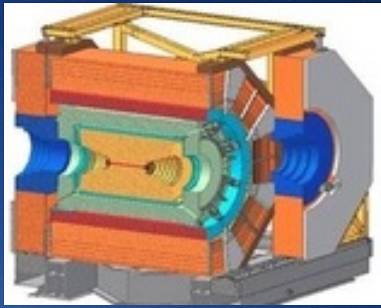
Hirschegg 2014



XYZ physics at BESIII

Zhiqing Liu (JGU Mainz)

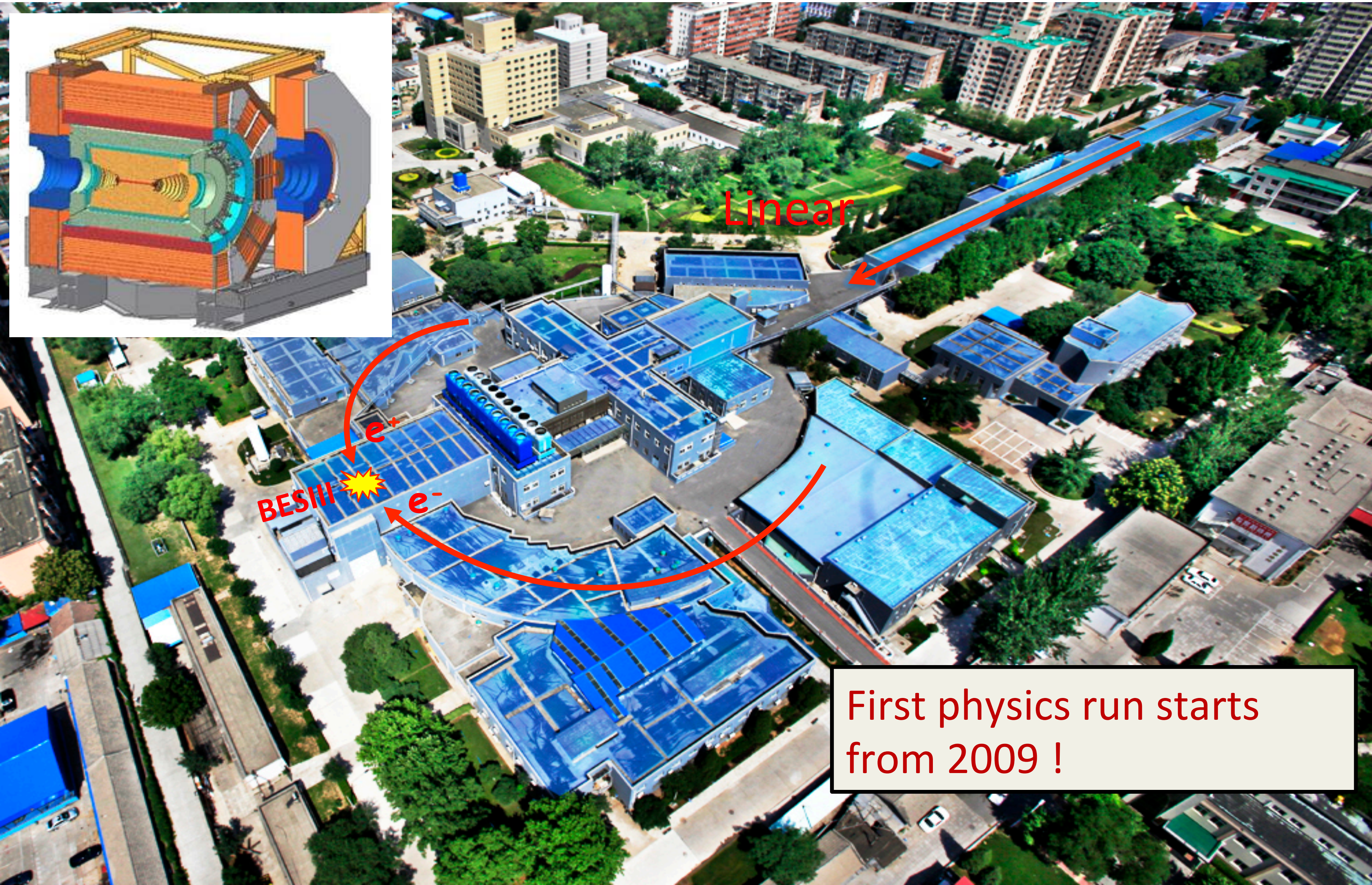
On behalf of BESIII Collaboration

liuz@uni-mainz.de

Outline

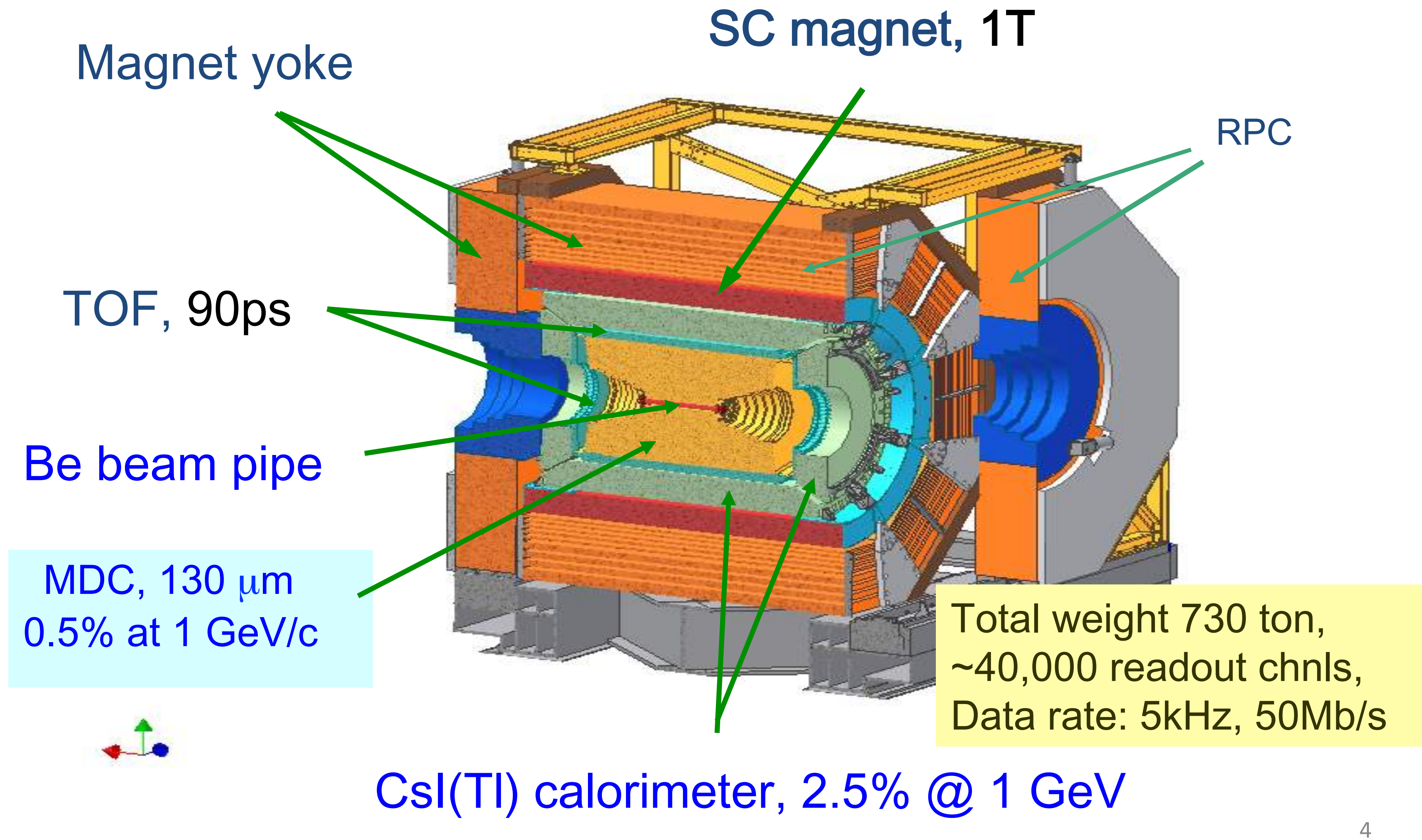
- Introduction
- Observation of $Z_c(3900)$.
- Observation of $Z_c(4020)$ & $Z_c(4025)$.
- Observation of $Y(4260) \rightarrow \gamma X(3872)$.
- Ongoing analysis & Future plan.
- Summary

Beijing Electron Positron Collider (BEPC II)



First physics run starts from 2009 !

BESIII Detector



BEPC II storage ring

Double ring:
symmetric collider

CMS energy:
2.0 - 4.6 GeV

Design Luminosity @ ψ(3770):
(70% achieved, ~20/pb per day)
1×10^{33} $cm^{-2}s^{-1}$

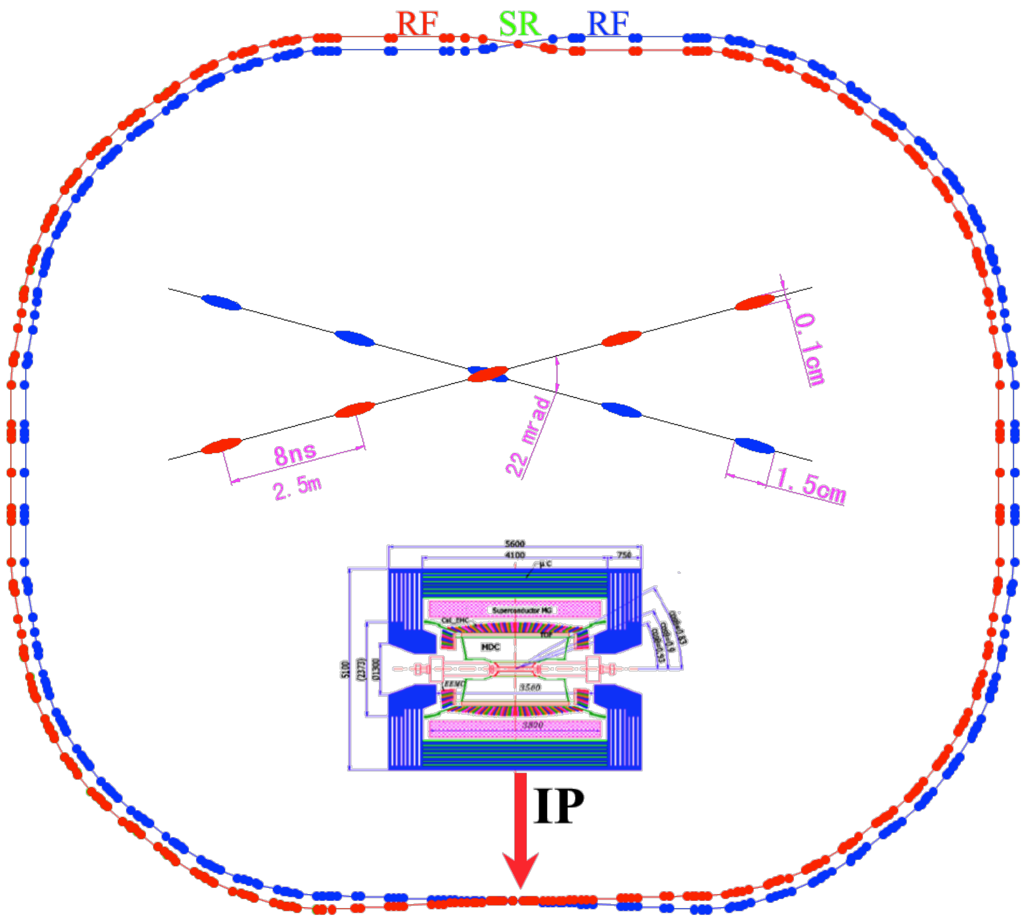
Energy spread:
1.1 MeV @ 3.686 GeV

No. of bunches:
93

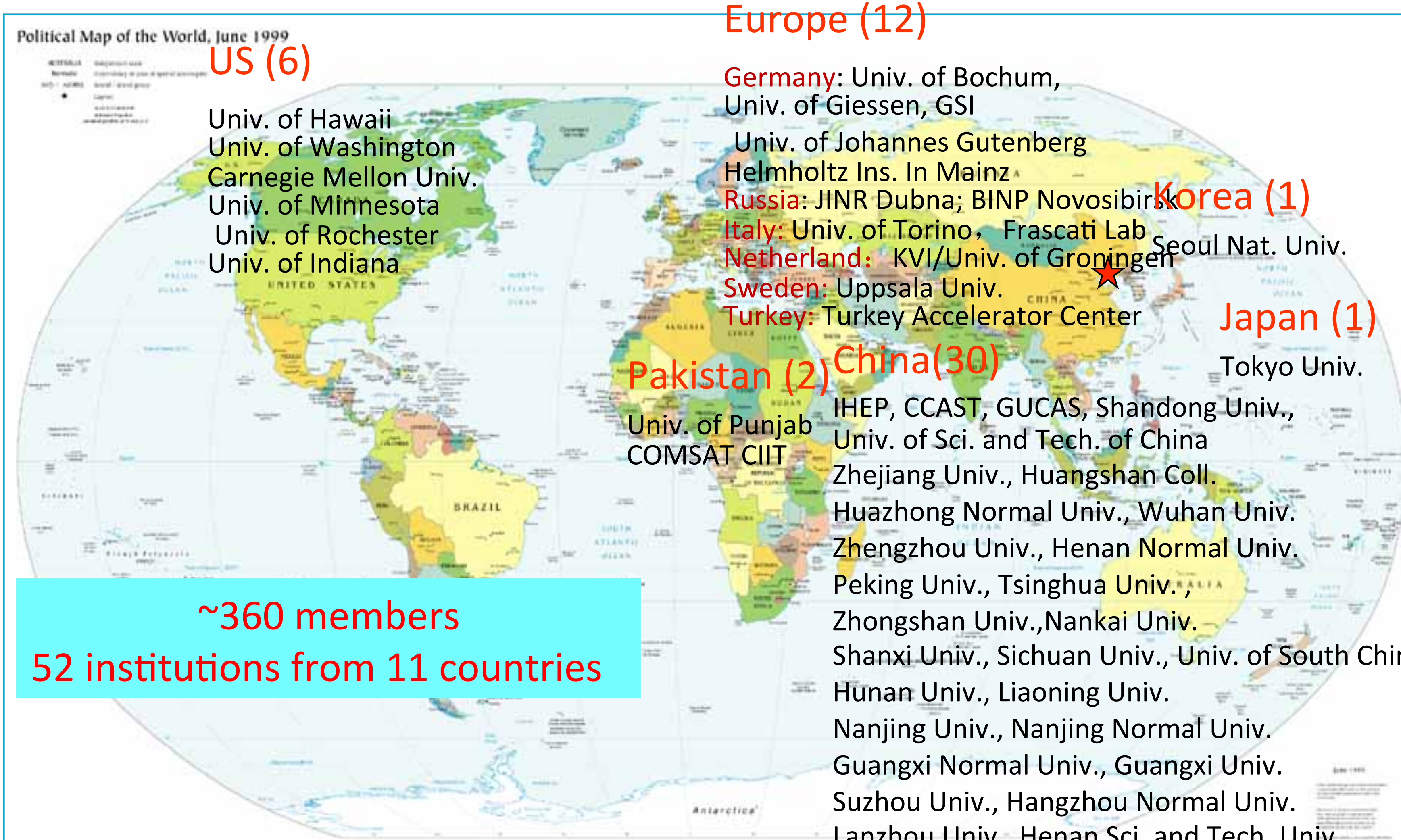
Bunch length:
1.5 cm

Total current:
0.91 A

Circumference:
237 m



The BESIII Collaboration



US (6)

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

Europe (12)

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

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

China(30)

IHEP, CCAST, GUCAS, 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.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Hong Kong Univ., Hong Kong Chinese Univ.

