NEWS ON Z_c STATES AT BESIII

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FOR BESIII COLLABORATION

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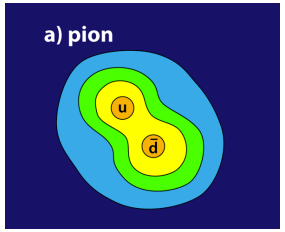
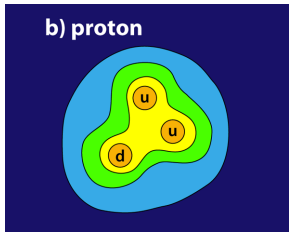
HADRONS

- Quark model:

Mesons

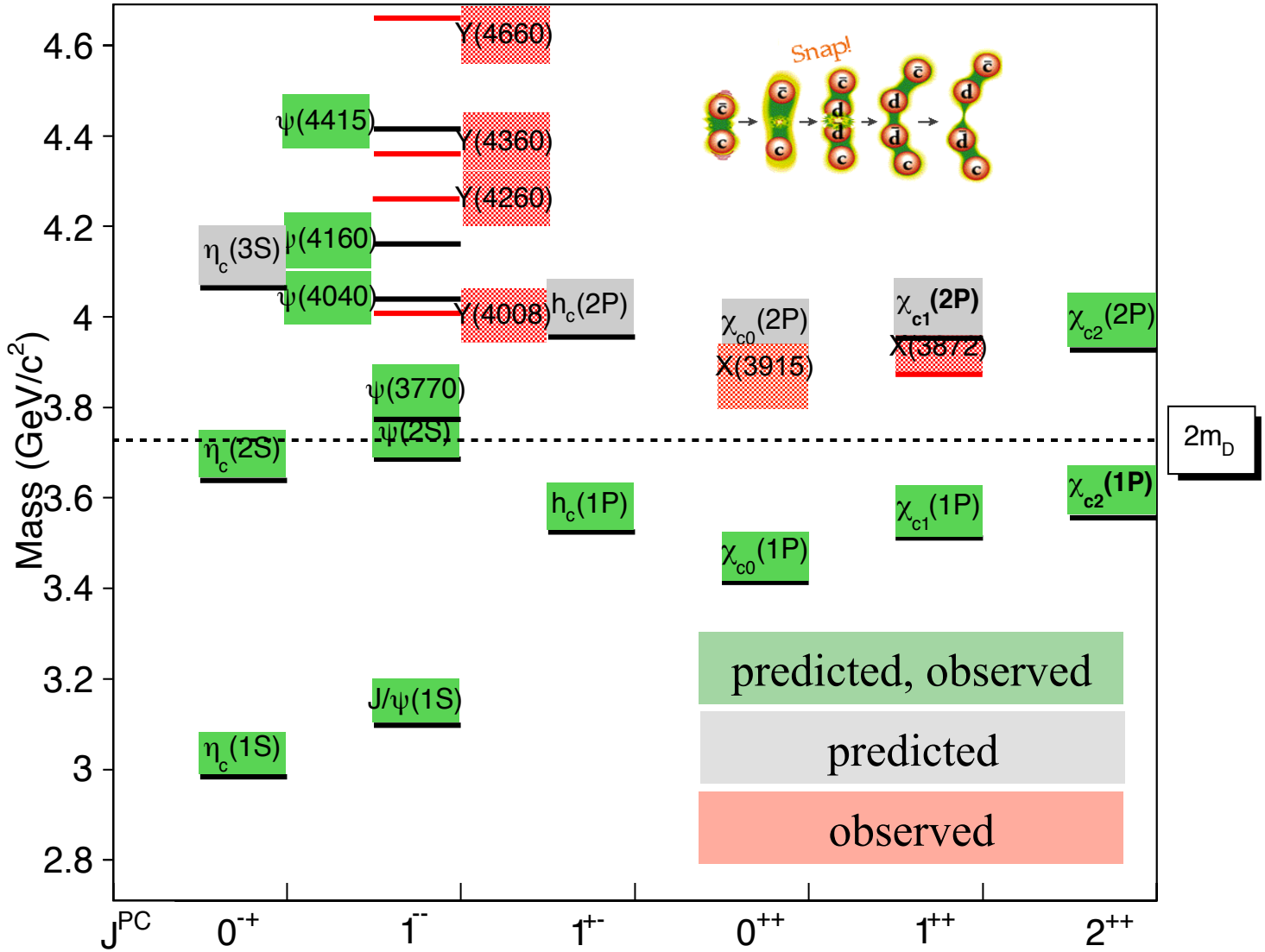


Baryons



- Hadrons with other configurations not excluded:
  - Glueball: (gg, ggg, …)
  - Hybrid: ($q\bar{q}g$, …)
  - Multiquark state: ($qq\bar{q}\bar{q}$, $qqqq\bar{q}$, …)
  - Molecule: bound state of two hadrons

CHARMONIUM SPECTROSCOPY



Z(4430)
Z(4050)
Z(4250)
Z(4200)
$Z_c(3900)$
$Z_c(3885)$
$Z_c(4020)$
$Z_c(4025)$

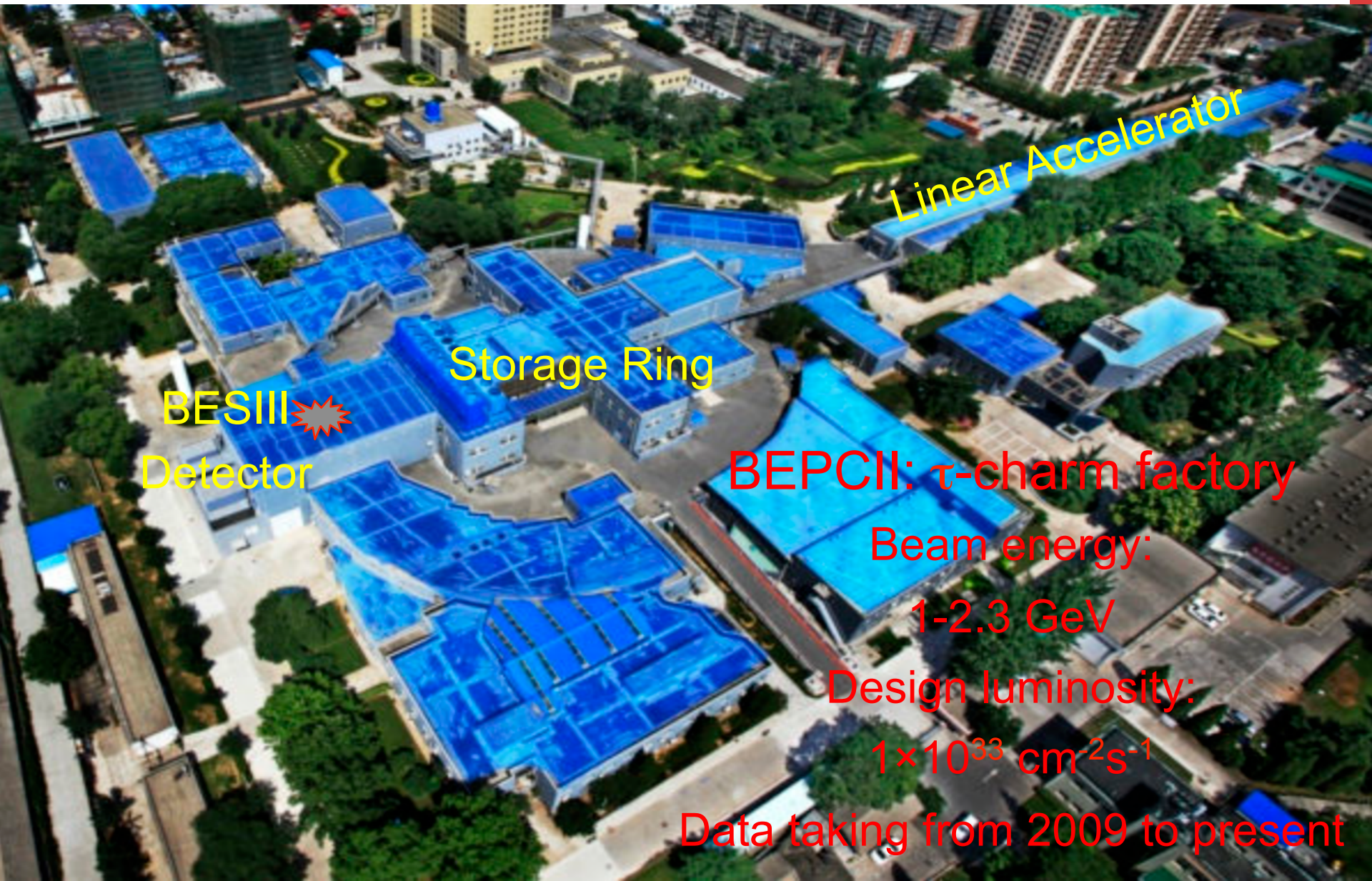
X(3940)
Z(3930)

