中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

BESIII

STUDIES OF XYZ AT BESIII

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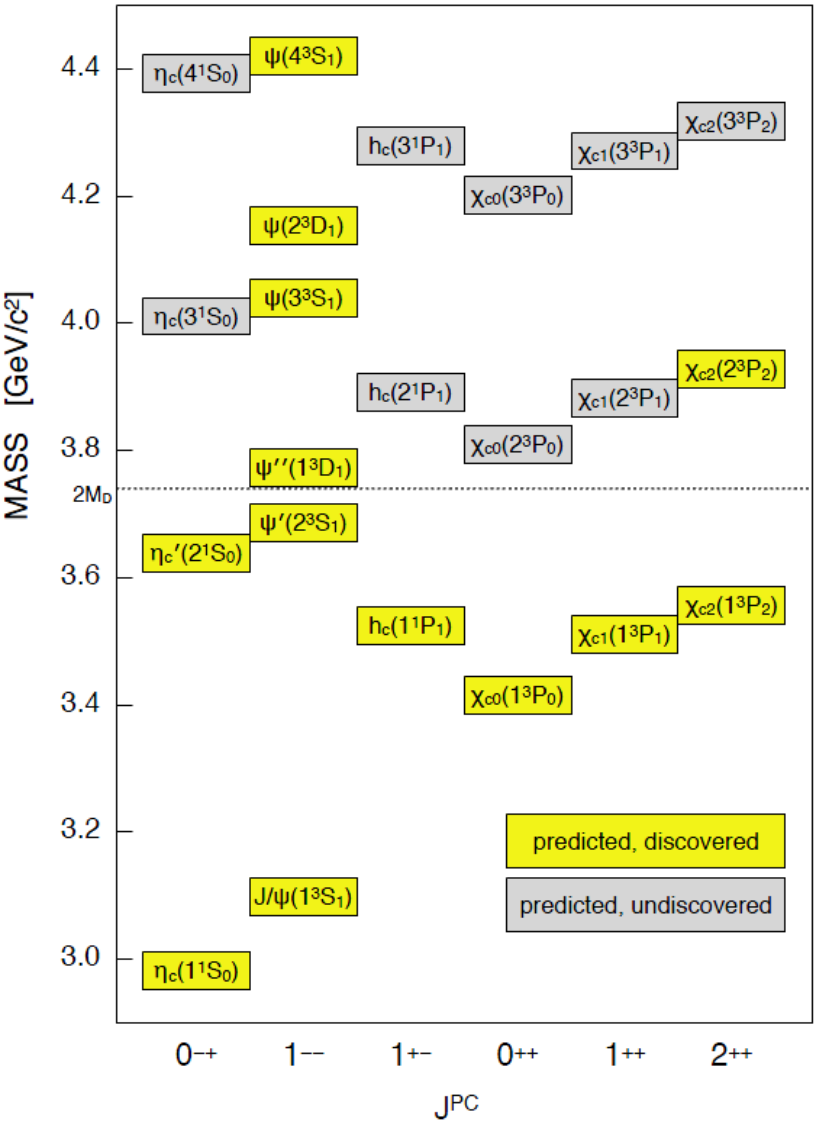
ICHEP2018 SEOUL
XXXIX INTERNATIONAL CONFERENCE ON high Energy PHYSICS
JULY 4 - 11, 2018 COEX, SEOUL

Outline

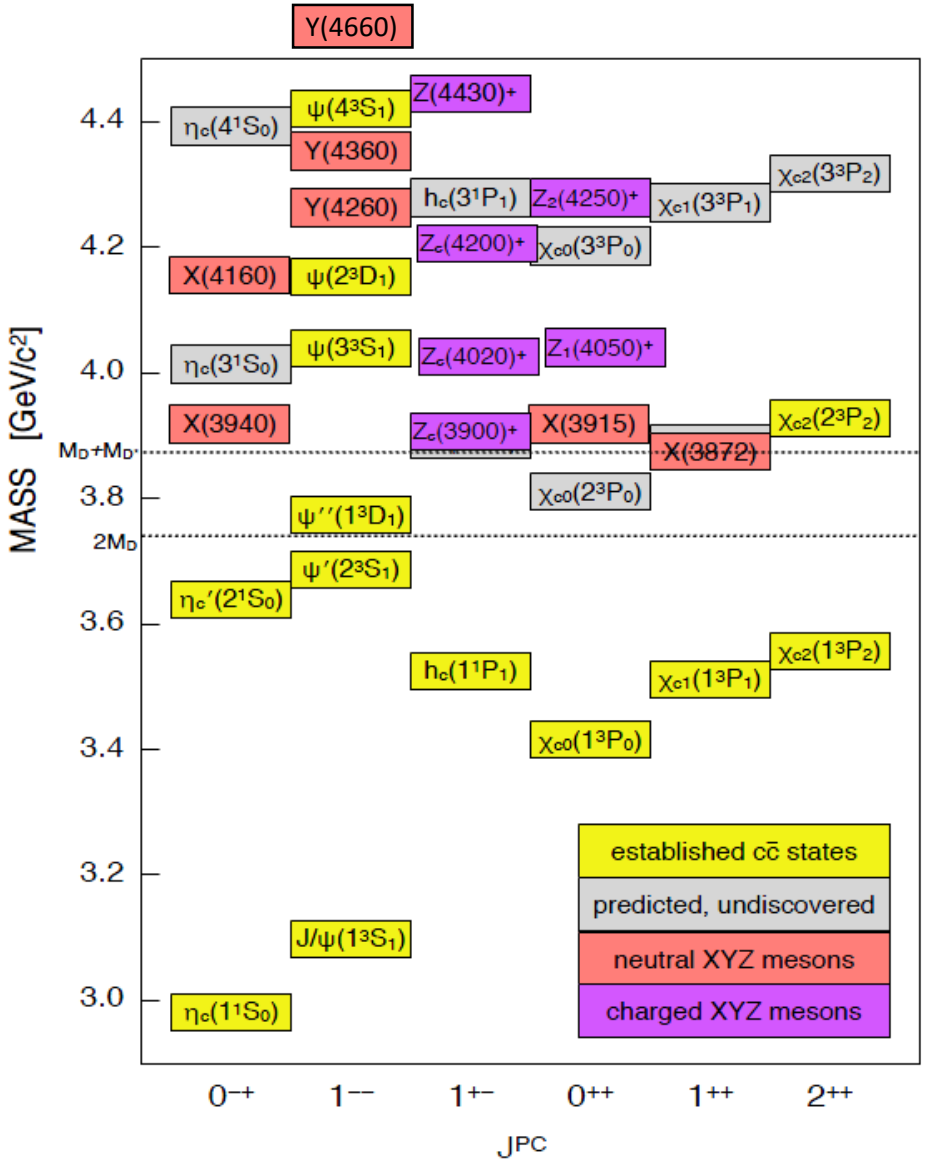
- Introduction
  - Charmonium and XYZ spectrum
  - BEPCII and BESIII
  - BESIII data samples
- Studies of XYZ states
- Summary and Outlook

Charmonium and XYZ spectrum



- **Below open-charm threshold**
  - ✓ Good agreement between experimental measurements and theoretical predictions
- **Above open-charm threshold**
  - Many expected states not discovered

