The Z_c states at BESIII

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Outline

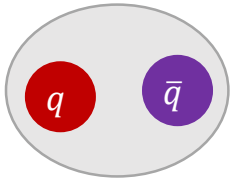
- **Introduction**
  - Hadrons and XYZ states

- **Z_c states at BESIII**
  - BESIII data samples for XYZ study
  - $Z_c(3900)/Z_c(3885)$, $Z_c(4020)/Z_c(4025)$

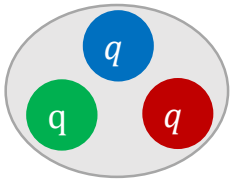
- **Summary**

Constitution of hadrons in QCD

- Quark Model

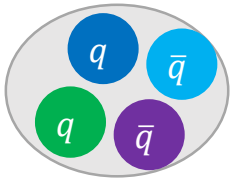


Mesons
Color-anticolor pairs

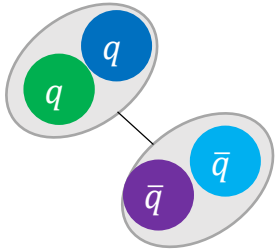


Baryons
Red-blue-green triplets

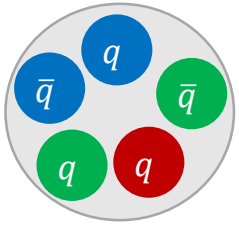
- Exotic states predicted by QCD



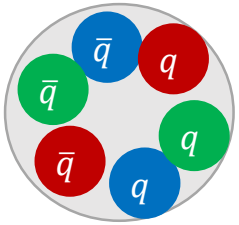
Tetraquark
Tightly bound
diquark&anti-diquark



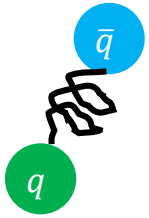
Molecule
Loosely bound
meson&anti-meson



Pentaquark
S=+1



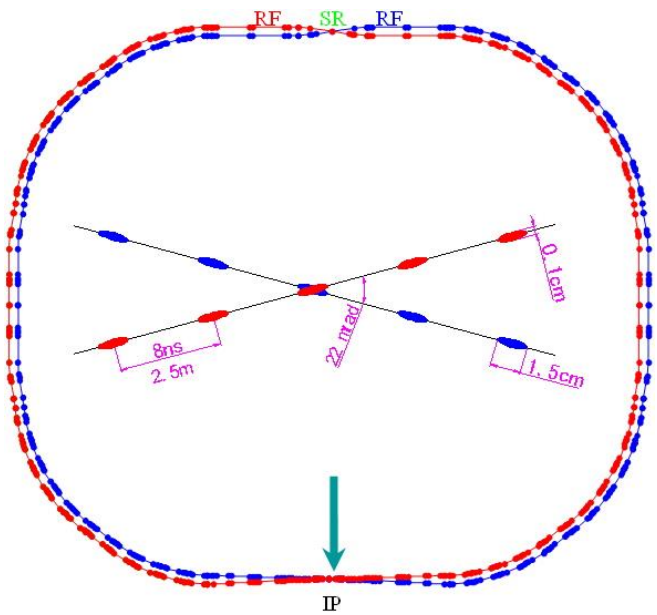
Six-quark state
Tightly bound
6 quarks

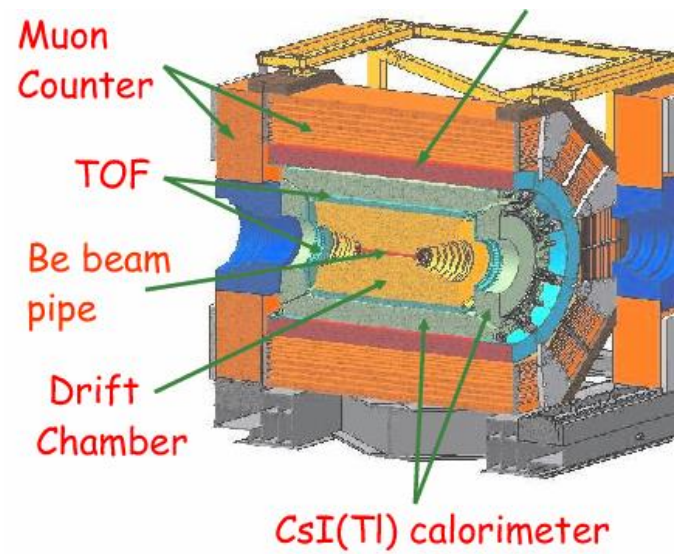


Hybrid
More than 2
quarks and gluon

. . . . . .

