Overall Design Considerations for a Detector System at HIEPA

plus more specific considerations for tracking subdetectors

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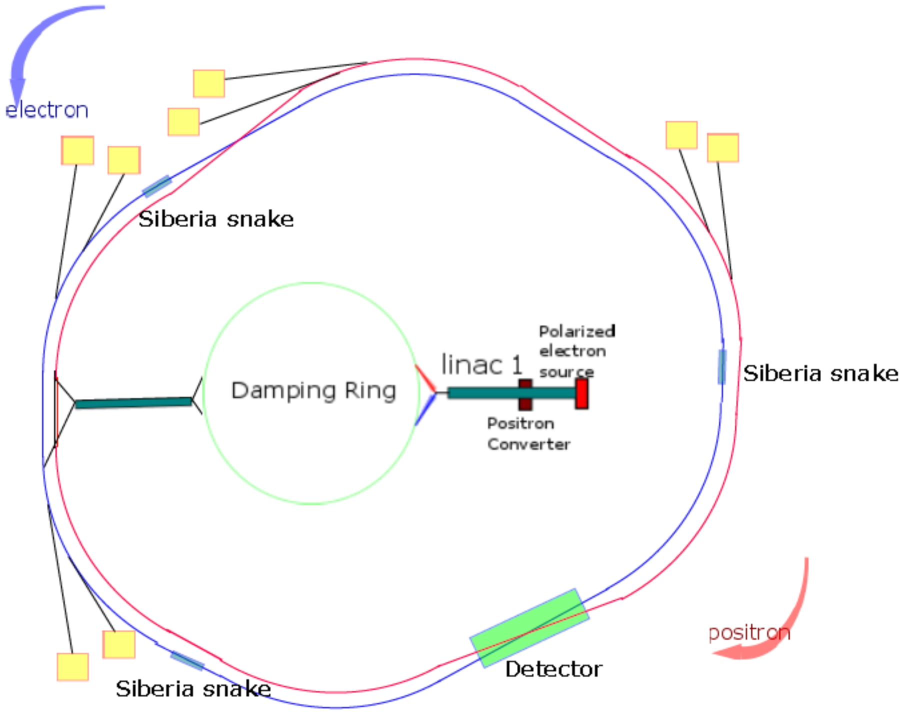
HIEPA Workshop-2018
UCAS Huairou Campus, Beijing
March 21, 2018

High Intensity Electron Positron Accelerator

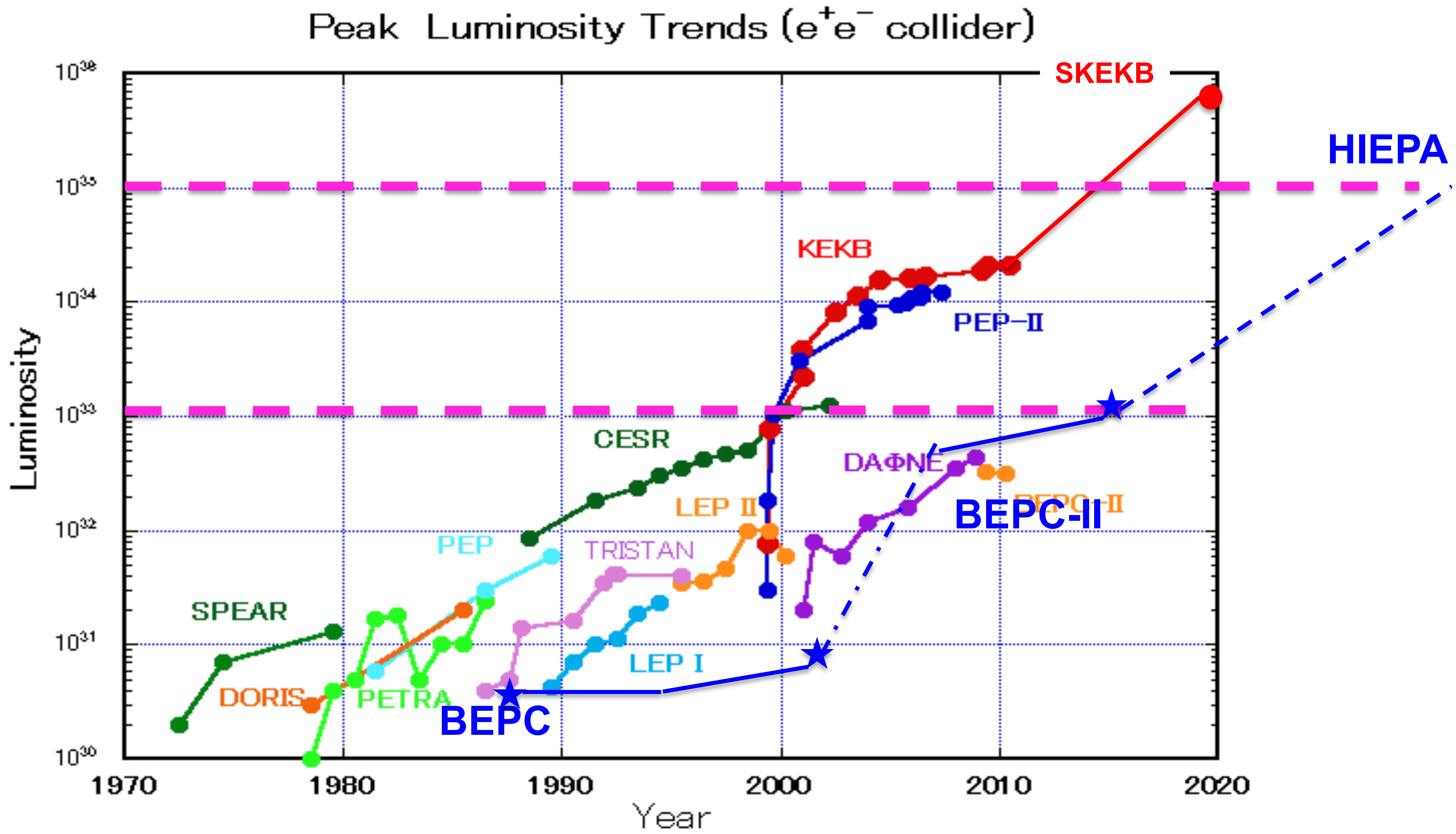
- **HIEPA** : a natural extension of BEPCII and a viable option for a post-BEPCII HEP project in China.



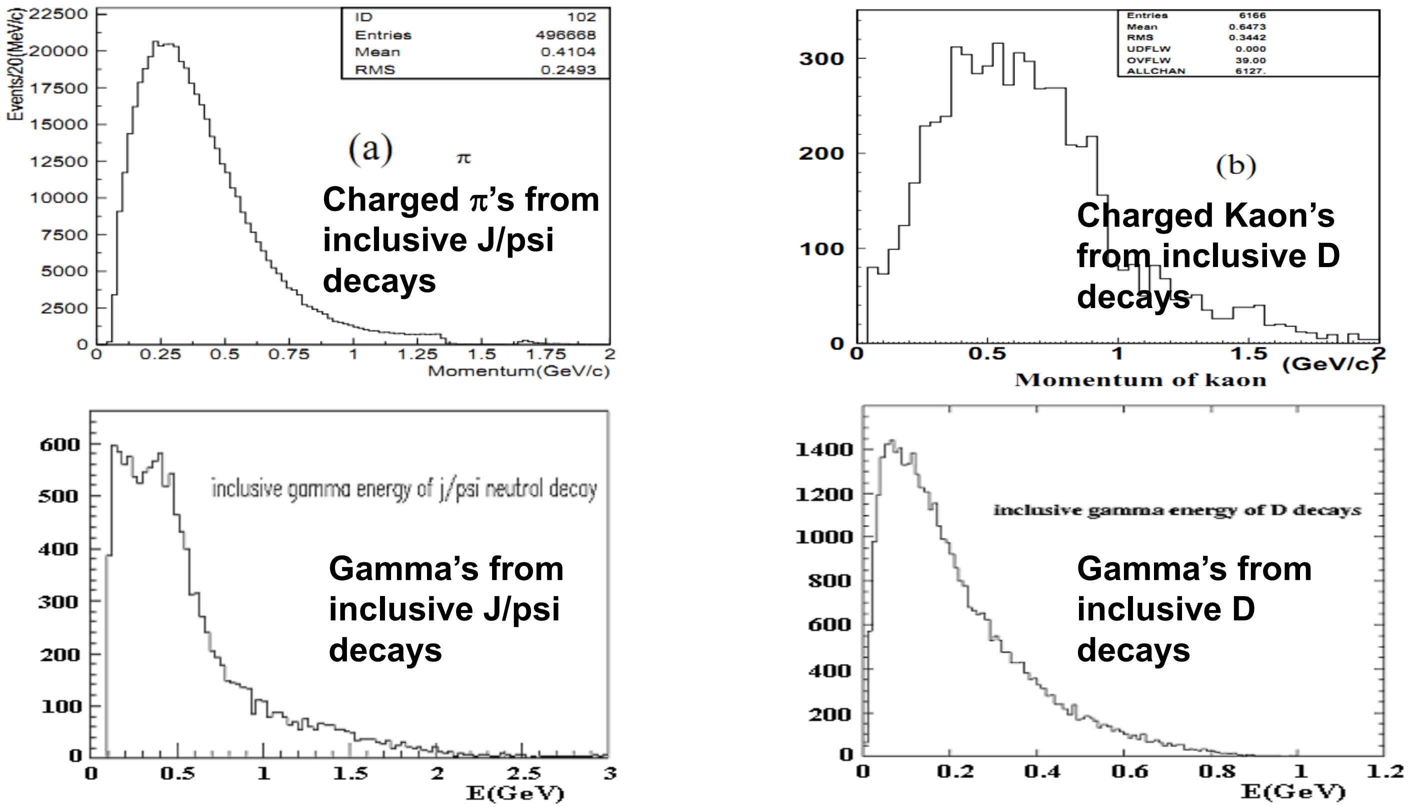
- E_{cm} = 2-7 GeV, $L=1\times10^{35}$ $cm^{-2}s^{-1}$ @4 GeV
- Symmetrical collision
- double-ring, 600-1000m
- Crab waist scheme
- Single beam polarized