Y(3940)
Y(4140)
X(4350)

CHARGED CHARMONIUM-LIKE STATES

- Decay into a charmonium, thus contains $c\bar{c}$
- Have electric charge, thus has two more light quarks
- Could exist in $\pi^{\pm}J/\psi$, $\pi^{\pm}\psi(2S)$, $\pi^{\pm}h_c$, $\pi^{\pm}\chi_{cJ}$,…
- Experimental search:
  - BESIII/CLEO-c: $e^+e^- \rightarrow \pi^{\pm}$ exotics,…
  - Belle/BaBar: $e^+e^- \rightarrow (\gamma_{ISR})\pi^{\pm}$ exotics,…
  - Belle/BaBar/LHCb: B->K exotics,…
  - CMS/ATLAS:

Beijing Electron Positron Collider-II



BEPCII: τ-charm factory

Beam energy:

1-2.3 GeV

Design luminosity:

1×10^{33} $cm^{-2}s^{-1}$

Data taking from 2009 to present

THE BESIII DETECTOR

SC Magnet: 1Tesla

Magnet yoke

TOF: (σ_T)

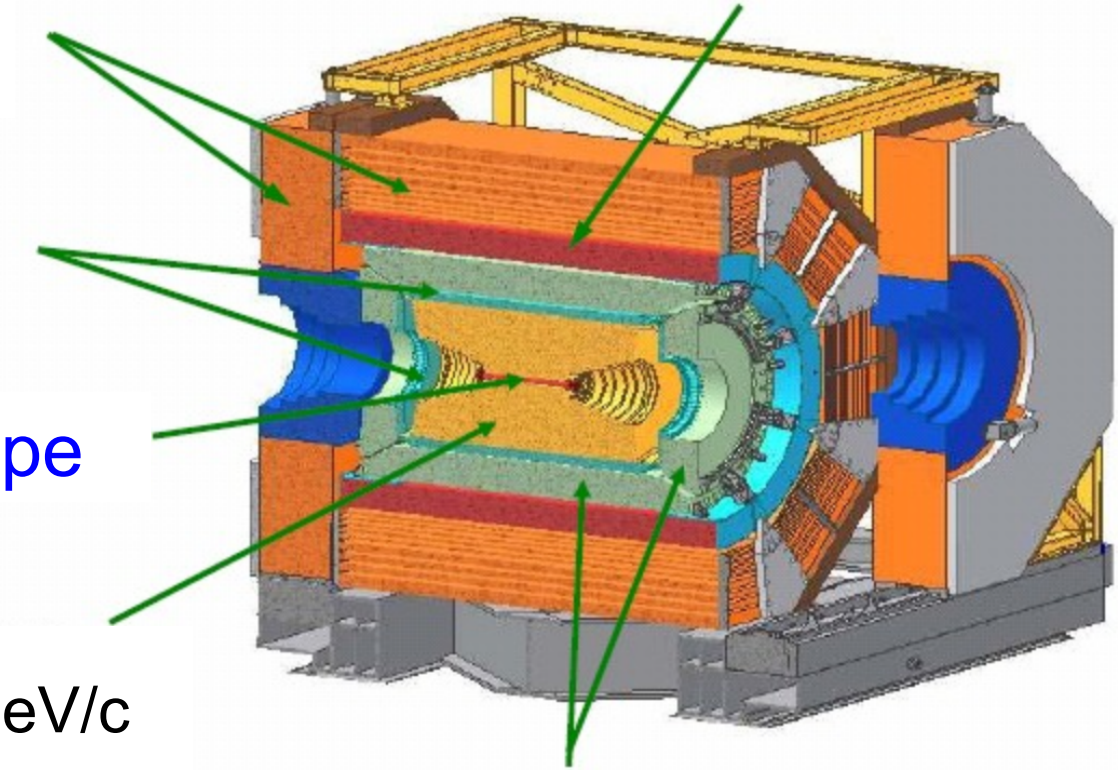
80 ps / 110 ps

Beam pipe

MDC:

σ_p/p: 0.5% at 1GeV/c

dE/dx: 6%



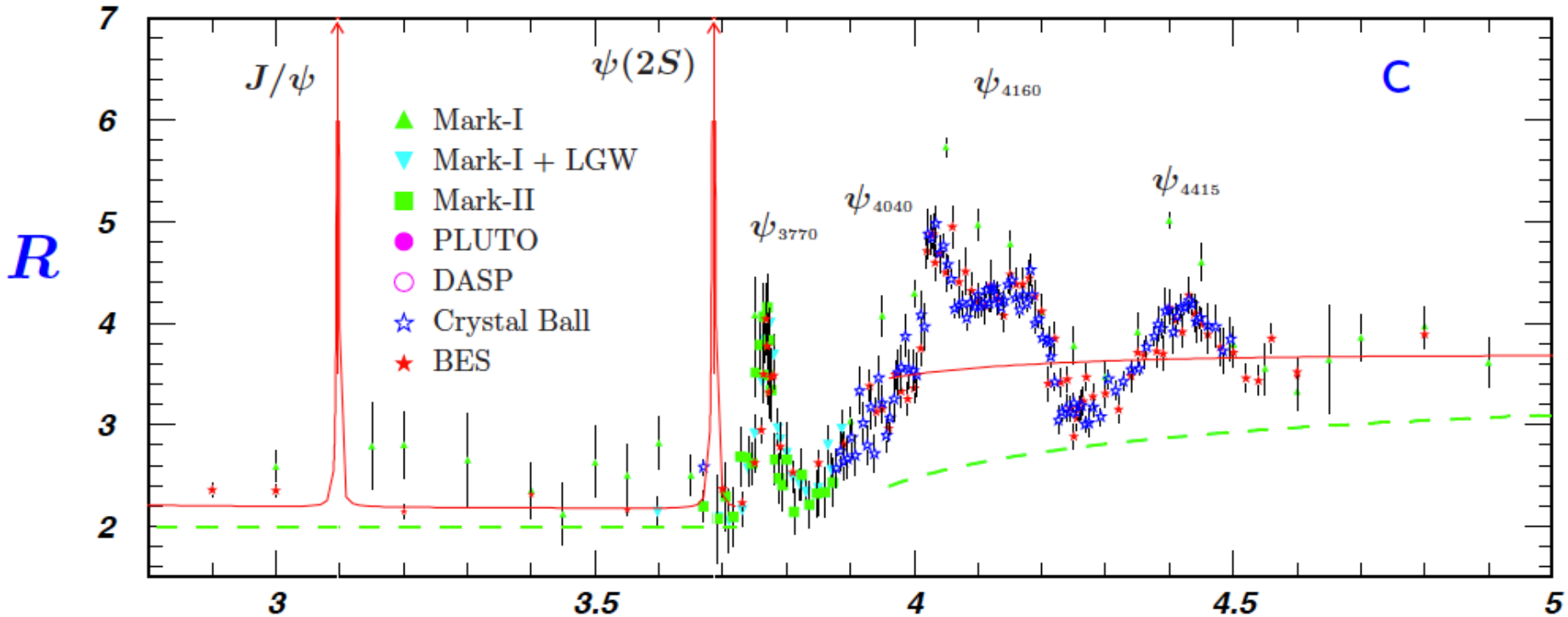
CsI calorimeter:

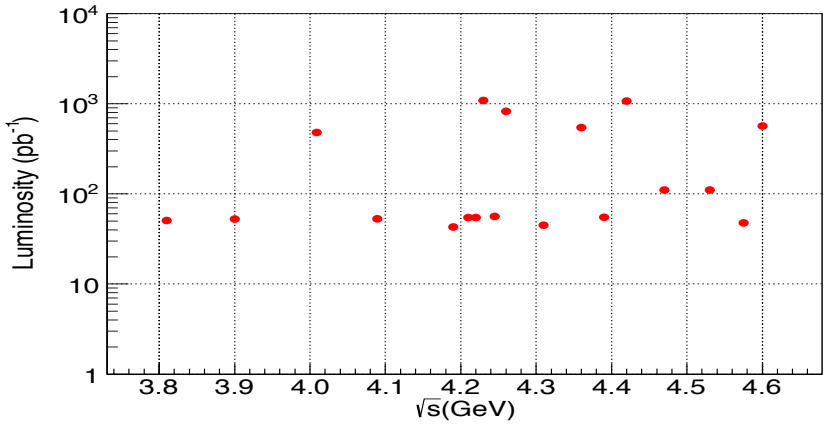
ΔE/E: 2.5% / 5.0% at 1 GeV; σ_Z: 0.6 cm/$\sqrt{E}$

