A High Intensity Electron-Positron Accelerator

— a possible extension of BEPCII

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October 25, 2016

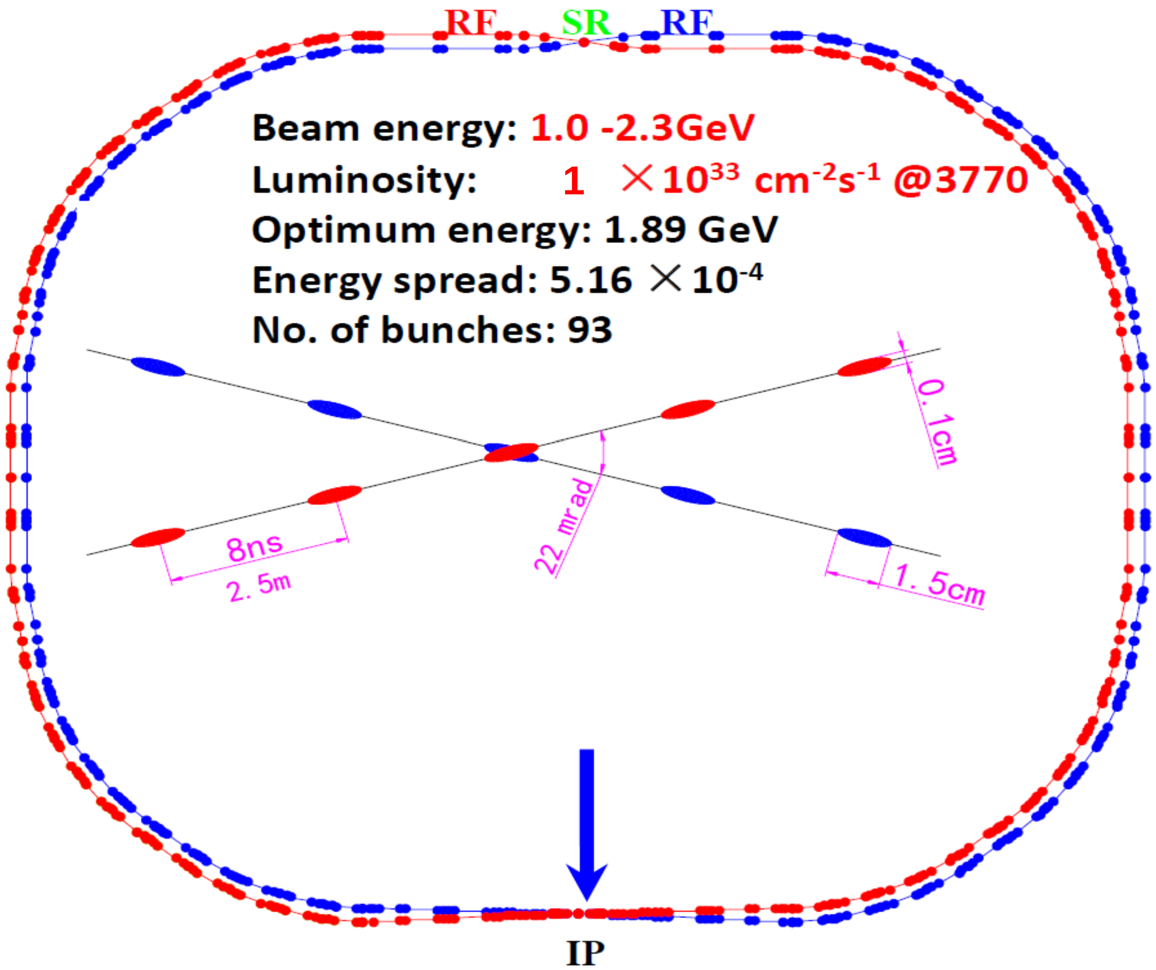
LAL, Paris

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, E_{cm}=2-4.6GeV
- 2008: BEPCII/BESIII commissioning
- 2009-now: BEPCII/BESIII physics running
  $\rightarrow L_{peak} = 1\times10^{33}\ cm^{-2}s^{-1}$

BEPCII

- A major upgrade of BEPC, $L_{peak} = 1 \times 10^{33}\ cm^{-2}s^{-1}$, a high-luminosity collider in the τ-c energy regime.
  - double-ring, large crossing-angle, super-conducting RF …



Milestones of BEPCII

Jan. 2004	Construction started
May. 4, 2004	Dismount of 8 linac sections
Dec. 1, 2004	Linac delivered e^- beams to BEPC
July 4, 2005	BEPC ring dismount started
Mar. 2, 2006	BEPCII ring installation started
Aug. 3, 2007	Shutdown for IR-SCQ installation
Mar. 28, 2008	Shutdown for BESIII installation
July 19, 2008	First hadron event observed
May 19, 2009	Luminosity reached $3.3\times10^{32}cm^{-2}s^{-1}$
July 17, 2009	Pass the National test & check
April 8, 2011	Luminosity reached $6.5\times10^{32}cm^{-2}s^{-1}$
April 2013	Zc(3900) found & confirmed
Nov. 20, 2014	Luminosity reached $8.53\times10^{32}cm^{-2}s^{-1}$
April 5, 2016	Luminosity reached $10.0\times10^{32}cm^{-2}s^{-1}$

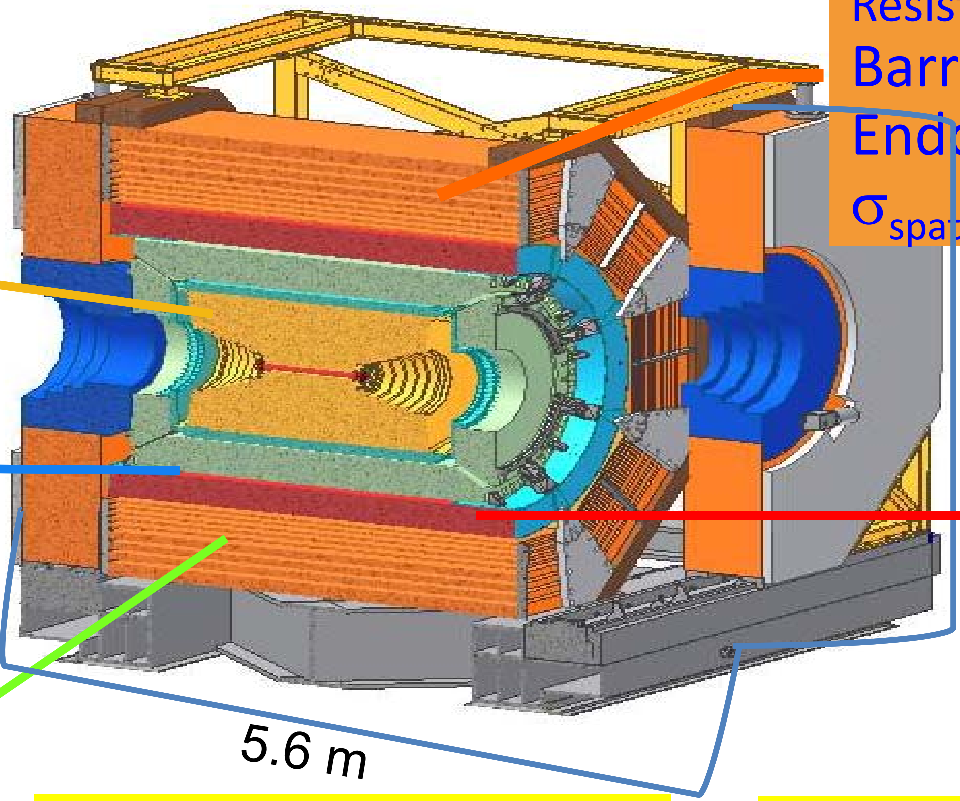
BESIII Detector

- 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}=115 μm, dE/dx~5%
σ_p/p = 0.5% @ 1 GeV

Time-of-flight (TOF)
Plastic scintillator/MRPC
σ_T(barrel): 68 ps
σ_T(endcap): 60 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/$\sqrt{E}$



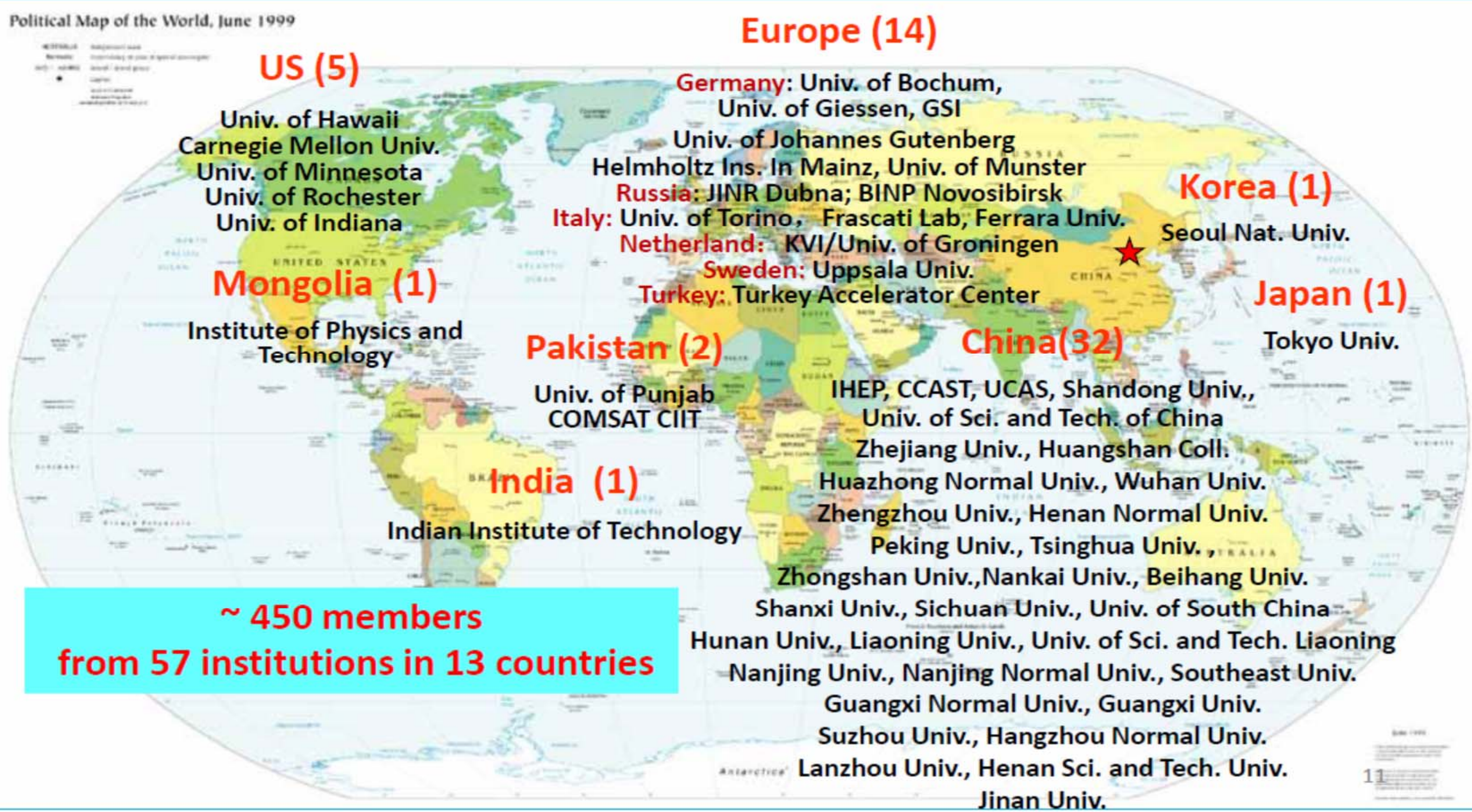
Muon counter
Resistive plate chamber
Barrel: 9 layers
Endcaps: 8 layers
$\sigma_{spatial}$: 1.4-1.7 cm

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

BESIII Collaboration



Europe (14)

Germany: Univ. of Bochum, Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz, Univ. of Munster
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino, Frascati Lab, Ferrara Univ.
Netherland: KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

US (5)

Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Mongolia (1)

Institute of Physics and Technology

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

India (1)

Indian Institute of Technology

Korea (1)

Seoul Nat. Univ.

Japan (1)

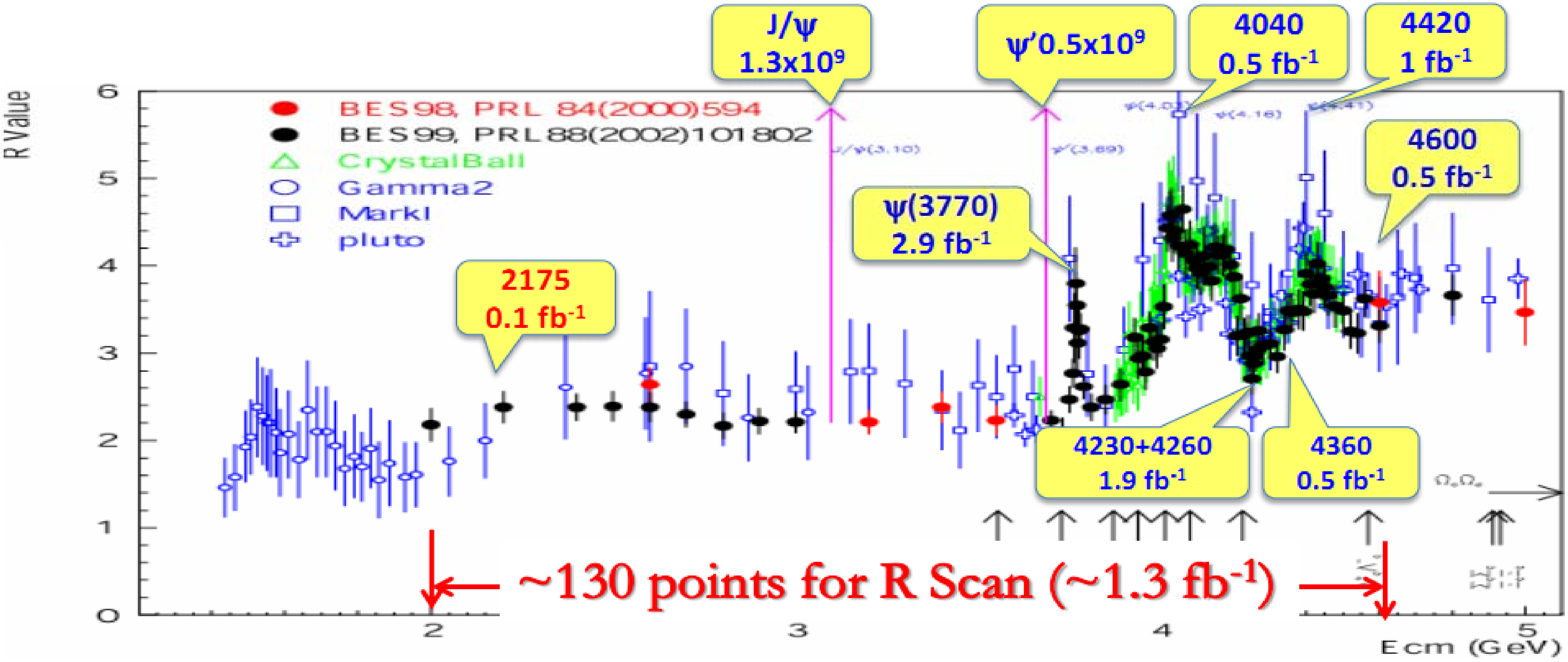
Tokyo Univ.

