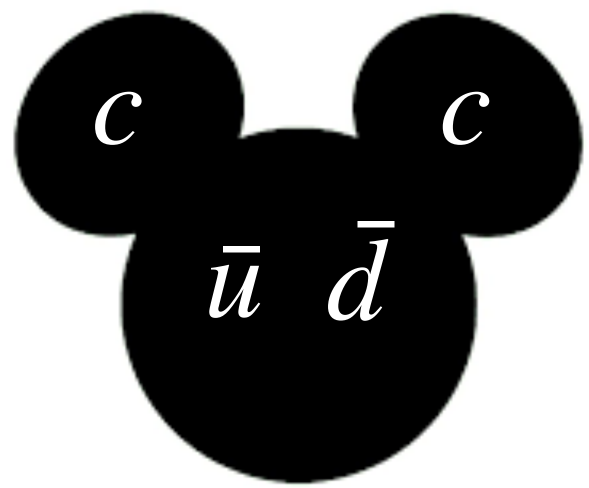
Spectroscopy highlights from around the world

Conference on Intersections in
Particle and Nuclear Physics

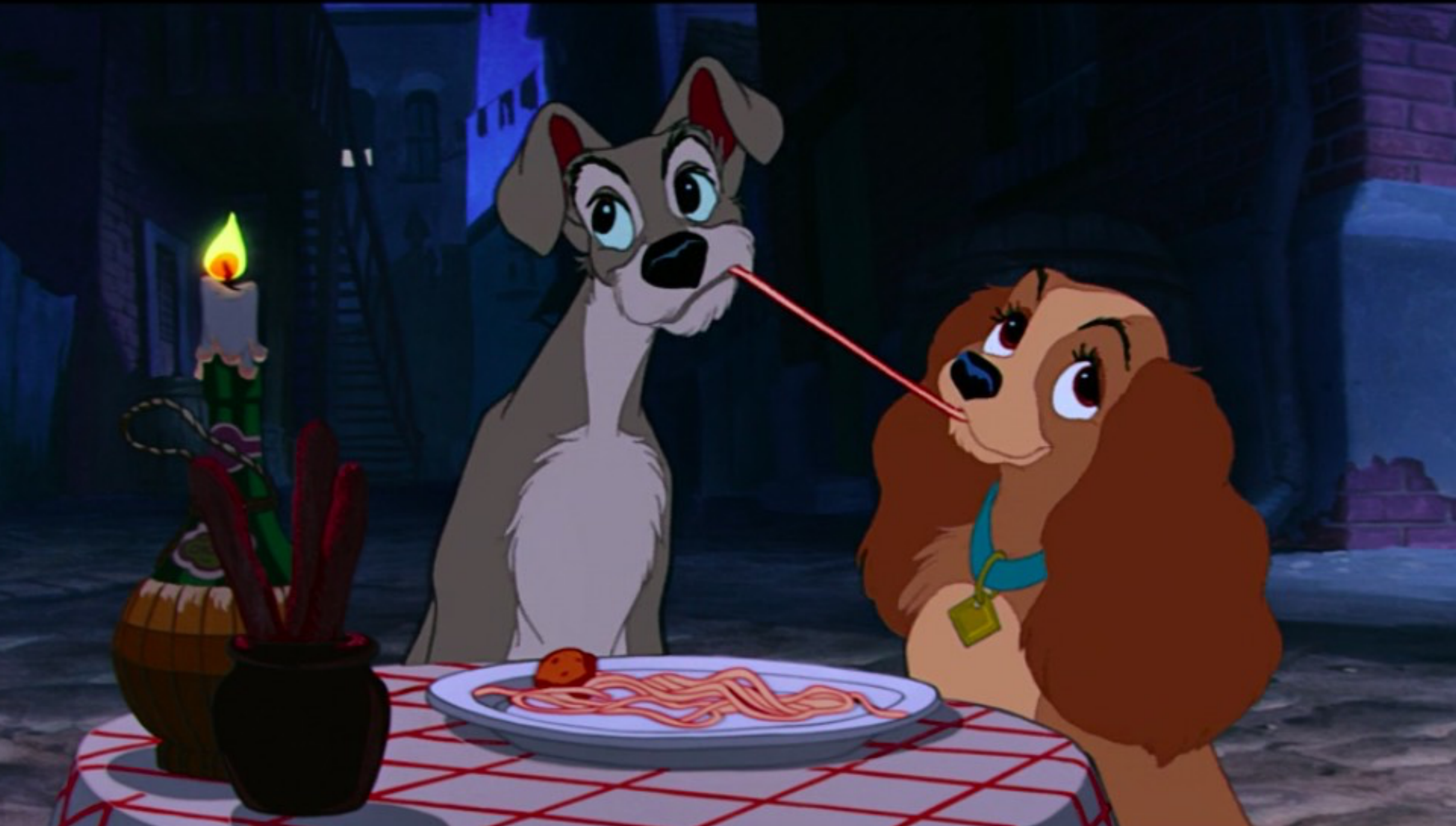


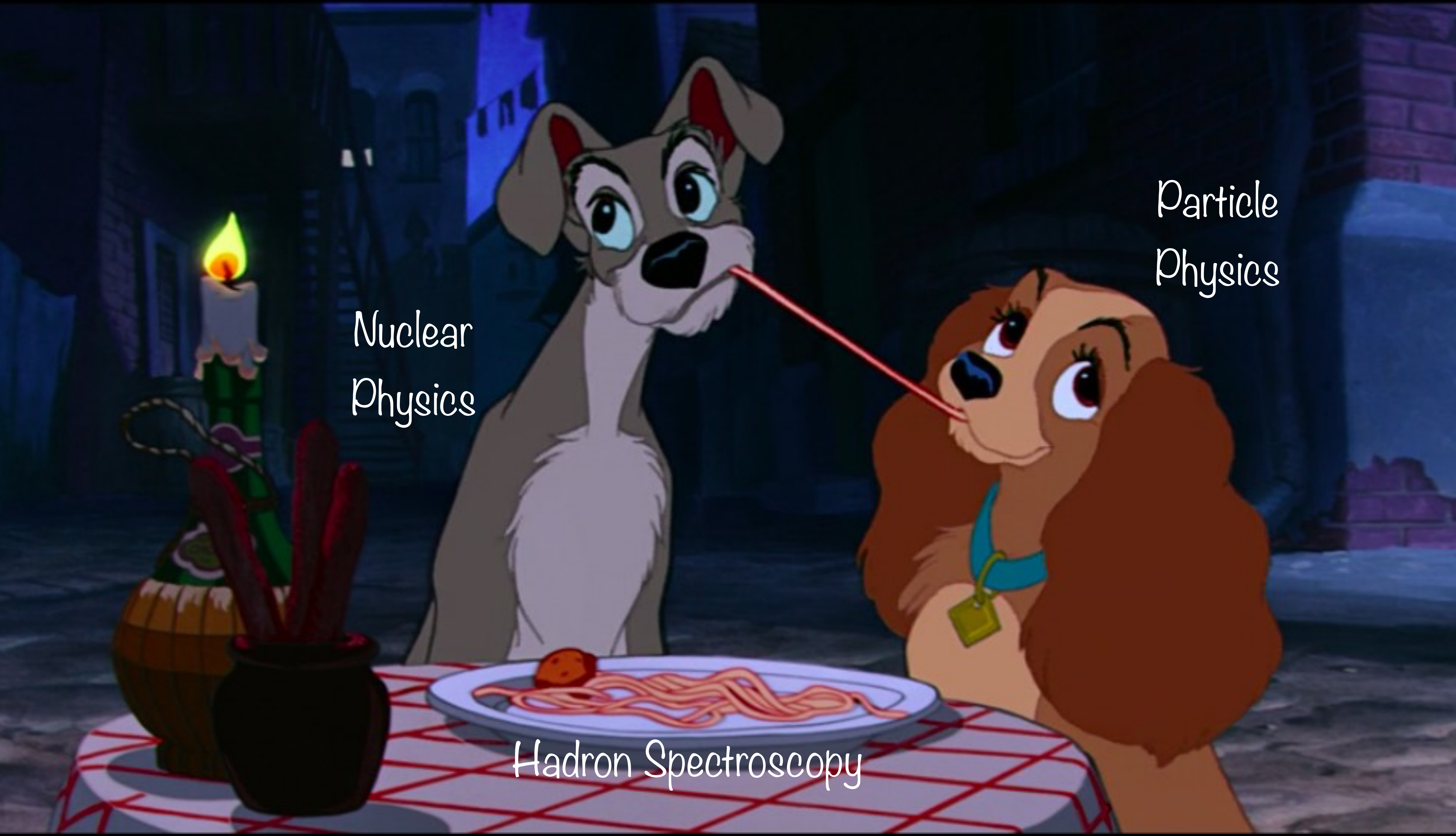
Lake Buena Visita, Florida
August 30 - September 4, 2022

Matthew Shepherd
Indiana University


Disney
BEAUTY
AND THE BEAST
Walt Disney

QCD
BEAUTY AND THE BEAST
$\mathcal{L}_{QCD}$




Particle
Physics
Nuclear
Physics
Hadron Spectroscopy

Hadron Spectroscopy and QCD

- Hypothesis: QCD generates unique features in the spectrum of hadrons
  - ... and in the properties of individual hadrons,
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A large community of participants

+ many others

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CIPANP 2022, Orlando
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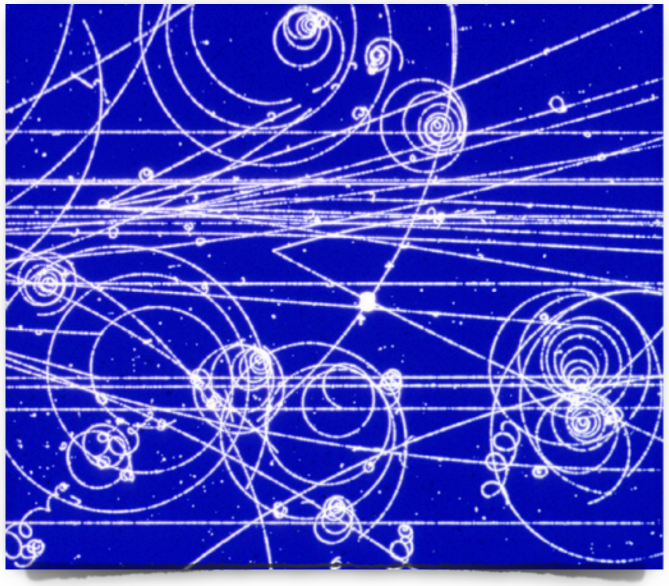

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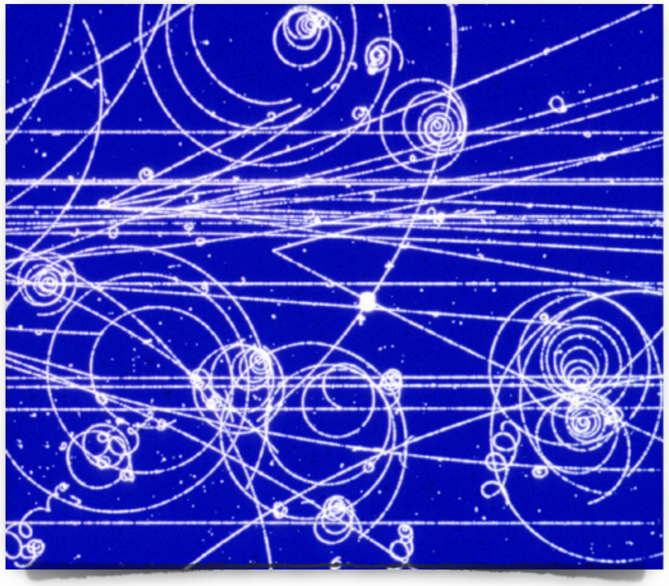

From the Hadron Spectrum to QCD and Back

The Quark Model

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**.

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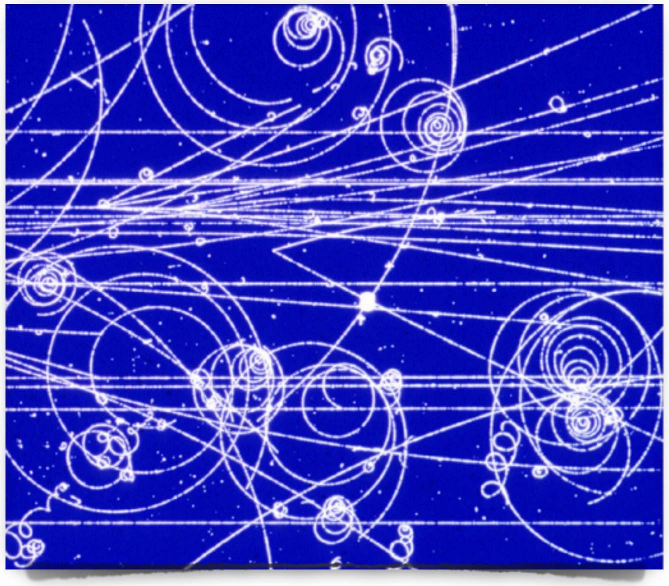

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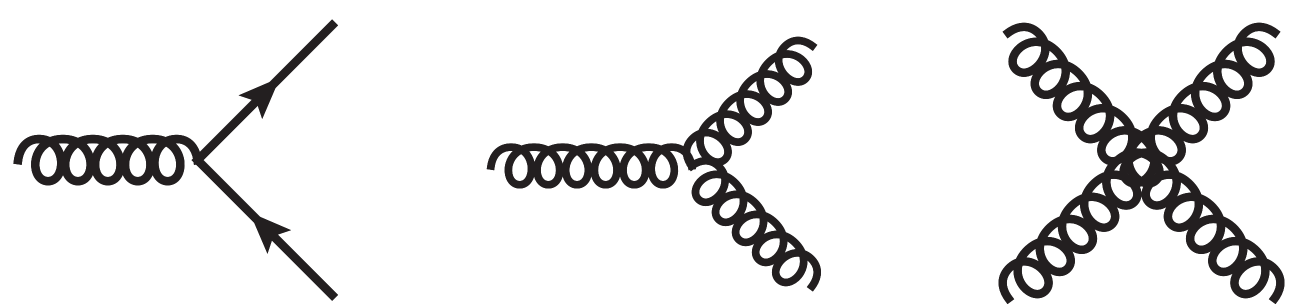
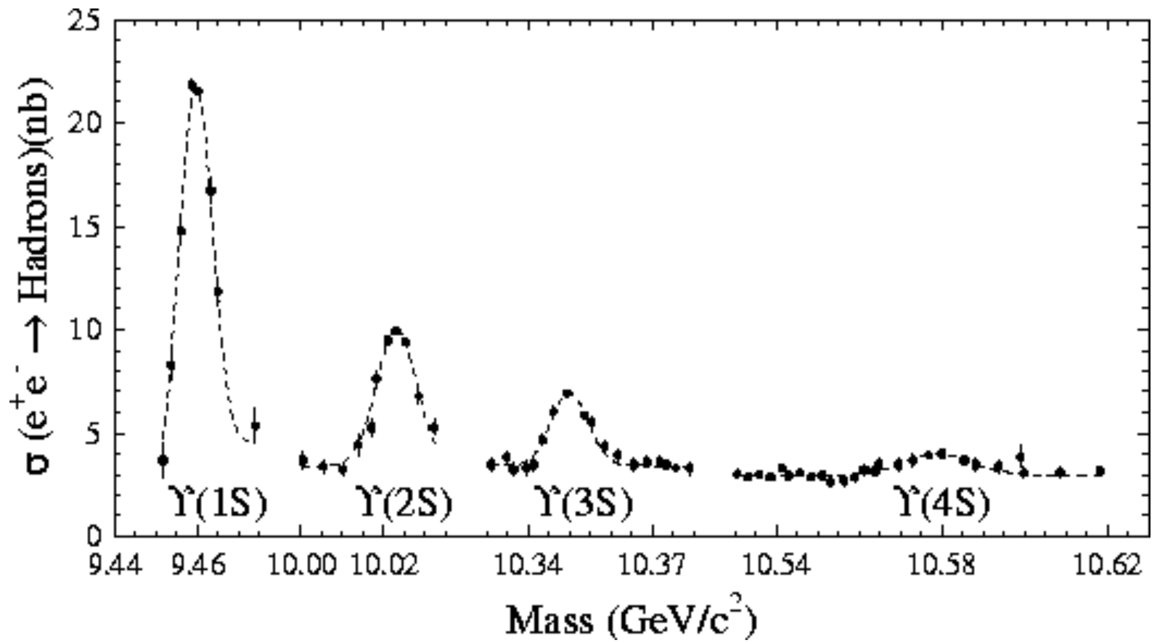
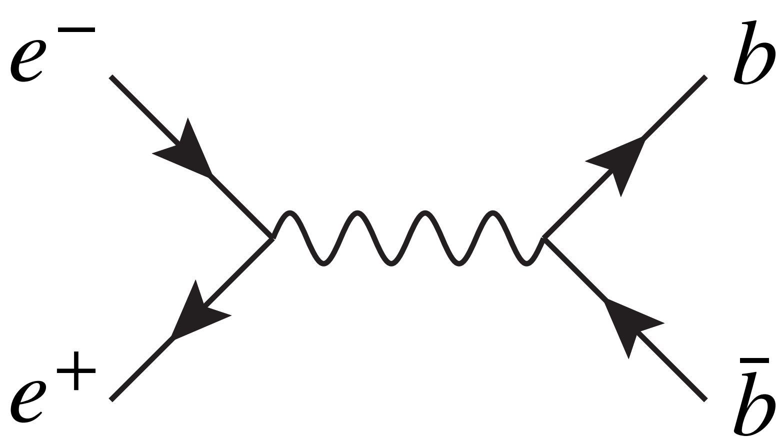
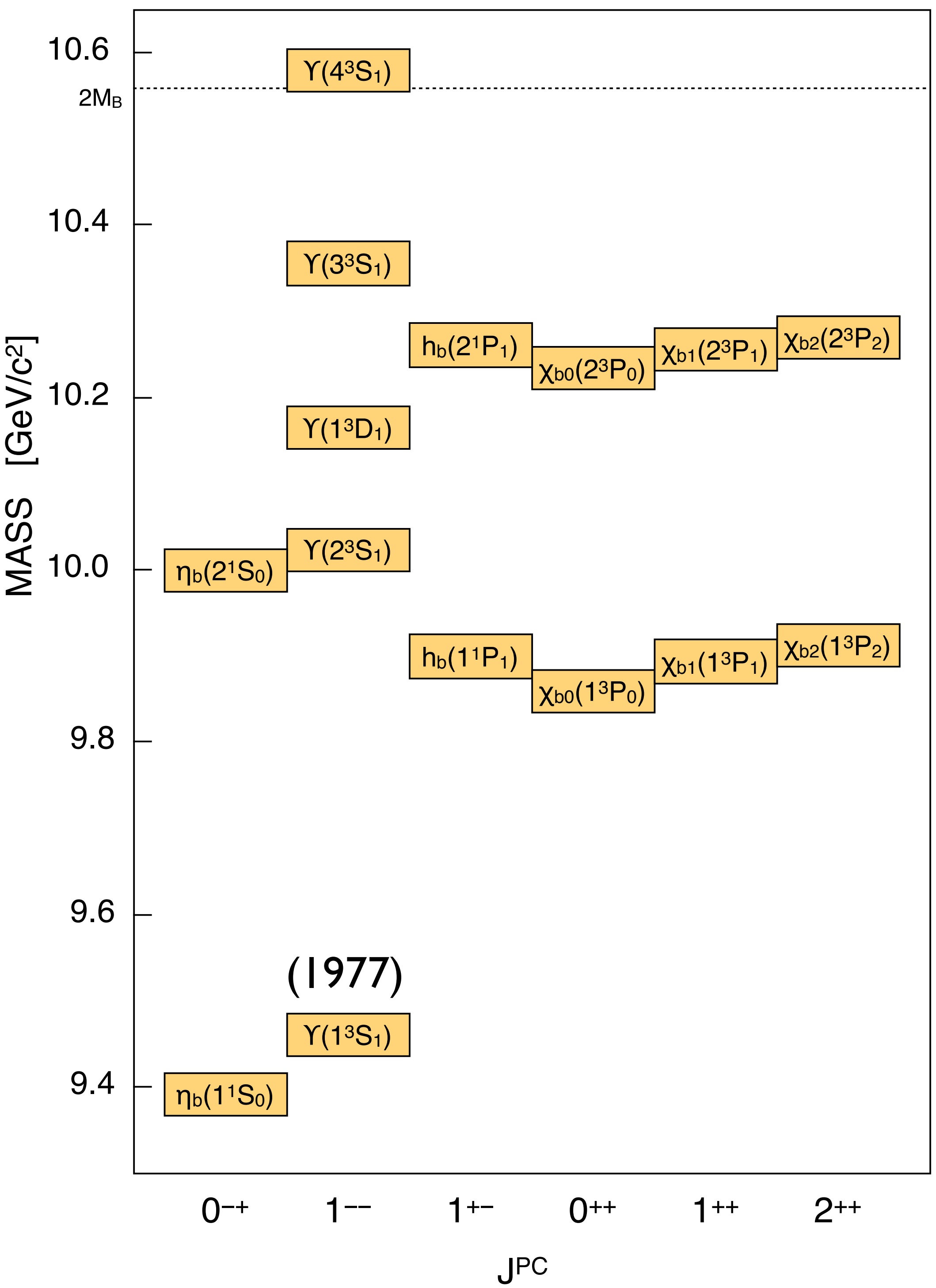


The $b\bar{b}$ system







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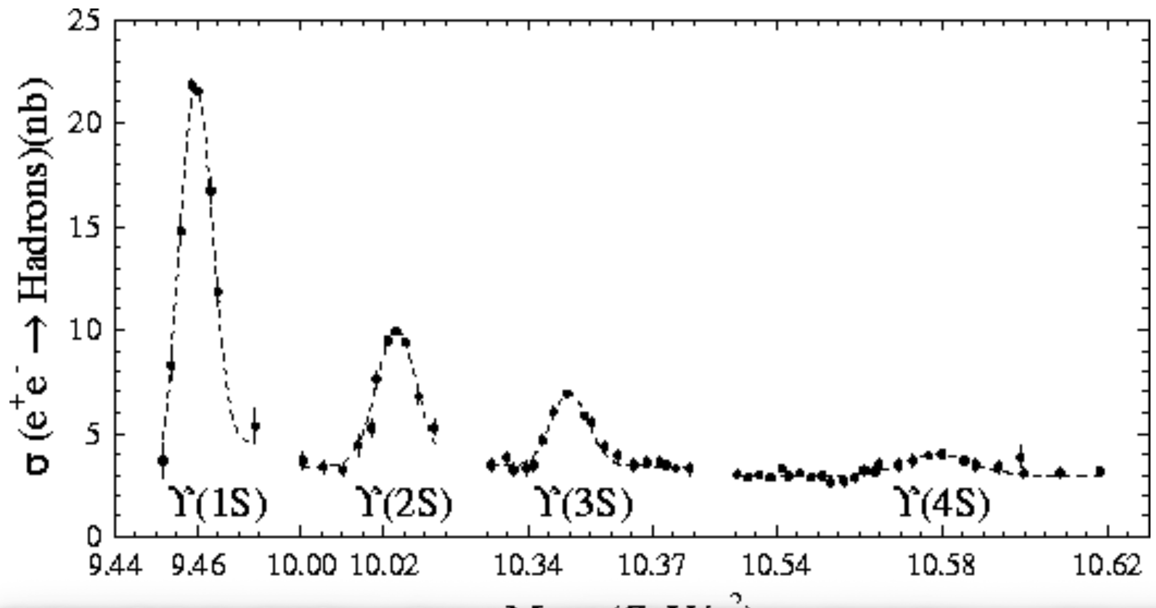
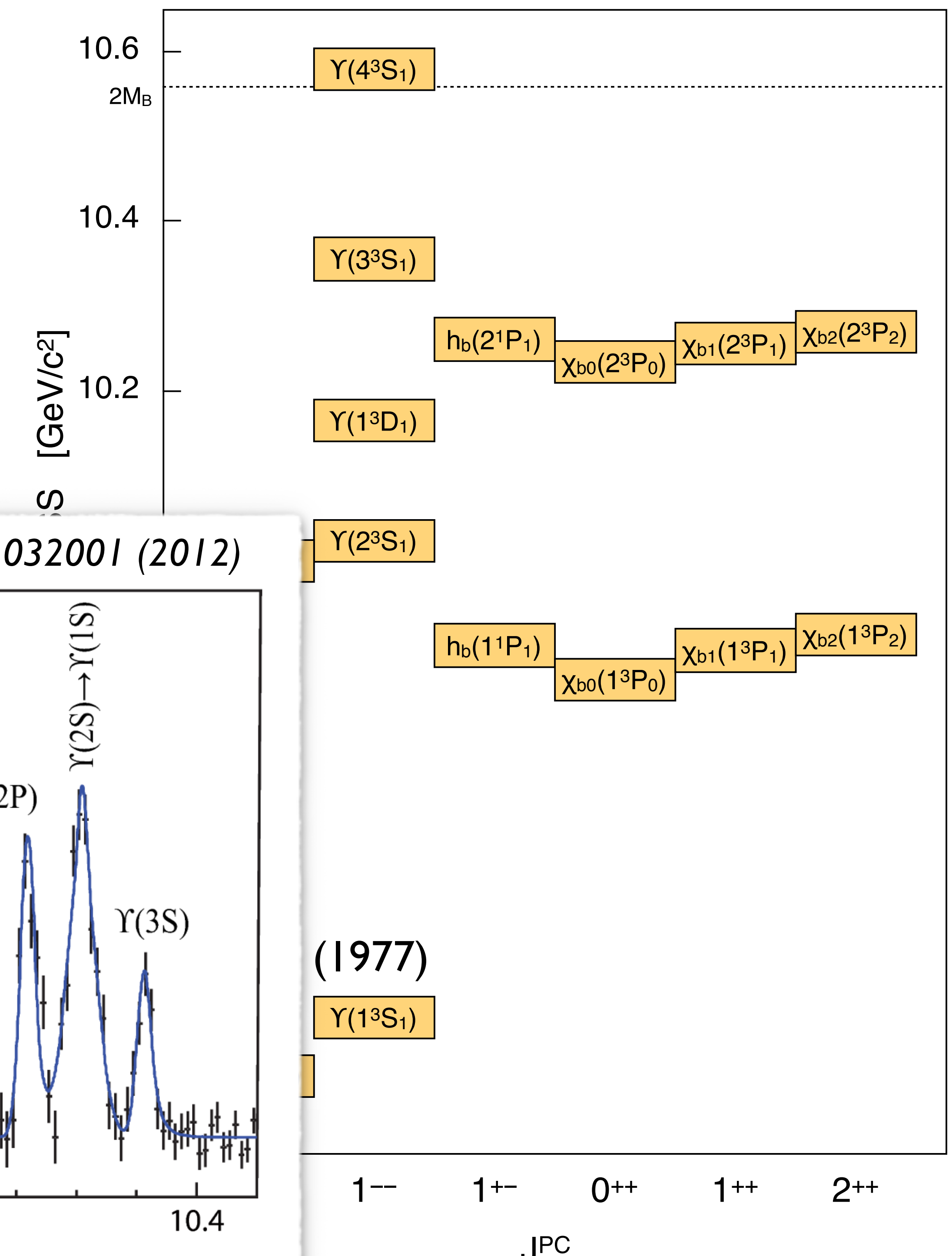
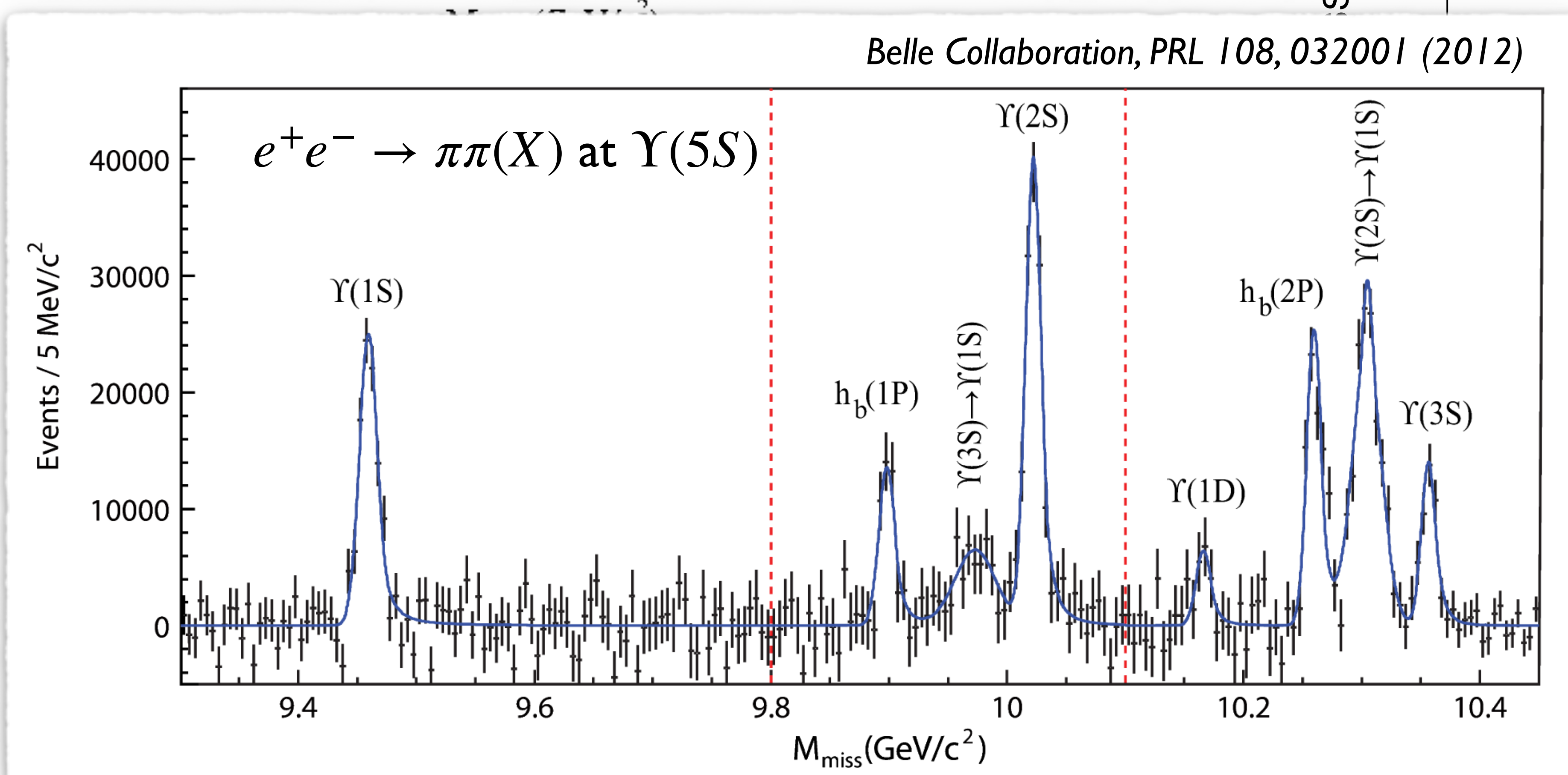
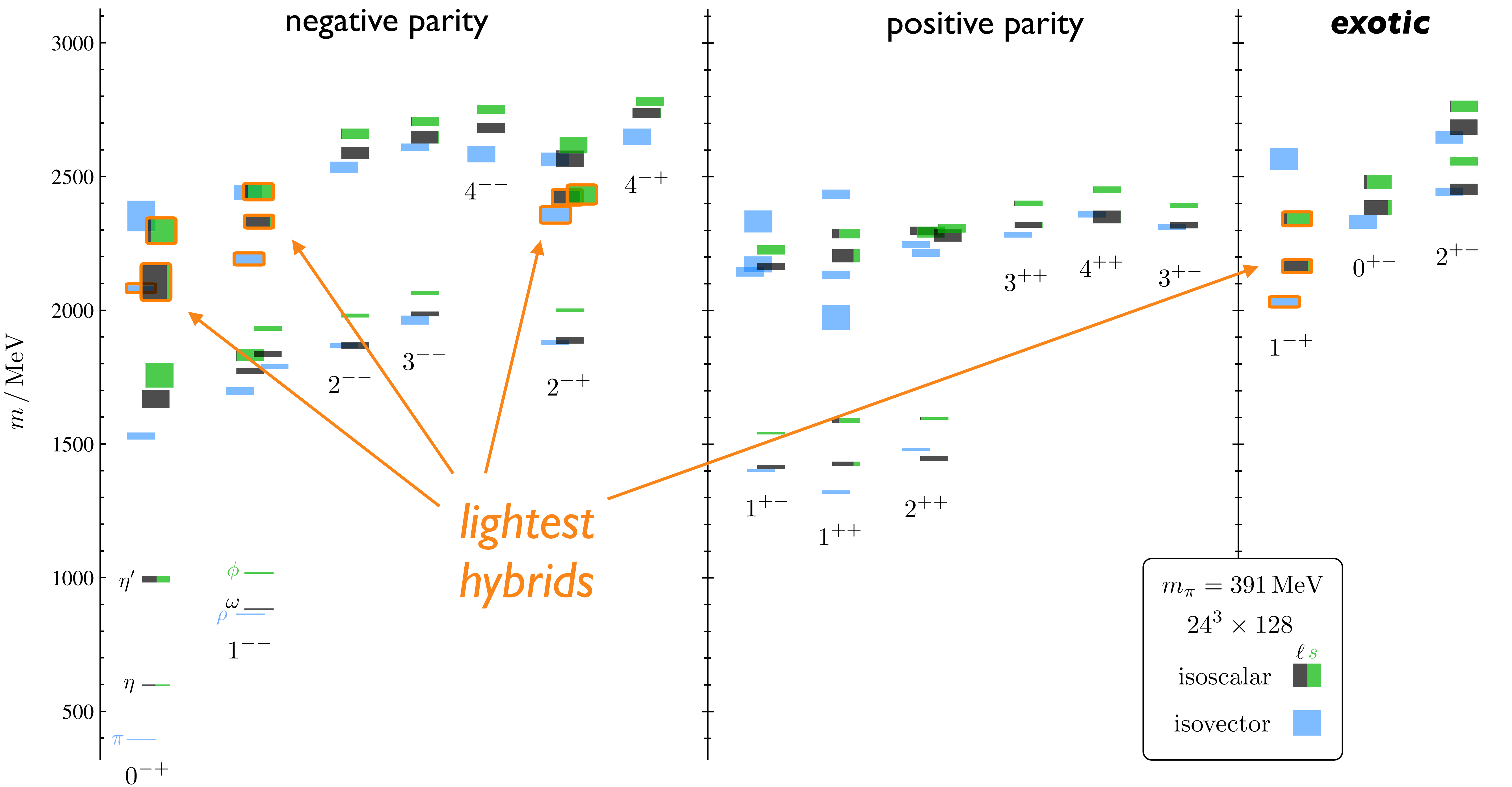






Light Quark Mesons from Lattice QCD

Dudek, Edwards, Guo, and Thomas, PRD 88, 094505 (2013)