BEPCII and BESIII

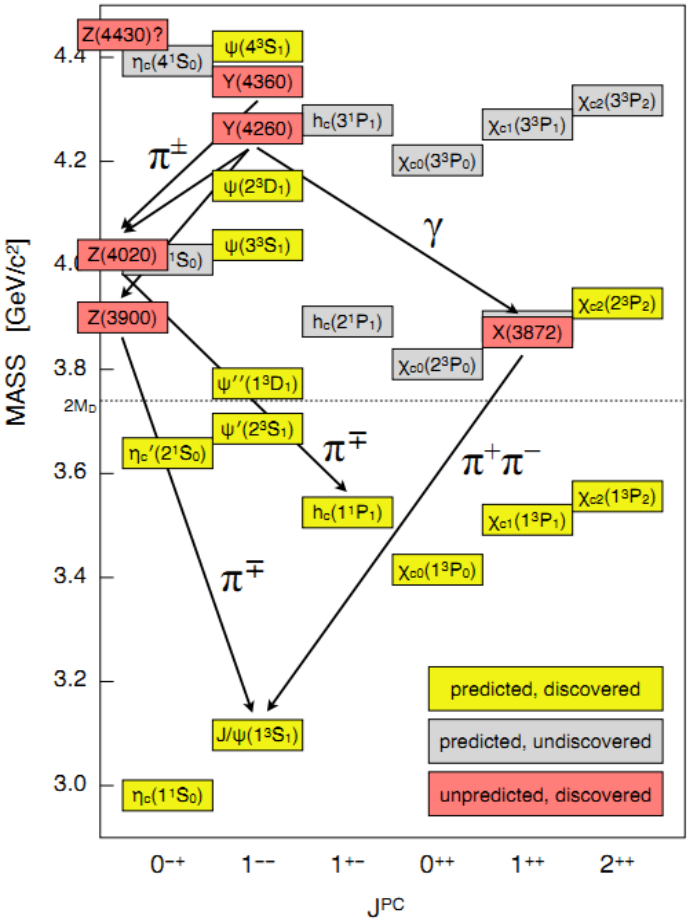




Double ring collider
Beam energy 1~2.3 GeV
Single beam current 0.91 A
Crossing angle: ± 11 mrad
Design luminosity @ψ(3770) = 10^{33} $cm^{-2}s^{-1}$
Achieved on 5th April, 2016
BEMS by Laser Compton back
Scattering $\Delta E/E \approx 5 \cdot 10^{-5}$
Energy spread: $5.16 \cdot 10^{-4}$

MDC: main drift chamber (He 60%, propane 40%) σ(p)/p < 0.5% @ 1 GeV
σ(xy) = 130 μm, 6% dE/dx for MIP pions
TOF: time of flight (two layers plastic scintillator):σ ~ 90ps (barrel)
EMC: CsI (Tl), barrel + 2 end caps: σE/E < 2.5%,σ(x) < 6 cm for 1 GeV
MUC: RPC:σ(x) < 2 cm
Important upgrades in the next future: CGEM, ETOF

Charmonium Spectroscopy



- **Below open charm threshold**

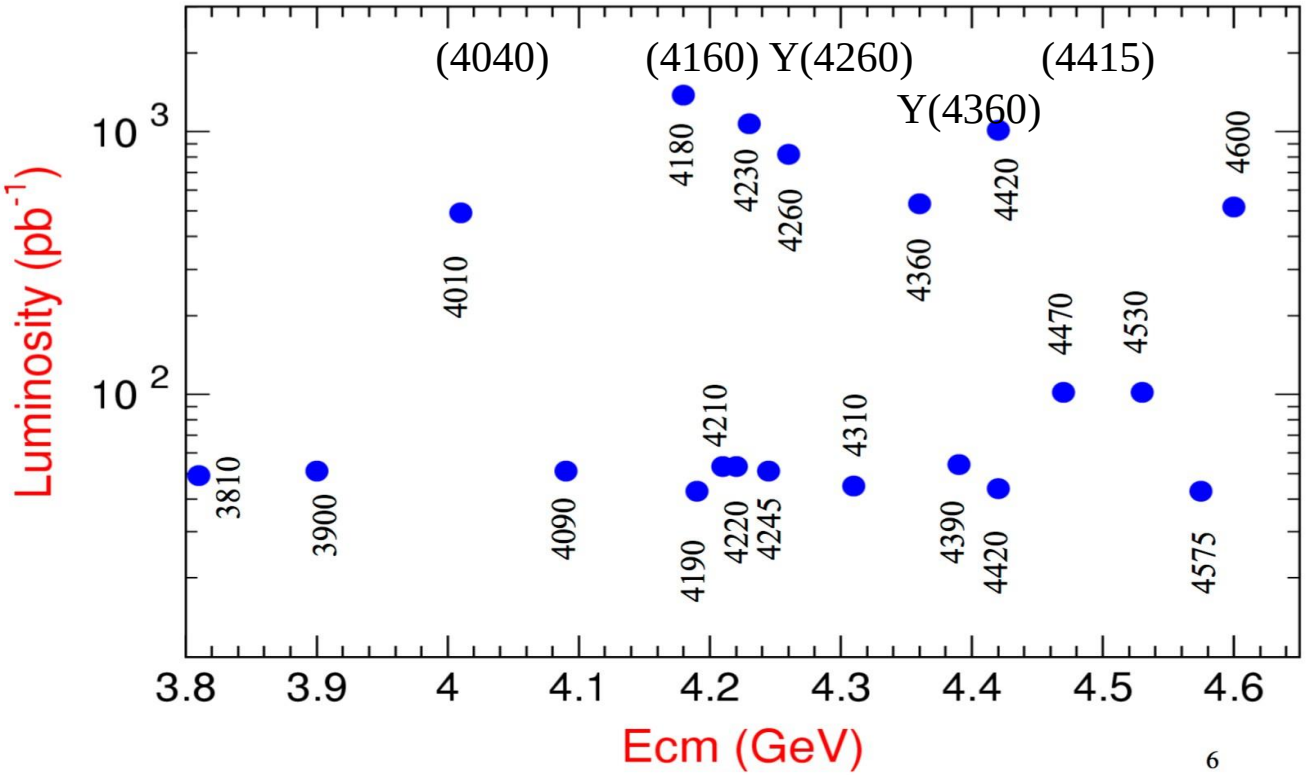
  Good agreement between discovery and theoretical prediction.

