Recent results for X- and Z- states at BESIII

Chunhua Li
(on behalf of the BESIII Collaboration)
Nanjing Normal University

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Outline

- Introduction
- Recent results of X and Z states from BESIII
  - Search for X(3872)→$K_sK^{\pm}\pi^{\mp}$ and $K^*(892)^{\pm,0}K^{\mp,0}$
  - Search for 1^{-+} charmoniumlike exotic states via e+e-→γ($\eta\eta_c$, $\eta'\eta_c$, $D_sD_{s1}(2536)$)
  - PWA of $e^+e^-\to \pi^+\pi^- J/\psi$
  - Multi-channel joint analysis of $T_{ccbar}(4020)$
  - Search for new Z_{cs} states in $e^+e^-\to K^+K^-\psi(3686)$ system
- Summary

Hadrons

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

- Meson:$q\bar{q}$, Baryon:qqq
- QCD allows hadrons beyond meson and baryon exist

...ero for all known baryons and ...teresting example of such a ... the triplet has spin $\frac{1}{2}$ and ...r particles d^-, s^-, u^o and b^o ... the leptons. ...e elegant scheme can be ...w non-integral values for the ...ense entirely with the basic ... to the triplet t the following $= -\frac{1}{3}$, and baryon number $\frac{1}{3}$. ...nembers $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of ...'' 6) q and the members of the

way the selection of specific components of the F-spin by electromagnetism and the weak interactions determines the choice of isotopic spin and hyper-charge directions.

Even if we consider the scattering amplitudes of strongly interacting particles on the mass shell only and treat the matrix elements of the weak, electro-magnetic, and gravitational interactions by means

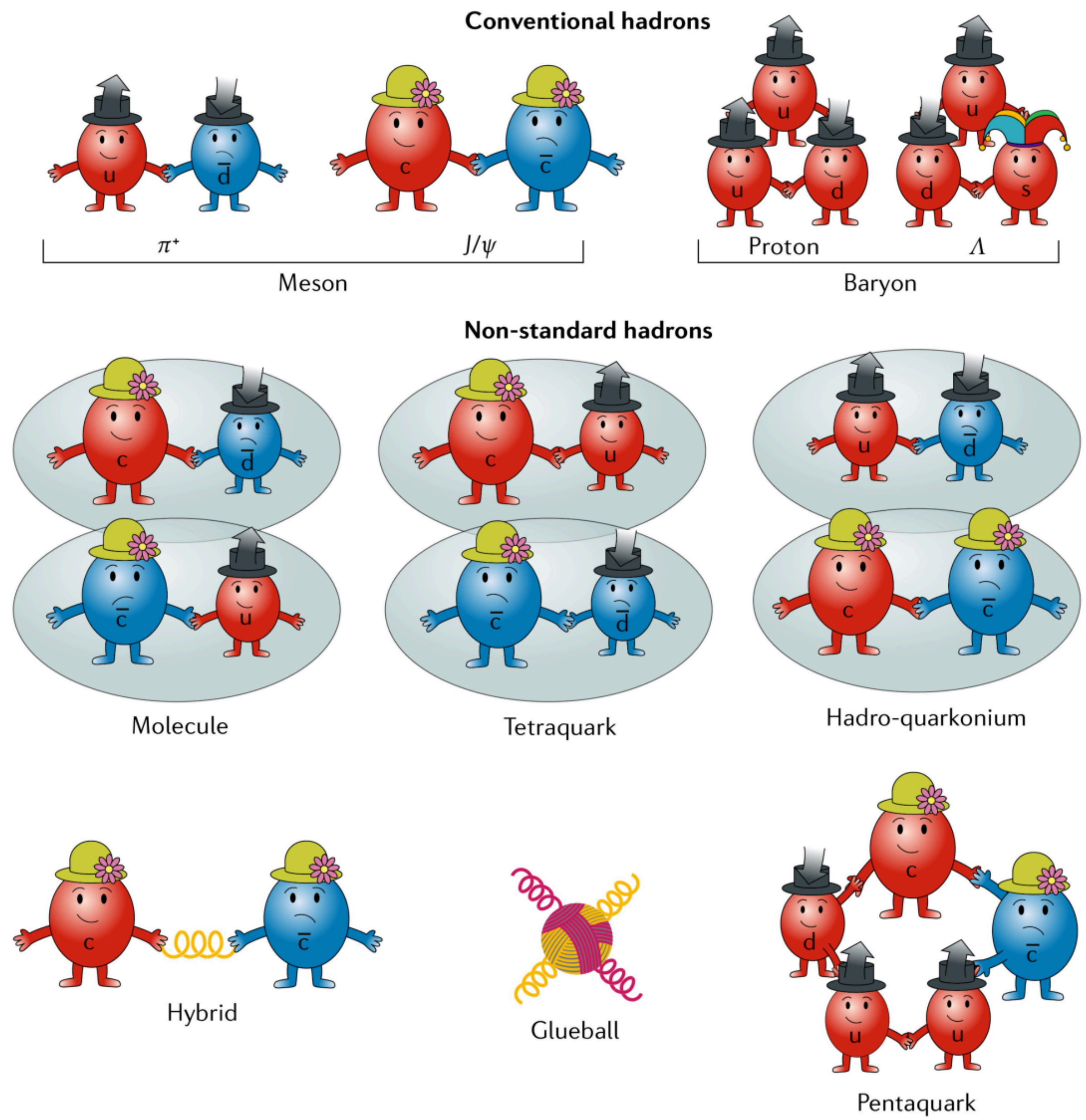
anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations $(q q q)$, $(q q q q \bar{q})$, etc., while mesons are made out of $(q \bar{q})$, $(q q \bar{q} \bar{q})$, etc. It is assuming that the lowest baryon configuration $(q q q)$ gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration $(q \bar{q})$ similarly gives just **1** and **8**.

