Hadron Spectroscopy Highlights from BESIII

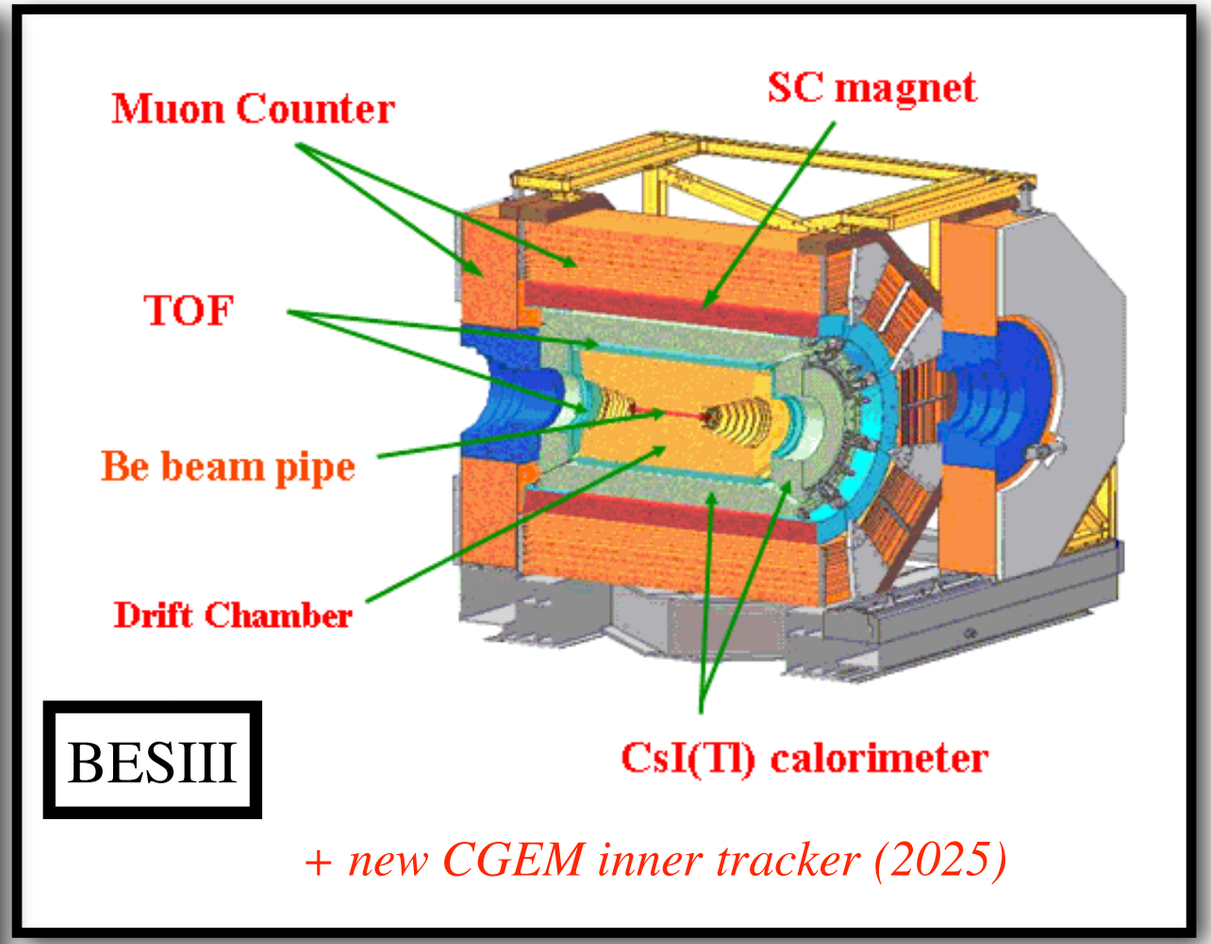
Ryan Mitchell
(for the BESIII Collaboration)
Indiana University

CIPANP 2025
Madison, Wisconsin
June 11, 2025

The BESIII Experiment

BEPCII: Beijing Electron Positron Collider
symmetric e^+e^- collisions at E_{CM} between 1.8 and 5.0 GeV

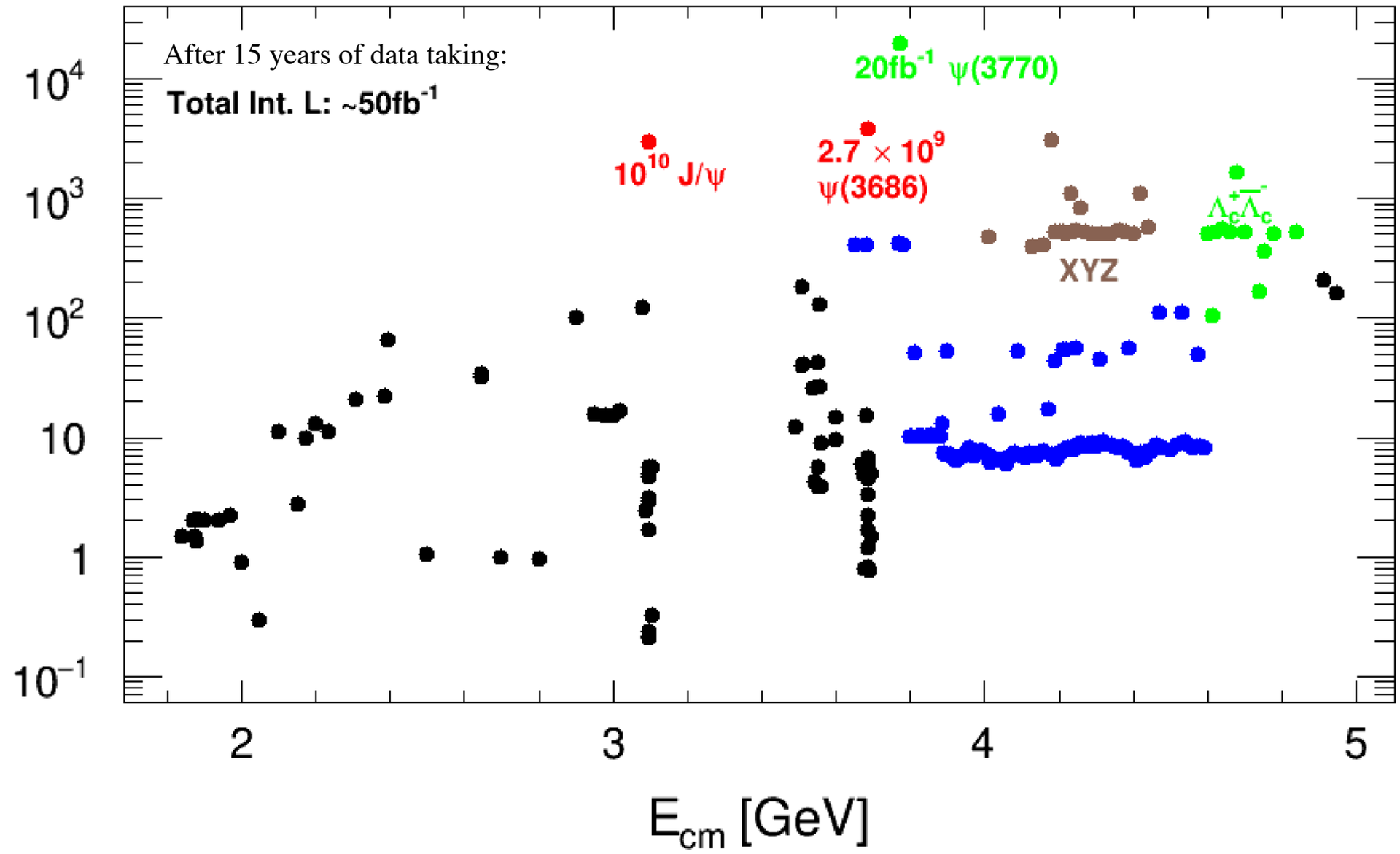
BESIII: Beijing Spectrometer
general purpose detector, running since 2009

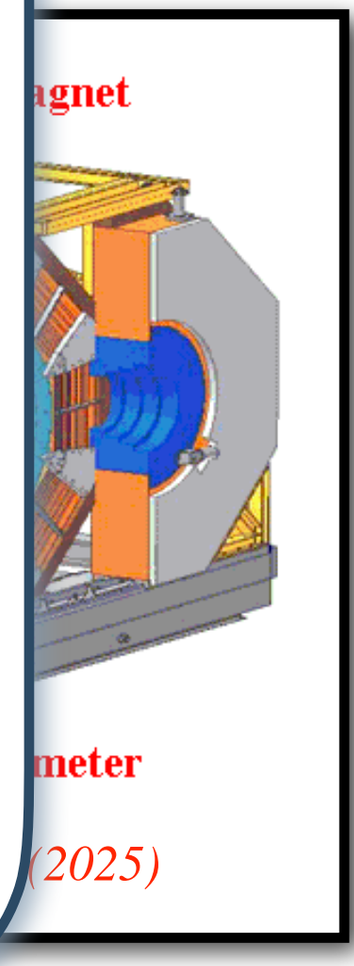


Physics topics span a wide range of topics: light quark spectroscopy; light meson decays; hyperon physics; initial state radiation and two photon fusion; precision open charm decays; charmonium spectroscopy; spectroscopy of exotic "XYZ" states; etc. etc.

The BESIII Experiment

http://english.ihep.cas.cn/bes/ui/ds/202109/t20210923_284001.html





Physics topics span a wide range of topics: light quark spectroscopy; light meson decays; hyperon physics; initial state radiation and two photon fusion; precision open charm decays; charmonium spectroscopy; spectroscopy of exotic "XYZ" states; etc. etc.

The BESIII Experiment

BE

symmetr

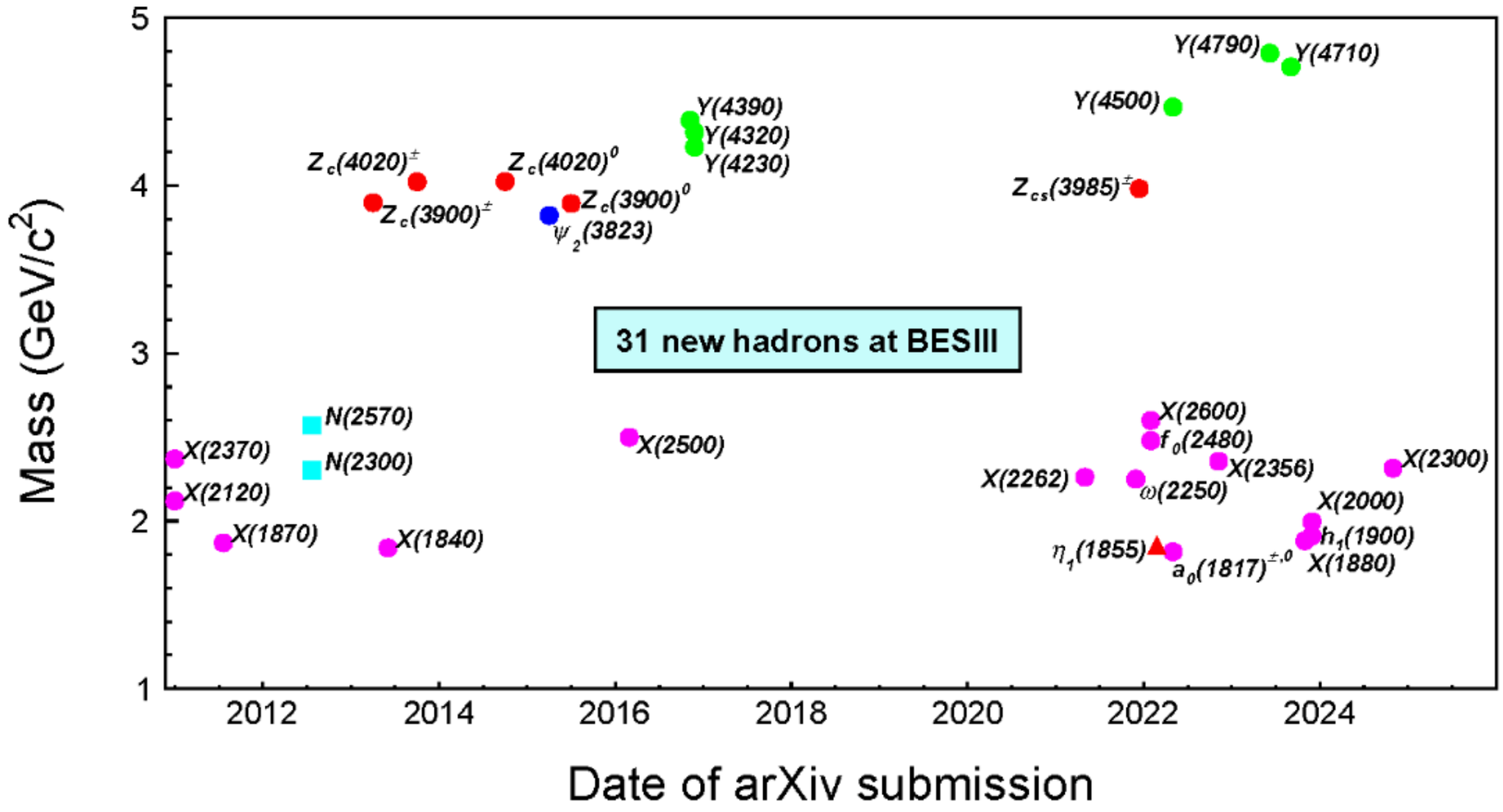
2009

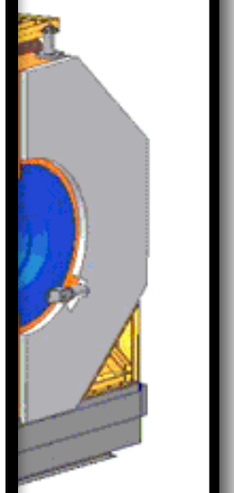
Beijing

BE

"New hadrons discovered at BESIII," Z. Q. Liu, R. E. Mitchell, Sci.Bull. 68 (2023) 2148-2150

updates: http://english.ihep.cas.cn/bes/re/pu/NewParticles/





Physics topics span a wide range of topics: light quark spectroscopy; light meson decays; hyperon physics; initial state radiation and two photon fusion; precision open charm decays; charmonium spectroscopy; spectroscopy of exotic "XYZ" states; etc. etc.

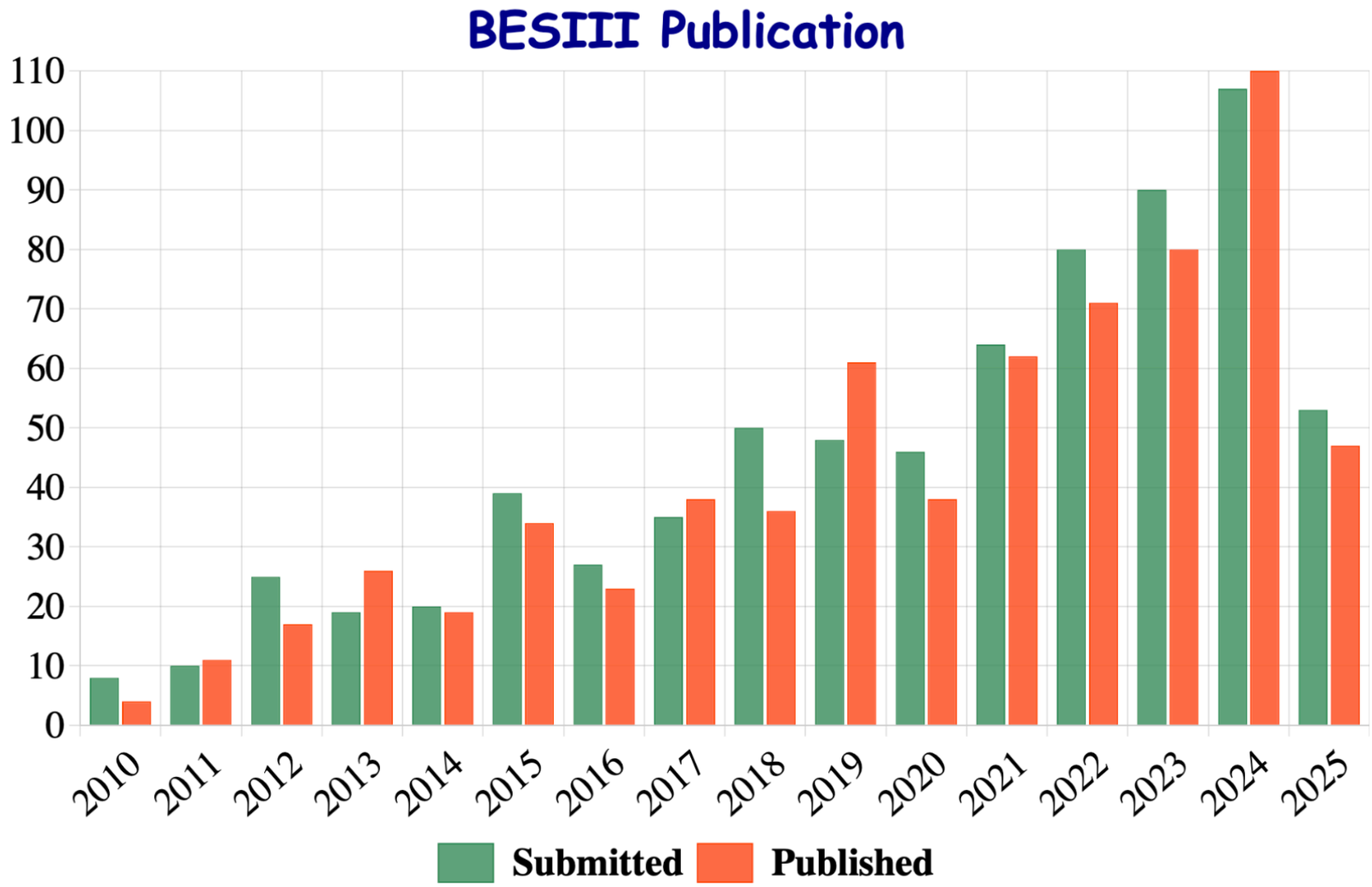
The BESIII Experiment

BEPCII: Bei

symmetric e^+e^- co

Beijing, China

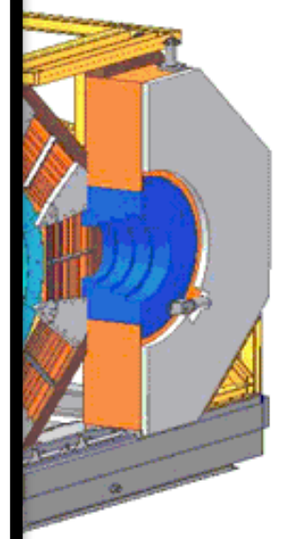
Nsubmitted = 721, Npublished = 677



eter

since 2009

agnet



meter

(2025)

Physics topics span a wide range of topics: light quark spectroscopy; light meson decays; hyperon physics; initial state radiation and two photon fusion; precision open charm decays; charmonium spectroscopy; spectroscopy of exotic "XYZ" states; etc. etc.

