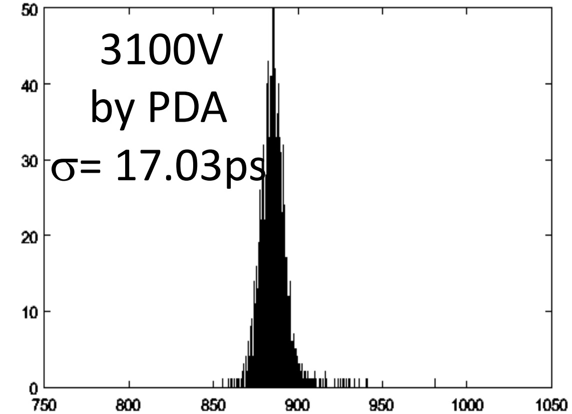
Intrinsic time resolution can reach to ~30 ps (preliminary)



Picosecond Timing TOF @ USTC







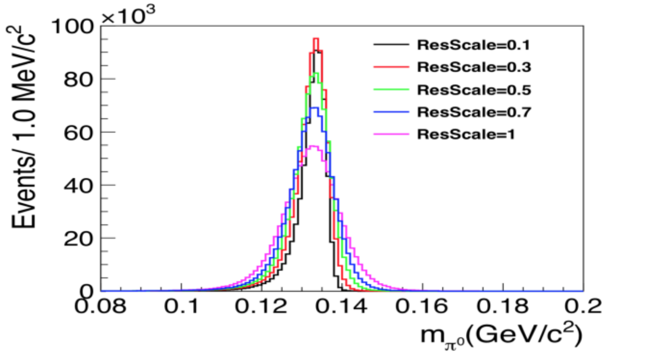
PDA(Programmable Differential Amp) LMH6881/2 +
DDD(Dual-threshold Differential Discriminator)
Low threshold: 28.7 mV, High threshold: 390.6 mV

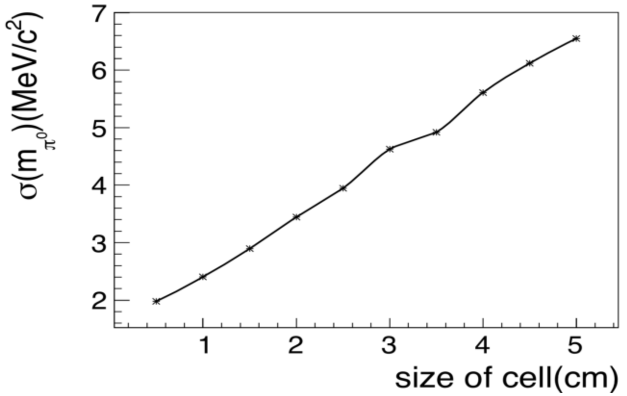
EMCal System

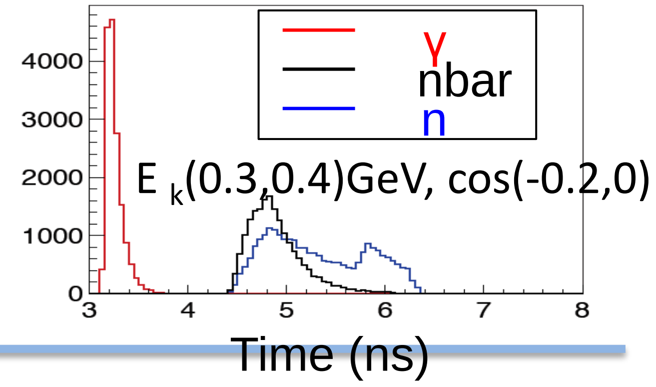
- **General requirement**
  - High efficiency for low energy γ
  - Excellent energy resolution
  - Fast response and Radiation hardened
- **Better position resolution**
  - To improve the kinematic variables of neutral particles
  - High granularity
- **Better time resolution**
  - To separate γ/neutron

Technology option :

Crystal + novel photon detector (e.g. SiPM)

