XYZ physics at BESIII

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for the BESIII Collaboration

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SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

International Symposium
Lepton and Hadron Physics at Meson-Factories
13-15 Oct. Messina (Sicily)

Outline

- Observation of X(3872) in e^+e^- → $\gamma X(3872)$
- Study of the Y-family states
- A variation of Z_c
  - $Z_c(3900)$ and $Z_c(3885)$
  - $Z_c(4020)$ and $Z_c(4025)$
- Summary

The BESIII detector

SC Magnet: 1Tesla

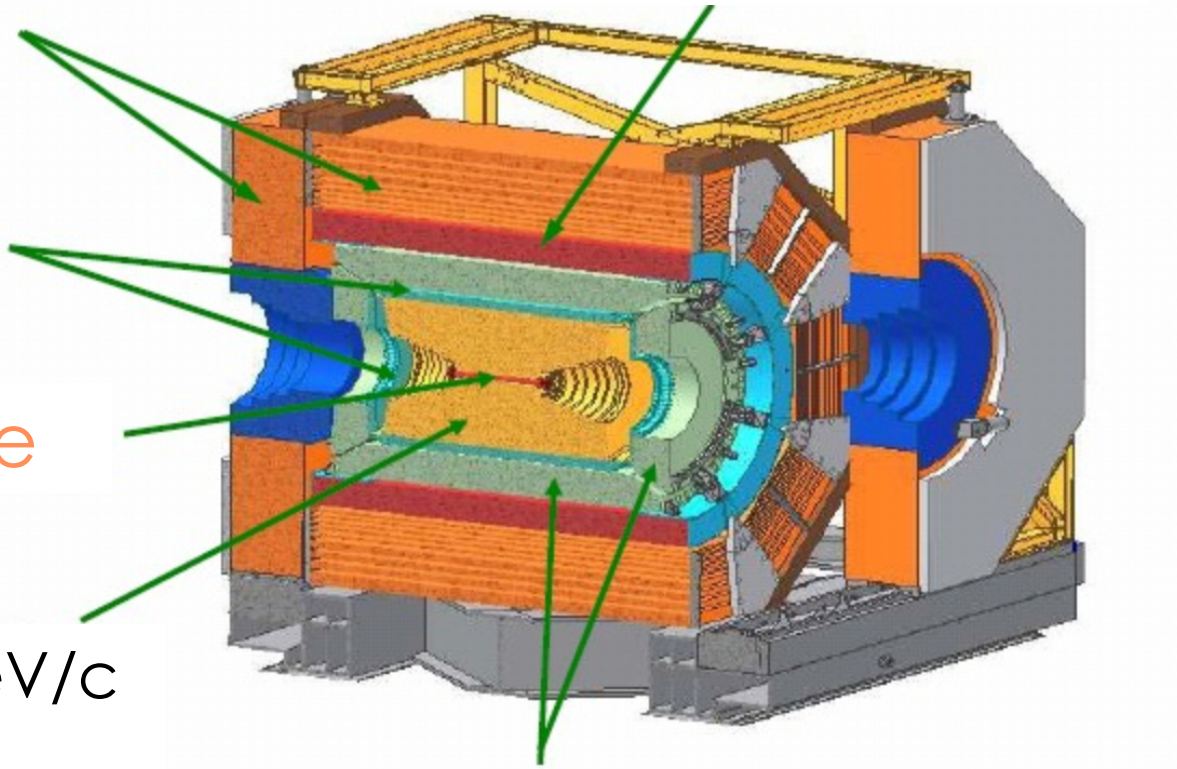
Magnet yoke

TOF: (σ_T)

Barrel: 80 ns

Endcap:110 ns

Beam pipe



MDC:

σ_p/p: 0.5% at 1GeV/c

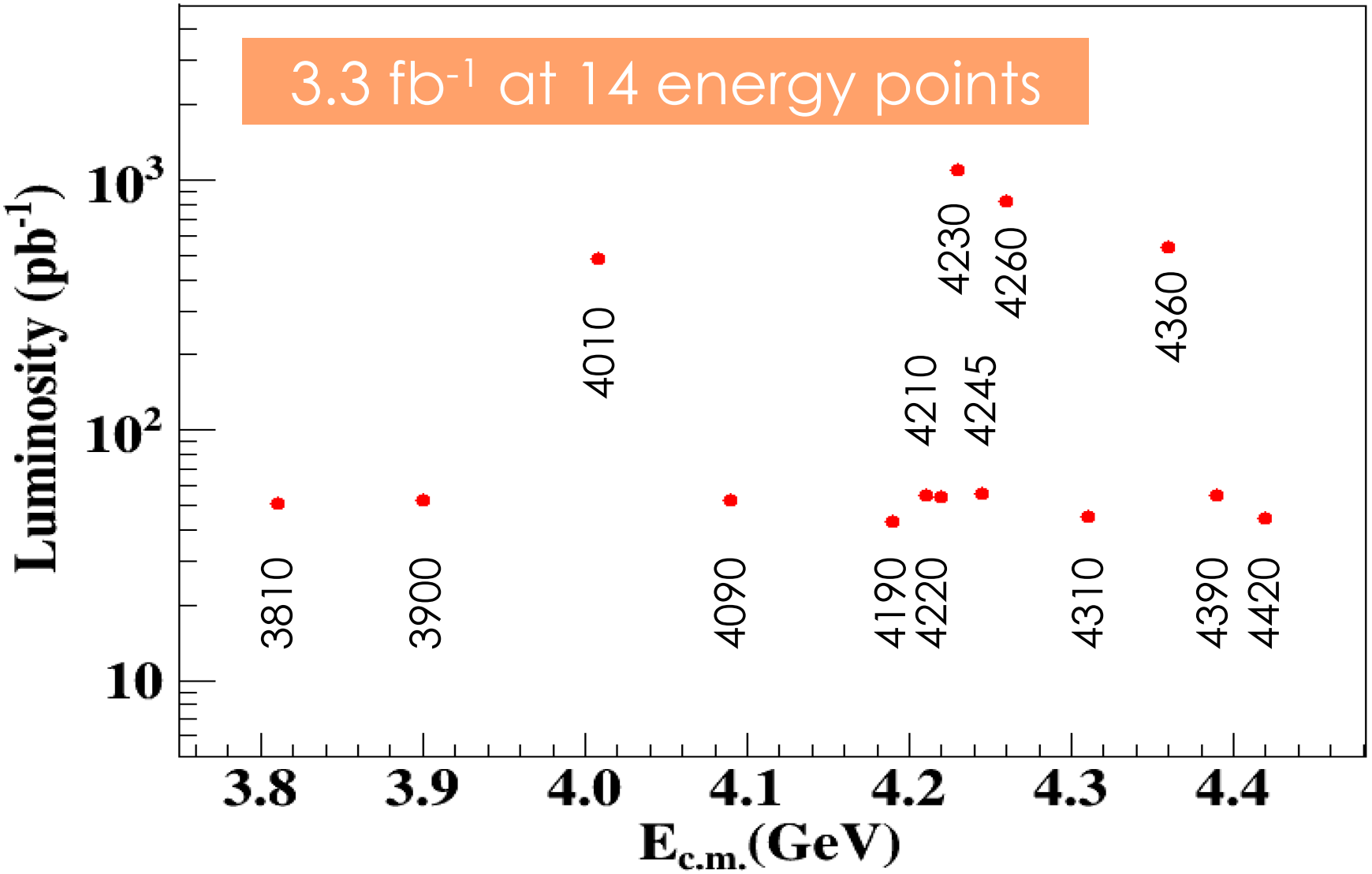
σ_{xy}: 130 μm

dE/dx: 6%

CsI calorimeter:

