XVI International Conference on Hadron Spectroscopy

Exotic Z_c states at BESIII

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Outline

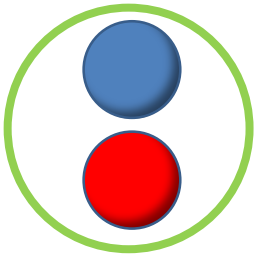
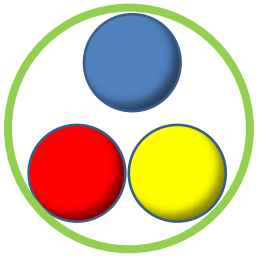
- Introduction
- Charged Z_c states at BESIII

  ($Z_c(3900)^{\pm}$, $Z_c(3885)^{\pm}$, $Z_c(4020)^{\pm}$, $Z_c(4025)^{\pm}$)
- Neutral Z_c states at BESIII

  ($Z_c(3900)^0$, $Z_c(3885)^0$, $Z_c(4020)^0$, $Z_c(4025)^0$)
- Summary and Outlook

Hadrons: normal & exotic

- **Conventional hadrons** are composed from 2 (meson) or 3 (baryon) quarks

Naive Quark model: meson  baryon 

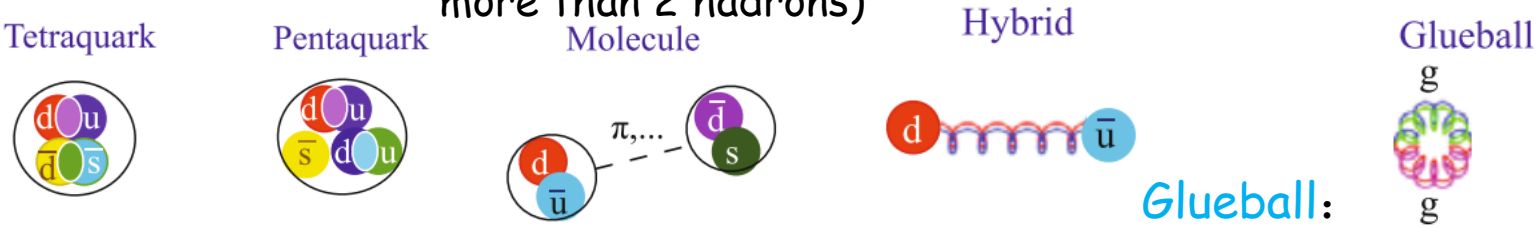
- **QCD allows** hadrons with $N_{quarks} \neq 2, 3$

Exotic States:

Multiquark state: ($N_{quarks} > 3$)

Molecule: (bound state of more than 2 hadrons)

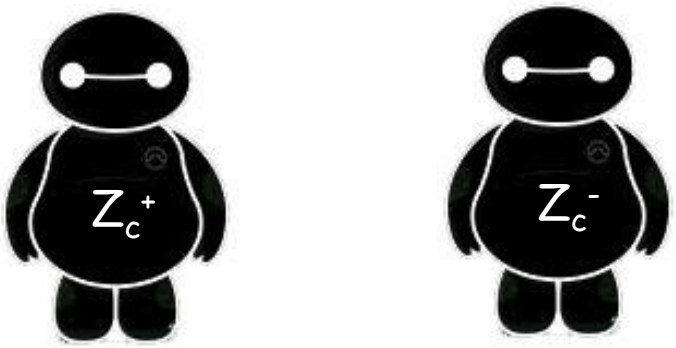
Hybrid: (N_{quarks} = 2 + excited gluon)



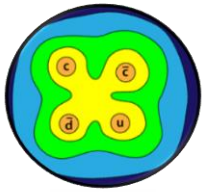
Glueball: (N_{quarks} = 0 (gg, ggg, ...))

diquark-diantiquark diquark-diquark-antiquark

S. L. Olsen, Front. Phys. 10, 101401 (2015)

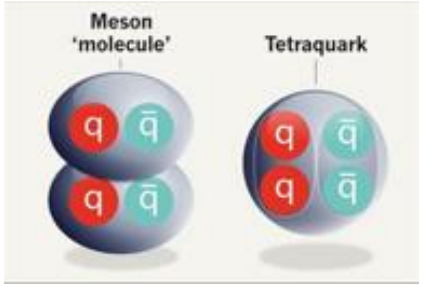


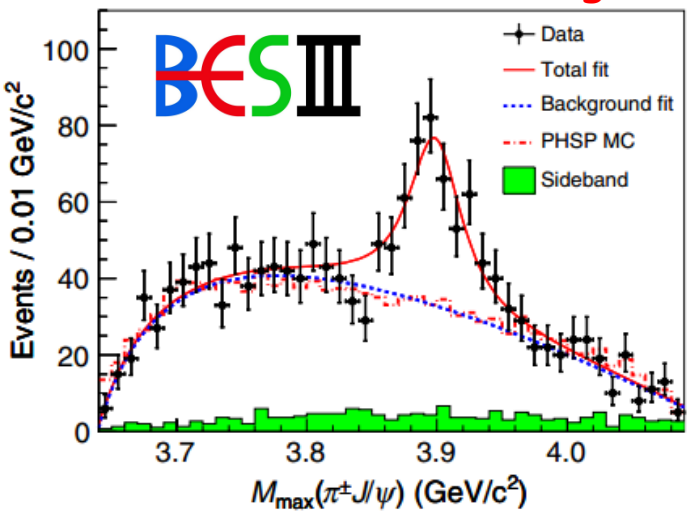
Charged Z_c States at BESIII



Discovery of $Z_c(3900)^{\pm}$

Charged charmonium-like structure





Phys. Rev. Lett. **110**, 252001 (2013)

