Exotics and Charmonia at BESIII

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On behalf of BESIII Collaboration

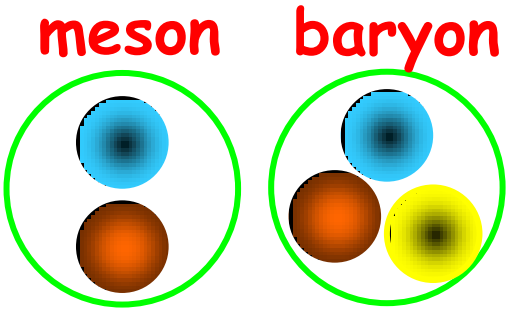
27th Rencontres de Blois, May 31 - June 05, 2015

Outline

- Introduction
  - Hadrons: normal & exotic
  - BEPCII and BESIII
- The X-Y- Z states at BESIII
  - Observation of X states
  - Observation of Y states
  - Observation of Z_c states
- Summary & Outlook

Hadrons: normal & exotic

◆ In the quark model:

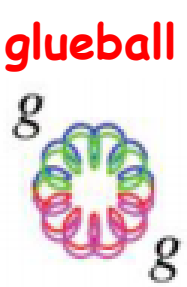


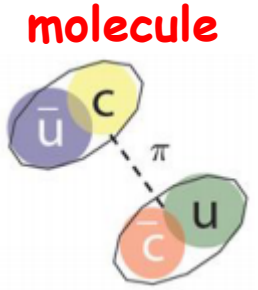
➢ Hadrons are composed from

- ✓ 2 quarks (qqbar)-**meson**
- ✓ 3 quarks (qqq)-**baryon**

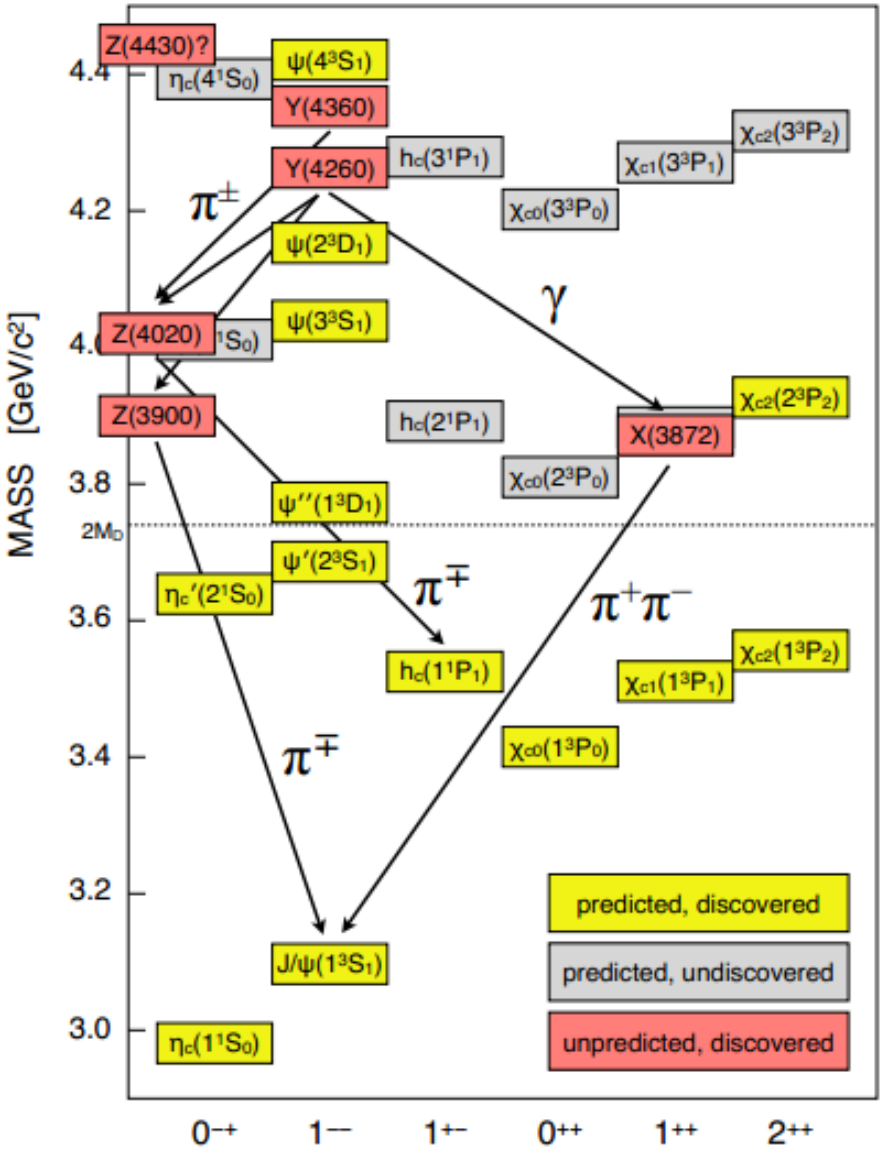
➢ QCD allows hadrons with other configurations

- ✓ **Glueball**: N_{quarks} = 0 (gg, ggg, …)
- ✓ **Hybrid**: N_{quarks} = 2 (or more)+excited gluon
- ✓ **Multiquark state**: N_{quarks} > 3
- ✓ **Molecule**: bound state of more than 2 hadrons
- ✓ ……





Charmonium & XYZ states



- **States in Charmonium region:**

  Not all of them are charmonia.

- **Below open-charm threshold:**

  Good agreement between discovery and theoretical prediction.

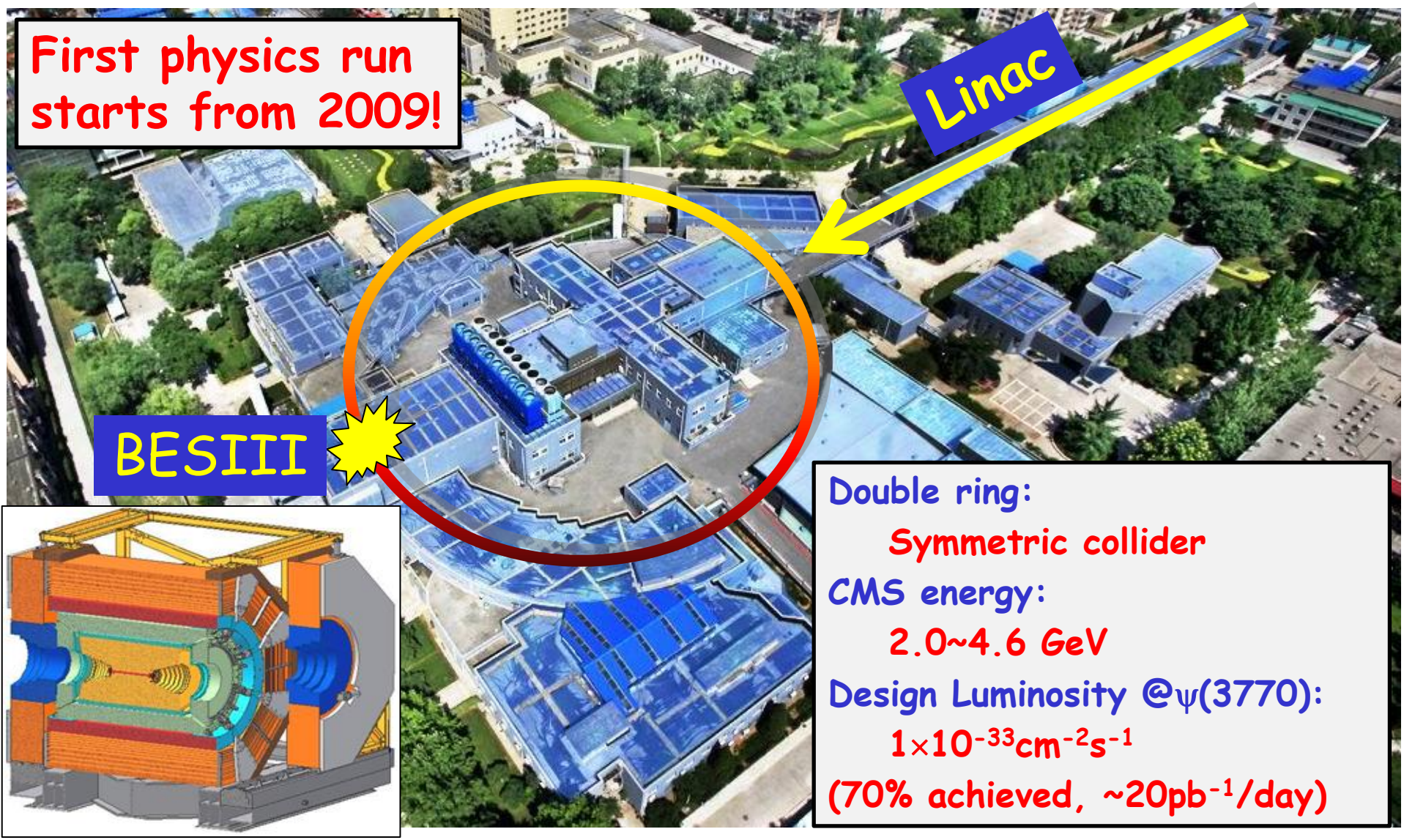
- **Above open-charm threshold:**

  Some new states: with charmonium in final sates, but not an obvious charmonium states. (Charmonium-like or XYZ)

Charmonium?
Hybrid?
Multiquark?
Molecule?

