The vector charmonia at BESIII

and how to interpret them

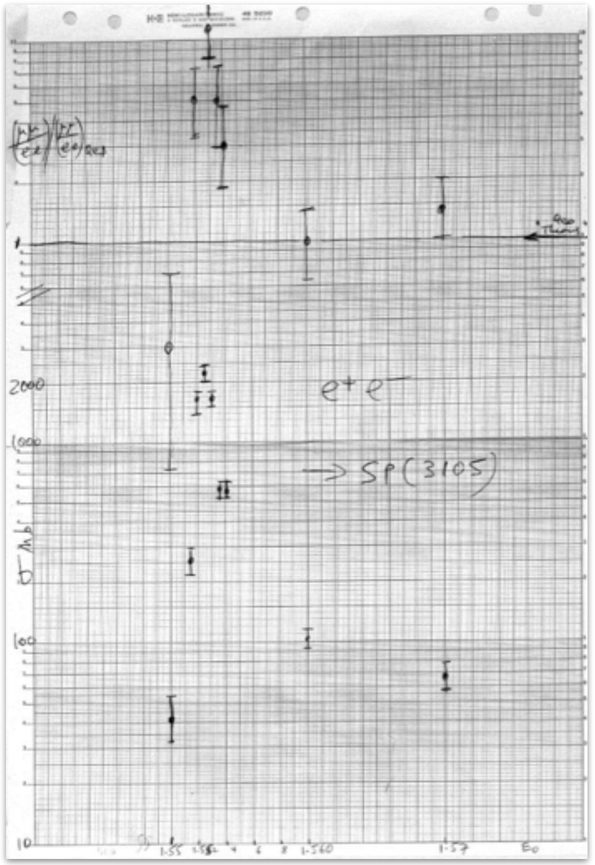
18th International Workshop on Meson Physics - June 29th, 2026

Nils Hüsken
Johannes Gutenberg-Universität Mainz

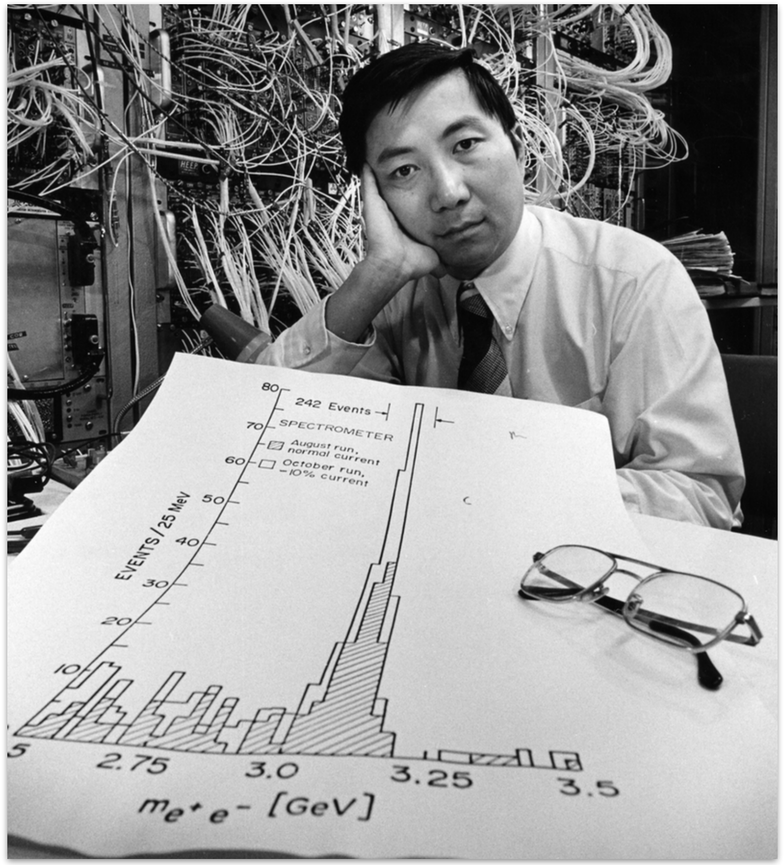
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

JG|U

Vector charmonia



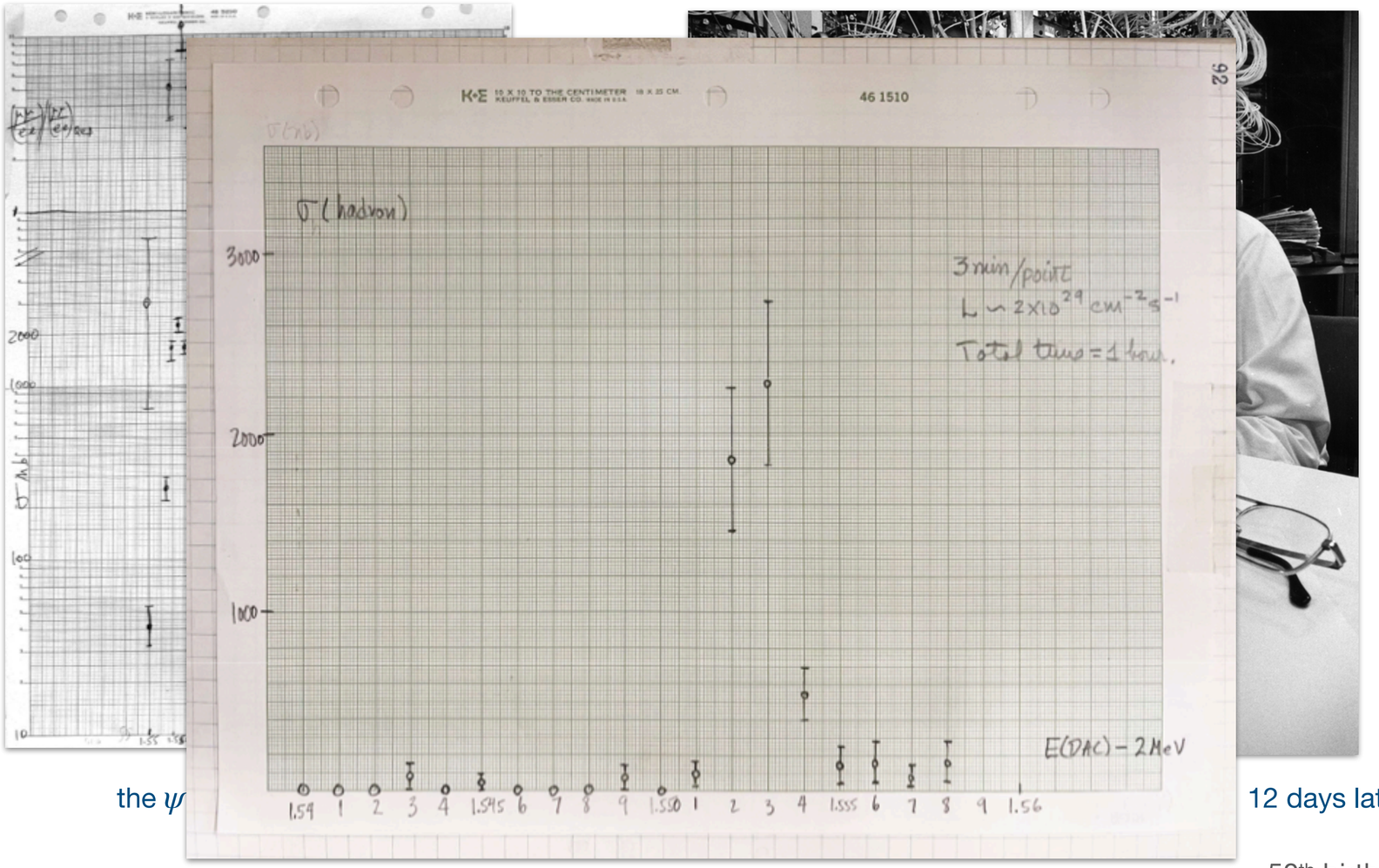
the ψ as seen at SLAC



S. Ting with the J particle

50th birthday in 2024:
https://indico.slac.stanford.edu/event/9040/
https://indico.ihep.ac.cn/event/23322/

Vector charmonia



the ψ

12 days later: discovery of the ψ'

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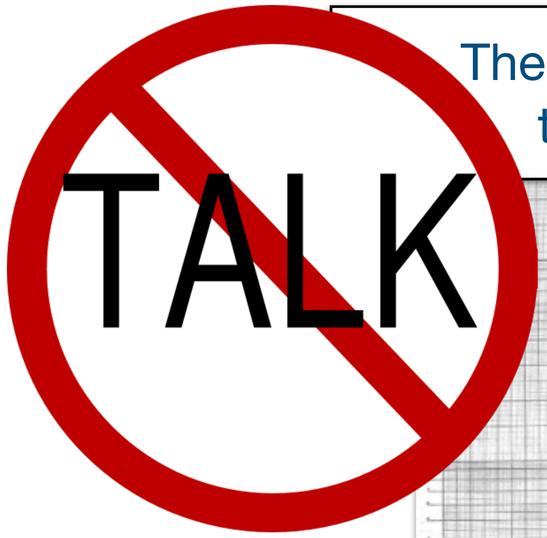
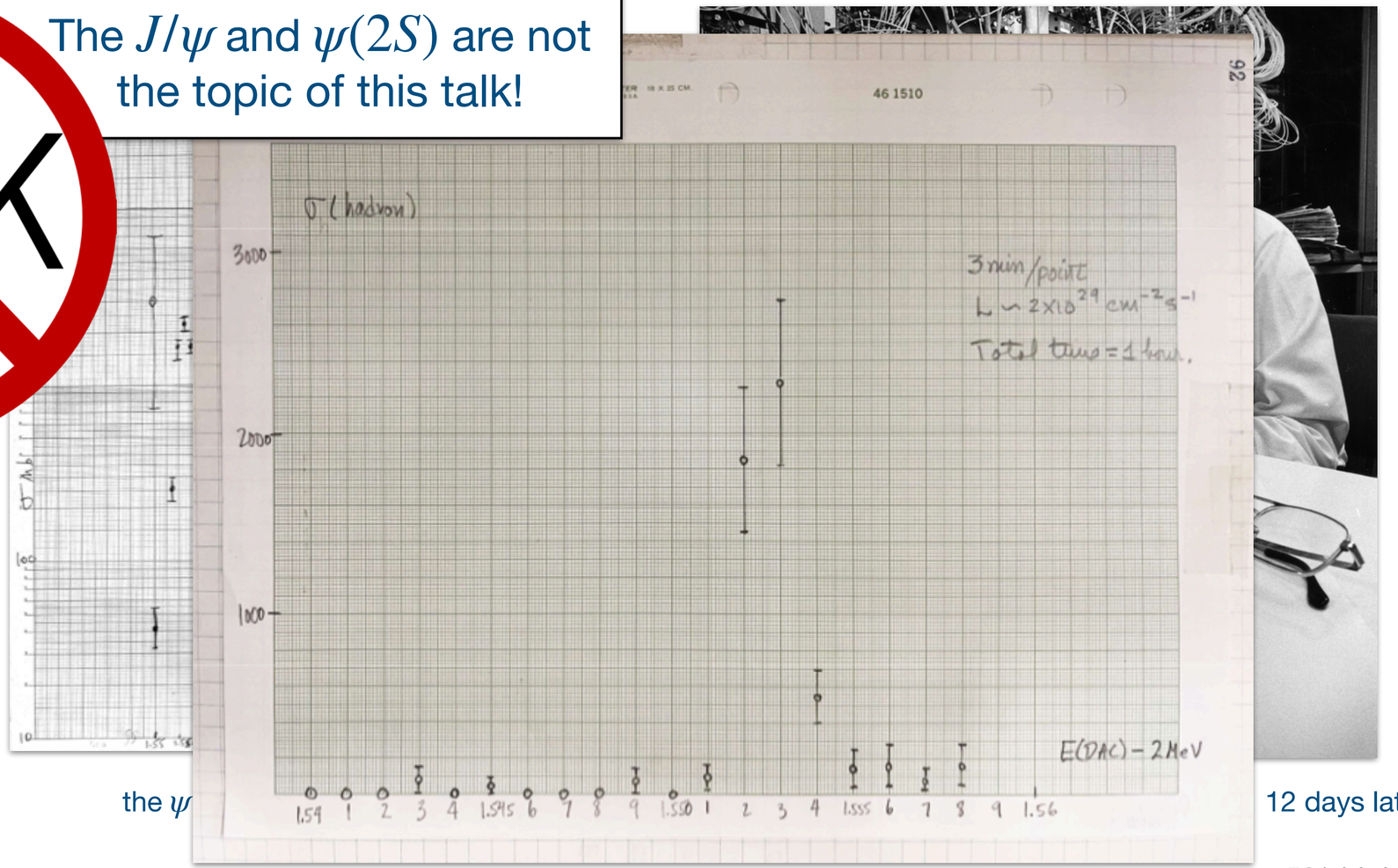
Vector charmonia



The J/ψ and $\psi(2S)$ are not the topic of this talk!



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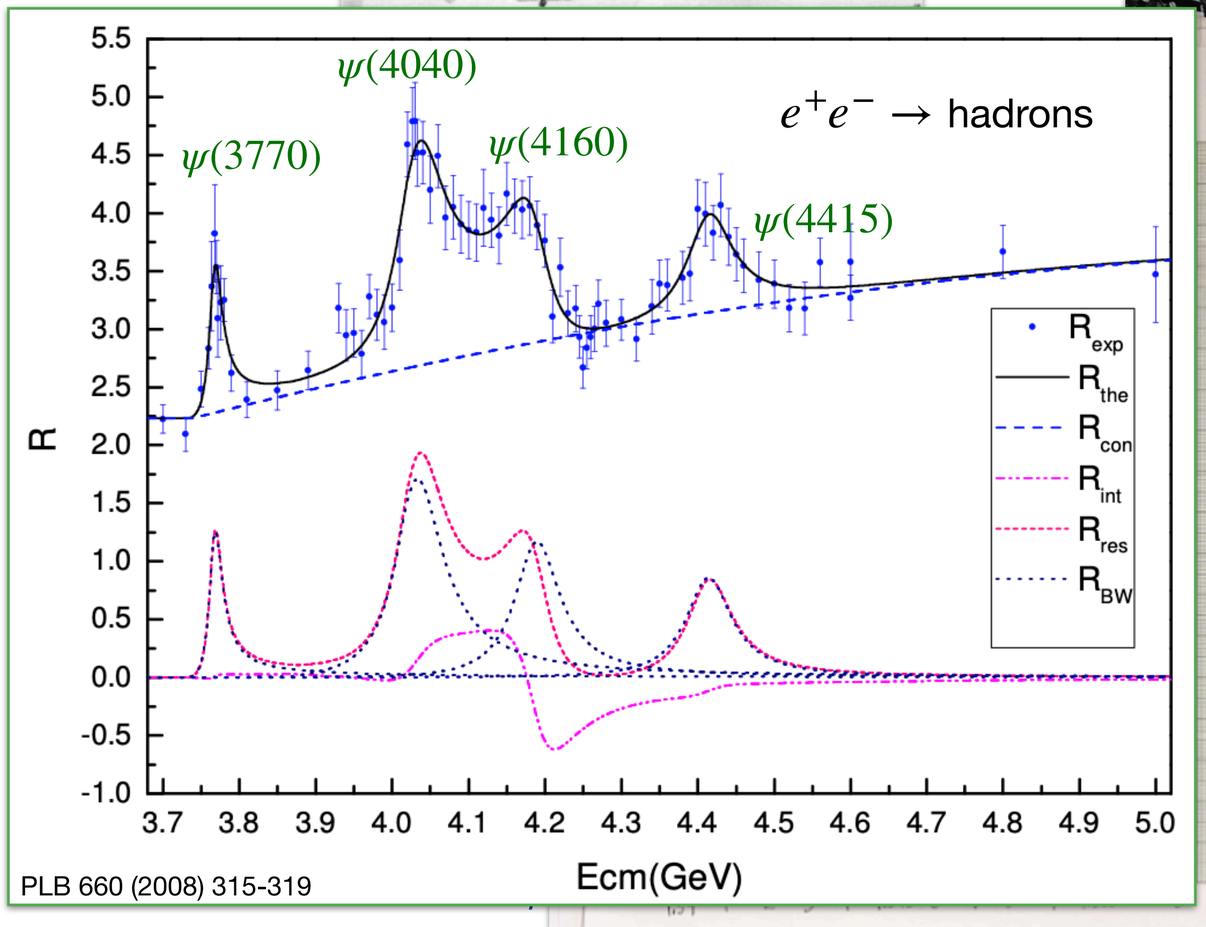
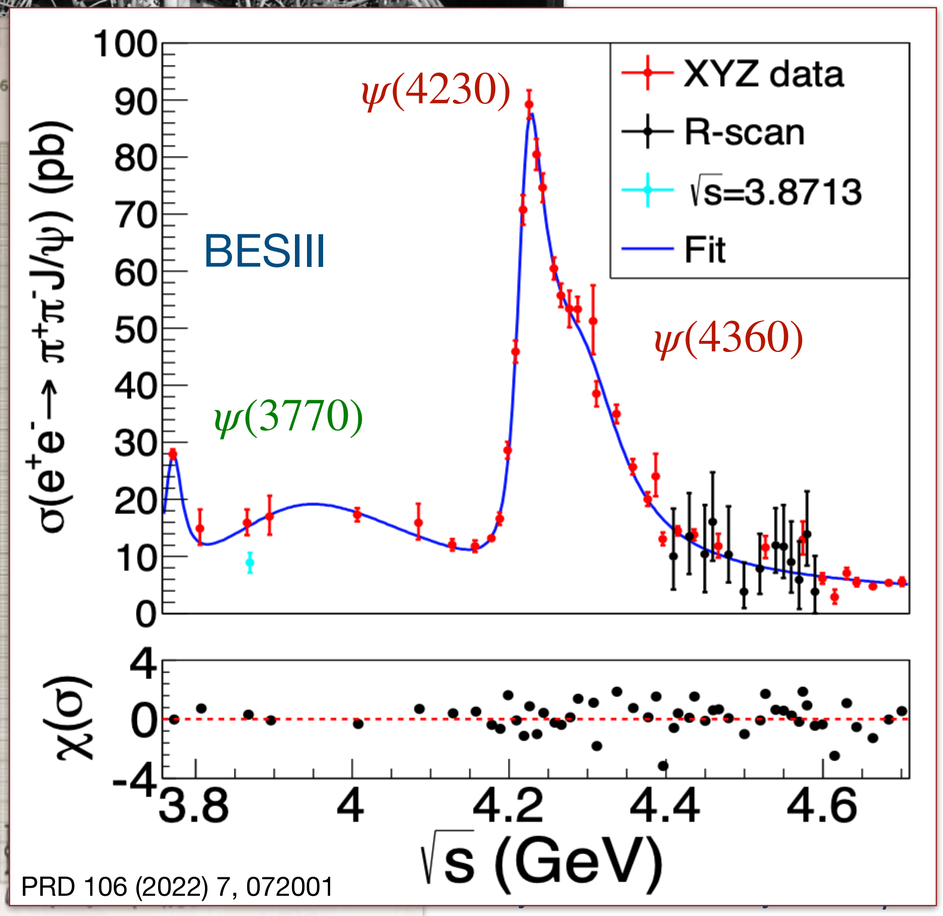


PLB 660 (2008) 315-319



PRD 106 (2022) 7, 072001

50th birthday in 2024:
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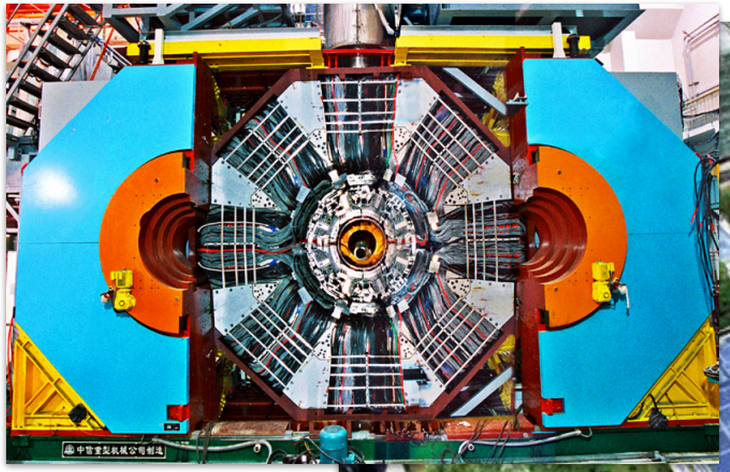
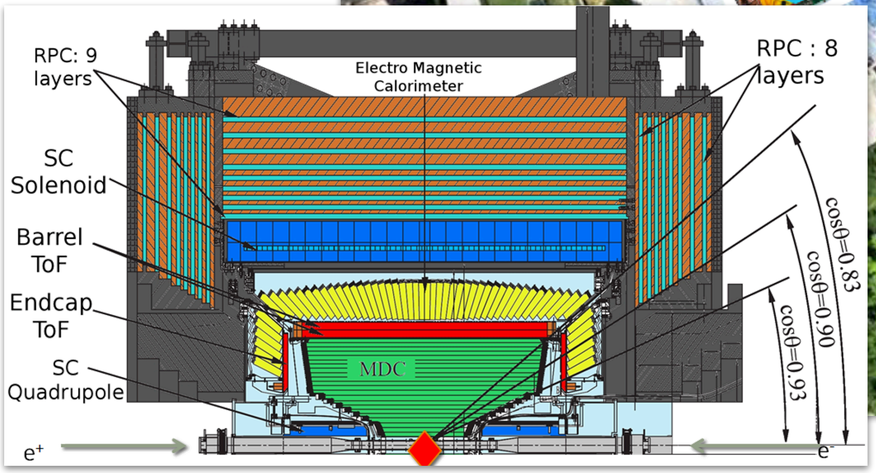
… at BESIII

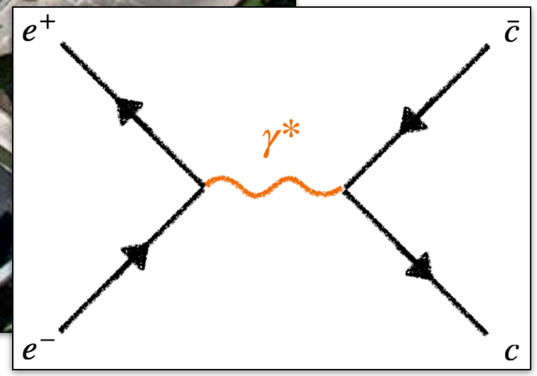


- e^+e^- collisions in the τ-charm region: 2-5 GeV
- in operation since 2008
- luminosity of $> 10^{33}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$
- around 700 members from 86 institutes in 16 countries

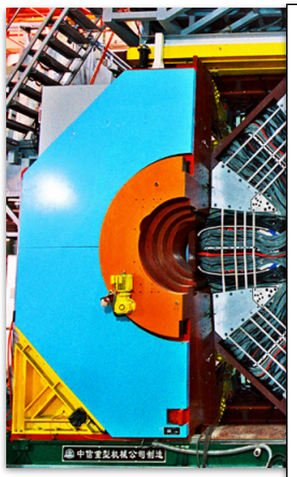


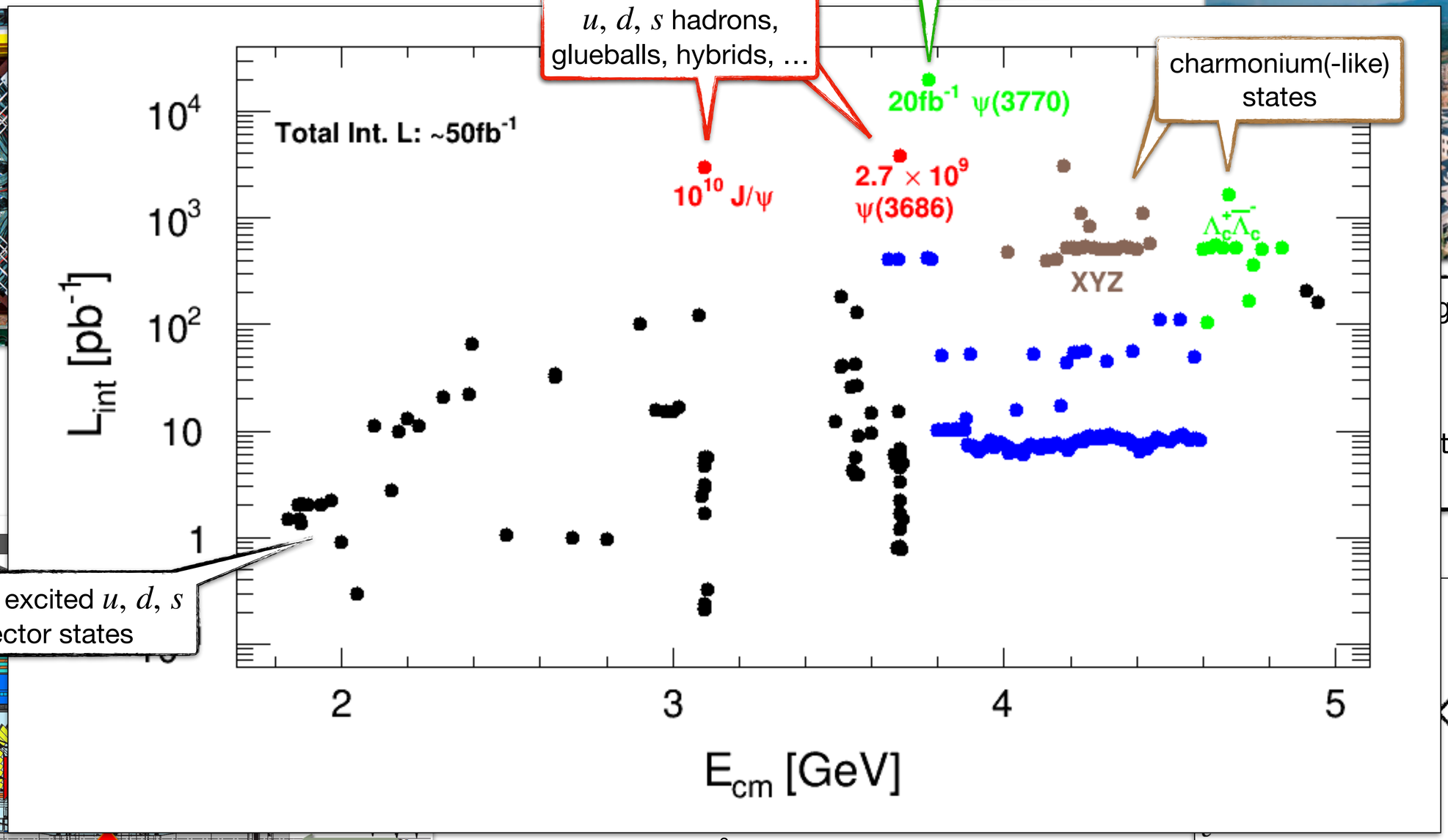
Beijing Spectrometer - BESIII

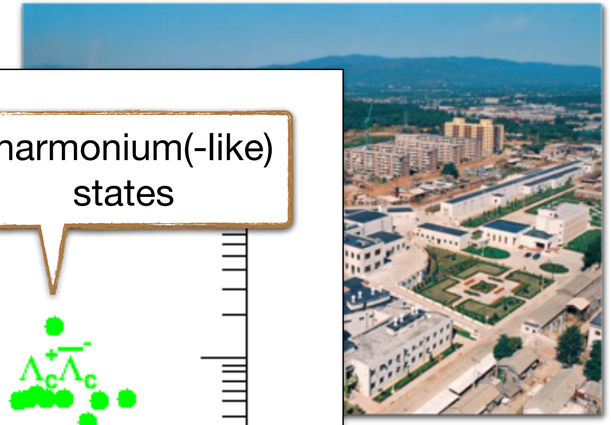
- drift chamber in 1 T magnetic field
- time of flight detector
- electromagnetic calorimeter
- muon counter



