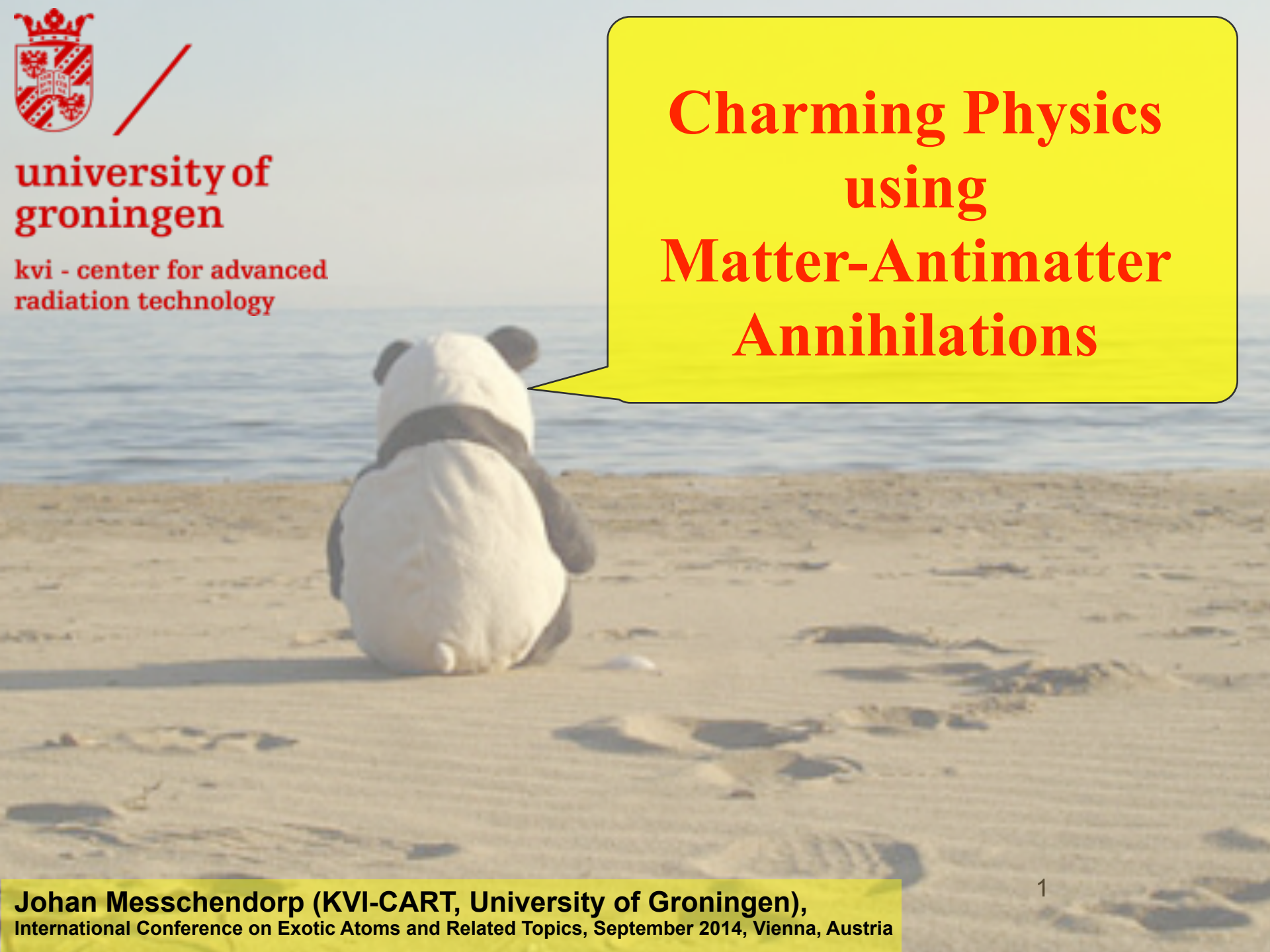

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Charming Physics using Matter-Antimatter Annihilations

Johan Messchendorp (KVI-CART, University of Groningen),

International Conference on Exotic Atoms and Related Topics, September 2014, Vienna, Austria

university of groningen

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Charming Physics using Matter-Antimatter Annihilations

BESIII

p̄anda

Johan Messchendorp (KVI-CART, University of Groningen),

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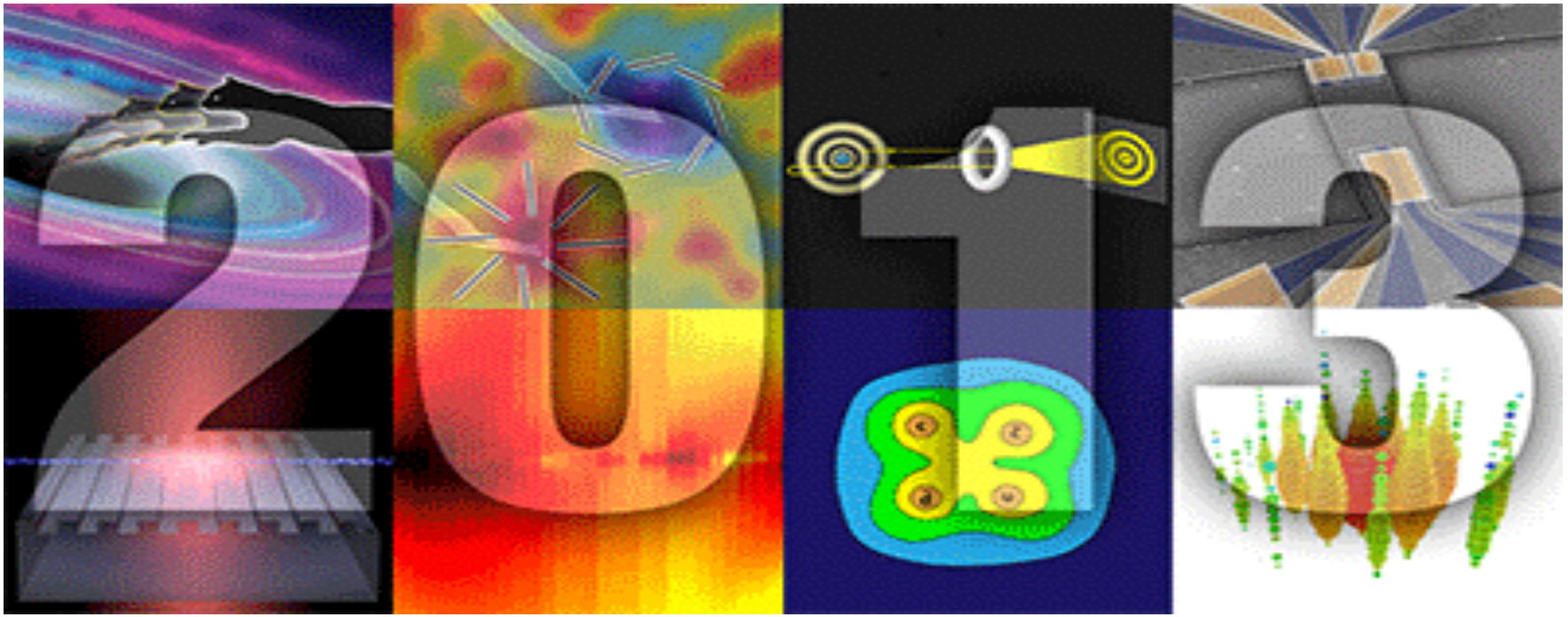
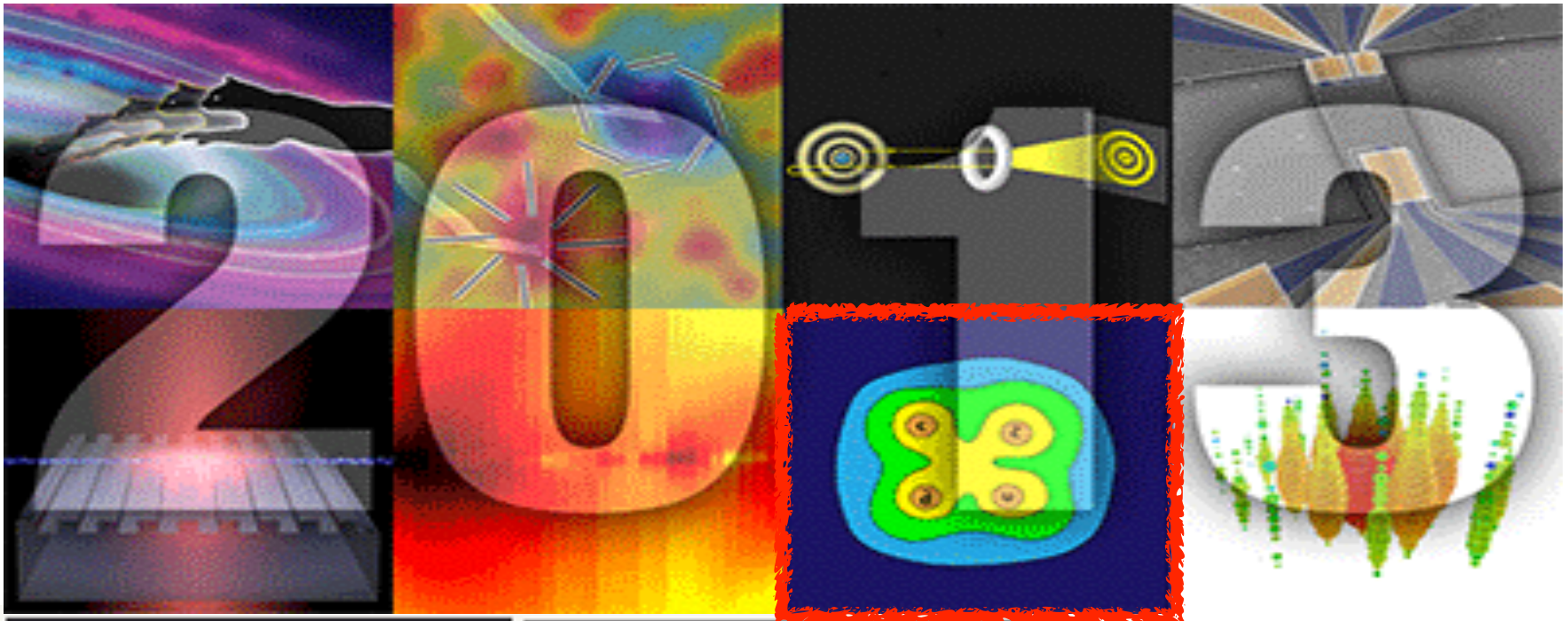
Physics highlight of 2013

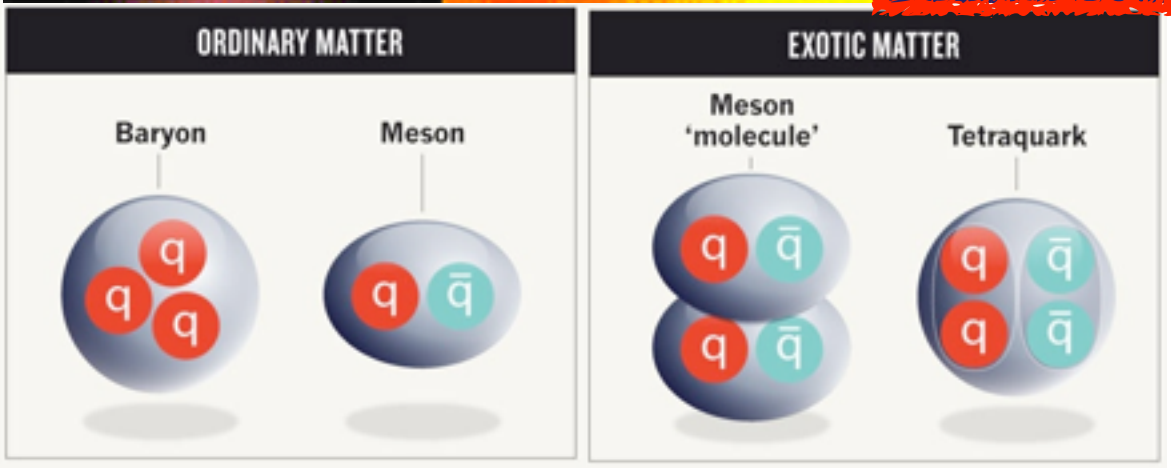
Physics 6, 138 (2013)



Physics highlight of 2013

Physics 6, 138 (2013)





THIS TALK (and more!)

Back to 1974: the "November Revolution"

PRL33, 1404 (1974)

Experimental Observation of a Heavy Particle J†

J. J. Aubert, U. Becker, P. J. Biggs, J. Burger, M. Chen, G. Everhart, P. Goldhagen, J. Leong, T. McCorriston, T. G. Rhoades, M. Rohde, Samuel C. C. Ting, and Sau Lan Wu

Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

and

Y. Y. Lee

Brookhaven National Laboratory, Upton, New York 11973

(Received 12 November 1974)

$$p + \mathrm{Be} \rightarrow J(\rightarrow e^+e^-) + X$$

PRL33, 1406 (1974)

Discovery of a Narrow Resonance in e^+e^- Annihilation*

J.-E. Augustin,† A. M. Boyarski, M. Breidenbach, F. Bulos, J. T. Dakin, G. J. Feldman, G. E. Fischer, D. Fryberger, G. Hanson, B. Jean-Marie,† R. R. Larsen, V. Lüth, H. L. Lynch, D. Lyon, C. C. Morehouse, J. M. Paterson, M. L. Perl, B. Richter, P. Rapidis, R. F. Schwitters, W. M. Tanenbaum, and F. Vannucci‡

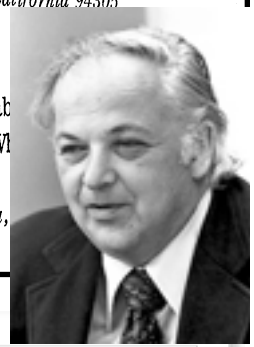
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and

G. S. Abrams, D. Briggs, W. Chinowsky, C. E. Friedberg, G. Goldhab, J. A. Kadyk, B. Lulu, F. Pierre,§ G. H. Trilling, J. S. Wh, J. Wiss, and J. E. Zipse

Lawrence Berkeley Laboratory and Department of Physics, University of California,

(Received 13 November 1974)

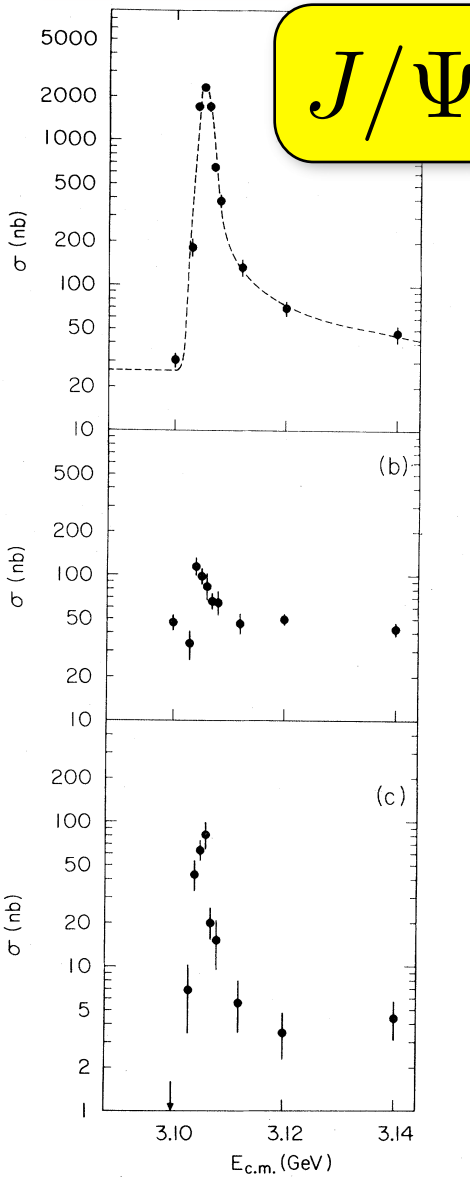


$$e^+ + e^- \rightarrow \psi(3105) \rightarrow \ldots$$

J/Ψ

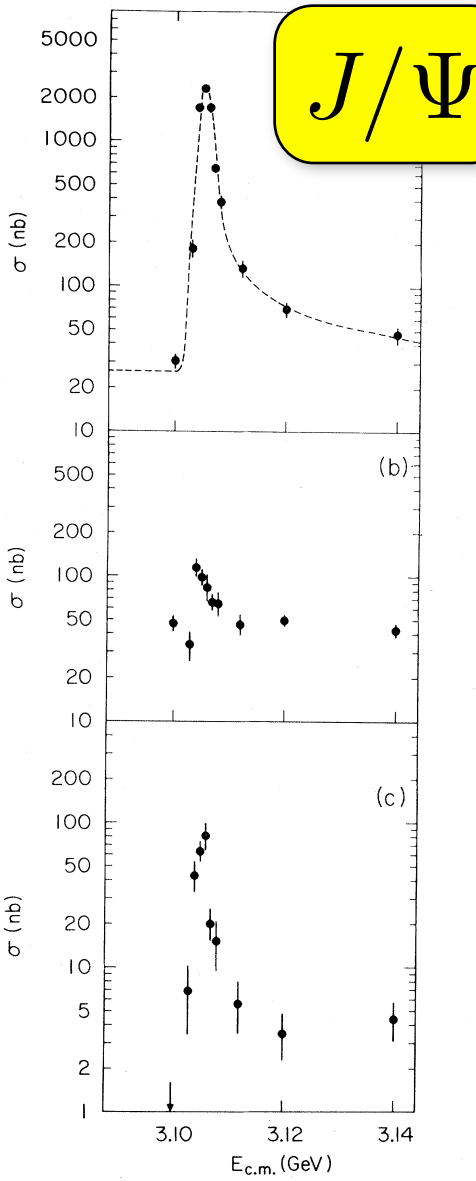
40th year anniversary!

Back to 1974: the "November Revolution"



What could be its nature?

Back to 1974: the "November Revolution"



What could be its nature?

Baryon-Antibaryon Nuclei?

Goldhaber(s), PRL34, 36 (1975)

Spin-1 alternative to GIM?

Schwinger, PRL34, 37 (1975)

Three charm quarks (partners to u,d,s)?

Barnett, PRL34, 41 (1975)

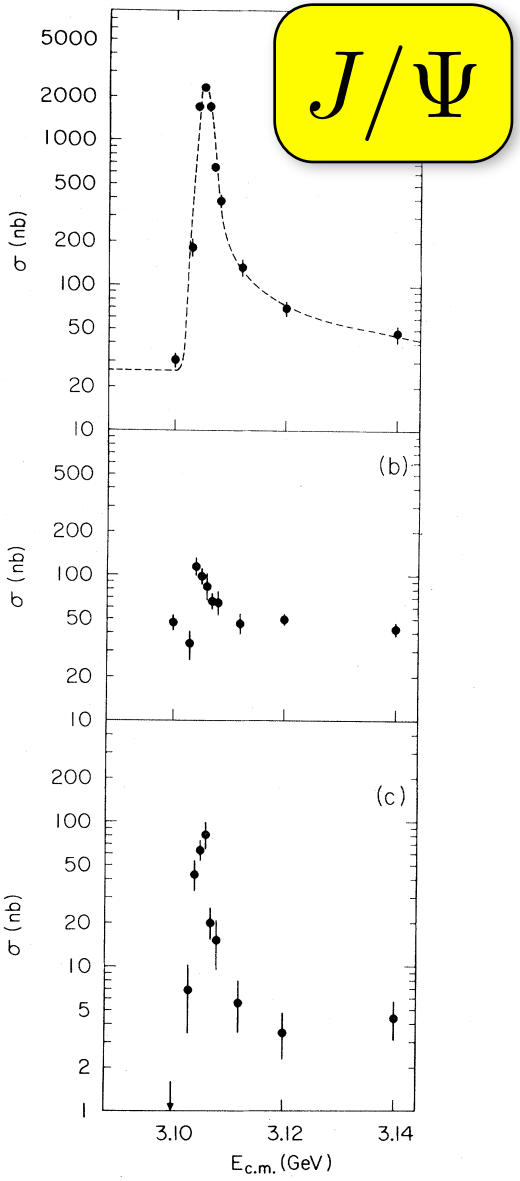
Lighter weak-force boson?

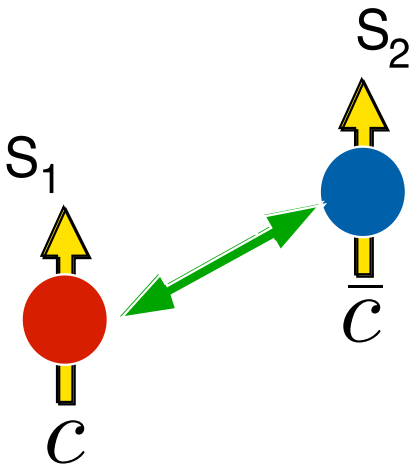
Sakurai, PRL34, 56 (1975)

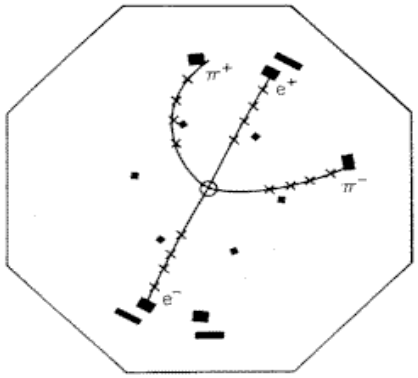
Charmonium - charm-anticharm bound state!

Appelquist & Politzer, PRL34, 43 (1975)
De Rujula & Glashow, PRL34, 46 (1975)

Back to 1974: the "November Revolution"







1976: Nobel Prize to Ting&Richter
for the discovery of the charm quark

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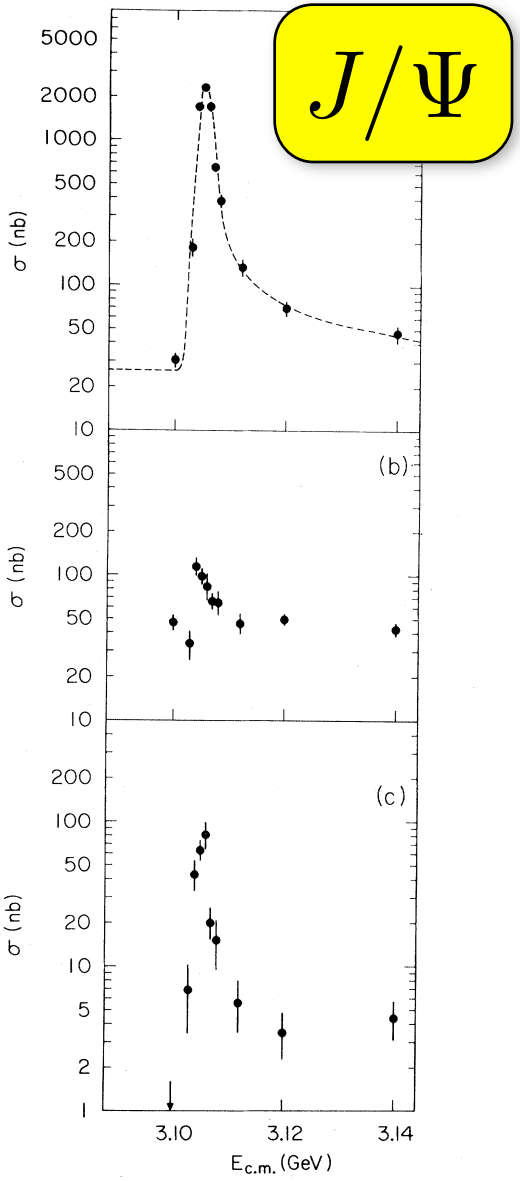
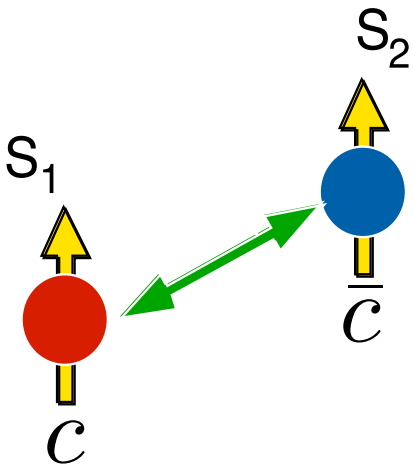
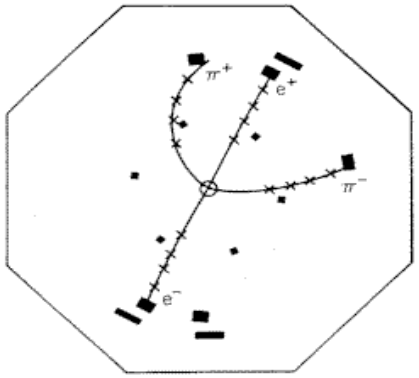




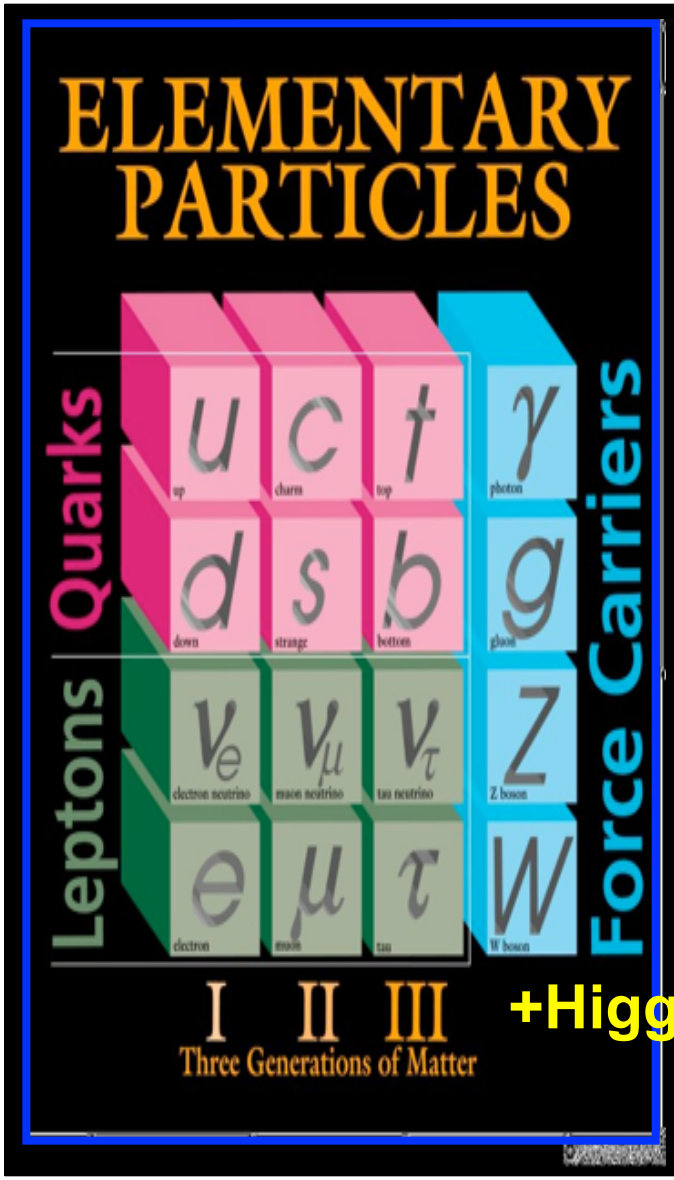


1976: Nobel Prize to Ting&Richter
for the discovery of the charm quark

next available Greek letter was
"iota" ι = "insignificance"

Be happy they skipped that one!