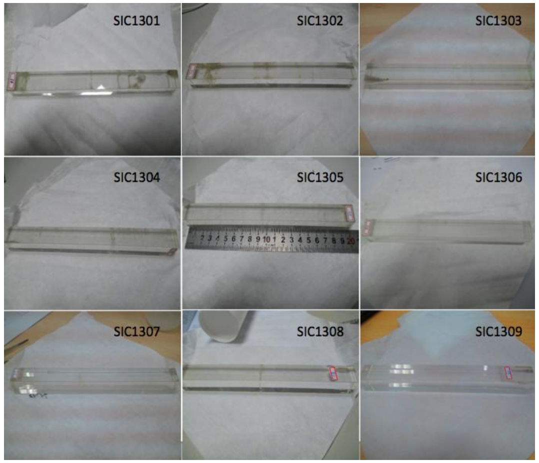


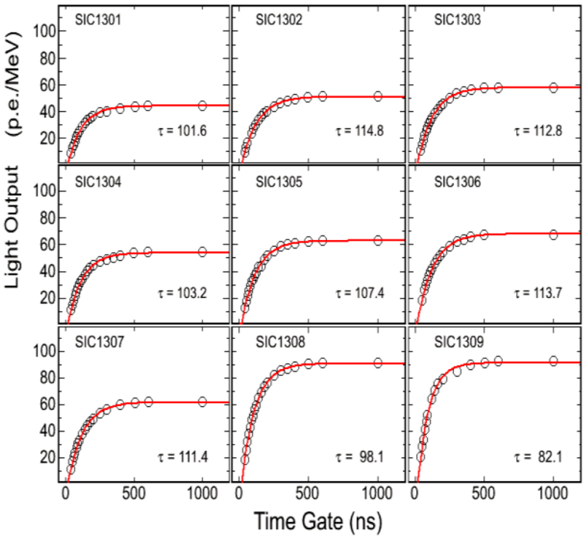




Crystal Options

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 6	100 26,2.4	30 10	40
Light Yield ^{b,c} (%)	165	3.6 1.1	3.4 0.5/0.25	0.30 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 Belle2 1st SuperB 2nd	Belle2 3rd	CMS, ALICE PANDA Belle2 2nd	SuperB 1st (Hybrid)





Crystal Options

	Light Yield	Radiation hardness	Faster response	Cost
CsI(Tl)	☺	☹	☹	☺
Pure CsI	☹	☺	☺	☺
PWO	☹	☺	☺	☺
BGO	☺	☺	☺	☹
LYSO	☺	☺	☺	☹

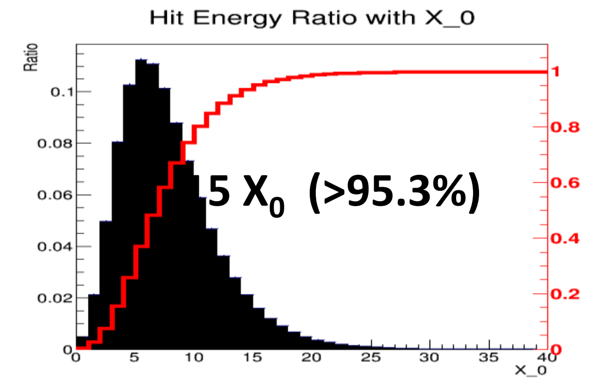
- **Barrel ECAL : CsI(Tl) or pure CsI could be considered.**
- **Endcap ECAL : LYSO is considered even expensive price.**