- **Above open charm threshold**

  Many expected states are not observed

  Many unexpected states are observed: XYZ states

Data samples for XYZ states at BESIII

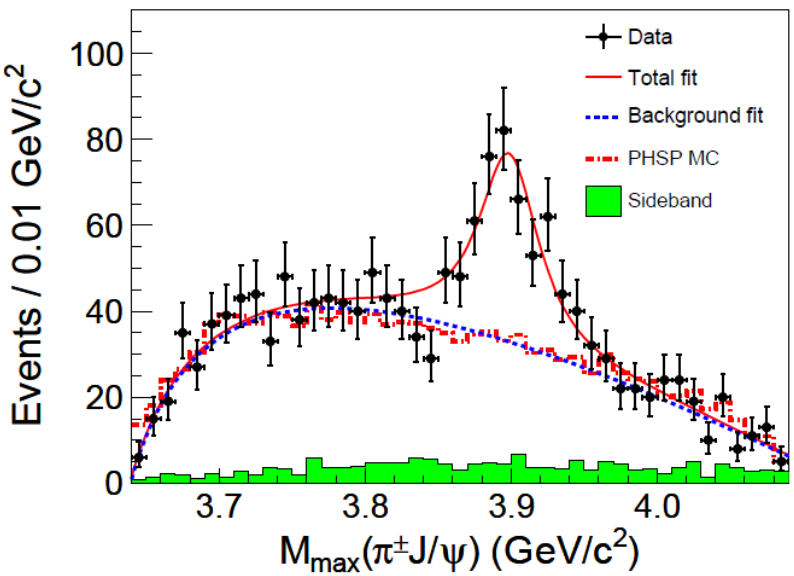


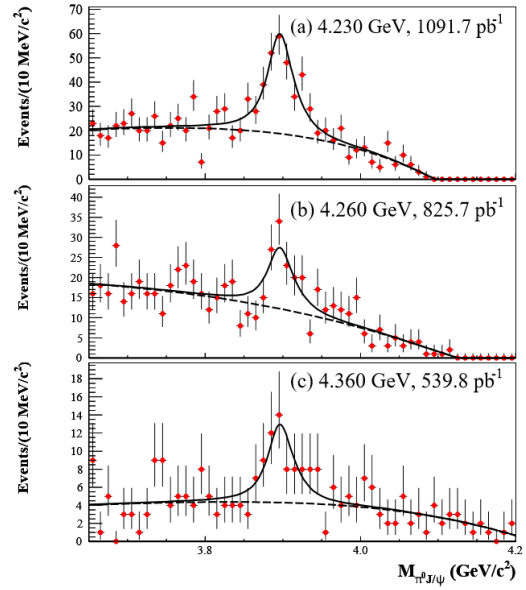
- Large data samples around Ψ(4040), Ψ(4160), Y(4260), Y(4360), Ψ(4415) and Y(4600)

