XYZ states at BESIII

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On behalf of the BESIII collaboration

DESY & IHEP China

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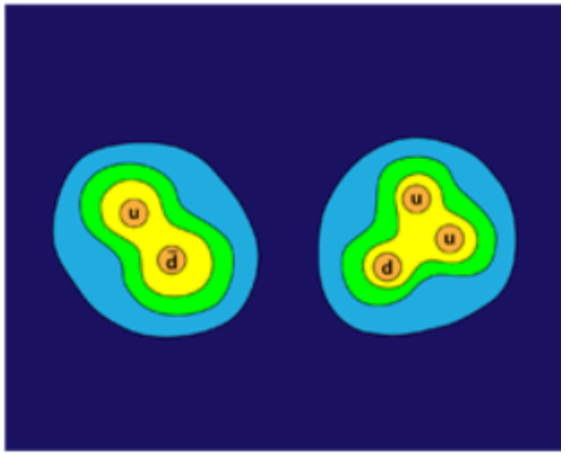
Introduction

Hadrons in quark model

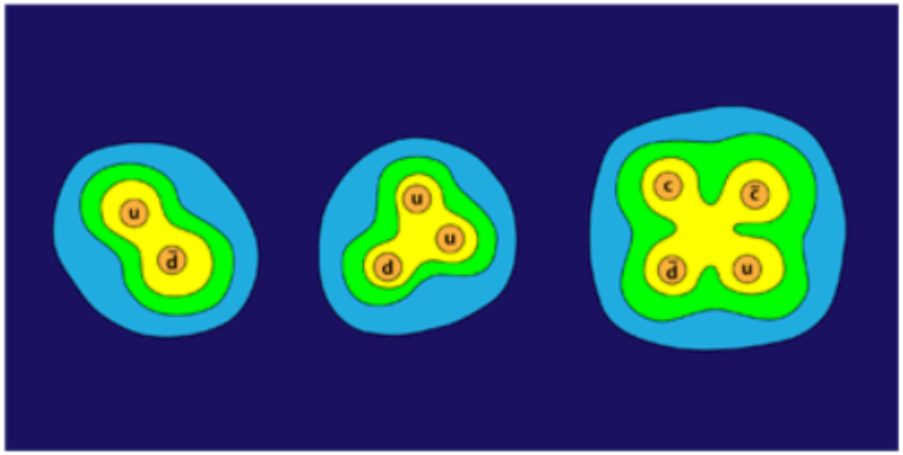


Why there are only two types of hadron?

- Other types of clusters were probably broad
- Strongly mixed with conventional hadrons

Introduction

Hadrons in quark model

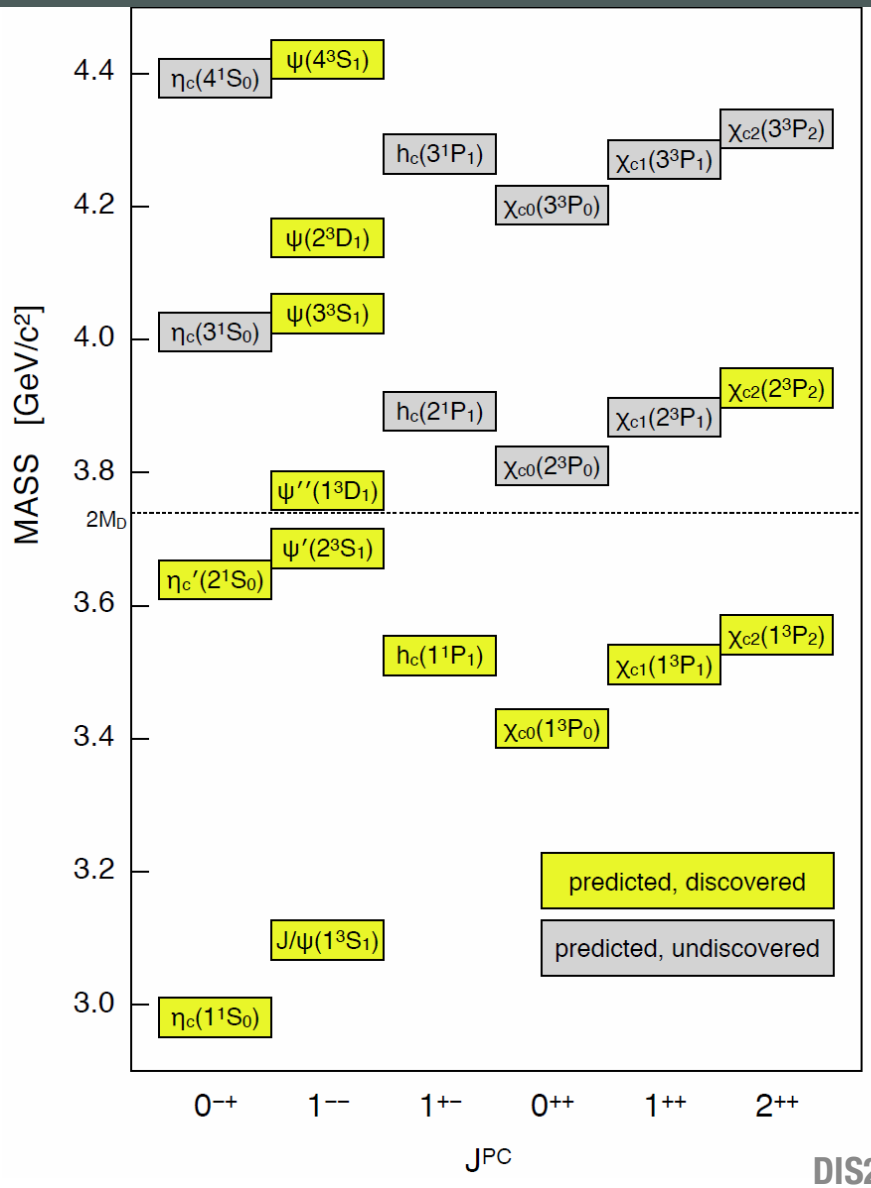


Recent discoveries of charged heavy quarkonium prove the existence of new type of hadron.

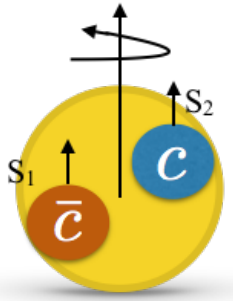
This talk will include:

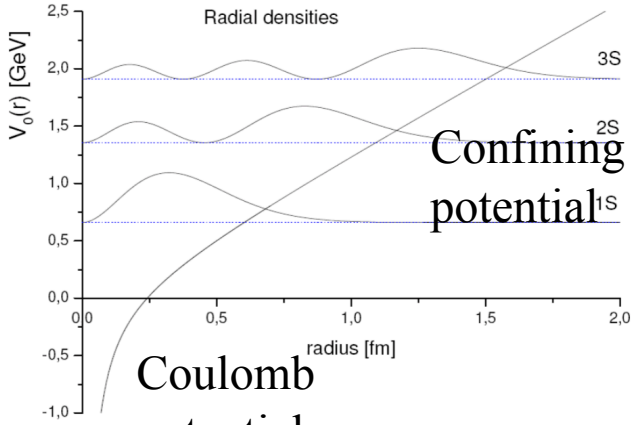
- The discovery of charged charmonium-like states Zc and Zc' at BESIII.
- Some new features of the X and Y states.
- Relationship between the XYZ states.

Charmonium



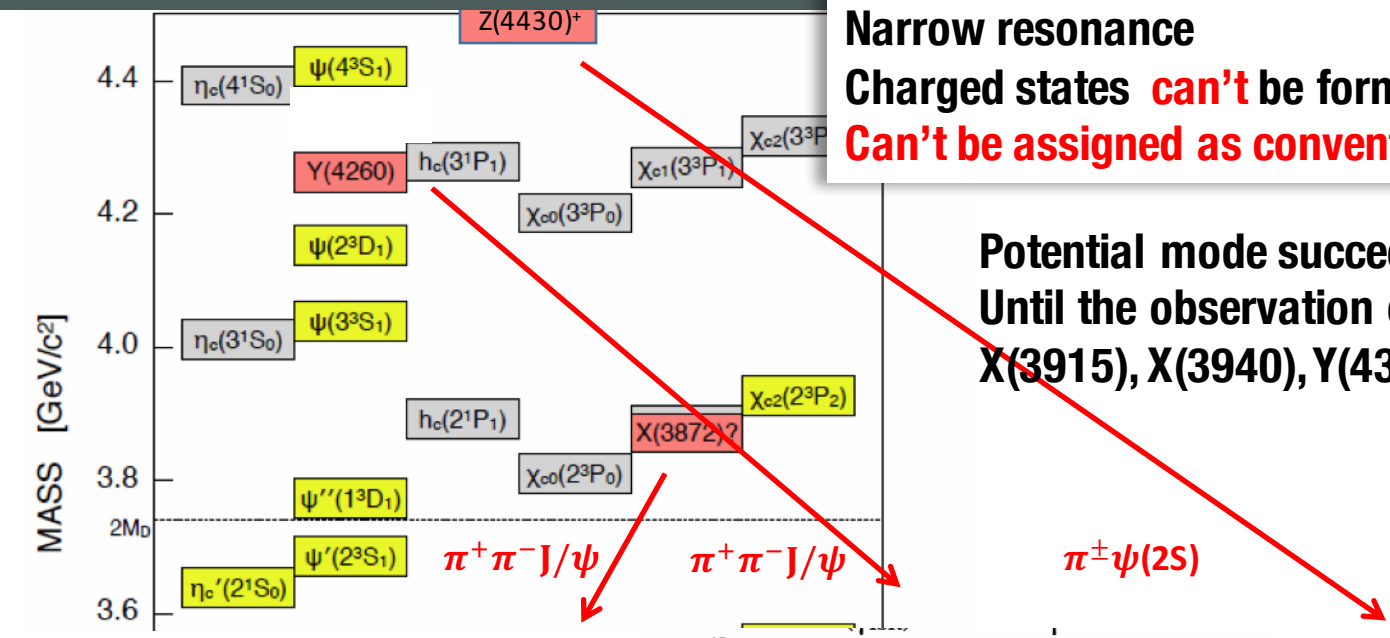
Potential mode succeeds for many years !



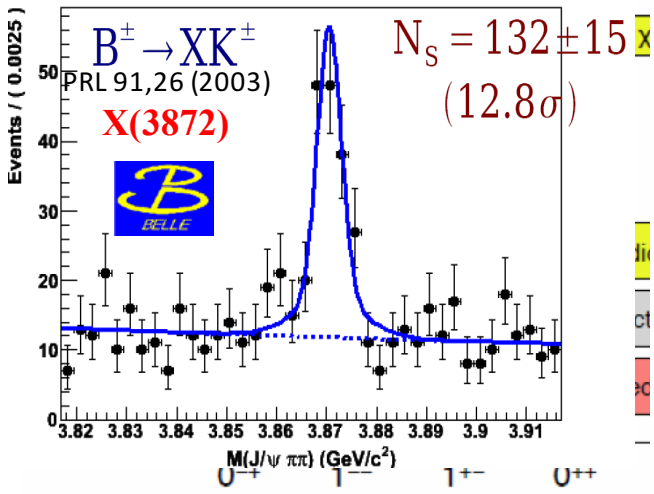


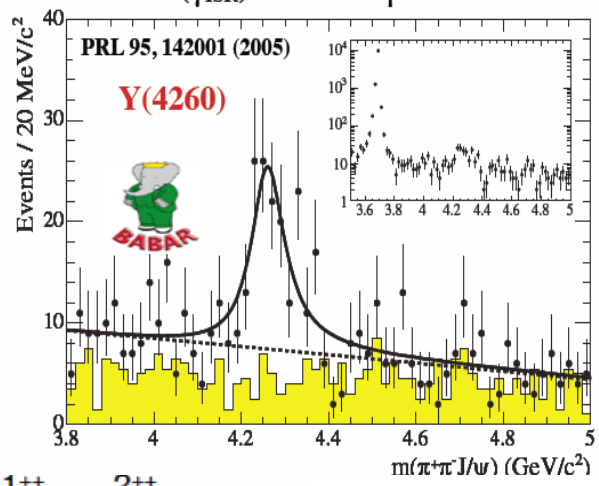
Exotic Charmonium

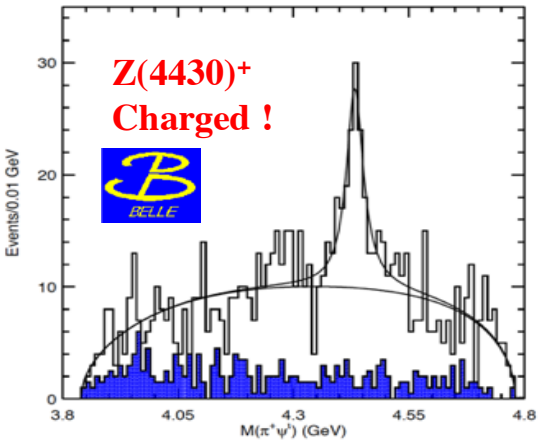
Strong coupling to hidden-charm states
Narrow resonance
Charged states can't be formed by quark-antiquark
Can't be assigned as conventional charmonium



Potential mode succeeds for many years !
Until the observation of X(3872) at Belle
X(3915), X(3940), Y(4360), Y(4660), Z(4050)…



