Overview on BESIII recent results

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(for the BESIII Collaboration)

YongPyong-High1 2015

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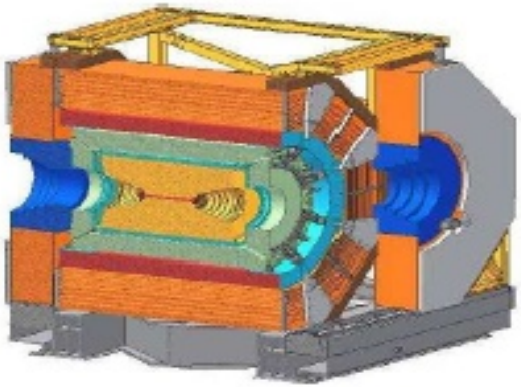
Bird view of BEPCII

BESIII at BEPCII



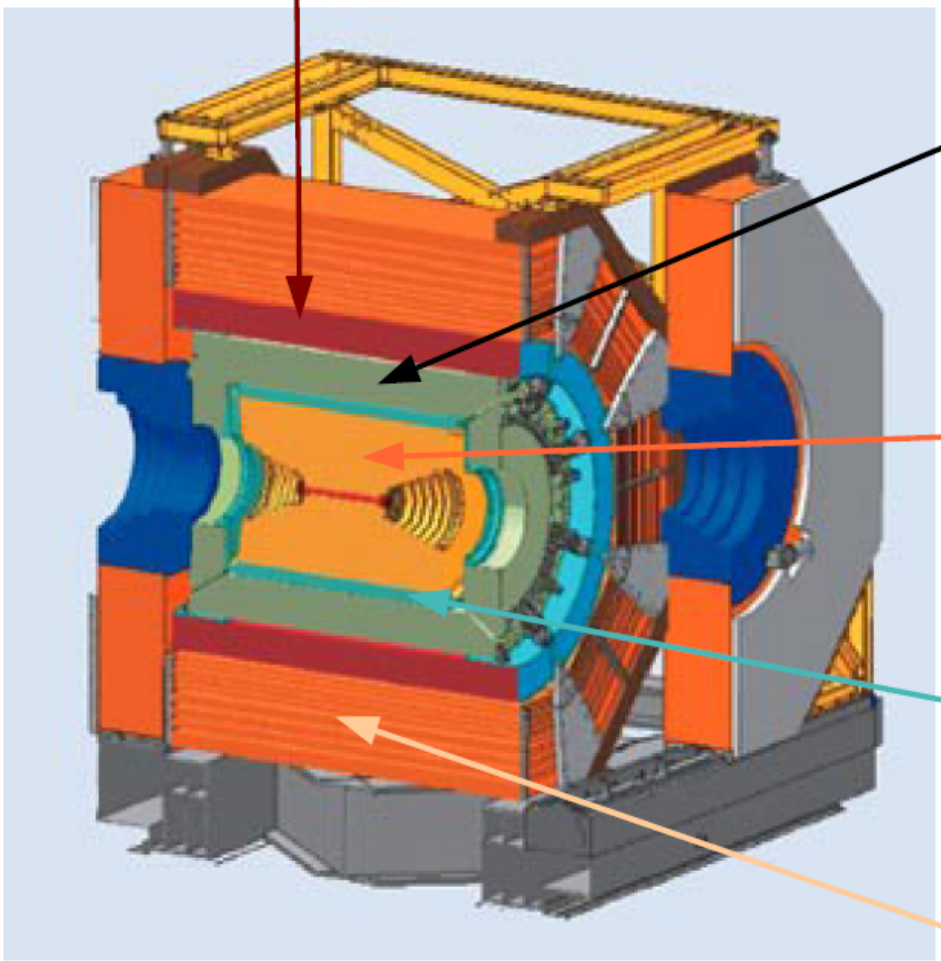
τ –charm physics

- Charmonium(-like) physics
- Light hadron spectroscopy
- Charm physics
- τ physics

The BES-III detector

NIM A614, 345(2010)

Super conducting magnet: 1 T



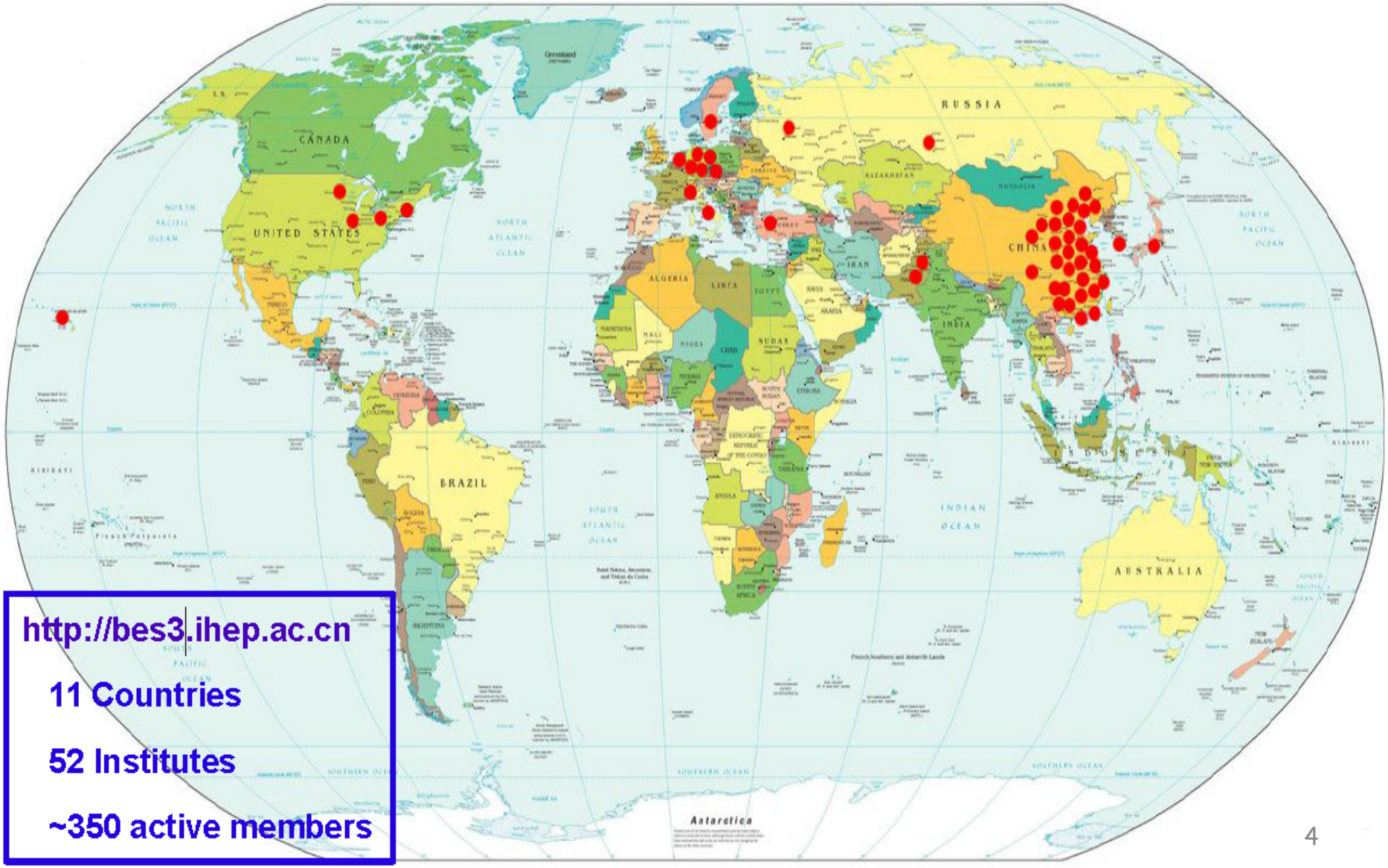
EMC: CsI cristal
- Energy resolution: **2.5% @1GeV**
- Spatial resolution: **6mm**

MDC:
- Spatial resolution: σ_{xy}**= 120μm**
- Momentum resolution:**0.5% @ 1GeV**
- **dE/dx** resolution: 6%

TOF:
Time resolution: **100ps** (barrel)
110ps (endcaps)

Muon ID:
9 layers RPC, 8 for endcaps

The BES-III Collaboration



http://bes3.ihep.ac.cn

11 Countries

52 Institutes

~350 active members

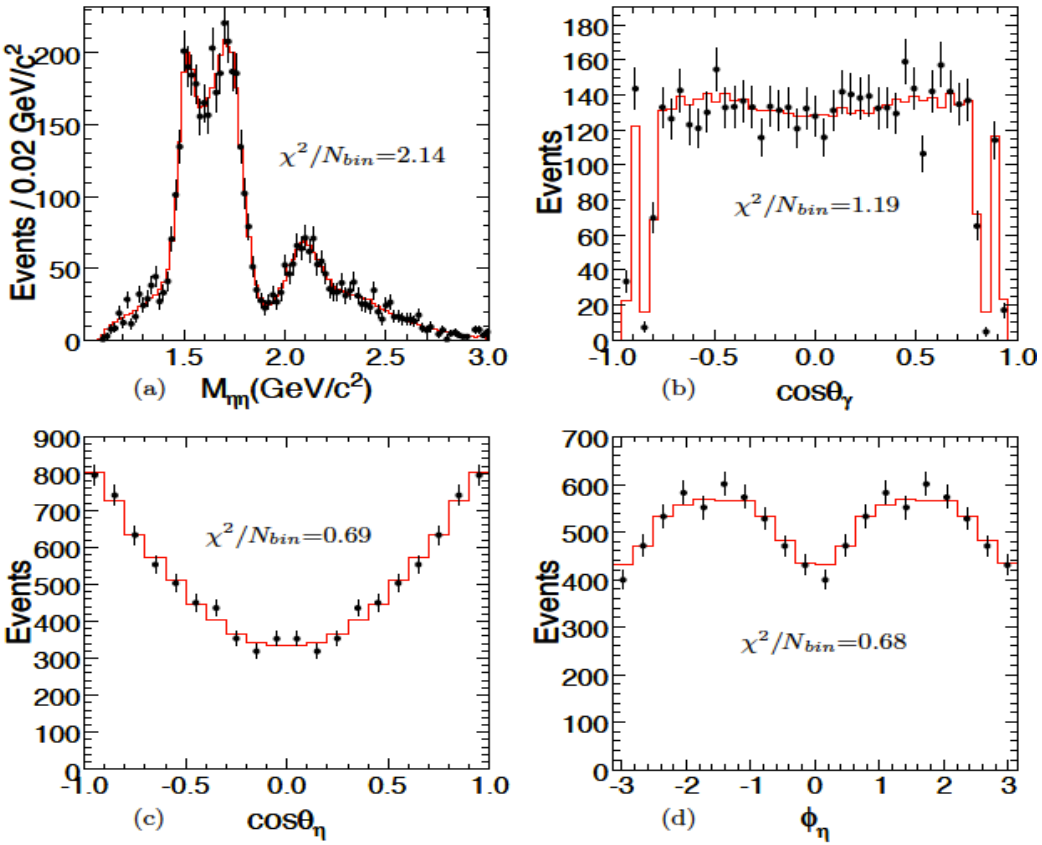
Outline

- Hadron spectroscopy
- charmonium-like physics
- Charm physics
- Summary

Hadron spectroscopy

PWA in J/Ψ→γηη

Phys. Rev. D. 87, 092009 (2013)

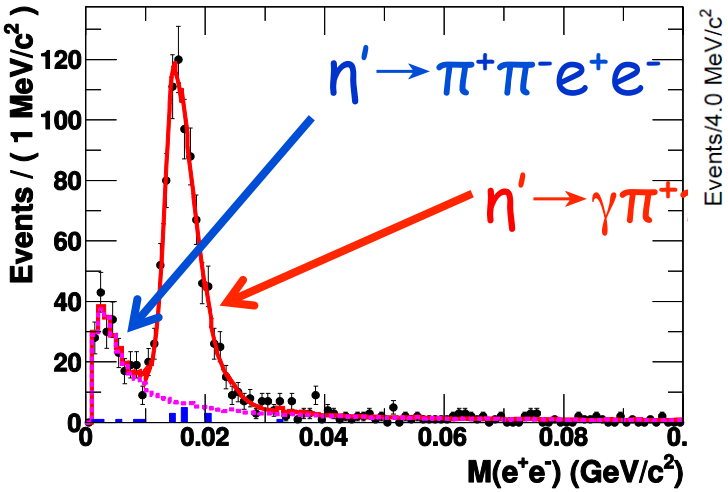


- $f_0(1710)$ and $f_0(2100)$ are dominant scalars
- $f_0(1500)$ exists (8.2σ)
- $f_2'(1525)$ is the dominant tensor
- $f_2(1810)$ and $f_2(2340)$ exist (6.4 and 7.6σ)
- No evidence for $f_J(2220)$

Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0σ
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9σ
$f_2'(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6σ

η and η′ physics at BESIII

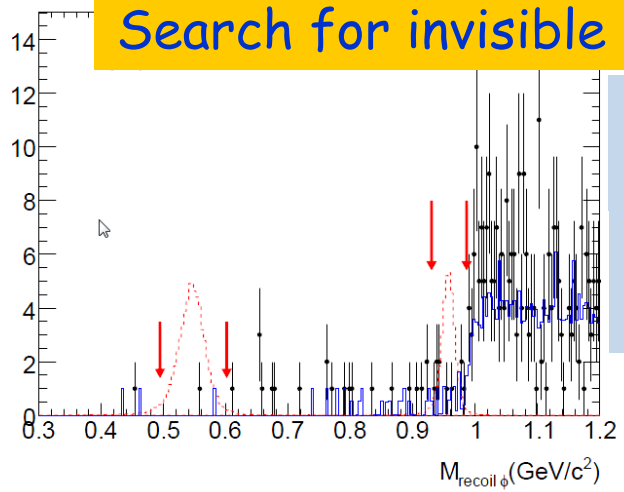
PRD87, 092011 (2013)



$B(\eta' \to \pi^+\pi^- e^+ e^-) = (2.11 \pm 0.12 \pm 0.15) \times 10^{-3}$

PRD87, 032006 (2013)

Search for invisible decays



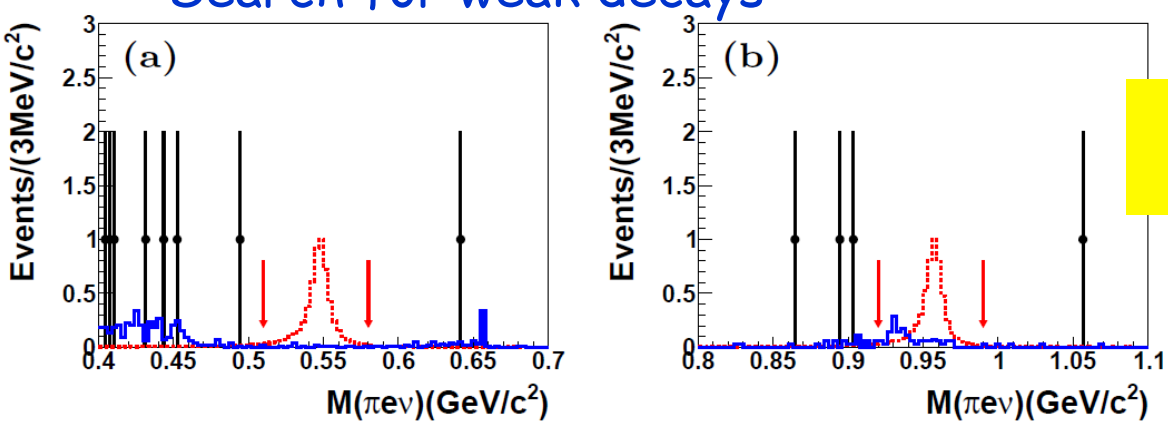
Theory:
PRD 72, 103508(2005)
$BR(\eta \to \chi\chi) \sim 7.4 \times 10^{-5}$
$BR(\eta' \to \chi\chi) \sim 8.1 \times 10^{-7}$

$B(\eta \to \text{invisible}) < 1.0 \times 10^{-4}$

$B(\eta' \to \text{invisible}) < 5.3 \times 10^{-4}$

@90%C.L.

Search for weak decays



$B(\eta \to \pi^- e^+ \nu + c.c.) < 1.7 \times 10^{-4}$
$B(\eta' \to \pi^- e^+ \nu + c.c.) < 2.2 \times 10^{-4}$

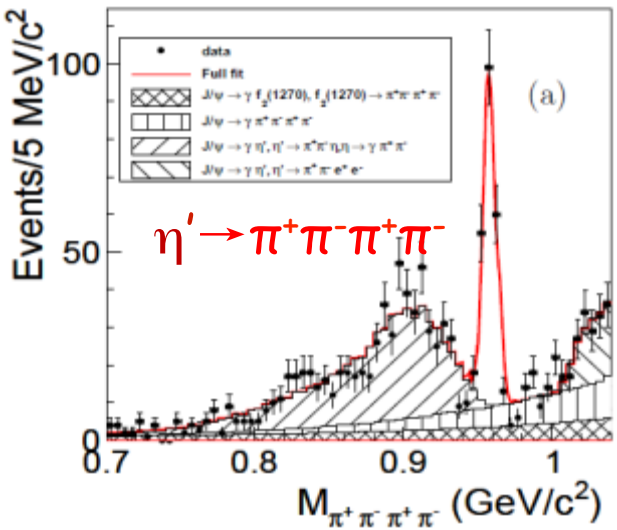
@90%C.L.

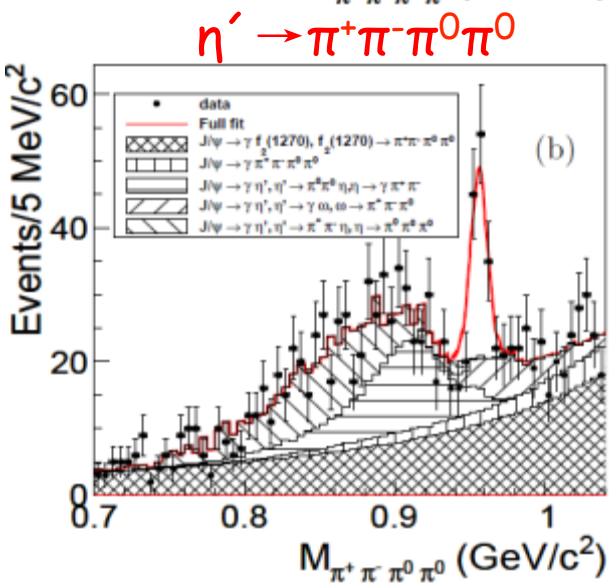
theory: $\sim 10^{-8} - 10^{-9}$

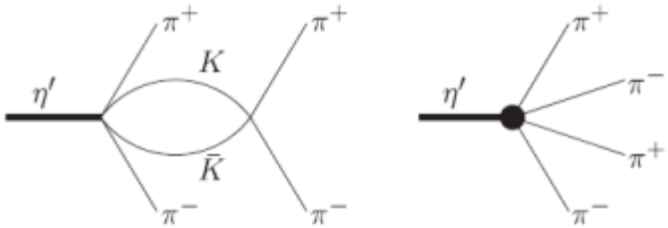
PRD87, 032006 (2013)

Prog. Part. Nucl. Phys. 46, 413 (2001)

$\eta' \to \pi^+\pi^-\pi^+\pi^-, \pi^+\pi^-\pi^0\pi^0$





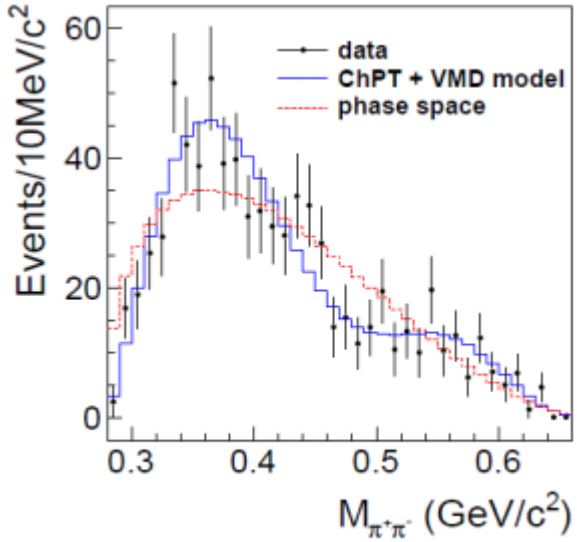


ChPT+VMD:
only occur at $O(p^6)$

ChPT+VMD : $B(\eta' \to \pi^+\pi^-\pi^+\pi^-) = (1.0 \pm 0.3) \times 10^{-4}$
$B(\eta' \to \pi^+\pi^-\pi^0\pi^0) = (2.4 \pm 0.7) \times 10^{-4}$

F.K. Guo, B. Kubis, A. Wirzba,Phys. Rev. D 85,014014 (2012)

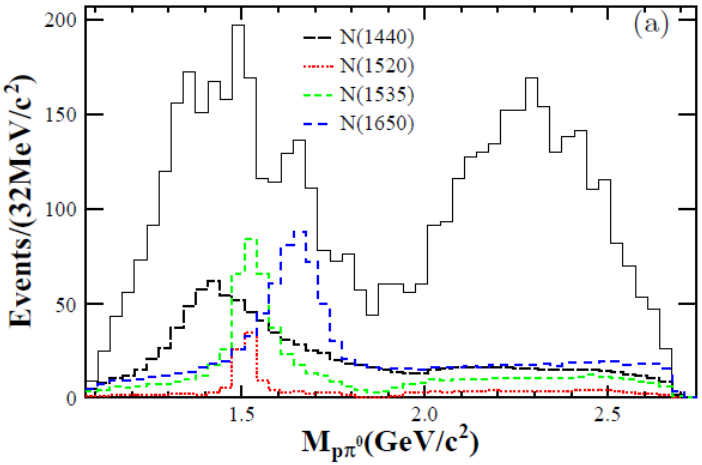
$B(\eta' \to \pi^+\pi^-\pi^+\pi^-) = (8.63 \pm 0.69 \pm 0.64) \times 10^{-5}$
$B(\eta' \to \pi^+\pi^-\pi^0\pi^0) = (1.82 \pm 0.35 \pm 0.18) \times 10^{-4}$



PRL113,039903(2014)

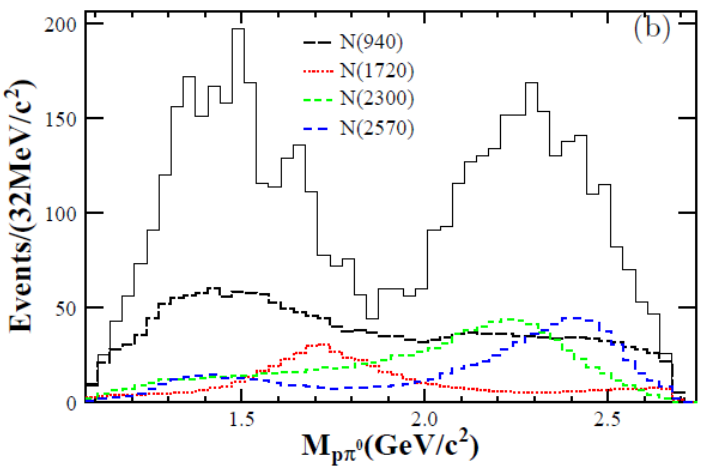
PWA results on N* baryons in $\psi' \to \pi^0 p\bar{p}$

Phys.Rev.Lett. 110 (2013) 022001



- 2-body decay:
  $\psi(2S) \to X\pi^0, X \to p\bar{p}$
  $\psi(2S) \to p\bar{N}^*, \bar{N}^* \to \bar{p}\pi^0$ + c.c.
- isospin conservation:
  Δ suppressed

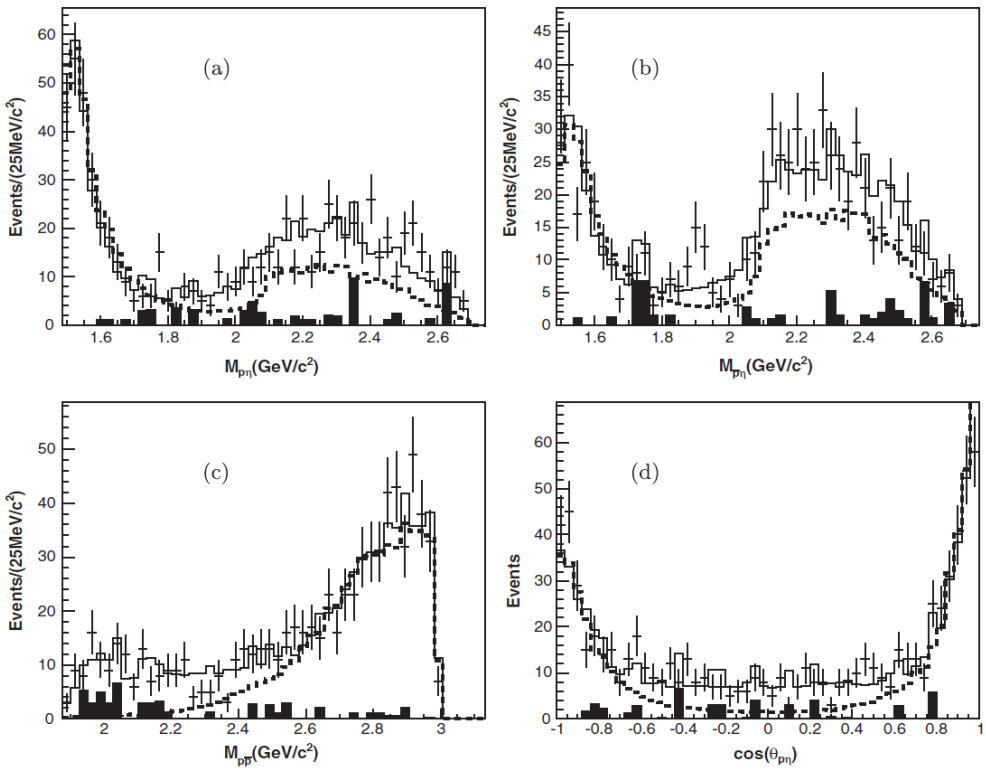
Two new baryonic excited states are observed !



