Overview of BESIII physics

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11th Workshop on Hadron physics in China and Opportunities Worldwide
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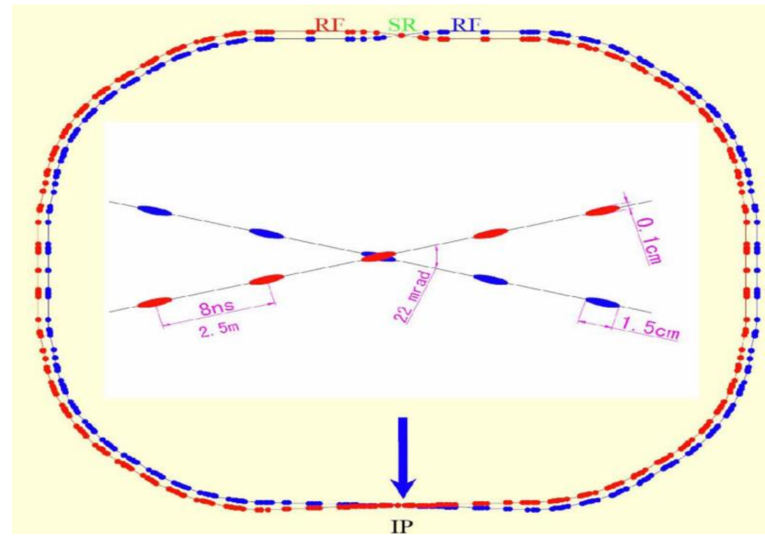
Beijing Electron Positron Collider (BEPC)

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

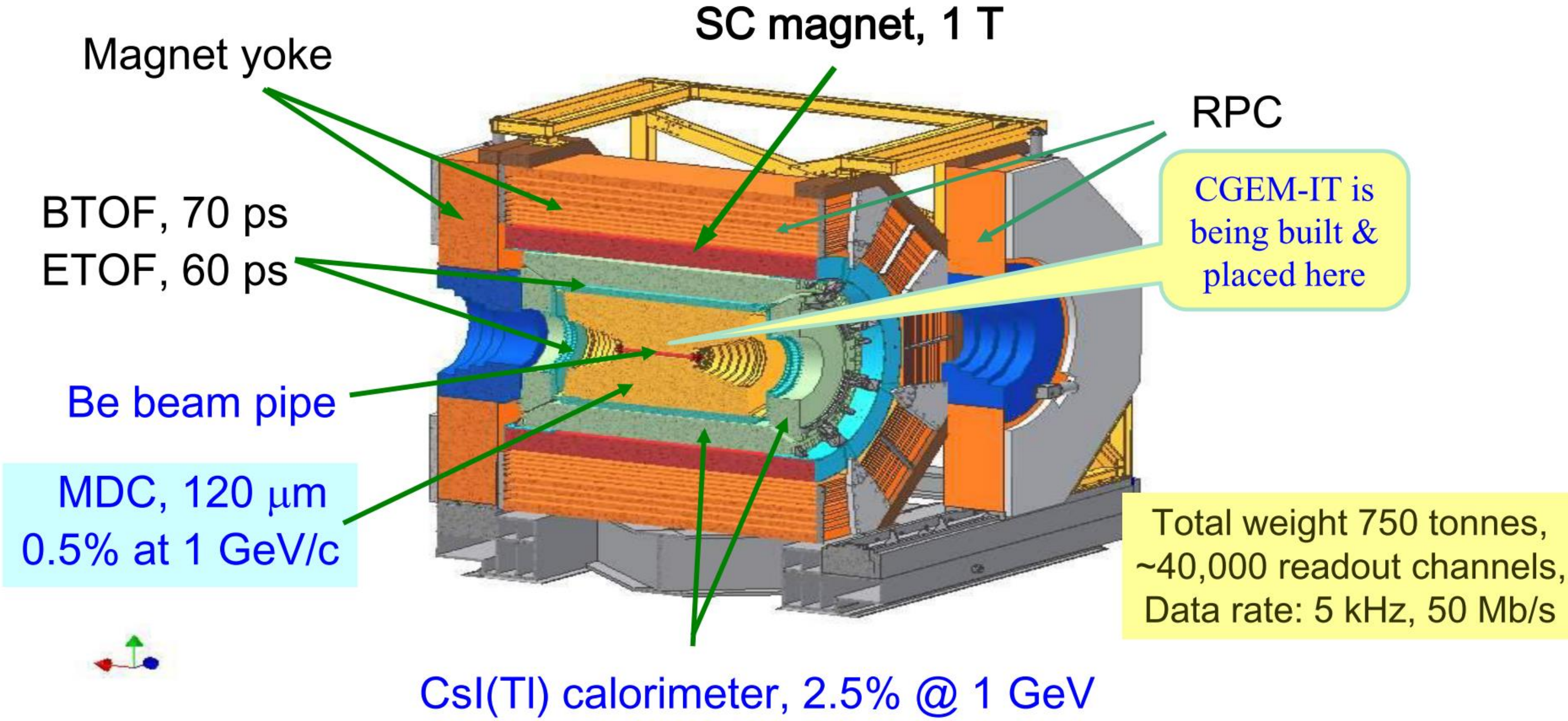
Beam energy	1 GeV to 2.3 GeV
Optimum energy	1.89 GeV
Single beam current	0.91 A
Crossing angle	± 11 mrad



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

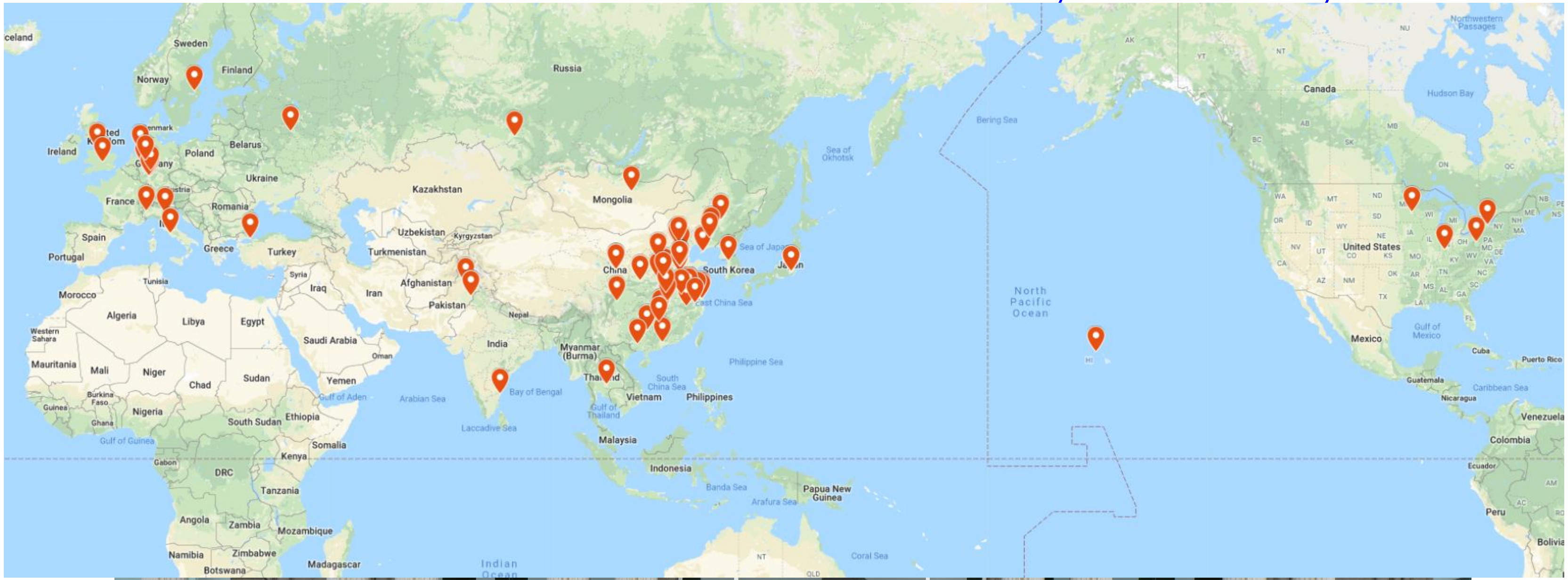


full operation since 2008

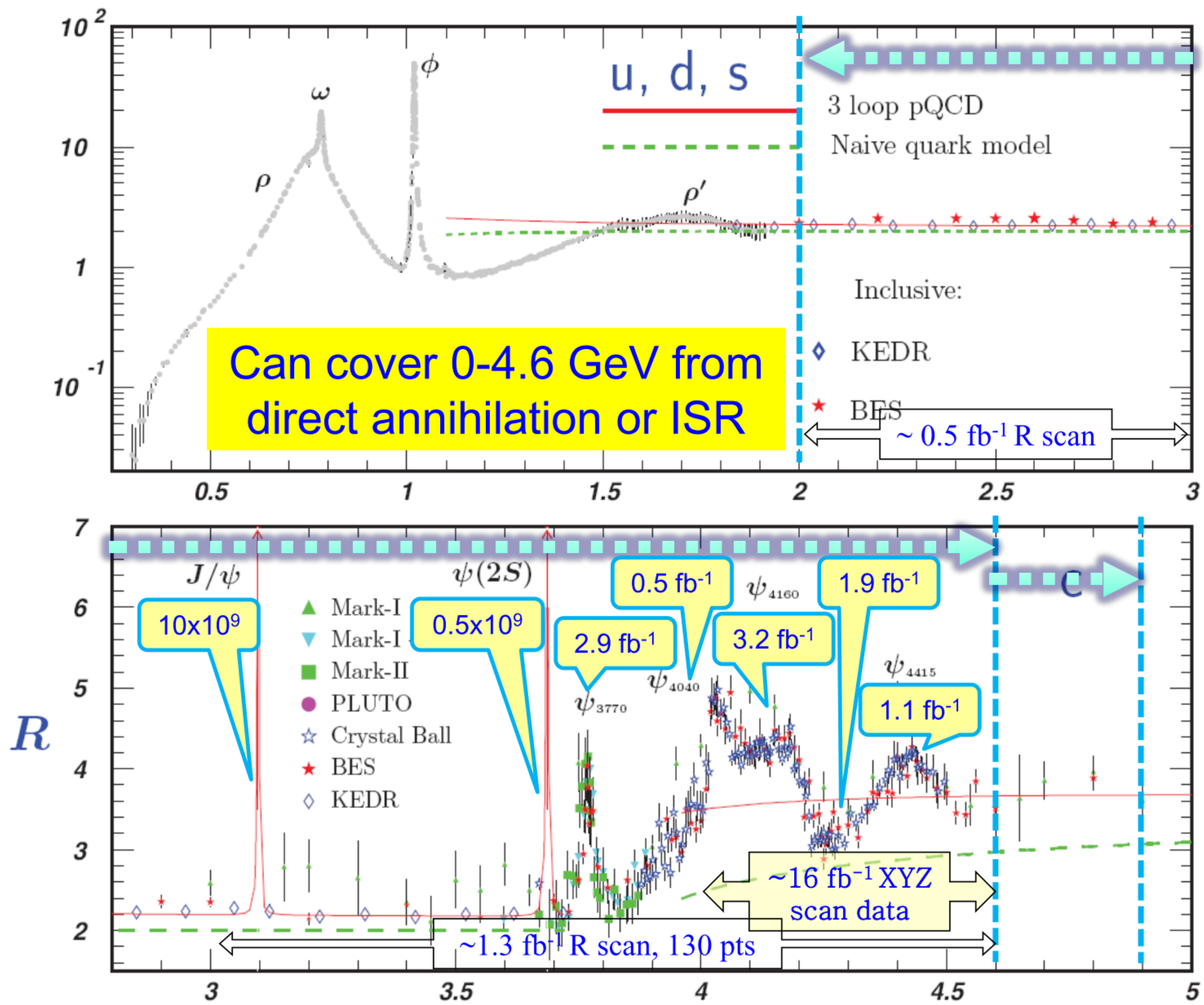
all subdetectors are in good status

BESIII collaboration

15 countries, 72 institutes, ~500 members

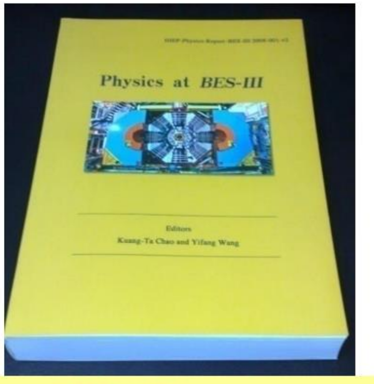


10 years of data taking at BESIII



Rich physics program

- Light hadron spectroscopy
  - Full spectra: conventional/exotic hadrons QCD
  - How quarks form a hadron?   non-pQCD
- Charm physics
  - CKM matrix elements   ➔ SM and beyond
  - DDbar mixing and CPV ➔ SM and beyond
- Charmonium physics
  - Spectroscopy and transitions ➔ pQCD & non-pQCD
  - New states above open charm thresholds ➔ exotic hadrons?
  - pQCD: "$\rho\pi$ puzzle" ➔ a probe to non-pQCD or pQCD?
- Tau physics and QCD
  - Precision measurement of the tau mass and R values
- Search for rare and forbidden decay modes

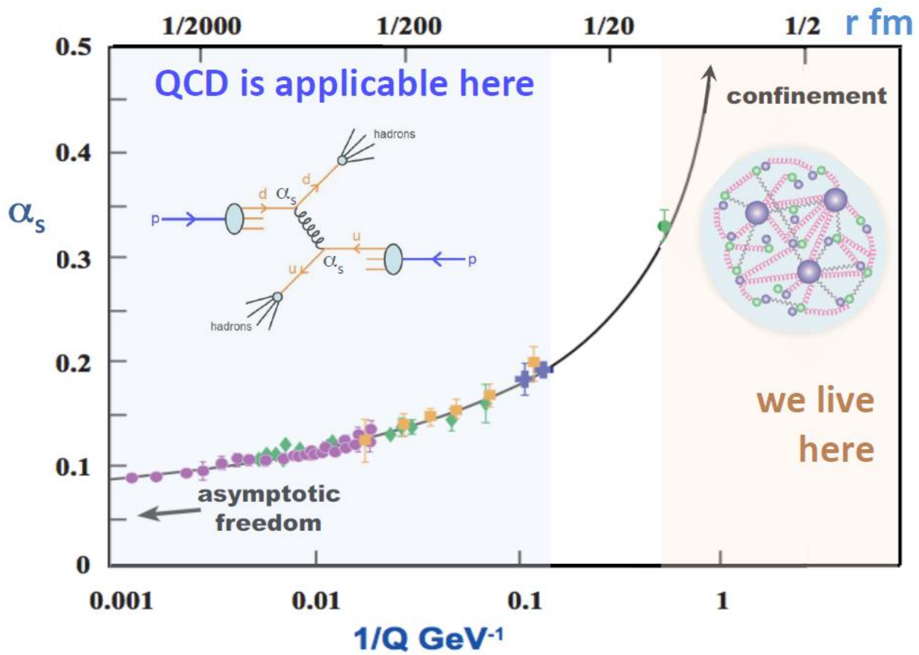


hep-ex/0809.1869
IJMP A V24, No 1 (2009) supp

Selected topics

- XYZ particles: X(3872), Y(4260), Zc(3900)
- Light hadrons: glueballs & more
- Charm(meson) physics
- Baryons: form factors & polarization [See Haibo's talk]

