RUHR-UNIVERSITÄT BOCHUM

RUB

Recent Results from BESIII

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Ruhr-Universität Bochum
(on behalf of the BESIII Collaboration)

Hadron 2023
June 5-10, 2023

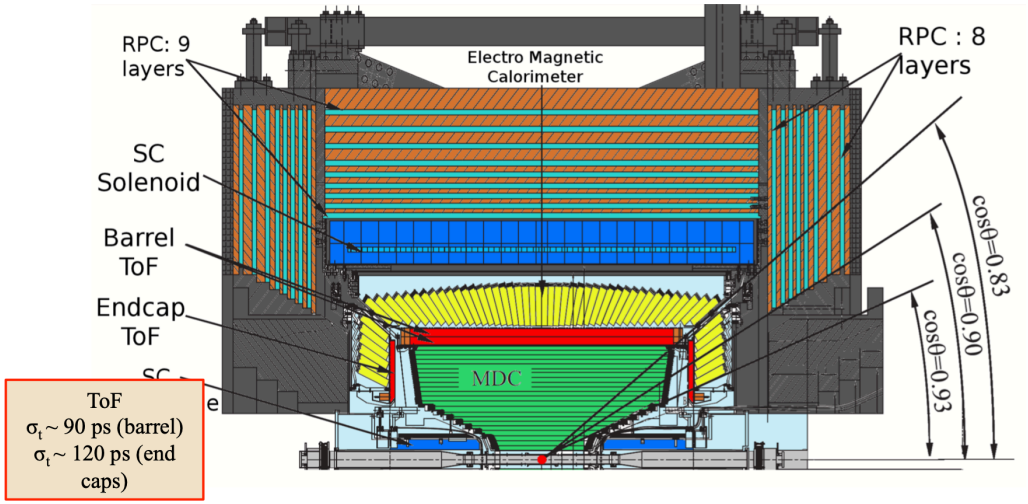
DFG

BESIII

BESIII at BEPC II

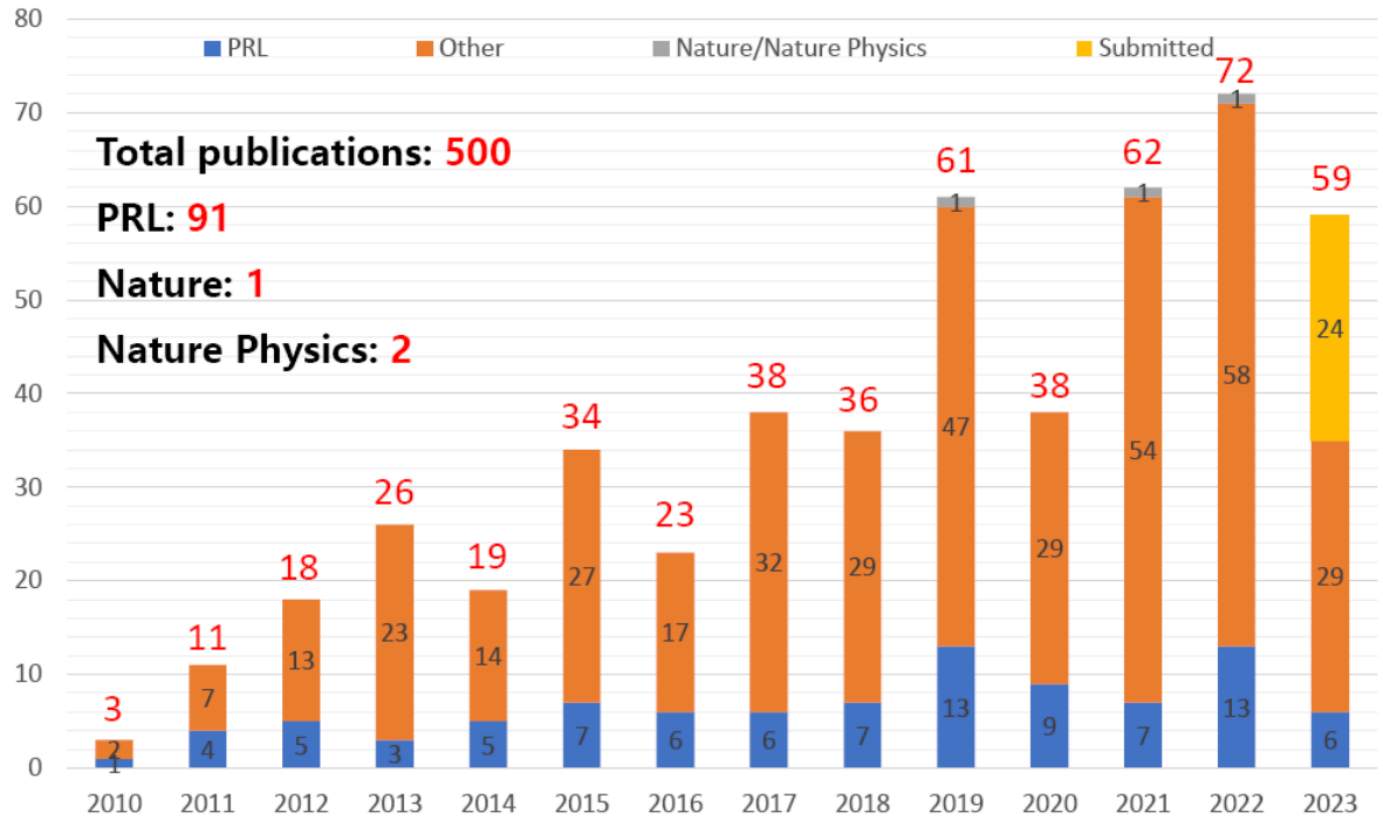
Symmetric e^+e^- collider BEPC II
$\sqrt{s}$ = 2.0 - 4.6 GeV (~5 GeV since 2019)
design luminosity achieved:
1×10^{33} cm^{-2}s^{-1} (at $\psi(3770)$)
operating since 2008

BESIII detector
- charged particle tracking
- particle identification
- electromagnetic calorimeters
- almost 4π coverage

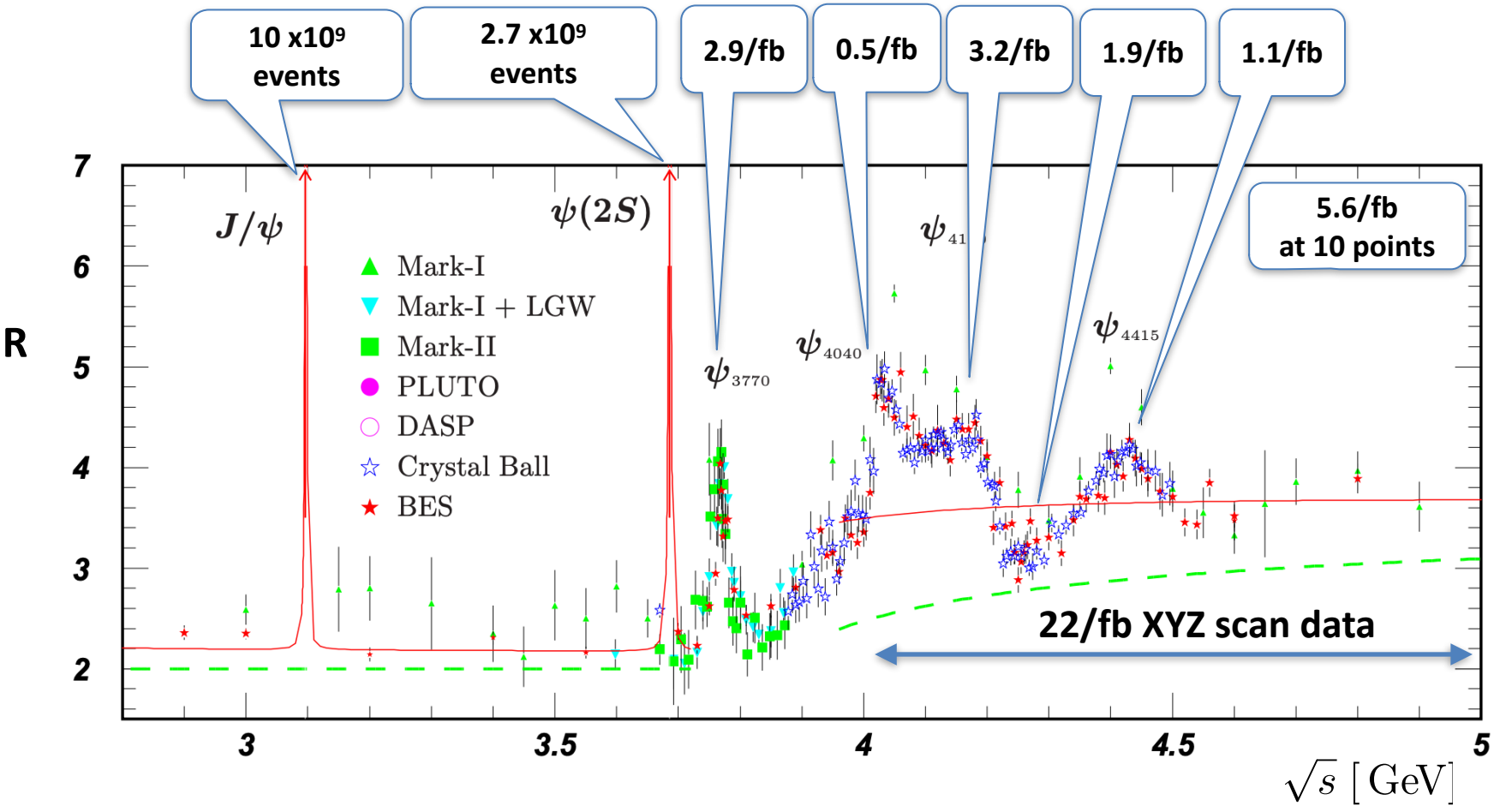


BESIII at BEPC II

BESIII publications (May 9, 2023)

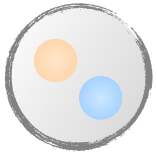


Data Samples



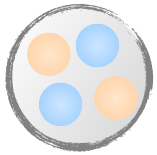
Exotic Hadrons

Conventional mesons ($q\bar{q}$)

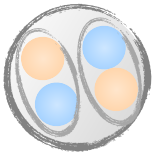


Exotic hadrons: other color-neutral configurations

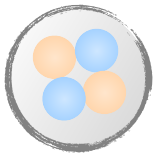
multi-quarks ($qq\bar{q}\bar{q}$)



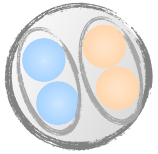
molecules $[q\bar{q}][q\bar{q}]$



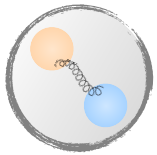
compact tetraquarks $q\bar{q}q\bar{q}$



diquark-antidiquarks



hybrids ($q\bar{q}g$)



