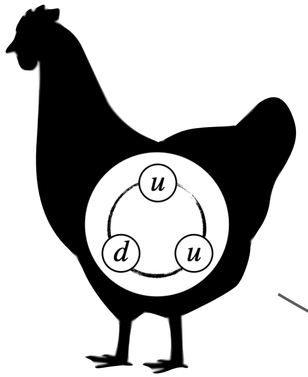
Hadron spectroscopy at BESIII

Nils Hüsken
JGU Mainz

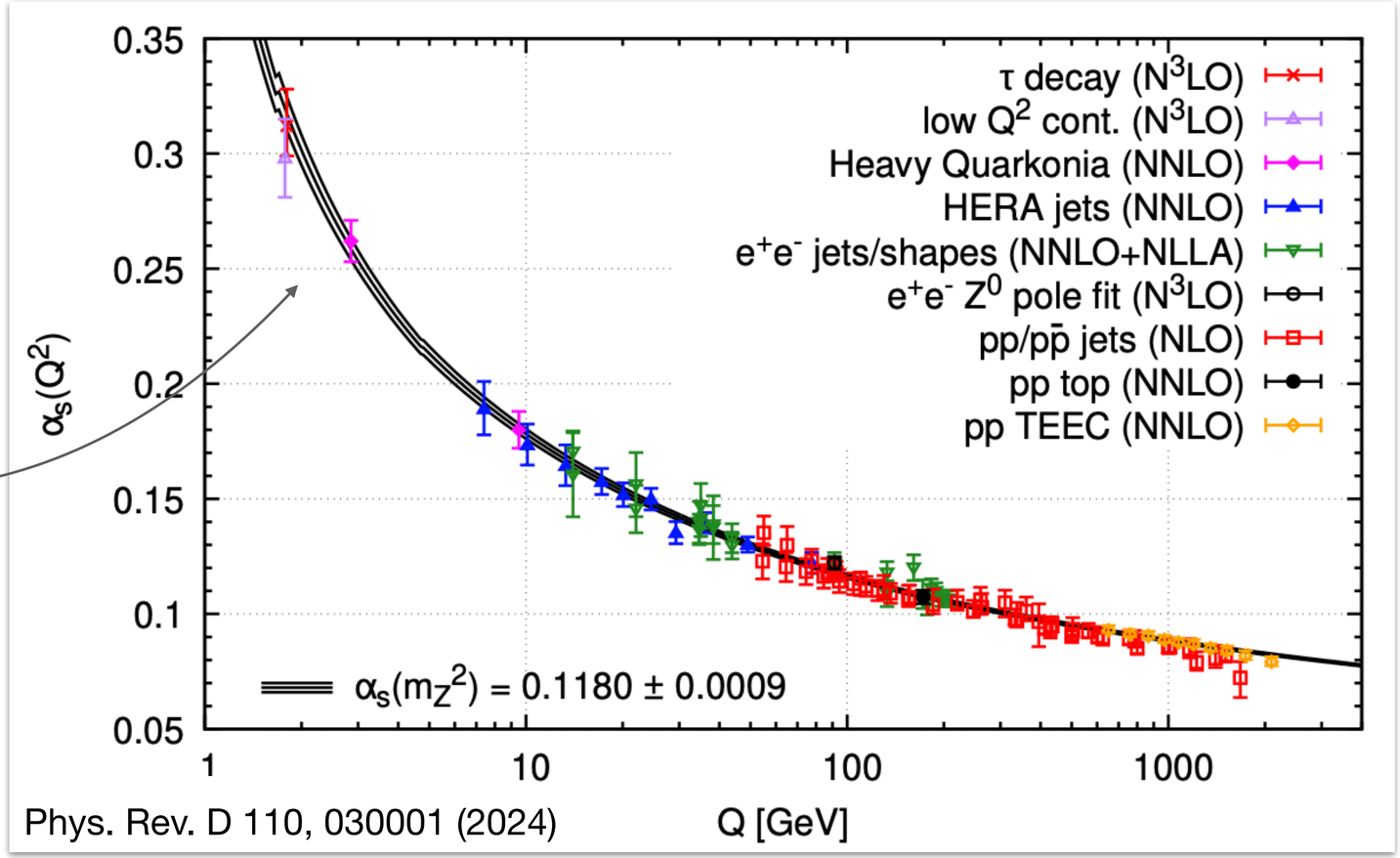
European Nuclear Physics Conference 2025

Hadron spectroscopy…

hadron

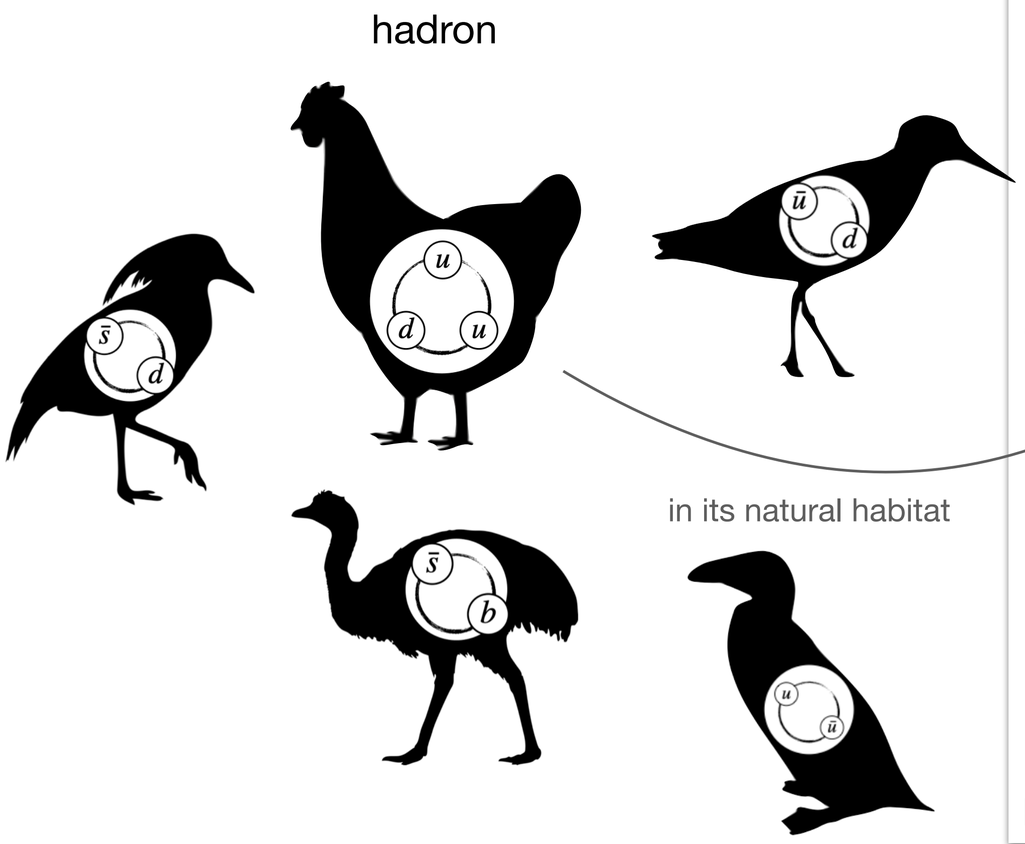


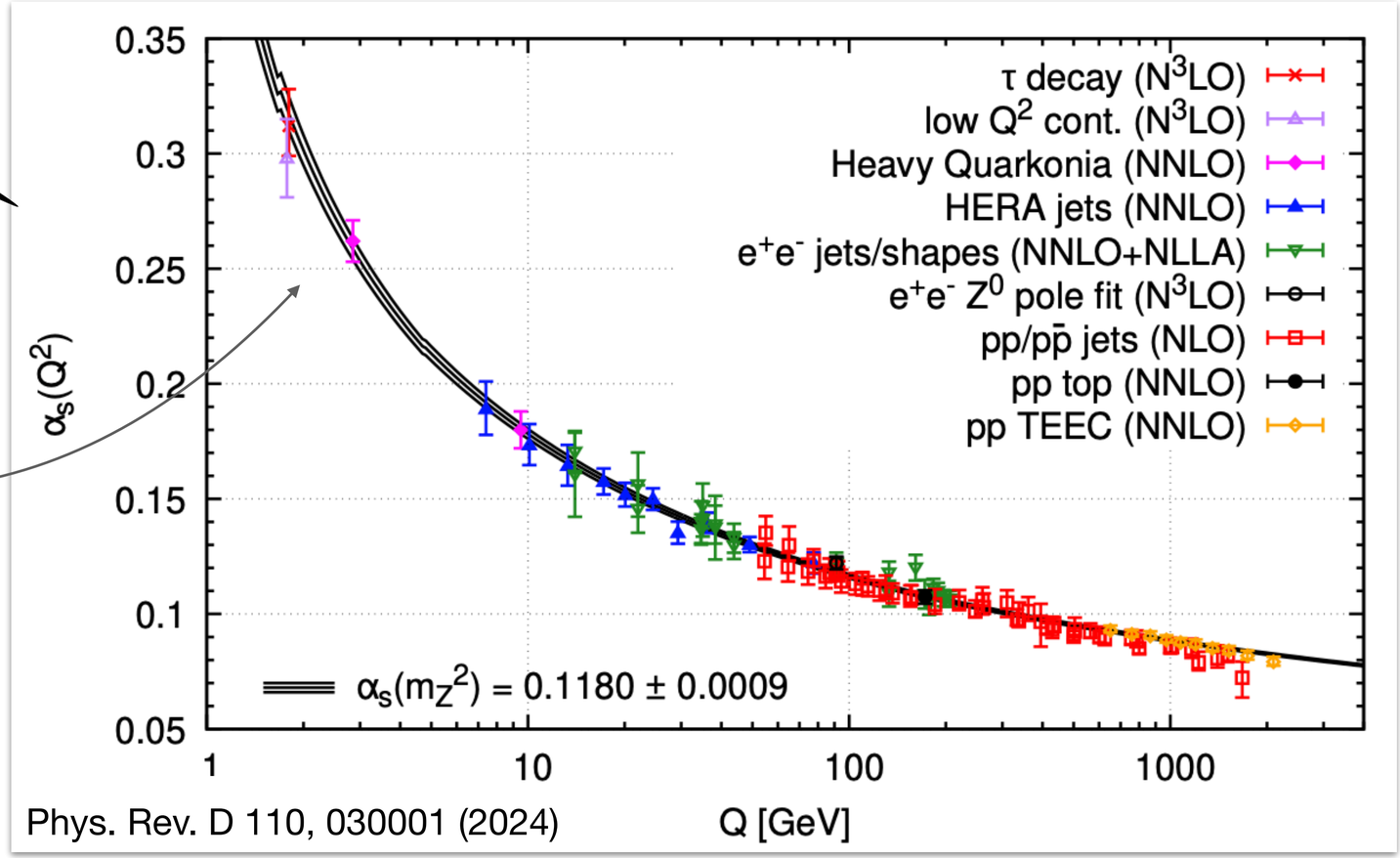
in its natural habitat



we use hadrons to study the strong interaction in the non-perturbative regime

Hadron spectroscopy…





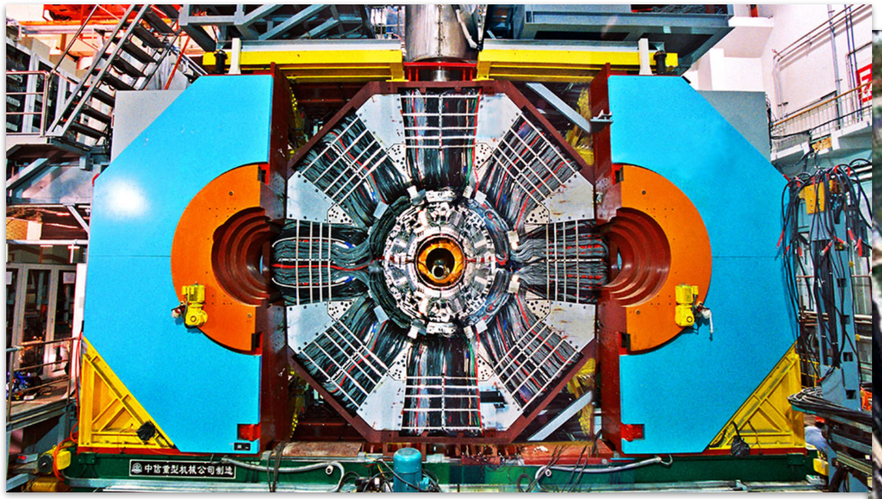
in spectroscopy, we do that by studying the variety of different hadrons realized in nature

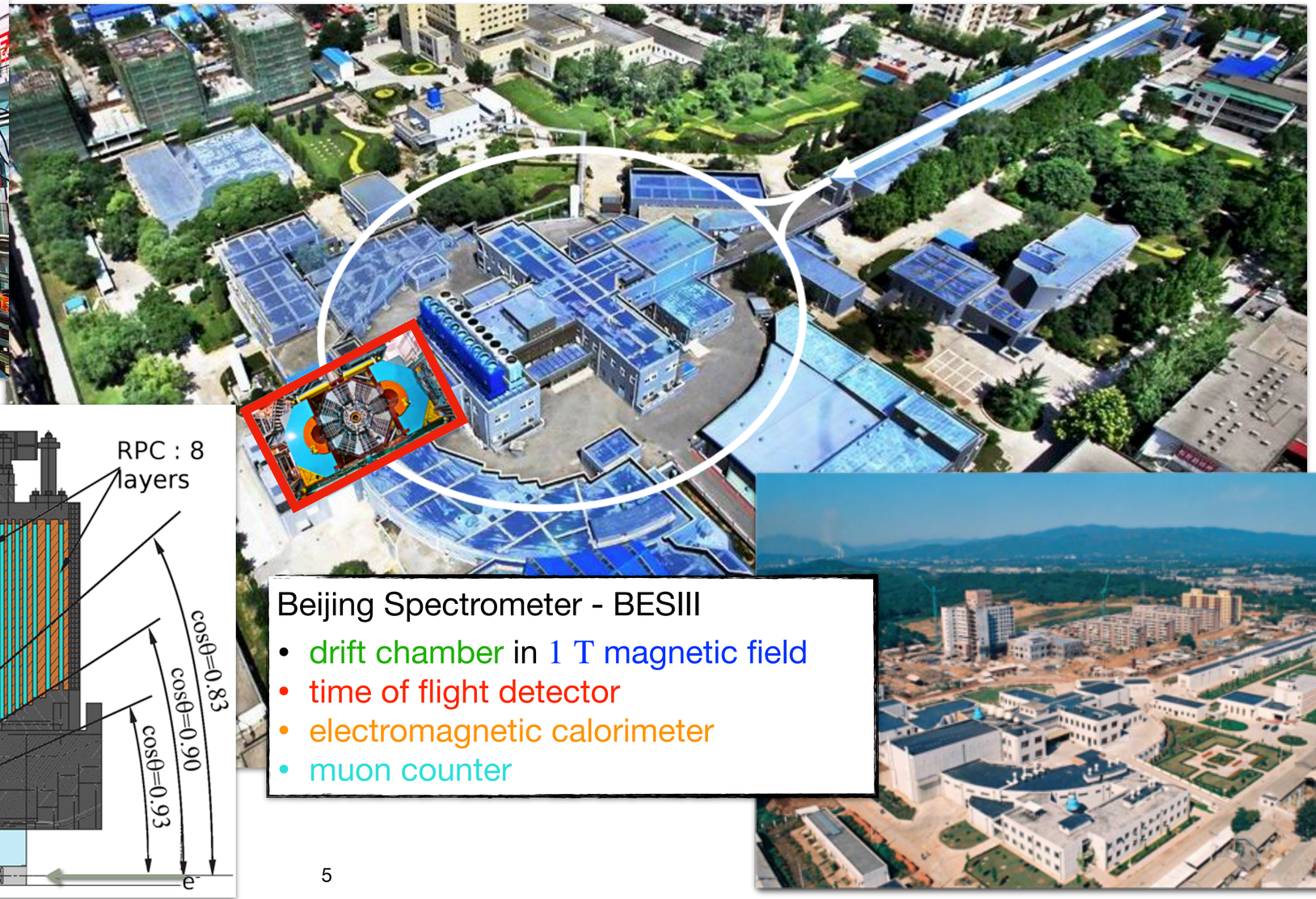
… at BESIII

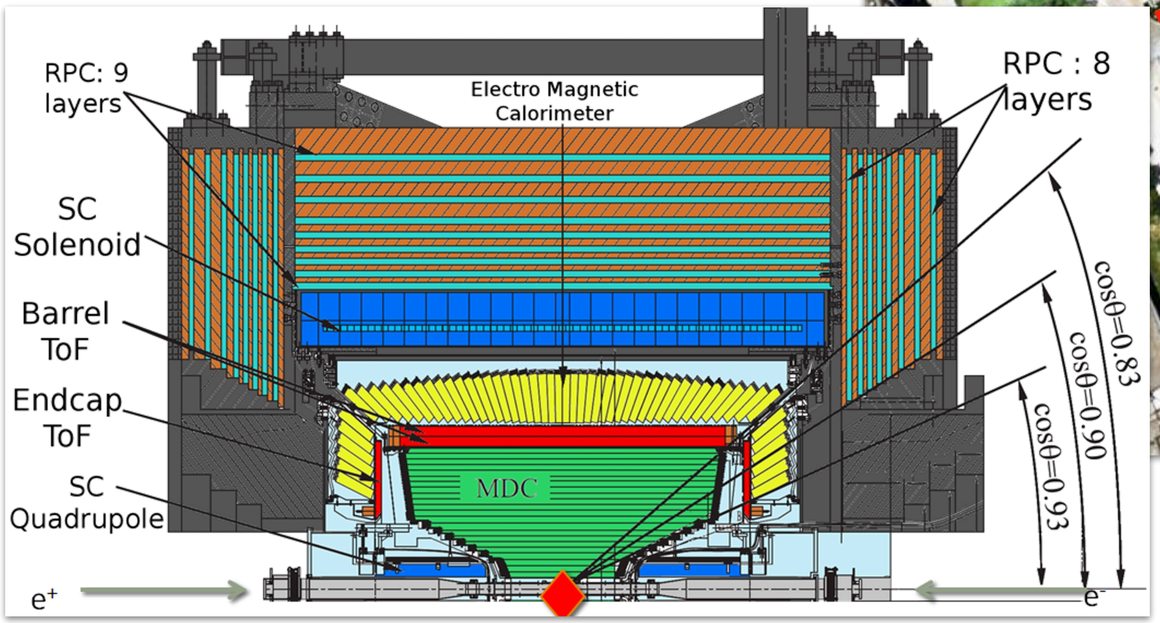
Beijing Electron Positron Collider - BEPC-II(U)

