BESIII Prospects

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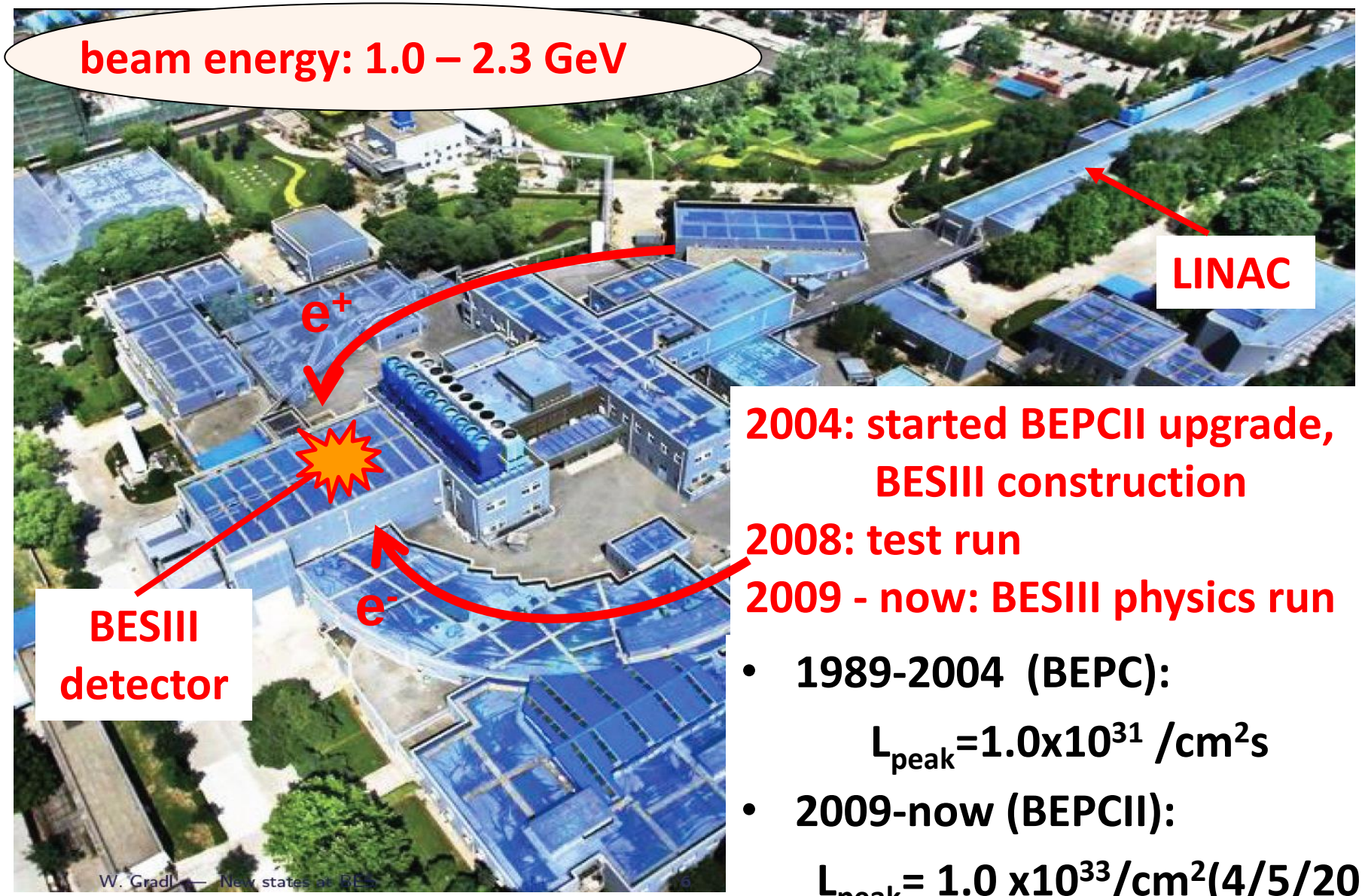
Outline

- Introduction
- Status of BESIII
- Highlights of BESIII
- Upgrade plan and physics prospects
- Summary

Beijing Electron Positron Collider (BEPC)



2004: started BEPCII upgrade, BESIII construction

2008: test run

2009 - now: BESIII physics run

- 1989-2004 (BEPC):

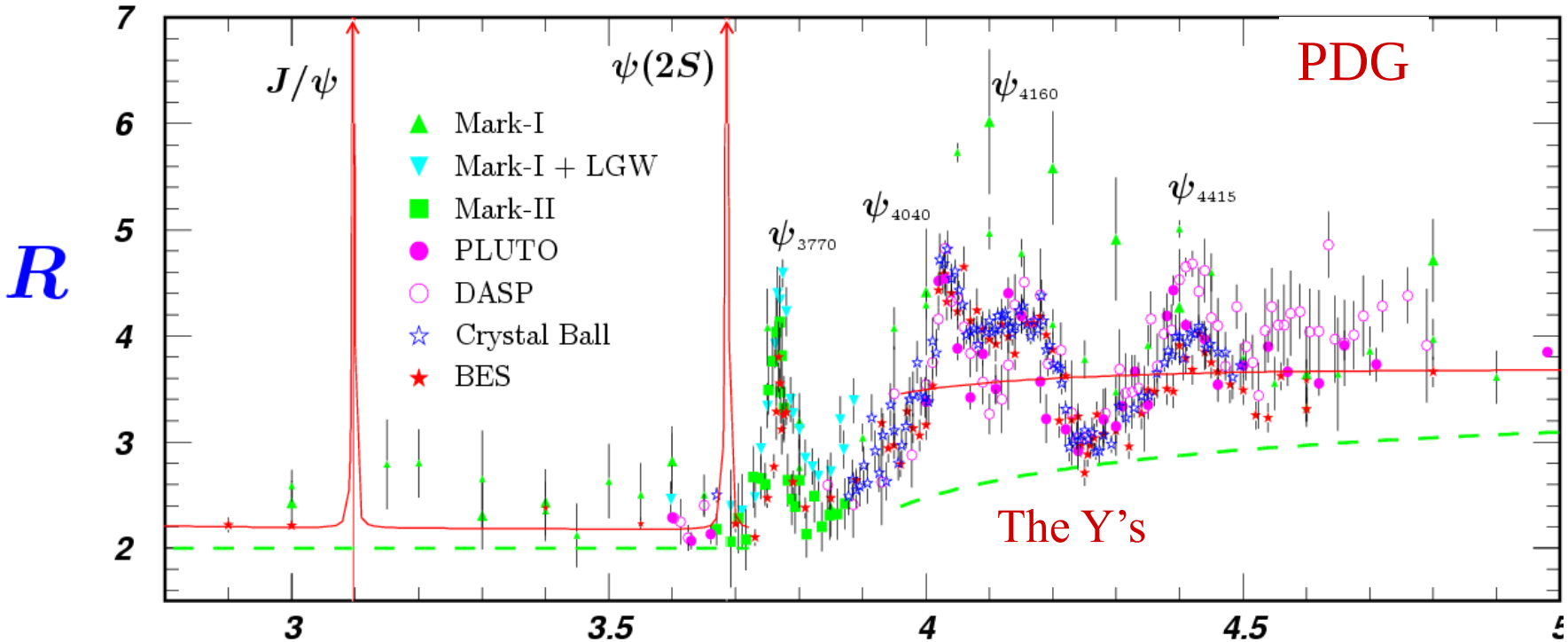
  $L_{peak}=1.0\times10^{31}\ /cm^2s$

- 2009-now (BEPCII):

  $L_{peak}= 1.0\times10^{33}/cm^2$(4/5/2016)

Features of the BEPC Energy Region

- Rich of **resonances:** charmonia and charmed mesons
- **Threshold** characteristics (pairs of τ, D, D_s, …)
- **Transition between** smooth and resonances, perturbative and non-perturbative QCD
- Energy location of the **new hadrons: glueballs, hybrids, multi-quark states**

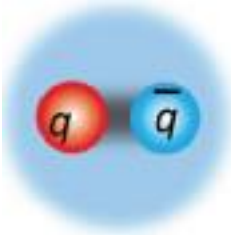


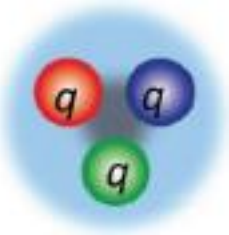
New forms of hadrons

- **Conventional hadrons consist of 2 or 3 quarks：**

Naive Quark Model：

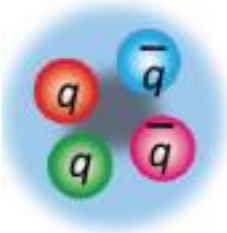
meson



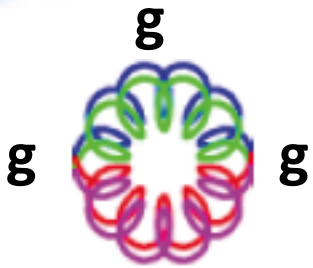


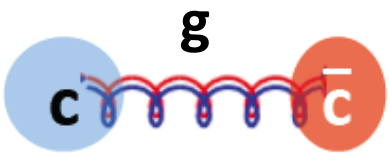
baryon

- **QCD predicts the new forms of hadrons:**
  - Multi-quark states： Number of quarks >＝ 4



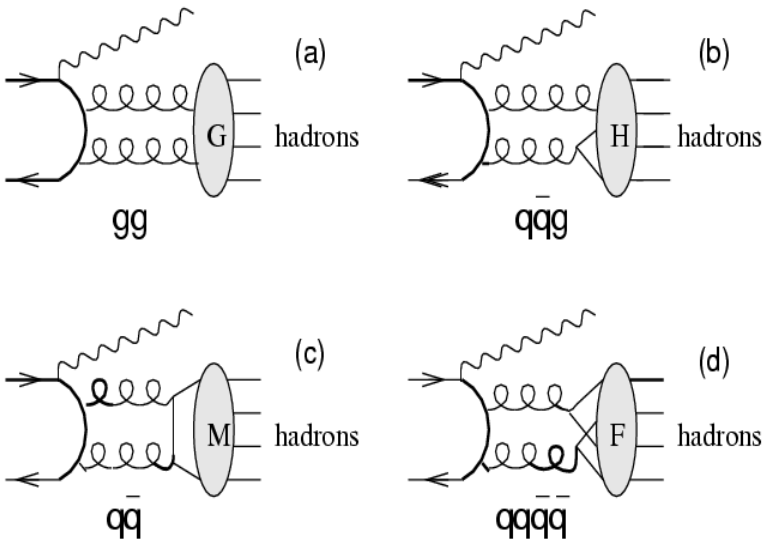
  - Hybrids： $q\bar{q}g$， qqqg …
  - Glueballs： gg， ggg …





None of the new forms of hadrons is settled !

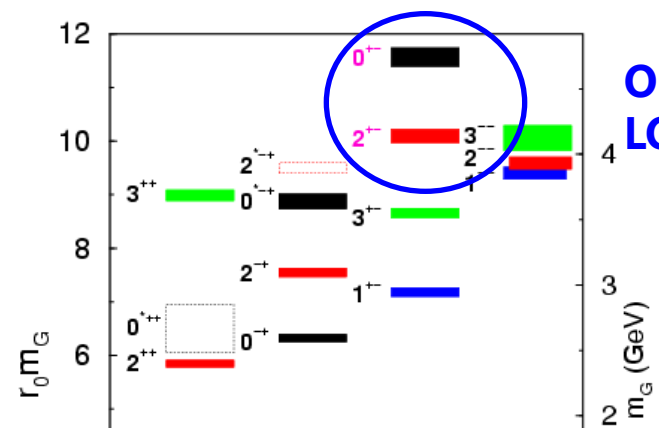
Charmonium decays provide ideal hunting ground for light glueballs and hybrids



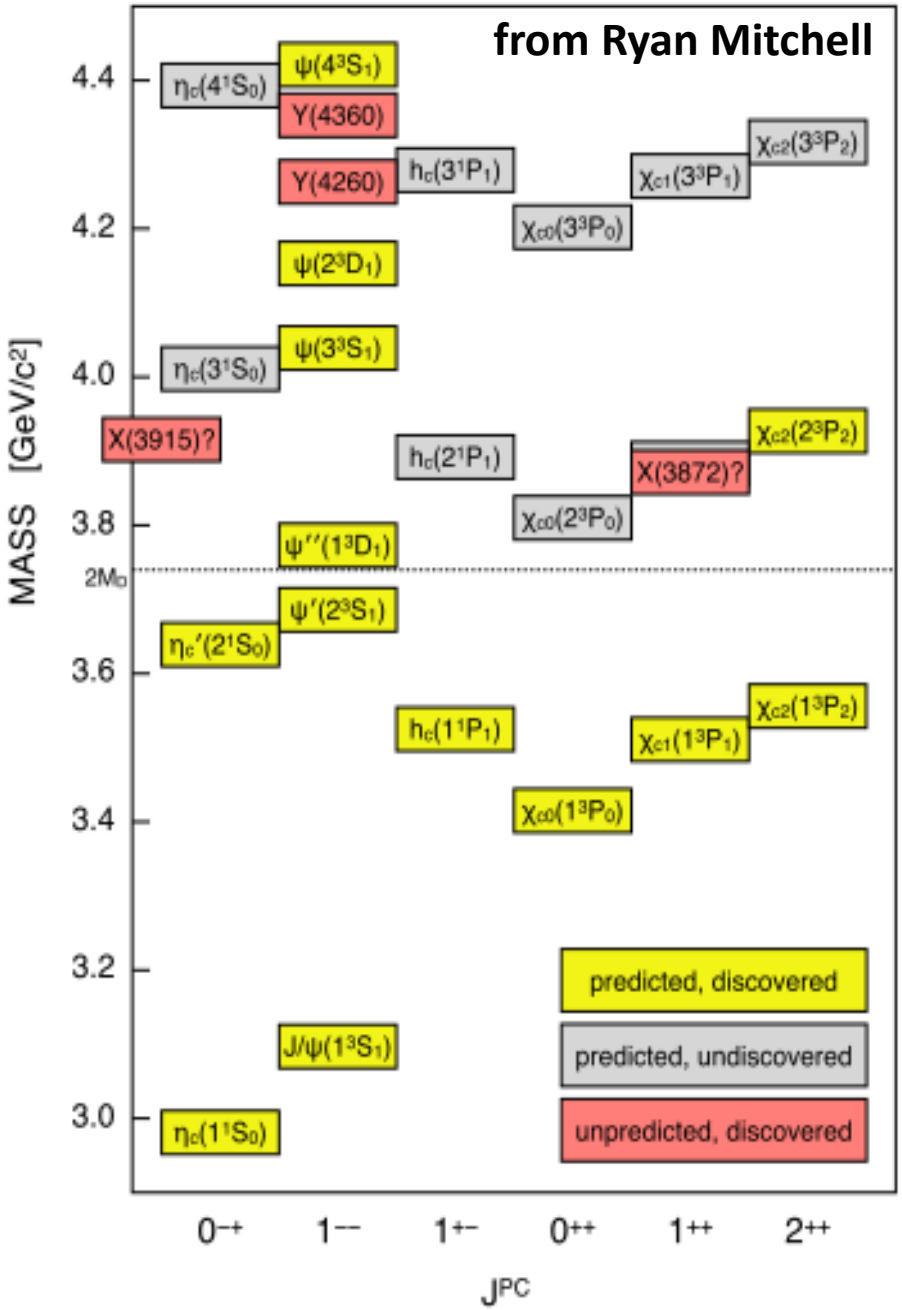
$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2), \Gamma(J/\psi \to \gamma H) \sim O(\alpha\alpha_s^3),$