Z_c states at BESIII

• $Z_c(3900)^{\pm}$ in $e^+e^- \to \pi^+ \pi^- J/\psi$	PRL 110,252001 (2013)
• $Z_c(3900)^0$ in $e^+e^- \to \pi^0 \pi^0 J/\psi$	PRL 115, 112003 (2015)
• $Z_c(3885)^{\pm}$ in $e^+e^- \to \pi^+ (D\bar{D}^*)^-$	PRL 112, 022001 (2014)
• $Z_c(3885)^0$ in $e^+e^- \to \pi^0 (D\bar{D}^*)^0$	PRL 115, 222002 (2015)
• $Z_c(4020)^{\pm}$ in $e^+e^- \to \pi^+ \pi^- h_c$	PRL 111.242001 (2013)
• $Z_c(4020)^0$ in $e^+e^- \to \pi^0 \pi^0 h_c$	PRL 113,212002 (2014)
• $Z_c(4025)^{\pm}$ in $e^+e^- \to \pi^+ (D^*\bar{D}^*)^-$	PRL 112,132001 (2013)
• $Z_c(4025)^0$ in $e^+e^- \to \pi^0 (D^*\bar{D}^*)^0$	PRL 115, 182002 (2015)

$e^+e^- \to \pi\, Z_c(3900) \to \pi\, \pi\, J/\psi$

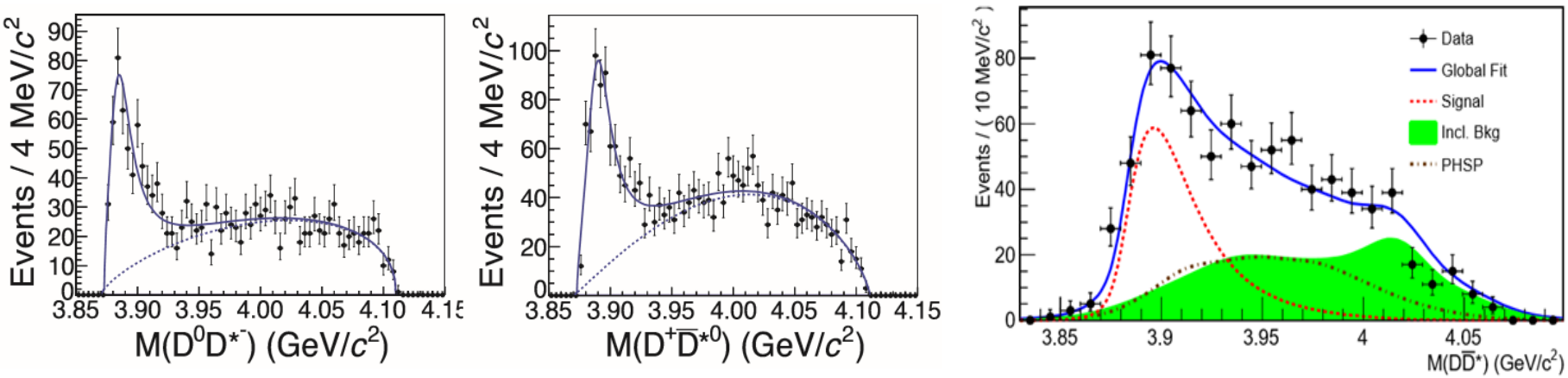




- $Z_c(3900)^{\pm}$ was observed in the $\pi^{\pm}J/\psi$ mass spectrum by BESIII ,with a statistical significance greater than 8σ. This result was soon confirmed by Belle and CLEO-c data.
- $Z_c(3900)^0$ with a significance of 10.4σ was observed by BESIII in $e^+e^- \to \pi^0\pi^0\, J/\psi$ with c.m. energy ranges from 4.19 to 4.42 GeV. It is in agreement with the previously reported 3.5 σ evidence for $Z_c(3900)^0$ with CLEO-c data.
- $Z_c(3900)^{\pm}$ carries one electric charge and couples to charmonium, which should contain at least four quarks to satisfy charge = 1.
- The mass and width of $Z_c(3900)^{\pm}$ and $Z_c(3900)^0$ are consistent. It may indicate they are isospin triplets.

$Z_c(3900)$	Mass(MeV)	Width(MeV)
$Z_c(3900)^{\pm}$	3899.0±3.6±4.9	46 ±10±20
$Z_c(3900)^0$	3894.8±2.3±2.7	29.6±8.2±8.2

