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Recent studies about XYZ particles at BESIII

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BESIII

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Research Training Group

Outline

The charmonium and charmonium-like sector

The BESIII experiment

Recent studies about XYZ particles at BESIII in the reactions

$$e^+e^- \to \phi\Lambda\bar{\Lambda}$$

$$e^+e^- \to \eta\psi(2S)$$

$$e^+e^- \to e^+e^- \to \eta_c + \pi^+\pi^-\pi^0, \pi^+\pi^-, \pi^0\gamma$$

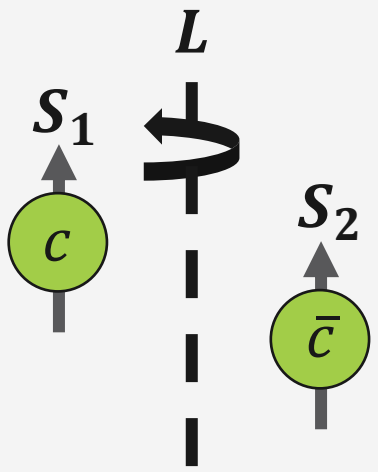
$$e^+e^- \to e^+e^- \to K^+\left(D_s^- D^{*0} + D_s^{*-} D^0\right)$$

$$e^+e^- \to p\bar{p}\eta, p\bar{p}\omega$$

The heavy charmonium sector $c\bar{c}$

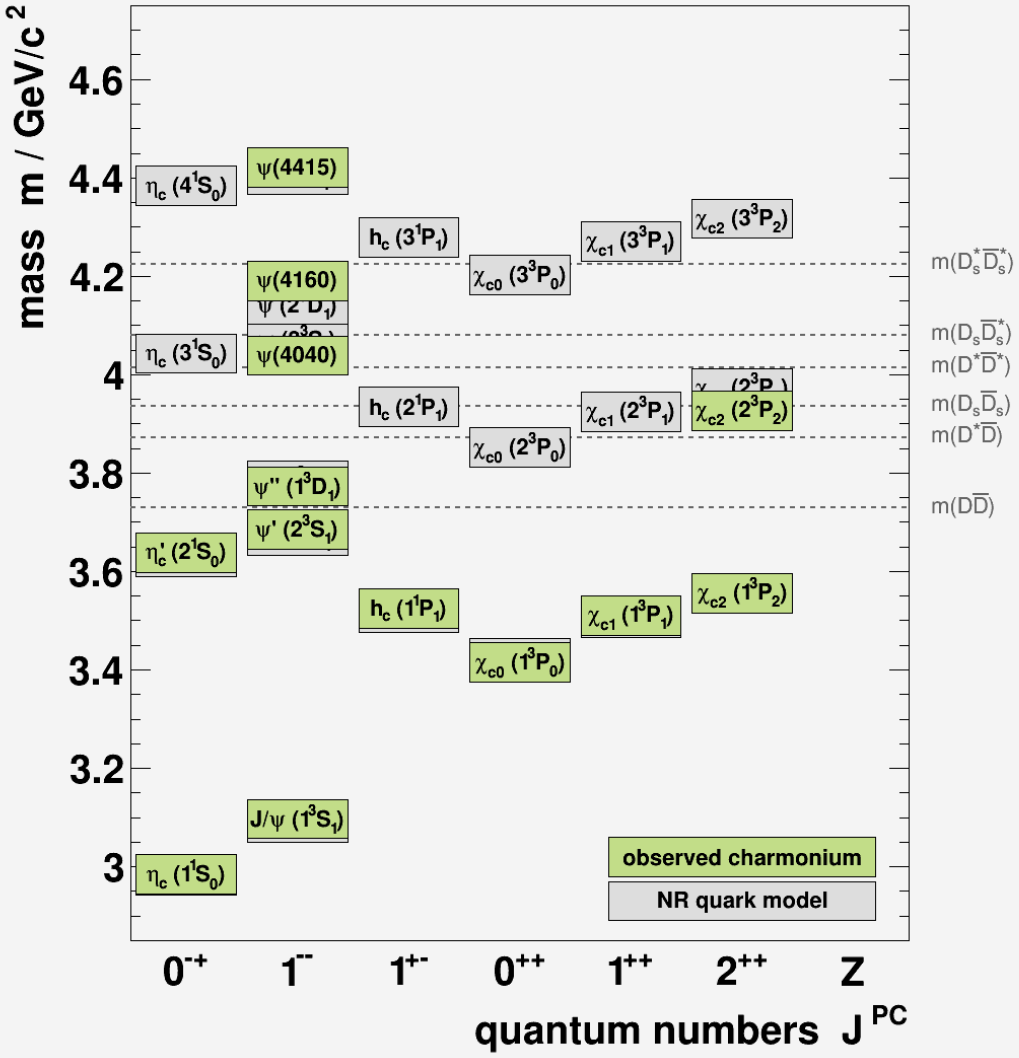
Nonrel. potential model to derive spectrum