BEPCII and BESIII

First physics run starts from 2009!



Double ring:

Symmetric collider

CMS energy:

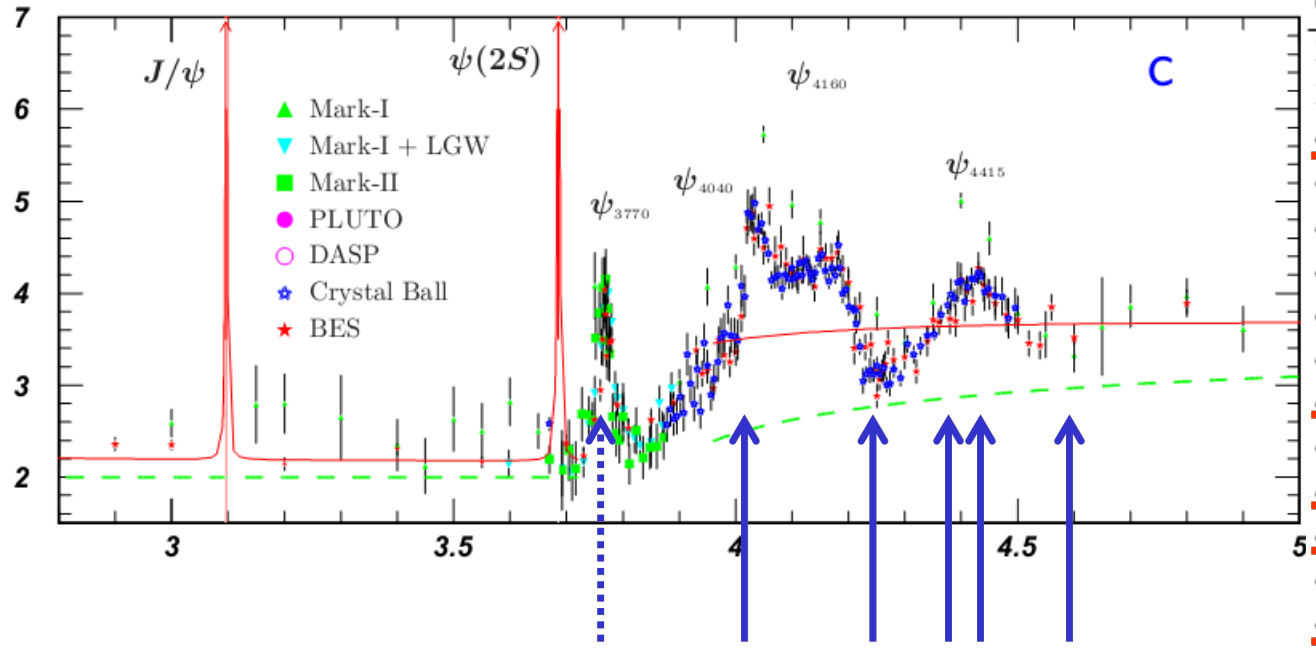
2.0~4.6 GeV

Design Luminosity @ψ(3770):

$1\times10^{-33}cm^{-2}s^{-1}$

(70% achieved, ~$20pb^{-1}$/day)

BESIII data samples for XYZ study (5/fb)



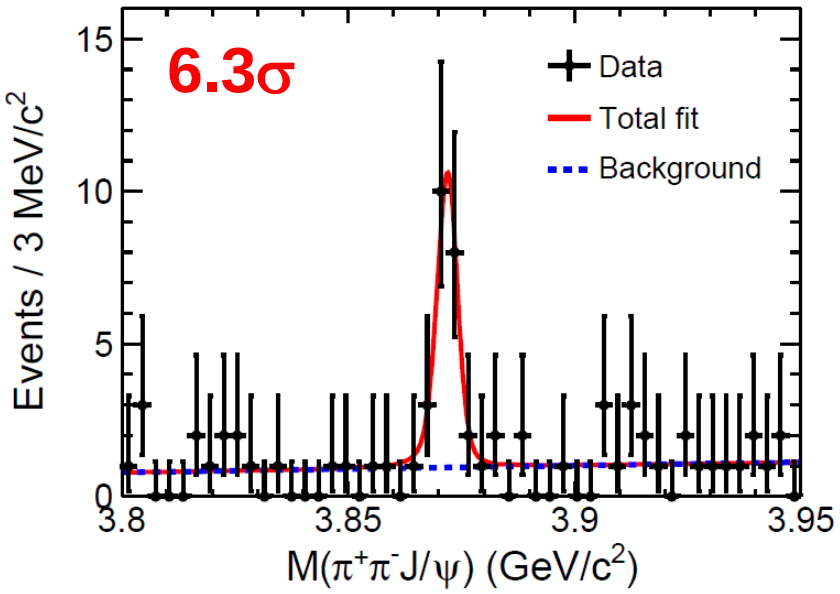
CM energy (GeV)	L (pb^{-1})
3.810	50.54±0.03
3.900	52.61±0.03
4.009	481.96±0.01
4.090	52.63±0.03
4.190	43.09±0.03
4.210	54.55±0.03
4.220	54.13±0.03
4.230^{1}	44.40±0.03
4.230^{2}	1047.34±0.14
4.245	55.59±0.04
4.260^{1}	523.74±0.10
4.260^{2}	301.93±0.08
4.310	44.90±0.03
4.360	539.84±0.10
4.390	55.18±0.04
4.420^{1}	44.67±0.03
4.420^{2}	1028.89±0.13
4.470	109.94±0.04
4.530	109.98±0.04
4.575	47.67±0.03
4.600	566.93±0.11

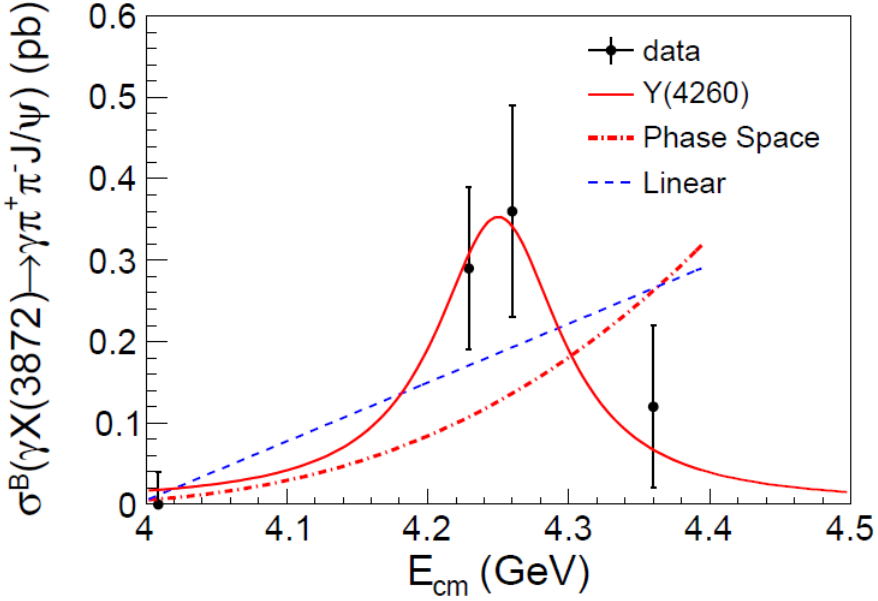
- Huge data sets around ψ(4040), Y(4260), Y(4360), ψ(4420), Y(4600).

