重味奇特强子态

郭玉萍 复旦大学

On Behalf of BESIII Collaboration

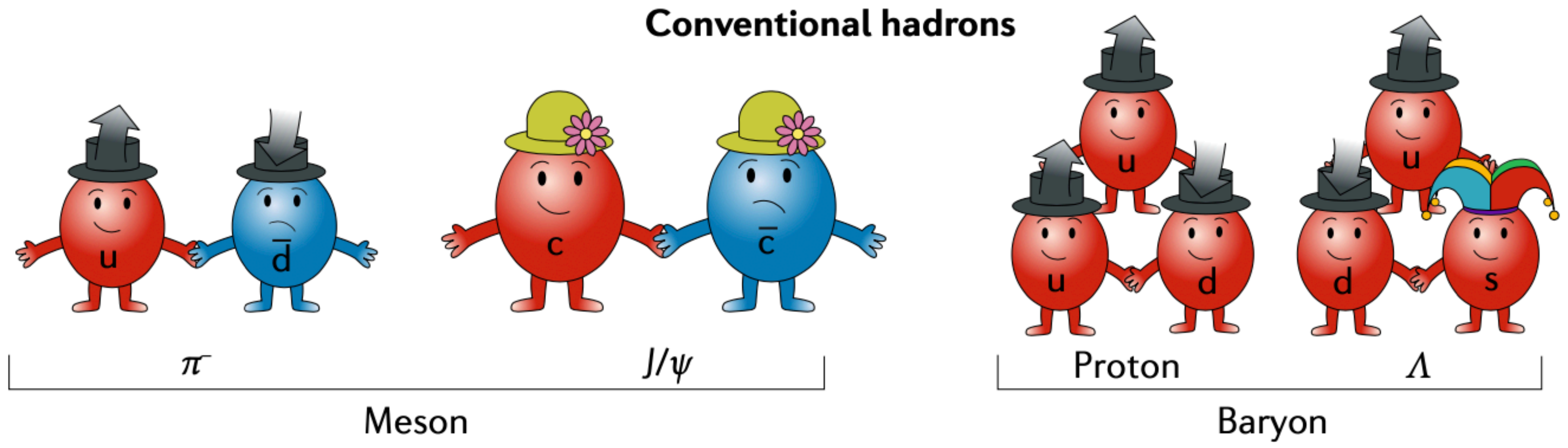
第二十届全国中高能核物理大会

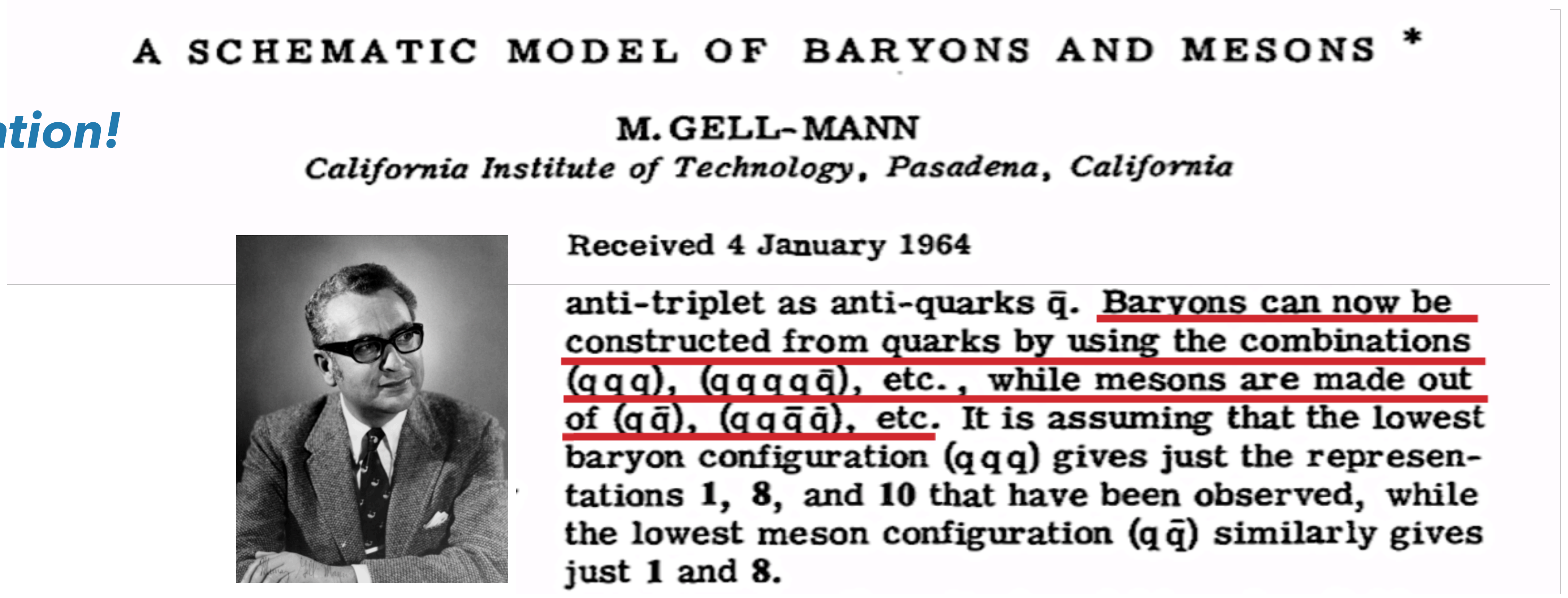
Hadrons

FUDAN UNIVERSITY

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

Lowest Configuration!



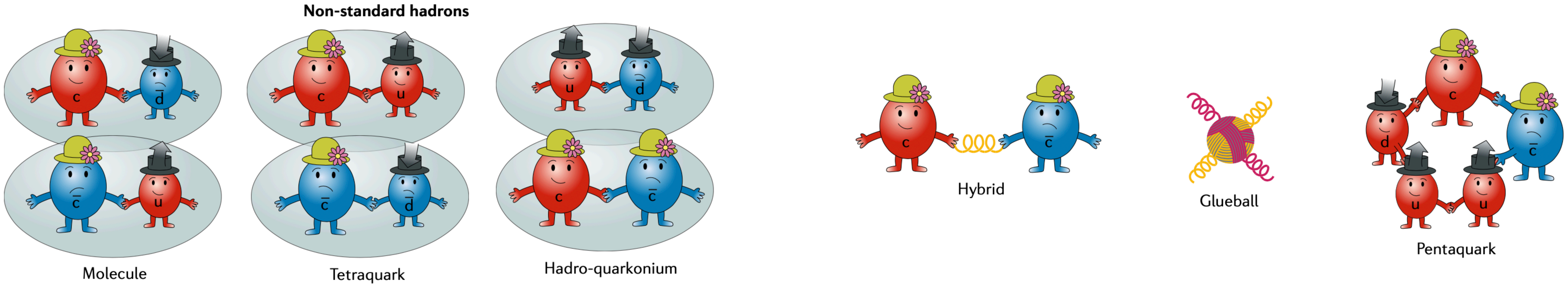

A SCHEMATIC MODEL OF BARYONS AND MESONS *

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

Received 4 January 1964

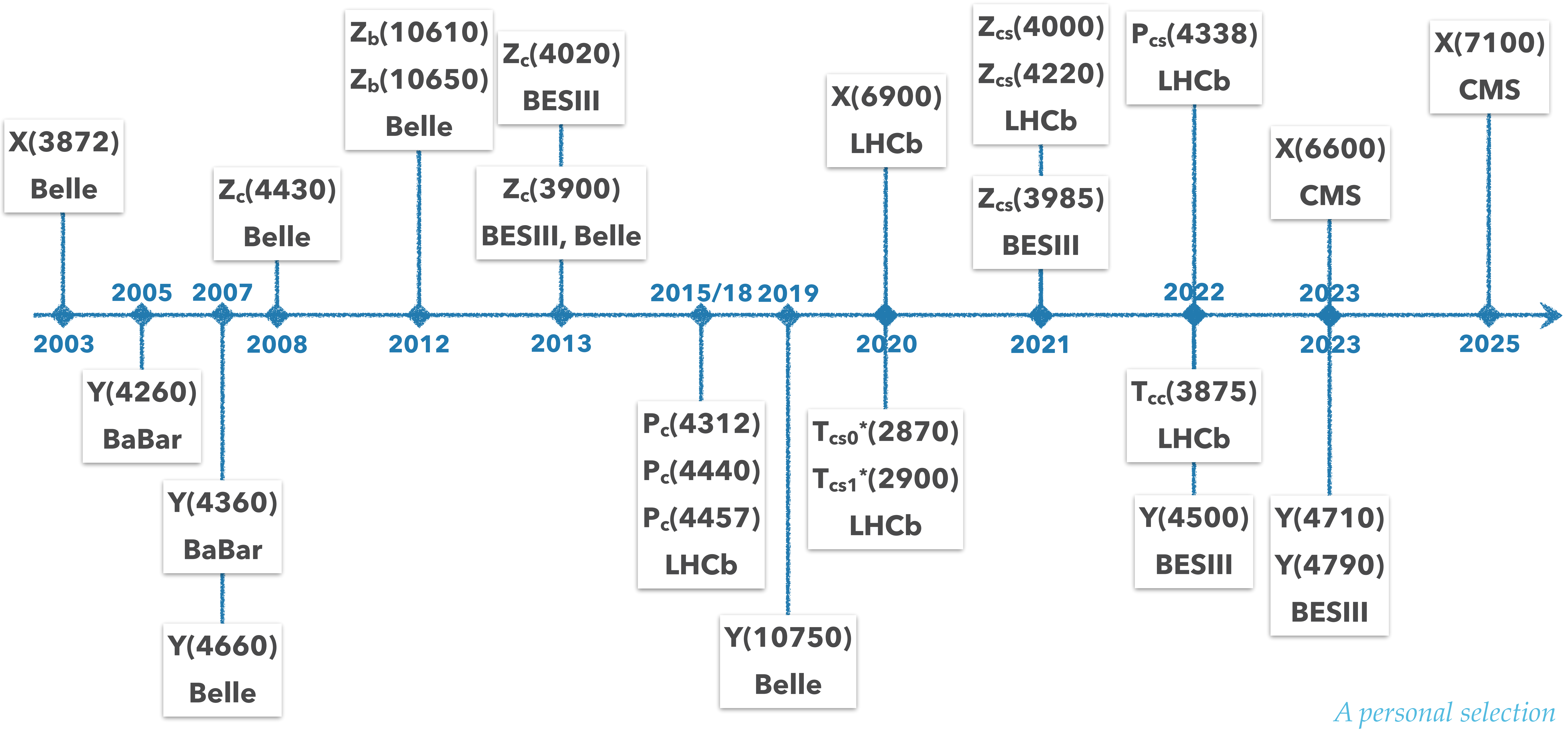
anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations $(q\,q\,q)$, $(q\,q\,q\,q\,\bar{q})$, etc., while mesons are made out of $(q\,\bar{q})$, $(q\,q\,\bar{q}\,\bar{q})$, etc. It is assuming that the lowest baryon configuration $(q\,q\,q)$ gives just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

- **Exotic hadrons:**



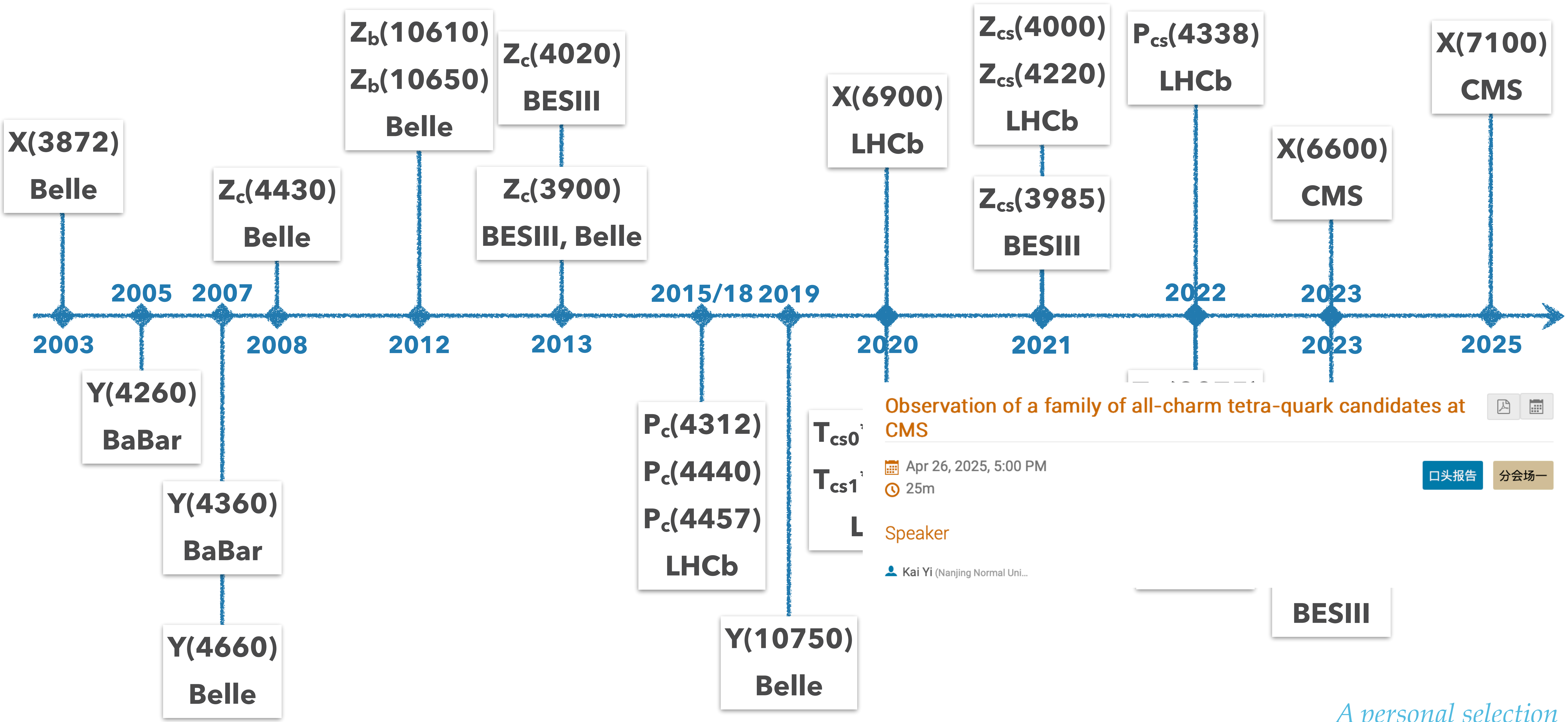
C. Z. Yuan, S. L. Olsen, Nature Reviews Physics 1, 480 (2019)

Exotic Hadron Candidates



A personal selection

Exotic Hadron Candidates



A personal selection

Exotic Hadron Candidates

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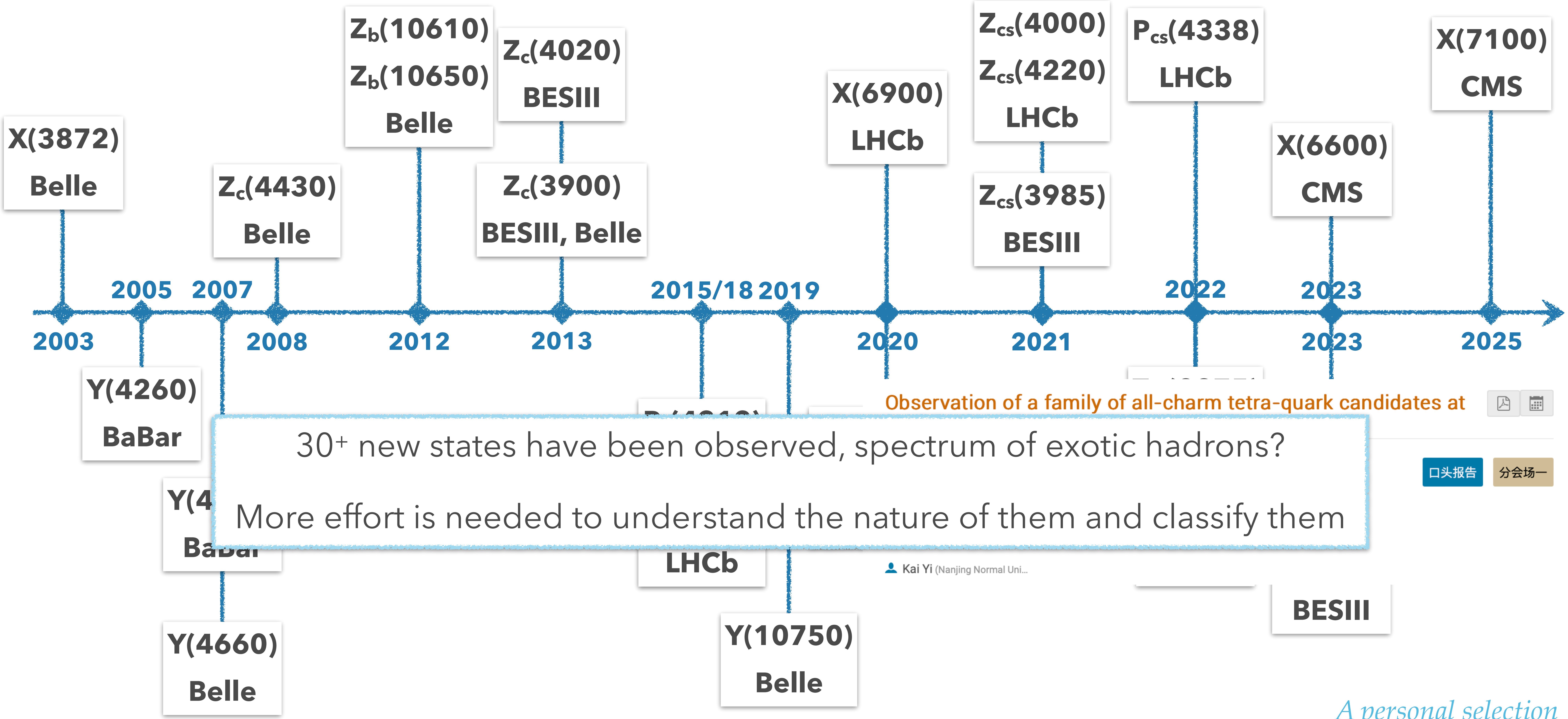
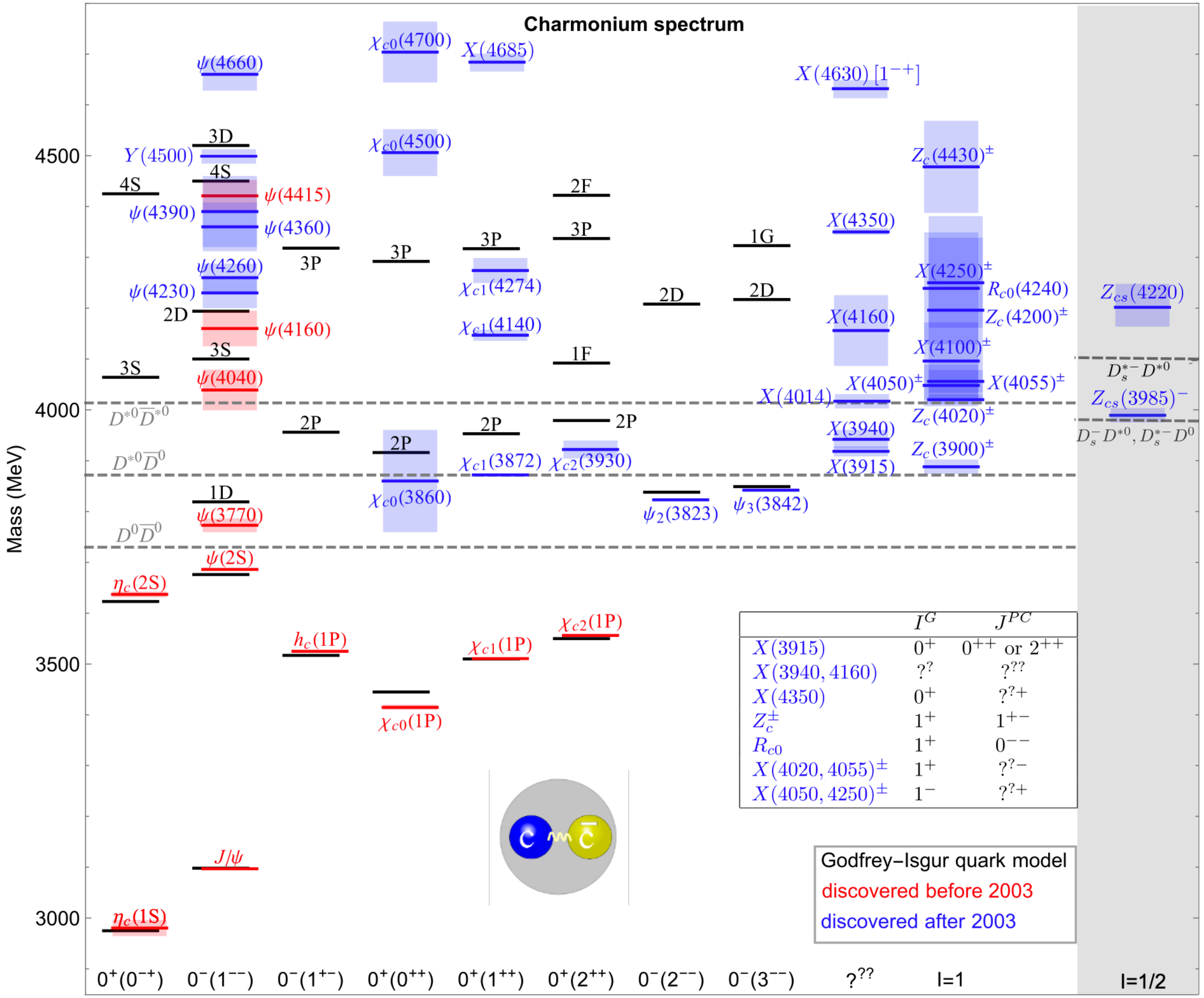


30+ new states have been observed, spectrum of exotic hadrons?

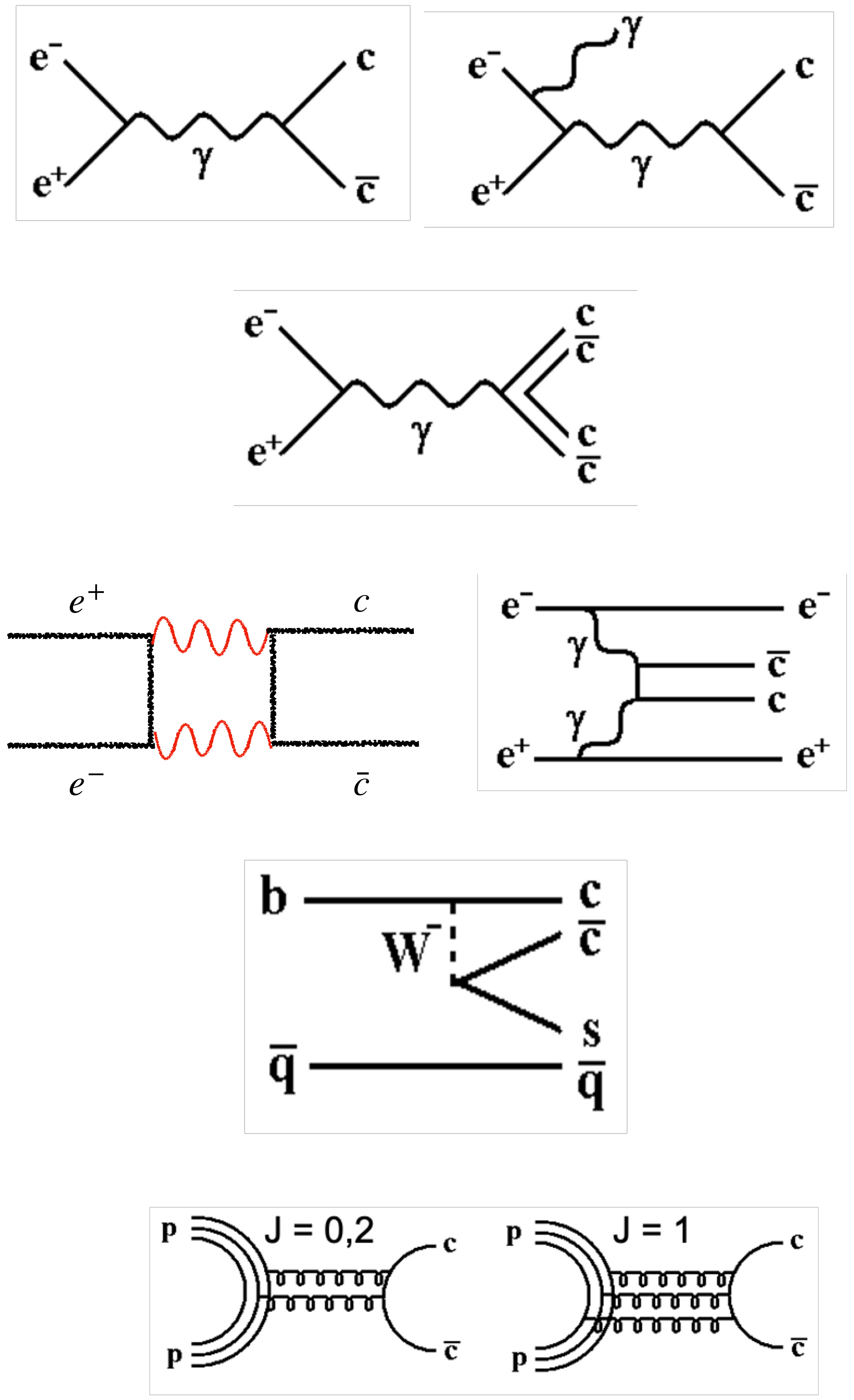
More effort is needed to understand the nature of them and classify them

A personal selection

Charmonium Spectroscopy



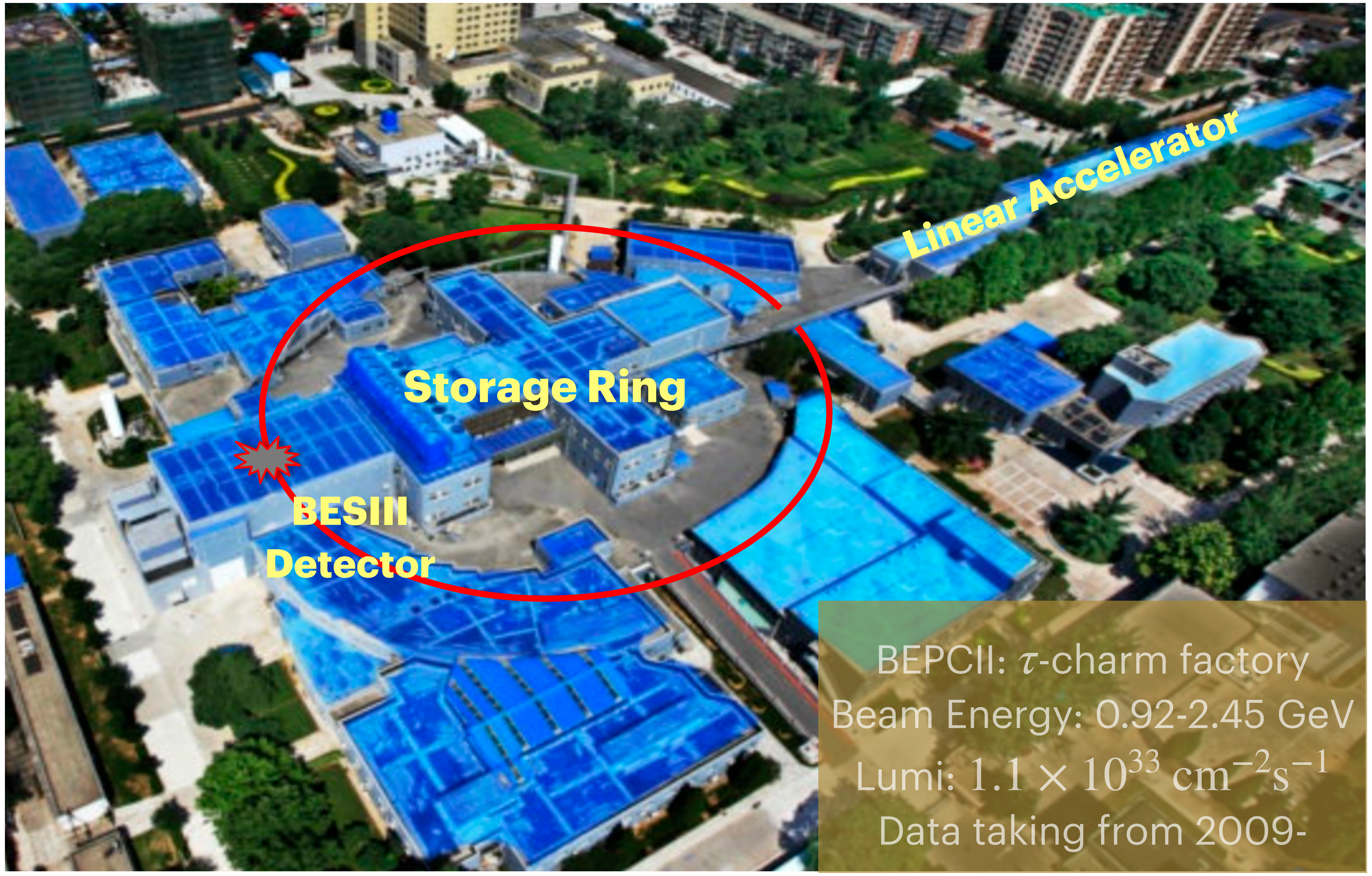
from F. K. Guo



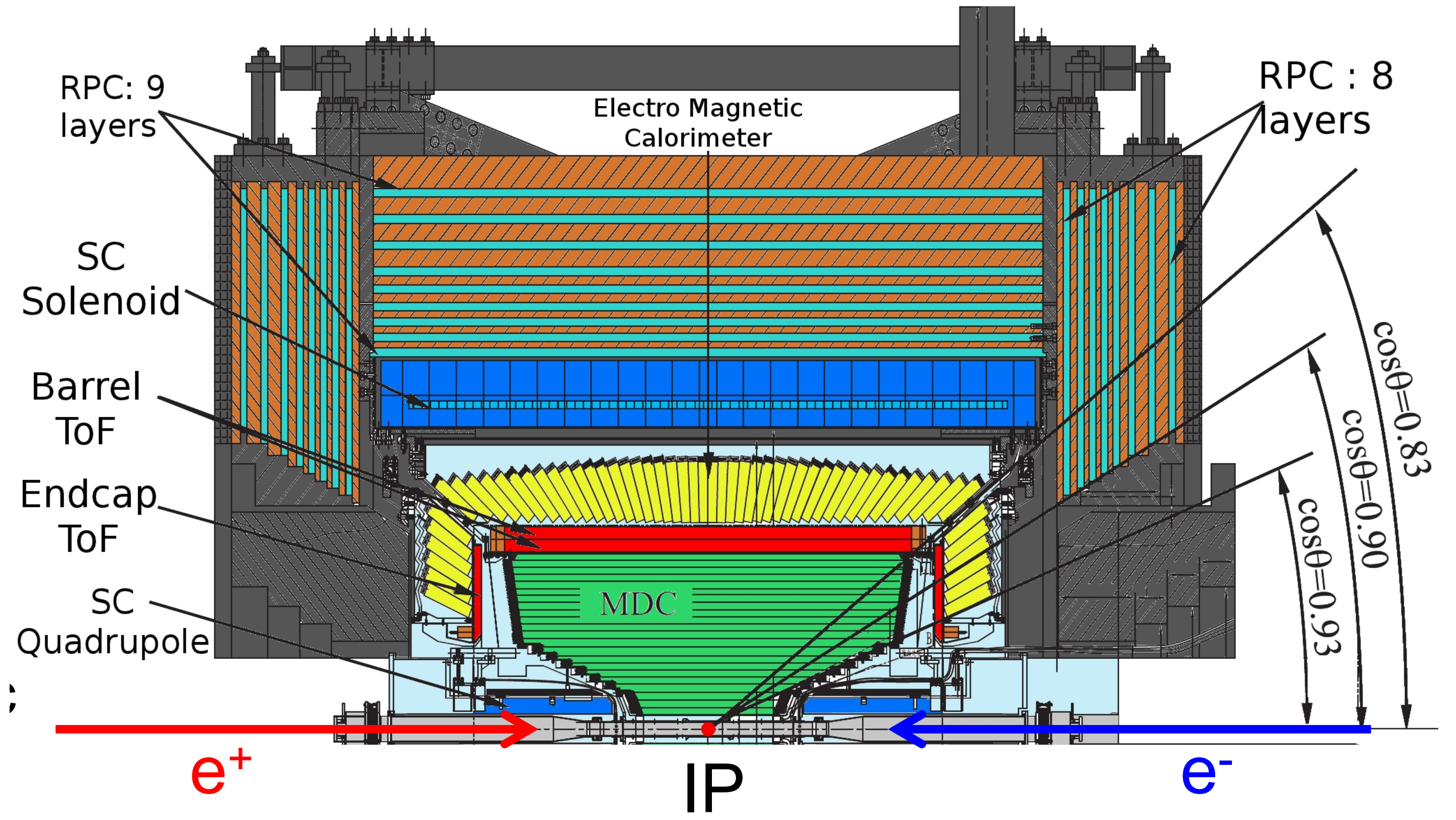
All quantum numbers

...

Beijing Electron Positron Collider II and BESIII



Solenoid Magnet: 0.9/1.0 T



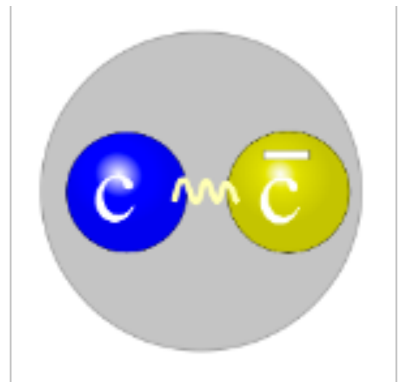
MUC $\sigma_{R\Phi}$: 2 cm

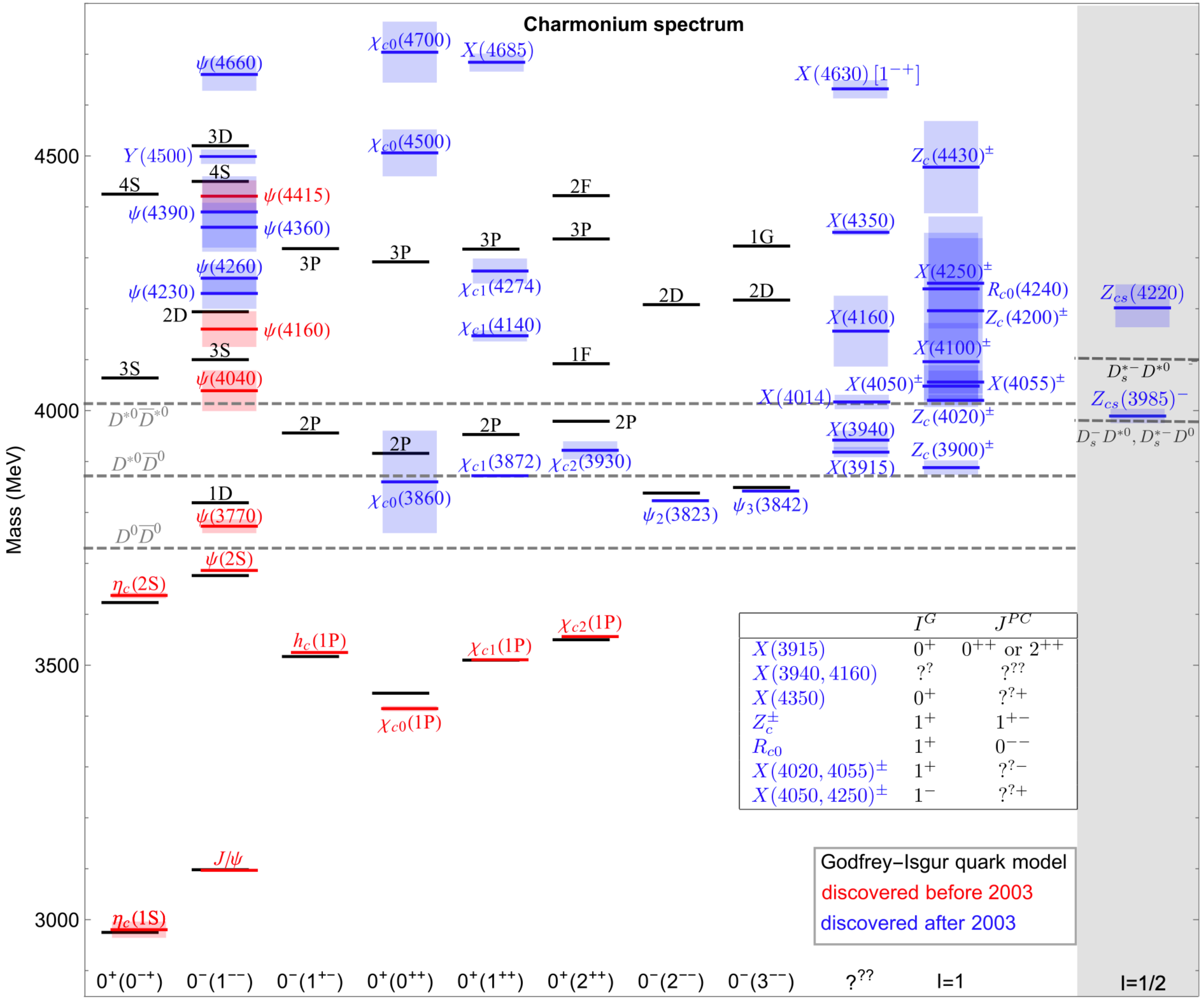
TOF
σ_T :80 ps
110 ps (60 ps)

MDC
dE/dx: 6%
σ_p/p: 0.5% at 1GeV/c

EMC
ΔE/E: at 1GeV
2.5%
5.0%
σ_Z: 0.6 cm/√E

Charmonium Production at BESIII





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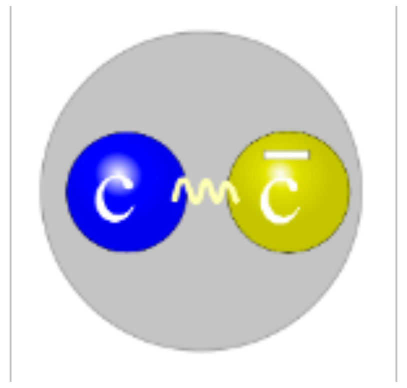
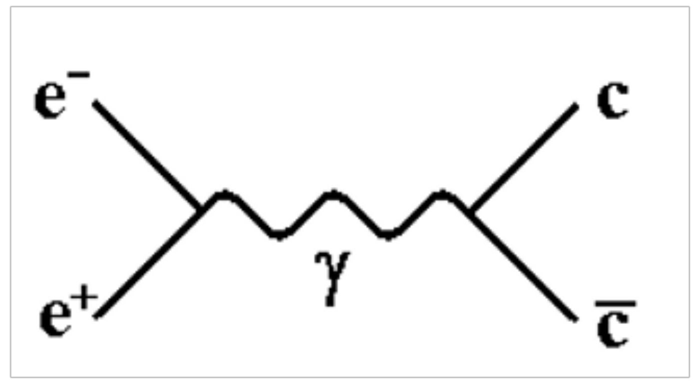
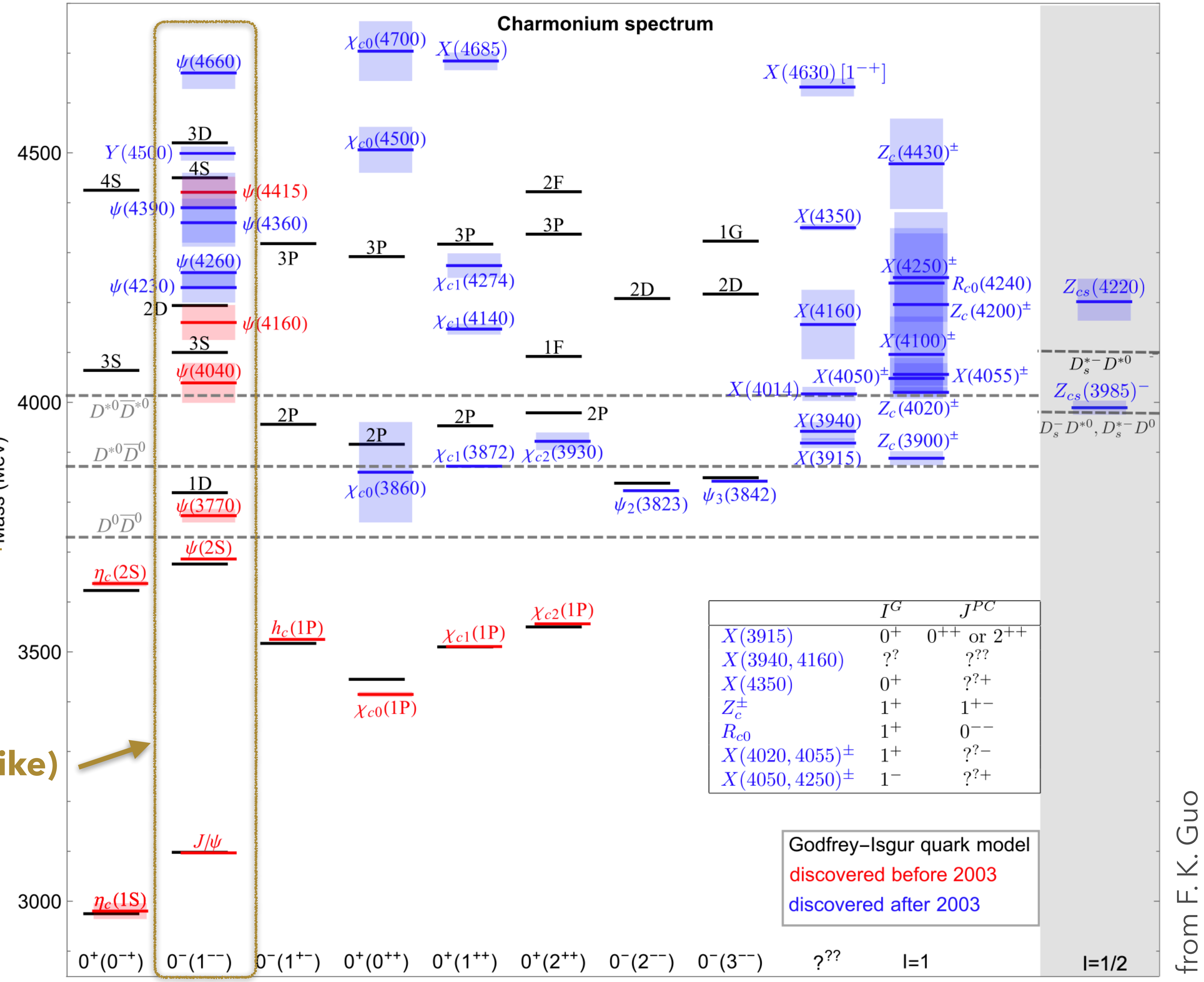




$J^{PC} = 1^{--}$



Vector Charmonium(-like)

Charmonium Production at BESIII

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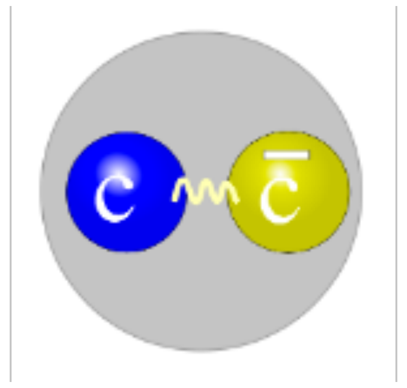

