Exotic Hadrons at BESIII

Yuping Guo (guoyp@fudan.edu.cn)

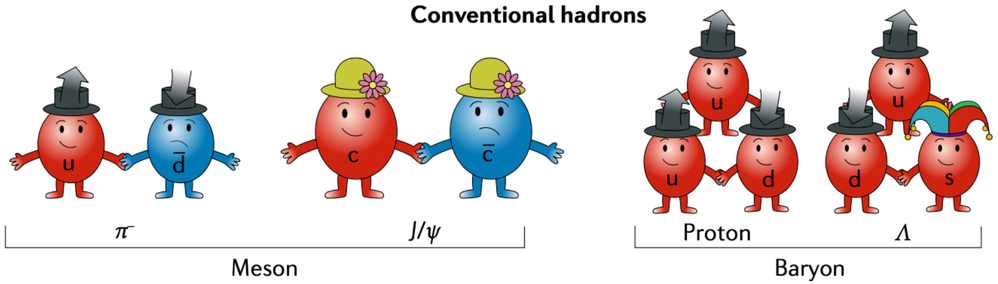
On behalf of the BESIII Collaboration

14th International Workshop on e^+e^- collisions from Phi to Psi 2026

Hadrons

- **Quark Model** [1964 by Gell-Mann and Zweig]

Lowest Configuration!

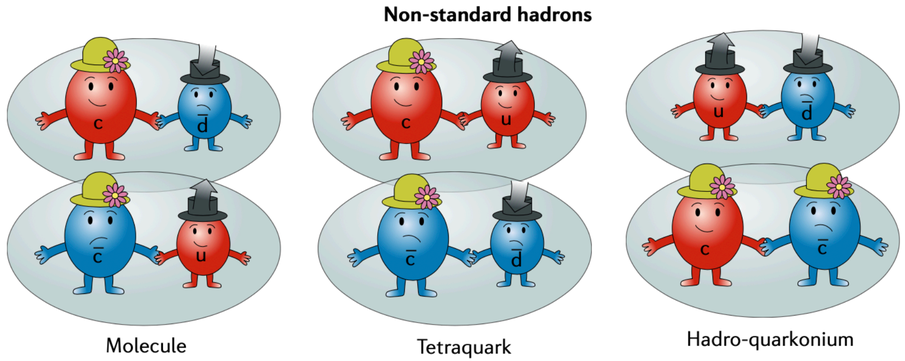


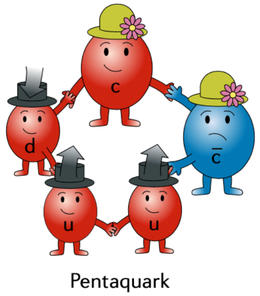
A SCHEMATIC MODEL OF BARYONS AND MESONS *

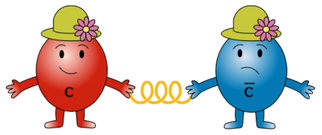
M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations (qqq), $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. It is assuming that the lowest baryon configuration (qqq) 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**.





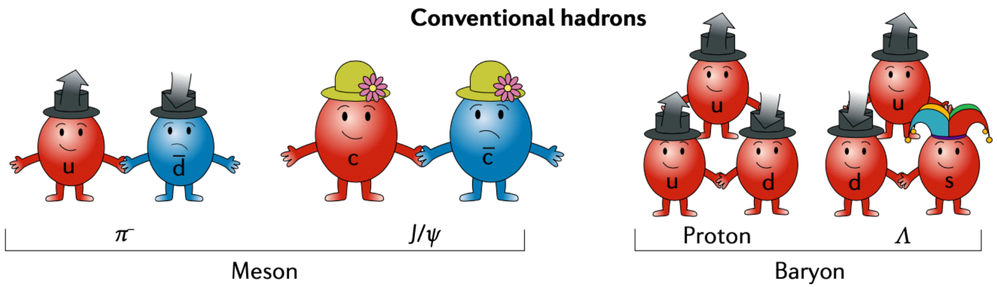


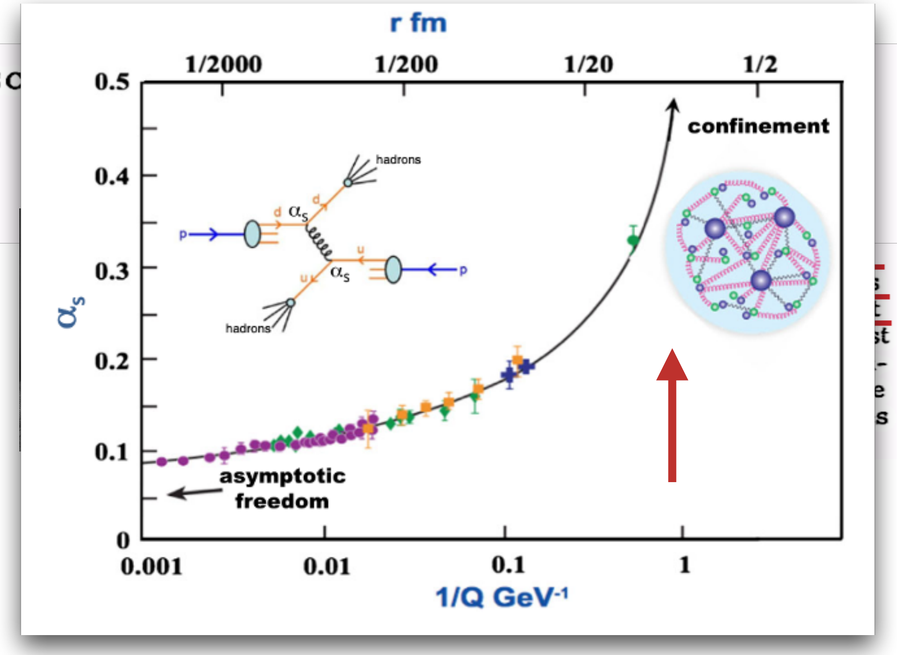
C. Z. Yuan, S. L. Olsen, Nature Reviews Physics 1, 480 (2019)

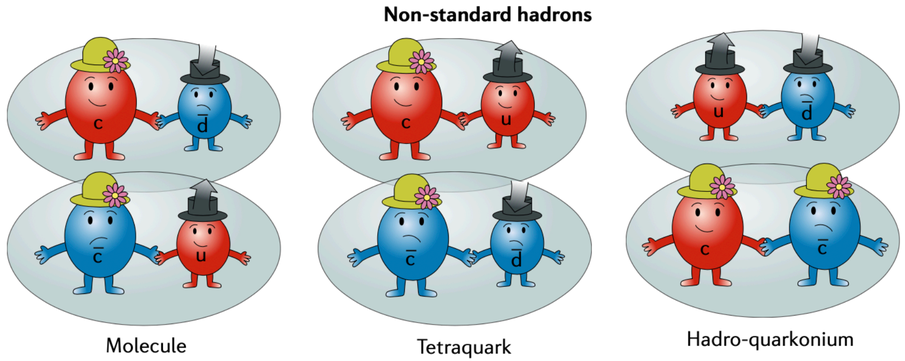
Hadrons

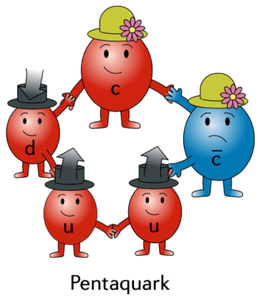
- **Quark Model** [1964 by Gell-Mann and Zweig]

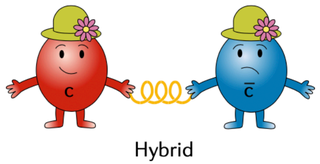
Lowest Configuration!





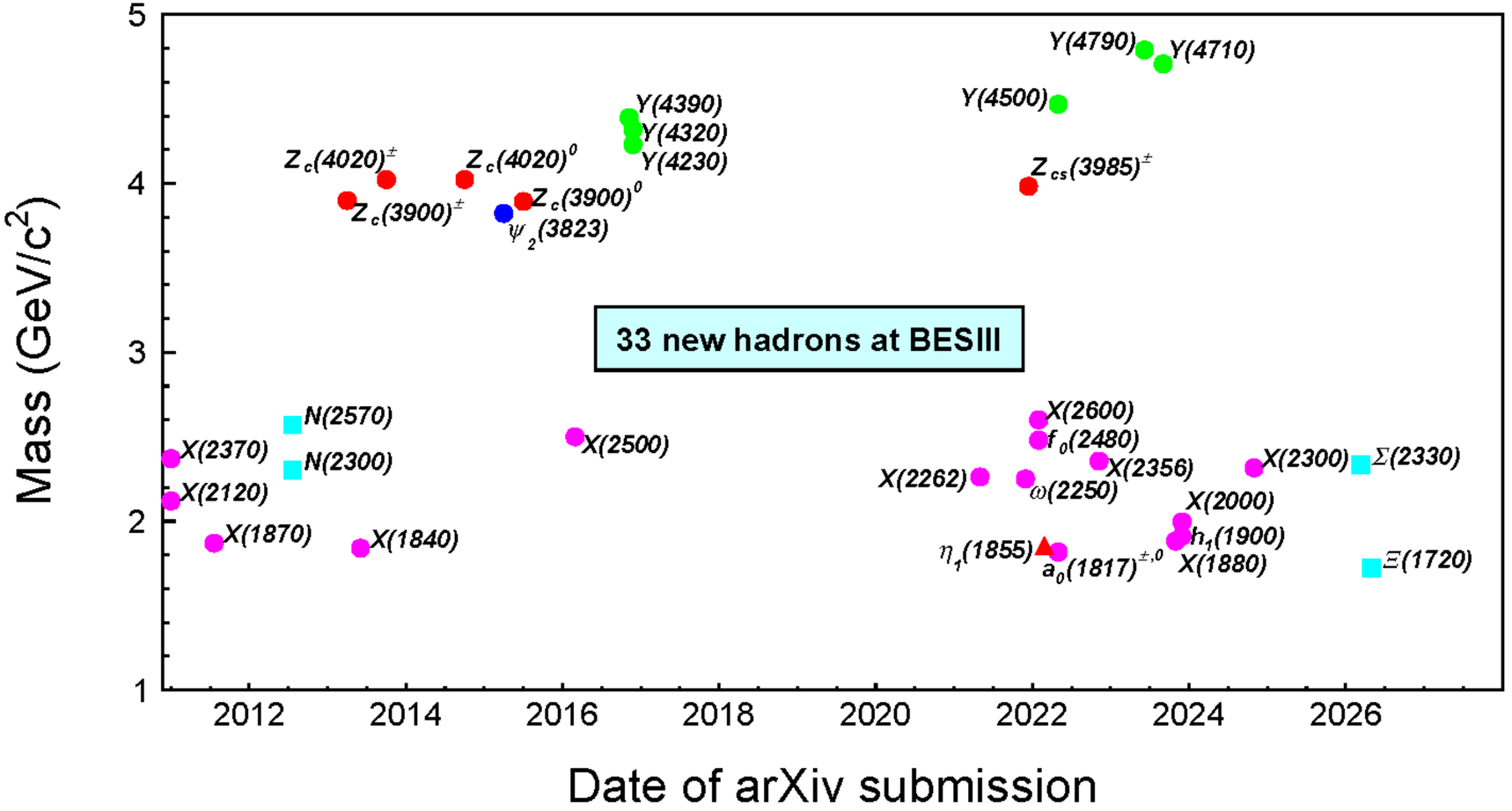




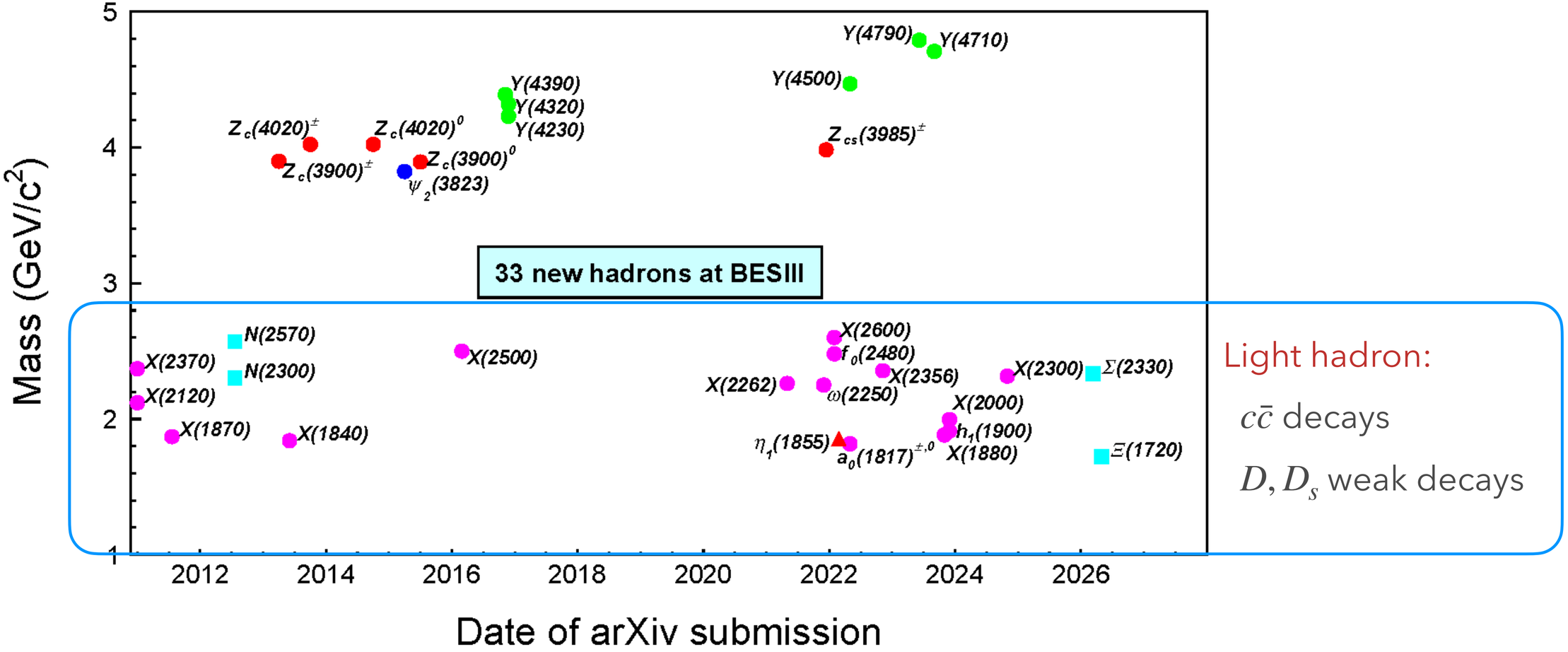


C. Z. Yuan, S. L. Olsen, Nature Reviews Physics 1, 480 (2019)

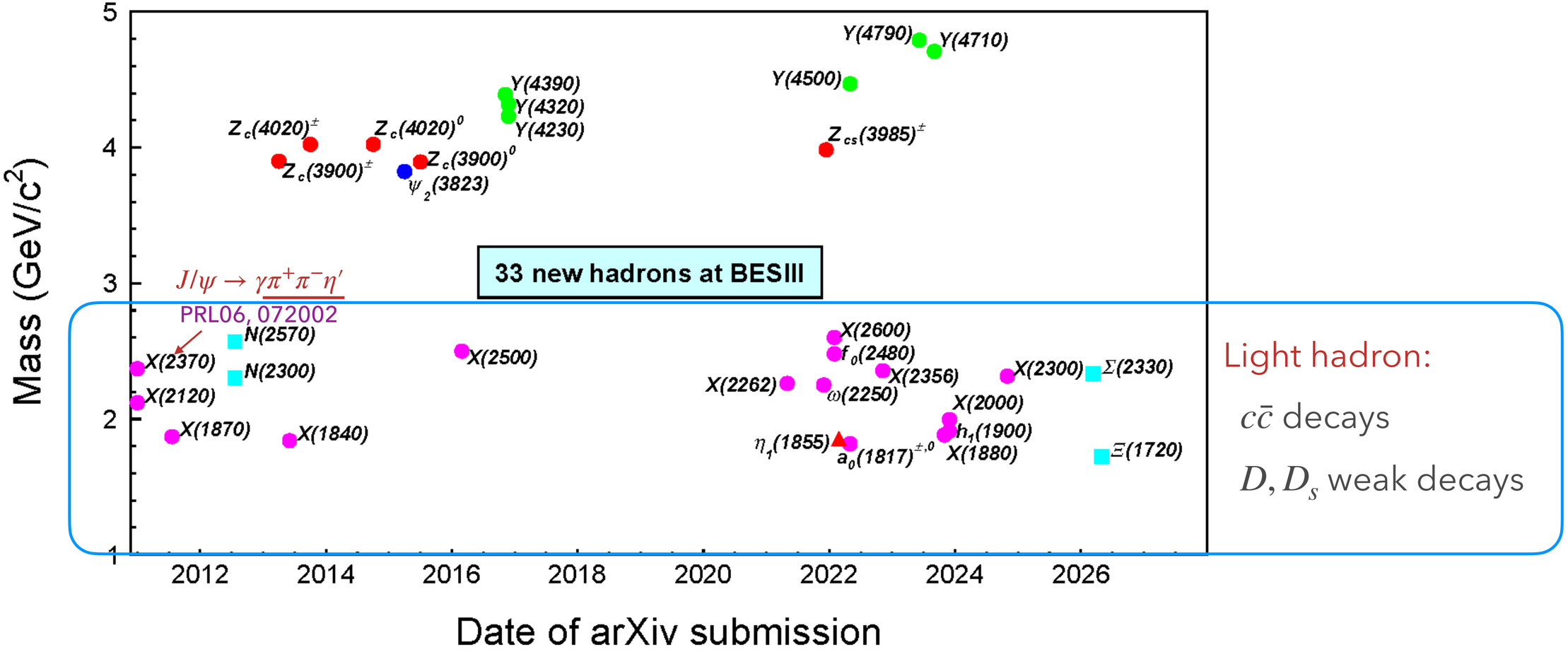
New Hadrons Discovered at BESIII



New Hadrons Discovered at BESIII



New Hadrons Discovered at BESIII

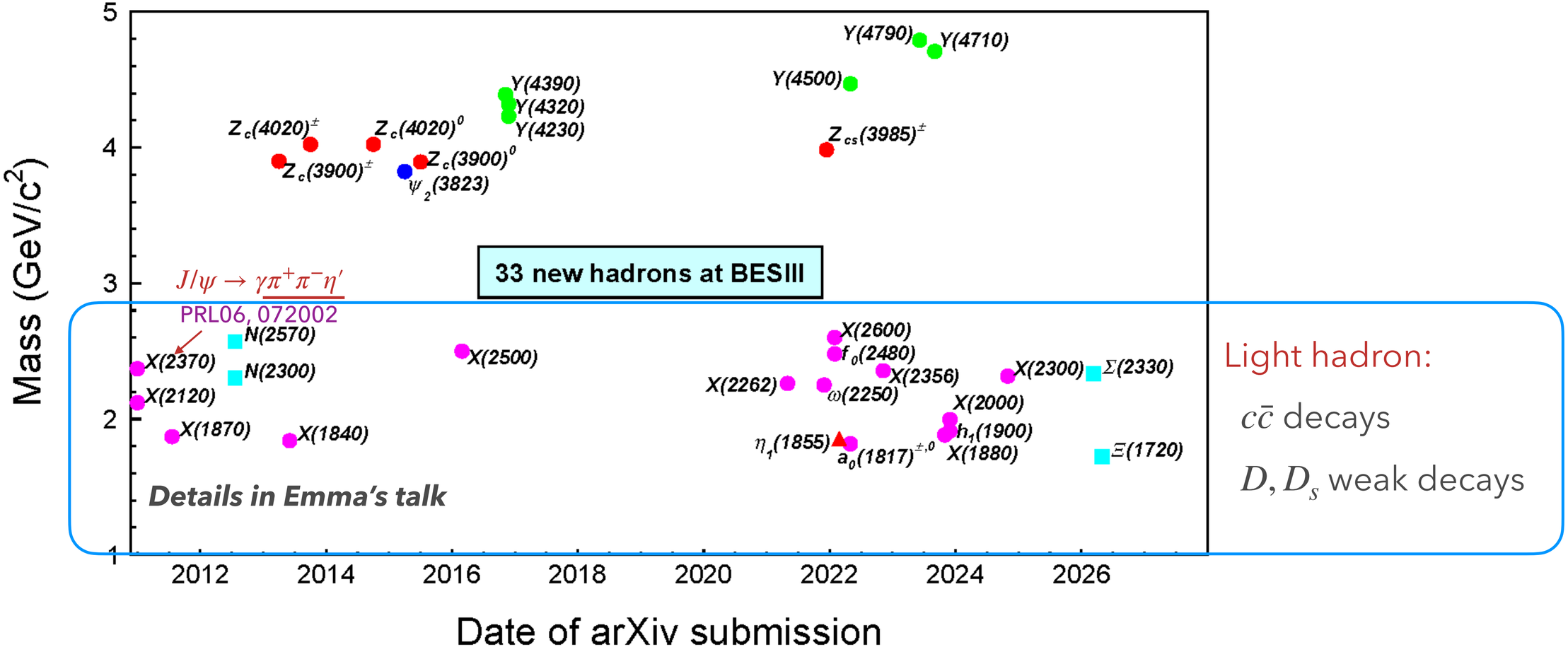


Light hadron:

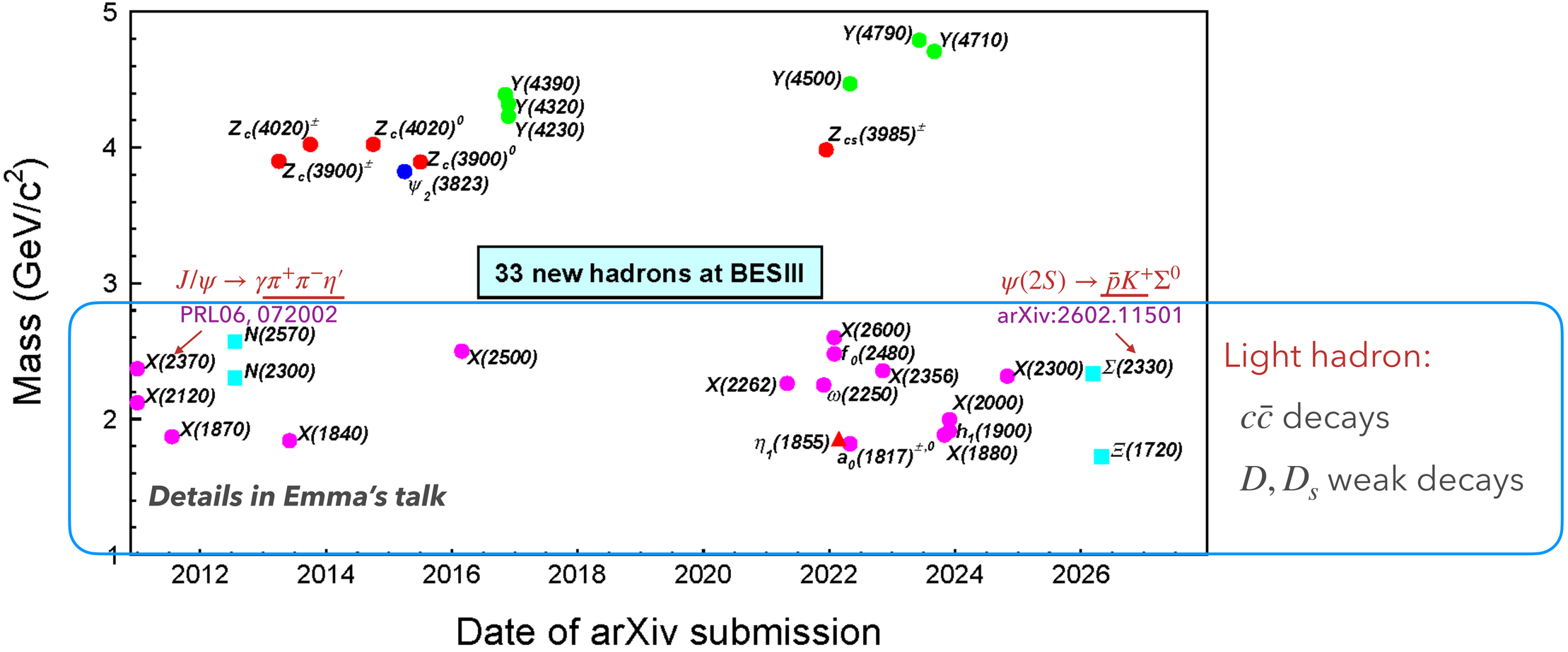
$c\bar{c}$ decays

D, D_s weak decays

New Hadrons Discovered at BESIII



New Hadrons Discovered at BESIII

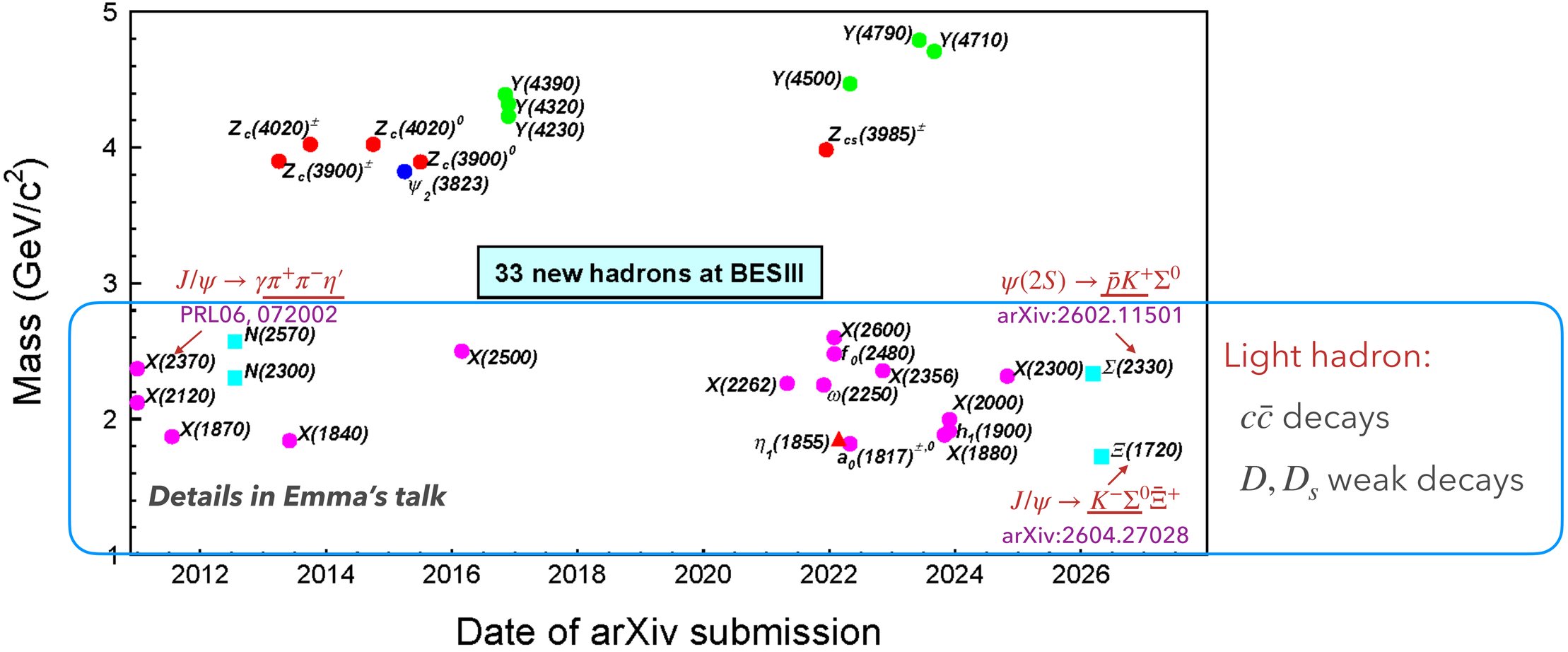


Light hadron:

$c\bar{c}$ decays

D, D_s weak decays

New Hadrons Discovered at BESIII

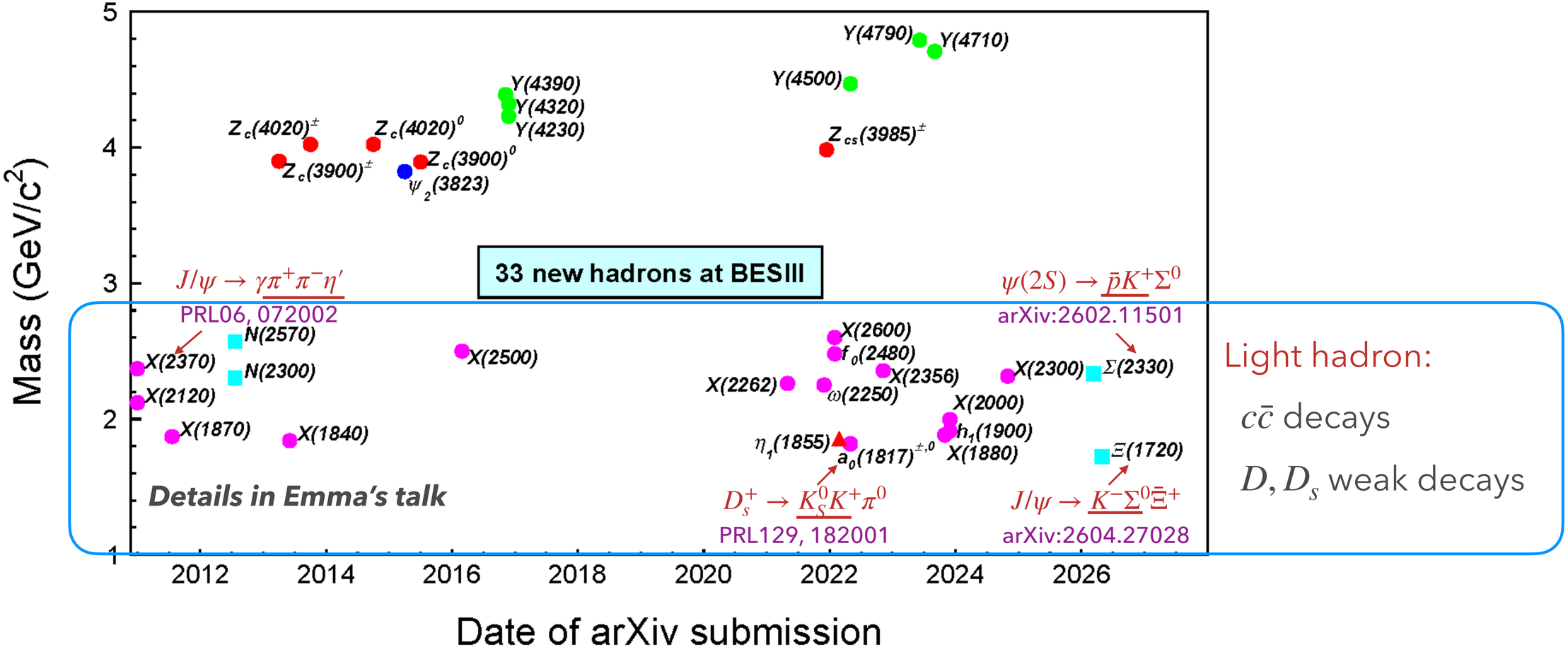


Light hadron:

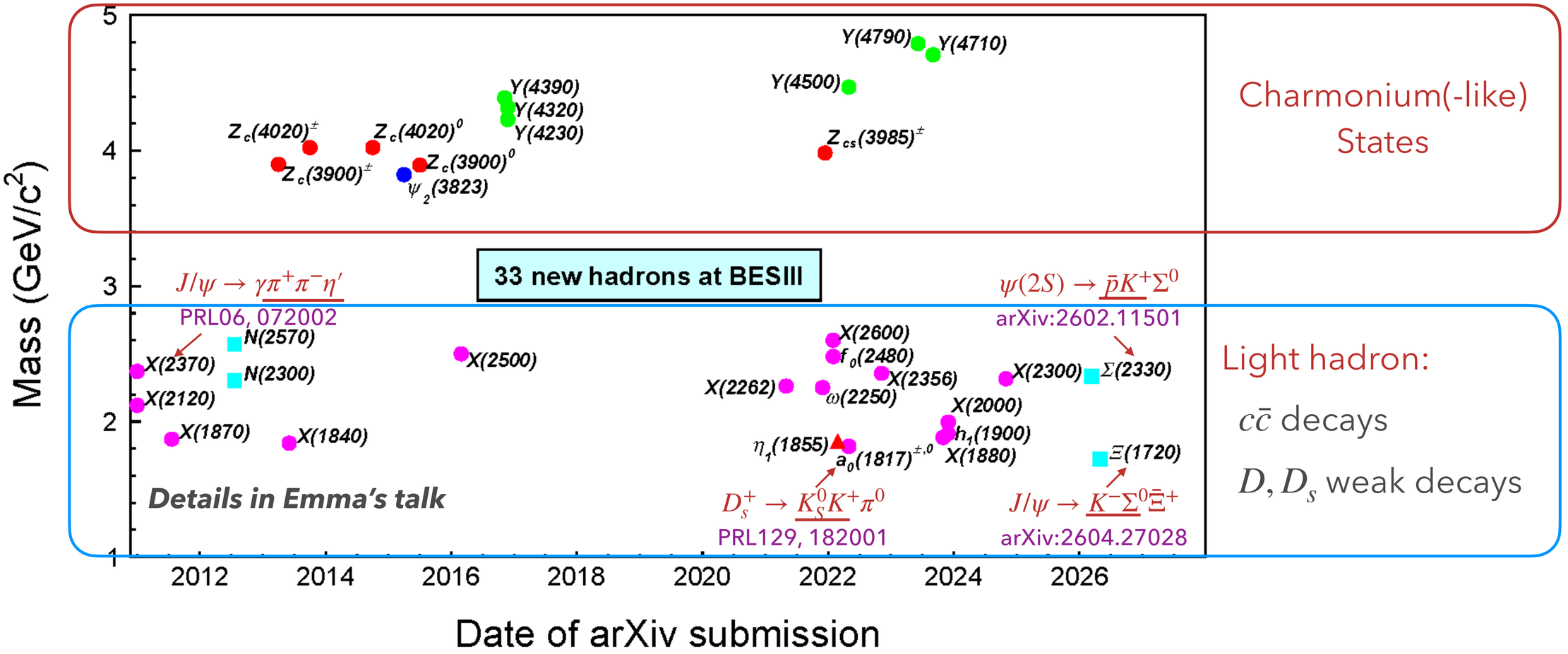
$c\bar{c}$ decays

D, D_s weak decays

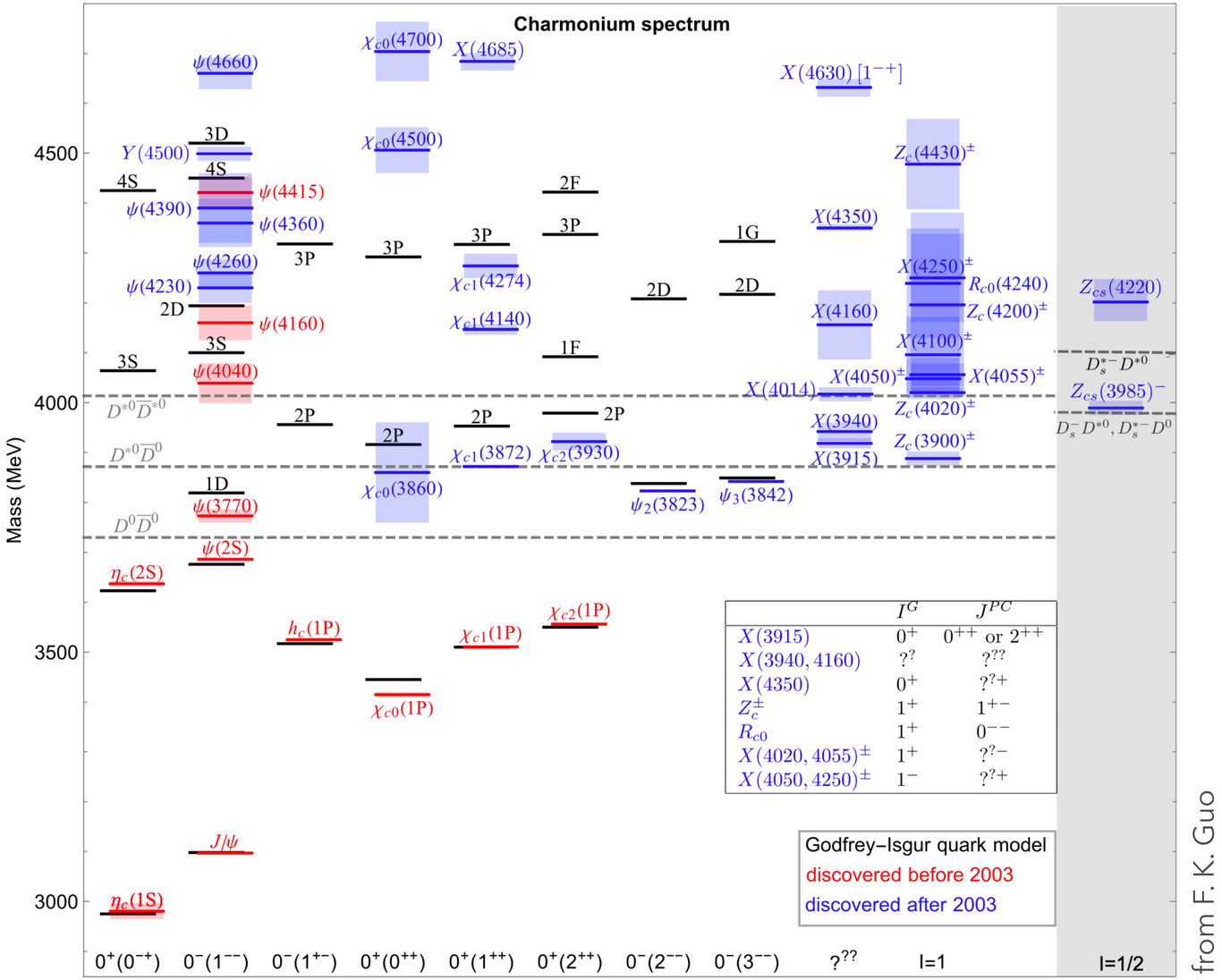
New Hadrons Discovered at BESIII



New Hadrons Discovered at BESIII

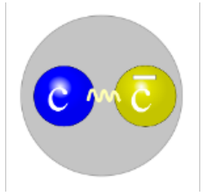


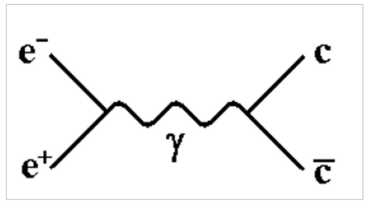
Charmonium Spectroscopy



from F. K. Guo

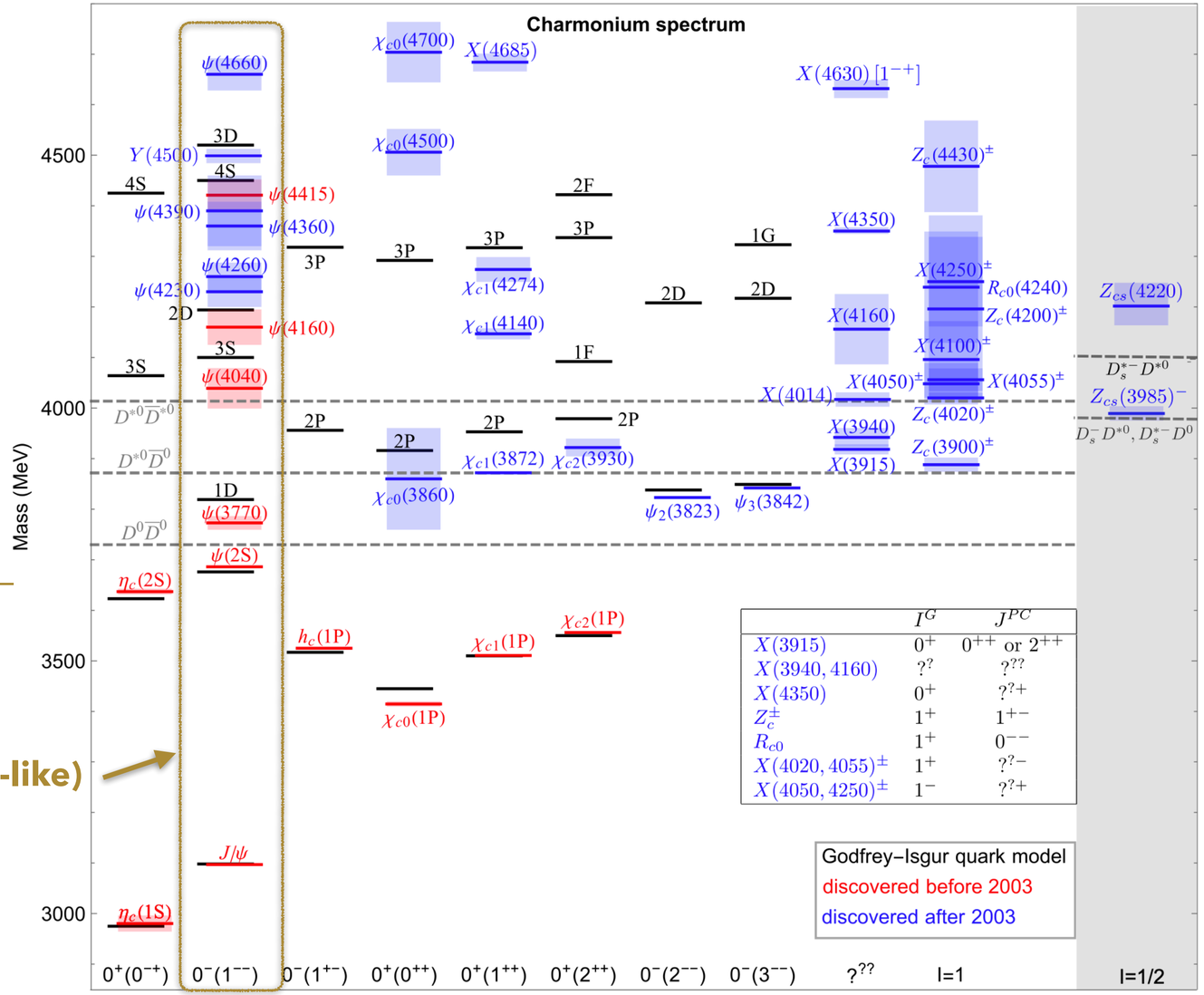
Charmonium Spectroscopy





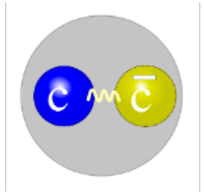
$J^{PC} = 1^{--}$

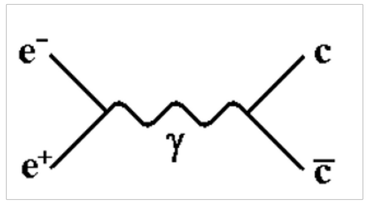
Vector Charmonium(-like)



from F. K. Guo

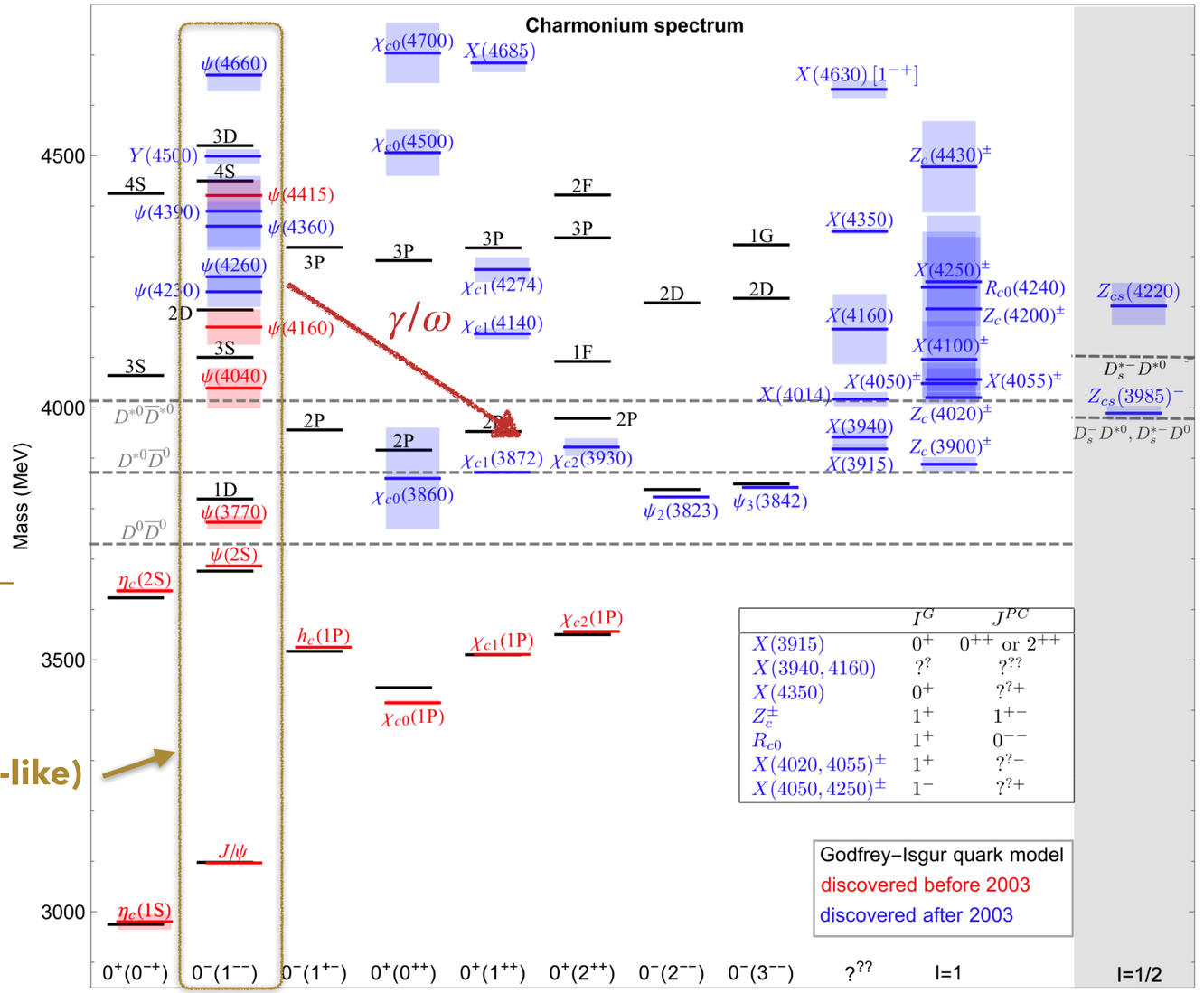
Charmonium Spectroscopy





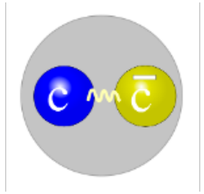
$J^{PC} = 1^{--}$

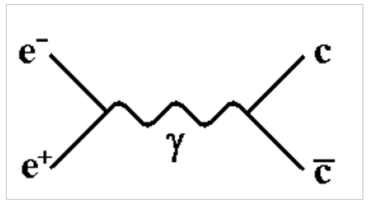
Vector Charmonium(-like)



from F. K. Guo

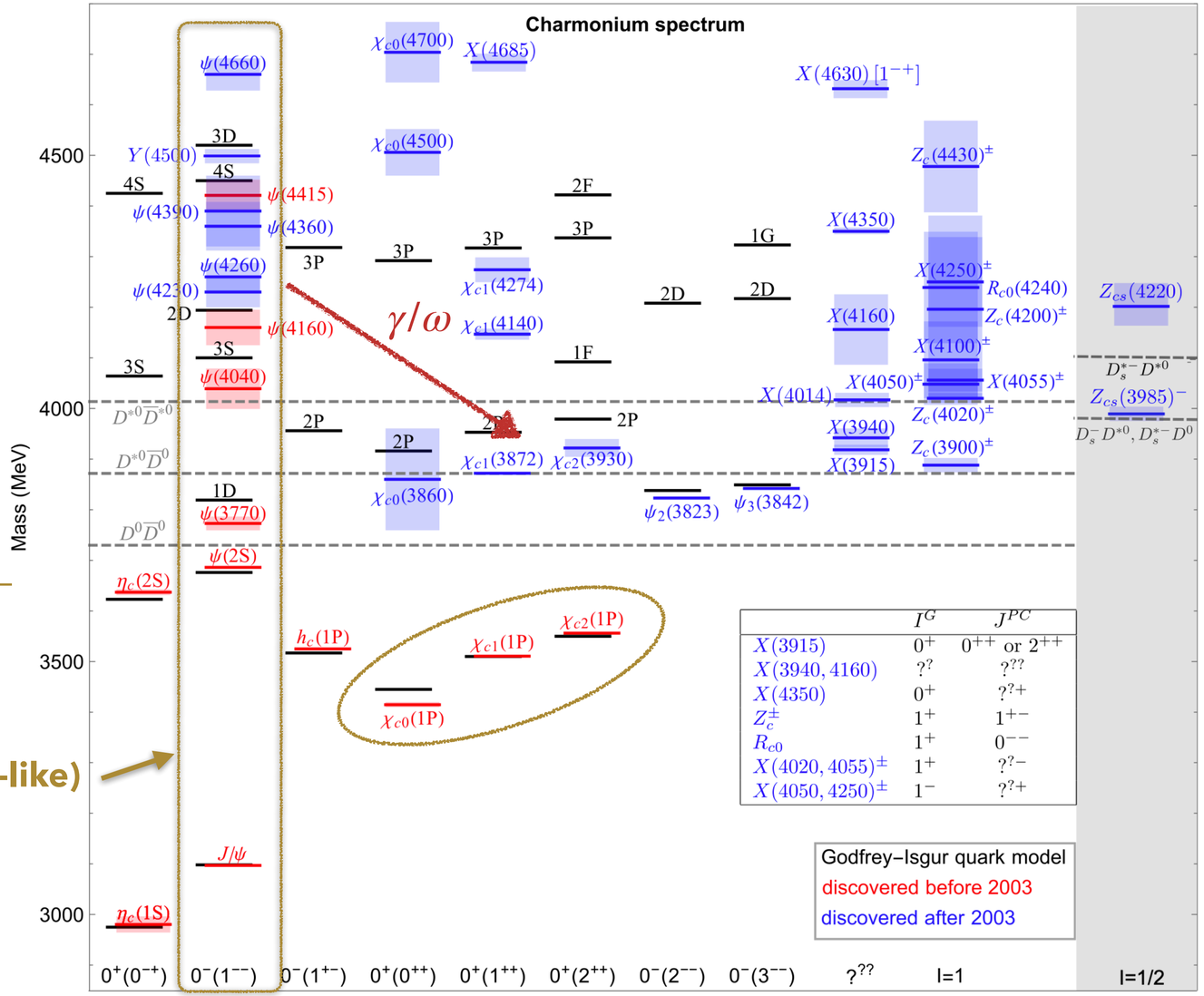
Charmonium Spectroscopy



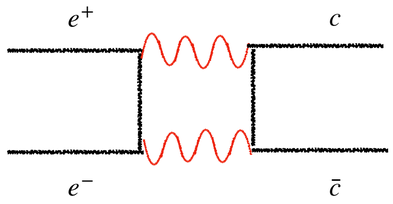


$J^{PC} = 1^{--}$

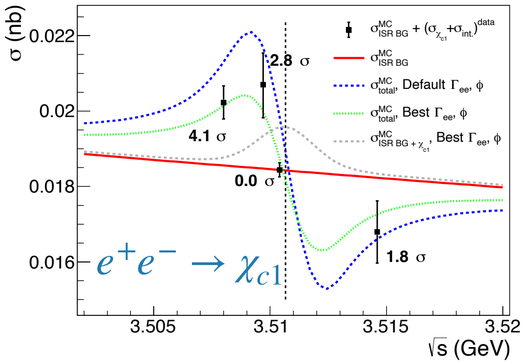
Vector Charmonium(-like)

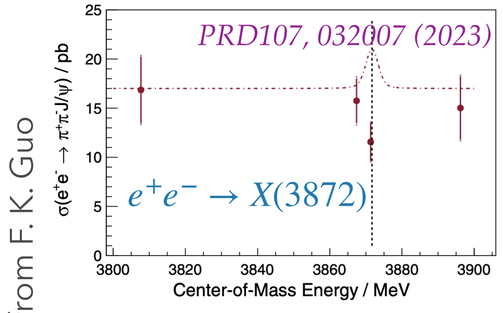


C-even states



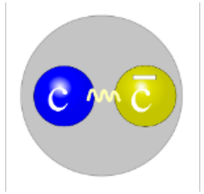
PRL129, 122001 (2022)

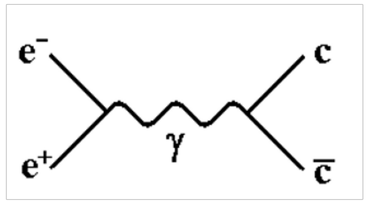




from F. K. Guo

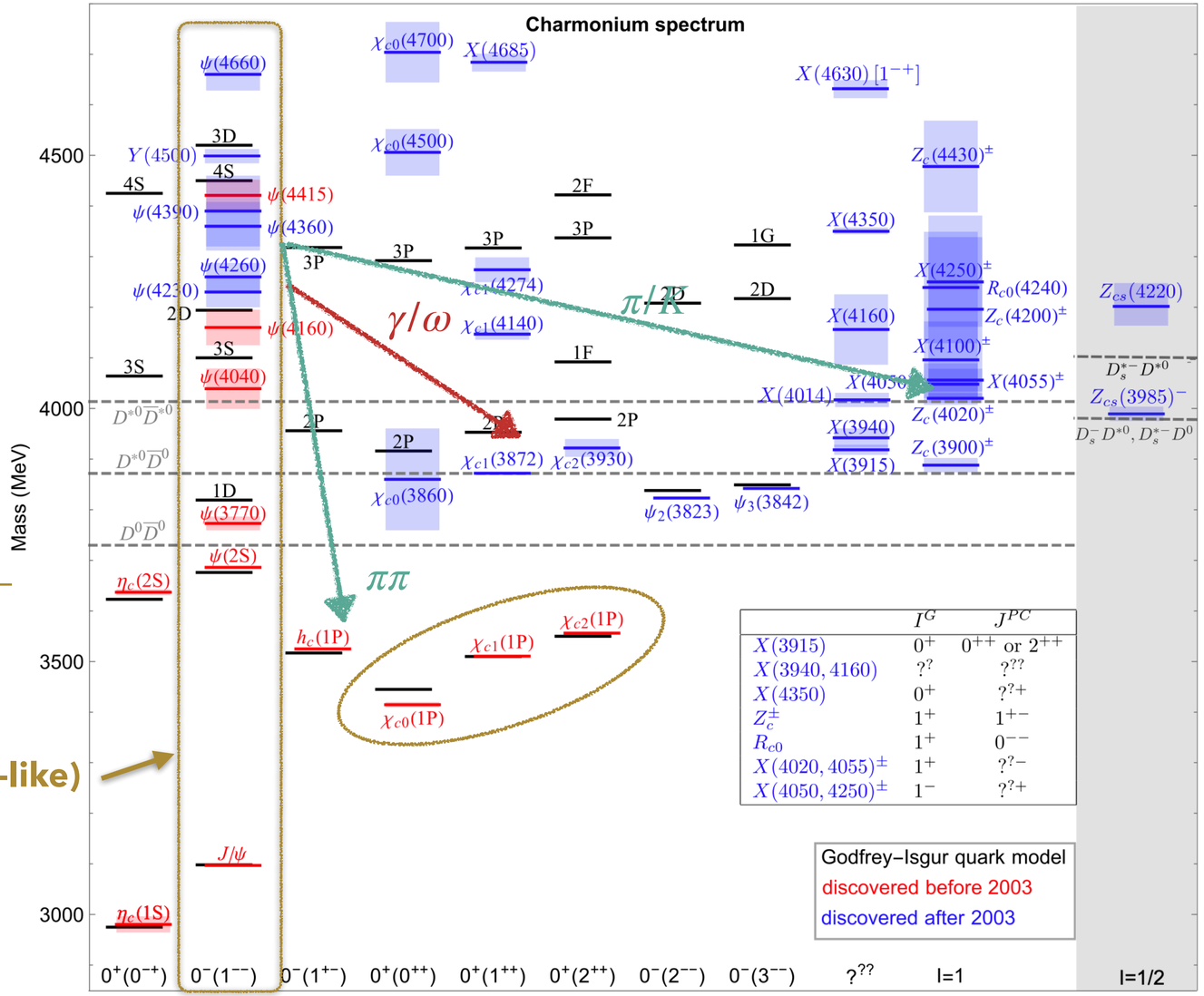
Charmonium Spectroscopy





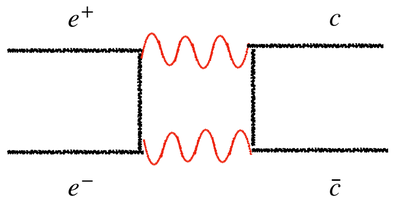
$J^{PC} = 1^{--}$

Vector Charmonium(-like)