Hadron Spectroscopy Highlights from BESIII

BEPCII: Beijing Electron Positron Collider

symmetric e^+e^- collisions

BESIII: Beijing Spectrometer

running since 2009

Beijing, China

(TI) calorimeter

tracker (2025)

<u>This Talk *(a small subset of recent results)*:</u>

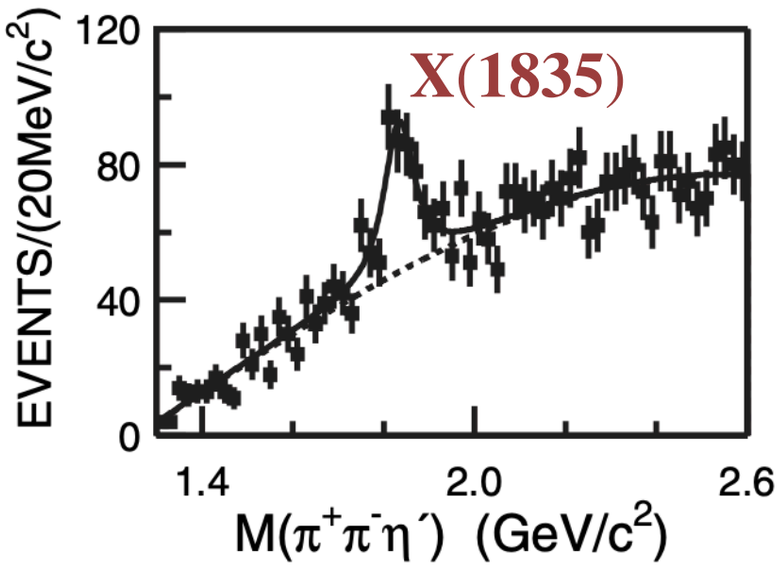
1. Glueball Candidates in Radiative ψ Decays
2. The $\pi_1(1600)$ in χ_{c1} Decays
3. Updates on the $X(3872)$ *(aka $\chi_{c1}(3872)$)*
4. Updates on the Y States *(aka ψ states)*
5. Updates on the $Z_c(3900)$ *(aka $T_{c\bar{c}1}(3900)$)*

Physics topics span a wide range of topics: light quark spectroscopy; light meson decays; hyperon physics; initial state radiation and two photon fusion; precision open charm decays; charmonium spectroscopy; spectroscopy of exotic "XYZ" states; etc. etc.

1. Glueball Candidates in Radiative ψ Decays

A striking example of the richness of J/ψ radiative decays is in $J/\psi \to \gamma\pi^+\pi^-\eta'$…

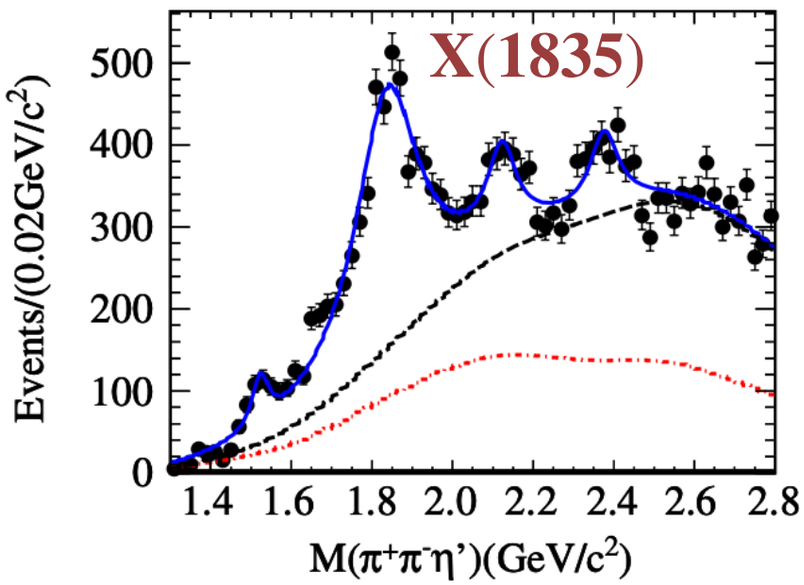
BESII $J/\psi \to \gamma\pi^+\pi^-\eta'$ (2005)



Phys.Rev.Lett. 95 (2005) 262001

0.058 billion J/ψ

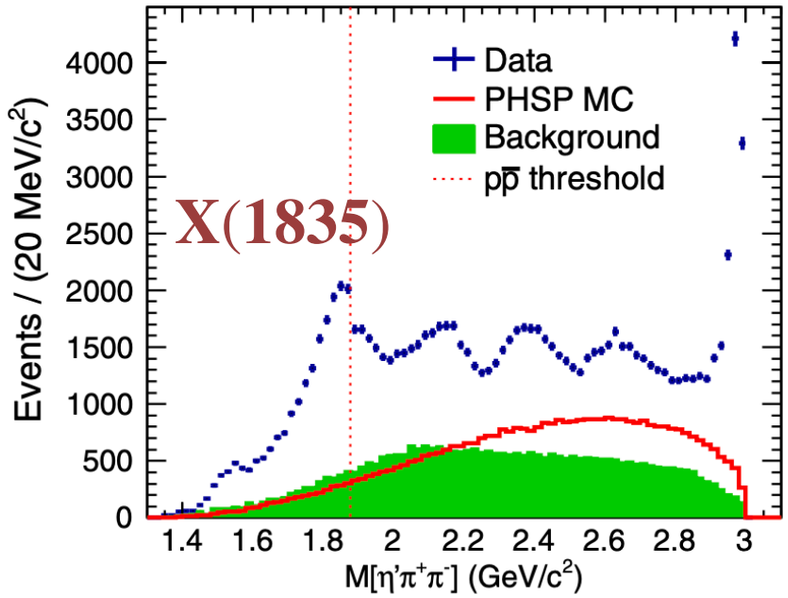
BESIII $J/\psi \to \gamma\pi^+\pi^-\eta'$ (2011)



Phys.Rev.Lett. 106 (2011) 072002

0.225 billion J/ψ

BESIII $J/\psi \to \gamma\pi^+\pi^-\eta'$ (2016)



Phys.Rev.Lett. 117 (2016) 4, 042002

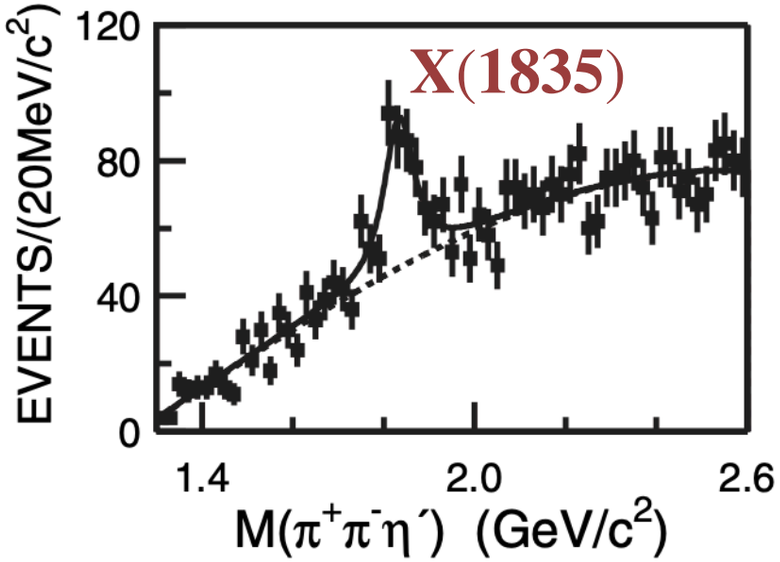
1.3 billion J/ψ

With more and more J/ψ decays, more and more features appear:
$X(1835)$ (with a sharp dip at $p\bar{p}$ threshold), $X(2120)$, $X(2370)$, $X(2600)$, $\eta_c(1S)$

1. Glueball Candidates in Radiative ψ Decays

A striking example of the richness of J/ψ radiative decays is in $J/\psi \to \gamma\pi^+\pi^-\eta'$…

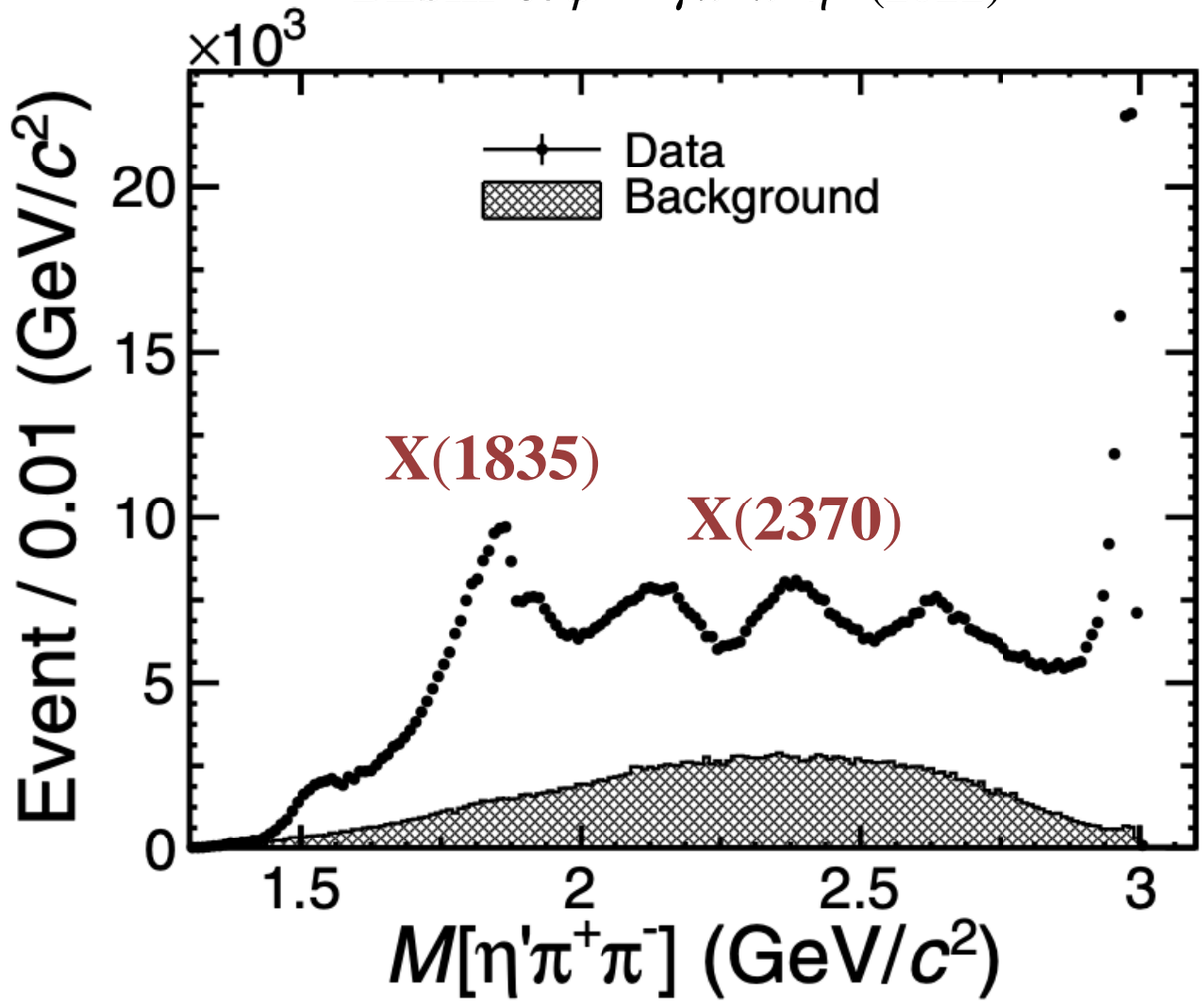
BESII $J/\psi \to \gamma\pi^+\pi^-\eta'$ (2005)



Phys.Rev.Lett. 95 (2005) 262001

0.058 billion J/ψ

BESIII $J/\psi \to \gamma\pi^+\pi^-\eta'$ (2022)



Phys.Rev.Lett. 129 (2022) 4, 042001

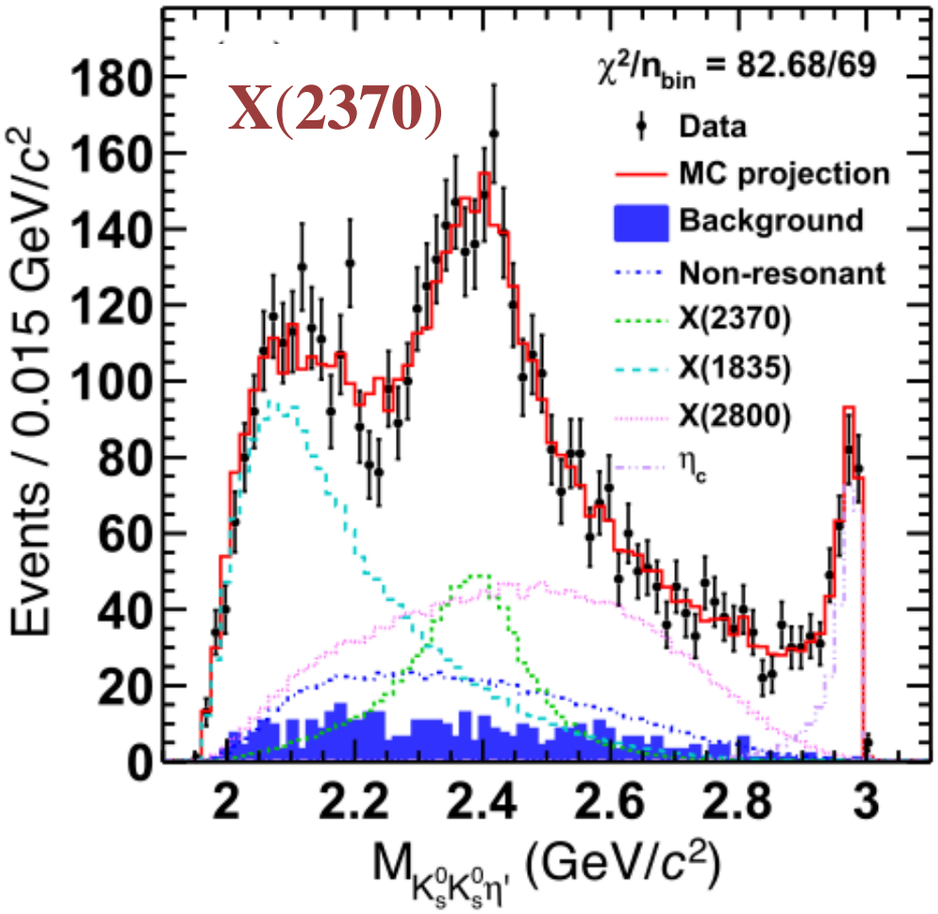
10 billion J/ψ

The $X(2370)$ is a strong candidate for a pseudoscalar glueball (based on lattice QCD predictions)!