- e^+e^- collisions in the τ-charm region: 2-5 GeV
- in operation since 2008

… at BESIII



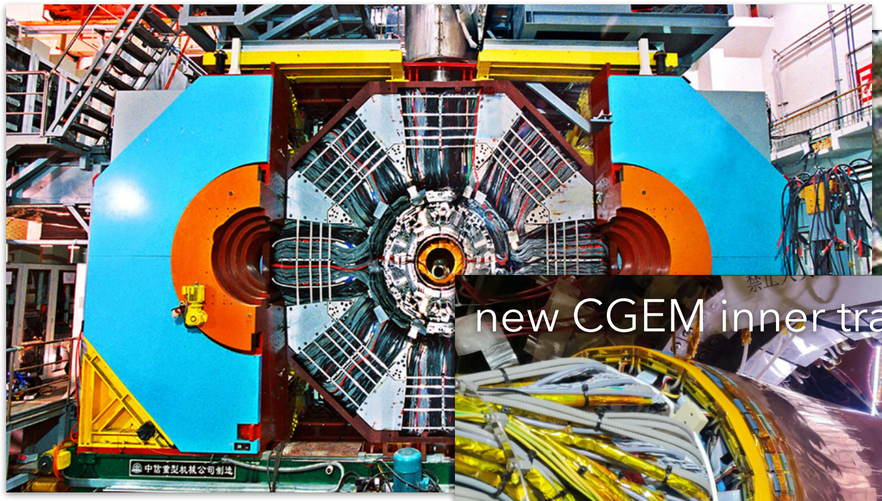


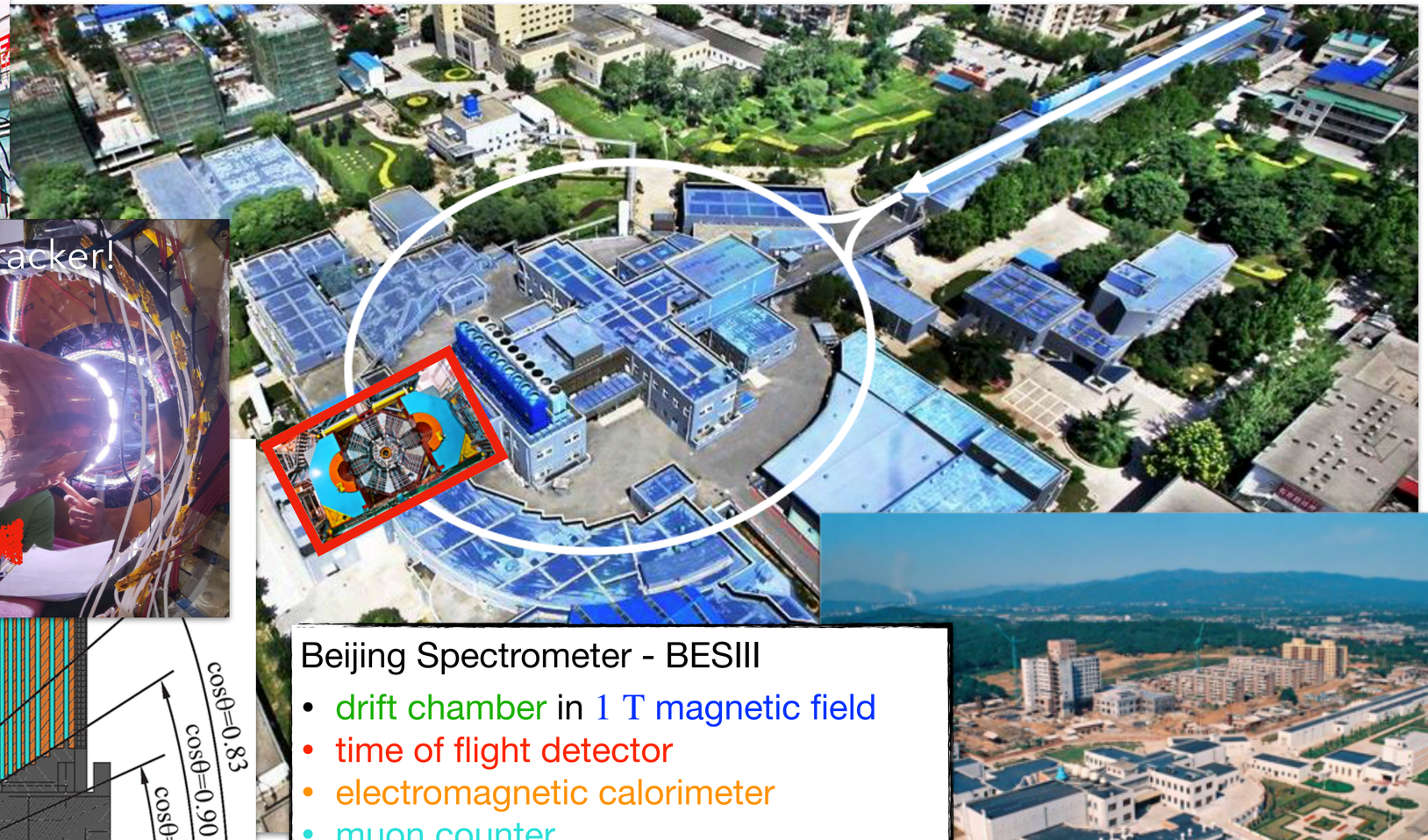


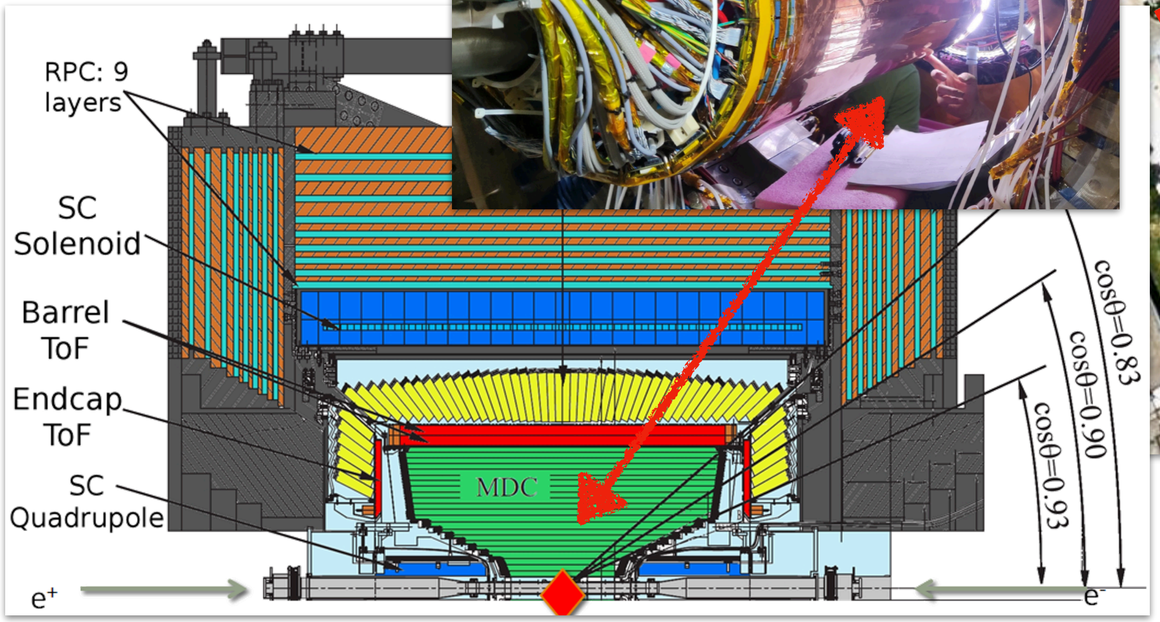
Beijing Spectrometer - BESIII

- drift chamber in 1 T magnetic field
- time of flight detector
- electromagnetic calorimeter
- muon counter

… at BESIII





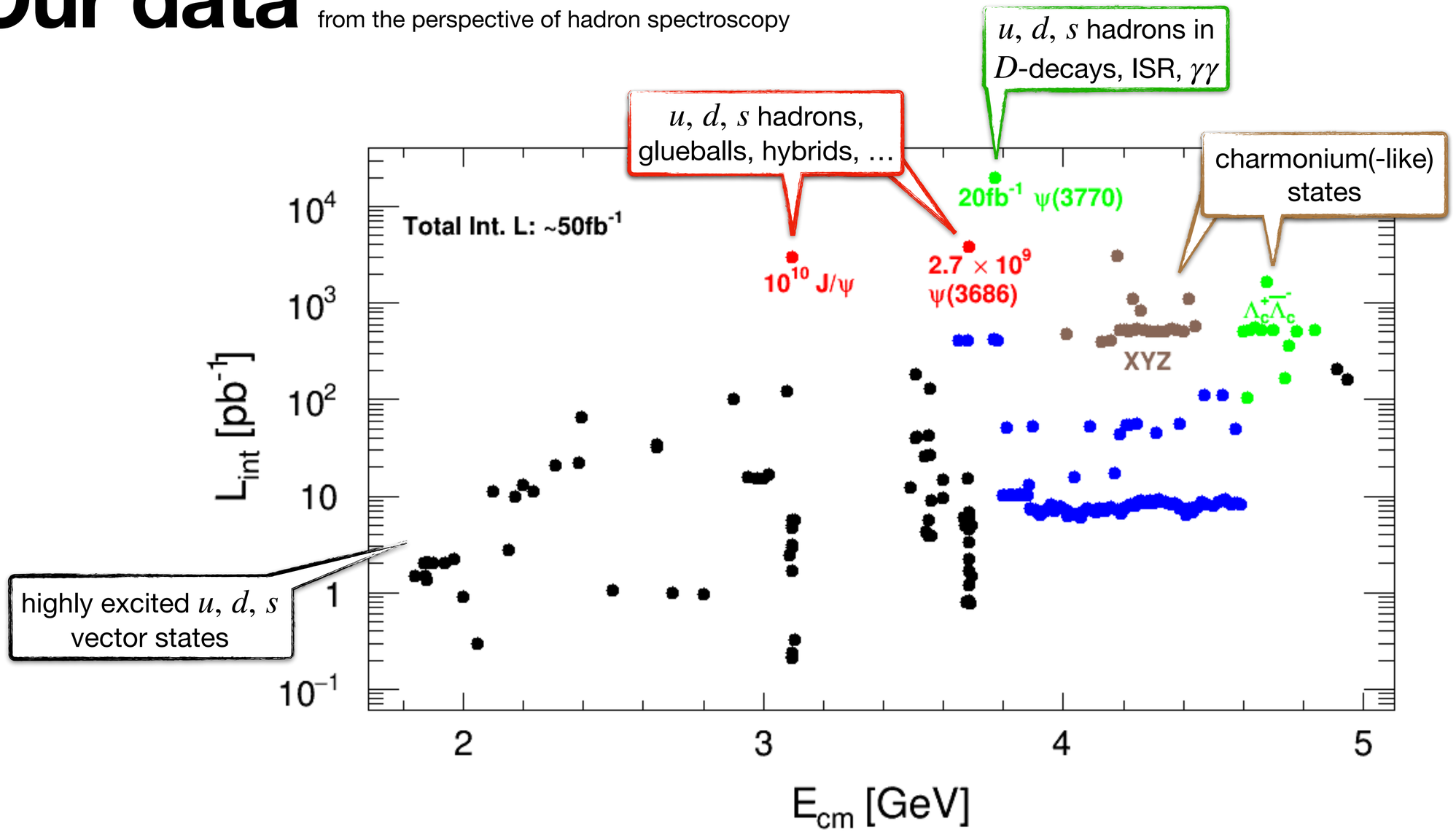


Beijing Spectrometer - BESIII

- drift chamber in 1 T magnetic field
- time of flight detector
- electromagnetic calorimeter
- muon counter

Our data

from the perspective of hadron spectroscopy



Recent examples

A) a glueball candidate in radiative J/ψ decays?

B) the hybrid meson $\pi_1(1600)$ in χ_{c1} decays

C) searching for excited Ω baryons in e^+e^- collisions

D) updates on charmonium(-like) ψ states

E) updates on the charged charmonium-like $Z_c(3900)$

Recent examples

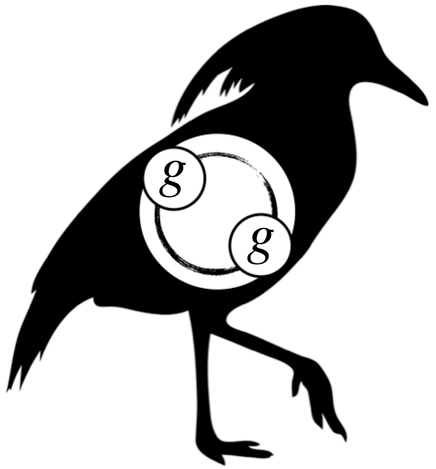
A) a glueball candidate in radiative J/ψ decays?

B) the hybrid meson $\pi_1(1600)$ in χ_{c1} decays

C) searching for excited Ω baryons in e^+e^- collisions

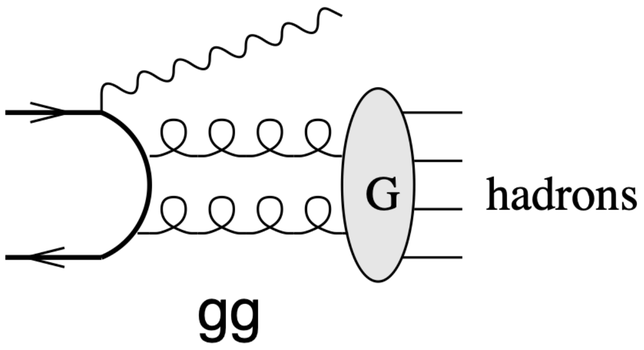
D) updates on charmonium(-like) ψ states

E) updates on the charged charmonium-like $Z_c(3900)$



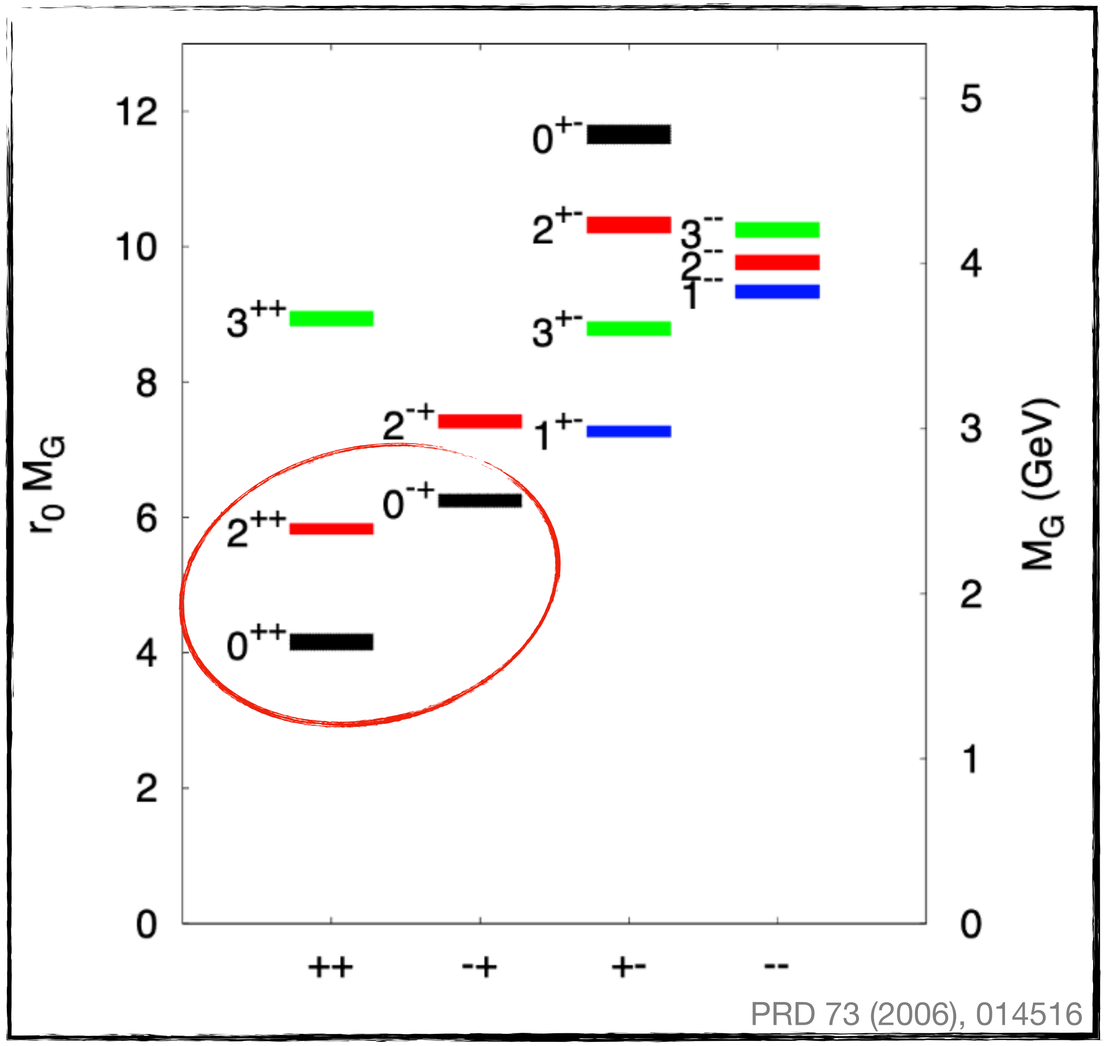
Pseudoscalars in radiative J/ψ decays

why radiative J/ψ decays are so important:



eConf C020620 (2002) THAT07

- gluon-rich environment favors production of glueballs
- relative production rates compared to e.g. purely EM processes hold key information on gg content

