$Z_c(4020)$ and $Z_c(3900)$ in πh_c

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for BESIII Collaboration

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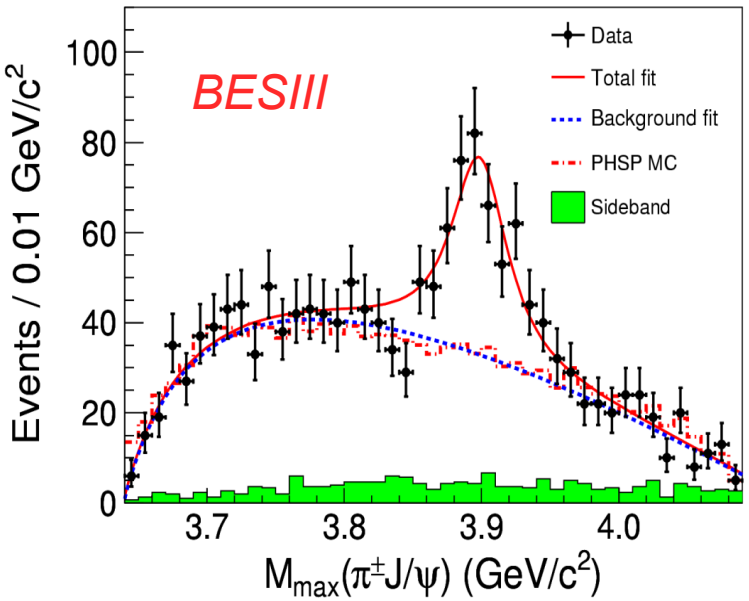
Introduction

- Observation of $Z_c(3900)$ in $e^+e^- \to \pi^+\pi^- J/\psi$ at BESIII, BELLE, and CLEO-c**



- At least four quarks
- Has electric charge
- Nature unclear

***BESIII: PRL110, 252001*
Belle: PRL110, 252002
CLEO-c : 1304.3036

- Tetraquarks? → partner at low mass region
- Hadronic molecules?→ partner around D*D* threshold
- Meson loop?
- Threshold effect?
- …

A partner above/below?

Introduction

- Observation of $Z_c(4025)$ in $e^+e^- \to \pi^+(D^*D^*\text{-bar})^- + c.c.$ talked by Xiaorui

  BESIII: 1308.2760

- Observation of $Z_b(10610)$ and $Z_b(10650)$ in the $\pi\pi\Upsilon(1S, 2S, 3S)$ and $\pi\pi h_b(1P, 2P)$ processes at BELLE

  PRL100, 112001; 1103.3419

- CLEO-c observed $\pi^+\pi^- h_c$ at $E_{c.m.}$=4170MeV, also see hints of a rise in the $\pi^+\pi^- h_c$ cross section at $E_{c.m.}$=4260MeV using 13.2 pb^{-1} scan data

  PRL107, 041803

- Worth search in the $\pi^+\pi^-$ plus other charmonium final states, we report such a study in $\pi^+\pi^- h_c$ and check a charged pion and h_c invariant mass spectrum with large data sample above 4.0 GeV

Data samples

Center-of-Mass energy (MeV)	Luminosity (pb^{-1})
3810	$50.54 \pm 0.03 \pm 0.50$
3900	$52.61 \pm 0.03 \pm 0.53$
4090	$52.63 \pm 0.03 \pm 0.53$
4190	$43.09 \pm 0.03 \pm 0.43$
4210	$54.55 \pm 0.03 \pm 0.54$
4220	$54.13 \pm 0.03 \pm 0.54$
4230	$(44.40 \pm 0.03 \pm 0.44)+(1047.34 \pm 0.13 \pm 10.47)$
4245	$55.59 \pm 0.03 \pm 0.56$
4260	$(523.74 \pm 0.09 \pm 5.24)+(301.93 \pm 0.07 \pm 3.02)$
4310	$44.90 \pm 0.03 \pm 0.45$
4360	$539.84 \pm 0.10 \pm 5.40$
4390	$55.18 \pm 0.03 \pm 0.55$
4420	$44.67 \pm 0.03 \pm 0.45$

Offline luminosity with uncertainty at 1% level
total luminosity~3.3 fb^{-1} (with 4009 data)

Decay channels

- $e^+e^- \to \pi^+\pi^- h_c$, relatively low momentum pions, good resolution
- h_c reconstructed with $\gamma\eta_c$, ~50% of the h_c decays
- η_c reconstructed with 16 hadronic decay modes, ~40% of the η_c decays

$\eta_c \to X_i$, X_i={pp-bar, $\pi^+\pi^- K^+K^-$, $\pi^+\pi^-$pp-bar, $2(K^+K^-)$, $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$, $2(\pi^+\pi^-)K^+K^-$, $K_S^0K^+\pi^-$+c.c., $K_S^0K^+\pi^-\pi^+\pi^-$+c.c., $K^+K^-\pi^0$, pp-barπ^0, $K^+K^-\eta$, $\pi^+\pi^-\eta$, $\pi^+\pi^-\pi^0\pi^0$, $2(\pi^+\pi^-)\eta$, $2(\pi^+\pi^-\pi^0)$ },