Charmonium and XYZ spectrum

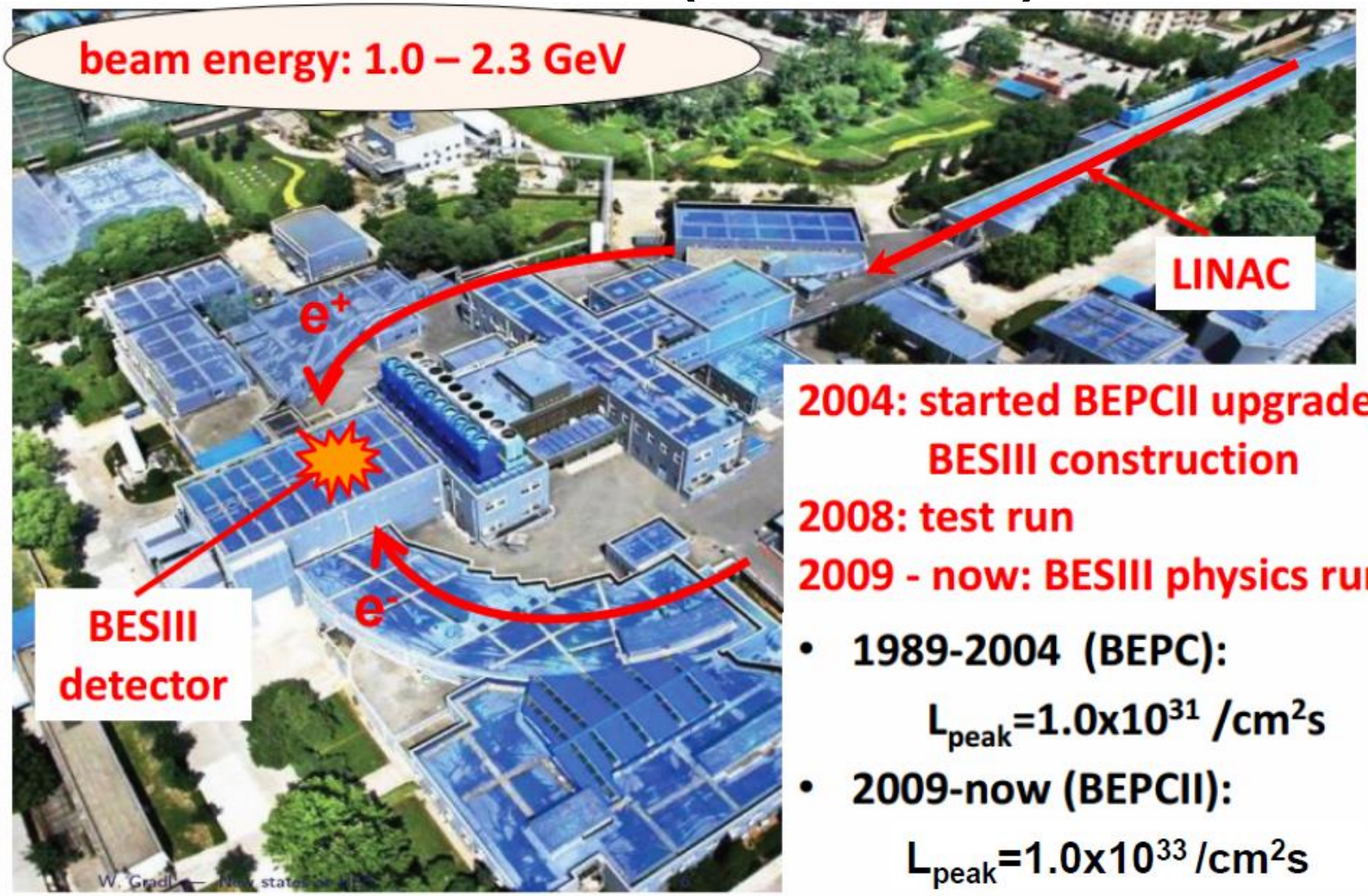


- ➢ **Below open-charm threshold**
  - ✓ Good agreement between experimental measurements and theoretical predictions
- ➢ **Above open-charm threshold**
  - Many expected states not discovered
  - Many unexpected states observed:
    - charmonium final states
    - no conventional charmonium states assignment
    - called **charmonium-like or XYZ states**

➢ **To do list**

- ☐ New decay modes of known charmonium(-like) states
- ☐ New charmonium(-like) states

Beijing Electron and Positron Collider(BEPCII)



2004: started BEPCII upgrade,
BESIII construction

2008: test run

2009 - now: BESIII physics run

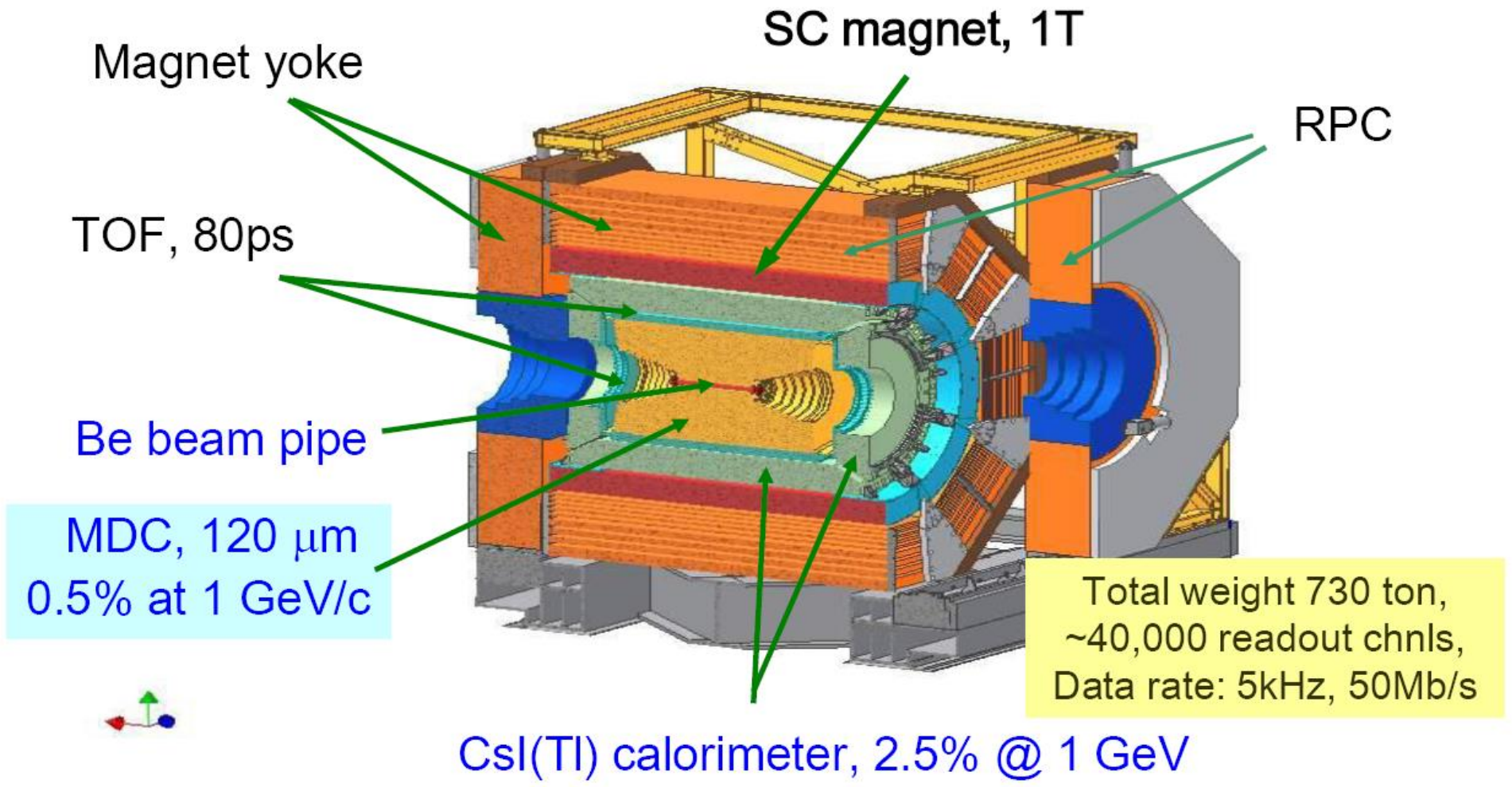
- 1989-2004 (BEPC):

