Study of QCD exotics at BESIII

(for BESIII collaboration)
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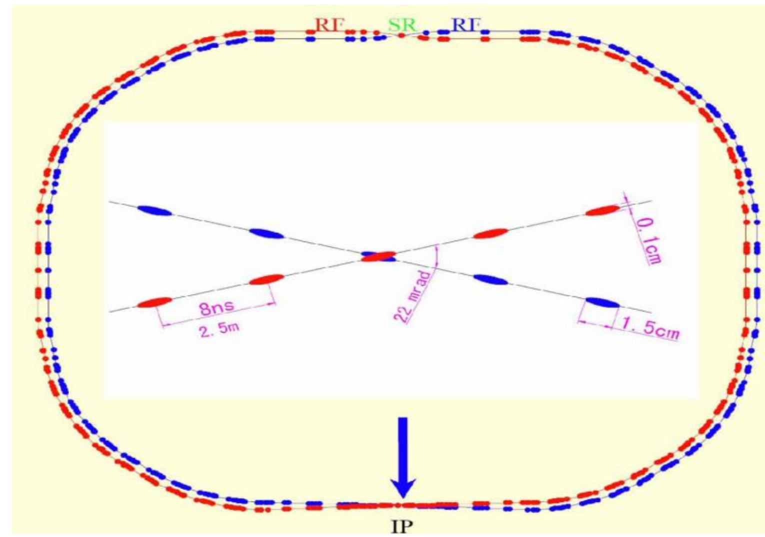
Beijing Electron Positron Collider (BEPC)



Upgrade of BEPC (started 2004,
first collisions July 2008)

Beam energy	1 GeV to 2.3 GeV
Optimum energy	1.89 GeV
Single beam current	0.91 A
Crossing angle	± 11 mrad

Design luminosity $1 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Achieved in 2016

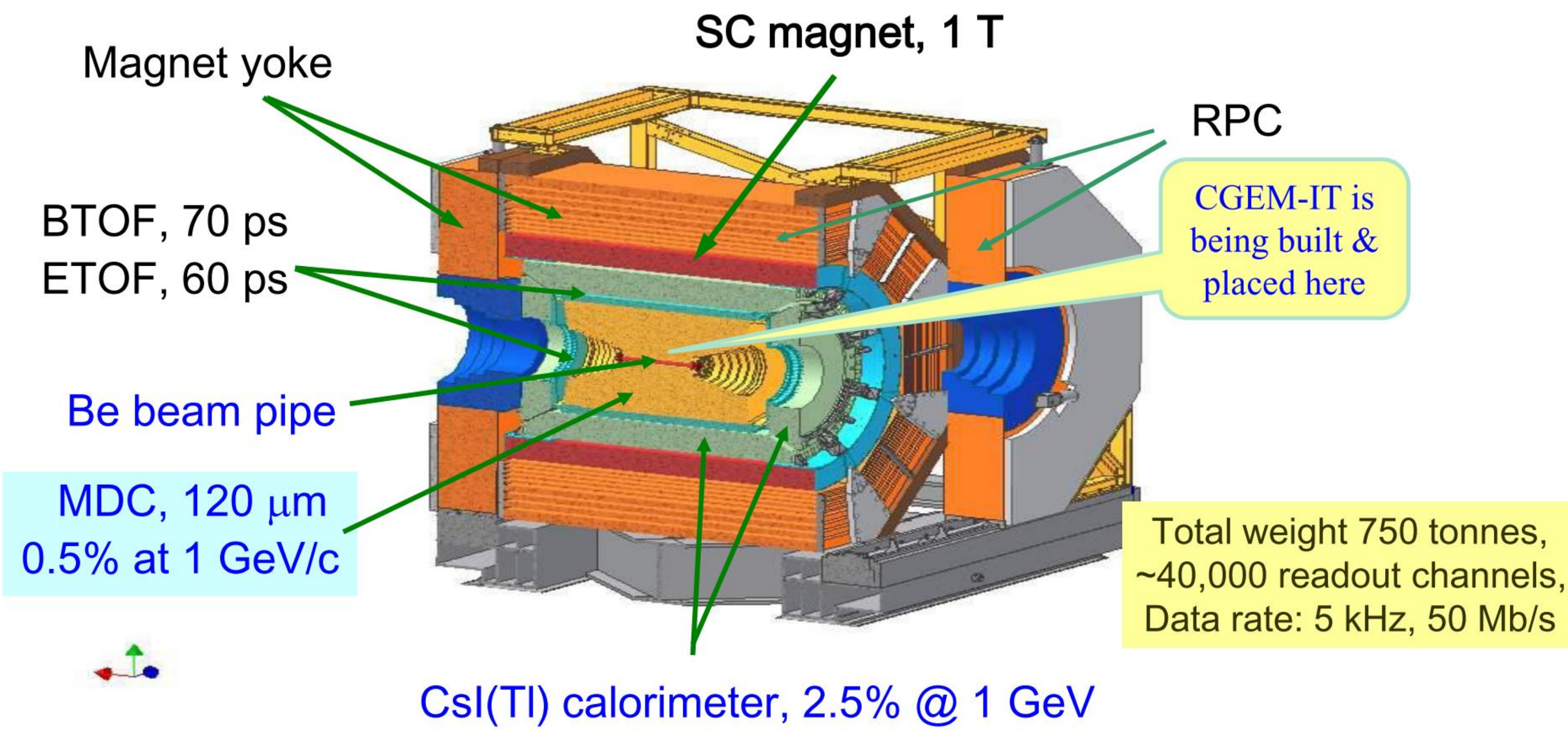
Beam energy measurement:

Laser Compton backscattering

$\Delta E/E \approx 2 \times 10^{-5}$

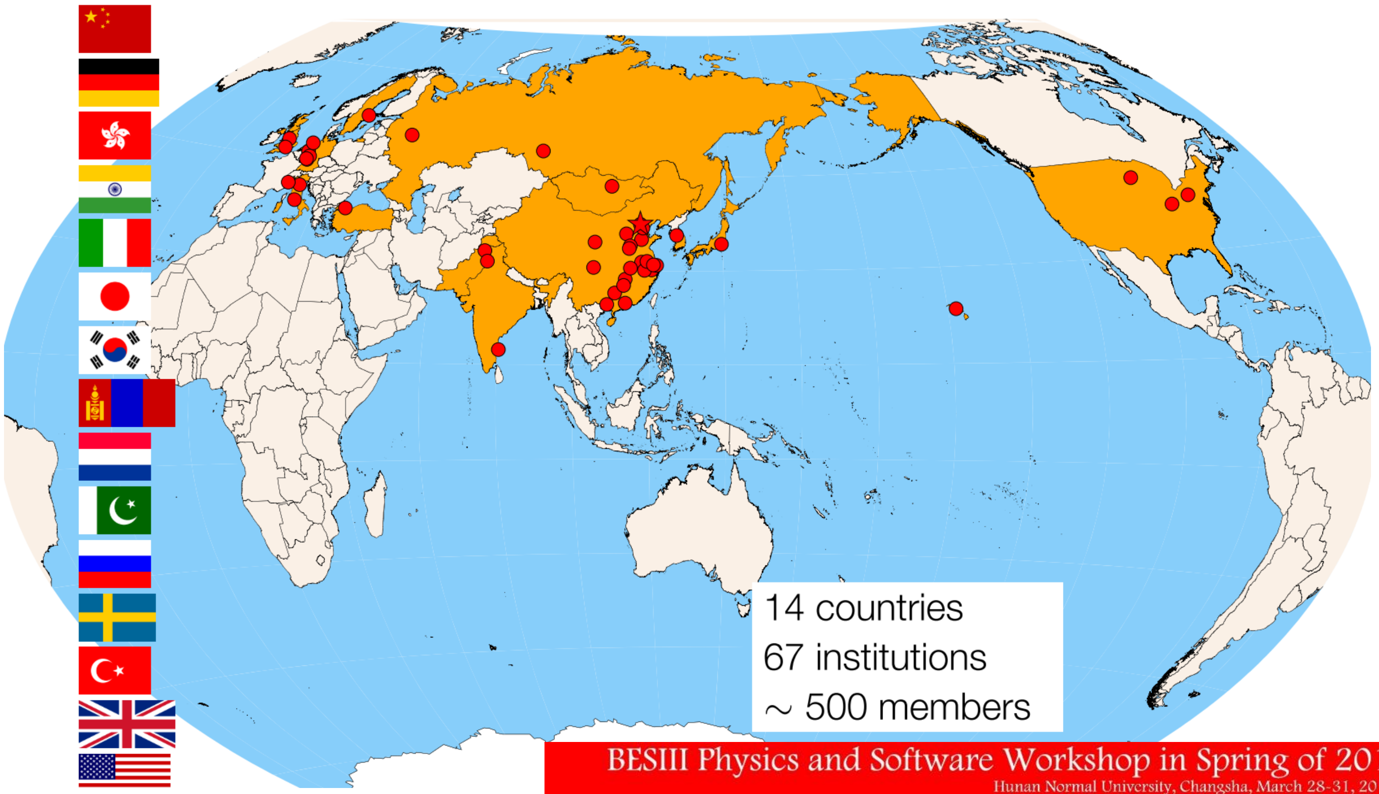
(contributes ≈ 50 keV to m_τ uncertainty)

