Post-BEPCII in China
HIEPA

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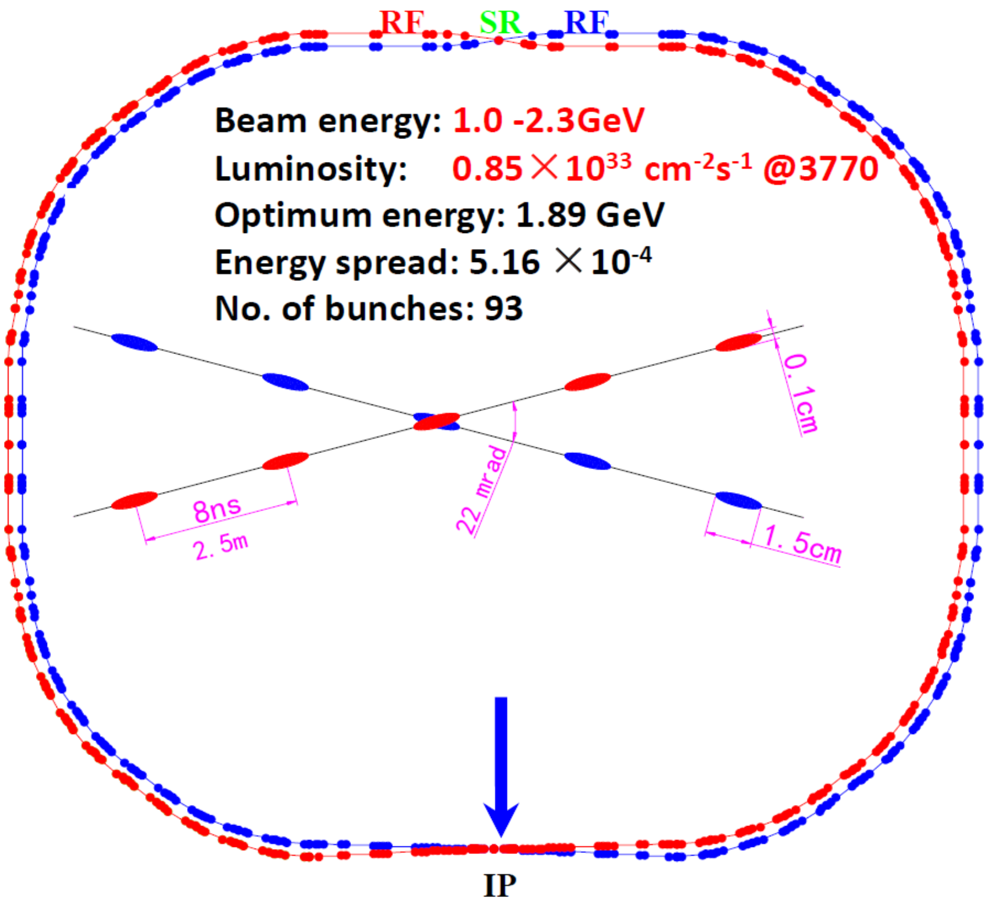
Beijing Electron Positron Collider

- 1989-2004: BEPC/BES(II) $\rightarrow L_{peak} = 1.0\times10^{31}\ cm^{-2}s^{-1}$
- 2004-2008: BEPCII/BESIII upgrade
- 2008: BEPCII/BESIII commissioning
- 2009-now: BEPCII/BESIII physics running $\rightarrow L_{peak} = 0.85\times10^{33}\ cm^{-2}s^{-1}$

BEPCII

- A major upgrade to BEPC
  - double-ring, large crossing-angle, super-conducting RF …
  - luminosity increase ~ two orders of magnitude



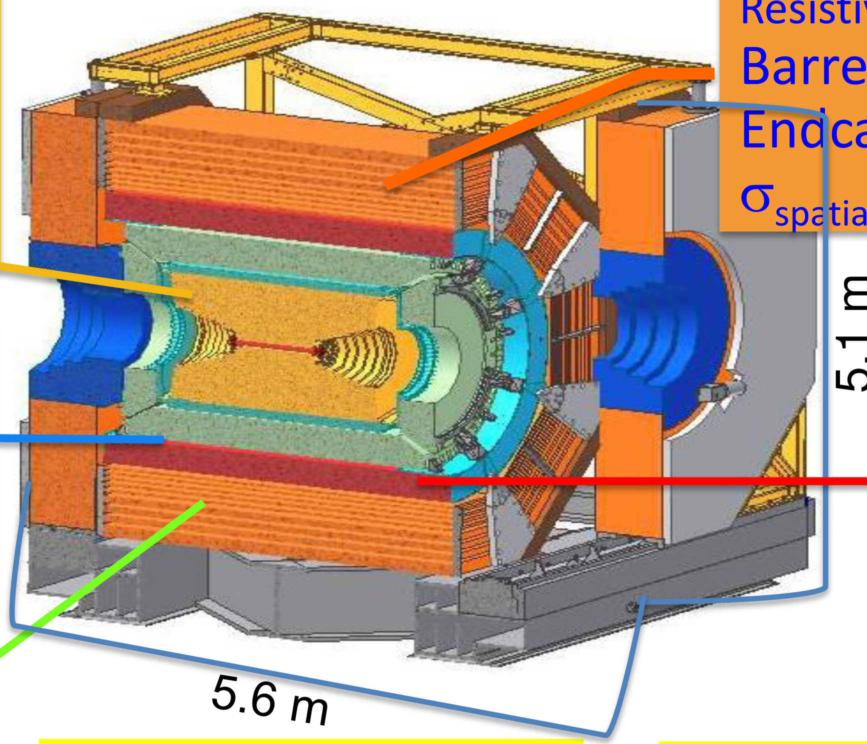
The BESIII Detector

- A high-performance detector operating in the τ-c energy regime

Drift chamber (MDC)
Small cell, 43 layer
Gas He/C_3H_8=40/60
σ_{xy}=130 μm, dE/dx~6%
σ_p/p = 0.5% @ 1 GeV

Time-of-flight (TOF)
Plastic scintillator
σ_T(barrel): 90 ps
σ_T(endcap): 110 ps

ECAL calorimeter
CsI(Tl): L=28 cm (15X_0)
Energy range: 0.02-2GeV
$\sigma_E/\sqrt{E}$ = 2.5% @ 1GeV
σ_l = 0.5-0.7 cm/$\sqrt{E}$



Muon counter
Resistive plate chamber
Barrel: 9 layers
Endcaps: 8 layers
$\sigma_{spatial}$: 1.4-1.7 cm

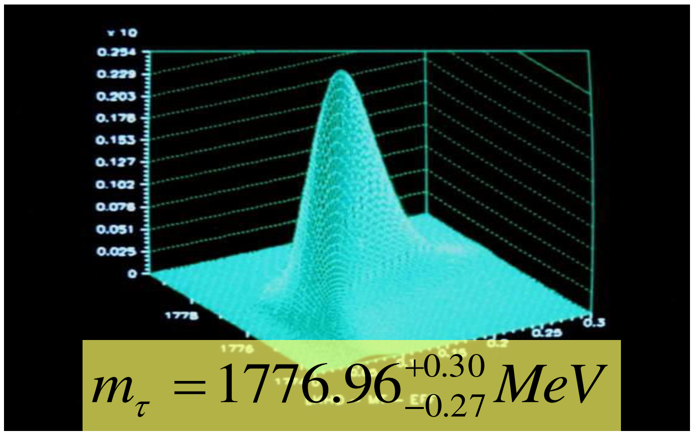
1T super-conducting magnet

RO channels: 10^4
Event rate: 4 kHz
Data size: 50 MB/s

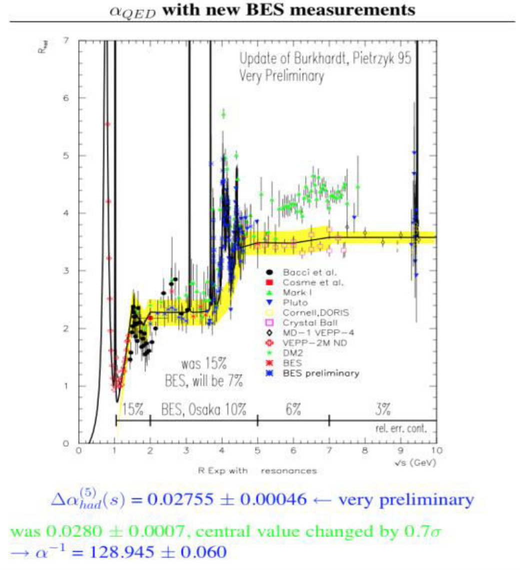
Grid computing
CPU: 3200 core
Storage: 2.2 pB