$\Delta E/E$: 2.5% / 5.0% at 1 GeV; σ_Z: 0.6 cm/$\sqrt{E}$

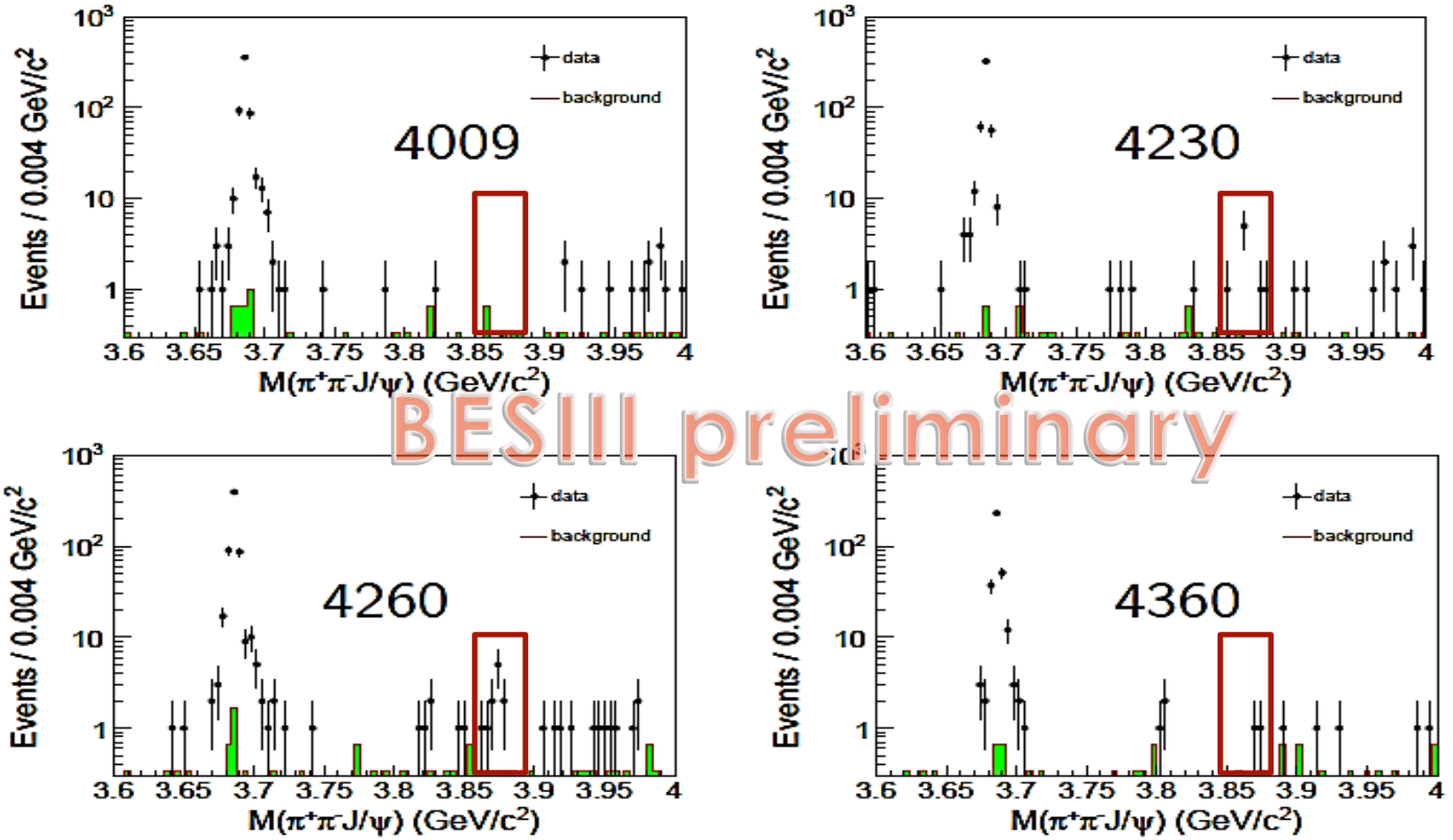
Data collected for XYZ study



X(3872)

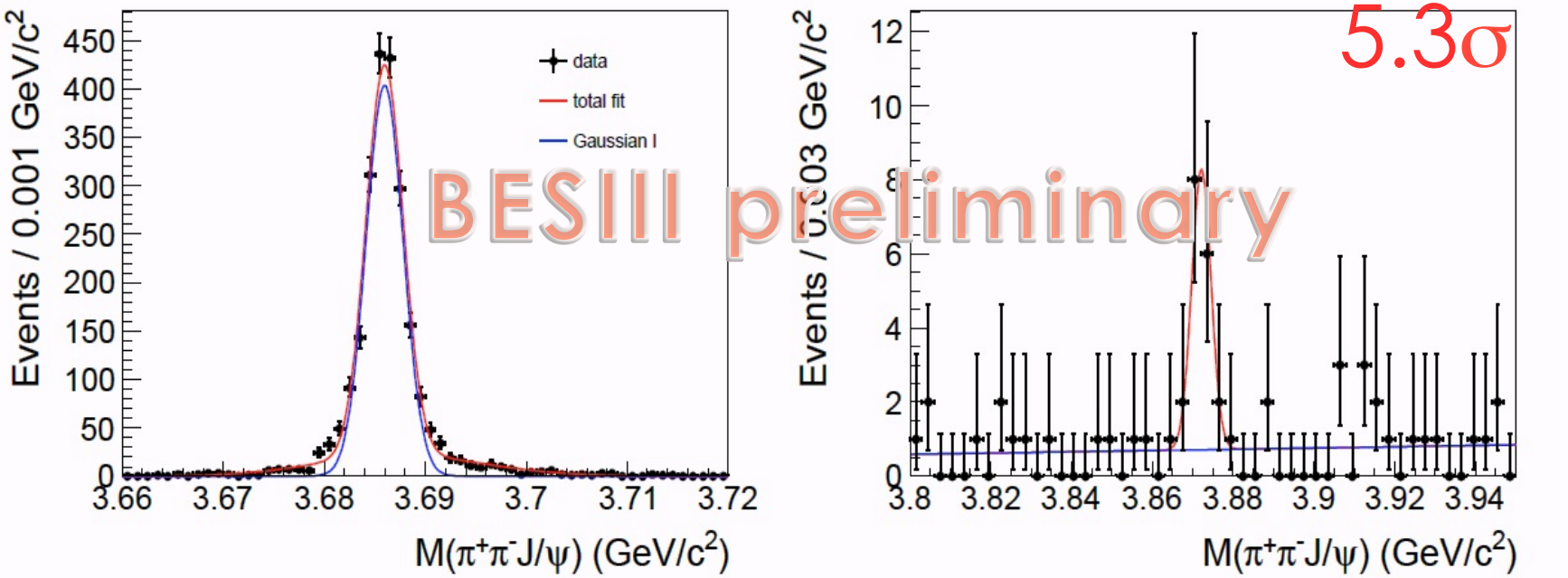
- Observed by Belle in $B^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}J/\psi$ [PRL91,262001(2003)]
- Mass close to $D^0\bar{D}^{*0}$ threshold, narrow width
- Nature (very likely exotic)
  - Loosely $D^0\bar{D}^{*0}$ bound state?
  - Mixture of excited χ_{c1} and $D^0\bar{D}^{*0}$ bound state?
  - Many other possibilities (if it is not χ'_{c1}, where is χ'_{c1}?)
- $J^{PC}=1^{++}$ [CDF (PRL98,132002); LHCb (EPJC72,1972)]
- Production
  - in pp collison – rate similar to charmonia
  - In B decays – KX similar to $c\bar{c}$; K*X smaller than $c\bar{c}$
  - $Y(4260) \rightarrow \gamma X(3872)$ [BESIII]

Observation of $e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma\pi^+\pi^- J/\psi$



Clear ISR ψ' signal for data validation; X(3872) signal at around 4.23-4.26 GeV

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



- Clear ISR ψ' signal: good reference for mass, mass resolution and cross section calibration.
  - $N(\psi')=1242$; Mass=3685.96±0.05 MeV; σ_M=1.84 ±0.06 MeV
- Fits to the sum $\pi^+\pi^- J/\psi$ mass spectrum:
  - N(X(3872))=15.0±3.9; M(X(3872)) = 3872.1±0.8±0.3 MeV

[PDG = 3871.68 ±0.17 MeV]

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

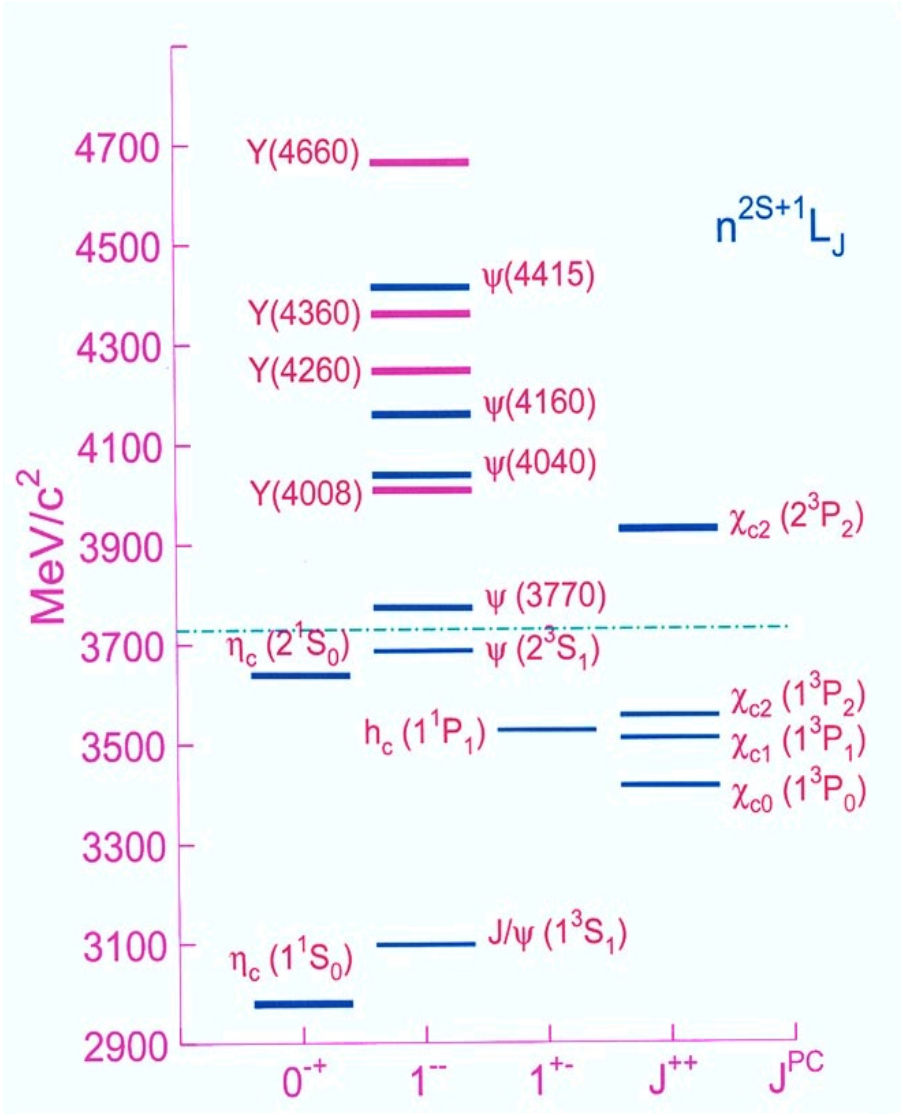
$\sqrt{s}$ (GeV)	$\sigma^B[e^+e^- \to \gamma X(3872)] \cdot \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ (pb)
4.009	< 0.13 at 90% C.L.
4.230	$0.32 \pm 0.15 \pm 0.02$
4.260	$0.35 \pm 0.12 \pm 0.02$
4.360	< 0.39 at 90% C.L.