BESIII detector

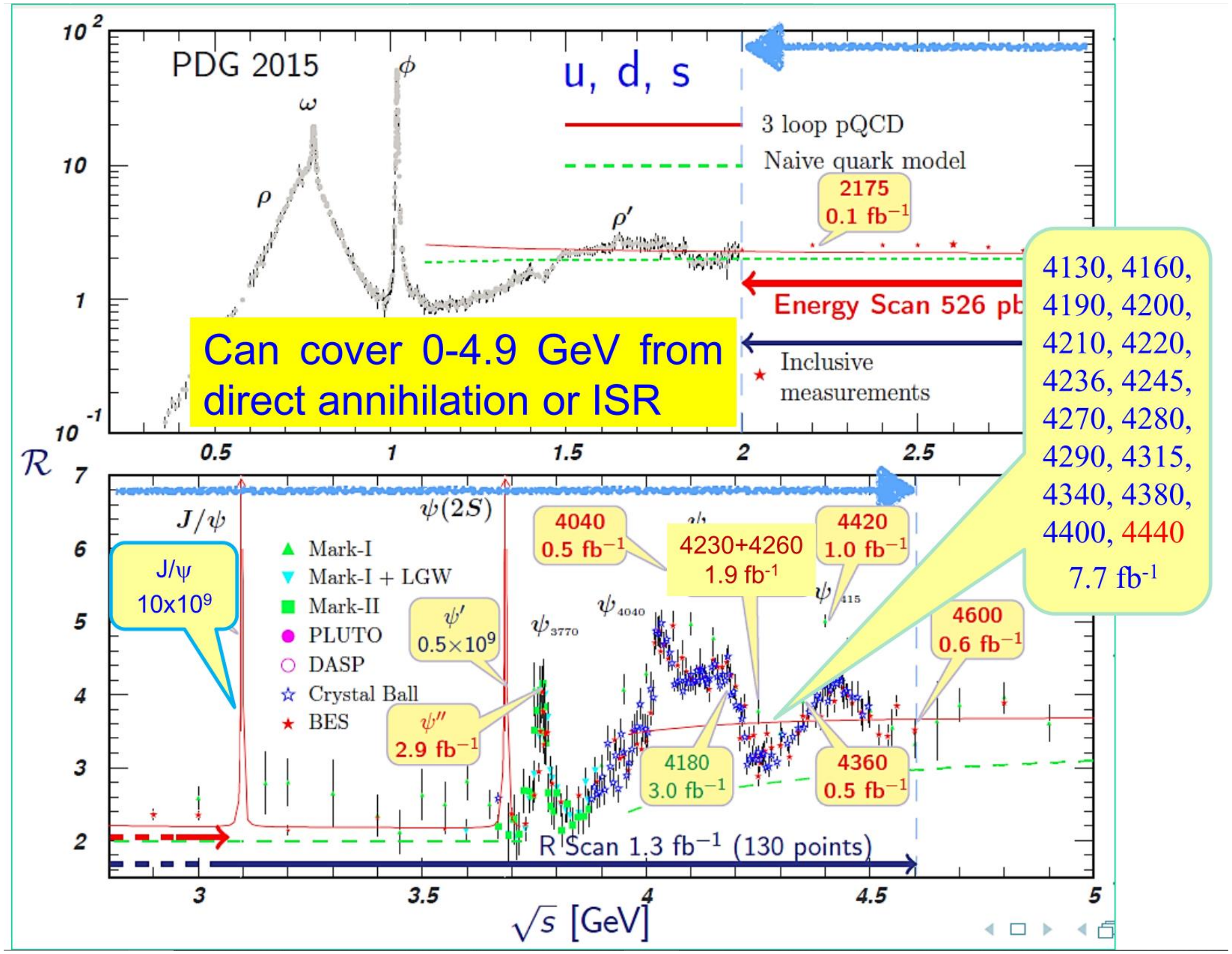


full operation since 2008
all subdetectors are in good status

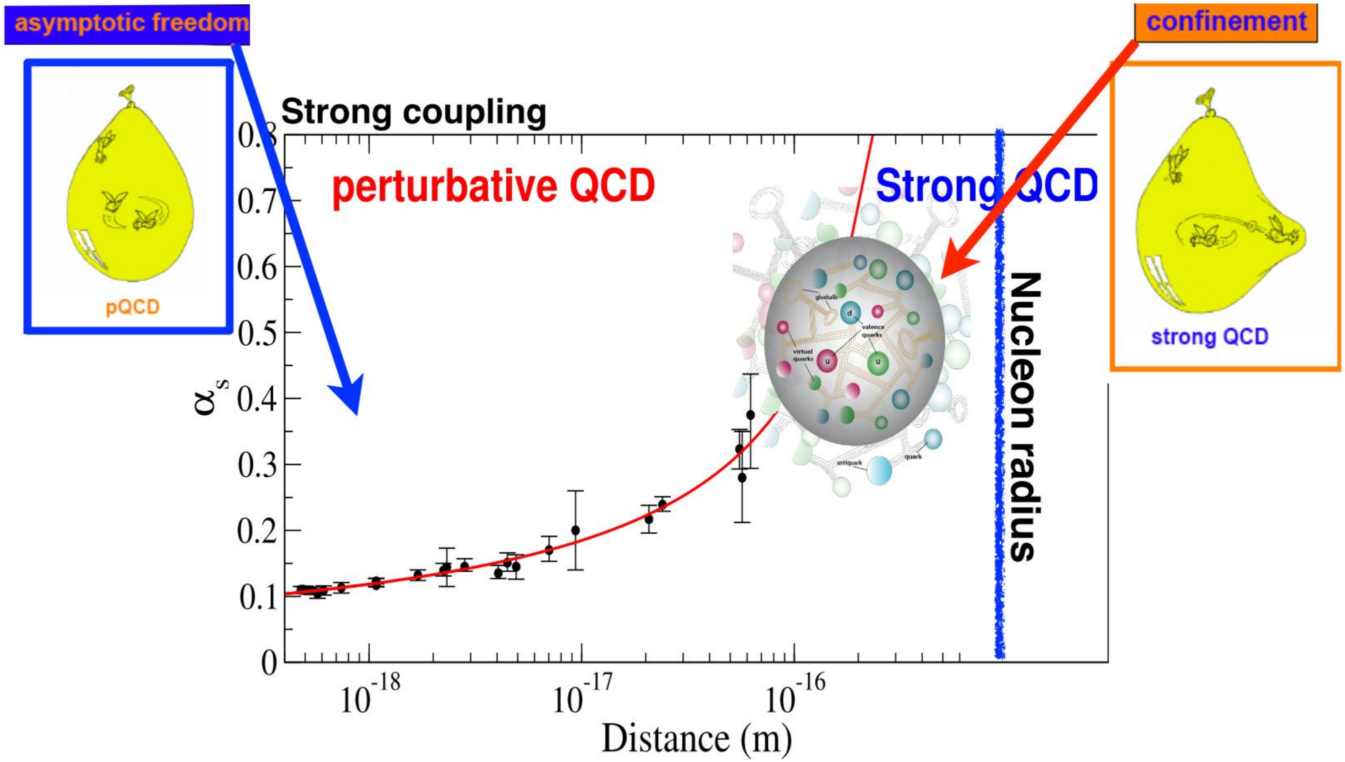
BESIII collaboration



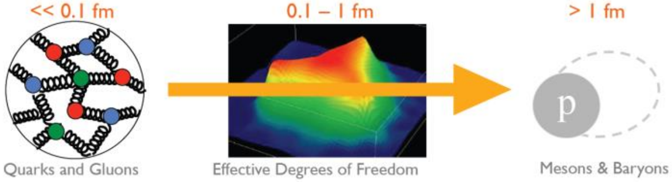
10 years of data taking at BESIII



Hadron spectroscopy



- Testing QCD in the confinement regime
- Revealing the fundamental degrees of freedom

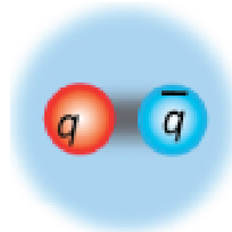


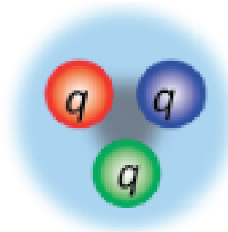
QCD exotics

- Conventional hadrons consist of 2 or 3 quarks：

Naive Quark Model：

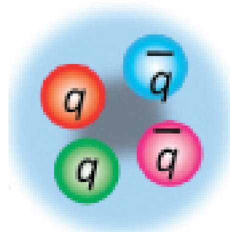
meson

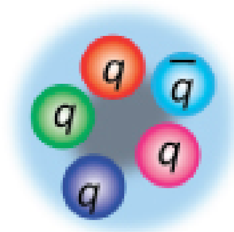




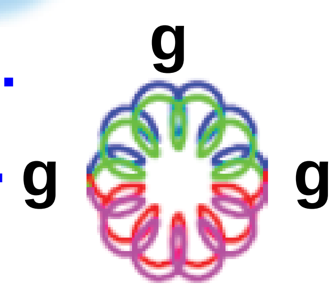
baryon

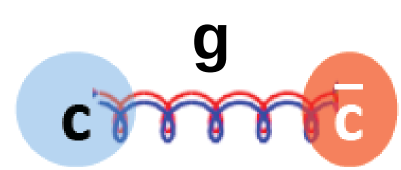
- **QCD predicts the new forms of hadrons:**
  - **Multi-quark states： Number of quarks ≥ 4**





  - **Hybrids：** $\bar{q}$**qg， qqqg …**
  - **Glueballs：** **gg， ggg …**





Not established yet

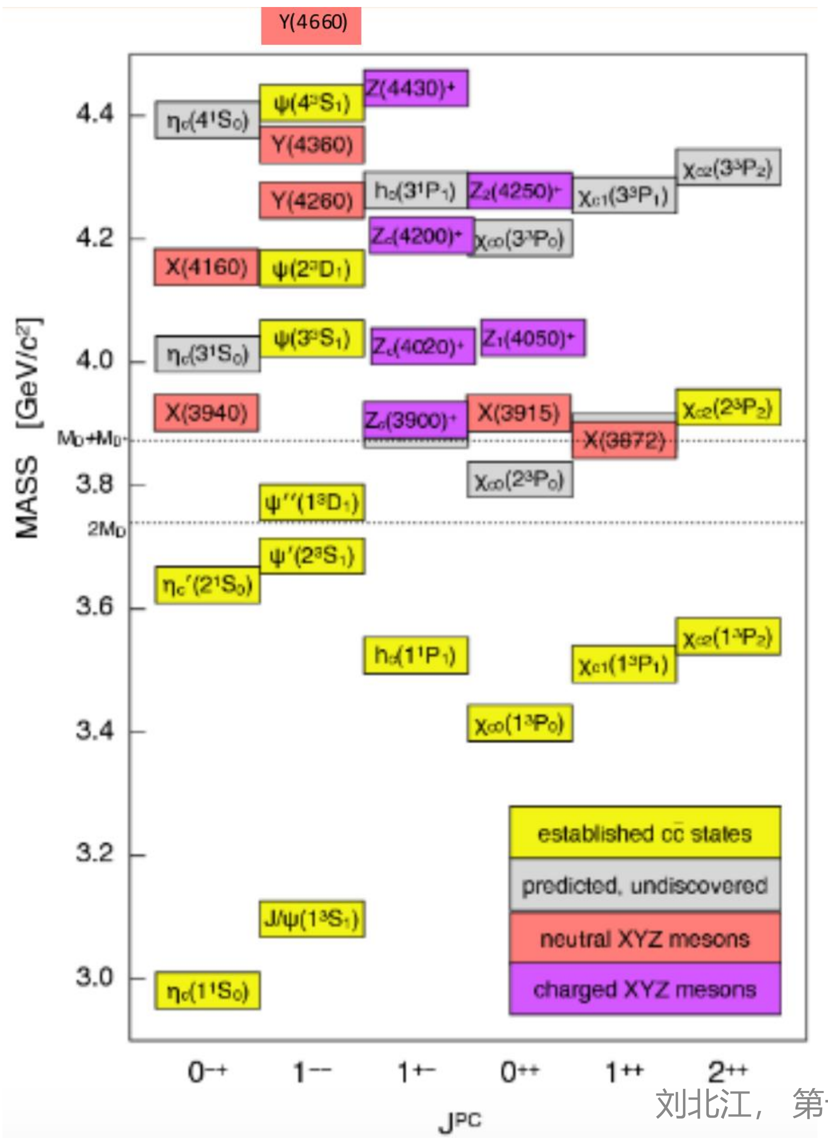
Selected topics

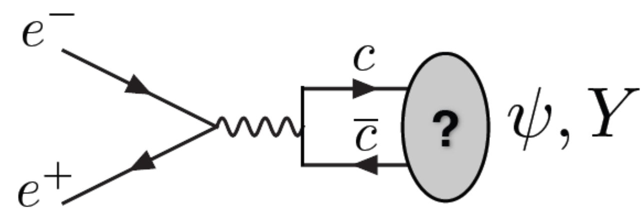
- XYZ states
  - $Z_c(3900)$
  - Y(4260)
  - X(3872)

- Glueball studies
  - scalar

[黄性涛, 6/25]

Charmonium and exotics at BESIII

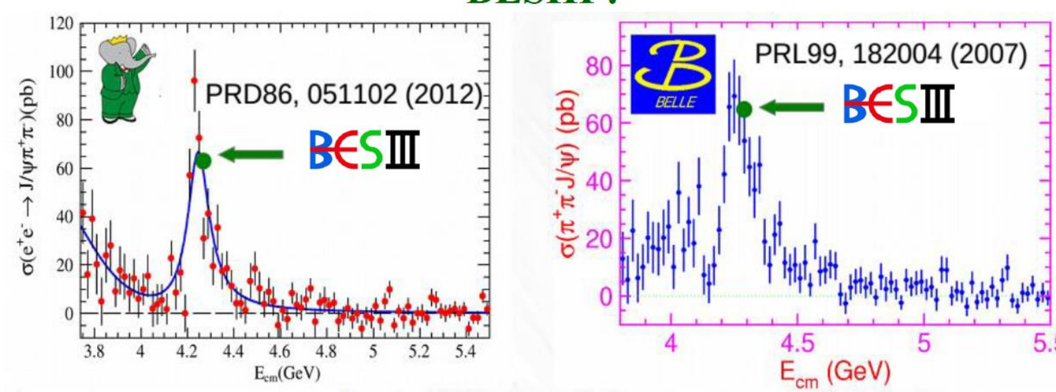




direct production of ψ , Y
radiative and hadronic transitions

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

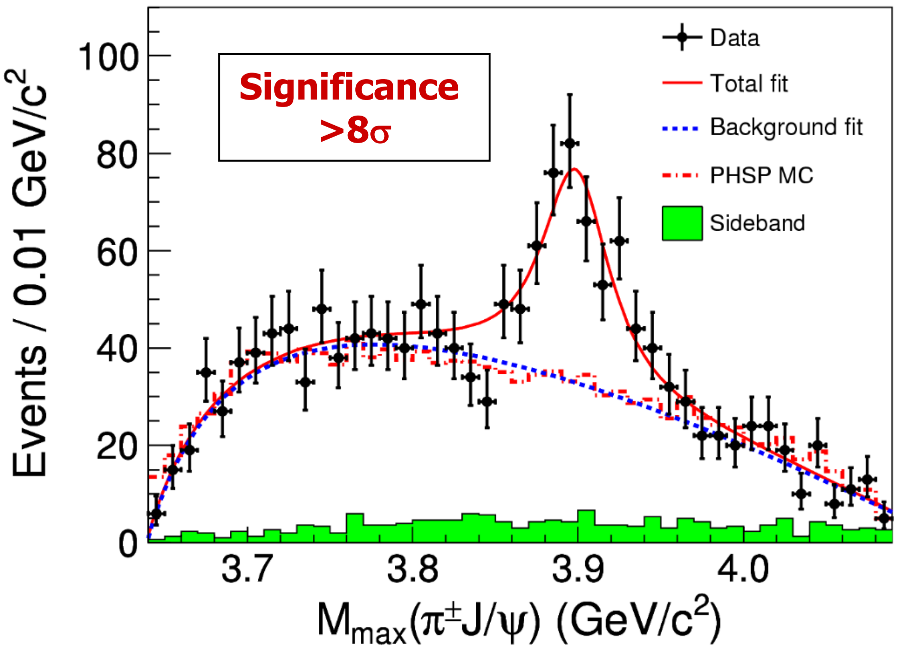
Compare running at **Belle and BaBar,** with one month at **BESIII !**



BESIII: $\sigma^B = 62.9 \pm 1.9 \pm 3.7$ pb

PRL 110, 252001 (2013)

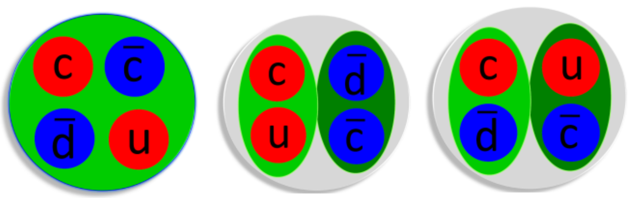
Discovery of the $Z_c(3900)$



In $e^+e^-\to\pi^+\pi^-J/\psi$ events at 4.26 GeV, a particle decays into $\pi^\pm J/\psi$ is observed!

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

  A $\bar{D}D^*$ molecule?