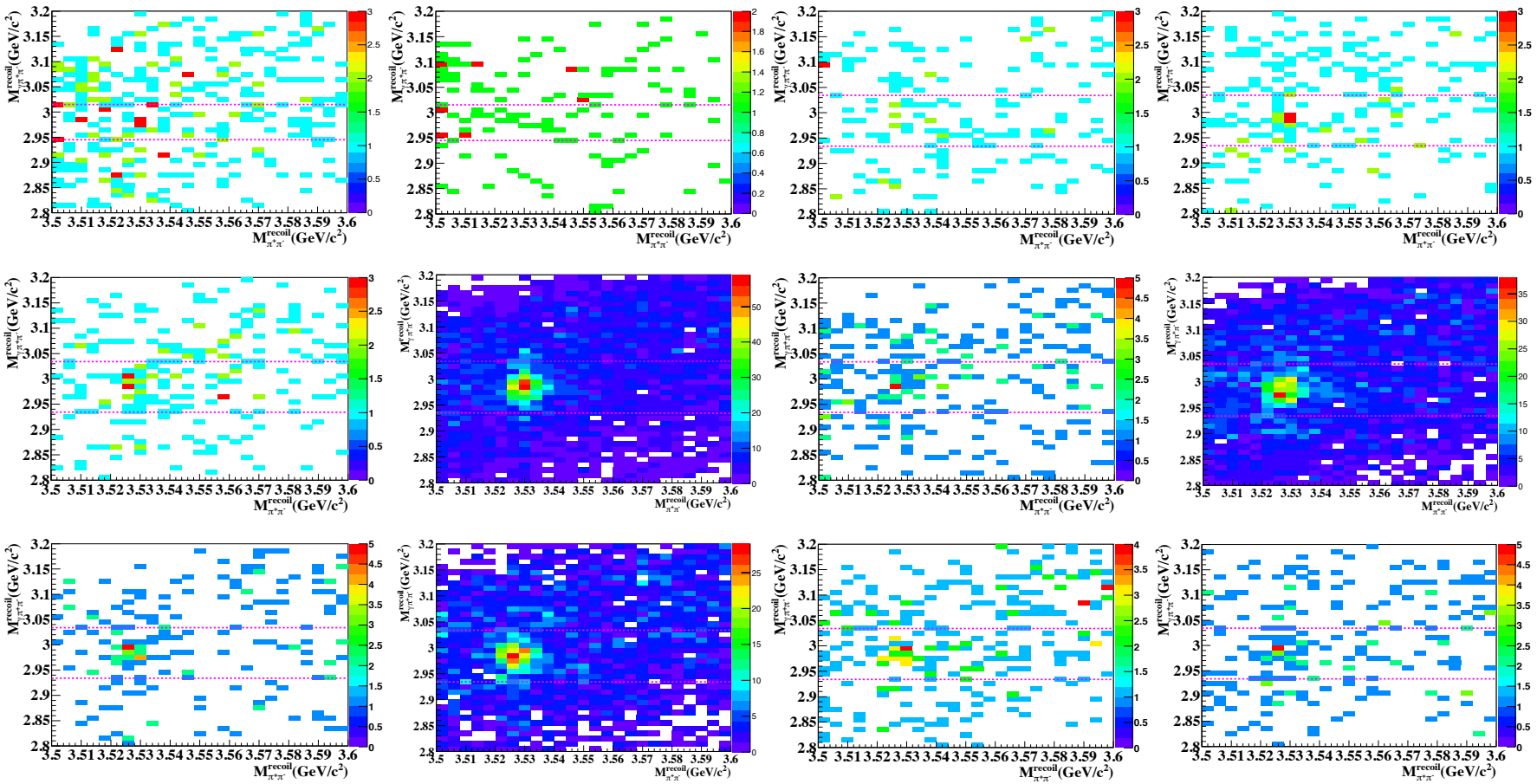
K_S^0 reconstructed with $\pi^+\pi^-$

π^0 and η reconstructed with $\gamma\gamma$

Event selection

- All the particles have been reconstructed
- Exactly number of charged tracks in each final state
- Neutral particles not less than the required numbers in the final states
- K_S^0 reconstructed using secondary vertex fit, best candidate with smallest χ^2
- π^0 and η mass window: 15 MeV around the nominal mass
- Use kinematic fit and PID to determine the species of the final state particles and select the neutral particles

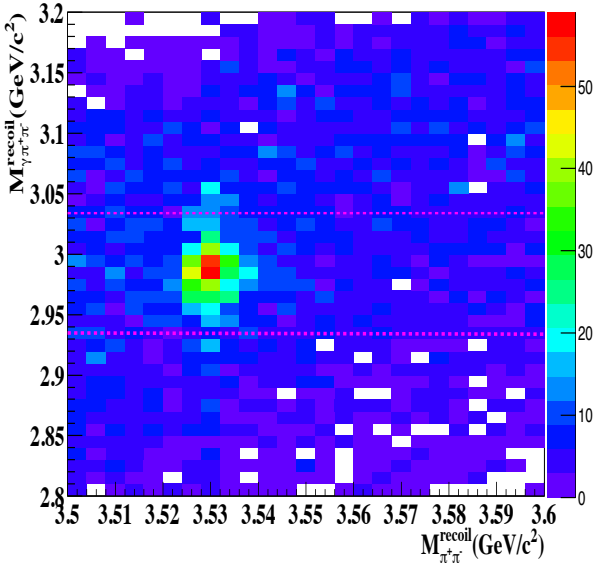
η_c and h_c signals in data



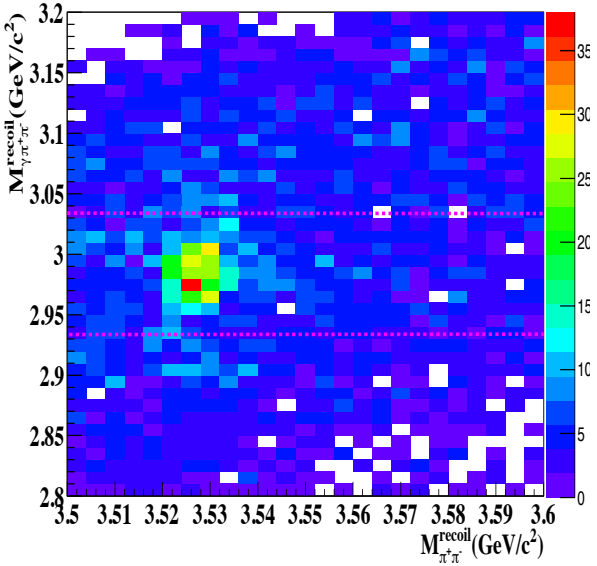
Center-of-Mass energy increased from 4009 MeV to 4420 MeV from top left to bottom right

