Recent results from BESIII

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Hadron Nuclear Physics 2013
July 18 – 22, 2013
Zhangjiajie, China

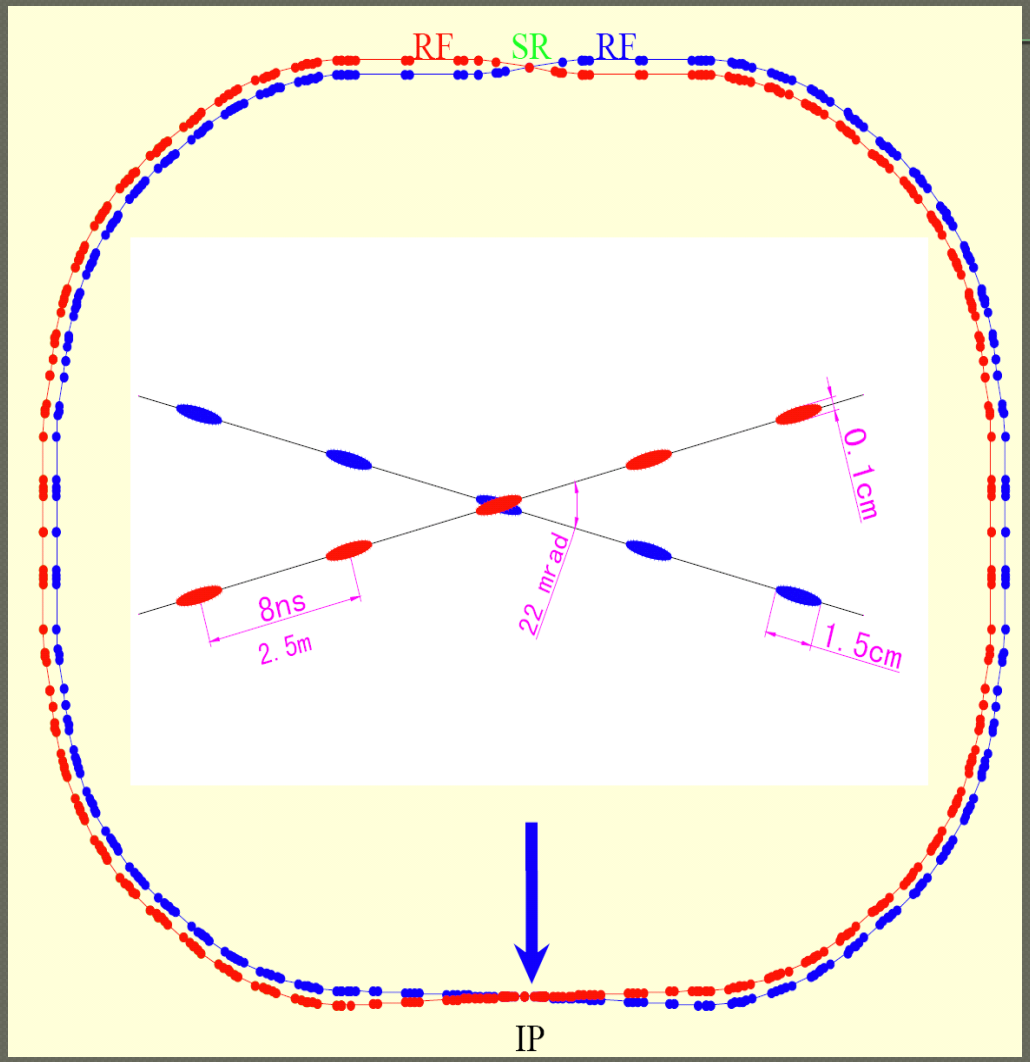
Outline

- Introduction to BESIII
- Selected BESIII results:
  - XYZ study
  - Light hadron spectrum
  - Charm physics
- Summary

BEPC II

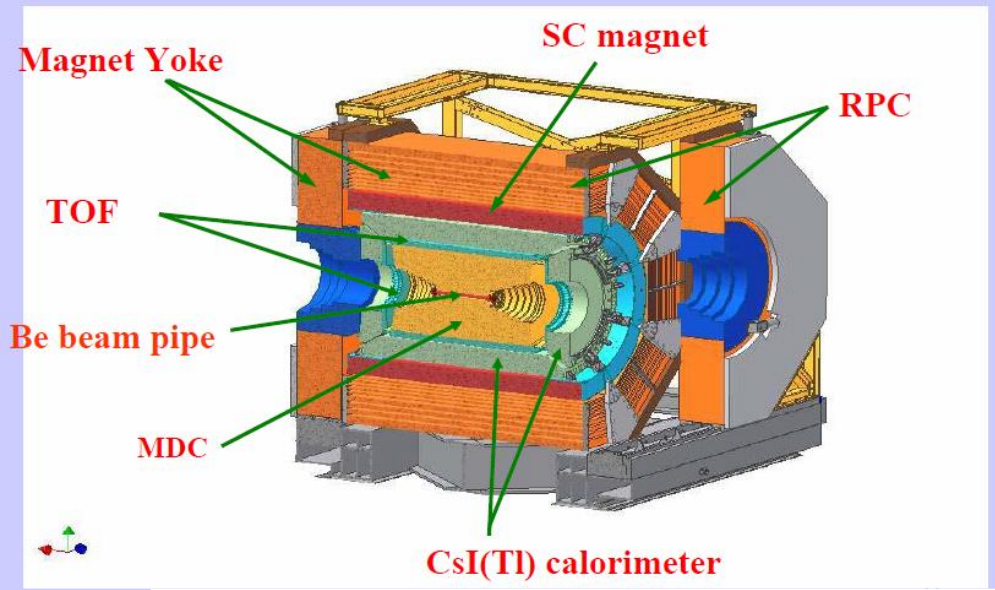
A high luminosity double-ring collider

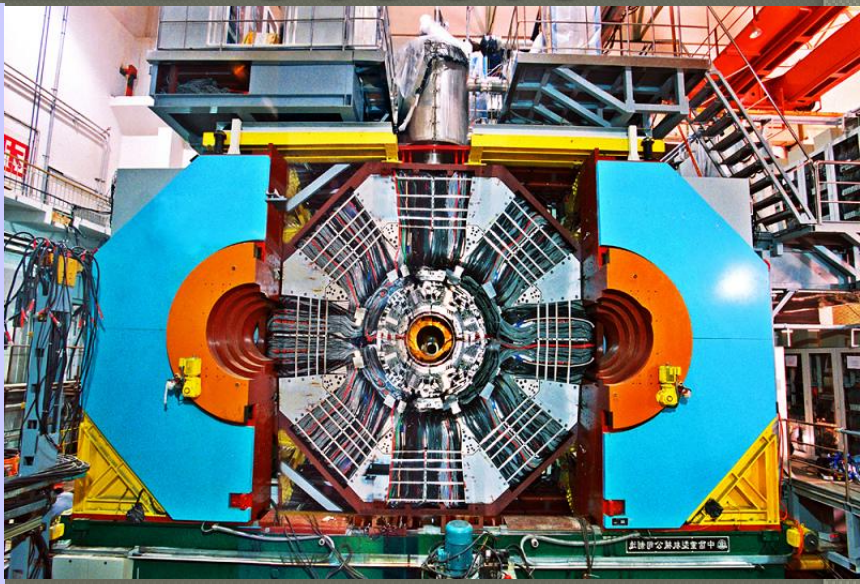
BEPC II



Beam energy:
1.0 – 2.3 GeV
Design Luminosity:
1×10^{33} cm^{-2} s^{-1}
Optimum energy:
1.89 GeV
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A
SR mode:
0.25A @ 2.5 GeV

BESIII Detector





Sub-detectors			Performance
MDC	Momentum resolution		0.5%@1GeV
	dE/dx resolution		6%
EMC	Energy resolution		2.5%@1GeV
	Spatial resolution		6 mm
TOF	Time resolution	Barrel	80 ps (Bhabha)
		Endcap	110 ps (Di-muon)
MUC	9 layers RPC, 8 layers for endcap		

BESIII Data Samples

- July 18, 2008: First e+e- collision event
- 2009 : 106 M $\psi(2S)$ events (x4 CLEOc)
  225 M J/ψ events (x4 BESII)
- 2010 - 2011 : 2.9 fb^{-1} $\psi(3770)$
- 2011 : ~ 0.5 fb^{-1} @ 4.01 GeV
  (D_S and XYZ spectroscopy)
  ~ 30 pb^{-1} τ mass scan
- 2012 : ~ 0.4 billion $\psi(2S)$
  ~ 1 billion J/ψ
  R scan [2.0, 3.65] GeV
- 2013: ~ 1.1, 0.8, 0.5 fb^{-1} @ 4.23, 4.26, 4.36 GeV
  and scan in vicinity

BESIII Collaboration

US (6)

Univ. of Hawaii
Univ. of Washington
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Europe (12)

Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In **Mainz**
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino, Frascati Lab, Ferrara Univ.
Netherland: KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

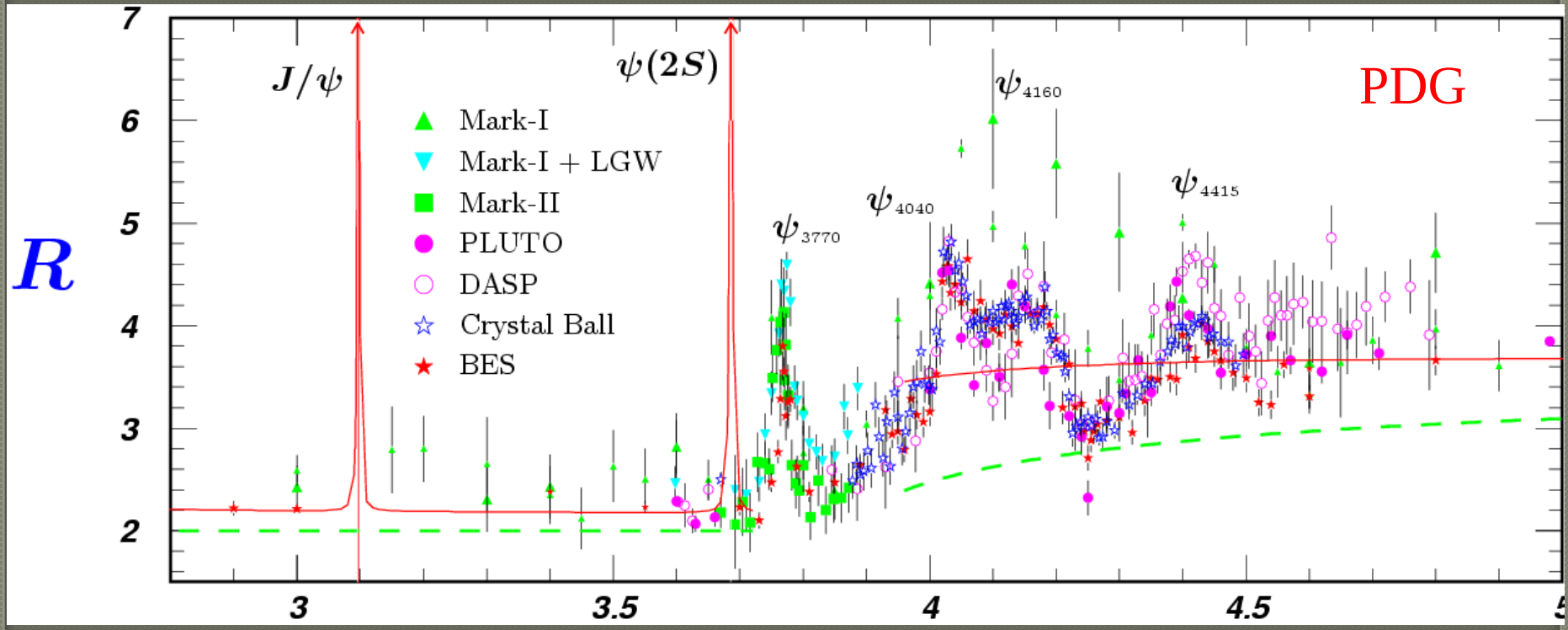
Univ. of Punjab
COMSAT CIIT

China(30)

IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ. , Beihang Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Hong Kong Univ., Hong Kong Chinese Univ.

~300 members
54 institutions from 11 countries

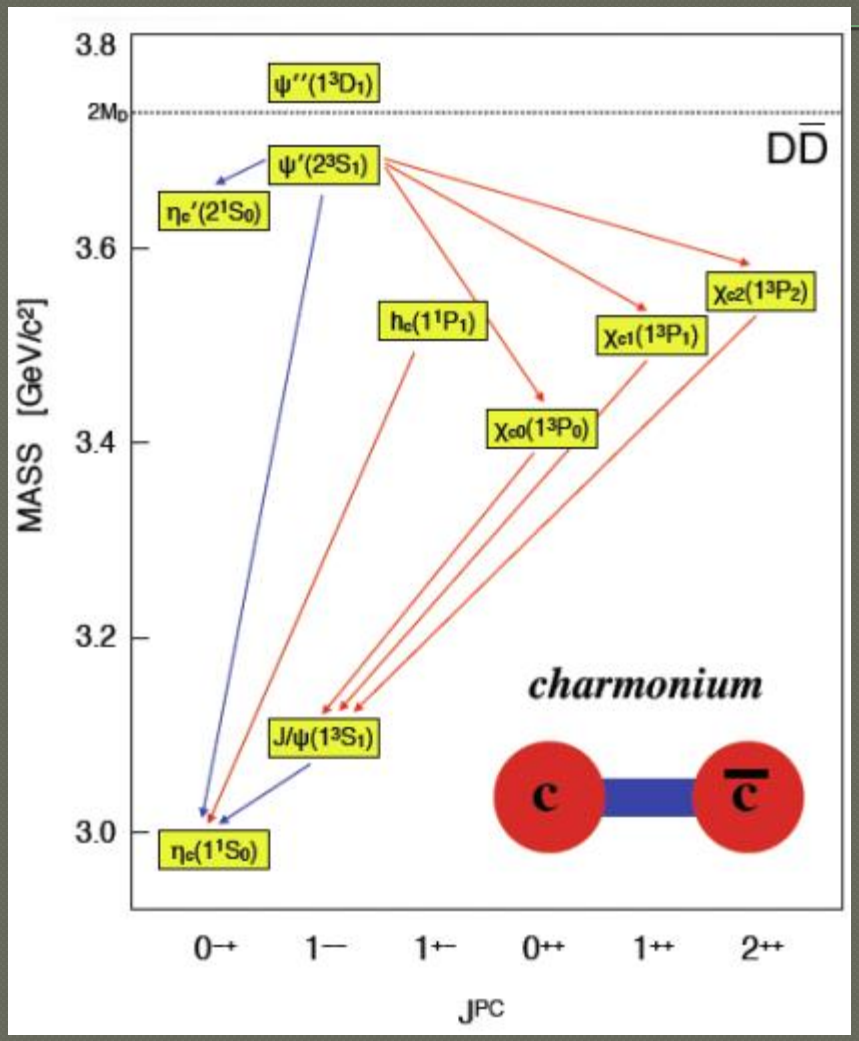
Production of charmonium(like) states



Vector ψ/Y states can be produced directly

C-even states can be produced from radiative transitions

Physics of τ-charm region



- Charmonium physics:
  - Spectroscopy
  - transitions and decays
- Light hadron physics:
  - meson & baryon spectroscopy
  - glueball & hybrid
  - two-photon physics
  - e.m. form factors of nucleon
- Open Charm physics:
  - (semi)leptonic + hadronic decays
  - decay constant, form factors
  - CKM matrix: Vcd, Vcs
  - D^0-D^0bar mixing and CP violation
  - rare/forbidden decays
- QCD & Tau physics:
  - precision R-measurement
  - Tau decays and tau mass scan
- …and many more.