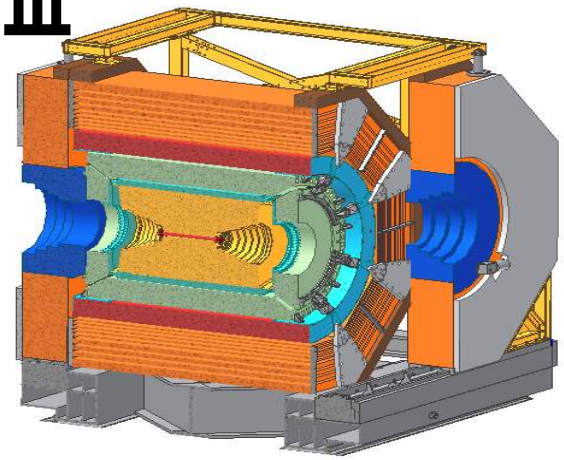




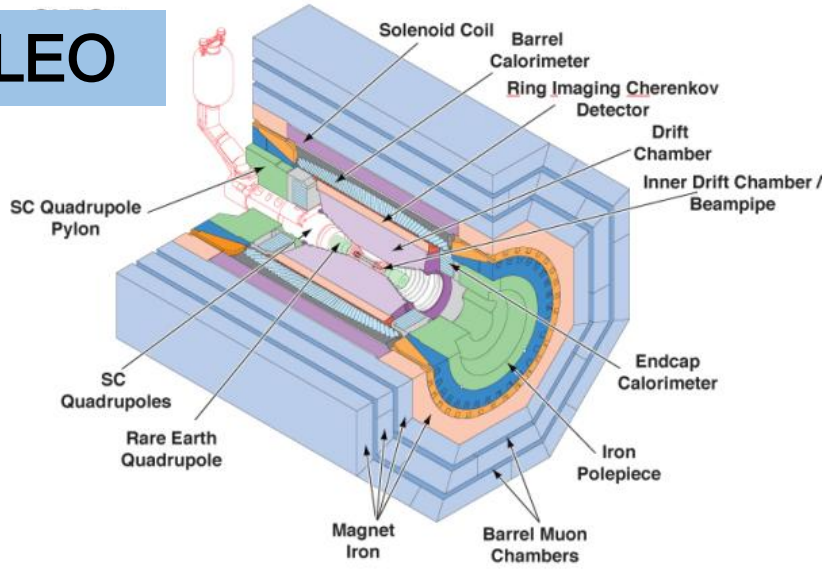
JPC 0⁻⁺ 1⁻⁻ 1⁺⁻ 0⁺⁺ 1⁺⁺ 2⁺⁺

Most states observed in e^+e^- experiment

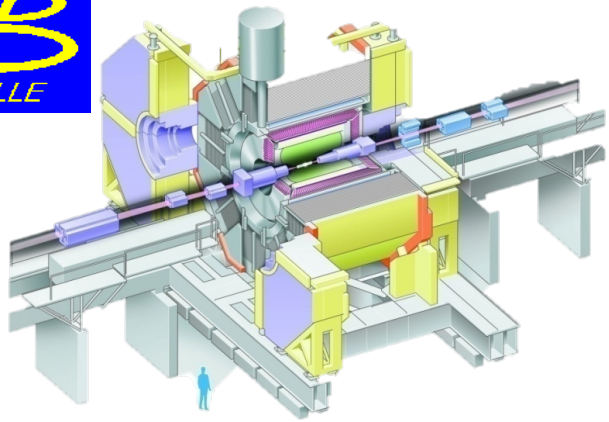
BESIII



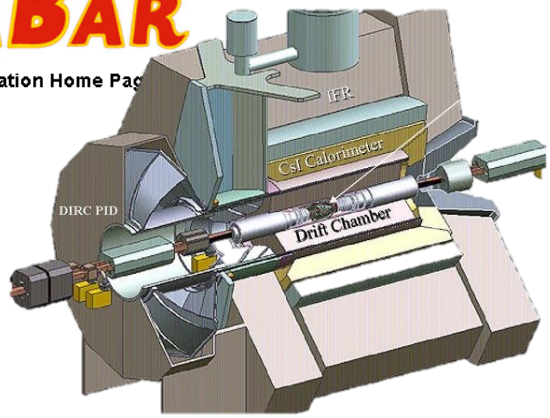
CLEO



BELLE



BABAR



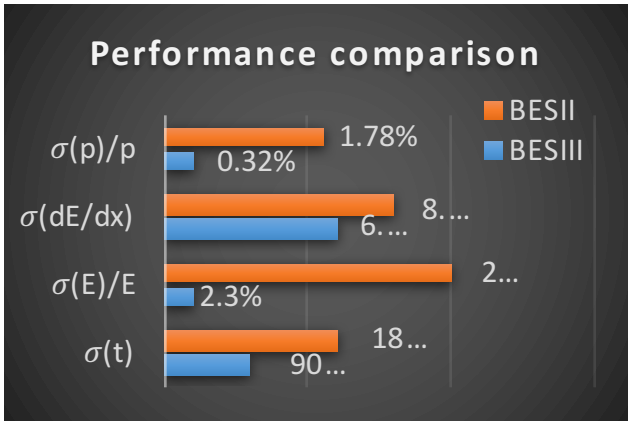
+ MK3, DM2, ... old generation

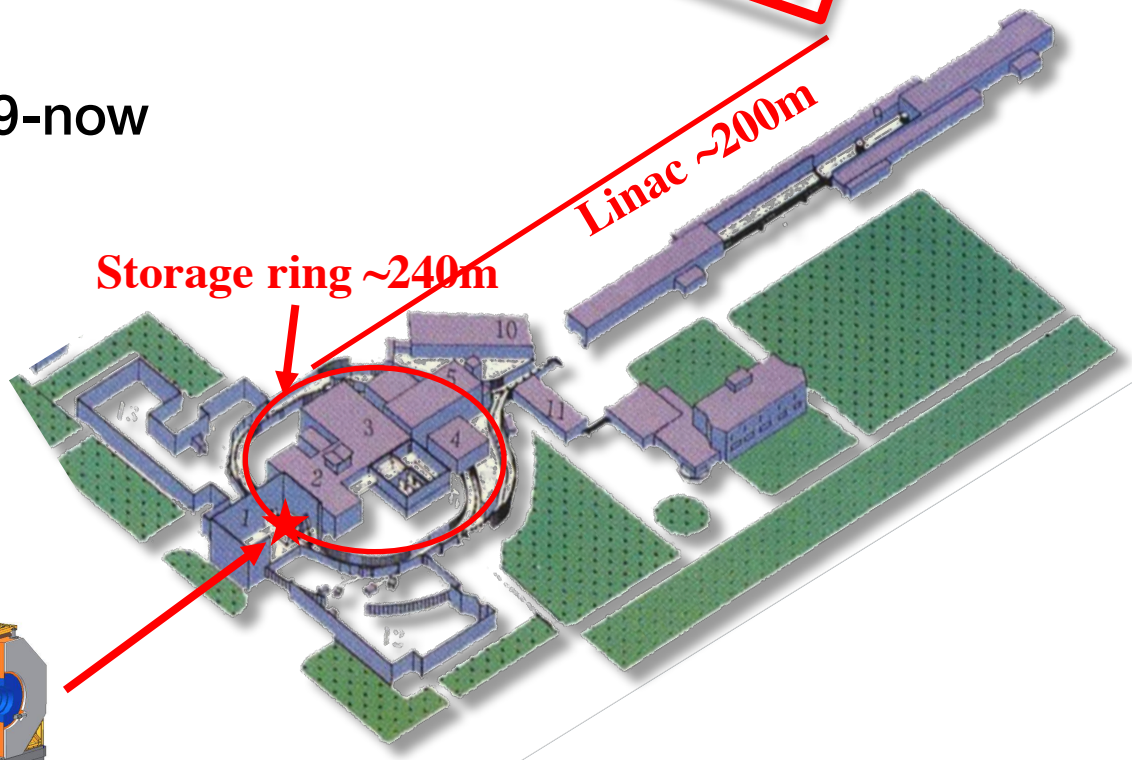
BEPCII & BESIII

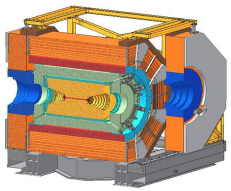
Beijing **E**lectron **P**ositron **C**ollider II (BEPC II)

- A unique e^+e^- machine in the τ-charm energy region until CLEOc.
- Designed luminosity: $10^{33}\ cm^{-2}s^{-1}$ @ 3.77 GeV
- $\sqrt{s} = 2\sim4.6$ GeV
- Taking data from 2009-now

Achieved !







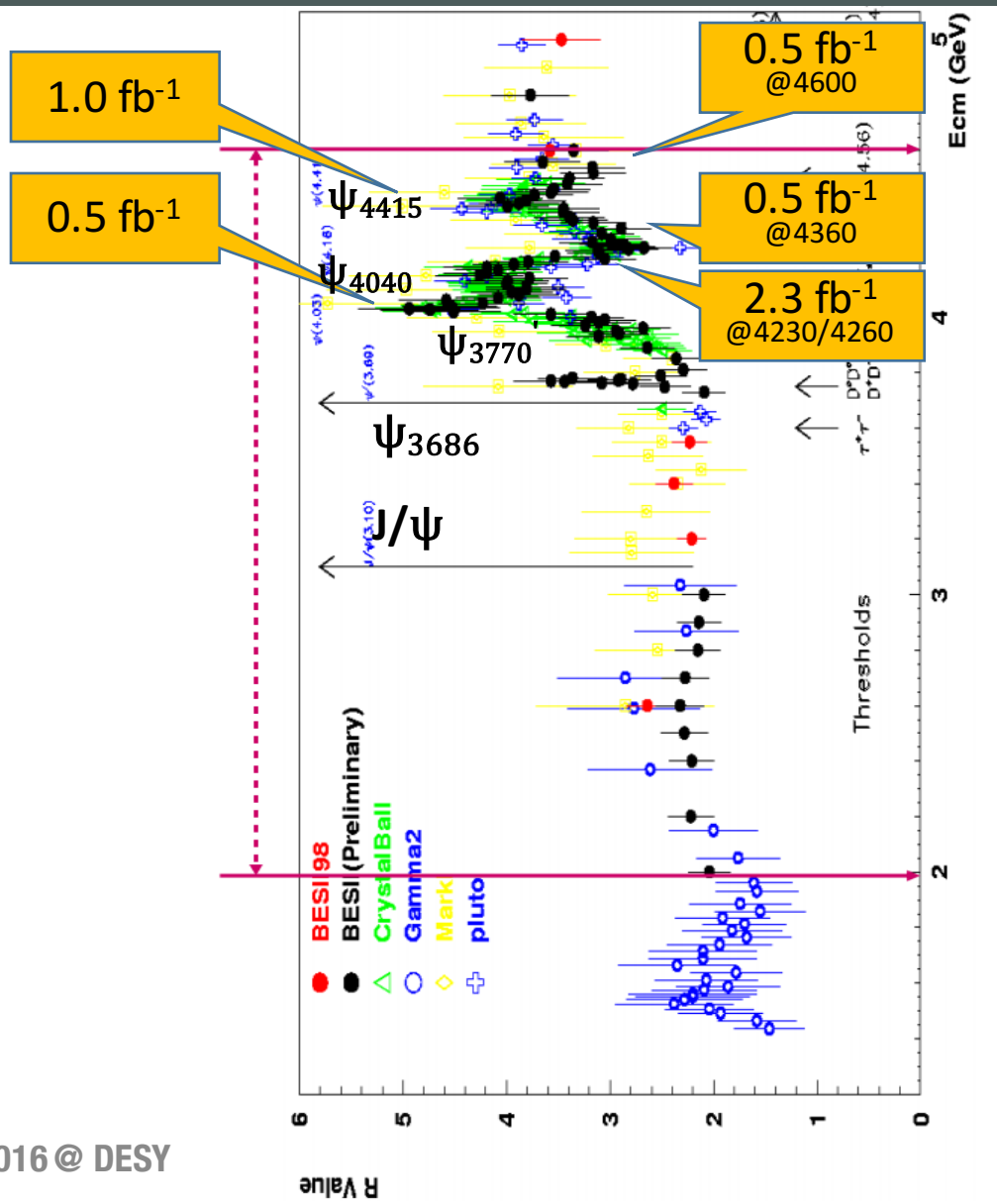
BESIII Detector

XYZ Physics at BESIII

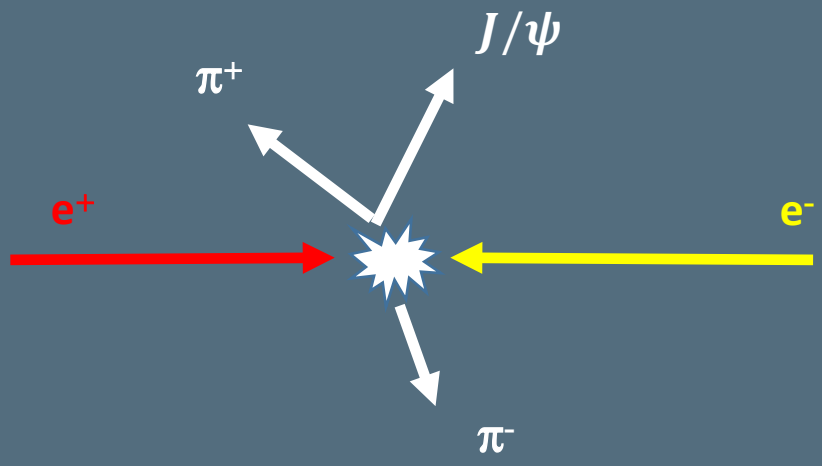
From 2013, BESIII start to operate at $\sqrt{S}$ > 4.0 GeV for XYZ physics

Focus on:

- Search for charged Z states in di-pion transition.
- Study of X states by radiative /hadronic transition.
- Study of Y states in various exclusive processes.