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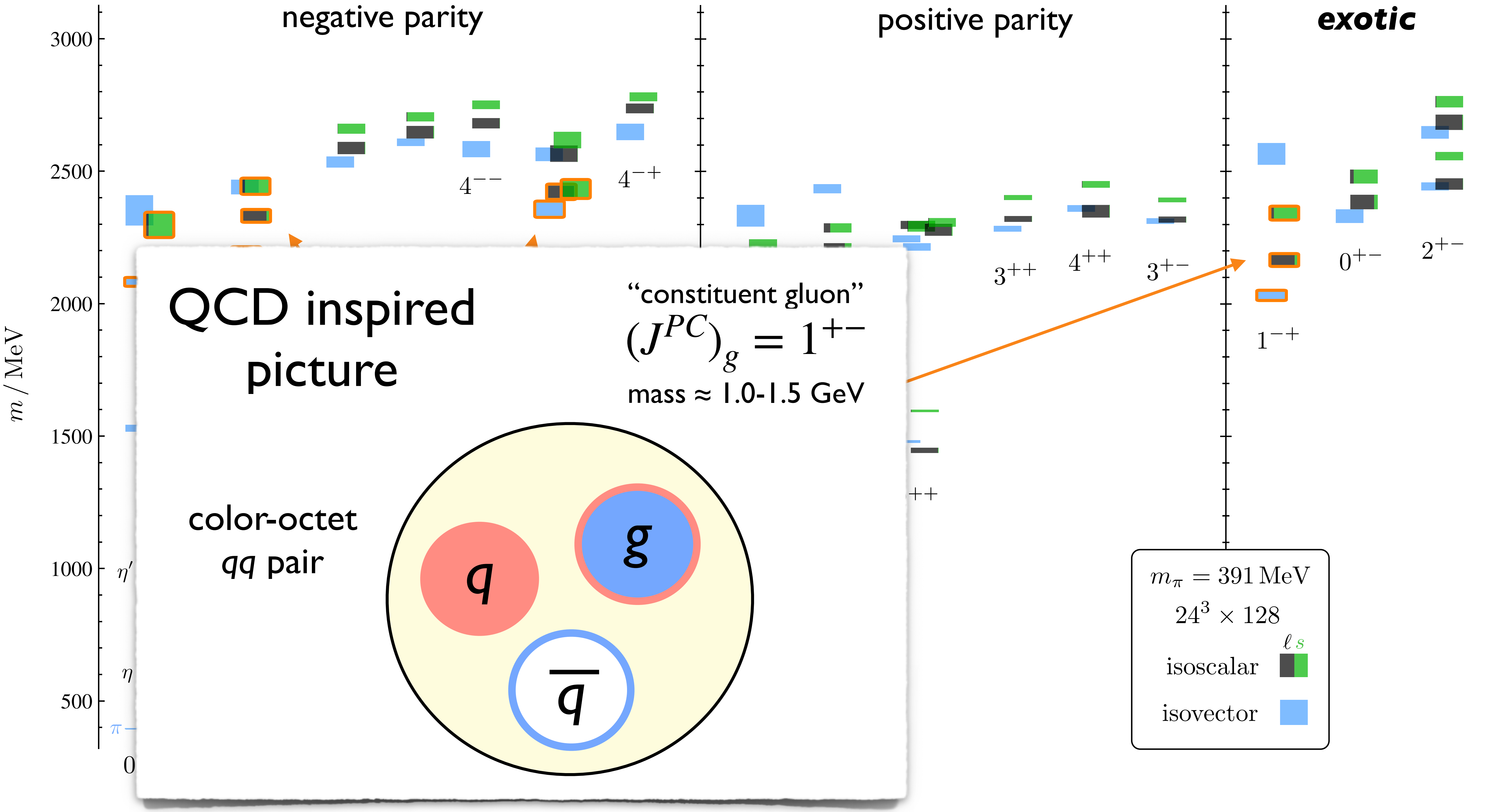

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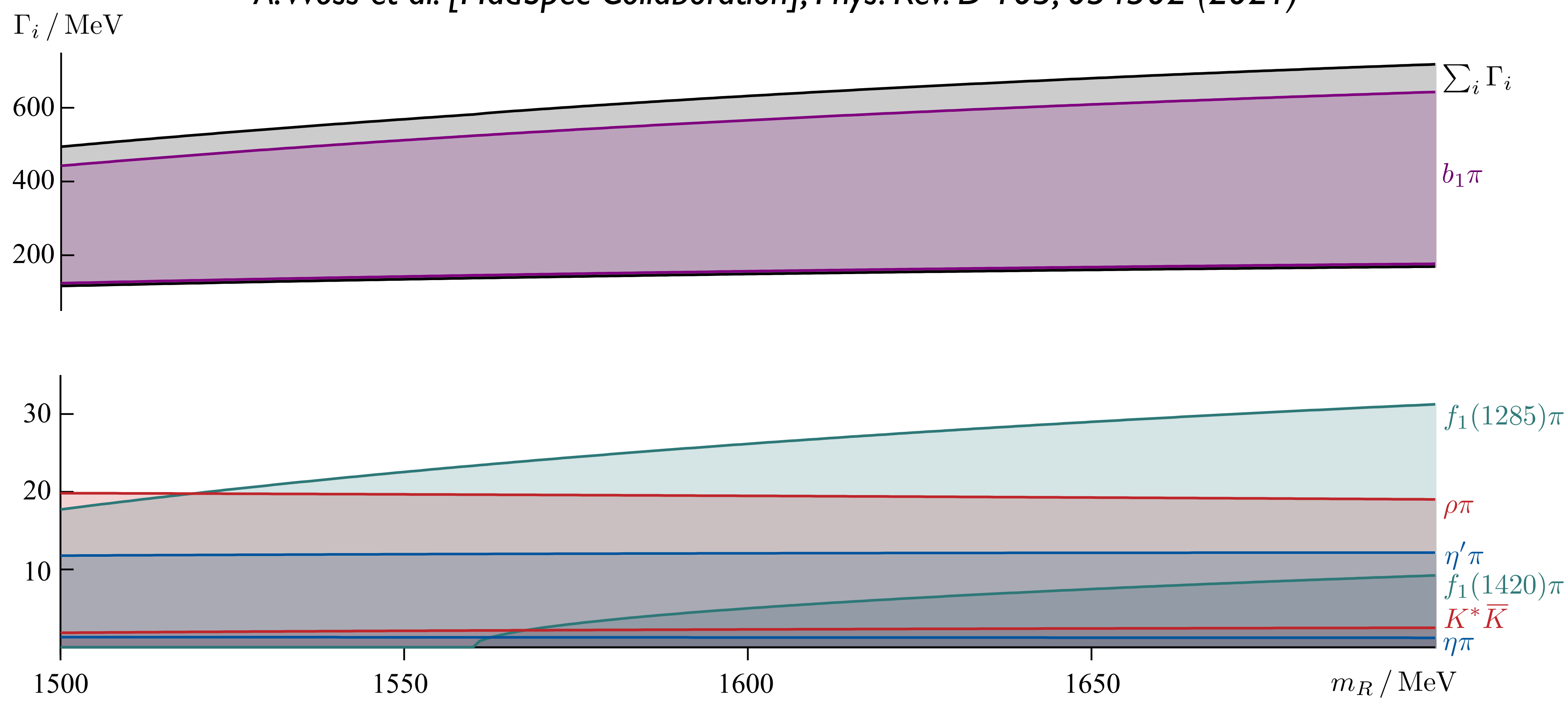
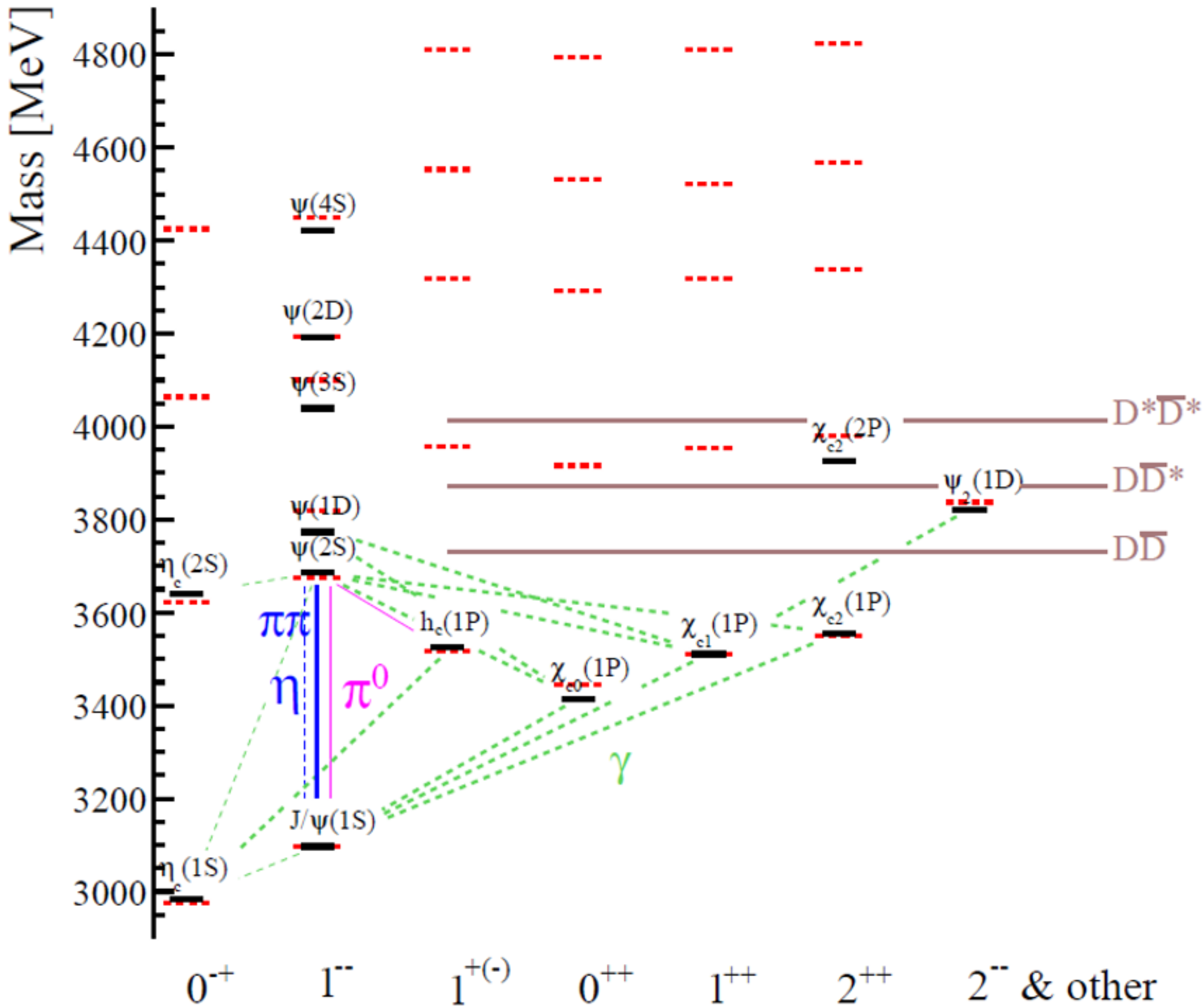
State of the art: partial widths of exotic hybrid resonances

Exotic π_1 couplings from lattice QCD

A. Woss et al. [HadSpec Collaboration], Phys. Rev. D 103, 054502 (2021)



A new zoo of $c\bar{c}$ hadrons



credit: Tomasz Skwarnicki

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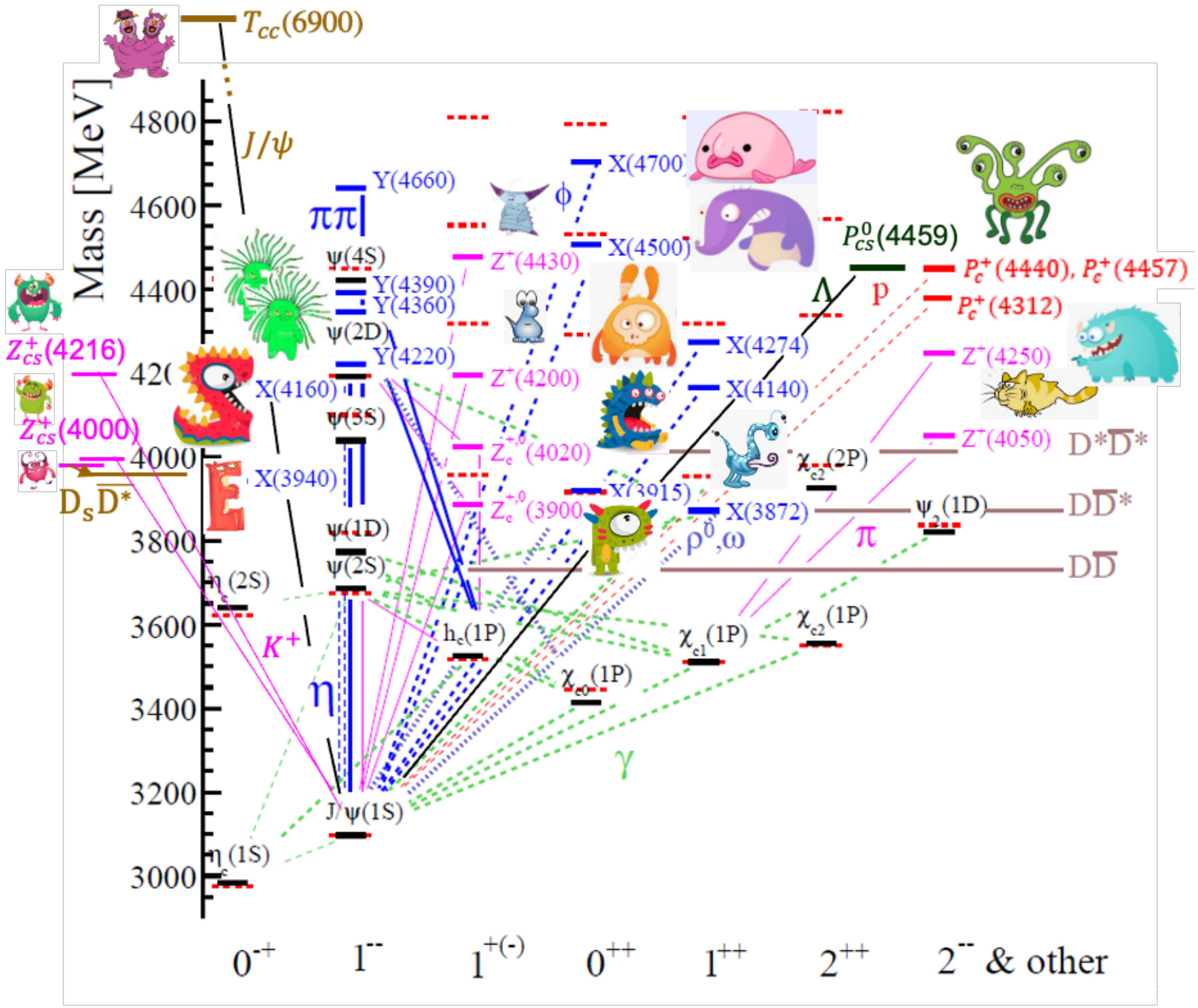

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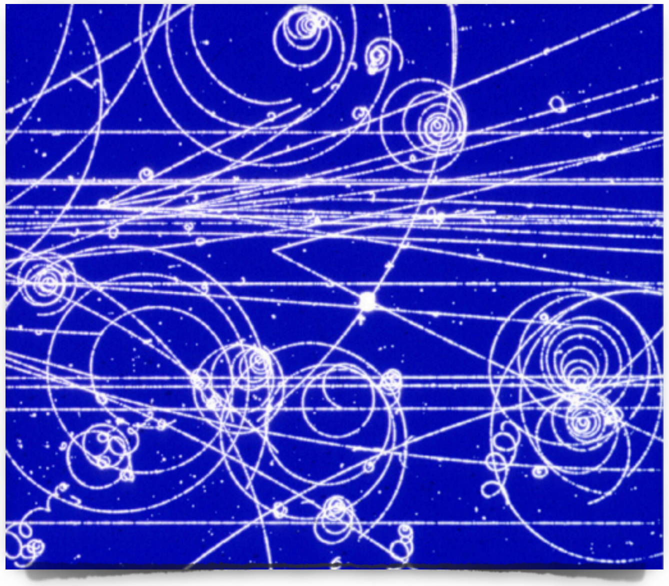

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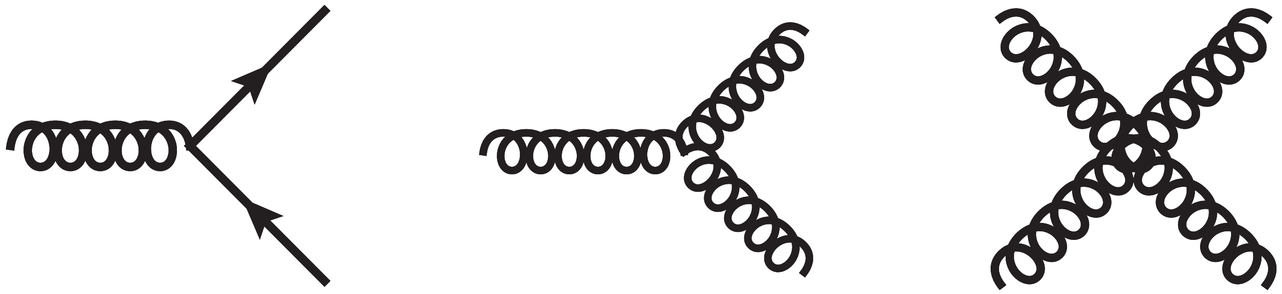

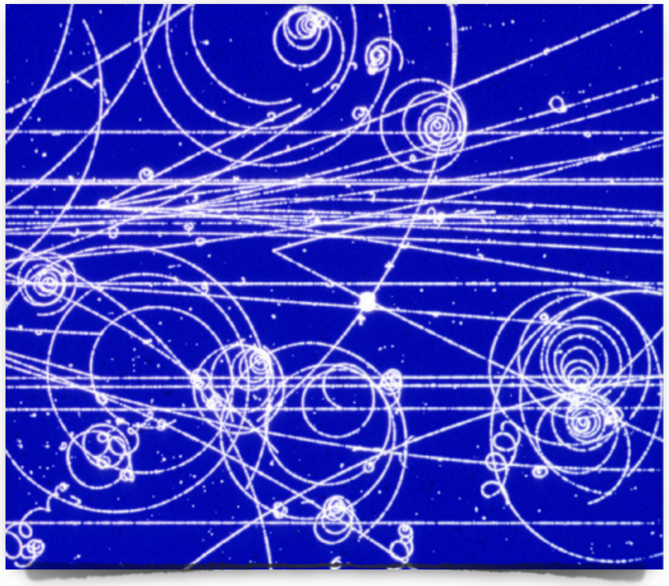

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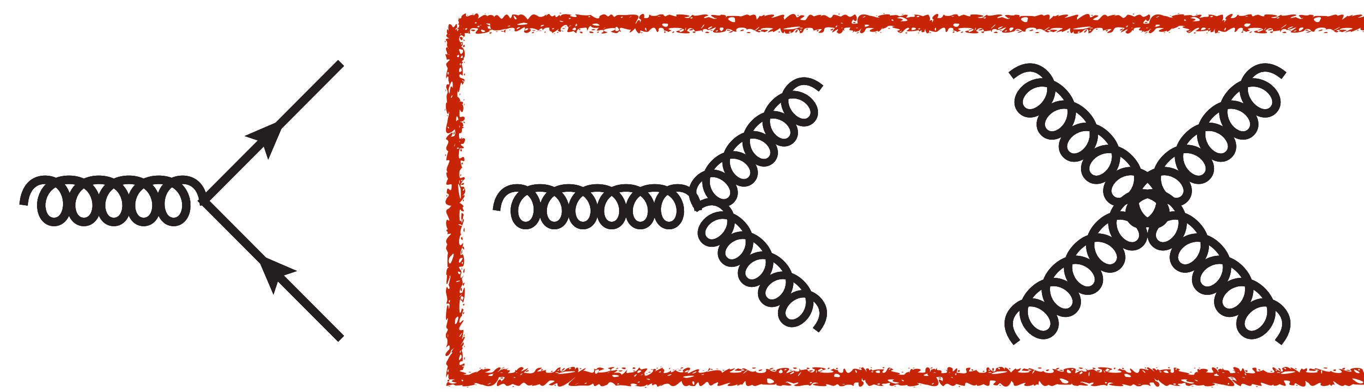
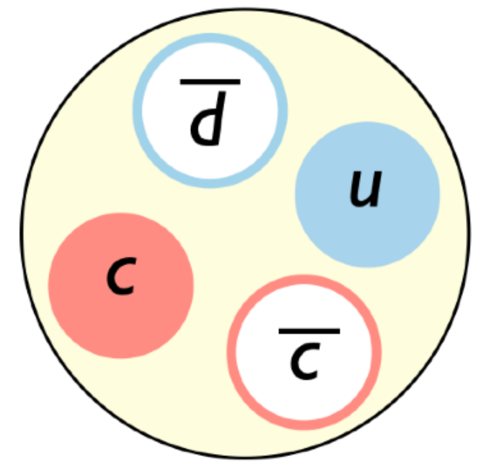
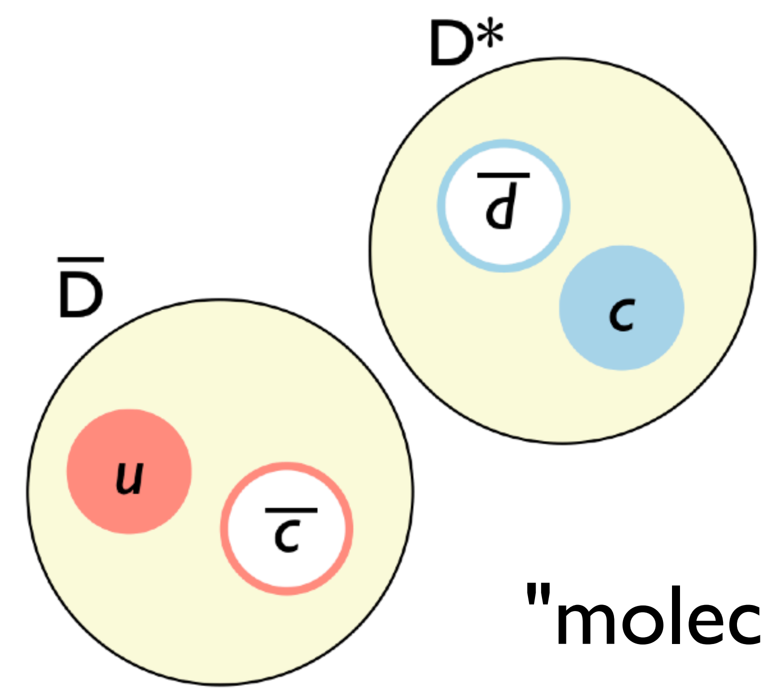


Observations beyond simple charmonium ($c\bar{c}$)

- Overpopulation of the spectrum
- Heavy mesons with net charge
- Mesons with unusual decay products
  - two charm quarks
  - two charm quarks and two anti-charm quarks
- Underlying structure and full spectrum?



"tetraquark"

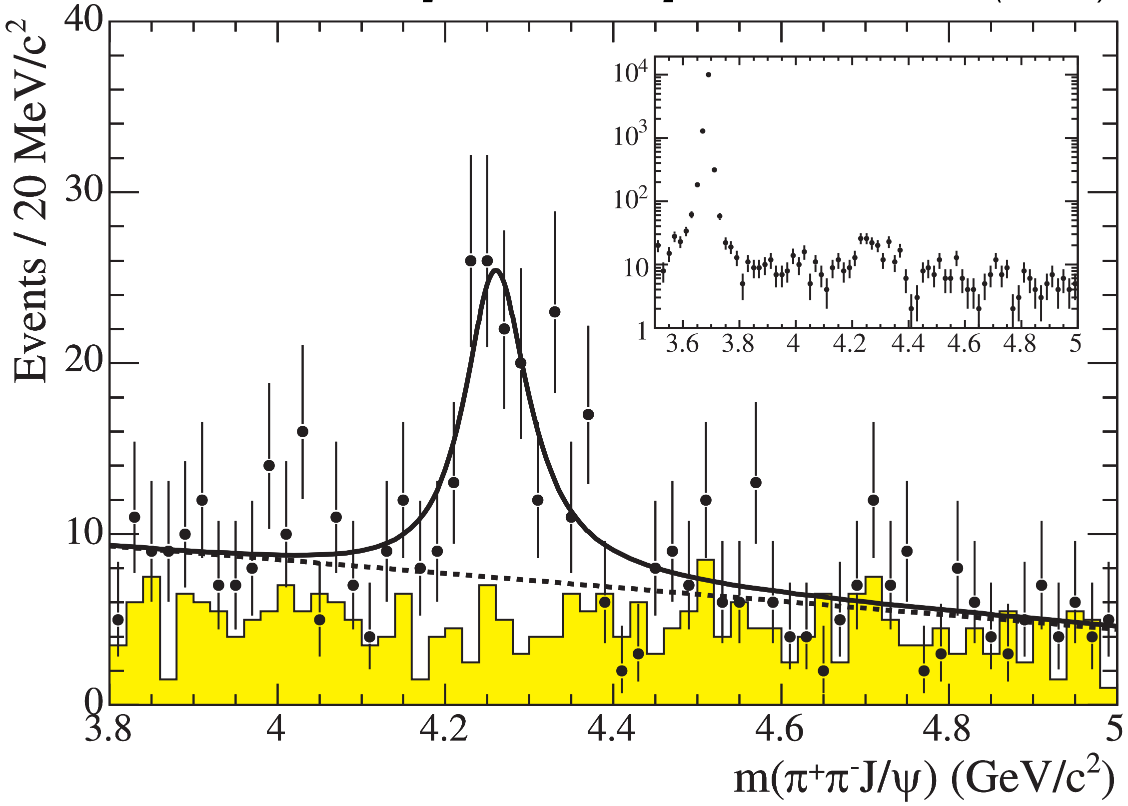


"molecule"

...or some other explanation

Overpopulation of Quark Model Charmonium

B. Aubert [BaBar Collab.], PRL 95, 142001 (2005)



"$Y(4260)$" in
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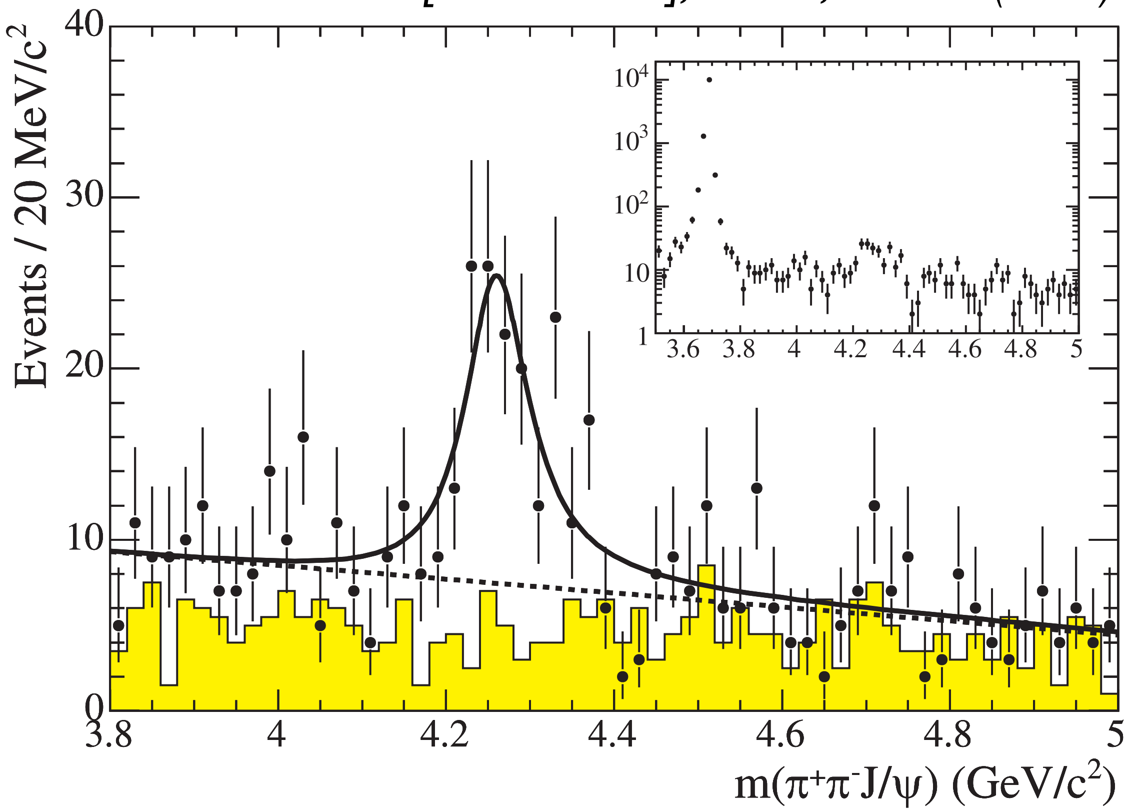

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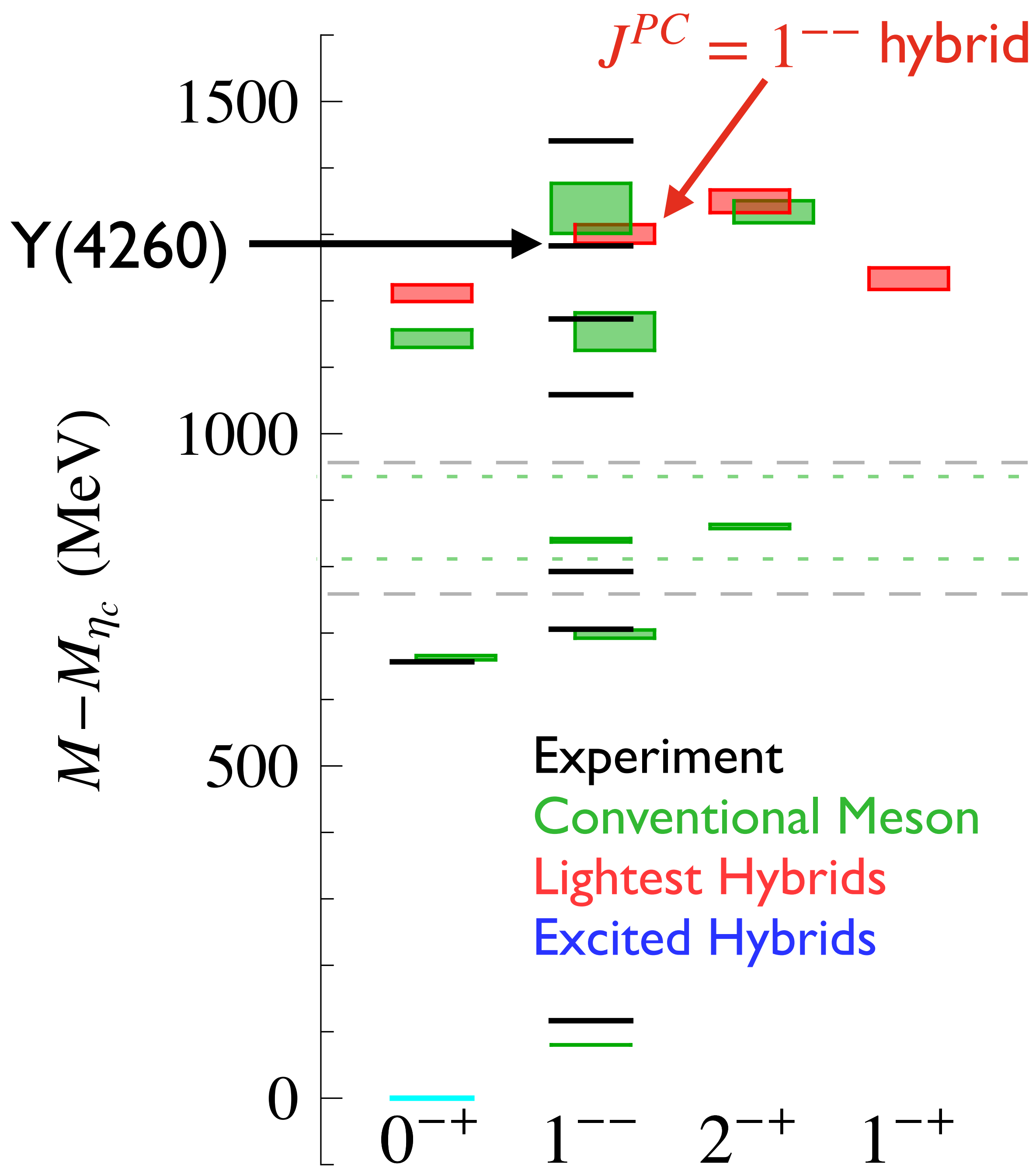
L. Liu et al. [Hadron Spectrum Collab.], JHEP07 126 (2012)



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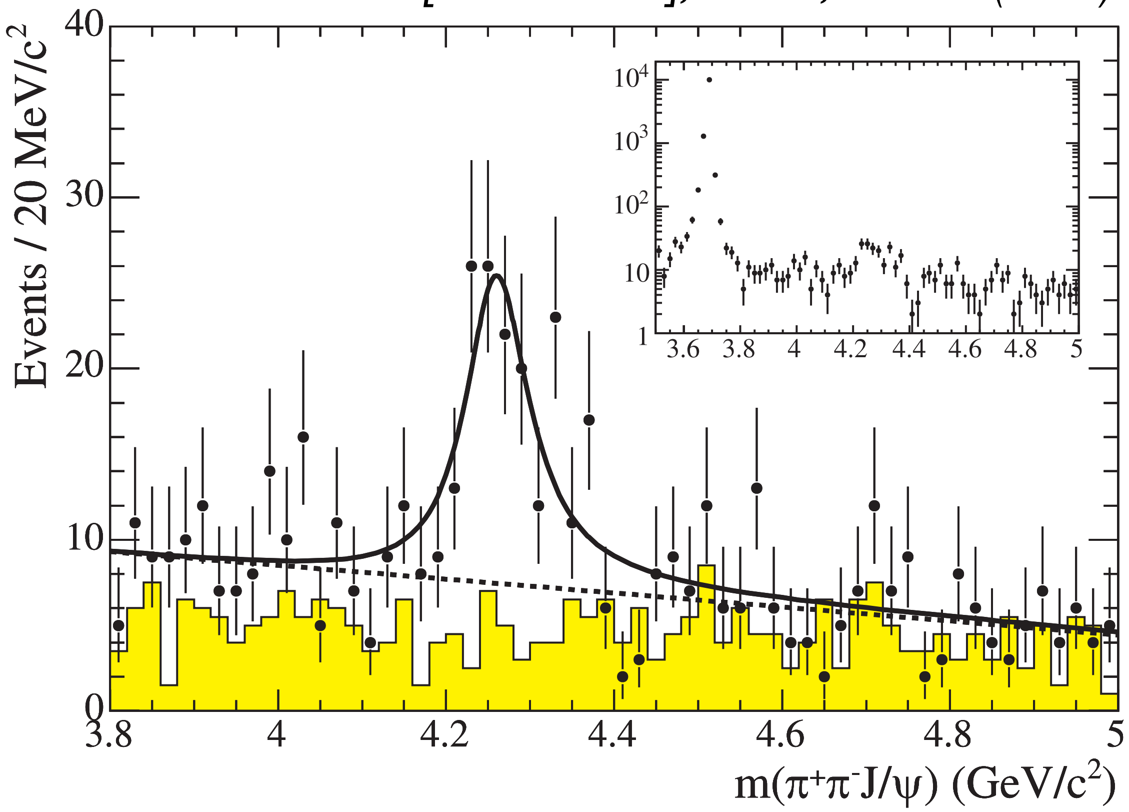

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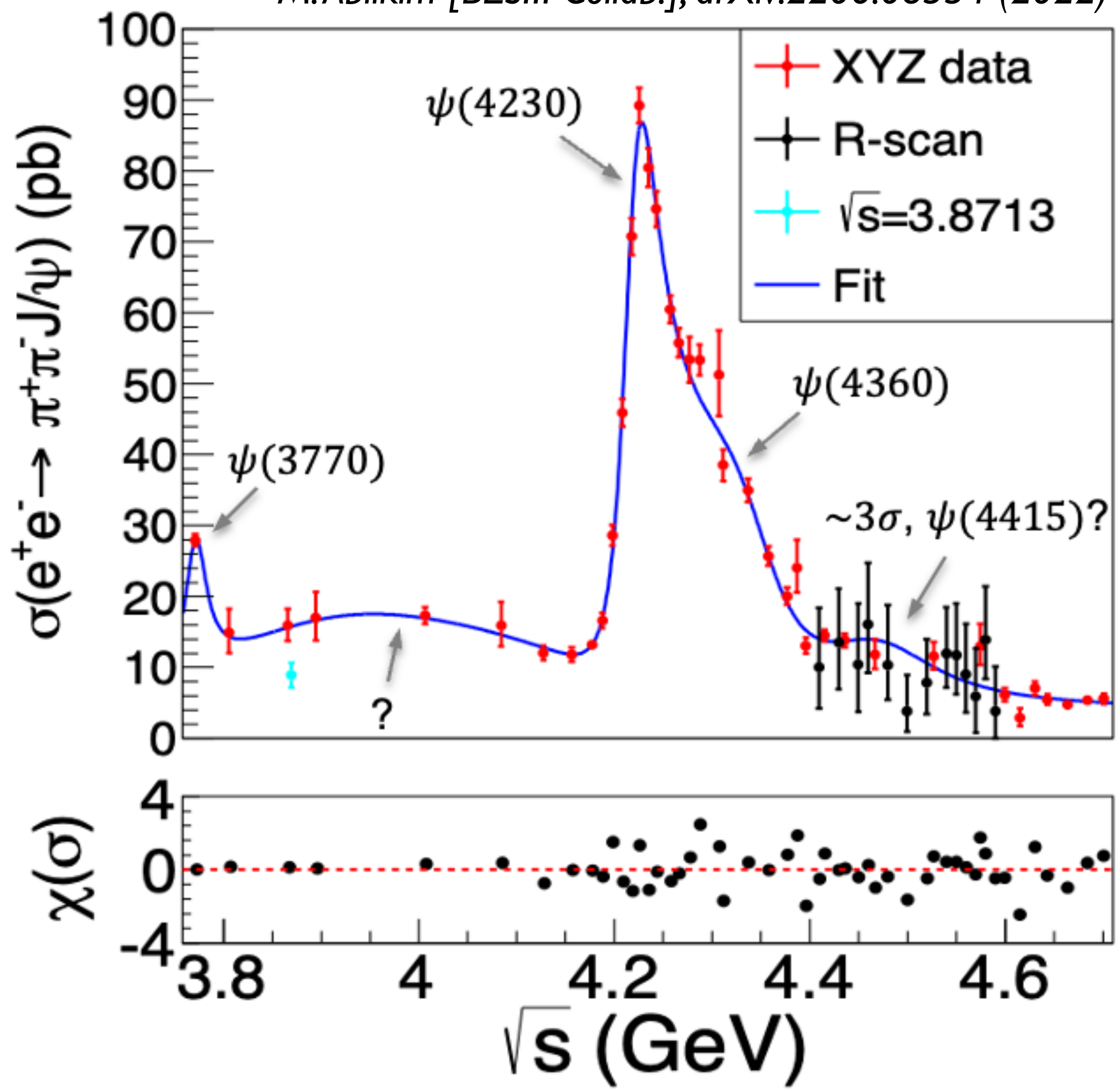
M. Ablikim [BESIII Collab.], arXiv:2206.08554 (2022)