$\Gamma(J/\psi \to \gamma M) \sim O(\alpha\alpha_s^4), \Gamma(J/\psi \to \gamma F) \sim O(\alpha\alpha_s^4)$

- "Gluon-rich" process
- Clean high statistics data samples from e+e- annihilation
- $I(J^{PC})$ filter in strong decays of charmonium



Odd-balls in LQCD



Charmonium spectroscopy

- Charmonium states below open charm threshold are all observed

Above open charm threshold:

- many expected states not observed
- many unexpected observed

Z(4430)
Z(4250)
Z(4050)
Z(3900)

X(3872)

XYZ(3940)

X(3915)
X(4160)
Y(4008)
Y(4140)
Y(4260)
Y(4360)
X(4350)
Y(4660)

Precision measurement of CKM elements
-- Test EW theory

CKM matrix elements are fundamental SM parameters that describe the mixing of quark fields due to weak interaction.

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

CKM matrix

BESIII + B factories + LQCD

Three generations of quark?

Unitary matrix?

Expected precision < 2% at BESIII

BESIII + B factories + LHCb + LQCD

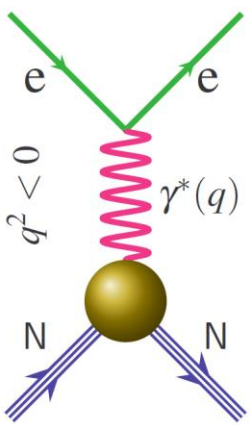
Precision measurement of CKM matrix elements
-- a precise test of SM model
New physics beyond SM?

Nucleon Form Factor

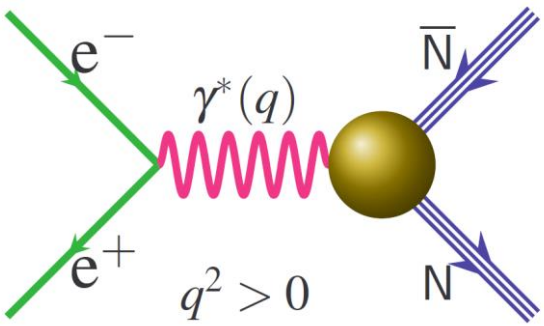
- **Fundamental properties of the nucleon**
  - **Connected to charge, magnetization distribution**
  - **Crucial testing ground for models of the nucleon internal structure**
  - **Necessary input for experiments probing nuclear structure, or trying to understand modification of nucleon structure in nuclear medium**
- **Can be measured from space-like processes (eN) (precision 1%) or time-like process (e^+e^- annihilation) (precision 10%-30%)**

eN → eN

Space-like:
FF real



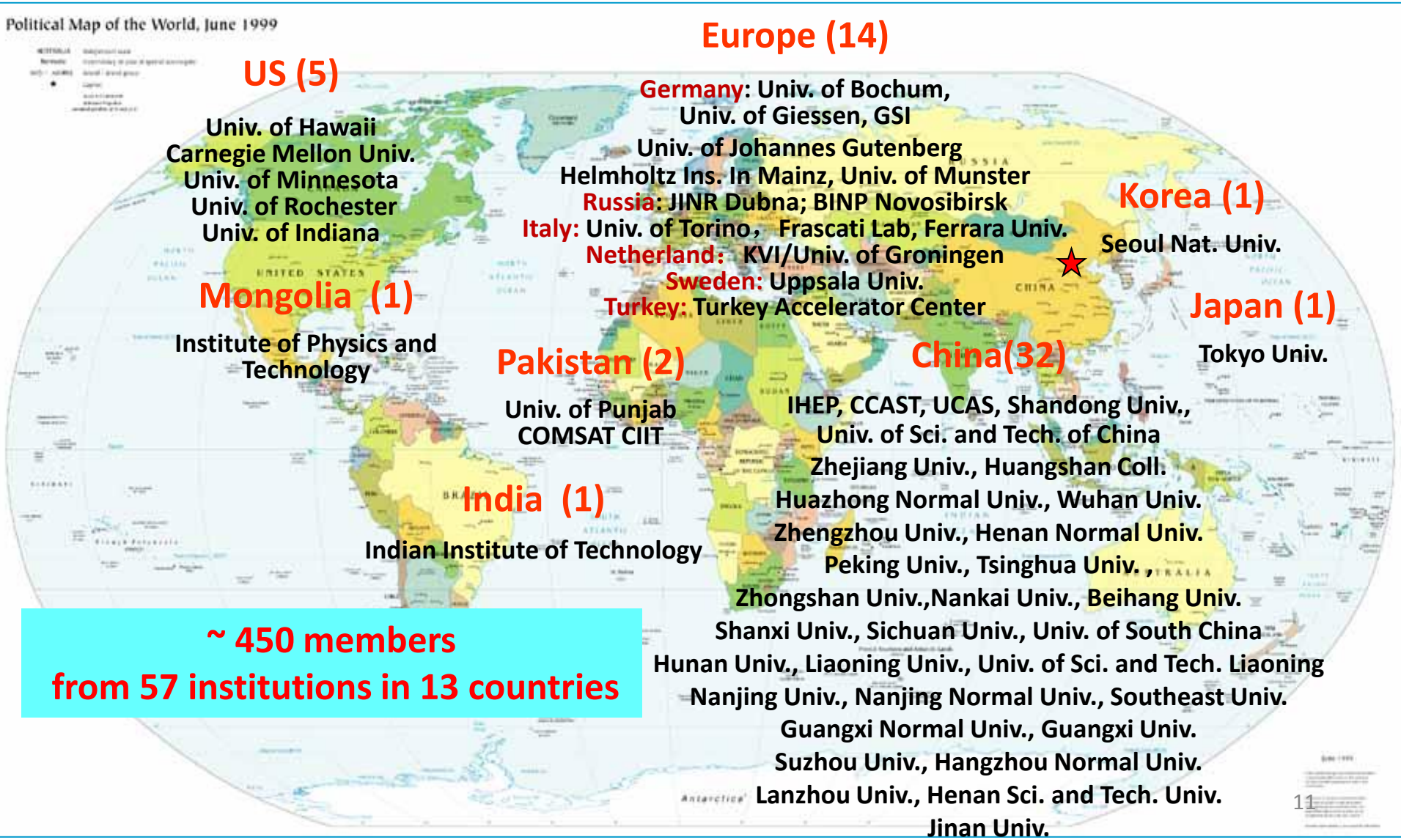
$e^+e^- \leftrightarrow N\bar{N}, \Lambda\bar{\Lambda}$



Time-like:
FF complex

Status of BESIII

BESIII Collaboration



US (5)

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

Mongolia (1)

Institute of Physics and Technology

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

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

India (1)

Indian Institute of Technology

Korea (1)

Seoul Nat. Univ.

Japan (1)

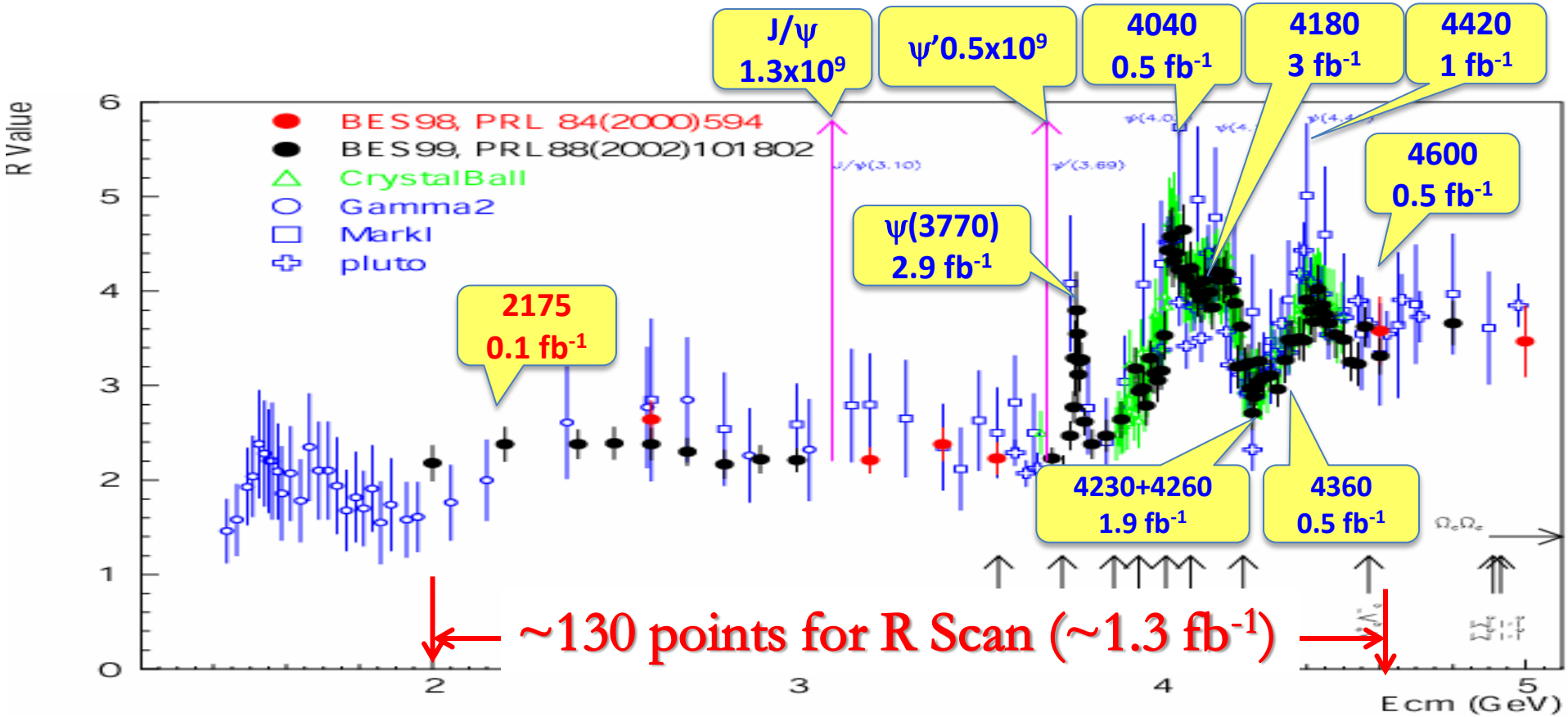
Tokyo Univ.