1971: the birth of QCD

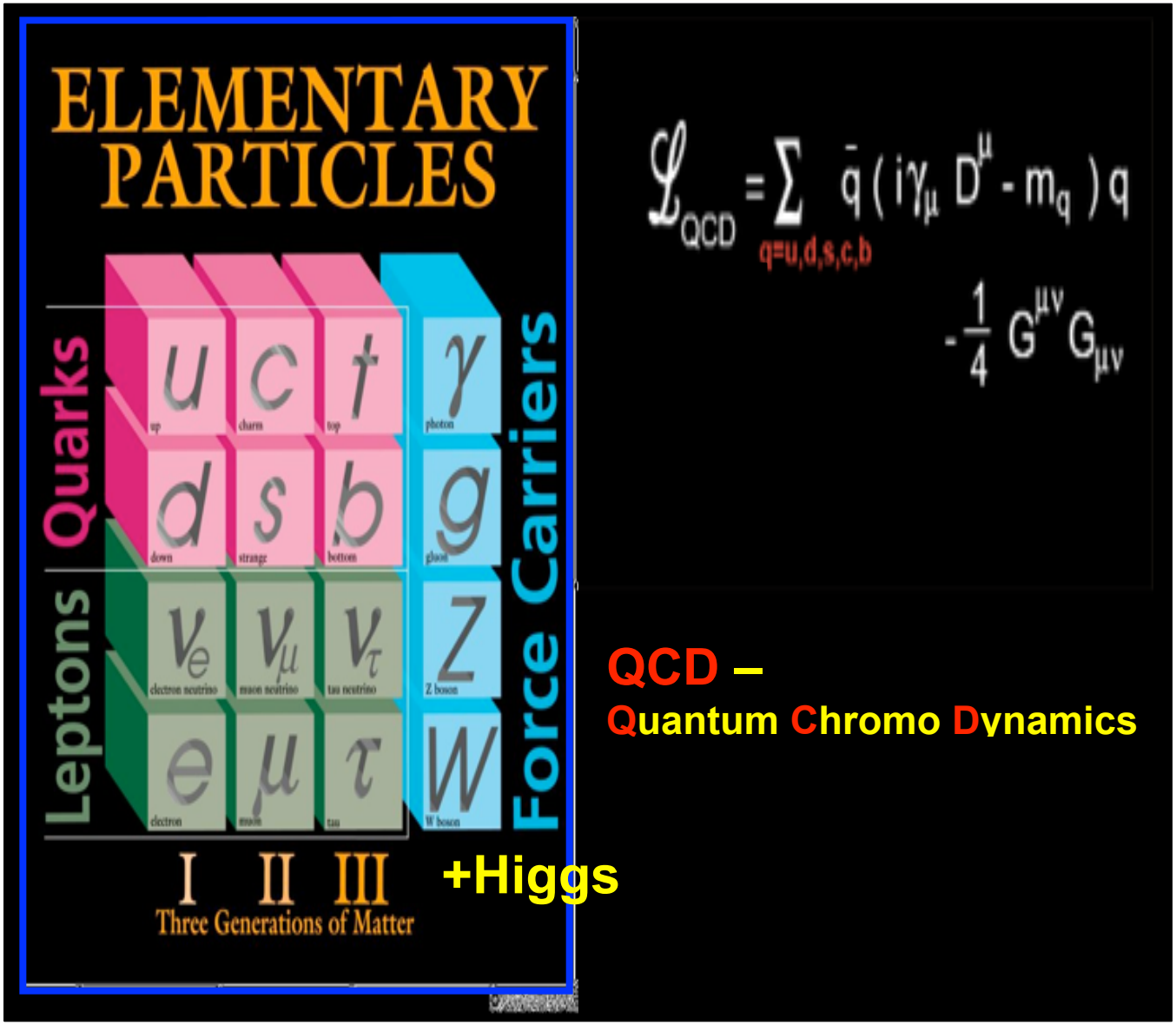


+Higgs

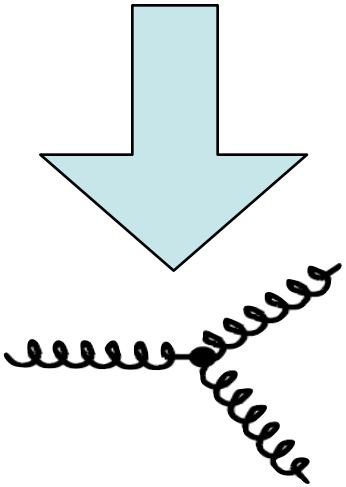
$$\mathcal{L}_{QCD} = \sum_{q=u,d,s,c,b} \bar{q}\,(i\gamma_\mu D^\mu - m_q)\,q \; - \frac{1}{4} G^{\mu\nu} G_{\mu\nu}$$

QCD –
Quantum Chromo Dynamics

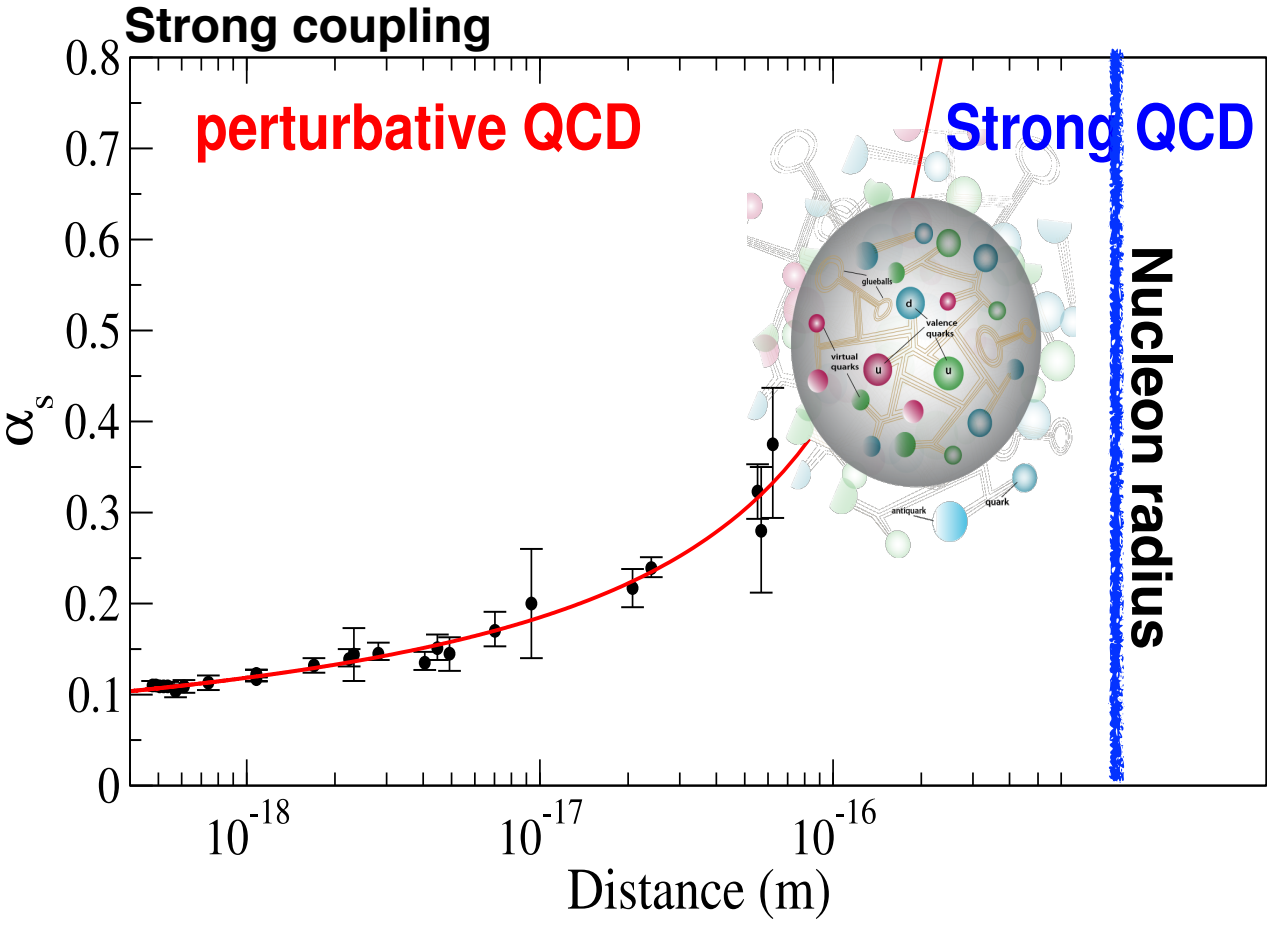
1971: the birth of QCD



Quarks and gluons carry **color** charge



QCD, its consequences



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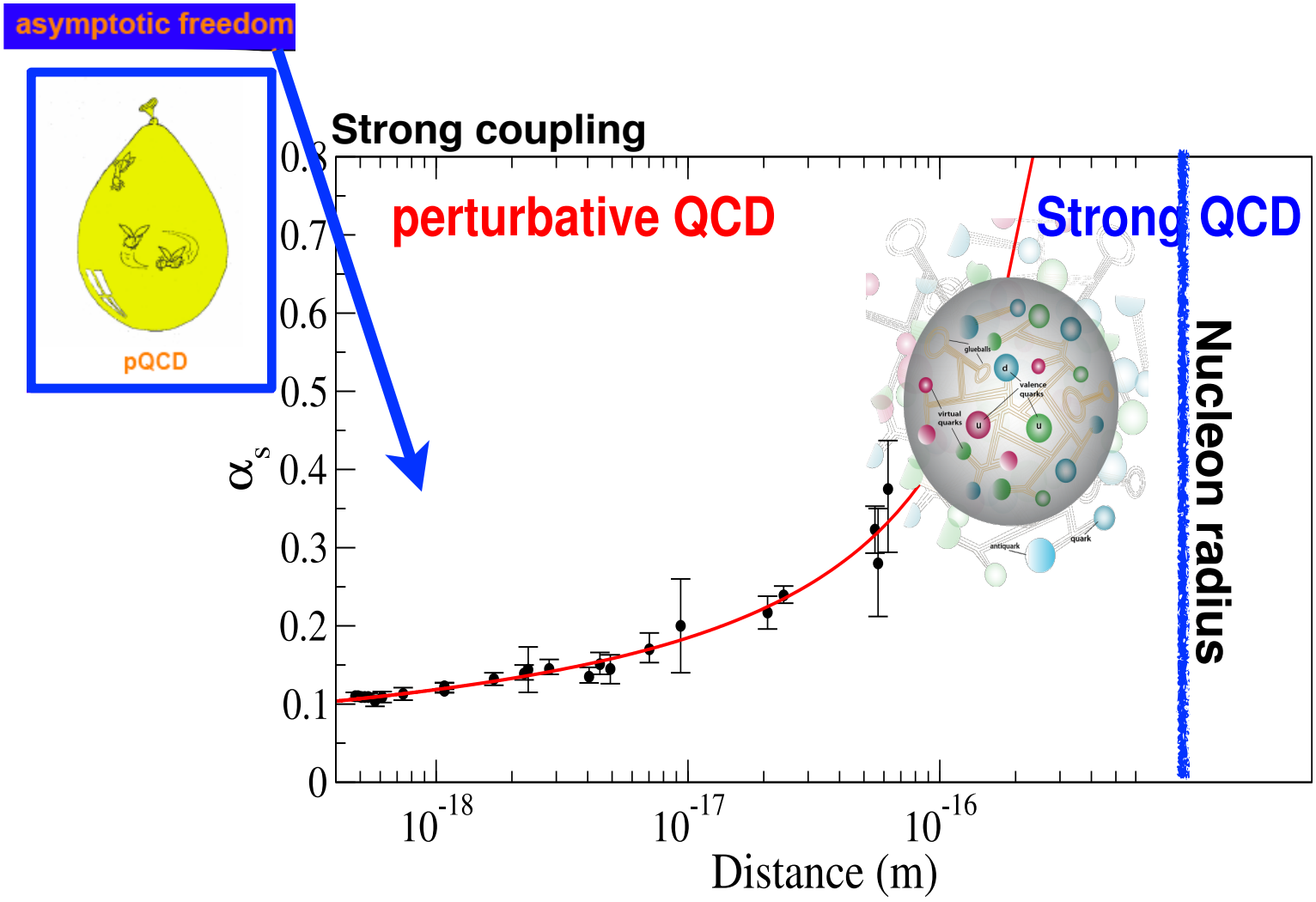

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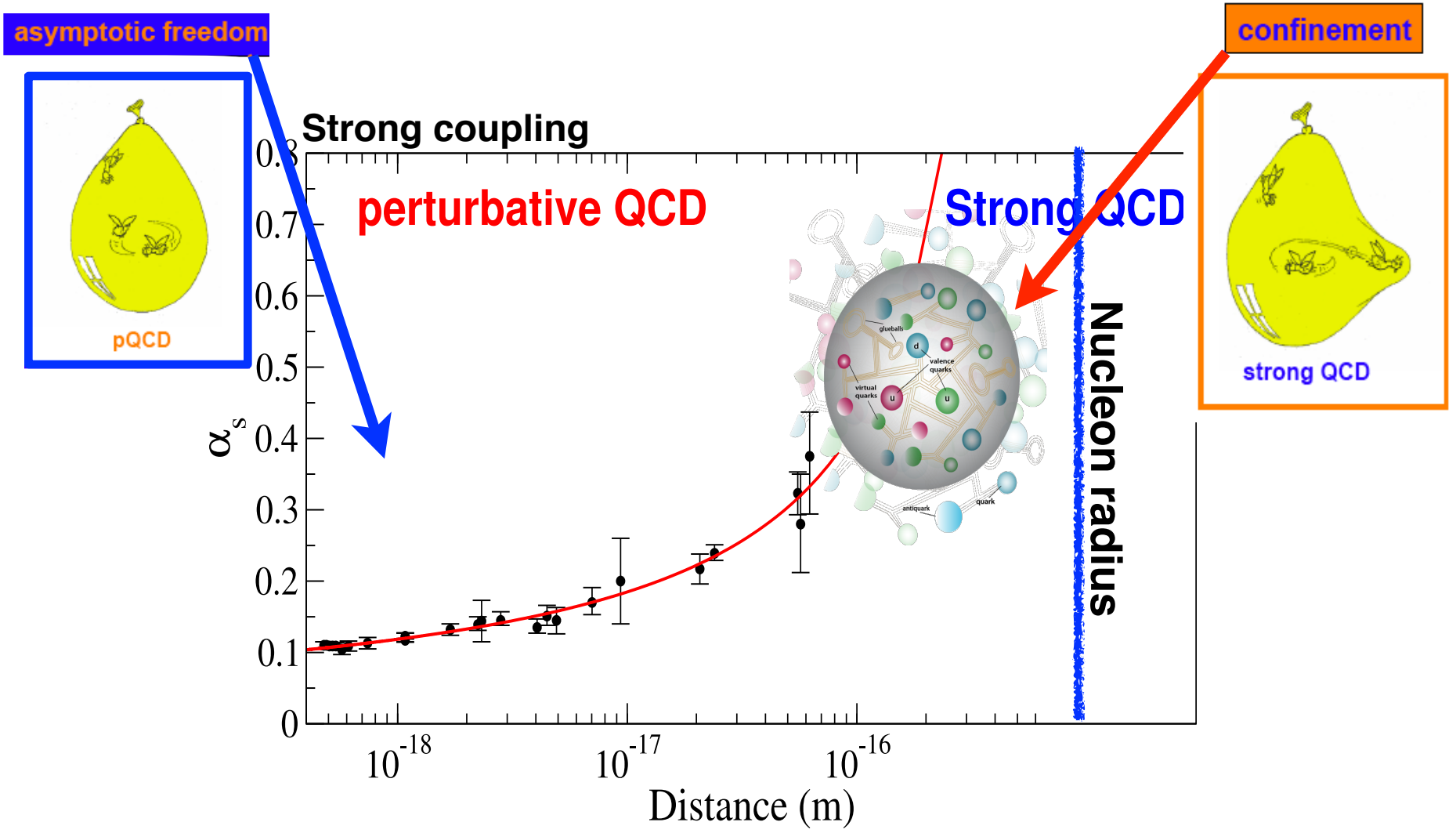

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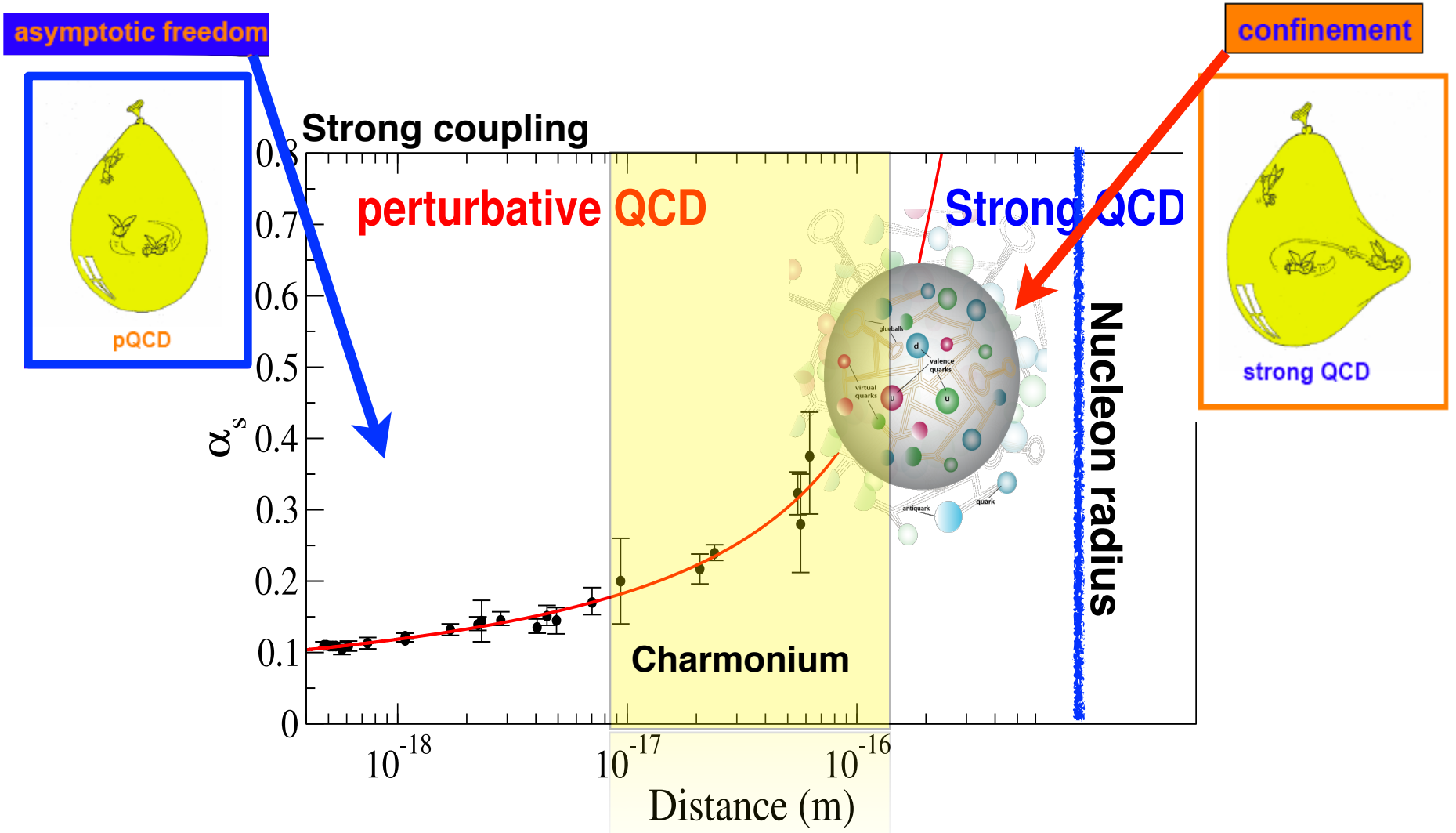
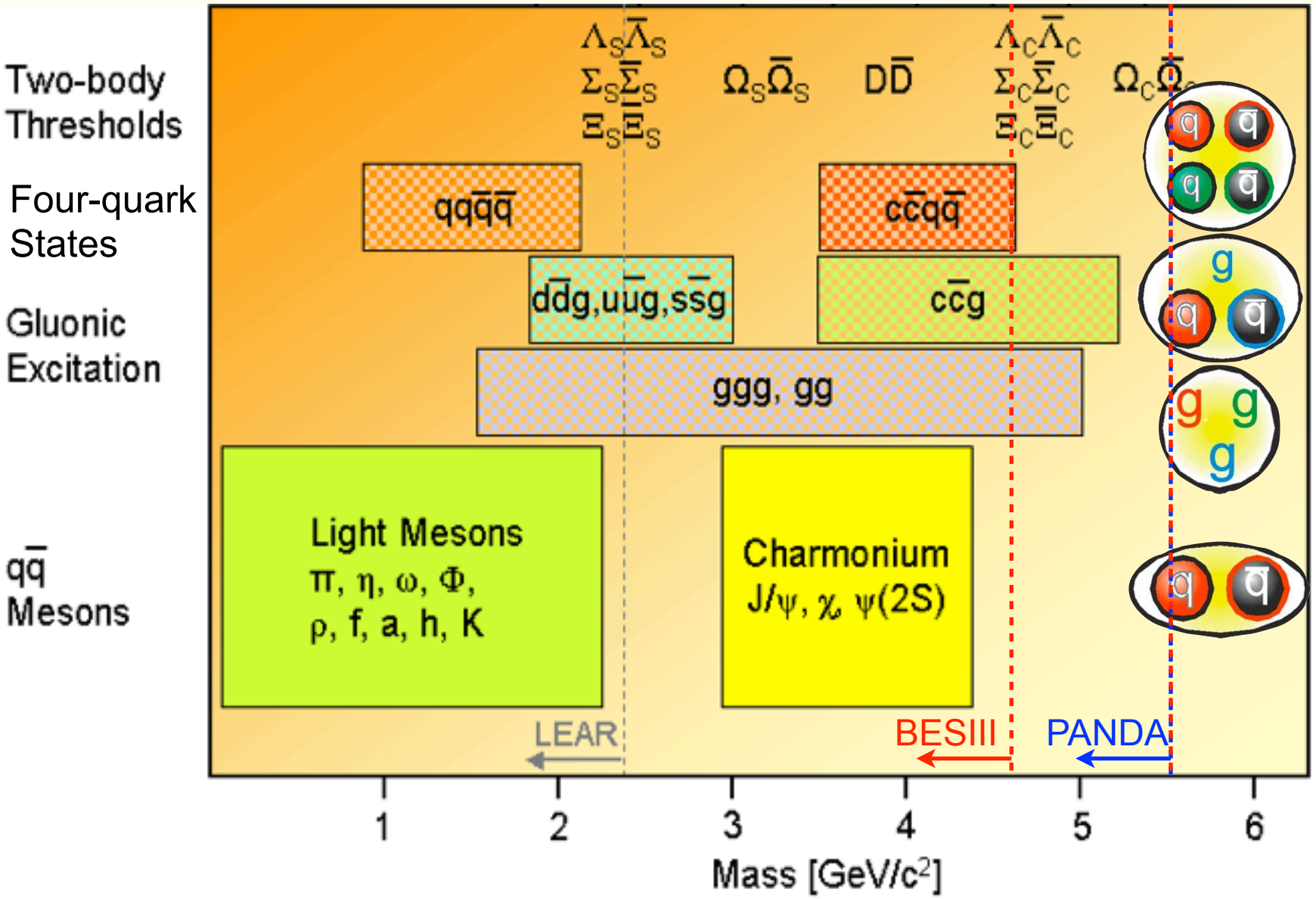


Meson spectroscopy and beyond



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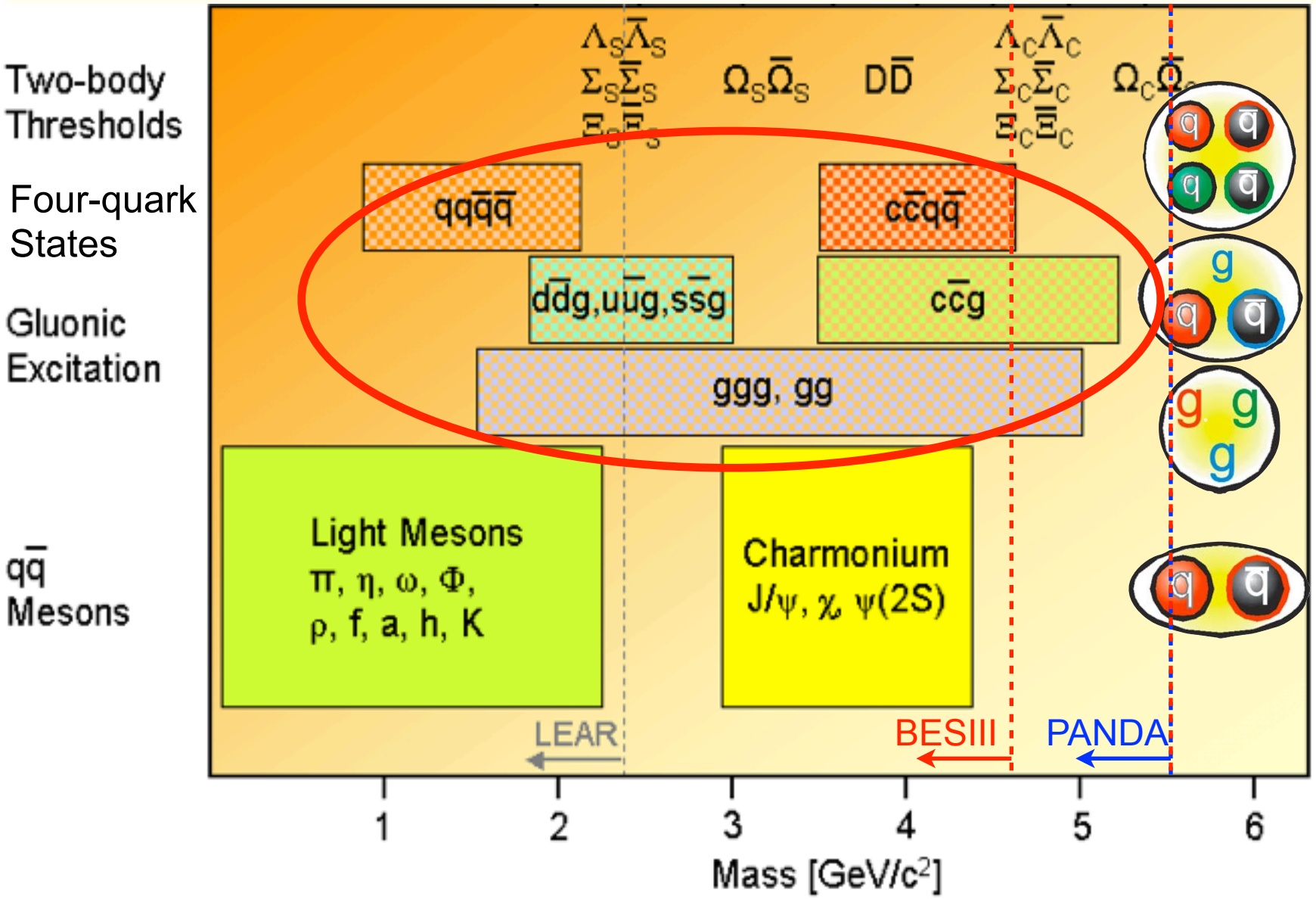

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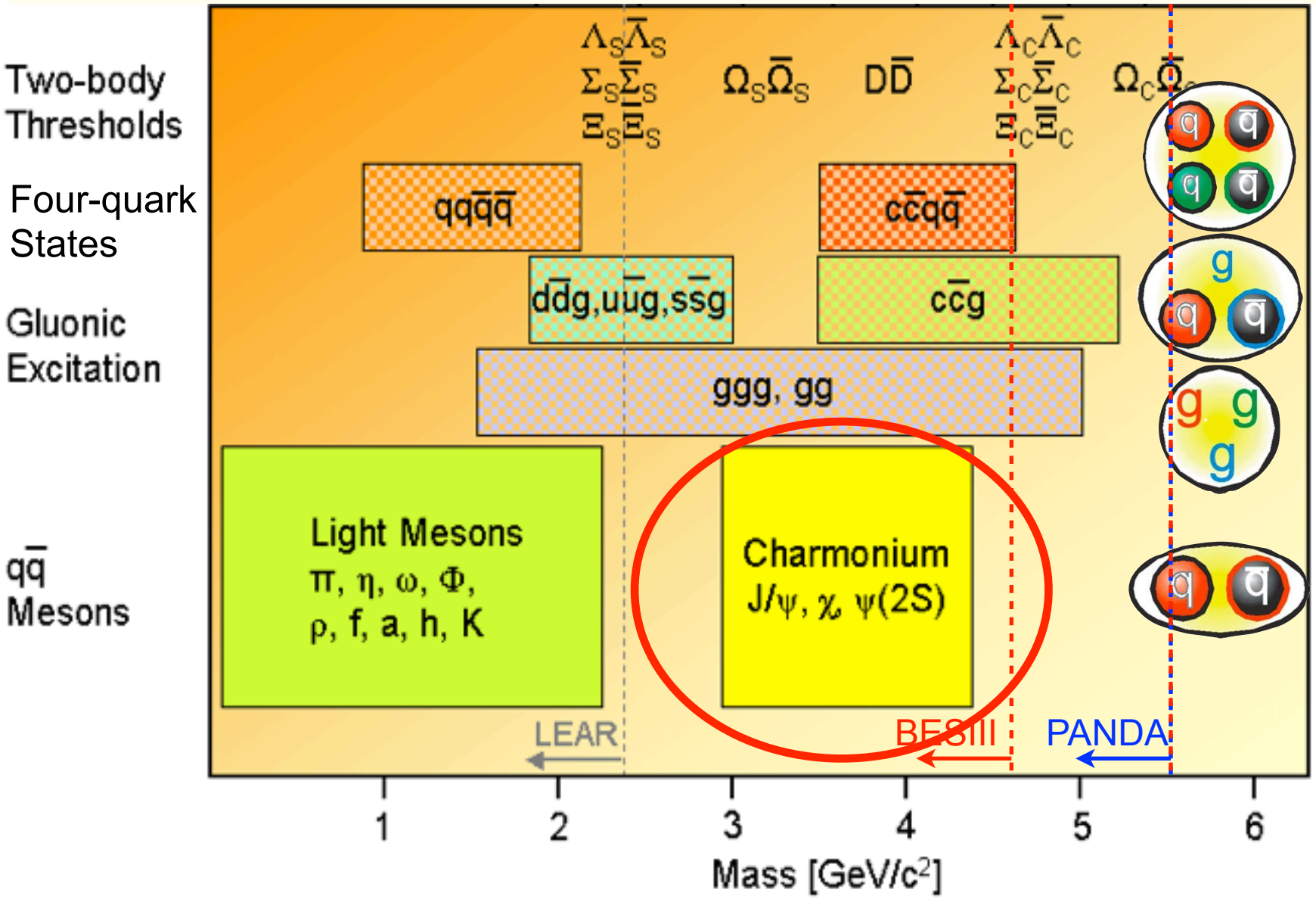
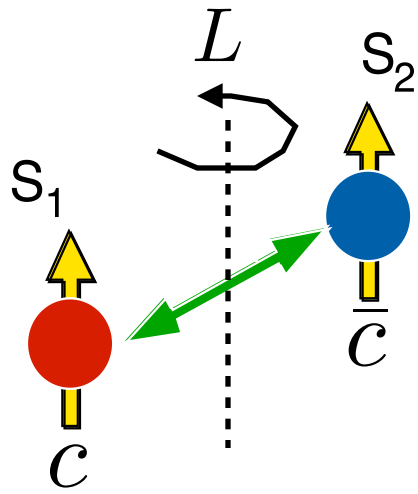


Charmonium - the "positronium" of QCD



$S = S_1 + S_2$

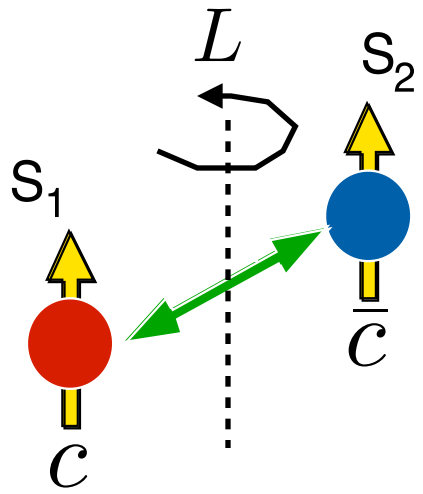
$J = L + S$

$P = (-1)^{L+1}$

$C = (-1)^{L+S}$

$I = 0$

Charmonium - the "positronium" of QCD



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Example from Barnes, Godfrey, Swanson:

$$V_0^{(c\bar{c})}(r) = -\frac{4}{3}\frac{\alpha_s}{r} + br + \frac{32\pi\alpha_s}{9m_c^2}\tilde{\delta}_\sigma(r)\vec{S}_c \cdot \vec{S}_{\bar{c}}$$

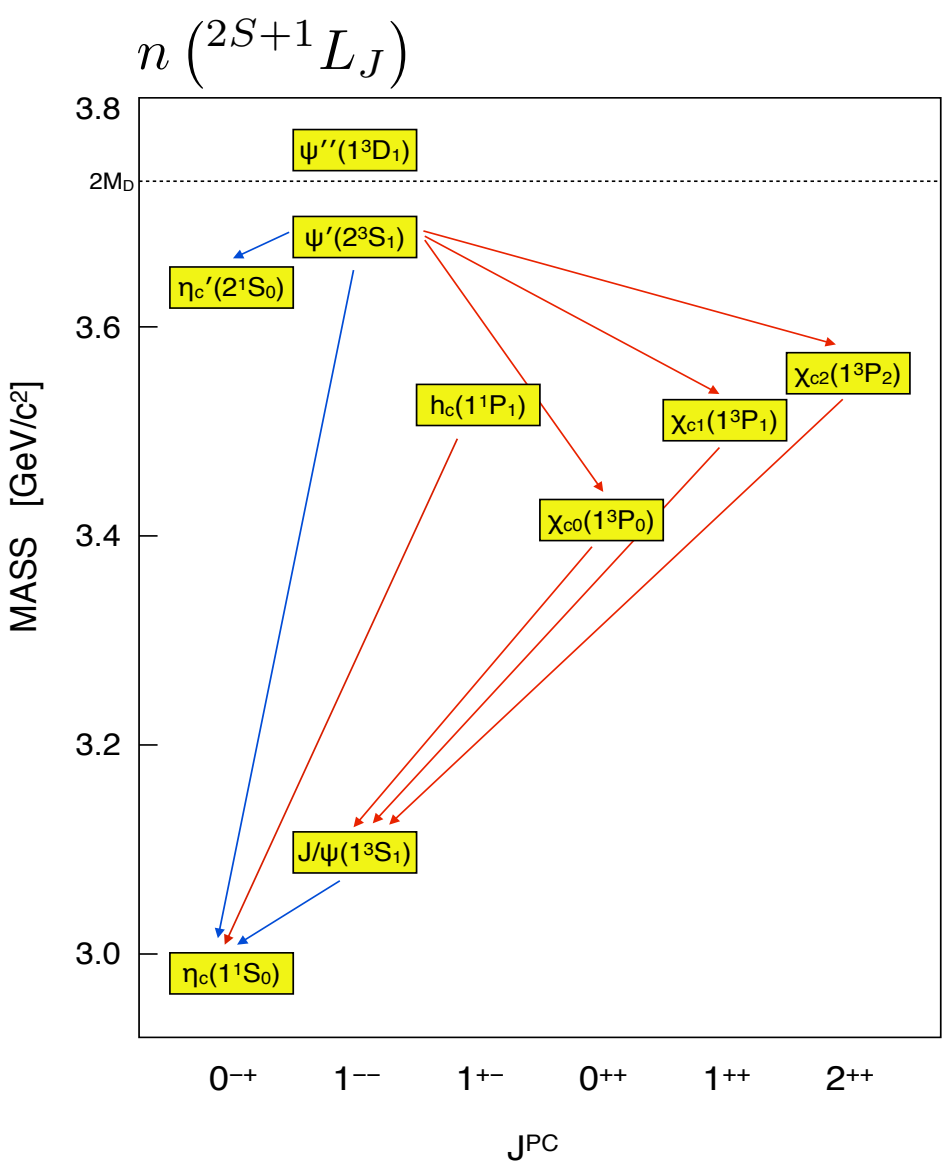
(Coulomb + Confinement + Contact)