(see Nils Hüsken's talk this afternoon)

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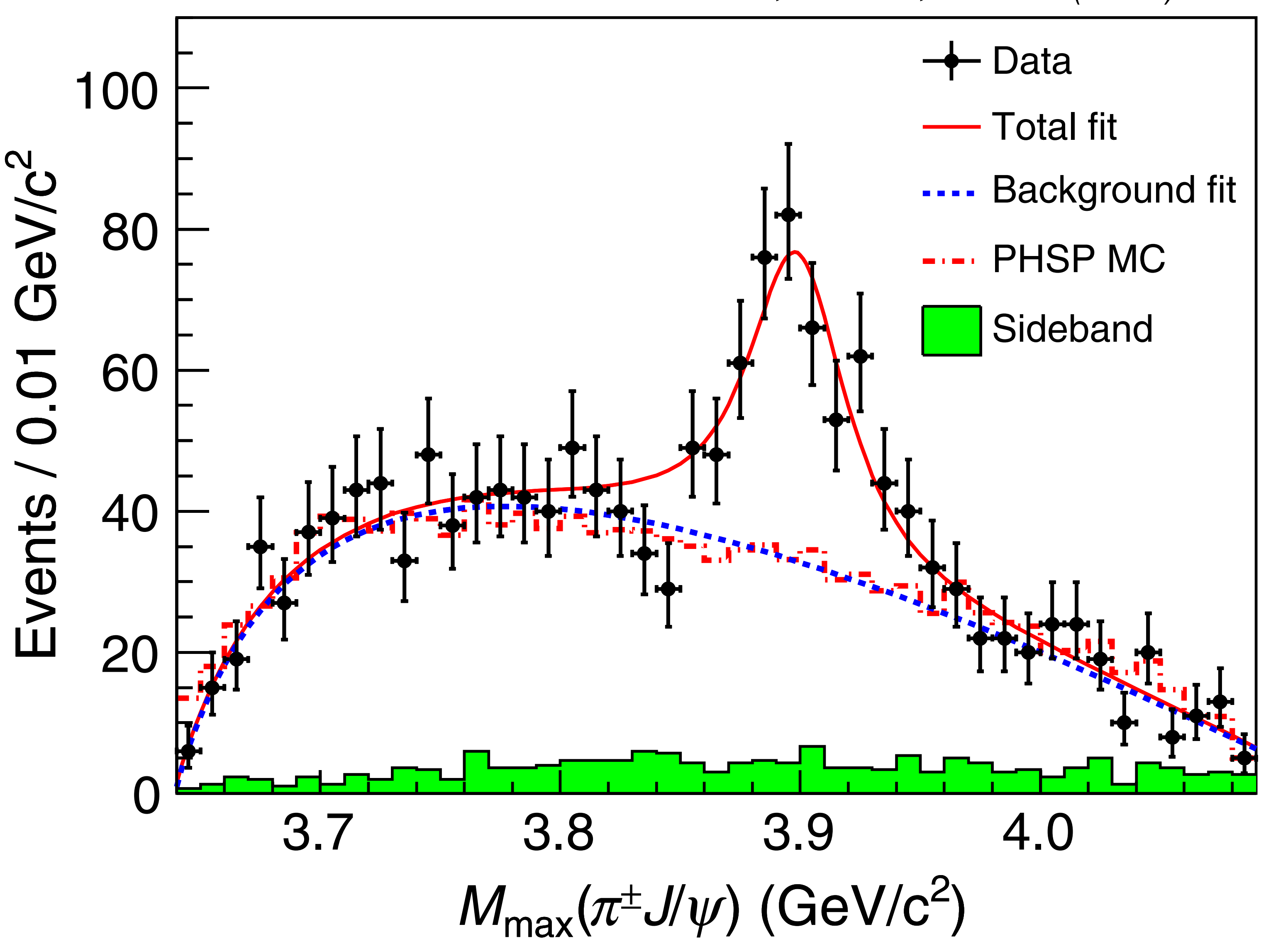
BESIII Collaboration, PRL 110, 252001 (2013)



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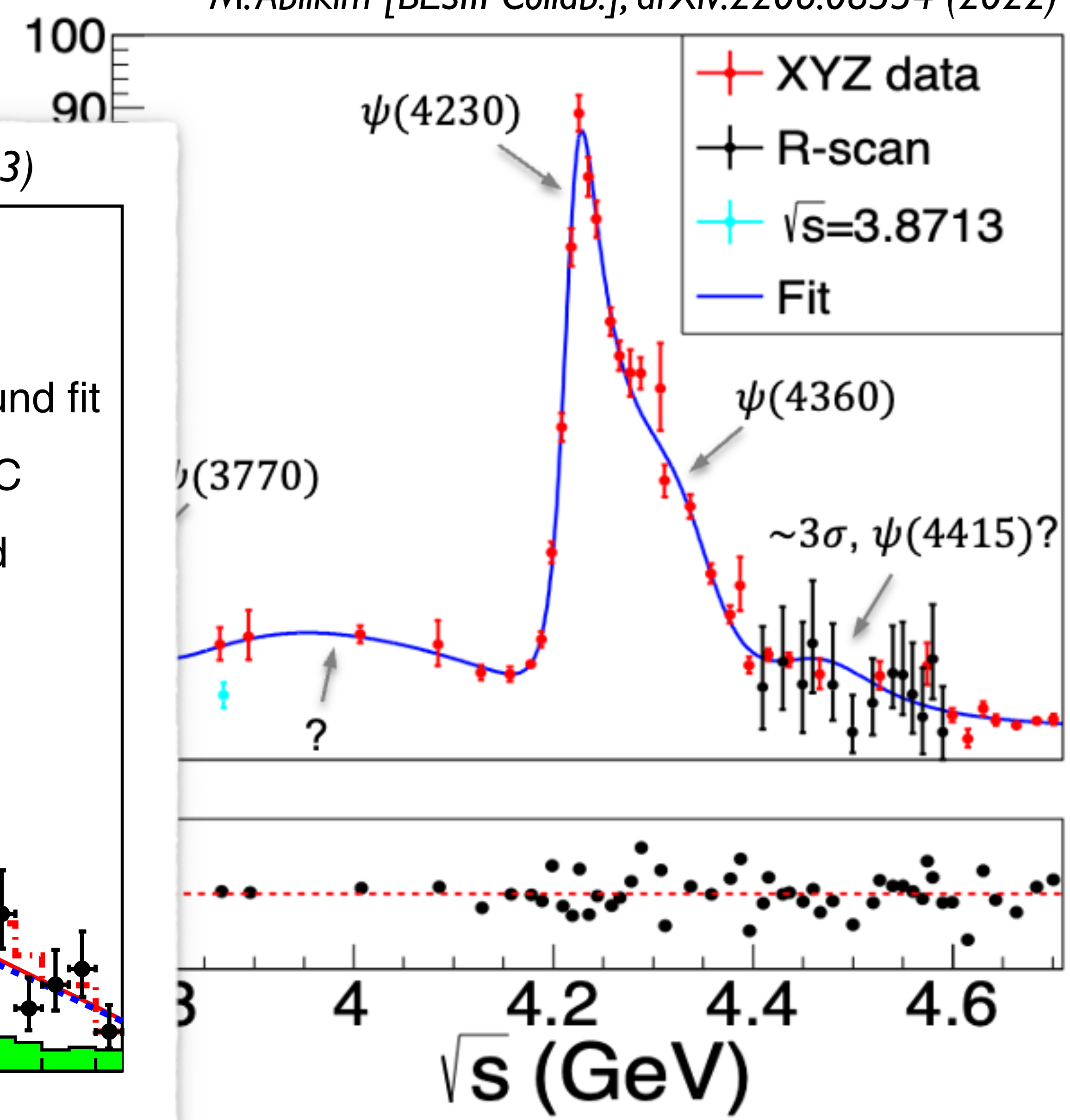

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Heavy Charged Tetraquark Candidates

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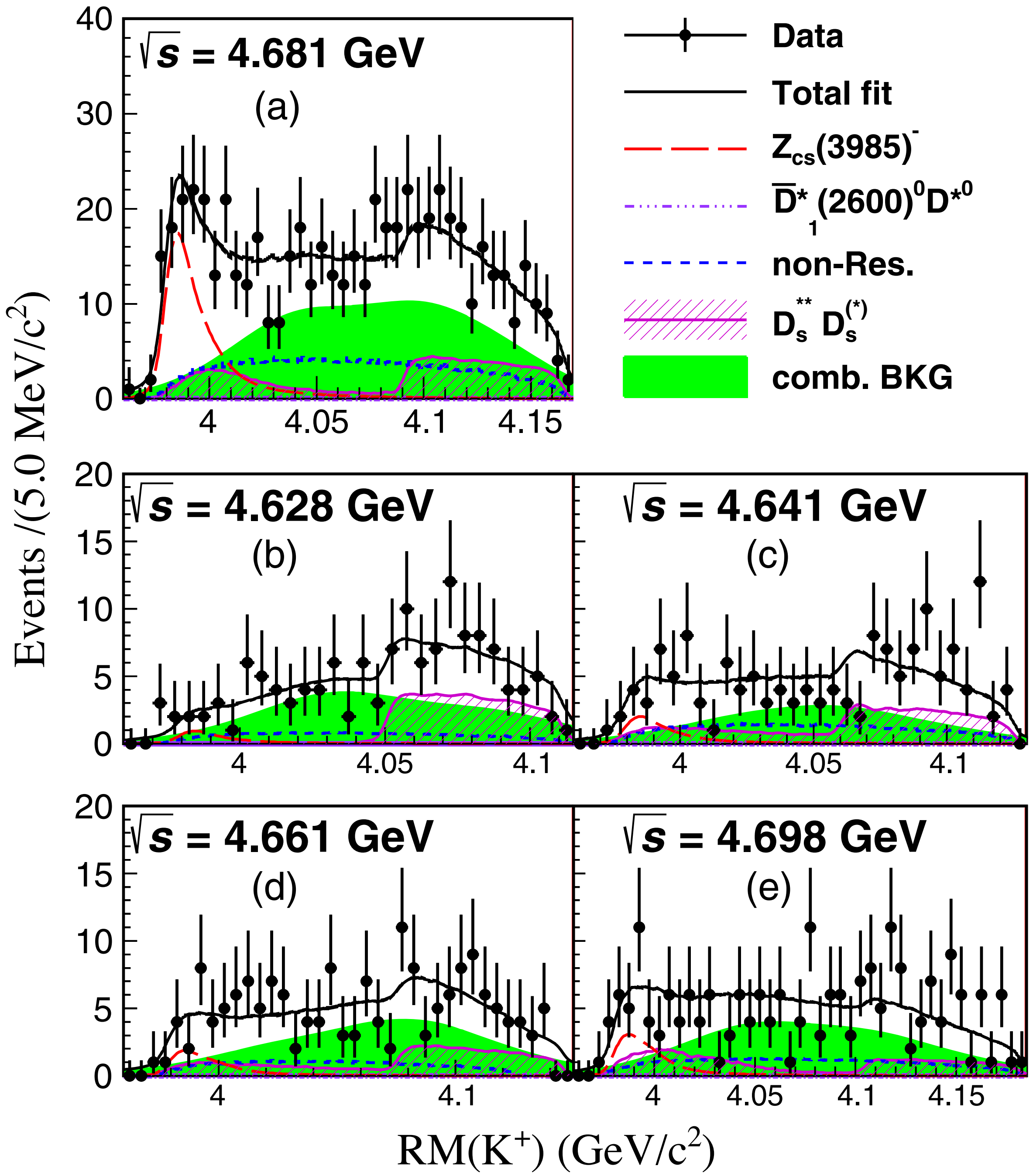
- Many years after discovery of charged Z_c states and analogous Z_b the picture becomes stranger with recent discovery of $Z_{cs} = c\bar{c}s\bar{q}$
  - $e^+e^- \to K^+Z_{cs}^-,\ Z_{cs} \to D_s^- + X$

M. Ablikim et al. [BESIII], PRL 126 (2021) 10, 102001



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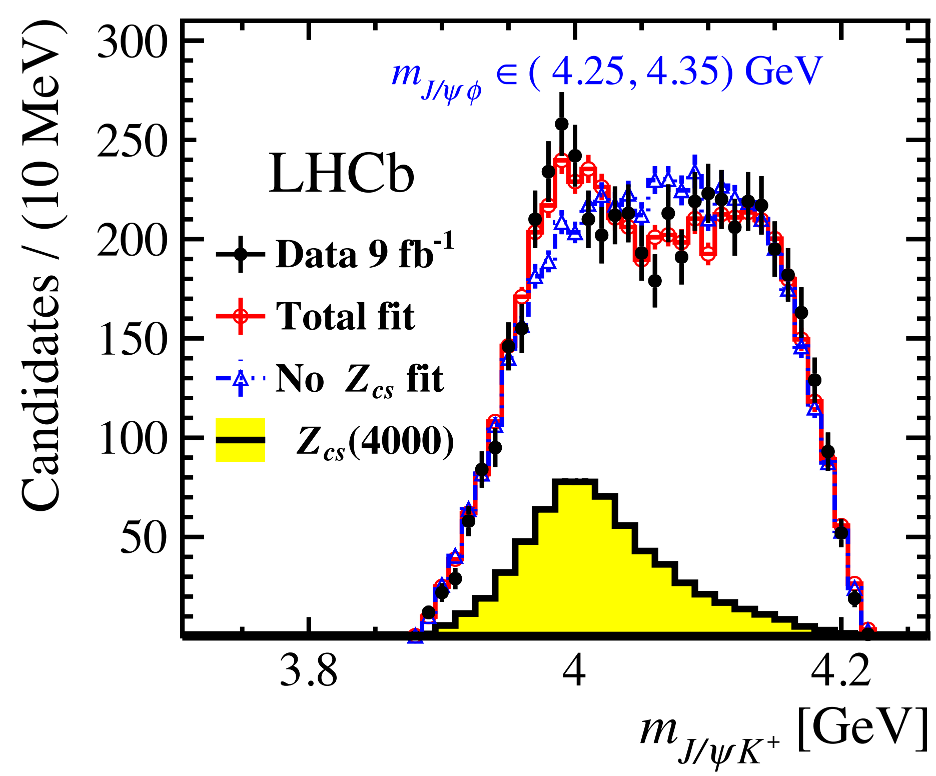
R. Aaij et al. [LHCb Collaboration], PRL 127, 082001 (2021)



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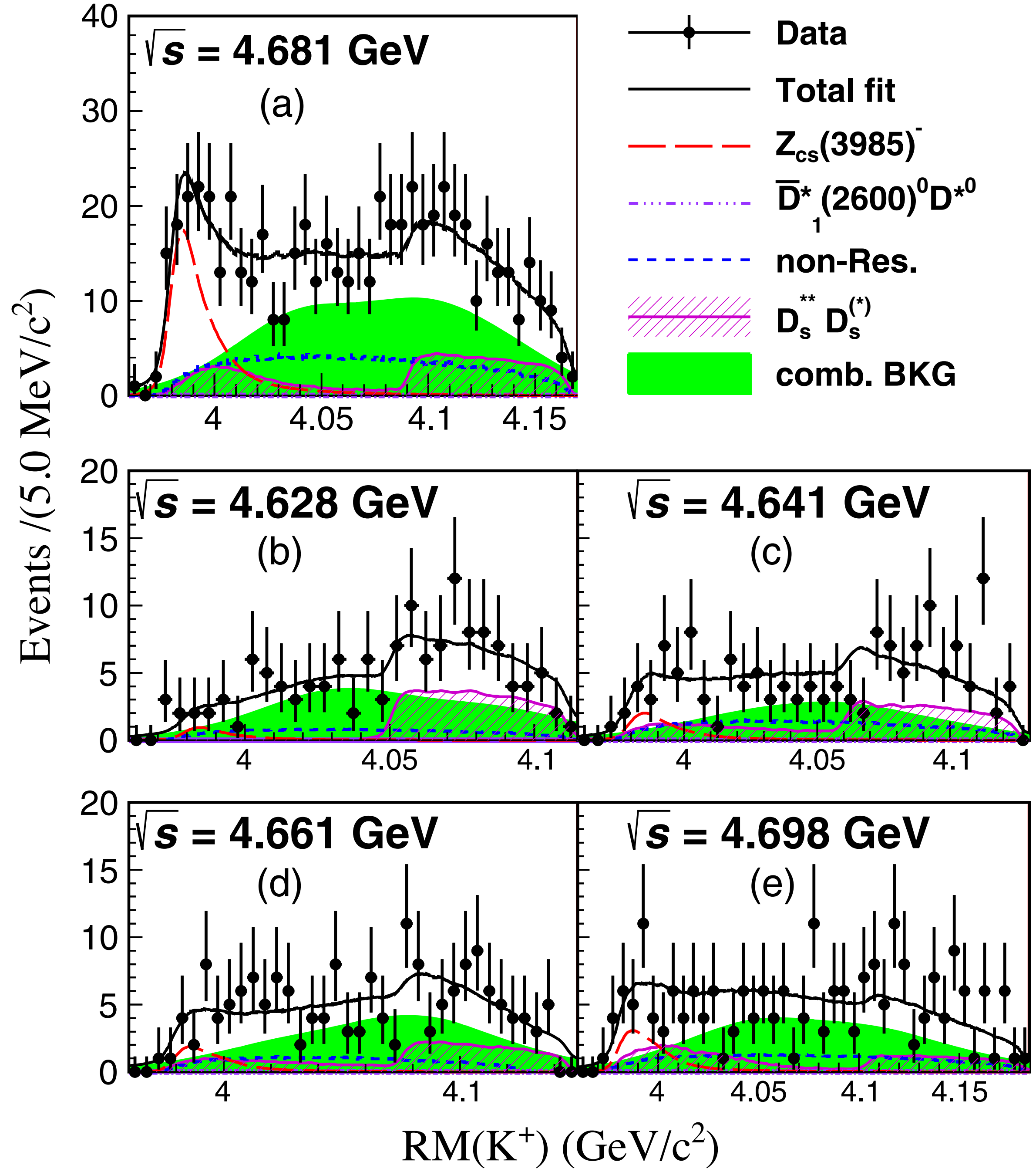

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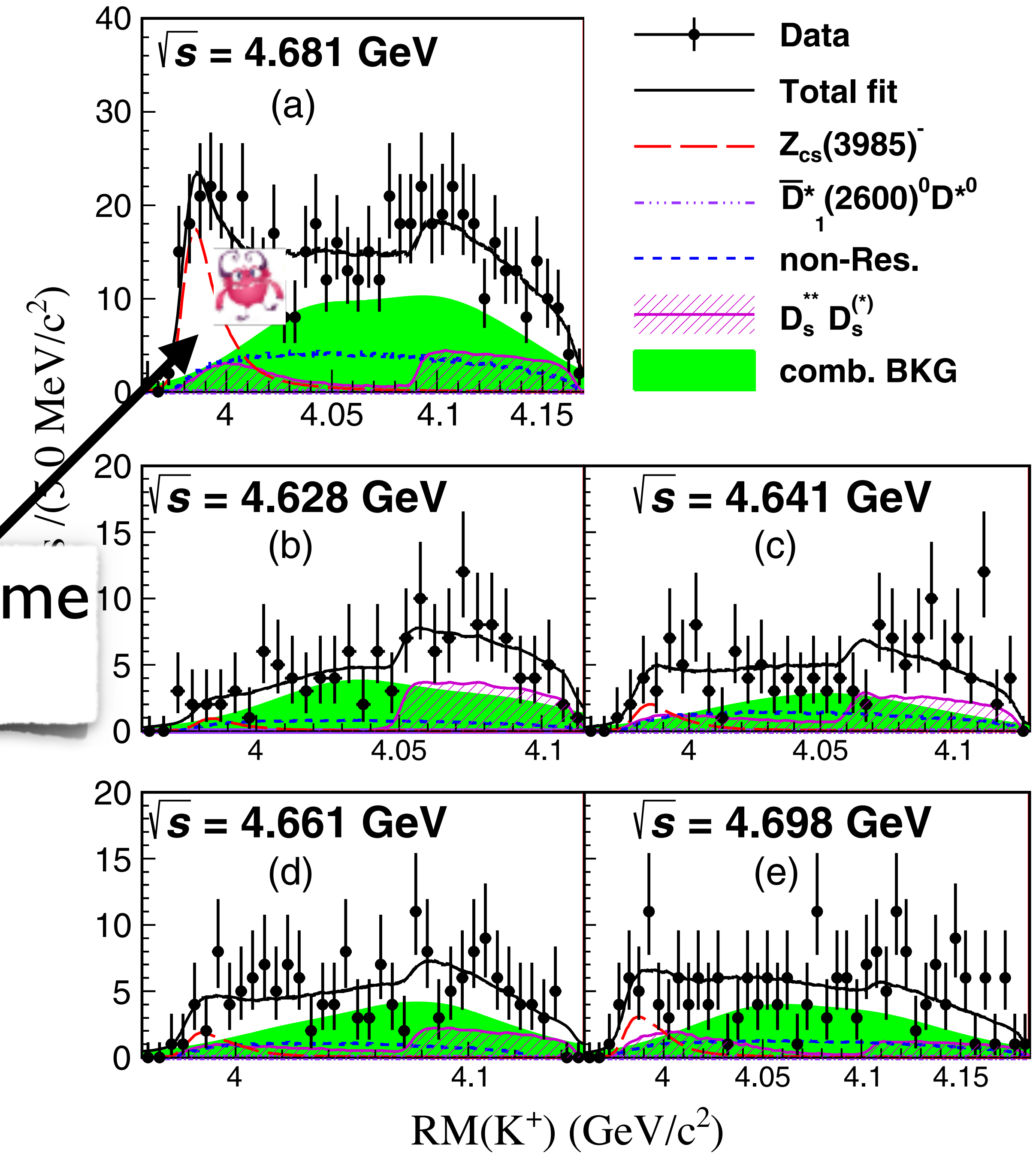

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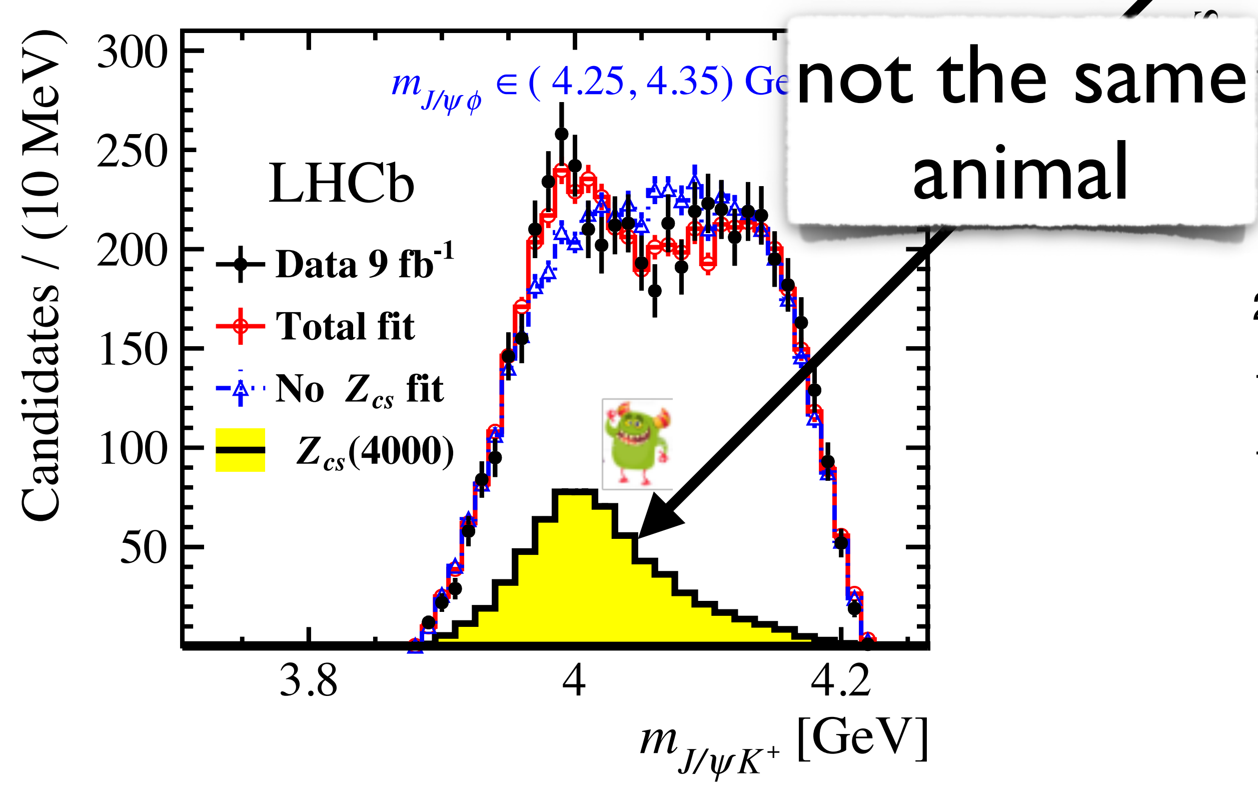


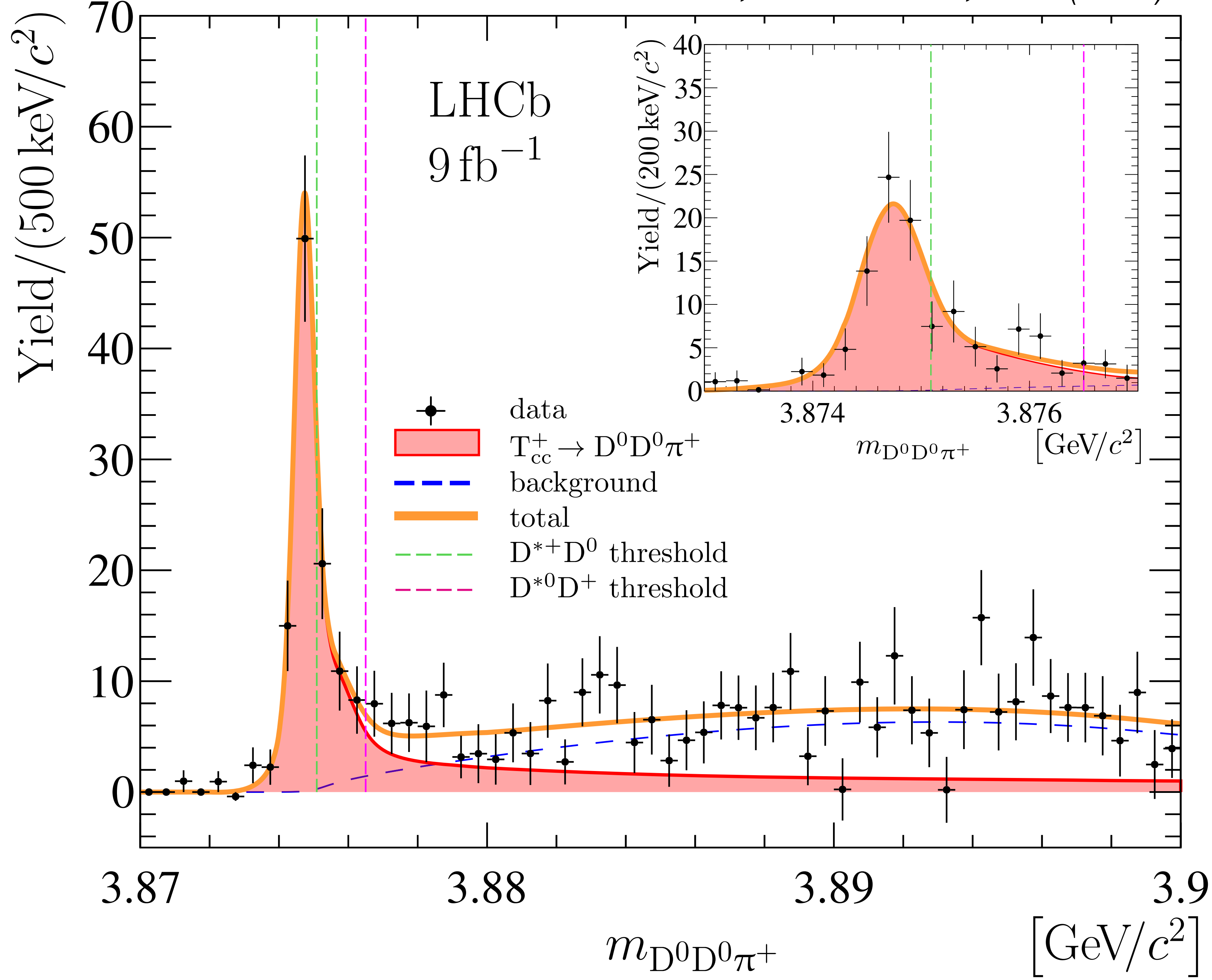
not the same animal

(see Nils Hüsken's talk this afternoon)

Doubly-Charmed Tetraquark ($cc\bar{u}\bar{d}$)

- only known meson to be composed of two charm quarks: T_{cc}^{+}
- a few hundred keV below open-charm threshold

LHCb Collab., Nat. Comm. 13, 3351 (2022)



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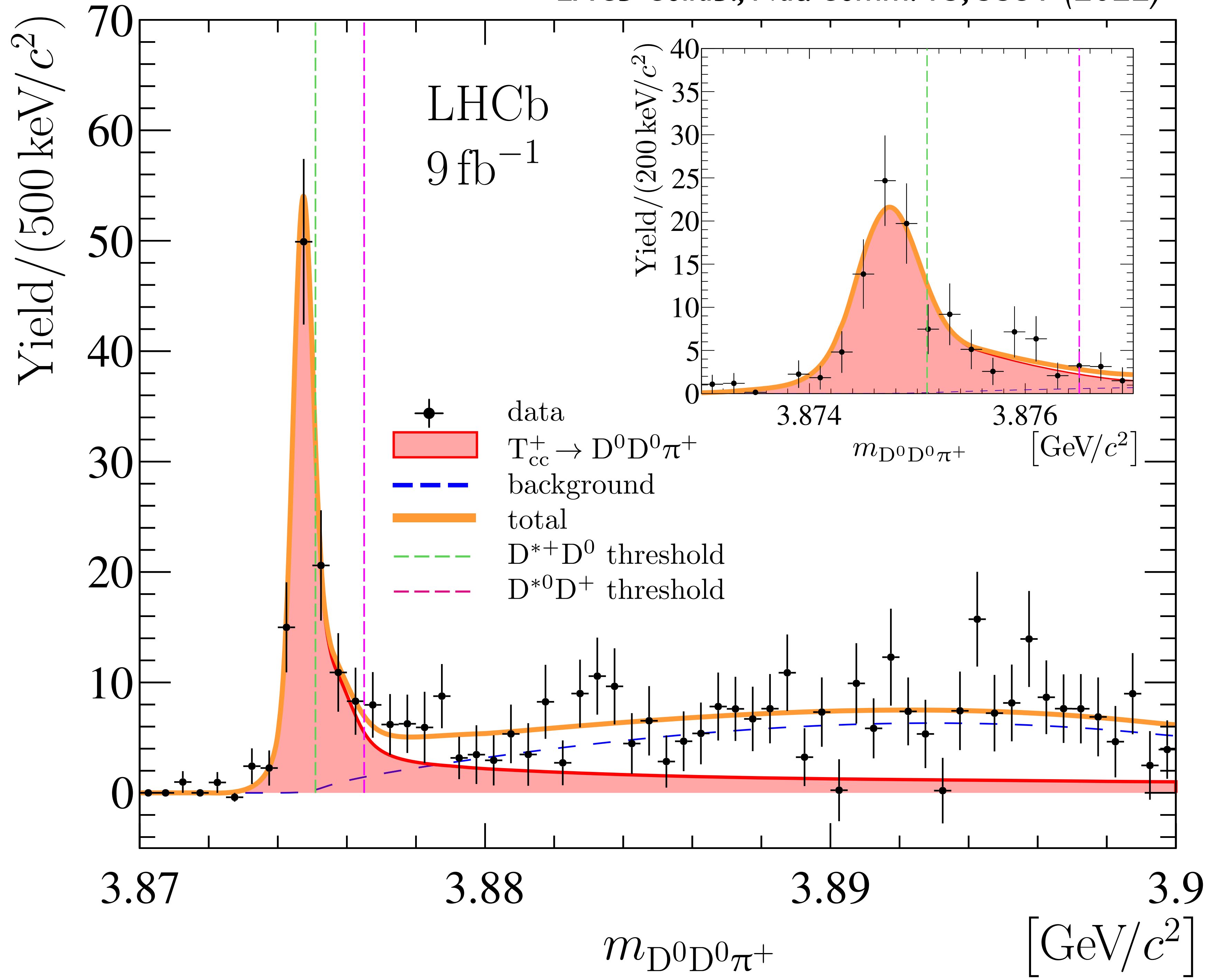
- only known meson to be composed of two charm quarks: T_{cc}^{+}
- a few hundred keV below open-charm threshold
- interpretation: compact tetraquark that decays strongly via an off-shell D^* meson
- b-quark analogue (if it exists) should be deeply bound

LHCb Collab., Nat. Comm. 13, 3351 (2022)



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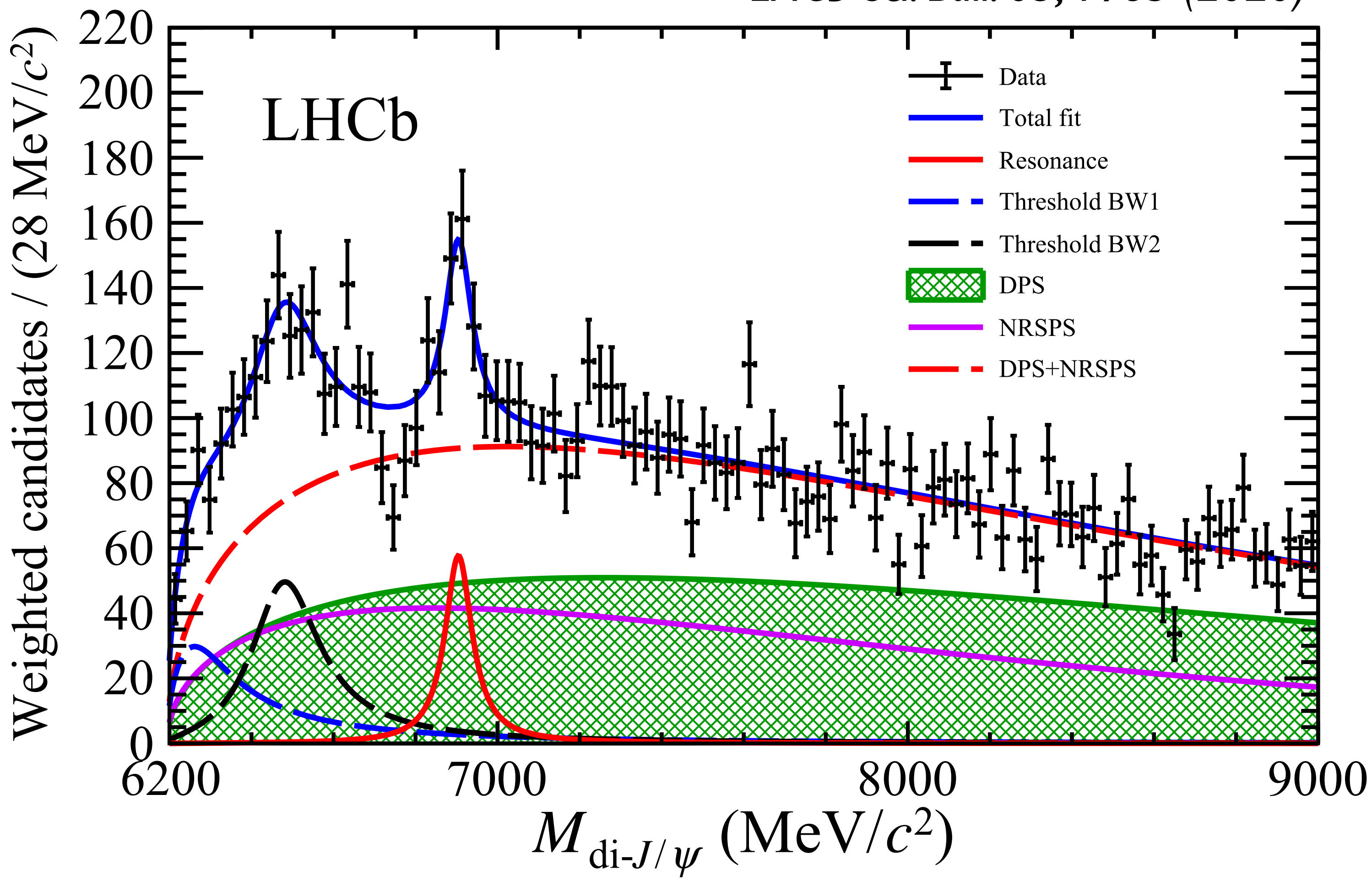
More charm $cc\bar{c}\bar{c}$: $X(6900) \to (J/\psi)(J/\psi)$

LHCb Sci. Bull. 65, 1983 (2020)



Tetraquark or Molecule?