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

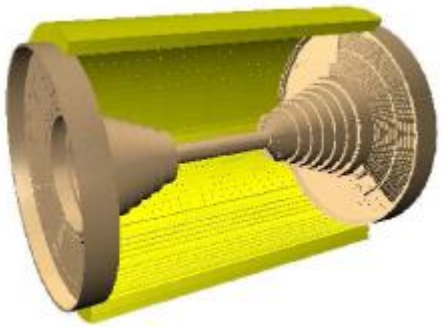
BESIII data samples



World largest J/ψ, ψ(2S), ψ(3770), ψ(4180), Y(4260), …
produced directly from e^+e^- collision

BESIII Detector

MDC

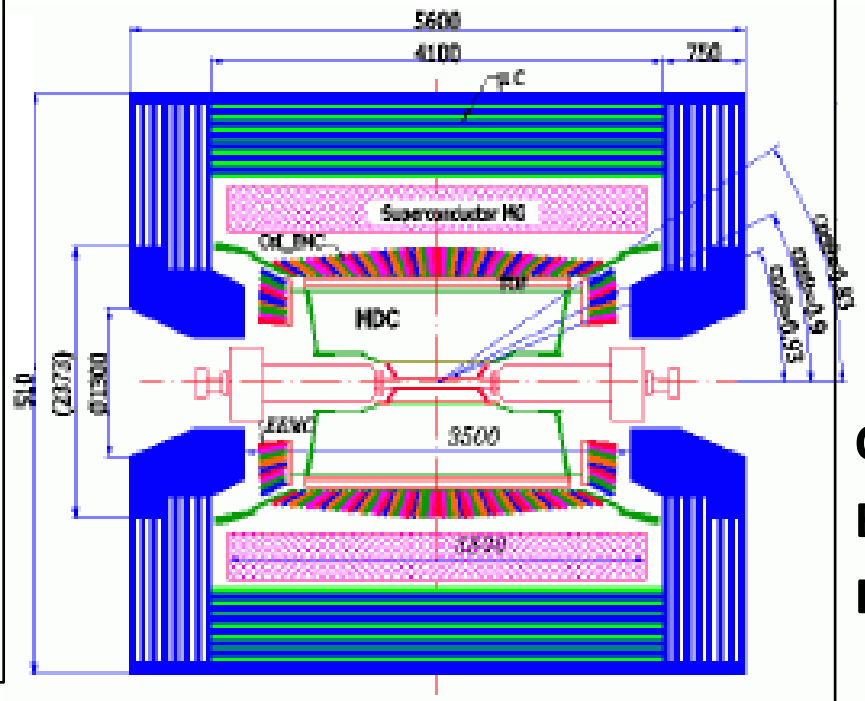


R inner: 63mm ;

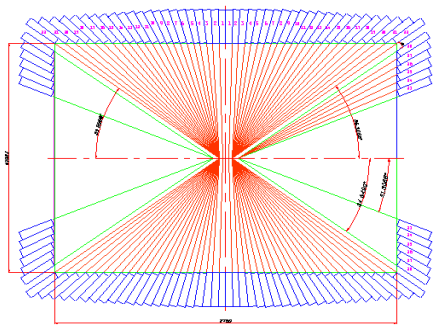
R outer: 810mm

Length: 2582 mm

Layers: 43



CsI(Tl) EMC



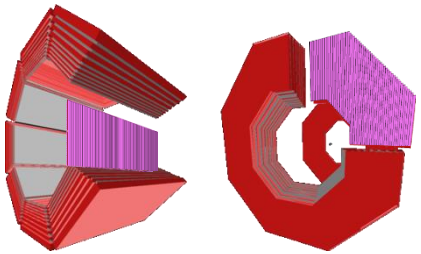
Crystals: 28 cm(15 X_0)

Barrel: $|\cos\theta|<0.83$

Endcap:

$0.85 < |\cos\theta| < 0.93$

RPC MUC



BMUC: 9 layers – 72 modules

EMUC: 8 layers – 64 modules

TOF

BTOF: two layers

ETOF: 48 scintillators for each

MRPC --- new ETOF

BESIII Detector Performance

Exps.	MDC Spatial resolution	MDC dE/dx resolution	EMC Energy resolution
CLEOc	110 μm	5%	2.2-2.4 %
Babar	125 μm	7%	2.67 %
Belle	130 μm	5.6%	2.2 %
BESIII	115 μm	<5% (Bhabha)	2.4%

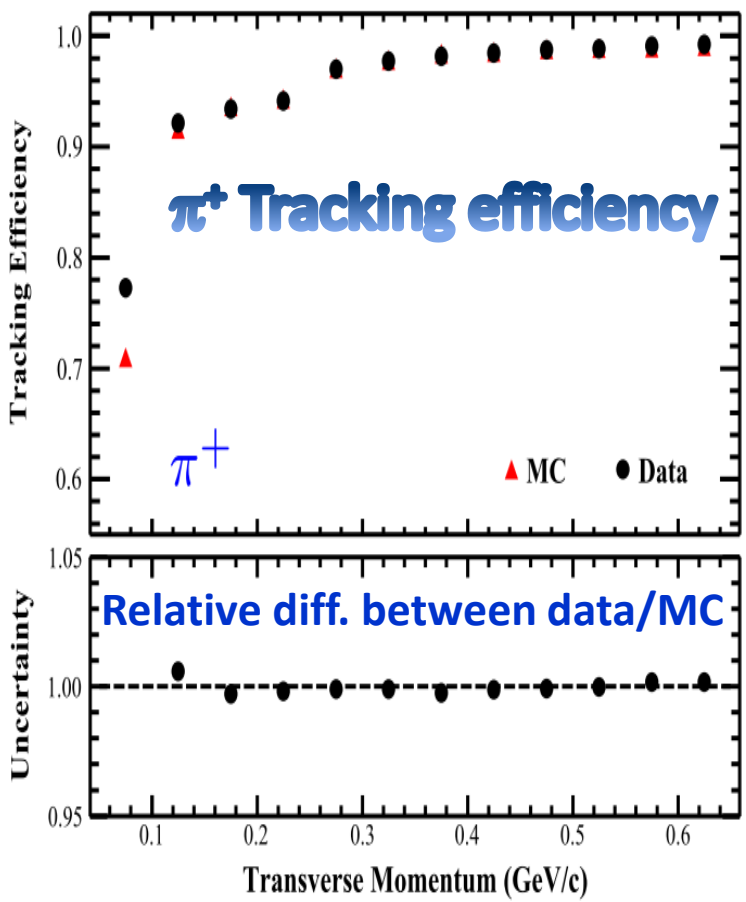
Exps.	TOF Time resolution
CDFII	100 ps
Belle	90 ps
BESIII	68 ps (BTOF) 60 ps (ETOF)

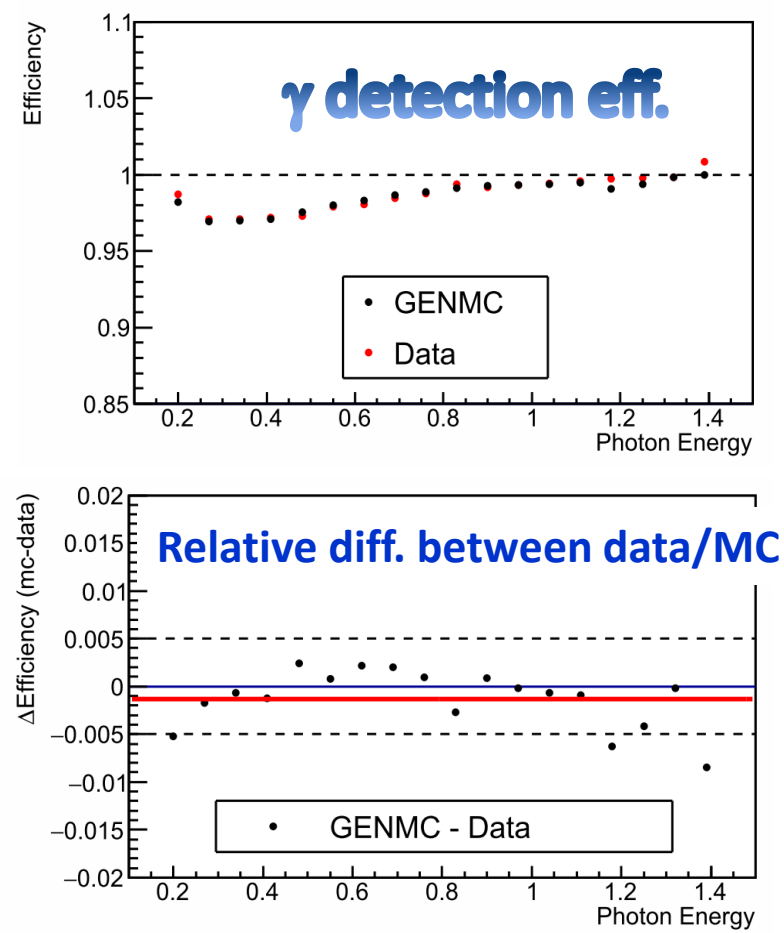
MUC: Efficiency ~ 96%

BG level: < 0.04 Hz/cm^2(B-MUC), < 0.1 Hz/cm^2(E-MUC)

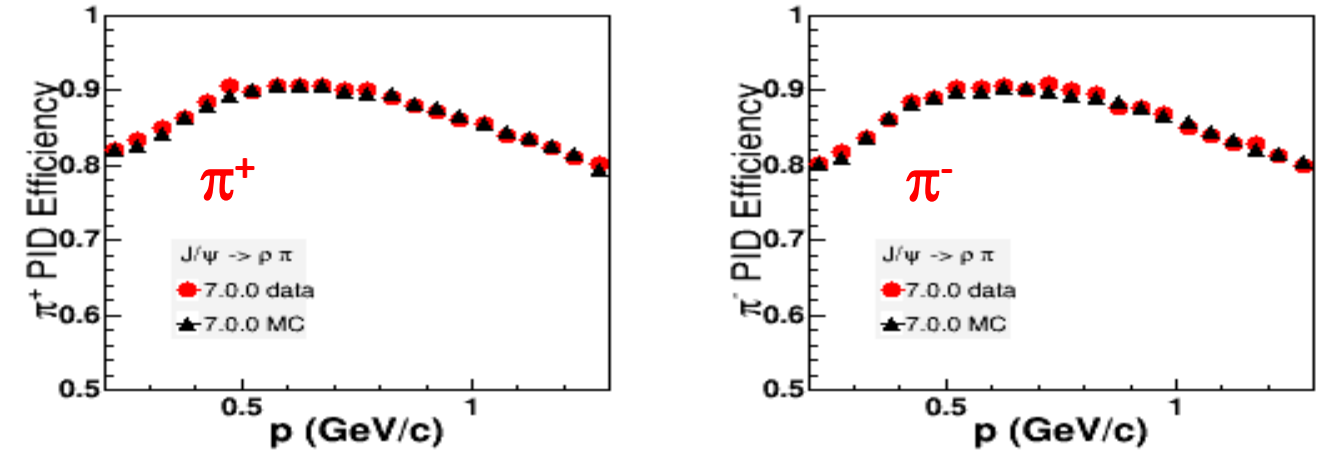
Data/Monte-Carlo Consistency

- For tracking efficiency data/MC difference < 1%
- For photon detection efficiency data/MC difference < 1%

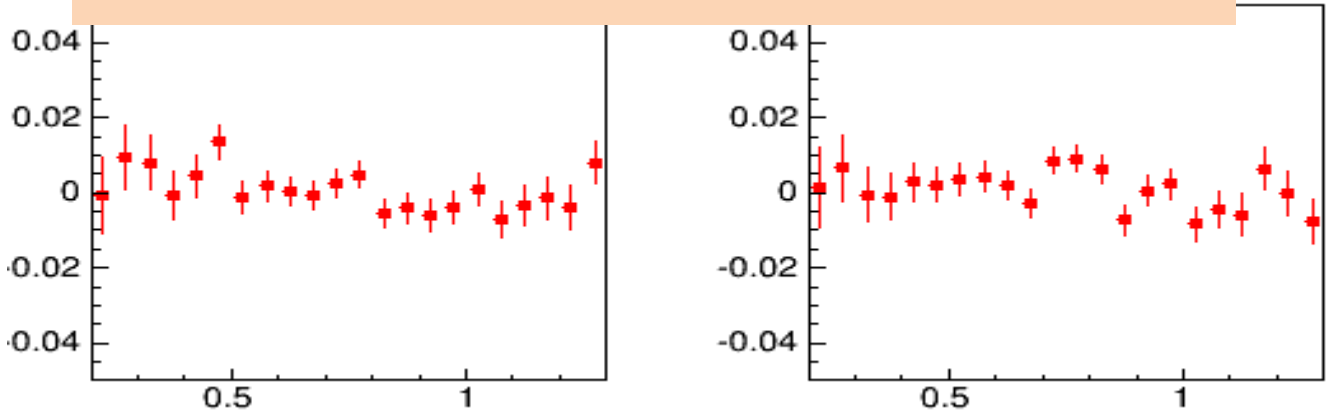




- **For particle identification efficiency, data/MC difference <2% (BTOF+ dE/dx)**



Relative difference between data and MC



Selected BESIII highlights

- **Hadron spectroscopy**
  - **XYZ**
  - **Light hadron spectroscopy**
- **Λ_c absolute branching fractions**

(For more results and details, please see other BESIII talks at this workshop)

6 plenary:

Gang Rong (IHEP): Leptonic, semi-leptonic and rare decays at BESIII

Xiaorui Lyu (UCAS): Overview on charm baryons decays (BESIII, LHCb, ...)