  $L_{peak}=1.0\times10^{31}$ /cm^{2}s

- 2009-now (BEPCII):

  $L_{peak}=1.0\times10^{33}$ /cm^{2}s

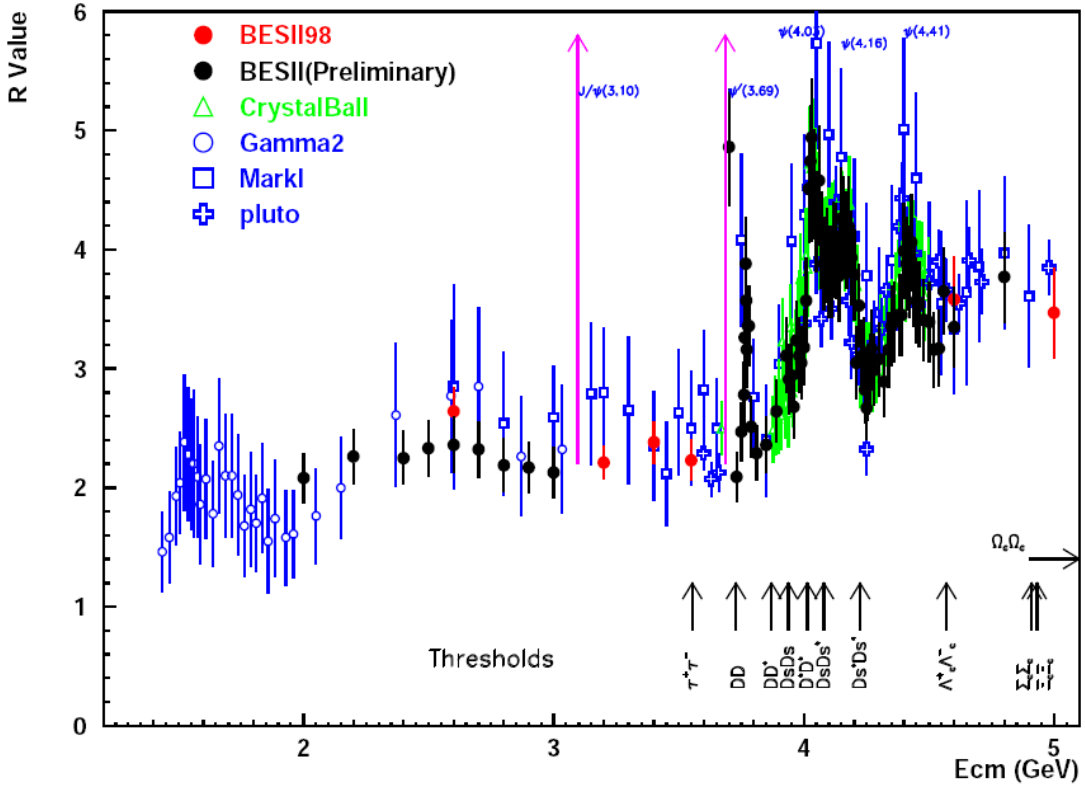
The BESIII detector



Has been in full operation since 2008!

BESIII data Samples

2009: 106M ψ(2S)
225M J/ψ
2010: 975 pb^{-1} at ψ(3770)
2011: 2.9 fb^{-1} at **ψ(3770)** *(total)*
482 pb^{-1} at **4.01 GeV**
2012: 0.45B **ψ(2S)** *(total)*
1.3B **J/ψ** *(total)* 2018 → 5.0B J/ψ
2013: 1092 pb^{-1} at **4.23 GeV**
826 pb^{-1} at **4.26 GeV**
540 pb^{-1} at **4.36 GeV**
~50 pb^{-1} at **3.81, 3.90, 4.09, 4.19, 4.21**
4.22, 4.245, 4.31, 4.39, 4.42 GeV
2014: 1029 pb^{-1} at **4.42 GeV**
110 pb^{-1} at **4.47 GeV**
110 pb^{-1} at **4.53 GeV**
48 pb^{-1} at **4.575 GeV**
567 pb^{-1} at **4.6 GeV**
0.8 fb^{-1} **R-scan** from 3.85 to 4.59 GeV (104 points)
2015: **R-scan** from 2-3 GeV + **2.175 GeV** data
2016: ~3fb^{-1} at 4.18 GeV (for **D$_s$**)
2017. 500/pb each for 7 energy points between 4.19~4.28 GeV
400/pb around chic_c1
200/pb around X(3872)



~ 130 points for R scan (~1.3 fb^{-1})

~ 8 fb^{-1} above 4.0 GeV in total

Studies of XYZ states

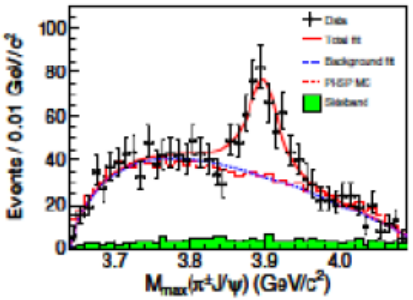
- The Z_c states — Phys. Rev. Lett 119, 072001 (2017)

  ----- Determination of J^P of $Z_c(3900)$

- $e^+e^- \to \pi^0\pi^0\psi(3686)$ — Phys. Rev. D 97, 071101(R) (2018)
- $e^+e^- \to K\bar{K}J/\psi$ — Phys. Rev. D 97, 052001 (2018)
- $e^+e^- \to \pi^+D^0D^{*-}$ — Preliminary result
- $e^+e^- \to \phi\chi_{c1,2}$ — Phys. Rev. D 97, 032008 (2018)

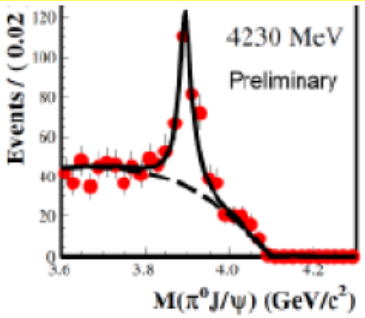
The Z_c states

PRL 110, 252001 (2013)



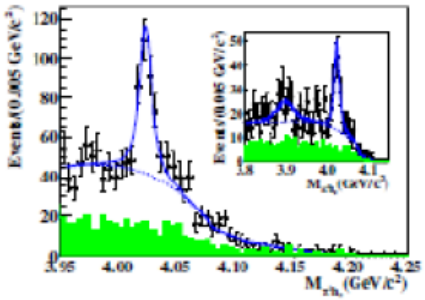
$e^+e^- \to \pi^-\pi^+ J/\psi$

PRL 115, 112003 (2015)



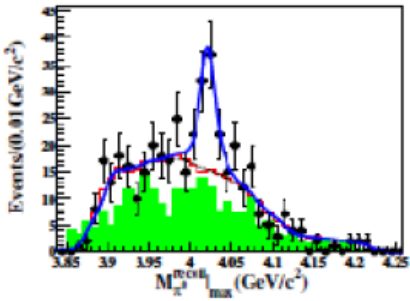
$e^+e^- \to \pi^0\pi^0 J/\psi$

PRL 111, 242001(2013)