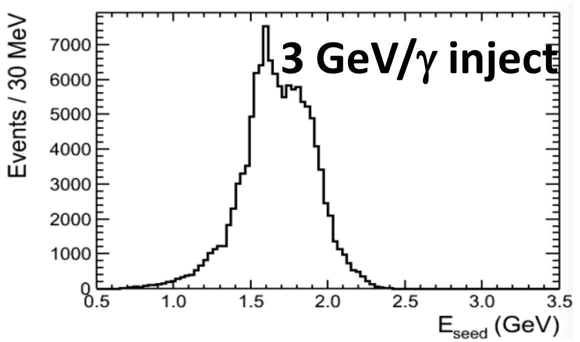
Optimization

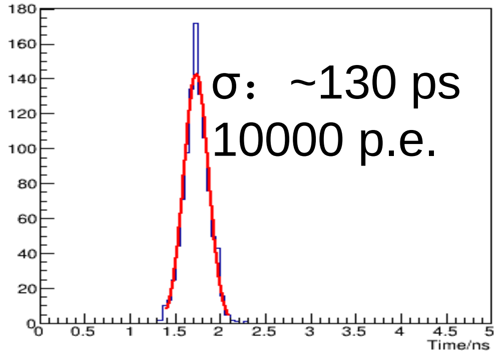
- **Radiation length : $15X_0$**
  - Energy deposition : >95.3%
  - Dynamic range of SD ： 1 MeV ~ 2500 MeV
- **Time resolution ：**

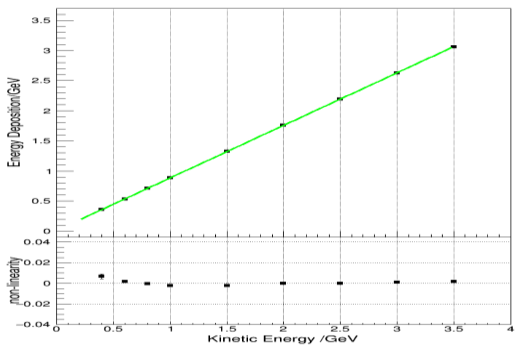
$$\sigma=\frac{1}{\sqrt{N_{pe}}}\sqrt{\left(\frac{1}{2.354}\right)^2\{\tau_{scin}^2+[\frac{n(n-1)L}{2c}]^2+\tau_{PMT}^2\}}$$

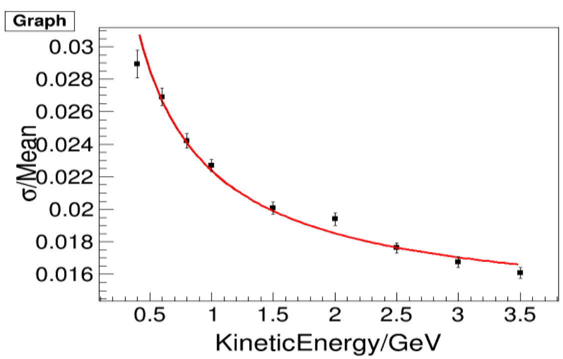
  - better than 100 *ps* at high energy(>1 GeV)
  - Depends on the physics requirement
- **Granularity :**
  - Balance between energy and position regions