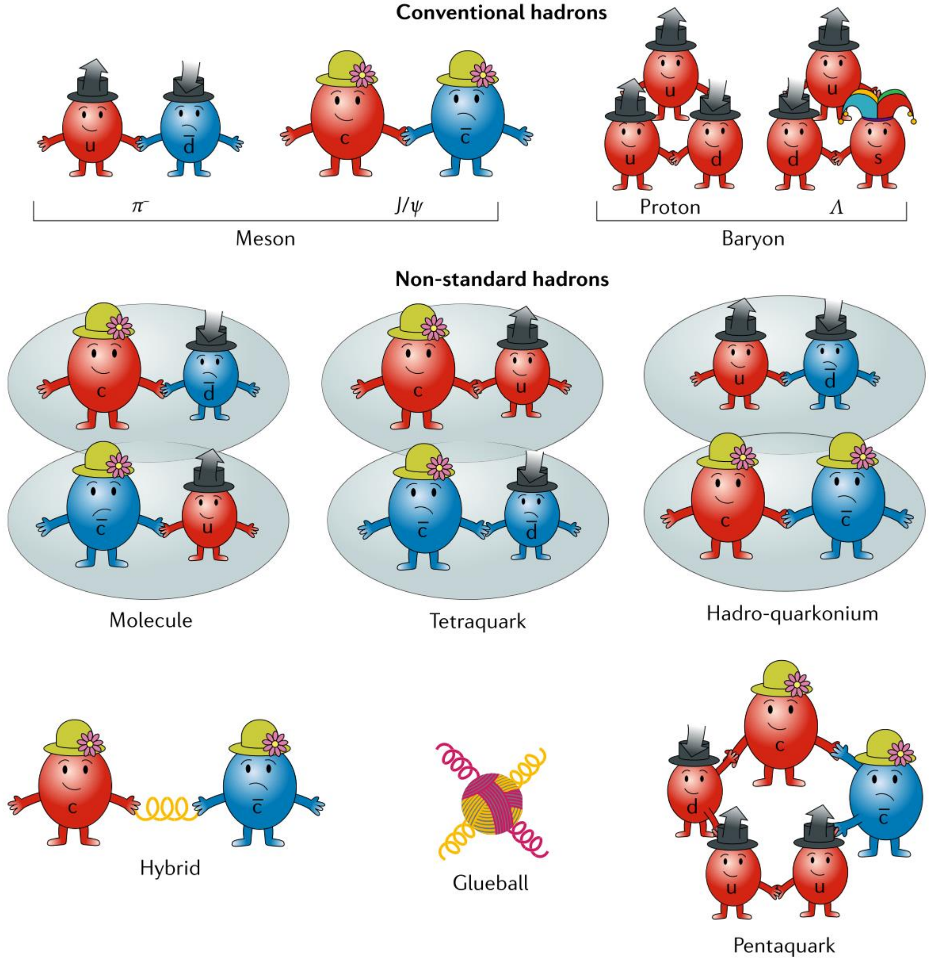
Hadron spectroscopy



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

QCD exotics

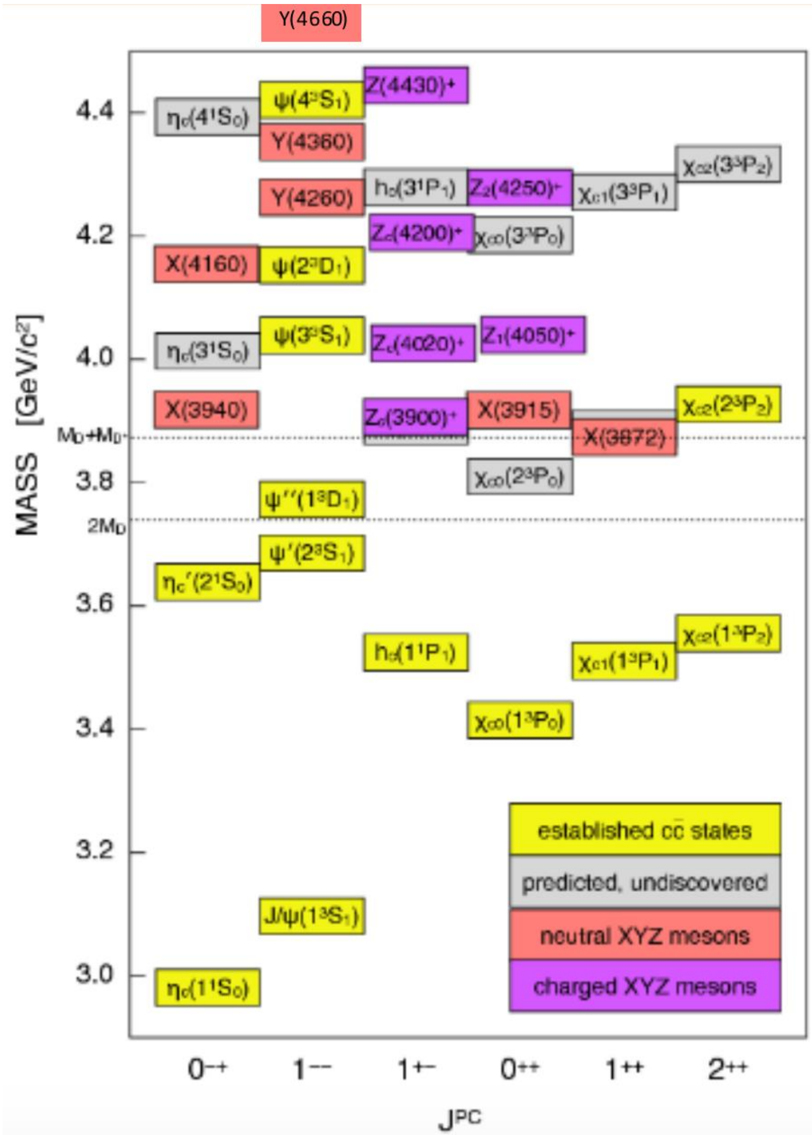
QCD predicts
new forms of hadrons

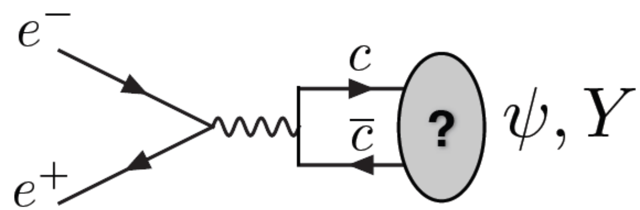


From Nature Rev.Phys. 1 (2019) no.8, 480

critical for the quantitative understanding of confinement

Charmonium and exotics at BESIII

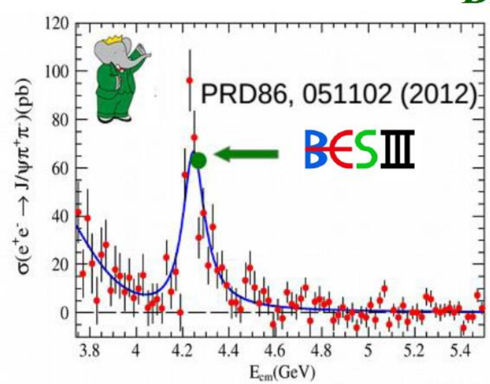


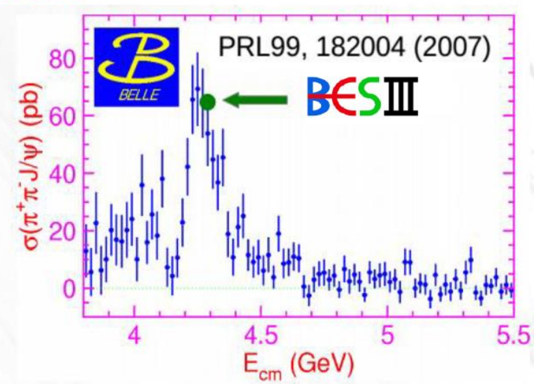


direct production of ψ , Y
radiative and hadronic transitions

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

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

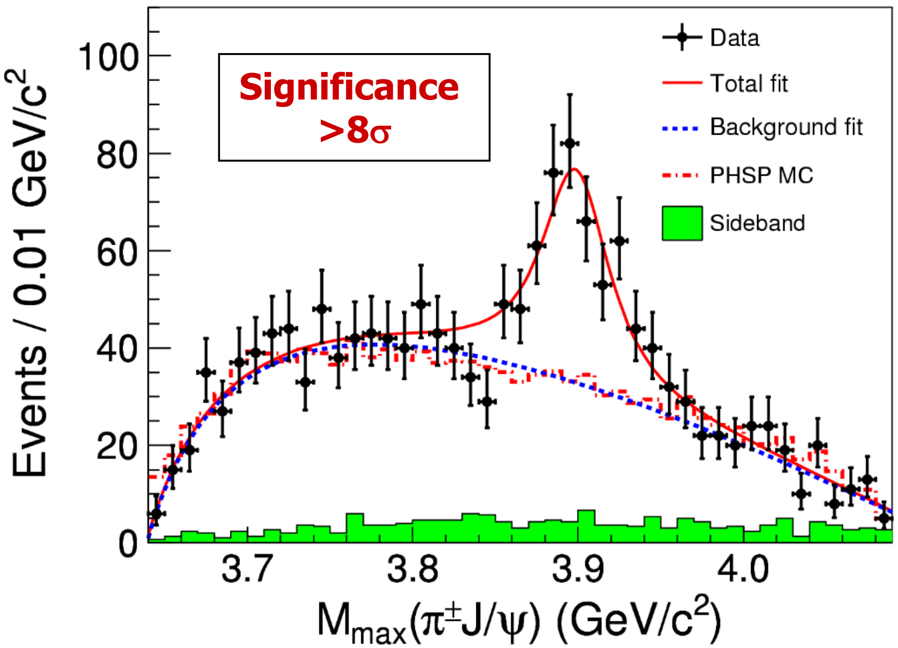




BESIII: $\sigma^B = 62.9 \pm 1.9 \pm 3.7$ pb

PRL 110, 252001 (2013)

Discovery of the $Z_c(3900)$

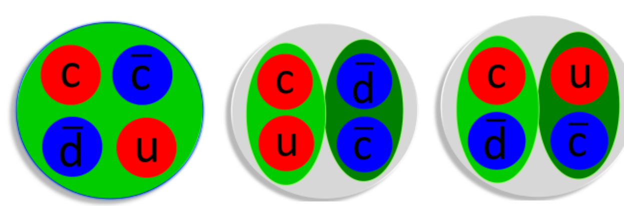


- ➢ Mass = (3899.0±3.6±4.9) MeV
- ➢ Width = (46±10±20) MeV
- ➢ Fraction = (21.5±3.3±7.5)%

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

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

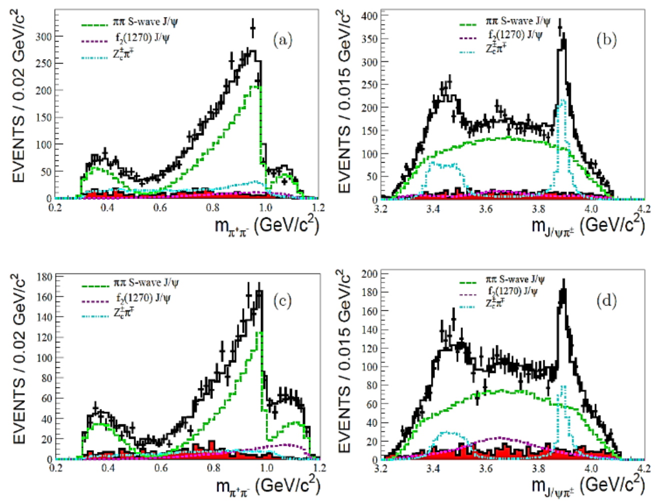


PRL110, 252001 (2013)

Properties of the $Z_c(3900)$

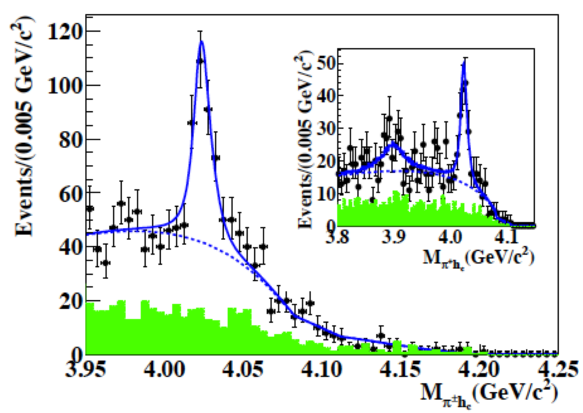
PRL 119, 072001 (2017)

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



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)

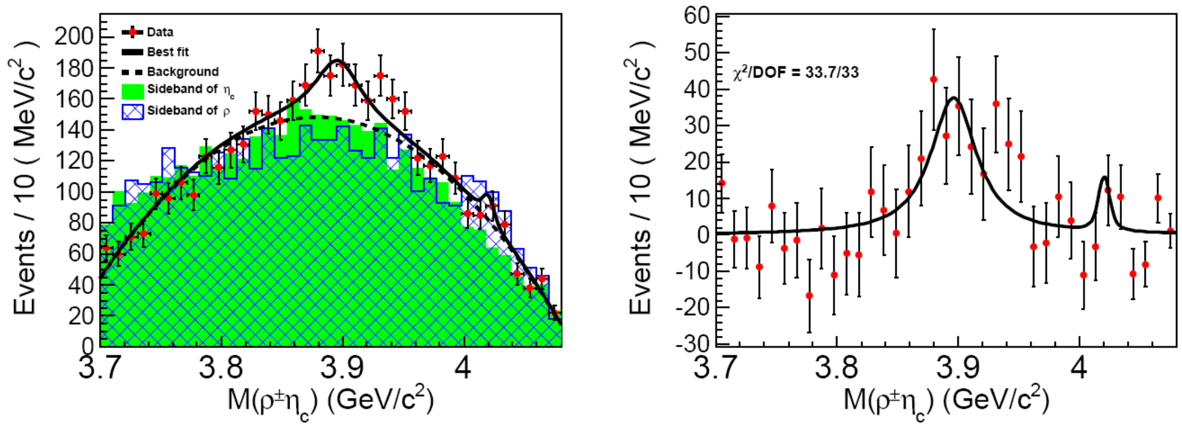
arXiv:1906.00831

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%
$\eta_c \to K_S K\pi$	~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 $Z_c \to \rho\eta_c$