- Decay to J/ψ → contains $c\bar{c}$
- Electric charge → contains $u\bar{d}$

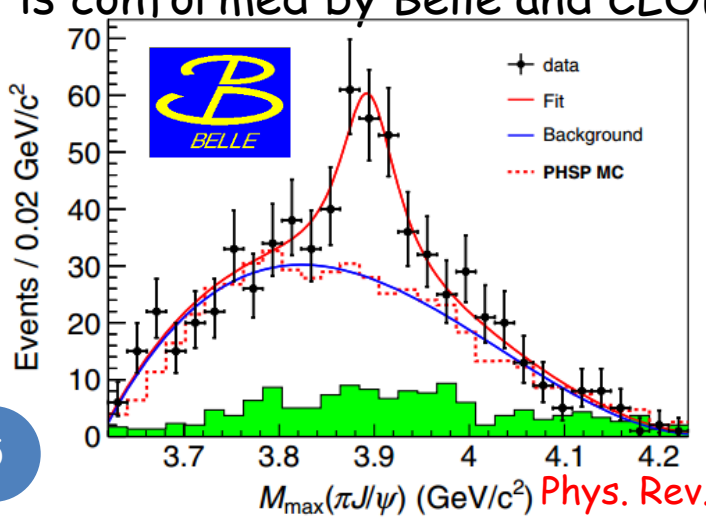
m = (3899.0±3.6±4.9) MeV/c²

Γ = (46±10±20) MeV

$\sigma[e^+e^- \to \pi^+\pi^- J/\psi\,]$ = (62.9±1.9±3.7) pb @4.26 GeV

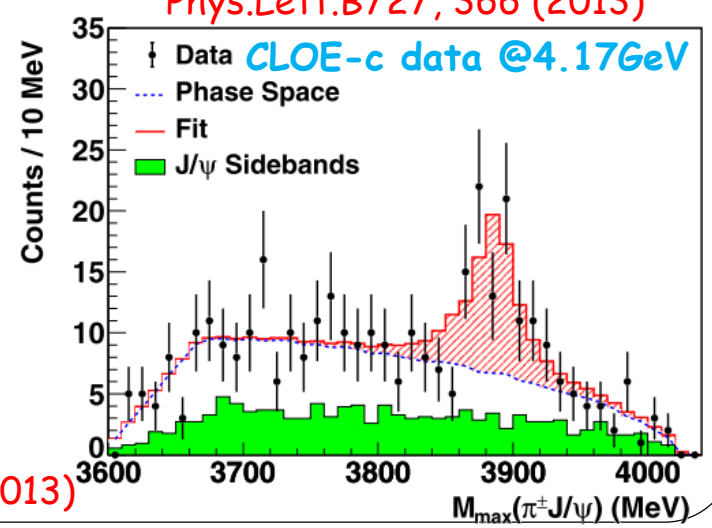
$$\frac{\sigma[e^+e^- \to \pi^{\pm} Zc(3900)^{\mp} \to \pi^+\pi^- J/\psi]}{\sigma[e^+e^- \to \pi^+\pi^- J/\psi\,]} = (21.5 \pm 3.3 \pm 7.5)\%$$

It is conformed by Belle and CLOE-c data

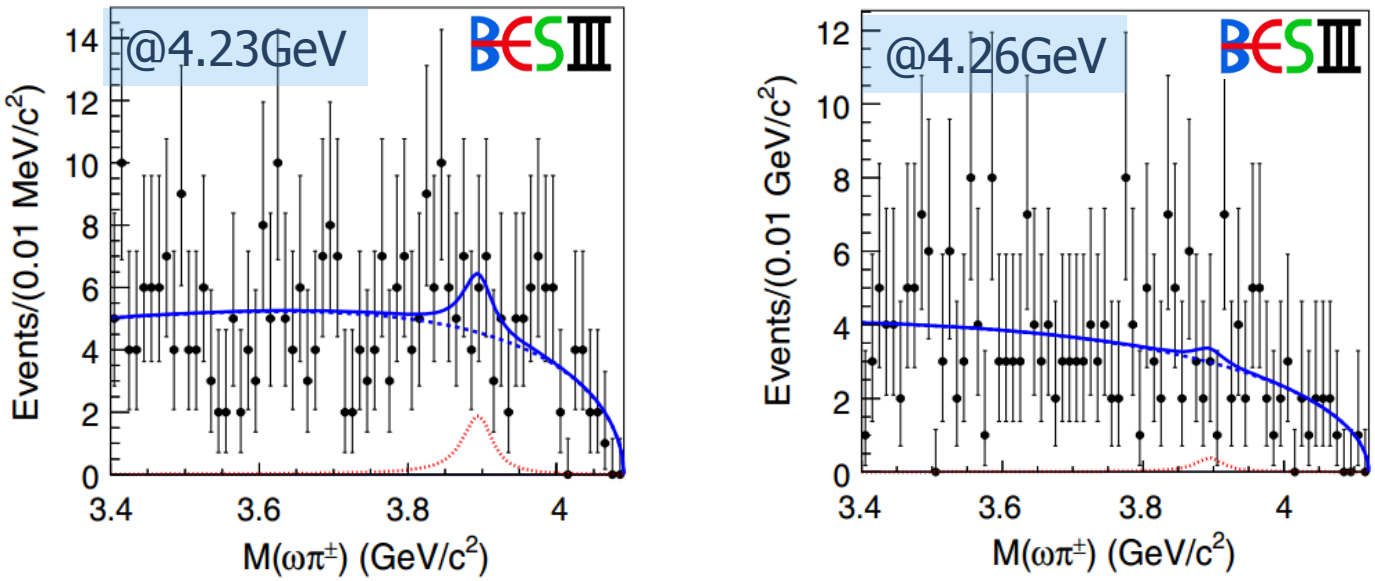


Phys. Rev. Lett. **110**, 252001 (2013)

Phys.Lett.B727, 366 (2013)



Search for $Z_c(3900)^{\pm} \rightarrow$ light hadrons



Phys. Rev. D**92**, 032009 (2015)

No significant $Z_c \rightarrow \omega\ \pi$

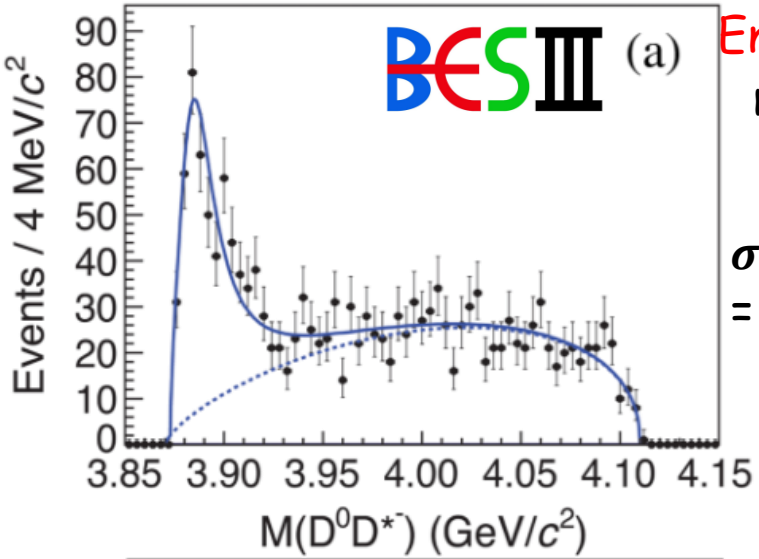
$\sigma[e^+e^- \rightarrow \pi^{\pm} Z_c\,(3900)^{\mp}, Z_c\,(3900) \rightarrow \omega\pi] <$ 0.26 pb @4.23 GeV

$\sigma[e^+e^- \rightarrow \pi^{\pm} Z_c\,(3900)^{\mp}, Z_c\,(3900) \rightarrow \omega\pi] <$ 0.18 pb @4.26 GeV

$\mathrm{Br}(Z_c\,(3900) \rightarrow \omega\pi) <$ 0.2% ($\Gamma_{\omega\pi} < 70\ keV$) @90% C.L.

