Connecting the XYZ at BESIII

Ryan Mitchell

Indiana University

Bormio 2014

January 31, 2014

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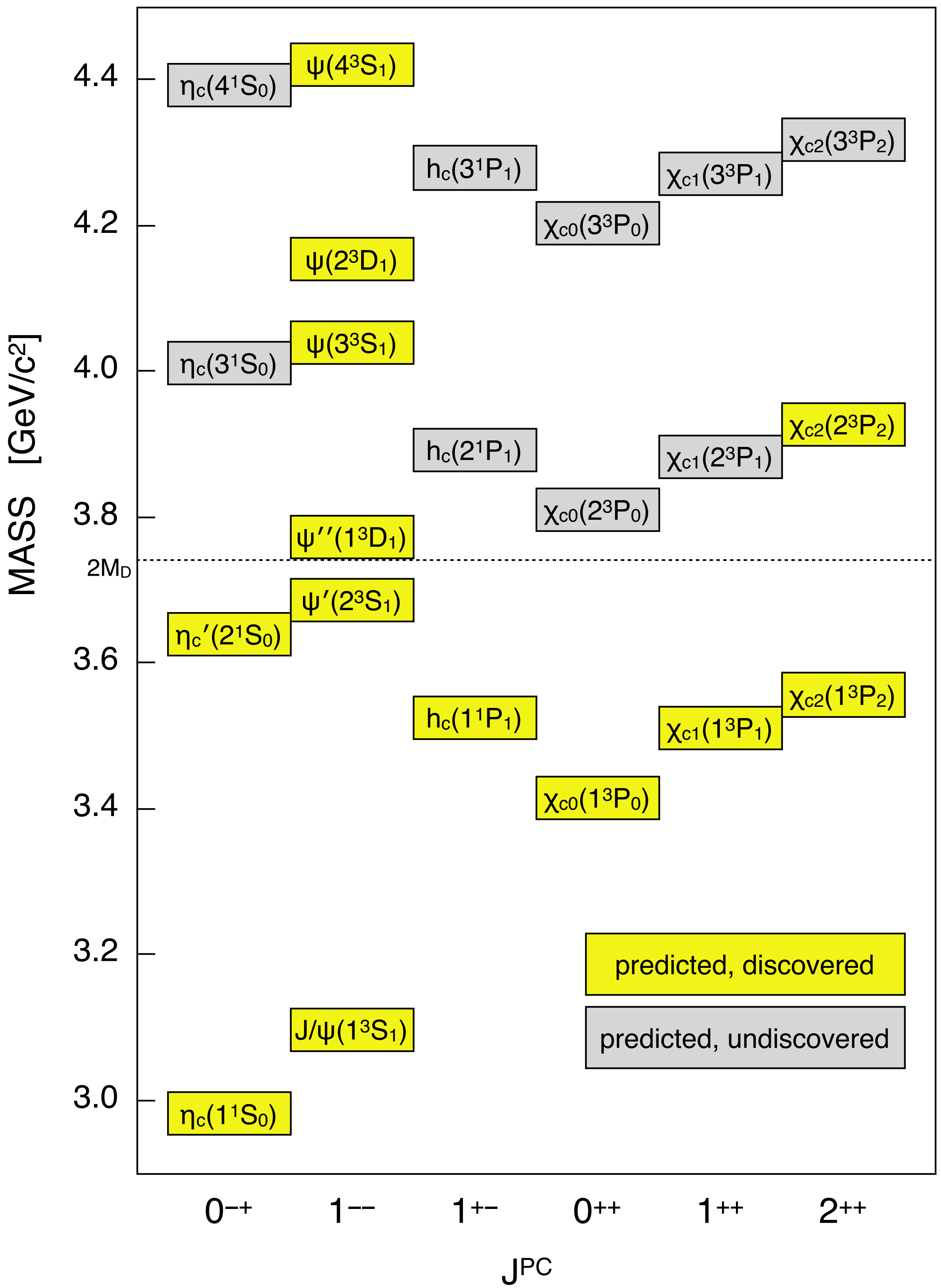

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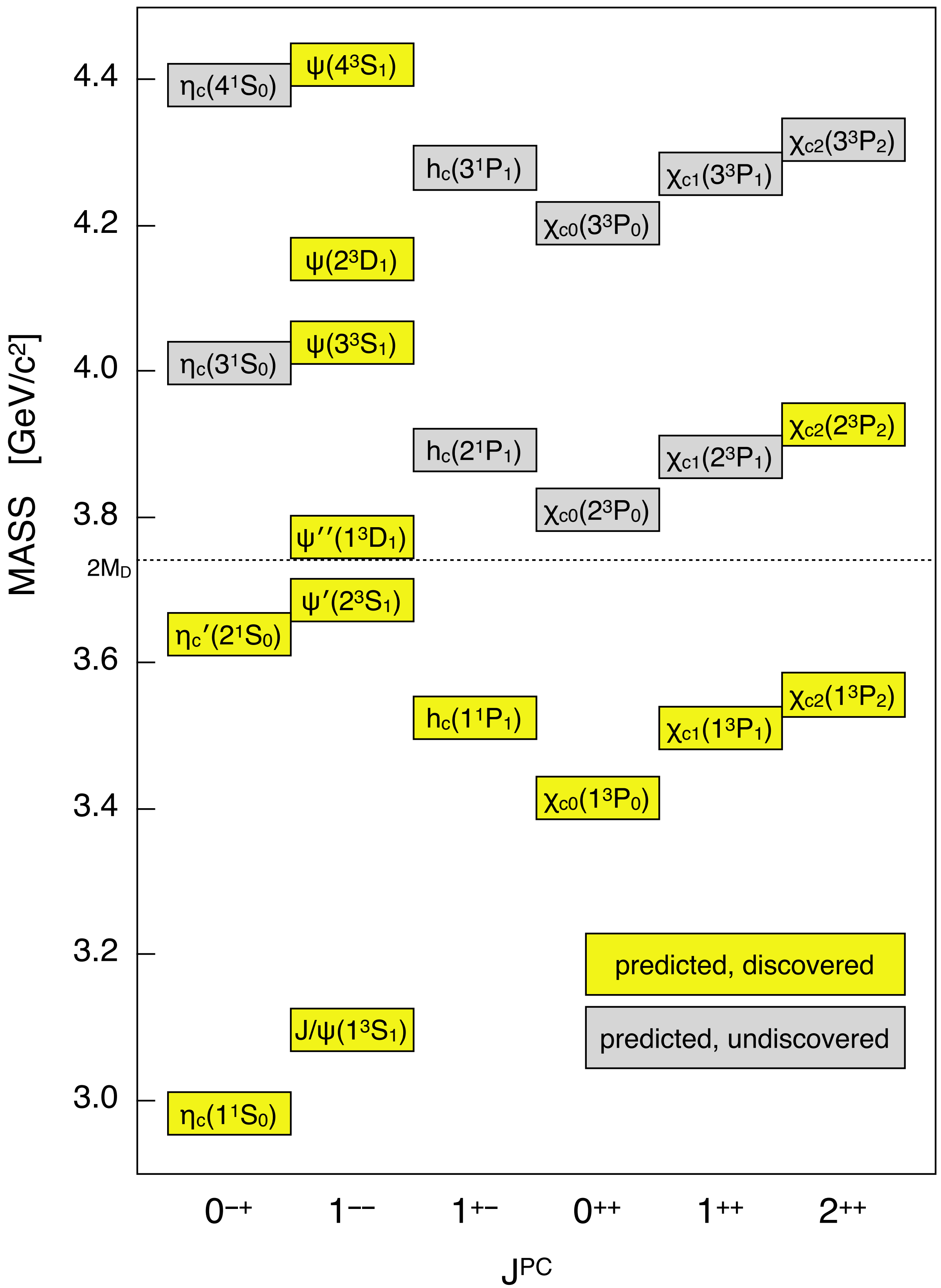

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Example potential from Barnes, Godfrey, Swanson:

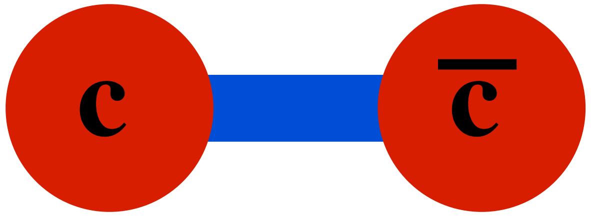
$$V_0^{(c\bar{c})}(r) = -\frac{4}{3}\frac{\alpha_s}{r} + br + \frac{32\pi\alpha_s}{9m_c^2}\tilde{\delta}_\sigma(r)\vec{S}_c \cdot \vec{S}_{\bar{c}}$$

(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

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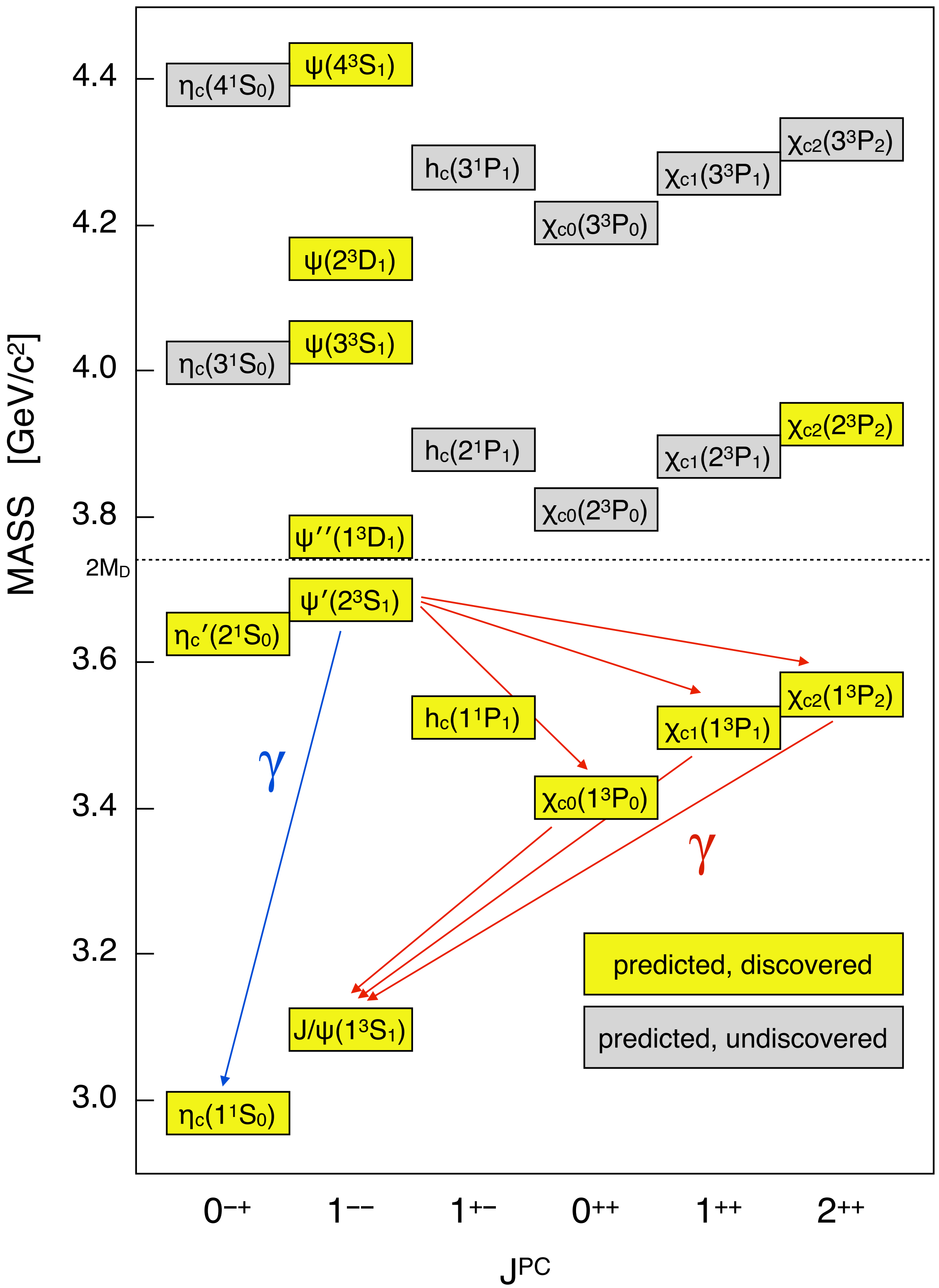