Selected Achievements from BEPC(II)/BES(II)(III)

τ mass measurement



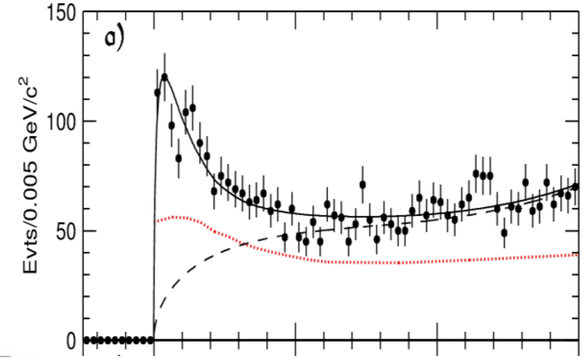
R value measurement



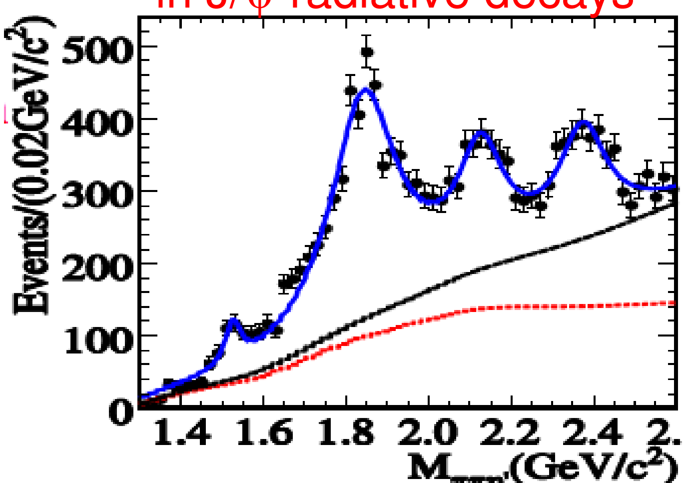
Near threshold pp enhancement

X(1835) MASS

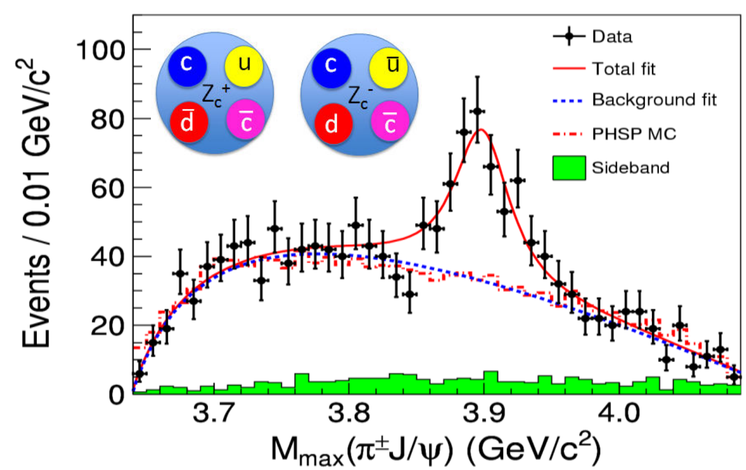
VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1833.7± 6.1± 2.7	264	ABLIKIM	05R	BES2	$J/\psi \rightarrow \gamma\pi^+\pi^-\eta'$



High mass resonances in J/ψ radiative decays



Zc(3900)

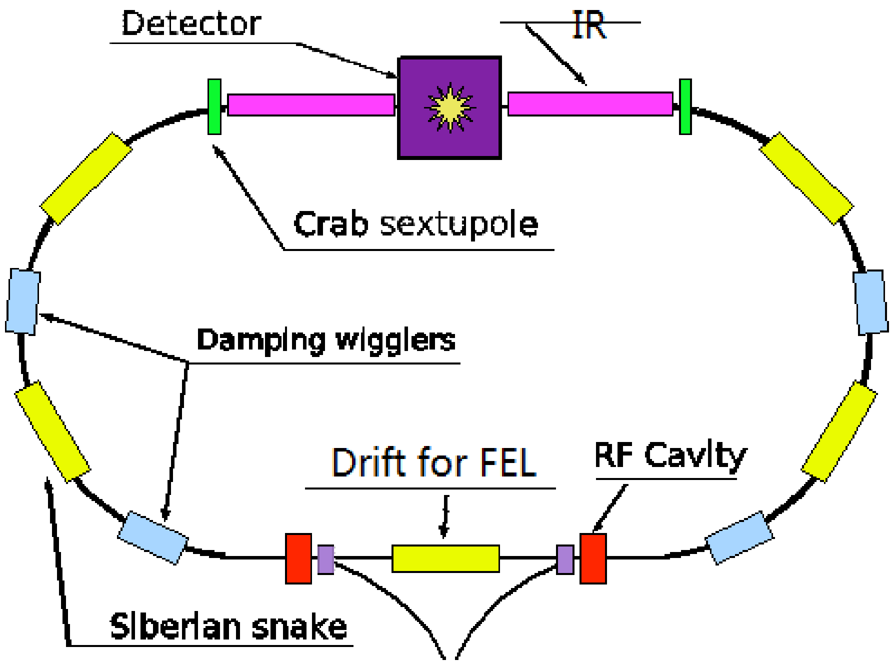


Post-BEPC2

- BEPC made China's mark in high energy physics in the world. BEPCII, as a successor, went on to establish China's lead in τ-c physics.
  - The two projects have been a big success together, with many world-class achievements made.
- Shall we continue with such a success after BEPCII?
  - **YES** !

High Intensity Electron Positron Accelerator

- **HIEPA** : a post-BEPCII HEP project being envisaged in China.
  - To be an ultimate **τ-c** machine, and moreover, a multifunctional and multidisciplinary complex, well beyond BEPCII.