Predicted by theory and (many) **confirmed** by experiment



$$S = S_1 + S_2$$
$$J = L + S$$

$$P = (-1)^{L+1}$$
$$C = (-1)^{L+S}$$

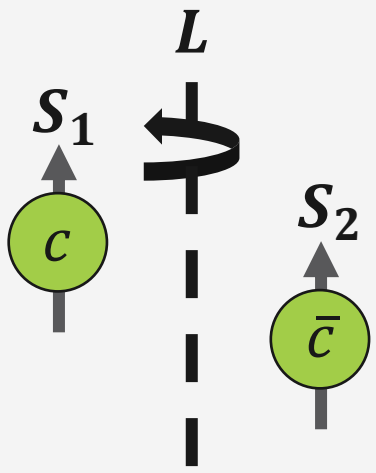


The heavy charmonium sector $c\bar{c}$

Nonrel. potential model to derive spectrum

Predicted by theory and (many) **confirmed** by experiment

$m > m_{D\bar{D}}$: OZI-allowed open charm decays



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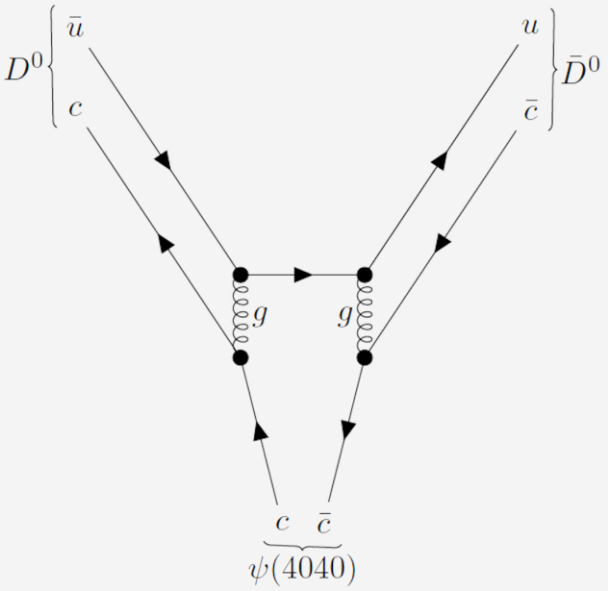
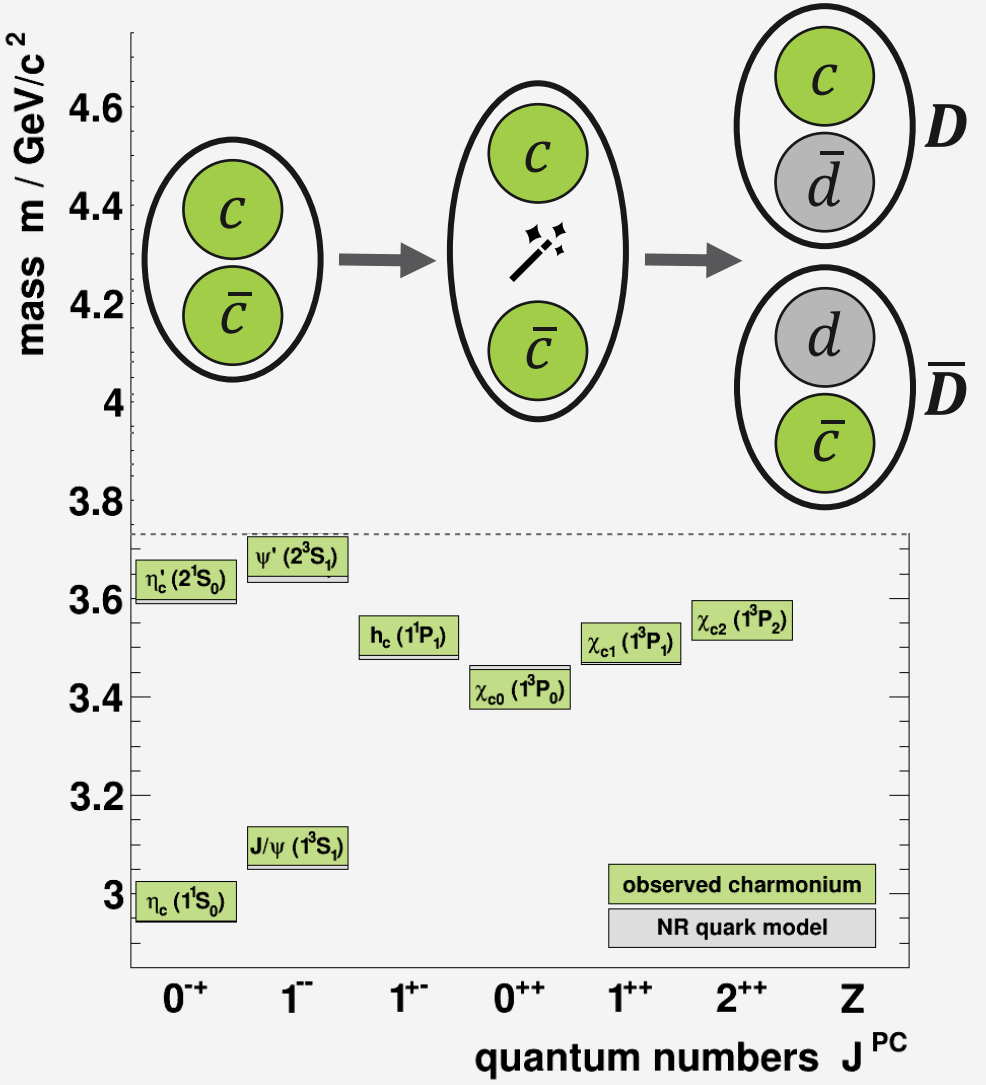


