Recent progress on the XYZ studies at BESIII

Wei Shan

(on behalf of BESIII Collaboration)

Hunan Normal University

Outline

- Introduction

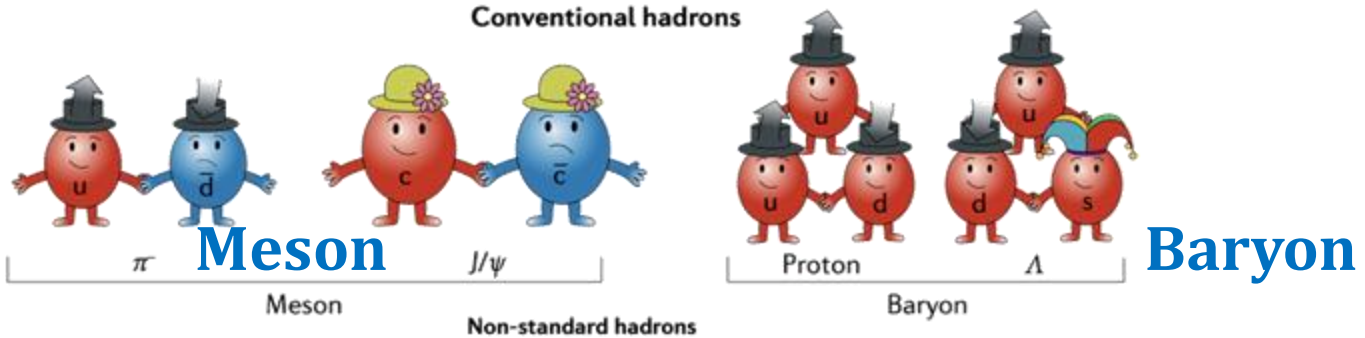
- Recent XYZ studies at BESIII
  - ✓ Hidden charm processes ($e^+e^- \to \pi^+\,\pi^-\,h_c/\,K^0K^-\pi^+J/\psi$)
  - ✓ Charmed baryon pairs near kinematic threshold
    or baryonic molecular state ($e^+e^- \to \Sigma_c\bar{\Sigma}_c/\Lambda_c^+\bar{\Sigma}_c^-$, H_c^+ $(\Lambda_c^+\bar{\Sigma}_c^0)$)
  - ✓ 1^{-+} molecular state ($e^+e^- \to \gamma D_s^+ D_{s1}^-(2536)$)

- Summary and Outlook

Introduction

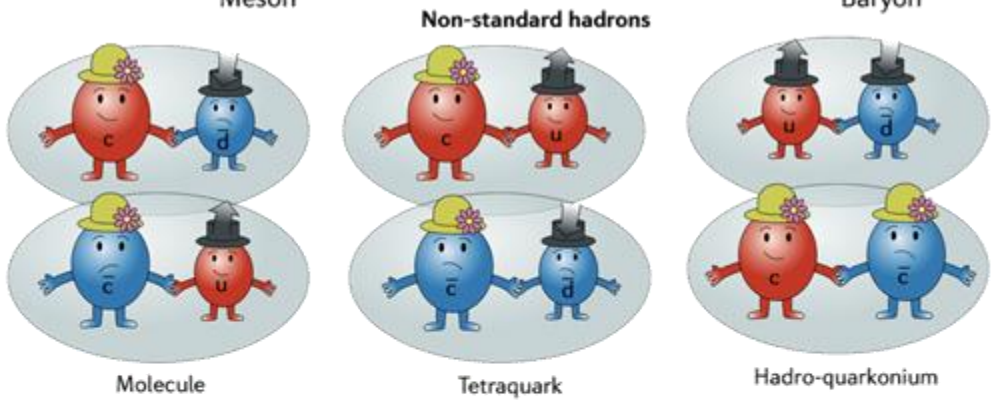
- **Conventional hadrons** are composed from 2 (meson) or 3 (baryon) quarks.

Naive Quark model:



- **QCD allows** hadrons with $N_{quarks} \neq 2, 3$.

Exotic States:



Nature Reviews Physics 1, 480 (2019)

Charmonium-like (XYZ) states

From F.K. Guo

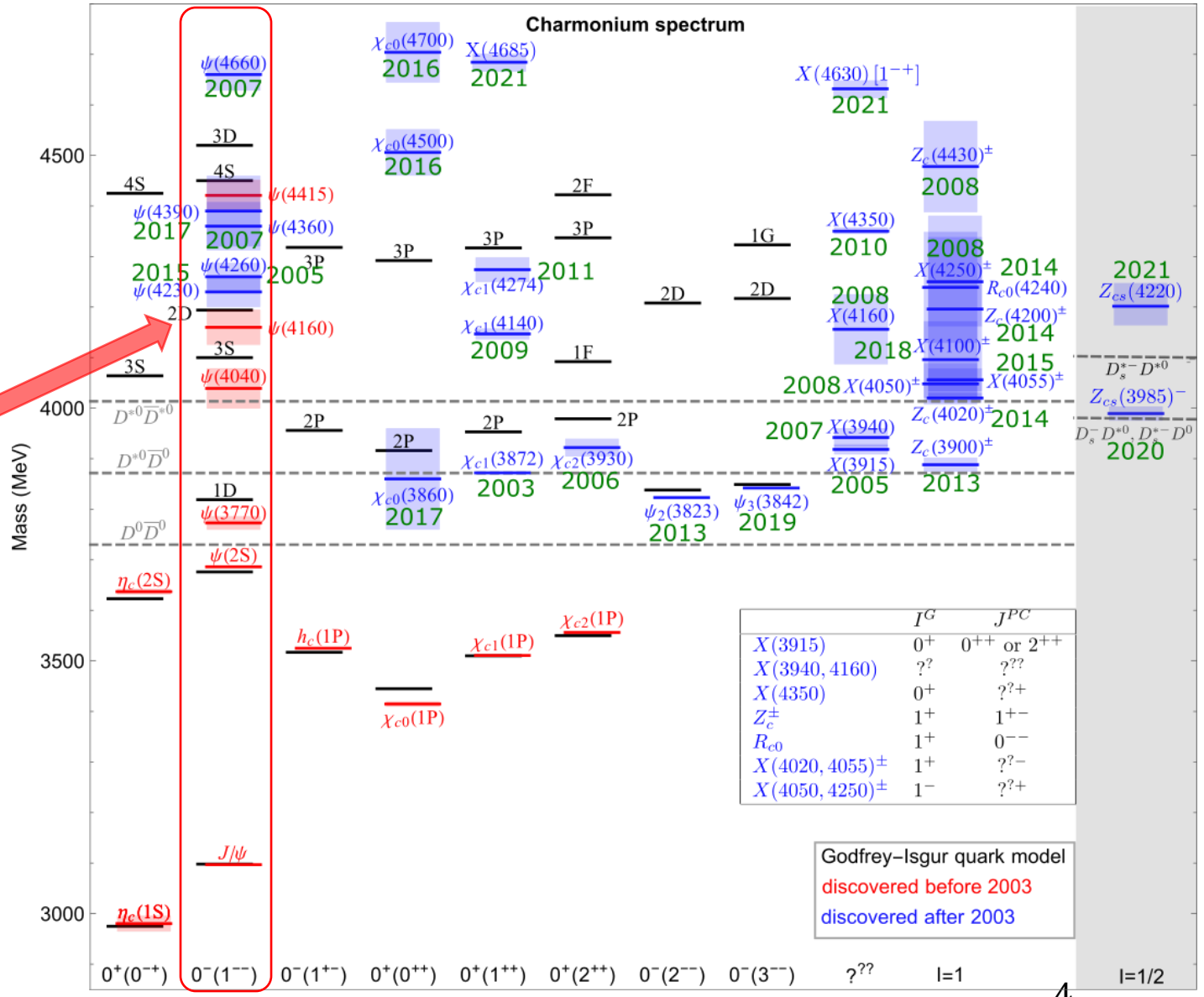
XYZ states: do not fit in the naïve quark model