- E_{cm} = 2-7 GeV, L=(0.5-1)×10^{35} $cm^{-2}s^{-1}$ @4 GeV
- ~650m double-ring, single beam polarized
- Synchrotron radiation
- Potential for FEL

HIEPA Parameters

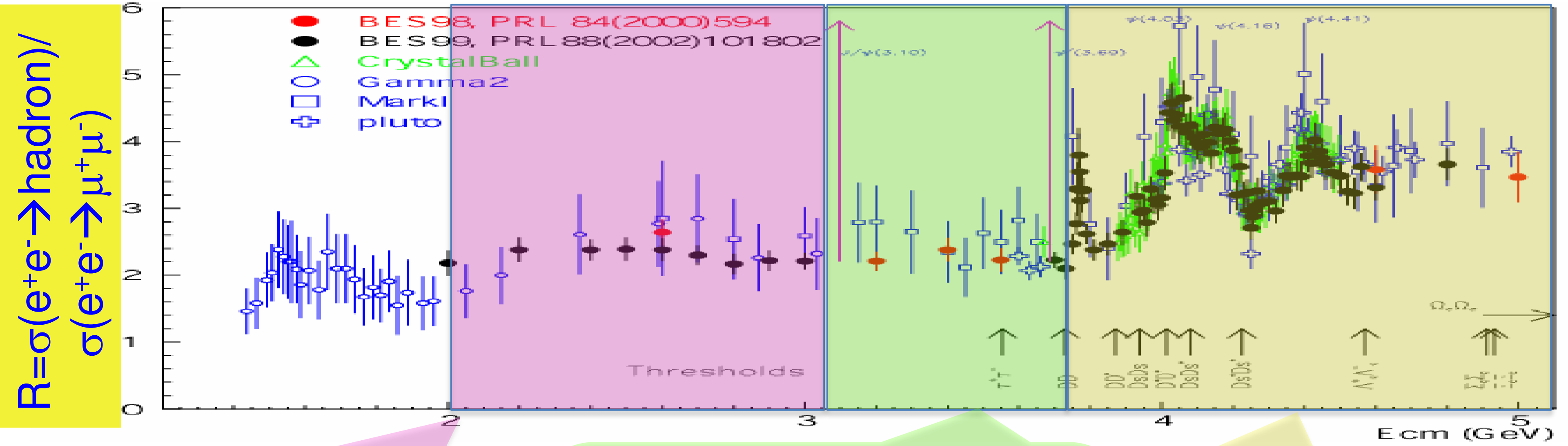
HIEPA技术指标	
束流优化**能量**	2 GeV
对撞质心能量	2-7GeV**可**调，优化4GeV
束流流强	2A
对撞亮度	> 0.5 ×10^{35}/(cm^2·s)
束流发射度	0.1nm·rad
光源亮度	10^{17}~10^{21} Ph./(s mm^2 mrad^2 0.1%BW)
辐射类型	**弯**铁辐射、插入元件辐射
寿命	Top-up
轨道周长	648 m
高频频率	500 MHz
谐波数	1080
聚焦结构类型	7BA，组合型
周期数	24
直线节长度	5m×12，9m×10，81m×2（**其中一个**为对撞区）

A super τ-charm factory！

Critical Aspects in HIEPA R&D

- Physics design studies of very-high-luminosity circular e^+e^- accelerators
- Injection technology
- Super-conducting magnets and RF cavities
- Beam polarization technology
- Insertion devices
- Vacuum technology
- High-resolution beam monitoring
- ……

Physics in the τ-c Energy Region



- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ leptons

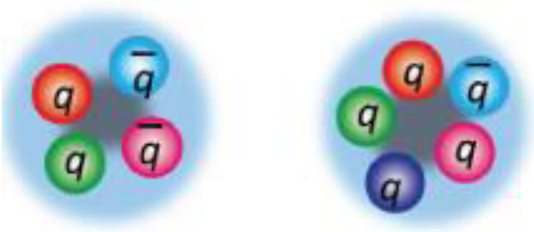
- XYZ particles
- Physics with D mesons
- f_D and f_{Ds}
- D^0-$\overline{D}^0$ mixing
- Charm baryons

R scan

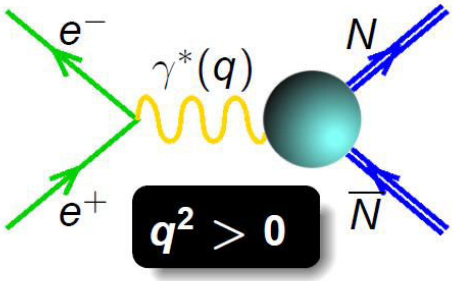
- **Precision $\Delta\alpha_{QED}$, a_μ, charm quark mass extraction.**
- **Hadron form factor(nucleon, Λ, π).**

Highlights in HIEPA Physics Program

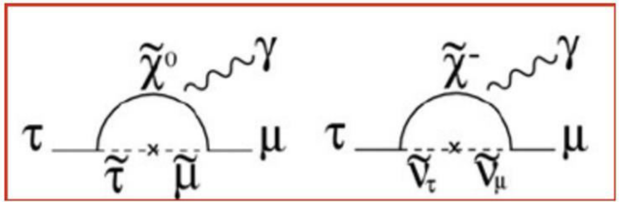
- Search for new forms of hadrons and studies of their properties.



- Measurements and studies of the nucleon/hadron electromagnetic form factors (NEFFs) and QCD study in non-perturbative region.



- Search for new physics beyond the SM

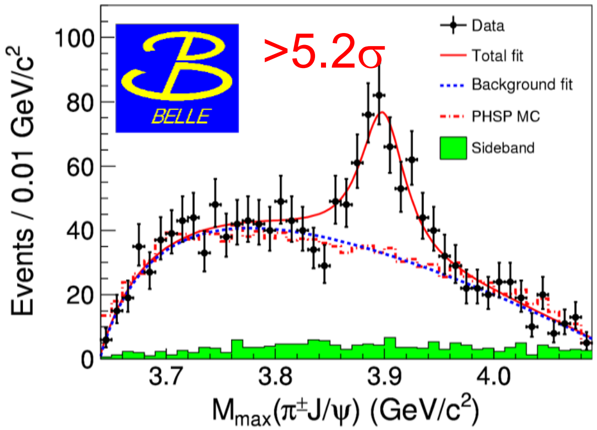


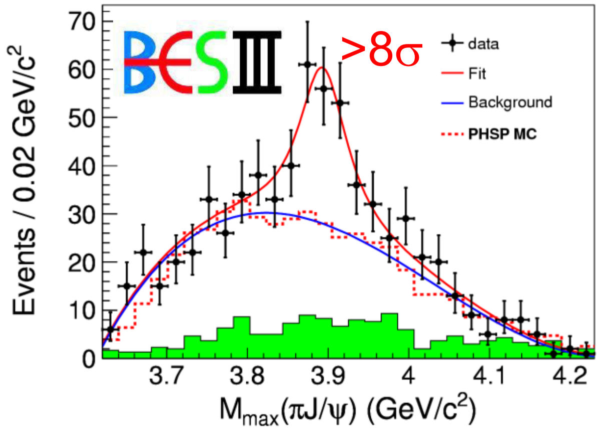
- ……

Physics Potential of HIEPA

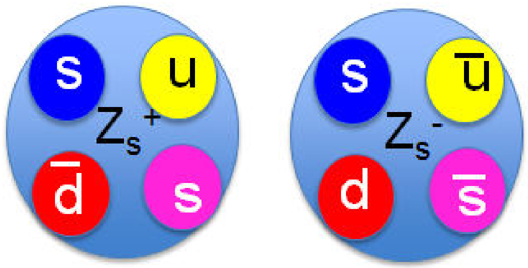
Zc(3900) significance

10 years @BELLE ~ 1 month @BESIII ~ < 1 day @HIEPA



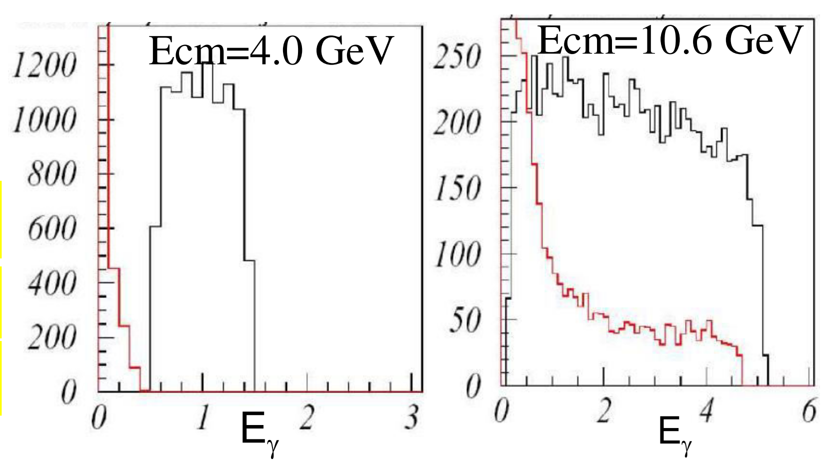


Zs?@HIEPA



$\tau \to \mu\gamma$

UL (STCF 1-2 years @ HIEPA) ≤ UL (12-15 years @ super-B)