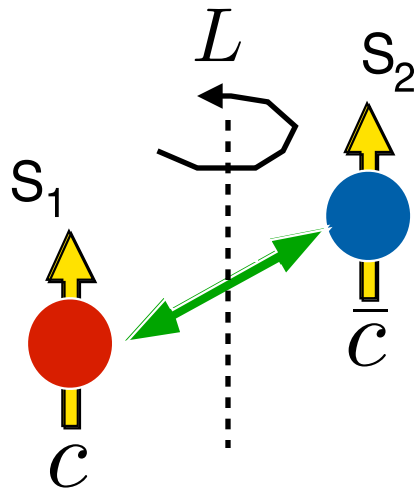
$$V_{\text{spin-dep}} = \frac{1}{m_c^2}\left[\left(\frac{2\alpha_s}{r^3} - \frac{b}{2r}\right)\vec{L}\cdot\vec{S} + \frac{4\alpha_s}{r^3}T\right]$$

(Spin-Orbit + Tensor)

PRD72, 054026 (2005)

Charmonium - the "positronium" of QCD





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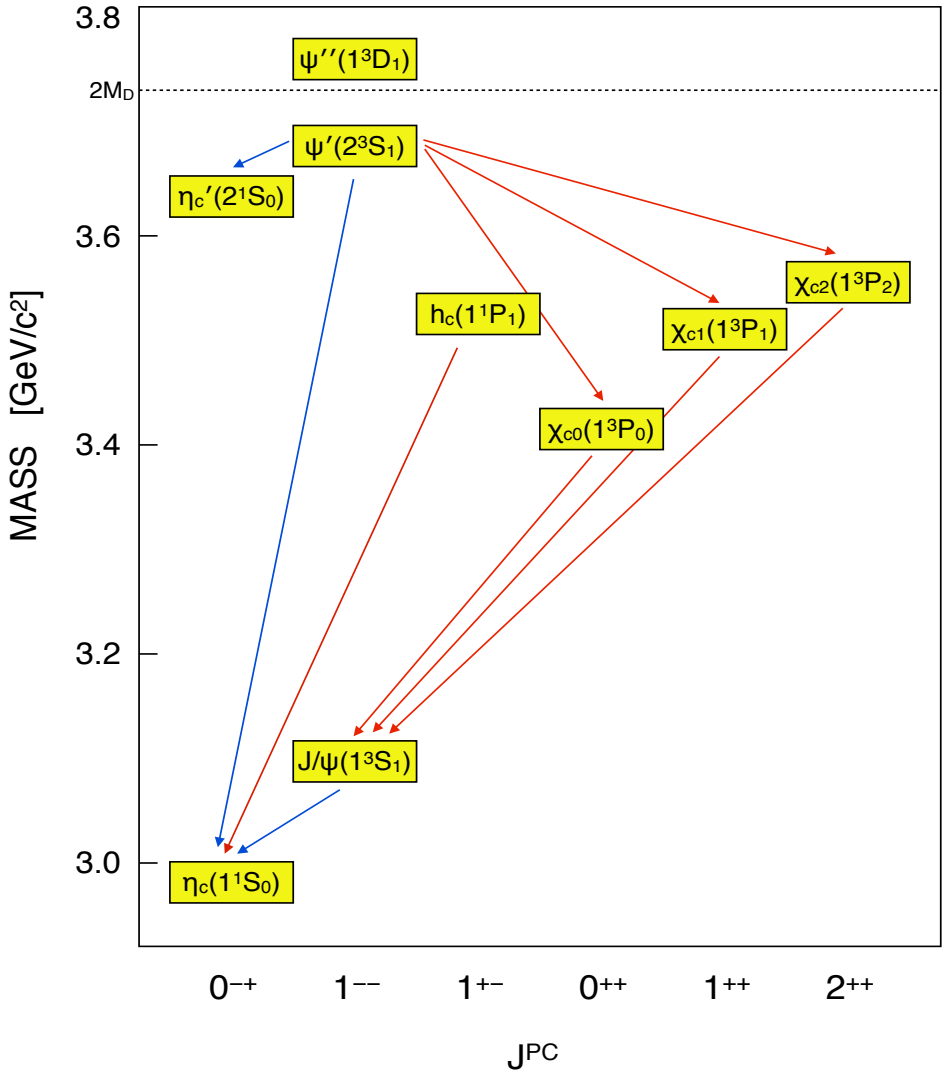

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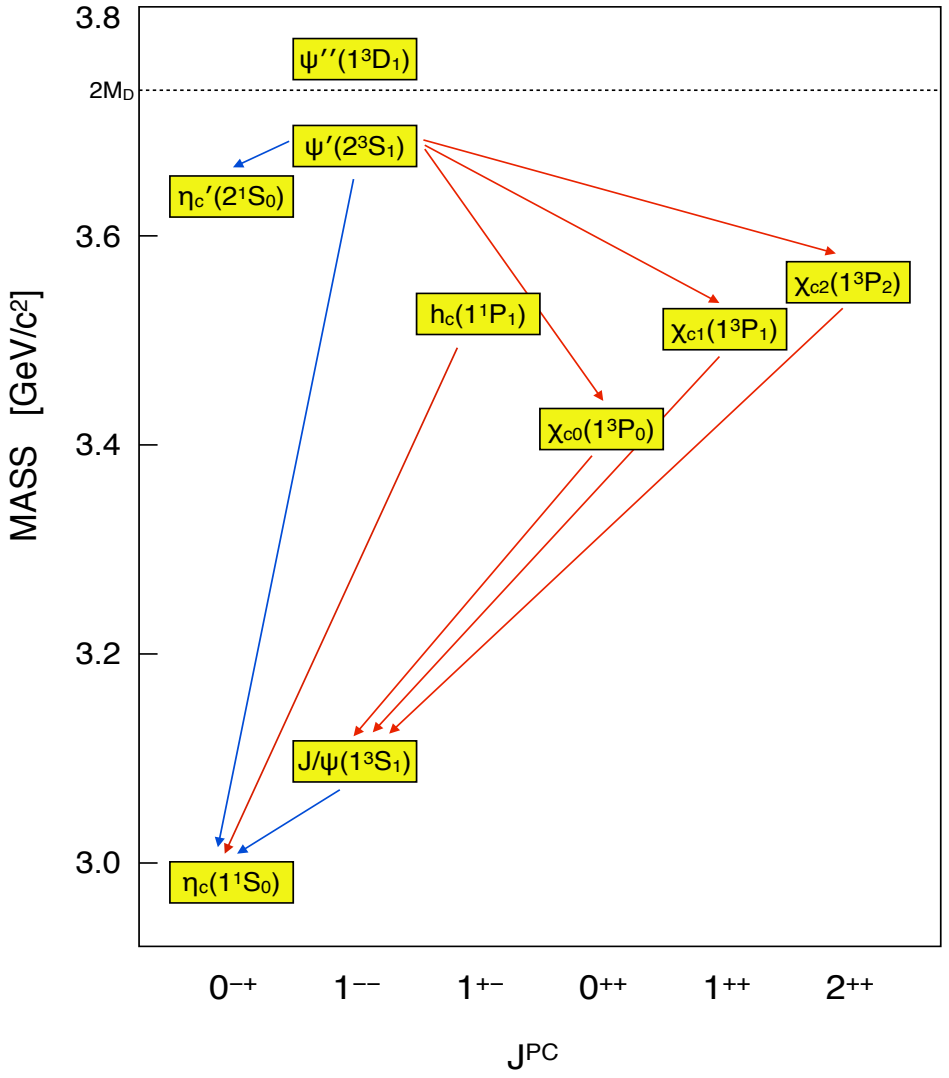
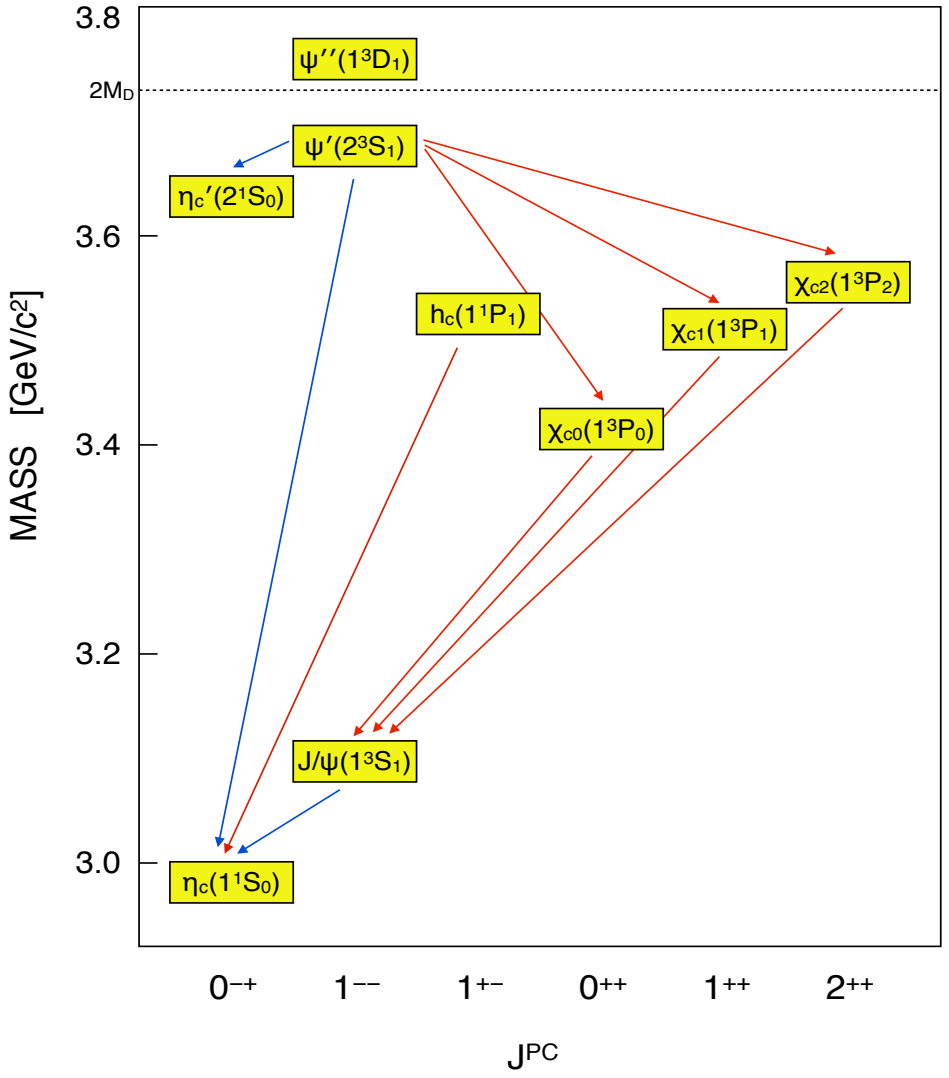


Narrow quantum states
- beacons of QCD
- hardly overlapping
- background suppressed
- ideal experimental probes

Charmonium - the "positronium" of QCD



Narrow quantum states
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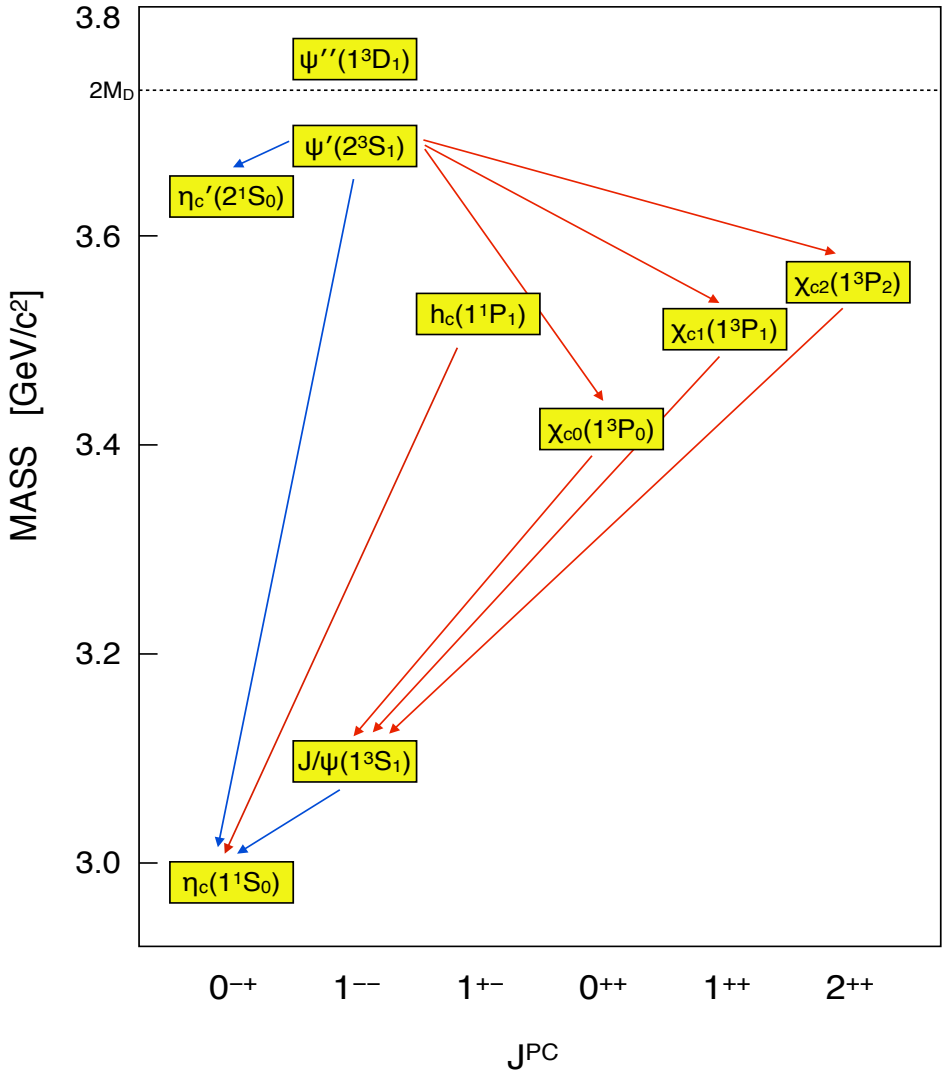
Heavy charm quarks
- dominant non-relativistic
- probes regime between perturbative and strong QCD

Charmonium - the "positronium" of QCD



Narrow quantum states
- beacons of QCD
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Heavy charm quarks
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- probes regime between perturbative and strong QCD

Physics!
- confinement potential
- search for exotic hadrons
- QCD dynamics
- beyond standard model

BESIII: today's charmonium factory

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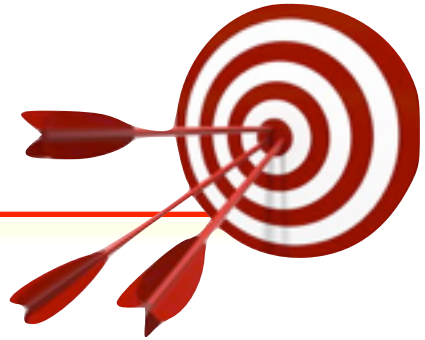
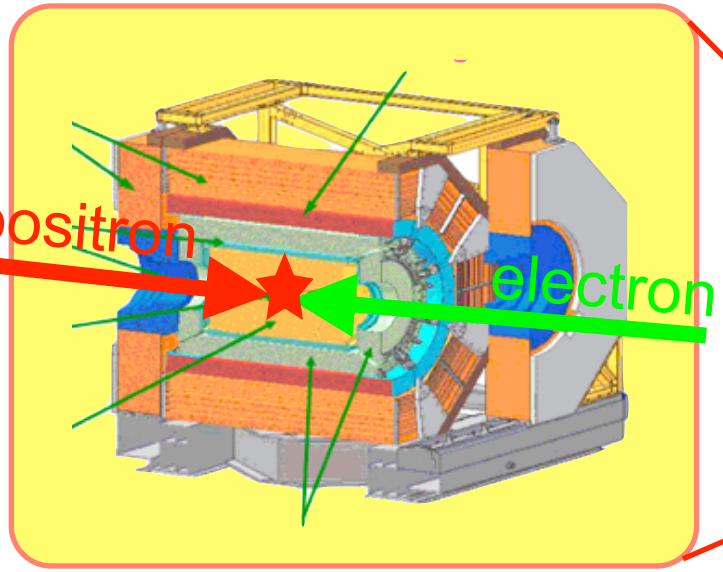
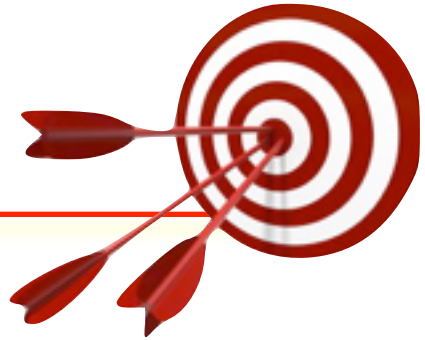
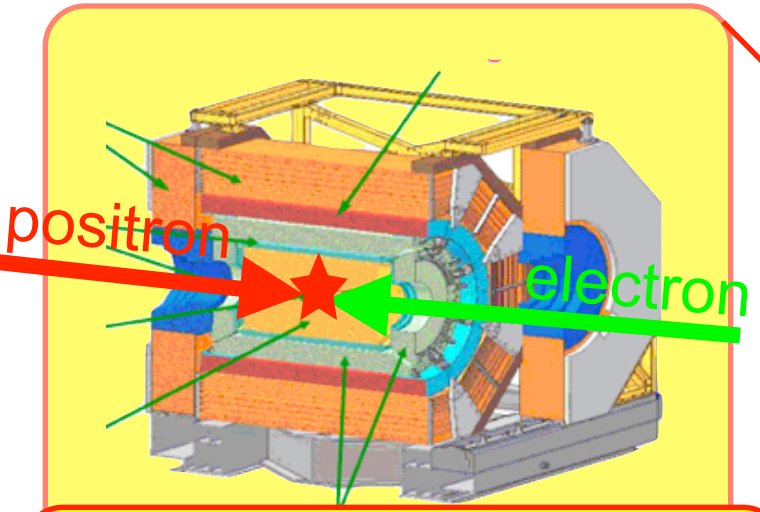




BEijing **S**pectrometer - **III**

BESIII: today's charmonium factory





BEijing **S**pectrometer - **III**

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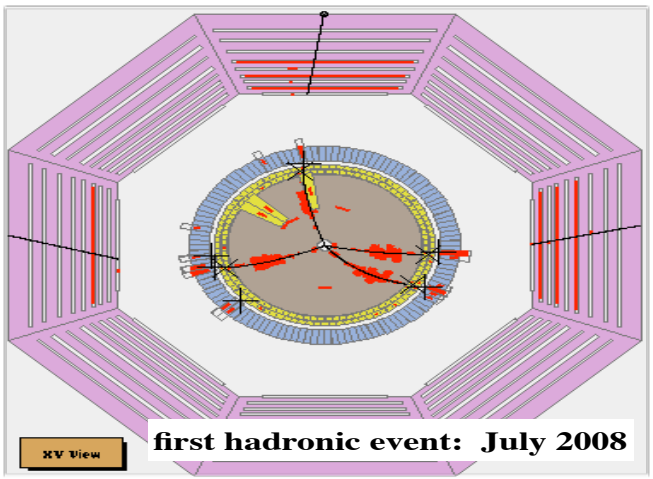
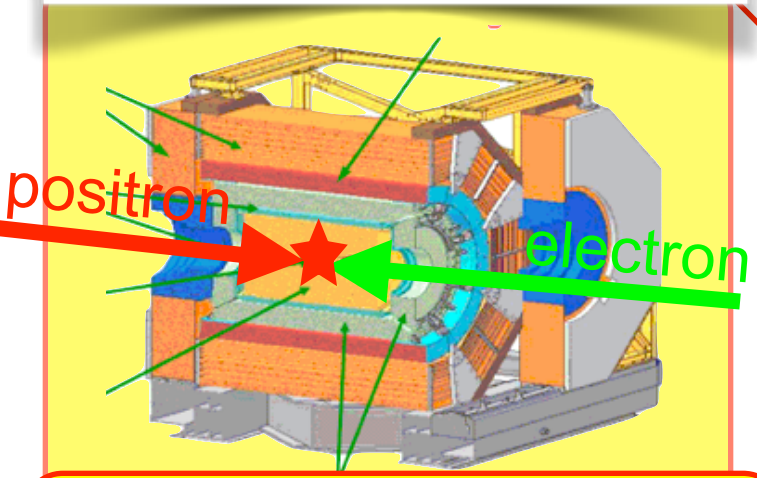
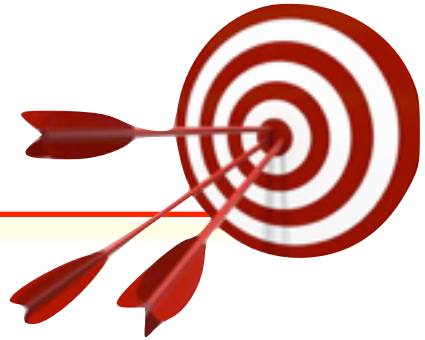


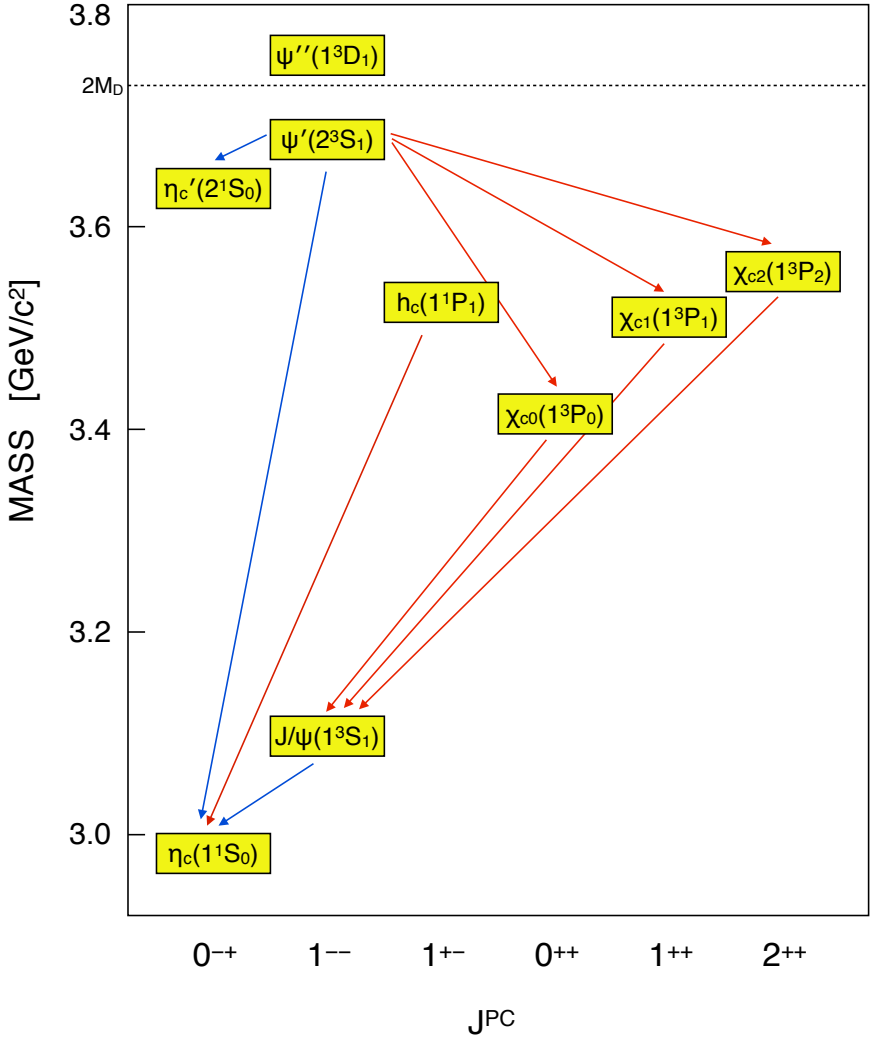
July 2008: first hadronic event
March 2009: physics data taking
Today: world's largest data set



BEijing **S**pectrometer - **III**

A few "old" highlights of BESIII





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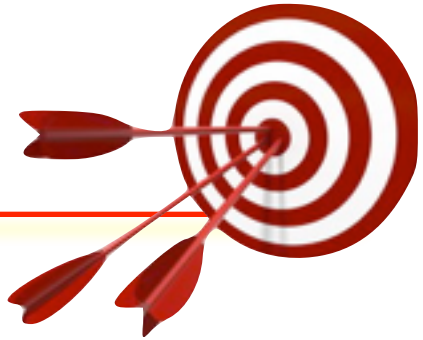
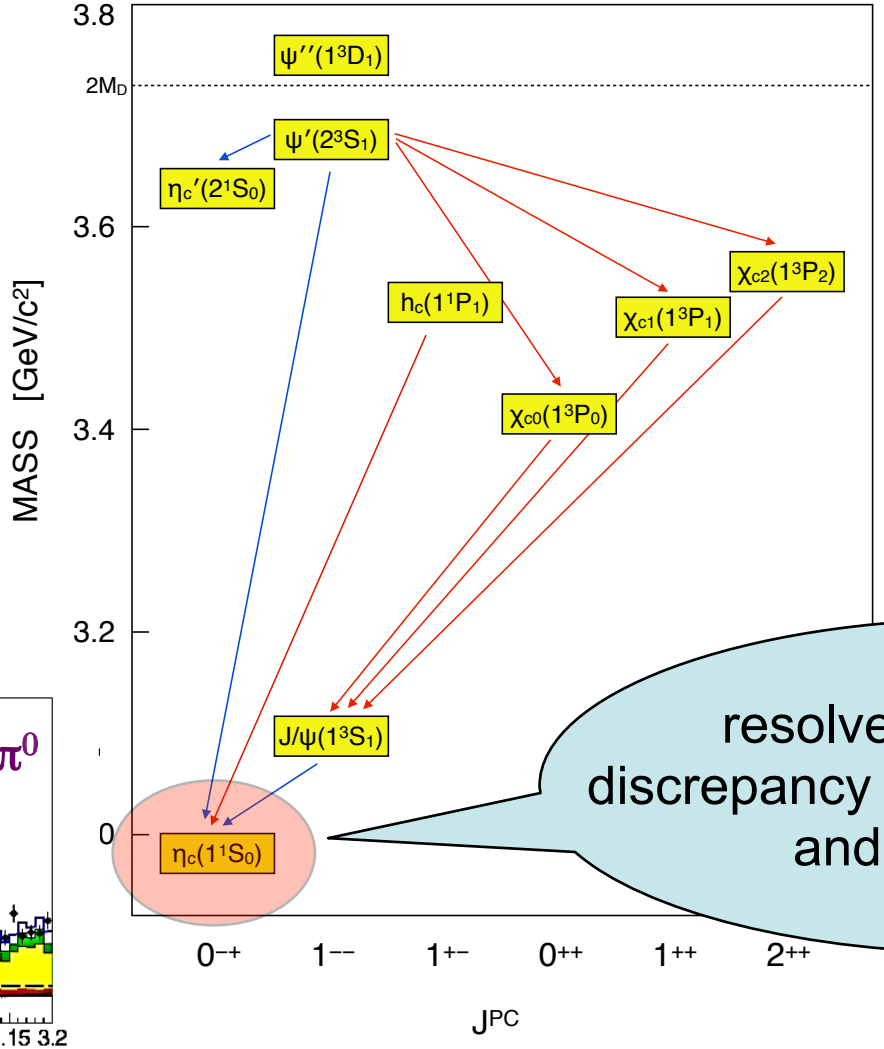
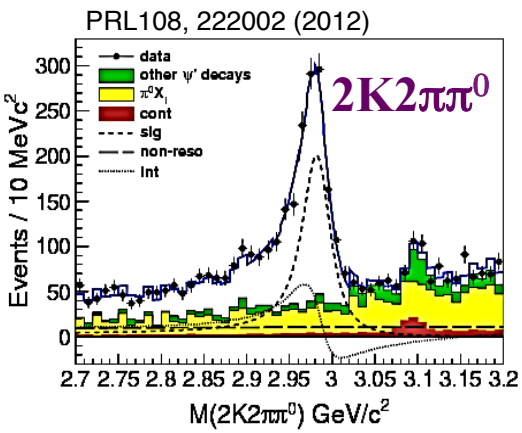




resolved long-standing discrepancy between experiments and Lattice QCD

PRL108, 222002 (2012)



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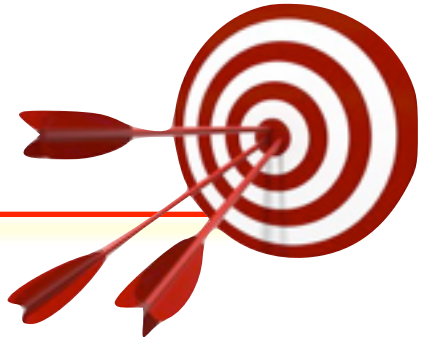
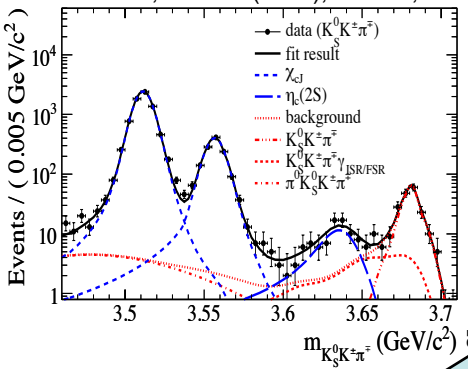
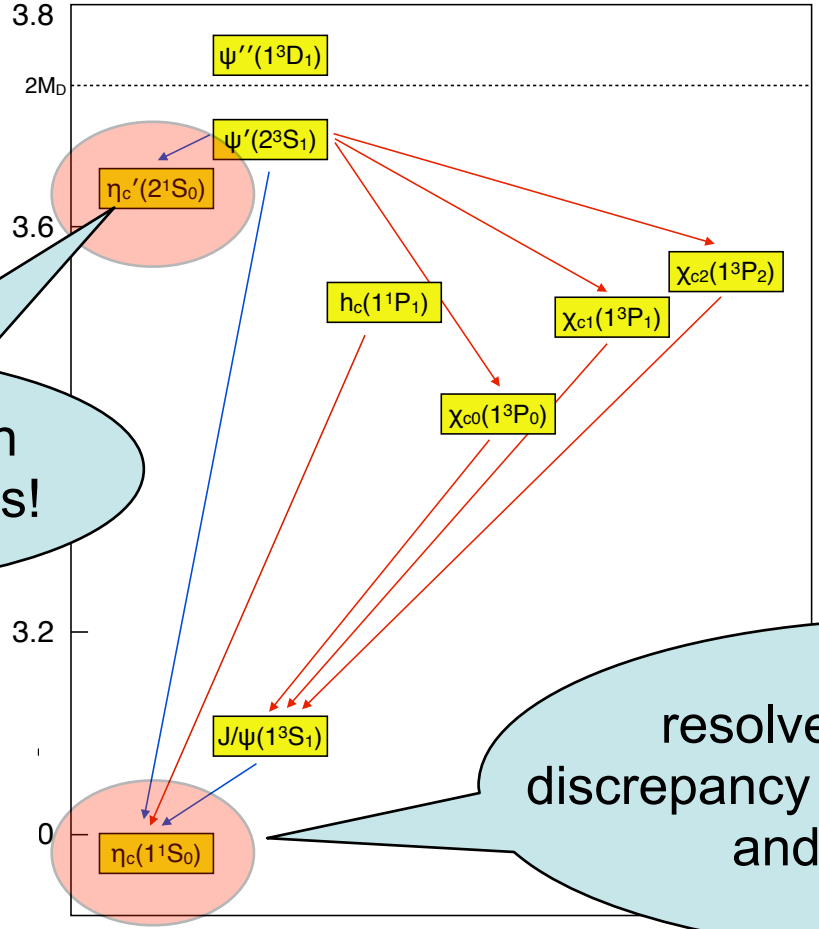


PRL109, 042003 (2012), PRD87, 052005 (2013)



now discovered in radiative transitions!