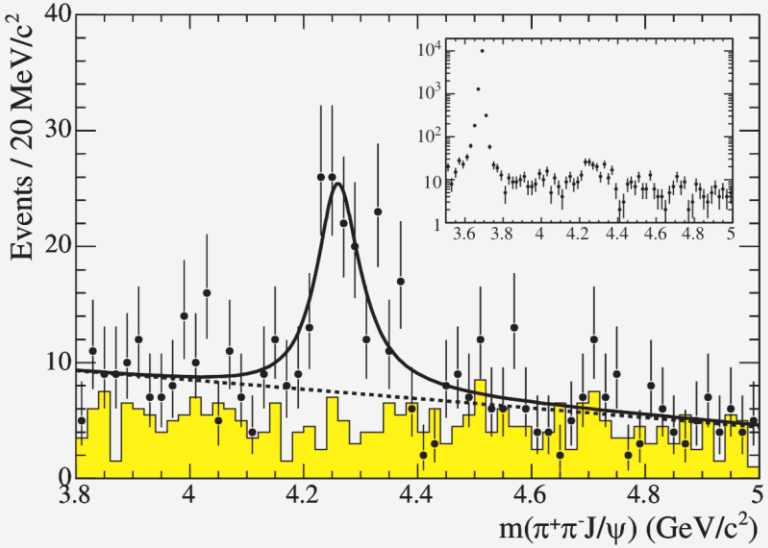


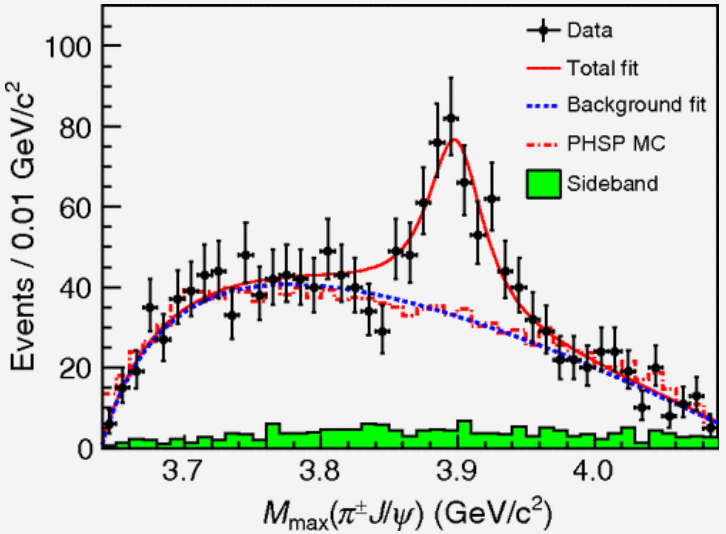
The heavy charmonium sector $c\bar{c}$

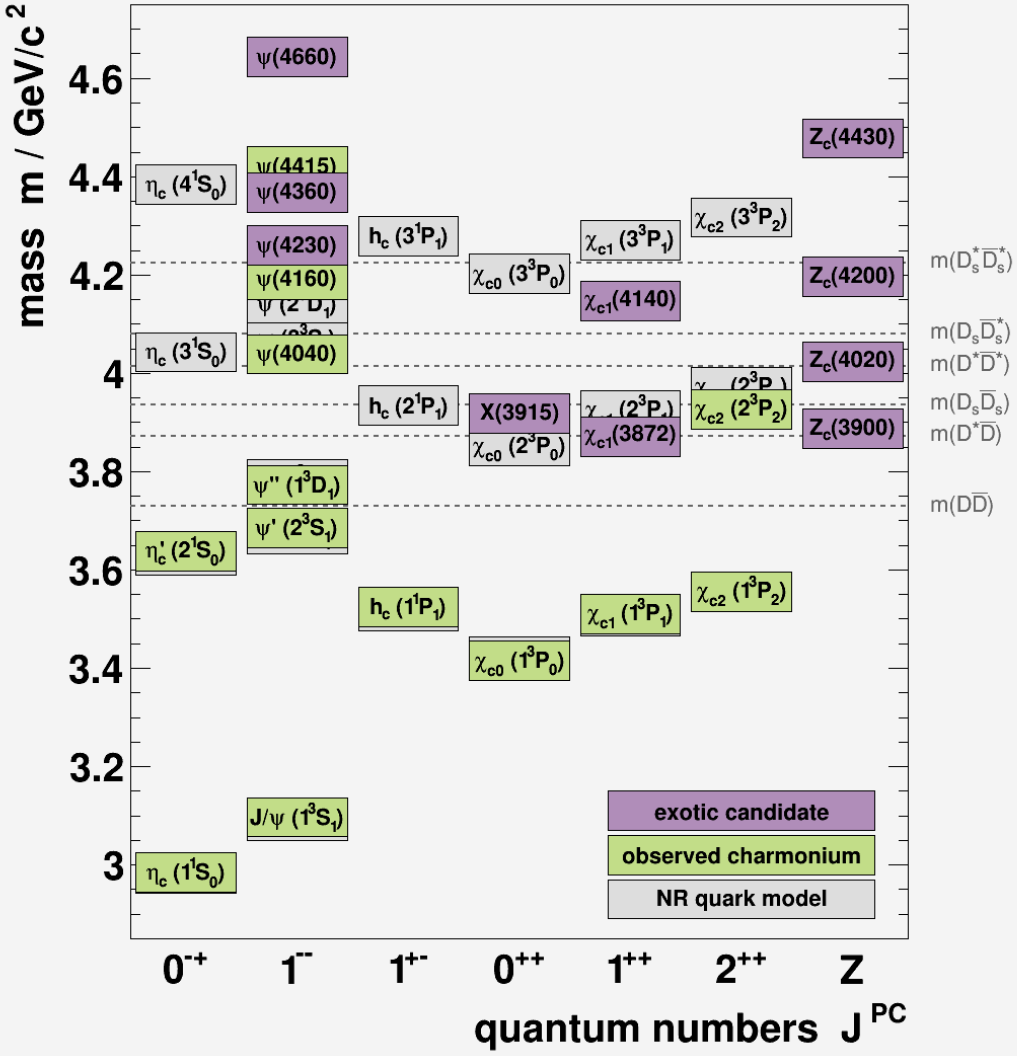
Unexpected overpopulation measured

$\psi(4260)$ discovered by BABAR[1], observed at **BESIII**[2] coupling to $J/\psi\pi^+\pi^-$

$Z_C(3900)$ discovered at **BESIII**[3] **and Belle**[4]**,** coupling to $J/\psi\pi^\pm$







1:Phys. Rev. Lett. **95**, 142001, 2:Phys. Rev. Lett. **110**, 252001, 3:Phys. Rev. Lett. **110**, 252001, 4:Phys. Rev. Lett. **110**, 252002

The heavy charmonium sector $c\bar{c}$

Unpredicted XYZ states have small coupling to $D\bar{D}$

… but observed in many **charmonium transitions, e.g.**

$\psi(4260) \rightarrow J/\psi\pi^+\pi^-$

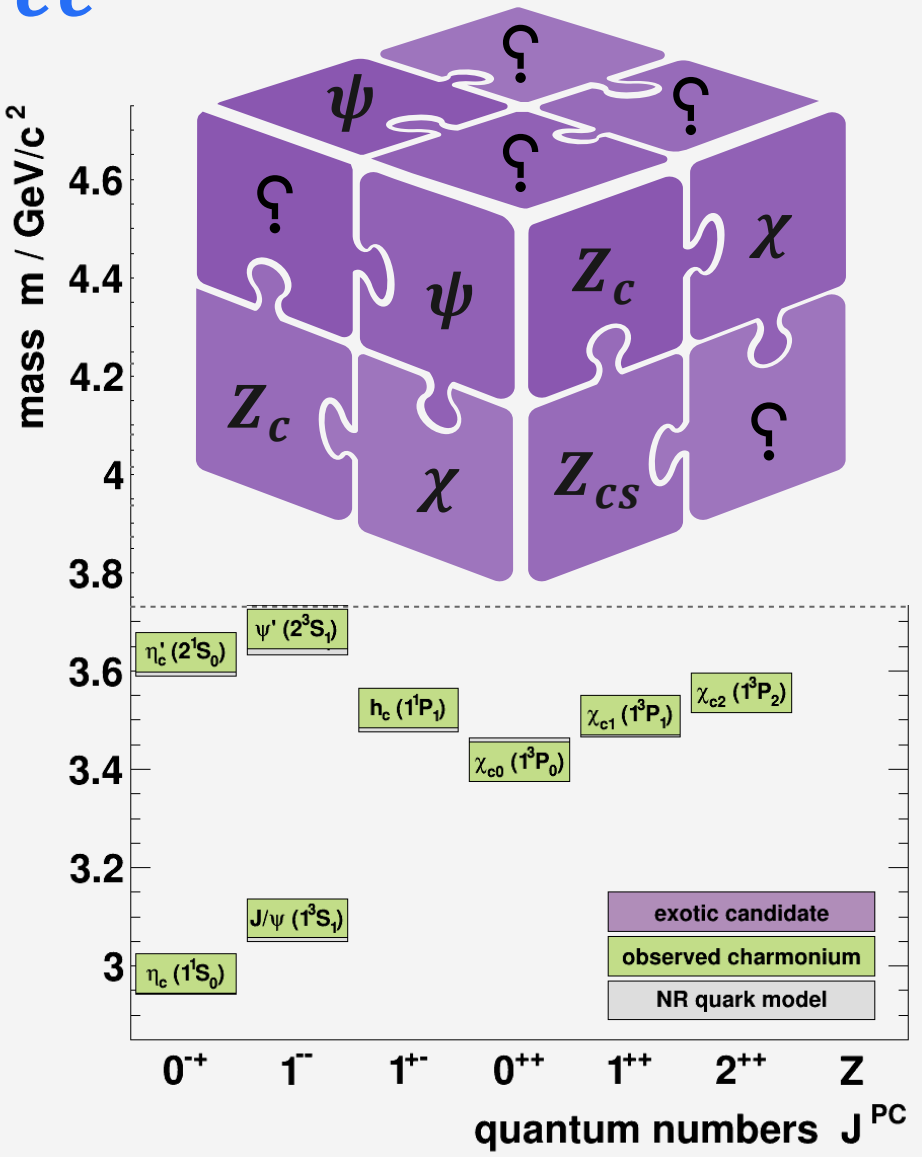
$\psi(4260) \rightarrow h_c\pi^+\pi^-$ [1]

$\psi(4260) \rightarrow \psi(2S)\pi^+\pi^-$ [2]