BESIII preliminary

- X(3872) seems from Y(4260) decays
- Take $\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$ = (62.9±1.9±3.7) pb into account [BESIII measurement], and assume the branching fraction $B(X(3872) \to \pi^+\pi^- J/\psi)$= 5% (large than 2.6% in PDG)

$$\frac{\sigma^B[e^+e^- \to \gamma X(3872)]}{\sigma^B(e^+e^- \to \pi^+\pi^- J/\psi)}$$ ~11%

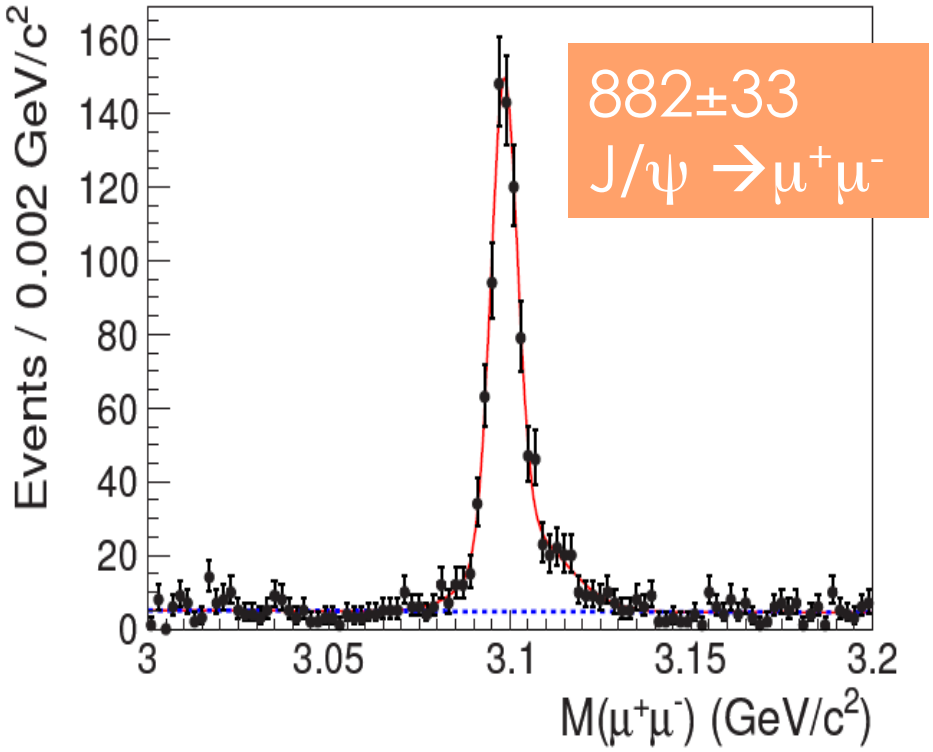
The Y states

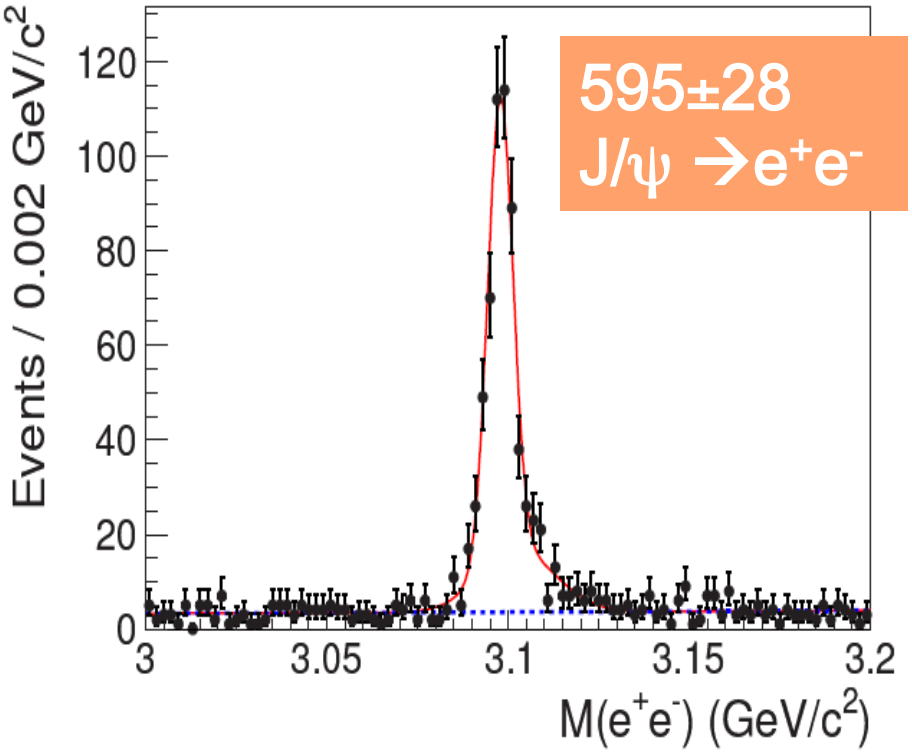


- Mainly from B factory via ISR process
- Y(4008): $e^+e^- \rightarrow \gamma\pi^+\pi^- J/\psi$ process [Belle, but not BaBar]
- Y(4260): $e^+e^- \rightarrow \gamma\pi^+\pi^- J/\psi$ process [BaBar, CLEO, and Belle]
- Y(4360):$e^+e^- \rightarrow \gamma\pi^+\pi^-\psi(2S)$ process [BaBar and Belle]
- Y(4660):$e^+e^- \rightarrow \gamma\pi^+\pi^-\psi(2S)$ process [Belle and BaBar]

Select $e^+e^- \to \pi^+\pi^- J/\psi$ at 4.26 GeV

[BESIII: PRL110, 252001]

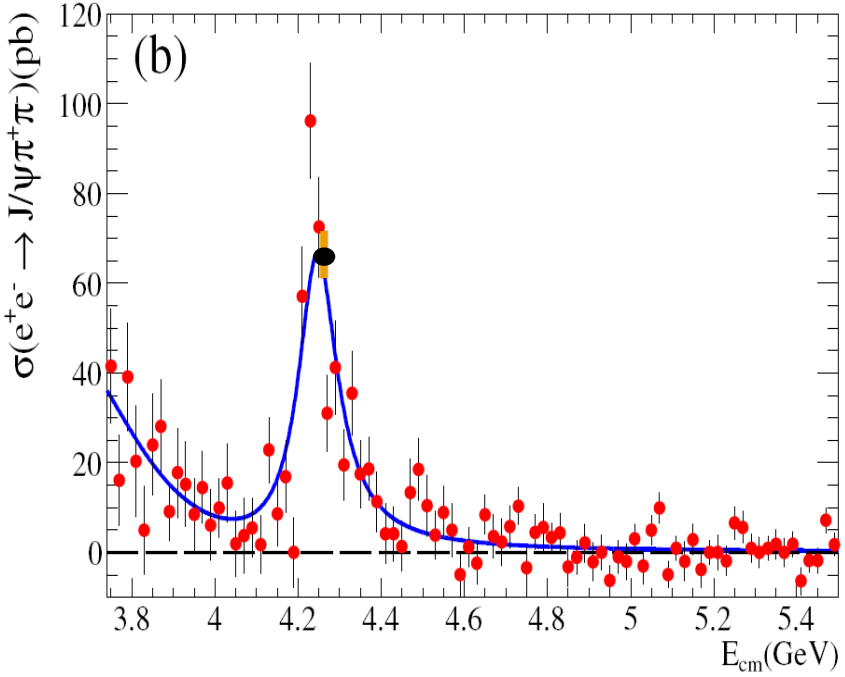




- Select 4 charged tracks and reconstruct J/ψ with lepton pair.
- Very clean sample, very high efficiency (~45%).
- $\sigma(e^+e^- \to \pi^+\pi^- J/\psi) = (62.9 \pm 1.9 \pm 3.7)$ pb 525 pb^{-1} data