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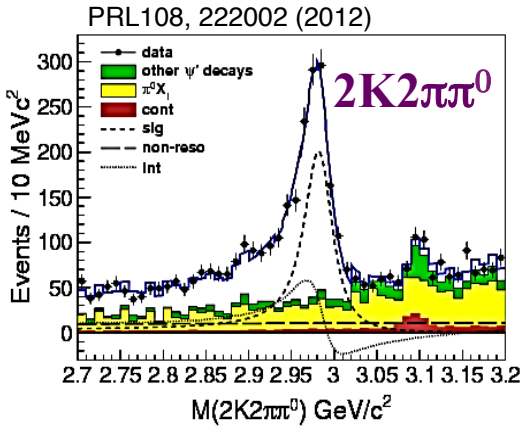

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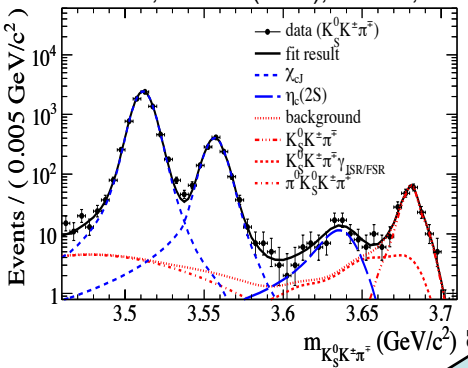
A few "old" highlights of BESIII

PRL109, 042003 (2012), PRD87, 052005 (2013)



~150 keV mass accuracy
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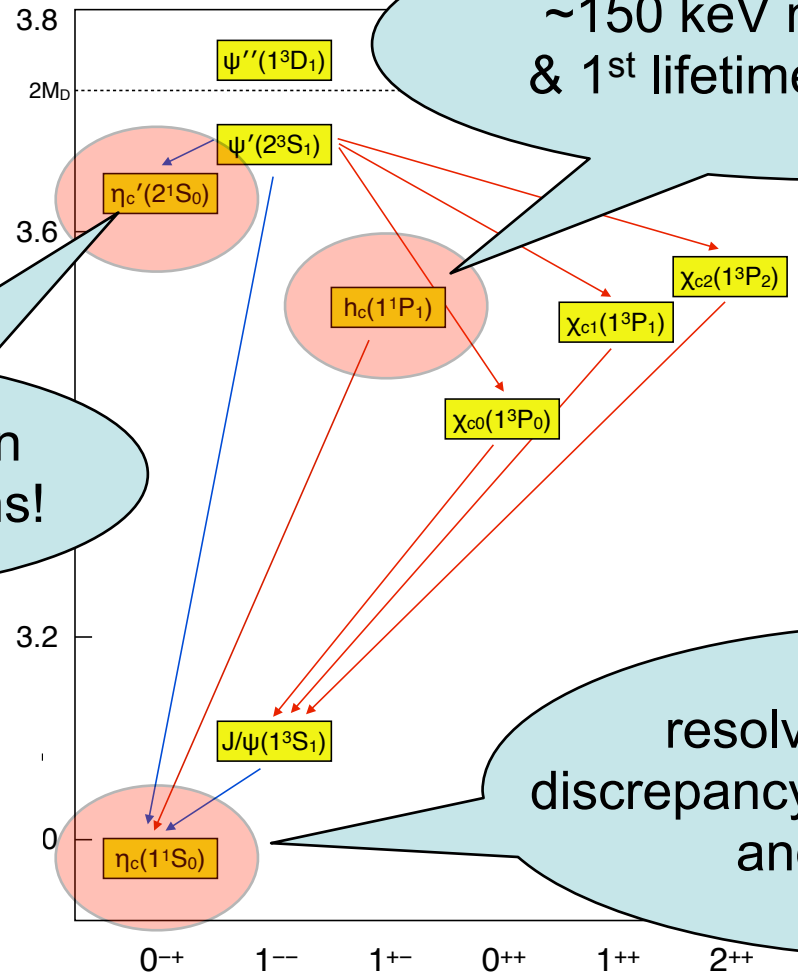
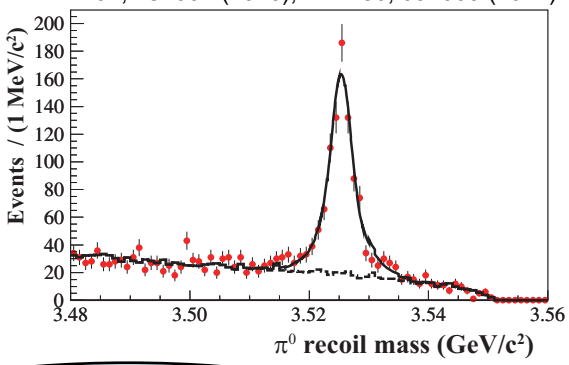
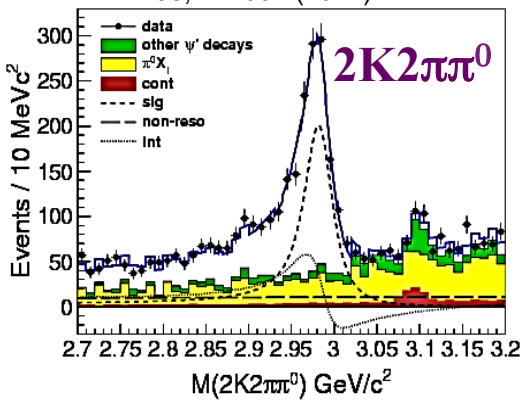


PRL104, 132002 (2010), PRD 86, 092009 (2012)



PRL108, 222002 (2012)



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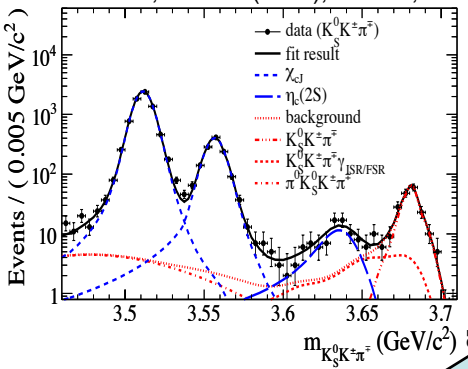

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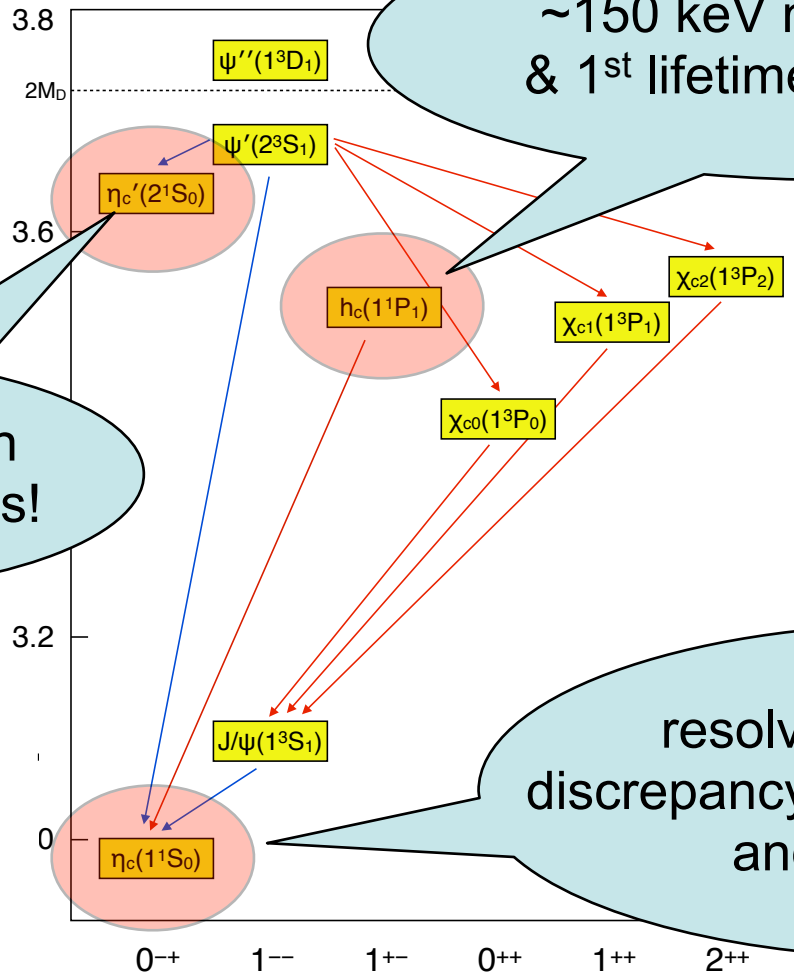

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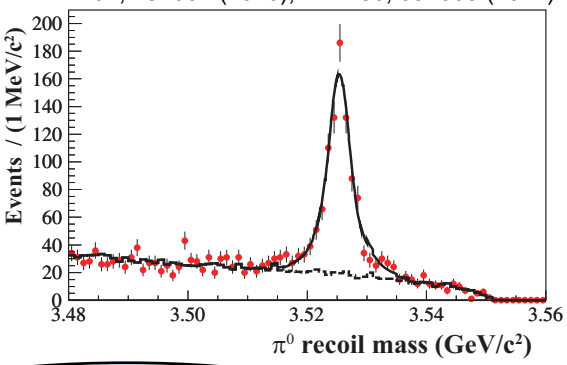

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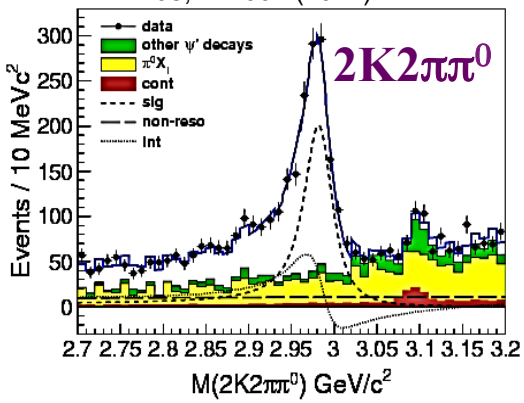

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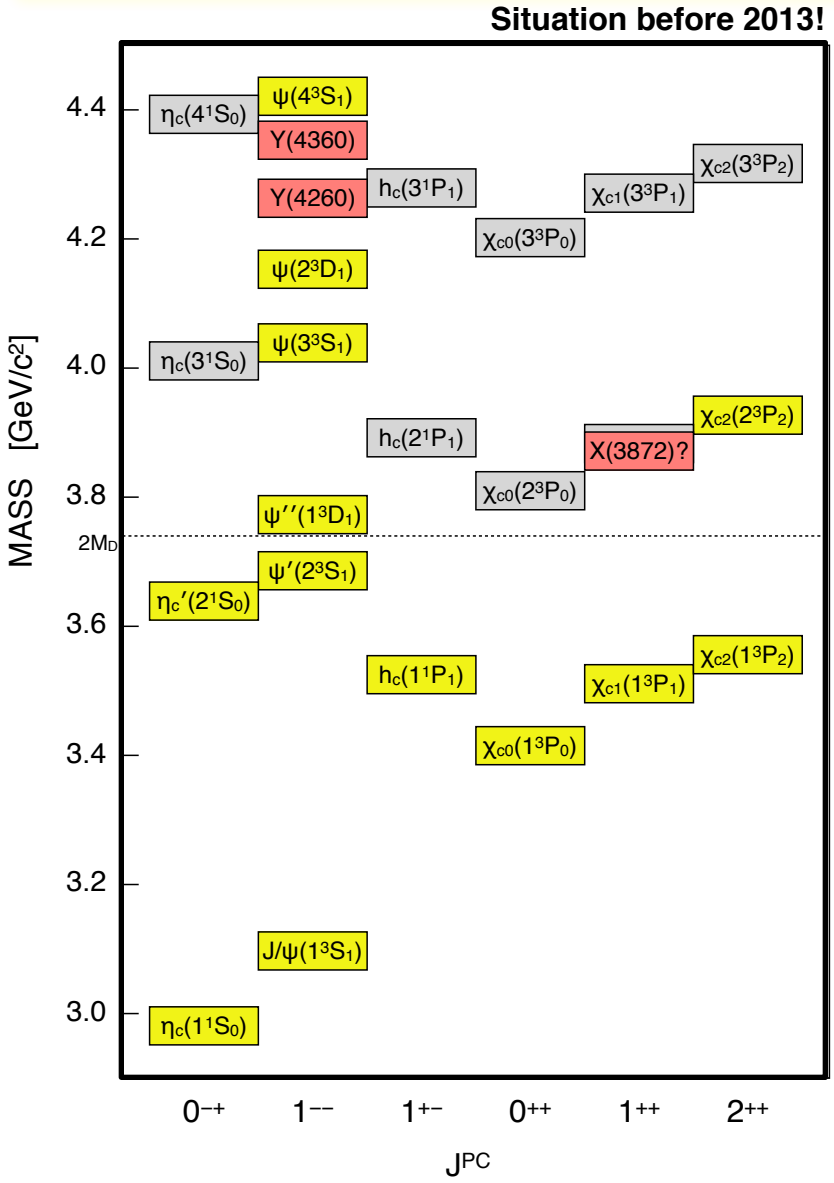
... and many more!

Charmonium: precision & discovery!



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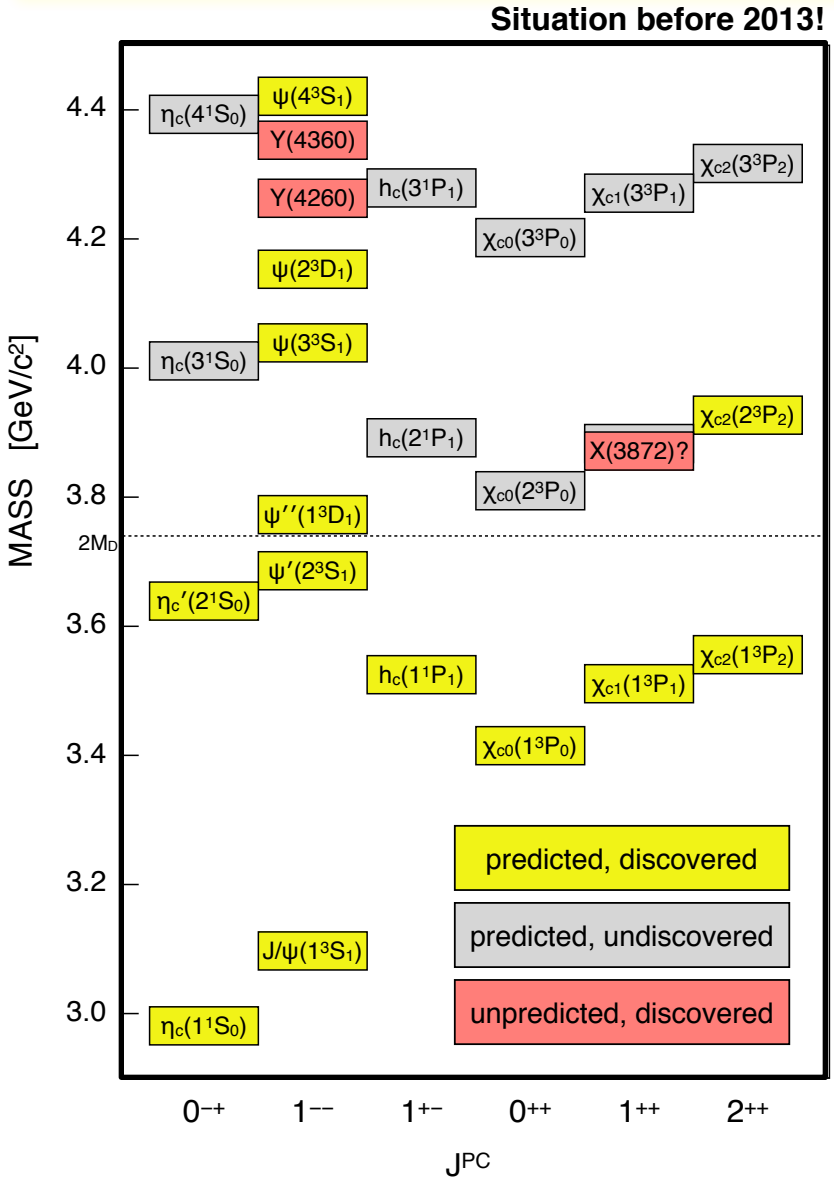

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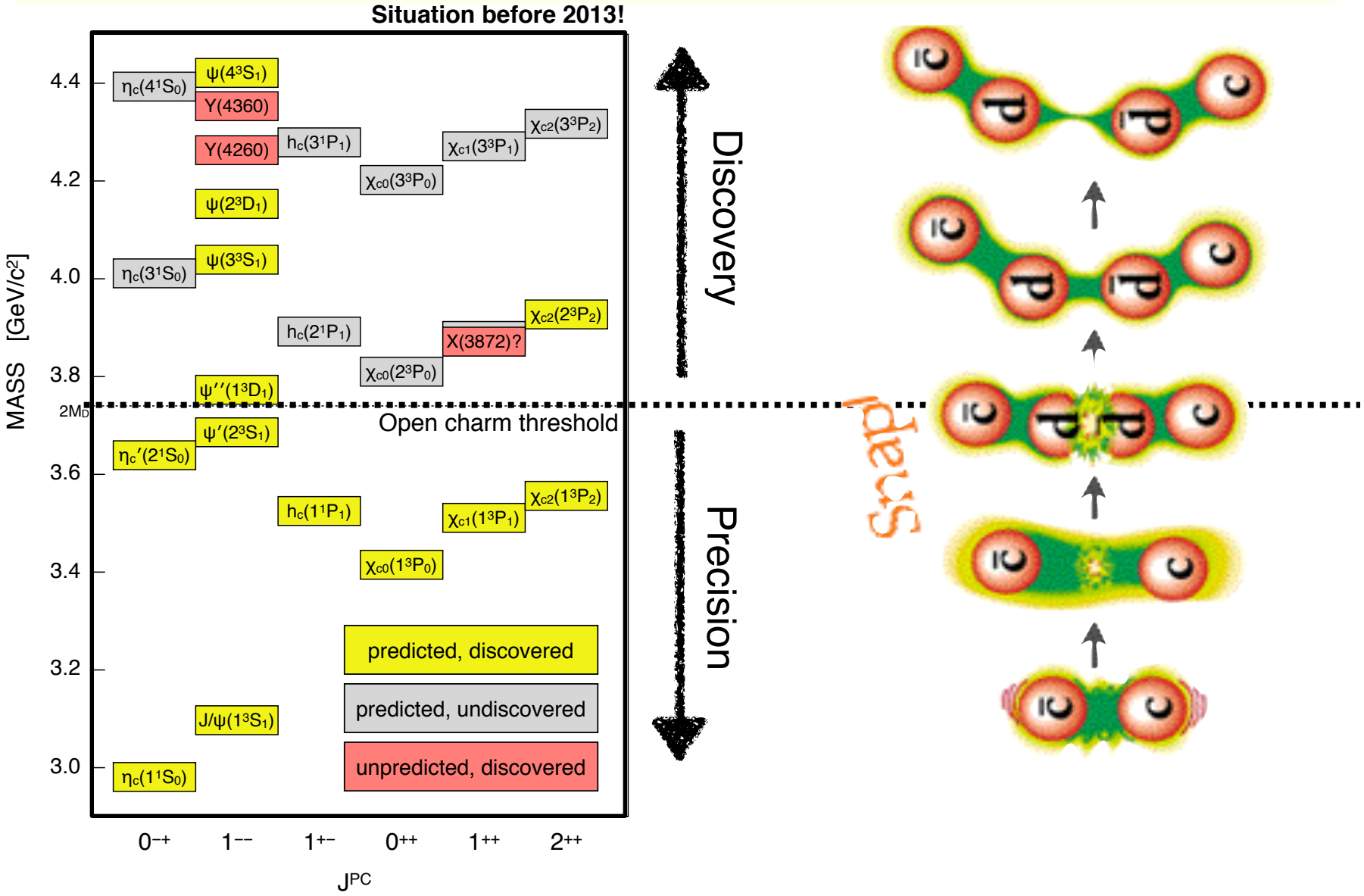

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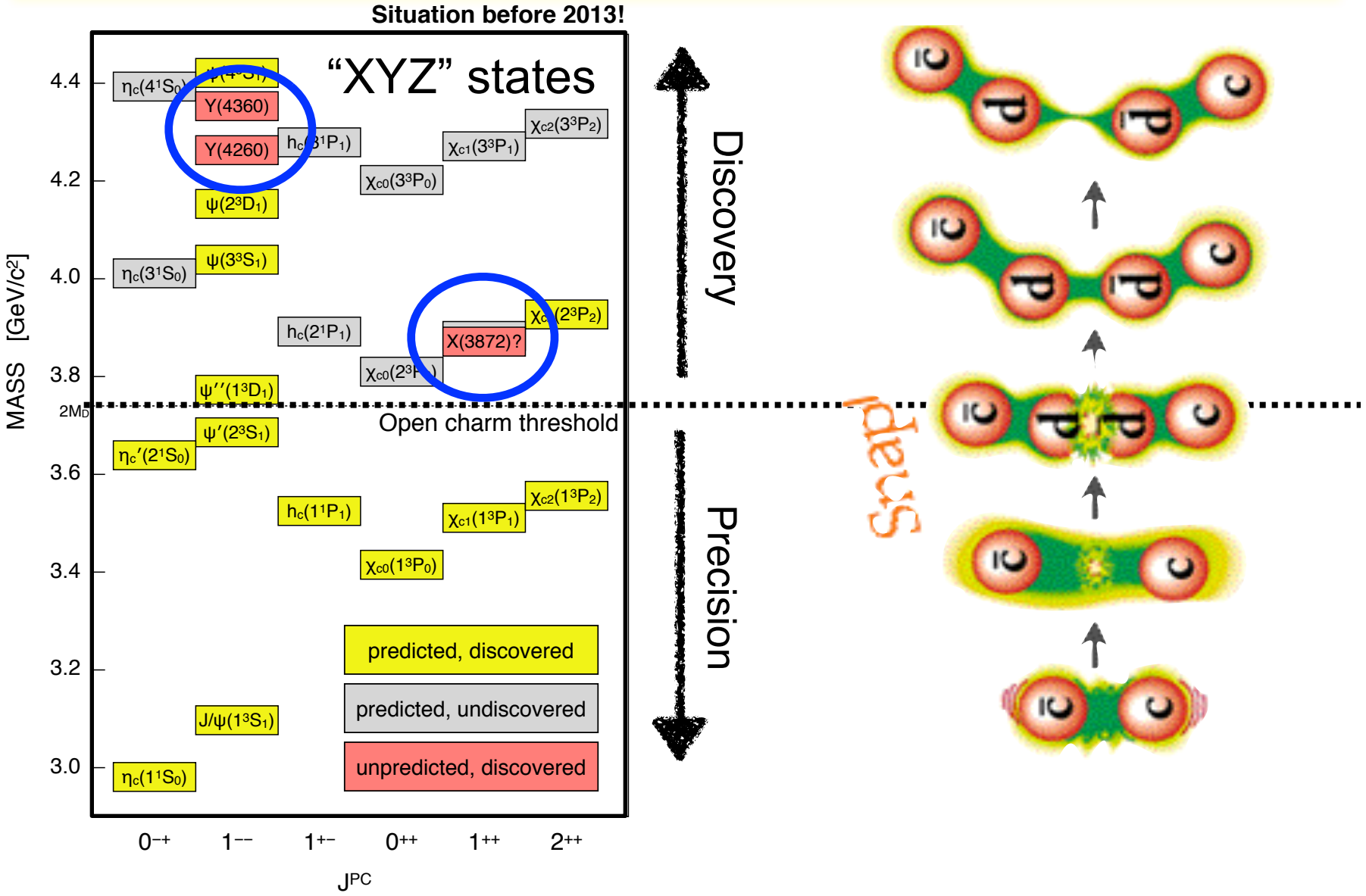
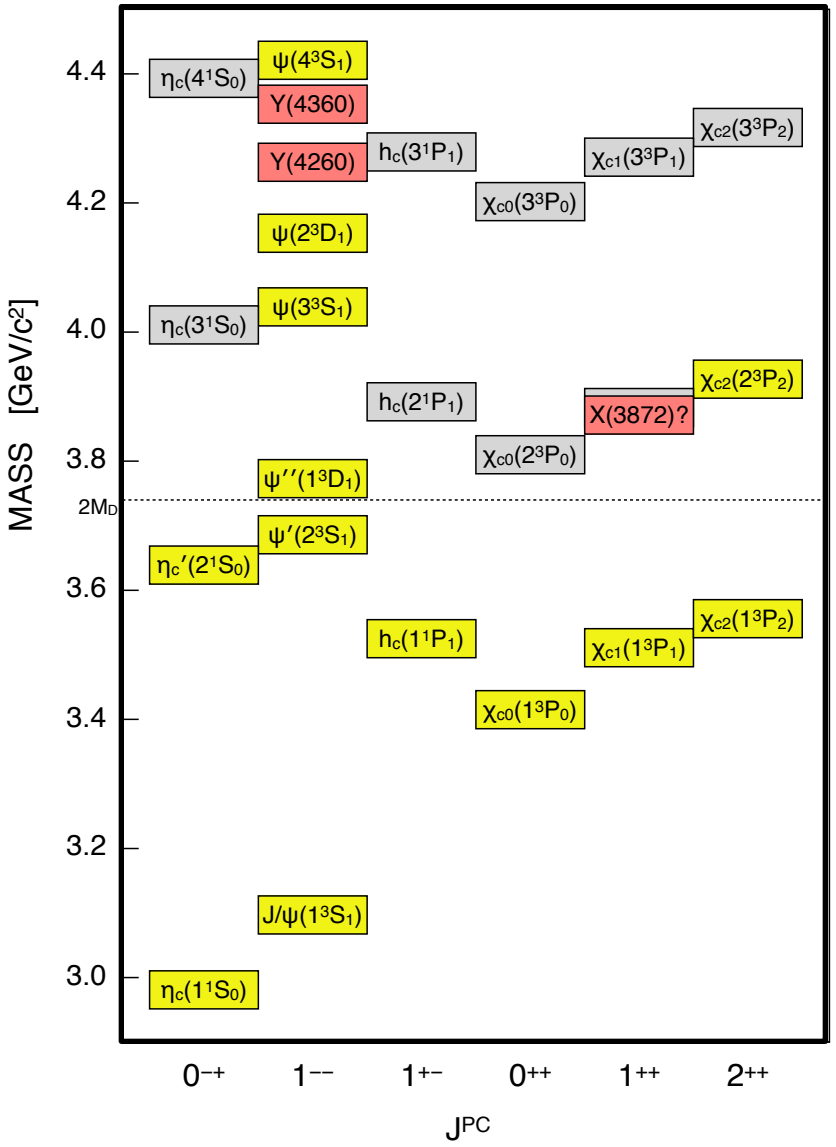


X(3872): the "Poster Boy" of a new era!