…**theoretical interpretations**:

compact tetraquarks, molecules, hybrids, hadrocharmonia,…

…**strategy:** search in many possible decay channels



1:Phys. Rev. Lett. **118**, 092002, 2:Phys. Rev. D **96**, 032004

Outline

The charmonium and charmonium-like sector

The BESIII experiment

Recent studies about XYZ particles at BESIII

$$e^+e^- \to \phi\Lambda\bar{\Lambda}$$

$$e^+e^- \to \eta\psi(2S)$$

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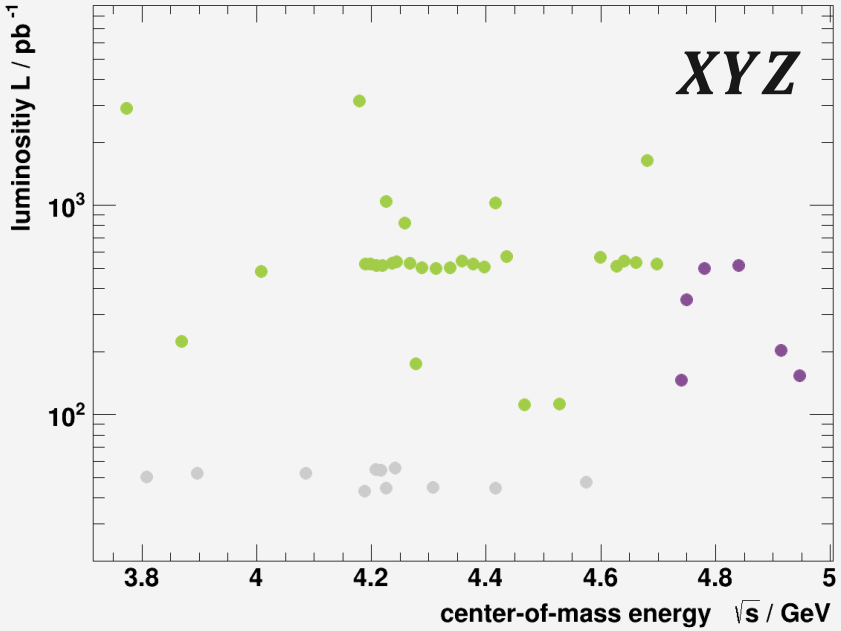
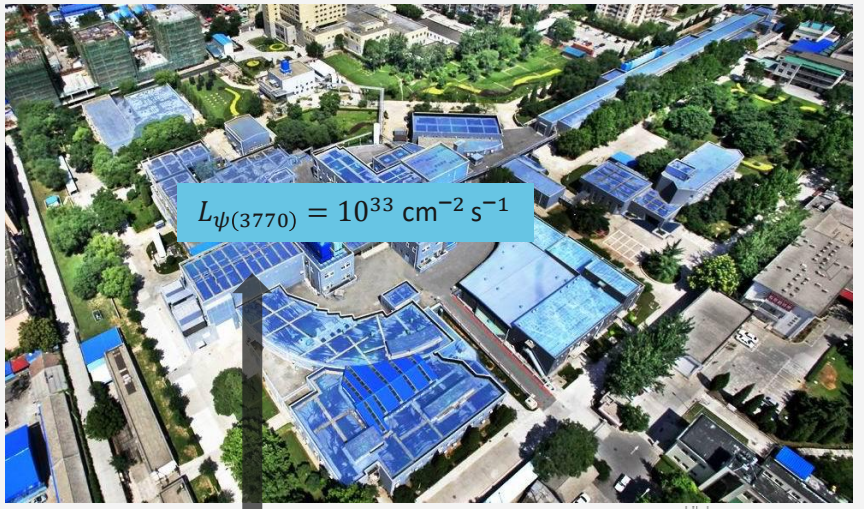
The BESIII experiment at IHEP located in Beijing

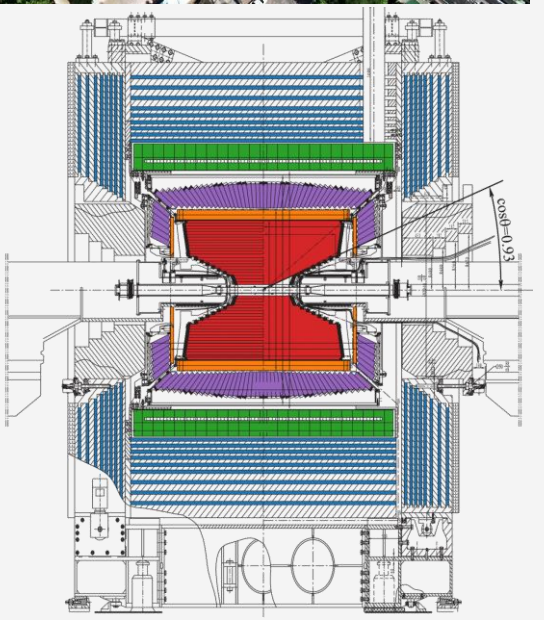


$\sqrt{s} = 2.0 - 5.0$ GeV

$J^{PC} = 1^{--}$ **produced directly**

World's largest data sample at J/ψ and $\psi(2S)$ resonance





MDC: Wire chamber

TOF: plastic scintillator

EMC: CsI(Tl) crystal

SC: Solenoid magnet with B = 1 T

RPC: μ-Veto: μ/π PID

→ PID using dE/dx and TOF

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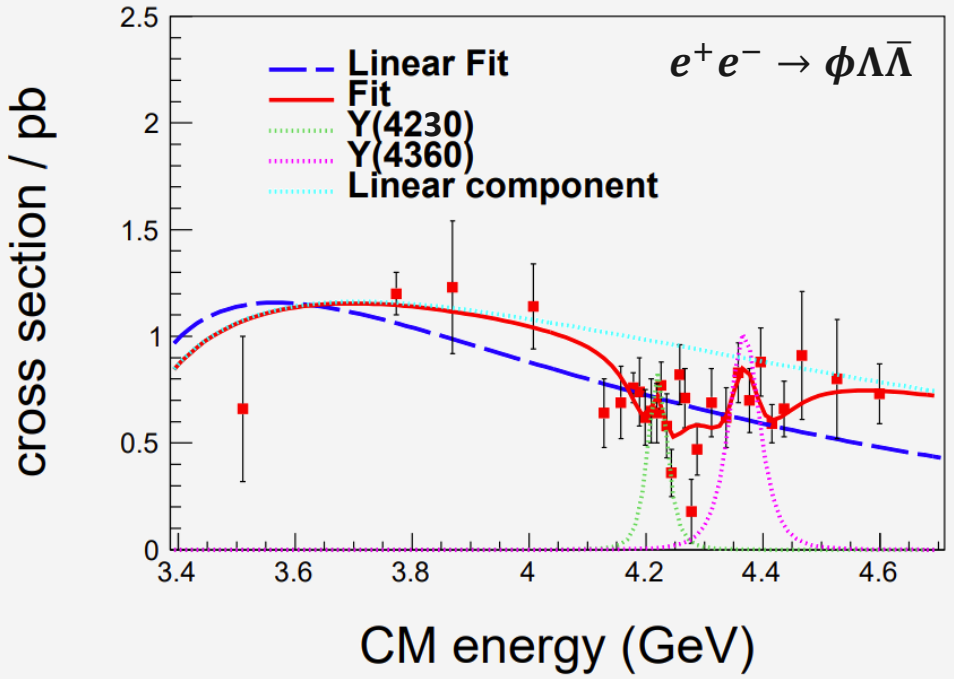
$$e^+e^- \to p\bar{p}\eta, p\bar{p}\omega$$

$e^+e^- \to \phi\Lambda\bar{\Lambda}$

$\psi(4230)$ interpreted as diquark-antidiquark $cs\bar{c}\bar{s}$

→ Decays to final states containing $s\bar{s}$, e.g. $\psi \to f_0(980)J/\psi$ in $e^+e^- \to \psi \to \pi^+\pi^- J/\psi$