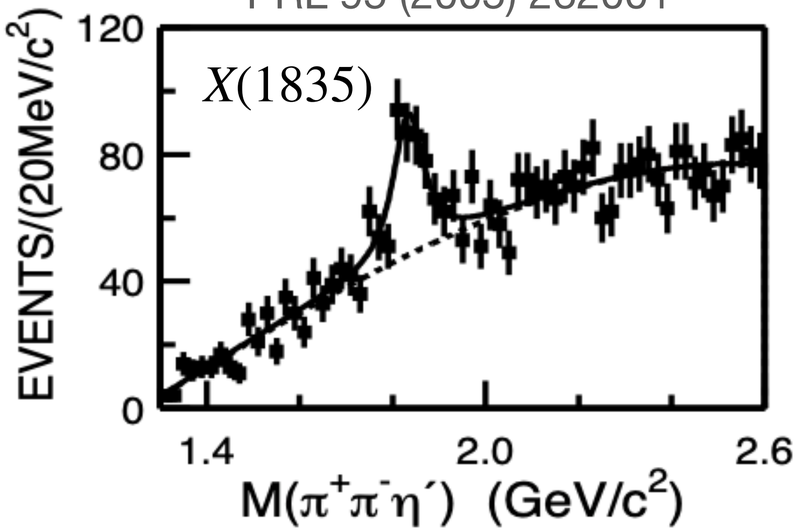


PRD 73 (2006), 014516

Pseudoscalars in radiative J/ψ decays

$J/\psi \to \gamma\eta'\pi^+\pi^-$ or: why you can never have too many J/ψ

PRL 95 (2005) 262001

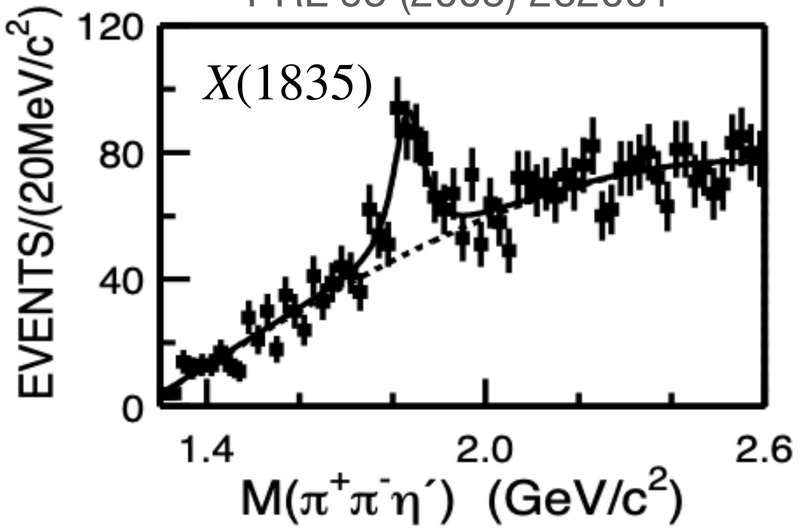


58×10^6 J/ψ

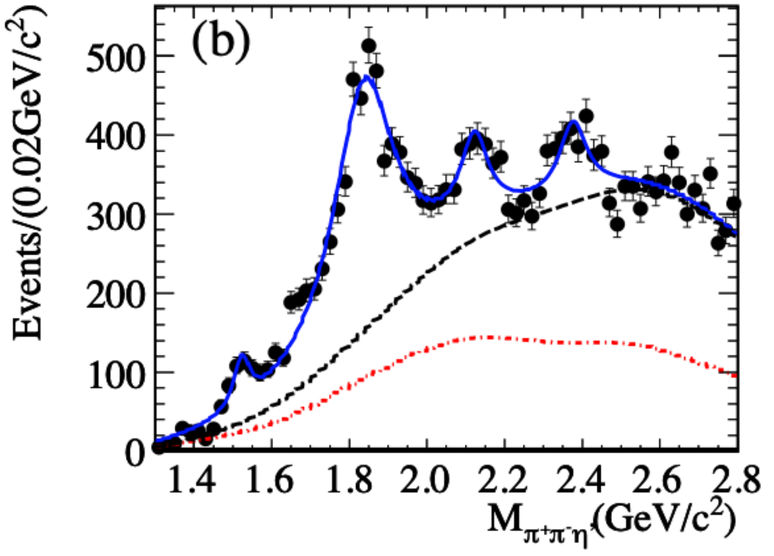
Pseudoscalars in radiative J/ψ decays

$J/\psi \to \gamma\eta'\pi^+\pi^-$ or: why you can never have too many J/ψ

PRL 95 (2005) 262001



PRL 106 (2011) 072002

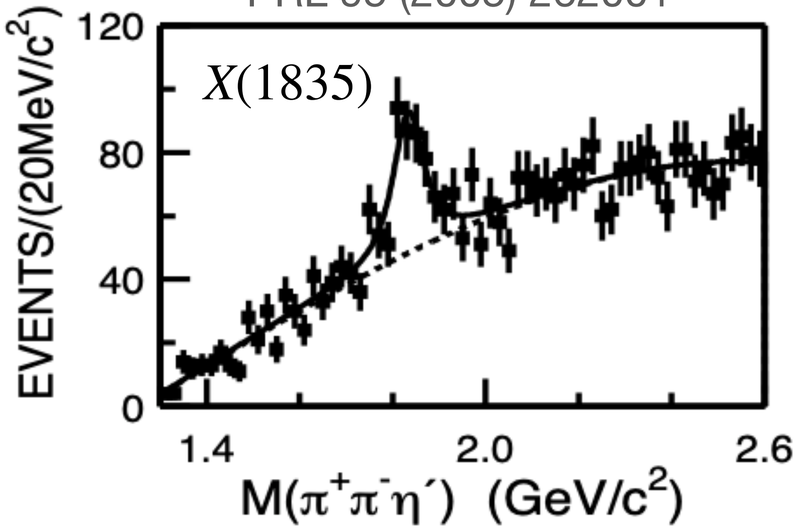


58×10^6 J/ψ → 225×10^6 J/ψ

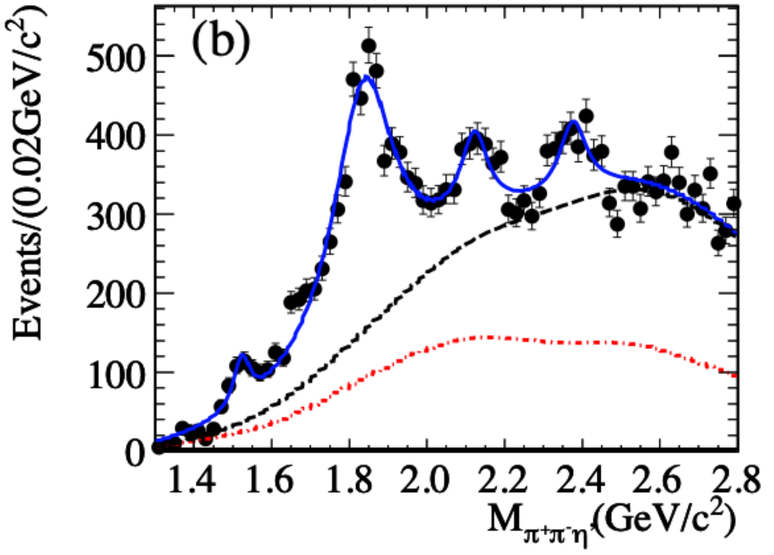
Pseudoscalars in radiative J/ψ decays

$J/\psi \to \gamma\eta'\pi^+\pi^-$ or: why you can never have too many J/ψ

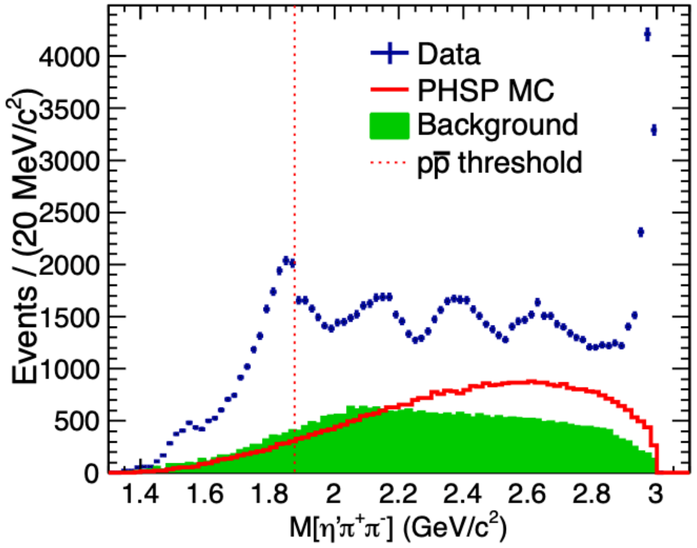
PRL 95 (2005) 262001



PRL 106 (2011) 072002



PRL 117 (2016) 4, 042002

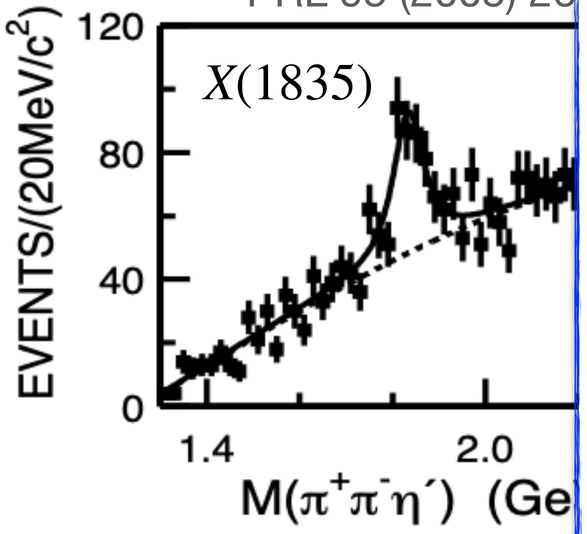


58×10^6 J/ψ → 225×10^6 J/ψ → 1.3×10^9 J/ψ

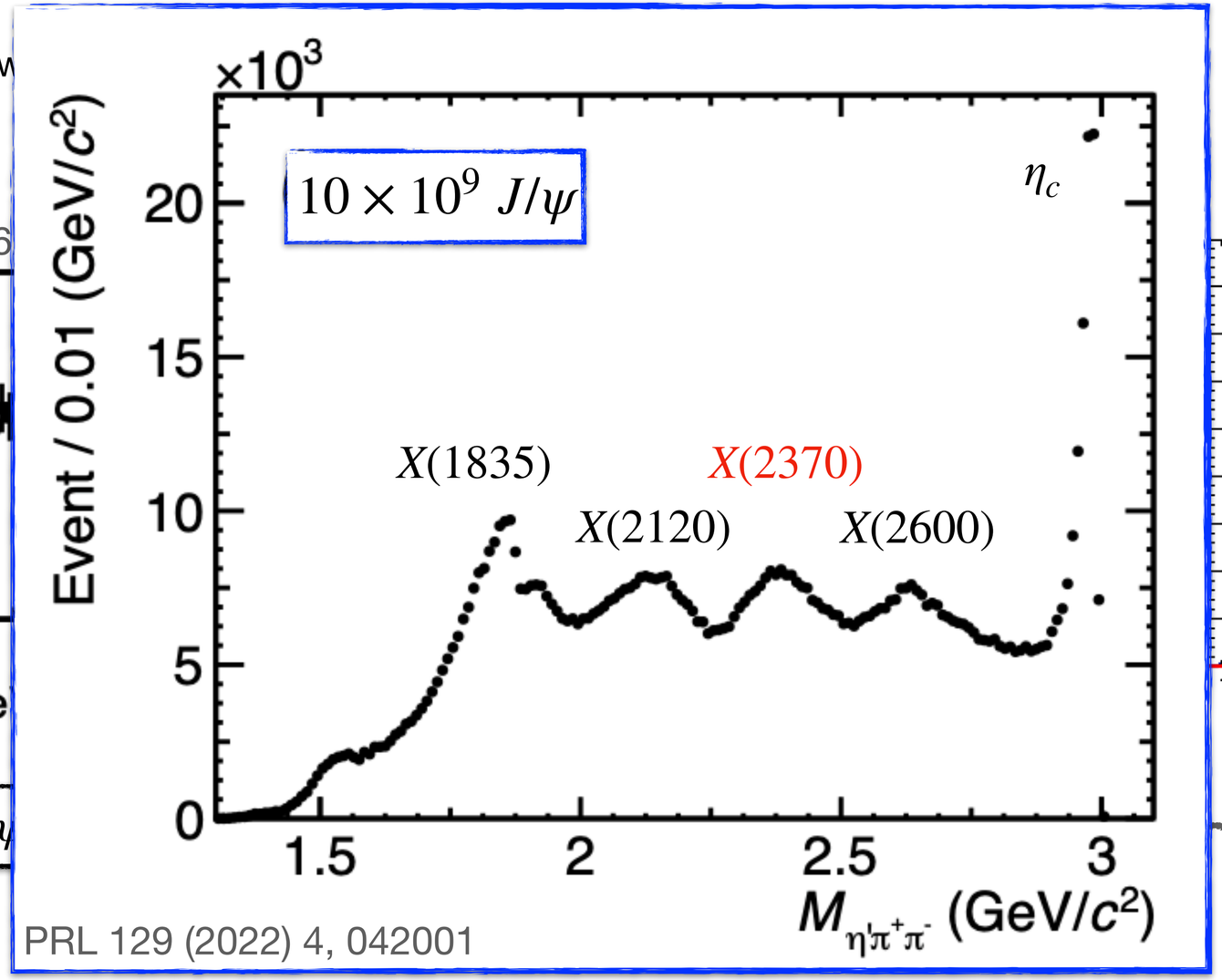
Pseudoscalars in radiative J/ψ decays

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

PRL 95 (2005) 26

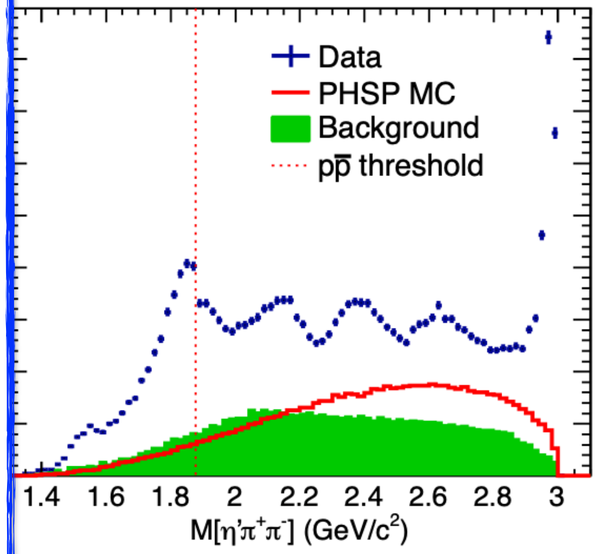


58×10^6 J/ψ



PRL 129 (2022) 4, 042001

PRL 117 (2016) 4, 042002



1.3×10^9 J/ψ

The $X(2370)$

Bericht
10.05.2024
Lesedauer ca. 2 Minuten
Drucken
Teilen

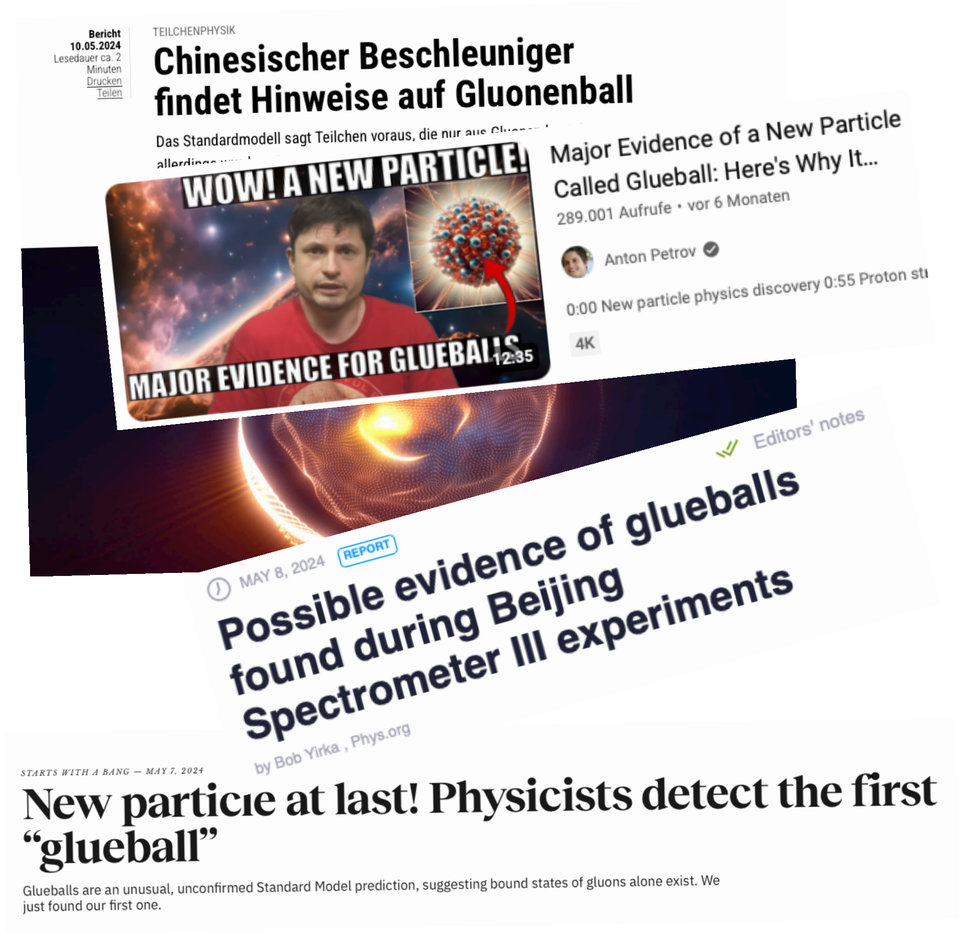
TEILCHENPHYSIK

Chinesischer Beschleuniger findet Hinweise auf Gluonenball

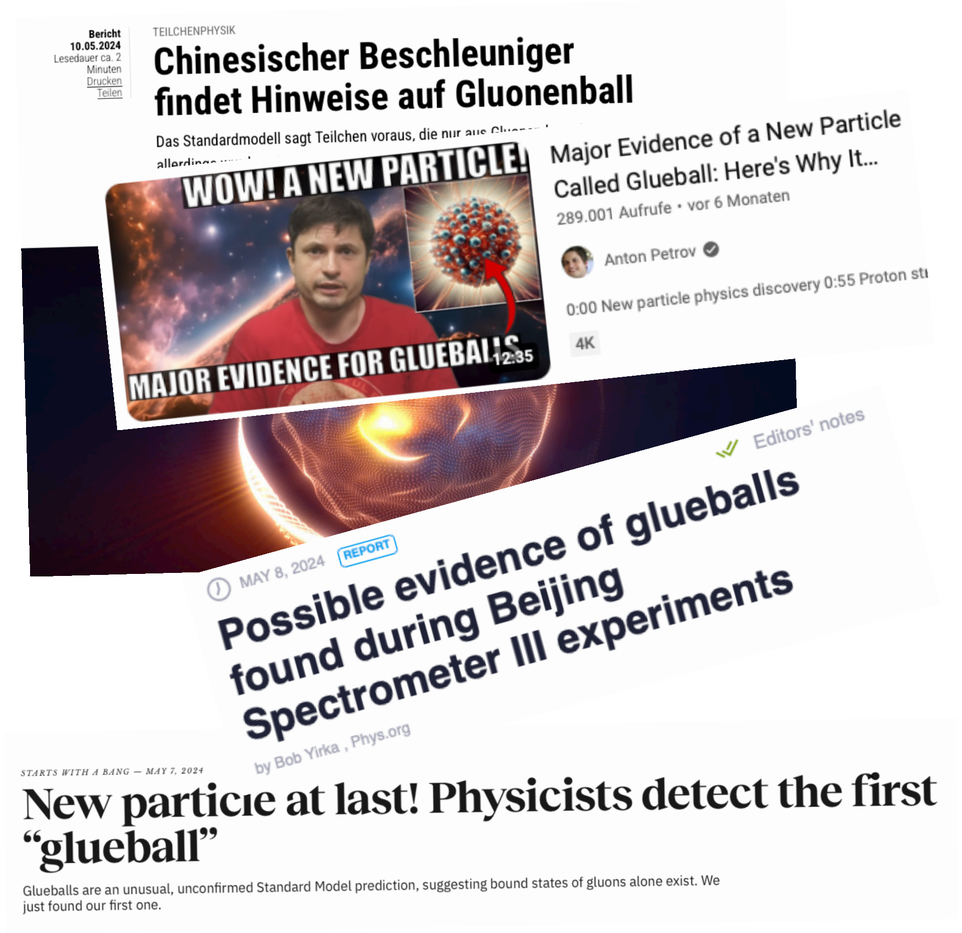
Das Standardmodell sagt Teilchen voraus, die nur aus Gluonen bestehen – allerdings wurden sie noch nie beobachtet. Nun scheint ein chinesischer Beschleuniger solche Gluonenbälle erstmals nachgewiesen zu haben.

von Manon Bischoff

The $X(2370)$


Bericht
10.05.2024
Lesedauer ca. 2 Minuten
Drucken
Teilen
TEILCHENPHYSIK