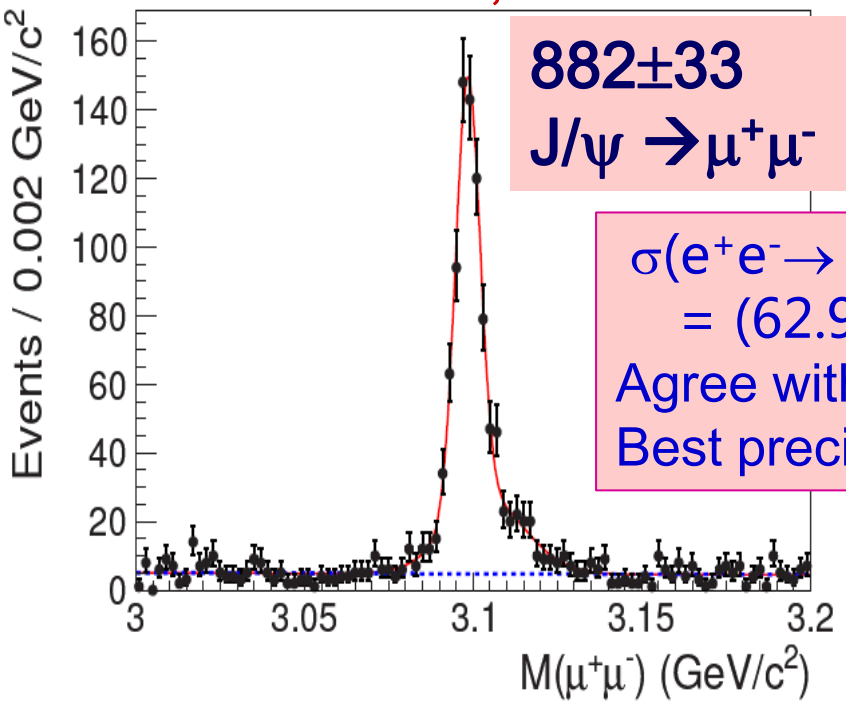
Selected BESIII results

- XYZ study
  - Zc(3900) $\rightarrow \pi J/\psi$
  - Zc(4020) $\rightarrow \pi h_c$
  - Zc(4025) $\rightarrow$ D*D*
  - e+e-$\rightarrow \gamma$X(3872)
- Charm decays
  - $D^+ \rightarrow \mu^+\nu$
  - $D^0 \rightarrow K/\pi e\nu$
- Light hadron spectrum
  - study of $\eta\eta$ system
  - excited nucluon $\psi(3686) \rightarrow p\ \bar{p}\ \pi^0(\eta)$

Observation of $Z_c(3900)$

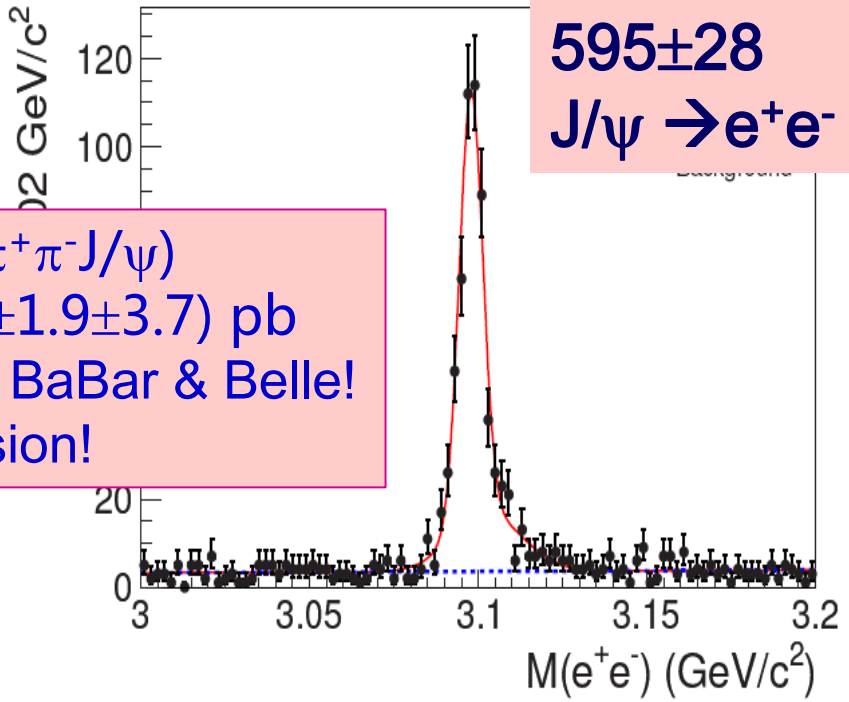
- Select $e^+e^- \to \pi^+\pi^- J/\psi$ at 4.26 GeV (525/pb)

BESIII: PRL110, 252001



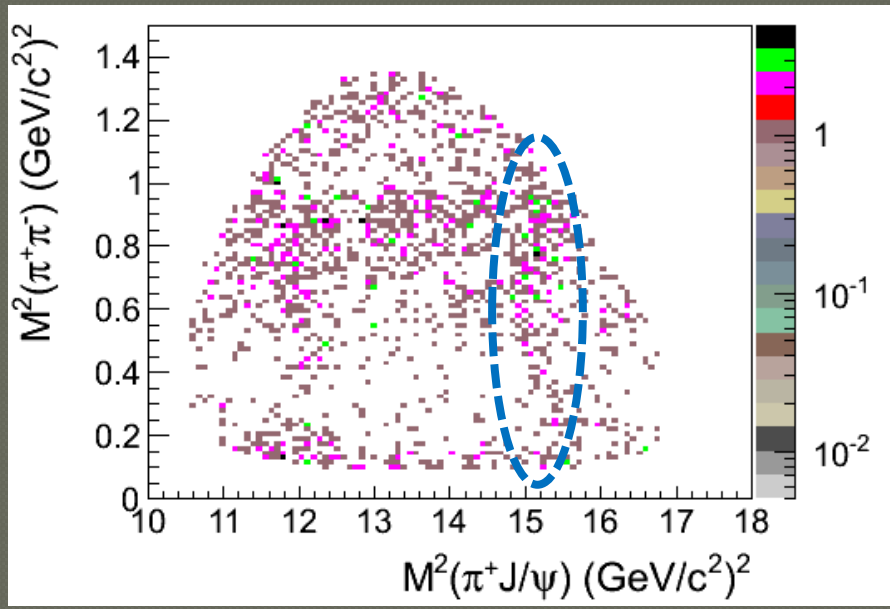
882±33
$J/\psi \to \mu^+\mu^-$

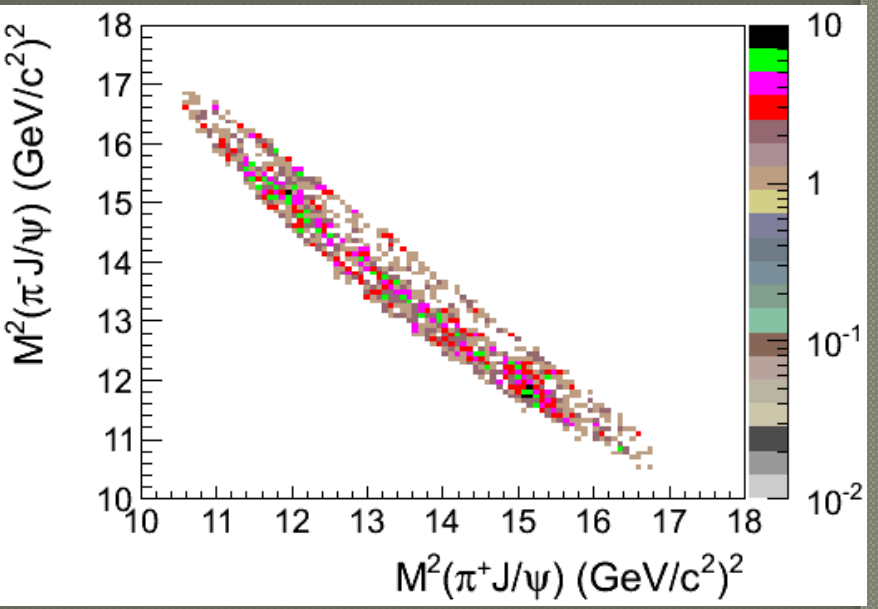
$\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$
$= (62.9 \pm 1.9 \pm 3.7)$ pb
Agree with BaBar & Belle!
Best precision!