The X states

Observation of $e^+e^- \to \gamma X(3872)$

PRL 112, 092001 (2014)





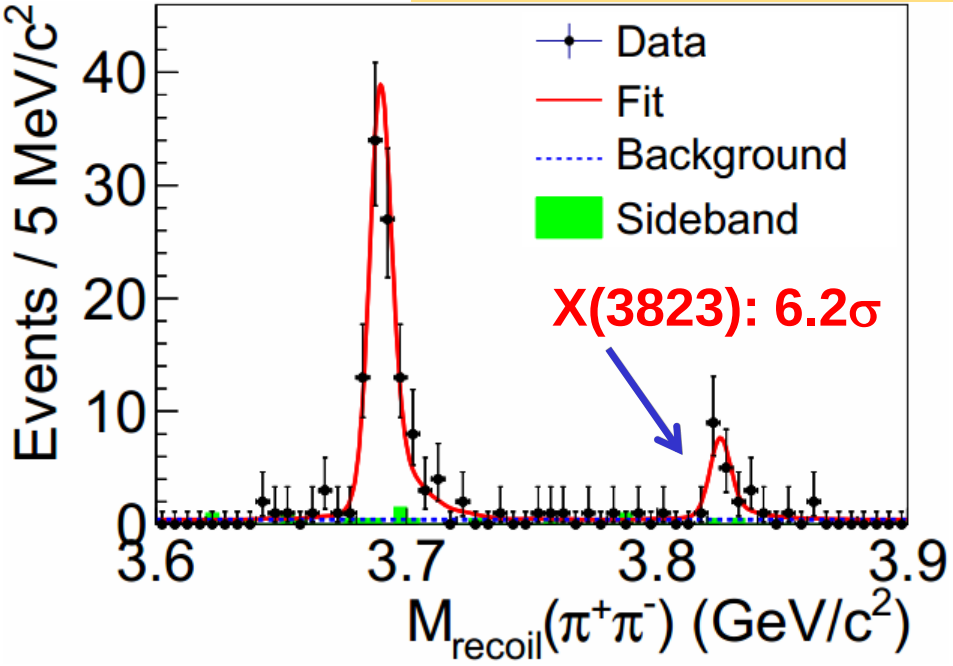
- BESIII observed $e^+e^- \to \gamma X(3872) \to \pi^+\pi^- J/\psi$.
- It seems that X(3872) is from the radiative transition of Y(4260).

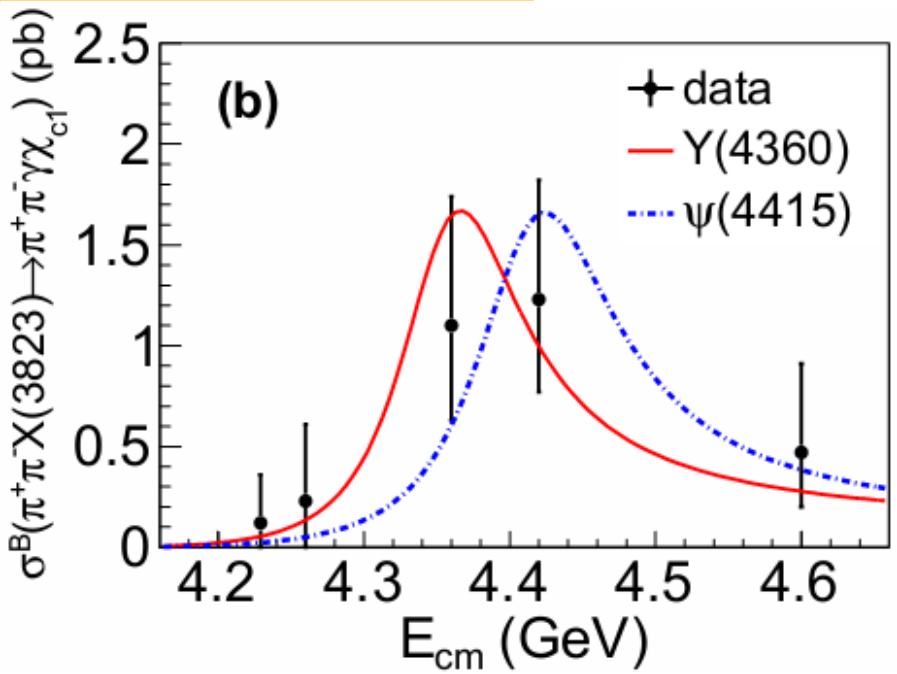
$\frac{\sigma(e^+e^- \to \gamma X(3872))}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)} \sim 10\%$, Large transition ratio.

- May new decay mode: Y(4260) $\to \gamma X(3872)$.

Observation of $e^+e^-\to\pi^+\pi^-X(3823)$

arXiv:1503.08203 (Accepted by PRL)



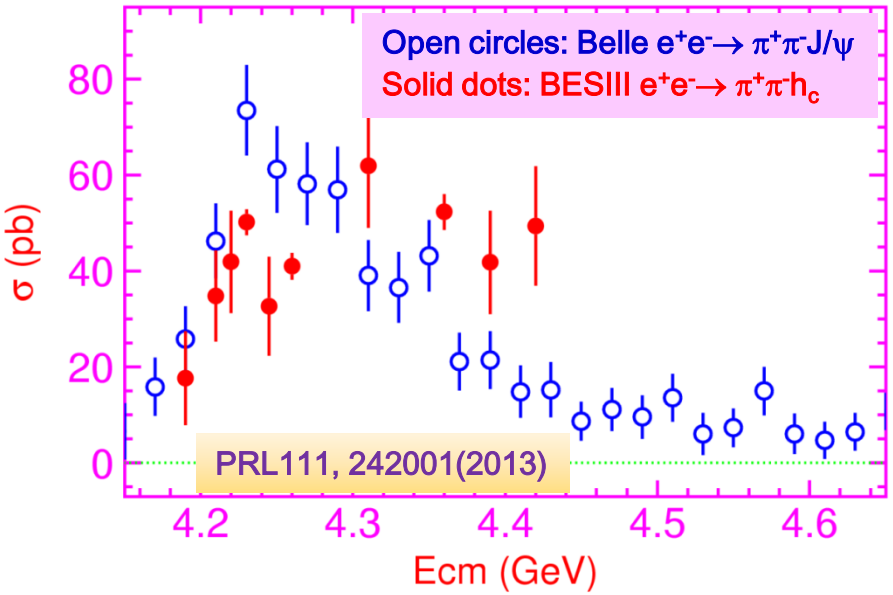


- BESIII observed $e^+e^-\to\pi^+\pi^-X(3823)\to\pi^+\pi^-\gamma\chi_{c1}$.
- M=3821.7±1.3±0.7MeV/c, Consistent with Belle's results (PRL111, 032001). Candidate for $\psi(1^3D_2)$.
- For the energy dependent cross section of $e^+e^-\to\pi^+\pi^-X(3823)$, both Y(4360) and $\psi(4415)$ line shape give reasonable description.

The Y states

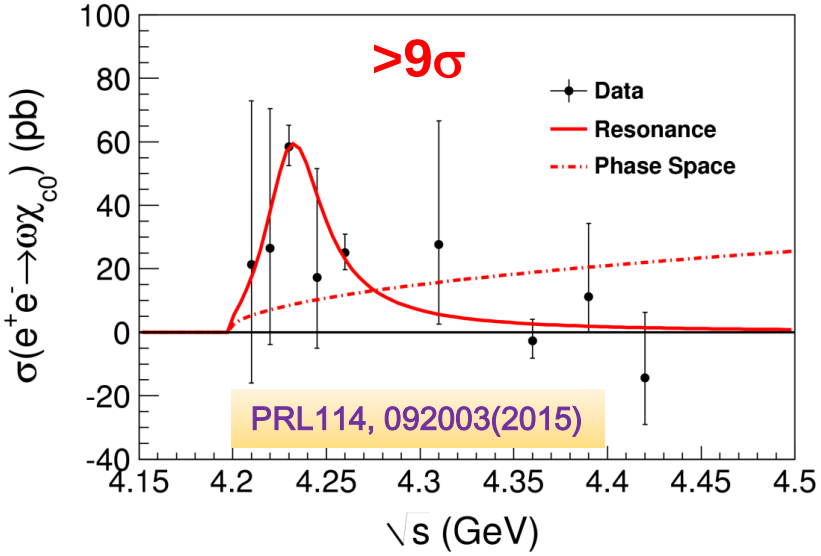
(vectors)