… at BESIII

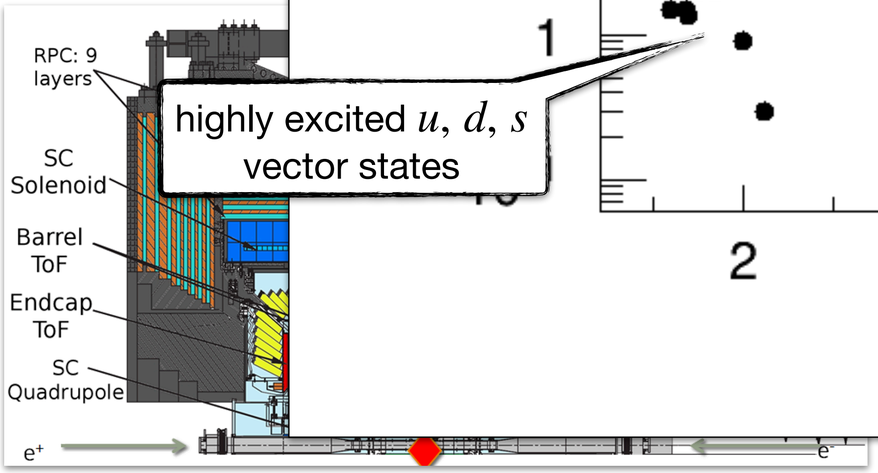


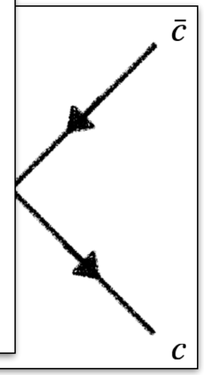




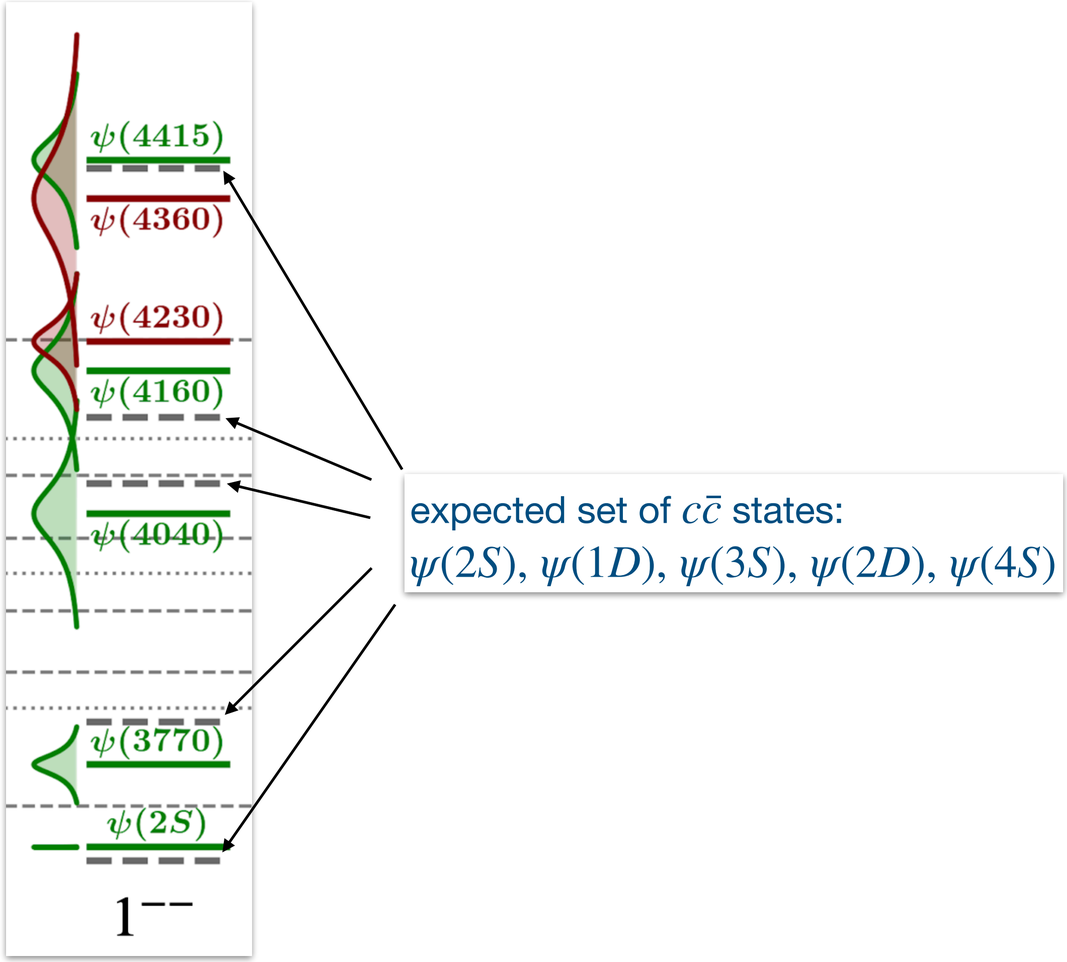
gion: 2-5 GeV

titutes in 16



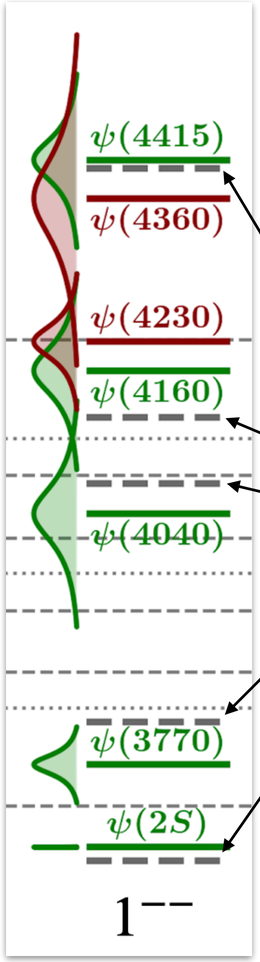


Vector charmonia



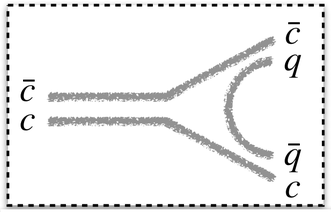
plot from Huesken, Norella, Polyakov, MPLA 40 (2025) 17n18, 2530002
QM-states from Barnes, Godfrey, Swanson, PRD 72 (2005) 054026

Vector charmonia



expected set of $c\bar{c}$ states:
$\psi(2S)$, $\psi(1D)$, $\psi(3S)$, $\psi(2D)$, $\psi(4S)$

$D\bar{D}$



clear expectation for those $c\bar{c}$ states:
above threshold, open-flavour decays dominate

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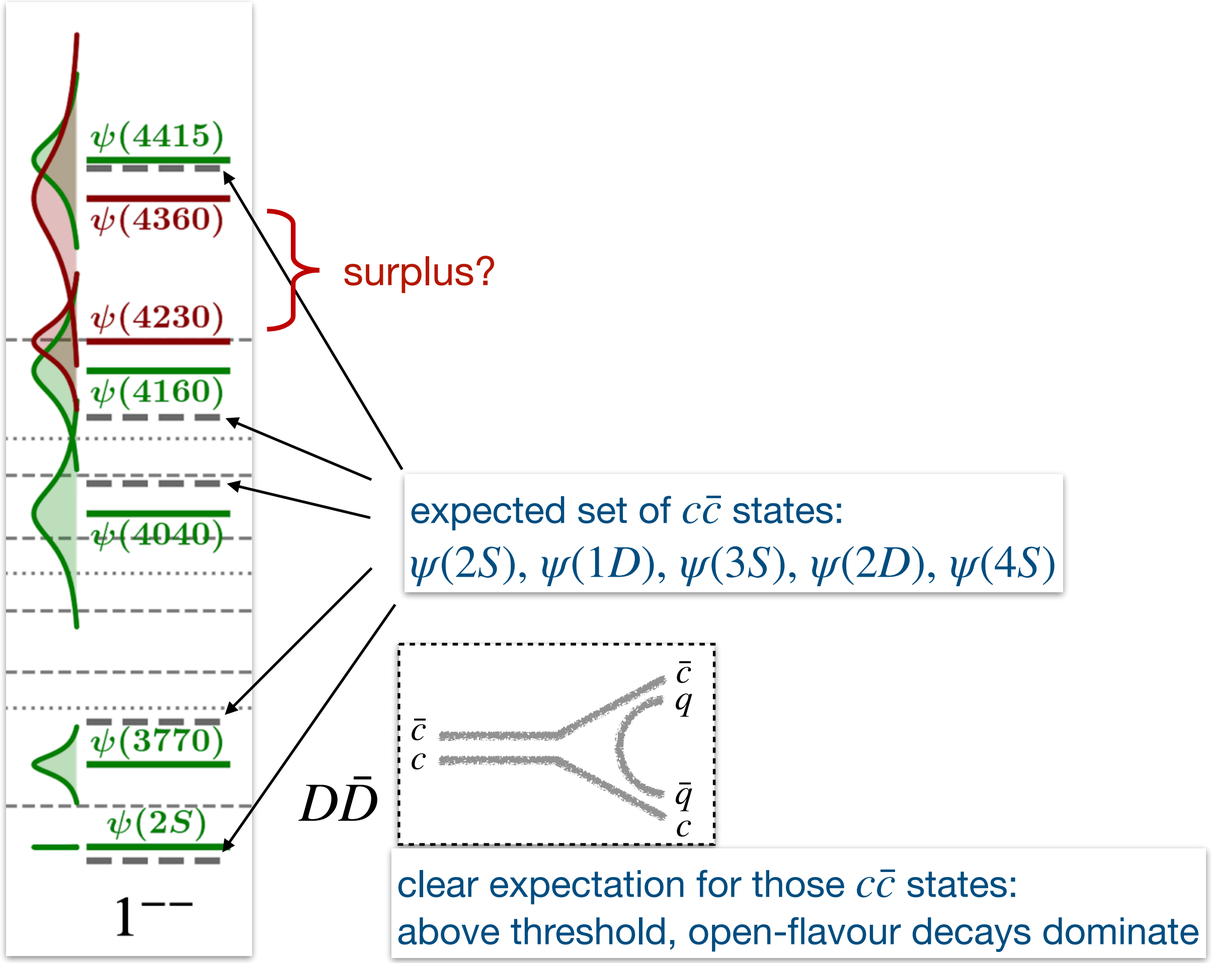
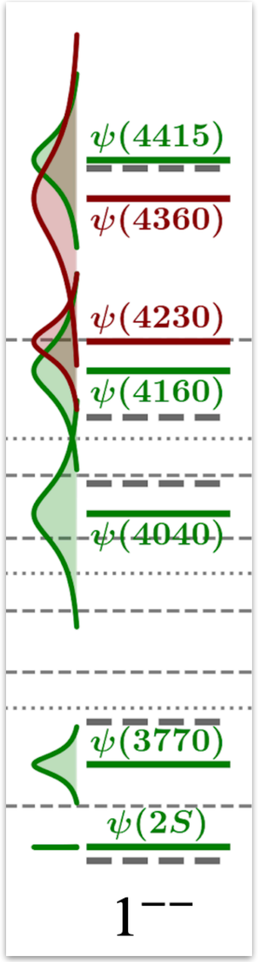
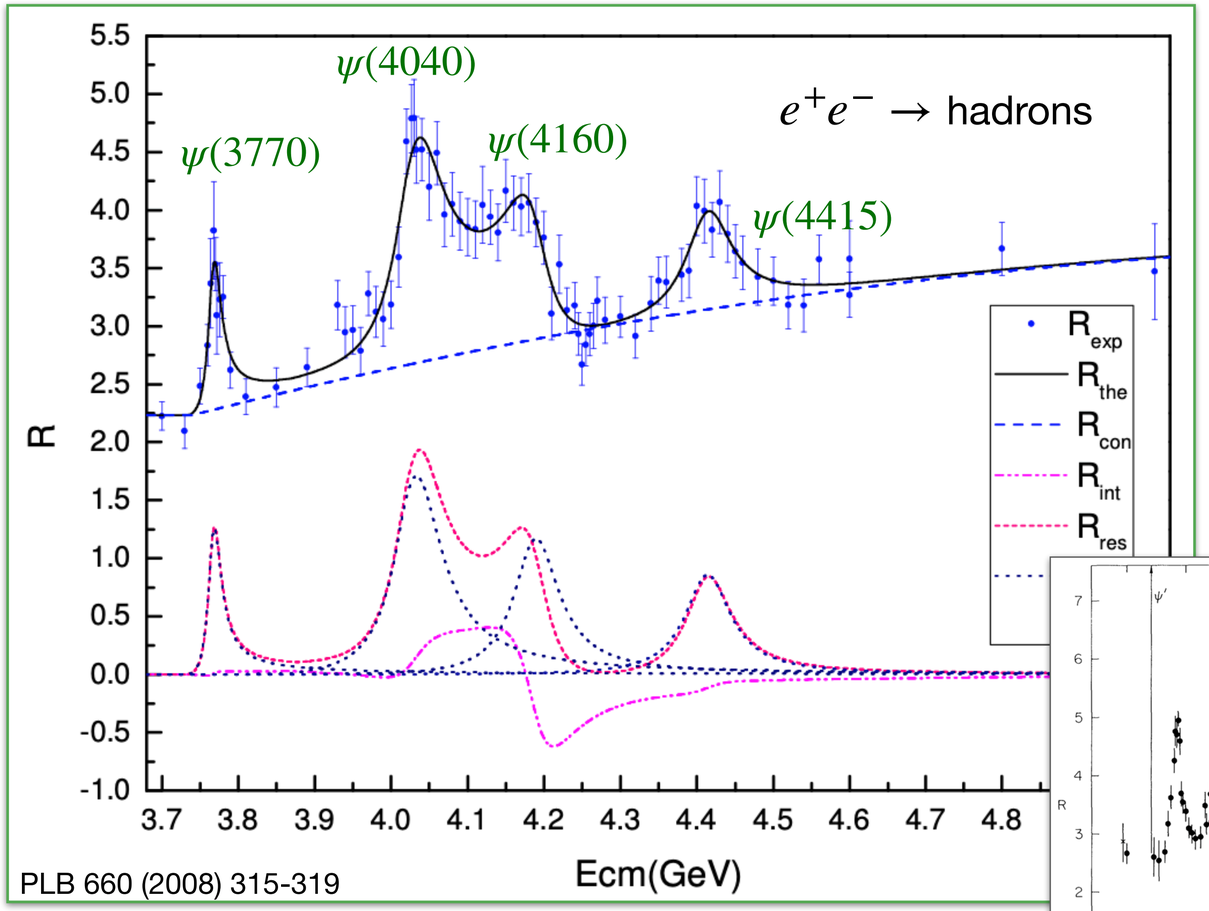
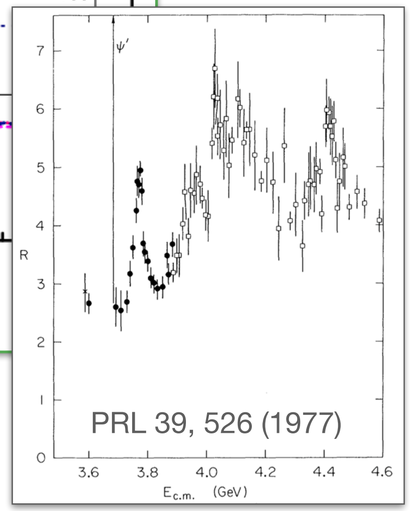


plot from Huesken, Norella, Polyakov, MPLA 40 (2025) 17n18, 2530002
QM-states from Barnes, Godfrey, Swanson, PRD 72 (2005) 054026

The conventional states





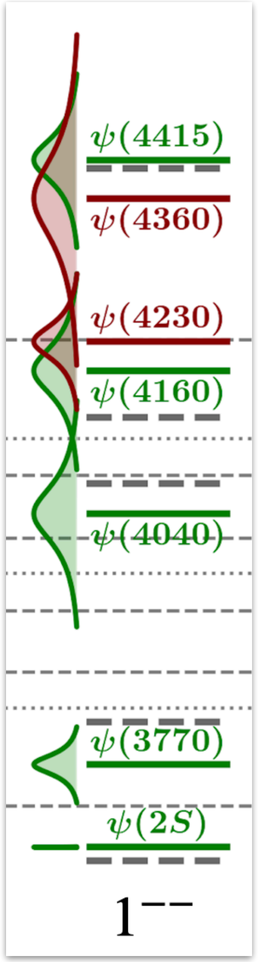


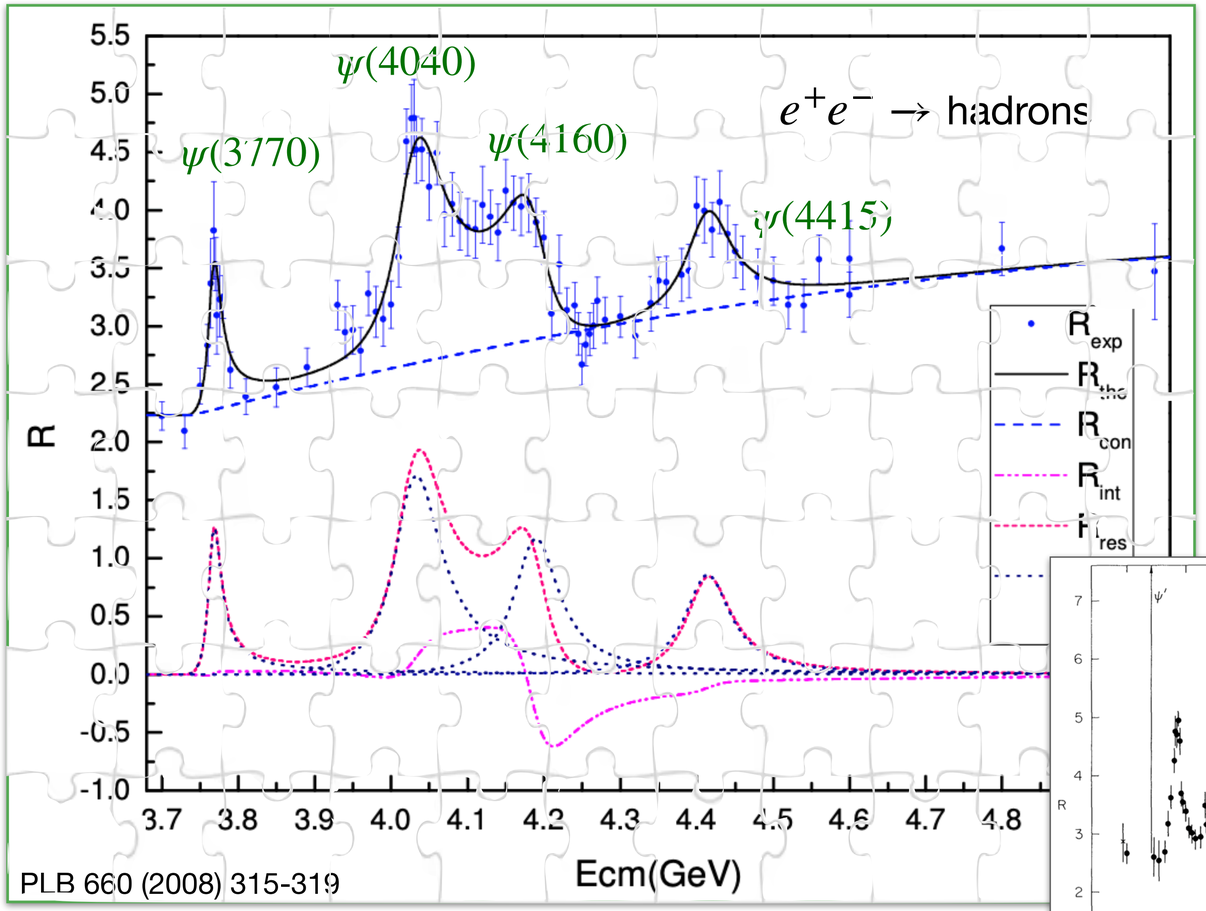
bumps in inclusive cross section usually identified as the vector-charmonium states:

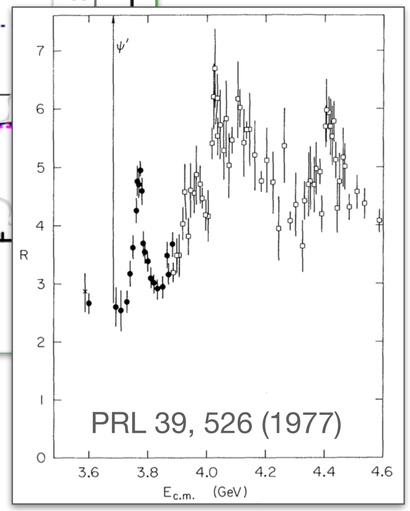
$$\psi(1D),\ \psi(3S),\ \psi(2D),\ \psi(4S)$$