Chinesischer Beschleuniger findet Hinweise auf Gluonenball
Das Standardmodell sagt Teilchen voraus, die nur aus
WOW! A NEW PARTICLE!
MAJOR EVIDENCE FOR GLUEBALLS
12:35
Major Evidence of a New Particle Called Glueball: Here's Why It...
289.001 Aufrufe • vor 6 Monaten
Anton Petrov
0:00 New particle physics discovery 0:55 Proton st
4K
Editors' notes
MAY 8, 2024
REPORT
Possible evidence of glueballs found during Beijing Spectrometer III experiments
by Bob Yirka , Phys.org
STARTS WITH A BANG — MAY 7, 2024
New particle at last! Physicists detect the first "glueball"
Glueballs are an unusual, unconfirmed Standard Model prediction, suggesting bound states of gluons alone exist. We just found our first one.

The $X(2370)$

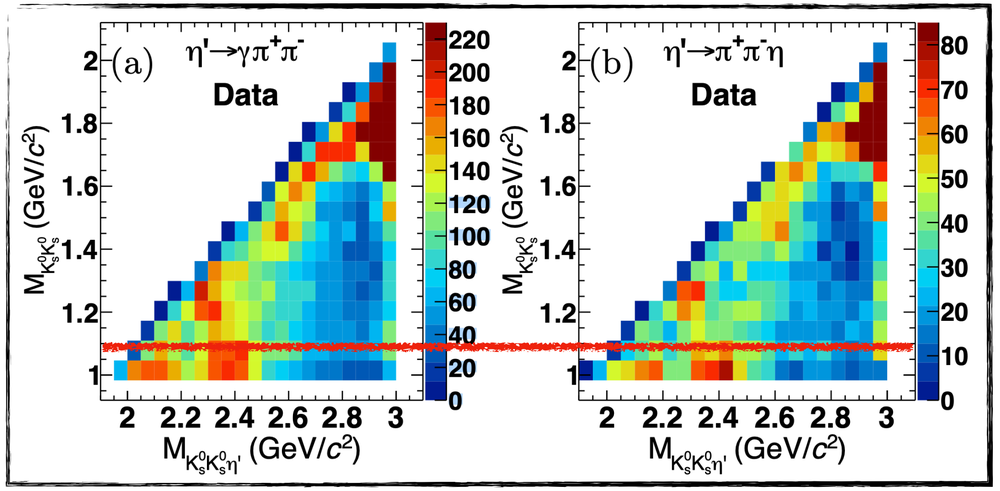


so, what is behind this?

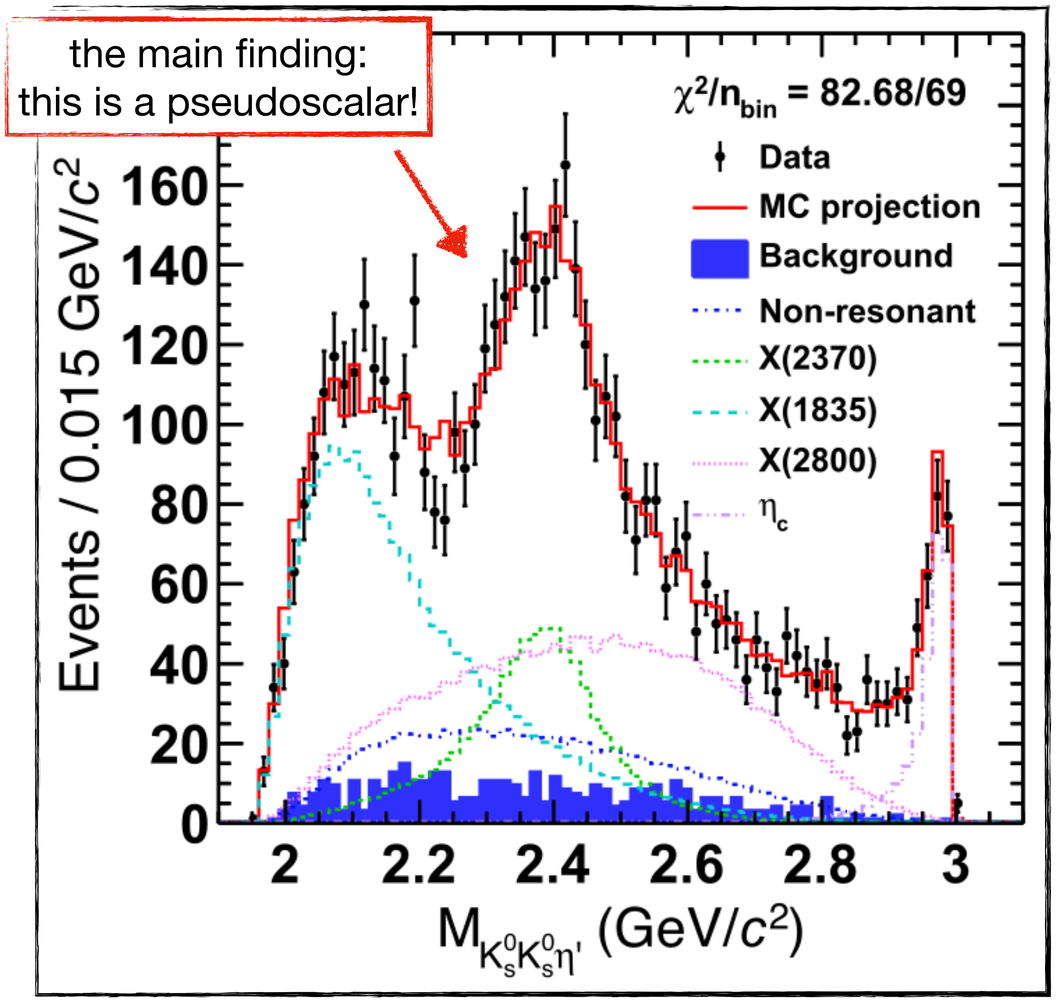
The $X(2370)$

Spin-parity of $X(2370)$ in $J/\psi \to \gamma K_S^0 K_S^0 \eta'$

- clear signal of $X(2370) \to K_S^0 K_S^0 \eta'$
- selection of near-threshold $K_S^0 K_S^0$ pairs allows for spin-parity determination



PRL 132, 181901 (2024)
selected to PRL's Collection of the Year

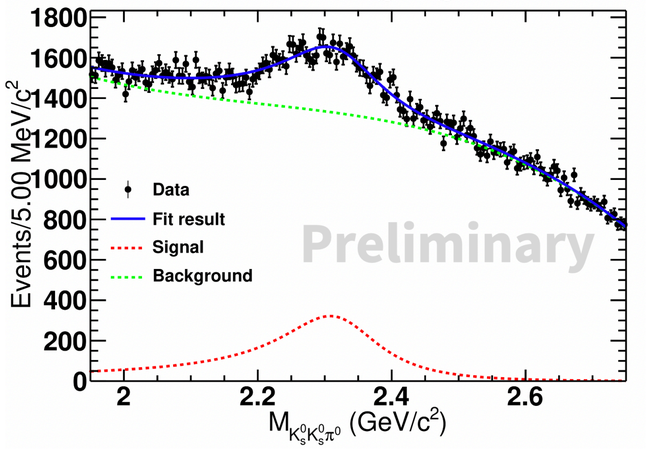


The $X(2370)$

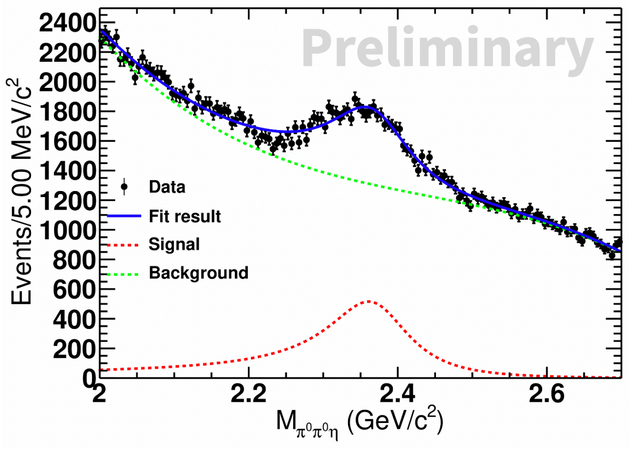
PRL 132, 181901 (2024)
selected to PRL's Collection of the Year

- solid evidence for a new pseudoscalar in multiple final states

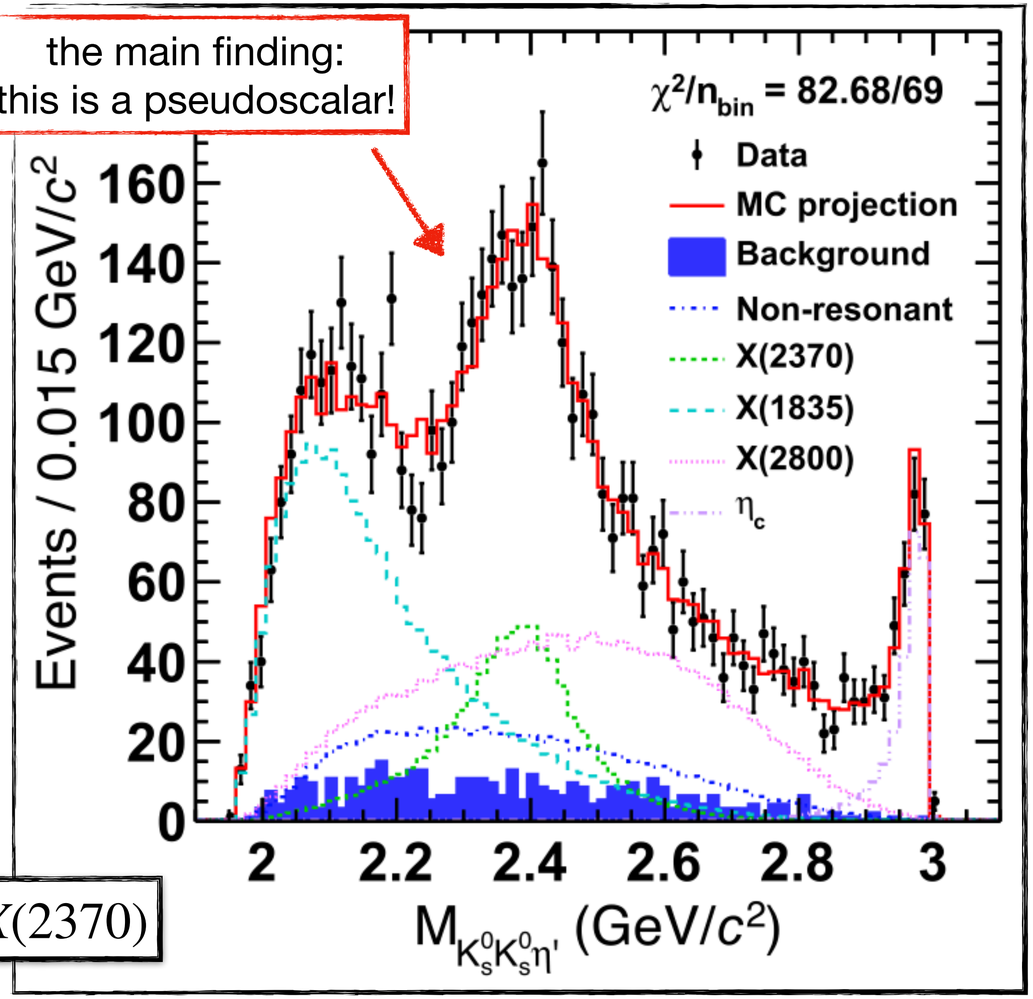
$J/\psi \to \gamma K_S^0 K_S^0 \pi^0$



$J/\psi \to \gamma \eta \pi^0 \pi^0$



- possibly through $f_0(980)\eta'$ and $a_0(980)\pi$ intermediate states



we need to know much more to say anything about the nature of the $X(2370)$

Recent examples

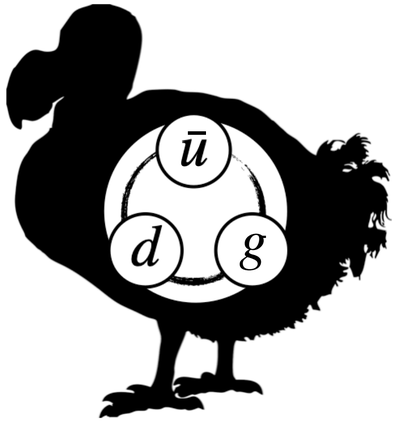
A) a glueball candidate in radiative J/ψ decays?