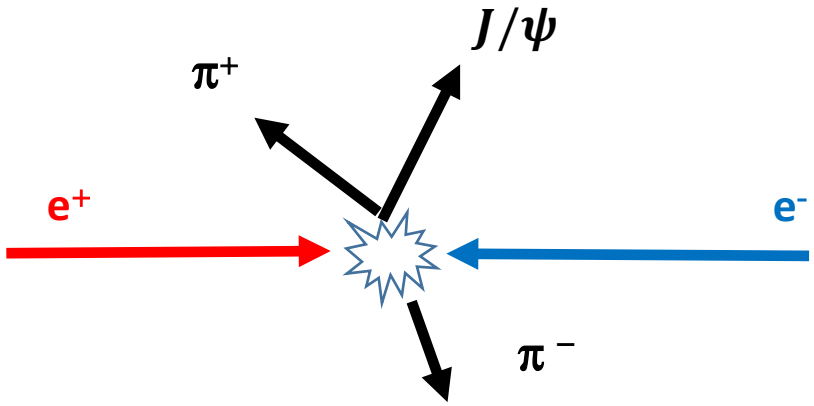


The Z states



Situation of XYZ physics before 2013

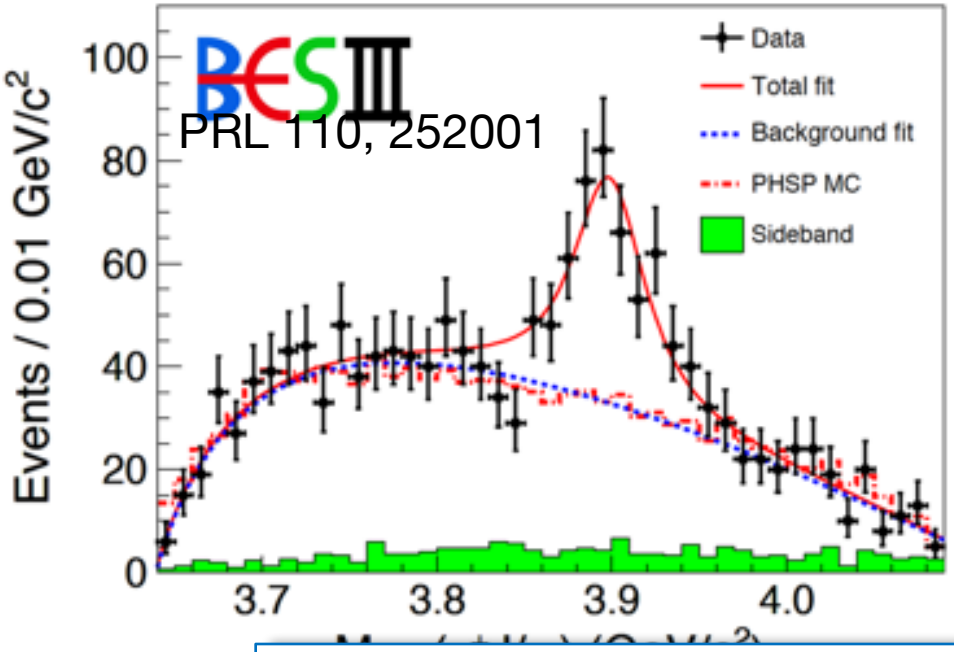
- we can not exclude XY states form conventional charmonium definitely.
- Charged charmonium-like states are only observed by one experiment.
- Investigate $e^+e^- \to \pi^+\pi^- J/\psi$ at peak of its production cross section to search charged exotic state.

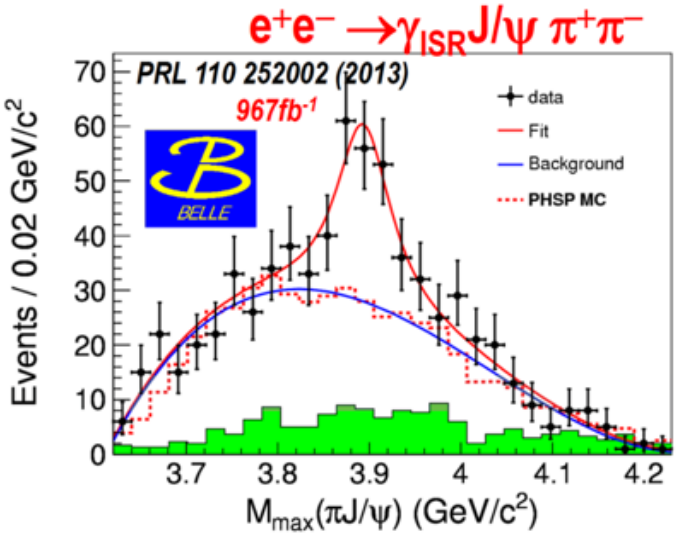


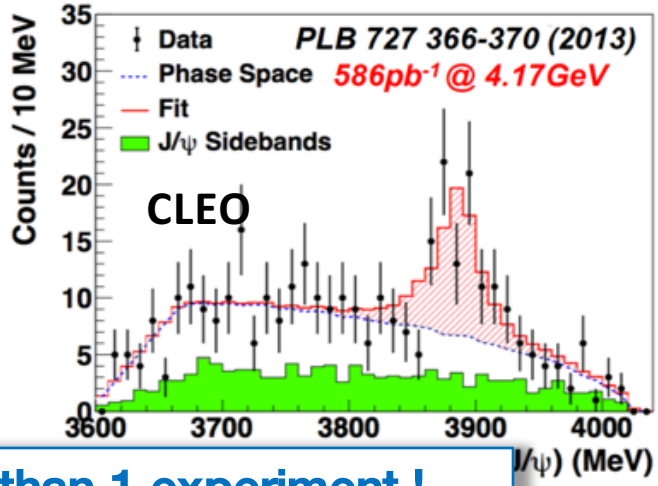
Discovery of Zc(3900)$^{\pm}$

Break through in 2013 !

- A new charged charmonium-like state, named Zc(3900), is observed at BESIII
- Also observed at Belle and CLEO experiments.



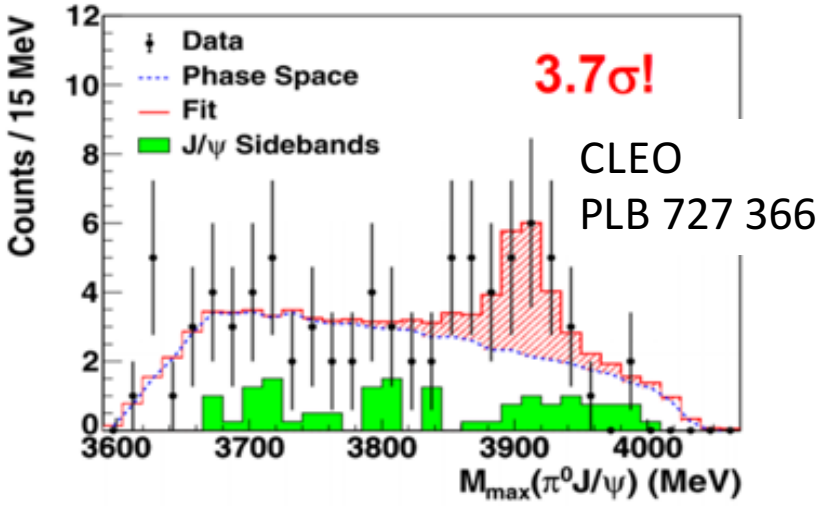




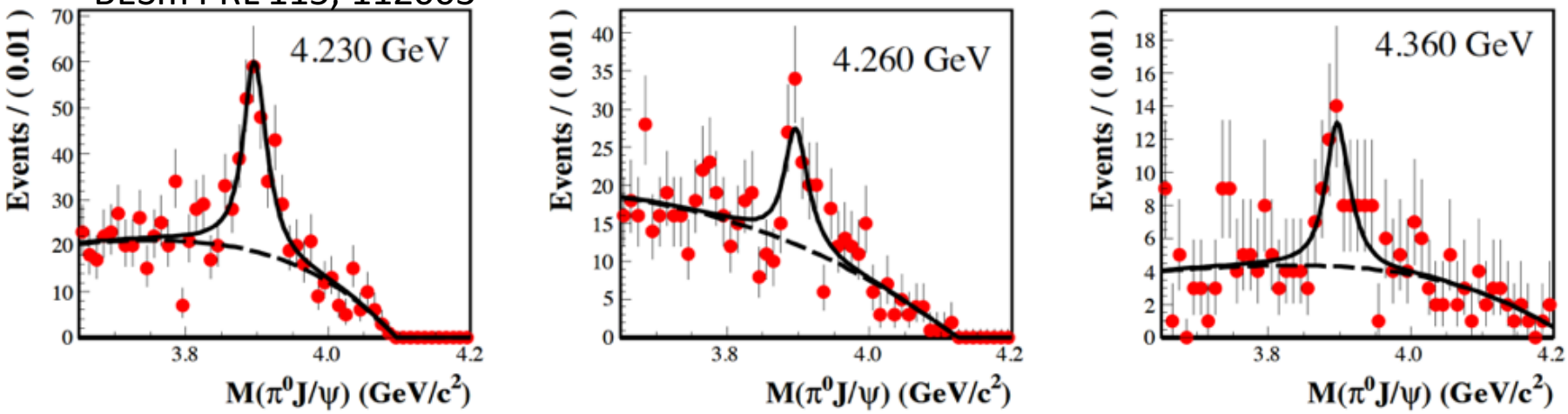
The first Z state observed by more than 1 experiment !
New type of hadron beyond meson and baryon exist !

Discovery of Zc(3900)^0

- If the Zc(3900)$^{\pm}$ exists, its iso-spin partner should be found in the $e^+e^- \to \pi^0\pi^0 J/\psi$ process.
- CLEO and BESIII confirm the existence of Zc(3900)^0 !



BESIII PRL 115, 112003

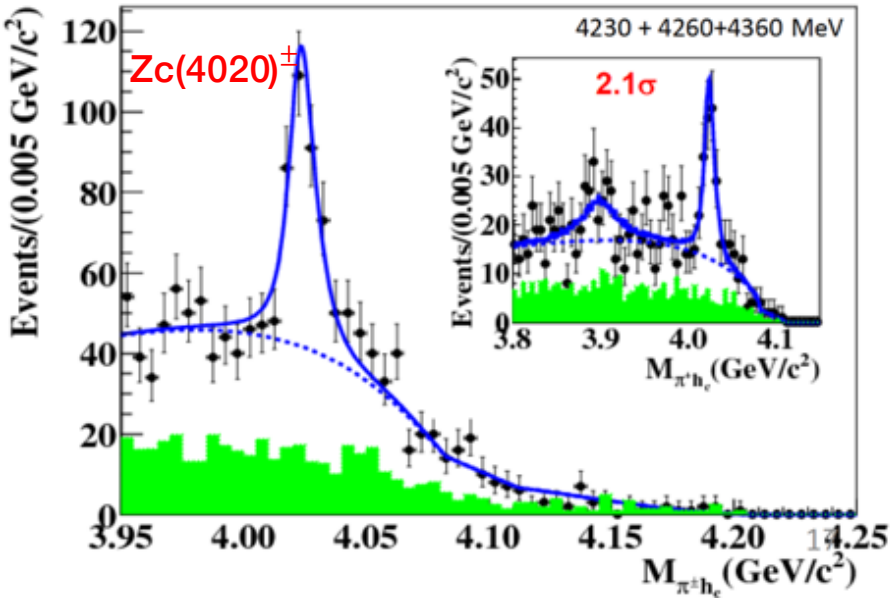


The iso-spin triplet Zc(3900) state has been established!

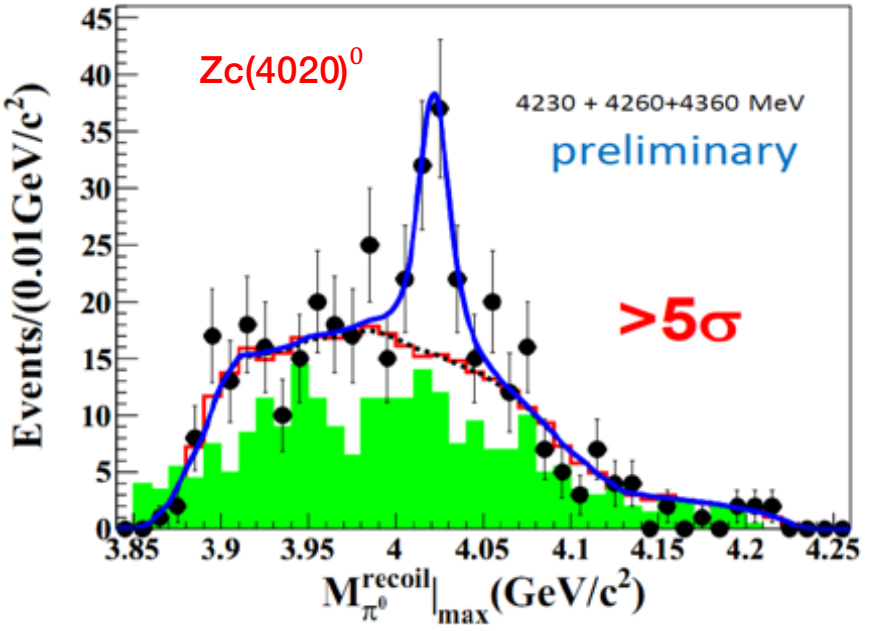
Discovery of Zc(4020) (Zc')

- Following the observation of Zc(3900), the $Zc(4020)^{\pm}$ and $Zc(4020)^{0}$ are observed in the $e^+e^- \to \pi^+\pi^- h_c$ and $e^+e^- \to \pi^0\pi^0 h_c$.