Yutie Liang (Giessen U.): Charmonium and Exotics Production and Spectroscopy at BESIII

Minggang ZHAO (NKU): CP Violation, Mixing and non-leptonic decays at BESIII

Jake Bennett (Minnesota U.): Amplitude analyses (BESIII and B factories)

12 parallel:

Jianbin Jiao (SDU): Study of decay psi(1S,2S) -> baryon pairs

Liang Yan (Torino): Hadronic transitions above 4 GeV at BESIII

Ronggang Ping (IHEP): Radiative transitions above 4 GeV at BESIII

Elisa Fioravanti(Ferrara): Studies of charmonium decays at BESIII

Guang Zhao (IHEP): Ds physics at BESIII

Zhenglei Dou (NJU): Study of D0(+) -> P (P=Peudecalor) e+ nu at BESIII

Lei Zhang (TSU): Study of D0(+) to V (V=Vector) e+ nu at BESIII

Yu Lu (IHEP): Amplitude analysis of D0 to K-pi+pi+pi- and measurements of D two body decays

Wenjing Zheng (SDU): Measurements of CP asymmetries of D+ to KS/L X

Jingyi Zhao (IHEP): Non-DD-bar decays of psi(3770)

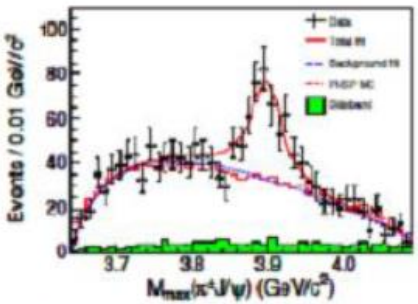
Binlong Wang (UCAS): Hadronic decays of Lamda_c

Fengyun Li (PKU): Search for low-mass new physics at BESIII

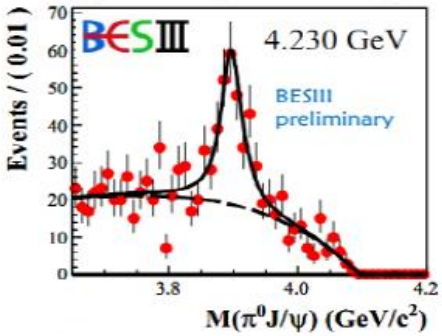
1 poster

Giulio Mezzadri (Ferrara): Measurement of the relative phase between strong and electromagnetic decay amplitudes of Charmonia at BESIII

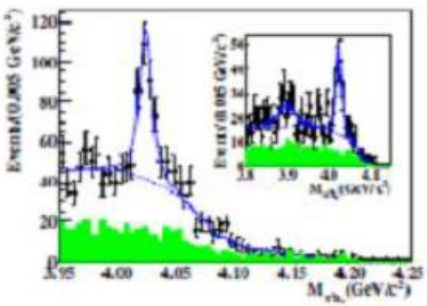
Summary of Zc's at BESIII



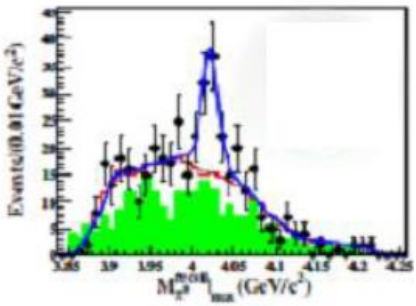
$e^+e^- \to \pi^-\pi^+ J/\psi$



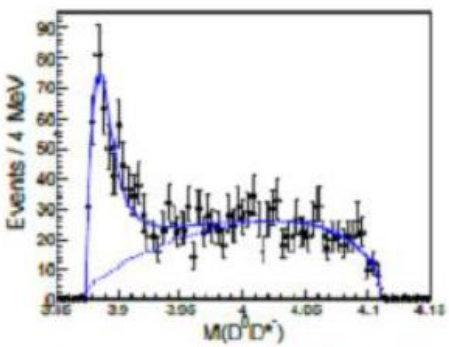
$e^+e^- \to \pi^0\pi^0 J/\psi$



$e^+e^- \to \pi^-\pi^+ h_c$

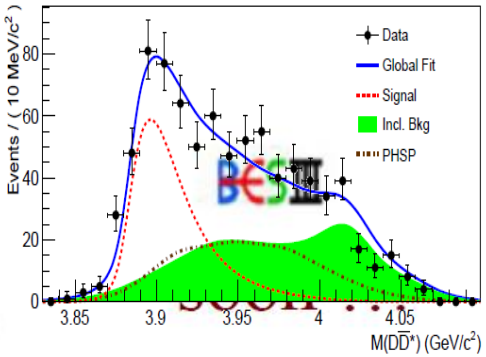


$e^+e^- \to \pi^0\pi^0 h_c$



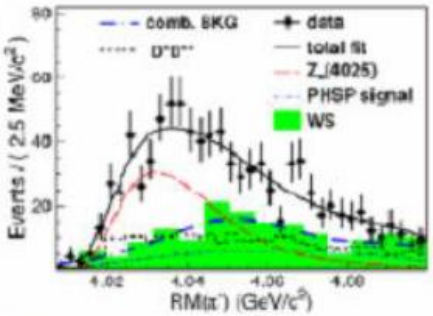
$e^+e^- \to \pi^-(D\bar{D}^*)^+$

$Z_c(3900)^+$?



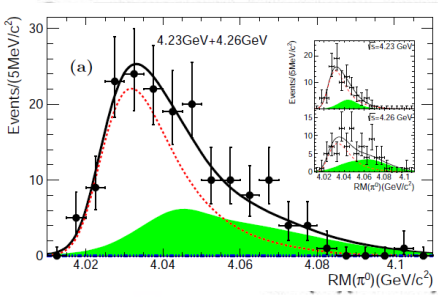
$e^+e^- \to (D\bar{D}^*)^0\pi^0$

$Z_c(3900)^0$?



$e^+e^- \to \pi^-(D^*\bar{D}^*)^+$

$Z_c(4020)^+$?



$e^+e^- \to \pi^0(D^*\overline{D^*})^0$

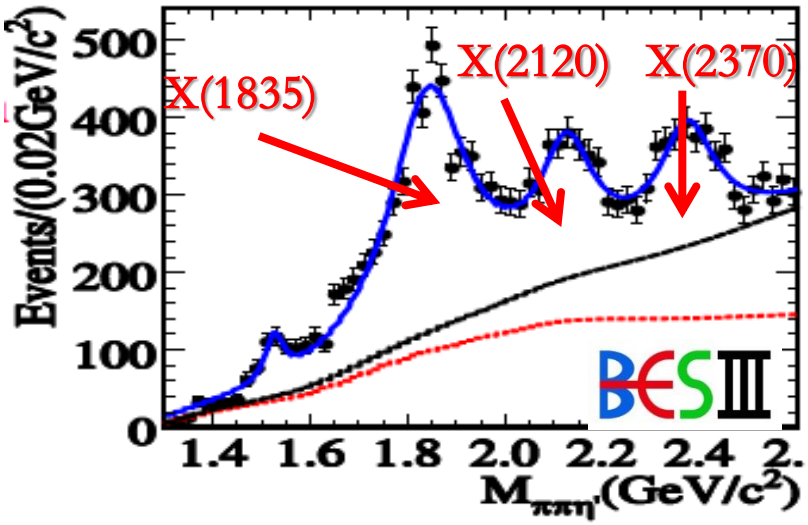
$Z_c(4020)^0$?

Summary of Zc's at BESIII

$Z_c^{\pm}(3900)$	$Z_c^{\pm}(4020)$
$e^+e^- \rightarrow \pi^+\pi^- J/\psi$ M=3899.0±3.6±4.9MeV Γ = 46±10±20 MeV	$e^+e^- \rightarrow \pi^+\pi^- h_c$ M= 4022.9±0.8±2.7MeV Γ = 7.9±2.7±2.6 MeV
Z_c^0 (3900)	**Z_c^0(4020)**
$e^+e^- \rightarrow \pi^0\pi^0 J/\psi$ M=3894.8±2.3 MeV Γ =29.6±8.2 MeV	$e^+e^- \rightarrow \pi^0\pi^0 h_c$ M=4023.9±2.2±3.8 MeV Γ Fixed at $Z_c^{\pm}$(4020)

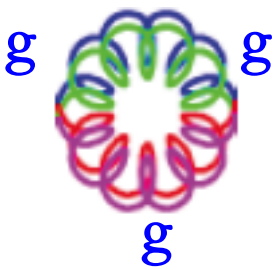
$Z_c^{\pm}(3885)$	$Z_c^{\pm}(4025)$
$e^+e^- \rightarrow \pi(D^*D)^{\pm}$ M=3882.2±1.1±1.5 MeV Γ =26.5±1.7±2.1 MeV	$e^+e^- \rightarrow \pi(D^*D^*)^{\pm}$ M= 4026.3±2.6±3.7 MeV Γ = 24.8±5.6±7.7 MeV
Z_c^0(3885)	**Z_c^0(4025)**
$e^+e^- \rightarrow \pi^0(D^*D)^0$ M=3885.7±5.7±8.4 MeV Γ = 35±12±15 MeV	$e^+e^- \rightarrow \pi^0(D^*D^*)^0$ M= 4025.5±4.7±3.1 MeV Γ = 23.0±6.0 ±1.0MeV

2013: BESIII confirmed X(1835) and observed X(2120) & X(2370)



BESIII:

PRL. 108 (2011)112003

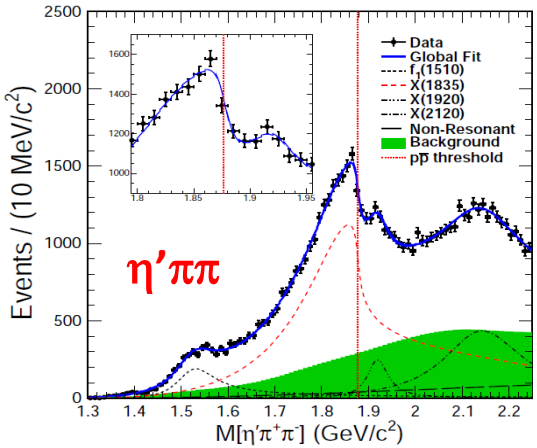


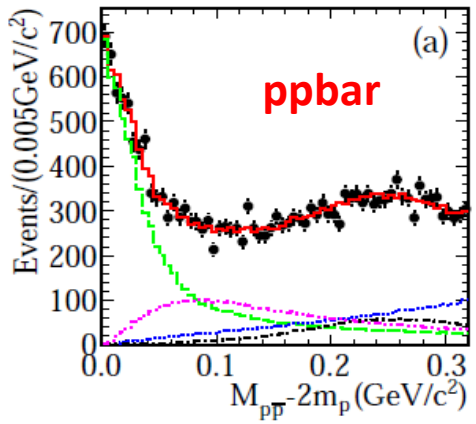
- spin-parity ?
- more decay modes?

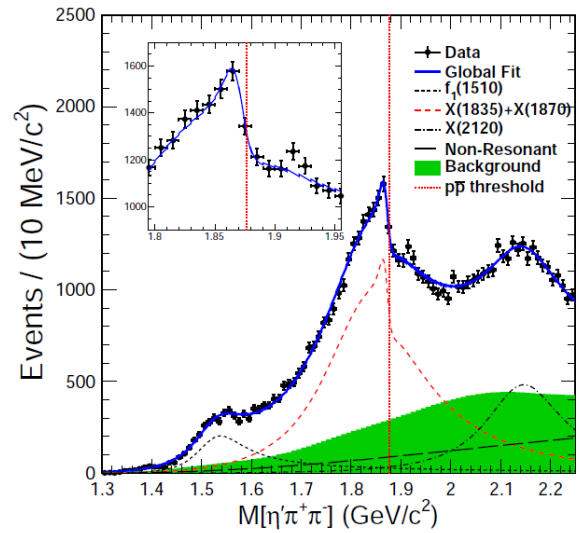
- First observation of high mass resonances in J/ψ radiative decays
- LQCD predicts 0^{-+} glueball to be at 2.4 GeV/c^2.
- X(2120)/X(2370) ?
  - ✓ 0^{-+} glueball?

- Nature of X(2120)/X(2370) ? 0^{-+} glueball ?
- X(1835) ? multi-quark state?

X(1835) lineshape: significant distortion





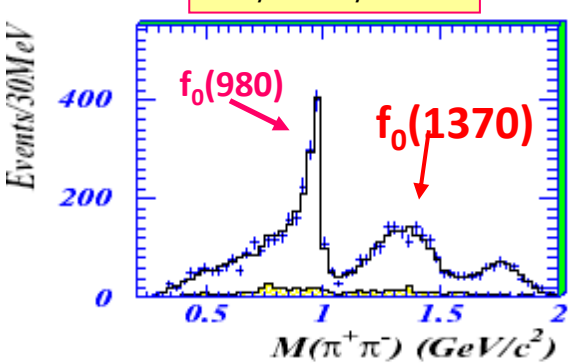


Flatte formula:
X(1835) → ppbar, η'ππ
Strong coupling to ppbar
X(1920) significant

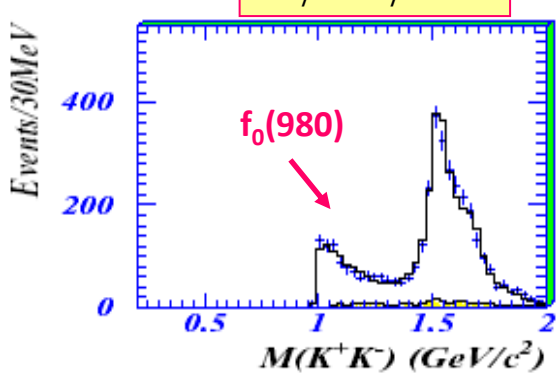
Coherent sum
of two BWs
X(1835)+X(1870)

X(1920) not needed

$J/\psi \to \phi\pi^+\pi^-$



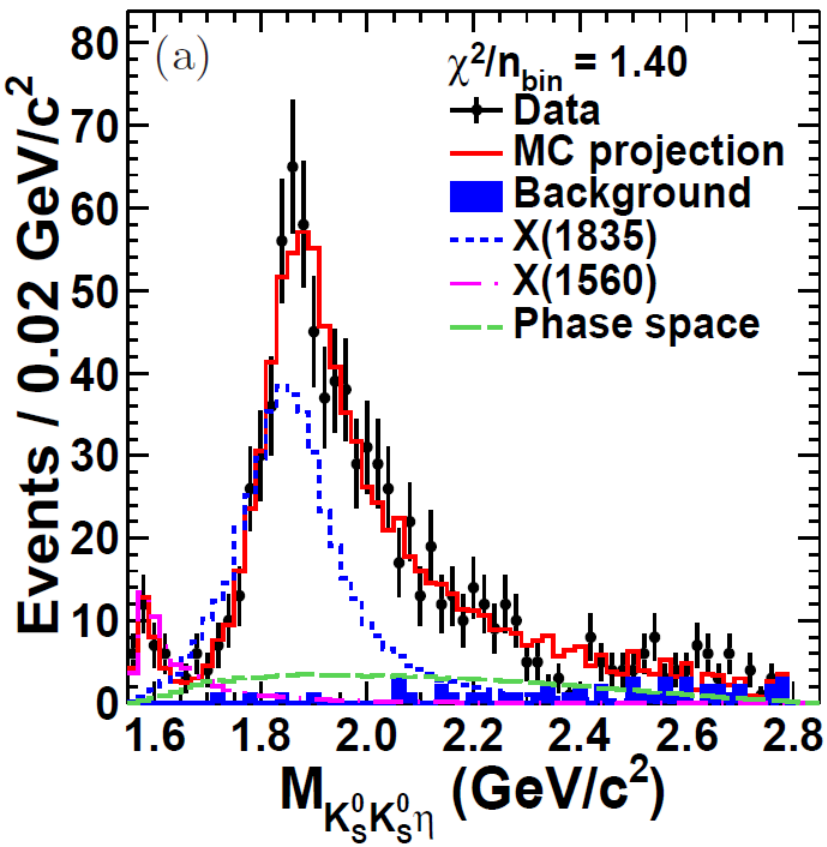
$J/\psi \to \phi K^+K^-$



PRL 117 (2016) 042002

Observation and spin-parity determination of X(1835) in $J/\psi \to \gamma K_s K_s \eta$