It may indicate that the annihilation of $c\bar{c}$ in $Z_c(3900)^{\pm}$ is suppressed.

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



Enhancement near $D\bar{D}^*$ mass threshold is observed

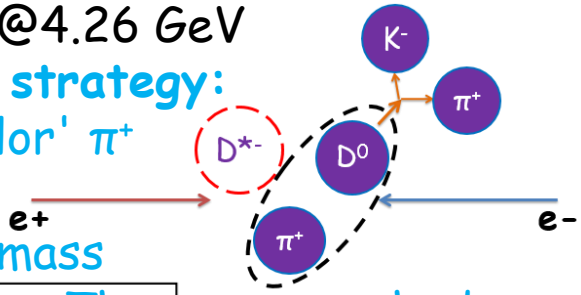
m_{pole} = (3883.9±1.5±4.2) MeV/c²

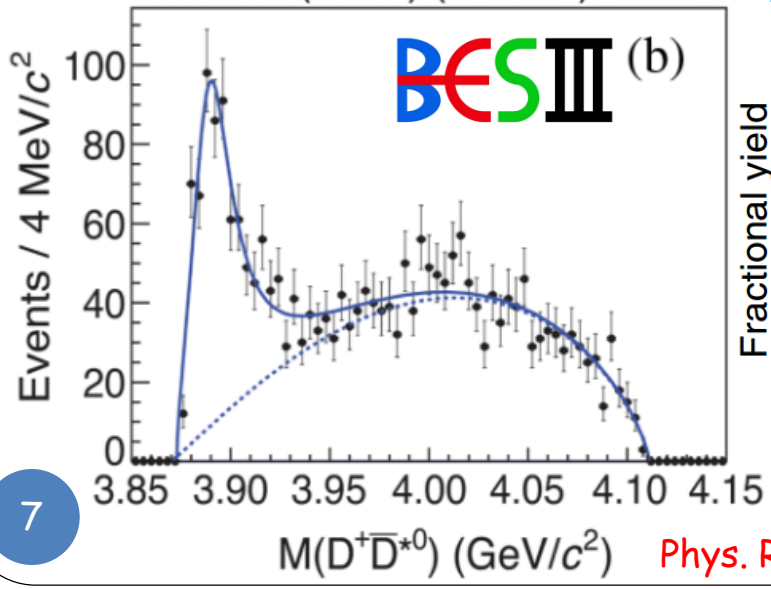
Γ_{pole} = (24.8±3.3±11.0) MeV

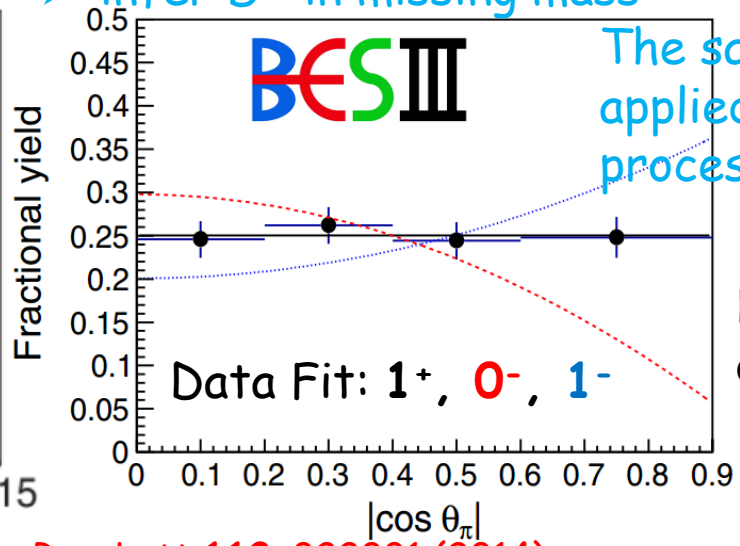
$\sigma[e^+e^- \to Z_c(3885)^{\pm}\pi^{\mp} \to (D\bar{D}^*)^{\pm}\pi^{\mp}]$
= (83.5±6.5±22.0) pb @4.26 GeV

Single D tag analysis strategy:

- reconstruct 'bachelor' π^+
- And $D^0 \to K^-\pi^+$
- infer D^{*-} in missing mass







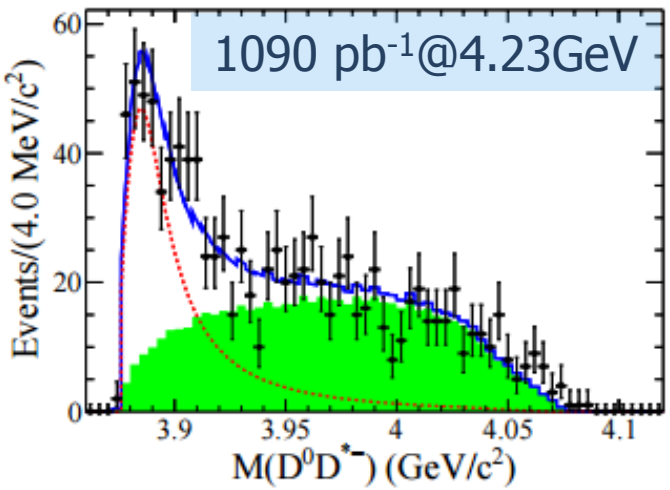
The same method applied in the $D^+\bar{D}^{*0}\pi^-$ process

Data favors $J^P=1^+$ over 0^- and 1^-

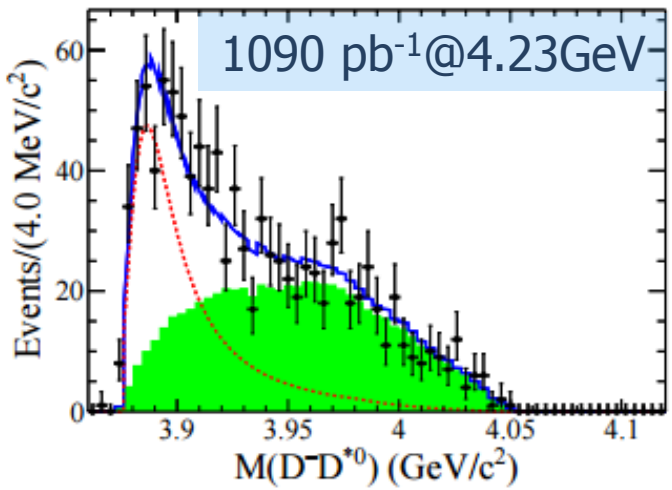
Phys. Rev. Lett **112**, 022001 (2014)