X: $J^{PC} \neq 1^{--}$ neutral non-vector states

X(3823) X(3872) X(6900)…

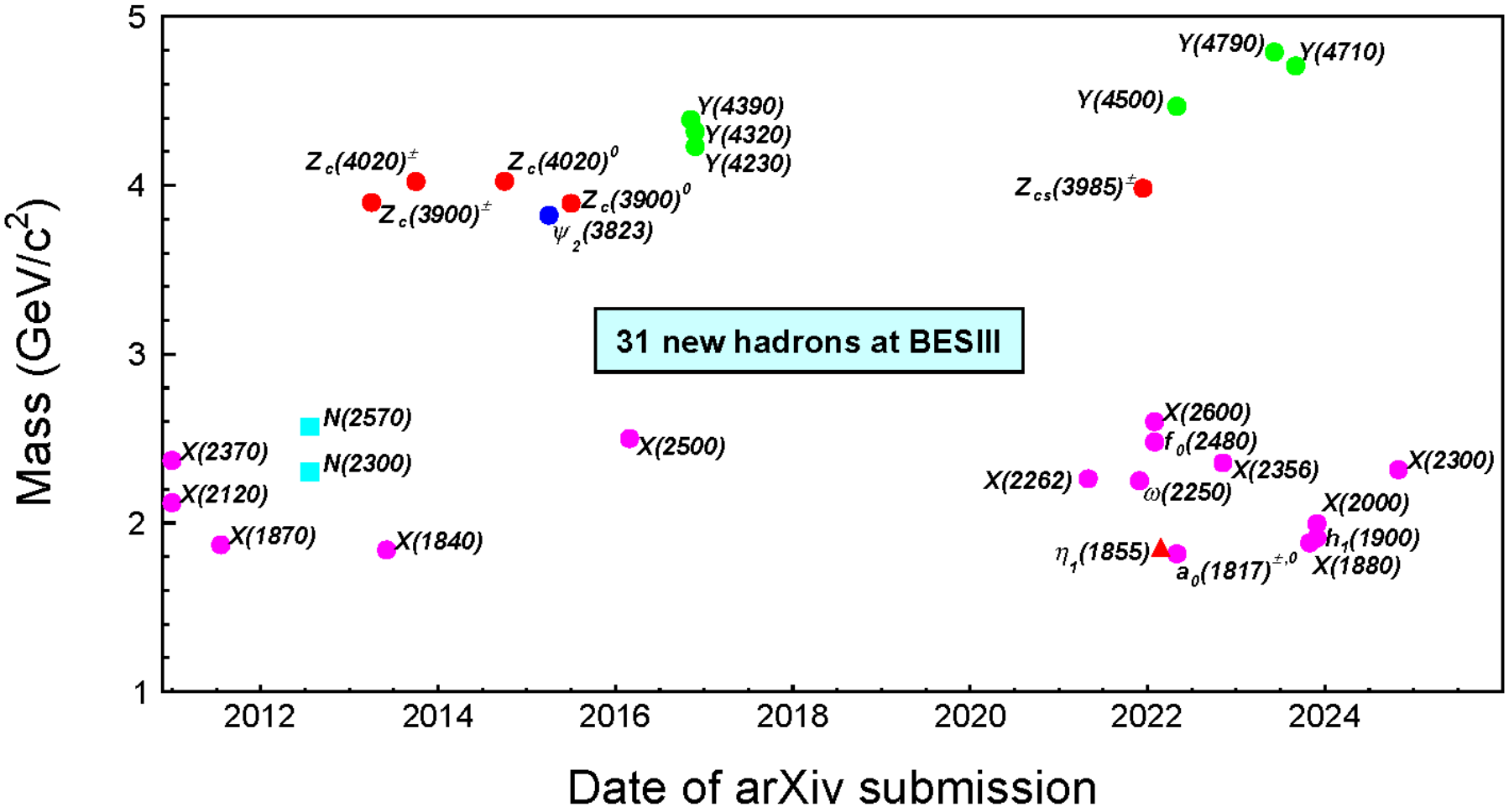
Y: $J^{PC} = 1^{--}$ neutral vector states produced in e^+e^- annihilation or initial state radiation(ISR)

Z: Z_c I=1 charmonium-like states



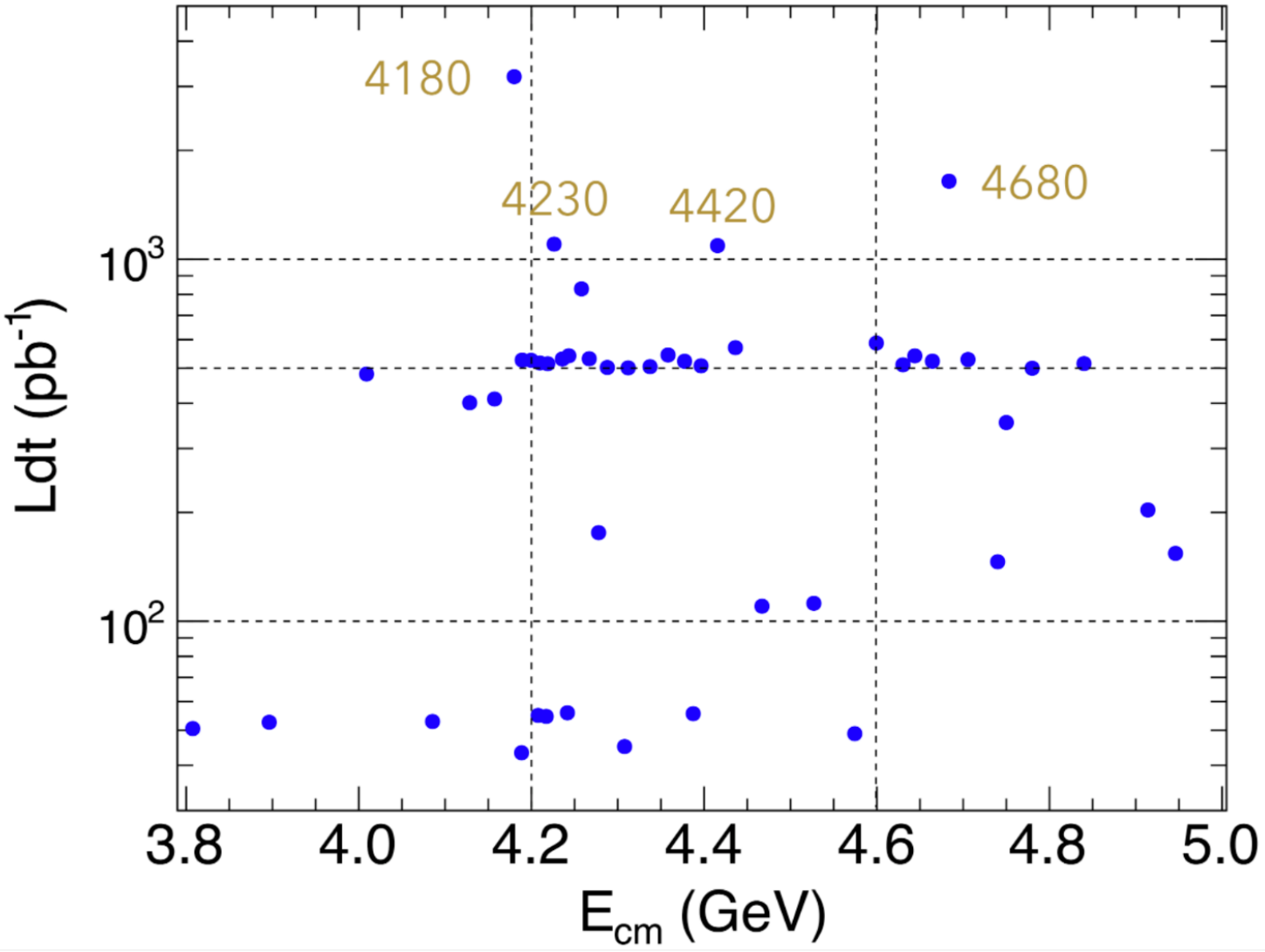
New particle at BESIII

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



Ref: https://doi.org/10.1016/j.scib.2023.08.025

XYZ+R-scan Dataset at BESIII



XYZ samples:

E_{cm} =3.8-4.96 GeV:

(46 energy points)

~22 fb^{-1}

Small R-scan samples:

E_{cm} =3.8-4.6 GeV:

(151 energy points)