η_c and h_c signals in data

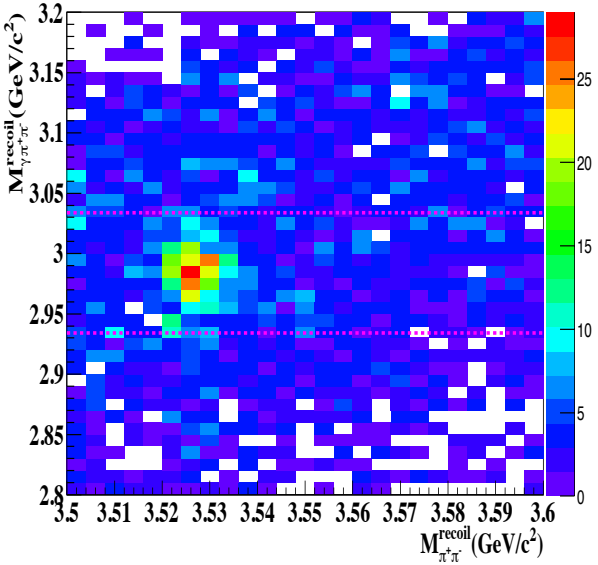
4230 MeV



4260 MeV

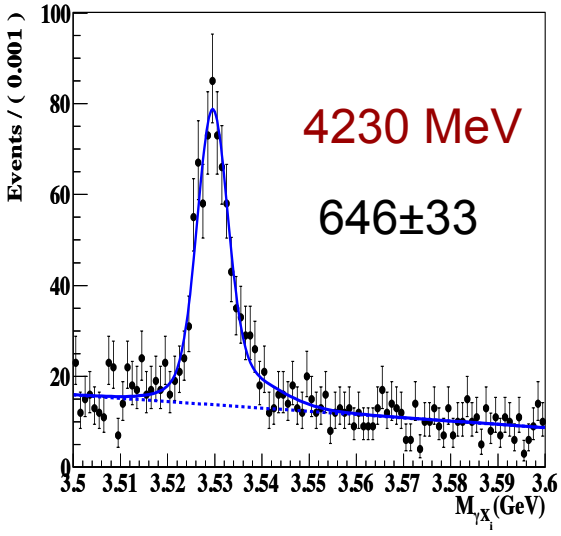


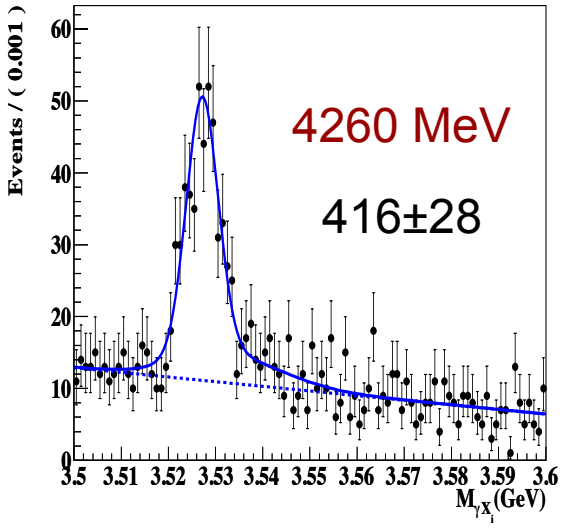
4360 MeV

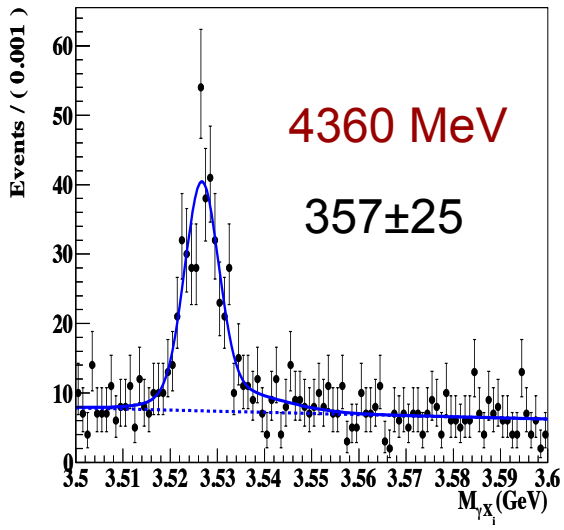


Mass window of η_c: ~50 MeV around the nominal mass of η_c

h_c signals in data





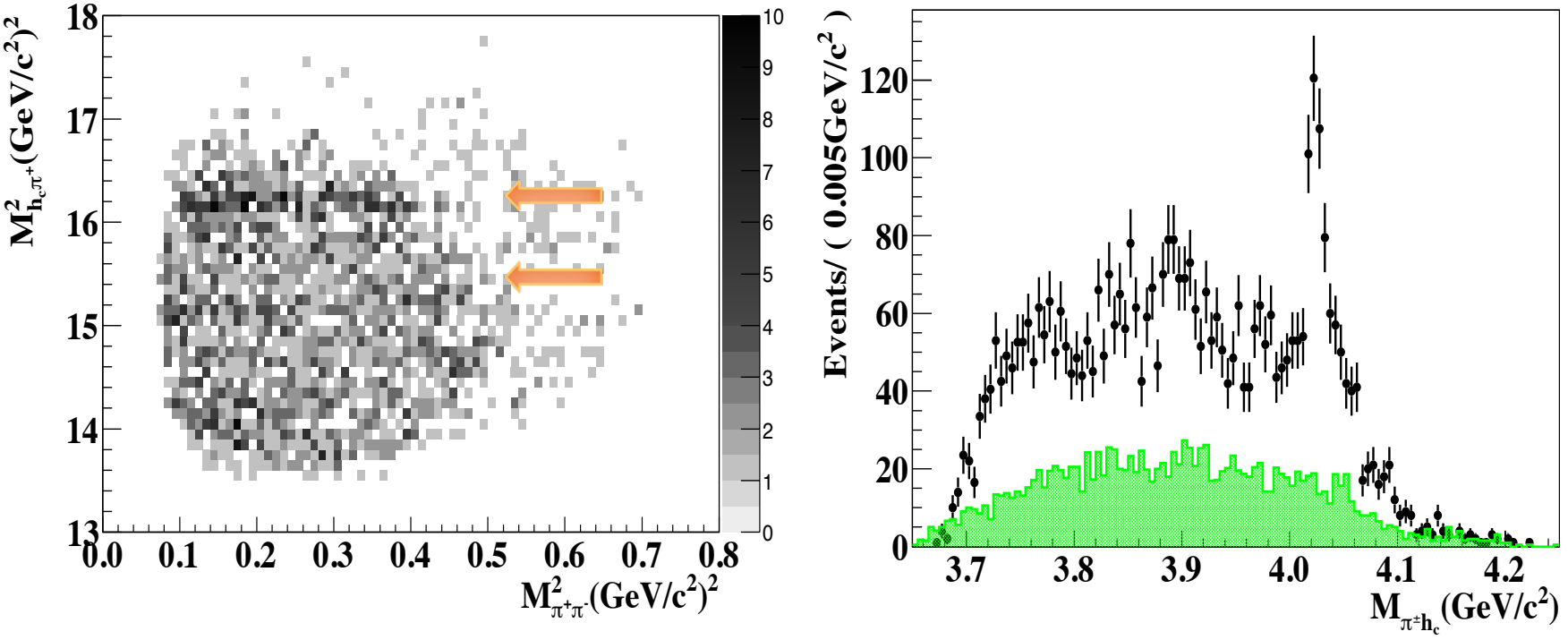


- Fit PDF:
  - Signal: MC signal shape convolved with a Gaussian function
  - Background: linear function
- h_c signal region: [3.518, 3.538] GeV
- h_c sideband region: [3.490, 3.510] GeV and [3.560, 3.580] GeV, twice as wide as signal region

Dalitz plot and 1D projection

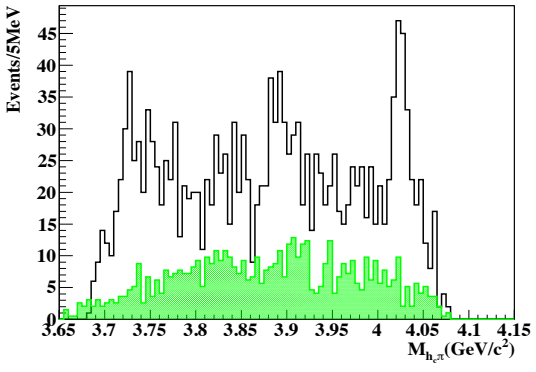
Summed over all data samples

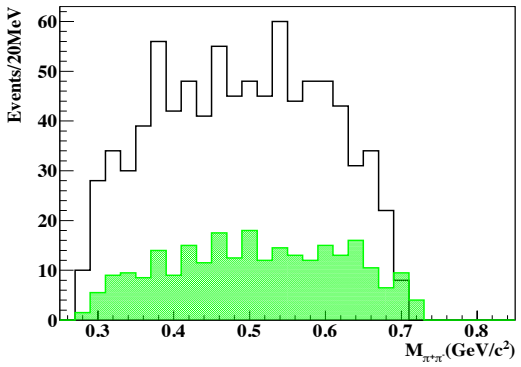
Clear peak around 4020 MeV, and hint at $Z_c(3900)$