1. Glueball Candidates in Radiative ψ Decays

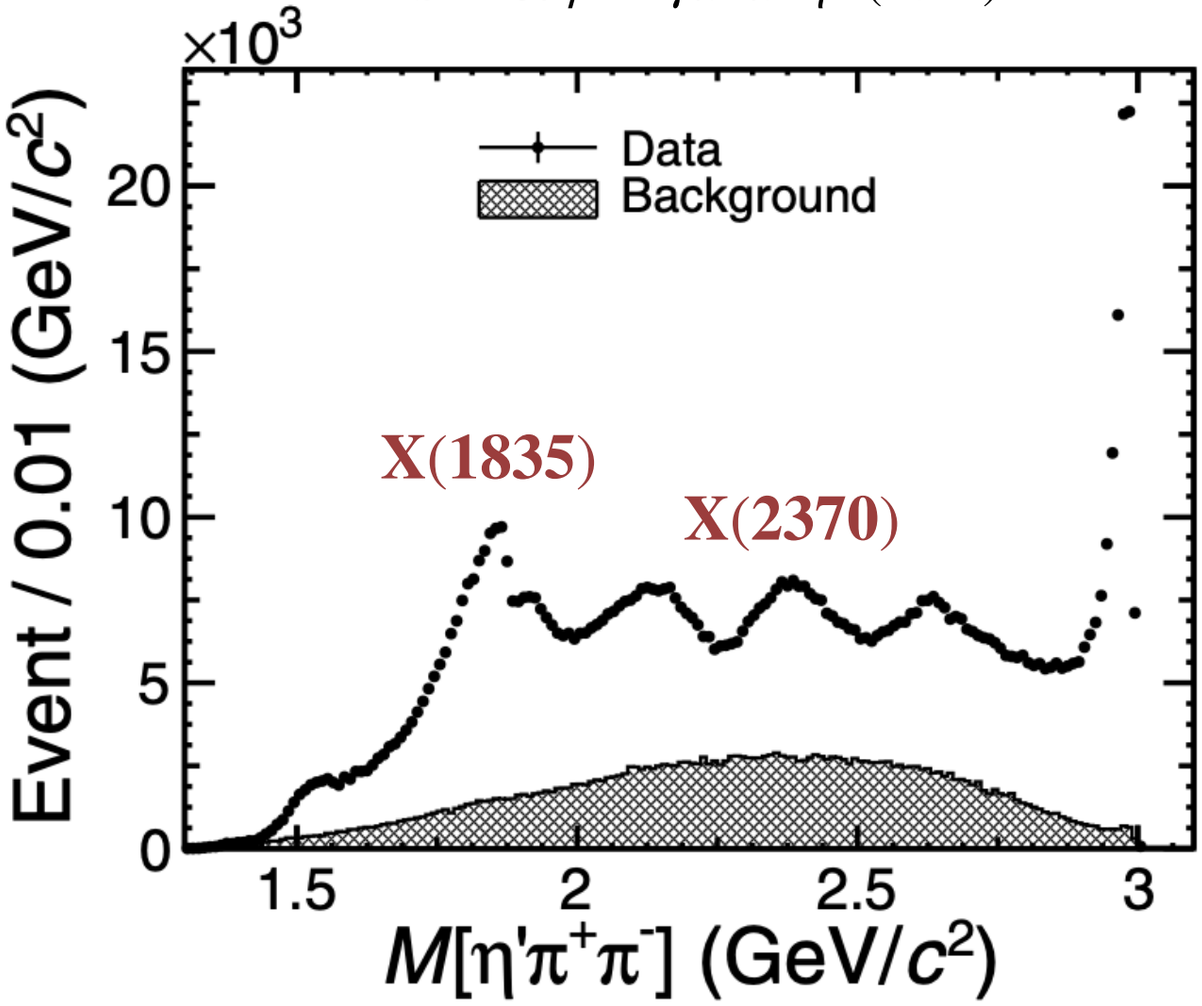
The J^{PC} of the X(2370) has recently been measured to be 0^{-+} in $J/\psi \to \gamma K_S^0 K_S^0 \eta'$…

BESIII $J/\psi \to \gamma K_S^0 K_S^0 \eta'$ (2024)



Phys.Rev.Lett. 132 (2024) 18, 181901

BESIII $J/\psi \to \gamma\pi^+\pi^-\eta'$ (2022)



Phys.Rev.Lett. 129 (2022) 4, 042001

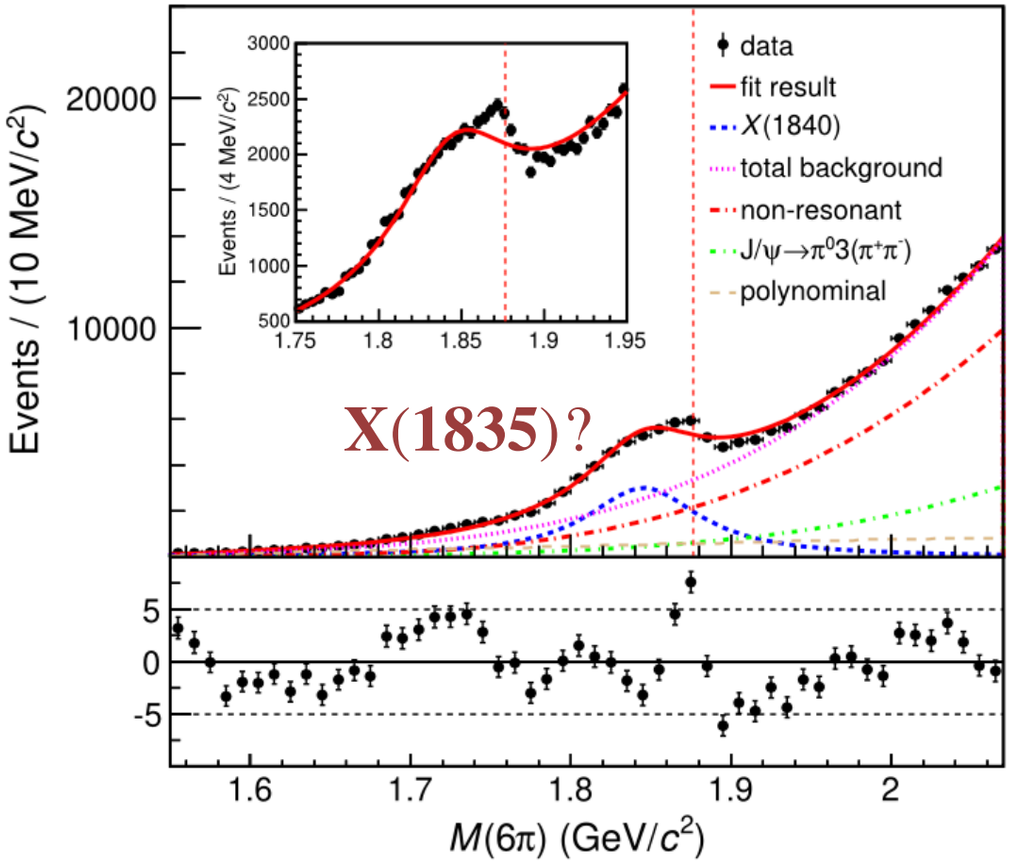
The $X(2370)$ is a strong candidate for a pseudoscalar glueball (based on lattice QCD predictions)!

10 billion J/ψ

1. Glueball Candidates in Radiative ψ Decays

In addition to $J/\psi \to \gamma\pi^+\pi^-\eta'$, other radiative decays also show complex structure at the $p\bar{p}$ threshold, for example $J/\psi \to \gamma 3(\pi^+\pi^-)$…

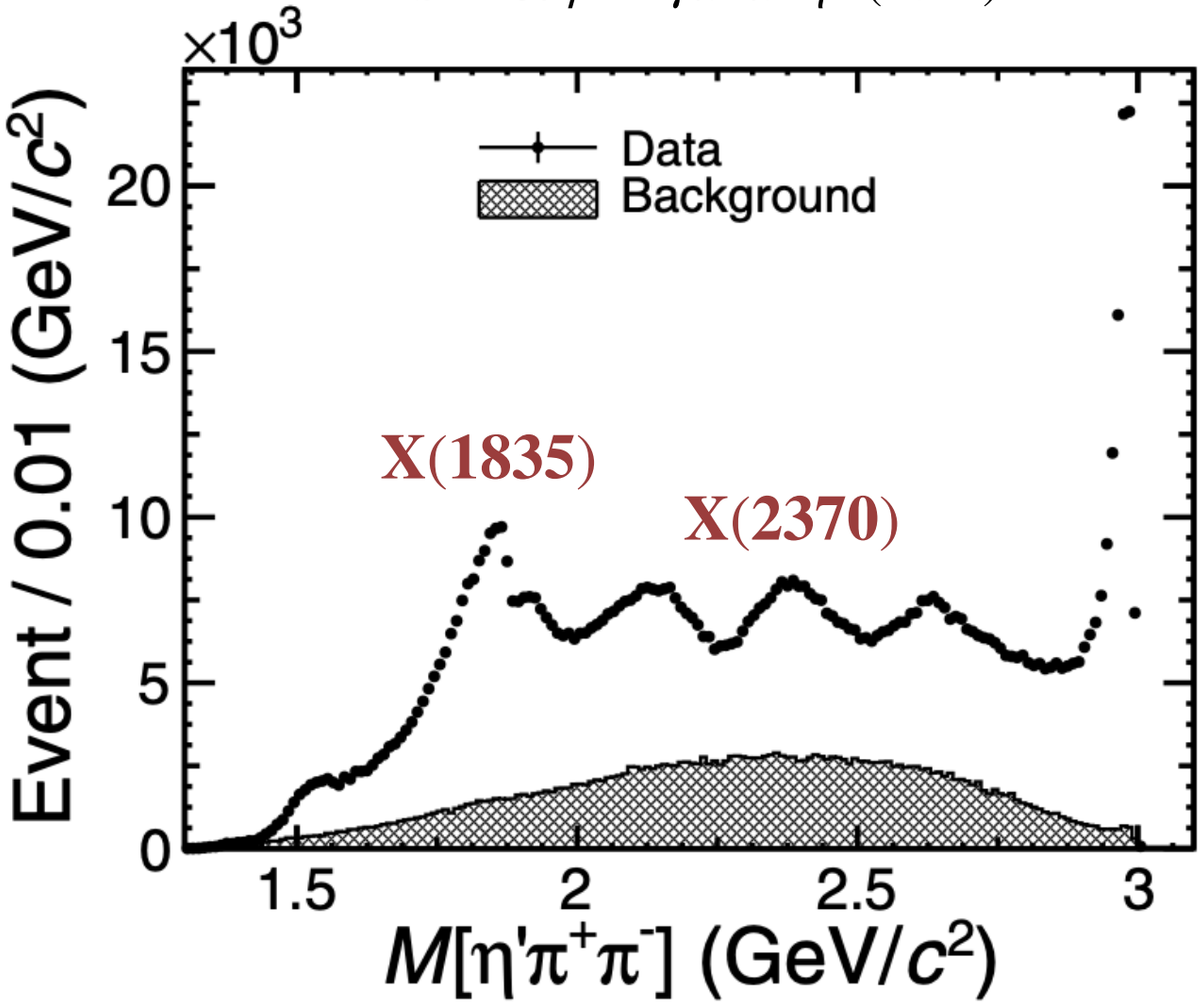
BESIII $J/\psi \to \gamma 3(\pi^+\pi^-)$ (2024)



Phys.Rev.Lett. 132 (2024) 15, 151901

Growing evidence for a $p\bar{p}$ bound state?

BESIII $J/\psi \to \gamma\pi^+\pi^-\eta'$ (2022)



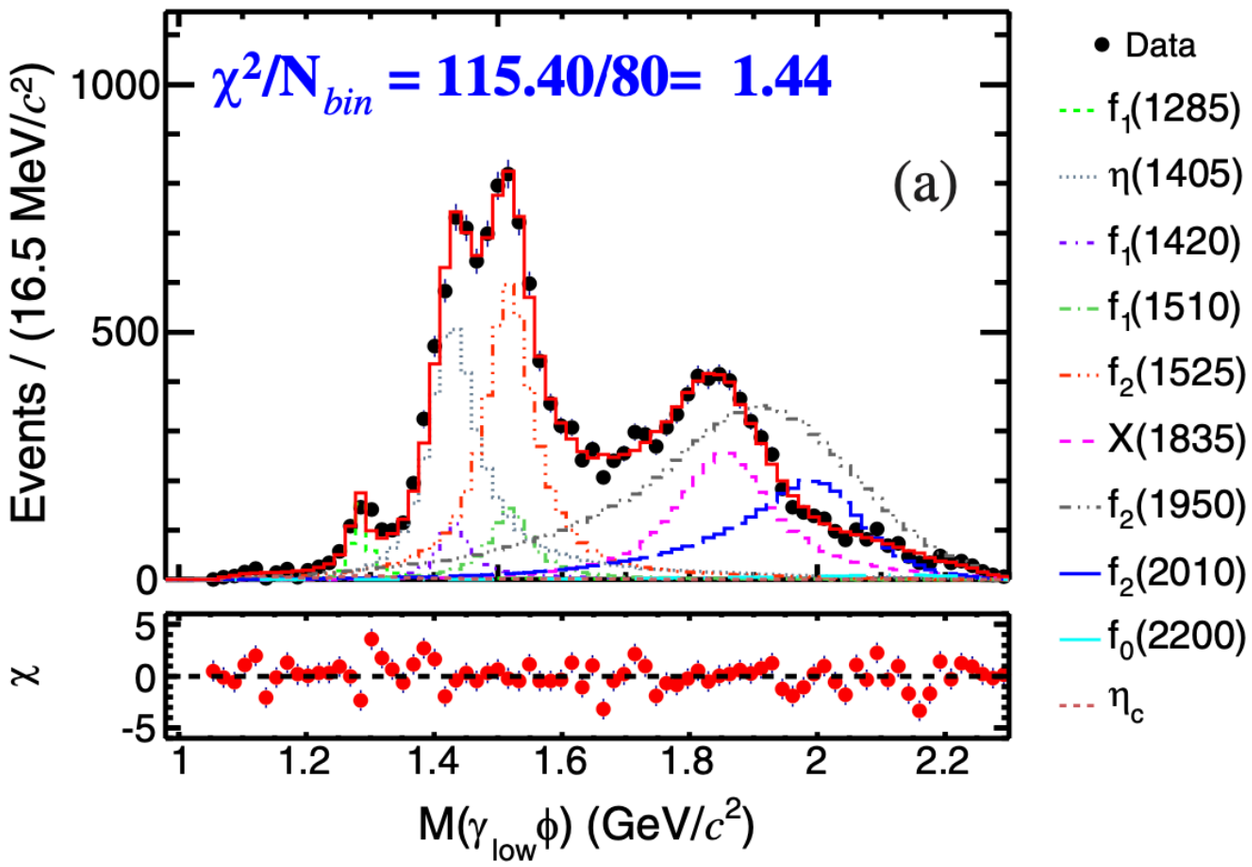
Phys.Rev.Lett. 129 (2022) 4, 042001

10 billion J/ψ

1. Glueball Candidates in Radiative ψ Decays

The decay $J/\psi \to \gamma\gamma\phi$ gives access to radiative decays of the mesons produced in radiative decays of the J/ψ…

BESIII $J/\psi \to \gamma\gamma\phi$ (2025)



Phys.Rev.D 111 (2025) 5, 052011

$\mathcal{B}(J/\psi \to \gamma X) \times \mathcal{B}(X \to \gamma\phi)$

Resonance	$\mathcal{B}(\times 10^{-6})$	Significance
$f_1(1285)$	$0.29 \pm 0.03^{+0.11}_{-0.09}$	17.3σ
$f_1(1420)$	$0.55 \pm 0.07^{+0.18}_{-0.17}$	9.0σ
$\eta(1405)$	$3.57 \pm 0.18^{+0.59}_{-0.61}$	18.9σ
$f_1(1510)$	$0.78 \pm 0.09^{+0.34}_{-0.30}$	5.3σ
$f_2(1525)$	$2.76 \pm 0.18^{+0.90}_{-0.61}$	16.4σ
$X(1835)$	$3.37 \pm 0.19^{+0.78}_{-1.10}$	15.3σ
$f_2(1950)$	$9.96 \pm 0.60^{+3.44}_{-2.13}$	13.1σ
$f_2(2010)$	$4.63 \pm 0.43^{+1.42}_{-1.46}$	11.3σ
$f_0(2200)$	$0.20 \pm 0.04^{+0.05}_{-0.07}$	6.3σ
η_c	$0.21 \pm 0.03^{+0.05}_{-0.07}$	12.9σ

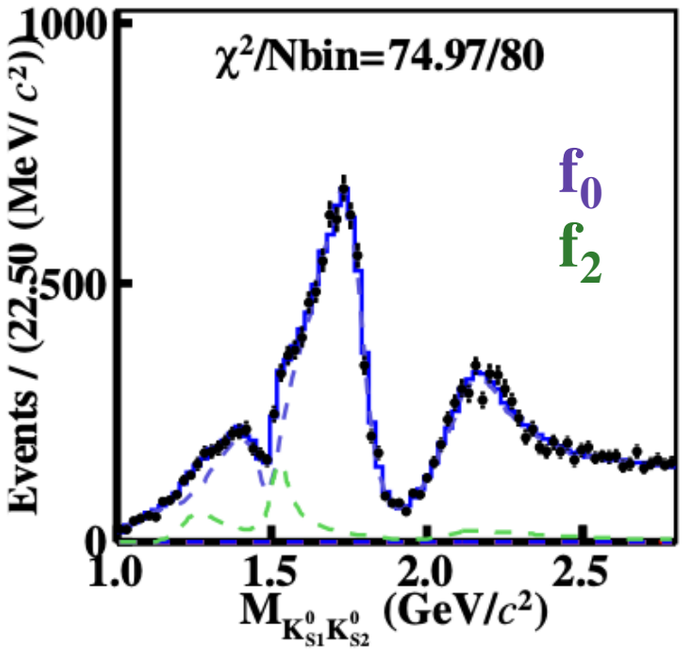
The decay $X \to \gamma\phi$ should be enhanced for $s\bar{s}$ states.