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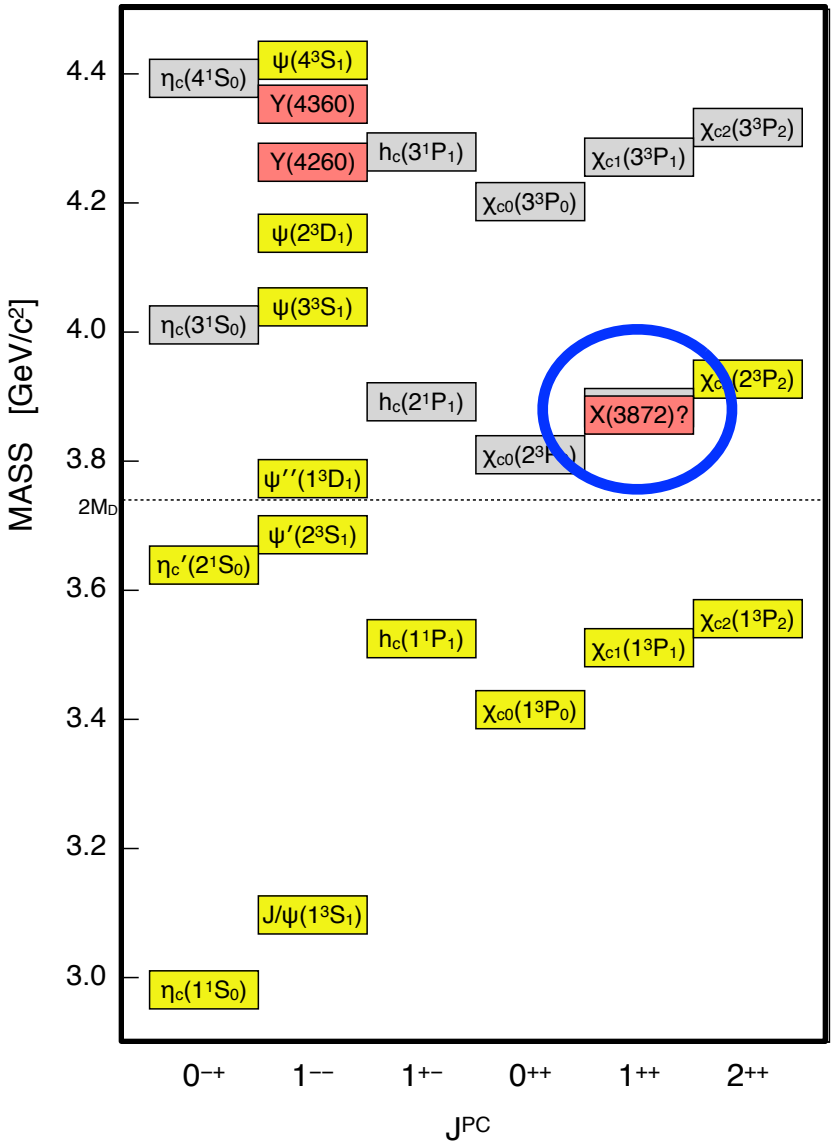

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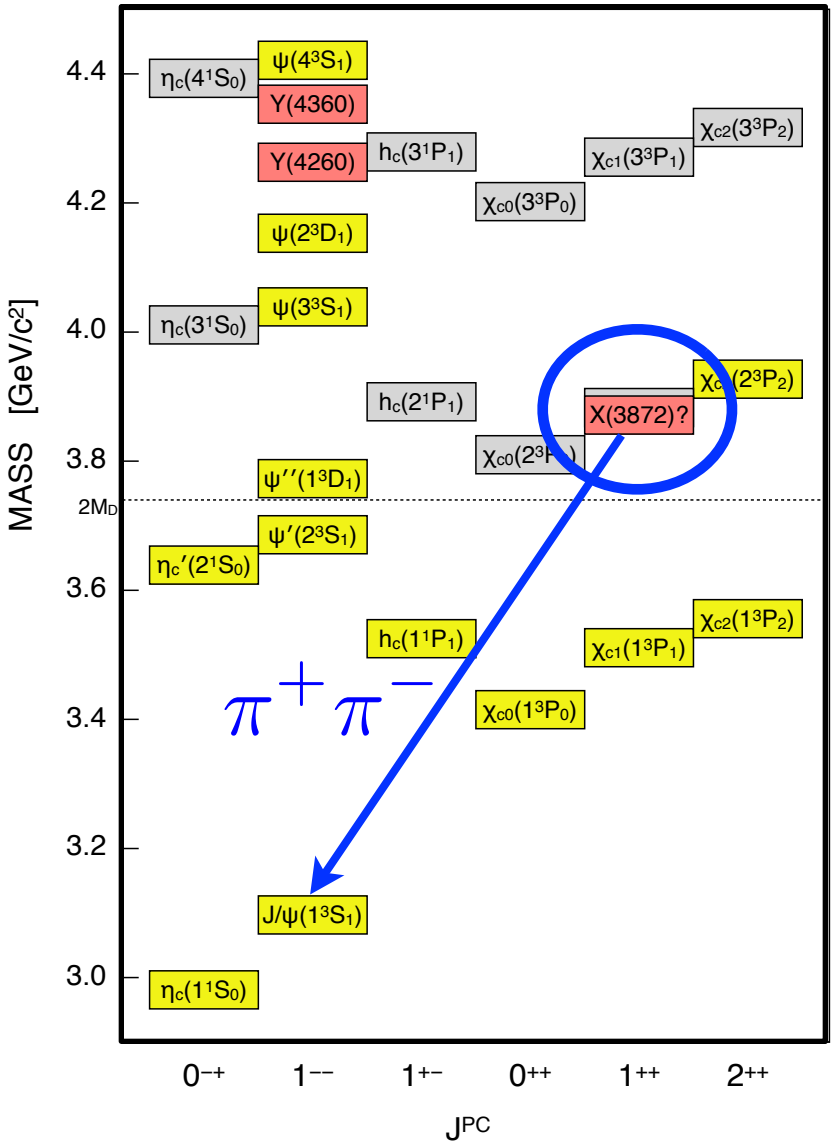
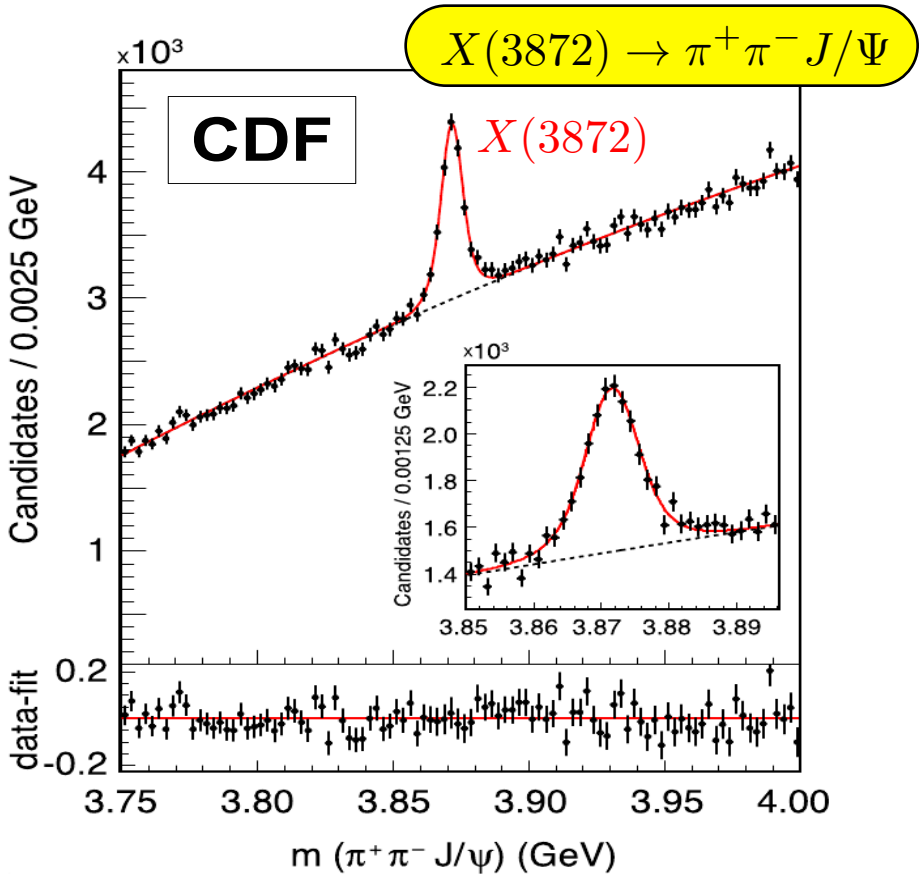


Discovered by Belle in 2003

Confirmed by *many* other experiments



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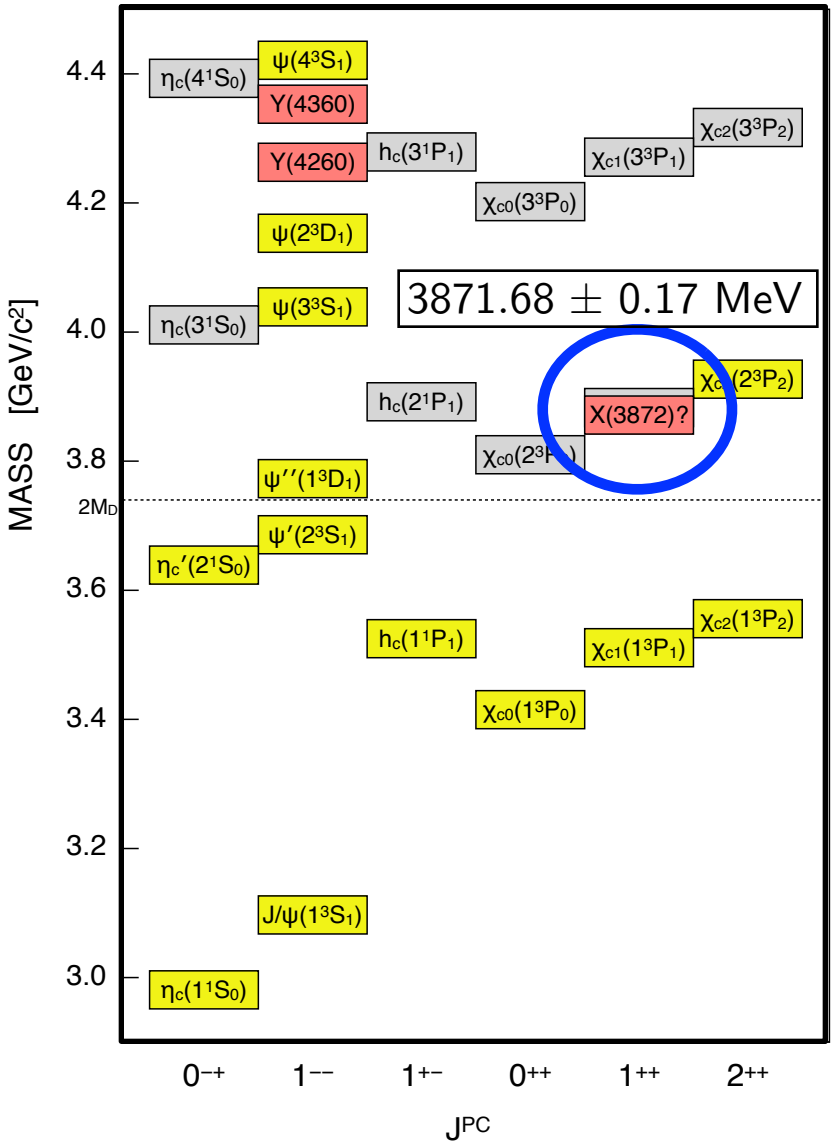

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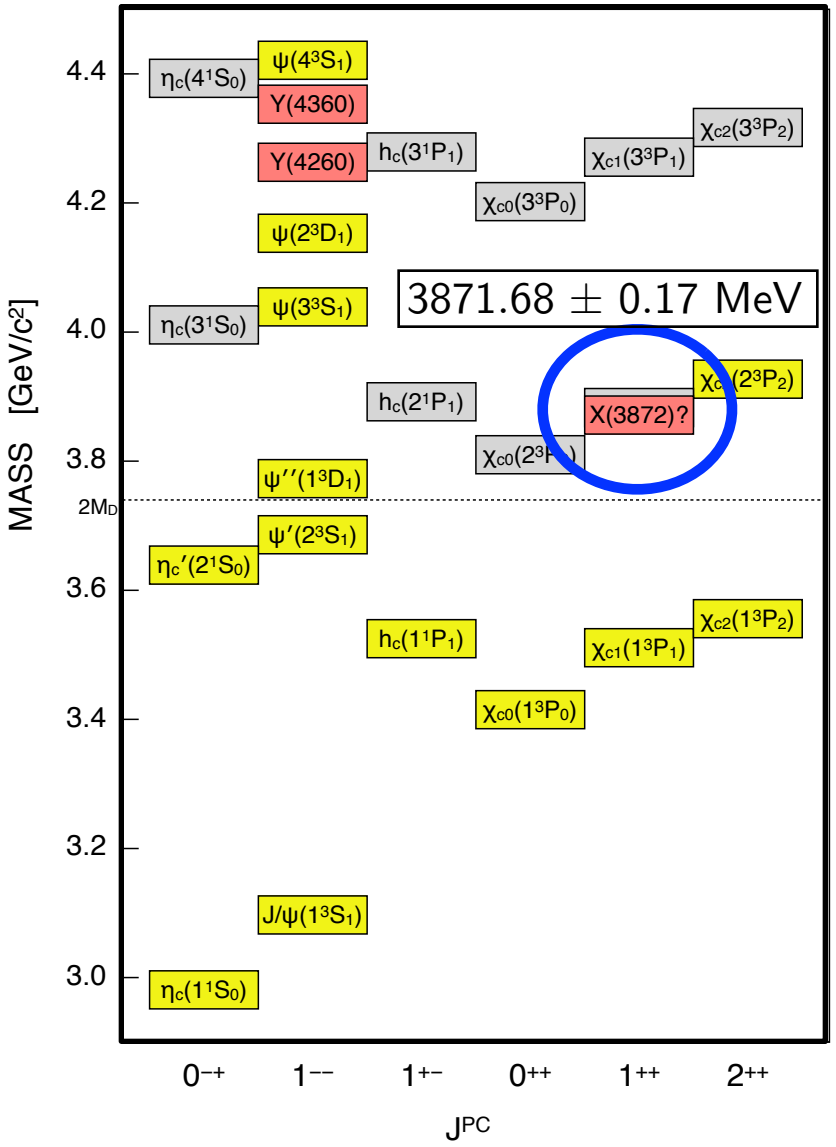

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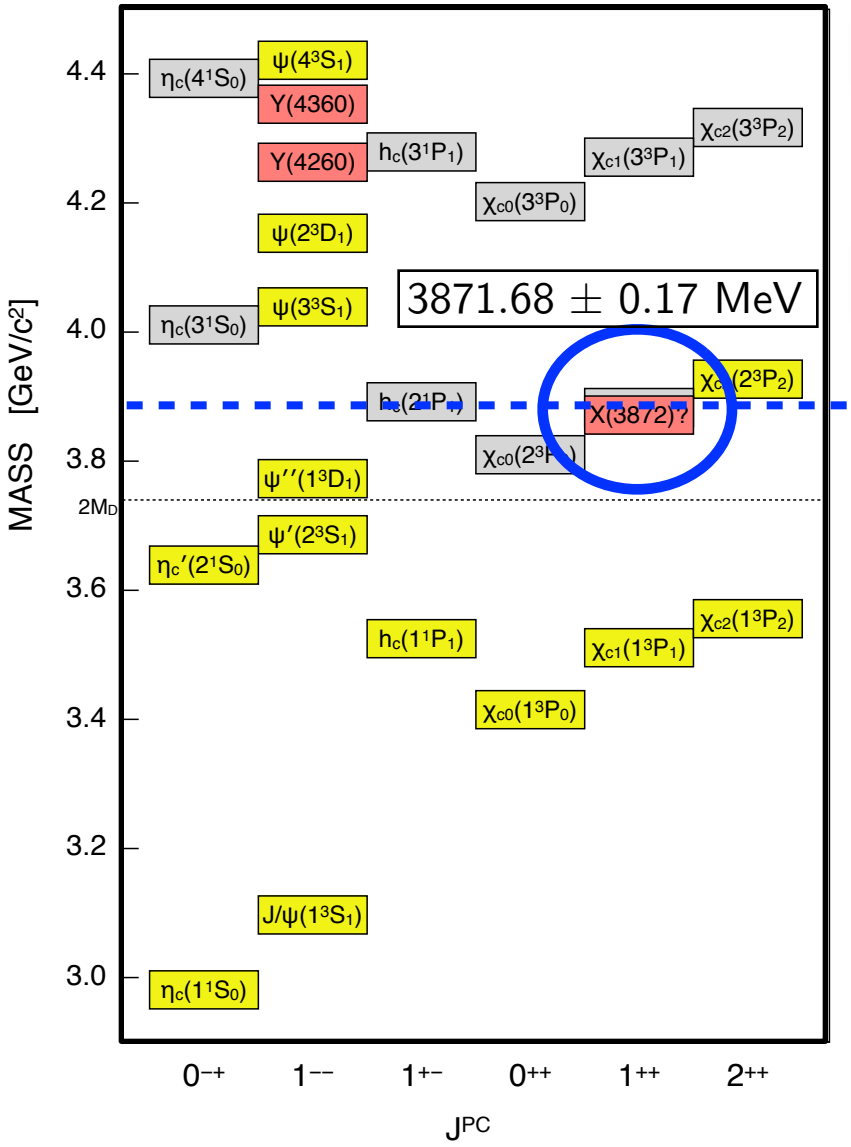

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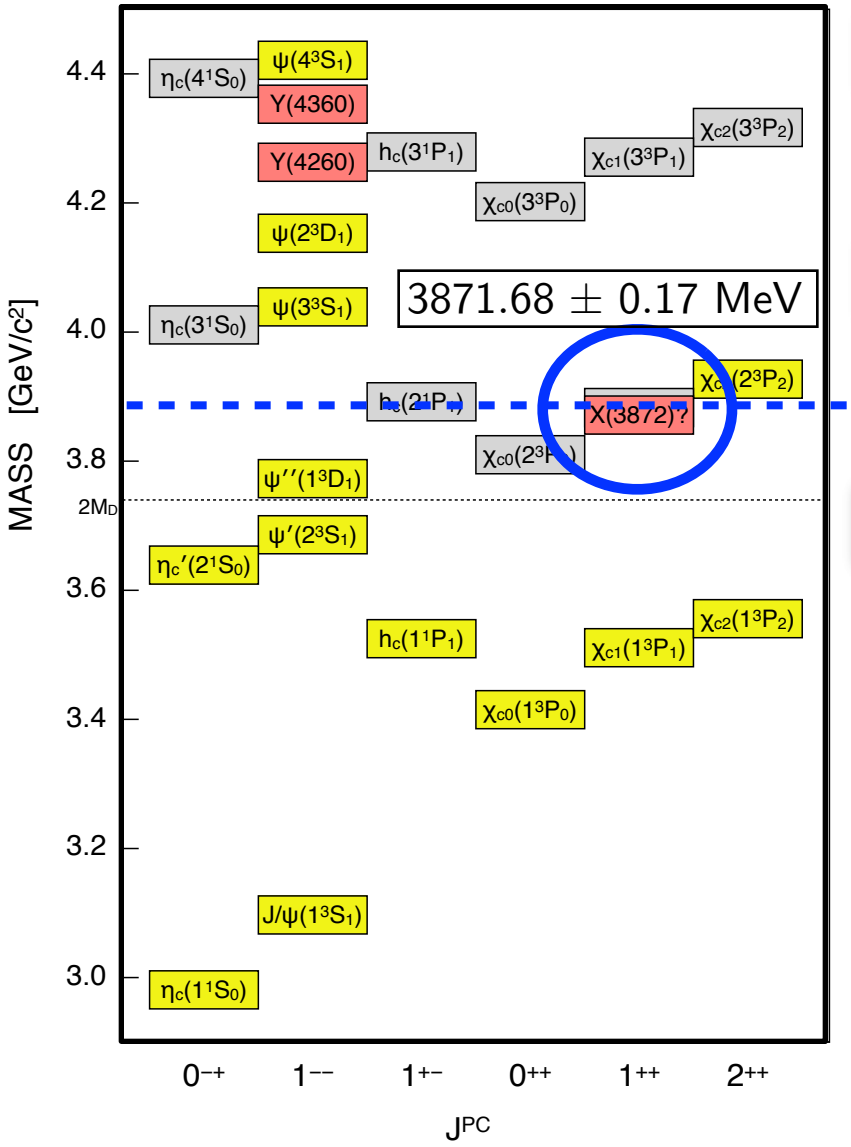

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$$B(X \to \rho J/\Psi) \approx B(X \to \omega J/\Psi)$$

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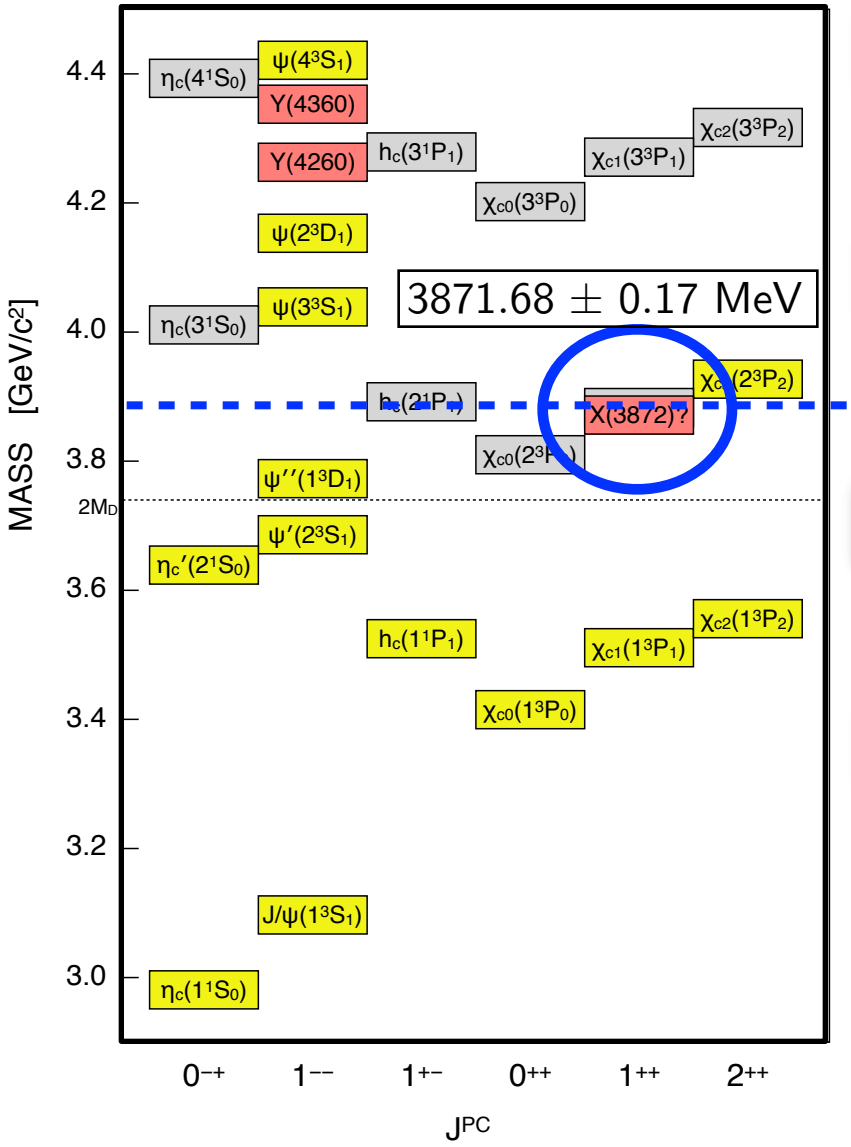

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PRL110, 222001 (2013)

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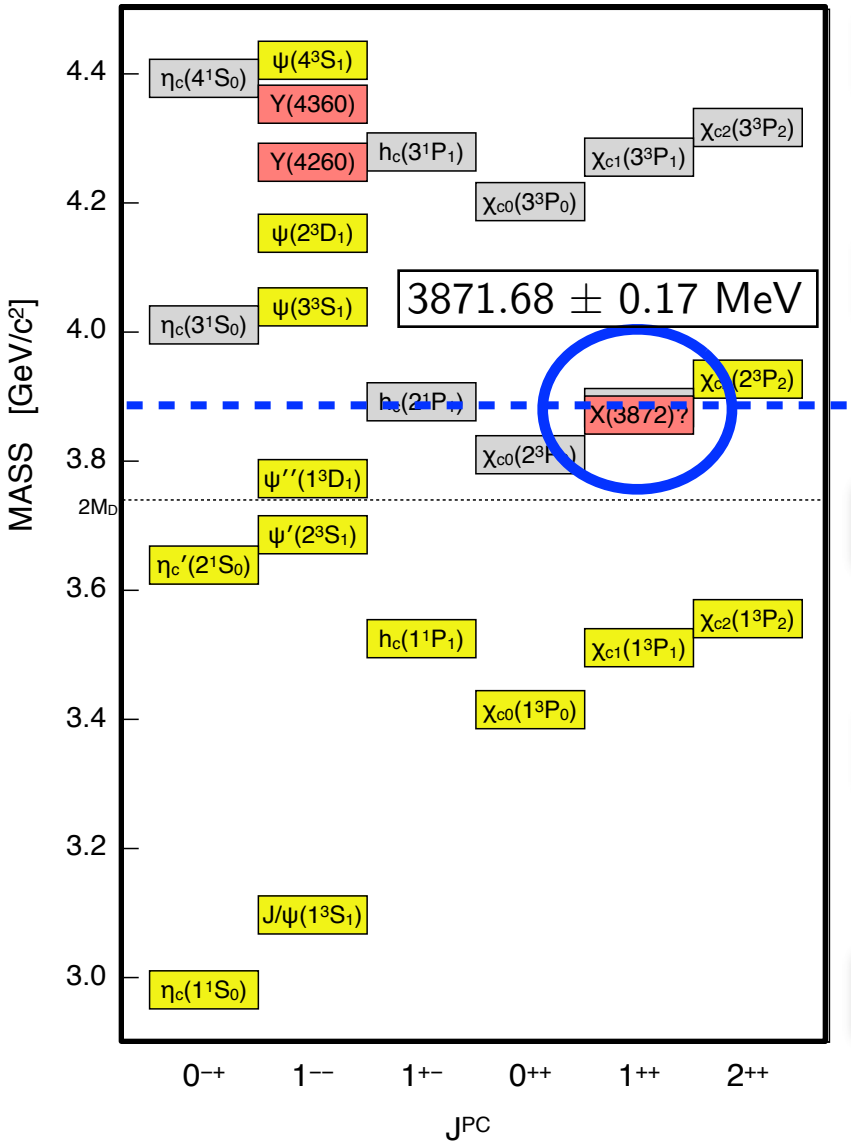

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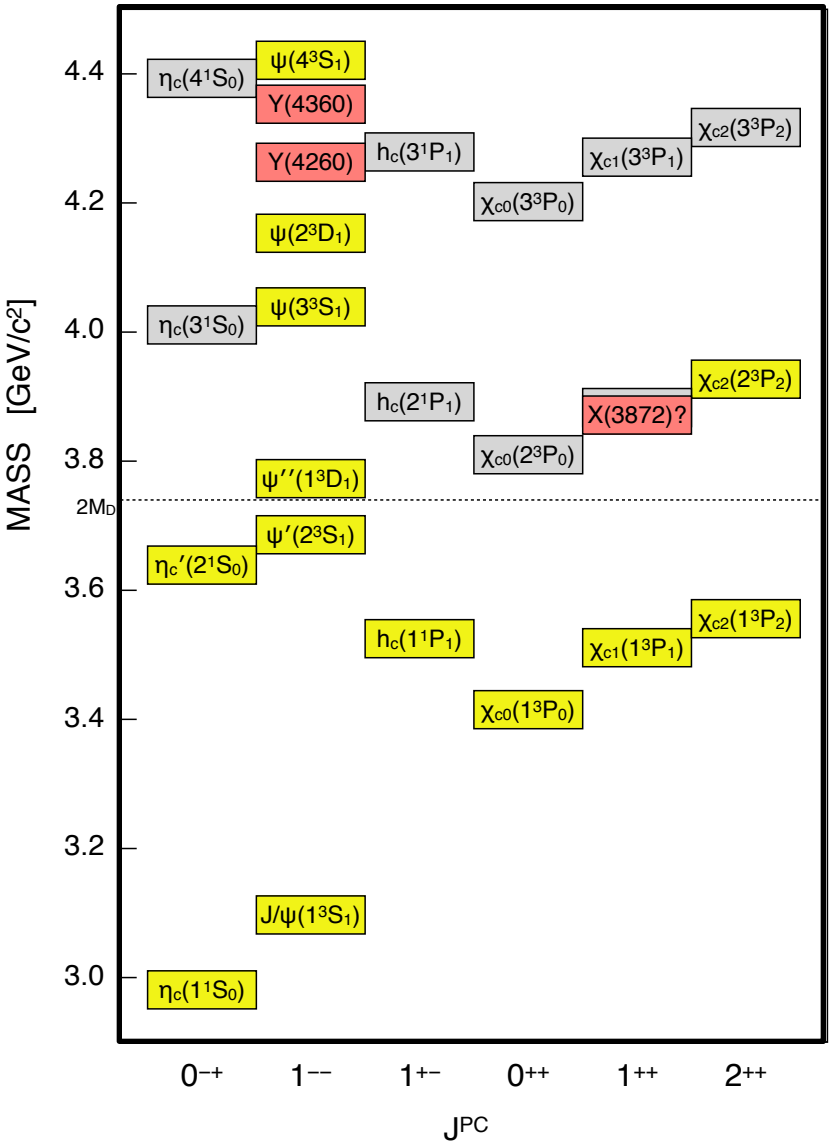
PRL110, 222001 (2013)

What is its nature?

Y(4260,4360): other exotics?



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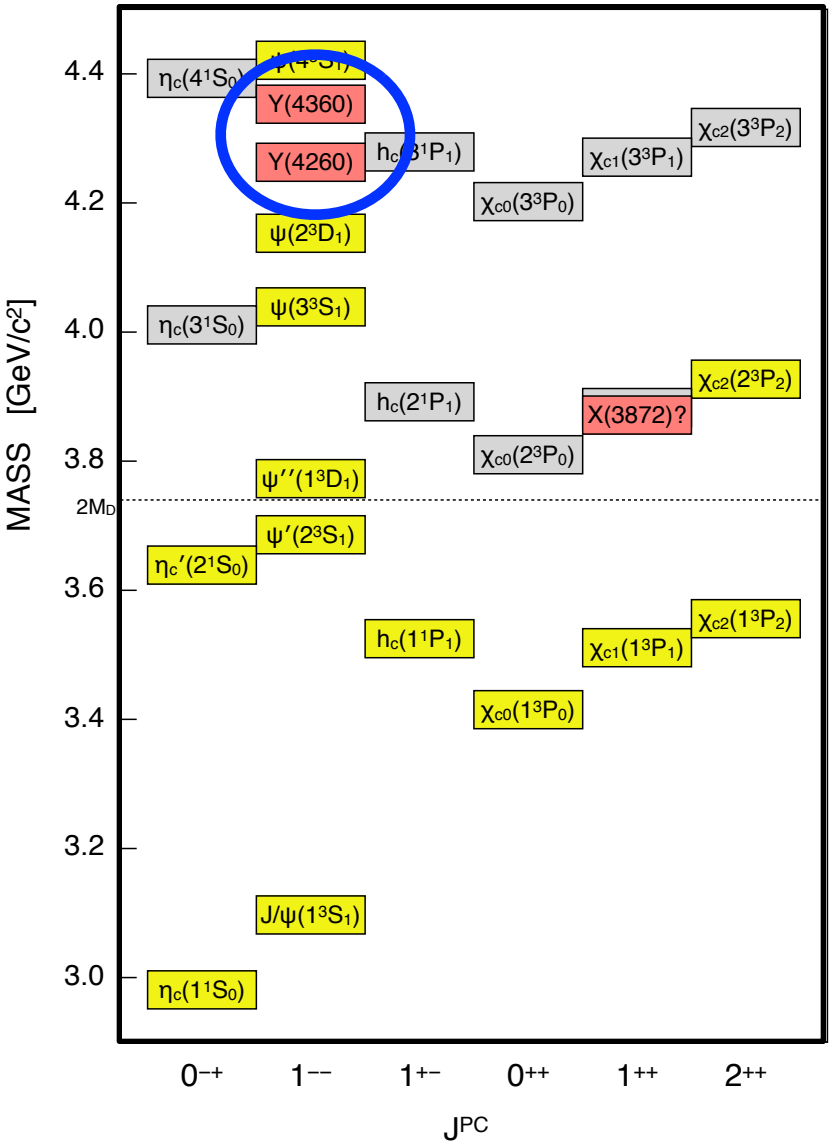