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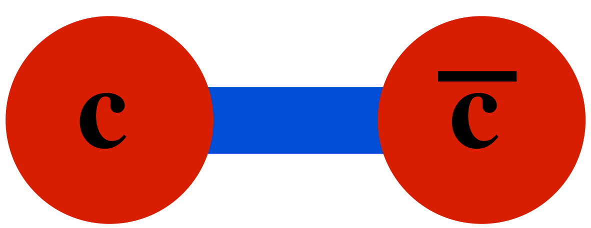

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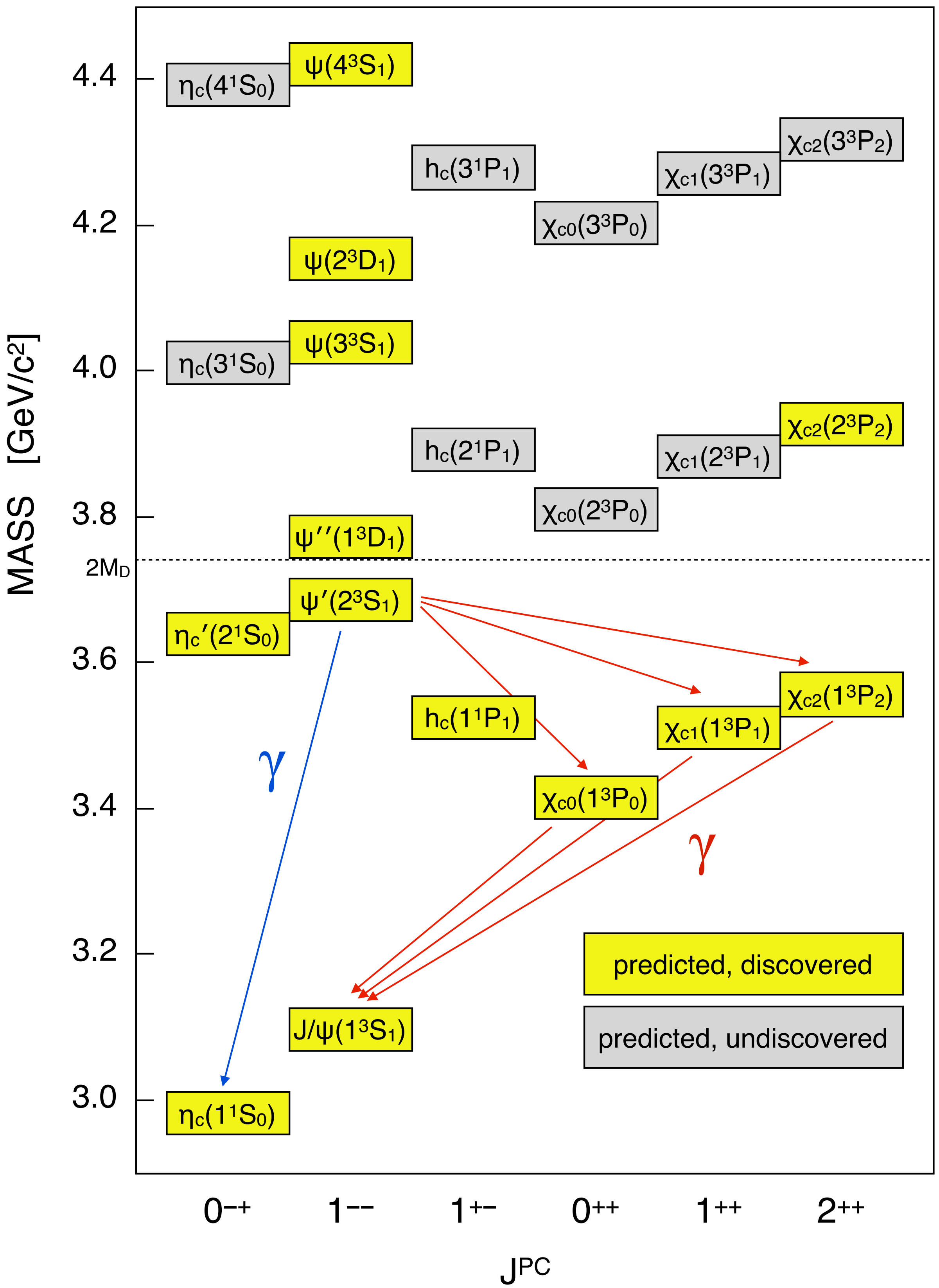

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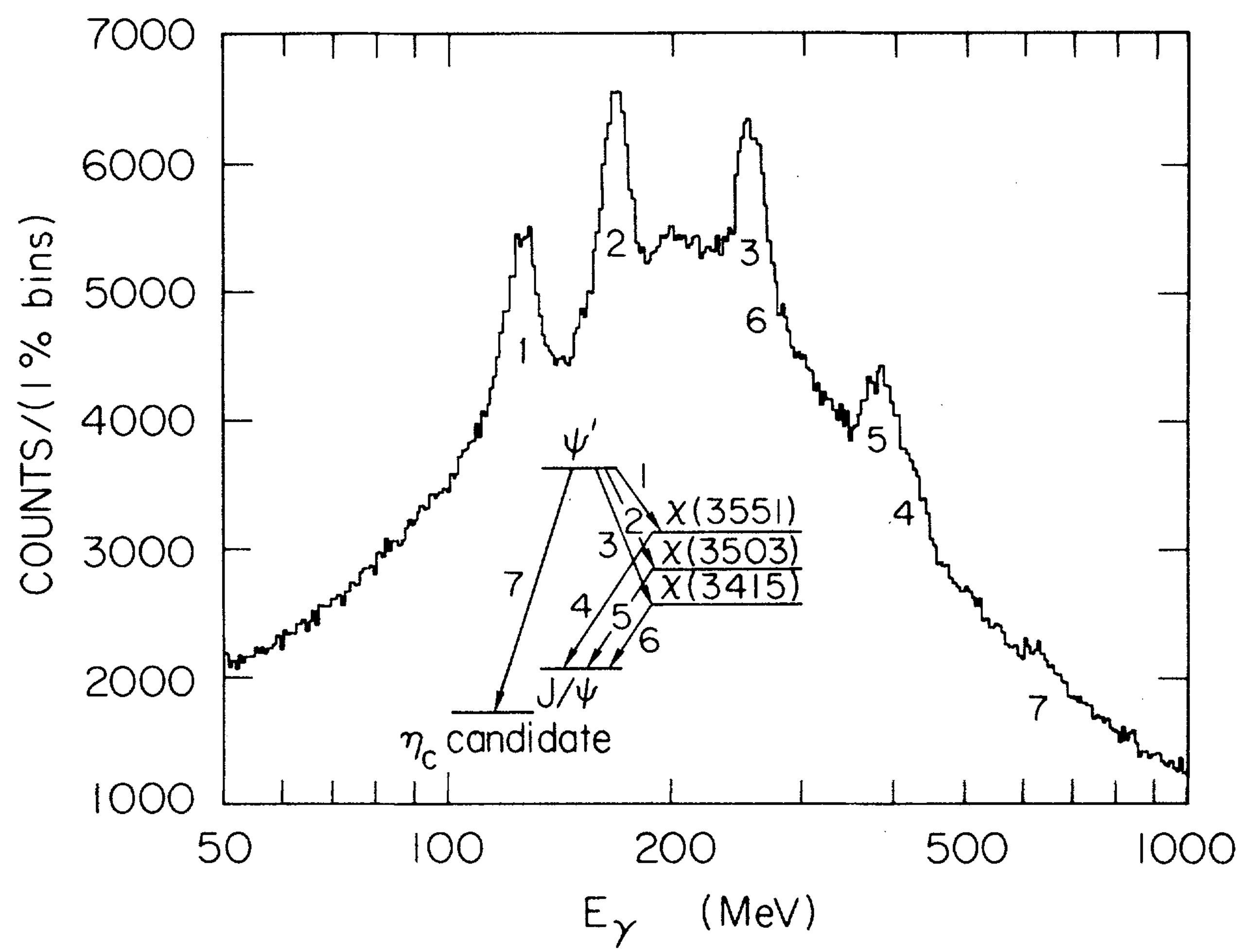
Crystal Ball at SLAC
(discovery of η_c)



PRL45, 1150 (1980)

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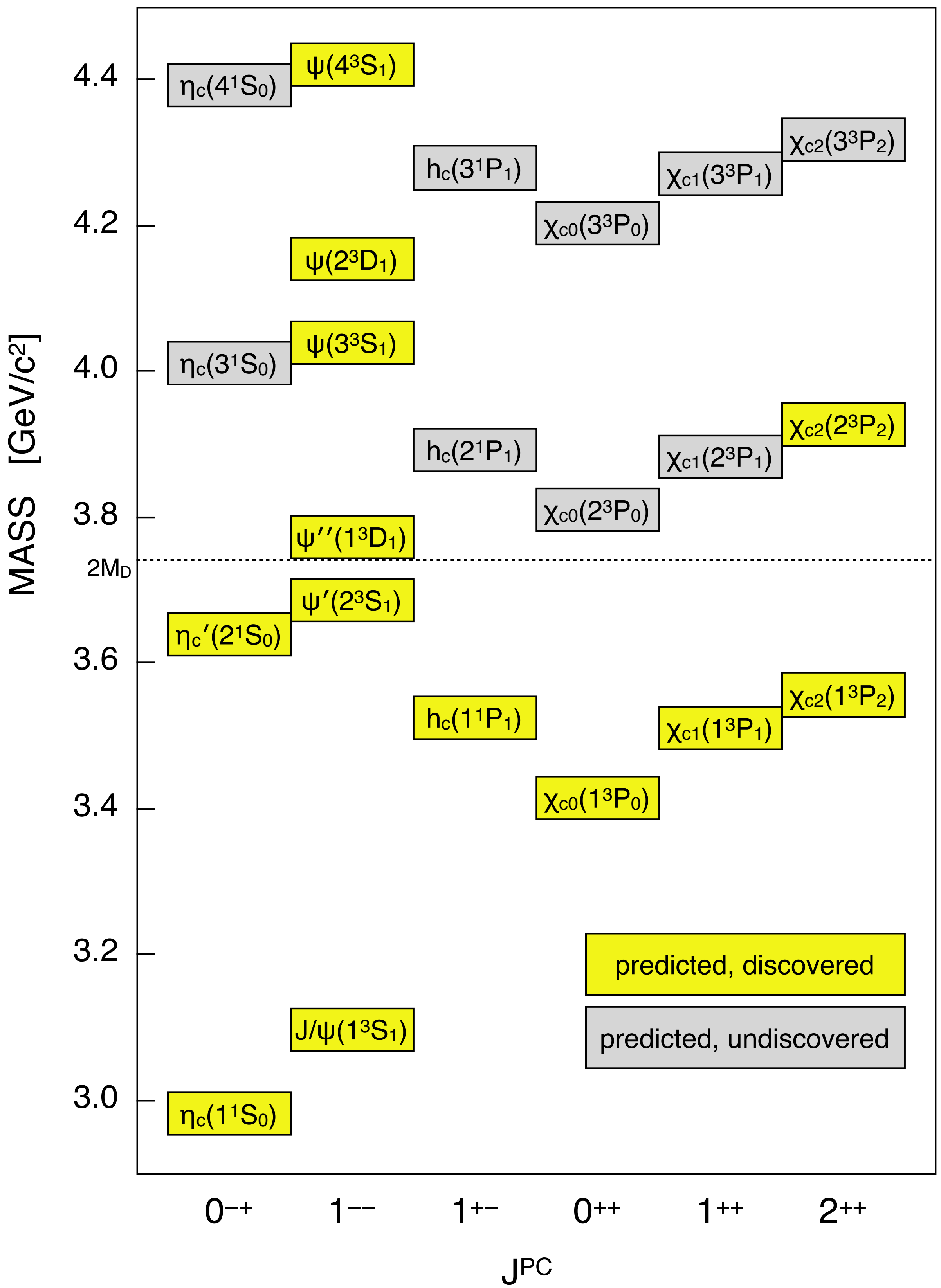