AN SU_3 MODEL FOR STRONG INTERACTION SYMMETRY AND ITS BREAKING

G. Zweig *)
CERN - Geneva

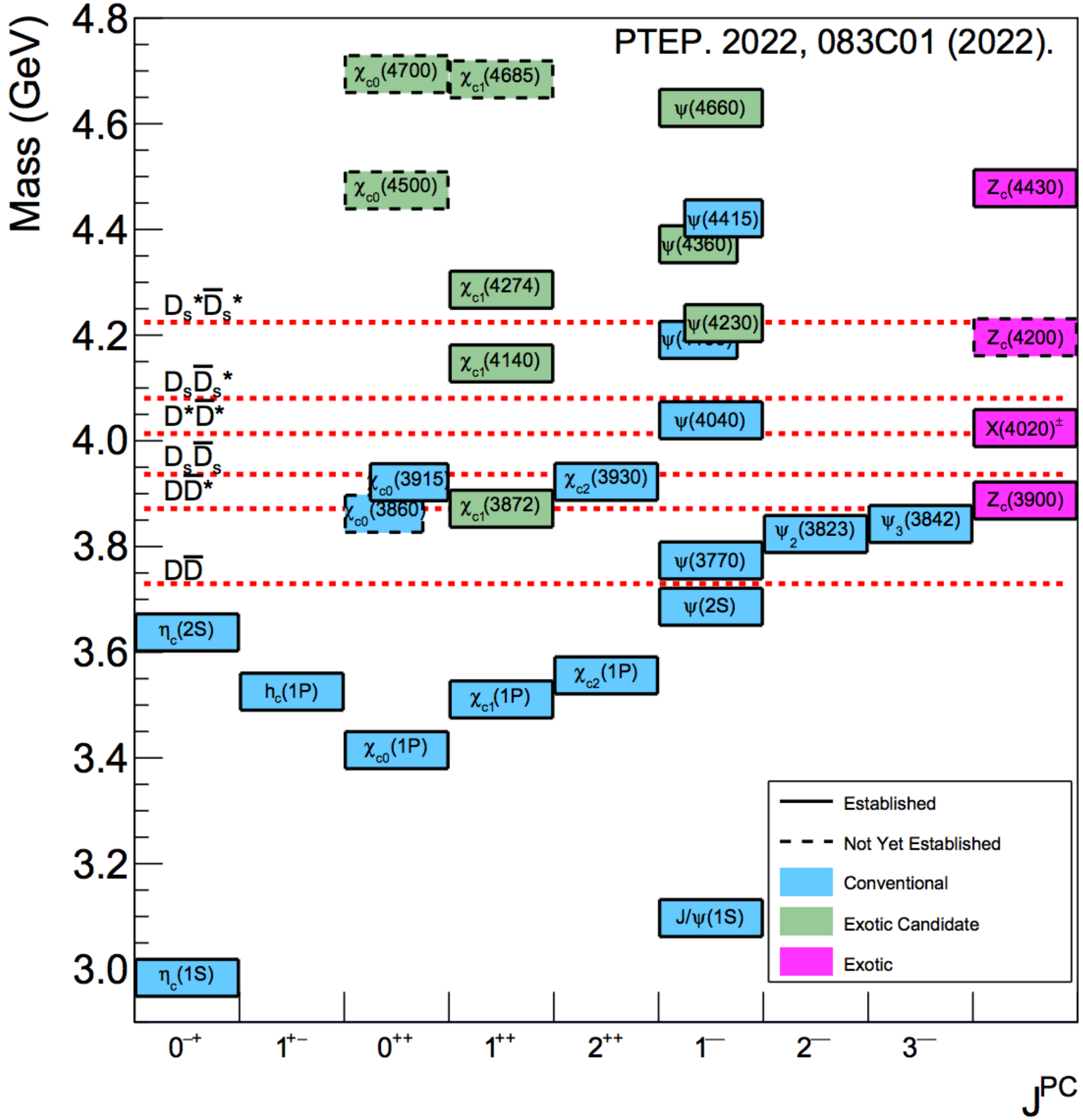
Both mesons and baryons are constructed from a set of three fundamental particles called aces. The aces

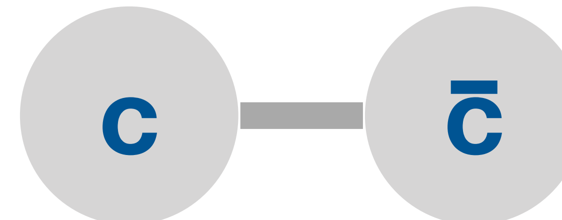
In general, we would expect that baryons are built not only from the product of three aces, AAA, but also from $\bar{A}AAAA$, $\bar{A}\bar{A}AAAAA$, etc., where $\bar{A}$ denotes an anti-ace. Similarly, mesons could be formed from $\bar{A}A$, $\bar{A}\bar{A}AA$ etc. For the low mass mesons and baryons we will assume the simplest possibilities, $\bar{A}A$ and AAA, that is, "deuces and treys".



CZY & S.L. Olsen, *Nature Reviews Physics* **1**, 480 (2019)

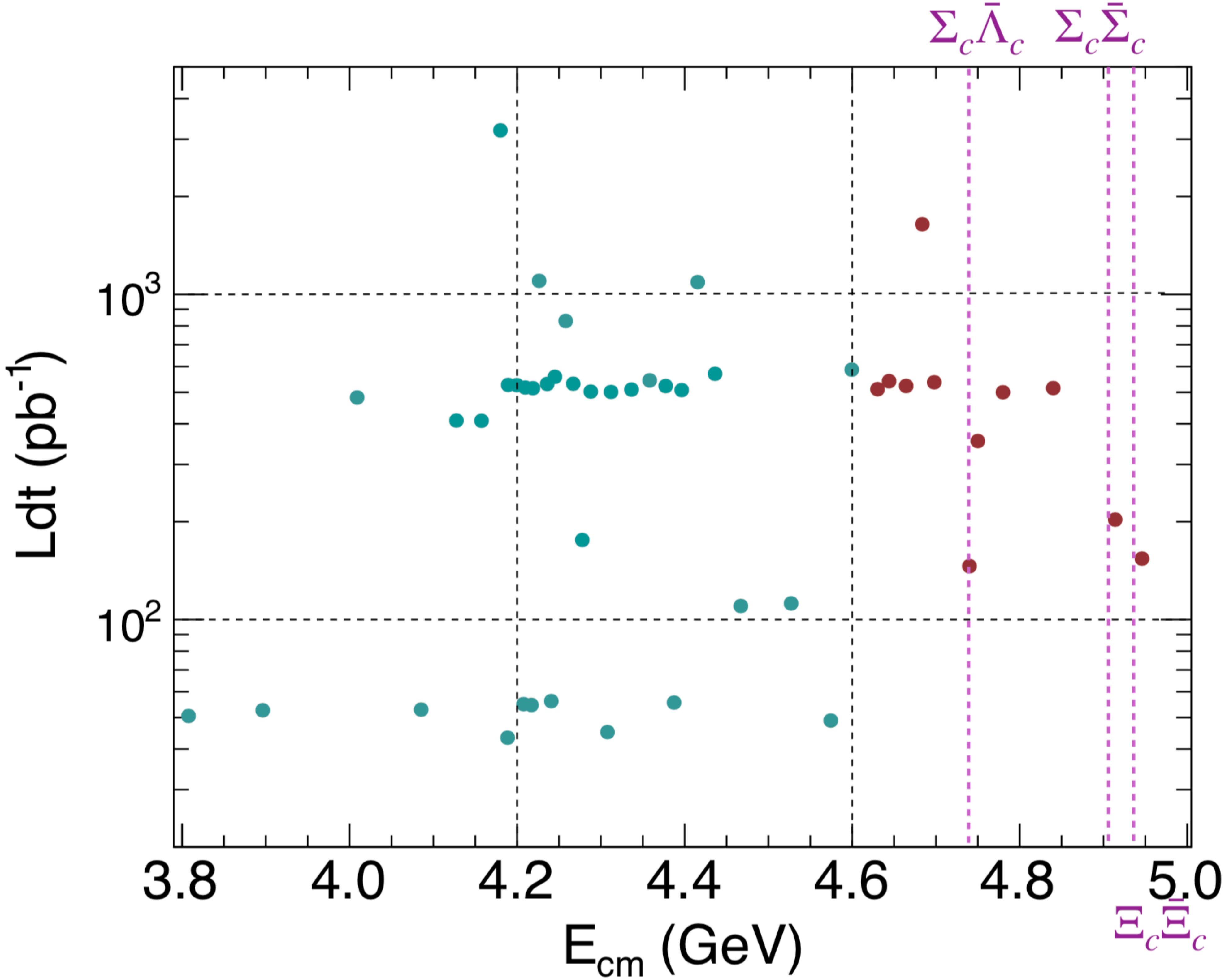
Charmonium(-like) Spectrum





- The charmonium spectrum is calculated with the potential model.
- Good agreement between theory and experiment below the open-charm threshold.
- Exotic candidates are observed at experiments above the open-charm thresholds.