China(32)

IHEP, CCAST, UCAS, Shandong Univ., Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ., Beihang Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ., Univ. of Sci. and Tech. Liaoning
Nanjing Univ., Nanjing Normal Univ., Southeast Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Jinan Univ.

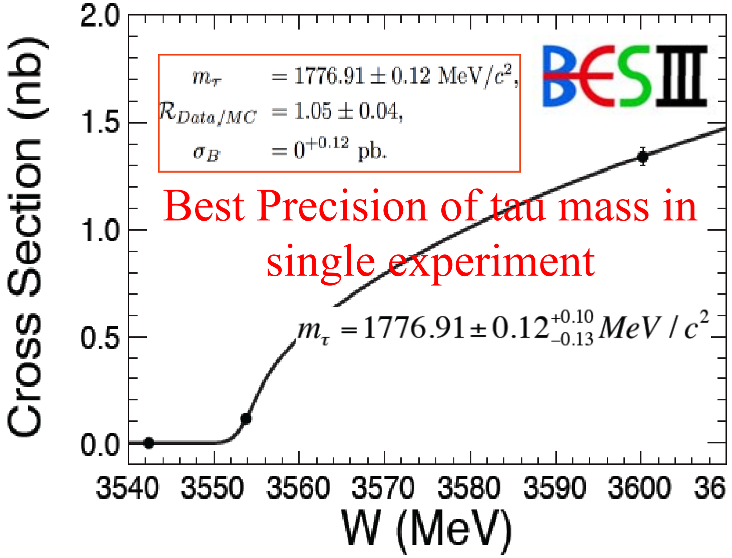
~ 450 members
from 57 institutions in 13 countries

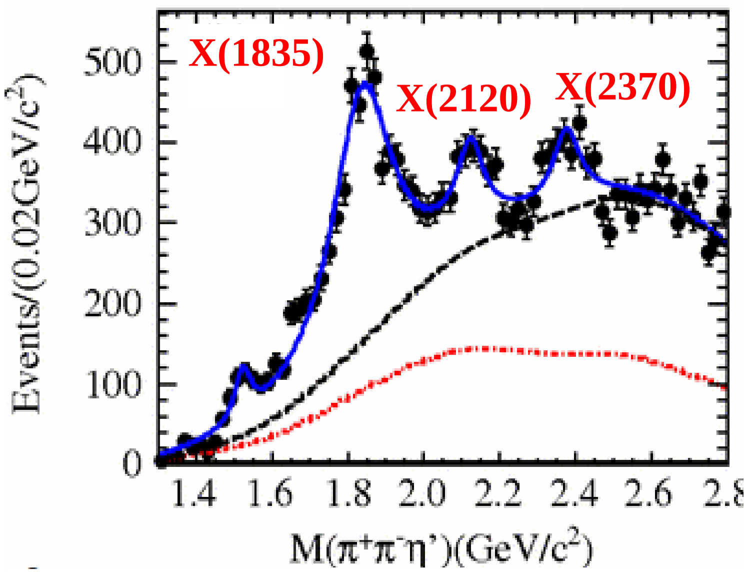
Collision Data from BEPCII/BESIII

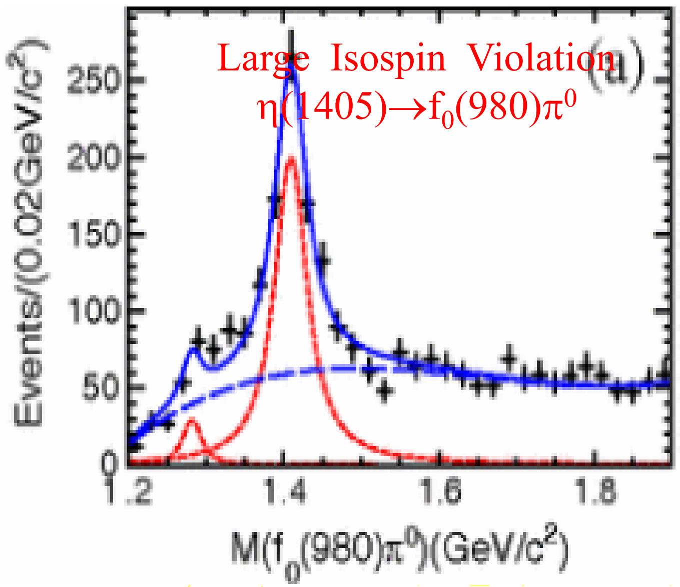


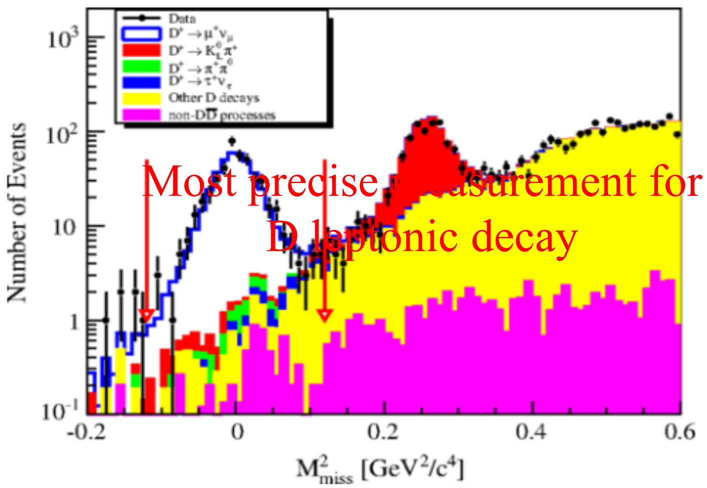
- The world's largest data samples of J/ψ, ψ(2s), ψ(3770), Y(4260) produced in e+e- collisions, allowing to deeply explore physics in the τ-c energy regime.

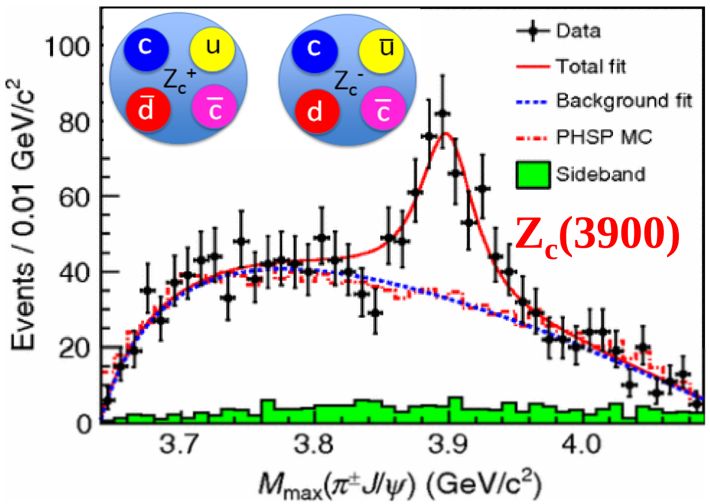
Fruitful Physics Results

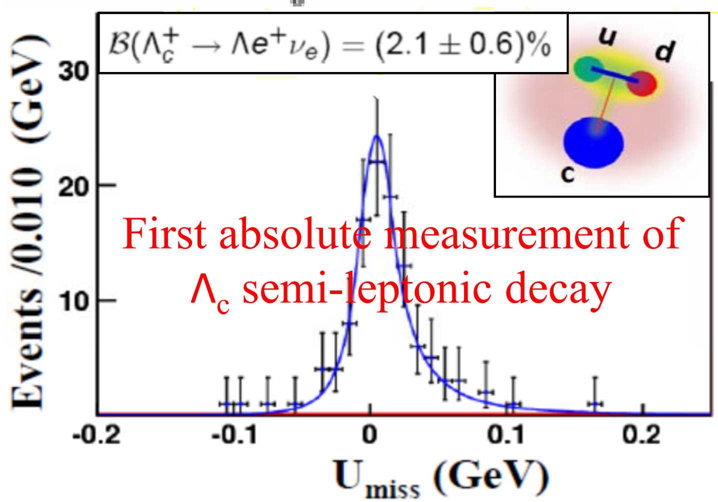








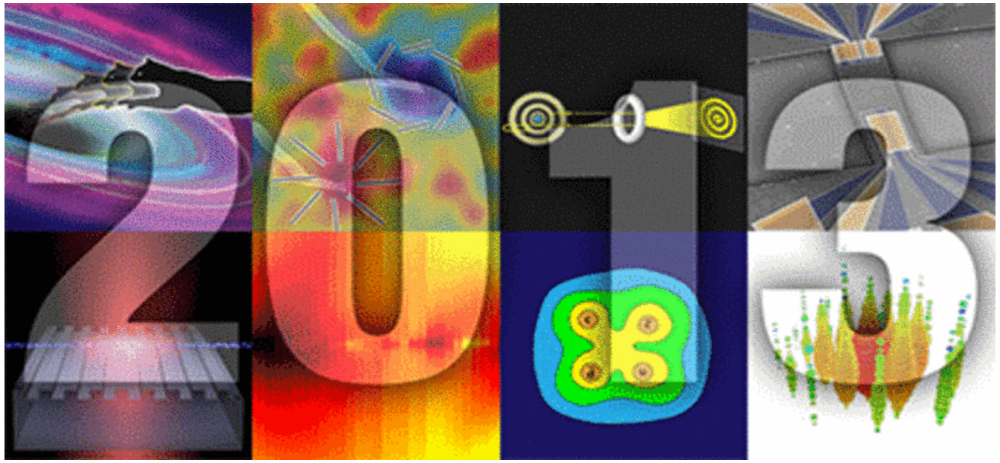


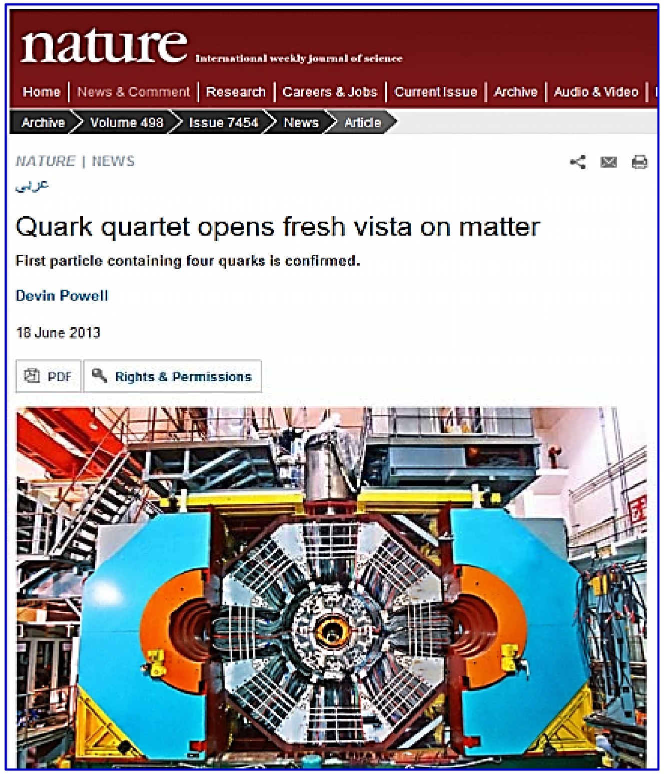


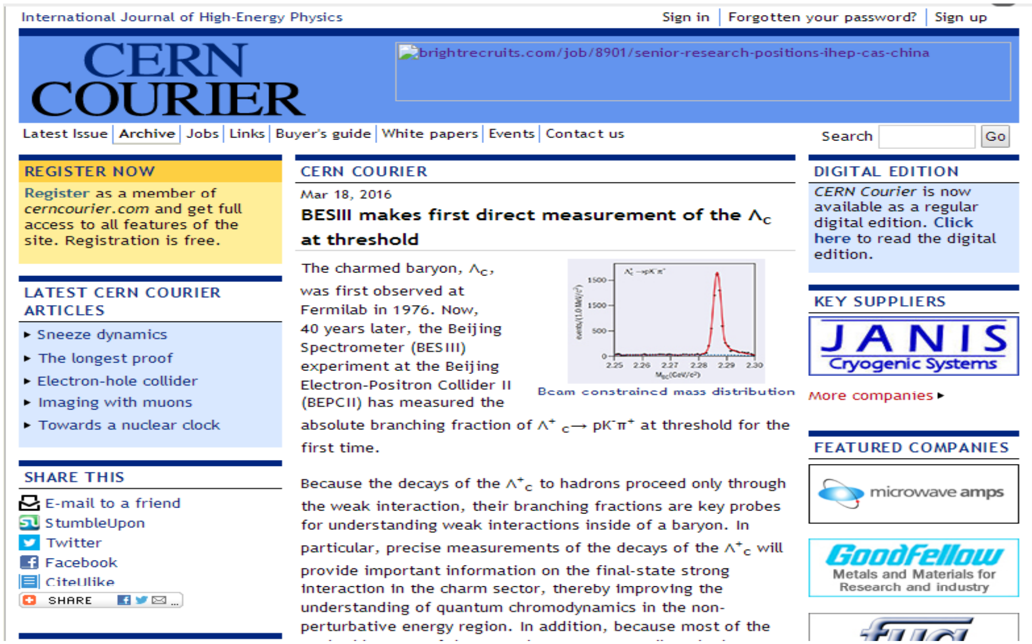
~130 publications up to now, with many significant results