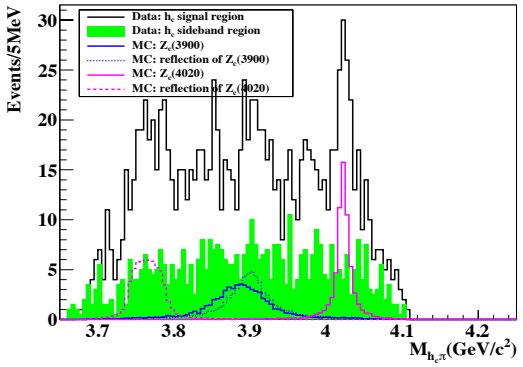
1D projections at different energy

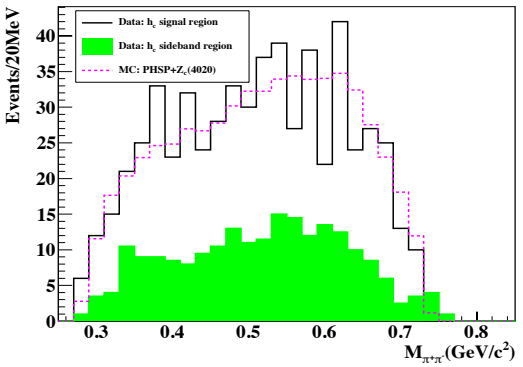
4230 MeV



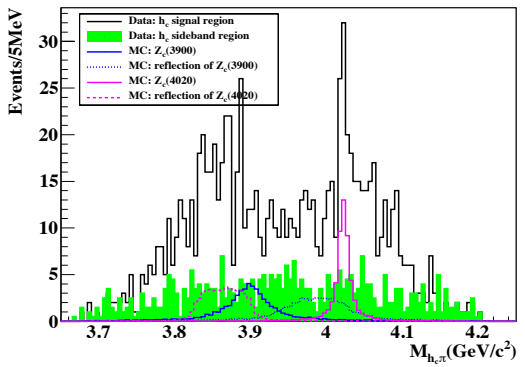


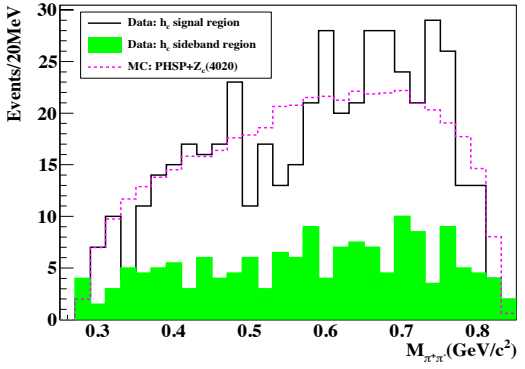
4260 MeV





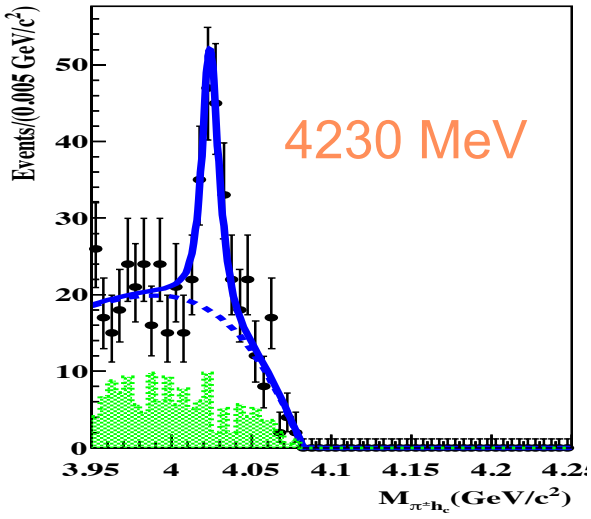
4360 MeV

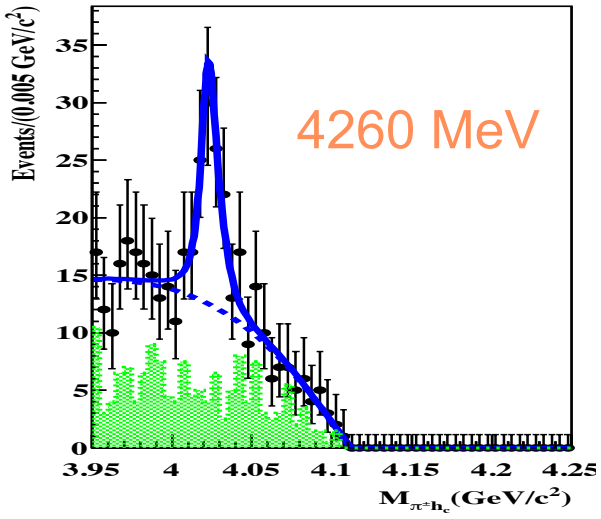


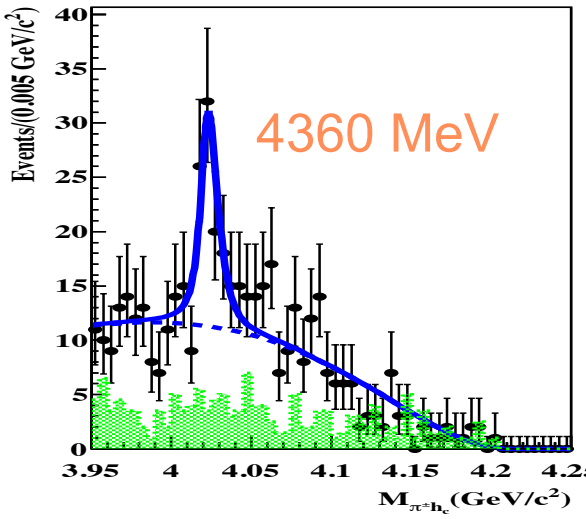


- $Z_C(4020)$ at three energy points, reflections shifted when center-of-mass energy changed
- No obvious structures in $\pi^+\pi^-$ mass spectrum

The $Z_c(4020)$ signal

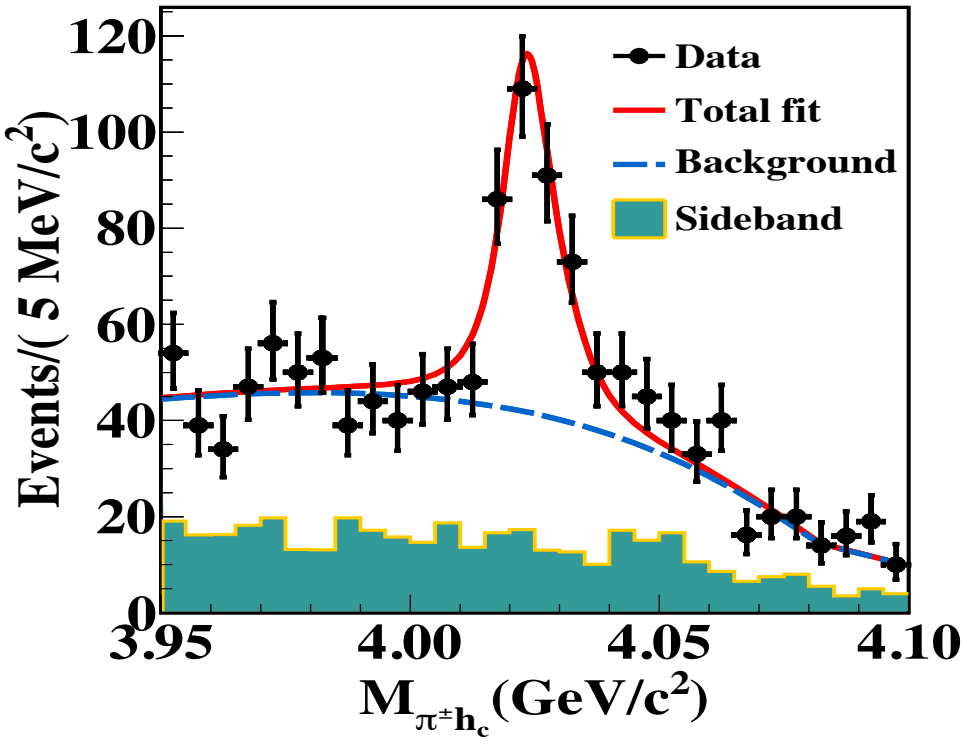






- Simultaneous fit to the three energy points; neglect possible interference
- Fit PDF:
  - Signal: constant width relativistic Breit-Wigner convolved with a Gaussian function; phase space factor ($J^{PC}=1^+$, pq^3) and efficiency correction considered
  - Background: ARGUS function