$\chi_{c0}\chi_{c0}$ threshold: 6825 MeV
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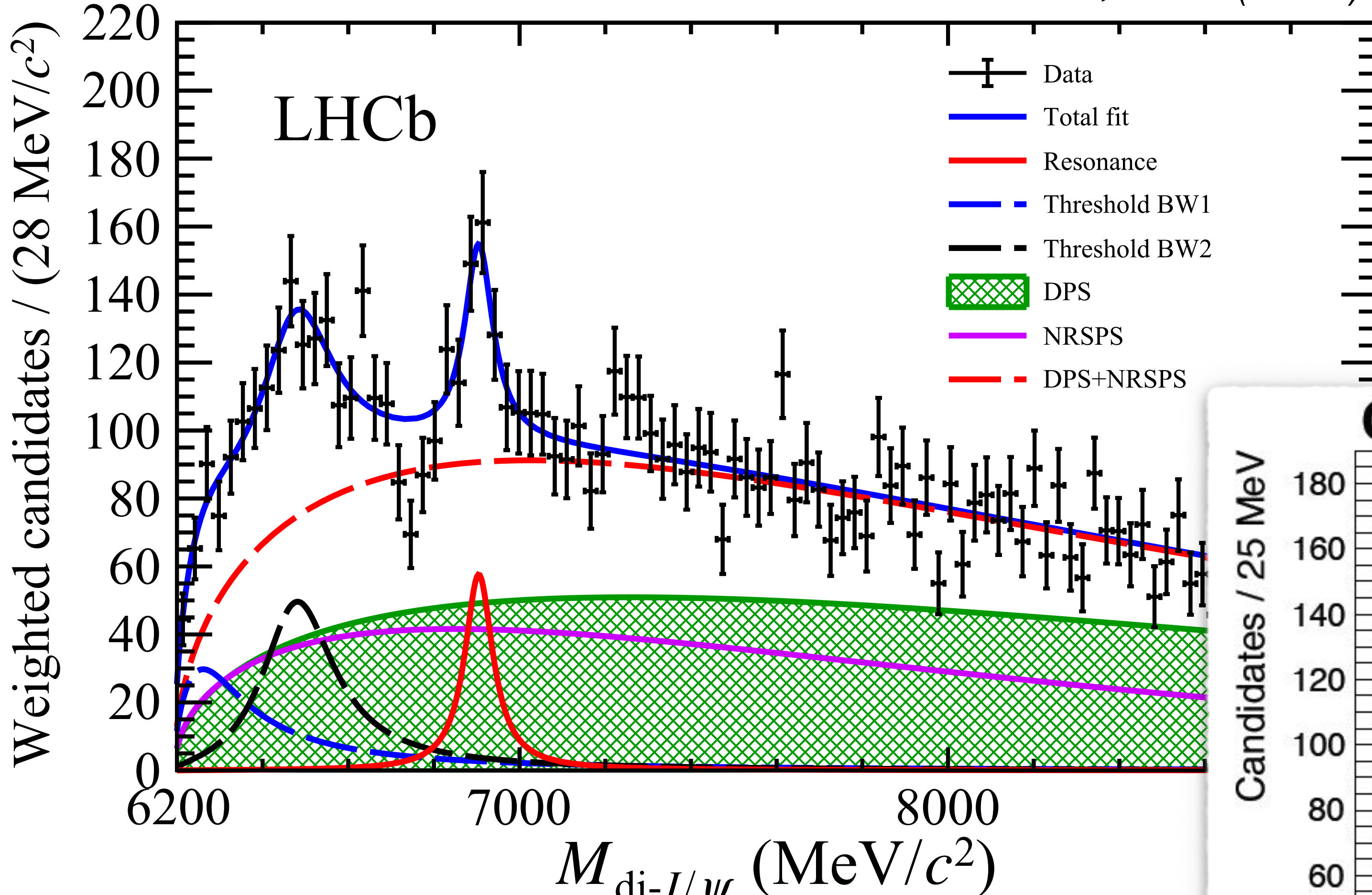

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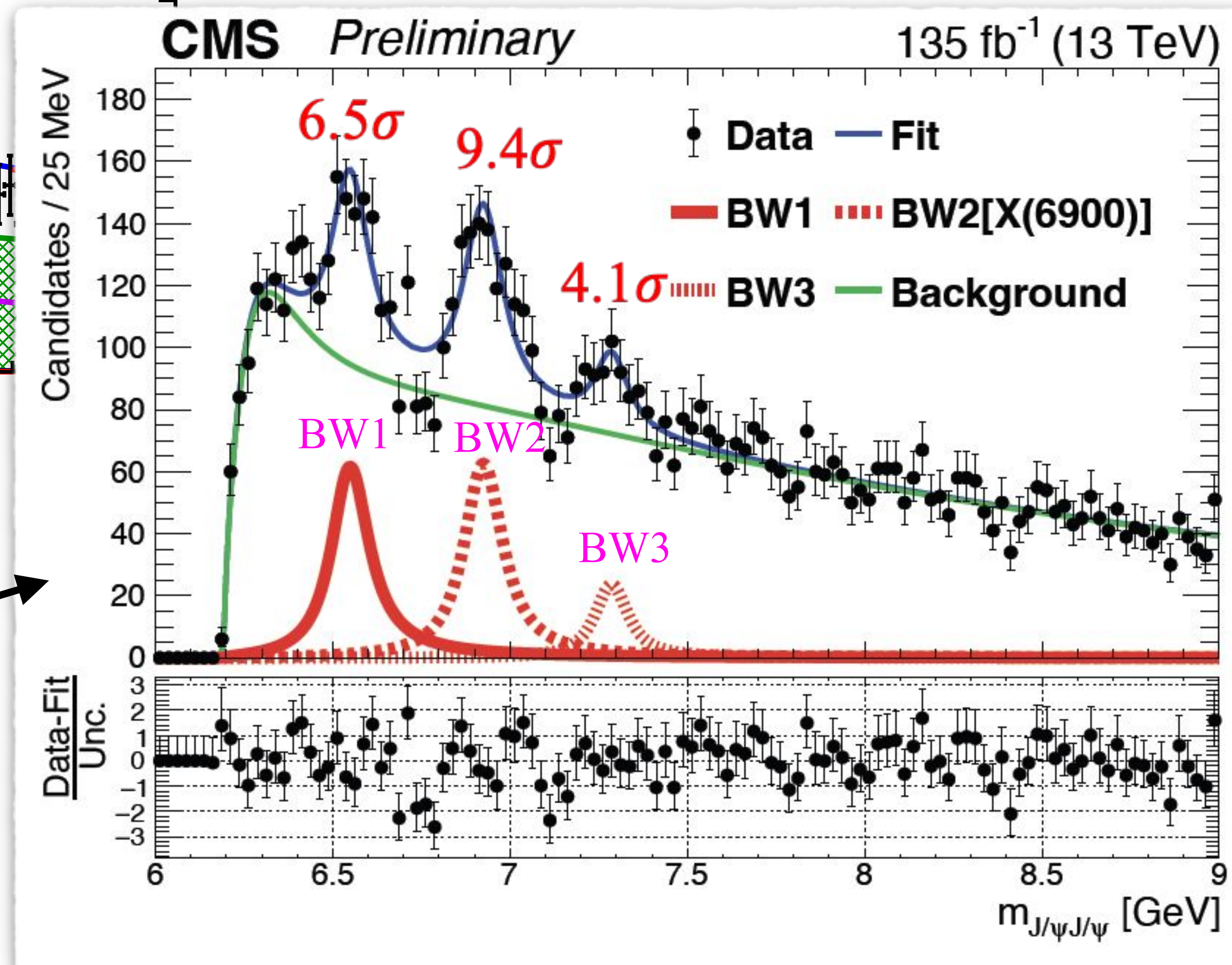
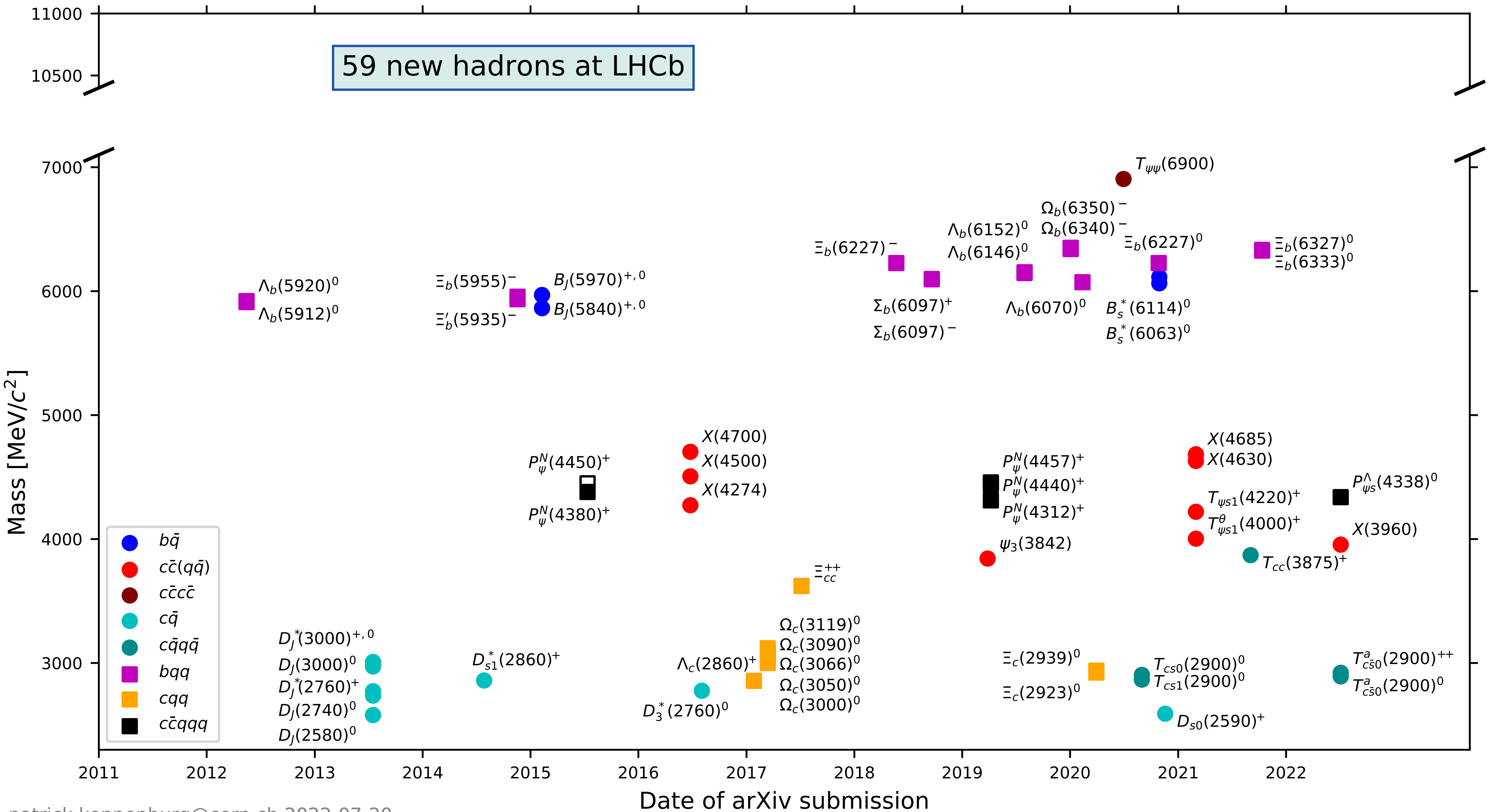


From the talk by Jane Nachtman on Thursday afternoon

Exciting times for hadron spectroscopy!



patrick.koppenburg@cern.ch 2022-07-20

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Comments on Heavy Quark States

- strong evidence for quark model states beyond qqq and $q\bar{q}$ -- underlying structure and origin?

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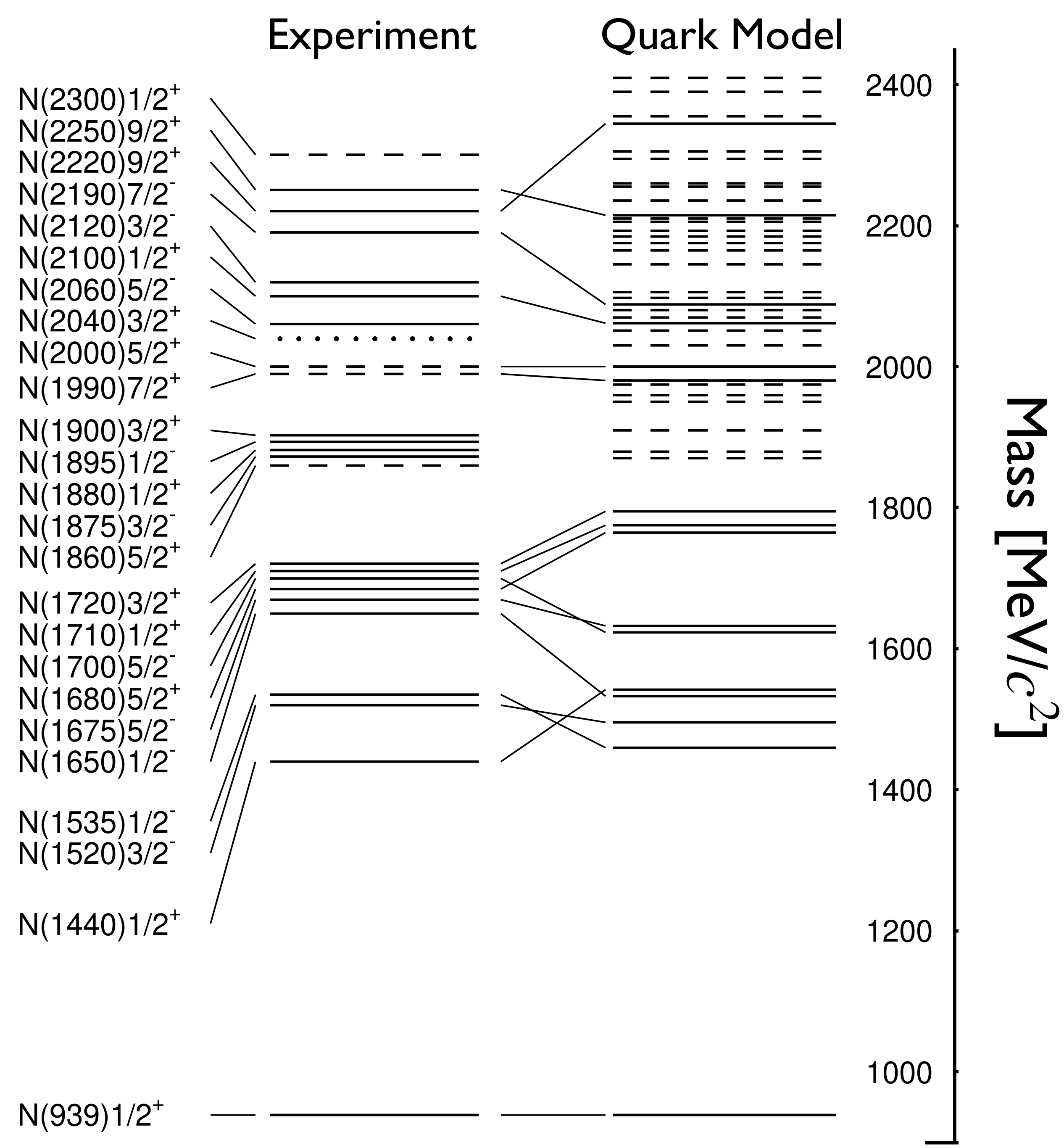
Nucleon Excitations



R.L.Workman et al. [PDG], Prog.Theor. Exp. Phys. 2022, 083C01 (2022)

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- questions/issues:
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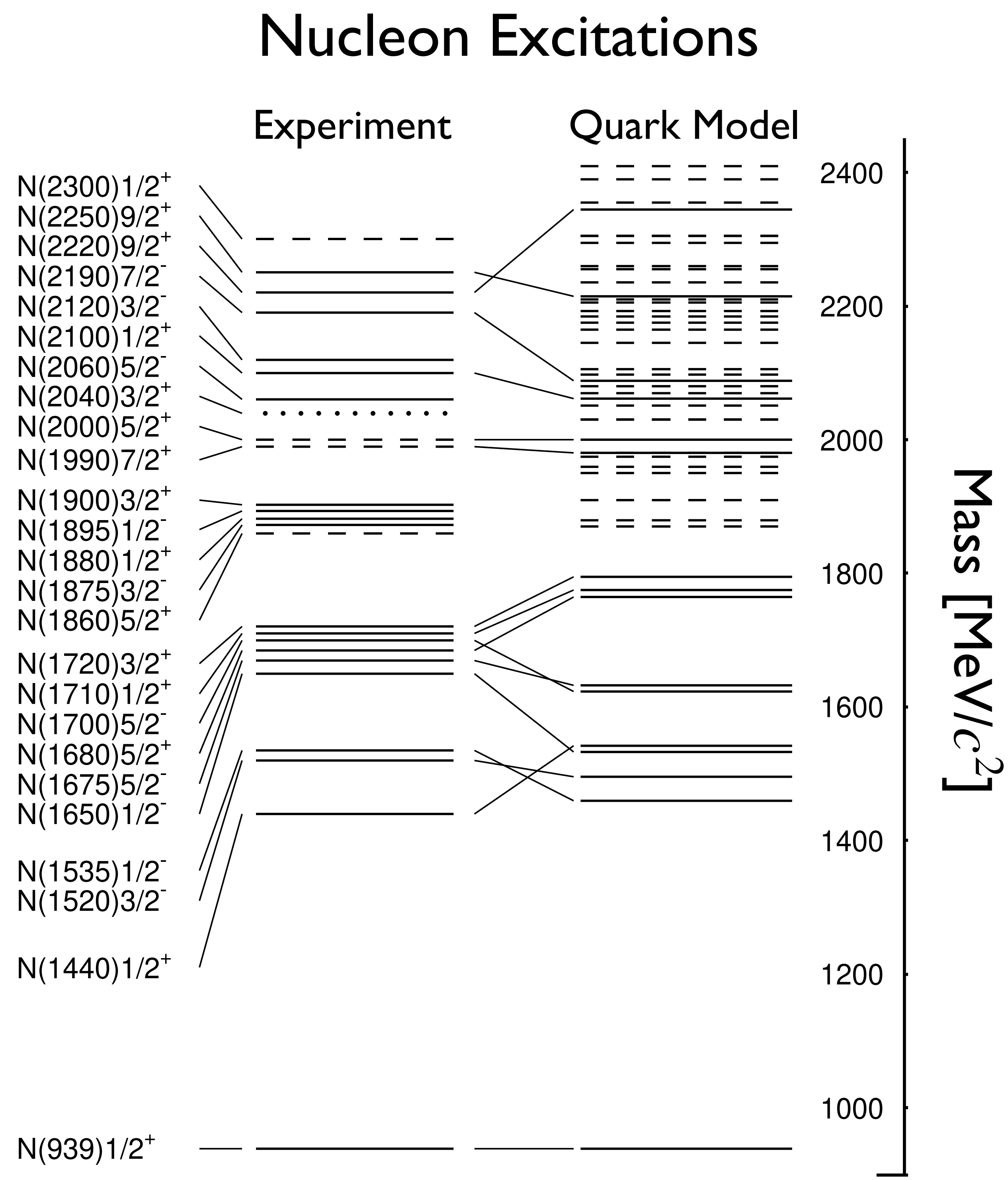
  - three-body dynamics



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- light quark degrees of freedom are challenging
- questions/issues:
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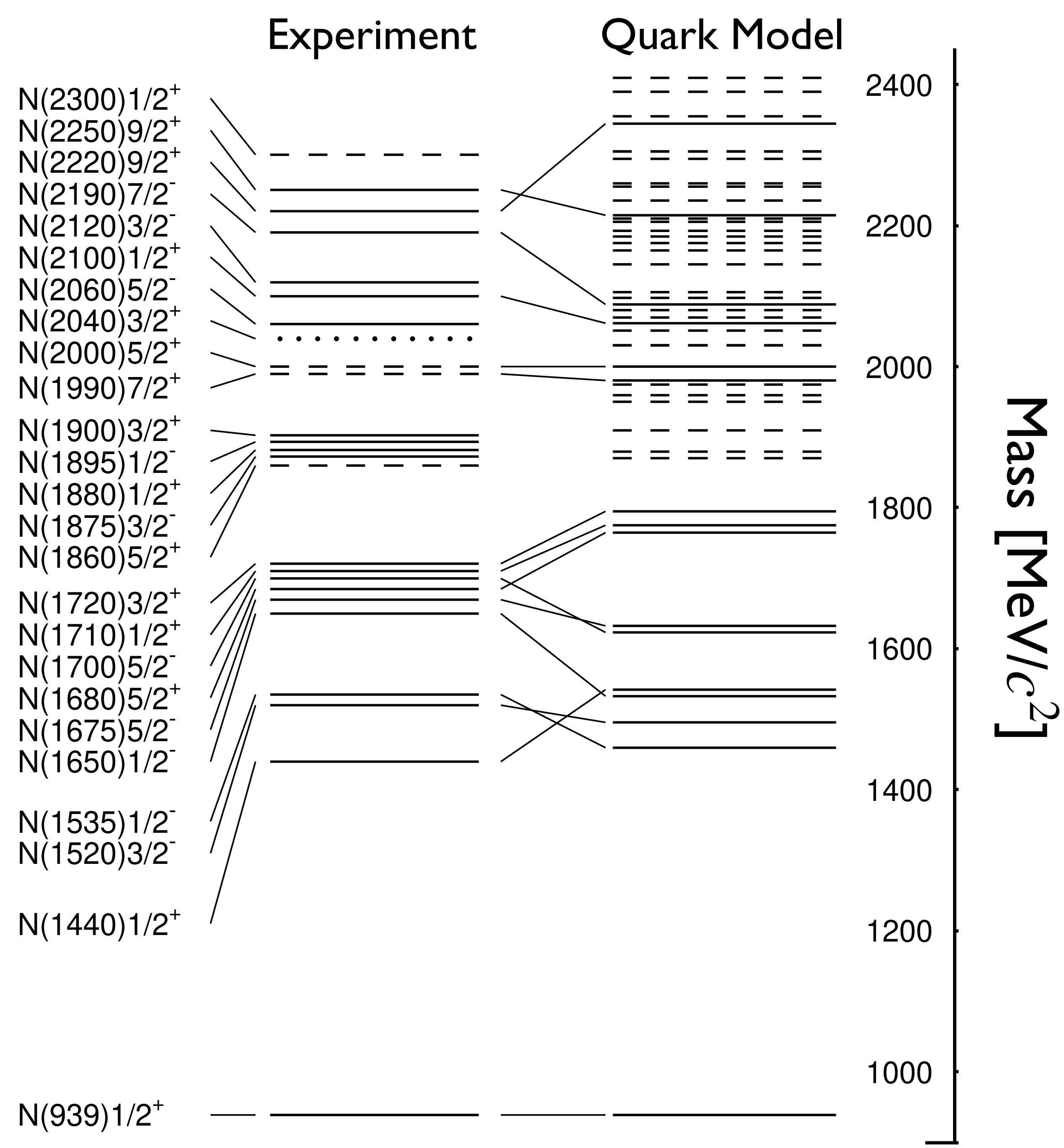
  - three-body dynamics
- no evidence (yet) of gluonic degrees of freedom
  - e.g., exotic J^{PC} states with $c\bar{c}$

Nucleon Excitations



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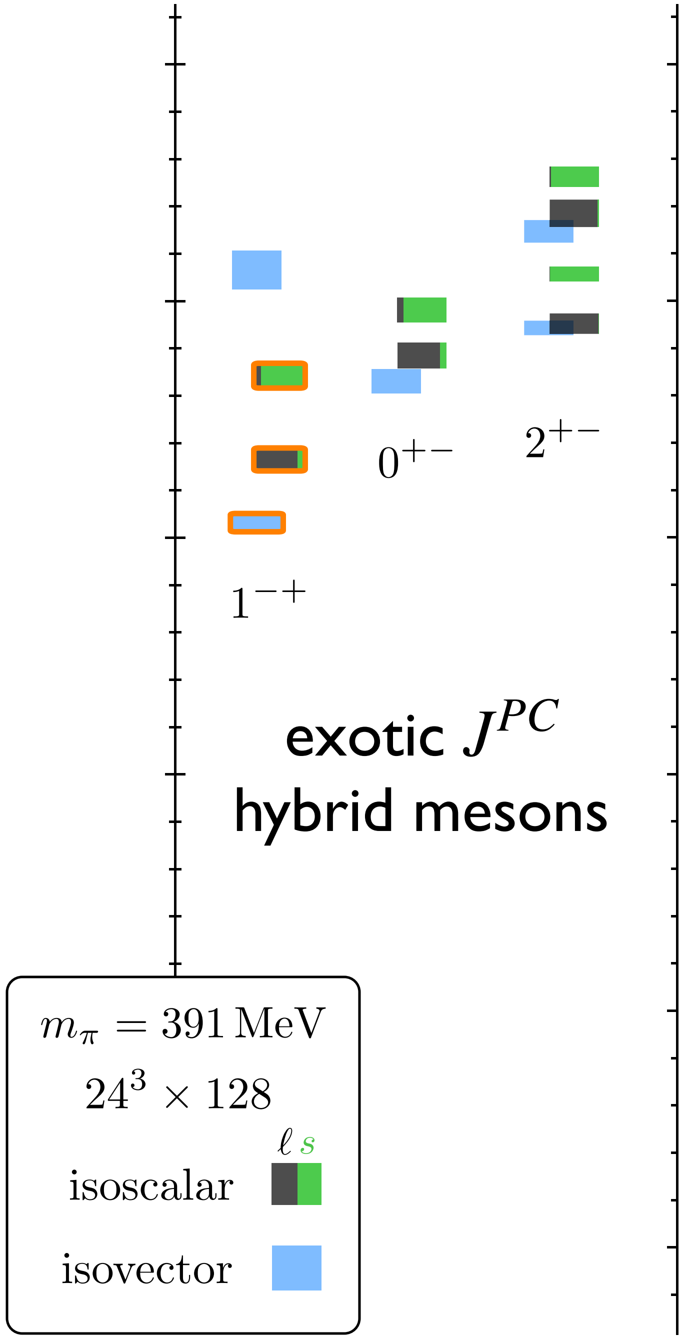

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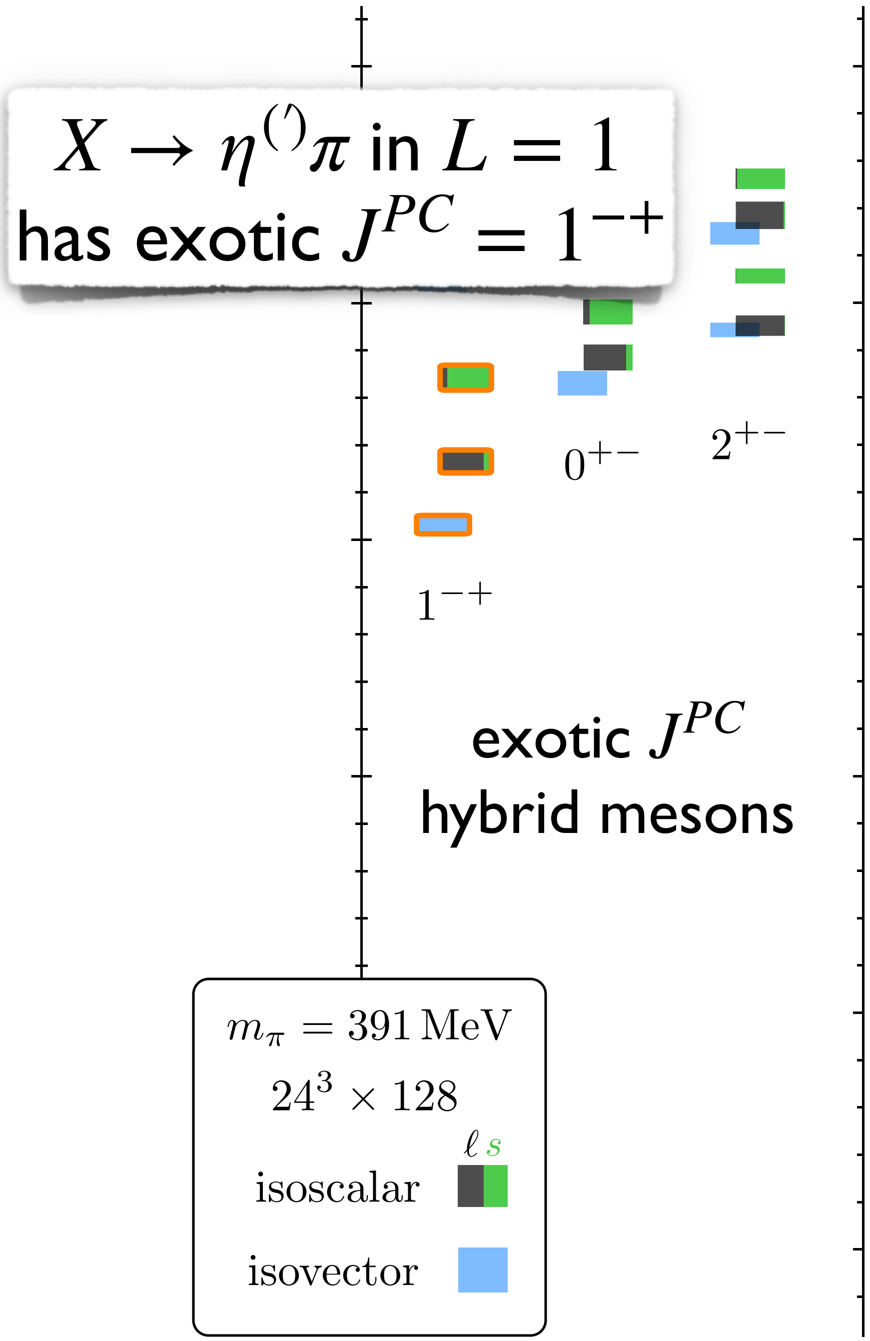

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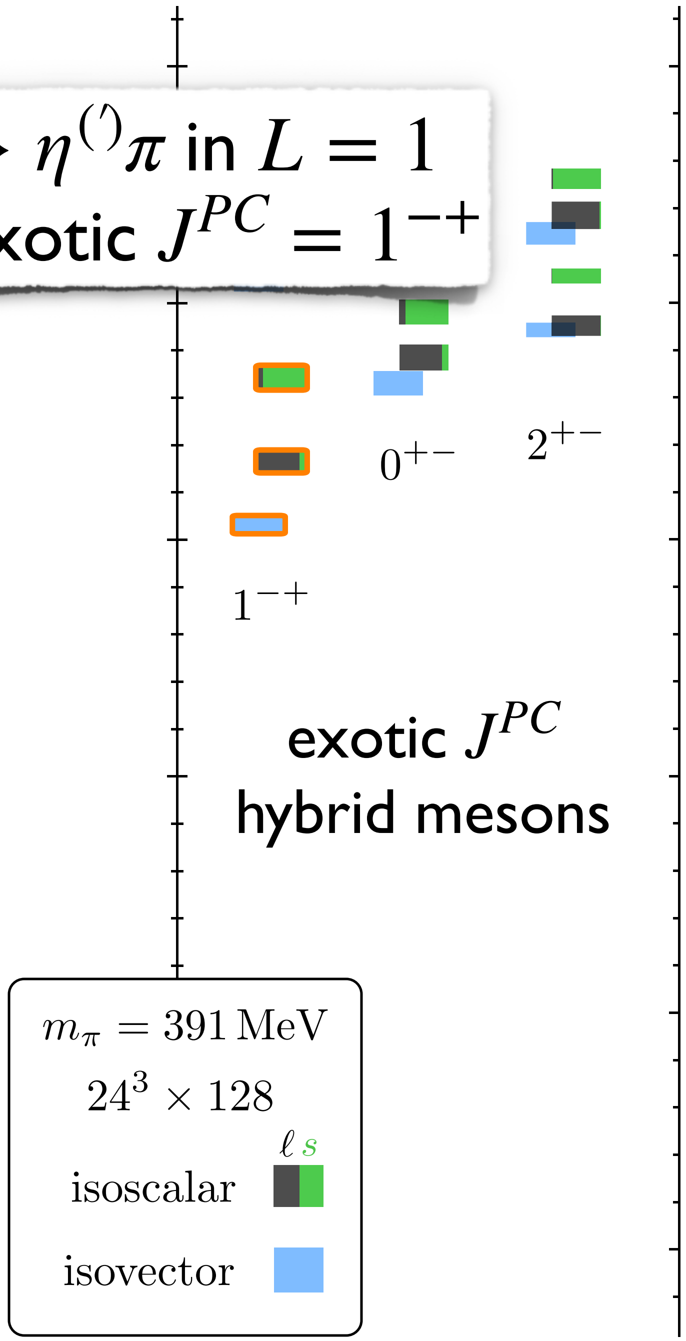