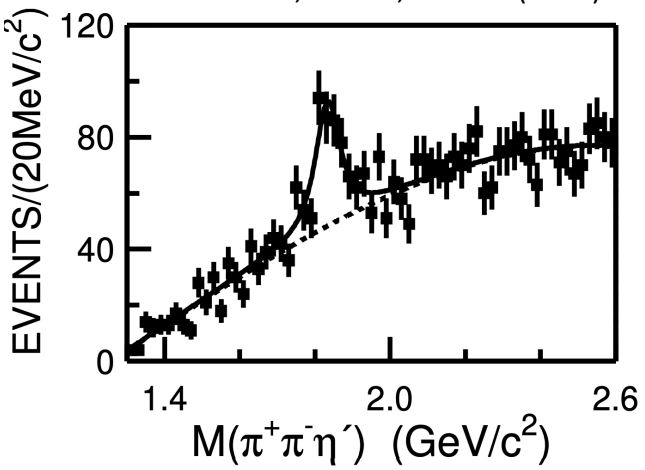
glueballs (gg, ggg)

gluonic degrees of freedom

$J/\psi \to \gamma\pi^+\pi^-\eta'$

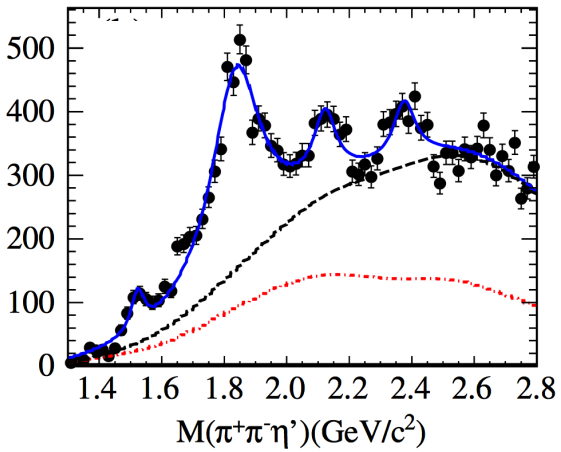
58M J/ψ events

BES, PRL 95, 262001 (2005)



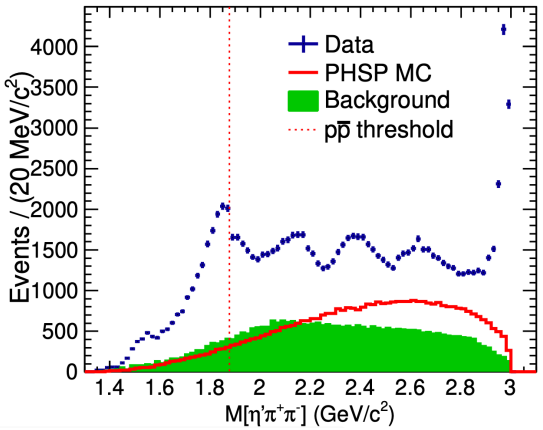
225M J/ψ events

BESIII, PRL 106, 072002 (2011)



1090M J/ψ events

BESIII, PRL 117, 042002 (2016)



Structure at or close to the pp̄ threshold: *X*(1835)
Lineshape parameterization: Flatte or two interfering Breit-Wigner

Additional structures with increasing statistics: *X*(2120), *X*(2370) and ….

$J/\psi \to \gamma\pi^+\pi^-\eta'$

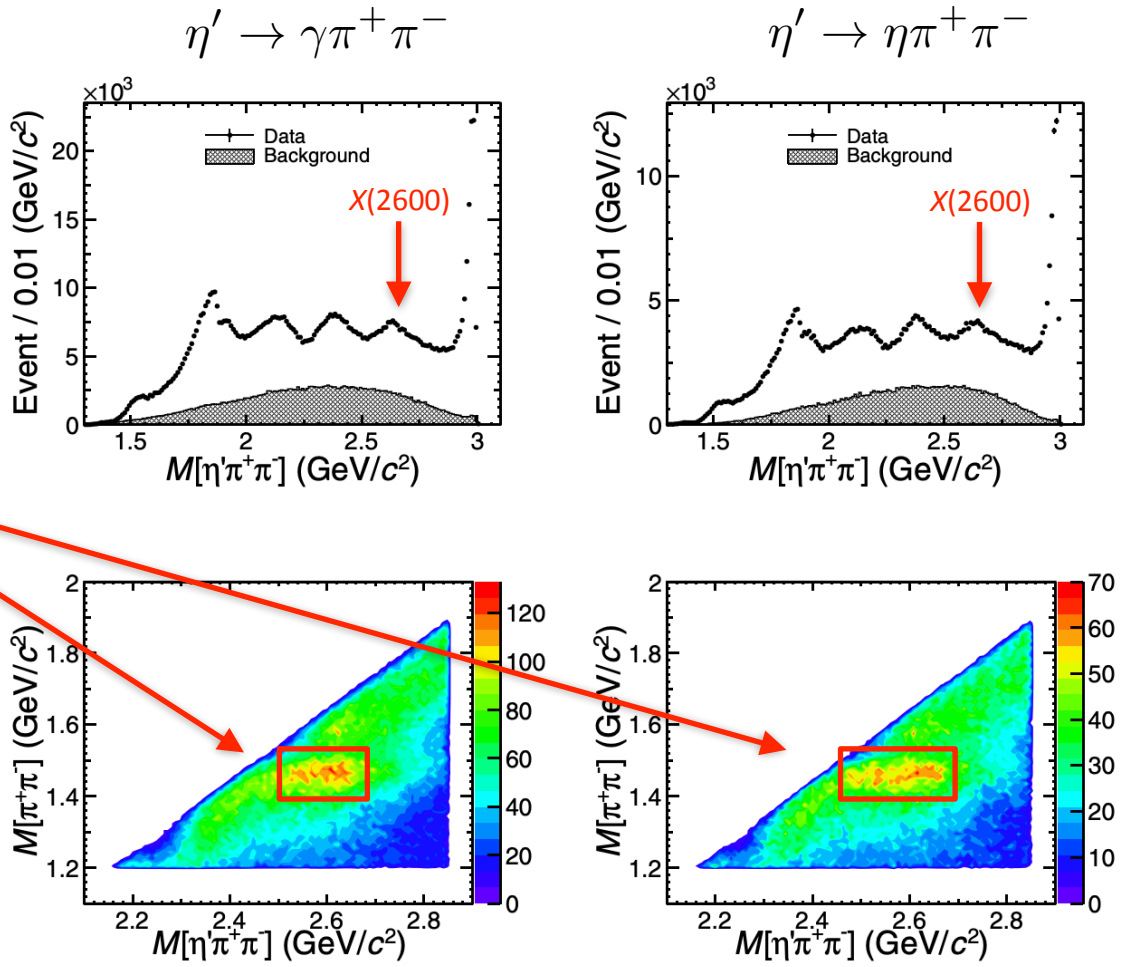
BESIII, PRL 129, 042001 (2022)

10087M J/ψ events

Confirmation of *X*(1835), *X*(2120) and *X*(2370)

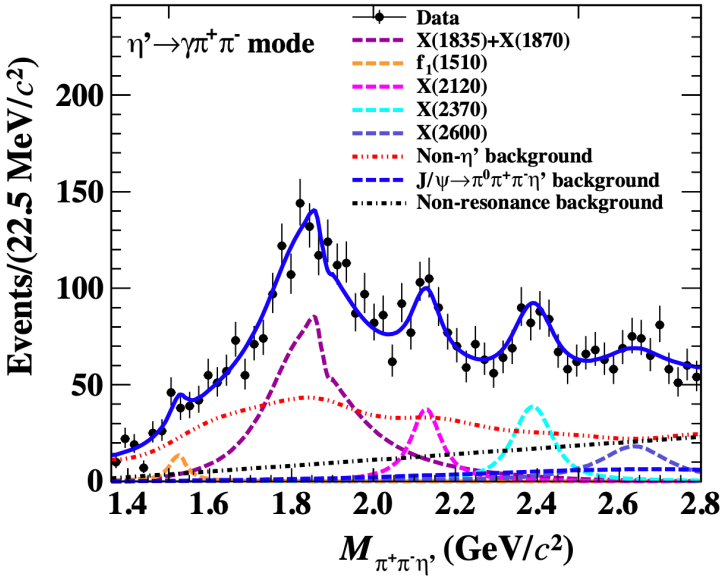
New structure *X*(2600)
C=+1, J^P unknown

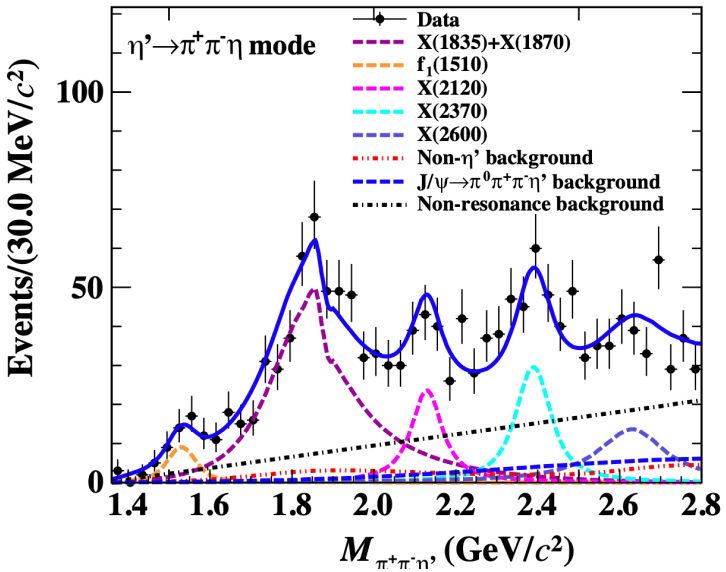
connected to a complex structure in the $\pi\pi$ system around 1500 MeV



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

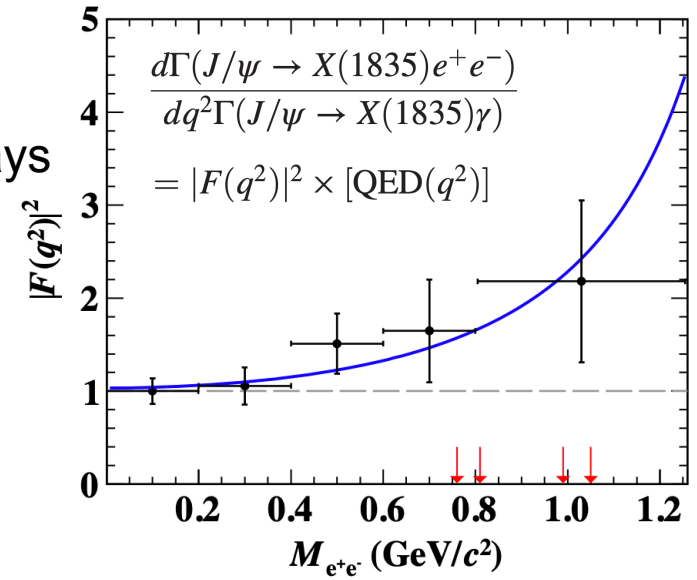
BESIII, PRL 129, 022002 (2022)





Confirmation of *X*(1835), *X*(2120) and *X*(2370) previously seen in rad. J/ψ decays

Access em. J/ψ -*X*(1835) transition form factor can provide additional information on structure of *X*(1835)



X(1835)

Seen at BESIII in

$J/\psi \to \gamma\pi^+\pi^-\eta'$ — BESIII, PRL 129, 042001 (2022)

$J/\psi \to \gamma 3(\pi^+\pi^-)$ — BESIII, PRD 88, 091502(R) (2013)

$J/\psi \to \gamma\eta K_S^0 K_S^0$ — BESIII, PRL 115, 091803 (2015)

$J/\psi \to \gamma\gamma\phi$ — BESIII, PRD 97, 051101(R) (2018)

$J/\psi \to e^+e^-\eta'\pi^+\pi^-$ — BESIII, PRL 129, 022002 (2022)

suggests ss̄ component, excited η' ?