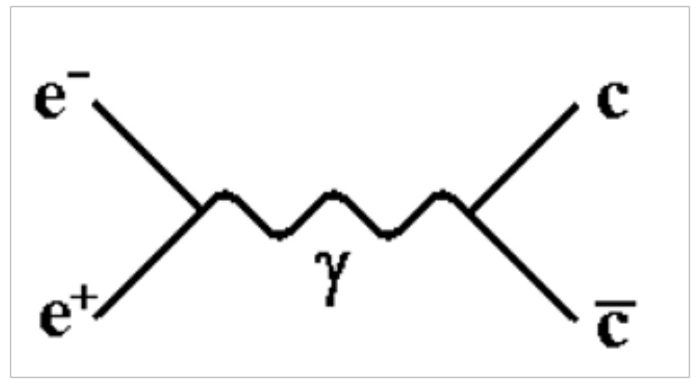

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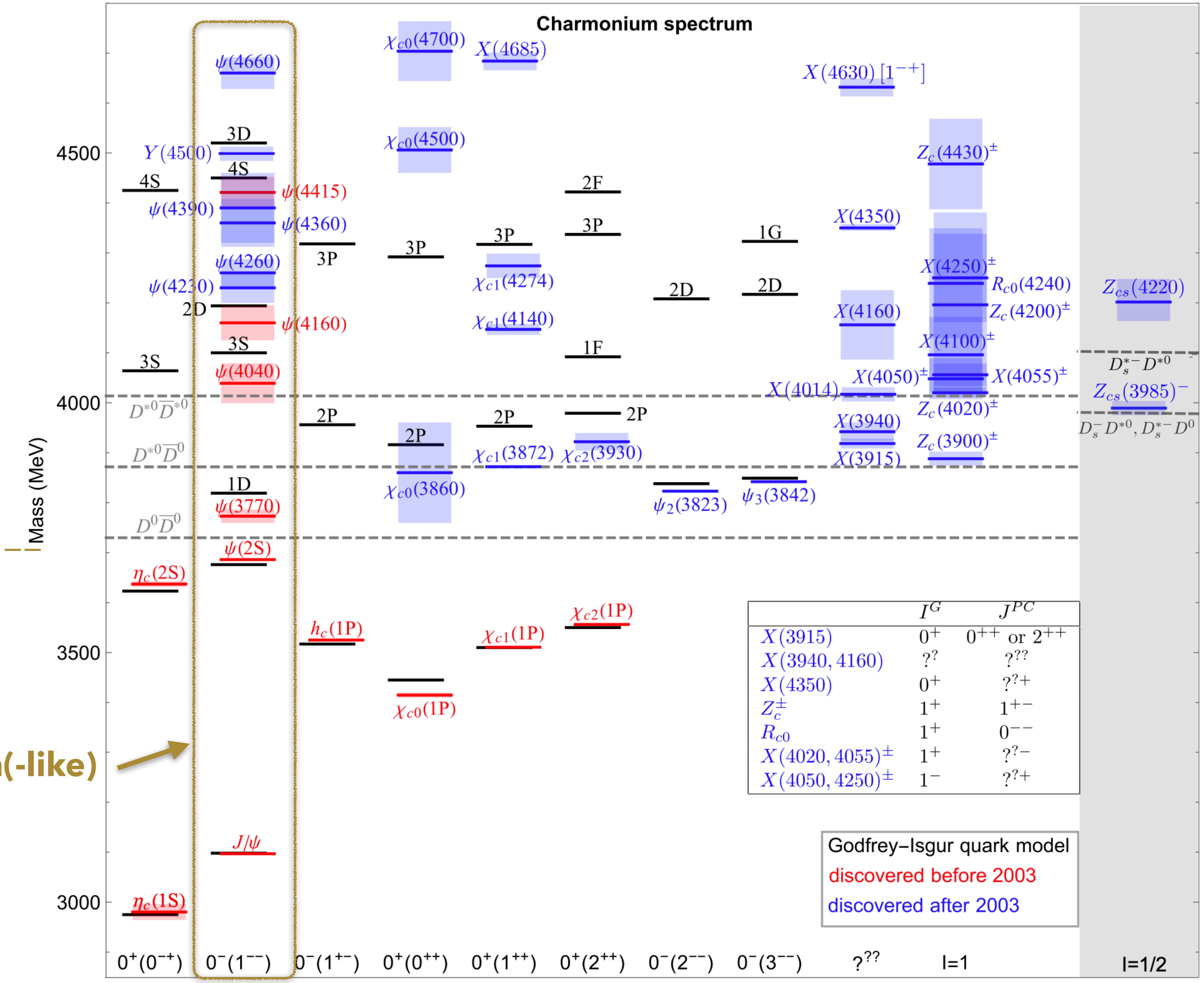
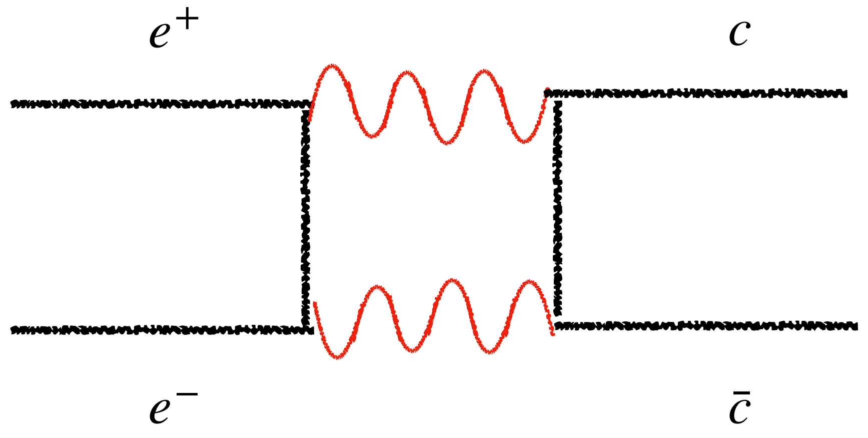
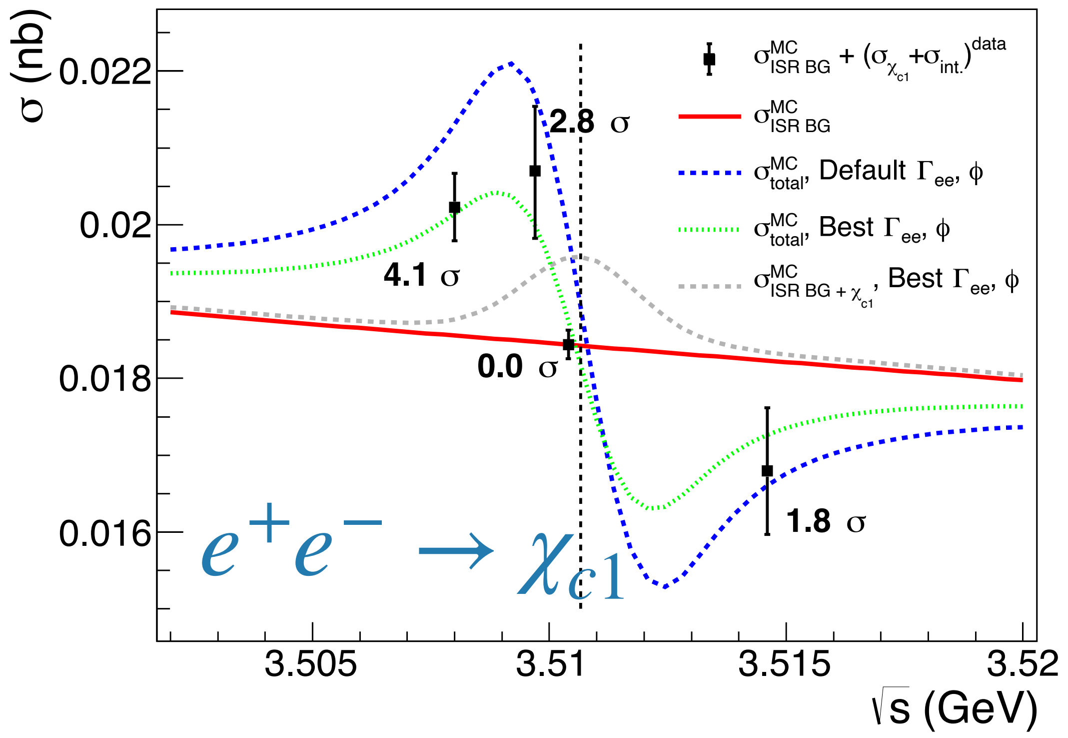


from F. K. Guo

C-even states

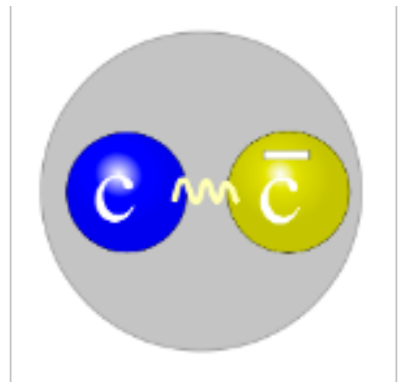


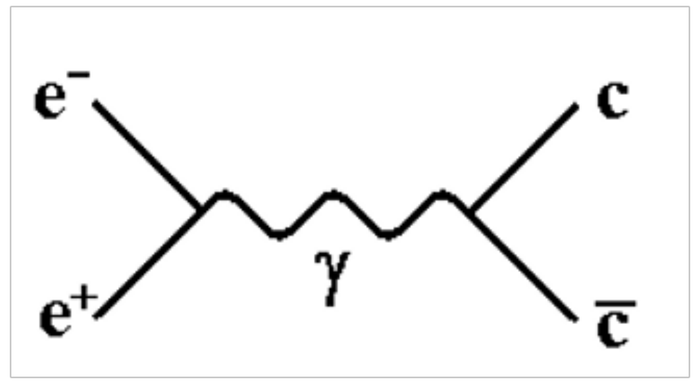
PRL129, 122001 (2022)



$$\Gamma_{ee} = (0.12^{+0.13}_{-0.08})\ \text{eV}$$

Charmonium Production at BESIII





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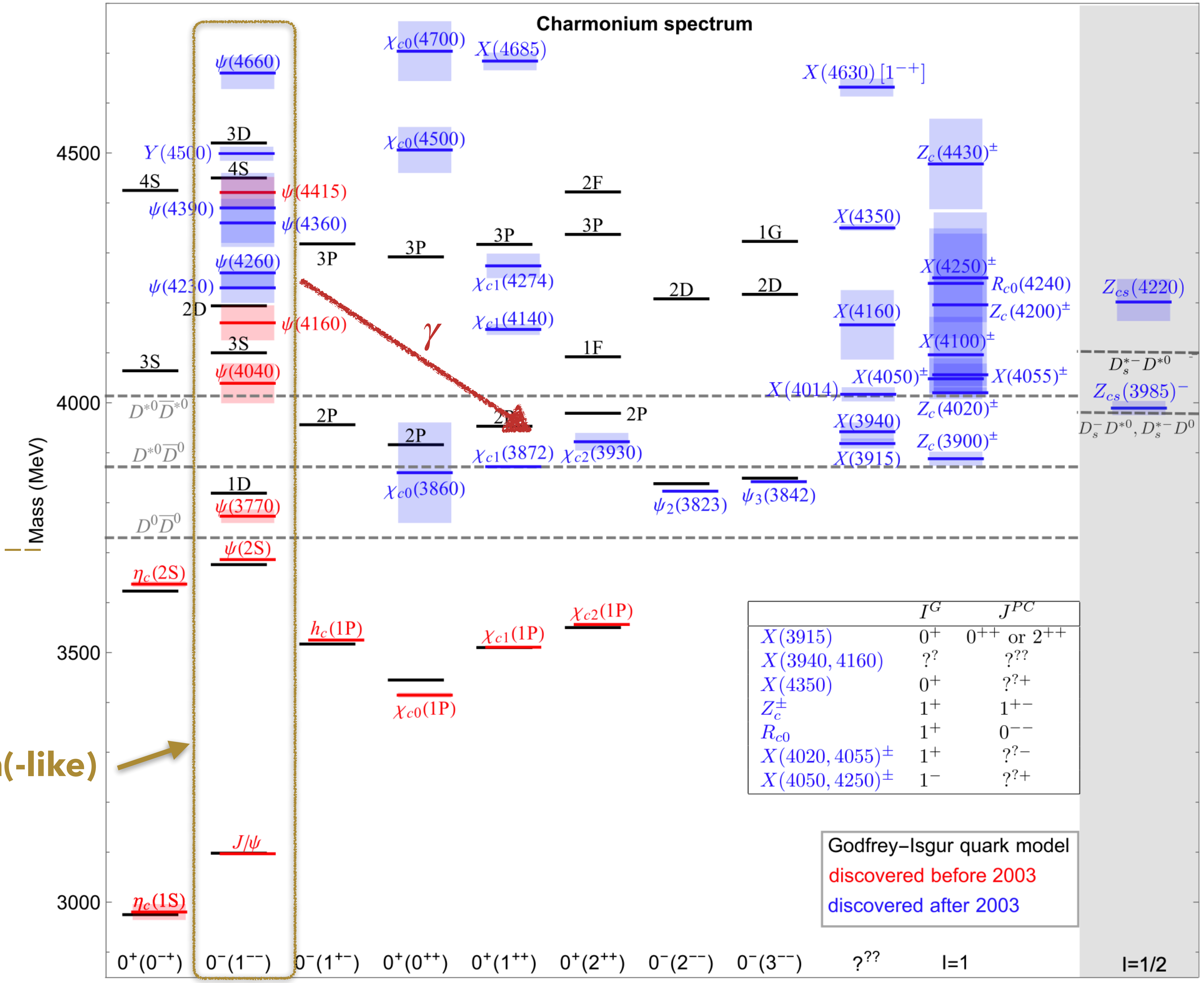

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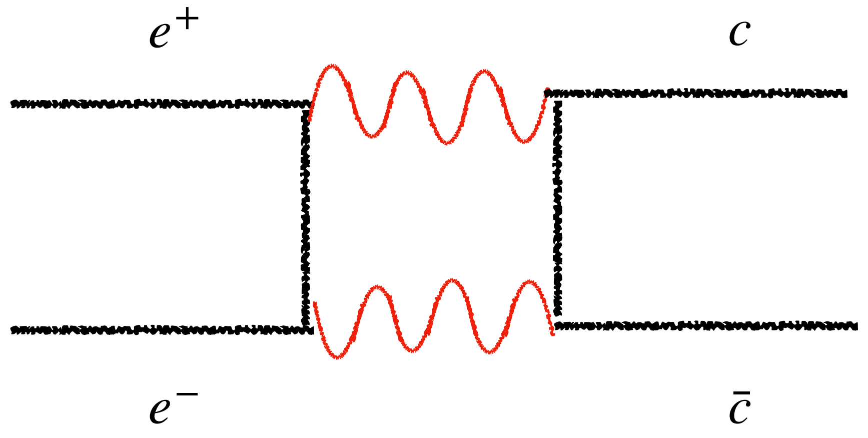

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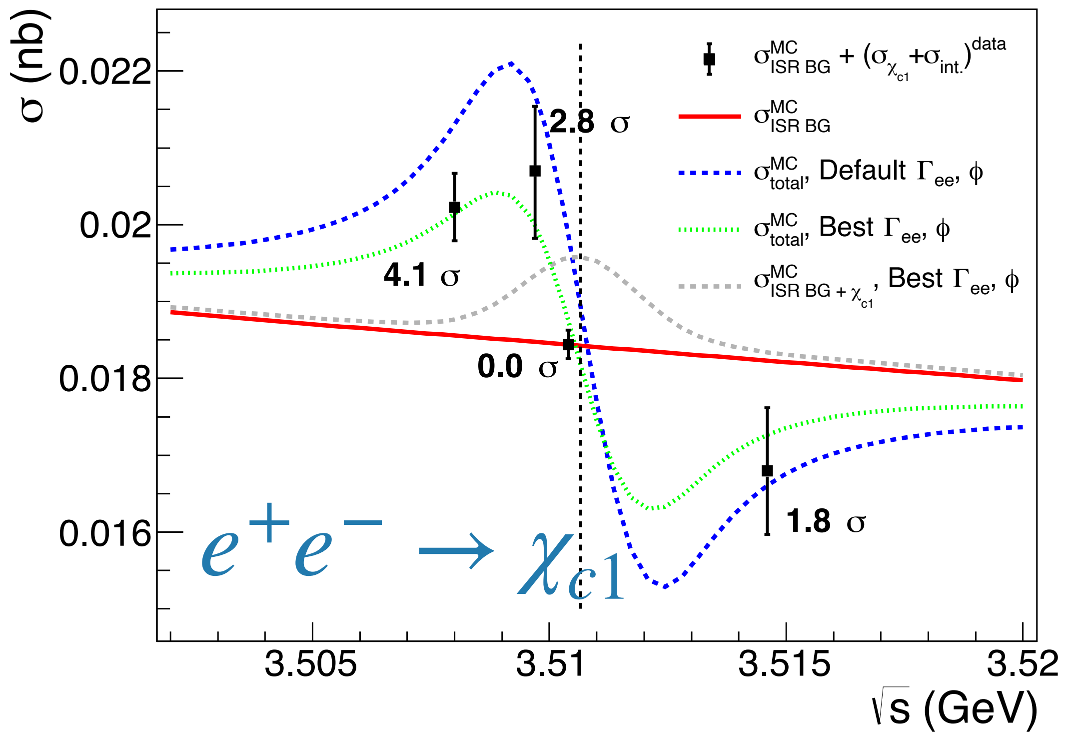

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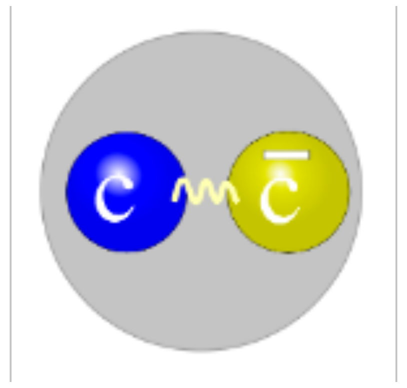

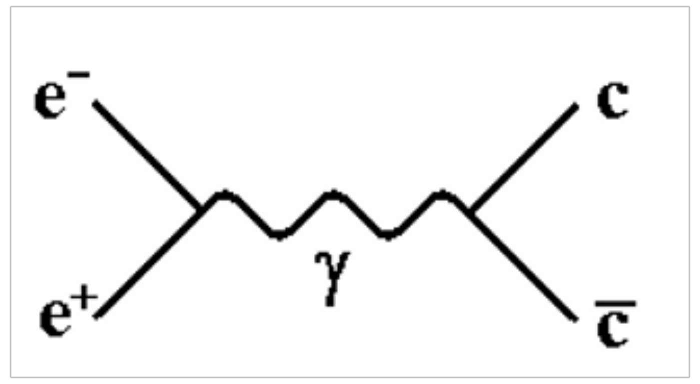

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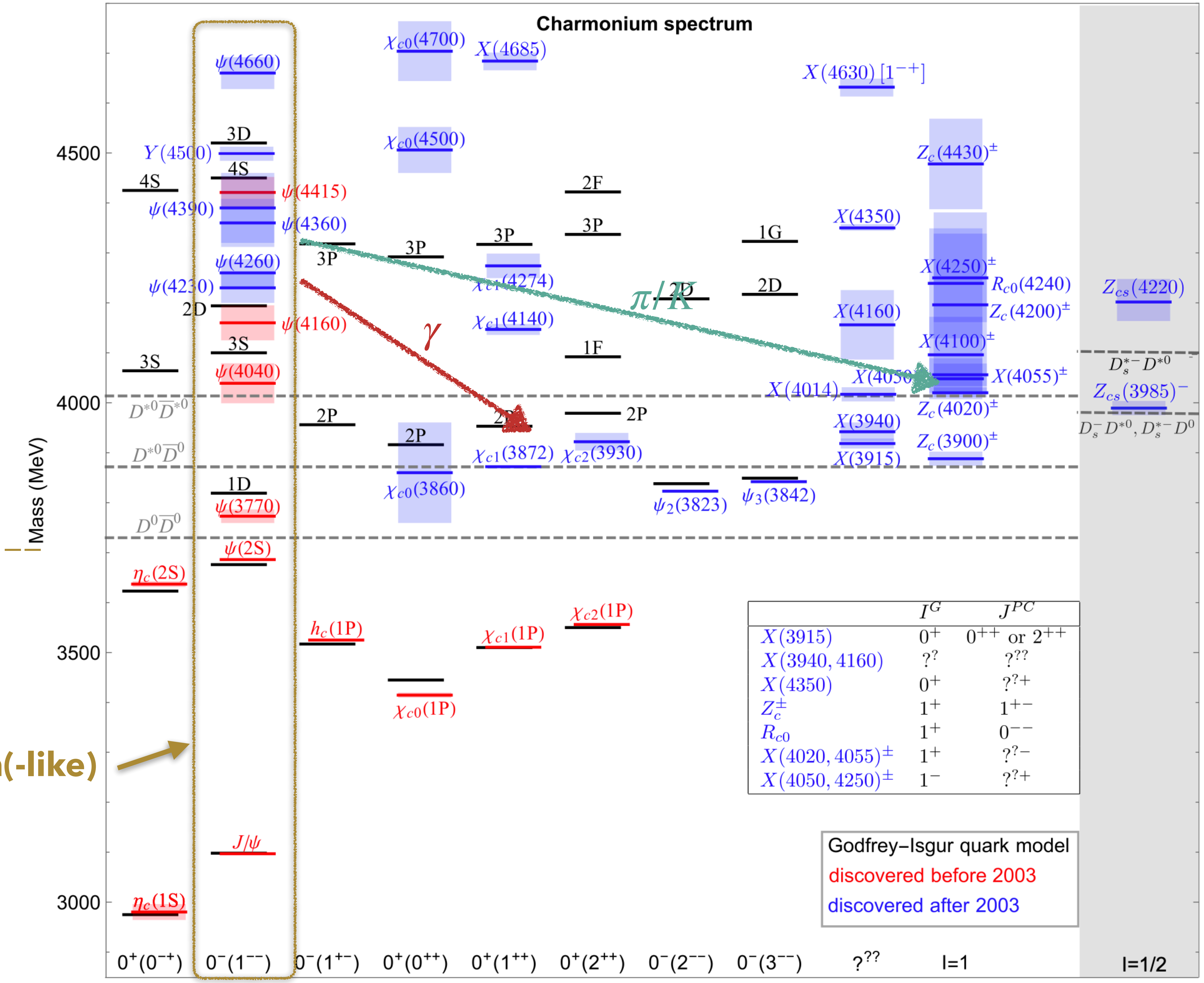

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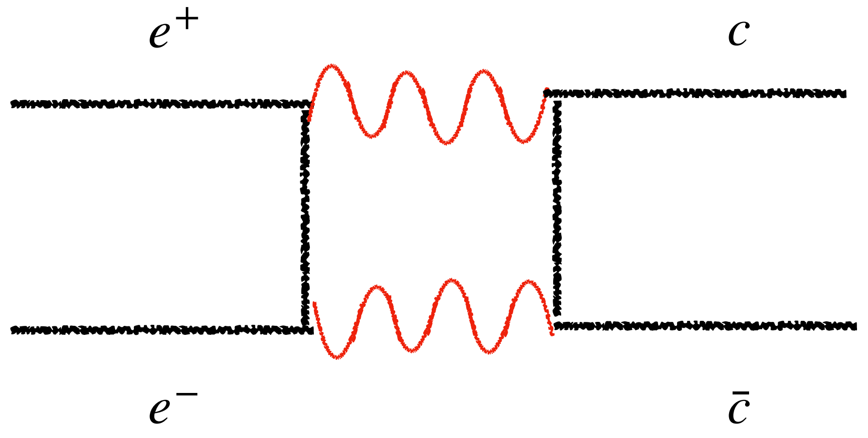

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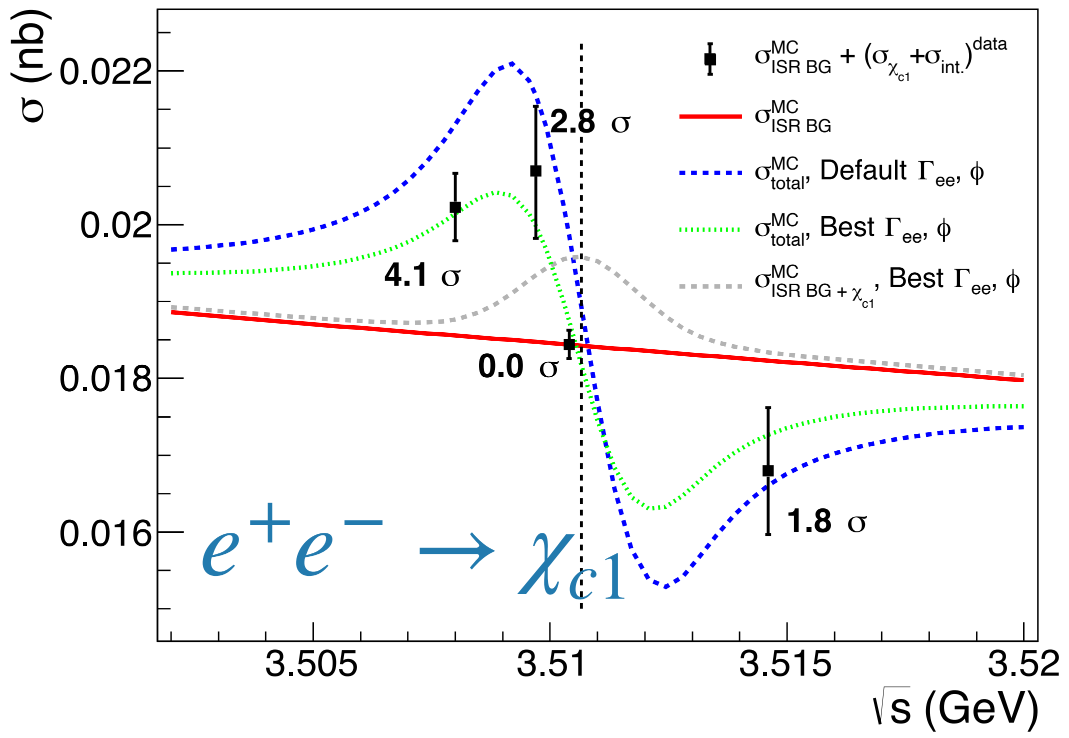
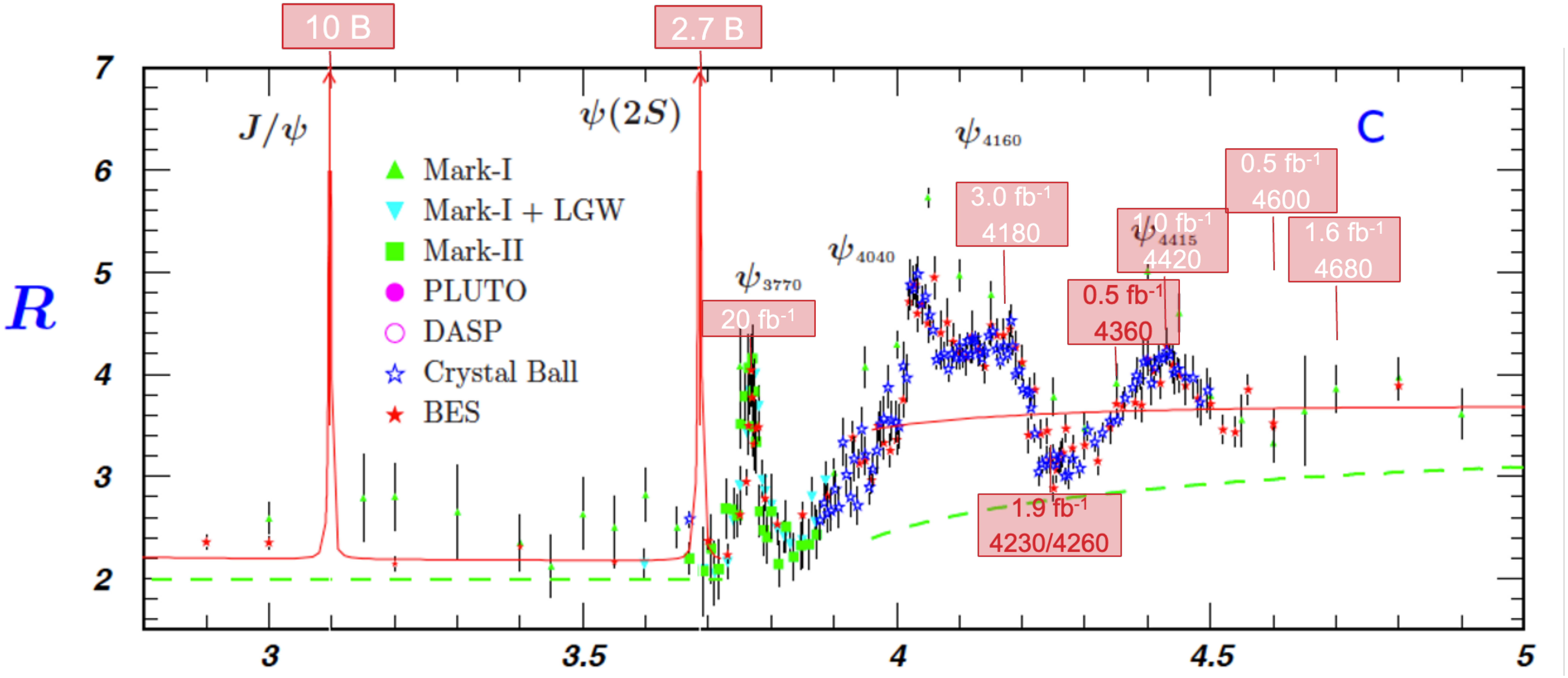


$\Gamma_{ee} = (0.12^{+0.13}_{-0.08})$ eV

BESIII Data Samples



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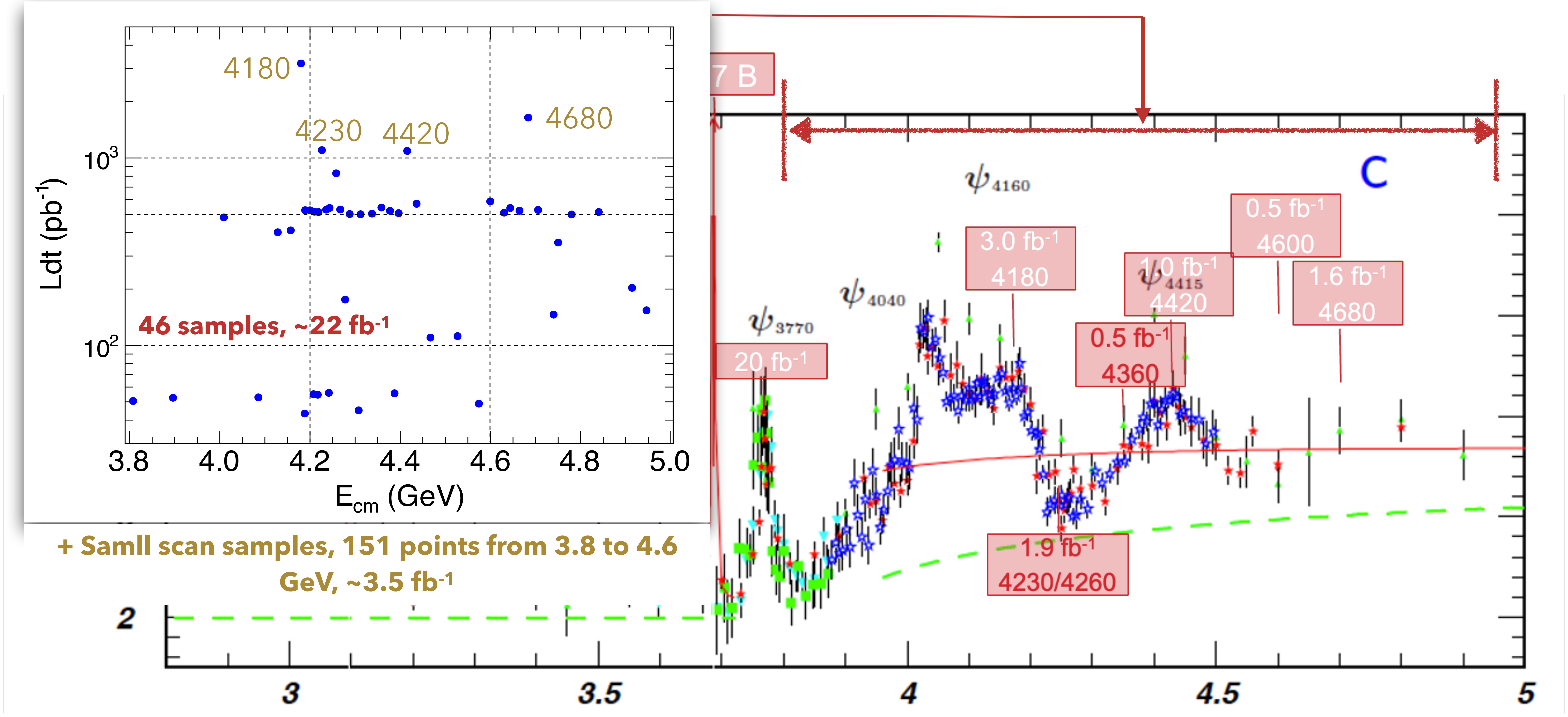
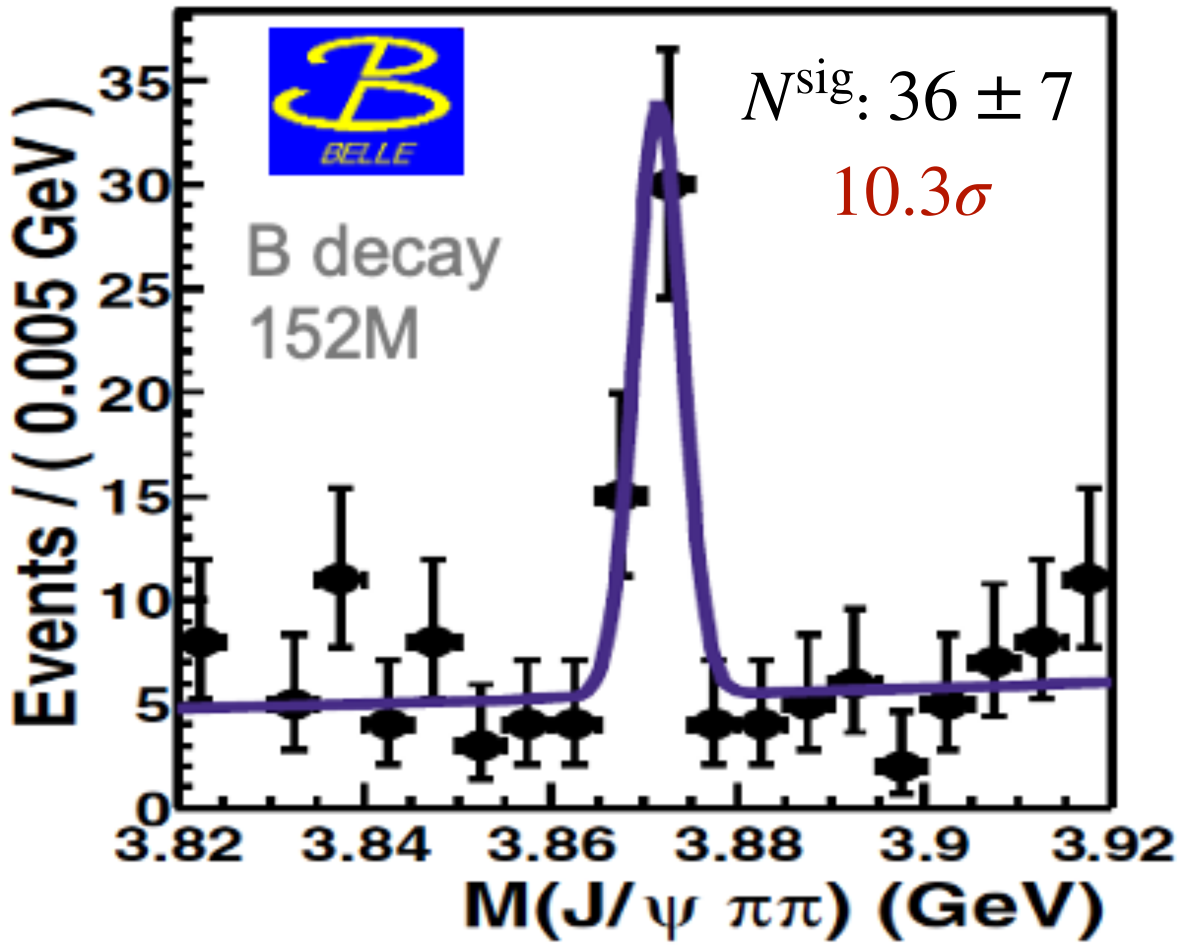


+ Samll scan samples, 151 points from 3.8 to 4.6 GeV, ~3.5 fb^{-1}

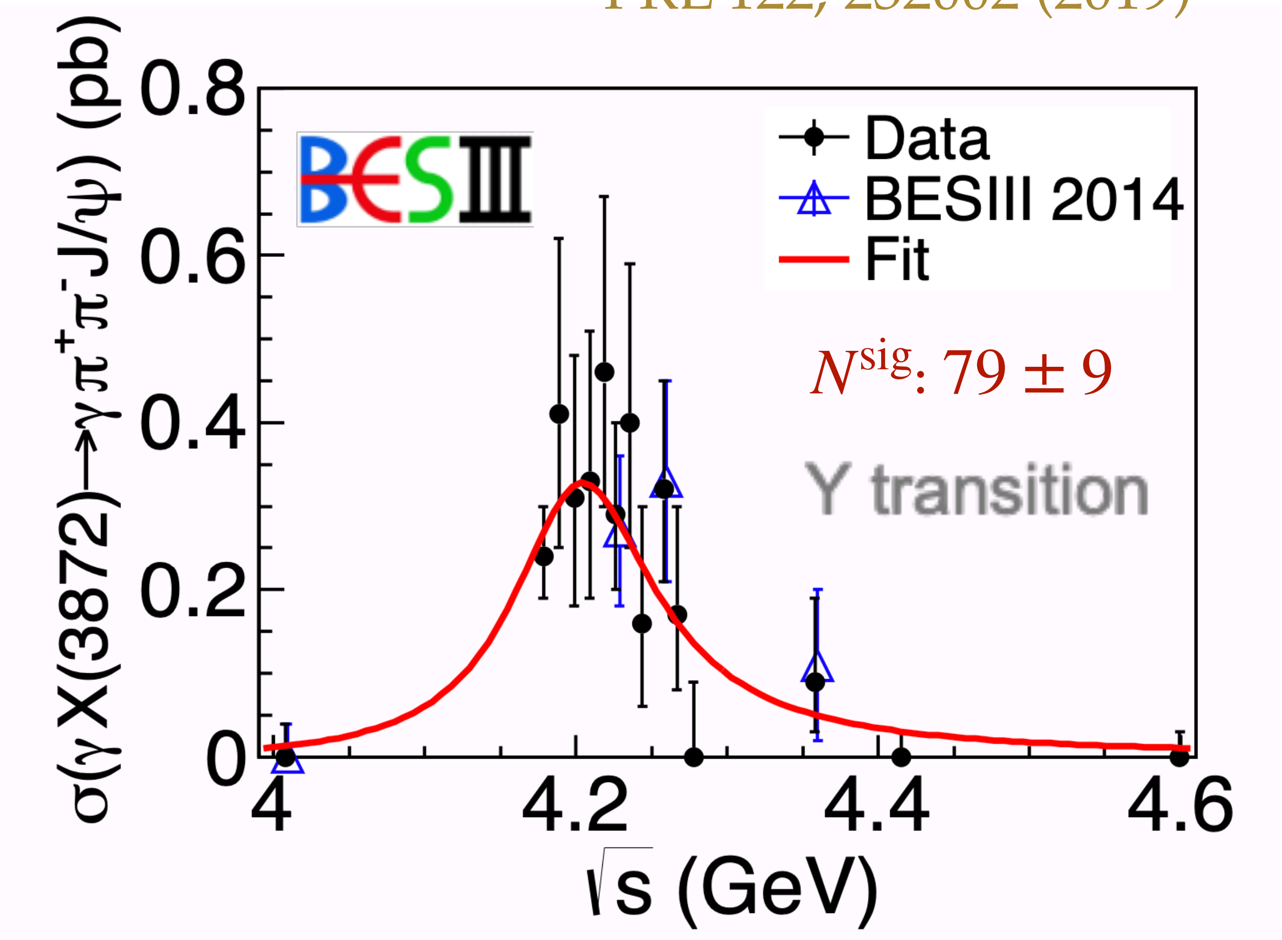
X(3872) [$\chi_{c1}(3872)$]

- 2003, observed by Belle experiment in $B^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}J/\psi$ process
- $J^{PC} = 1^{++}$ [2013, LHCb] PRL 110, 222001 (2013)
- Production: B decays, B_s decays, Λ_b decays,
  $p\bar{p}$ collision, pp collision, $PbPb$ collision,
  e^+e^- radiative/hadronic transition, $\gamma\gamma^*$ process
- Decay: $D^0\bar{D}^{*0}$, $\pi^+\pi^-J/\psi$, $\pi^+\pi^-\pi^0J/\psi$, $\pi^0\chi_{cJ}$, $\gamma J/\psi$, $\gamma\psi(2S)$

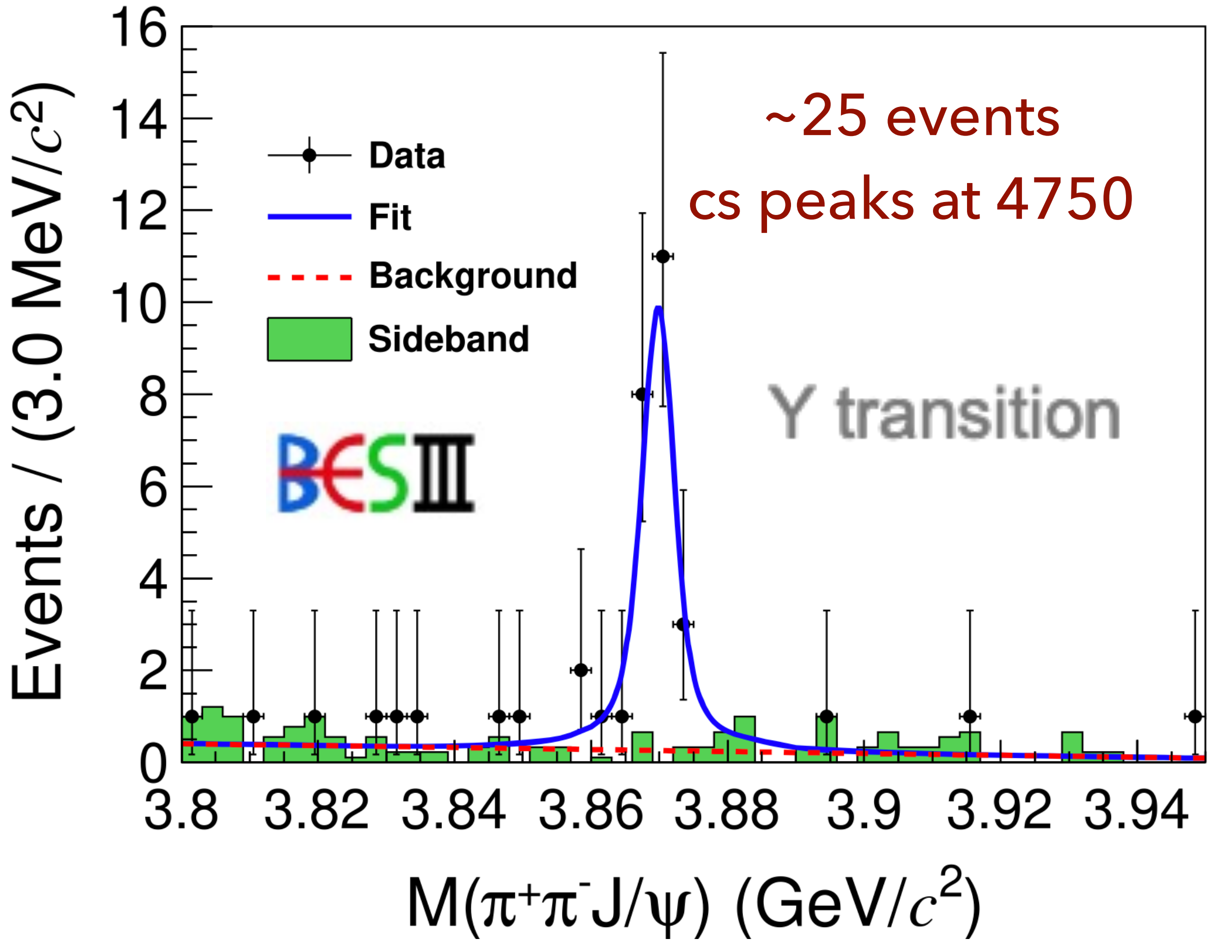
PRL 91, 262001 (2003)