XYZ Data Samples at BESIII



X(3872) charmless light hadron decay

PRD 113, L071102 (2026)

- No X(3872) charmless light hadron decays are observed in experiment so far.
- In a molecular nature of X(3872), Ref.[PRD 106, 074015 (2022)] predicted Br(X(3872)→VV, VP) via intermediate meson loops

Final states	$\theta = 0$	$\theta = \pi/6$	$\theta = \pi/4$
$\rho\rho$	$(0.15\text{–}7.86) \times 10^{-3}$	$(0.06\text{–}3.20) \times 10^{-2}$	$(0.83\text{–}4.29) \times 10^{-2}$
$K^{*+}K^{*-}$	$(0.08\text{–}4.11) \times 10^{-3}$	$(0.06\text{–}3.08) \times 10^{-3}$	$(0.04\text{–}2.05) \times 10^{-3}$
$K^{*0}\bar{K}^{*0}$	···	$(0.11\text{–}5.36) \times 10^{-3}$	$(0.02\text{–}1.07) \times 10^{-2}$
$\omega\omega$	$(0.03\text{–}1.55) \times 10^{-3}$	$(0.12\text{–}6.28) \times 10^{-3}$	$(0.16\text{–}8.41) \times 10^{-3}$
$\rho^0\omega$	$(0.03\text{–}1.56) \times 10^{-3}$	$(0.02\text{–}1.25) \times 10^{-4}$	$(0.03\text{–}1.31) \times 10^{-3}$
$\rho^{\pm}\pi^{\mp}$	$(0.09\text{–}4.40) \times 10^{-2}$	$(0.004\text{–}1.87) \times 10^{-1}$	$(0.05\text{–}2.53) \times 10^{-1}$
$K^{*+}K^{-}$ + c.c.	$(0.08\text{–}3.99) \times 10^{-2}$	$(0.06\text{–}2.99) \times 10^{-2}$	$(0.04\text{–}1.99) \times 10^{-2}$
$K^{*0}\bar{K}^{0}$ + c.c.	···	$(0.11\text{–}5.66) \times 10^{-2}$	$(0.02\text{–}1.13) \times 10^{-1}$

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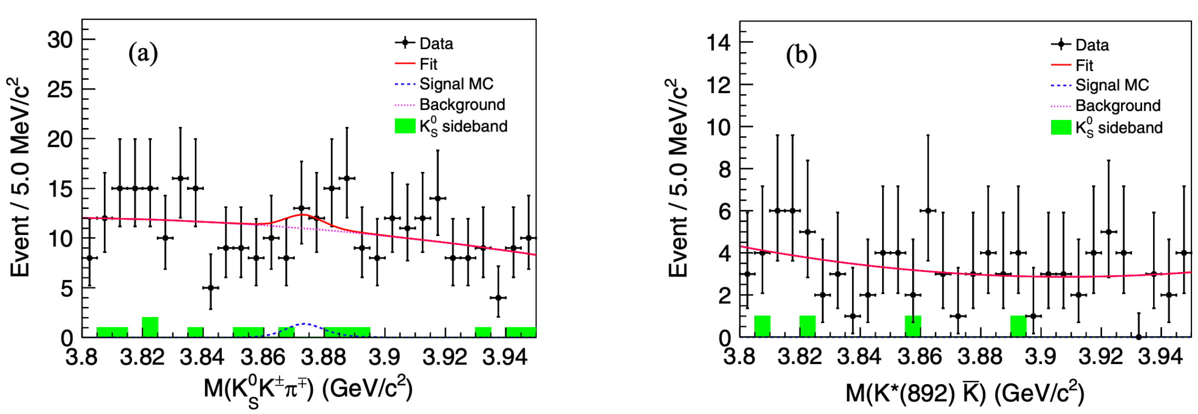
- Search for X(3872)→KsK±π∓ and K*(892)±,0K∓,0 at √s = 4.16-4.34 GeV



$$\frac{\mathcal{B}[X(3872)\to K^0_S K^\pm\pi^\mp]}{\mathcal{B}[X(3872)\to\pi^+\pi^- J/\psi]} < 0.07$$

$$\frac{\mathcal{B}[X(3872)\to K^*(892)\bar{K}]}{\mathcal{B}[X(3872)\to\pi^+\pi^- J/\psi]} < 0.10$$

With

$$\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) = (4.3 \pm 1.4)\%$$

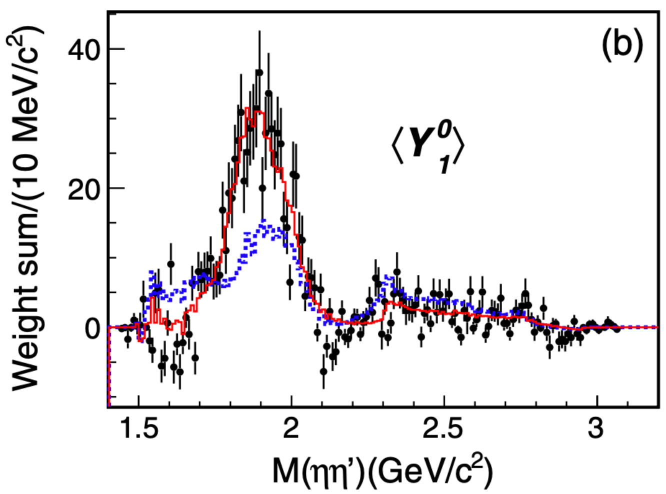
↓

$$\mathcal{B}[X(3872) \to K^*(892)\bar{K}] < 0.60 \times 10^{-2}$$

	$\chi_{c1}(1P)$
$K^*(892)^0\bar{K}^0$ + c.c.	$(1.04 \pm 0.15) \times 10^{-3}$
$K^*(892)^+K^-$ + c.c.	$(1.22 \pm 0.23) \times 10^{-3}$

Search for 1^{-+} exotic states

- Search for $J^{PC}=1^{-+}$ exotics
  - Conventional mesons within quark model can not produce states with $J^{PC} = 0^{--}, 1^{-+}, 2^{+-}$…
  - Experimental observation would reveal their unambiguous exotic signatures.
- BESIII observed $J^{PC}=1^{-+}$ isoscalar resonance $\eta_1(1855)$ in $J/\psi \rightarrow \gamma(\eta\eta')$