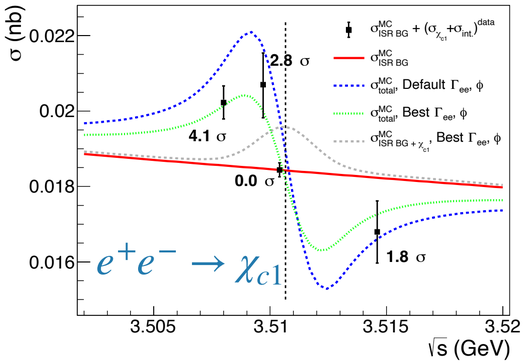


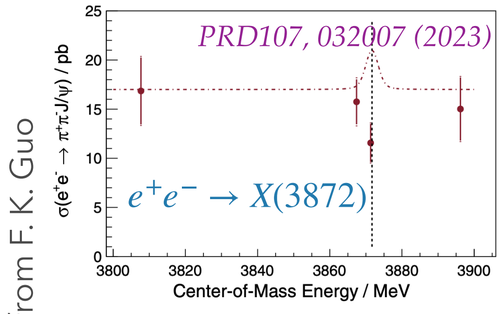
	I^G	J^{PC}
$X(3915)$	0^+	0^{++} or 2^{++}
$X(3940, 4160)$	$?^?$	$?^{??}$
$X(4350)$	0^+	$?^{?+}$
$Z_c^{\pm}$	1^+	1^{+-}
R_{c0}	1^+	0^{--}
$X(4020, 4055)^{\pm}$	1^+	$?^{?-}$
$X(4050, 4250)^{\pm}$	1^-	$?^{?+}$

C-even states



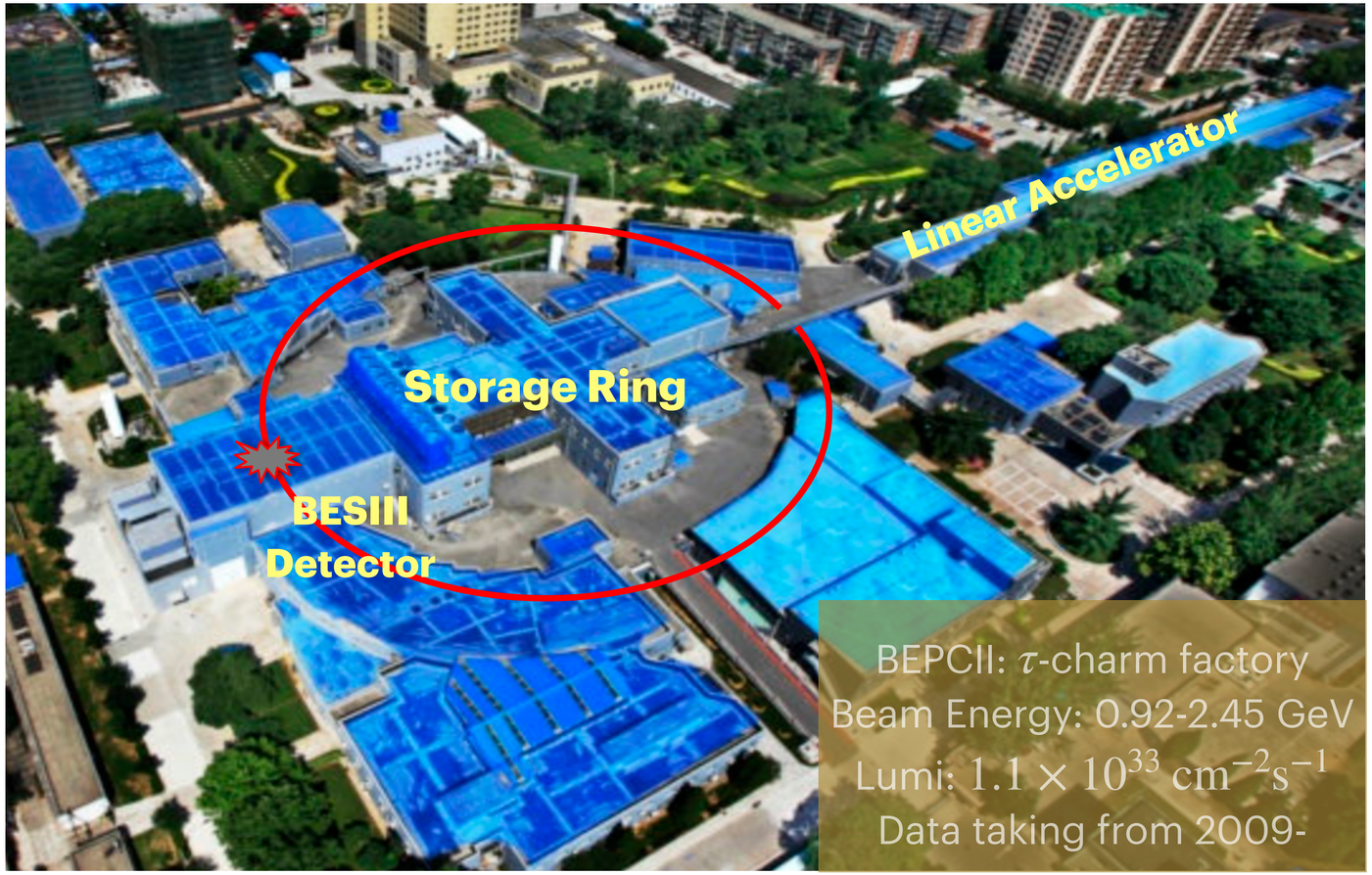
PRL129, 122001 (2022)





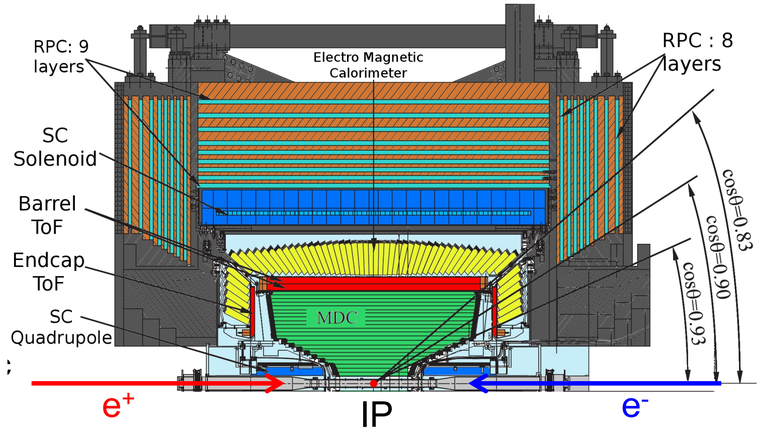
from F. K. Guo

BEPCII and BESIII



BEPCII: τ-charm factory
Beam Energy: 0.92-2.45 GeV
Lumi: 1.1×10^{33} cm^{-2}s^{-1}
Data taking from 2009-

Solenoid Magnet: 0.9/1.0 T



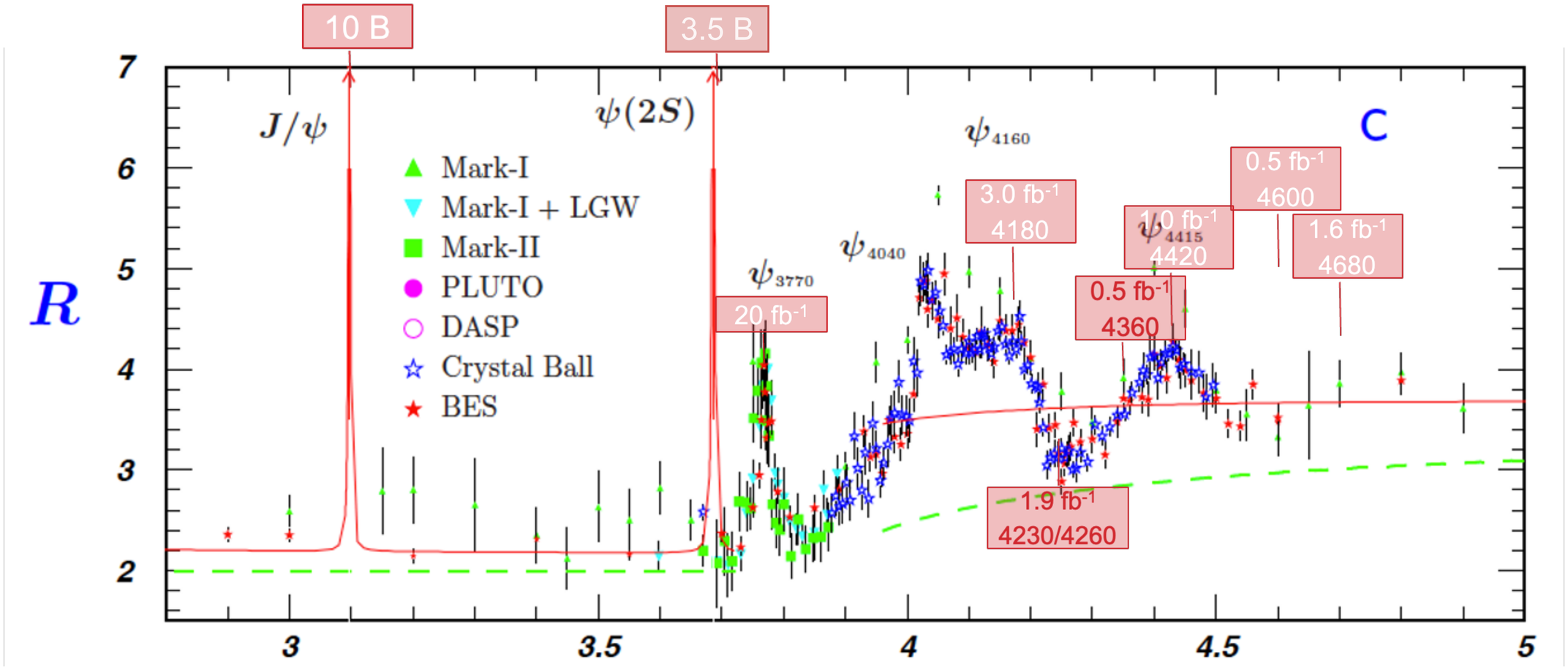
MUC $\sigma_{R\Phi}$: 2 cm

TOF
σ_T :80 ps
110 ps (60 ps)

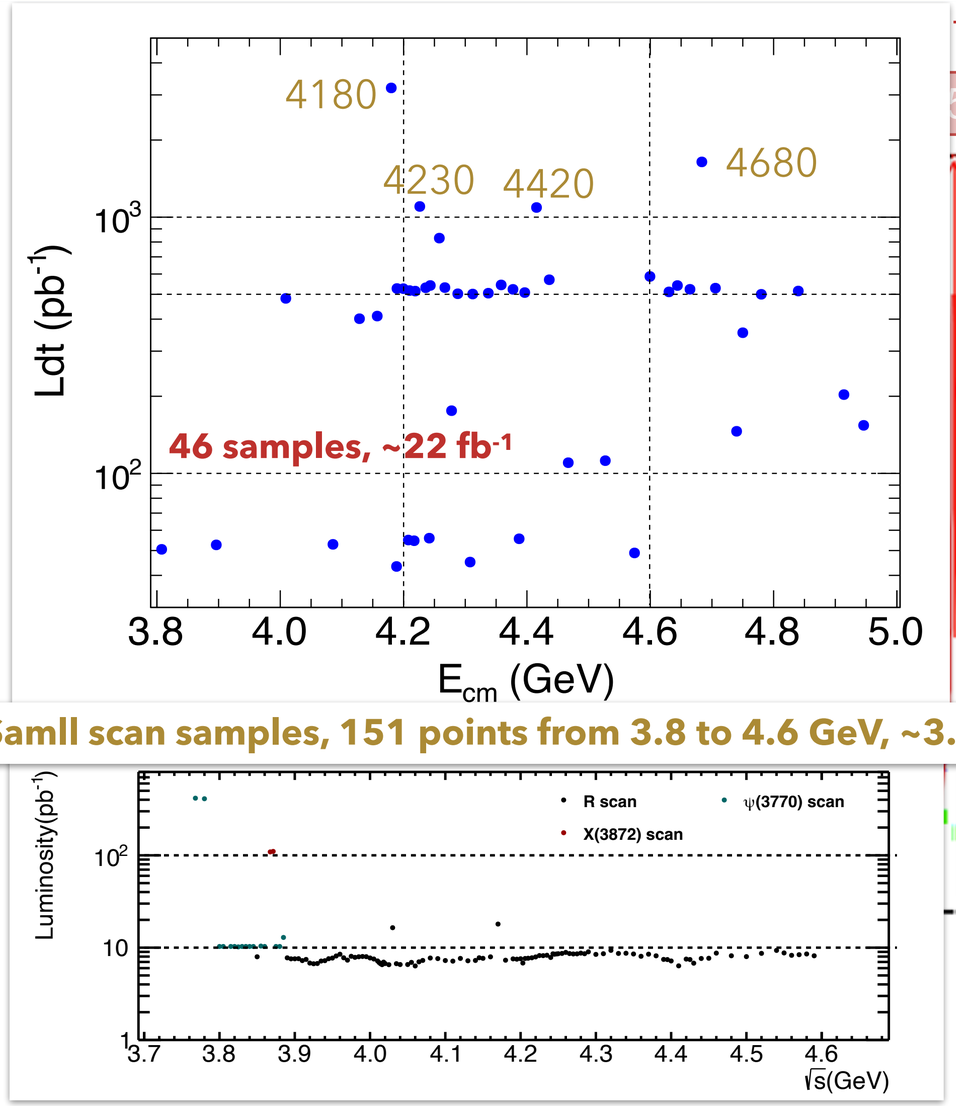
MDC
dE/dx: 6%
σ_p/p: 0.5% at 1GeV/c

EMC
$\Delta E/E$: at 1GeV
2.5%
5.0%
σ_Z: 0.6 cm/$\sqrt{E}$

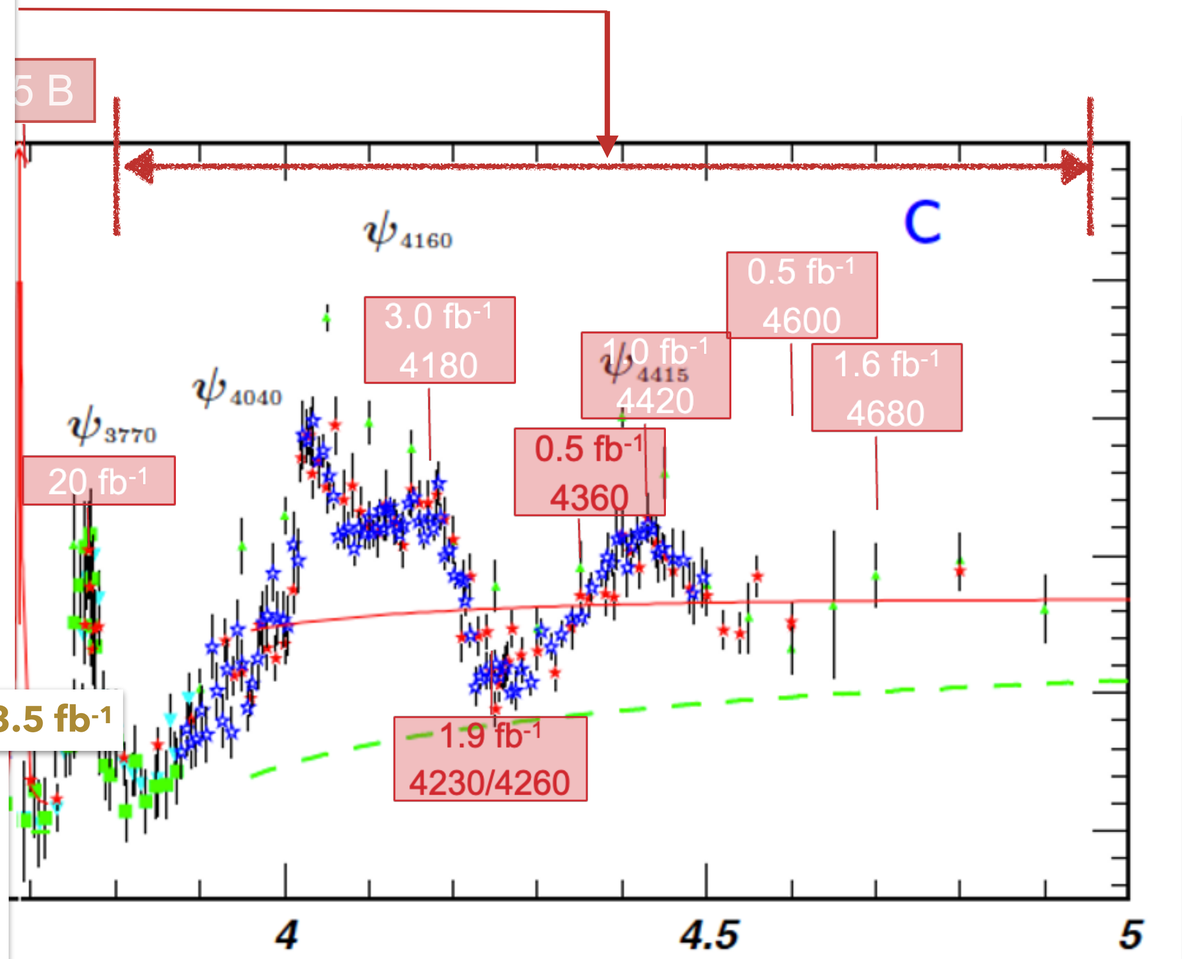
BESIII Data Samples



BESIII Data Samples



+ Samll scan samples, 151 points from 3.8 to 4.6 GeV, ~3.5 fb^{-1}



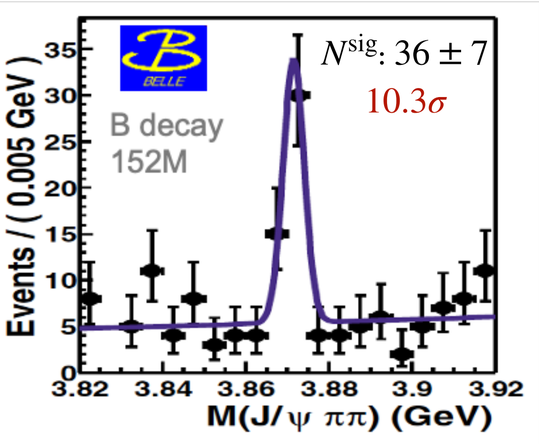
Selected Results

- Properties of C-even states
  - Production and decay properties of $X(3872)$ *PRD110, 012006 (2024), PRD 110, L031103 (2024)* *PRD 113, L071102 (2026)*
  - Search for 1^{-+} states: $\eta\eta_c$, $\eta'\eta_c$, $D_sD_{s1}(2536)$ *PRD111, 112007 (2025), PRD112, 032002 (2025)*
- Vector states from exclusive cross section measurements
  - Hidden charm process: $l.h.+c\bar{c}$ ***details in Maoqiang's Talk***
  - Open charm process: charmed meson (+ $l.h.$s)
- News of Z_c states:
  - $Z_c(3900)$ production from $e^+e^-\to\pi^+\pi^-J/\psi$ *PRD112, 092013 (2025)*
  - Multi-channel joint analysis for $Z_c(4020)$ *arXiv: 2603.05564*
  - Z_{cs} in KJ/ψ, $K\psi(2S)$, and $K\pi J/\psi$ *PRL 131, 211902 (2023), JHEP 02, 120 (2025), arXiv:2407.20009, arXiv: 2510.13274(accepted by JHEP)* ***Not in this talk***
- Bound state around $\Lambda_c\bar{\Sigma}_c$ threshould *PRD112, 114044 (2025)*

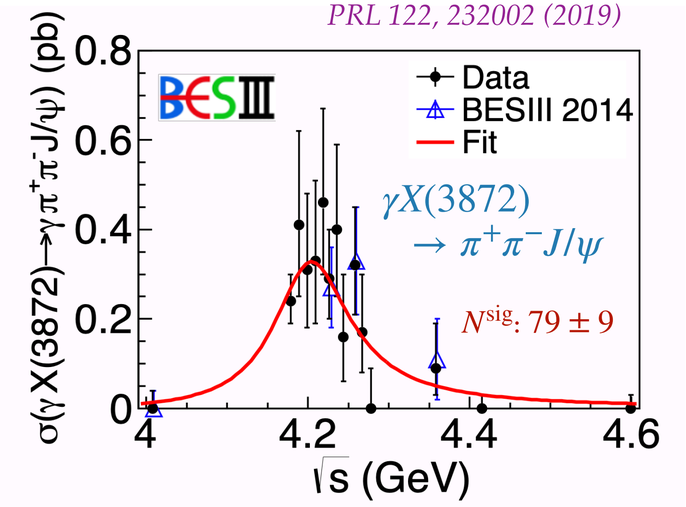
$X(3872)$ [$\chi_{c1}(3872)$]

- 2003, observed by Belle experiment in $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$ process
- Mass: (3871.64 ± 0.06) MeV, very close to $D\bar{D}^{*}$ threshold
  $[E_b = -0.05 \pm 0.12$ MeV$]$
- BW width: (1.19 ± 0.21) MeV
- Production: B/B_s decays, Λ_b decays, $p\bar{p}/pp$ collision, $PbPb$ collision, $e^{+}e^{-}$ radiative/hadronic transition, $\gamma\gamma^{*}$ process

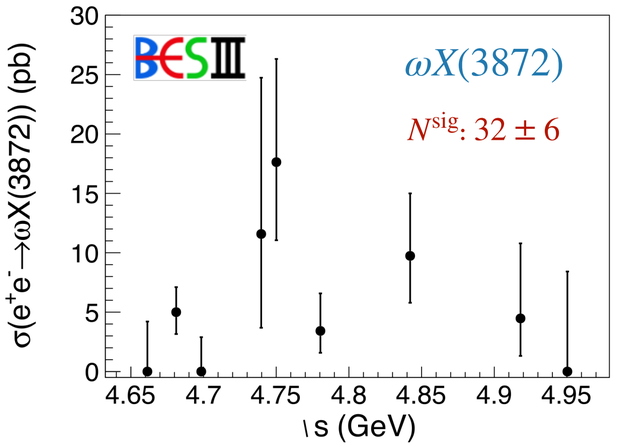
PRL 91, 262001 (2003)



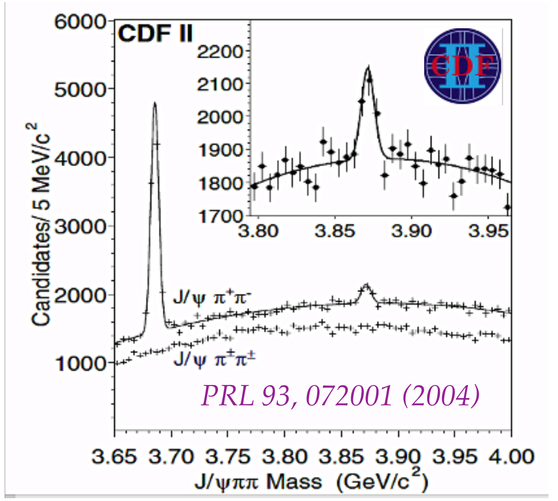
PRL 122, 232002 (2019)



PRL 130, 151904 (2023), PRD 110, 012006 (2024)

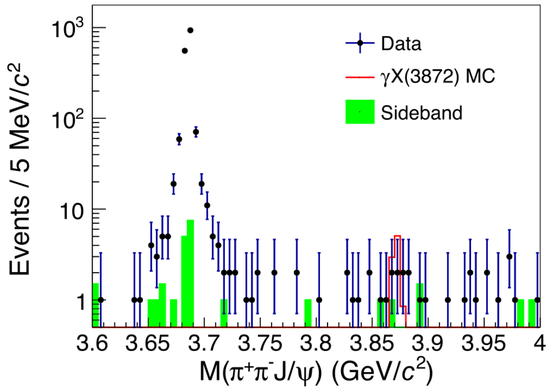


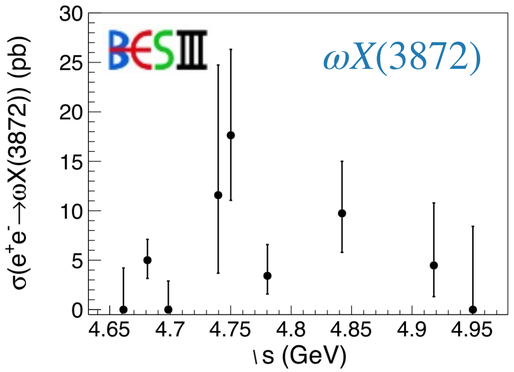
PRL 93, 072001 (2004)

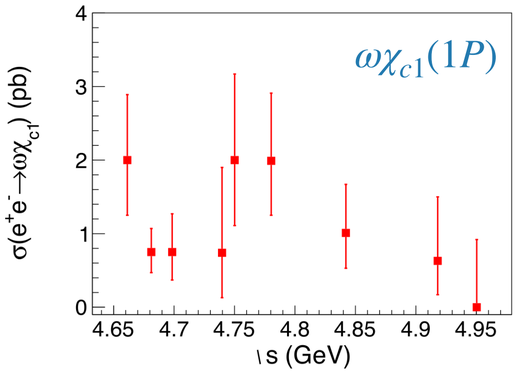


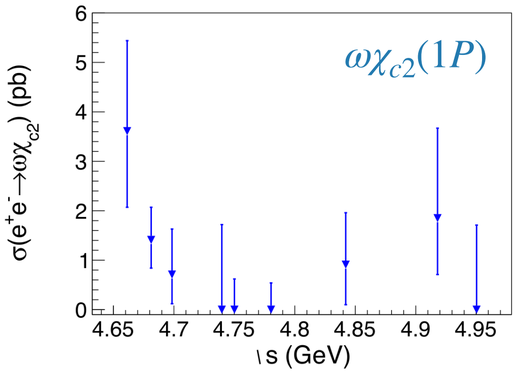
Production of $X(3872)$

- Nature of $X(3872)$ still under debate: molecule, tetraquark state, or a mixture with a sizable $\chi_{c1}(2P)$ component
- Using data samples $\sqrt{s}$ from 4.66 to 4.95 GeV, two production ratios are studied
  - $R = \dfrac{\sigma[e^+e^- \to \gamma X(3872)]}{\sigma[e^+e^- \to \omega X(3872)]} < 0.23$ at 90% C. L. *PRD 110, 012006 (2024)*
  - $R_{1,2} = \dfrac{\sigma[e^+e^- \to \omega X(3872)]}{\sigma[e^+e^- \to \omega\chi_{c1,2}(1P)]}$: $R_1 = 5.2 \pm 1.0 \pm 1.9$; $R_2 = 5.5 \pm 1.1 \pm 2.4$









- No obvious $e^+e^- \to \phi X(3872)$ signal at 4.914 and 4.946 GeV, upper limits of the cross section at 90% C.L. are 0.85 and 0.96 pb *PRD 110, L031103 (2024)*

X(3872) Decays

Mode	Ratio to $X(3872) \to \pi^+\pi^- J/\psi$	UL	Reference
$\gamma J/\psi$	0.79 ± 0.28 3.5σ	$\cdots$	PRL124,242001(2020)
$\gamma\psi(2S)$	-0.03 ± 0.22	< 0.42	
$\gamma D^0\bar{D}^0$	0.54 ± 0.48	< 1.58	
$\pi^0 D^0\bar{D}^0$	-0.13 ± 0.47	< 1.16	
$D^{*0}\bar{D}^0 + c.c.$	11.77 ± 3.09	$\cdots$	
γD^+D^-	$0.00^{+0.48}_{-0.00}$	< 0.99	
$\omega J/\psi$	$1.6^{+0.4}_{-0.3} \pm 0.2$	$\cdots$	PRL122,232002(2019)
$\pi^0\chi_{c1}$	$0.88^{+0.33}_{-0.27} \pm 0.10$	$\cdots$	PRL122,202001(2019)
$\pi^0\chi_{c2}$	$0.40^{+0.37}_{-0.27} \pm 0.04$	< 1.1	
$\pi^0\chi_{c0}$	$\cdots$	< 3.6	PRD105,072009(2022)
$\pi^+\pi^-\chi_{c0}$	$\cdots$	< 0.56	
$\pi^0\pi^0\chi_{c0}$	$\cdots$	< 1.7	
$\pi^0\pi^0\chi_{c1}$	$\cdots$	< 1.1	PRD110,072015(2024)
$\pi^0\pi^0\chi_{c2}$	$\cdots$	< 0.5	
$\pi^+\pi^-\chi_{c1}$	$\cdots$	< 0.18	PRD109,L071101(2024)
$\gamma\psi_2(3823)[\to \gamma\chi_{c1}]$	$\cdots$	< 0.075	PRD110,012012(2024)
$\pi^+\pi^-\eta$	$\cdots$	< 0.12	PRD109,L011102(2024)
$K^0_S K^\pm\pi^\mp$	$\cdots$	< 0.07	PRD113,L071102(2026)
K^*K	$\cdots$	< 0.10	
$\gamma J/\psi$	$0.38 \pm 0.20 \pm 0.01$ 2.3σ	< 0.83	PRD110,012006(2024)