PRL 111, 242001



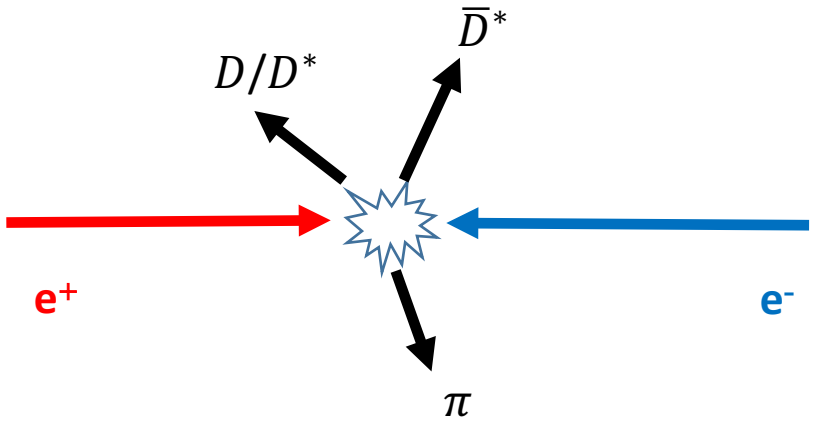
PRL 113, 212002



The iso-spin triplet Zc(4020)

Study of open charm decays

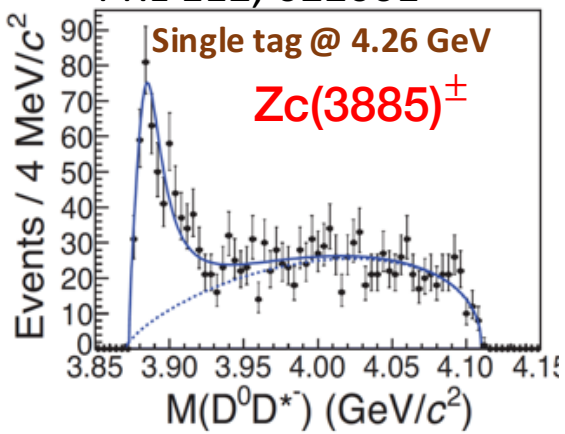
- Zc(3900) is just ~20 MeV/c^2 above the $D\overline{D}^*$ mass threshold.
- Zc(4020) is also slightly higher than the threshold of $D^*\overline{D}^*$
- One natural explanation is that these Z states are S-wave $D\overline{D}^*$ and $D^*\overline{D}^*$ molecular states or molecular-type resonances.
- Investigation of open charm decays of Z may be helpful!

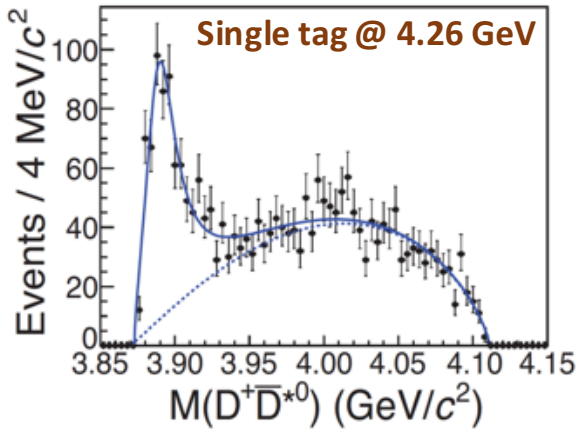


Discovery of $Zc(3885)^{\pm}$

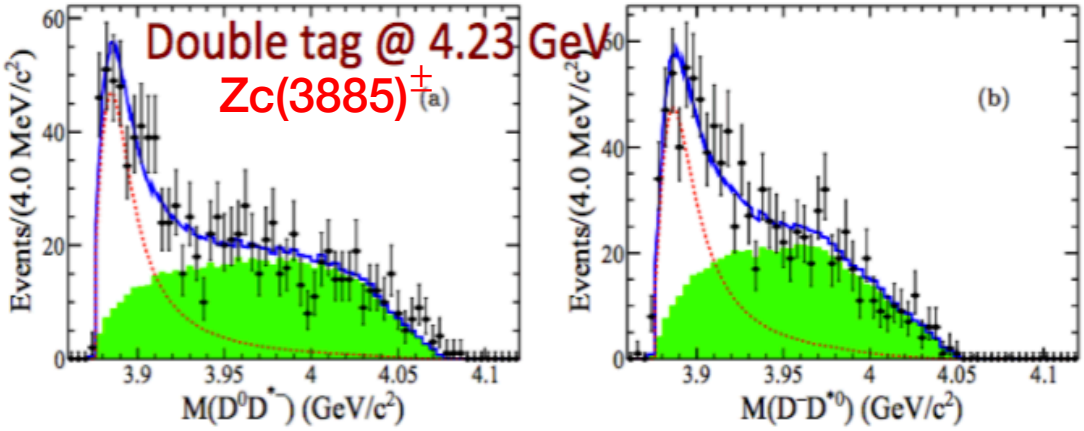
- Probe the process: $e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}$
- Charged narrow resonances are observed in the $D\bar{D}^*$ system, named $Zc(3885)^{\pm}$.

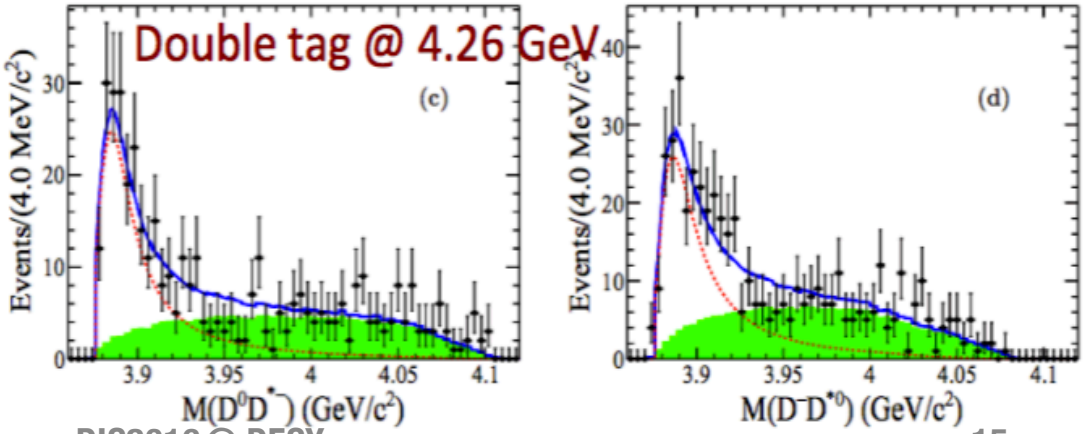
PRL 112, 022001





Phys. Rev. D 92, 092006

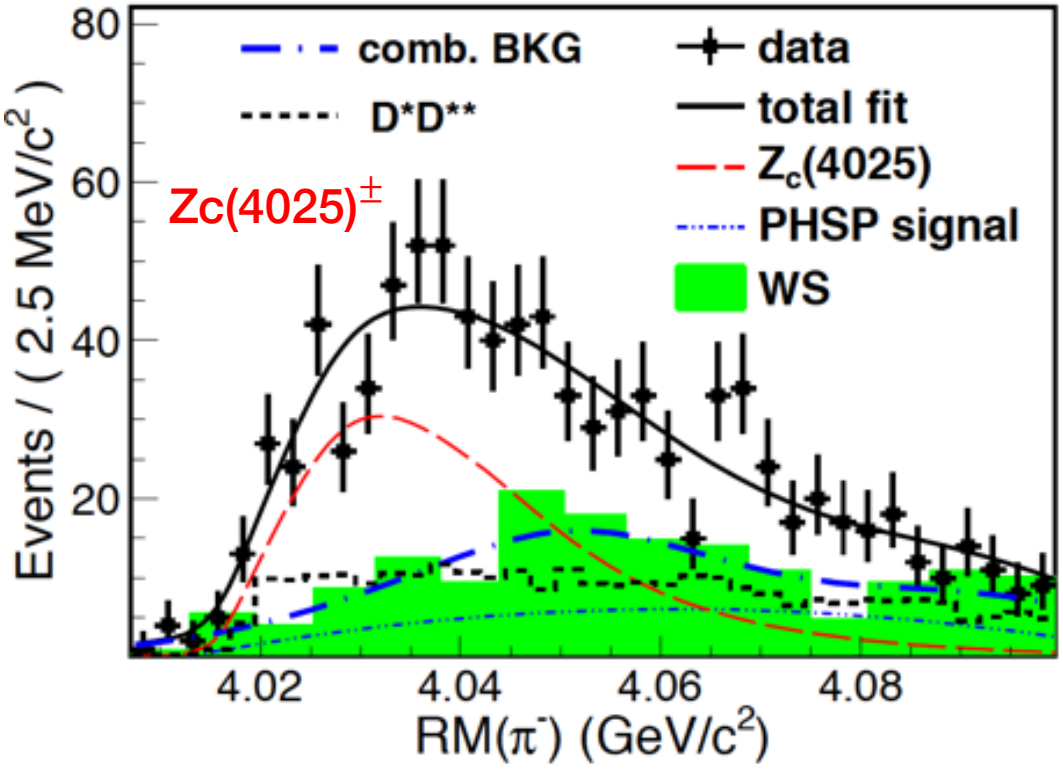




Discovery of $Zc(4025)^{\pm}$

- Charged narrow resonance are observed in the $D^*\overline{D}^*$ system in the $e^+e^- \to \pi^{\pm}(D^*\overline{D}^*)^{\mp}$, named $Zc(4025)^{\pm}$.

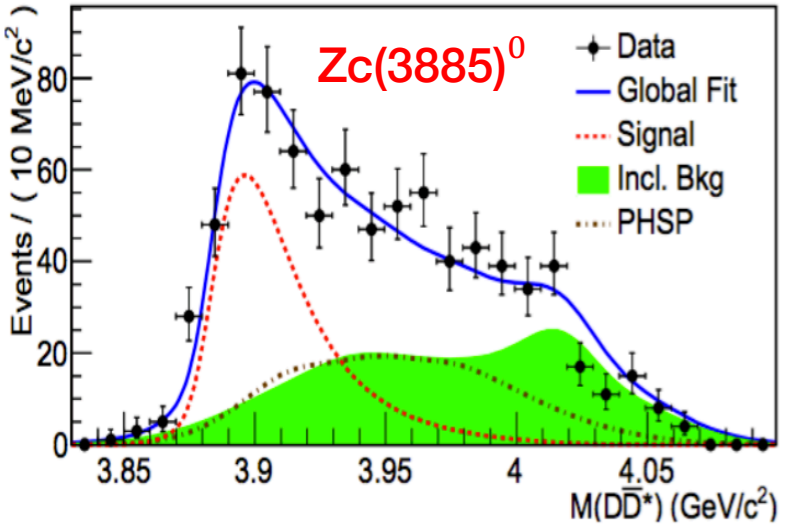
PRL 112, 132001(2013)



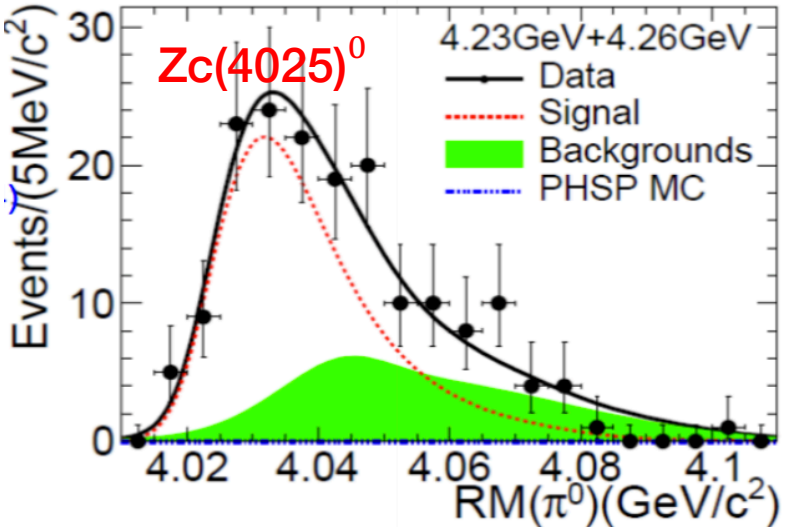
Observation of their neutral partners

- As expected, neutral $Zc(3885)^0$ and $Zc(4025)^0$ are also observed in the $D^0\bar{D}^{*0}$ and $D^{*0}\bar{D}^{*0}$ system.