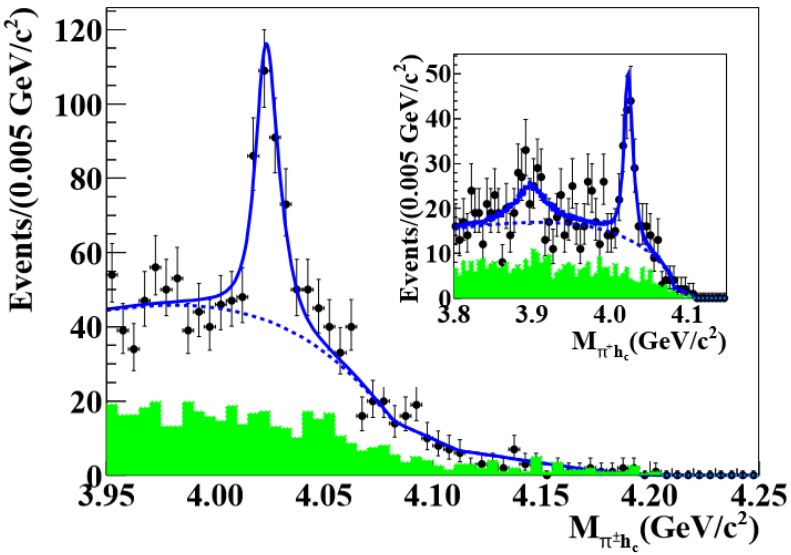
$e^+e^- \to \pi\, Z_c(3885) \to \pi\,(D\bar{D}^*)$

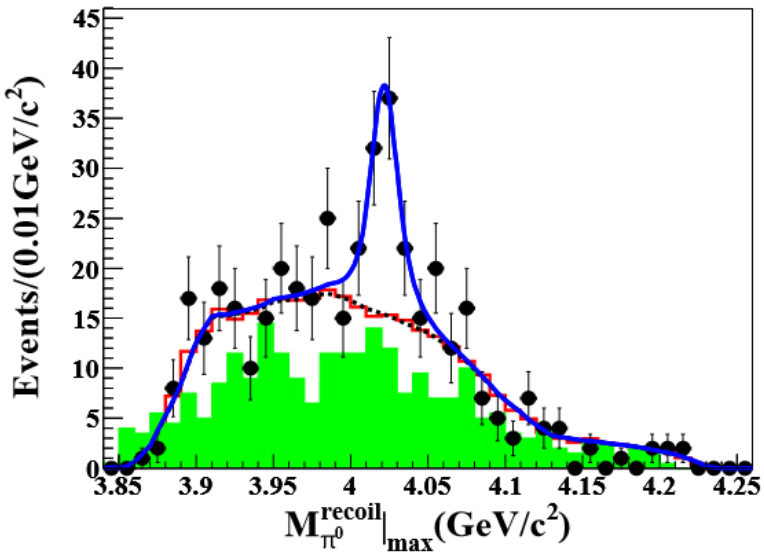


- $Z_c(3885)^{\pm}$ was observed in the $(D\bar{D}^*)^{\pm}$ invariant mass distribution with a significance greater than 10.4σ. Its angular distribution favors a $J^P = 1^+$ and disfavors 1^- or 0^-.
- $Z_c(3885)^0$ was observed in the $(D\bar{D}^*)^0$ invariant mass distribution with a significance greater than 12σ.
- The mass and width of $Z_c(3900)^{\pm}$ and $Z_c(3900)^0$ are consistent. It may indicates they are isospin triplets.
- An important question is whether $Z_c(3885)$ is the same state as $Z_c(3900)$, since they have relatively close mass and width.
- Assuming $Z_c(3885)$ and $Z_c(3900)$ are the states, we obtain the fraction $\frac{\Gamma(Z_c(3885)\to D^*\bar{D}^*)}{\Gamma(Z_c(3900)\to \pi J/\psi)} = 6.2 \pm 1.1 \pm 2.7$. The ratio is much smaller than typical values for conventional charmonium states above open charm threshold, for instance, $\frac{\Gamma(\psi(3770)\to D^*\bar{D}^*)}{\Gamma(\psi(3770)\to \pi\pi J/\psi)} = 482 \pm 84$, $\frac{\Gamma(\psi(4040)\to D^*\bar{D}^*)}{\Gamma(\psi(4040)\to \eta J/\psi)} = 192 \pm 27$, which suggests very different dynamics in the Y(4260)- $Z_c(3900)$ system.

$Z_c(3885)$	Mass(MeV)	Width(MeV)	
$Z_c(3885)^{\pm}$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 1.0$	→ Single D tag
$Z_c(3885)^{\pm}$	$3881.7 \pm 1.6 \pm 2.6$	$26.6 \pm 2.0 \pm 2.3$	→ Double D tag
$Z_c(3885)^0$	$3885.7\,^{+4.3}_{-5.7} \pm 8.4$	$35\,^{+11}_{-12} \pm 15$	