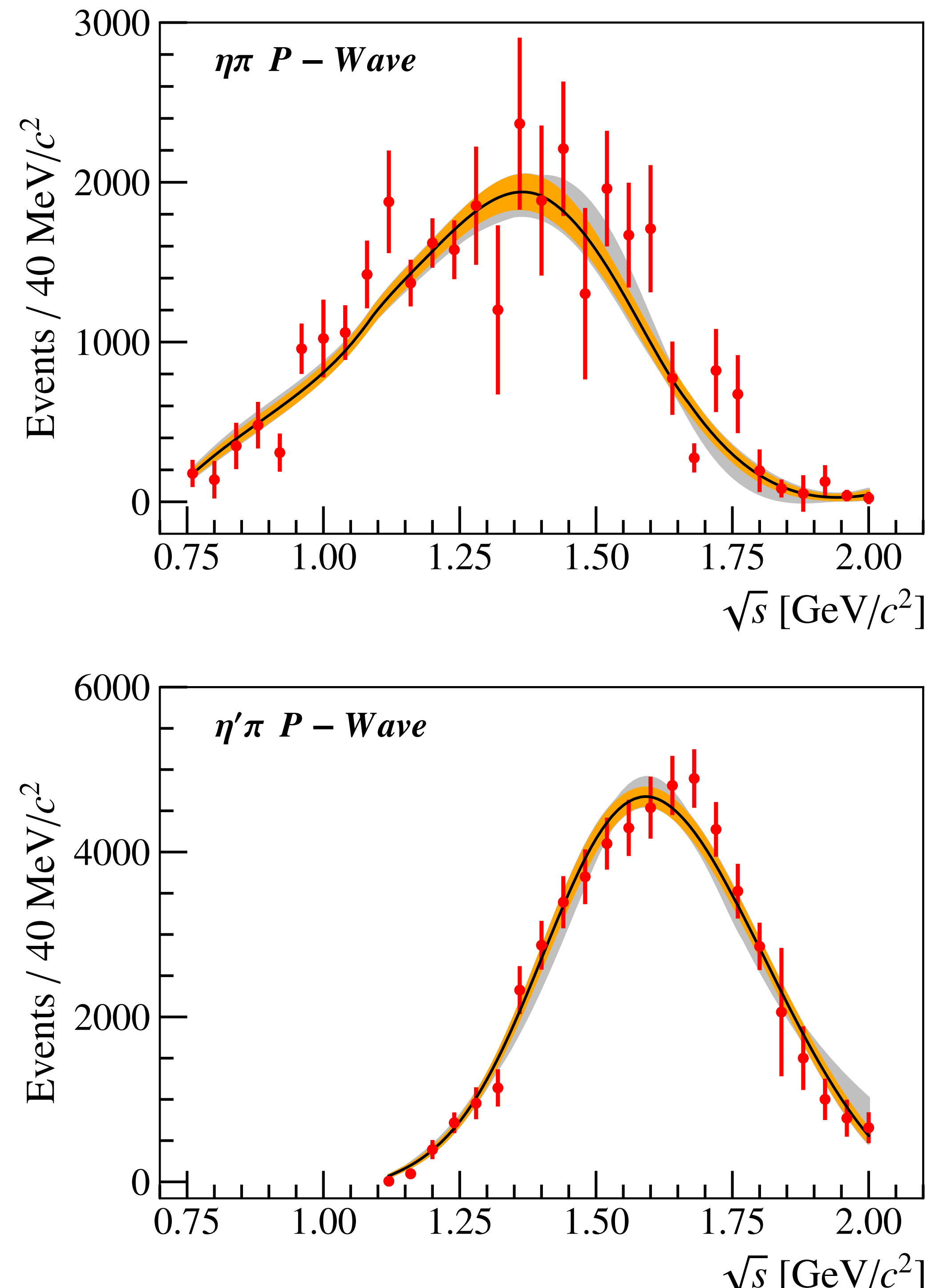

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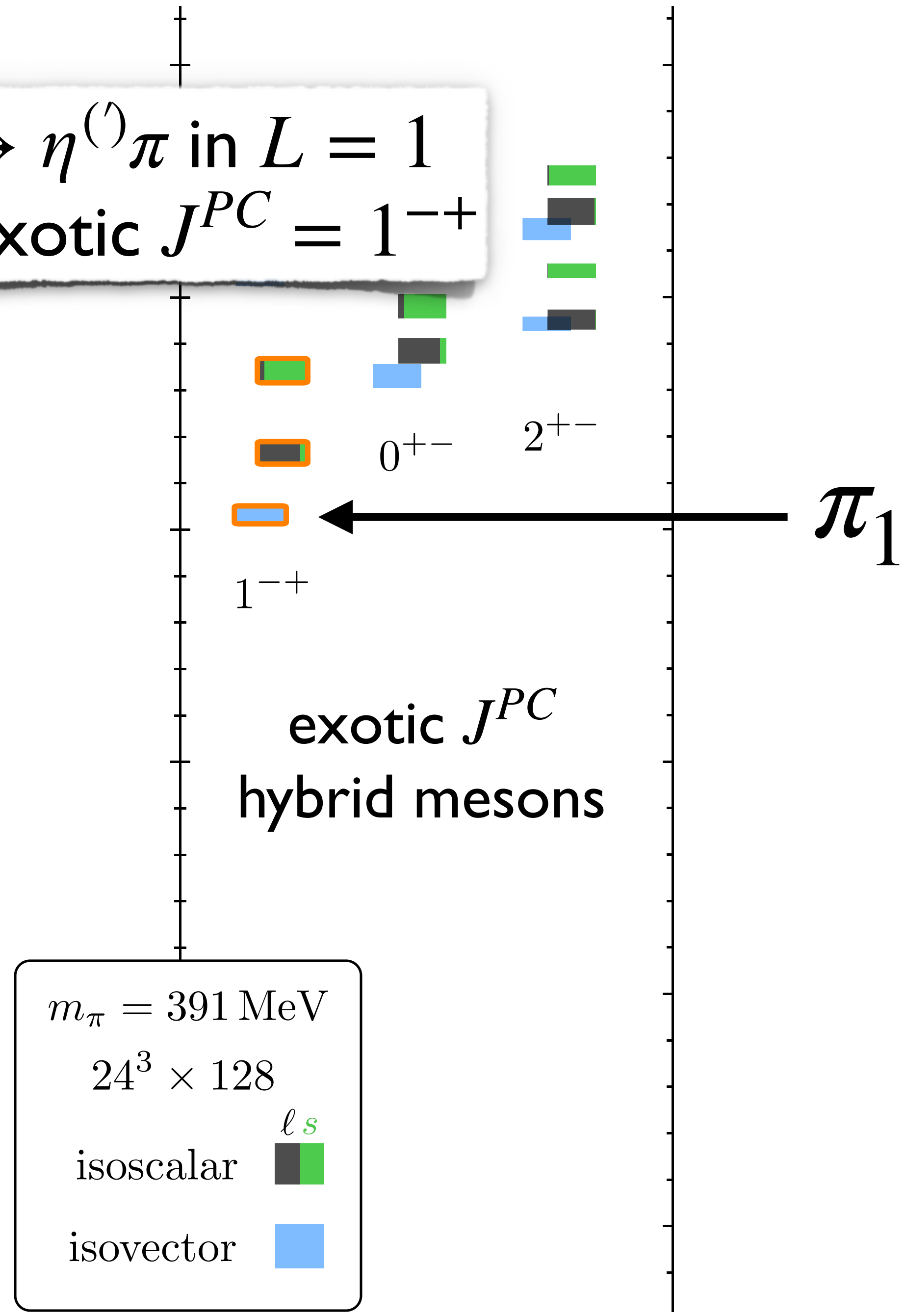

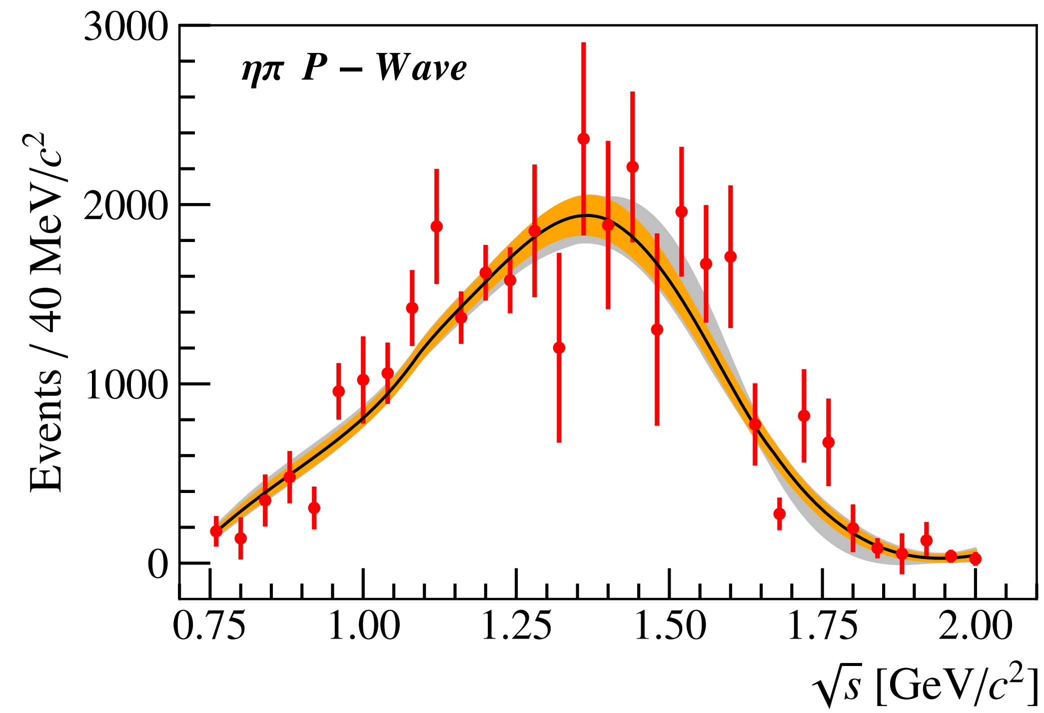

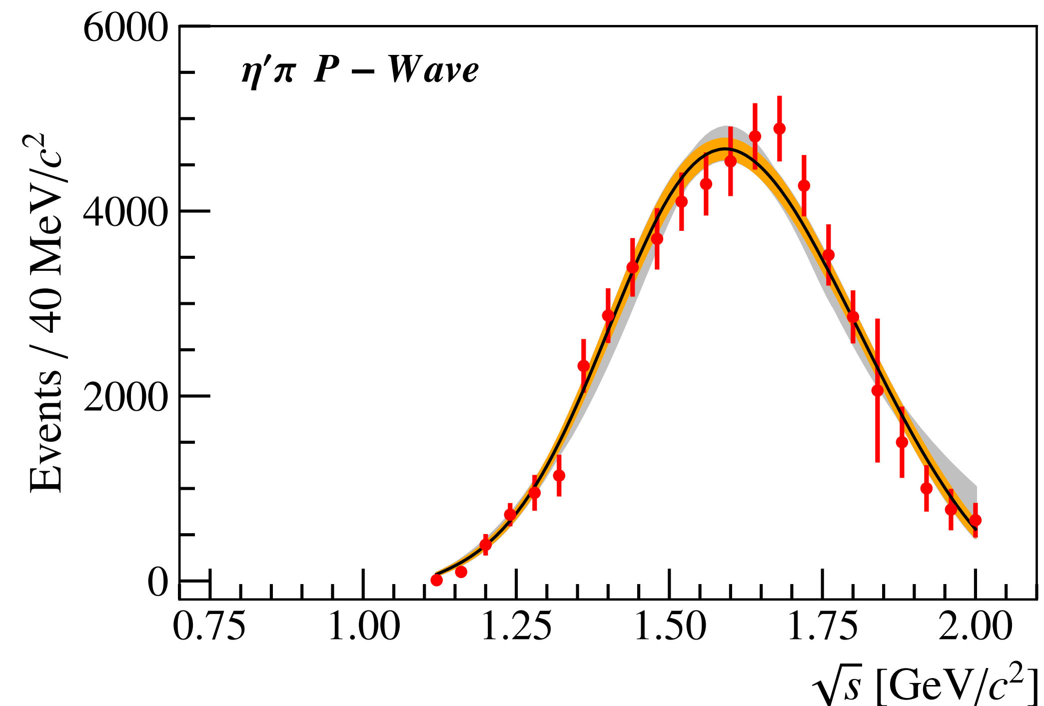

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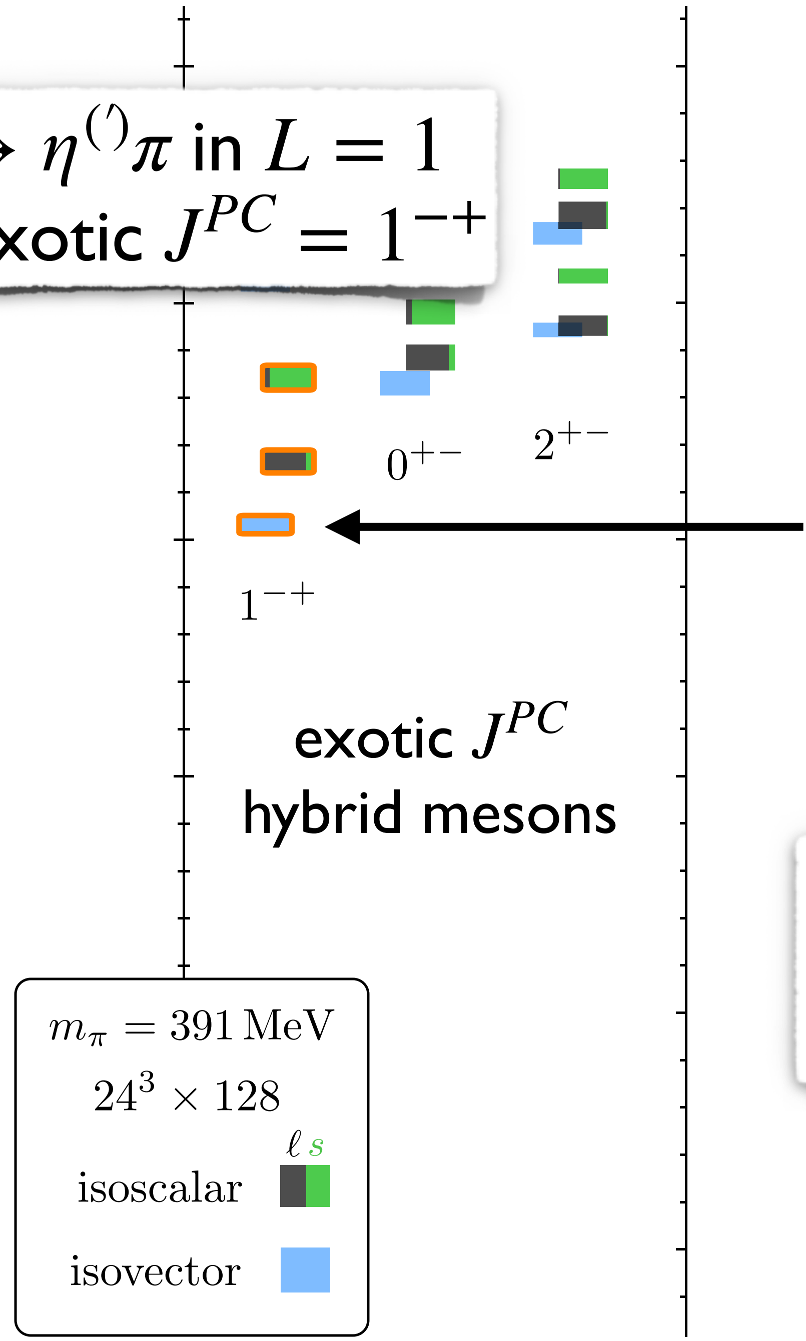

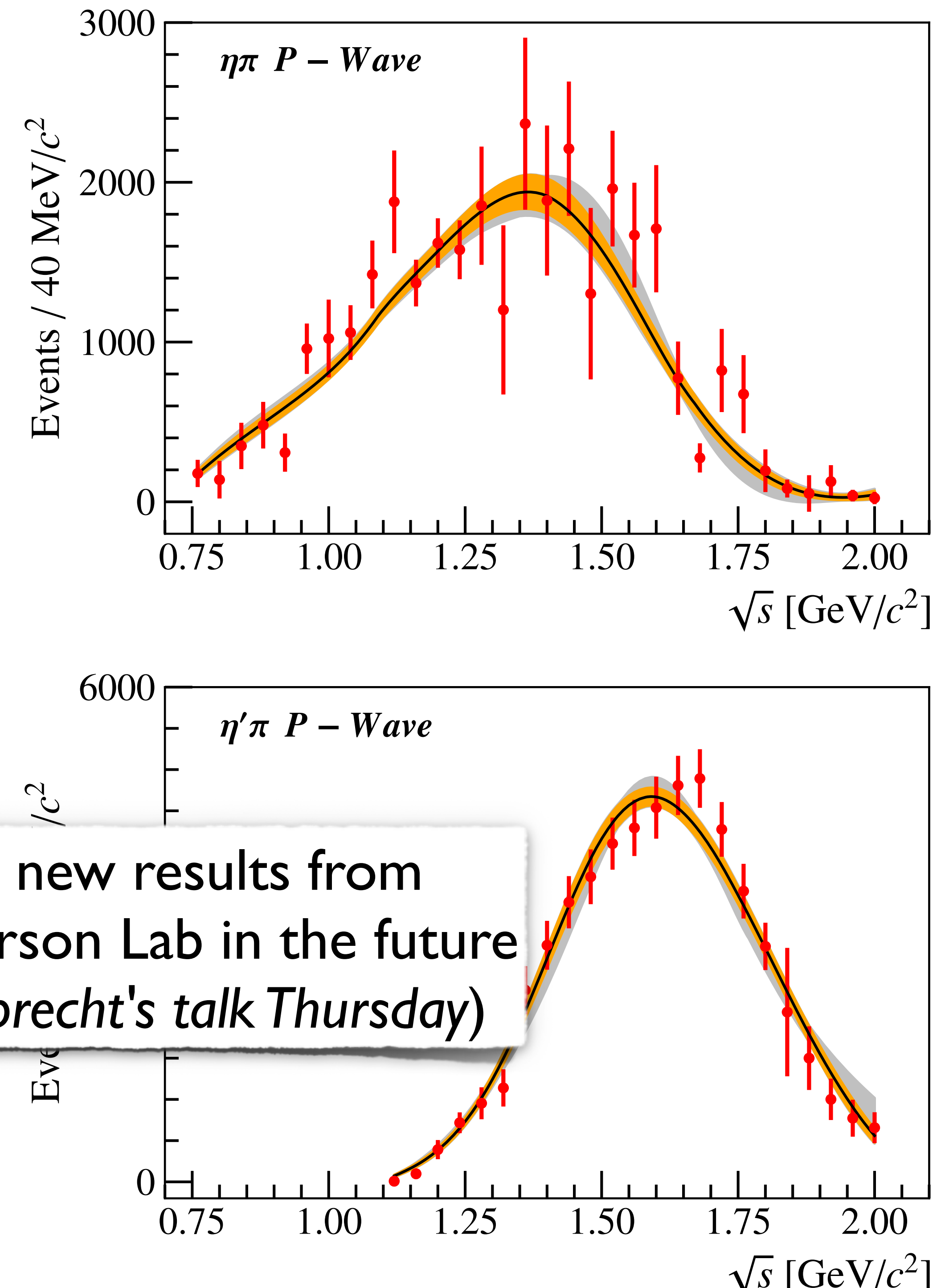

Anticipate new results from GlueX at Jefferson Lab in the future (*see Malte Albrecht's talk Thursday*)

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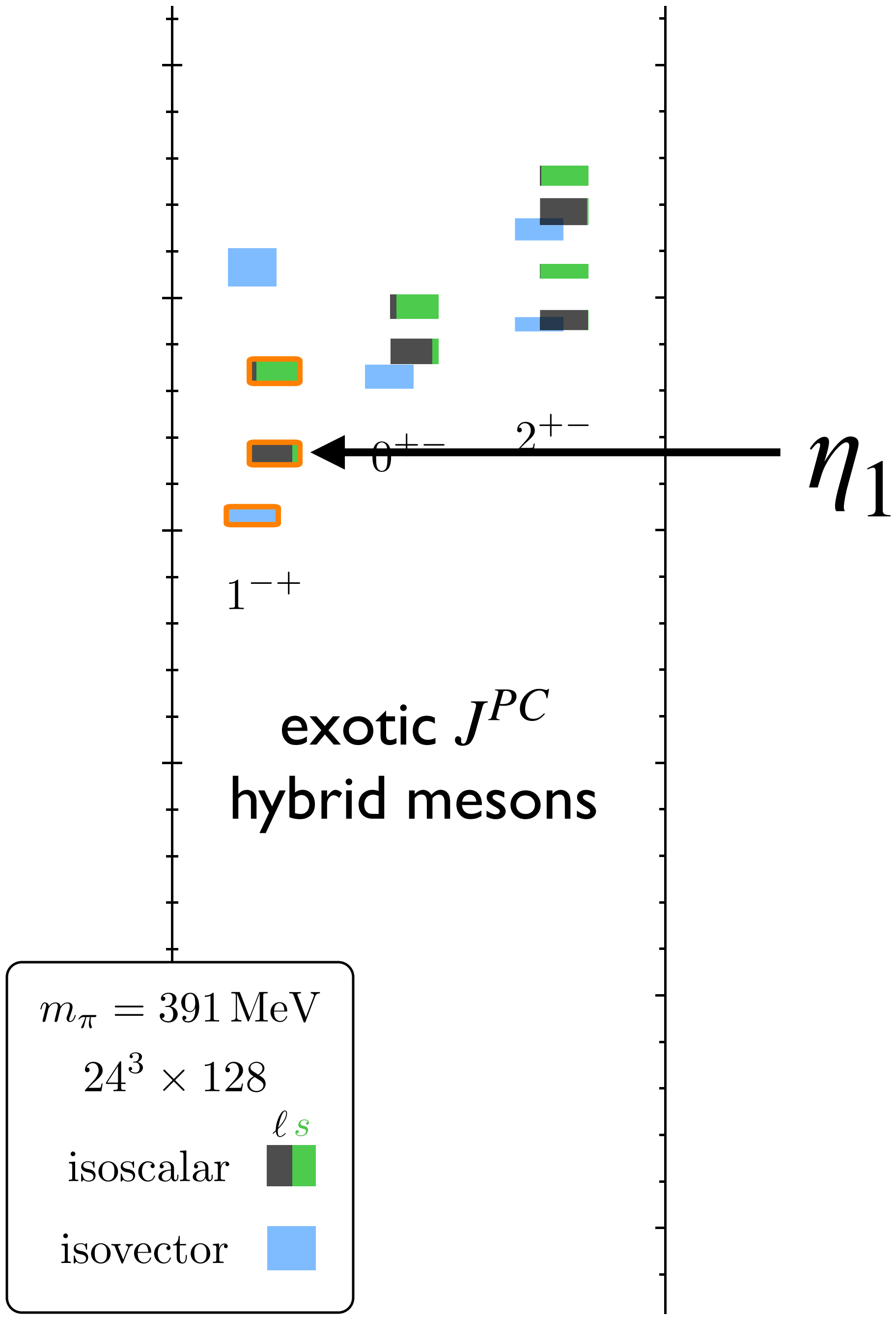

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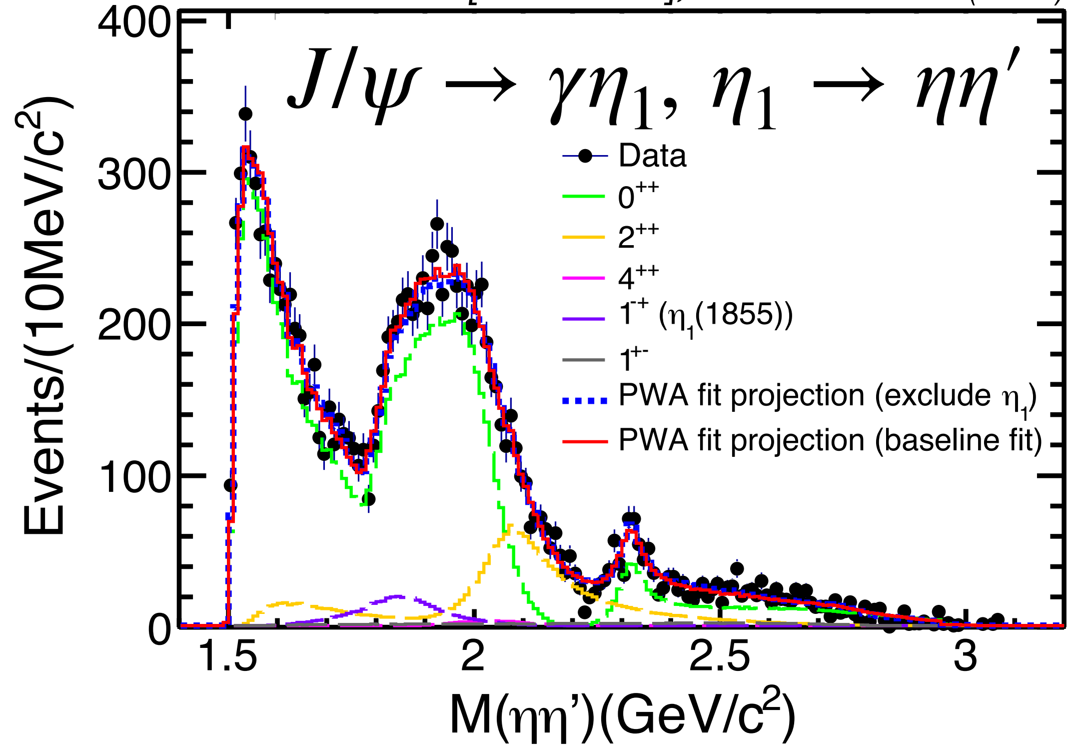

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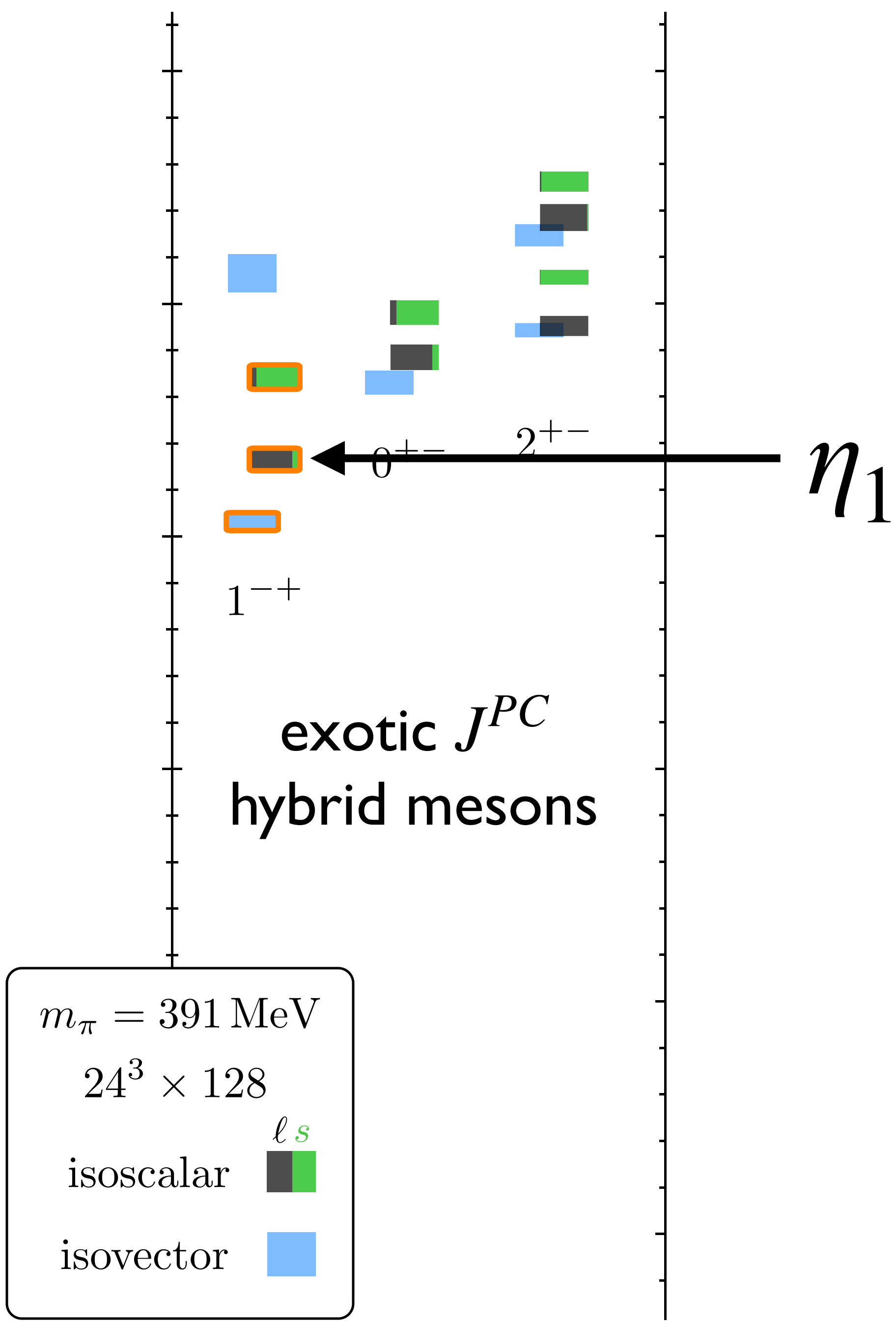

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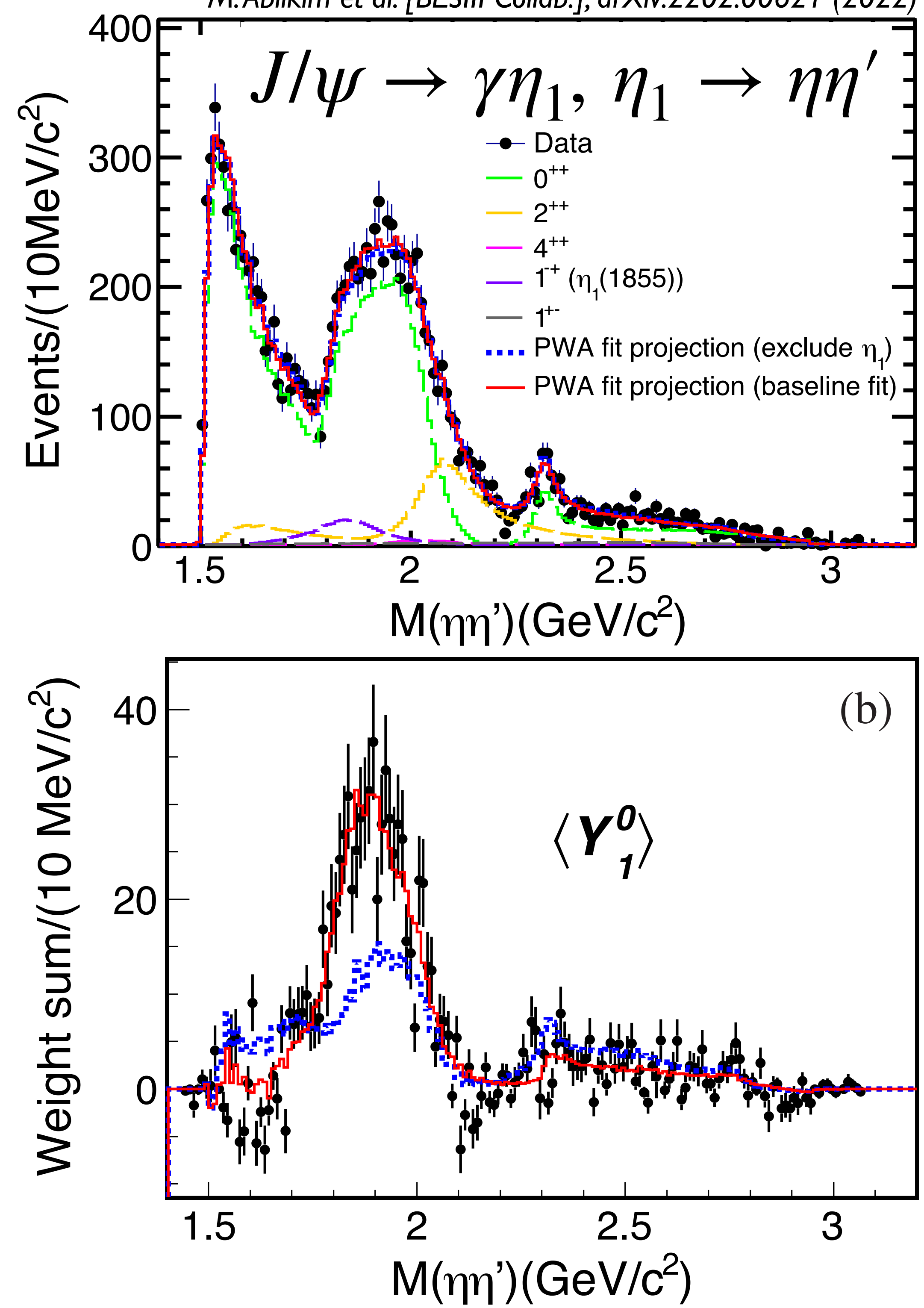

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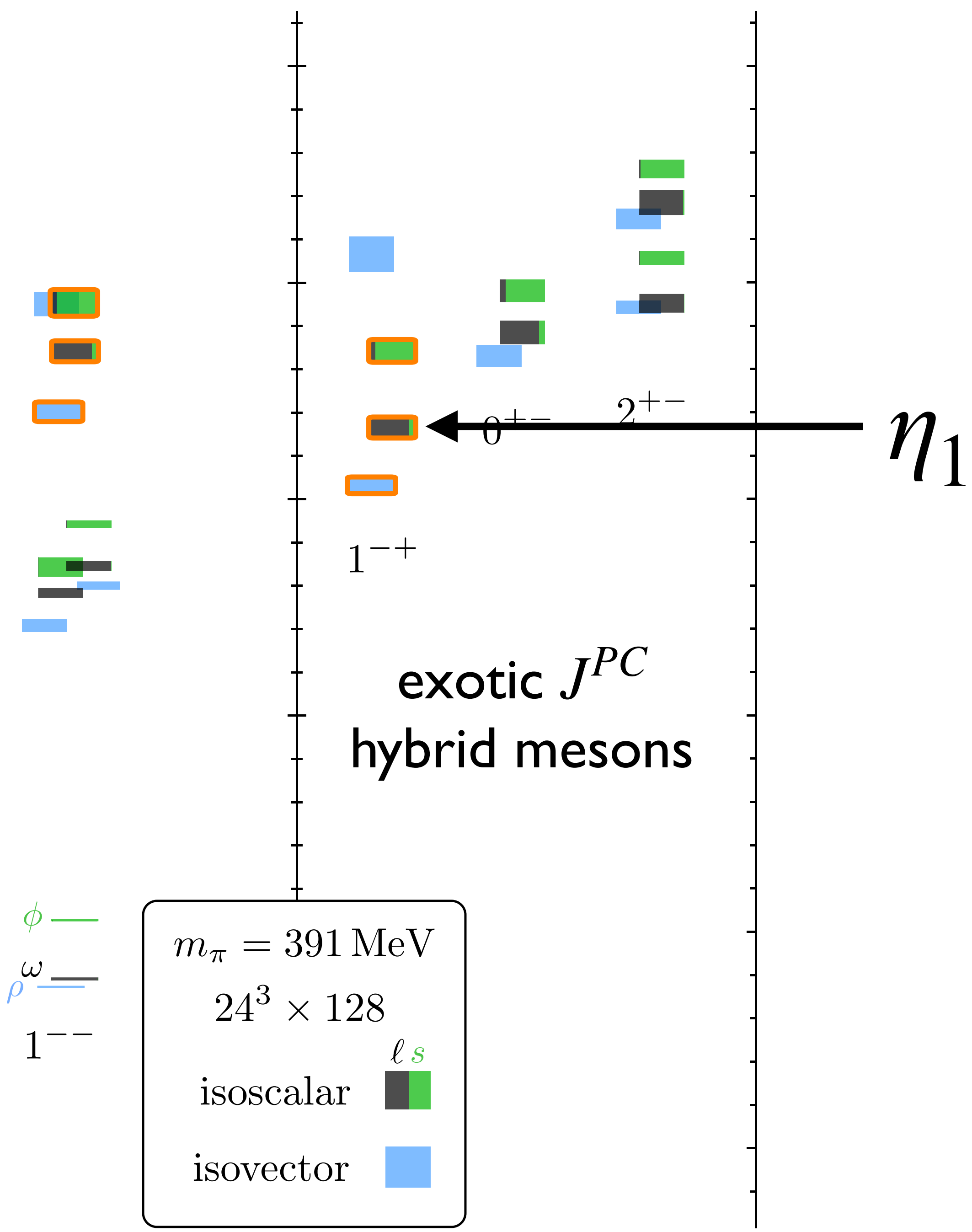