Observation of $e^+e^-\to\pi^+\pi^-h_c(1P)$



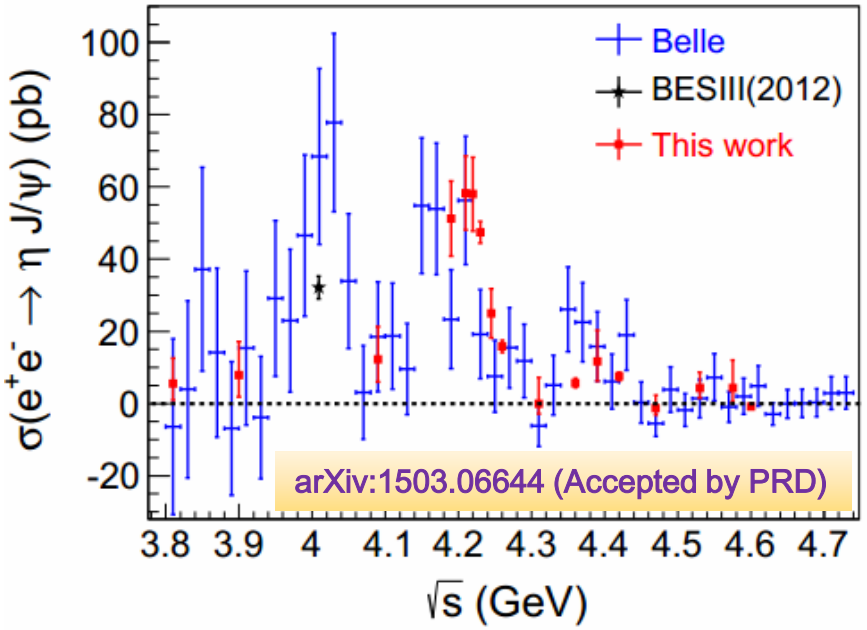
- $\sigma(e^+e^-\to\pi^+\pi^-h_c)\sim\sigma(e^+e^-\to\pi^+\pi^-J/\psi)$, but line shape different.
- Local maximum ~ 4.23 GeV for $\sigma(e^+e^-\to\pi^+\pi^-h_c)$, Narrow structure?
- Broad structure at high energy region? Need more data at high energies to complete the line shape measurement.

Observation of $e^+e^-\to\omega\chi_{c0}$



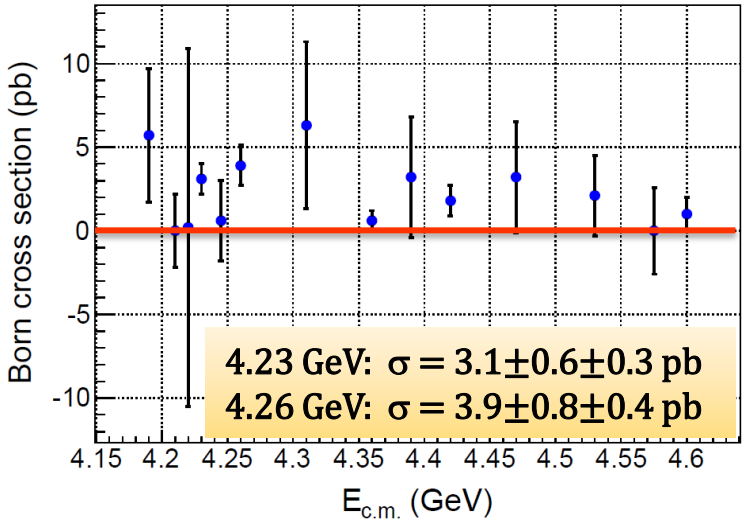
- Fit with a single BW:
  $M = 4230\pm8\pm6$ MeV
  $\Gamma = 38\pm12\pm2$ MeV
- Signal does not arise from the decays of Y(4260).

Observation of $e^+e^-\to\eta J/\psi$



- Agree with previous results with improved precision.
- The cross section peaks around 4.2 GeV: $\psi(4160)\to\eta J/\psi$.

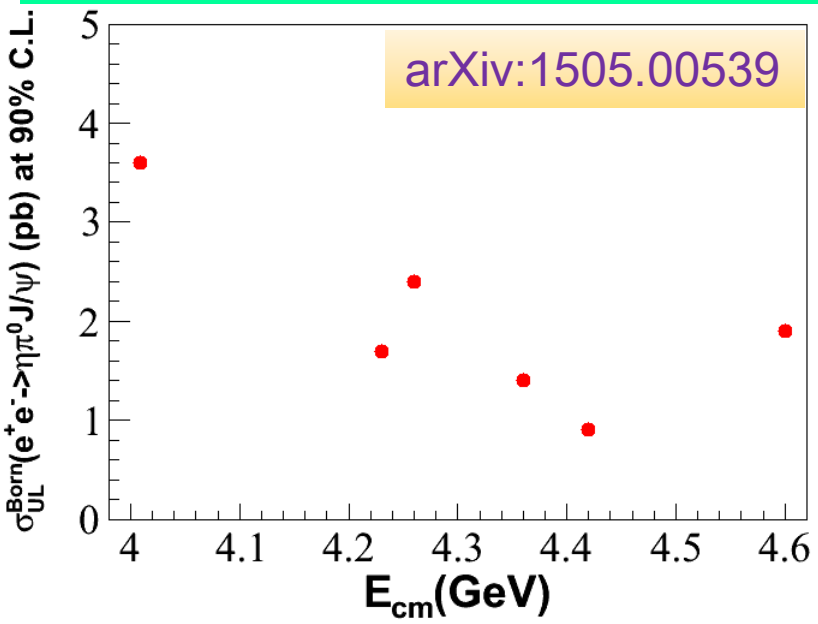
Observation of $e^+e^-\to\eta' J/\psi$



- $e^+e^-\to\eta' J/\psi$ are observed at 4.230GeV and 4.260GeV.
- First observation, cannot tell the line shape due to statistics

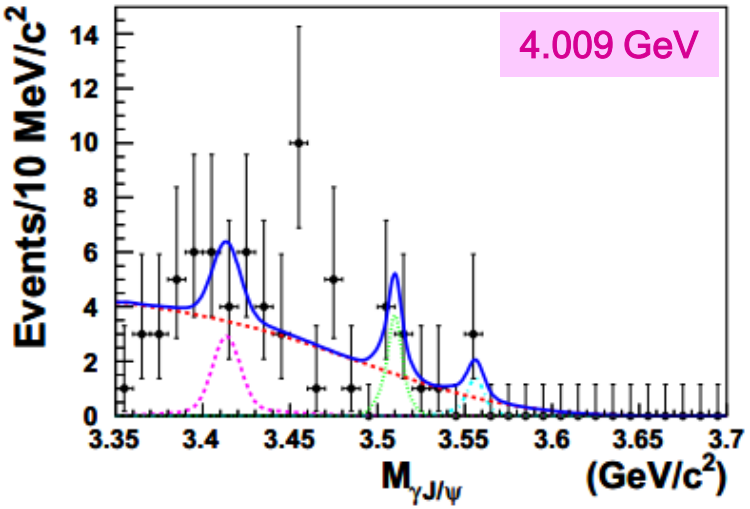
BESIII Preliminary

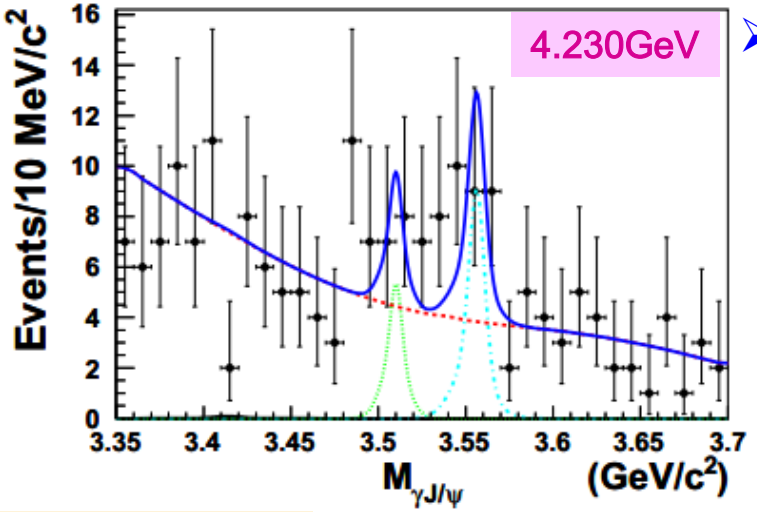
No significant signal of $e^+e^-\to\eta\pi^0J/\psi$



- Model predictions of $e^+e^-\to\eta\pi^0J/\psi$ Y(4260) as a D_1D molecule:
  [X. Wu et al., PRD 89, 054038]
- Need more luminosity to reach the sensitivity.