$e^+e^- \to \pi\, Z_c(4020) \to \pi\, \pi\, h_c$

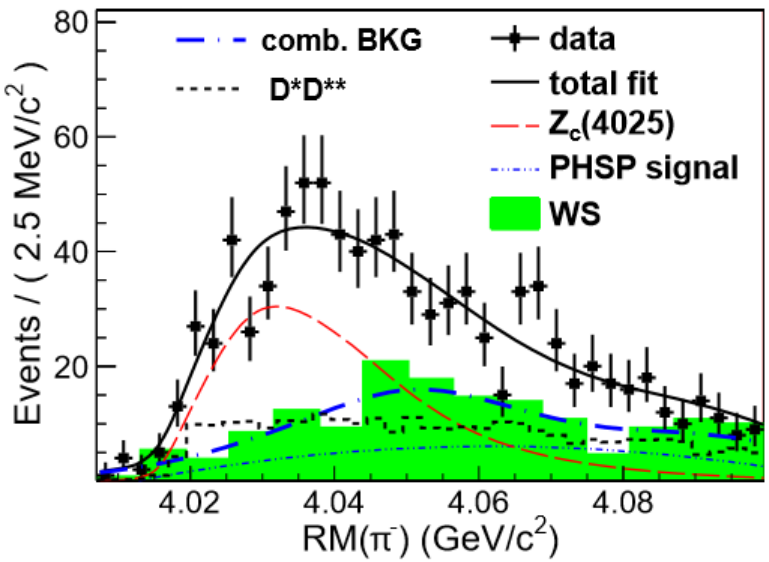


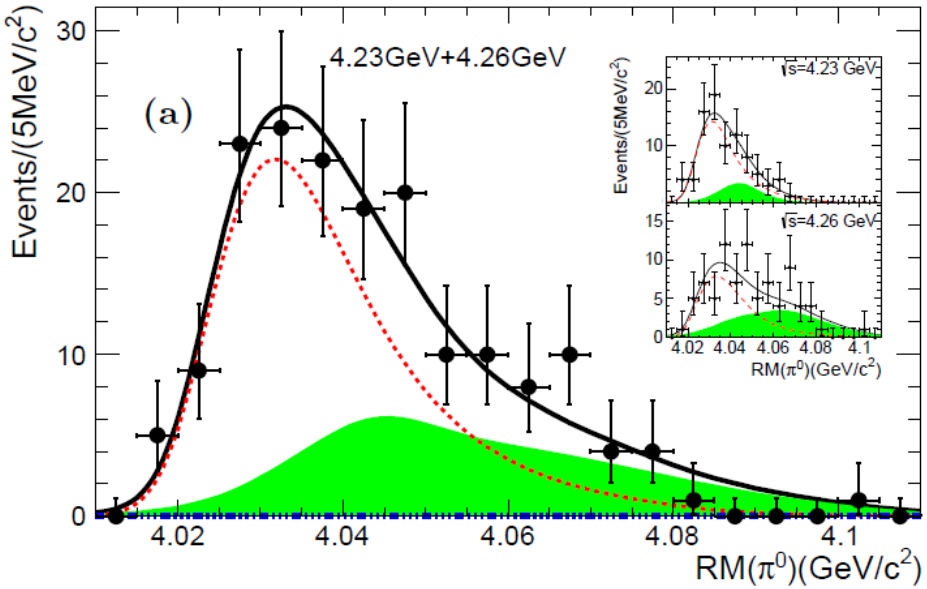


- $Z_c(4020)^{\pm}$ was observed by BESIII at c.m. energies 3.9 to 4.42 GeV with a significance greater than 8.9 σ. There's a hint for $Z_c(3900)^{\pm} \to \pi^{\pm} h_c$. The resonant parameters are fixed according to previous BESIII measurement.
- $Z_c(4020)^0$ was observed for the first time with 4.23, 4.26 and 4.36 GeV data at BESIII. The born cross-section were about half of those for $e^+e^- \to \pi^+\pi^- h_c$, which shows agreement with expectations based on isospin symmetry. In the fitting, the width was fixed due to the low statistics.
- This observations shows the isospin violation is relatively small.

$Z_c(4020)$	Mass(MeV)	Width(MeV)
$Z_c(4020)^{+/-}$	4022.9±0.8±2.7	7.9±2.7±2.6
$Z_c(4020)^0$	4023.8±2.2±3.8	Fixed(=7.9)