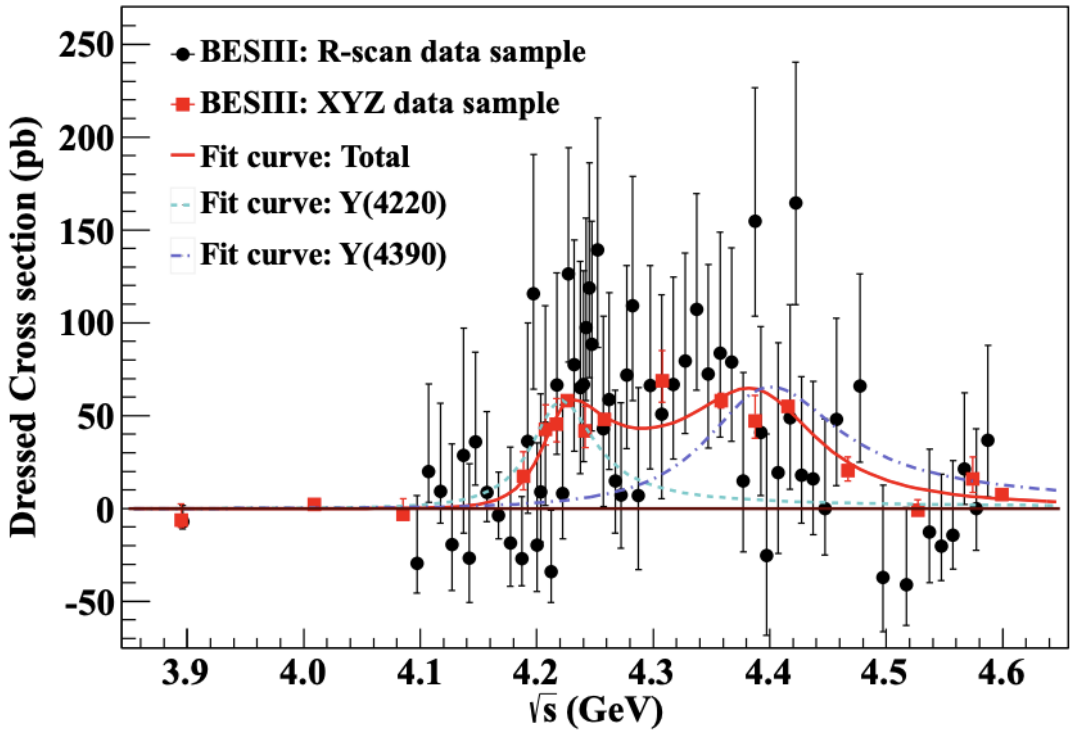
~3.5 fb^{-1}

Hidden Charm processes

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

40 pb^{-1} (XYZ data sample)+ 20 pb^{-1} (R-scan data sample)

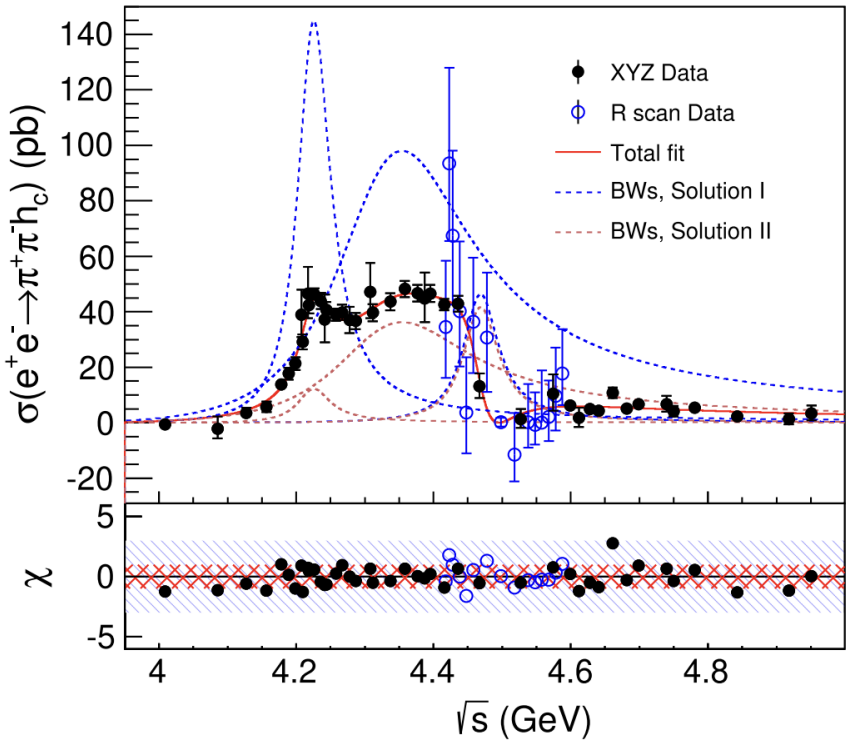
Evidence of Two Resonant Structures
Y(4220), Y(4390)



Phys.Rev.Lett. 118 , 092002 (2017)

22.2 fb^{-1} (XYZ + R-scan data samples)

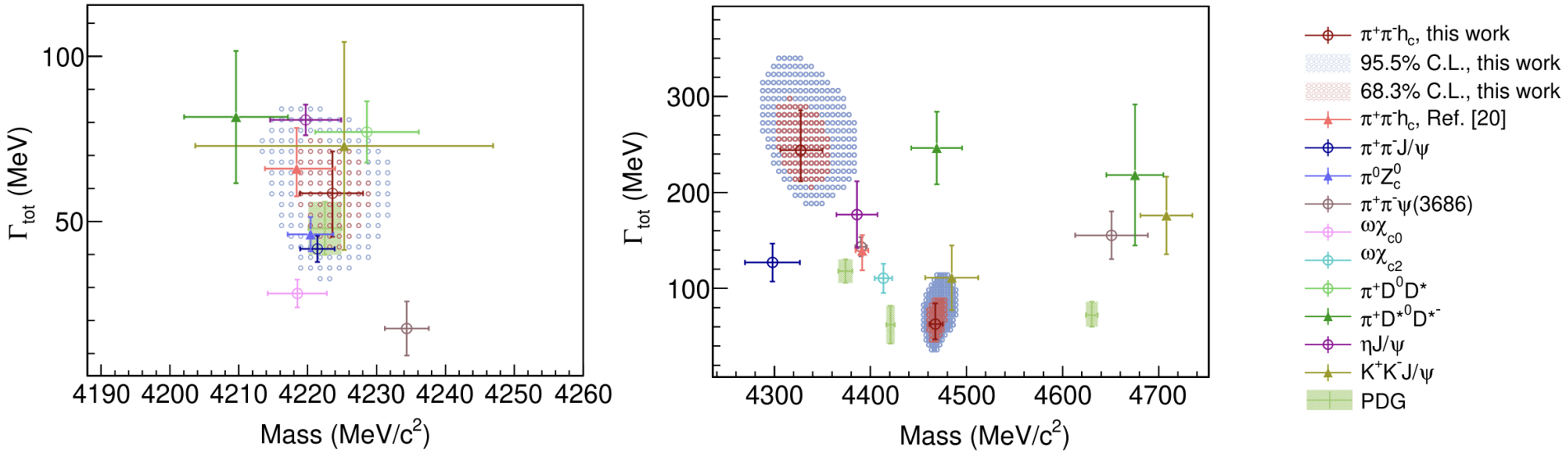
Observation of Three Resonant Structures
Y(4220), Y(4360), Y(4460)



Phys.Rev.Lett. 135, 071901 (2025)

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

Y(4220) Y(4360), Y(4460) Phys.Rev.Lett. 135, 071901 (2025)