~360 members
52 institutions from 11 countries

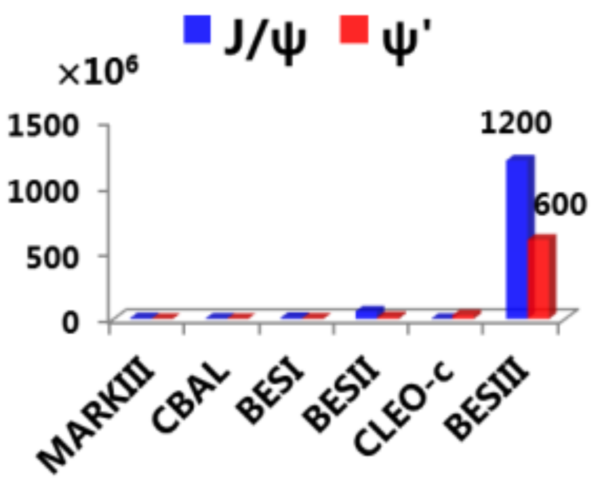
What can we do at BESIII?

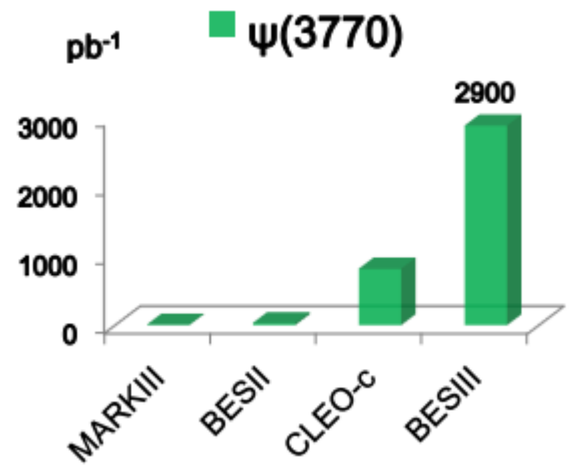
- We have collected world's largest charmonium data sample!
- 225M+~1000M J/ψ events.

  J/ψ decay, light hadrons
- 106M+~500M $\psi(2S)$ events.

  Charmonium
- ~2.9/fb $\psi(3770)$ data.

  D meson



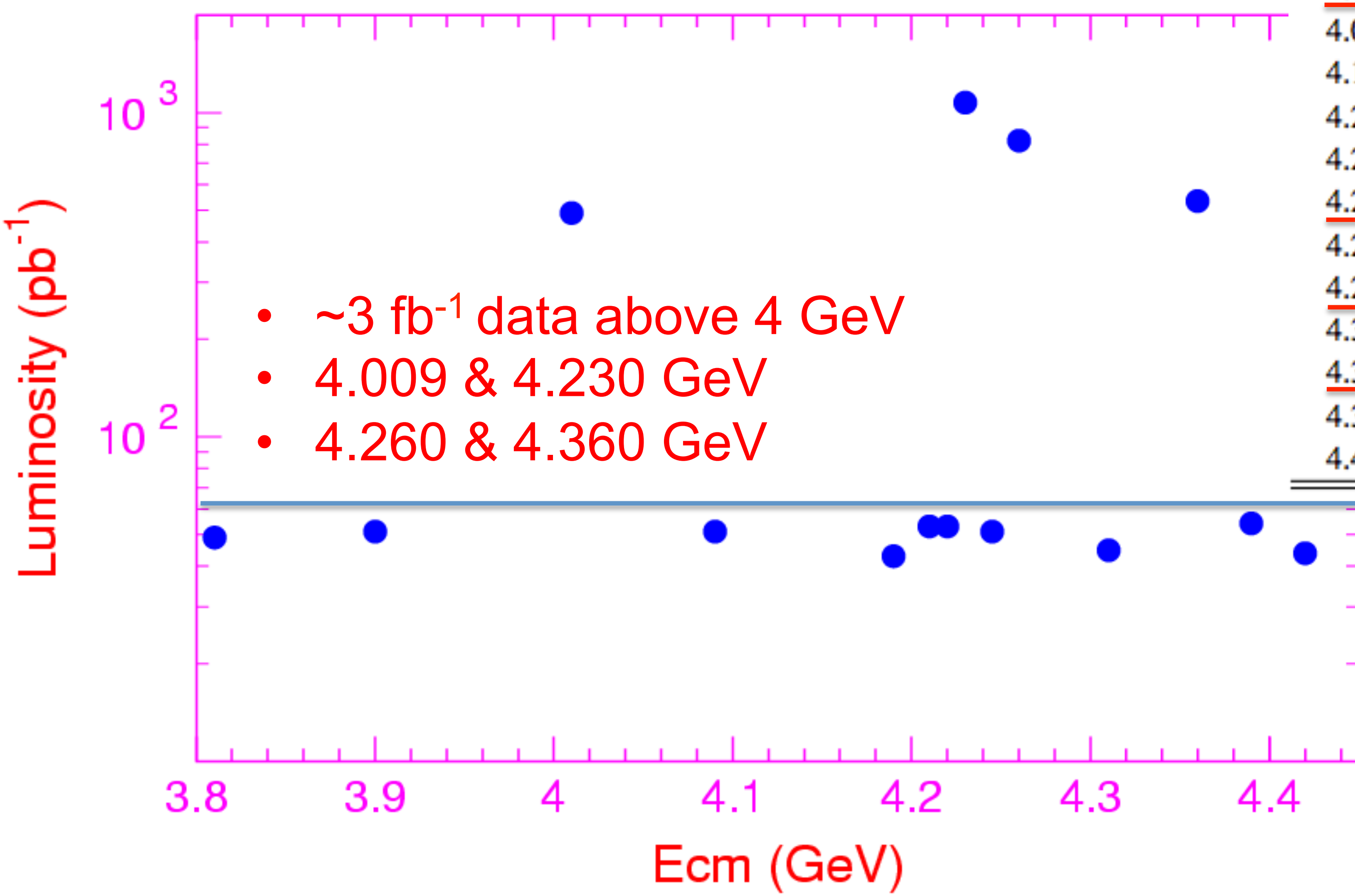


NOT the whole story,

XYZ physics !

XYZ Physics at BESIII

$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})
3.900	52.8
4.009	482.0
4.090	51.0
4.190	43.0
4.210	54.7
4.220	54.6
4.230	1090.0
4.245	56.0
4.260	826.8
4.310	44.9
4.360	544.5
4.390	55.1
4.420	44.7



- ~3 fb^{-1} data above 4 GeV
- 4.009 & 4.230 GeV
- 4.260 & 4.360 GeV

XYZ Physics at BESIII

$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})
3.900	52.8
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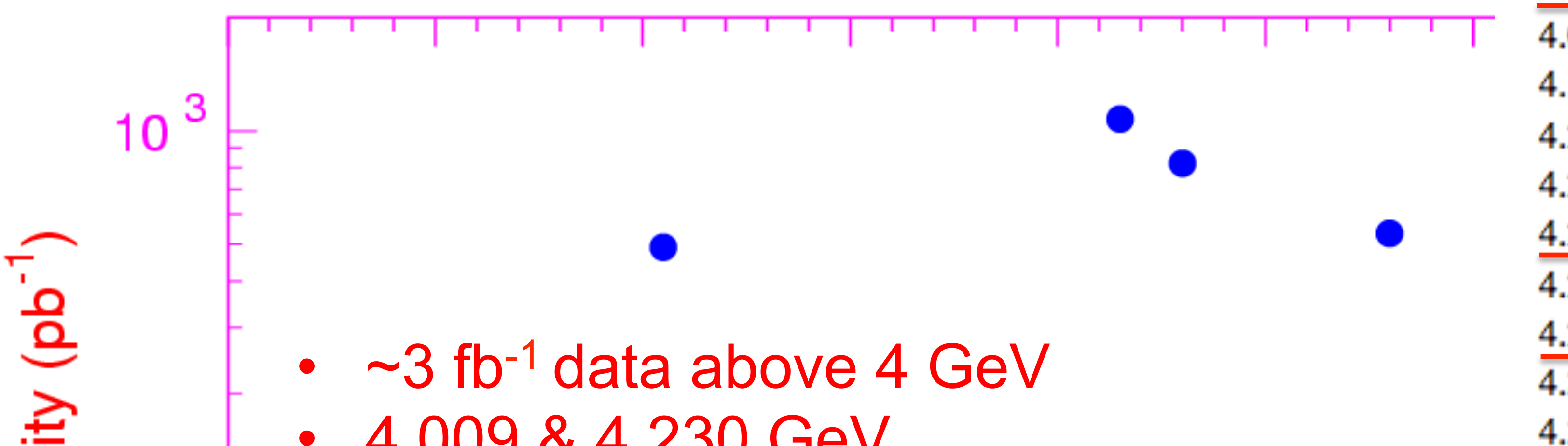
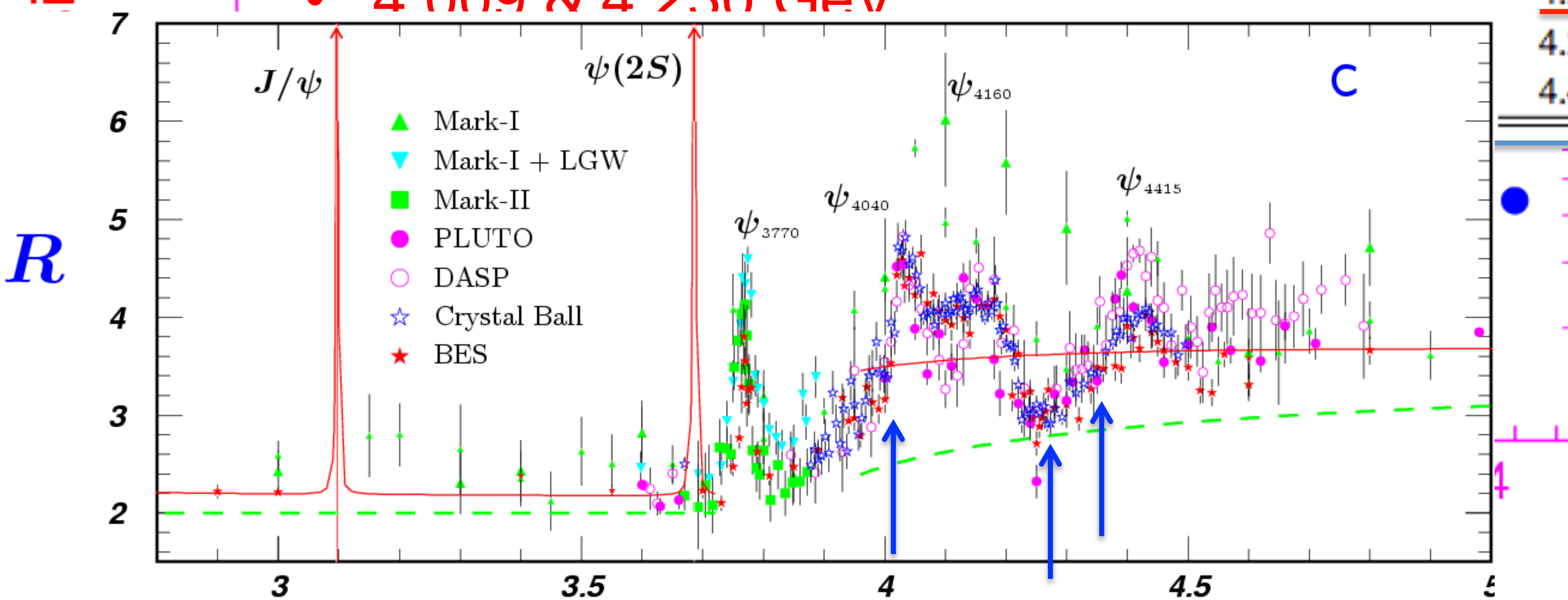
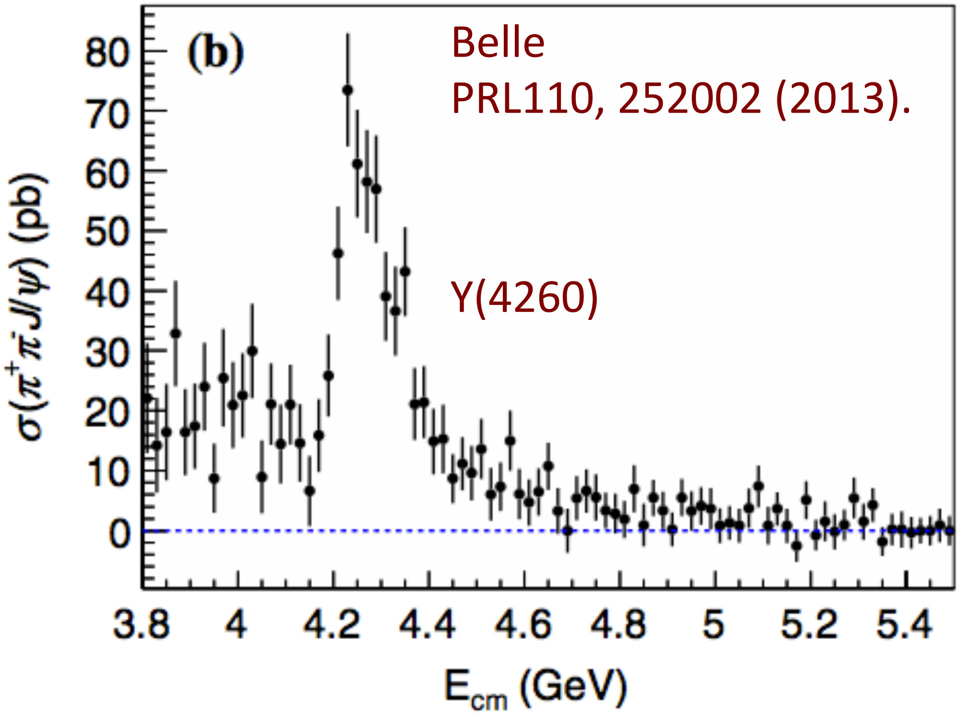