DATA SAMPLES

$\sqrt{s}$	Previous data	BESIII data
J/ψ	58 M (BESII)	1.3 B
$\psi(3686)$	28 M (CLEO)	0.1 B + 0.4 B
$\psi(3770)$	0.8 fb^{-1} (CLEO)	2.9 fb^{-1}
$\psi(4040)$/ $Y(4260)$/$Y(4360)$/ $\psi(4415)$/$Y(4660)$	0.6 fb^{-1} @ 4170 (CLEO)	5 fb^{-1} @ 18 energy points
R scan/τ scan		25 pb^{-1} τ scan; R scan @ 2230, 2400, 2800, 3400, 107 energy points above 3850 Scan at low energy region

XYZ DATA SETS

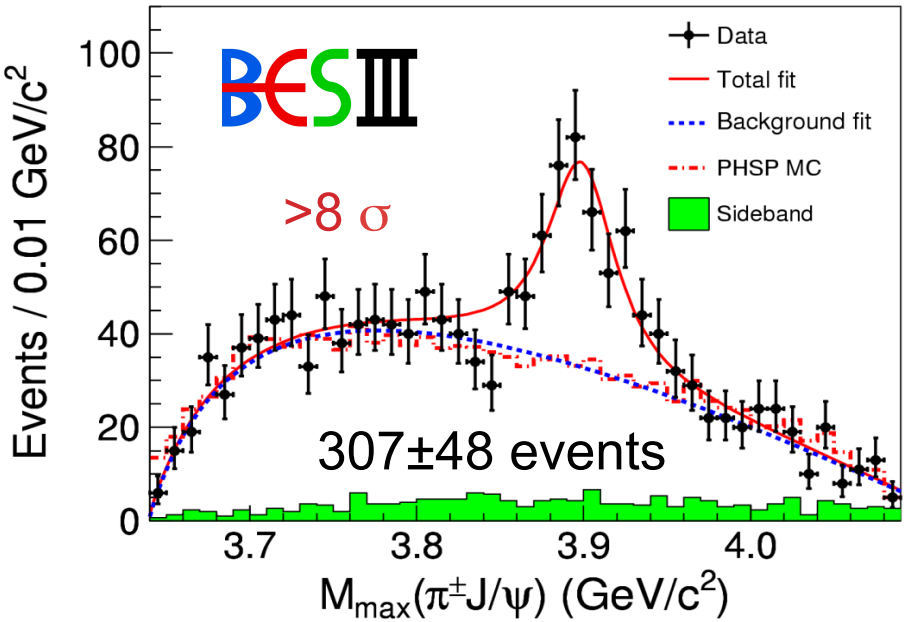


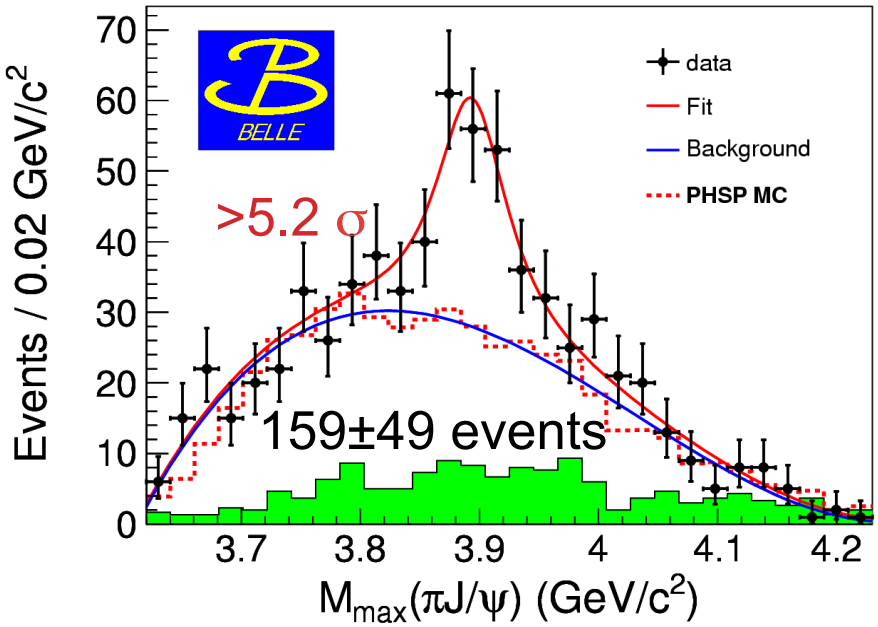


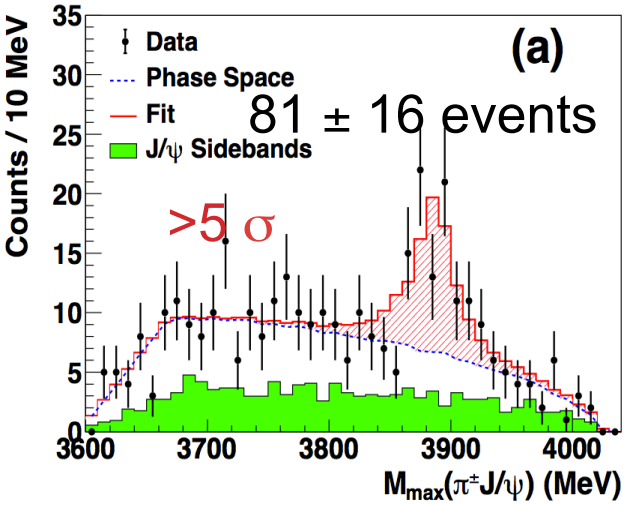
$Z_c(3900)^{\pm}$

- **Observed in $\pi^{\pm}J/\psi$ mass spectrum**
  - BESIII: 525 pb^{-1} data at $\sqrt{s}$=4.260 GeV, $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ [PRL110, 252001(2013)]
  - Belle: 967 fb^{-1} data in Υ(nS) resonsnce region, $e^+e^- \rightarrow \gamma_{ISR}\pi^+\pi^- J/\psi$, select events with $\pi^+\pi^- J/\psi$ in Y(4260) region [PRL110, 252002 (2013)]
  - CLEO-c data: 586 pb^{-1} data at $\sqrt{s}$=4.170 GeV, $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ [PLB727, 366-370(2013)]
- **Contain at least four quarks, good candidate for an exotic state**

$Z_c(3900)^{\pm}$







	BESIII	BELLE	CLEO-c
M (MeV)	3899.0±3.6±4.9	3894.5±6.6±4.5	3886±4±2
Γ (MeV)	46±10±20	63±24±26	37±4±8
R(%)	21.5±3.3±7.5	29.0±8.9	32±8±10

$Z_c(3885)^{\pm}$

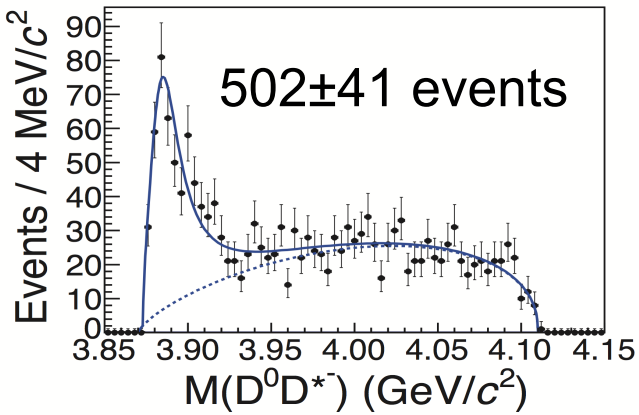
[PRL112, 022001 (2014)]

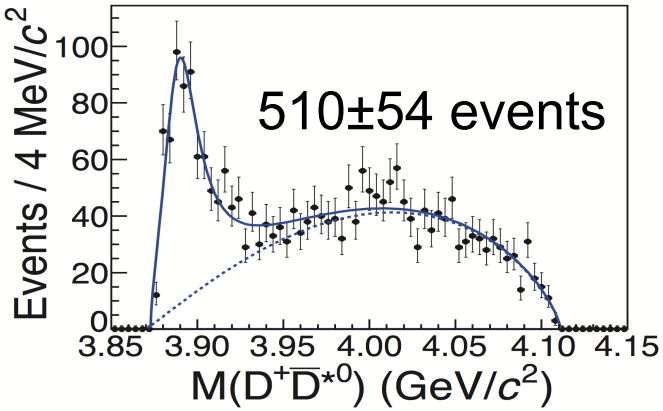
525 pb^{-1} data at 4.260 GeV

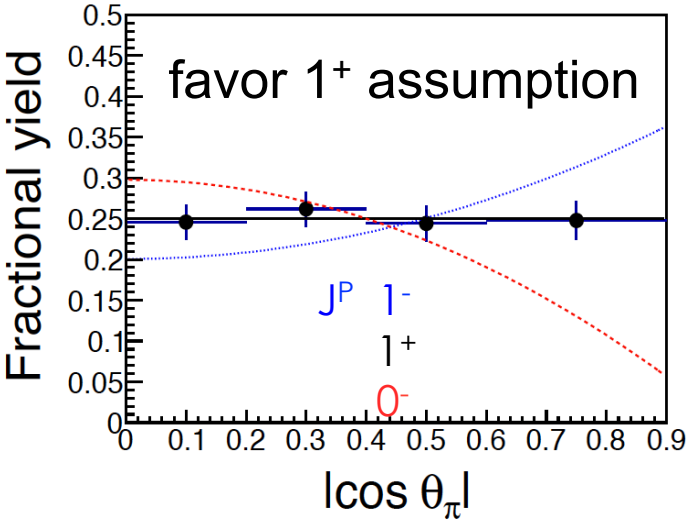
Partial reconstruction, single D tag:

$e^+e^- \rightarrow \pi^+(D^0D^{*-})/\pi^+(D^-D^{*0})$ + c.c.