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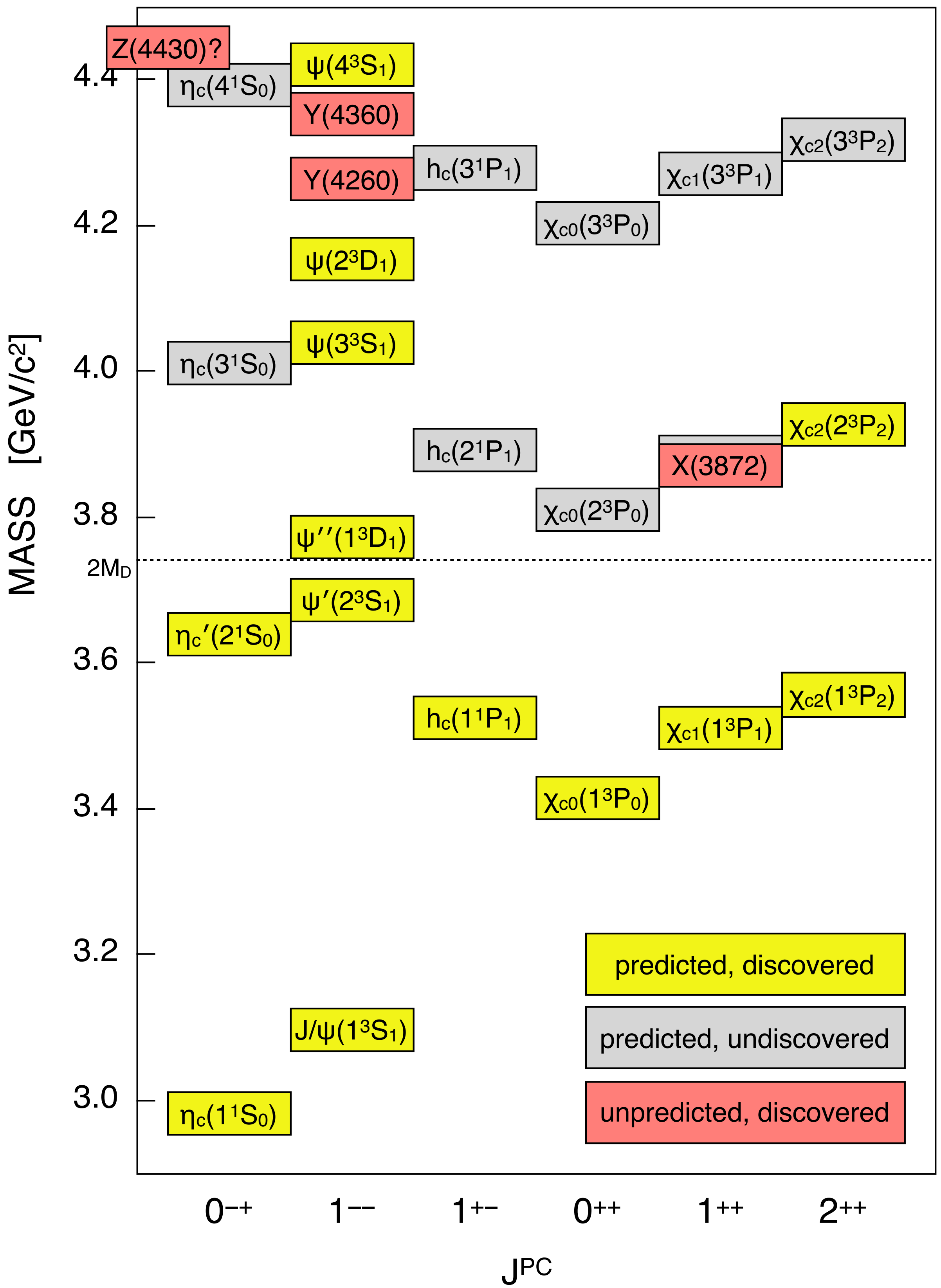

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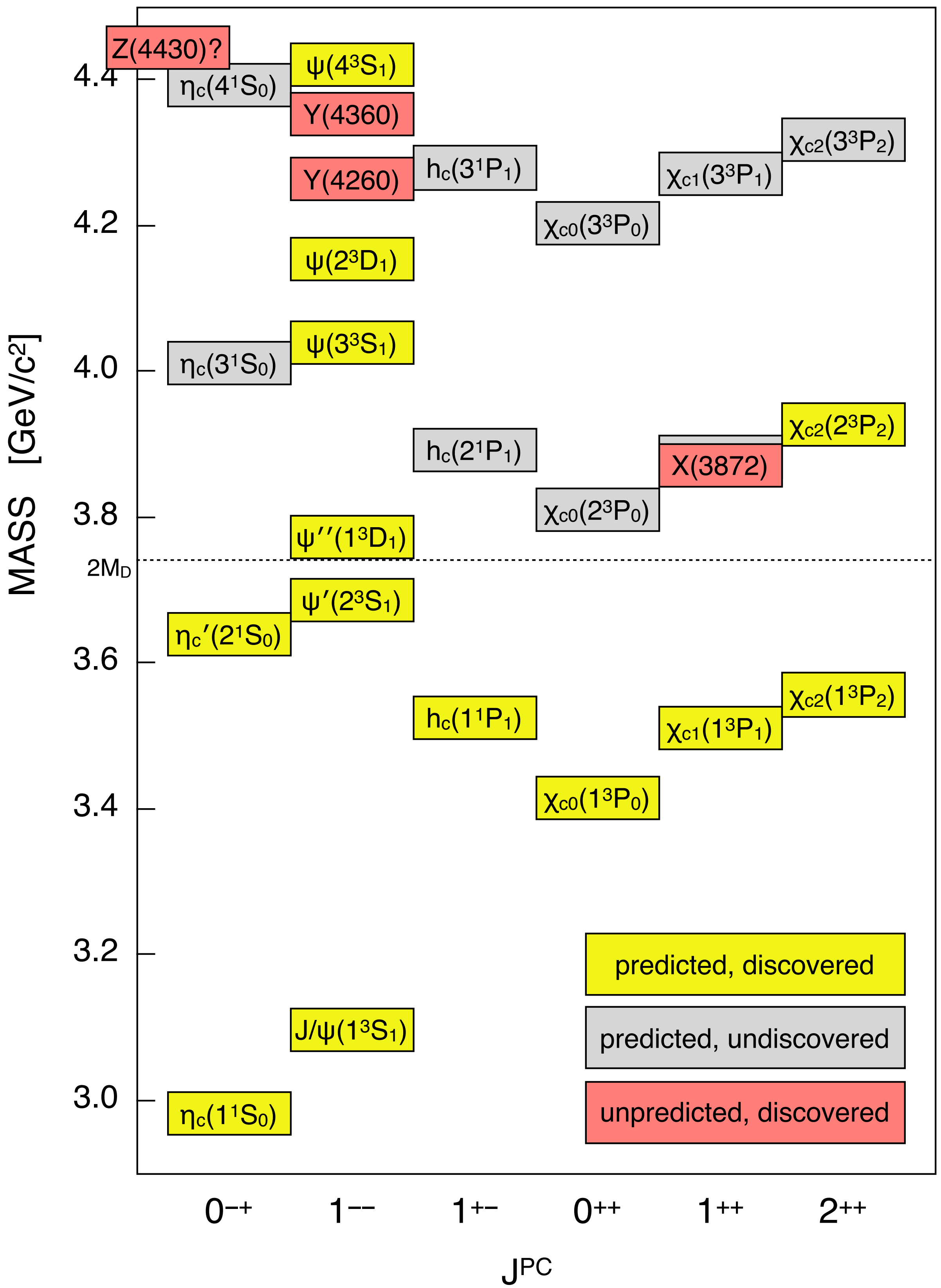
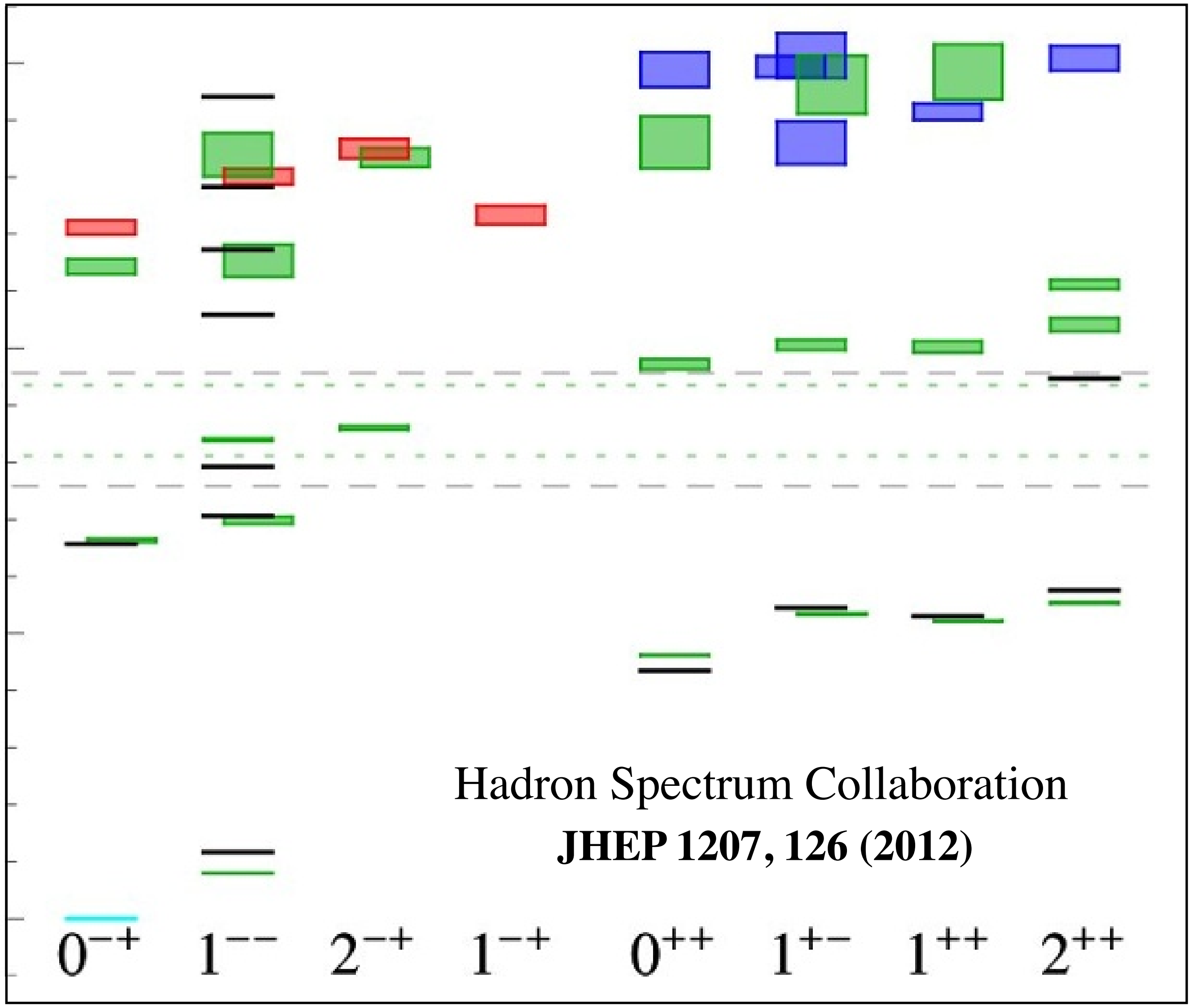


Example lattice QCD calculation:



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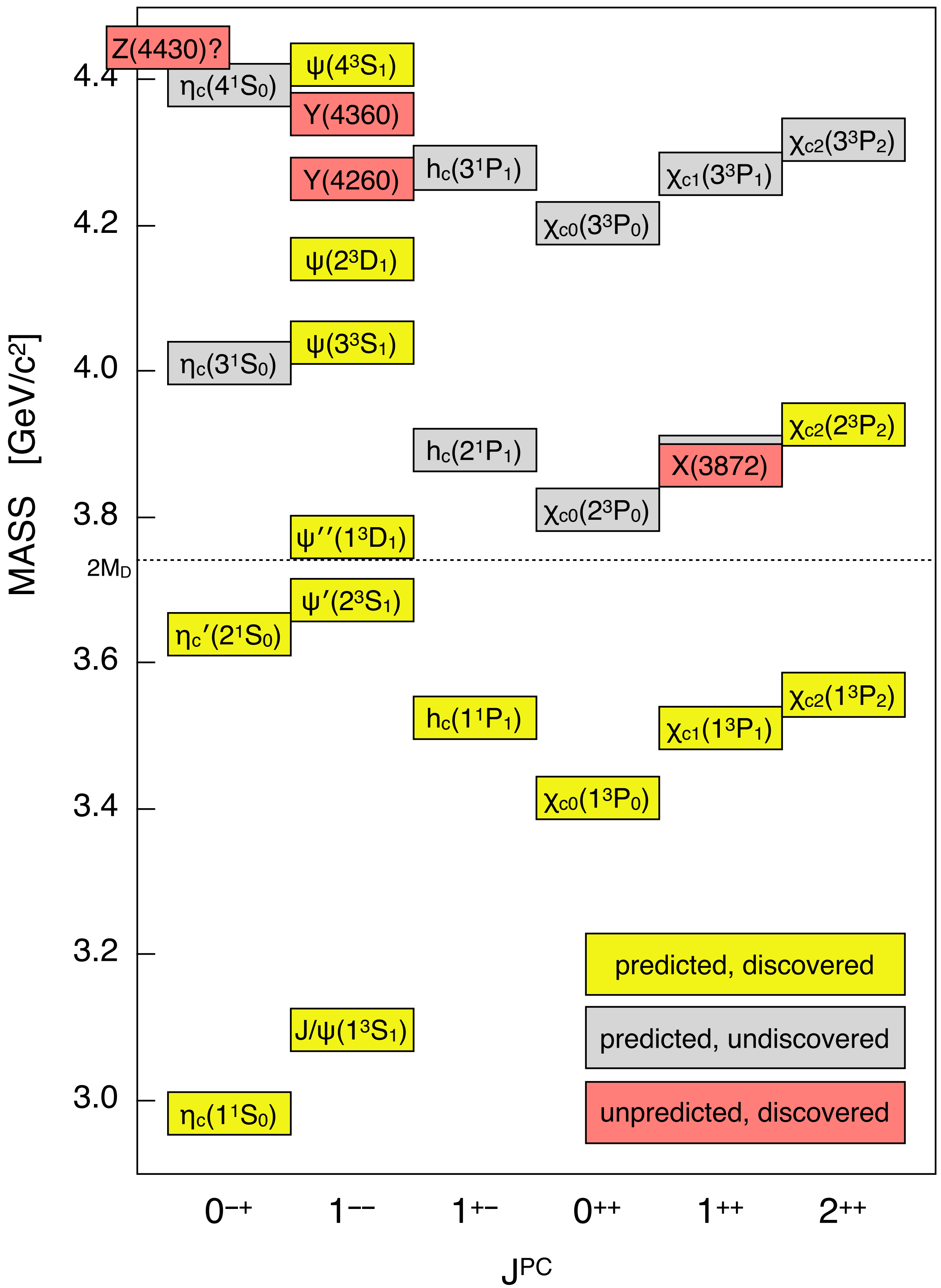