An super τ-c machine far beyond BEPCII

HIEPA in Perspective



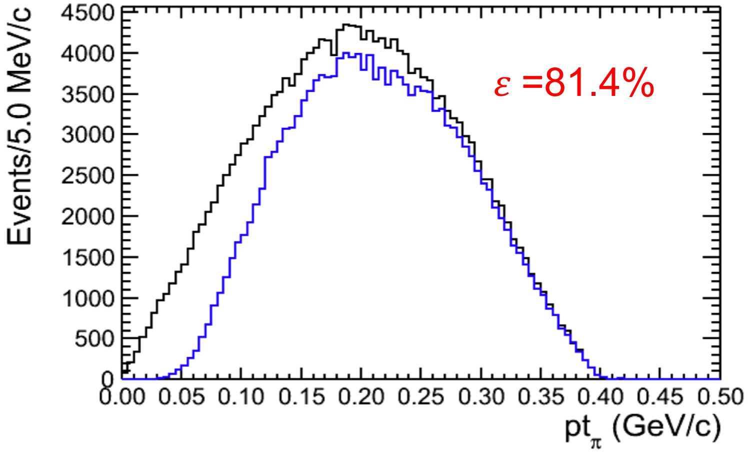
A Glimpse of Final States at HIEPA



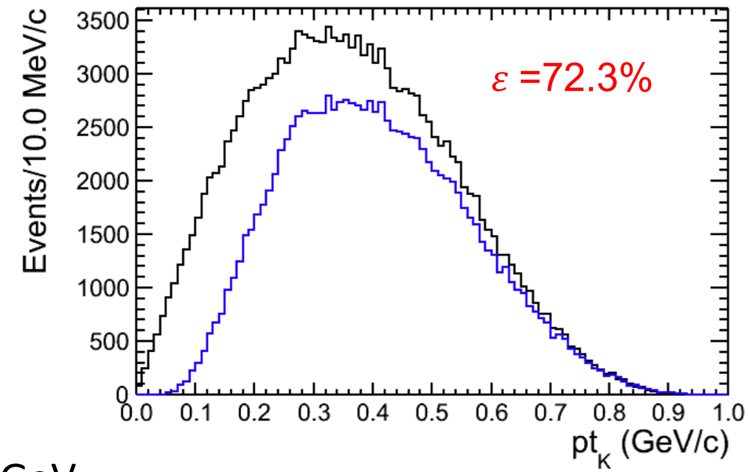
- Final-state particles are largely of low momentum /energy (< 1GeV/c)
- Designs of the HIEPA detector have to match this important feature of final states.

More Specific about Low Momentum

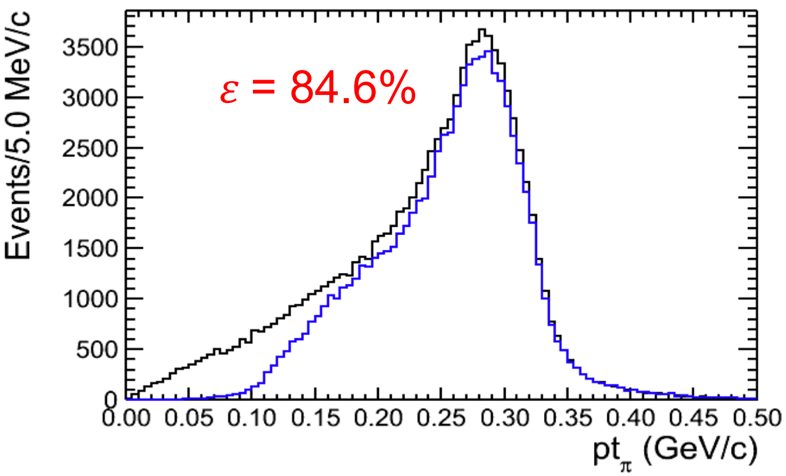
- Charmonium and XYZ physics
  - $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$

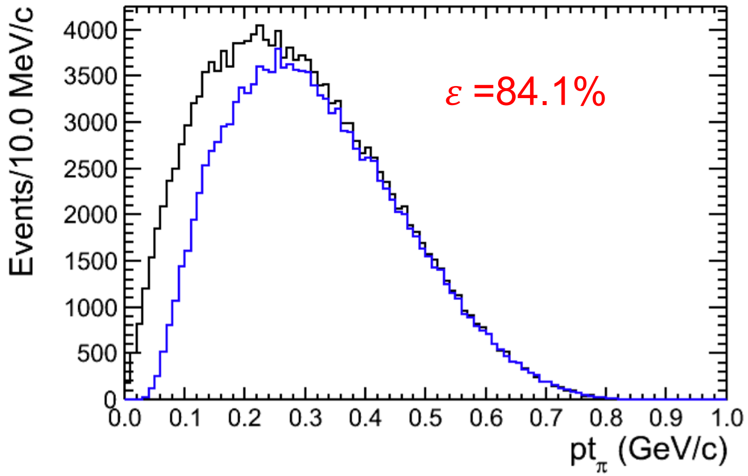


- Charm Physics
  - $D^0 \rightarrow K^-\pi^+\pi^-\pi^+$



- $e^+e^- \rightarrow \pi Z_c \rightarrow \pi^+\pi^-\psi(2S) \rightarrow \pi^+\pi^- J/\psi$ at 4.42 GeV



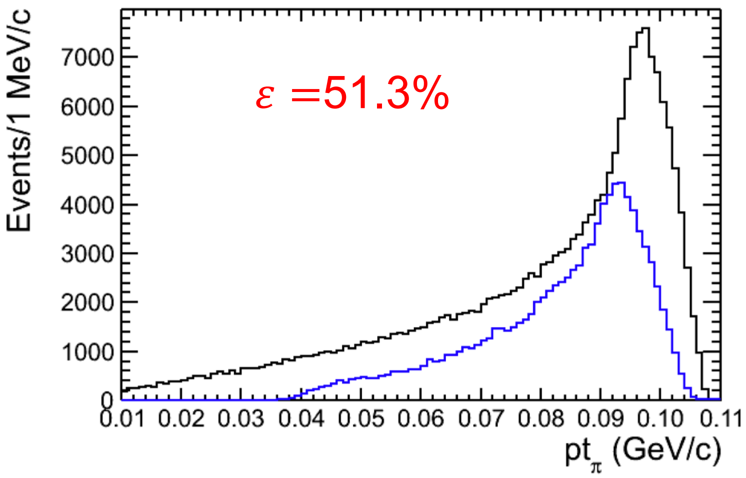


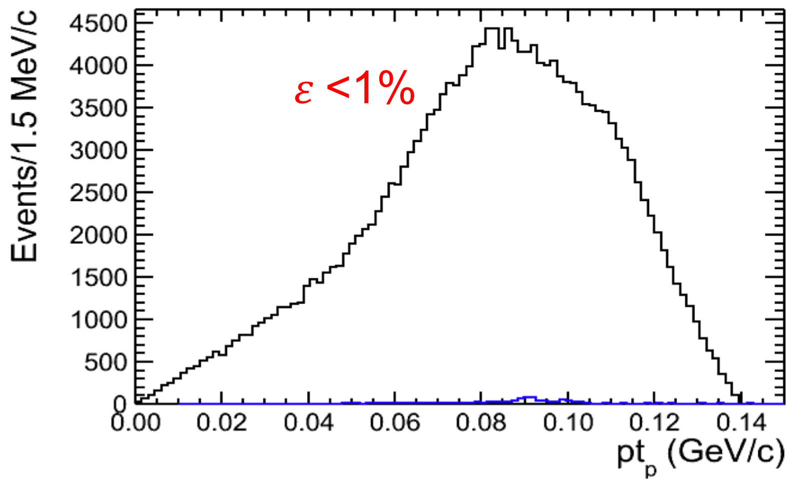
BES3 plots by Dr. Xiaorong Zhou

Black: truth, Blue: reco

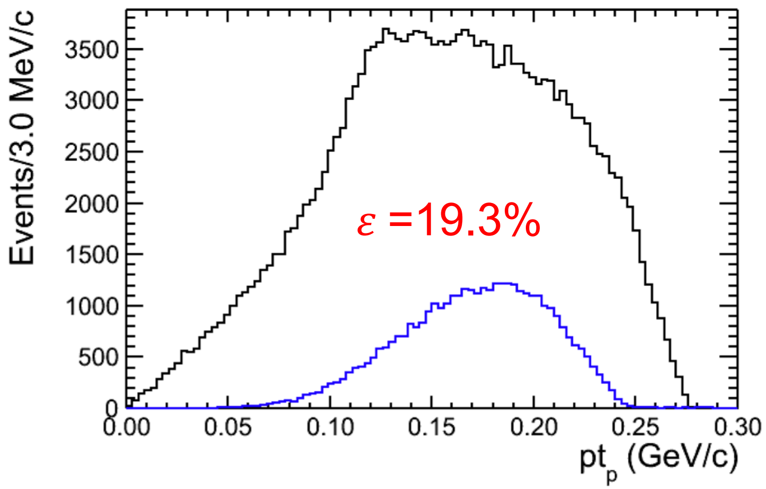
More Extreme Cases

- Baryon pair threshold production
  - $e^+e^- \to \Lambda\bar{\Lambda} \to p\bar{p}\pi^+\pi^-$ at 2.2324 GeV