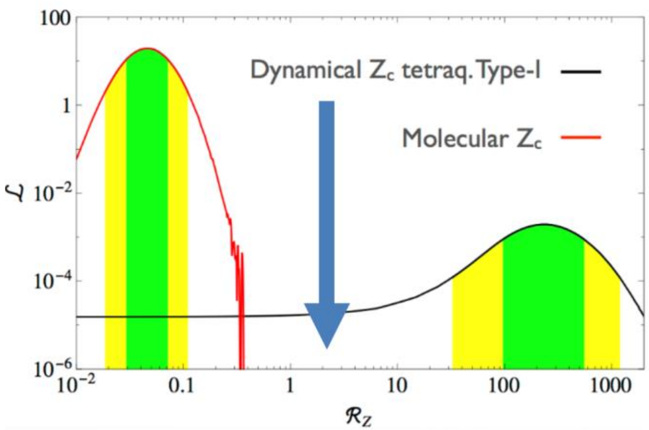
- Measure Born cross section at 4.23 GeV:

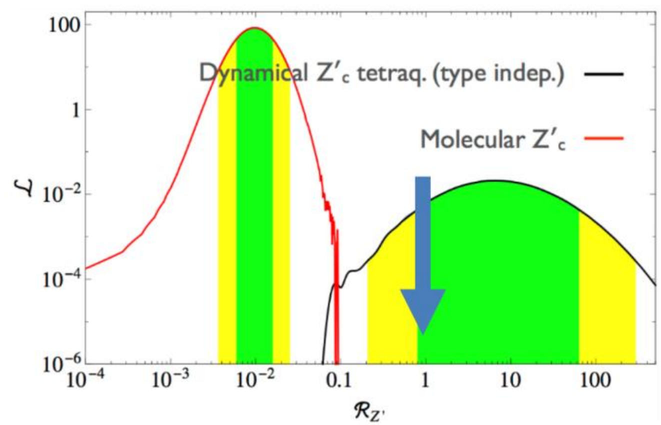
$$\sigma^B(e^+e^- \to \pi^+\pi^-\pi^0\eta_c) = (46\ ^{+12}_{-11} \pm 10\ )\ \text{pb}$$

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

	$\sqrt{s} = 4.226$ 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)



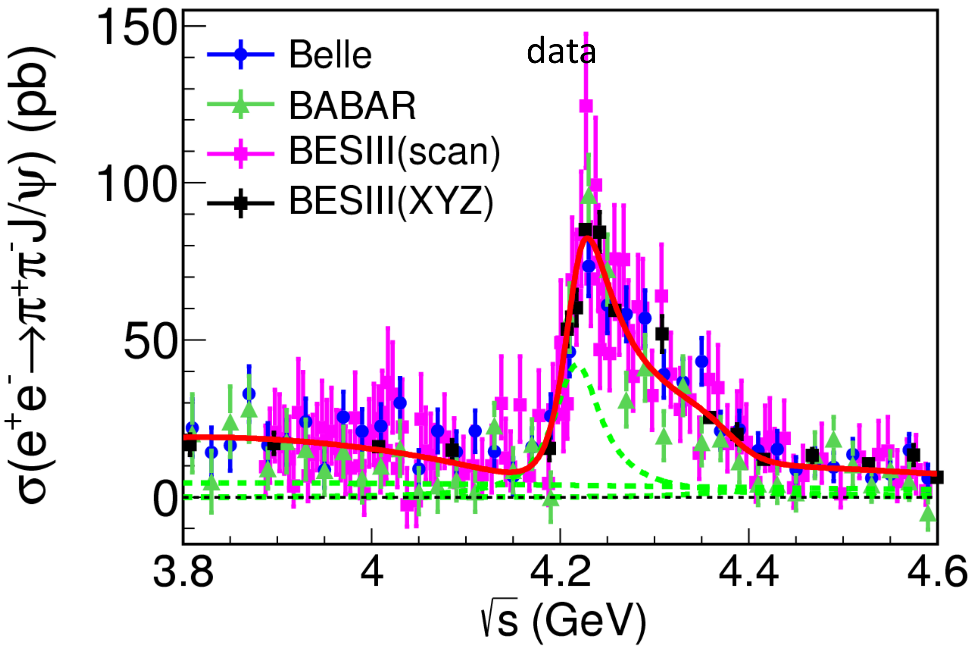


$$R_z = \frac{B(Z_c \to \rho\eta_c)}{B(Z_c \to \pi J/\psi)} \qquad R_{z'} = \frac{B(Z_c' \to \rho\eta_c)}{B(Z_c' \to \pi h_c)}$$

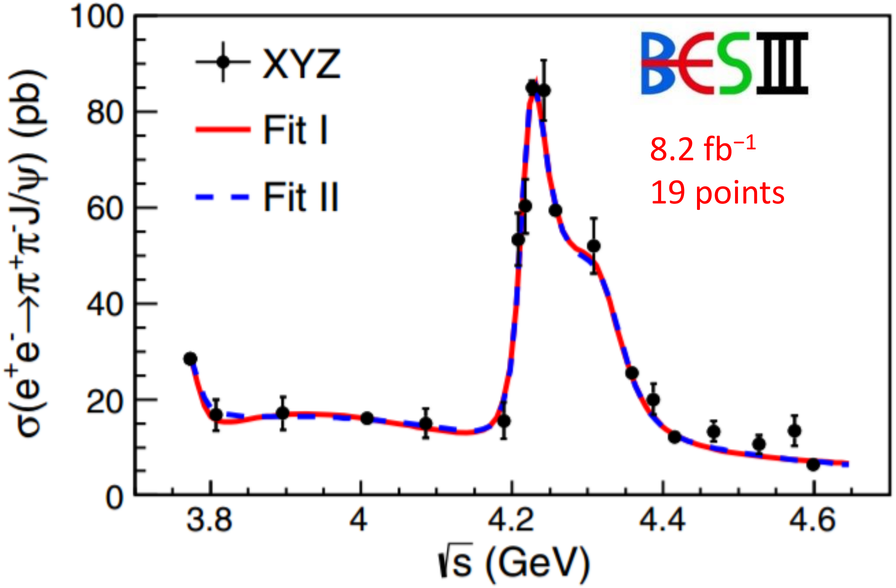
Z_c states have both tetraquark and molecule components?

Refined calculations needed!

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



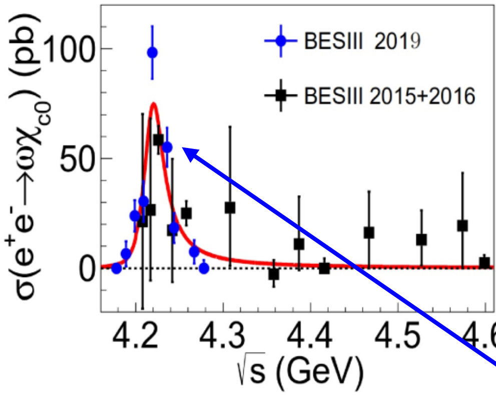
PRL118, 092001 (2017)



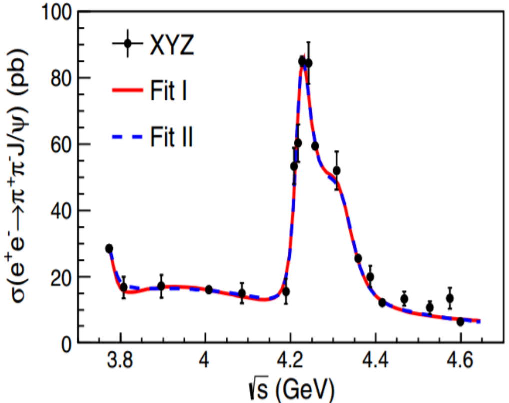
- Most precise cross section measurment to date from BESIII
- Y(4220): M = 4222.0 $\pm$ 3.1 $\pm$ 1.4 MeV, Γ = 44.1 $\pm$ 4.3 $\pm$ 2.0 MeV
  (lower) (narrower)
- Y(4320): M = 4320.0 $\pm$ 10.4 $\pm$ 7.0 MeV, Γ = $101.4^{+25.3}_{-19.7} \pm 10.2$ MeV

Y(4260)➔Y(4220): more modes

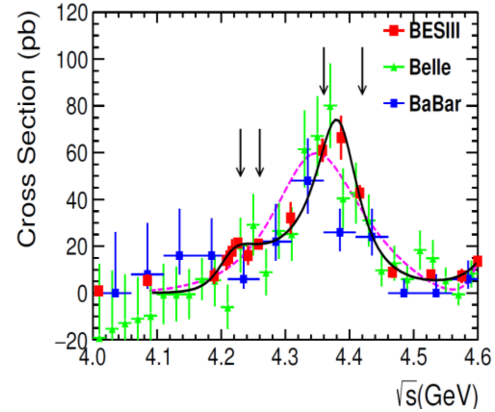
PRD99, 091103 (2019)



PRL118, 092001 (2017)

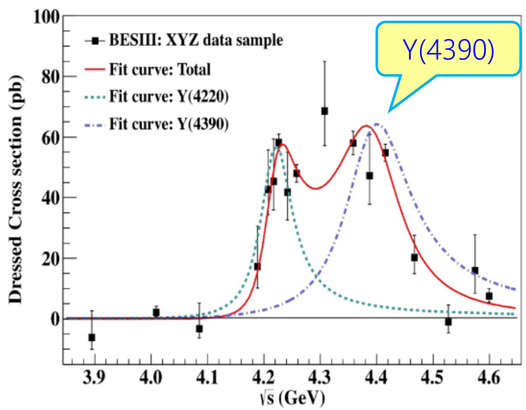


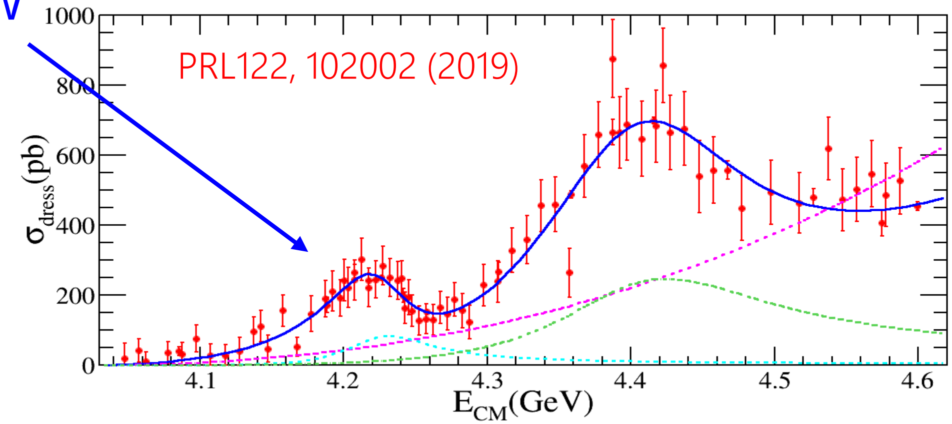
PRD96, 032004 (2017)



NEW

PRL118, 092002 (2017)





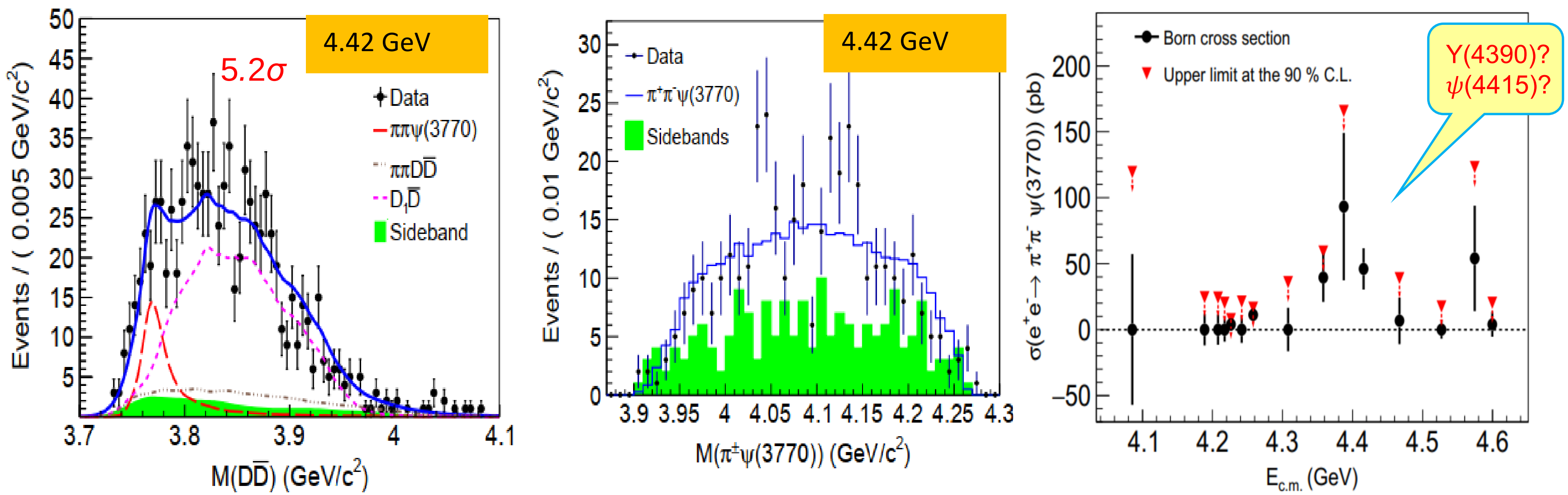
Y(4220) appears in $\omega\chi_{c0}$, $\pi^+\pi^-J/\psi$, $\pi^+\pi^-\psi'$, $\pi^+\pi^-h_c$, $D^0D^{*-}\pi^+$