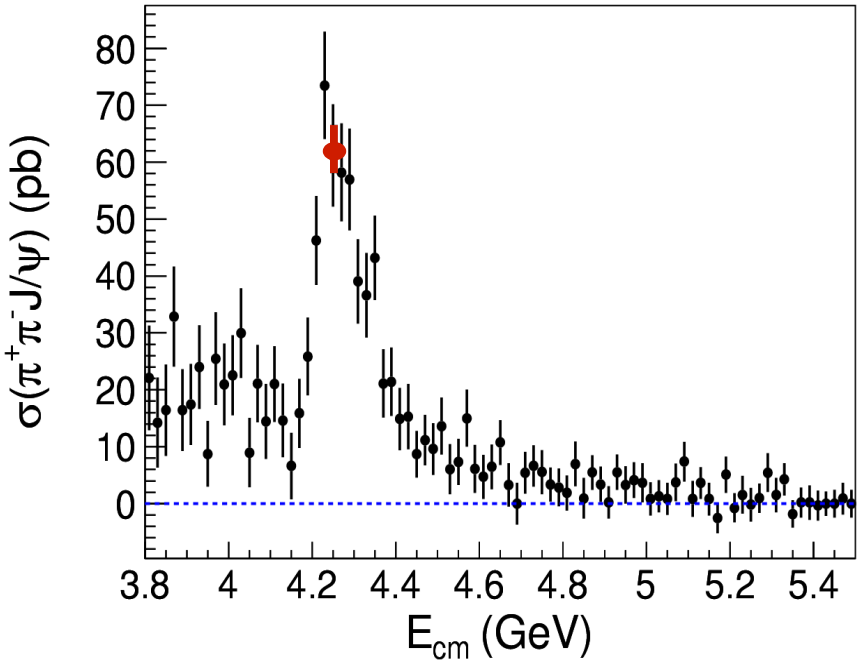
Cross section of $e^+e^- \to \pi^+\pi^- J/\psi$

[BaBar: PRD86, 051102]



BESIII: PRL110, 252001

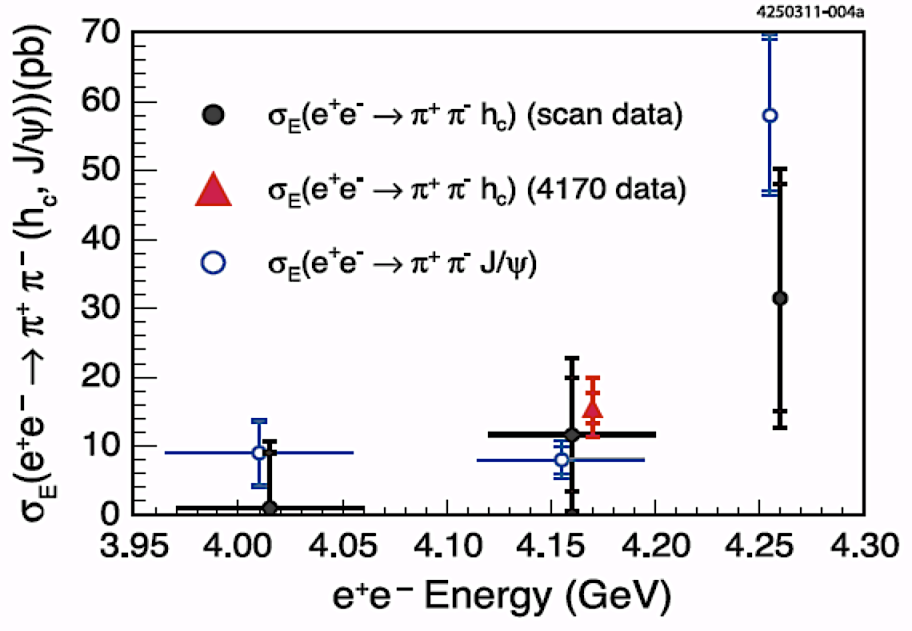
[Belle: PRL110, 252002]



BESIII: $\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$
= (62.9±1.9±3.7) pb
Agree with BaBar & Belle!
Best precision!

BESIII is measuring cross sections at more energy points, and will take more data

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



[PRL 107, 041803 (2011)]

- CLEO-c observed h_c at $E_{c.m.}$=4.170 GeV using 586 pb^{-1} of 4170 data
- See hints of a rise in the $\pi^+\pi^- h_c$ cross section at $E_{c.m.}$=4.260 GeV using 13.2 pb^{-1} scan data

- Cross section comparable to $\pi^+\pi^- J/\psi$ process
- Limited energy points and statistics

→ Larger data samples above 4.0 GeV and more energy points at BESIII

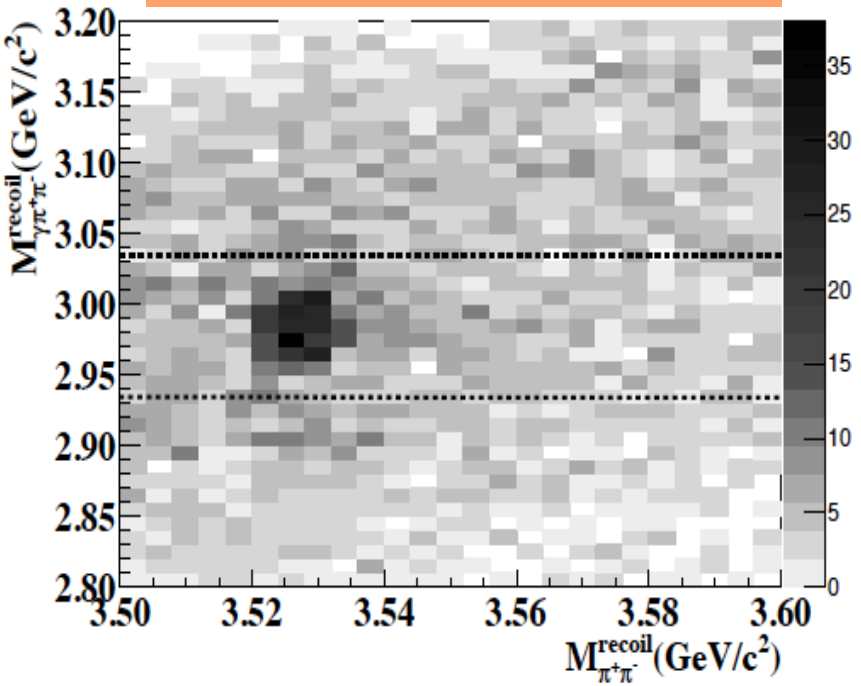
$e^+e^- \to \pi^+\pi^- h_c(1P)$ at BESIII

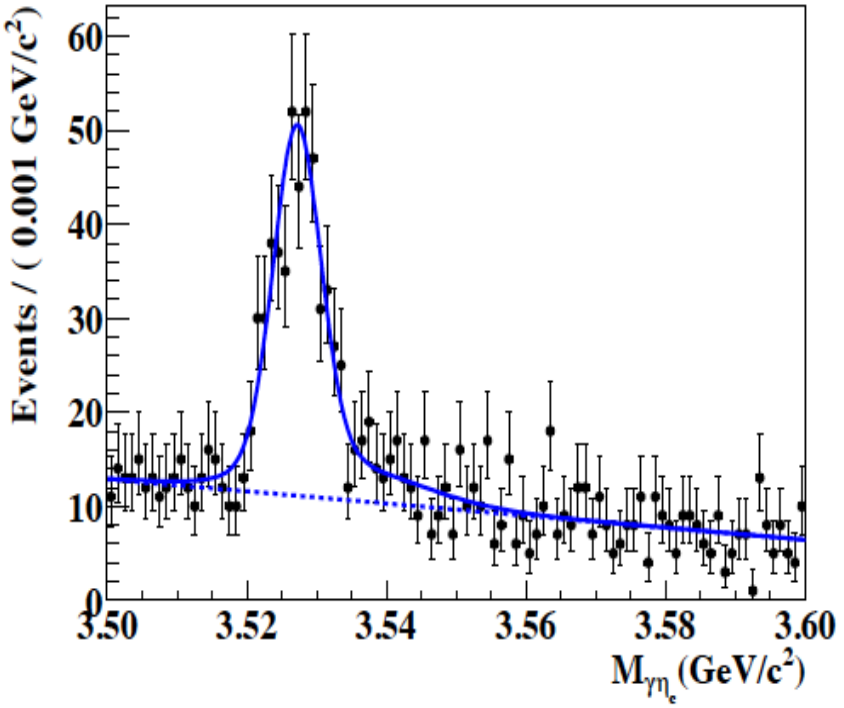
$h_c \to \gamma\eta_c$, $\eta_c \to$ hadrons