  - $e^+e^- \to \Sigma^+\bar{\Sigma} \to p\bar{p}\pi^0\pi^0$ at 2.3864 GeV



Very low momentum protons suffer severely from material effect

BES3 plots by Dr. Xiaorong Zhou

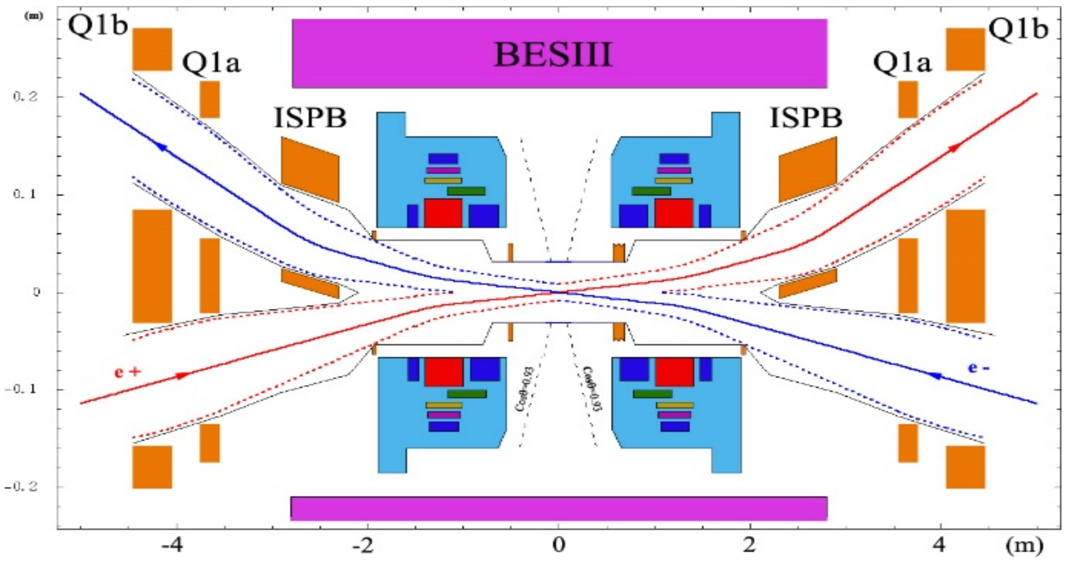
Black: truth, Blue: reco

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 HIEPA

- **Overall requirements**
  - Efficient and fast triggering
  - Efficient and precise reconstruction of exclusive final states
  - High rate capability and radiation tolerance around IP and in forward regions
- **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)

Detector Requirements for HIEPA

- **PID**
  - π/K separation up to 2GeV, compact and low mass
- **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
- **Magnet**
  - Desirable to be adjustable from 0.5- 1.0 T

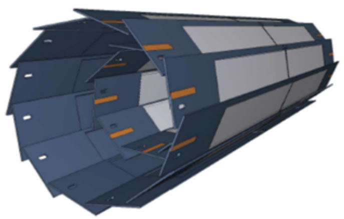
Inner & Outer Trackers

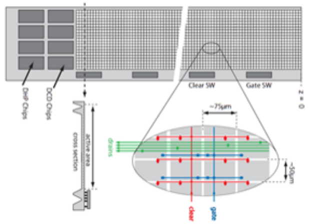
- Dominant factors in low p tracking: multiple scattering and energy loss
- So driving force in design of tracking system: low mass.
- Special design is required for inner tracking to cope with the very high level of radiation close to IP
  - An inner-outer separate design is optimal.
- Detector technology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

Inner Tracker Technologies

DEPFET

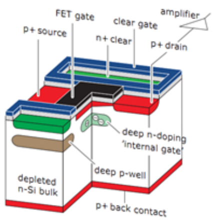
- Two layers of PXD: 1.8 cm and 2.2 cm in radius, consisting of 8 and 12 modules for innermost layer and the second, respectively.



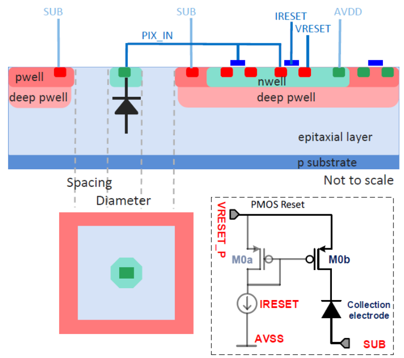


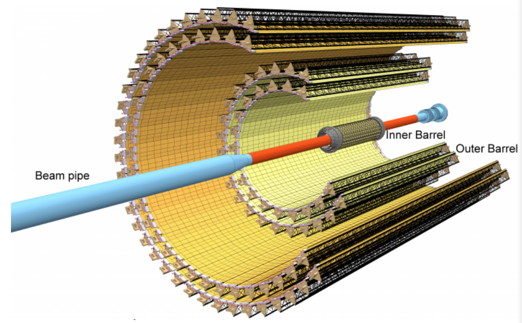
Number of pixels per module	250 x 1536
Pixel size (r-phi, z)	50μm x (60-75) μm
Frame time	20 μs
Material budget per layer	0.15% X_0
Resolution (r-phi, z)	<10μm, < 20μm
Occupancy at 1.8 cm radius	0.2 hits $\mu m^{-2}s^{-1}$
Radiation environment	~1 Mrad/year

DEPFET Technology



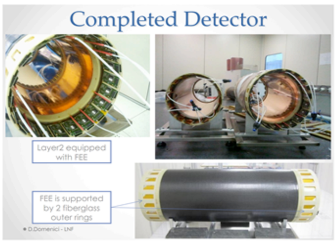
MAPS (ALPIDE)

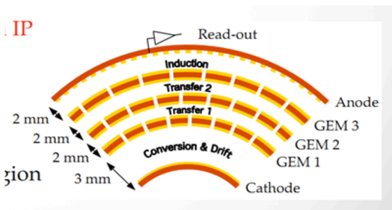




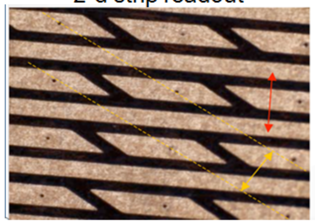
Pixel size: 29*27μm, high resistivity epitaxial, deep PWELL, reverse bias, global shutter (<10 μs), triggered or continuous readout, resolution < 5um, material budget <0.3%X_o

Cylindrical GEM





2-d strip readout

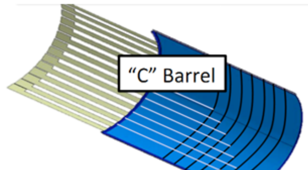


X pitch 650μm → X res 190 μm
V pitch 650μm → Y res 350 μm

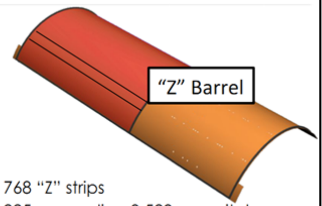
Material Budget	
Total 1 layer	0.49%
Total 4 layers	1.95%

Pixel readout would be required for the innermost layers at HIEPA

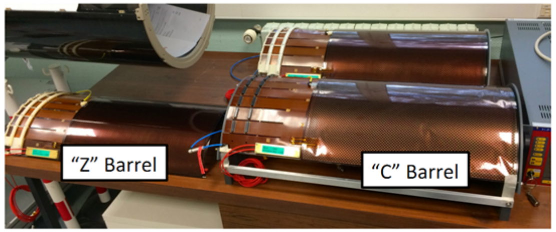
Cylindrical MicroMegas

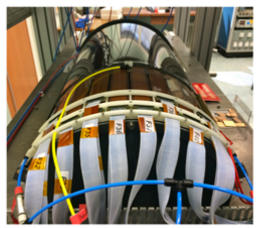


- 1152 "C" strips
- Pitch from 0.67 to 0.33 mm
- 221 mm radius
- PCB thickness 100 μm
- Drift thickness 250 μm
- Drift Field 2.4kV on 3 mm gap