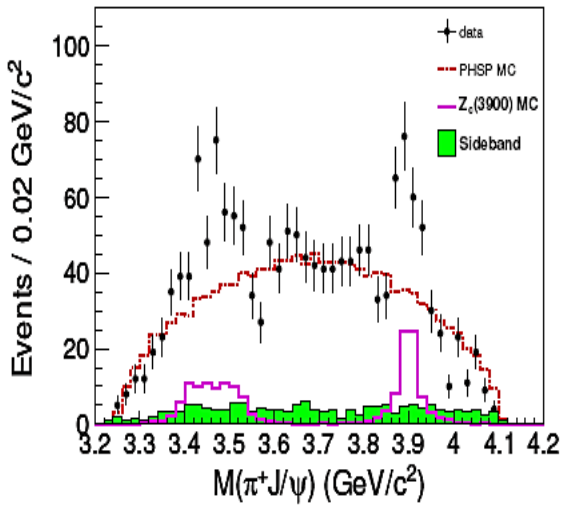


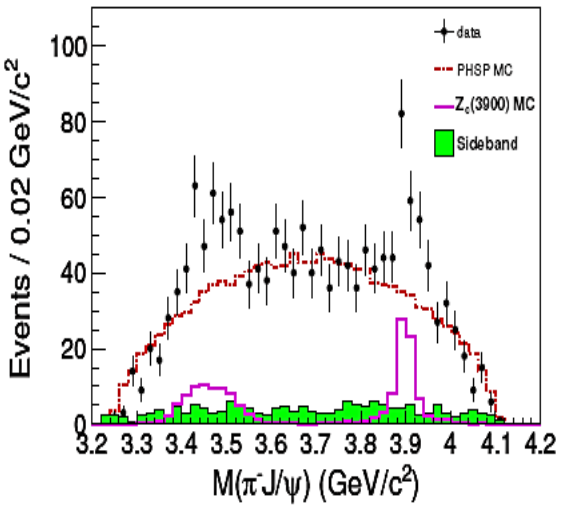
595±28
$J/\psi \to e^+e^-$

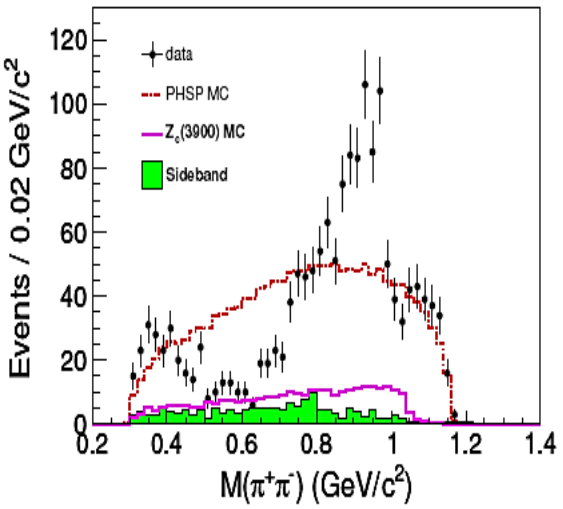
Observation of $Z_c(3900)$



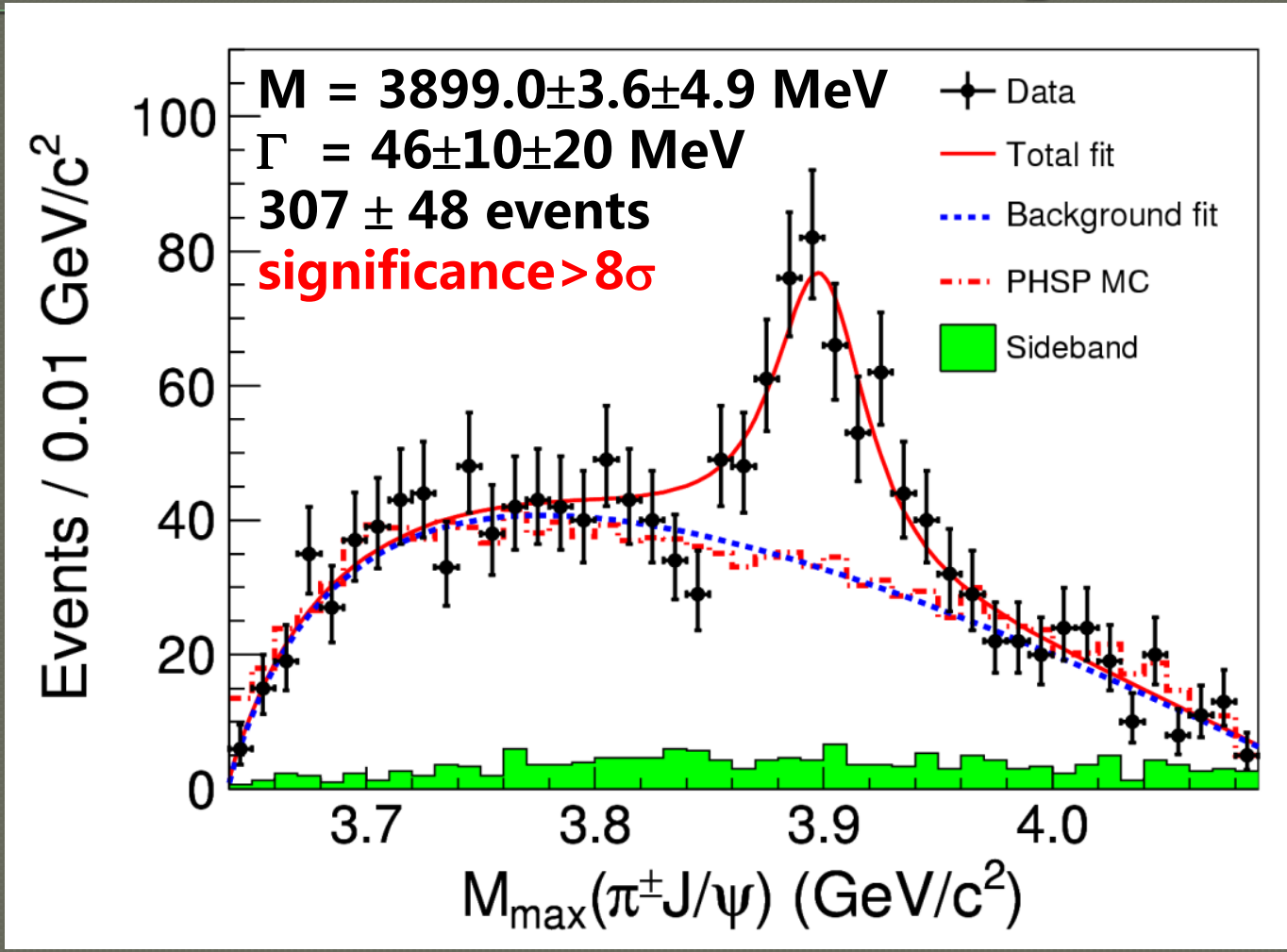






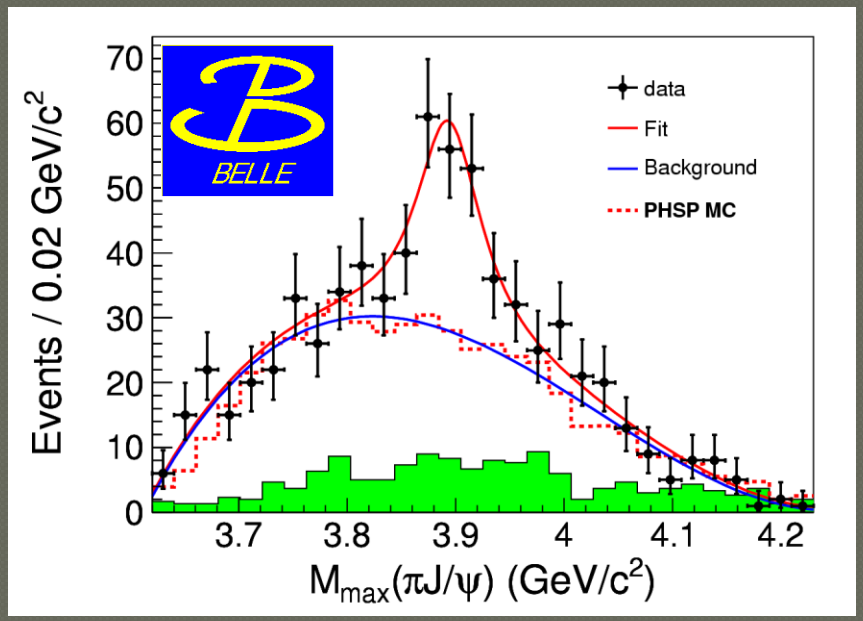


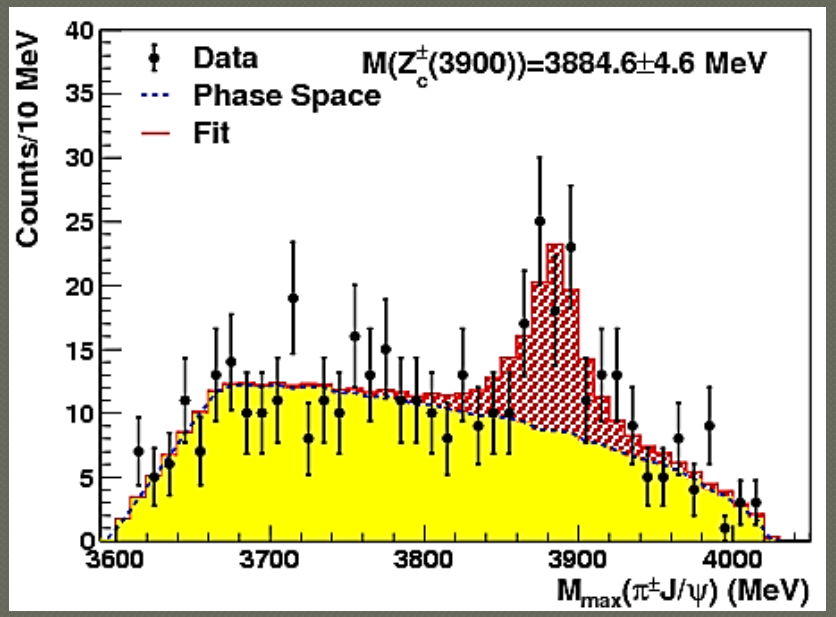
Observation of $Z_c(3900)$



BELLE :
$e^+e^- \to \pi^+\pi^- J/\psi$ from ISR
PRL 110, 252002(2013)

CLEOc data at 4.17 GeV
arXiv: 1304.3036





- M = 3894.5±6.6±4.5 MeV
- Γ = 63±24±26 MeV
- 159 ± 49 events
- >5.2σ

- M = 3885±5±1 MeV
- Γ = 34±12±4 MeV
- 81 ± 20 events
- 6.1σ

The nature of $Z_c(3900)$?

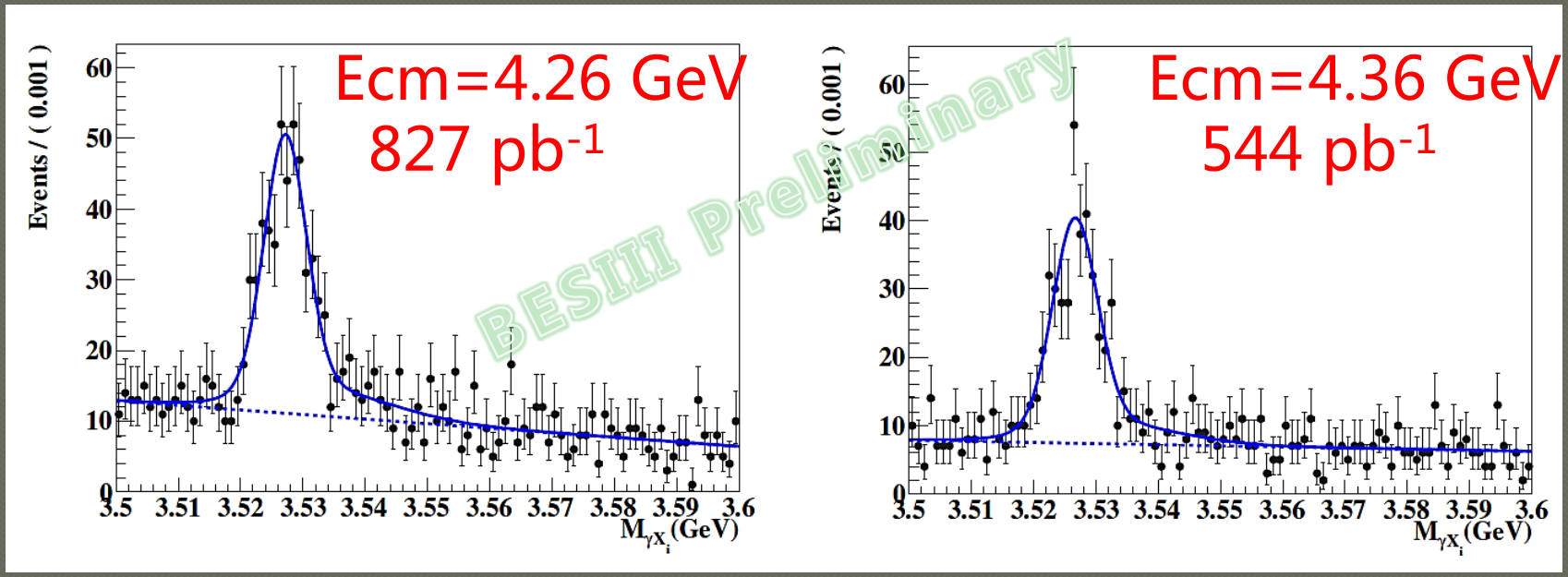
- Couples to $c\bar{c}$
- Has electric charge
- At least 4-quarks

- $\bar{D}D^*$ molecule?
- Tetraquark state?
- Cusp?
- Threshold effect?
- … …

Predictions and more experimental information will be essential to understand its nature.

$e^+e^- \to \pi^+\pi^- h_c(1P)$

- $h_c \to \gamma\eta_c$, $\eta_c \to$hadrons (16 exclusive decay modes)



$N(h_c)=416\pm28$

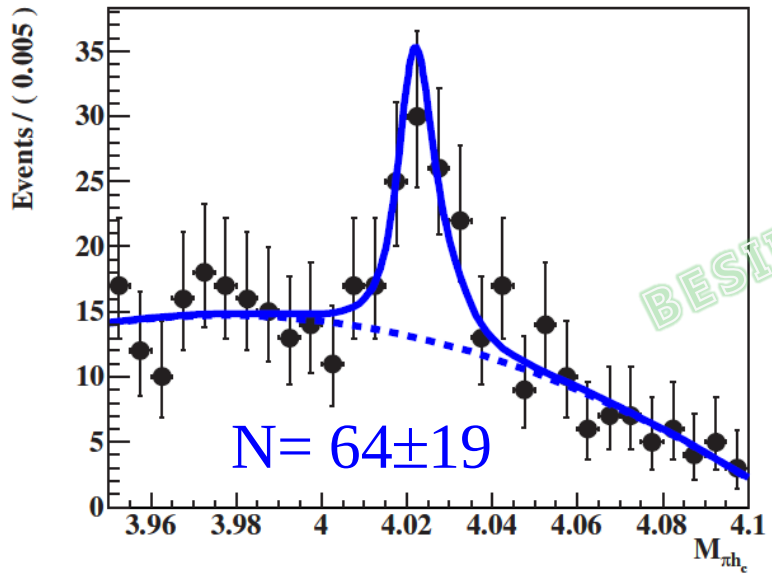
$\sigma^B = 41.0\pm2.8\pm7.4$ pb

$N(h_c)=357\pm25$

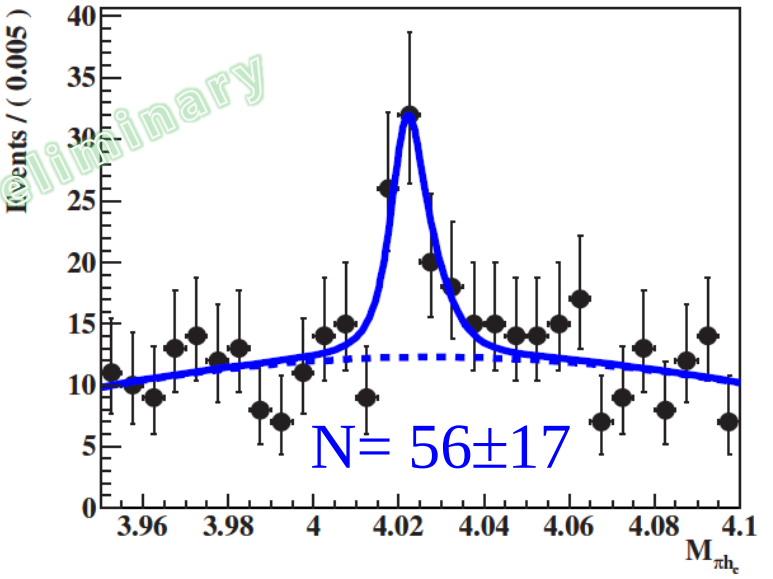
$\sigma^B = 52.3\pm3.7\pm9.2$ pb

$e^+e^- \to \pi Z_c(4020) \to \pi^+\pi^- h_c(1P)$

Ecm=4.26 GeV



Ecm=4.36 GeV

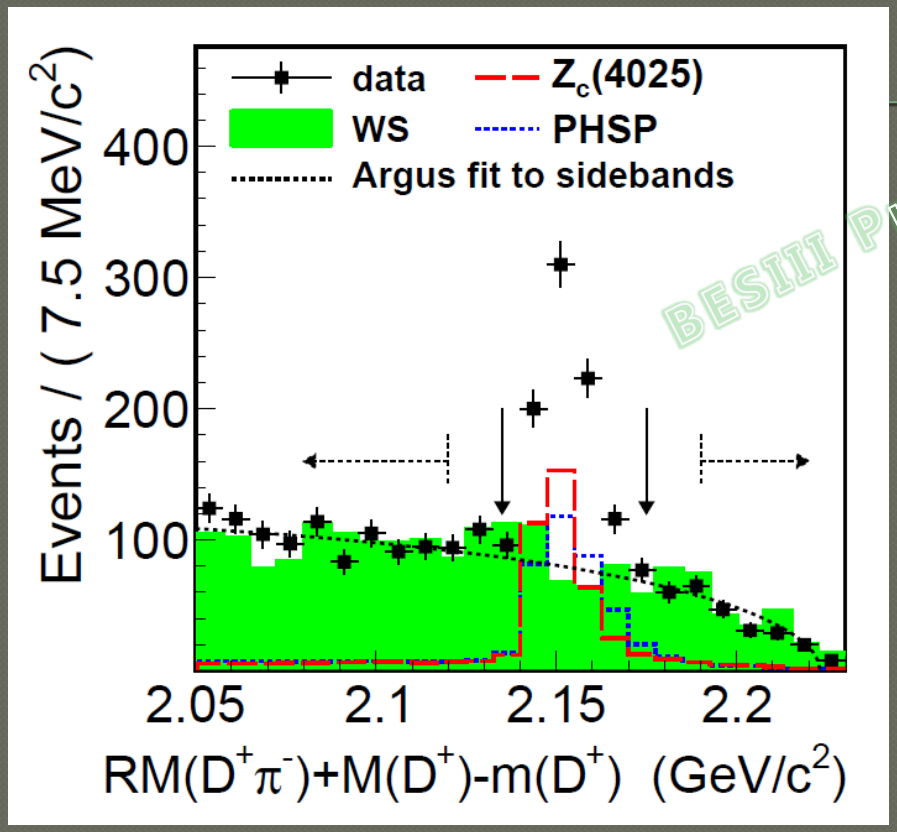


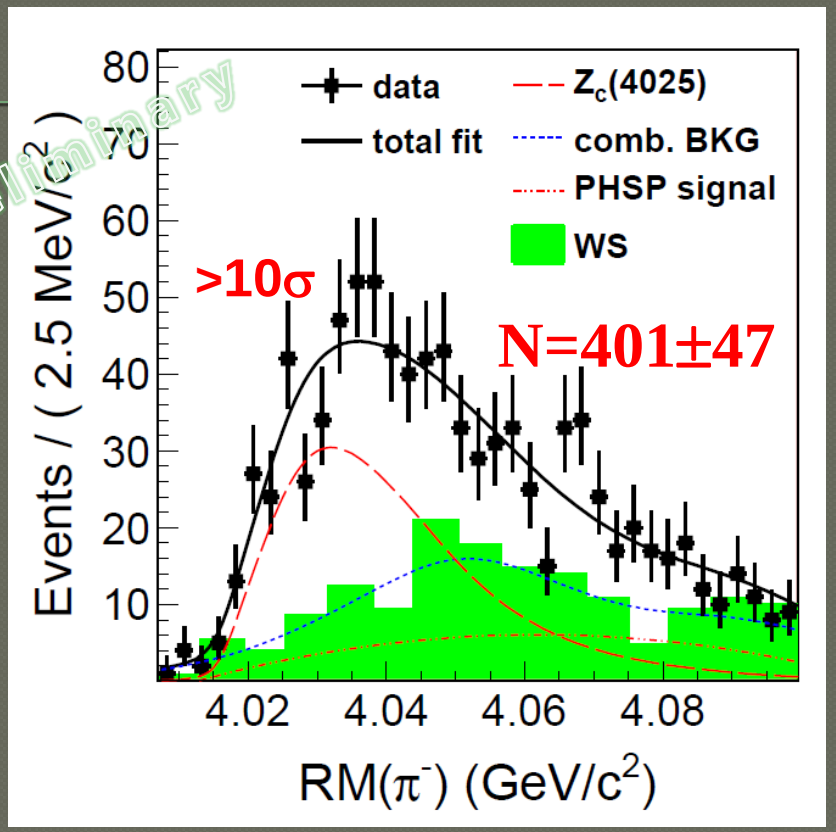
Simultaneous fit to 4.26/4.36 GeV data and 16 η_c decay modes. **6.4σ**