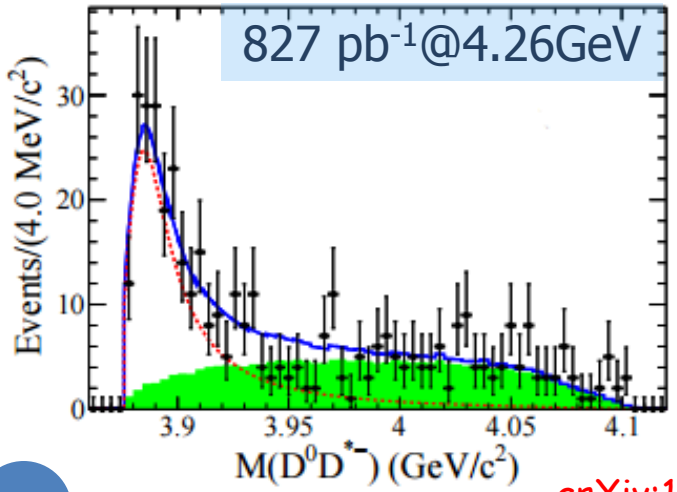
Observation of $Z_c(3885)^{\pm}$ in $e^+e^- \to (D\bar{D}^*)^{\pm}\pi^{\mp}$ using double D tag method

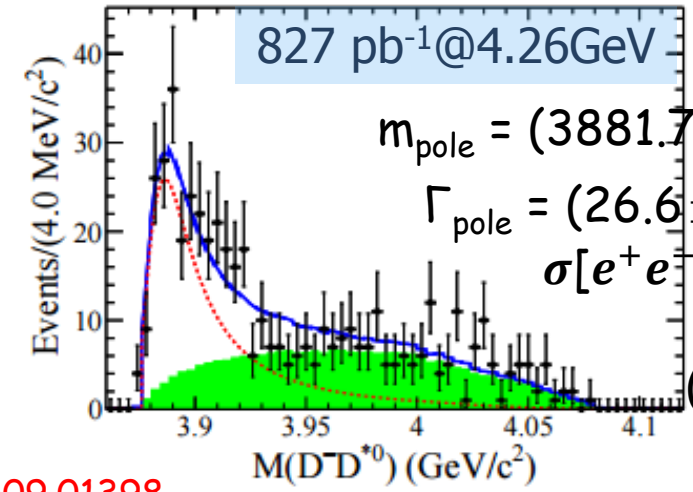
$e^+e^- \to \pi^+ D^0 D^{*-}$



$e^+e^- \to \pi^+ D^- D^{*0}$







New!

Double D tag analysis strategy: Tag 'bachelor' π^+ and two D mesons

m_{pole} = (3881.7 ± 1.6 ± 2.1) MeV/c^2

Γ_{pole} = (26.6 ± 2.0 ± 2.3) MeV

$\sigma[e^+e^- \to Z_c(3885)^{\pm}\pi^{\mp} \to (D\bar{D}^*)^{\pm}\pi^{\mp}]$ = (108.4 ± 6.9 ± 9.1) pb @4.26 GeV

arXiv:1509.01398

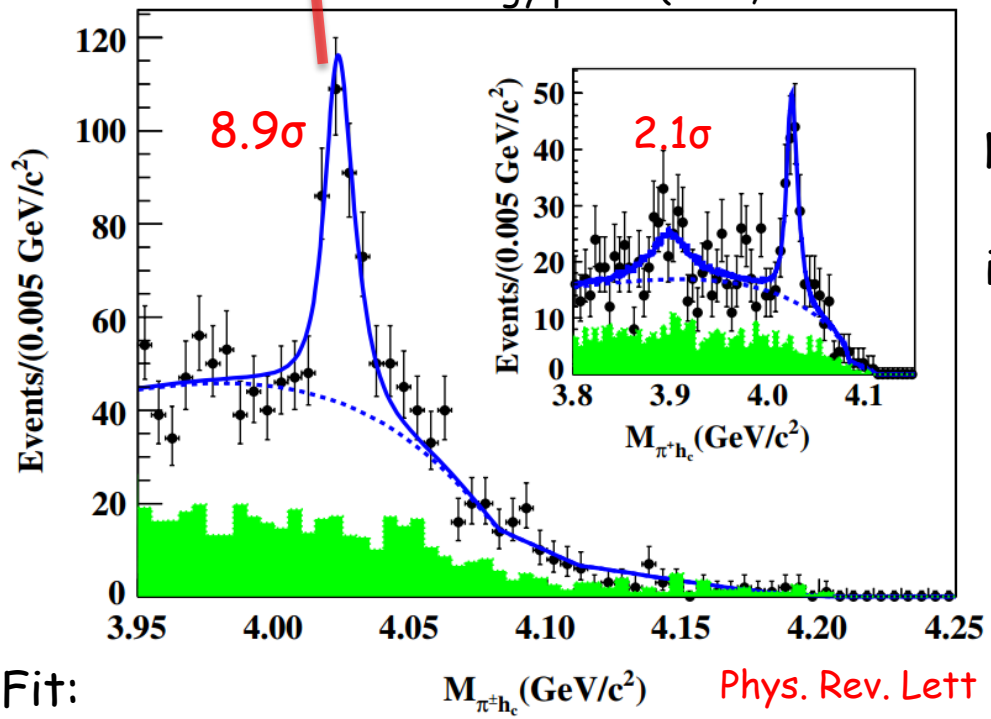
The measured m_{pole}, Γ_{pole}, σ and J^P are consistent with single D tag results.

Observation of $Z_c(4020)^{\pm}$ in $e^+e^- \to \pi^+\pi^- h_c$

Charged charmonium-like structure

$h_c \to \gamma\eta_c$
$\eta_c \to X_i$, X_i signifies 16 hadronic decay modes

summed over data at all energy points(4.23, 4.26&4.36 GeV)



No significant $Z_c(3900)^{\pm} \to \pi^{\pm} h_c$ is observed.