A very successful experiment

Significant Impact







Important role in τ-charm physics

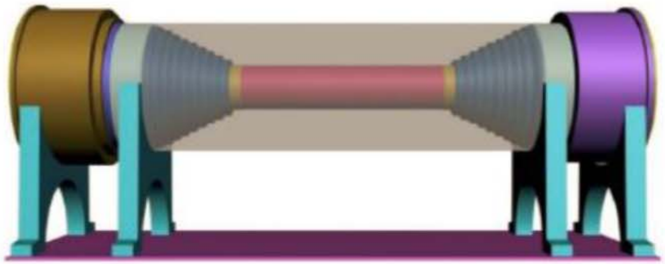
BESIII Upgrade

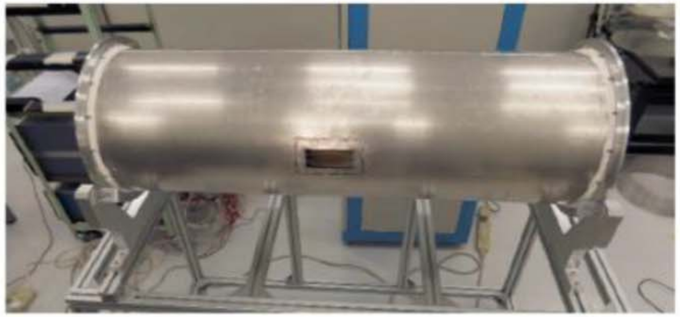
- Drift chamber: Malter effect occurred in the inner chamber in 2012. Cured by addition of water. Inner chamber needs to be replaced. Two options:
  - A new inner drift chamber, which has been built by IHEP, largely identical to the existing one.
  - A cylindrical GEM chamber, which is being built by an Italian group in collaboration with other groups.
- ETOF: time resolution compromised by multiple hits on a single scintillator unit. Scintillator-based ETOF has been upgraded with MRPC to mitigate the effect.
  - Pad-readout MRPC
- Other possible upgrade is under discussion
  - Barrel PID …

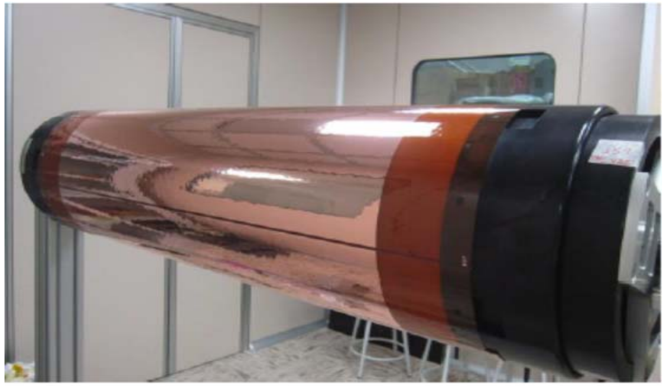
Inner Tracker Upgrade

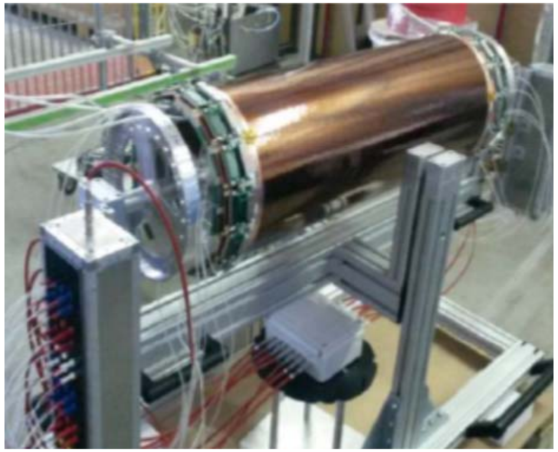
Cylindrical GEM chamber

New inner drift chamber



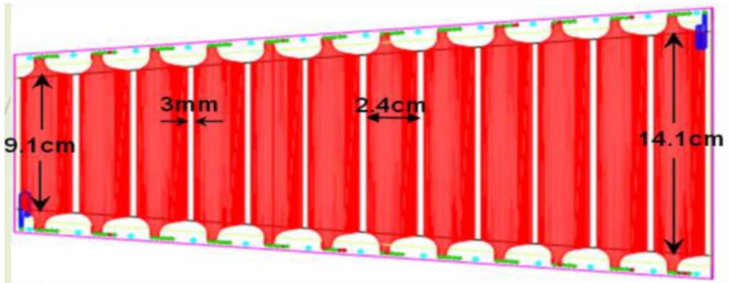


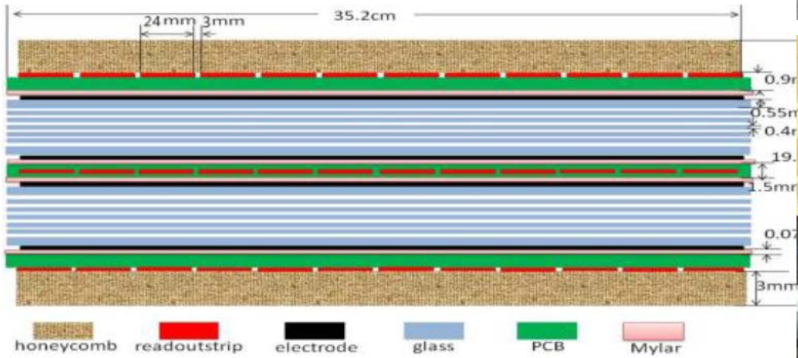


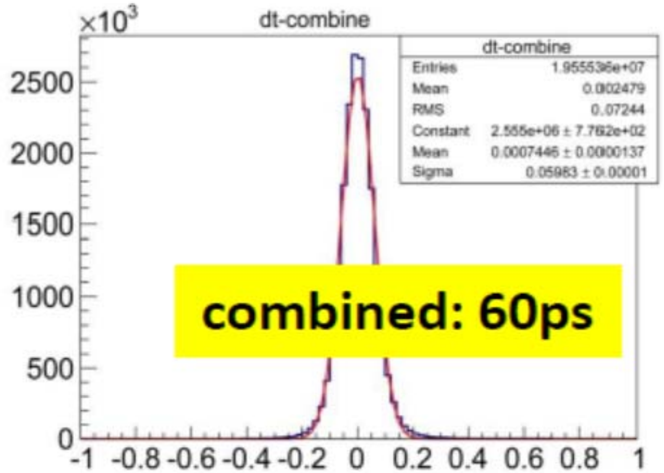


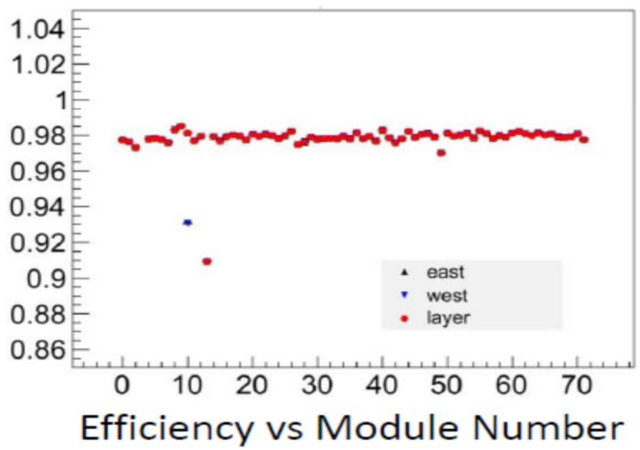
ETOF upgrade

- A joint project by USTC & IHEP
- All MRPC modules installed. The new ETOF system commissioned and in physics running already.



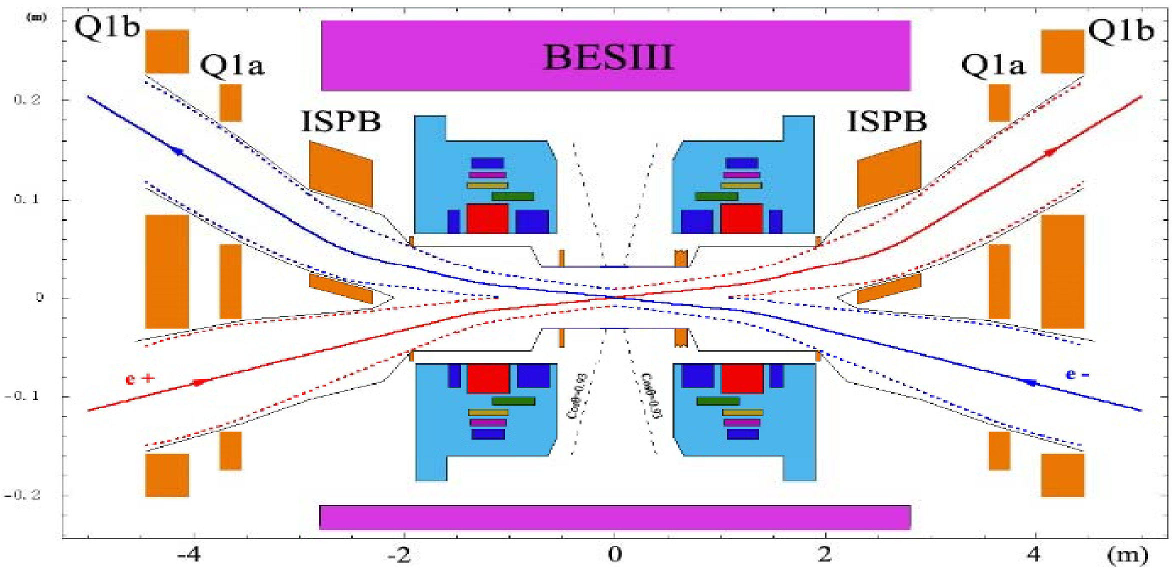






BEPCII Upgrade

- To increase beam energy (beyond 2.3 GeV)
- Three scenarios under discussion
  - 2.35 GeV: cooling, magnet power supply
  - 2.45 GeV: new ISPB magnets
  - >2.45 GeV: no actual scheme yet

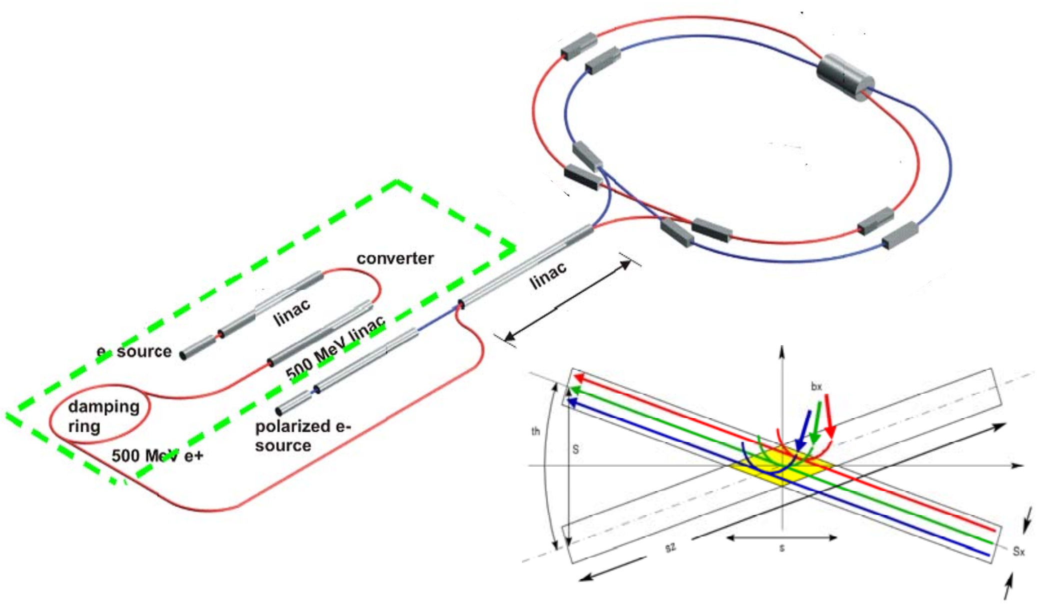


Post-BEPCII

- BEPC made China's mark in high energy physics on the world stage. BEPCII, as a successor, went on to establish China's strong position in τ-c physics.
  - The two projects have been a big success together, with many world-class achievements made.
- To fully explore the τ-c physics, a high intensity electron-positron accelerator (HIEPA, L~100*BEPCII, E_{cm}=2-7GeV) is considered necessary.
- It would be also a natural extension of BEPCII as a possible option for a post-BEPCII HEP project in China.

High Intensity Electron Positron Accelerator

- **HIEPA** : a possible option for a post-BEPCII HEP project in China.
  - To be an ultimate **τ-c** machine, and moreover, a multifunctional and multidisciplinary complex, far beyond BEPCII.