$e^+e^- \to \gamma X(3872)$

$\Rightarrow e^+e^- \to \omega X(3872)$

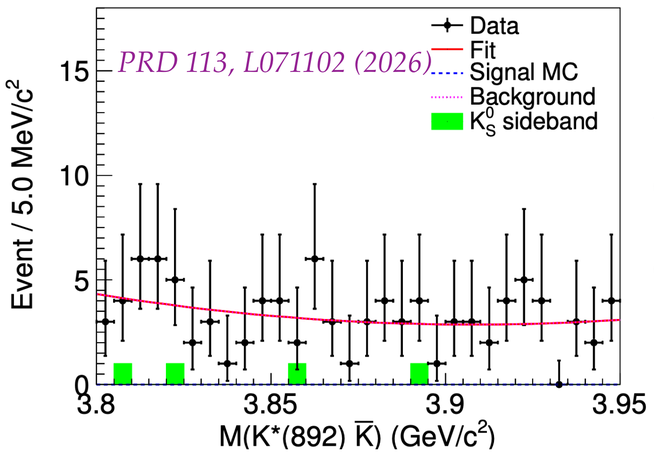
X(3872) Decays

Mode	Ratio to $X(3872) \to \pi^+\pi^- J/\psi$	UL
$\gamma J/\psi$	0.79 ± 0.28 3.5σ	$\cdots$
$\gamma\psi(2S)$	-0.03 ± 0.22	< 0.42
$\gamma D^0\bar{D}^0$	0.54 ± 0.48	< 1.58
$\pi^0 D^0\bar{D}^0$	-0.13 ± 0.47	< 1.16
$D^{*0}\bar{D}^0 + c.c.$	11.77 ± 3.09	$\cdots$
γD^+D^-	$0.00^{+0.48}_{-0.00}$	< 0.99
$\omega J/\psi$	$1.6^{+0.4}_{-0.3} \pm 0.2$	$\cdots$
$\pi^0\chi_{c1}$	$0.88^{+0.33}_{-0.27} \pm 0.10$	$\cdots$
$\pi^0\chi_{c2}$	$0.40^{+0.37}_{-0.27} \pm 0.04$	< 1.1
$\pi^0\chi_{c0}$	$\cdots$	< 3.6
$\pi^+\pi^-\chi_{c0}$	$\cdots$	< 0.56
$\pi^0\pi^0\chi_{c0}$	$\cdots$	< 1.7
$\pi^0\pi^0\chi_{c1}$	$\cdots$	< 1.1
$\pi^0\pi^0\chi_{c2}$	$\cdots$	< 0.5
$\pi^+\pi^-\chi_{c1}$	$\cdots$	< 0.18
$\gamma\psi_2(3823)[\to \gamma\chi_{c1}]$	$\cdots$	< 0.075
$\pi^+\pi^-\eta$	$\cdots$	< 0.12
$K^0_S K^\pm\pi^\mp$	$\cdots$	< 0.07
K^*K	$\cdots$	< 0.10
$\gamma J/\psi$	$0.38 \pm 0.20 \pm 0.01$ 2.3σ	< 0.83

$X(3872)$ Charmless Decay

A good platform to study the nature of $X(3872)$, *PRD106,074015(2022)*
branching fractions predicted based on a molecular picture

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

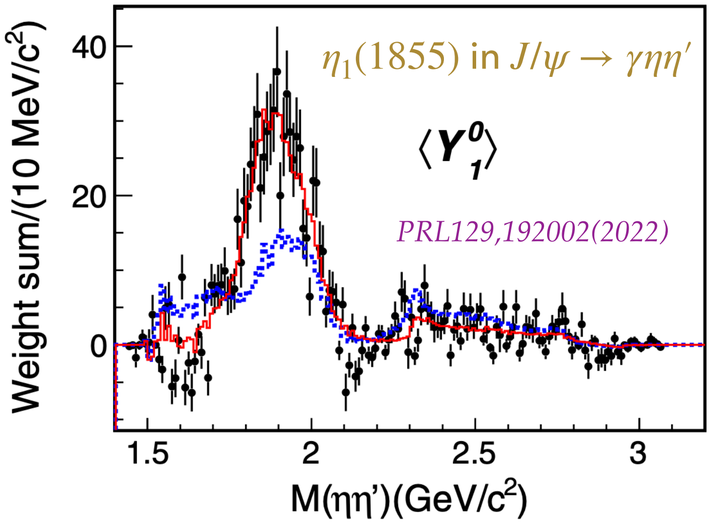


$B[X(3872) \to K^*K] < 0.60 \times 10^{-2}$

- Same order as $\chi_{c1}(1P)$ decays
- Falls within the lower region of theoretical predicton ranges

Search for 1^{-+} States

- $\eta_1(1855)$ observed in light hadron sector



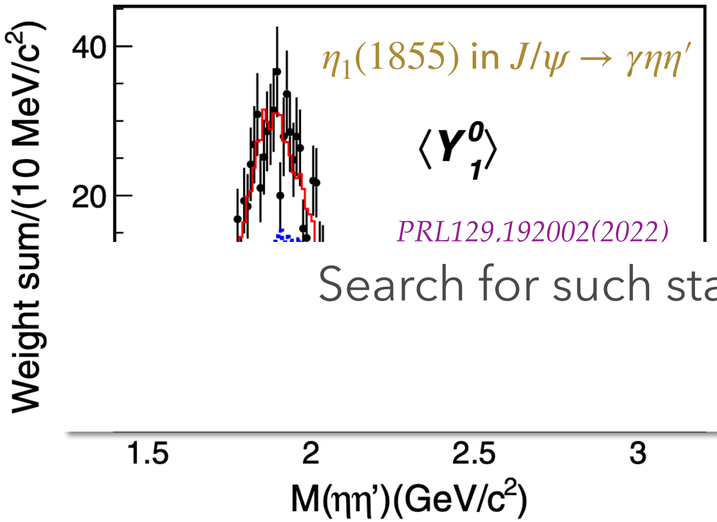
	Widths (MeV)					
	$1^{--}Y(4260)$			$1^{-+}\eta_{c1}(4240)$		
Mode	$\Lambda_1=1.5$	$\Lambda_1=2.0$	$\Lambda_1=2.4$	$\Lambda_1=1.5$	$\Lambda_1=2.0$	$\Lambda_1=2.4$
$\pi\pi$	0	0	0	0.4	3.7	9.6
$D^*\bar{D}^*$	18.1	26.7	31.3	20.2	29.4	33.5
πZ_c	~0	~0	~0	~0	~0	~0
$\pi\rho$	0.1	0.8	2.3	0.06	0.4	1.3
$D\bar{D}$	0.02	0.02	0.02	0.02	0.02	0.02
$\eta\eta_c$	0	0	0	3.9	13.9	22.7
$\eta\chi_{c1}$	0	0	0	4.1	11.7	17.4
ηh_c	1.3	3.9	5.8	0	0	0
$\sigma\chi_{c0}$	0	0	0	0.4	1.0	1.3
$\eta J/\psi$	0.4	1.4	2.6	0	0	0
$\sigma J/\psi$	0.03	0.1	0.2	0	0	0
$\omega\sigma$	0.04	0.3	0.8	0	0	0
$\omega J/\psi$	0	0	0	0.003	0.01	0.02
$\omega\chi_{c0}$	0.03	0.09	0.1	0	0	0
$D\bar{D}^*$	0.04	0.07	0.08	0.04	0.06	0.08
$D\bar{D}^*\pi$	1.9	1.9	1.9	3.0	3.0	3.0
Total	21.9	35.3	45.1	32.1	63.2	88.9

- In a molecular picture, several 1^{-+} states were predicted, with masses close to hadron pair thresholds *PRD89,114013(2014)* *PRD101,076003(2020)*
- In LQCD calculations, 1^{-+} hybrid states with mass around 4.13 GeV and 4.33 GeV, decaying donimantly to open charm modes: $D_sD_s^*, D_1\bar{D}, D^*\bar{D}, D^*\bar{D}^*$ *PRD109,094513(2024)*

JHEP07(2012)126, JHEP12(2016)089,PRD102,014023 (2020)

Search for 1^{-+} States

- $\eta_1(1855)$ observed in light hadron sector

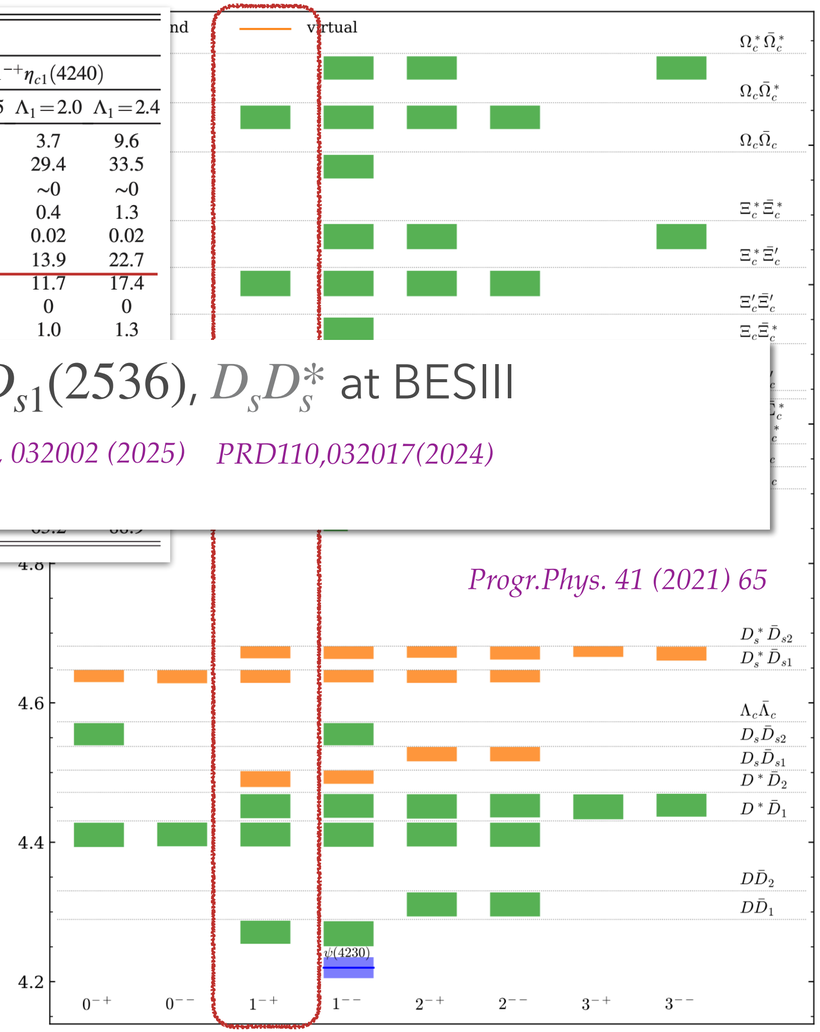


PRL129.192002(2022)

	Widths (MeV)					
	$1^{--}Y(4260)$			$1^{-+}\eta_{c1}(4240)$		
Mode	$\Lambda_1=1.5$	$\Lambda_1=2.0$	$\Lambda_1=2.4$	$\Lambda_1=1.5$	$\Lambda_1=2.0$	$\Lambda_1=2.4$
$\pi\pi$	0	0	0	0.4	3.7	9.6
$D^*\bar{D}^*$	18.1	26.7	31.3	20.2	29.4	33.5
πZ_c	~0	~0	~0	~0	~0	~0
$\pi\rho$	0.1	0.8	2.3	0.06	0.4	1.3
$D\bar{D}$	0.02	0.02	0.02	0.02	0.02	0.02
$\eta\eta_c$	0	0	0	3.9	13.9	22.7
$\eta\chi_{c1}$	0	0	0	4.1	11.7	17.4
ηh_c	1.3	3.9	5.8	0	0	0
$\sigma\chi_{c0}$	0	0	0	0.4	1.0	1.3

Search for such state in $e^+e^- \to \gamma\eta\eta_c$, $\gamma\eta'\eta_c$, $\gamma D_s D_{s1}(2536)$, $D_s D_s^*$ at BESIII

PRD111, 112007 (2025) *PRD112, 032002 (2025)* *PRD110,032017(2024)*



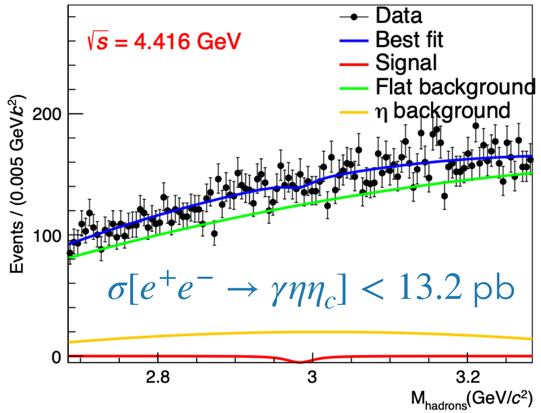
Progr.Phys. 41 (2021) 65

- In a molecular picture, several 1^{-+} states were predicted, with masses close to hadron pair thresholds *PRD89,114013(2014)* *PRD101,076003(2020)*
- In LQCD calculations, 1^{-+} hybrid states with mass around 4.13 GeV and 4.33 GeV, decaying donimantly to open charm modes: $D_s D_s^*, D_1\bar{D}, D^*\bar{D}, D^*\bar{D}^*$ *PRD109,094513(2024)*

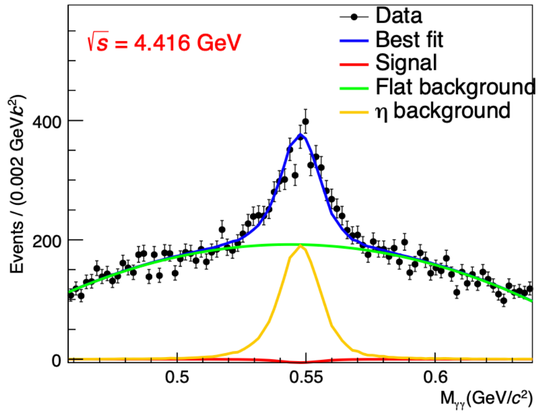
JHEP07(2012)126, JHEP12(2016)089,PRD102,014023 (2020)

Search for 1^{-+} States

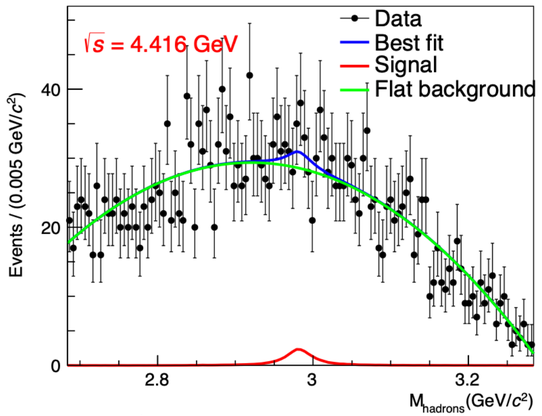
$e^+e^- \to \gamma\eta\eta_c$ and $\gamma\eta'\eta_c$, 4.26 to 4.68 GeV

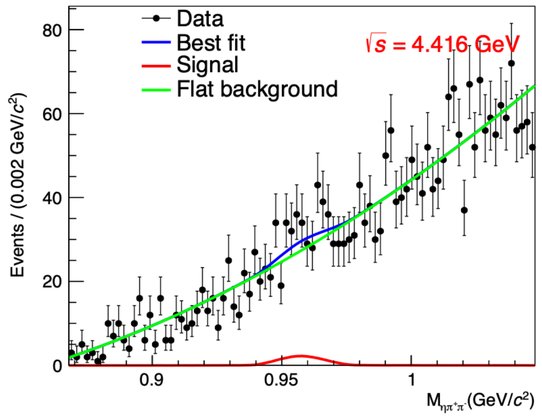


$\sigma[e^+e^- \to \gamma\eta\eta_c] < 13.2$ pb



PRD111, 112007 (2025)

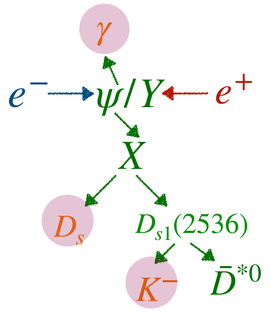


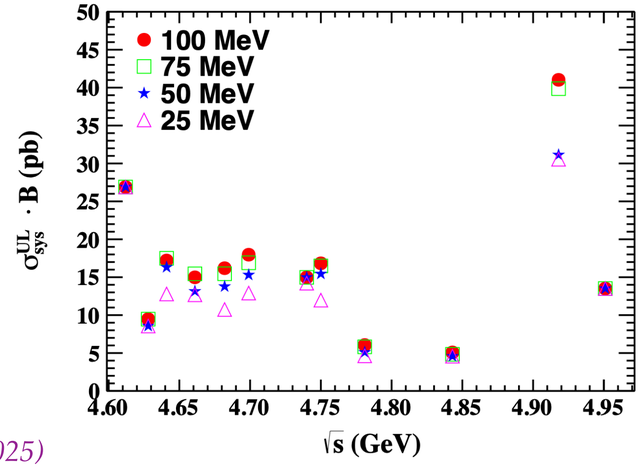


$\sigma[e^+e^- \to \gamma\eta'\eta_c] < 41.9$ pb

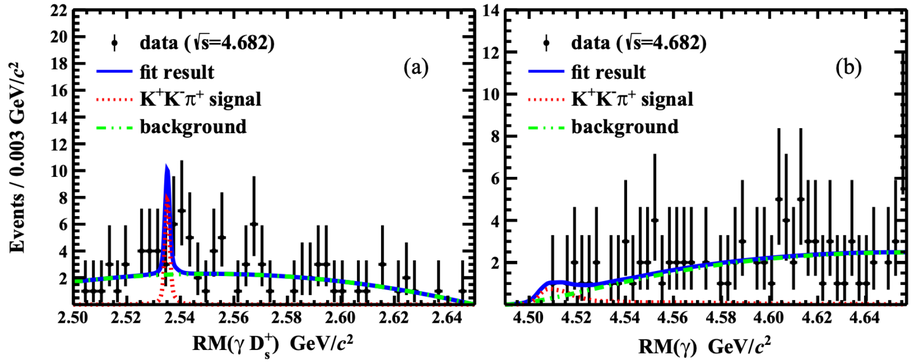
$e^+e^- \to \gamma X \to \gamma D_s D_{s1}(2536)$

4.61 to 4.95 GeV



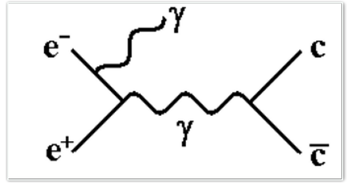


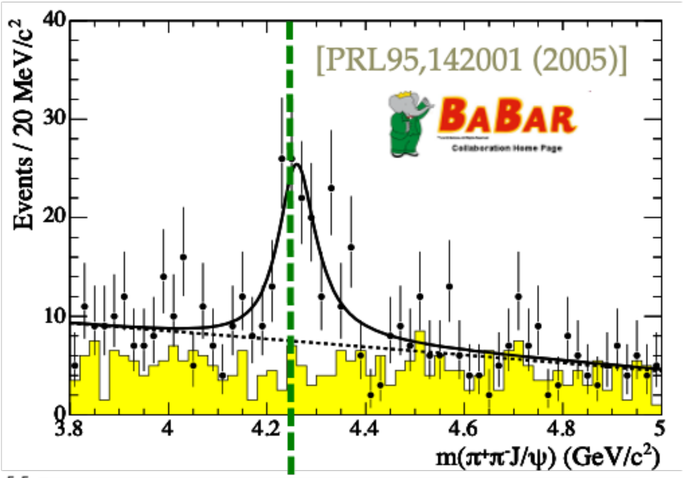
PRD112, 032002 (2025)



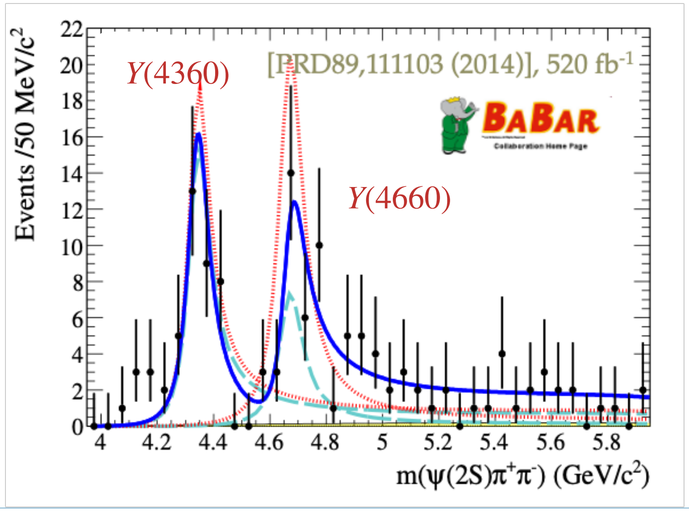
Y States [ψ(mass)]

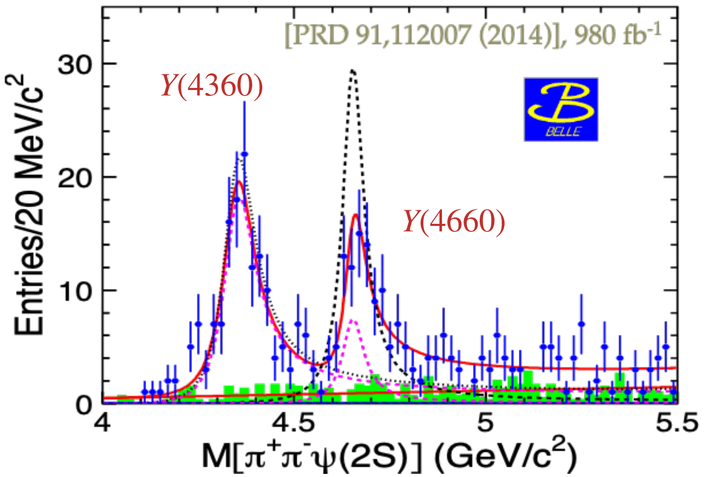
- $Y(4260)$, discovered in ISR process at BaBar, $e^+e^- \to \gamma_{\rm ISR}\pi^+\pi^- J/\psi$
  - Confirmed by CLEO and Belle
  - Mass > 4 GeV, above $D\bar{D}$ threshold
  - Not observed in inclusive hadron cross section
  - Not observed in open charm pair cross section

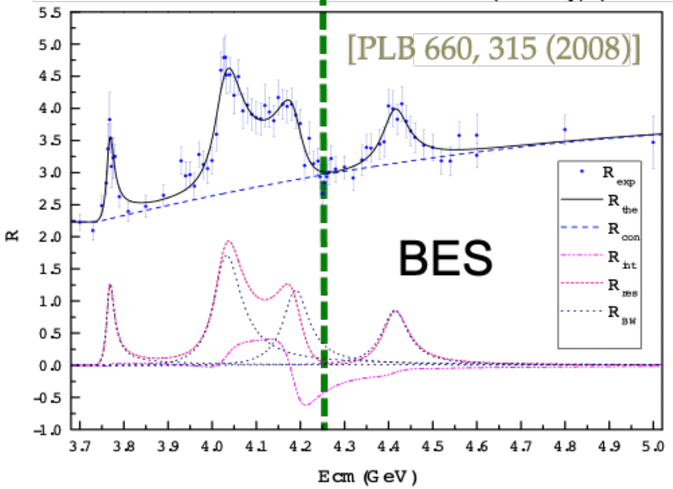




- Later, $Y(4360)$ was reported by BaBar, $Y(4660)$ was discovered at Belle, both in $e^+e^- \to \gamma_{\rm ISR}\pi^+\pi^-\psi(2S)$ process

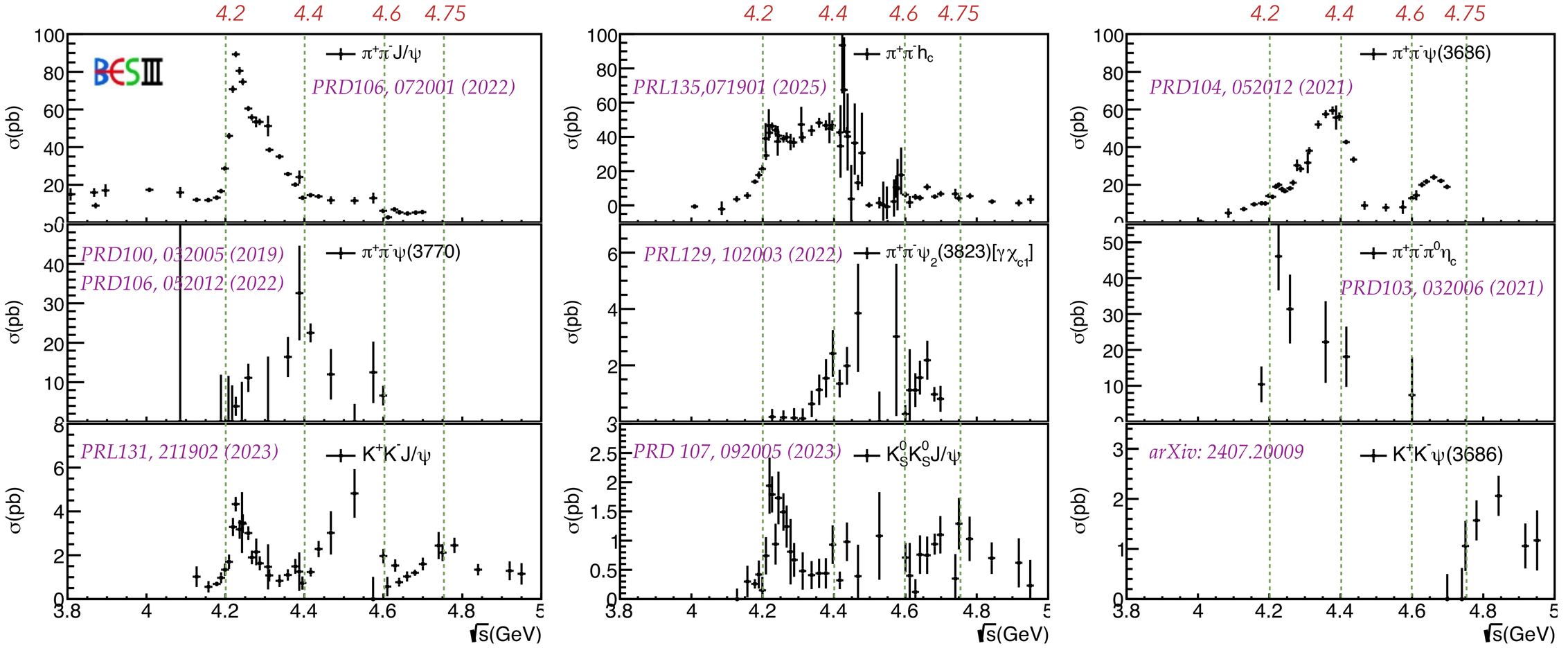






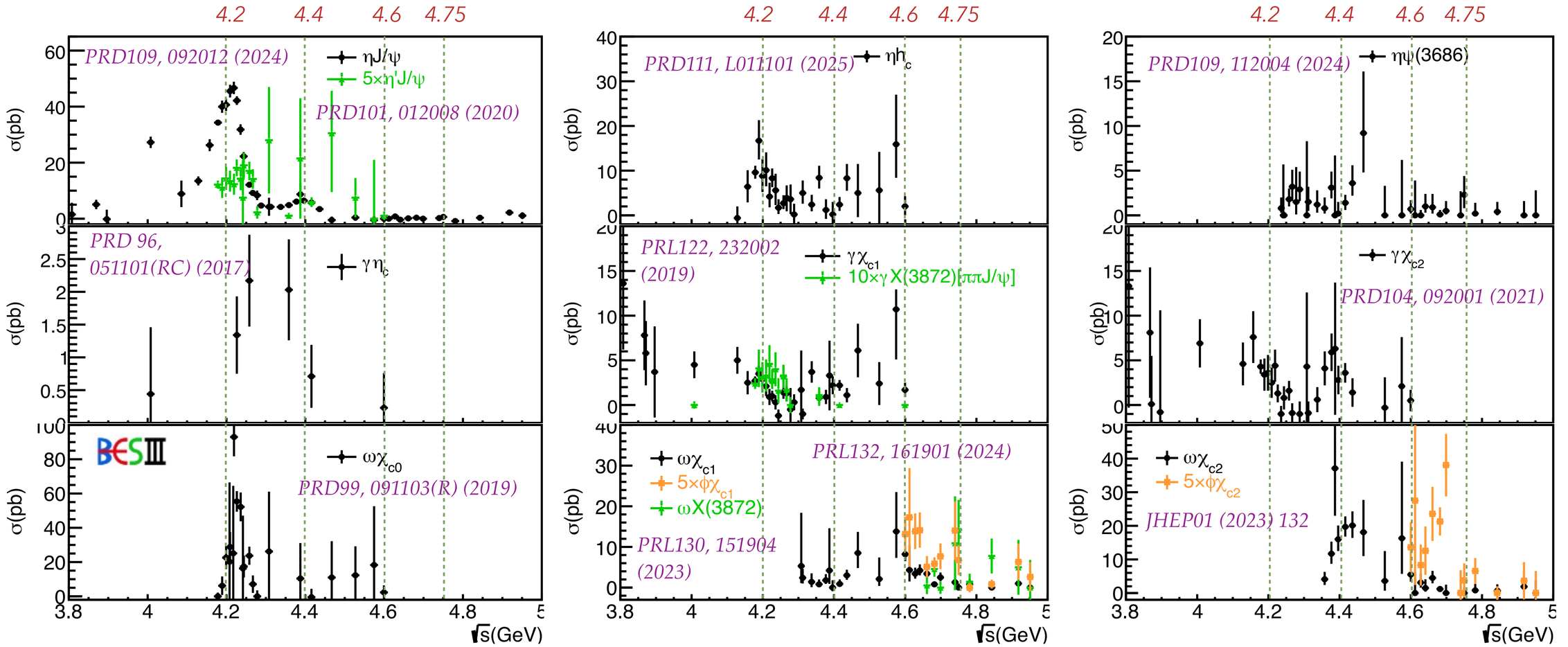
Precise CS Measurements

- Using unique fine scan data samples above 3.8 GeV, cross section measurements of **hidden charm**, open charm, and light hadron processes