Mass~4220 MeV, width~ 60 MeV

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

PRD 100 032005

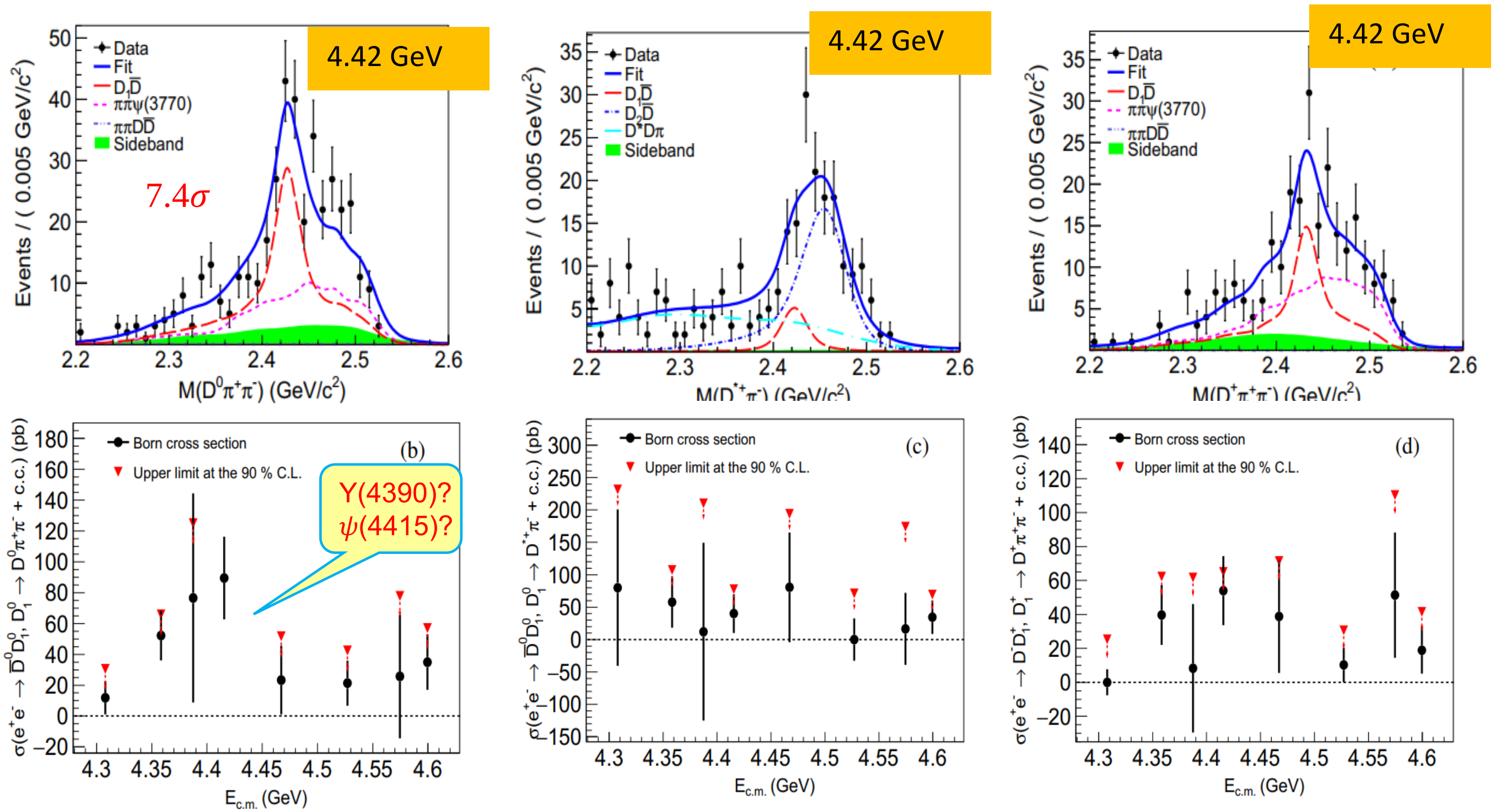
- Study the intermediate states of $e^+e^- \to \pi^+\pi^- D^0\bar{D}^0$, $e^+e^- \to \pi^+\pi^- D^+ D^- \bar{D}^0$
  - $D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-$ and $K^-\pi^+\pi^+\pi^-\pi^0$
  - $D^+ \to K^-\pi^+\pi^+, K^-\pi^+\pi^+\pi^0, K_S^0\pi^+, K_S^0\pi^+\pi^0$, and $K_S^0\pi^+\pi^+\pi^-$



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

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

PRD 100 032005

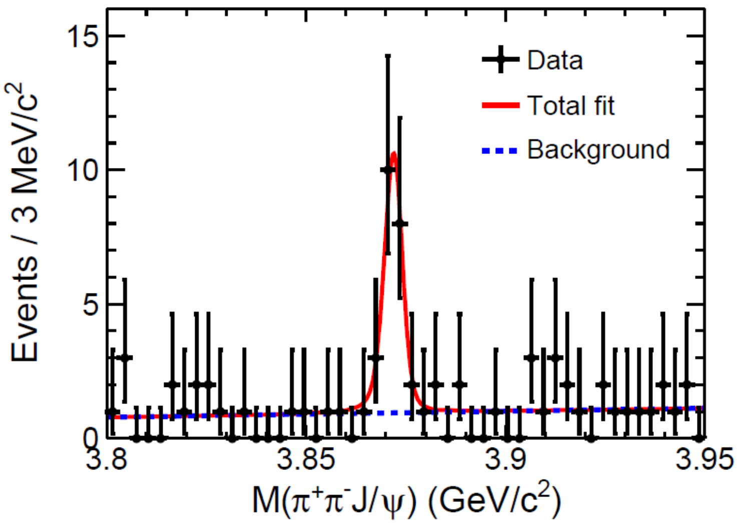


- Three different decay channels ($D^0\pi^+\pi^-$, $D^{*+}\pi^-$, and $D^+\pi^+\pi^-$) are used to search for $D_1(2420)$
- Clear structure in the line-shape of $e^+e^- \to D_1(2420)\bar{D}$
- No $D_1(2420)\bar{D}$ near threshold enhancement → Y(4260) not a $D_1(2420)\bar{D}$ molecule?

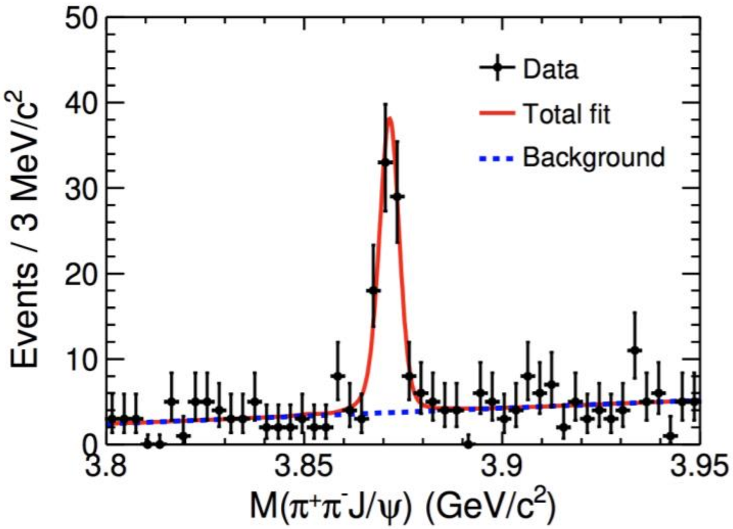
Observation of $e^+e^- \rightarrow \gamma X(3872)$

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

PRL 112, 092001



PRL122, 232002



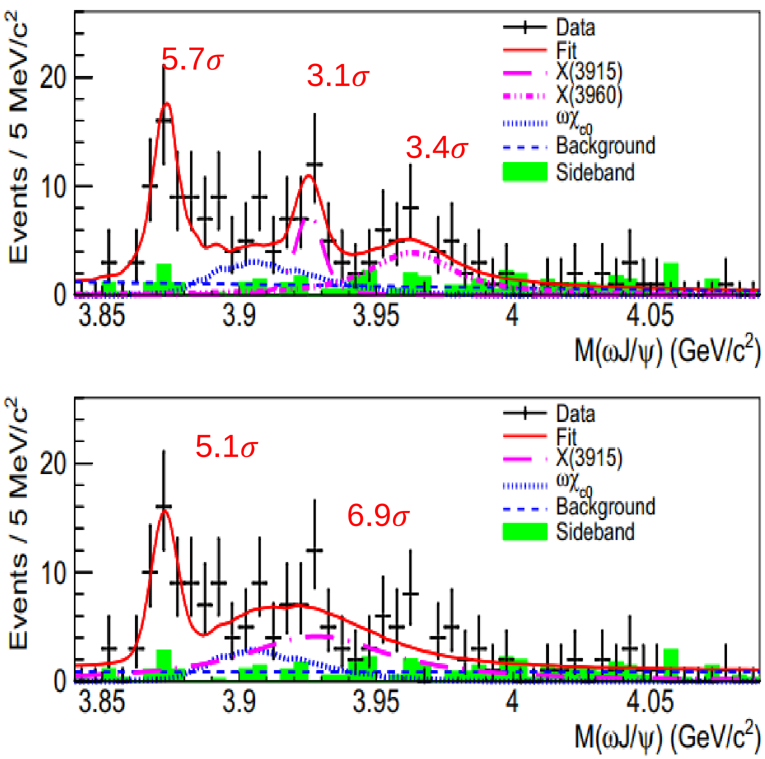
4.0 fb^{-1}, 20±5 evts

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))

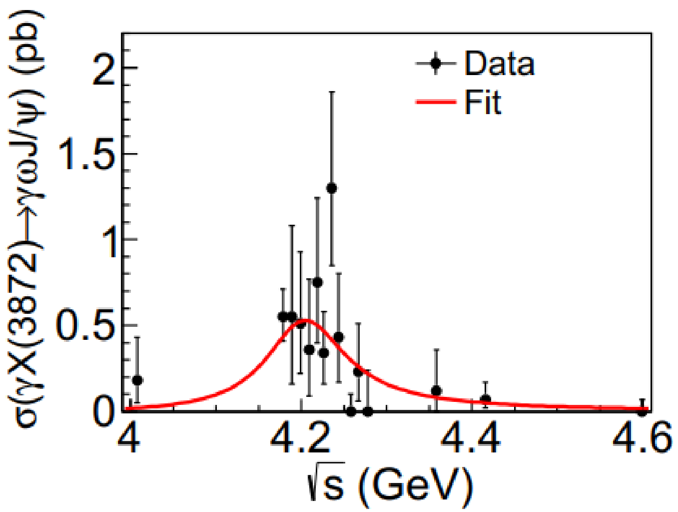
$$N_{sig}(X(3872)) = 40 \pm 8 \pm 2$$

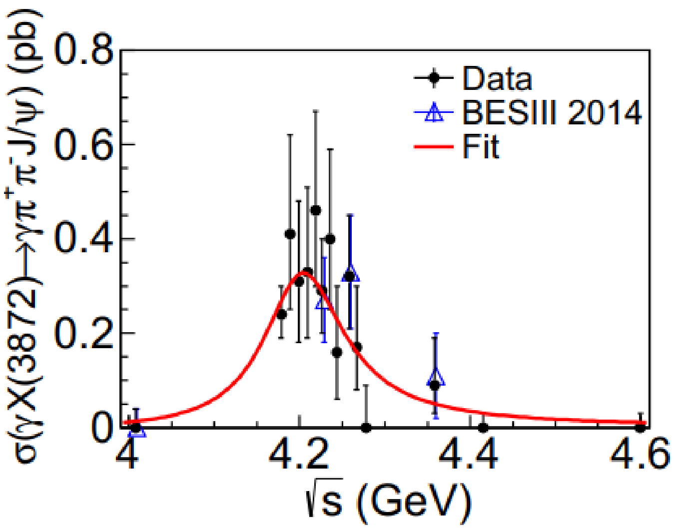
	Mass	Width
$X(3872)$	3873.3 ± 1.1 (3872.8 ± 1.2)	1.2 (1.2)
$X(3915)$	3926.4 ± 2.2 (3932.6 ± 8.7)	3.8 ± 7.5 (59.7 ± 15.5)
$X(3960)$	3963.7 ± 5.5	33.3 ± 34.2

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

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

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

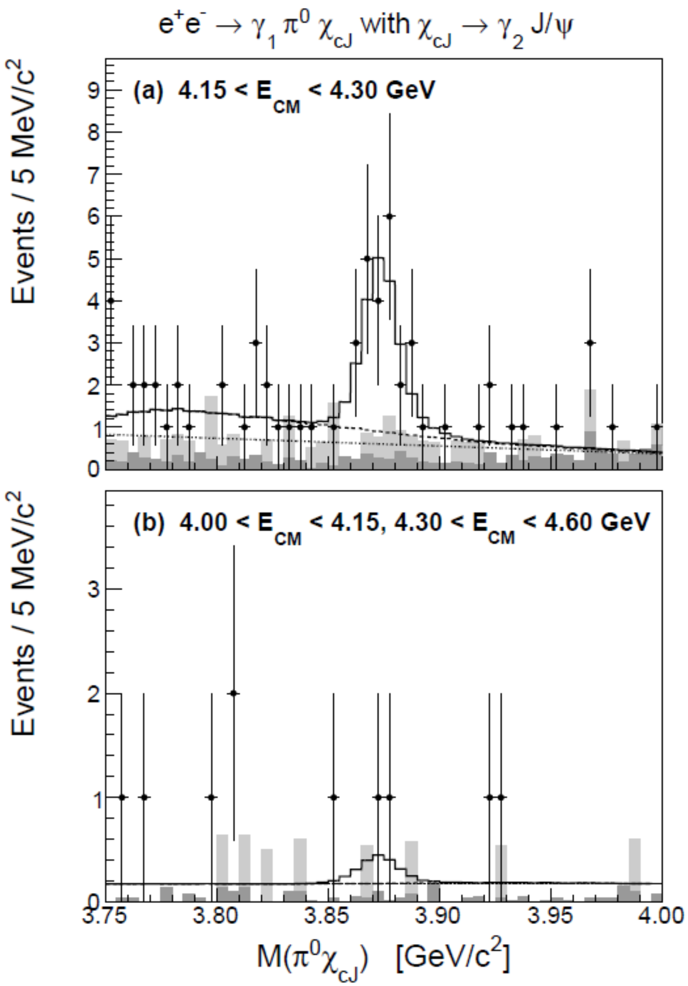
$$\mathcal{R} \equiv \frac{\mathcal{B}(X(3872)\to\omega J/\psi)}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)} = 1.6^{+0.4}_{-0.3} \pm 0.2,$$

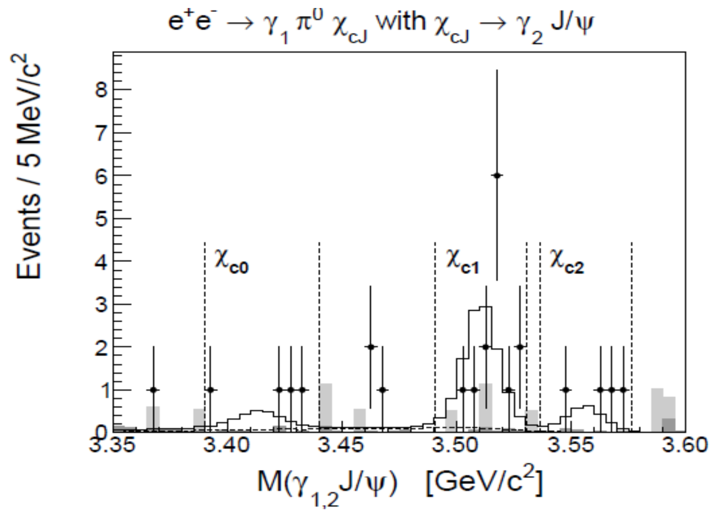
previous measurement: 0.8±0.3 from BaBar

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 $>5\sigma$

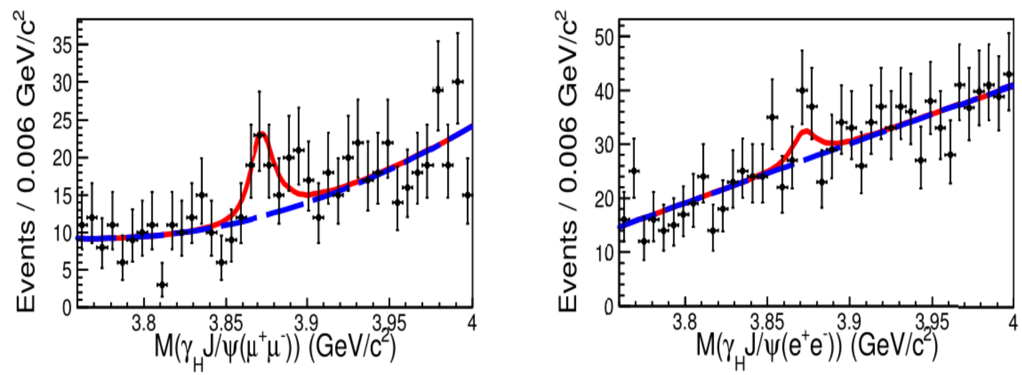
Measurements of $X(3872) \to \gamma J/\psi, \gamma\psi(3686)$

preliminary

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

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

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



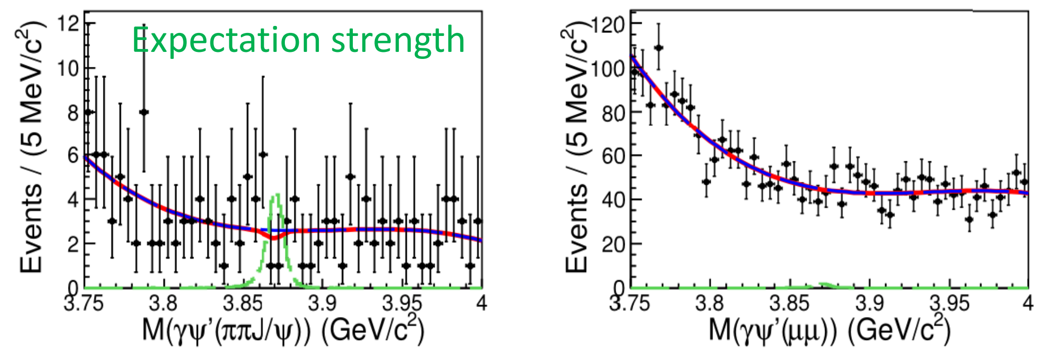
- Simultaneous fit; significance $> 3.5\sigma$

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

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

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

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



- Simultaneous fit; NO evident signal!