$\downarrow$ $K^-\pi^+$ $\qquad$ $\downarrow$ $K^+\pi^-\pi^-$







$M = 3883.9 \pm 1.5 \pm 4.2$ MeV

$\Gamma = 24.8 \pm 3.3 \pm 11.0$ MeV

$\sigma \times B = 85.3 \pm 6.6 \pm 22.0$ pb

$$\frac{\Gamma(Z_c(3885)\text{->}DD^*)}{\Gamma(Z_c(3900)\text{->}\pi J/\psi)} = 6.2 \pm 1.1 \pm 2.7$$

482±84 for $\psi(3770)$

$Z_c(4020)^{\pm}$ AND $Z_c(4025)^{\pm}$

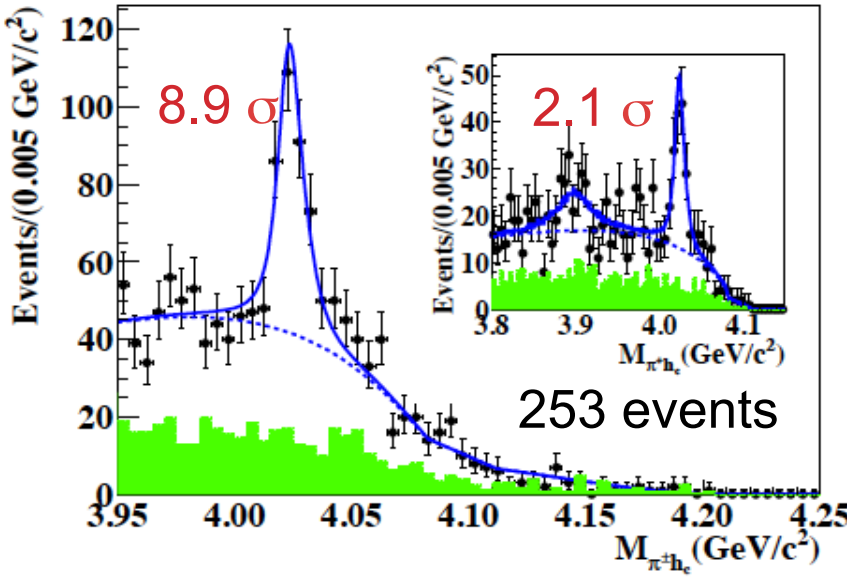
- **$Z_c(4020)^{\pm}$:** [PRL111, 242001 (2013)]
  - $e^+e^- \rightarrow \pi^+\pi^- h_c$, $h_c \rightarrow \gamma\eta_c$, $\eta_c \rightarrow$ hadronic final states
  - narrow peak in $\pi^{\pm}h_c$ mass spectrum
  - 2.3 fb^{-1} data at $\sqrt{s}$=4.230, 4.260, and 4.360 GeV
- **$Z_c(4025)^{\pm}$: partial reconstruction, single D tag**
  - $e^+e^- \rightarrow \pi^+(D^{*+}D^{*0})$+c.c.; structure in $M^{recoil}(\pi^{\pm})$

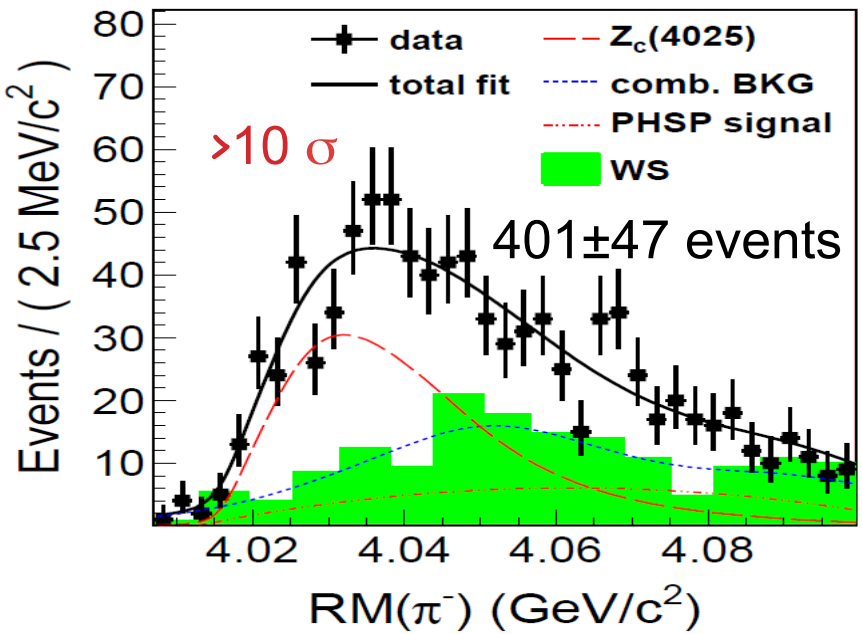
    $D^{*+} \rightarrow D^+\pi^0$, $D^{*0} \rightarrow D^0\pi^0$

    $D^+ \rightarrow K^-\pi^+\pi^+$

    [PRL112, 132001 (2014)]
  - 827 pb^{-1} data at $\sqrt{s}$=4.260 GeV

$Z_c(4020)^{\pm}$ AND $Z_c(4025)^{\pm}$





	Mass (MeV)	Width (MeV)
$Z_c(4020)$	4022.9±0.8±2.7	7.9±2.7±2.6
$Z_c(4025)$	4026.3±2.6±3.7	24.8±5.6±7.7

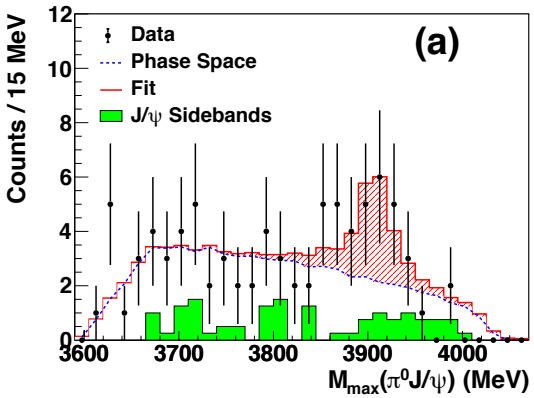
$$\frac{\Gamma(Z_c(4025)\text{->}D^*\bar{D}^*)}{\Gamma(Z_c(4020)\text{->}\pi h_c)} = 12\pm5$$

WHAT'S Z_c STATES

- **Theoretical interpretation:**
  - Tetraquark?
  - Hadronic molecule?
  - Threshold effect?
  - Meson loop?
  - ……
- **New efforts from experimental side:**
  - neutral partner
  - improved measurement
  - new decay modes search