Resonance	M(MeV/c^2)	Γ(MeV/c^2)	ΔS	ΔN_{dof}	C.L.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	4	12.2σ
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94\ -44}$	55.6	6	9.6σ
$N(2300)$	$2300^{+40+109}_{-30-0}$	$340^{+30+110}_{-30-58}$	120.7	4	15.0σ
$N(2570)$	2570^{+19+34}_{-10-10}	250^{+14+69}_{-24-21}	78.9	6	11.7σ

PWA results on N* baryons in $\psi' \to \eta p \bar{p}$

Phys. Rev. D 88, 032010 (2013)



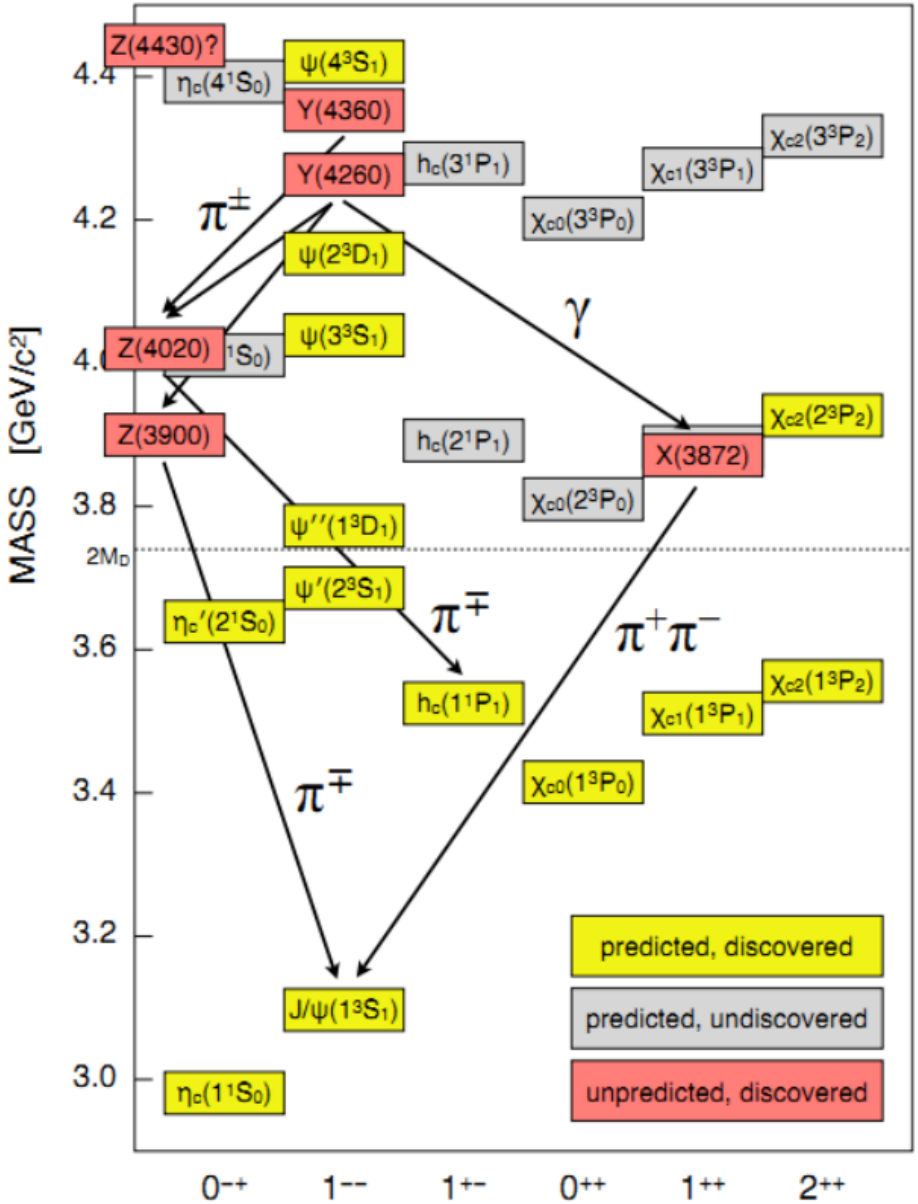
M= $1524 \pm 5^{+10}_{-4}$ MeV/c^2

$\Gamma =$ 130^{+27+57}_{-24-10} MeV/c^2

$$B(\psi(2S) \to N(1535)\bar{p}) \times B(N(1535) \to p\eta) + \text{c.c.} = (5.2 \pm 0.3^{+3.2}_{-1.2}) \times 10^{-5}$$

Charmonium-like physics

Charmnonium spectrum



- Below the open charm threshold the spectrum is well understood
  - very good agreement between predicted and discovered states
- Above the threshold the situation in more complex
  - only few of the predicted states have been found
  - in the last decades many new states have been observed with properties that are not consistent with expectations for charmonium: X, Y, Z

X states:

- charmonium-like states with $J^{PC} \neq 1^{--}$. Observed in B decays, $p\bar{p}$ and pp collisions

Y states:

- charmonium-like states with $J^{PC} = 1^{--}$ .Observed in direct e^+e^- annihilation or in ISR

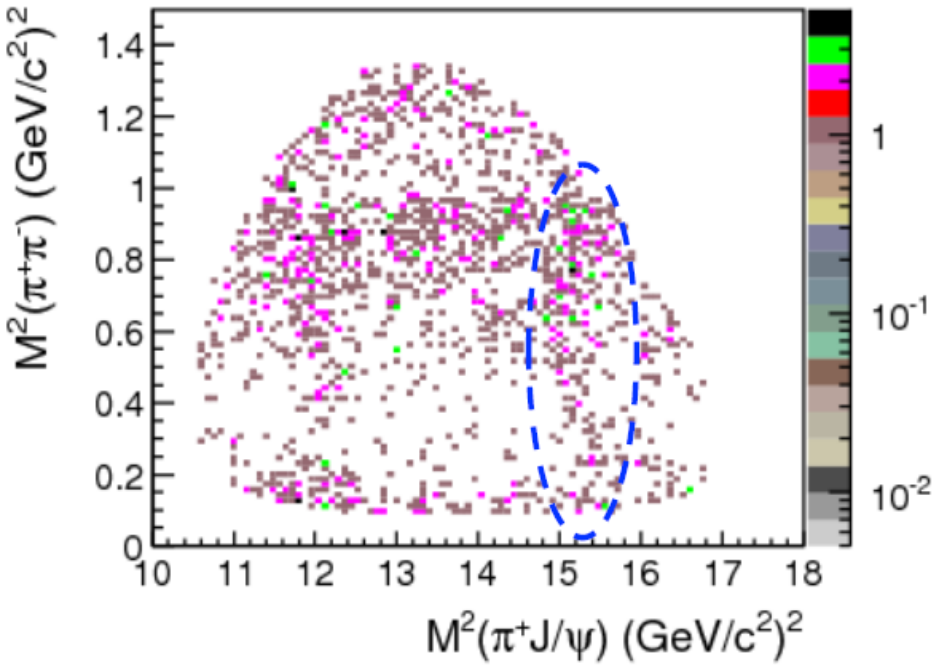
Z states:

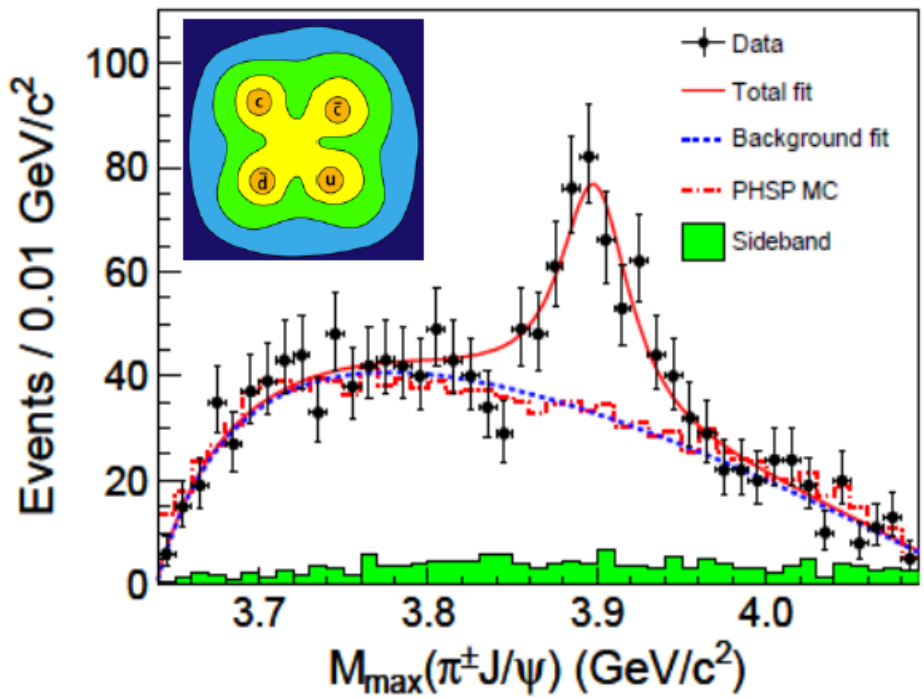
- charmonium-like states . Must contain at least a cc and a light qq pair

Z sates search at BESIII

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

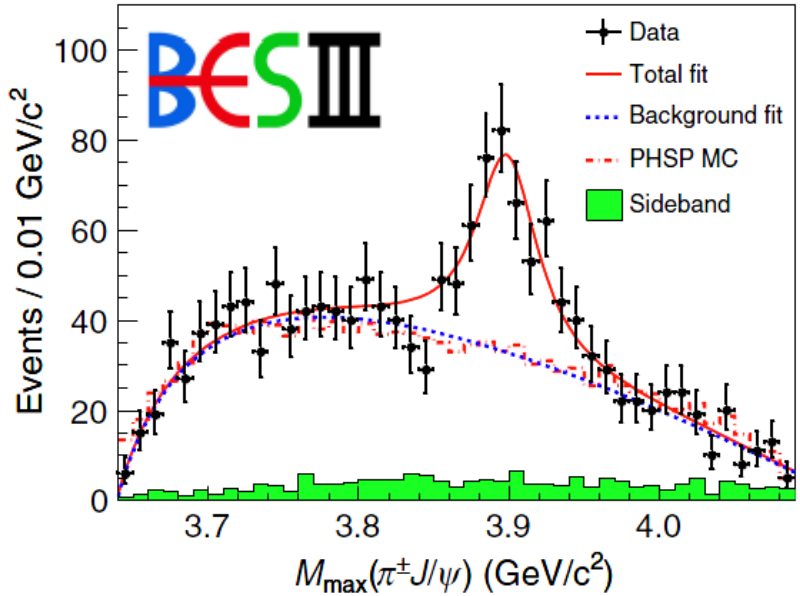
- Requiring J/ψ mass window: [3.08,3.12] GeV, we have 1595 signal events, with purity ~90%.