no other structure observed here

The conventional states







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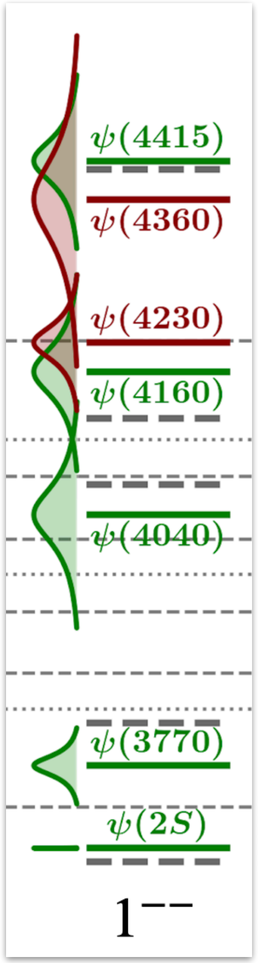
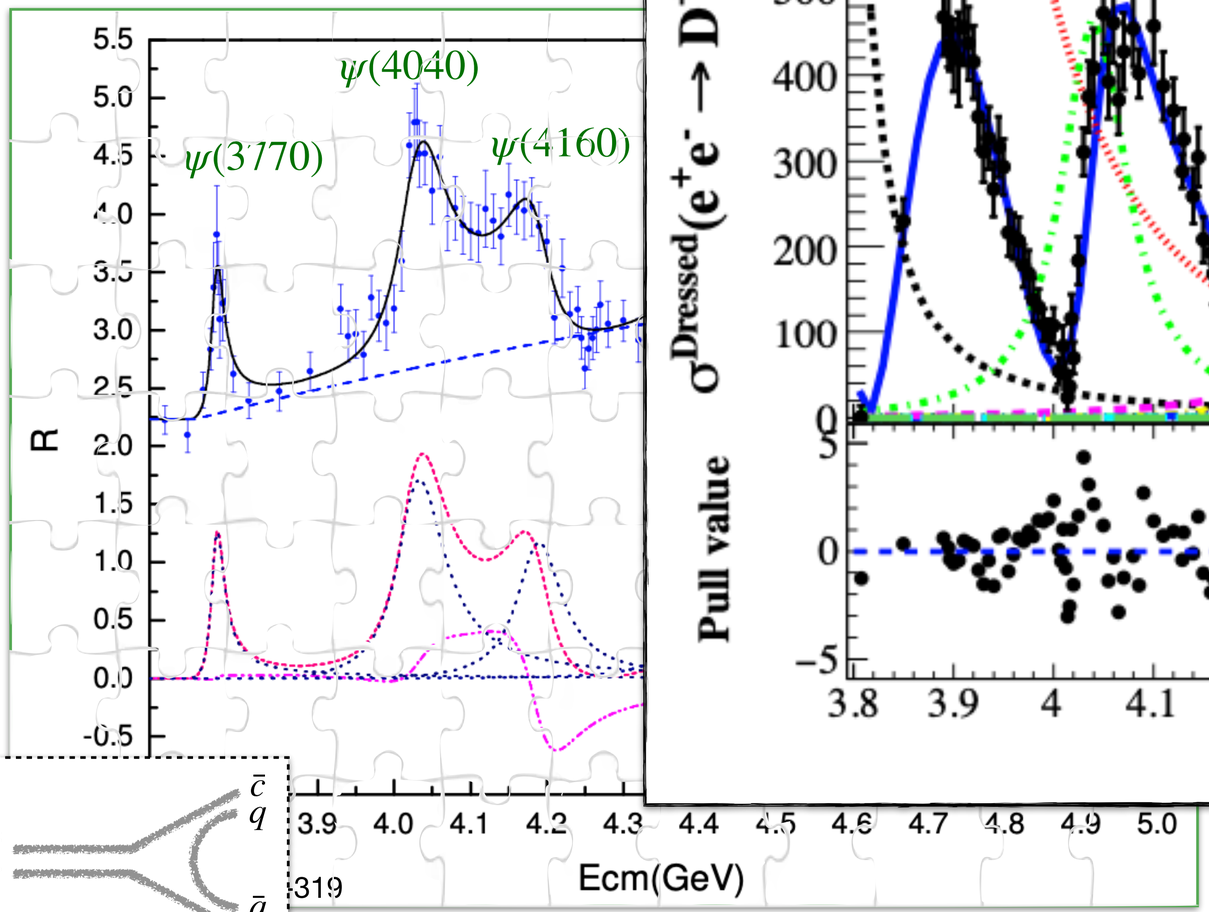
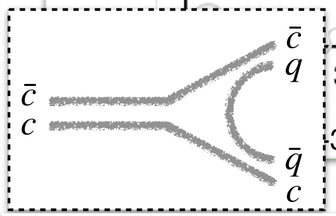
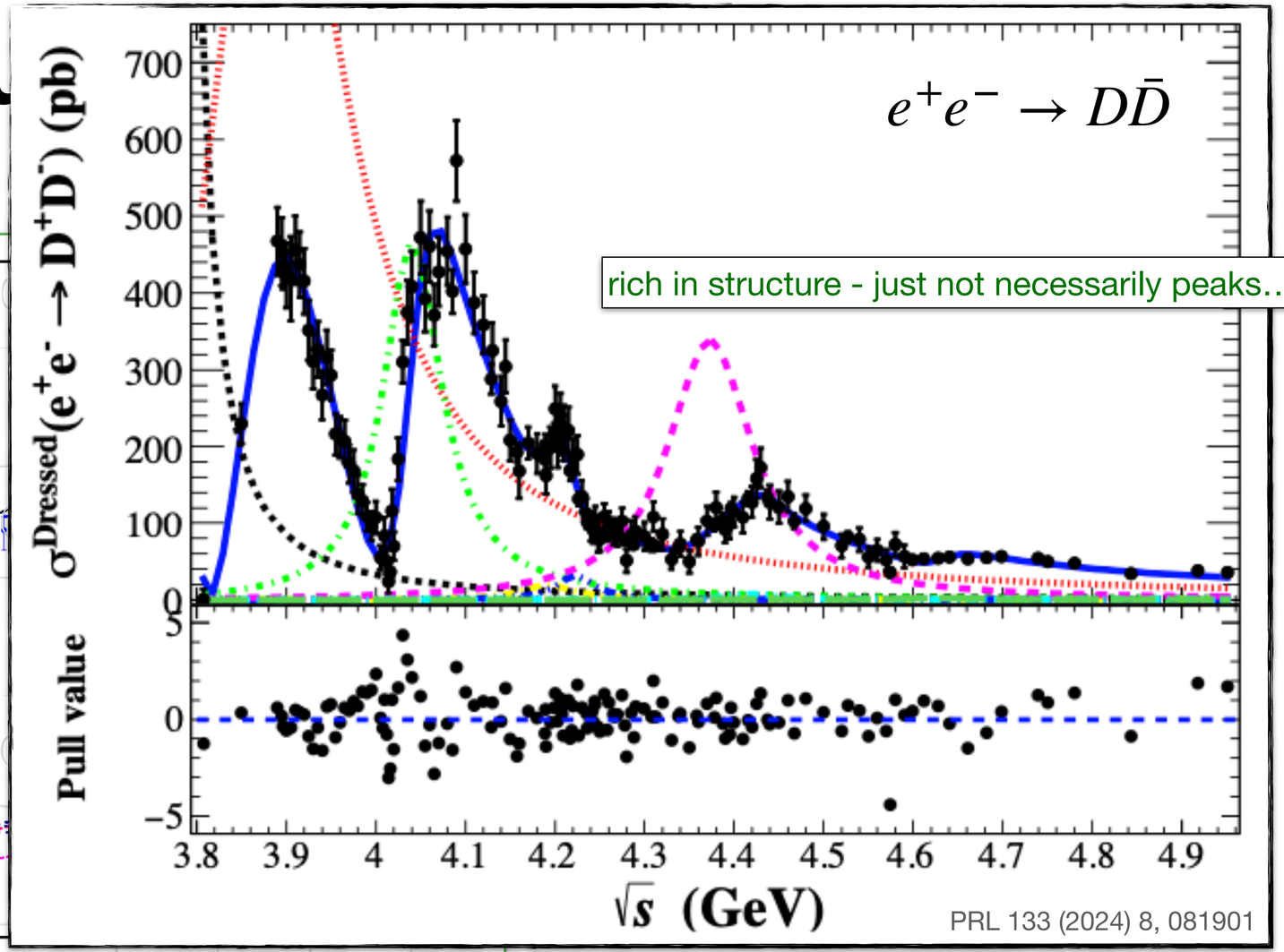
Open-charm produ







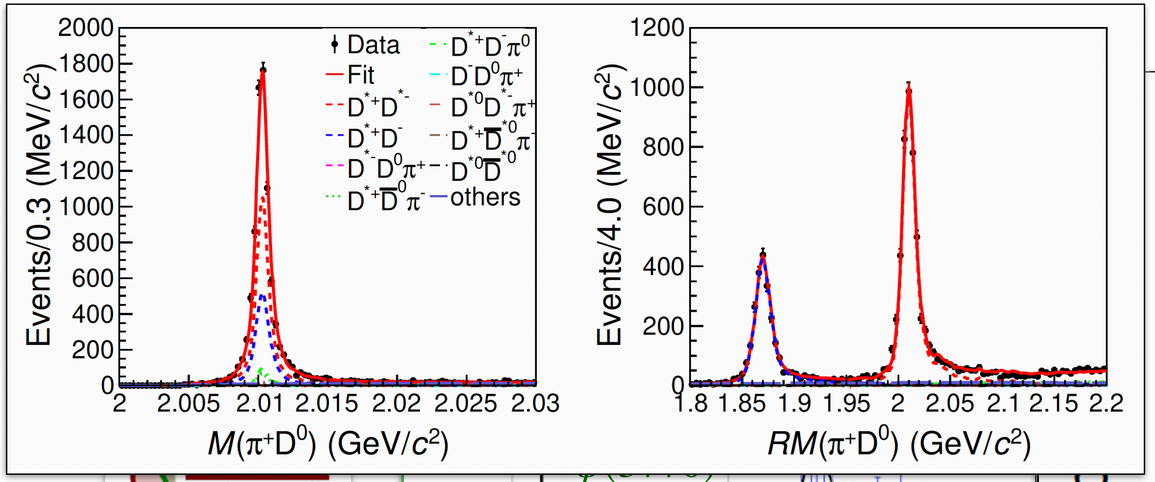


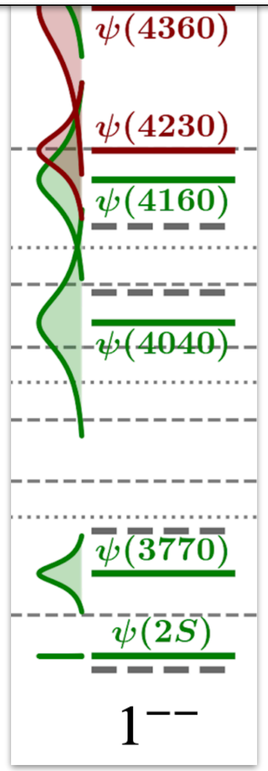
PRL 133 (2024) 8, 081901

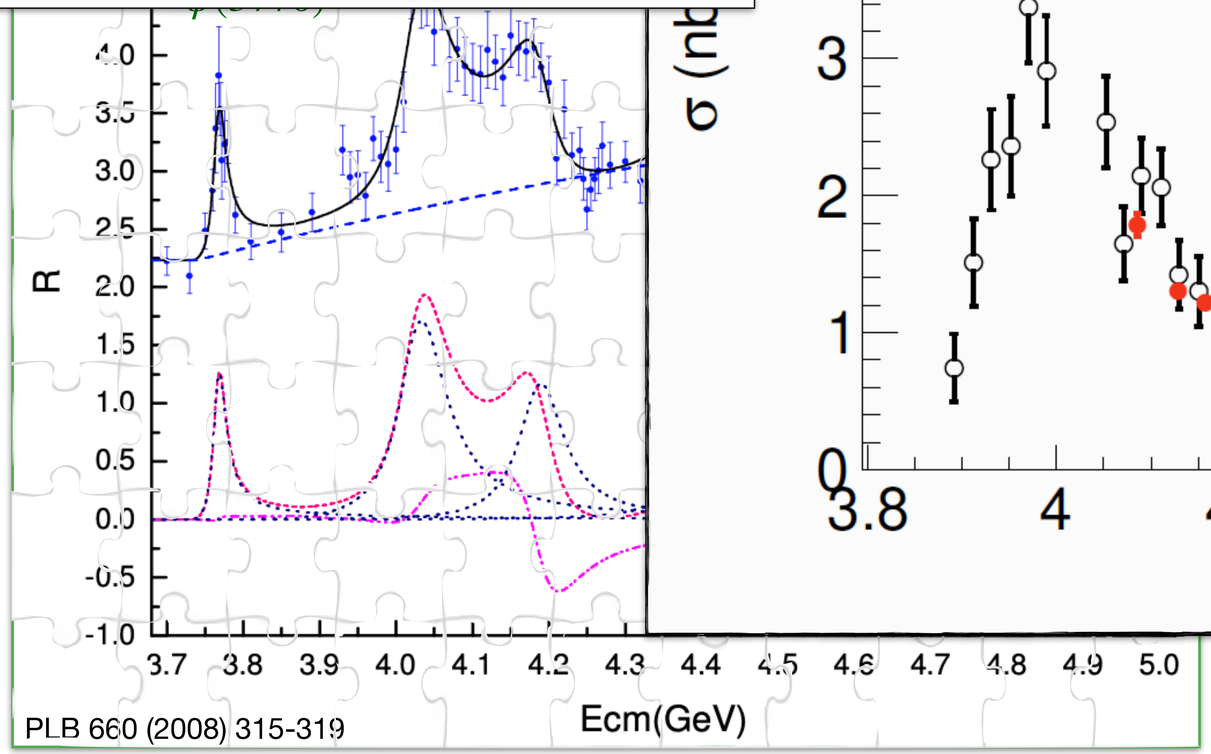
rich in structure - just not necessarily peaks…

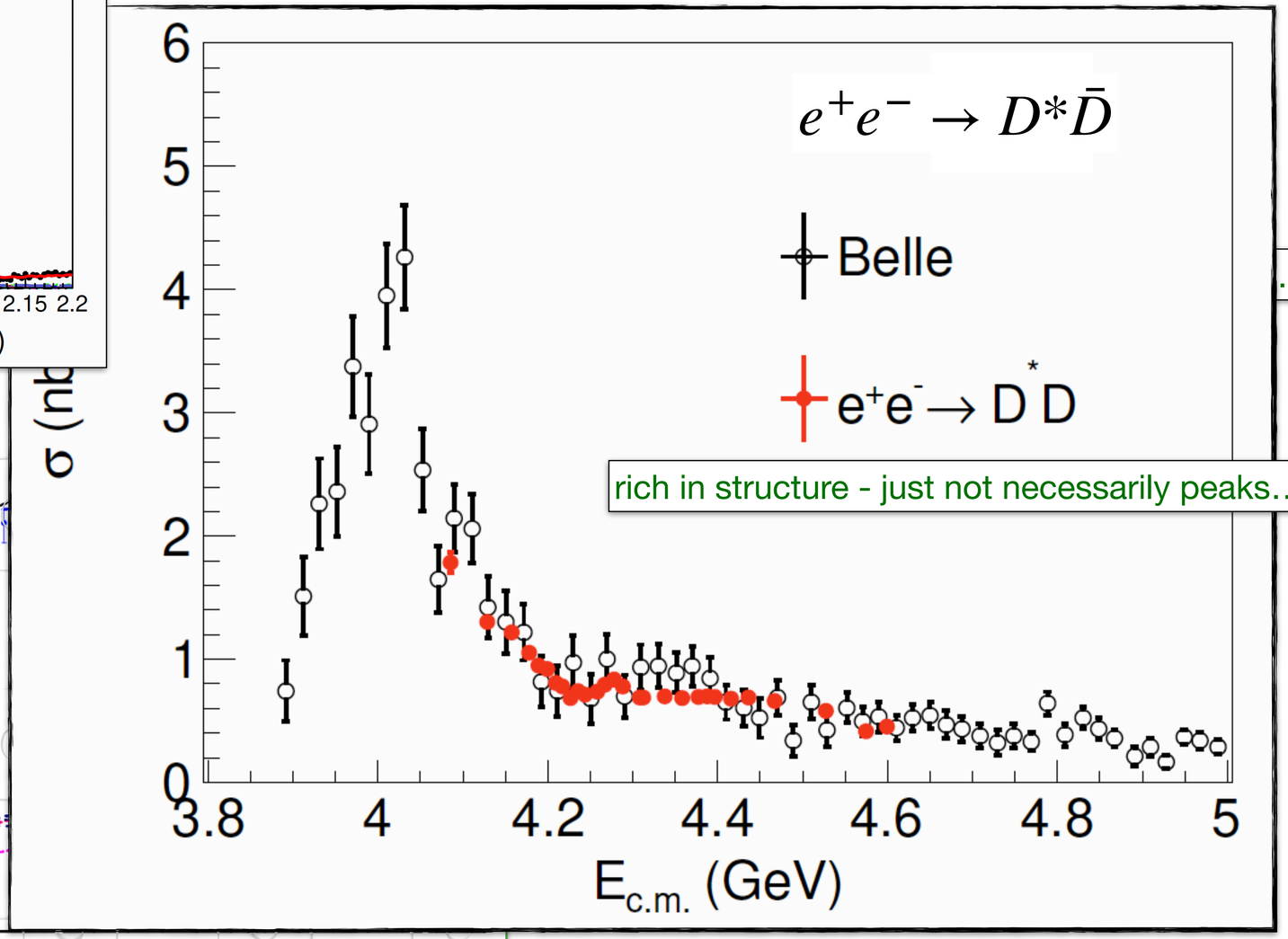
single-tag measurement:
$D^+ \to K^-\pi^+\pi^+$, $D^0 \to K^-\pi^+\pi^+\pi^-$

clear expectation for those $c\bar{c}$ states:
above threshold, open-flavour decays dominate









rich in structure - just not necessarily peaks…

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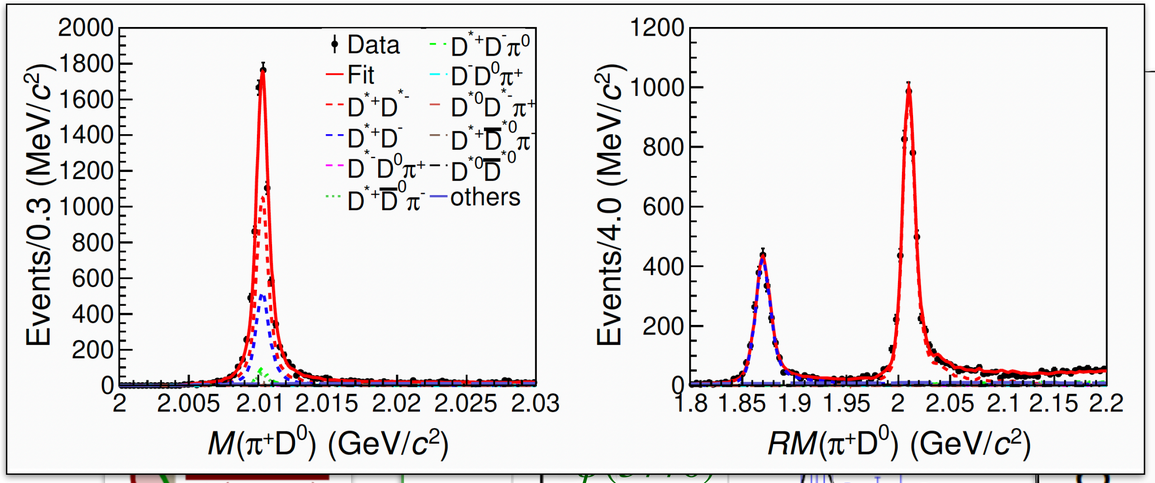
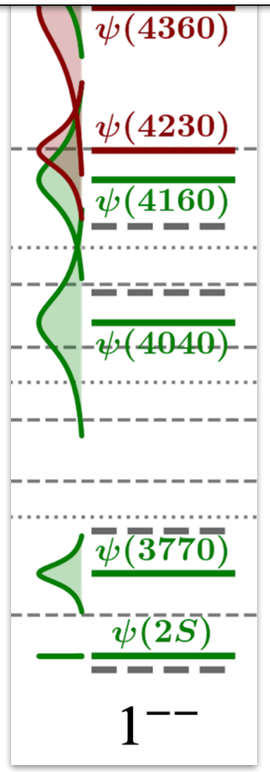
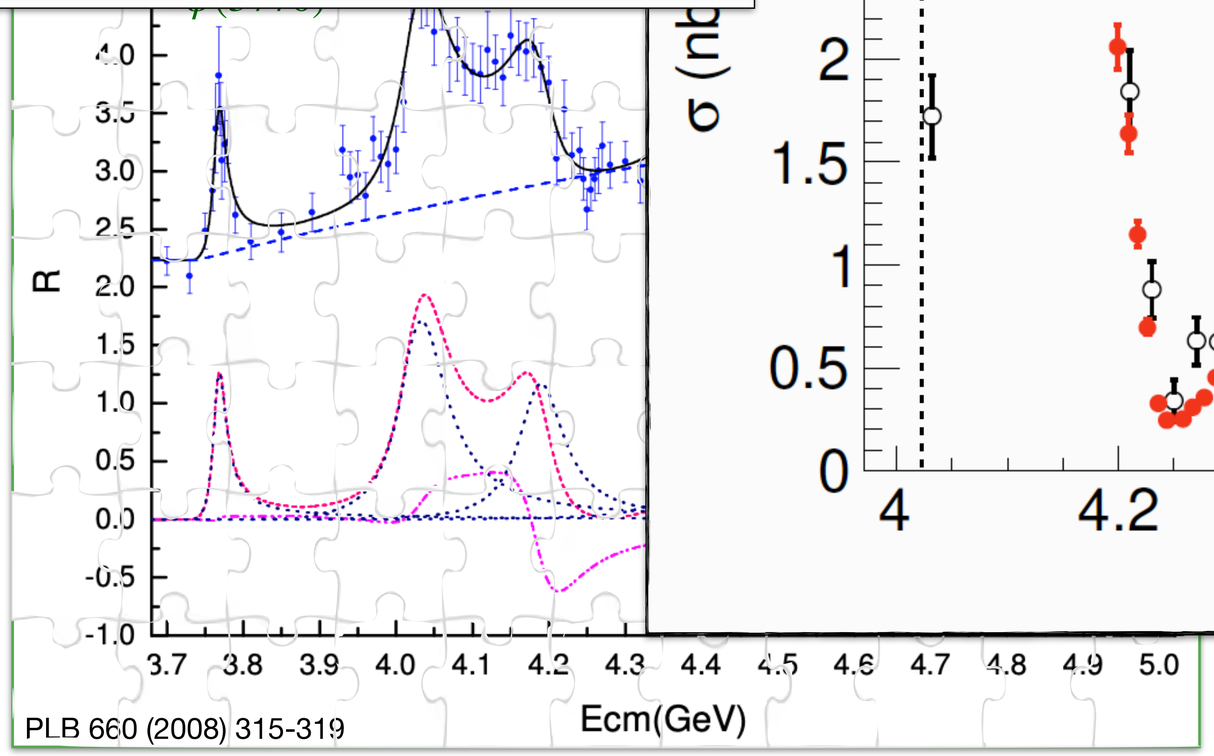
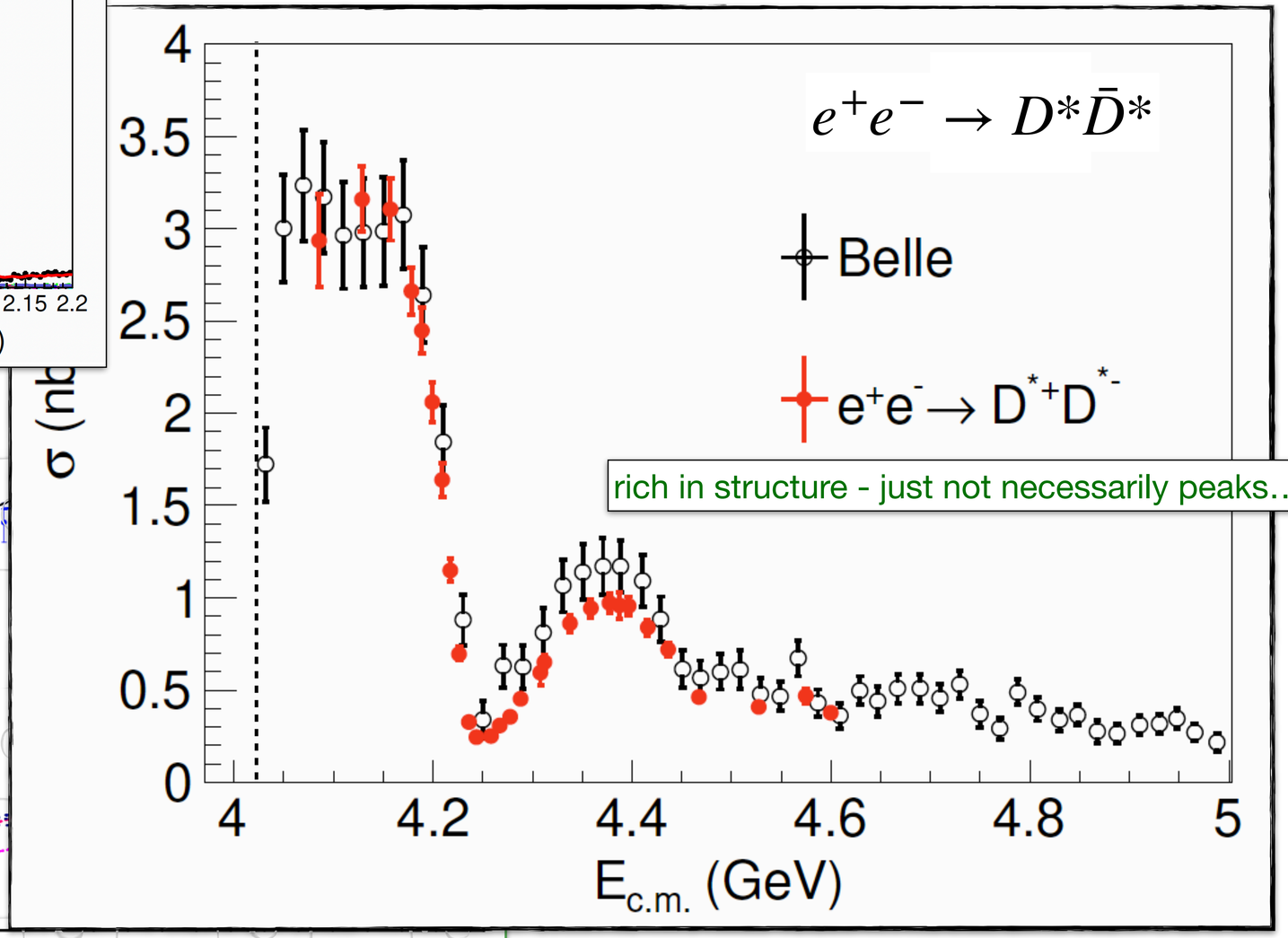
single-tag measurement:
$D^{*+} \to K^-\pi^+\pi^+$









rich in structure - just not necessarily peaks…

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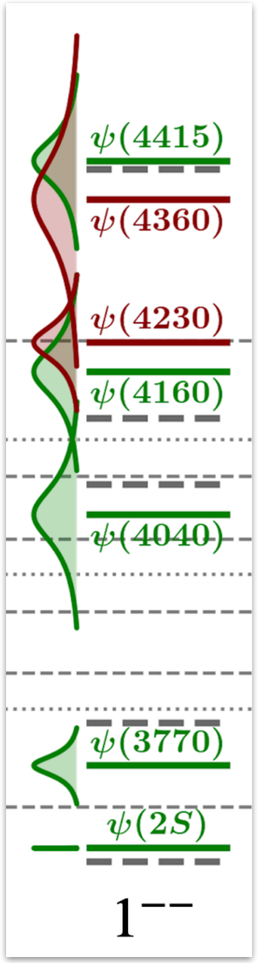
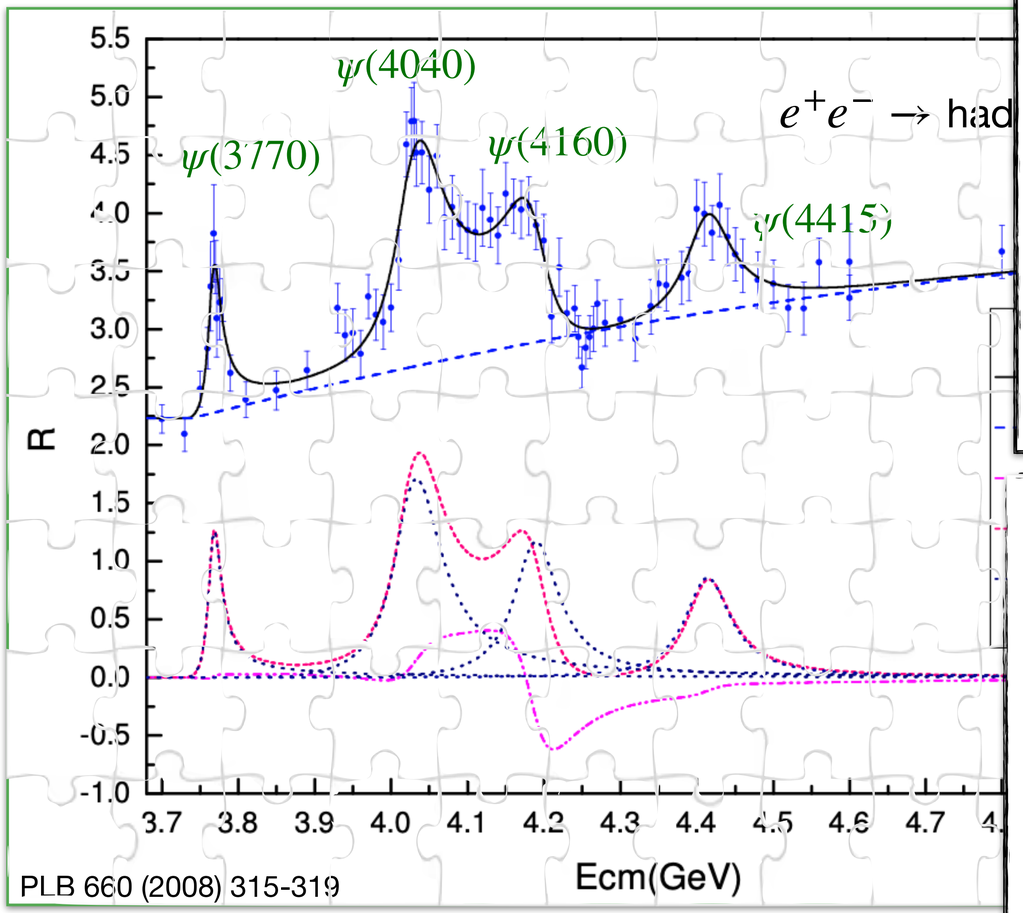
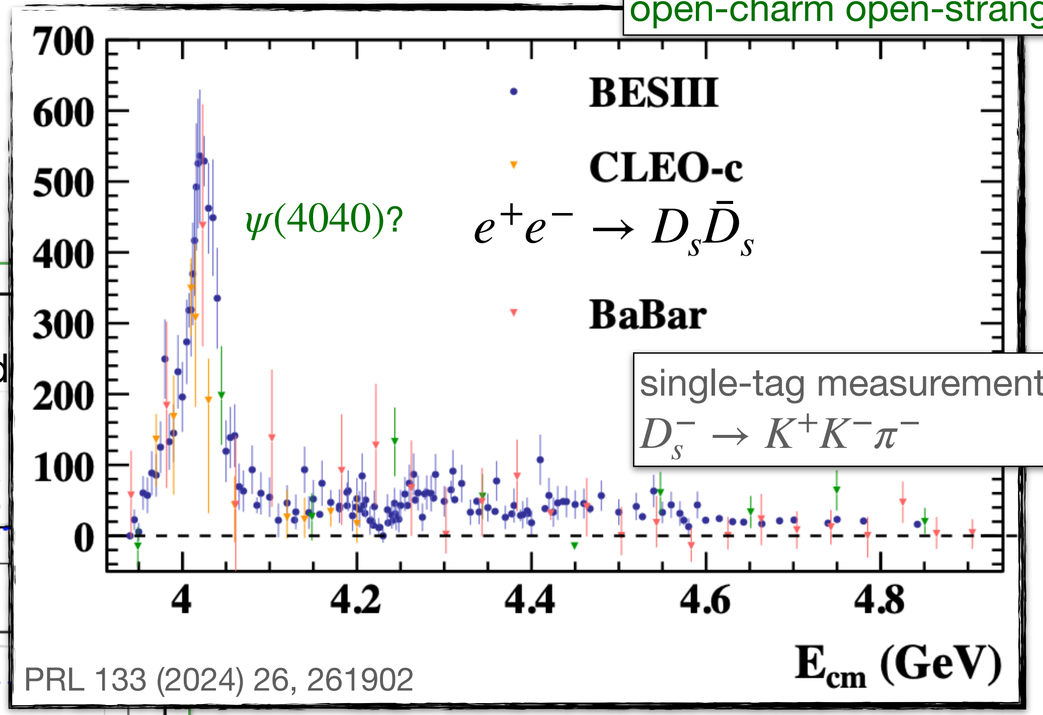
single-tag measurement:
$D^{*+} \to K^-\pi^+\pi^+$