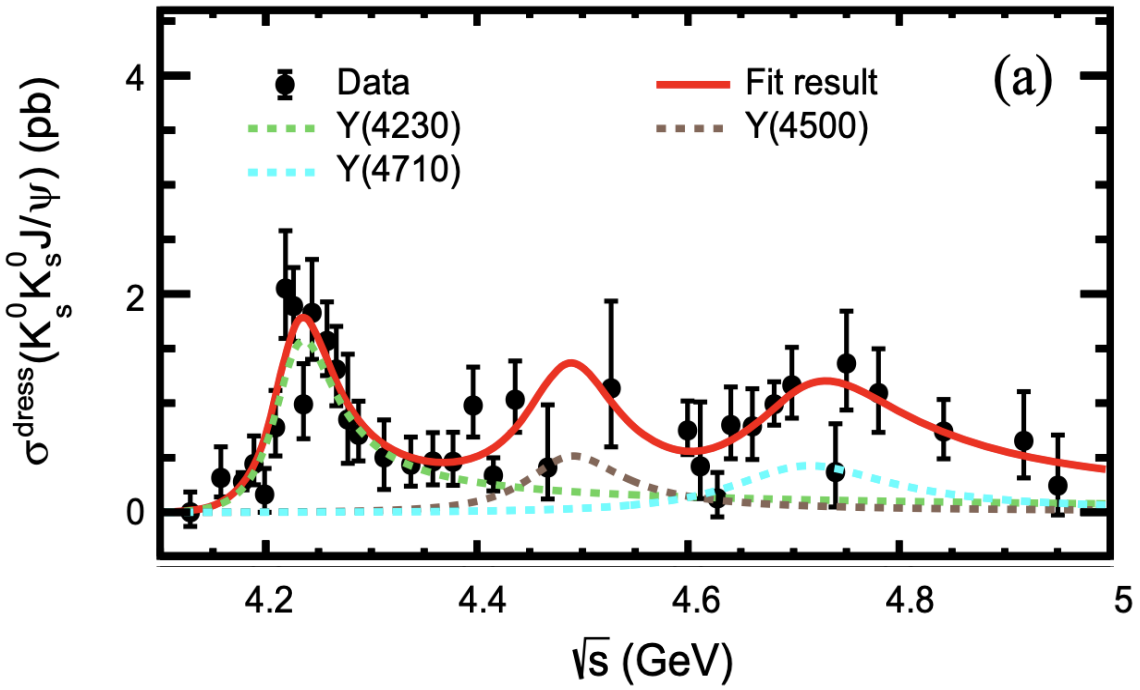


Parameter	R_1	R_2	R_3
M (MeV/c^2)	$4223.6^{+3.6+2.6}_{-3.7-2.9}$	$4327.4^{+20.1+10.7}_{-18.8-9.3}$	$4467.4^{+7.2+3.2}_{-5.4-2.7}$
Γ (MeV)	$58.5^{+10.8+6.7}_{-11.4-6.5}$	$244.1^{+34.0+24.2}_{-27.1-18.3}$	$62.8^{+19.2+9.9}_{-14.4-7.0}$
$\Gamma_{ee} \cdot \mathcal{B}(R \to \pi^+\pi^- h_c)$ (eV)	$10.2^{+1.2+1.4}_{-1.5-1.4}$ $(0.9^{+0.4+0.3}_{-0.4-0.2})$	$29.1^{+5.7+4.4}_{-3.9-3.4}$ $(10.8^{+2.5+1.9}_{-1.8-1.5})$	$3.9^{+3.5+1.7}_{-1.7-0.5}$ $(3.5^{+3.0+1.5}_{-1.6-0.7})$
ϕ (rad)	...	$3.6^{+0.1+0.1}_{-0.1-0.1}$ $(0.7^{+0.3+0.2}_{-0.3-0.2})$	$0.7^{+0.3+0.1}_{-0.3-0.2}$ $(-2.2^{+0.3+0.2}_{-0.3-0.1})$

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

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

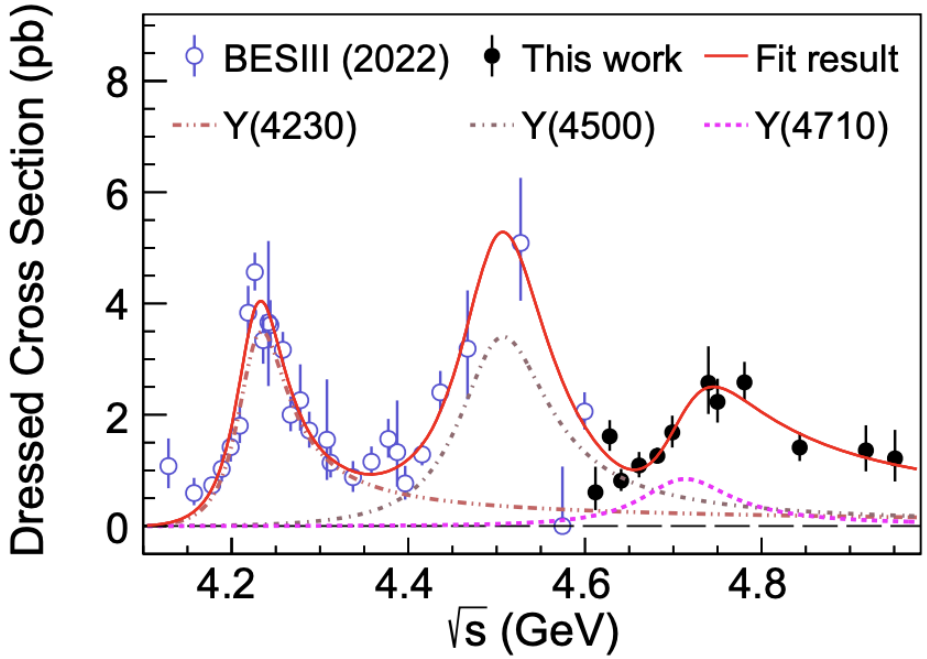
Y(4230), Y(4500), Y(4710)



Phys. Rev. D 107, 092005(2023)

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

Y(4230), Y(4500), Y(4710)

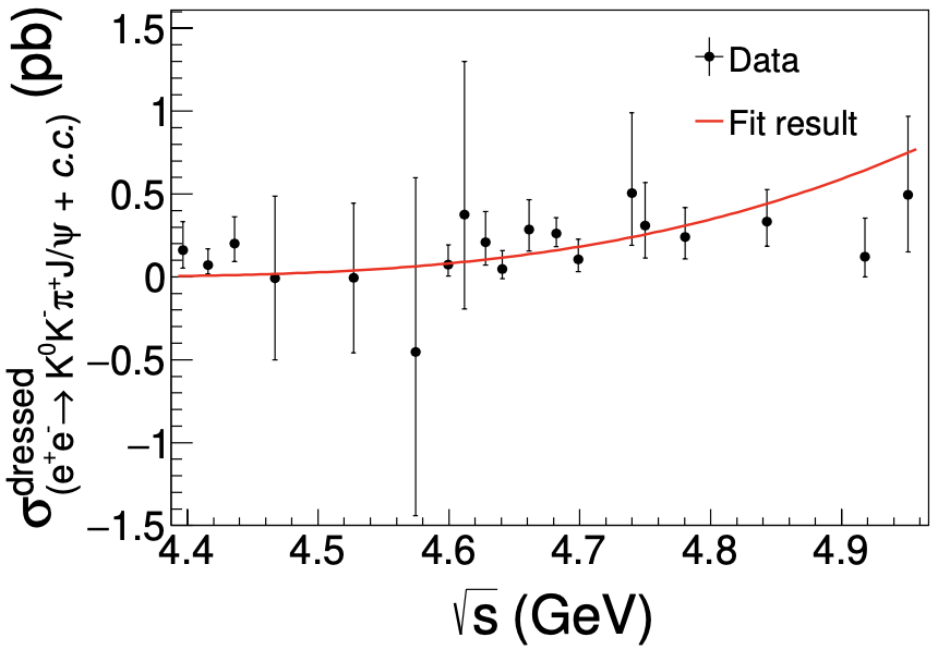


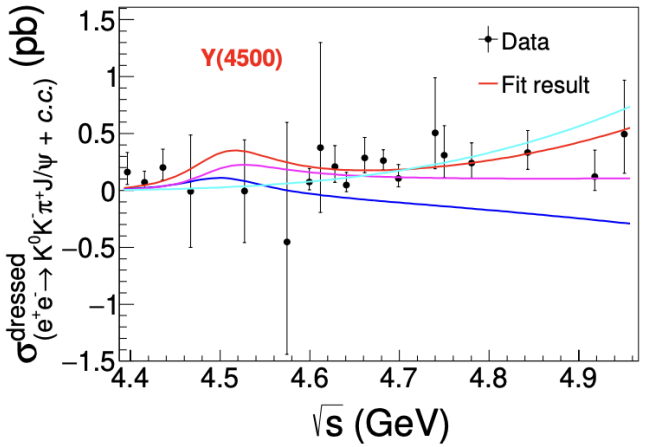
Phys. Rev. Lett. 131, 211902(2023)

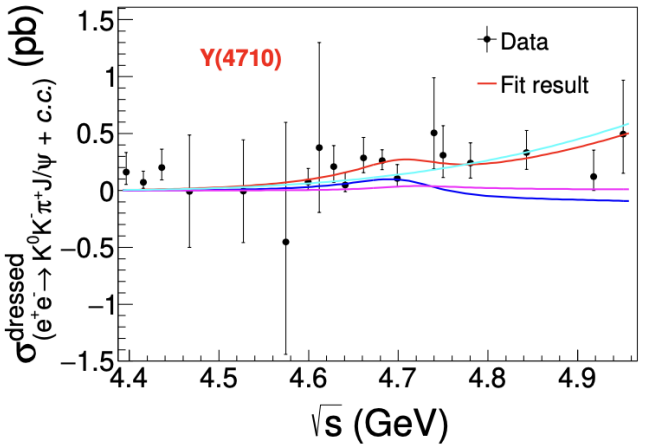
No significant Z_{cs} states are found in these processes due to limited statistics.