G_{EM} Measurements

Babar(~5 years): 469 fb^{-1} , 10-24%

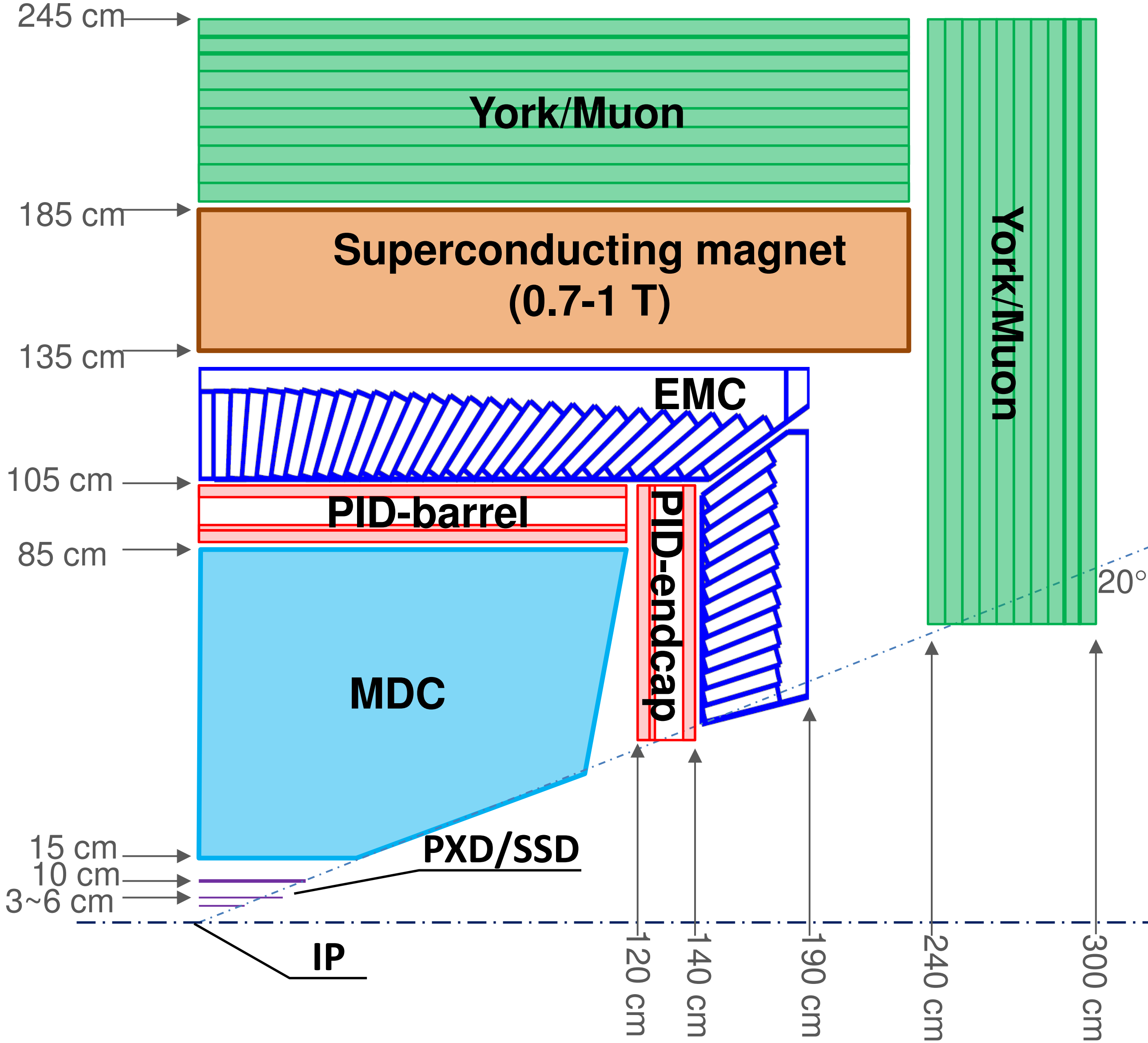
BESIII(~4 months): 0.4 fb^{-1} , 10%

Nsig	$\delta R_{EM}/R_{EM}$	$\delta\sigma/\sigma$	L(pb^{-1})	comment
3881	9.5%	1.6%	16.630	BESIII expected
389898	0.96%	0.16%	1670.69	HIEPA (~1 week)

Detector Requirements for HIEPA

- **Overall requirements**
  - Efficient and fast triggering
  - Efficient and precise reconstruction of exclusive final states
  - High rate capability and radiation tolerance, particularly in endcaps
- **Vertexing (or inner tracking)**
  - Vertexing not very critical for HIEPA, more to combine with a central tracker for tracking (inner tracking)
- **Central tracking**
  - large acceptance, low mass, high efficiency (down to p<~0.1 GeV) and high resolution (p <~ 1GeV)
- **PID**
  - π/K separation up to 2GeV, compact and low mass
- **e/γ measurement**
  - Good energy and position resolution in 0.02-2 GeV
- **μ detection**
  - Low momentum threshold (p<~0.4GeV)
  - high μ efficiency and π suppression power

Conceptual Detector Layout



PXD

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

MDC

- σ_{xy}=130 μm
- σ_p/p =0.5% at 1 GeV
- dE/dx<7%

PID

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

EMC

Energy range: 0.02-2GeV

At 1 GeV	σ_E (%)
Barrel(Cs(I):	2
Endcap (Cs):	4

MUD

- μ/π suppression power >10

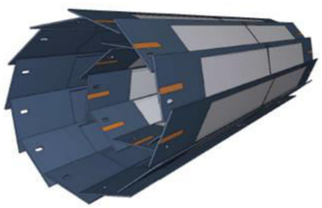
Inner & Outer Trackers

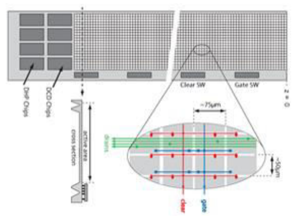
- Dominant factor in tracking: multiple scattering, so driving force in design of tracking system: low mass.
- Special design is required for inner tracking to cope with the very high level of radiation close to IP. So an inner-outer separate design is optimal.
- Detector technology options
  - Inner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

Inner Tracker Technologies

DEPFET

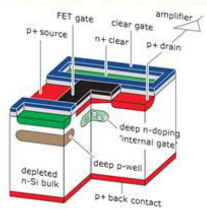
- Two layers of PXD: 1.8 cm and 2.2 cm in radius, consisting of 8 and 12 modules for innermost layer and the second, respectively.