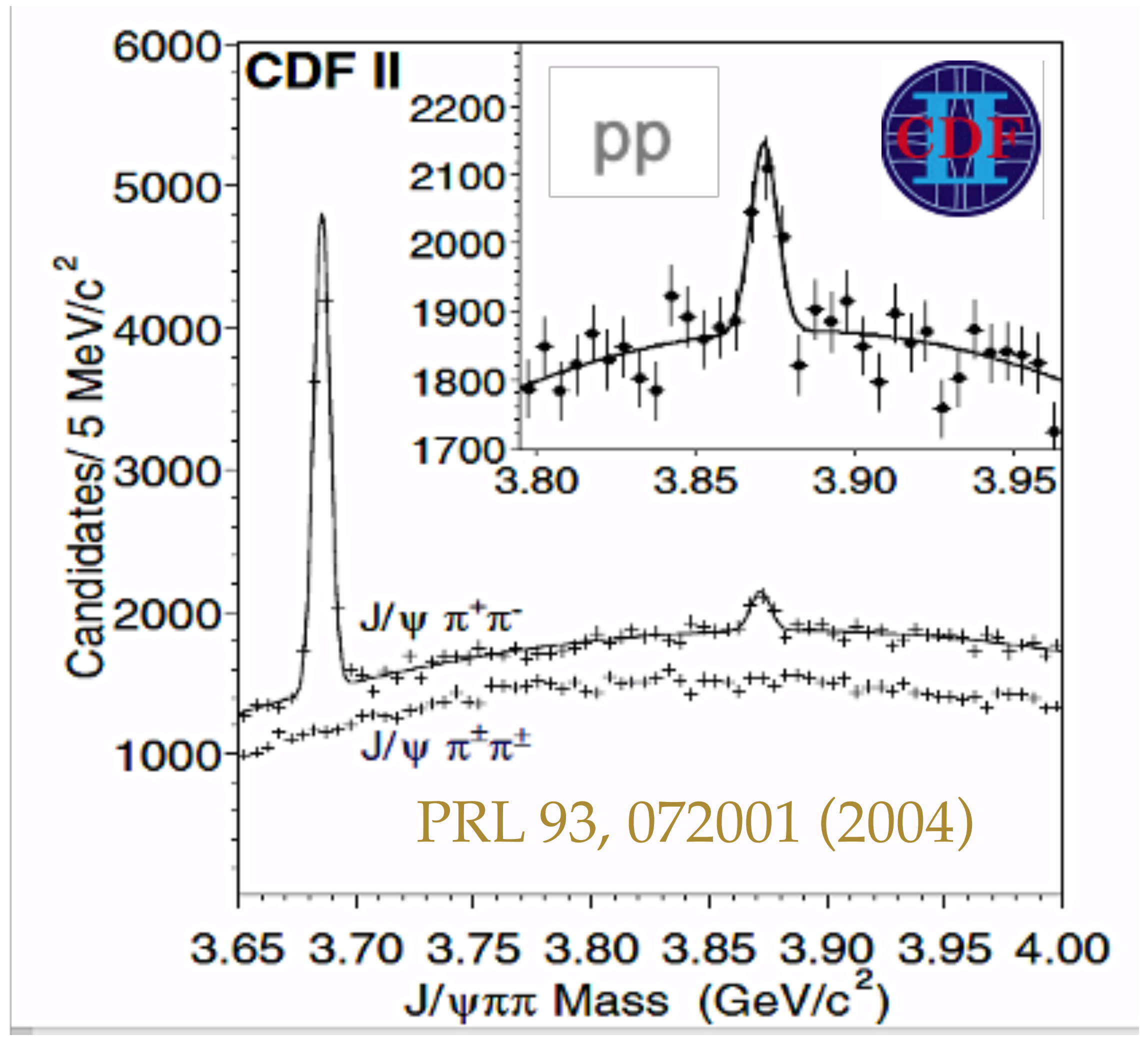


PRL 122, 232002 (2019)



PRL130, 151904 (2023)





PRL 93, 072001 (2004)

X(3872) Mass

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$\chi_{c1}(3872)$ MASS FROM $J/\psi X$ MODE — 3871.64 ± 0.06 MeV

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
3871.64 ± 0.06	**OUR AVERAGE**				
$3870.2 \pm 0.7 \pm 0.3$	24.6	ABLIKIM	2023W	BES3	$e^+ e^- \to J/\psi(1S)\pi^+\pi^-\omega$
$3871.64 \pm 0.06 \pm 0.01$	19.8k	[1] AAIJ	2020S	LHCB	$B^+ \to J/\psi\pi^+\pi^- K^+$
$3871.9 \pm 0.7 \pm 0.2$	20	ABLIKIM	2014	BES3	$e^+ e^- \to J/\psi\pi^+\pi^-\gamma$
$3871.95 \pm 0.48 \pm 0.12$	0.6k	AAIJ	2012H	LHCB	$p\,p \to J/\psi\pi^+\pi^- X$
$3871.85 \pm 0.27 \pm 0.19$	170	[2] CHOI	2011	BELL	$B \to K\pi^+\pi^- J/\psi$
$3873\,^{+1.8}_{-1.6} \pm 1.3$	27	[3] DEL-AMO-SANCH..	2010B	BABR	$B \to \omega J/\psi K$
$3871.61 \pm 0.16 \pm 0.19$	6k	[4, 3] AALTONEN	2009AU	CDF2	$p\,\overline{p} \to J/\psi\pi^+\pi^- X$
$3871.4 \pm 0.6 \pm 0.1$	93.4	AUBERT	2008Y	BABR	$B^+ \to K^+ J/\psi\pi^+\pi^-$
$3868.7 \pm 1.5 \pm 0.4$	9.4	AUBERT	2008Y	BABR	$B^0 \to K^0_S\, J/\psi\pi^+\pi^-$
$3871.8 \pm 3.1 \pm 3.0$	522	[5, 3] ABAZOV	2004F	D0	$p\,\overline{p} \to J/\psi\pi^+\pi^- X$

- Mass very close to $D\bar{D}^*$ mass threshold: [(3871.69 ± 0.11) MeV]
- $E_b = -0.05 \pm 0.12$ MeV [deuteron: 2.2 MeV]

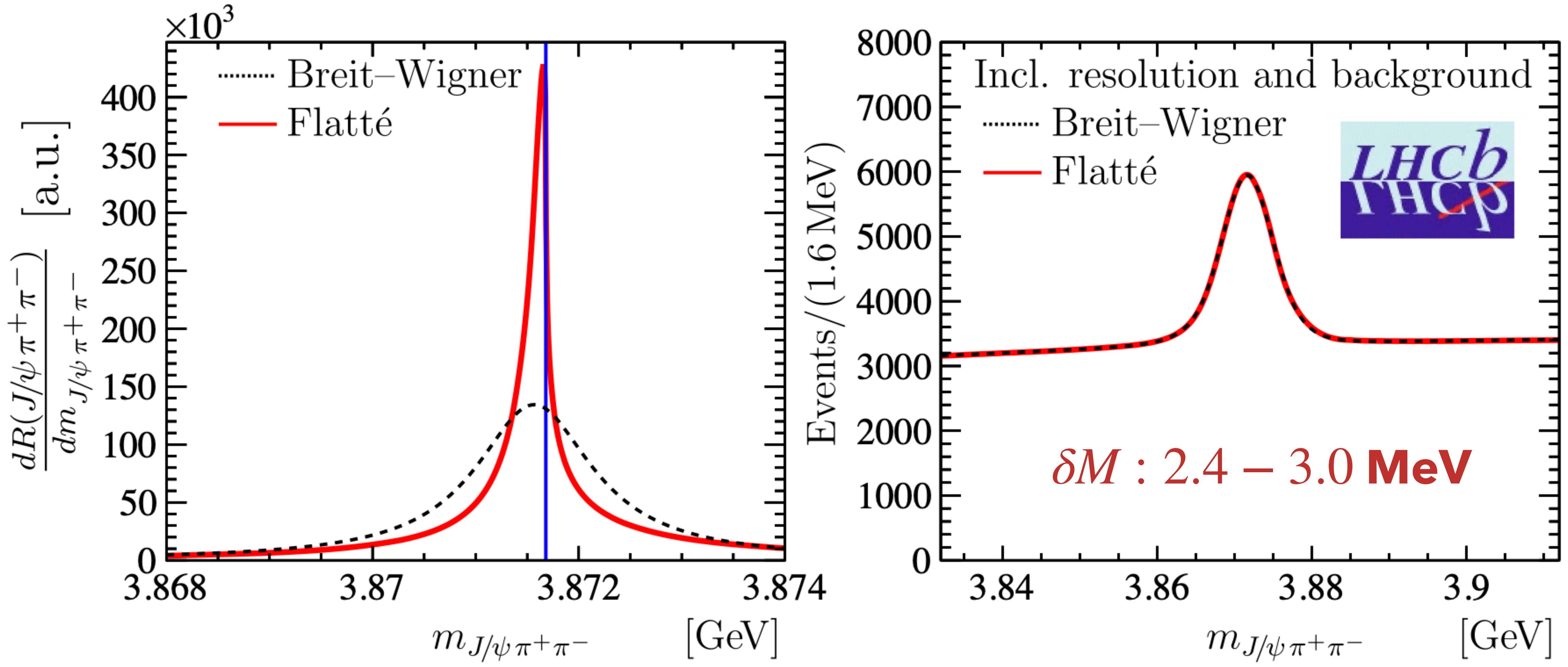
X(3872)-Width

$\chi_{c1}(3872)$ WIDTH — 1.19 ± 0.21 MeV (S = 1.1)

VALUE (MeV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
1.19 ± 0.21	OUR AVERAGE	Error includes scale factor of 1.1.				
$1.39 \pm 0.24 \pm 0.10$		15.6k	[1] AAIJ	2020AD	LHCB	$p\,p \to J/\psi\pi^+\pi^- X$
$0.96\ ^{+0.19}_{-0.18} \pm 0.21$		4.2k	[2] AAIJ	2020S	LHCB	$B^+ \to J/\psi\pi^+\pi^- K^+$

LHCb: PRD 102, 092005 (2020)

BW Width



LHCb: PRD 102, 092005 (2020)

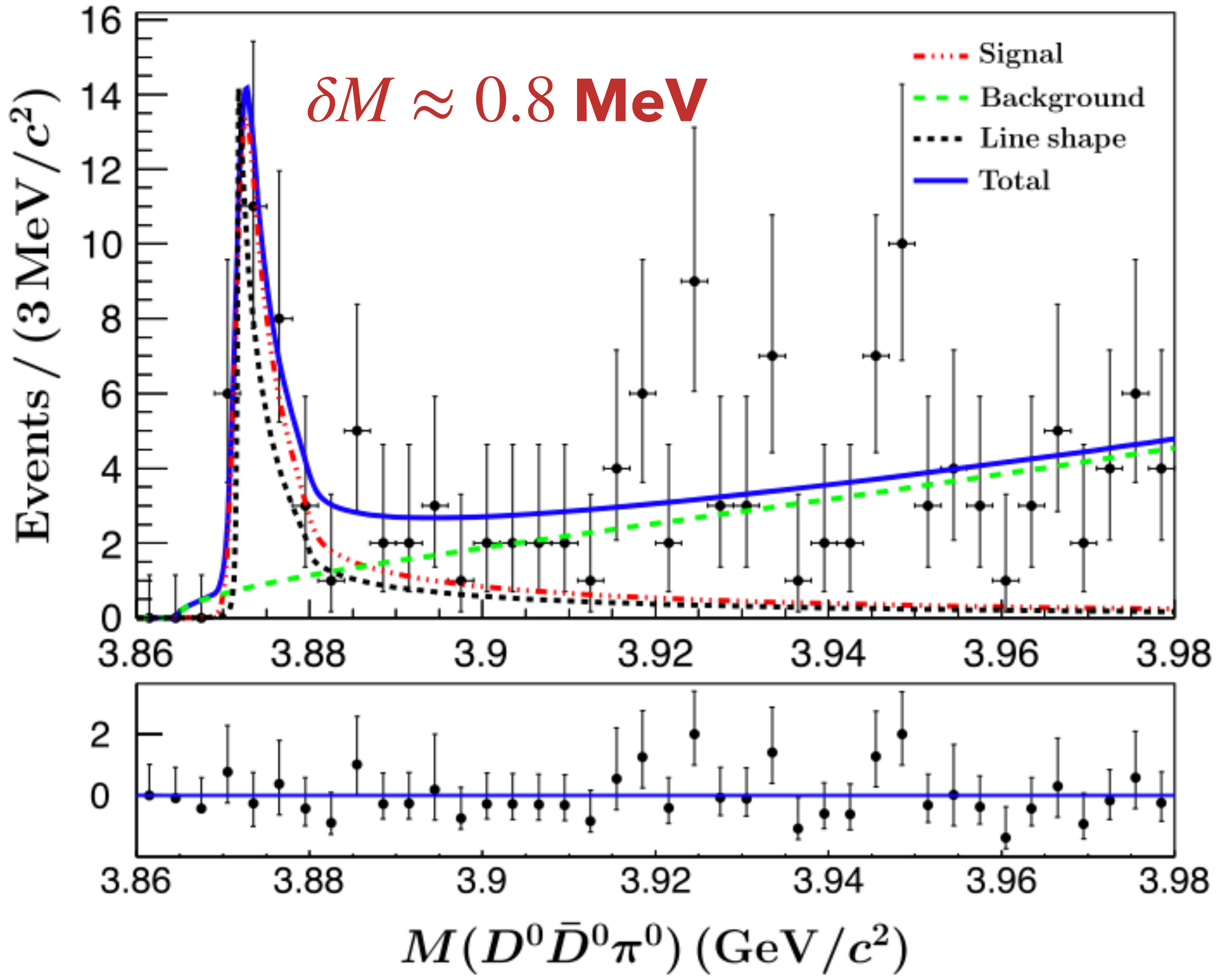
- Flatté parameterization:

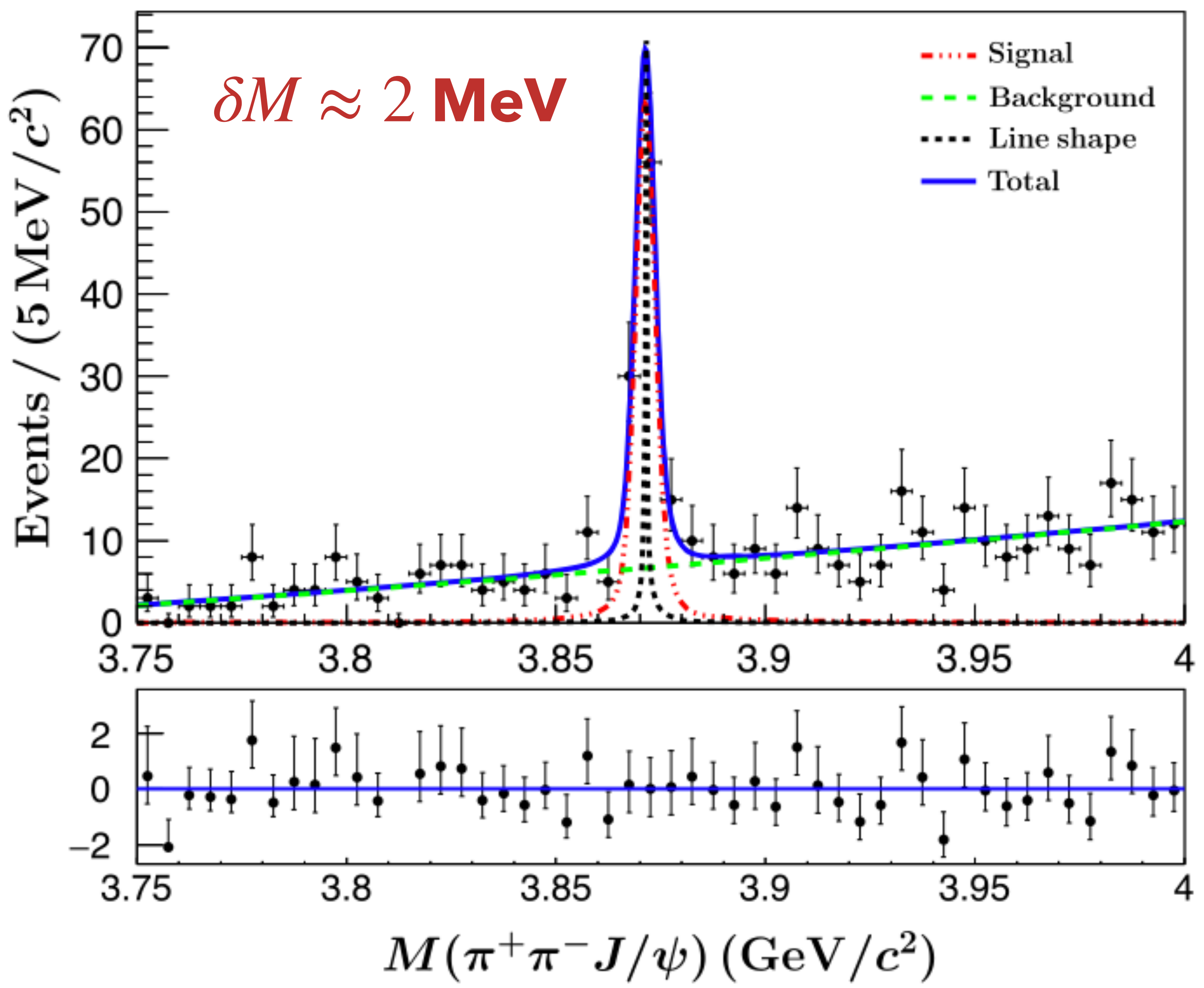
$$\frac{dR(J/\psi\pi^+\pi^-)}{dE} \propto \frac{\Gamma_\rho(E)}{|D(E)|^2}$$

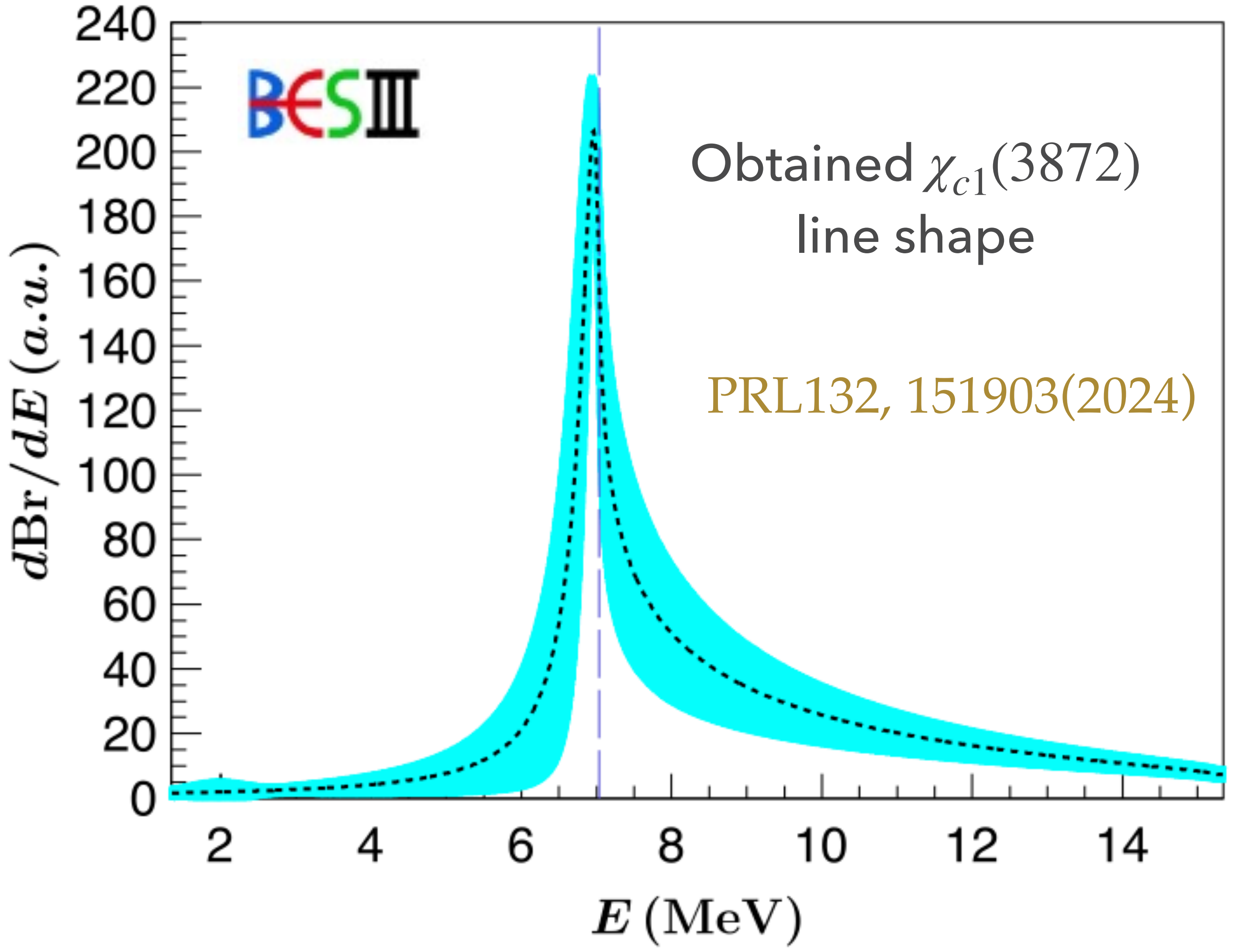
$$D(E) = E - E_f + \frac{i}{2}[g(k_1 + k_2) + \Gamma_\rho(E) + \Gamma_\omega(E) + \Gamma_0]$$

FWHM:$0.22^{+0.06+0.25}_{-0.08-0.17}$ MeV, depends strongly on the coupling to open-charm final state

Coupled-channel Analysis of X(3872)







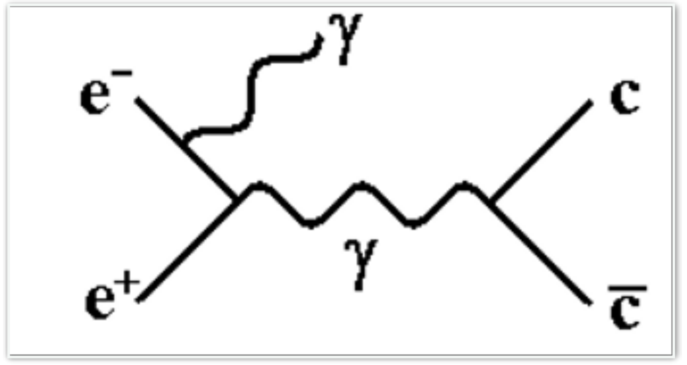
$M_X = (3871.63 \pm 0.13^{+0.06}_{-0.05})$ MeV

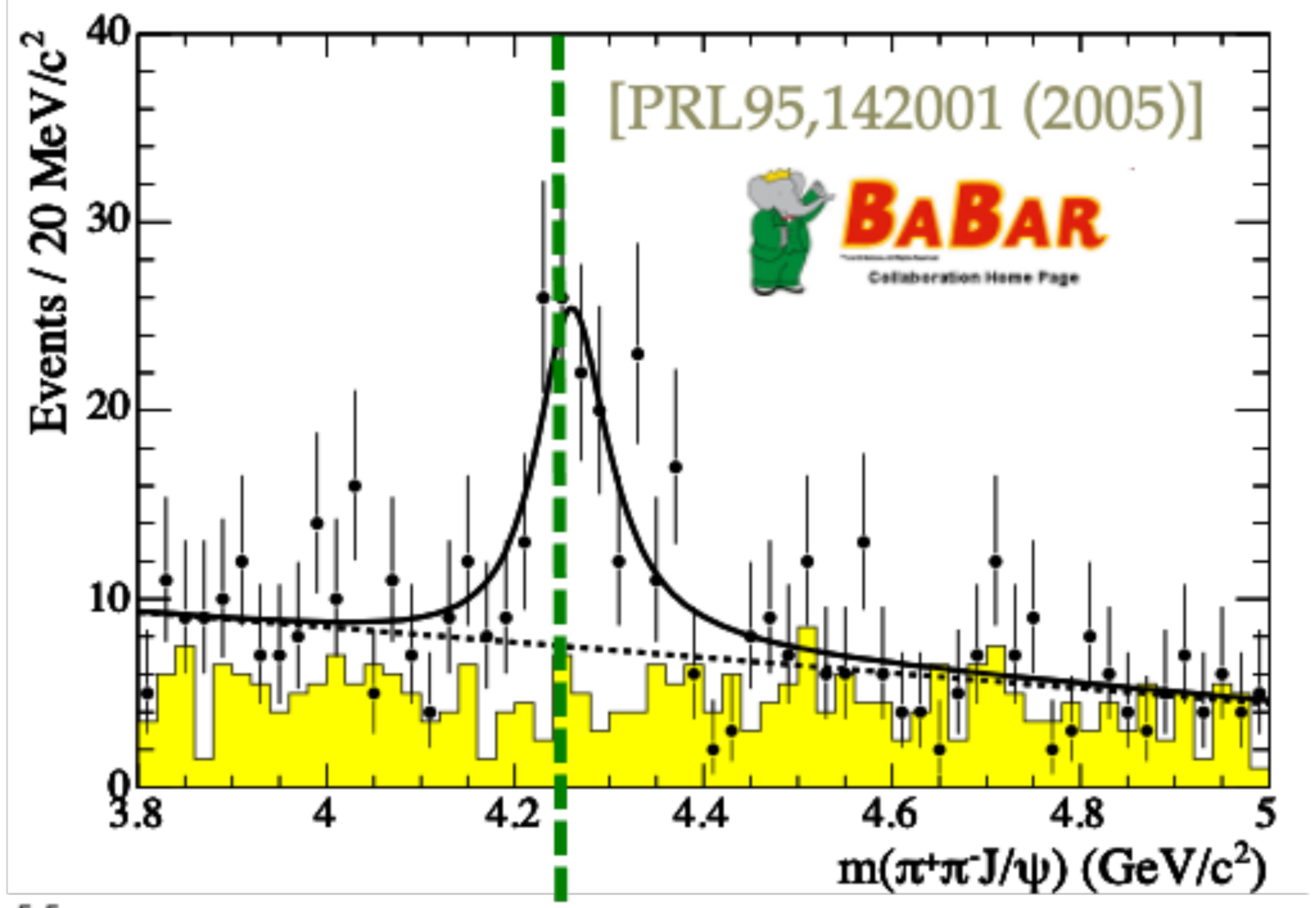
- $$\frac{dB(D^0\bar{D}^0\pi^0)}{dE} = \boldsymbol{B}\frac{1}{2\pi} \times \frac{g * k_{\mathrm{eff}}(E)}{|D(E)|^2} \times \mathrm{Br}(D^{*0} \to D^0\pi^0)$$
  $$\frac{dB(\pi^+\pi^- J/\psi)}{dE} = \boldsymbol{B}\frac{1}{2\pi} \times \frac{\Gamma_{\pi^+\pi^- J/\psi}}{|D(E)|^2}$$
- Including the $D^*\bar{D}$ self energy term; the width of D^*; the coupled channel effect in the parameterization
- Weinberg's compositeness: Z=1 - pure elemental state; Z=0 -pure bound state

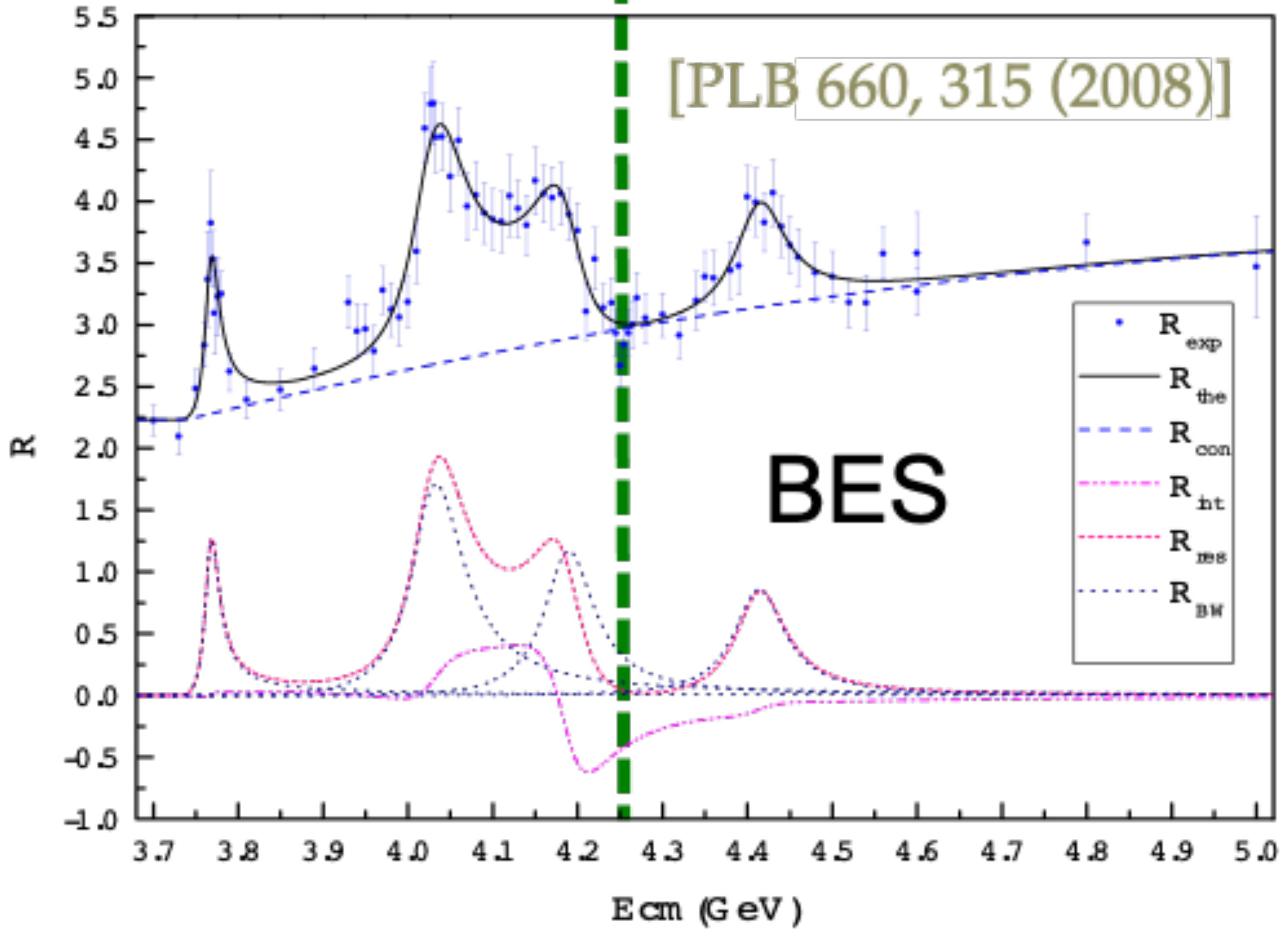
Parameters	BESIII	LHCb
g	$0.16 \pm 0.010^{+1.12}_{-0.11}$	$0.108 \pm 0.003^{+0.005}_{-0.006}$
Re[EI] (MeV)	$7.04 \pm 0.15^{+0.07}_{-0.08}$	7.10
Im[EI] (MeV)	$-0.19 \pm 0.08^{+0.14}_{-0.19}$	-0.13
$\Gamma[\pi^+\pi^- J/\psi]/\Gamma[D^0\bar{D}^{*0}]$	$0.05 \pm 0.01^{+0.01}_{-0.02}$	0.11 ± 0.03
FWHM (MeV)	$0.44^{+0.13+0.38}_{-0.35-0.25}$	$0.22^{+0.06+0.25}_{-0.08-0.17}$
Z	0.18	0.15 (0.33)

Y States[ψ(mass)]

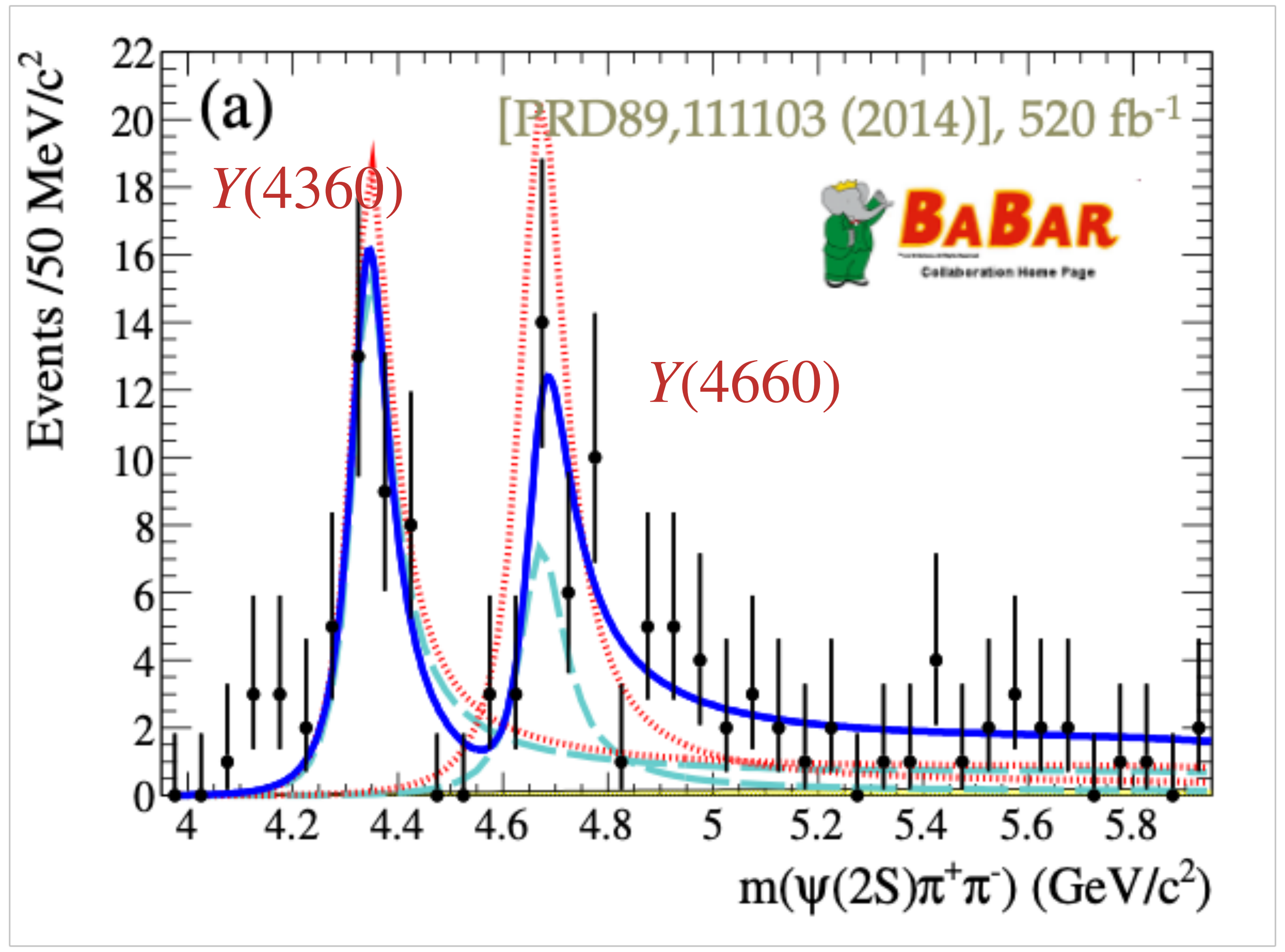
- $Y(4260)$, discovered in ISR process at BaBar, $e^+e^- \to \gamma_{\rm ISR}\pi^+\pi^- J/\psi$
  - Confirmed by CLEO and Belle
  - Mass > 4 GeV, above $D\bar{D}$ threshold
  - Not observed in inclusive hadron cross section
  - Not observed in open charm pair cross section

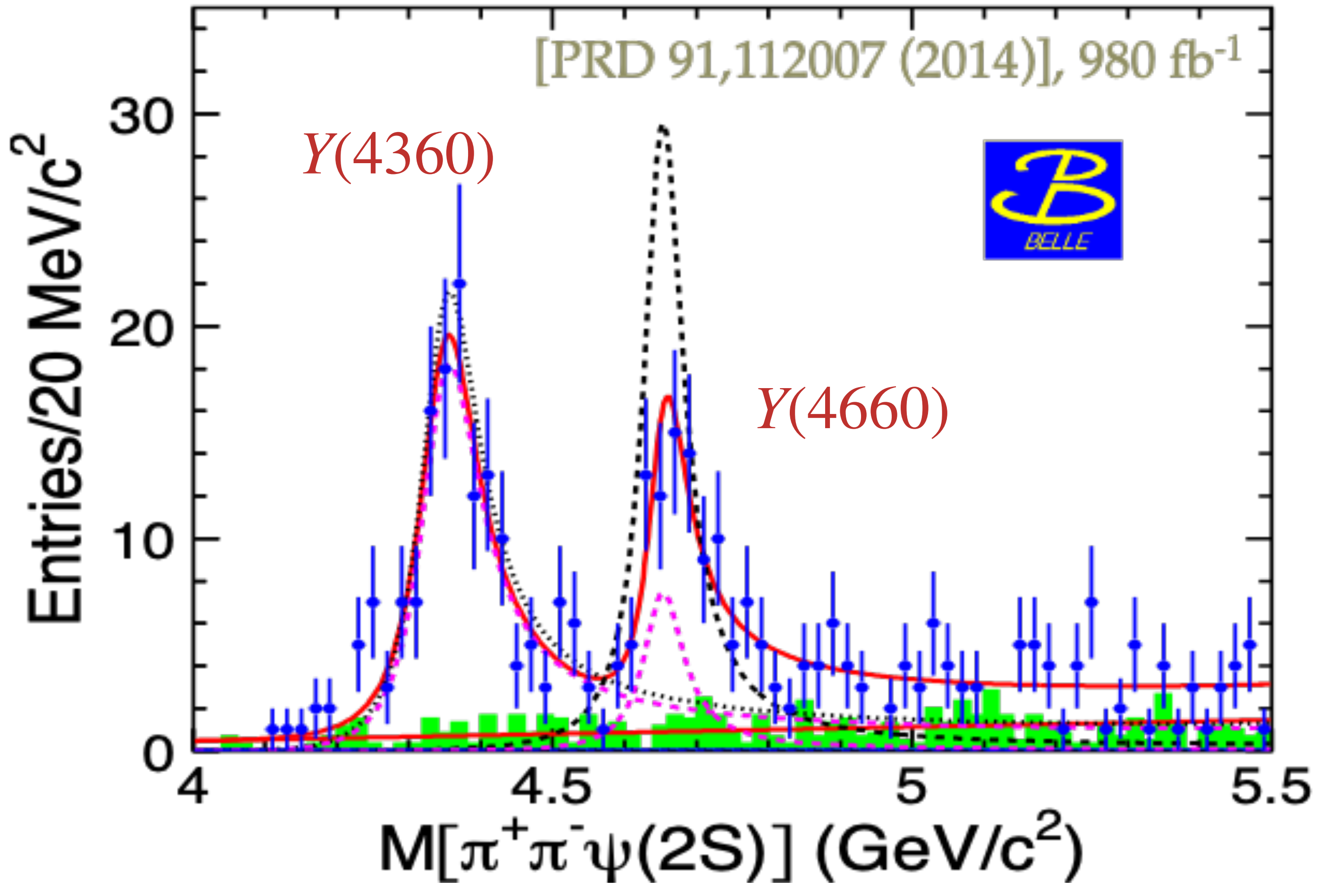






- Later, $Y(4360)$ was discovered at BaBar, $Y(4660)$ was discovered at Belle, both in $e^+e^- \to \gamma_{\rm ISR}\pi^+\pi^-\psi(2S)$ process





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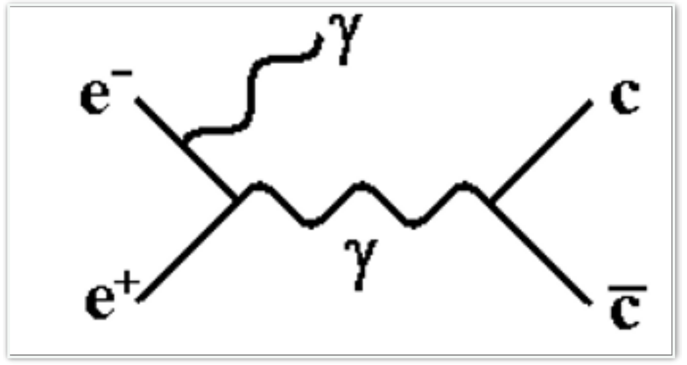