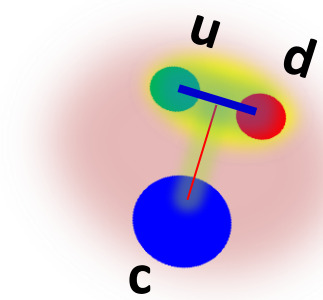
Phys. Rev. Lett. 115, 091803 (2015)



- Measure the spin-parity of X(1835) to be 0^{-+};
- Found new decay mode of X(1835)

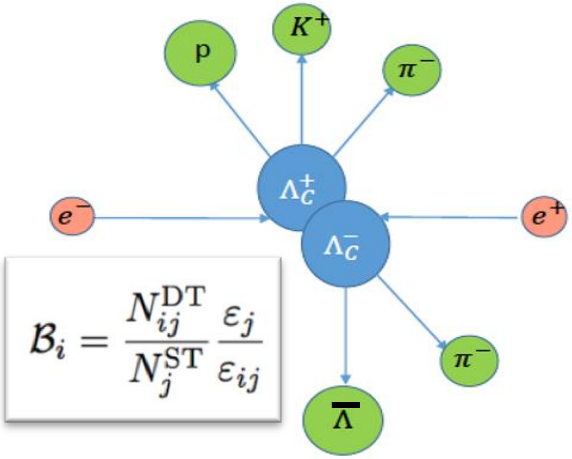
Λc^+ : the lightest charmed baryon

- Its property is crucial input for *b*- and *c*- baryons, as many of their decays go to Λc



- However, the experimental data are very old and in poor precisions.
  - ✓ Absolute BF of Λ_c^+ decays are still not well determined since its discovery 30 years ago.
    PDG2014: δB/B ~25%; BELLE2014: δB/B ~4.7%
  - ✓ Tagging technique @BESIII will provide *the most simple and straightforward measurement*
- BESIII accumulates 567/pb data near Λ_c^+ -pair threshold

Absolute BFs of Λ_c^+ hadronic decays



$$\mathcal{B}_i = \frac{N_{ij}^{\mathrm{DT}}}{N_j^{\mathrm{ST}}} \frac{\varepsilon_j}{\varepsilon_{ij}}$$

PRL 116, 052001 (2016)

567/pb @ 4.6 GeV

Mode	This work (%)	PDG (%)	BELLE $\mathcal{B}$
pK_S^0	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK_S^0\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0	
$\Lambda\pi^+$	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7	
$\Sigma^0\pi^+$	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28	
$\Sigma^+\pi^0$	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0	
$\Sigma^+\omega$	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0	

- **The absolute BF can be obtained by the ratio of double tag yields to single tag yields.**
- **a global least square fit to 12 hadronic modes**

[Chinese Phys. C37(2013)106201]

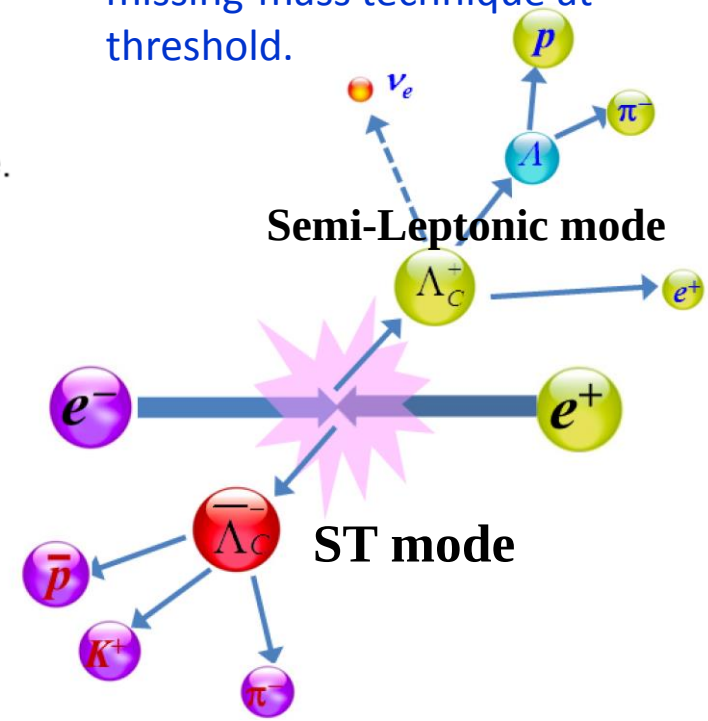
- ✓ **First direct measurement on Λc BFs at threshold**
- ✓ **$B(pK^-\pi^+)$: BESIII precision comparable with Belle's**
- ✓ **Improved precisions of the other 11 modes significantly**

BF for $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$

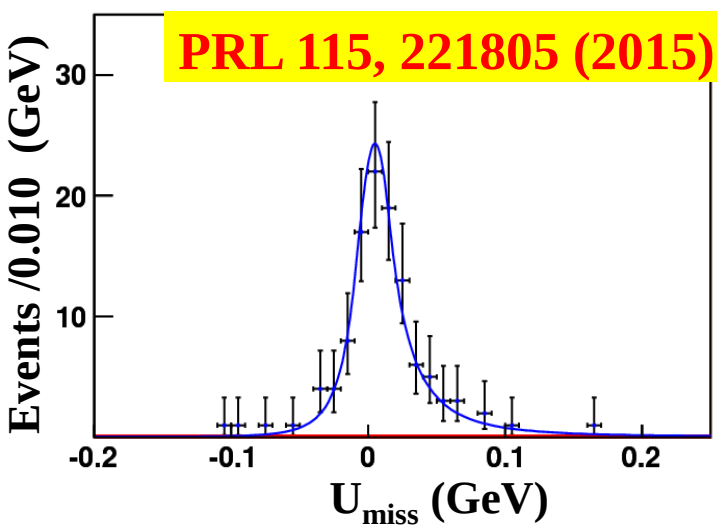
- $\Lambda_c^+ \to \Lambda e^+ \nu_e$ is a $c \to s l^+ \nu_l$ dominated process.
- Urgently needed for LQCD calculations.
- No direct absolute measurement for $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ available.

$$\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (2.1 \pm 0.6)\% \qquad \text{PDG 2014}$$

The tagging method and missing-mass technique at threshold.



11 hadronic single tag modes are used



$$B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.20)\%$$

- First absolute measurement of the semi-leptonic decay
- Statistics limited
- Best precision to date: twofold improvement
- We also measure the muonic mode: stay tuned

Upgrade plan and physics prospects

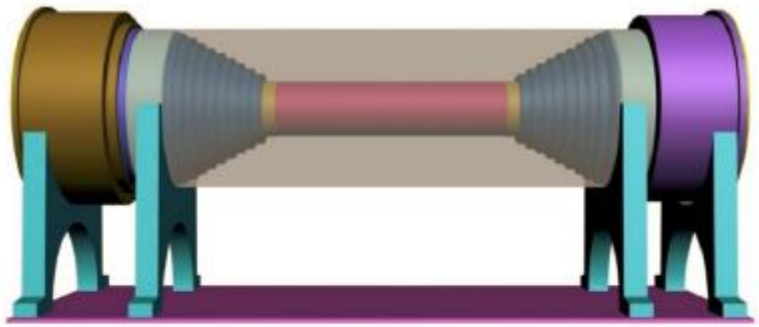
BESIII upgrade

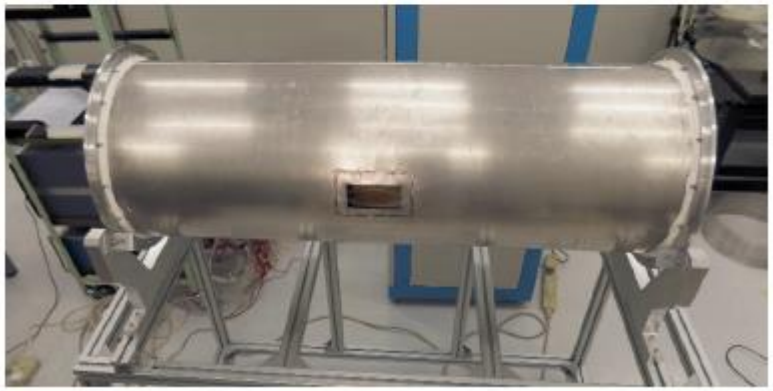
- MDC: Malter effect found in inner chamber in 2012, add water vapor to the chamber to cure the aging problem.
  - New inner chamber, built by IHEP, is ready now.
  - CGEM as the inner chamber ongoing : Italy group in collaboration with other groups.

- New ETOF (built by USTC & IHEP) was installed last year to improve the time resolution.

- Other possible upgrade plan is under discussion

New Inner Drift Chamber



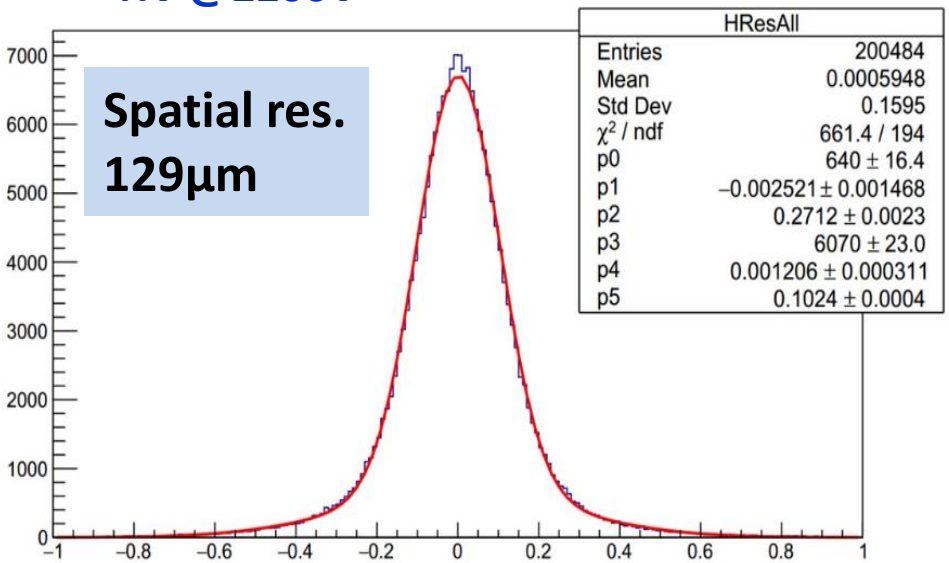


- An aluminum outer cylinder was manufactured for the chamber cosmic-ray test
- The outer cylinder was assembled after wiring had been finished

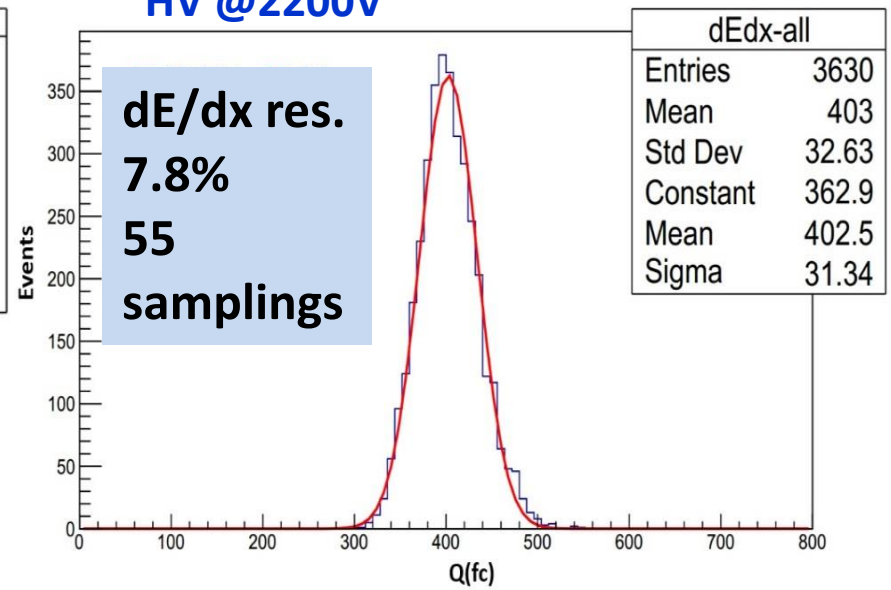
The performance of the new chamber

After half year's cosmic ray test, the efficiency > 99%

HV @2200V



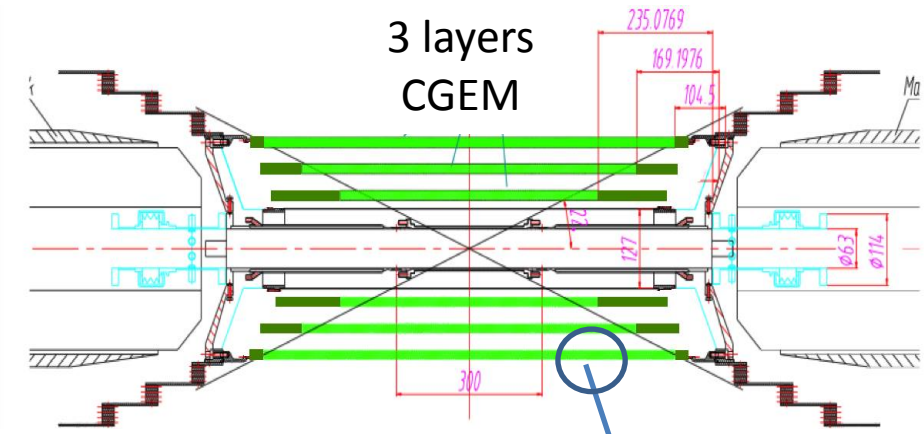
HV @2200V



The chamber is stored in a clean room and is ready to be replaced.