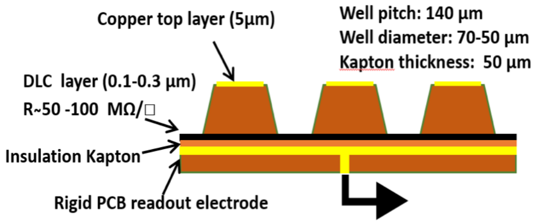
- 768 "Z" strips
- 225 mm radius, 0.529 mm pitch
- PCB thickness 200 μm
- Drift thickness 250 μm
- Drift Field 2.4kV on 3 mm gap
- 0.37% of X0

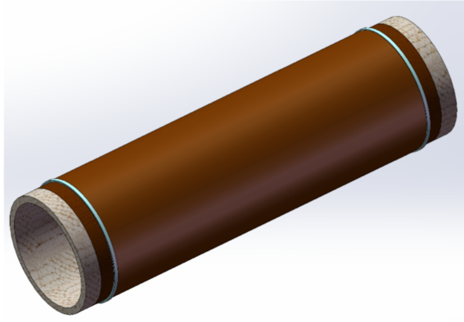




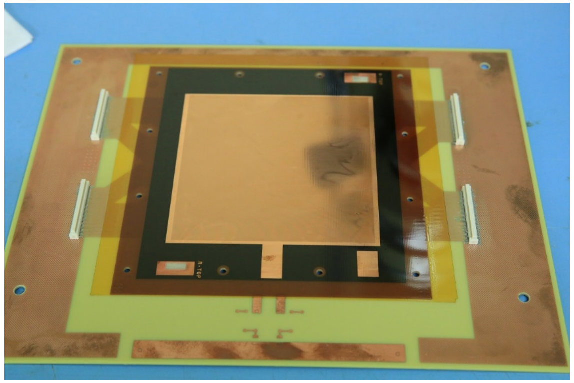
A new MPGD : uRWELL

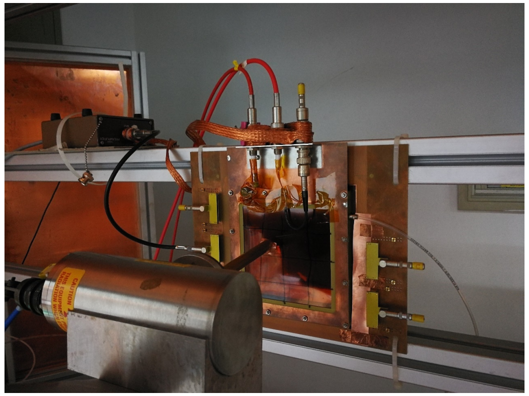
- Very compact, spark protected, simple to assemble, flexible in shapes (rather easy to make a cylindrical detector)

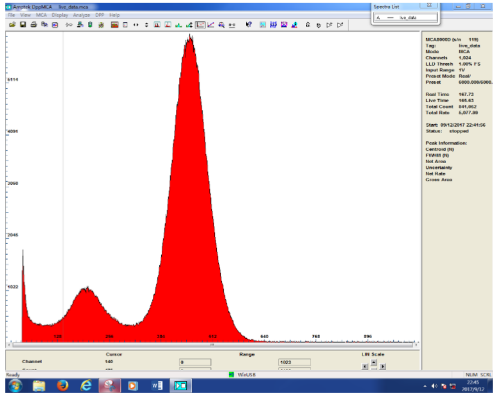




- A possible solution to HIEPA inner tracking. R&D underway at USTC.

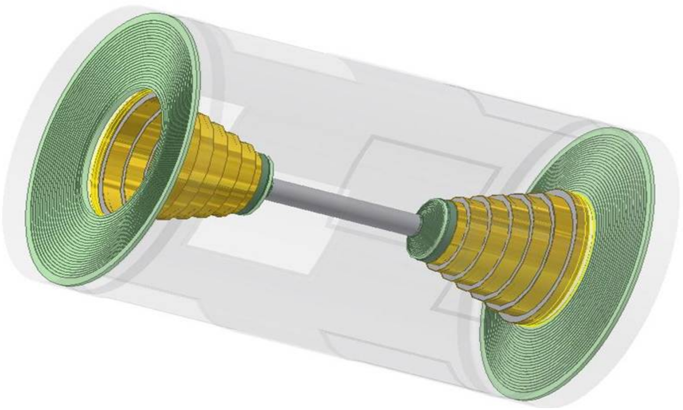






Outer Tracker: A Drift Chamber

- BESIII drift chamber can serve as a good starting point
  - 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