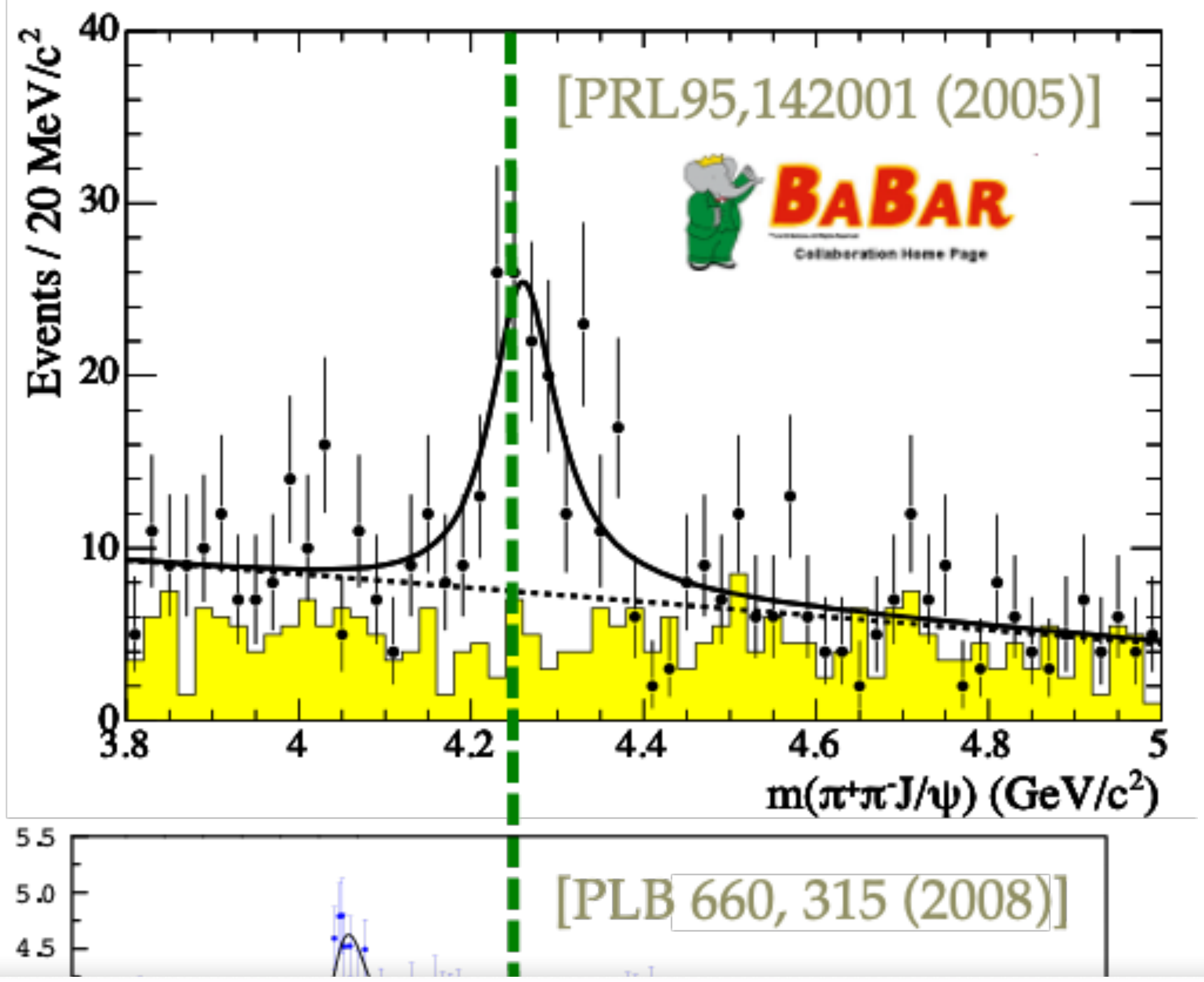

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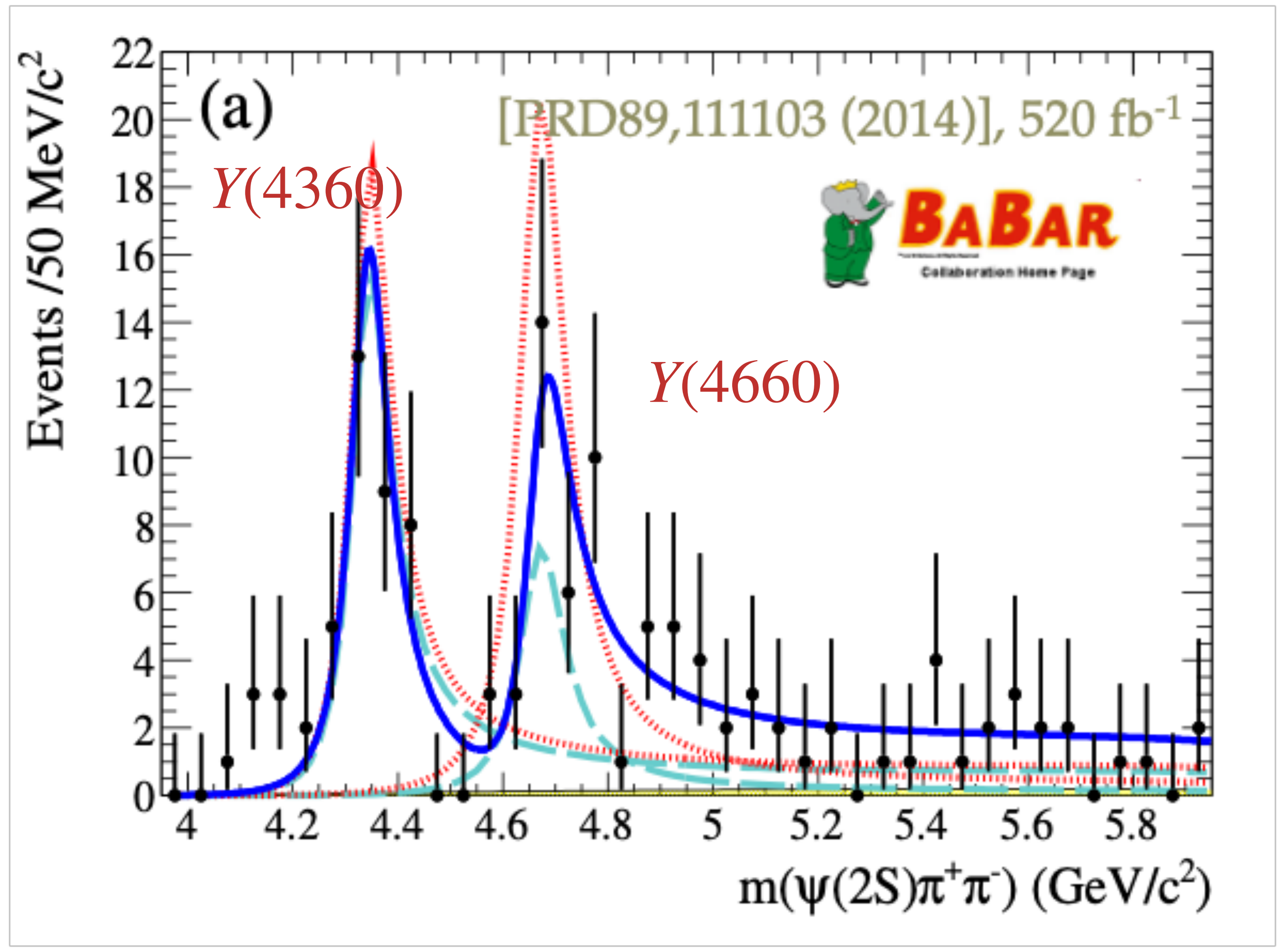
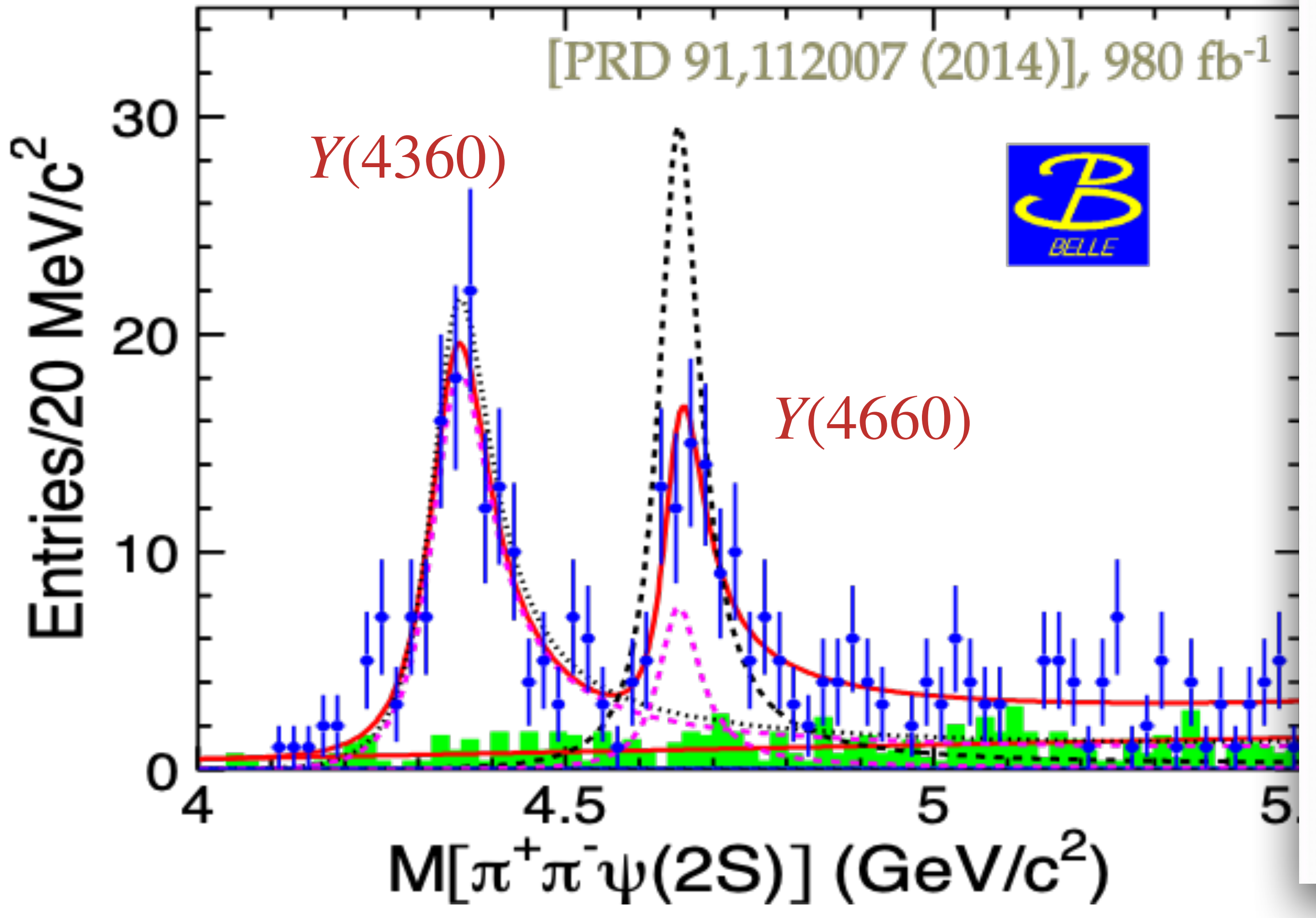
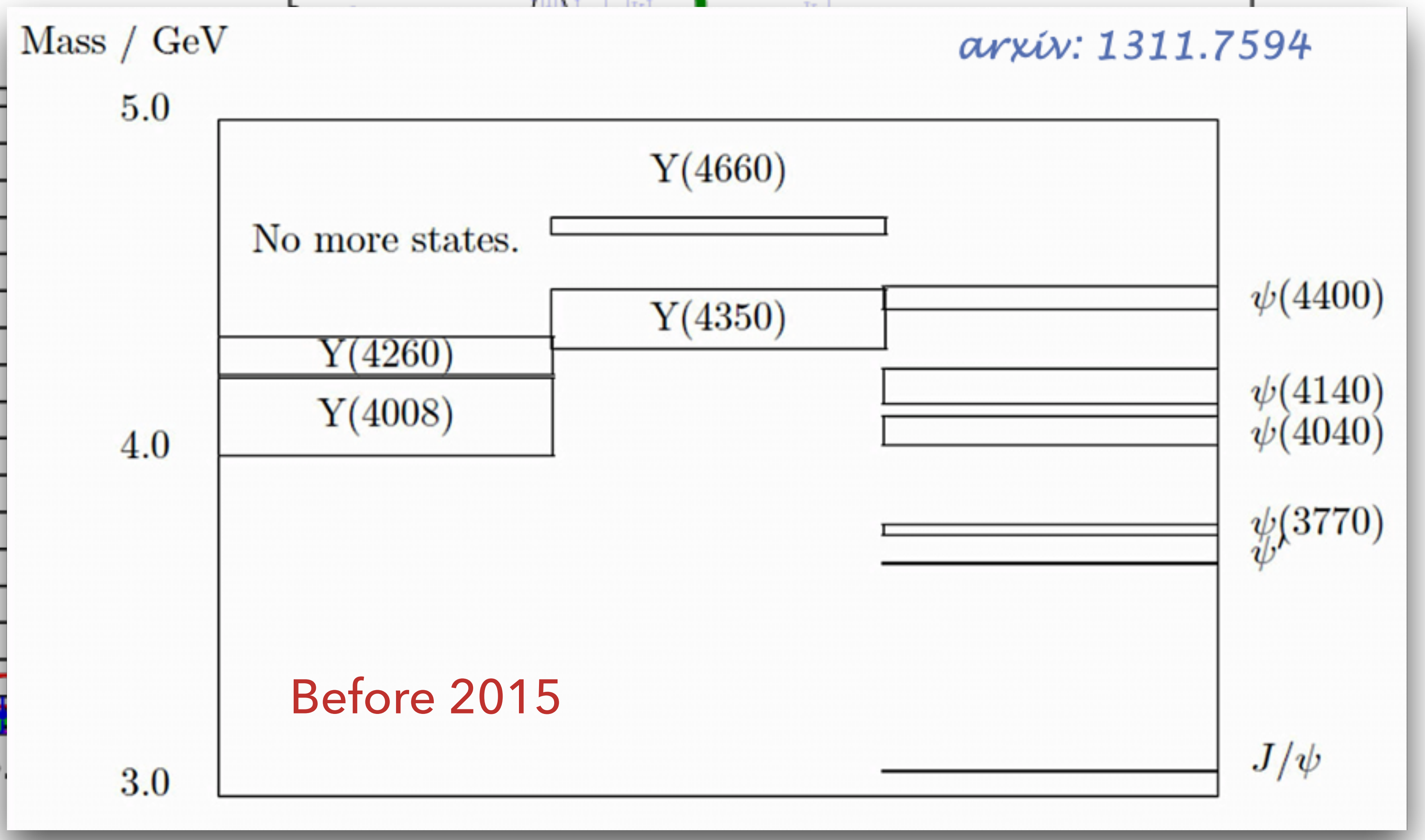
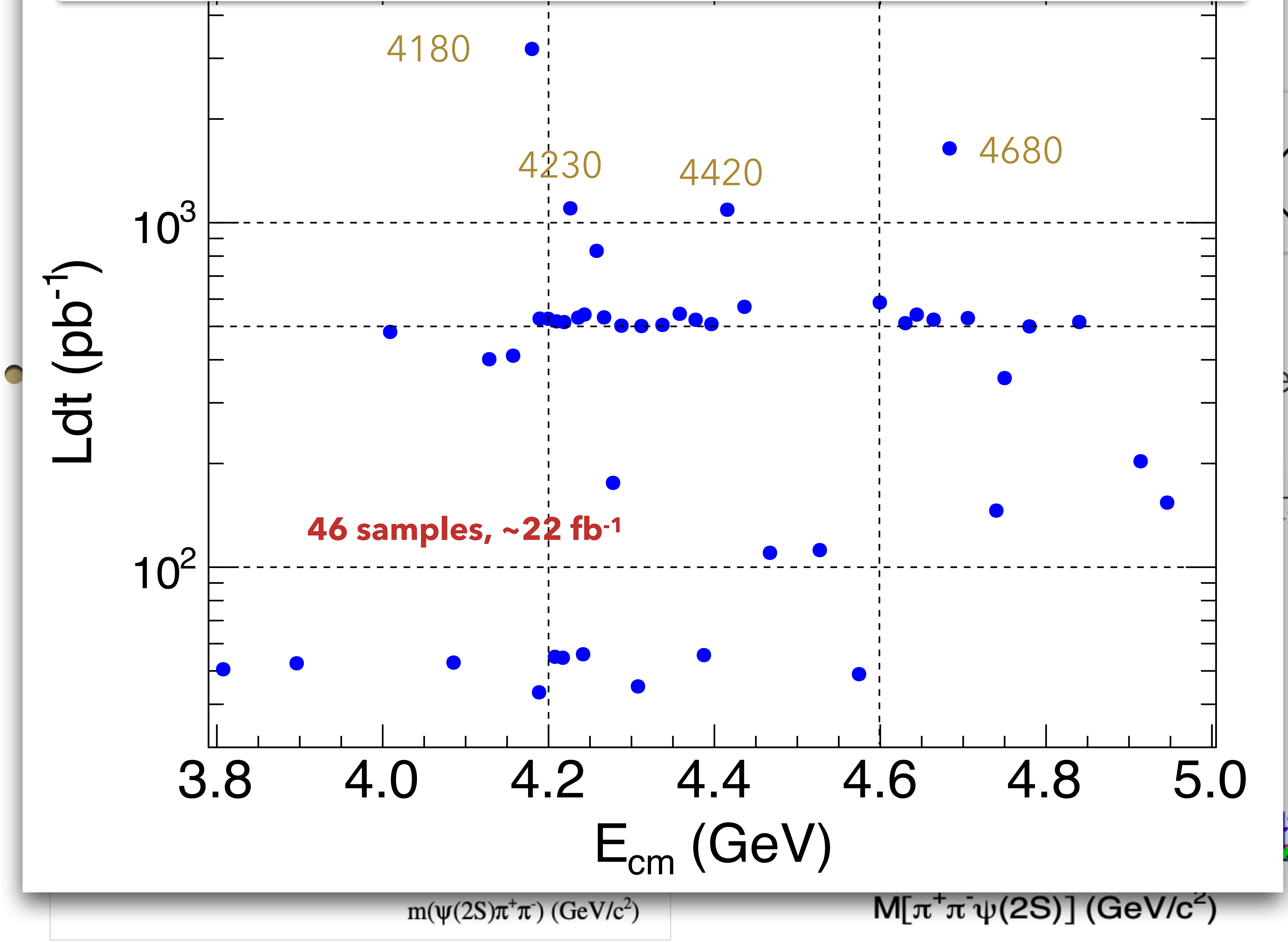


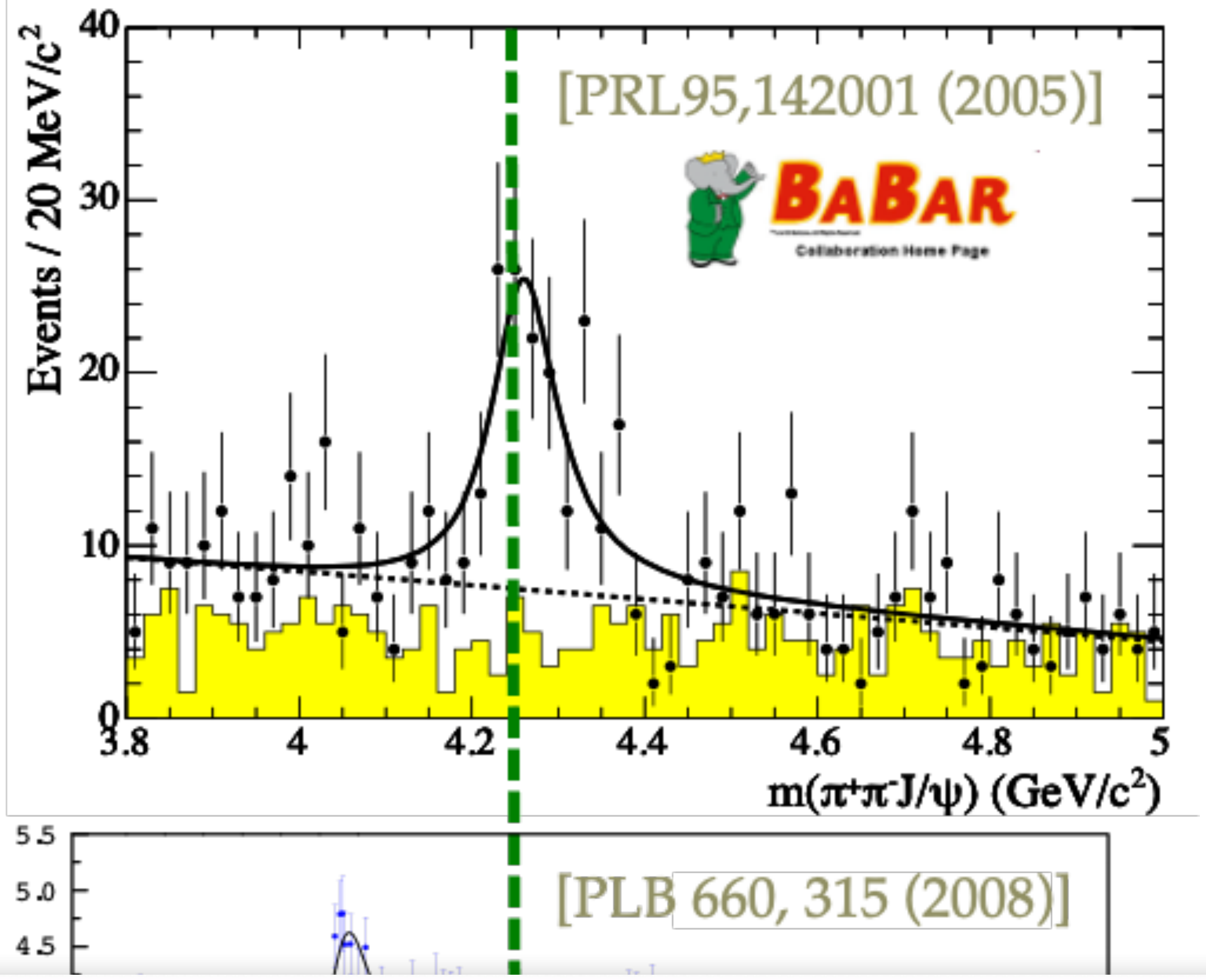


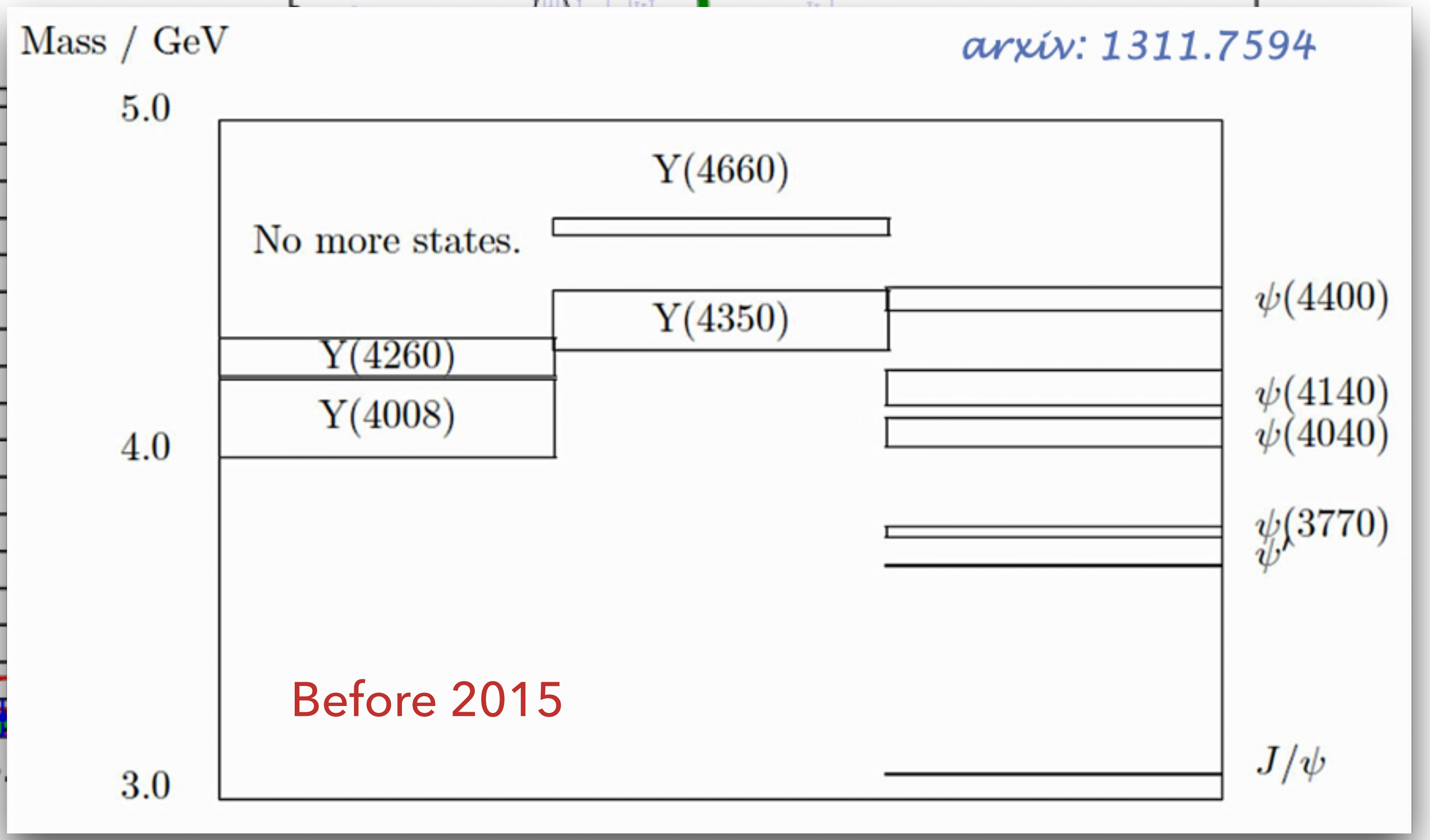


Y States[ψ(mass)]

Can measure $\sigma[e^+e^- \to h_i]$ (CS) with high precision ⇒ Y states







Overview of CS measurements at BESIII

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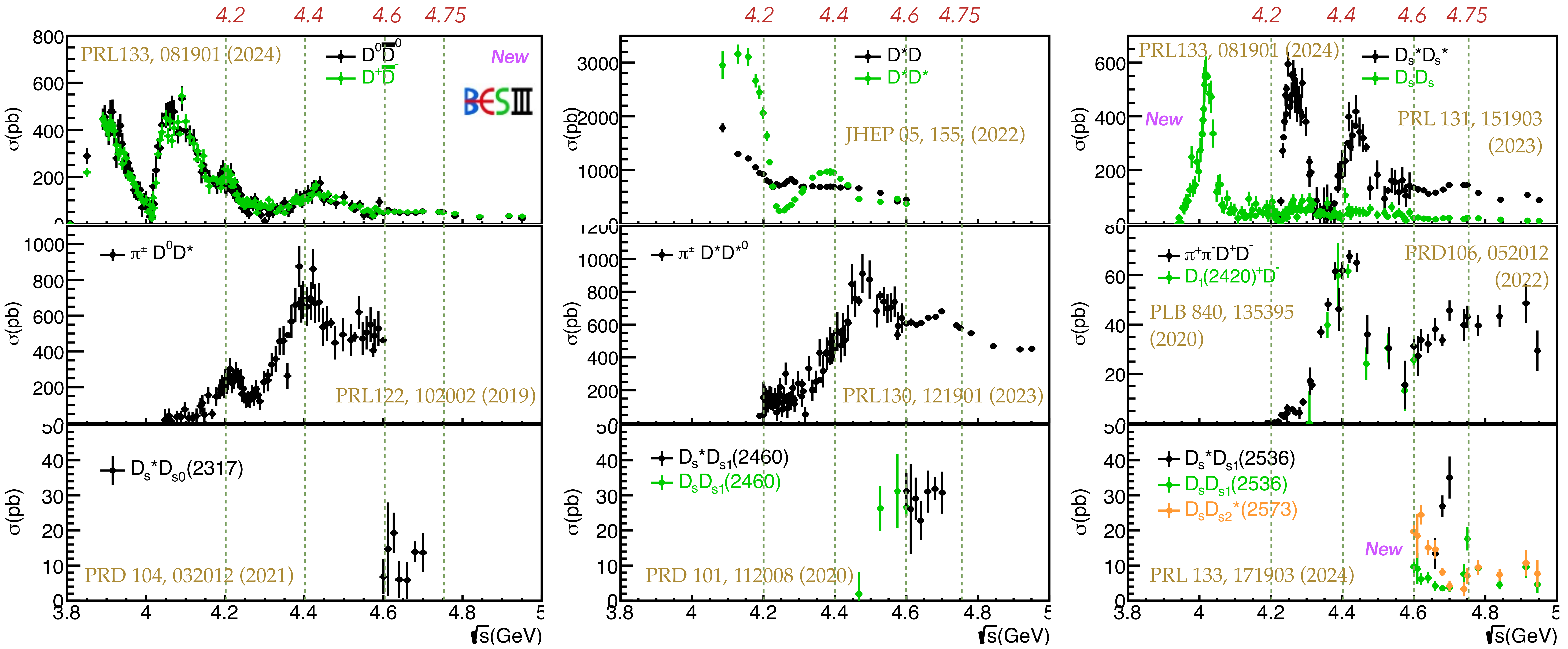
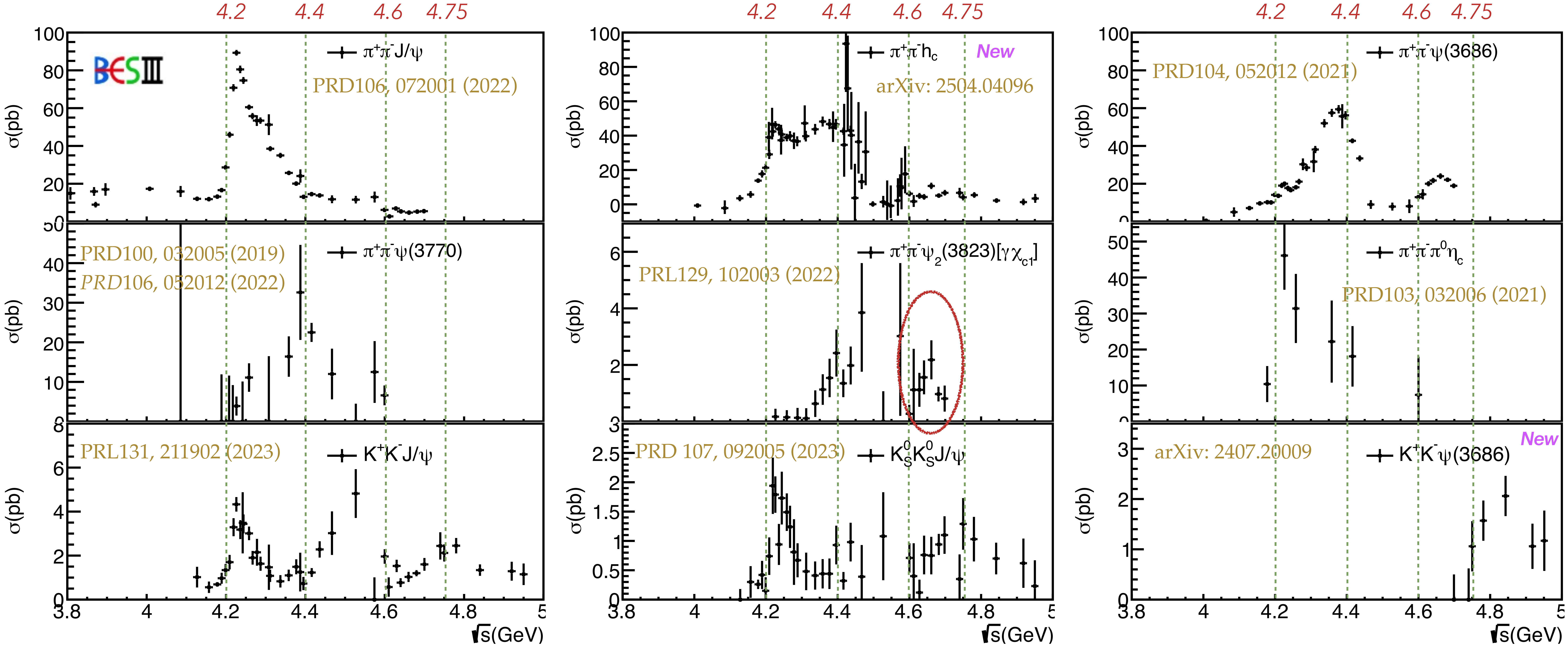
- Precise cross section measurements of open charm, hidden charm, and light hadron processes



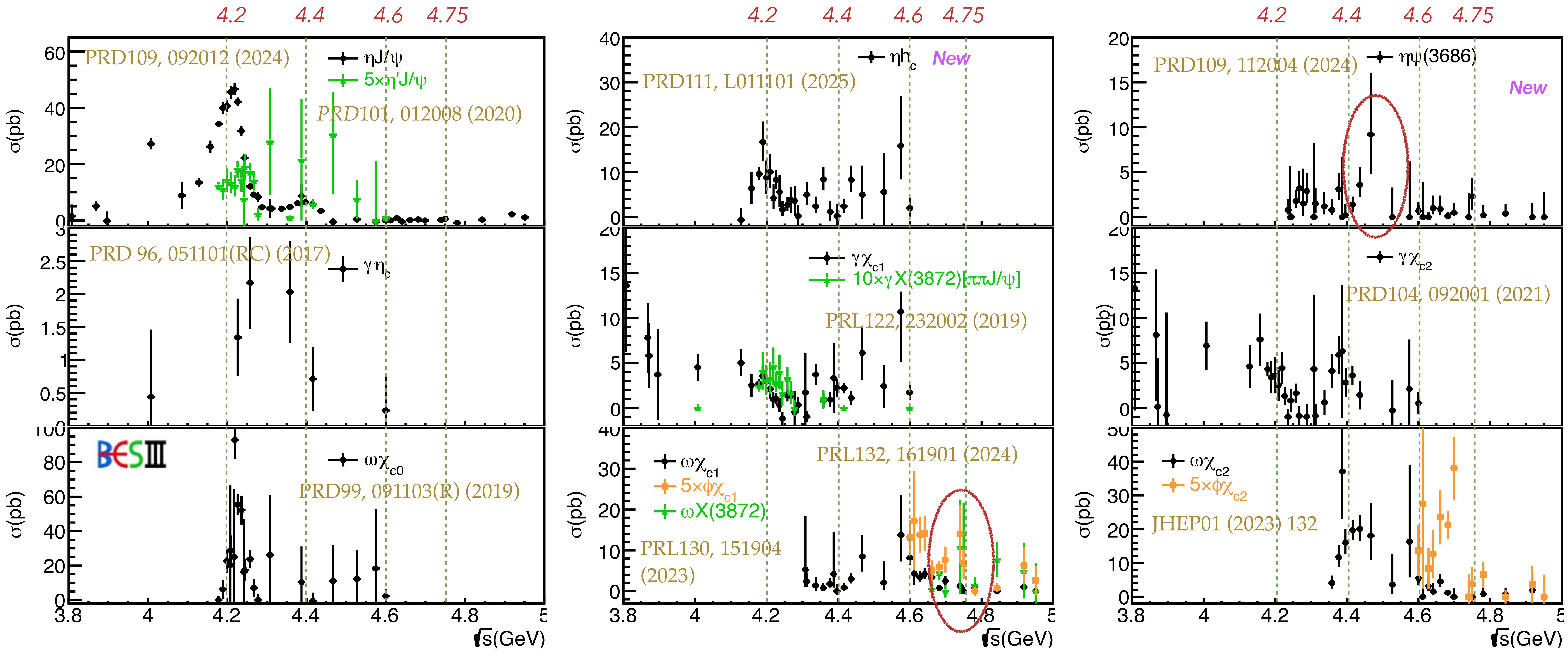
Overview of CS measurements at BESIII

- Precise cross section measurements of open charm, hidden charm, and light hadron processes



Overview of CS measurements at BESIII

- Precise cross section measurements of open charm, hidden charm, and light hadron processes



Y(4260)⇒Y(4230)+Y(43xx)

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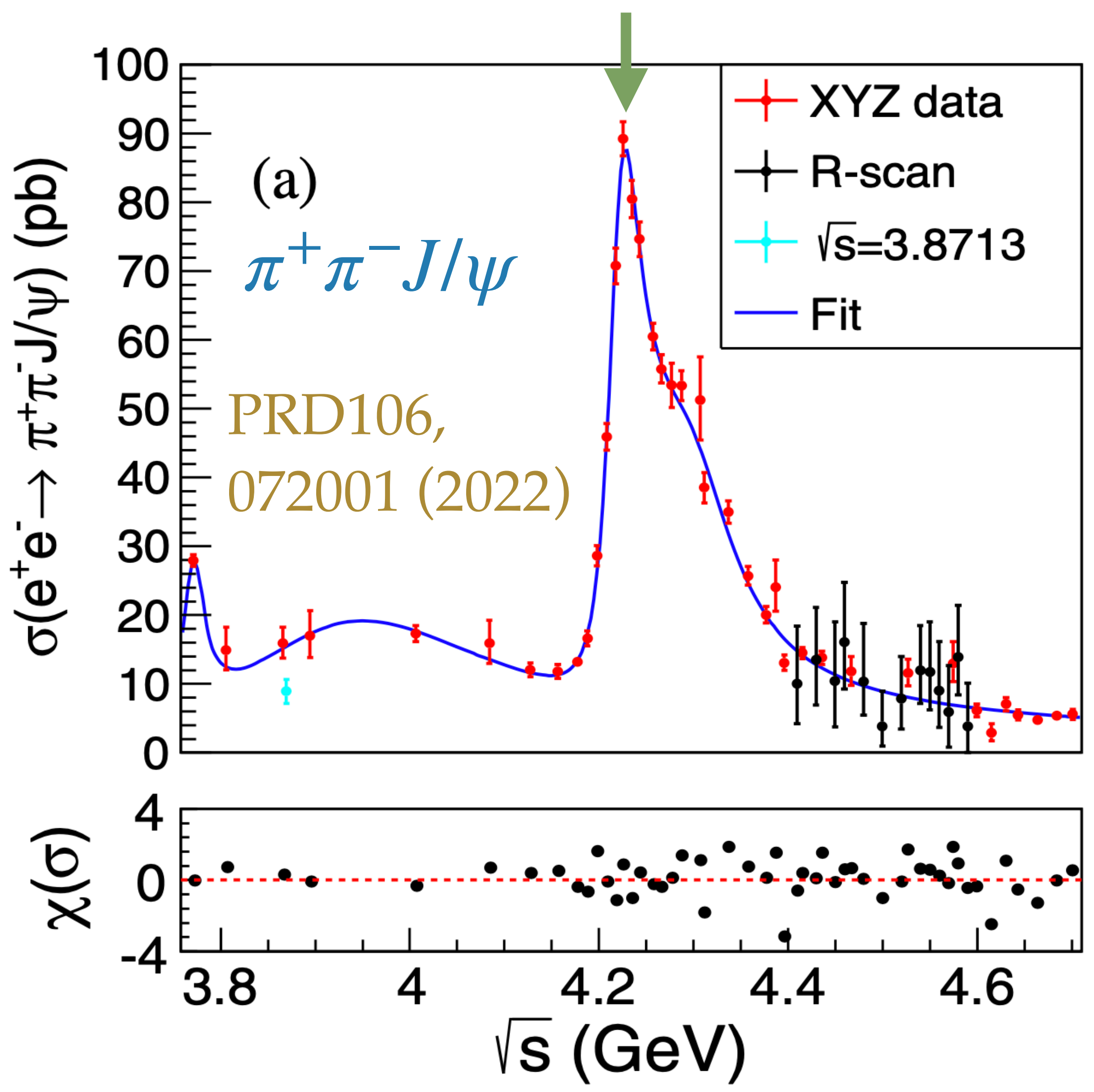
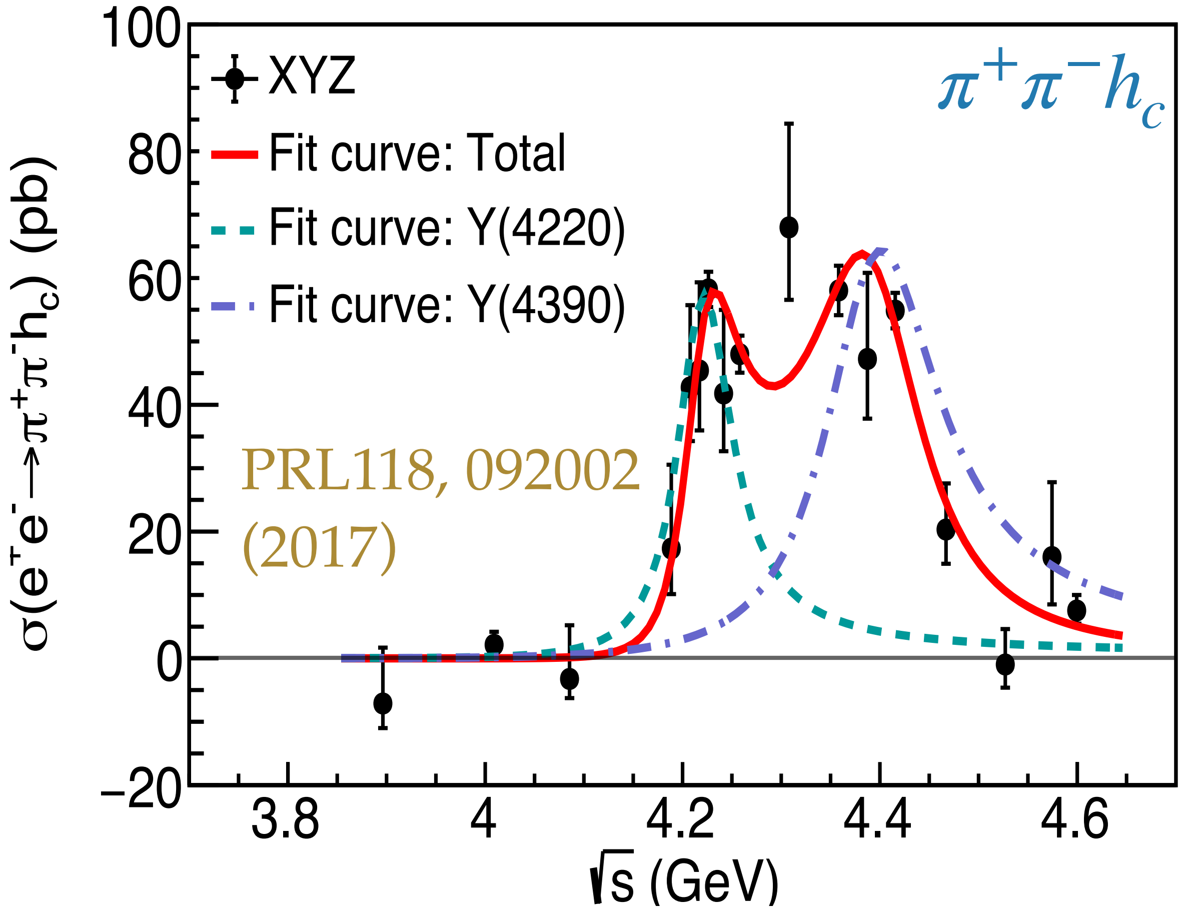
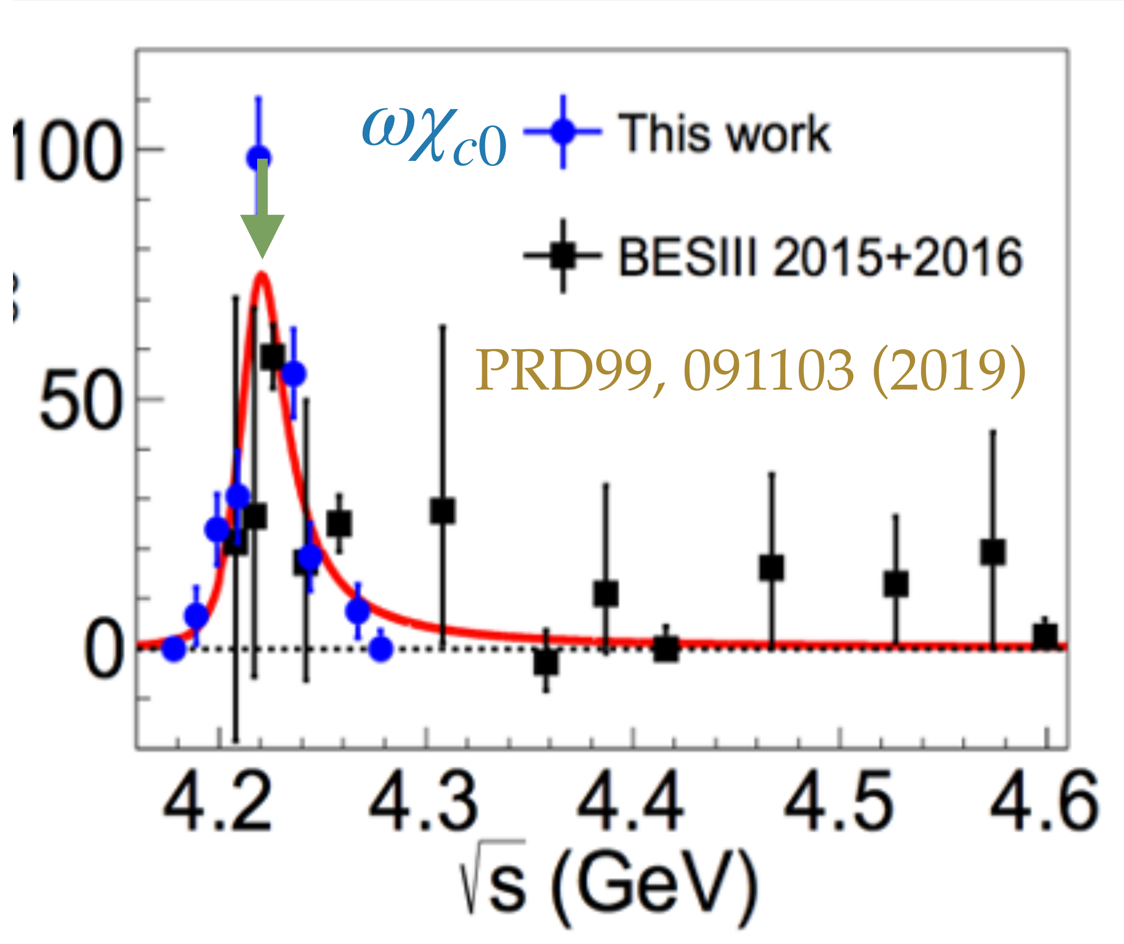
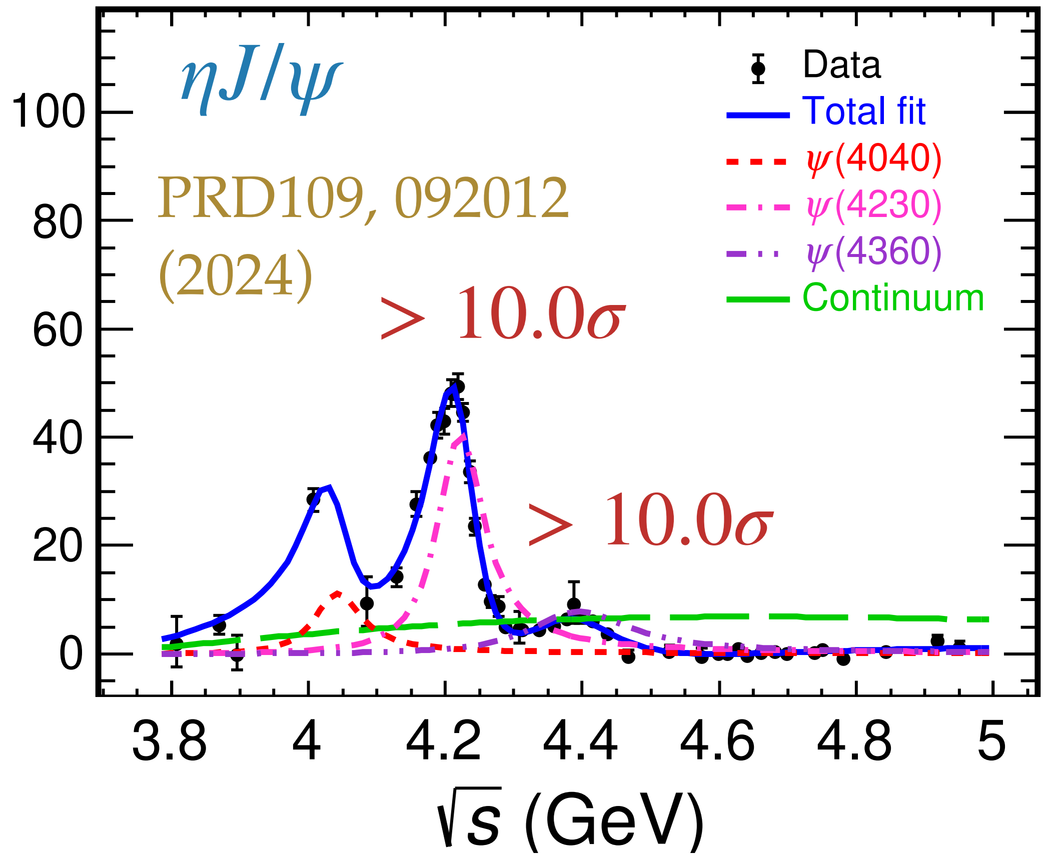
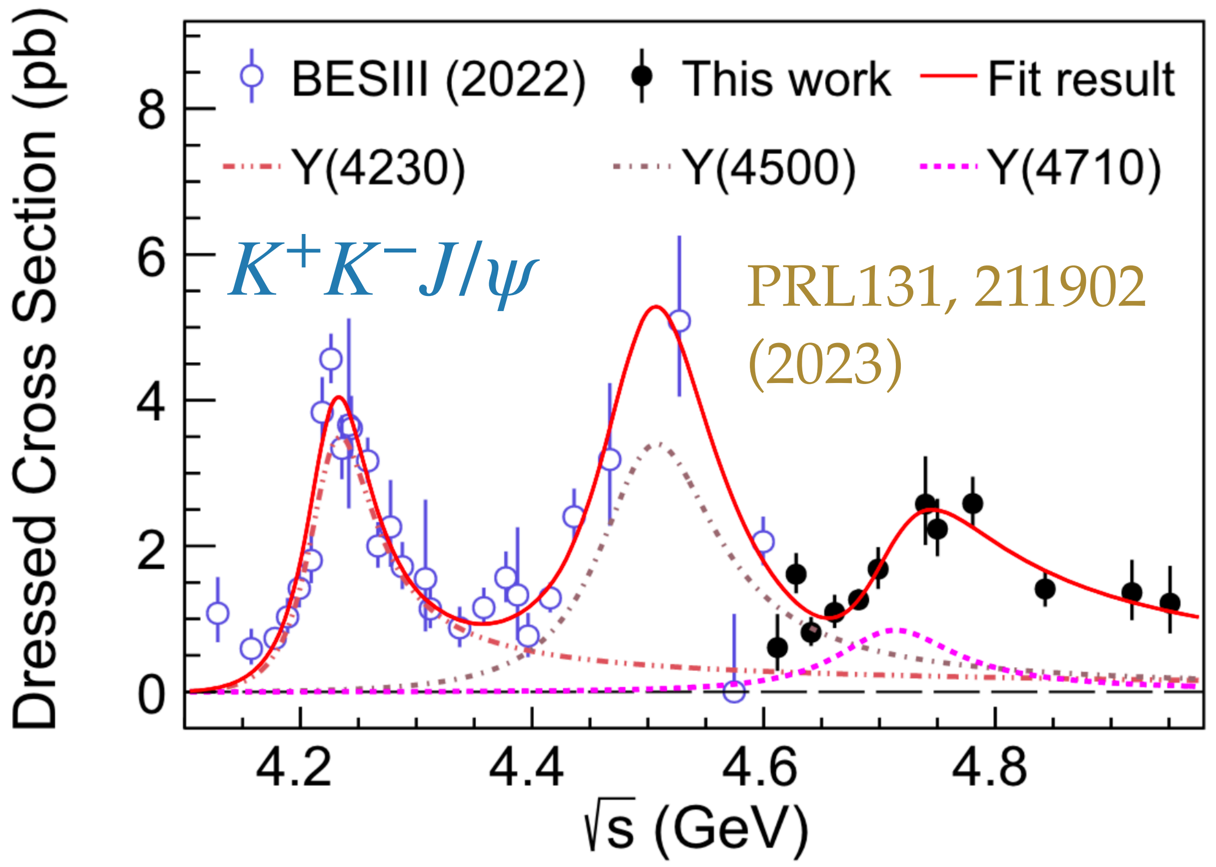
BESIII