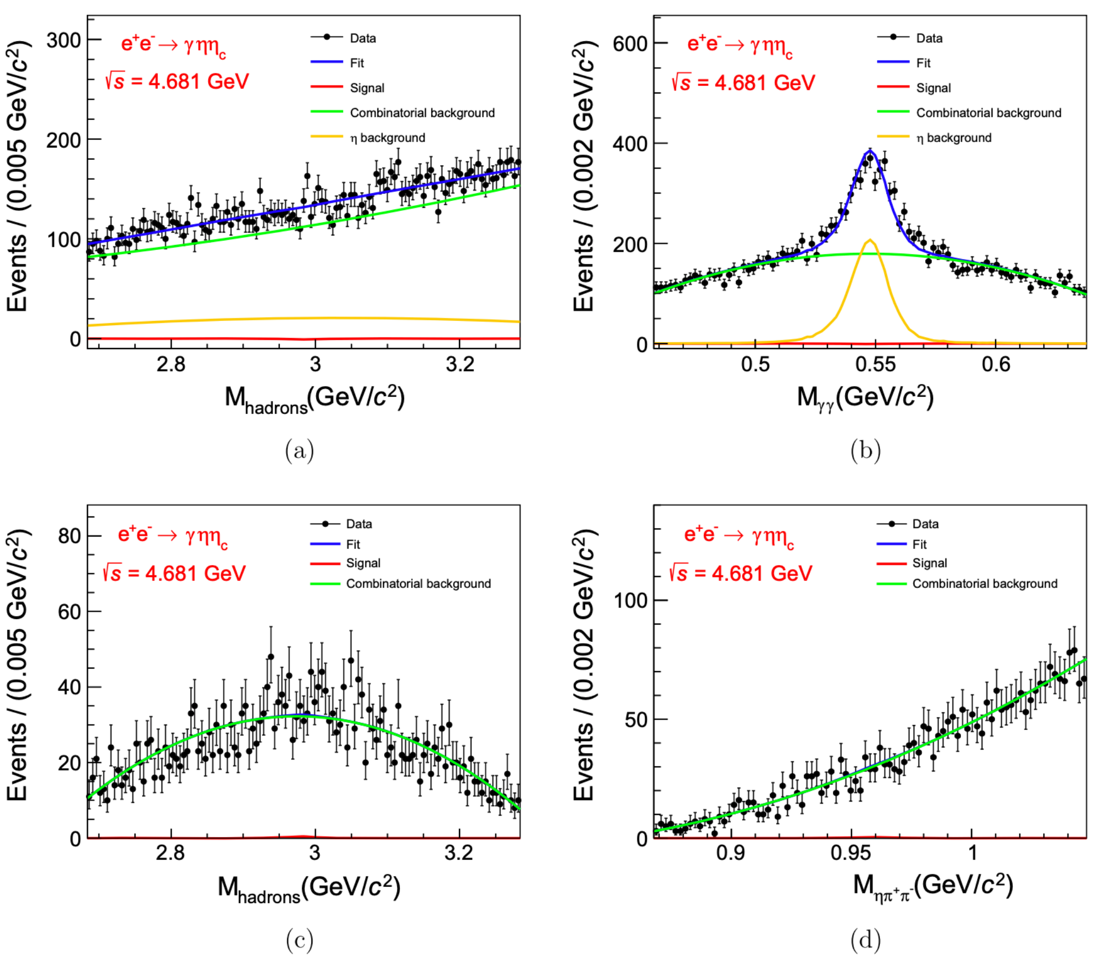


PRL 129, 192002 (2022)

- Search for 1^{-+} charmoniumlike exotic states via $e^+e^- \rightarrow \gamma(\eta\eta_c, \eta'\eta_c, D_sD_{s1}(2536))$
  - In a molecular picture, several 1^{-+} states were predicted, with masses close to hadron pair thresholds. PRD89,114013(2014),PRD101,076003(2020)
  - LQCD calculate 1^{-+} hybrid states with mass 4.13-4.33 GeV, decaying dominantly to $D_sD^*_s$, D_1D, D^*D, D^*D^* PRD89,114013(2014), JHEP07(2012)126, JHEP12(2016)089,PRD102,014023 (2020)

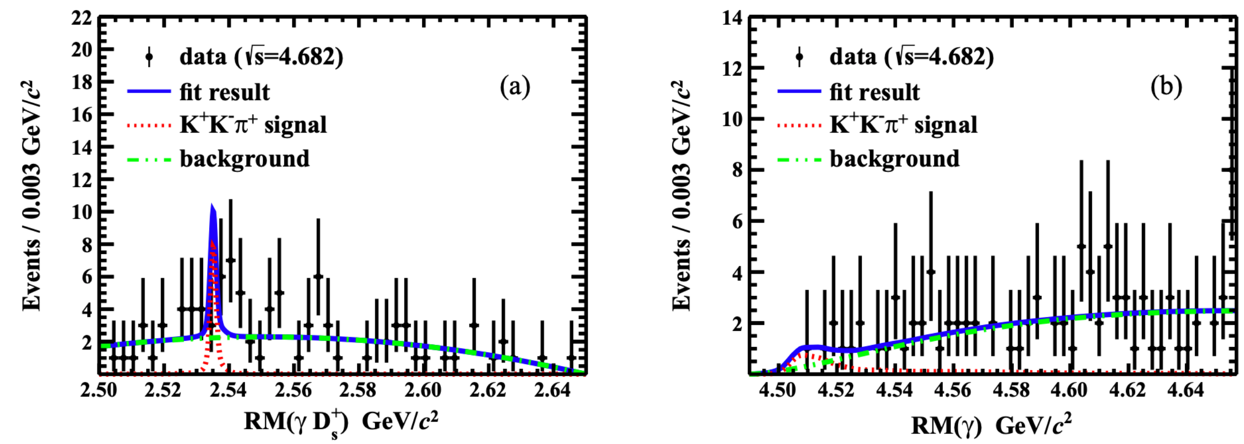
Search for 1^{-+} exotic states

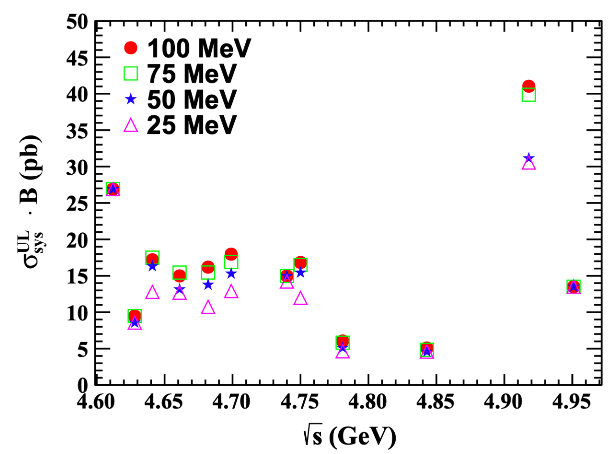
- Search for $J^{PC}=1^{-+}$ exotics in $e^+e^- \to \gamma(\eta\eta_c, \eta'\eta_c)$ at $\sqrt{s}$=4.258-4.681 GeV
- Provide the production upper limits



PRD 111, 112007 (2025)

- Search for 1^{-+} exotic in $ee \to \gamma D_s D_{s1}(2536)$ at $\sqrt{s}$=4.612-4.951 GeV





PRD 112, 032002 (2025)