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

PDG average: 2.6

Measurements of $\mathrm{X(3872)} \to \mathrm{D^0\overline{D}^{*0}},\ \gamma\mathrm{D^+D^-}$

preliminary

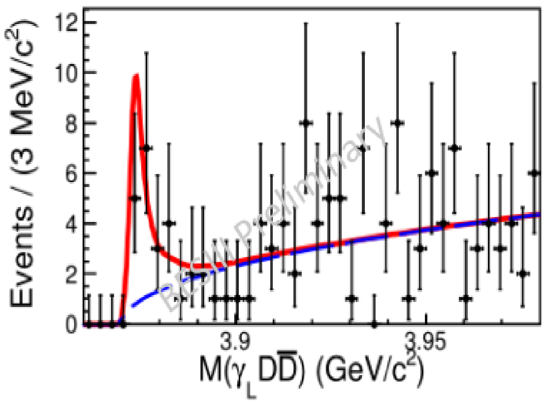
$X(3872) \to D^0\overline{D}^{*0} + c.c.$

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

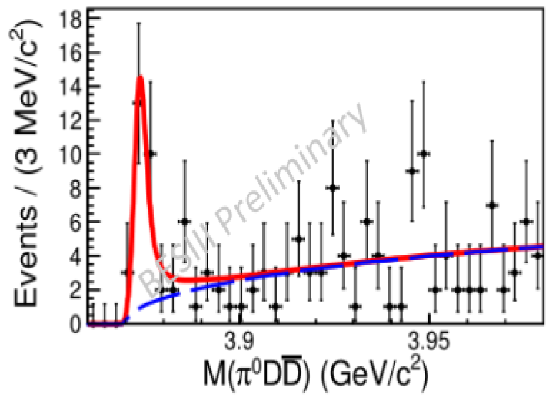
$D^0 \to K\pi, K\pi\pi, K\pi\pi\pi$

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

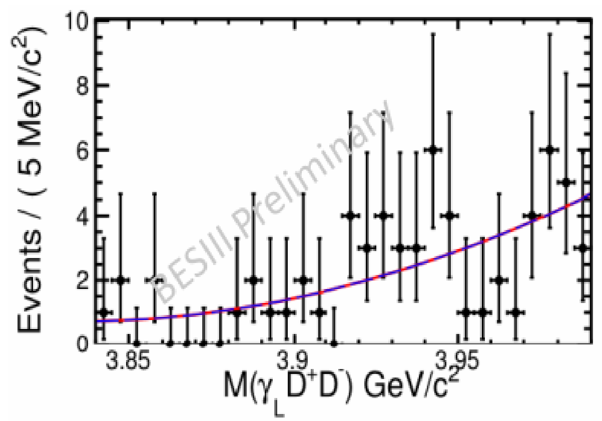
$D^{\pm} \to K\pi\pi, K\pi\pi\pi$



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



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



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

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

No evident signal for $\gamma D^+ D^-$

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

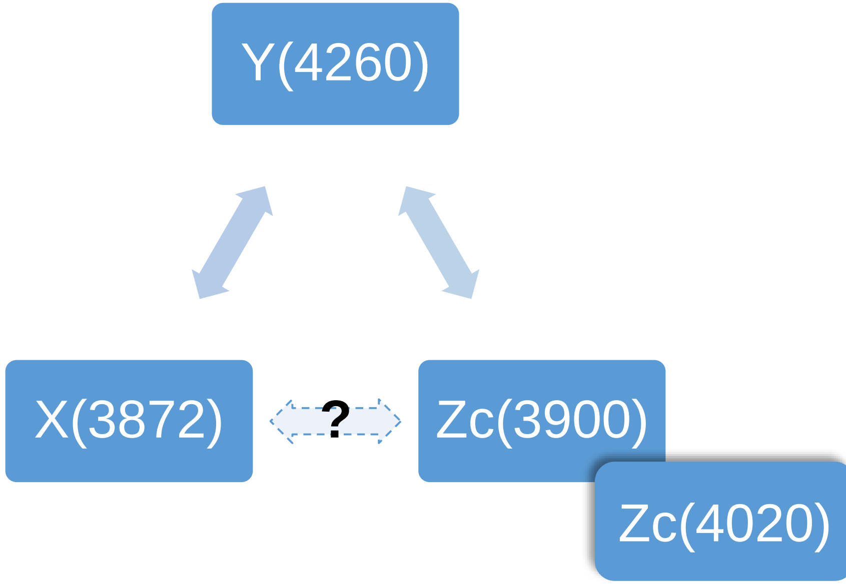
mode	$D^{*0}\bar{D}^0 + c.c.$	$\gamma J/\psi$	$\gamma\psi'$	γD^+D^-	$\omega J/\psi$	$\pi^0\chi_{c1}$
ratio	14.81 ± 3.80	0.79 ± 0.28	< 0.42	< 0.99	$1.7^{+0.4}_{-0.3} \pm 0.2$ [27]	$0.88^{+0.33}_{-0.27} \pm 0.10$ [37]

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/…

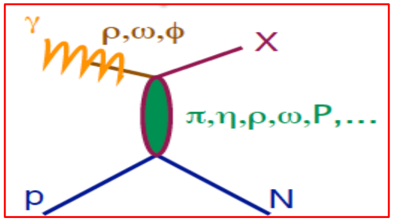
Further experimental efforts needed:

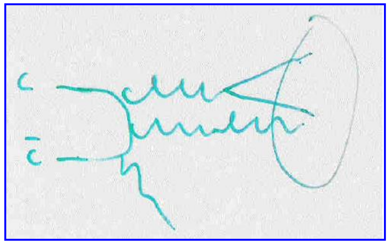
Production/Decay mechanism;

Resonance parameters (any kinematic dependency?);

Partners? …

GlueX@JLab
BESIII

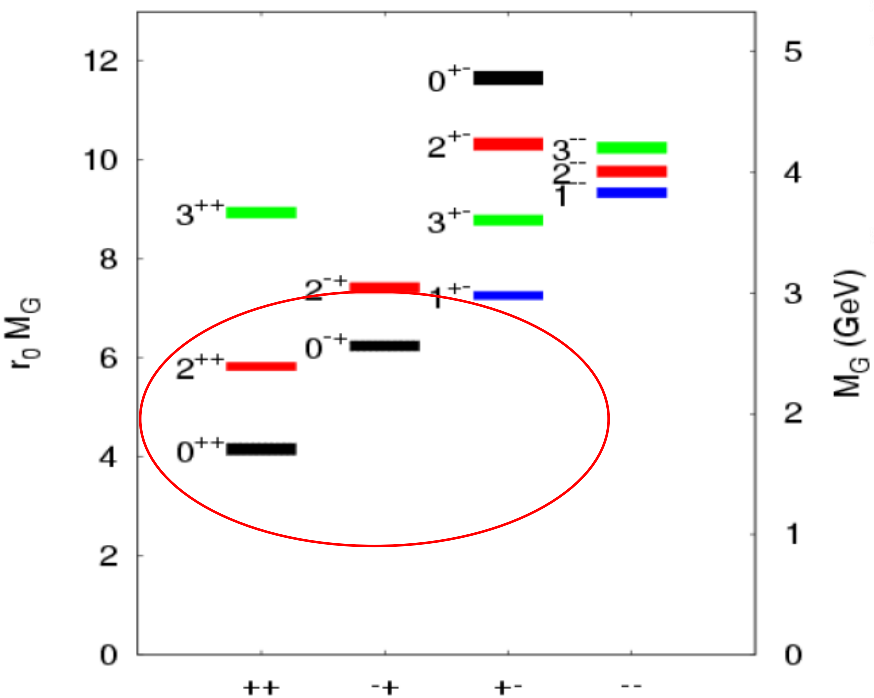




Light hadron physics

Glueball

What role do gluonic excitations play in the spectroscopy of light mesons, and can they help explain confinement?



Glueballs from Quenched LQCD

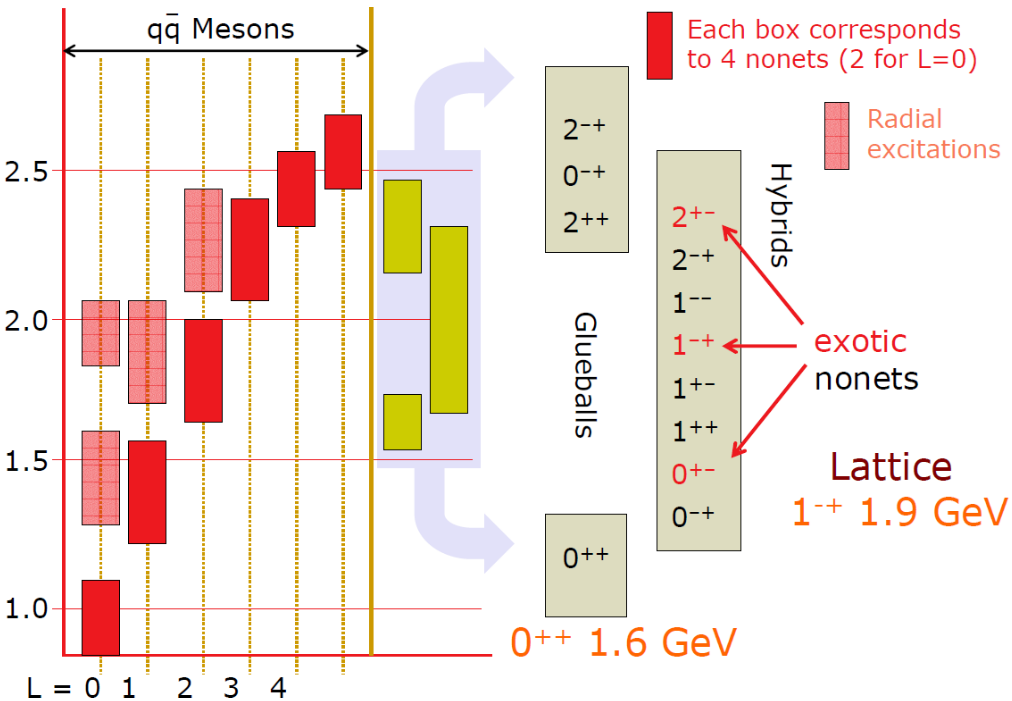
	m_π (MeV)	$m_{0^{++}}$ (MeV)	$m_{2^{++}}$ (MeV)	$m_{0^{-+}}$ (MeV)
$N_f = 2$	938	1417(30)	2363(39)	2573(55)
	650	1498(58)	2384(67)	2585(65)
$N_f = 2+1$ [22]	360	1795(60)	2620(50)	—
quenched [13]	—	1710(50)(80)	2390(30)(120)	2560(35)(120)
quenched [14]	—	1730(50)(80)	2400(25)(120)	2590(40)(130)

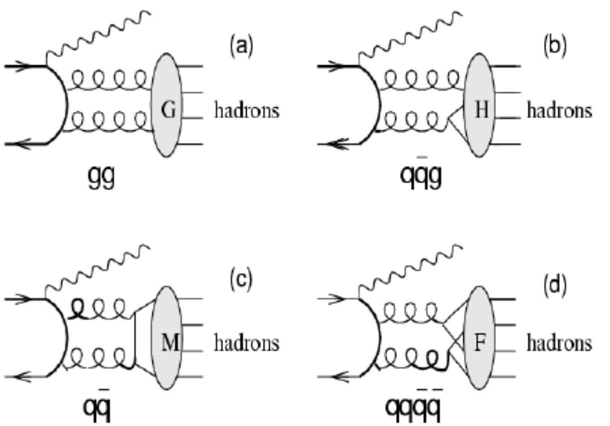
Low lying glueballs with ordinary quantum number
→mixing with qqbar mesons

Systematic studies needed

PRD60, 034509; PRD73, 014516;
PRD82, 034501; CPC 42 093103

Systematic study of glueball at BESIII





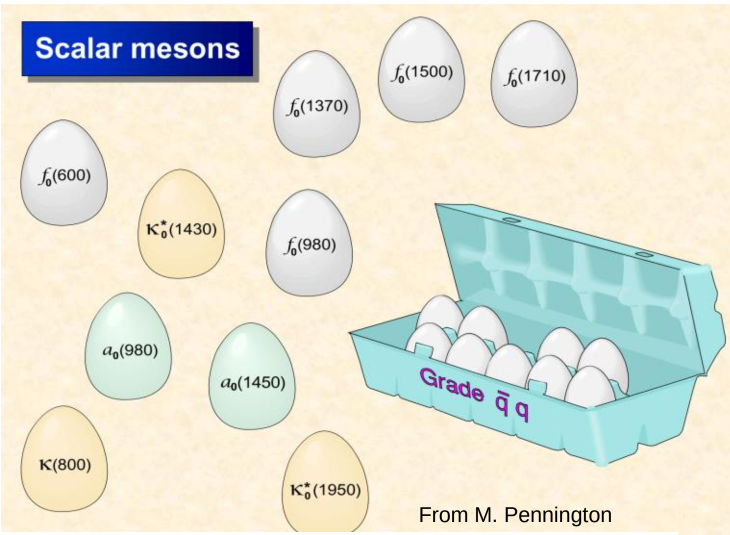
$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2), \Gamma(J/\psi \to \gamma H) \sim O(\alpha\alpha_s^3),$

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

Charmonium decays provides an ideal hunting ground for light glueballs

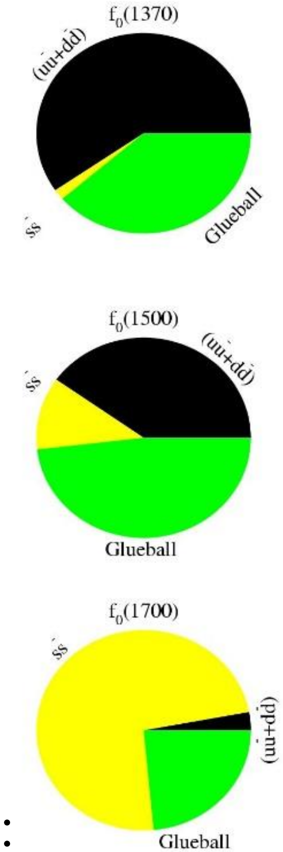
- **"Gluon-rich" process**
- **Clean high statistics data samples from e^+e^- production**
- **$I(J^{PC})$ filter in strong decays of charmonium**

Overpopulated scalar mesons



From M. Pennington

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

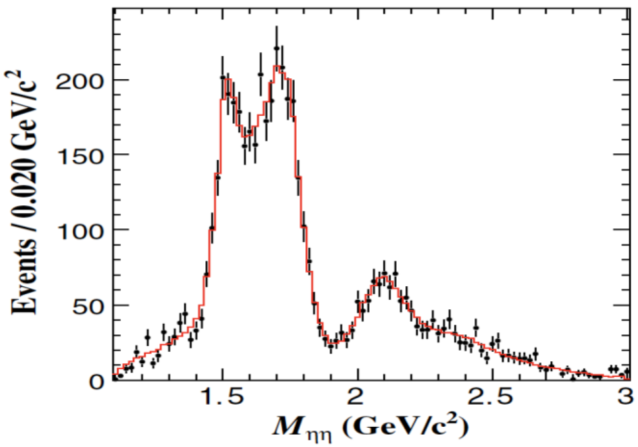


Mixing scheme：
$f_0(1500)$, $f_0(1710)$

Which one has more gluonic component?