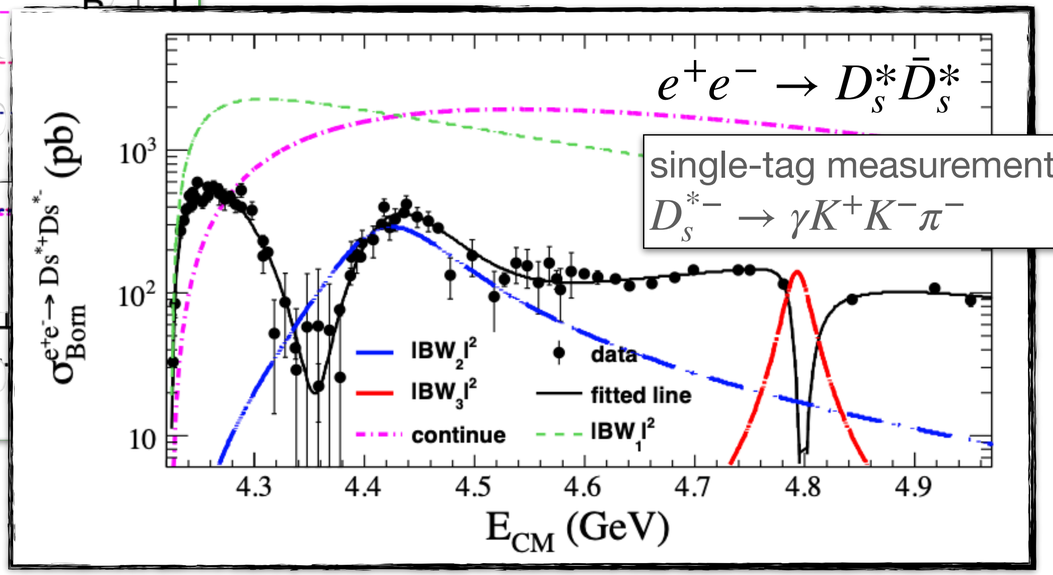
Open-charm production

open-charm open-strange

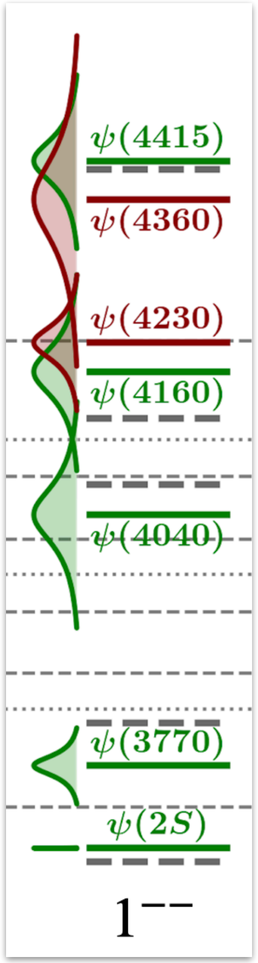


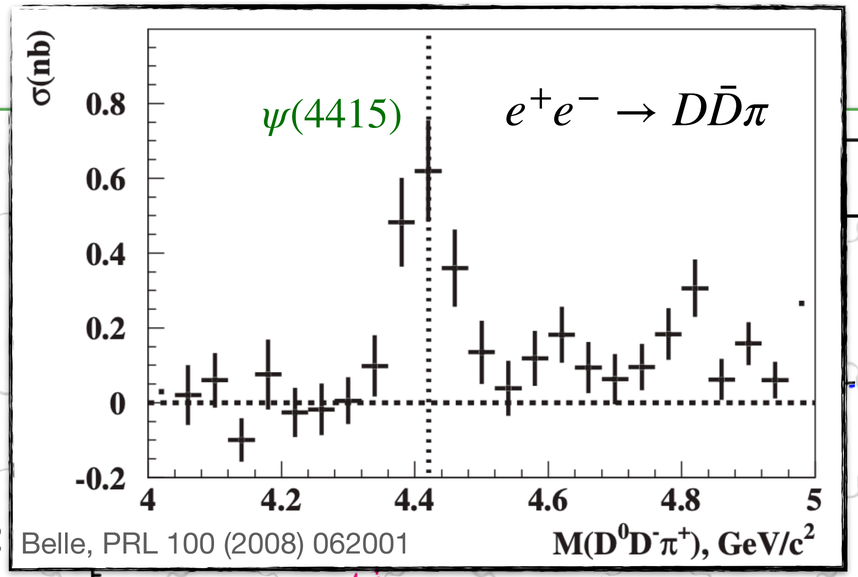


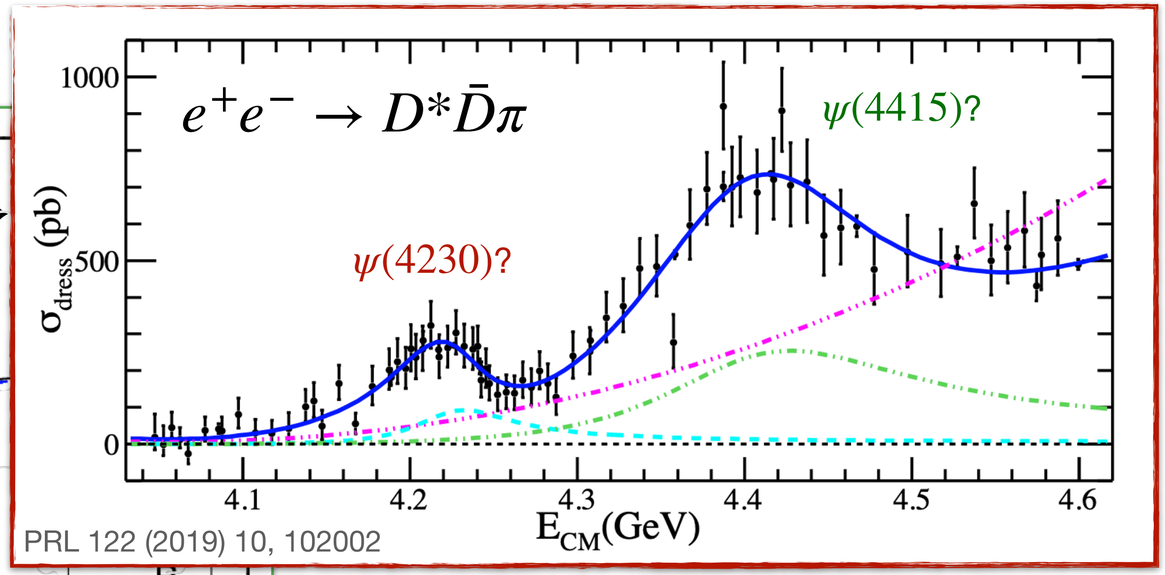


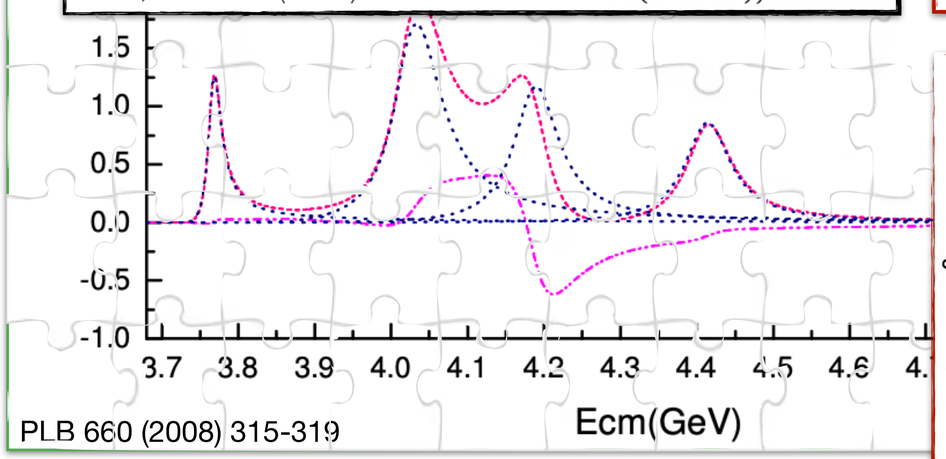


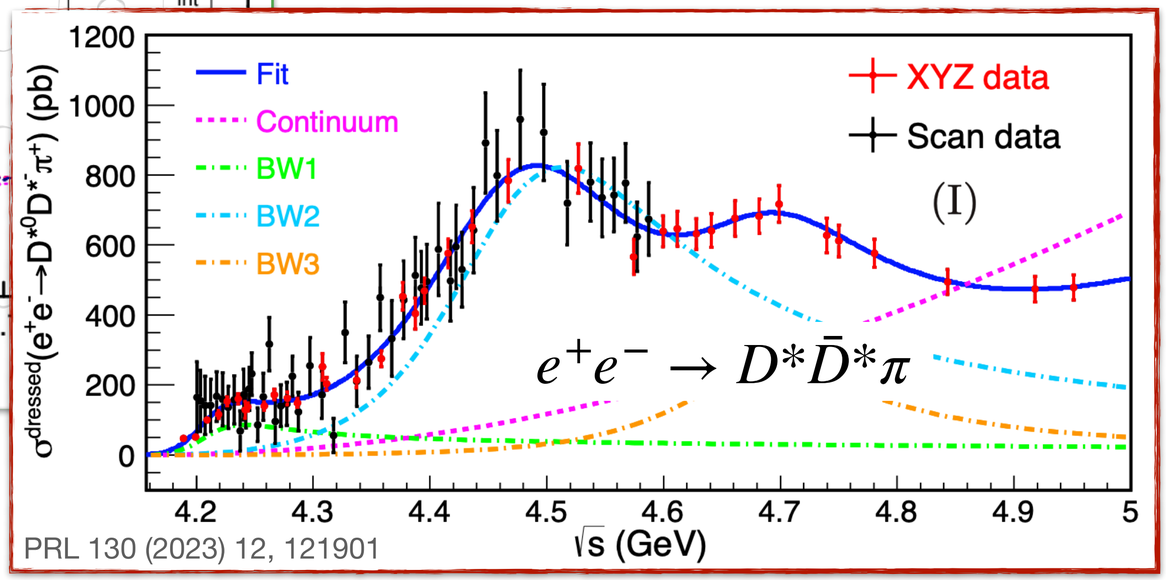
Three-body open-charm production





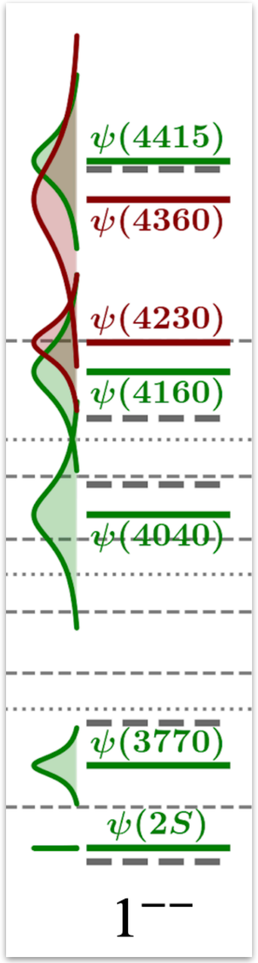


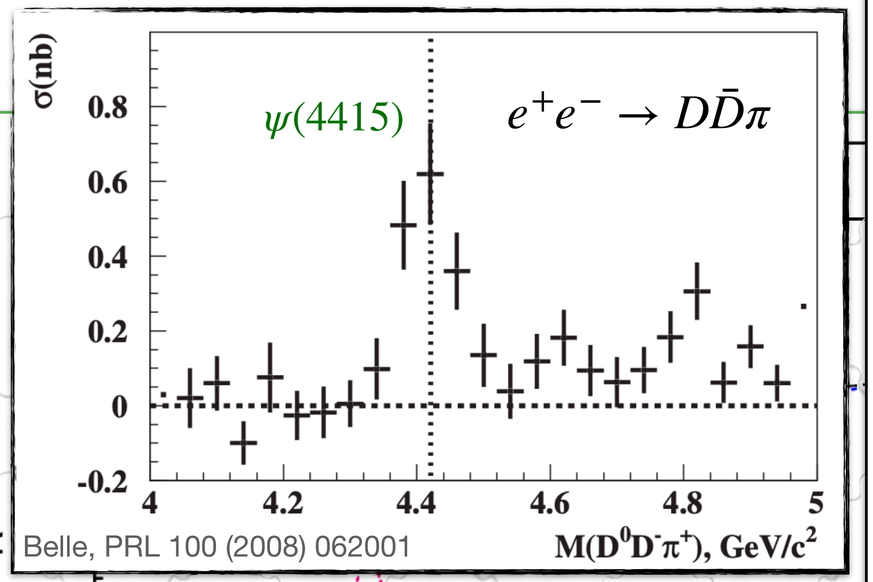


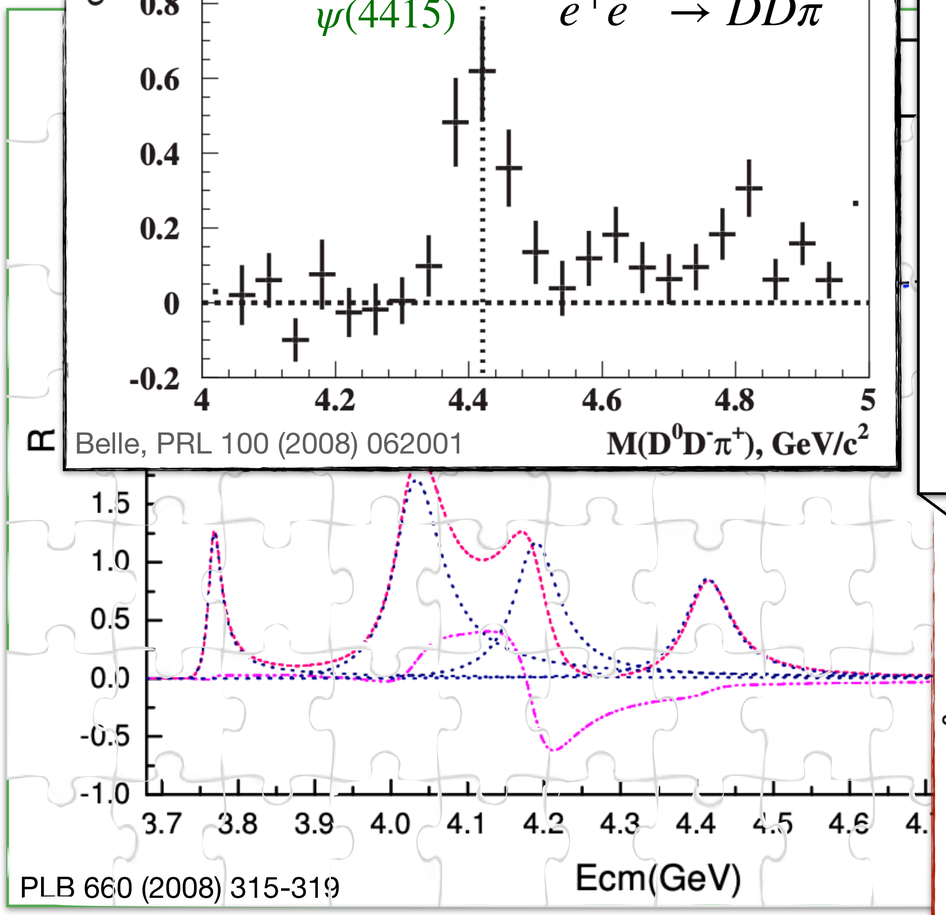


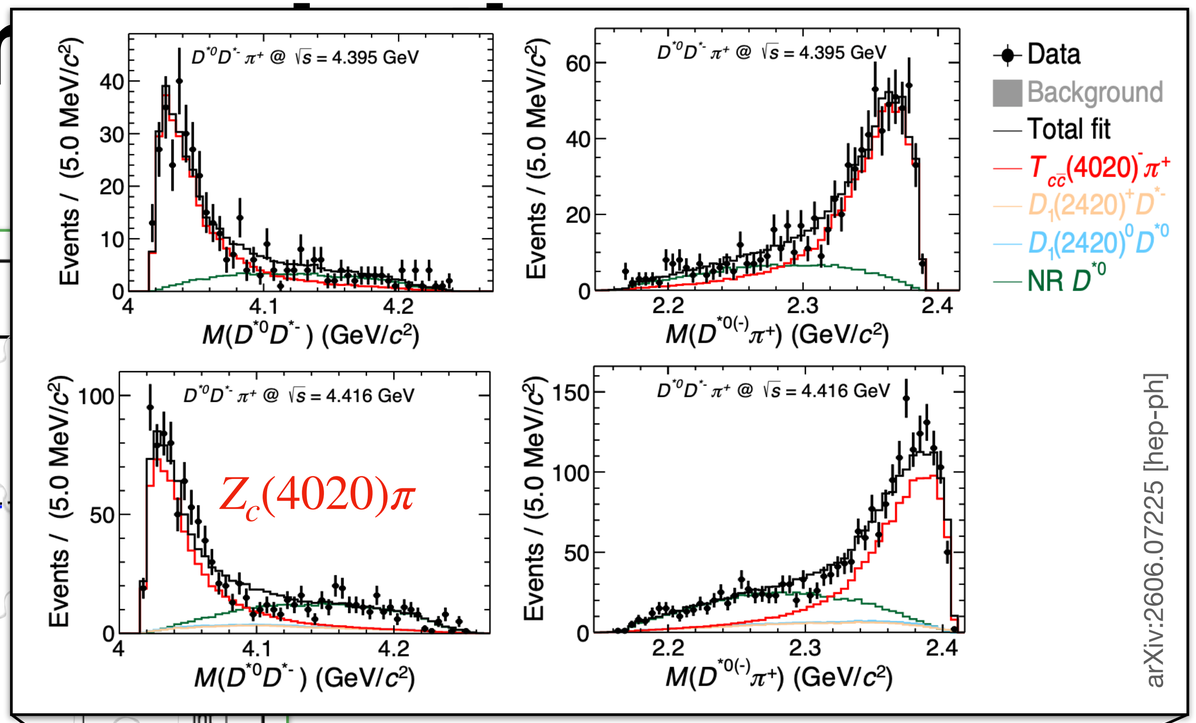
see talk by Chunhua Li, today at 18:05

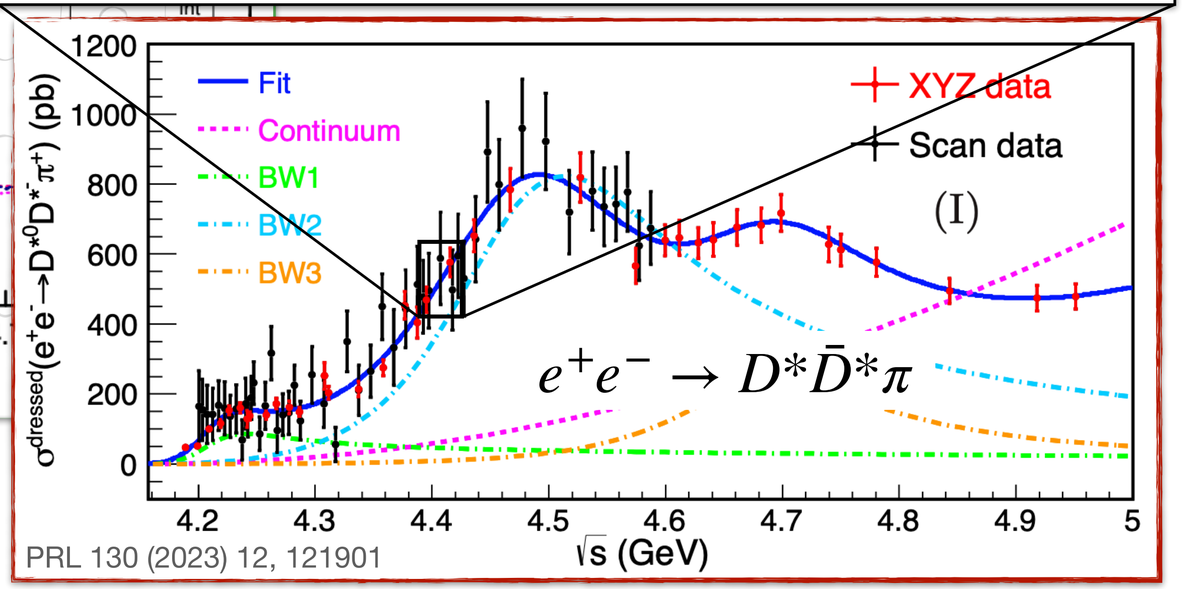
Three-body open-charm











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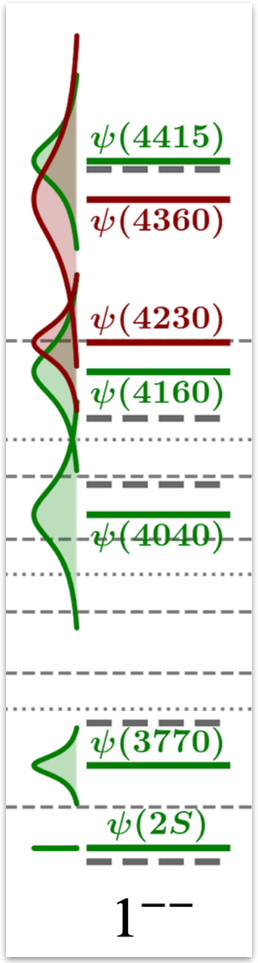
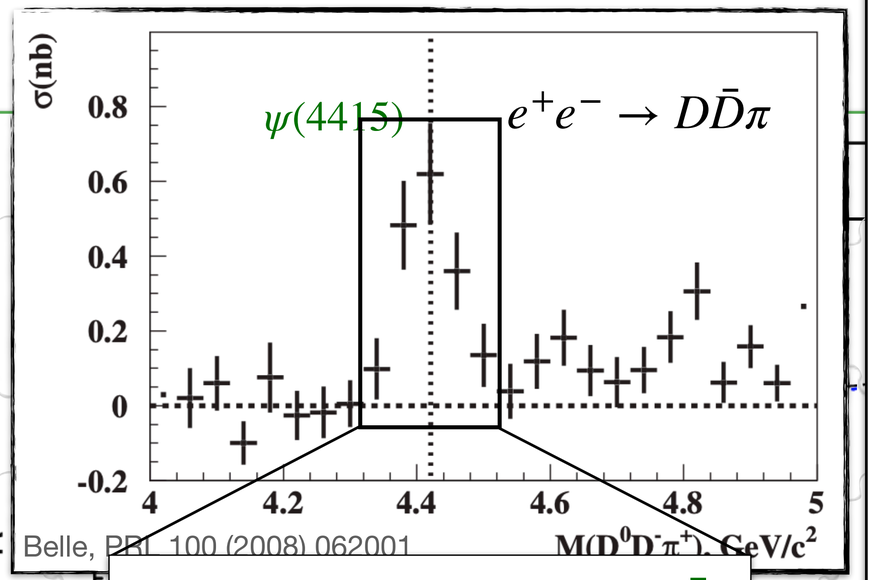
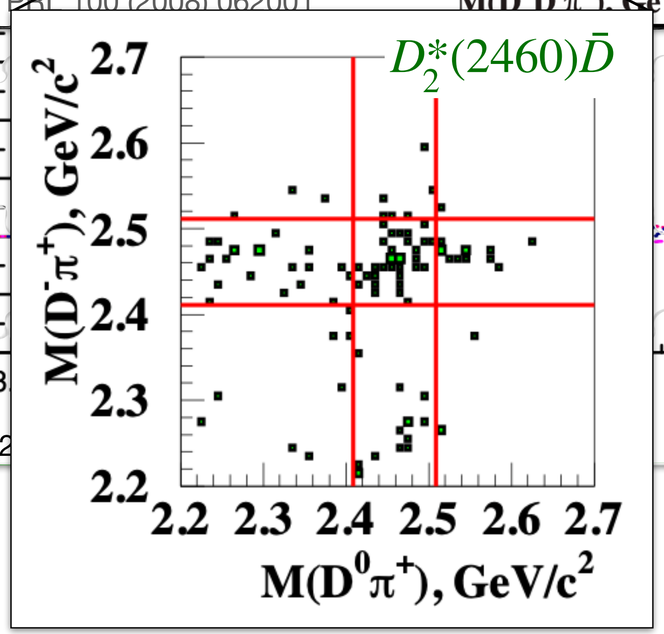
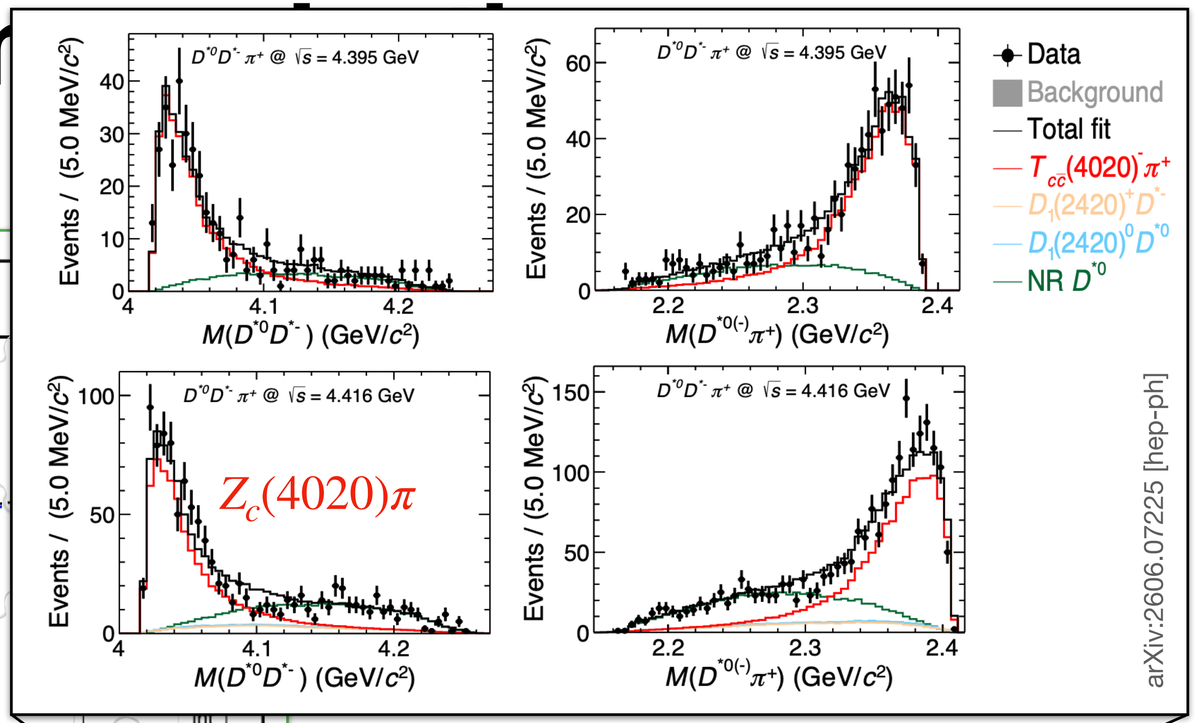
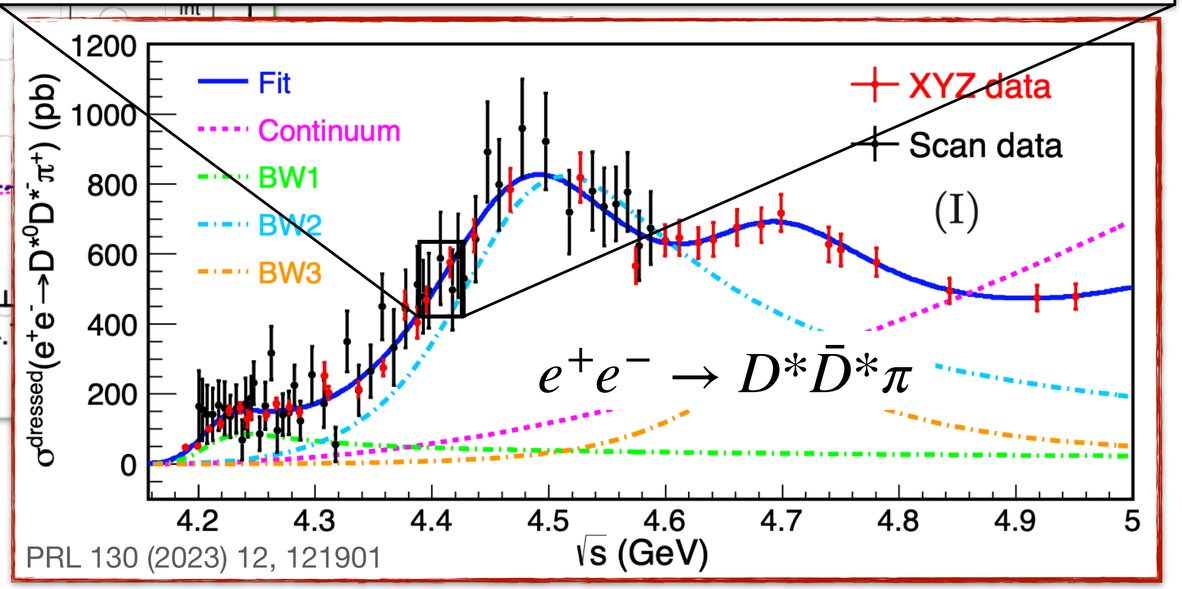


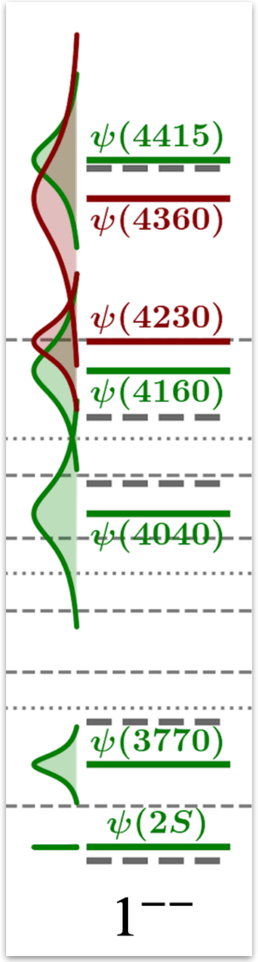


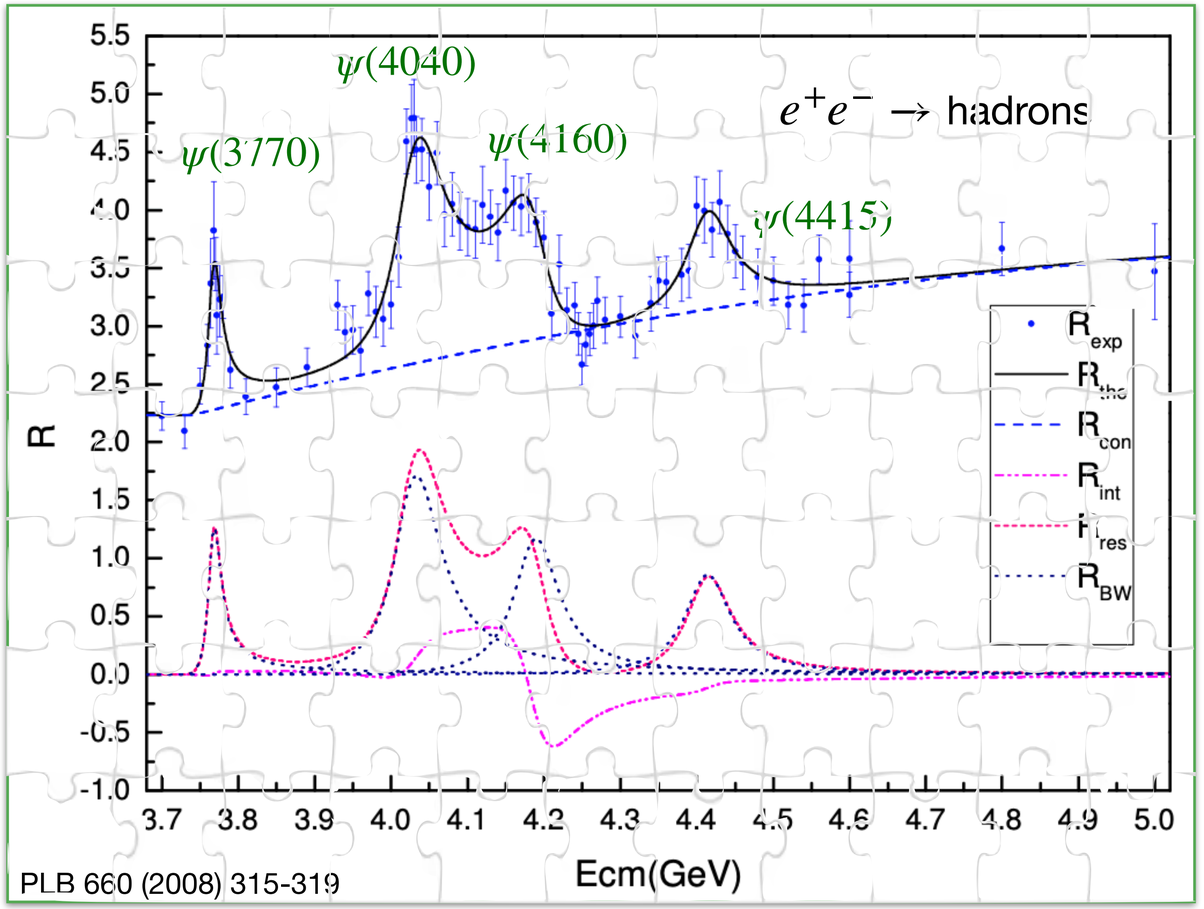




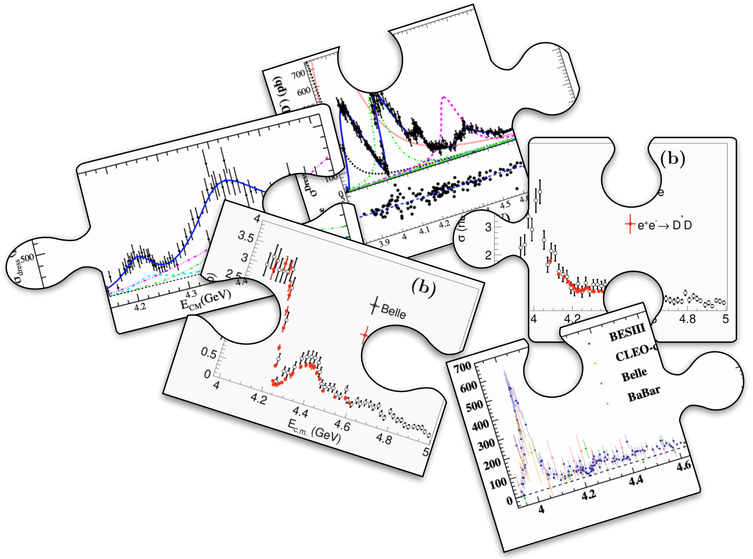


The conventional states