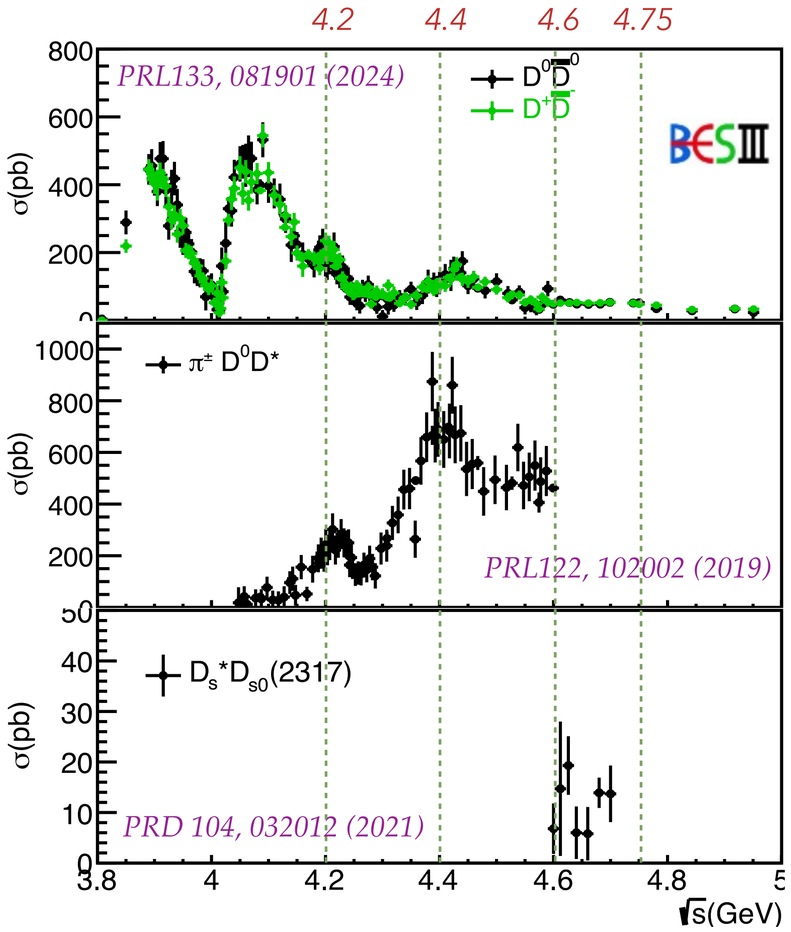
Precise CS Measurements

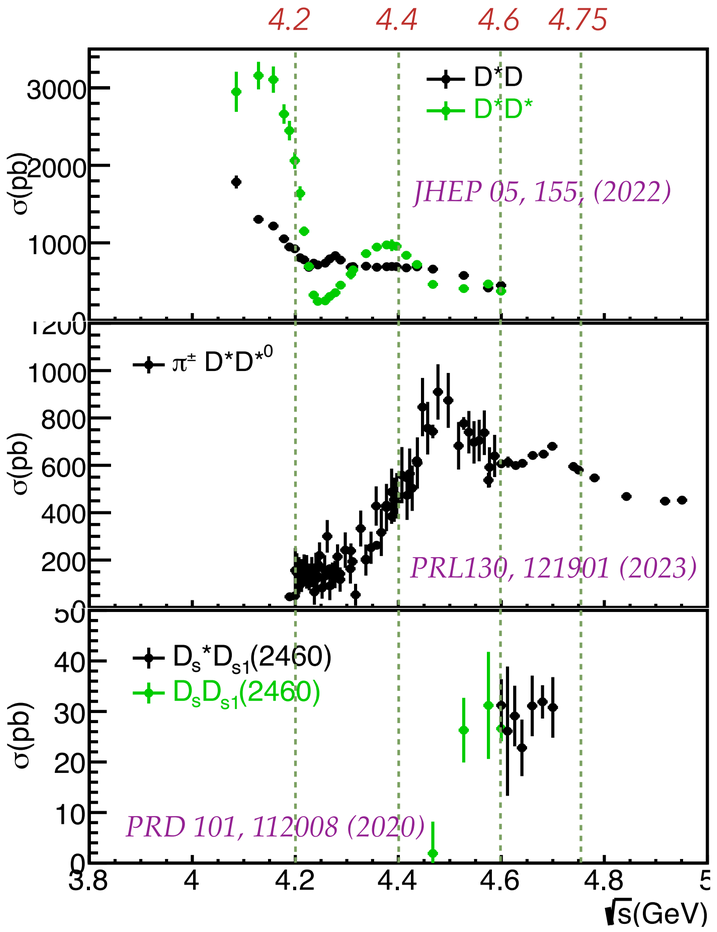
- Using unique fine scan data samples above 3.8 GeV, cross section measurements of **hidden charm**, open charm, and light hadron processes

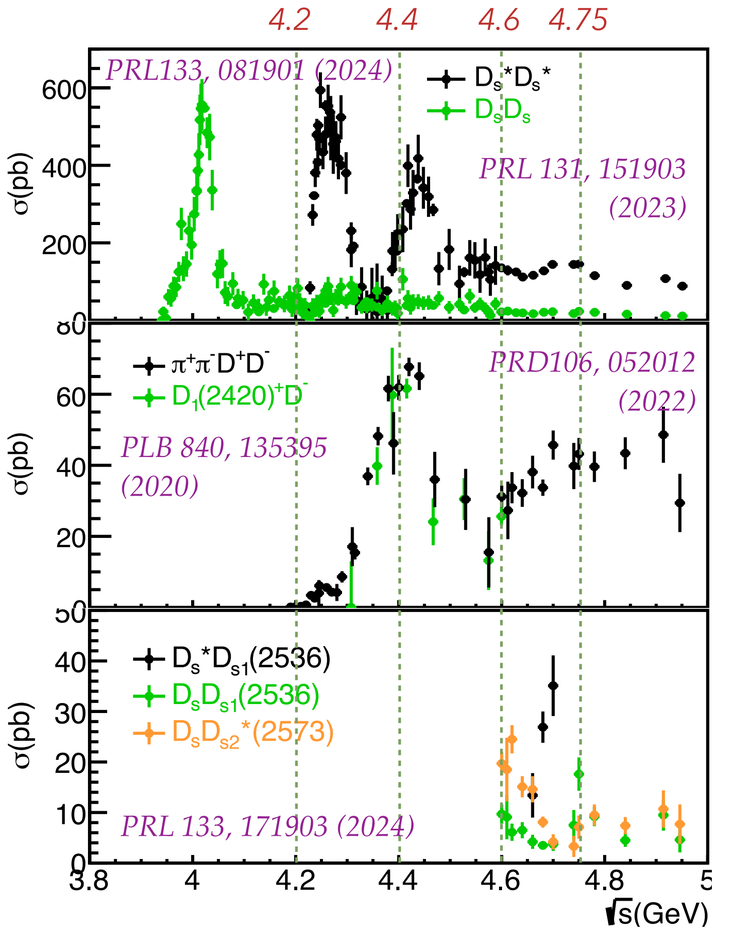


Precise CS Measurements

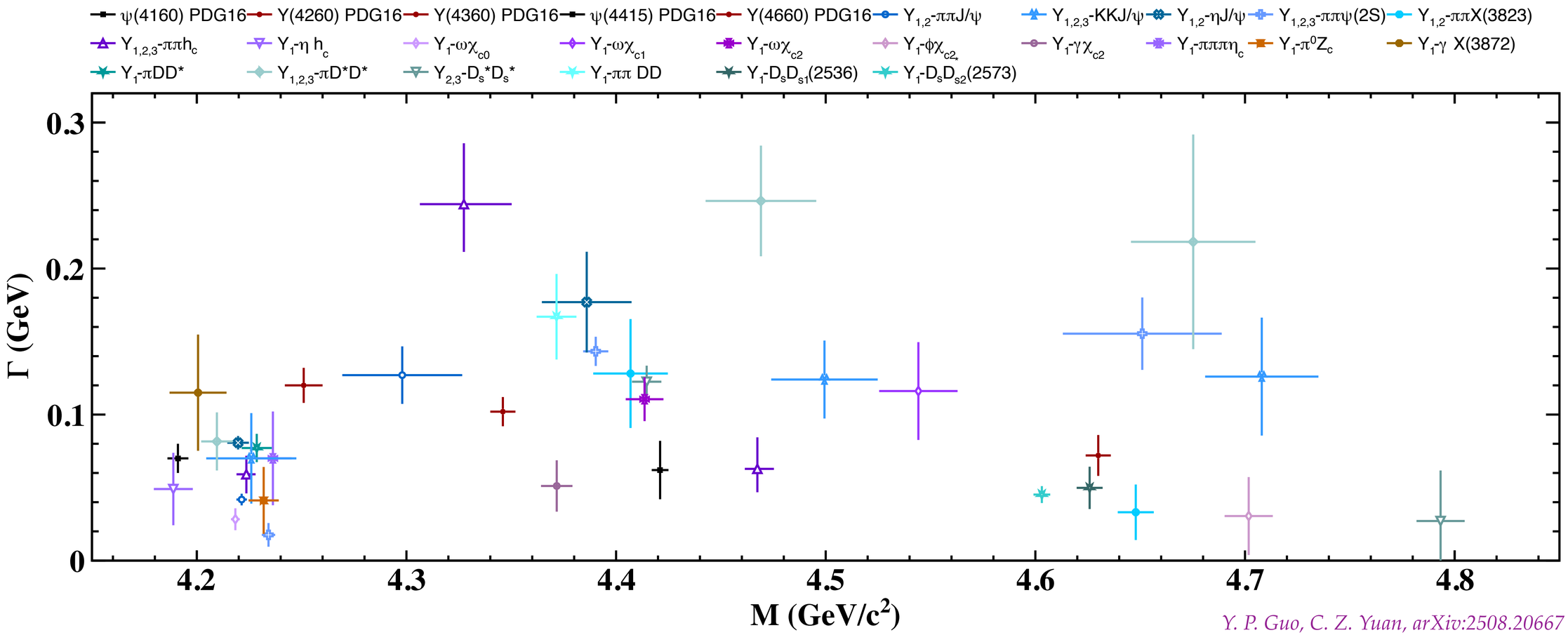
- Using unique fine scan data samples above 3.8 GeV, cross section measurements of hidden charm, **open charm**, and light hadron processes







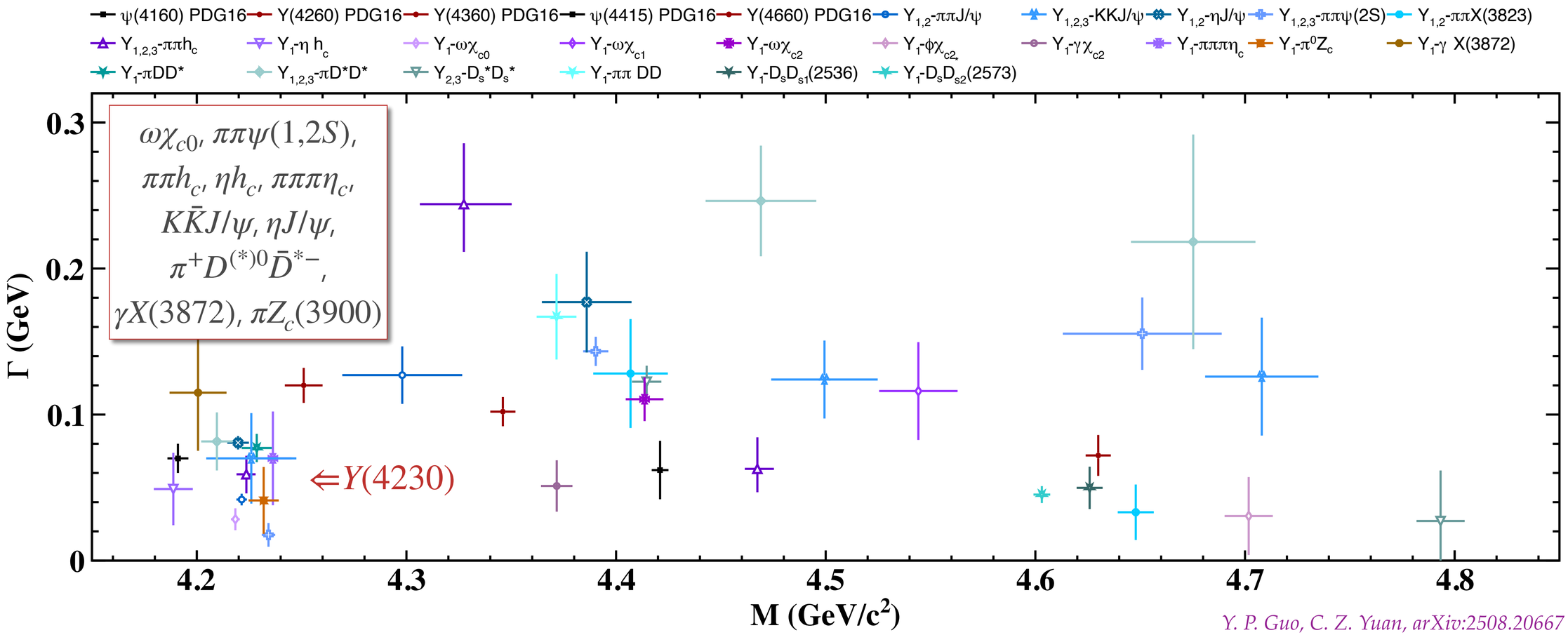
Parameters of Vector States from Single Channel



Y. P. Guo, C. Z. Yuan, arXiv:2508.20667

Typical parameterization of the cross section line shape: $\sigma(s) = |\frac{c}{s^n} + \sum_k BW_k(s)e^{i\phi_k}|^2$

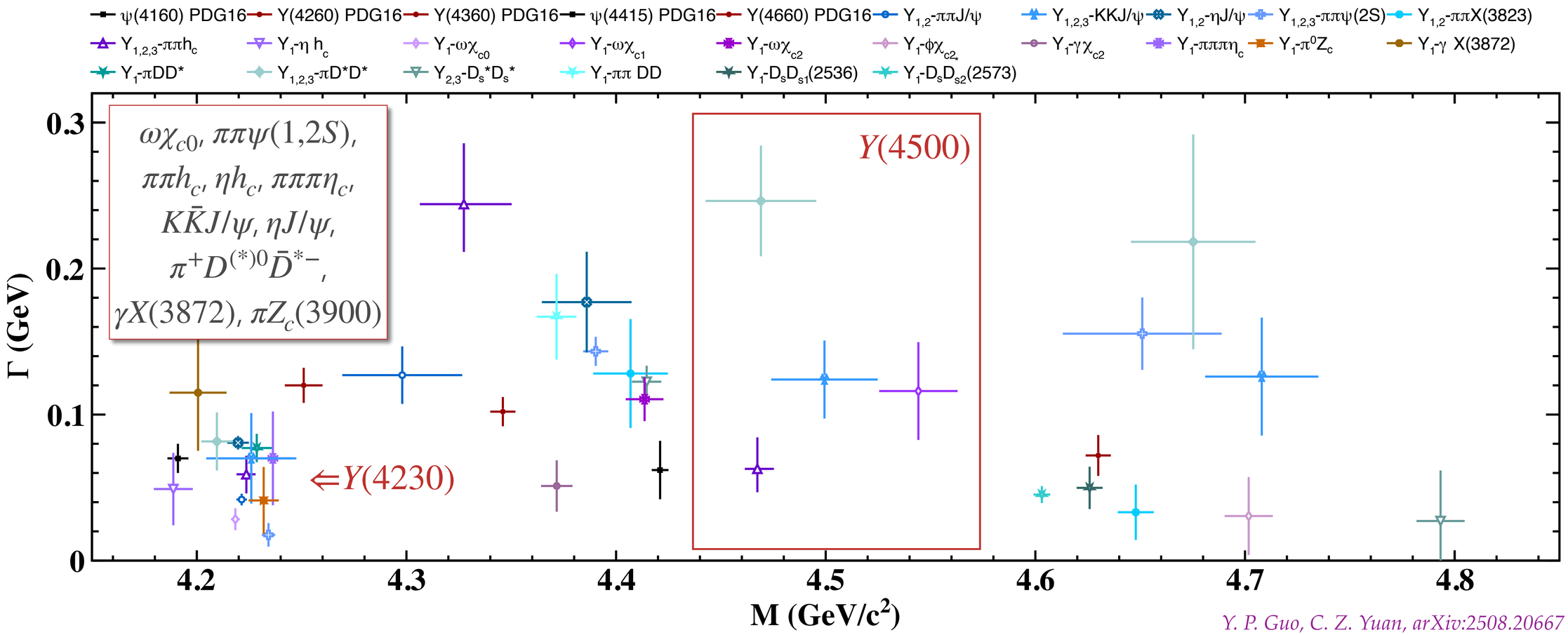
Parameters of Vector States from Single Channel



Y. P. Guo, C. Z. Yuan, arXiv:2508.20667

Typical parameterization of the cross section line shape: $\sigma(s) = |\frac{c}{s^n} + \sum_k BW_k(s)e^{i\phi_k}|^2$

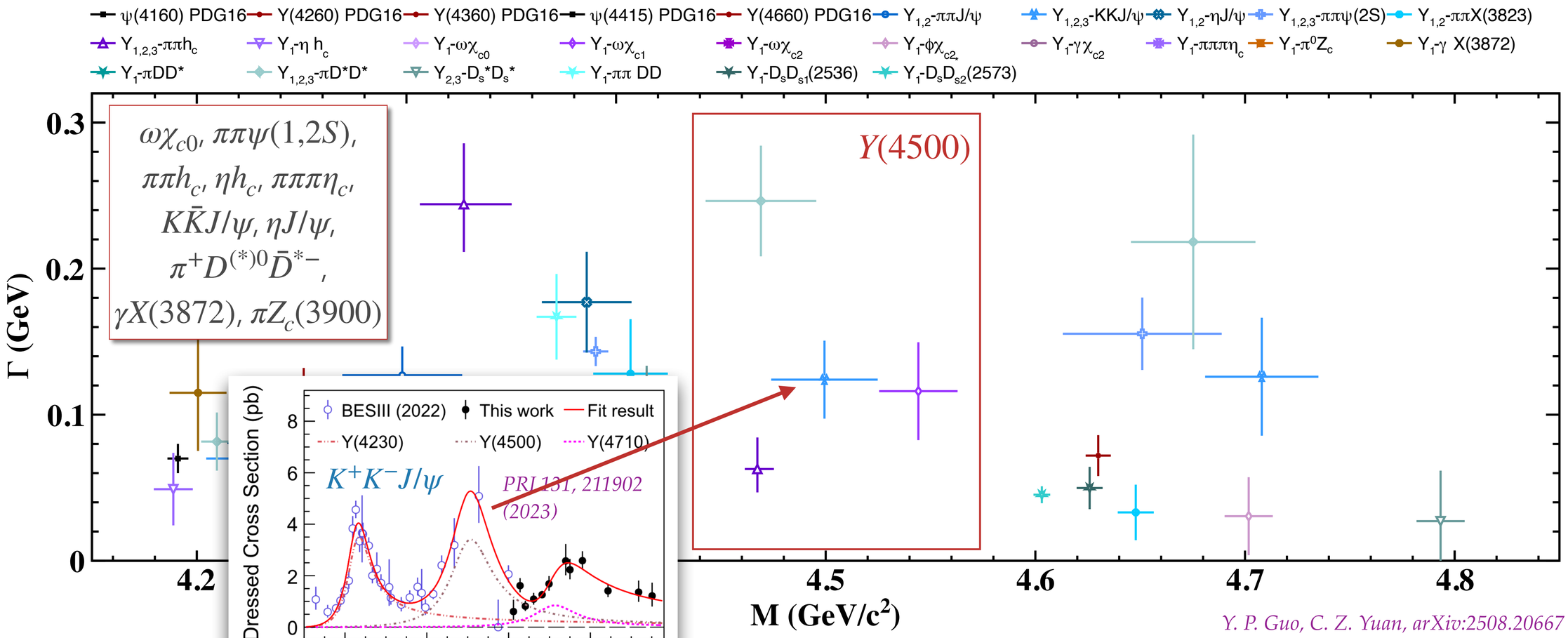
Parameters of Vector States from Single Channel



Y. P. Guo, C. Z. Yuan, arXiv:2508.20667

Typical parameterization of the cross section line shape: $\sigma(s) = |\frac{c}{s^n} + \sum_k BW_k(s)e^{i\phi_k}|^2$

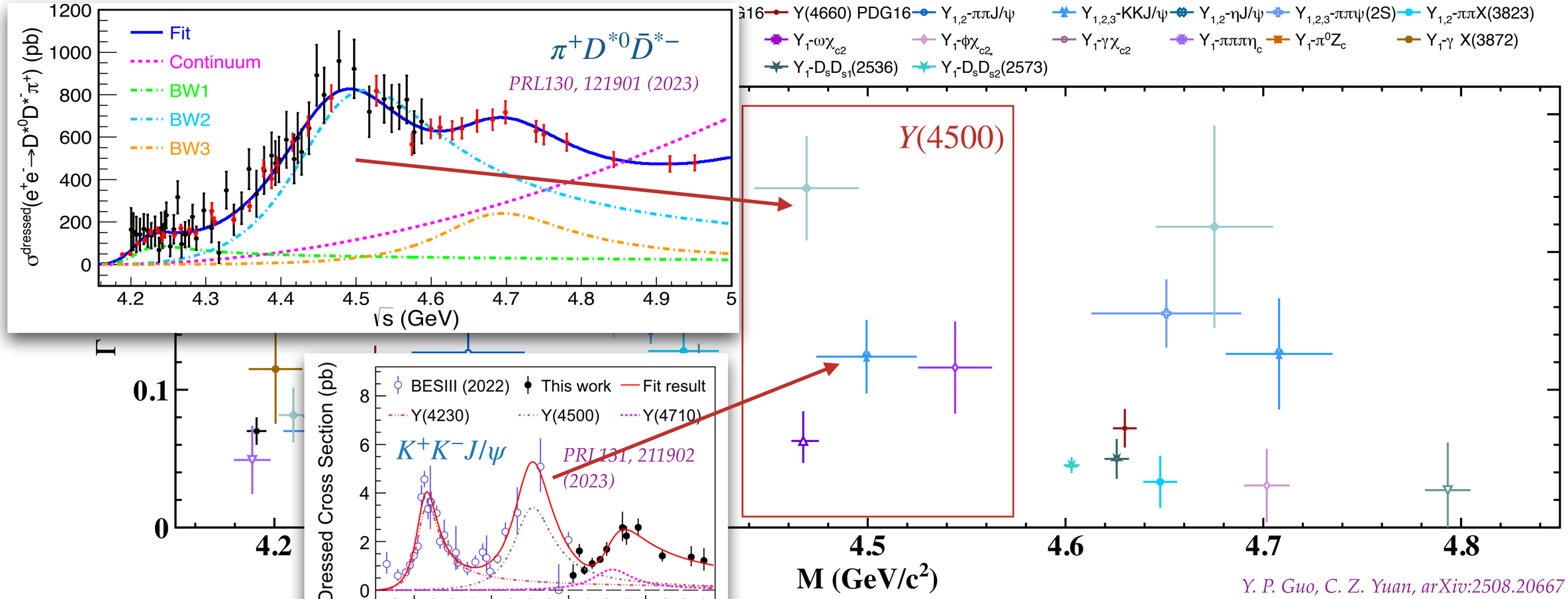
Parameters of Vector States from Single Channel



Y. P. Guo, C. Z. Yuan, arXiv:2508.20667

Typica[illegible] section line shape: $\sigma(s) = |\frac{c}{s^n} + \sum_k BW_k(s)e^{i\phi_k}|^2$

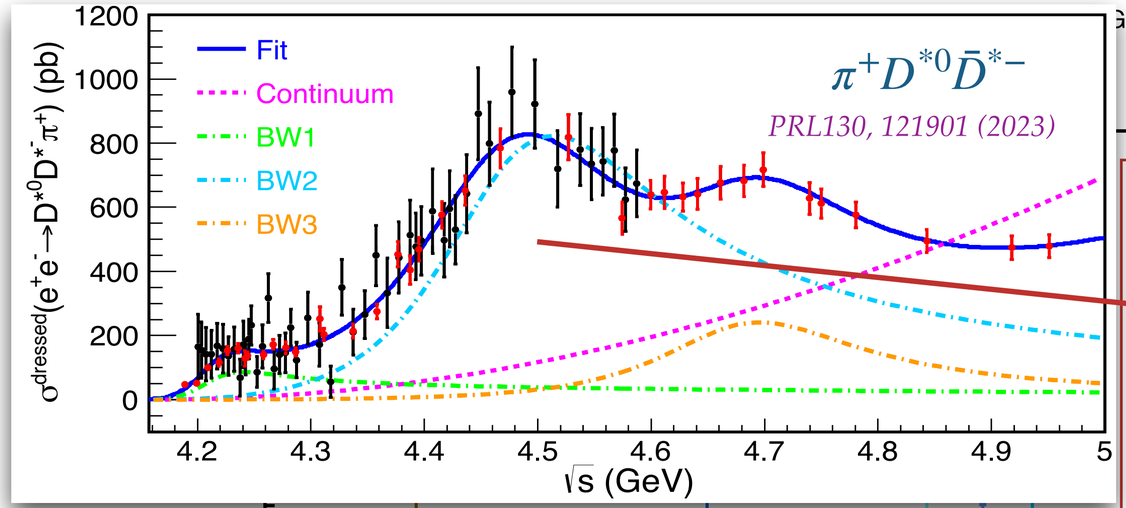
Parameters of Vector States from Single Channel



Y. P. Guo, C. Z. Yuan, arXiv:2508.20667

Typica[illegible] section line shape: $\sigma(s) = |\frac{c}{s^n} + \sum_k BW_k(s)e^{i\phi_k}|^2$

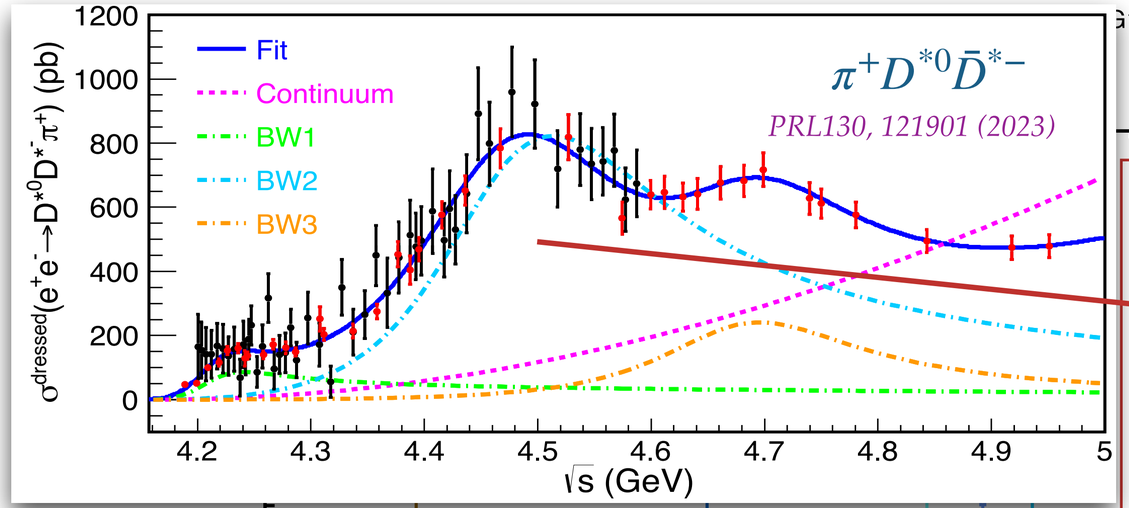
Parameters of Vector States from Single Channel