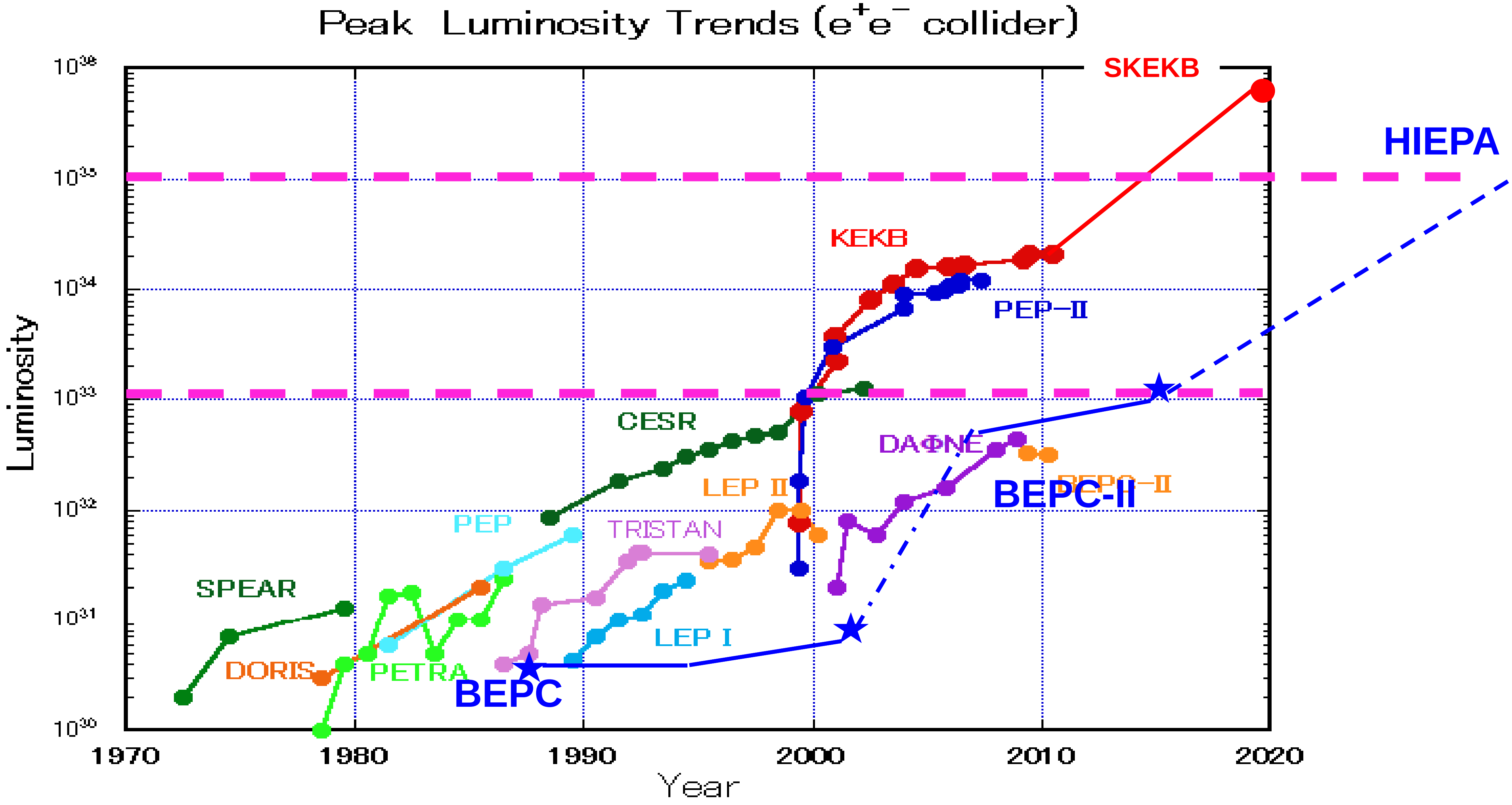
- E_{cm} = 2-7 GeV, L=1×10^{35} $cm^{-2}s^{-1}$ @4 GeV
- Symmetrical collision
- double-ring, 600-1000m
- Crab waist scheme
- Single beam polarized
- Synchrotron radiation

HIEPA Parameters

Beam energy (GeV)	2	Revolution frequency (MHz)	0.302
Circumference (m)	992.8	Harmonic number	1656
Coupling factor	0.005	$\beta_{x,\ y}$ @ IP (mm)	1000, 1.0
Emittance (nm.rad)	10	Beam-beam parameter	0.06
Bunch length (mm)	10	Number of bunch	540
Momentum compaction	0.001	Bunch current (mA)	5.0
SR energy loss/turn (MeV)	0.716	Beam current (A)	2.7
Synchrotron tune	0.0128	SR power (MW)	1.93
RF voltage (MV)	2.0	Energy spread	8.12E-4
RF frequency (MHz)	500.06	Luminosity ($cm^{-2}s^{-1}$)	1.05E35

A super τ-charm factory

HIEPA in Perspective

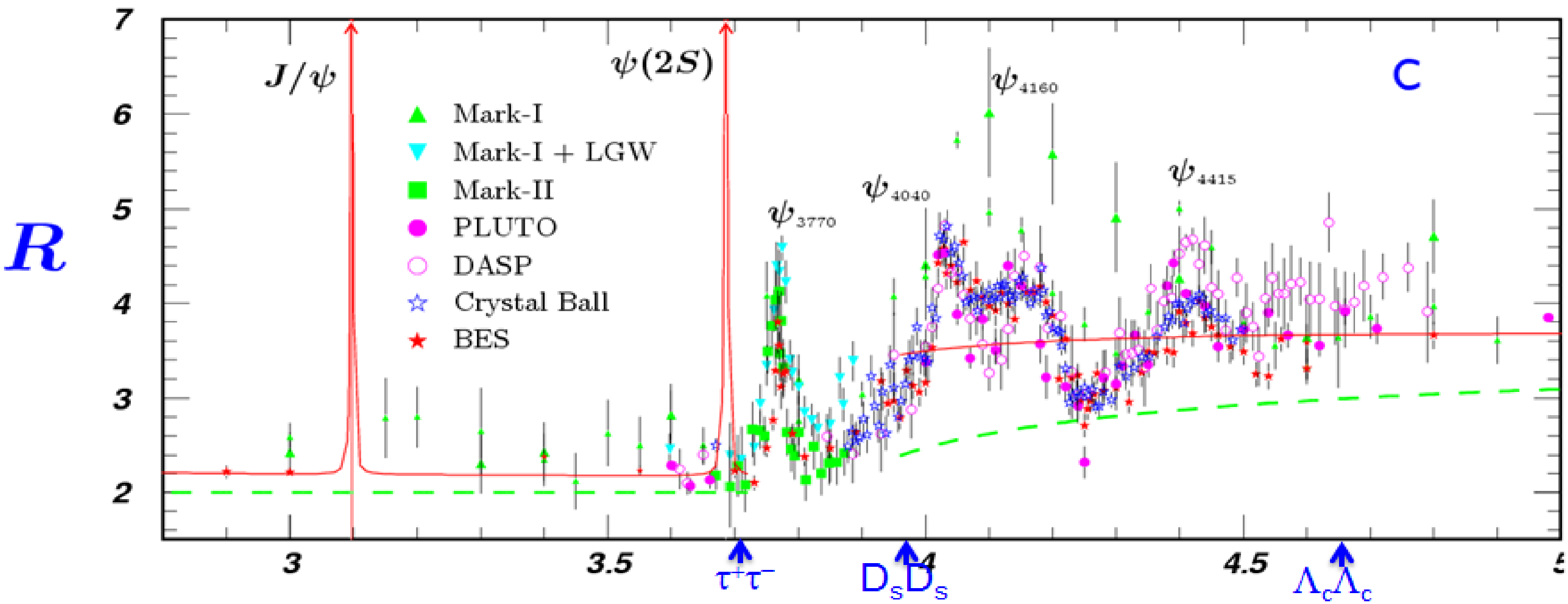


R&D Required for HIEPA

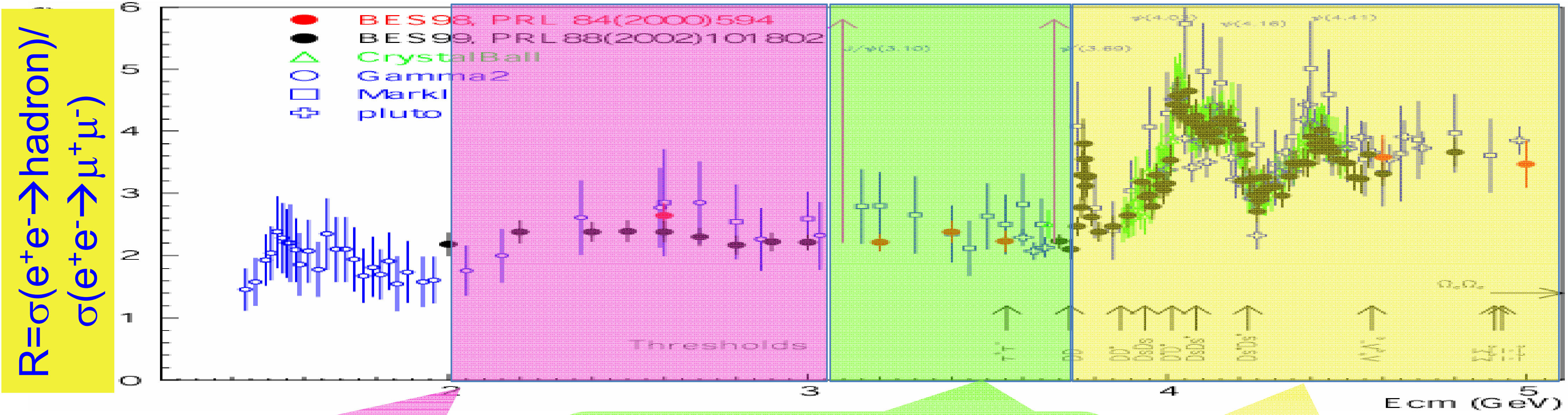
- Physics design studies
- Injection technology
- Super-conducting magnets and RF cavities
- Beam polarization technology
- Insertion devices
- Vacuum technology
- High-resolution beam monitoring
- ……

Features of τ-c Energy Region

- Rich in resonances: charmonia and charm mesons
- Threshold production: pair production of τ, D, D_s …
- Transition between smooth line-shapes and resonances, perturbative and non-perturbative QCD
- Home to exotic hadron states: glue-balls, hybrids and multi-quark states



Rich Physics in 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-$\bar{D}^0$ mixing
- Charm baryons

R scan

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

Physics Program at HIEPA

- ***Precision test of SM***
  - R Scan, Hadron form factor (nucleon, Λ, π), $\Delta\alpha_{QED}$, a_u
  - tau lepton decays, lepton universality test
  - CKM matrix, Decay constants (f_D/f_{Ds}), form factors
  - Neutral D mixing and strong phase

- ***hadron physics***
  - meson, baryon, hyperon spectroscopy
  - threshold effects
  - Glueball: direct test of QCD at low energy
  - Multiquark, exotics, hybrids…..
  - Charmonium(-like) spectroscopy
  - Charmed baryon decays

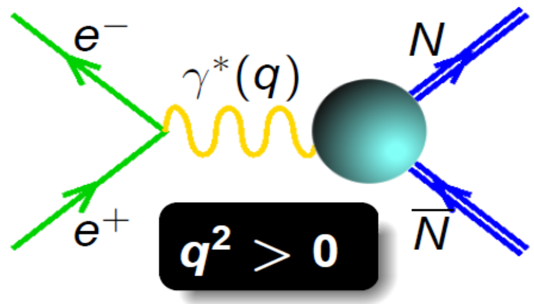
- ***New physics(tiny/forbidden in SM)***
  - Rare charmonium decays：LFV, LNV, BNV…
  - Rare charm decay : FCNC, LFV, LNV, invisible
  - Rare tau decay : FCNC, LFV, LNV
  - Rare light meson decay : $\eta/\eta'/\omega/\phi$

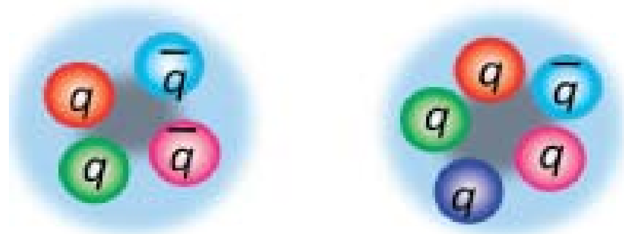
- ***Exotic phyics***
  - Light dark matter :
    light Higgs boson(a_0), U boson
  - New interactions

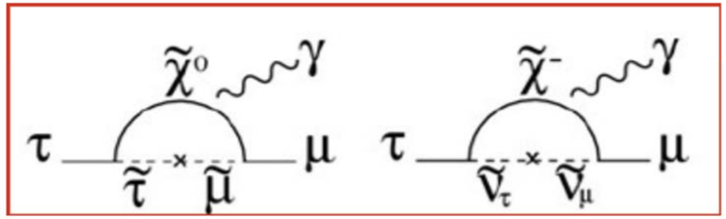
- ***CP Violation***
  - Unexpected large CPV in tau or charm: tiny in SM
  - CP violation in baryon/hyperon/charm baryon

Highlights

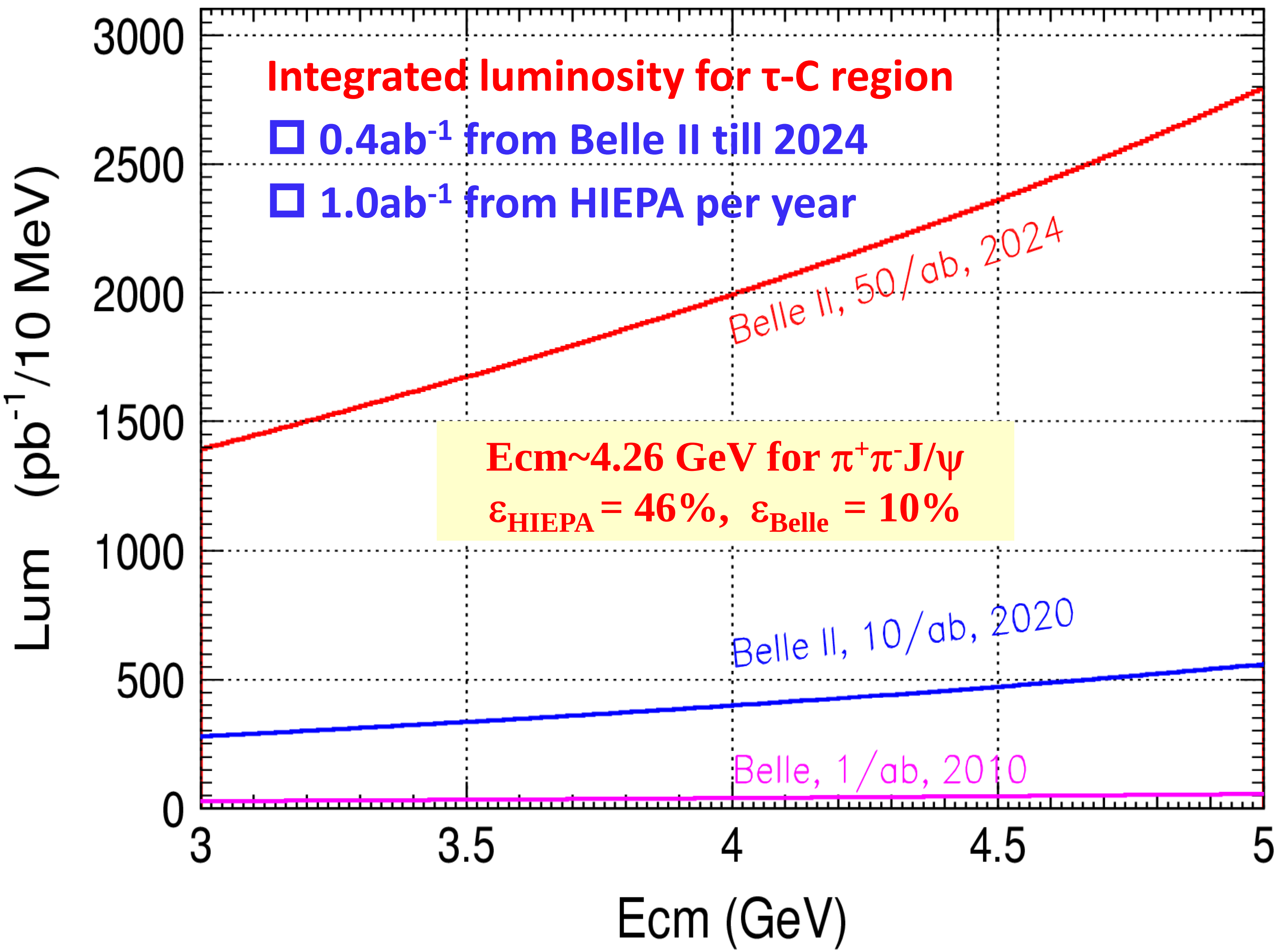
- Precision measurements: hadron EM form factors, CKM, f_D/f_{Ds}, tau decays, R scan ...
- Search for new forms of hadrons (glueball, multi-quark, hybrid ...) and studies of their properties.
- Search for new physics (LFV, CPV, exotics ...) beyond the SM
- ……