B) the hybrid meson $\pi_1(1600)$ in χ_{c1} decays

C) searching for excited Ω baryons in e^+e^- collisions

D) updates on charmonium(-like) ψ states

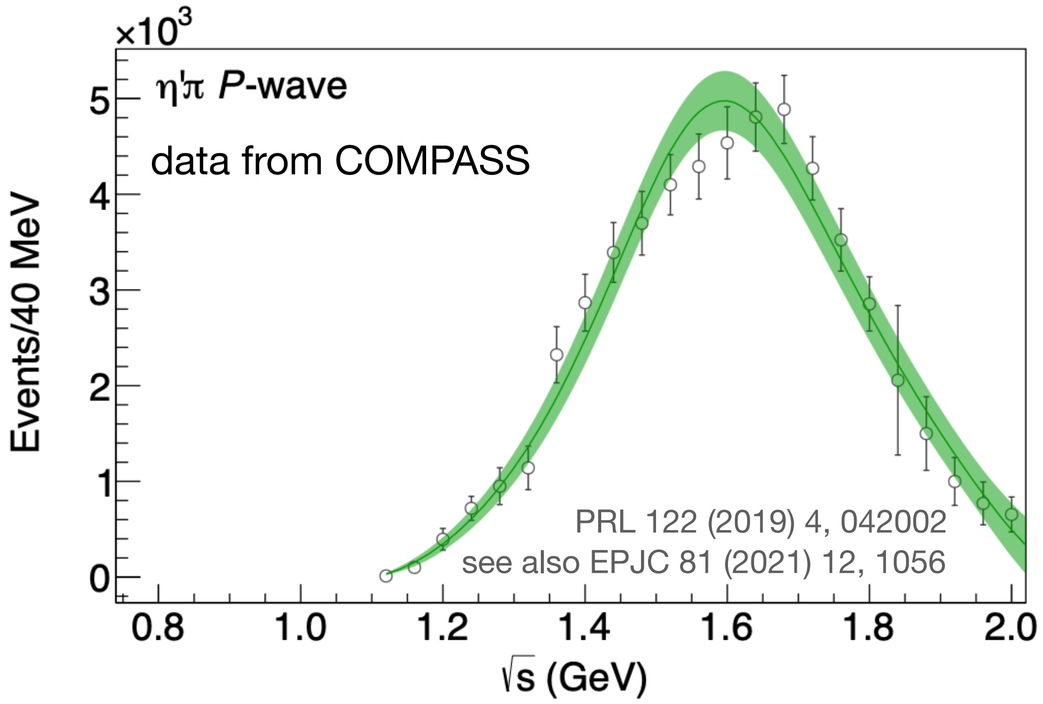
E) updates on the charged charmonium-like $Z_c(3900)$



The $\pi_1(1600)$

and the case for a large $\psi(2S)$ dataset

- well established hybrid meson candidate, many detailed measurements for example by COMPASS

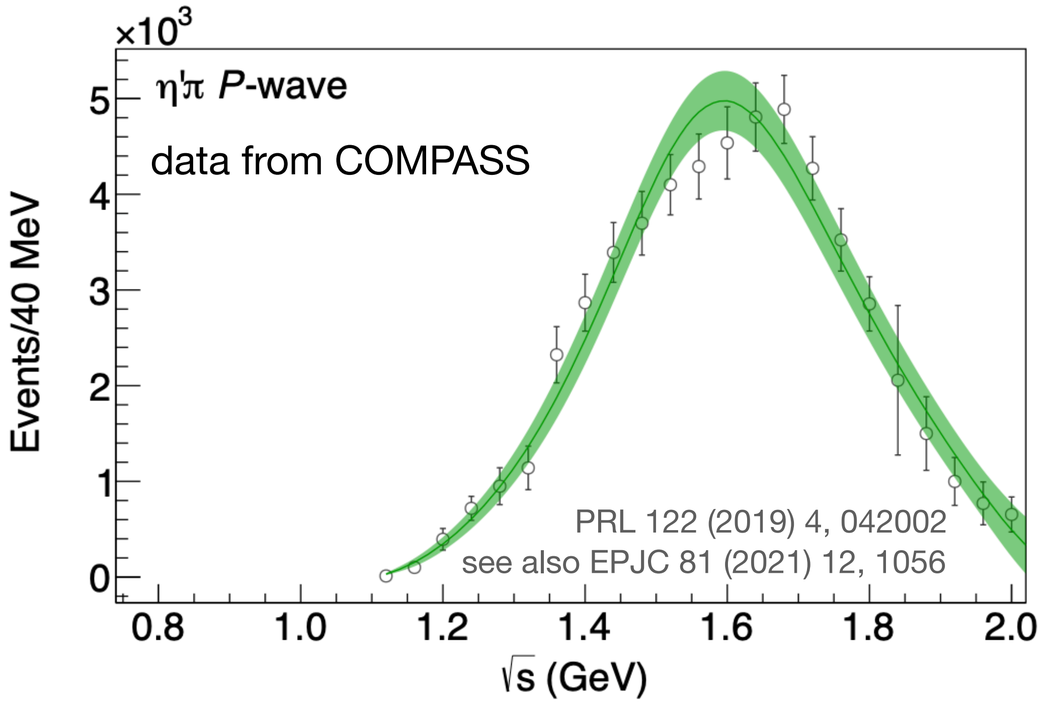


- what about other production processes?
  see talk by F. Afzal on Tuesday morning

The $\pi_1(1600)$

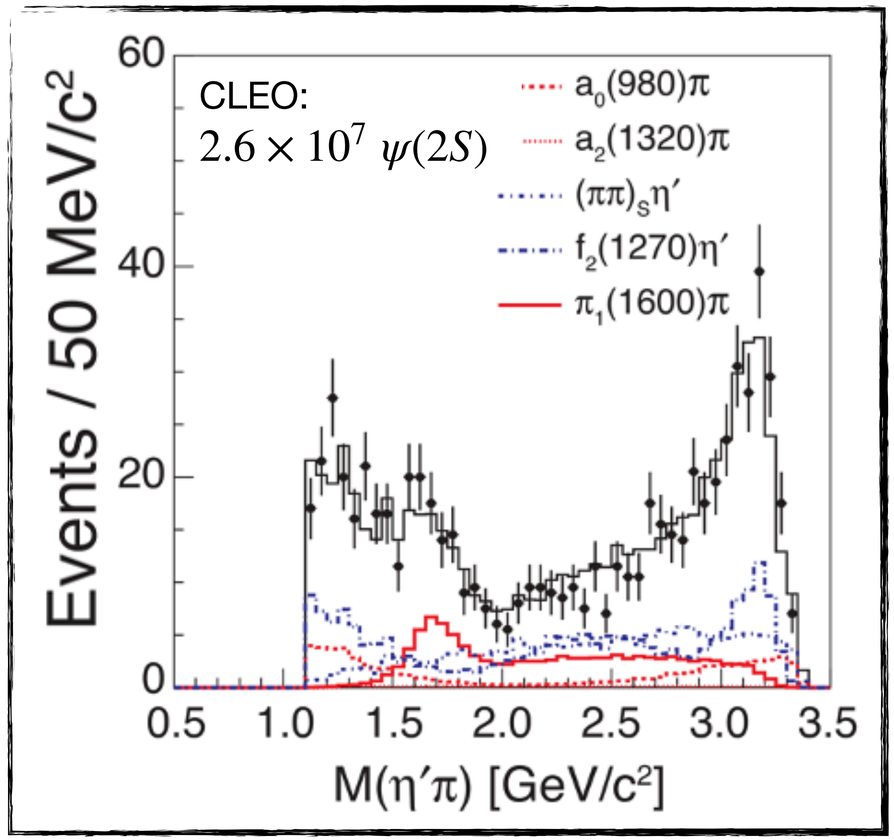
and the case for a large $\psi(2S)$ dataset

- well established hybrid meson candidate, many detailed measurements for example by COMPASS



- what about other production processes?
  see talk by F. Afzal on Tuesday morning

$$\psi(2S) \to \gamma\chi_{c1}, \quad \chi_{c1} \to \eta'\pi\pi$$



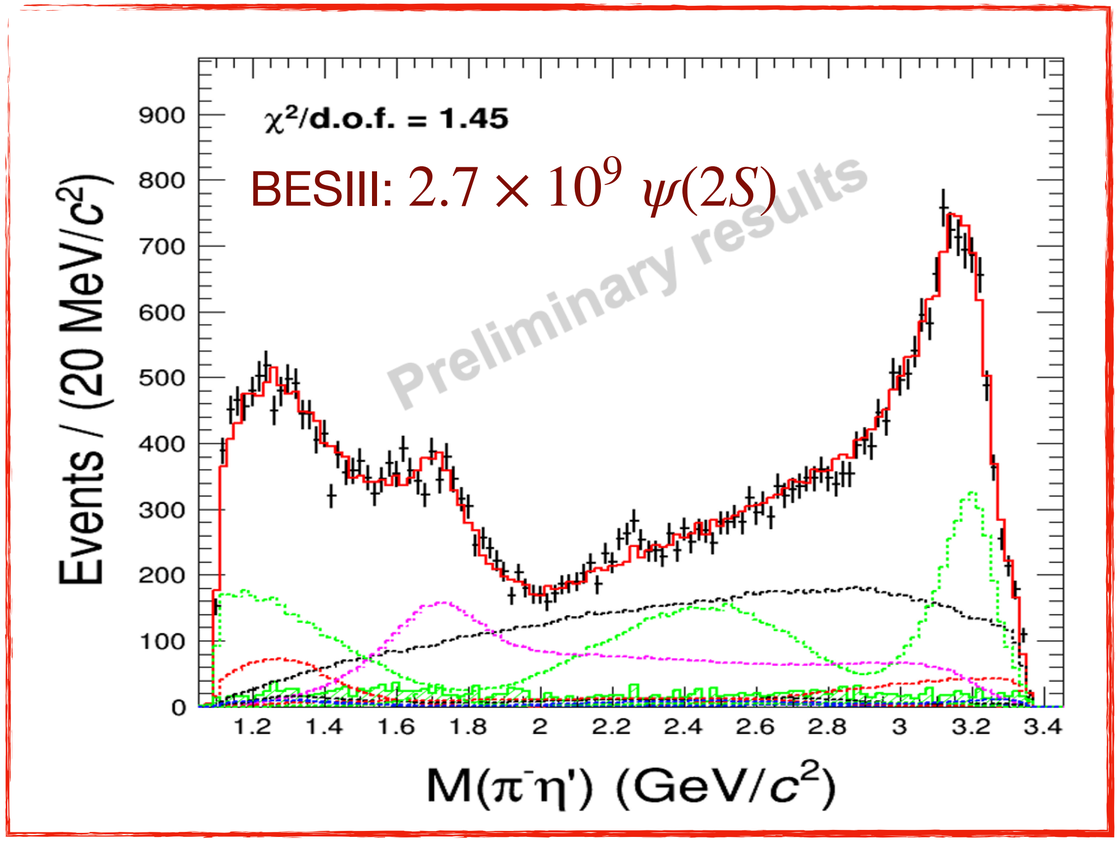
PRD 84, 112009 (2011)

CLEO saw a $\pi_1(1600)$-like bump, but no evidence for phase-motion

The $\pi_1(1600)$

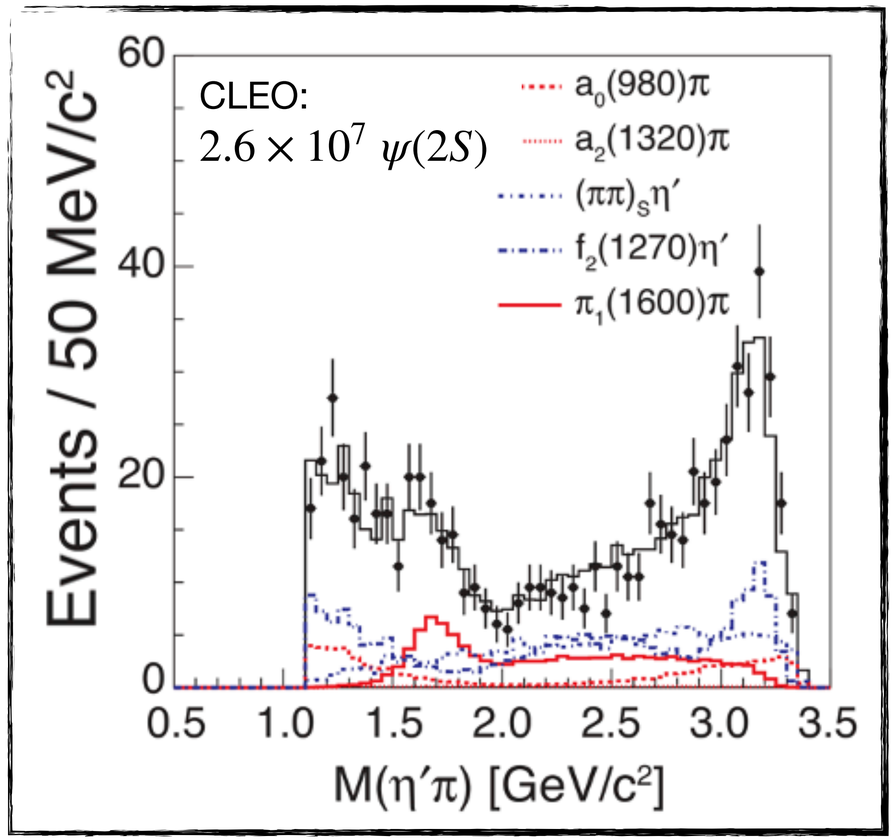
and the case for a large $\psi(2S)$ dataset

clear signal of $\chi_{c1} \to \pi_1(1600)\pi$ with $\approx 100\times$ more data



established production now allows to look for other decay modes

$\psi(2S) \to \gamma\chi_{c1}, \quad \chi_{c1} \to \eta'\pi\pi$



PRD 84, 112009 (2011)

CLEO saw a $\pi_1(1600)$-like bump, but no evidence for phase-motion

Recent examples

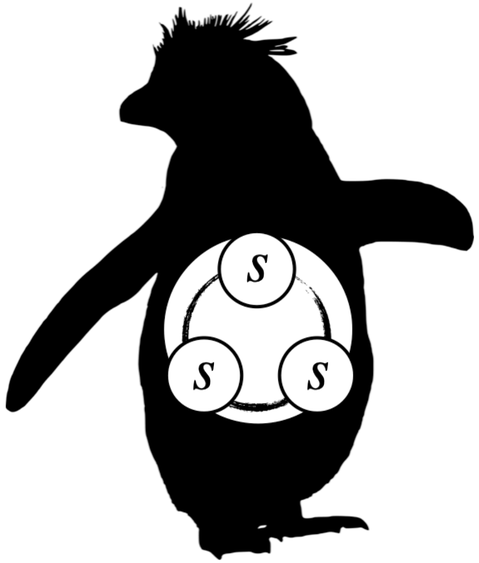
A) a glueball candidate in radiative J/ψ decays?

B) the hybrid meson $\pi_1(1600)$ in χ_{c1} decays

C) searching for excited Ω baryons in e^+e^- collisions

D) updates on charmonium(-like) ψ states

E) updates on the charged charmonium-like $Z_c(3900)$



Search for excited Ω states

Citation: S. Navas *et al.* (Particle Data Group), Phys. Rev. D **110**, 030001 (2024) and 2025 update

$\Omega(2012)^-$ $\quad I(J^P) = 0(?^-)$

Mass $m = 2012.5 \pm 0.6$ MeV
Full width $\Gamma = 6.4^{+3.0}_{-2.6}$ MeV

$\Omega(2012)^-$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Xi^0 K^-$	seen	403
$\Xi^- \overline{K}^0$	seen	392
$\Xi^- \pi^+ K^-$	seen	224

$\Omega(2250)^-$ $\quad I(J^P) = 0(?^?)$

Mass $m = 2252 \pm 9$ MeV
Full width $\Gamma = 55 \pm 18$ MeV

$\Omega(2250)^-$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Xi^- \pi^+ K^-$	seen	532
$\Xi(1530)^0 K^-$	seen	437

this is a screenshot of the complete list of excited Ω baryons from the PDG 2025 summary table

Search for excited Ω states

Citation: S. Navas *et al.* (Particle Data Group), Phys. Rev. D **110**, 030001 (2024) and 2025 update

Ω(2012)⁻ $I(J^P) = 0(?^-)$

Mass $m = 2012.5 \pm 0.6$ MeV
Full width $\Gamma = 6.4^{+3.0}_{-2.6}$ MeV

Ω(2012)⁻ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Xi^0 K^-$	seen	403
$\Xi^- \overline{K}^0$	seen	392
$\Xi^- \pi^+ K^-$	seen	224

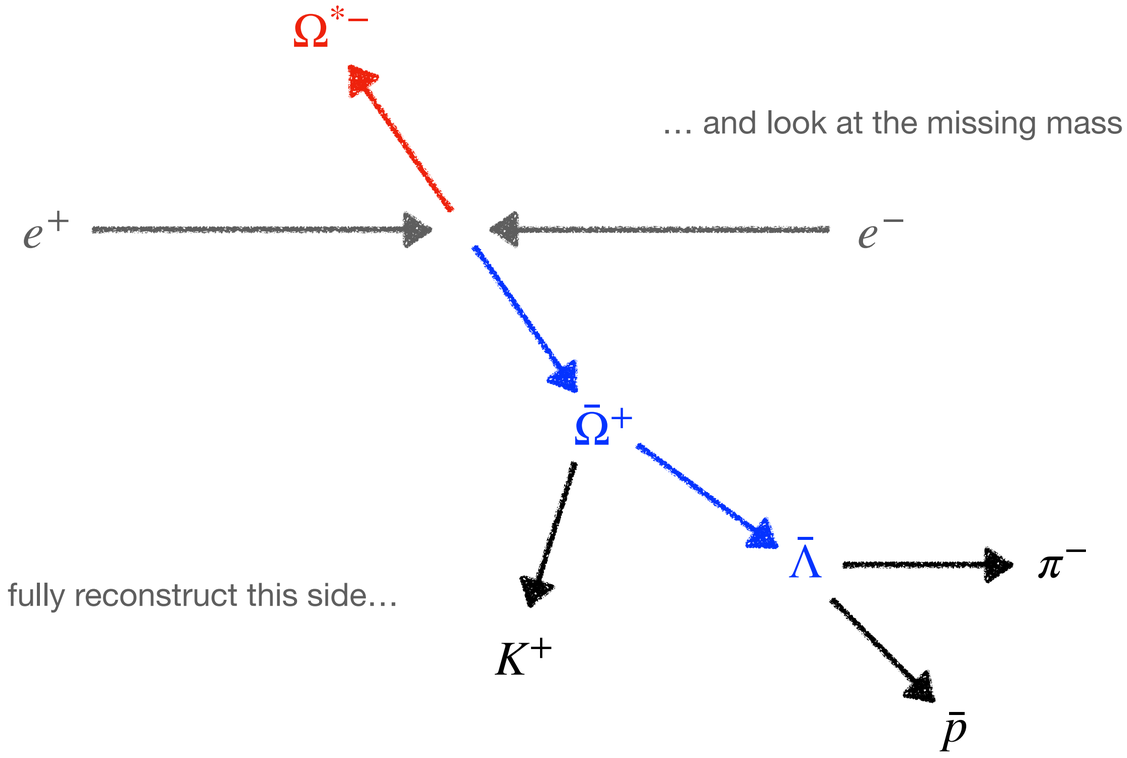
Ω(2250)⁻ $I(J^P) = 0(?^?)$

Mass $m = 2252 \pm 9$ MeV
Full width $\Gamma = 55 \pm 18$ MeV

Ω(2250)⁻ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Xi^- \pi^+ K^-$	seen	532
$\Xi(1530)^0 K^-$	seen	437