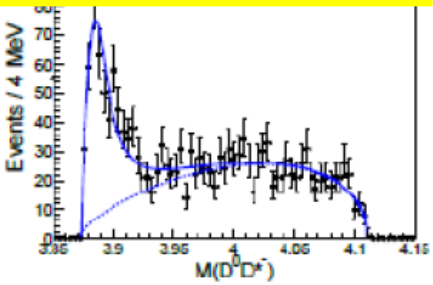
$e^+e^- \to \pi^-\pi^+ h_c$

PRL113,212002 (2014)



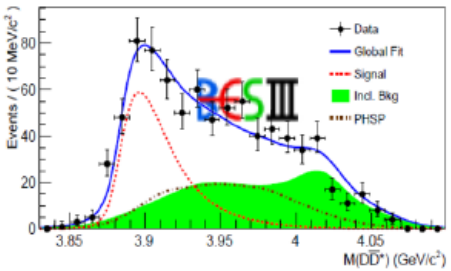
$e^+e^- \to \pi^0\pi^0 h_c$

ST: PRL 112, 022001(2014)
DT: PRD92, 092006 (2015)



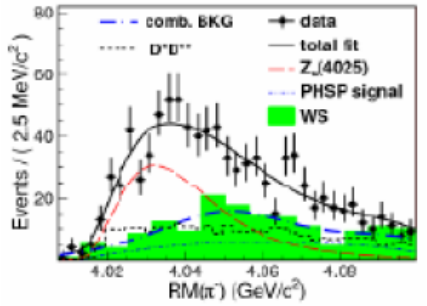
$e^+e^- \to \pi^-(D\bar{D}^*)^+$

PRL 115, 222002 (2015)



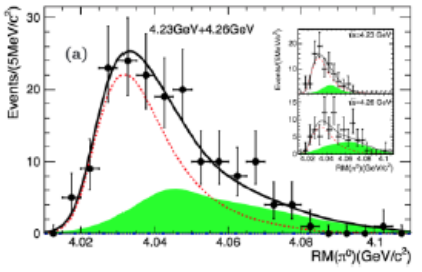
$e^+e^- \to \pi^0(D^*\bar{D}\ )^0$

PRL 112, 132001 (2014)



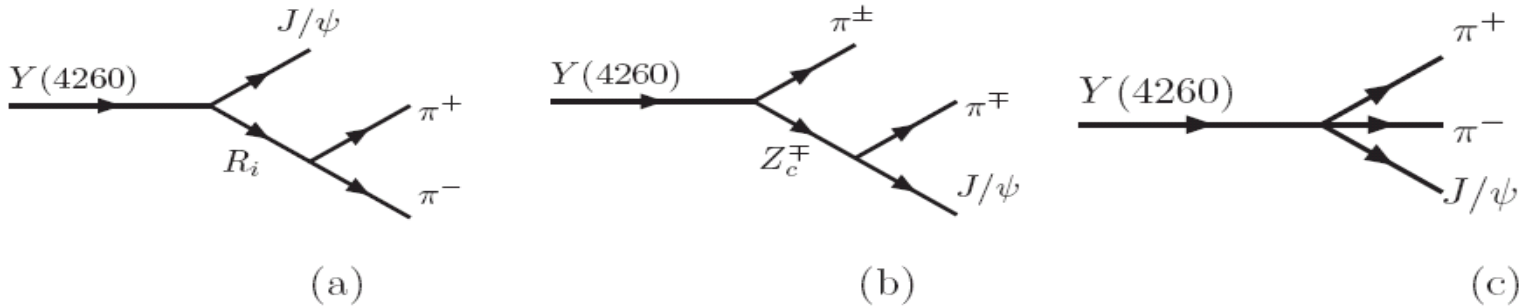
$e^+e^- \to \pi^-(D^*\bar{D}^*)^+$

PRL115, 182002 (2015)

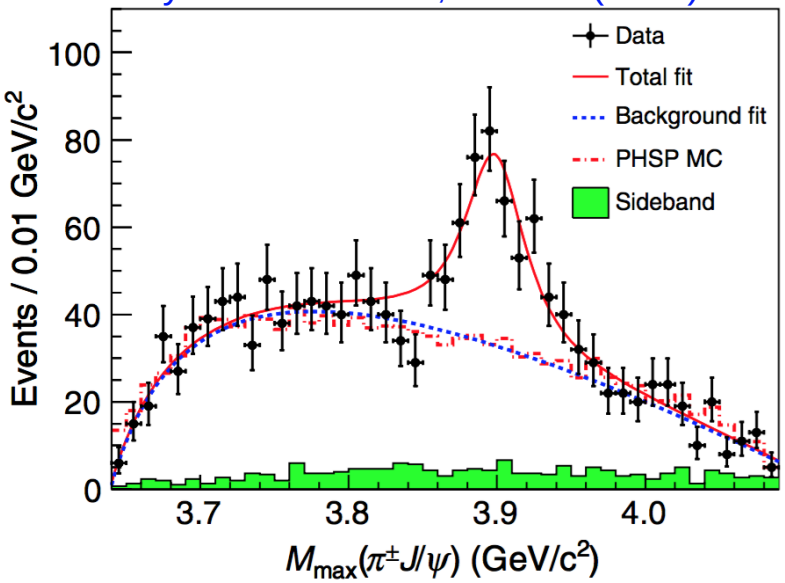


$e^+e^- \to \pi^0(D^*\bar{D}^*)^0$

Determination of J^P of $Z_c(3900)$



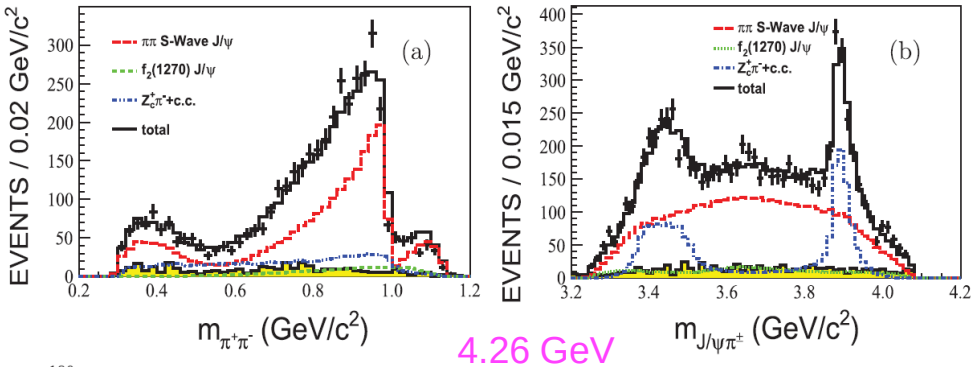
Phys. Rev. Lett 110, 252001 (2013)



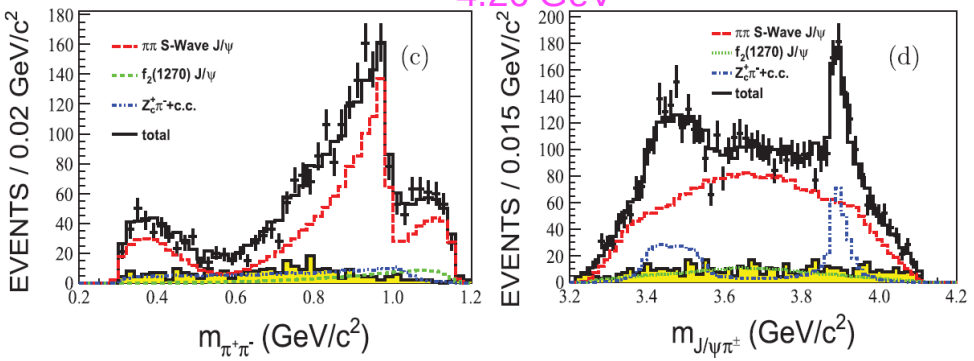
- Six contributions are considered in the amplitude:
  - $\sigma(500)$, $f_0(980)$, $f_2(1270)$, and $f_0(1370)$ in the $\pi^+\pi^-$ mass spectrum;
  - $Z_c(3900)^\pm$ in the $\pi^\pm$J/ψ mass spectrum;
  - The nonresonant process:$e^+e^- \to \pi^+\pi^-$J/ψ.
- Five J^P assumptions: 0^-, 1^-, 1^+, 2^-, and 2^+.