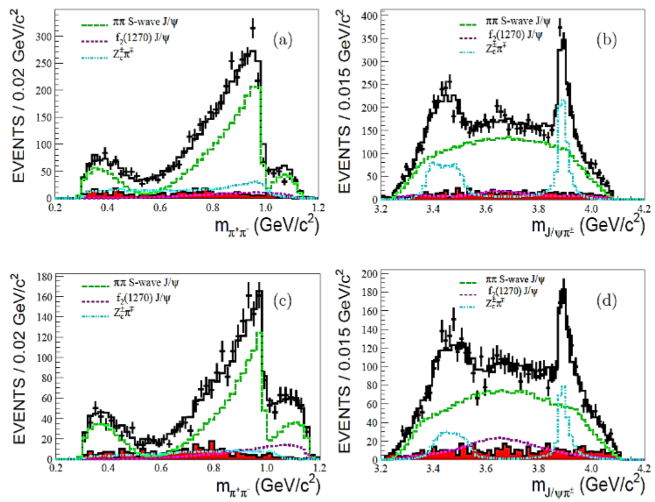
- ➢ Mass = (3899.0±3.6±4.9) MeV
- ➢ Width = (46±10±20) MeV
- ➢ Fraction = (21.5±3.3±7.5)%

PRL110, 252001 (2013)

Properties of the $Z_c(3900)$

- $I^G=1^+$
- $J^{PC}=1^{+-}$
- Decay modes
  - ✓ $\pi J/\psi$
  - ✓ $\bar{D}D^*$
  - ✓ **$\rho\eta_c$ (4.2σ)**
  - ✓ πh_c (2.1σ)
  - ✓ Not seen in light hadrons

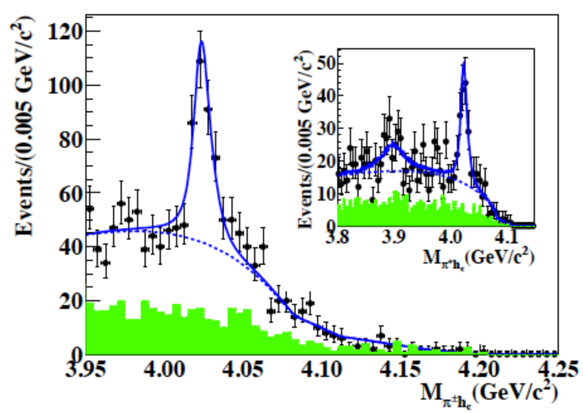
PRL 119, 072001 (2017)



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

- JP=1+
- Asymmetric line shape
- Significant $f_0(980)$ contribution
- $\pi^+\pi^-$ D-wave fraction increases as E_{cm} increases

- Partner state: $Z_c(4020)$
  - ✓ $I^G=1^+$; $J^{PC}=?^{?-}$
  - ✓ Couples to πh_c and $\bar{D}^*D^*$
  - ✓ Couples possibly to $\pi\psi'$
  - ✓ M=4022.9±2.8 MeV
  - ✓ Γ=7.9±3.7 MeV



PRL 111, 242001 (2013)

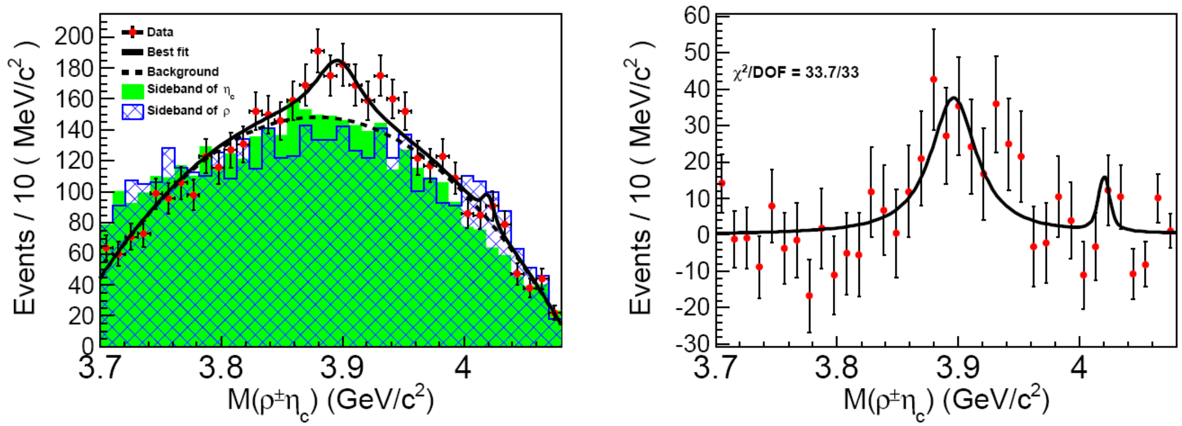
arXiv:1906.00831

Evidence for $Z_c \to \rho\eta_c$

- $e^+e^- \to \pi^+\pi^-\pi^0\eta_c$
- $\eta_c \to$ 9 hadronic decays

Decay mode	BR
$\eta_c \to p\bar{p}$	~0.13%
$\eta_c \to 2(K^+K^-)$	~0.15%
$\eta_c \to \pi^+\pi^-K^+K^-$	~1.50%
$\eta_c \to K^+K^-\pi^0$	~1.20%
$\eta_c \to p\bar{p}\pi^0$	~0.18%
$\eta_c \to K_SK\pi$	~1.80%
$\eta_c \to \pi^+\pi^-\eta$	~1.60%
$\eta_c \to K^+K^-\eta$	~0.57%
$\eta_c \to \pi^+\pi^-\pi^0\pi^0$	~2.40%

- Strong evidence of $e^+e^- \to \pi Z_c$, $Z_c \to \rho\eta_c$ at $\sqrt{s} = 4.23$, statistical significance is 4.2σ. (3.9σ including systematics)
- $e^+e^- \to \pi Z_c', Z_c' \to \rho\eta_c$ not seen



$e^+e^- \to \pi Z_c, Z_c \to \rho\eta_c$ @ 4.23 GeV arXiv:1906.00831

Evidence for $Z_c \to \rho\eta_c$

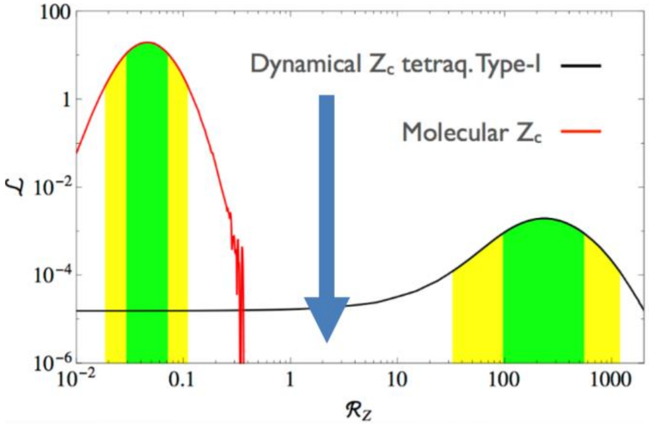
- Measure Born cross section at 4.23 GeV:

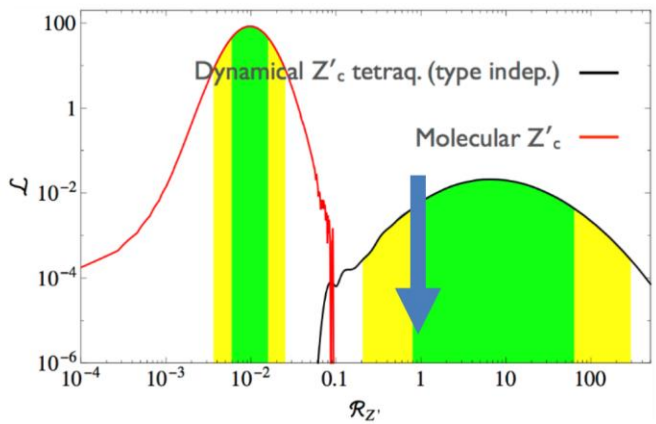
$$\sigma^B(e^+e^- \to \pi^+\pi^-\pi^0\eta_c) = (46\ ^{+12}_{-11} \pm 10\ )\ \text{pb}$$

$$\sigma^B(e^+e^- \to \pi Z_c, Z_c \to \rho\,\eta_c) = (48 \pm 11 \pm 11\ )\ \text{pb}$$

	$\sqrt{s} = 4.226$ GeV	$\sqrt{s} = 4.258$ GeV	$\sqrt{s} = 4.358$ GeV	Type-I	Type-II	Molecule
$R_{Z_c(3900)}$	2.2 ± 0.9	< 5.6	...	230^{+330}_{-140}	$0.27^{+0.40}_{-0.17}$	$0.046^{+0.025}_{-0.017}$
$R_{Z_c(4020)}$	< 1.6	< 0.9	< 1.4		$6.6^{+56.8}_{-5.8}$	$0.010^{+0.006}_{-0.004}$

A.Esposito, A.L.Guerrieri, A.Pilloni, Phys. Lett. B 746, 194 (2015)

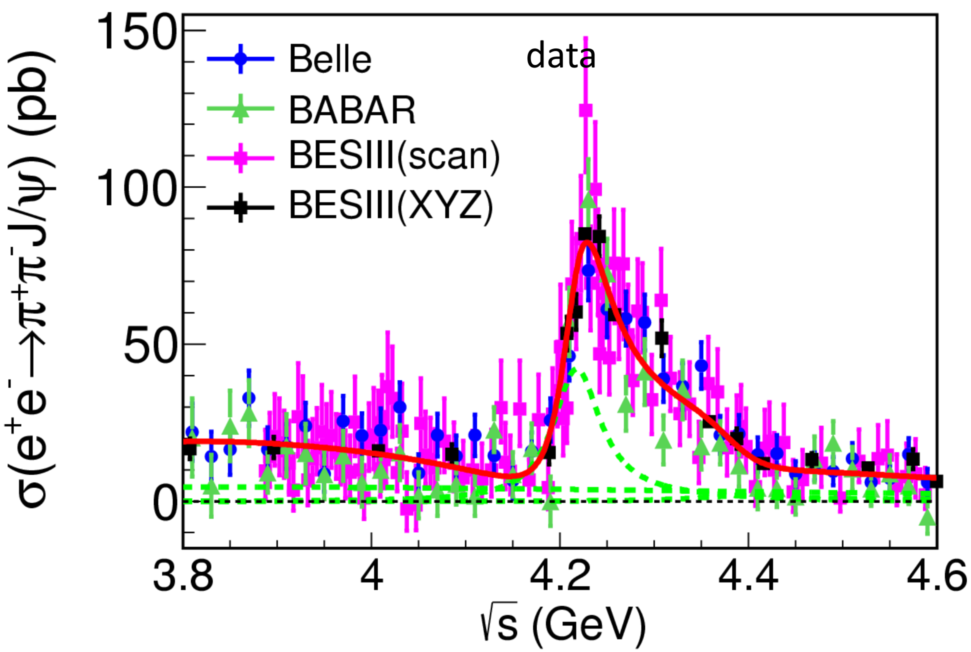




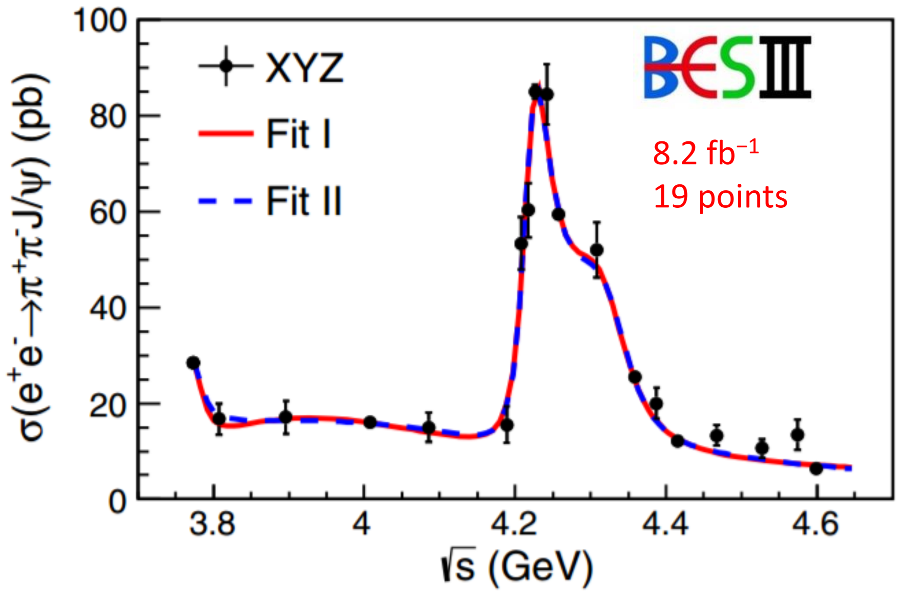
$$R_z = \frac{B(Z_c \to \rho\eta_c)}{B(Z_c \to \pi J/\psi)} \qquad R_{z'} = \frac{B(Z'_c \to \rho\eta_c)}{B(Z'_c \to \pi h_c)}$$

Z_c states have both tetraquark and molecule components? Refined calculations needed!