M = 4021.8±1.0±2.5 MeV; Γ= 5.7±3.4±1.1 MeV

$$R = \frac{\sigma(e^+e^- \to \pi^\pm Z_c^\mp \to \pi^+\pi^- h_c(1P))}{\sigma(e^+e^- \to \pi^+\pi^- h_c(1P))} = (16.2 \pm 4.1 \pm 0.7)\% \qquad (16.6 \pm 5.2 \pm 0.8)\%$$

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



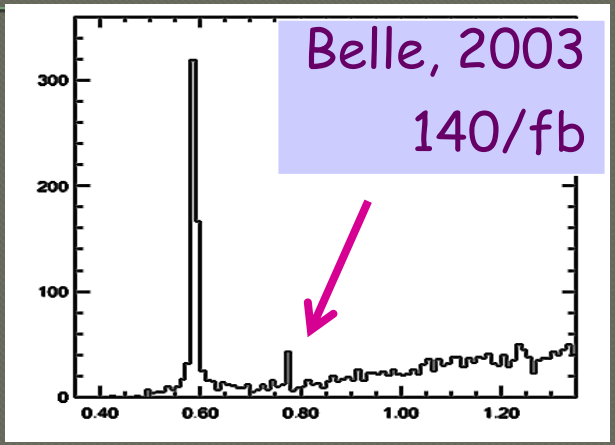


M = 4026.3±2.6±3.7 MeV; Γ= 24.8±5.7±7.7 MeV

$$R = \frac{\sigma(e^+e^- \to \pi^\pm Z_c^\mp \to \pi^\pm (D^*\bar{D}^*)^\mp)}{\sigma(e^+e^- \to \pi^\pm (D^*\bar{D}^*)^\mp)} = (65 \pm 9 \pm 6)\,\%$$

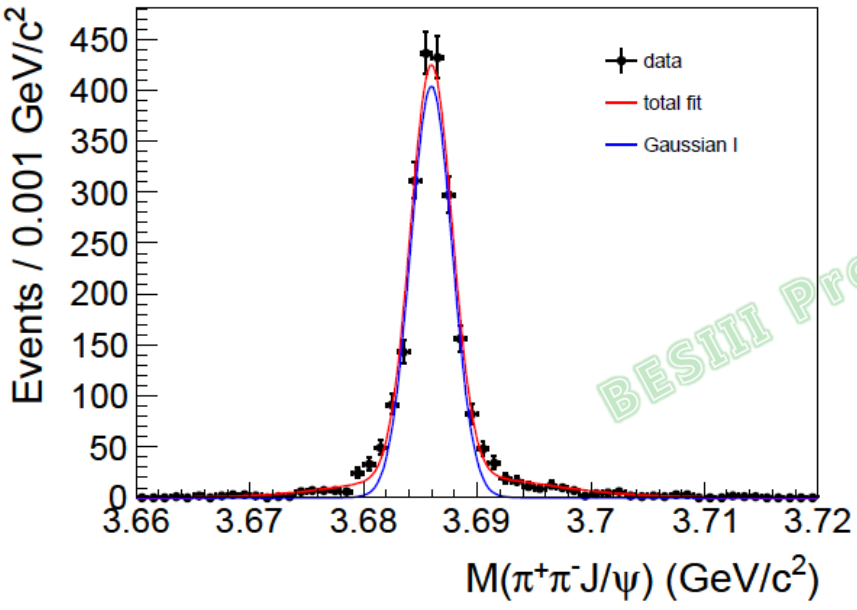
$$\sigma(e^+e^- \to \pi^\pm (D^*\bar{D}^*)^\mp) = (137 \pm 9 \pm 15)\ \text{pb}$$

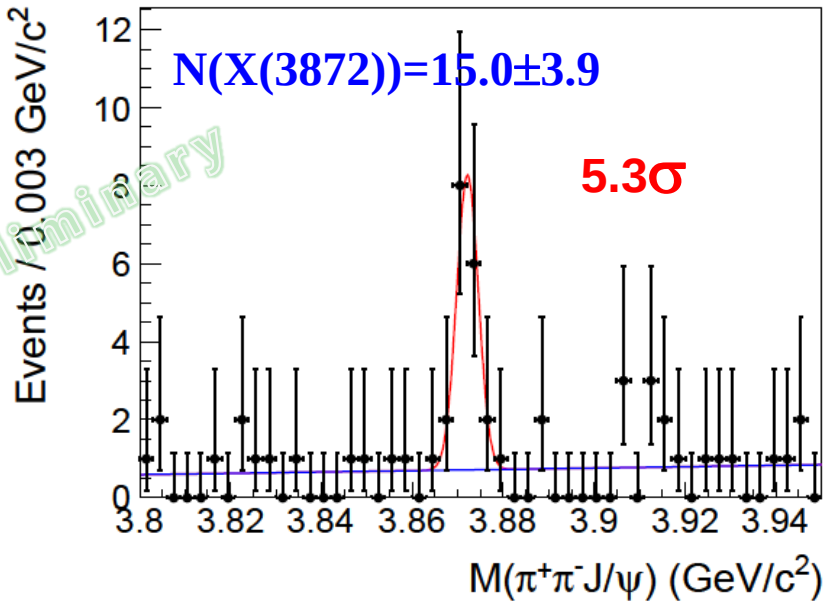
X(3872)



- First observed by Belle
- Mass: very close to $\bar{D}^0 D^{*0}$ threshold
- Width: very narrow, <1.2 MeV
- $J^{PC} = 1^{++}$ (LHCb)
- Production
  - in $\bar{p}p$/pp collison – rate similar to charmonia
  - In B decays – KX similar to $\bar{c}c$, K*X smaller than $\bar{c}c$

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

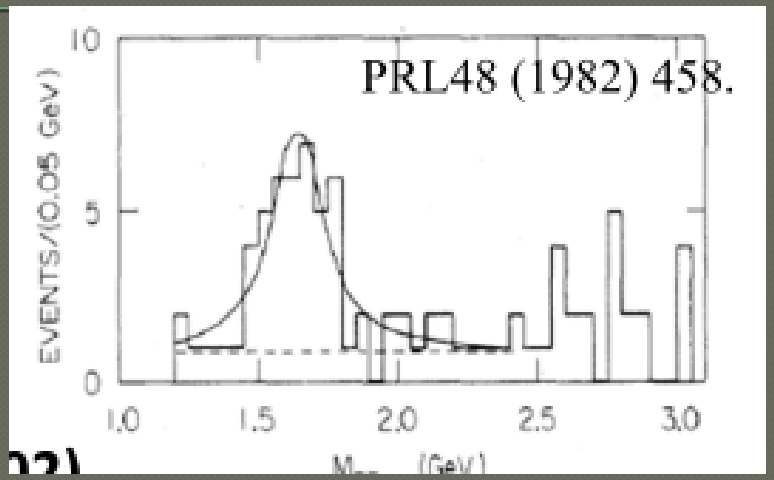




- ISR ψ' signal is used for rate, mass, and mass resolution calibration.
- ψ' : Mass=3685.96±0.05 MeV; σ_M=1.84 ±0.06 MeV
- M(X(3872)) = 3872.1±0.8±0.3 MeV
  [PDG: 3871.68 ±0.17 MeV]

glueball search – Study of ηη system

- First observed f0(1710) from J/ψ radiative decays to ηη by Crystal Ball in 1982

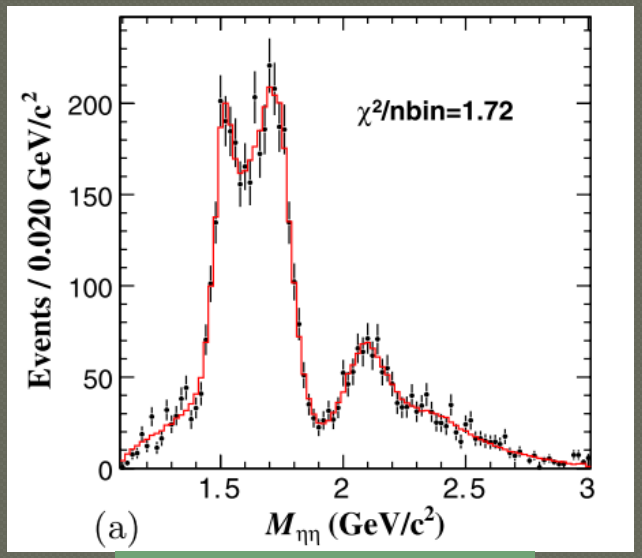


- Crystal Barrel Collaboration (2002) analyzed the three final states $\pi^0\pi^0\pi^0$, $\eta\pi^0\pi^0$ and $\pi^0\eta\eta$ with K matrix formalism. Found a 2^{++} (~1870), but no $f_0(1710)$
- E835 (2006): $\bar{p}p \rightarrow \pi^0\eta\eta$, found $f_0(1500)$ and $f_0(1710)$
- WA102 and GAMS all identified f0(1710) in ηη

Study of ηη system

LQCD: lowest mass glueball with 0^{++} is in 1.5 – 1.7 GeV

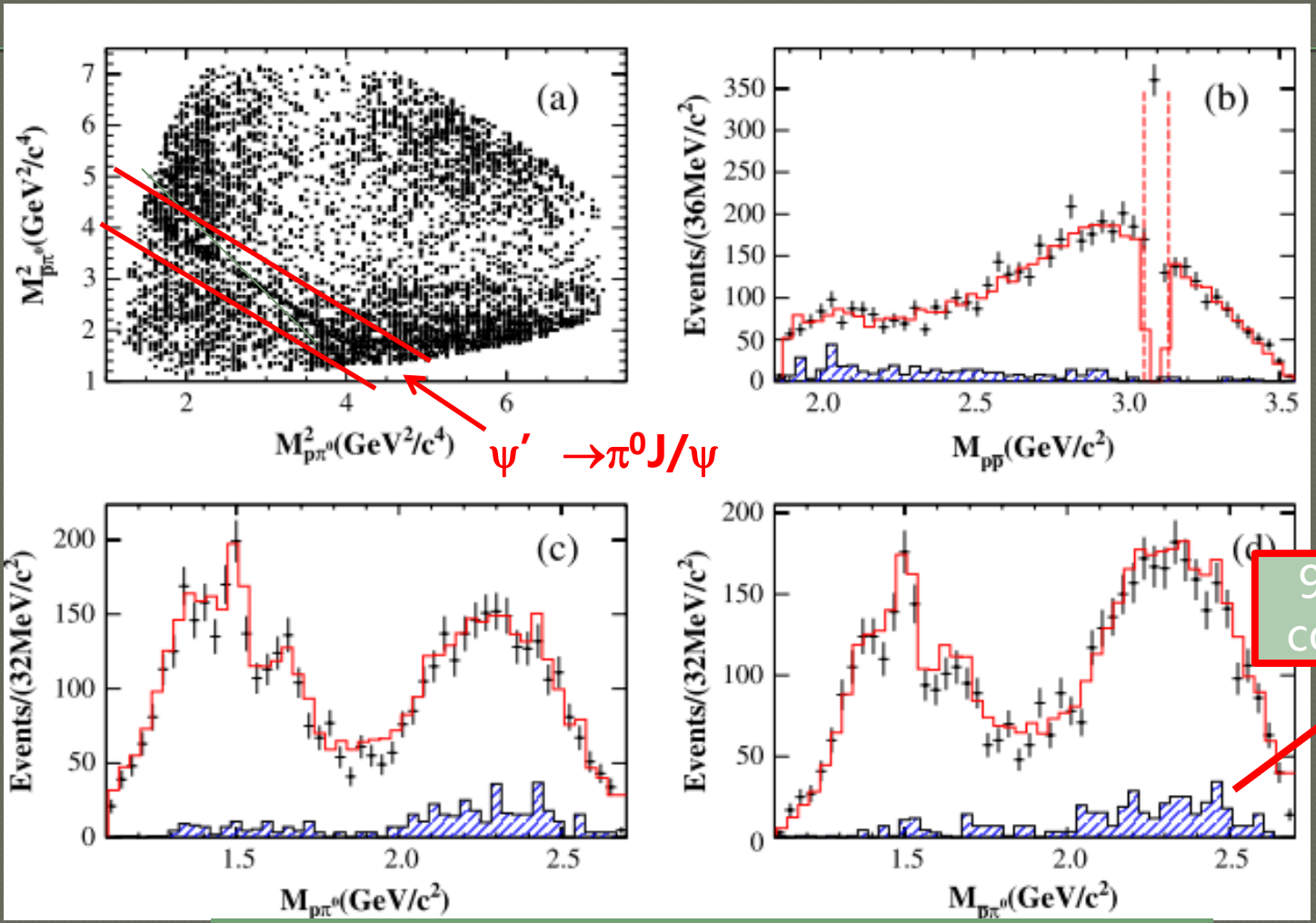
- $f_0(1710)$ and $f_0(2100)$ are dominant scalars
- $f_0(1500)$ exists (8.2σ)
- f_2' (1525) is the dominant tensor



PRD 87, 092009 (2013)