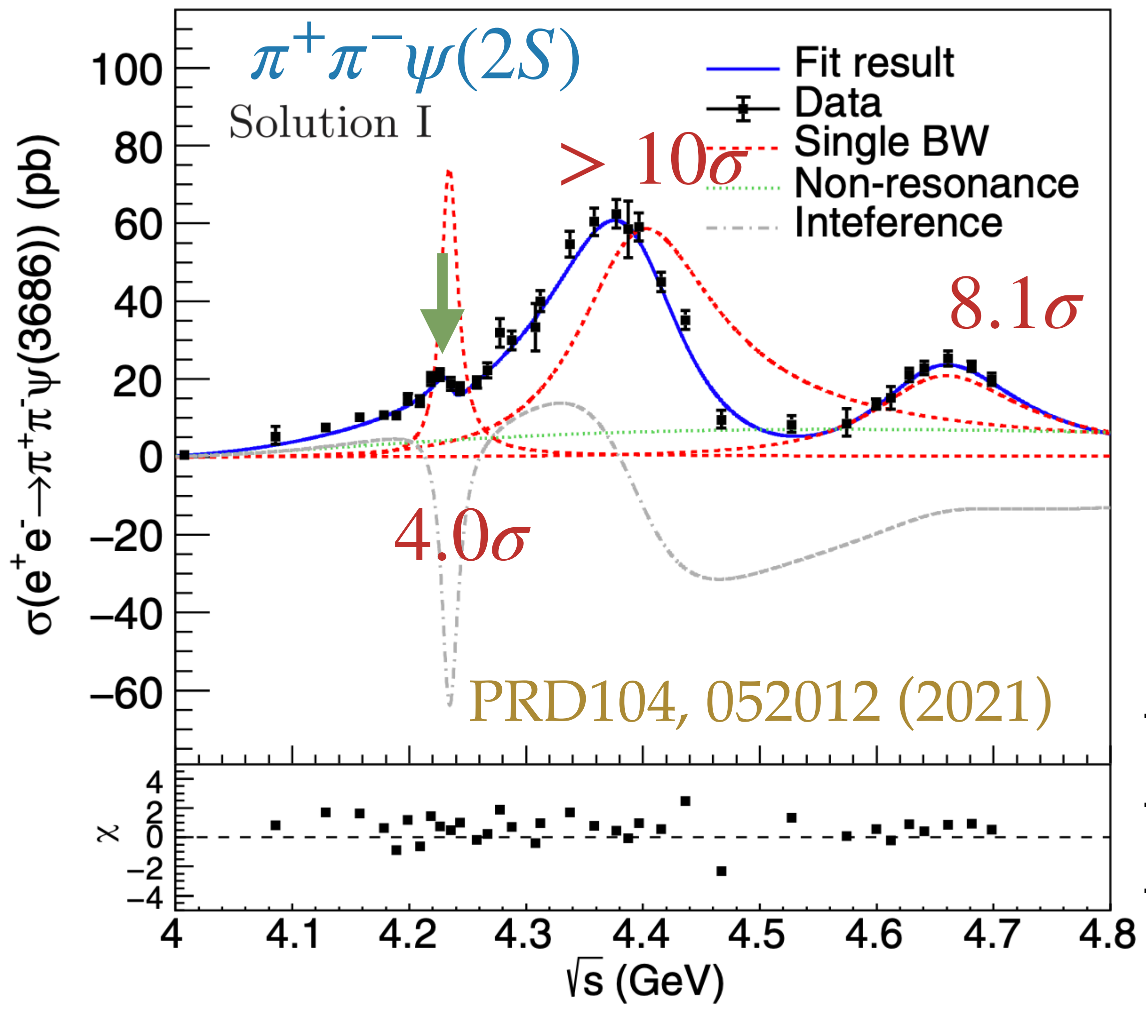


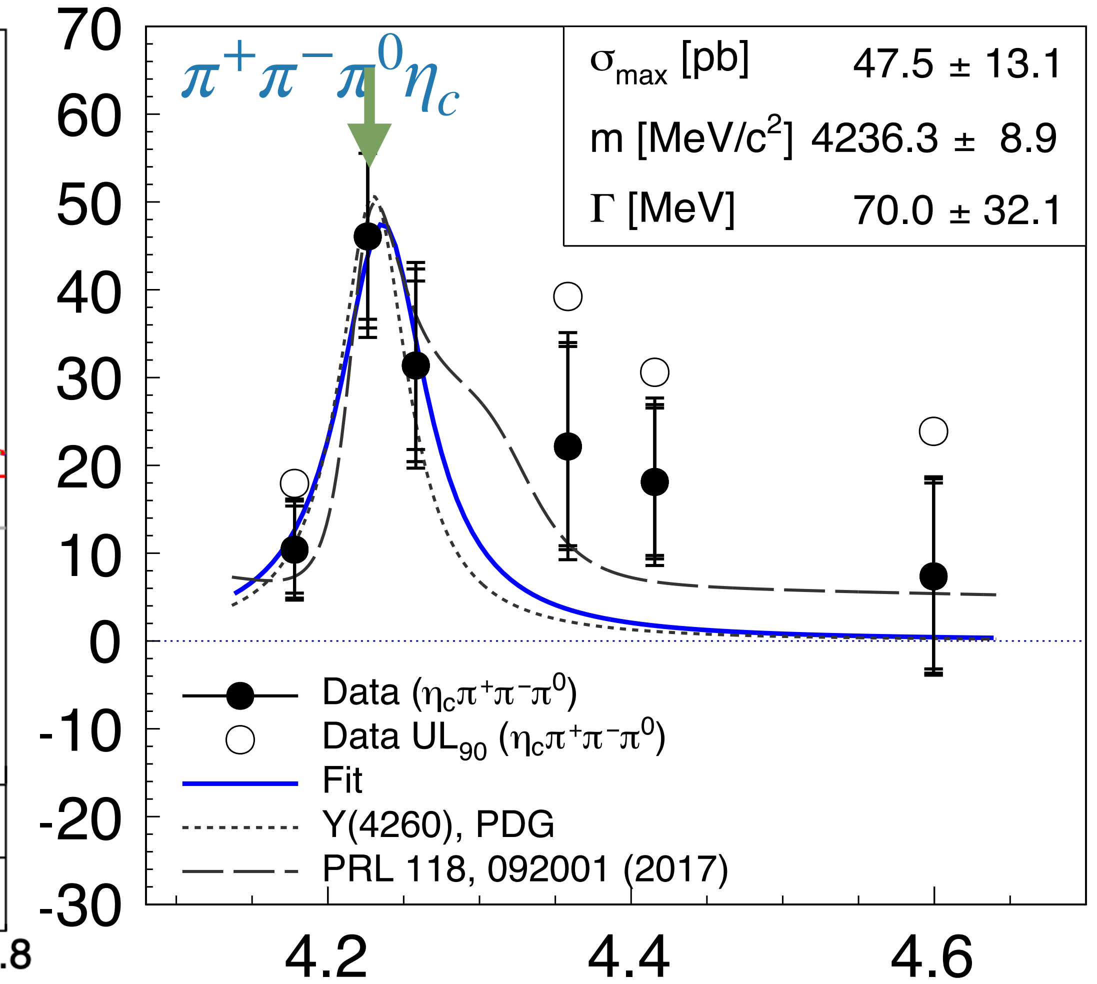




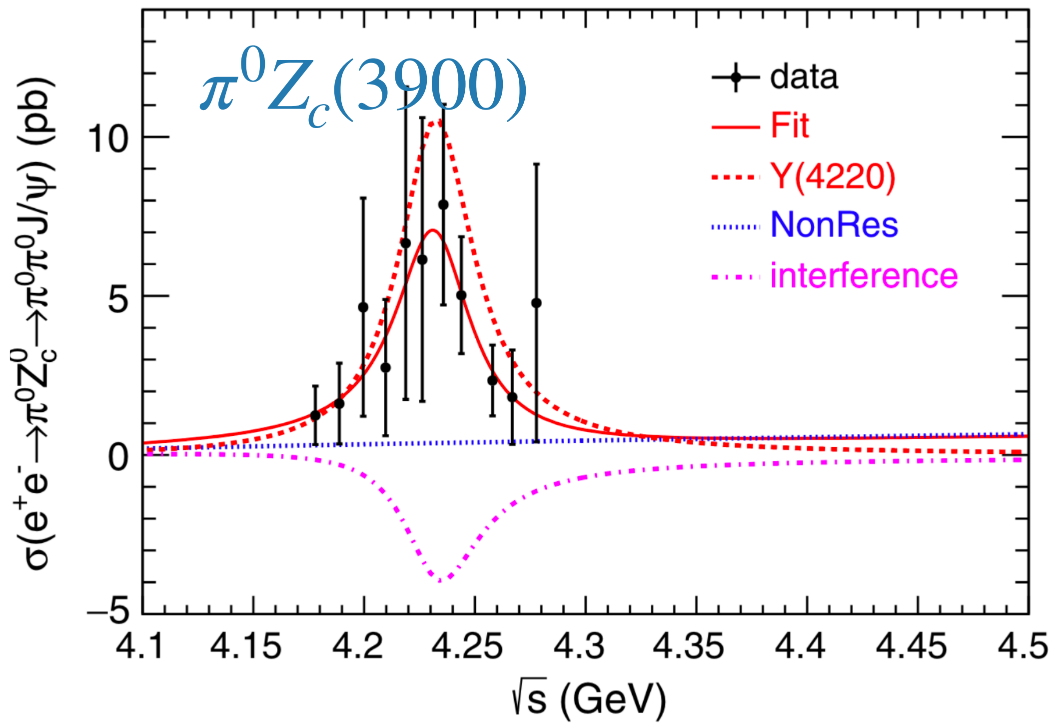








PRD103, 032006 (2021)



PRD102, 012009 (2020)

Y(4230) in Open Charm Process

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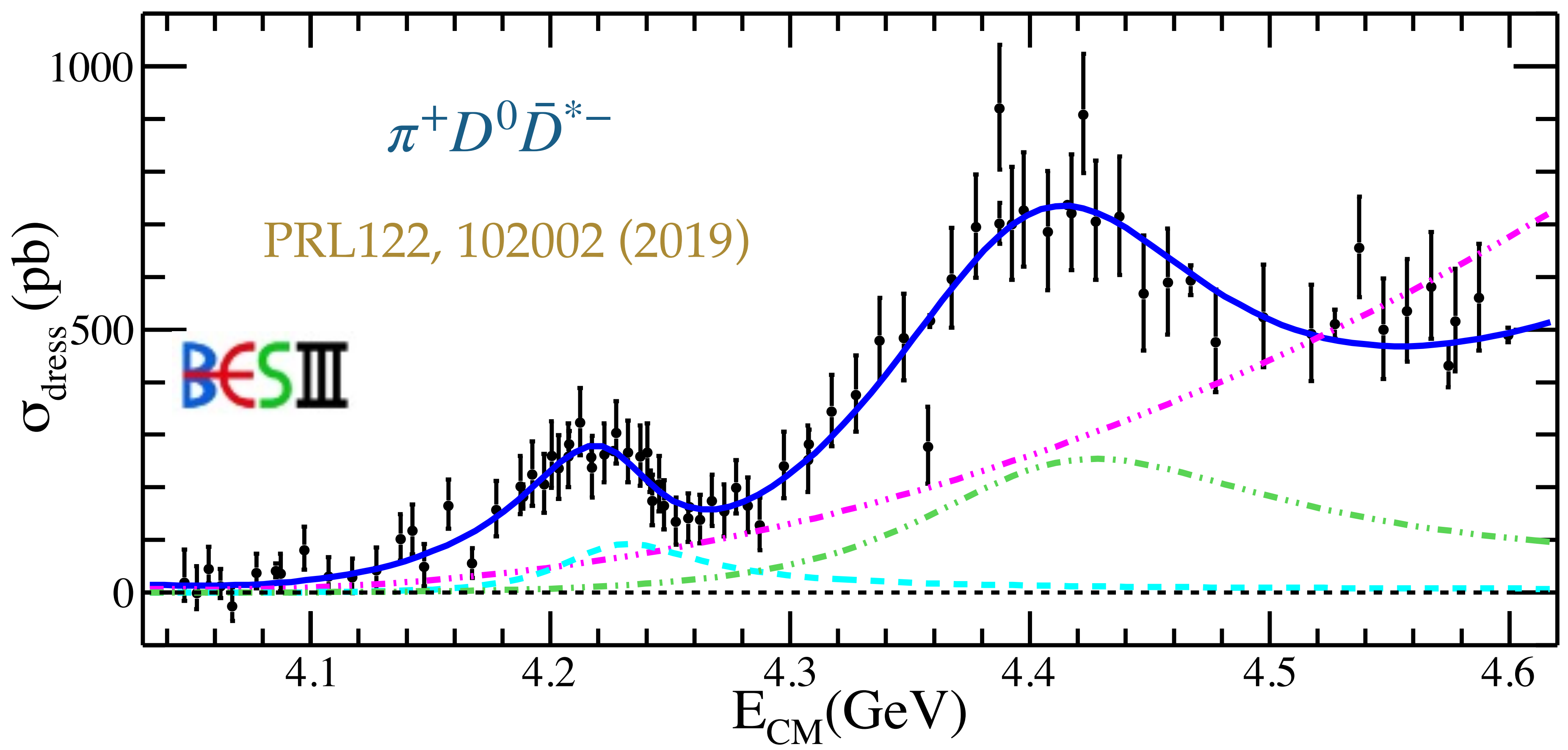
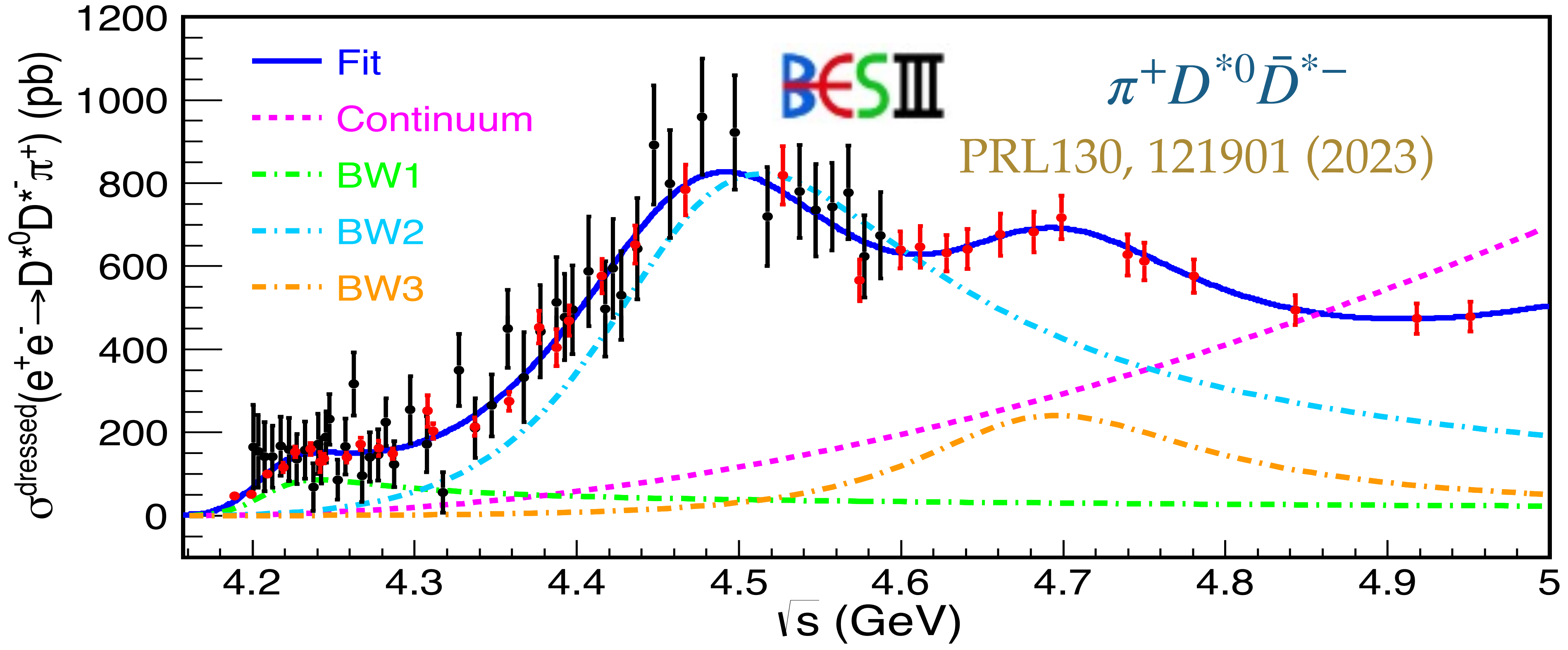
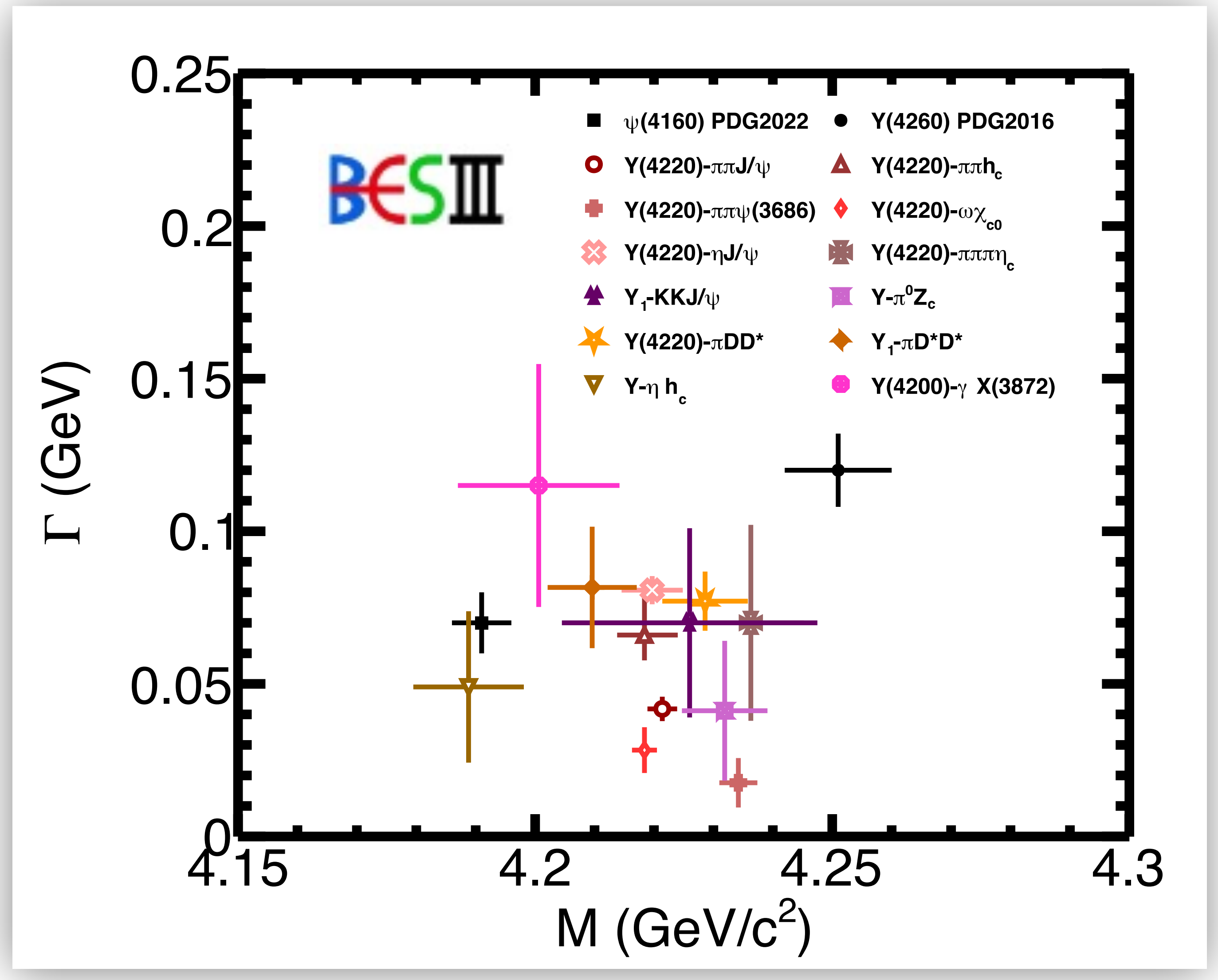




Mass and width from different process



⇑

determined with BW parameterization

consider possible interference

⇓

$\Gamma_{ee}B$(eV)	$\pi^+\pi^-J/\psi$	$\pi^+\pi^-h_c$	$\omega\chi_{c0}$	$\pi^+\pi^-\psi(2S)$	$\eta J/\psi$	K^+K^-J/ψ	$\pi^0 Z_c(3900)^0$	$\pi^\pm(D\bar{D}^*)^\mp$	$\pi^\pm(D^*\bar{D}^*)^\mp$
Min	1.7[0.2]	4.6[2.9]	2.5[0.2]	0.02[0.01]	4.0[0.5]	0.29[0.10]	0.22[0.25]	8.6[1.6]	4.8[0.9]
Max	14.6[1.2]			1.64[0.83]	11.9[1.1]	0.42[0.15]	0.53[0.15]	77.4[10.1]	22.4[9.0]

Y(4230) in Open Charm Process

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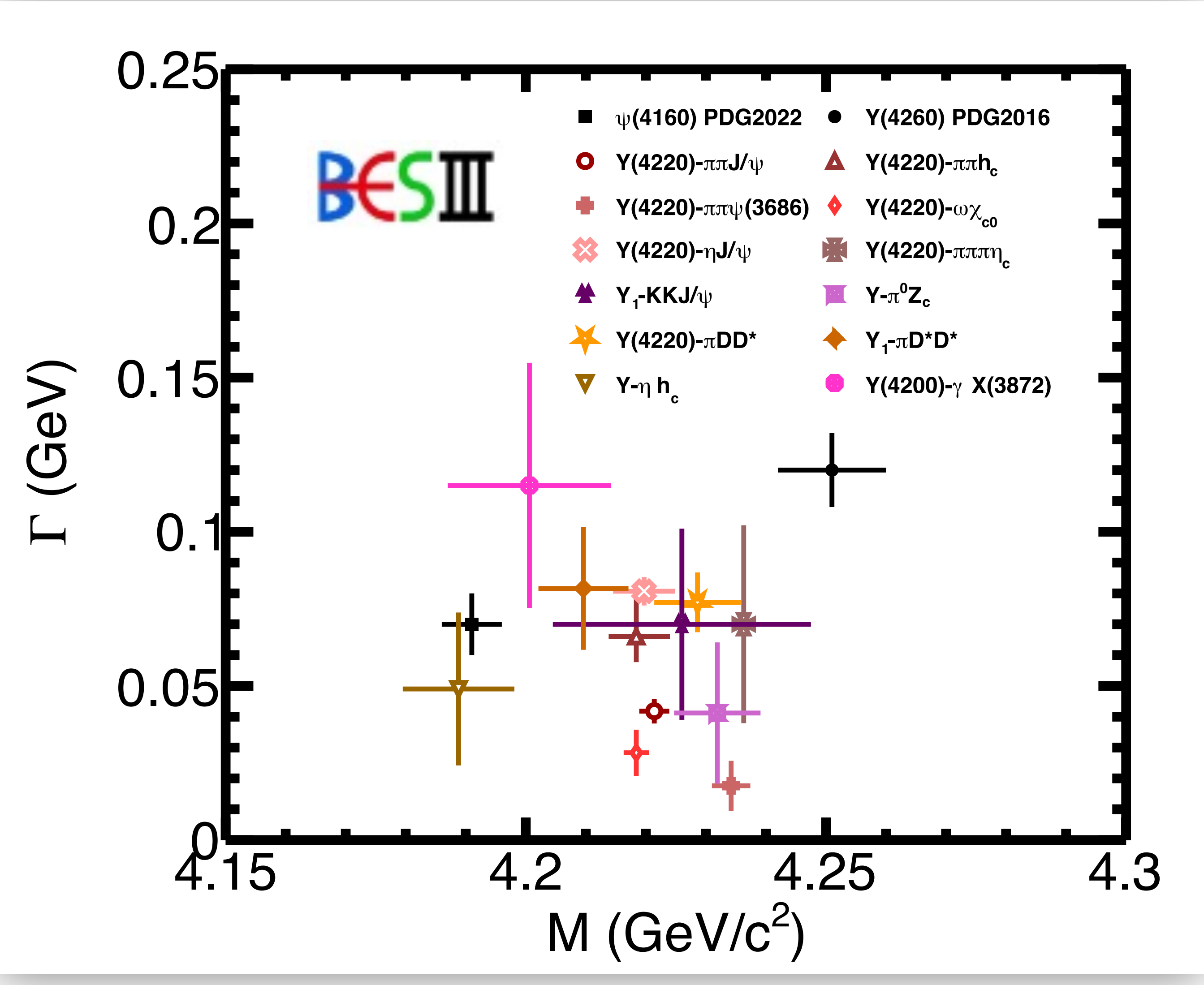
- Y(4260) has fine structures
- Mass around 4220 MeV, width around 50 MeV;
  varies in different modes ⇒ need more sophisticated model
- It has decay modes, hidden charm and open charm final states: $\omega\chi_{c0}$, $\pi\pi J/\psi$, $\pi\pi h_c$, $\pi\pi\psi(2S)$, $\pi\pi\pi\eta_c$, $K\bar{K}J/\psi$, $\eta J/\psi$, $\pi^+D^0D^{*-}$, $\pi^+D^{*0}\bar{D}^{*-}$, $\gamma X(3872)$, ηh_c, $\pi Z_c(3900)$

Mass and width from different process



⇑

determined with BW parameterization

consider possible interference

⇓

<table>
<tr><th>$\Gamma_{ee}B$ (eV)</th><th>$\pi^+\pi^-J/\psi$</th><th>$\pi^+\pi^-h_c$</th><th>$\omega\chi_{c0}$</th><th>$\pi^+\pi^-\psi(2S)$</th><th>$\eta J/\psi$</th><th>K^+K^-J/ψ</th><th>$\pi^0Z_c(3900)^0$</th><th>$\pi^\pm(D\bar{D}^*)^\mp$</th><th>$\pi^\pm(D^*\bar{D}^*)^\mp$</th></tr>
<tr><td>Min</td><td>1.7[0.2]</td><td rowspan="2">4.6[2.9]</td><td rowspan="2">2.5[0.2]</td><td>0.02[0.01]</td><td>4.0[0.5]</td><td>0.29[0.10]</td><td>0.22[0.25]</td><td>8.6[1.6]</td><td>4.8[0.9]</td></tr>
<tr><td>Max</td><td>14.6[1.2]</td><td>1.64[0.83]</td><td>11.9[1.1]</td><td>0.42[0.15]</td><td>0.53[0.15]</td><td>77.4[10.1]</td><td>22.4[9.0]</td></tr>
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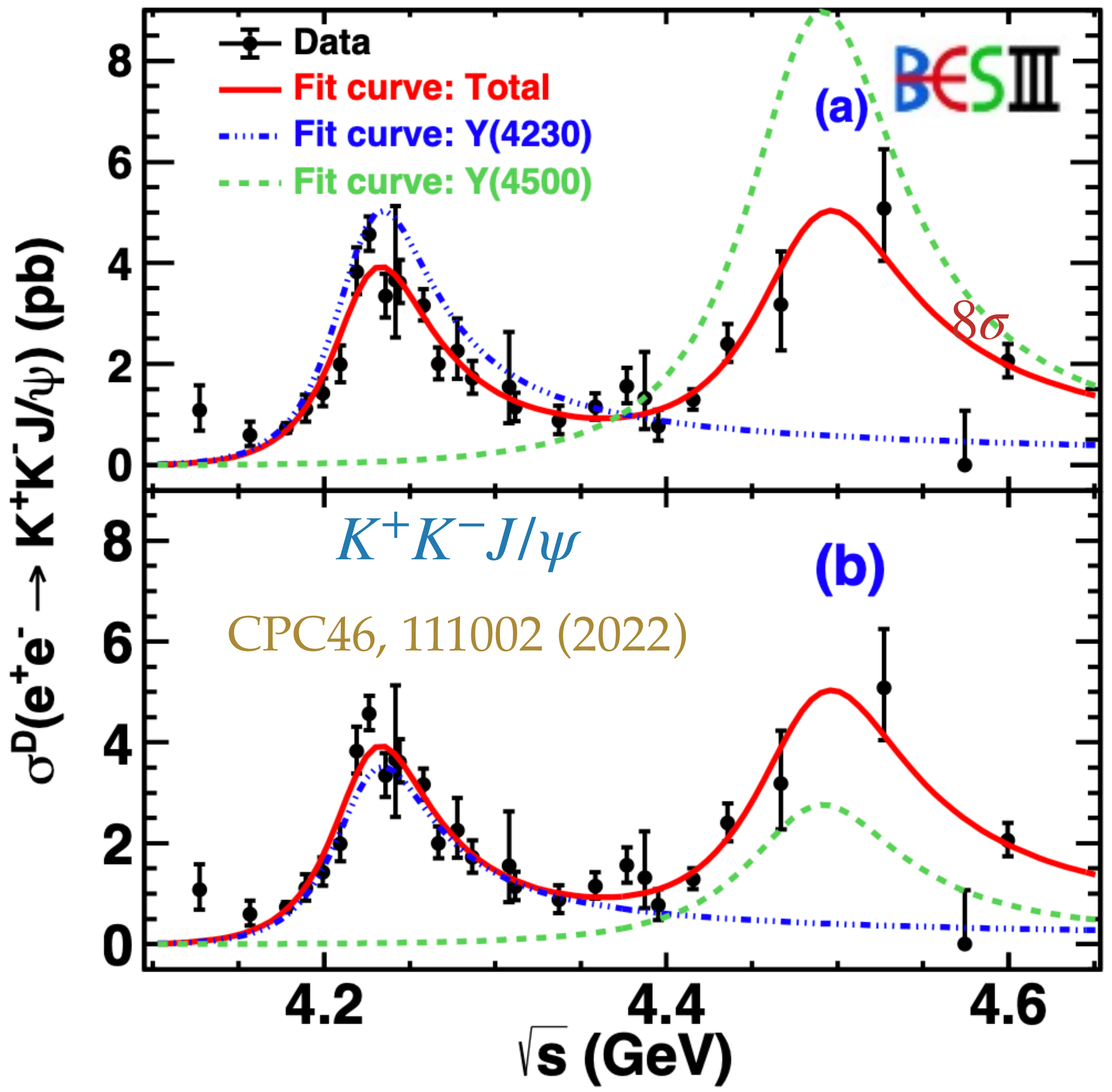
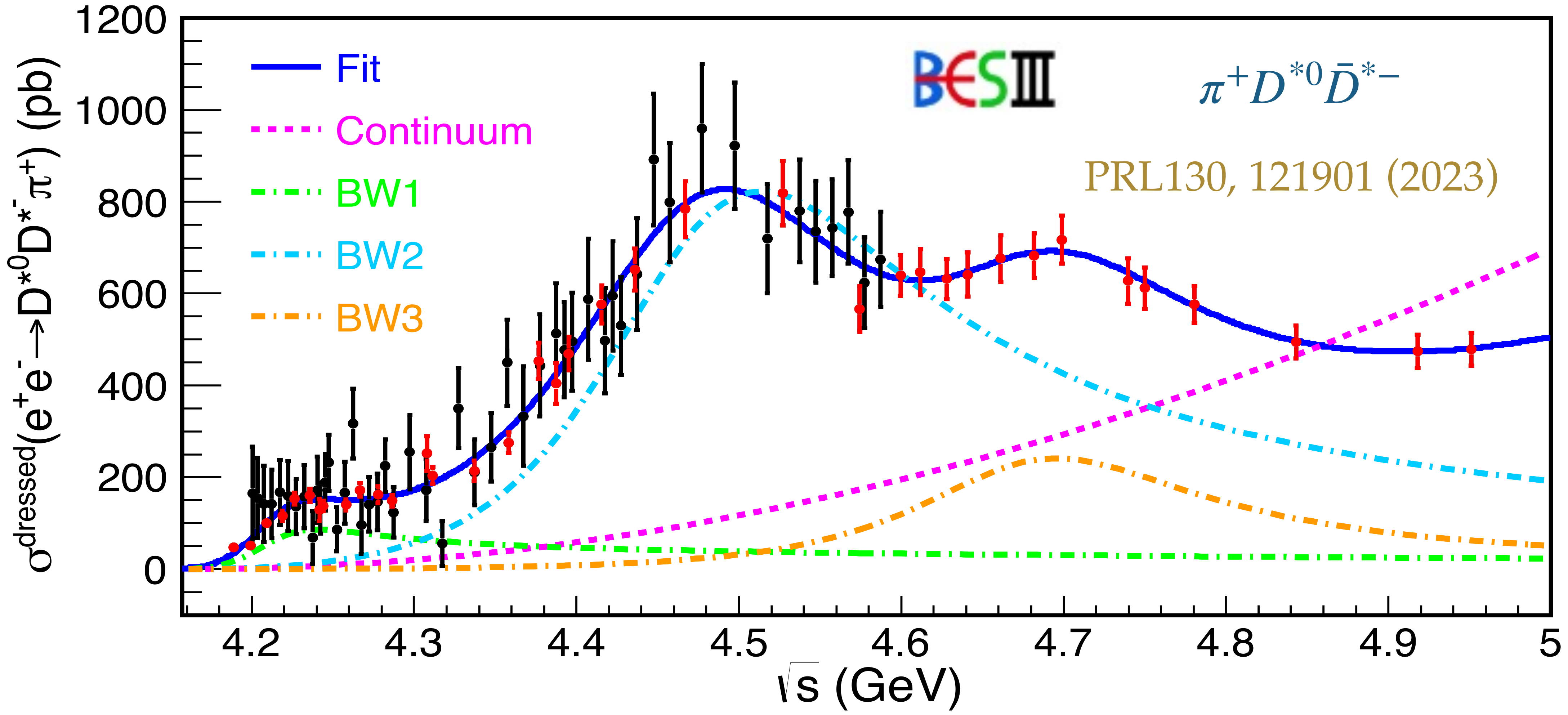
Observation of Y(4500)

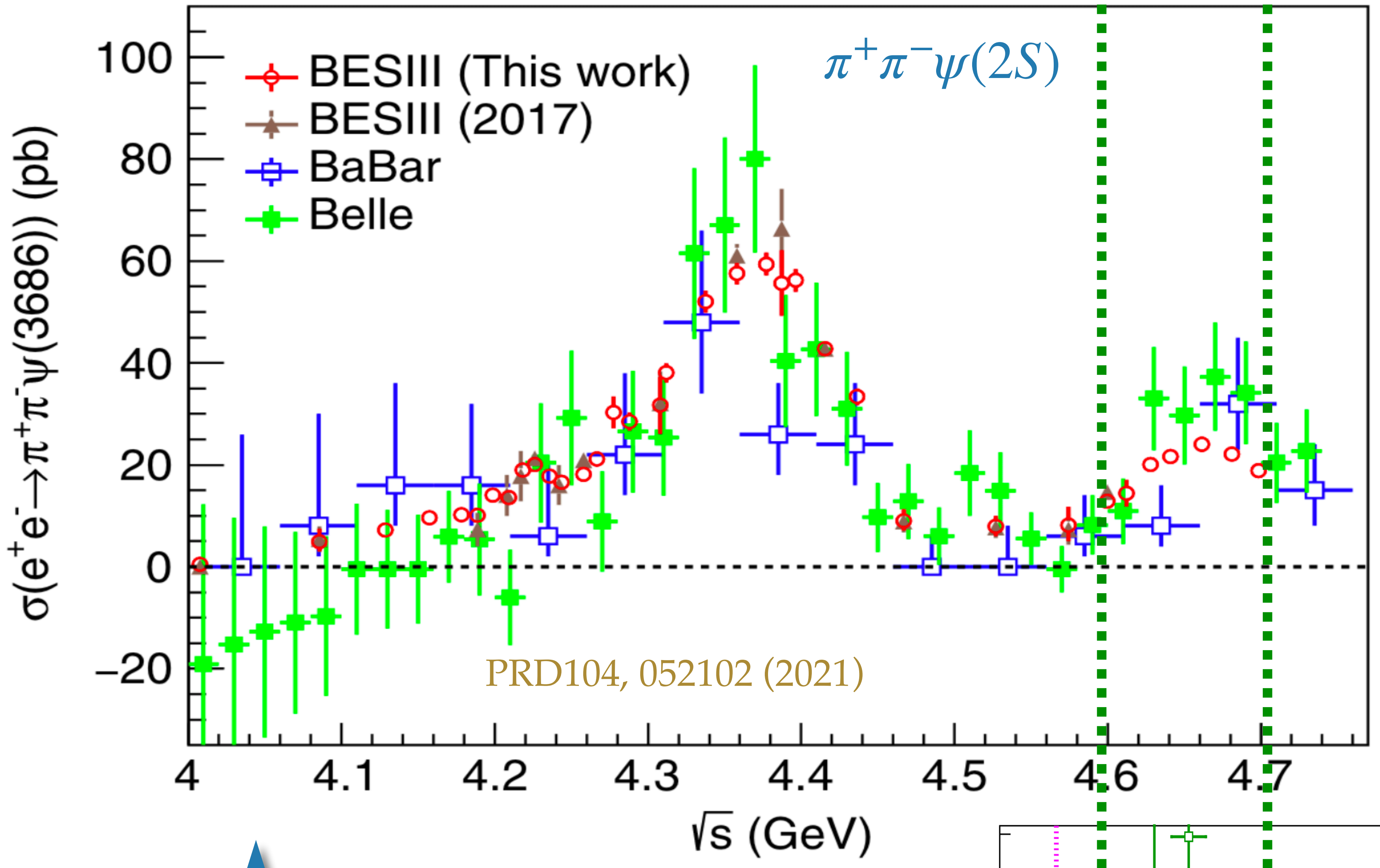




BW2: $M = 4469.1 \pm 26.2 \pm 3.6\ \mathrm{MeV}/c^2$, $\Gamma = 246.3 \pm 36.7 \pm 9.4$ MeV