Physics Potential of HIEPA

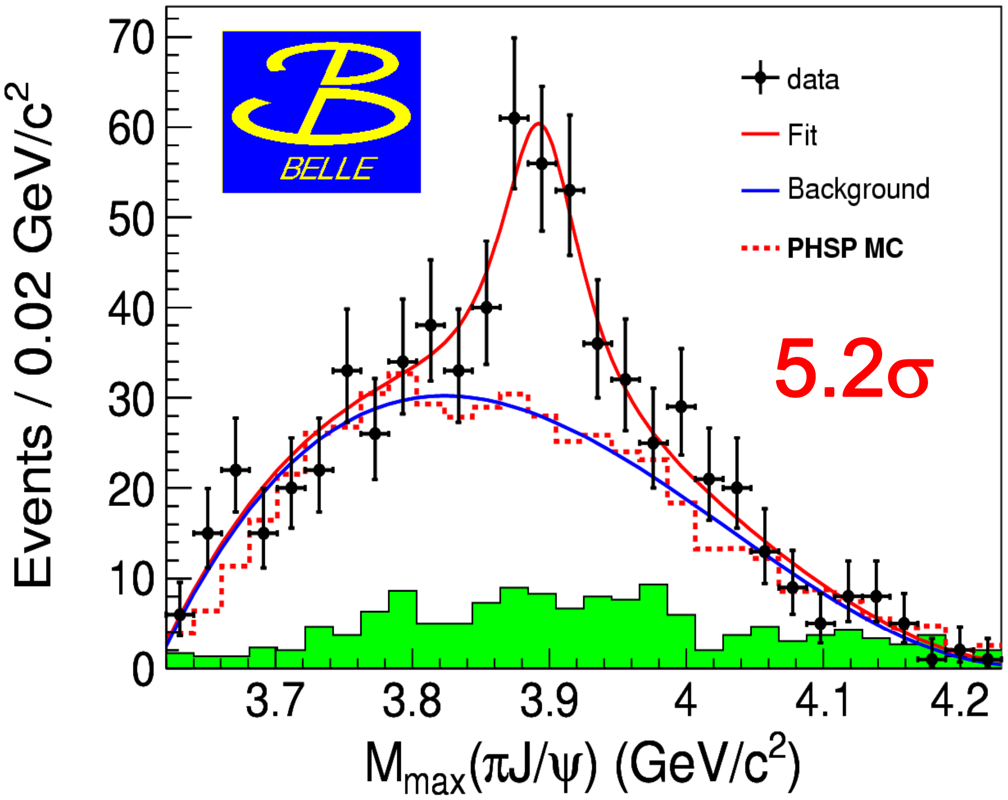


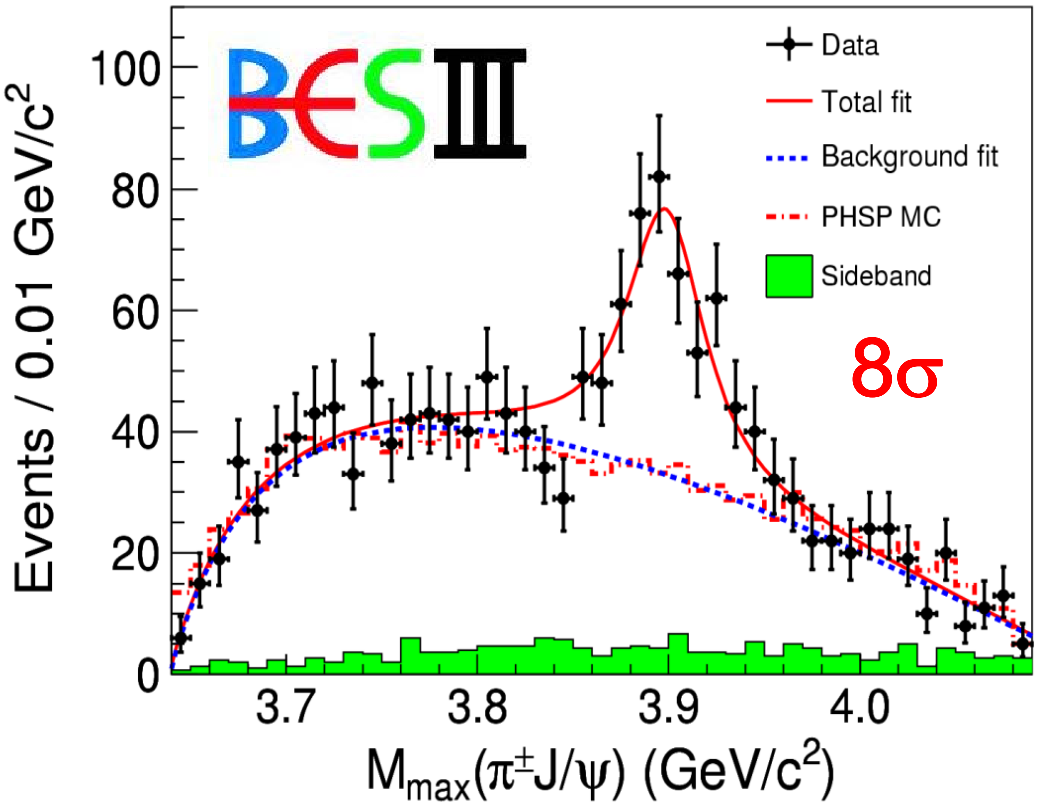
Charmonium(like) States

$Z_c(3900)$ significance

Belle with ISR, 967 fb^{-1} from **10 years** of running

BESIII, 0.525 fb^{-1} from **one month** of running





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

CPV in τ decay

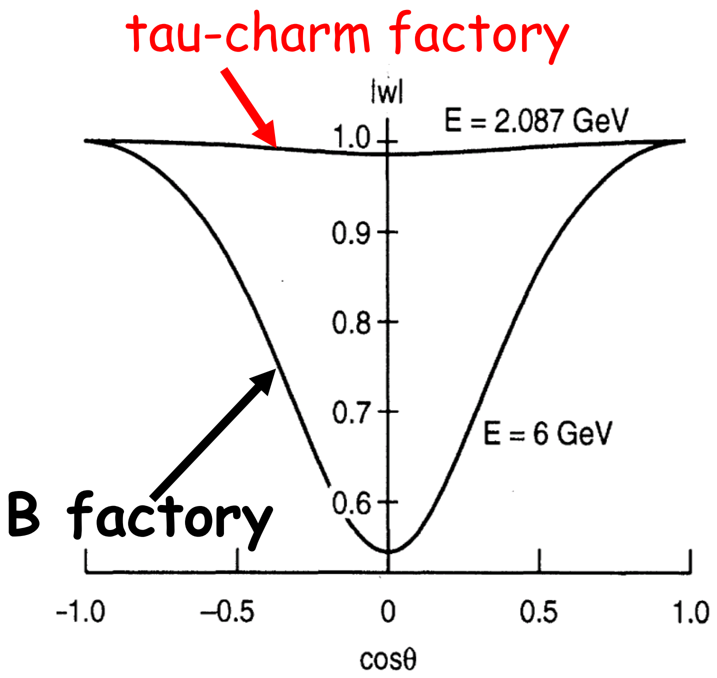
Use T-odd rotationally invariant products : e.g.

$$P_2^{\tau} \cdot (\vec{P}_{\pi^+} \times \vec{P}_{\pi^0})$$

in τ^+ and τ^- decays to >=2 hadrons such as :

$\tau^- \to \pi^-\pi^0\nu_\tau / k^-\pi^0\nu_\tau$, $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau / K^-\pi^+\pi^-\nu_\tau$,

polarized beam is needed



"Figure Of Merits"

$$\begin{aligned} \text{merit} &= \text{luminosity} \times \bar{w}_Z \times \text{ total cross section} \\ &\propto \text{luminosity} \times (w_1 + w_2) \\ &\quad \times \sqrt{1 - a^2}a^2(1 + 2a) \ , \end{aligned}$$

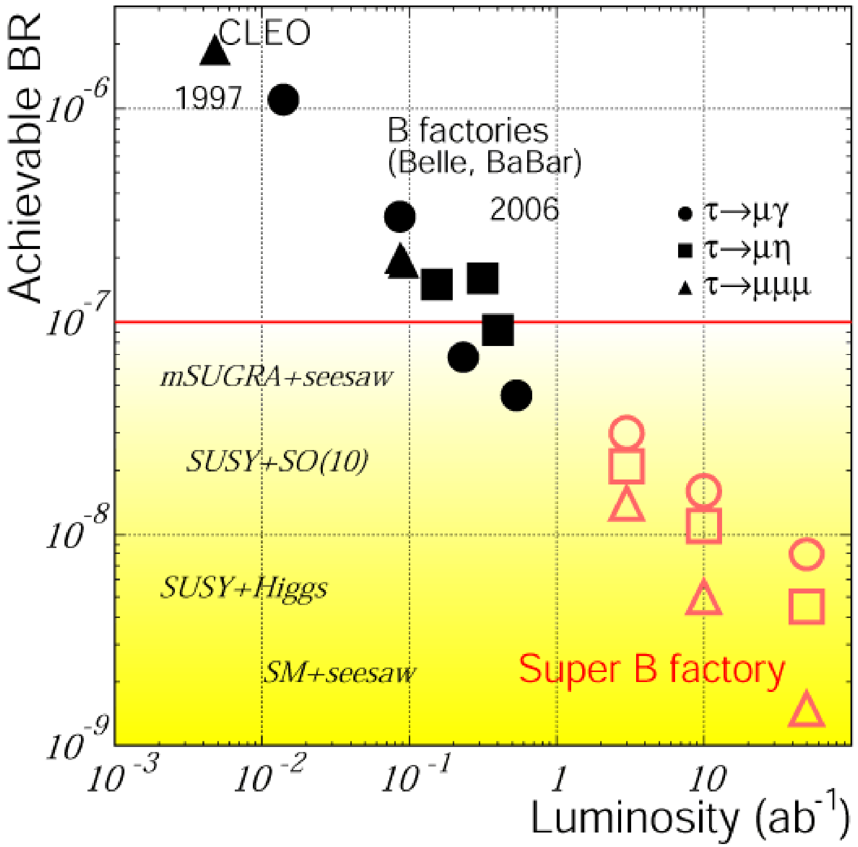
Y. S. Tsai, P.R.D51:3172,1995

BESIII @ 4.25 ($10^{33}cm^{-2}s^{-1}$) FoM=1

Super B @ ($10^{36}cm^{-2}s^{-1}$) FoM=65

HIEPA @ 4.25 ($10^{35}cm^{-2}s^{-1}$) FoM=100

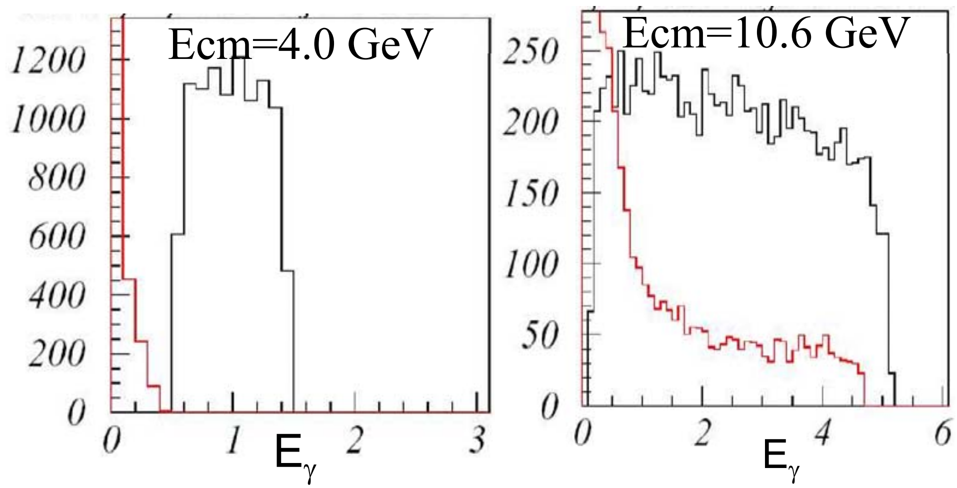
LFV in τ decay



τ→μγ

- **Current limit** : ~ 4×10^{-8} (5×10^{8} τ-pairs)
  - BABAR: $516 fb^{-1}$, BELLE: $545 fb^{-1}$
- **Υ(4S) @ Super B factory**
  - main background: $e^+e^- \to \tau^+\tau^-\gamma$
  - Expected limit: **3×10^{-9}**@$75 ab^{-1}$(7×10^{10} τ-pairs)