The $Z_c(4020)$ signal



- Mass:

  4022.9±0.8±2.7 MeV/c^2
- Width:

  7.9±2.7±2.6 MeV
- $Z_c(4020)$ signals:

  114±25 at 4230 MeV;

  72±17 at 4260 MeV;

  67±15 at 4360 MeV

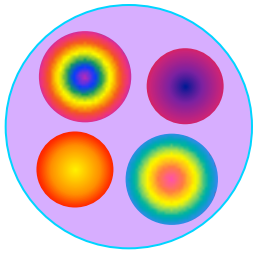
significance : 8.9 σ

- Fit the three data samples separately
- Fit the π^+h_c and π^-h_c mass spectrum separately

fit yields consistent

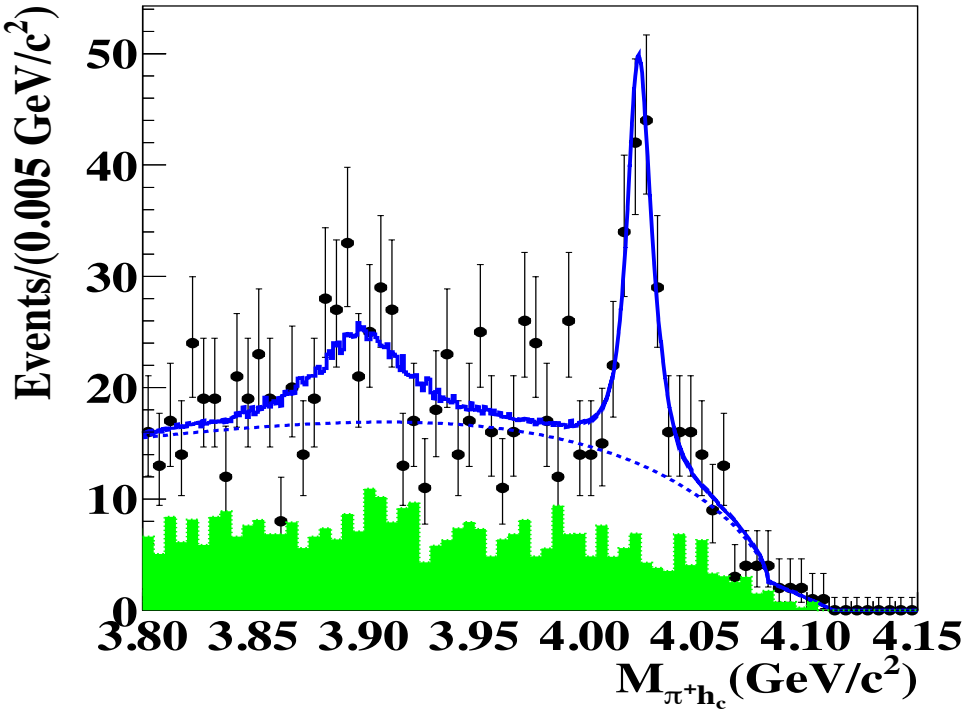
What's $Z_c(4020)$

- Similar to $Z_c(3900)$
  - Couples to cc-bar
  - Has electric charge
  - At least four quarks



- ~6 MeV above the D*D* threshold (4017 MeV), looks more like molecules
- Very narrow, and much narrow than $Z_c(3900)$
- Parameters consistent with $Z_c(4025)$ within 1.5σ
- Whether they are the same states need further study → couple channels analysis?

The $Z_c(3900)$ signal



significance : 2.1 σ

Upper limits of the $\pi Z_c(3900)$ cross section at 90% C.L.:

<13 pb at 4230 MeV

<11 pb at 4260 MeV

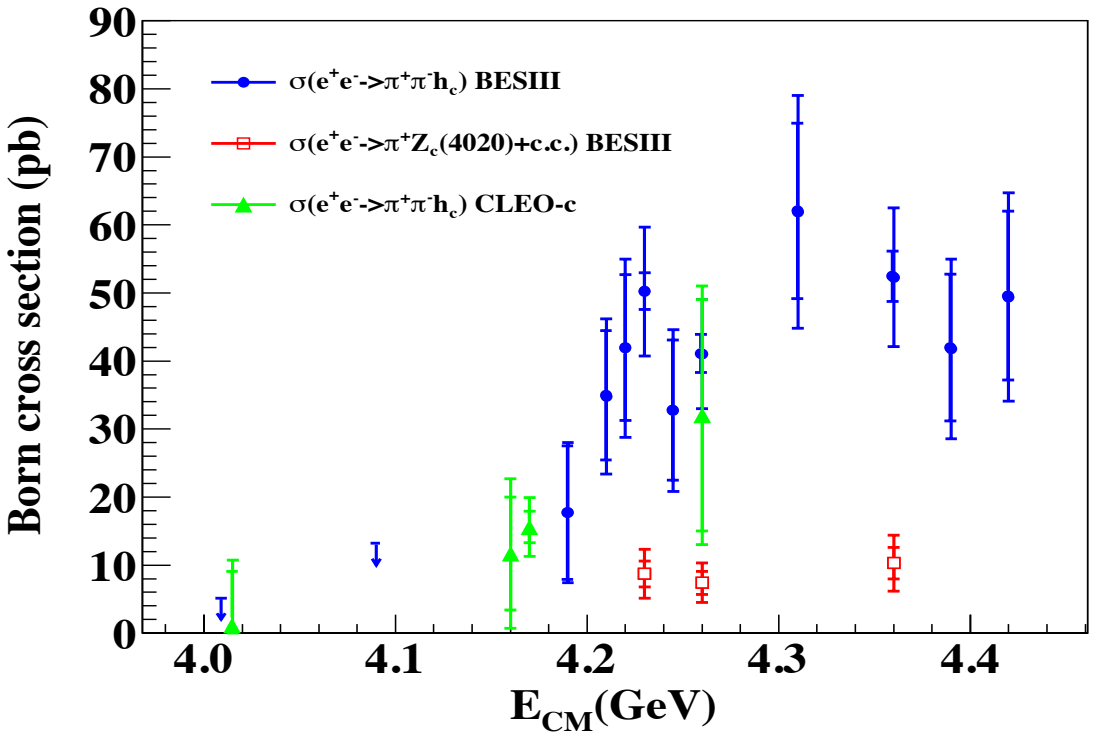
- Simultaneous fit to data sample at 4230 MeV and 4260 MeV; no interference
- Parameters of $Z_c(3900)$ fixed to BESIII's measurement