Y. P. Guo, C. Z. Yuan, arXiv:2508.20667

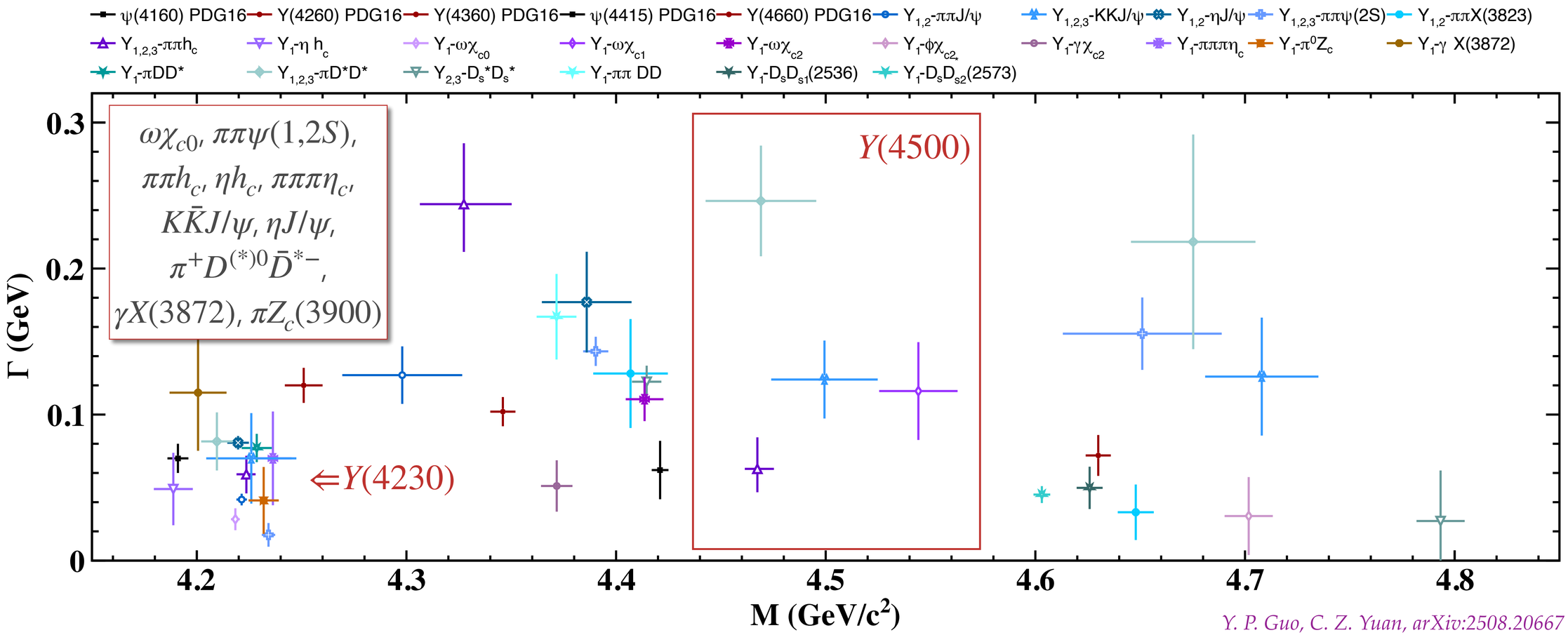
Typical parameterization of the cross section line shape: $\sigma(s) = |\frac{c}{s^n} + \sum_k BW_k(s)e^{i\phi_k}|^2$

Parameters of Vector States from Single Channel



Typica[illegible] section line shape: [illegible]

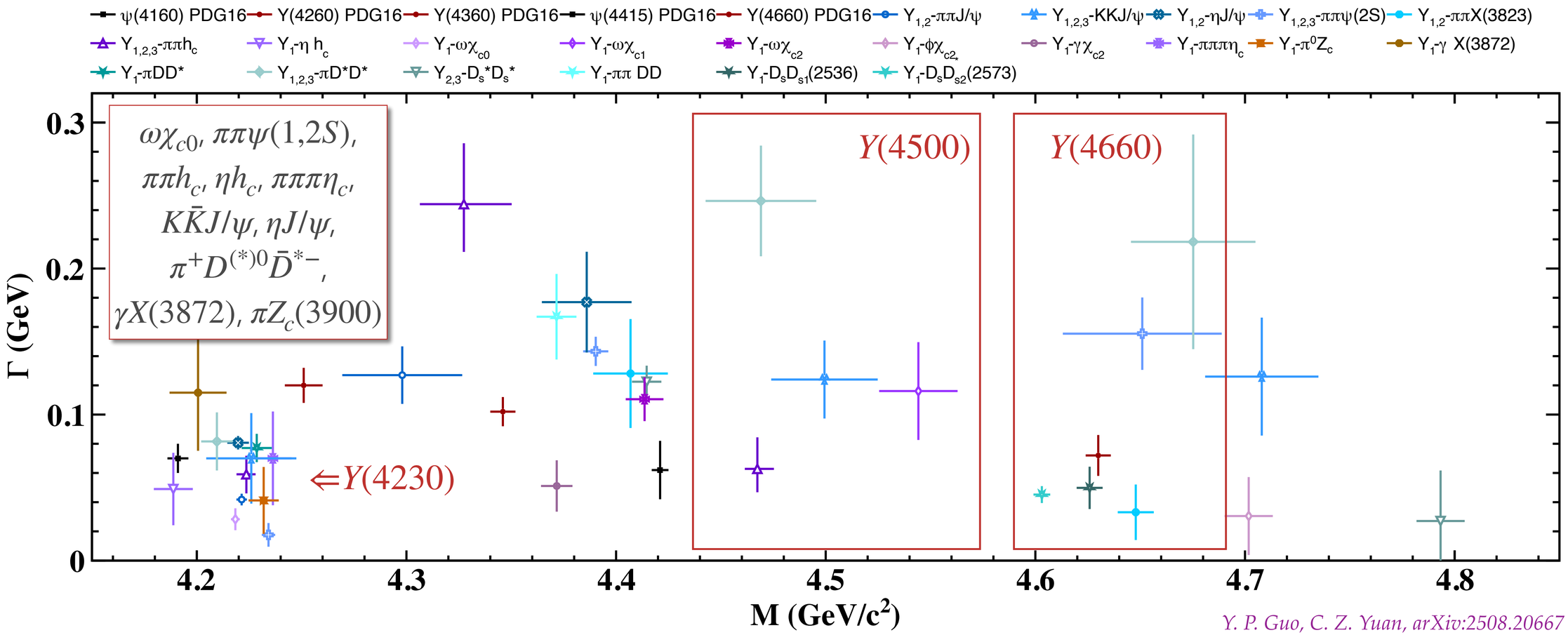
Parameters of Vector States from Single Channel



Y. P. Guo, C. Z. Yuan, arXiv:2508.20667

Typical parameterization of the cross section line shape: $\sigma(s) = |\frac{c}{s^n} + \sum_k BW_k(s)e^{i\phi_k}|^2$

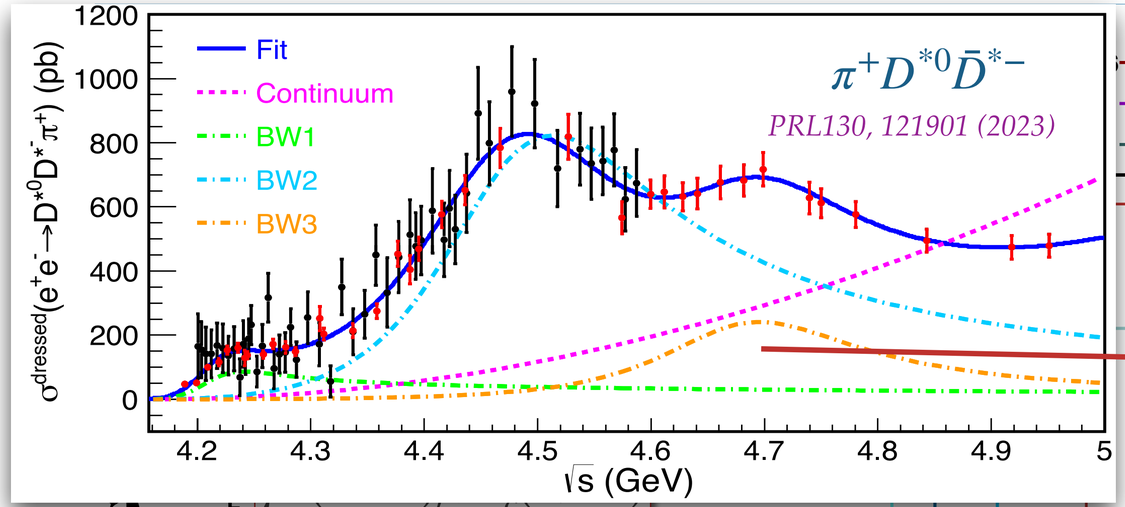
Parameters of Vector States from Single Channel



Y. P. Guo, C. Z. Yuan, arXiv:2508.20667

Typical parameterization of the cross section line shape: $\sigma(s) = |\frac{c}{s^n} + \sum_k BW_k(s)e^{i\phi_k}|^2$

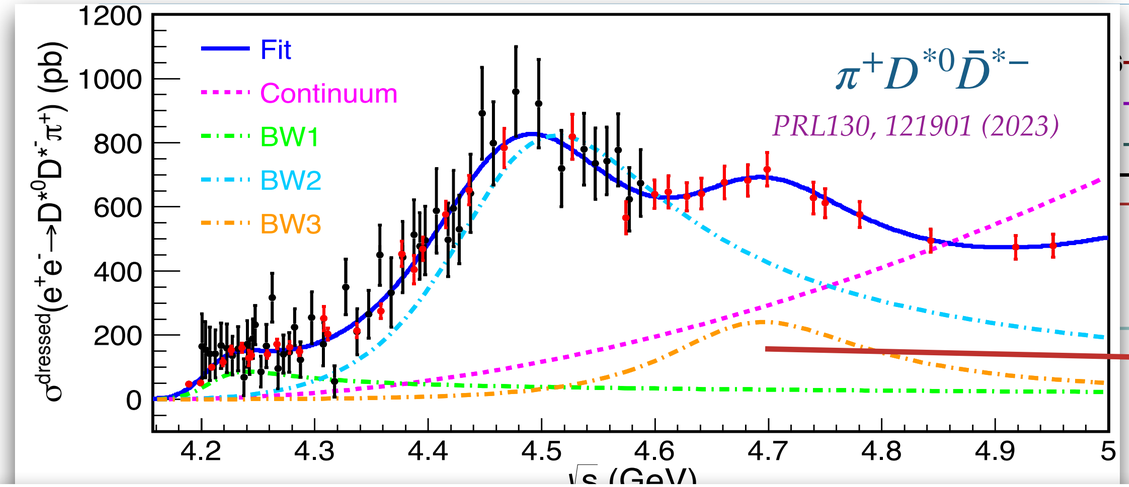
Parameters of Vector States from Single Channel

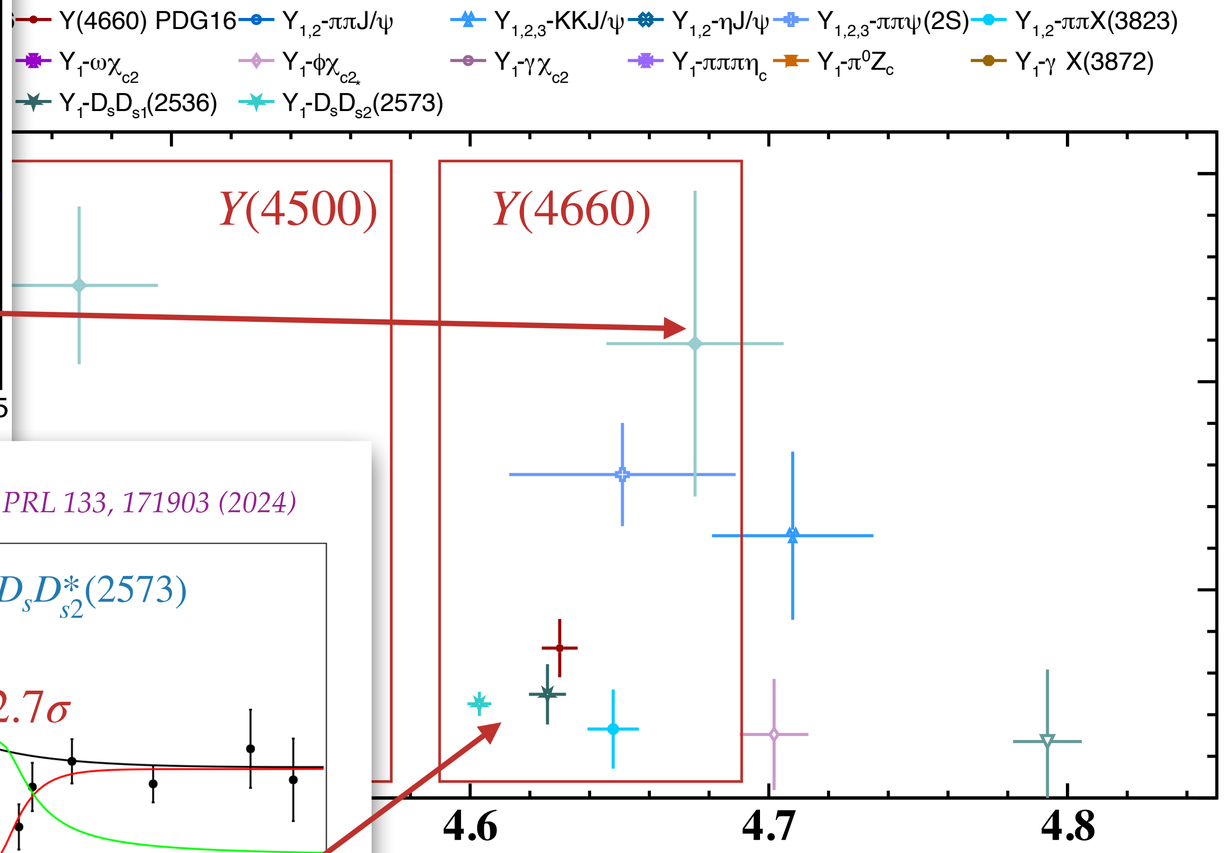


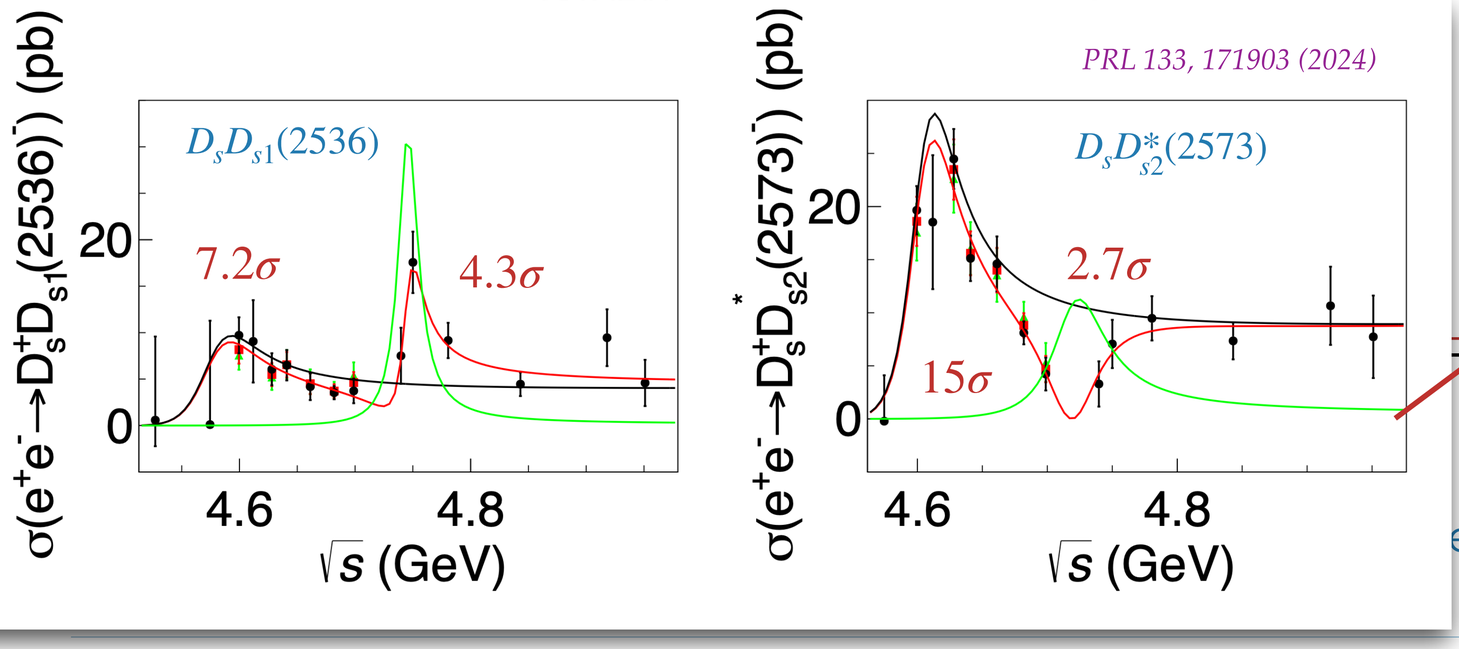
Y. P. Guo, C. Z. Yuan, arXiv:2508.20667

Typical parameterization of the cross section line shape: $\sigma(s) = |\frac{c}{s^n} + \sum_k BW_k(s)e^{i\phi_k}|^2$

Parameters of Vector States from Single Channel



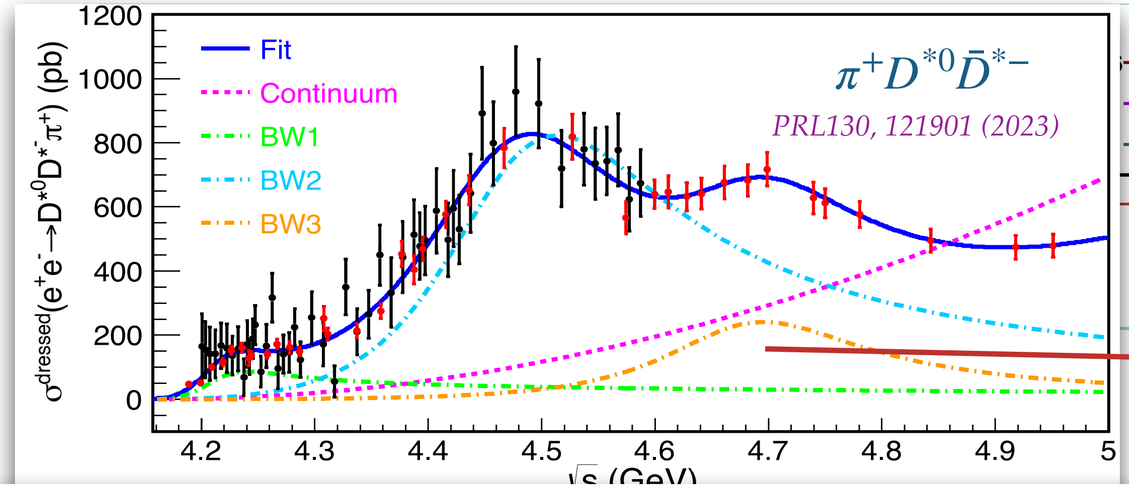


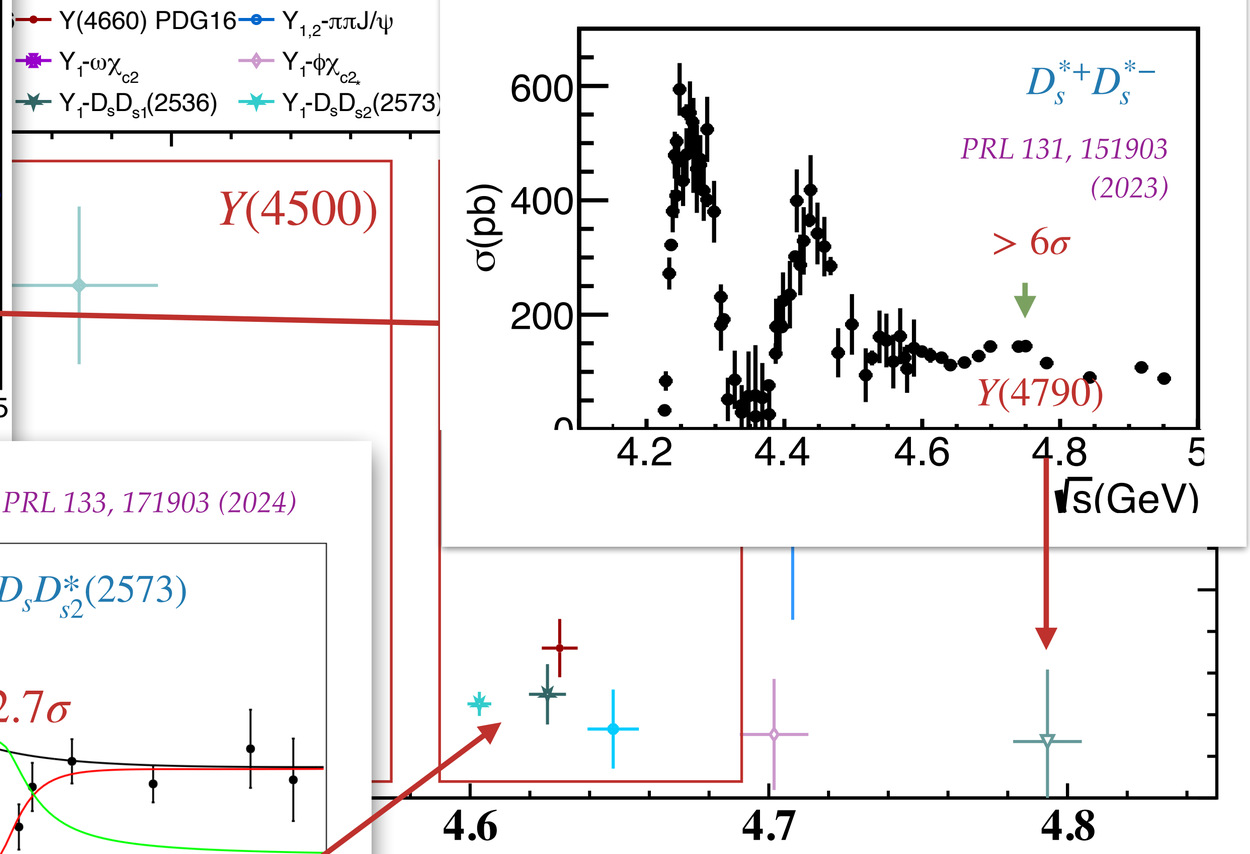


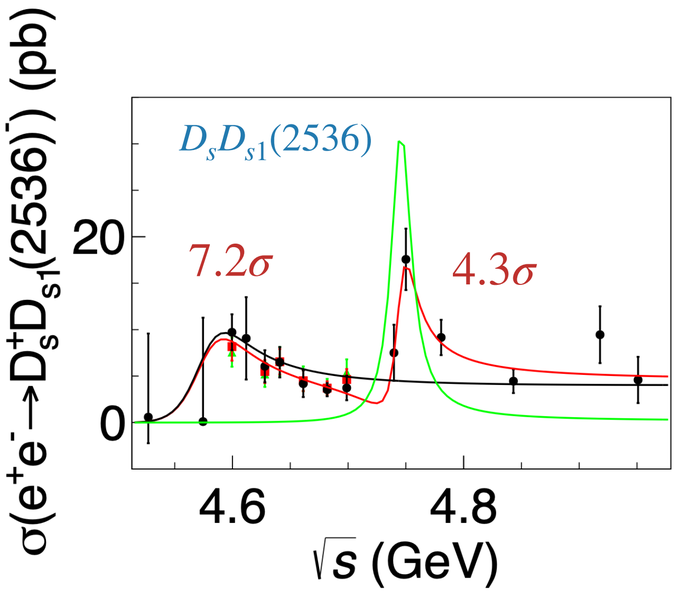
Y. P. Guo, C. Z. Yuan, arXiv:2508.20667

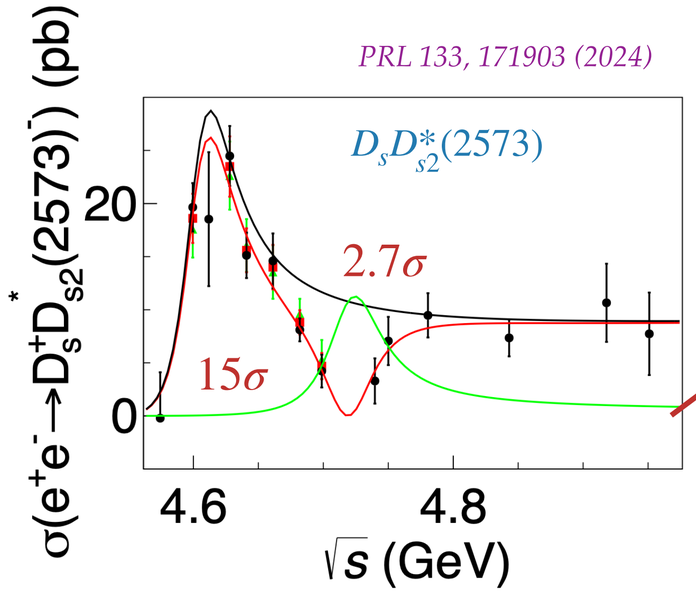
e: $\sigma(s) = |\frac{c}{s^n} + \sum_k BW_k(s)e^{i\phi_k}|^2$

Parameters of Vector States from Single Channel







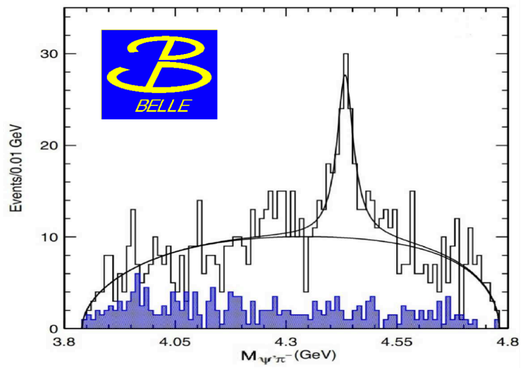


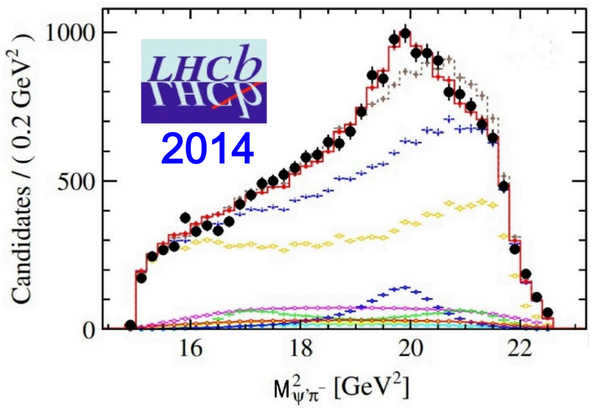
Y. P. Guo, C. Z. Yuan, arXiv:2508.20667

e: $\sigma(s) = |\frac{c}{s^n} + \sum_k BW_k(s)e^{i\phi_k}|^2$

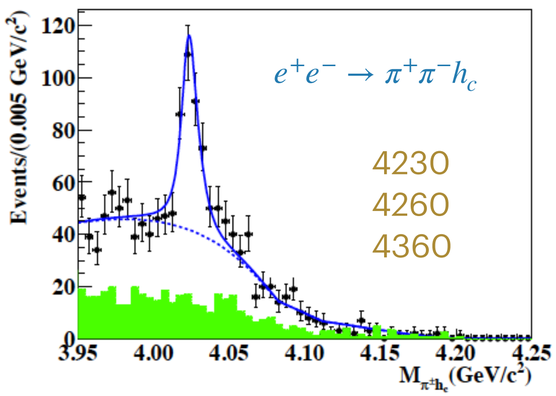
Four-Quark Matter: Z_c

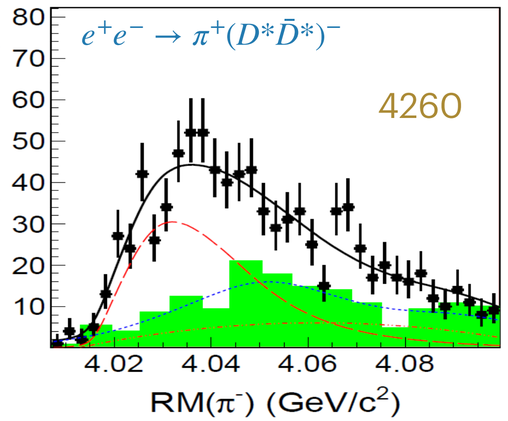
$Z_c(4430)$



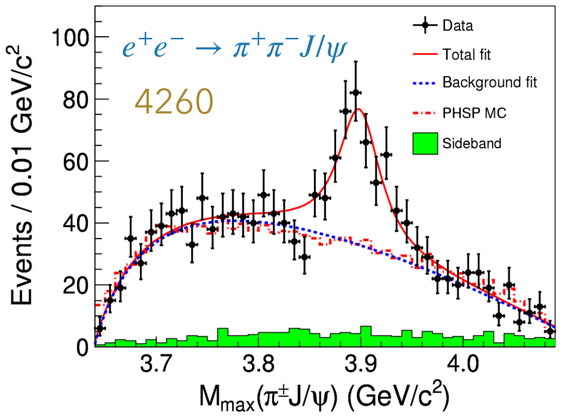


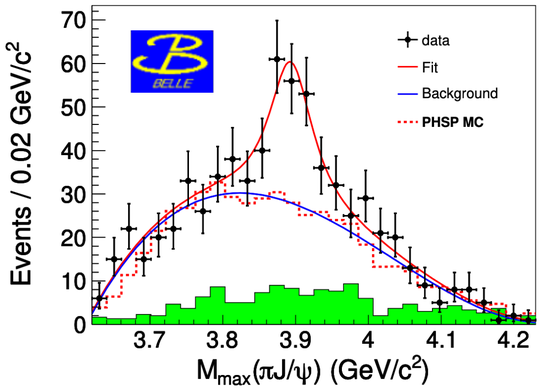
$Z_c(4020)/Z_c(4025)$ *PRL111, 242001 (2013) PRL112, 132001 (2014)*

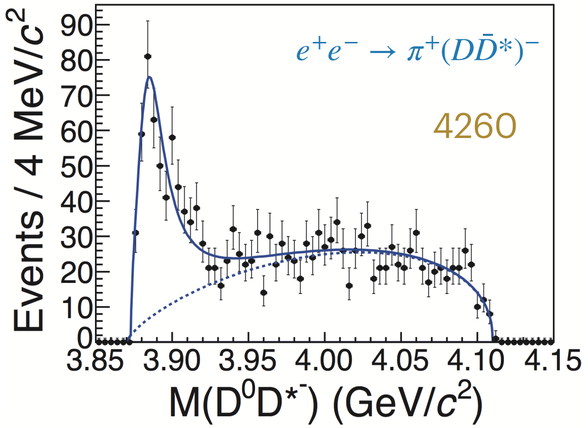




$Z_c(3900)/Z_c(3885)$ *PRL110, 252001 (2013), PRL110, 252002 (2013) PRL112, 022001 (2014)*





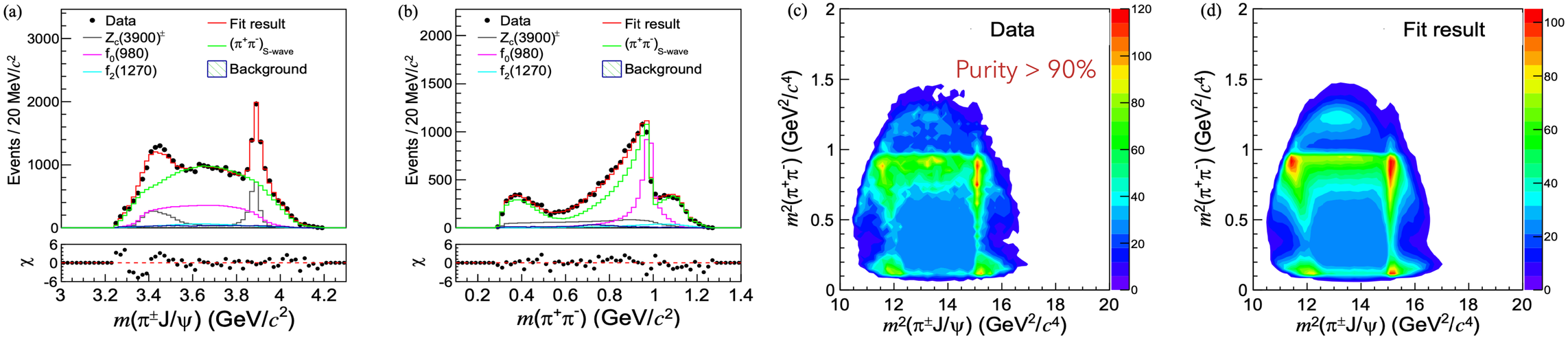


- Produced in e^+e^- annihilation or b-flavor hadron decays
- Typically in h+charmonium final states
- Intrinsic nature unclear, exotic states? kinematic effects?