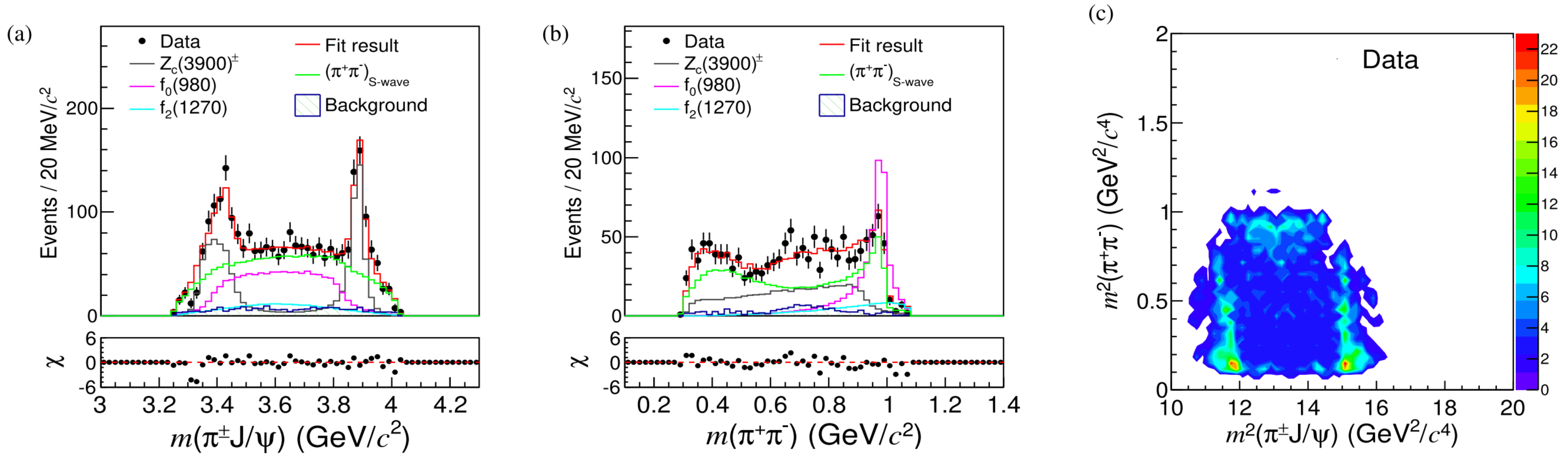
PWA of $e^+e^- \longrightarrow \pi^+\pi^- J/\psi$

PRD 112, 092013 (2025)

- Dataset: $\sqrt{s} = 4.1271 - 4.3583$ GeV
- PWA includes the processes

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

$$e^+e^- \to f_j(\to \pi^+\pi^-)J/\psi \quad f_0(500), f_0(980), f_0(1370), \text{or } f_2(1270)$$



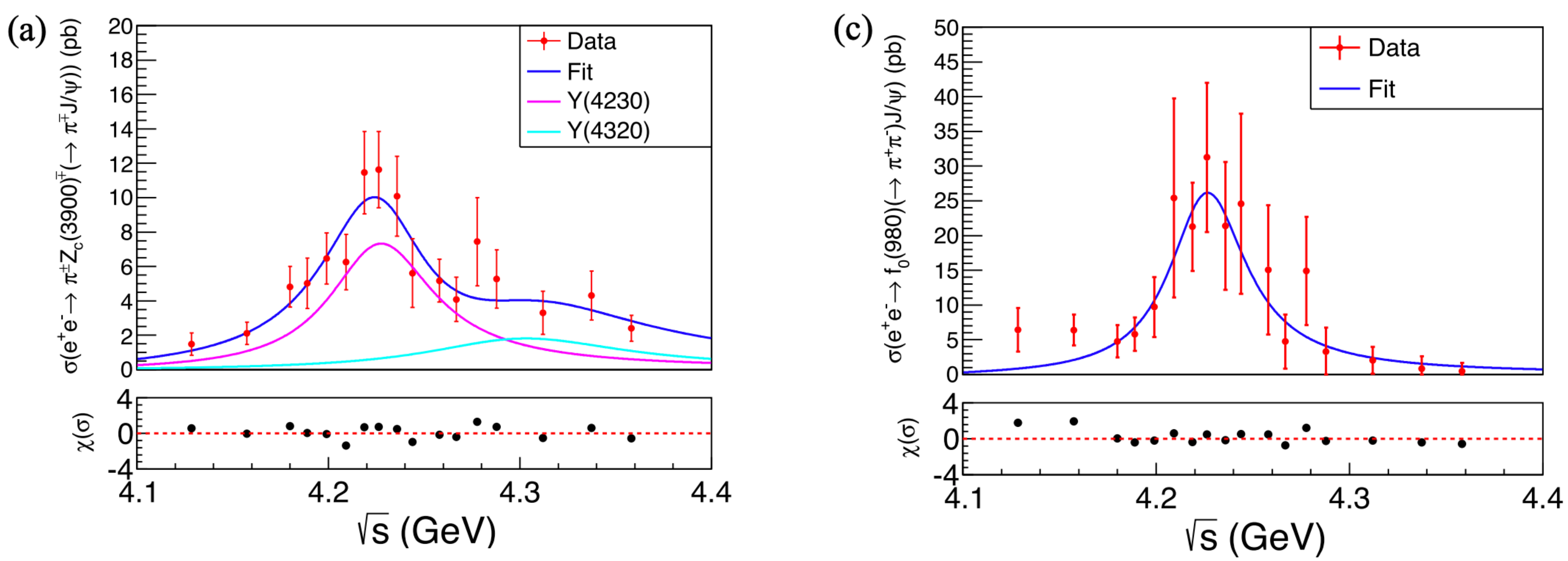
PWA of $e^+e^- \to \pi^+\pi^- J/\psi$

PRD 112, 092013 (2025)

- Determine $Z_c(3900)$ mass and width

$$M = 3884.6 \pm 0.7 \pm 3.3\ \mathrm{MeV}/c^2$$
$$\Gamma = 37.2 \pm 1.3 \pm 6.6\ \mathrm{MeV}/c^2$$

- Fit to $\sqrt{s}$-dependent cross sections of $\pi Z_c(3900)$ and $f_0(980)J/\psi$

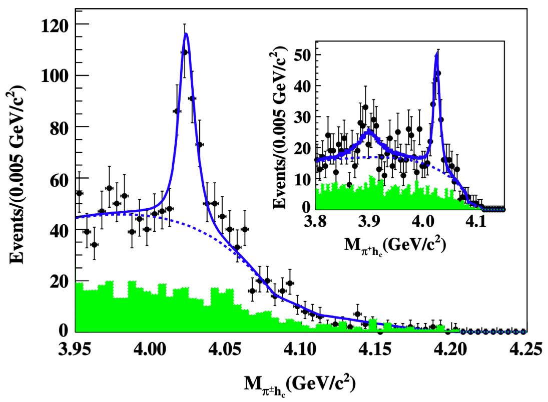


- Determine $\psi(4220)$ mass and width

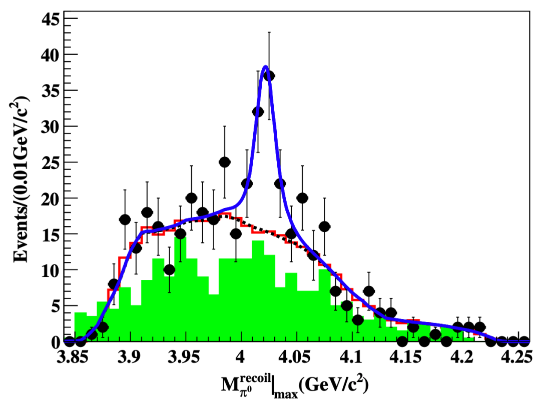
$$M = 4225.7 \pm 4.1 \pm 3.4\ \mathrm{MeV}/c^2$$
$$\Gamma = 57.5 \pm 9.4 \pm 12.1\ \mathrm{MeV}$$