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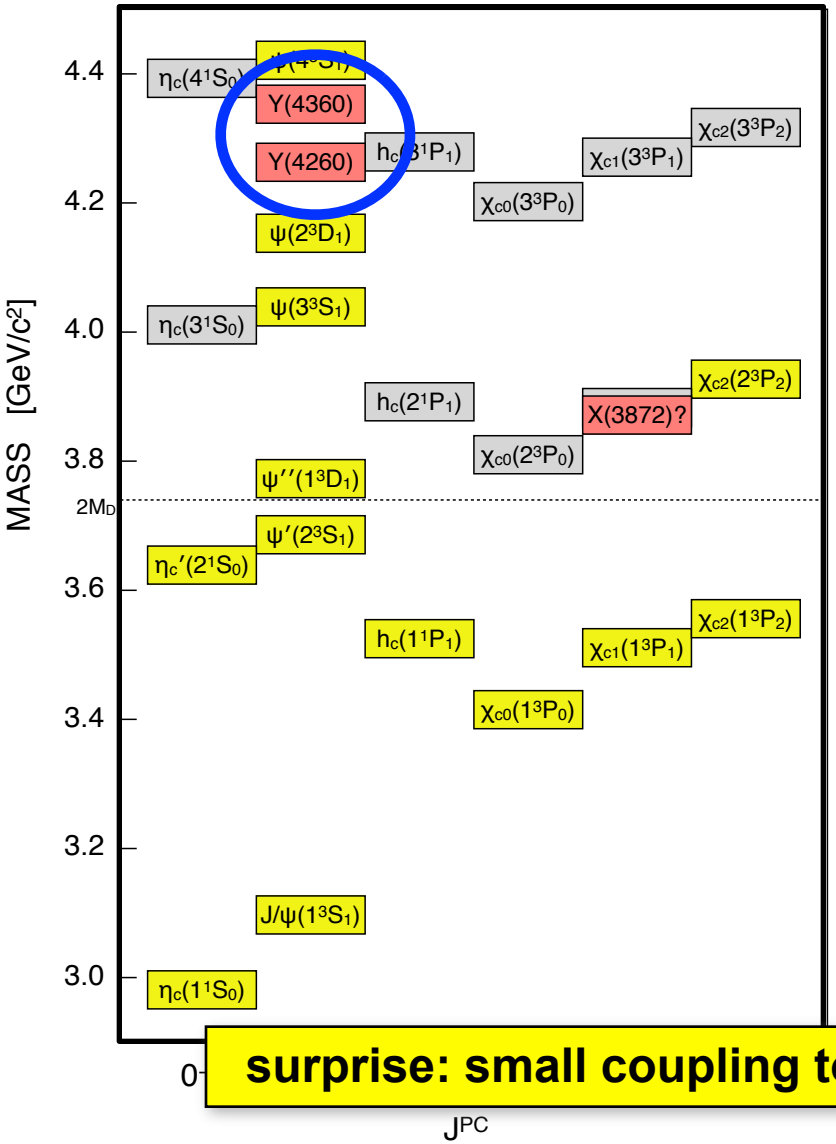
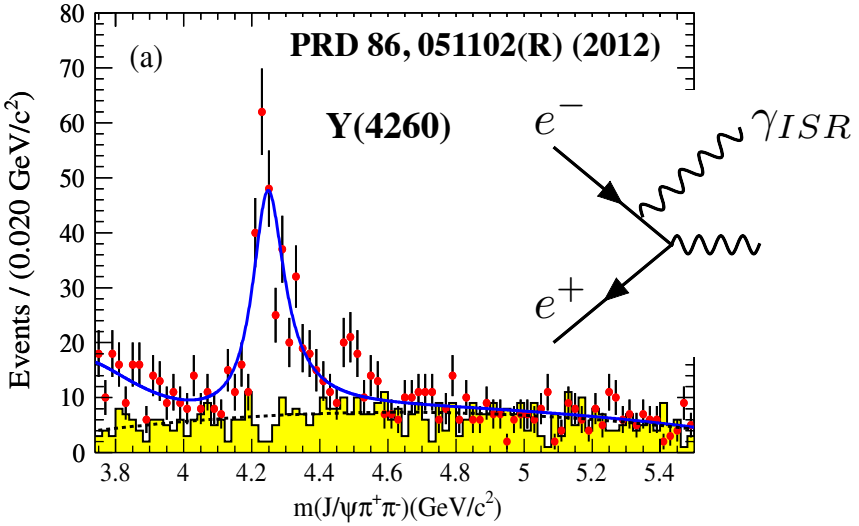
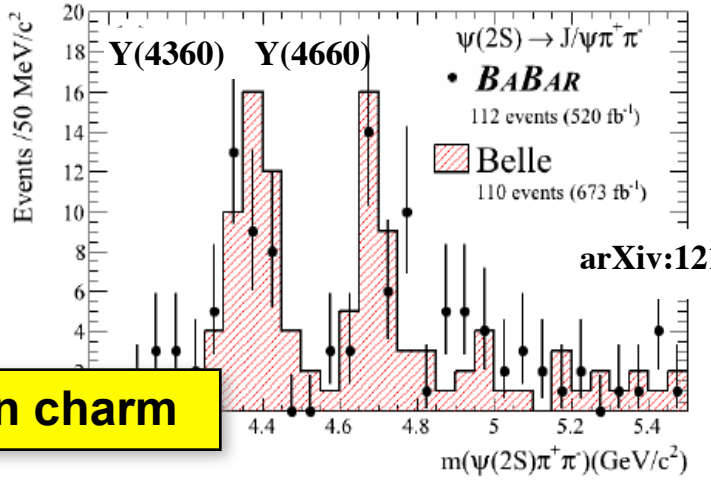


$e^+e^-(\gamma_{ISR}) \rightarrow \pi^+\pi^- J/\psi$ at BaBar



$e^+e^-(\gamma_{ISR}) \rightarrow \pi^+\pi^-\psi(2S)$ at BaBar and Belle



arXiv:1211.6271

surprise: small coupling to open charm

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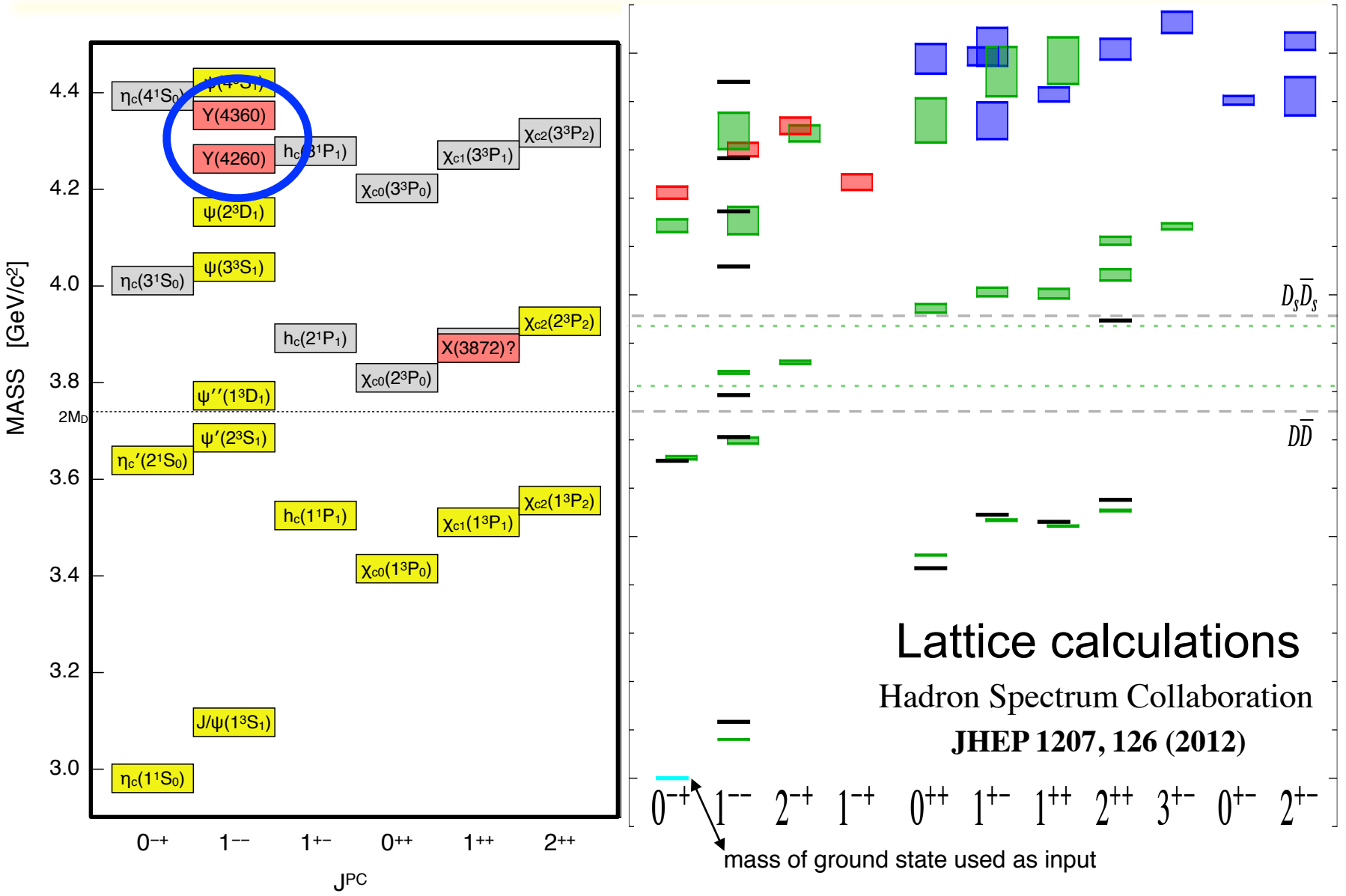

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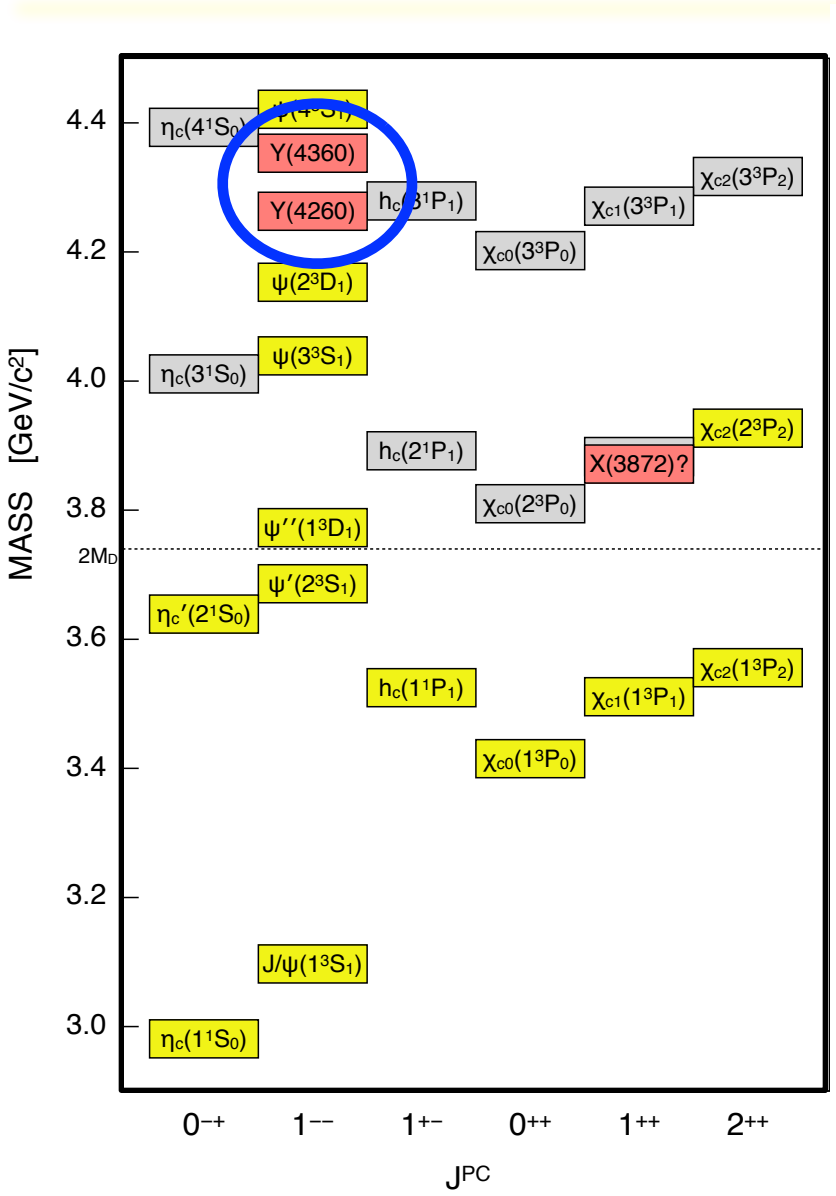
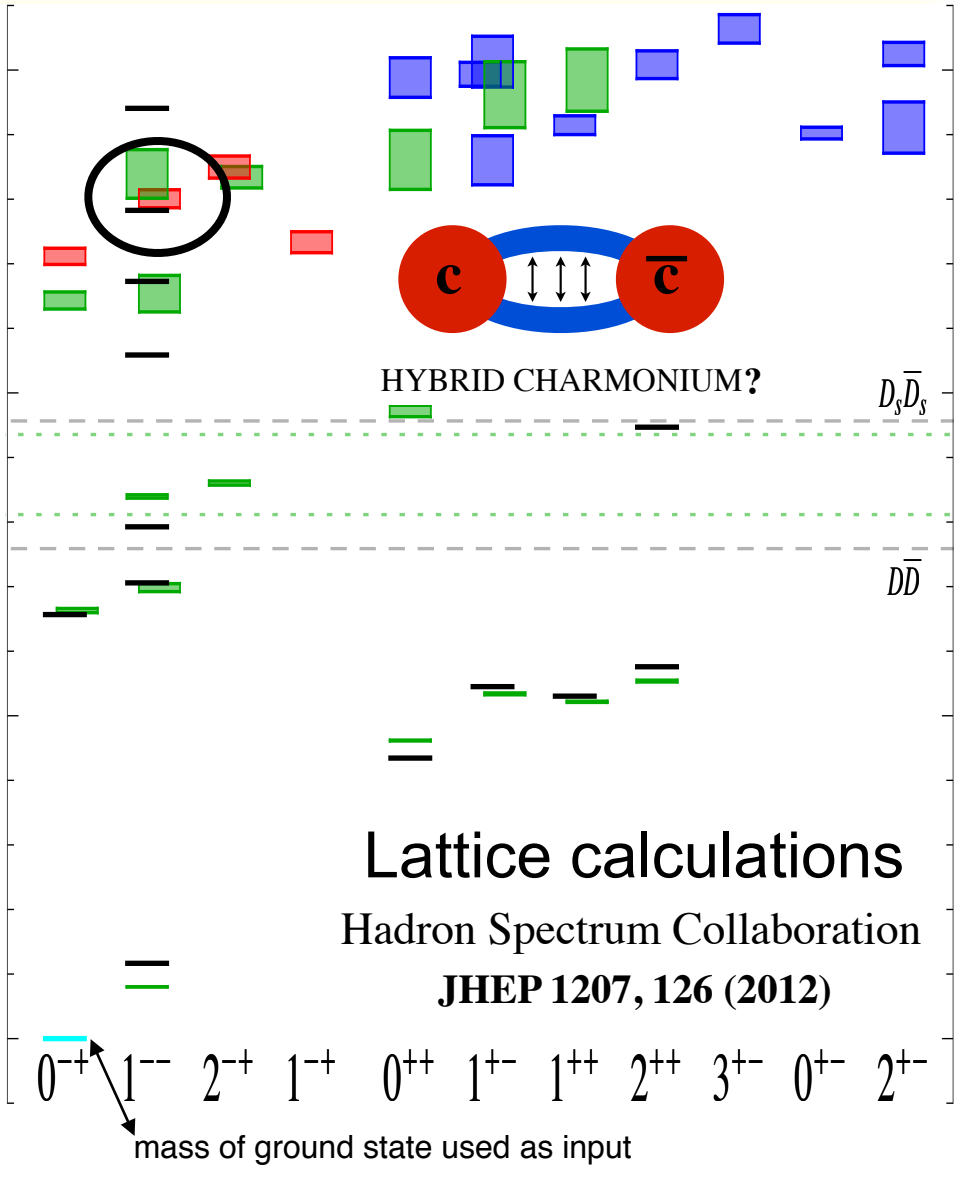
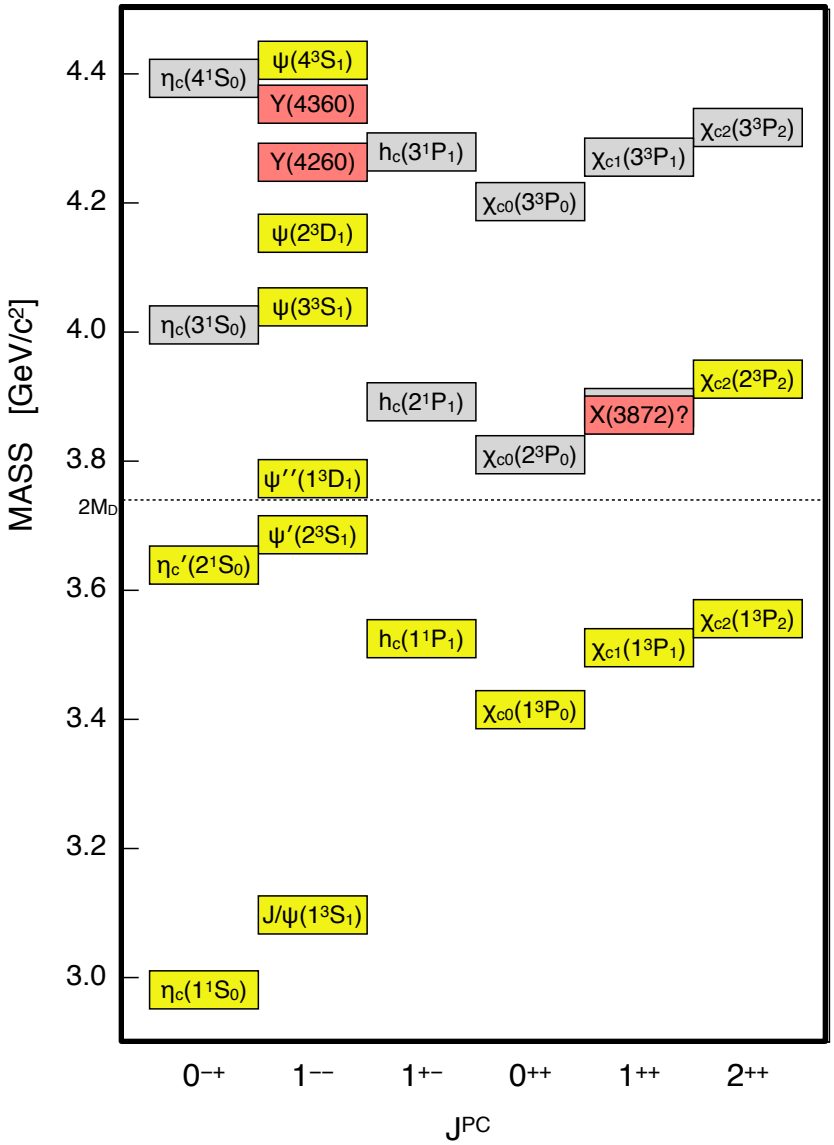




BESIII - in action!



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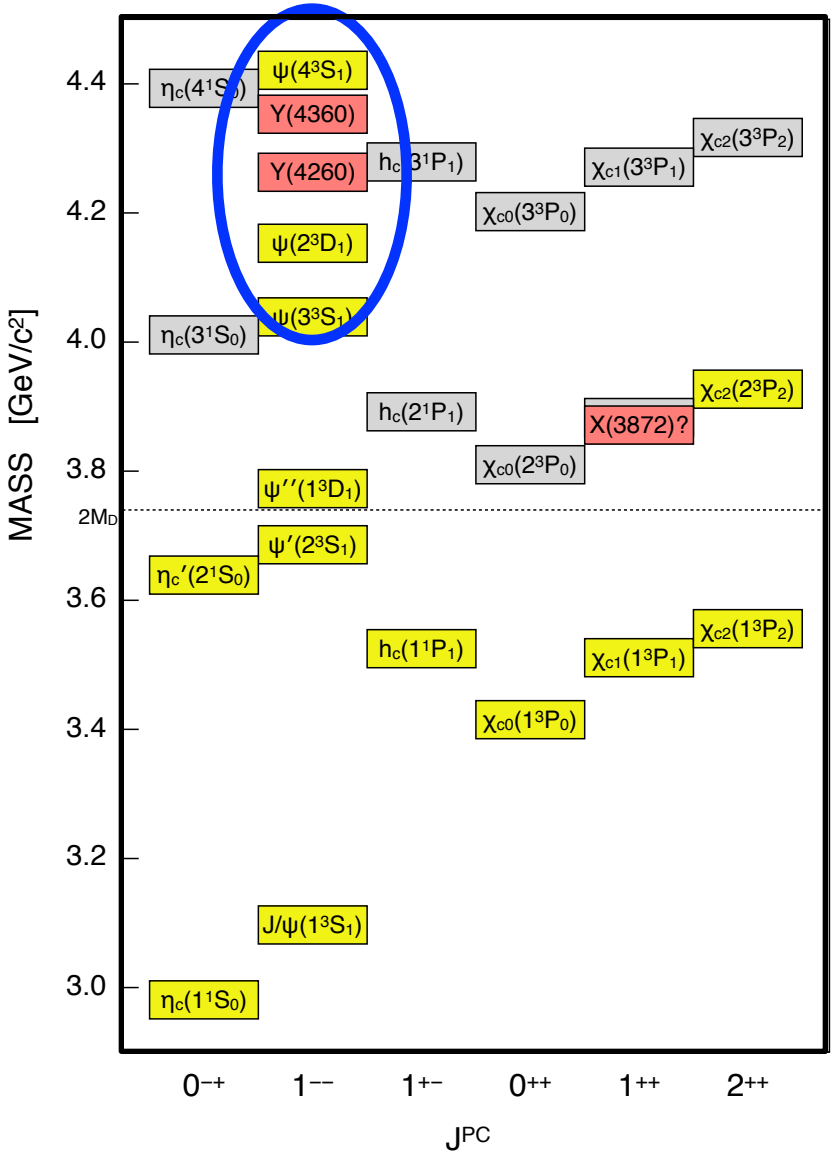

"XYZ" data taken at Ecm=3.8-4.6 GeV

Study the 1^{--} line shape, "Y-scan"

Study hadronic & electromagn. decays to (un)conventional charmonium states

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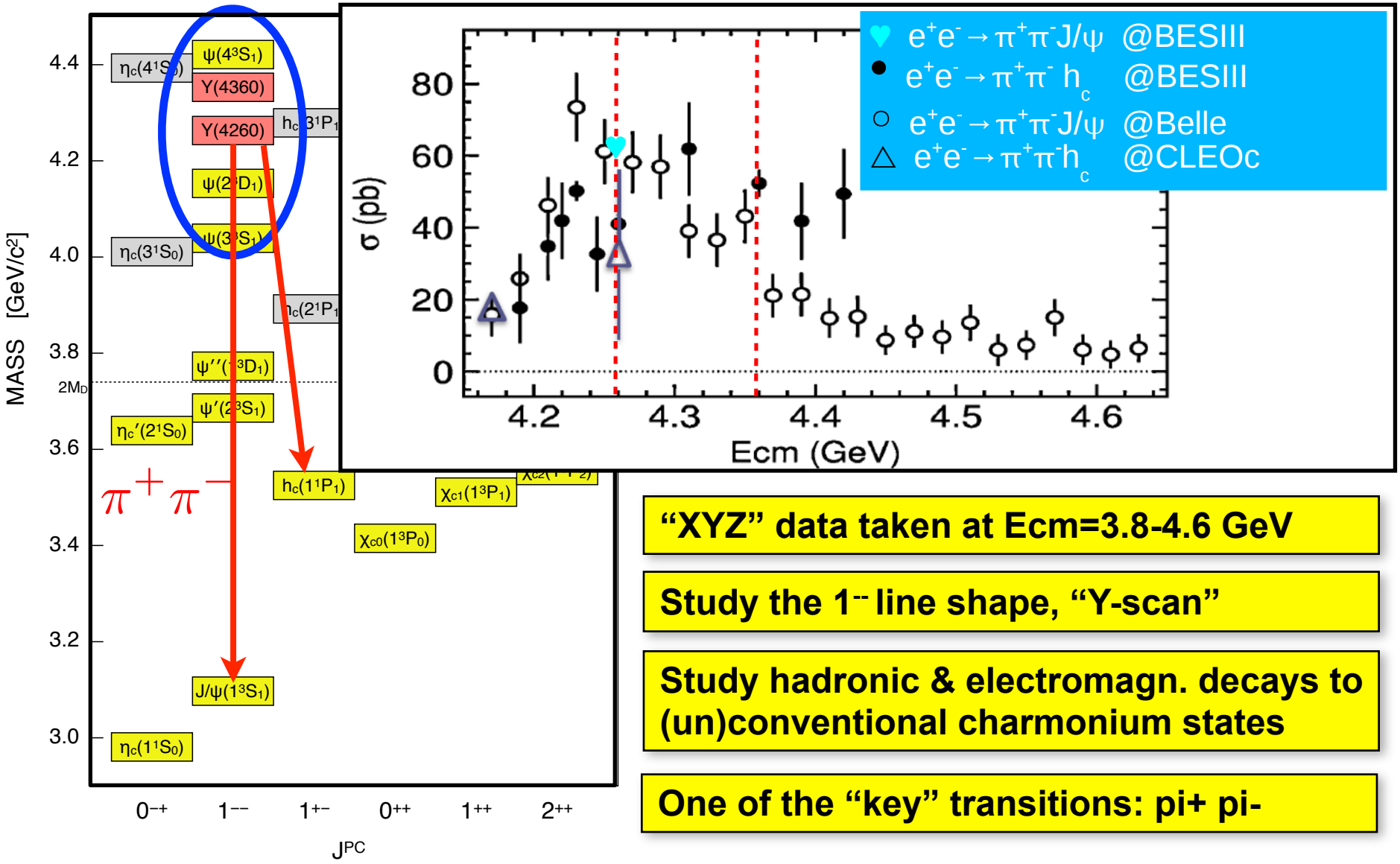

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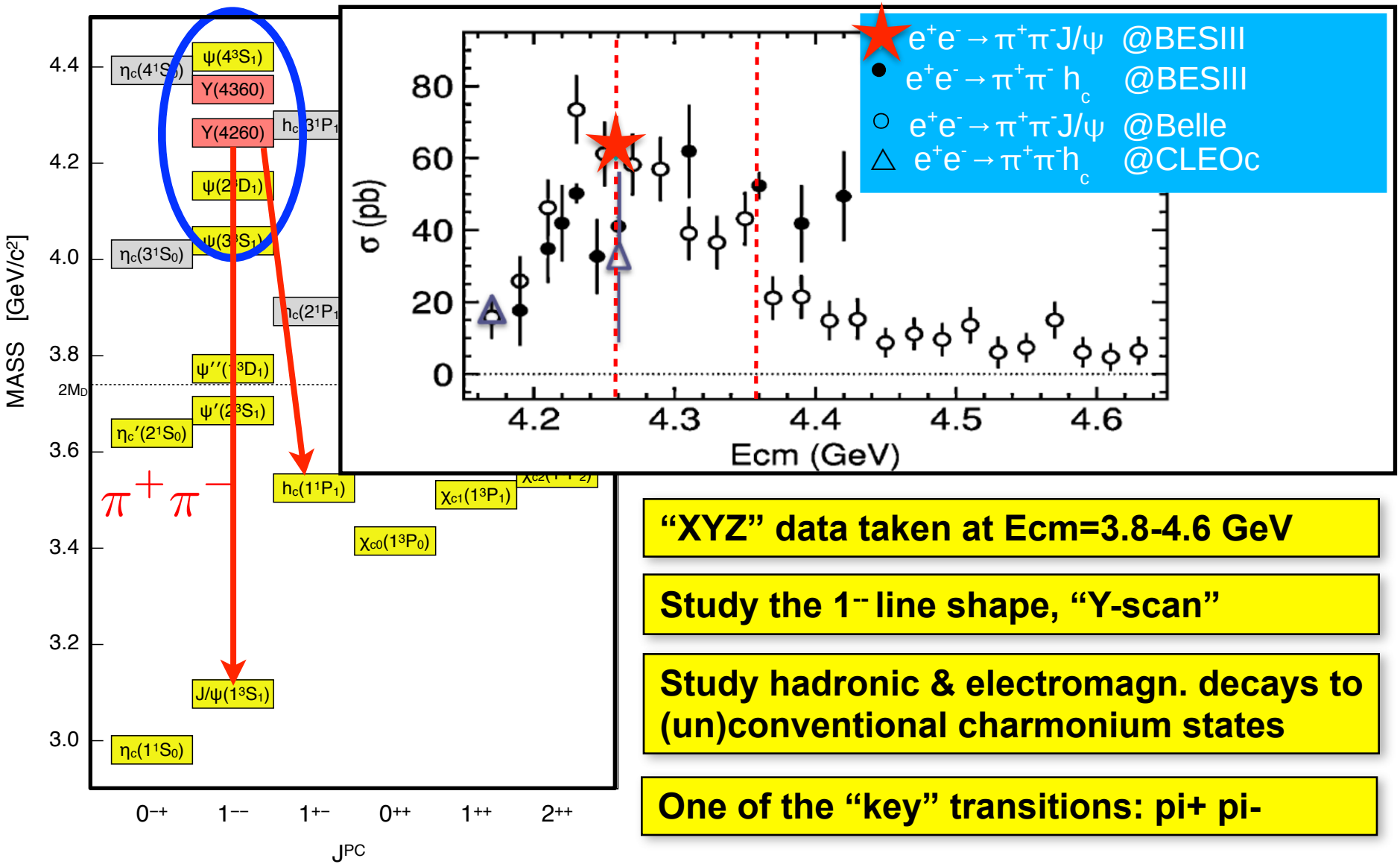

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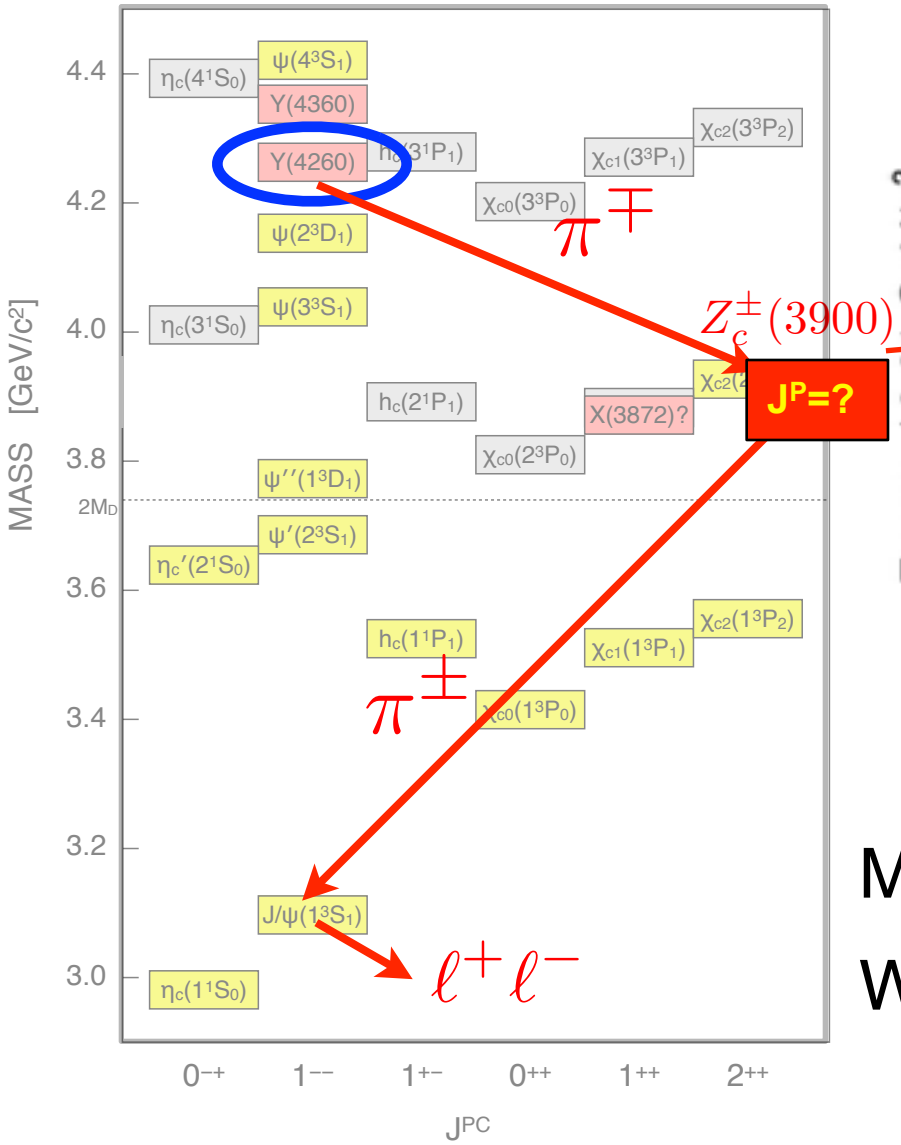
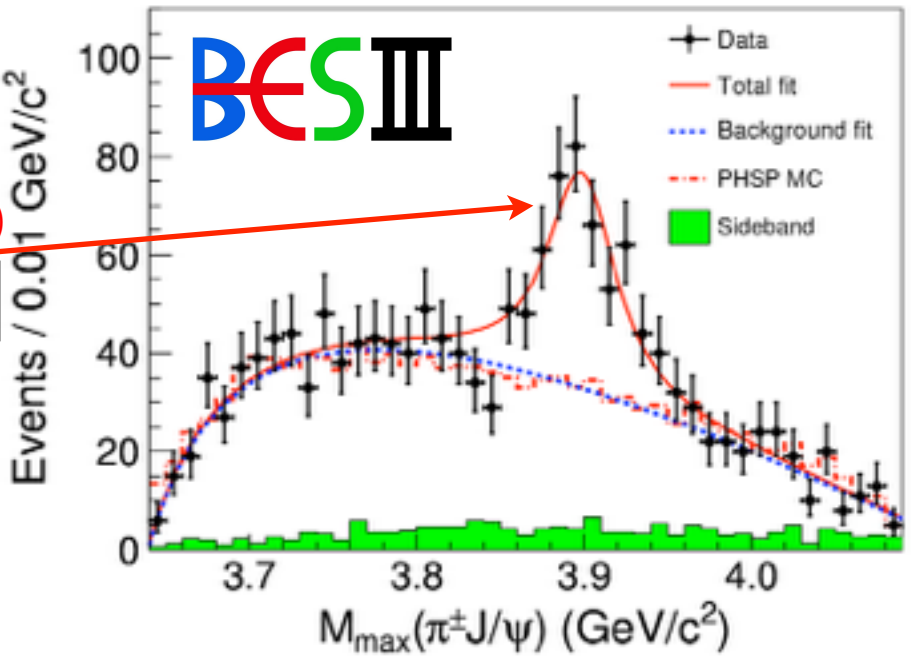
The $Z_c(3900)$ was born...



$$e^+e^- \to \pi^+\pi^- J/\Psi$$

PRL110, 252001 (2013)



Mass $3899.0 \pm 3.6 \pm 4.9$ MeV/c²

Width $46 \pm 10 \pm 20$ MeV

Why the excitement?