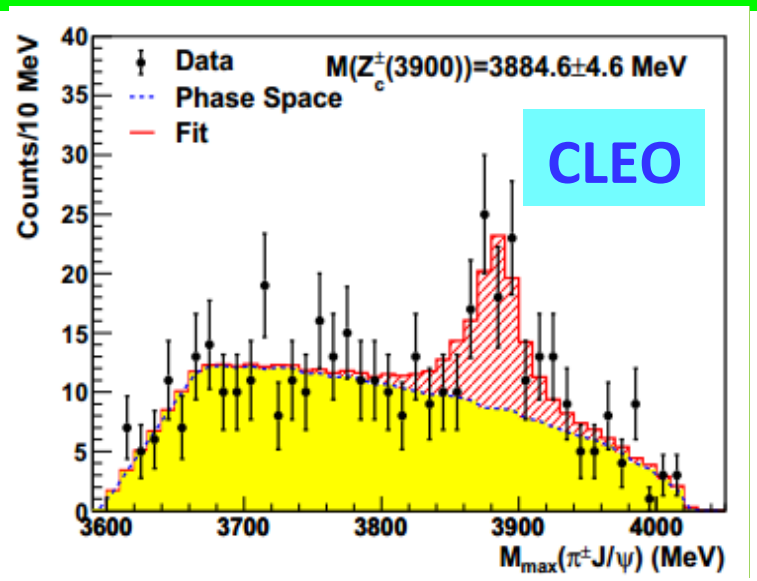


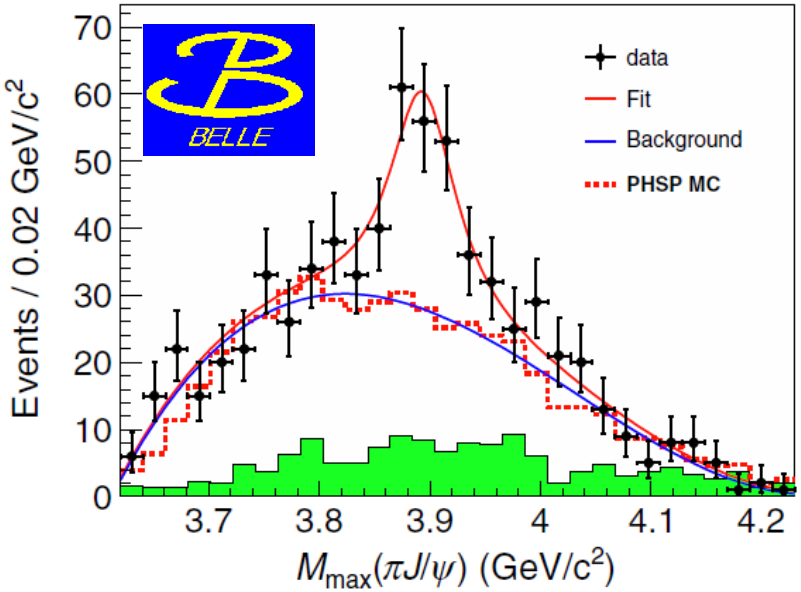


1. New charged resonance, exotic 4 quark hadron?!
2. Fit $M_{max}(\pi^\pm J/\psi)$ mass distribution; avoid cross counting
3. S-Wave Breit Wigner; phase space factor; efficiency corrected.
4. M=(3899.0±3.6±4.9)MeV; Γ=(46±10±20)MeV.
5. Statistical significance: >8σ, discovery!

Comparisons between different experiments on $Z_c(3900)^{\pm}$



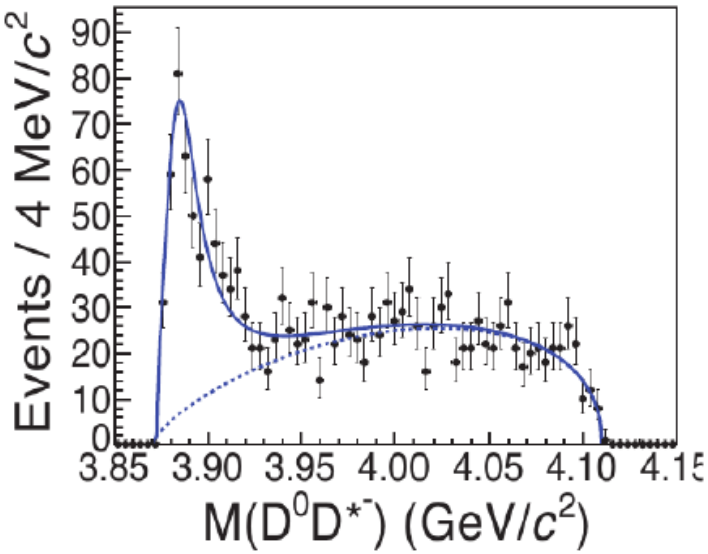


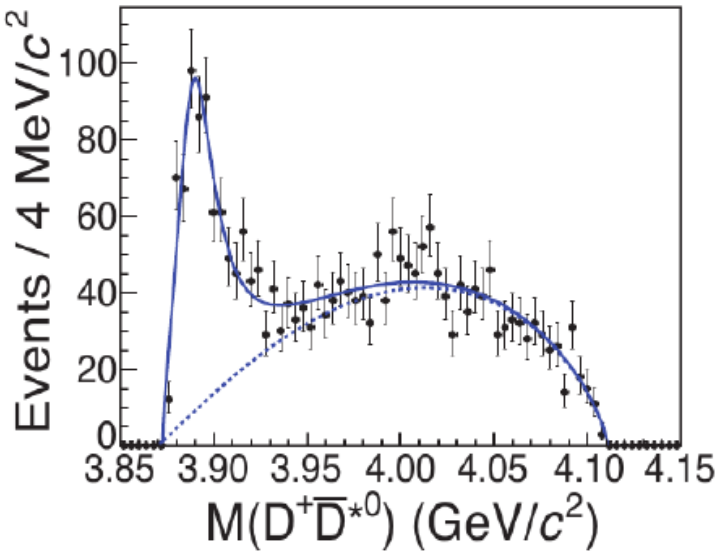


1. CLEO: PLB 727 (2013) 366
M=3886±6±4 MeV,
Γ=33±6±7 MeV.
2. Belle: PRL 110, 252002 (2013)
M=(3894.5±6.6±4.5) MeV;
Γ=(63±24±26) MeV.
3. BESIII: PRL 110, 252001 (2013)
M=(3899.0±3.6±4.9) MeV;
Γ=(46±10±20)MeV

$$e^+e^- \to \pi^\pm Zc(3885)^\mp \to \pi^\pm (D\bar{D}^*)^\mp$$

PRL 112, 022001 (2014)





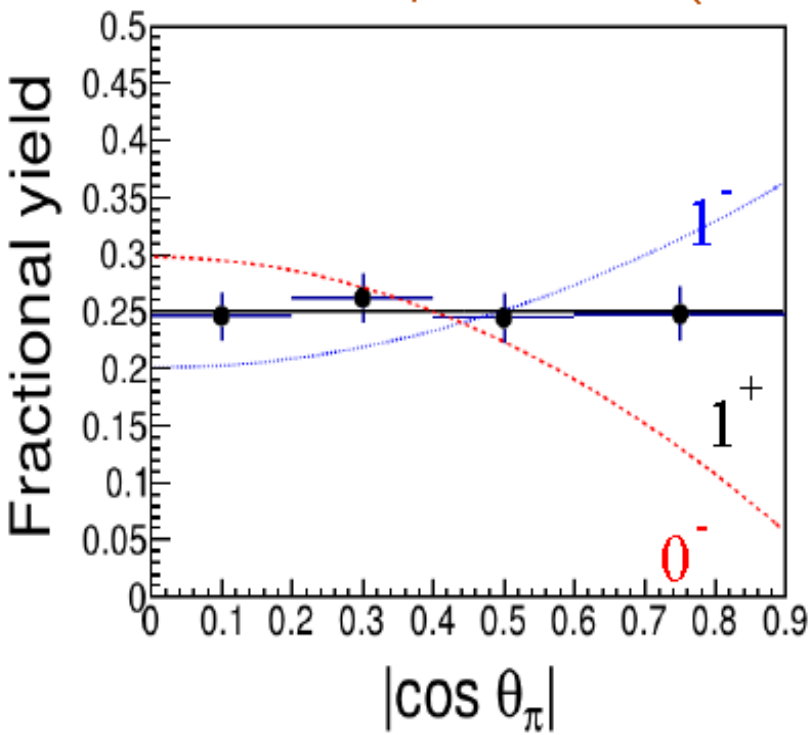
M = 3882.2±1.5 MeV
Γ = 24.6±3.3 MeV
N(Zc)=502 ± 41

M = 3885.5±1.5 MeV
Γ = 24.9±3.2 MeV
N(Zc)=710 ± 54

M = 3883.9±1.5±4.2 MeV
Γ = 24.8±3.3±11.0 MeV

Quantum numbers of Zc(3885)

PRL 112, 022001 (2014)



$\cos(\theta_\pi)$ – angle of bachelor π^+ in the CMS

$J^P=0^-$, $dN/d\cos(\theta_\pi) \sim 1-\cos^2(\theta_\pi)$

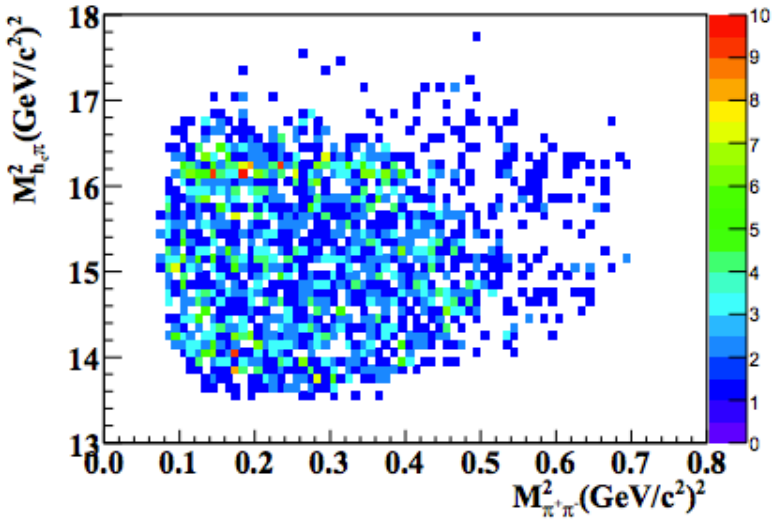
$J^P=1^-$, $dN/d\cos(\theta_\pi) \sim 1+\cos^2(\theta_\pi)$

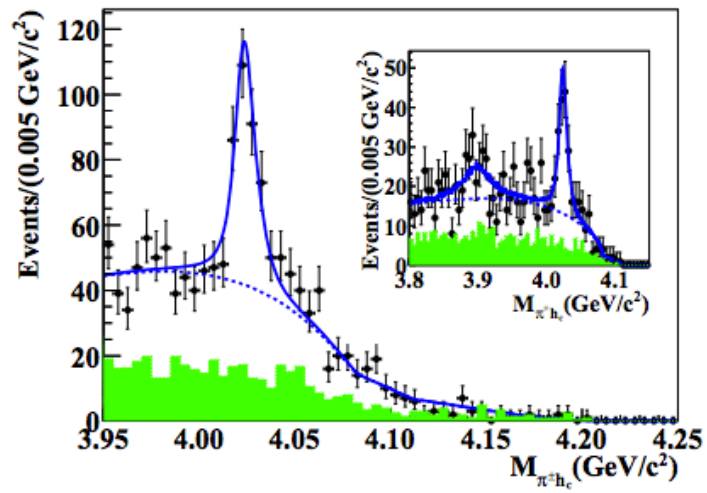
$J^P=1^+$, $dN/d\cos(\theta_\pi) \sim$ flat

$J^P=0^+$, parity conservation

- If Zc(3885) is Zc(3900): $\dfrac{\Gamma(Z_c(3900) \to D\overline{D^*})}{\Gamma(Z_c(3900) \to \pi J/\psi)} = 6.2 \pm 1.1 \pm 2.7$

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

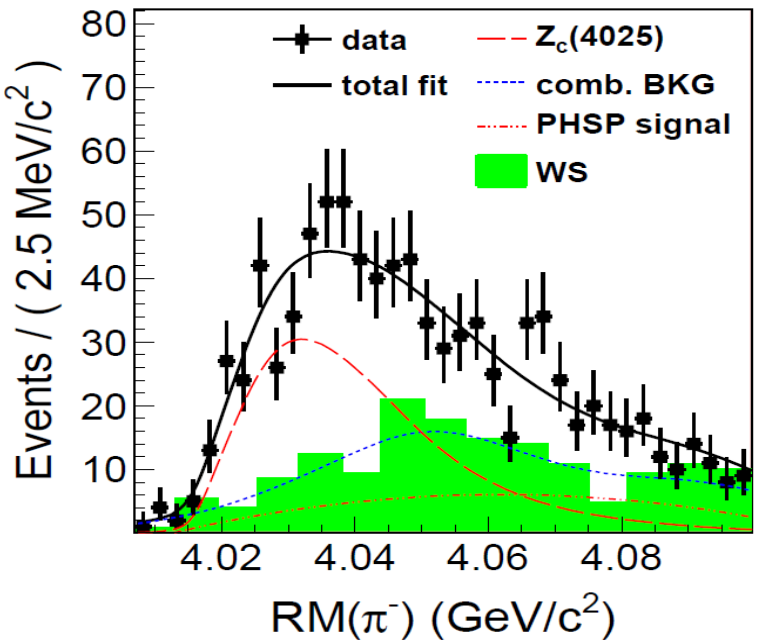




- 1D projection of $M(\pi^\pm h_c)$ invariant mass distribution.
- M[Zc(4020)]=(4022.9±0.8±2.7)MeV; Γ[Zc(4020)]=(7.9±2.7±2.6)MeV. Significance:>8.9σ
- No significant signal for $Z_c(3900)^\pm \to \pi^\pm h_c$ (<2.1σ)