→ Expected to decay into $\phi\Lambda\bar{\Lambda}$



$\psi(4230)$: **4.2σ**

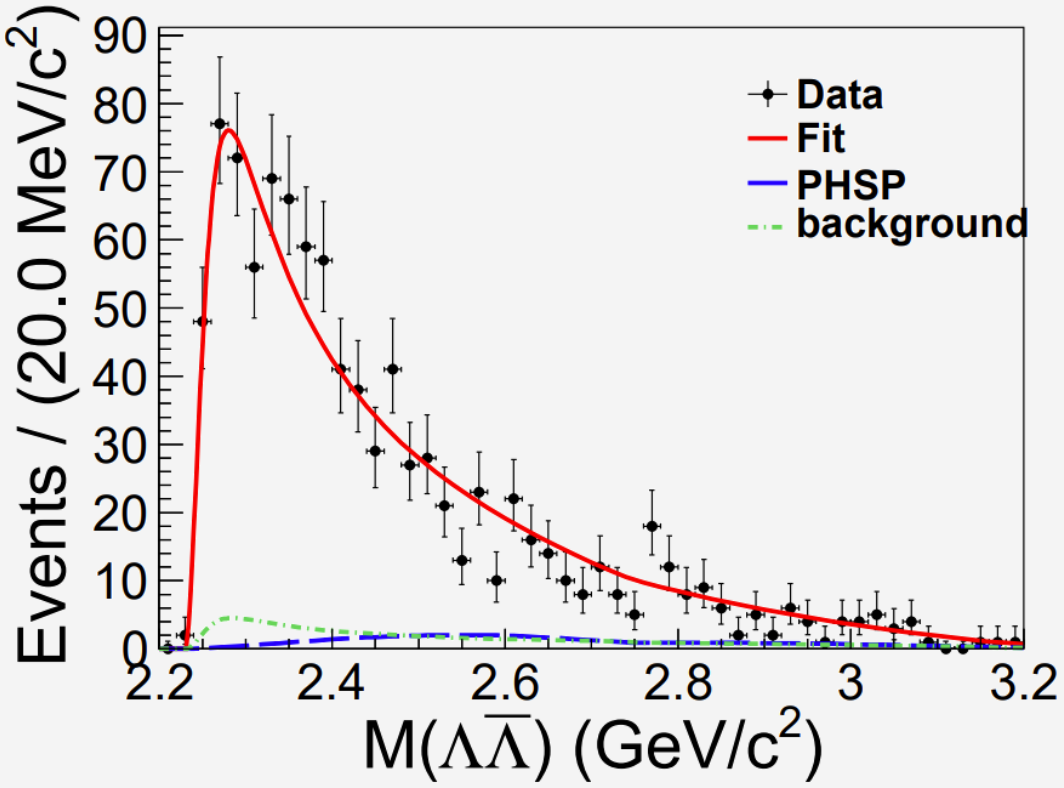
$\psi(4360)$: **3.1σ**

Large interference between continuum processes and resonances

$e^+e^- \to \phi\Lambda\overline{\Lambda}$

Near-threshold enhancements observed involving baryon-antibaryon pairs, here: $C = +$

→ Spin-parity can be determined studying the angular distributions



$\chi(2260)$: **>25σ**

$m = 2262 \pm 4\ \mathrm{MeV}/c^2$

$\Gamma = 72 \pm 5\ \mathrm{MeV}$

→ No matched resonance in the PDG

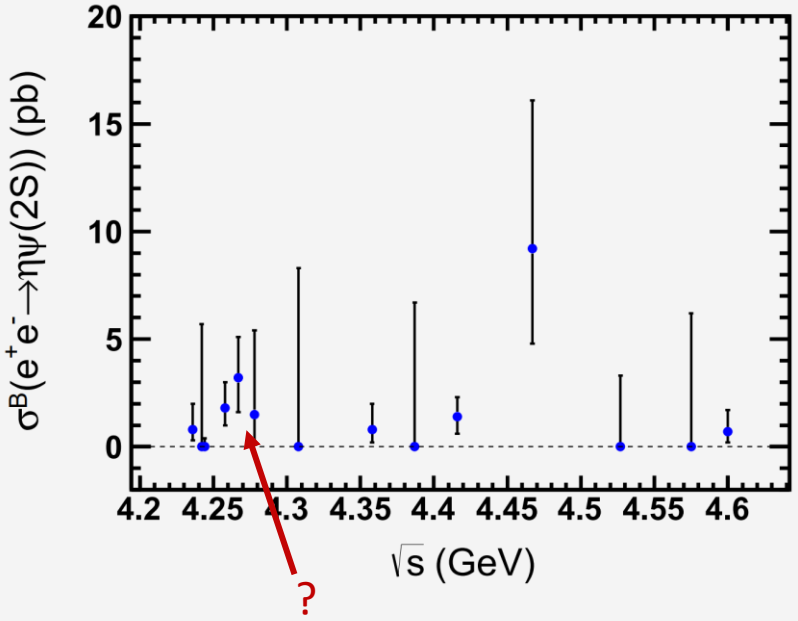
→ $J^{PC} = 2^{++}, 2^{-+}$ favored,
0^{-+} rejected (no $\eta(2225)$!)