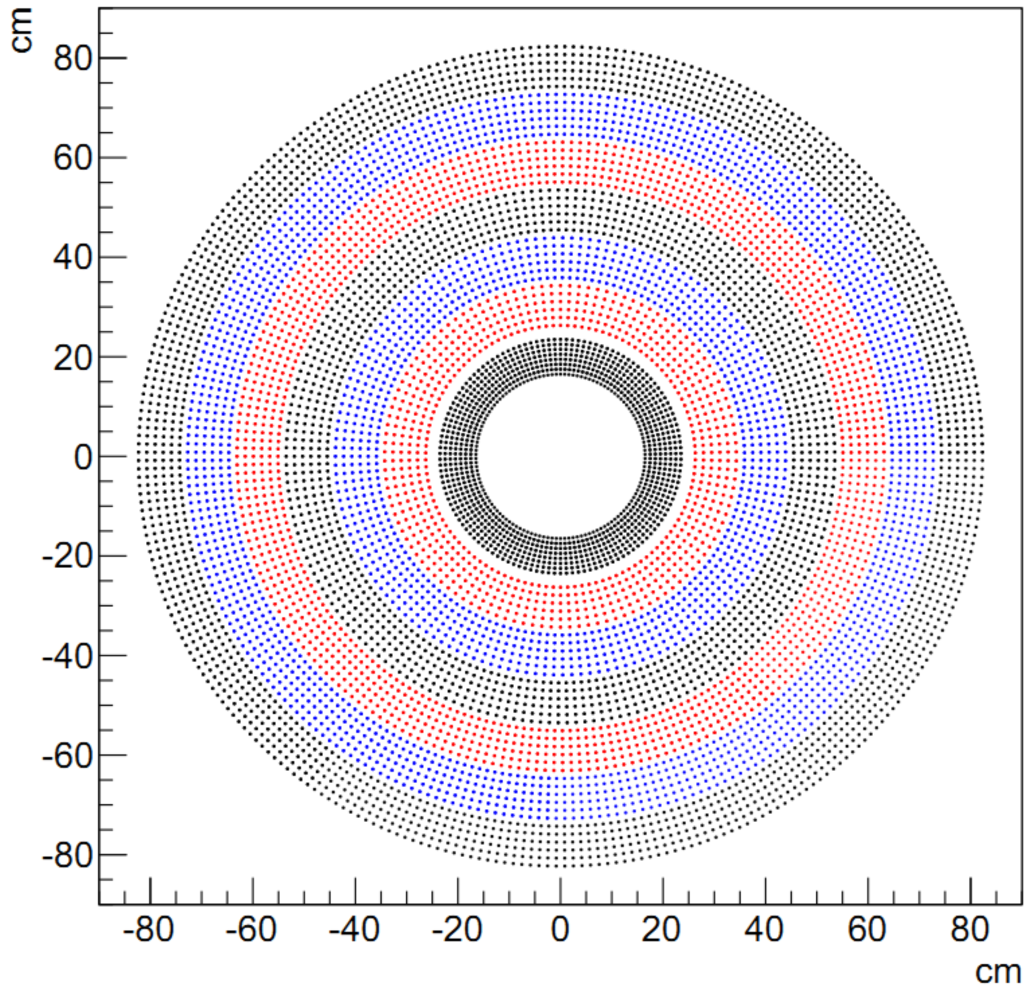
$$\sigma_x \sim 130\mu m$$

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

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

BESIII Drift Chamber

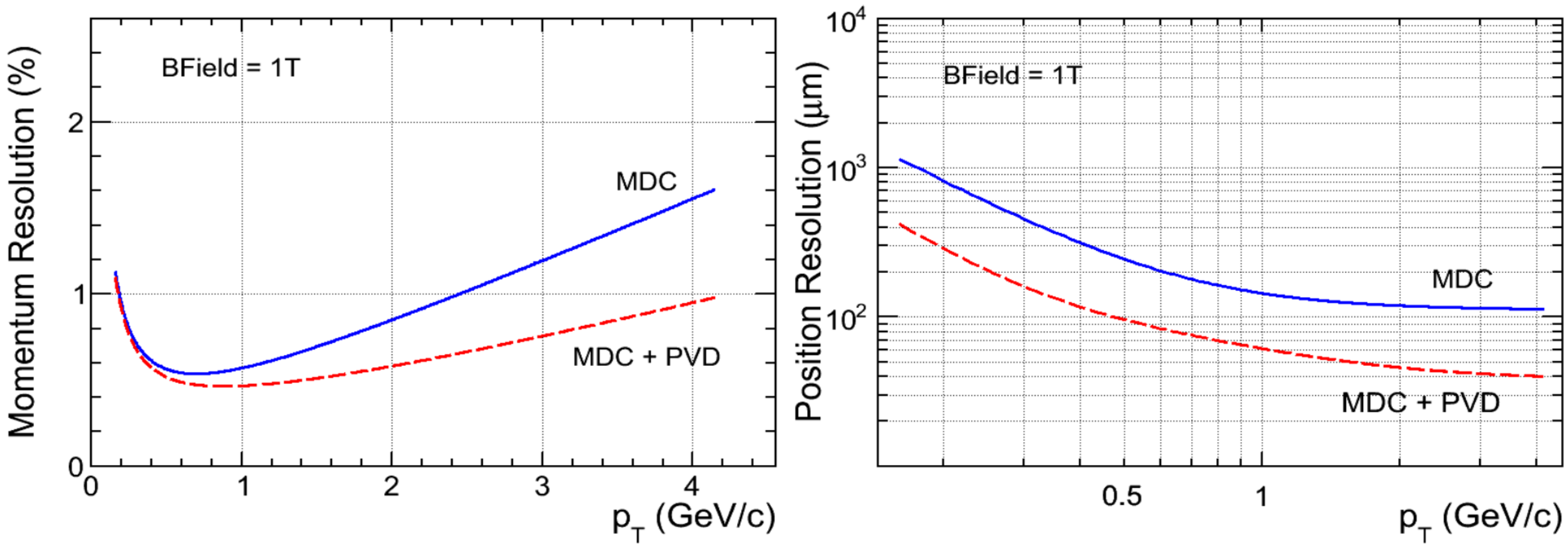
A Drift Chamber for HIEPA



- 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%

Combination of inner and outer trackers

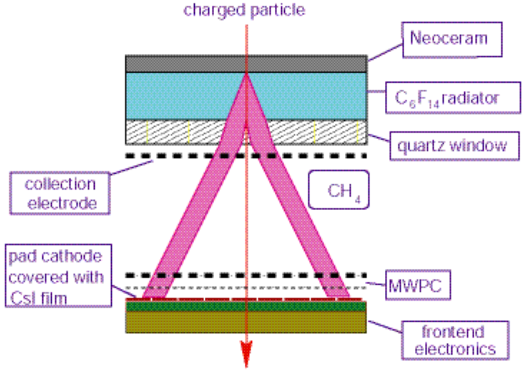
Detector	radius (cm)	material (% X_0)	resolution (μm)
MDC Outer 9-48	23.5-82	0.0045 /layer	130
MDC Inner 1-8	15-22	0.0051 /layer	130
PXD 3rd layer	10	0.15	50
PXD 2 layers	3/6	0.15 /layer	50
Beam pipe	2	0.15	–



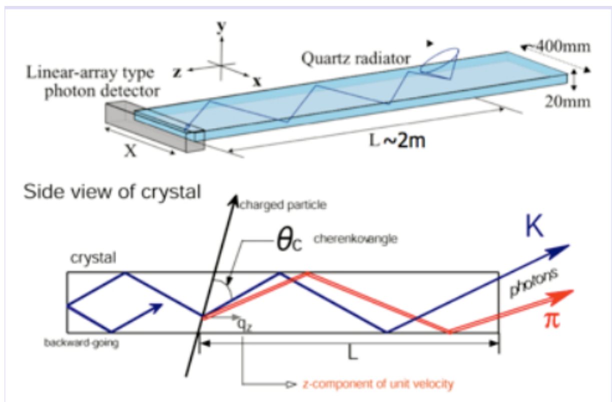
PID Detector

- π/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, …

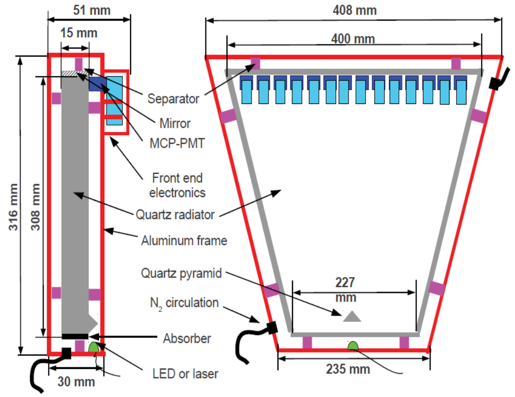
ALICE HMPID



iTOP for BELLE2

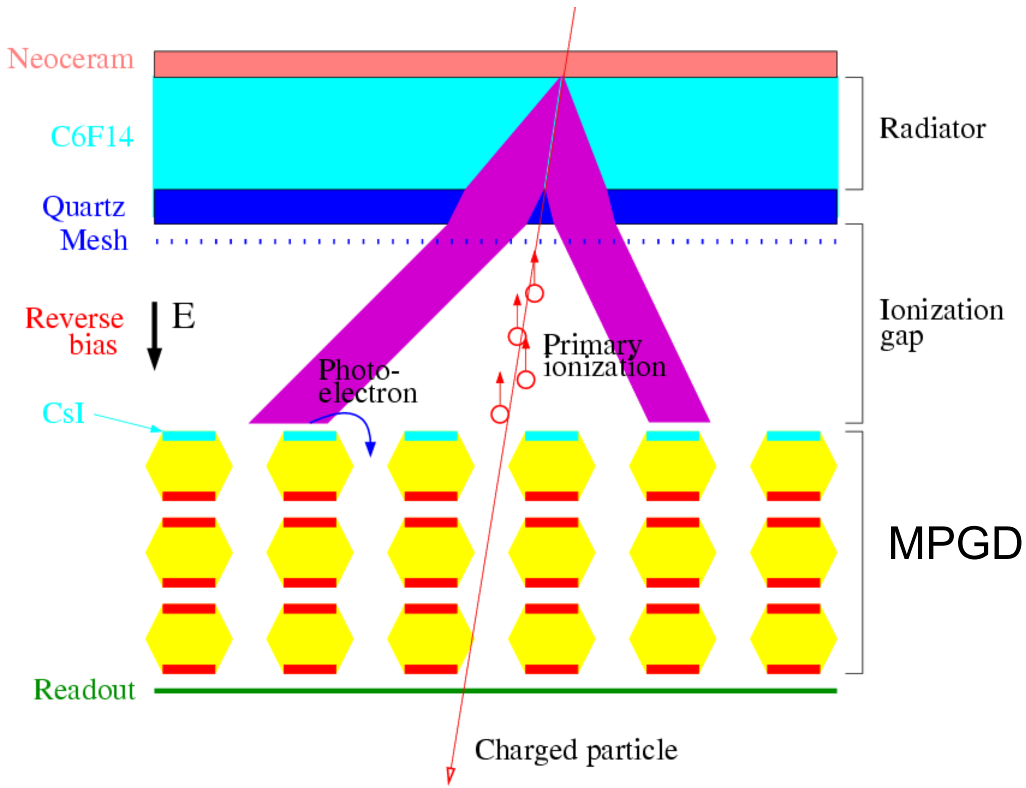


FTOF for superB

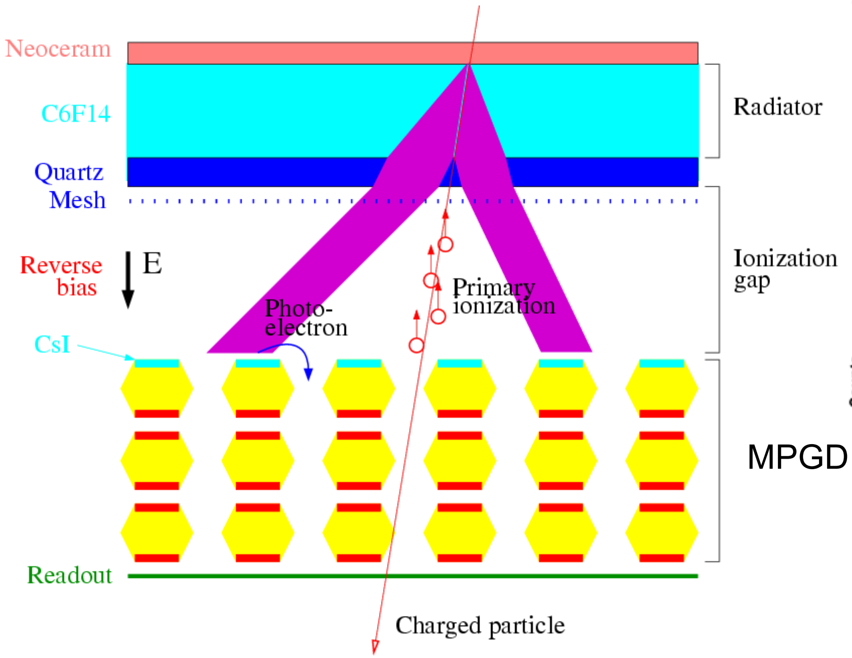


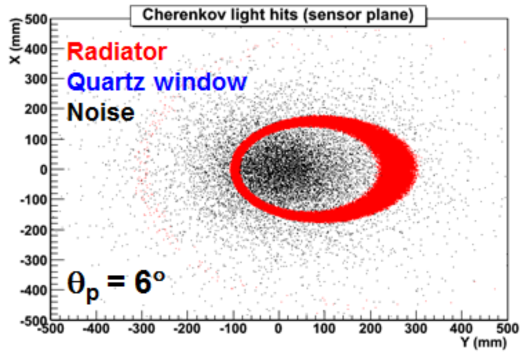
A RICH Design for HIEPA

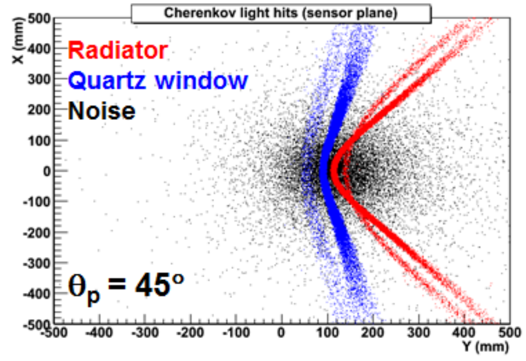
- Proximity focusing RICH, similar to ALICE HMPID design, but with CsI-coated MPGD readout
  - avoid photon feedback
  - less ion backflow to CsI
  - Fast response, high rate capacity
  - Radiation hard
- Proximity gap ~10cm
- Radiator: liquid C_6F_{14}, n~1.3, UV detection