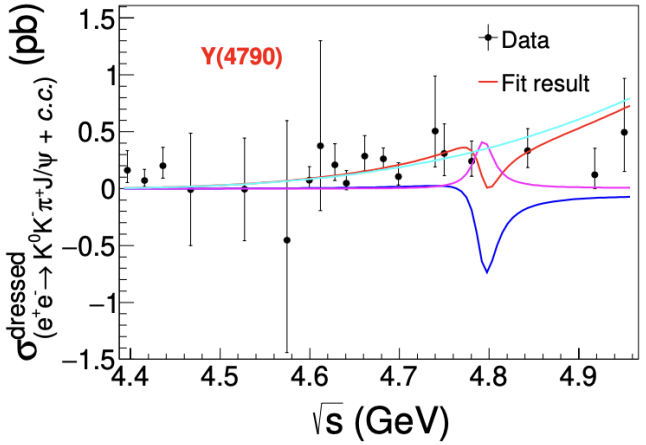
$e^+e^- \to K^0K^-\pi^+J/\psi$ at BESIII

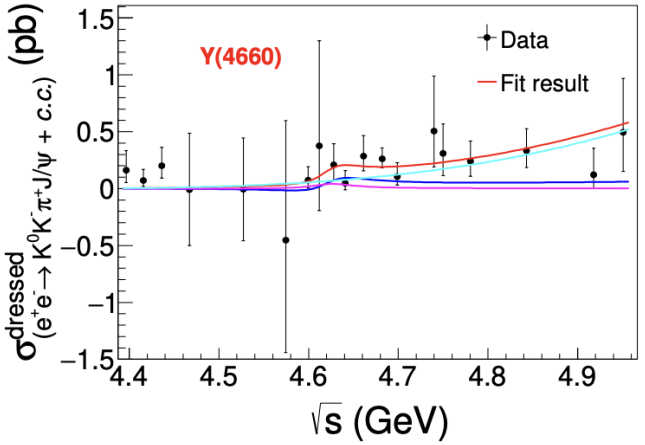
arXiv:2510.13274







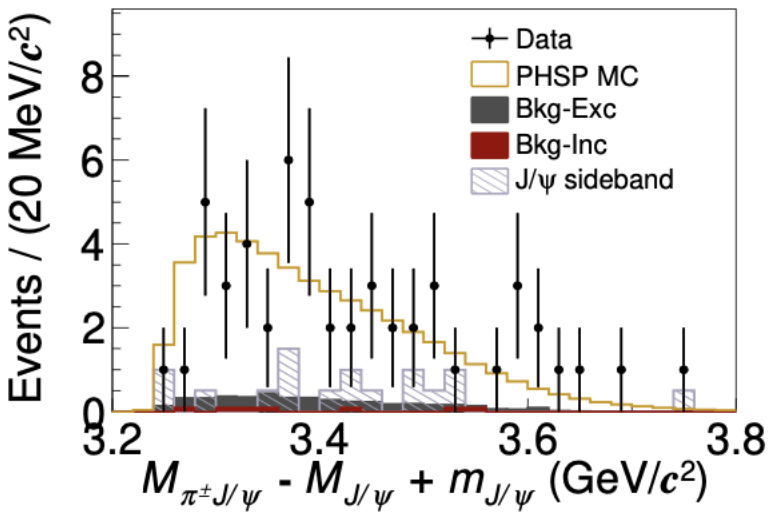


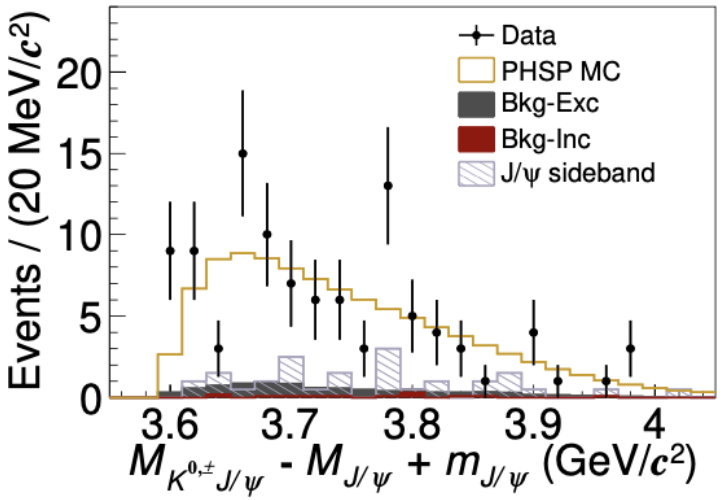


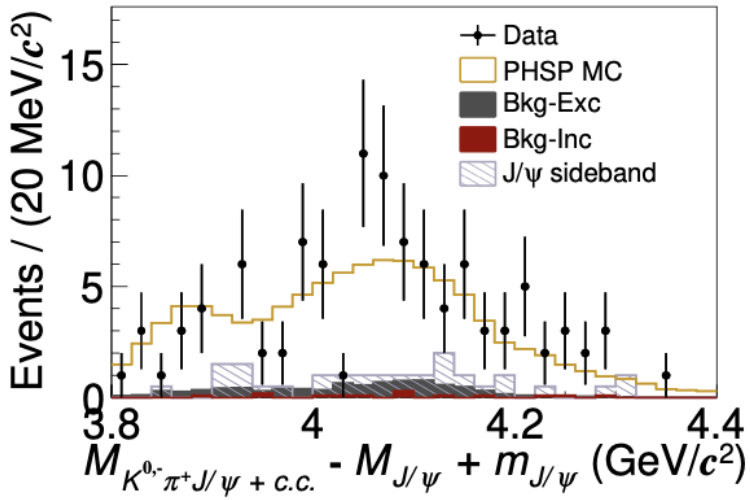
No significant Y states are found in $e^+e^- \to K^0K^-\pi^+J/\psi$ due to limited statistics.

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

arXiv:2510.13274





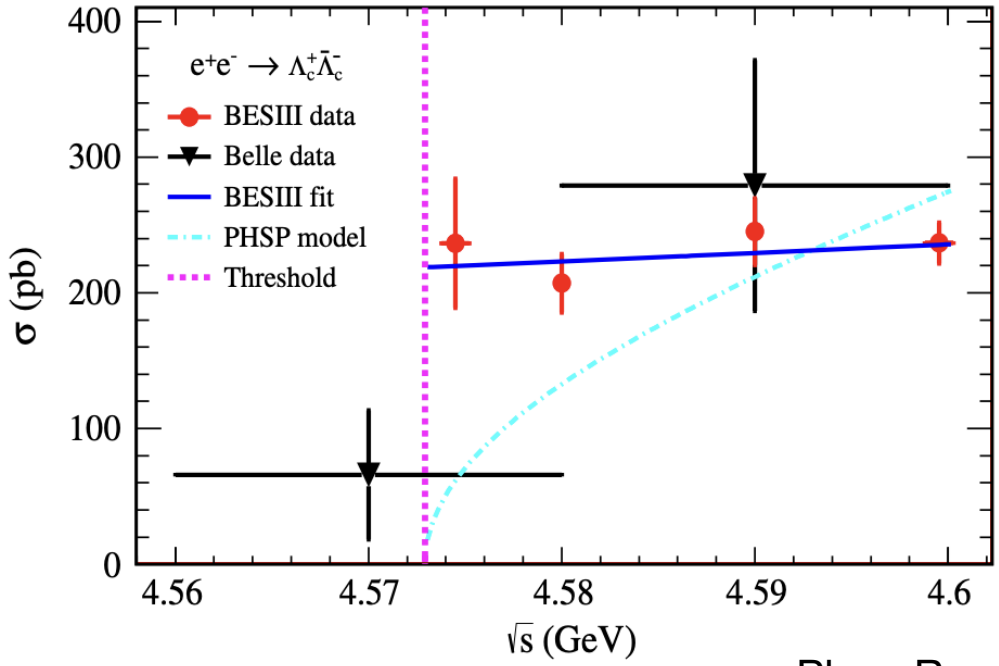


No significant Z_c and Z_{cs} states are found in $e^+e^- \to K^0K^-\pi^+J/\psi$ due to limited statistics.

Charmed baryon pairs/baryonic molecular state (near kinematic threshold)

$e^+e^- \to \Sigma_c\bar{\Sigma}_c/\Lambda_c^+\bar{\Sigma}_c^-$ at BESIII

- Spin-1/2 baryons pairs ($B\bar{B}$) at threshold production.
  - ✓ observe baryon's internal structures indirectly.
  - ✓ probe the understanding of strong interaction.
- The cross section of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$
  - ✓ Belle – peak
  - ✓ BESIII - plateau



Energy thresholds:

- ✓ $\Lambda_c^+\bar{\Sigma}_c^-$: 4.74 GeV
- ✓ $\Sigma_c\bar{\Sigma}_c$: 4.91 GeV