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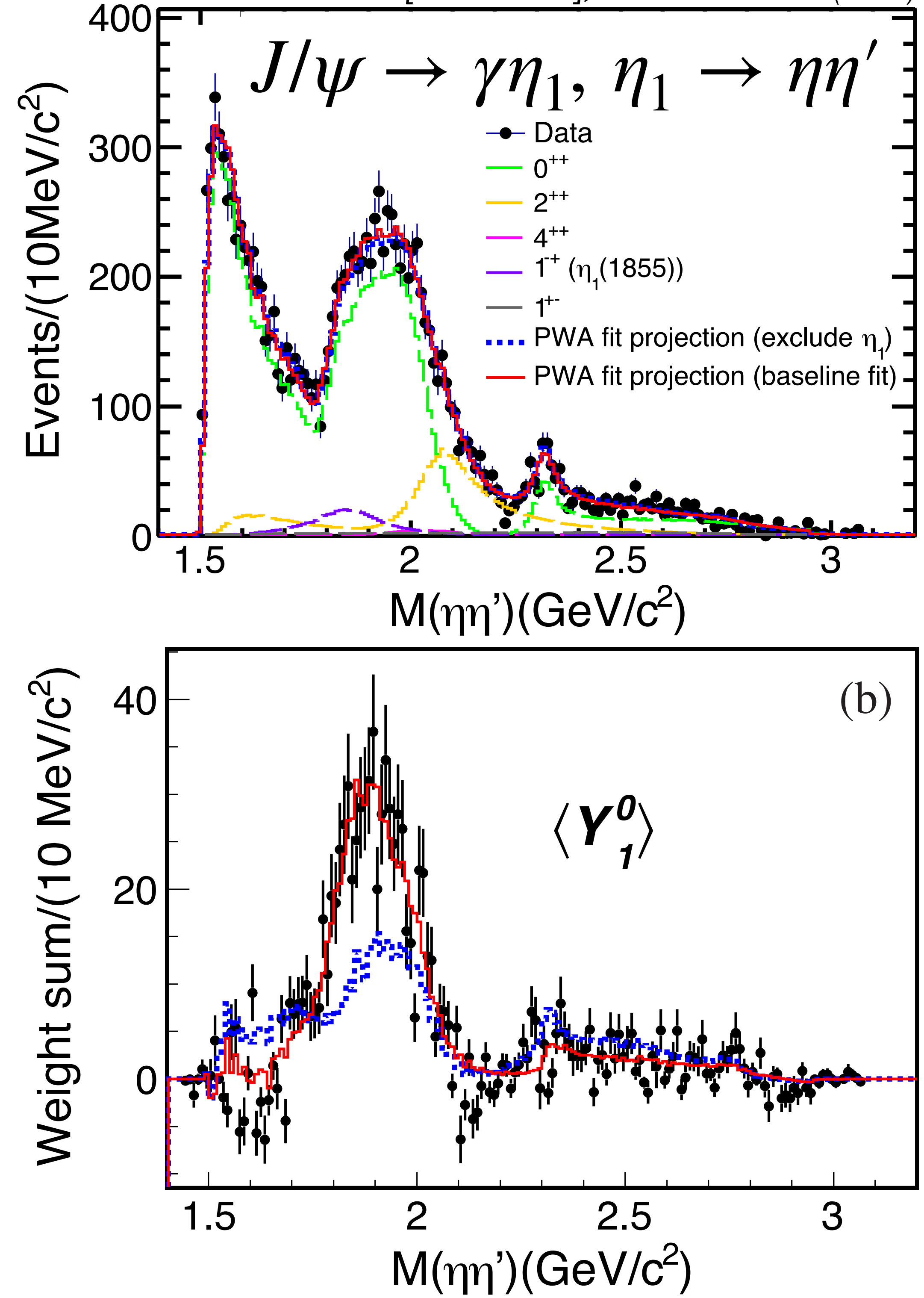

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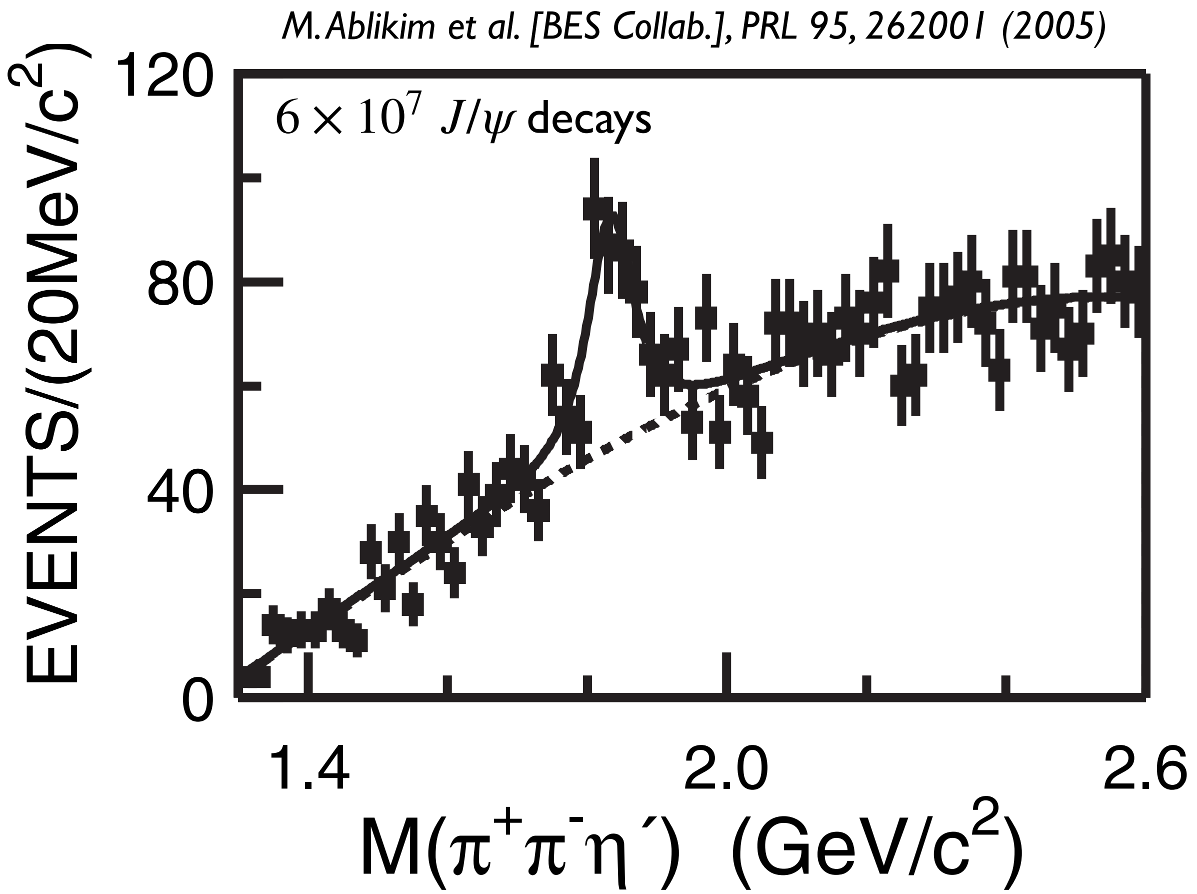
- need predictions for complementary production mechanisms and the data to make definitive tests of those predictions

More data means more fun: $J/\psi \to \gamma\eta'\pi\pi$



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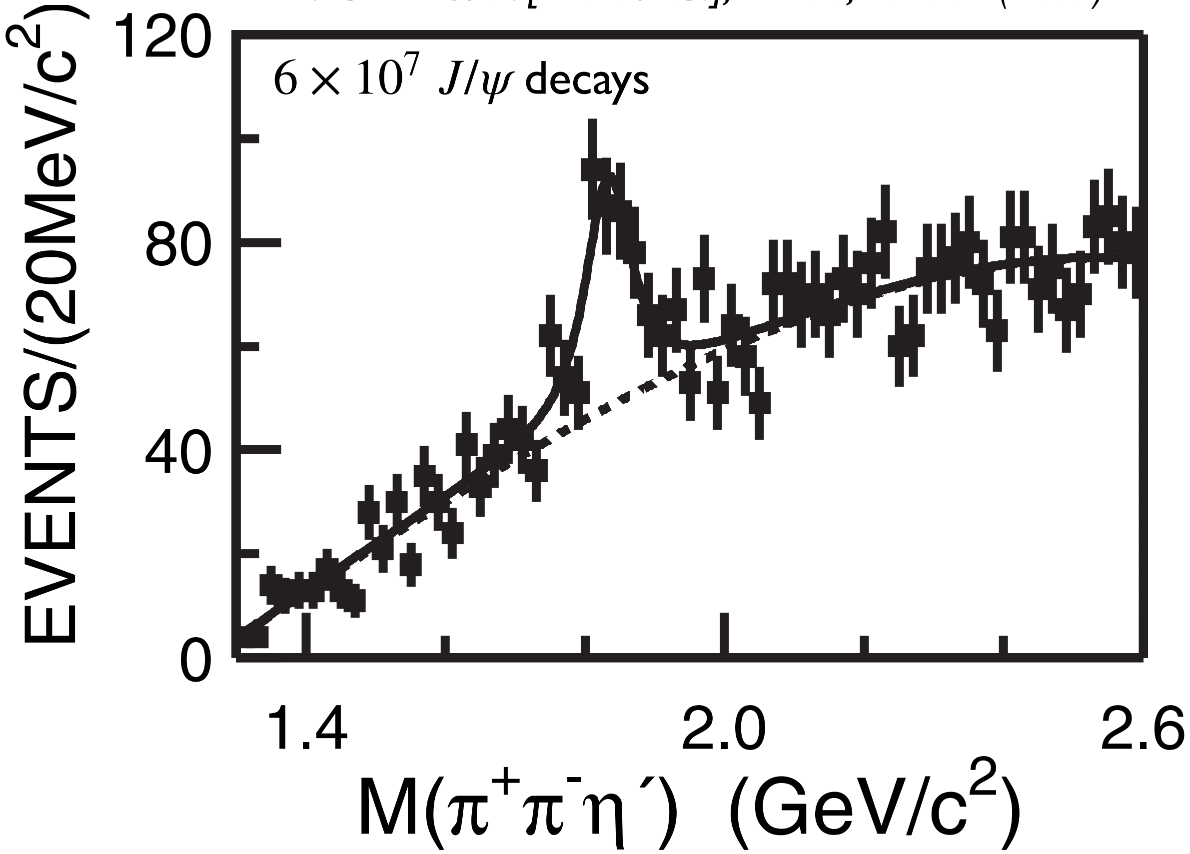

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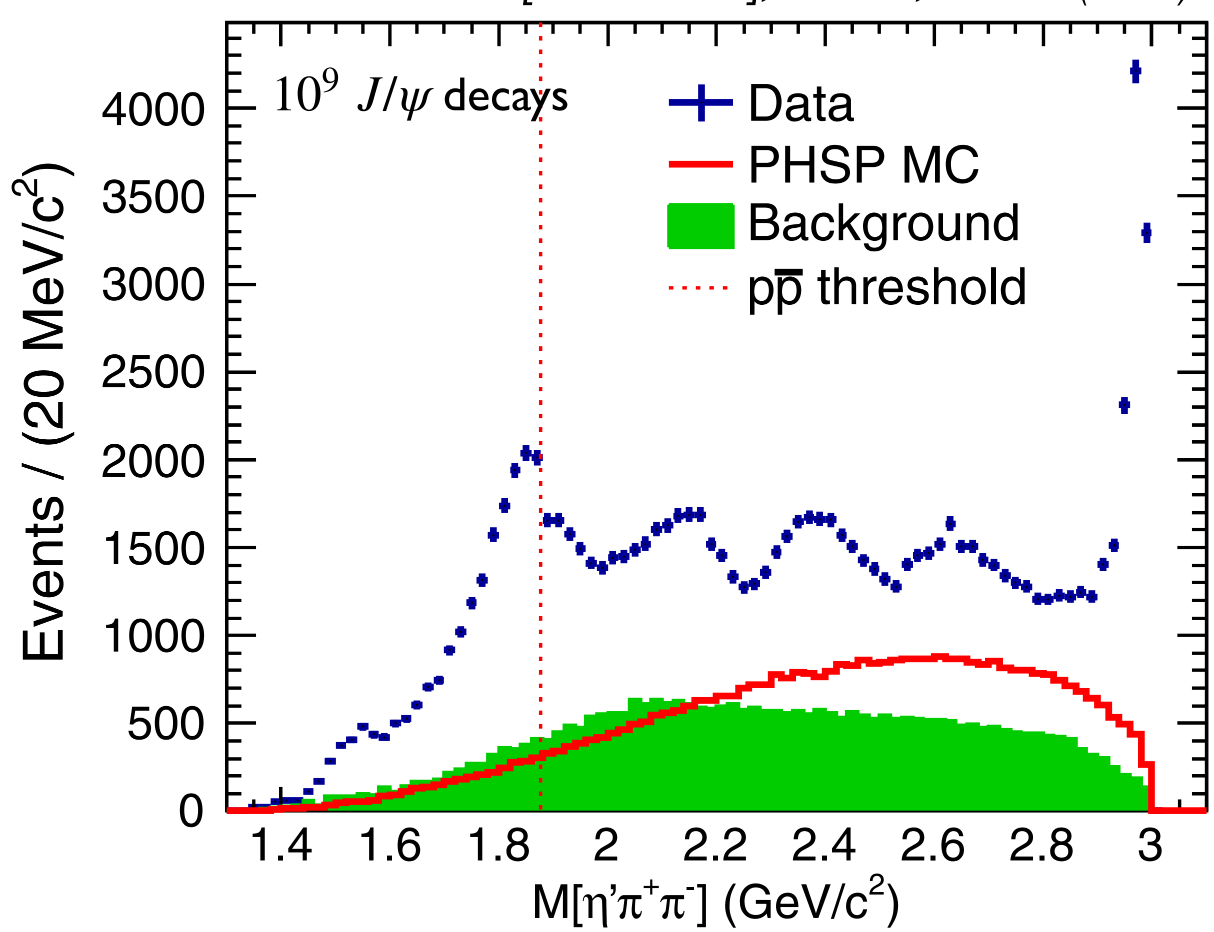

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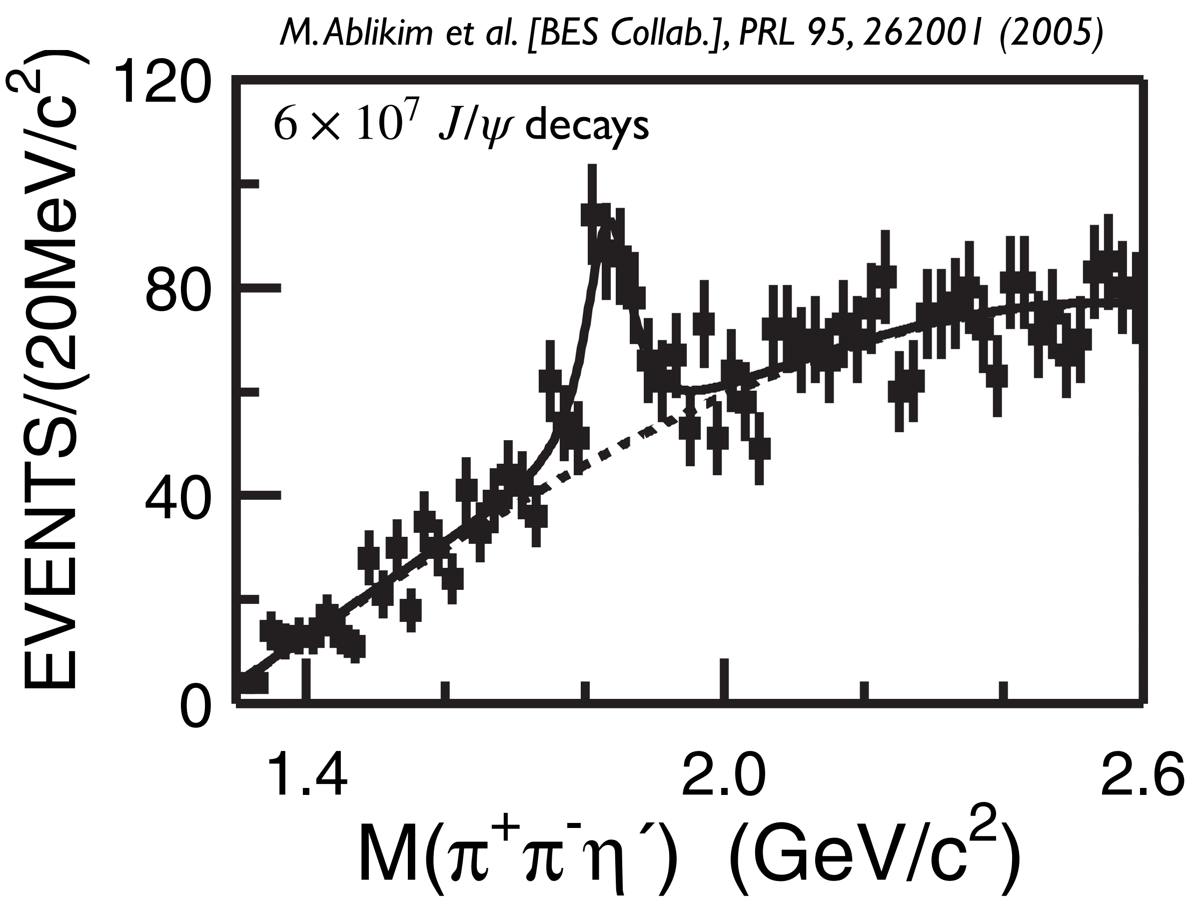

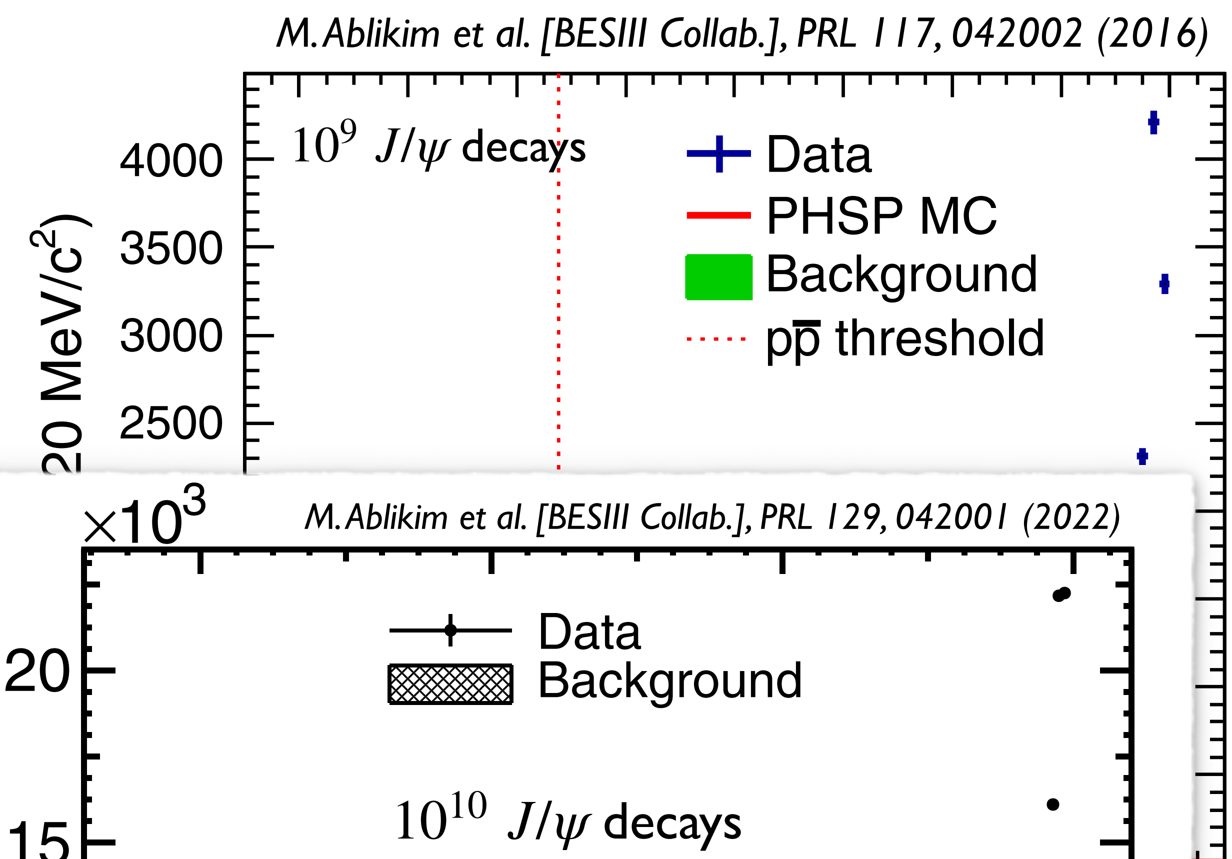

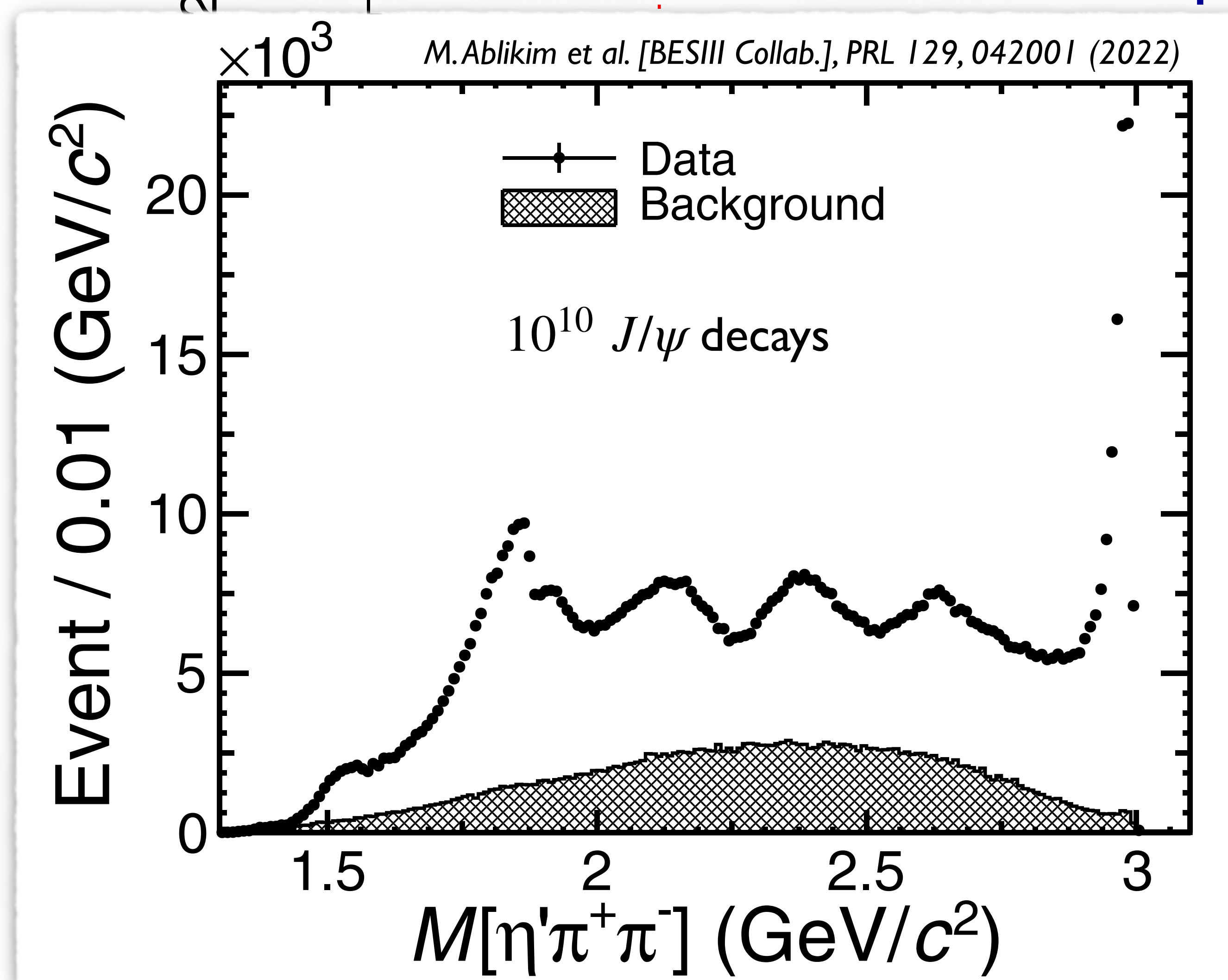

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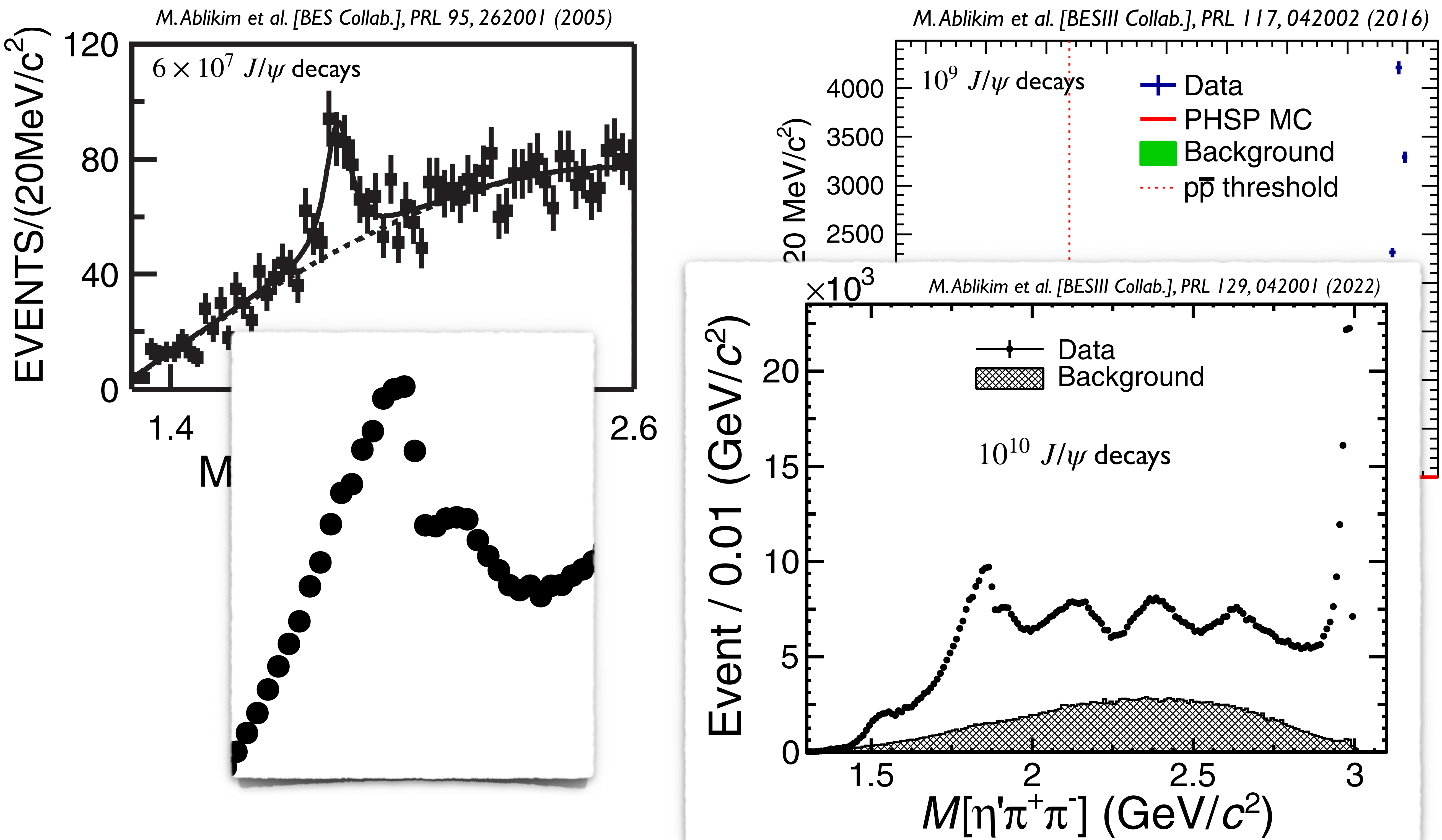
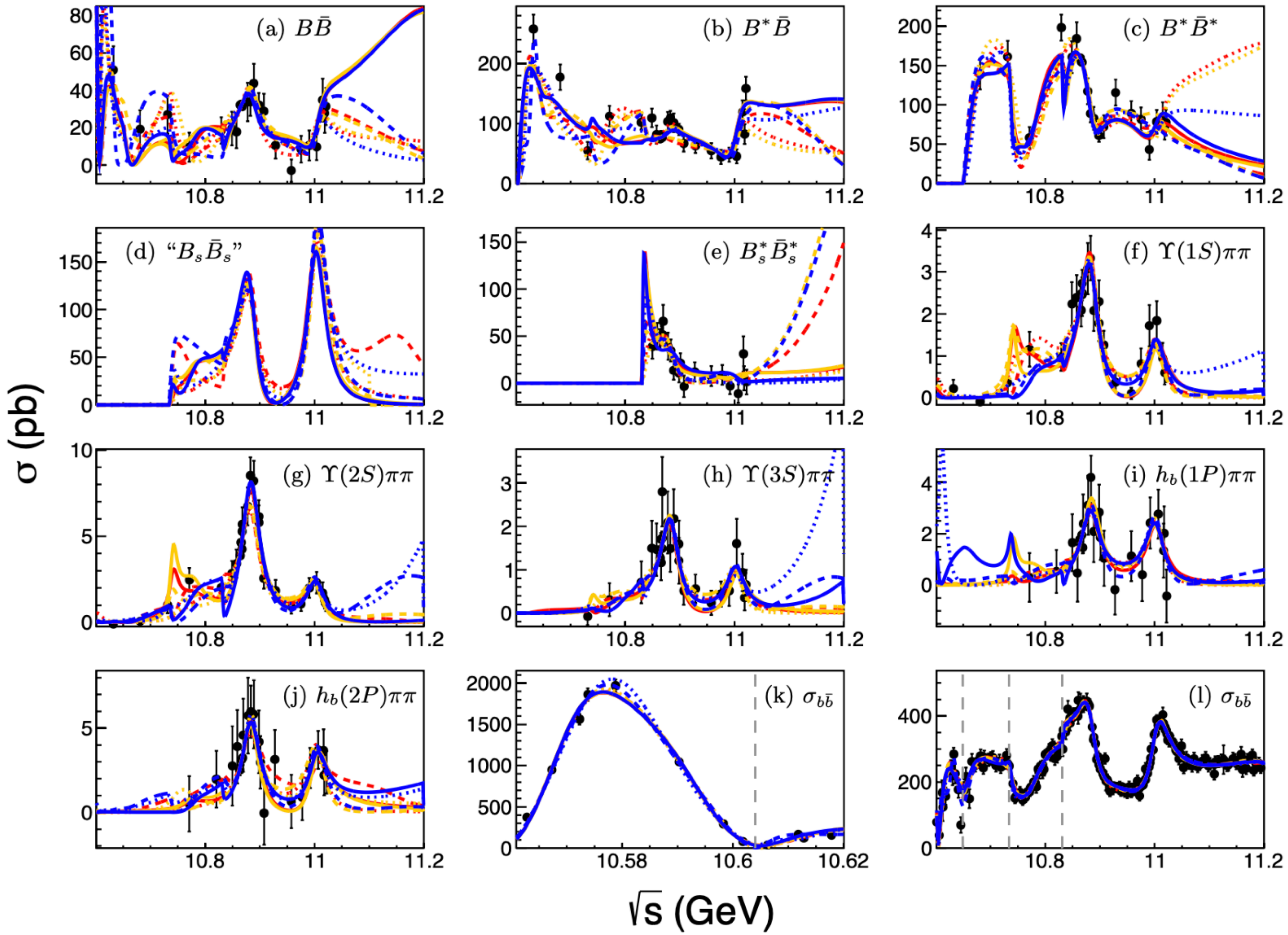


How many resonances do you see?

using new data from Belle:
R. Mizuk et al. [Belle], JHEP 6, 137 (2021)



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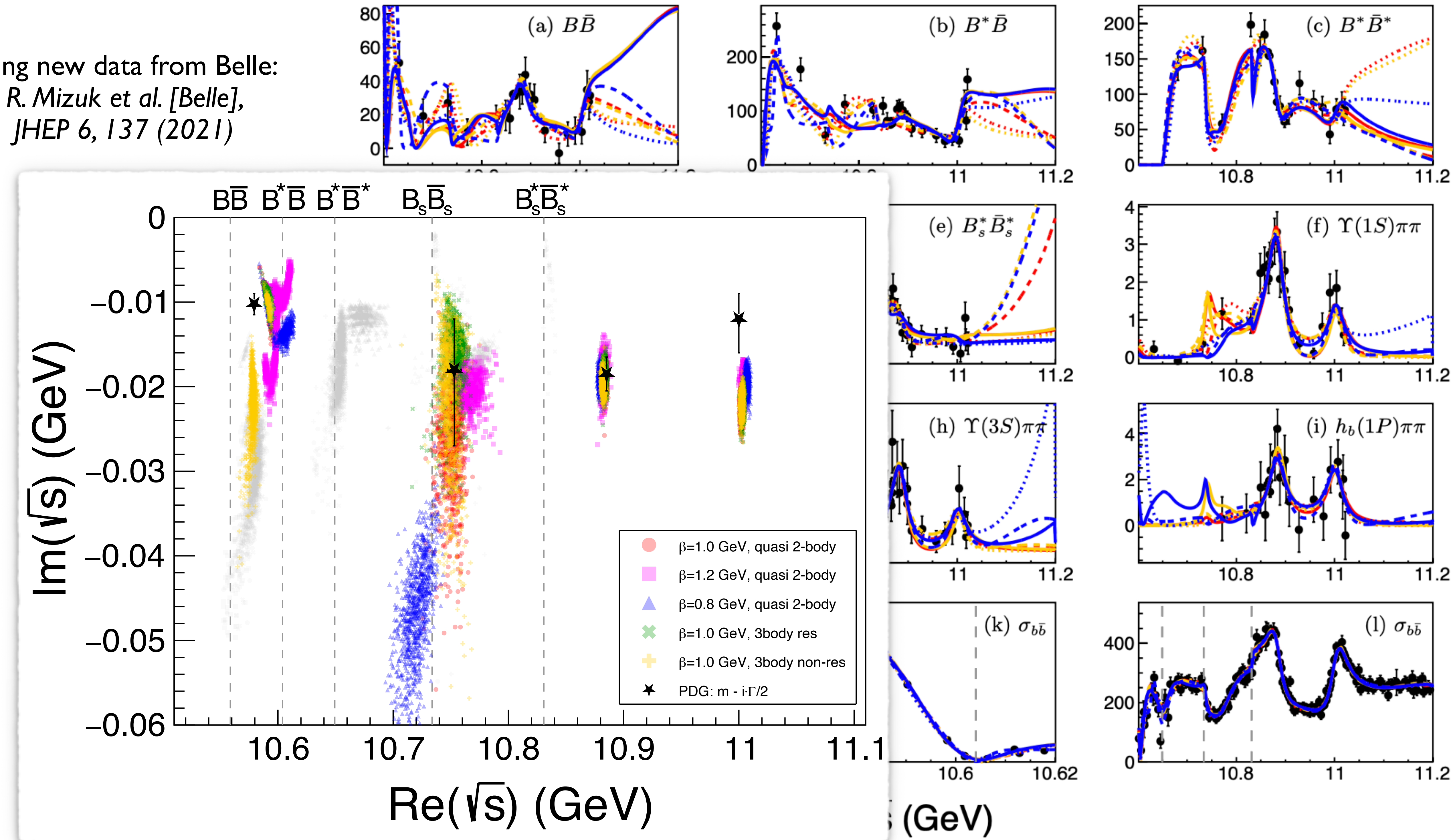