PRL110, 252001 (BESIII) (2013)

Zc(3900)

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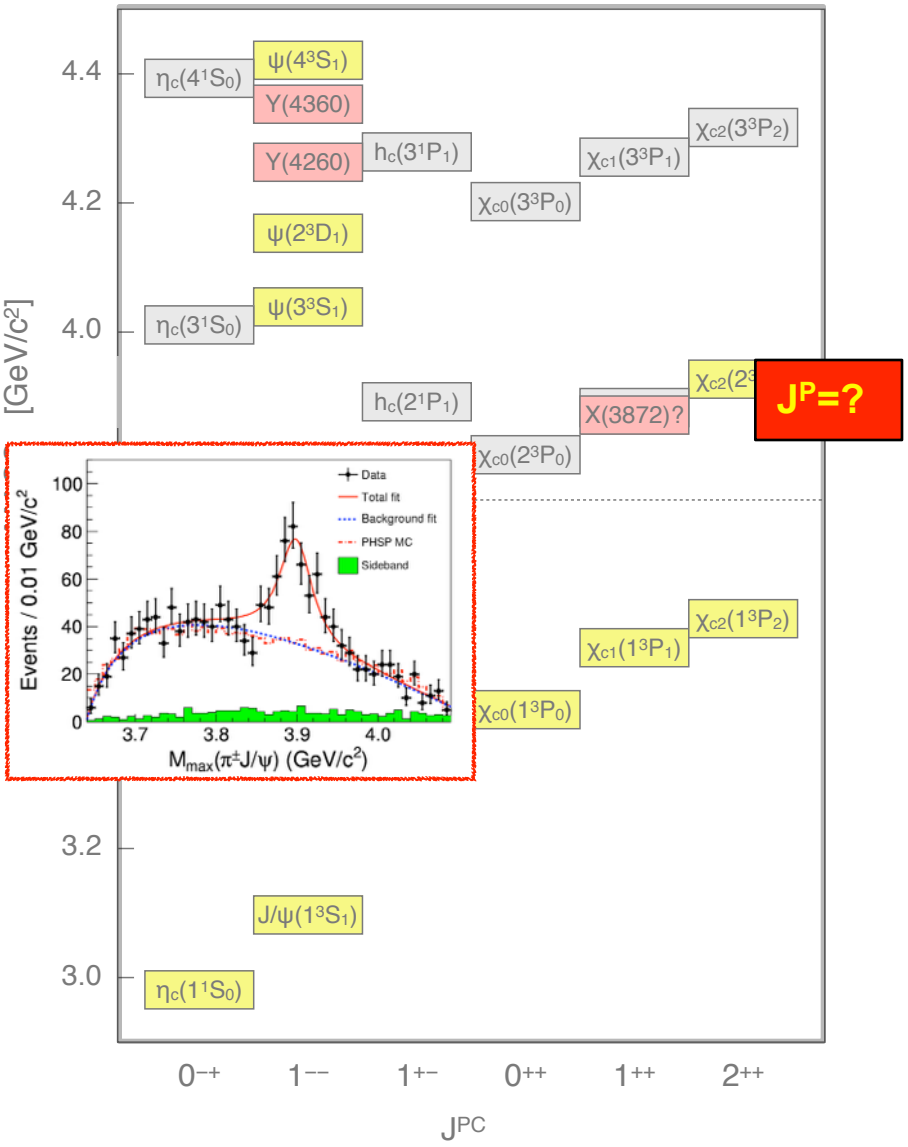

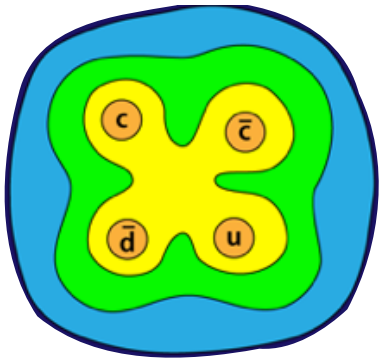

Zc(3900)

A charged and charmonium-rich state

At least 4 quarks involved

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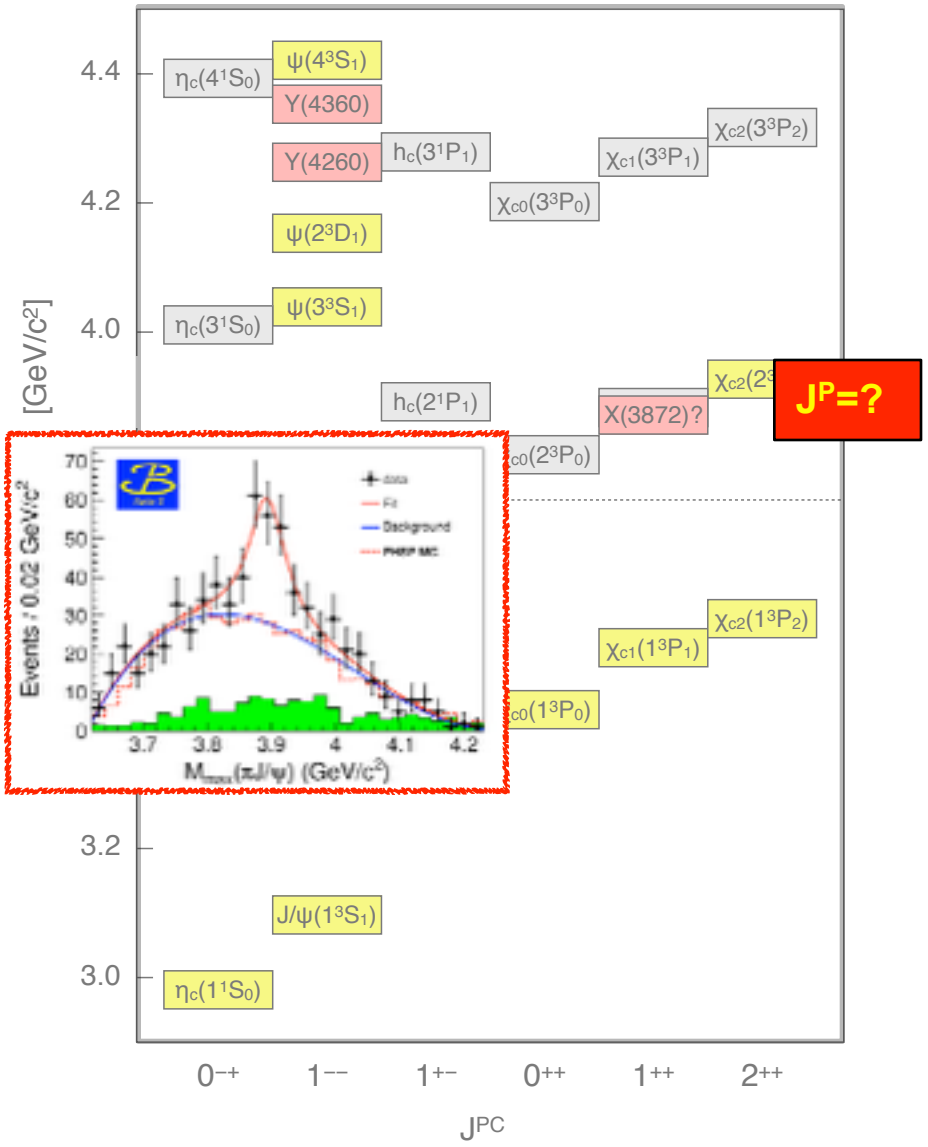
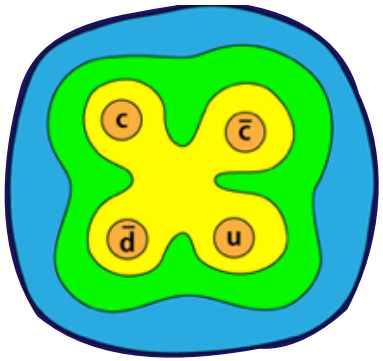
PRL110, 252001 (BESIII), 252002 (Belle) (2013)



JP=?



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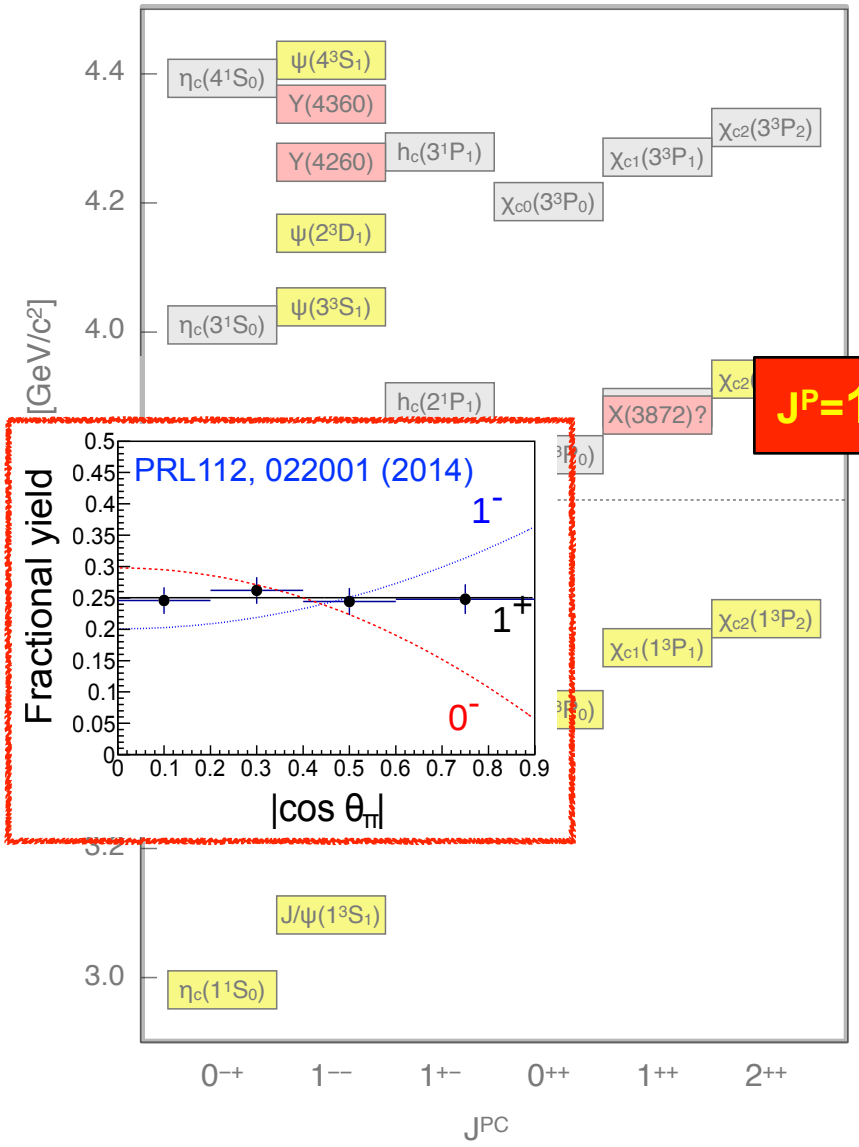

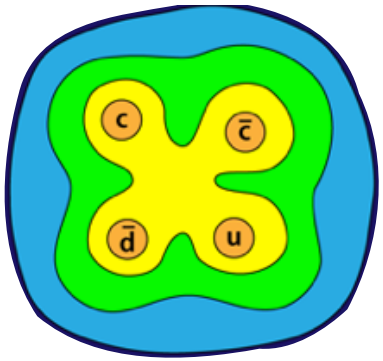

$J^P=1^+$

Zc(3900) Zc(3885)

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DD* decay strongly hints to $J^P=1^+$

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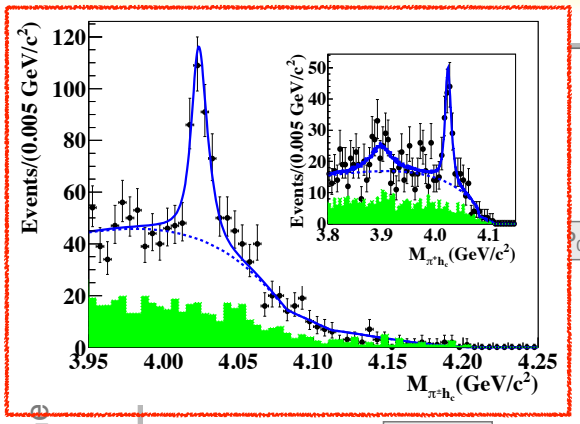
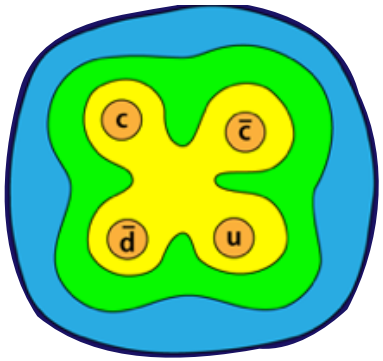


PRL111, 242001 (2013)



$J^P=?$ Zc(4020,4025)

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Z_c' state found: ~120 MeV/c^2 heavier!

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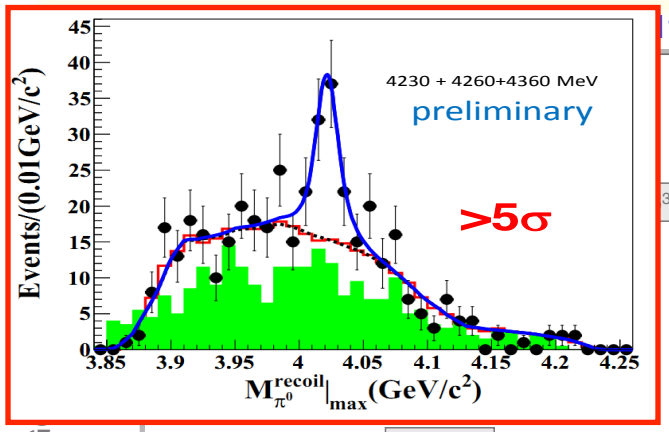

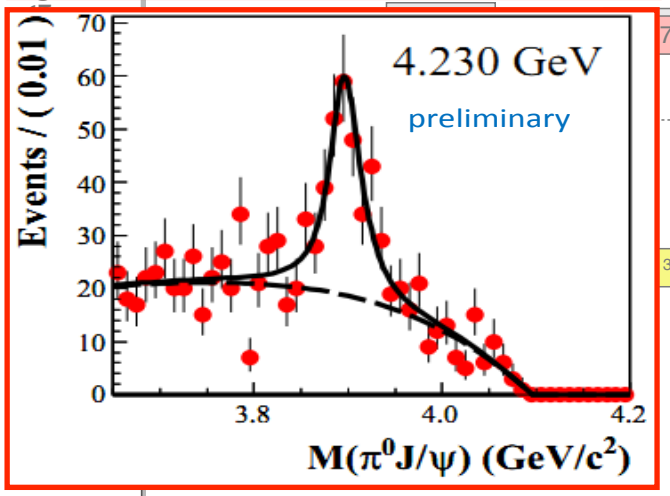

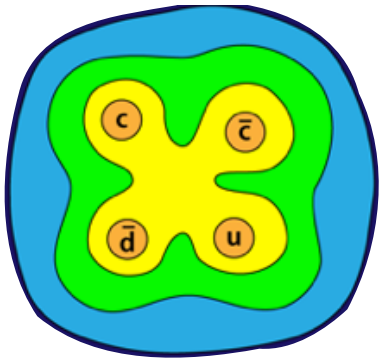

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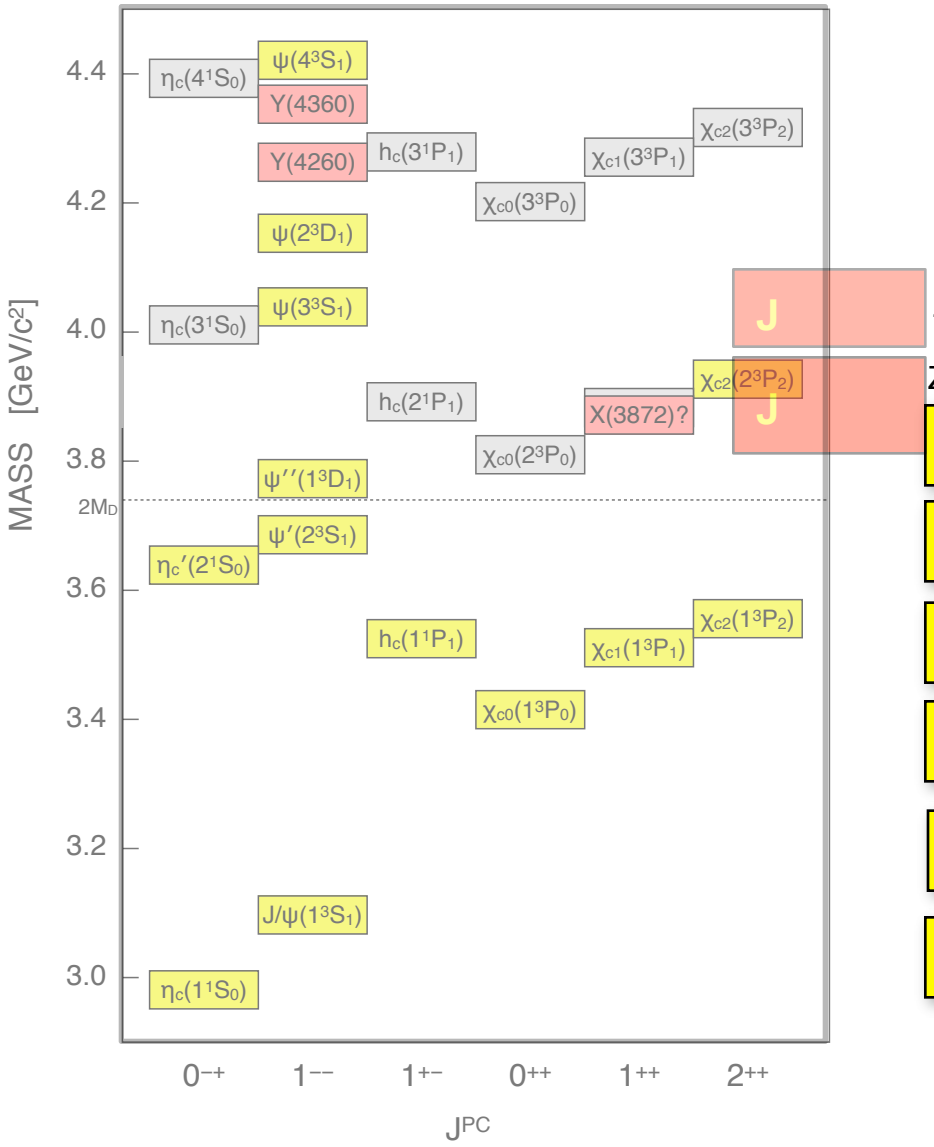
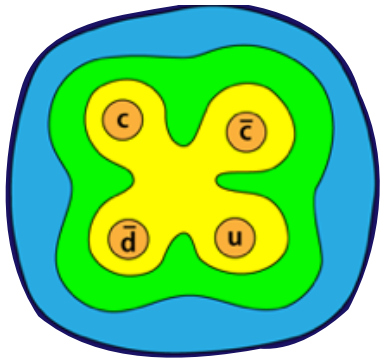
- Isospin triplet established!

Why the excitement?

PRL110, 252001 (BESIII), 252002 (Belle) (2013)





A <u>charged</u> and <u>charmonium</u>-rich state

At least 4 quarks involved

Confirmed by Belle and Cleo-c data

DD* decay strongly hints to $J^P=1^+$

Z_c' state found: ~120 MeV/c^2 heavier!

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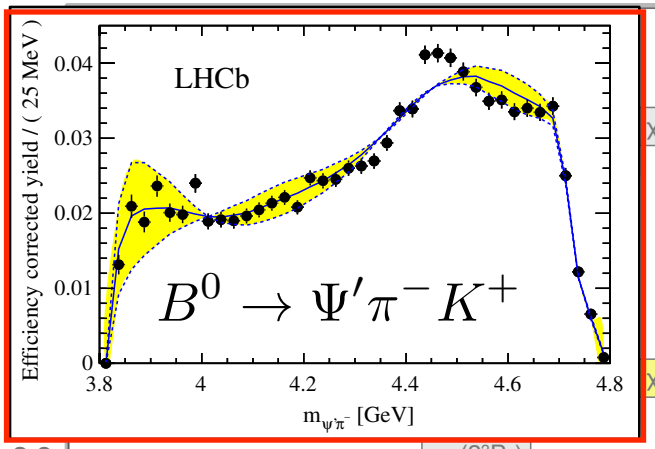

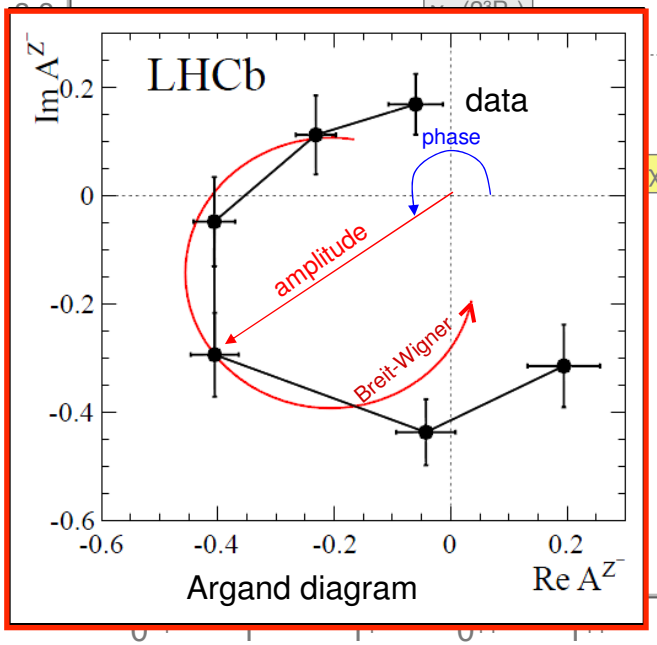

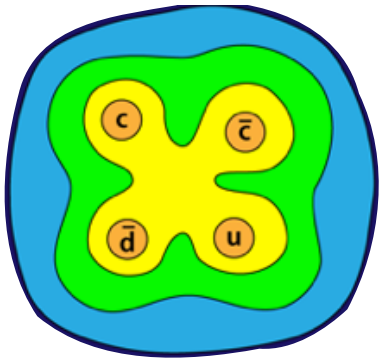

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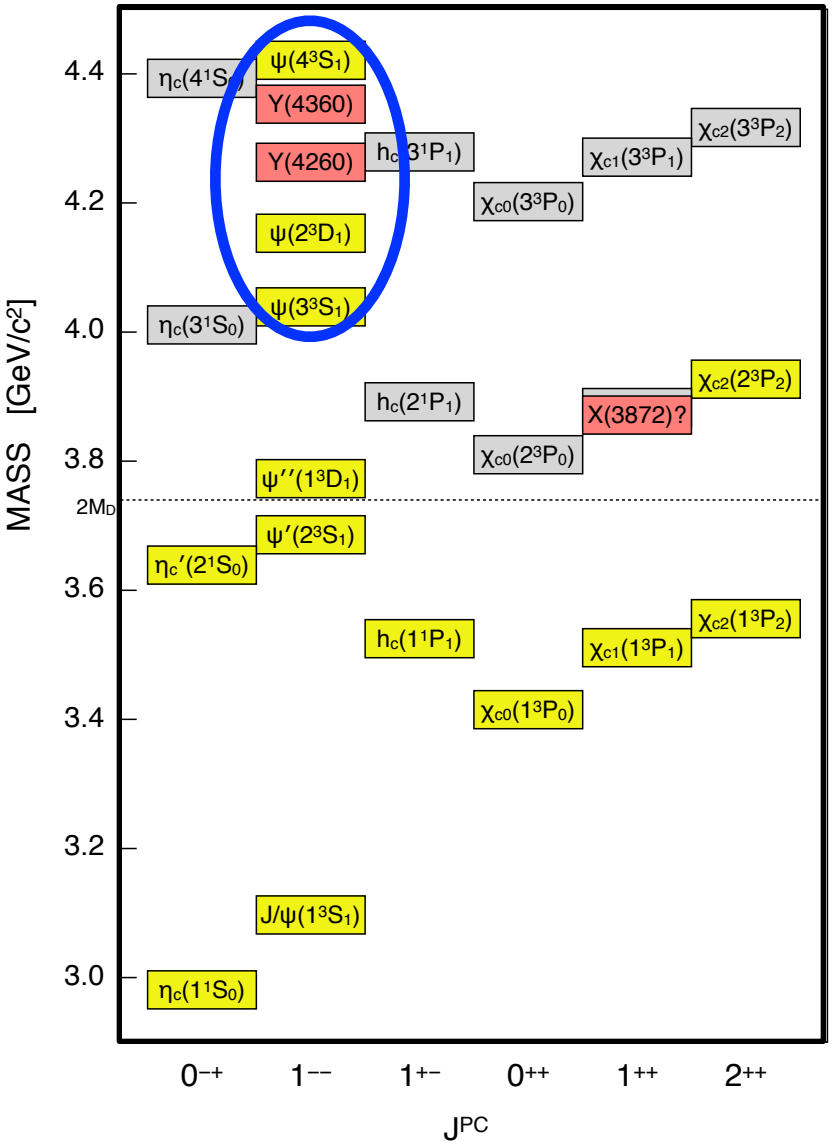
$Z_c(4430)$ rediscovered by LHCb

X(3872) in radiative transitions

PRL 112, 092001 (2014)



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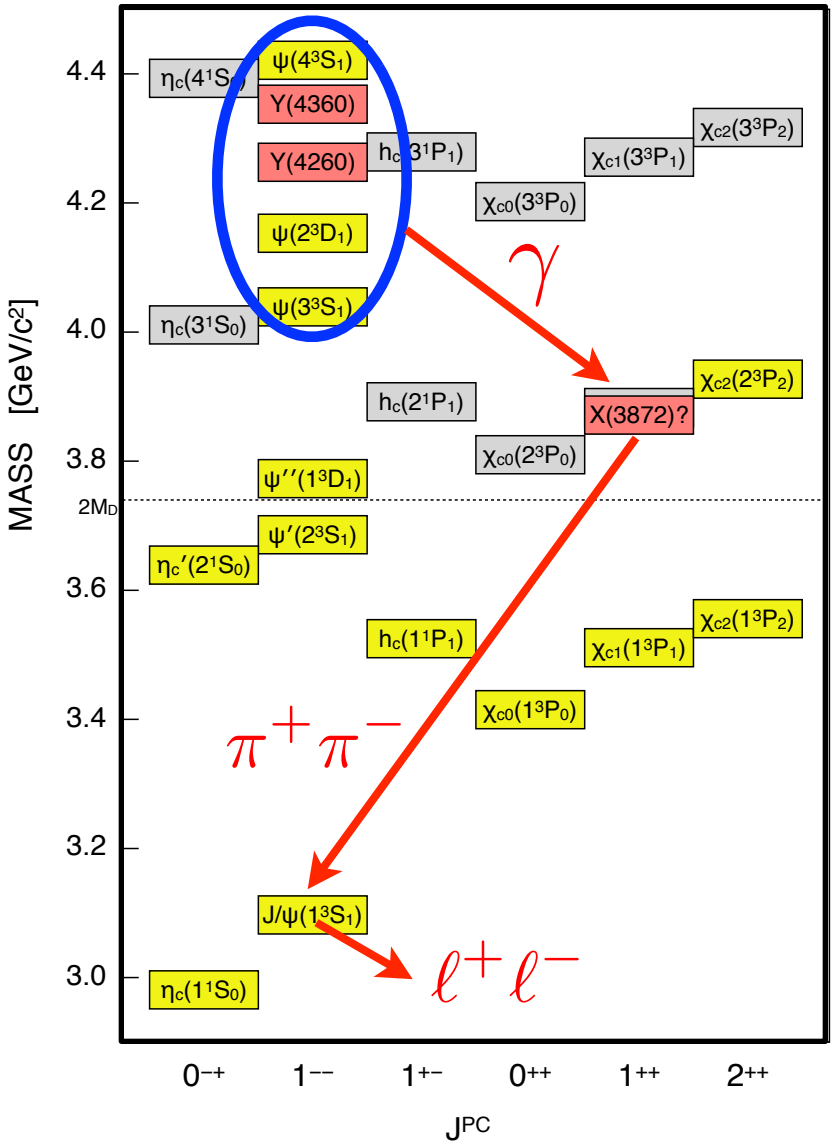

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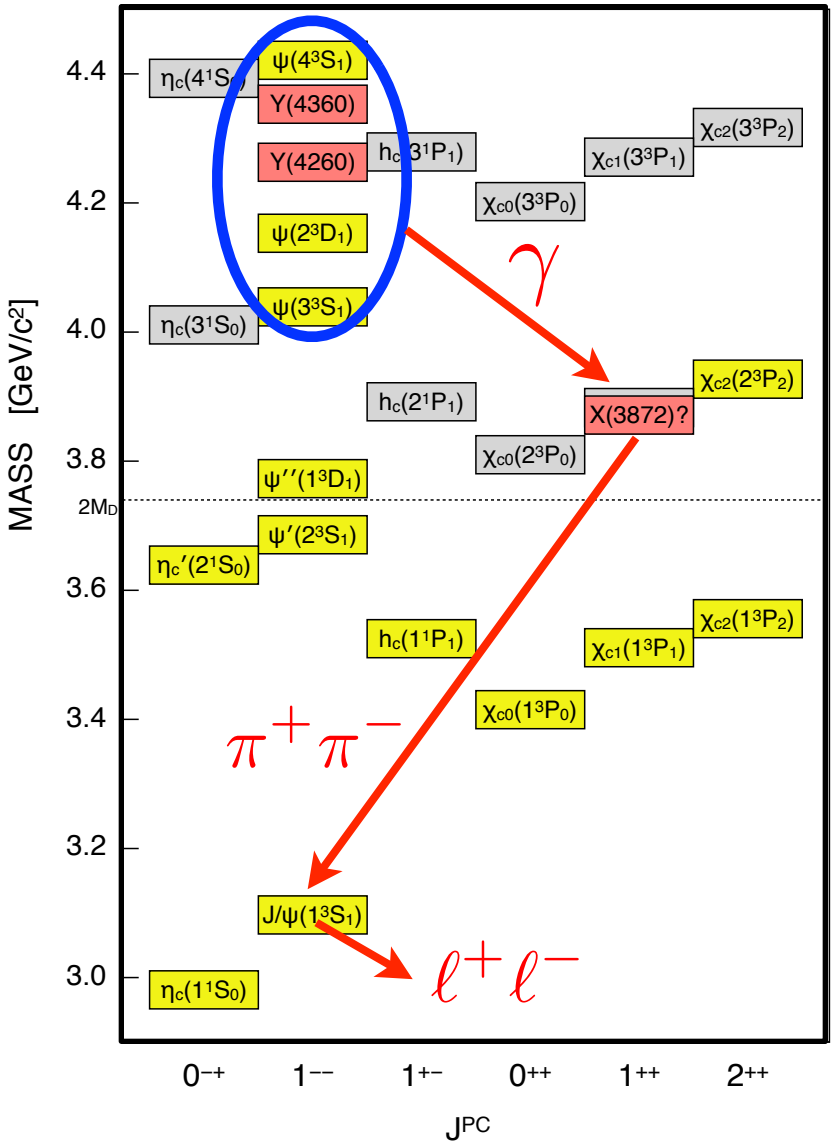