$Z_c(3900)$ Production

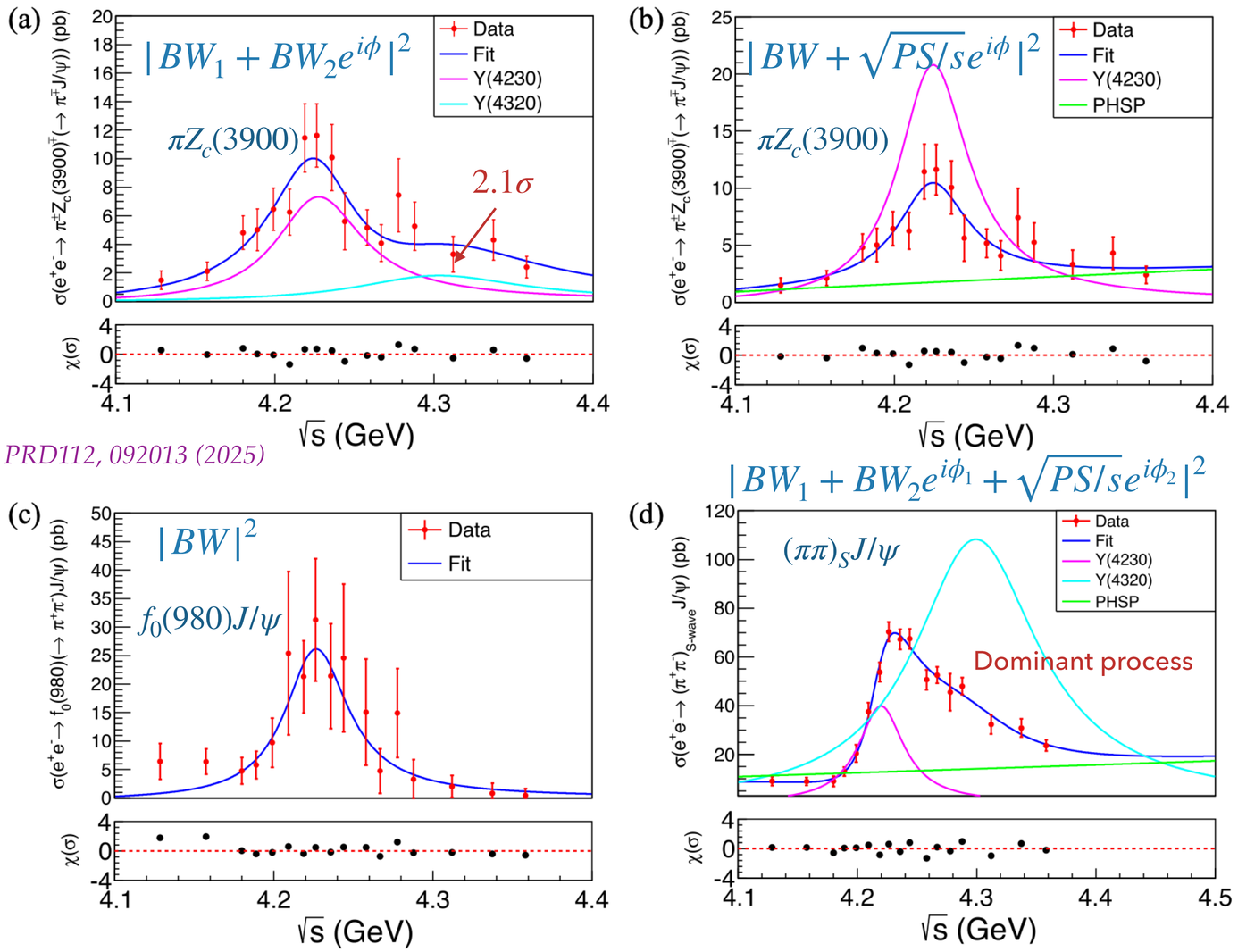
- Data samples from 4.1271 to 4.3583 GeV, corresponding to a total $L = 12.0\ \mathrm{fb}^{-1}$
- Helicity-convariant formulism, including $e^+e^- \to \pi^\pm Z_c(3900)^\mp(\to \pi^\mp J/\psi)$ and $e^+e^- \to f_j(\to \pi^+\pi^-)J/\psi$
  - $Z_c(3900)$ parametrized with a constant-width relativistic BW function
  - $f_0(980)$ with Flatte formula, $f_0(500)$, $f_0(1370)$, $f_2(1270)$ with constant-width relativistic BW functions; Or $(\pi\pi)_s$ with K-matrix

PRD112, 092013 (2025)



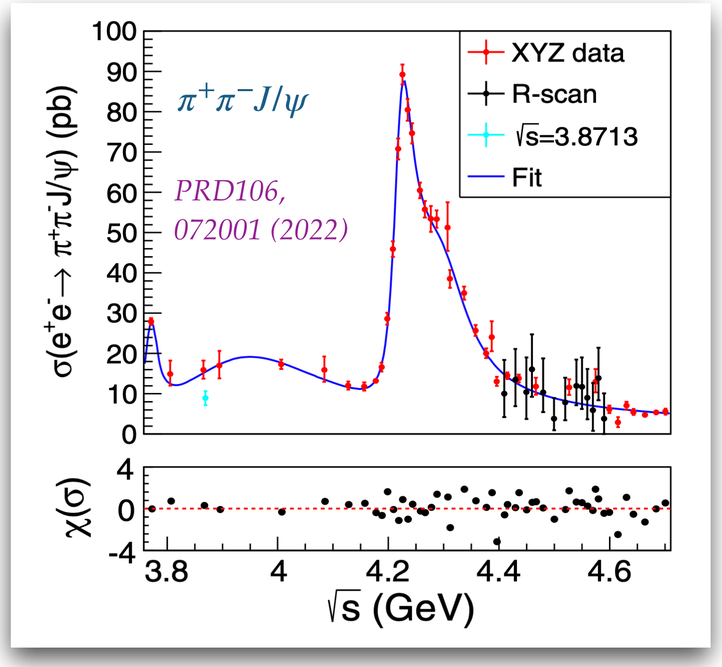
- Mass and width of $Z_c(3900)$: $M = 3884.6 \pm 0.7 \pm 3.3$ MeV/c^2; $\Gamma = 37.2 \pm 1.3 \pm 6.6$ MeV

$Z_c(3900)$ Production



PRD112, 092013 (2025)

- Average mass and width of $Y(4230)$:
  $M = 4225.7 \pm 4.1 \pm 3.4$ MeV/c^2
  $\Gamma = 57.5 \pm 9.4 \pm 12.1$ MeV

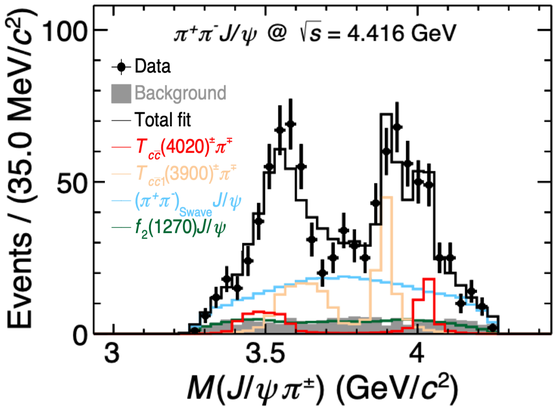


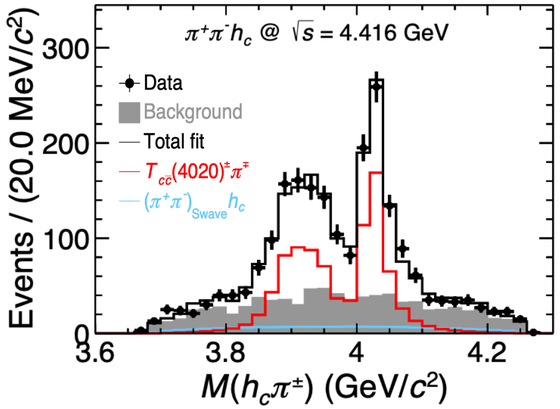
- $Y(4230)$ from $\pi^+\pi^- J/\psi$:
  $M = 4221.4 \pm 1.5 \pm 2.0$ MeV/c^2
  $\Gamma = 41.8 \pm 2.9 \pm 2.7$ MeV

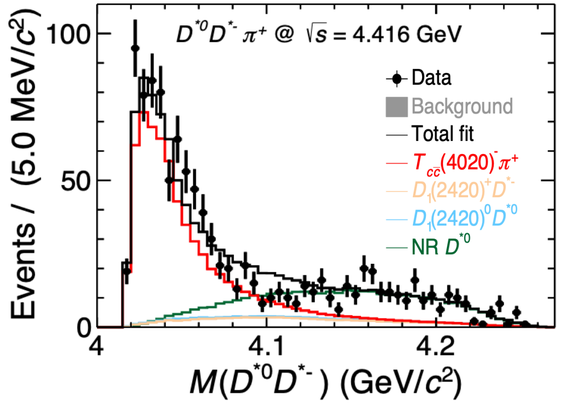
Multi-channel Analysis for $Z_c(4020)$

- Data samples at 4.400 and 4.415 GeV, total luminosity $L \approx 1.6\ \mathrm{fb}^{-1}$
- Joint analysis of three channels: $e^+e^- \to \pi^+\pi^- J/\psi,\ \pi^+\pi^- h_c,\ \pi D^{0*}\bar{D}^{*-}$

arXiv: 2603.05564

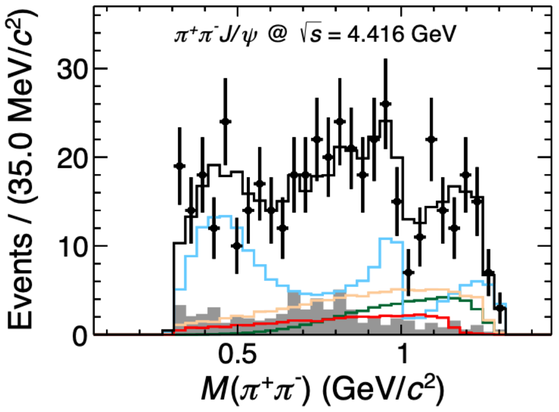


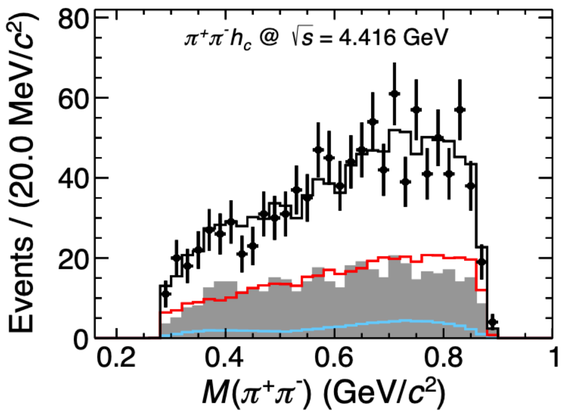


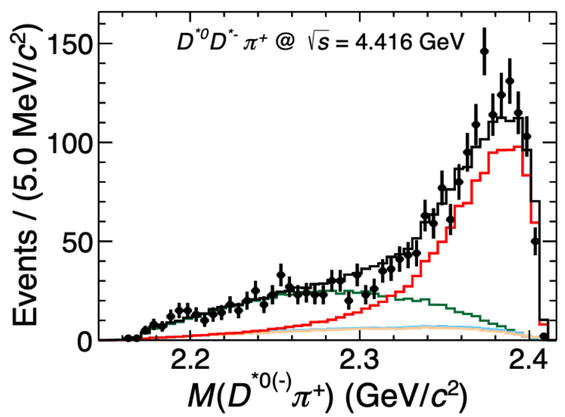


$$\frac{B[Z_c(4020) \to \pi J/\psi]}{B[Z_c(4020) \to D^{*0}\bar{D}^{*-}]} = (3.6 \pm 0.6 \pm 1.6) \times 10^{-3}$$

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





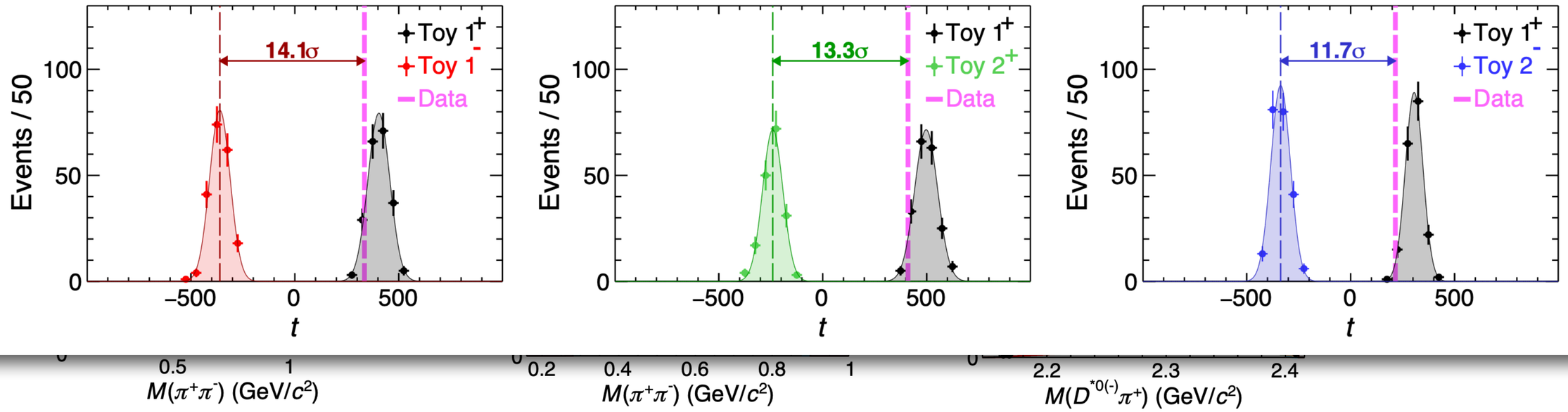


Multi-channel Analysis for $Z_c(4020)$

- Data samples at 4.400 and 4.415 GeV, total luminosity $L \approx 1.6\ \mathrm{fb}^{-1}$
- Joint analysis of three channels: $e^+e^- \to \pi^+\pi^- J/\psi,\ \pi^+\pi^- h_c,\ \pi D^{0*}\bar{D}^{*-}$

arXiv: 2603.05564

J^P of $Z_c(4020)$ determined to be 1^+ with significance $> 10\sigma$



Bound State of $\Lambda_c\bar{\Sigma}_c$

- Predicted spectrum of hadronic molecules consisting of a pair of charmed-anticharmed hadrons

Bound State of $\Lambda_c\bar{\Sigma}_c$

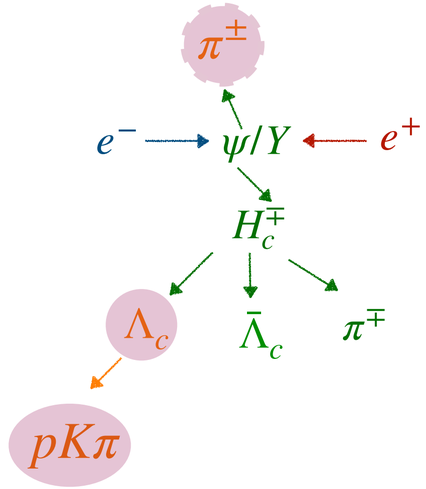
- Predicted spectrum of hadronic molecules consisting of a pair of charmed-anticharmed hadrons

Bound State of $\Lambda_c\bar{\Sigma}_c$

- Predicted spectrum of hadronic molecules consisting of a pair of charmed-anticharmed hadrons

- Data samples at 4.92 and 4.95 GeV, total luminosityl $L \approx 360\ \mathrm{pb}^{-1}$
- $e^+e^- \to \pi^\pm H_c^\mp[\to \pi^\mp \Lambda_c \bar{\Lambda}_c]$ with partial reconstruction technique

PRD112, 114044 (2025)

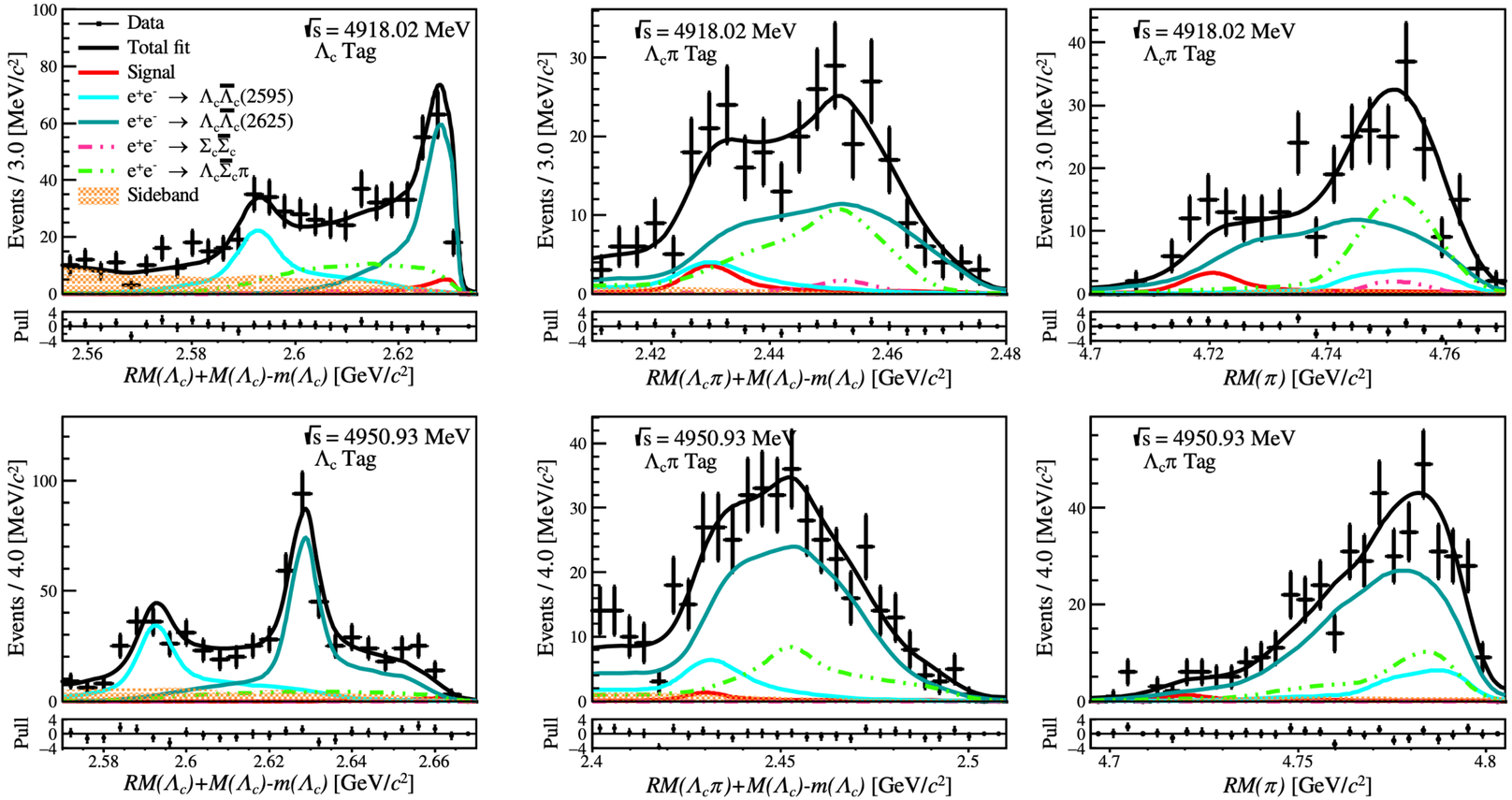


Bound State of $\Lambda_c\bar{\Sigma}_c$

FUDAN UNIVERSITY

PRD112, 114044 (2025)

- Simultaneous fit of two tag methods: Λ_c tag and $\Lambda_c\pi$ tag
- Bakcground processes: $\Lambda_c\bar{\Lambda}_c^*$ [size fixed to existing measurements] + $\Sigma_c\bar{\Sigma}_c$, $\Sigma_c\bar{\Lambda}_c\pi$ [free]



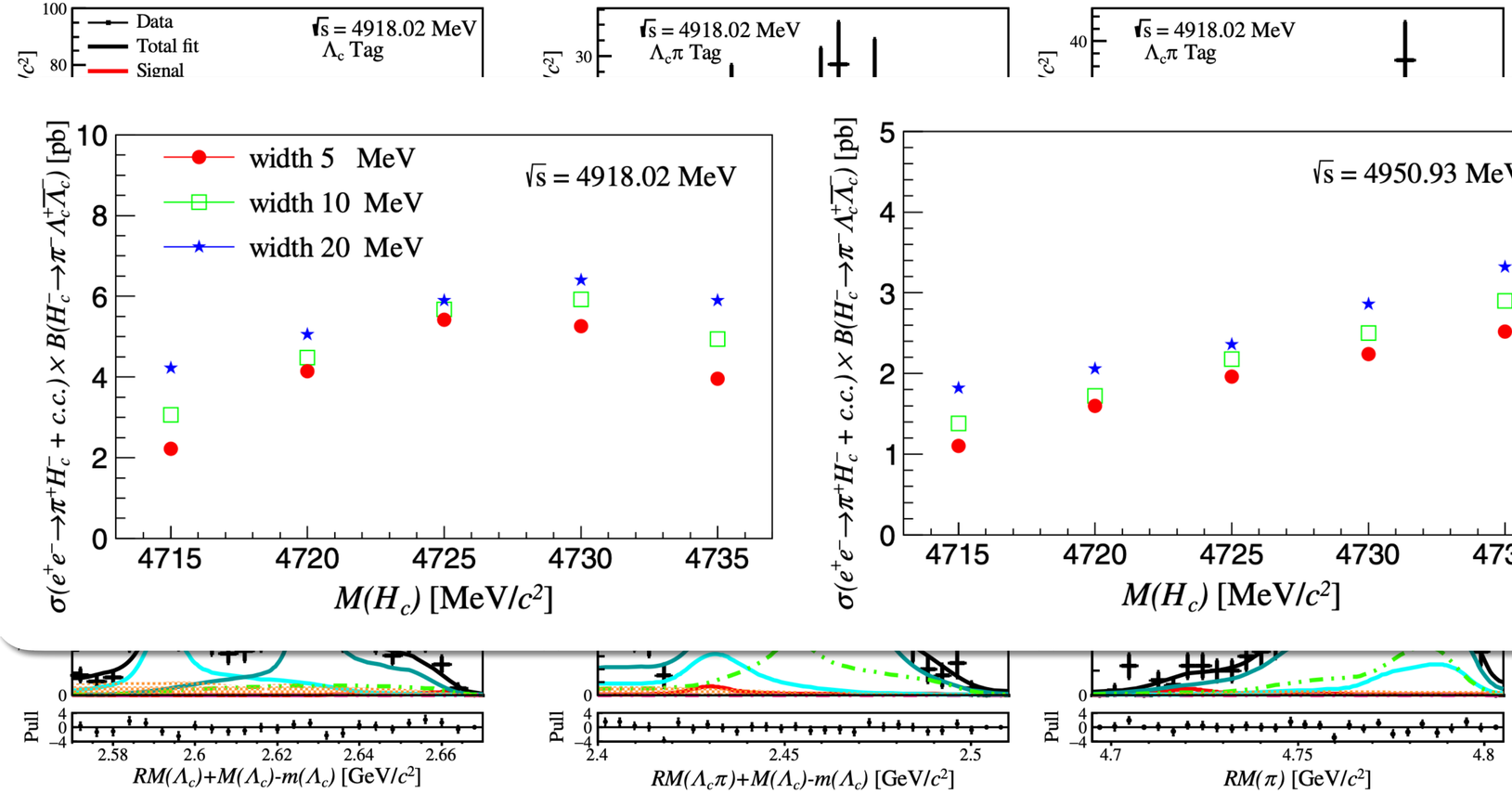
- No obvious signal

Bound State of $\Lambda_c\bar{\Sigma}_c$

- Simultaneous fit of two tag methods: Λ_c tag and $\Lambda_c\pi$ tag

PRD112, 114044 (2025)

- Bakcground processes: $\Lambda_c\bar{\Lambda}_c^*$ [size fixed to existing measurements] + $\Sigma_c\bar{\Sigma}_c$, $\Sigma_c\bar{\Lambda}_c\pi$ [free]



- No obvious signal

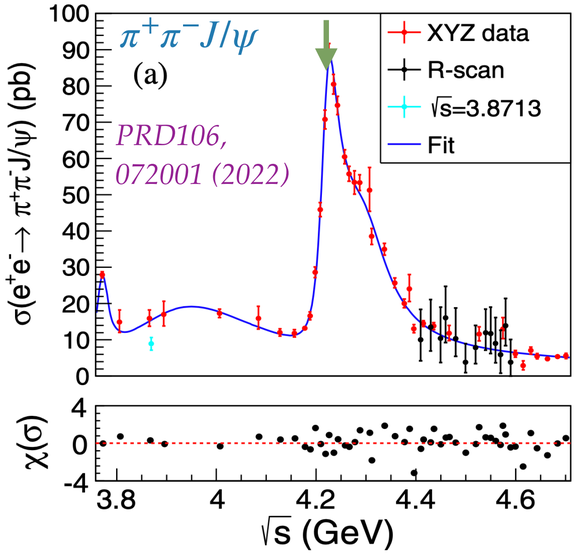
Summary

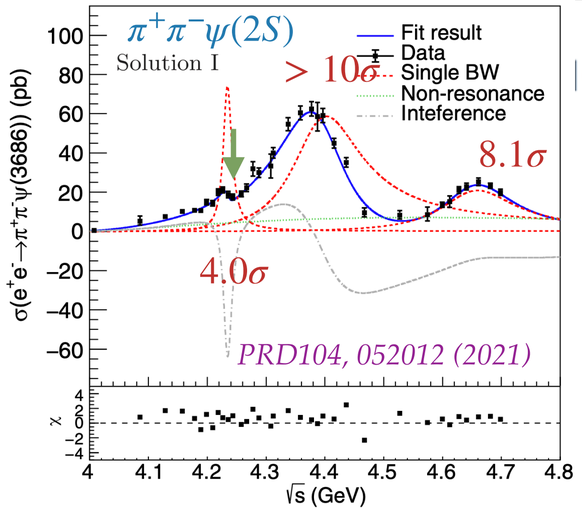
- Light and heavy exotic hadrons can be studied at BESIII using the largest J/ψ, $\psi(2S)$, $\psi(3770)$ data sample and the unique fine scan data sample between $\sqrt{s}$=3.8 to 4.95 GeV
- **Recent progress in charmonium region:**
  - Production of $X(3872)$ together with a vector state (γ, ω) is observed; new decay modes of $X(3872)$ have been searched
  - Cross sections of exclusive processes are measured with high precision, revealing vector structures in the cs line shapes, mostly accumulated around 4.23 GeV, 4.5 GeV, and 4.7 GeV ⇒ better parametrization needed!
  - $Z_c(3900)$ production in $e^+e^- \to \pi Z_c(3900)$ investigated with PWA, enhancement shows around 4.23 GeV
  - Quantum number of $Z_c(4020)$ determined to be 1^+, new information of decay branching fraction ratios
- BEPCII finished upgrade, increase the luminosity at $\sqrt{s}$=4.7 GeV by a factor of 3 (achieved), and extend the $\sqrt{s}$ up to 5.6 GeV; Currently taking data at $\sqrt{s} = 4.68$ GeV; more exciting results are expected!