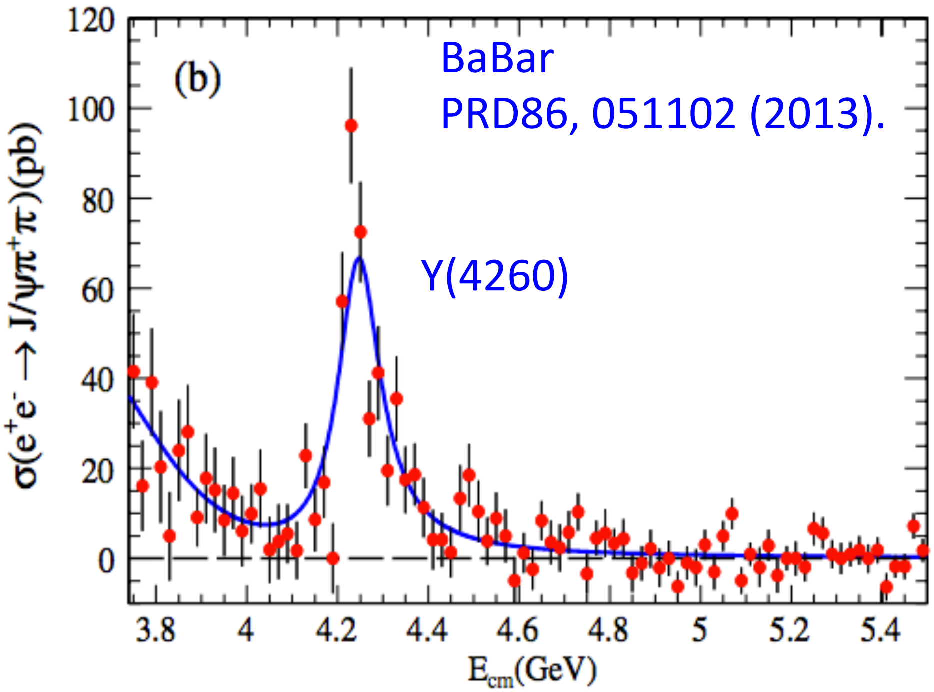
- ~3 fb^{-1} data above 4 GeV
- 4.009 & 4.230 GeV



I. Discovery of $Z_c(3900)$

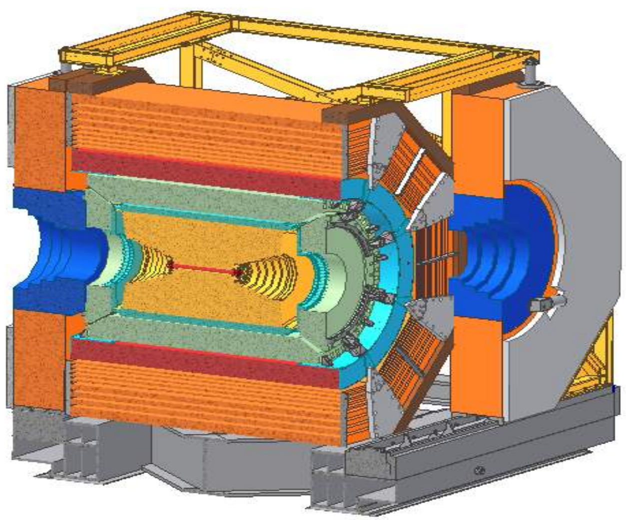
The Y(4260)→$\pi^+\pi^- J/\psi$





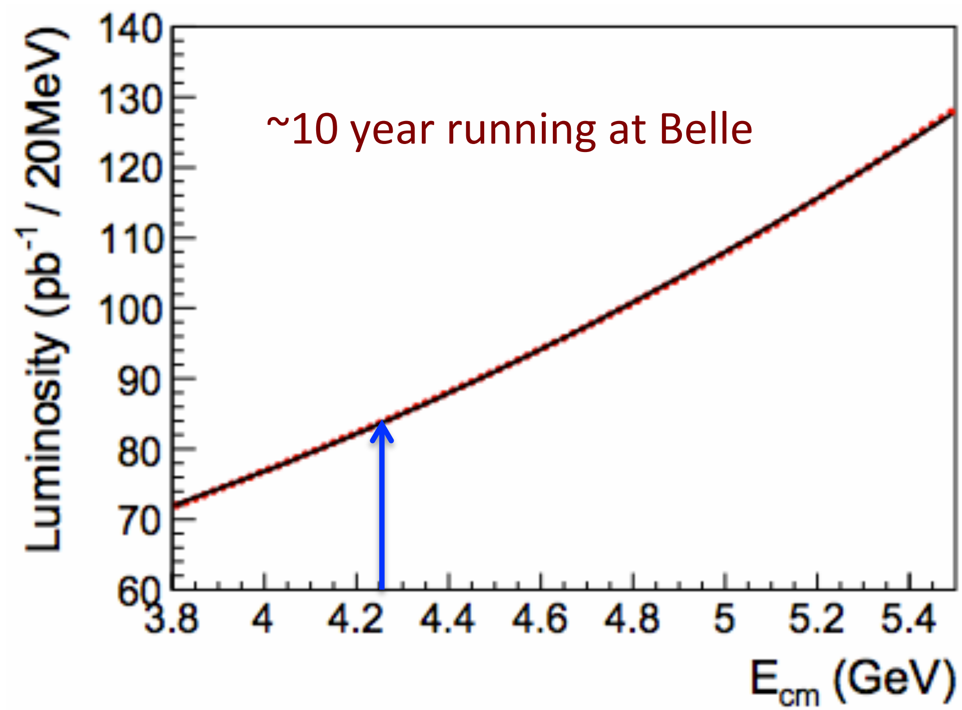
1. The Y(4260) resonance was observed by BABAR and Belle.
2. Based on data set ~10.58 GeV, using the initial-state-radiation (ISR) method.
3. The Y(4260) also interpreted to be an exotic hadron candidate.

Study Y(4260) at BESIII



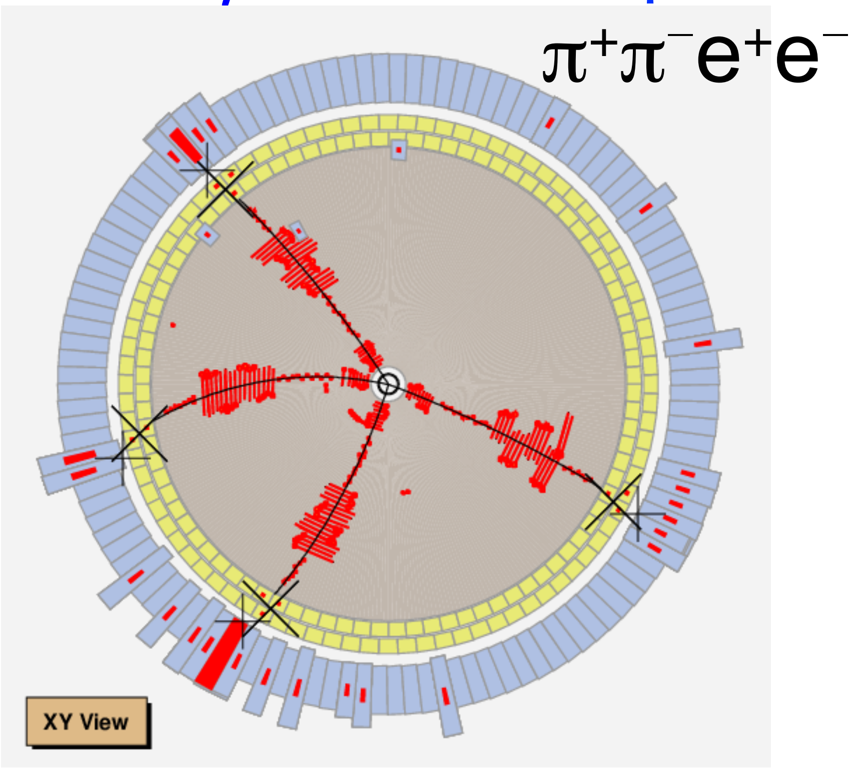
- BESIII is a symmetric collider.
- CM energy: 2 GeV – 4.6 GeV
- Design Lum=$1*10^{33}$ /cm^2/s
- Focus on one energy point, then more competitive than B factory

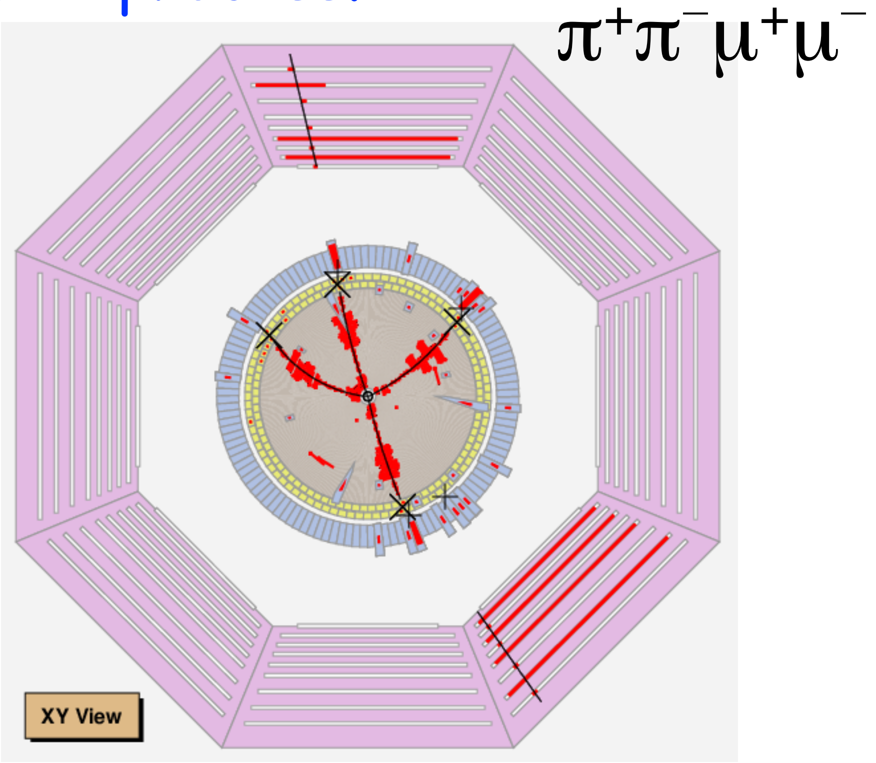
- Effective ISR luminosity (QED).
- L(total)~967 fb^{-1} @ ~10 GeV.
- ~85 pb^{-1}/20 MeV at 4.26 GeV.
- What's about BESIII?
- ~20 pb^{-1} /day around 4.26 GeV.



Study Y(4260) at BESIII

- Dec, 2012 to Jan, 2013, BESIII accumulate 525 pb^{-1} data @ 4.26 GeV, world's largest data set!
- Study e+e-→$\pi^+\pi^- J/\psi$ exclusive process.

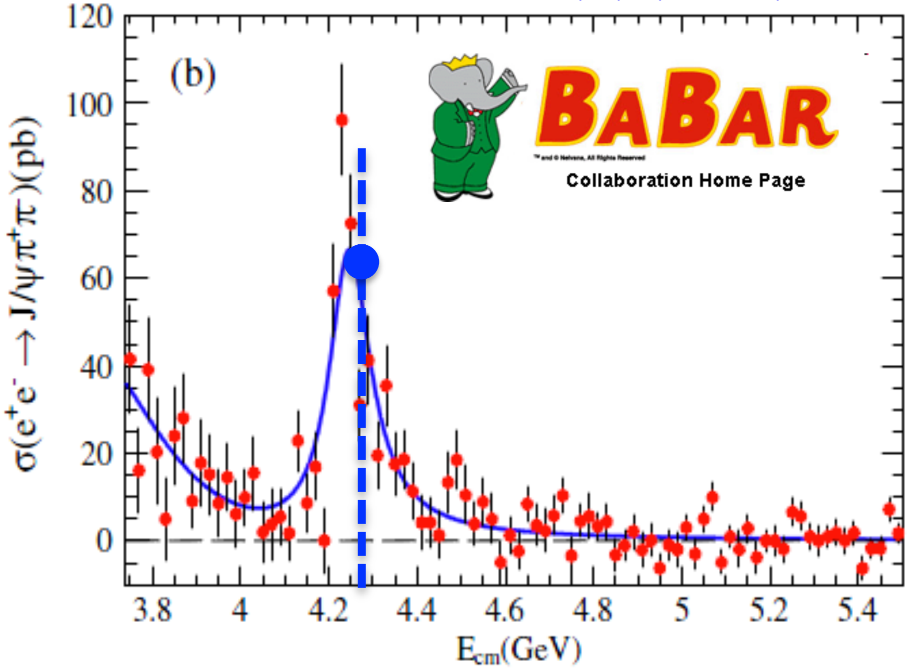




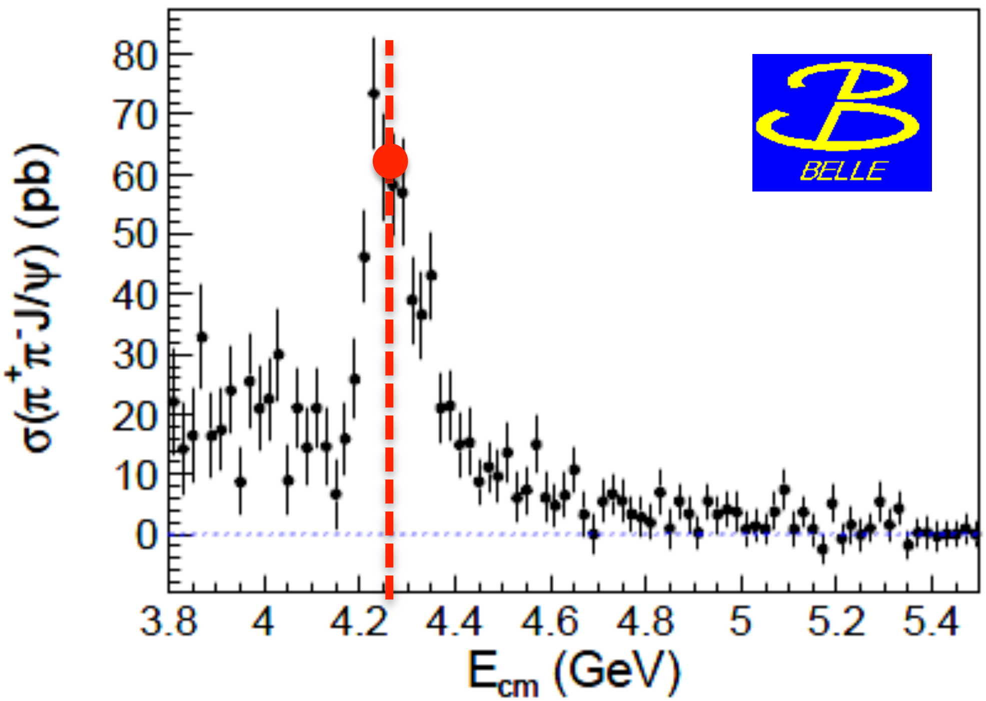
1. Very simple and straightforward analysis.
2. The produced vector charmonium(like) state almost in rest frame.
3. Y(4260)→$\pi^+\pi^- J/\psi$, four charged track detected.