$\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$: Y(4260) ➔ Y(4220)



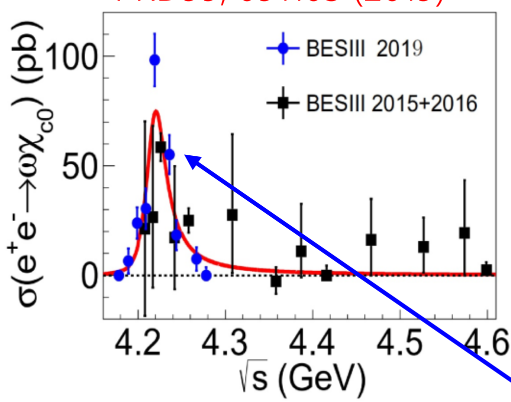
PRL118, 092001 (2017)



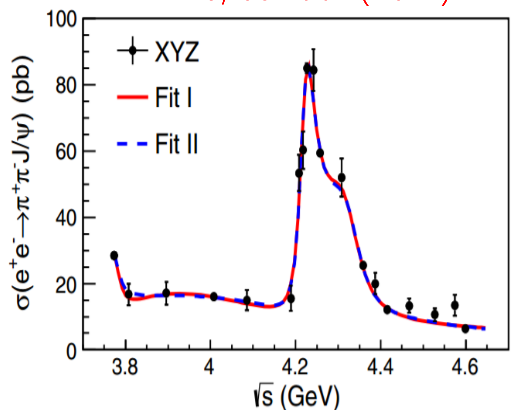
- Most precise cross section measurment to date from BESIII
- Y(4220): M = 4222.0 ± 3.1 ± 1.4 MeV, Γ = 44.1 ± 4.3 ± 2.0 MeV
  (lower) (narrower)
- Y(4320): M = 4320.0 ± 10.4 ± 7.0 MeV, Γ = $101.4^{+25.3}_{-19.7}$ ± 10.2 MeV

Y(4260)➔Y(4220): more modes

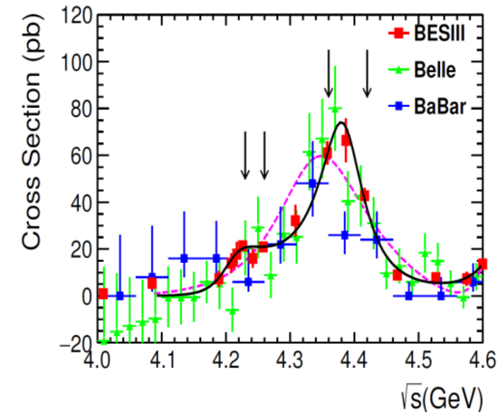
PRD99, 091103 (2019)



PRL118, 092001 (2017)

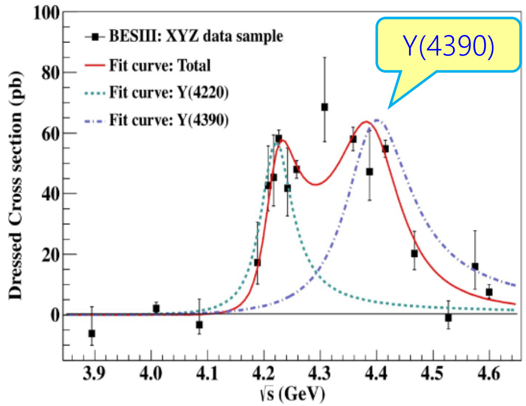


PRD96, 032004 (2017)

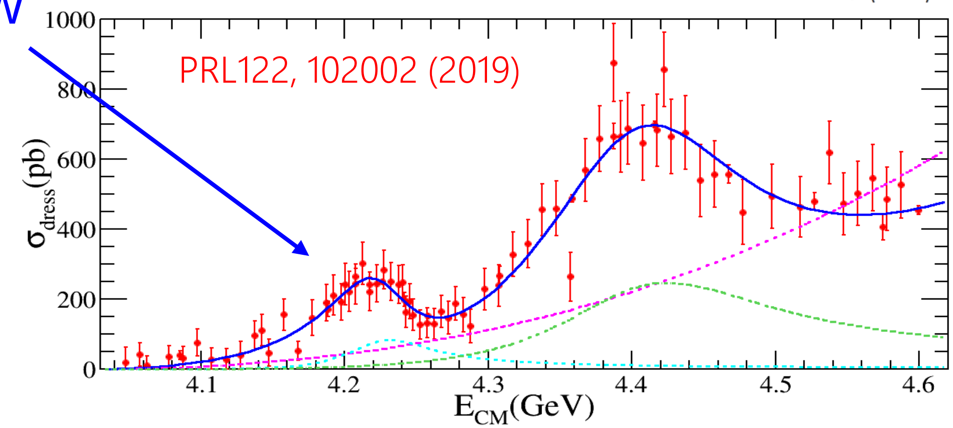


NEW

PRL118, 092002 (2017)



PRL122, 102002 (2019)



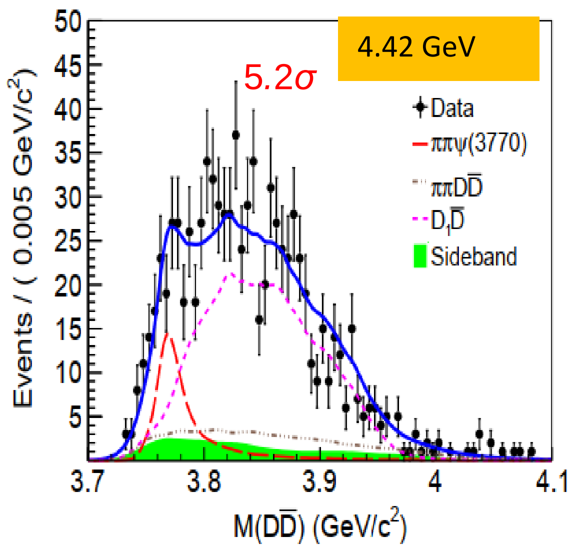
Y(4220) appears in $\omega\chi_{c0}$, $\pi^+\pi^- J/\psi$, $\pi^+\pi^-\psi'$, $\pi^+\pi^- h_c$, $D^0 D^{*-}\pi^+$

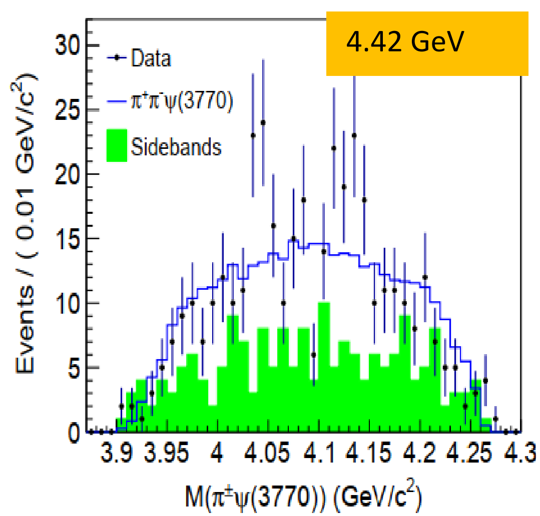
Mass~4220 MeV, width~ 60 MeV

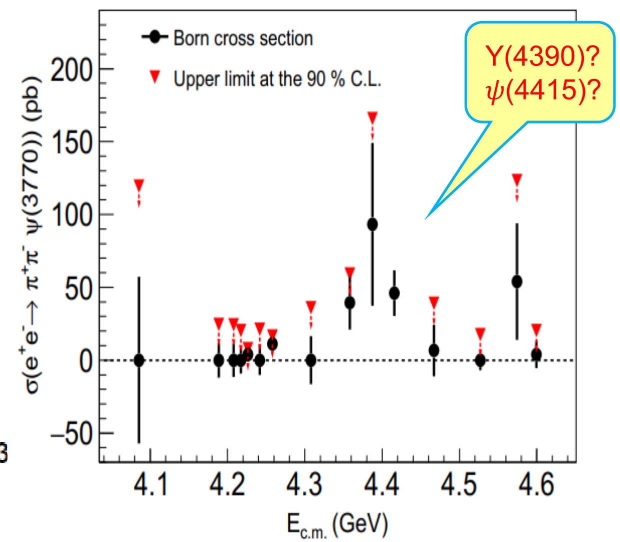
$e^+e^- \to \pi^+\pi^-\psi(3770)$

arXiv:1903.08126

- Study the intermediate states of $e^+e^- \to \pi^+\pi^- D^0\bar{D}^0$, $e^+e^- \to \pi^+\pi^- D^+D^-\bar{D}^0$
  - $D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-$ and $K^-\pi^+\pi^+\pi^-\pi^0$
  - $D^+ \to K^-\pi^+\pi^+, K^-\pi^+\pi^+\pi^0, K_S^0\pi^+, K_S^0\pi^+\pi^0$, and $K_S^0\pi^+\pi^+\pi^-$





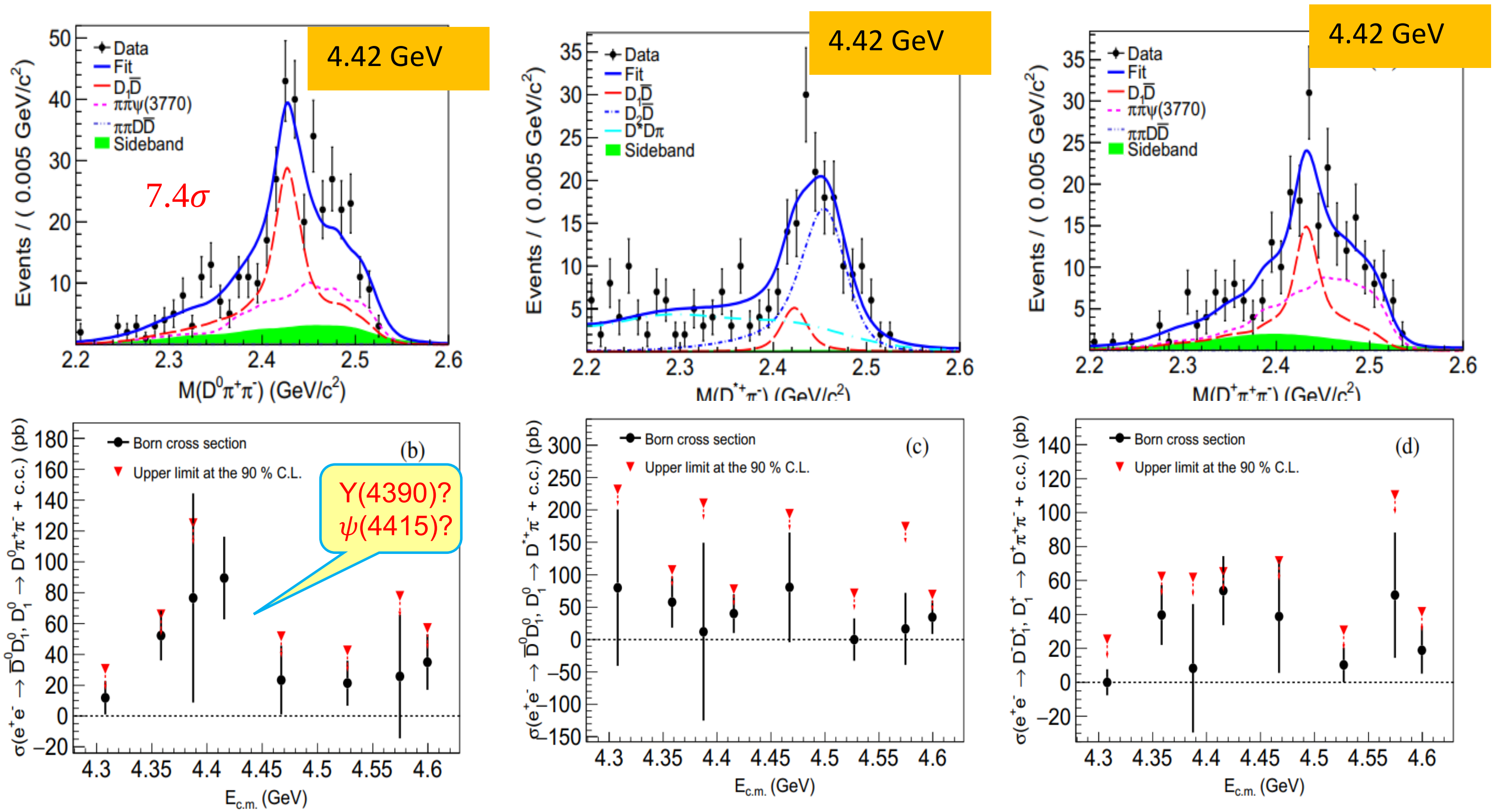


- $e^+e^- \to \pi^+\pi^-\psi(3770)$ is observed for the first time, no evidence for $\psi(1^3D_3)$
- Hints of Z_c in $M(\pi^\pm\psi(3770))$ at 4.04 and 4.13 GeV in $\sqrt{s}$ = 4.42 GeV data
- Clear structure in line-shape of $\pi^+\pi^-\psi(3770)$

16

$e^+e^- \to D_1(2420)\bar{D}$

arXiv:1903.08126

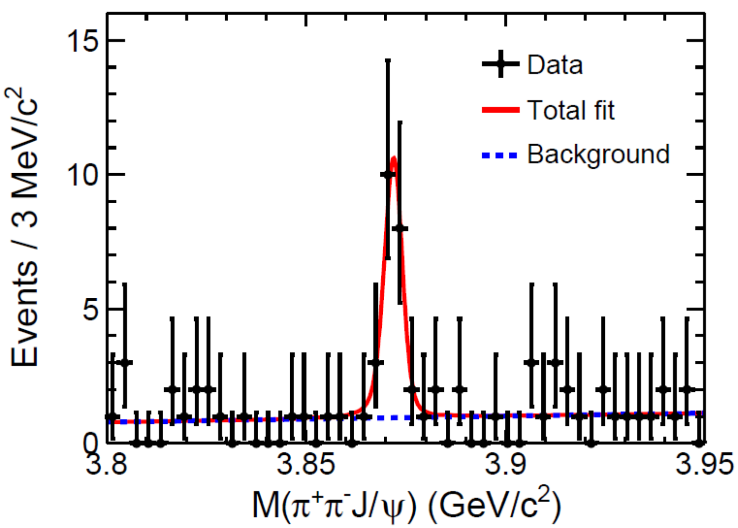


- Three different decay channels ($D^0\pi^+\pi^-$, $D^{*+}\pi^-$, and $D^+\pi^+\pi^-$) are used to search for $D_1(2420)$
- Clear structure in the line-shape of $e^+e^- \to D_1(2420)\bar{D}$
- No $D_1(2420)\bar{D}$ near threshold enhancement → Y(4260) not a $D_1(2420)\bar{D}$ molecule?