Determination of J^P of $Z_c(3900)$

4.23 GeV



4.26 GeV



- Simultaneous fit to data samples at 4.23 GeV and 4.26 GeV. $Z_c(3900)^+$ and $Z_c(3900)^-$ states are assumed as isospin partner, share the same mass and coupling constants;
- $Z_c(3900)^{\pm}$ is parameterized with Flatte-like formula:

$$BW(s) = \frac{1}{s - M^2 + i(g_1'\rho_{\pi J/\psi}(s) + g_2'\rho_{D^*D}(s))},$$

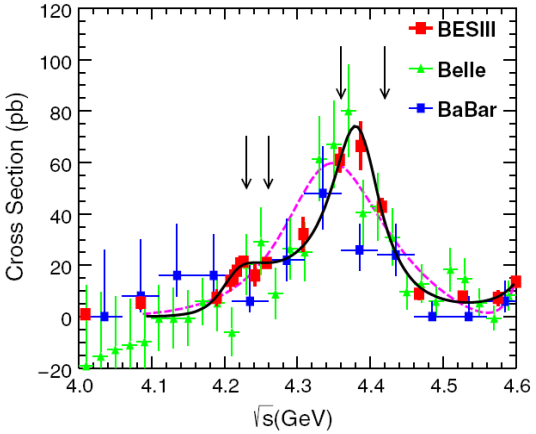
Hypothesis	$\Delta(-2\ln L)$	Δ(ndf)	Significance
1^+ over 0^-	94.0	13	7.6σ
1^+ over 1^-	158.3	13	10.8σ
1^+ over 2^-	151.9	13	10.5σ
1^+ over 2^+	96.0	13	7.7σ

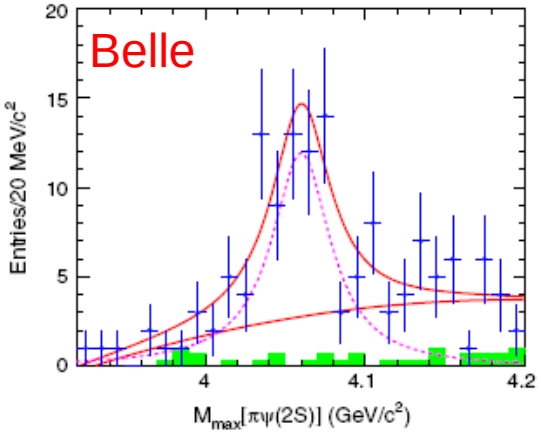
Z_c	Mass	g_1' (GeV^2)	g_2'/g_1'
1^+	3901.5±2.7±38.0	0.075±0.006±0.025	27.1±2.0±1.9

- J^P of Z_c favor to be 1^+ with statistical significance larger than 7σ over other quantum numbers;
- g_2'/g_1' is consistent with previous result 27.1±13.1, estimated based on the measured decay width ratio of $Z_c(3885)^{\pm} \to (D\bar{D}^*)^{\pm}$ and $Z_c(3900)^{\pm} \to \pi^{\pm}J/\psi$.

$e^+e^- \to \pi^0\pi^0\psi(3686)$

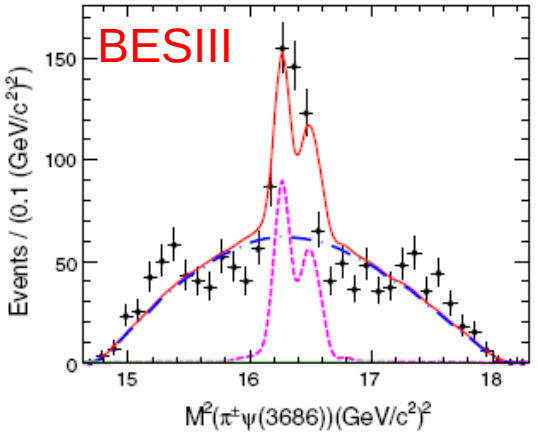
Belle: Phys. Rev. D 91, 112007 (2015) & BESIII: Phys. Rev. D 96, 032004 (2017)





Mass = $(4054 \pm 3 \pm 1)$ MeV/c²

Width = (45±11±6) MeV



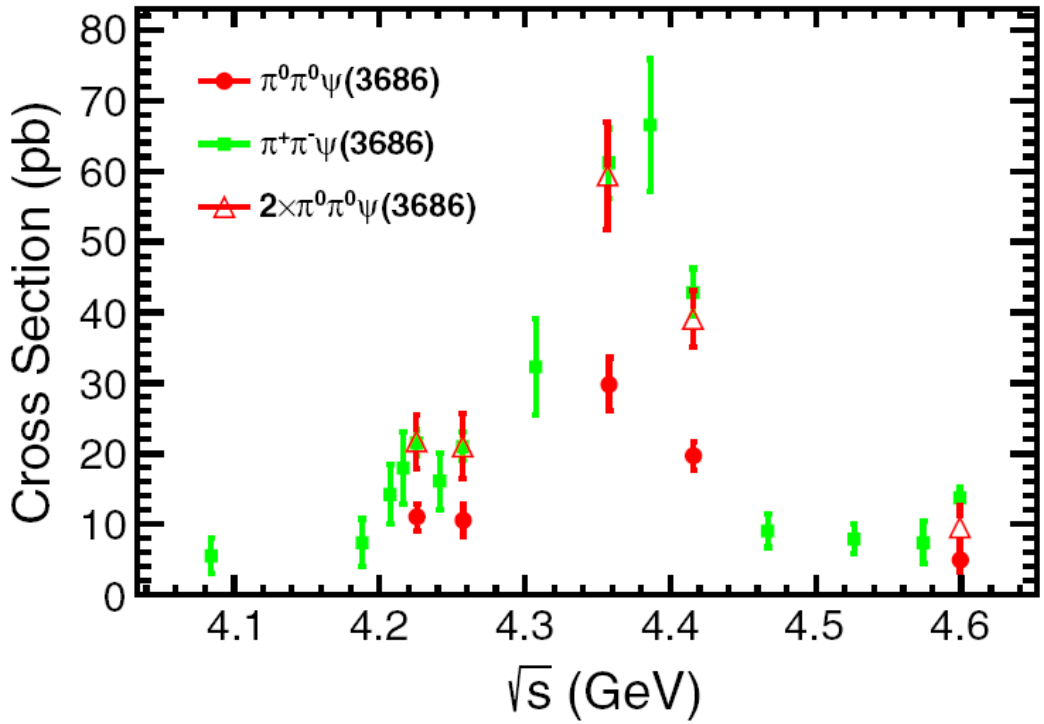
Mass = (4032.1 ± 2.4) MeV/c²

Width = (26.1±5.3) MeV

- Y(4360) was observed and subsequently confirmed in $e^+e^- \to (\gamma_{ISR})\pi^+\pi^-\psi(3686)$ by BABAR, Belle, and BESIII, it is interesting to study the Y(4360) in $\pi^0\pi^0$ transition to $\psi(3686)$ and to examine the isospin symmetry;
- A charmoniumlike structure observed in $\pi^\pm\psi(3686)$ invariant mass by BESIII and Belle measurements. We can search for its neutral isospin partner in $e^+e^- \to \pi^0\pi^0\psi(3686)$.
- The width of the intermediate state in BESIII measurement varies in a wide range for different kinematic region within the data set, more data and theoretical input are necessary.