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

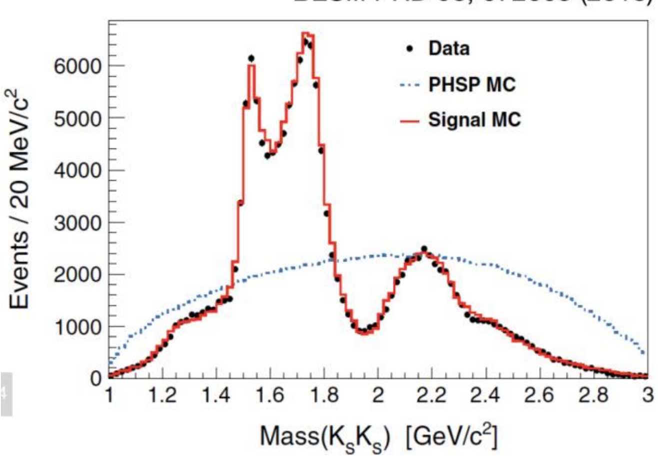
BESIII PRD 87, 092009 (2013)



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)	$M_{\rm PDG}$ (MeV/c^2)	Γ (MeV/c^2)	$\Gamma_{\rm PDG}$ (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?

$$\Gamma(J/\psi \to \gamma G_{0^+}) = \frac{4}{27}\alpha \frac{|p|}{M^2_{J/\psi}}|E_1(0)|^2 = 0.35(8)keV$$
$$\Gamma/\Gamma_{tot} = 0.33(7)/93.2 = 3.8(9)\times 10^{-3}$$

CLQCD, Phys. Rev. Lett. 110, 021601 (2013)

Experimental results

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

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

Flavor-blindness of glueball decays

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

*with chiral suppression

PRL 98 149103

$$\Gamma(G \to \pi\pi)/\Gamma(G \to K\bar{K}) \approx \frac{f_\pi^4}{f_K^4} \approx 0.48$$

$$\frac{1}{P.S.}\Gamma(G \to \pi\pi : K\bar{K} : \eta\eta) \approx 1.3 : 3.16 : 1$$

$f_0(1710)$ largely overlapped with scalar glueball?

Tensor glueball candidate?

$$\boxed{\begin{aligned}\Gamma(J/\psi \to \gamma G_{2^+}) &= 1.01(22)keV \\ \Gamma(J/\psi \to \gamma G_{2^+})/\Gamma_{tot} &= 1.1 \times 10^{-2}\end{aligned}}$$

CLQCD, Phys. Rev. Lett. 111, 091601 (2013)

Experimental results

$$\mathrm{Br}(J/\psi \to \gamma f_2(2340) \to \gamma\eta\eta) = (3.8^{+0.62}_{-0.65}{}^{+2.37}_{-2.07}) \times 10^{-5}$$

Phys.Rev. D87, 092009 (2013)

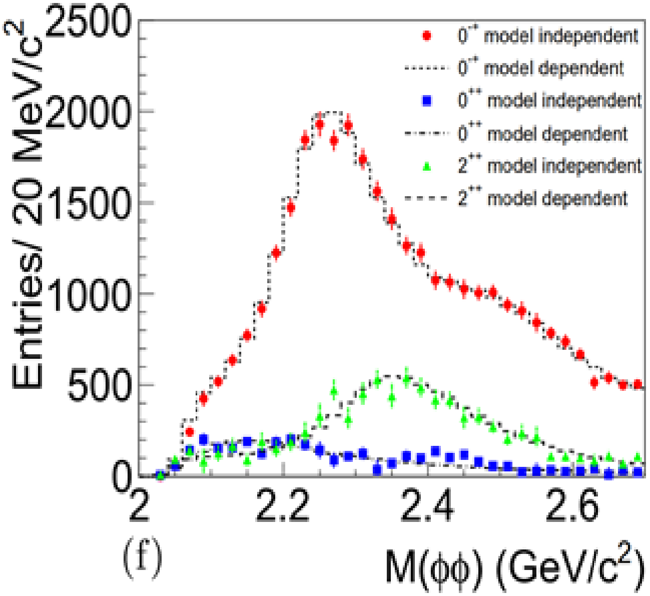
$$\mathrm{Br}(J/\psi \to f_2(2340) \to \gamma\phi\phi) = (1.91 \pm 0.14^{+0.72}_{-0.73}) \times 10^{-4}$$

Phys.Rev. D93, 112011 (2016)

$$\mathrm{Br}(J/\psi \to \gamma f_2(2340) \to \gamma K_S K_S) = (5.54^{+0.34}_{-0.40}{}^{+3.82}_{-1.49}) \times 10^{-5}$$

Phys.Rev. D98, 072003 (2018)

BESIII $J/\psi \to \gamma\phi\phi$



$f_2(2010)$, $f_2(2300)$ and $f_2(2340)$ stated in $\pi^- p$ reactions are observed with a strong production of $f_2(2340)$

It is desirable to search for more decay modes

Light meson decays

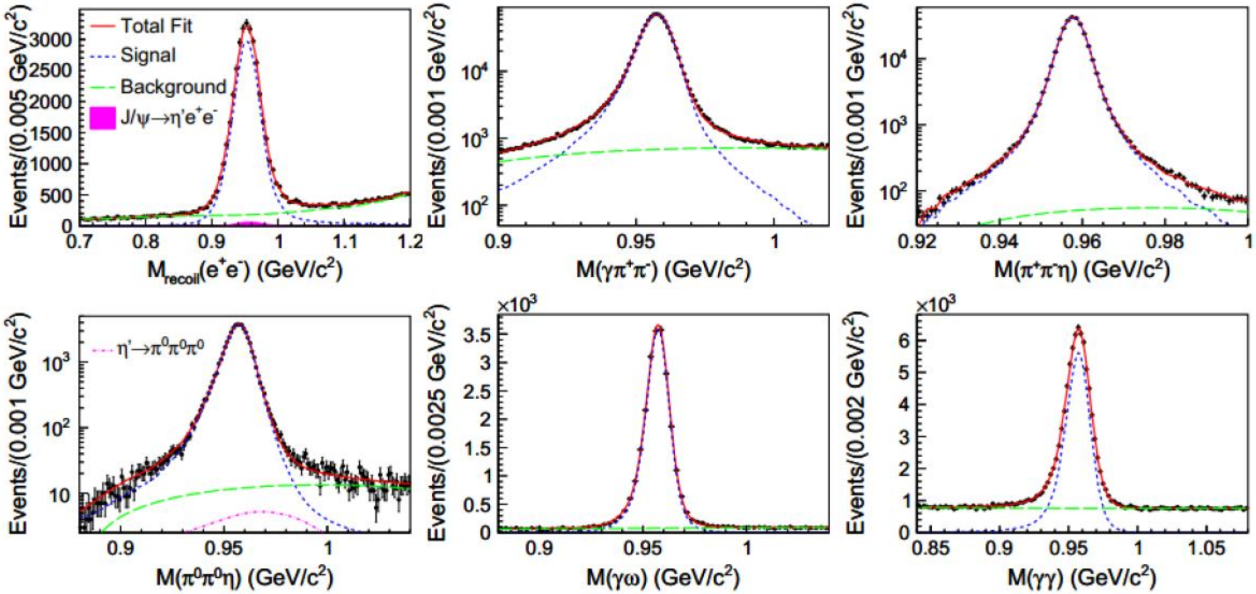
- To study light meson decays with unprecedented precision
  - BESIII: 10^{10} $J/\psi \to$ ~10^7 η , ~5×10^7 η', ~10^7 ω
- Unique place to test fundamental symmetries in QCD at low energy region
- Probe physics beyond the Standard Model (SM) ,

E.g.

$\eta/\eta' \to 2\gamma$	chiral anomaly
$\eta/\eta' \to \pi^+\pi^-\pi^0$	quark masses
$\eta' \to \gamma\pi^+\pi^-$	box anomaly
$\eta/\eta' \to \pi\pi$	CP violation
$\eta/\eta' \to \mu^+\mu^-\pi^0$,$e^+e^-\pi^0$	C violation
$\eta/\eta' \to \mu\ e$	LF violation

Precision measurement of the branching fractions of η' decays

PRL 122, 142002



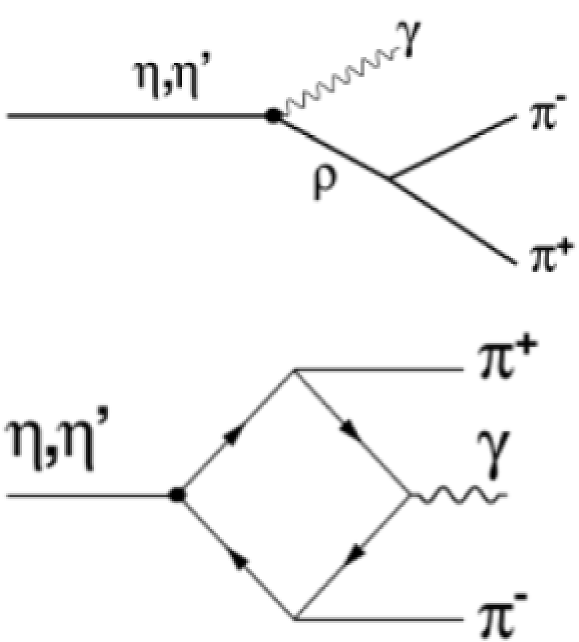
Decay Mode	$N^{\mathrm{obs}}_{\eta' \to X}$	$\varepsilon_{\eta' \to X}(\%)$	$\mathcal{B}(\eta' \to X)(\%)$	
			This measurement	PDG
$\eta' \to \gamma\pi^+\pi^-$	913106±1052	44.11	29.90±0.03±0.55	28.9±0.5
$\eta' \to \eta\pi^+\pi^-$	312275±570	27.75	41.24±0.08±1.24	42.6±0.7
$\eta' \to \eta\pi^0\pi^0$	51680±238	9.08	21.36±0.10±0.92	22.8±0.8
$\eta' \to \gamma\omega$	22749±163	14.98	2.489±0.018±0.074	2.62±0.13
$\eta' \to \gamma\gamma$	70669±349	43.79	2.331±0.012±0.035	2.22±0.08

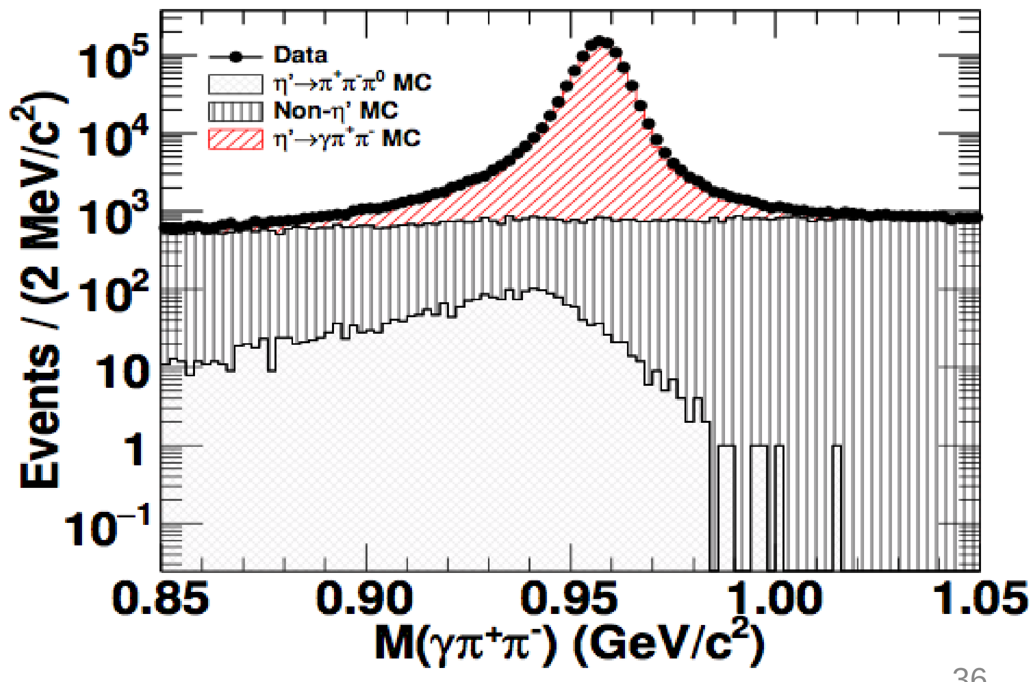
First direct measurement of absolute BF of η'

$\eta' \to \gamma\pi^+\pi^-$ decay dynamics

- high term of WZW ChPT$\to$ box anomaly
- studied by many experiments (CB, L3 …)
- no consistent picture due to limited statistics
  - ρ mass shift or not ?
  - box anomaly or not ?