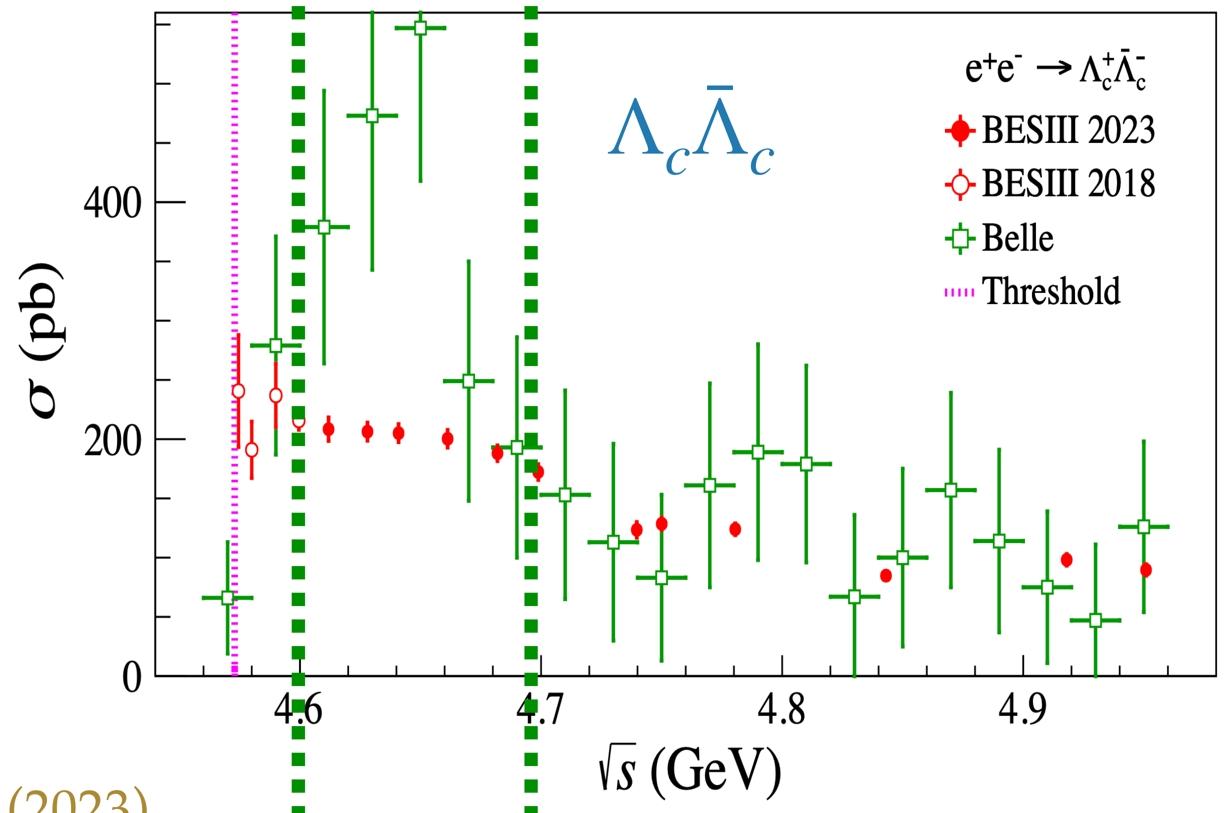
- $M = 4484.7 \pm 13.3 \pm 24.1\ \mathrm{MeV}/c^2$
  $\Gamma = 111.1 \pm 30.1 \pm 15.2$ MeV
- A 5S-4D mixing state (J. Z. Wang et al. PRD99, 114003 (2019) [Width 2σ larger]
- A heavy-antiheavy hadronic molecule (X. K. Dong et al. Prog. Phys. 41, 65 (2021))
- A $cs\bar{c}\bar{s}$ state from LQCD (T. W. Chiu et al. PRD73, 094510 (2006))
- Assuming structures in KKJ/ψ and $\pi D^*\bar{D}^*$ are the same, $B[Y \to \pi D^*\bar{D}^*]/B[Y \to K\bar{K}J/\psi]$~$10^2$, inconsistent with hidden-strangeness tetraquark nature (F. Z. Peng et al. PRD107, 016001 (2023))

New Decay Modes of Y(4660)

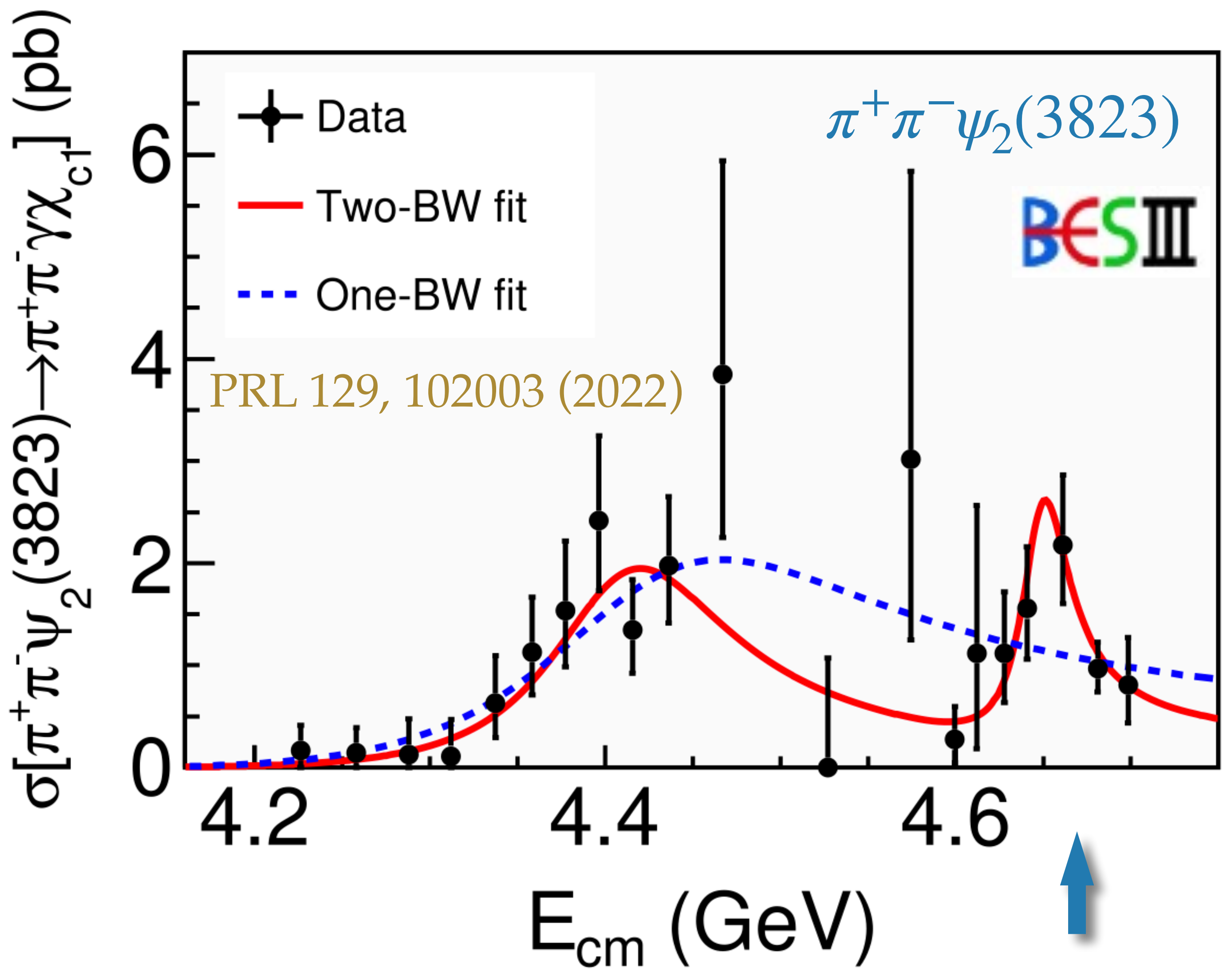


Mass: $4651.0 \pm 37.8 \pm 2.1$ MeV

Width: $155.4 \pm 24.8 \pm 0.8$ MeV



PRL131, 191901 (2023)



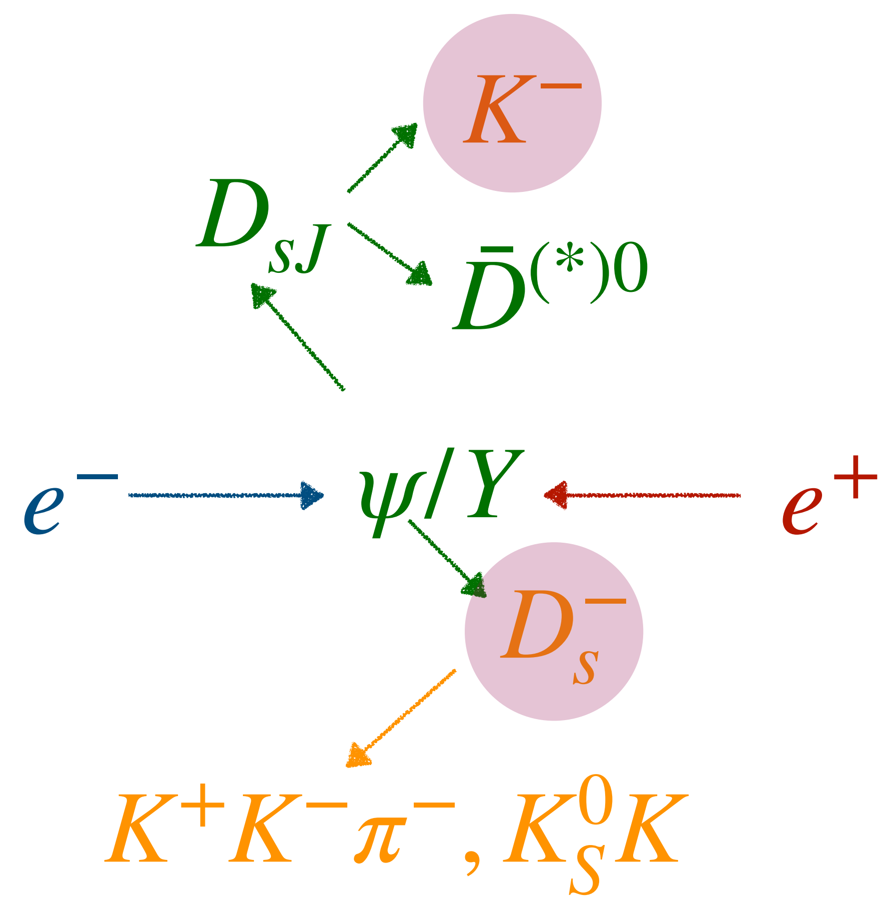
Mass: $4647.9 \pm 8.6 \pm 0.8$ MeV

Width: $33.1 \pm 18.6 \pm 4.1$ MeV

Second hadronic transition decay mode since its discovery

Y(4660) in $D_sD_{s1}(2536)$ and $D_sD^*_{s2}(2573)$

- 15 data samples corresponding to a total integrated lum. of 6.6 fb^{-1} from $\sqrt{s}$=4.53 to 4.95 GeV



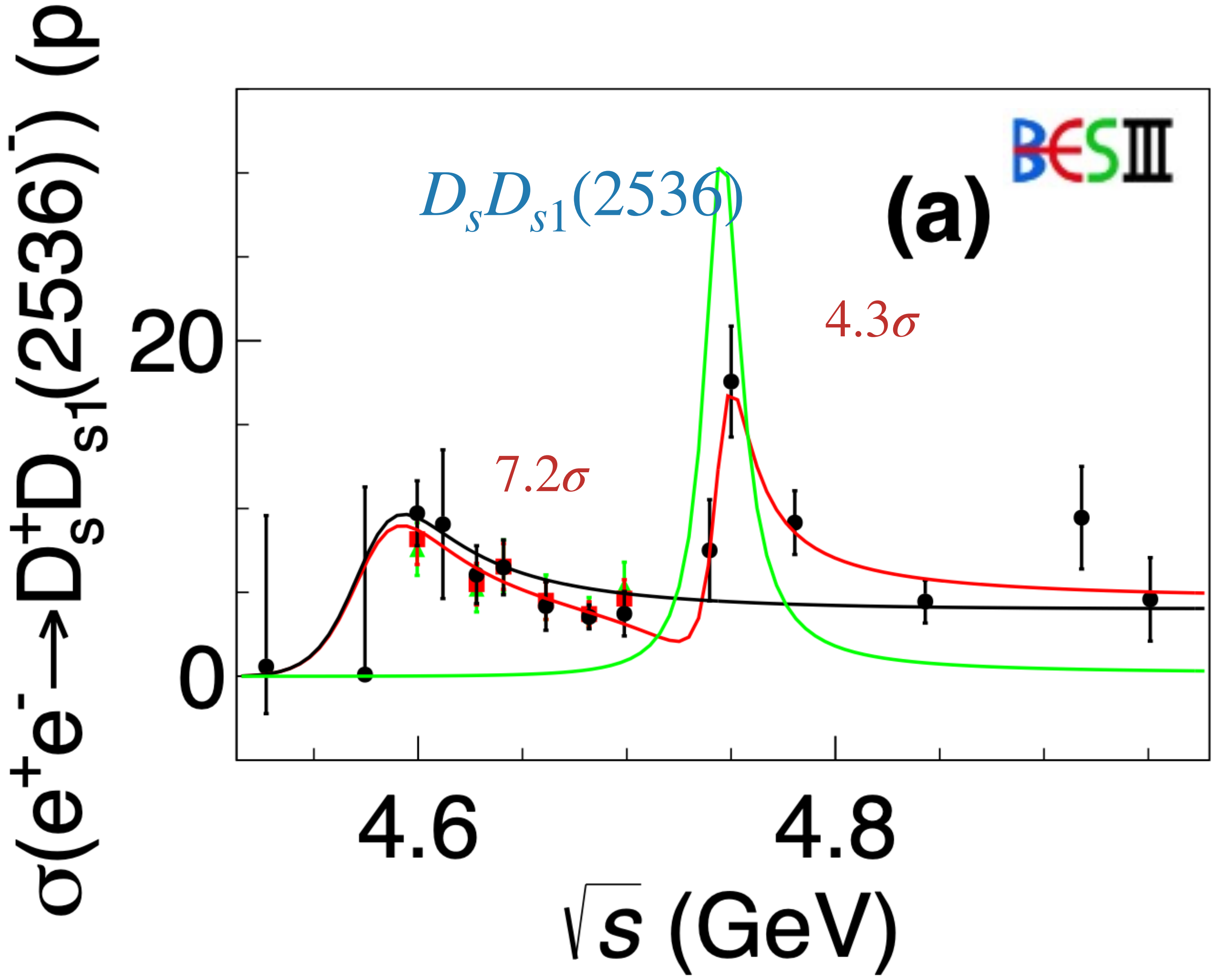
Y(4660)

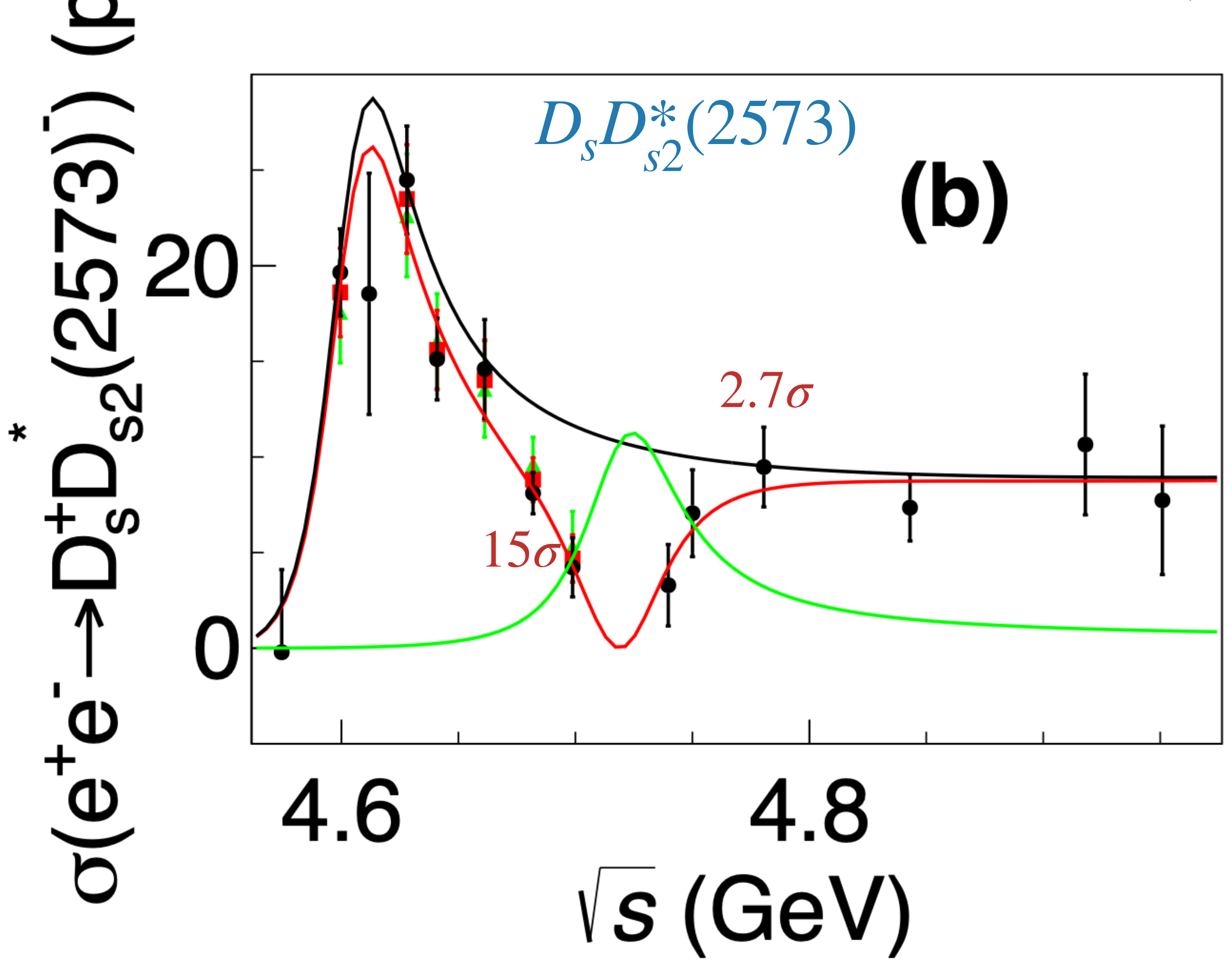
PDG	4641 ± 10 MeV (S = 2.7)
	73^{+13}_{-11} MeV (S = 1.7)

$\pi\pi\psi(2S)$
Mass: $4651.0 \pm 37.8 \pm 2.1$ MeV
Width: $155.4 \pm 24.8 \pm 0.8$ MeV
$\pi\pi\psi_2(3823)$
Mass: $4647.9 \pm 8.6 \pm 0.8$ MeV
Width: $33.1 \pm 18.6 \pm 4.1$ MeV

Partial reconstruction

PRL 133, 171903 (2024)





	R1	R2
Mass (MeV/c²)	4584[14, 68]	4749.9[8.2, 6.7]
Width (MeV)	57[12, 211]	24.9[8.0, 7.8]

	R1	R2
Mass (MeV/c²)	4603.1[3.9, 0.8]	4720[13, 2]
Width (MeV)	45.2[5.7, 0.7]	50[12, 1]

Mass and width consistent with ISR studies at Belle, but cs much smaller

Precise Measurement of $\sigma[e^+e^- \to \pi^+\pi^-h_c]$

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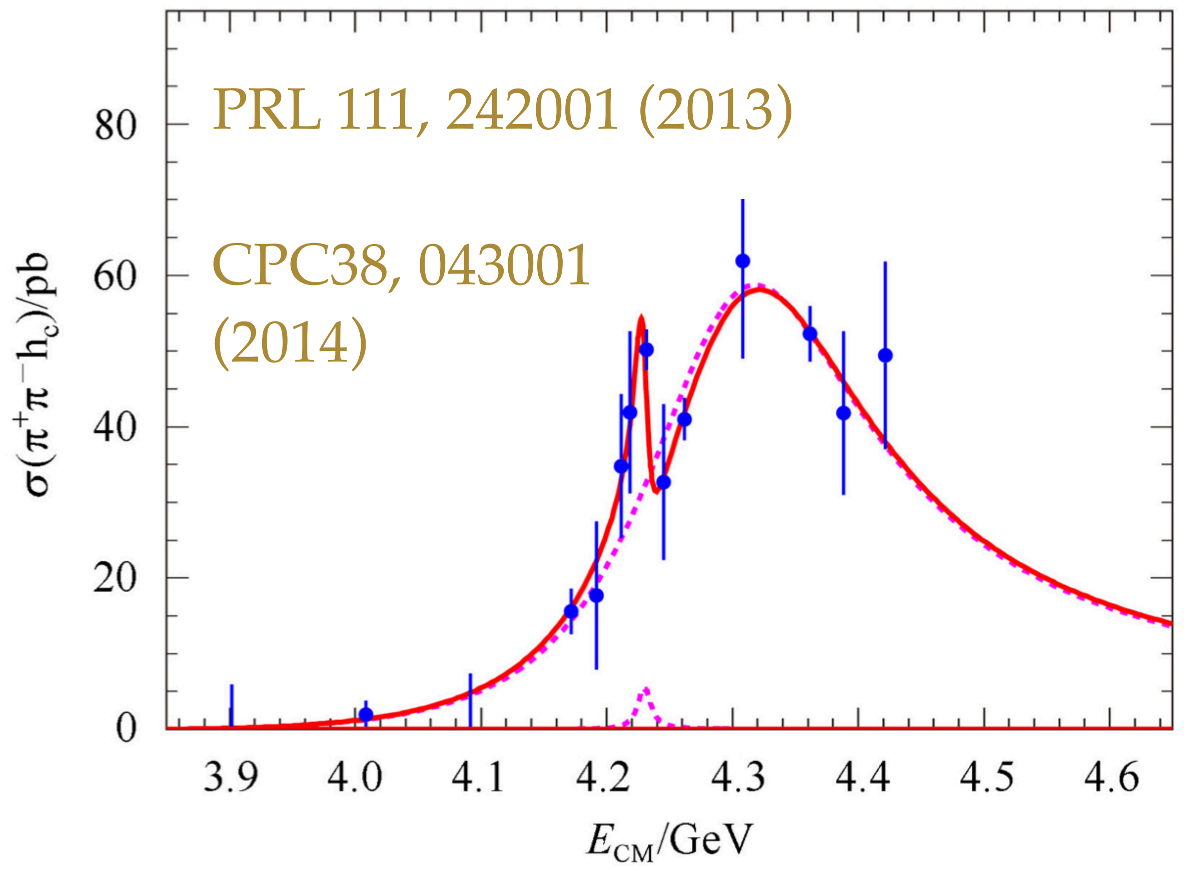
- The $e^+e^- \to \pi^+\pi^-h_c$ process was observed by CLEO at $\sqrt{s}$=4.17 GeV [10σ] PRL107, 041803 (2011)
- The cross section of $e^+e^- \to \pi^+\pi^-h_c$ was measured by BESIII at $\sqrt{s}$ from 3.9 to 4.6 GeV, two resonant structures was observed PRL118, 092002 (2017)
- New data (27 data samples) between $\sqrt{s}$=4.18 to 4.95 GeV has been collected by BESIII



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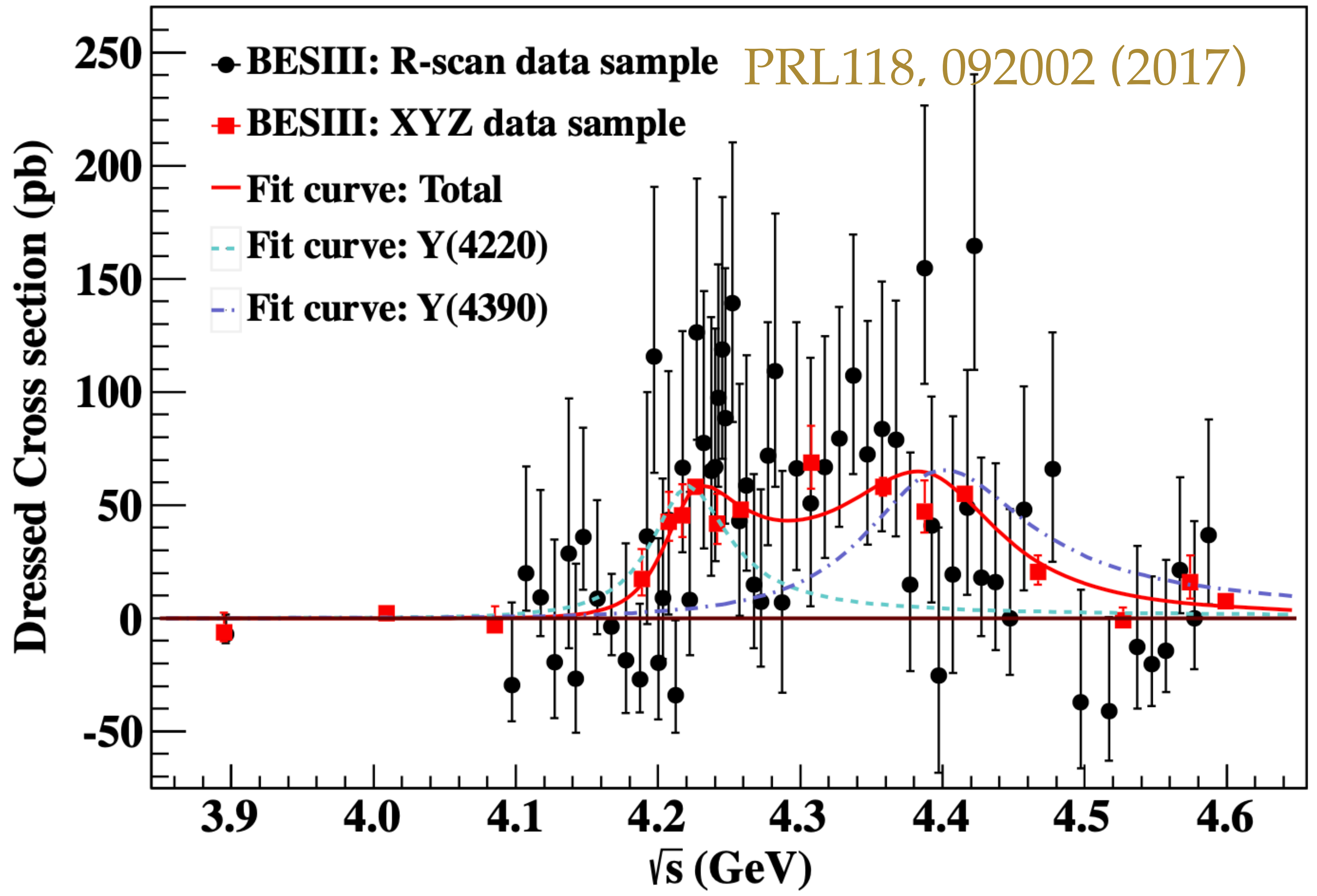

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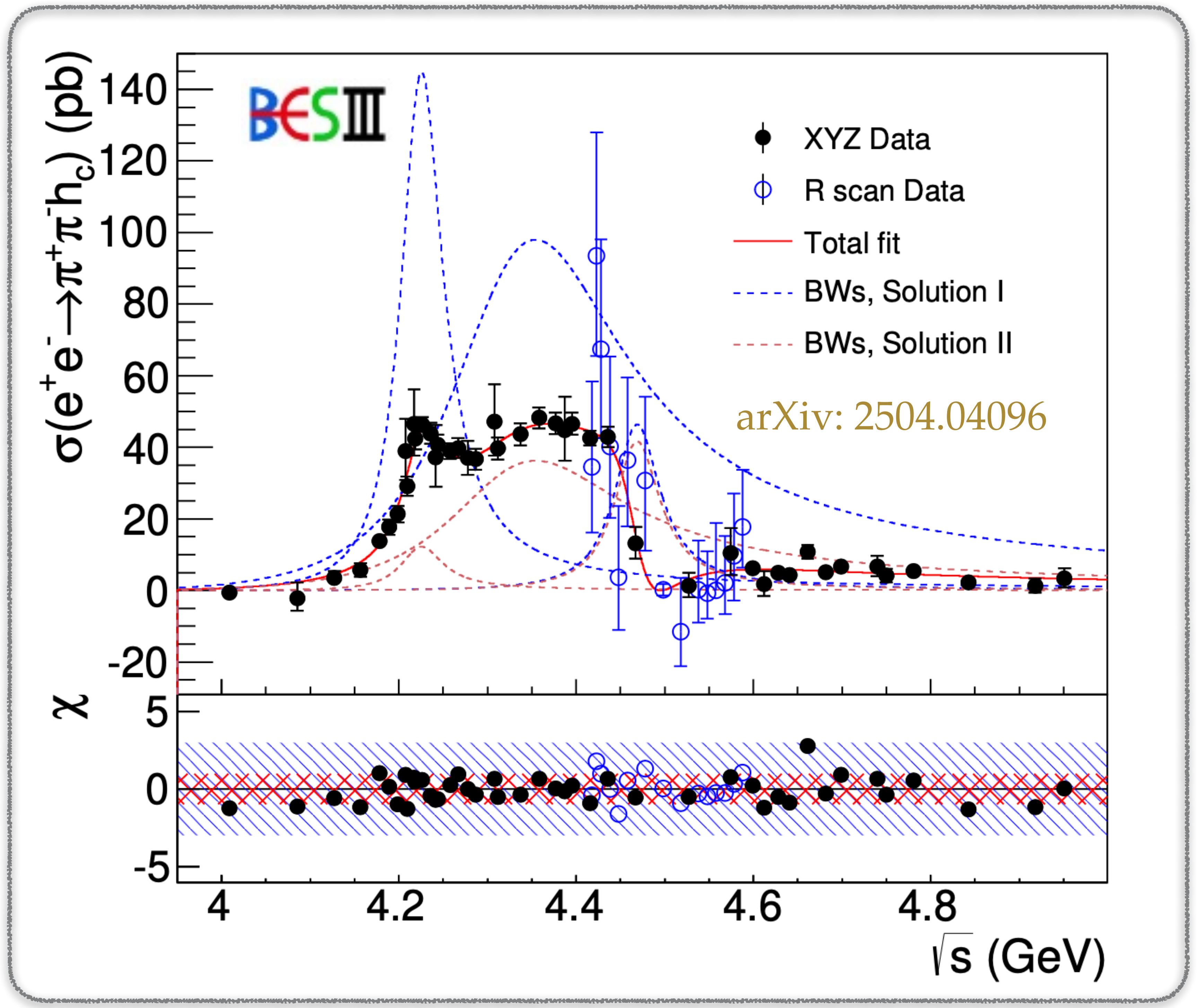
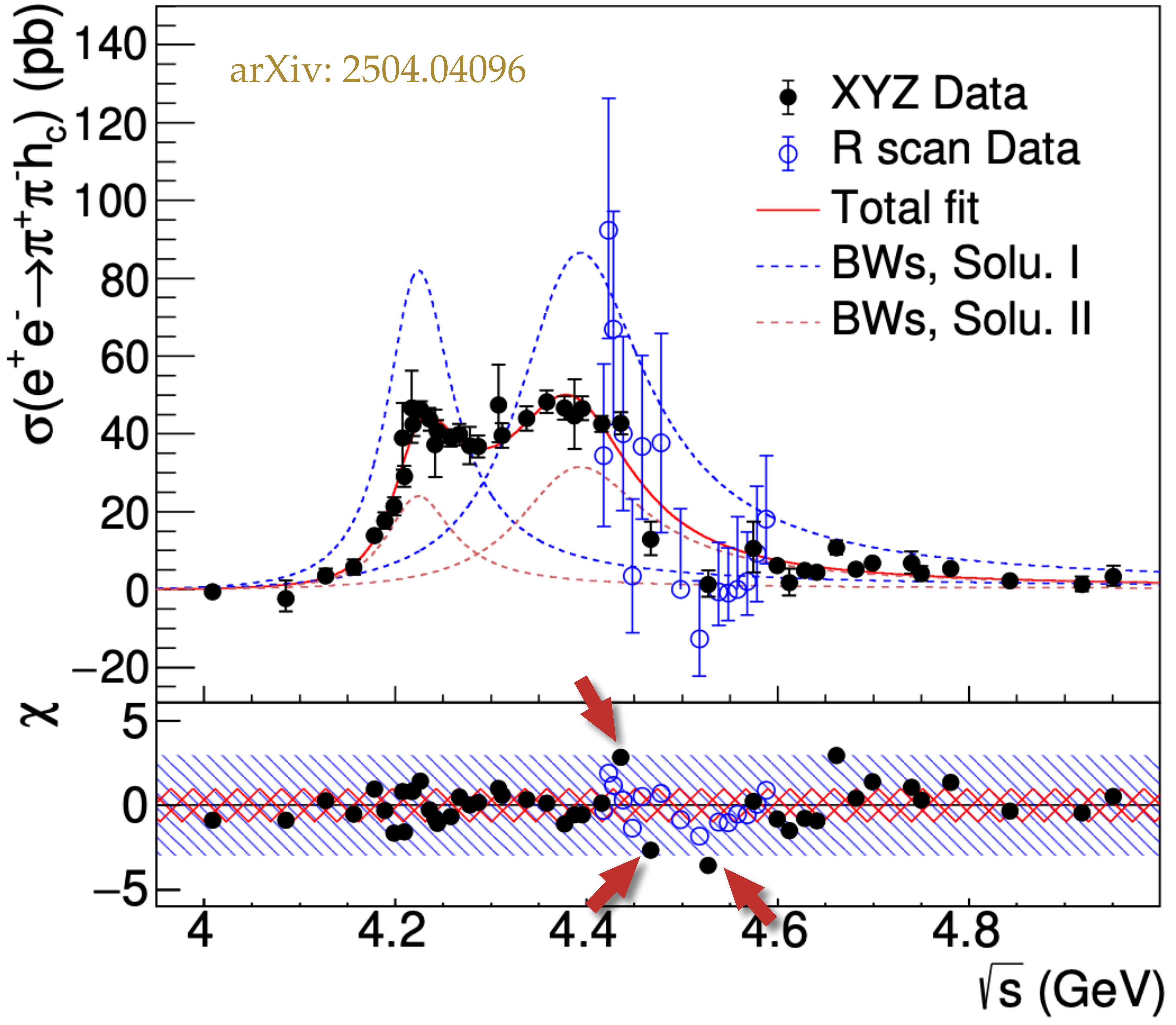


Precise Measurement of $\sigma[e^+e^- \to \pi^+\pi^-h_c]$



- Test of resonance structures:
  - Starting with two coherent BWs, add one more BW, two more BWs, one more BW and a continuum termt
  - Check significance of each addtional term
  - Baseline model: $\sigma^{\text{dressed}} = |BW_1 + BW_2 e^{i\phi_2} + BW_3 e^{i\phi_3}|^2$
  - Significance of the third resonance: 5.4σ
  - Significance of addtional contribution smaller than 1σ

Precise Measurement of $\sigma[e^+e^- \to \pi^+\pi^-h_c]$

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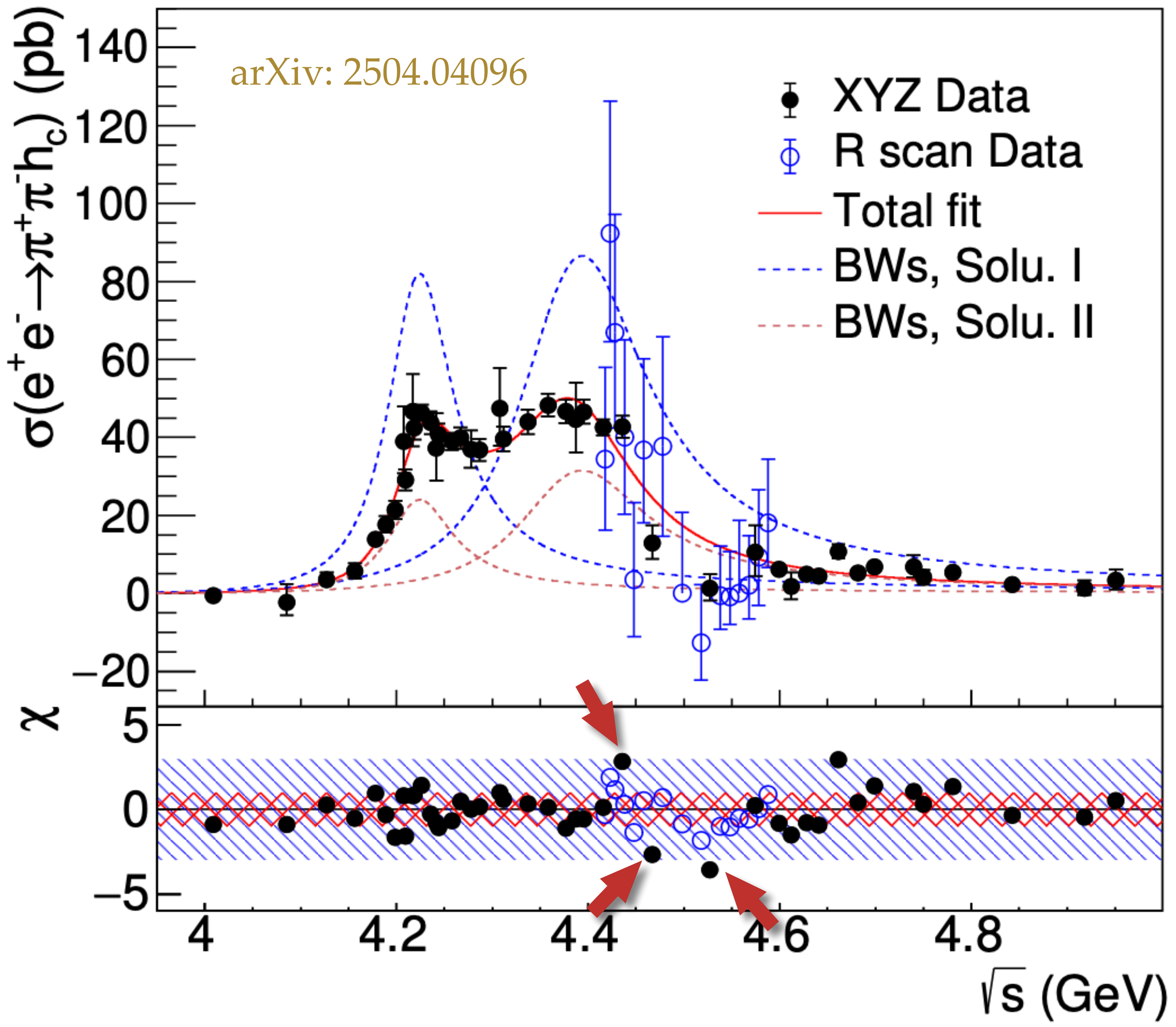
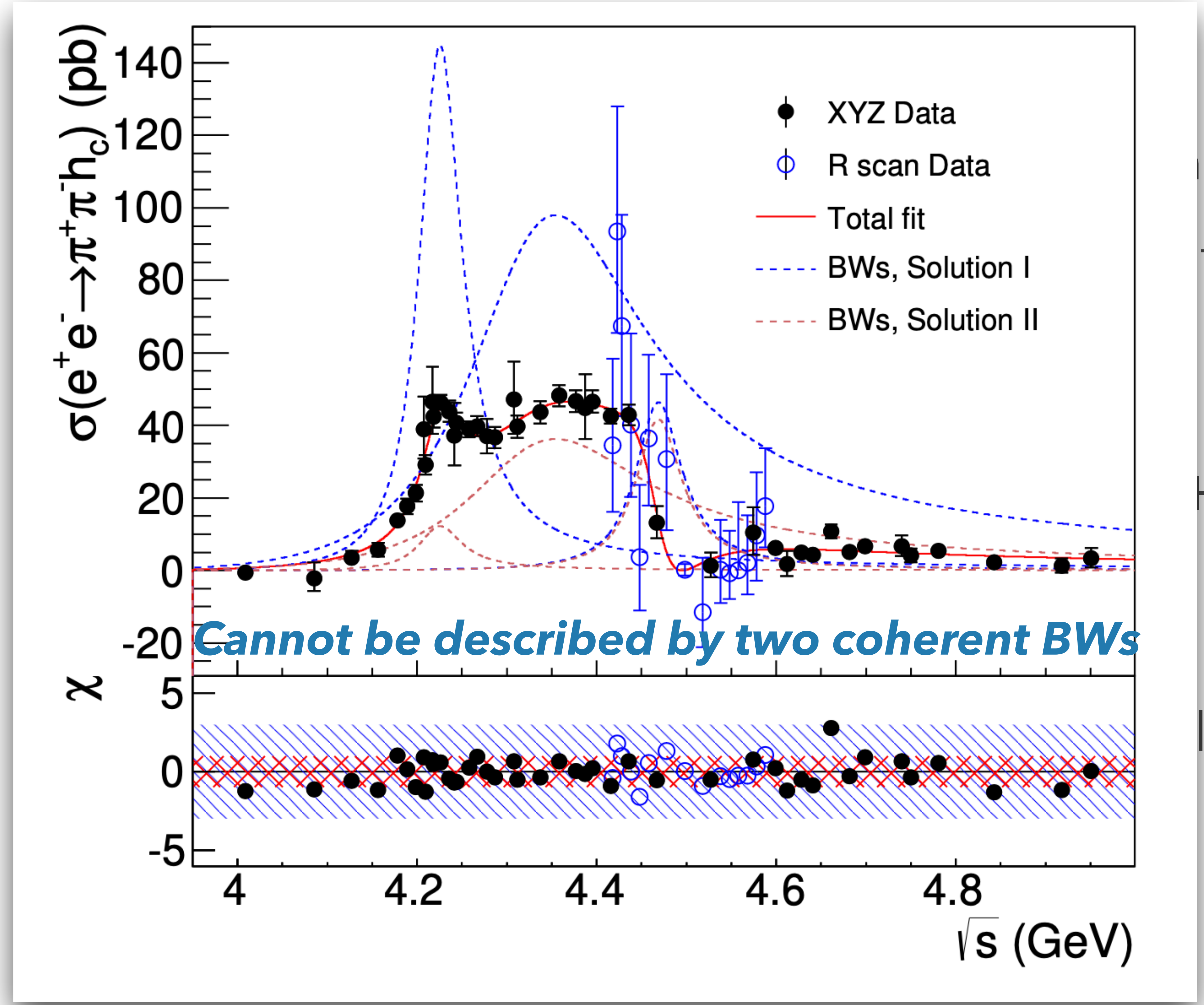