Evidence for $e^+e^-\to\gamma\chi_{cJ}$



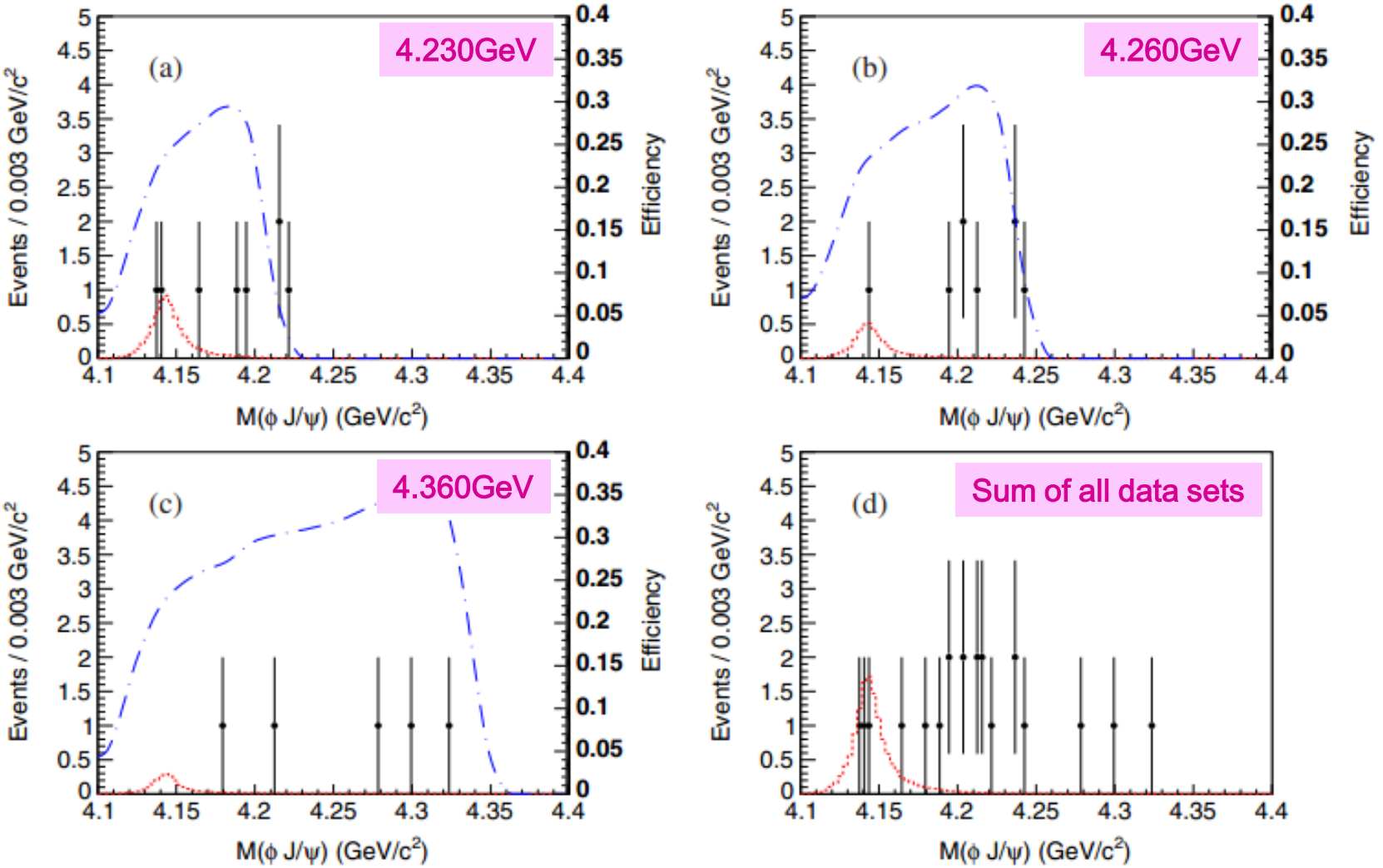


- Evidence for:
  $e^+e^-\to\gamma\chi_{c1}$ 3.0σ
  $e^+e^-\to\gamma\chi_{c2}$ 3.4σ

Chinese Phys. C 39, 041001 (2015)

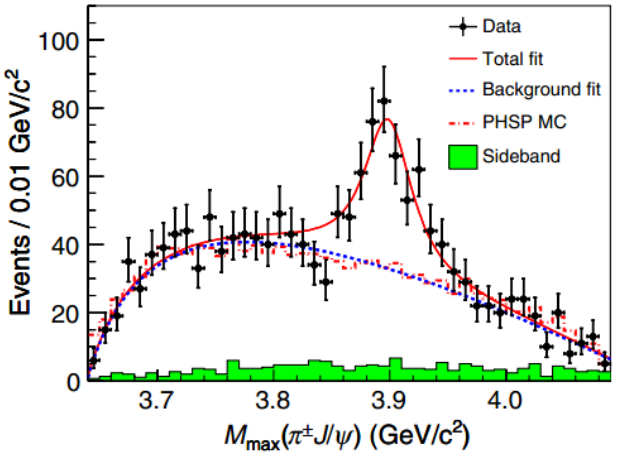
No significant signal of $e^+e^- \to \gamma Y(4140)$

PRD 91, 032002(2015)

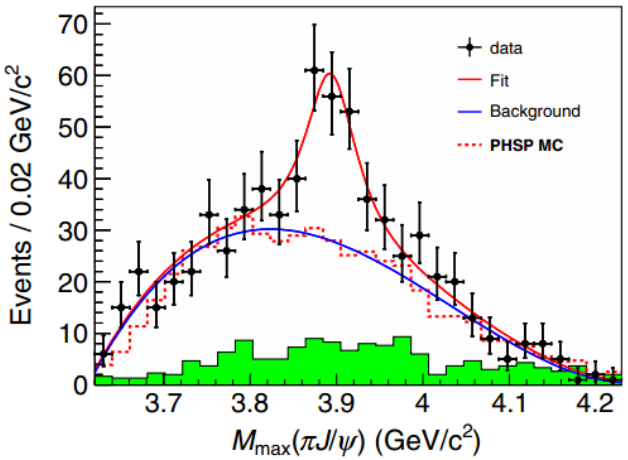


The Z_c states

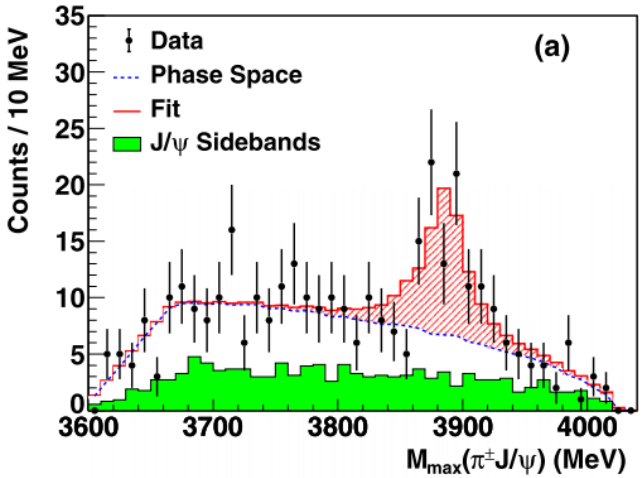
Observation $Zc(3900)^{\pm}$ in $e^+e^- \to \pi^+\pi^- J/\psi$



BESIII data at 4.26 GeV
(PRL 110, 252001)



Belle with ISR data
(PRL 110, 252002)

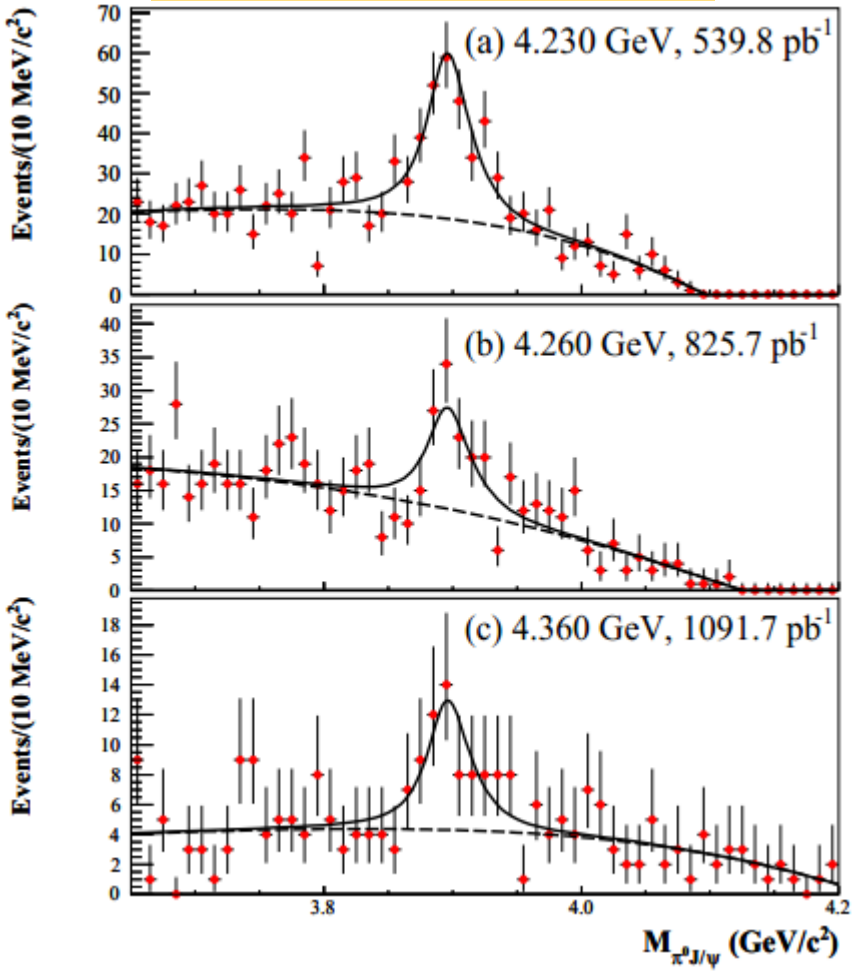


CLEOc data at 4.17 GeV
(PLB 727, 366)