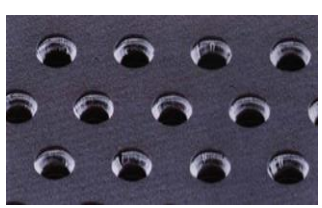
Cylindrical GEM Inner Tracker

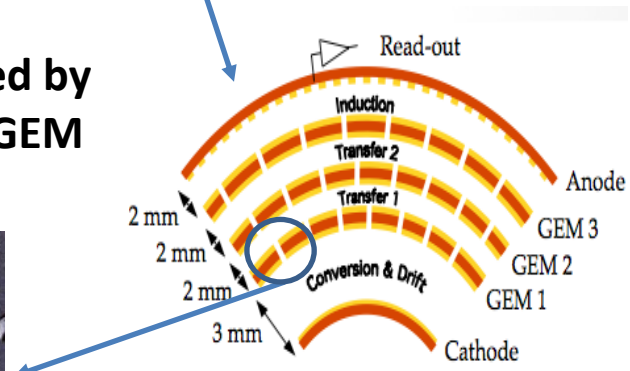
BESIII is building a cylindrical GEM detector (CGEM-IT) to replace the BESIII Inner MDC to recover some efficiency loss due to aging and to improve the secondary vertex resolution.



- **Low Material budget ≤ 1.5% of X_0 for all layers**
- **High Rate capability: ~10^4 Hz/cm^2**
- **Coverage: 93%**
- **Spatial resolution $\sigma_{r\phi}$ ~130 μm in 1 T magnetic filed**
- **Operation duration at least 5 years**

Each layer composed by a triple cylindrical GEM

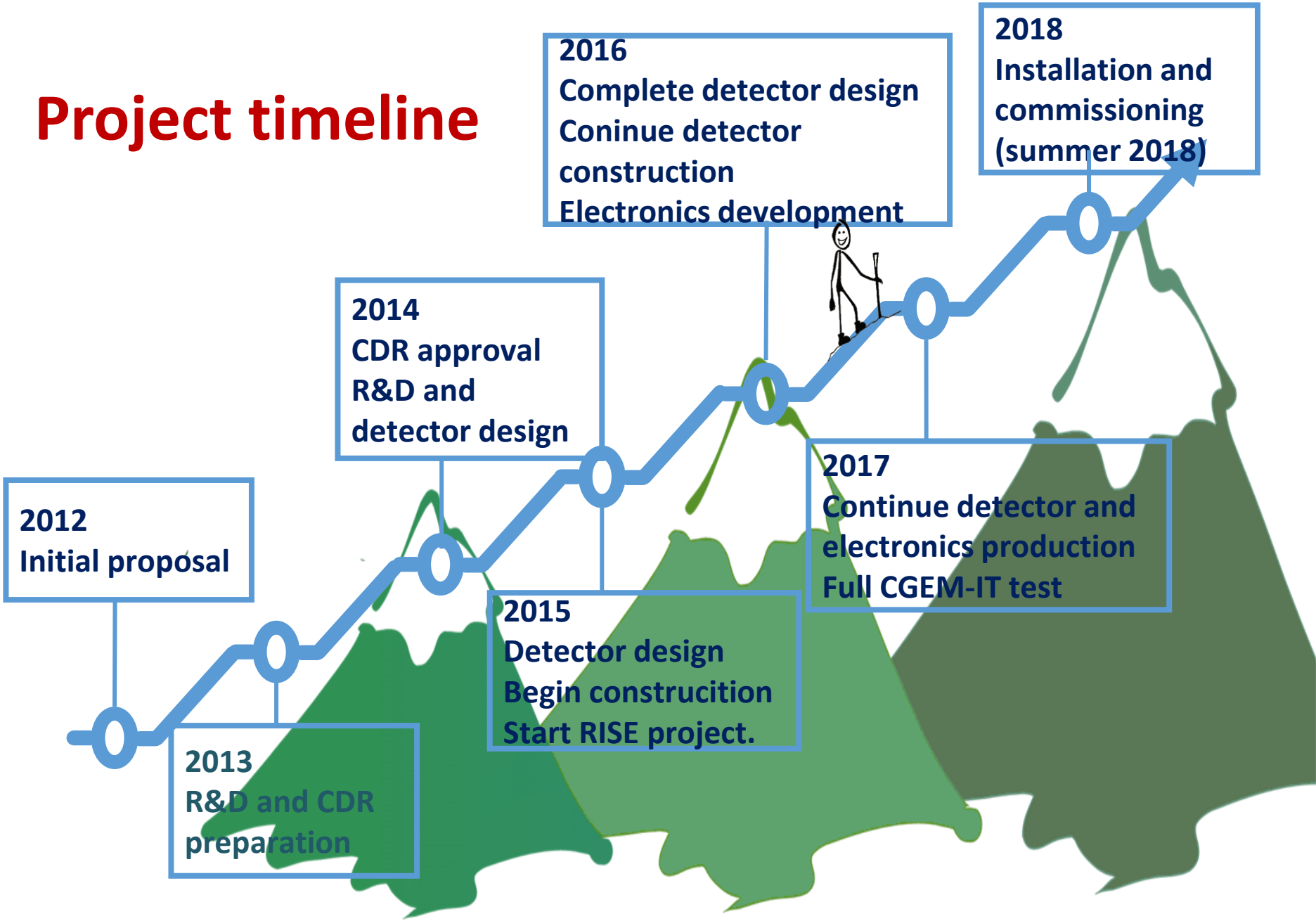




The CGEM is co-funded by the European Commission Research and Innovation Staff Exchange (RISE) project 2015-2018.

Formation of a consortium: INFN (Ferrara, Frascati, Perugia and Torino), Mainz, Uppsala, IHEP

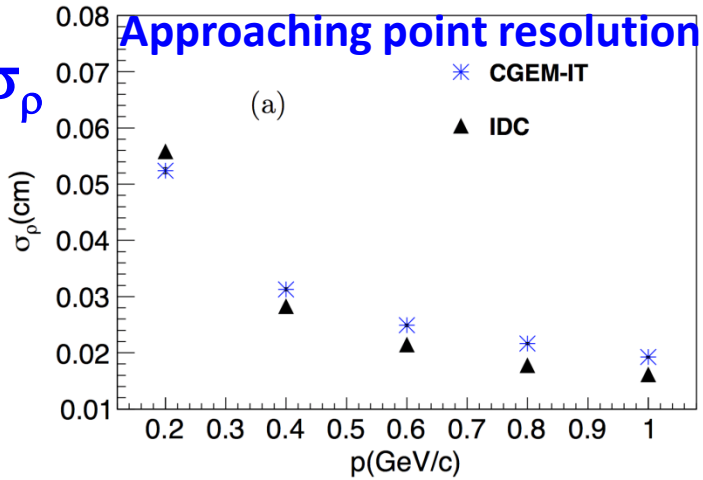
Project timeline



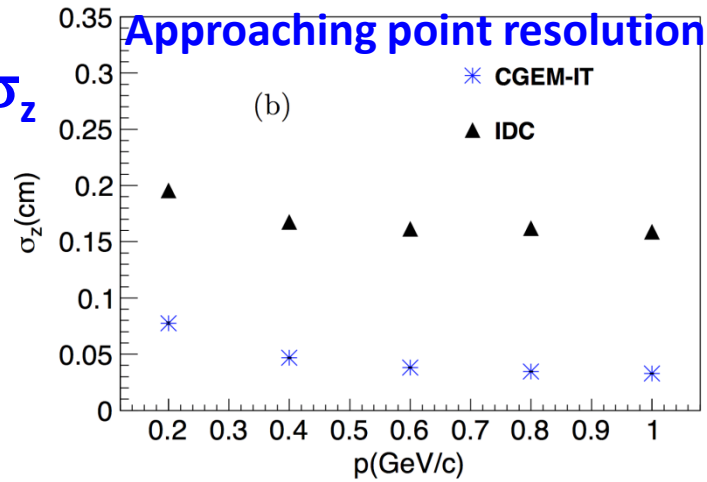
Expected performance of CGEM

Track fitting with Kalman Filter

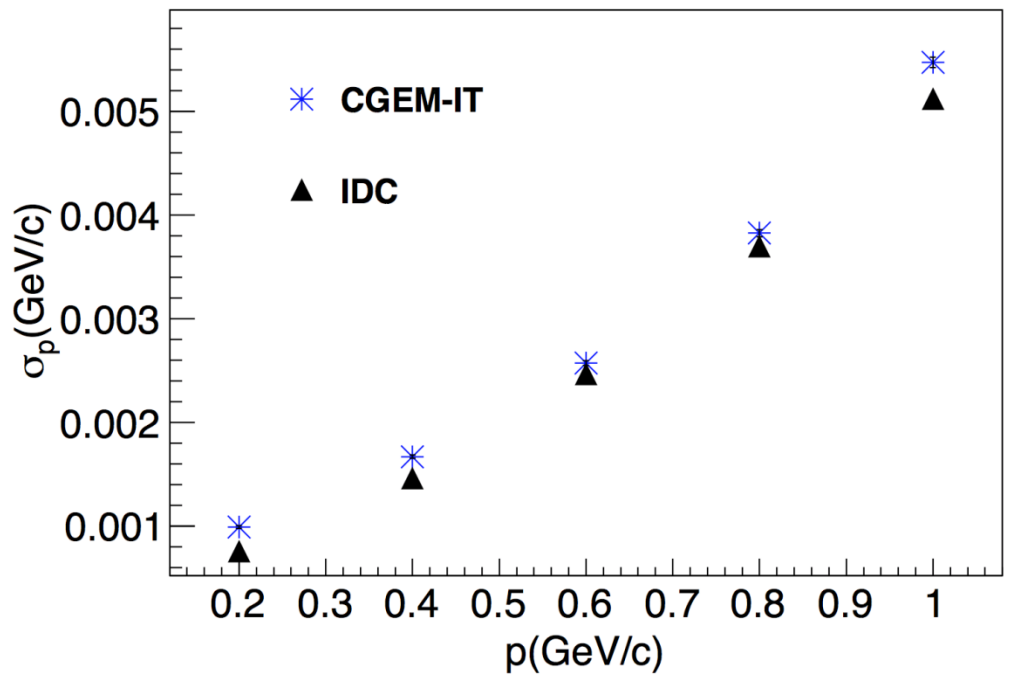
σ_ρ



σ_z

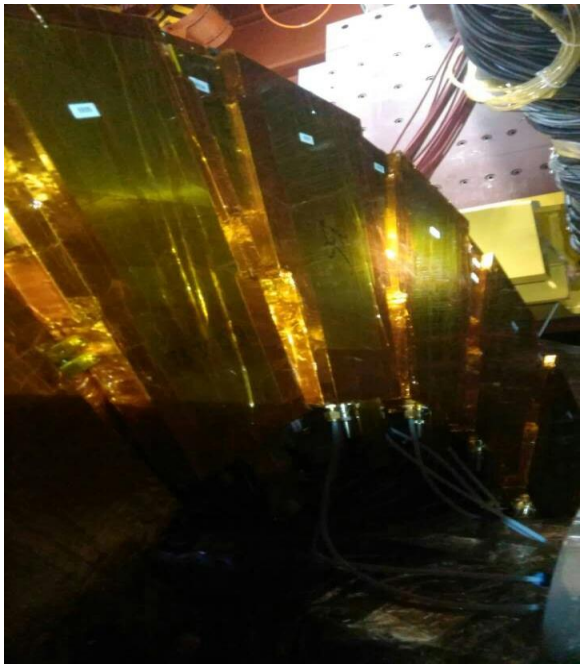


Momentum resolution

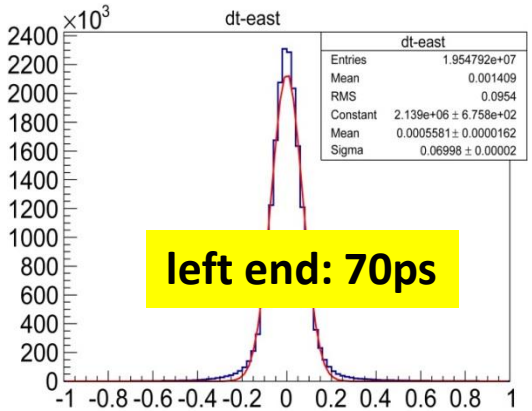


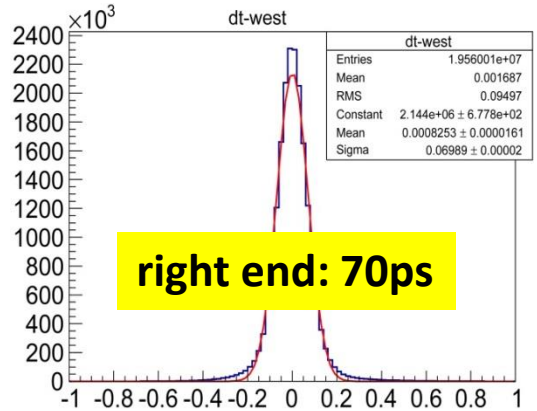
Installation of MRPC Endcap TOF

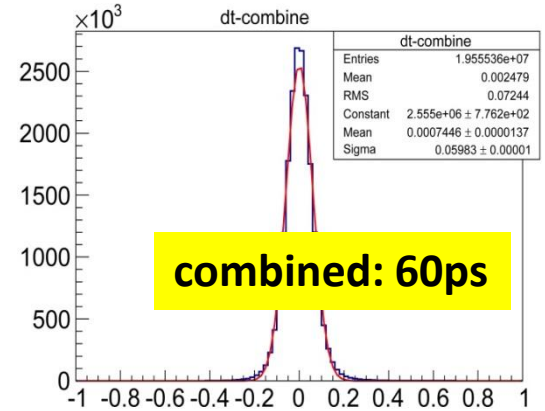
- Scintillator Endcap TOF: time resolution for π is 138ps.
- New MRPC Endcap-TOF built
- The installation of MRPC ETOF completed in the Oct. of 2015