PRL111 242001 (2014)

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



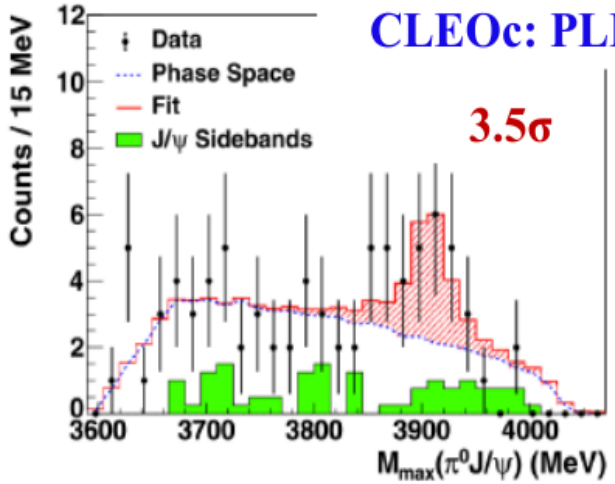
M=4026.3±2.6±3.7 MeV
Γ=24.8±5.6±7.7 MeV
N=401±47
Significance>10σ

PRL 112 132001 (2014)

- if $Z_c(4025)^\pm$ is the $Z_c(4020)^\pm$observed in the $\pi^\pm h_c$ spectrum:

$$\frac{\Gamma(Z_c(4020) \to D^*\bar{D}^*)}{\Gamma(Z_c(4020) \to \pi h_c)} = 12 \pm 5$$

$e^+e^- \to \pi^0 Z_c(3900)^0 \to \pi^0\pi^0 J/\psi$



CLEOc: PLB 727, 366

BESIII PRELIMINARY!

- 2.8fb^{-1} data at 10 energy points from 4230~4420 MeV
- $Z_c(3900)^0$ is observed clearly at:

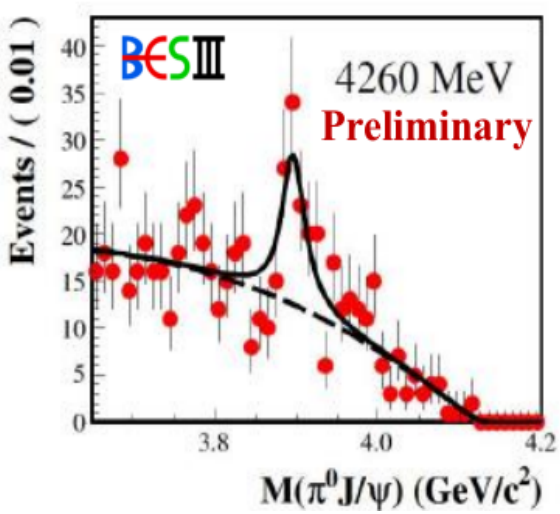
  E_{cm}=4230, 4260, 4360MeV

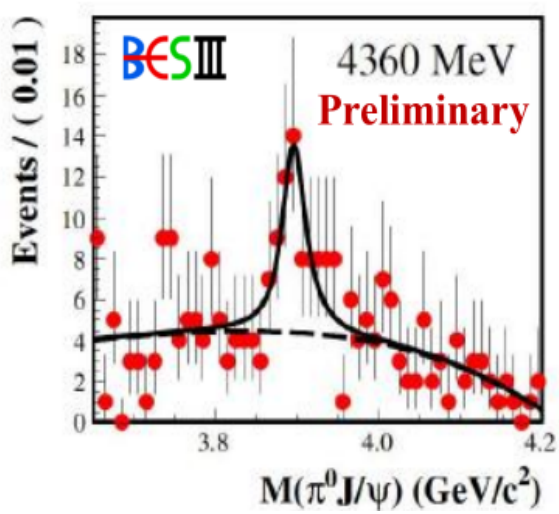
$M = (3894.8 \pm 2.3)\ MeV/c^2$

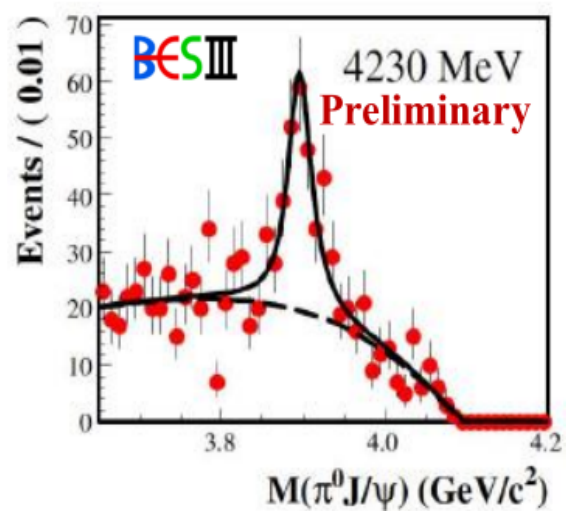
$\Gamma = (29.6 \pm 8.2)\ MeV/c^2$

10.4σ

An isospin triplet for $Z_c(3900)$ has been established



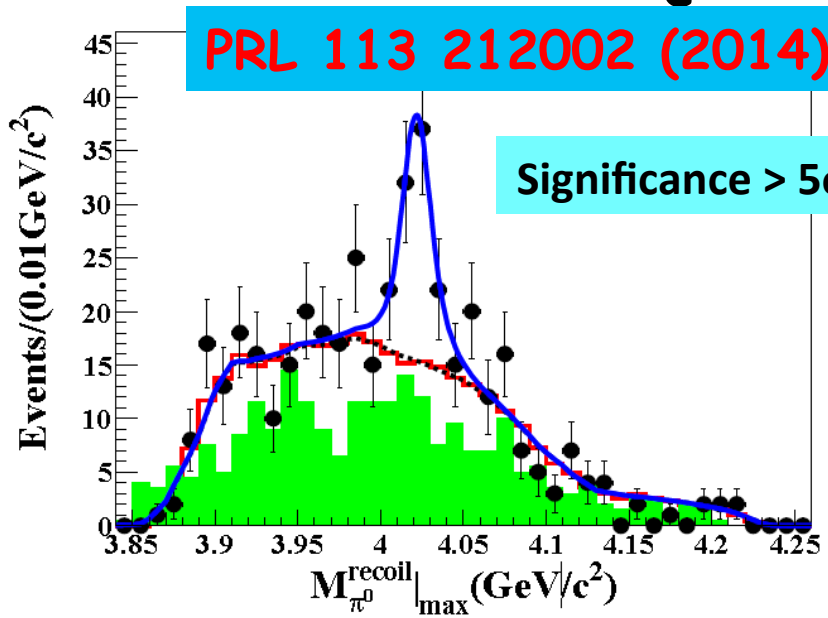


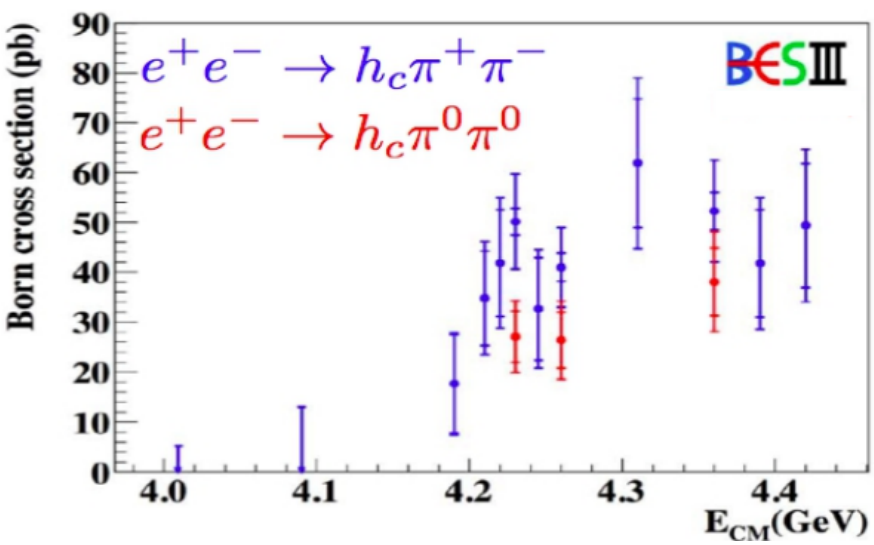


$e^+e^- \to \pi^0 Z_c(4020)^0 \to \pi^0\pi^0 h_c$

- Observe $Z_c(4020)^0$ structure in $\pi^0 h_c$ mass distribution.
- $M[Z_c(4020)^0]$ =4023.6±4.5 MeV with a fixed width
- It is the neutral isospin partner of the $Z_c(4020)^{\pm}$.

PRL 113 212002 (2014)





Cross sections for $e^+e^- \to \pi^+\pi^- h_c$ and $e^+e^- \to \pi^0\pi^0 h_c$ are in agreement with isospin conservation within 2σ: $R_{\pi\pi hc}$ =0.63±0.09

An isospin triplet for $Z_c(4020)$ has also been established.

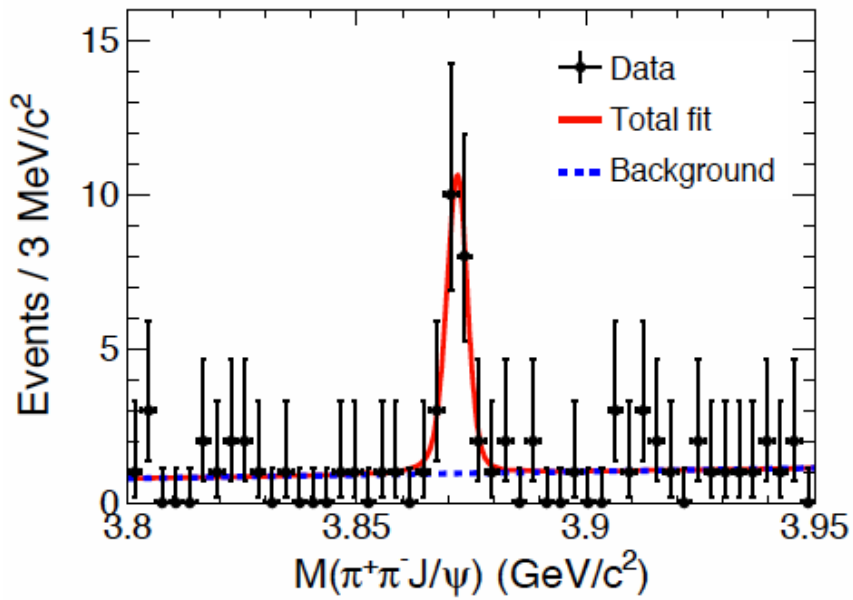
Summary of Z states

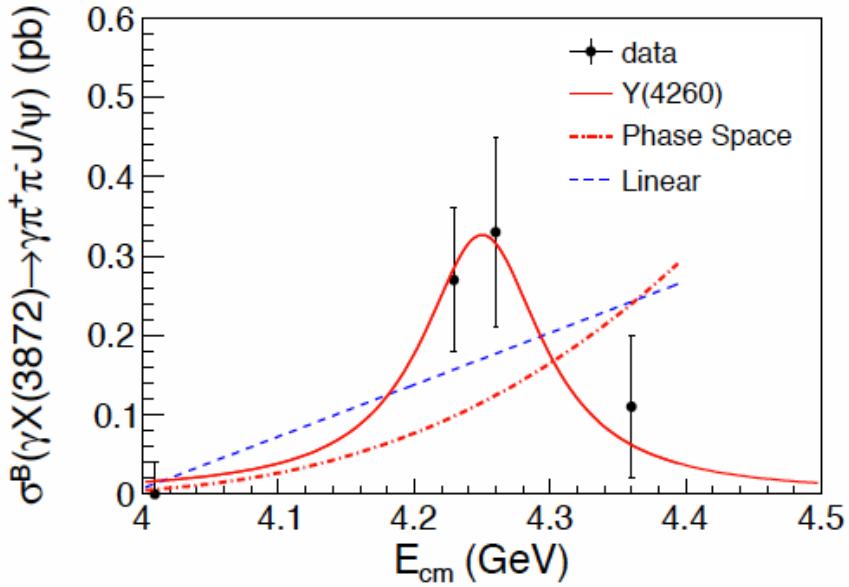
Channel	Mass (MeV/c^2)	Width (MeV/c^2)
$J/\psi\pi^{\pm}$	3899.0±3.6±4.9	46±10±20
$J/\psi\pi^{0}$	3894.8±2.3	29.6±8.2
$(DD^*)^{+}$	3883.9±1.5±4.2	24.8±3.3±11.0
$h_c\pi^{\pm}$	4022.9±0.8±2.7	7.9±2.7±2.6
$h_c\pi^{0}$	4023.6±2.2±3.9	Fixed
$(D^*D^*)^{+}$	4026.3±2.6±3.7	24.0±5.6±7.7