Note the absence of the $f_0(1710)$ and $X(2370)$ [$\eta(2370)$], for example.

1. Glueball Candidates in Radiative ψ Decays

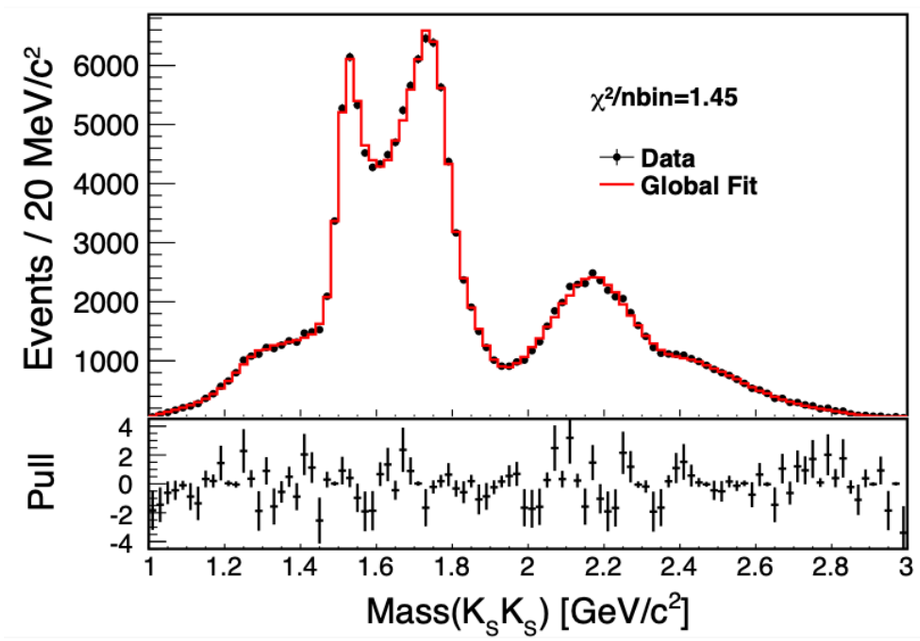
Use $\psi(2S)$ radiative decays to support and check conclusions based on J/ψ radiative decays…

BESIII $\psi(2S) \to \gamma K_S^0 K_S^0$ (2025)



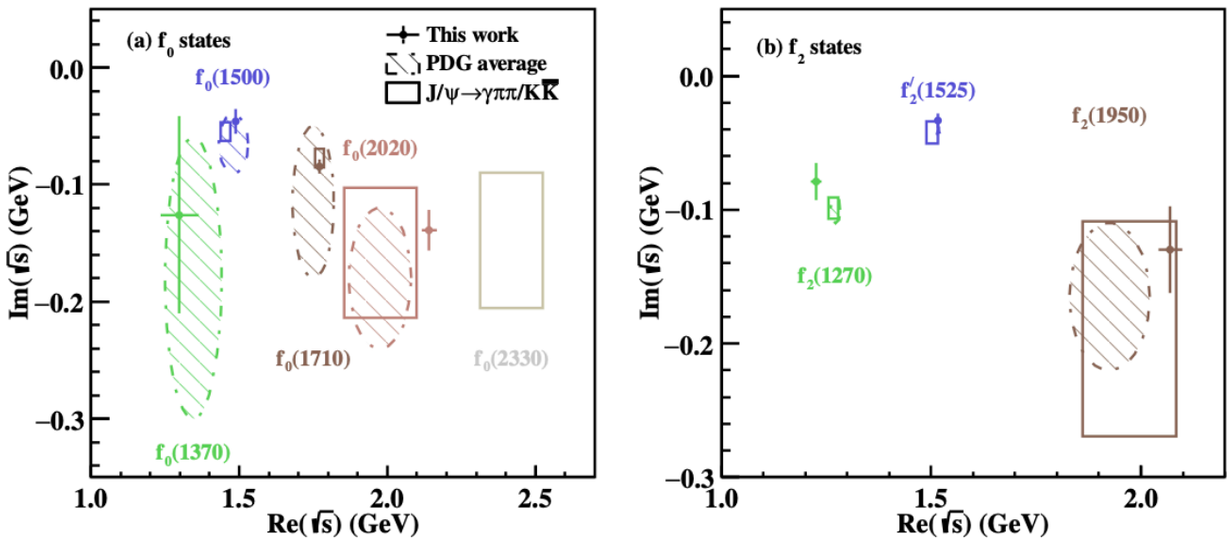
e-Print: 2502.13540 [hep-ex]

BESIII $J/\psi \to \gamma K_S^0 K_S^0$ (2018)



Phys.Rev.D 98 (2018) 7, 072003

The masses and widths of the f_0 $[f_0(1500), f_0(1710), f_0(2020)]$ and f_2 $[f_2(1270), f_2'(1525), f_2(1950)]$ are consistent between J/ψ and $\psi(2S)$ decays. Production is different.



Hadron Spectroscopy Highlights from BESIII

BEPCII: Beijing Electron Positron Collider

symmetric e^+e^- collisions

BESIII: Beijing Spectrometer

running since 2009

Beijing, China

(TOF) calorimeter

tracker (2025)

<u>This Talk *(a small subset of recent results)*:</u>

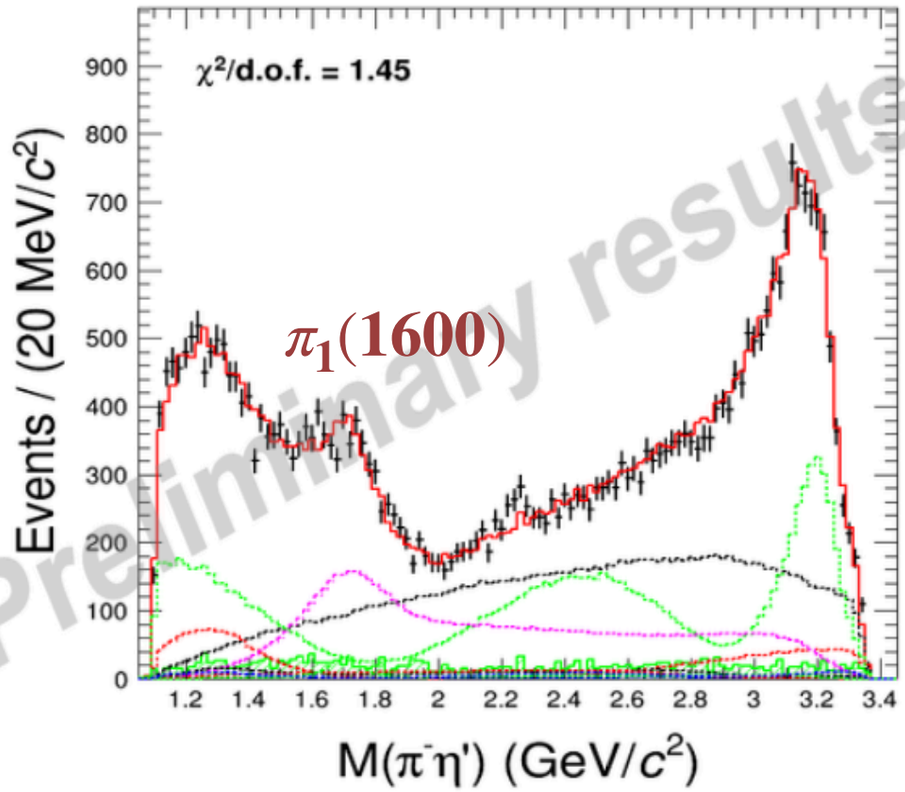
1. Glueball Candidates in Radiative ψ Decays
2. The $\pi_1(1600)$ in χ_{c1} Decays
3. Updates on the $X(3872)$ *(aka $\chi_{c1}(3872)$)*
4. Updates on the Y States *(aka ψ states)*
5. Updates on the $Z_c(3900)$ *(aka $T_{c\bar{c}1}(3900)$)*

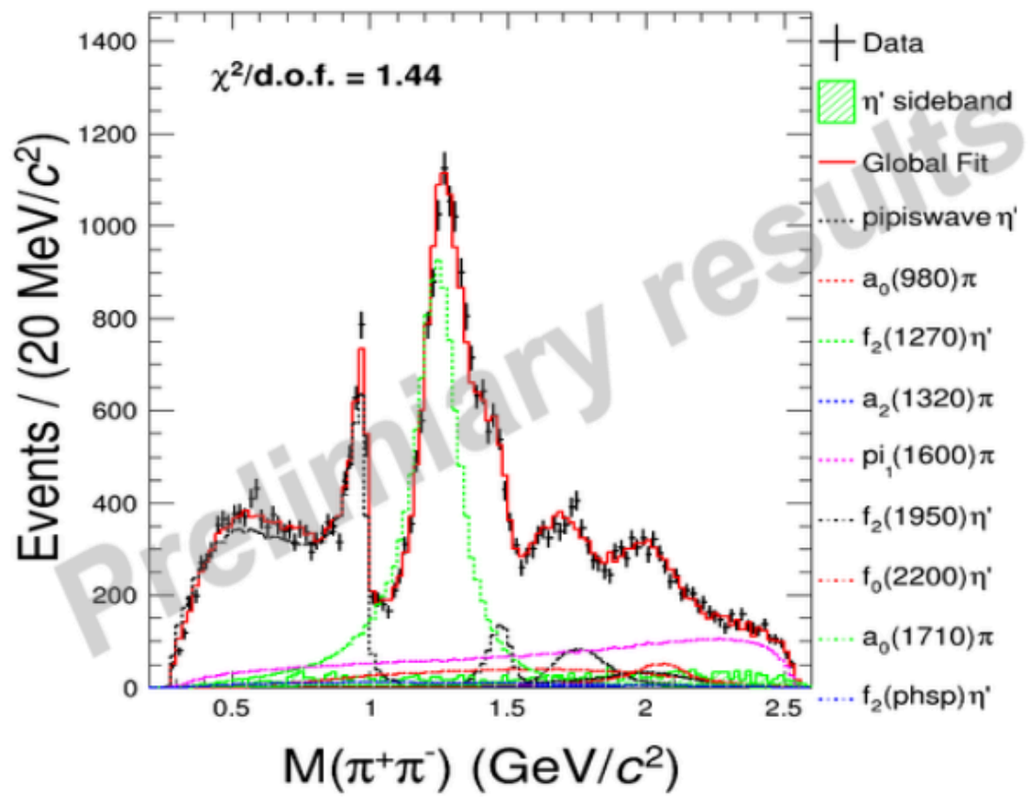
Physics topics span a wide range of topics: light quark spectroscopy; light meson decays; hyperon physics; initial state radiation and two photon fusion; precision open charm decays; charmonium spectroscopy; spectroscopy of exotic "XYZ" states; etc. etc.

2. The $\pi_1(1600)$ in χ_{c1} Decays

BESIII has access to the spin-exotic $\pi_1(1600)$ in χ_{c1} decays…

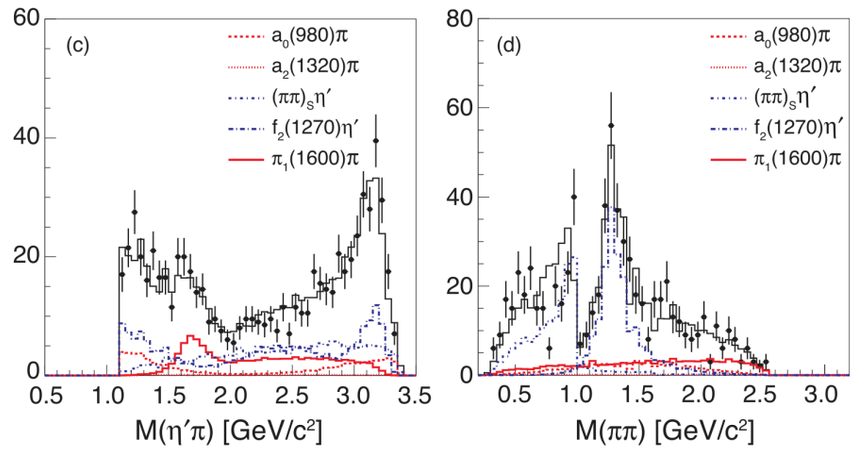
BESIII $\psi(2S) \to \gamma\chi_{c1}$; $\chi_{c1} \to \pi^+\pi^-\eta'$ (2025, preliminary)





With 2.7 billion $\psi(2S)$ decays, this is a factor of 100 more statistics than CLEOc.
This production mode gives BESIII access to more decays of the $\pi_1(1600)$ [eg $b_1\pi$].

CLEOc $\psi(2S) \to \gamma\chi_{c1}$; $\chi_{c1} \to \pi^+\pi^-\eta'$ (2011)



Phys.Rev.D 84 (2011) 112009

Hadron Spectroscopy Highlights from BESIII

BEPCII: Beijing Electron Positron Collider

symmetric e^+e^- collisions

BESIII: Beijing Spectrometer

running since 2009

Beijing, China

(Π) calorimeter

tracker (2025)

This Talk *(a small subset of recent results)*:

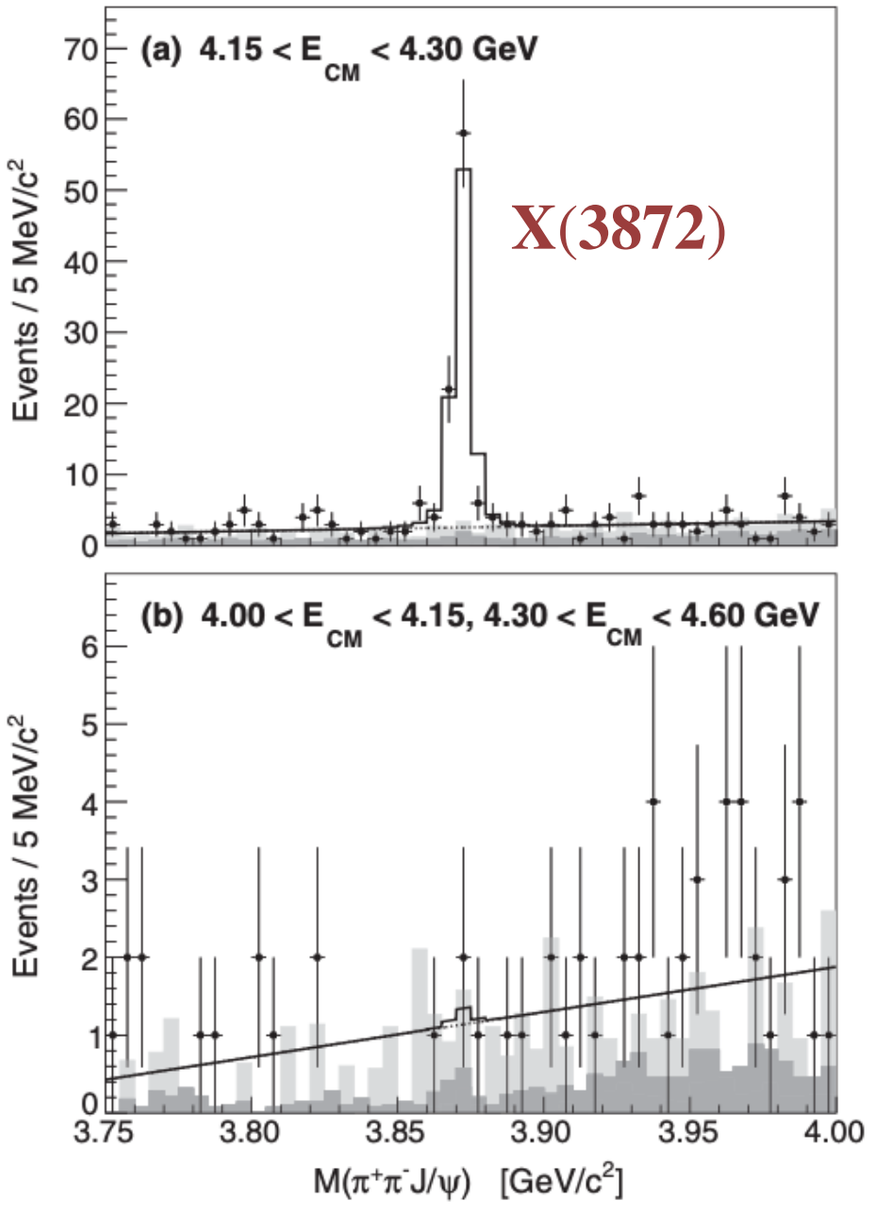
1. Glueball Candidates in Radiative ψ Decays
2. The $\pi_1(1600)$ in χ_{c1} Decays
3. Updates on the $X(3872)$ *(aka $\chi_{c1}(3872)$)*
4. Updates on the Y States *(aka ψ states)*
5. Updates on the $Z_c(3900)$ *(aka $T_{c\bar{c}1}(3900)$)*

Physics topics span a wide range of topics: light quark spectroscopy; light meson decays; hyperon physics; initial state radiation and two photon fusion; precision open charm decays; charmonium spectroscopy; spectroscopy of exotic "XYZ" states; etc. etc.