Simultaneous Fit:

Phys. Rev. Lett **111**, 242001 (2013)

m = (4022.9±0.8±2.7) MeV/c² Γ = (7.9±2.7±2.6) MeV

$\sigma[e^+e^- \to \pi^{\pm} Z_c(4020)^{\mp} \to \pi^+\pi^- h_c]$ = (8.7±1.9±2.8±1.4) pb @4.23 GeV

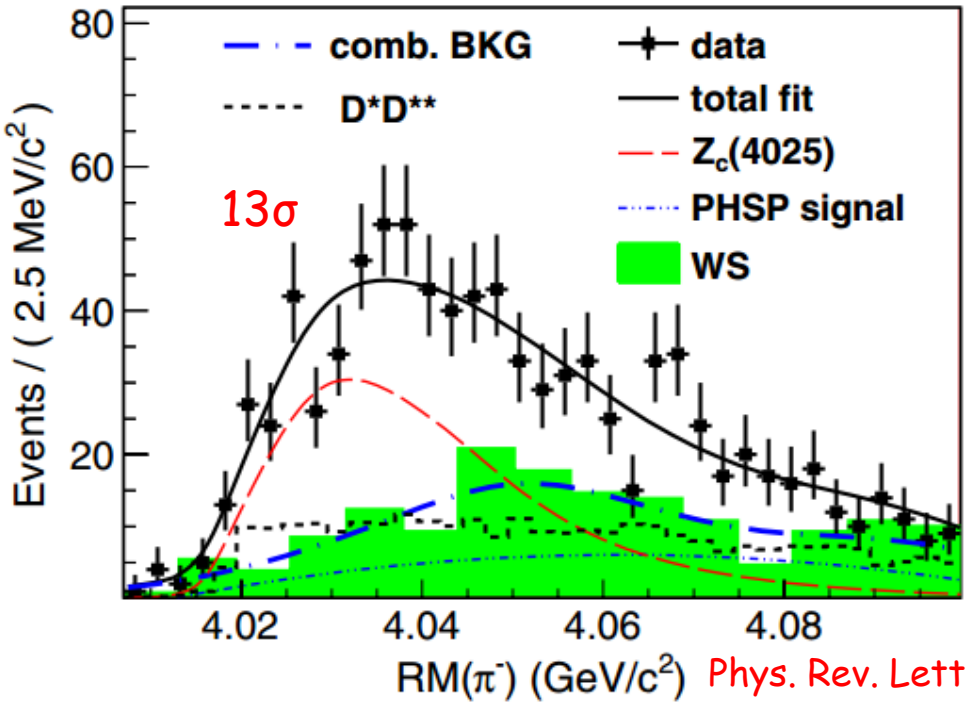
$\sigma[e^+e^- \to \pi^{\pm} Z_c(4020)^{\mp} \to \pi^+\pi^- h_c]$ = (7.4±1.7±2.1±1.2) pb @4.26 GeV

$\sigma[e^+e^- \to \pi^{\pm} Z_c(4020)^{\mp} \to \pi^+\pi^- h_c]$ = (10.3±2.3±3.1±1.6) pb @4.36 GeV

stat. sys. Br.

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

A structure near $D^*\bar{D}^*$ mass threshold is observed



Phys. Rev. Lett **112**, 132001 (2014)

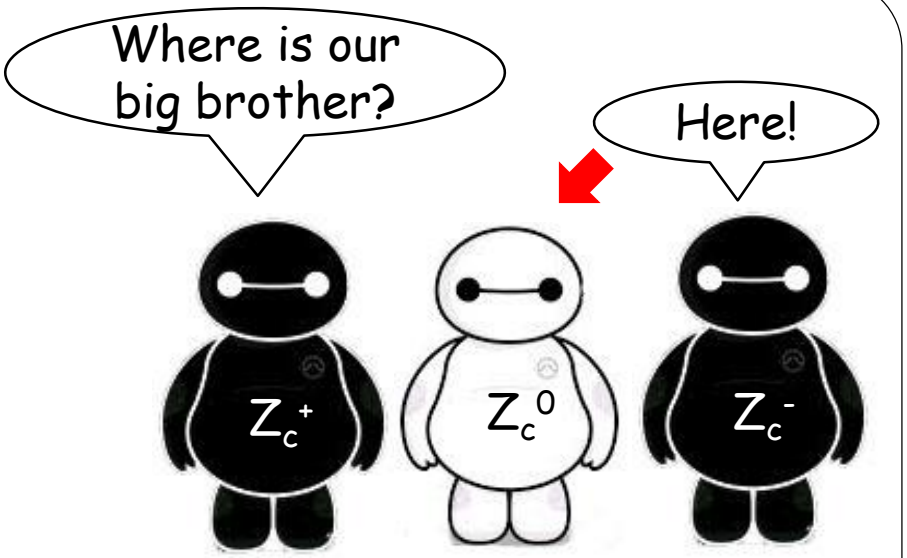
Single D tag analysis strategy:

- Tag $D^+ \to K^-\pi^+\pi^+$
- Reconstruct 'bachelor' π^-
- reject backgrounds from $e^+e^- \to D^{(*)}\bar{D}^{(*)}$
- Require an additional π^0 to suppress the background
- use signature in the recoiling mass against $D^+\pi^-$ to identify the process $e^+e^- \to D^{*+}\bar{D}^{*0}\pi^-$

m = (4026.3±2.6±3.7) MeV/c² Γ = (24.8±5.6±7.7) MeV

$\sigma[e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}]$ = (137±9±15) pb @4.26 GeV

$$\frac{\sigma[e^+e^- \to Z_c(4025)^{\pm}\pi^{\mp} \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}]}{\sigma[e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}]} = (65\pm9\pm6)\% \text{ @4.26GeV}$$

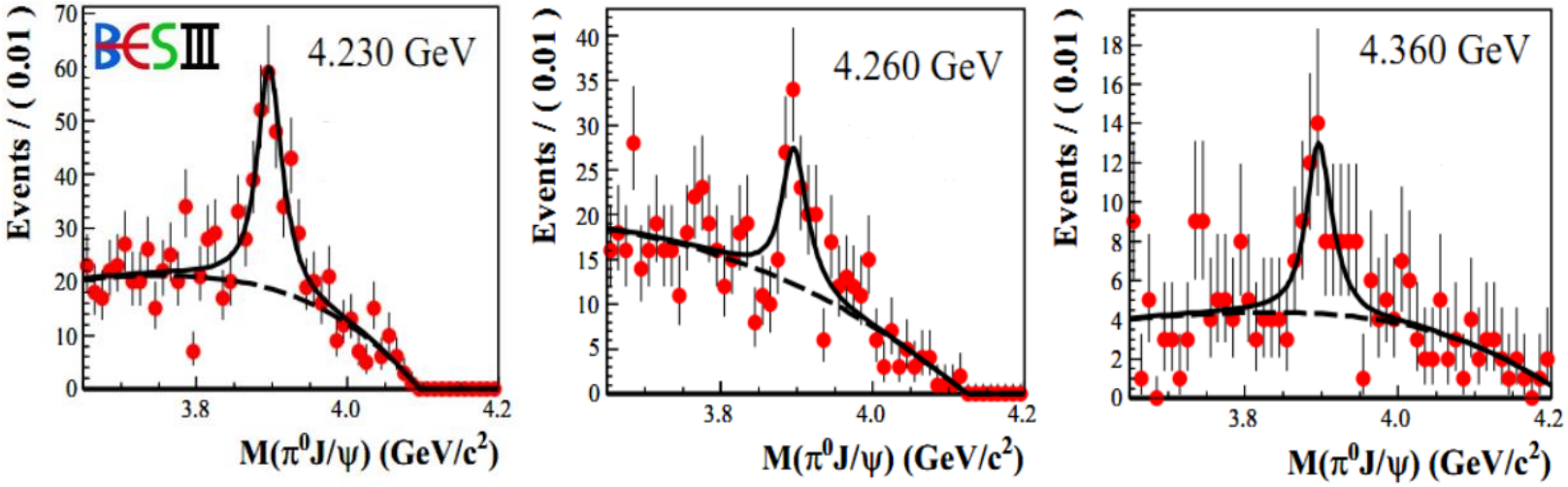


Neutral Z_c States at BESIII

?