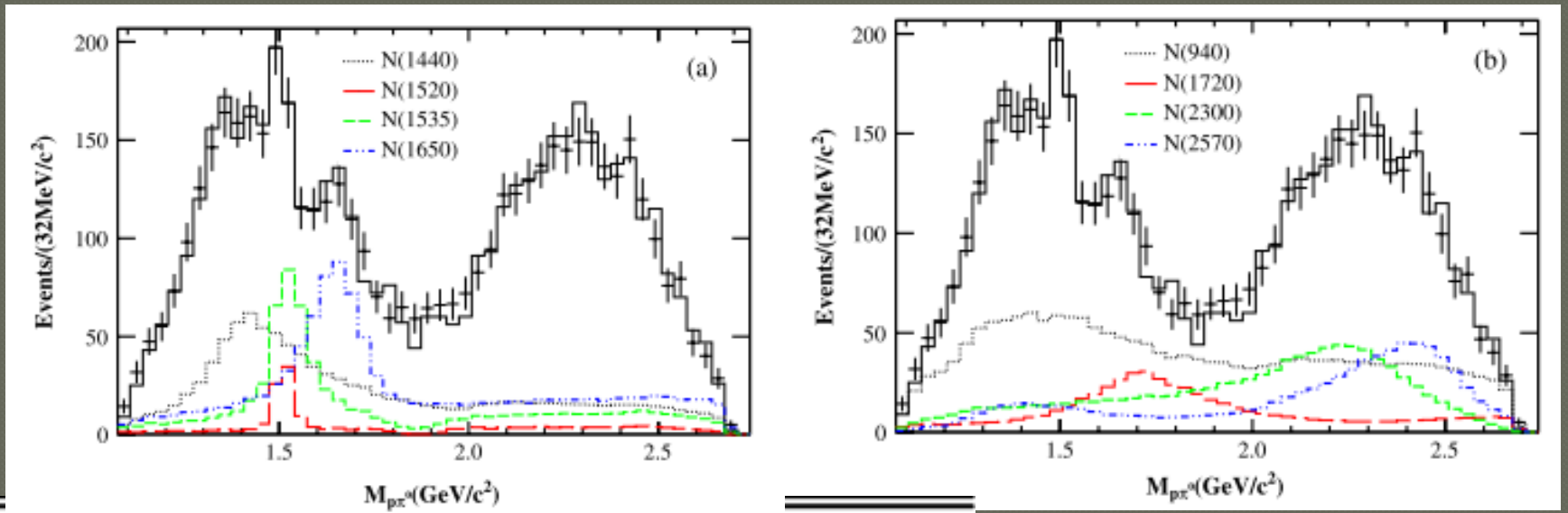
Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	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

$\psi(3686) \to p\ \bar{p}\ \pi^0$



Phys. Rev. Lett. 110, 022001 (2013)

$\psi(3686) \to p\ \bar{p}\ \pi^0$



Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	ΔS	ΔN_{dof}	Sig.	N	B.F.$(\times 10^{-5})$
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ	$1870^{+90+487}_{-90-327}$	$6.42^{+0.20+1.78}_{-0.20-1.28}$
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ	$1060^{+90+459}_{-90-227}$	$3.58^{+0.25+1.59}_{-0.25-0.84}$
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ	190^{+14+64}_{-14-48}	$0.64^{+0.05+0.22}_{-0.05-0.17}$
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	4	12.2σ	$673^{+45+263}_{-45-256}$	$2.47^{+0.28+0.99}_{-0.28-0.97}$
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94-44}$	55.6	6	9.6σ	$1080^{+77+382}_{-77-467}$	$3.76^{+0.28+1.37}_{-0.28-1.66}$
N(2300)	$\mathbf{2300^{+40+109}_{-30-0}}$	$\mathbf{340^{+30+110}_{-30-58}}$	**120.7**	**4**	$\mathbf{15.0\sigma}$	$510^{+27+50}_{-27-197}$	$1.79^{+0.10+0.24}_{-0.10-0.71}$
N(2570)	$\mathbf{2570^{+19+34}_{-10-10}}$	$\mathbf{250^{+14+69}_{-24-21}}$	**78.9**	**6**	$\mathbf{11.7\sigma}$	$948^{+68+394}_{-68-213}$	$2.62^{+0.28+1.12}_{-0.28-0.64}$
						$795^{+45+127}_{-45-83}$	$2.13^{+0.08+0.40}_{-0.08-0.30}$

$J^P = 1/2+$

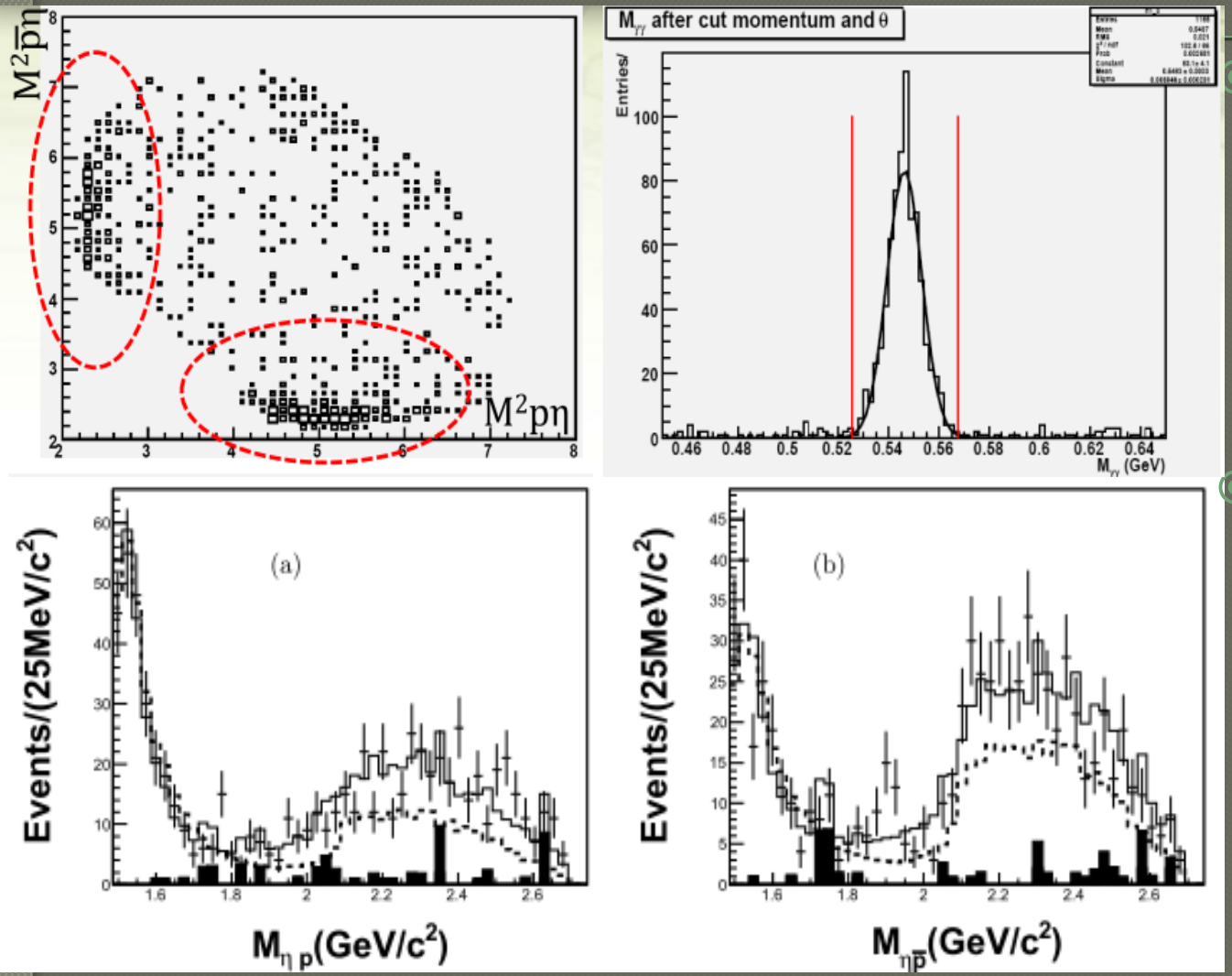
$J^P = 5/2-$

$\psi(3686) \to p\ \bar{p}\ \pi^0$

- Using 106 M $\psi(3686)$ data, detailed PWA of $\psi(3686) \to p\ \bar{p}\ \pi^0$ are performed.
- Two new N* are observed, N(2300) (1/2+) and N(2570) (5/2-)
- Mass and width of 5 well-known N* are measured, agree with data in PDG
- No clear evidence for N(1885) and N(2065)

PRL 110, 022001 (2013)

$\psi(3686) \to p\ \bar{p}\ \eta$



- N(1535) and PHSP(1/2-) are significant in this analysis
- MC projection is consistent with data

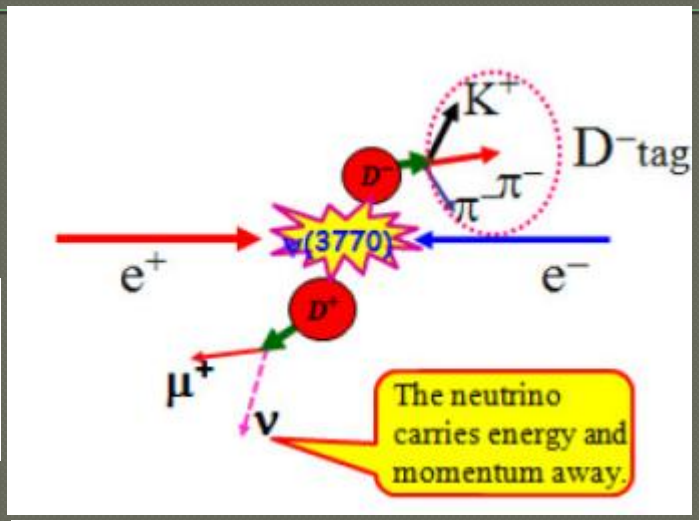
arXiv : 1304.1973

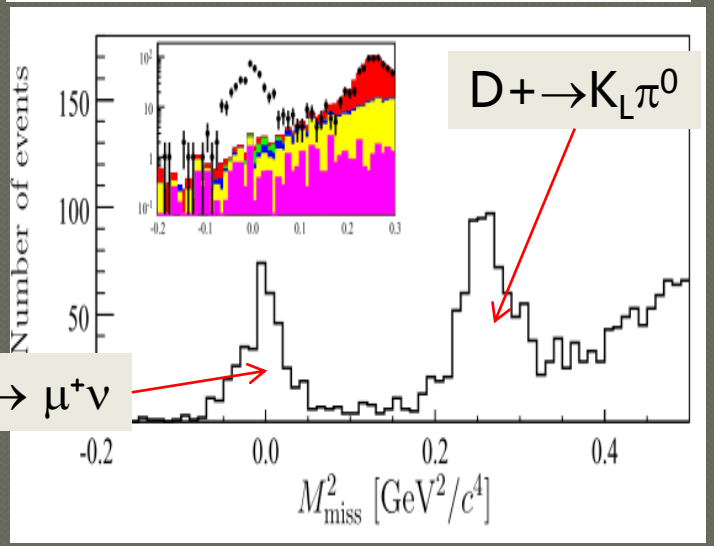
$D^+ \to \mu^+\nu$

- Tag D^-, select $D^+ \to \mu^+\nu$

$$\Gamma(D^+ \to l^+ \upsilon_l) = \frac{G_F^2 f_{D^+}^2}{8\pi} |V_{cd}|^2 m_l^2 m_{D^+} (1 - \frac{m_l^2}{m_{D^+}^2})^2$$

- All quantities are well measured except f_D
- Using 9 D^- tag modes in 2.9 fb^{-1} data