3. Updates on the $X(3872)$ (aka $\chi_{c1}(3872)$)

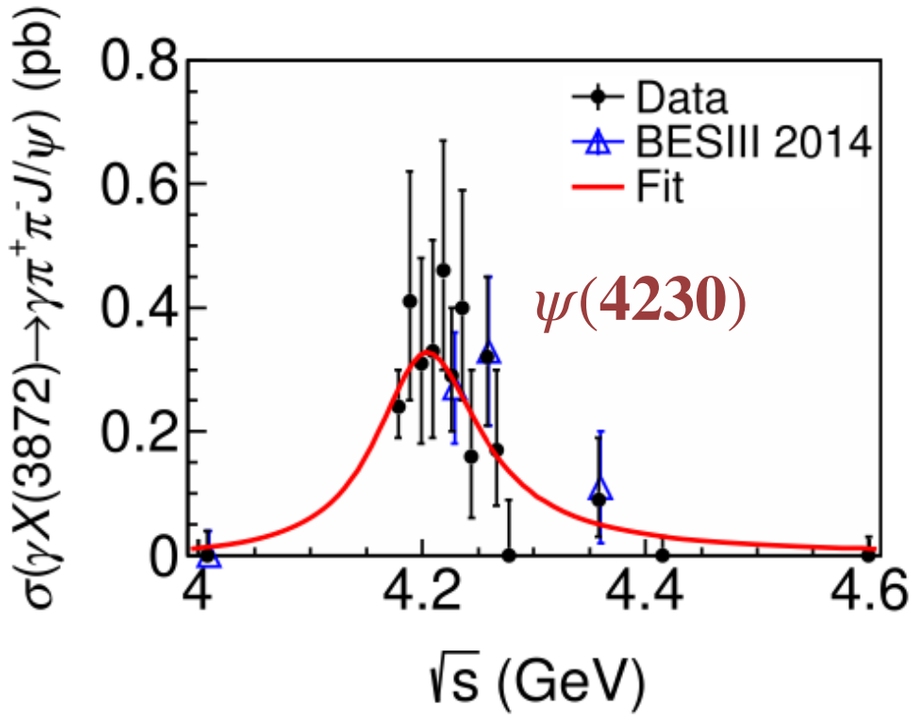
BESIII produces the $X(3872)$ using $e^+e^- \to \gamma X(3872)$ at center-of-mass energies around 4.2 GeV…

BESIII $e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$ (2019)



BESIII, Phys.Rev.Lett. 122 (2019) 20, 202001

BESIII $e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$ (2019)



BESIII, Phys.Rev.Lett. 122 (2019) 23, 232002

(1) This provides another handle into the structure of the $X(3872)$:

eg $e^+e^- \to \bar{D}^0 D_1(2420) \to \gamma \bar{D}^0 D^{*0} \to \gamma X(3872)$

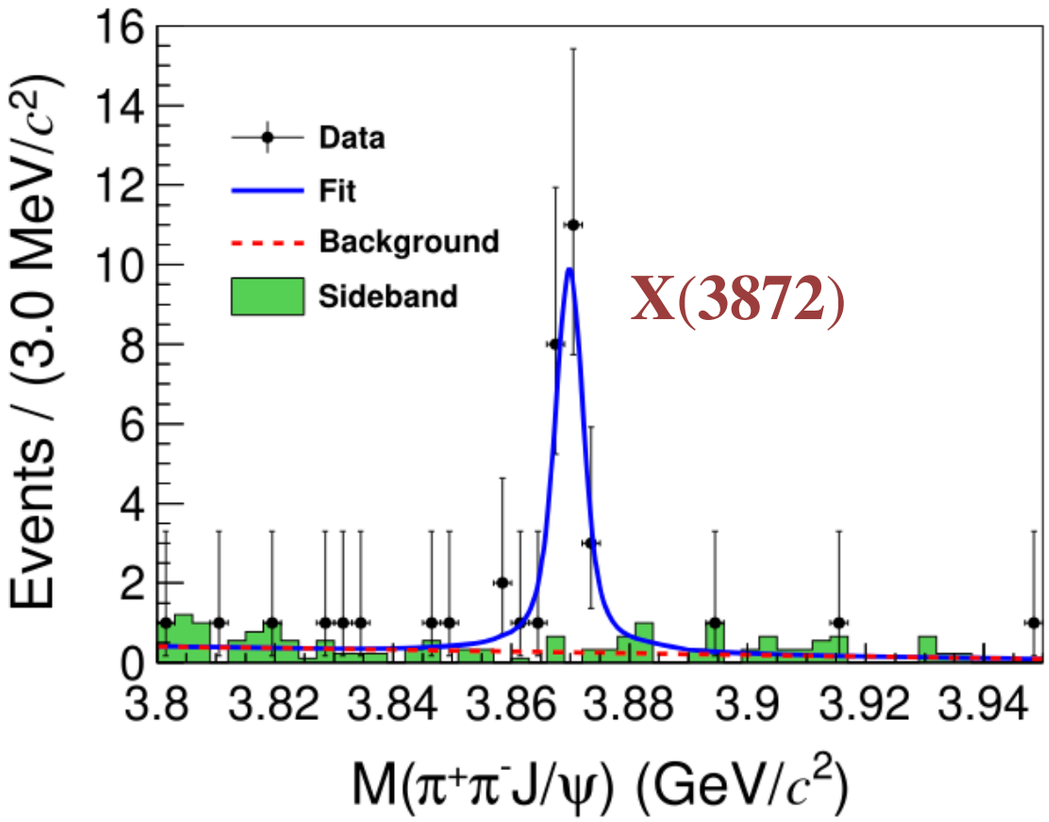
(2) It also provides access to new $X(3872)$ decay modes:

eg $\omega J/\psi, \bar{D}^0 D^{*0}, \pi^0 \chi_{c1}, \gamma J/\psi, \gamma\psi(2S)$

3. Updates on the $X(3872)$ (aka $\chi_{c1}(3872)$)

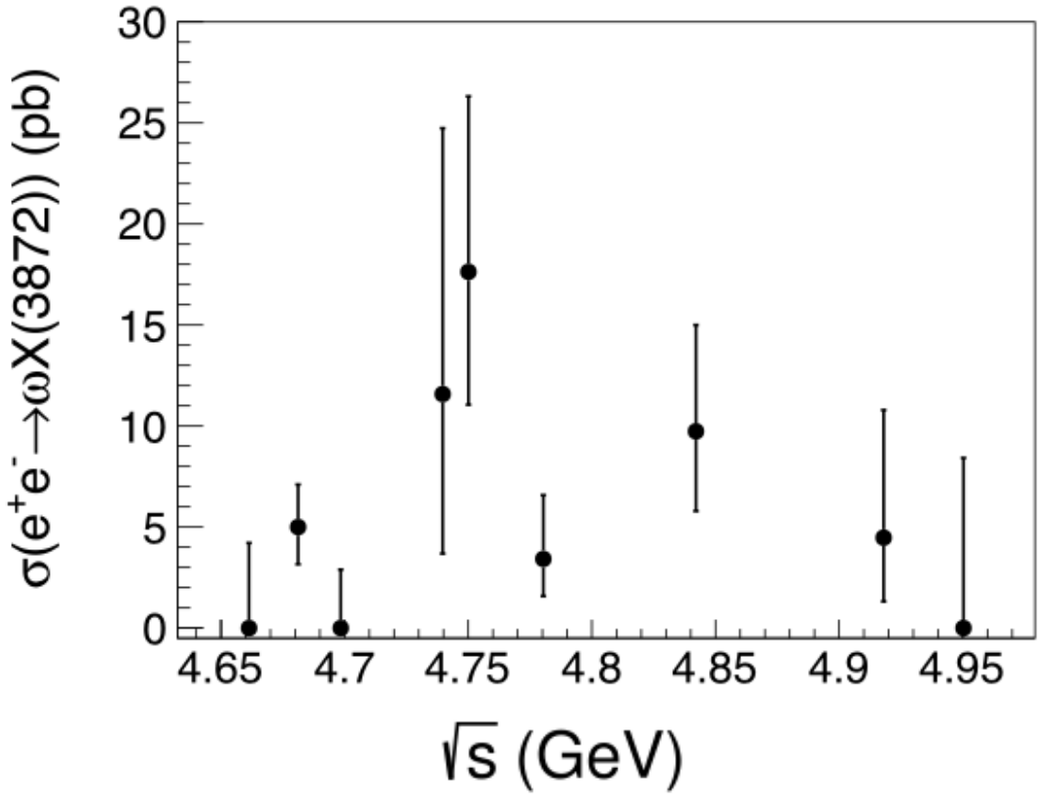
BESIII also produces the $X(3872)$ using $e^+e^- \to \omega X(3872)$ at higher center-of-mass energies…

BESIII $e^+e^- \to \omega(\pi^+\pi^- J/\psi)$ (2023)



Phys.Rev.Lett. 130 (2023) 15, 151904

BESIII $e^+e^- \to \omega(\pi^+\pi^- J/\psi)$ (2024)



Phys.Rev.D 110 (2024) 1, 012006

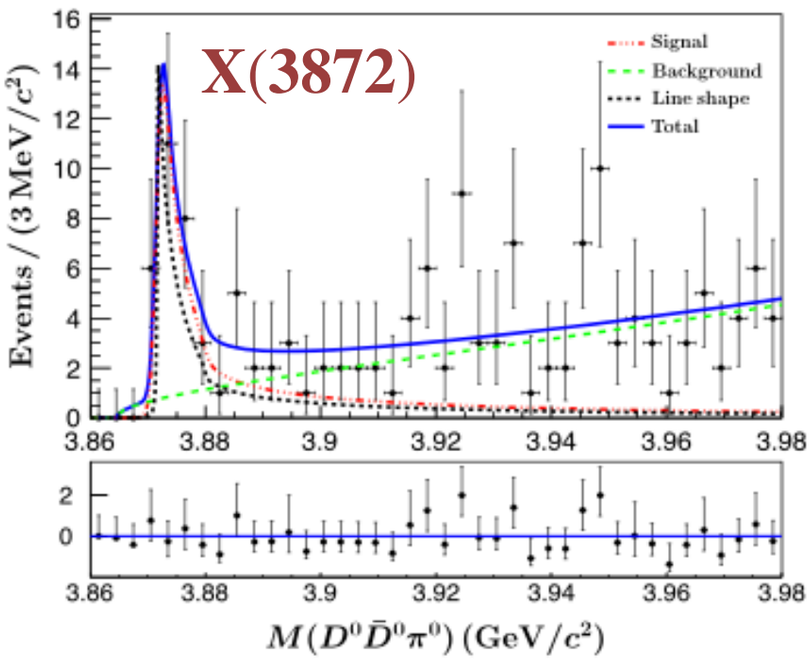
New production mechanism provides cross-checks on decay modes (eg $X(3872) \to \gamma J/\psi$).

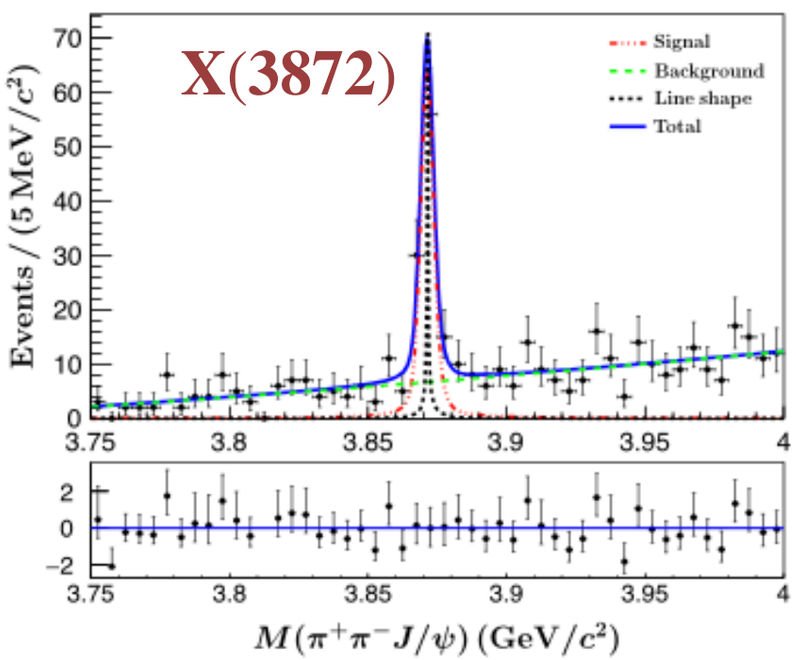
More data is required to study the $\sqrt{s}$ dependence of the cross section.

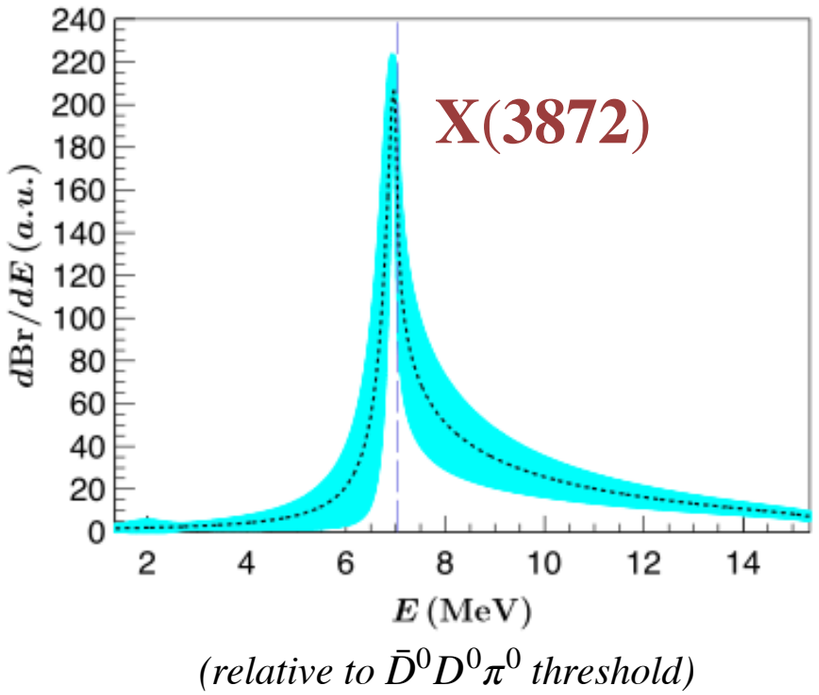
3. Updates on the $X(3872)$ (aka $\chi_{c1}(3872)$)

Using both $X(3872) \to \bar{D}^0 D^{*0}$ and $X(3872) \to \pi^+\pi^- J/\psi$ gives access to the T-matrix pole position…

BESIII $e^+e^- \to \gamma(\bar{D}^0 D^{*0})$ and $e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$ (2024)







BESIII, Phys.Rev.Lett. 132 (2024) 15, 151903

Using a Flatte parameterization with $\bar{D}D^*$ and $\rho J/\psi$ coupled channels…

T-matrix pole position: $(3871.70 \pm 0.15^{+0.07}_{-0.08}) - i(0.19 \pm 0.08^{+0.14}_{-0.19})$ MeV

The real part is still consistent with the $\bar{D}^0 D^{*0}$ threshold (3871.70 ± 0.11 MeV/c^2), and the imaginary part leads to a width of 0.38 MeV.