- **Nature of these states ?**
  - **Tetraquark L. Maiani, A. Ali et al**
  - **Hadronic molecule U.-G. Meissner, F.K. Guo et al.**
  - **Hadro-charmonium M. B. Boloshin**
  - **Meson loop Q. Zhao et al.**
  - **ISPE model X. Liu et al**
  - **...**

X states search at BESIII

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



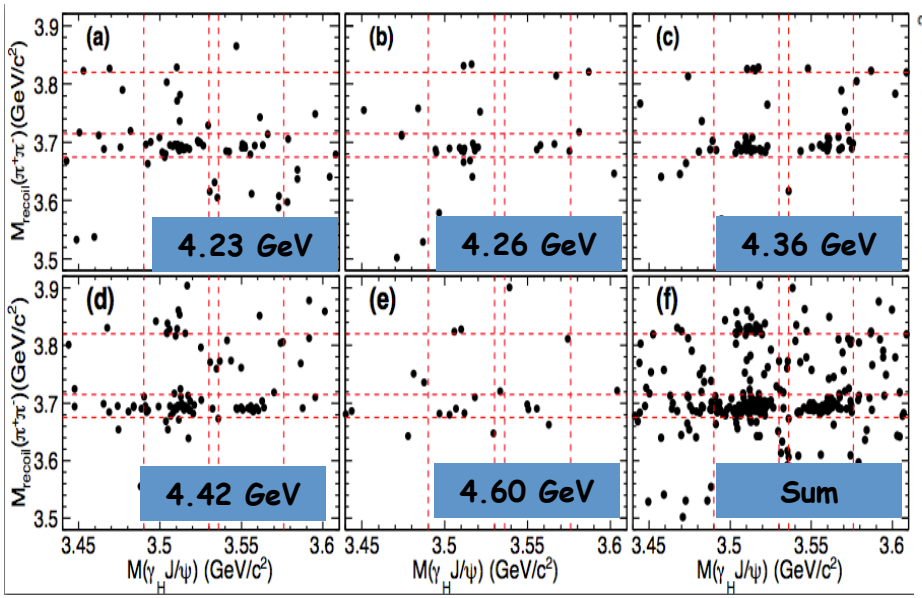


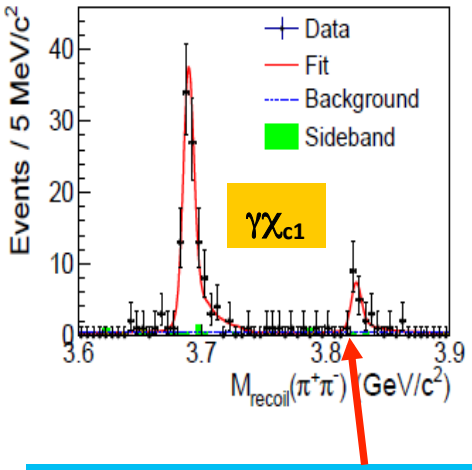
PRL 112 092001 (2014)

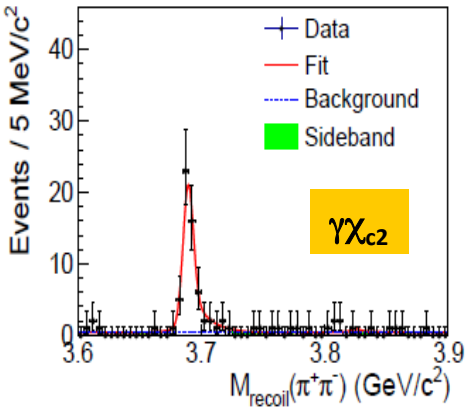
- M = (3871.9±0.7±0.2) MeV, Γ<2.4 MeV, Significance:6.3σ
- production in *Y*(4260) decay suggestive, but not conclusive

$$\frac{\mathcal{B}[Y(4260)\to\gamma X(3872)]}{\mathcal{B}(Y(4260)\to\pi^+\pi^- J/\psi)} = 0.1$$

$e^+e^- \to \pi^+\pi^- X(3823) \to \pi^+\pi^-\gamma\chi_{c1}$

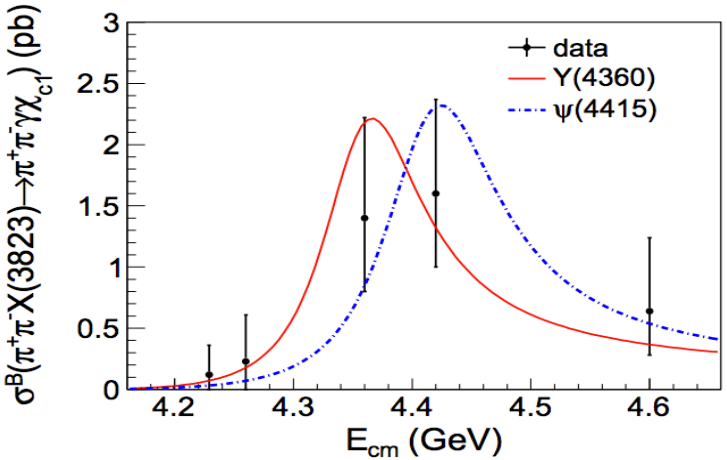






Fit: M=3821.7±1.3±0.7 MeV;
Significance: 6.7σ, observation

BESIII preliminary



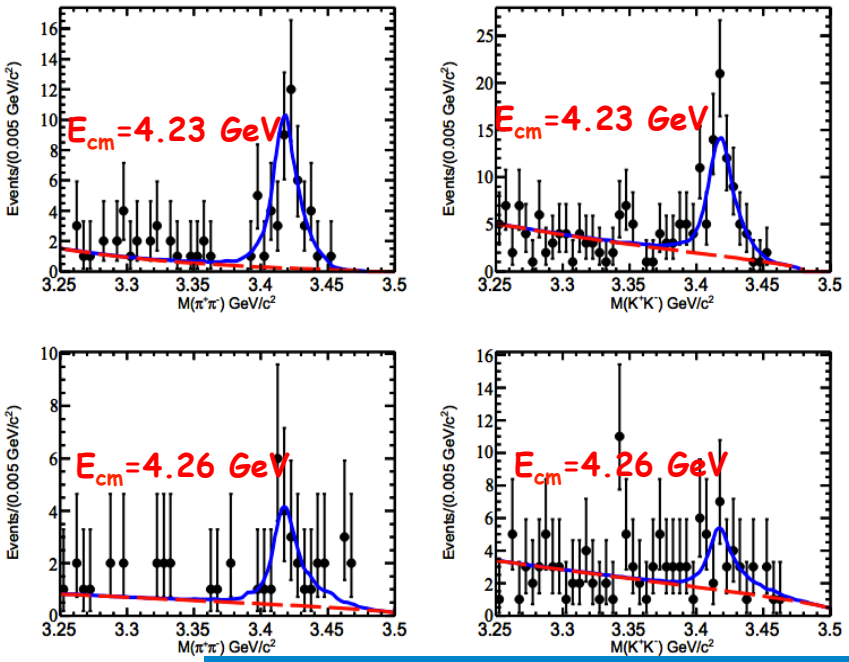
X(3823) as the $\psi(1^3D_2)$

- Mass argees with $\psi(1^3D_2)$
- Narrow width (<16 MeV @90% C.L.)
- $R=B[X(3823)\to\chi_{c2}]/B[X(3823)\to\gamma\chi_{c1}]<0.43$ @ 90% C.L.
  Agree with predicted ~0.2
- $1^1D_2 \to \gamma\chi_{c1}$ forbidden; $1^3D_3 \to \gamma\chi_{c1}$ amplitude=0.

Y states search at BESIII

$e^+e^- \to \omega\chi_{c0}$

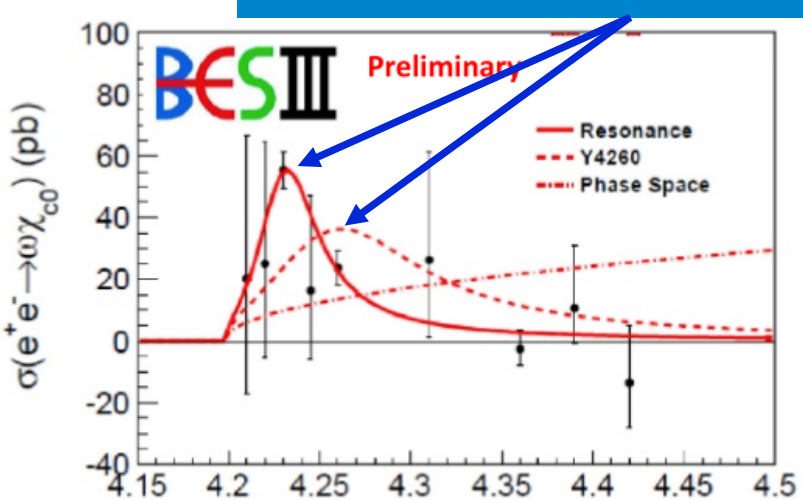
arXiv:1410.6538



$\omega \to \pi^+\pi^-\pi^0$,
$\chi_{c0} \to \pi^+\pi^-, K^+K^-$

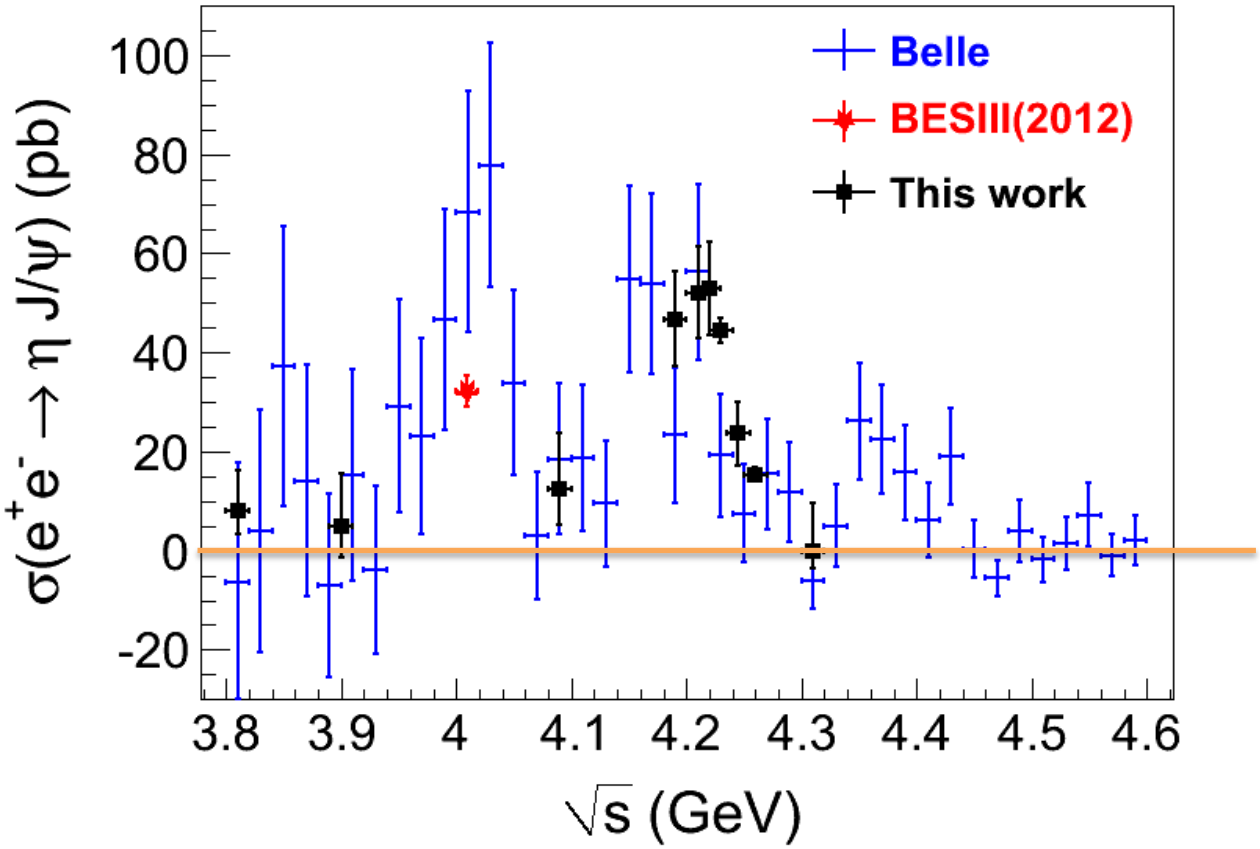
$\sqrt{s}$ (GeV)	σ^{Born} (pb^{-1})
4.23	55.4±6.0±5.9
4.26	23.7±5.3±3.5

This is not consistent with the Y(4260) (!?)