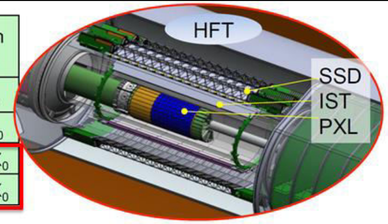
Number of pixels per module	250 x 1536
Pixel size (r-phi, z)	50µm x (60-75) µm
Frame time	20 µs
Material budget per layer	0.15% X_0
Resolution (r-phi, z)	<10µm, < 20µm
Occupancy at 1.8 cm radius	0.2 hits $\mu m^{-2} s^{-1}$
Radiation environment	~1 Mrad/year

DEPFET Technology



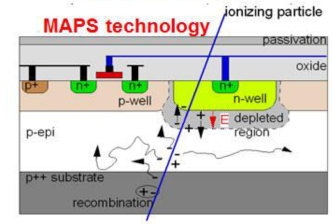
MAPS

Detector	Radius (cm)	Hit Resolution R/φ - Z (µm - µm)	Radiation length
SSD	22	30 / 860	1.5 %X_0
IST	14	170 / 1800	1.32 %X_0
PIXEL	8	12 / 12	~0.37 %X_0
	2.6	12 / 12	~0.37 %X_0



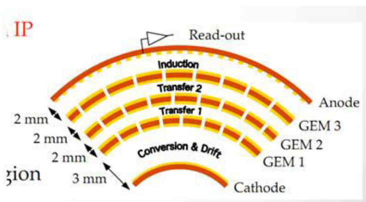
- SSD: single-layer double-side strips
- IST: one layer of strips
- **PIXEL**
  - MAPS technique : sensor and signal processing integrated → low material, low power consumption
  - Integration time: 200µs
  - pixel pitch: 20 µm *20µm
  - 2cm*20cm ladder, 10 ladder in total
  - double layers

MAPS technology

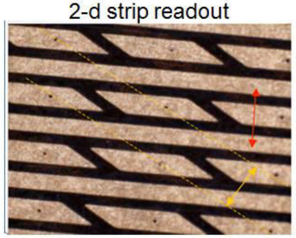


A prototype pixel ladder

Cylindrical GEM



2-d strip readout



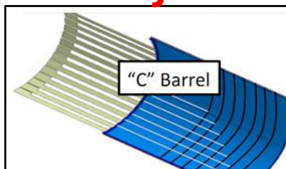
X pitch 650µm → X res 190 µm

V pitch 650µm → Y res 350 µm

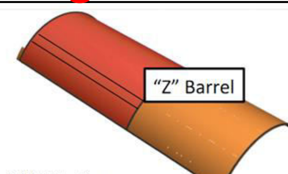
Material Budget	
Total 1 layer	0.49%
Total 4 layers	1.95%

Pixel readout would be required for the innermost layers at HIEPA

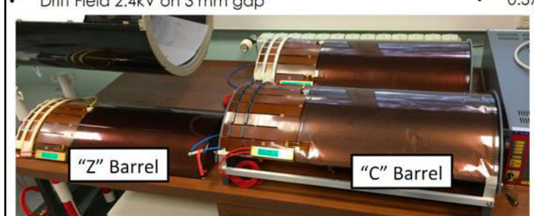
Cylindrical MicroMegas



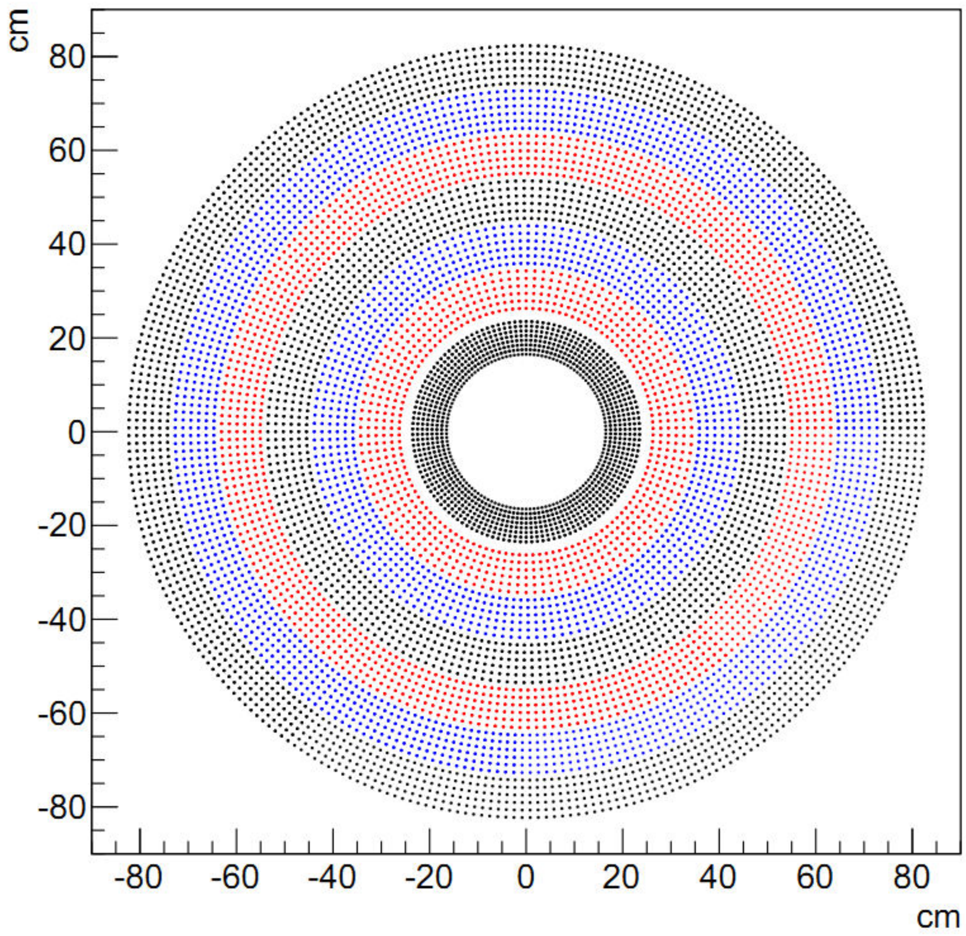
- 1152 "C" strips
- Pitch from 0.67 to 0.33 mm
- 221 mm radius
- PCB thickness 100 µm
- Drift thickness 250 µm
- Drift Field 2.4kV on 3 mm gap