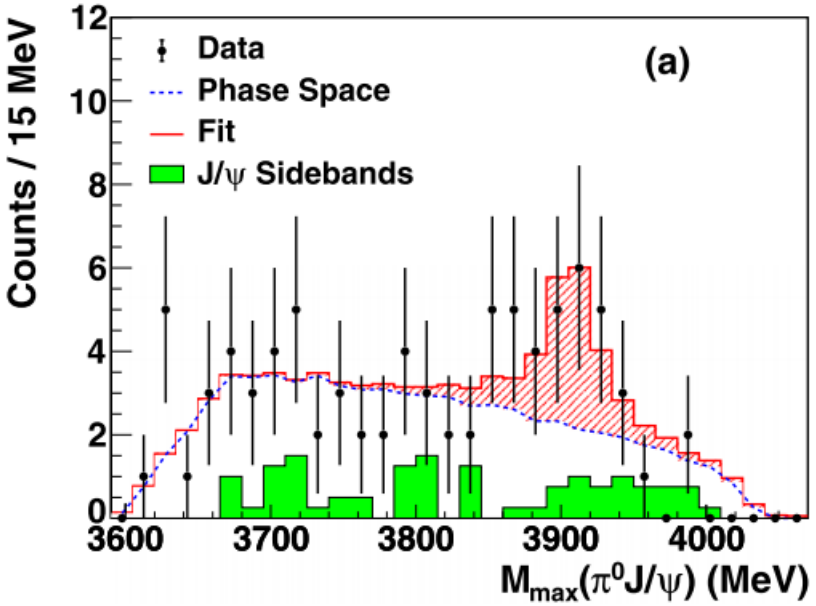
Experiment	Mass (MeV)	Width (MeV)	Significance
BESIII	3899.0±3.6±4.9	46±10±20	> 8.0 σ
Belle	3894.5±6.6±4.5	63±24±26	5.2 σ
CLEO-c	3886±4±2	37±4±8	> 5.0 σ

Observation $Zc(3900)^0$ in $e^+e^- \to \pi^0\pi^0 J/\psi$

BESIII Preliminary



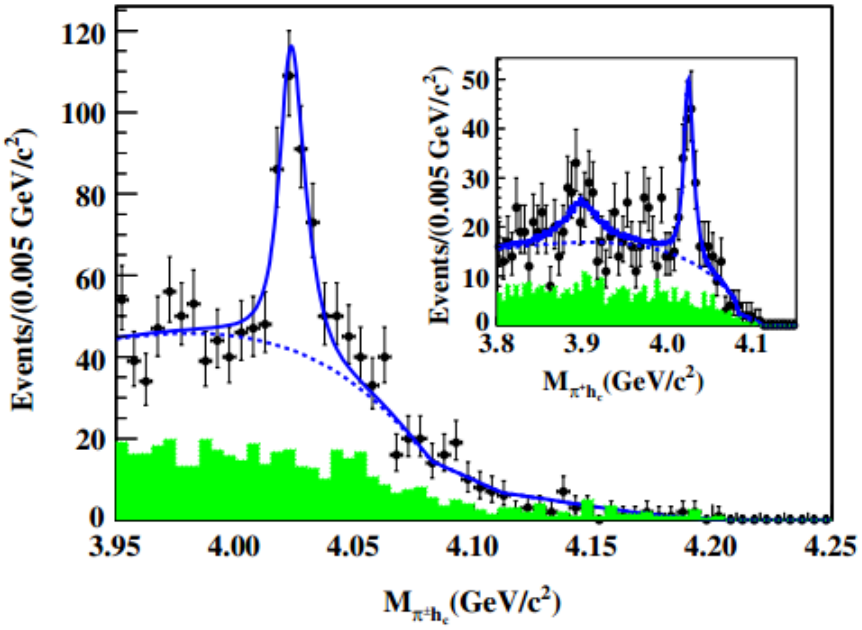
- **Simultaneous fit:**
  - Significance = 10.4σ
  - M = 3894.8±2.3±2.7MeV
  - Γ= 29.6±8.2±8.2MeV
- **Isospin triplet is established!**



CLEOc data at 4.17 GeV (PLB 727, 366)

Observation $Zc(4020)^{\pm/0}$ in $e^+e^- \to \pi^+\pi^- h_c/\pi^0\pi^0 h_c$

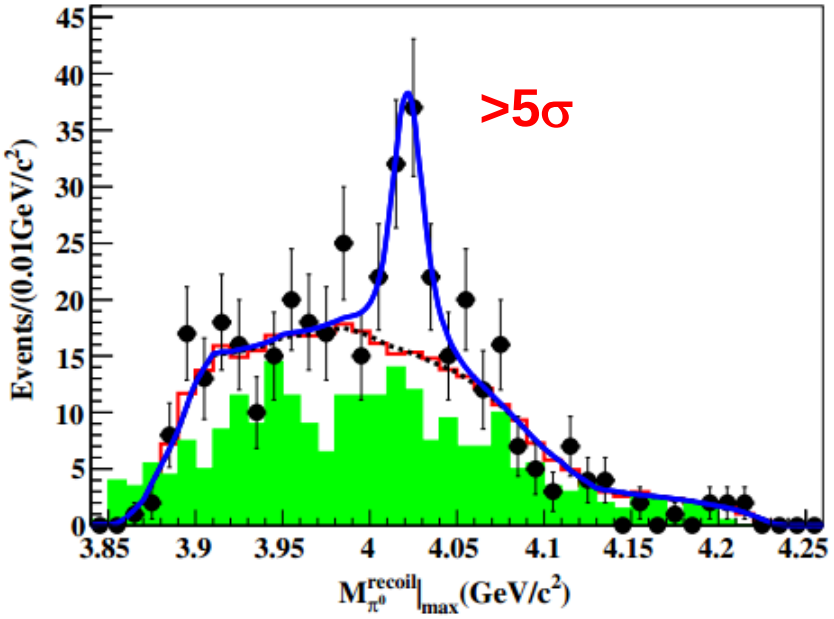
PRL111, 242001(2013)



$M=4022.9\pm0.8\ \pm2.7$ MeV

$\Gamma=7.9\pm2.7\ \pm2.6$ MeV

PRL113, 212002(2014)



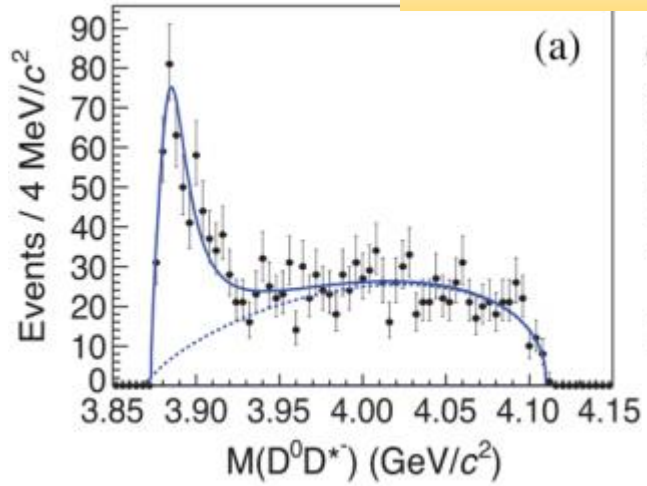
$M=4023.9\pm2.2\ \pm3.8$ MeV

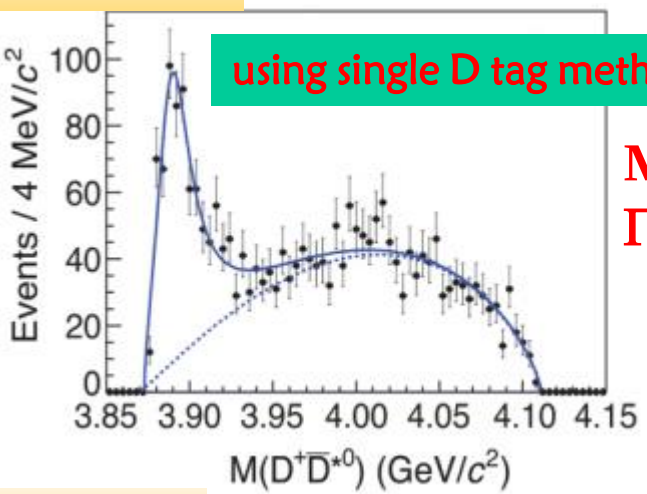
Width is fixed to be same as its charged partner.