Hadron Spectroscopy Highlights from BESIII

BEPCII: Beijing Electron Positron Collider

symmetric e^+e^- collisions

BESIII: Beijing Spectrometer

running since 2009

Beijing, China

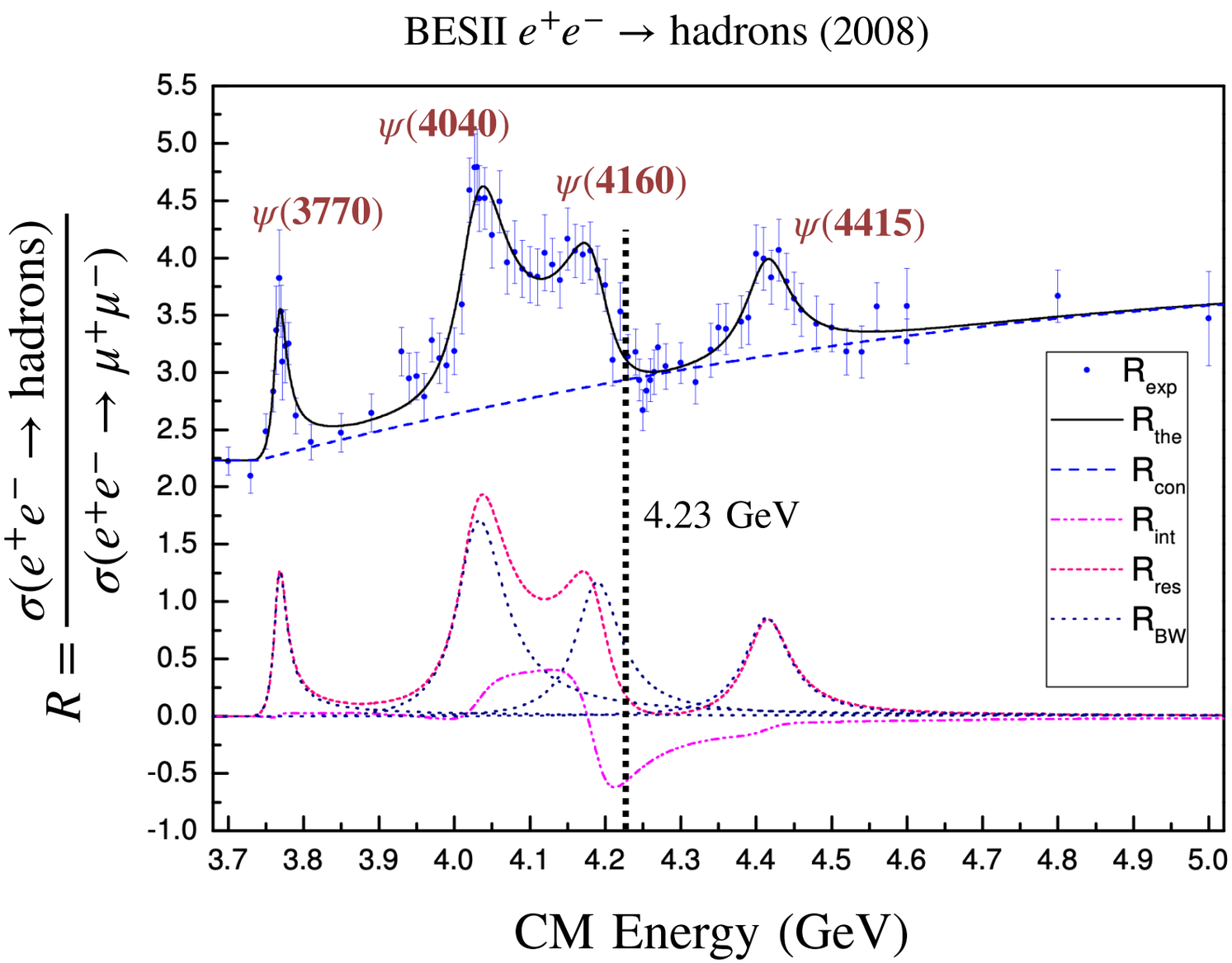
<u>This Talk *(a small subset of recent results)*:</u>

1. Glueball Candidates in Radiative ψ Decays
2. The $\pi_1(1600)$ in χ_{c1} Decays
3. Updates on the $X(3872)$ *(aka $\chi_{c1}(3872)$)*
4. Updates on the Y States *(aka ψ states)*
5. Updates on the $Z_c(3900)$ *(aka $T_{c\bar{c}1}(3900)$)*

Physics topics span a wide range of topics: light quark spectroscopy; light meson decays; hyperon physics; initial state radiation and two photon fusion; precision open charm decays; charmonium spectroscopy; spectroscopy of exotic "XYZ" states; etc. etc.

4. Updates on the Y States (aka ψ states)

Vector states of charmonium can be studied using e^+e^- annihilation…



BESII, Phys.Lett.B 660 (2008) 315-319

The system of vector states looks complete in the inclusive e^+e^- spectrum:

$$\psi(3770) \approx \psi(1^3D_1)$$

$$\psi(4040) \approx \psi(3^3S_1)$$

$$\psi(4160) \approx \psi(2^3D_1)$$

$$\psi(4415) \approx \psi(4^3S_1)$$

Notes:

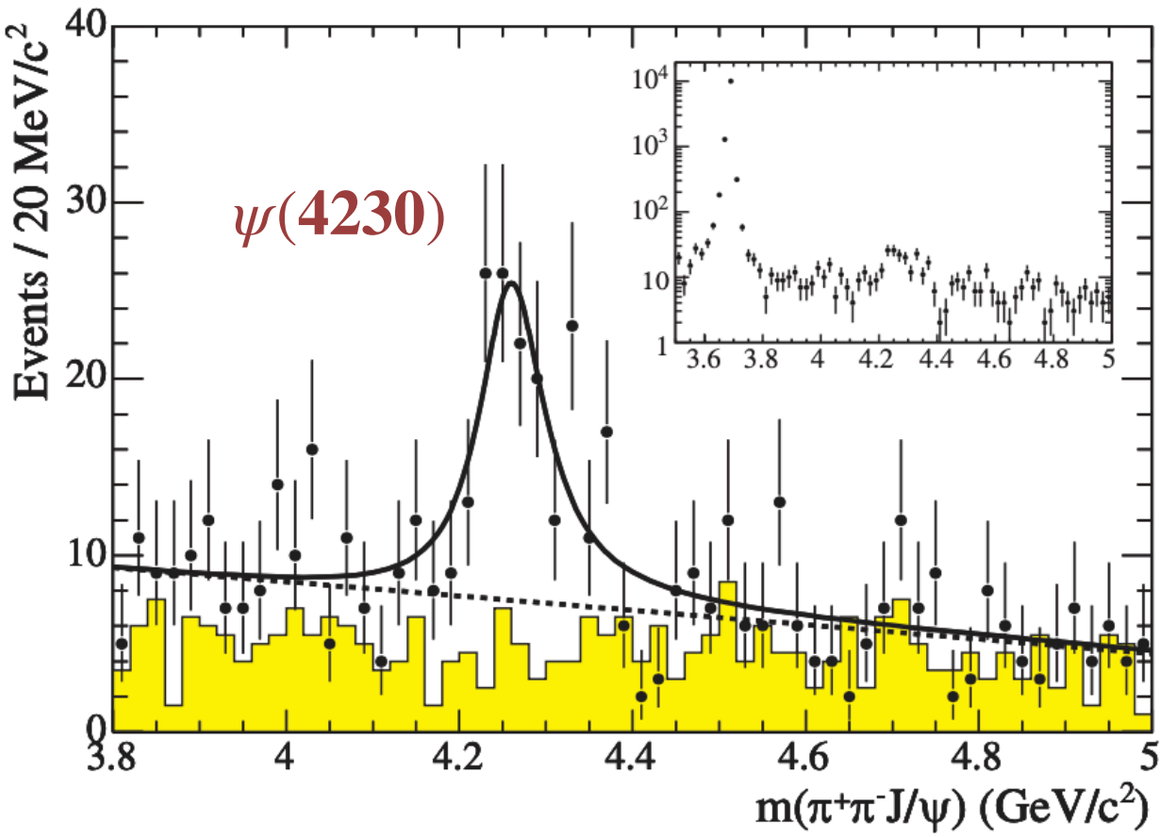
Expect a more precise measurement of R from BESIII soon!

Resonance parameters are sensitive to the parameterization used.

4. Updates on the Y States (aka ψ states)

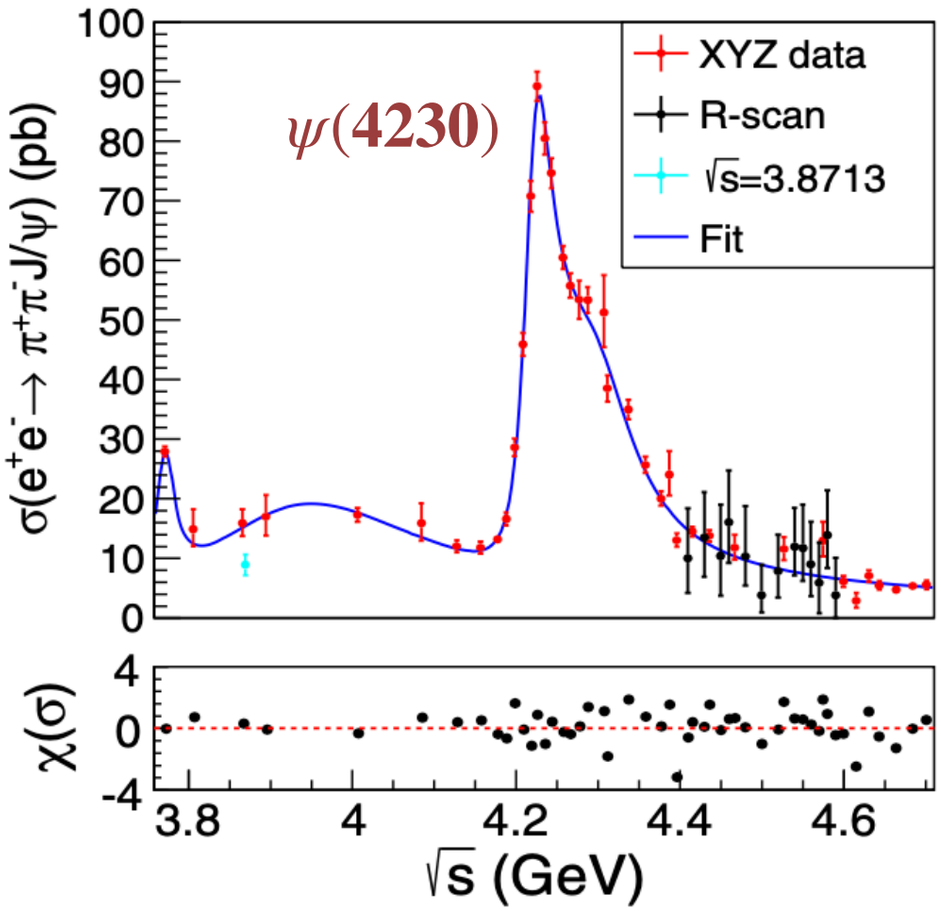
The $Y(4260)$ (now $\psi(4230)$) was first seen in the exclusive cross section for $e^+e^- \to \pi^+\pi^- J/\psi$…

BaBar $e^+e^-(\gamma_{\rm ISR}) \to \pi^+\pi^- J/\psi$ (2005)



BaBar, Phys.Rev.Lett. 95 (2005) 142001

BESIII $e^+e^- \to \pi^+\pi^- J/\psi$ (2022)



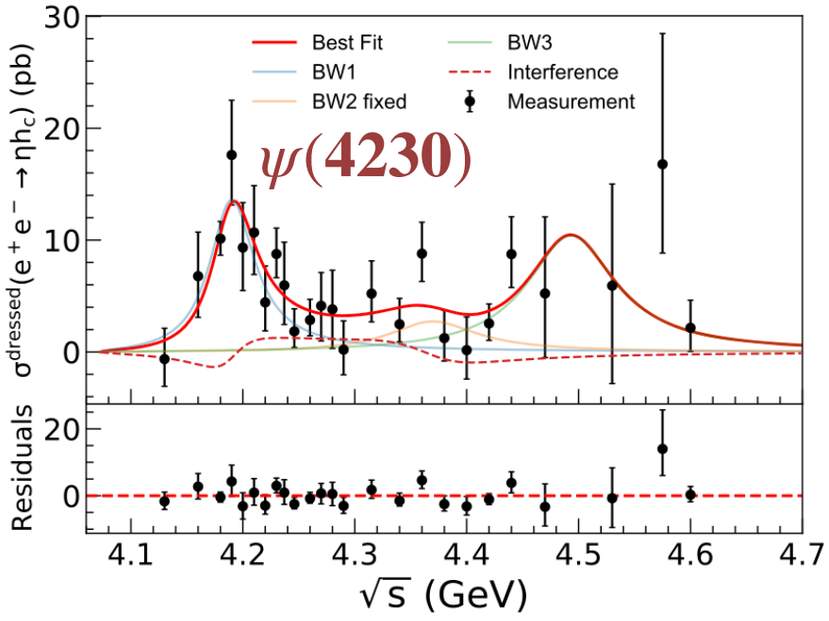
BESIII, Phys.Rev.D 106 (2022) 7, 072001

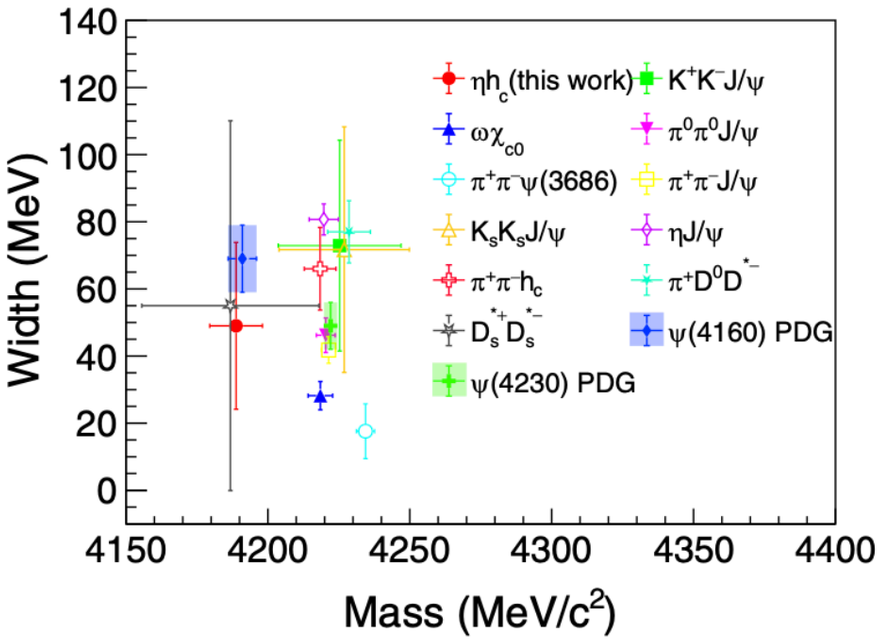
The exclusive cross section for $e^+e^- \to \pi^+\pi^- J/\psi$ shows structure not apparent in the inclusive e^+e^- cross section.

4. Updates on the Y States (aka ψ states)

Besides $e^+e^- \to \pi^+\pi^- J/\psi$, other exclusive cross sections also show signs of a $\psi(4230)$…

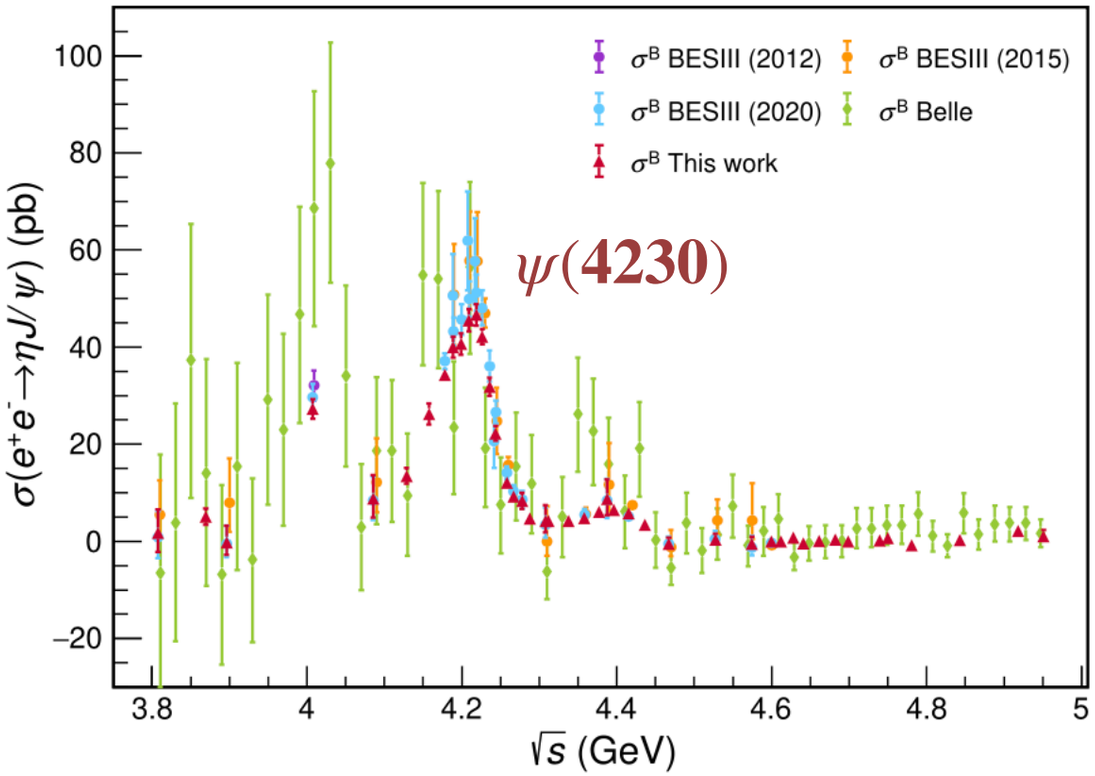
BESIII $e^+e^- \to \eta h_c$ (2025)





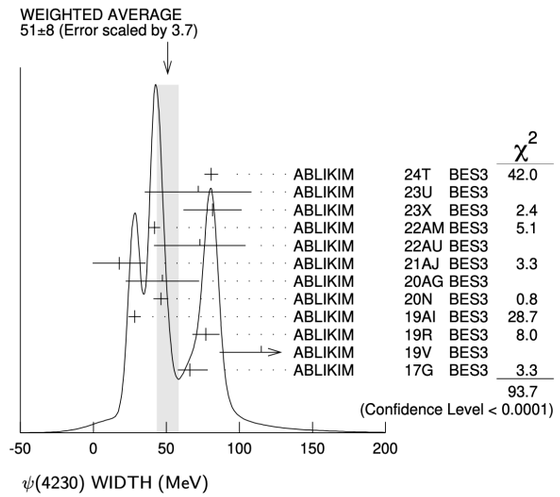
BESIII, Phys.Rev.D 111 (2025) 1, L011101