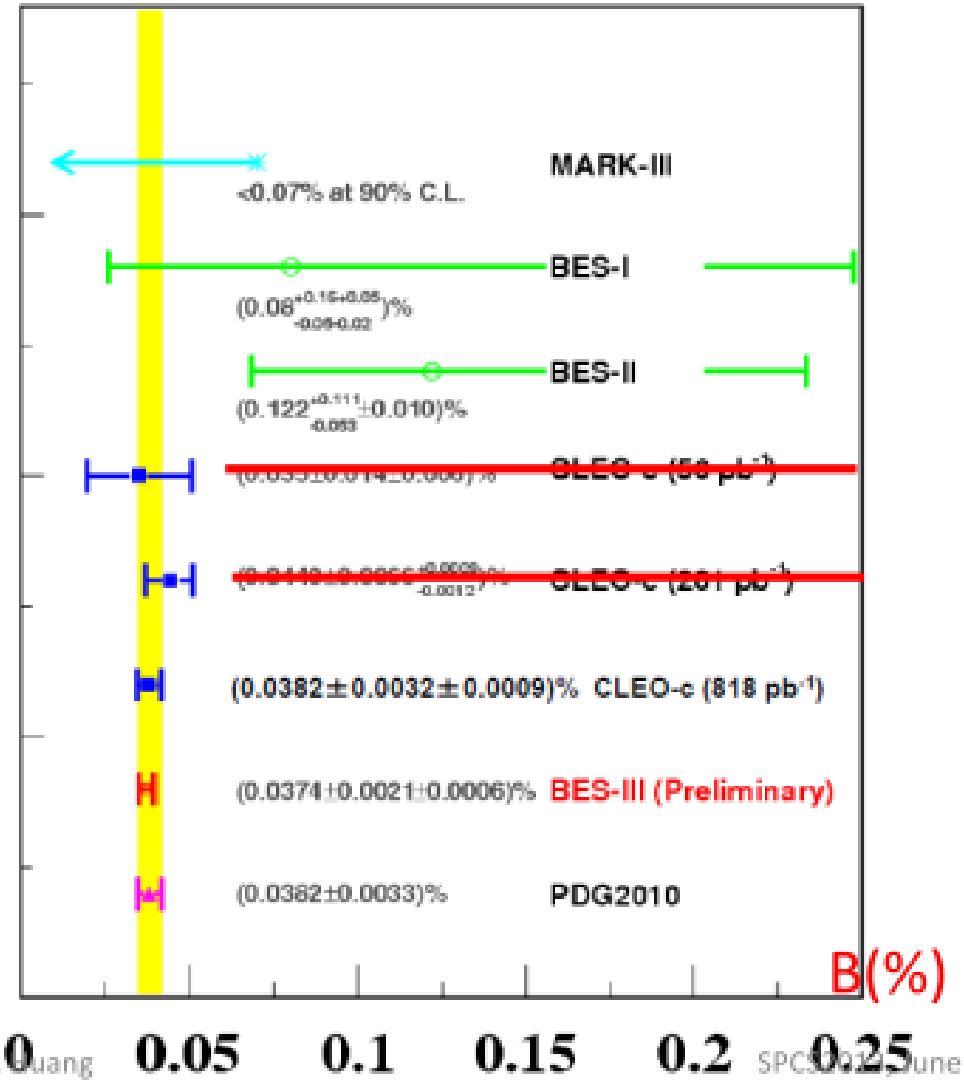


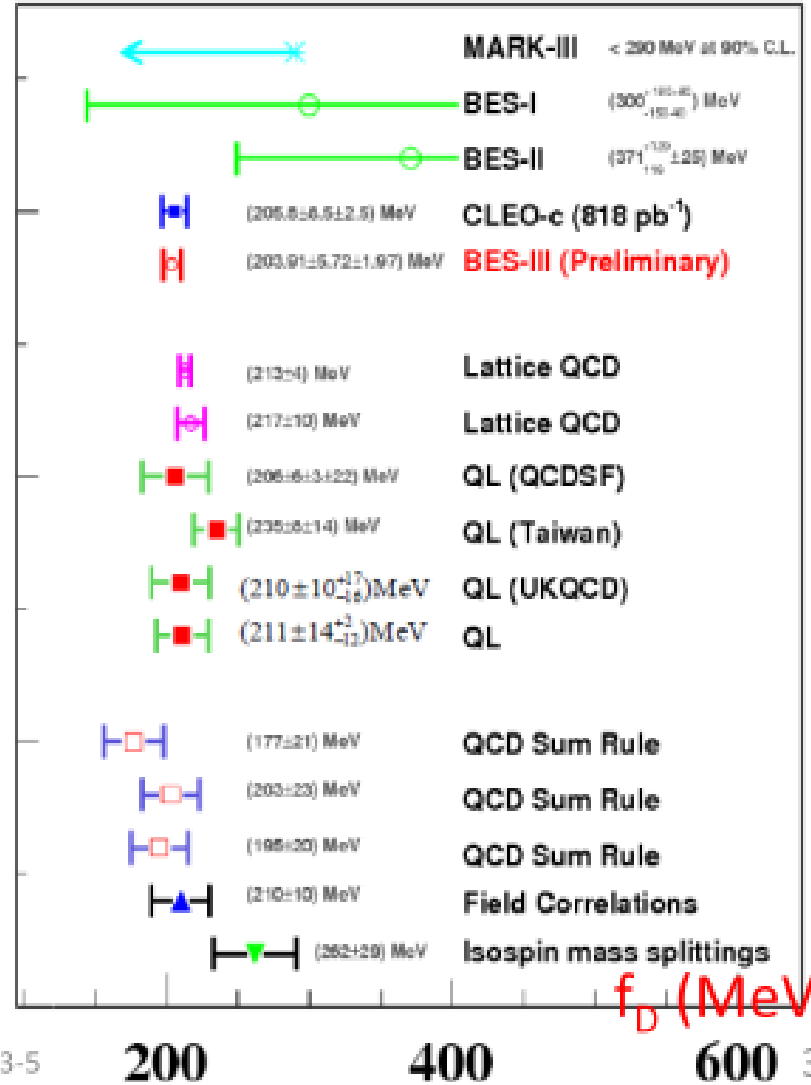


$D^+ \to \mu^+\nu$: Preliminary Results

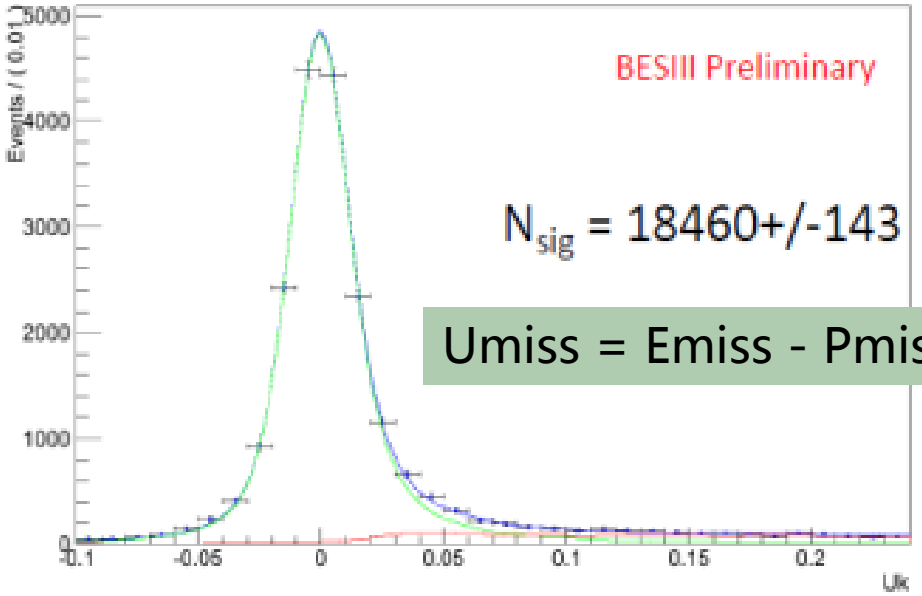
$N(D^+ \to \mu^+\nu) = 377.3 \pm 20.6$

$B(D^+ \to \mu^+\nu) = (3.74 \pm 0.21^{stat} \pm 0.06^{sys}) \times 10^{-4}$ $f_D^+ = (203.91 \pm 5.72^{stat} \pm 1.97^{sys})$ MeV

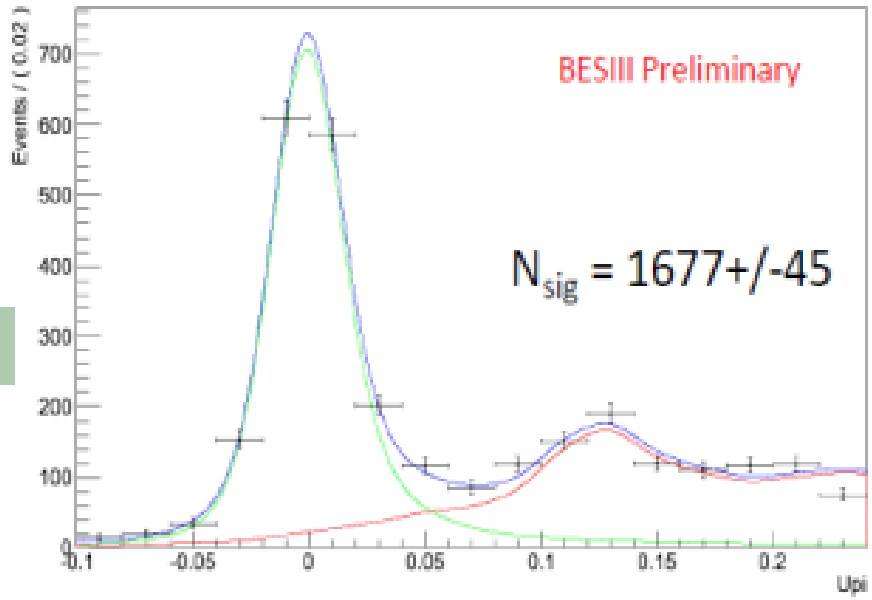




$D^0 \to K/\pi\, e\, \nu$



D^0 -> K e ν



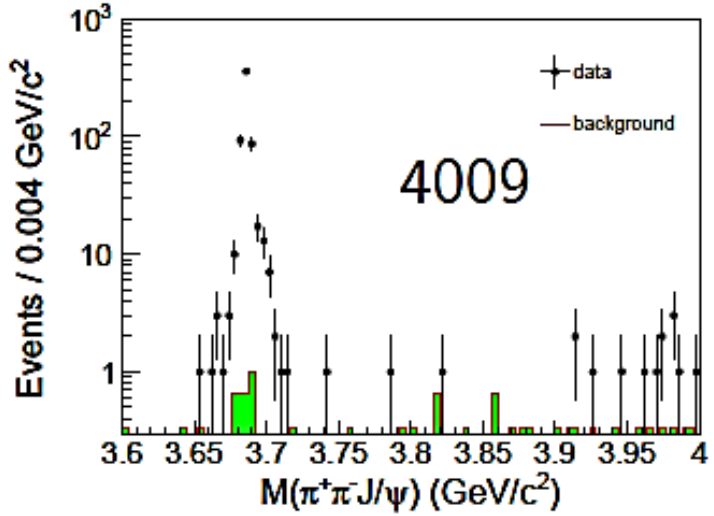
D^0 -> π e ν

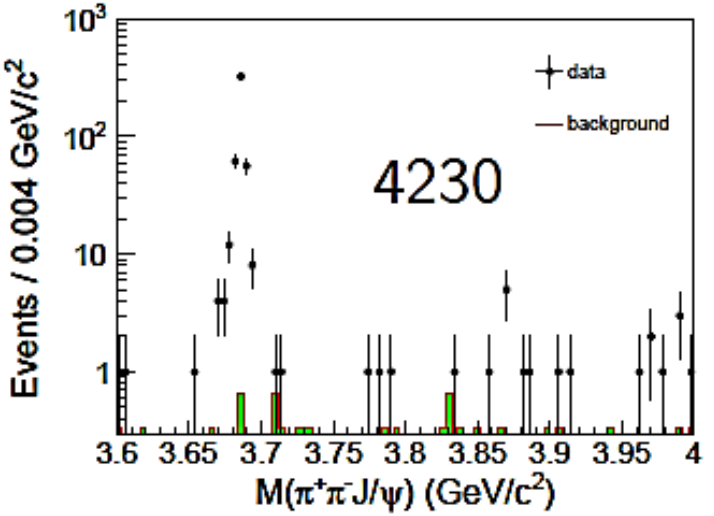
Mode	measured branching fraction(%)	PDG	CLEOc
$\bar{D}^0 \to K^+ e^- \bar{\nu}$	3.542 ±0.030±0.067	3.55 ±0.04	3.50 ±0.03 ±0.04
$\bar{D}^0 \to \pi^+ e^- \bar{\nu}$	0.288 ±0.008±0.005	0.289 ±0.008	0.288 ±0.008±0.003

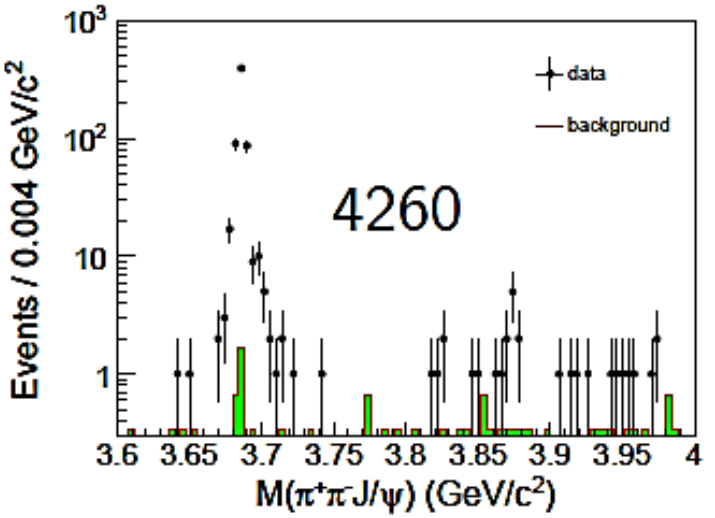
BESIII preliminary, with 0.92 fb^{-1} data, will improve with full 2.9 fb^{-1} soon. Form factor measurement ongoing.

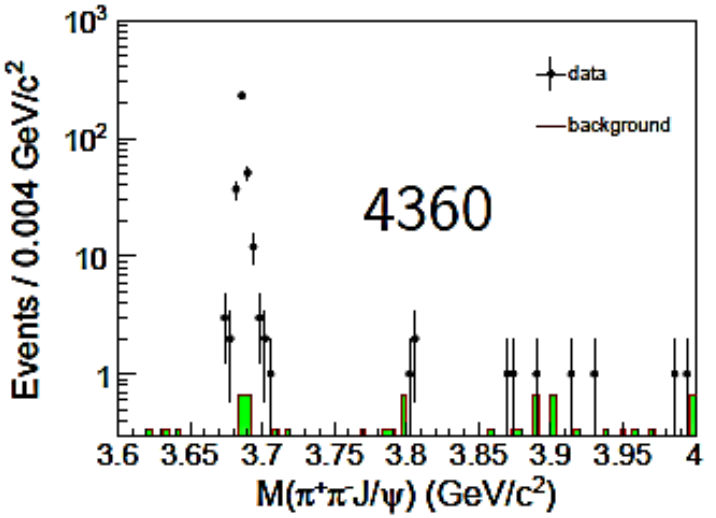
Summary

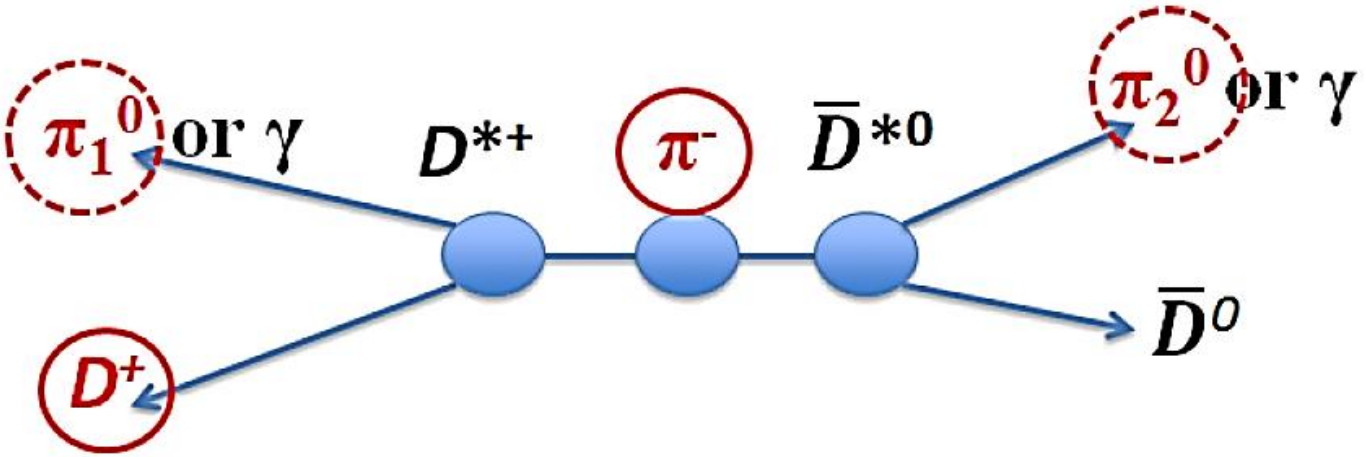
- BESIII has been successfully operating since 2008: world largest data samples at J/ψ, ψ(3686), ψ(3770), Y(4260), and so on
- Excellent for precision measurements and new discoveries.
- Fruitful results had been obtained, more will come.