- 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



Outer Tracker: A Drift Chamber

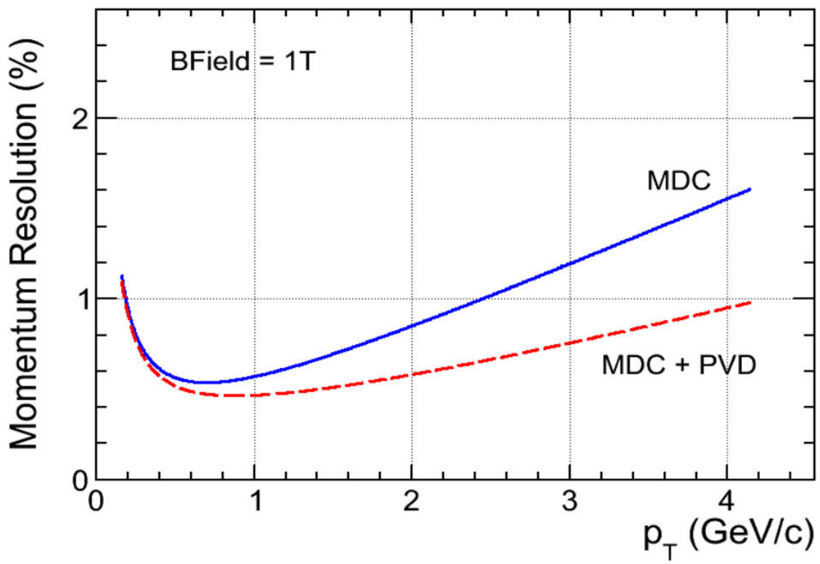


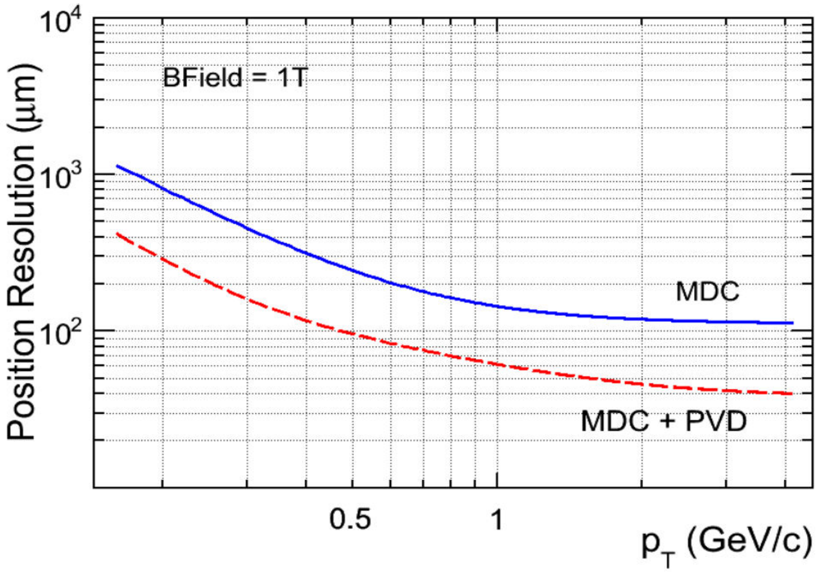
- Rin = 15 cm
- Rout = 85 cm
- L = 2.4 m
- B = 1 T
- He/C_2H_6 (60/40)
- Cell size =1.0cm(inner),1.6cm(outer)
- Sense wire: 20 um W
- Field wire: 110 um Al
- # of layers = 44
- Layer configuration: 8A-6U-6V-6A-6U-6V-6A
- Carbon fiber for both inner and outer walls
- Expected spatial resolution: <130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

Combination of inner and outer trackers

MDC + Belle-II PXD

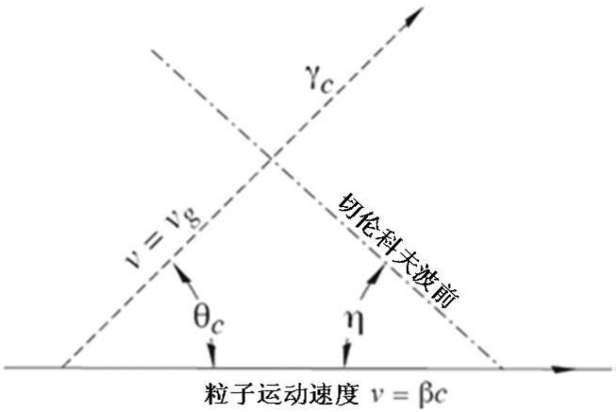
Detector	radius (cm)	material (%X_0)	resolution (μm)
MDC Outer 9-48	23.5-82	0.0045 /layer	130
MDC Inner 1-8	15-22	0.0051 /layer	130
PXD 3rd layer	10	0.15	50
PXD 2 layers	3/6	0.15 /layer	50
Beam pipe	2	0.15	–





PID Detector

- π/K separation up to 2GeV.
  - Very tough for TOF. Cherenkov technology is favorable
  - Low p region covered by trackers through dE/dx
- Compact and low mass (<$0.5X_0$)
- Detector types
  - Threshold Cherenkov detectors
  - Imaging Cherenkov detectors
    - RICH (large momentum range)
    - DIRC (rather large volume for readout)
    - TOP (very compact, also very "delicate")

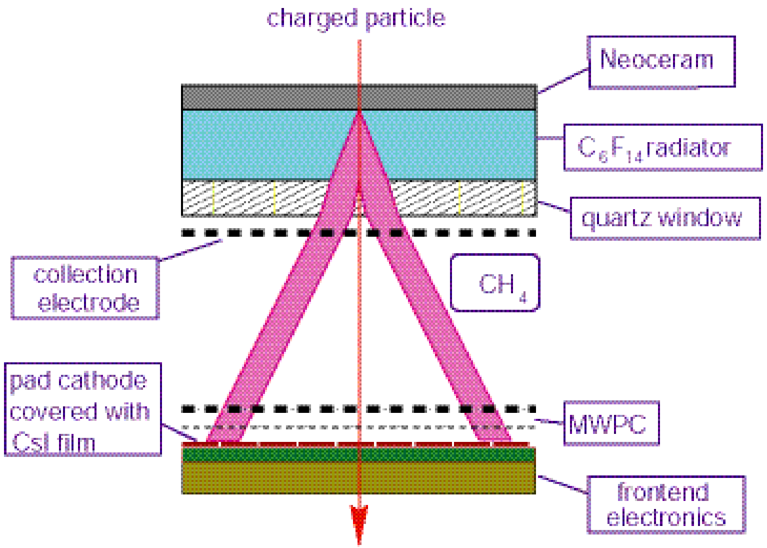


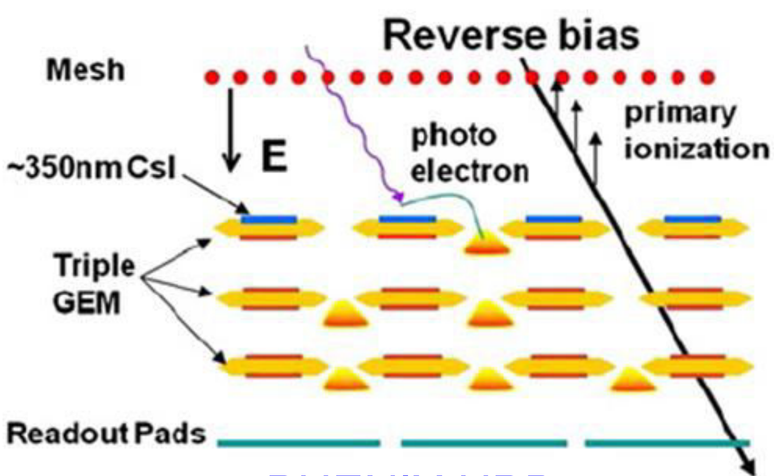
$$\cos\theta_c = \frac{1}{\beta n}$$

Baseline PID Design

- RICH: 0.8<p<2GeV
- Detector layout similar to ALICE HMPID.
- Readout similar to PHENIX HBD (GEM+CsI) Radiator: liquid C_6F_{14}, n~ 1.3
- Immune to B field. Same detector structure in barrel and endcaps.

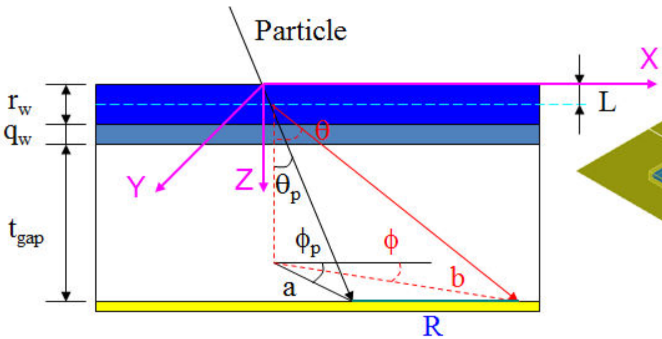
ALICE HMPID

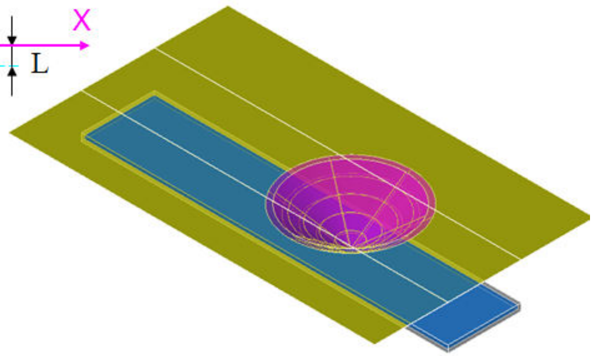




PHENIX HBD

Geant4 Simulation





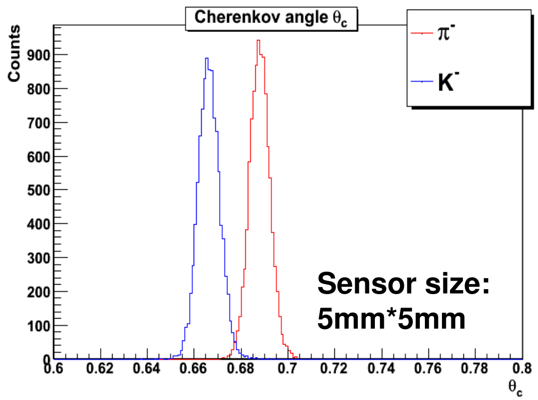
$$\tan\phi = \frac{y - L\tan\theta_p \sin\phi_p}{x - L\tan\theta_p\cos\phi_p}$$