Cross Section at BESIII

PRD **86**,051102(R) (2012).



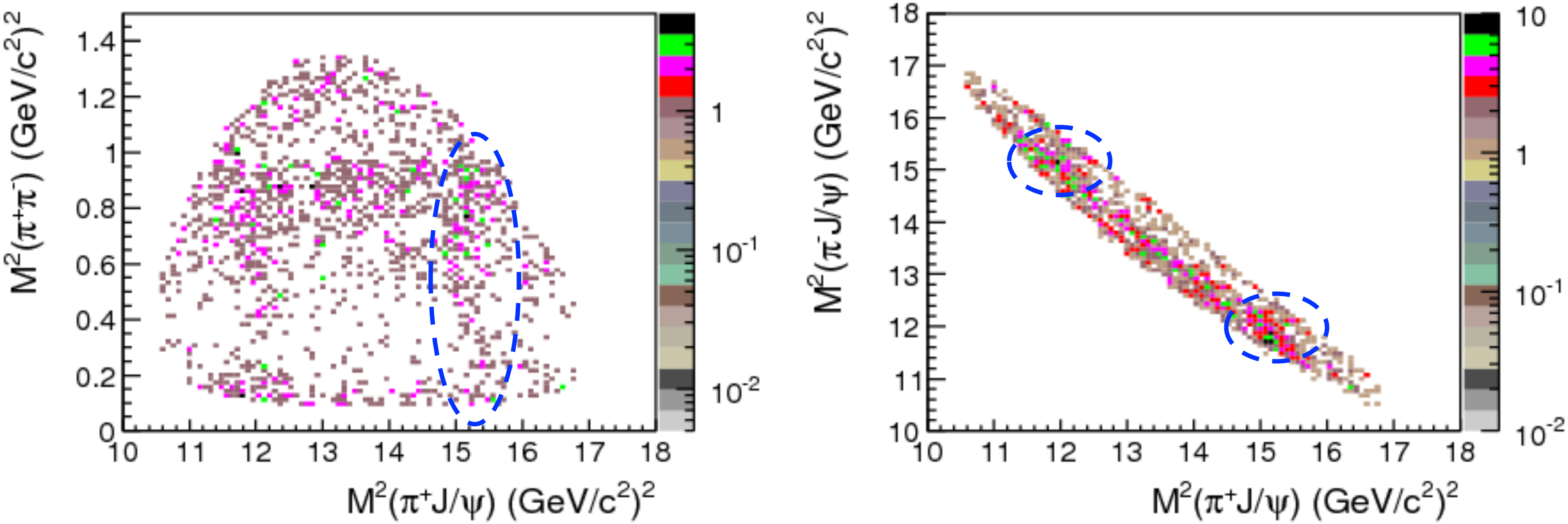
PRL **110**,252002 (2013).



1. Lum=525 pb^{-1} @ BESIII
2. $N(\mu^+\mu^-)$=882±33; $N(e^+e^-)$=595±28.
3. Born cross section: σ^B=(62.9±1.9±3.7) pb @ BESIII.
4. Good agreement with Belle and BaBar.
5. Analysis is valid and unbiased.

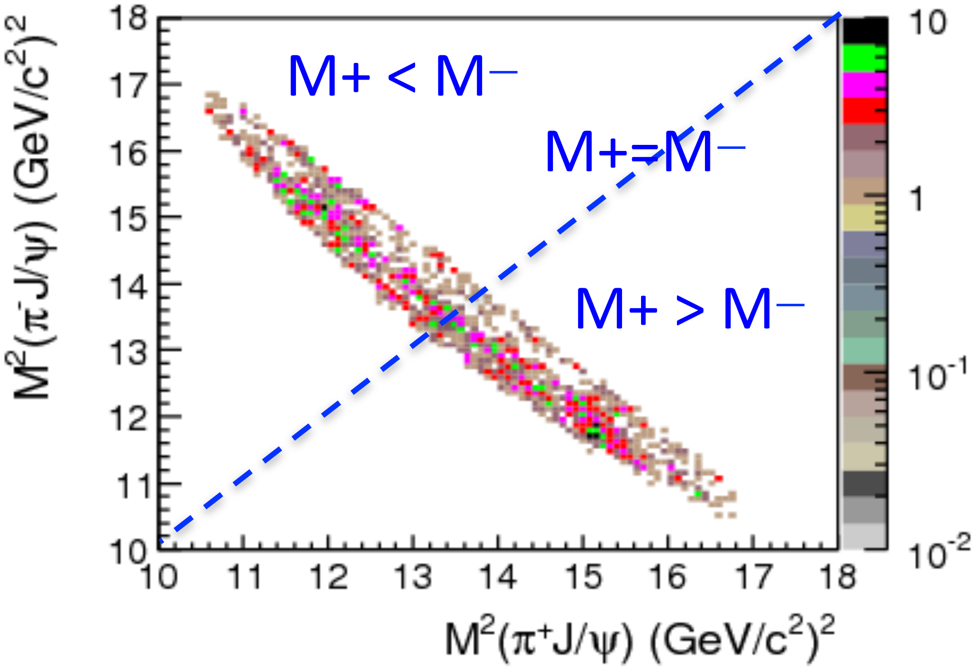
Intermediate state——$Z_c(3900)$

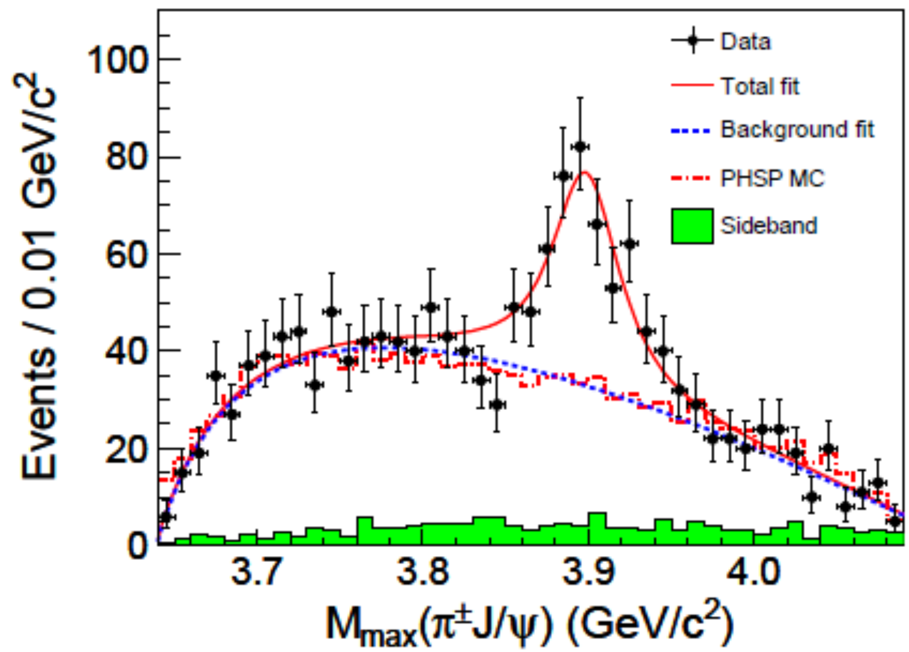
- Requiring J/ψ mass window: [3.08,3.12] GeV, we have 1595 signal events, with purity ~90%.



1. Intermediate states both in $M(\pi^+\pi^-)$ mass distribution and $M(\pi^\pm J/\psi)$ mass distribution.
2. A clear band in the $M(\pi^\pm J/\psi)$ invariant mass projection.
3. Phase space reflection between $M(\pi^+J/\psi)$ and $M(\pi^-J/\psi)$.

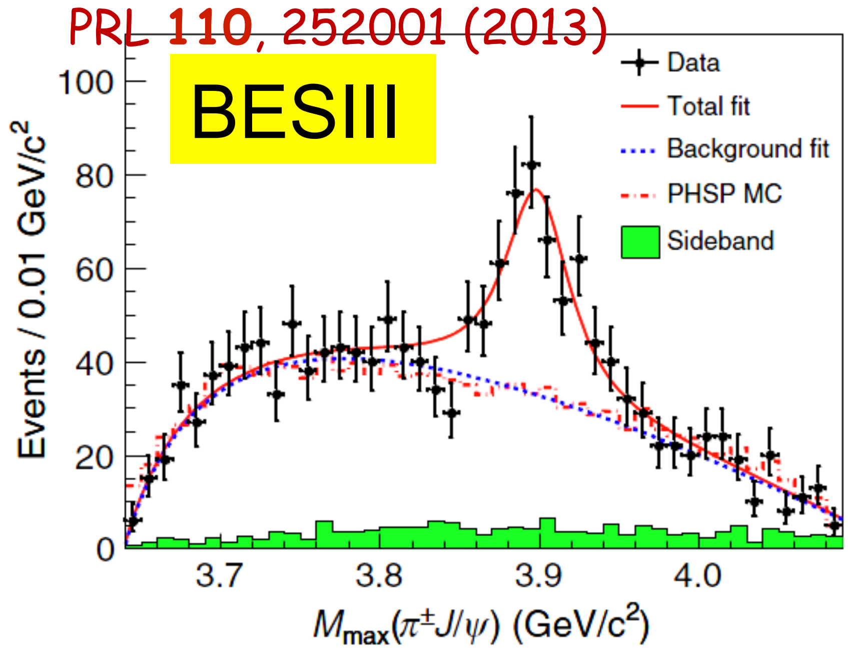
Intermediate state——$Z_c(3900)$

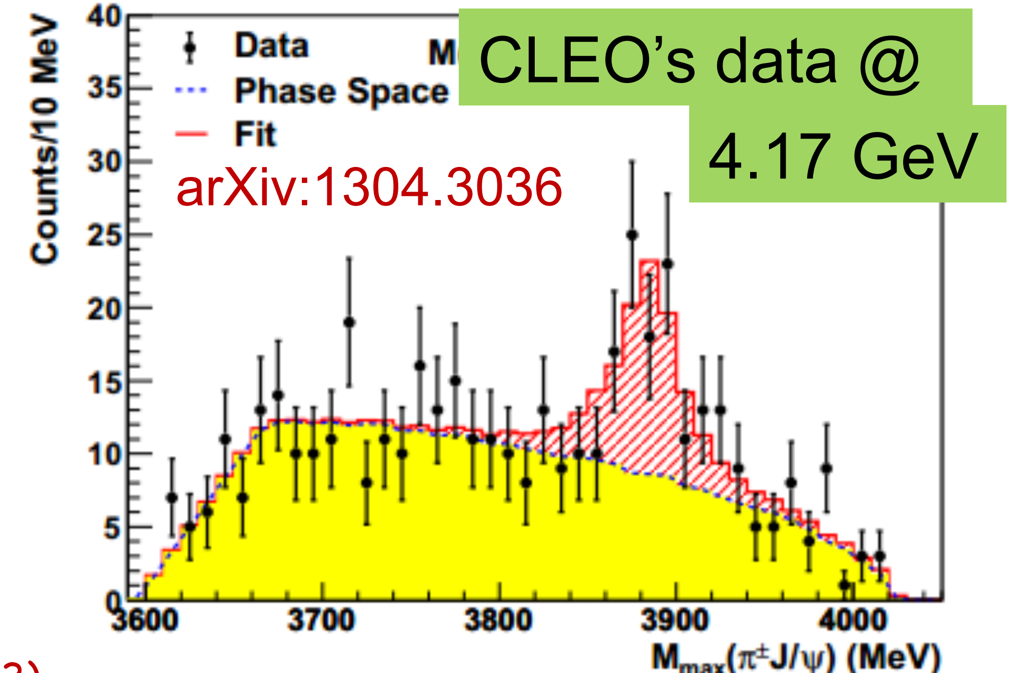


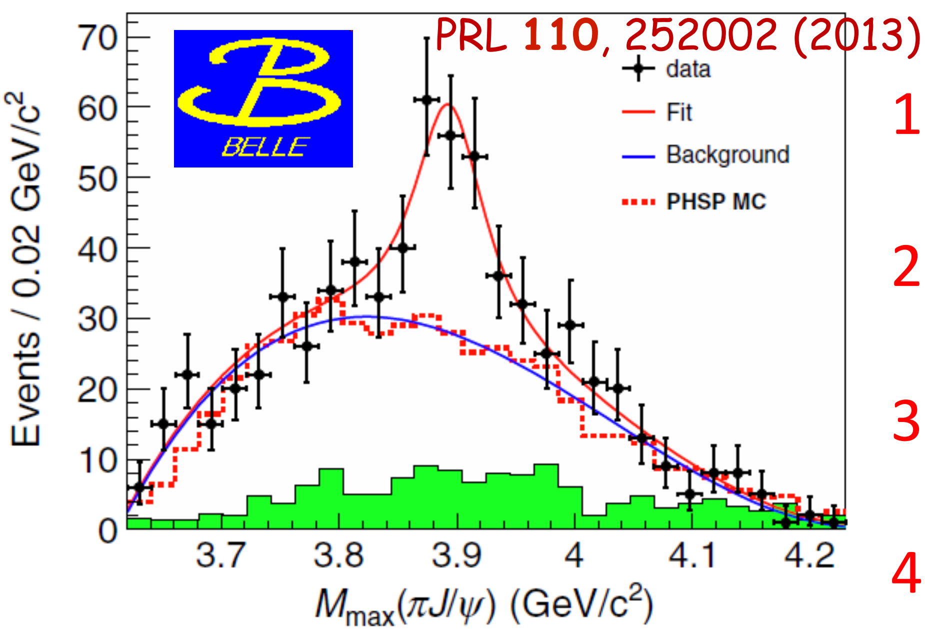


1. First stage, 1D fit to extract resonant parameters.
2. Divided by diagonal line of the dalitz plot and fit $M_{max}(\pi^\pm J/\psi)$ mass distribution; best way to avoid cross counting.
3. S-Wave Breit Wigner; p*q phase space factor; efficiency corrected.
4. M=(3899.0±3.6±4.9)MeV; Γ=(46±10±20)MeV.
5. Statistical significance: >8σ, discovery!