4009
data
background
Events / 0.004 GeV/c²
M(π⁺π⁻J/ψ) (GeV/c²)


4230
data
background
Events / 0.004 GeV/c²
M(π⁺π⁻J/ψ) (GeV/c²)

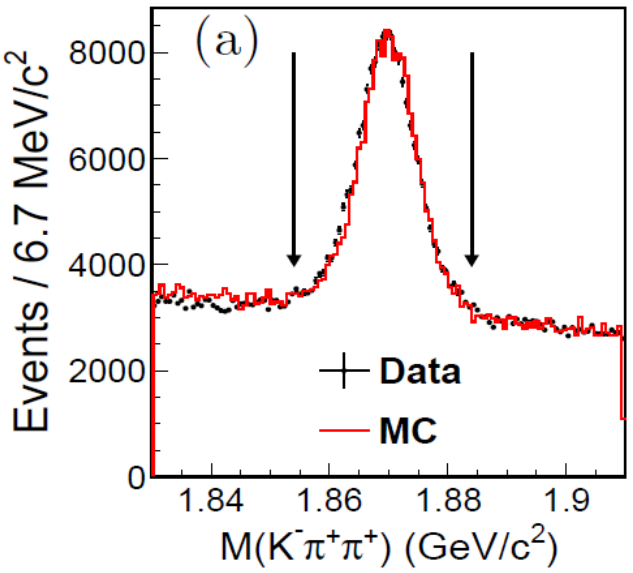

4260
data
background
Events / 0.004 GeV/c²
M(π⁺π⁻J/ψ) (GeV/c²)

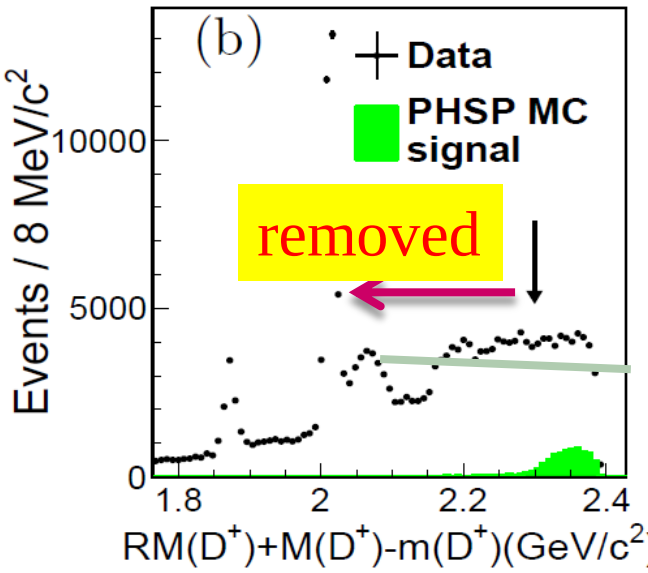

4360
data
background
Events / 0.004 GeV/c²
M(π⁺π⁻J/ψ) (GeV/c²)



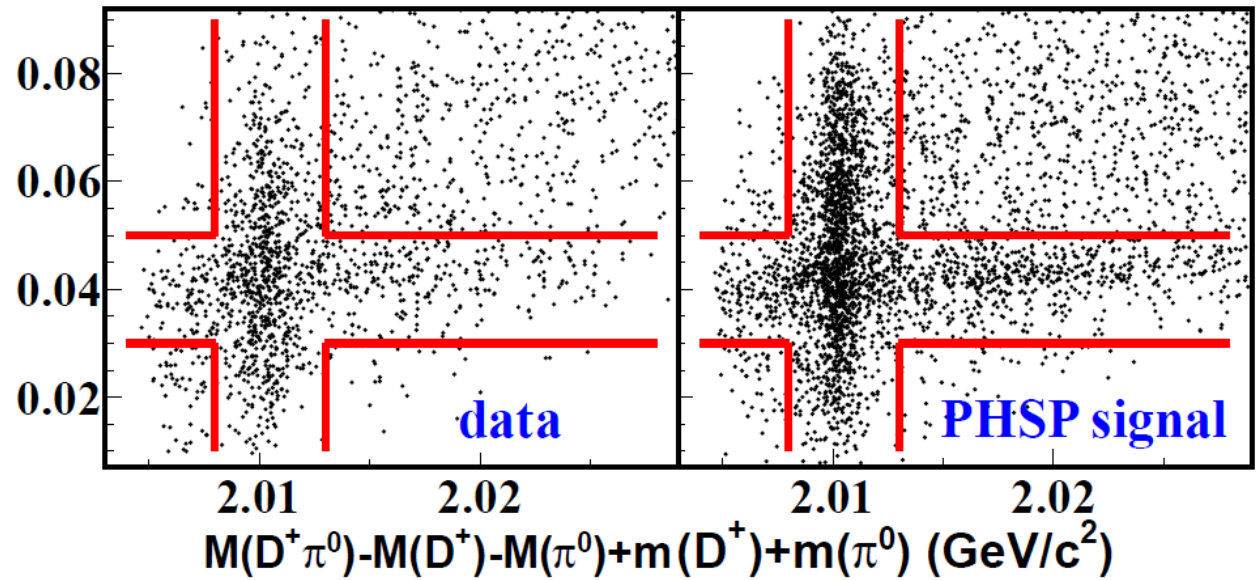
Topology of the decays of the signal process. Thick line circled D^+ and π^- are detected in the final states and at least one of the dashed line circled π_1^0 or π_2^0 is tagged.

$e^+e^- \to \pi^- (D^*\bar{D}^*)^+ + c.c.$ at BESIII



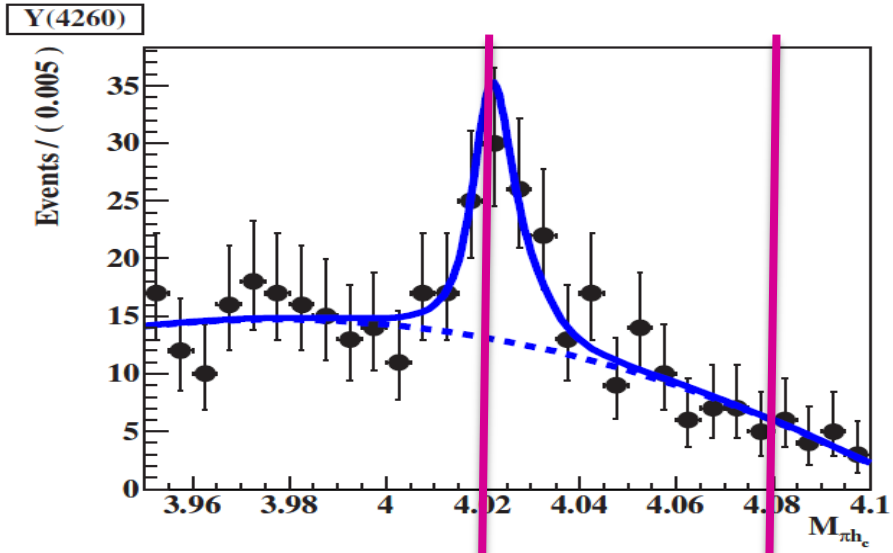


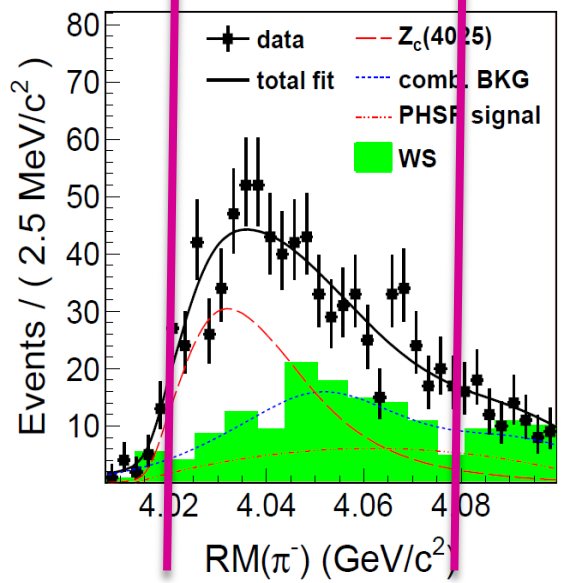
Remove DD, DD*, D*D*, DsDs, …



BESIII preliminary

$Z_c(4020)=Z_c(4025)$?





BESIII preliminary

The Zc' is found!

- M(4020) = 4021.8±1.0±2.5 MeV
- M(4025) = 4026.3±2.6±3.7 MeV
- Γ(4020) = 5.7±3.4±1.1 MeV
- Γ(4025) = 24.8±5.7±7.7 MeV

Close to D*D* threshold=4017 MeV

Mass consistent with each other but width ~2σ difference

Interference with other amplitudes may change the results

Coupling to $\bar{D}$*D* is much larger than to πh_c if they are the same state

Will fit with Flatte formula

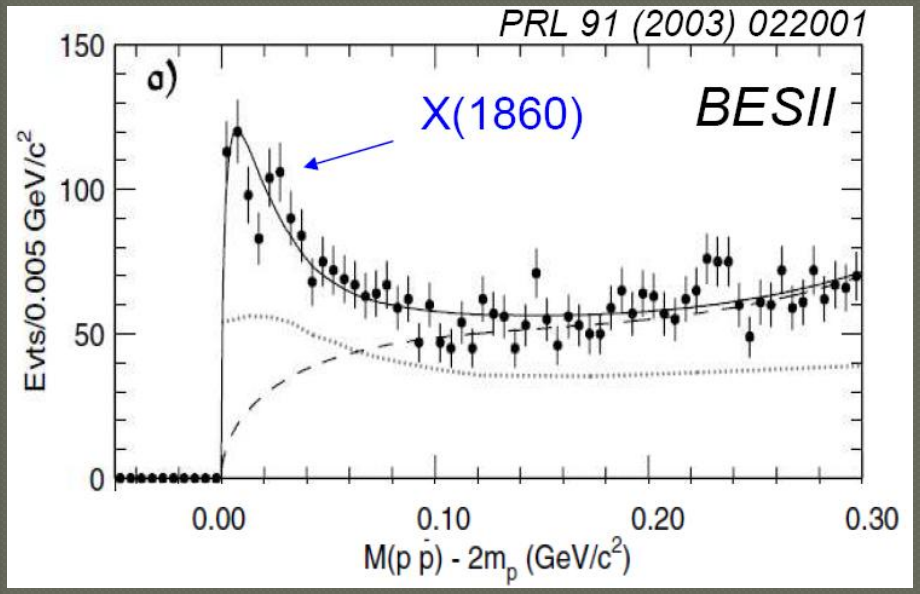
$\sqrt{s}$ (GeV)	$\sigma^B[e^+e^- \to \gamma X(3872)] \cdot \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ (pb)
4.009	< 0.13 at 90% C.L.
4.230	$0.32 \pm 0.15 \pm 0.02$
4.260	$0.35 \pm 0.12 \pm 0.02$
4.360	< 0.39 at 90% C.L.

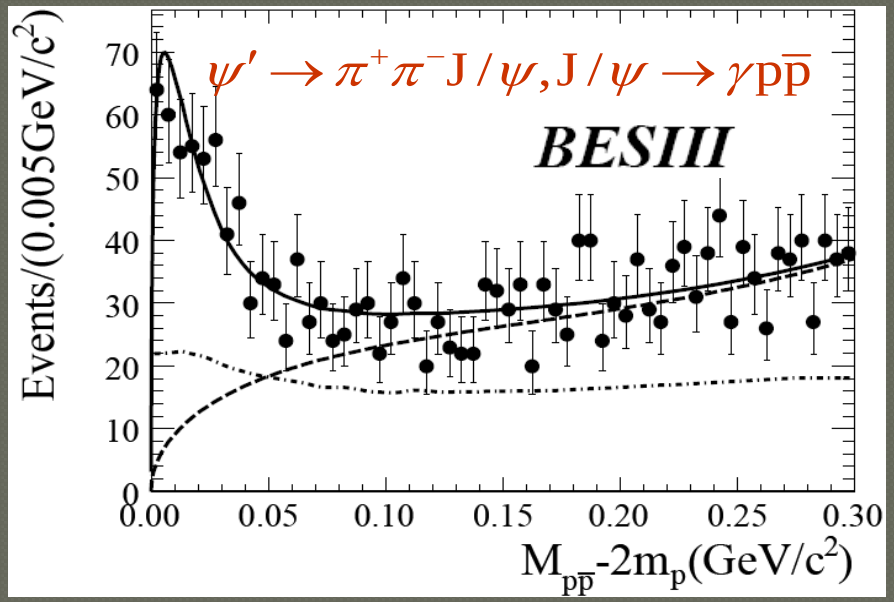
It seems X(3872) is from Y(4260) decays. At 4.26 GeV,
$\sigma^B(e^+e^- \to \pi^+\pi^- J/\psi) = (62.9 \pm 1.9 \pm 3.7)$ pb,

$$\frac{\sigma[e^+e^- \to \gamma X(3872)] \cdot \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)} = (5.6 \pm 2.0) \times 10^{-3}$$

If we take $\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) \sim 5\%$, (>2.6% in PDG)
$\frac{\sigma(e^+e^- \to \gamma X(3872))}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)} \sim 11.2\%$ Large transition ratio !

$\bar{p}p$ threshold enhancement

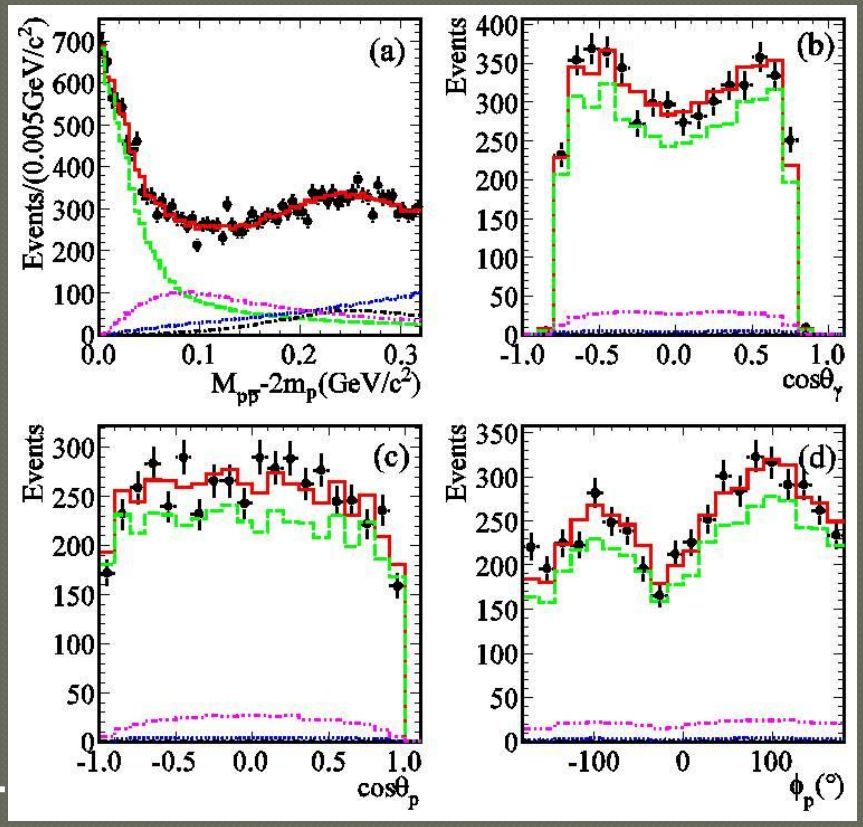




- Observed at BESII, confirmed at BESIII
- Many possibilities: ordinary meson/ $\bar{p}p$ bound states/multiquark/glueball/final states interaction (FSI)