Phys. Rev. D 97, 052001 (2018)

$e^+e^- \to \pi^0\pi^0\psi(3686)$

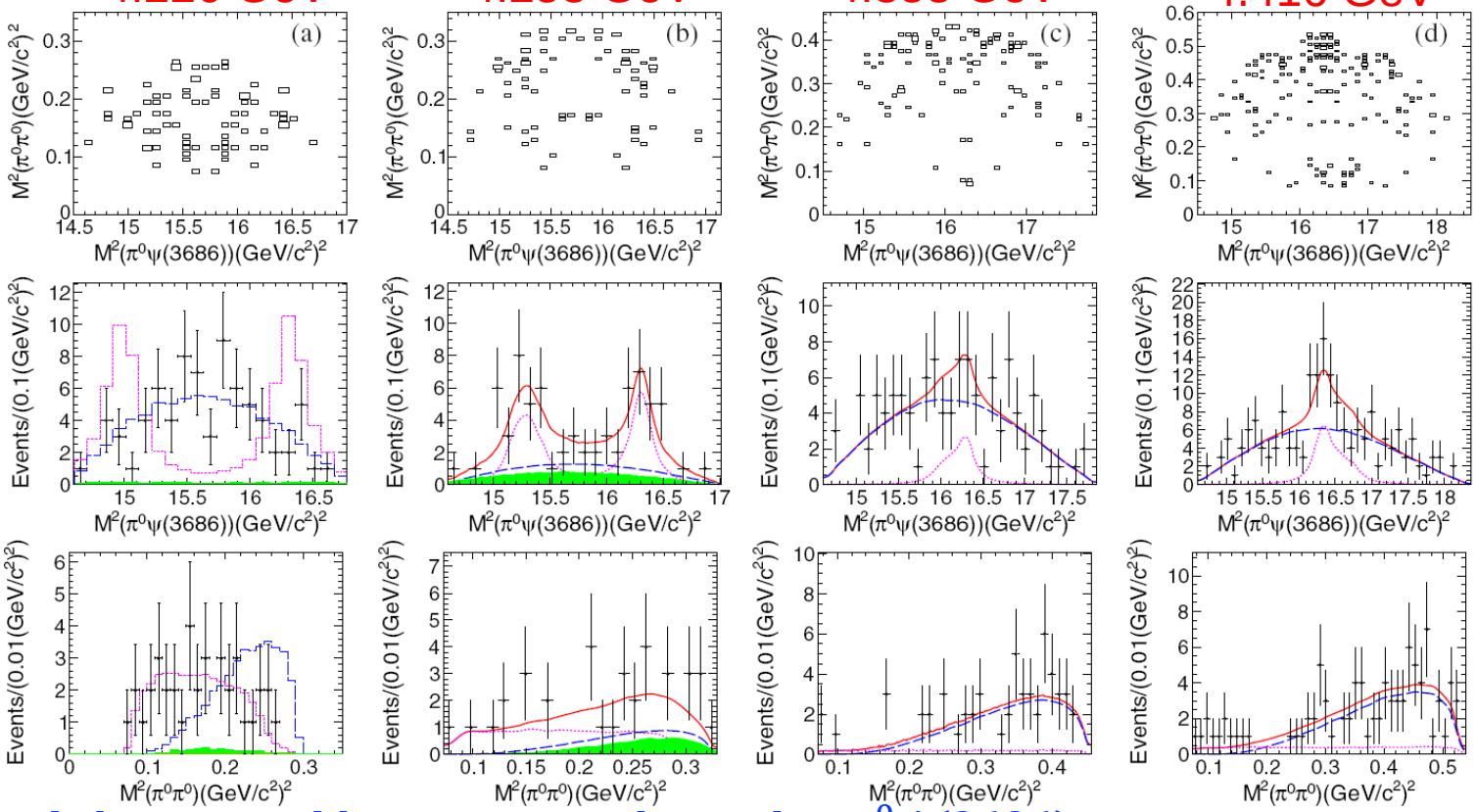


- Decay channel: $e^+e^- \to \pi^0\pi^0\psi(3686)$, $\psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to \ell^+\ell^-(\ell = e \ or \ \mu)$;
- 16 energy points from $\sqrt{s}$ = 4.008 to 4.600 GeV, the total luminosity is about 5.2 fb^{-1};
- The result of cross section measurement is consistent with the charged mode from isospin symmetry.

Phys. Rev. D 97, 052001 (2018)

$e^+e^- \to \pi^0\pi^0\psi(3686)$

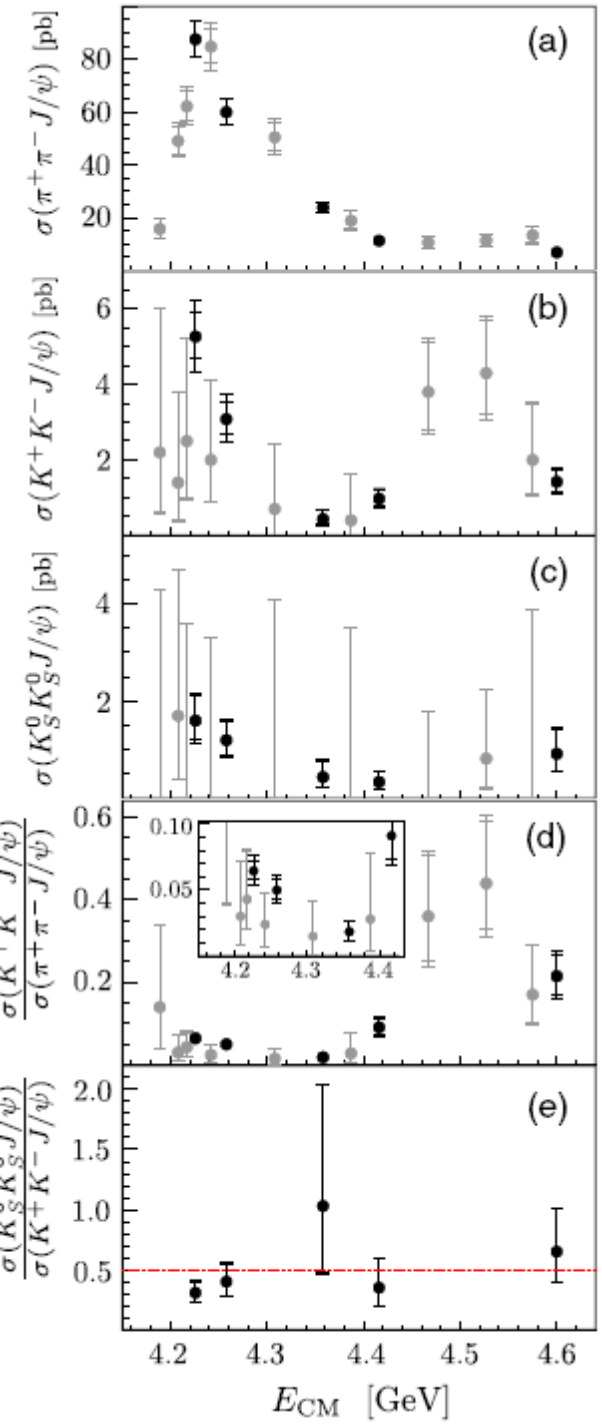
4.226 GeV | 4.258 GeV | 4.358 GeV | 4.416 GeV