Good News





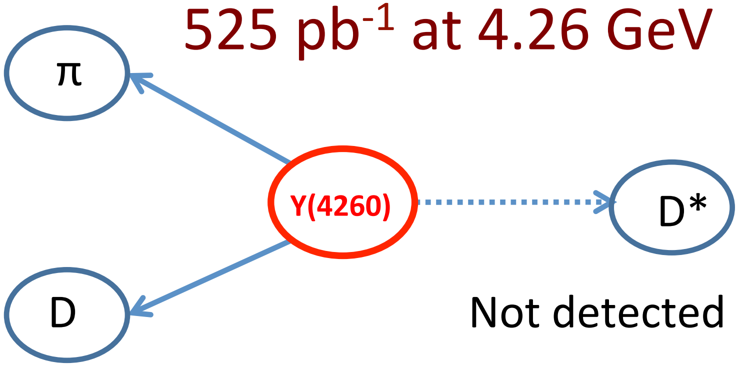


1. CLEO's data: M=3886±6±4 MeV, Γ=33±6±7 MeV.
2. Belle: M=(3894.5±6.6±4.5) MeV; Γ=(63±24±26) MeV.
3. BESIII: M=(3899.0±3.6±4.9) MeV; Γ=(46±10±20)MeV
4. $Z_c(3900)=Z(3900)^{\pm}$.

$Z_c(3885)^{\pm} \rightarrow (DD^{*})^{\pm}$

Partial reconstruction technique

525 pb^{-1} at 4.26 GeV



$\pi^{\pm}(DD^{*})^{\mp}$ includes 4 decay modes:

1) $\pi^+ D^0 D^{*-}$+c.c., $D^{*-} \rightarrow \pi^0 D^-$
2) $\pi^+ D^- D^{*0}$+c.c., $D^{*0} \rightarrow \gamma/\pi^0 D^0$

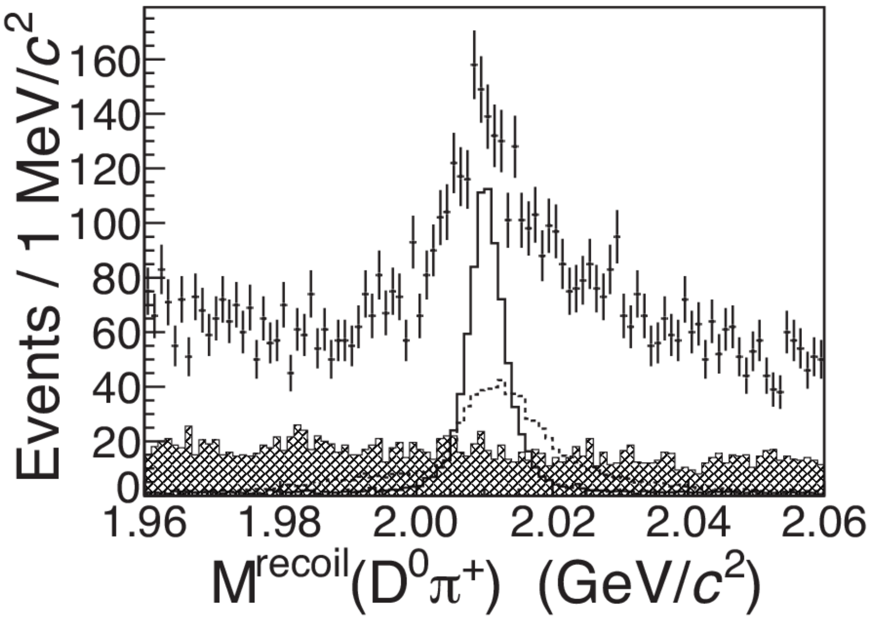
We only reconstruct the bachelor pion and a single D.

1. If we tag a π^+ and D^0, we select the events:
   $\pi^+ D^0 D^{*-}$ and $\pi^+ D^- D^{*0}$ ($D^{*0} \rightarrow \gamma/\pi^0 D^0$)
2. If we tag a π^+ and D^-, we select the events:
   $\pi^+ D^0 D^{*-}$ ($D^{*-} \rightarrow \pi^0 D^-$) and $\pi^+ D^- D^{*0}$ ($D^{*0} \rightarrow \gamma/\pi^0 D^0$)
3. Sometimes there are cross feeding events, but it's OK.

Recoil mass of πD

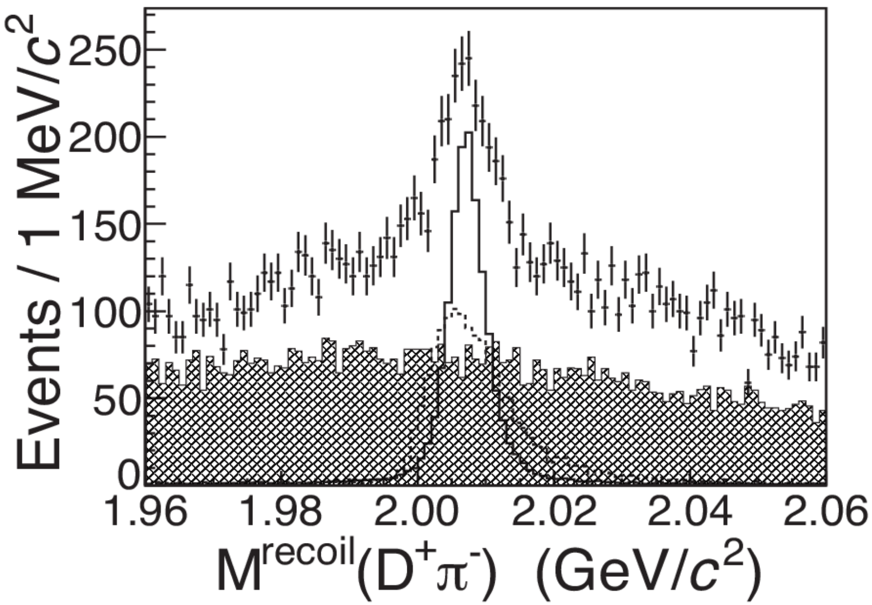
π^+D^0 tagging method

Dots with error bars: Data
Solid: $e^+e^-\to\pi^+D^0D^{*-}$
Dash: $e^+e^-\to\pi^+D^-D^{*0}$, where DD* from Z_c
Hatch: Events from D^0 sideband



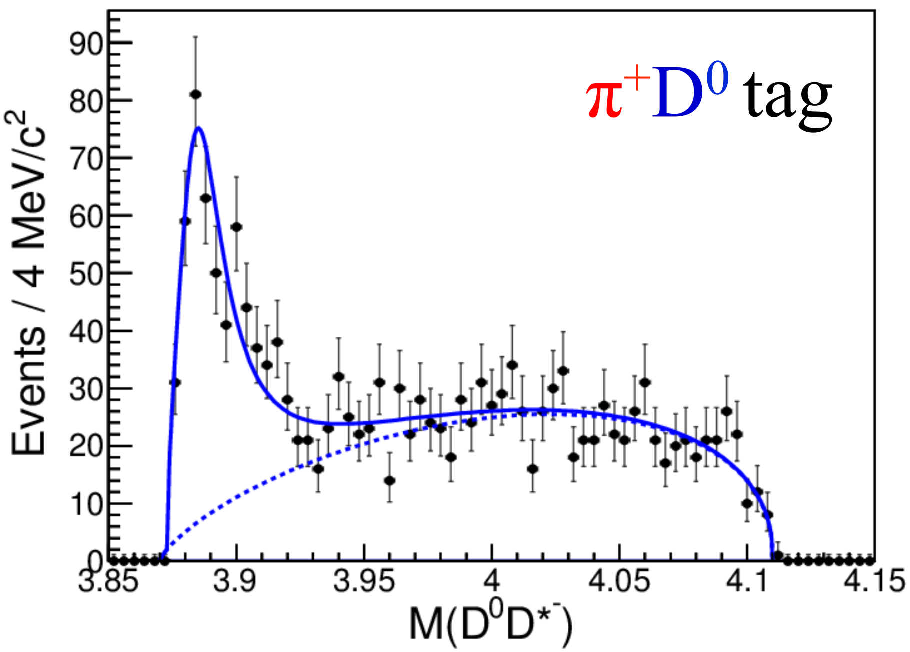
π^+D^- tagging method

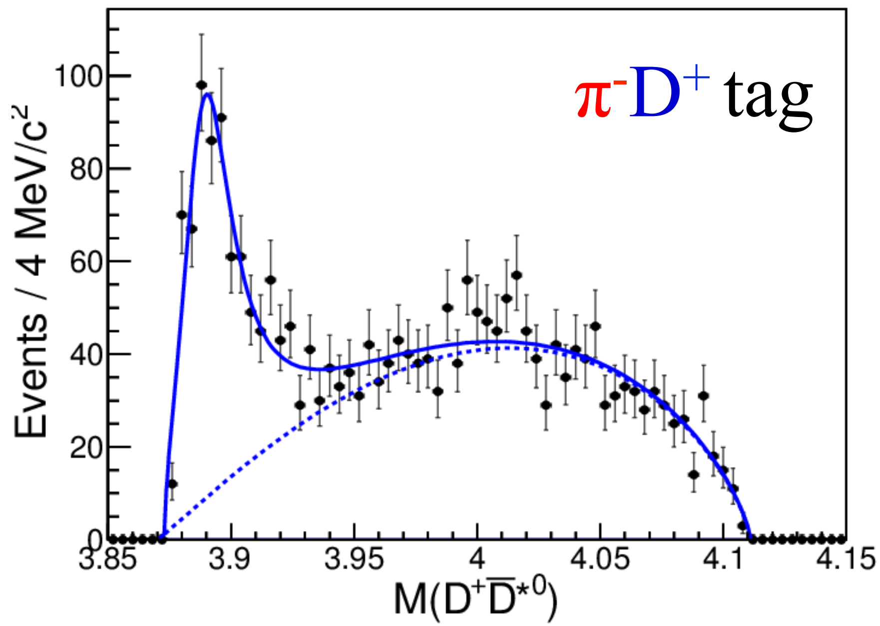
Dots with error bars: Data
Solid: $e^+e^-\to\pi^+D^-D^{*0}$
Dash: $e^+e^-\to\pi^+D^0D^{*-}$, where DD* from Z_c
Hatch: Events from D^- sideband



- Clear signal of D*
- Mass constraint to D*, $\chi^2<30$

Mass Spectrum by recoil π





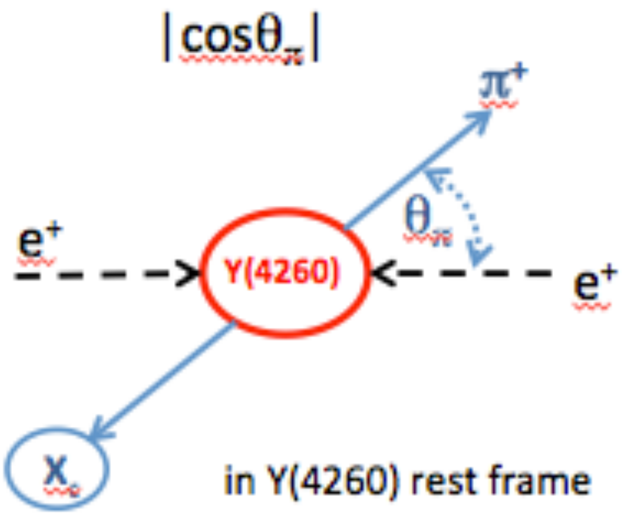
- Peak near threshold.
- Angular distribution (πD) disfavor DD_1 component.
- Fit with mass dependent BW, report pole position.
- Polynomial background.

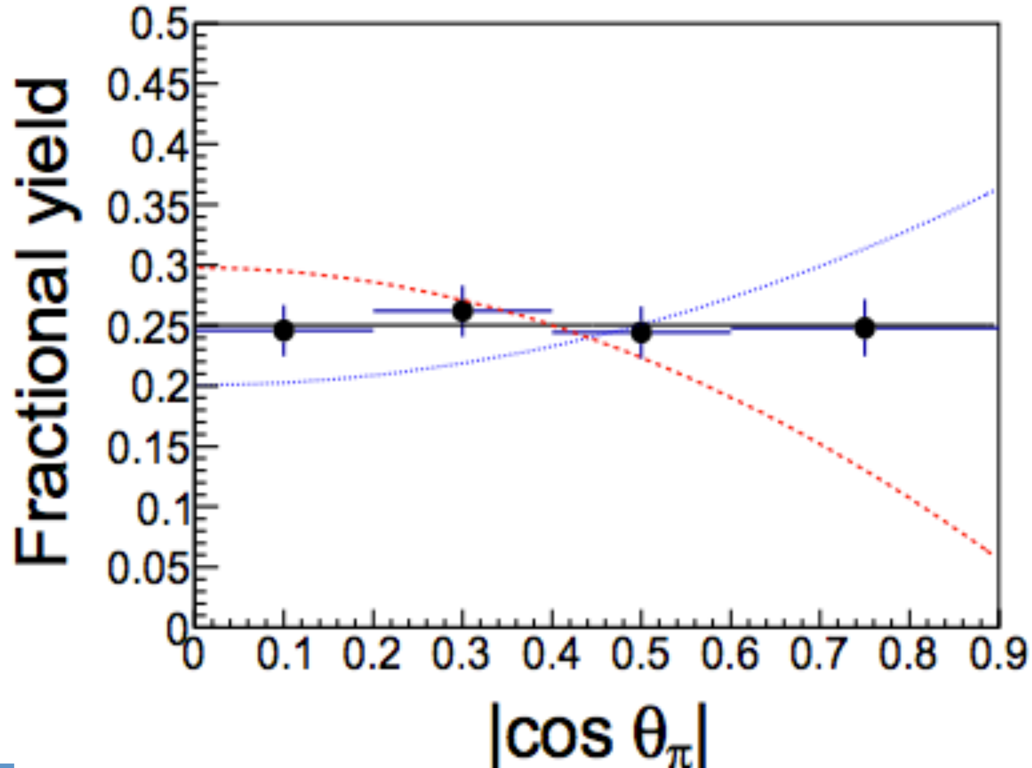
$Z_c(3885)=Z_c(3900)$

Production rate are much higher than $\pi^{\pm}J/\psi$!