Phys. Rev. Lett. 115, 222002



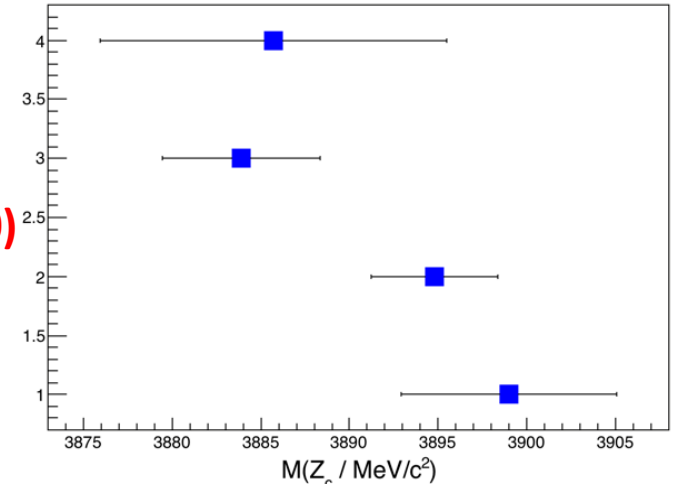
Phys. Rev. Lett. 115, 182002



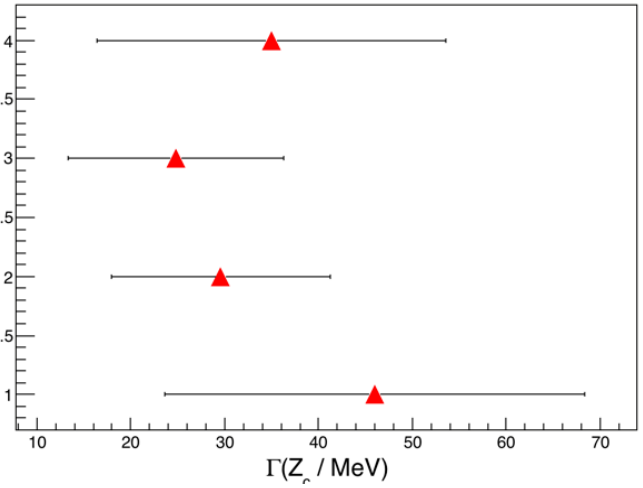
Summary of Z – resonant parameters

Mass **Width**

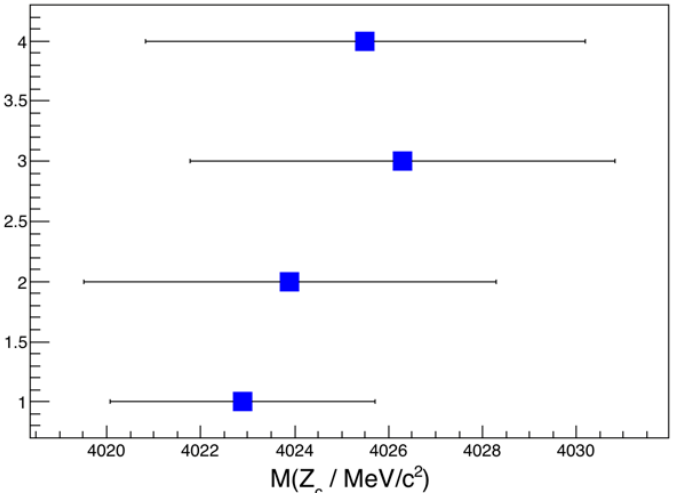
Zc(3900)



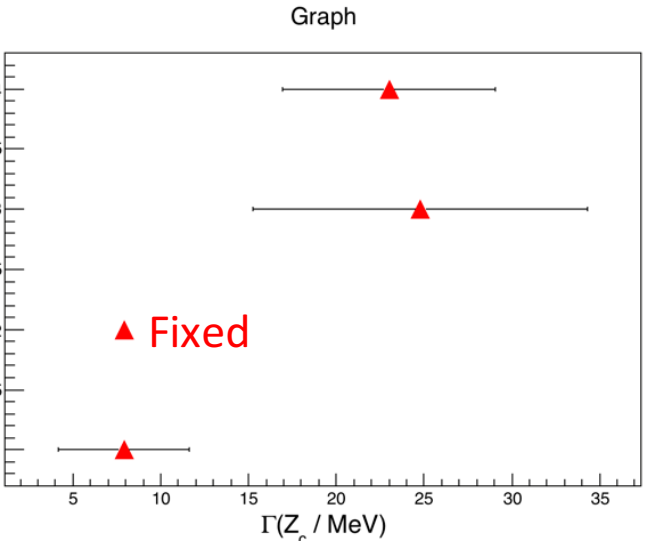
$Zc(3885)^0$
$Zc(3885)^{\pm}$
$Zc(3900)^0$
$Zc(3900)^{\pm}$



Zc(4020)



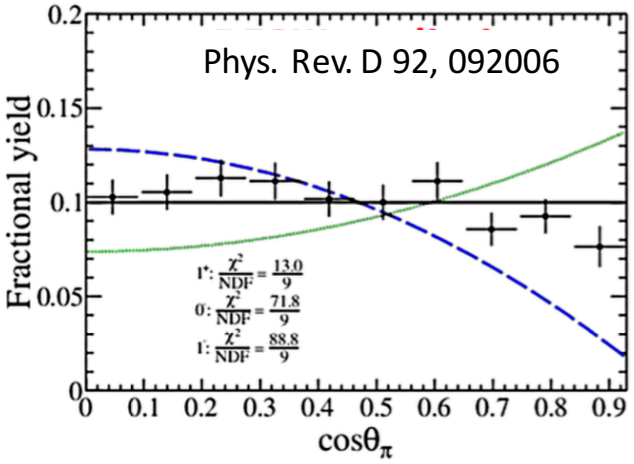
$Zc(4025)^0$
$Zc(4025)^{\pm}$
$Zc(4020)^0$
$Zc(4020)^{\pm}$



Summary of Z – J^P

Angular analysis of Zc(3885)

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



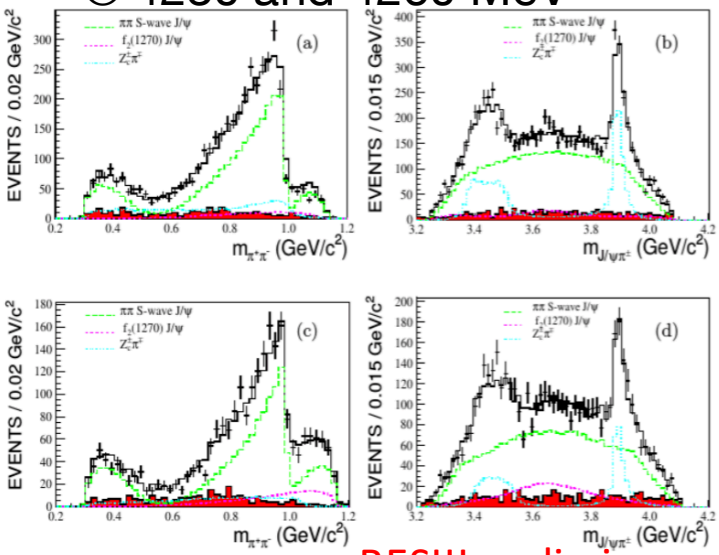
Efficiency corrected event yield in 10 bins in $|\cos\theta_\pi|$

data clearly favour $J^P = 1^+$ for $D\bar{D}^*$ structure

confirms J^P for $Z_c(3885)$ from single-tags

Both Zc(3900) and Zc(3885) favor $J^P=1^+$

PWA of $e^+e^- \to \pi^+\pi^- J/\psi$ @ 4230 and 4260 MeV

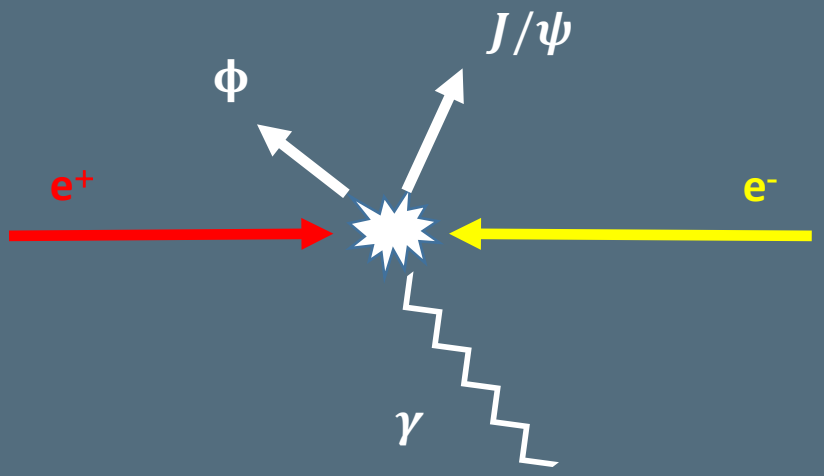


BESIII preliminary

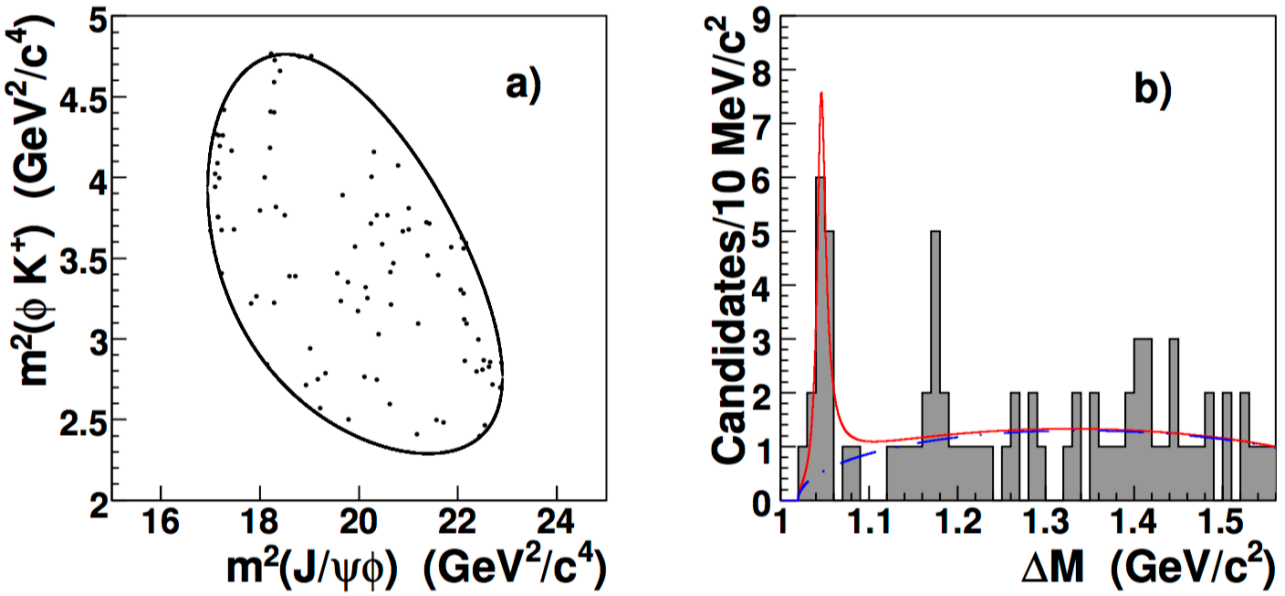
J^P	$\Delta(-2\ln L)$	significance
1^+ over 0^-	89.0	7.3σ
1^+ over 1^-	214.0	$> 8\sigma$
1^+ over 2^-	103.6	$> 8\sigma$
1^+ over 2^+	387.0	$> 8\sigma$

Data clearly favours $J^P = 1^+$

The X states



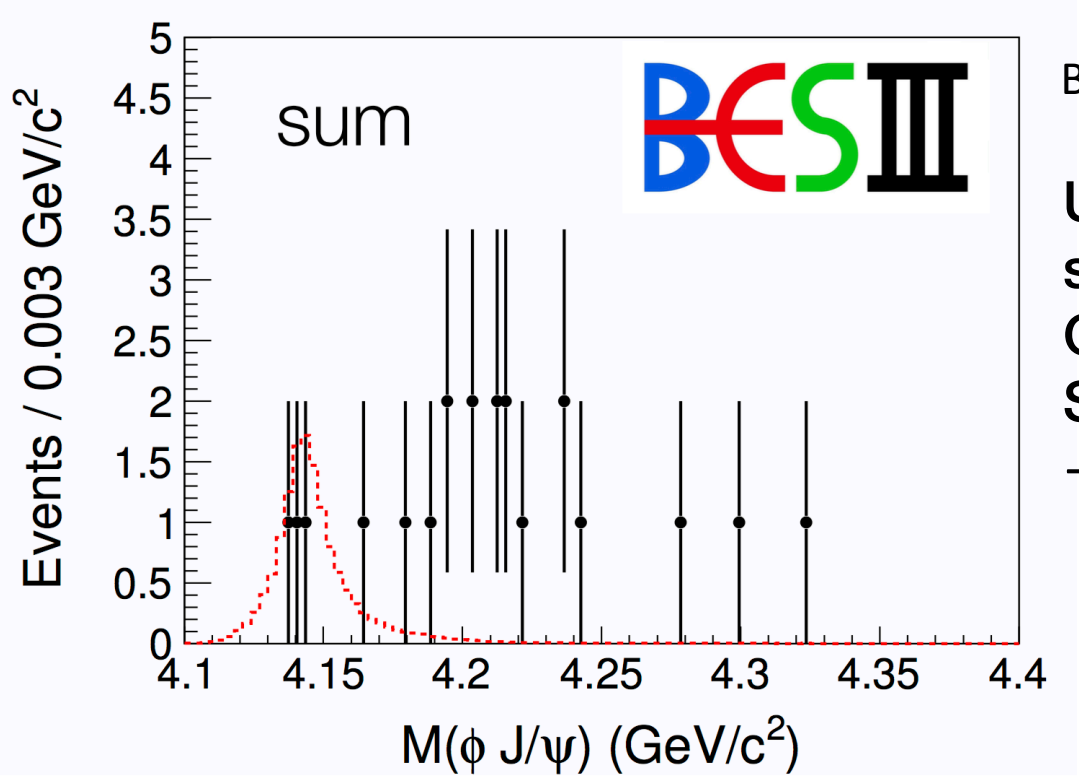
Search for $X(4140)$



CDF, PRL **102**, 242002, (2009)

CDF first reported evidence for X(4140) → J/ψϕ in B^+ → J/ψϕK^+, also claimed by D0 and CMS.
Not seen by LHCb, Belle (B decays and γγ events), or BABAR