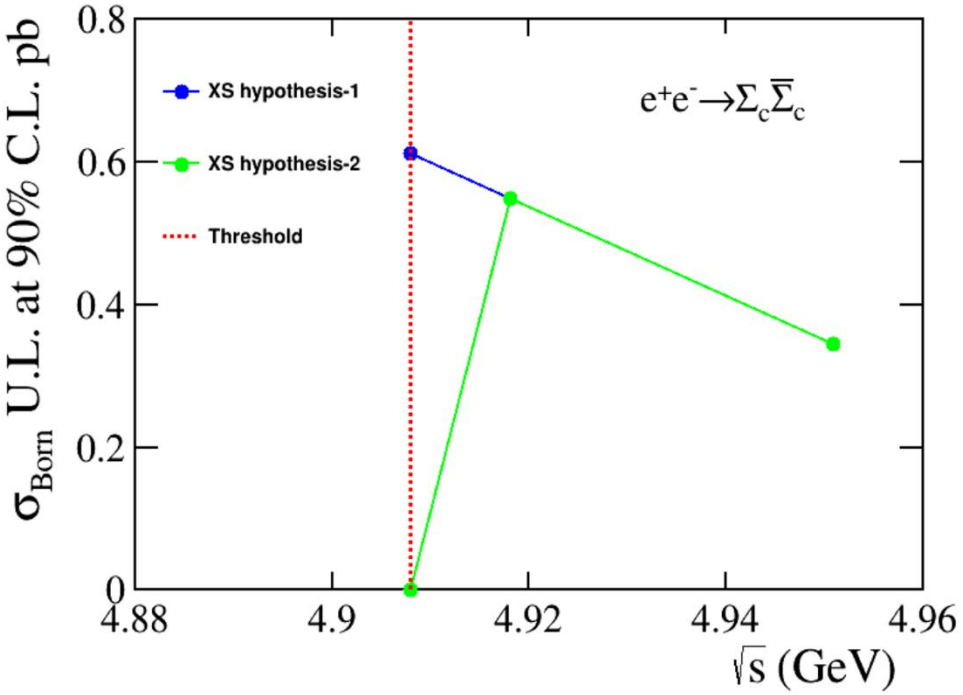
$\sqrt{s}$ =4.750, 4.781, 4.843, 4.918, and 4.951 GeV

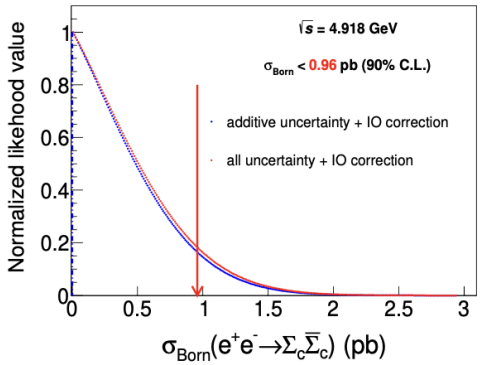
$L = 1.77\ \text{fb}^{-1}$

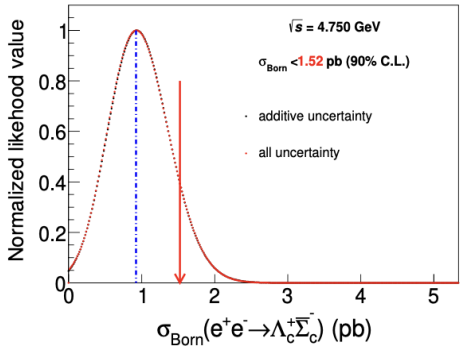
Phys. Rev. Lett. 120, 132001 (2018)

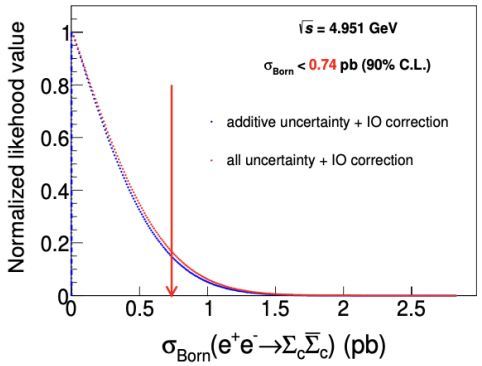
$e^+e^- \to \Sigma_c\bar{\Sigma}_c/\Lambda_c^+\bar{\Sigma}_c^-$ at BESIII

arXiv:2508.18594









XS hypothesis-1: threshold enhancement
XS hypothesis-2: no threshold enhancement

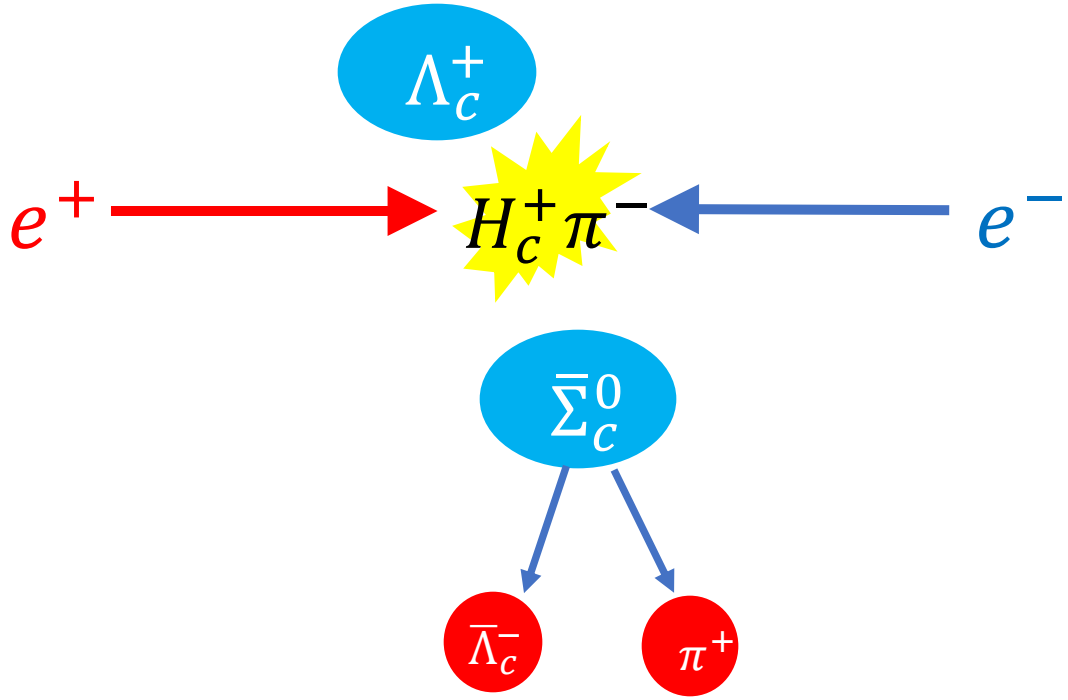
Comparing the cross section of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ near the threshold (~250 pb) , a suppression of at least $O(10^2)$.

$\sqrt{s}$	4.750 GeV	4.781 GeV	4.843 GeV	4.918 GeV	4.951 GeV
$R(\sigma)$ (%)	< 1.1	< 0.6	< 1.5	< 3.4	< 1.6
$\sigma_{\rm Born}(e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-)$ (pb)	$134 \pm 3 \pm 4$	$127 \pm 2 \pm 4$	$83 \pm 2 \pm 3$	$96 \pm 3 \pm 4$	$88 \pm 4 \pm 3$
$\sigma_{\rm Born}(e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-)$ (pb)	< 1.52	< 0.76	< 1.26	< 3.26	< 1.38

Search for $H_c^{\pm} \to \Lambda_c \bar{\Sigma}_c$ in $e^+e^- \to \Lambda_c^+ \bar{\Lambda}_c^- \pi^+ \pi^-$ at BESIII

- Many structures are observed near the mass threshold of hadron pairs. Similar states are also proposed near the charmed baryon pair.
- For bound state, the mass is below the mass of the pair system, such as the one in $\Lambda_c \bar{\Sigma}_c$, system, which will decay to $\Lambda_c \bar{\Lambda}_c \pi$.

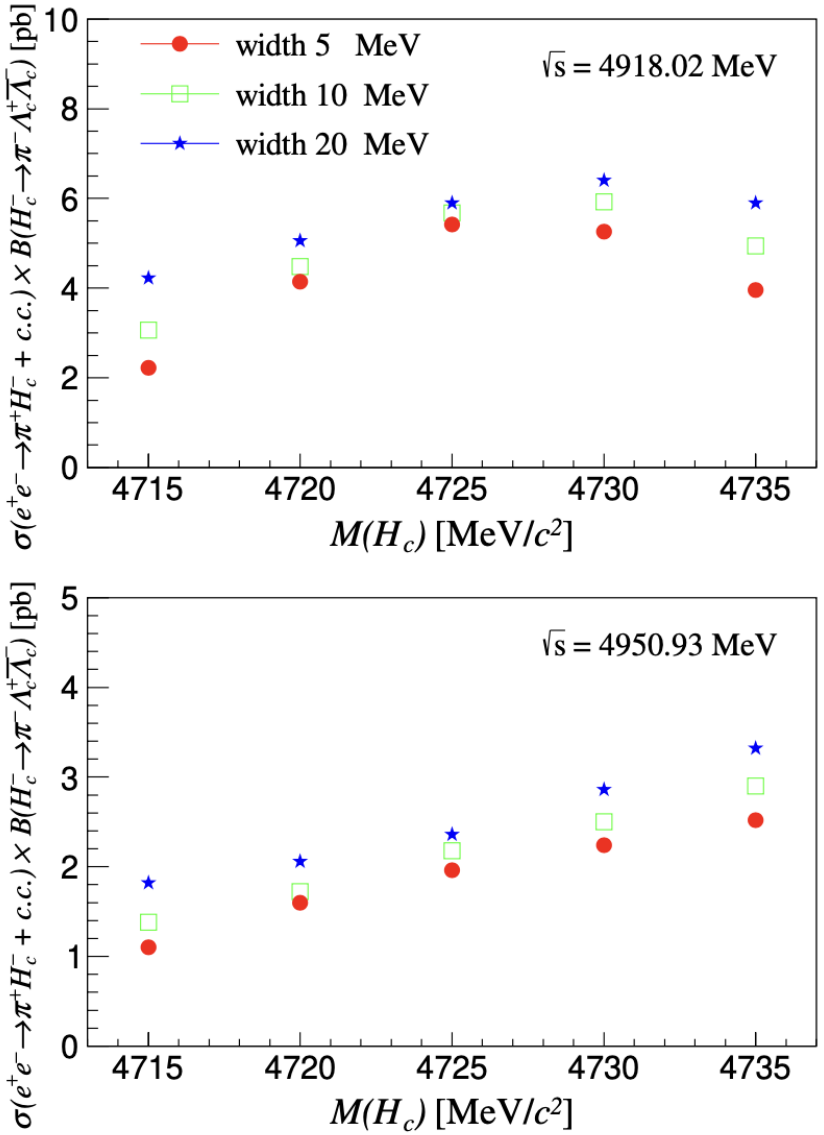
The spectrum of hadronic molecules consisting of a pair of charmed-anticharmed hadrons with (I, S) = (1, 0).[1]