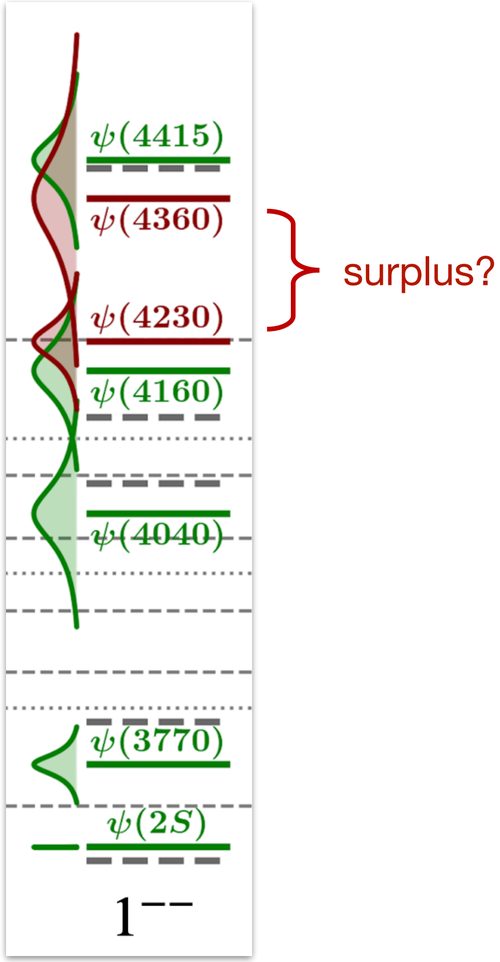


if each individual piece to this puzzle has complicated structure,

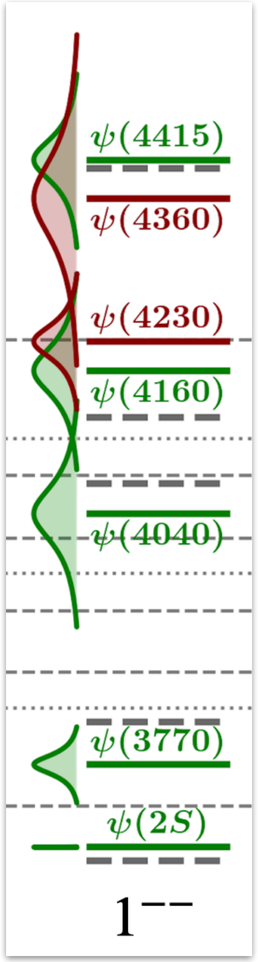


can we really interpret $e^+e^- \to$ hadrons in terms of just four peaks?

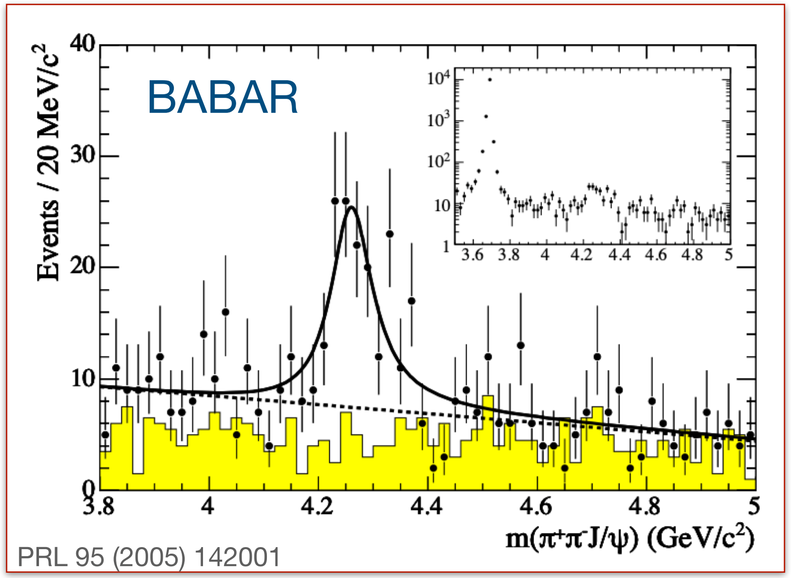
Hidden-charm production



Hidden-charm production



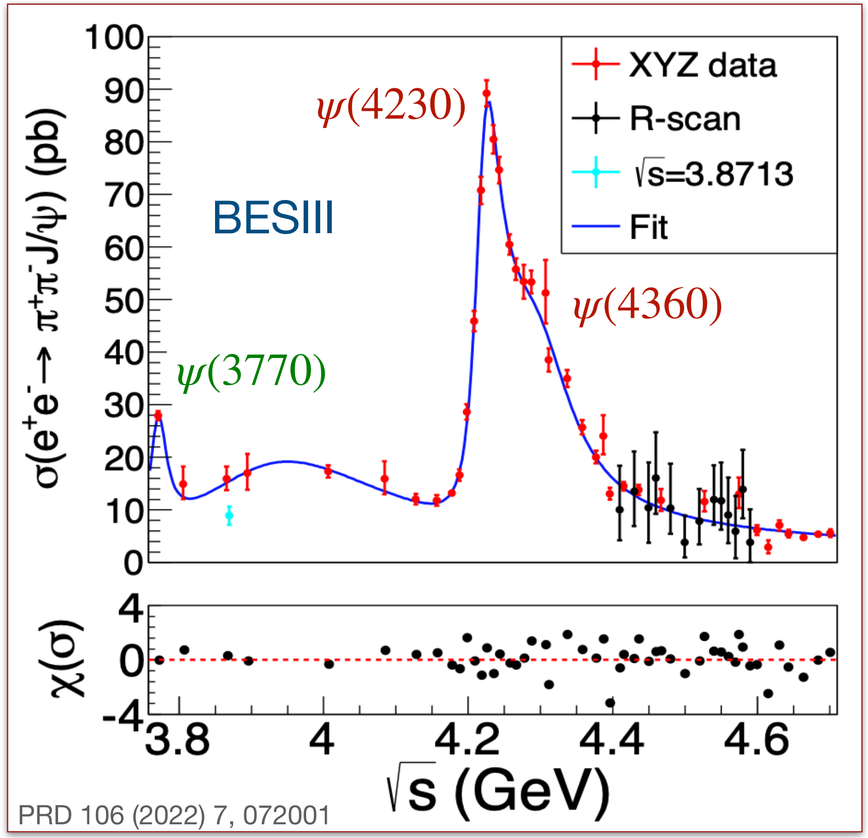
surplus?



PRL 95 (2005) 142001

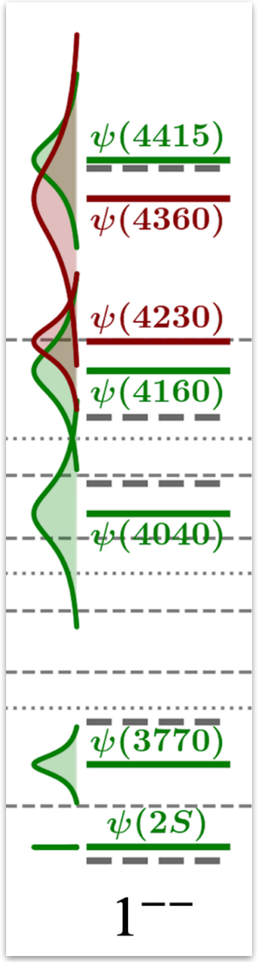
going against the expectation:

- $\psi(4230)$, $\psi(4360)$ decaying to $(q\bar{q})(c\bar{c})$
- there were no missing 1^{--} $c\bar{c}$ states

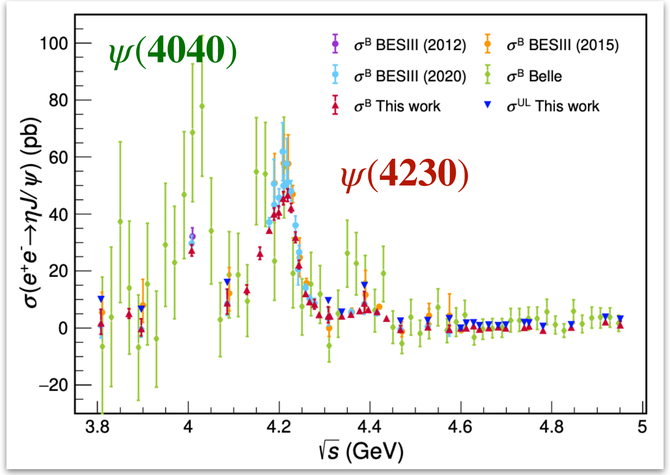


PRD 106 (2022) 7, 072001

Hidden-charm production

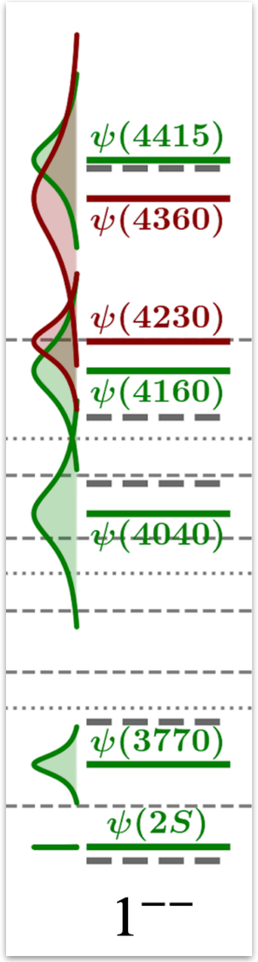


$e^+e^- \to \eta J/\psi$

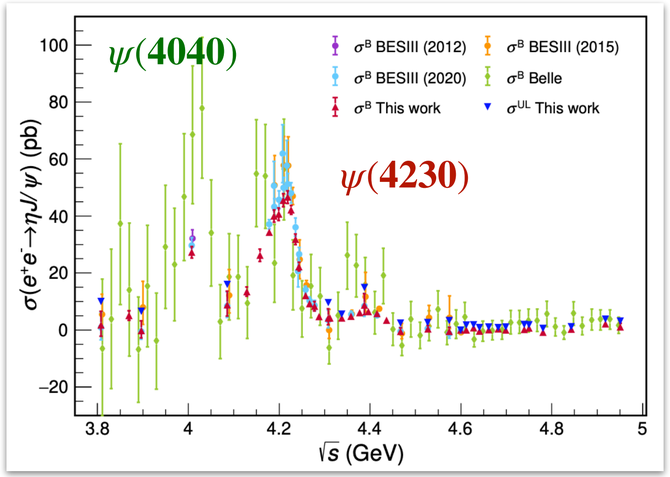


PRD 109 (2024) 9, 092012

Hidden-charm production

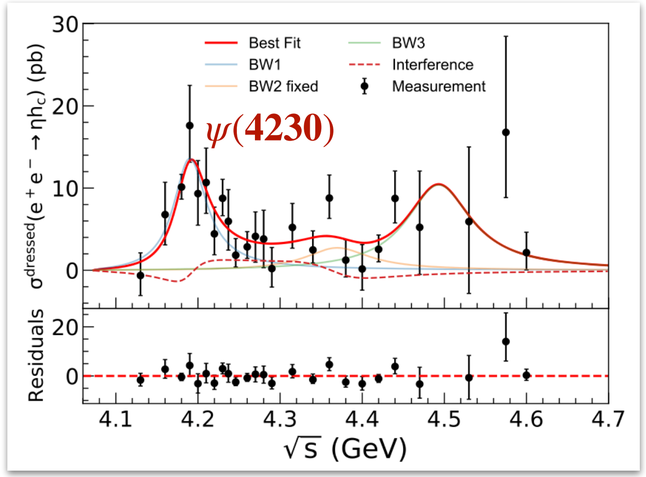


$e^+e^- \to \eta J/\psi$



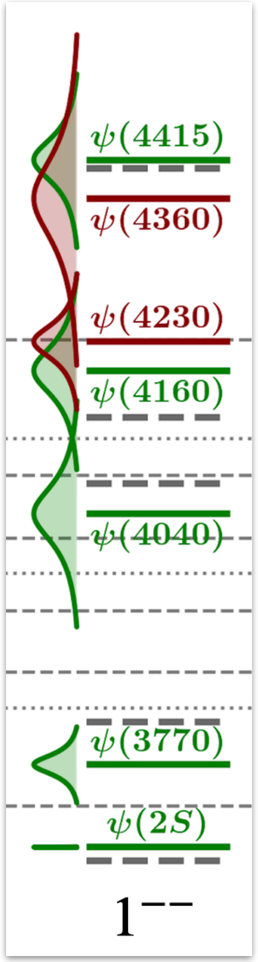
PRD 109 (2024) 9, 092012

$e^+e^- \to \eta h_c$

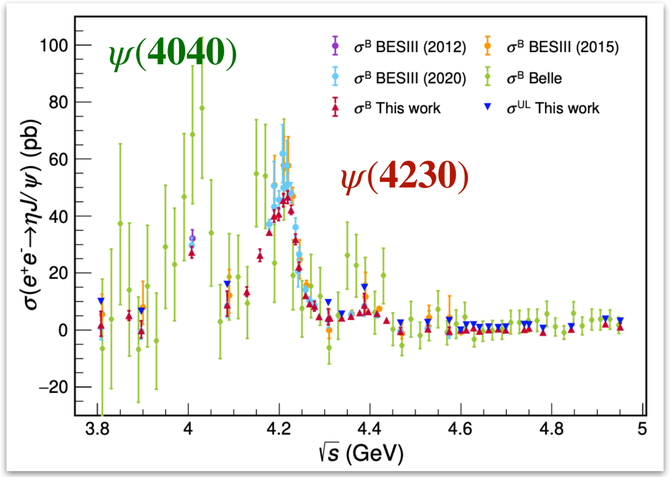


PRD 111, L011101 (2025)