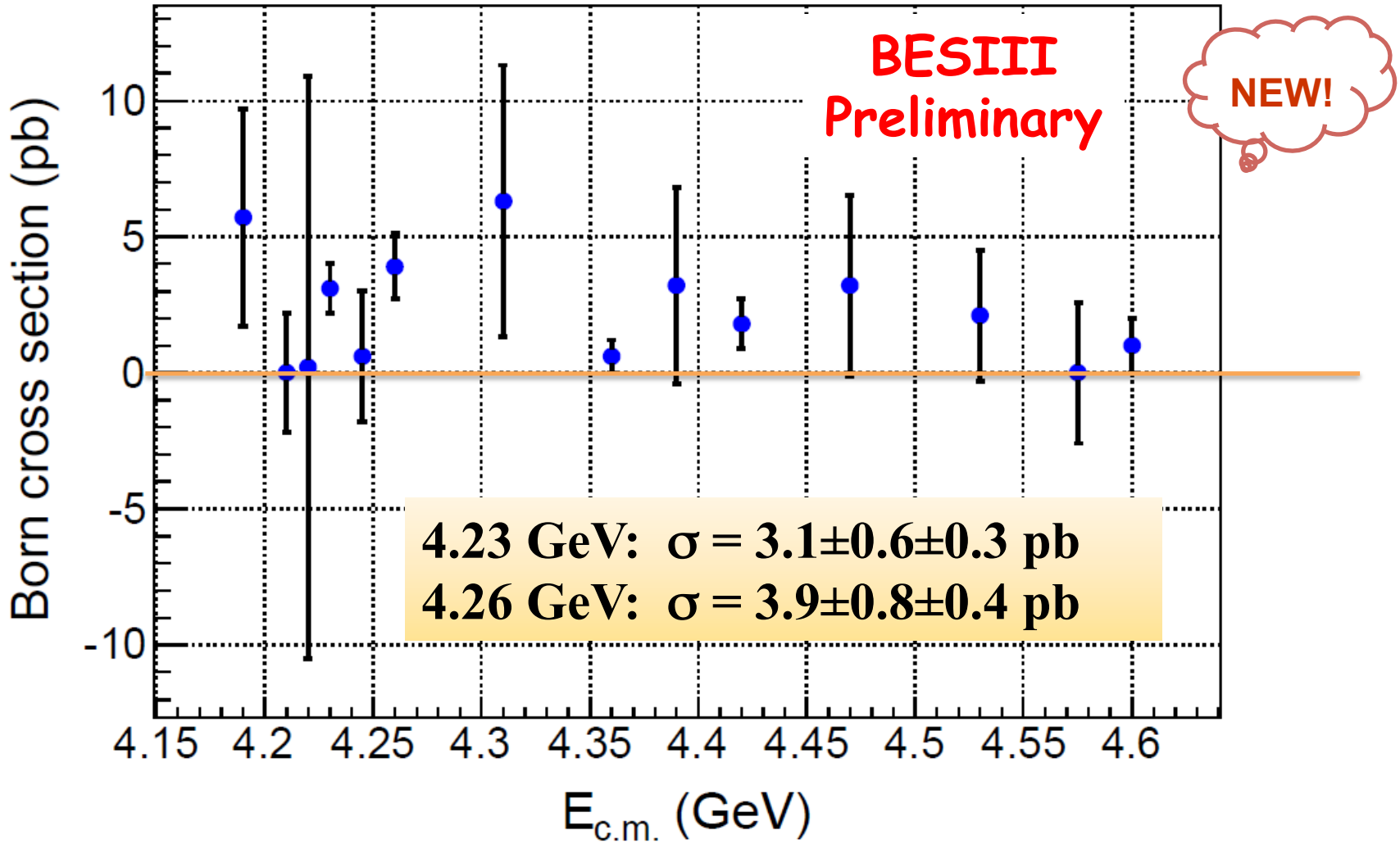
Assuming the $\omega\chi_{c0}$ signals come from a resonance, we extract the $\Gamma_{ee} \cdot B(\omega\chi_{c0})$, mass, and width of the resonance to be (2.9±0.7± 0.4) eV, M=(4230±8±6) MeV/c^2, and (38±12±2) MeV.

Observation of $e^+e^- \rightarrow \eta J/\psi$ (preliminary)



- Agree with previous results with improved precision
- The cross section peaks around 4.2 GeV
- Analysis of high energy points underway

Observation of $e^+e^- \rightarrow \eta' J/\psi$



- First observation, cannot tell the line shape due to statistics

Evidence for $e^+e^- \rightarrow \gamma\chi_{cJ}$

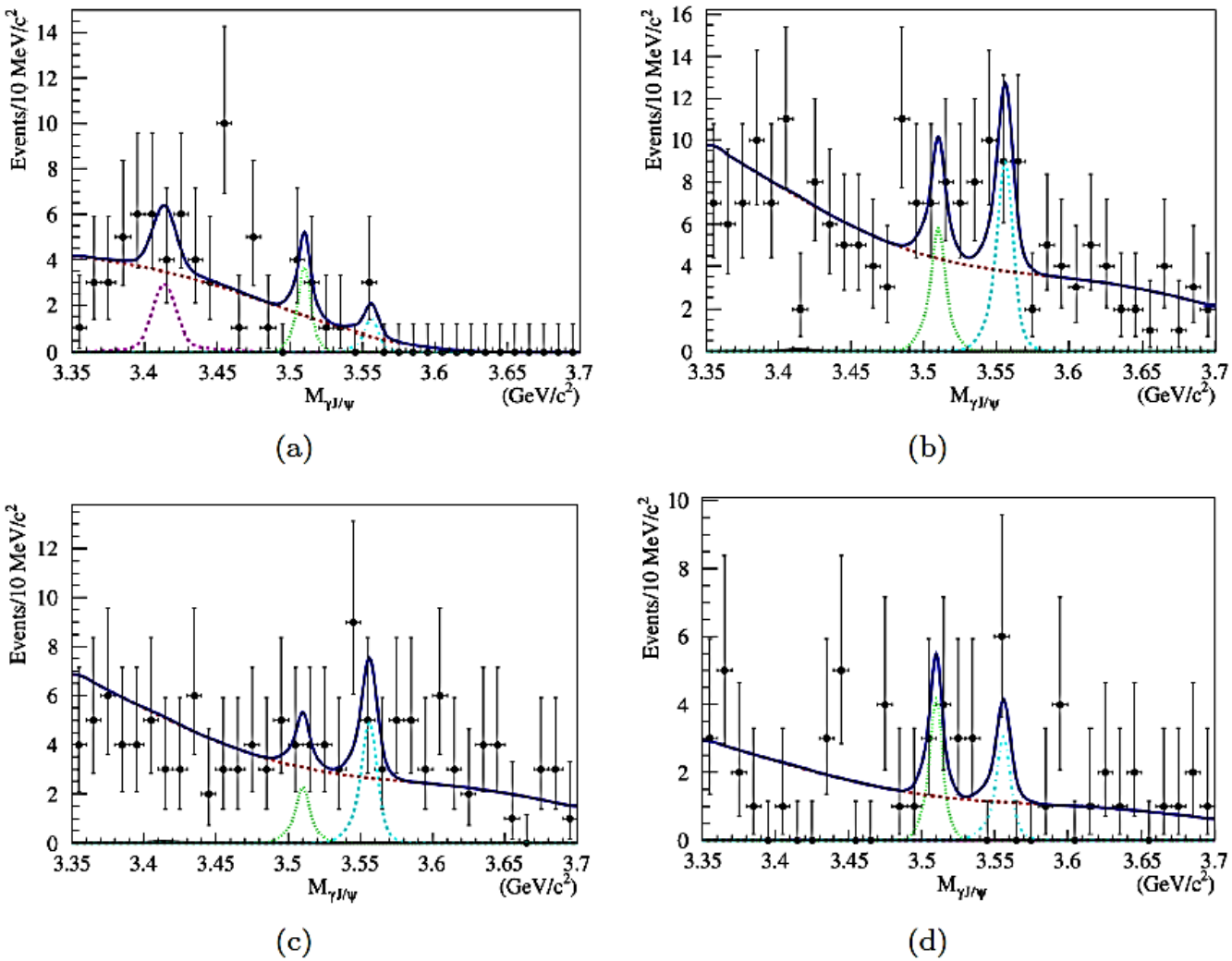


Fig. 2. The distribution of $\gamma J/\psi$ invariant mass, $M_{\gamma J/\psi}$, and fit results for data at $\sqrt{s} = 4.009$ (a), 4.230 (b), 4.260 (c) and 4.360 GeV (d). The solid lines show the total fit results. The χ_{cJ} signals are shown as dashed lines, dotted lines, and dash-dotted lines, for J = 0, 1, and 2, respectively. The backgrounds are indicated by red dashed lines.

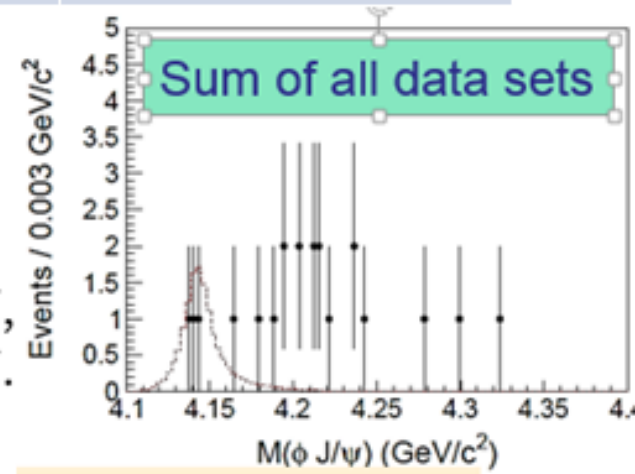
BESIII: arXiv:1411.6336, CPC (in press)

No significant $e^+e^- \rightarrow \gamma Y(4140)$

Upper limit at the 90% C.L. for $\sigma^B \cdot \mathcal{B} = \sigma^B\left(e^+e^- \rightarrow \gamma Y(4140)\right) \cdot \mathcal{B}(Y(4140) \rightarrow \phi J/\psi)$

$\sqrt{s}$ (GeV/c^2)	Luminosity (pb^{-1})	$(1+\delta)$	n^{prod}	$\sigma^B \cdot \mathcal{B}$ (pb)
4.23	1094	0.840	<339	<0.35
4.26	827	0.847	<207	<0.28
4.36	545	0.944	<179	<0.33

Systematic uncertainty is considered.



Compared with $X(3872)$ production. PRL 112, 092001

$$\sigma^B\left(e^+e^- \rightarrow \gamma X(3872)\right) \cdot \mathcal{B}(X(3872) \rightarrow \pi^+\pi^- J/\psi)$$
$= 0.27 \pm 0.09(\text{stat}) \pm 0.02(\text{syst})$ pb at $\sqrt{s} = 4.23$ GeV,
$= 0.33 \pm 0.12(\text{stat}) \pm 0.02(\text{syst})$ pb at $\sqrt{s} = 4.26$ GeV.

Take $\mathcal{B}(X(3872) \rightarrow \pi^+\pi^- J/\psi) = 5\%$. arXiv: 0910.3138
And $\mathcal{B}(Y(4140) \rightarrow \phi J/\psi) = 30\%$, molecular calculation, PRD 80, 054019.

$\frac{\sigma^B(e^+e^- \rightarrow \gamma Y(4140)}{\sigma(e^+e^- \rightarrow \gamma X(3872))} \leq 0.1$ at $\sqrt{s}$=4.23 and 4.26 GeV.