Isospin partner

Observation of $Z_c(3900)^0$



arXiv:1506.06018, accepted by PRL

Study $e^+e^- \to \pi^0\pi^0 J/\psi$ at different E_{cm}

Simultaneous Fit:

$m = (3894.8 \pm 2.3 \pm 2.7)$ MeV/c^2

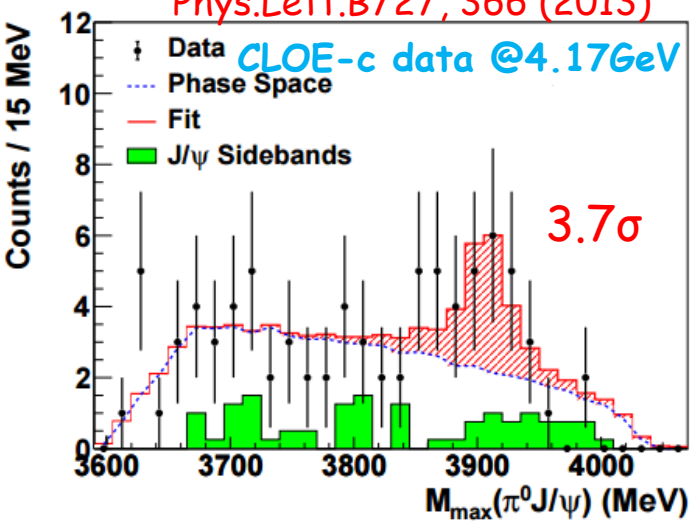
$\Gamma = (29.6 \pm 8.2 \pm 8.2)$ MeV

Significance: 10.4σ

$Z_c(3900)^{\pm/0}$

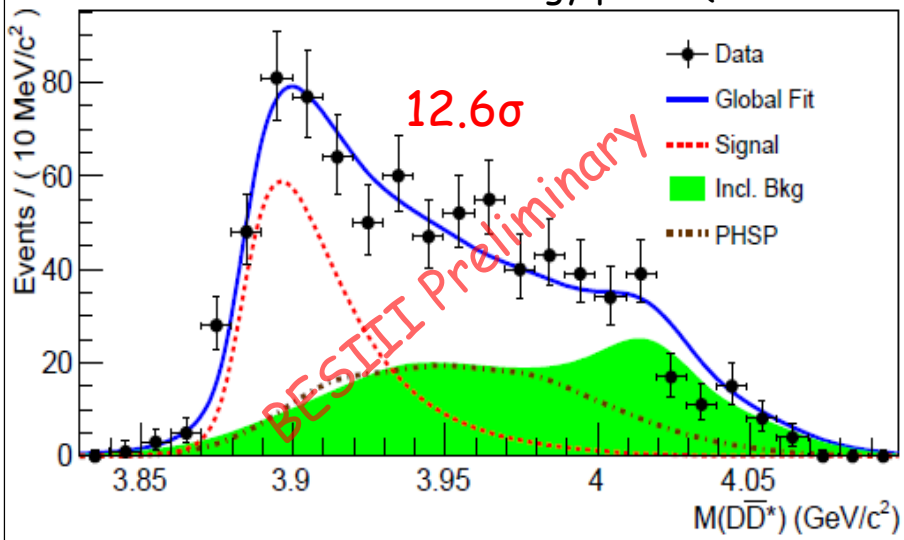
Isospin triplet is established

Phys.Lett.B727, 366 (2013)



Observation of $Z_c(3885)^0$ in $e^+e^- \to (D\bar{D}^*)^0\pi^0$

summed over data at all energy points(4.23&4.26 GeV)



$m_{pole} = (3885.7^{+4.3}_{-5.7} \pm 8.4)$ MeV/c^2

$\Gamma_{pole} = (35^{+11}_{-12} \pm 15)$ MeV

$\sigma[e^+e^- \to Z_c(3885)^0\pi^0 \to (D\bar{D}^*)^0\,\pi^0]$

= $(77 \pm 13 \pm 17)$ pb @4.23 GeV

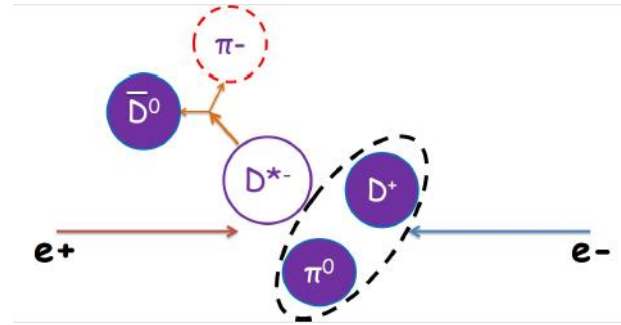
$\sigma[e^+e^- \to Z_c(3885)^0\pi^0 \to (D\bar{D}^*)^0\,\pi^0]$

= $(47 \pm 9 \pm 10)$ pb @4.26 GeV

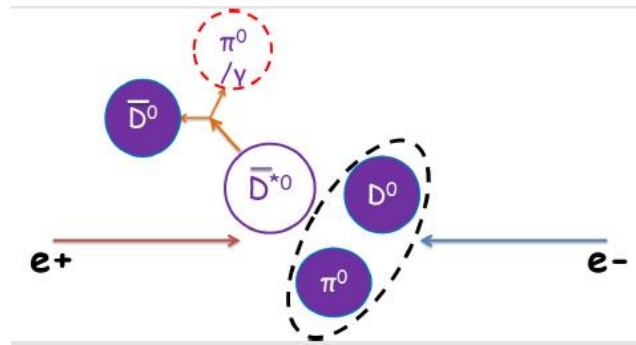
Another isospin triplet is established

$Z_c(3885)^{\pm/0}$

Double D tag analysis strategy:



$e^+e^- \to D^+D^{*-}\pi^0 \to D^+\bar{D}^0\pi^-\pi^0$

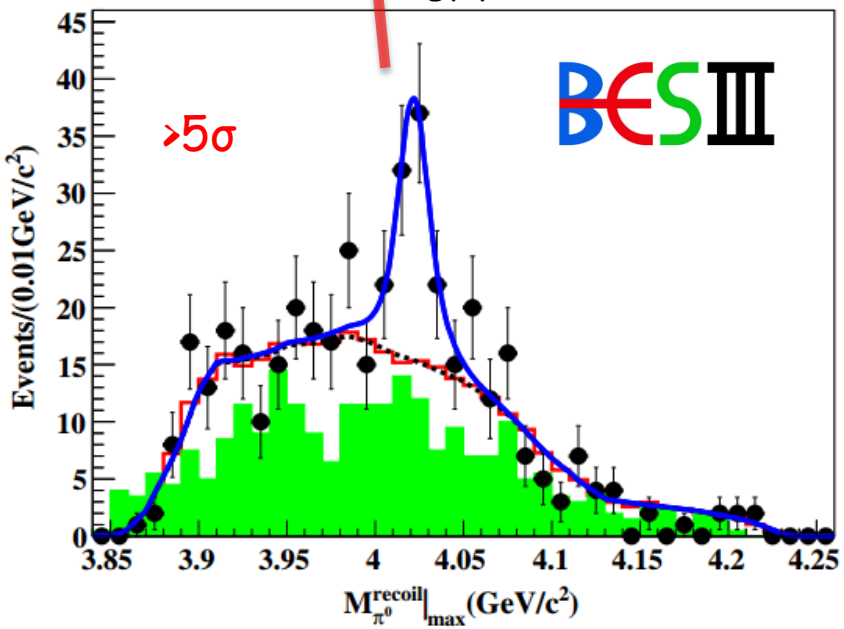


$e^+e^- \to D^0\bar{D}^{*0}\pi^0 \to D^0\bar{D}^0\pi^0\pi^0$

Observation of $Z_c(4020)^0$ in $e^+e^- \to \pi^0\pi^0 h_c$

Narrow neutral structure on $\pi^0 h_c$ mass spectrum

summed over data at all energy points(4.23, 4.26 & 4.36 GeV)



Phys. Rev. Lett **113**, 212002 (2014)

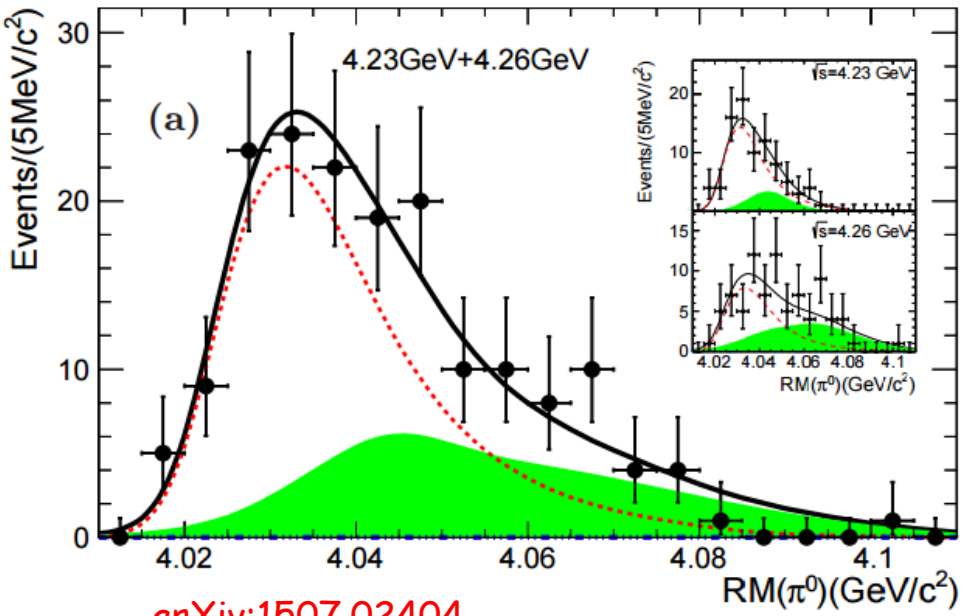
m = (4023.9±2.2±3.8) MeV/c²

Γ is fixed to be same as its charged partner $Z_c(4020)^{\pm}$

Cross sections for $e^+e^- \to \pi^+\pi^- h_c$ and $e^+e^- \to \pi^0\pi^0 h_c$ are consistent with isospin conservation!

Isospin triplet is established $Z_c(4020)^{\pm/0}$

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



arXiv:1507.02404

$m_{pole} = (4025.5^{+2.0}_{-4.7} \pm 3.1)$ MeV/c^2

$\Gamma_{pole} = (23.0 \pm 6.0 \pm 1.0)$ MeV

$\sigma[e^+e^- \to Z_c(3885)^0\pi^0 \to (D\bar{D}^*)^0\,\pi^0]$

= $(61.6 \pm 8.2 \pm 9.0)$ pb @4.23 GeV

$\sigma[e^+e^- \to Z_c(3885)^0\pi^0 \to (D\bar{D}^*)^0\,\pi^0]$

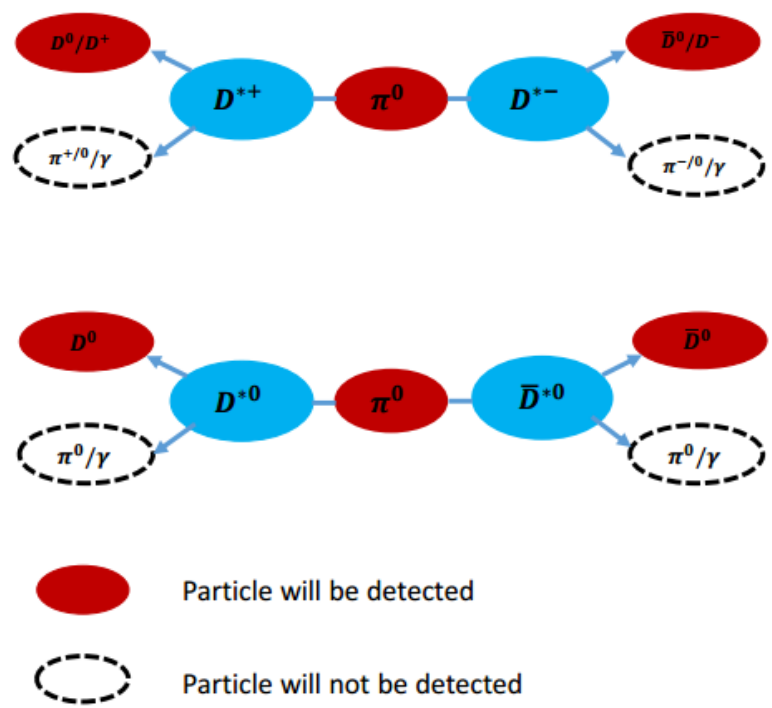
= $(43.4 \pm 8.0 \pm 5.4)$ pb @4.26 GeV

Another isospin triplet is established

$Z_c(4025)^{\pm/0}$

New!