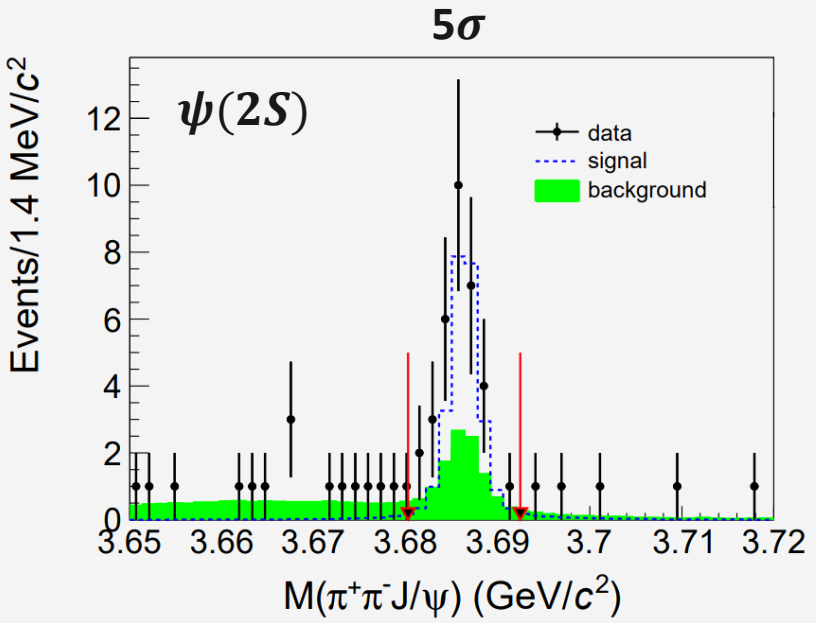
$e^+e^- \to \eta\psi(2S)$

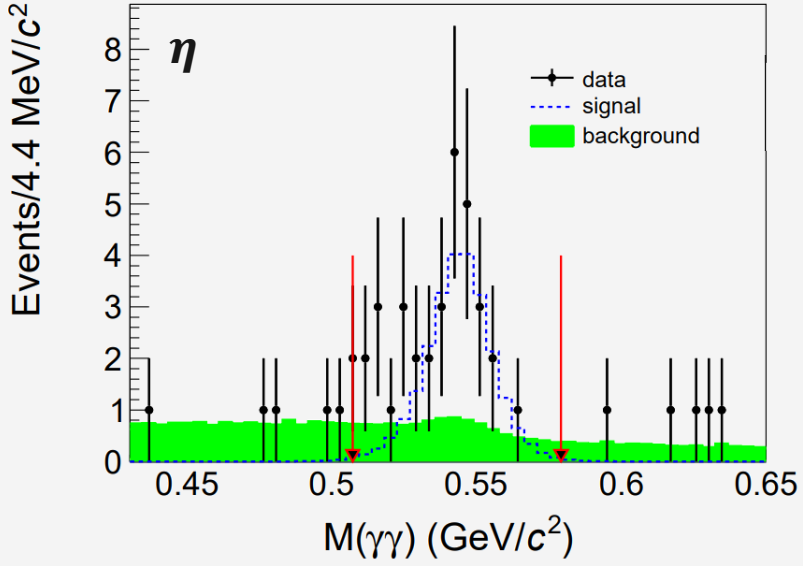
Besides $\pi\pi$ hadronic transitions, search for $\psi(4230) \to \eta + c\bar{c}$

$e^+e^- \to \psi(4220/4390) \to \eta J/\psi$[1] observed at BESIII with >6σ

No significant structure in $\eta\psi(2S)$ → collect more data, missing track technique







1:Phys. Rev. D **102**, 031101(R)

$e^+e^- \to \eta_c + \pi^+\pi^-\pi^0, \pi^+\pi^-, \pi^0\gamma$

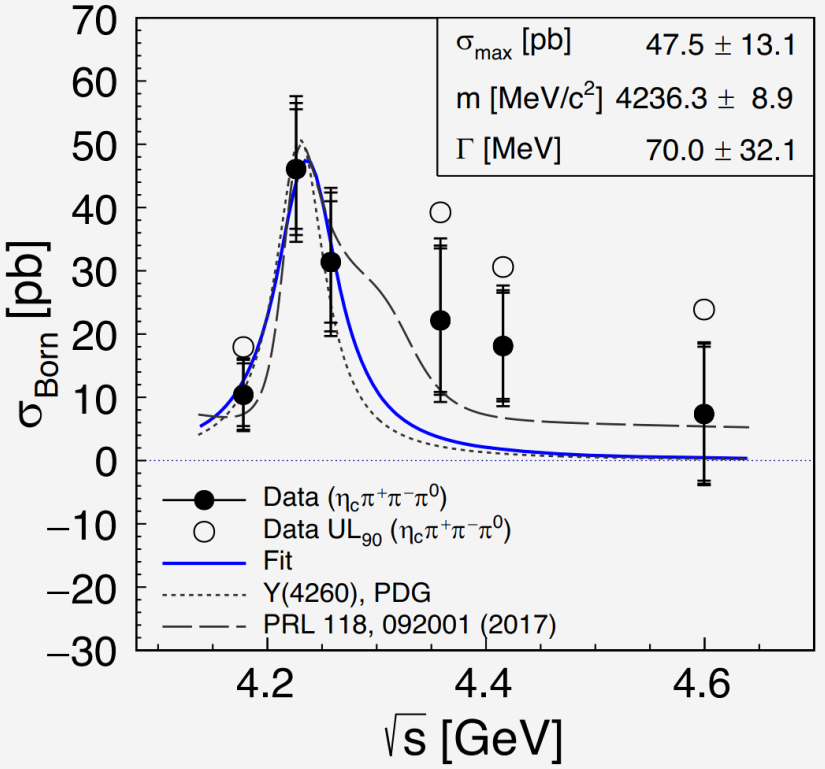
Newly observed $\chi(3872)$, $Z_c(3900)$ and $Z_c(4020)$ found close to $D\bar{D}^*$ and $D^*\bar{D}^*$ thresholds with $J^P(D\bar{D}) = 0^+$

→ Z_c expected to decay into $\eta_c\pi$, also search for $\psi \to \eta_c$+ light recoils

$e^+e^- \to \eta_c\pi^+\pi^-\pi^0$ observed for the first time
→ In agreement with the production of $\psi(4260)$ decaying to $\eta_c\pi^+\pi^-\pi^0$

Upper limits for $e^+e^- \to \eta_c + \pi^+\pi^-, \pi^0\gamma$

No significant signal is found for a charged $Z_c^\pm \to \eta_c\pi^\pm$



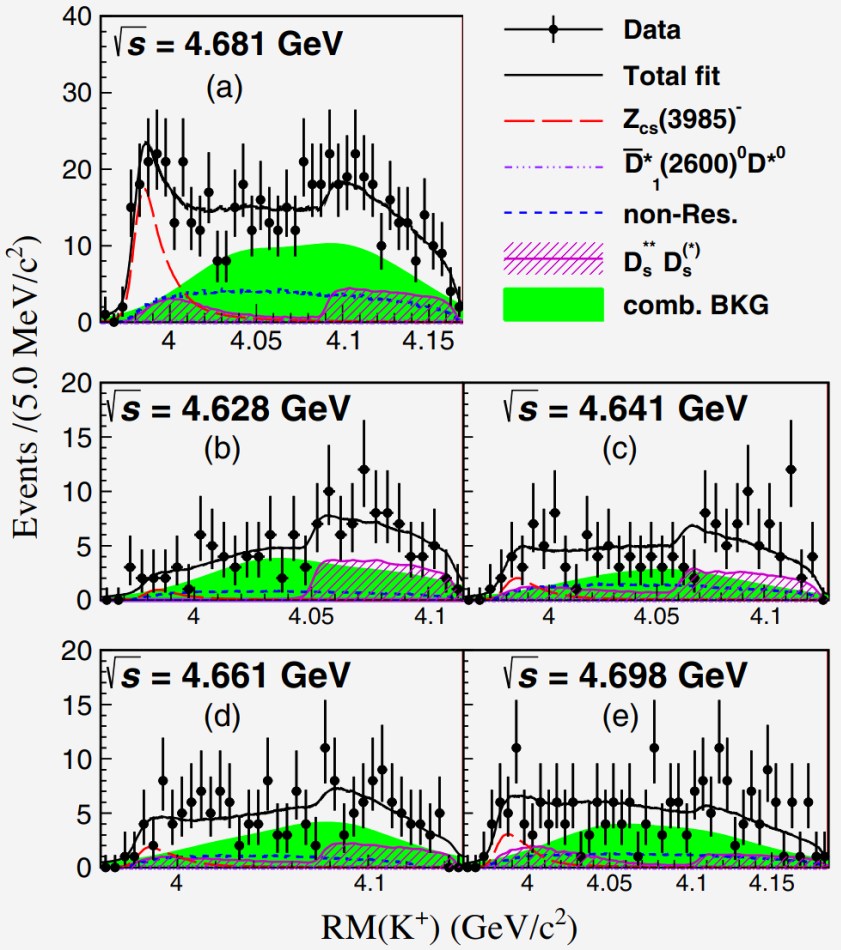
$e^+e^- \to K^+\left(D_s^- D^{*0} + D_s^{*-} D^0\right)$

Observation of $Z_c^{\pm 0}(c\bar{c}q\bar{q})$ with $q = u, d$ have opened a new chapter in HEP