Search for $X(4140)$

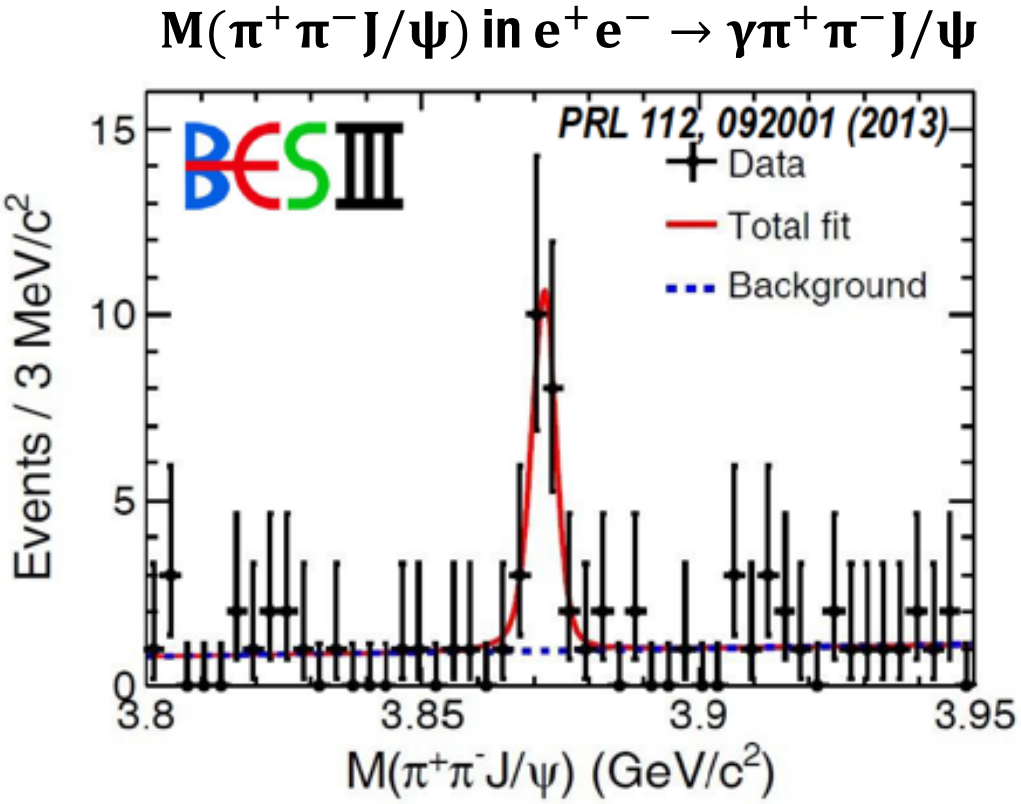


BESIII, PRD 91, 032002 (2015)

Use BESIII's large data samples from 4.23 – 4.36 GeV (2.47 fb^{-1} in total) Search for X(4140) in e^+e^- →γJ/ψφ

$\sqrt{s}$/ GeV	4.23	4.26	4.36
$\sigma \times \mathcal{B}(X(3872))$/pb	0.27 ± 0.09	0.33 ± 0.12	0.11 ± 0.09
$\sigma \times \mathcal{B}(Y(4140))$/pb	< 0.35	< 0.28	< 0.33

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



Analyze ~2.9 fb^{-1} data at 4.009, 4.23, 4.26, 4.36 GeV

- X(3872) was observed with 6.3σ significance.
- M[X(3872)]=3871.9±0.7±0.2 MeV, Γ<2.4 MeV @ 90% C.L.

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

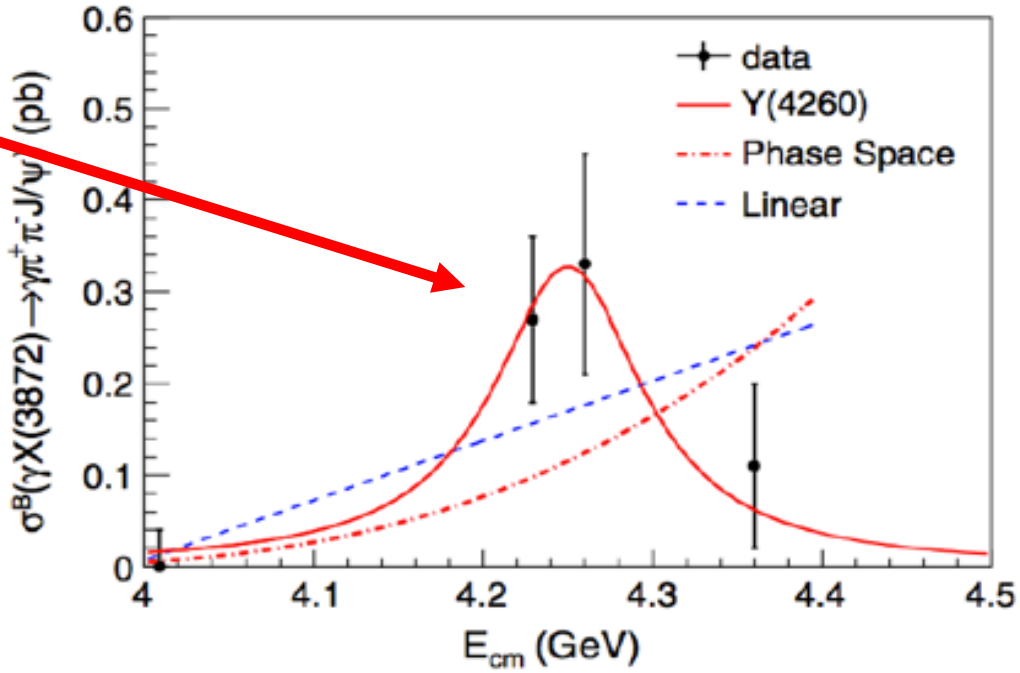
Central-of-mass energy dependent cross section peaks at 4.26 GeV.

Suggest that there might be some commonality in the nature of the X(3872), Y(4260), and Zc(3900)

Zc is also produced in Y(4260) decay!

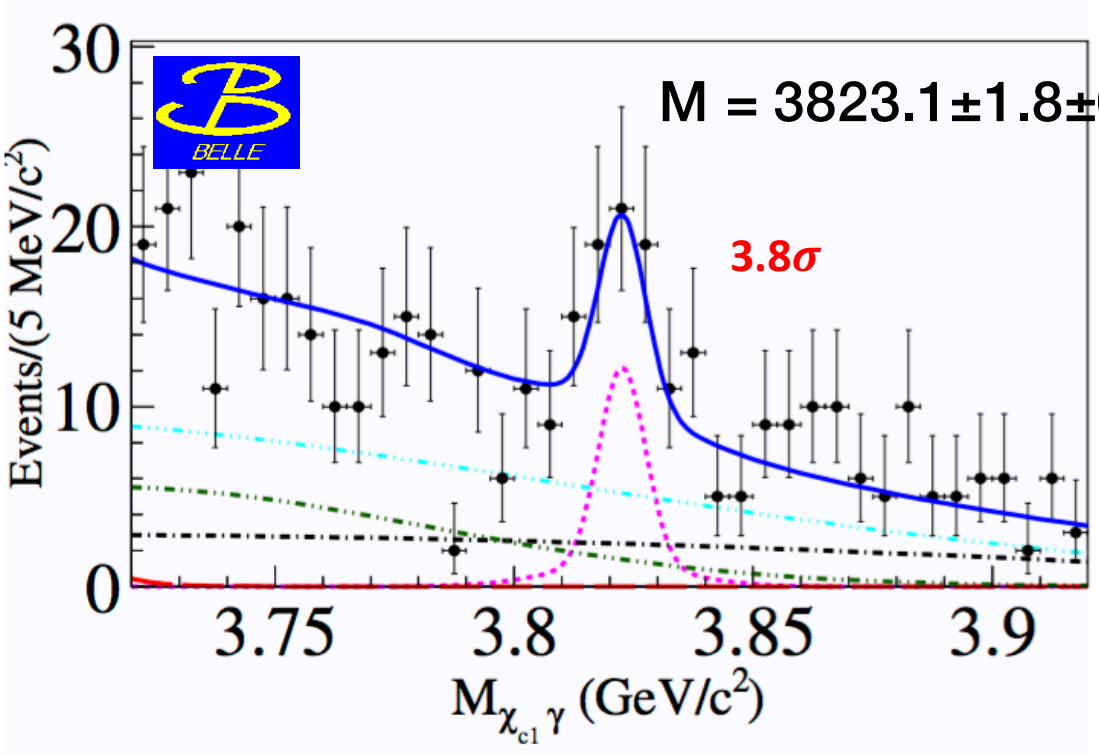
Cross section

$e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi$



→ Suggests production in *Y*(4260) decays

Observation of X(3823)

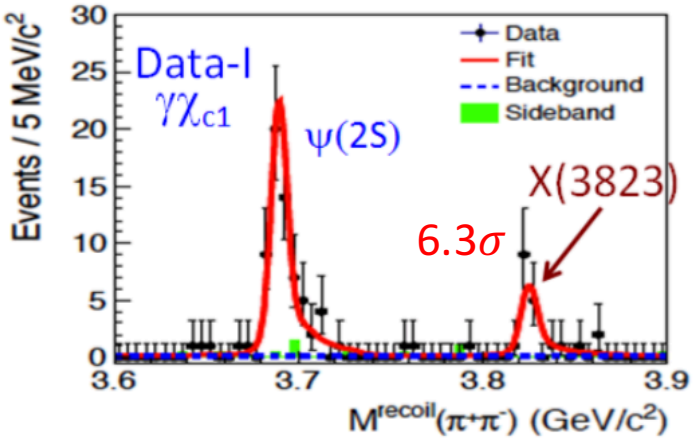


- Using full Belle data set of 772 × 106 BB events $B \to K\gamma\chi_{c1}$
- Simultaneous fit to B^+ and B^0

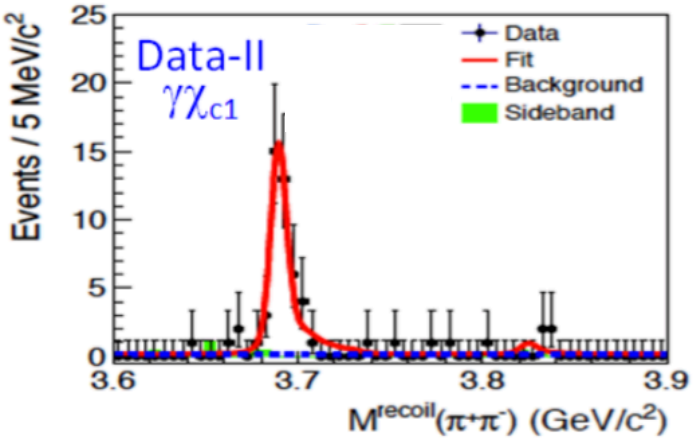
Observation of X(3823)

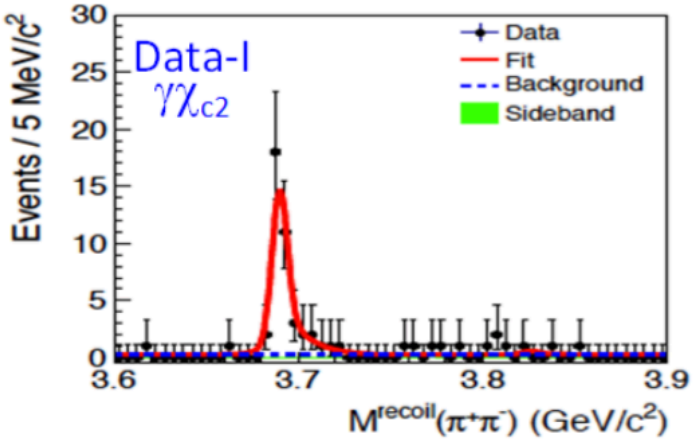
$\mathbf{M_{rec}(\pi^+\pi^-)}$ **in** $\mathbf{e^+e^- \to \pi^+\pi^-\gamma\chi_{c1}}$ **with** $\chi_{c1} \to \gamma J/\psi$