Cross section

$$\sigma^B = \frac{n_{h_c}^{\rm obs}}{\mathcal{L}(1+\delta)\mathcal{B}_{h_c}\sum_i \epsilon_i \mathcal{B}_i}$$

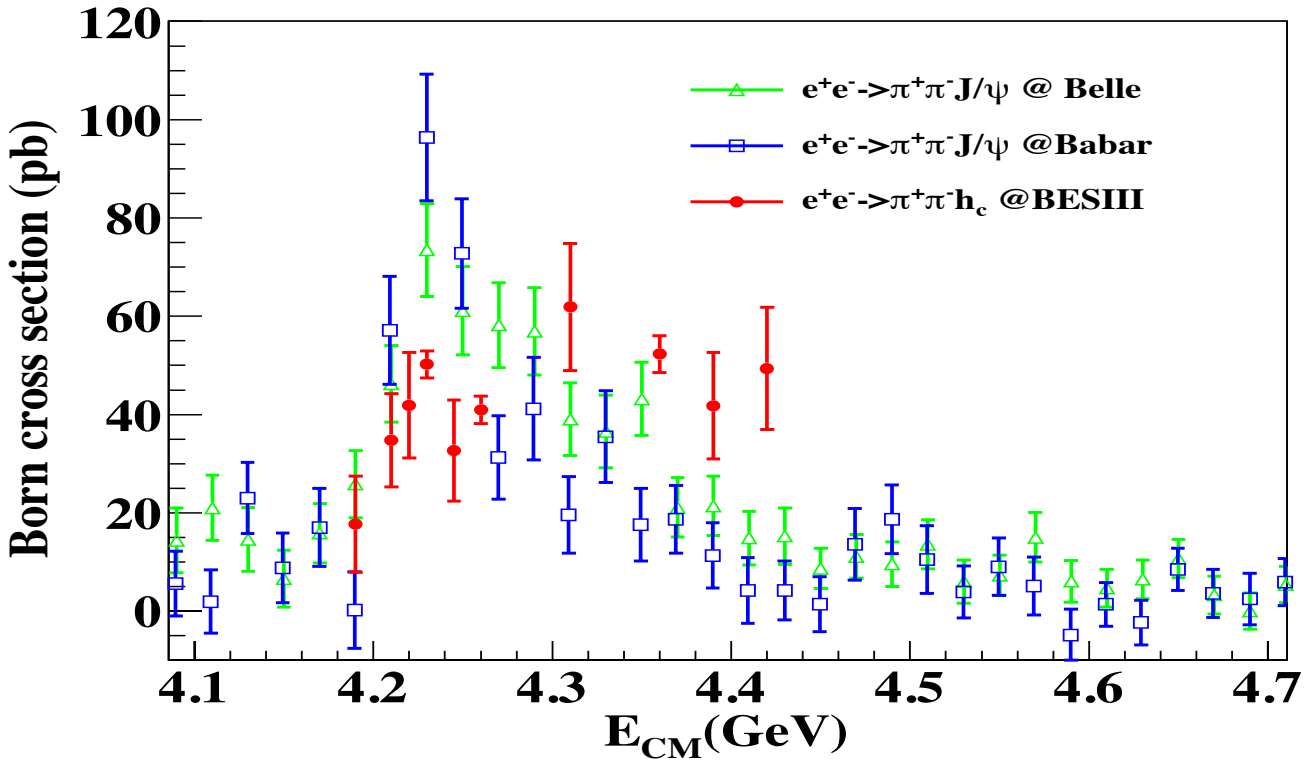
$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})	$n_{h_c}^{\rm obs}$	$\sigma(e^+e^- \to \pi^+\pi^- h_c)$ (pb)
3.900	52.8	< 2.3	< 8.3
4.009	482.0	< 13	< 5.0
4.090	51.0	< 6.0	< 13
4.190	43.0	8.8 ± 4.9	$17.7 \pm 9.8 \pm 1.6 \pm 2.8$
4.210	54.7	21.7 ± 5.9	$34.8 \pm 9.5 \pm 3.2 \pm 5.5$
4.220	54.6	26.6 ± 6.8	$41.9 \pm 10.7 \pm 3.8 \pm 6.6$
4.230	1090.0	646 ± 33	$50.2 \pm 2.7 \pm 4.6 \pm 7.9$
4.245	56.0	22.6 ± 7.1	$32.7 \pm 10.3 \pm 3.0 \pm 5.1$
4.260	826.8	416 ± 28	$41.0 \pm 2.8 \pm 3.7 \pm 6.4$
4.310	44.9	34.6 ± 7.2	$61.9 \pm 12.9 \pm 5.6 \pm 9.7$
4.360	544.5	357 ± 25	$52.3 \pm 3.7 \pm 4.8 \pm 8.2$
4.390	55.1	30.0 ± 7.8	$41.8 \pm 10.8 \pm 3.8 \pm 6.6$
4.420	44.7	29.1 ± 7.3	$49.4 \pm 12.4 \pm 4.5 \pm 7.6$