Assuming **SU(3) flavor symmetry,** strange partners $Z_{cs}^{\pm 0}(c\bar{c}s\bar{q})$ should exist, predicted with a mass around $D_s^- D^{*0}$ and $D_s^{*-} D^0$

→ Observed enhancement, called $Z_{cs}^-(3985)$, near $D_s^- D^{*0}$ and $D_s^{*-} D^0$ thresholds with 5.3σ

$$m = 3985.5^{+1.8}_{-2.6} \pm 2.1\ \text{MeV}/c^2$$
$$\Gamma = 12.8^{+5.3}_{-4.4} \pm 3.0\ \text{MeV}$$



$e^+e^- \to p\bar{p} + \eta, \omega$

No observation of $\psi(4260) \to$ **light hadrons**

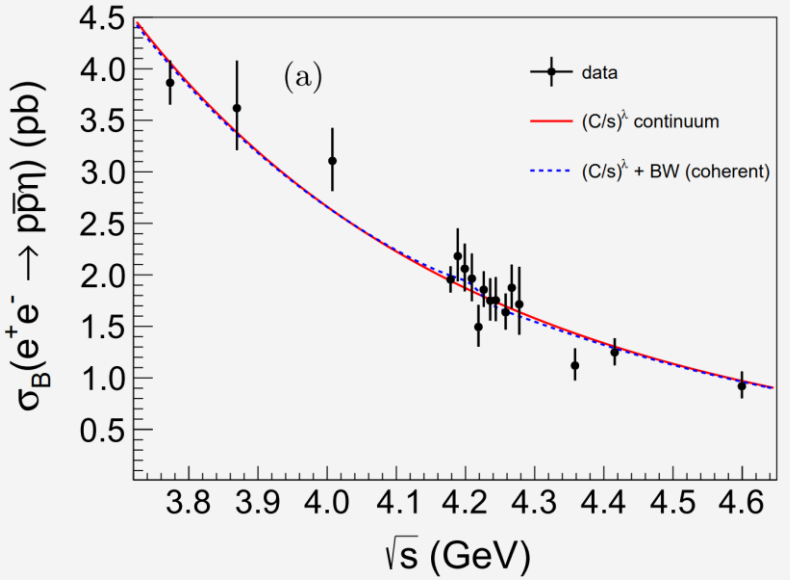
Final states containing $p\bar{p}$ **pair** very interesting:

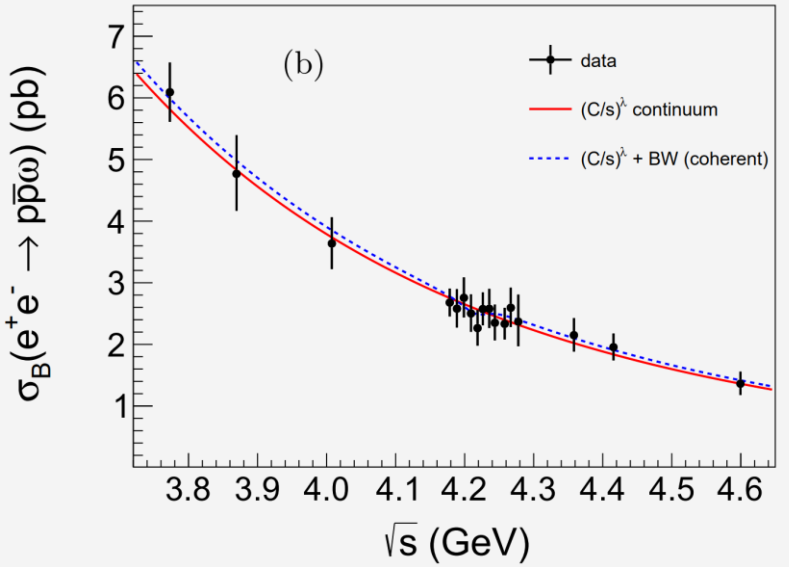
$\psi \to p\bar{p}h \overset{1}{\Longleftrightarrow} p\bar{p} \to \psi h$, $h =$ unflavored light meson

→ PANDA

No significant structure in $p\bar{p}\eta$ nor in $p\bar{p}\omega$

→ $p\bar{p}\eta'$ already started, looks promising





1:Phys. Rev. D **73**, 096003

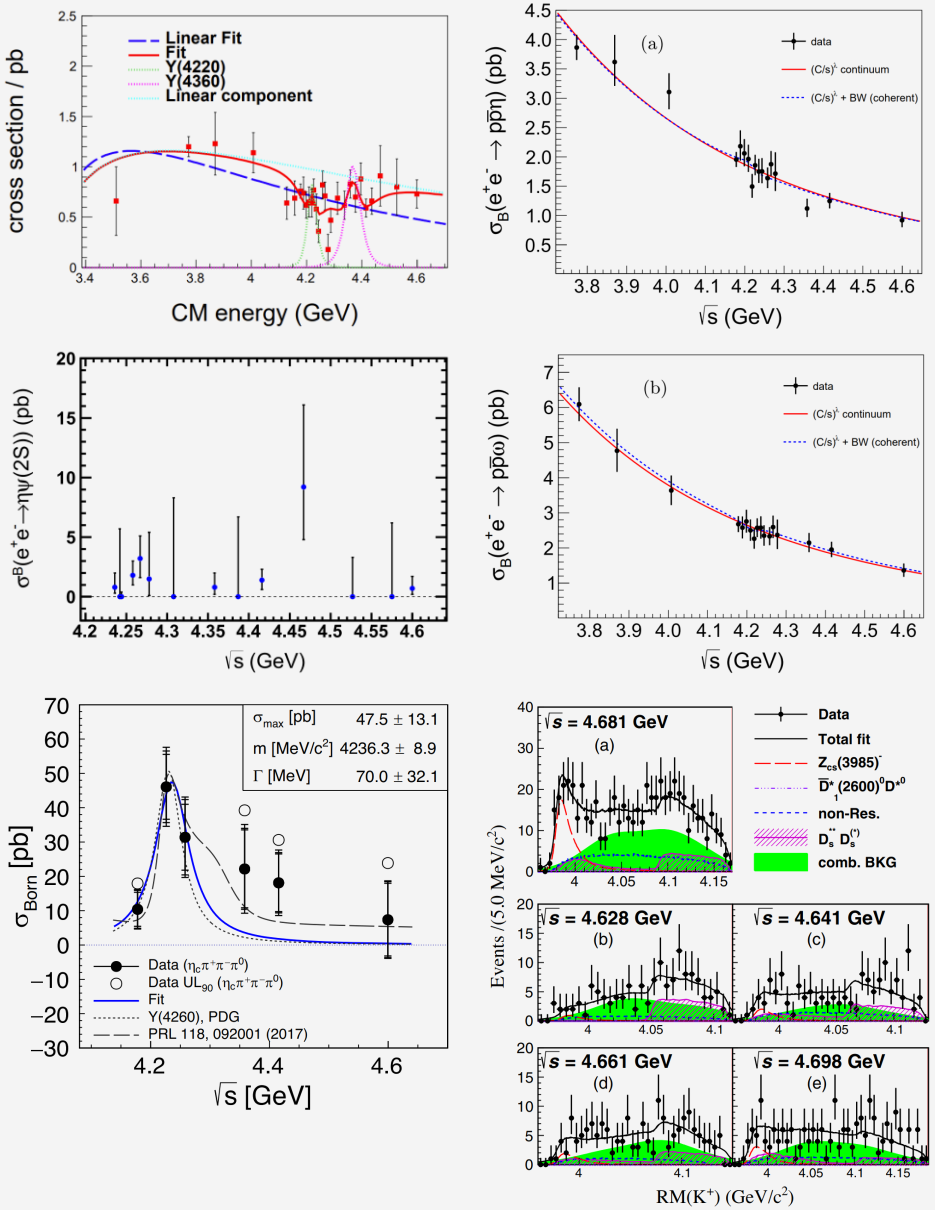
Summary

Recent studies with very high accuracy on

- Vector charmonium(-like) states ψ
- Charged charmonium-like states $Z_c^{\pm 0}$
- Neutral charmonium-like states χ