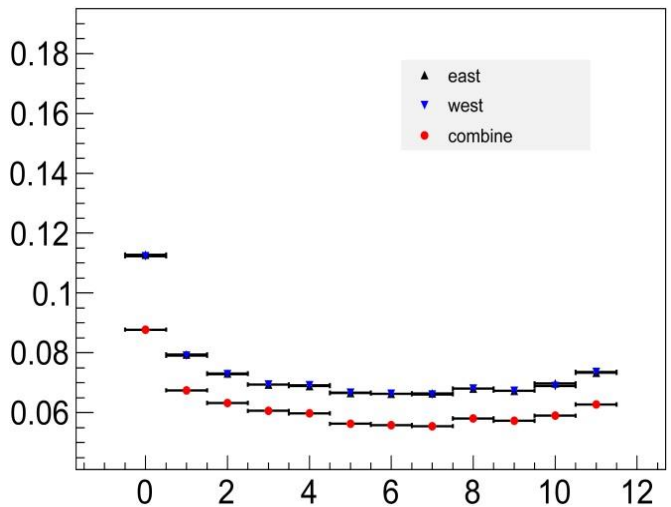


MRPC Endcap TOF

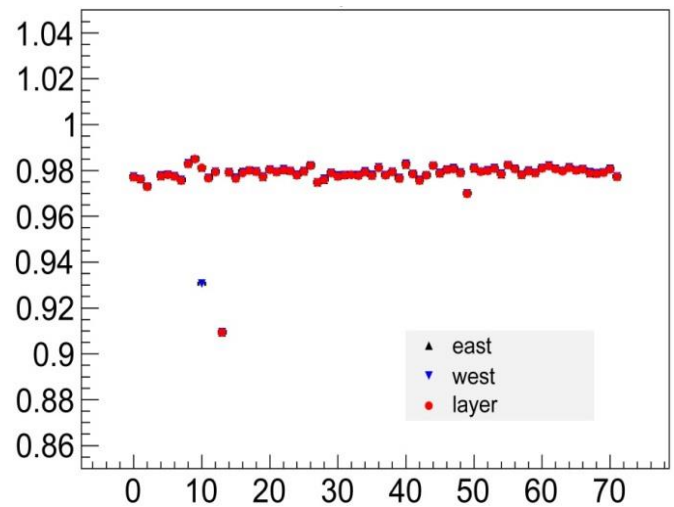








Time resolution vs Strip Number



Efficiency vs Module Number

Time resolution of 60ps achieved; Efficiency ~97%

Data/MC discrepancy – Main source of the syst. err.

$\varepsilon_{data}/\varepsilon_{MC}$-1	2010	2016	2019?
Tracking eff./track	~2%	~1%	~0.5%
PID/track	~2%	~1%	~0.5%
Photon eff./photon	~1%	0.5-1%	~0.5%

- **BEPC2**
  - **Replace one cavity in summer of 2017 (~3 months for the replacement, takes time for ramping up).**
  - **mini-workshop with machine people for the possible upgrade of BEPC2**
    - **Top up plan ?**
    - **Increase the beam energy ?**

      currently: 2.30 GeV

      I: → 2.35 GeV (hardware replacement, ….)

      II: 2.35 GeV < E < 2.45 GeV

      bottleneck: ISPB, new magnet and power supply

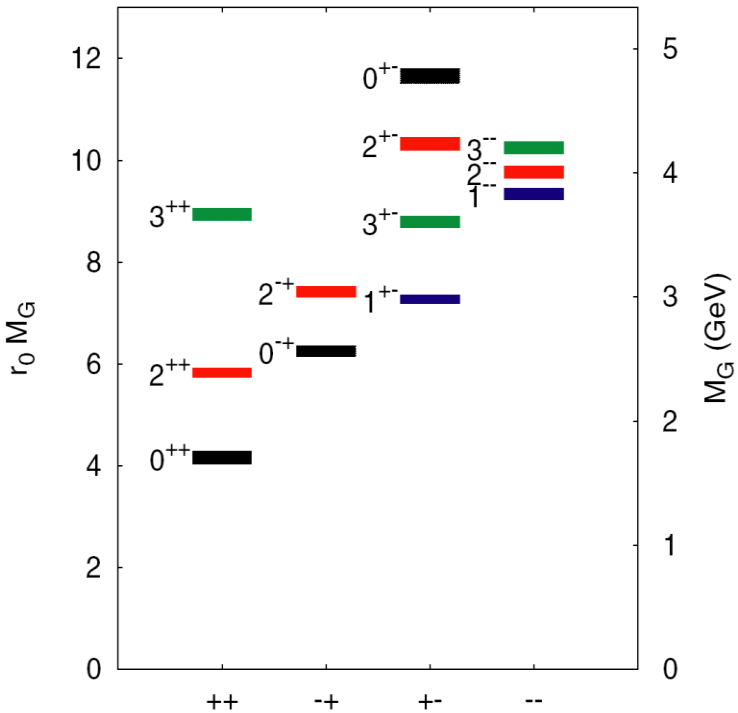
      III: > 2.45 GeV bottleneck: ISPB and SCQ

BESIII data taking status & plan

	Previous data	BESIII present & future	Goal
J/ψ	BESII 58M	1.2 B 20* BESII	10 B
ψ'	CLEO: 28 M	0.5 B 20* CLEOc	3 B
ψ"	CLEO: 0.8/fb	2.9/fb 3.5*CLEOc	20 /fb
Above open charm threshold	CLEO: 0.6/fb @ ψ(4160)	0.5/fb @ ψ(4040) 2.3/fb@~4260, 0.5/fb@4360 0.5/fb@4600, 1/fb@4420	5-10 /fb
R scan & Tau	BESII	3.8-4.6 GeV at 105 energy points 2.0-3.1 GeV at 20 energy points	
Y(2175)		100 pb^{-1}	
ψ(4170)		3 fb^{-1} (this run)	
4.2-4.3 GeV		5 fb^{-1} (next run)	

Glueball search

PRD73,014516(2006) Y.Chen et al



$J/\psi \to \gamma$ pseudoscalar+pseudoscalar

- $J/\psi \to \gamma\eta\eta$, $\gamma\eta\eta'$, $\gamma\eta'\eta'$
- $J/\psi \to \gamma\pi\pi$, $\gamma K\underline{K}$

  Couple channel analysis

  K-matrix

$J/\psi \to \gamma$ vector +vector

$J/\psi \to \gamma\,\gamma$ vector, …

- LQCD : the lightest glueball is 0^{++}, mass ~ 1.5-1.7 GeV

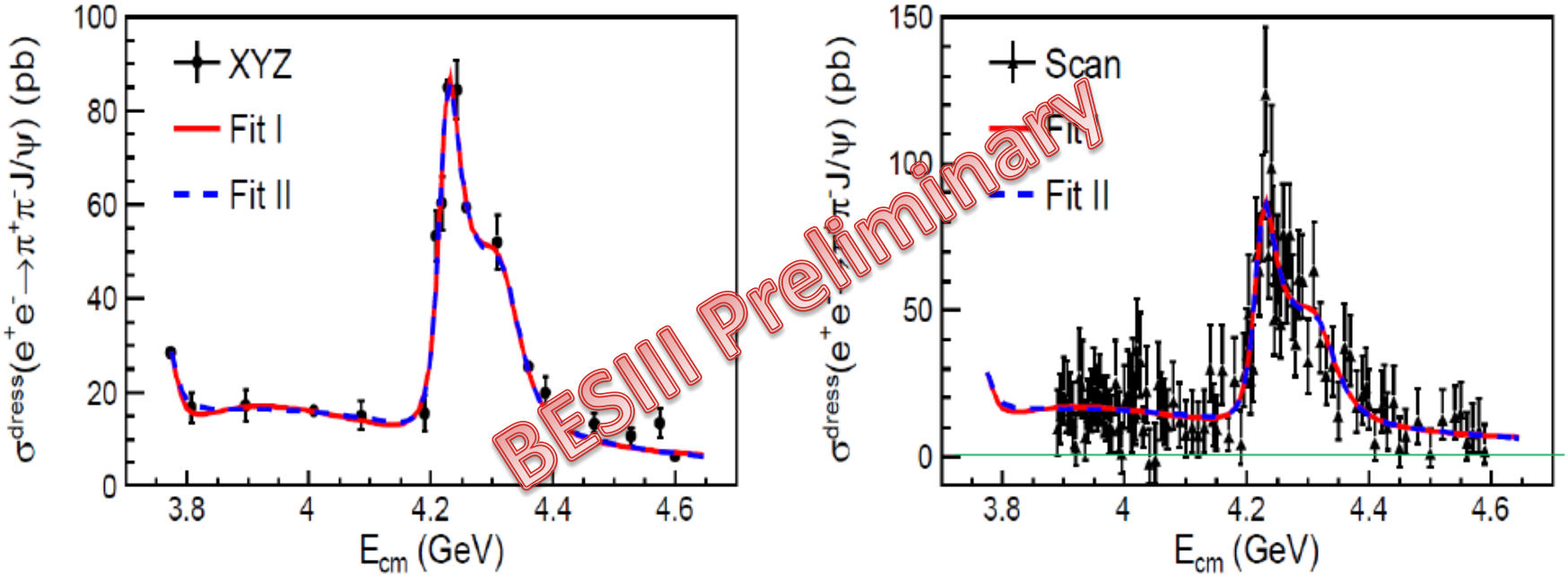
  the lightest 2^{++} glueball: mass~ 2.4 GeV

  the lightest 0^{-+}, mass > 2.3 GeV

Puzzles on XYZ (one example)

BESIII

$e^+e^- \to \pi^+\pi^- J/\psi$ at BESIII



Two resonances? What are they?

Prospects of Charm Physics at BESIII

Data at 3.773 or 4.18 GeV

	Systematic	Statistical	
		~3 fb^{-1}	+10 fb^{-1}
$\Delta f_{D+}/f_{D+}$	~0.9%^{BESIII}	2.6%	1.3%
$\Delta f_{Ds+}/f_{Ds+}(\mu+\tau)$	~1.4%$^{CLEO\text{-}c}$	~1.4%	~0.7%
$\Delta f_{D\to K}/f_{D\to K}$	~0.5%^{BESIII}	0.4%	0.2%
$\Delta f_{D\to\pi}/f_{D\to\pi}$	~0.7%^{BESIII}	1.3%	0.6%
$\lvert V_{cs}\rvert^{Ds+\to l+\nu}(\mu+\tau)$	~1.4%$^{CLEO\text{-}c}$	~1.4%	~0.7%
$\lvert V_{cs}\rvert^{D0\to K\text{-}e+\nu}$	2.5%^{BESIII}(2.4%^{LQCD})	0.4%	0.2%
$\lvert V_{cd}\rvert^{D+\to\mu+\nu}$	2.1%^{BESIII}(1.9→0.5%^{LQCD})	2.6%	1.3%
$\lvert V_{cd}\rvert^{D0\to\pi\text{-}e+\nu}$	4.5%^{BESIII}(4.4%^{LQCD})	1.3%	0.6%
(c_i,s_i) in $D^0\to K^0\pi^+\pi^-$	constrain to γ/ϕ_3	2.1%(tot)	1.4%(tot)
$\Lambda_c^+\to pK^-\pi^+$		4.8% (0.6fb^{-1}@4.6)	~2% (3fb^{-1}@4.6X)

Summary

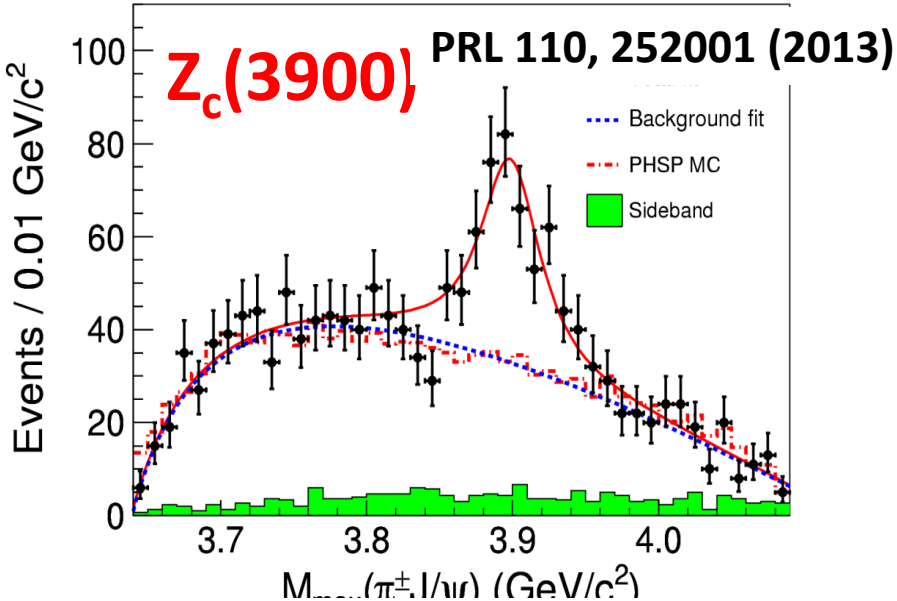
- **BESIII: successfully operating since 2009**
  – Collected large data samples in the τ-charm mass region
- **Study of X, Y and Z states**
- **Light hadron spectroscopy from charmonium and charm decays**
- **Charmed mesons and baryons**
- **R-QCD regions:**