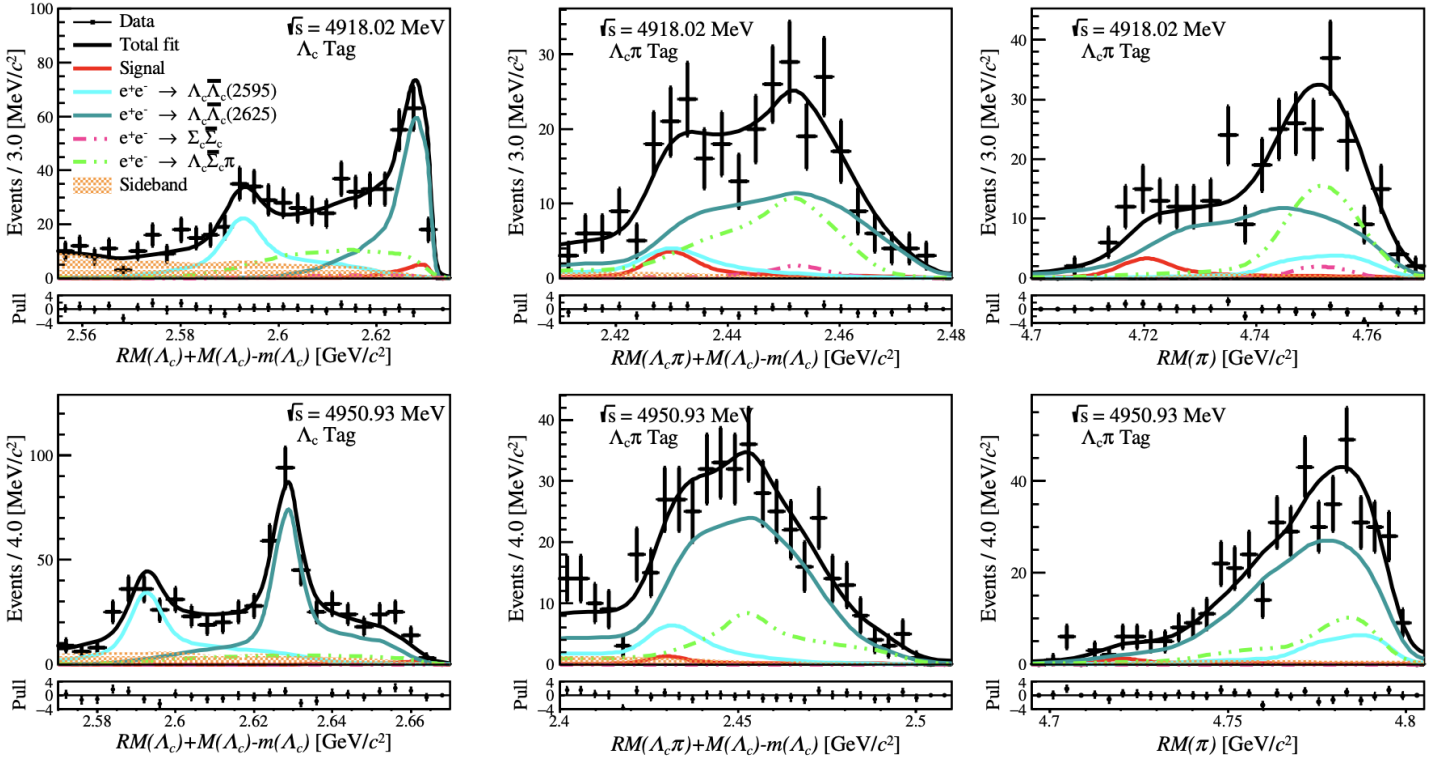


[1] X. K. Dong, et al. 2021 Commun. Theor. Phys. 73 125201

Search for $H_c^{\pm} \to \Lambda_c \bar{\Sigma}_c$ in $e^+e^- \to \Lambda_c^+ \bar{\Lambda}_c^- \pi^+ \pi^-$ at BESIII

arXiv:2508.16871





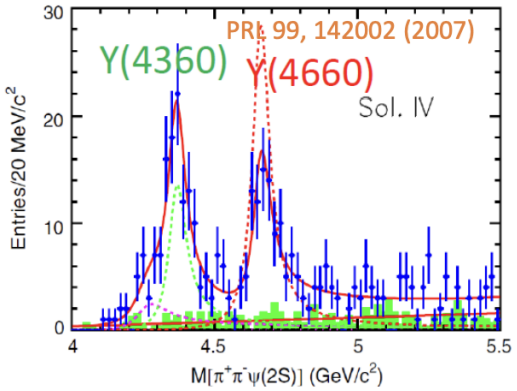
Upper limits of cross section for all signal *Hc* with different width and mass assumption.

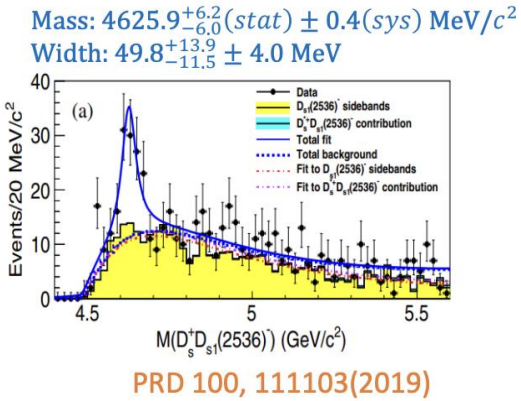
Measurements of Born cross sections for $e^+e^- \to \Lambda_c^+ \bar{\Lambda}_c(2595)^- + \text{c.c.}$ and $e^+e^- \to \Lambda_c^+ \bar{\Lambda}_c(2625)^- + \text{c.c.}$ at $\sqrt{s} = 4918.0$ and 4950.9 MeV Phys. Rev. D109, L071104 (2024)

1^{-+} molecular state

Search 1^{-+}state in $e^+e^- \to \gamma D_s^+ D_{s1}^-(2536)$

- Some theories postulate that Y(4660) is the possible candidate for the molecular state of $D_s^{(*)+} D_{s1,2}^-$ or $D^{(*)}\overline{D}_{1,2}$ [1-3].
- Searching for molecular sate X ($J^{PC} = 1^{-+}$), formed by $D_s^+ D_{s1}^-(2536)$, to test the hypothesis that whether Y(4660) is a molecular state.
- Based on the calculation of the potential model, the exotic hadronic molecule (X) with $J^{PC} = 1^{-+}$ is probed to be possible in the radiative transition of the vector molecules (Y), $Br(Y \to \gamma X) \geq O(10^{-3})$ [2].
- The first measurement of the resonance parameters of Y(4660) in the electromagnetic decay could solve the mass and width mystery of Y(4660).