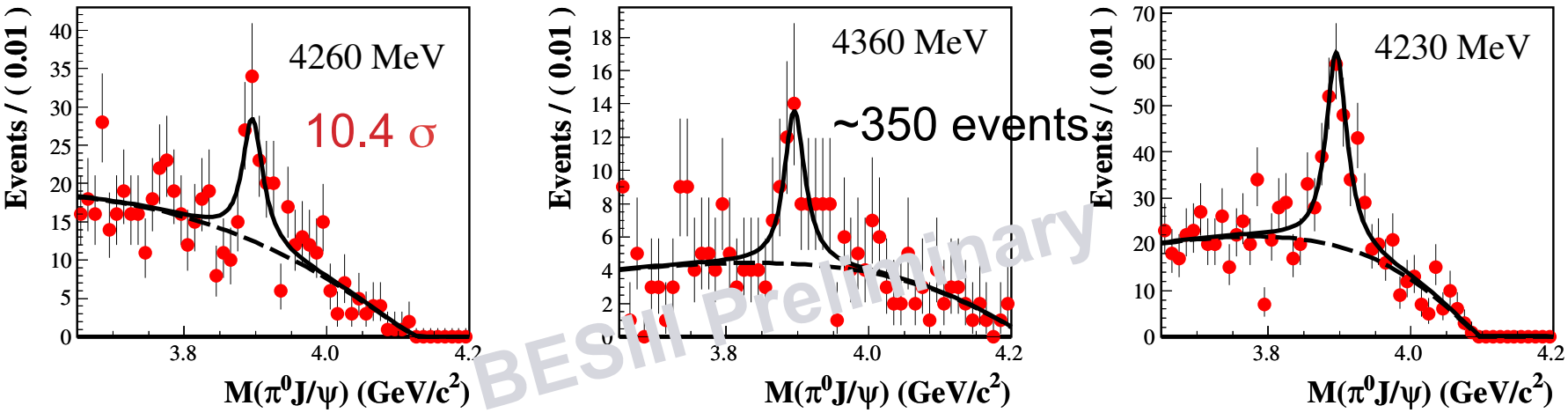
$Z_c(3900)^0$

- **First search using CLEO-c data sample at 4.170 GeV**
  - $e^+e^- \rightarrow \pi^0\pi^0 J/\psi$, check $\pi^0 J/\psi$ mass spectrum
  - evidence with 3.5 σ



- **Same channel studied at BESIII**
  - 2.8 fb^{-1} data sample from 4.19 ~ 4.42 GeV
  - three large data samples at $\sqrt{s}$=4.230, 4.260, and 4.360 GeV used to extract parameters of $Z_c(3900)^0$
  - full data sample used to study $Z_c(3900)^0$ production V.S. center-of-mass energy

$Z_c(3900)^0$

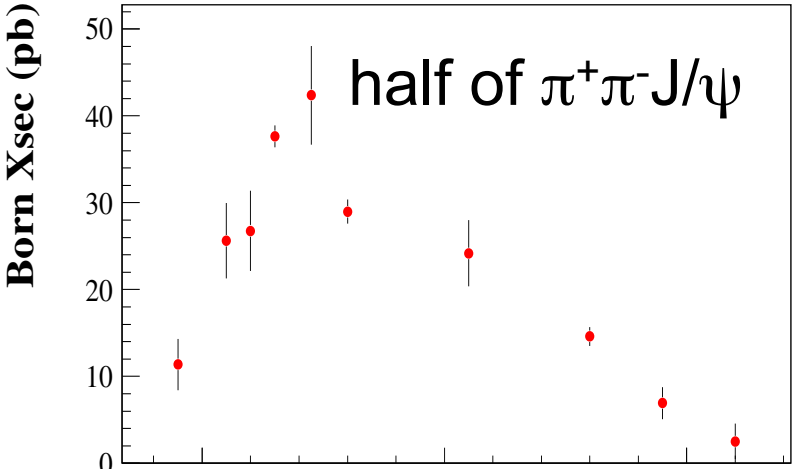


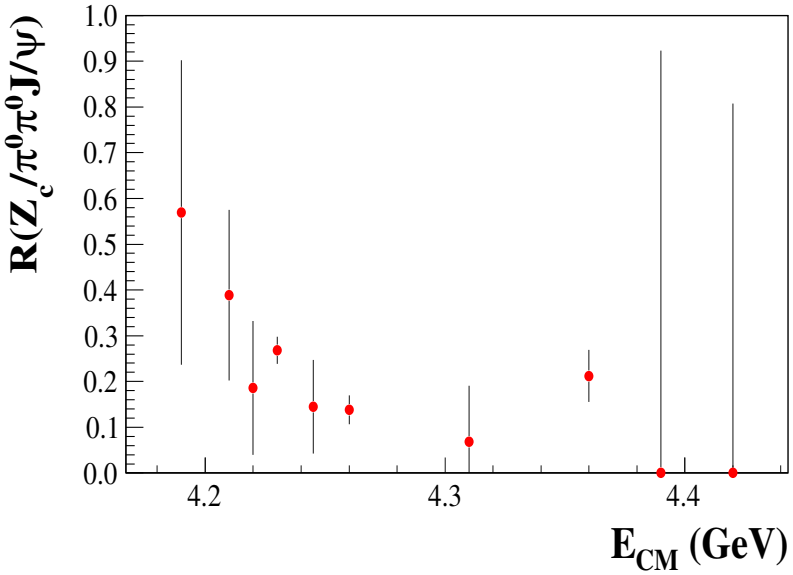
Signal: S-wave BW convolved with Three-Gaussian

Background: Argus formula

	Mass / MeV/c^2	Width / MeV
BESIII: $Z_c(3900)^{\pm}$	3899.0±3.6±4.9	46±10±20
BESIII: $Z_c(3900)^0$	3894.8±2.3±2.7	29.6±8.2±8.2
CLEO-c: $Z_c(3900)^0$	3904±9±5	37 (fixed)

$Z_c(3900)^0$



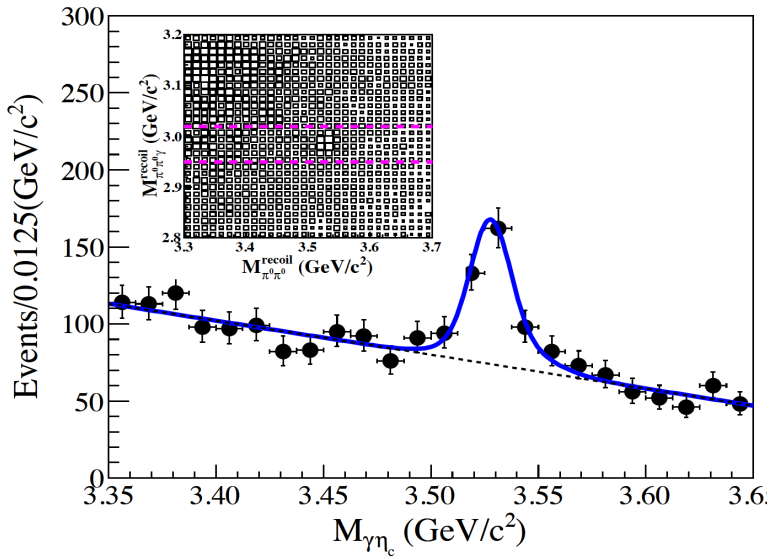


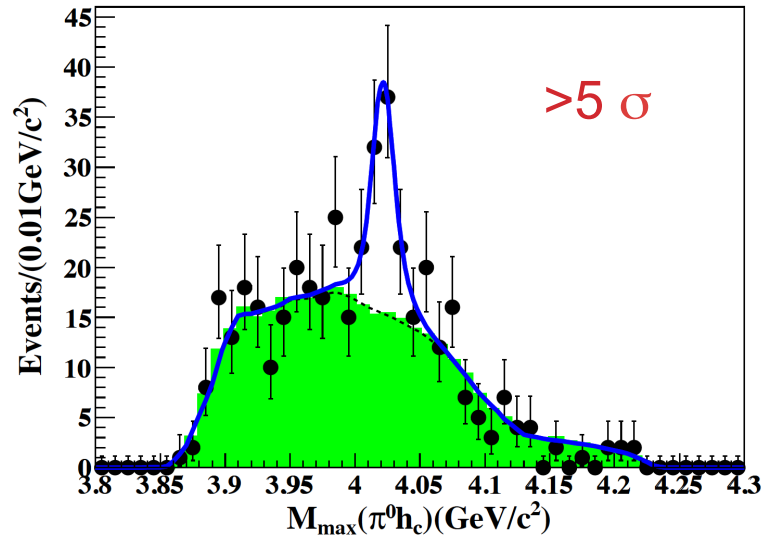
√s (GeV)	R (neutral)	R (charge)
4.230	0.27±0.03±0.01	--
4.260	0.14±0.03±0.01	0.22±0.03±0.08
4.360	0.21±0.06±0.01	--

$Z_c(4020)^0$

[PRL113, 212002 (2014)]

- $e^+e^- \rightarrow \pi^0\pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$, $\eta_c \rightarrow$ hadronic final states
- 2.3 fb^{-1} data at $\sqrt{s}$=4.230, 4.260, and 4.360 GeV