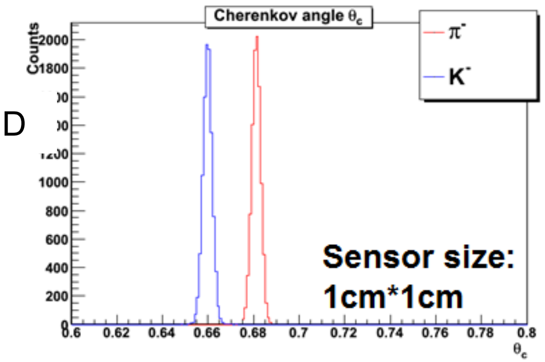


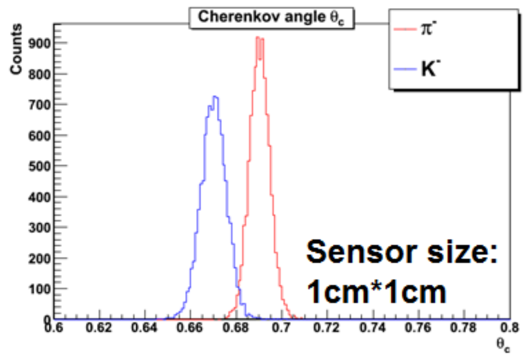
Performance Simulation



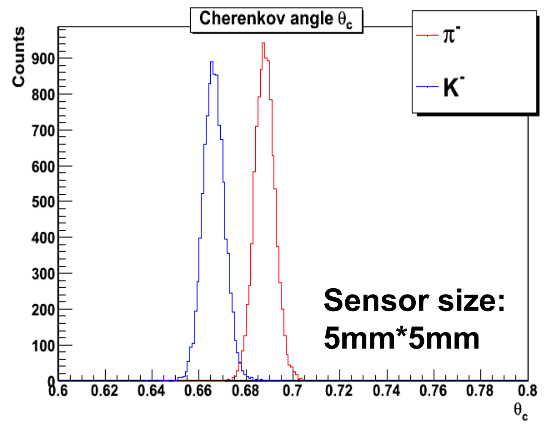






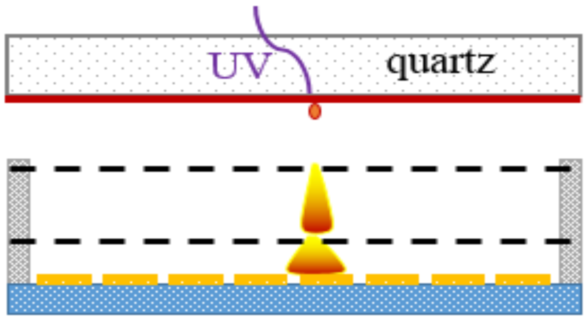


The π/K separation requirement can be met with a RICH detector.

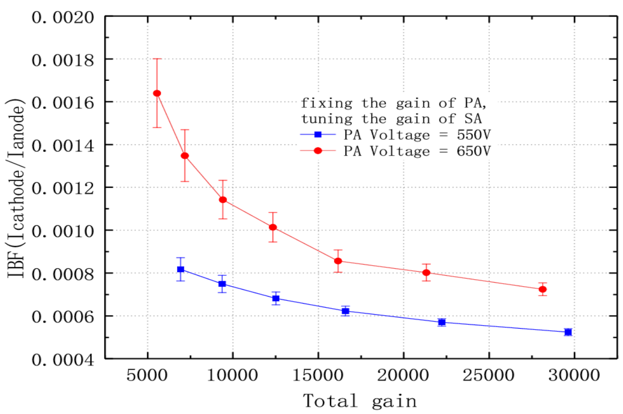


MPGD Photon Detector R&D

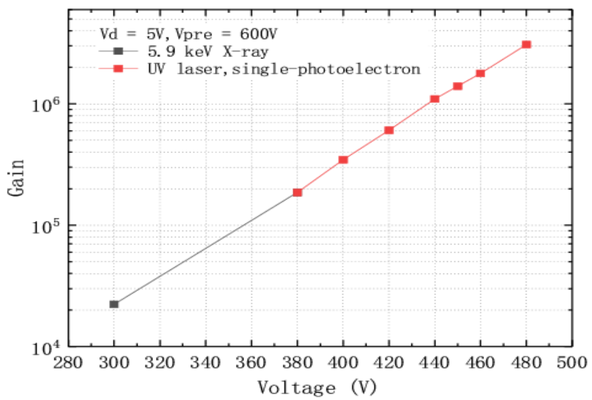
- A double-mesh Mircromegas detector is being developed at USTC
  - High gain and very low ion backflow
  - Very suitable for single photon detection (with a proper photon-electron converter)
  - A promising photon detector option for RICH



IBF ~ 0.05%

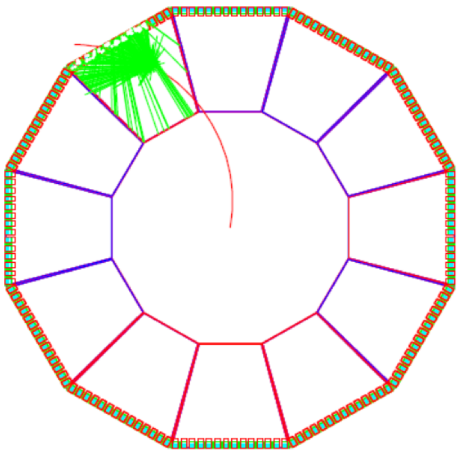


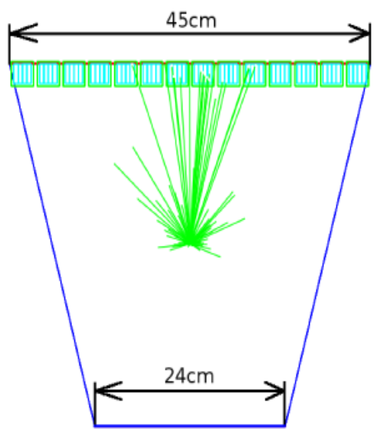
Gain ~ 3×10^6

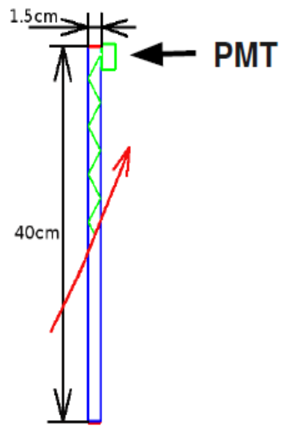


DIRC-like TOF for Endcaps

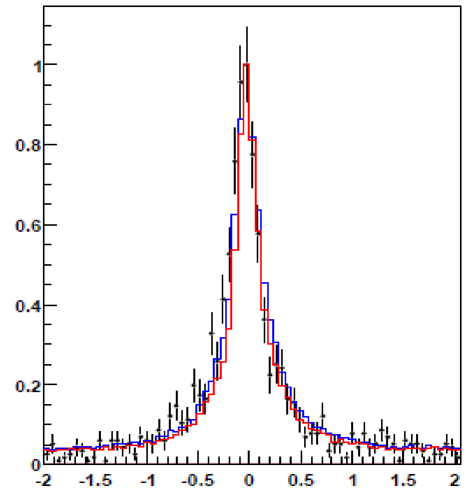
- DIRC-like forward TOF detector (FTOF: quartz + MCP-PMT) was developed at LAL for the SuperB factory project.
- Also an endcap PID option for HIEPA.
  - Flight length ~ 1.4 m for endcaps. ~30ps time resolution is required for pi/K separation to reach 2GeV.