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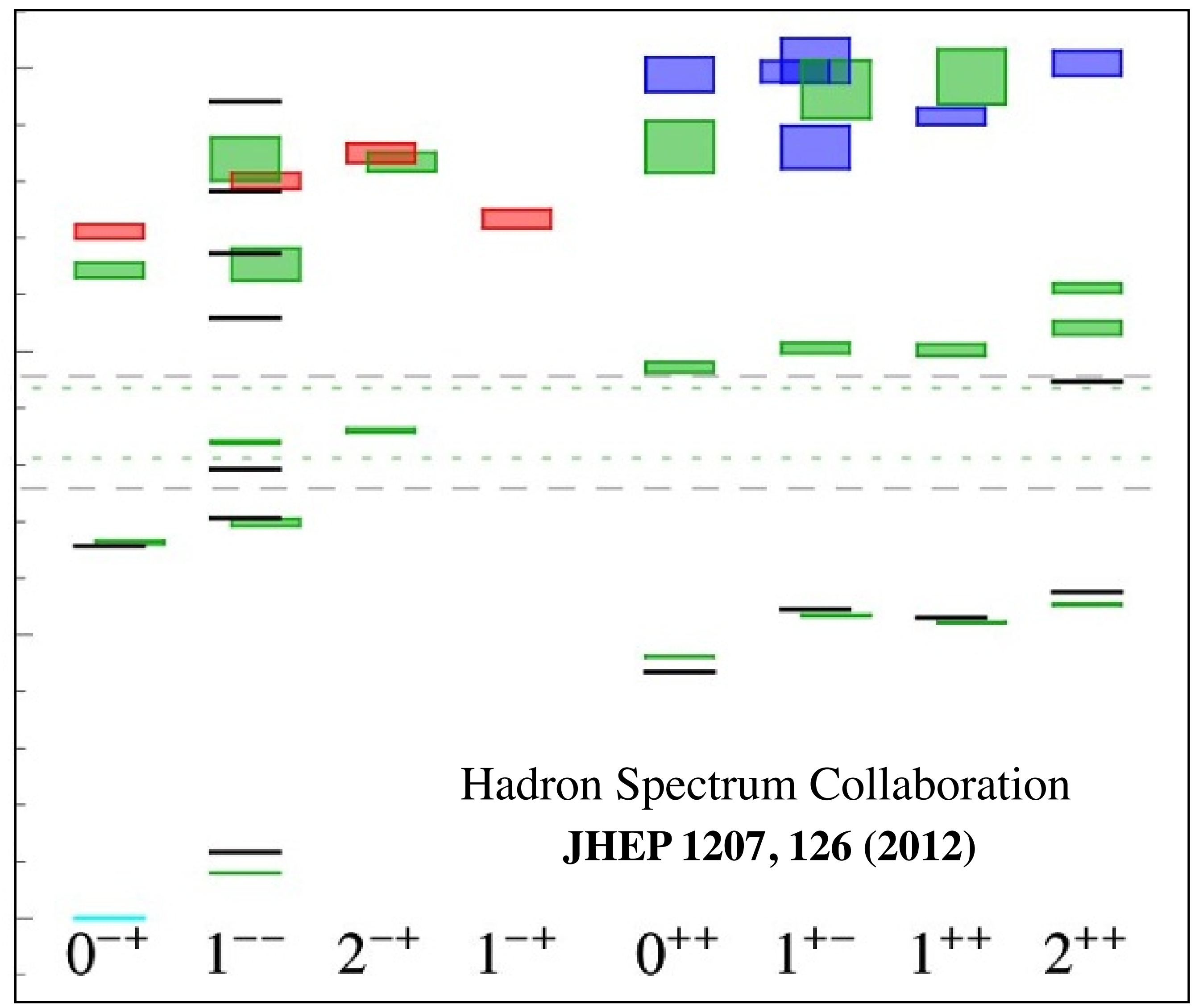
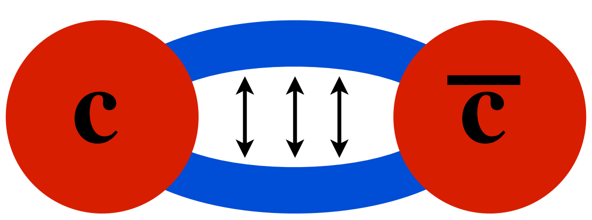
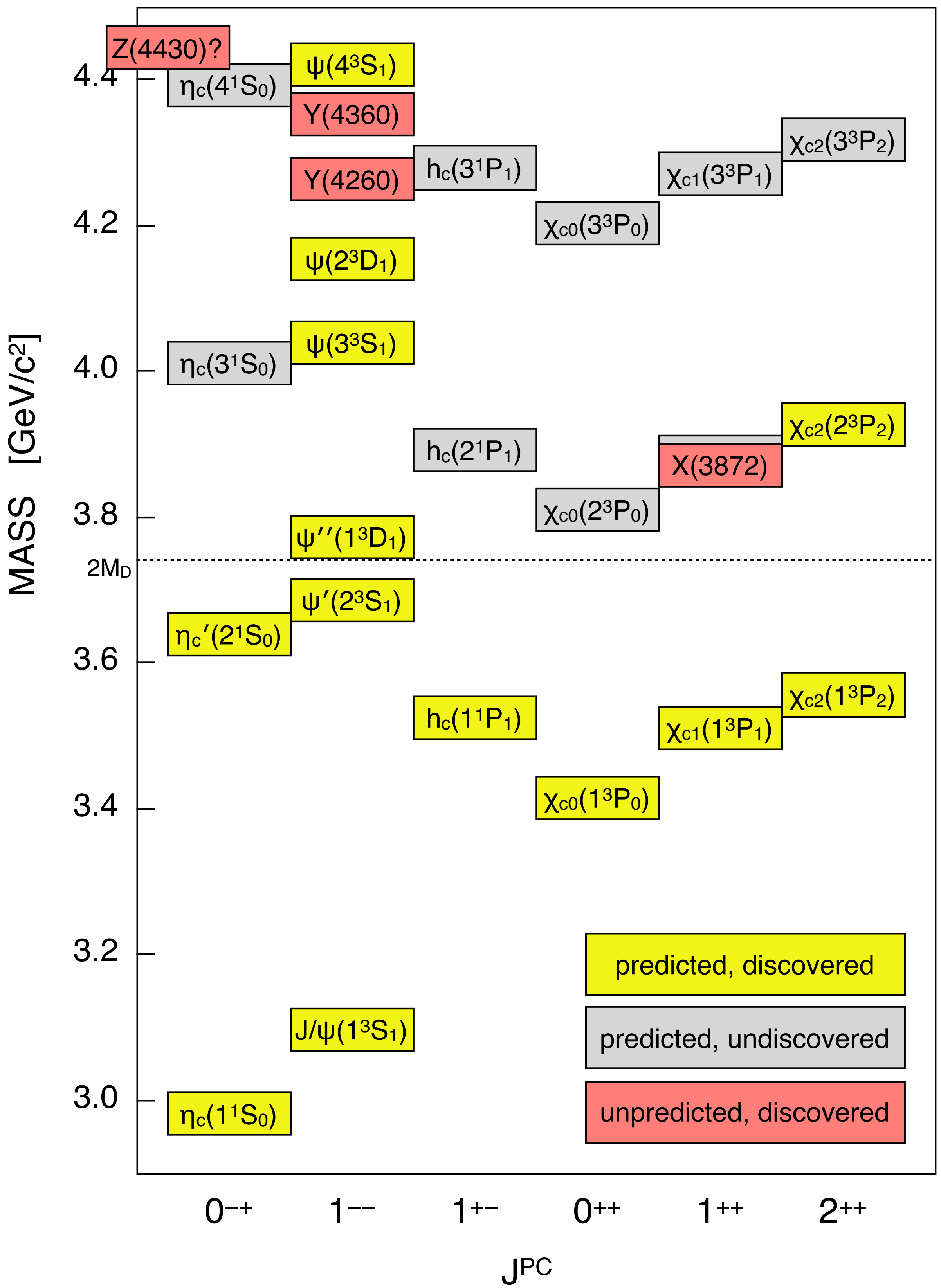




HYBRID CHARMONIUM

Connecting the XYZ at BESIII



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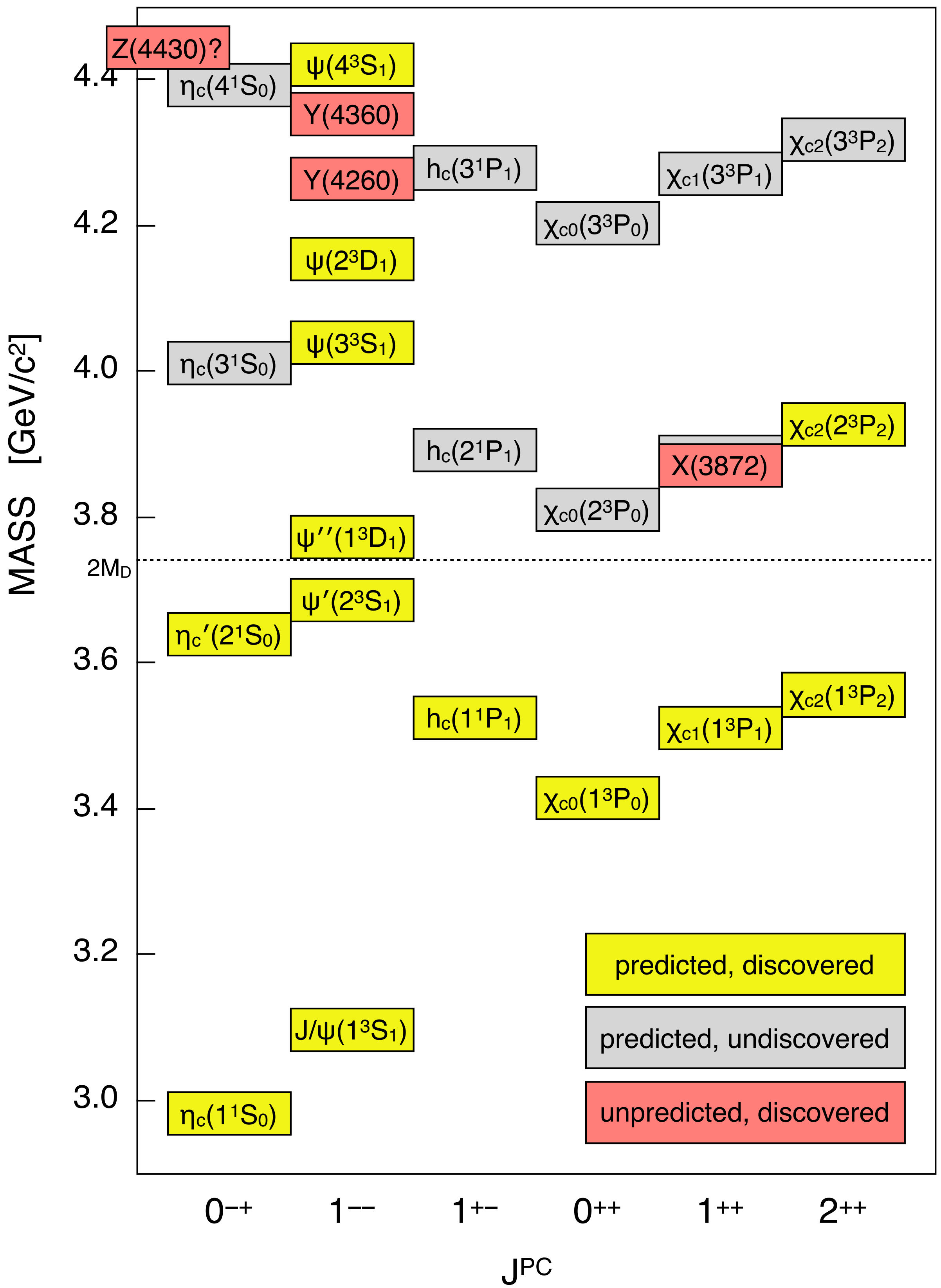