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

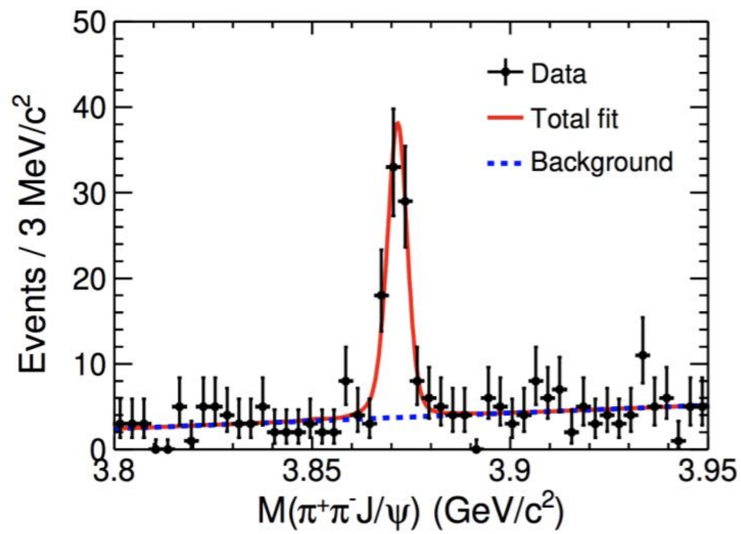
$X(3872) \rightarrow \pi^+\pi^- J/\psi$

PRL 112, 092001



4.0 fb^{-1}, 20±5 evts

PRL122, 232002

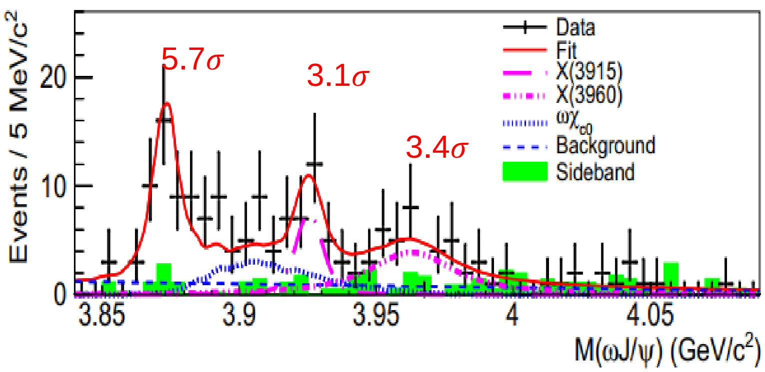


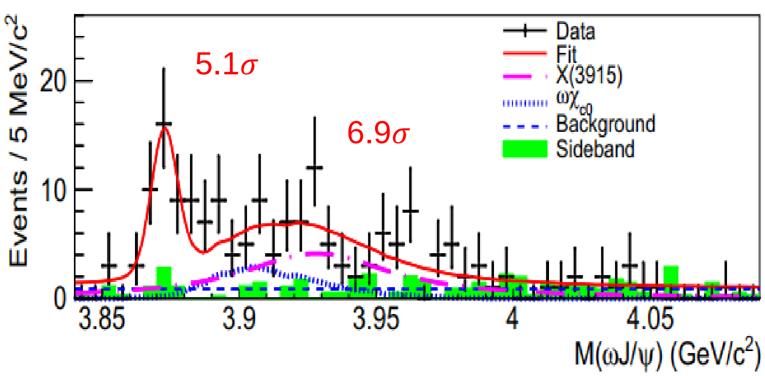
11.6 fb^{-1}, 79±9 evts

Observation of $X(3872) \to \omega J/\psi$ PRL122, 232002

There were only evidence at Belle (4.3σ) and BaBar (4σ)

- Signal process: $e^+e^- \to \gamma X \to \gamma\omega J/\psi$, with $\omega \to \pi^+\pi^-\pi^0$, $J/\psi \to l^+l^-$





Signal PDF:

✓ 3 resonances: (X(3872), X(3915) and X(3960))

$$N_{sig}(X(3872)) = 45 \pm 9 \pm 3$$

✓ Two resonances: (X(3872), X(3915))

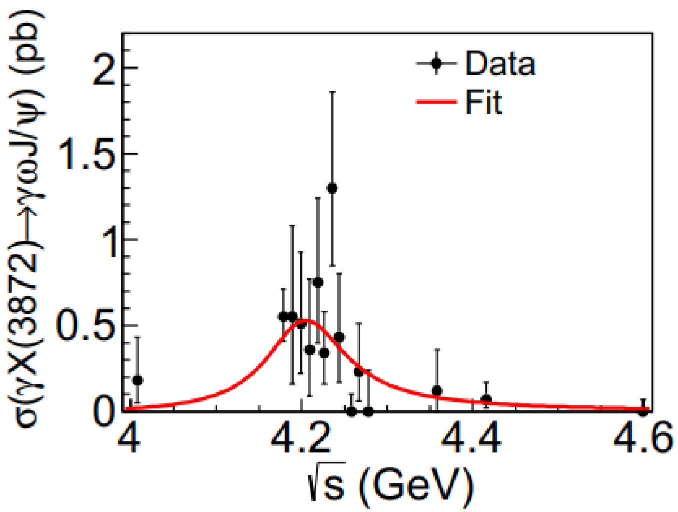
$$N_{sig}(X(3872)) = 40 \pm 8 \pm 2$$

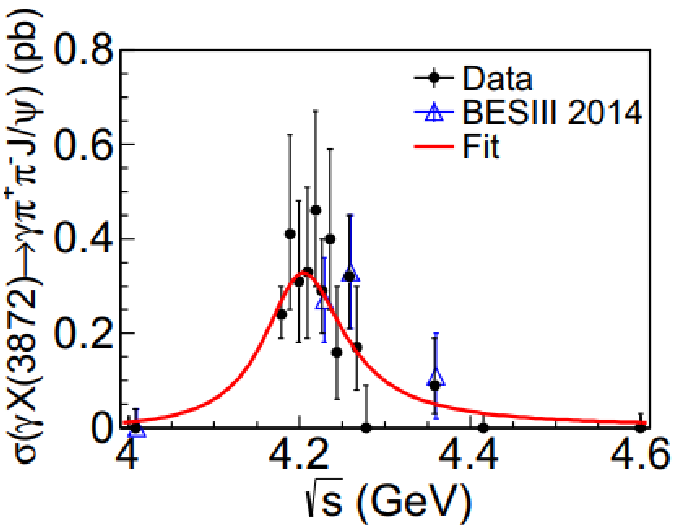
	Mass	Width
$X(3872)$	3873.3 ± 1.1 (3872.8 ± 1.2)	1.2 (1.2)
$X(3915)$	3926.4 ± 2.2 (3932.6 ± 8.7)	3.8 ± 7.5 (59.7 ± 15.5)
$X(3960)$	3963.7 ± 5.5	33.3 ± 34.2

two hypotheses different by only 2.5σ

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

PRL122, 232002





A simultaneous fit to

the $X(3872) \to \omega J/\psi$ and $\pi^+\pi^- J/\psi$ cross section gives

$$\mathrm{M}\big(Y(4200)\big) = 4200.6^{+7.9}_{-13.3} \pm 3.0\ \mathrm{MeV}/c^2$$

$$\Gamma\big(Y(4200)\big) = 115^{+38}_{-26} \pm 12\ \mathrm{MeV}$$

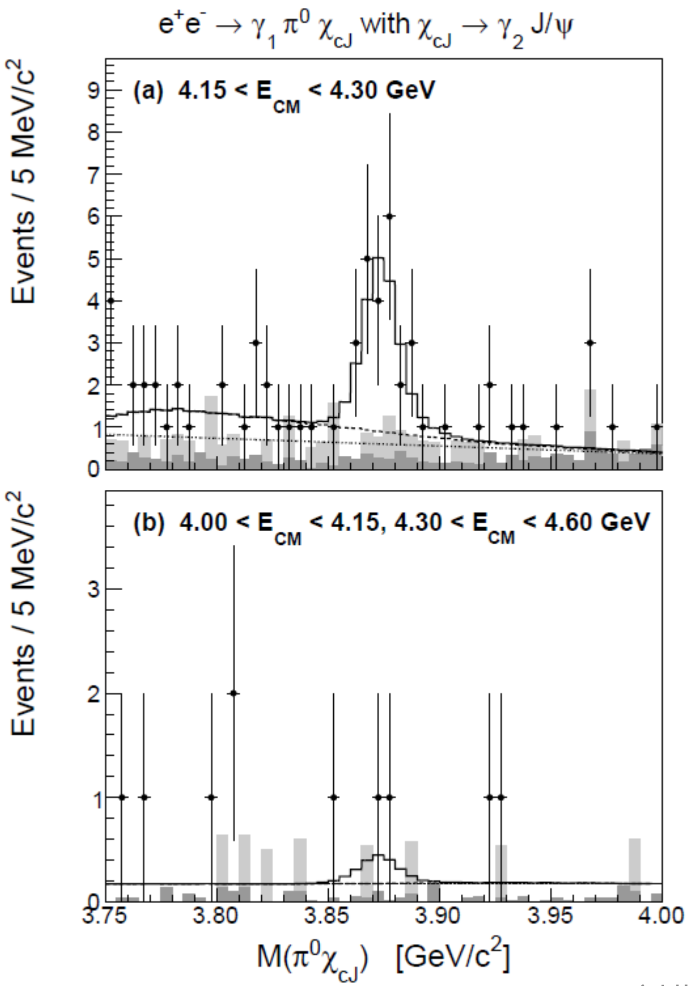
$$\mathcal{R} \equiv \frac{\mathcal{B}(X(3872)\to\omega J/\psi)}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)} = 1.6^{+0.4}_{-0.3} \pm 0.2,$$

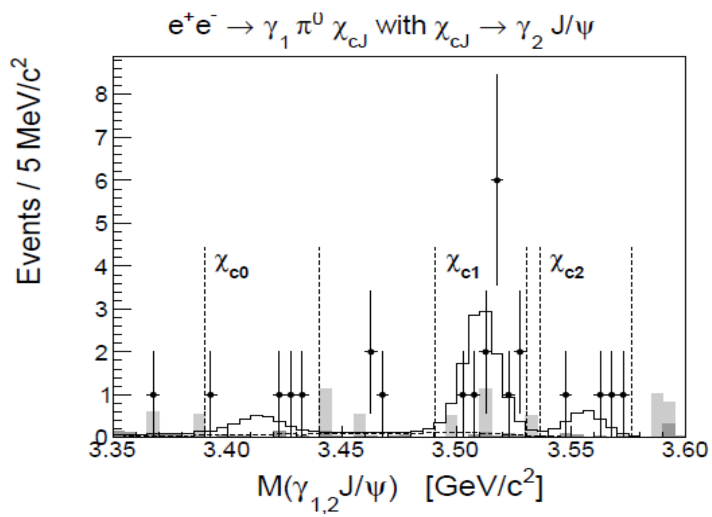
previous measurement: 0.8±0.3 from BaBar

Observation of $X(3872) \to \pi^0 \chi_{c1}(1P)$

PRL 122, 202001

$e^+e^- \to \gamma X(3872)$, $X(3872) \to \pi^0 \chi_{cJ}$ (with $\chi_{cJ} \to \gamma J/\psi$, $J/\psi \to l^+l^-$)





- Clear signal of $X(3872)$ in Y(4260) region, $N_{X(3872)} = 16.9^{+5.2}_{-4.9}$
- No $X(3872)$ events outside of $Y(4260)$
- Clear cluster of $\chi_{c1}(1P)$ events in X(3872) mass window
- First observation of $X(3872) \to \pi^0 \chi_{c1}(1P)$ with significance $>5\sigma$

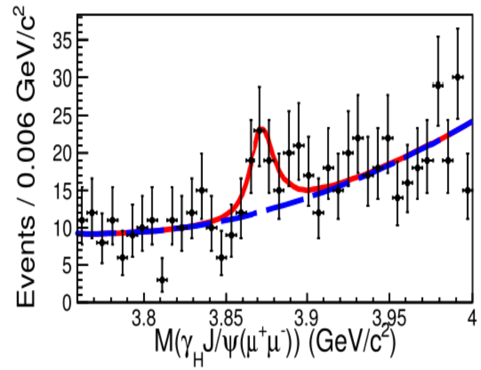
Measurements of $X(3872) \to \gamma J/\psi, \gamma\psi(3686)$

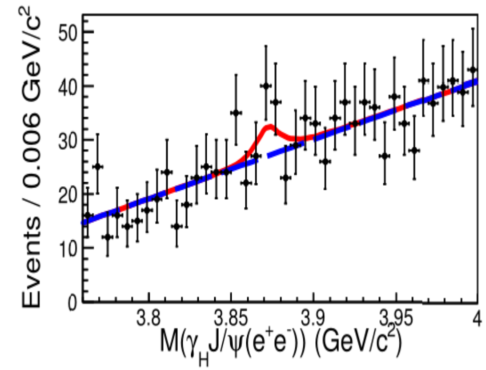
preliminary

$X(3872) \to \gamma J/\psi$

$J/\psi \to \mu\mu/ee$

Belle (4.9σ); BaBar (3.6σ); LHCb (>5σ)





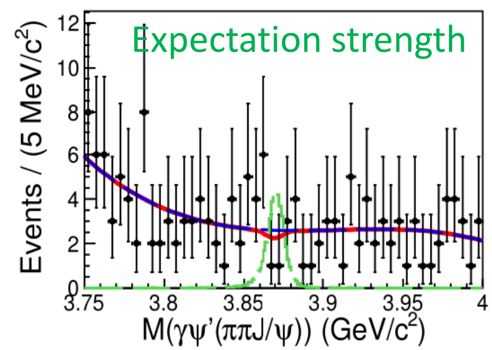
- Simultaneous fit; significance $> 3.5\sigma$

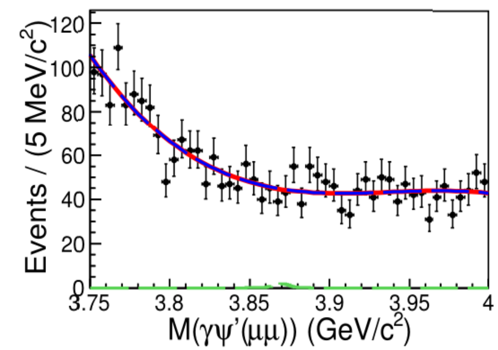
$X(3872) \to \gamma\psi(3686)$

$\psi(3686) \to \pi^+\pi^- J/\psi$

$\psi(3686) \to \mu\mu$

Belle (0.4σ); BaBar (3.5σ); LHCb (4.4σ)