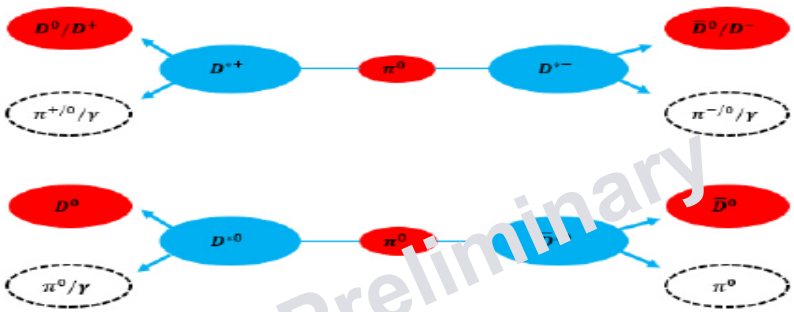


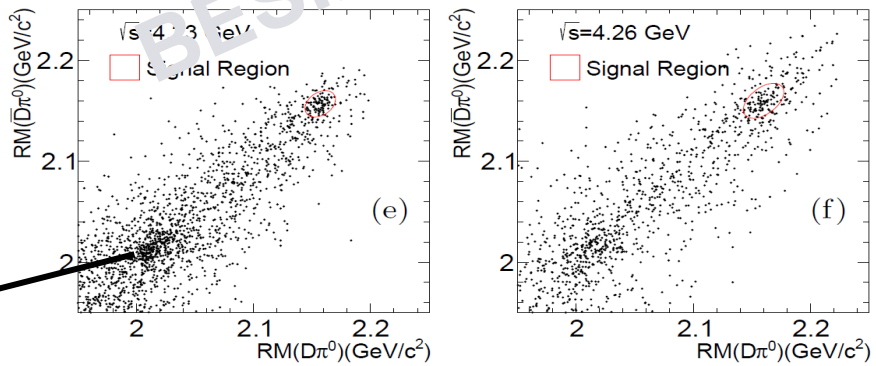


- Width fixed to charged $Z_c(4020)$
- Interference neglect
- M= 4023.6±2.2±3.9 MeV [M= 4022.9±0.8±2.7 MeV]

$Z_c(4025)^0$

- **Partial reconstruction, double D tag:**
  - $e^+e^- \rightarrow (D^{*0}D^{*0})^0\pi^0$ / $(D^{*+}D^{*-})^0\pi^0$
  - $D^0 \rightarrow K^-\pi^+$; $K^-\pi^+\pi^0$; $K^-\pi^+\pi^+\pi^-$ (~26%)
  - $D^+ \rightarrow K^-\pi^+\pi^+$ (~9%)
  - Tag bachelor π^0:
    - not from D*
    - γ can not form other π^0
  - Selection $D^*D^*\pi^0$ using recoil mass of π^0D
- **1.9 fb^{-1} data at $\sqrt{s}$=4.230 and 4.260 GeV**

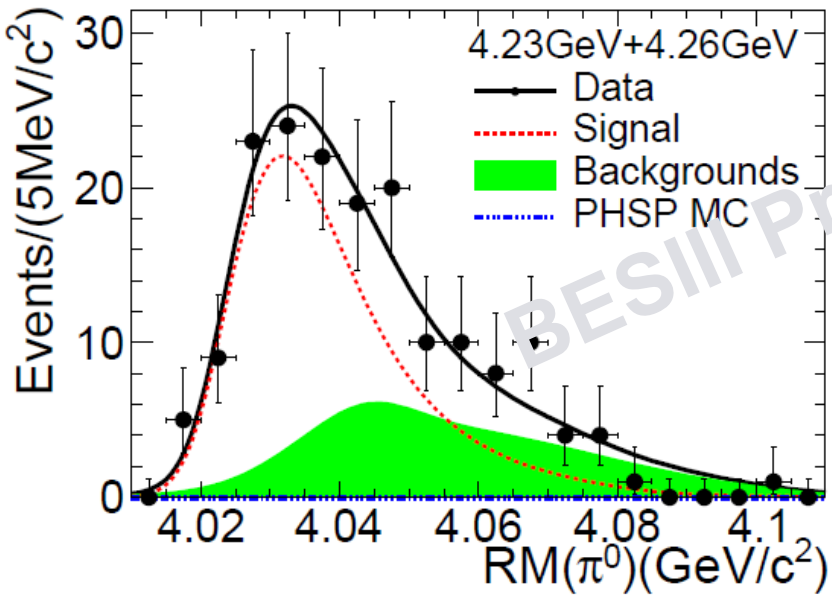




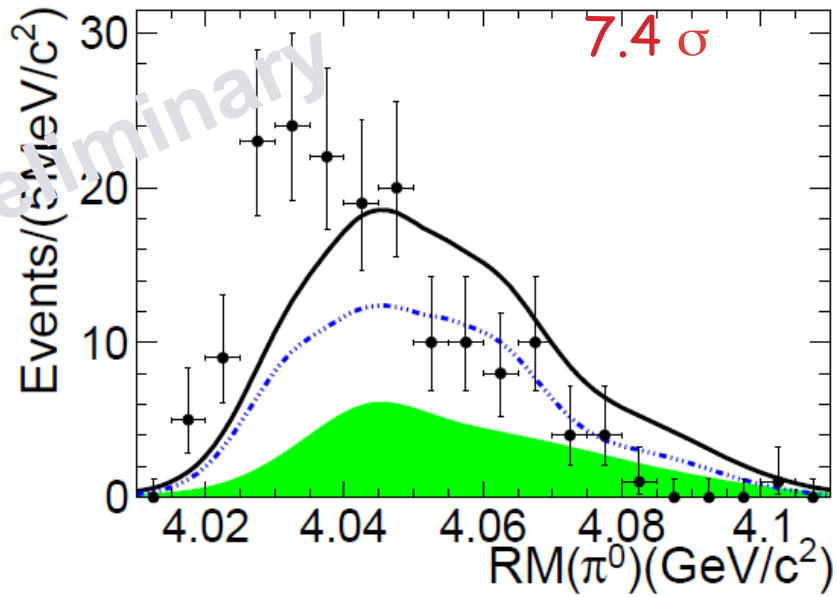
$DD^*\pi^0$

$Z_c(4025)^0$

signal + PHSP + background



PHSP + background

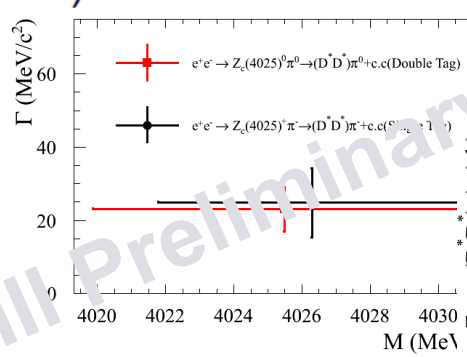


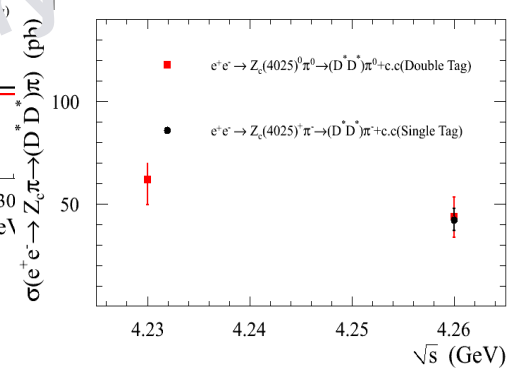
$M = 4025.5^{+2.0}_{-4.7} \pm 3.1$ MeV

$\Gamma = 23.0 \pm 6.0 \pm 1.0$ MeV

$\sigma \times B = 61.6 \pm 8.2 \pm 9.0$ pb 4230

$43.4 \pm 8.0 \pm 5.4$ pb 4260





$Z_c(3885)^{\pm}$: CONFIRMATION

- **Partial reconstruction, double D tag:**
  - $e^+e^- \rightarrow \pi^+(D^0 D^{*-})/\pi^+(D^- D^{*0})$ + c.c.