Double D tag analysis strategy:



Summary of Z_c states at BESIII

State	Mass (MeV/c^2)	Width (MeV)	Decay	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	$24.8 \pm 3.3 \pm 11.0$ Single D tag	$(D\bar{D}^*)^{\pm}$	$e^+e^- \to (D\bar{D}^*)^{\pm}\pi^{\mp}$
	$3881.7 \pm 1.6 \pm 2.1$ Double D tag	$26.6 \pm 2.0 \pm 2.3$ Double D tag	$(D\bar{D}^*)^{\pm}$	$e^+e^- \to (D\bar{D}^*)^{\pm}\pi^{\mp}$
$Z_c(3885)^0$	$3885.7^{+4.3}_{-5.7} \pm 8.4$ (preliminary)	$35^{+11}_{-12} \pm 15$	$(D\bar{D}^*)^0$	$e^+e^- \to (D\bar{D}^*)^0\pi^0$
$Z_c(4020)^{\pm}$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	$\pi^{\pm} h_c$	$e^+e^- \to \pi^+\pi^- h_c$
$Z_c(4020)^0$	$4023.9 \pm 2.2 \pm 3.8$	fixed	$\pi^0 h_c$	$e^+e^- \to \pi^0\pi^0 h_c$
$Z_c(4025)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	$D^*\bar{D}^*$	$e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}$
$Z_c(4025)^0$	$4025.5^{+2.0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$	$D^*\bar{D}^*$	$e^+e^- \to (D^*\bar{D}^*)^0\pi^0$

What's the nature of these Z_c states?

- Tetraquark state?
- $D^{(*)}\bar{D}^{(*)}$molecule state?
- Hadro-charmonium?
- Meson loop?
- FSI?
- ISPE model?
- Cusp?
- …

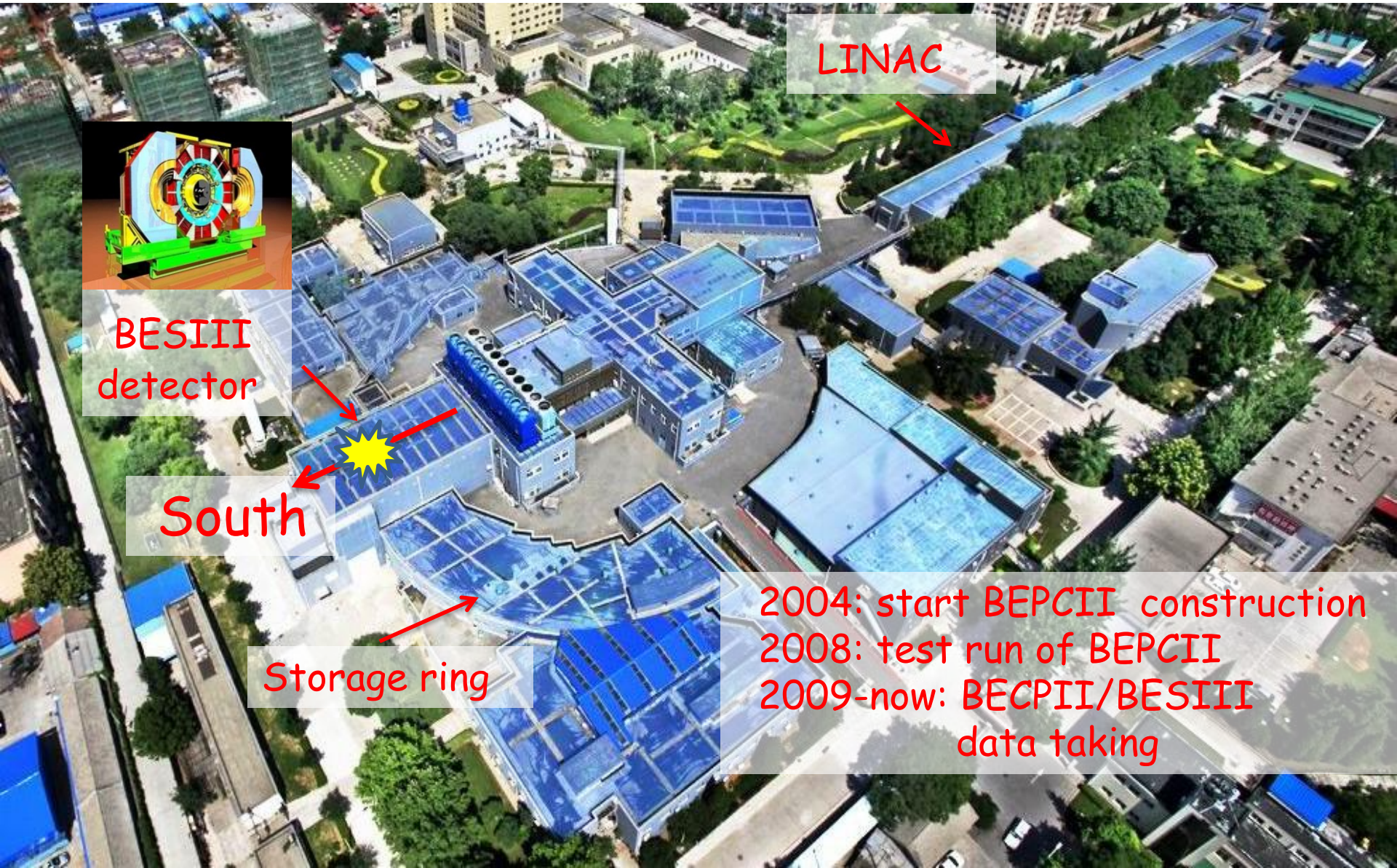
Summary & Outlook

- Recent results of charged and neutral Z_c states (Z_c (3900)$^{\pm/0}$, Z_c (3885)$^{\pm/0}$, Zc (4020)$^{\pm/0}$, Z_c (4025)$^{\pm/0}$) at BESIII are presented.
- Great efforts are needed to understand these Z_c states both by the theorists and experimenters.
- More data are expected to study exotic Z_c states.

  (to pin down their spin-parity, search for other decay modes…)
- More exciting results of BESIII will be coming soon, and new Z_c states will come into a 'zoo' of exotic states.

Back up

Bird view of BEPCII



BESIII detector