Connected to the structure seen in $J/\psi \to \gamma p\bar{p}$ at pp̄ threshold?

One or two states at threshold (lineshape study)

Further studies ongoing

Exotic Gluonic Hadrons

LQCD: spectrum of glueballs and hybrids

Glueballs

$f_0(1500)$, $f_0(1710)$: mixed glueball-$q\bar{q}$ candidates

also 0^{-+} and 2^{++} candidates observed

mixing with $q\bar{q}$ complicates clear identification

Hybrids

lightest spin-exotic: 1^{-+} around 2 GeV/c^2

1^{-+} isovectors: $\pi_1(1400)$ and $\pi_1(1600)$

recently described with 1 pole in $\pi\eta$ and $\pi\eta'$

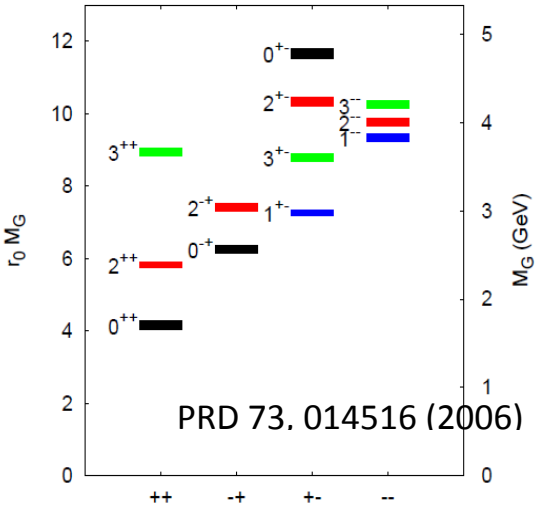
R. Rodas et al. (JPAC), PRL 122, 042002 (2019) [Compass data]

B. Kopf et al, EPJC81, 1056 (2021) [Crystal Barrel, Compass, $\pi\pi$ scat. data]

Production is linked to gluon-rich processes,

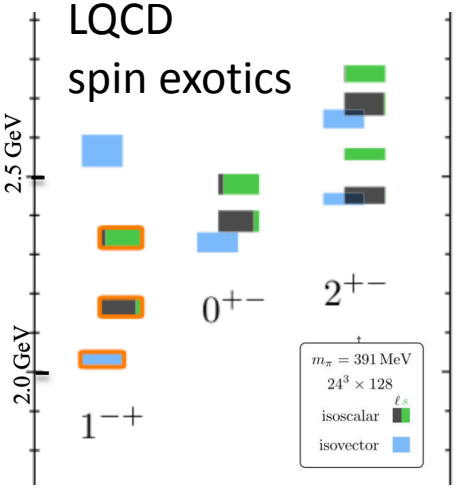
e.g. radiative J/ψ decays

LQCD Glueball Spectrum



PRD 73. 014516 (2006)

LQCD
spin exotics



PRD 88, 094505 (2013)

Spin-exotic isoscalar

BESIII, PRL 129, 19, 192002 (2022)
BESIII, PRD 106, 7, 072012 (2022)

PWA of $J/\psi \to \gamma\eta\eta'$

15k selected events, background level ~11%

veto $\phi \to \gamma\eta$

best fit with 11 components:

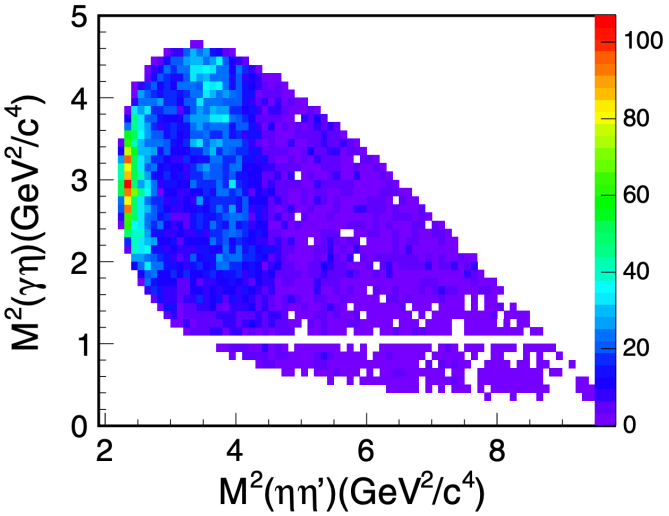
5 components 0^{++} $\eta\eta'$

2 components 2^{++} $\eta\eta'$

1 component 4^{++} $\eta\eta'$

2 components 1^{+-} $\gamma\eta$

1 significant (>19σ) component 1^{-+} $\eta\eta'$



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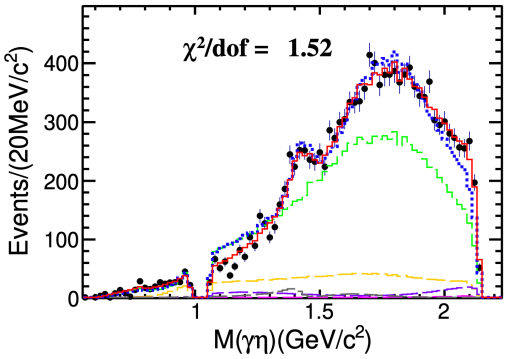
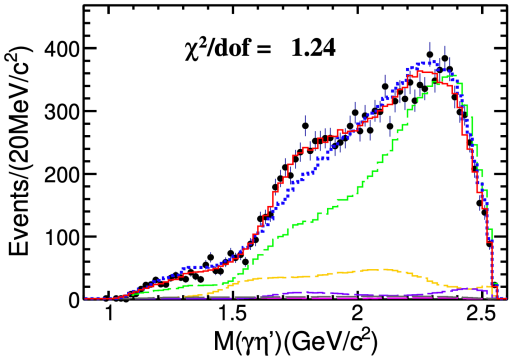
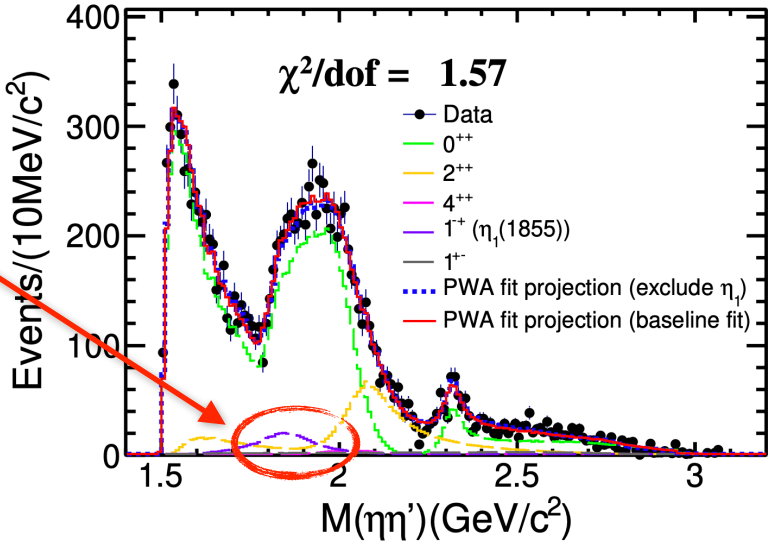




$\eta_1(1855)$ $J^{PC} = 1^{-+}$

$m = 1855 \pm 9^{+6}_{-1}\,\mathrm{MeV}$

$\Gamma = 188 \pm 18^{+3}_{-8}\,\mathrm{MeV}$



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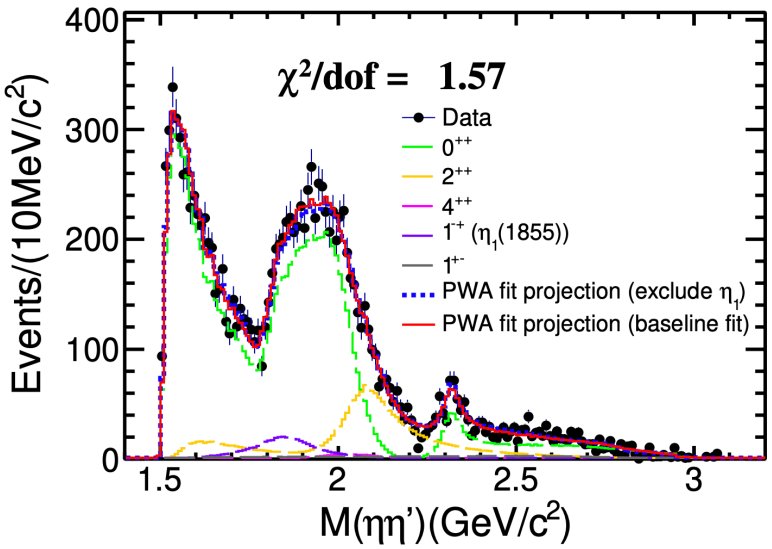
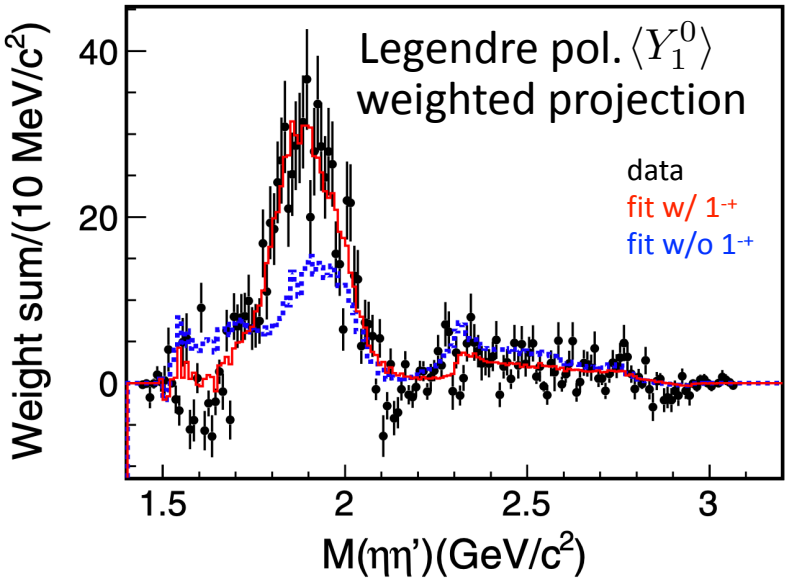
isoscalar partner of $\pi_1(1400)$/ $\pi_1(1600)$?