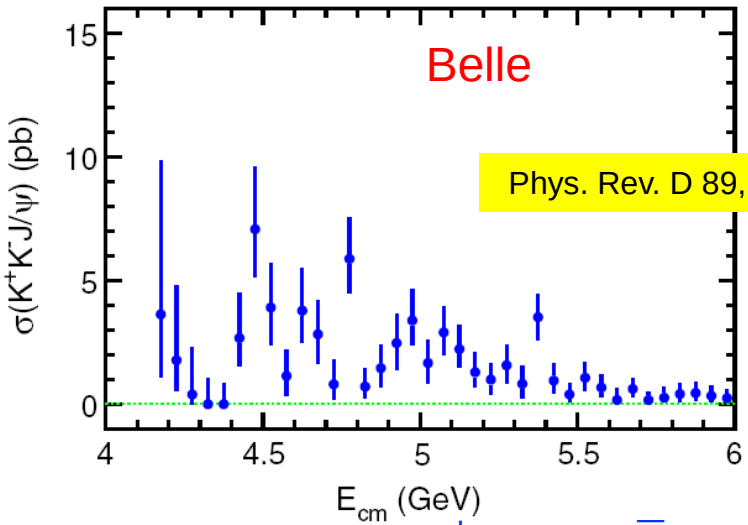


- A neutral charmoniumlike structure is observed in $\pi^0\psi(3686)$ invariant mass;
- A simple fit with S-wave Breit-Wigner function is performed, and yield a mass with mass (4038.7 ± 6.5) MeV/c^2, which confirms the structure in the charged mode;
- No obvious $Z_c(3900)^0$ state is observed in the fit.

Phys. Rev. D 97, 071101(R) (2018)

$e^+e^- \to K\bar{K}J/\psi$

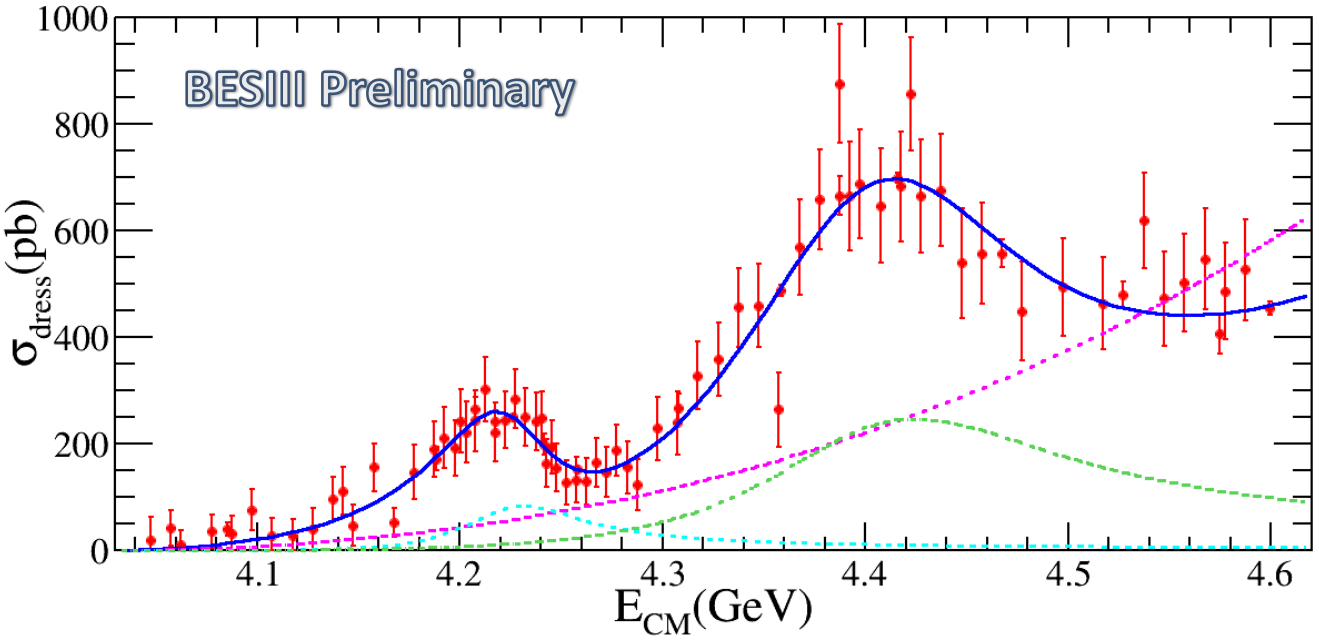




Phys. Rev. D 89, 072015 (2014)

- Measure the cross section of $e^+e^- \to K\bar{K}J/\psi$ at c.m. energies from 4.189 to 4.600 GeV.
- The energy dependence of the cross section for $e^+e^- \to K^+K^-J/\psi$ is shown to differ from that for $\pi^+\pi^-J/\psi$ in the region around the Y(4260);
- The ratio of cross sections for $e^+e^- \to K^+K^-J/\psi$ and $e^+e^- \to K_S^0K_S^0J/\psi$ is consistent with expectations from isospin conservation.

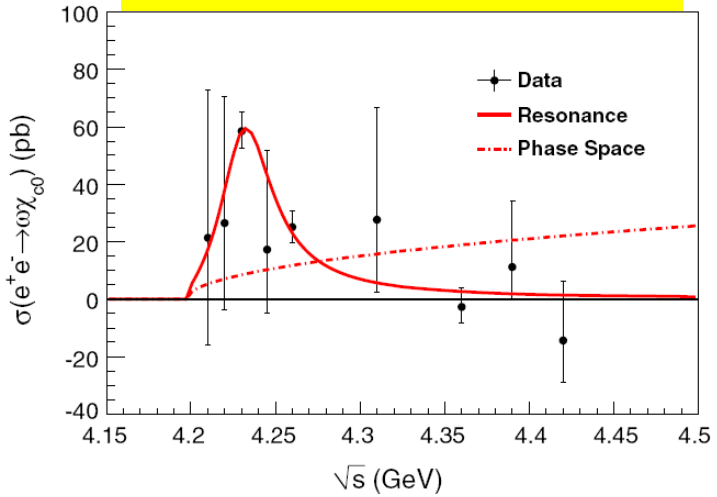
$e^+e^- \to \pi^+ D^0 D^{*-}$



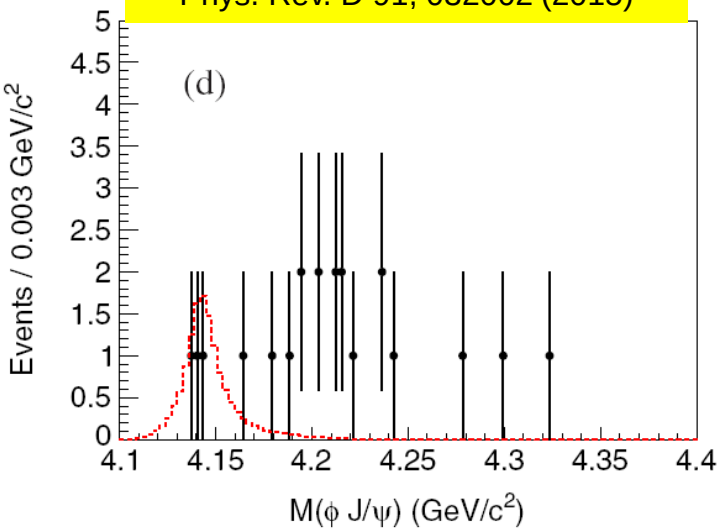
- Most precise cross section measurement for center-of-mass energy from 4.05 to 4.60 GeV;
- Fit with a coherent sum of three-body phase space term (pink dashed triple-dot line) and two Breit-Wigner functions (green dashed double-dot line and aqua dashed line);
- The statistical significance of two resonant assumption over one resonant assumption is greater than 10σ;
- $M(Y(4220))$ = (4224.8±5.6±4.0) MeV/c^2, $\Gamma(Y(4220))$ = (72.3±9.1±0.9) MeV.
- $M(Y(4390))$ = (4400.1±9.3±2.1) MeV/c^2, $\Gamma(Y(4390))$ = (181.7±16.9±7.4) MeV.