	$Z_c(3885) \to D\bar{D}^*$
Mass (MeV/c^2)	$3883.9 \pm 1.5 \pm 4.2$
Γ (MeV)	$24.8 \pm 3.3 \pm 11.0$
$\sigma \times \mathcal{B}$ (pb)	$83.5 \pm 6.6 \pm 22.0$

Spin-Parity of $Z_c(3885)$

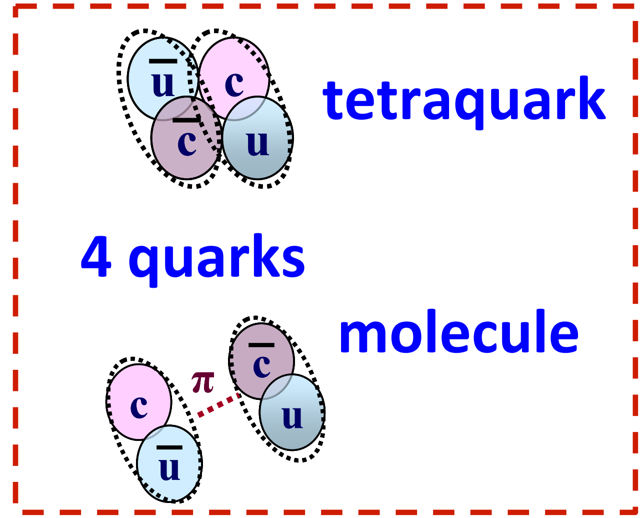




J^P	L	$dN/d\|\cos\theta_\pi\|$
1^+	S-wave	flat
0^-	P-wave	$\sin^2\theta_\pi$
1^-	P-wave	$1+\cos^2\theta_\pi$

Favor $J^P=1^+$

The nature of $Z_c(3900)$?



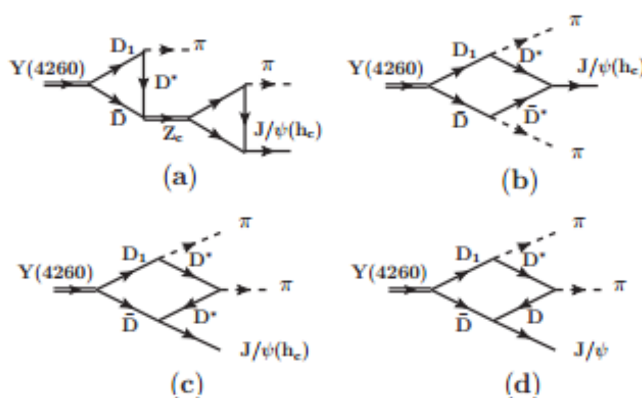
1. Tetraquarks
- arXiv:1110.1333, 1303.6857
- arXiv:1304.0345, 1304.1301…

2. Hadronic molecules
- arXiv:1303.6608, 1304.2882, 1304.1850…

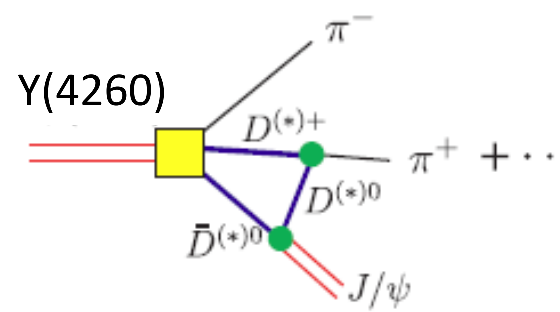
3. Four quark state
- arXiv:1304.0380…

Exotic!

4. Meson loop
- arXiv:1303.6355
- arXiv:1304.4458…



Meson loop



ISPE model

5. ISPE model
- arXiv:1303.6842…

6. …

$Z_c(4020)$ & $Z_c(4025)$

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

$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})
3.900	52.8
4.009	482.0
4.090	51.0
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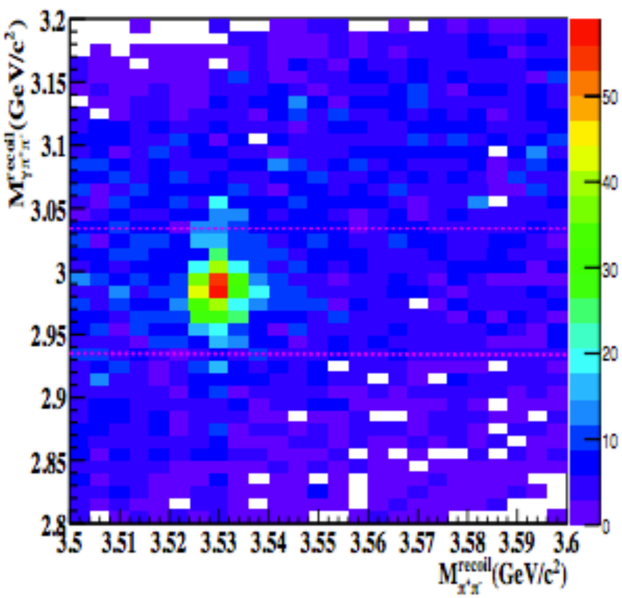
4.220	54.6
4.230	1090.0
4.245	56.0
4.260	826.8
4.310	44.9
4.360	544.5
4.390	55.1
4.420	44.7

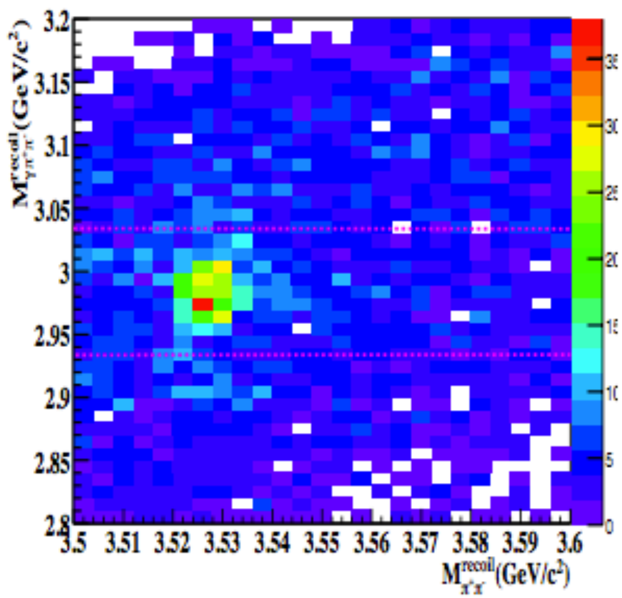
Data above/near 4 GeV, with luminosity 3.3 fb^{-1}

- $h_c \to \gamma\eta_c$, $\eta_c \to$ hadrons [16 exclusive decay modes]
  - p pbar, $\pi^+\pi^-K^+K^-$, $\pi^+\pi^-$p pbar, $2(K^+K^-)$, $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$
  - $2(\pi^+\pi^-)K^+K^-$, $K_S^0K^+\pi^-$+c.c., $K_S^0K^+\pi^-\pi^+\pi^-$+c.c., $K^+K^-\pi^0$
  - ppbarπ^0, $K^+K^-\eta$, $\pi^+\pi^-\eta$, $\pi^+\pi^-\pi^0\pi^0$, $2(\pi^+\pi^-)\eta$, $2(\pi^+\pi^-\pi^0)$
  - ~50% h_c decay & 40% of η_c decay.