PWA of $J/\psi \to \gamma\eta'\eta'$

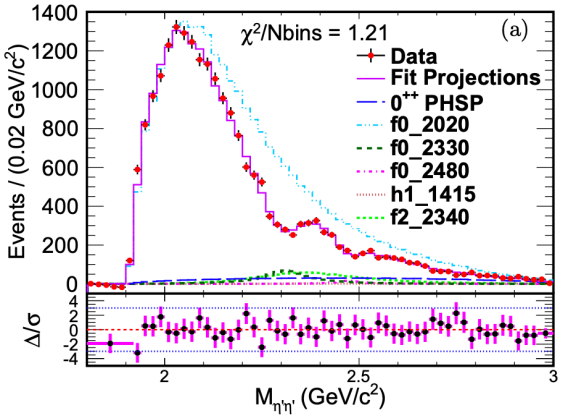
BESIII, PRD 105, 072002 (2022)

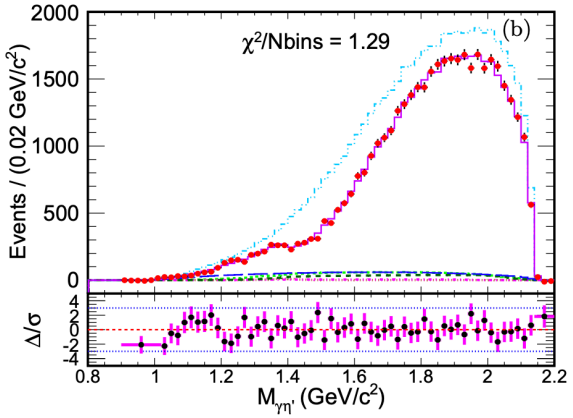
PWA of $J/\psi \to \gamma\eta'\eta'$

about 23k selected events

best fit with 6 components:

- 4 components 0^{++} $\eta'\eta'$
- 1 component 2^{++} $\eta'\eta'$
- 1 component 1^{+-} $\gamma\eta'$





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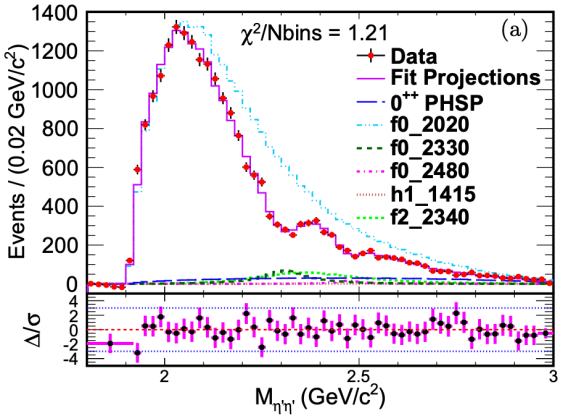
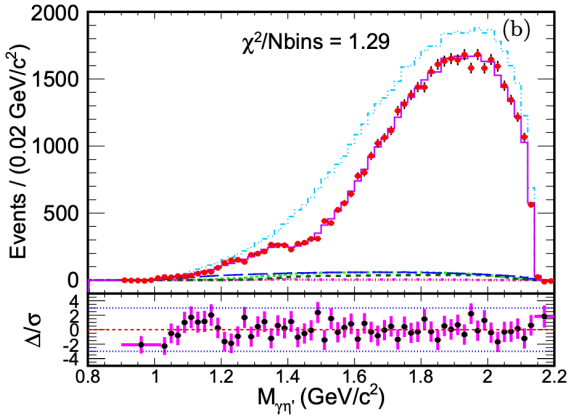




new $f_0(2480) \to \eta'\eta'$ [5.2σ]

$m = 2470 \pm 4^{+4}_{-6}\,\mathrm{MeV}/c^2$

$\Gamma = 75 \pm 9^{+11}_{-8}\,\mathrm{MeV}$

$f_0(2020)$, $f_0(2330)$, $f_2(2340)$ seen in $\eta'\eta'$ for the first time

$f_0(2020)$ also seen in coupled channel analyses including BESIII data for $J/\psi \to \gamma\pi^0\pi^0, \gamma K^0_S K^0_S$

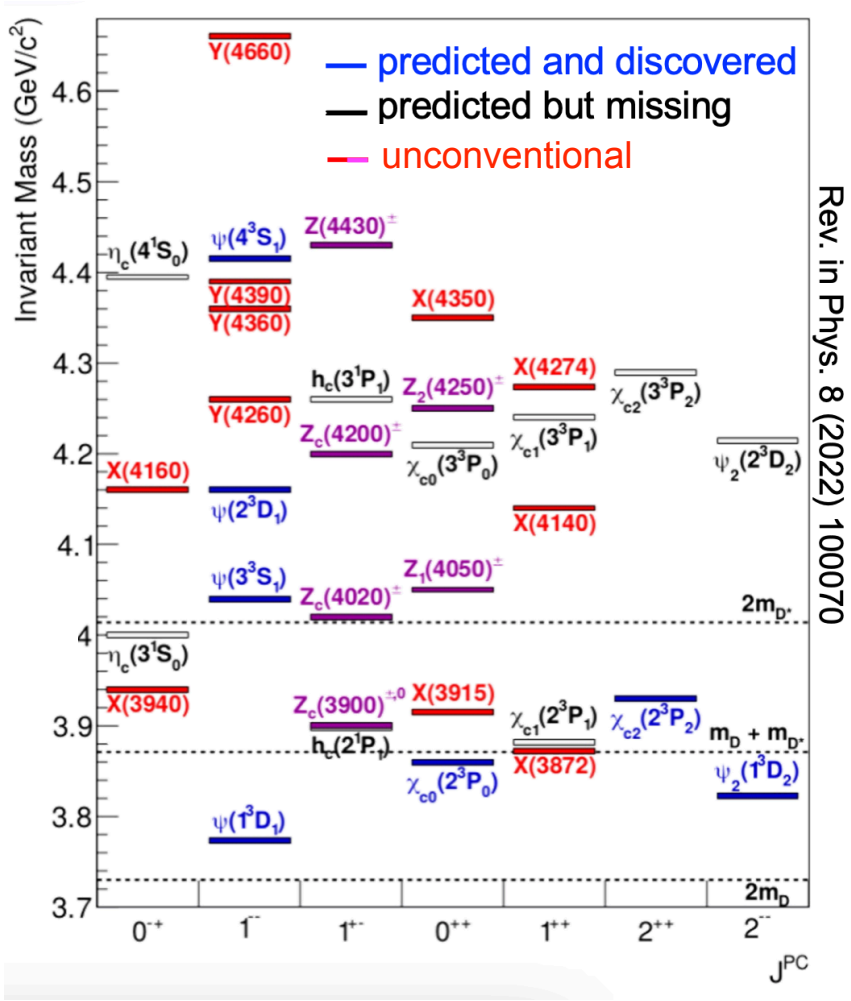
A. Rodas et al. (JPAC), EPJ C82, 80 (2022)

A. V. Sarantsev et al., PLB 816, 136227 (2021)

Charmonium-(like) States

- Spectrum of lower charmonium states well described by potential models
- Few broad vector states above the open charm threshold known by 2003

- Since then, states with unexpected properties observed



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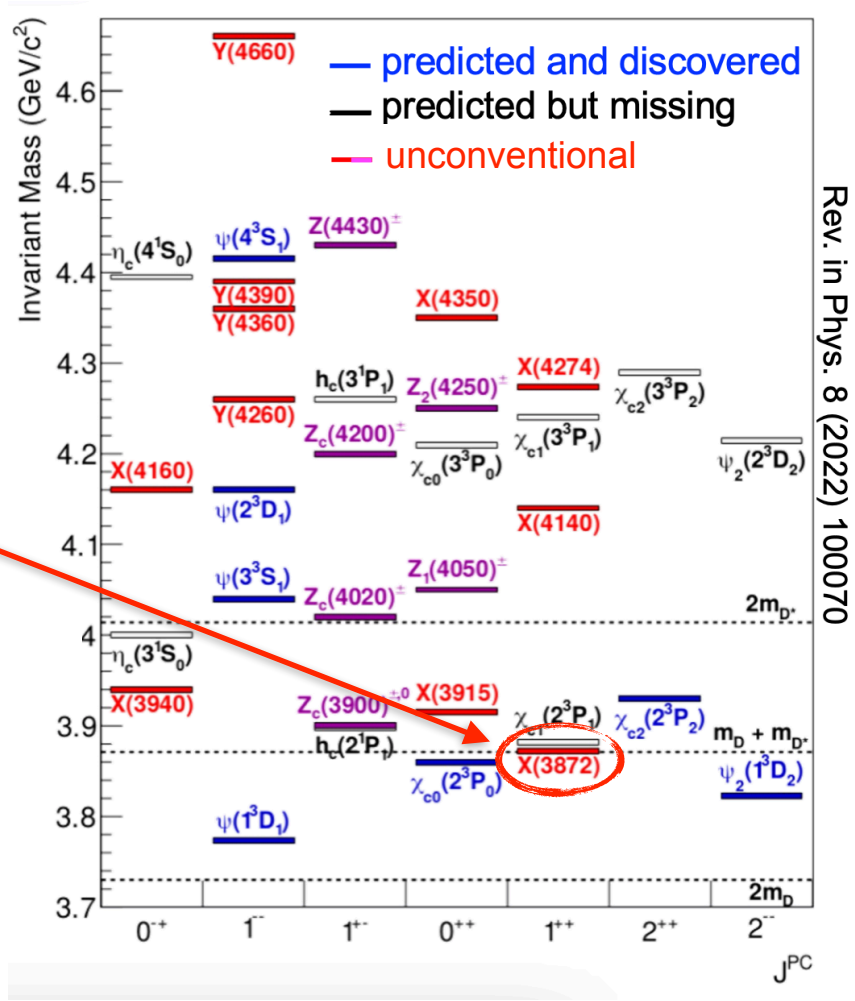
  - *Y*: new vector states
  - *Z*: charged (+neutral) multiquark candidates



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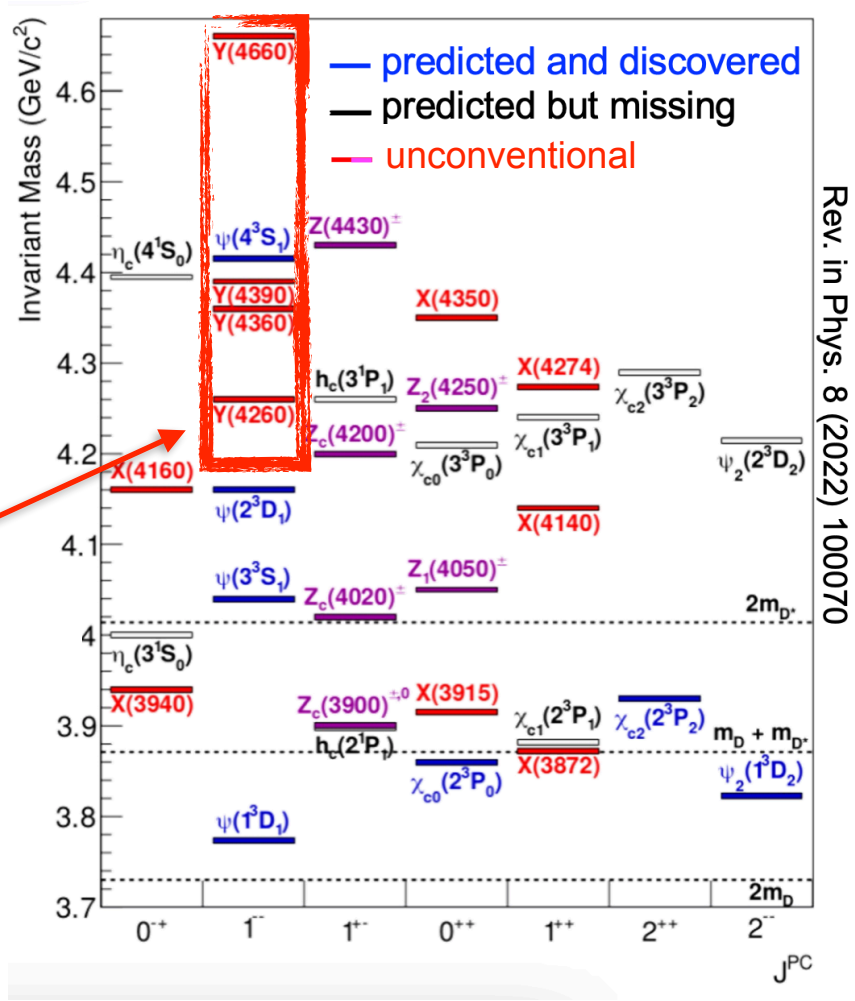