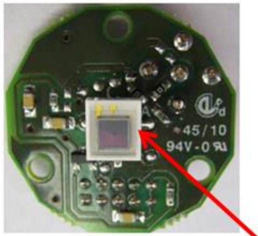




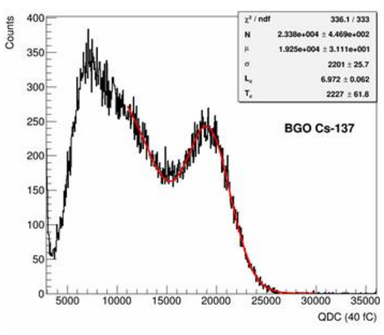


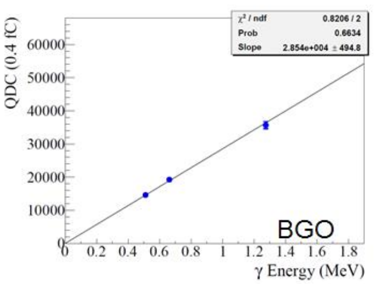
SiPM Technology

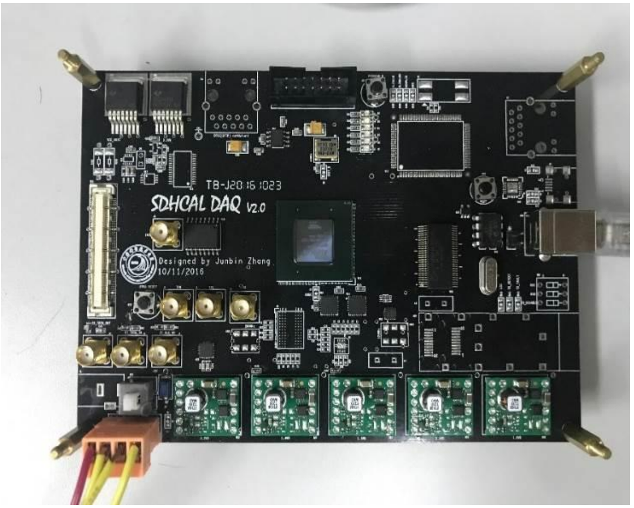
- **SiPM: a novel and rapidly-developing photo-sensor technology**
  - **High gain, low equivalent noise, B-field resistant, good time resolution**
- **R&D at USTC**



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

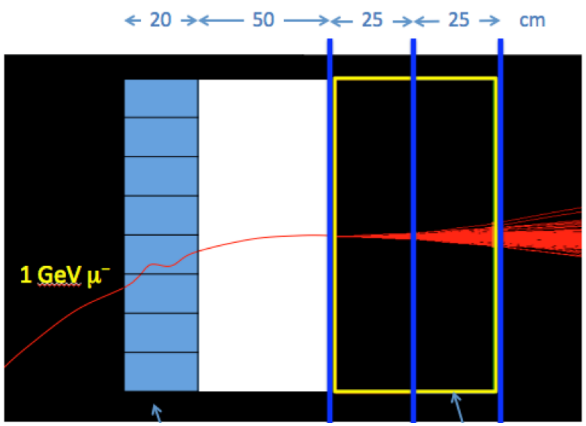


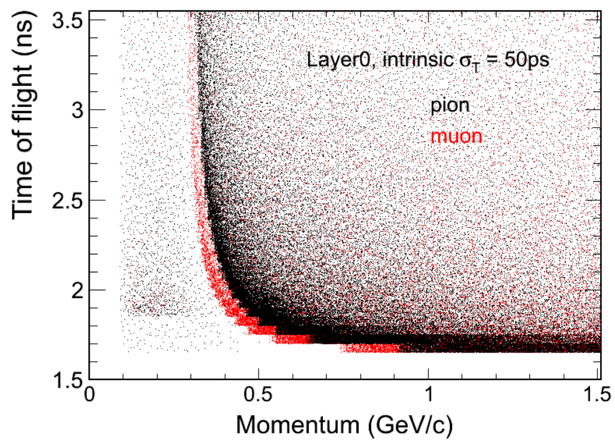


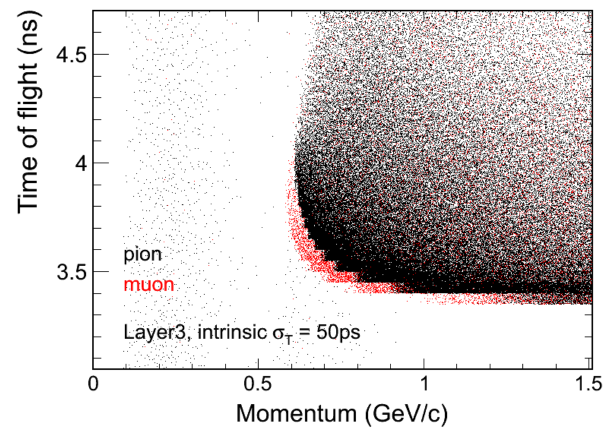


μ detection

- **Low** **momentum** **threshold (p~0.4 GeV)**
- **high μ efficiency and μ/π suppression power>10 (30）**
- **Idea to lower muon detection threshold:**
  - measuring TOF at entrance to iron yoke — a timing muon detector.
  - Can be realized with MRPC technology

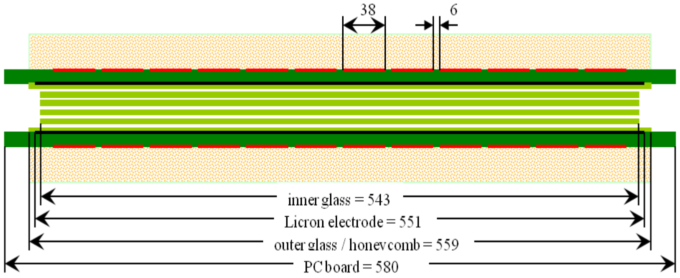






- Below 400 MeV, μ and π can be well separated
- Below 300 MeV, μ can't reach iron yoke