~0.9M events





PRL 120,242003

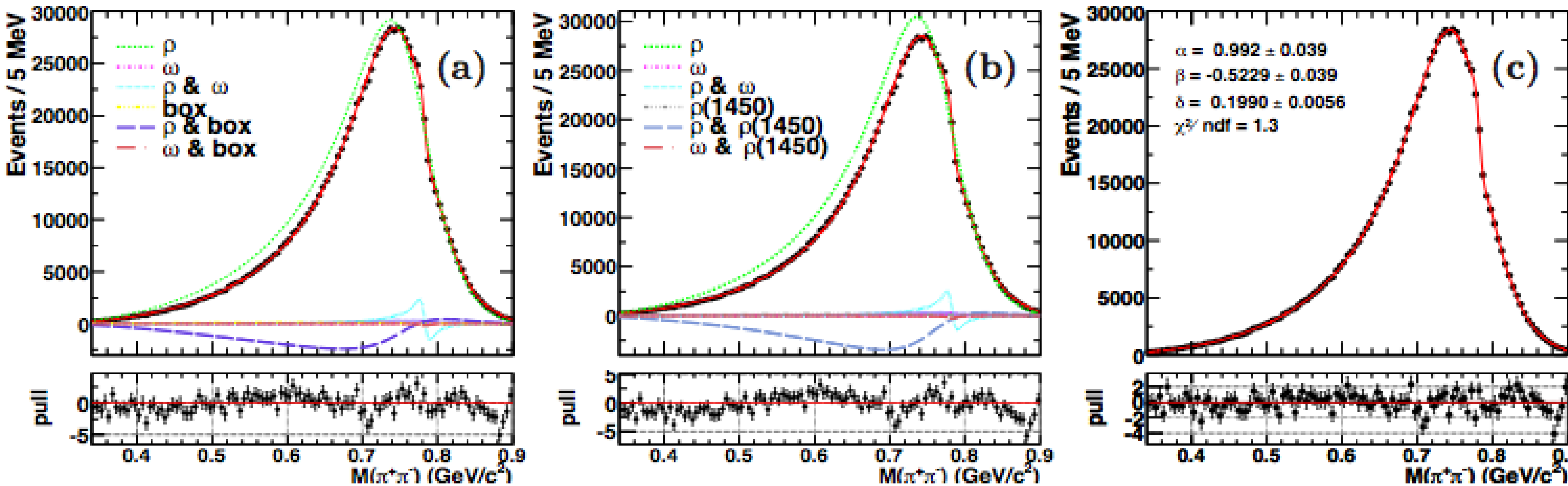
Model-(in)dependent fit

PRL 120, 242003

fit with ρ (770)-ω-box anomaly

fit with ρ (770)-ω-ρ (1450)

$P(s_{\pi\pi}) = 1 + a\, s_{\pi\pi} + b\, O(s^2_{\pi\pi}) + d\, BW_w$



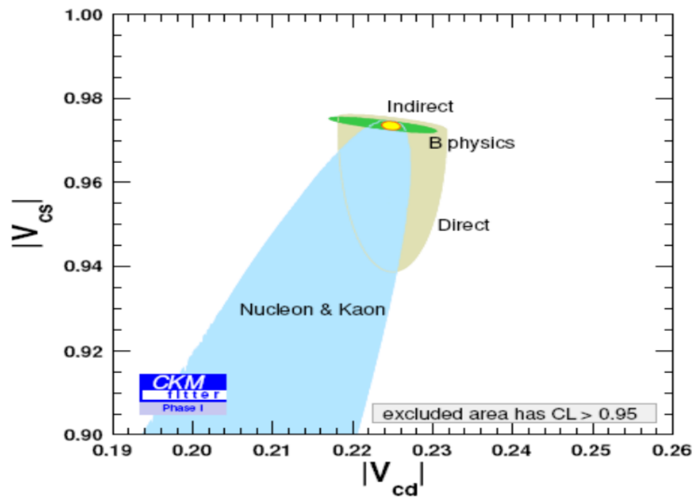
✓ ρ(770)-ω cannot describe data well

✓ Extra contribution (maybe ρ (1450) or box-anomaly) is also necessary

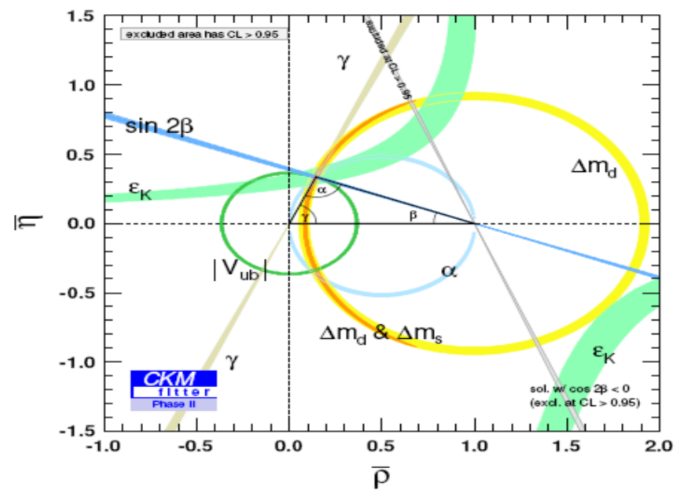
Crystal barrel: $a = (1.80 \pm 0.49 \pm 0.04)\mathrm{GeV}^{-2}$
$b = (0.04 \pm 0.36 \pm 0.03)\mathrm{GeV}^{-4}$
GAMS-2000: $a = (2.7 \pm 1.0)\mathrm{GeV}^{-2}$

* Physics Letters B 707 (2012) 184-190

- **Direct measurements of $|V_{cs}|$ and $|V_{cd}|$**

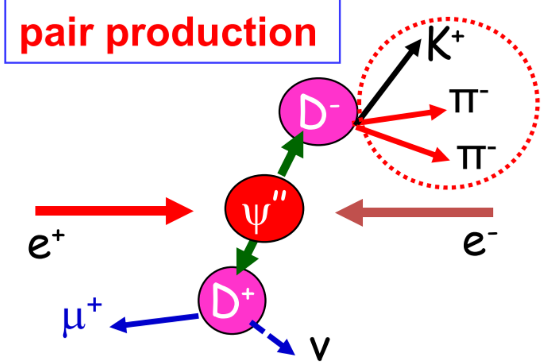


- **Indirect contribution on γ/ϕ_3**



Charm (meson) physics

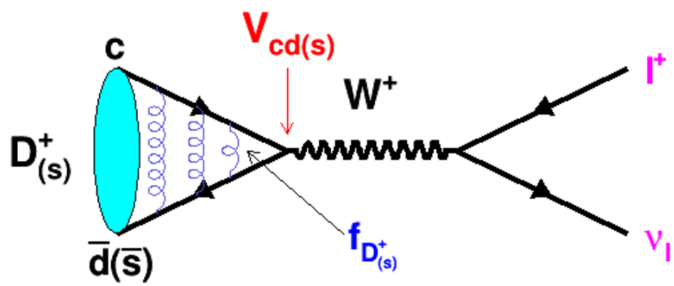
Illustration of pair production

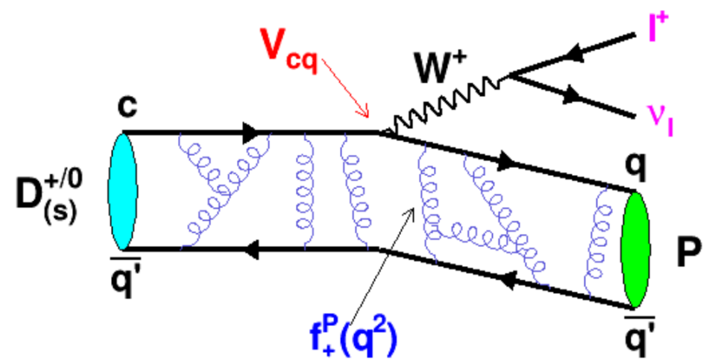


Leptonic & semileptonic decays

(Semi)leptonic D decays provide an ideal bridge to access

quark mixing element |Vcs(d)| and decay constant/form factors, which parameterizing weak and strong effects, respectively





$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f_{D^+_{(s)}}^2}{8\pi}|V_{cd(s)}|^2 m_\ell^2 m_{D^+_{(s)}}\left(1-\frac{m_\ell^2}{m_{D^+_{(s)}}^2}\right)^2$$

$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2|V_{cd(s)}|^2}{24\pi^3}p^3|f_+(q^2)|^2$$

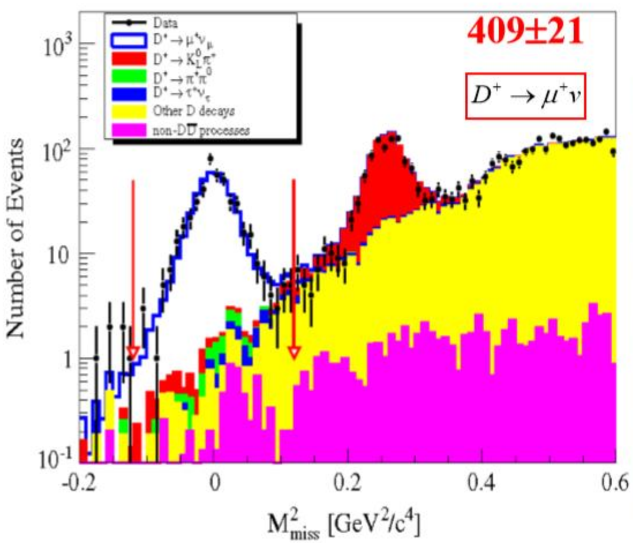
1. $|V_{cs(d)}|$: better test on CKM matrix unitarity
2. (Semi-)leptonic $D_{(s)}$ decays allow for LFU tests
3. $f_{D(s)+}$, $f_+^{K(\pi)}(0)$: test of LQCD

$$U = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$f_{D^+}|V_{cd}|$ from $D^+ \to l^+ \nu$

2.93 fb^{-1} data@ 3.773 GeV

PRD89, 051104 (2014)

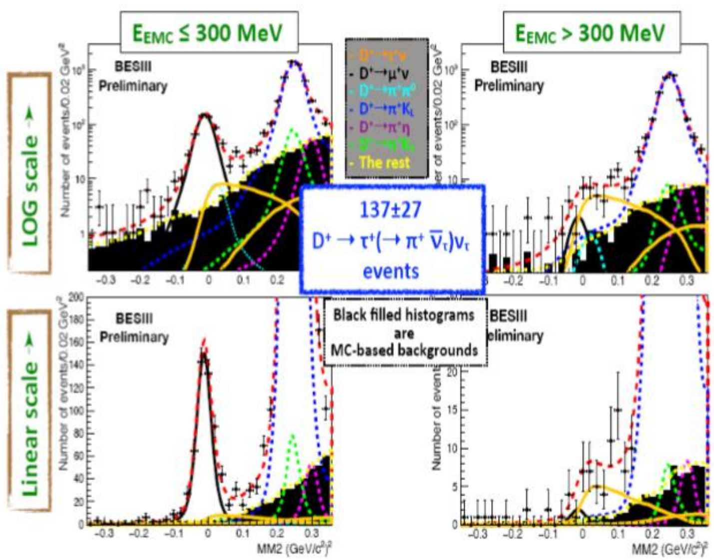


$$B[D^+ \to \mu^+ \nu] = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}$$

$$f_{D^+}|V_{cd}| = 45.75 \pm 1.20 \pm 0.39 \text{ MeV}$$

$D^+ \to \tau^+ \nu$

BESIII preliminary



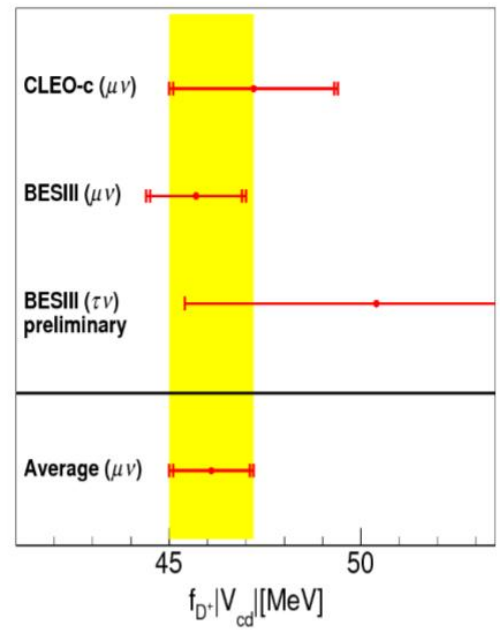
$$B[D^+ \to \tau^+ \nu] = (1.20 \pm 0.24_{stat}) \times 10^{-3}$$

$$f_{D^+}|V_{cd}| = 50.4 \pm 5.0_{stat} \text{ MeV}$$

statistical error dominant

New inputs from PDG2018:

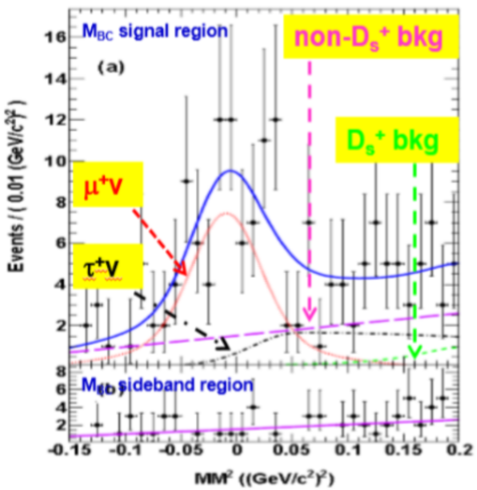
	value
m_μ	0.1056583745(24) GeV
m_τ	1.77686(12) GeV
m_{D^+}	1.86965(5) GeV
τ_{D^+}	1.040(7) ps
G_F	$1.1663787(6) \times 10^{-5}$ GeV^{-2}



$f_{D_s^+}|V_{cs}|$ from $D_s^+ \to l^+ v$

0.48 fb^{-1} data@4.01 GeV

PRD94, 072004 (2016)



$$B[D_s^+ \to \mu^+ v] = (5.17 \pm 0.75 \pm 0.21) \times 10^{-3}$$

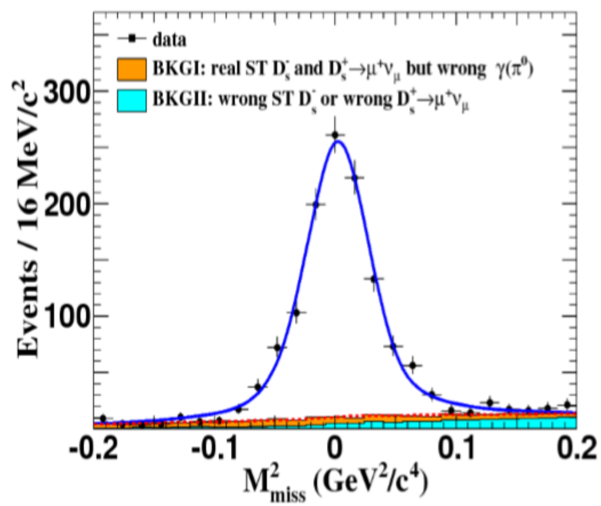
$$B[D_s^+ \to \tau^+ v] = (3.28 \pm 1.83 \pm 0.37)\%$$

$$f_{D_s^+}|V_{cs}| = 239 \pm 17 \pm 5 \text{ MeV } [\mu]$$

$$f_{D_s^+}|V_{cs}| = 193 \pm 54 \pm 11 \text{ MeV } [\tau]$$

3.19 fb^{-1} data@4.178 GeV

PRL122, 071802 (2019)