Hidden-charm production

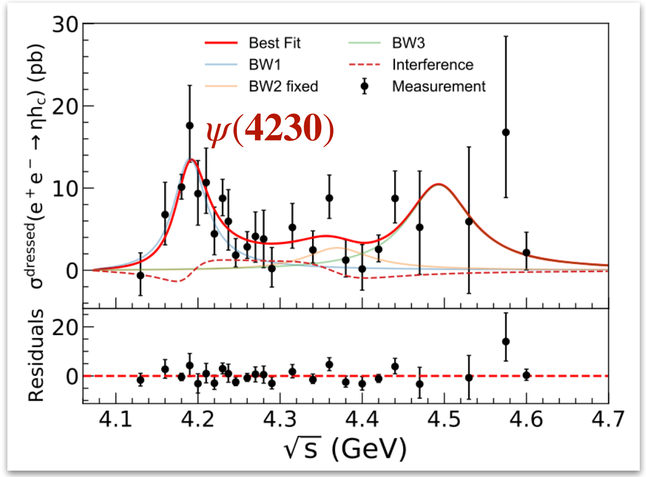


$e^+e^- \to \eta J/\psi$



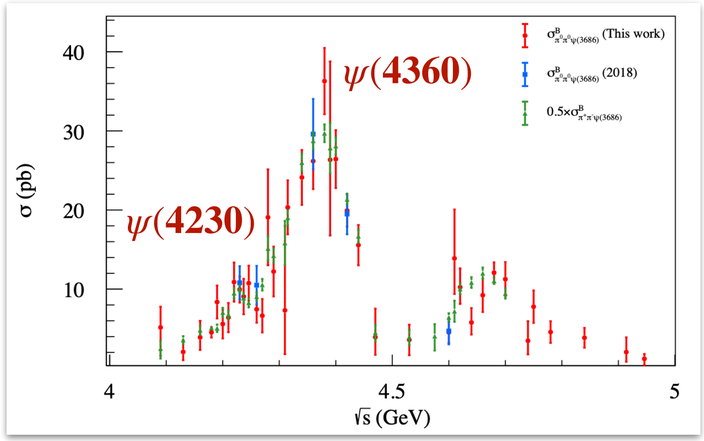
PRD 109 (2024) 9, 092012

$e^+e^- \to \eta h_c$



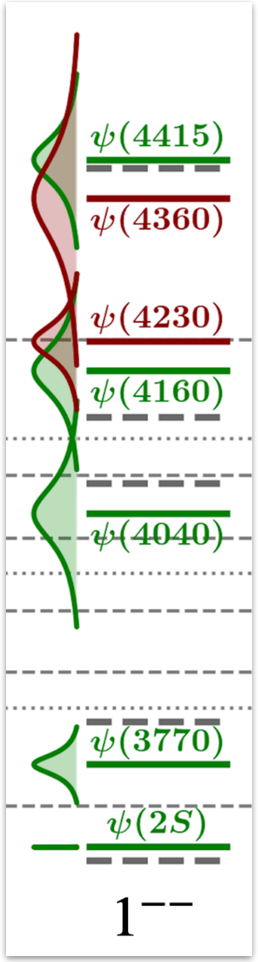
PRD 111, L011101 (2025)

$e^+e^- \to \pi^0\pi^0\psi(2S)$

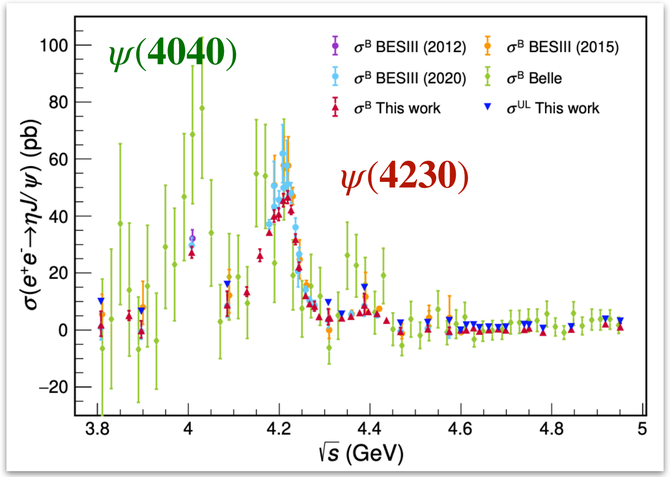


arXiv:2601.02136 [hep-ex]

Hidden-charm production

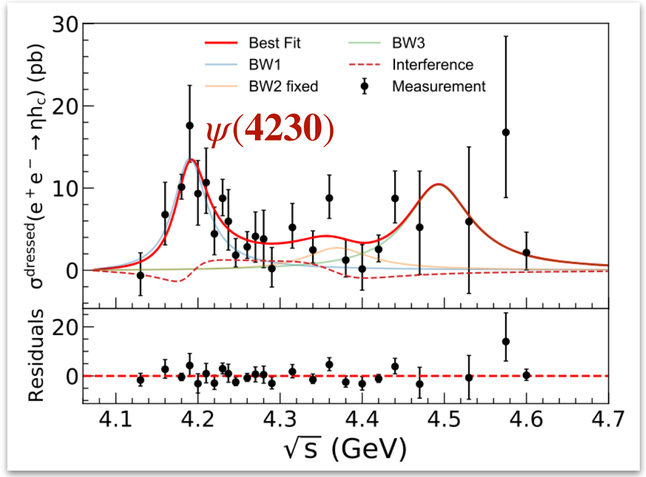


$e^+e^- \to \eta J/\psi$



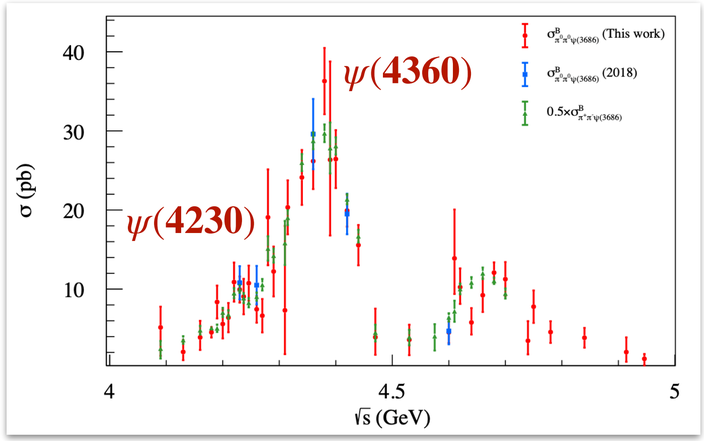
PRD 109 (2024) 9, 092012

$e^+e^- \to \eta h_c$



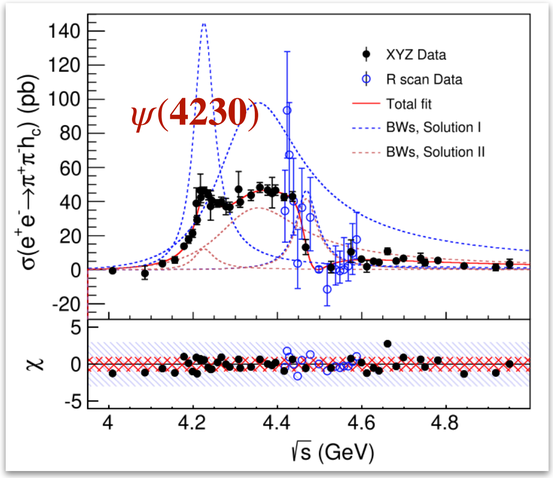
PRD 111, L011101 (2025)

$e^+e^- \to \pi^0\pi^0\psi(2S)$



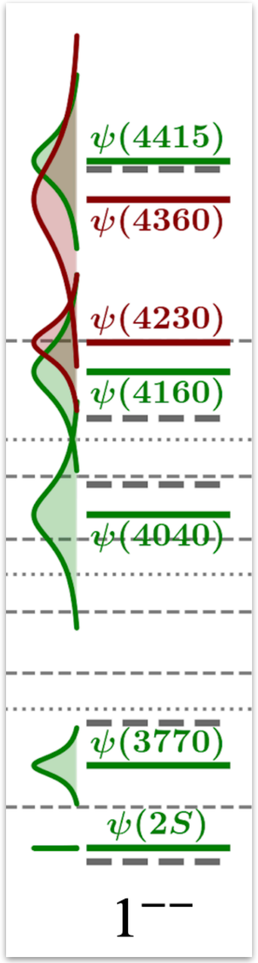
arXiv:2601.02136 [hep-ex]

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

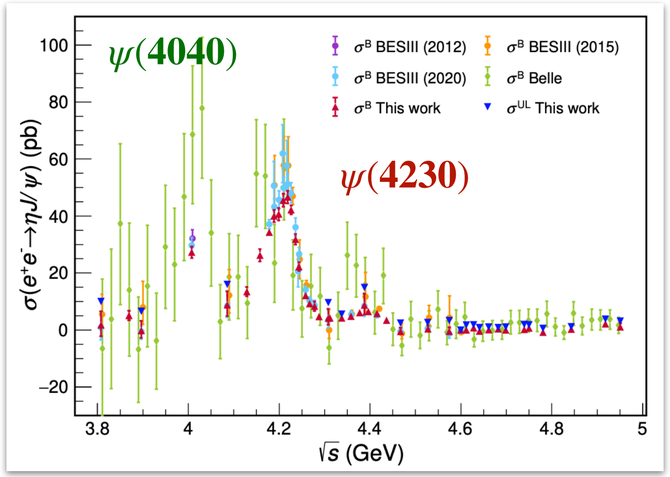


PRL 135, 071901 (2025)

Hidden-charm production

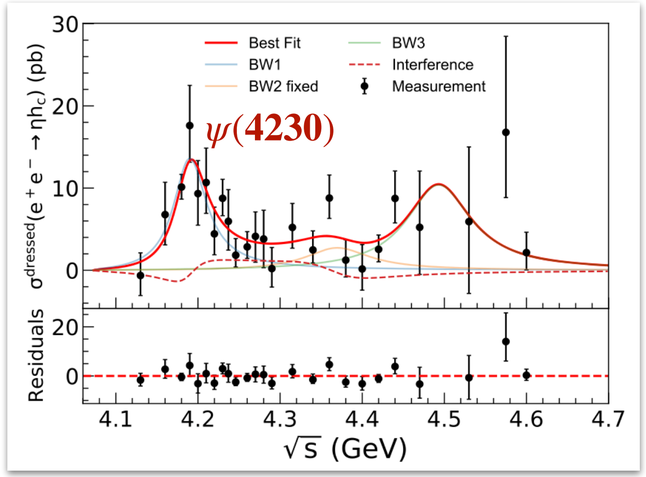


$e^+e^- \to \eta J/\psi$



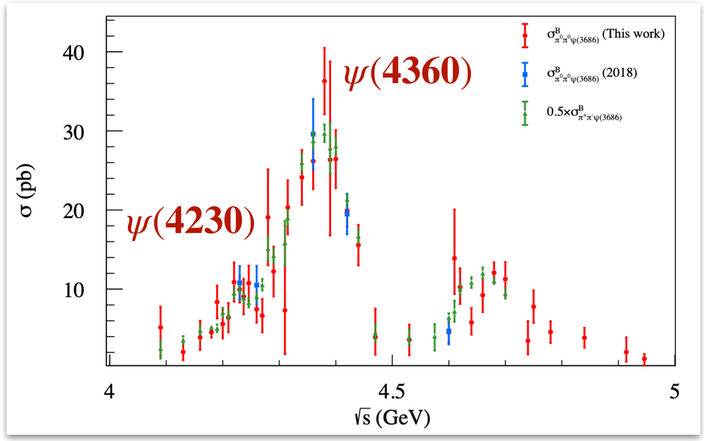
PRD 109 (2024) 9, 092012

$e^+e^- \to \eta h_c$



PRD 111, L011101 (2025)

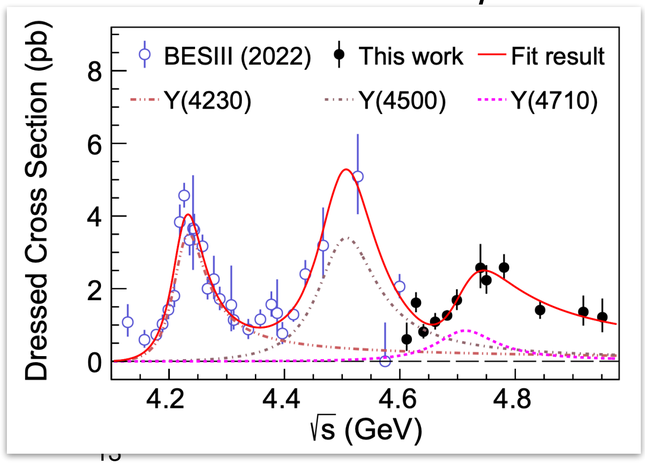
$e^+e^- \to \pi^0\pi^0\psi(2S)$



arXiv:2601.02136 [hep-ex]

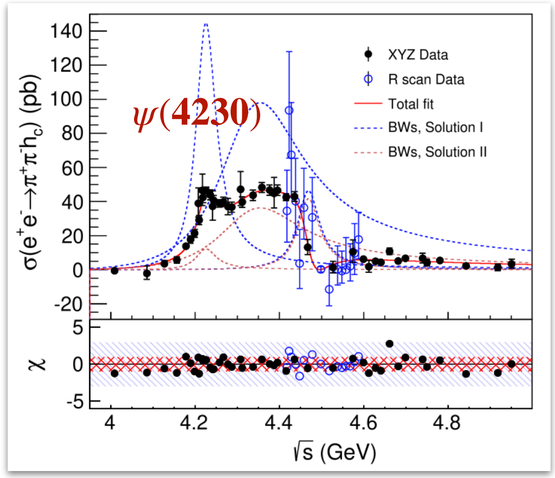
… decaying to $(q\bar{q})(c\bar{c})$ in many different ways

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



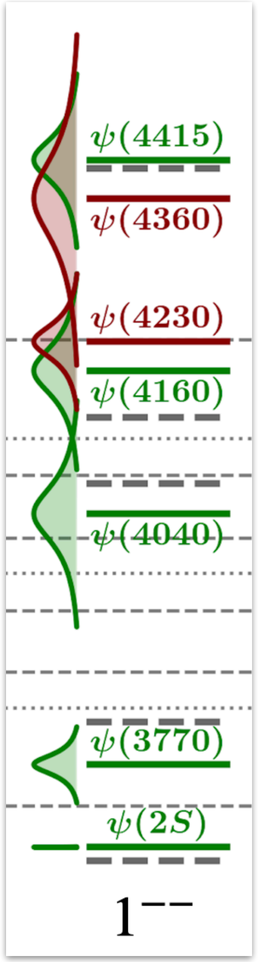
PRL 131 (2023) 21, 211902

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

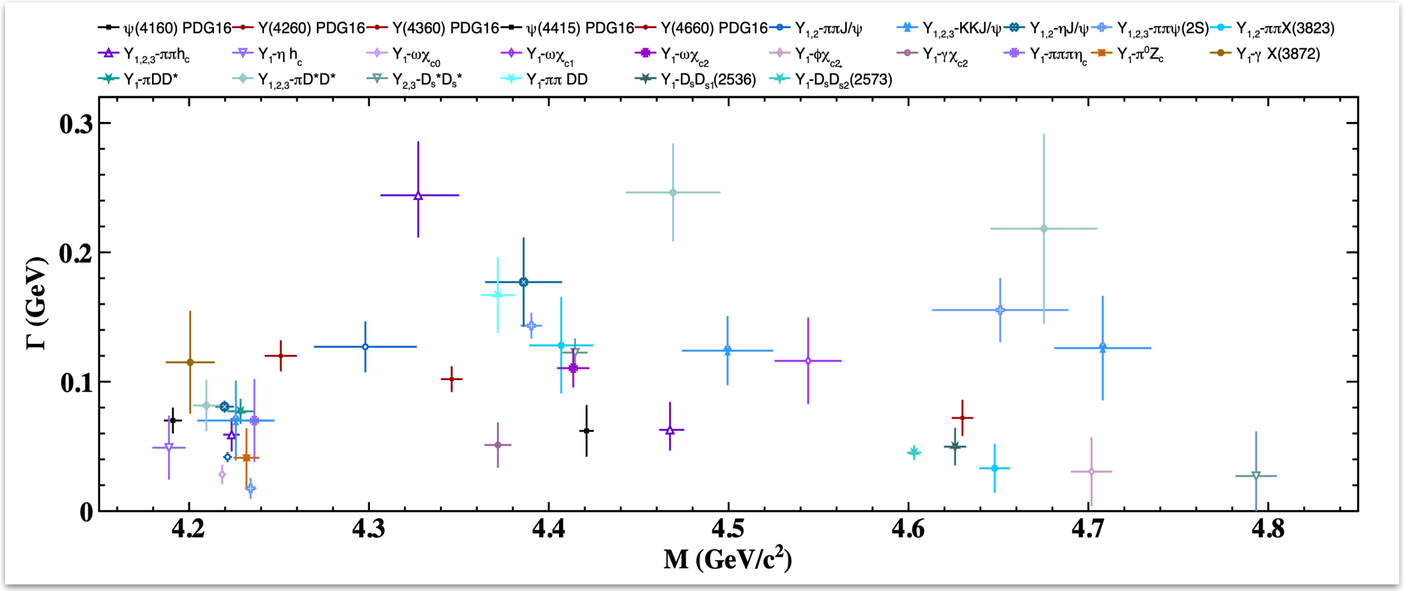


PRL 135, 071901 (2025)

Where do we stand?



- four conventional $c\bar{c}$ states as peaks in the inclusive $e^+e^- \to \text{hadrons}$ cross section
- at least two (?) more states in hidden-charm + light hadron(s)



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

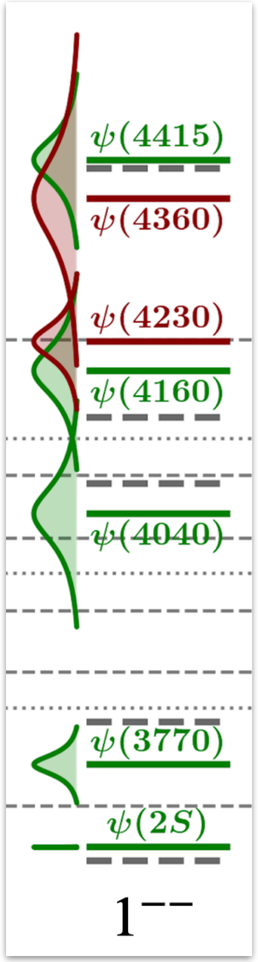
- highly non-trivial lineshapes for the exclusive open-flavour processes

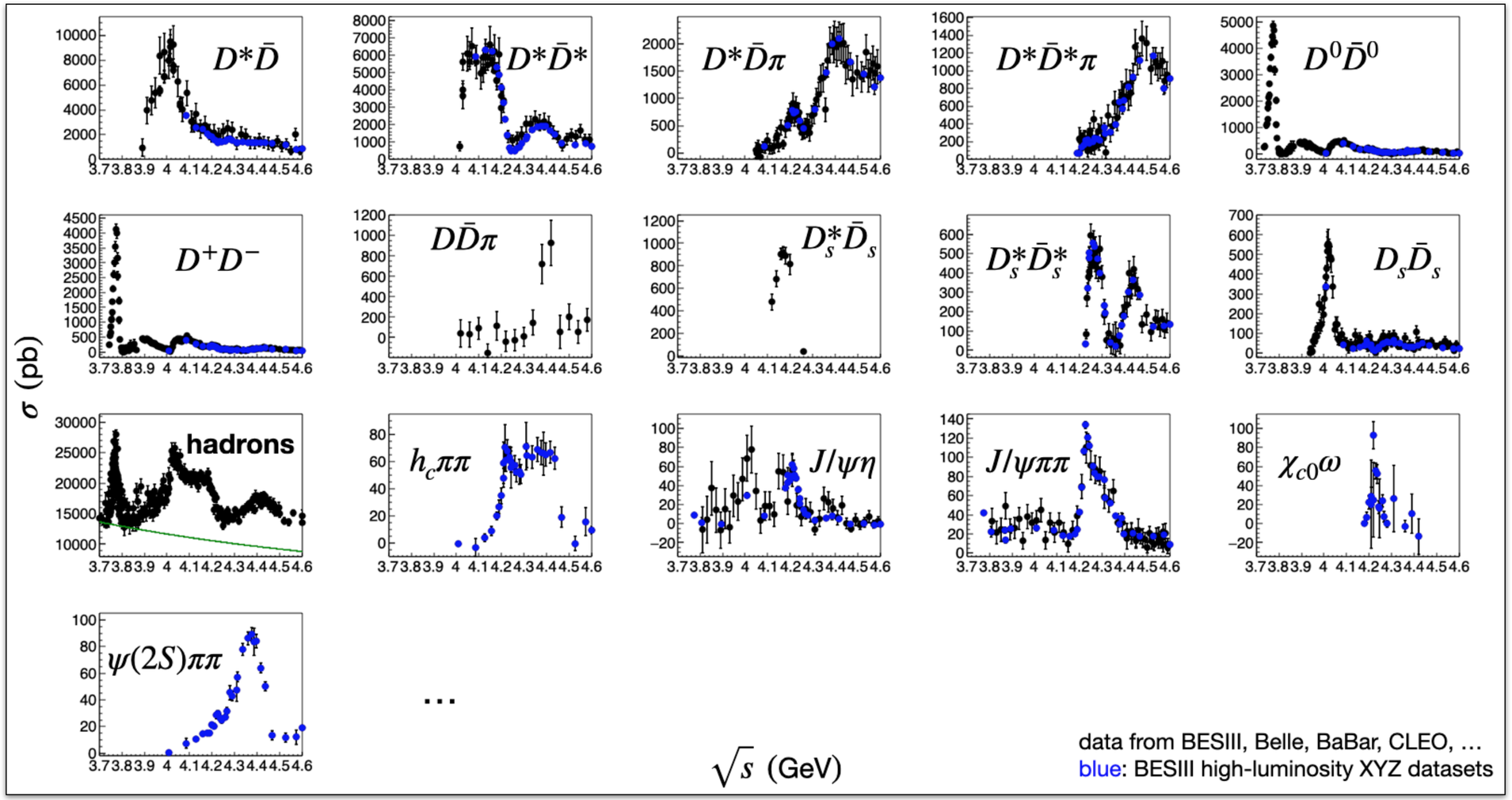
→ interpretation requires global coupled-channel analyses

see also talk by C. Hanhart on Thursday

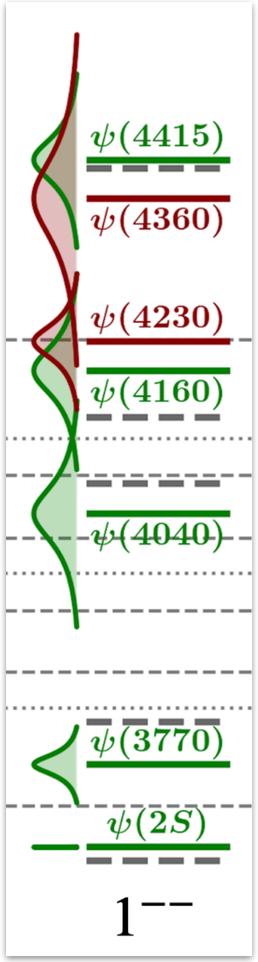
Where do we stand?

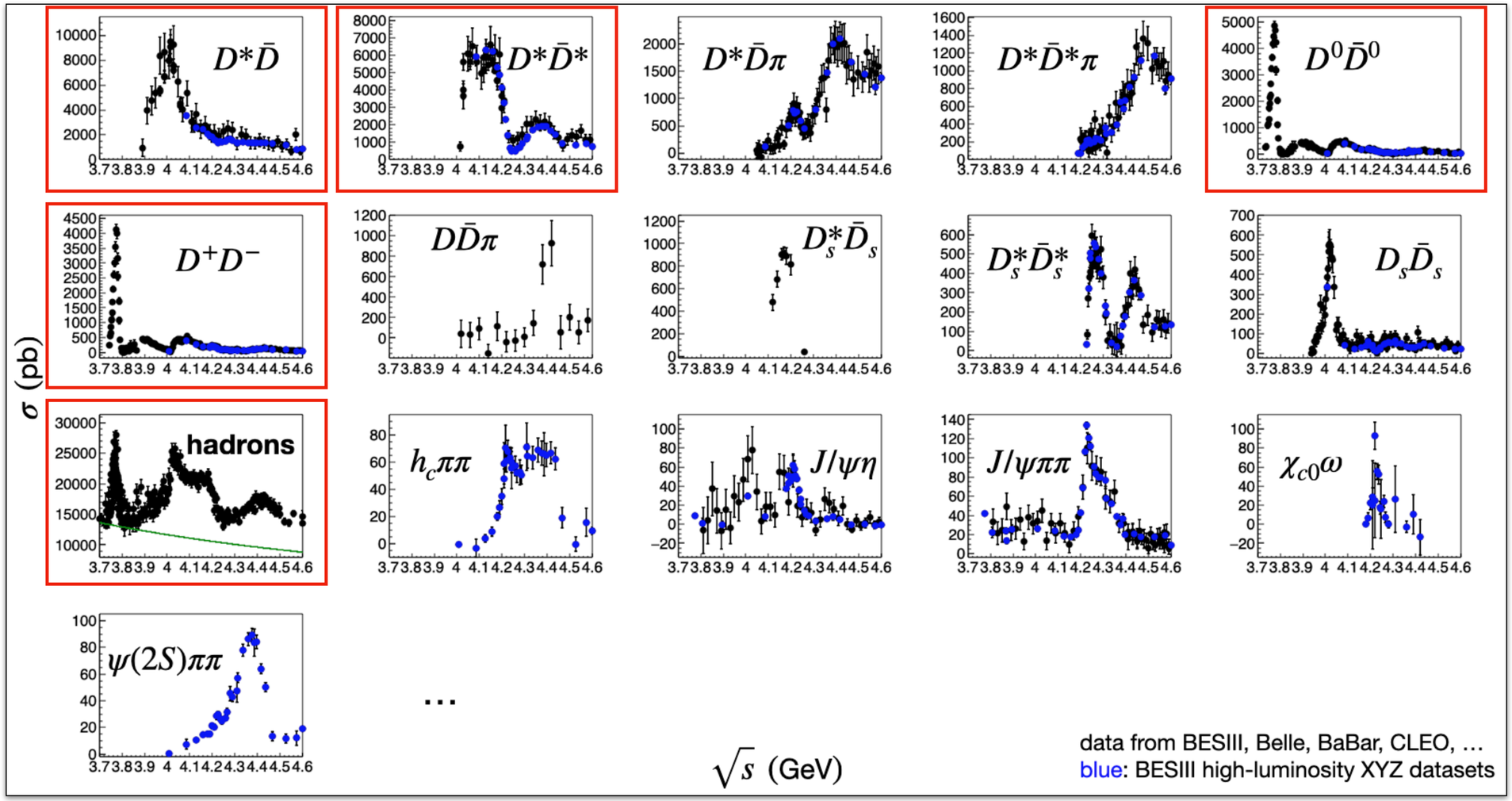
BESIII high-luminosity scans of the XYZ region are key!