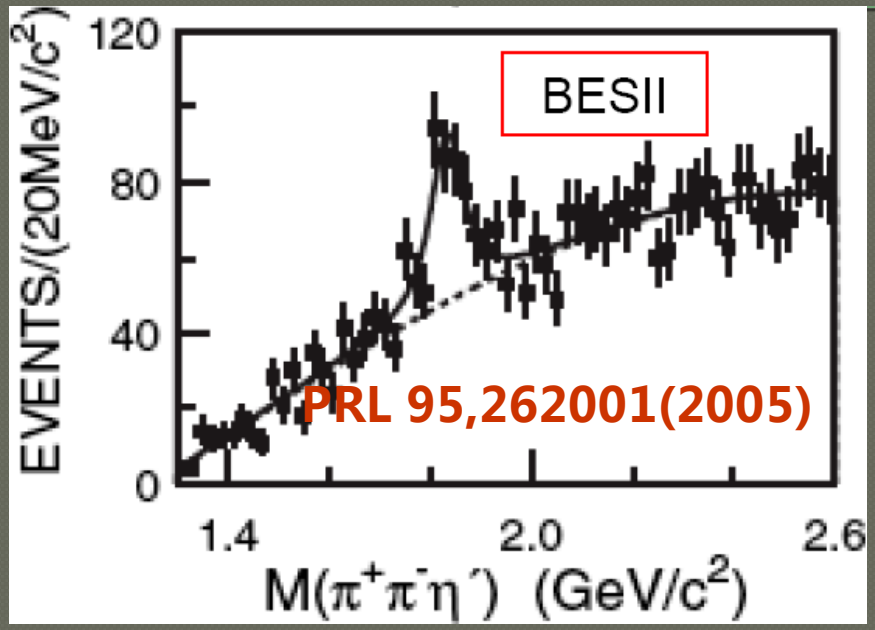
PWA of $J/\psi \to \gamma p \bar{p}$

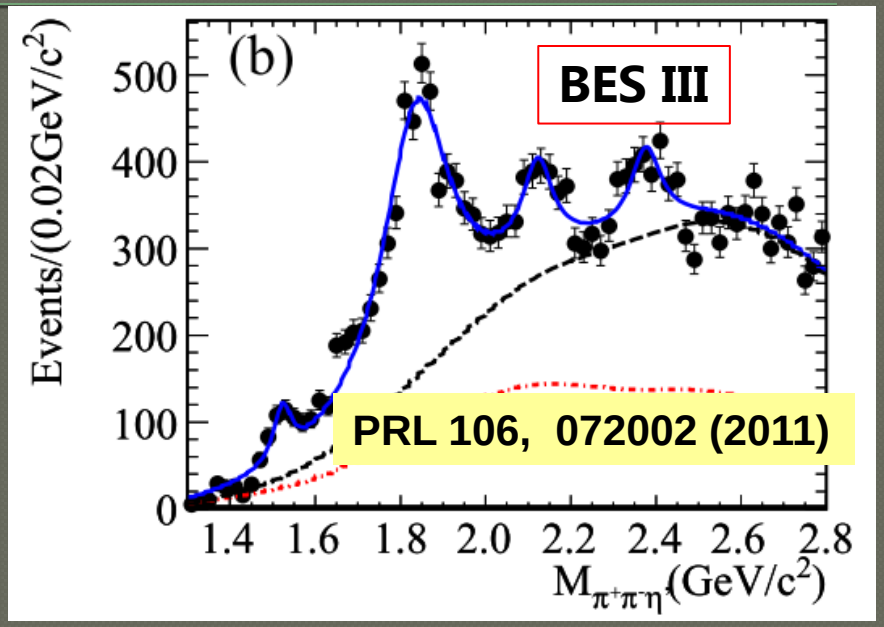
- The fit with a BW and S-wave FSI (I=0) factor can well describe the $p\bar{p}$ mass threshold structure
- $J^{PC}=0^{-+}$ >6.8σ better than other J^{PC} assignments.
- $M = 1832^{+19}_{-5}$ (stat.) $^{+18}_{-17}$ (sys.) ±19 (model) MeV/c^2
  $\Gamma = 13 \pm 39$ (stat.) $^{+10}_{-13}$ ±4(model) MeV/c^2 or $\Gamma < 76$ MeV/c^2 at 90% C.L.



PRL 108, 112003 (2012)

X(1835)



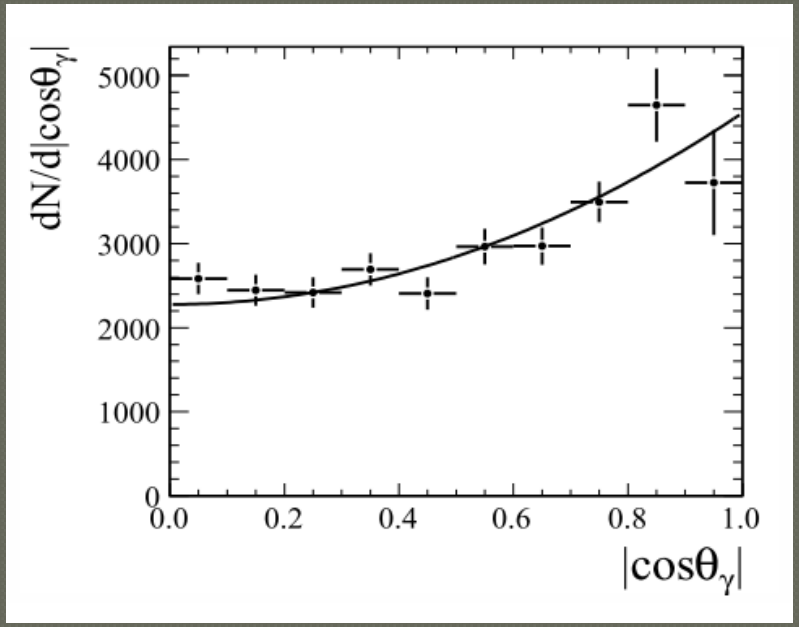


M = 1833.7±6.1±2.7 MeV/c²
Γ= 67.7±20.3±7.7 MeV/c²
B(J/ψ→γX) x B(X→$\pi^+\pi^-\eta'$)
= (2.2±0.4±0.4) x 10^{-4}
sig. = 7.7σ

- *pp bound state? η excitation? same as X(pp)?*
- *Two additional structures are observed at BESIII*

X(1835)

Resonance	M (MeV/c^2)	Γ (MeV/c^2)	significance
X(1835)	$1836.5\pm3.0^{+5.6}_{-2.1}$	$190\pm9^{+38}_{-36}$	>> 20σ
X(2120)	$2122.4\pm6.7^{+4.7}_{-2.7}$	$83\pm16^{+31}_{-11}$	> 7.2σ
X(2370)	$2376.3\pm8.7^{+3.2}_{-4.3}$	$83\pm17^{+44}_{-6}$	> 6.4σ



For X(1835)

$Br(J/\psi\rightarrow\gamma X(1835))\bullet Br(X(1835)\rightarrow\pi^+\pi^-\eta')$

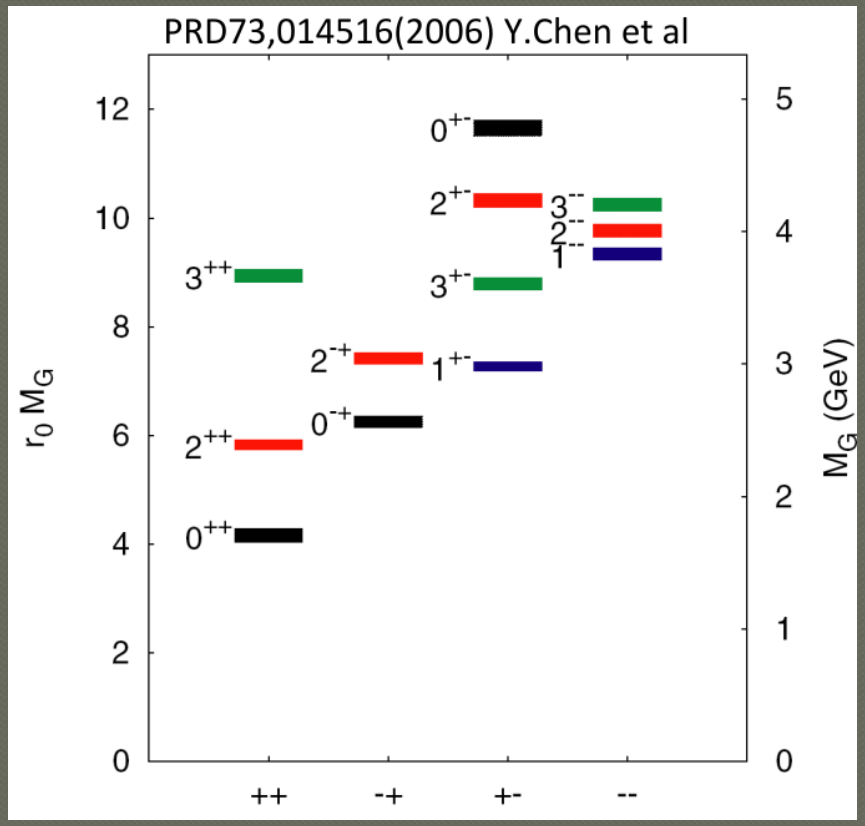
$= (2.87\pm0.09^{+0.49}_{-0.52})\times10^{-4}$

The polar angle of the photon in J/ψ CMS is consistent with expectation for pseudoscalar

PWA is needed, inference among the resonances needs to be considered.

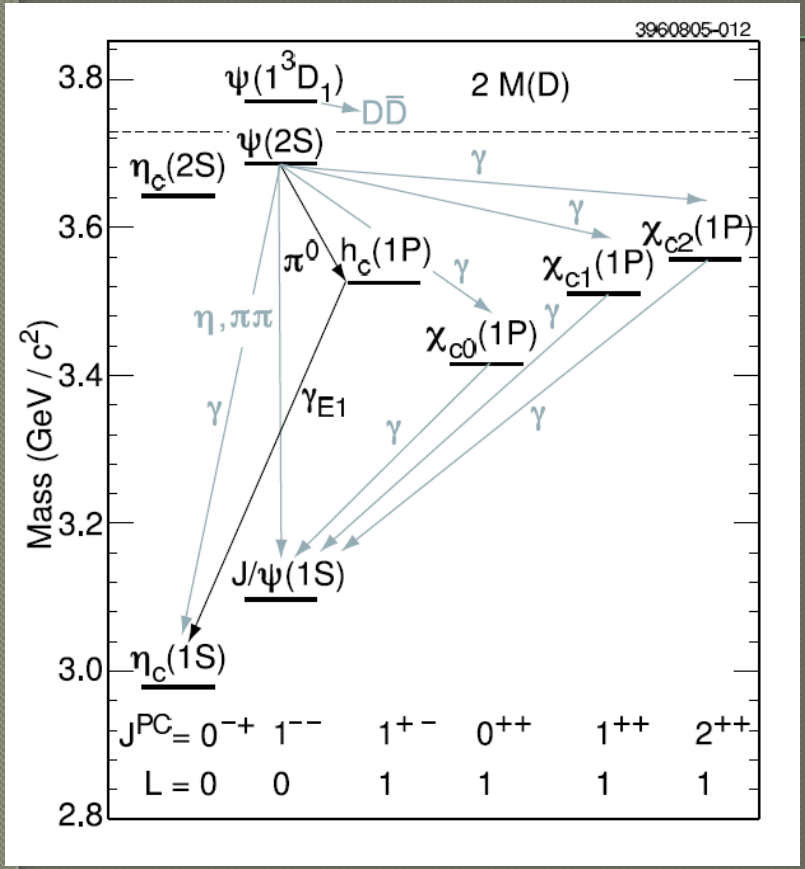
Why are X(2120)/X(2370) interesting?

- It is the first time in J/ψ radiative decays resonant structures are observed in the 2.4 GeV region, it is interesting since:
  - LQCD predicts that the lowest lying pseudoscalar glueball : around 2.4 GeV
  - $J/\psi \rightarrow \gamma\pi\pi\eta'$ decay is a good channel to find 0^{-+} glueballs
- Nature of X(2120)/X(2370)
  - Pseudoscalar glueball?
  - η/η' excited states?
  - ……



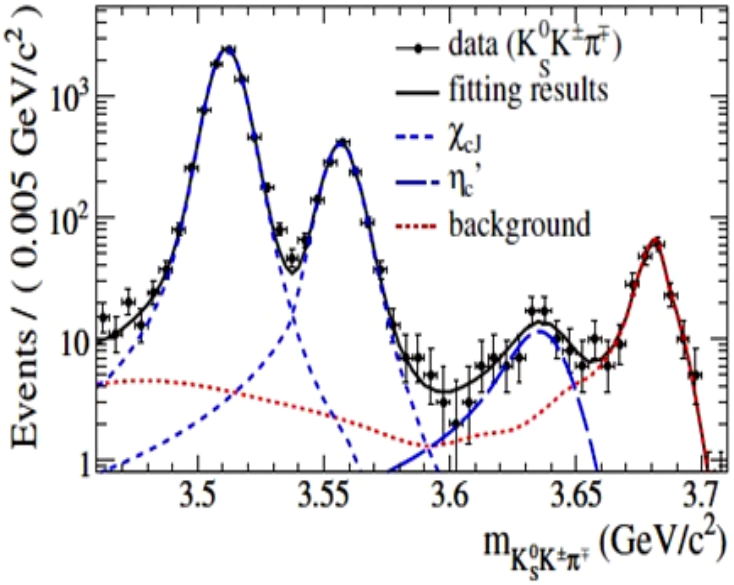
PRD82, 074026, 2010 (J.F. Liu, G.J. Ding and M.L. Yan)
PRD83, 114007, 2011 (J.S. Yu, Z.F. Sun, X. Liu, Q. Zhao)

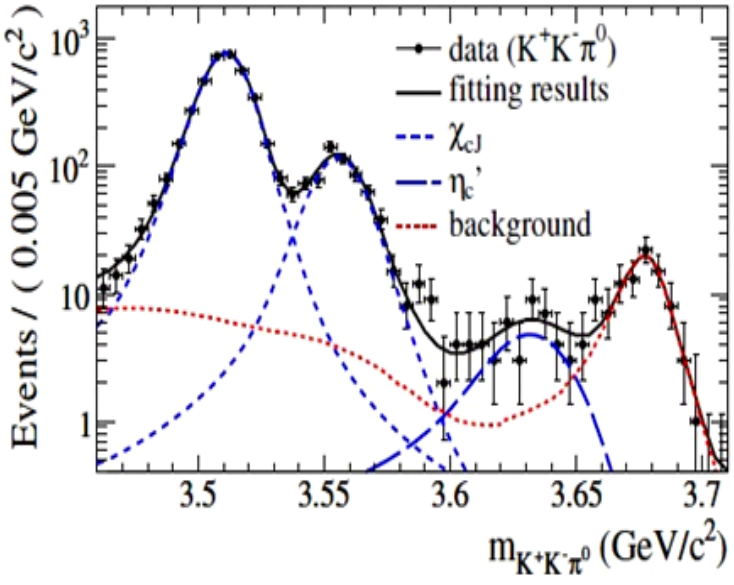
Measurement of charmonium states



- Precise measurement of the charmonium ground state η_C
  PRL 108, 222002 (2012)
  PRD 86, 092009 (2012)
- Determine the properties of h_c
  PRL 104, 132002 (2010)
  PRD 86, 092009 (2012)
- First observation of $\eta_C(2S)$
  PRL 109, 042003 (2012)

First observation of $\psi' \to \gamma\eta_c(2S)$





- Observed signal in $K_sK^+\pi^-$+c.c., found evidence in $K^+K^-\pi^0$
- First measured $Br(\psi' \to \gamma\eta_c(2S)) = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$

Potential model expectation: $(0.1\text{-}6.2)\times 10^{-4}$ PRL 89 162002 (2002)

CLEOc: $<7.6\times 10^{-4}$ PRD 81 052002 (2010)