- Simultaneous fit; NO evident signal!

$$\frac{\mathcal{B}[X(3872)\to\gamma\psi(3686)]}{\mathcal{B}[X(3872)\to\gamma J/\psi]} < 0.59 \text{ at } 90\% \text{ C.L.}$$

PDG average: 2.6

Measurements of $X(3872) \to D^0\bar{D}^{*0}$, γD^+D^-

preliminary

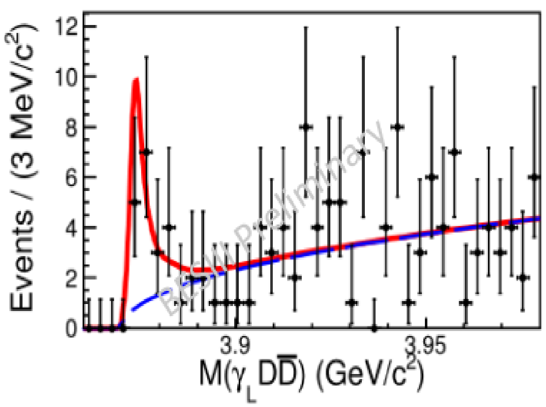
$X(3872) \to D^0\bar{D}^{*0} + c.c.$

$D^{*0} \to \gamma D^0, \pi^0 D^0$

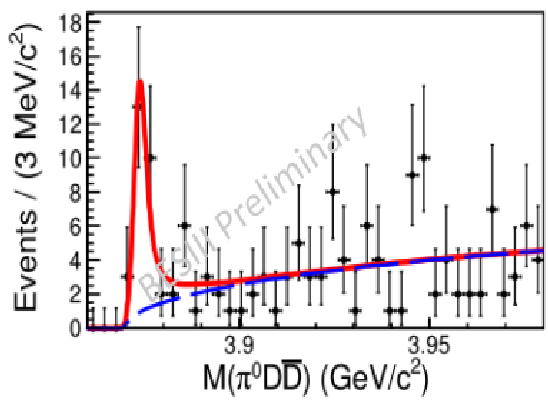
$D^0 \to K\pi, K\pi\pi, K\pi\pi\pi$

$X(3872) \to \gamma D^+D^-$

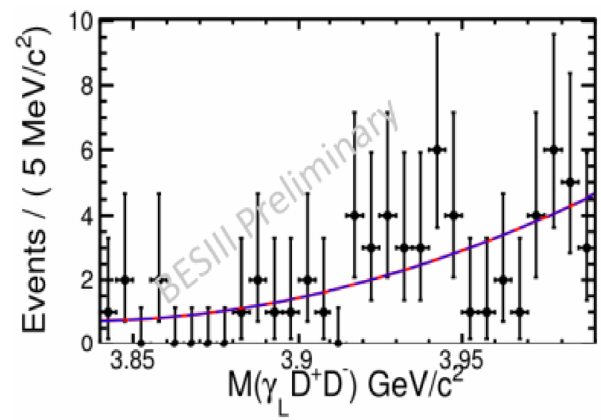
$D^\pm \to K\pi\pi, K\pi\pi\pi$



$N_{DD^*} = (25.5 \pm 4.4)$



$N_{DD^*} = (32.5 \pm 5.5)$



$N_{\gamma D^+D^-} = 0.0^{+0.5}_{-0.0}$

- Simultaneous fit on $D^{*0} \to \gamma D^0$ and $\pi^0 D^0$
- Significance $> 7.4\sigma$

No evident signal for γD^+D^-

Relative branching ratio compared with $X(3872) \to \pi^+\pi^- J/\psi$

mode	$D^{*0}\bar{D}^0 + c.c.$	$\gamma J/\psi$	$\gamma\psi'$	γD^+D^-	$\omega J/\psi$	$\pi^0\chi_{c1}$
ratio	14.81 ± 3.80	0.79 ± 0.28	< 0.42	< 0.99	$1.7^{+0.4}_{-0.3} \pm 0.2$ [27]	$0.88^{+0.33}_{-0.27} \pm 0.10$ [37]

X(3872) decay BRs

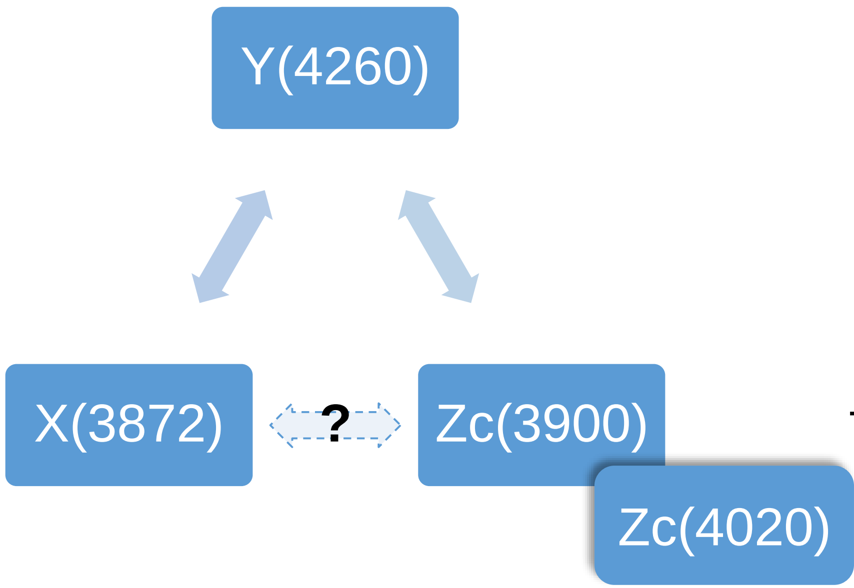
mode	$D^{*0}\bar{D}^0 + c.c.$	$\gamma J/\psi$	$\gamma\psi'$	γD^+D^-	$\omega J/\psi$	$\pi^0\chi_{c1}$
ratio	14.81 ± 3.80	0.79 ± 0.28	< 0.42	< 0.99	$1.7^{+0.4}_{-0.3} \pm 0.2$ [27]	$0.88^{+0.33}_{-0.27} \pm 0.10$ [37]

With recent $\mathrm{B}(X(3872) \to \pi^+\pi^- J/\psi)$ = (4.1±1.3)% from BaBar, one gets

B(known)=(1+14.81+0.79+1.7+0.88)*4.1%
= 19.2x4.1% ~ (79±32)%!

Find more decay modes, and/or improve the precisions

Emerging connections between XYZ



Two isospin triplets

What is the nature?

Molecule/Tetraquark/
Hybrid/…
Threshold effects/…

Further experimental efforts needed:

Production/Decay mechanism;
Resonance parameters (any kinematic dependency?);
Partners? …

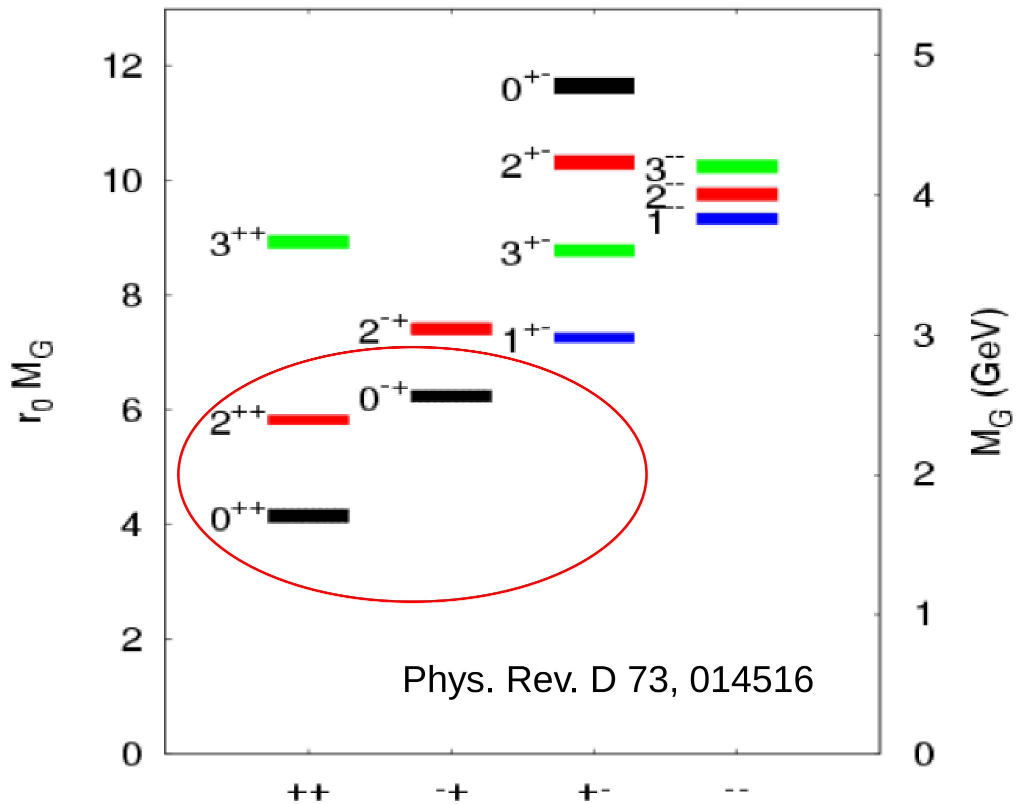
Selected topics

- XYZ states
  - $Z_c(3900)$
  - Y(4260)
  - X(3872)

- Glueball studies
  - scalar

[黄性涛, 6/25]

Glueball

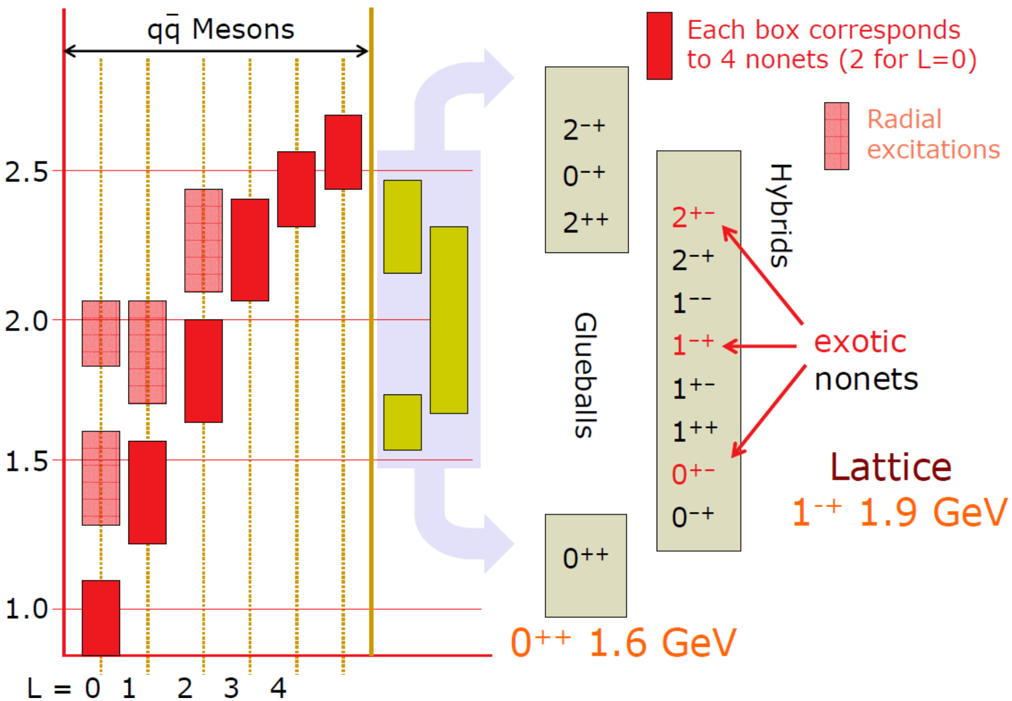


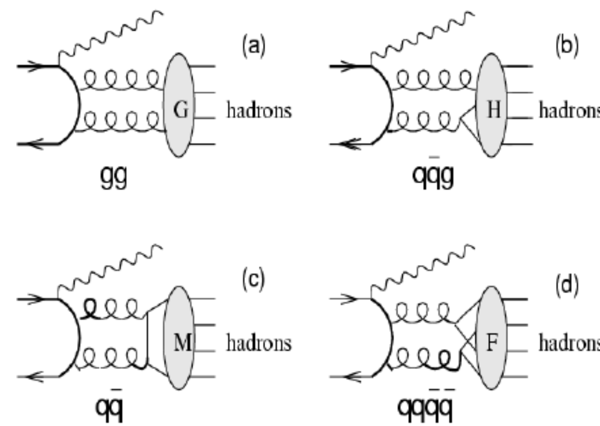
Glueballs from Quenched LQCD

Low lying glueballs with ordinary quantum number
→mixing with qqbar mesons

Systematic studies needed

Glueball





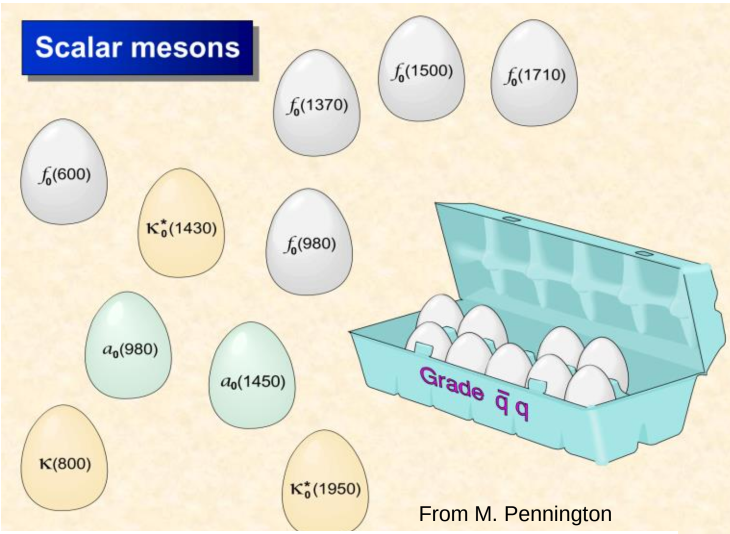
$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2), \Gamma(J/\psi \to \gamma H) \sim O(\alpha\alpha_s^3),$