Another isospin triplet is established!

Observation of $Z_c(3885)^{\pm}$ in $e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}$

PRL112, 022001(2014)

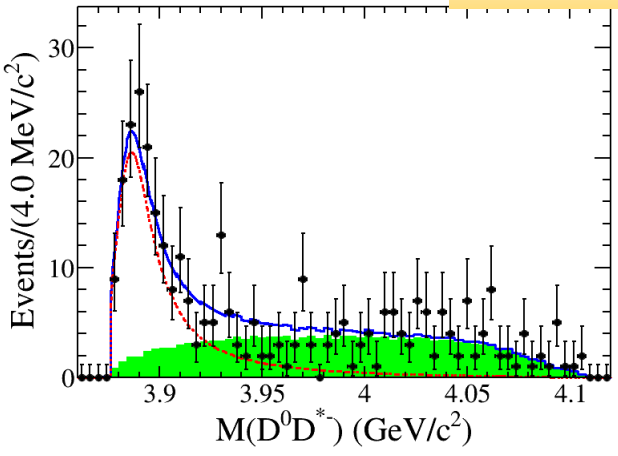


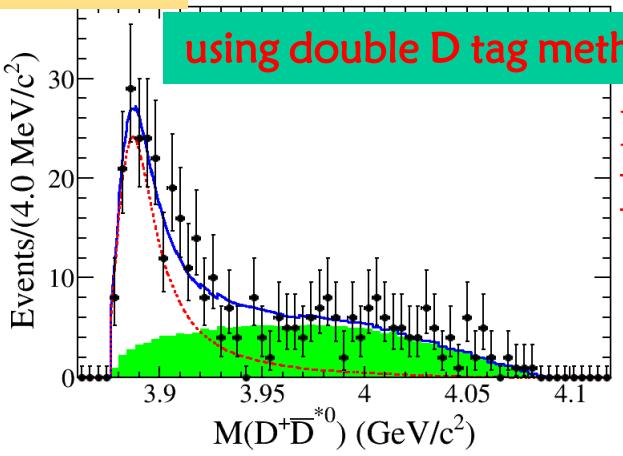


using single D tag method

M=3883.9±1.5±4.2 MeV
Γ=24.8±3.3 ±11.0 MeV

BESIII Preliminary



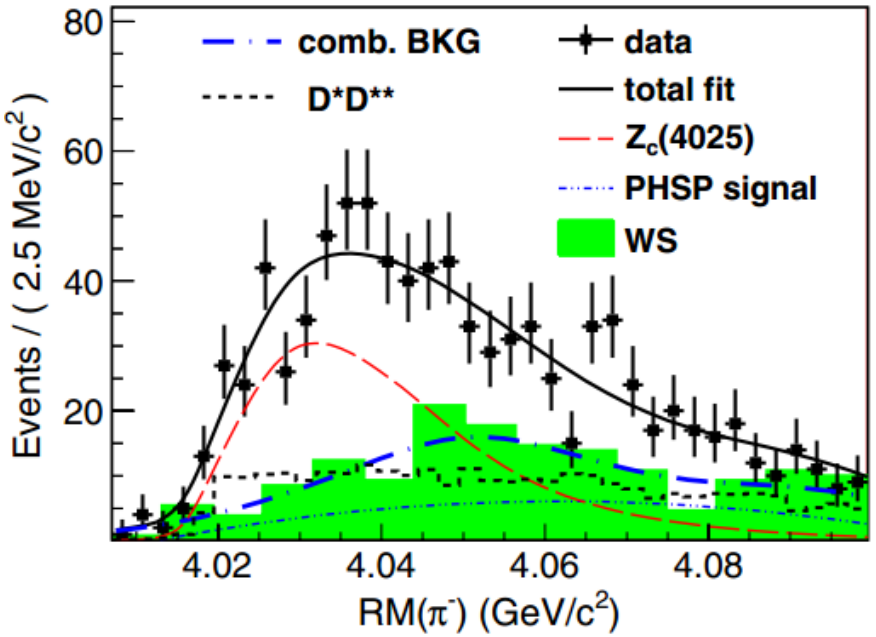


using double D tag method

M=3884.3±1.2±1.5 MeV
Γ=23.8±2.1 ±2.6 MeV

Observation of $Z_c(4025)^{\pm/0}$ in $e^+e^- \to \pi^{\pm/0}(D^*\bar{D}^*)^{\mp/0}$

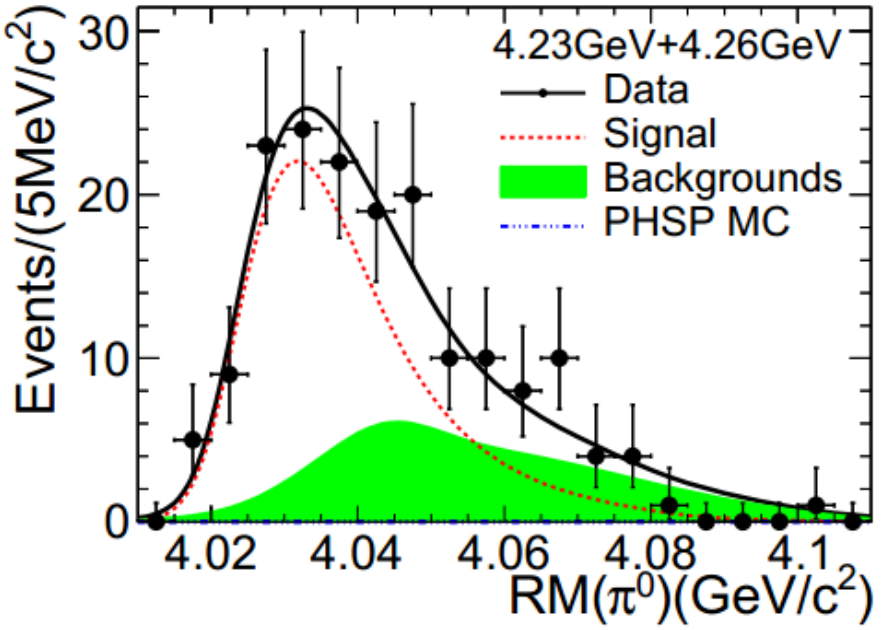
PRL112, 132001(2014)



$M=4026.3\pm2.6\pm3.7$ MeV

$\Gamma=24.8\pm5.6\pm7.7$ MeV

BESIII Preliminary



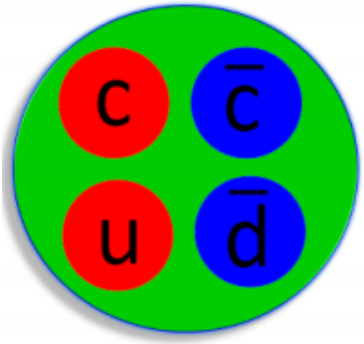
$M=4025.5\pm4.7\pm3.1$ MeV

$\Gamma=23.0\pm6.0\pm1.0$ MeV

Another isospin triplet is established!

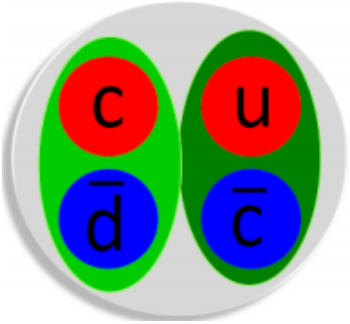
New class of states: Zc

- At least four quarks, not conventional meson.