Cross section



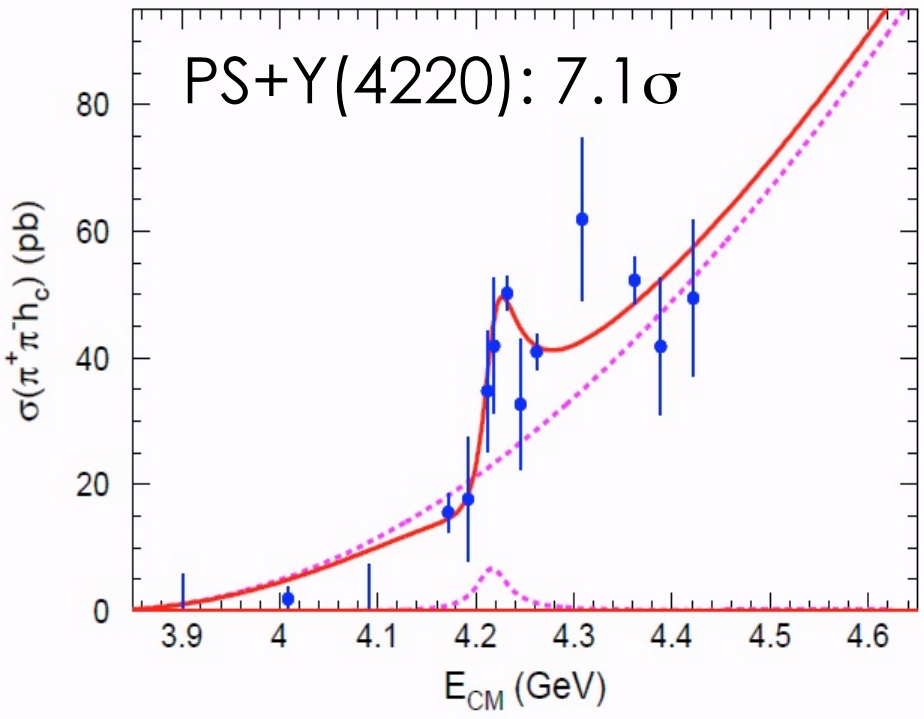
- Cross section of $\pi^+\pi^- h_c$ consistent with CLEO-c, same order of magnitude as those of $\pi^+\pi^- J/\psi$
- Cross section of $\pi Z_c(4020)$ around 10 pb, uniform at the three energy points

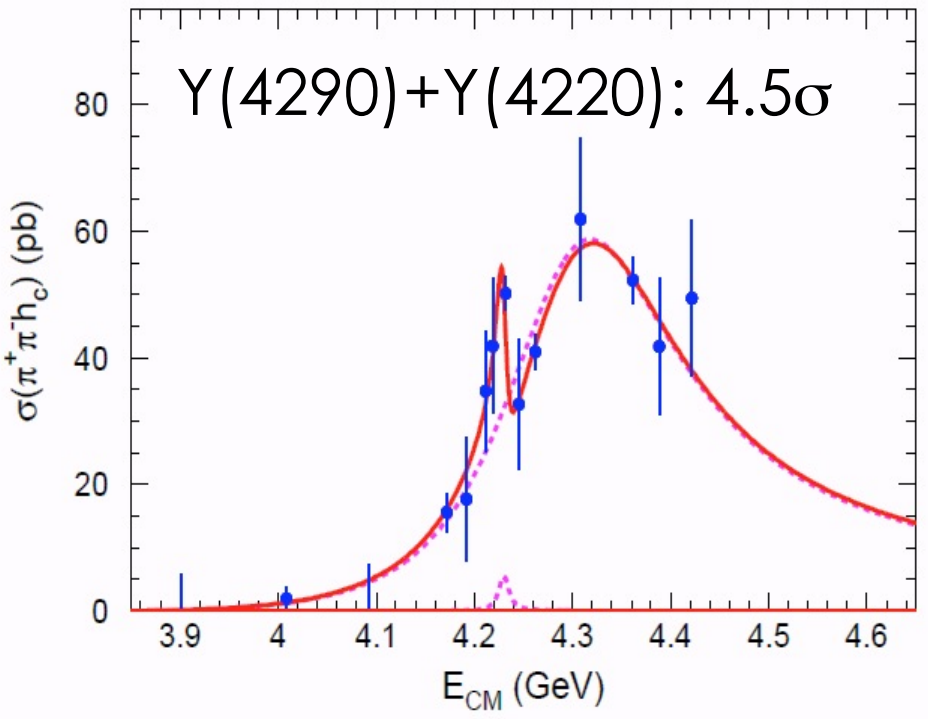
Cross section -compare to $\pi\pi J/\psi$



- Local maximum around 4.23 GeV
- Broad structure at high energy region? Need more data at high energies

Structure in $e^+e^- \to \pi^+\pi^- h_c$?





Common sys. errors not included in these fits! (cf. arXiv:1310.2190)

Narrow structure at 4.22 GeV? More data at around 4.22 GeV!

Broad structure at 4.29 GeV? More data at above 4.4 GeV!

CZY: arXiv:1310.0280: fit to BESIII and CLEOc data

Summary

- Observed another charged charmoniumlike state, $Z_c(4020)$, in its $\pi^{\pm}h_c$ decay mode
- Not a conventional hadron
- No significant $Z_c(3900)$ in $\pi^{\pm}h_c$ final state
- Observed a different $\pi^+\pi^-h_c$ lineshape
- More study are need to help understand its nature
  - Search for at the other decay modes
  - Study of its neutral partner
  - Spin-parity
  - …

THANK YOU!

Thank you !