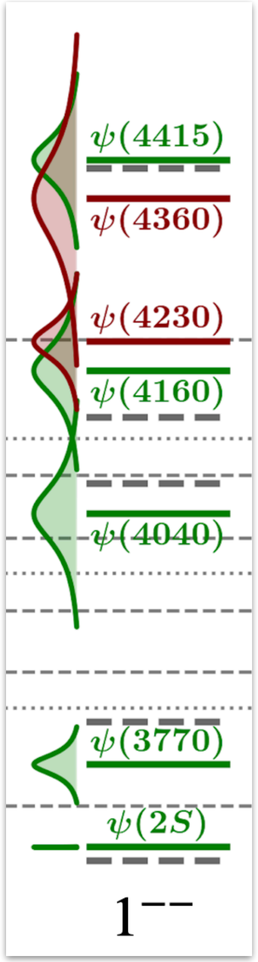


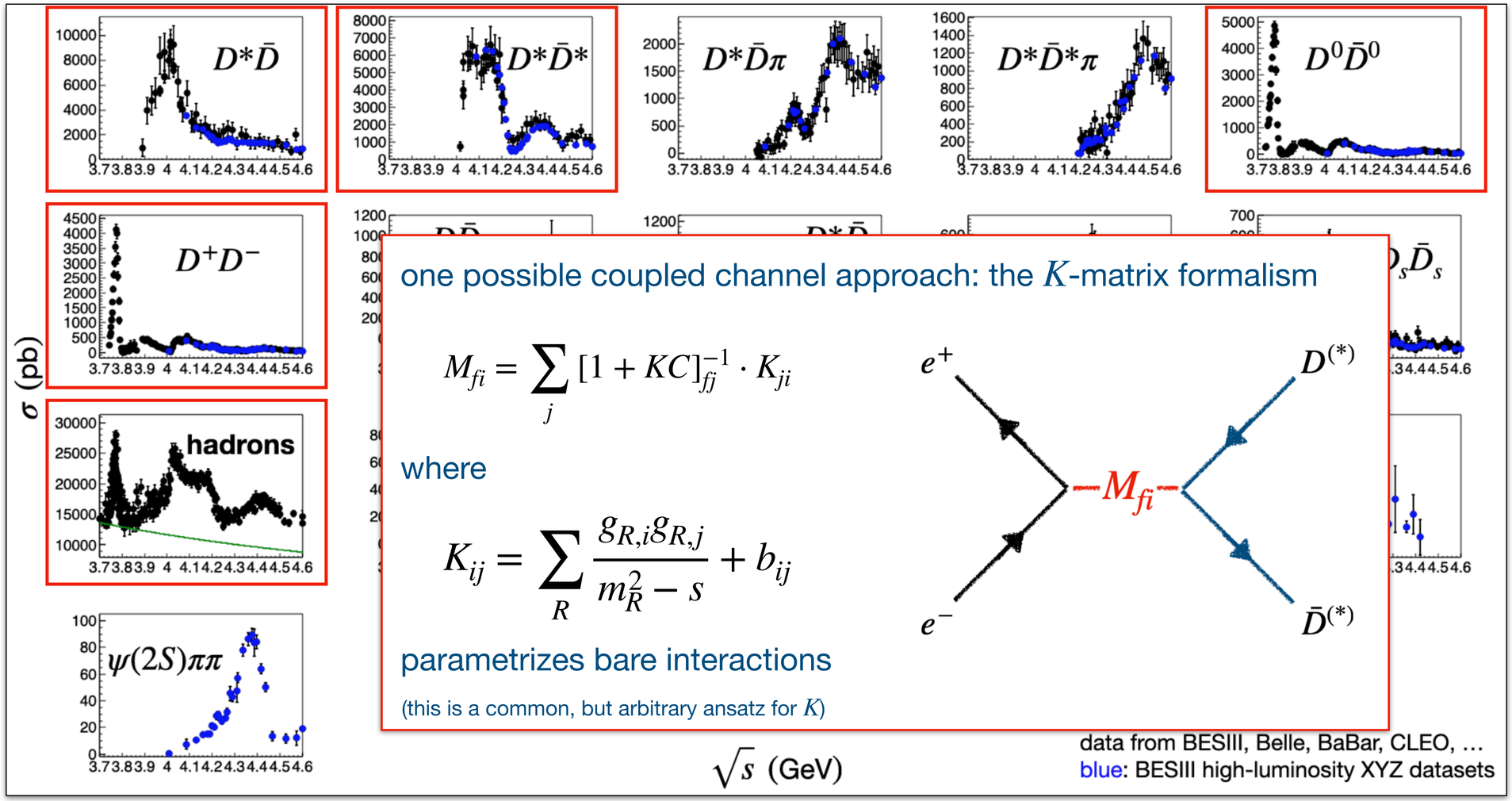
Where do we stand?



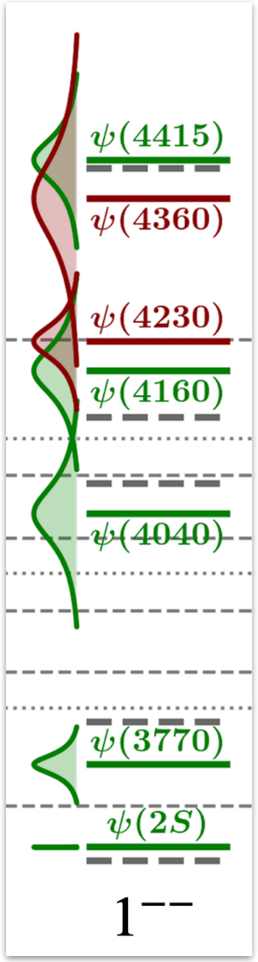


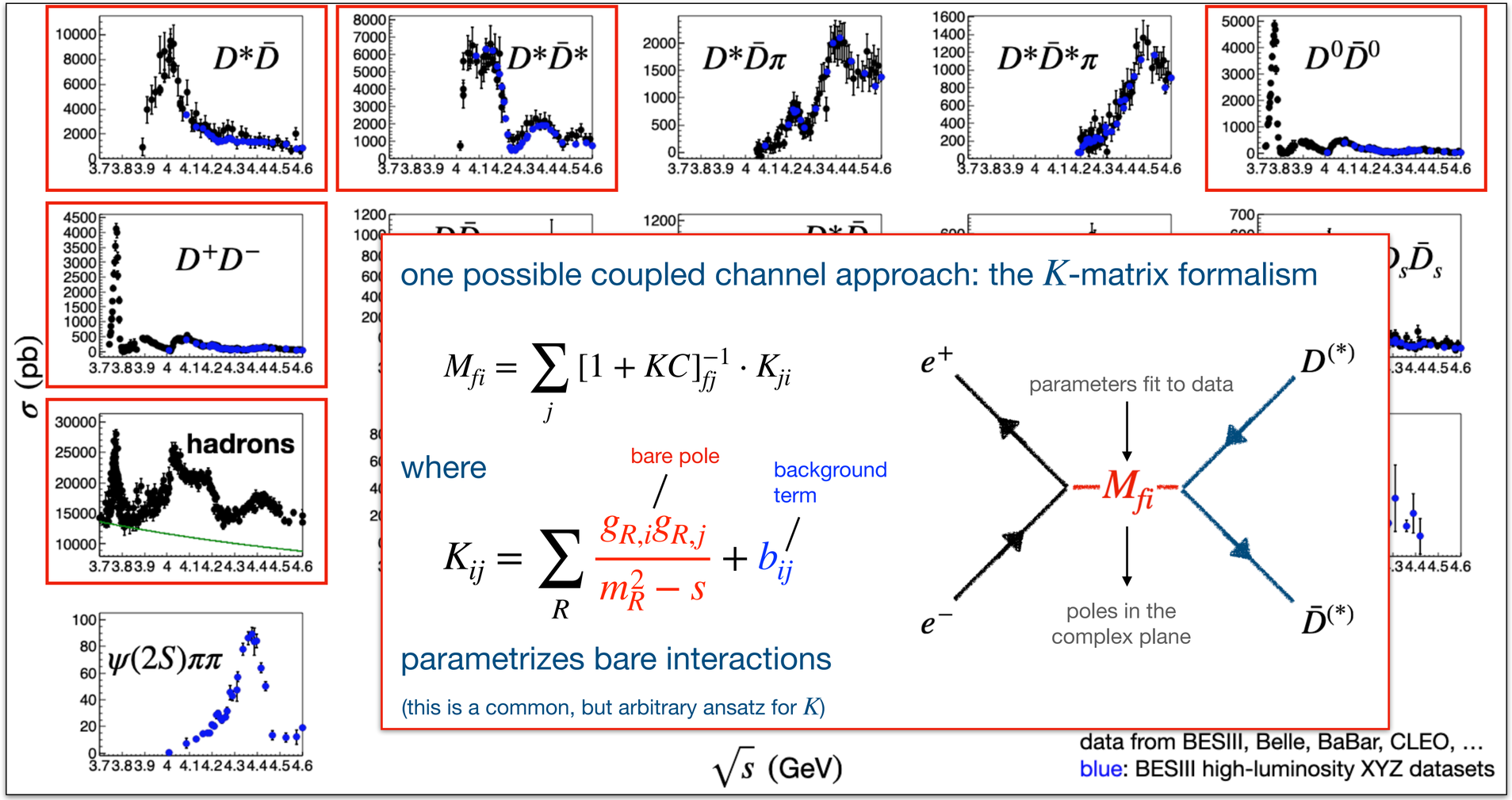
Where do we stand?





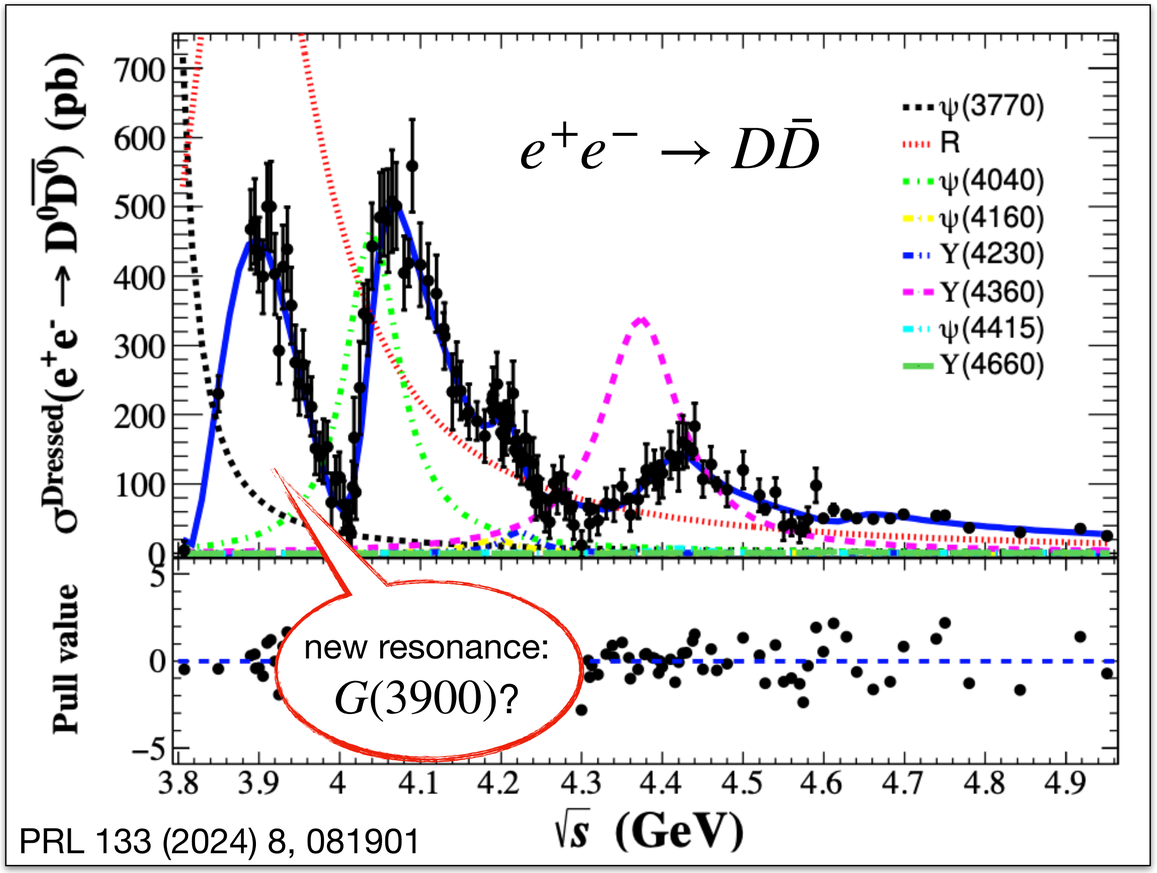
Where do we stand?





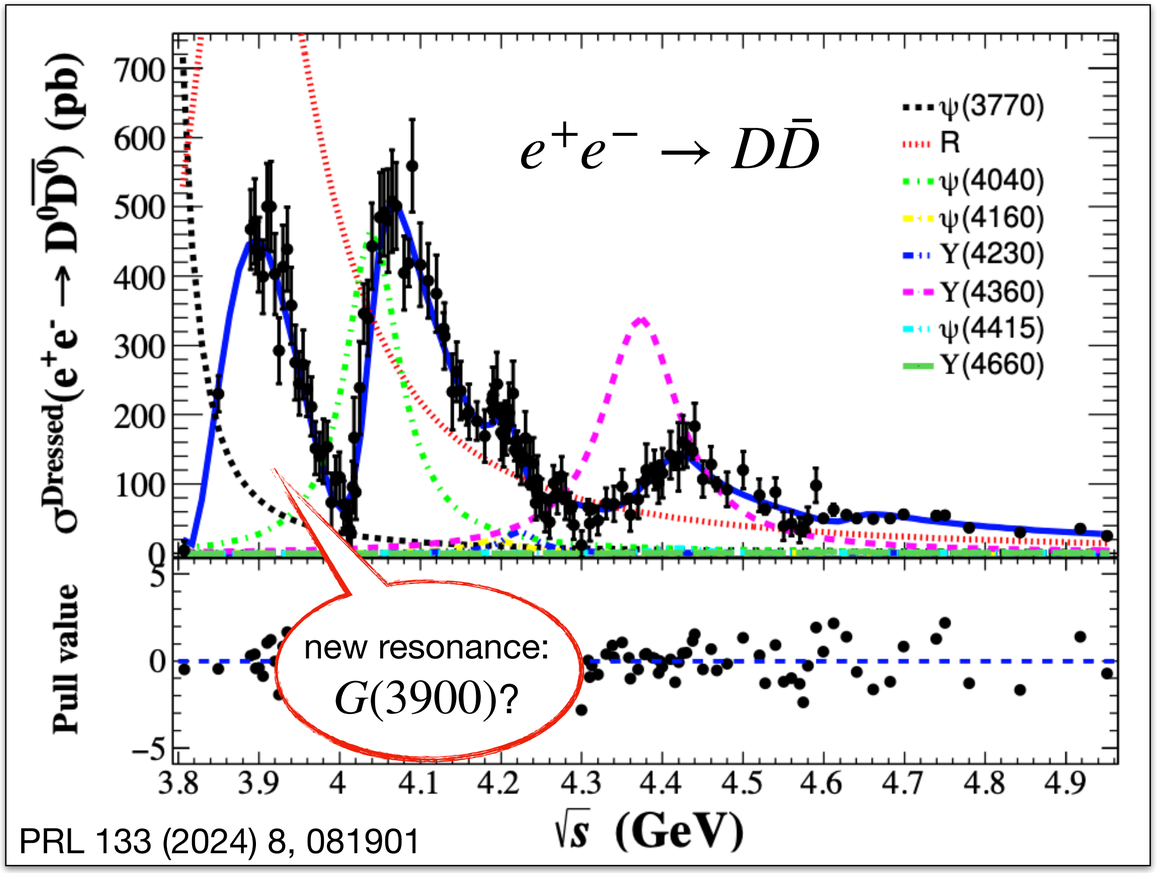
A piece of the puzzle

the $G(3900)$



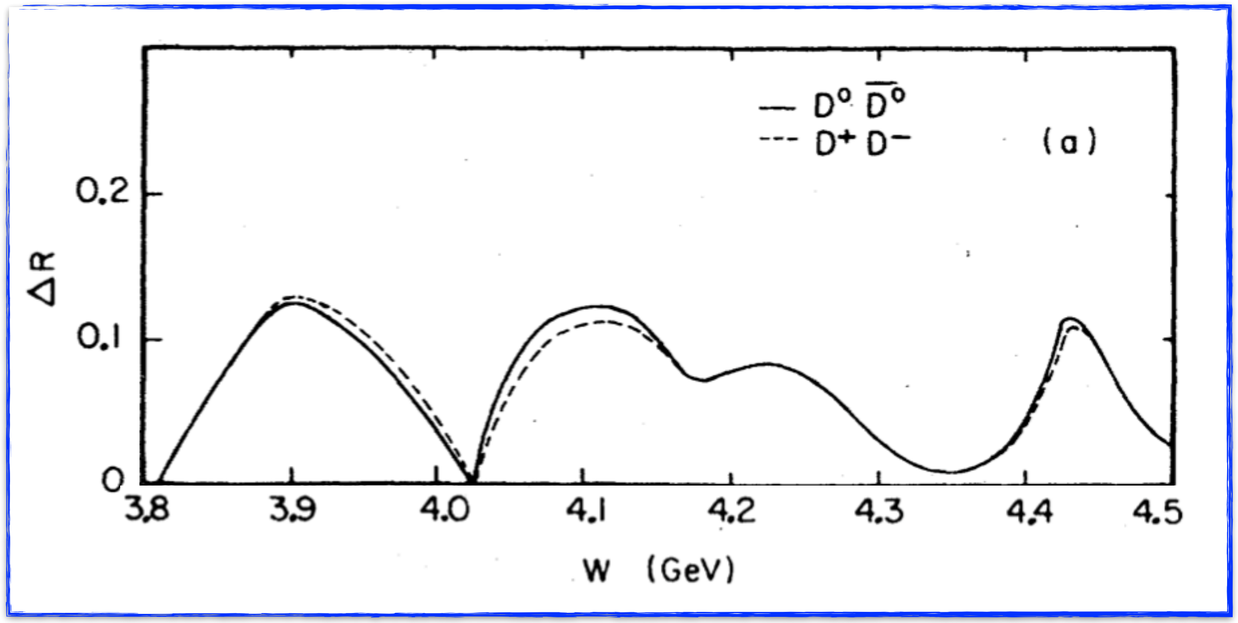
A piece of the puzzle

the $G(3900)$



PRL 133 (2024) 8, 081901

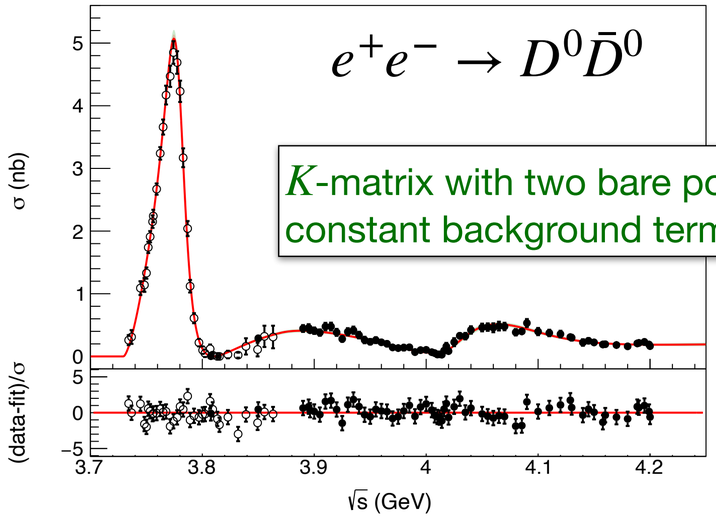
Eichten et al., Phys. Rev. D 21 (1980) 203



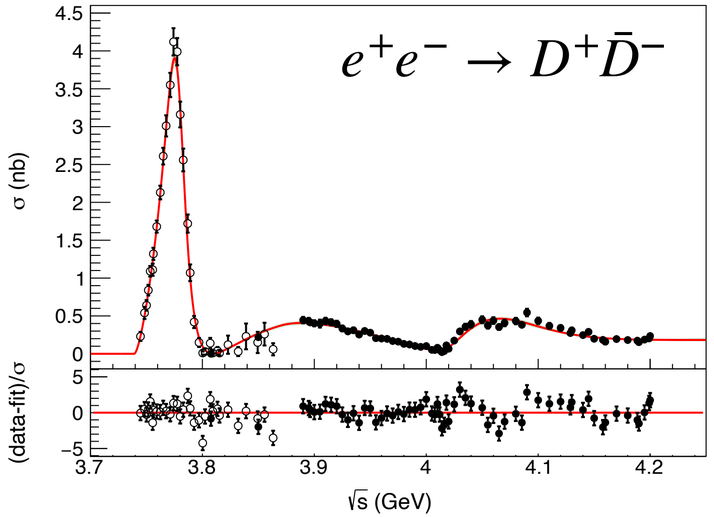
In our calculation there is some weak structure in the 3.9–4.0 GeV region. It does not arise from a $c\bar{c}$ resonance, but from the opening of the $D\bar{D}^* + D^*\bar{D}$ channel and a decrease in the $D\bar{D}$ channel due to a nearby zero in the $3S$ decay amplitude.

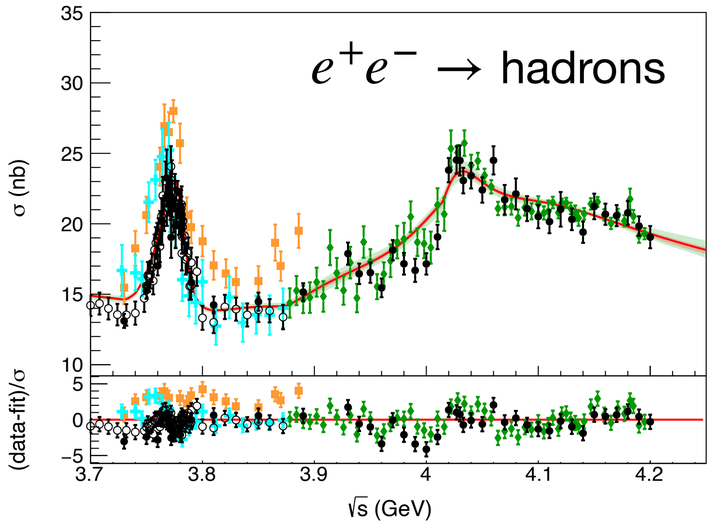
A piece of the puzzle

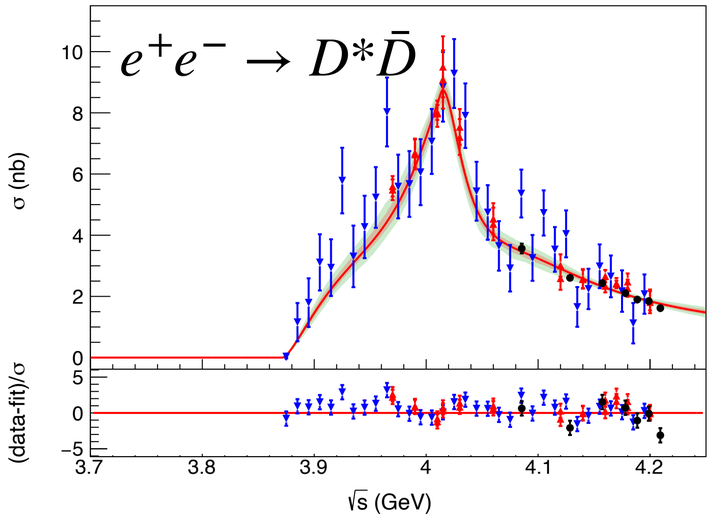
NH, R. Lebed, R. Mitchell, E. Swanson, Y. Wang, C. Yuan
PRD 109 (2024) 11, 114010