~ 80ps per PE



EMC

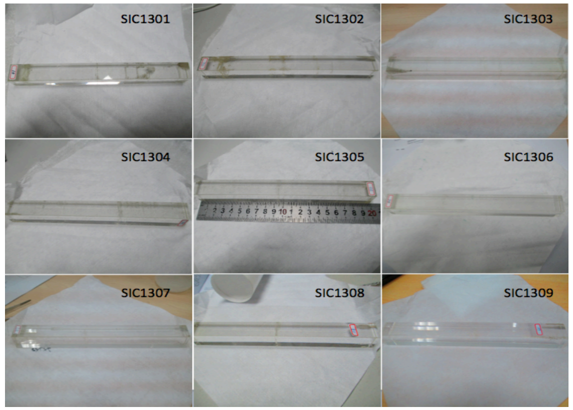
- Main performance requirements
  - High efficiency for low energy γ
  - Good energy resolution in low energy region
  - Good position resolution (for γ)
  - Fast response
  - Radiation hardened
- Technology option
  - Crystal + novel photon detector (e.g. SiPM)

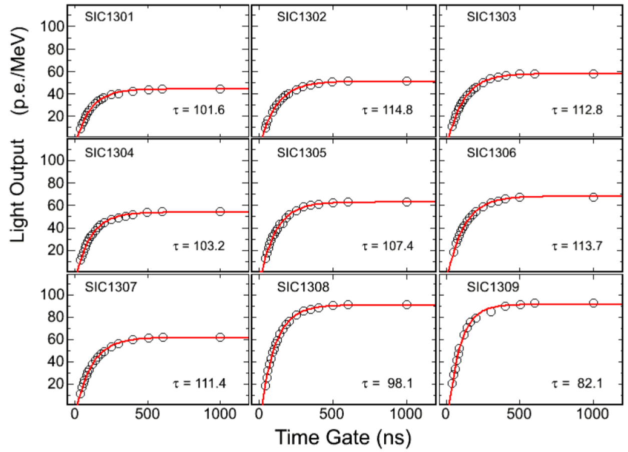
Crystal Options

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)

Different options for barrel and endcaps

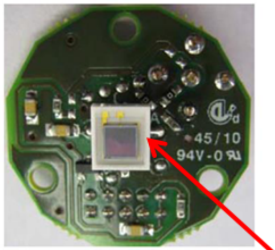
R&D on BSO



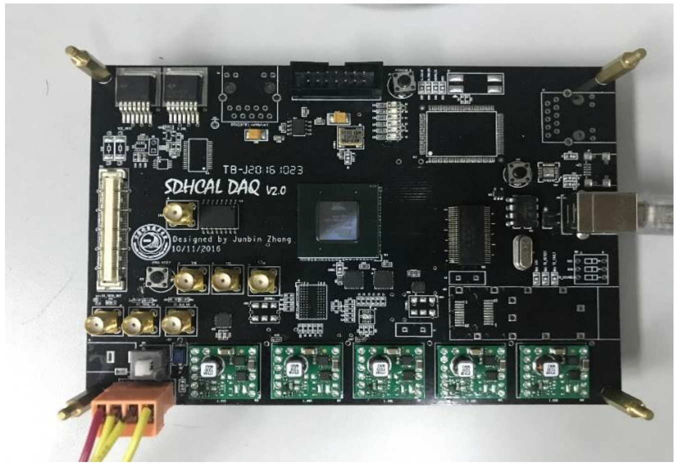


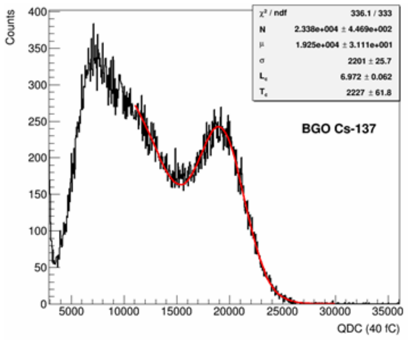
SiPM Technology

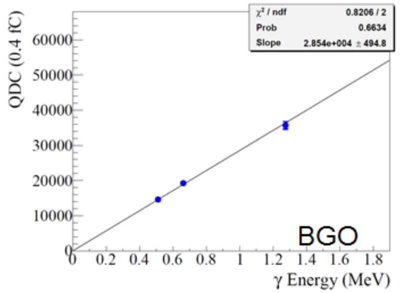
- SiPM: a novel and rapidly-developing photo-sensor technology
  - High gain, low equivalent noise, B-field resistant, good time resolution
- R&D at USTC



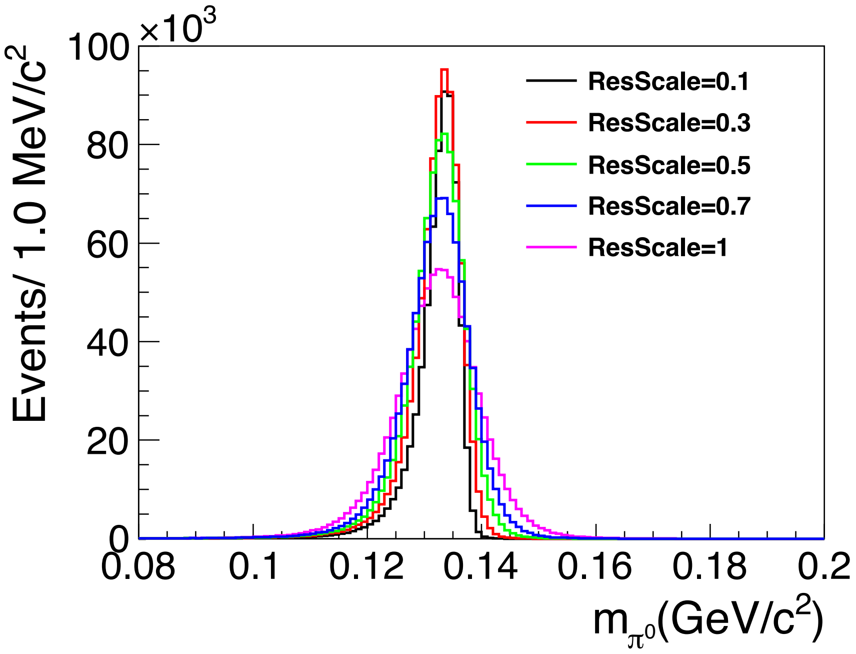
Hamamatsu S10362-33-050C, 3x3 mm^2



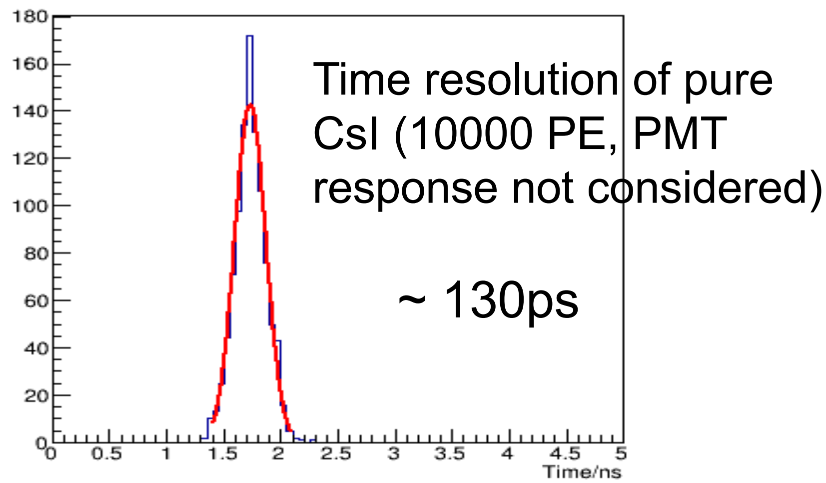




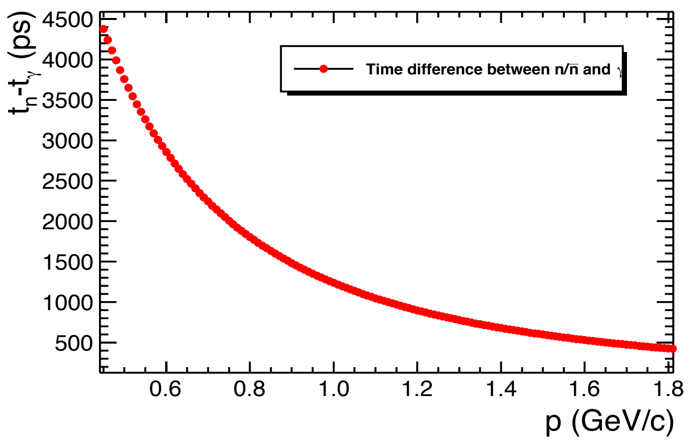
Aspects Other Than Energy



A timing ECAL !



Difference in TOF of n and γ



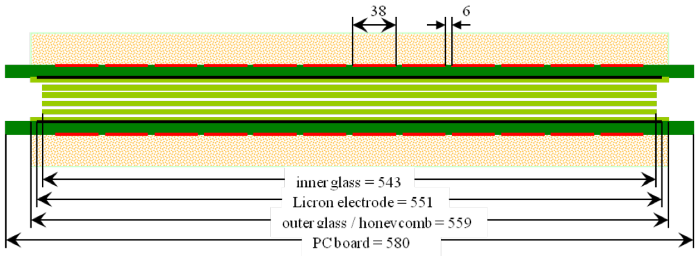
The position resolution of ECAL has a significant impact on object/event reconstruction involving γ .