Multi-channel joint analysis of $T_{c\bar{c}}(4020)$

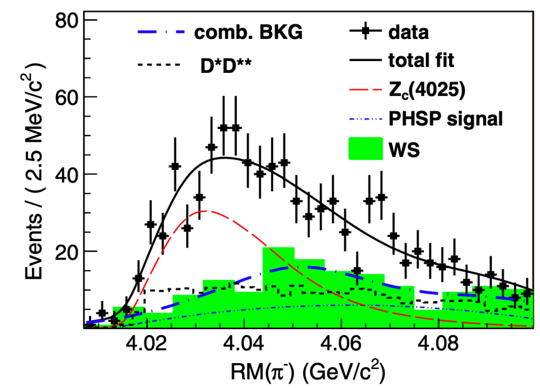
- Isotriplet states: Tcc(4020)/Tcc(4025) observed in πh_c, D*D*bar



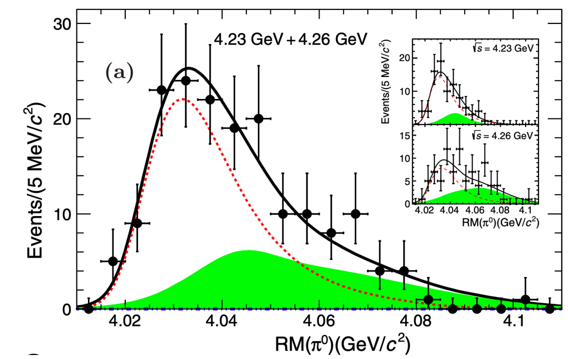
PRL 111, 242001 (2013)



PRL 113, 212002 (2014)

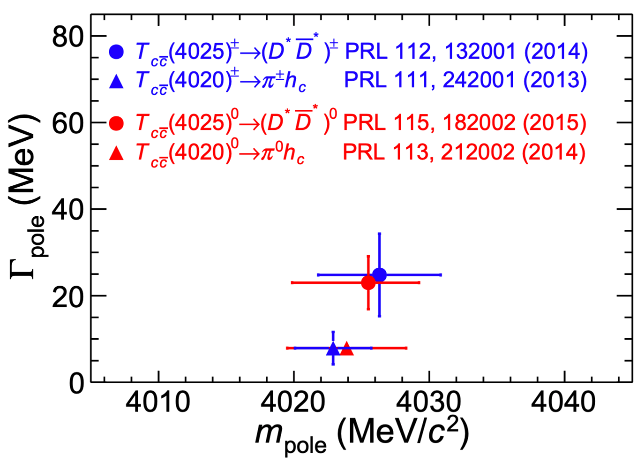


PRL 112, 132001 (2014)



PRL 115, 182002 (2015)