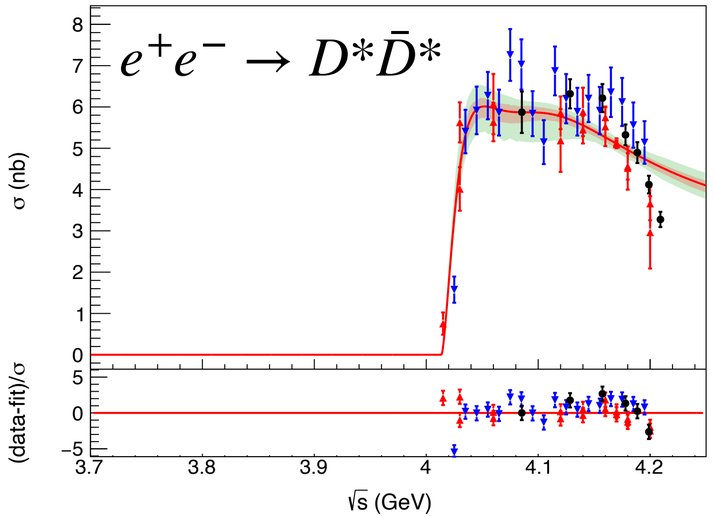


K-matrix with two bare poles, constant background terms







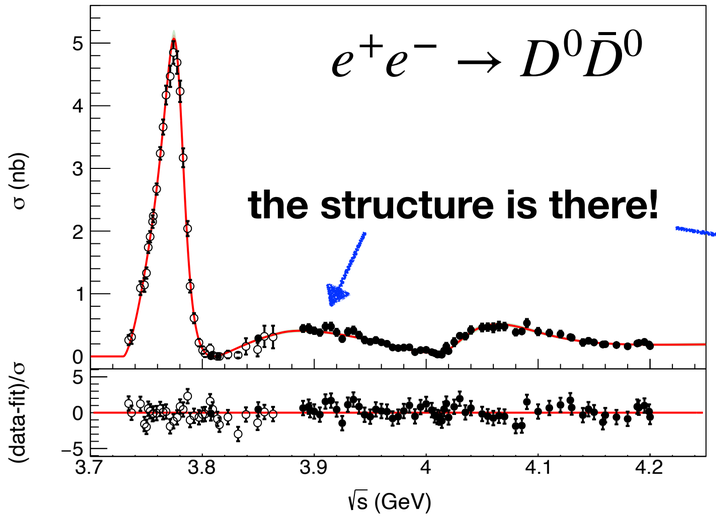


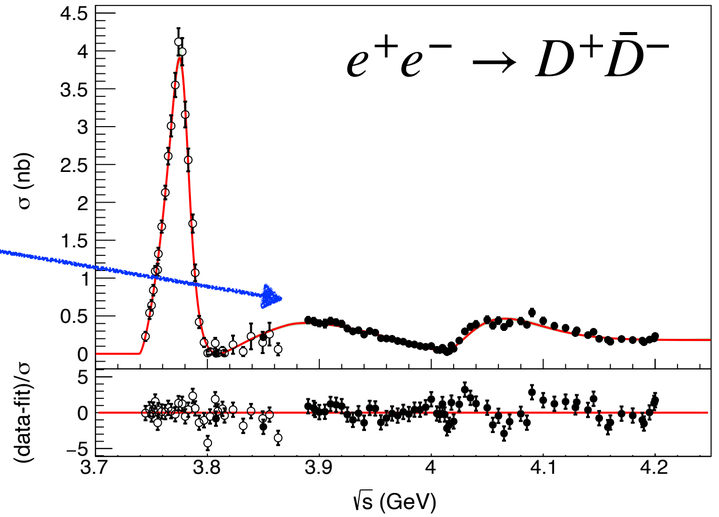
fit result
68% CL
90% CL

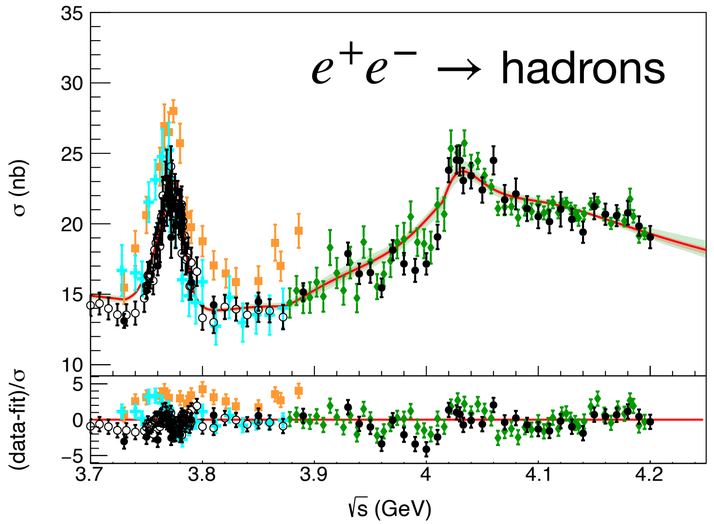
Data from:
BESIII (unoff.) Andy Julin, University of Minnesota
BESIII: PRL 133 (2024) 8, 081901
BESIII: JHEP 05 (2022) 155
Belle: Phys.Rev.D 97 (2018) 1, 012002
CLEO: Phys.Rev.D 80 (2009) 072001
BES: PRL 88, 101802 (2002)
BESII: PRL 97, 262001 (2006)
SPEAR: PRL 39, 526 (1977);
A. Osterheld et al. 86; Schindler 79

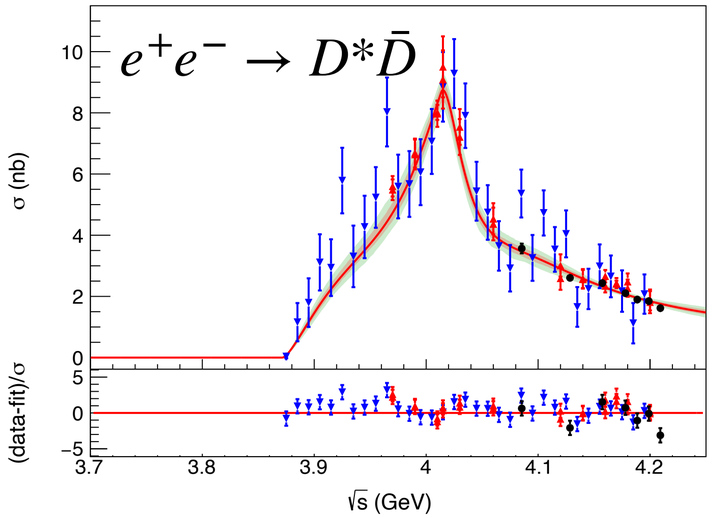
A piece of the puzzle

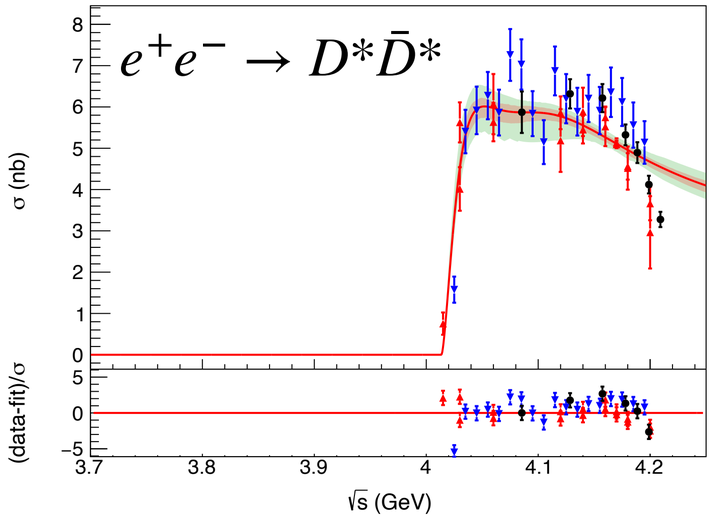
NH, R. Lebed, R. Mitchell, E. Swanson, Y. Wang, C. Yuan
PRD 109 (2024) 11, 114010

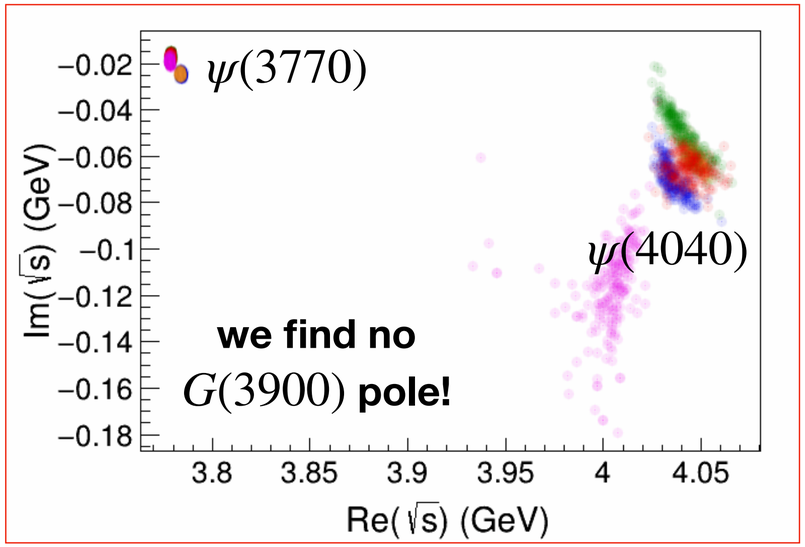






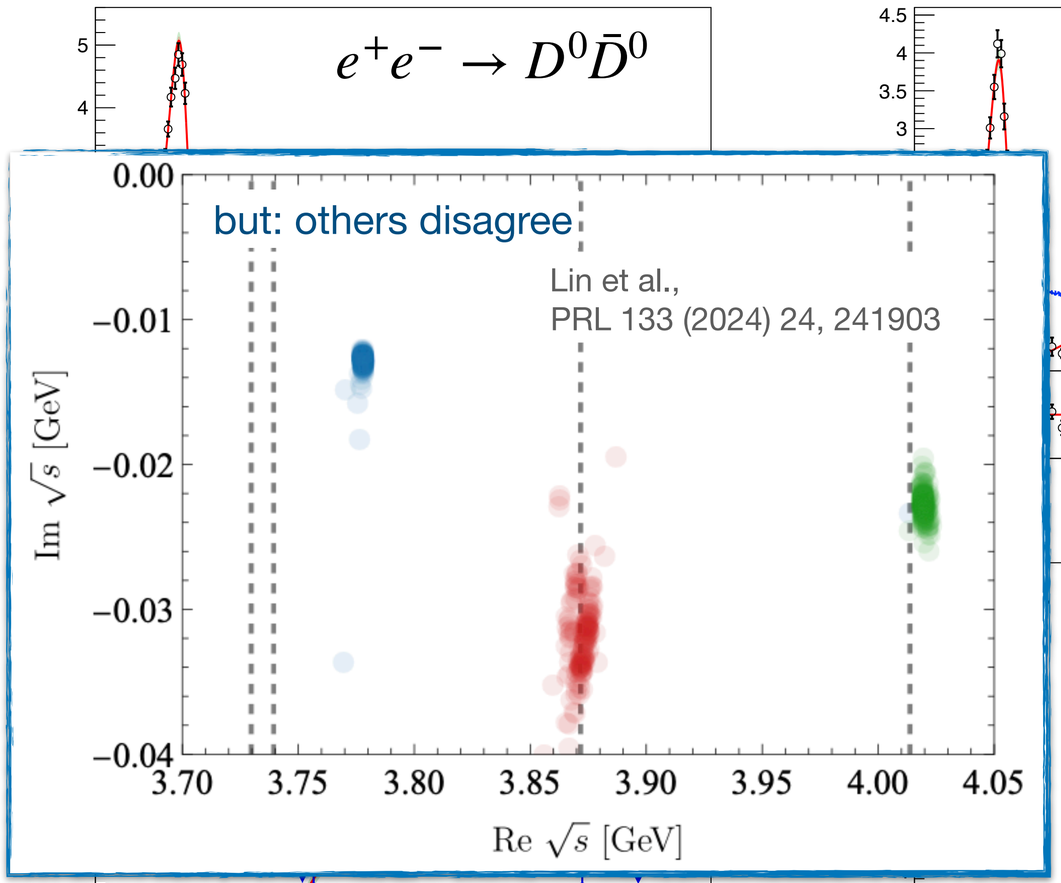


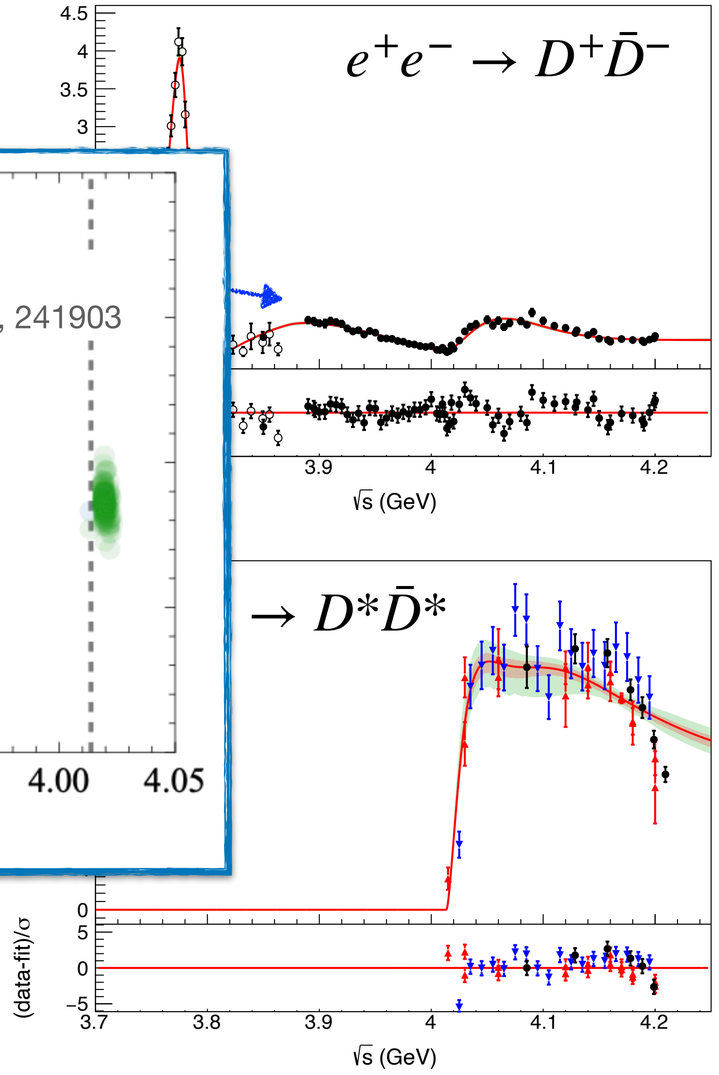


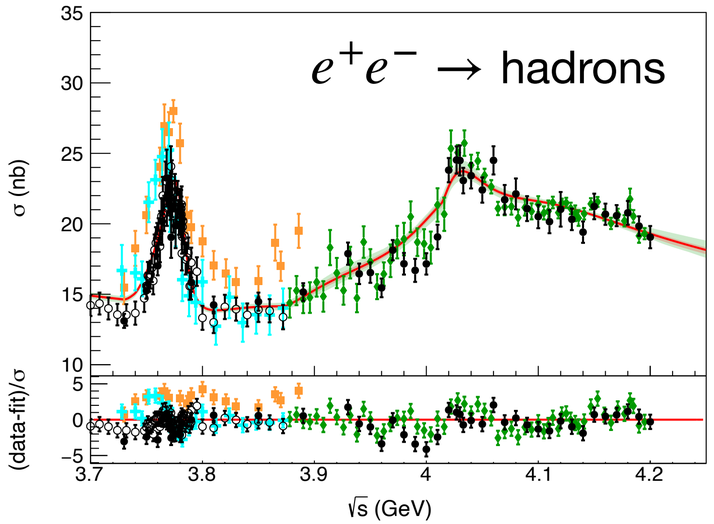


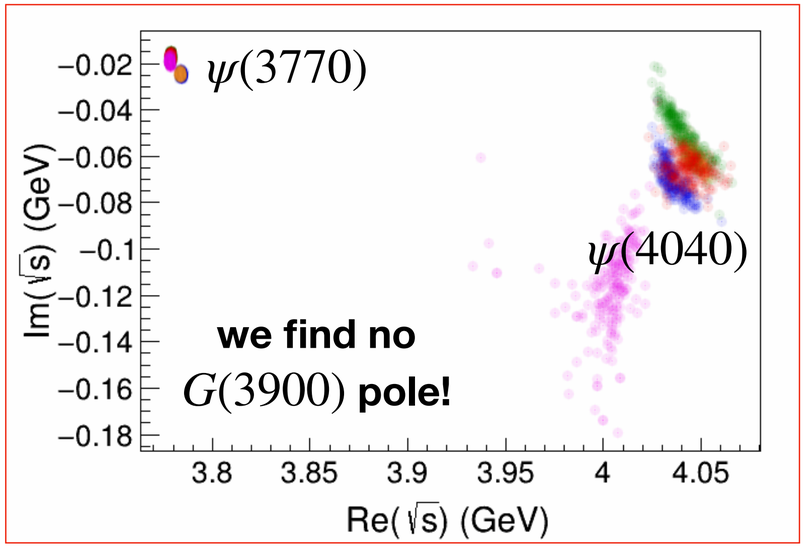
A piece of the puzzle

NH, R. Lebed, R. Mitchell, E. Swanson, Y. Wang, C. Yuan
PRD 109 (2024) 11, 114010









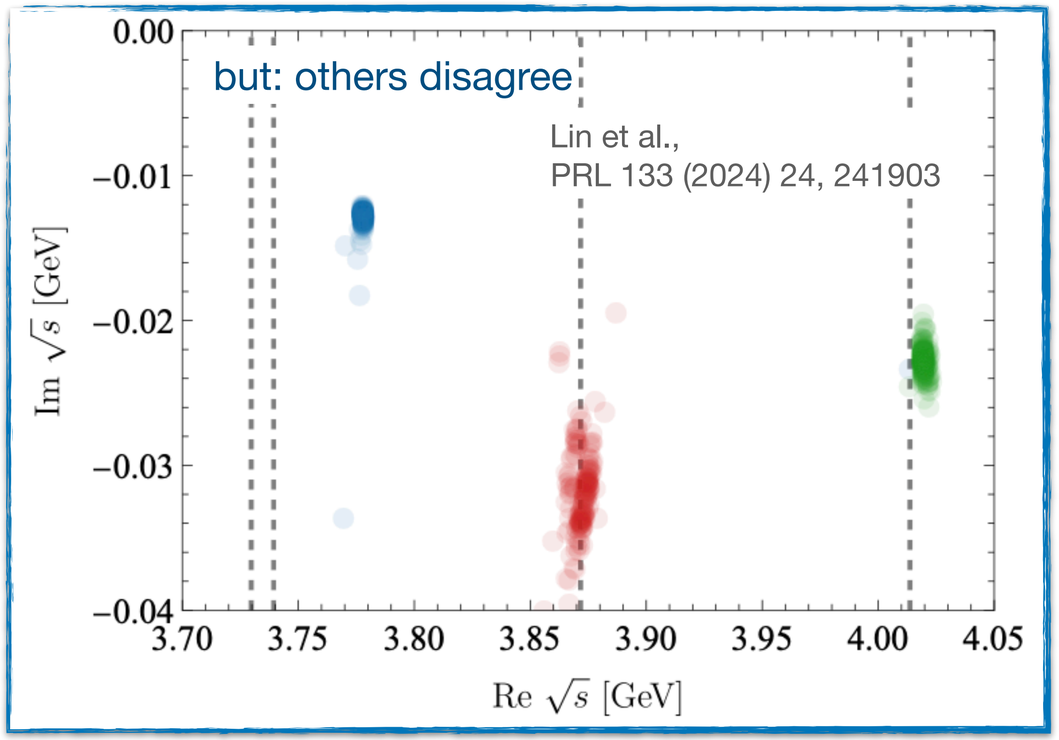
Many ways…

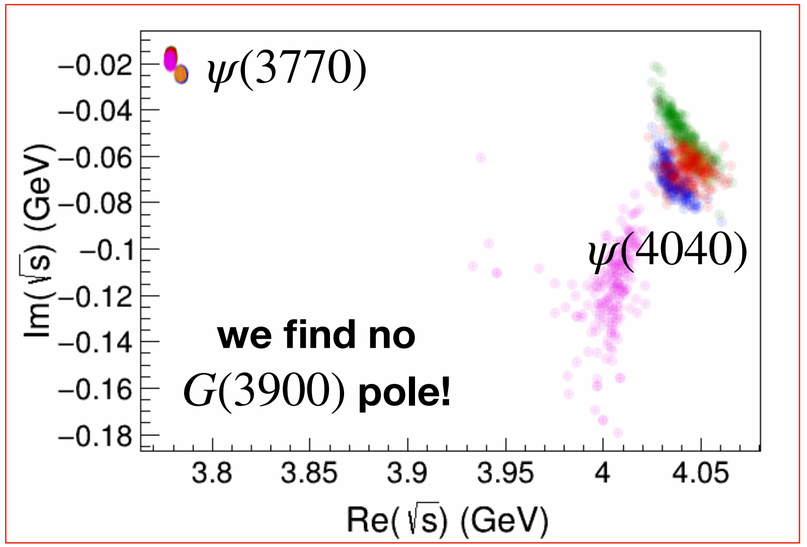
as so often, the devil is in the details: $M_{fi} = \sum_j [1 + KC]^{-1}_{fj} \cdot K_{ji}$

- was our ansatz too simplistic?
- how strongly does the existence of a new resonance depend on model assumptions?
- many different ways to write a K-matrix…
- poles required by the data usually stable under model variation

  see NH, E. Swanson, A. Szczepaniak, PRD 113 (2026) 11, 116021 for a toy-study

→ we can use that as a tool





it is (very) valuable to compare (many) different models!

also: Salnikov, Milstein, PRD 109 (2024) 11, 114015
Nakamura et al., PRD 112 (2025) 5, 054027

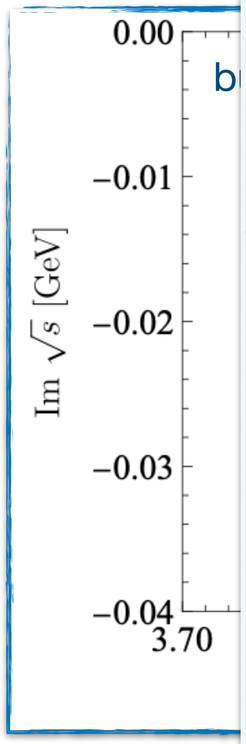
Many ways…

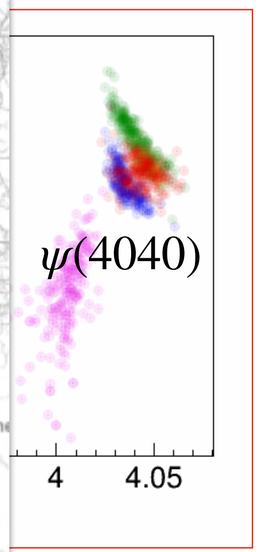
… lead to Rome

$+ KC]^{-1}_{fj} \cdot K_{ji}$

depend on

3 (2026) 11, 116021



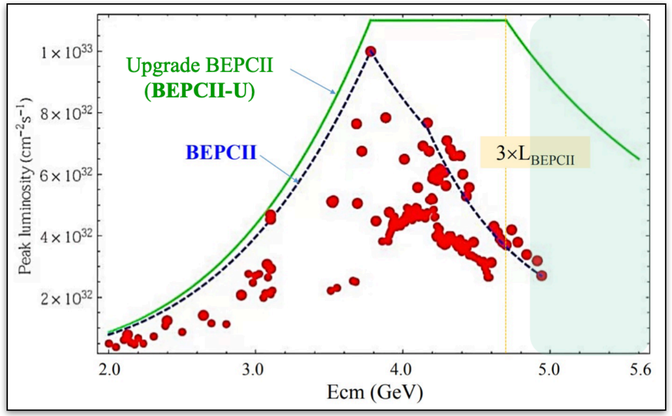


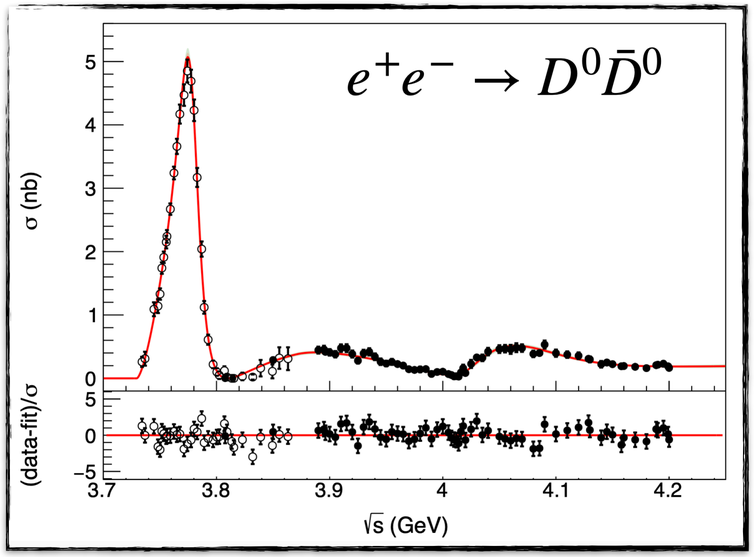
→ try many more ways, identify the common poles

also: Salnikov, Milstein,
Nakamura et al., F

How well do we know vector charmonia?

- a lot of effort has gone into finding new exotic hadrons - but surprisingly little is known about regular vector charmonia
- we have the necessary data, but there is no free lunch:
  → this is no bump-hunt, simple interpretations tend to fail
  → coupled channel effects matter & global analyses are key - but hard!
- the future is bright: BESIII keeps producing high quality data





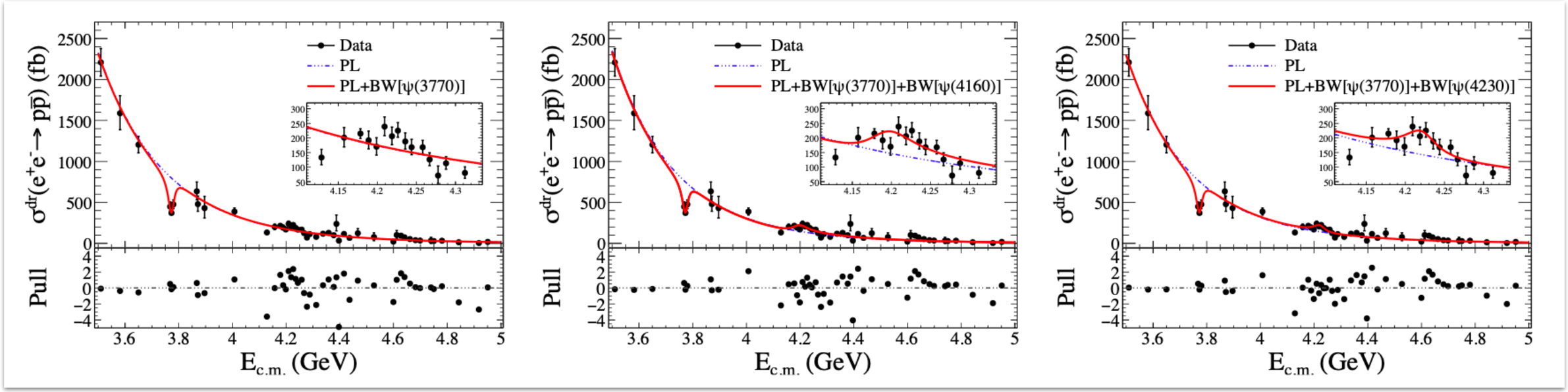
- very active field with many different approaches - some examples:
- many things still to be learned!

Lin et al., PRL 133 (2024) 24, 241903
Nakamura et al., PRD 112 (2025) 5, 054027
Cleven et al., PRD 90 (2014) 7, 074039
L. von Detten et al., PRD 109 (2024) 11, 116002
X.-K. Dong et al., arXiv:2606.06180 [hep-ph]

New: $e^+e^- \to p\bar{p}$

- new measurement of the cross section for $e^+e^- \to p\bar{p}$ shows structure

$\psi(3770)$ 6.6σ $\psi(4160)$ 4.6σ $\psi(4230)$ 4.8σ



- if interpreted with a Breit-Wigner, we find a signal for $\psi(3770) \to p\bar{p}$, plus a second structure near 4.2 GeV
- angular distribution gives access to $|G_M|$ and $R = |G_E|/|G_M|$ in the time-like region

arXiv:2606.22759
arXiv:2606.22762

Thank you for your attention!