BESIII $e^+e^- \to \eta J/\psi$ (2024)



BESIII, Phys.Rev.D 109 (2024) 9, 092012

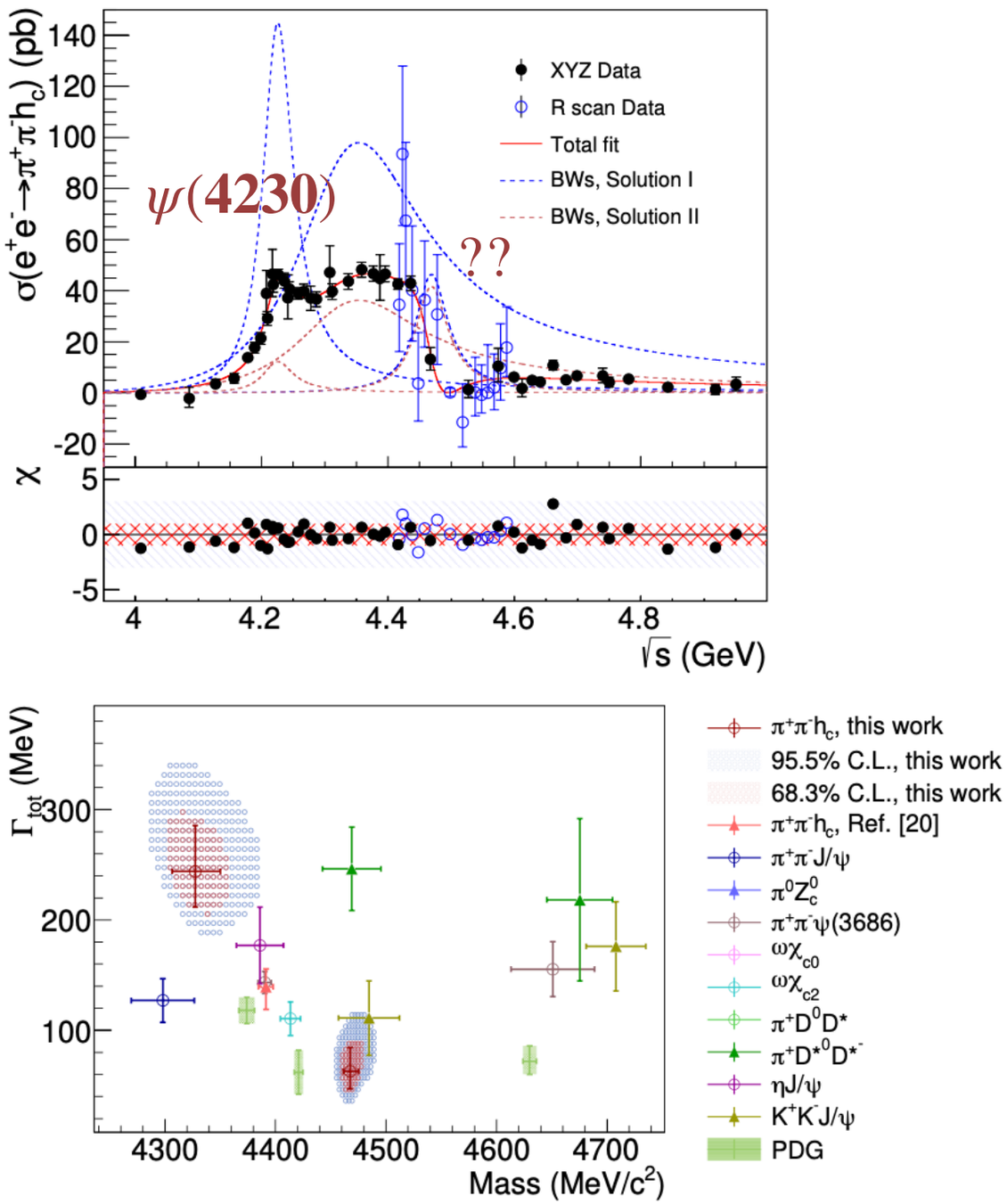
The mass of the $\psi(4230)$ is fairly consistent among exclusive channels, but the width is not!



4. Updates on the Y States (aka ψ states)

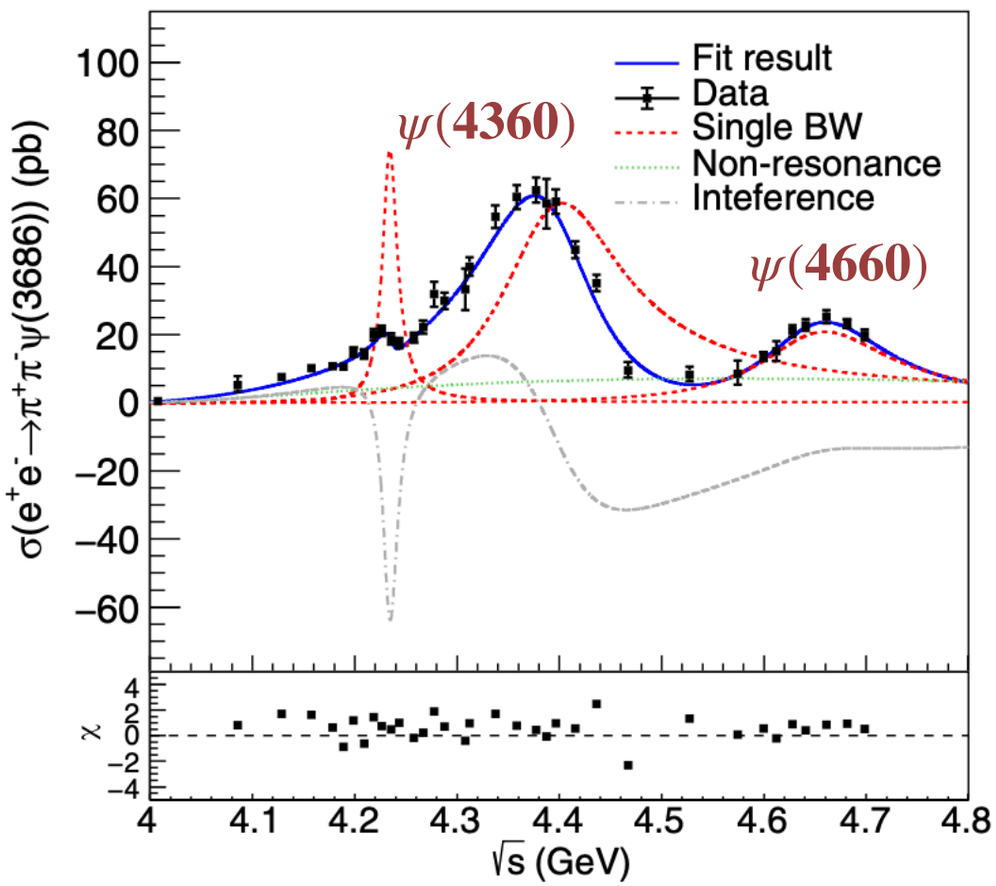
Many channels also show structure at higher masses…

BESIII $e^+e^- \to \pi^+\pi^- h_c$ (2025)



BESIII, e-Print: 2504.04096

BESIII $e^+e^- \to \pi^+\pi^-\psi(2S)$ (2021)



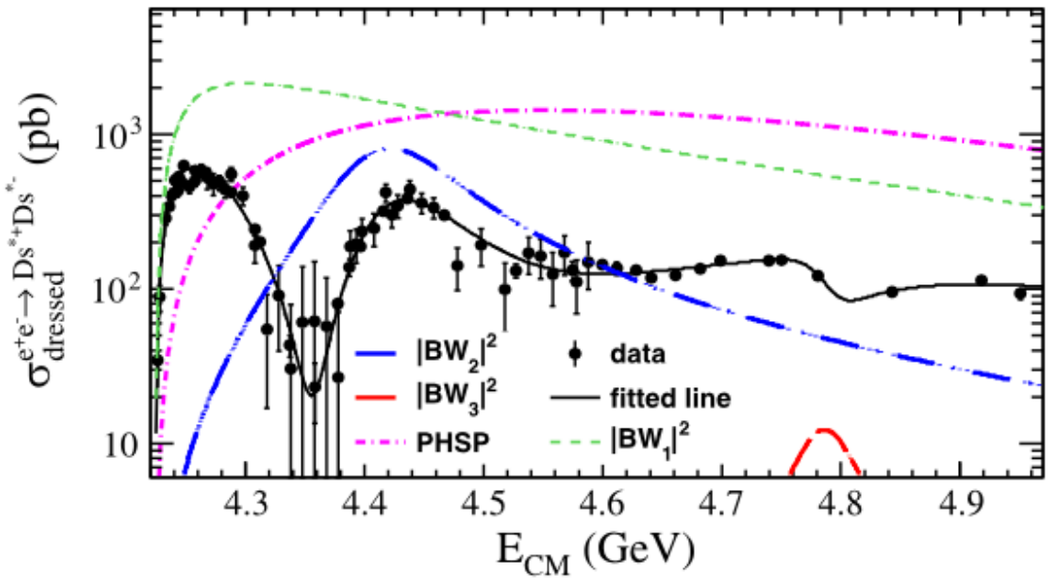
BESIII, Phys.Rev.D 104 (2021) 5, 052012

At masses above the $\psi(4230)$, there is little consistency between exclusive channels.

4. Updates on the Y States (aka ψ states)

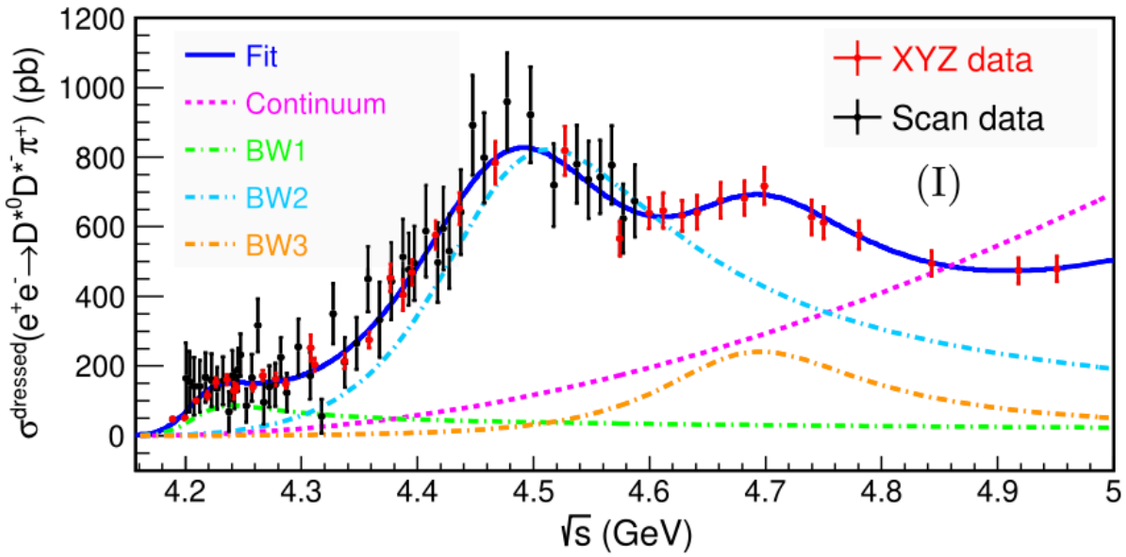
Open charm channels generally have larger cross sections and show even more complex structure…

BESIII $e^+e^- \to D_s^{*+}D_s^{*-}$ (2023)



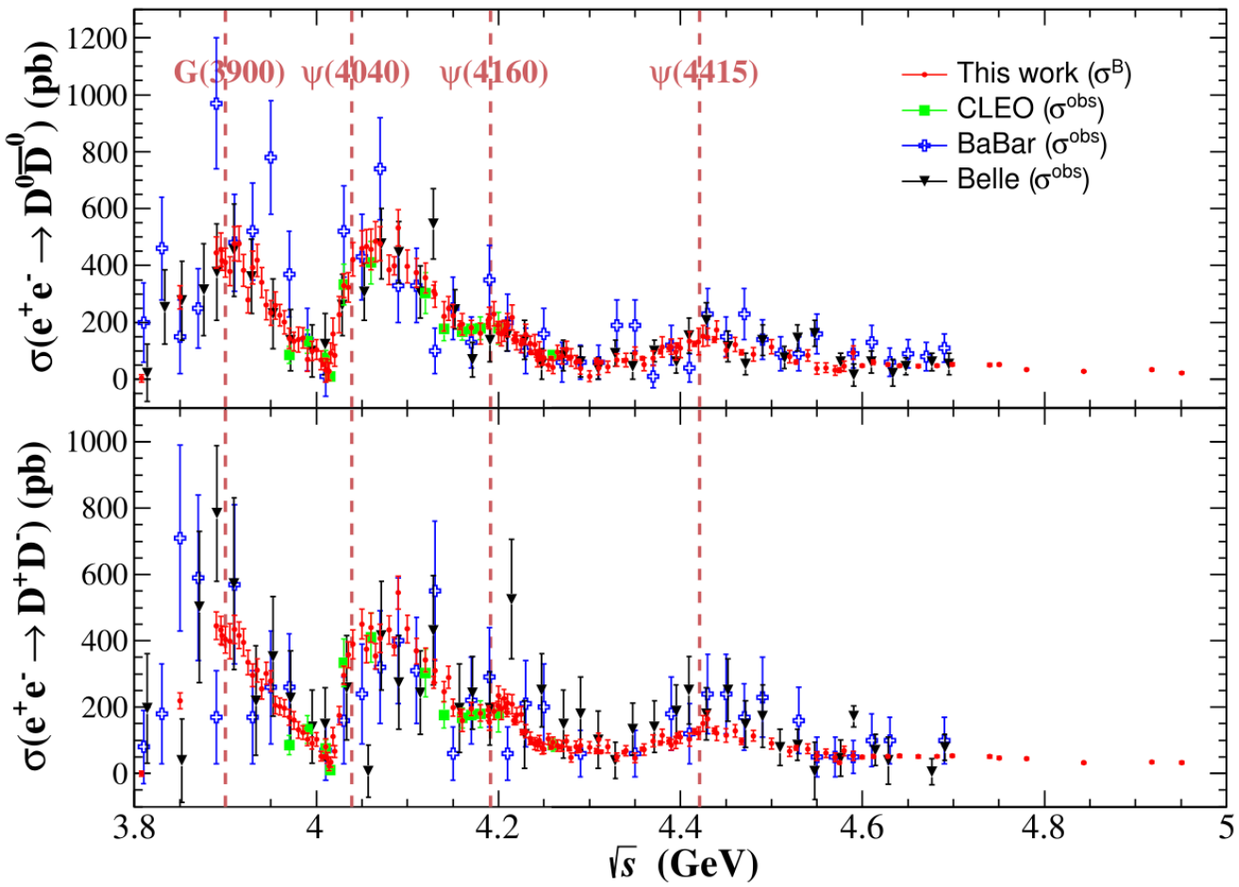
BESIII, Phys.Rev.Lett. 131 (2023) 15, 151903

BESIII $e^+e^- \to \pi^+D^{*0}D^{*-}$ (2023)



BESIII, Phys.Rev.Lett. 130 (2023) 12, 121901

BESIII $e^+e^- \to D^0\bar{D}^0$, D^+D^- (2024)