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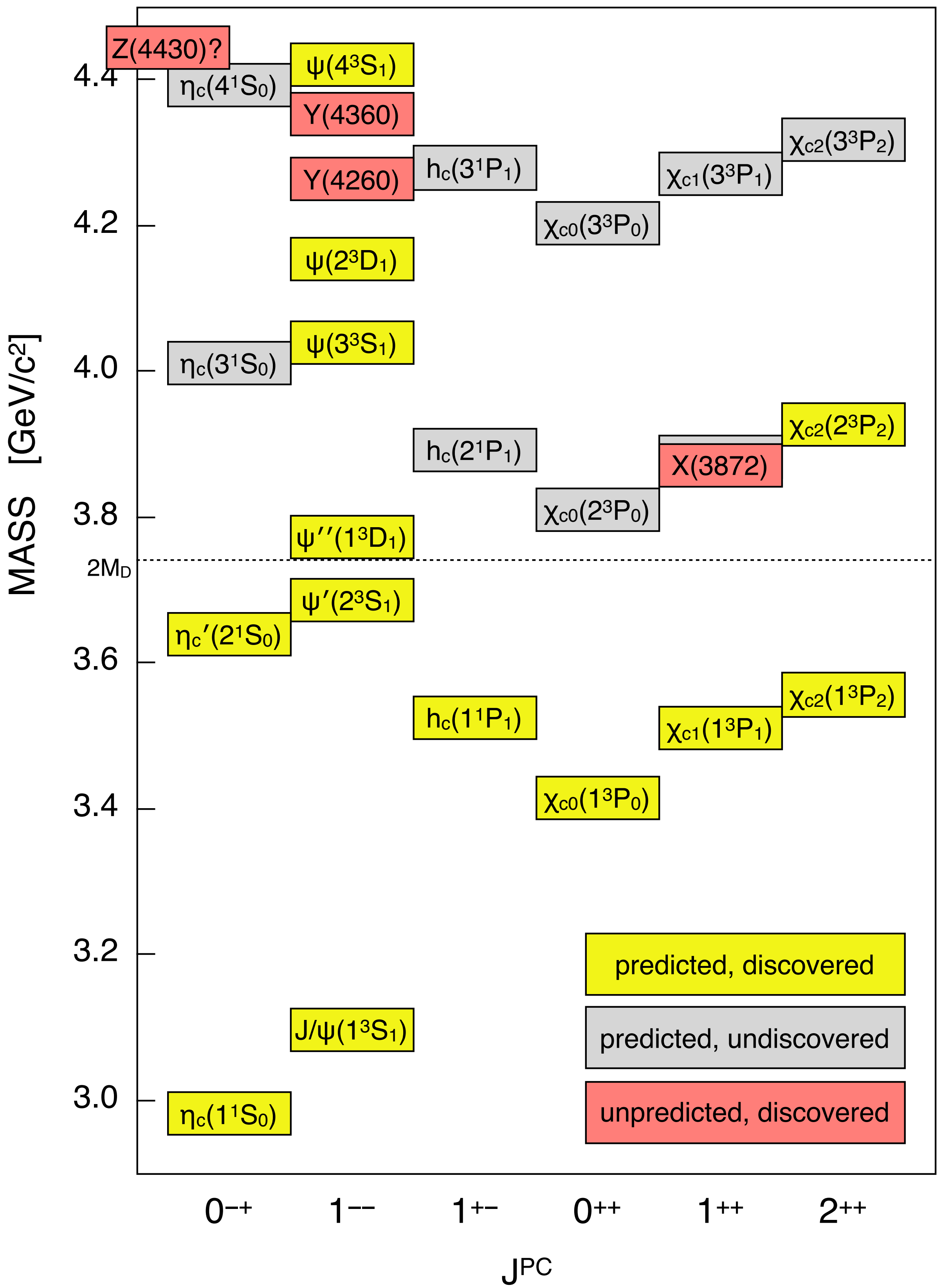

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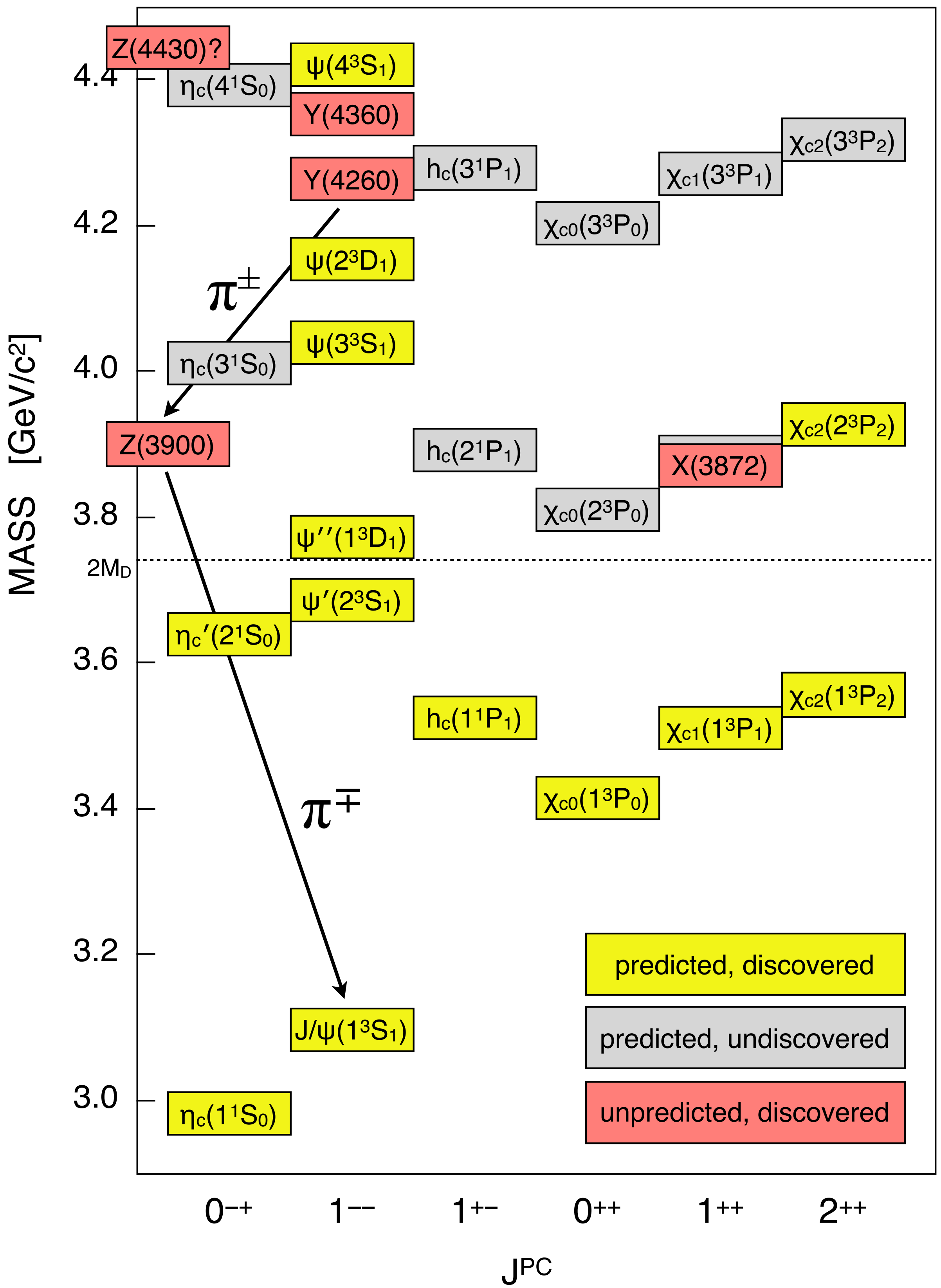

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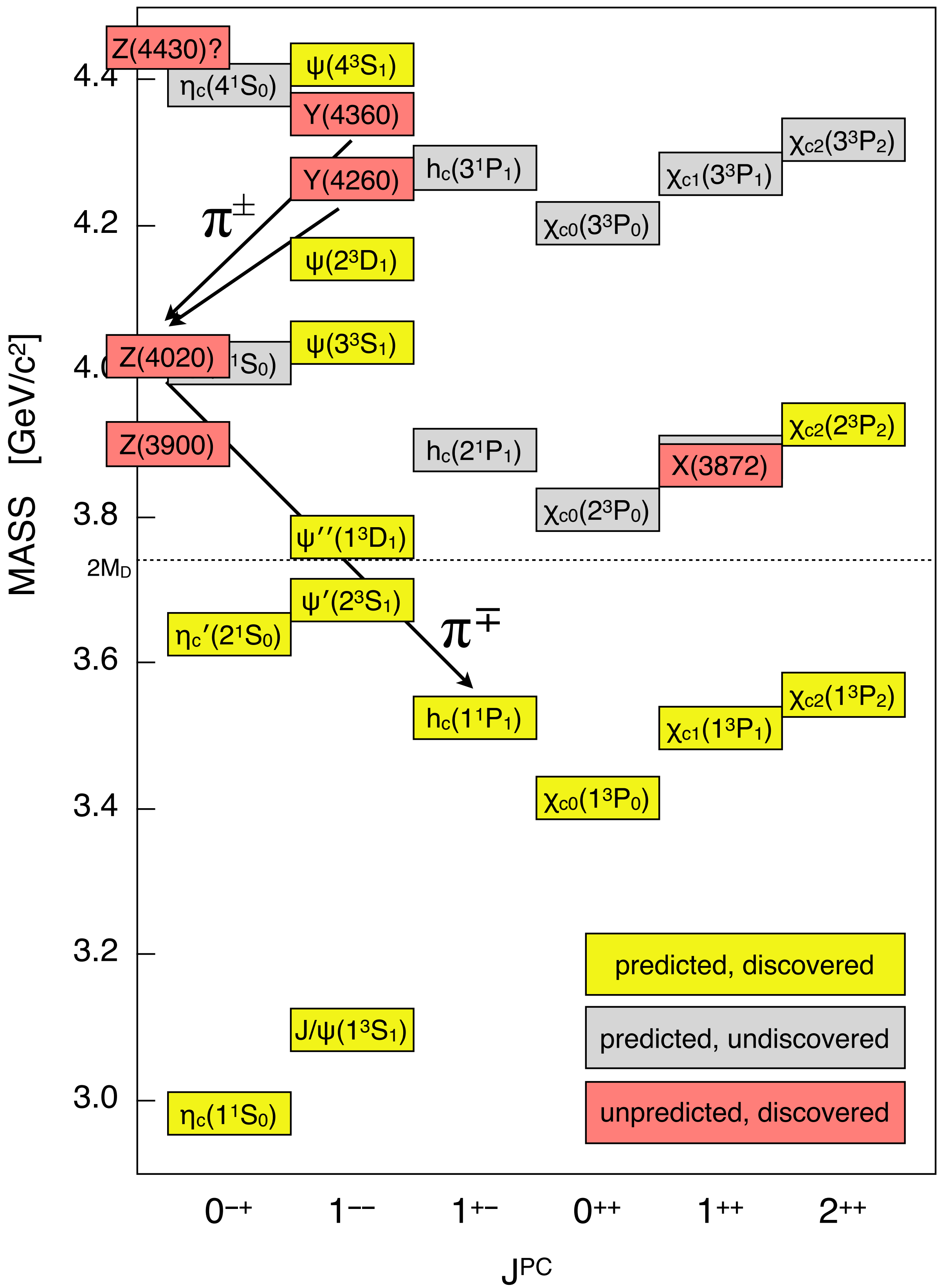