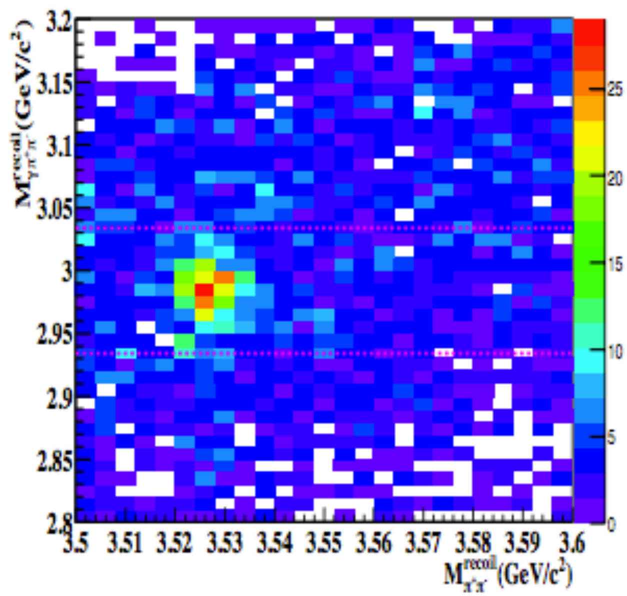
4230 MeV



4260 MeV

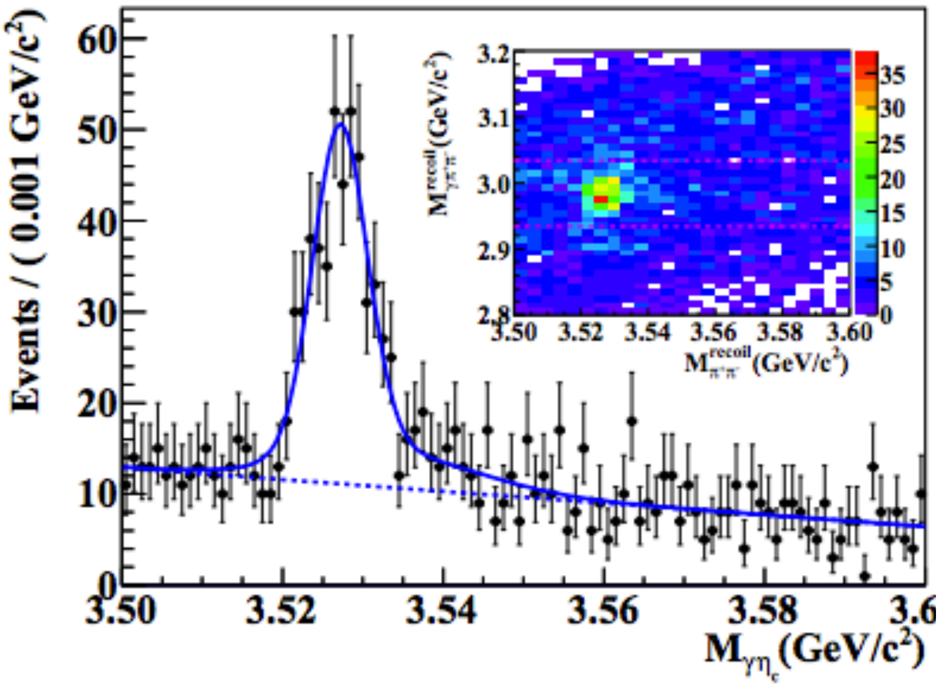


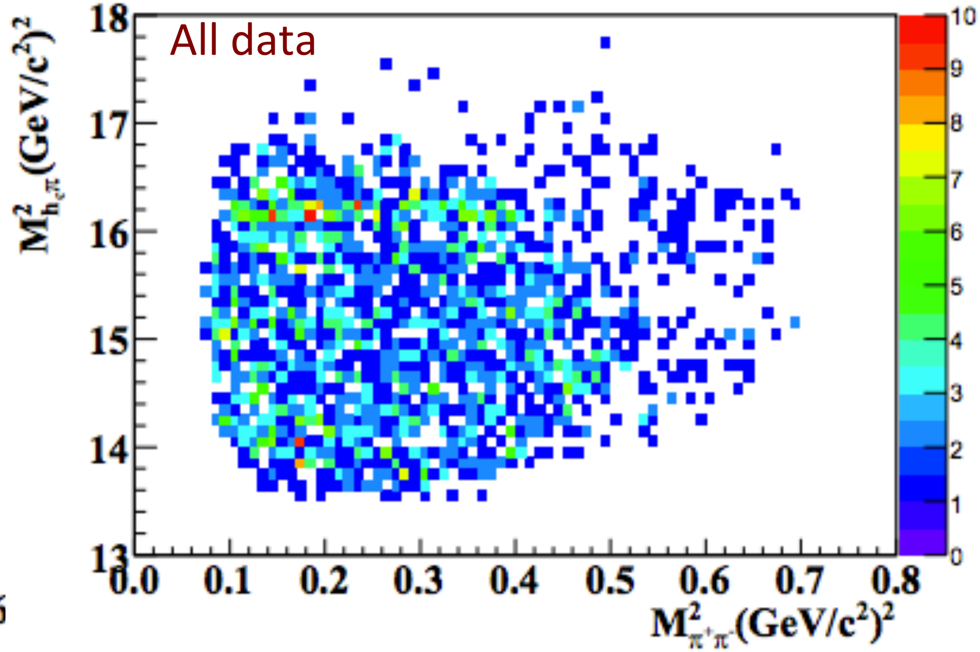
4360 MeV



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

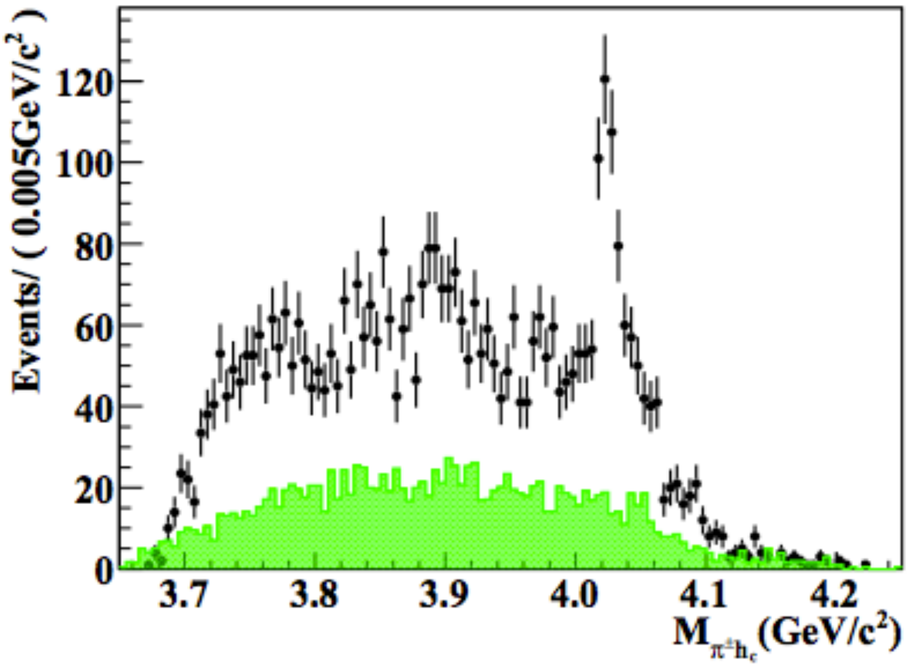
4.26 GeV data

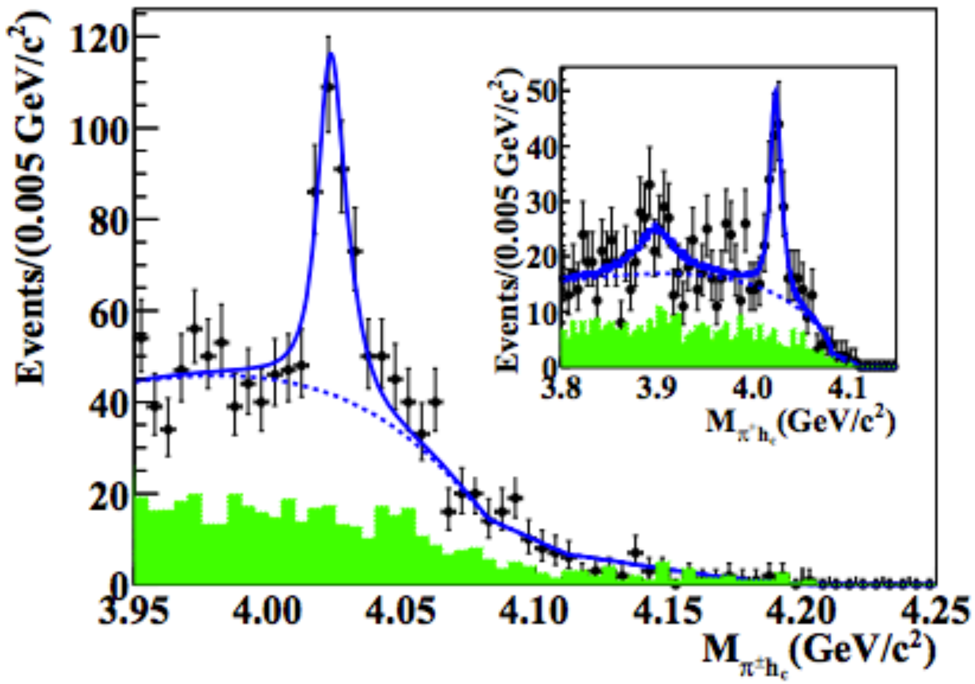




1. Good h_c signal.
2. h_c signal region: [3.518, 3.538] GeV, sideband: [3.49, 3.51] & [3.56, 3.58] .
3. Events accumulate around $M(\pi^{\pm}h_c)$~16 GeV^2

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

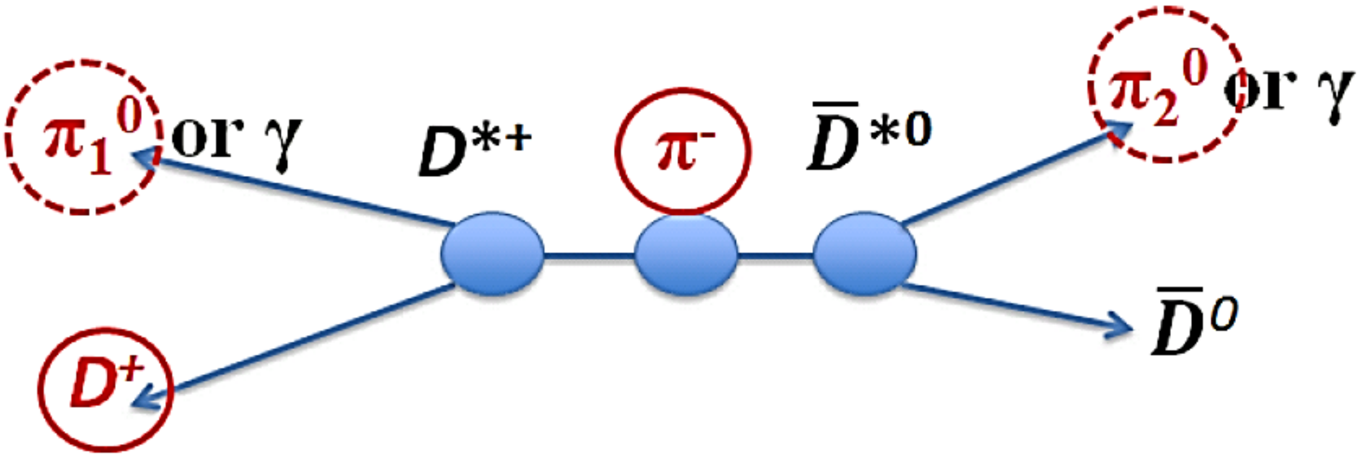




1. 1D projection of $M(\pi^{\pm}h_c)$ invariant mass distribution.
2. Signal: BW function convolving Gaussian+bkg; efficiency has been applied; phase space included.
3. $M[Z_c(4020)]=(4022.9\pm0.8\pm2.7)$ MeV; $\Gamma[Z_c(4020)]=(7.9\pm2.7\pm2.6)$ MeV.

$e^+e^- \to \pi^- (D^*\underline{D}^*)^+ + c.c.$ at BESIII

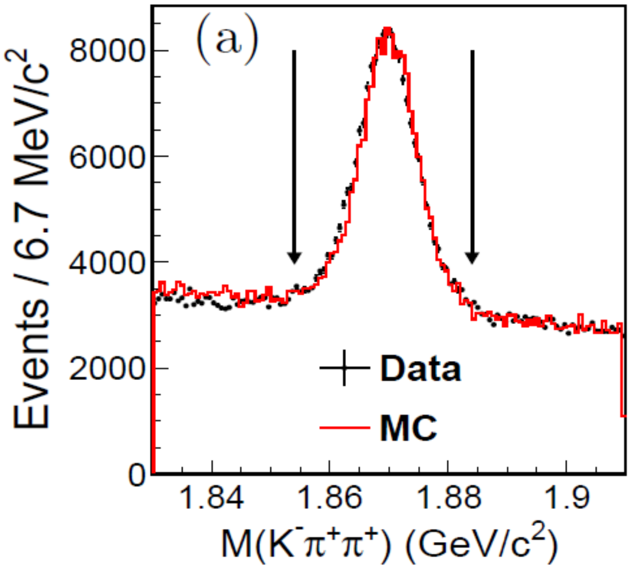
- 827 pb^{-1} data at Ecm=4.26 GeV
- Tag a D^+ and a bachelor π^-, reconstruct one π^0 to suppress the background.

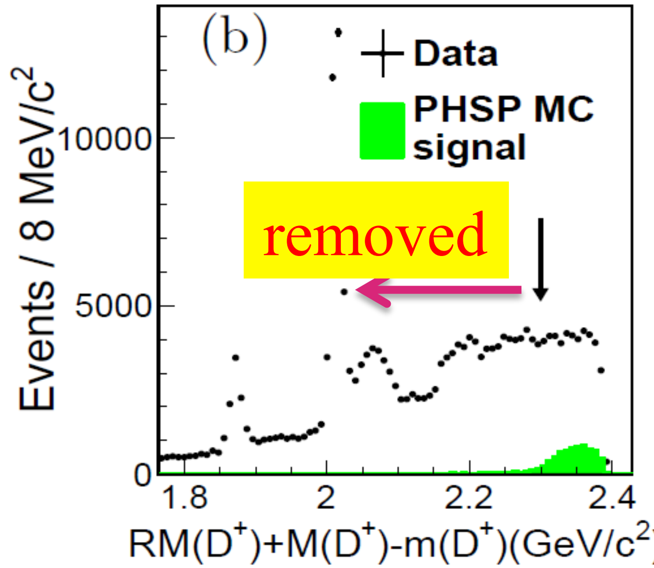


Topology of the decays of the signal process. Thick line circled D^+ and π^- are detected in the final states and at least one of the dashed line circled π_1^0 or π_2^0 is tagged.

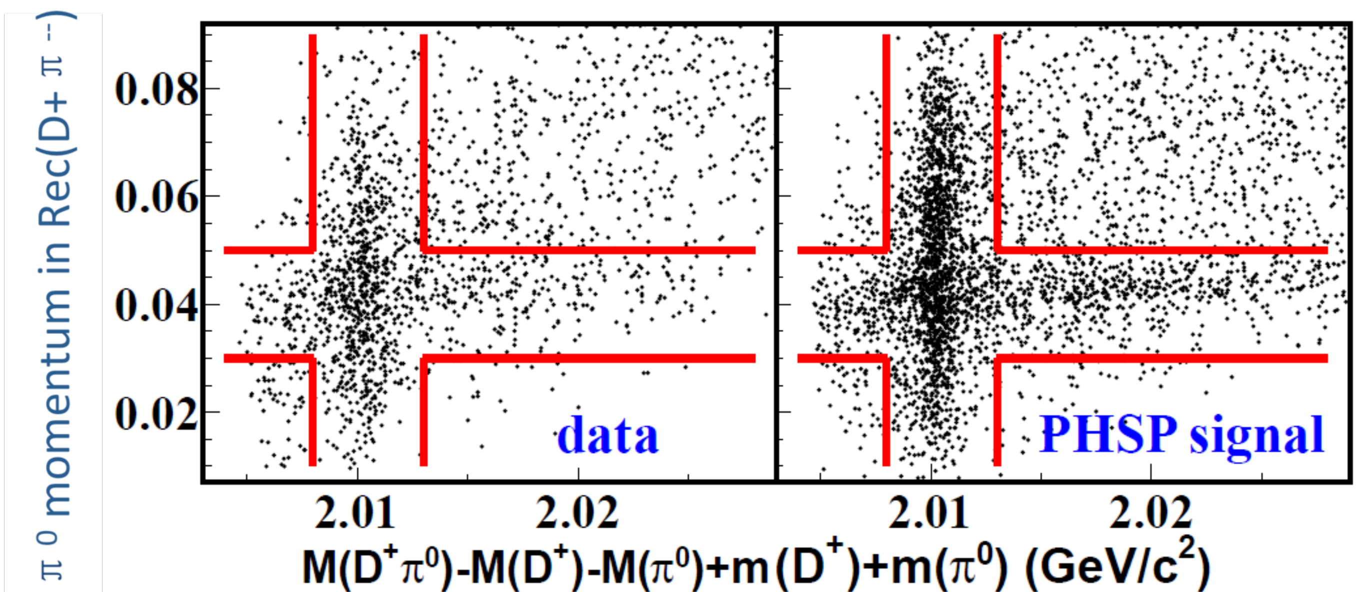
BESIII: 1308.2760

$e^+e^- \to \pi^- (D^*D^*)^+$+c.c. at BESIII





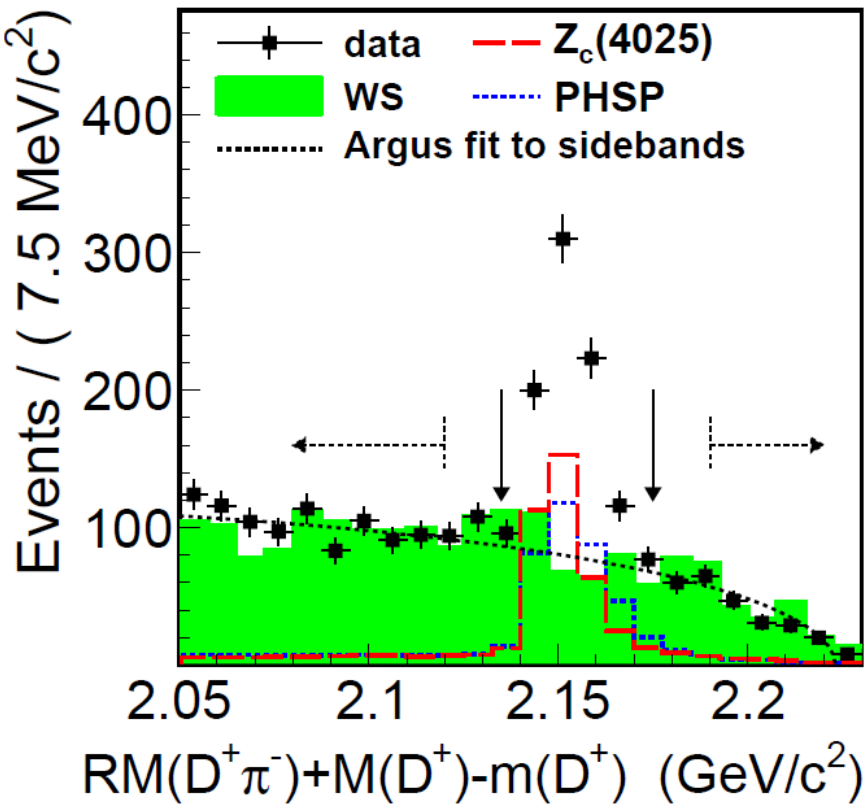
Remove DD, DD*, D*D*, DsDs, …

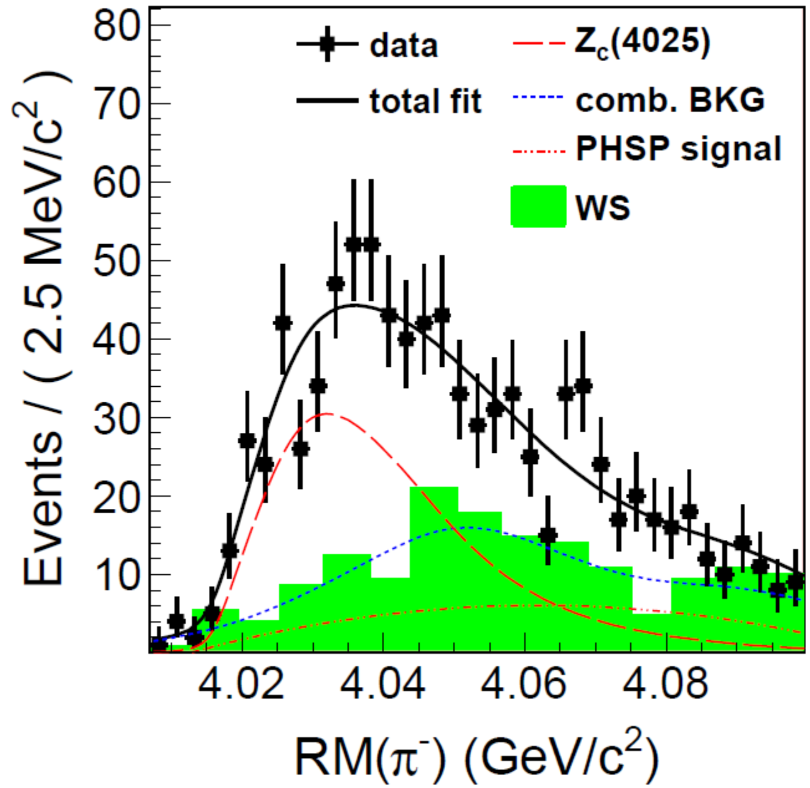


BESIII 1308.2760

p*: [0.03, 0.05]
$M(D^+\pi^0)$: [2.008, 2.013]

$e^+e^- \rightarrow \pi Z_c(4025) \rightarrow \pi^- (D^*\underline{D}^*)^+$+c.c.