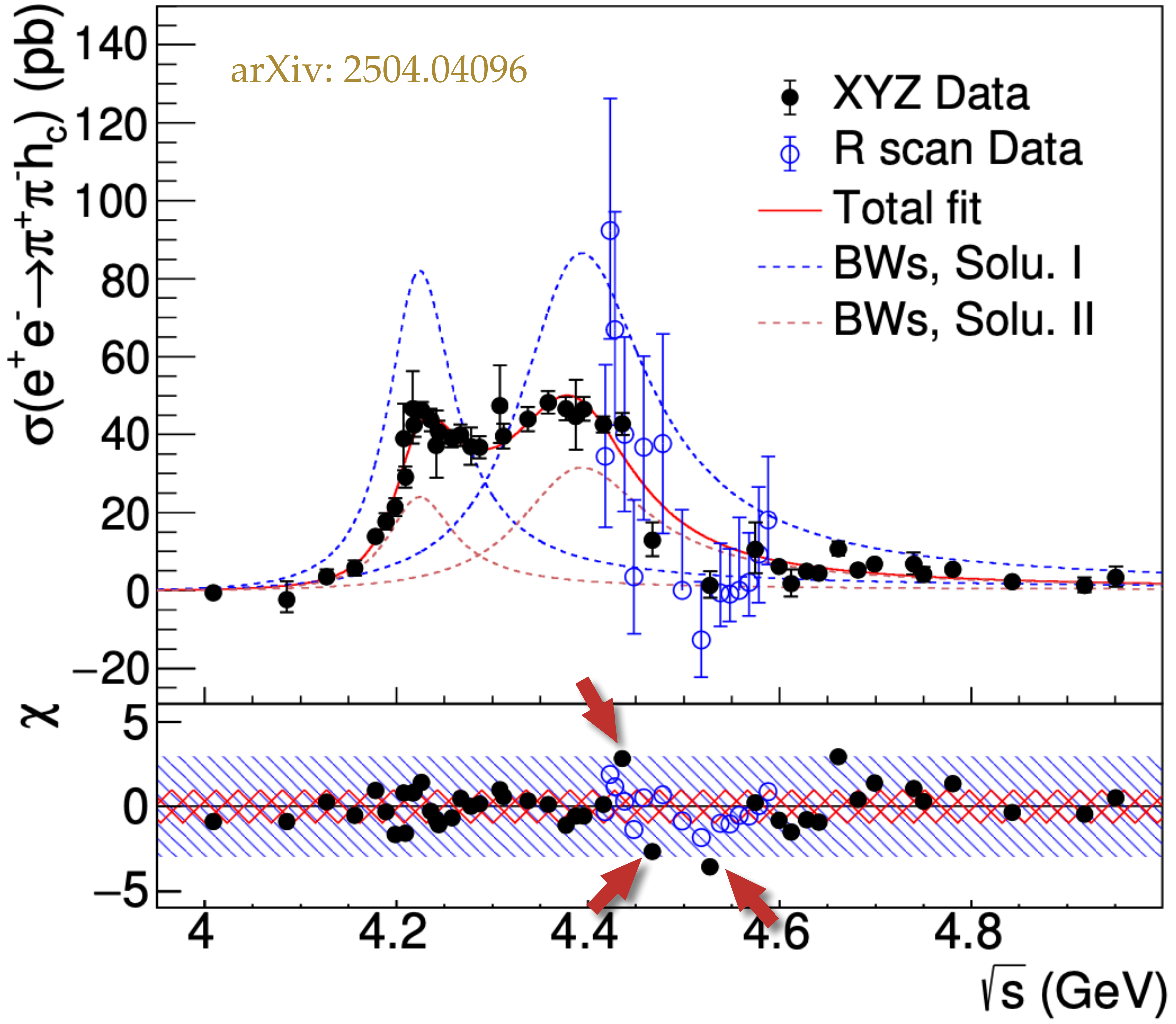
ore BW, two

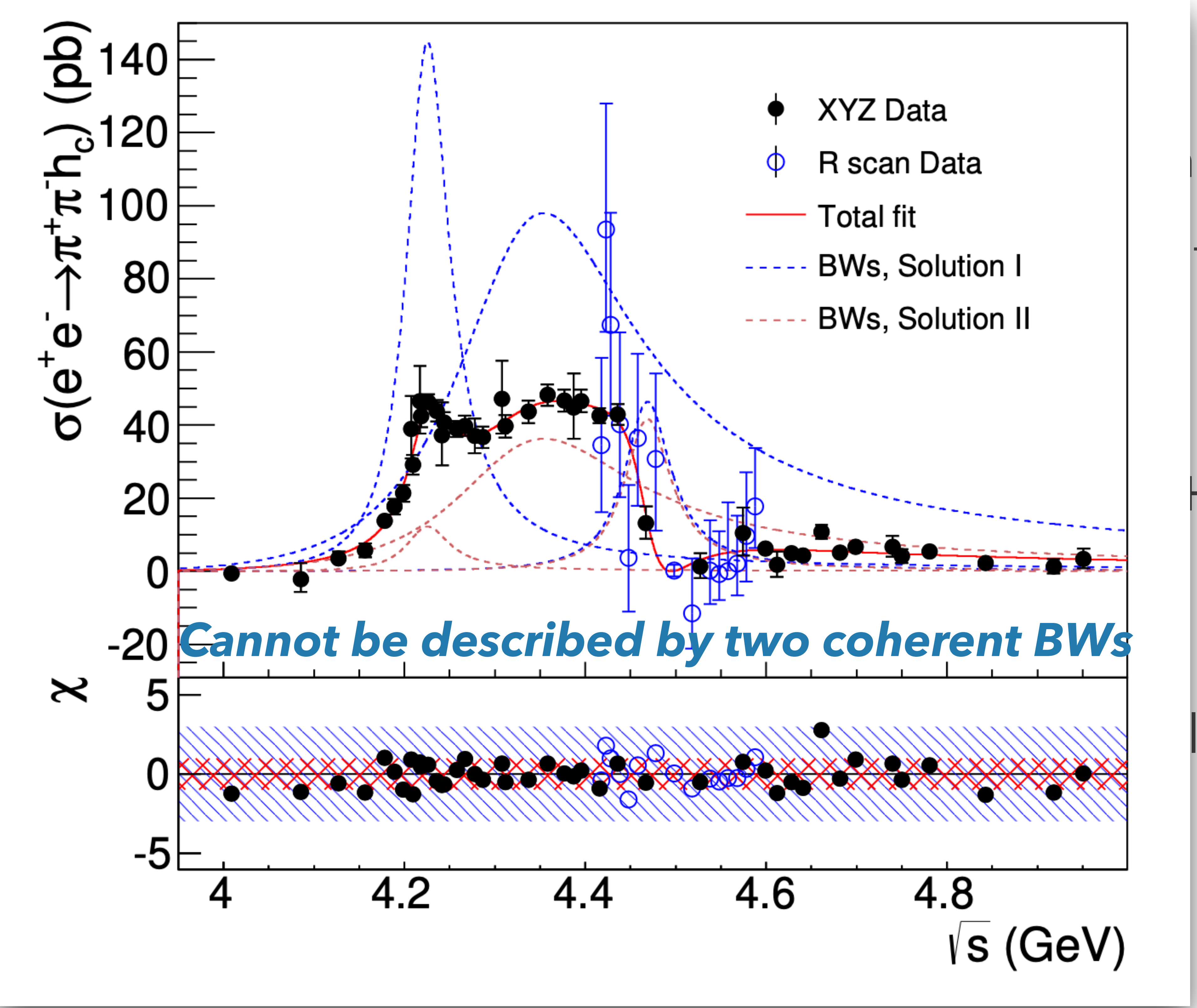
termt

$+ BW_3e^{i\phi_3}|^2$

ler than 1σ

Precise Measurement of $\sigma[e^+e^- \to \pi^+\pi^- h_c]$





ore BW, two

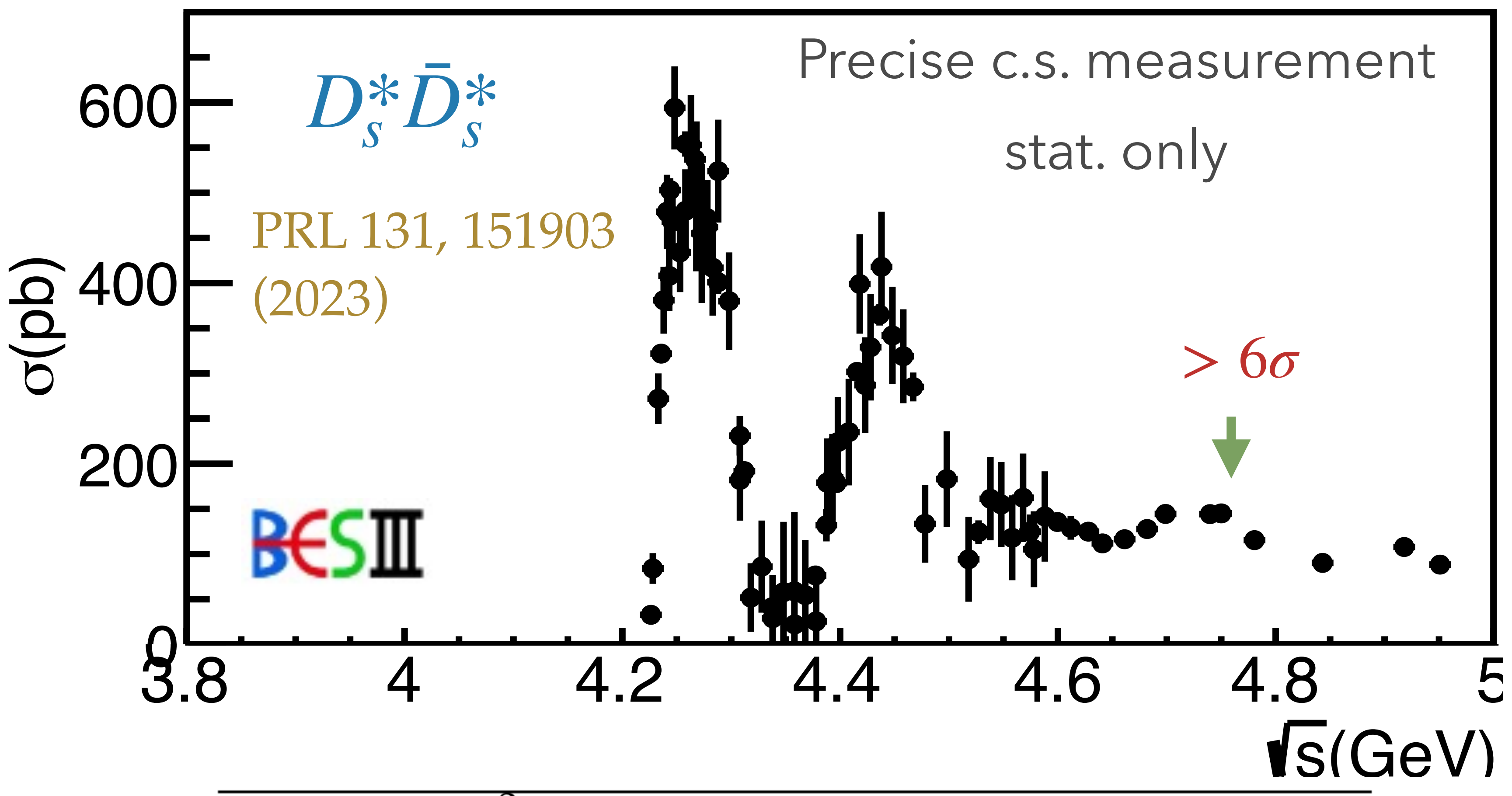
termt

$+ BW_3 e^{i\phi_3}|^2$

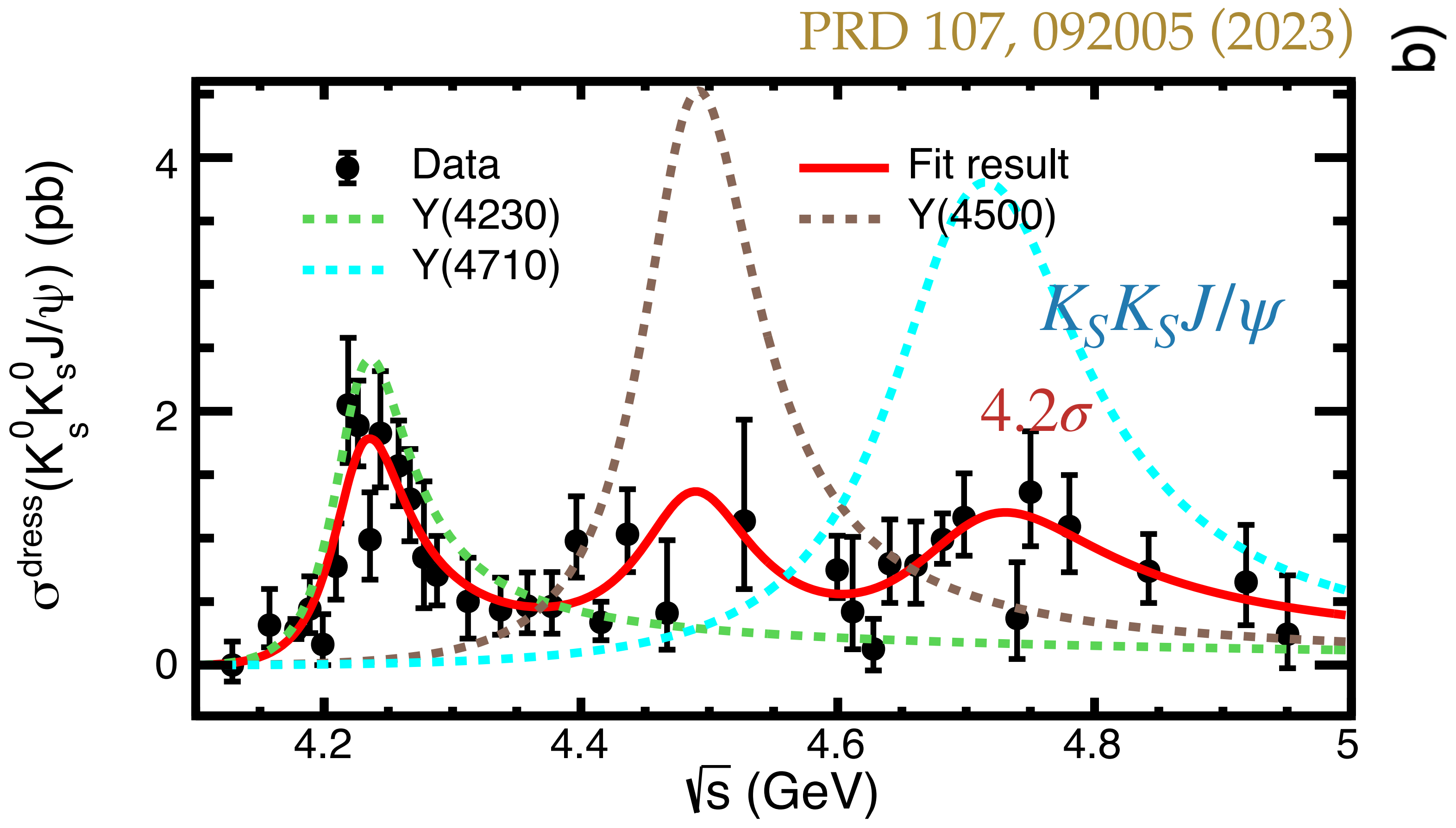
ler than 1σ

- No obvious resonance structure is found at around $\psi(4660)$, in tension with tetraquark explanation EPJC 78, 29 (2018)
- In $S-D$ mixing scheme, $4S-3D$, $5S-4D$ states are located in this mass region, only three are observed in this mode PRD99, 114003 (2019)

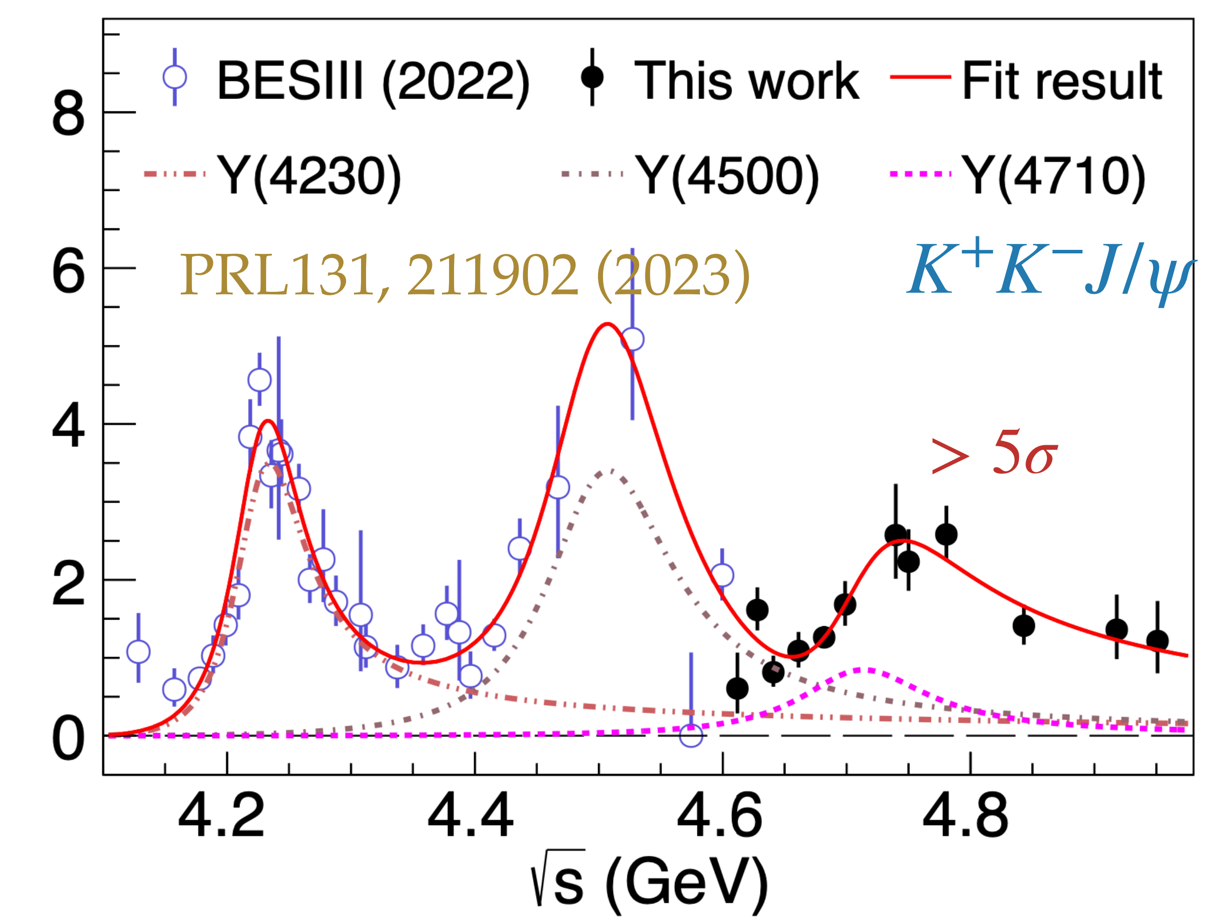
Observation of Y(4710)/Y(4790)



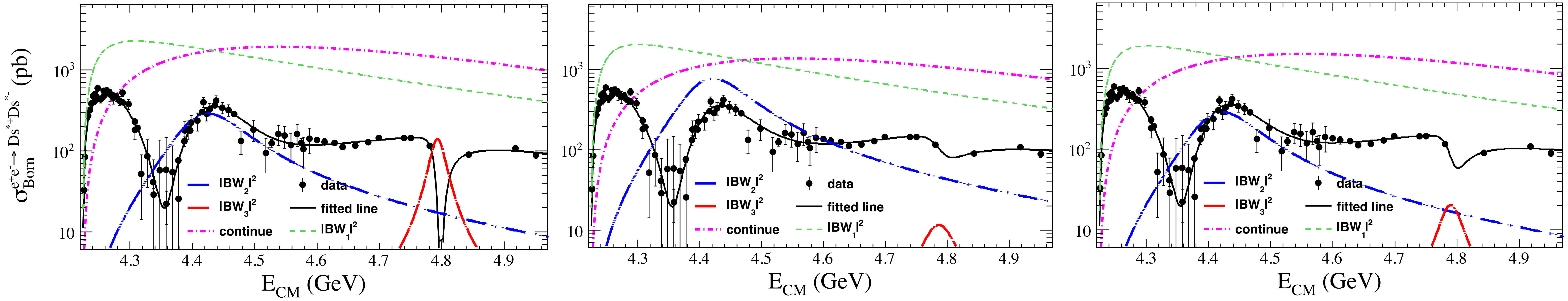
M_1 (MeV/c^2)	4186.5±9.0	4193.8±7.5	4195.3±7.5
Γ_1 (MeV)	55±17	61.2±9.0	61.8±9.0
M_2 (MeV/c^2)	4414.5±3.2	4412.8±3.2	4411.0±3.2
Γ_2 (MeV)	122.6±7.0	120.3±7.0	120.0±7.0
M_3 (MeV/c^2)	4793.3±7.5	4789.8±9.0	4786±10
Γ_3 (MeV)	27.1±7.0	41±39	60±35



Y(4710): $(4704 \pm 52 \pm 70)$ MeV/c^2
$(183 \pm 114 \pm 96)$ MeV



Y(4710): $(4708^{+17}_{-15} \pm 21)$ MeV/c^2
$(126^{+27}_{-23} \pm 30)$ MeV



Sophisticated Models Needed

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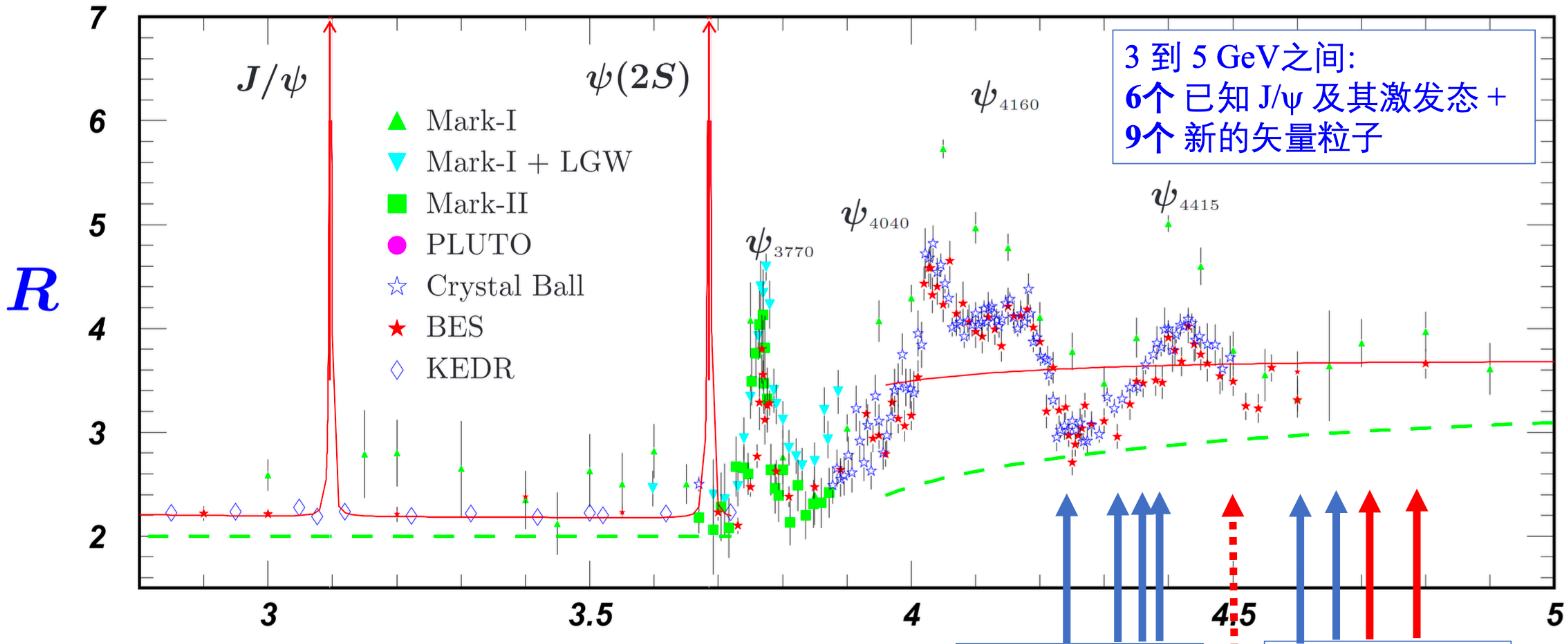

3 到 5 GeV之间:
6个 已知 J/ψ 及其激发态 +
9个 新的矢量粒子

Y(4230), Y(4320), Y(4360), Y(4390)

Y(4500)

Y(4630), Y(4660), Y(4710), Y(4790)

Besides vector charmonium ($c\bar{c}$) states, we also expect $c\bar{c}g$ hybrids, and $c\bar{c}q\bar{q}$ tetraquark states. Have they already been observed?

30

Sophisticated Models Needed

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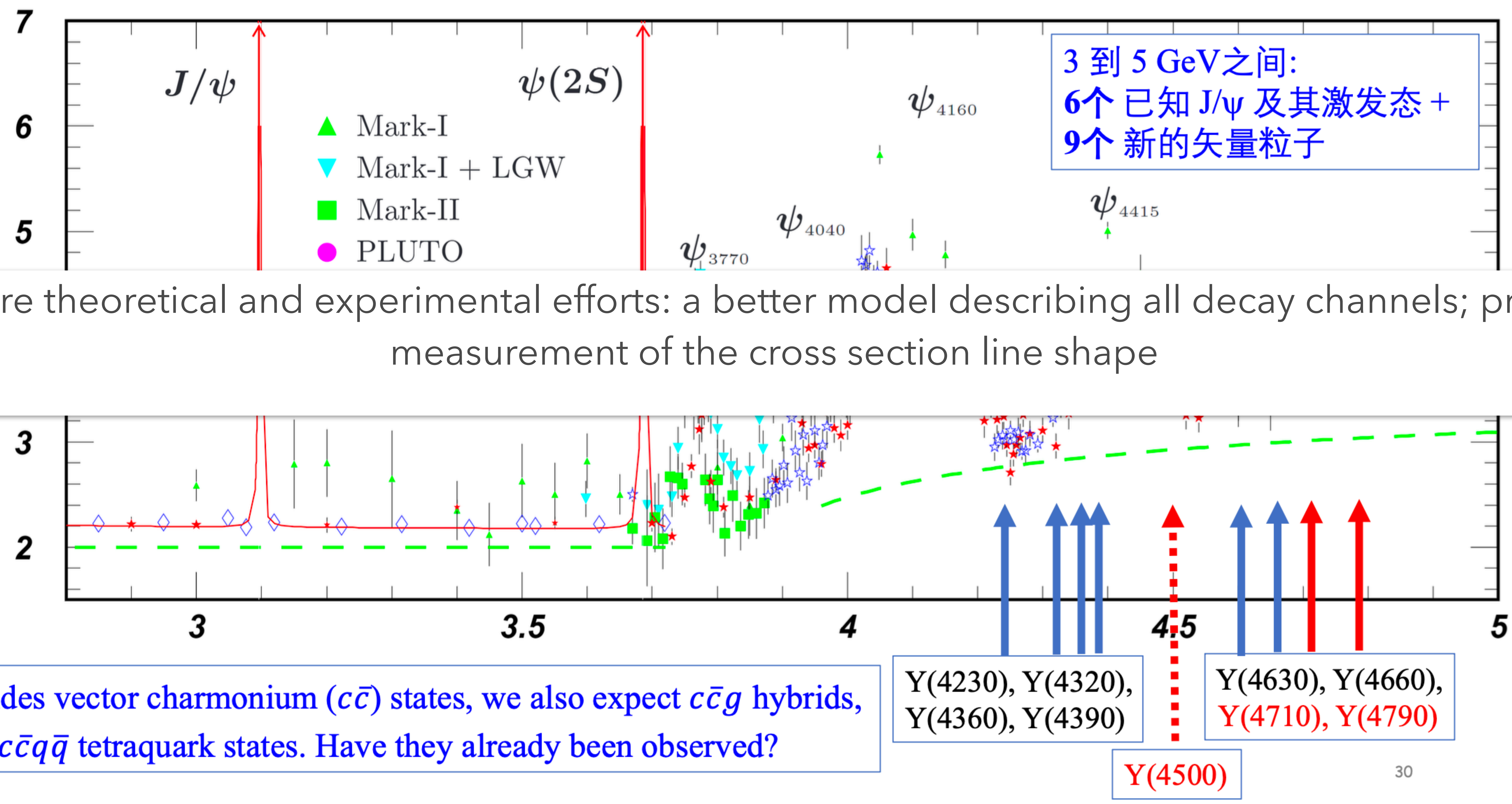


More theoretical and experimental efforts: a better model describing all decay channels; precise measurement of the cross section line shape

Besides vector charmonium ($c\bar{c}$) states, we also expect $c\bar{c}g$ hybrids, and $c\bar{c}q\bar{q}$ tetraquark states. Have they already been observed?

Sophisticated Models Needed

N. Husken, et al., arXiv:2404.03896

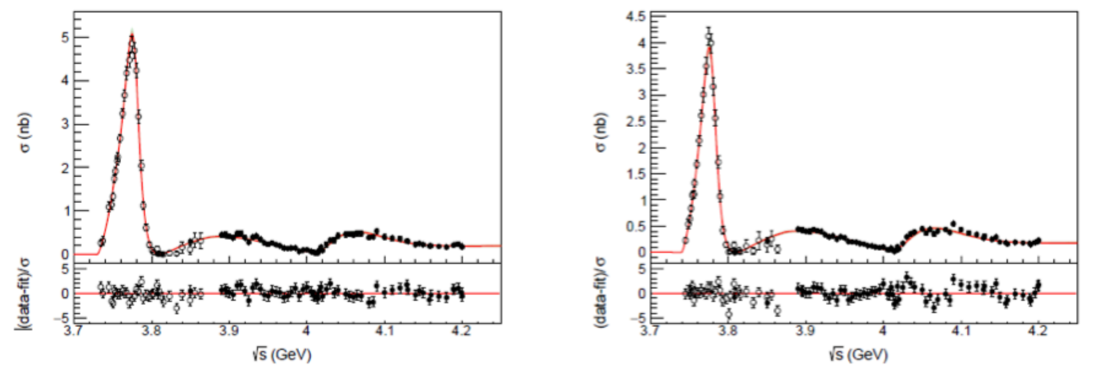


FIG. 2. Fit result for Model 1. Left: $e^+e^- \to D^0\bar{D}^0$. Right: $e^+e^- \to D^+D^-$. Open data points are the Born cross section values based on observed cross sections, as reported in Ref. [18]; closed data points are from Ref. [1].

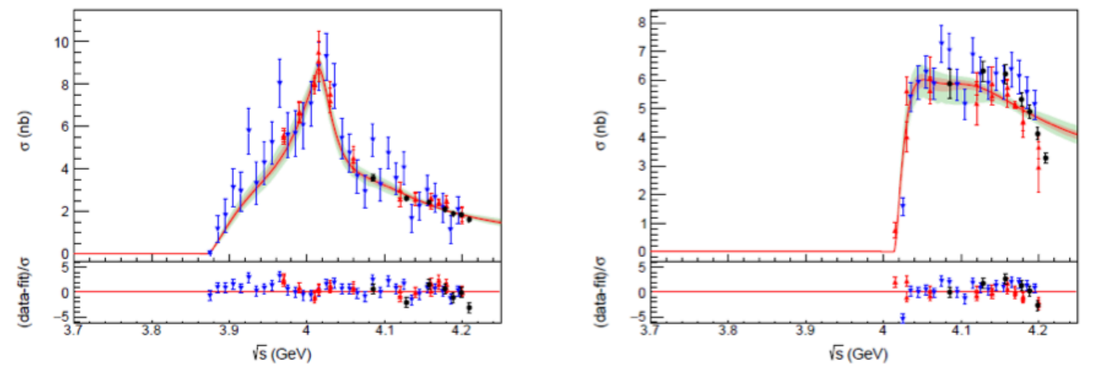


FIG. 3. Fit result for Model 1. Left: $e^+e^- \to D^*\bar{D}$. Right: $e^+e^- \to D^*\bar{D}^*$. The red region indicates the 68% confidence level, while green is the 90% confidence level. Black data points are from BESIII [21], red data is from CLEO-c [23, 24], blue data is from Belle [22].

S. G. Salnikov & A. I. Milstein, arXiv:2404.06160

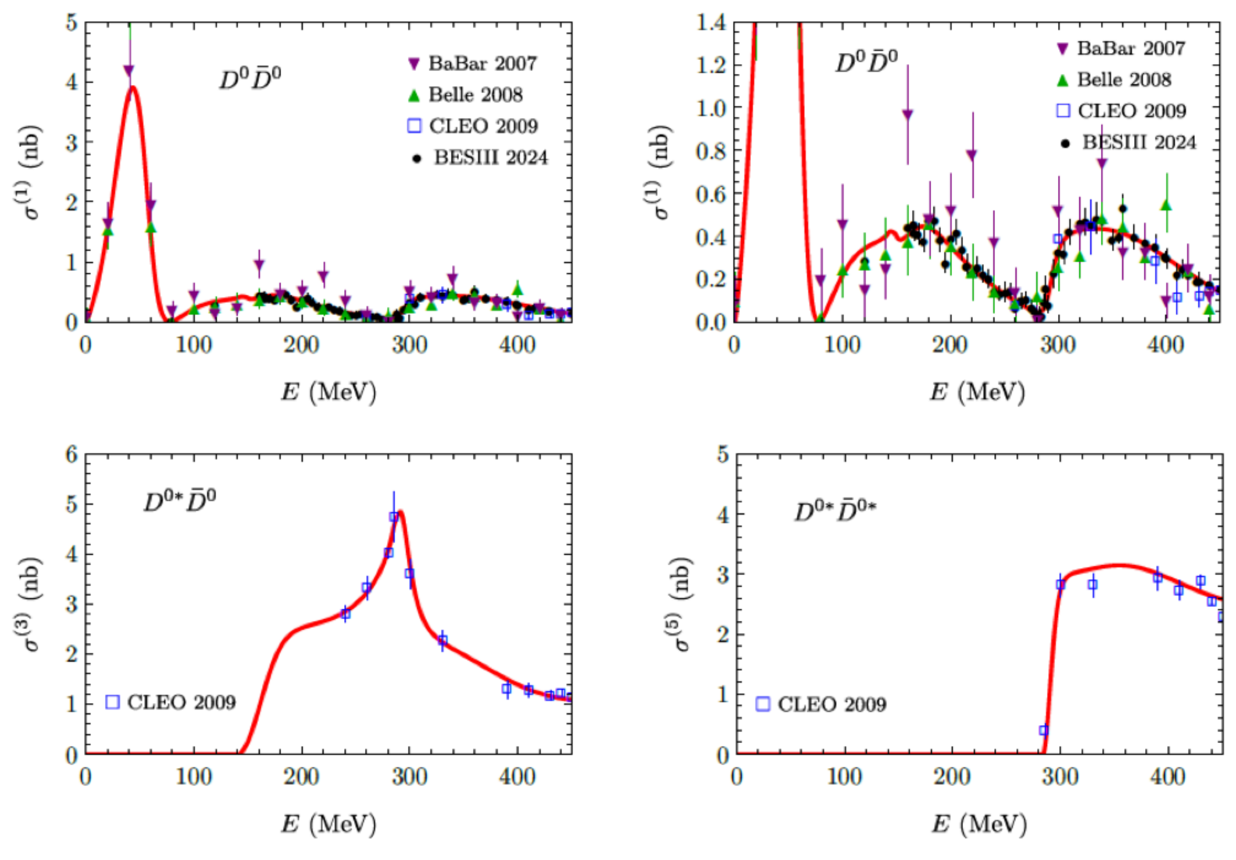


FIG. 1. Energy dependence of the cross sections for the production of neutral particles. Experimental data are taken from Refs. [32, 34–36, 39].

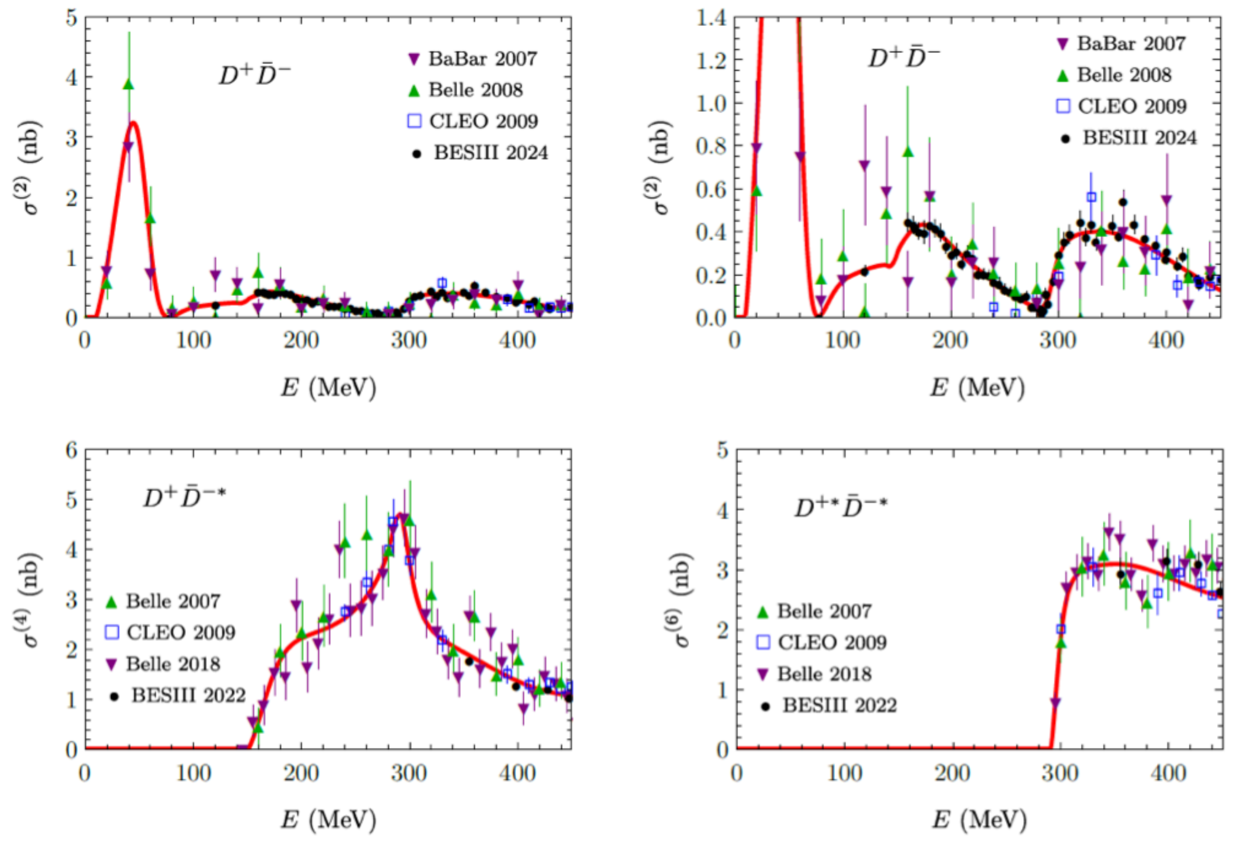
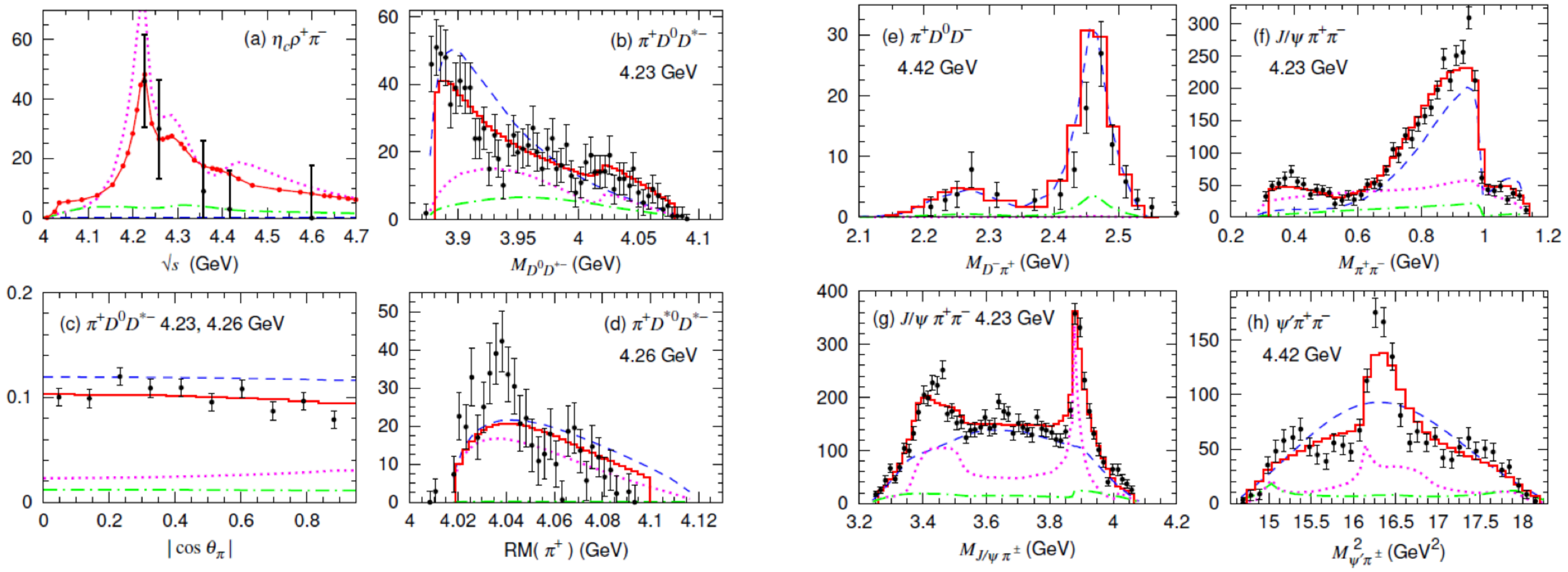


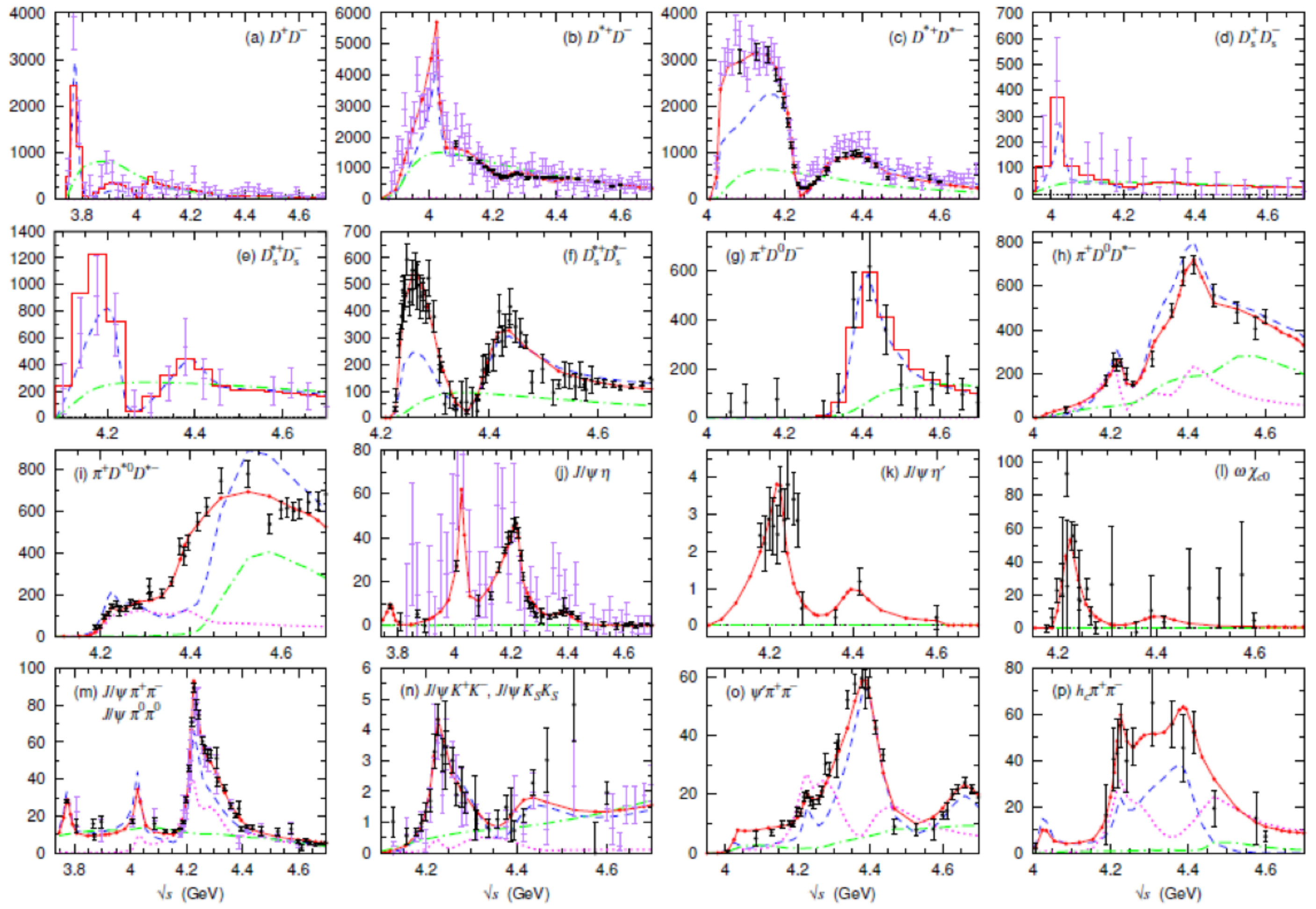
FIG. 2. Energy dependence of the cross sections for production of charged particles. Experimental data are taken from Refs. [32–39].