- Masses and widths

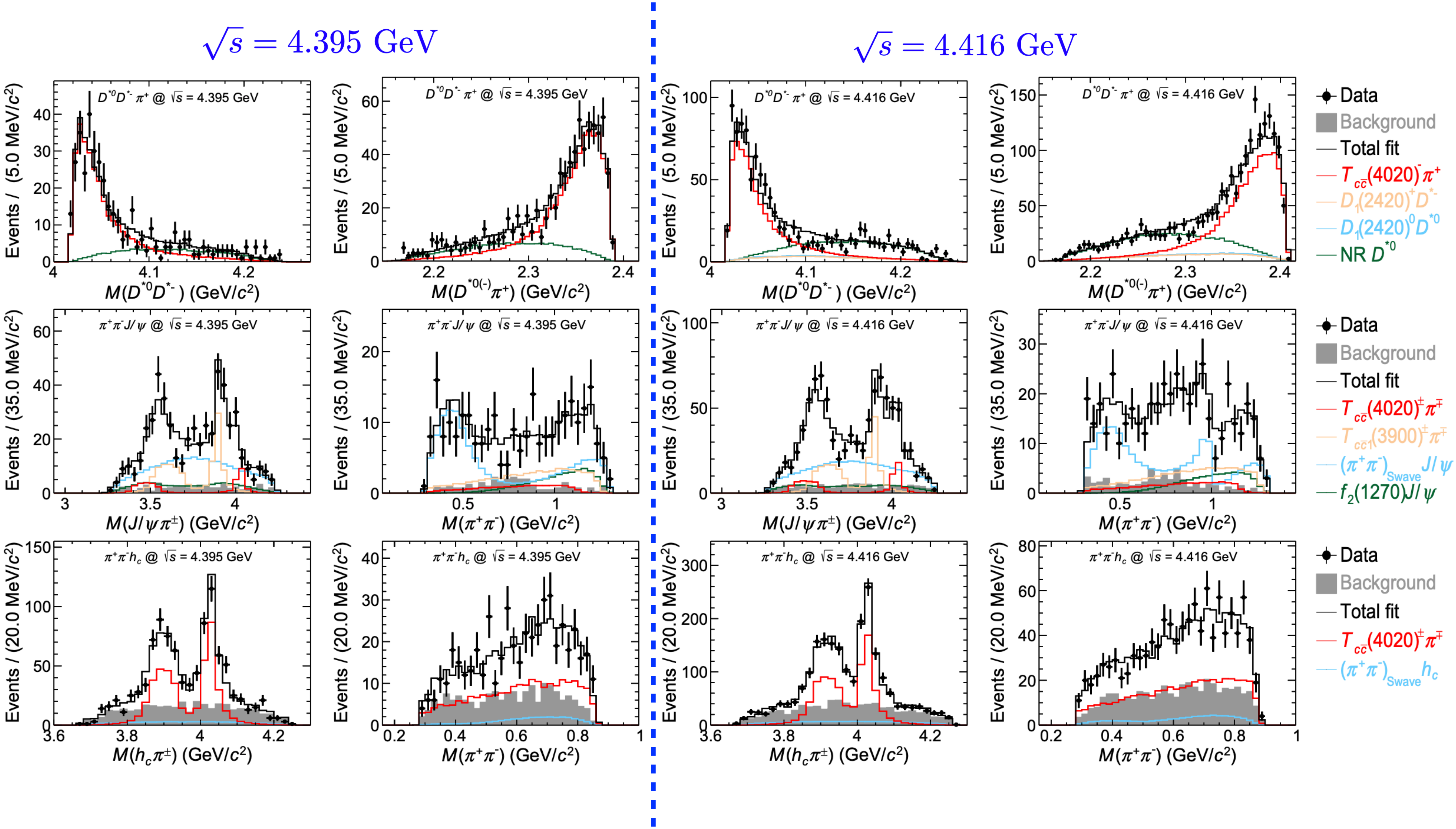


- Perform multi-channel joint PWA of the $T_{cc}(4020)$

$$T_{c\bar{c}}(4020)^- \to D^{*0}D^{*-},\ \pi^- J/\psi,\ \text{and}\ \pi^- h_c$$

Multi-channel joint analysis of $T_{c\bar{c}}(4020)$

arXiv:2603.05564



Multi-channel joint analysis of $T_{c\bar{c}}(4020)$

arXiv:2603.05564

- Poles

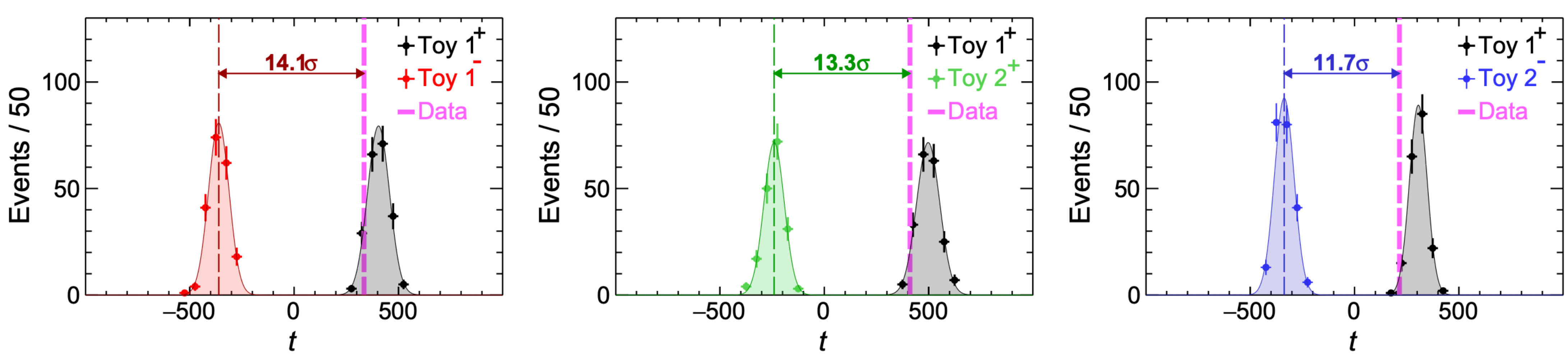
$$m_{\text{pole1}} = 4022.44 \pm 1.55\,\text{MeV}/c^2, \qquad m_{\text{pole2}} = 4023.01 \pm 1.35\,\text{MeV}/c^2,$$
$$\Gamma_{\text{pole1}} = 38.54 \pm 2.94\,\text{MeV}, \qquad \Gamma_{\text{pole2}} = 35.02 \pm 2.20\,\text{MeV}.$$

- Branching fractions

$$\frac{\mathcal{B}\left[T_{c\bar{c}}(4020)^- \to \pi^- J/\psi\right]}{\mathcal{B}[T_{c\bar{c}}(4020)^- \to D^{*0} D^{*-}]} = (3.6 \pm 0.6 \pm 1.6) \times 10^{-3}$$

$$\frac{\mathcal{B}\left[T_{c\bar{c}}(4020)^- \to \pi^- h_c\right]}{\mathcal{B}[T_{c\bar{c}}(4020)^- \to D^{*0} D^{*-}]} = (8.9 \pm 1.3 \pm 2.3) \times 10^{-2}$$

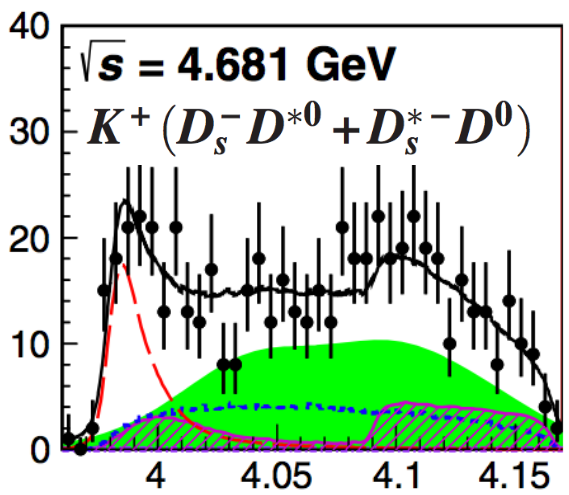
- $J^P = 1^+$ with a significance 11.7σ



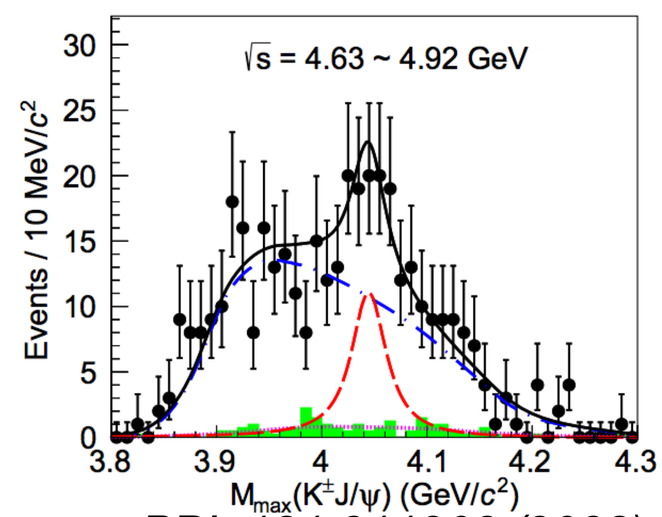
$$t \equiv -2[-\ln L^{1^+} - (-\ln L^{J^P})]$$

Study of $K^+K^-\psi(3686)$ system

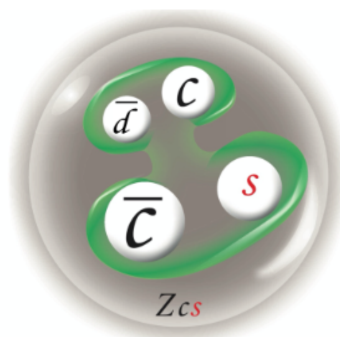
- Search for tetraquark candidates containing both strange and charm quarks are interesting
  - $Z_{cs}(3985)$ (5.3σ) is observed in
  - Hints (2.3σ) in the ($K^{\pm}J/\psi$) spectrum in K^+K^-J/ψ system



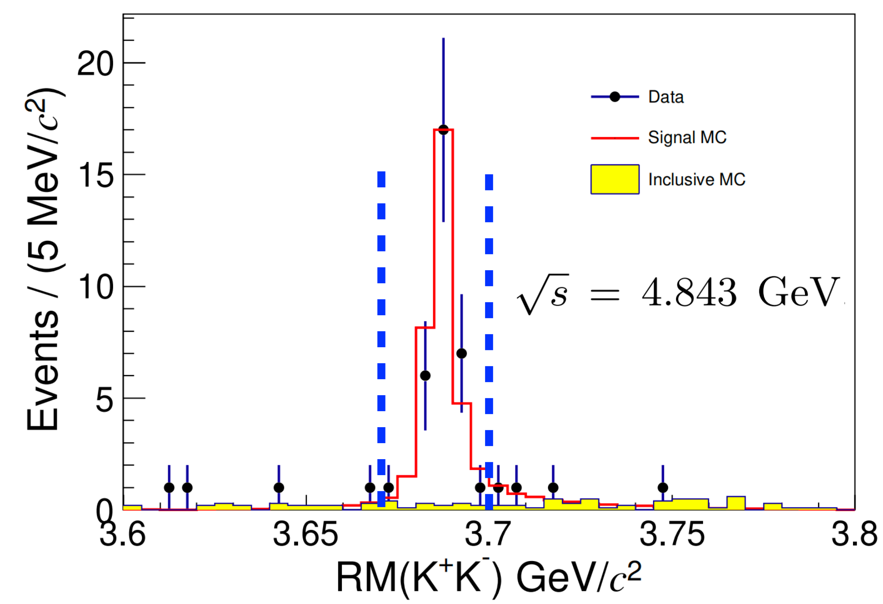
PRL 126,102001 (2021)