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

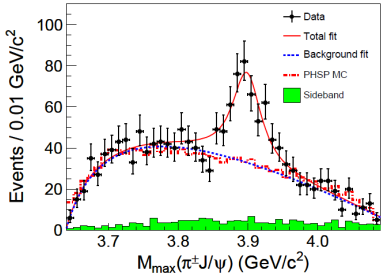




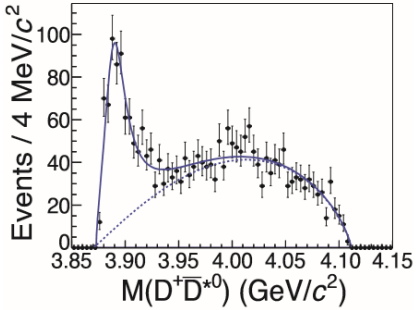
- $Z_c(4025)^{\pm}$ was observed in the process $e^+e^- \to \pi^{\mp}(D^*\bar{D}^*)^{\pm}$ process at 4.26 GeV by studying the $(D^*\bar{D}^*)^{\pm}$ invariant mass. The significance is larger than 12σ.
- $Z_c(4025)^0$ was observed in $(D^*\bar{D}^*)^0$ invariant mass by using data at 4.23 and 4.26 GeV with a significance great than 5σ.
- The resonant parameters and cross sections are very close to each other. Thus they may be the isospin triplets.
- Since $Z_c(4025)$ and $Z_c(4020)$ parameters agree with each other in 1.5σ, it is very possible that they are the same states.

$Z_c(4025)$	Mass(MeV)	Width(MeV)
$Z_c(4025)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$
$Z_c(4025)^0$	$4025.5\,^{+2.0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$

Summary of Z_c states at BESIII

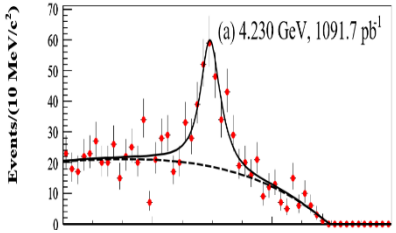


$e^+e^- \to \pi^+ \pi^- J/\Psi$

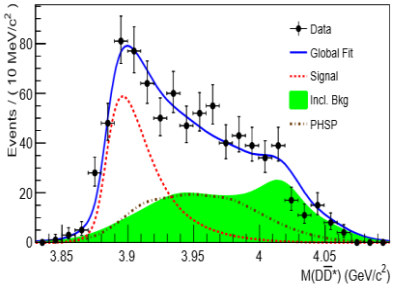


$e^+e^- \to \pi^+ (D\bar{D}^*)^-$

$Z_c(3900)^{\pm}$?

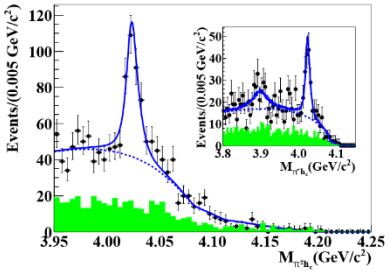


$e^+e^- \to \pi^0 \pi^0 J/\Psi$

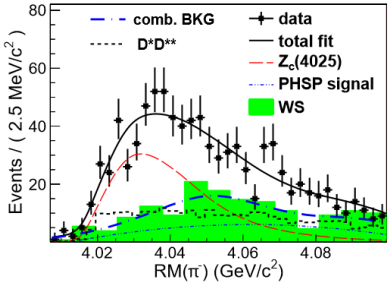


$e^+e^- \to \pi^0 (D\bar{D}^*)^0$

$Z_c(3900)^0$?

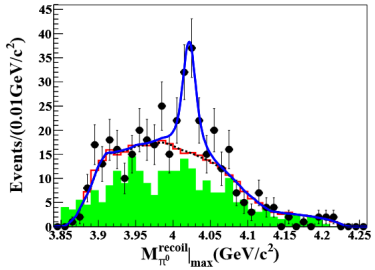


$e^+e^- \to \pi^+ \pi^- h_c$

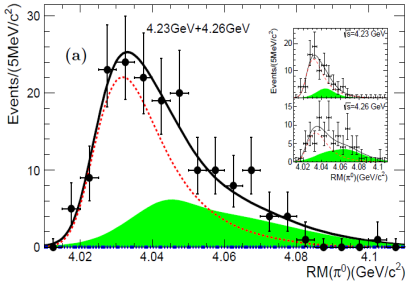


$e^+e^- \to \pi^+ (D^*\bar{D}^*)^-$

$Z_c(4020)^{\pm}$?



$e^+e^- \to \pi^0 \pi^0 h_c$



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

$Z_c(4020)^0$?