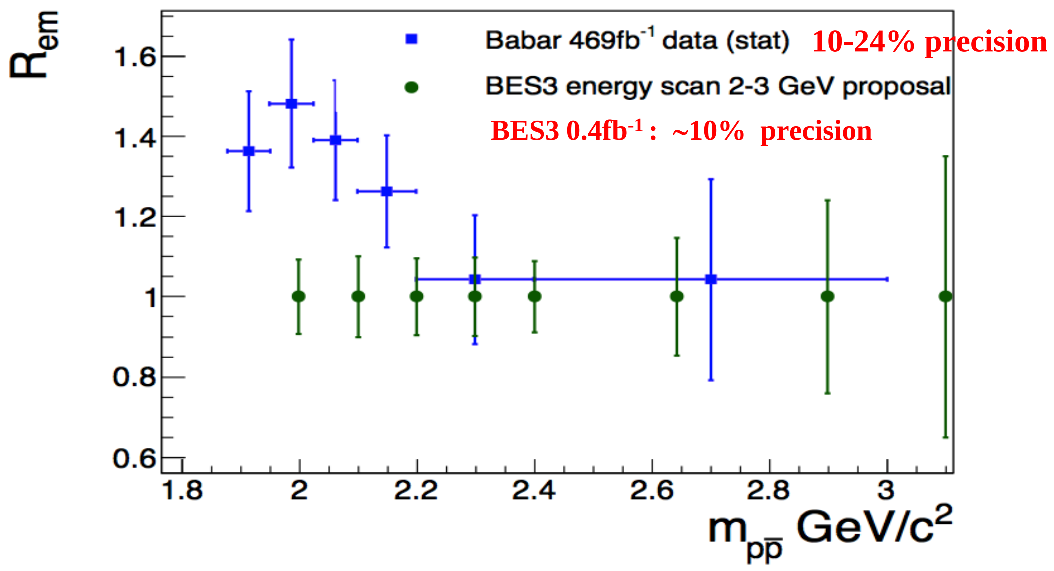
Background $e^+e^- \to \tau^+\tau^-\gamma$

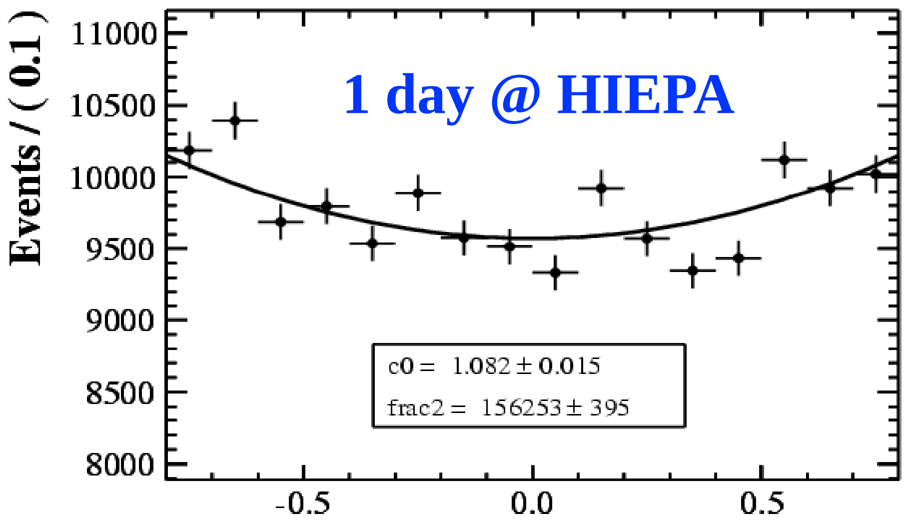


Expected limit @ HIEPA

$7 ab^{-1}$ (2.5×10^{10} τ pairs)	$\sigma_E/E=1.5\%$	$\sigma_E/E=2.5\%$
Signal ($Br=10^{-9}$)	17	15
Muon background	7	11
Pion background	83	271
Expected 90% CL upper limit	1.1×10^{-9}	3.0×10^{-9}
Expected 90% CL upper limit with stronger pion suppression (×3)	3.3×10^{-10}	5.1×10^{-10}

Proton EM Form Factors





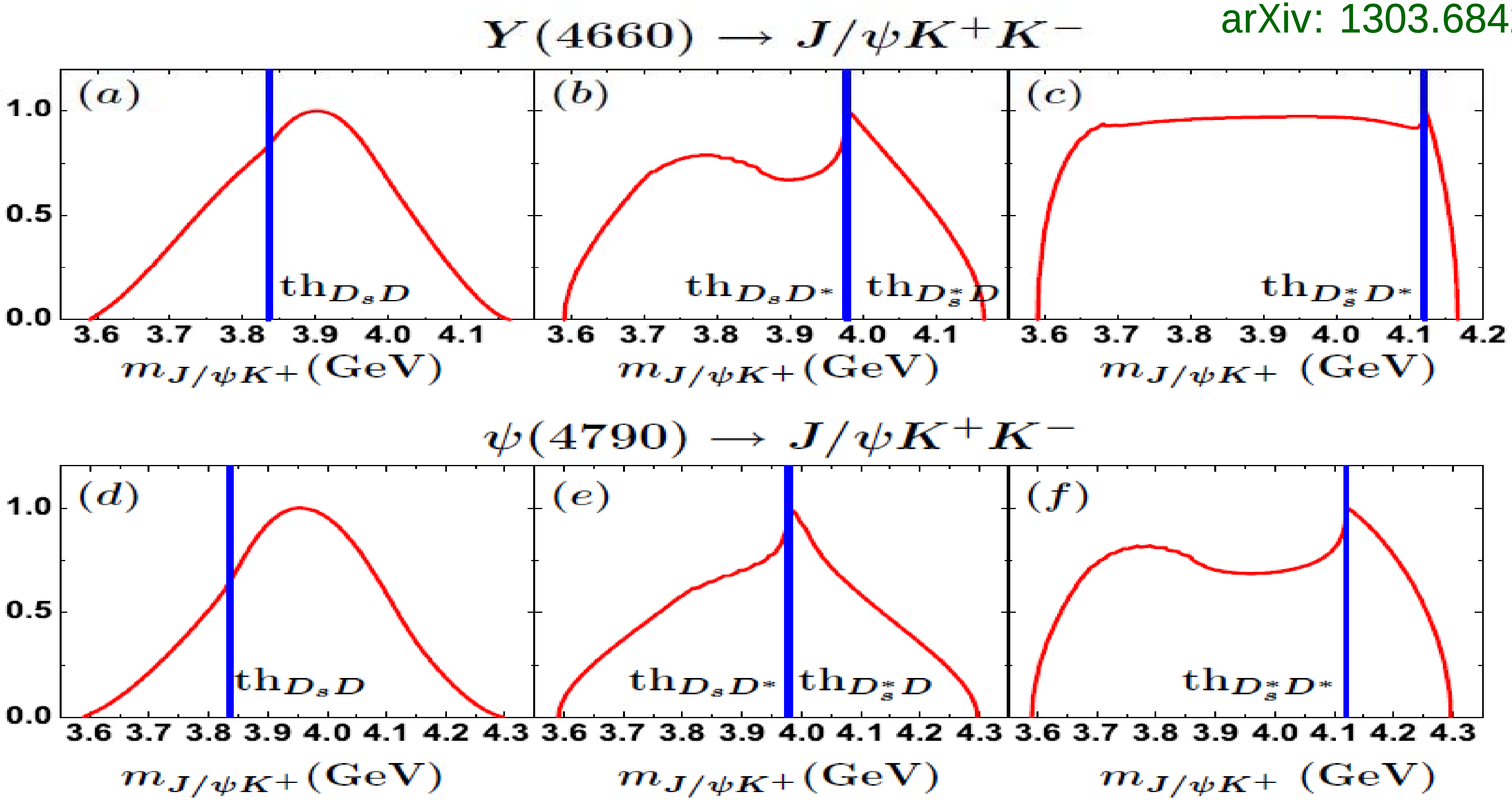
E_{cm}=2.23 GeV

Nsig	$\delta R_{EM}/R_{EM}$	$\delta\sigma/\sigma$	Luminosity (pb^{-1})	comment
614±24	24%	3.9%	2.631	BESIII test run
3881±62	9.5%	1.6%	16.630	BESIII expected
156253±395	1.5%	0.25%	669.533	HIEPAF reach 1 (1 day)
389898±624	0.96%	0.16%	1670.69	HIEPA reach 2 (2 days)

Using two days data, proton FF can reach a precision of 1% at HIEPA

Search for Z_{cs}

arXiv: 1303.6842

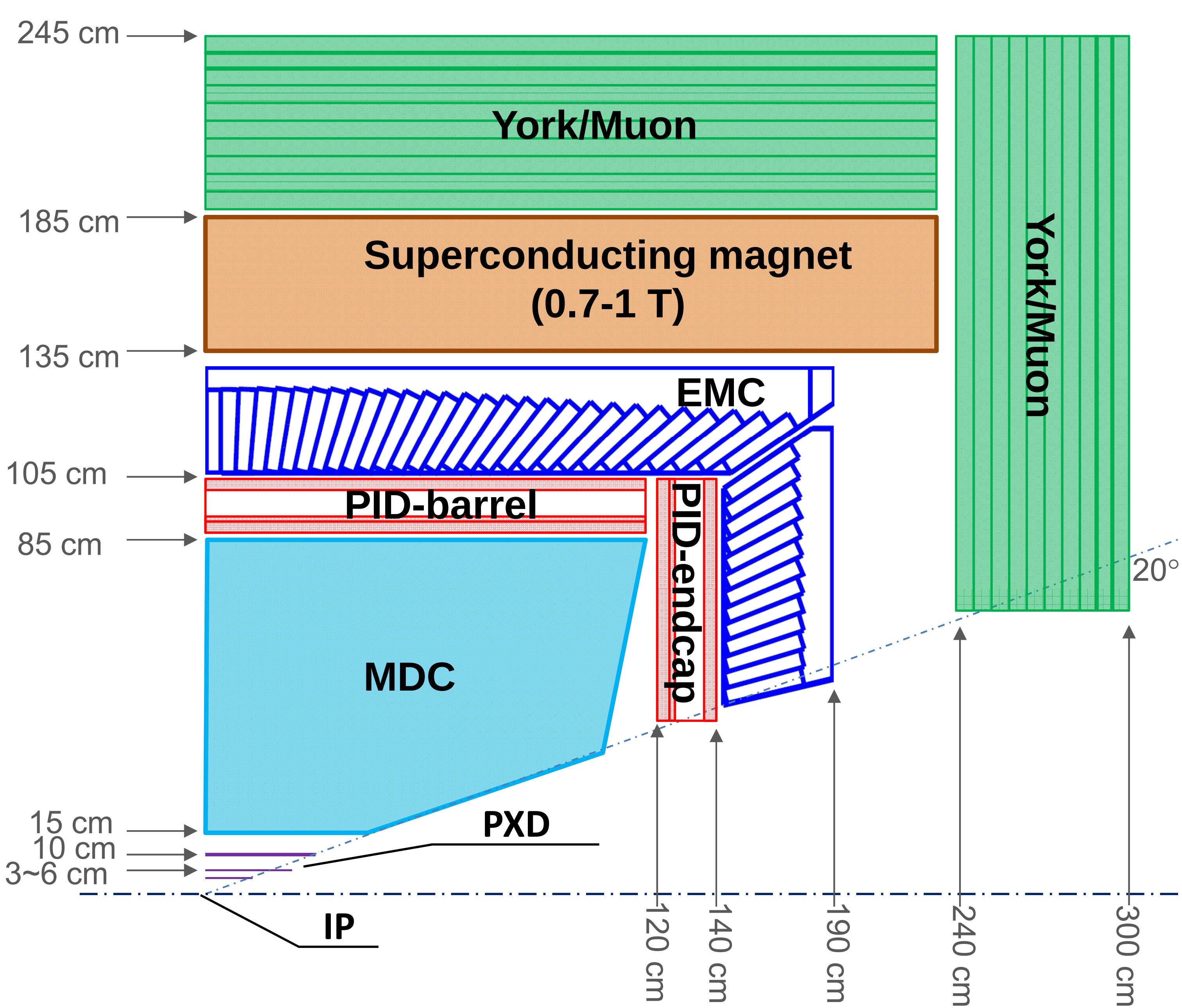


search for excited Z_c and Z_{cs} @ E_{cm}>4.5 GeV

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 forward
- **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**
  - 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
- ~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: 0.02-2GeV

At 1 GeV	σ_E (%)
Barrel:	2
Endcap:	4

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

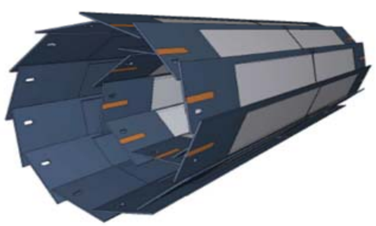
Inner & Outer Trackers

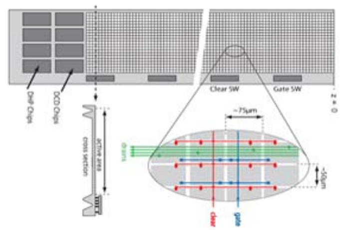
- Dominant factor in tracking: multiple scattering
- So driving force in design of tracking system: low mass.
- Special design is required for inner tracking to cope with the very high level of radiation close to IP. So an inner-outer separate design is optimal.
- Detector technology options
  - Inner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

Inner Tracker Technologies

DEPFET

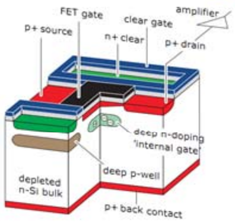
- Two layers of PXD: 1.8 cm and 2.2 cm in radius, consisting of 8 and 12 modules for innermost layer and the second, respectively.