BESIII: arXiv:1412.1867, PRD (in press)

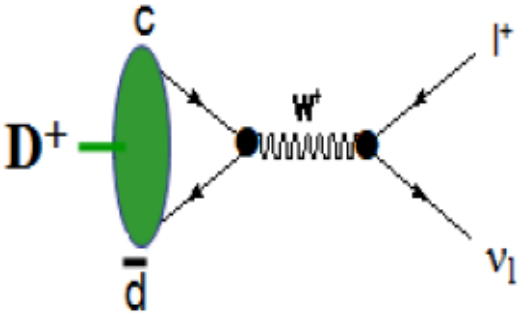
Charm physics

$D^+ \to \mu^+ \nu$ and Decay constant f_{D+}

- D^+ leptonic decays play an important role in understanding of the SM

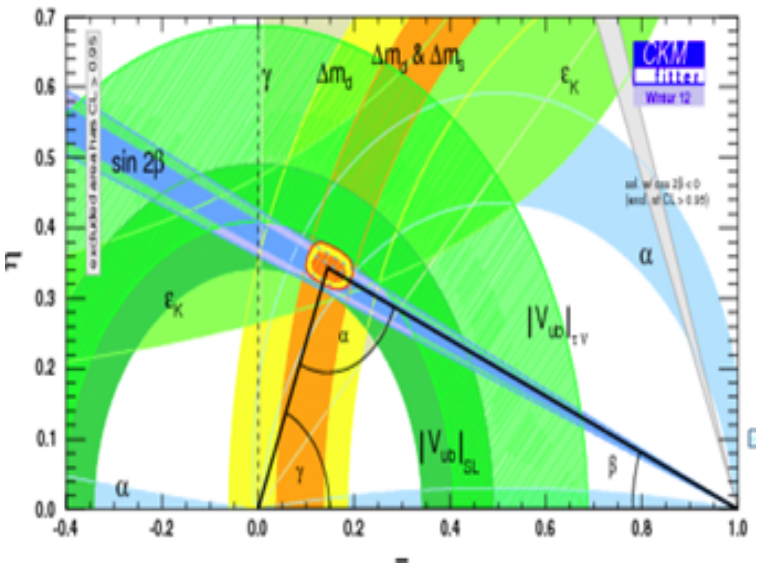
- Test LQCD calculation of f_D

$$\Gamma_{SM}(D^+_{(s)} \to l^+\nu) = \frac{G_F^2}{8\pi} m_l^2 m_{D_{(s)}} \left(1 - \frac{m_l^2}{m_{D_{(s)}}^2}\right)^2 |V_{cd(s)}|^2 f_{D^+_{(s)}}$$



- Precise measurement of $|V_{cd}|$

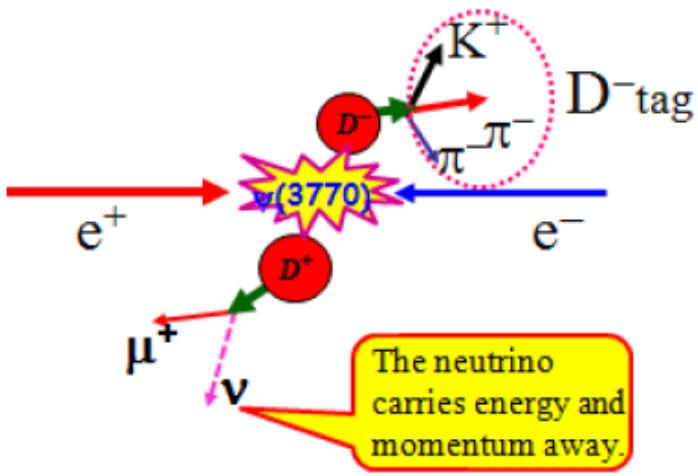
- Reduced width of band in triangle would lead to precisely test the SM, and search for new physics beyond the SM

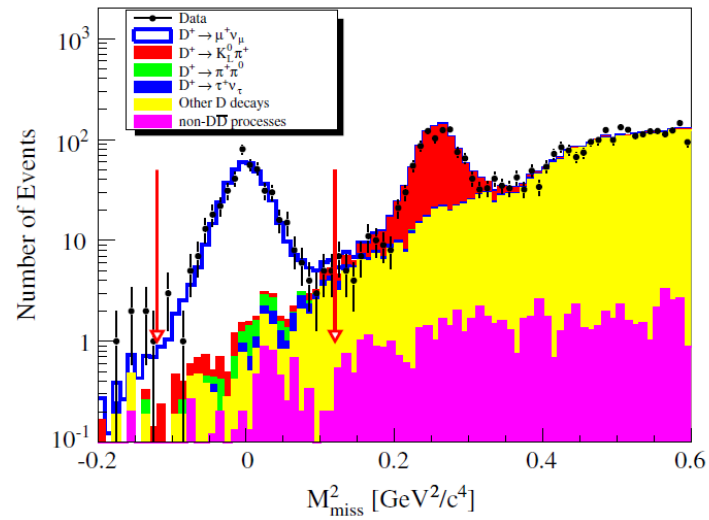


PRD 89, 051104 (2014)

$D^+ \to \mu^+ \nu$ and Decay constant f_{D+}

In the system recoiling against the singly tagged D^-, BES-III selected the purely leptonic decay events for $D^+ \to \mu^+ \nu$





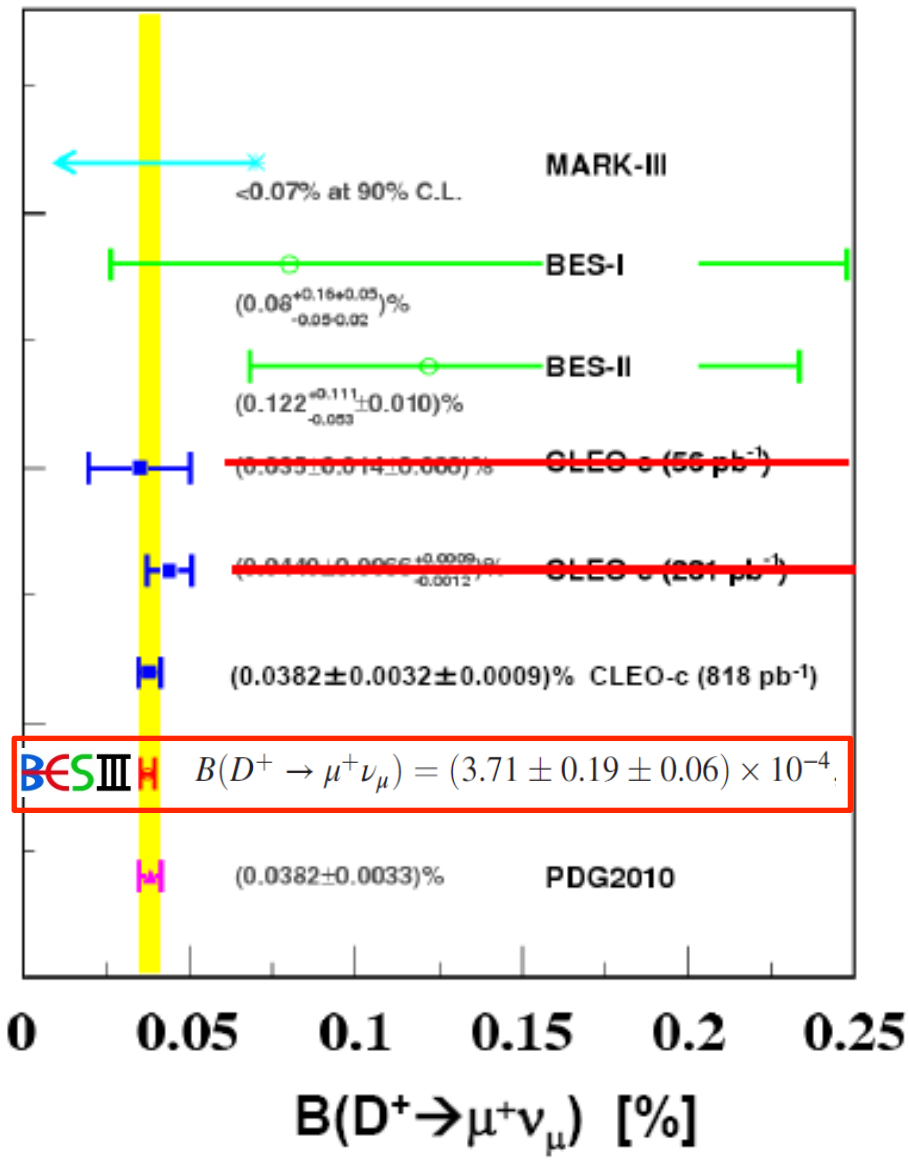
Br. & f_{D+} at BES-III

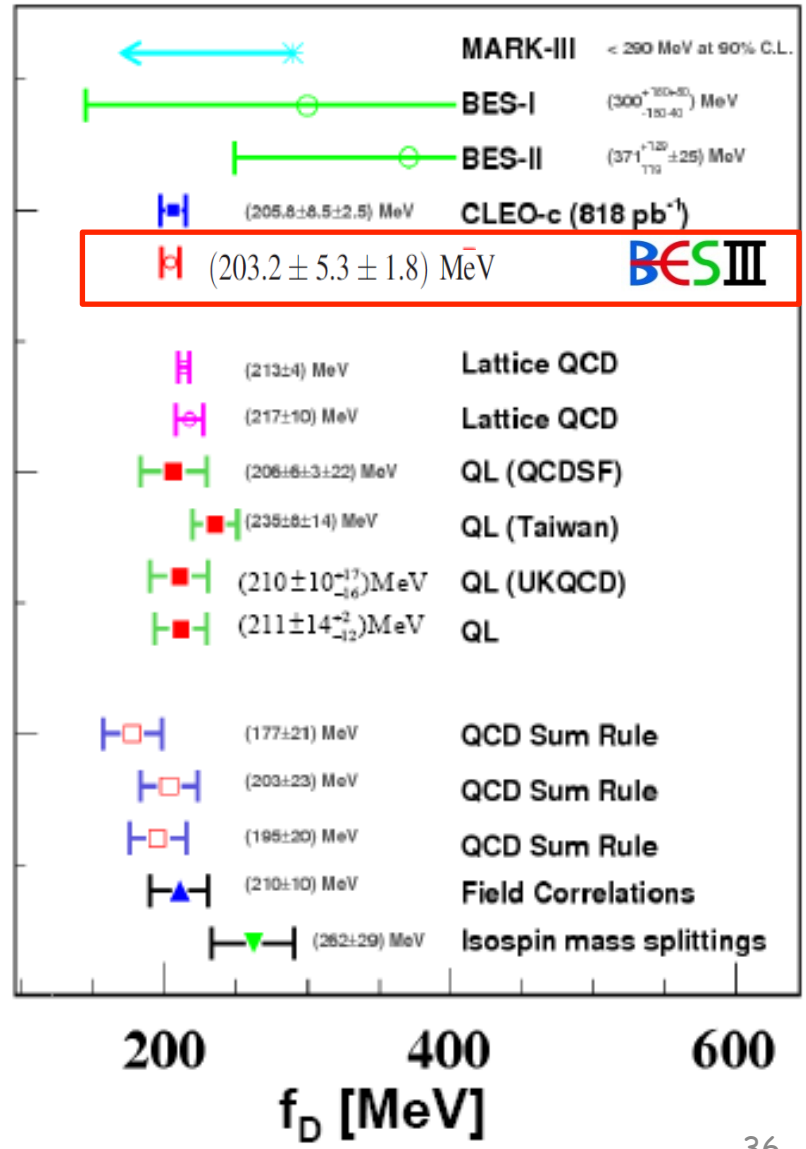
$$B(D^+ \to \mu^+ \nu_\mu) = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}.$$

$$f_{D^+} = (203.2 \pm 5.3 \pm 1.8)\ \text{MeV}$$

$$|V_{cd}| = 0.2210 \pm 0.0058 \pm 0.0047$$

Comparison of $B(D^+ \to \mu^+\nu)$ & f_D





Summary

- It is good place to search for N* and new resonance in hadron spectroscopy study at BESIII.
- X,Y,Z states are searched at BESIII, A lot of Z, X states are either observed or confirmed, i.e. $Z_c(3900)$, $Z_c(4020)$, X(3823), X(3872), much more are in progress.
- More precise measurement on $B(D^+ \rightarrow \mu^+\nu)$ and f_{D+} are available with BESIII's data.

Thank you!

Backup

Z_c charmonium-like meson

- **Well defined signature of event:**
  - **decay into known charmonium state**
  - **electric charge ==> Nquark ≥ 4**
- **Possible directions of searches:**

$\pi J/\psi$, $\pi\, h_c(1P)$, $\pi\psi'$, $\pi\chi_{cJ}$, πDD...