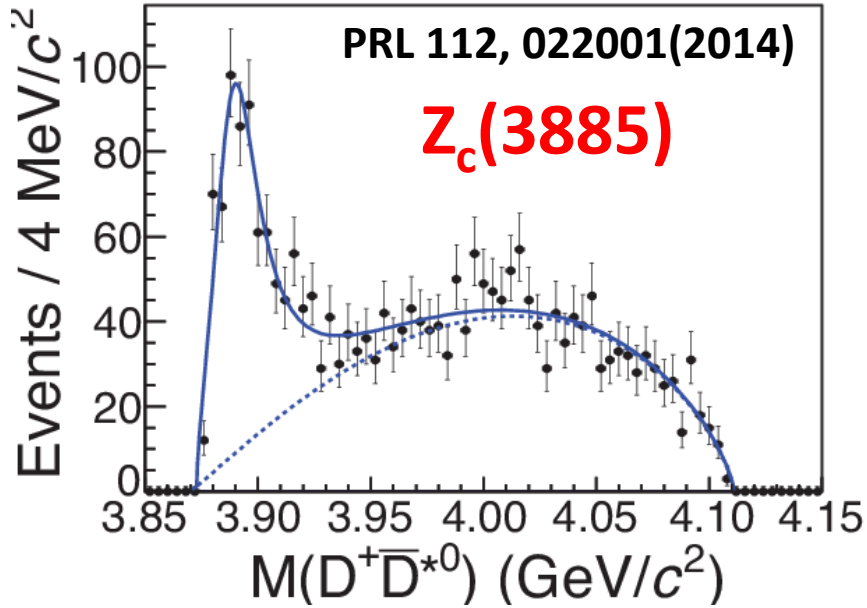
- **BEPCII/BESIII upgrade:** trackers, ETOF, beam energy ...

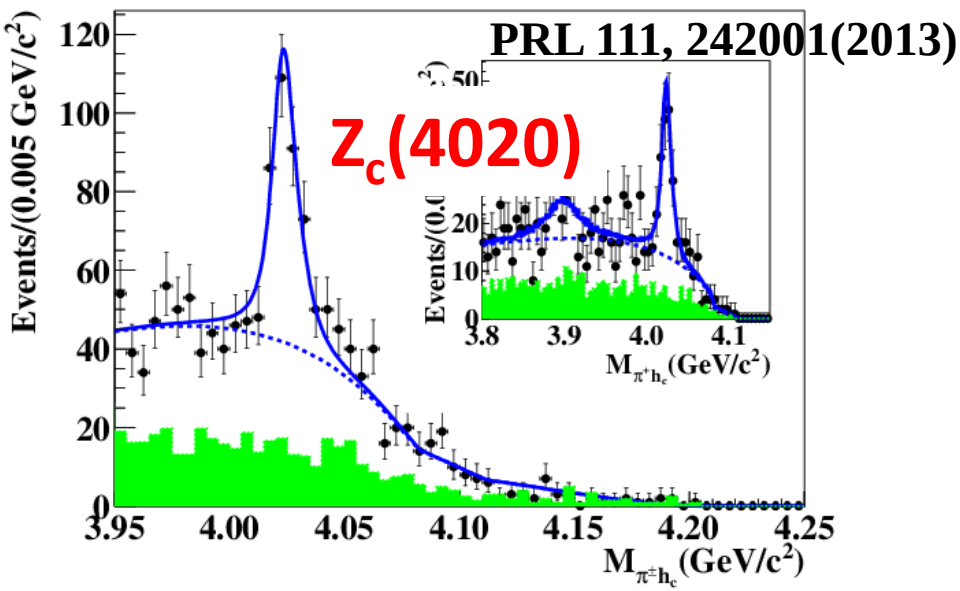
Thank you!

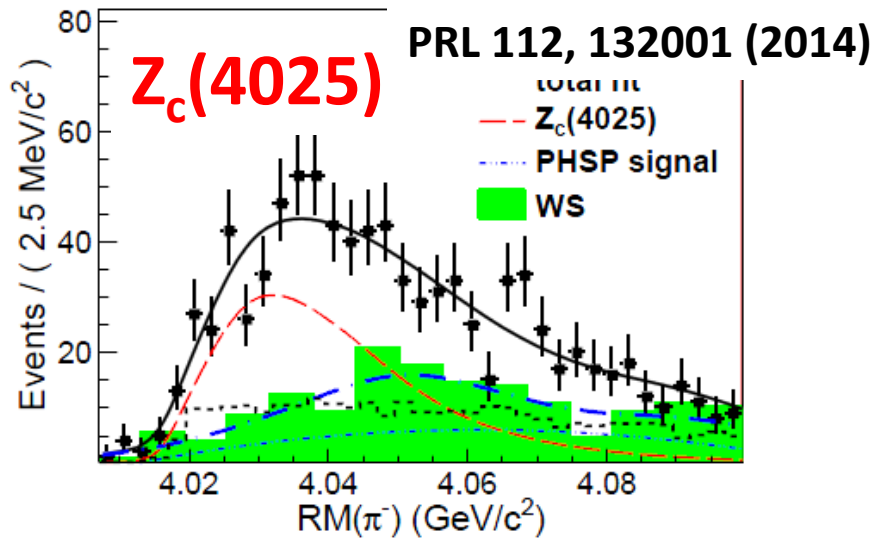
谢谢！

- 4 charged Zc's at BESIII



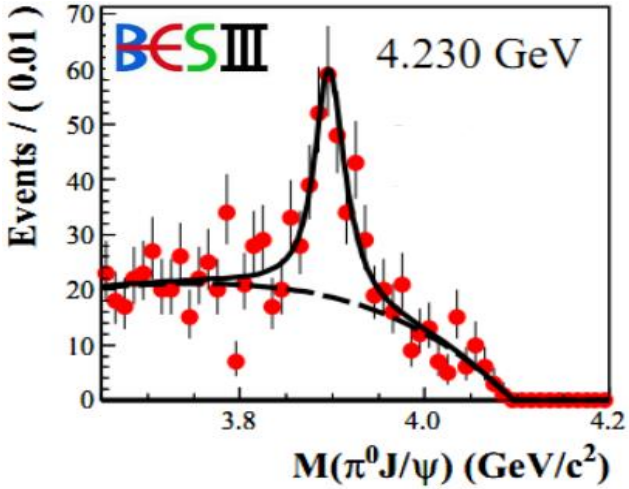






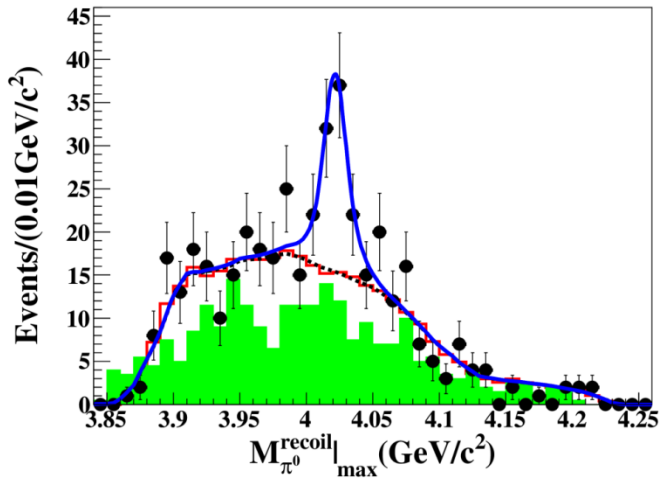
Neutral Zc(3900),Zc(3885),Zc(4020), Zc(4025)

$Z_c^0(3900)$ in $e^+e^- \rightarrow \pi^0\pi^0 J/\psi$



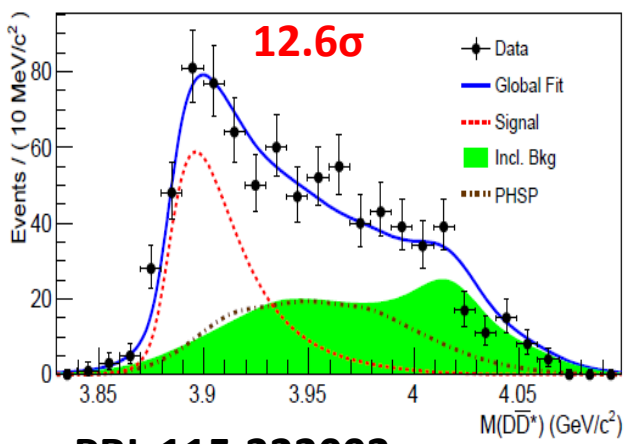
PRL,115,11,112003

$Z_c^0(4020) \rightarrow \pi^0 h_c$ in $e^+e^- \rightarrow \pi^0\pi^0 h_c$



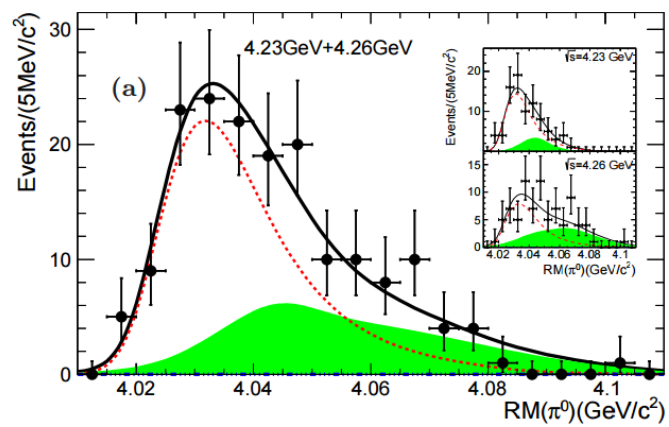
PRL, 113, 212002

$e^+e^- \rightarrow Z_c(3885)^0\pi^0 \rightarrow (D\bar{D}^*)^0\ \pi^0$



PRL.115.222002

$Z_c(4025)^0$ in $e^+e^- \rightarrow (D^*\bar{D}^*)^0\pi^0$

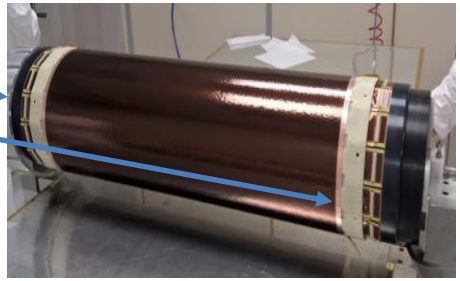


PRL,115,18,182002

Peculiarities and innovations of the BESIII design

- Materials and detector design

The detector must be very light: ≤ 1.5% of X_0: the mechanical rigidity is given by
- a kapton-Rohacell-Kapton sandwich in the active area.
- permaglass rings outside the sensitive area



- Combined time and charge readout
  - To achieve high tracking performance in strong magnetic field an hybrid, microTPC + charge centroid, readout will be used.

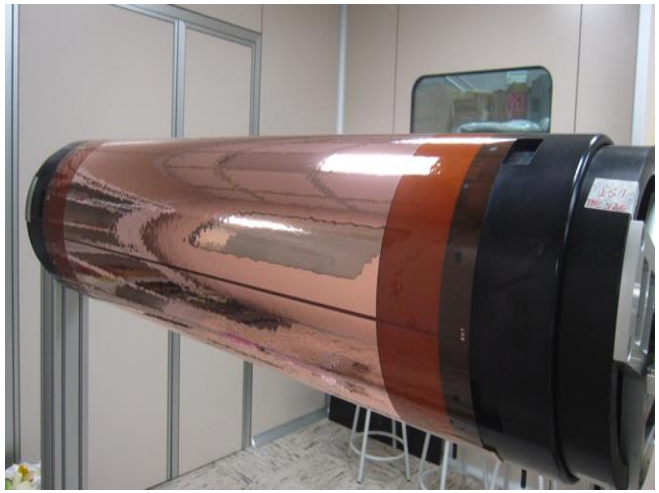
  - Successfully tested with beam on prototypes: first implementation of microTPC algorithms in strong magnetic field for GEM detectors.

- Frontend electronics
  - The hybrid readout will be carried out by a dedicated ASIC chip that is currently under development.

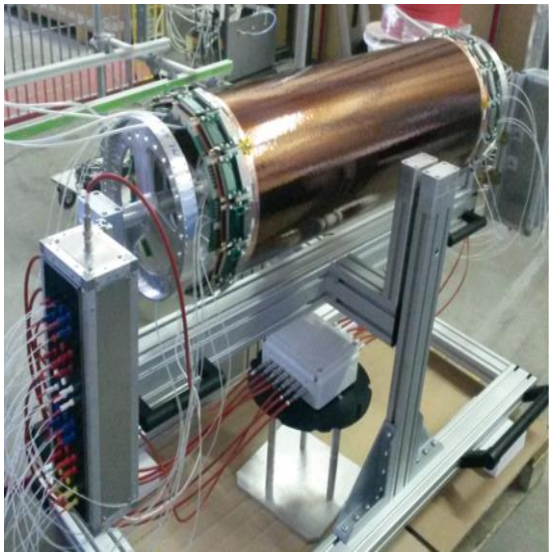
Status of the detector construction

The first CGEM-IT has been constructed, and recently validated with cosmics.

1) The 5 electrodes (cathode, anode and 3 GEM foils) are cylindrically shaped on aluminum molds,



2) They are then inserted one inside the other.



3) First detector layer being equipped with gas, HV and electronics