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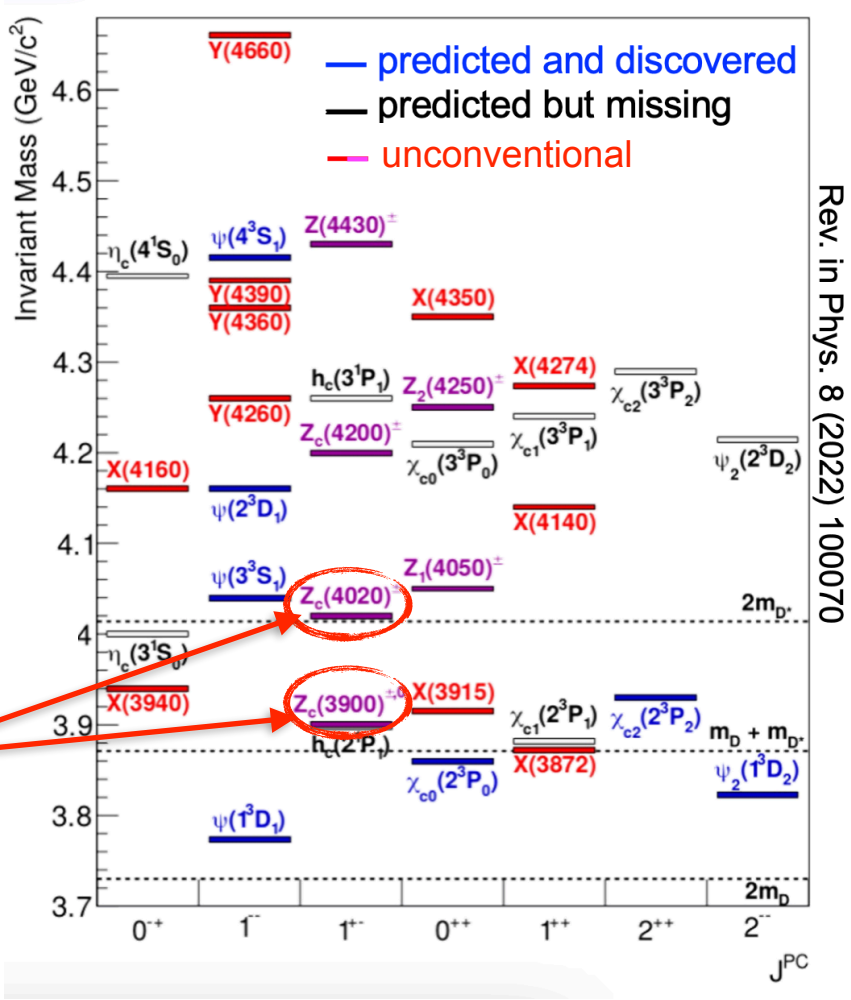
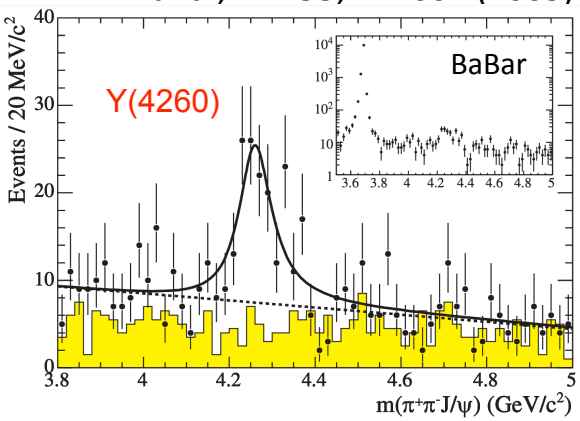


Y States: Hidden Charm

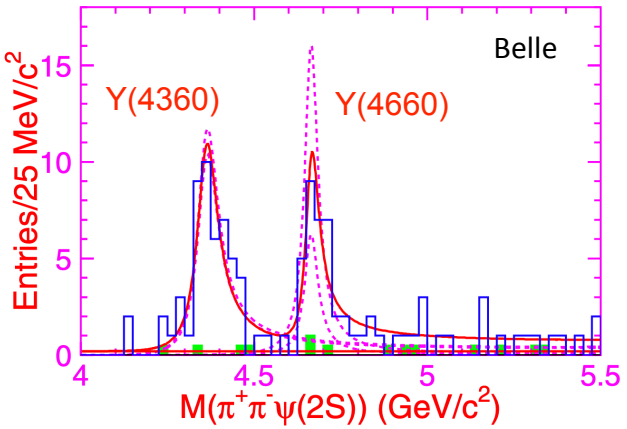
$J/\psi\,\pi^+\pi^-$

BaBar, PRL 95, 142001 (2005)

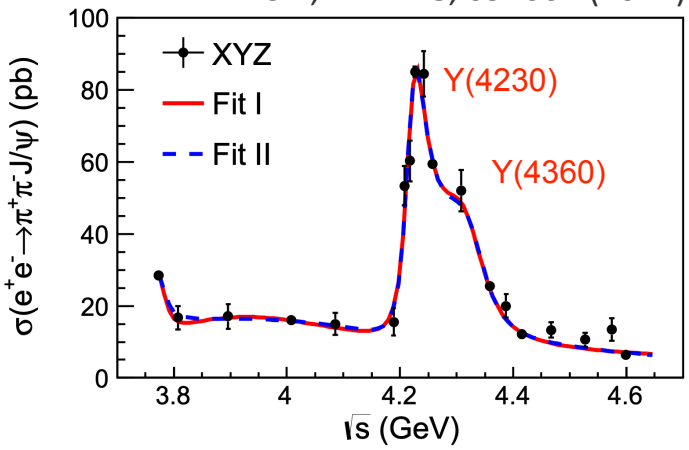


$\psi(2S)\pi^+\pi^-$

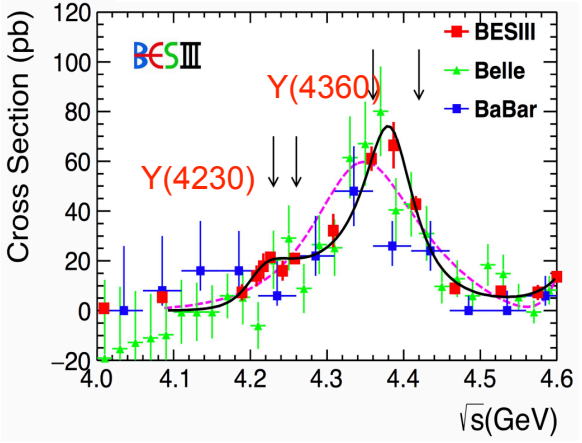
Belle, PRL 99, 142002 (2007)



BESIII, PRL 118, 092001 (2017)



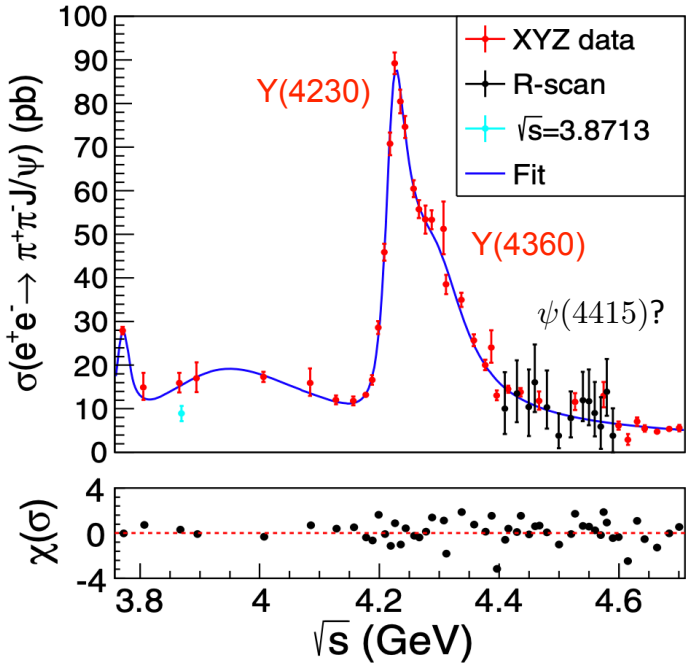
BESIII, PRD 96, 032004 (2017)]



Y States: Hidden Charm

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

BESIII, PRD 106, 072001 (2022)

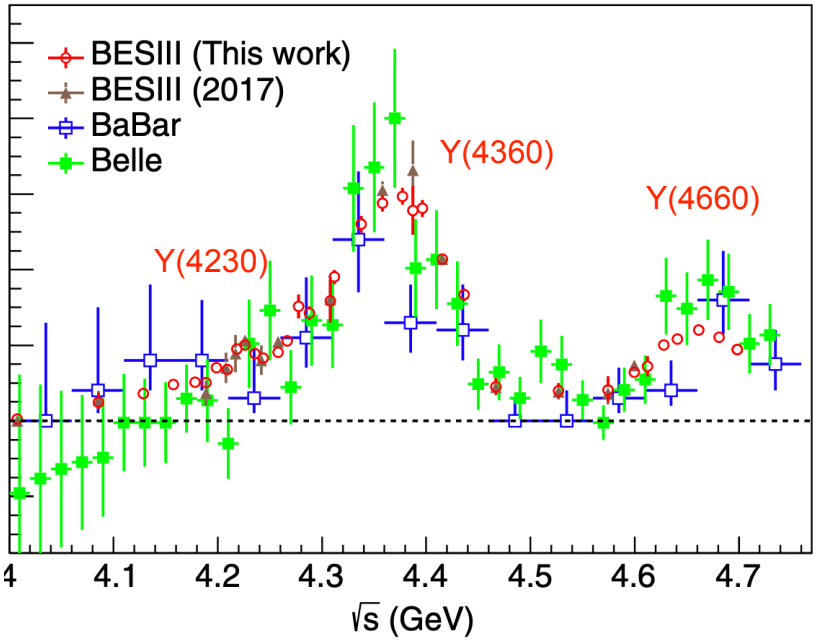


More data points and larger statistics: Y(4230) and Y(4360)

additional structure at ~4.5 GeV ?
has impact on Y(4230) parameters

$\psi(2S)\pi^+\pi^-$

BESIII, PRD 104, 052012 (2021)