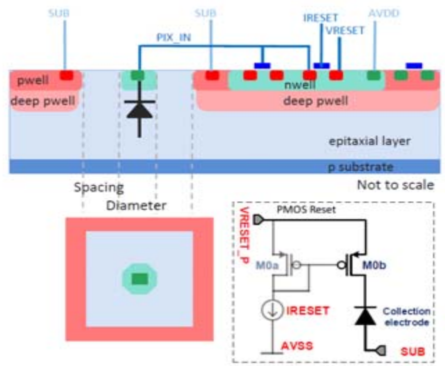


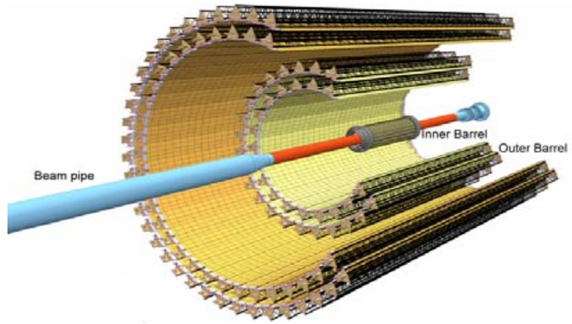
Number of pixels per module	250 x 1536
Pixel size (r-phi, z)	50μm x (60-75) μm
Frame time	20 μs
Material budget per layer	0.15% X_0
Resolution (r-phi, z)	<10μm, < 20μm
Occupancy at 1.8 cm radius	0.2 hits $\mu m^{-2} s^{-1}$
Radiation environment	~1 Mrad/year

DEPFET Technology



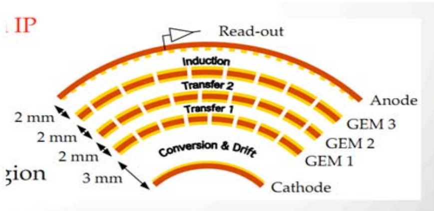
MAPS (ALPIDE)





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



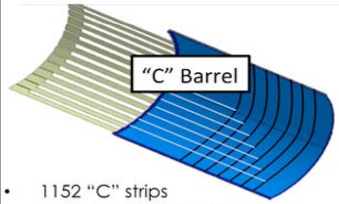
2-d strip readout

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

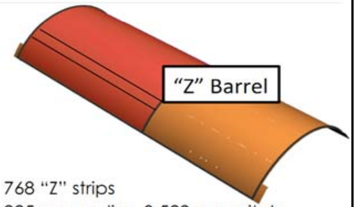
Material Budget	
Total 1 layer	0.49%
Total 4 layers	1.95%

Pixel readout would be required for the innermost layers at HIEPA

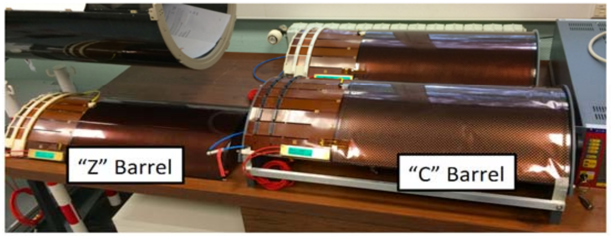
Cylindrical MicroMegas

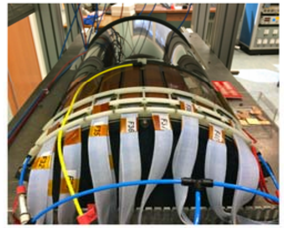


- 1152 "C" strips
- Pitch from 0.67 to 0.33 mm
- 221 mm radius
- PCB thickness 100 μm
- Drift thickness 250 μm
- Drift Field 2.4kV on 3 mm gap

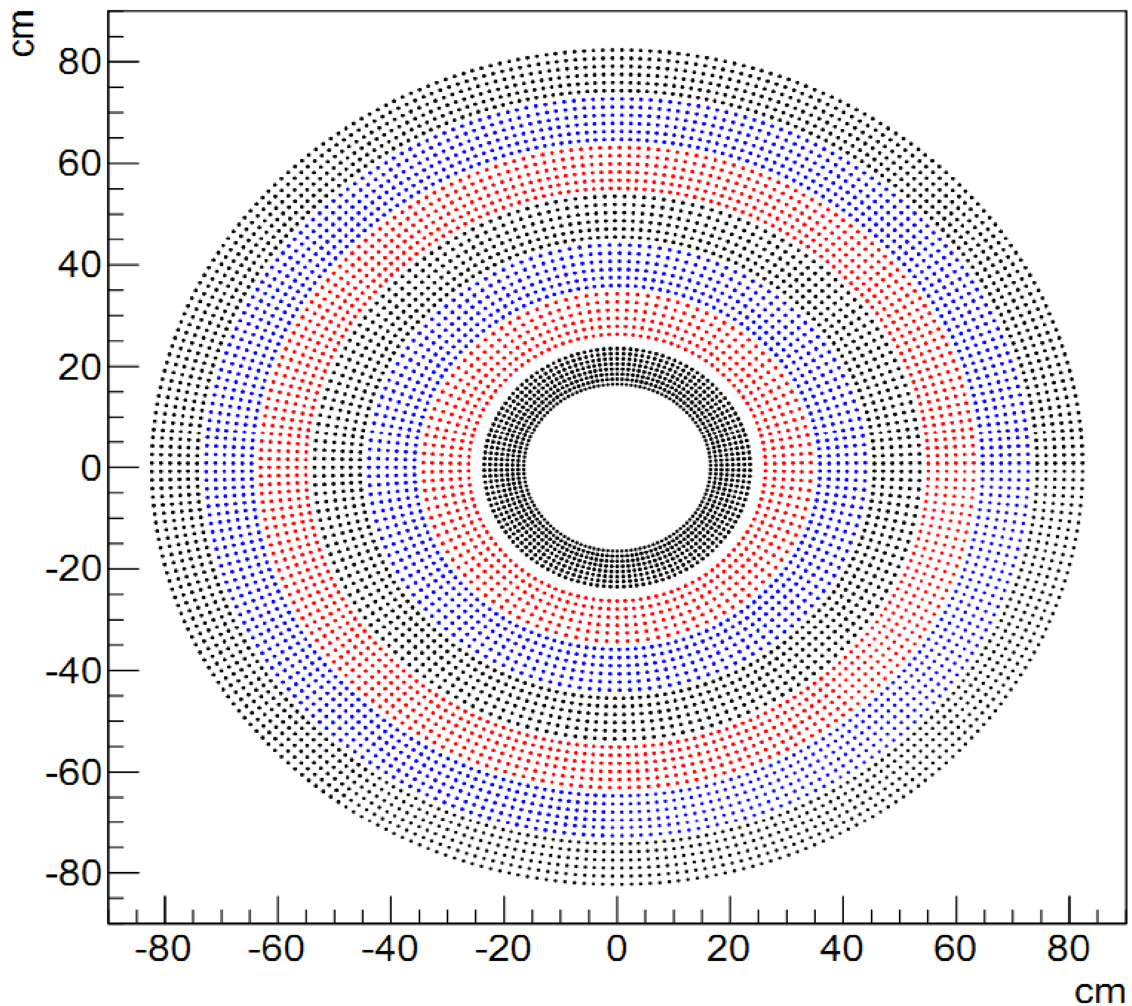


- 768 "Z" strips
- 225 mm radius, 0.529 mm pitch
- PCB thickness 200 μm
- Drift thickness 250 μm
- Drift Field 2.4kV on 3 mm gap
- 0.37% of X0

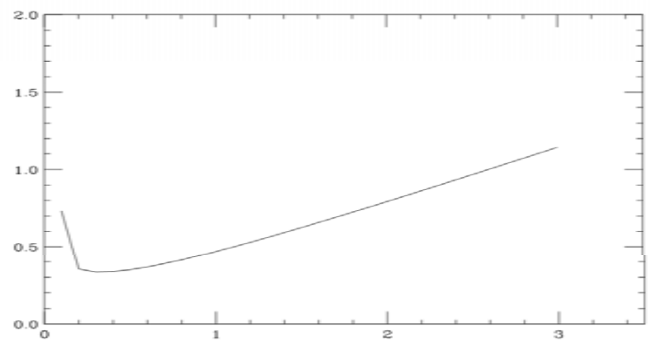




Outer Tracker: A Drift Chamber



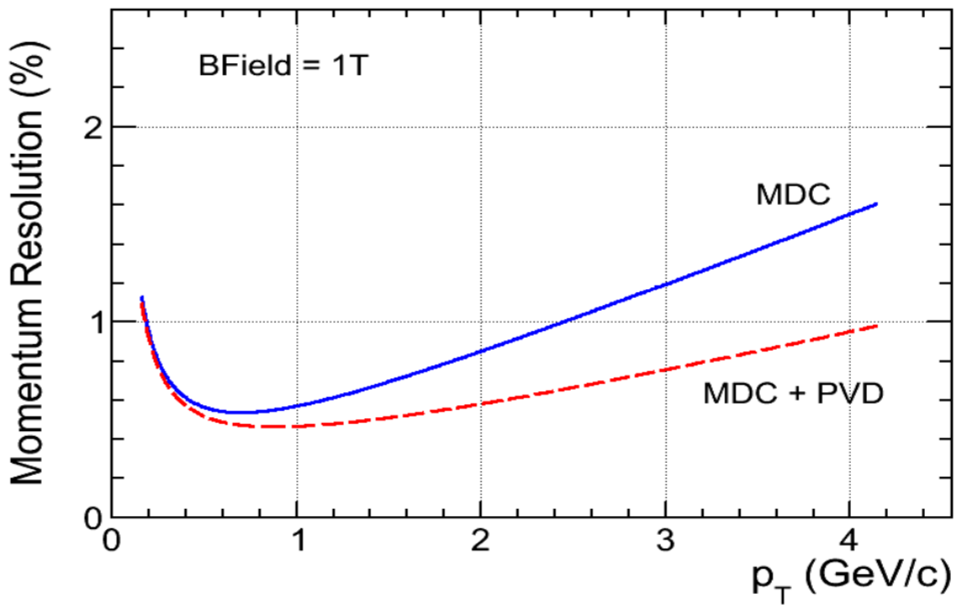
- Rin = 15 cm, Rout = 85 cm, L = 2.4 m
- B = 1 T
- He/C_2H_6 (60/40)
- Cell size =1.0cm(inner),1.6cm(outer)
- Sense wire: 20 um W
- Field wire: 110 um Al
- # of layers = 44
- Layer configuration: 8A-6U-6V-6A-6U-6V-6A
- Carbon fiber for both inner and outer walls
- Expected spatial resolution: <130μm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

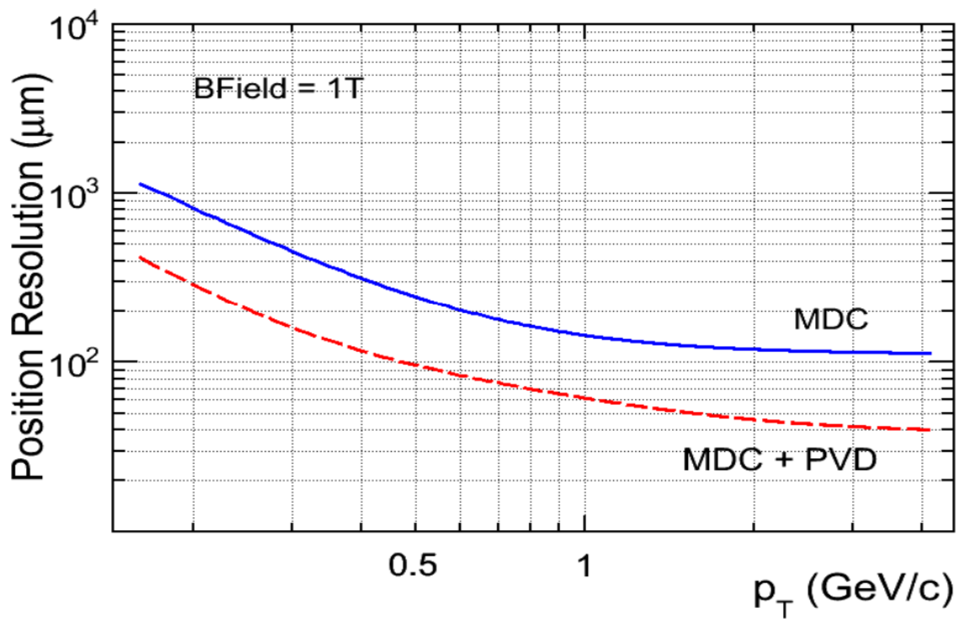


Combination of inner and outer trackers

MDC + Belle-II PXD

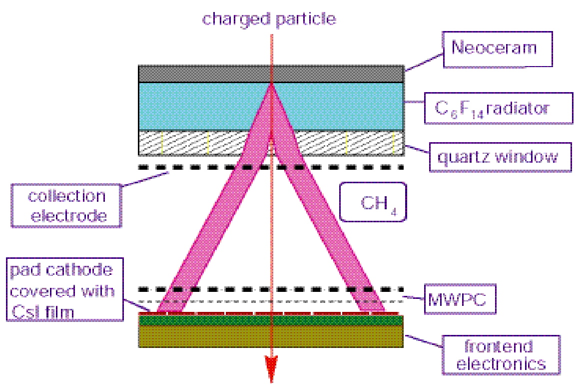
Detector	radius (cm)	material (%X_0)	resolution (μm)
MDC Outer 9-48	23.5-82	0.0045 /layer	130
MDC Inner 1-8	15-22	0.0051 /layer	130
PXD 3rd layer	10	0.15	50
PXD 2 layers	3/6	0.15 /layer	50
Beam pipe	2	0.15	–