✓ **Tetraquark state?**

Phys. Rev. D87,125018(2013); Phys. Rev. D88, 074506(2013);
Phys. Rev. D89,054019(2014); Phys. Rev. D90,054009(2014); …



✓ **$D^{(*)}\bar{D}^{(*)}$ molecule state?**

Phys. Rev. Lett. 111, 132003 (2013); Phys. Rev. D 89, 094026 (2014)
Phys. Rev. D 89, 074029 (2014); Phys. Rev. D 88, 074506 (2013); …

✓ **Final States Interaction?**

✓ **…**

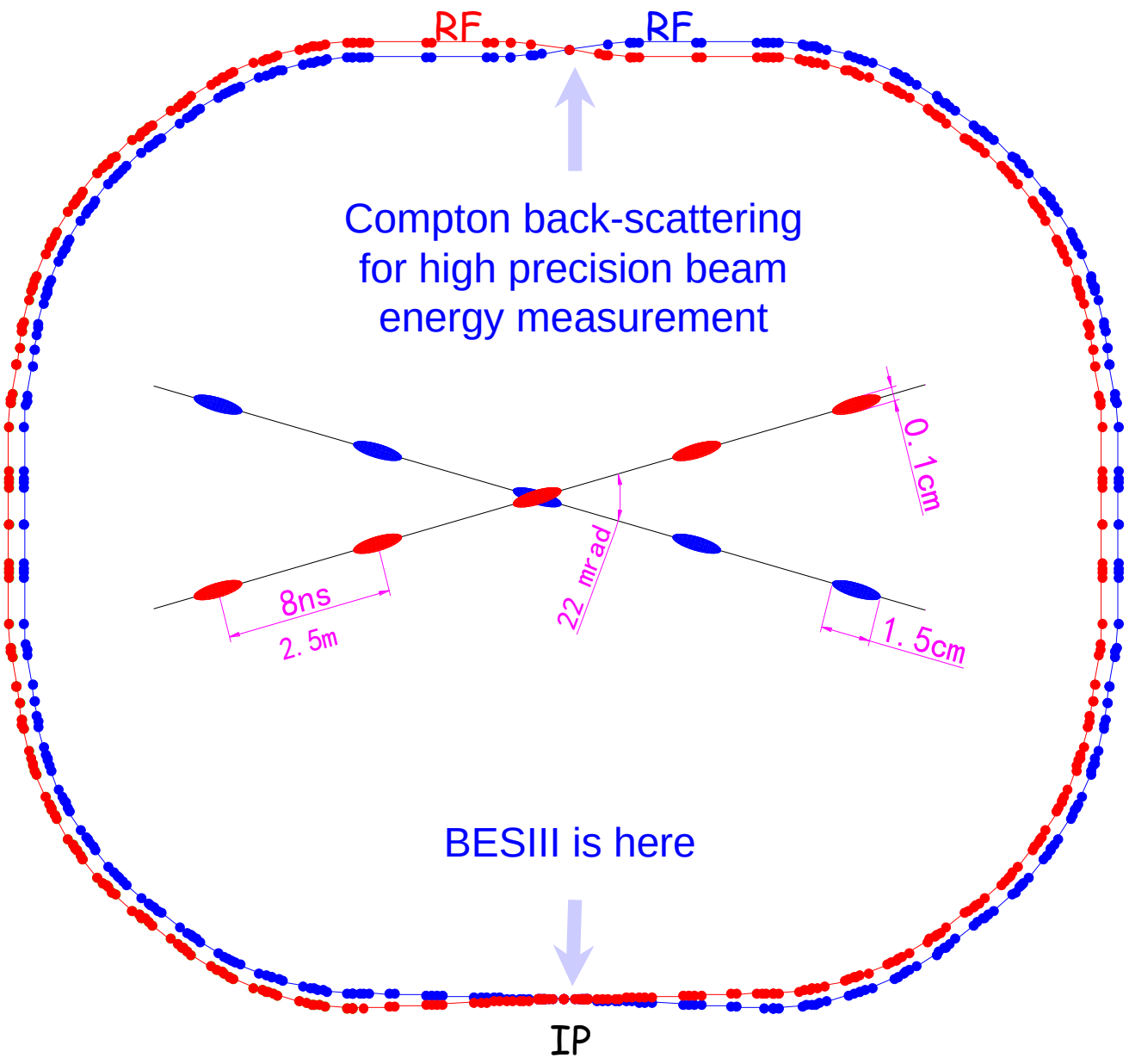
Summary & Outlook

- Lots of progress in the study of exotic and charmonia states at BESIII recently.
- Observation of $e^+e^- \to \gamma X(3872)$ & $\pi^+\pi^- X(3823)$.
- Measurements of many hidden charm final states.
- Observation of Zc states.
- BESIII may continue data taking until 2020-2022.

Thanks a lot!

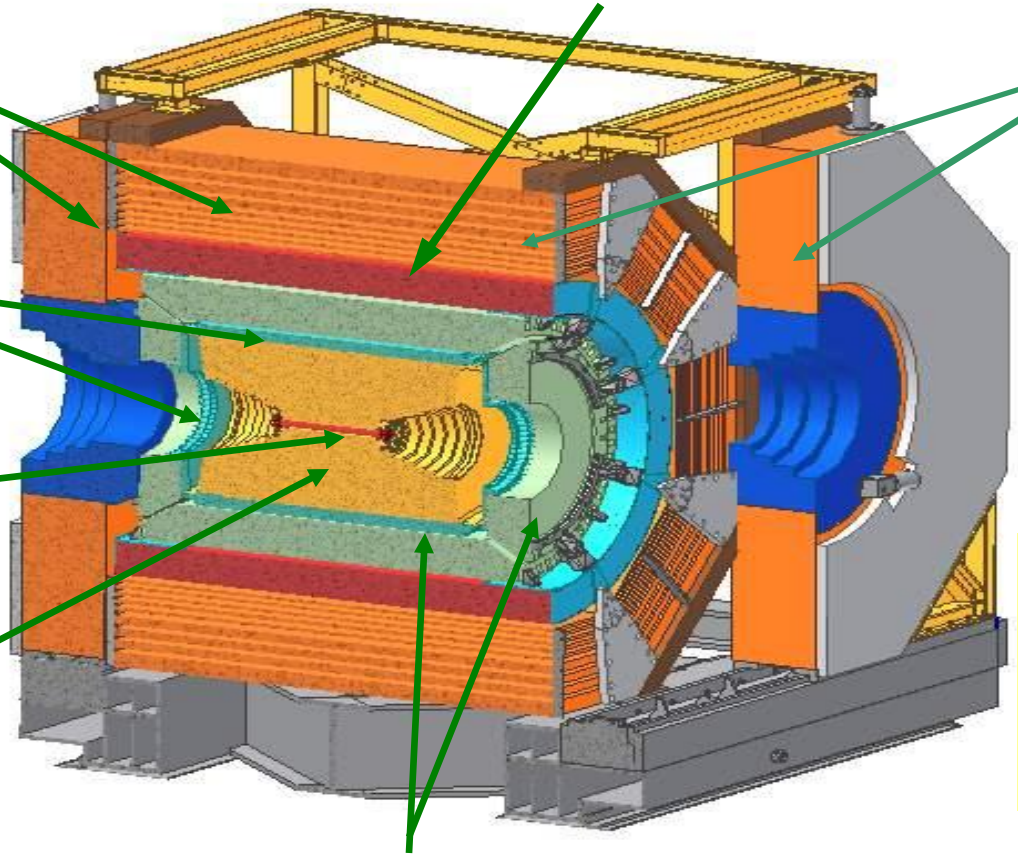
谢谢！

BEPC II: a double-ring machine



Beam energy:
1-2.3 GeV
Luminosity:
1×10^{33} $cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A
SR mode:
0.25A @ 2.5 GeV

The BESIII Detector



A total weight of 730t, ~40,000 readout channels, data rate 6,000Hz ~50Mb/s

Summary on Z_c states

The BESIII experiment discovered several Z_c states.

State	Mass(MeV)	Width(MeV)	Decay mode	Process
$Z_c(3900)^{\pm}$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	$\pi^{\pm} J/\psi$	$e^+e^- \to \pi^+\pi^- J/\psi$
$Z_c(3900)^0$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$	$\pi^0 J/\psi$	$e^+e^- \to \pi^0\pi^0 J/\psi$
$Z_c(3885)^{\pm}$	$3883.9 \pm 1.5 \pm 4.2$ [single D tag] $3884.3 \pm 1.2 \pm 1.5$ [double D tag]	$24.8 \pm 3.3 \pm 11.0$ [single D tag] $23.8 \pm 2.1 \pm 2.6$ [double D tag]	D^0D^{*-} D^-D^{*0}	$e^+e^- \to \pi^+ D^0 D^{*-}$ $e^+e^- \to \pi^+ D^- D^{*0}$
$Z_c(4020)^{\pm}$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	$\pi^{\pm} h_c$	$e^+e^- \to \pi^+\pi^- h_c$
$Z_c(4020)^0$	$4023.9 \pm 2.2 \pm 3.8$	fixed	$\pi^0 h_c$	$e^+e^- \to \pi^0\pi^0 h_c$
$Z_c(4025)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	$D^{*0}D^{*-}$	$e^+e^- \to \pi^+ (D^* \bar{D}^*)^-$