Fit to $\pi^\pm$ recoil mass yields 401±47 $Z_c(4025)$ events. significance>10σ

M[$Z_c(4025)$] =(4026.3±2.6±3.7) MeV; Γ[$Z_c(4025)$] =(24.8±5.6±7.7) MeV

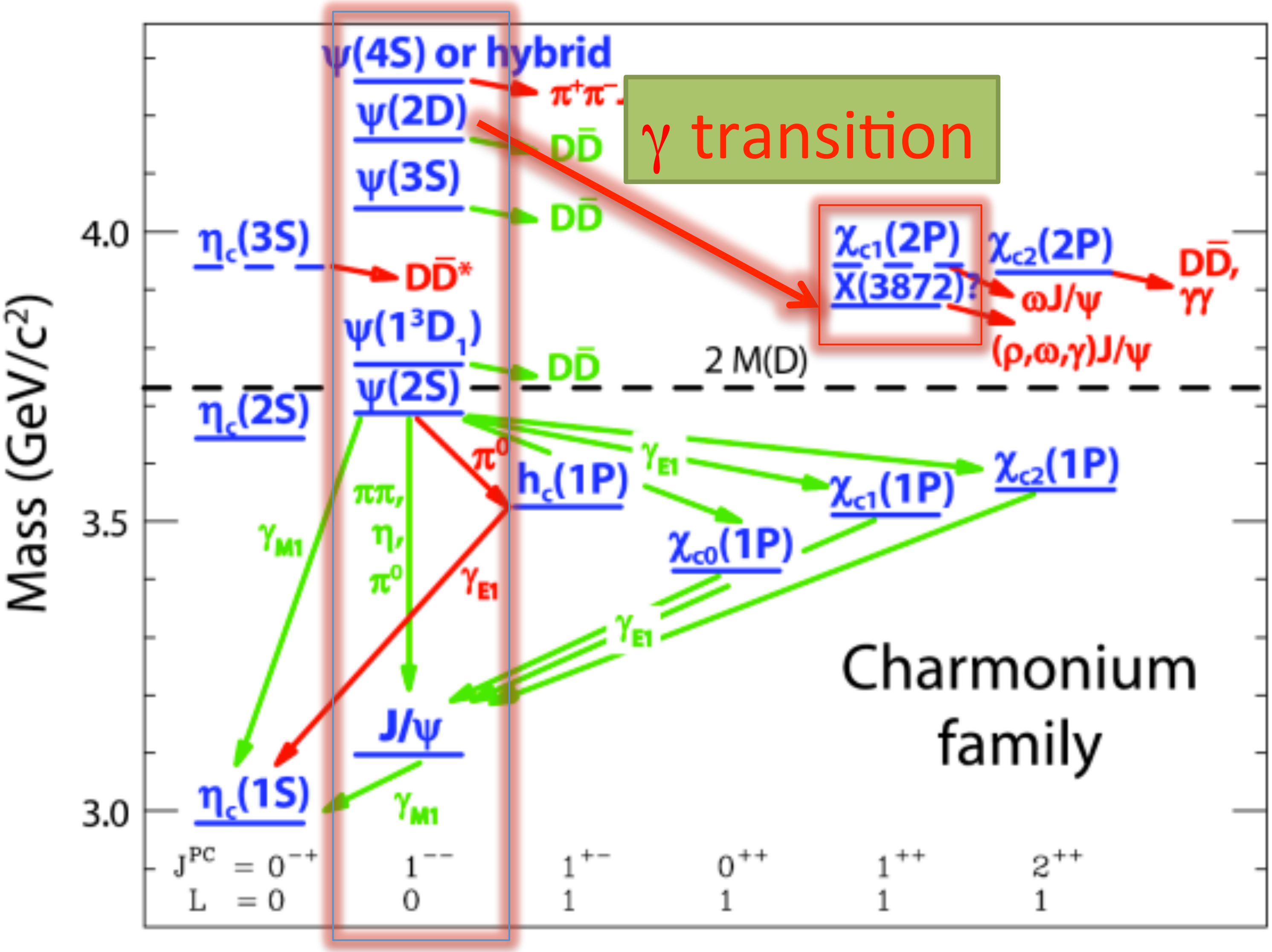
$$\sigma(e^+e^- \rightarrow \pi^\pm(D^*\overline{D^*})^\mp) = (137 \pm 9 \pm 15)\ \text{pb}$$

$$R = \frac{\sigma(e^+e^- \rightarrow \pi^\pm Z_c^\mp(4025) \rightarrow \pi^\pm(D^*\overline{D^*})^\mp)}{\sigma(e^+e^- \rightarrow \pi^\pm(D^*\overline{D^*})^\mp)} = (65 \pm 9 \pm 6)\%$$

BESIII: 1308.2760

$Y(4260) \rightarrow \gamma X(3872)$

Produce X(3872) at BESIII



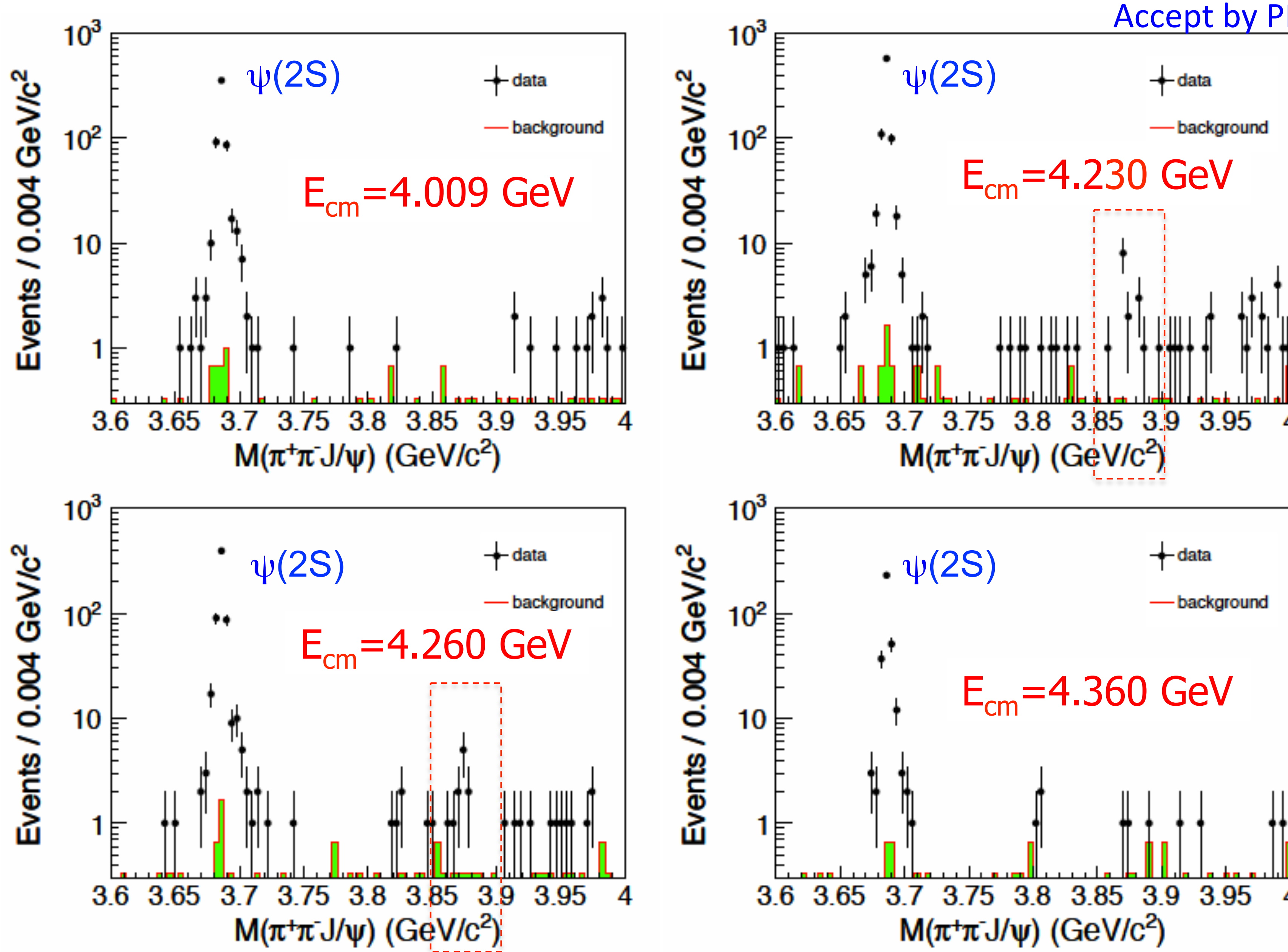
BESIII can produce lots of vector charmonium and charmoniumlike state.

ψ(4040)
Y(4260)
Y(4360)
…

LHCb: $J^{PC}=1^{++}$

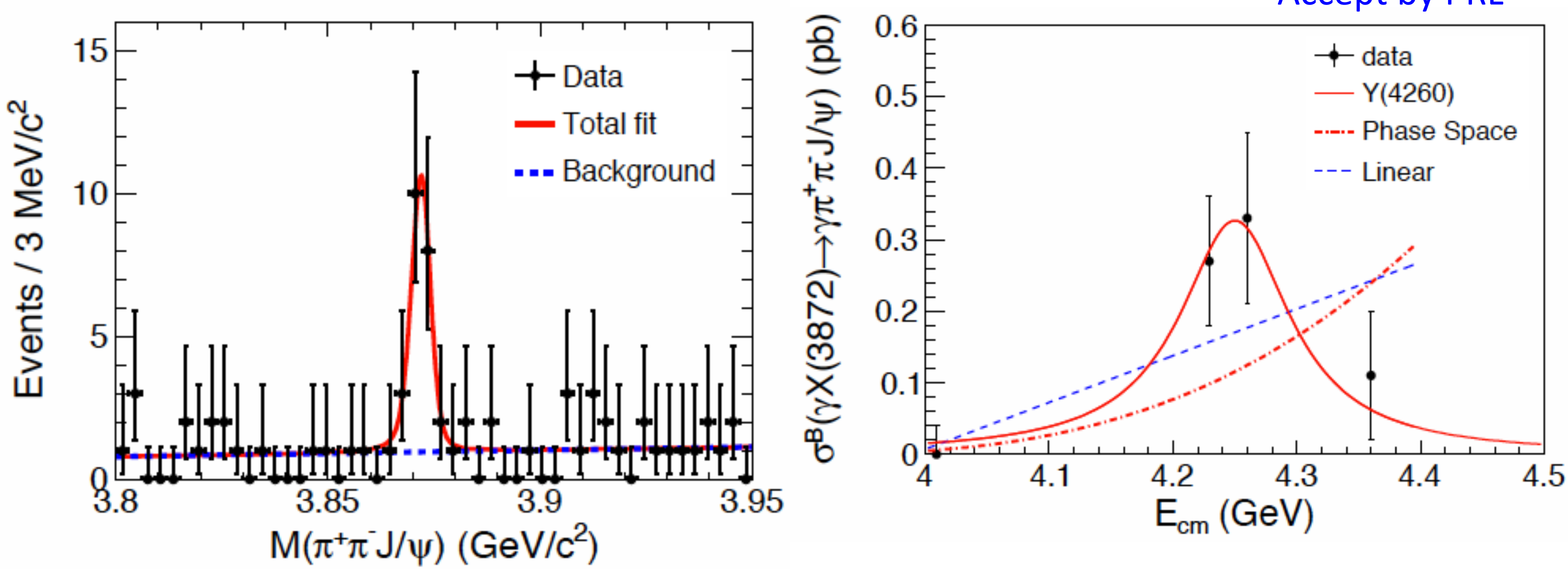
$e^+e^- \rightarrow \gamma(\pi^+\pi^- J/\psi)$ at BESIII

arXiv: 1310.4101
Accept by PRL



Y(4260)→γX(3872)

arXiv: 1310.4101
Accept by PRL



M=(3871.9±0.7±0.2) MeV

Γ<2.4 MeV

Significance: 6.3 σ

Fit with:

1. Y(4260): χ^2/ndf=0.49/3
2. E1 PHSP: χ^2/ndf=8.7/3
3. Linear: χ^2/ndf=5.5/2

What's next @ BESIII

1. PWA of $Y(4260) \rightarrow \pi^+\pi^- J/\psi$ with more data, more precise mass and width measurement of $Z_c(3900)$+Spin-parity.
2. line shape study of $\pi^+\pi^- J/\psi$, also $\pi Z_c(3900)$.
3. Try to distinguish different multi-quark models: tetraquark, hadron molecule: search for new decay modes, production rate…
4. Neutral partners, such as Z^0 and $Z^{0\prime}$
5. Take more data, search for strange partner…
6. Other puzzling XYZ states…

Summary

- BESIII observed a charged Charmonium-like state $Z_c(3900)$.
- Possible partner particle $Z_c(4020)$ & $Z_c(4025)$ also found.
- Observed $Y(4260) \rightarrow \gamma X(3872)$ radiative transition for the first time.
- Understand them with more data & effort.

Thank you !