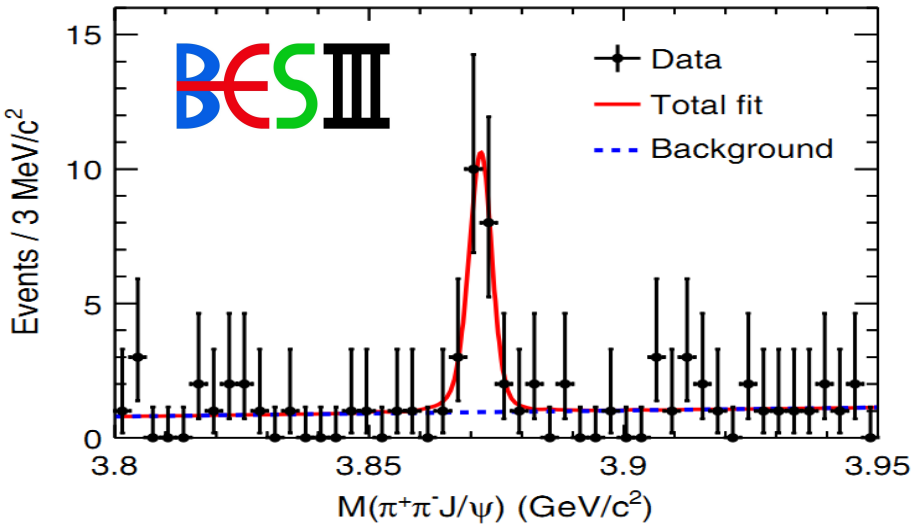

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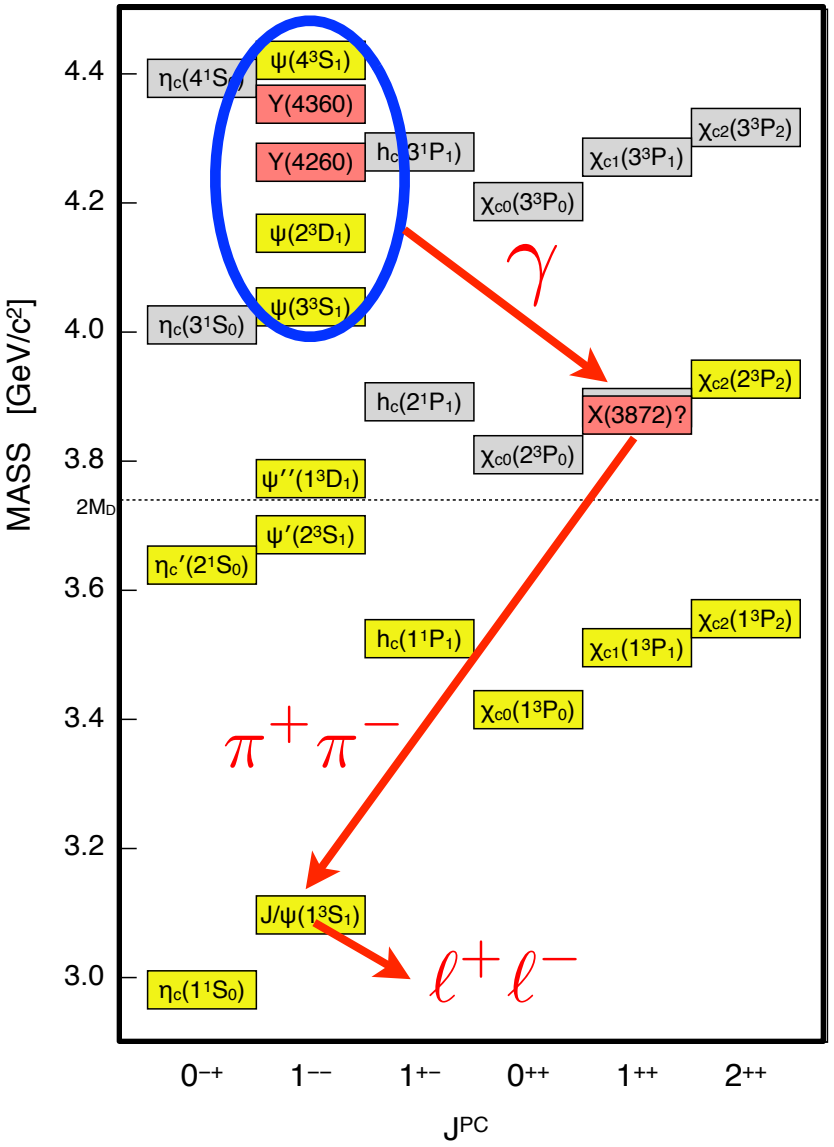

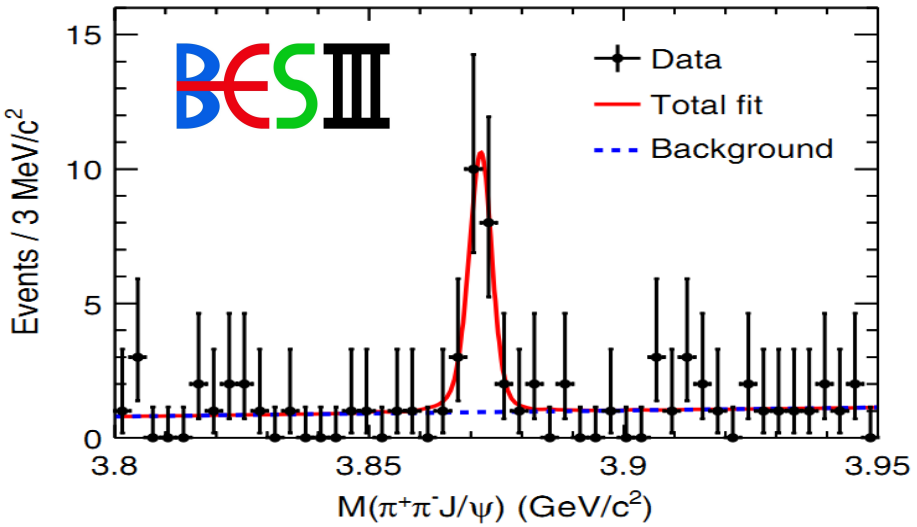

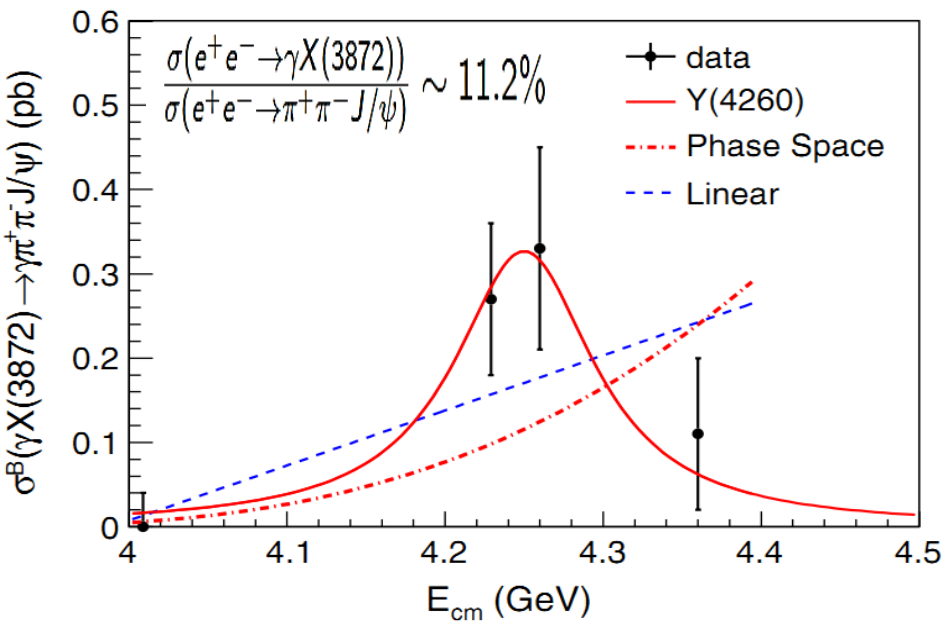

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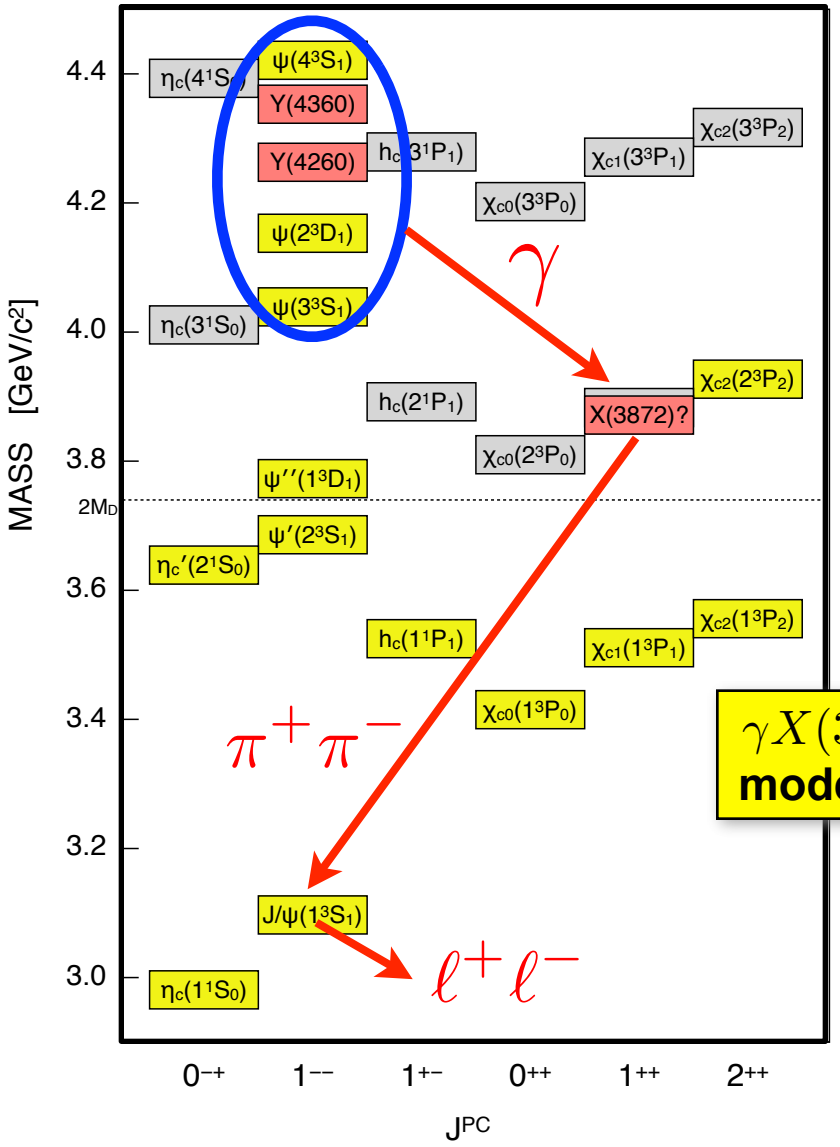
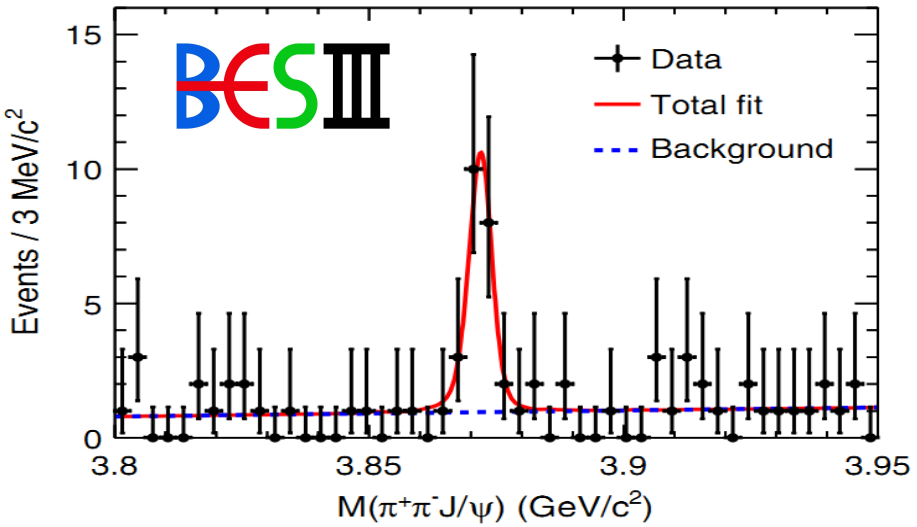
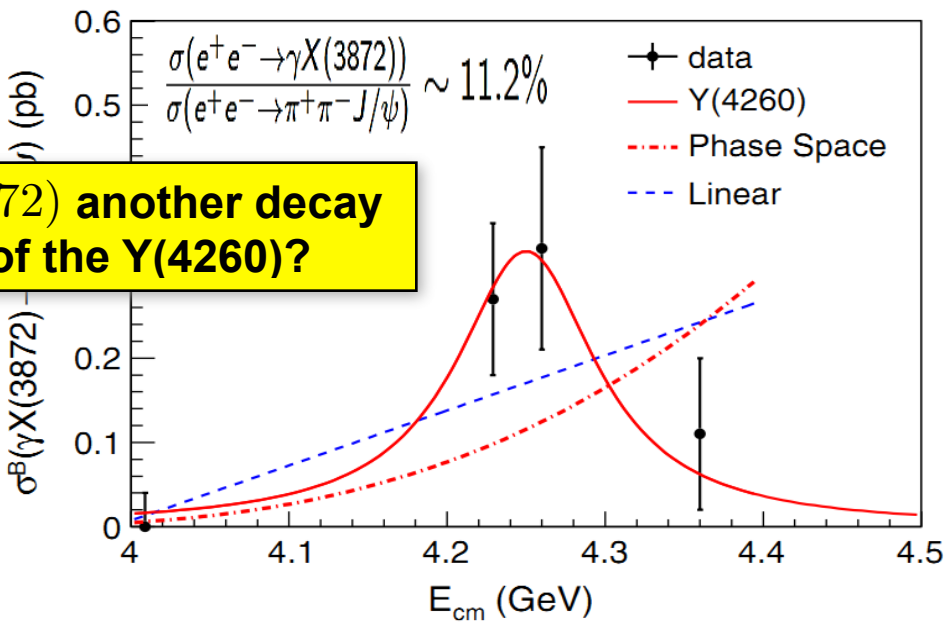




$\gamma X(3872)$ **another decay mode of the Y(4260)?**



New class of hadronic matter seen, but…

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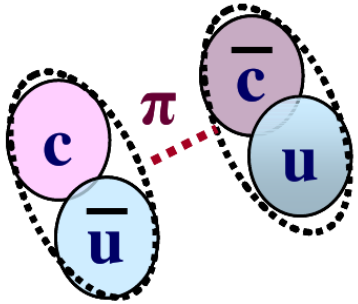
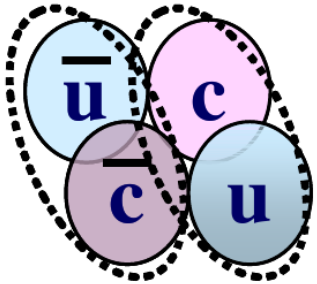


Voloshin; Tornqvist; Close; Braaten; Swanson; Hanhart…

tetra-quark?



Maiani, Piccinini, Polosa, Riquer, …

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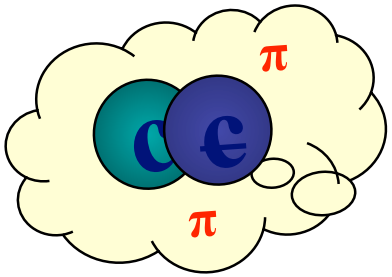
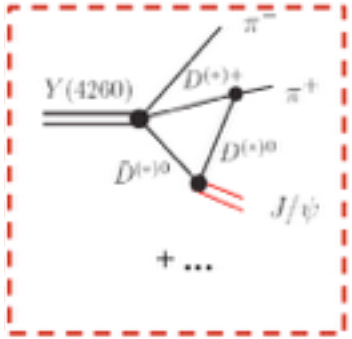


Voloshin, …

something else?



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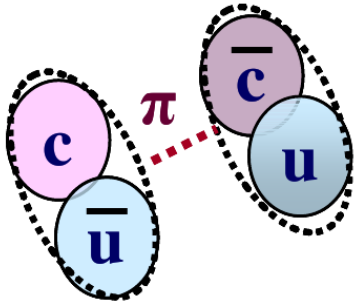

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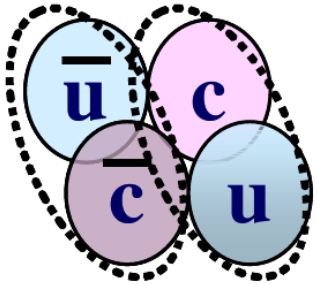

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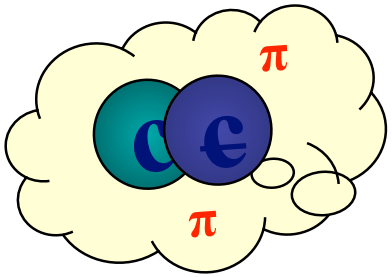

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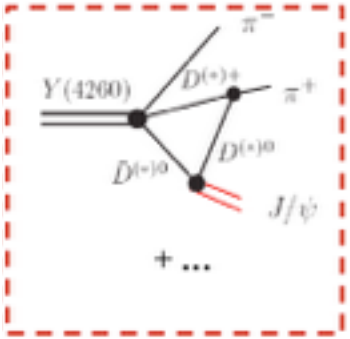

. . . .

Requires completing spectrum AND accurately determine properties

The next generation charmonium spectroscopy

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BESIII at IHEP, China

> electron+positron

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Scanning with cooled anti-protons: mass and width determination

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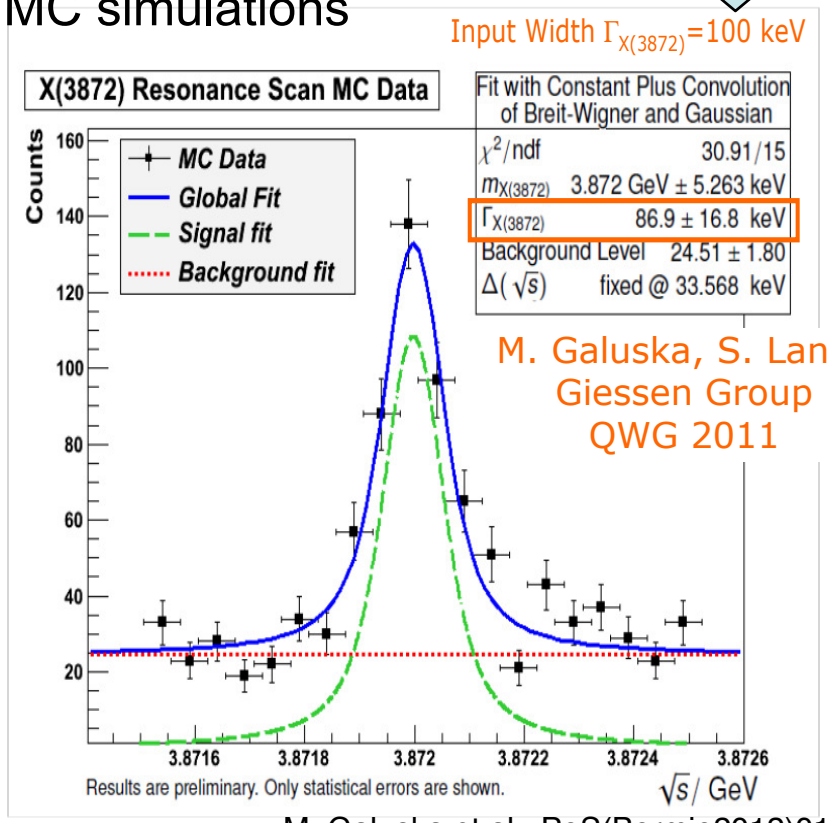
$$X(3872) \rightarrow J/\Psi\pi^+\pi^-$$

MC simulations



M. Galuska, S. Lange
Giessen Group
QWG 2011

M. Galuska et al., PoS(Bormio2012)018

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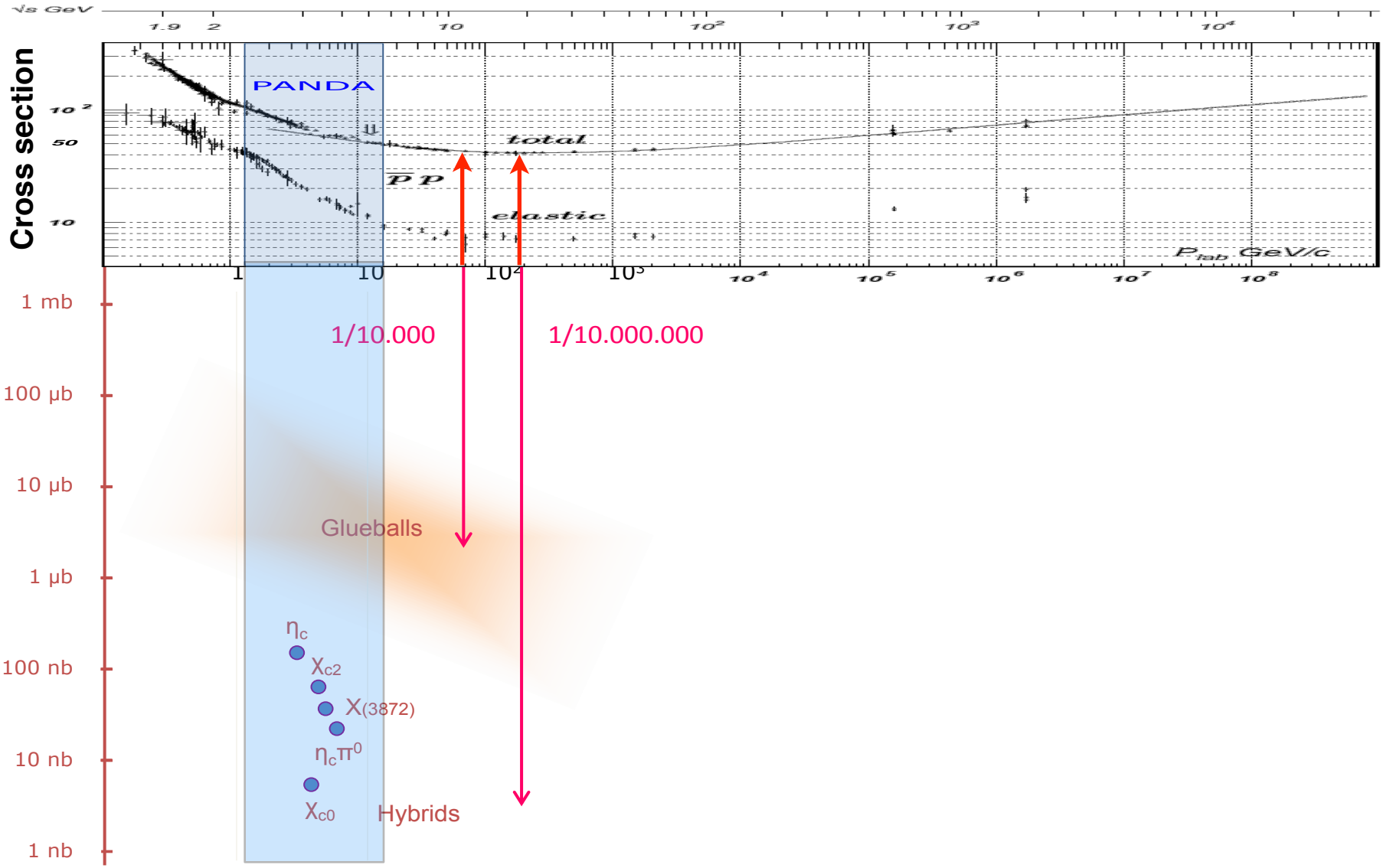
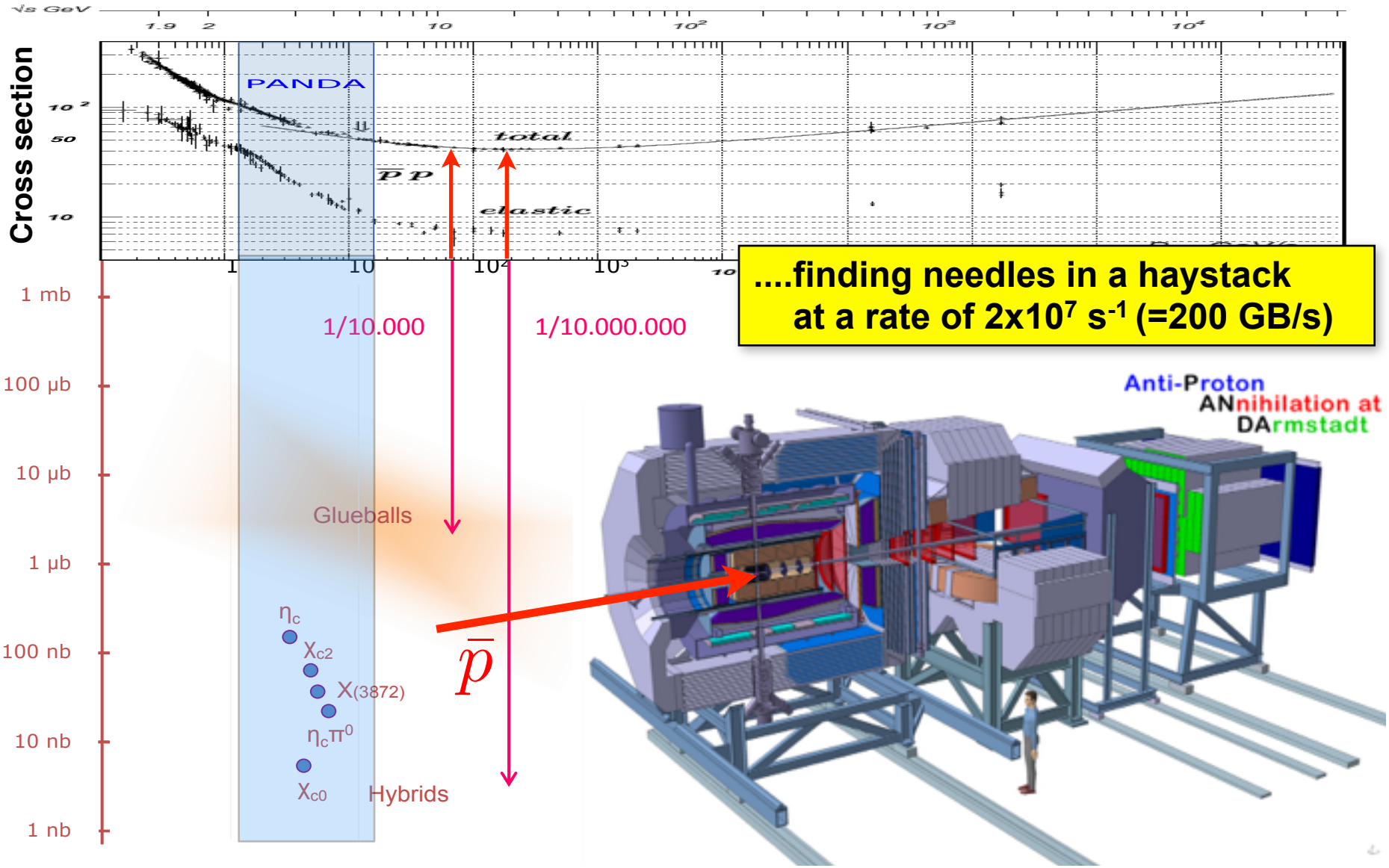
PANDA, the challenges



PANDA, the challenges



Charming DiZ$_c$overies using matter-antimatter annihilations

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The strong force fascinates:
confinement, origin of mass, exotic matter

Charmonium provides a unique window
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A new class of unconventional matter
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e^+e^- annihilations remain a discovery tool!

Future experiments (such as PANDA) aim
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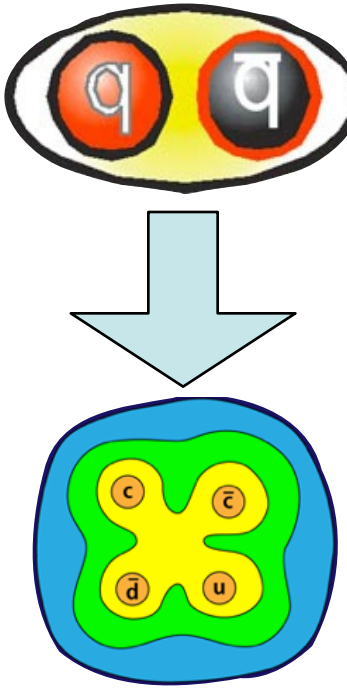

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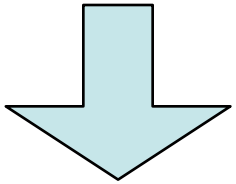

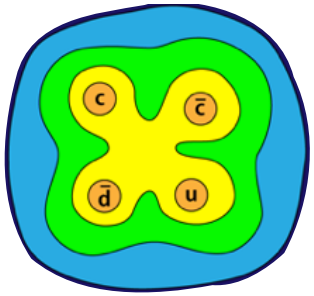

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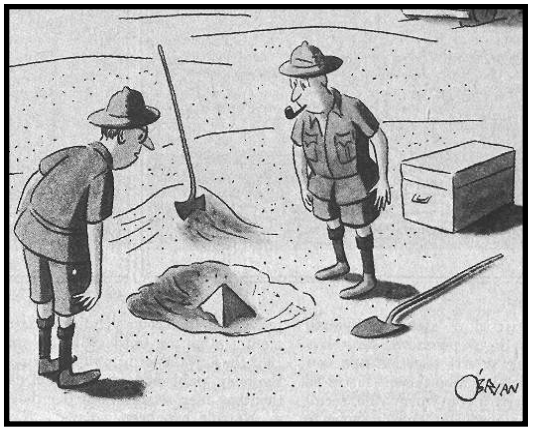

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Acknowledgments....

PANDA

>400 scientists
~60 institutes
16 countries

BESIII

>350 scientists
~53 institutes
12 countries

International collaborations with large common interests