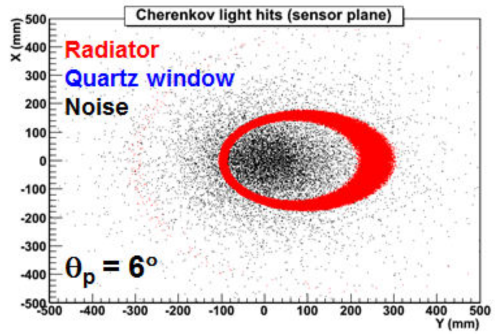
$$a = [(r_w\text{-}L) + q_w + t_{gap}]\tan\theta_p$$

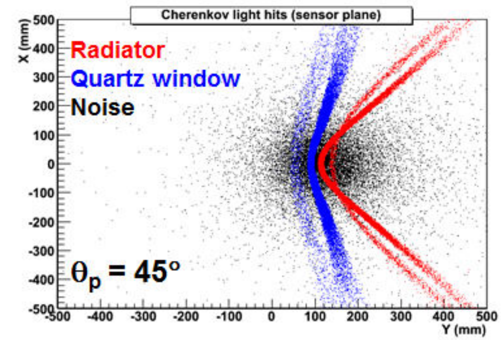
$$b = (r_w - L)\tan\theta + q_w\frac{n_f\sin\theta}{\sqrt{n_q^2 - n_f^2\sin^2\theta}} + t_{gap}\frac{n_f\sin\theta}{\sqrt{n_g^2 - n_f^2\sin^2\theta}}$$

$$R^2 = [a\cos\phi_p - b\cos\phi]^2 + [a\sin\phi_p - b\sin\phi]^2$$

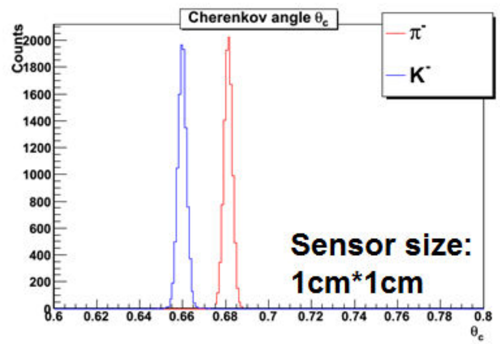
→ $$\cos\eta_c = \sin\theta_p\sin\theta\cos(\phi - \phi_p) + \cos\theta_p\cos\theta$$

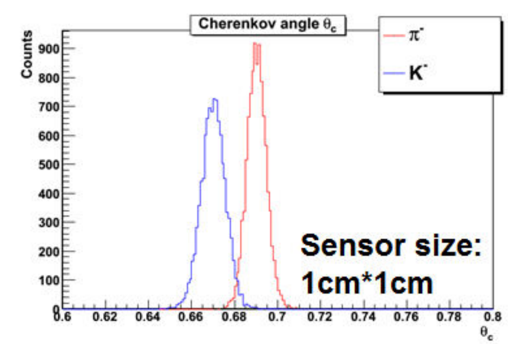






The π/K separation requirement can be met.





EMC

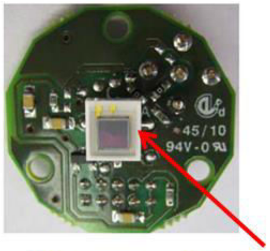
- Main performance requirements
  - Good energy resolution
  - Good spatial and angular resolution
  - Fast response
  - Good radiation tolerance
- Technology option
  - Crystal + SiPM

Candidate Crystals

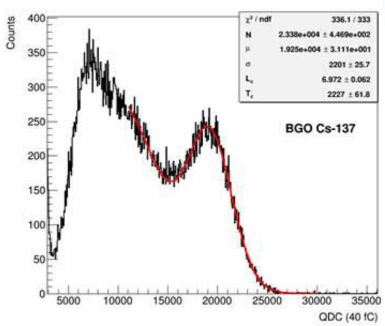
Crystal	CsI(Tl)	CsI	BSO	$PbWO_4$	LYSO(Ce)
Density (g/cm^3)	4.51	4.51	6.8	8.3	7.40
Melting Point (°C)	621	621	1030	1123	2050
Radiation Length (cm)	1.86	1.86	1.15	0.89	1.14
Molière Radius (cm)	3.57	3.57	2.2	2.0	2.07
Interaction Len. (cm)	39.3	39.3	23.1	20.7	20.9
Hygroscopicity	Slight	Slight	No	No	No
Peak 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)