recise

5

S. X. Nakamura, et al., arXiv:2312.17658





Four-Quark Matter: Z_c

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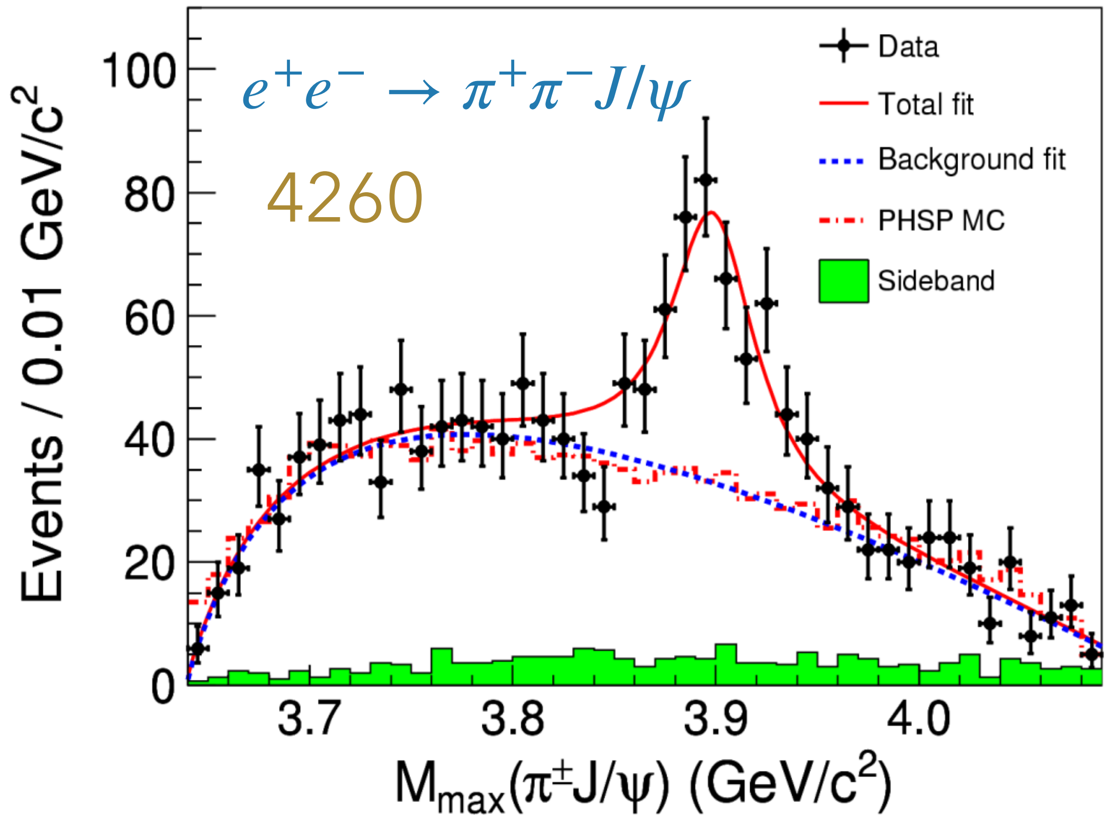
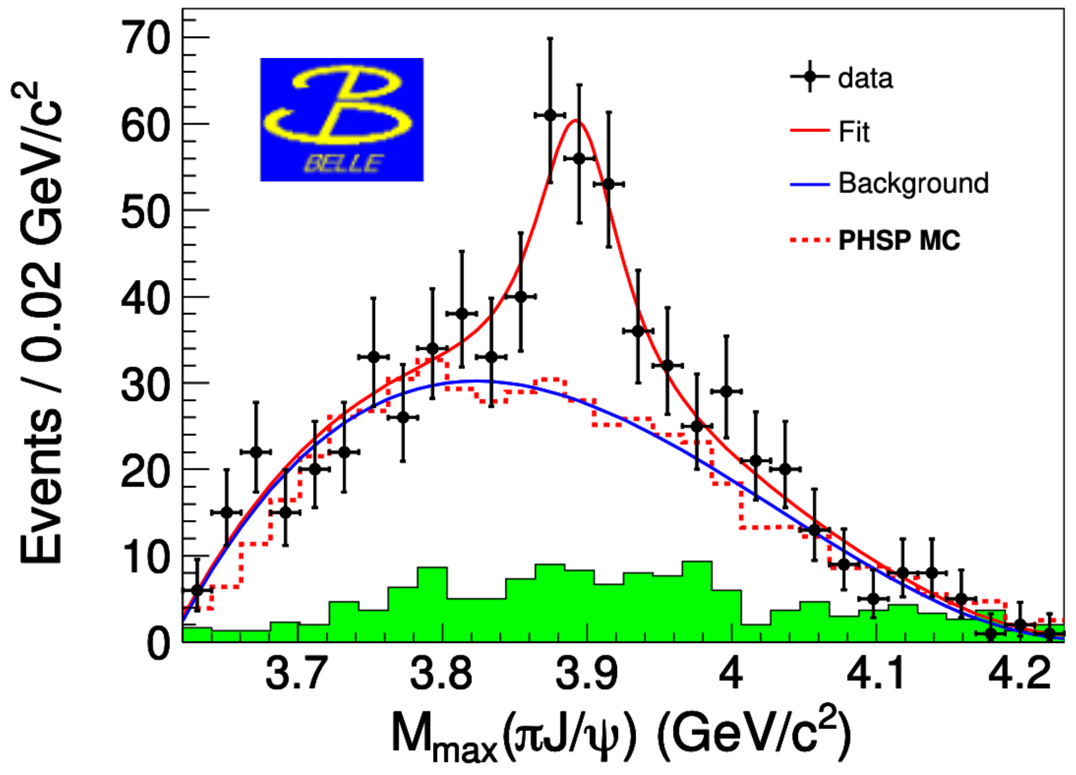
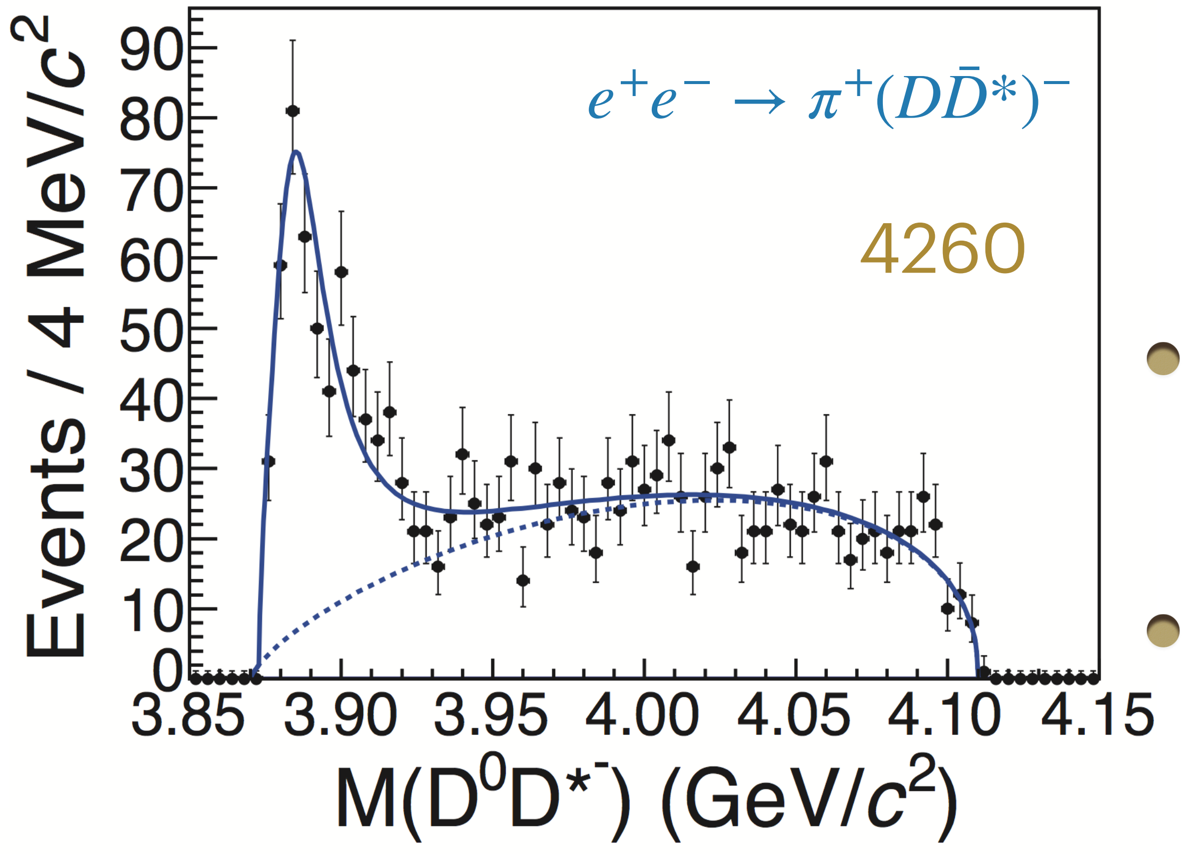
$Z_c(3900)/Z_c(3885)$

PRL110, 252001 (2013), PRL110, 252002 (2013) PRL112, 022001 (2014)

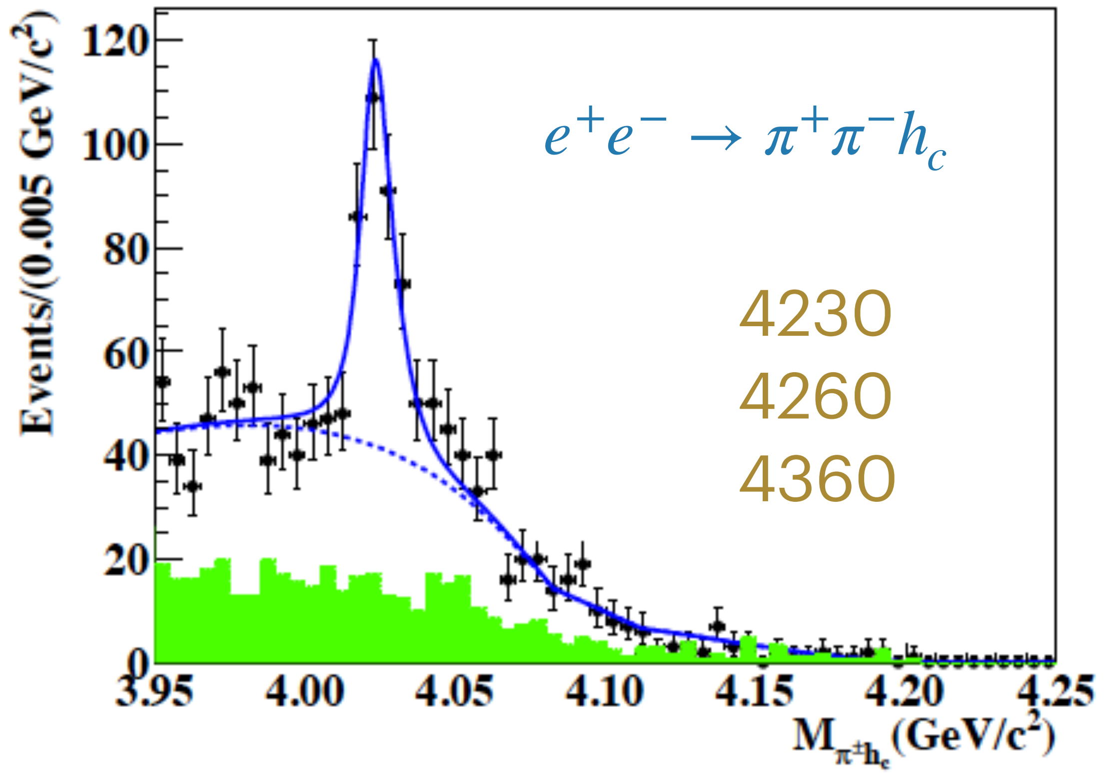


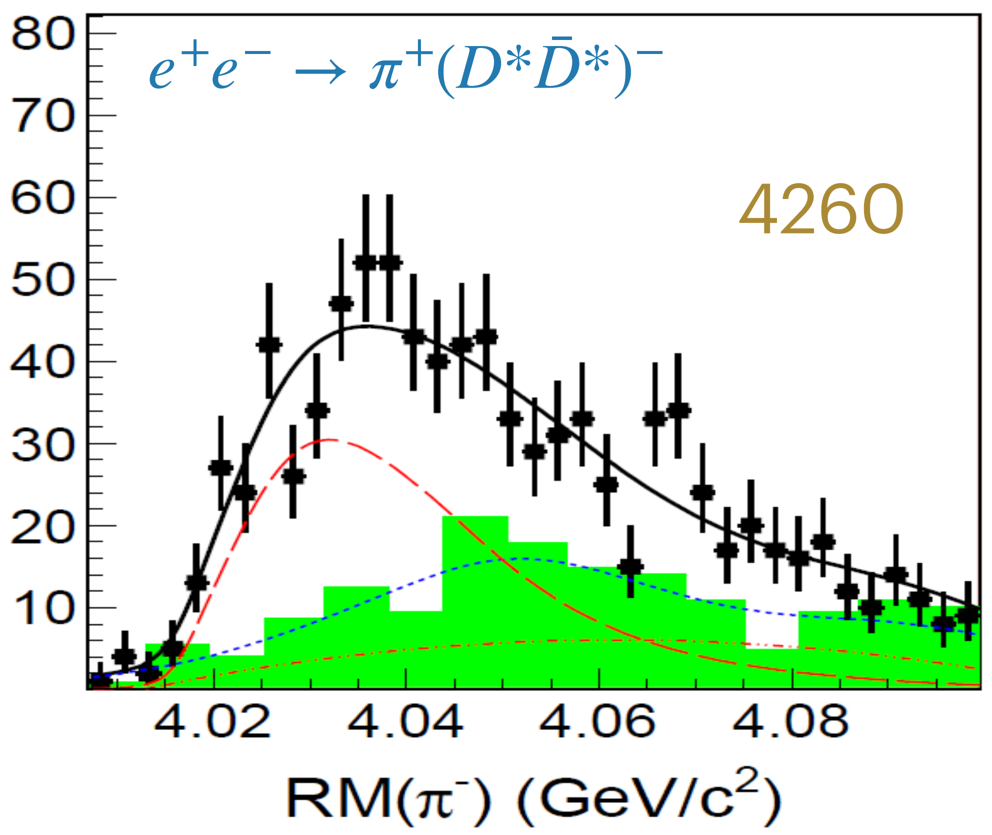




- Produced in e^+e^- annihilation or b-flavor hadron decays
- Typically in h+charmonium final states
- Intrinsic nature unclear, exotic states? kinematic effects?

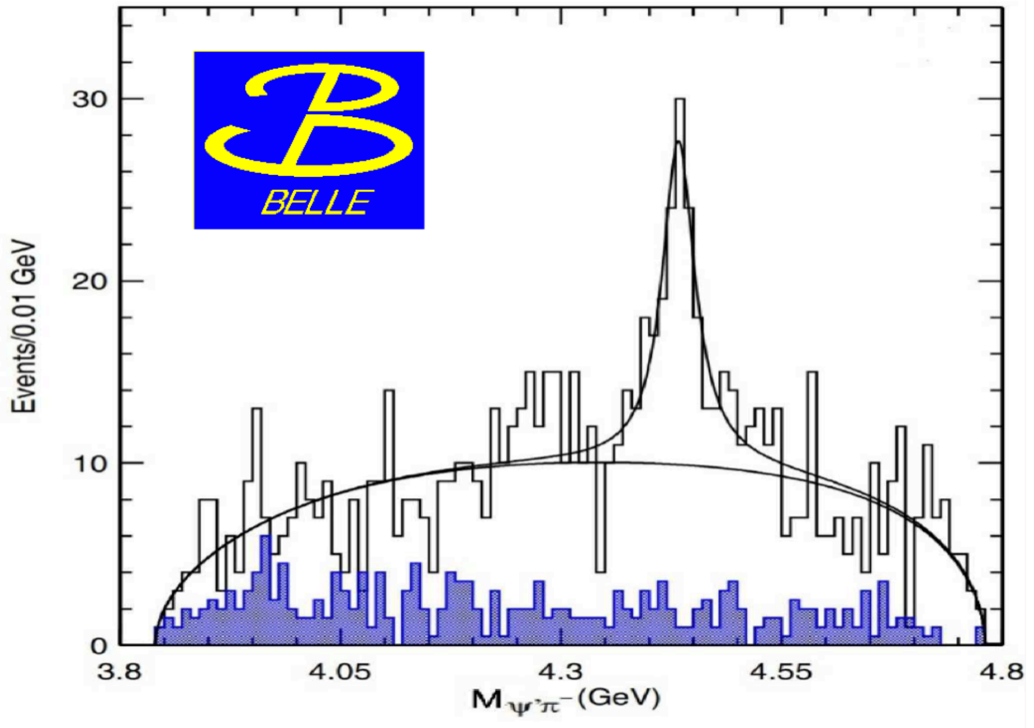
$Z_c(4020)/Z_c(4025)$

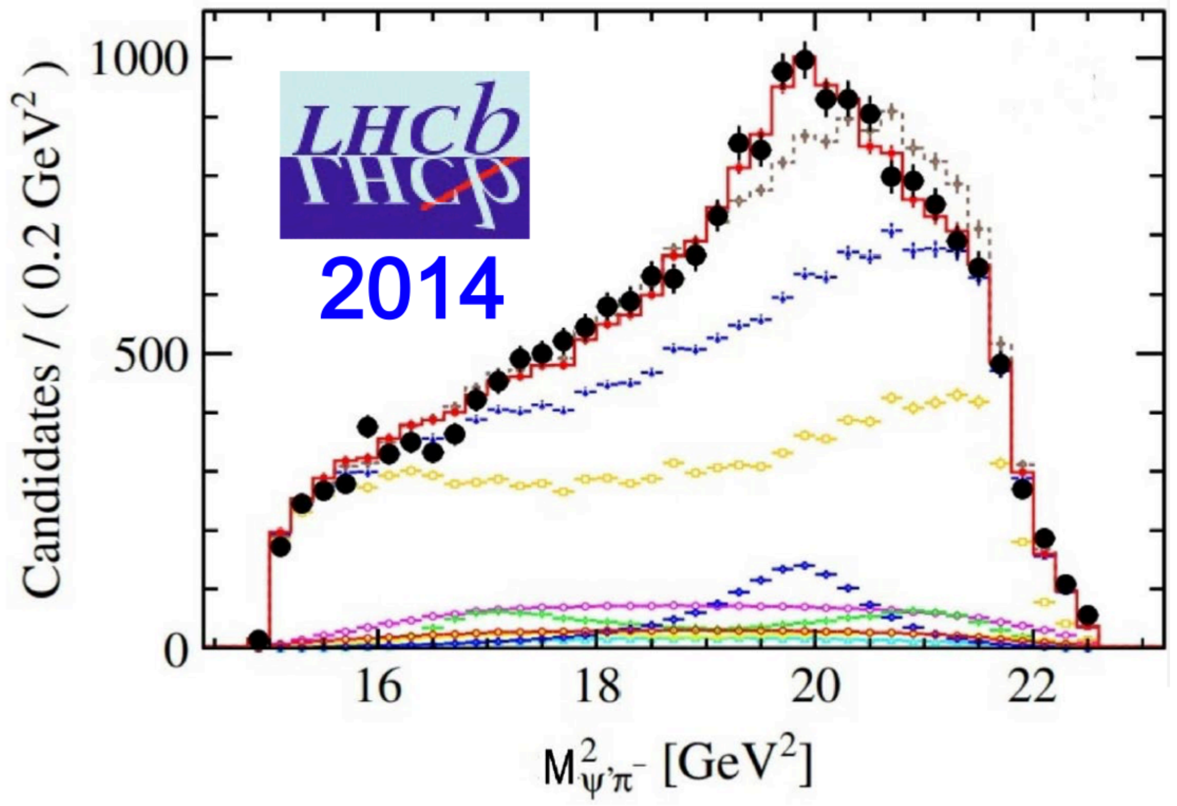




PRL111, 242001 (2013) PRL112, 132001 (2014)

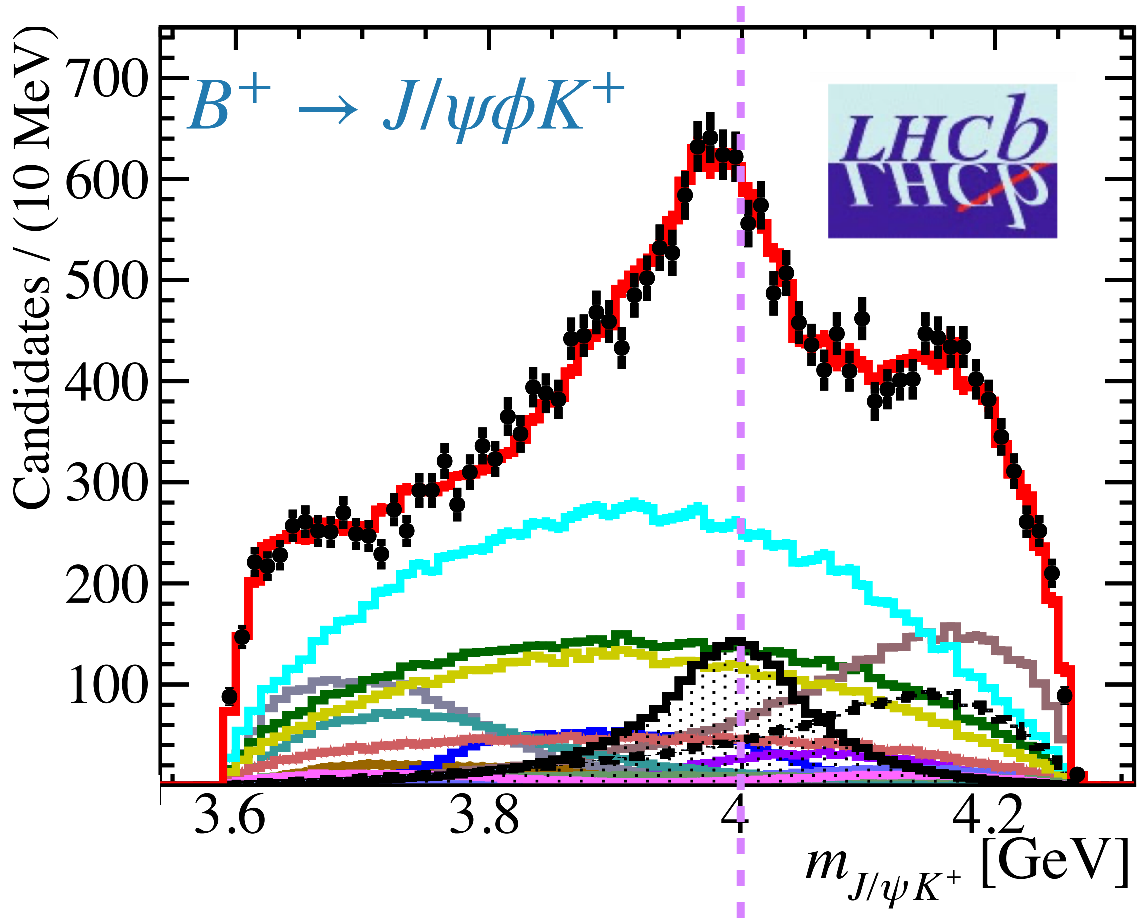
$Z_c(4430)$





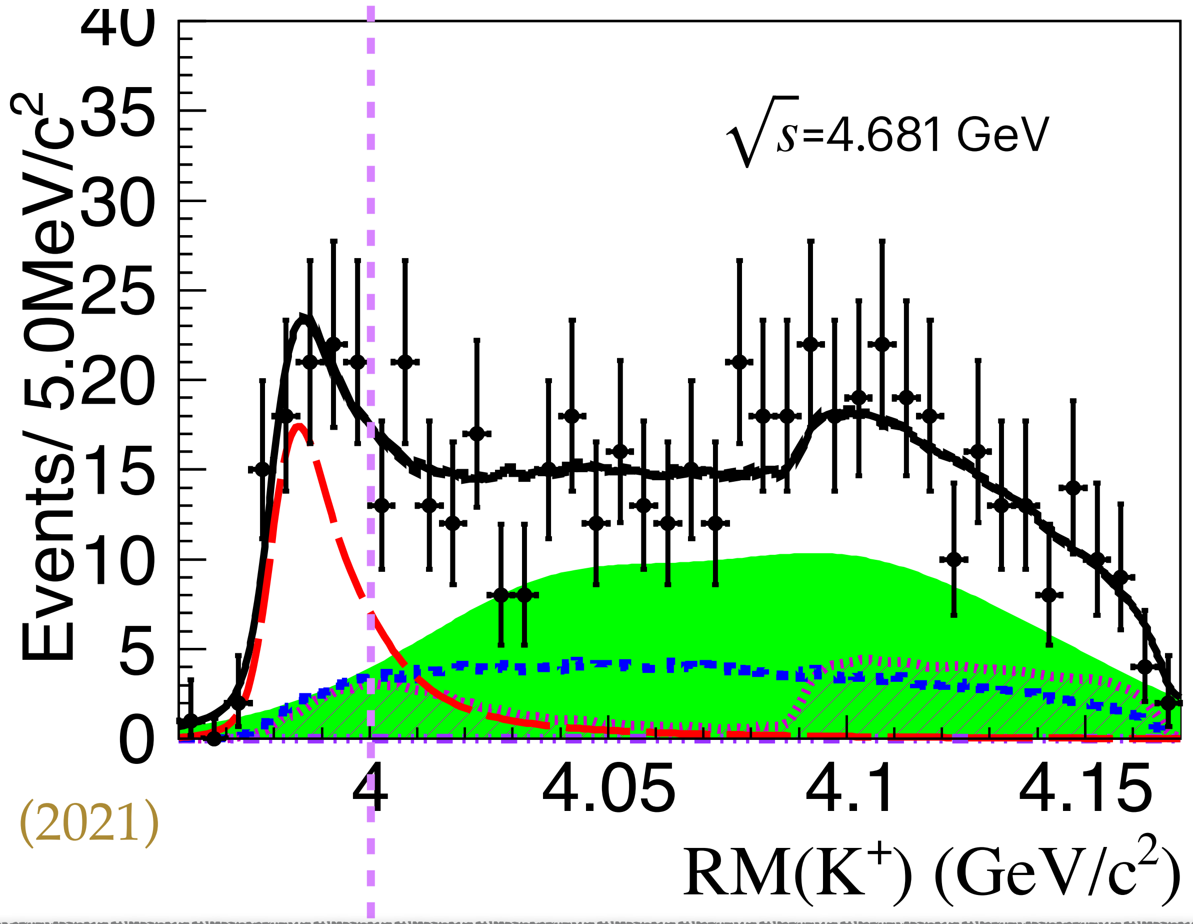
Strange Partner of Z_c

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



PRL126, 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

Studies in $D_sD^* + D_s^*D$ system from B decay and K^+K^-J/ψ system from e^+e^- annihilation are needed

Strange Partner of Z_c

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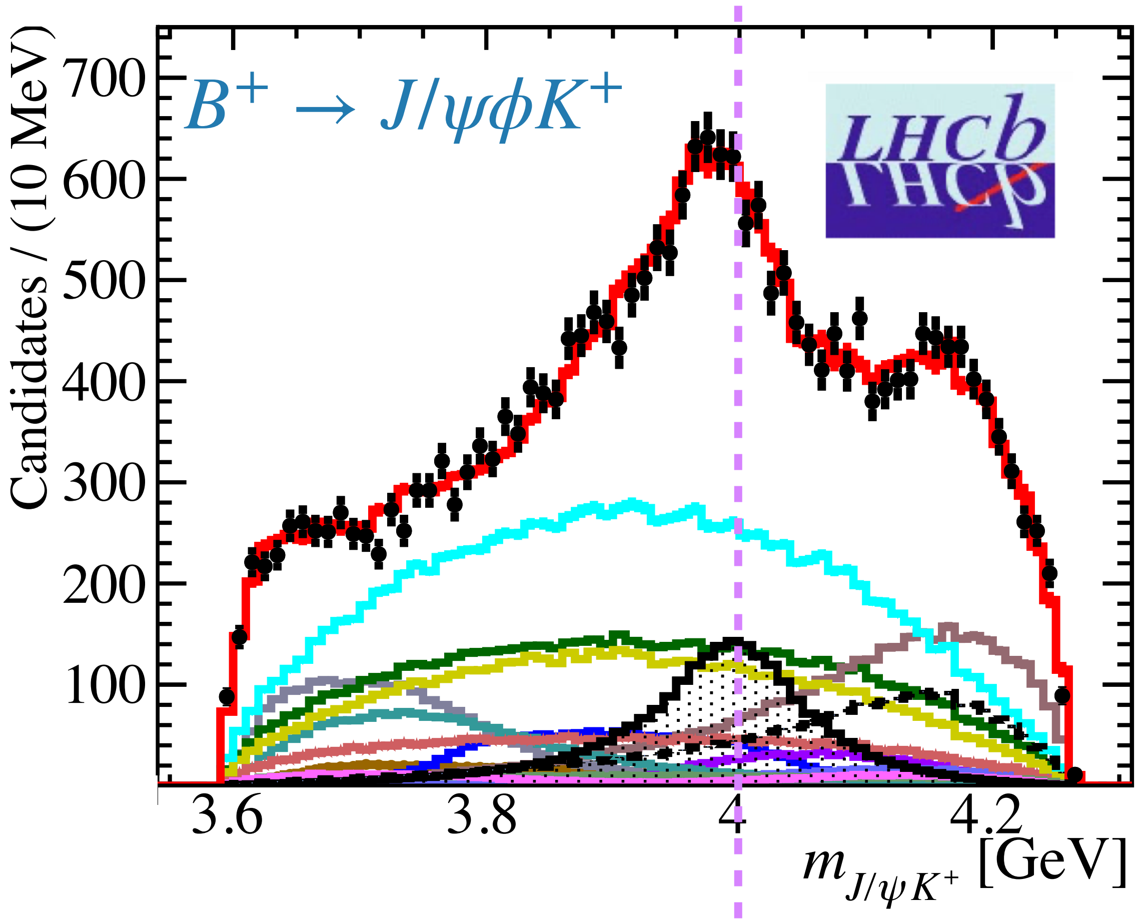
PRL 127, 082001 (2021)



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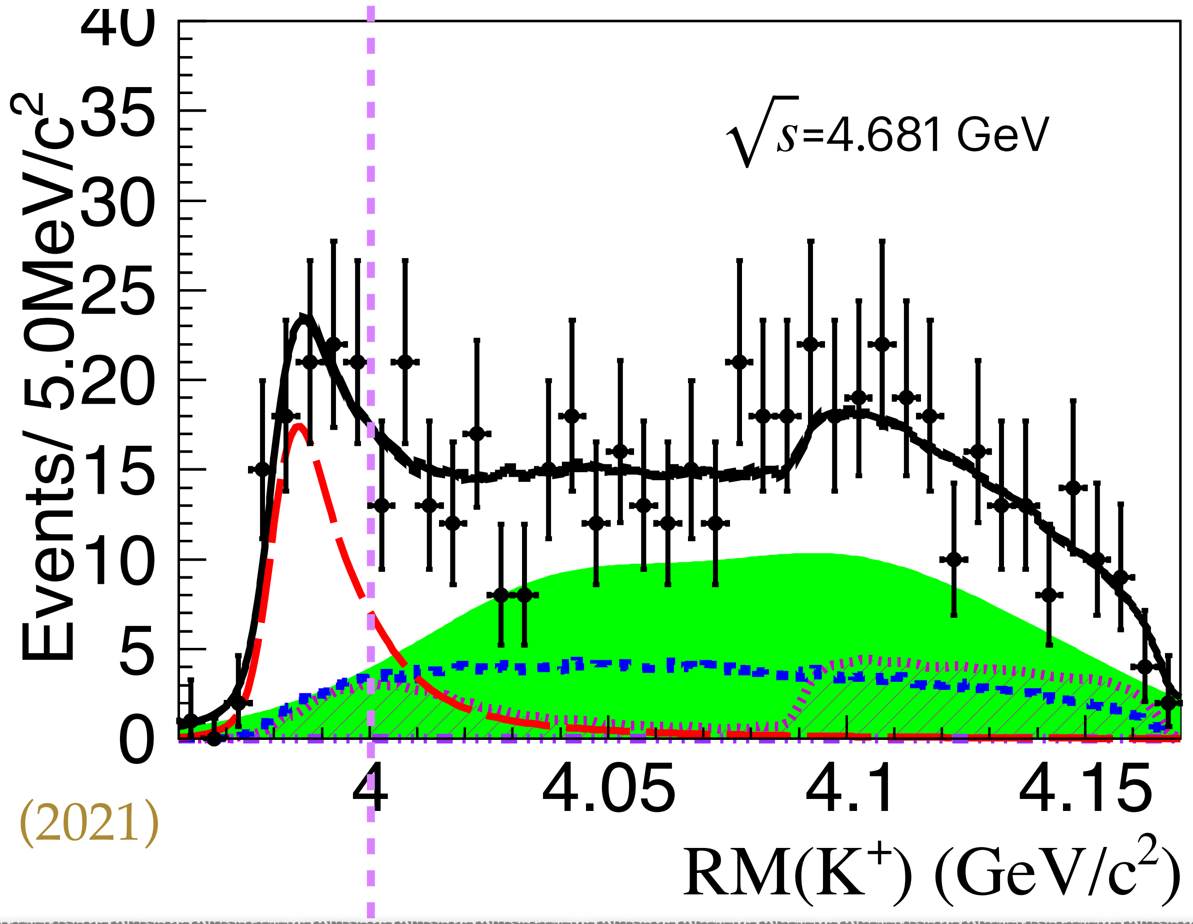

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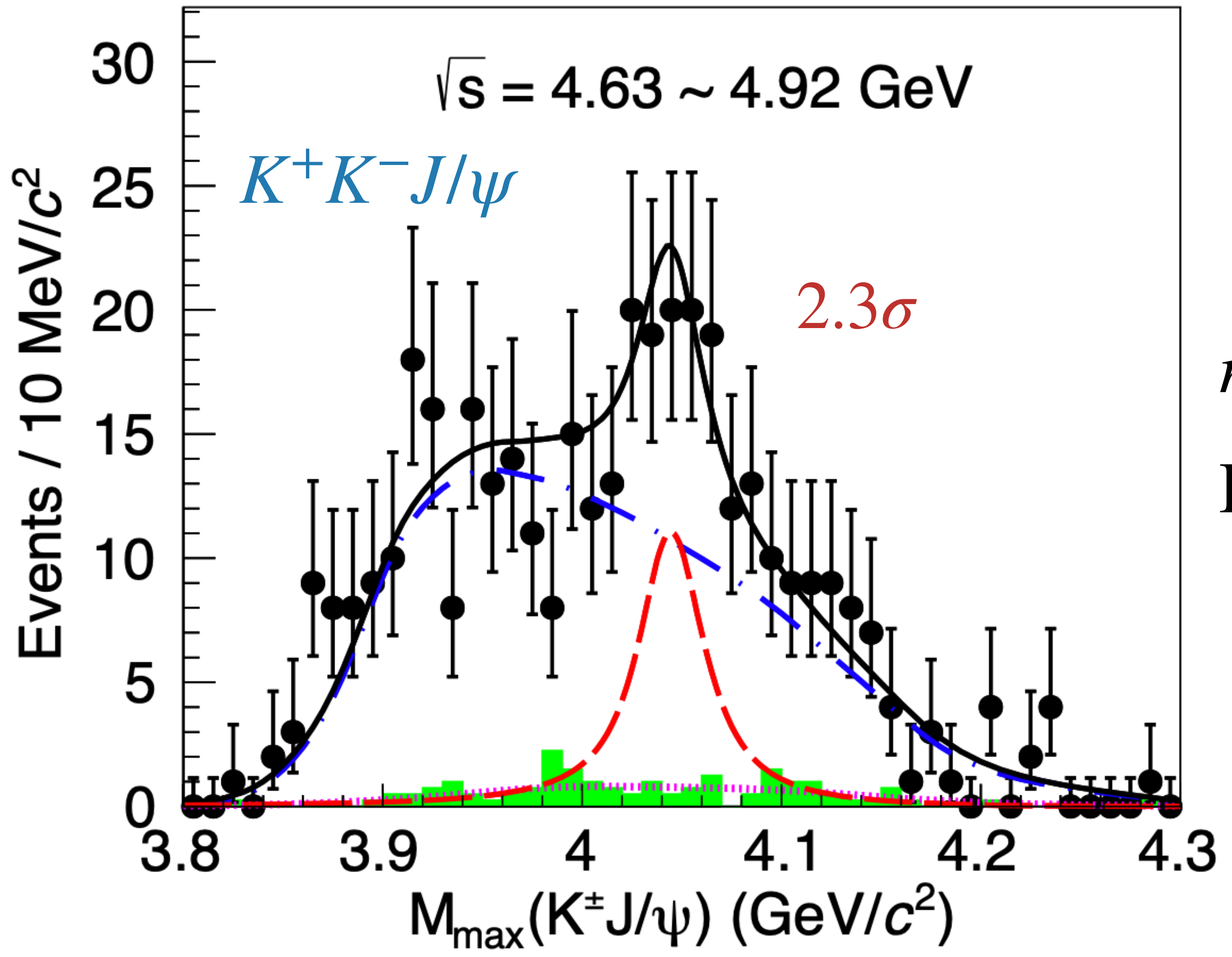


PRL131, 211902 (2023)

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

$\Gamma = 36 \pm 16$ MeV

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

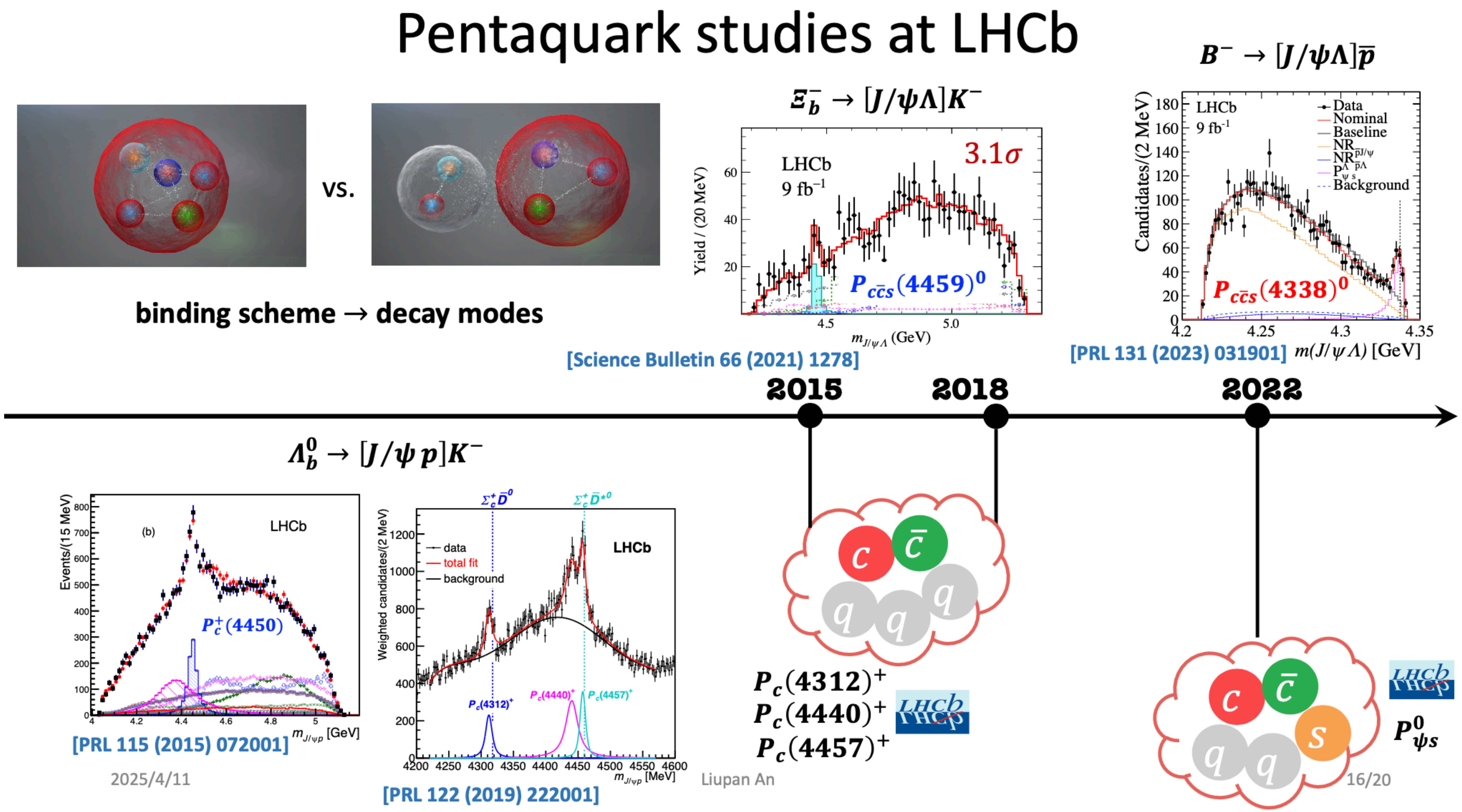
at 90% C. L.

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

Calculated with data in PRL 112, 022001 (2014)

Studies in $D_s D^* + D_s^* D$ system from B decay and K^+K^-J/ψ system from e^+e^- annihilation are needed

Pentaquark State



- Pentqquark in open charm modes
- Prompt production
- $\Lambda_b^0 \to \Lambda_c^+ \bar{D}^{(*)0} K^-$
- $\Lambda_b^0 \to \Sigma_c^{(*)++} D^{(*)-} K^-$
- No significant pentaquark, call for larger dataset

PR D110 (2024) 032001

EPJC 84 (2024) 575

PR D110 (2024) L031104

Borrowed from Liupan An @ 第十届XYZ研讨会

Summary

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- A lot of progress has been made in the experimental study of hadron spectroscopy and exotic hadrons
- Many candidates with exotic characteristics have been observed:
  - Z_Q: tetraquark with a $Q\bar{Q}$; P_Q: pentaquark with a $Q\bar{Q}$; Y: vector states with $J^{PC} = 1^{--}$; X: others
  - Some are close to the threshold ⇒ are good candidates for molecules, and full spectroscopy should be investigated
  - "Overpopulation problem" in vector states
  - Abnormal production/decay properties
- More results are expected in the near future with larger statistics, opportunities and challenges
  - BESIII [just finished upgrade, 3x luminosity optimized at 4.7 GeV]
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Thank You!