PRL 131,211902 (2023)



- We observed $ee \to K^+K^-\psi(3686)$ process at $\sqrt{s}=4.843$ GeV *arXiv: 2407.20009*
- We check the structures in $K^+K^-\psi(3686)$ system

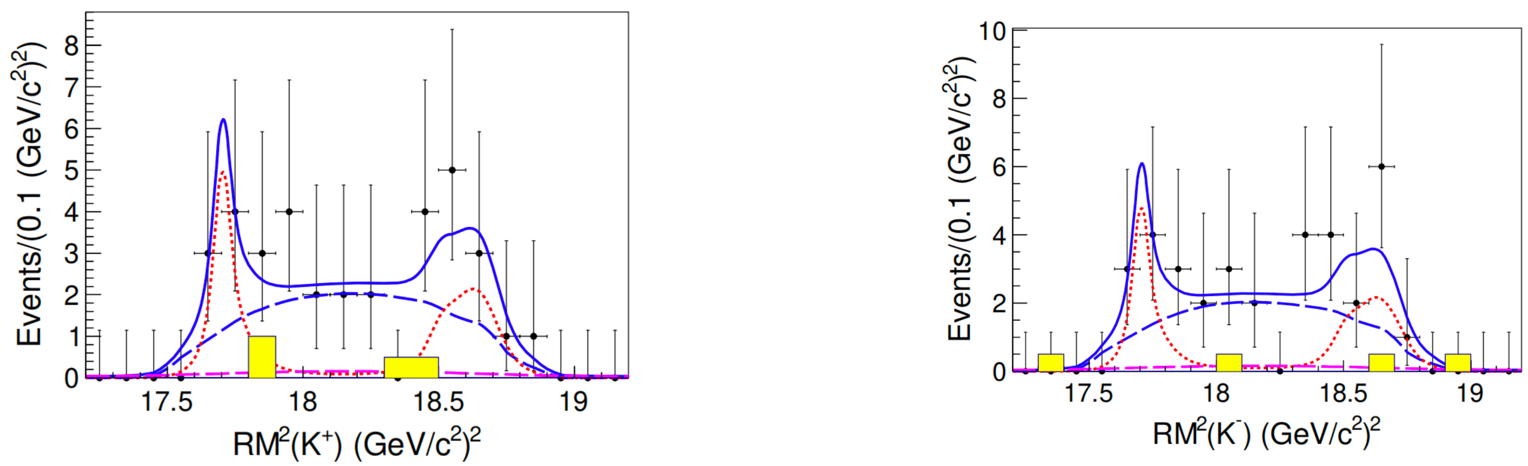


Study of $K^+K^-\psi(3686)$ system

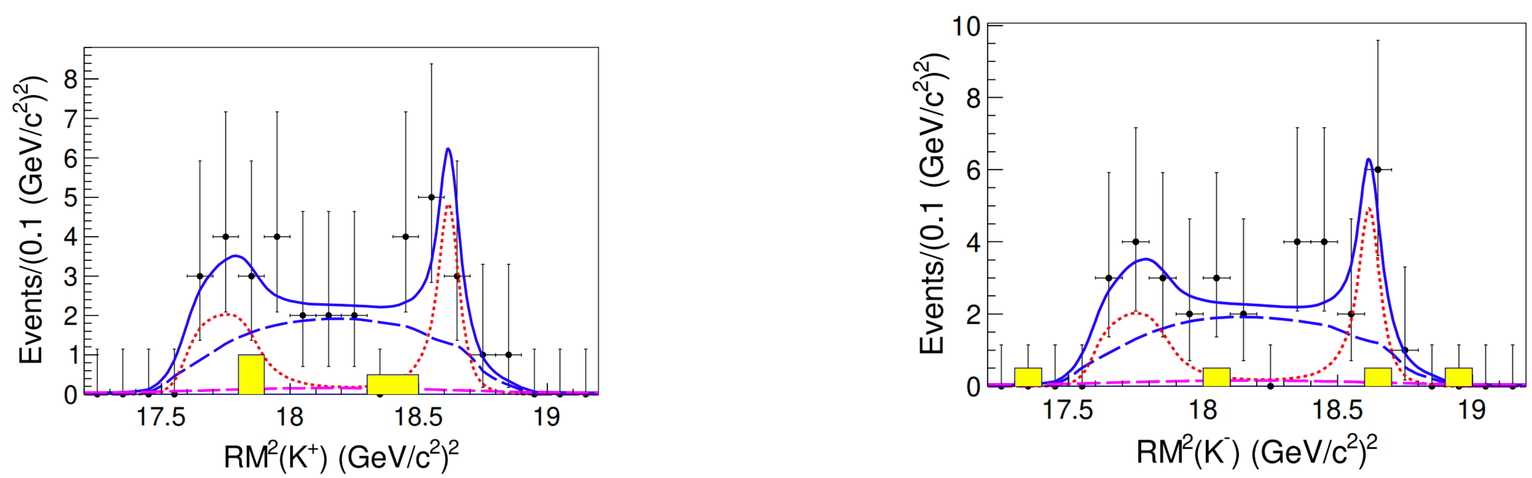
- There is discrepancy for the M(Kψ(3686)) spectrum between data and the non-resonant $K^+K^-\psi(3686)$ system
- More data is needed to obtain a robust conclusion

arXiv: 2407.20009

Fit I



Fit II



	M (MeV)	Γ (MeV)	N_{sig}	N_{phsp}	$-\ln\mathcal{L}$	significance
Fit I	4208.4 ± 3.1	6.1 ± 5.7	12.3 ± 5.0	20.1 ± 5.4	-112.1	1.2σ
Fit II	4316.0 ± 2.7	9.0 ± 8.6	13.4 ± 6.5	19.0 ± 6.7	-111.8	1.1σ

Summary

- BESIII keeps making contributions to the XYZ physics
  - Set upper limit of X(3872)→ $K^*(892)^{\pm,0}K^{\mp,0}$ (VP) to be $0.6\text{x}10^{-2}$.
  - Make search for 1^{-+} charmoniumlike exotic states via e+e-→γ($\eta\eta_c$, $\eta'\eta_c$, $D_sD_{s1}(2536)$)
  - Measure Zc(3900) and ψ(4260) resonant parameters via $e^+e^-\rightarrow \pi^+\pi^- J/\psi$ PWA
  - Determine $T_{cc}(4020)$ $J^P=1^+$ via multi-channel joint analysis of $T_{cc}(4020)$→DD*, πh_c, and πJ/ψ
  - Search for Z_{cs} states in ee→KKψ(3686) system.

- After the BEPCII upgrade, increased statistics and advanced analysis methods will bring more new results.