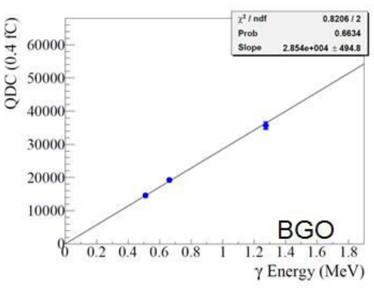
SiPM Technology

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

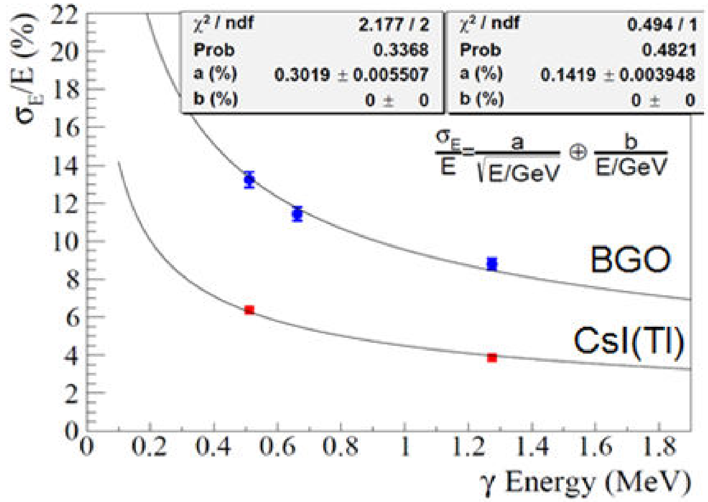


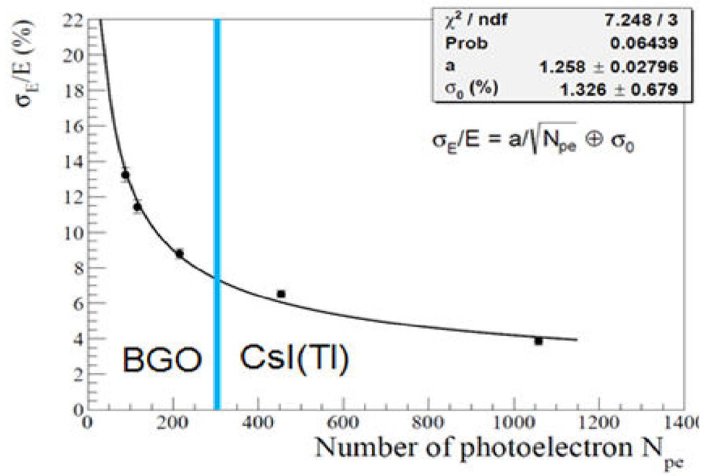
Hamamatsu S10362-33-050C, 3x3 mm^2



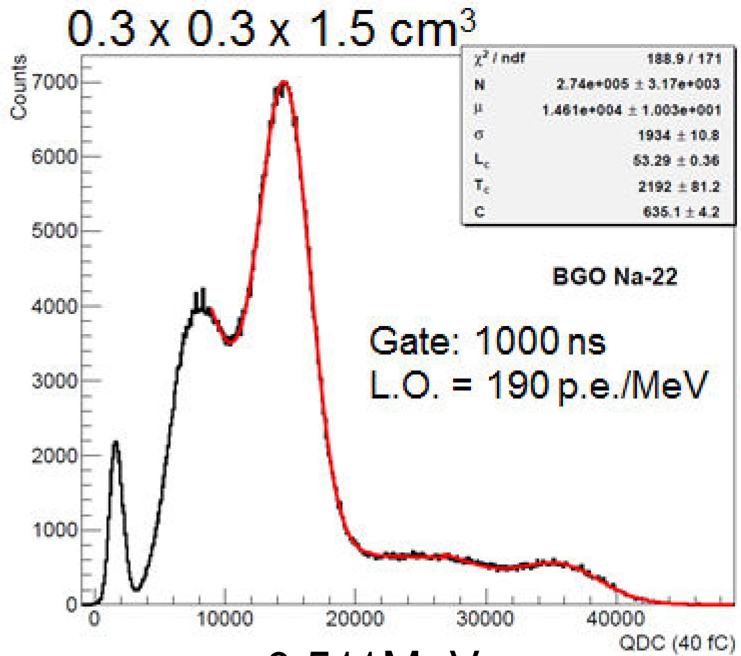


Energy Resolution





A few % resolution achieved at ~1 MeV, $\sigma_E/E \sim 1.26/\mathrm{sqrt}(N_{pe})$, still room for improvement



0.511MeV γ

BGO + SiPM: 13%*2.354 = 31%

CsI(TI)+SiPM: 6%*2.354= 14%

LYSO+SiPM: 5%*2.354= 12%

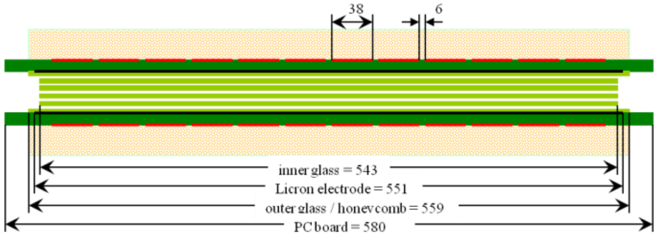
LSO/LYSO + PMT: 11-21%

LSO/LYSO + APD: 26-43%

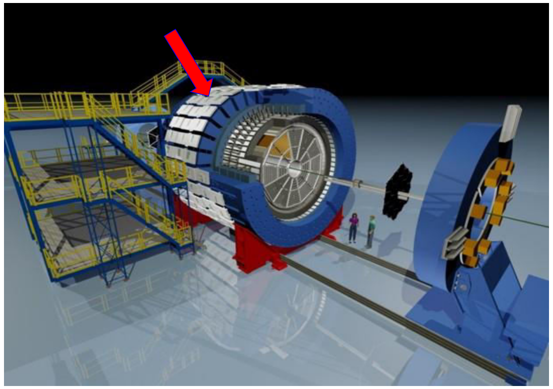
at 1GeV

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.



MTD at STAR



Long-Strip MRPC Module

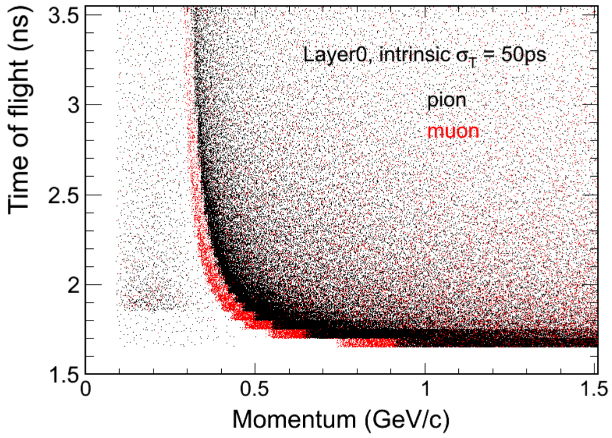
- Active area: 87 x 52 cm^2
- Read out strip: 87 cm x 3.8 cm
- Gas gaps: 0.25 mm x 5

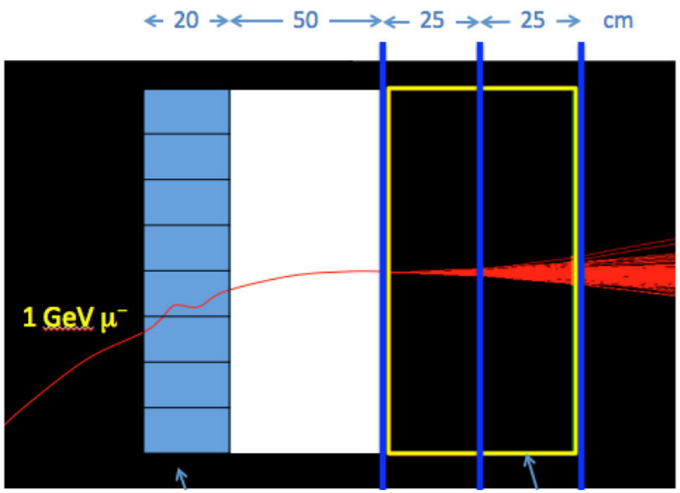
Performance:

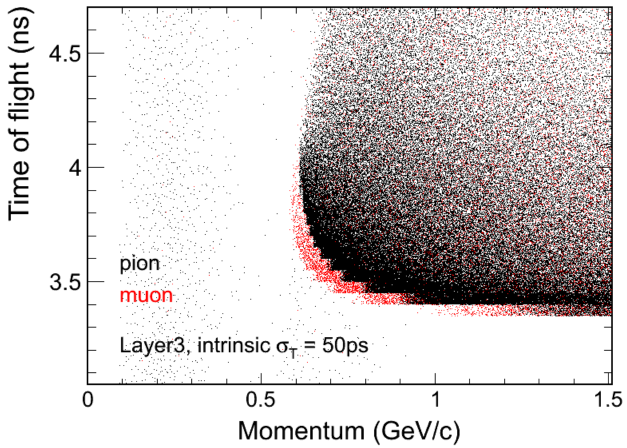
- Efficiency: > 98%
- Time resolution: < 80 ps
- Spatial resolution: 0.6 cm

μ/π separation power

- 11 layers RPC (3 MRPC)
- Operation mode
  - barrel: stream
  - endcaps: avalanche







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

Summary

- BEPC(II)/BES(II)(III) has made important achievements in particle physics with world impact, establishing China's strong leading position in τ-c physics in the world.
- Still very rich and yet unexplored physics in τ-c regime with lots of pressing fundamental questions to be addressed.
- HIEPA is a good candidate HEP project in China to continue with the success of BEPC(II) to fully explore the physics in τ-c regime.