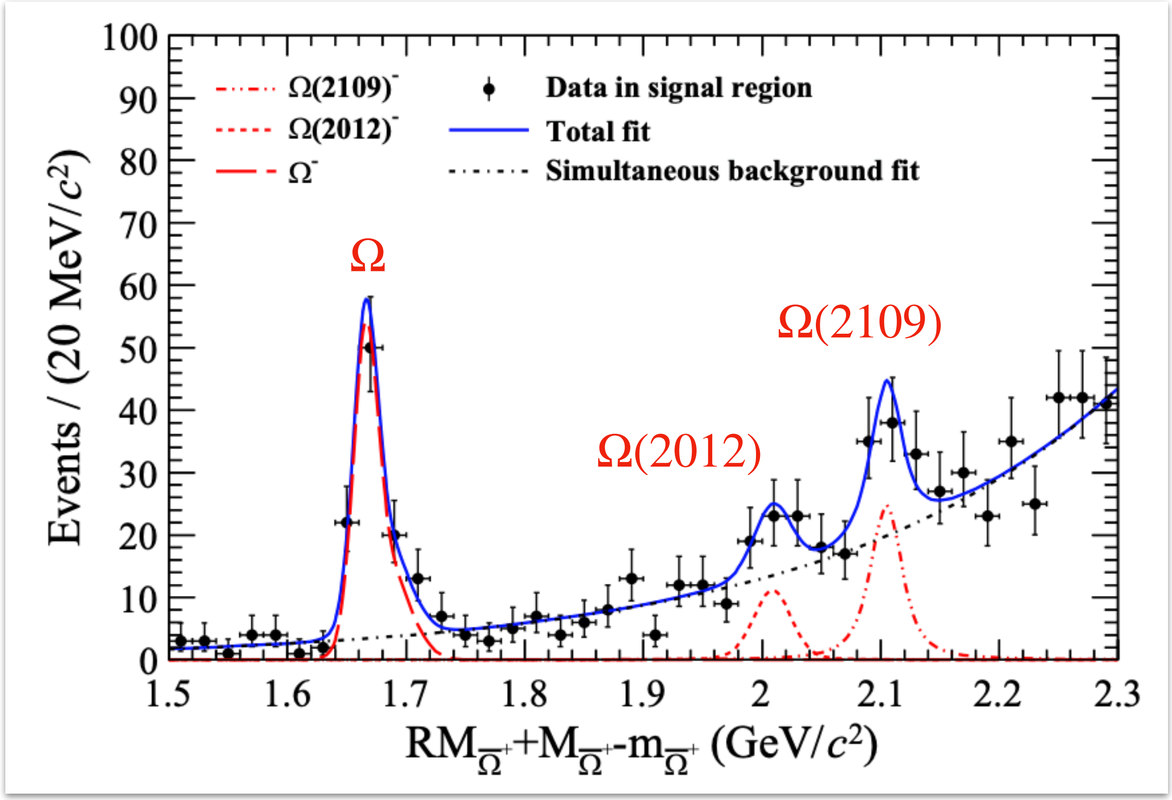
this is a screenshot of the complete list of excited Ω baryons from the PDG 2025 summary table

idea: search for excited Ω^{*-} states recoiling against an $\bar{\Omega}^+$



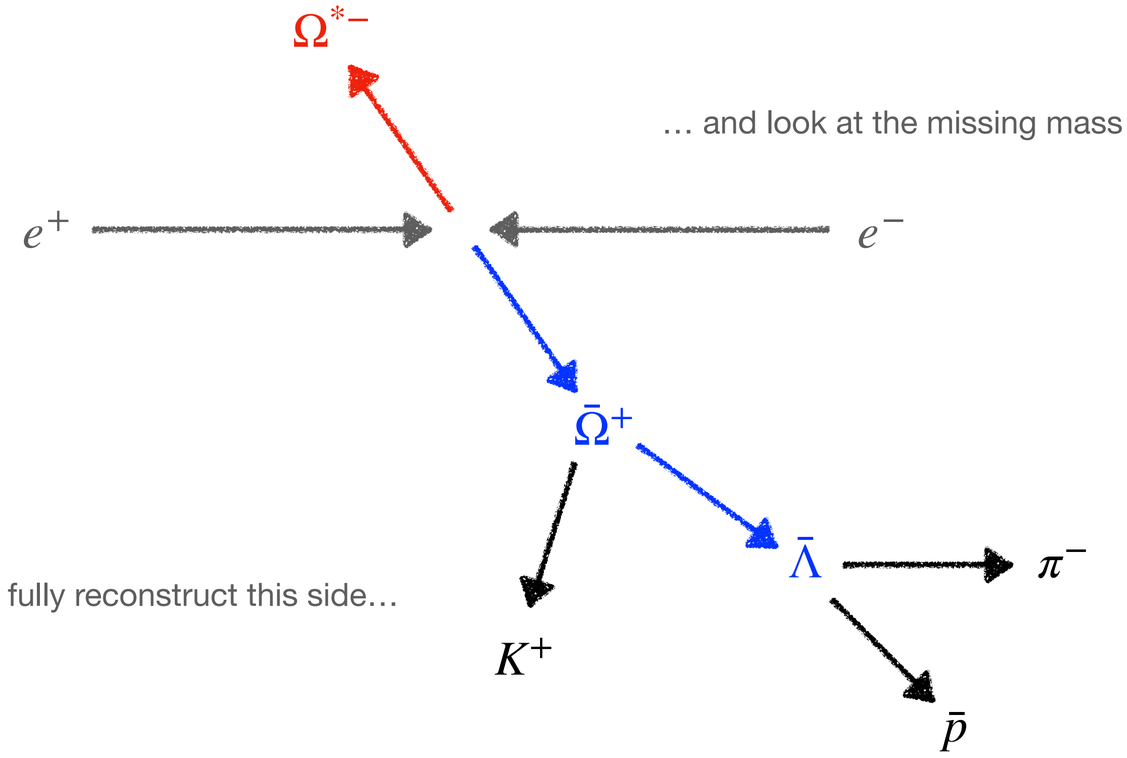
Search for excited Ω states

PRL 134, 131903 (2025)



- evidence for known $\Omega(2012)$ (3.5 σ)
- evidence for new $\Omega(2109)$ (4.1 σ)
- in good agreement with LQCD

idea: search for excited Ω^{*-} states recoiling against an $\bar{\Omega}^{+}$



Recent examples

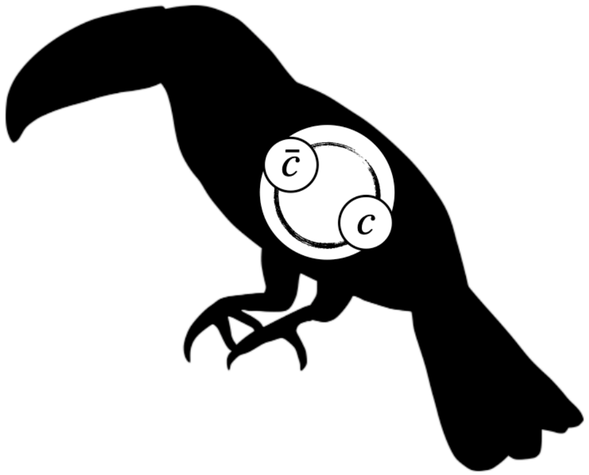
A) a glueball candidate in radiative J/ψ decays?

B) the hybrid meson $\pi_1(1600)$ in χ_{c1} decays

C) searching for excited Ω baryons in e^+e^- collisions

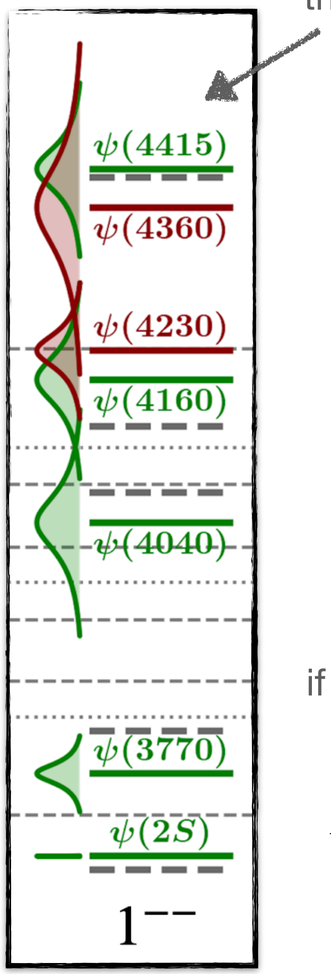
D) updates on charmonium(-like) ψ states

E) updates on the charged charmonium-like $Z_c(3900)$

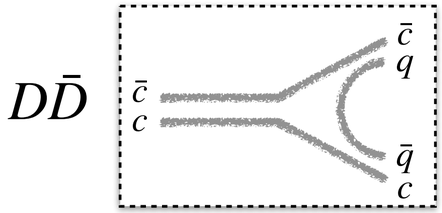


Charmonium(-like) states

these we can directly produce in e^+e^- collisions



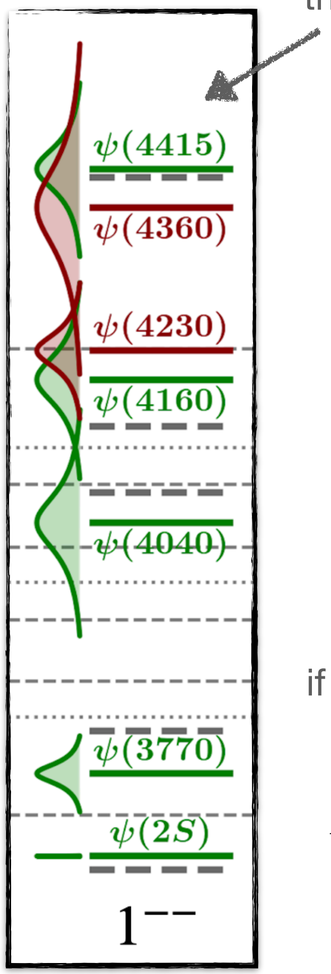
if $c\bar{c}$, we expect them to decay like this



MPLA 40 (2025) 17n18, 2530002

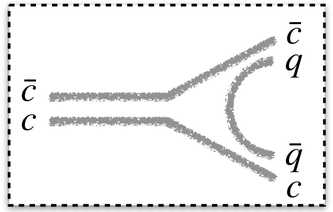
Charmonium(-like) states

these we can directly produce in e^+e^- collisions



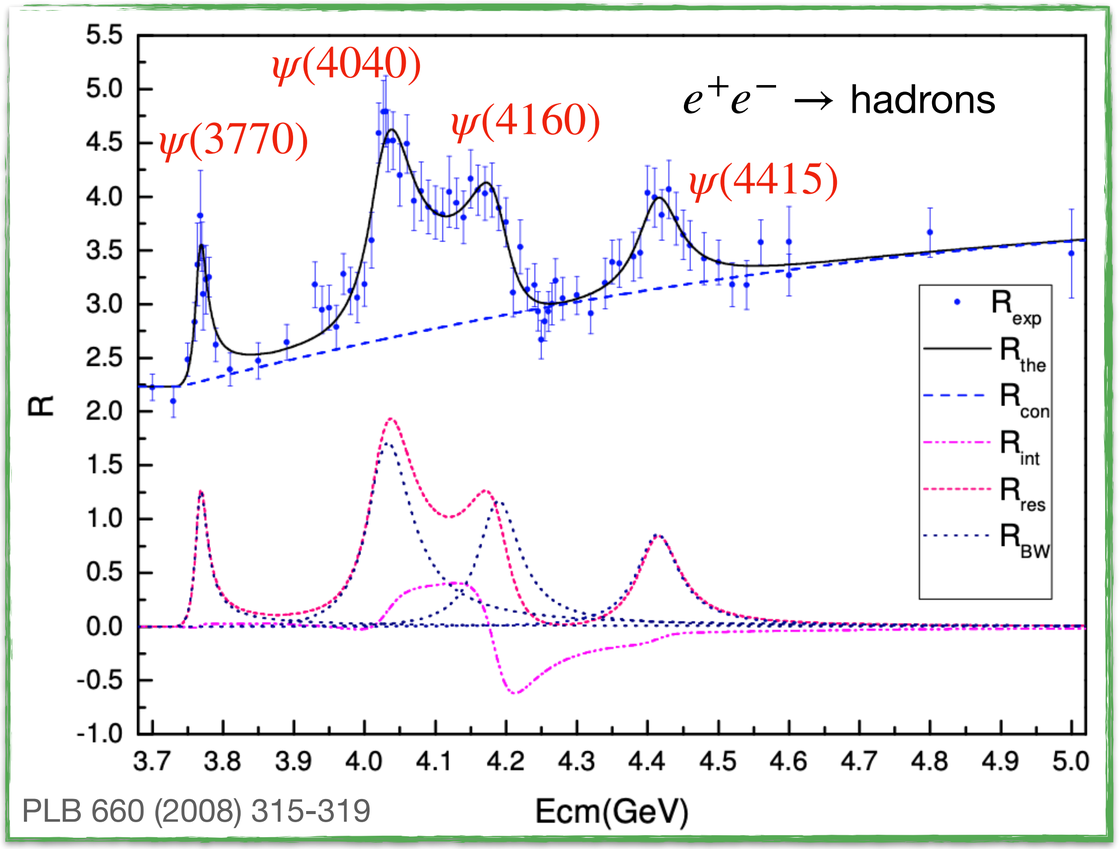
if $c\bar{c}$, we expect them to decay like this

$D\bar{D}$



MPLA 40 (2025) 17n18, 2530002

the inclusive cross section is in good agreement with our expectations

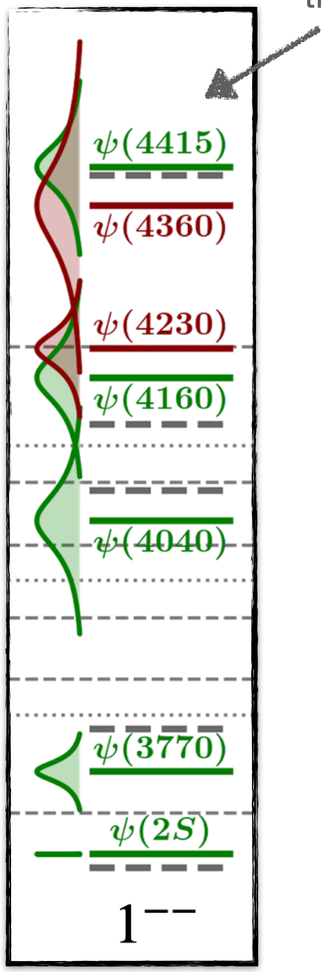


PLB 660 (2008) 315-319

a more precise measurement of R using BESIII data is in the works!