Discussion of the Z_c family

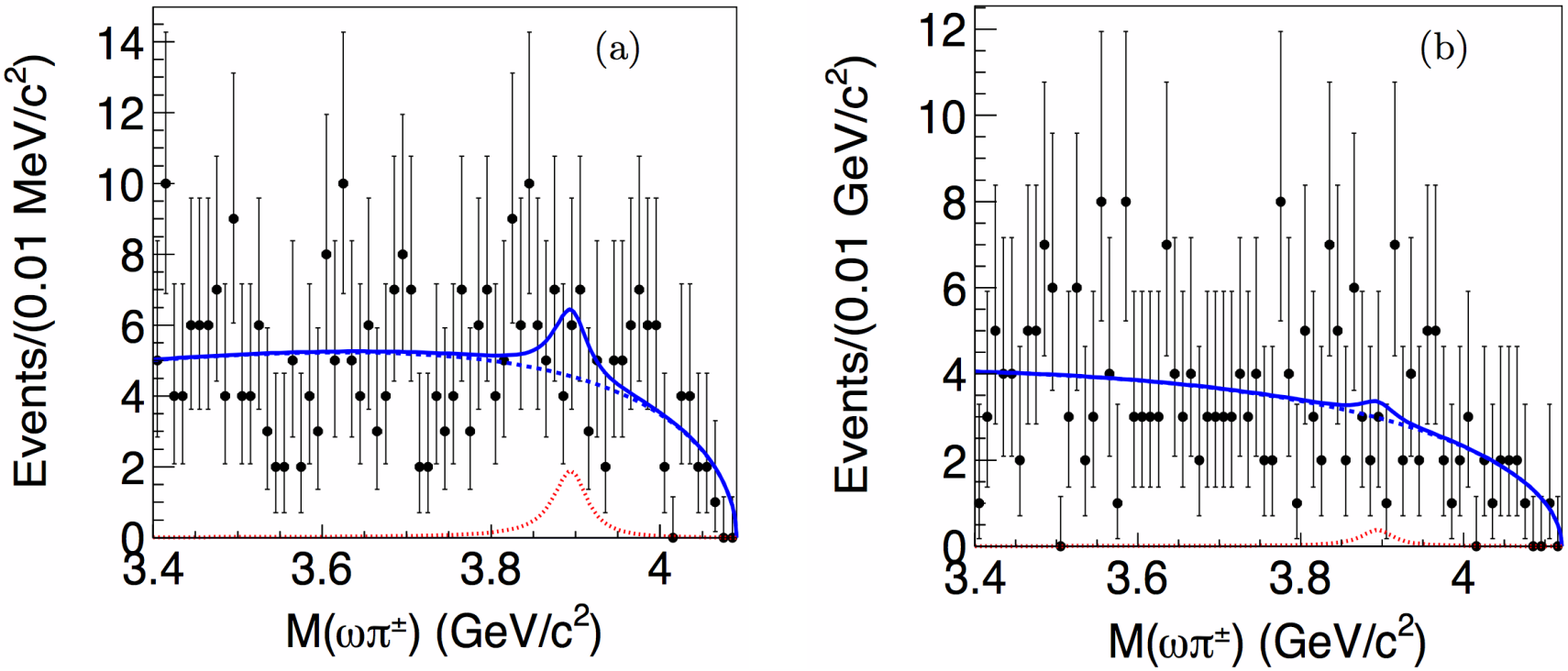
Z_c	Mass(MeV/c^2)	Width(MeV)	Decay Mode	J^P
$Z_c(3900)^+$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	$\pi^+ J/\Psi$	1^+
$Z_c(3900)^0$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$	$\pi^- J/\Psi$	
$Z_c(3885)^+$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 1.0$	$(DD^*)^+$	1^+
$Z_c(3885)^0$	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35^{+11}_{-12} \pm 15$	$(DD^*)^0$	
$Z_c(4020)^+$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	$\pi^+ h_c$	
$Z_c(4020)^0$	$4023.8 \pm 2.2 \pm 3.8$	Fixed to 7.9	$\pi^0 h_c$	
$Z_c(4025)^+$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	$(D^*D^*)^+$	
$Z_c(4025)^0$	$4025.5^{+2.0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$	$(D^*D^*)^0$	

Preliminary result from PWA

From angular distribution

- Charged Z_c decays into $\pi^{+/-}$ J/ψ ($\pi^{+/-}h_c$) → at least four valence quarks to satisfy charge=± 1
- Charged and neutral Z_c is consistent with isospin relationship → isospin triplets?
- Mass and widths of $Z_c(3900)$ and $Z_c(3885)$ ($Z_c(4020)$ and $Z_c(4025)$) are consistent within 2σ → the same states?

Search for $e^+e^- \to \pi Z_c(3900) \to \pi(\omega\pi)$



- Try to search for new decay channel of $Z_c(3900)$ to light hadrons
- No significant $Z_c \to \omega\pi$ is observed:

  $\sigma(e^+e^- \to \pi Z_c(3900) \to \pi(\omega\pi)) < 0.26$ pb @ 4.23 GeV

  $\sigma(e^+e^- \to \pi Z_c(3900) \to \pi(\omega\pi)) < 0.18$ pb @ 4.26 GeV

Summary

- Lots of progress in Z_c studies at BESIII. Such as the discovery of Z_c family:
  $Z_c(3900)$, $Z_c(3885)$, $Z_c(4020)$, $Z_c(4025)$

- Many other interesting results are on the way.

- Still remain many unanswered questions.

- BESIII will continue to study the XYZ states.

Thank you!