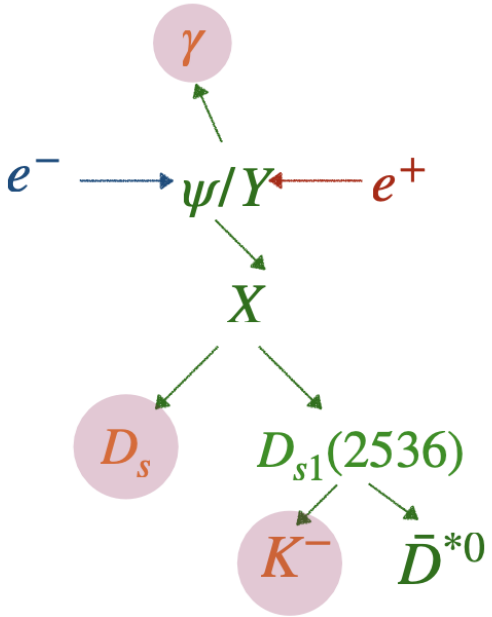


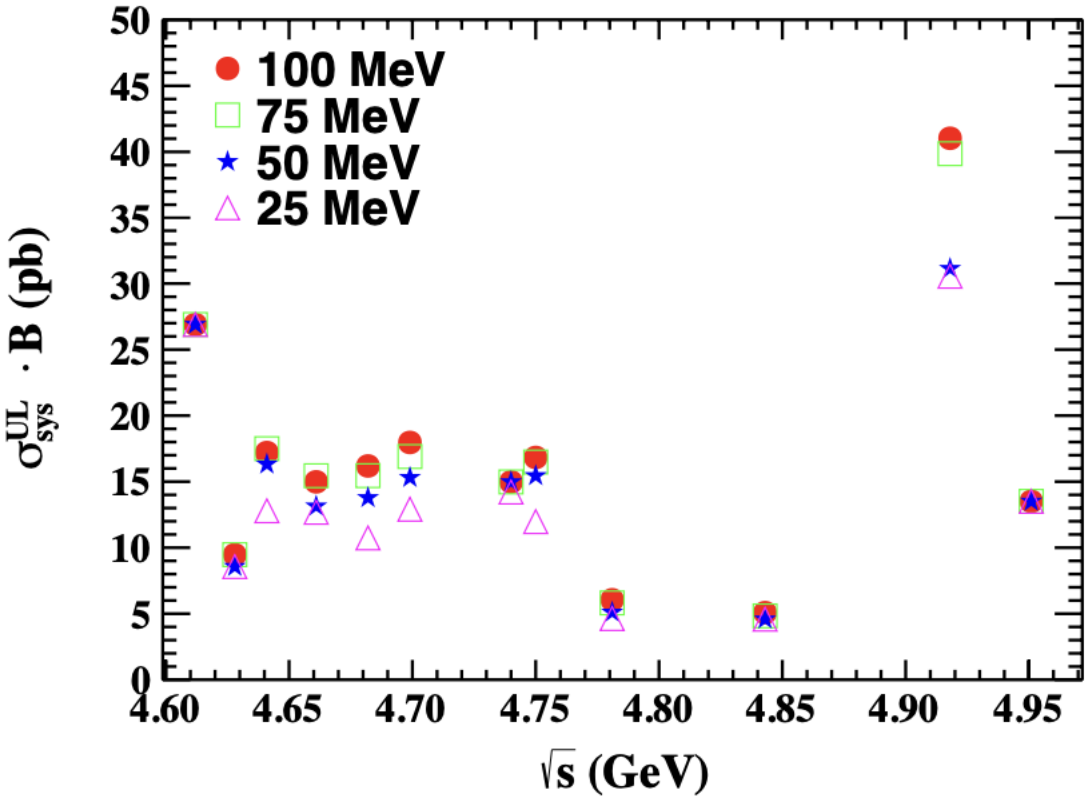
PRD 100, 111103(2019)

[1] PRD 90,034020(2014)
[2] PRD 89, 114013(2014)
[3] PRD 100, 111103(2019)

Search 1^{-+} state in $e^+e^- \to \gamma D_s^+ D_{s1}^-(2536)$

- $\sqrt{s} = 4.61 - 4.95$ GeV, $L = 5.8$ fb^{-1}
- Mass of X set to 4.503 GeV/c^2
- Partial Reconstruction





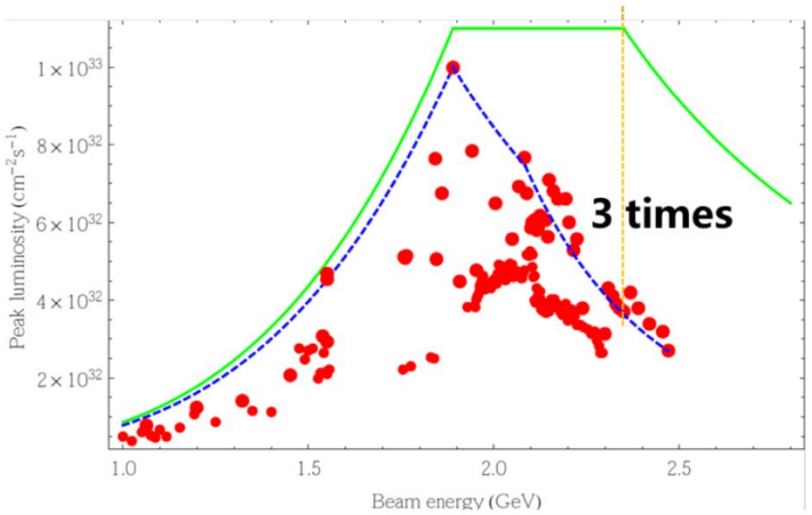
Phys. Rev. D 112, 032002 (2025)

Summary and Outlook

- The study of XYZ states continues to be a focus of research at BESIII.
- Ideal experimental scenario for charmonium(-like) spectroscopy.
- Some processes suffers from low statistics.
- New exciting results expected:
  - datasets in wider energy range (4.95 ~ 5.6 GeV) to be collected.
  - other approaches to be explored.

BEPCII will upgrade in both Lum. and Max. E

- Luminosity is increased by a factor 3 @ 2.35 GeV
- Maximun beam energy is increased up to 2.8 GeV



Backup

$e^+e^- \to \Sigma_c\bar{\Sigma}_c/\Lambda_c^+\bar{\Sigma}_c^-$ at BESIII

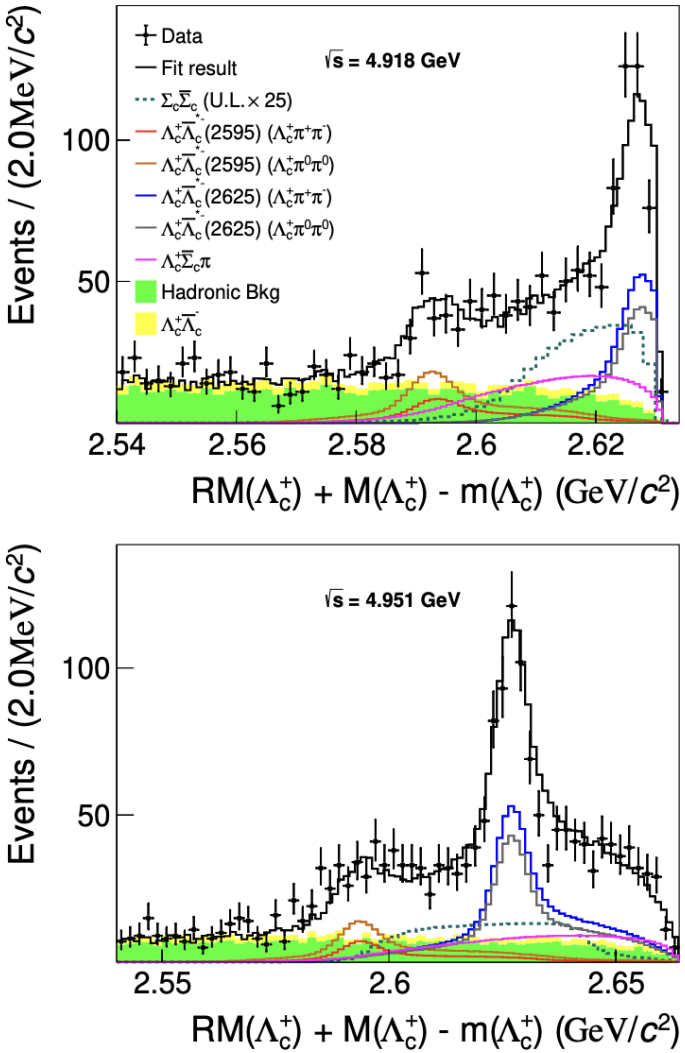


FIG. 1. One-dimensional fit results at $\sqrt{s} = 4.918$ GeV (top) and $\sqrt{s} = 4.951$ GeV (bottom) in the "Tag Λ_c^+" sample. The dots with error bars denote data, and the black solid curves correspond to the fit result. "Bkg" stays for the background. The dashed lines represent the MC distributions of the components $\Sigma_c^+\bar{\Sigma}_c^-$, $\Sigma_c^0\bar{\Sigma}_c^0$ and $\Sigma_c^{++}\bar{\Sigma}_c^{--}$. The "U.L. $\times$ 25" indicates the MC distribution normalized to 25 times the 90% confidence level upper limit of the $\Sigma_c\bar{\Sigma}_c$ observed cross section.

Search 1^{-+} state in $e^+e^- \to \gamma D_s^+ D_{s1}^-(2536)$