    $D^{*-} \rightarrow D^0\pi^-$, $D^{*0} \rightarrow D^0\pi^0$

$D^0 \rightarrow K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$, $K^-\pi^+\pi^+\pi^-\pi^0$ (~30%)

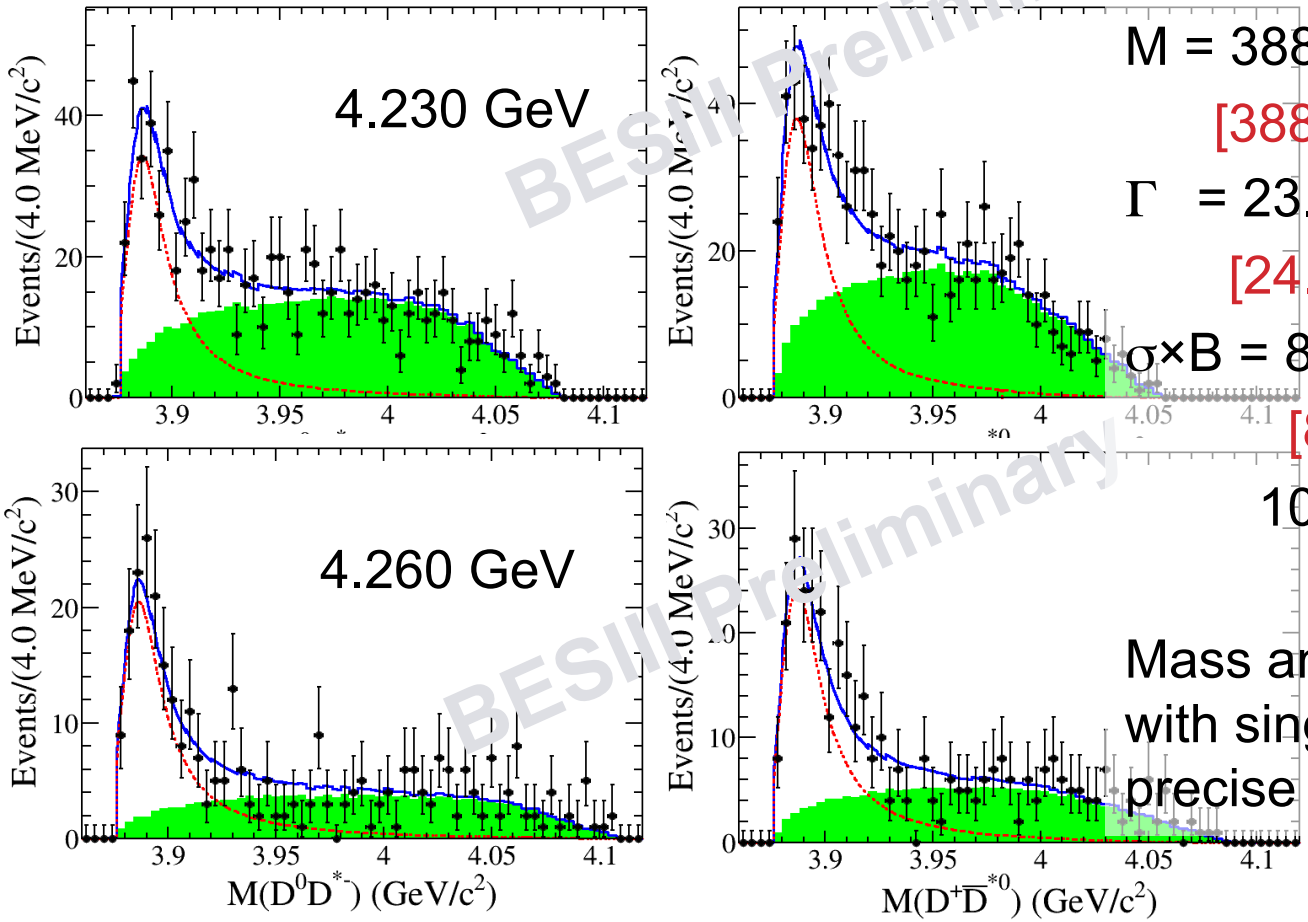
$D^- \rightarrow K^+\pi^-\pi^-$, $K^+\pi^-\pi^-\pi^0$, $K_S^0\pi^-$, $K_S^0\pi^-\pi^0$, $K_S^0\pi^+\pi^-\pi^-$, $K^+K^-\pi^-$ (~36%)

  - Presence of π from D* decay using momentum conservation
  - Tagged bachelor π not from D* decay
  - Require recoil of πD to select D*
- **1.9 fb^{-1} data at $\sqrt{s}$=4.230 and 4.260 GeV**

$Z_c(3885)^{\pm}$: CONFIRMATION

Signal: mass dependent BW

Background: shape from PHSP MC simulation



M = 3884.3±1.2±1.5 MeV

[3883.9±1.5±4.2]

Γ = 23.8±2.1±2.6 MeV

[24.8±3.3±11.0]

$\sigma\times B$ = 88.0±6.1±7.9 pb 4260

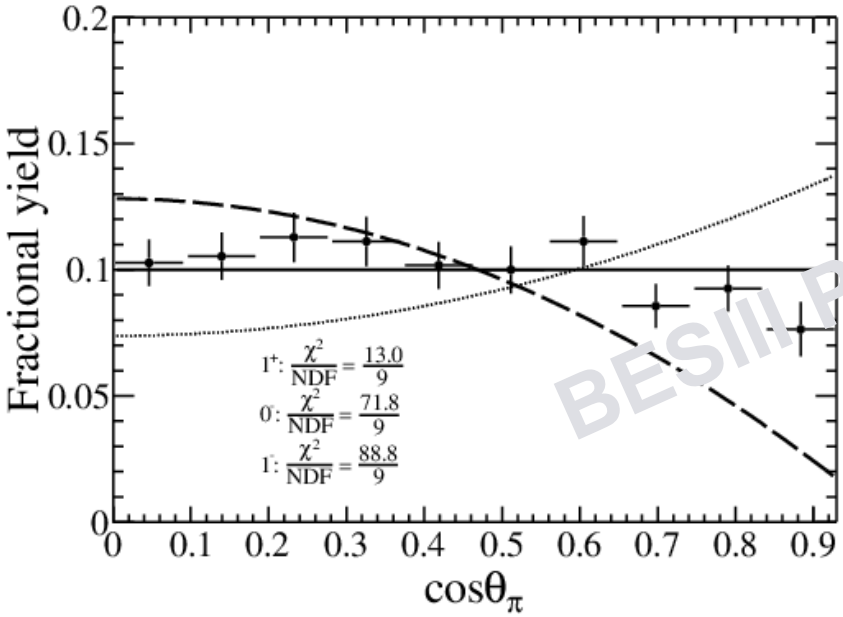
[85.3±6.6±22.0]

106.8±7.1±9.5 pb 4230

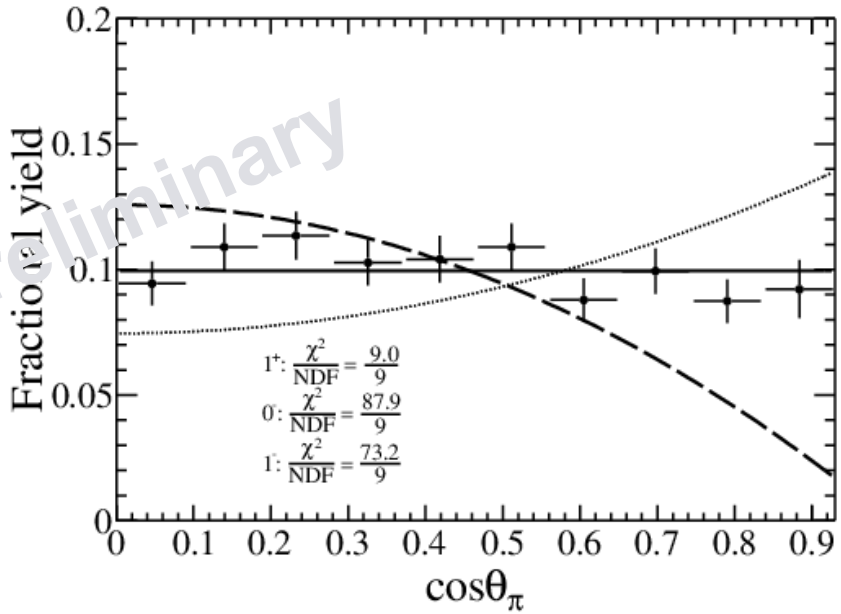
Mass and width consistent with single tag result, more precise

$Z_c(3885)^{\pm}$: CONFIRMATION

$e^+e^- \rightarrow \pi^+(D^0D^{*-})$.



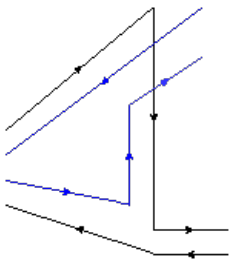
$e^+e^- \rightarrow \pi^+(D^-D^{*0})$.