arXiv: 1309.1896
Submitted to PRL

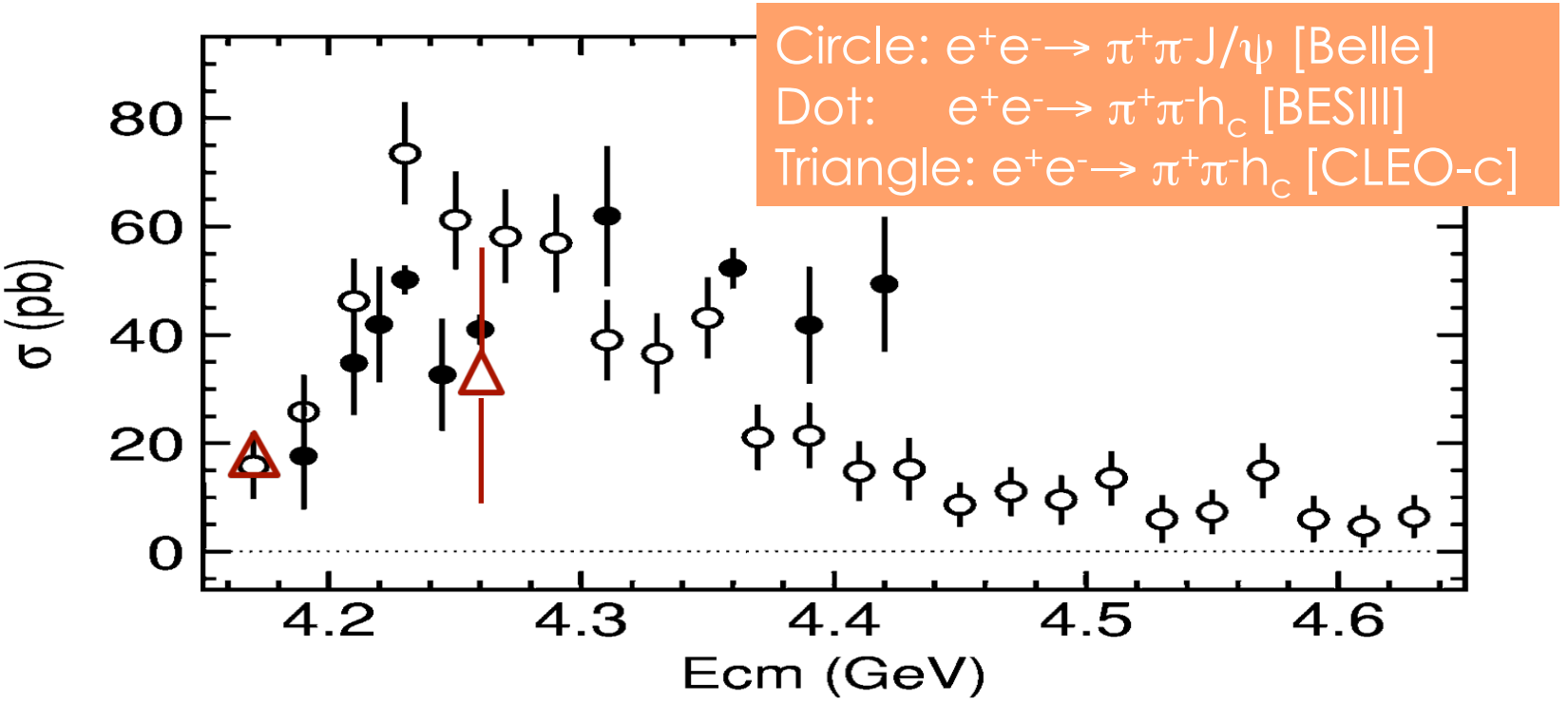
[16 exclusive decay modes, ~35% of the η_c decays]

$E_{c.m.}$ = 4.260 GeV





Comparison of $e^+e^- \to \pi^+\pi^- h_c$ and $\pi^+\pi^- J/\psi$

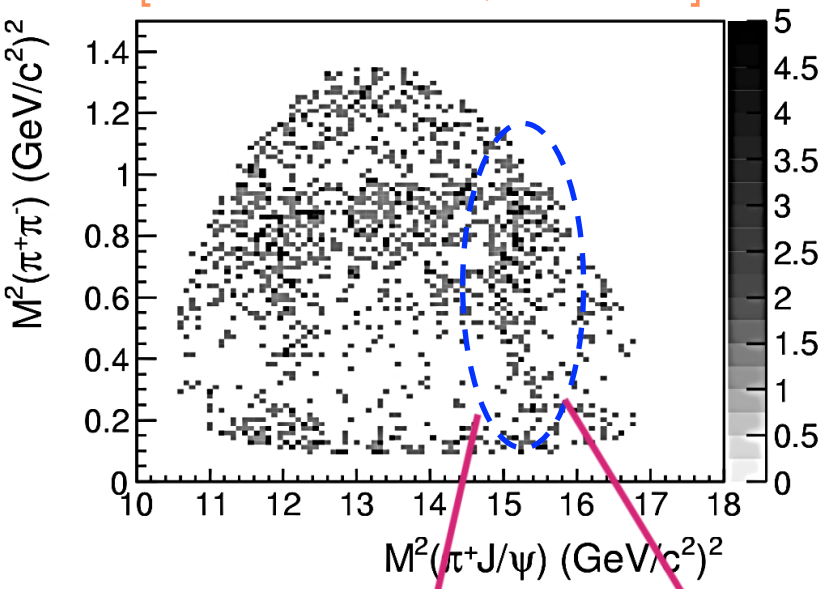


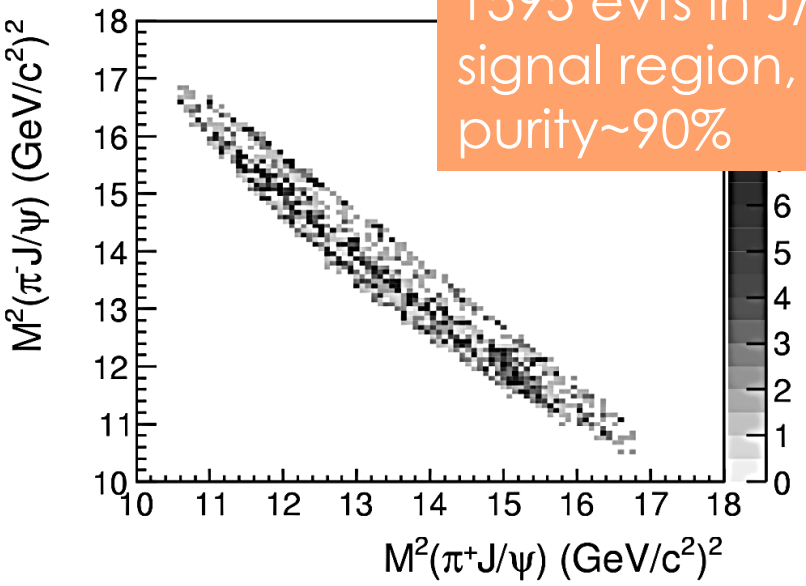
- $\sigma(e^+e^- \to \pi^+\pi^- h_c) \sim \sigma(e^+e^- \to \pi^+\pi^- J/\psi)$ but line shape different
- Local maximum ~ 4.23 GeV, broad structure at ~4.4 GeV?
- Hint for a vector cc-bar g hybrid? [PRD78, 056003 (Guo); 094504 (Dudek)]

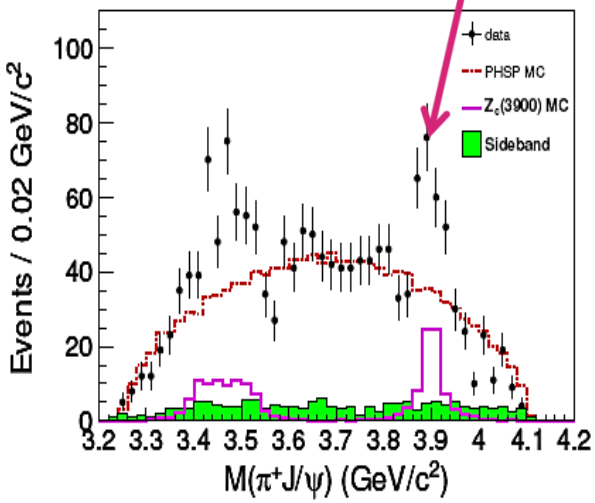
Observation of $Z_c(3900)$

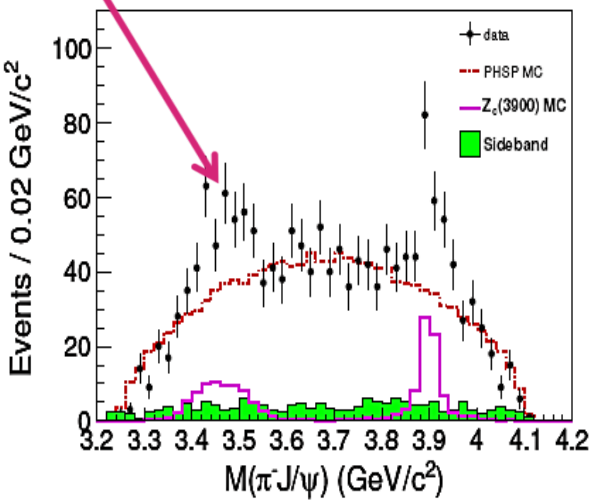
[BESIII: PRL110, 252001]

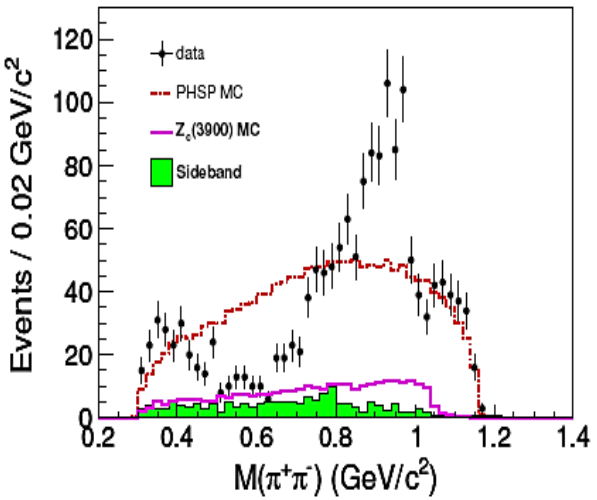
1595 evts in J/ψ signal region, purity~90%