Confirmation of Y(4230), Y(4360) and Y(4660)
first observation of Y(4660) at BESIII

Y States: Hidden Charm

BESIII, JHEP01,132 (2023)

Study of $e^+e^- \to \gamma\phi J/\psi$

$\sqrt{s}$ from 4.600 to 4.951 GeV (6.4 fb^{-1})

$e^+e^- \to \phi\chi_{c1}$ cross section does not feature significant resonant structure

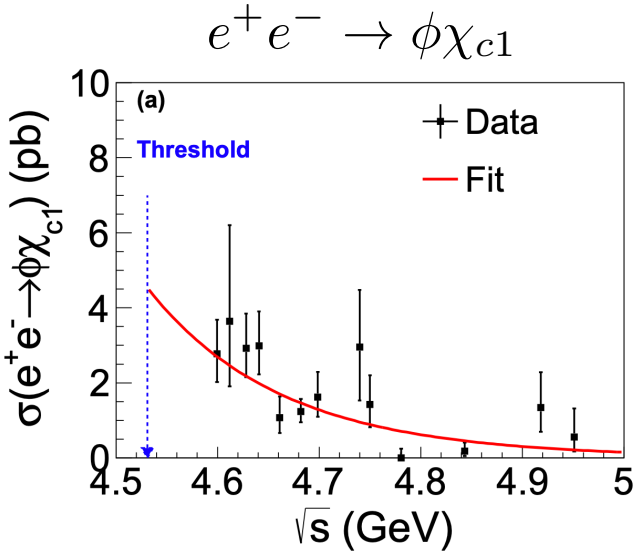
$e^+e^- \to \phi\chi_{c2}$ cross section

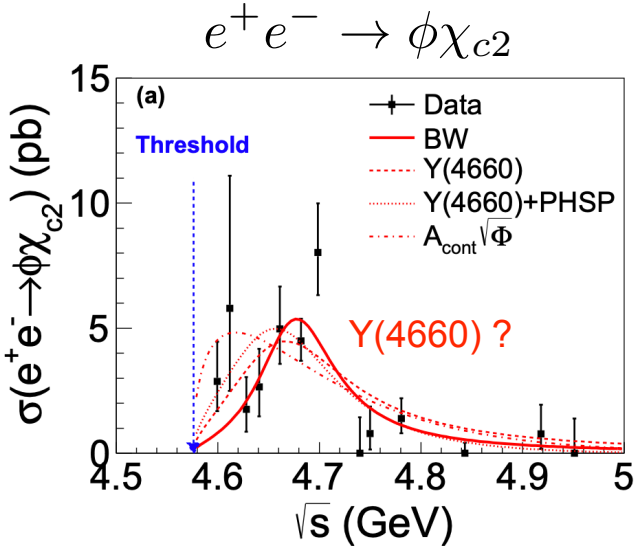
structure (3.1σ) at 4.67 GeV

$m = 4672.8 \pm 10.8 \pm 3.9\,\mathrm{MeV}/c^2$

$\Gamma = 93.2 \pm 19.8 \pm 9.4\,\mathrm{MeV}$

(consistent with Y(4660))

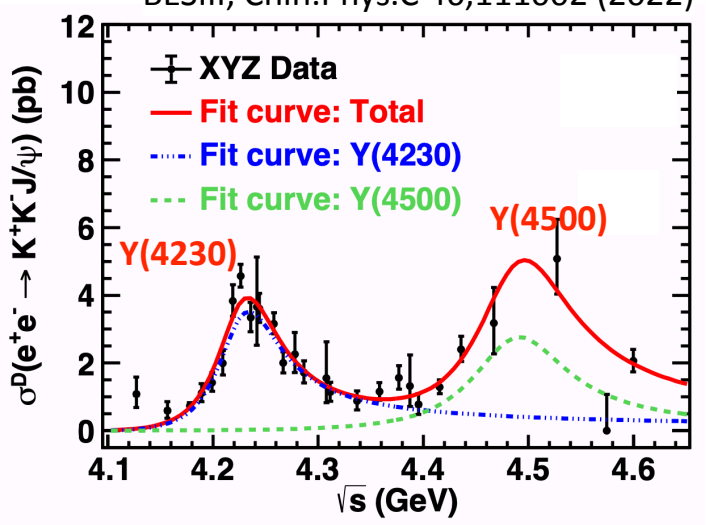




Y States: Hidden Charm

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

BESIII, Chin.Phys.C 46,111002 (2022)

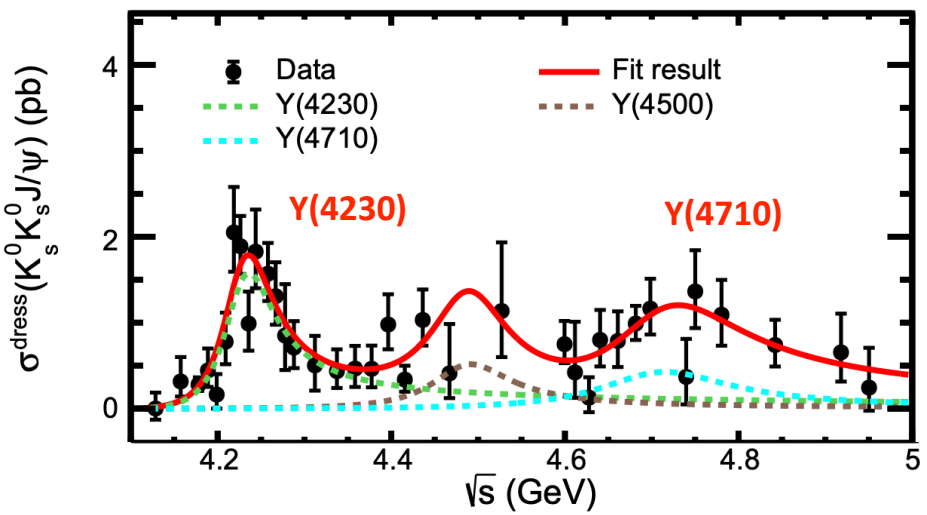


Observation of Y(4230) [20σ] and
new Y(4500) [8σ]

$$m = 4484.7 \pm 13.3 \pm 24.1\,\mathrm{MeV}/c^2$$
$$\Gamma = 111.1 \pm 30.1 \pm 15.2\,\mathrm{MeV}$$

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

BESIII, PRD 107, 092005 (2023)



Observation of Y(4230) [26σ]
no significant Y(4500) [1.4σ]
evidence for new Y(4710) [4.2σ]

$$m = 4704.0 \pm 52.3 \pm 69.5\,\mathrm{MeV}/c^2$$
$$\Gamma = 183.2 \pm 114.0 \pm 96.1\,\mathrm{MeV}$$

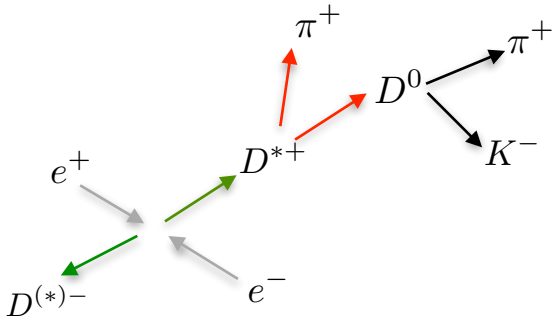
Y States: Open Charm Production

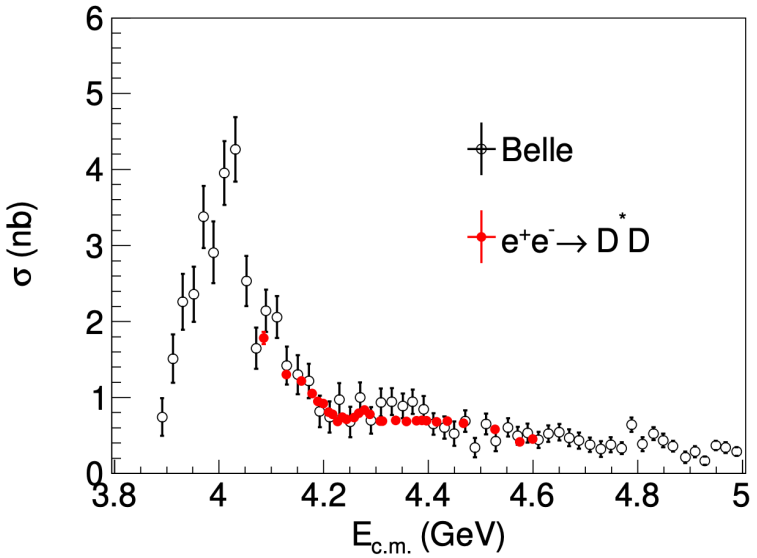
Coupling to open and hidden charm final states important to understand nature of Y states

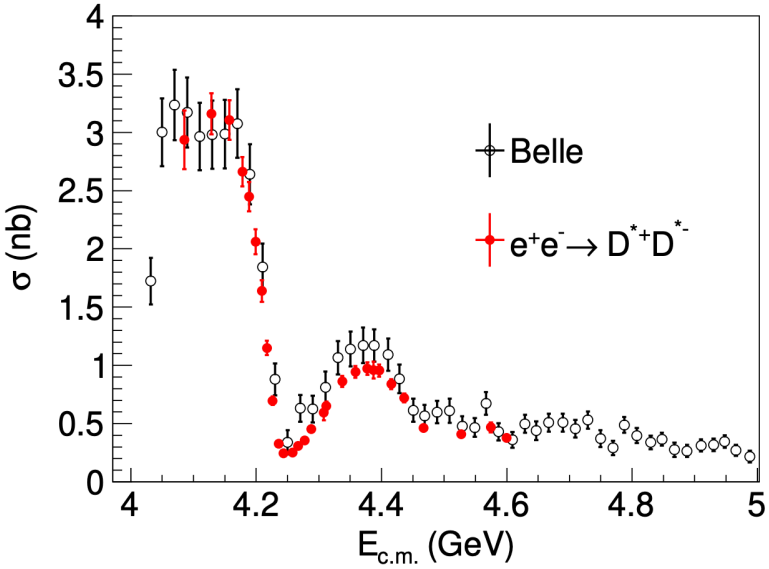
BESIII, JHEP 155 (2022)

Study $e^+e^- \to D^{*+}D^-$ and $e^+e^- \to D^{*+}D^{*-}$

Reconstruct $D^{*+} \to D^0\pi^+ \to K^-\pi^+\pi^+$, identify missing $D^{(\star)-}$