Recently, more data is taken between $\sqrt{s} = 4.60$ GeV and $\sqrt{s} = 4.95$ GeV → new $Z_{cs}(3985)^-$[1]

More analyses are in progress, e.g. $e^+e^- \to p\bar{p}\eta'$



1:Phys. Rev. Lett. **126**, 102001

Thank you

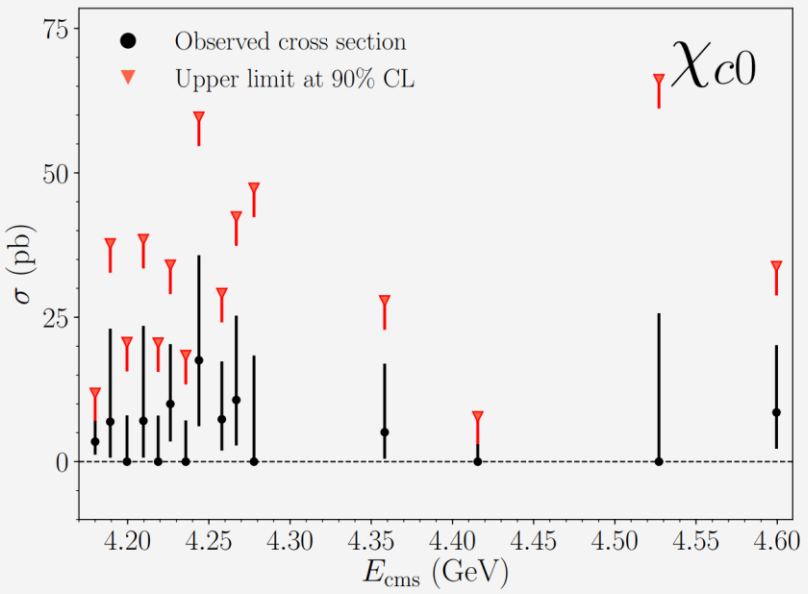
Backup

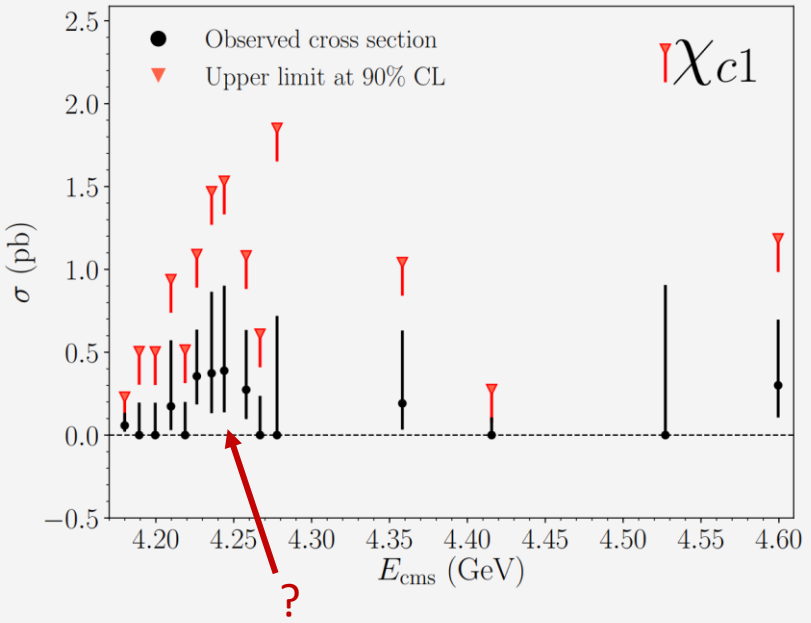
$e^+e^- \to \chi_{cJ}\pi^+\pi^-$

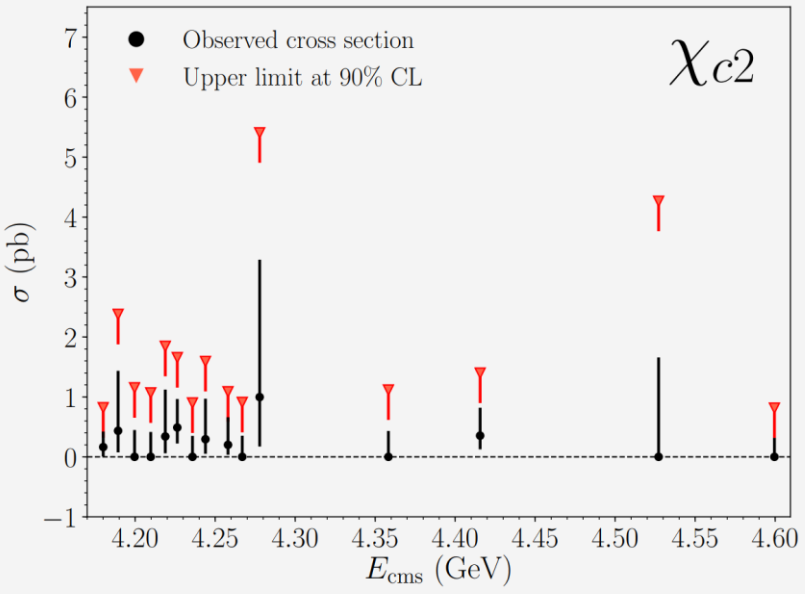
In 2008, Belle observed $Z_c^+(4050)$ and $Z_c^+(4250)$ in $\chi_{c1}\pi^+$ via $\bar{B}_0 \to K^-\pi^+\chi_{c1}$ [1]

Babar has found no evidence in the same reaction [2] → 90% C.L. upper limits

No significant $\chi_{cJ}\pi^+\pi^-$ signals → upper limits, also for $Z_c^\pm$ in $\chi_{cJ}\pi^\pm$ at BESIII







$e^+e^- \to \eta_c\eta\pi^+\pi^-$

$Z_c^{\pm 0}(3900)$ in $\pi\pi J/\psi$

$Z_c^{\pm 0}(4020)$ in $\pi\pi h_c$

} **Isospin triplets**

→ Possible unobserved triplet $Z_c^{\pm 0} \to \eta_c\pi^{\pm 0}$ and singlet $Z_c^0 \to \eta_c\eta$

→ Search in $\eta_c\eta\pi^+\pi^-$ at five different $\sqrt{s}$

$\pi\pi$ system with $L = 1$ to conserve *C*-parity

→ Mainly via $\rho \to \pi\pi$

η_c reconstructed in 16 exclusive decay modes