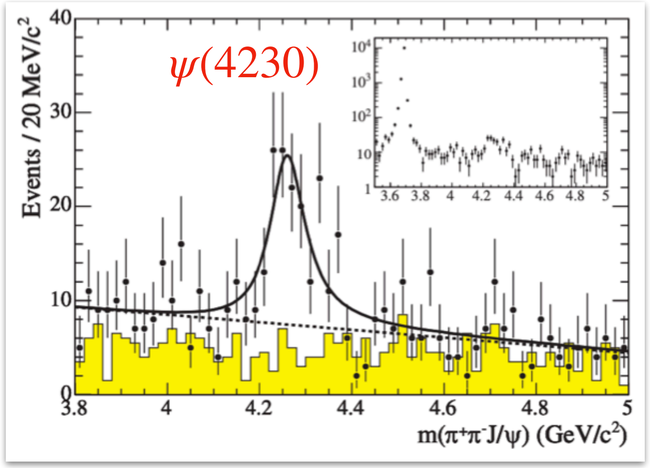
Charmonium(-like) states

these we can directly produce in e^+e^- collisions

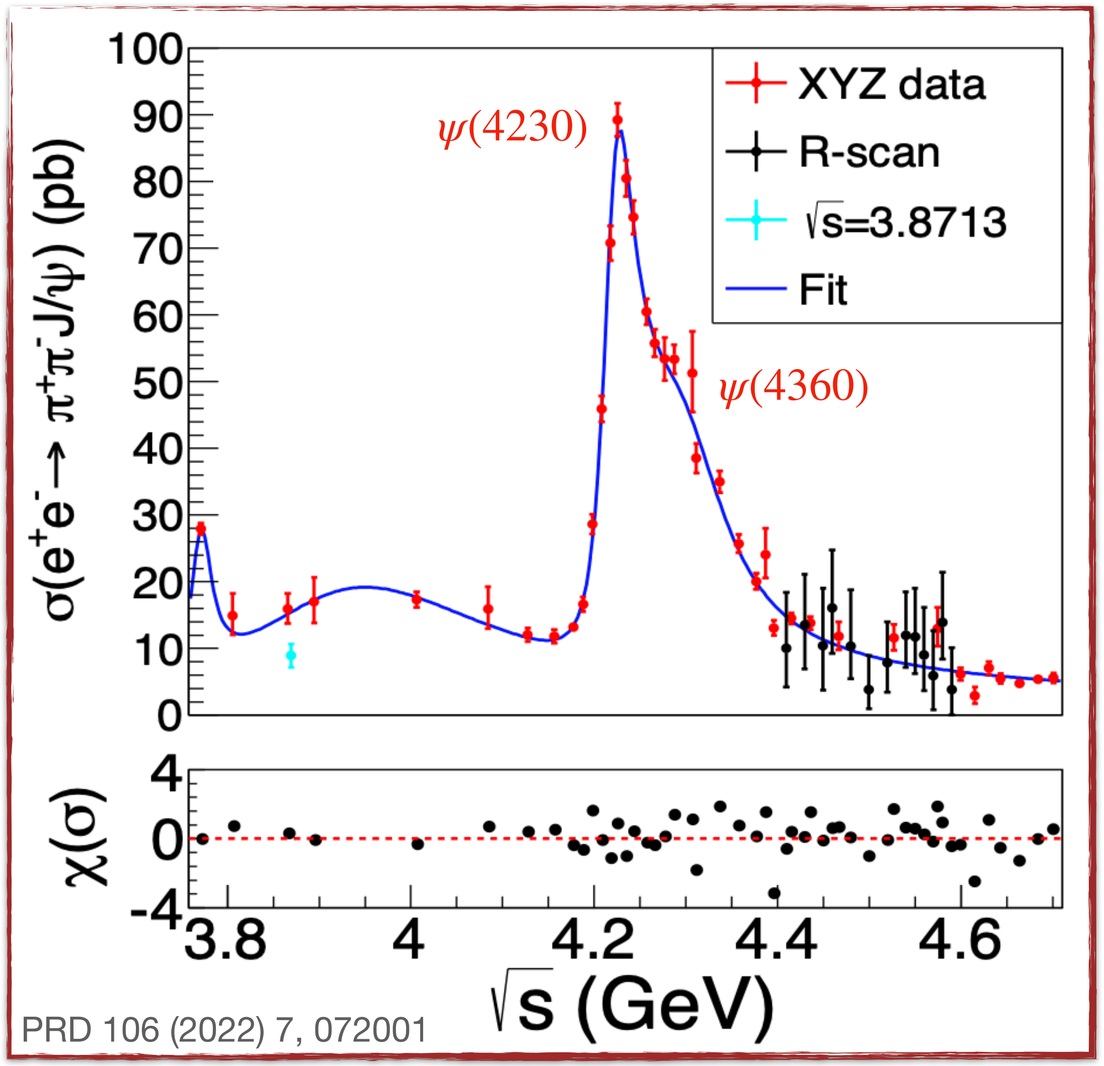


MPLA 40 (2025) 17n18, 2530002

exclusive cross sections such as $e^+e^- \to J/\psi\pi\pi$ show (exotic?) peaks



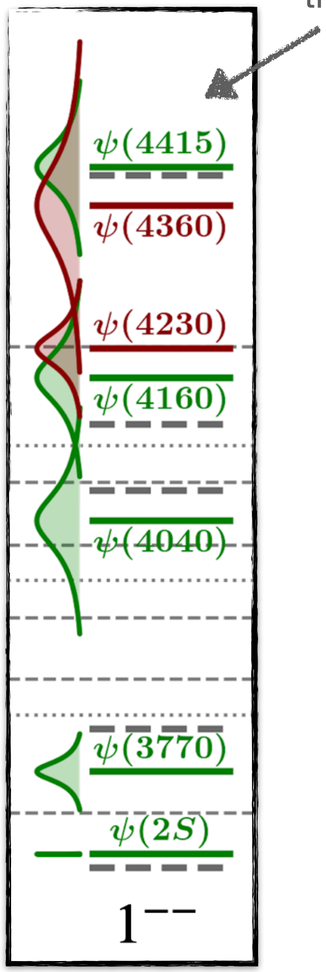
BABAR, PRL 95 (2005) 142001



PRD 106 (2022) 7, 072001

Charmonium(-like) states

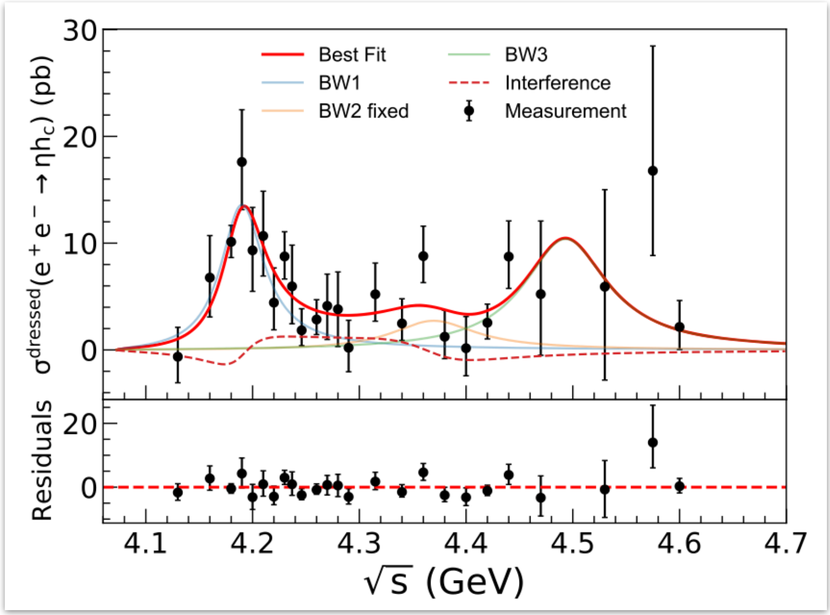
these we can directly produce in e^+e^- collisions



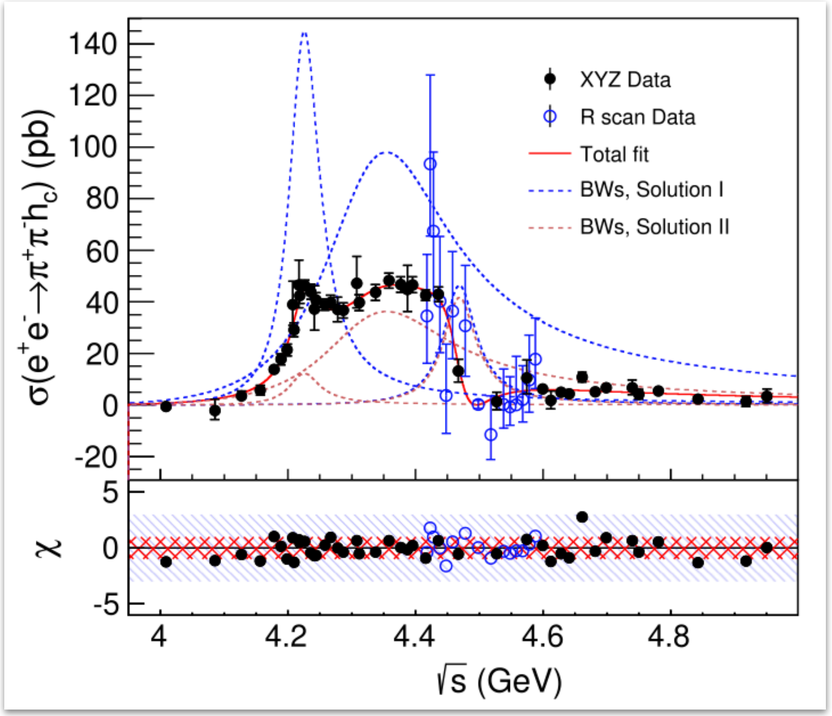
MPLA 40 (2025) 17n18, 2530002

similar structures are seen in many other processes

$e^+e^- \to \eta h_c$ PRD 111, L011101 (2025)

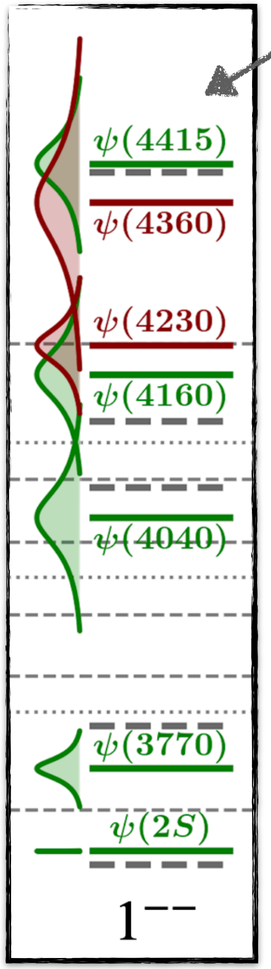


$e^+e^- \to h_c\pi^+\pi^-$ PRL 135, 071901 (2025)

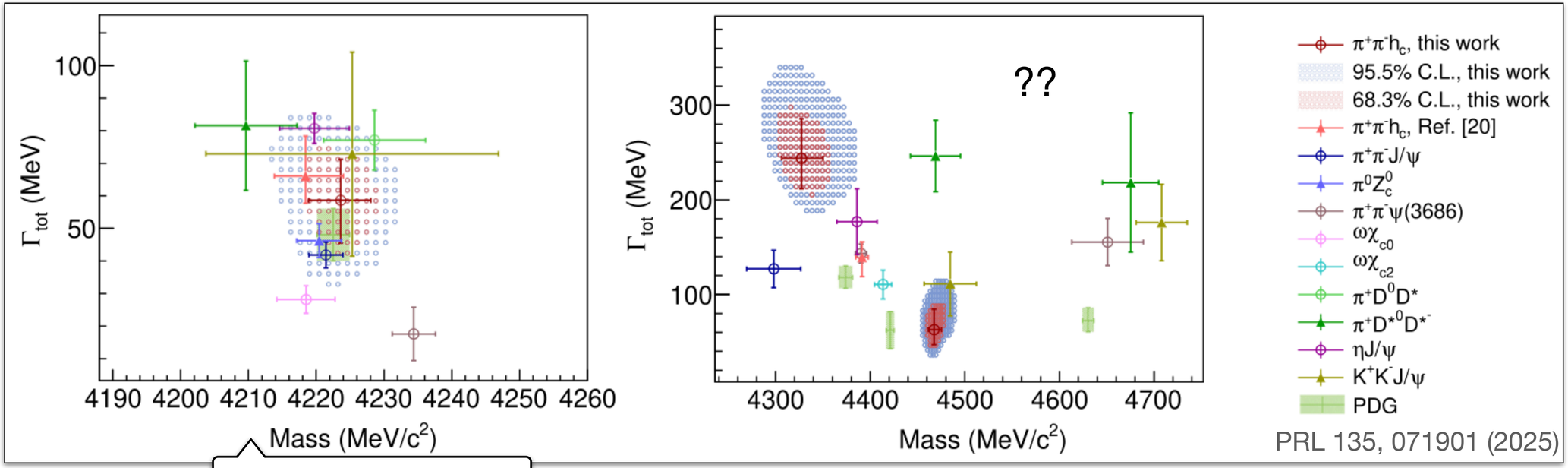


Charmonium(-like) states

these we can directly produce in e^+e^- collisions



similar structures are seen in many other processes



PRL 135, 071901 (2025)

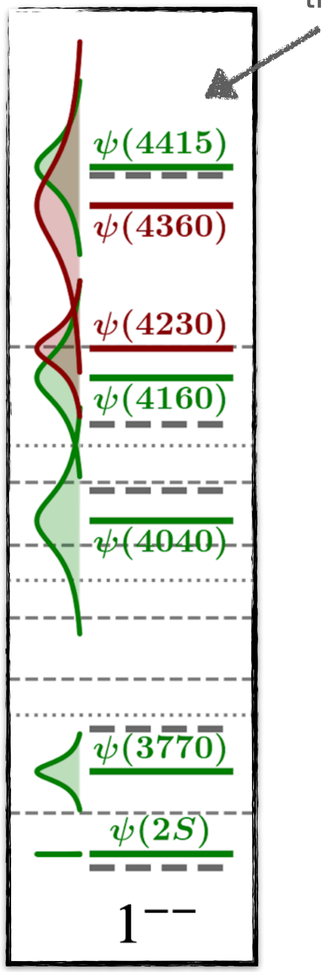
good agreement in mass, but not in width

these exclusive cross sections show structure not visible in the inclusive cross section - and vice versa

MPLA 40 (2025) 17n18, 2530002

Charmonium(-like) states

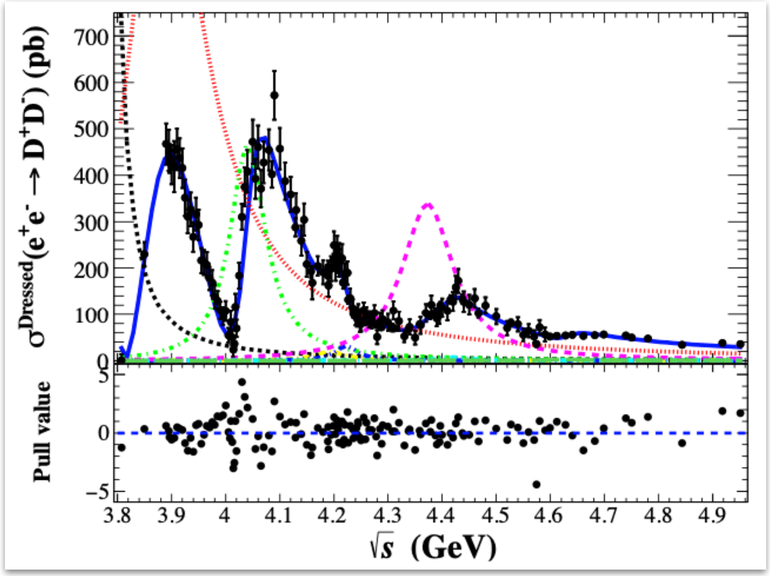
these we can directly produce in e^+e^- collisions



MPLA 40 (2025) 17n18, 2530002

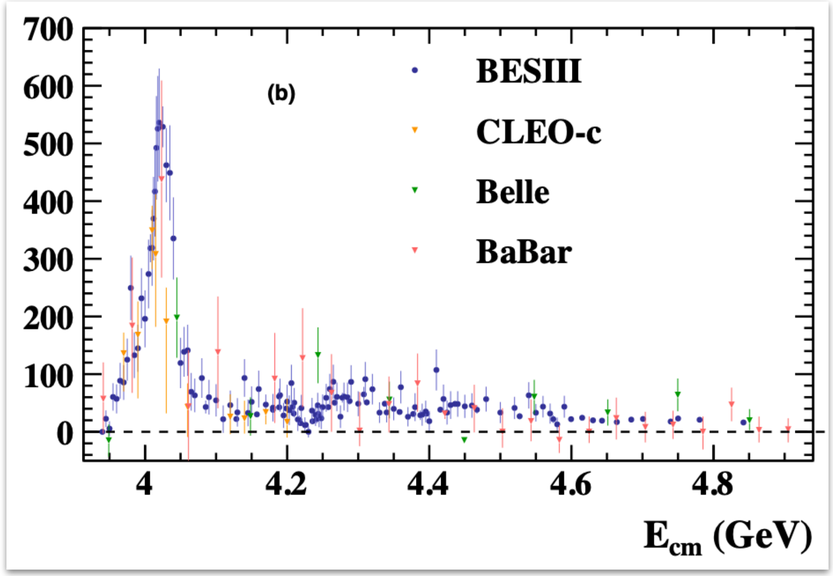
so how about exclusive open-charm cross sections?

$e^+e^- \to D\bar{D}$



PRL 133 (2024) 8, 081901

$e^+e^- \to D_s\bar{D}_s$

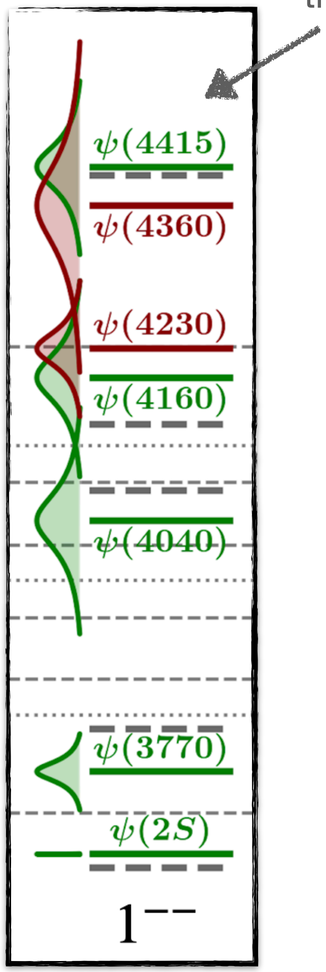


PRL 133 (2024) 26, 261902

much larger cross sections, even more complex structure

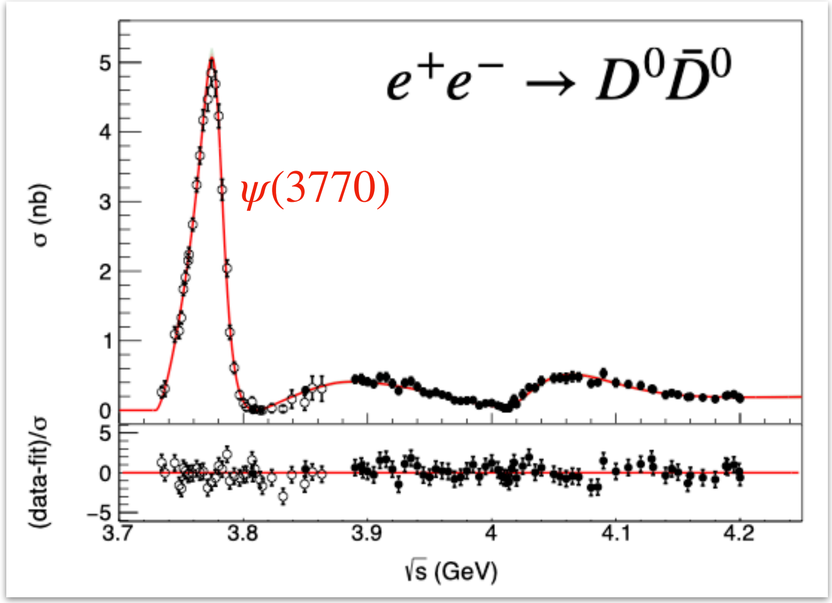
Charmonium(-like) states

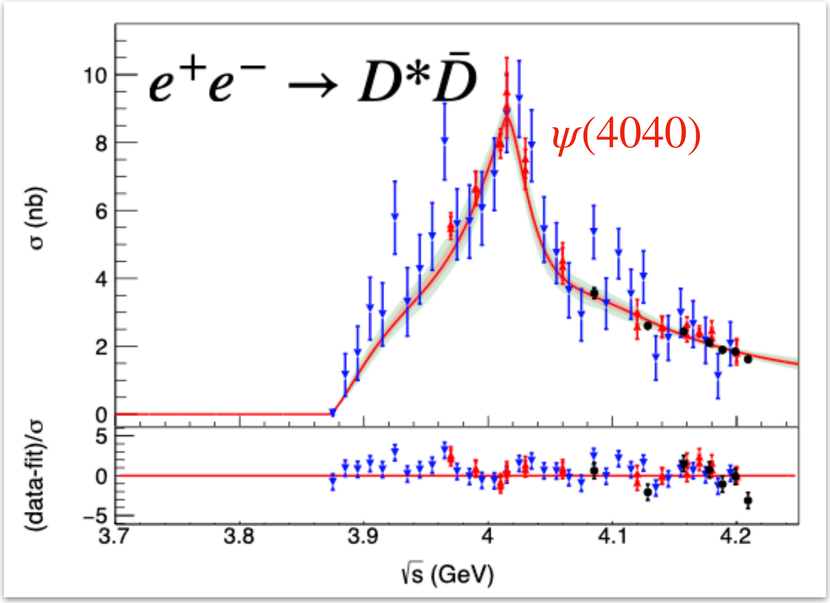
these we can directly produce in e^+e^- collisions



MPLA 40 (2025) 17n18, 2530002

interpretation requires global coupled channel analyses





NH et al., PRD 109 (2024) 11, 114010

simultaneous fit of $e^+e^- \to D\bar{D}$, $D^*\bar{D}$, $D^*\bar{D}^*$

one of multiple examples, ongoing effort

see also: Lin et al., PRL 133, 241903
Nakamura et al., arXiv:2312.17658 [hep-ph]
Cleven et al., PRD 90 (2014) 7, 074039
L. von Detten, PRD 109 (2024) 11, 116002

Recent examples

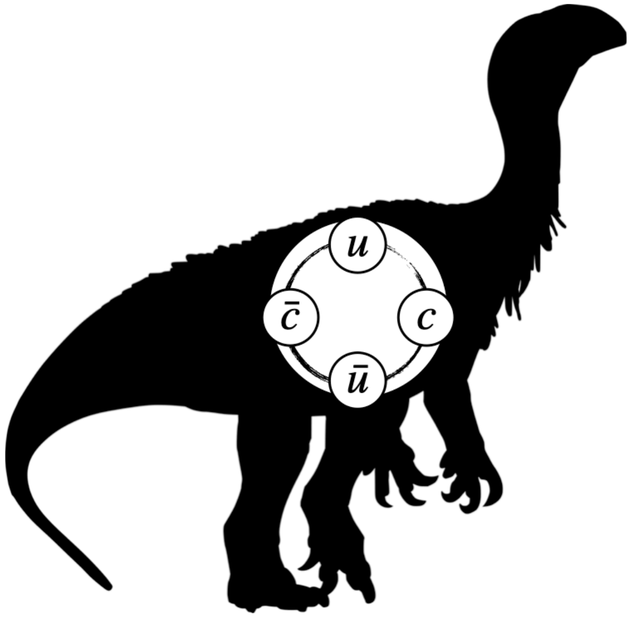
A) a glueball candidate in radiative J/ψ decays?