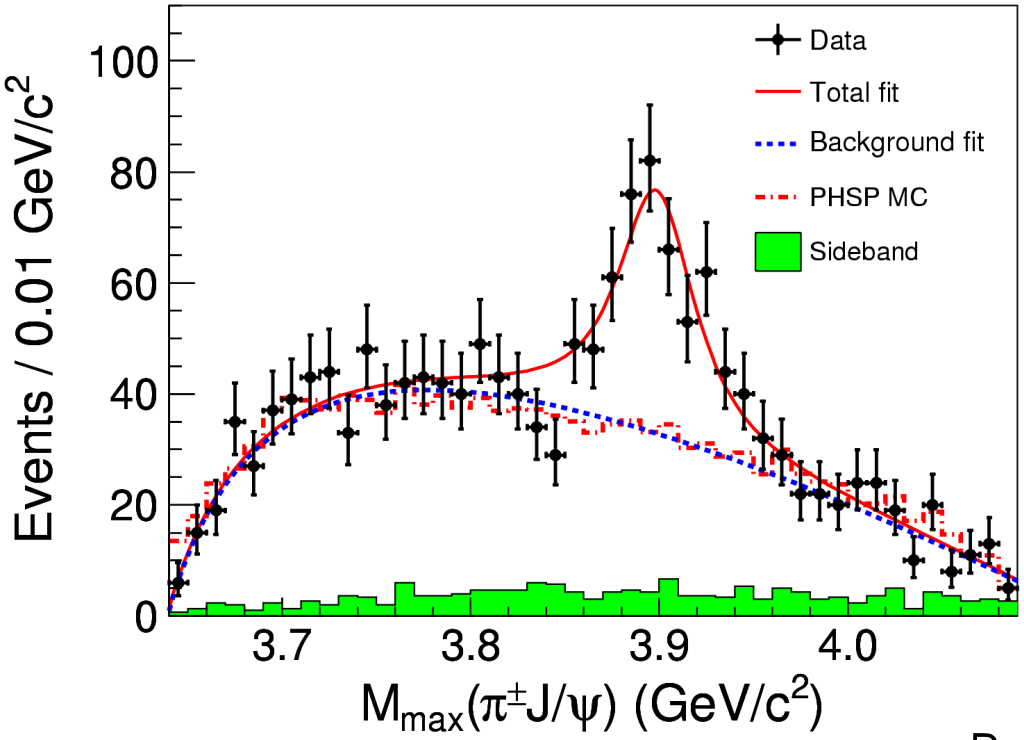








What is $Z_c(3900)$?



- M = 3899.0±3.6±4.9 MeV
- Γ = 46±10±20 MeV
- N= 307 ± 48 events

Significance >8σ

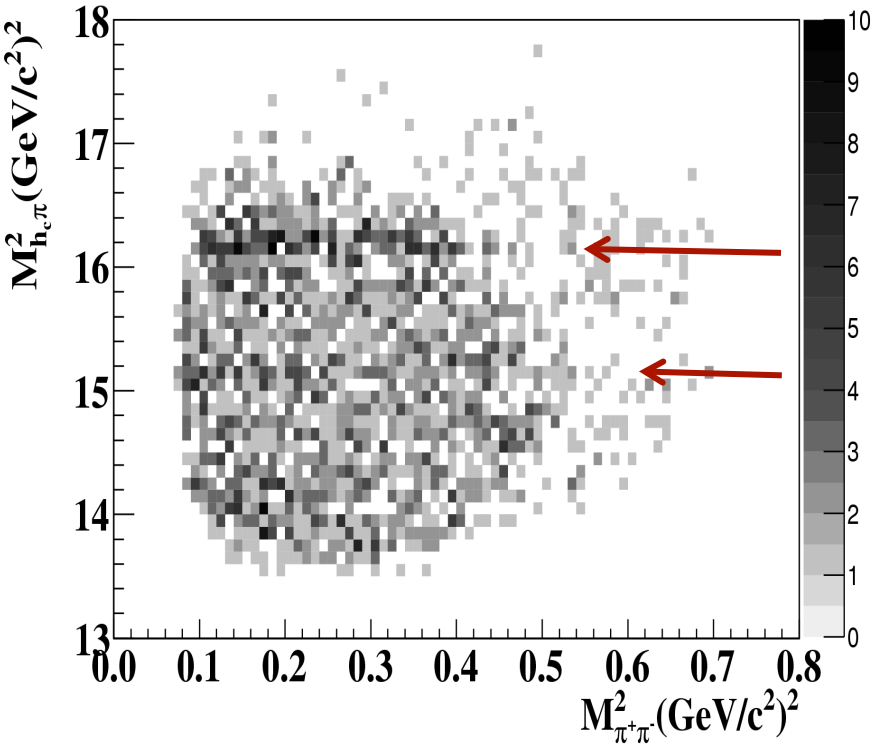
- Couples to cc-bar
- Has electric charge
- At least 4-quarks
- Nature unclear

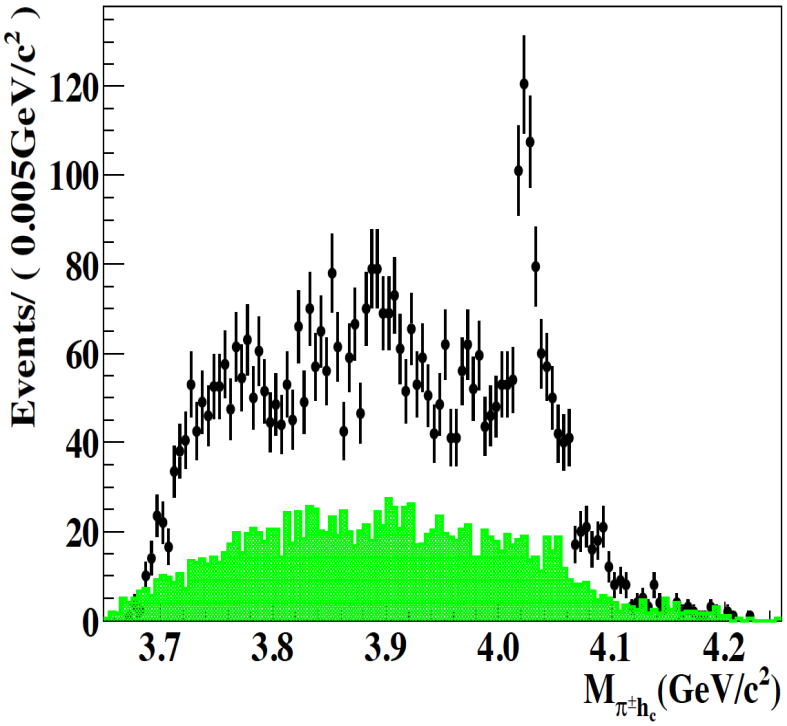
fit with S-wave Breit-Wigner with phase space factor and efficiency correction

Predictions and more experimental information will be essential to understand its nature.

→ A partner below/above Z_c?

Observation of $Z_c(4020)$

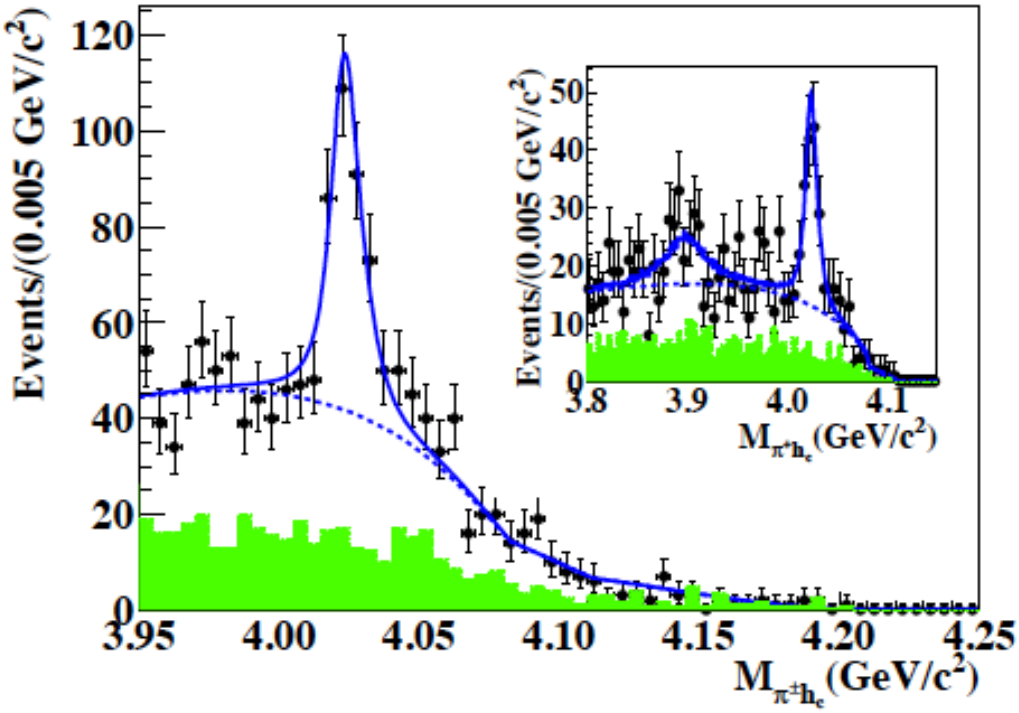




- Obvious structure around 4.2 GeV
- Hints of $Z_c(3900)$
- ~1500 events in h_c signal region at 4.230, 4.260 and 4.360 GeV, purity about 65%

arXiv: 1309.1896
Submitted to PRL

Observation of $Z_c(4020)$



- $\sigma(e^+e^-\rightarrow\pi^+\pi^-h_c)$:

  8.7±1.9±2.8±1.4 pb @ 4.230

  7.4±1.7±2.1±1.2 pb @ 4.260

  10.3±2.3±3.1±1.6 pb @ 4.360

- Simultaneously fit to 4.230/4.260/4.360 data (2.4 fb^{-1})
- M = 4022.9±0.8±2.7 MeV;
- Γ = 7.9±2.7±2.6 MeV

fit with consistent width relativistic Breit-Wigner with phase space factor and efficiency correction

Significance: 8.9σ ($Z_c(4020)$)
No significant $Z_c(3900)$ (2.1σ)

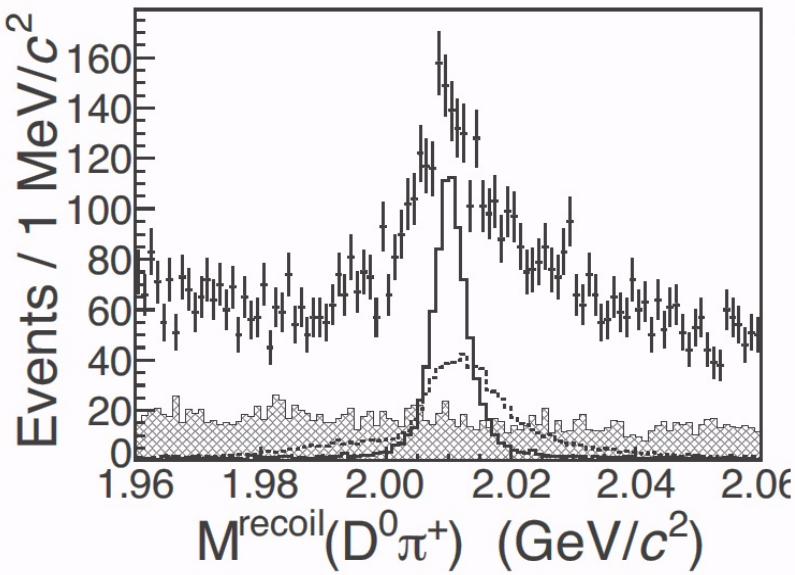
Observation of $Z_c(3885)$ in DD*-bar

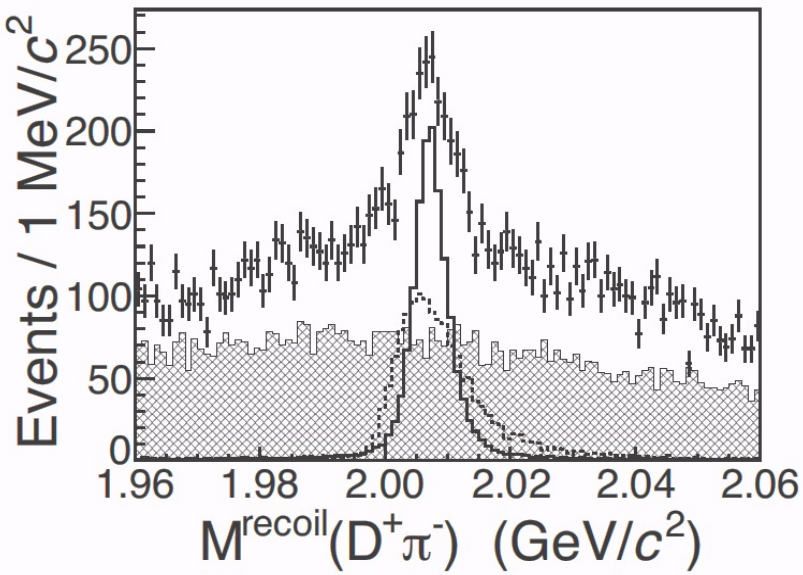
525 pb^{-1} data at 4.260 GeV

Strategy:

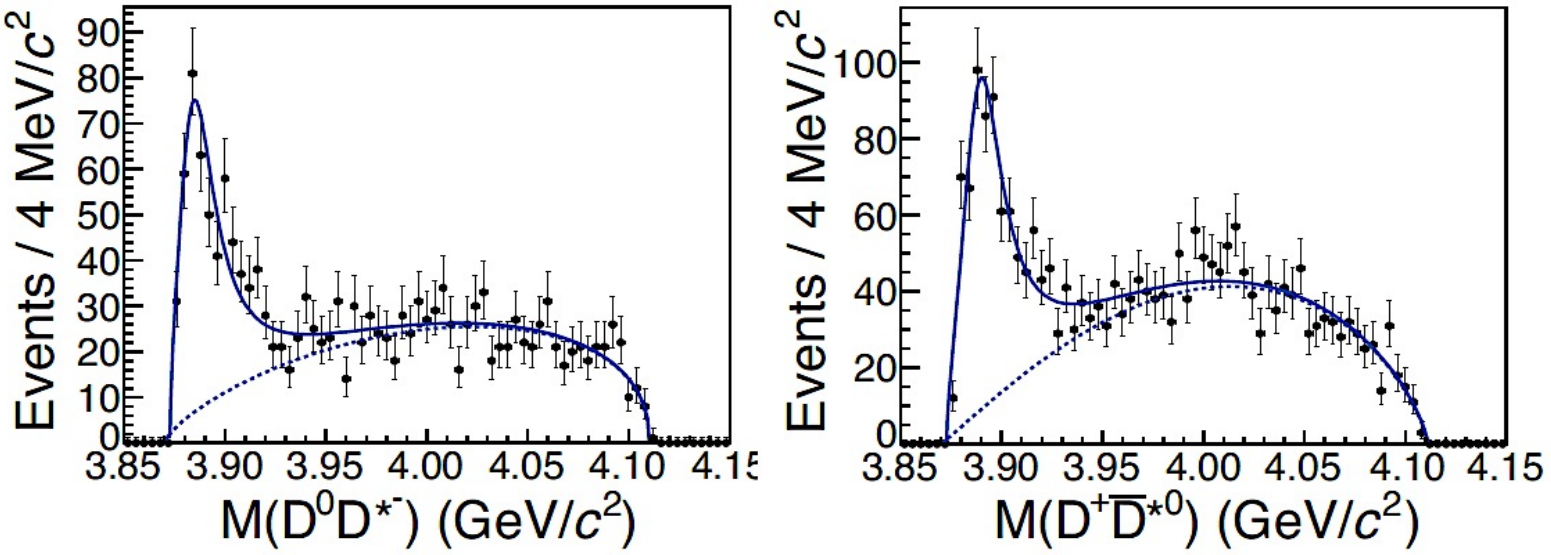
- reconstruct $D^0 \rightarrow K^-\pi^+ / D^+ \rightarrow K^-\pi^+\pi^+$;
- reconstruct "bachelor" π
- require D* in the missing mass using kinematic fit
- look at the recoil side of π

arXiv: 1310.1163
Submitted to PRL





Observation of $Z_c(3885)$ in DD*-bar



- M = 3883.9±1.5±4.2 MeV; Γ = 24.8±3.3±11.0 MeV
- σ×B = 85.3±6.6±22.0 pb

[pole position]

fit with mass-dependent-width BW with phase space and efficiency correction

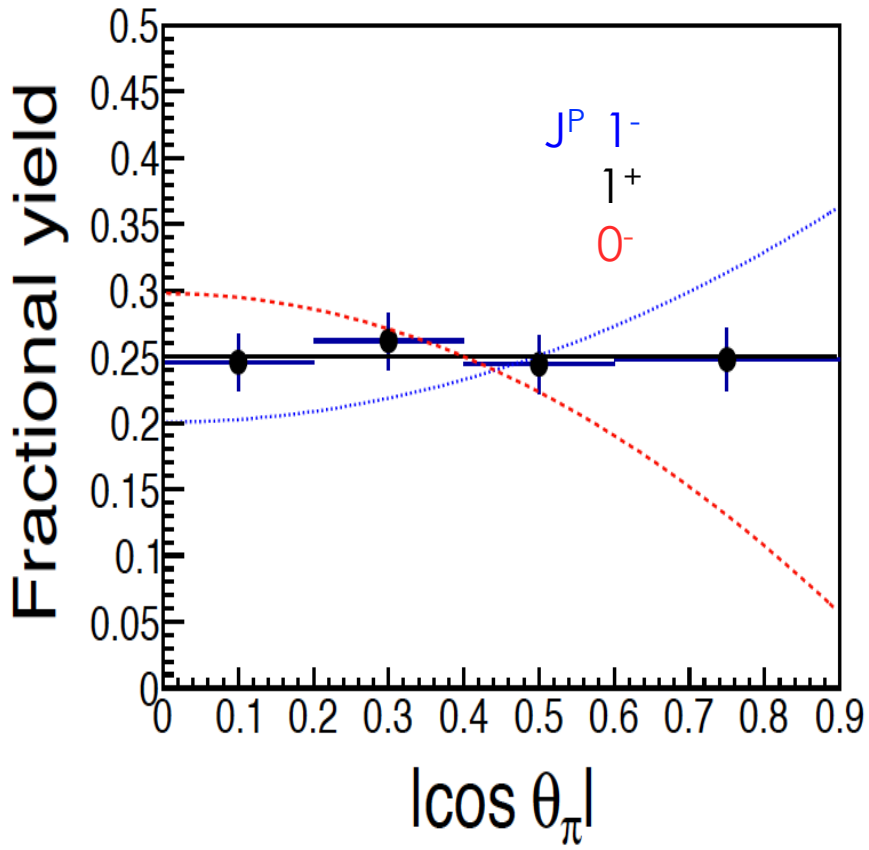
$$\frac{\Gamma(Z_c(3885)\to D\bar{D}^*)}{\Gamma(Z_c(3900)\to\pi J/\psi)} = 6.2\pm1.1\pm2.7$$