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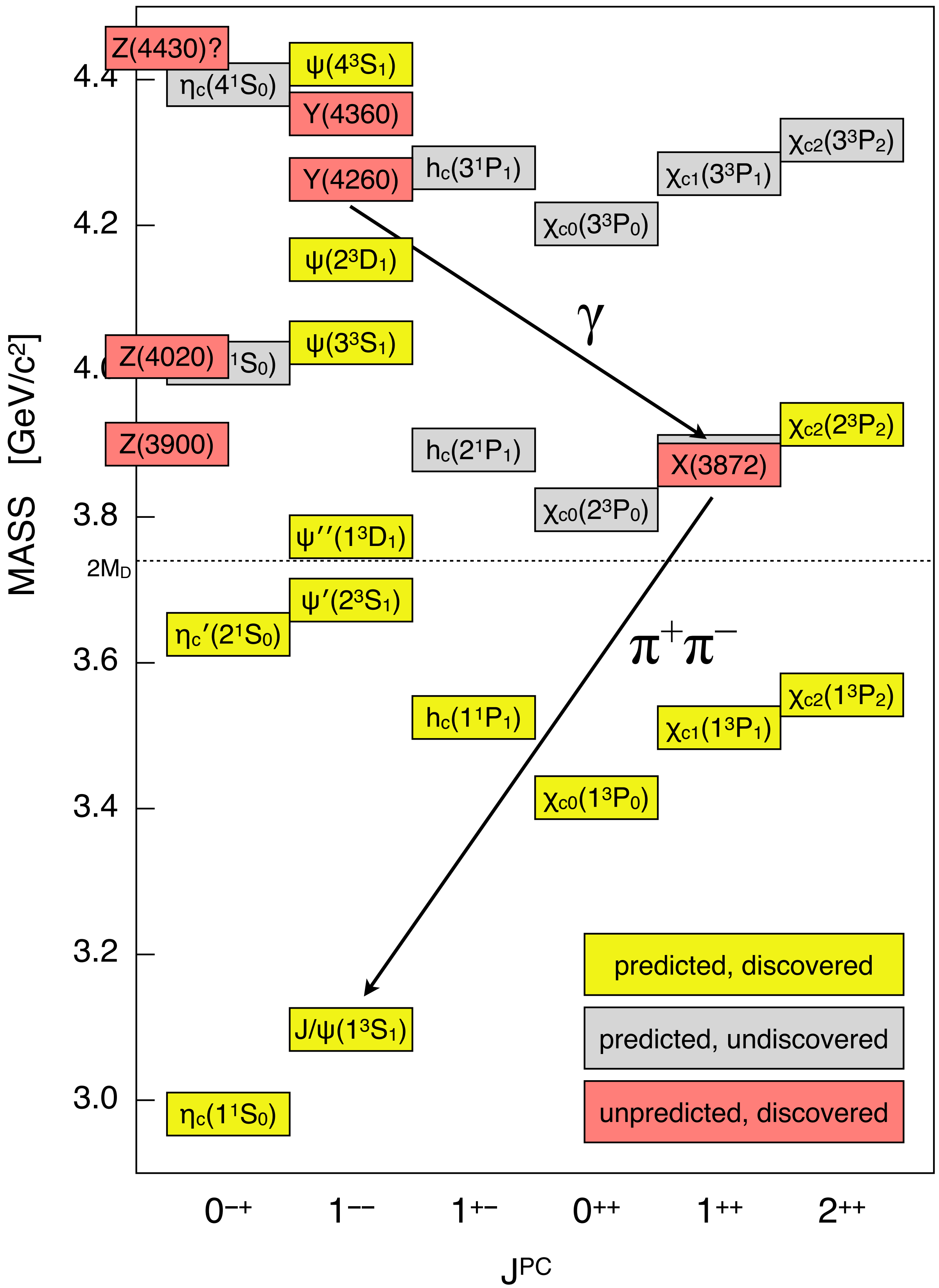

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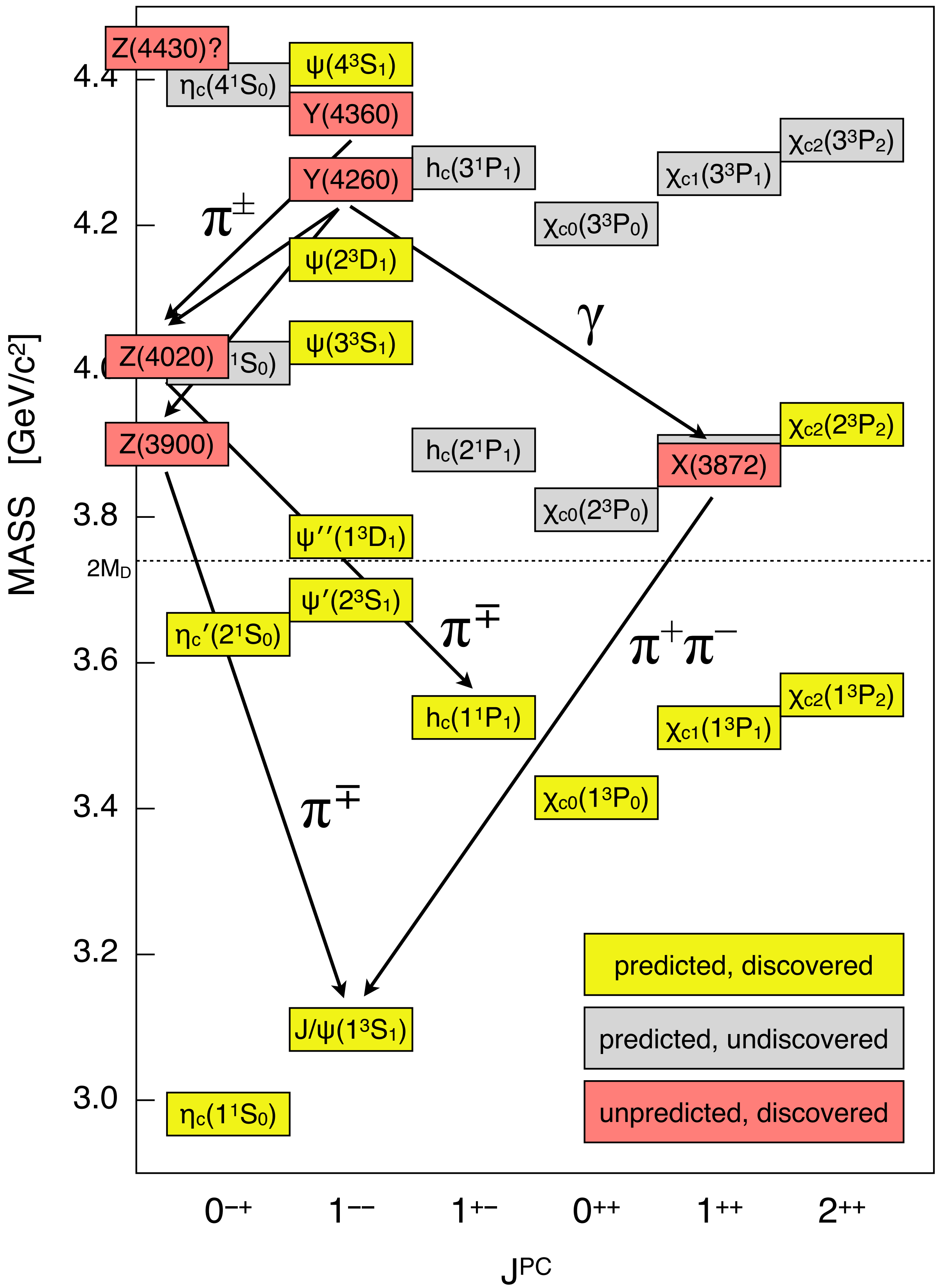

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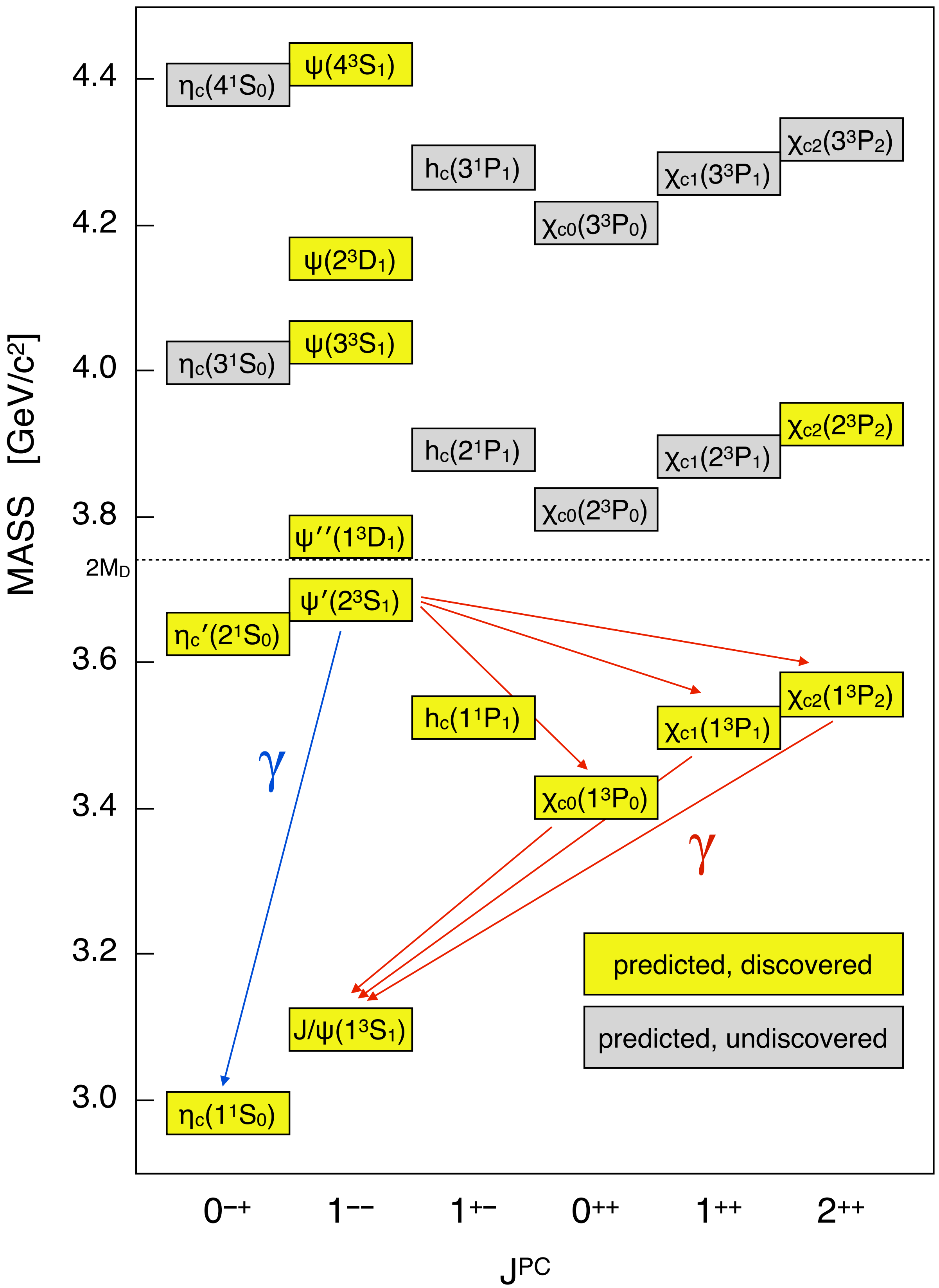