B) the hybrid meson $\pi_1(1600)$ in χ_{c1} decays

C) searching for excited Ω baryons in e^+e^- collisions

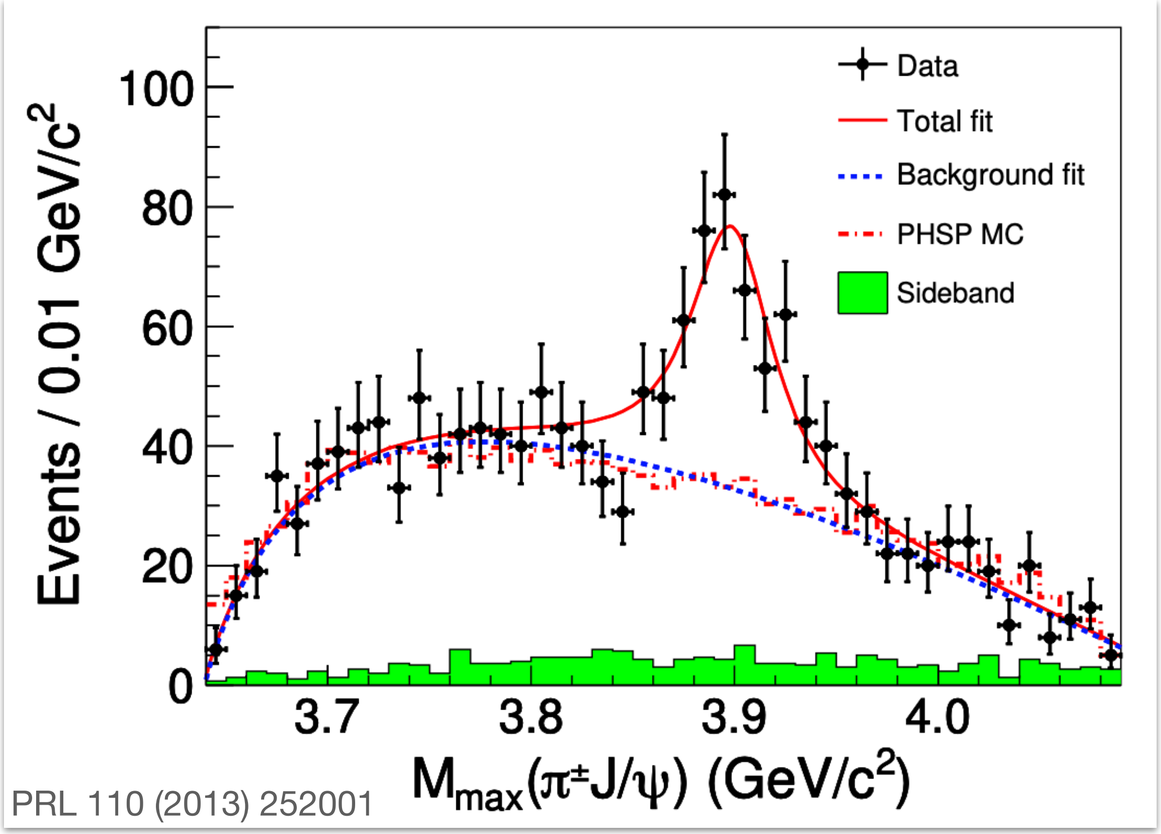
D) updates on charmonium(-like) ψ states

E) updates on the charged charmonium-like $Z_c(3900)$



Detailed study of the $Z_c(3900)$

$$e^+e^- \to \pi^\mp Z_c^\pm(3900), \quad Z_c^\pm(3900) \to J/\psi\pi^\pm$$



PRL 110 (2013) 252001

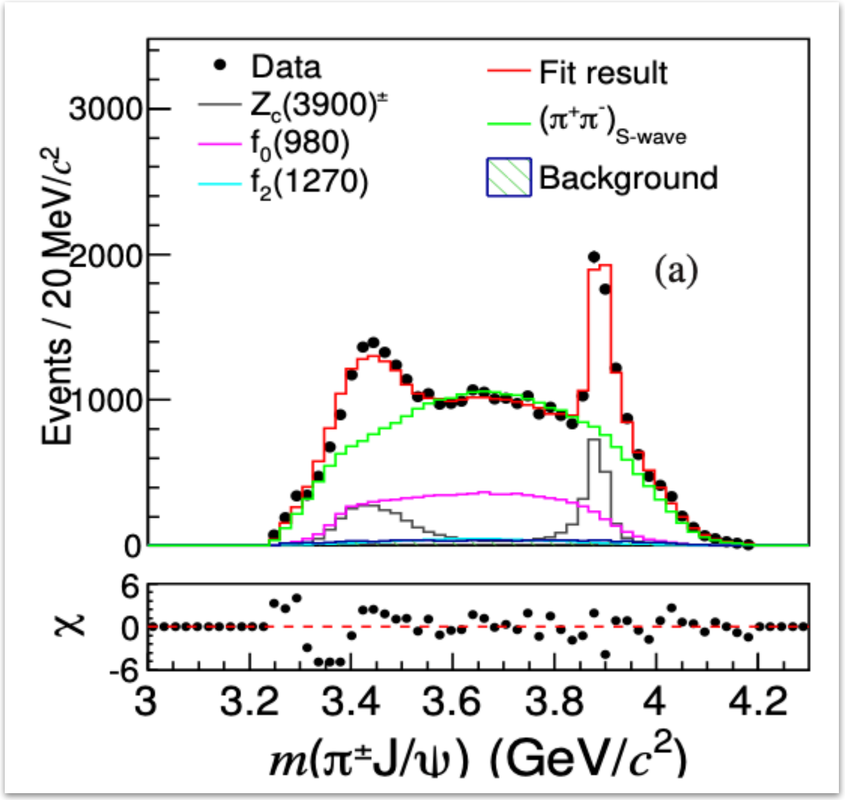
first seen in 2013 (simultaneously by BESIII and Belle)

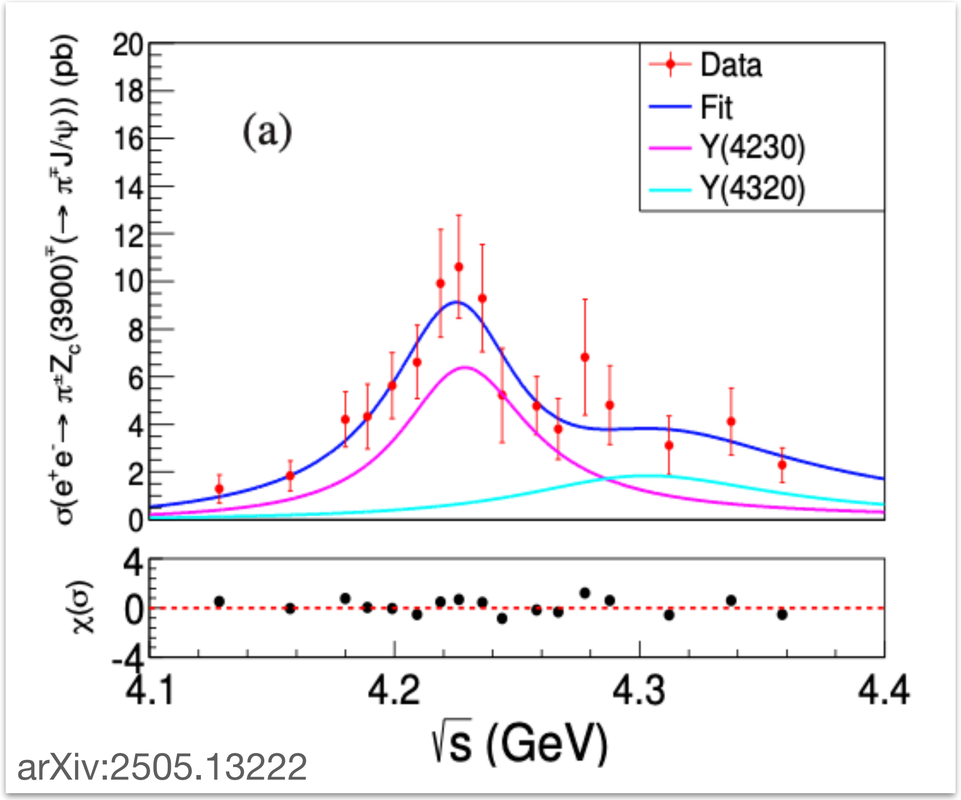
clearly exotic, as isovector with hidden-charm

yet, it's nature is still unclear

Detailed study of the $Z_c(3900)$

$e^+e^- \to \pi^\mp Z_c^\pm(3900), \;\; Z_c^\pm(3900) \to J/\psi\pi^\pm$





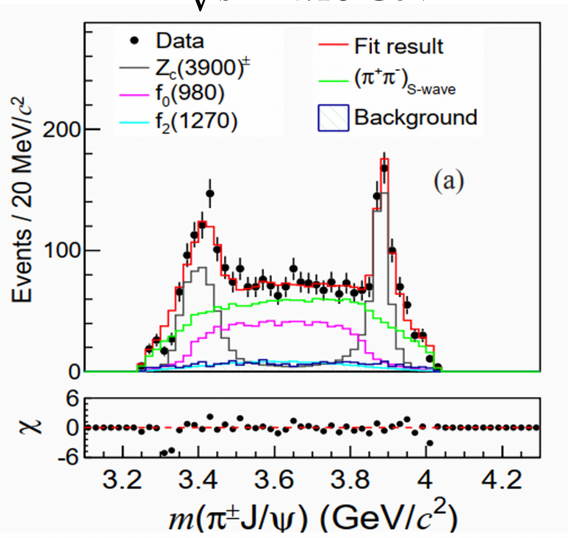
latest work uses all data between 4.1 and 4.4 GeV

$Z_c(3900)$ production near the $\psi(4230)$

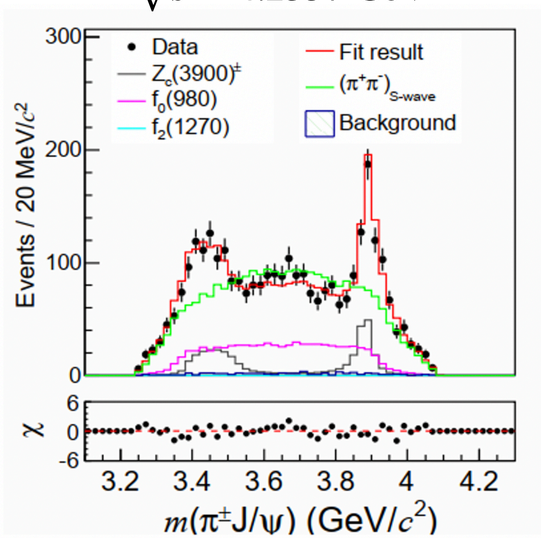
Detailed study of the $Z_c(3900)$

$$e^+e^- \to \pi^\mp Z_c^\pm(3900), \quad Z_c^\pm(3900) \to J/\psi\pi^\pm$$

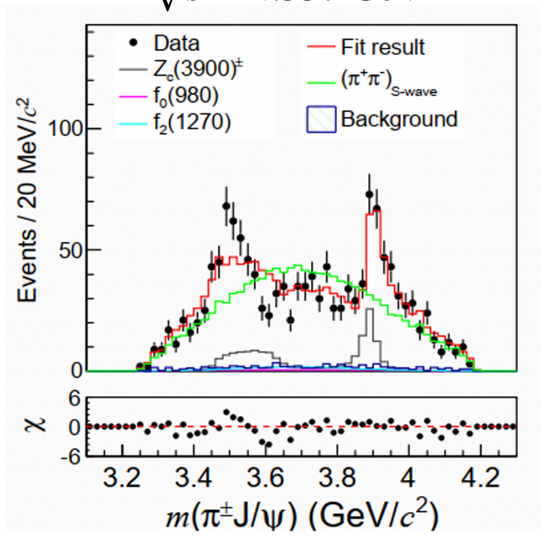
$\sqrt{s} = 4.18$ GeV



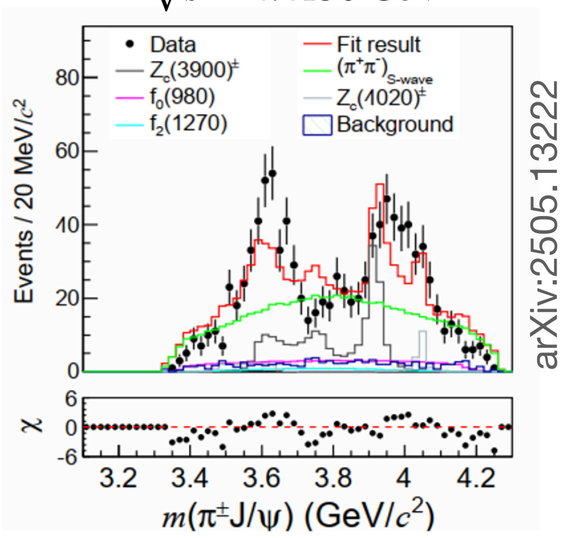
$\sqrt{s} = 4.2357$ GeV



$\sqrt{s} = 4.337$ GeV



$\sqrt{s} = 4.4156$ GeV



arXiv:2505.13222

acceptance corrected data is made available at 17 different center-of-mass energies

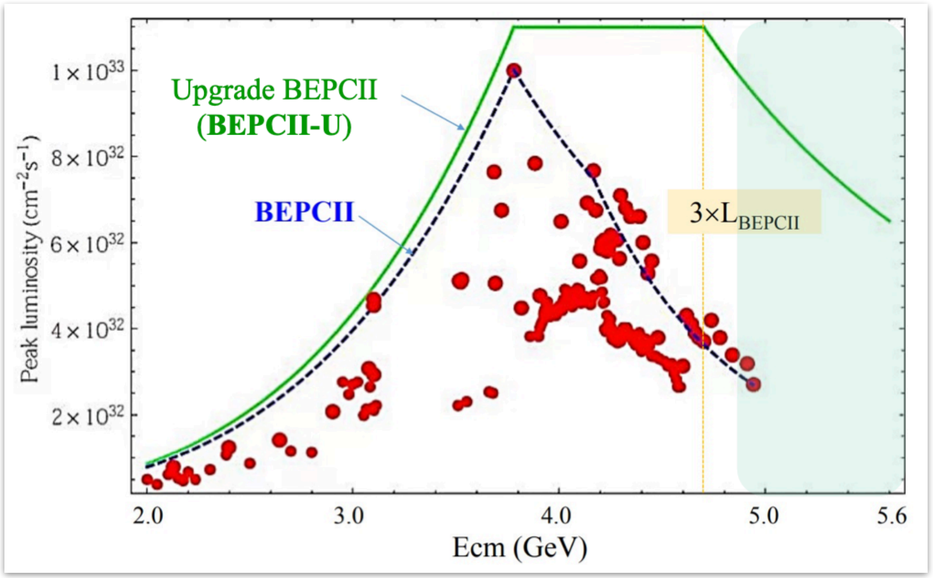
enabling detailed studies of the $Z_c(3900)$ lineshape

Summary

- BESIII remains a key contributor in hadron spectroscopy
  - legacy datasets on J/ψ, $\psi(2S)$ offer unique access to light-quark states, hybrids and glueballs
  - direct production of vector charmonium(-like) states, radiative and hadronic transitions to X, Z states

- much broader physics programme
  - open-charm physics
  - η, η' decays
  - hyperon physics
  - meson form factors
  - …

- recent upgrades to accelerator, data taking continues
  - higher energies up to 5.6 GeV
  - up to 3x higher luminosity in the XYZ region



Thank you for your attention!