Assuming $Z_c(3885)$ due to $Z_c(3900)$

Large non-DD-bar coupling

Quantum number of $Z_c(3885)$

- $\cos\theta_\pi$:
  - bachelor pion's pole angle (relative to beam direction) in the CMS



- 0^-: P-wave, with $J_Z=\pm1$
  → $\sin^2\theta_\pi$
- ~~$0^\pm$~~: parity conservation
- 1^-: P-wave, $1+\cos^2\theta_\pi$
- 1^+: S-wave/D-wave, D-wave small contribution →flat distribution

fits favor 1^+ assumption

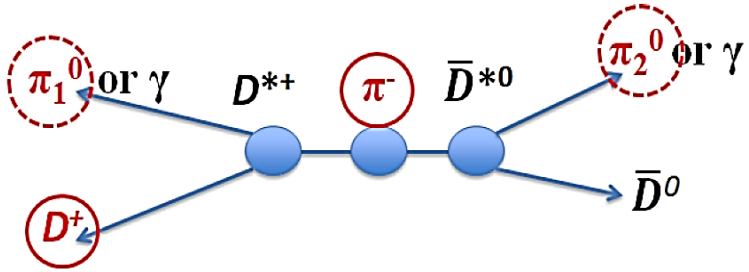
$e^+e^- \to \pi^- (D^*\underline{D}^*)^+ + c.c.$ at BESIII

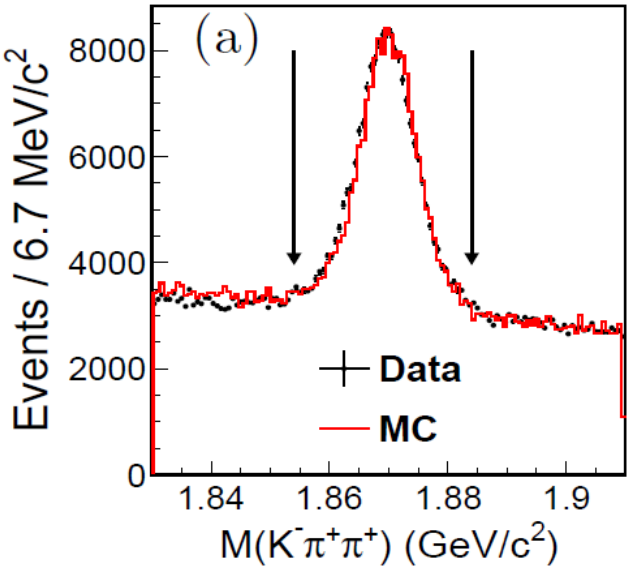
Strategy:

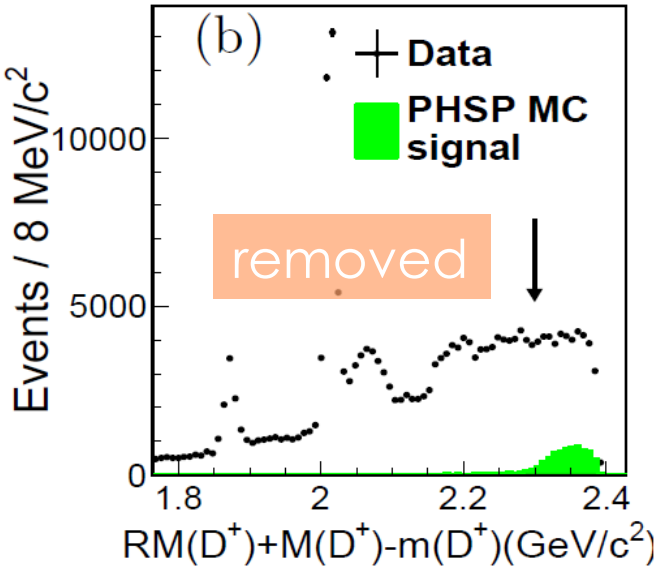
reconstruct D^+ from D^{*+};
reconstruct "bachelor" π
at least on π^0 from D* decays
looking at the recoil side of π

827 pb^{-1} data at 4.260 GeV

arXiv: 1308.2760
Submitted to PRL

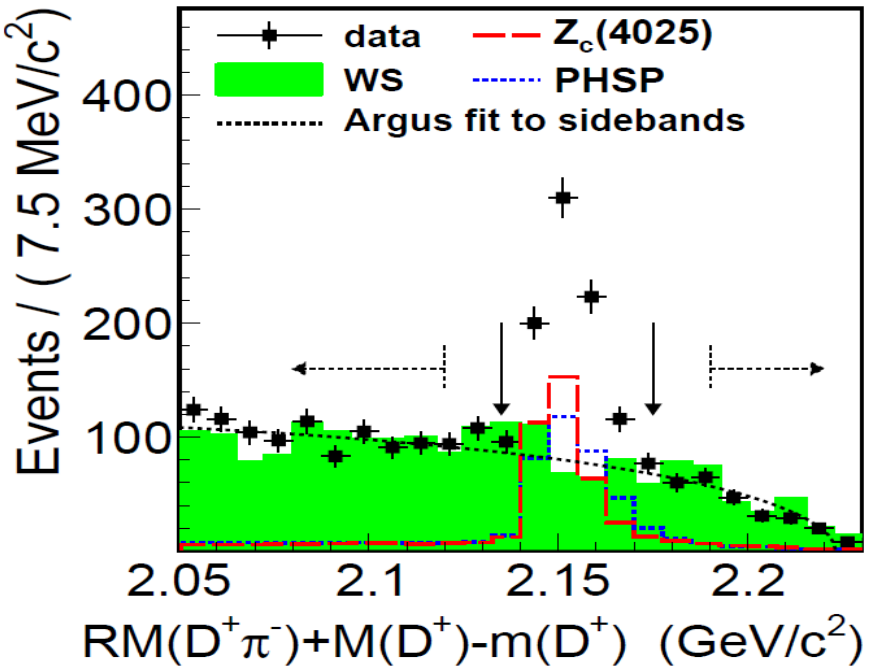


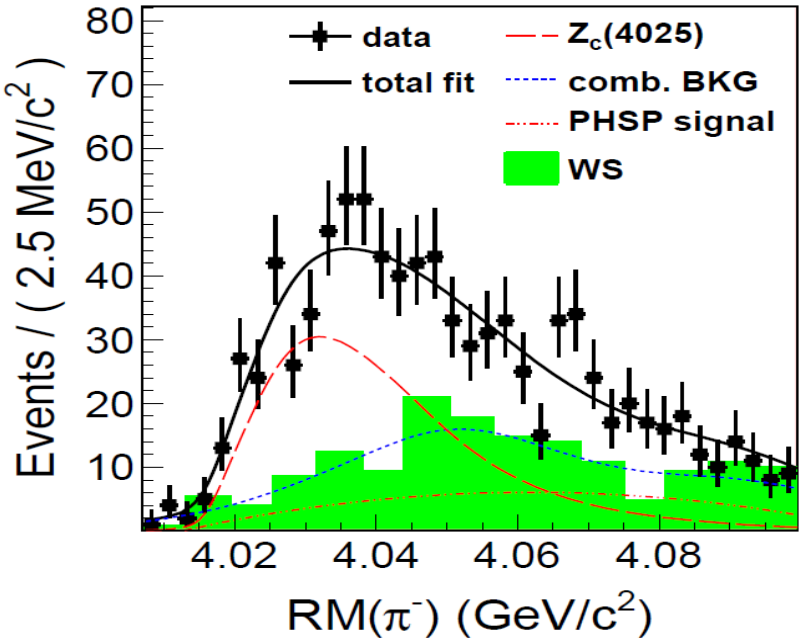




Removed:
DD
DD*
D*D*
D_sD_s
…

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





- Fit to $\pi^\pm$ recoil mass yields:
  - N= 401±47;
  - M= 4026.3±2.6±3.7 MeV ; Γ= 24.8±5.6±7.7 MeV

[pole position]

$\sigma(e^+e^- \to (D^*\bar{D}^*)^+\pi^- + c.c.) = (137 \pm 9 \pm 15)$ pb

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

Summary of Z_c

Channel	Mass (MeV/c^2)	Width (MeV)	
$\pi^{\pm}J/\psi$	3899.0±3.6±4.9	46±10±20	Close to DD* threshold (3875 MeV)
(DD*-bar)$^{\pm}$	3883.9±1.5±4.2	24.8±3.3±11.0	
	2σ difference	1σ difference	
$\pi^{\pm}h_c$	4022.9±0.8±2.7	7.9±2.7±2.6	Close to D*D* threshold (4017 MeV)
(D*D*-bar)$^{\pm}$	4026.3±2.6±3.7	24.8±5.6±7.7	
	1σ difference	2σ difference	

- At least 4-quarks; Charged; Near threshold;
- Couples to DD final states larger than charmonium final states;
- Whether they are two states need further understanding (couple channel analysis? quantum number determination? interference?)

Summary and next at BESIII?

- Fruitful XYZ results from BESIII
  - Observation of X(3872) from charmonium decay
  - Lineshape study using scan data
  - Observation of Z_c states
- Next plan:
  - Precise resonant parameters
  - Spin-parity of Z_c states
  - More decay modes and other XYZ states
  - Excited Z_c, Z_c' states? $Z_{cs} \rightarrow K J/\psi$ states?
  - More data at high energies

THANK YOU!