$\Gamma(J/\psi \to \gamma M) \sim O(\alpha\alpha_s^4), \Gamma(J/\psi \to \gamma F) \sim O(\alpha\alpha_s^4)$

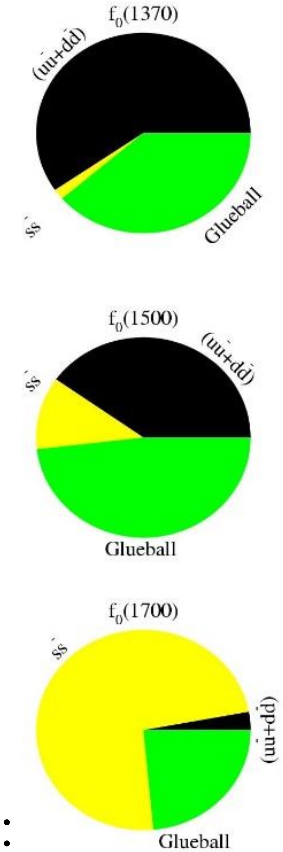
Charmonium decays provides an ideal hunting ground for light glueballs

- **“Gluon-rich” process**
- **Clean high statistics data samples from e^+e^- production**
- **$I(J^{PC})$ filter in strong decays of charmonium**

Overpopulated scalar mesons



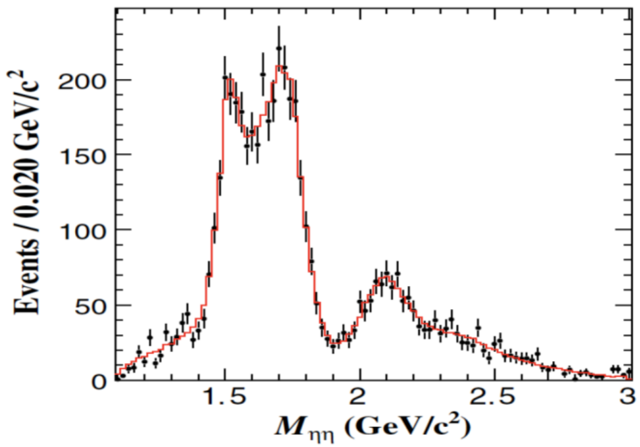
Name	Mass [MeV/c^2]	Width [MeV/c^2]
$f_0(600)$ *	400 – 1200	600 – 1000
$f_0(980)$ *	980 ± 10	40 – 100
$f_0(1370)$ *	1200 – 1500	200 – 500
$f_0(1500)$ *	1507 ± 5	109 ± 7
$f_0(1710)$ *	1718 ± 6	137 ± 8
$f_0(1790)$		
$f_0(2020)$	1992 ± 16	442 ± 60
$f_0(2100)$	2103 ± 7	206 ± 15
$f_0(2200)$	2189 ± 13	238 ± 50



Mixing scheme：
$f_0(1500)$, $f_0(1710)$
which one has more gluonic component?

Amplitude analysis of $J/\psi \to \gamma\eta\eta/K_S^0K_S^0$

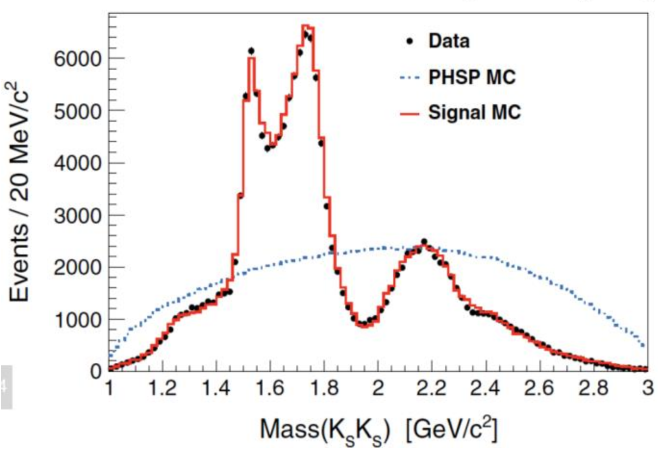
BESIII PRD 87, 092009 (2013)



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

Br of $f_0(1710)$ and $f_0(2100)$ ~10x larger than $f_0(1500)$

BESIII PRD 98, 072003 (2018)



Resonance	M (MeV/c^2)	M_{PDG} (MeV/c^2)	Γ (MeV/c^2)	Γ_{PDG} (MeV/c^2)	Branching fraction	Significance
$K^*(892)$	896	895.81 ± 0.19	48	47.4 ± 0.6	$(6.28^{+0.16+0.59}_{-0.17-0.52}) \times 10^{-6}$	35σ
$K_1(1270)$	1272	1272 ± 7	90	90 ± 20	$(8.54^{+1.07+2.35}_{-1.20-2.13}) \times 10^{-7}$	16σ
$f_0(1370)$	$1350 \pm 9^{+12}_{-2}$	1200 to 1500	$231 \pm 21^{+28}_{-48}$	200 to 500	$(1.07^{+0.08+0.36}_{-0.07-0.34}) \times 10^{-5}$	25σ
$f_0(1500)$	1505	1504 ± 6	109	109 ± 7	$(1.59^{+0.16+0.18}_{-0.16-0.56}) \times 10^{-5}$	23σ
$f_0(1710)$	$1765 \pm 2^{+1}_{-1}$	1723^{+6}_{-5}	$146 \pm 3^{+7}_{-1}$	139 ± 8	$(2.00^{+0.03+0.31}_{-0.02-0.10}) \times 10^{-4}$	$\gg 35\sigma$
$f_0(1790)$	$1870 \pm 7^{+2}_{-3}$	$\cdots$	$146 \pm 14^{+7}_{-15}$	$\cdots$	$(1.11^{+0.06+0.19}_{-0.06-0.32}) \times 10^{-5}$	24σ
$f_0(2200)$	$2184 \pm 5^{+4}_{-2}$	2189 ± 13	$364 \pm 9^{+4}_{-7}$	238 ± 50	$(2.72^{+0.08+0.17}_{-0.06-0.47}) \times 10^{-4}$	$\gg 35\sigma$
$f_0(2330)$	$2411 \pm 10 \pm 7$	$\cdots$	$349 \pm 18^{+23}_{-1}$	$\cdots$	$(4.95^{+0.21+0.66}_{-0.21-0.72}) \times 10^{-5}$	35σ
$f_2(1270)$	1275	1275.5 ± 0.8	185	$186.7^{+2.2}_{-2.5}$	$(2.58^{+0.08+0.59}_{-0.09-0.20}) \times 10^{-5}$	33σ
$f_2'(1525)$	1516 ± 1	1525 ± 5	$75 \pm 1 \pm 1$	73^{+6}_{-5}	$(7.99^{+0.03+0.69}_{-0.04-0.50}) \times 10^{-5}$	$\gg 35\sigma$
$f_2(2340)$	$2233 \pm 34^{+9}_{-25}$	2345^{+50}_{-40}	$507 \pm 37^{+18}_{-21}$	322^{+70}_{-60}	$(5.54^{+0.34+3.82}_{-0.40-1.49}) \times 10^{-5}$	26σ
0^{++} PHSP	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$(1.85^{+0.05+0.68}_{-0.05-0.26}) \times 10^{-5}$	26σ
2^{++} PHSP	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$(5.73^{+0.99+4.18}_{-1.00-3.74}) \times 10^{-5}$	13σ

Scalar glueball candidate?

Flavor-blindness of glueball decays

$$\frac{1}{P.S.}\Gamma(G \to \pi\pi : K\overline{K} : \eta\eta : \eta\eta' : \eta'\eta') = 3:4:1:0:1$$

CLQCD Phys. Rev. Lett. 110, 021601

$$\Gamma(J/\psi \to \gamma G_{0^+}) = \frac{4}{27}\alpha\frac{|p|}{M_{J/\psi}^2}|E_1(0)|^2 = 0.35(8)keV$$

$$\Gamma/\Gamma\_tot = 0.33(7)/93.2 = 3.8(9)\times 10^{-3}$$

Experiment

- $B(J/\psi \to \gamma f_0(1710) \to \gamma K\overline{K}) = (8.5^{+1.2}_{-0.9}) \times 10^{-4}$
- $B(J/\psi \to \gamma f_0(1710) \to \gamma\pi\pi) = (4.0\pm1.0)\times 10^{-4}$
- $B(J/\psi \to \gamma f_0(1710) \to \gamma\omega\omega) = (3.1\pm1.0)\times 10^{-4}$
- $B(J/\psi \to \gamma f_0(1710) \to \gamma\eta\eta) = (2.35^{+0.13+1.24}_{-0.11-0.74})\times 10^{-4}$

$\Rightarrow$ $B(J/\psi \to \gamma f_0(1710)) > 1.7\times 10^{-3}$

Largely overlapped with scalar glueball?

Glueball program at BESIII in a nutshell

	0^+	2^+	0^-
J/ψ→γPP			
J/ψ→γVV			
J/ψ→γPPP			

- **0^+, 2^+ : Coupled channel analyses**
  - **J/ψ→γPP**
  - **J/ψ→ω/φ + X**
- **0^- : trajectory, X(2370)**
  - **J/ψ→γPPP**
  - **J/ψ→γγ V**

J/ψ→γη η /η′η′/η η′/$\pi^0\pi^0$/K_SK_S

J/ψ→γωφ/φφ/ωω

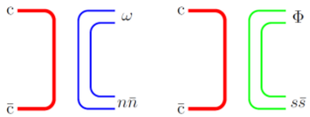
J/ψ→γ $\eta'\pi\pi$ /$\eta' KK$/$\eta\pi\pi$/$KK\pi$/ηKK/ $\pi\pi\pi$

- **PWA published**
- **Published, PWA undone**
- **Ongoing**

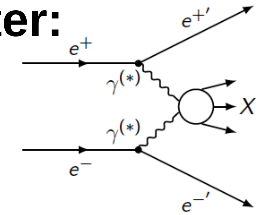
Flavor Filters:

J/ψ→γX →γ γ V

J/ψ→ω/φ + X



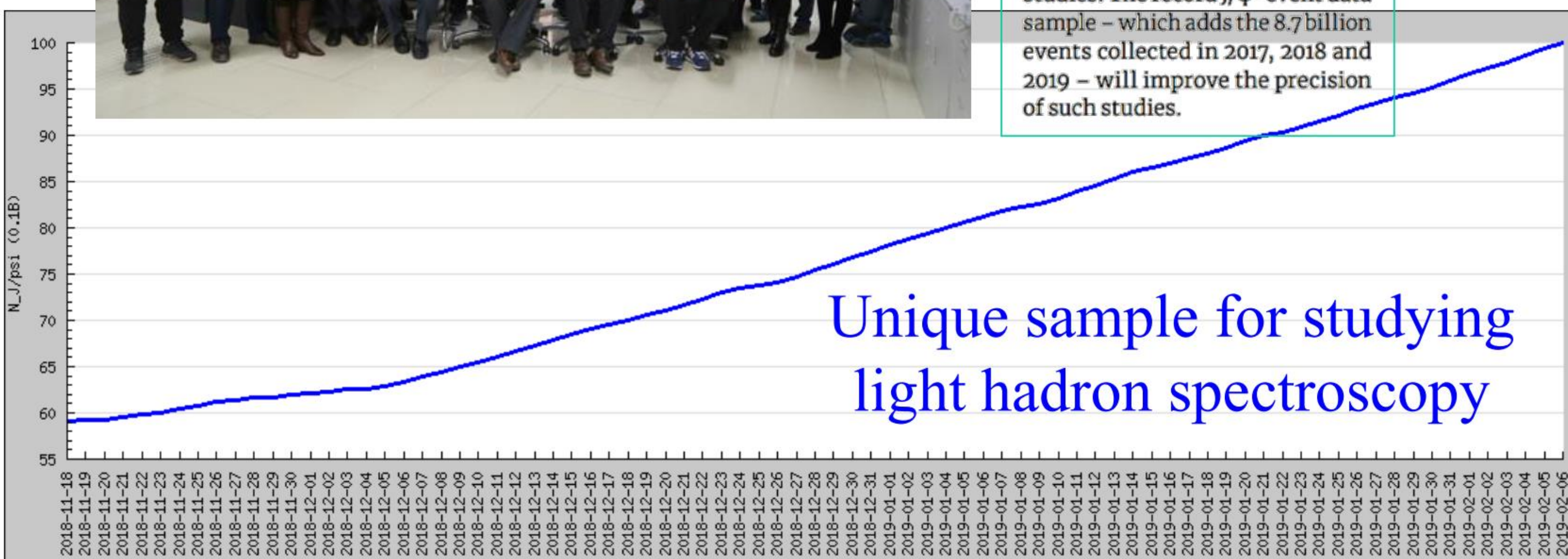
Anti filter:



10 Billion J/ψ events by Feb. 2019

BESIII amasses record J/ψ dataset
On 11 February, the BESIII experiment at the Beijing Electron Positron Collider in China finished accumulating a sample of 10 billion J/ψ events – the world's largest dataset produced directly from electron–positron annihilations. Decays of the J/ψ particle offer a clean laboratory for studying exotic hadrons composed of light quarks and gluons, including those composed of pure gluons. With 1.3 billion J/ψ events collected in 2009 and 2012, BESIII has reported many such studies. The record J/ψ-event data sample – which adds the 8.7 billion events collected in 2017, 2018 and 2019 – will improve the precision of such studies.