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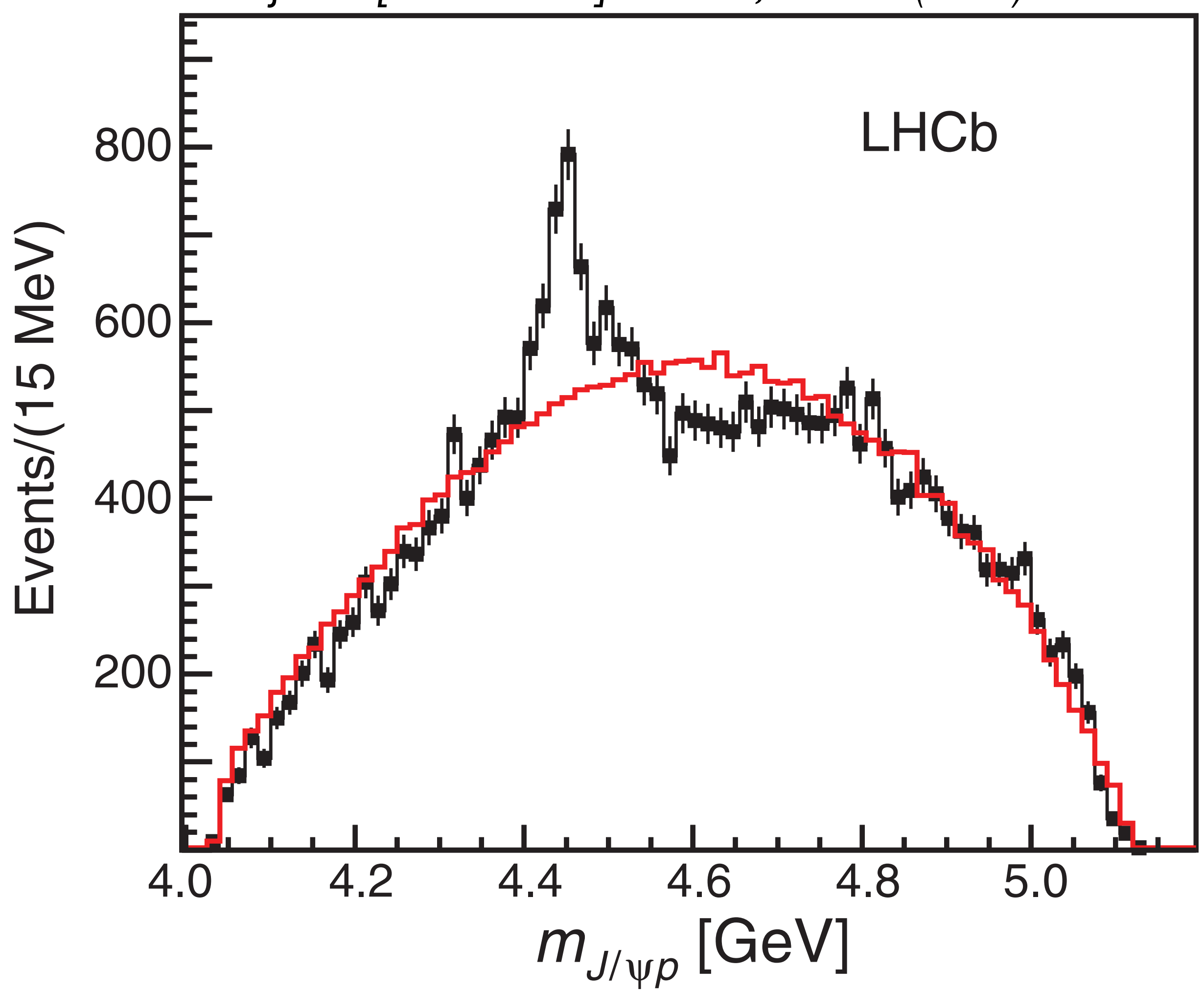

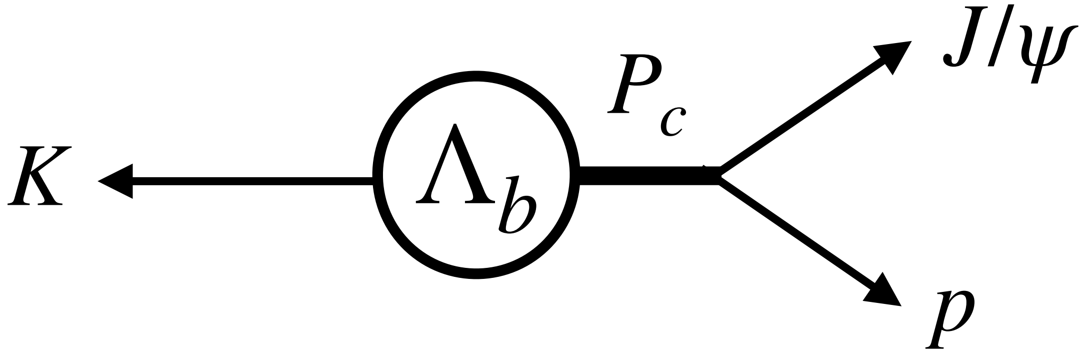

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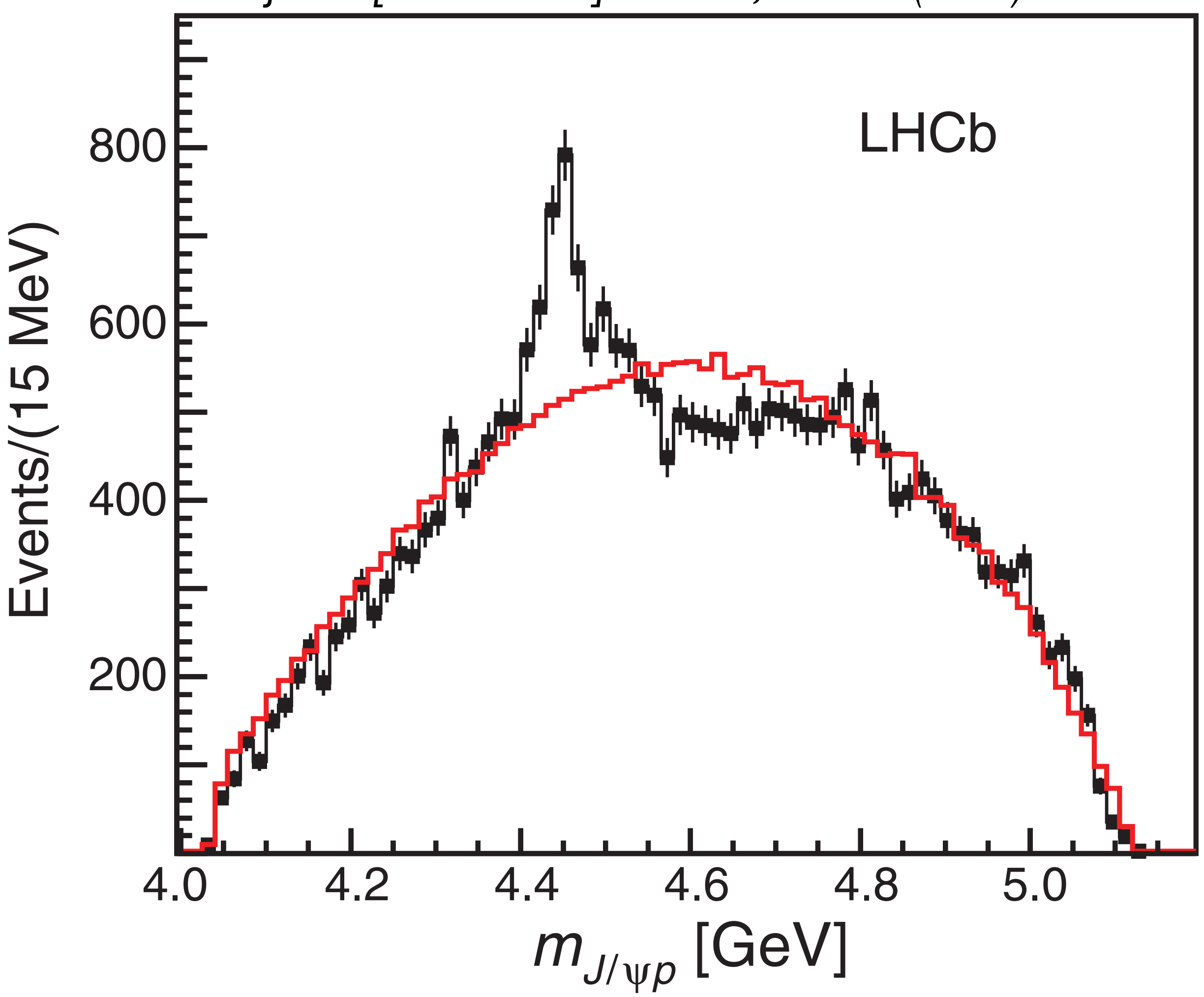

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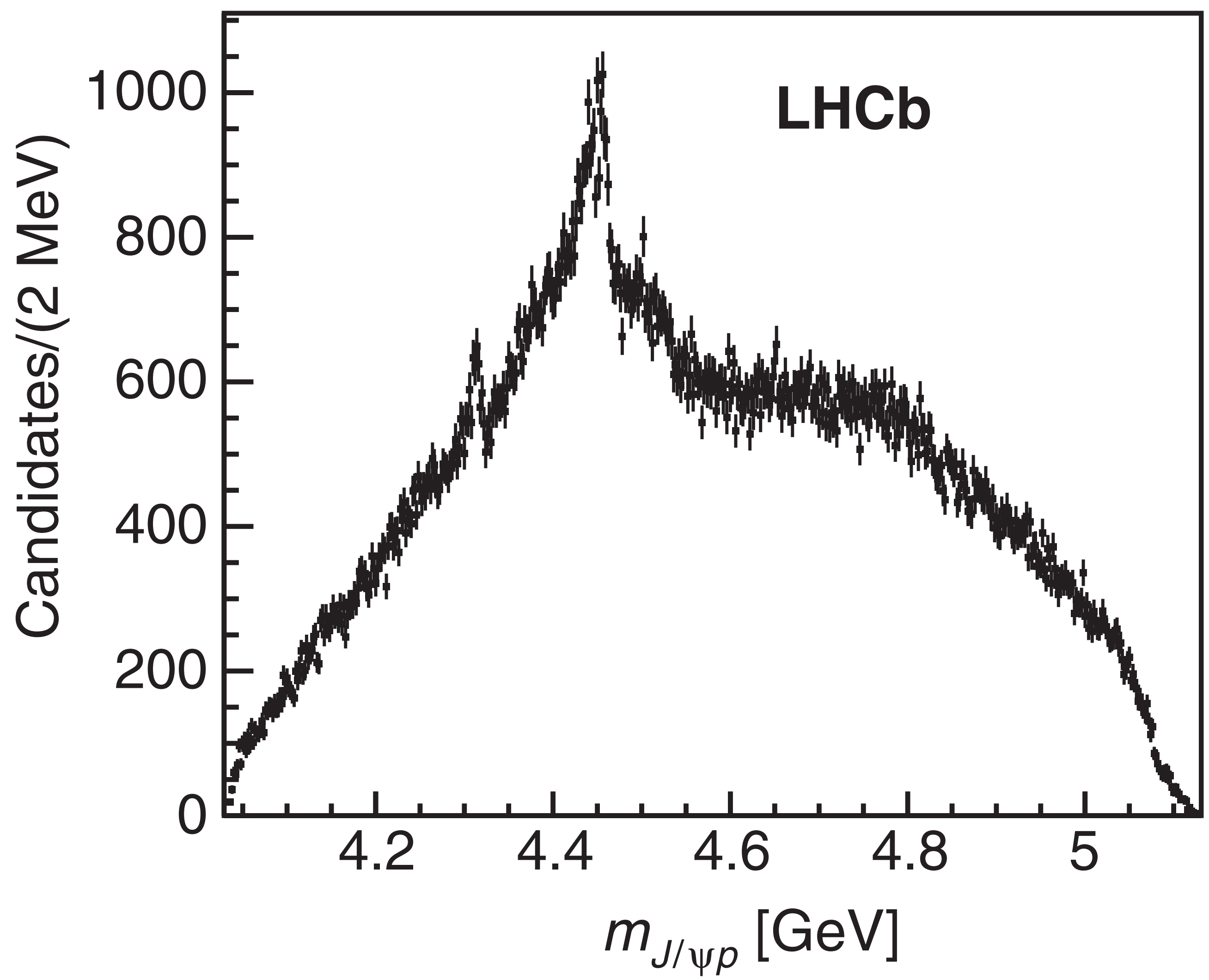

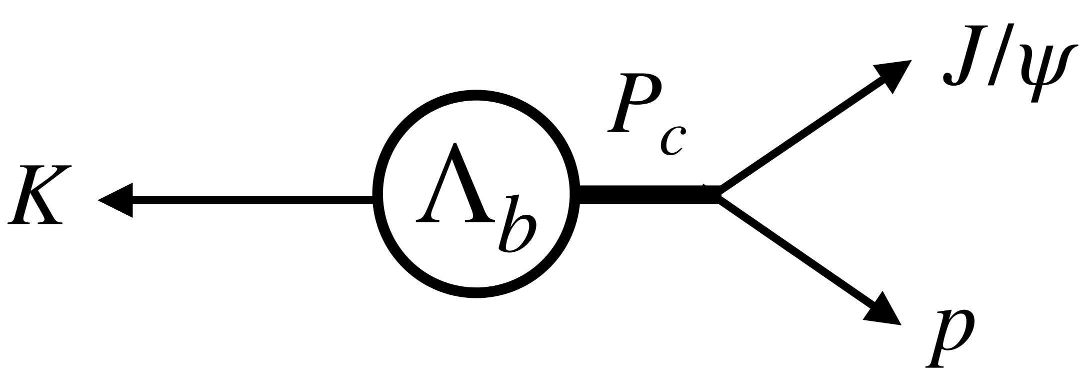

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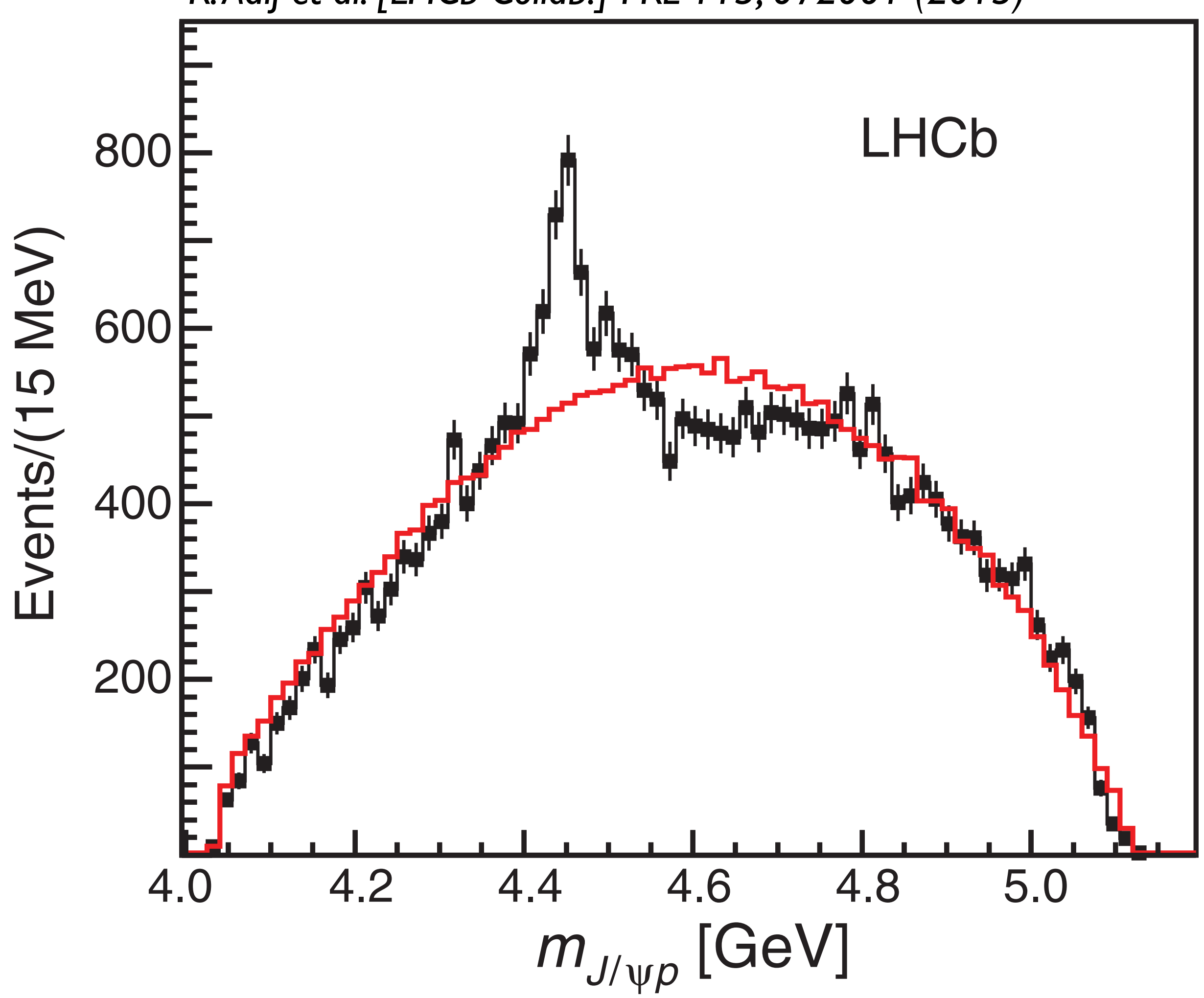

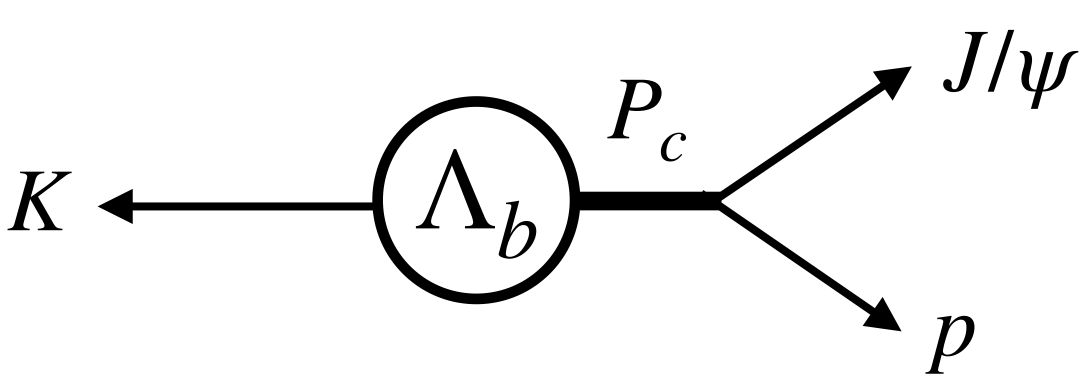

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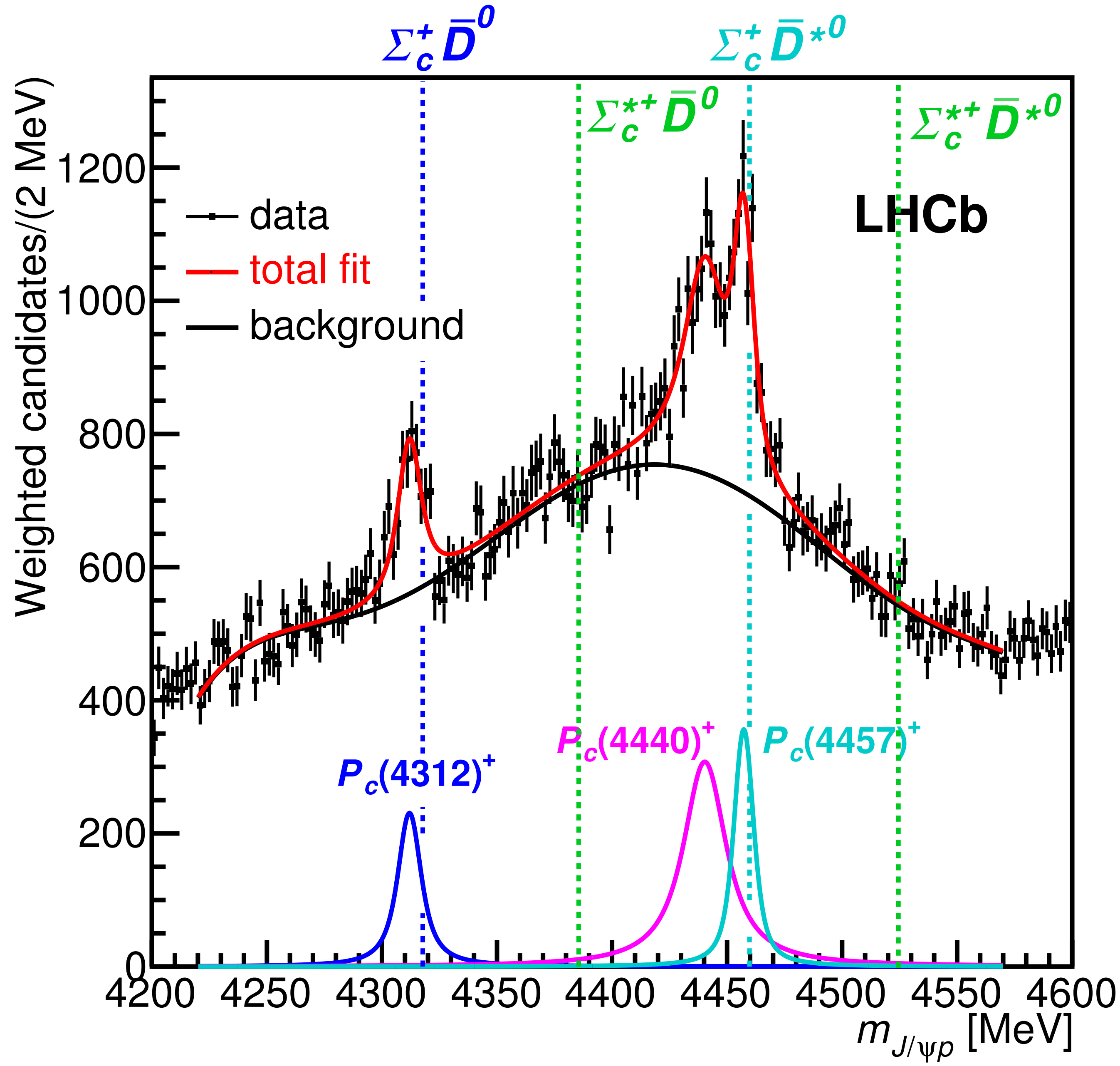

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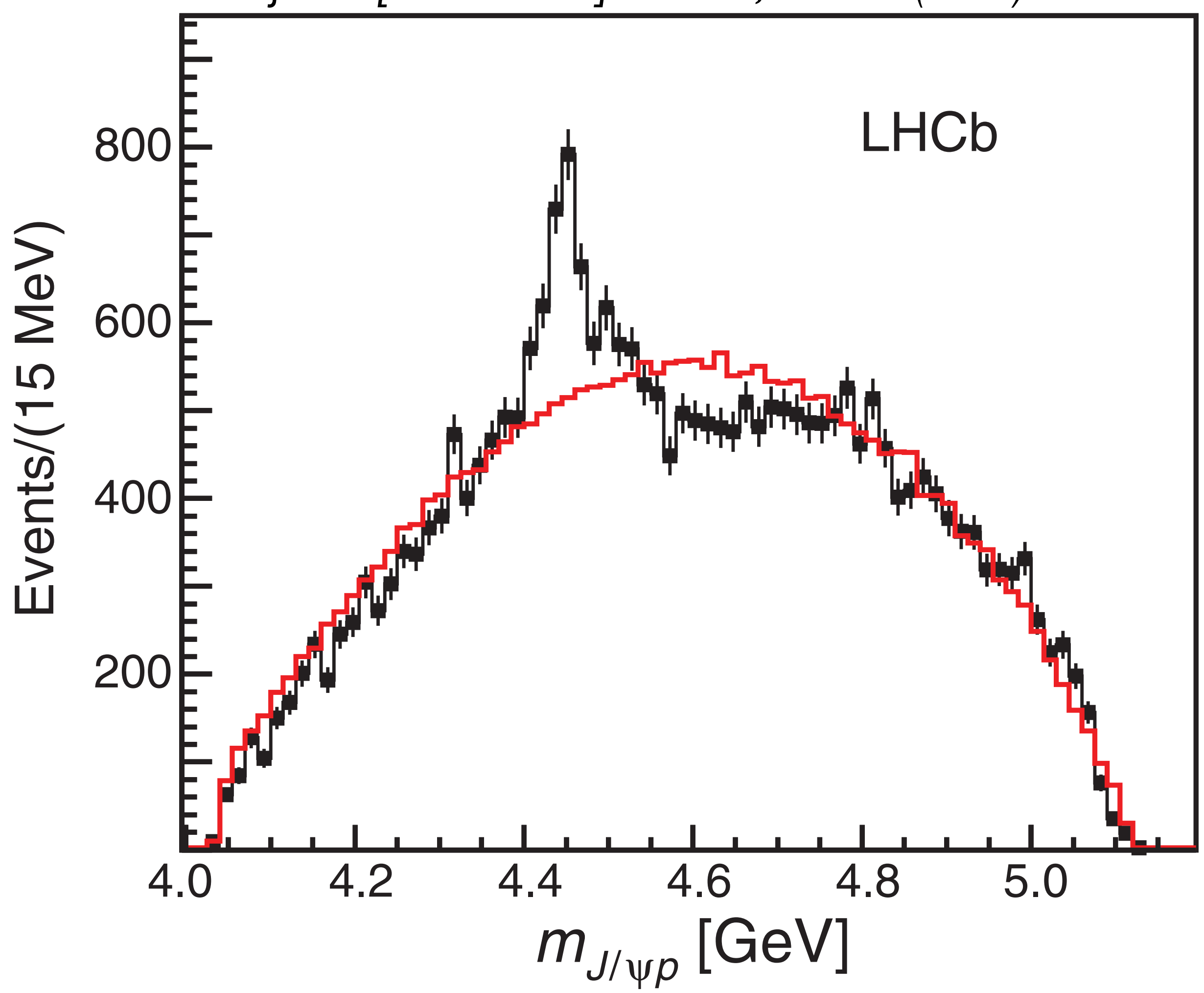

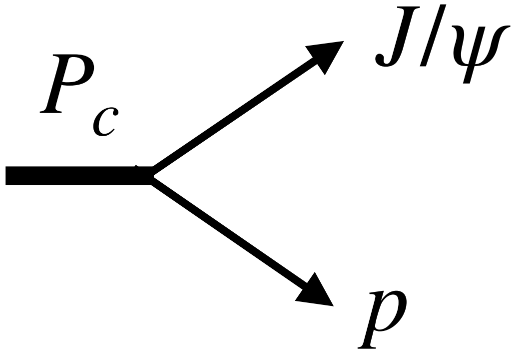

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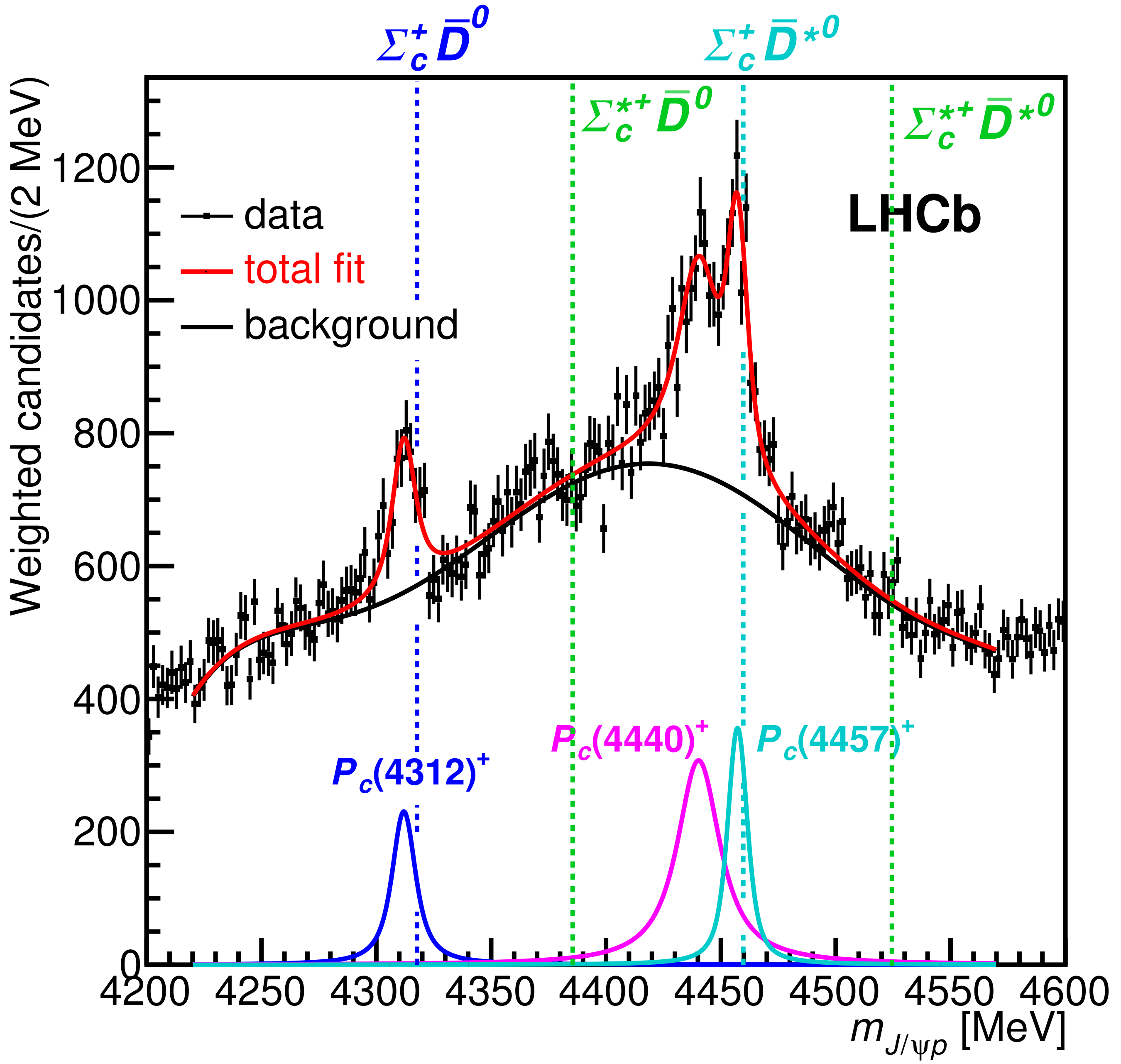

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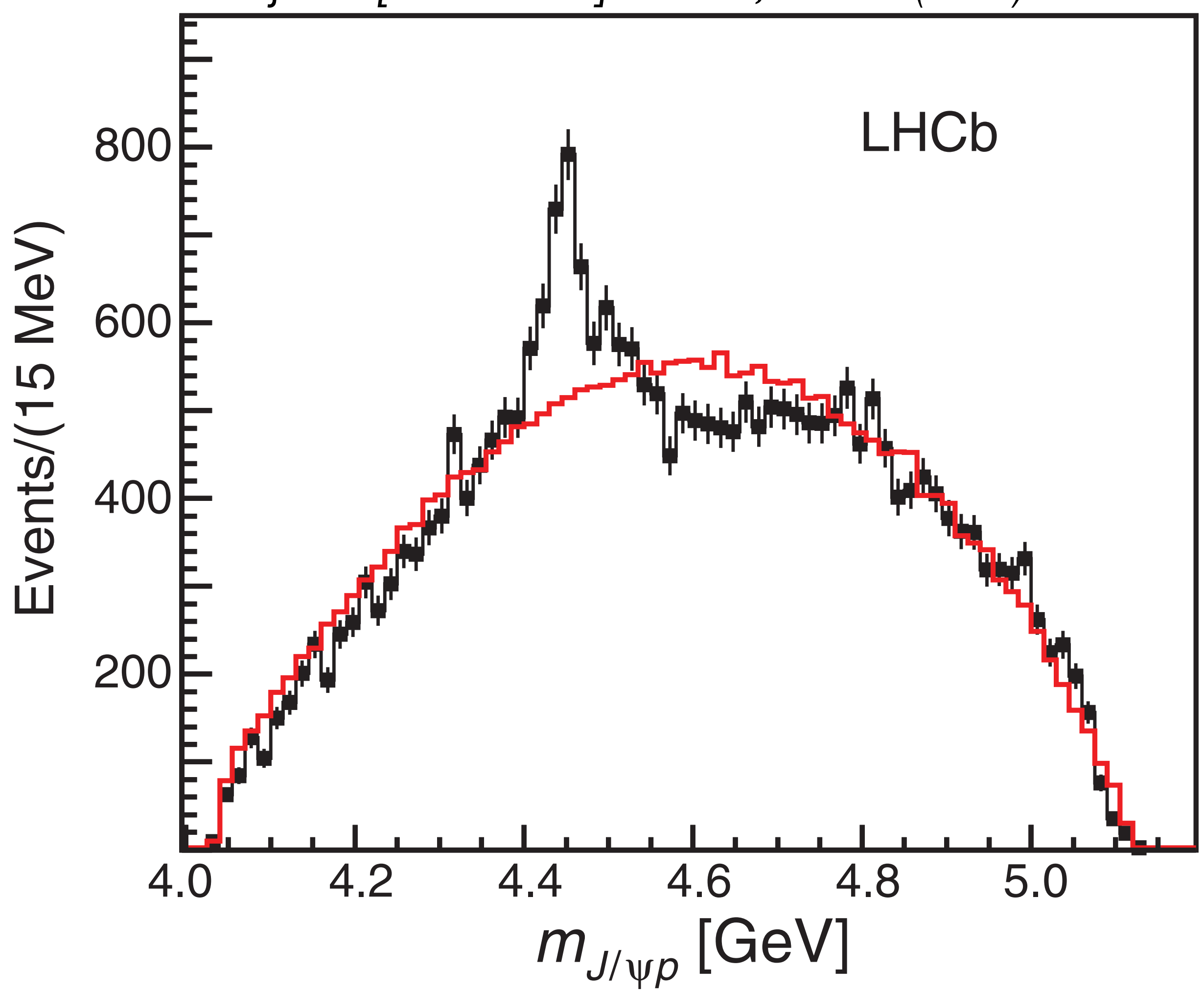

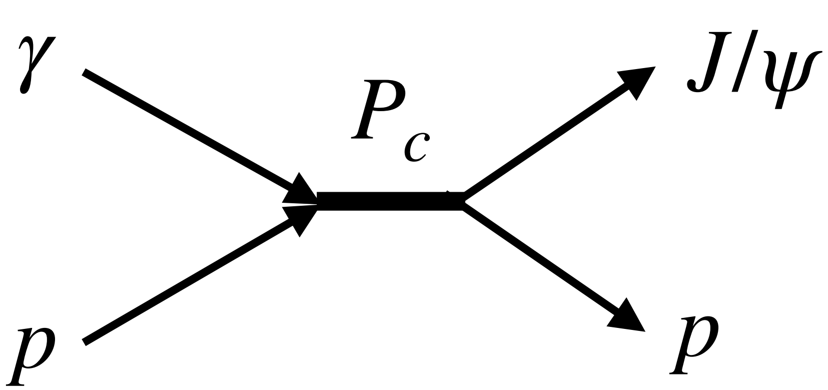

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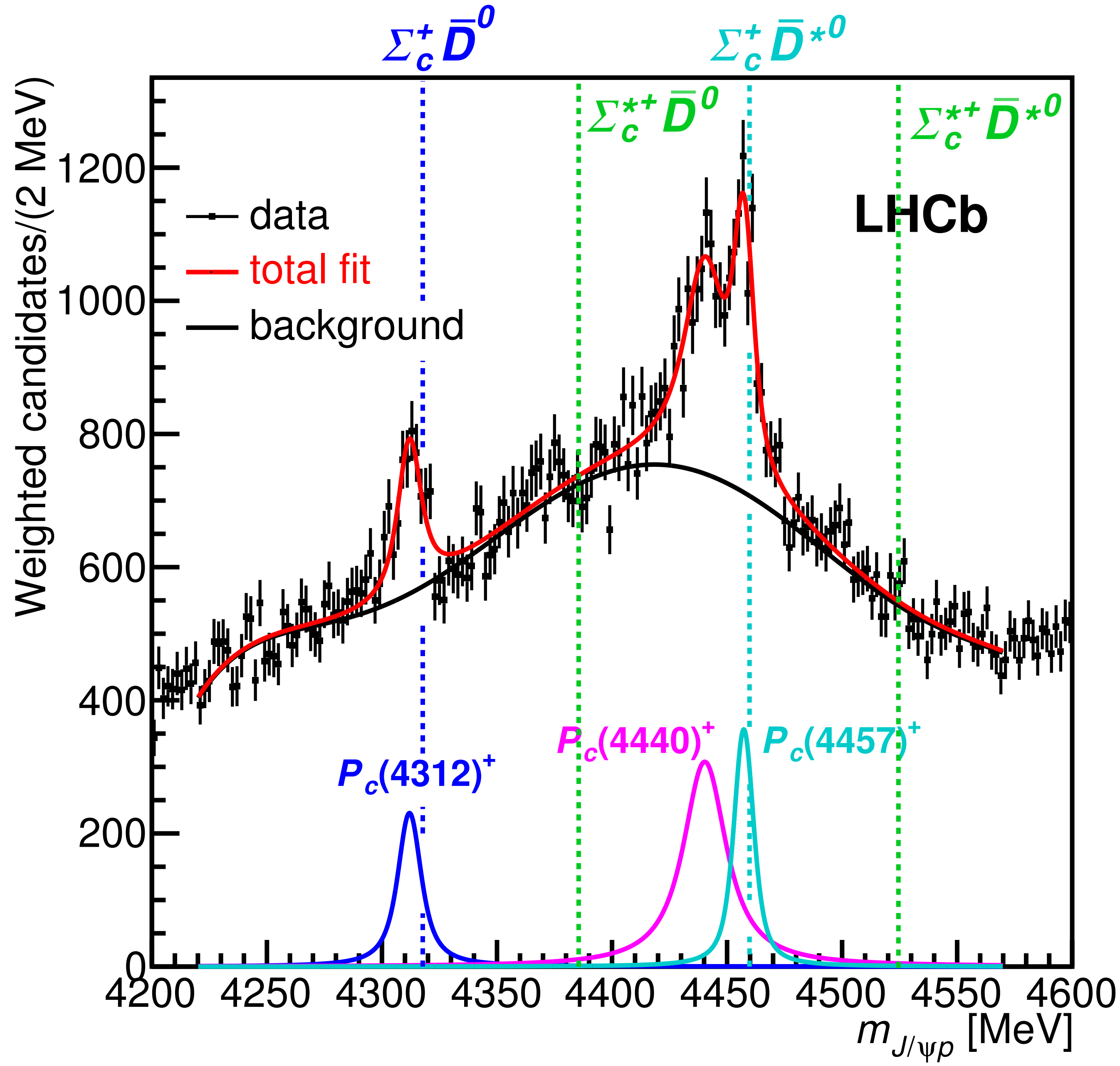