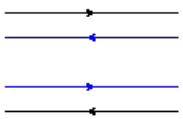
- **Dots with error bars: combined data**
  - solid: $J^P=1^+$; dashed: $J^P=0^-$; dotted: $J^P=1^-$
- **Data agrees with $J^P=1^+$ and disagrees with $J^P=0^-/1^-$**

$Z_c(3900)$ SEARCH IN $\omega\pi^{\pm}$

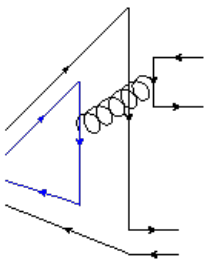
Explore new decay modes is crucial to identify the near threshold structures:



Hidden charm



Open charm

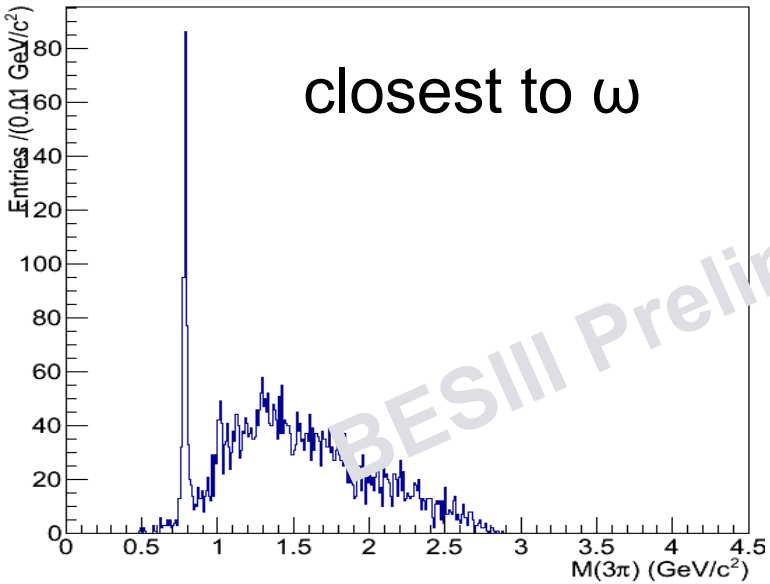


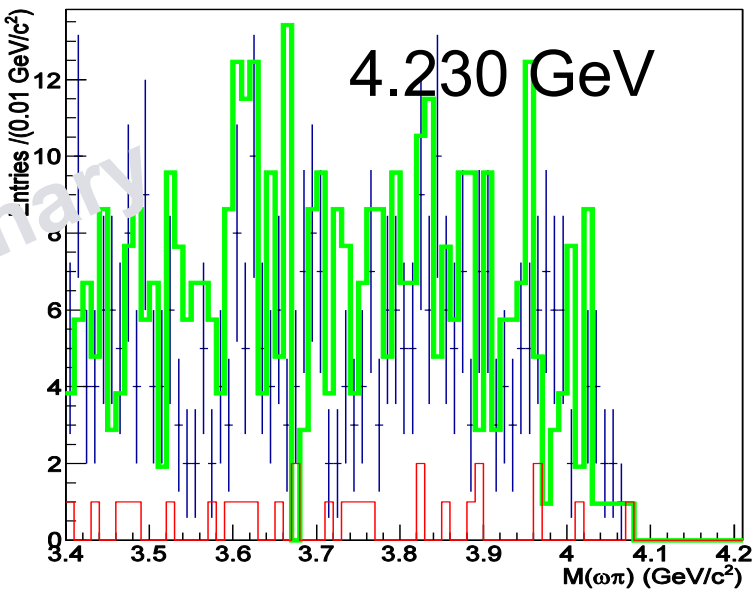
Annihilation to light hadrons is a unique signature

Threshold effect involved

- $e^+e^- \rightarrow \omega\pi^+\pi^-$
- 1.9 fb^{-1} data at $\sqrt{s}$=4.230 and 4.260 GeV

$Z_c(3900)$ SEARCH IN $\omega\pi^{\pm}$



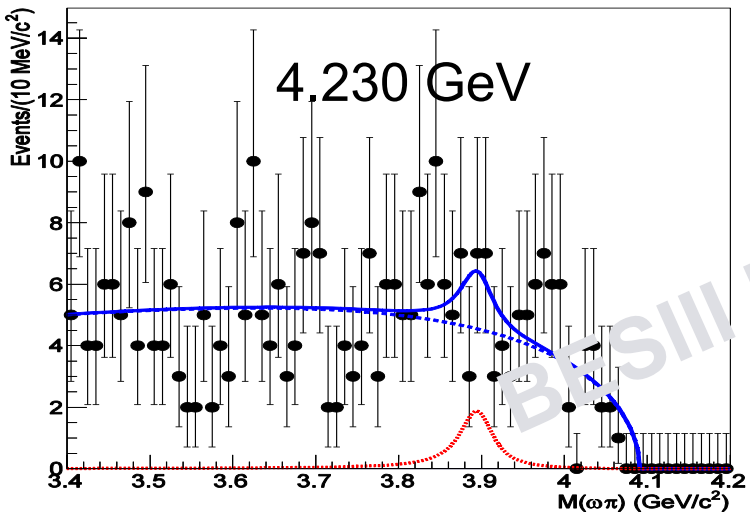


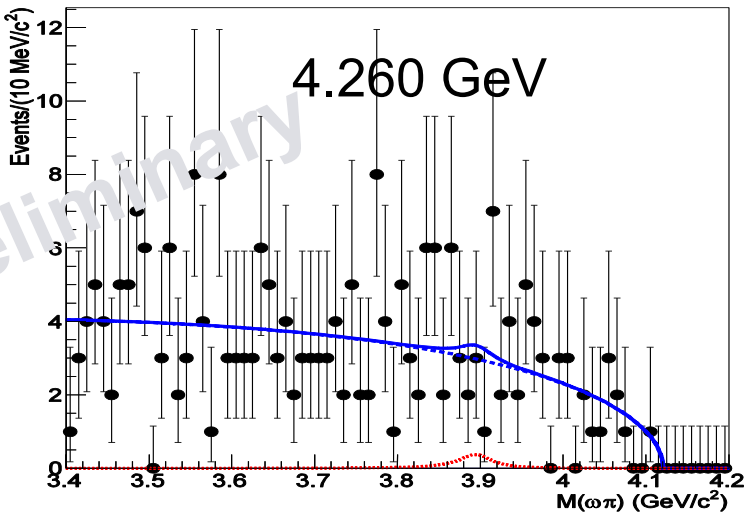
The dots with error bars: $M(\omega\pi^{\pm})$ from data in ω signal region

The red histogram: same distribution in ω sidebands region

The green histogram: backgrounds from inclusive MC sample, dominant from continuum

$Z_c(3900)$ SEARCH IN $\omega\pi^{\pm}$





Fit without interference:

Signal: acceptance weighted S-wave BW folded with Gaussian

Background: ARGUS

No significant $Z_c \rightarrow \omega\pi$ is observed :

$\sigma(e^+e^- \rightarrow Z_c\pi,\ Z_c \rightarrow \omega\pi) < 0.27$ pb

$\sigma(e^+e^- \rightarrow Z_c\pi,\ Z_c \rightarrow \omega\pi) < 0.18$ pb

SUMMARY OF Z_c STATES

State	Mass (MeV/c^2)	Width (MeV)	Note
$Z_c(3900)^{\pm,0}$	3899.0±3.6±4.9	46±10±20	BESIII, $\pi^{\pm}J/\psi$
	3894.5±6.6±4.5	63±24±26	Belle, $\pi^{\pm}J/\psi$
	3886±4±2	37±4±8	CLEO-c*, $\pi^{\pm}J/\psi$
	3883.9±1.5±4.2	24.8±3.3±11.0	BESIII, DD* single tag
	3884.3±1.2±1.5	23.8±2.1±2.6	BESIII, DD* double tag
	3904±9±5	--	CLEO-c*, π^0J/ψ
	3894.8±2.3±2.7	29.6±8.2±8.2	BESIII, π^0J/ψ
$Z_c(4020)^{\pm,0}$ BESIII	4022.9±0.8±2.7	7.9±2.7±2.6	$\pi^{\pm}h_c$
	4026.3±2.6±2.7	24.8±5.6±7.7	$(D^*D^*)^{\pm}$, single tag
	4023.6±2.3±3.9	-	π^0h_c
	$4025.5^{+2.0}_{-4.7}\pm3.1$	23.0±6.0±1.0	$(D^*D^*)^0$, double tag

SUMMARY

- A group of charge charmonium-like states has been observed
  - at least four quarks
  - mass close charm meson pair threshold
- Neutral partners of $Z_c(3900)$, $Z_c(4020)$, and $Z_c(4025)$ have been observed, make them isospin triplet stats
- $Z_c(3900)/Z_c(3885)$ only observed in $\pi J/\psi/DD^*$, not in $\pi h_c/D^*D^*$, while $Z_c(4020)/Z_c(4025)$ only in $\pi h_c/D^*D^*$
- Light hadronic final state $\omega\pi$ study shows no evidence of of $Z_c(3900)$
- More experimental effort is need to help understand their nature
  - product and decay modes study
  - quantum number determination

THANKS FOR THE ATTENTION!