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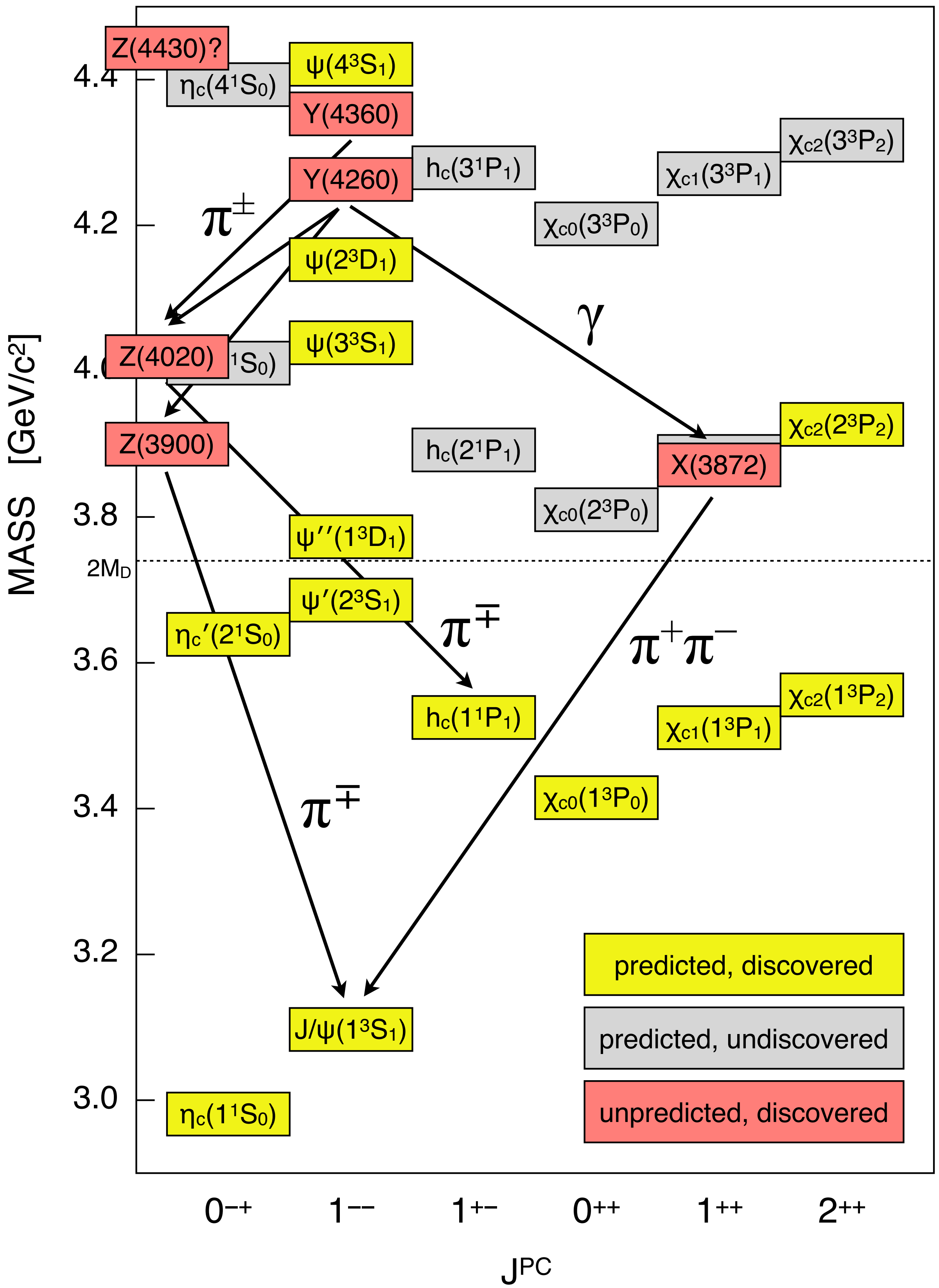

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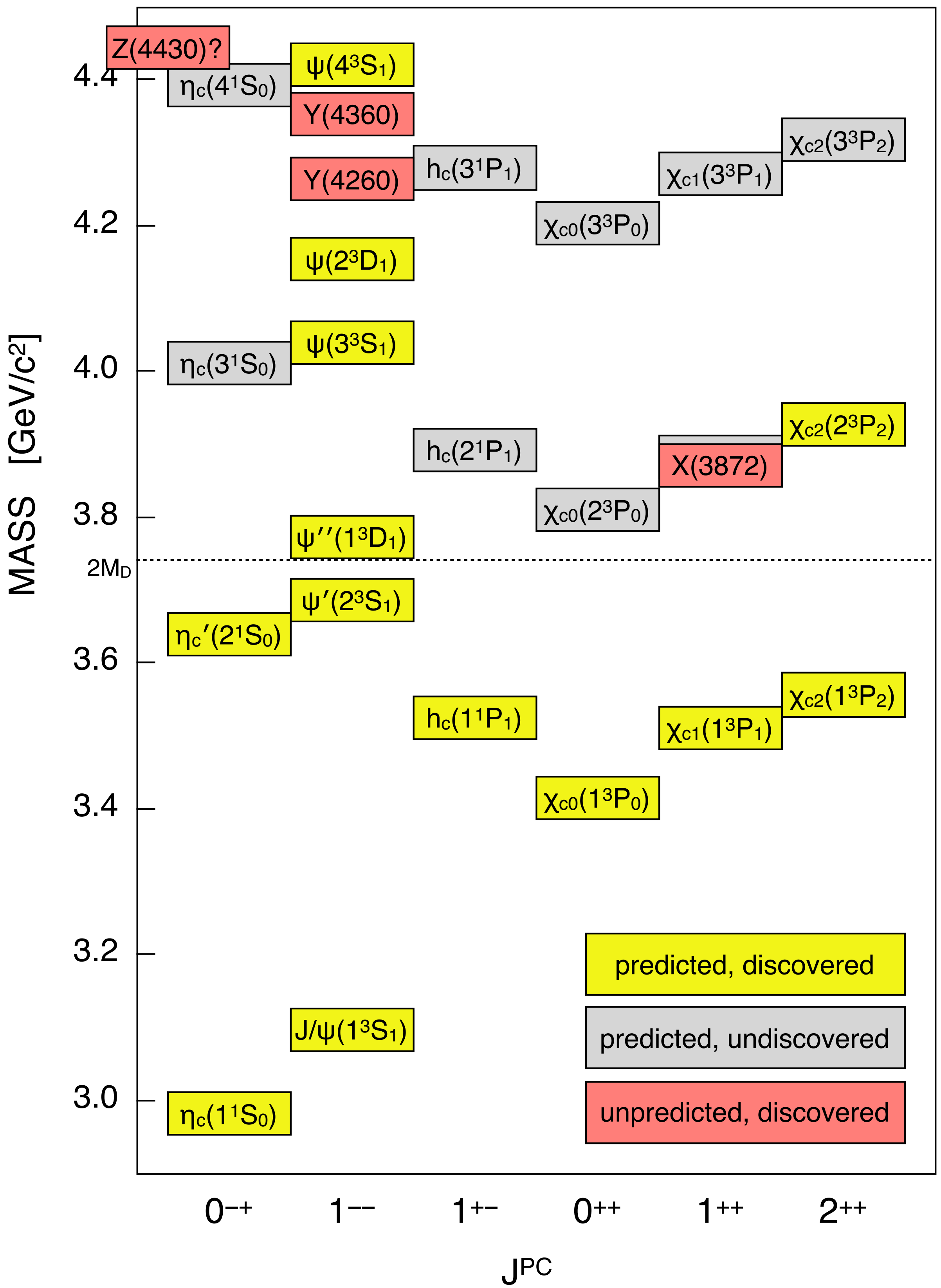

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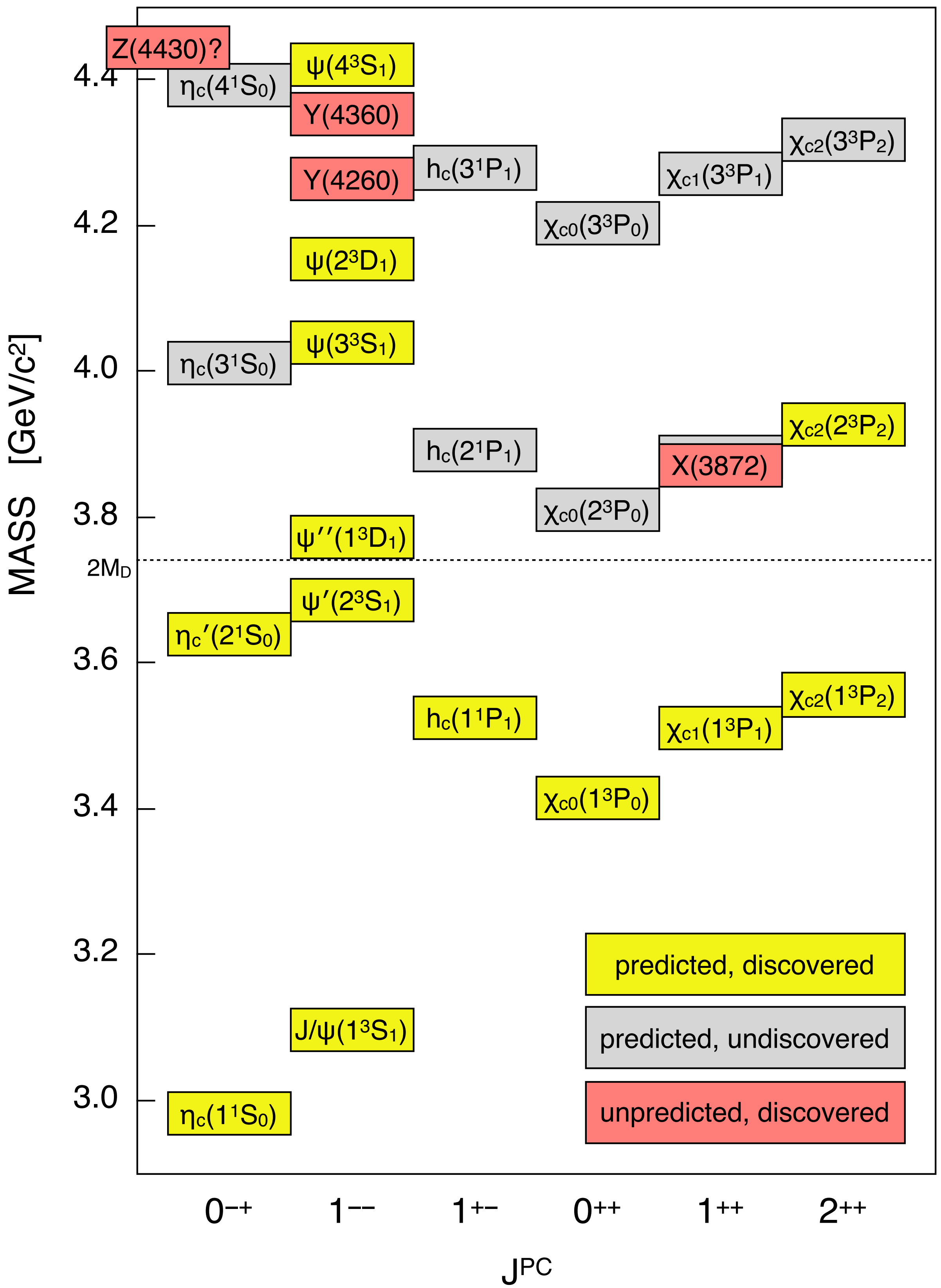

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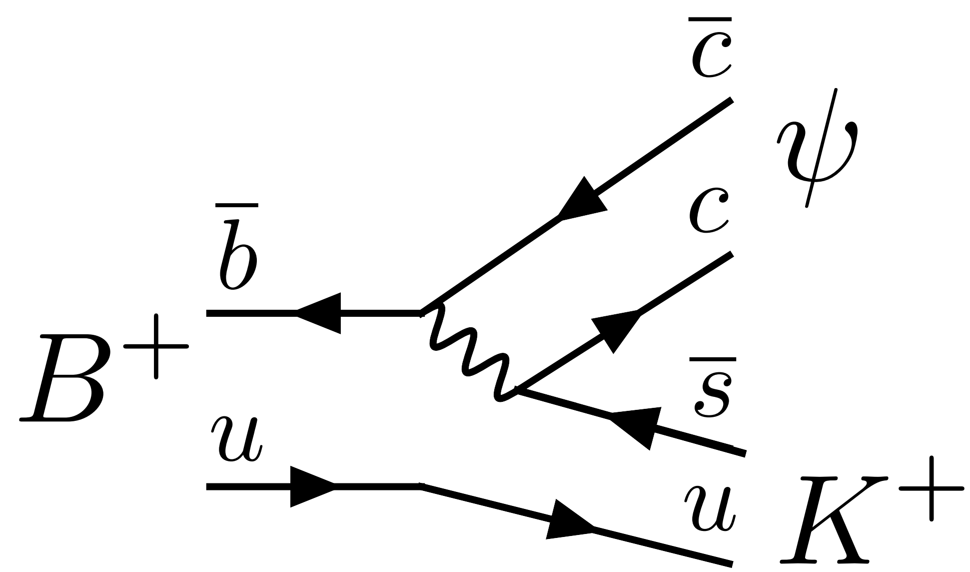