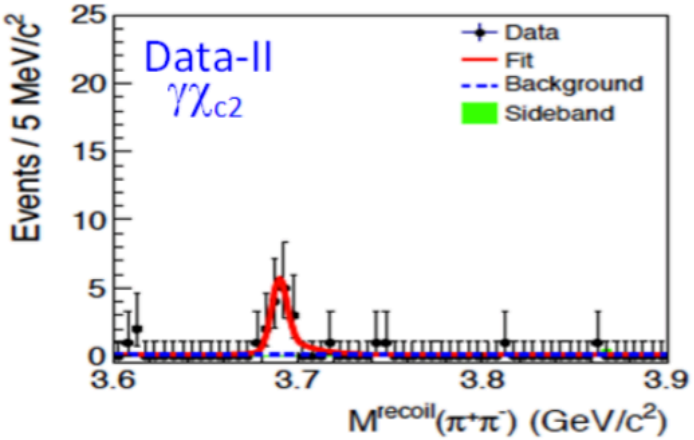
$\sqrt{S} \geq 4.36$GeV



$\sqrt{S} = 4.23$ and 4.26GeV







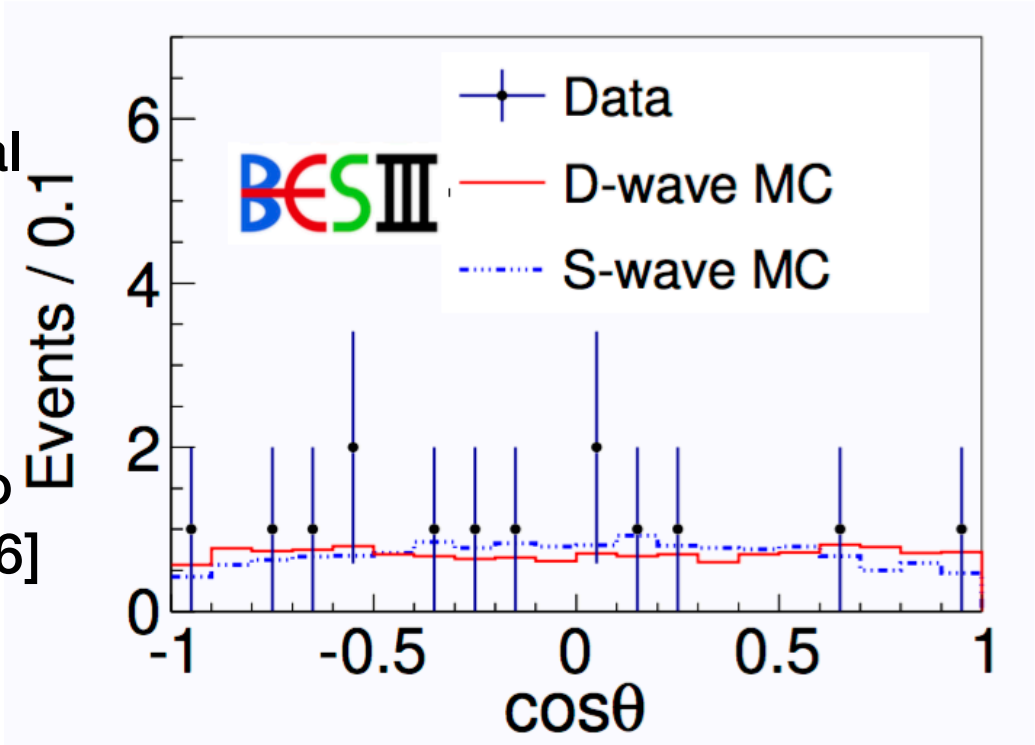
BESIII, PRL 115, 011803

Observation of X(3823)

Mass and width:
In agreement with potential model prediction for 1^3D_2

J^P by exclusion:

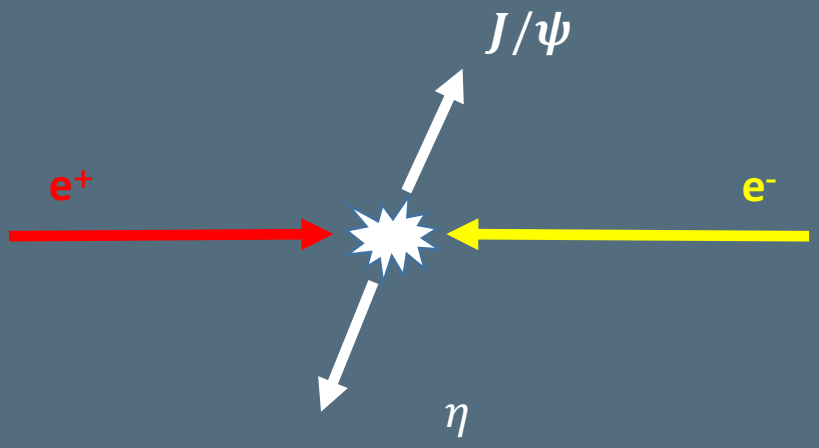
- $1^1D_2 \rightarrow \gamma\chi_{c1}$ forbidden
- $1^3D_3 \rightarrow \gamma\chi_{c1}$ expected to be small [PRD72 054026]



Good candidate for $\psi_2(1^3D_2)$!

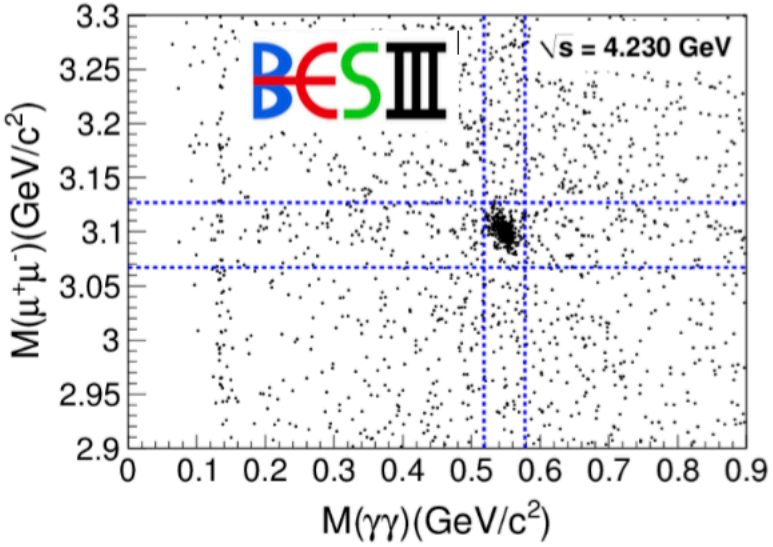
Angular distribution $\theta \equiv \angle(\pi\pi, \psi_2)$ assuming $\pi\pi$ system in S-wave: $1 + \cos^2\theta$ for spin 2

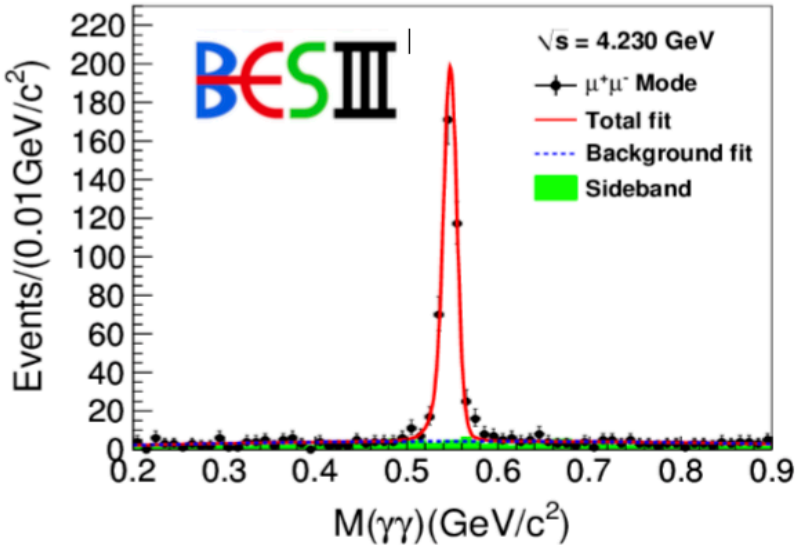
The Y states



Study of $e^+e^- \to \eta J/\psi$

Measure the cross section of $e^+e^- \to \eta J/\psi$
Understand its production mechanism

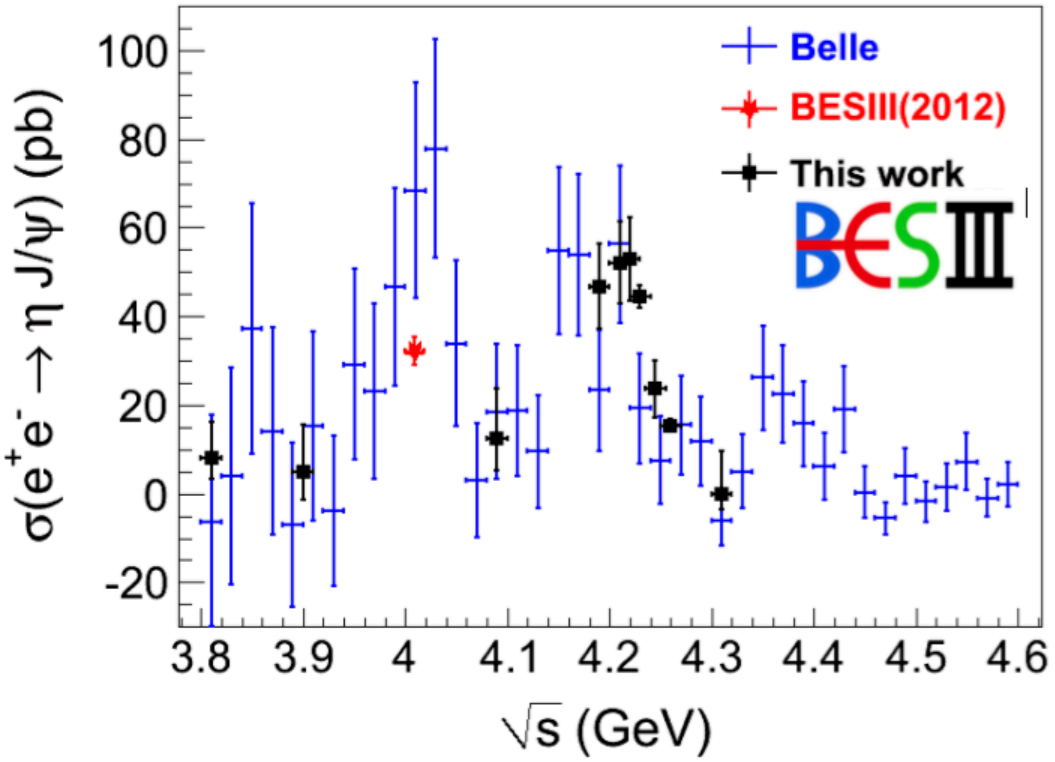




PRD91,11, 112005

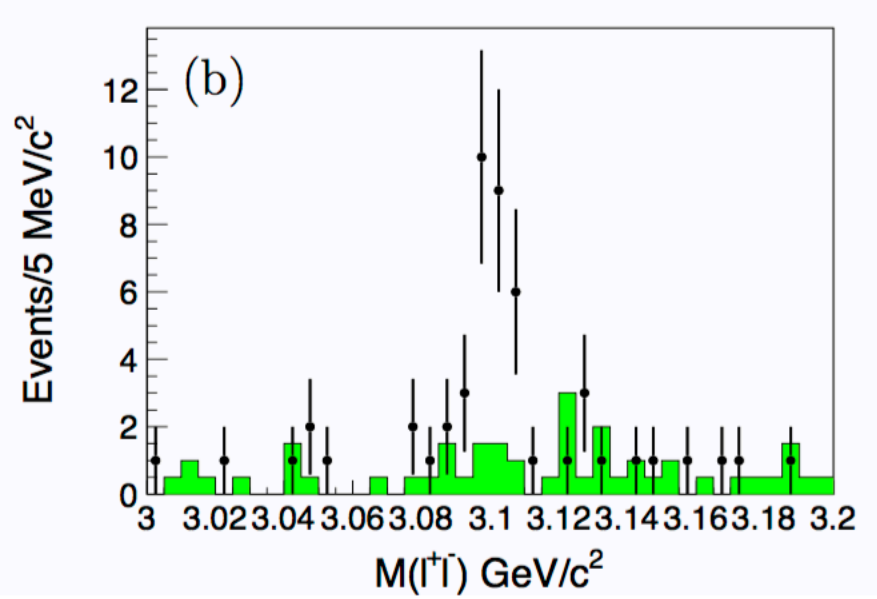
Study of $e^+e^- \to \eta J/\psi$

- Compare to $e^+e^- \to \gamma_{ISR}\eta J/\psi$ from Belle, *[PRD 87, 051101(R) (2013)]* Good agreement, significantly better precision
- Cross section peaks around 4.2 GeV.
- Also searched for $e^+e^- \to \pi^0 J/\psi$: no significant signal found

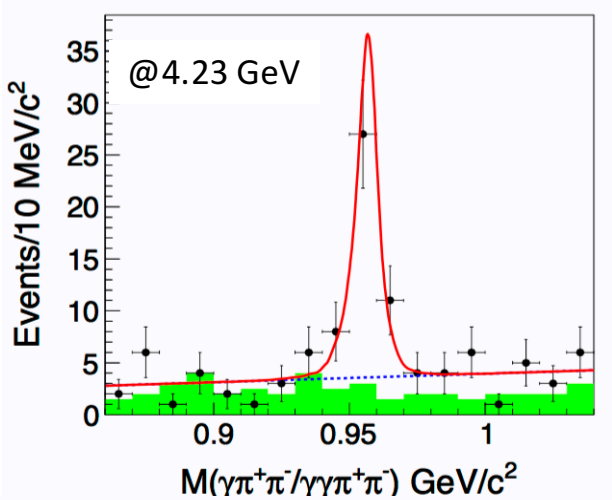


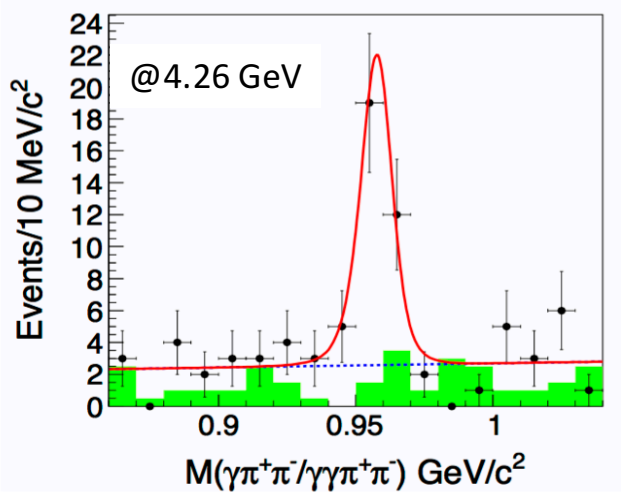
Study of $e^+e^- \to \eta' J/\psi$

- Search for $e^+e^- \to \eta' J/\psi$, and measure the cross section at each $\sqrt{s}$.
- η' is reconstructed by $\pi^+\pi^-\gamma$ and $\pi^+\pi^-\eta$