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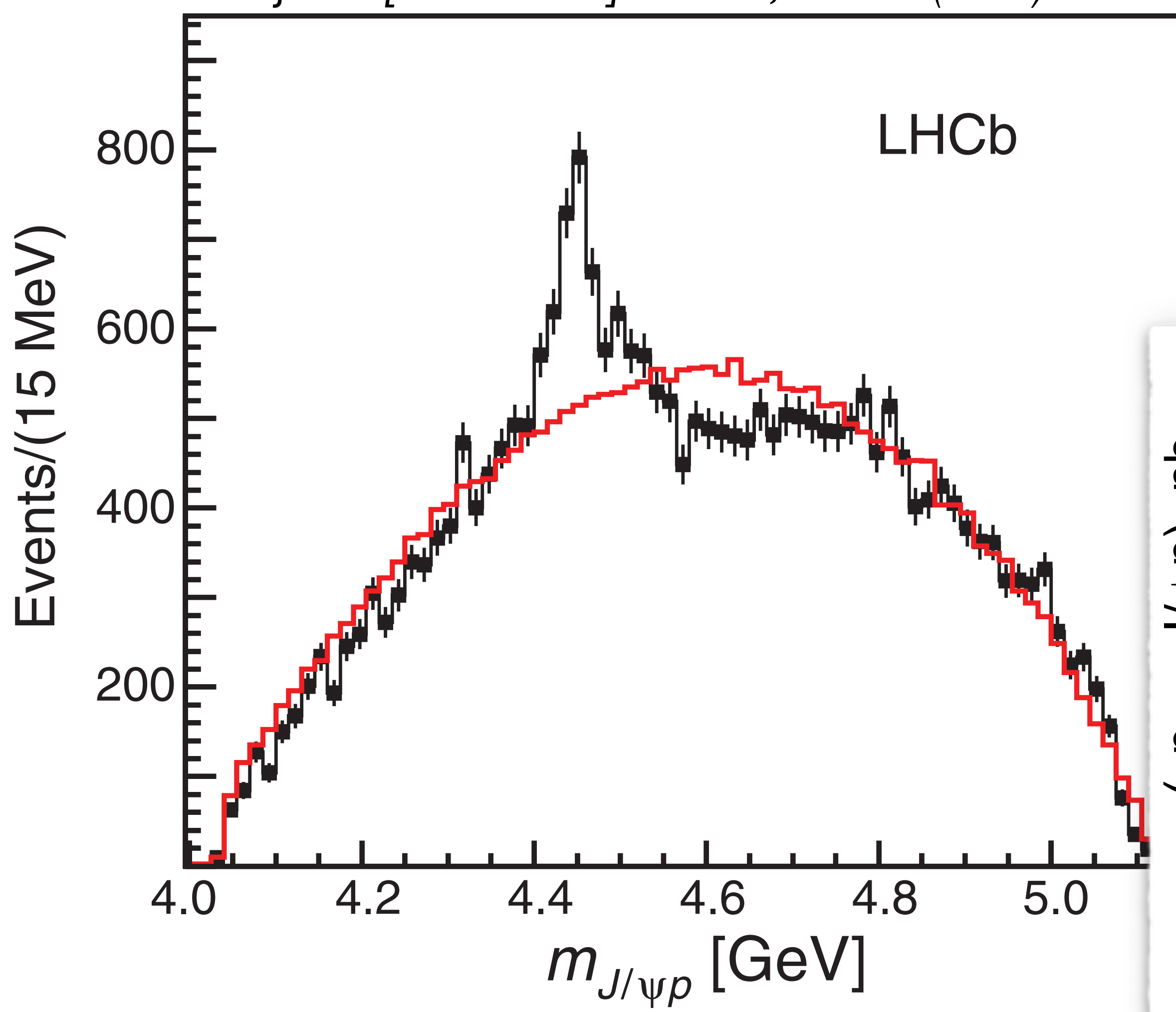

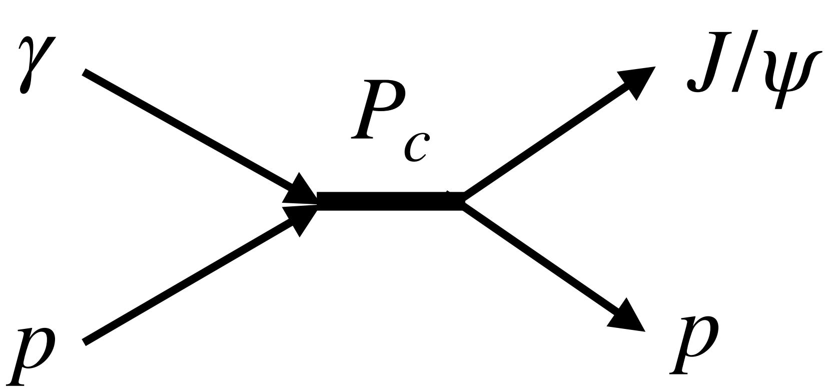

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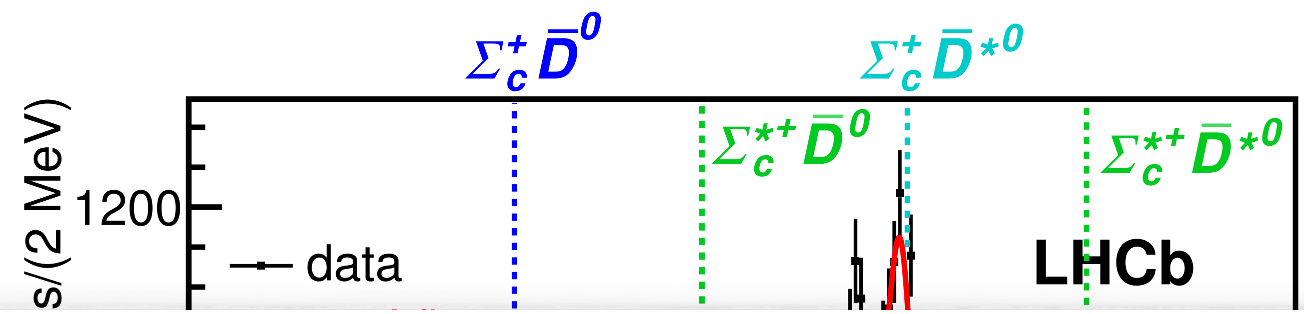

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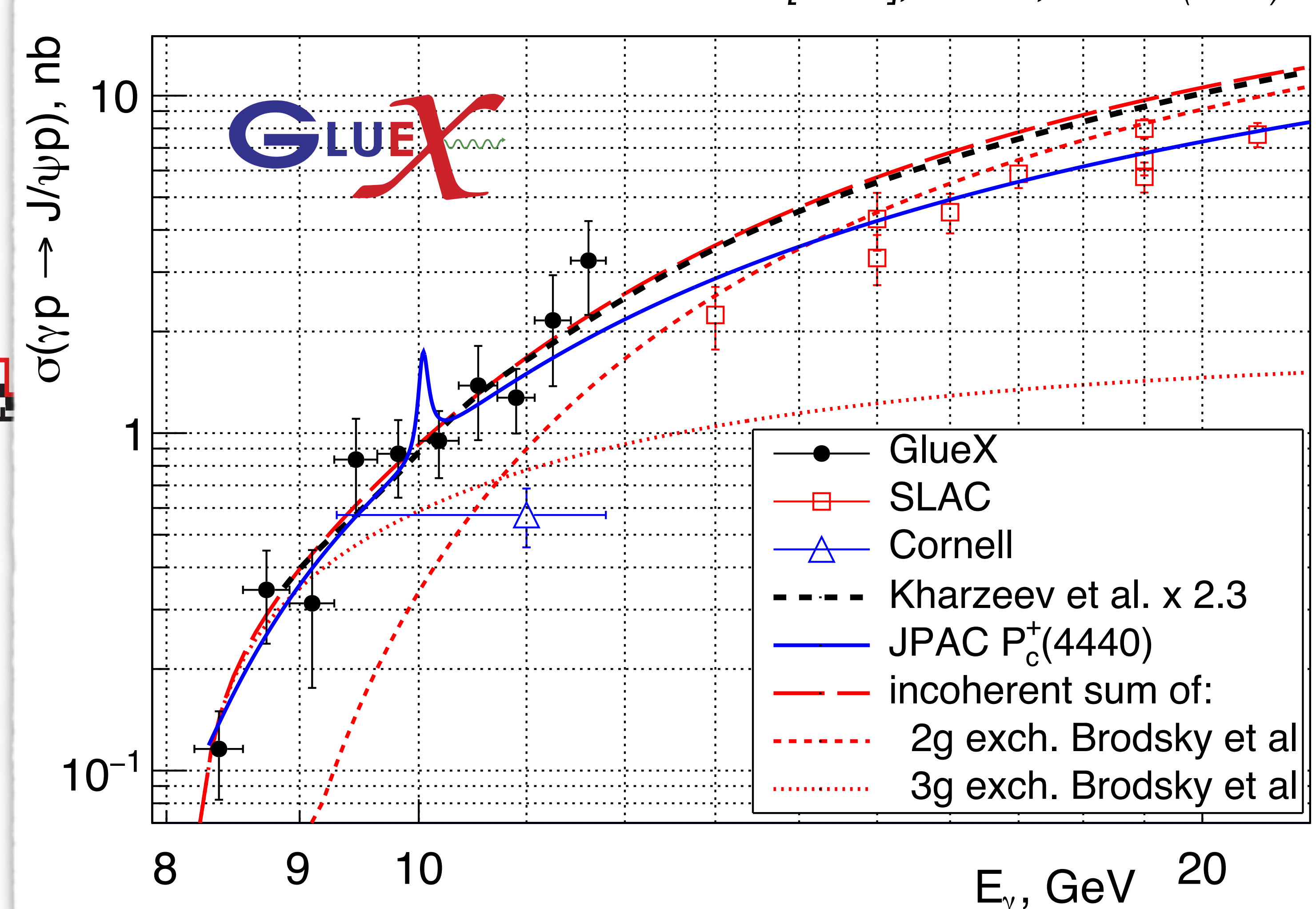

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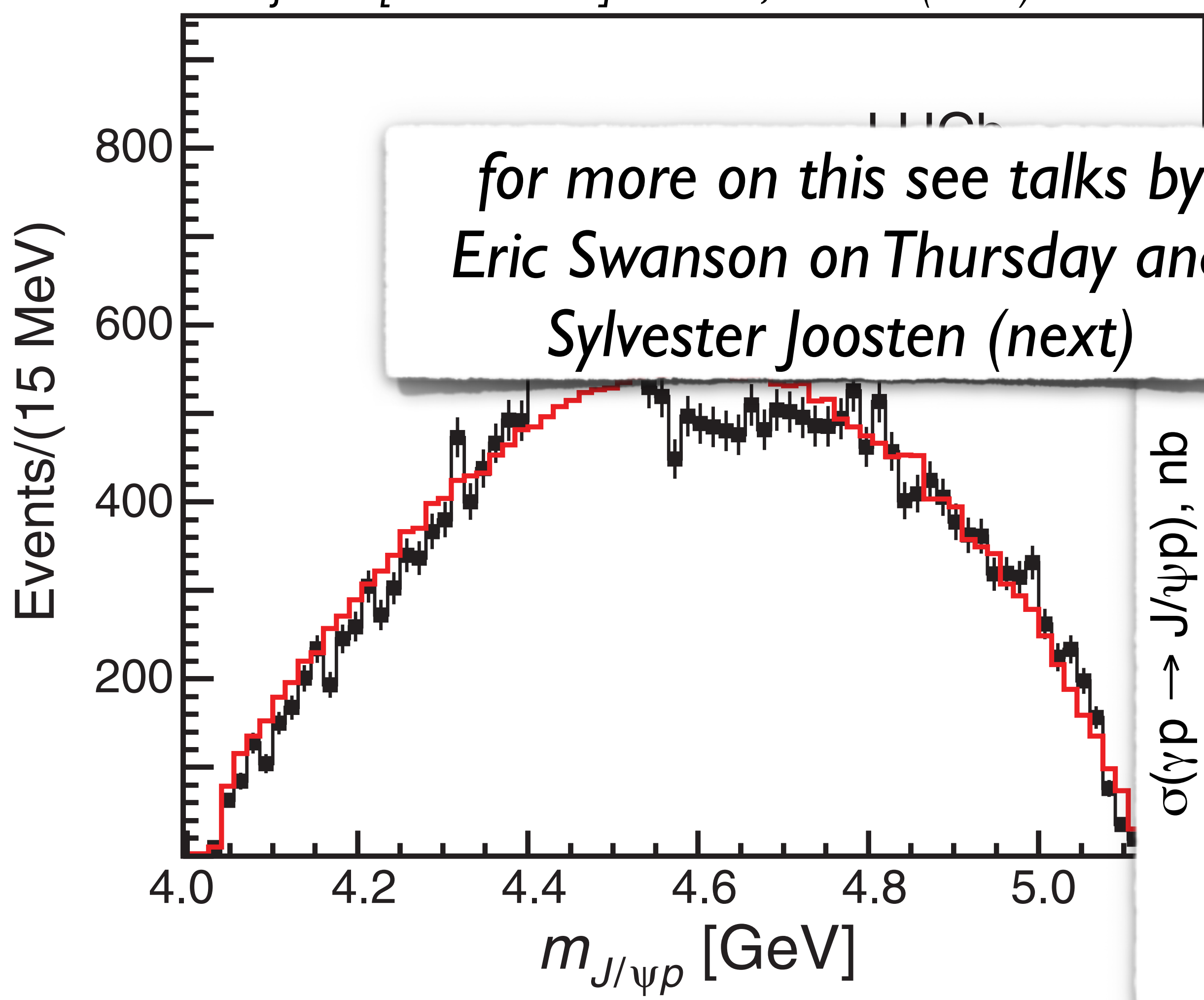

for more on this see talks by Eric Swanson on Thursday and Sylvester Joosten (next)

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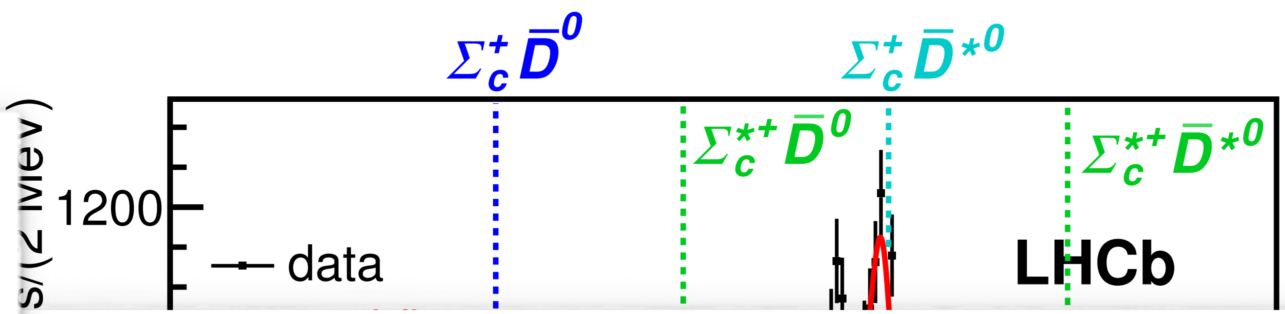

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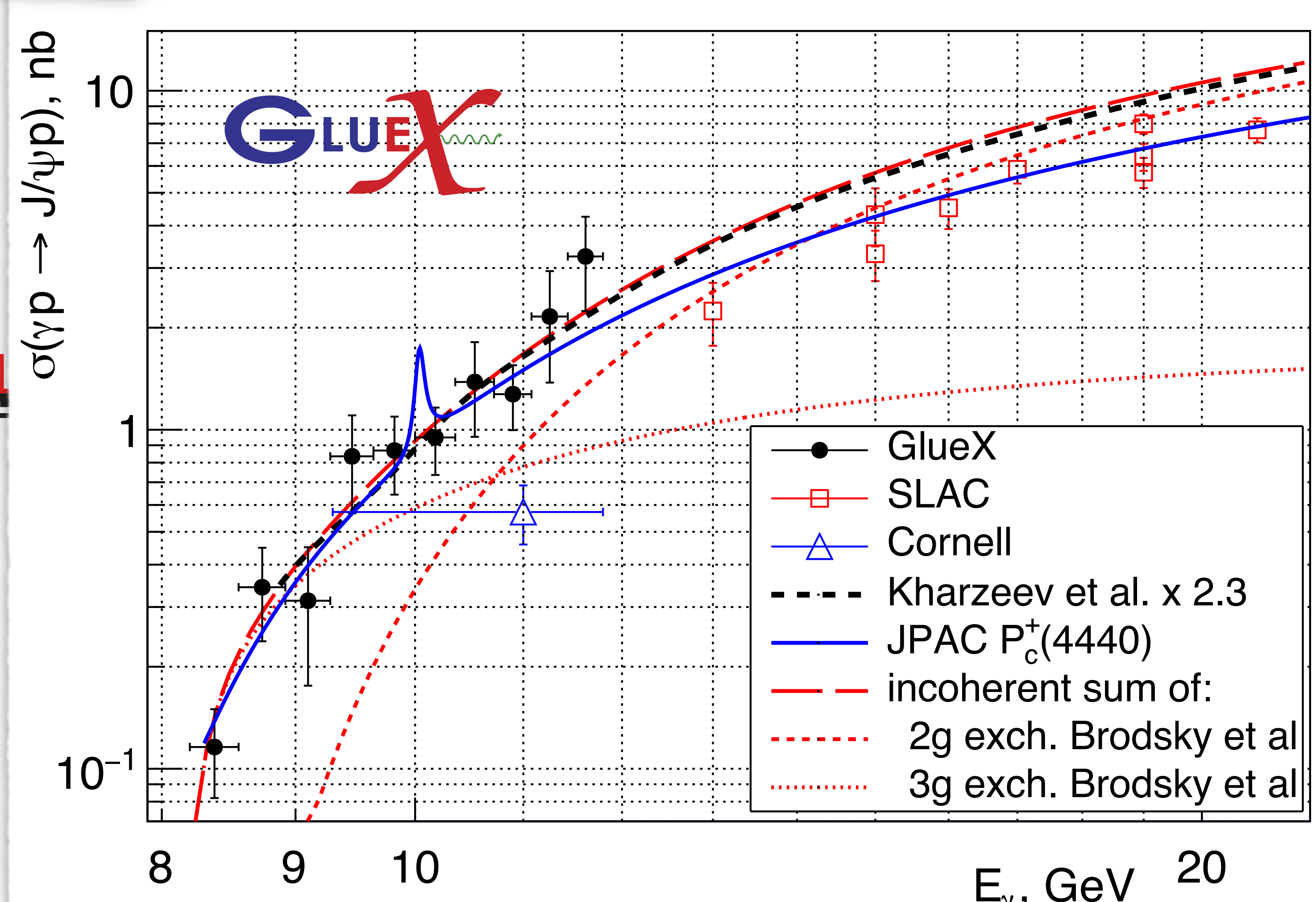
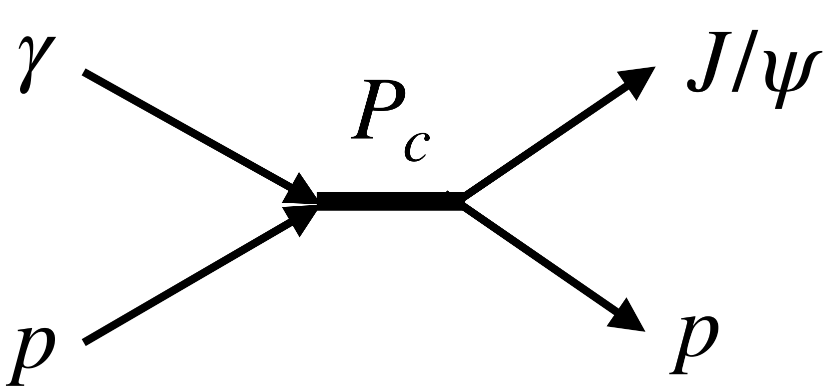
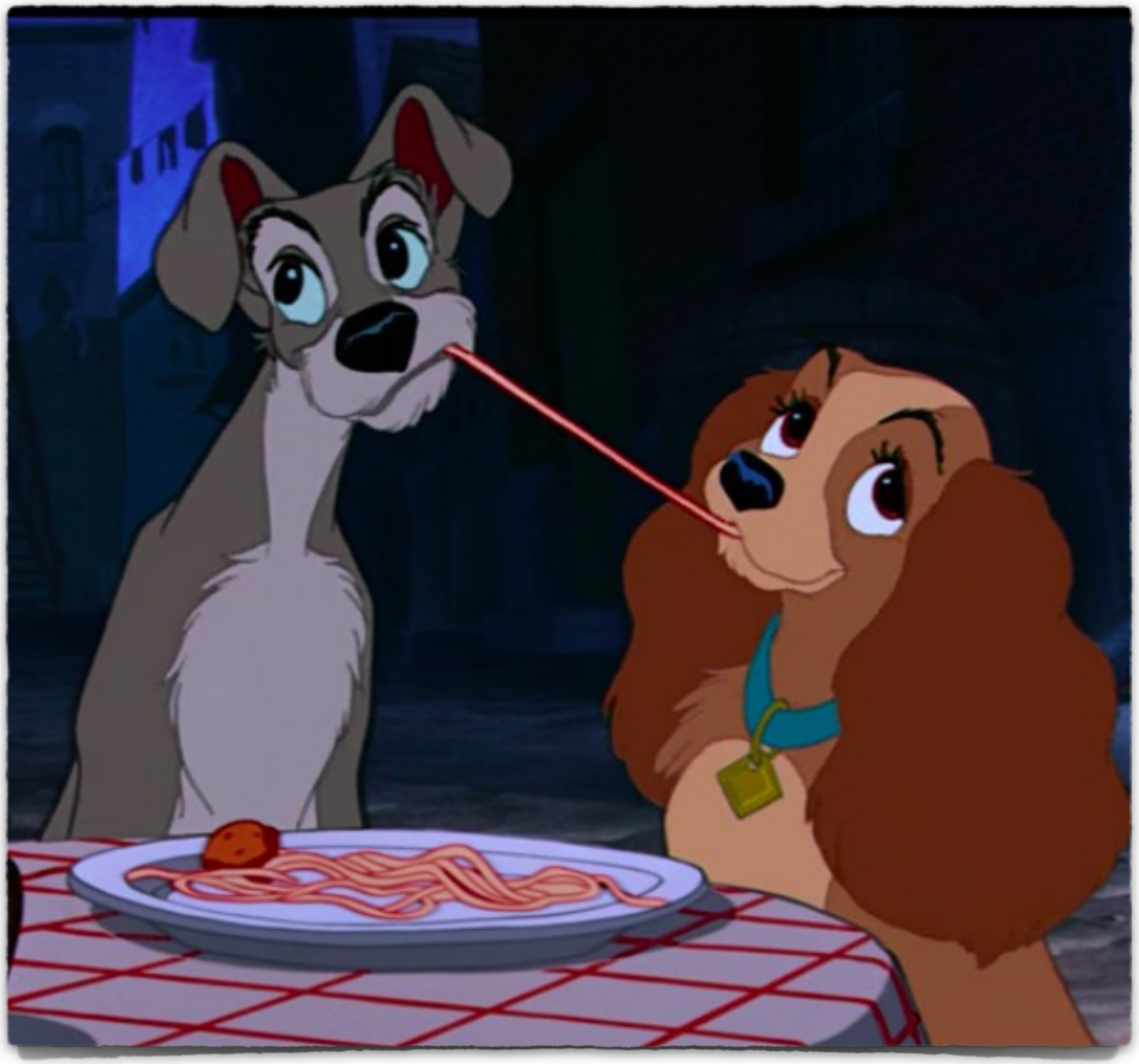




Conclusions and Outlook



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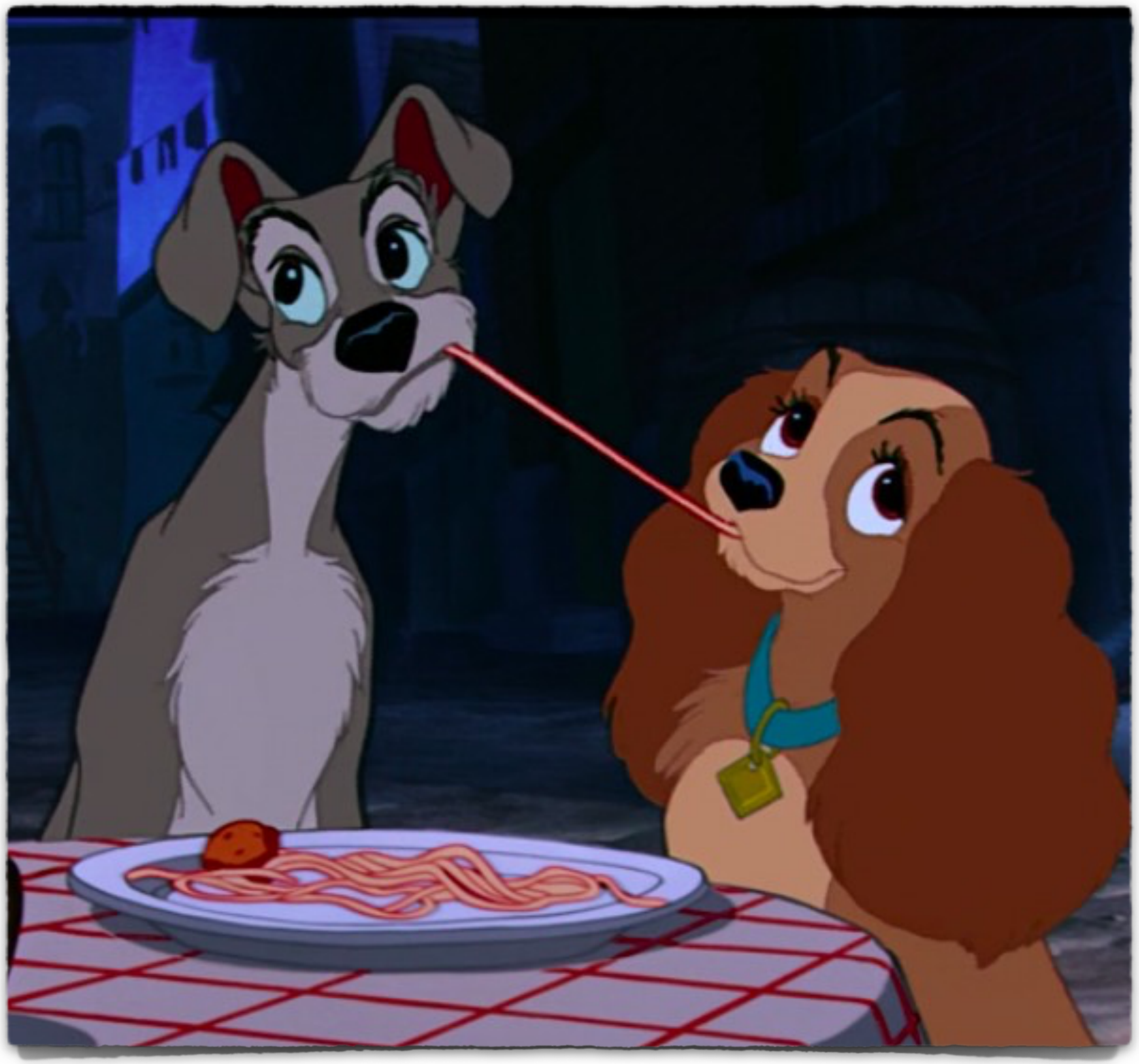

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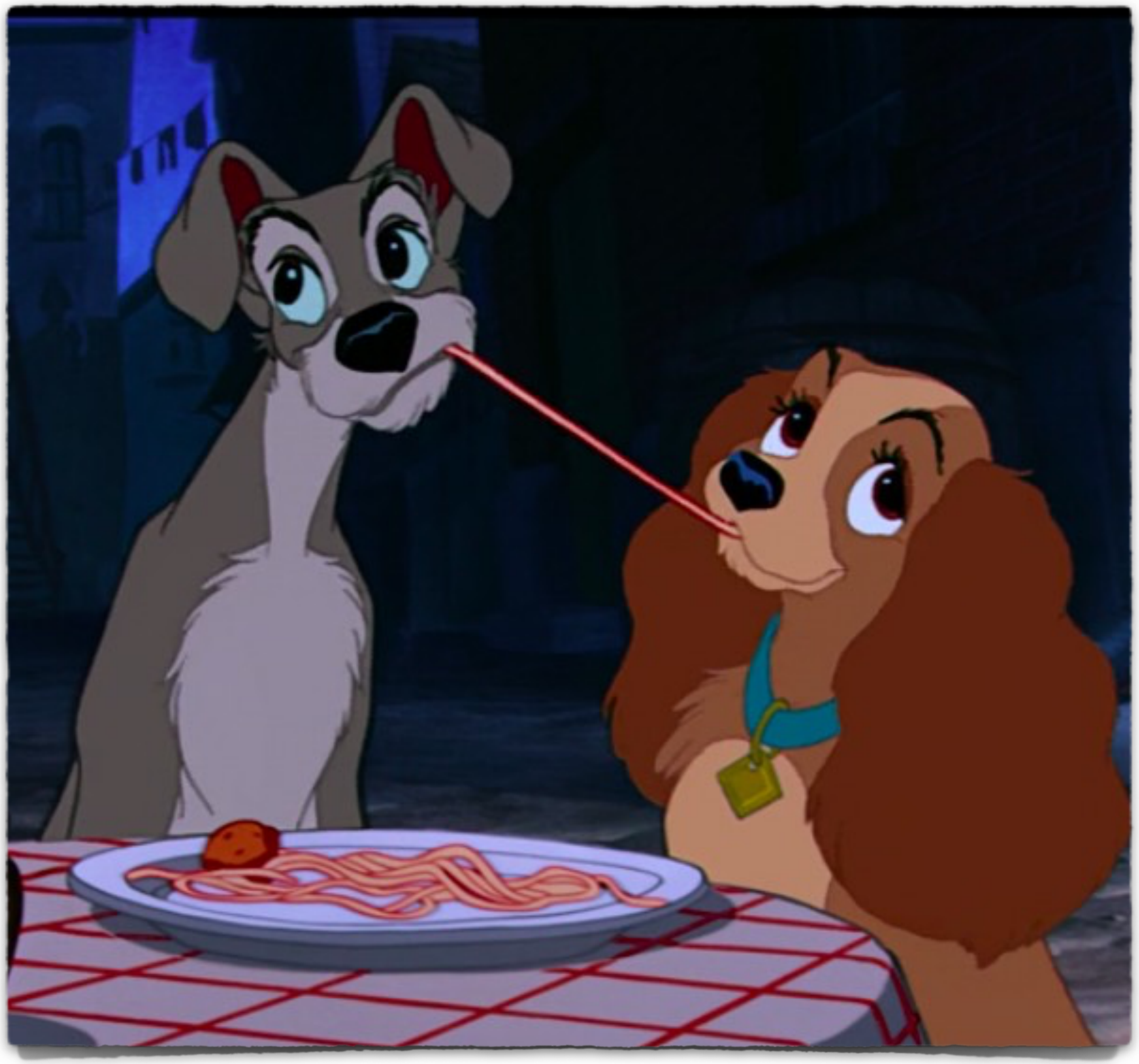

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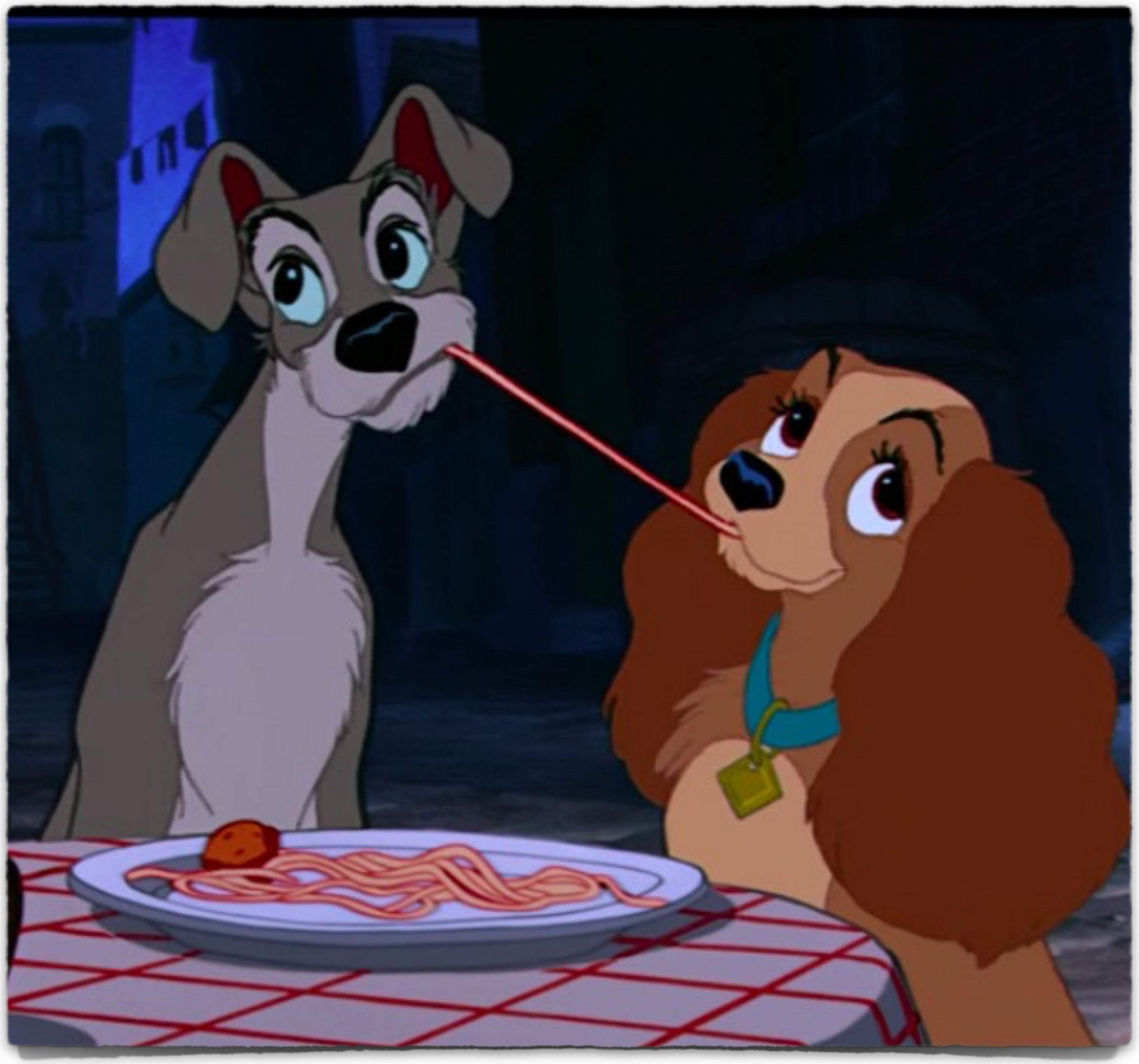
(postdoc opening: inspirehep.net/jobs/2146101)



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