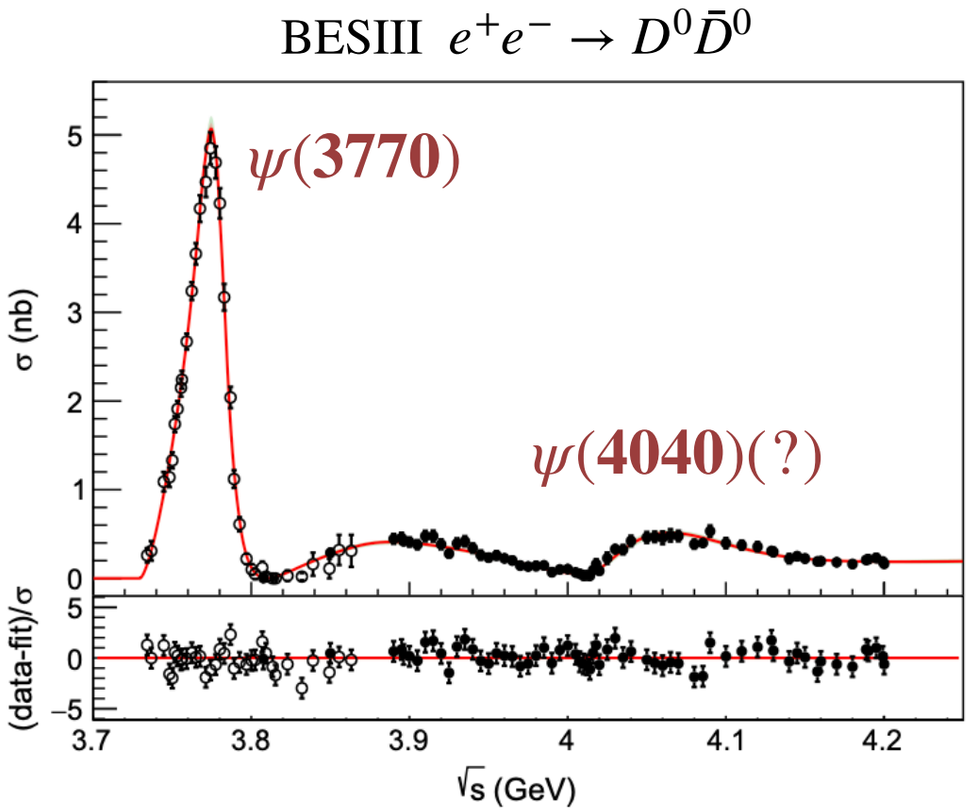


BESIII, Phys.Rev.Lett. 133 (2024) 8, 081901

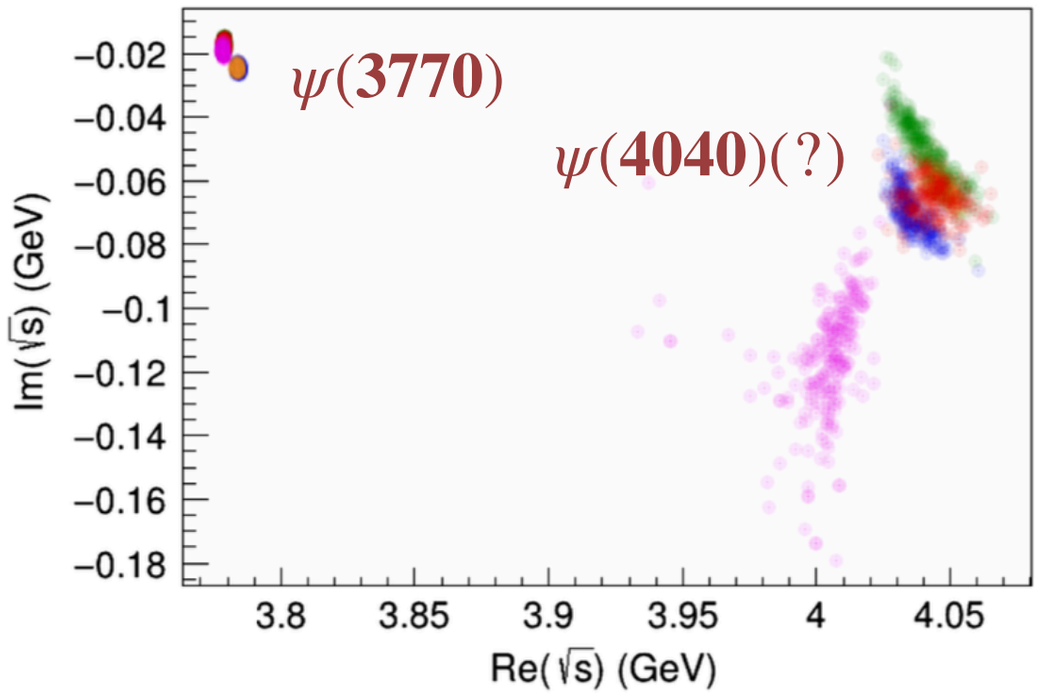
Fitting these requires a global coupled-channel analysis!

4. Updates on the Y States (aka ψ states)

As a pilot study (among several), fit the $e^+e^- \to \bar{D}D$, $\bar{D}^*D$ + cc, $\bar{D}^*D^*$ channels simultaneously using a K-matrix model…



N. Hüsken et al., Phys.Rev.D 109 (2024) 11, 114010



(colors represent various model choices, eg constraints among couplings)

$$\mathcal{M} = (1 + KC)^{-1}K$$

$$K_{\mu,\nu} = \sum_R \frac{g_{R:\mu}g_{R:\nu}}{m_R^2 - s} + f_{\mu,\nu}.$$

(using momentum-dependent resonant (g) and non-resonant (f) couplings)

Resonance properties (eg mass, width) can be strongly dependent on details of the fit parameterization, even for the $\psi(4040)$.

Hadron Spectroscopy Highlights from BESIII

BEPCII: Beijing Electron Positron Collider

symmetric e^+e^- collisions

BESIII: Beijing Spectrometer

running since 2009

Beijing, China

(EM) calorimeter

tracker (2025)

This Talk *(a small subset of recent results)*:

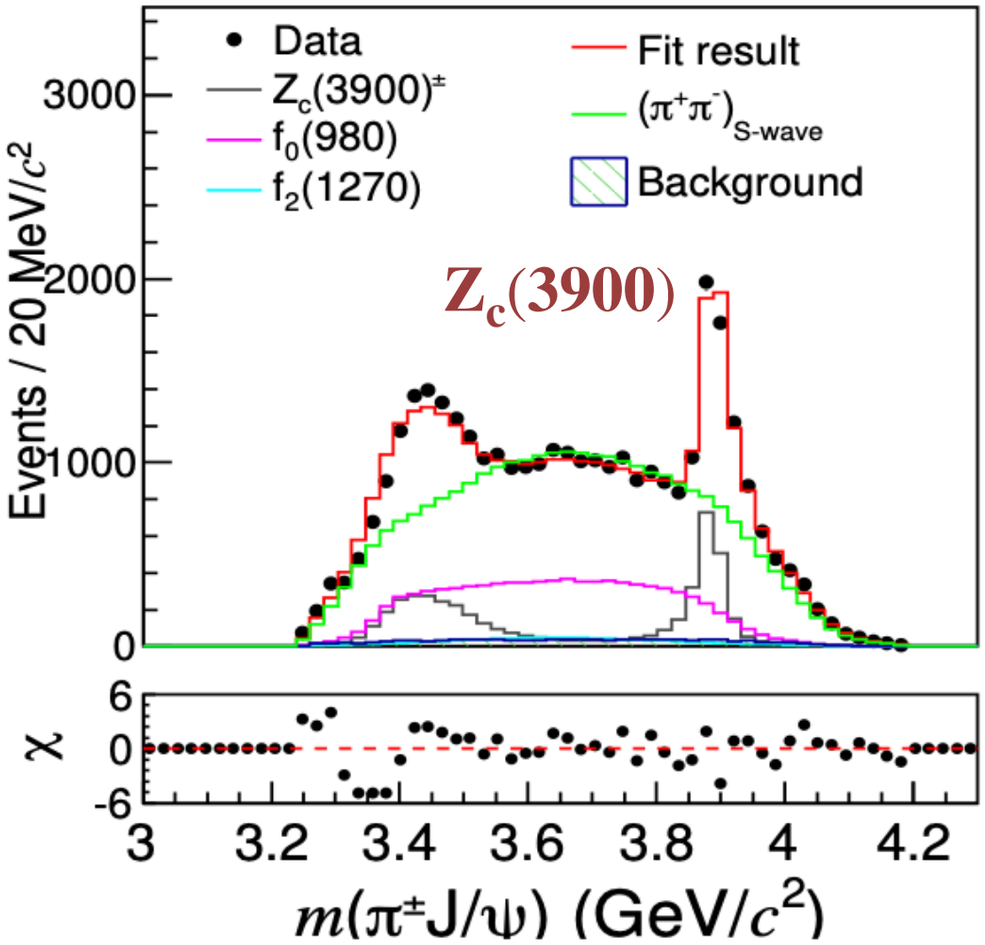
1. Glueball Candidates in Radiative ψ Decays
2. The $\pi_1(1600)$ in χ_{c1} Decays
3. Updates on the $X(3872)$ *(aka $\chi_{c1}(3872)$)*
4. Updates on the Y States *(aka ψ states)*
5. Updates on the $Z_c(3900)$ *(aka $T_{c\bar{c}1}(3900)$)*

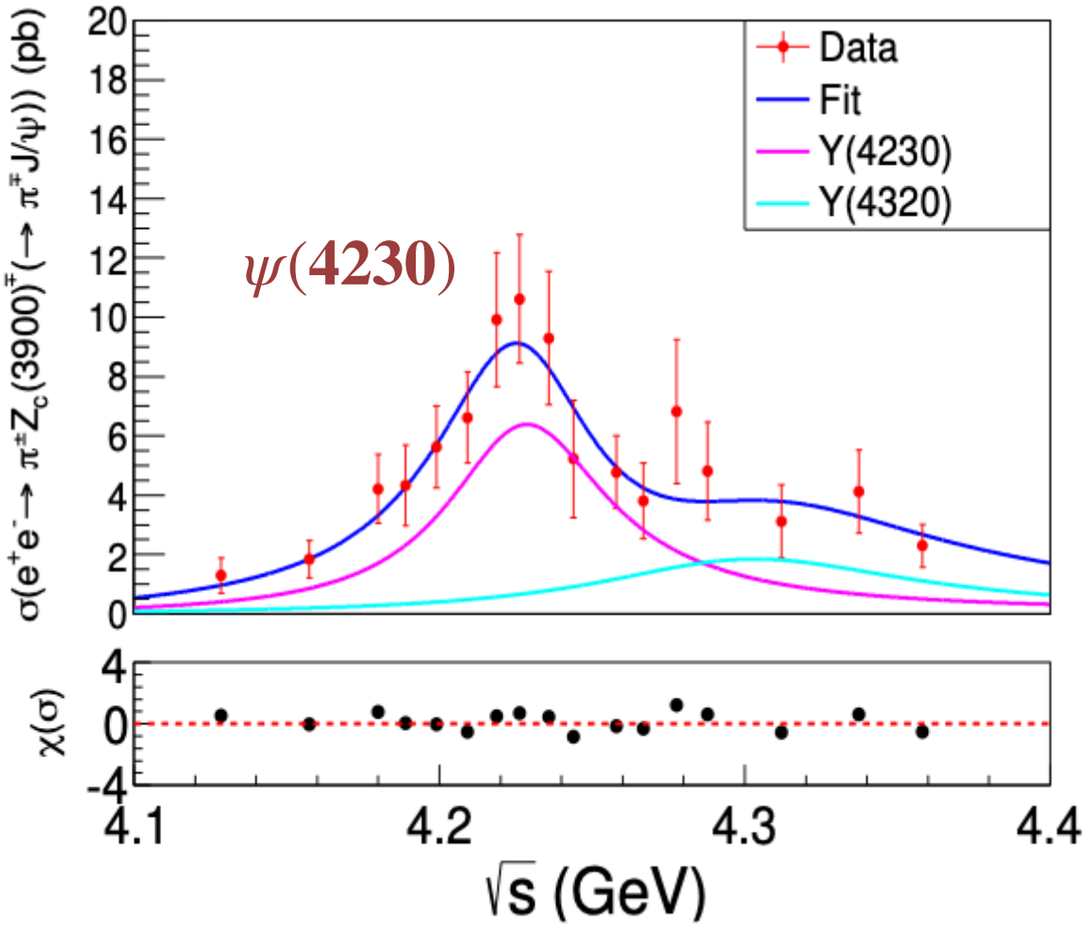
Physics topics span a wide range of topics: light quark spectroscopy; light meson decays; hyperon physics; initial state radiation and two photon fusion; precision open charm decays; charmonium spectroscopy; spectroscopy of exotic "XYZ" states; etc. etc.

5. Updates on the $Z_c(3900)$ (aka $T_{c\bar{c}1}(3900)$)

The $Z_c(3900)$ is produced through $e^+e^- \to \pi Z_c$ at center-of-mass energies near the $\psi(4230)$…

BESIII $e^+e^- \to \pi^+\pi^- J/\psi$ (2025)





e-Print: 2505.13222 [hep-ex]

The latest analysis uses all data (12 fb^{-1}) between 4.1 and 4.4 GeV.
Acceptance-corrected plots at each energy are available.
The new data are sensitive to the $Z_c(3900)$ line shape.

Hadron Spectroscopy Highlights from BESIII

BEPCII: Beijing Electron Positron Collider

symmetric e^+e^- collisions

BESIII: Beijing Spectrometer

running since 2009

Beijing, China

(TOF) calorimeter

tracker (2025)

<u>This Talk *(a small subset of recent results)*:</u>

1. Glueball Candidates in Radiative ψ Decays
2. The $\pi_1(1600)$ in χ_{c1} Decays
3. Updates on the $X(3872)$ *(aka $\chi_{c1}(3872)$)*
4. Updates on the Y States *(aka ψ states)*
5. Updates on the $Z_c(3900)$ *(aka $T_{c\bar{c}1}(3900)$)*

Physics topics span a wide range of topics: light quark spectroscopy; light meson decays; hyperon physics; initial state radiation and two photon fusion; precision open charm decays; charmonium spectroscopy; spectroscopy of exotic "XYZ" states; etc. etc.

lights from BESIII

Summary and Prospects:

BESIII remains a productive experiment with spectroscopy results spanning from light quark hadrons to exotic charmonium.

A new inner tracker (CGEM) was installed this year (2025).

The accelerator was upgraded in 2024-2025 to reach higher center-of-mass energies (5.6 GeV) and higher luminosities.

Data-taking is resuming now!
(starting with $\psi(2S)$ data)

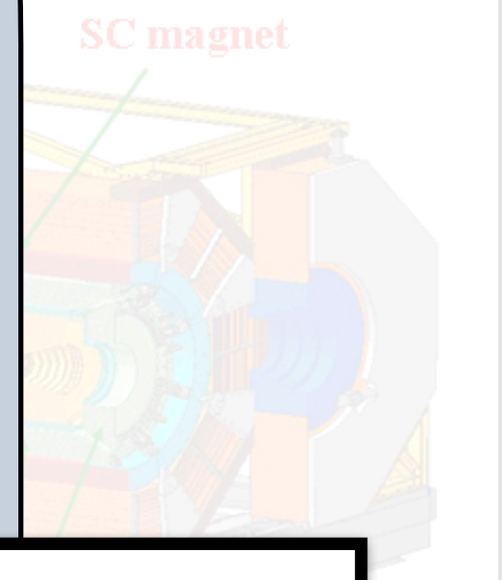
BESIII: Beijing Spectrometer

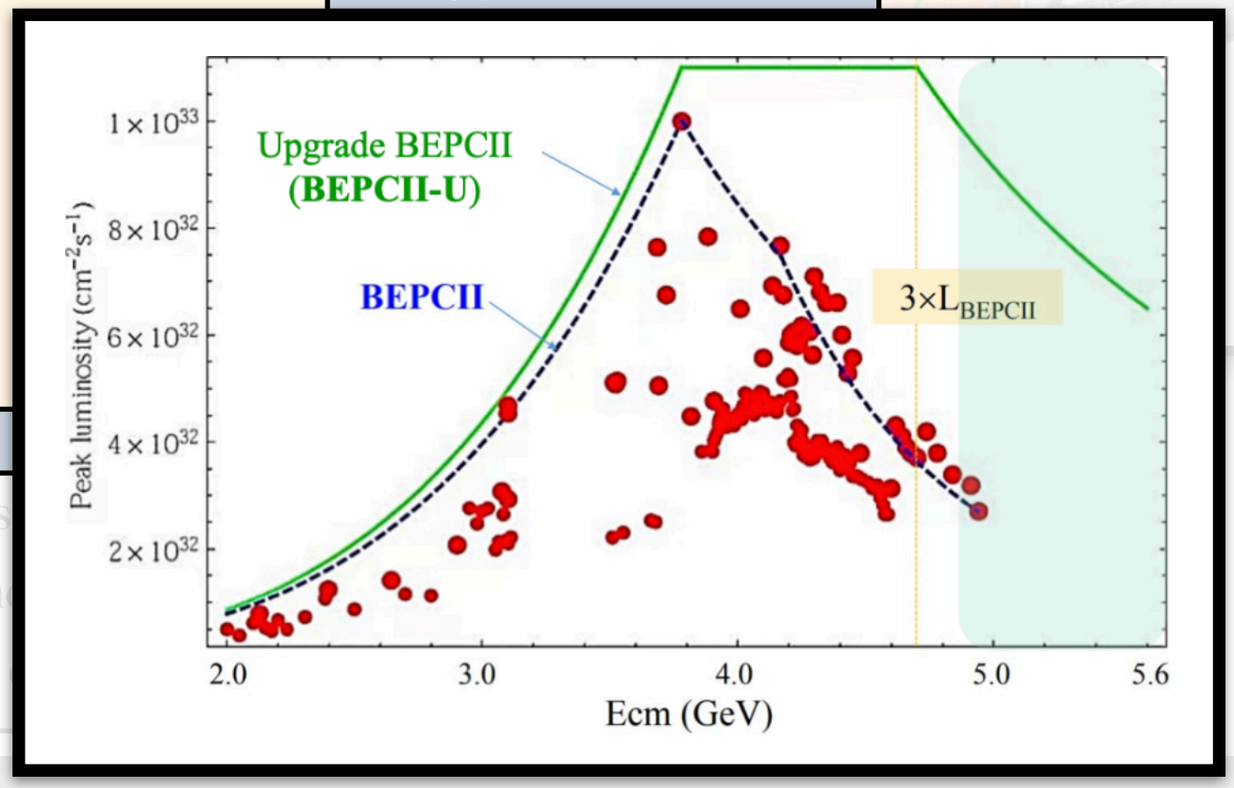
running since 2009

***cent results)*:**

lative ψ Decays

ka $\chi_{c1}(3872)$*)*





Physics topics span a wide range of topics
hyperon physics; initial state radiation an
charmonium spectroscopy; spectroscopy