CERN courier



Unique sample for studying light hadron spectroscopy

Summary

- The data with unprecedented statistical accuracy and clearly defined initial and final state properties brings BESIII great opportunities to investigate QCD exotics and many other topics
- BEPCII beam energy is upgraded from 2.3 to 2.45 GeV; top-up injection increases luminosity by 30%; peak luminosity upgrade at high energy is under discussion;
- BESIII will continue data taking for another 5-10 years and contribute more in these fields

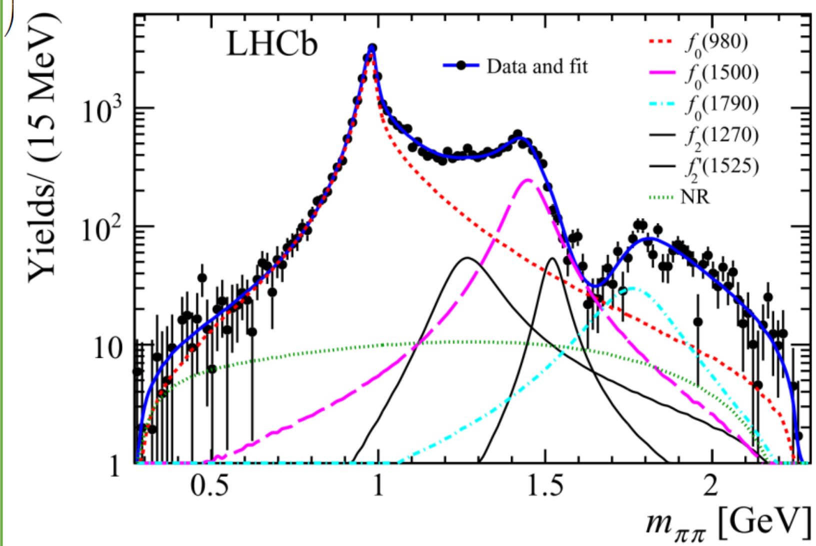
谢谢

About $f_0(1710)$

Phys.Rev. D92 (2015) no.9, 094006

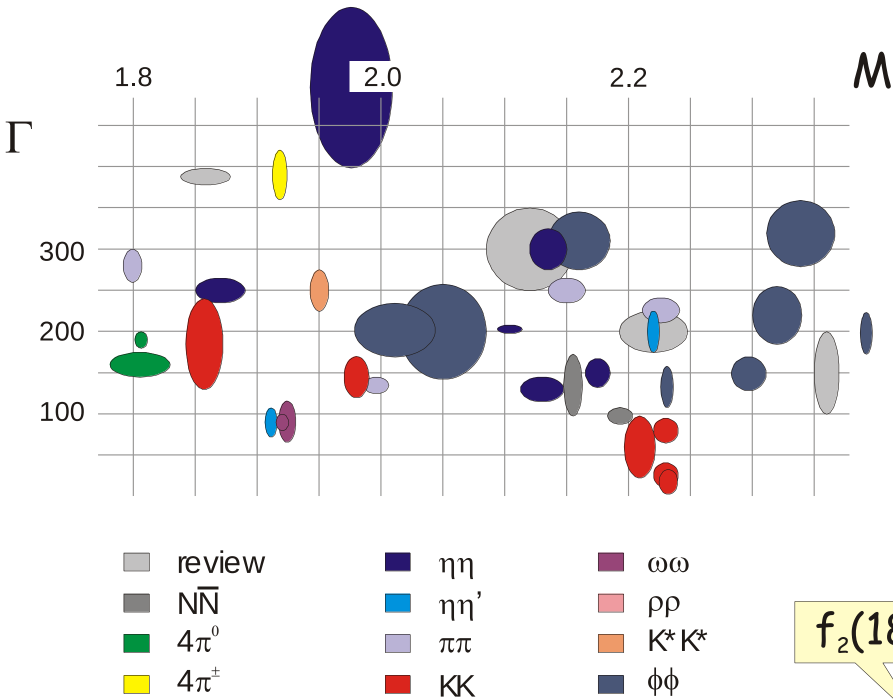
TABLE V: Comparison of two different types of models for the mixing matrices of the isosinglet scalar mesons $f_0(1370)$, $f_0(1500)$ and $f_0(1710)$. Experimental results are taken from Sec. III.

Experiment	Model I [28]	Model II [23]
$\begin{pmatrix} \lvert f_0(1370)\rangle \\ \lvert f_0(1500)\rangle \\ \lvert f_0(1710)\rangle \end{pmatrix} = (\ldots) \begin{pmatrix} \lvert N\rangle \\ \lvert S\rangle \\ \lvert G\rangle \end{pmatrix}$	$\begin{pmatrix} -0.91 & -0.07 & 0.40 \\ -0.41 & 0.35 & -0.84 \\ 0.09 & 0.93 & 0.36 \end{pmatrix}$	$\begin{pmatrix} 0.78(2) & 0.52(3) & -0.36(1) \\ -0.55(3) & 0.84(2) & 0.03(2) \\ 0.31(1) & 0.17(1) & 0.934(4) \end{pmatrix}$
Mass of the lightest scalar G in LQCD $\sim \mathcal{O}(1700)$MeV	$M_G \sim 1464 - 1519$ MeV	$M_G \sim 1665$ MeV
$\frac{\Gamma(J/\psi\to f_0(1710)\gamma)}{\Gamma(J/\psi\to f_0(1500)\gamma)} \sim \mathcal{O}(10)$	If $f_0(1500)$ is primarily a glueball, this ratio will be less than 1.	Yes, as $\lvert f_0(1710)\rangle \sim \lvert G\rangle$
$\frac{\Gamma(f_0(1710)\to\pi\pi)}{\Gamma(f_0(1710)\to K\bar{K})} = 0.31 \pm 0.05$	$f_0(1710)$ dominated by $s\bar{s}$	Chiral suppression
$\frac{\Gamma(f_0(1500)\to\pi\pi)}{\Gamma(f_0(1500)\to K\bar{K})} = 4.1 \pm 0.5$	If $f_0(1500)$ is primarily a glueball, this ratio will be of order unity. Needs a large mixing with $q\bar{q}$.	Well explained with the flavor octet structure of $f_0(1500)$.
$\frac{\Gamma(f_0(1710)\to\eta\eta)}{\Gamma(f_0(1710)\to K\bar{K})} = 0.48 \pm 0.15$	0.24	$0.52^{+0.33}_{-0.34}$
$\frac{\Gamma(f_0(1500)\to\eta\eta)}{\Gamma(f_0(1500)\to\pi\pi)} = \begin{cases} 0.230 \pm 0.097 \\ 0.18 \pm 0.03 \\ 0.080 \pm 0.033 \end{cases}$	0.19	$0.078^{+0.025}_{-0.027}$
$\frac{\Gamma(J/\psi\to f_0(1710)\omega)}{\Gamma(J/\psi\to f_0(1710)\phi)} = \begin{cases} 3.3 \pm 1.3 \\ 1.3 \pm 0.4 \end{cases}$	The ratio is naively less than 1. Needs large OZI-violating effects.	Yes, as $\lvert S\rangle$ is small in $f_0(1710)$
Non-observation of $f_0(1710)$ and observation of $f_0(1500)$ in $B_s \to J/\psi\pi^+\pi^-$ by LHCb	Dominant $f_0(1710)$ production followed by $f_0(1500)$	Dominant $f_0(1500)$ production, while $f_0(1710)$ is negligible
Near mass degeneracy of $a_0(1450)$ and $K_0^*(1430)$	No, it cannot be explained as $M_S - M_N \approx$ 200-300 MeV	Yes, as $M_S - M_N \approx 25$ MeV
$f_0(1500)$ not seen in $\gamma\gamma$ reactions except probably in $\gamma\gamma \to \pi^0\pi^0$	See Eq. (30)	See Eq. (30)

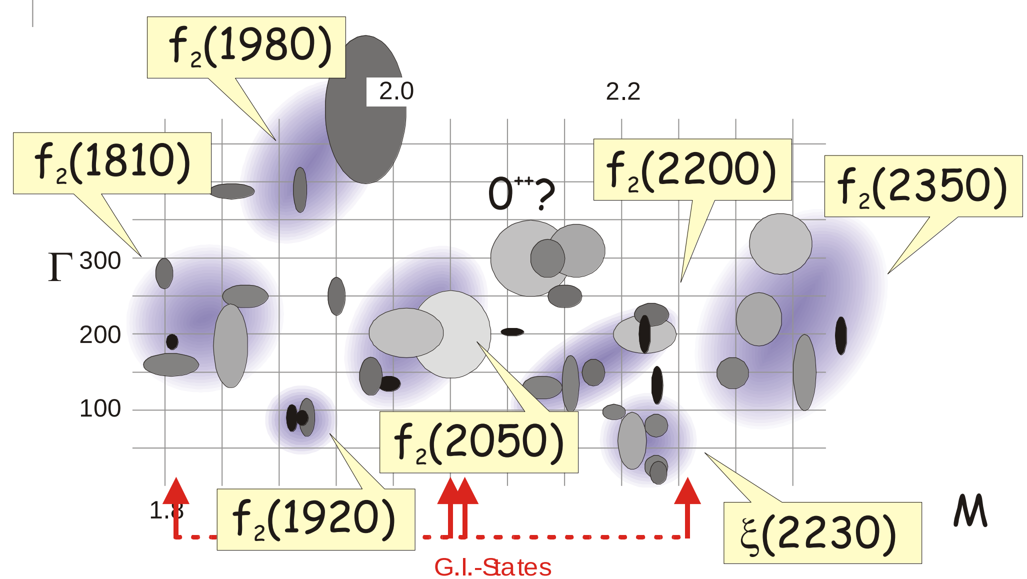


$B_s \to J/\psi\pi^+\pi^-$

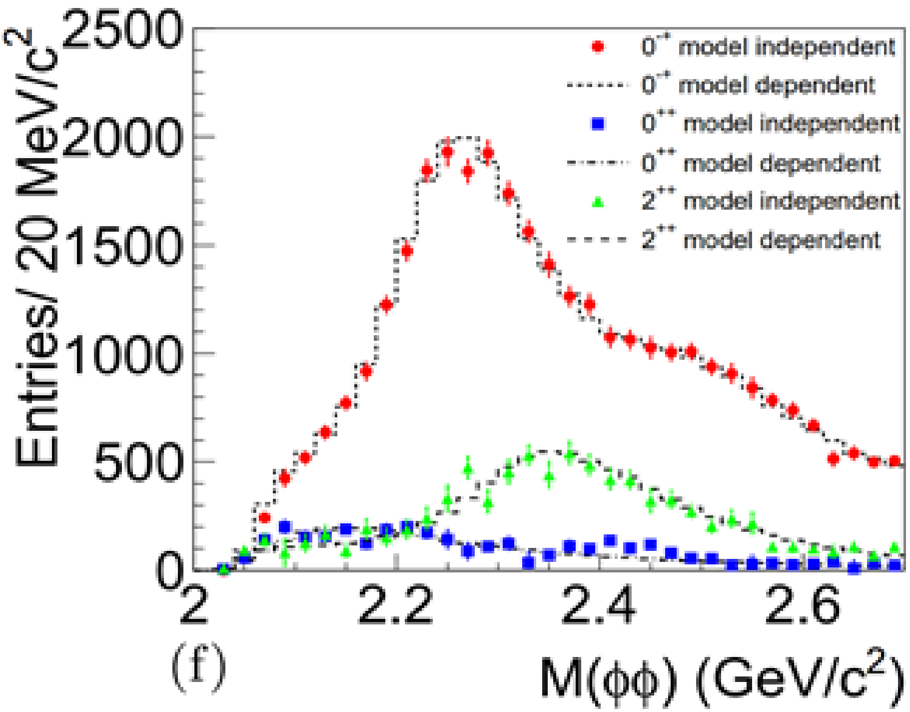
Tensor mesons



Still have large uncertainties



Partial Wave Analysis of $J/\psi \rightarrow \gamma\phi\phi$ [PR D93 112011]



(f)

Resonance	$M(\text{MeV}/c^2)$	$\Gamma(\text{MeV}/c^2)$	B.F.$(\times10^{-4})$	Sig.
$\eta(2225)$	2216^{+4+18}_{-5-11}	185^{+12+44}_{-14-17}	$(2.40\pm0.10^{+2.47}_{-0.18})$	28.1σ
$\eta(2100)$	2050^{+30+77}_{-24-26}	$250^{+36+187}_{-30-164}$	$(3.30\pm0.09^{+0.18}_{-3.04})$	21.5σ
$X(2500)$	2470^{+15+63}_{-19-23}	230^{+64+53}_{-35-33}	$(0.17\pm0.02^{+0.02}_{-0.08})$	8.8σ
$f_0(2100)$	2102	211	$(0.43\pm0.04^{+0.24}_{-0.03})$	24.2σ
$f_2(2010)$	2011	202	$(0.35\pm0.05^{+0.28}_{-0.15})$	9.5σ
$f_2(2300)$	2297	149	$(0.44\pm0.07^{+0.09}_{-0.15})$	6.4σ
$f_2(2340)$	2339	319	$(1.91\pm0.07^{+0.72}_{-0.69})$	10.7σ
0^{-+} PHSP			$(2.74\pm0.15^{+0.16}_{-1.48})$	6.8σ

- **Dominant contribution from pseudoscalars**
  - **η(2225) is confirmed;**
  - **η(2100) and X(2500) are observed with large significance.**
- **The three tensors $f_2(2010)$, $f_2(2300)$ and $f_2(2340)$ stated in π^-p reactions are also observed with a strong production of $f_2(2340)$.**
- **Model-dependent PWA results are well consistent with the results from MIPWA**