Y States: Open Charm Production

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

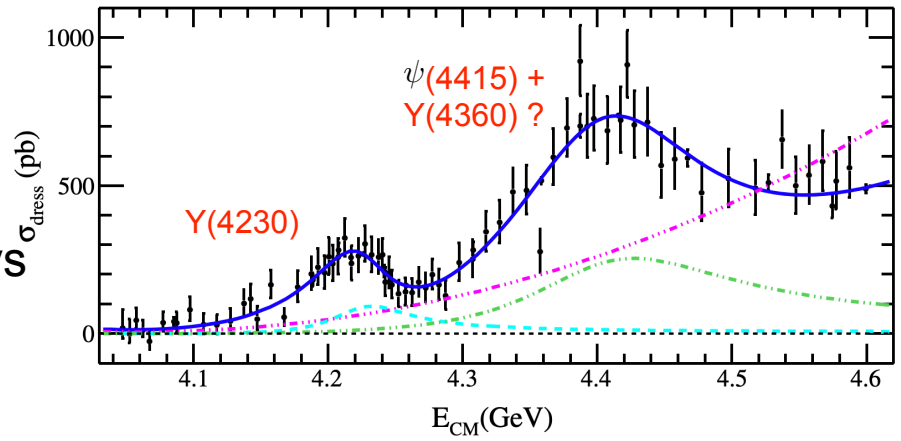
BESIII, PRL 122, 102002 (2019)

Y(4230)

$m = 4228.6 \pm 4.1 \pm 6.3\,\mathrm{MeV}/c^2$

$\Gamma = 77.0 \pm 6.8 \pm 6.3\,\mathrm{MeV}$

first observation in open charm decays

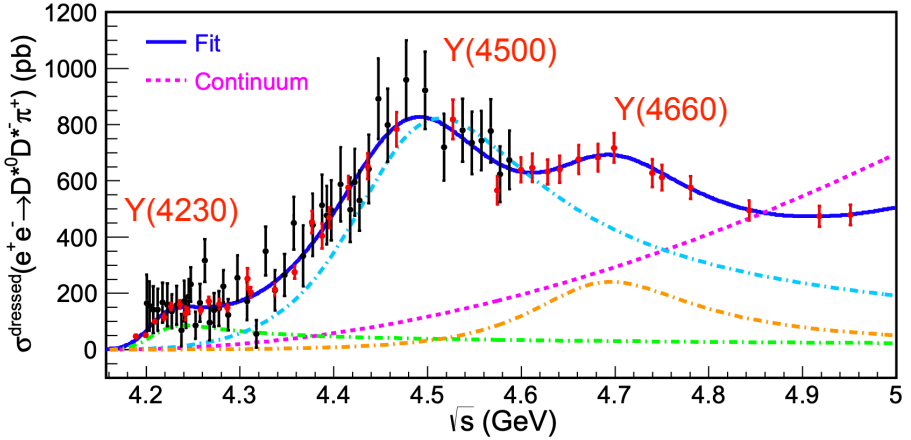


Structure at 4.4 GeV needs further investigation

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

BESIII, PRL 130, 121901 (2023)

Parameters of observed structures consistent with
Y(4230), Y(4500) and Y(4660)



Y States: Open Charm Production

$e^+e^- \to D_s^{*+} D_s^{*-}$

76 energy points between
4.226 and 4.95 GeV (~15.7 fb^{-1})

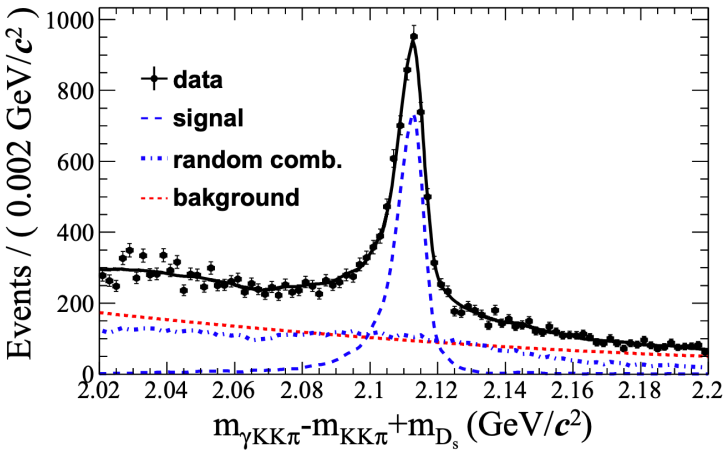
partial reconstruction of only one D_s^*

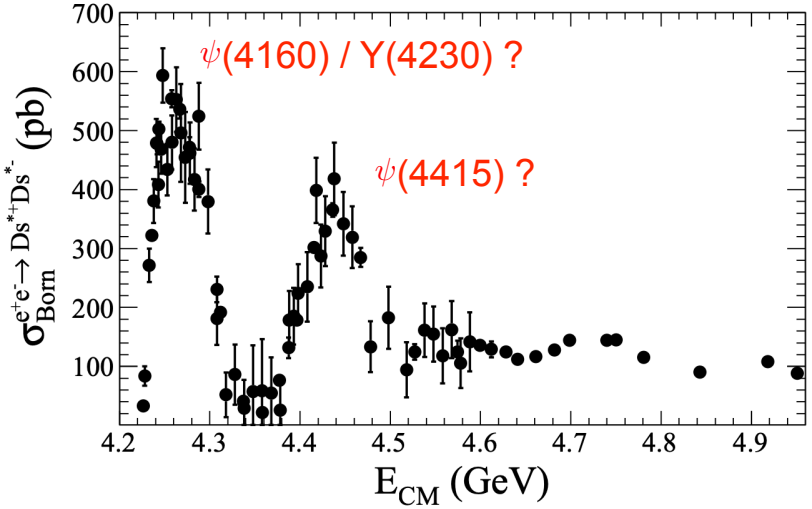
Two structures observed in the cross section at 4.2 GeV and 4.45 GeV

connected to ψ(4160) / Y(4230) and ψ(4415), respectively ?

comprehensive coupled channel fit required for more conclusions

BESIII, arXiv:2305.10789 [hep-ex] (2023)
submitted to PRL



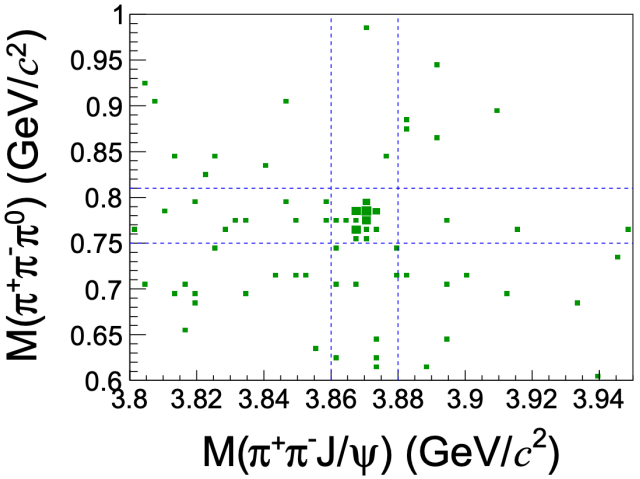


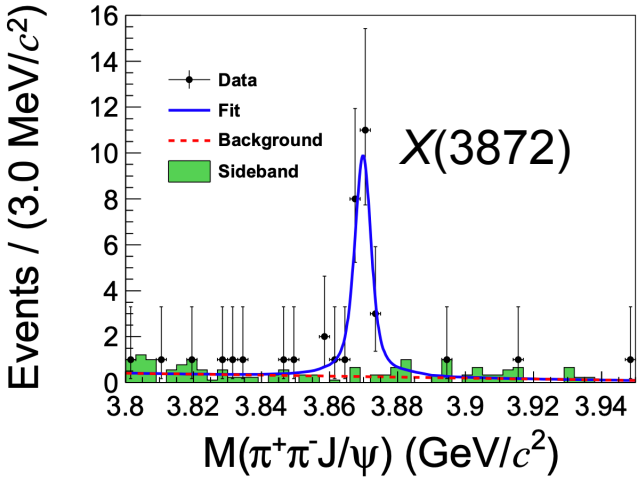
X(3872)

BESIII, PRL 130, 151904 (2023)

Study of $e^+e^- \to \omega(J/\psi\pi^+\pi^-)$
at nine center-of-mass energy points
between 4.661 and 4.951 GeV (4.7 pb-1)

Observation of a new *X*(3872)
production process (7.8σ significance)





Search for Direct $X(3872)$ Production

First scan for $e^+e^- \to J/\psi\,\pi^+\pi^-$
via $e^+e^- \to \gamma^*\gamma^* \to X$

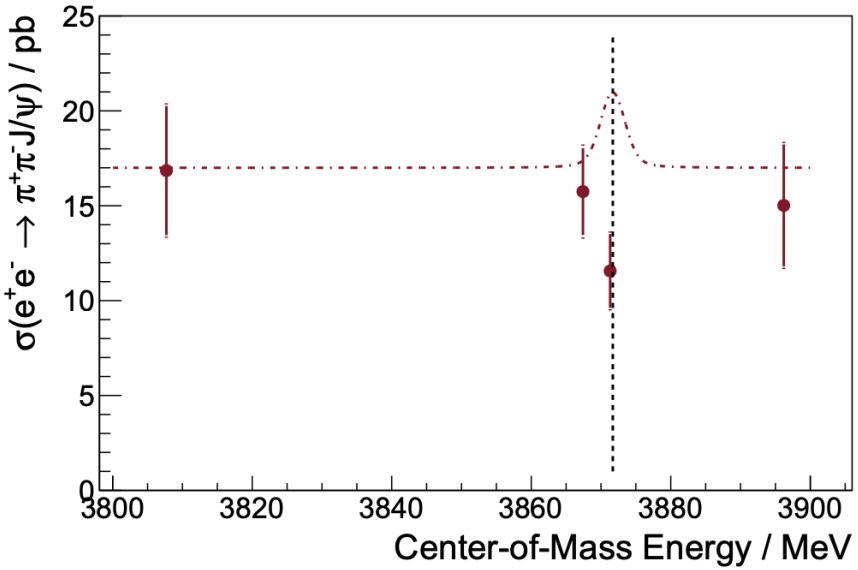
four center-of-mass energy points around $X(3872)$ (4.7 pb^{-1})

no significant production of $X(3872)$ observed

$$\Gamma_{ee} < 0.32\,\mathrm{eV}\ (90\%\ \mathrm{CL})$$

VMD expectation: $\Gamma_{ee} \gtrsim 0.03\,\mathrm{eV}$

BESIII, PRD 107, 032007 (2023)

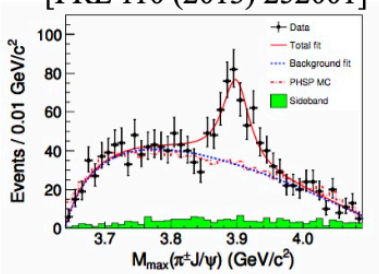


A. Denig et al. PLB 736, 221 (2014)

Z_c States at BESIII

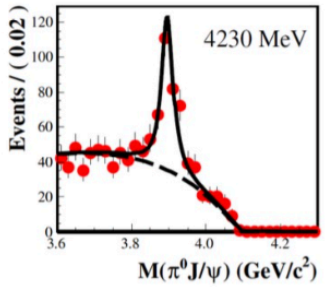
Hidden Charm

[PRL 110 (2013) 252001]



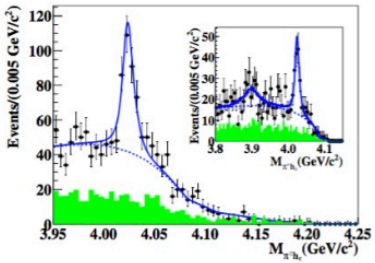
$e^+e^- \to \pi^-\pi^+ J/\psi$

[PRL 115 (2015) 112003]