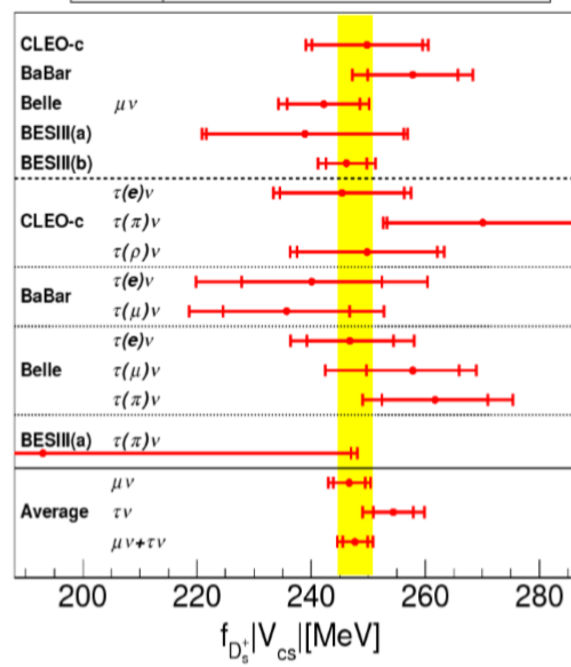


$$B[D_s^+ \to \mu^+ v] = (5.49 \pm 0.16 \pm 0.15) \times 10^{-3}$$

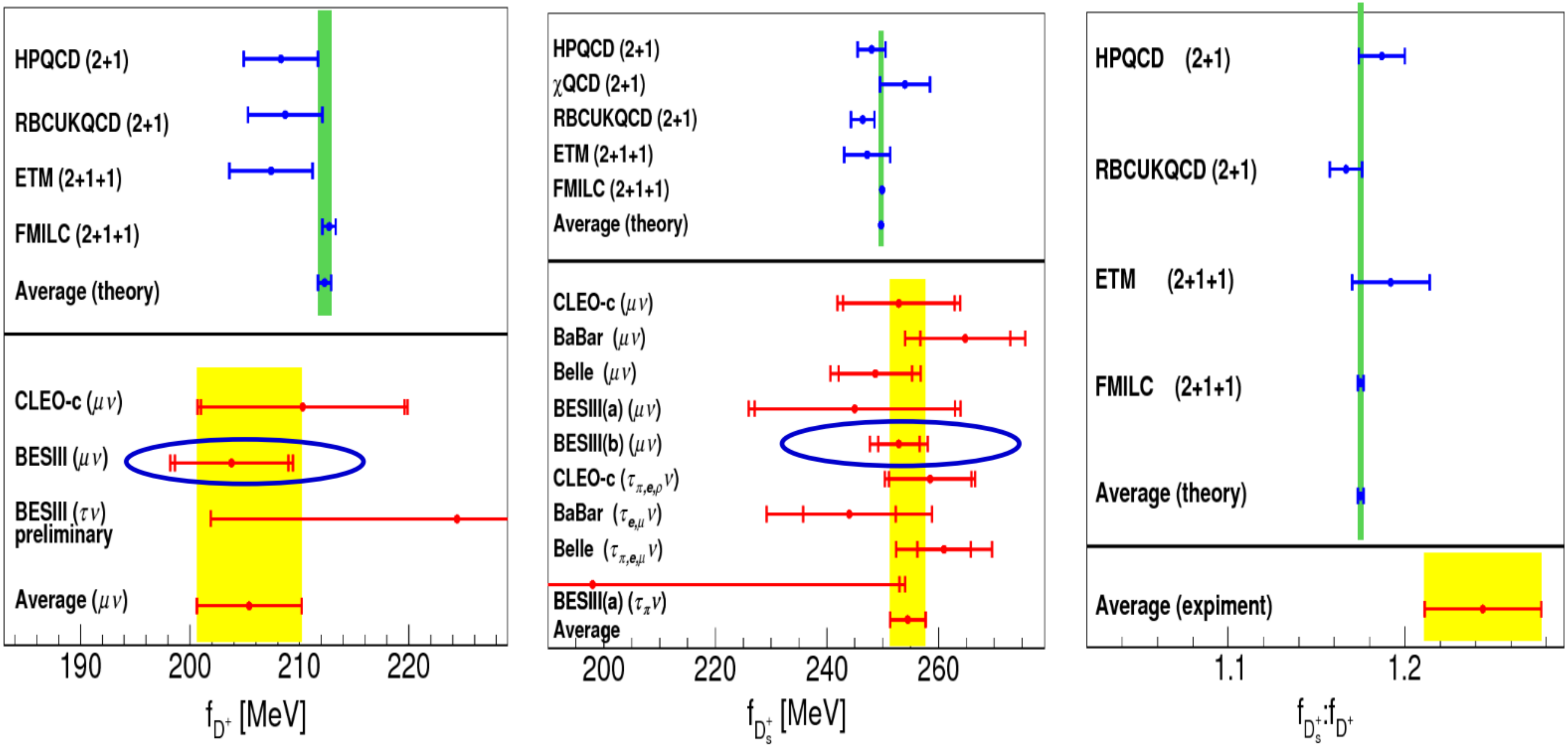
$$f_{D_s^+}|V_{cs}| = 246.2 \pm 3.6 \pm 3.5 \text{ MeV}$$

New inputs from PDG2018:

	value
m_μ	0.1056583745(24) GeV
m_τ	1.77686(12) GeV
$m_{D_s^+}$	1.96834(7) GeV
$\tau_{D_s^+}$	504(4) ps
G_F	$1.1663787(6)\times10^{-5}$ GeV^{-2}



Comparisons of f_{D+},f_{Ds+}, and f_{Ds+}:f_{D+}



- LQCD calculated f_{D+}, f_{Ds+}, f_{Ds+}:f_{D+} differ with experimental measurements by +1.5σ, -1.5σ, and -2σ

$f^K_+(0)|V_{cs}|$ from $D^0 \rightarrow K^-\mu^+\nu$

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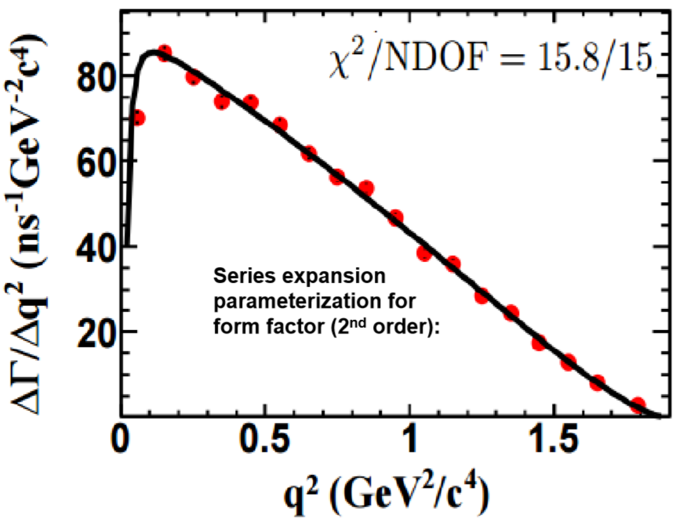
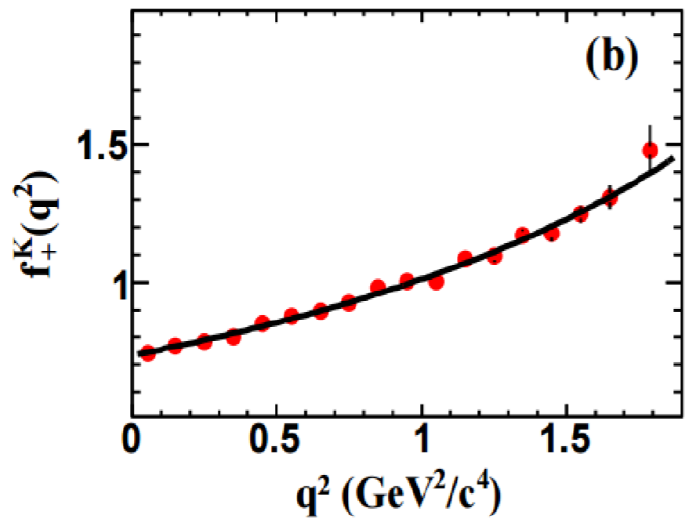
Differential partial widths

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2|V_{cs}|^2}{8\pi^3 m_D}|\vec{p}_K||f_+^K(q^2)|^2\left(\frac{W_0 - E_K}{F_0}\right)^2$$
$$\times\Big[\frac{1}{3}m_D|\vec{p}_K|^2 + \frac{m_\ell^2}{8m_D}(m_D^2 + m_K^2 + 2m_D E_K)$$
$$+ \frac{1}{3}m_\ell^2\frac{|\vec{p}_K|^2}{F_0} + \frac{1}{4}m_\ell^2\frac{m_D^2 - m_K^2}{m_D}\mathrm{Re}\left(\frac{f_-^K(q^2)}{f_+^K(q^2)}\right)$$
$$+ \frac{1}{4}m_\ell^2 F_0\left|\frac{f_-^K(q^2)}{f_+^K(q^2)}\right|^2\Big]$$

Assumed to be independent of q^2 following FOCUS's treatment (PLB607, 233 (2005))

$$q = p_\mu + p_\nu$$
$$W_0 = (m_D^2 + m_K^2 - m_\ell^2)/2m_D$$
$$F_0 = W_0 - E_K + m_\ell^2/2m_D$$





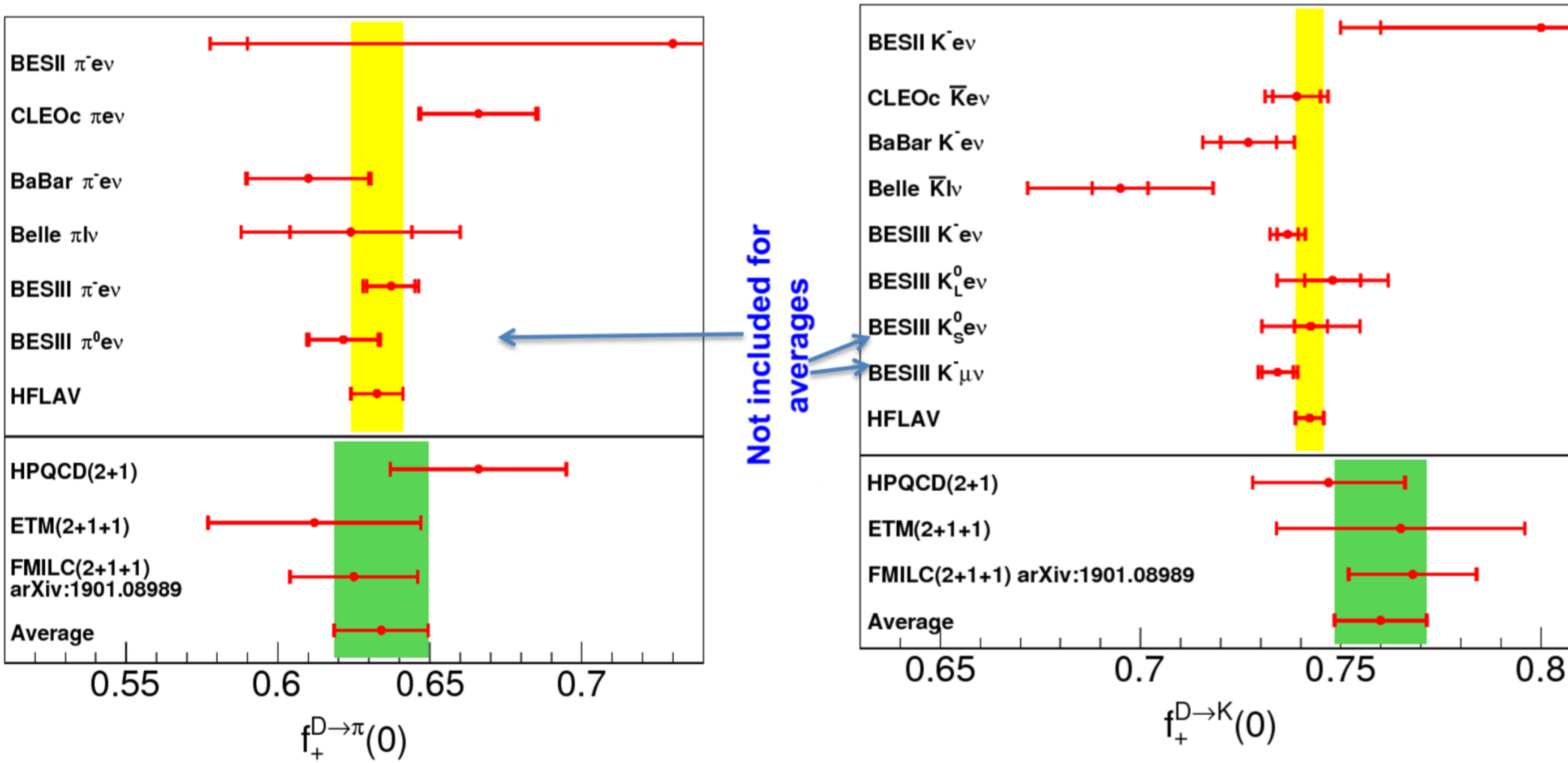
$$\boxed{f_+^K(0)\,|V_{cs}| = 0.7148(38)(29)}$$

Comparisons of form factors $f_+^{K(\pi)}(0)$

HFLAV16 averages based on a combined analysis of all D→K(π)lν measurements before 2016 using series expansion

$$f_+^K(0)\,|V_{cs}| = 0.7226(22)(26)$$

$$f_+^\pi(0)\,|V_{cd}| = 0.1426(17)(08)$$



Testing lepton universality at % level

Mode	D⁰ decay BR (%)	D⁺ decay BR (%)
$Ke\nu$	3.505±0.035	8.60±0.16
$K\mu\nu$	3.413±0.040	8.72±0.19
$\pi e\nu$	0.295±0.005	0.363±0.009
$\pi\mu\nu$	0.272±0.010	0.350±0.015

$$R_0^\pi = \frac{\Gamma(D^0 \to \pi^- \mu^+ \nu)}{\Gamma(D^0 \to \pi^- e^+ \nu)} = 0.922 \pm 0.037$$

$$R_+^\pi = \frac{\Gamma(D^+ \to \pi^0 \mu^+ \nu)}{\Gamma(D^+ \to \pi^0 e^+ \nu)} = 0.964 \pm 0.045$$

$$R_0^K = \frac{\Gamma(D^0 \to K^- \mu^+ \nu)}{\Gamma(D^0 \to K^- e^+ \nu)} = 0.974 \pm 0.014$$

$$R_+^K = \frac{\Gamma(D^+ \to \overline{K}^0 \mu^+ \nu)}{\Gamma(D^+ \to \overline{K}^0 e^+ \nu)} = 1.014 \pm 0.017$$

Theoretical expectation:

$$R^\pi = 0.985 \pm 0.002$$

$$R^K = 0.975 \pm 0.001$$

Summary

- The data with unprecedented statistical accuracy and clearly defined initial and final state properties brings BESIII great opportunities to investigate QCD exotics and precision measurement of SM
- 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 detector is in good status, inner detector upgrade in progress;
- BESIII will be running for another 5-10 years and contribute more in these fields