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

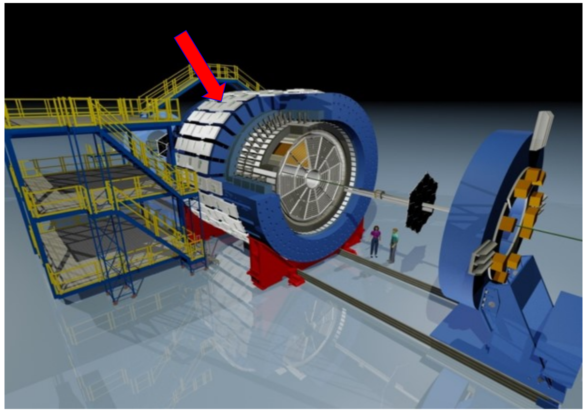
Precise ECAL timing is very useful in suppressing γ background

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
  - Rate capability a concern in certain detector regions



MTD at STAR



Long-Strip MRPC Module

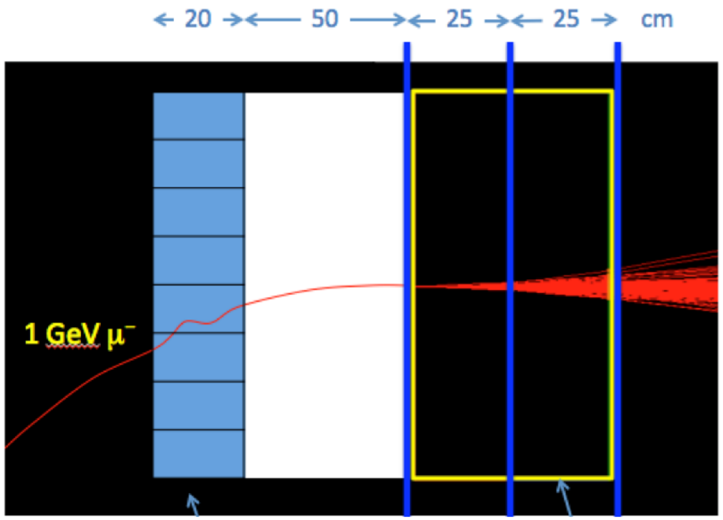
- Active area: 87 x 52 cm^2
- Read out strip: 87 cm x 3.8 cm
- Gas gaps: 0.25 mm x 5

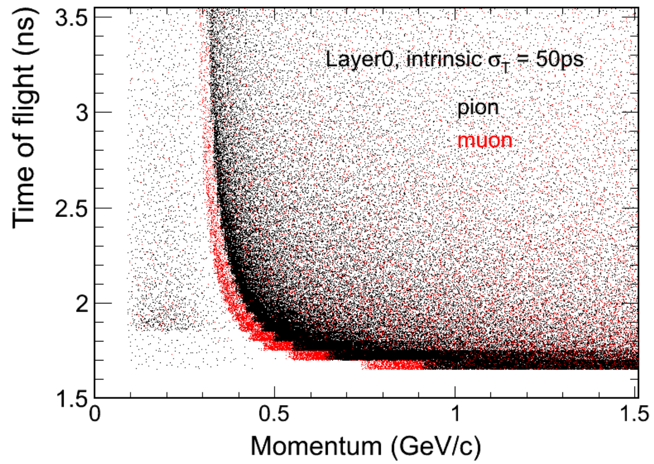
Performance:

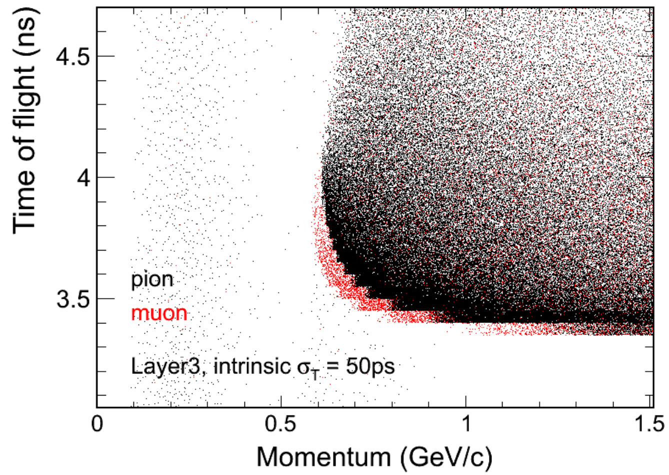
- Efficiency: > 98%
- Time resolution: < 80 ps
- Spatial resolution: 0.6 cm

Low Momentum μ/π Separation

- A few MRPC layers for precise timing





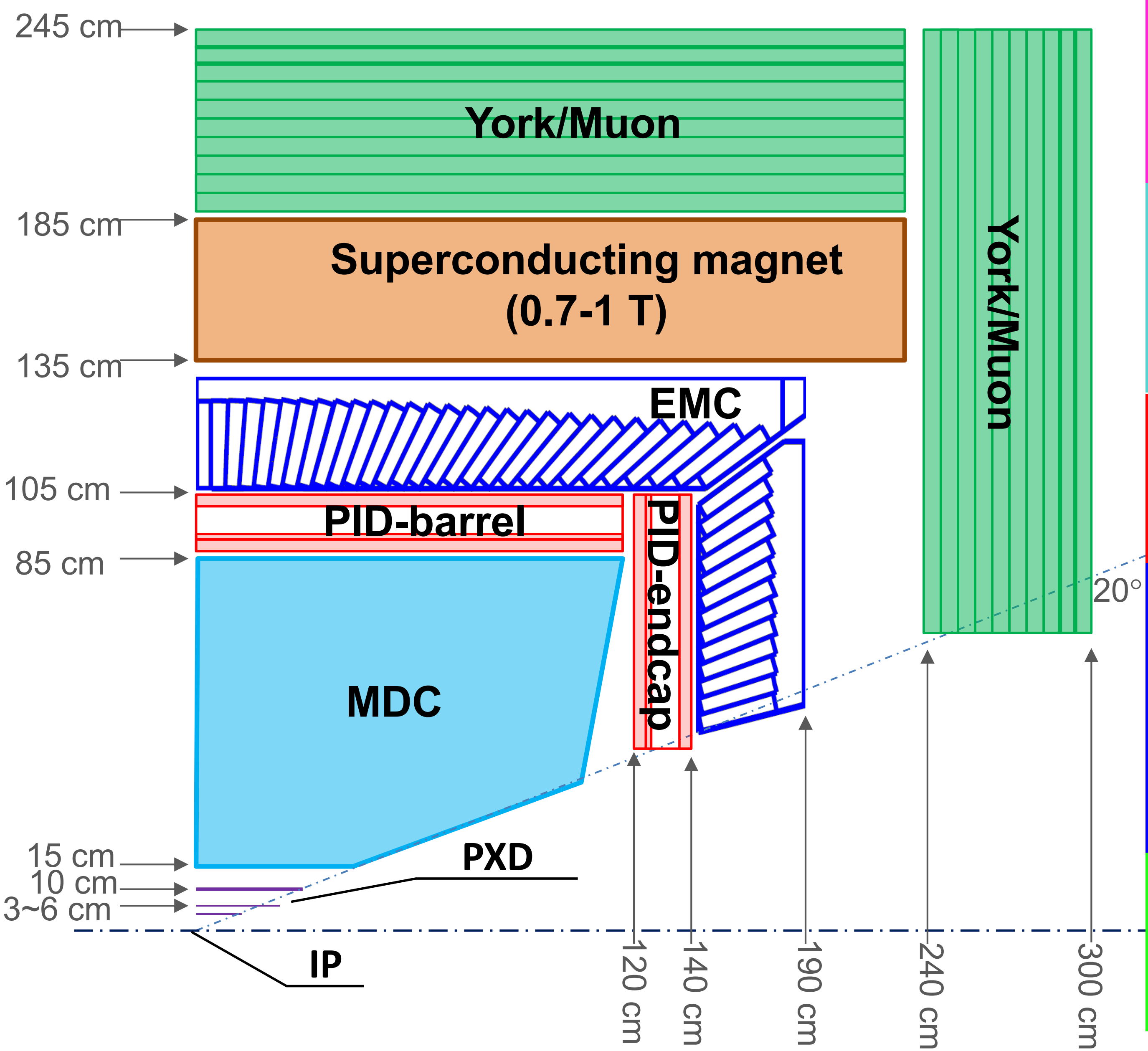


  - Below 400MeV, μ and π can be well separated
  - Below 300MeV, μ can't reach iron yoke

Design Consideration

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

Conceptual Detector Layout



PXD
- ~0.15%X_0 / layer
- σ_{xy}~50 μm

MDC
- σ_{xy}<~130 μm
- σ_p/p ~ 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	σ_E (%)
Barrel:	2
Endcap:	4

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

Summary

- Have presented preliminary considerations on the design of a detector system at HIEPA
  - Inner tracker: low mass silicon or MPGD
  - Outer tracker: small-cell drift chamber with helium gas
  - PID: RICH, or DIRC-like TOF for endcaps
  - EMC: fast crystal + SiPM (preferably with timing capability)
  - MUD: MRPC timing layers + RPC layers
- See previous slide for expected/required detector performance