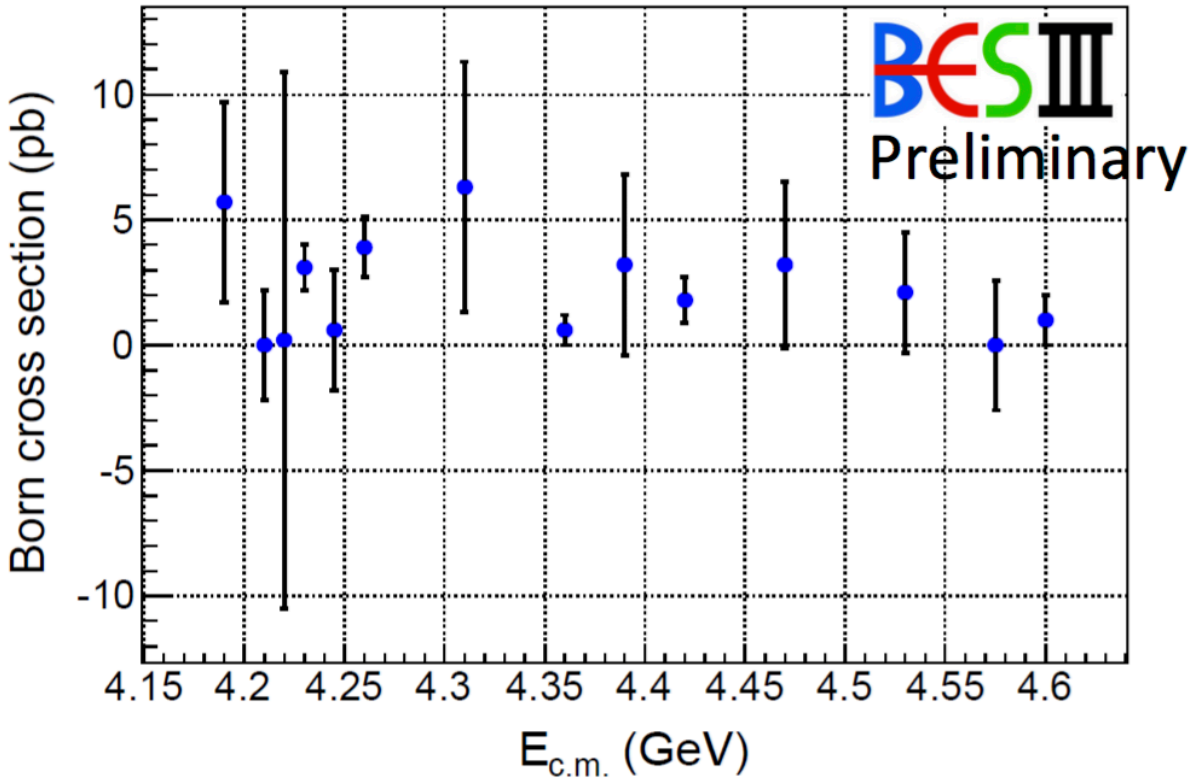


BESIII preliminary





Study of $e^+e^- \to \eta' J/\psi$

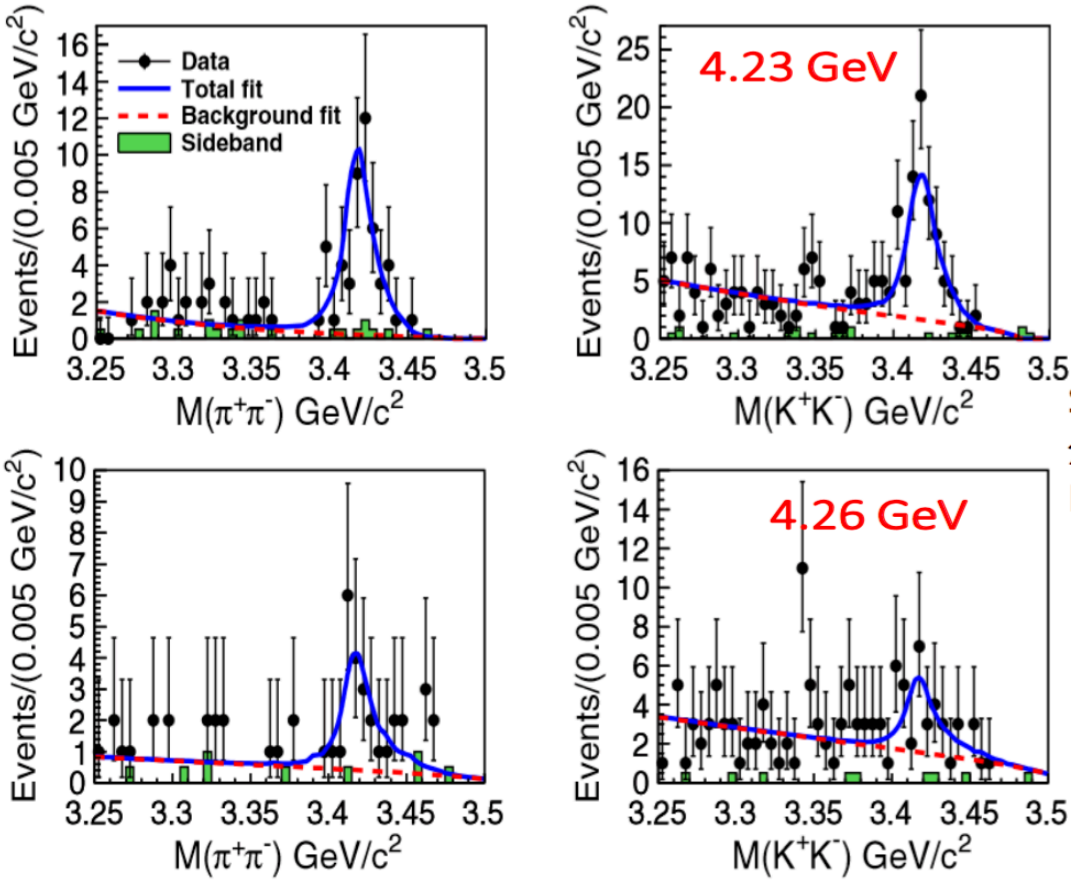


Energy (GeV)	4.300	4.310	4.400	4.420	4.500	4.530	4.600	4.600
Cross section(pb)	34.1	< 5.3	24.2	< 14.7	16.4	< 4.0	12.6	< 5.8

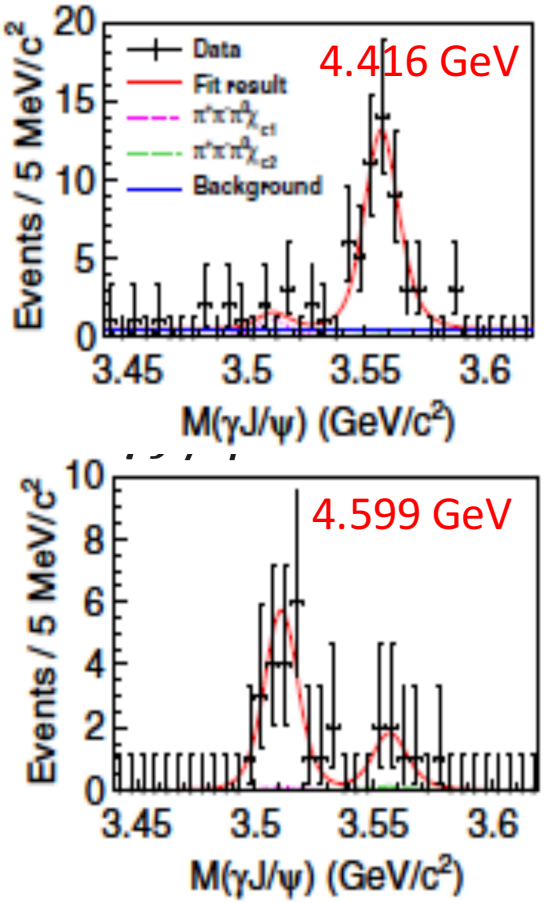
Lower than NRQCD calculation. (PRD 89, 074006(2014))

Study of $e^+e^- \to \omega\chi_{cJ}$

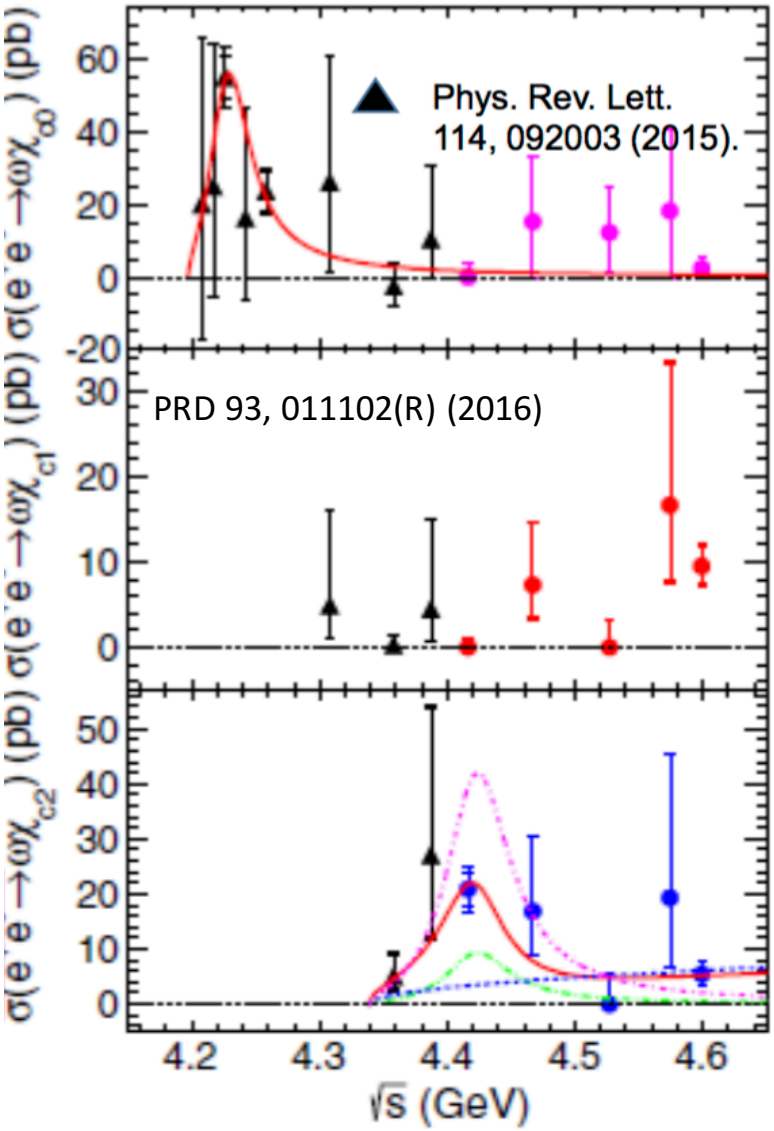
$e^+e^- \to \omega\chi_{c0}; \chi_{c0} \to K^+K^-/\pi^+\pi^-$



$e^+e^- \to \omega\chi_{c1,2}; \chi_{c1,2} \to \gamma J/\psi$



Study of $e^+e^- \to \omega\chi_{cJ}$



$\sigma(e^+e^- \to \omega\chi_{c0})$:
PS modified BW with
M = 4230±8±6 MeV/c² & Γ =(38±12±2) MeV
Significance > 9σ, Inconsistent with Y(4260)

$\sigma(e^+e^- \to \omega\chi_{c1})$:
Statistics is too small to draw a conclusion

$\sigma(e^+e^- \to \omega\chi_{c2})$:
Coherent sum of ψ(4415) BW and PHS

Discussion

- Inter structure of Z?
  - Hadronic molecules
  - Tetraquarks
  - Hadro-quarkonium

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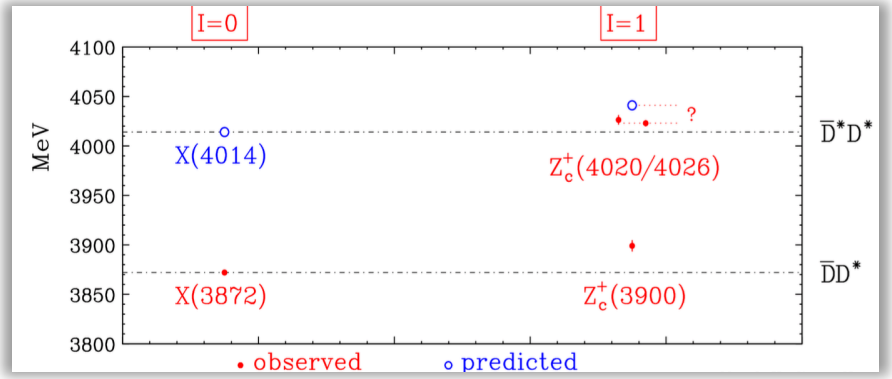

- Relationship between Z and X?
  - One possible scenario
  - Need more evidence

- Is Y(4260) a resonance or there have fine structure? More Y states?
  - More exclusive process & better precision

Summary

BESIII have made great contribution in exotic charmonium research since 2013.

- Z
  - Observation of Z(3900) provides strong evidence for the existence of tetra-quark states.
  - Systematic study of Z(3900) and Z(4020)
- X
  - Radiative transition between Y and X
  - Observation of X(3823)
- Y
  - More fine structures are observed in many exclusive processes

With the coming larger data, more exciting physics results will come soon!

The BESIII collaboration

11 countries
58 institutes
~450 members

Back up