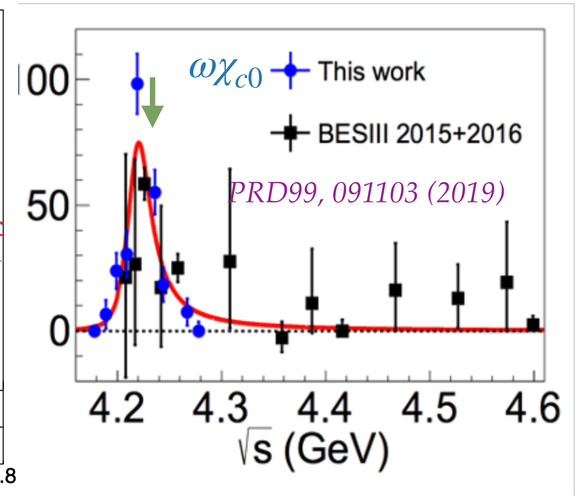
Thank you!

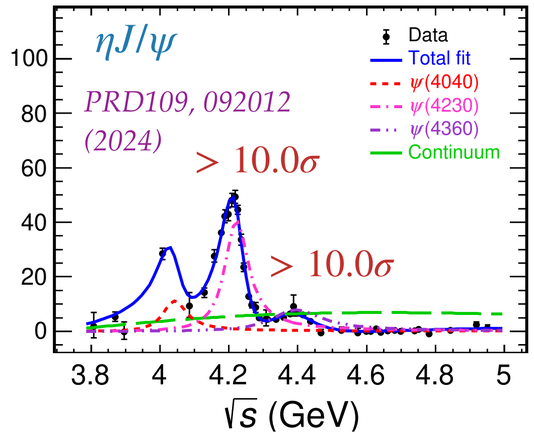
$Y(4260) \Rightarrow Y(4230)$

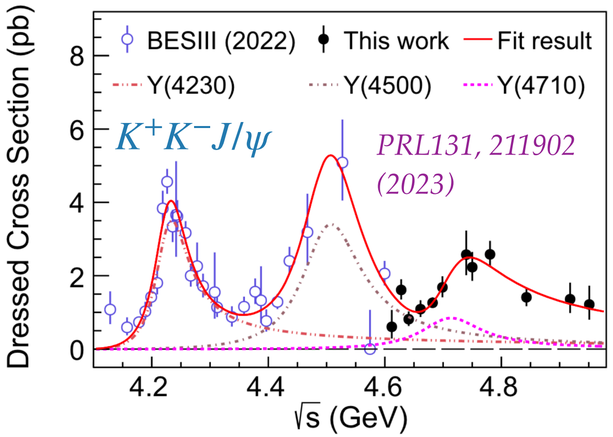
- Seen in more than 10 decay modes, including open charm final states

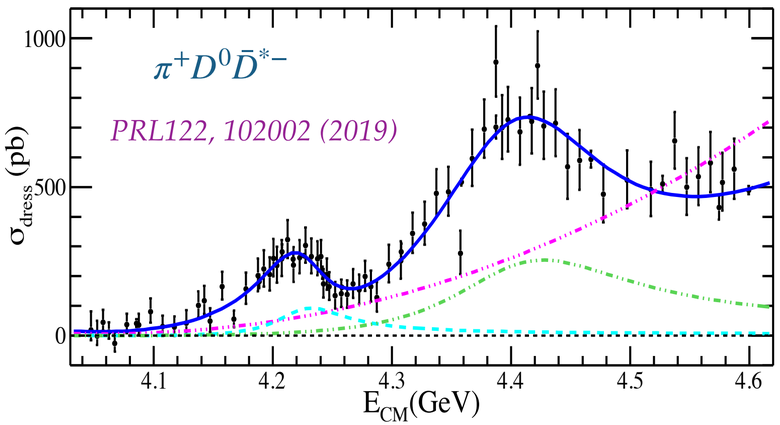


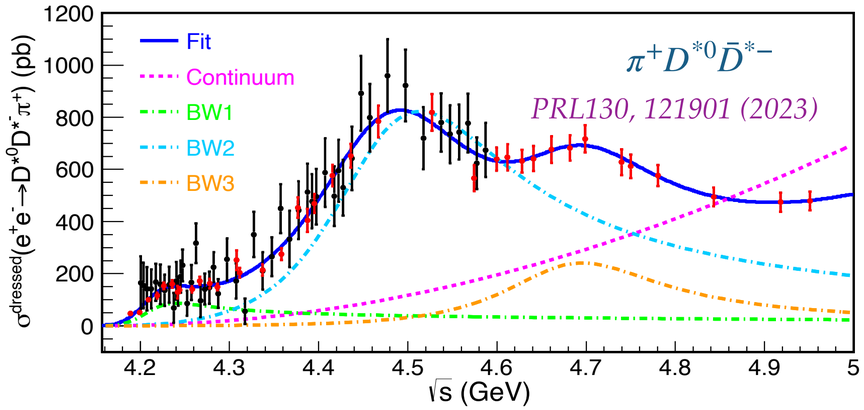




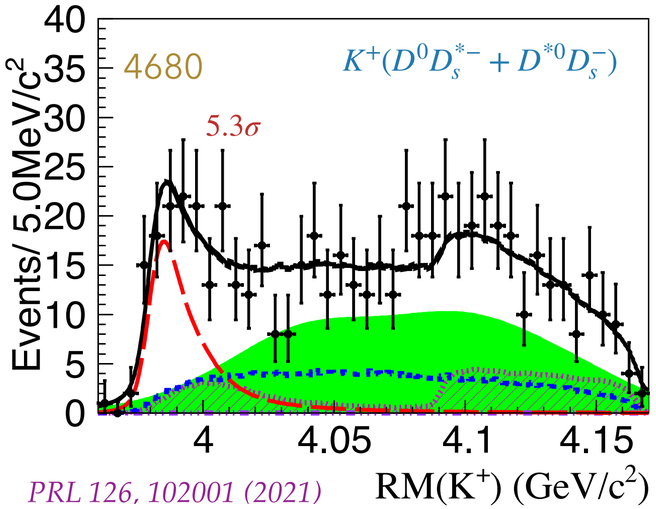








Z_{cs} in $e^+e^- \to K\bar{K} + c\bar{c}$

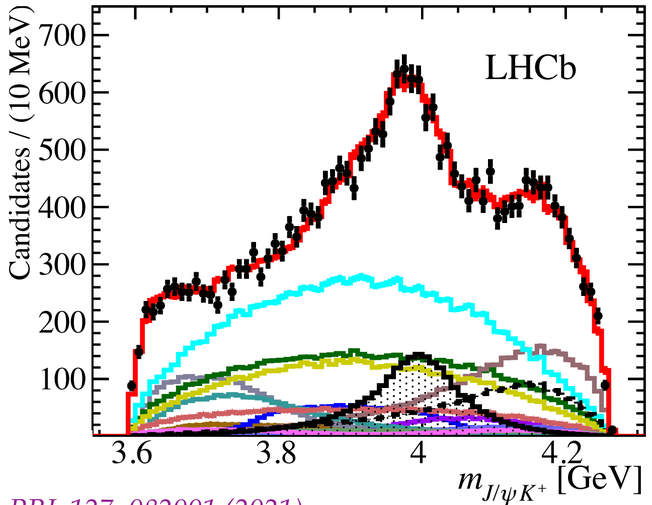


PRL 126, 102001 (2021)

$Z_{cs}(3985)$:

$m = 3985^{+2.1}_{-2.0} \pm 1.7$ MeV/c^2

$\Gamma = 13.8^{+8.1}_{-5.2} \pm 4.9$ MeV

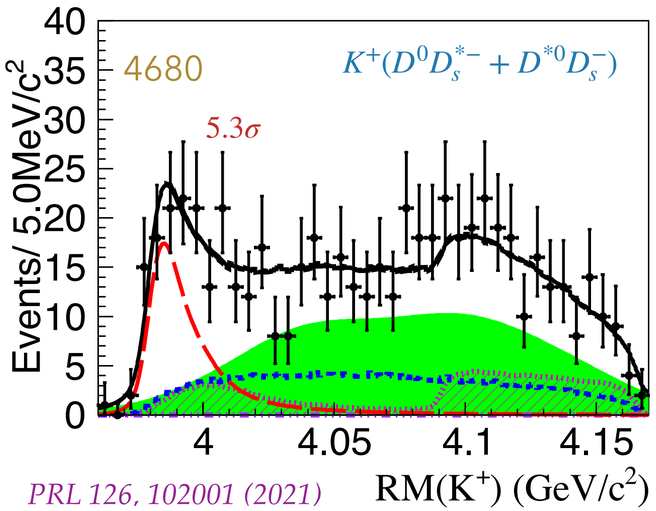


PRL 127, 082001 (2021)

$Z_{cs}(4000)$:

- $J^P = 1^+$
- $m = 4003 \pm 6^{+4}_{-24}$ MeV/c^2
- $\Gamma = 131 \pm 15 \pm 26$ MeV

Z_{cs} in $e^+e^- \to K\bar{K} + c\bar{c}$



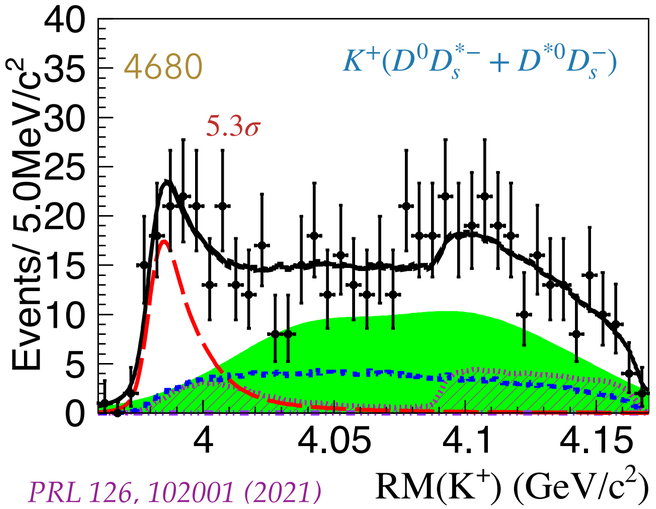
PRL 126, 102001 (2021)

$Z_{cs}(3985)$:

$m = 3985^{+2.1}_{-2.0} \pm 1.7$ MeV/c^2

$\Gamma = 13.8^{+8.1}_{-5.2} \pm 4.9$ MeV

Z_{cs} in $e^+e^- \to K\bar{K} + c\bar{c}$

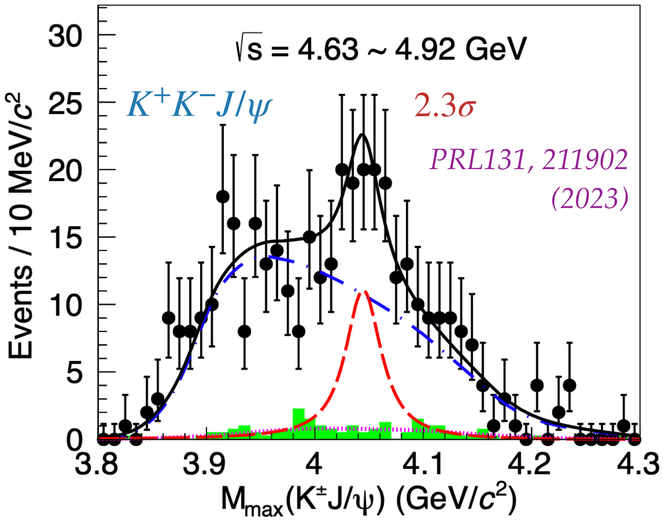


PRL 126, 102001 (2021)

$Z_{cs}(3985)$:

$m = 3985^{+2.1}_{-2.0} \pm 1.7$ MeV/c^2

$\Gamma = 13.8^{+8.1}_{-5.2} \pm 4.9$ MeV



PRL131, 211902 (2023)

$m = 4044 \pm 6$ MeV/c^2

$\Gamma = 36 \pm 16$ MeV

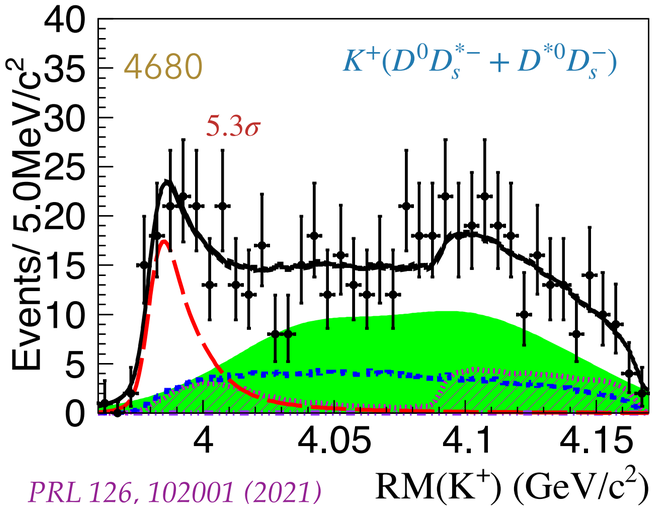
$$\frac{B[Z_{cs}(3985) \to KJ/\psi]}{B[Z_{cs}(3985) \to (\bar{D}^0 D_s^* + \bar{D}^{*0} D_s)]} < 0.03$$

at 90% C. L.

$$\frac{B[Z_c(3900) \to \pi^{\pm} J/\psi]}{B[Z_c(3900) \to (\bar{D}D^*)^{\pm}]} = 0.16 \pm 0.08$$

Calculated with data in PRL112, 022001 (2014)

Z_{cs} in $e^+e^- \to K\bar{K} + c\bar{c}$

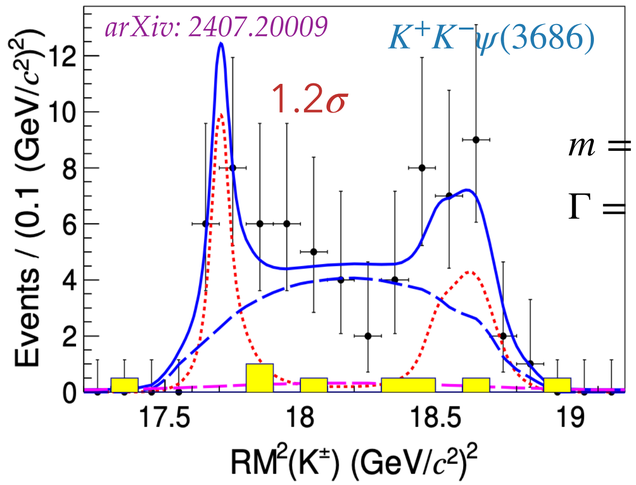


PRL 126, 102001 (2021)

$Z_{cs}(3985)$:

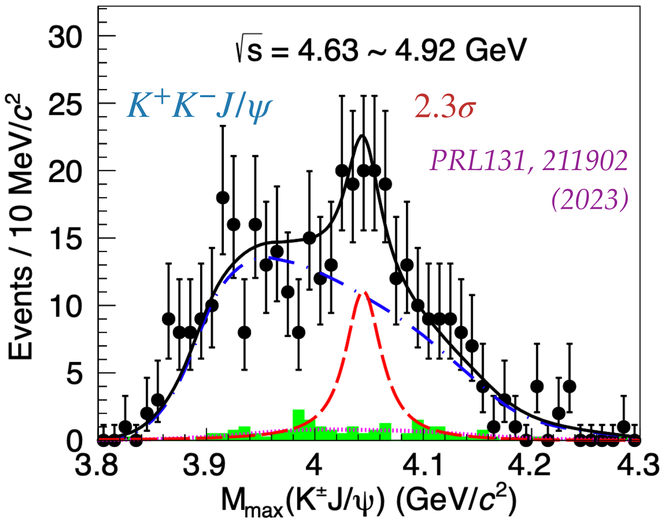
$m = 3985^{+2.1}_{-2.0} \pm 1.7$ MeV/c^2

$\Gamma = 13.8^{+8.1}_{-5.2} \pm 4.9$ MeV



$m = 4208.4 \pm 3.1$ MeV/c^2

$\Gamma = 6.1 \pm 5.7$ MeV

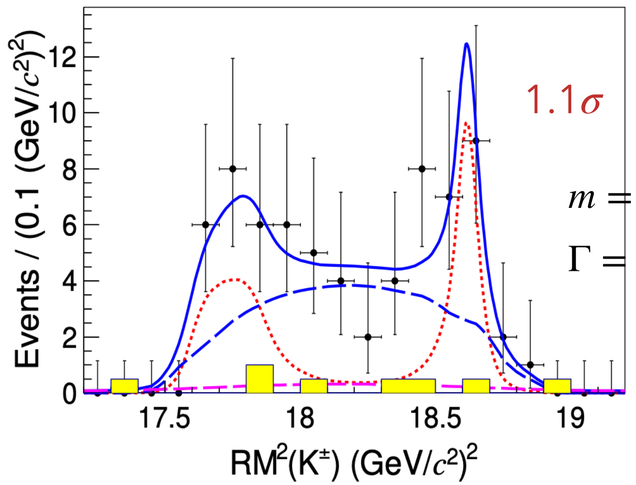


$m = 4044 \pm 6$ MeV/c^2

$\Gamma = 36 \pm 16$ MeV

$$\frac{B[Z_{cs}(3985) \to KJ/\psi]}{B[Z_{cs}(3985) \to (\bar{D}^0 D_s^* + \bar{D}^{*0} D_s)]} < 0.03$$

at 90% C. L.



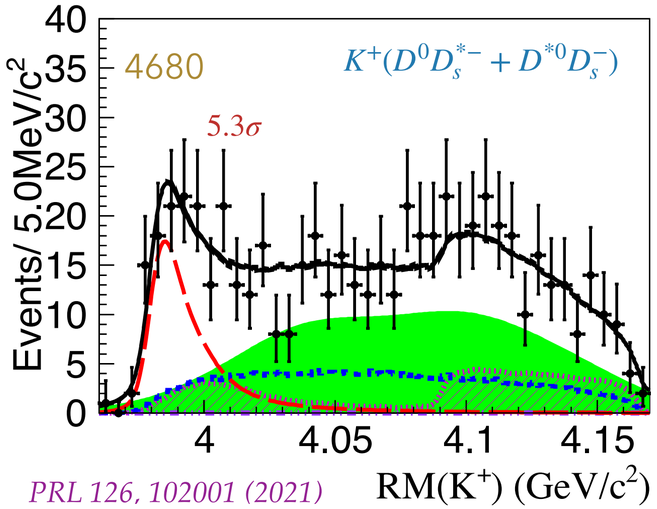
$m = 4316.0 \pm 2.7$ MeV/c^2

$\Gamma = 9.0 \pm 8.6$ MeV

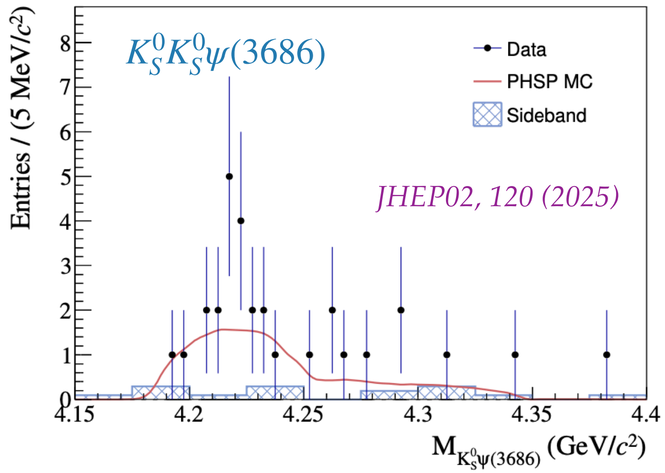
.08

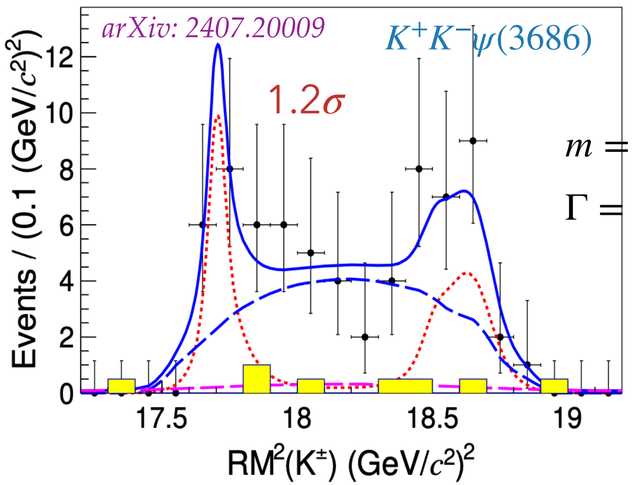
2014)

Z_{cs} in $e^+e^- \to K\bar{K} + c\bar{c}$



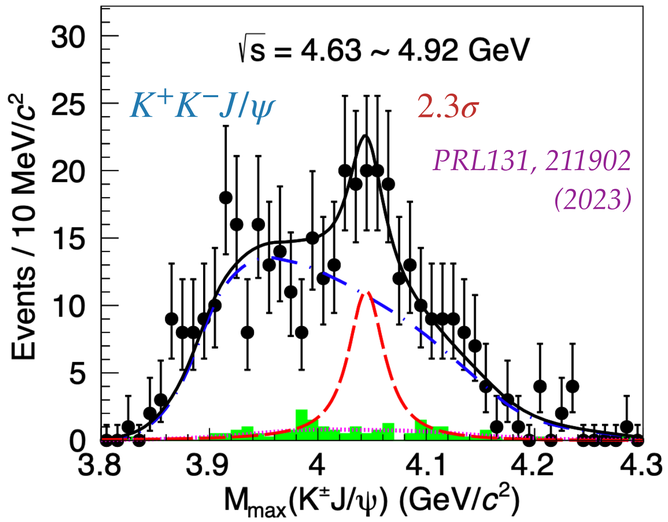
PRL 126, 102001 (2021)

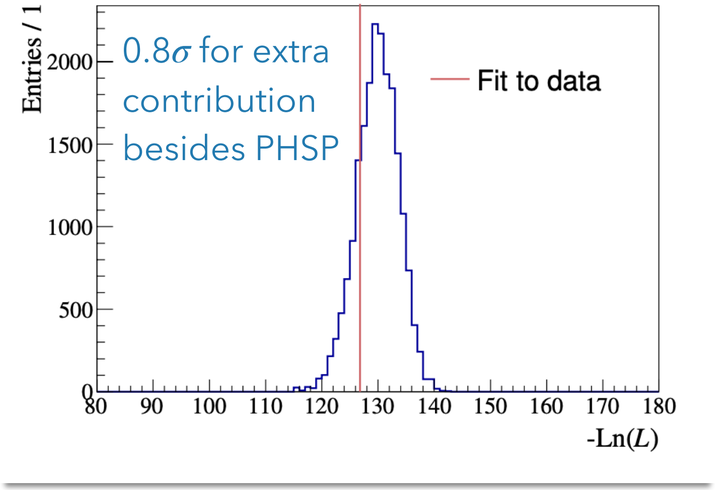


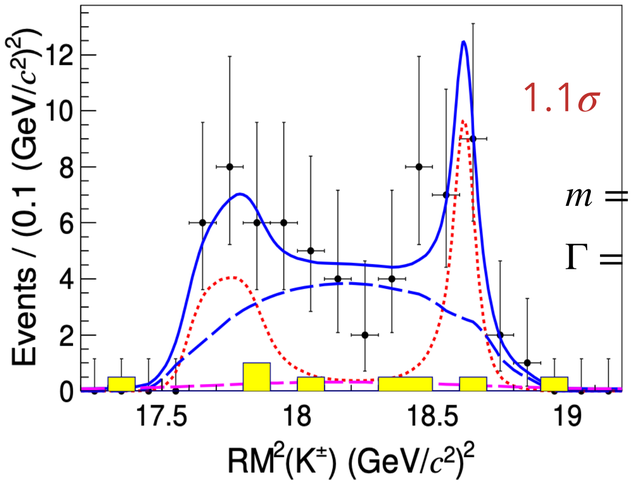


$m = 4208.4 \pm 3.1$ MeV/c^2

$\Gamma = 6.1 \pm 5.7$ MeV







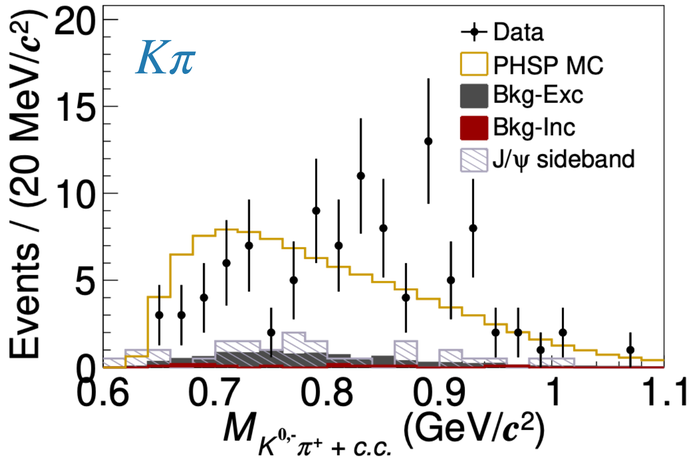
$m = 4316.0 \pm 2.7$ MeV/c^2

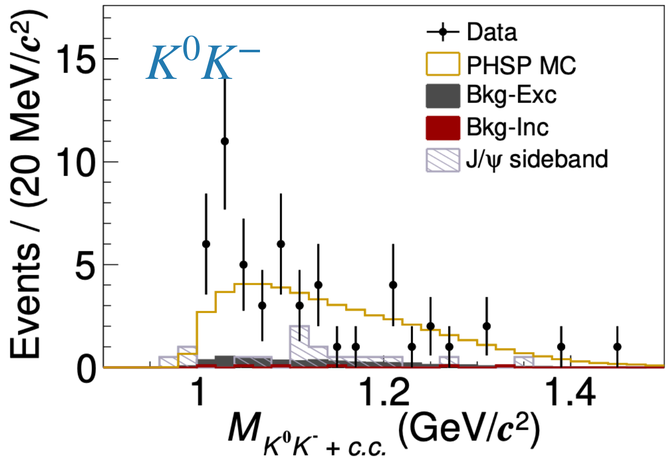
$\Gamma = 9.0 \pm 8.6$ MeV

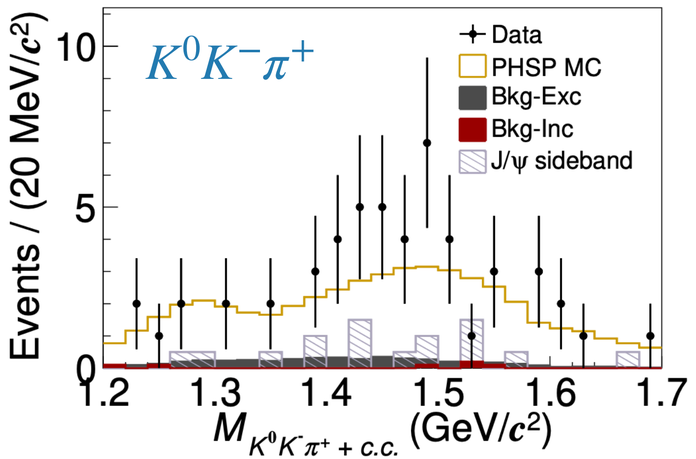
.08

2014)

Z_c and Z_{cs} in $e^+e^- \to K^0K^-\pi^+J/\psi$







arXiv: 2510.13274 (accepted by JHEP)