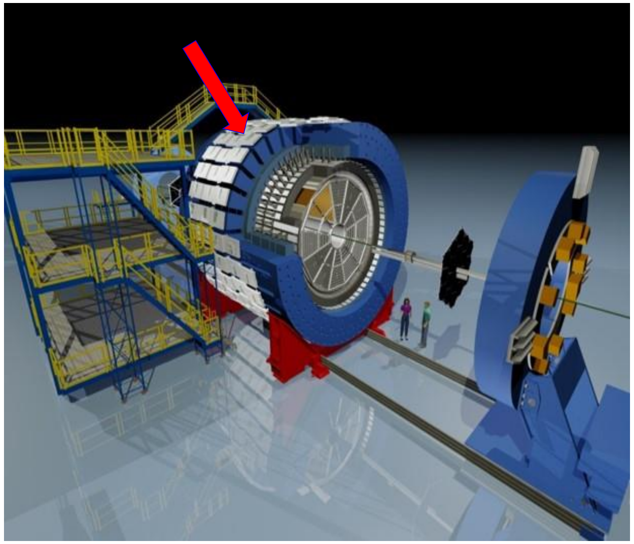
μ detection



Long-Strip MRPC Module at STAR

- Active area: 87 x 52 cm^2
- Read out strip: 87 cm x 3.8 cm
- Gas gaps: 0.25 mm x 5

MTD at STAR



Performance:

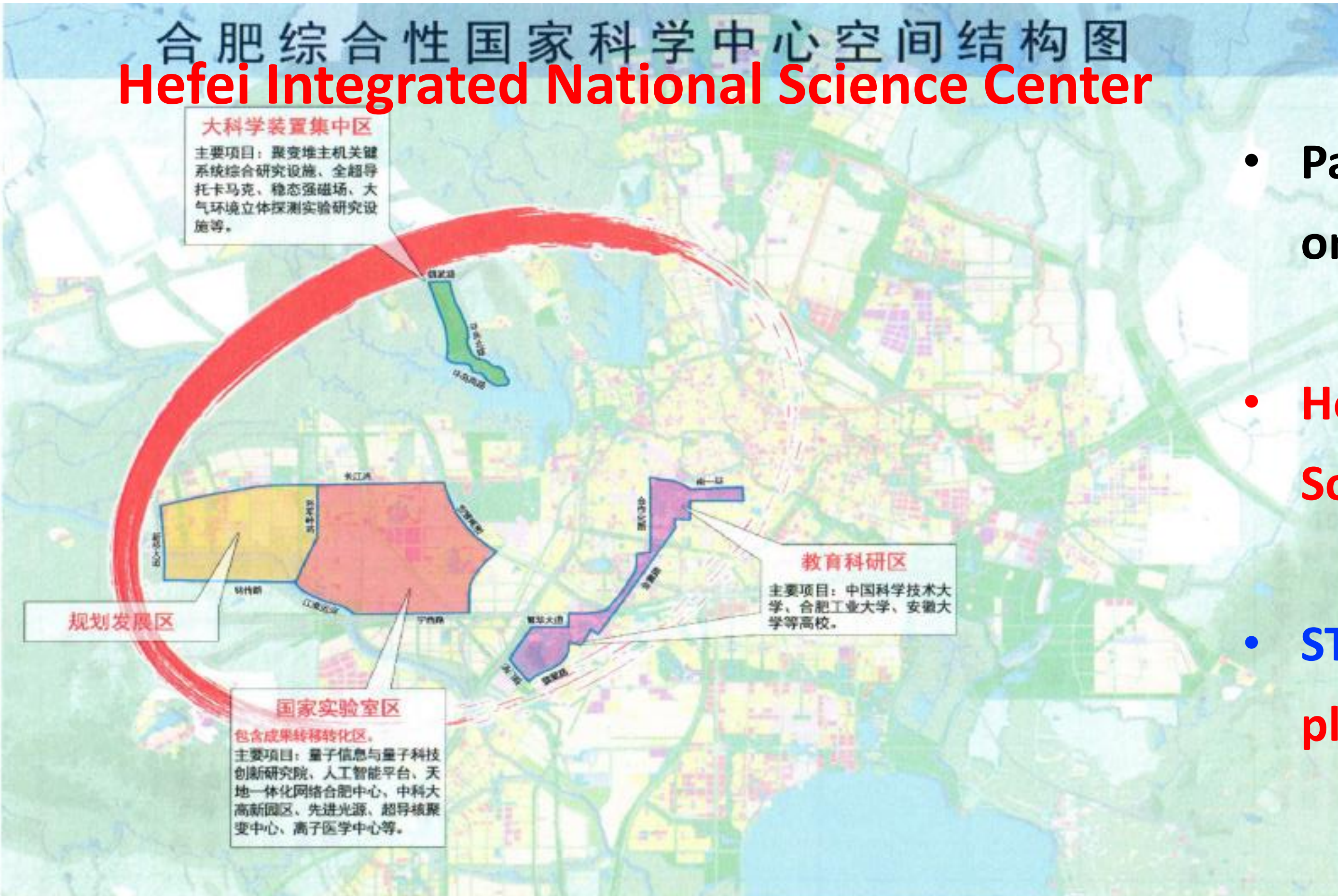
- Efficiency: > 98%
- Time resolution: < 80 ps
- Spatial resolution: 0.6 cm