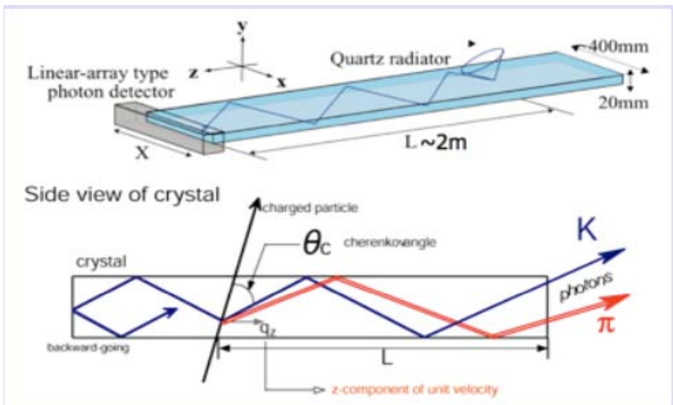


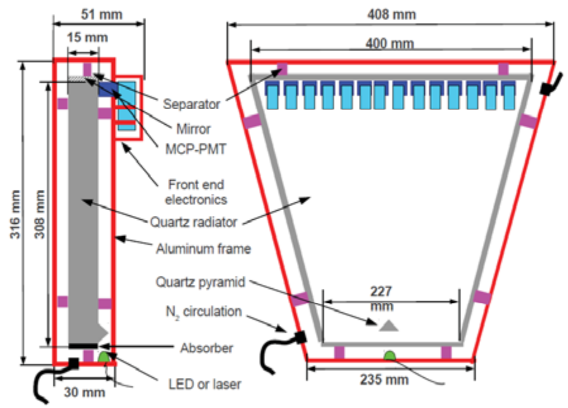


PID Detector

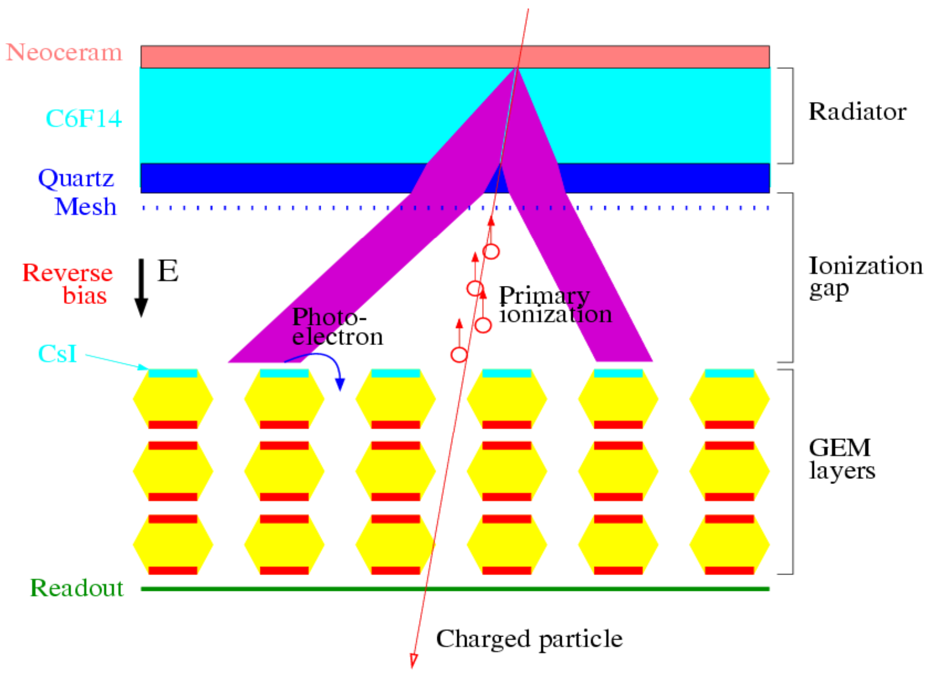
- π/K separation up to 2GeV.
  - Cherenkov-based technology is favorable.
  - Very low p region covered by trackers through dE/dx
- Compact (<20cm) and low mass (<0.5X_0)
- Detector options
  - RICH, DIRC-like

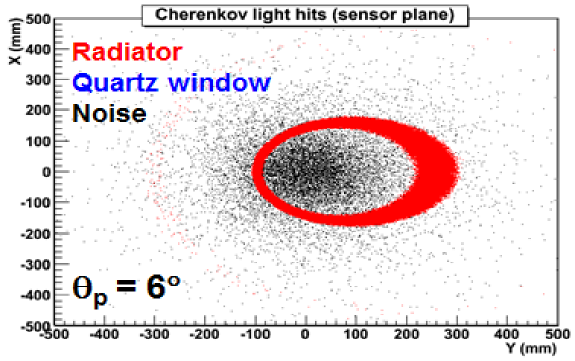


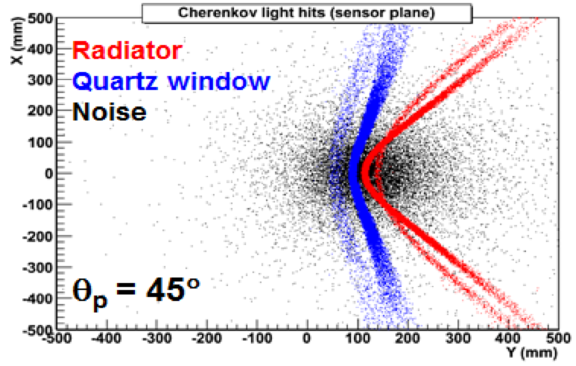


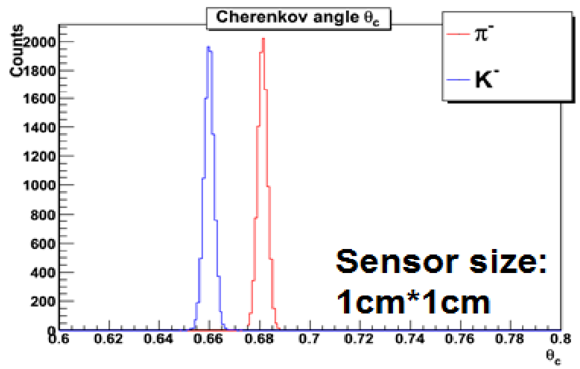


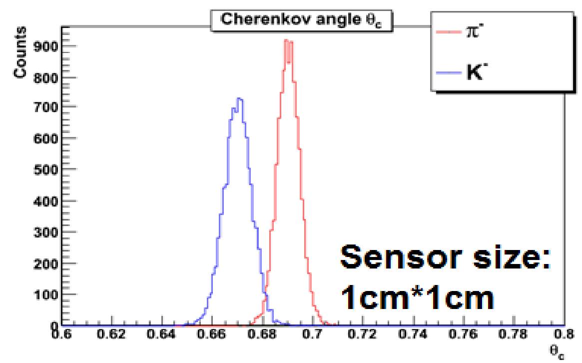
Performance Simulation



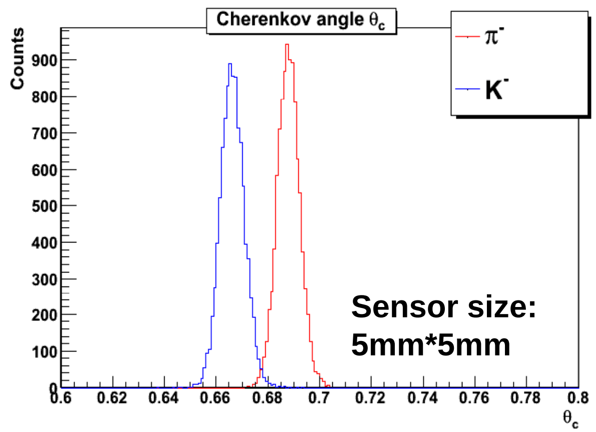








The π/K separation requirement can be met with a RICH detector.



EMC

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

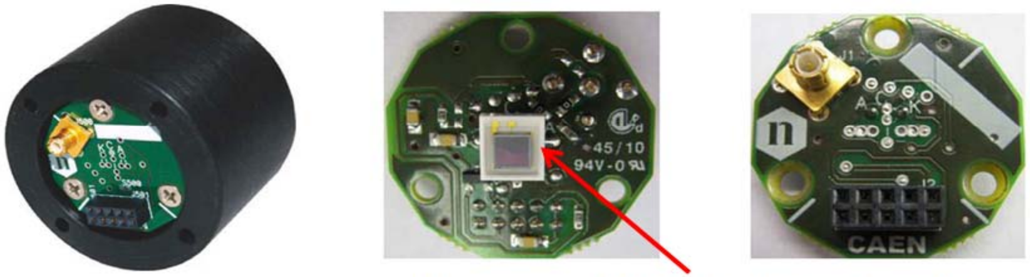
Crystal Options

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)

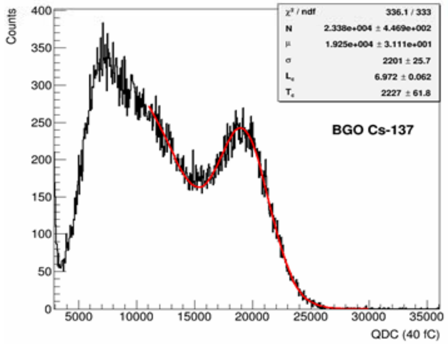
Different options for barrel and endcaps

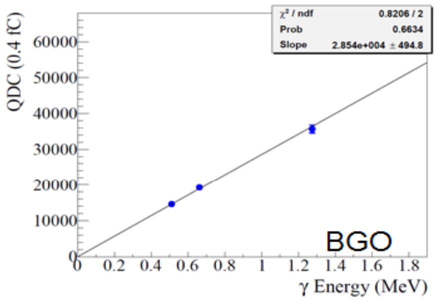
SiPM Technology

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



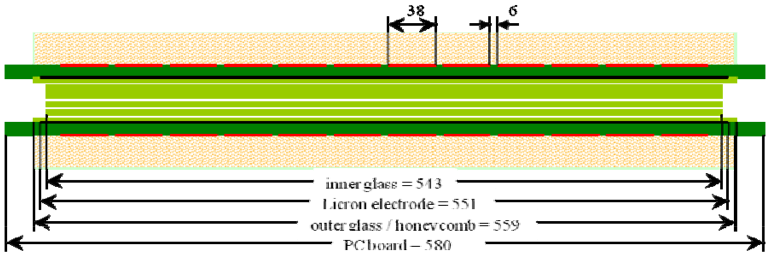
Hamamatsu S10362-33-050C, 3x3 mm^2



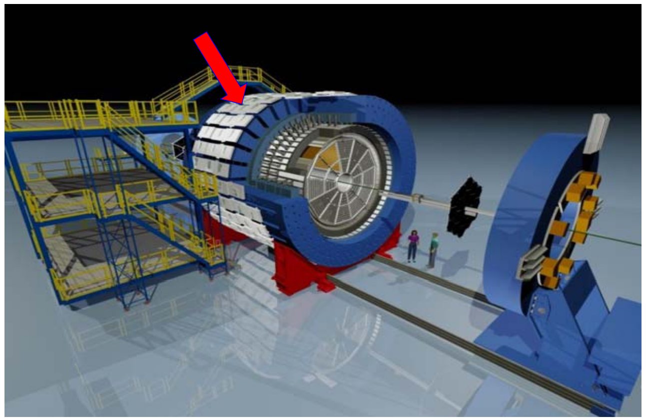


Muon Detector

- 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

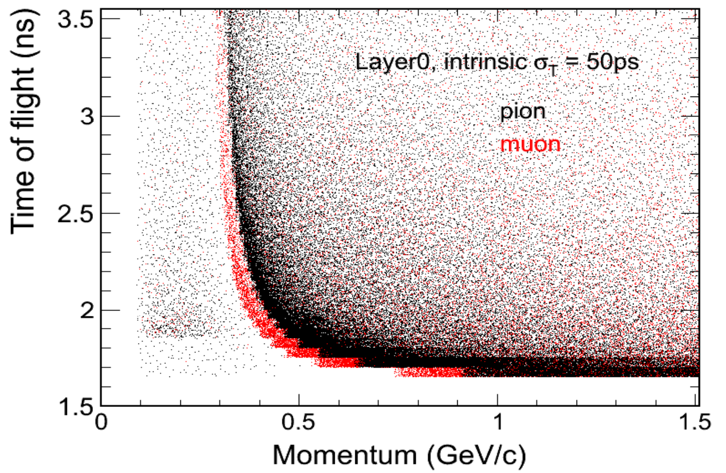
- Active area: 87 x 52 cm^2
- Read out strip: 87 cm x 3.8 cm
- Gas gaps: 0.25 mm x 5

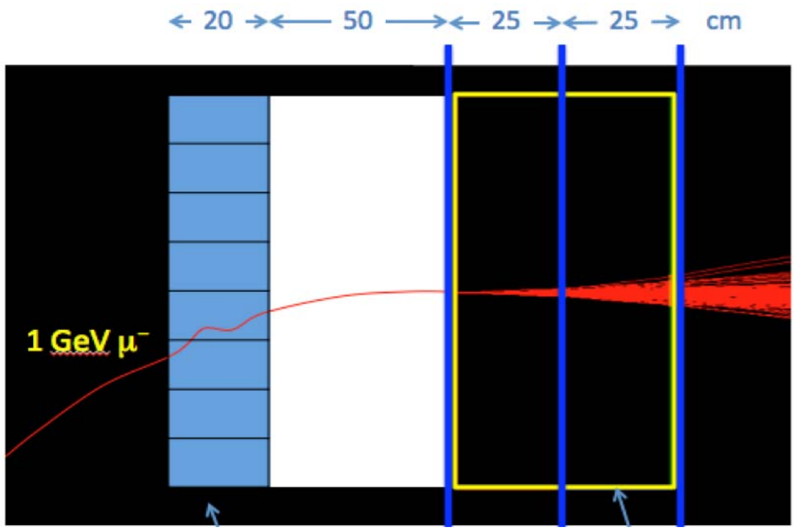
Performance:

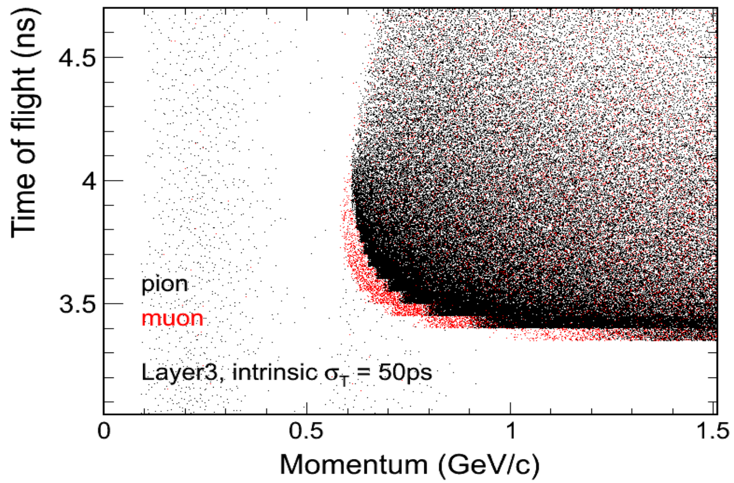
- Efficiency: > 98%
- Time resolution: < 80 ps
- Spatial resolution: 0.6 cm

μ/π separation power

- Inner: 3 MRPC layers
  - for precise timing
- Outer: 8 RPC layers







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

Summary

- BEPC(II)/BES(II)(III) have accomplished significant achievements in particle physics with world impact, and established China's strong position in τ-c physics in the world.
- Still very rich and yet unexplored physics in the τ-c regime with lots of pressing fundamental questions to be addressed.
- HIEPA would be a natural and yet much enhanced extension of BEPCII to continue with the success of BEPC(II) to fully explore the physics in the τ-c regime.
  – A possible option for a post-BEPCII HEP project in China

HEP Strategy Discussion in China

- The high energy physics association of China has organized 6 workshops dedicated to discussion on strategy for future development of China’s accelerator-based high energy physics in the past few years
  - Three options: CEPC, SZF, HIEPA
- Consensus reached in the latest strategy discussion
  - CEPC (incorporating SZF) is the first priority
  - Chinese HEP community should work together aiming to make CEPC eventually an international HEP project launched by China.
  - BEPCII/BESIII should be fully exploited (including upgrading the existing facilities in a proper way) in the process of achieving the above strategic goal.