$e^+e^- \to \phi\chi_{c1,2}$

Phys. Rev. Lett. 114, 092002 (2015)



Phys. Rev. D 91, 032002 (2015)

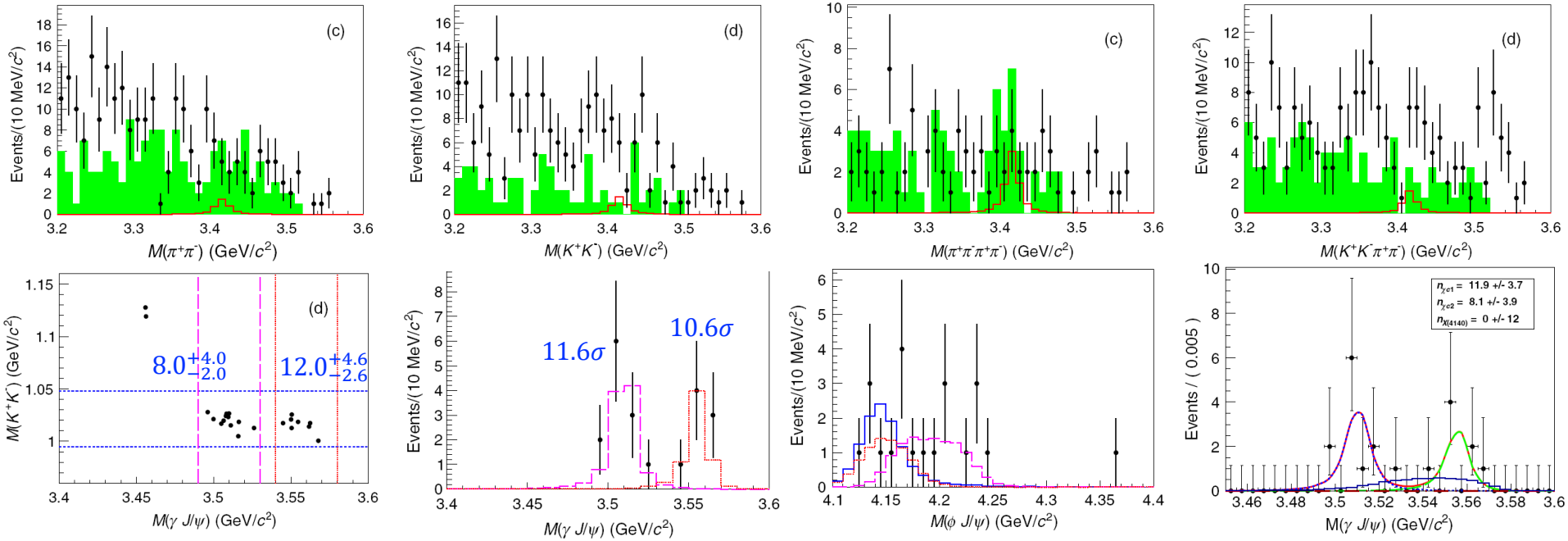


- BESIII has measured the cross section of $e^+e^- \to \omega\chi_{c0}$ and observed an intermediate resonance around 4226 MeV/c2.
- Considering that ω and ϕ have the same spin, parity, and isospin, $\omega\chi_{cJ}$ and $\phi\chi_{cJ}$ may have a similar production mechanism.
- We study the $e^+e^- \to \phi\chi_{c0,1,2}$ at $\sqrt{s} = 4.60$ GeV (567 pb^{-1}), where $\chi_{c0} \to \pi^+\pi^-, K^+K^-, K^+K^-\pi^+\pi^-$, and $\pi^+\pi^-\pi^+\pi^-$, $\chi_{c1,2} \to \gamma J/\psi, J/\psi \to \ell^+\ell^-(\ell = e \; or \; \mu)$, and $\phi \to K^+K^-$.

- BESIII has searched for the Y(4140) in the process of $e^+e^- \to \gamma\phi J/\psi$ with data samples at c.m. energies $\sqrt{s} = 4.23$, 42.6, and 4.36 GeV, but no obvious signal has been observed. We also can repeat this analysis at $\sqrt{s} = 4.60$ GeV.

Phys. Rev. D 97, 032008 (2018)

$e^+e^- \to \phi\chi_{c1,2}$



- No obvious $e^+e^- \to \phi\chi_{c0}$ signals are observed, the production $\sigma(e^+e^- \to \phi\chi_{c0}) < 5.4$ pb @ 90% C.L.;
- The first observation of $e^+e^- \to \phi\chi_{c1}$ and $\phi\chi_{c2}$, $\sigma(e^+e^- \to \phi\chi_{c1}) = 4.2^{+1.7}_{-1.0}$ pb and $\sigma(e^+e^- \to \phi\chi_{c2}) = 6.7^{+3.4}_{-1.7}$ pb;
- No obvious $e^+e^- \to \gamma Y(4140)$ signals are observed, $\sigma(e^+e^- \to \gamma Y(4140)) \times \mathcal{B}(Y(4140) \to \phi J/\psi) < 1.2$ pb @ 90% C.L..

Summary & Outlook

- Recent results of XYZ states at BESIII are presented. BESIII is an active and successful experiment for charmonium(-like) spectroscopy study.
- A new Z_c structure in $\pi\psi(3686)$?
- The J^P of $Z_c(3900)$ is determined to be 1^+.

- ➢ Continue to take data and increase the beam energy;
- ➢ Provide cutting-edge results in charmonium spectroscopy.

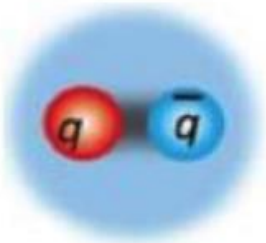
Thank You!

Backup

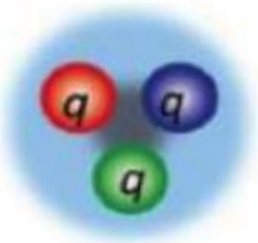
Hadrons: naive and exotic

- Naive quark model:
  - 2 quarks: meson ($q\bar{q}$)
  - 3 quarks: baryon (qqq)
- QCD predicts the exotic states:
  - Multiquark states: $N_{quarks} >= 4$
  - Molecule: bound state of hadrons
  - Hybrid: $N_{quarks} >= 2$ + gluon
  - Glueball: $N_{quarks} = 0$ (gg, ggg, ...)

meson

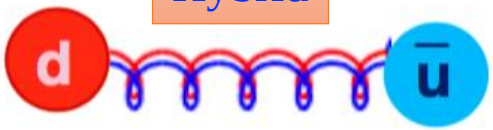


baryon

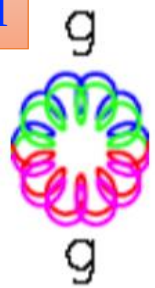


Multiquark

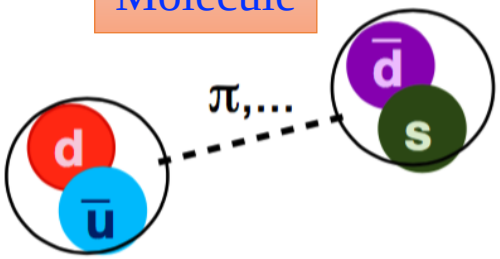
Hybrid



Glueball



Molecule



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