μ detection

- 2-3 inner layers with MRPC for precise timing
- ~8 outer layers with RPC
- RPC operation modes
  - Barrel: streamer
  - Endcap: avalanche
- π rejection power ~ 30

Candidate site: Hefei

One of the three integrated National Science Centers(NSC), which will play important role in 'Mega-science' of China in near future



- **Pay a lot of attention on accelerator facilities**
- **Hefei Advanced Light Source is under design**
- **STCF is listed in future plan**

Hefei as a NSC

- 900 km from Beijing
- 300 km from Shanghai
- 6M population

Funds

- Starting ¥ 10M (~$ 1.5M) endorsed by USTC;
- R&D ¥ 200M (~$ 30M) expected;
- Budget ¥ 4B (~$ 0.6B), from local government and/or Chinese Academy of Sciences?

- Domestic Workshops (2011, 2012, 2013, 2014, 2016)
- International Workshops (2015, 2018)

- USTC is now fully supporting STCF!

CDR → TDR → project application → construction → commissioning

Organization

Institutional Board

Steering Committee
Chair: Zhengguo Zhao

International Advisory Committee (IAC)

Project Director

Theory & MC simulation

- Light Hadron
- Charmonium, XYZ
- Charm decay, charm Spectroscopy
- Tau
- R&QCQ
- New Physics
- …….

Accelerator

- Design
- RF
- IP
- Vacuum
- Beam diagnose
- Linear….

Detector

- Tracking
- PID
- ECAL
- Muon
- SC
- Trigger, DAQ
- Software
- Computing & Network

Tentative Plan

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030-2040	2041-2042
Form International Collaboration														
Conception Design Report (CDR)														
Technical Design Report (TDR)														
Construction														
Commissioning														
Upgrade														

A unique precision frontier in the world for 30 years!

Summary

- **Launch R&D project for Super τ-c Facility (STCF) :**
  - double ring with circumference around 600~1000 m
  - e^+e^- collision with E_{cm} = 2 – 7 GeV, L = 1 × 10^{35} $cm^{-2}s^{-1}$
  - Polarized beam
- **The candidate site : Hefei Integrated National Science Center**
- **A dedicated machine for HEP, one of the crucial precision frontier**
  - rich physics program, unique for physics with c quark and τ leptons.
- **We initialized ¥ 10M (~$ 1.5M) funds for this year.**
- **An International coll. is essential for promoting the project.**
- **At USTC, different positions are opened for the STCF project.**

Welcome to join the effort!