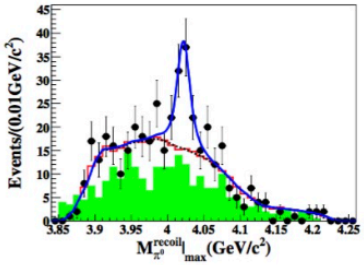
$e^+e^- \to \pi^0\pi^0 J/\psi$

[PRL 111 (2013) 242002]



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

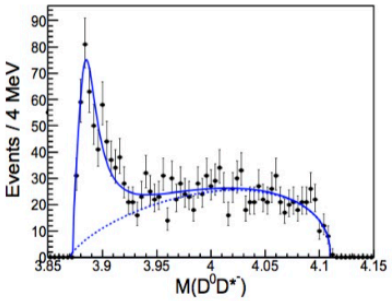
[PRL 113 (2014) 212002]



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

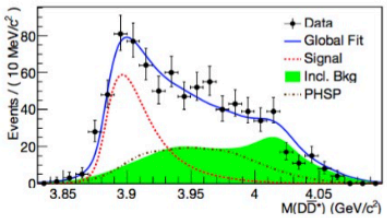
Open Charm

[PRL 112 (2014) 022001]

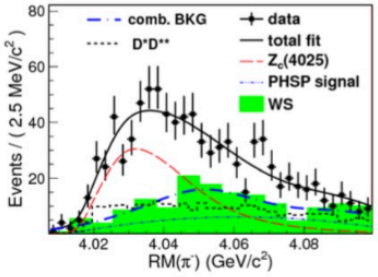


$e^+e^- \to \pi^-(D\bar{D}^*)^+$

[PRL 115 (2015) 222002]

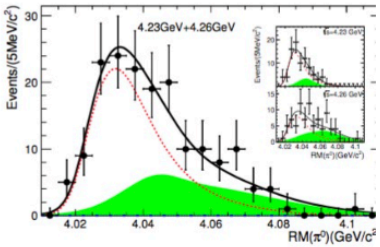


[PRL 112 (2013) 132001]



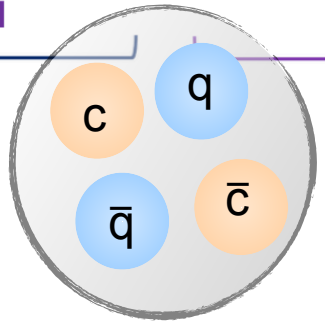
$e^+e^- \to \pi^-(D^*\bar{D}^*)^+$

[PRL 115 (2015) 182002]



Charged **Neutral** **Charged** **Neutral**

$Z_c(3900)^{\pm,0}$?



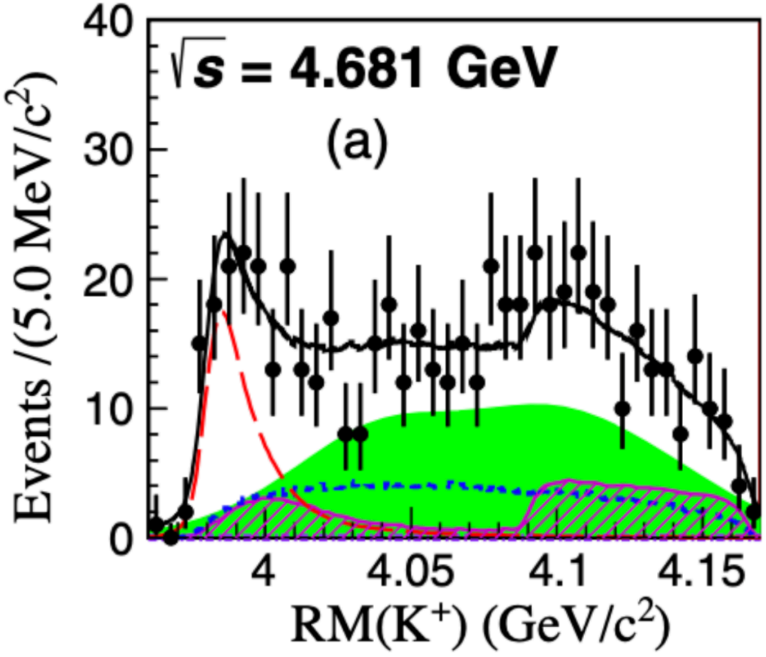
$Z_c(4020)^{\pm,0}$?

[courtesy: F. Nerling]

Strange Partner States Z_{cs}

$$e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$$

BESIII. PRL 126. 102001 (2021)

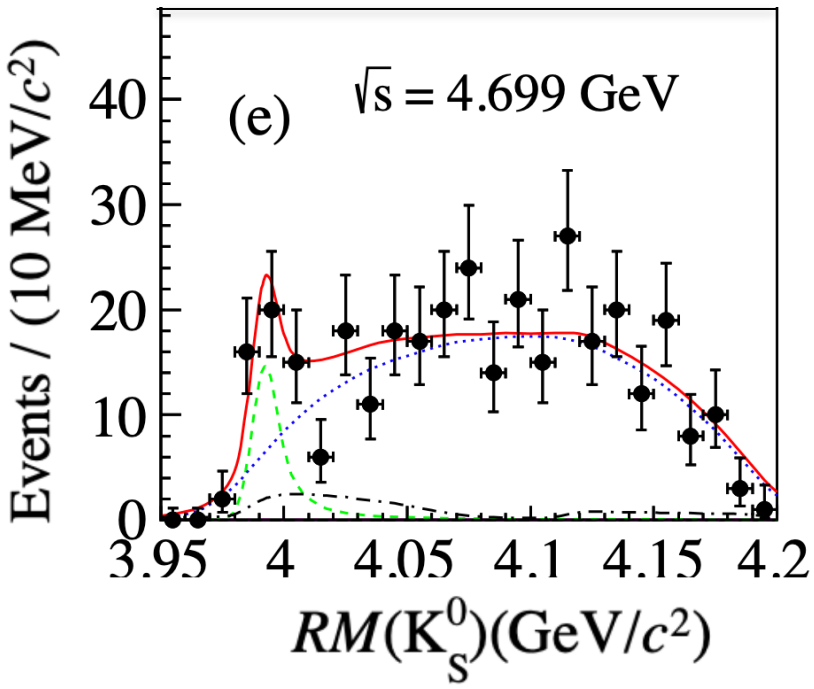


Observation of $Z_{cs}(3985)^+$

$$m = 3985.2^{+2.1}_{-2.0} \pm 1.7\,\mathrm{MeV}/c^2$$
$$\Gamma = 13.8^{+8.1}_{-5.2} \pm 4.9\,\mathrm{MeV}$$

$$e^+e^- \to K_S^0(D_s^+ D^{*-} + D_s^{*+} D^-)$$

BESIII, PRL 129, 112003 (2022)



Evidence (4.6σ) for neutral partner

$$m = 3992.2 \pm 1.7 \pm 1.6\,\mathrm{MeV}/c^2$$
$$\Gamma = 7.7^{+4.1}_{-3.8} \pm 4.3\,\mathrm{MeV}$$

Excited Strange Partner Z_{cs}'

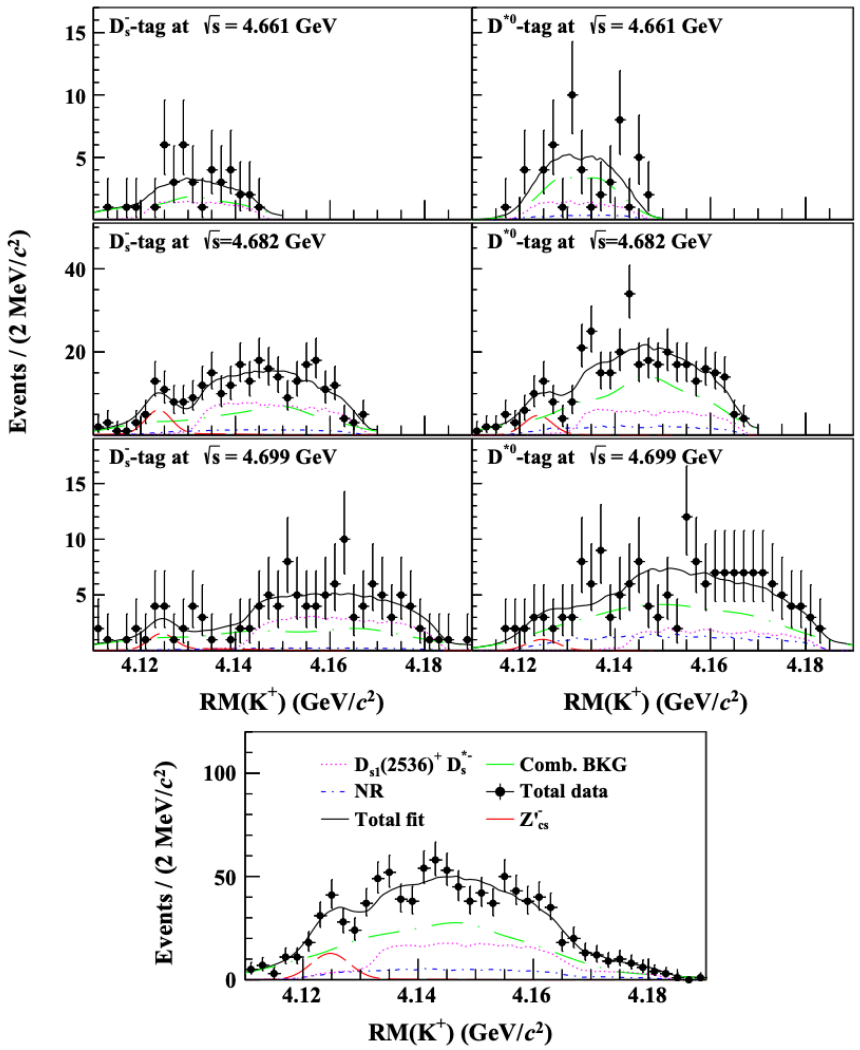
Search for excited partner of $Z_{cs}(3985)^+$ in $e^+e^- \to K^+ D_s^{*-} D^{0*}$

at three energy points (2.7 fb^{-1})
partial reconstruction w/ D_s or D^{0*} tag

Structure around 4.125 GeV
statistical significance 3.9σ
(2.1σ incl. sys. uncertainties)
$m = 4123.5 \pm 0.7 \pm 4.7\,\mathrm{MeV}/c^2$

Upper limit on
production cross section x BF
at each energy: $\mathcal{O}(1\,\mathrm{pb})$ at 90% CL

BESIII, Chin. Phys. C 47, 033001 (2023)



Summary and Outlook

- BESIII is successfully operating since 2008
  - 500+ submitted papers covering a broad physics program

- Excellent opportunities for hadron spectroscopy
  - light and charmonium sector
  - ongoing analyses of J/ψ , $\psi(2S)$ decays and e^+e^- annihilations up to 5 GeV

Further BEPCII upgrades in 2024:

c.-m. energy up to 5.6 GeV

3x luminosity increase in the *XYZ* region