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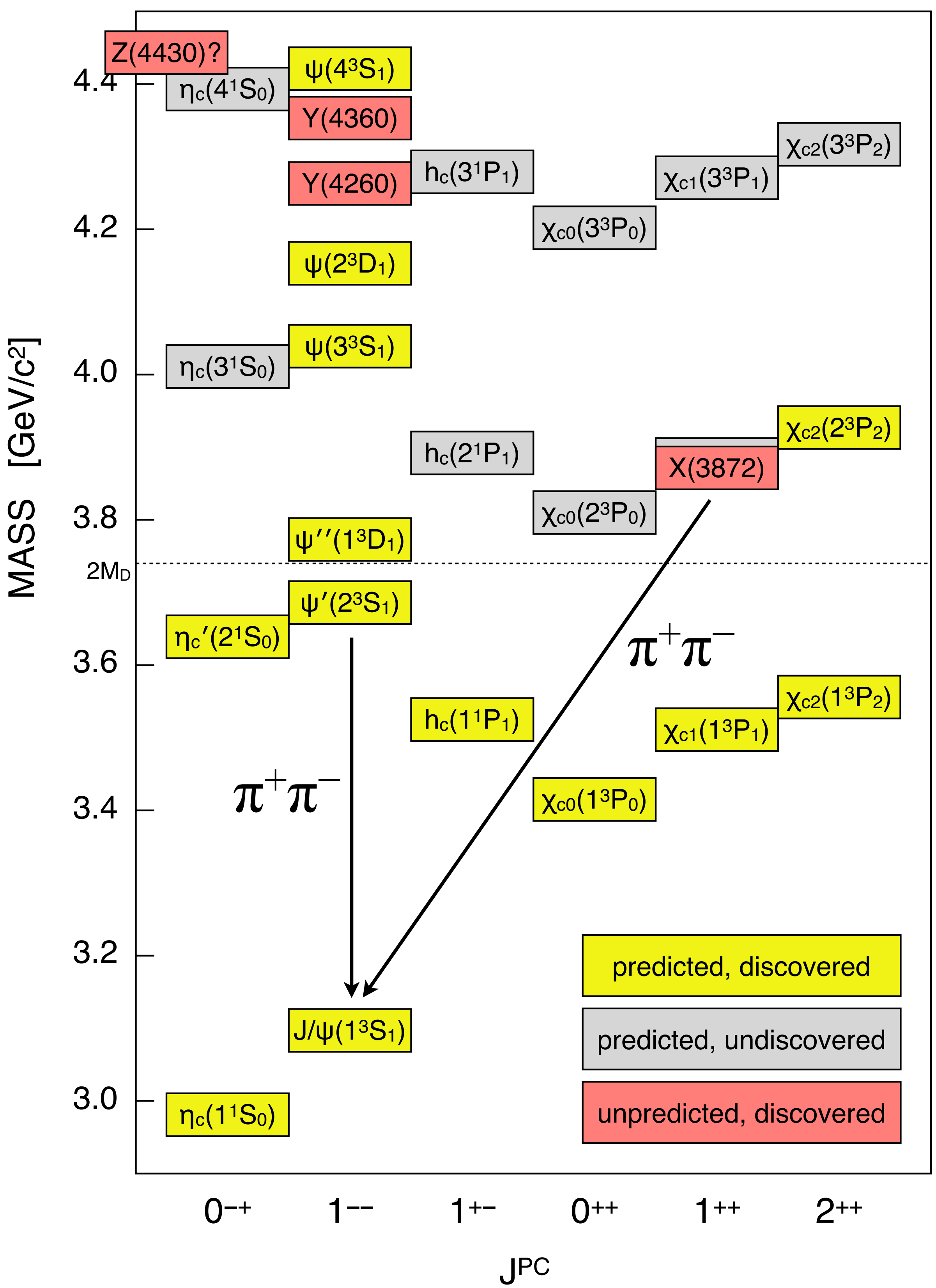

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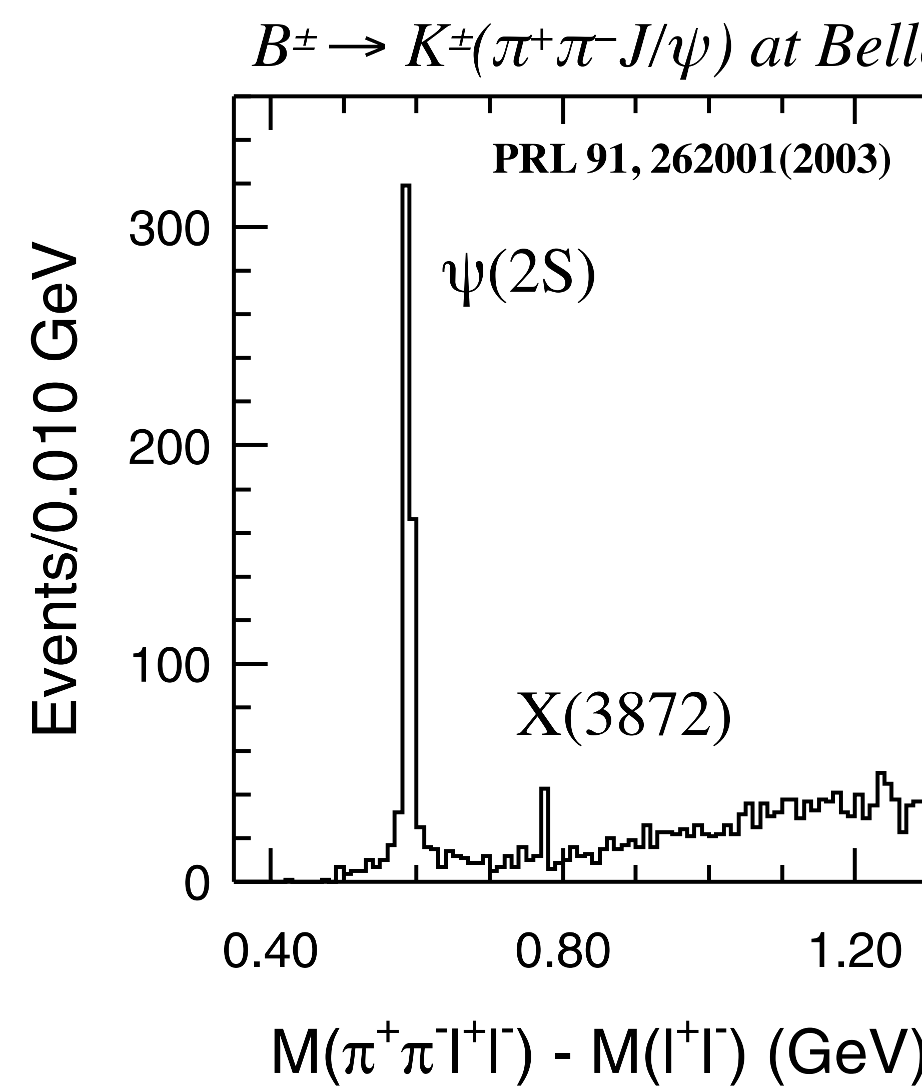

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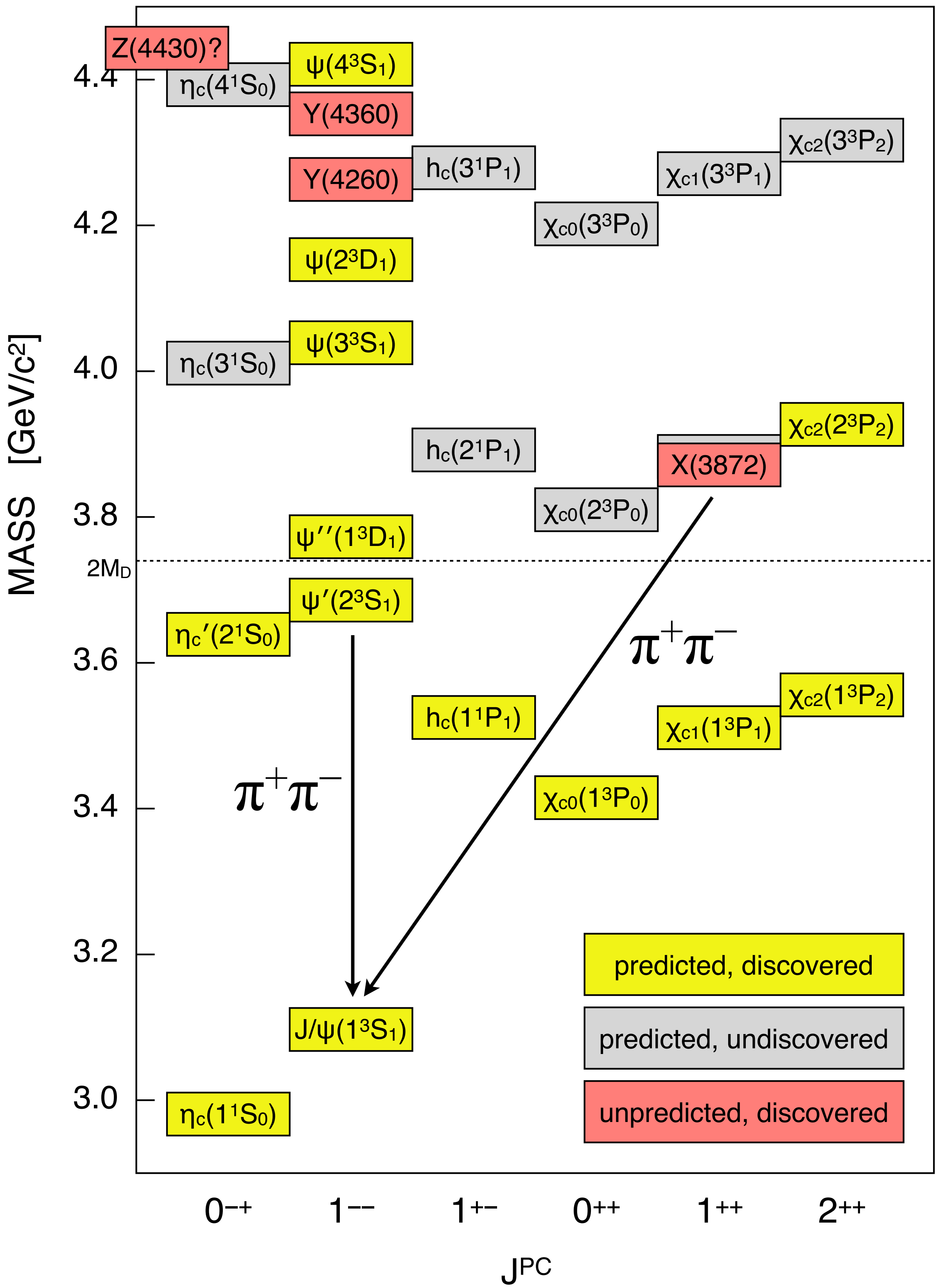

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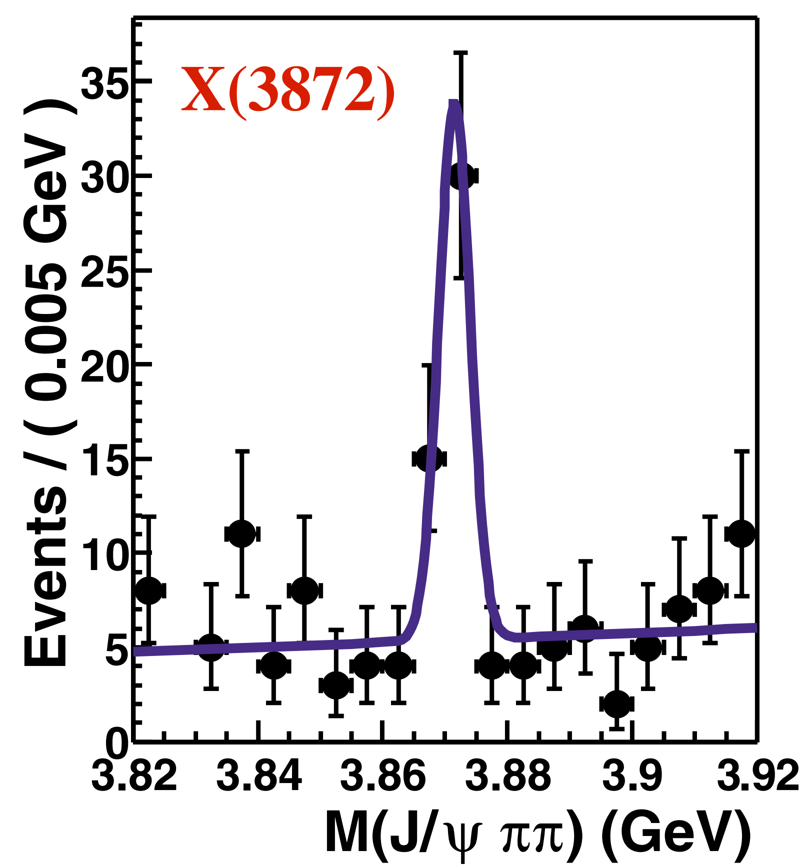
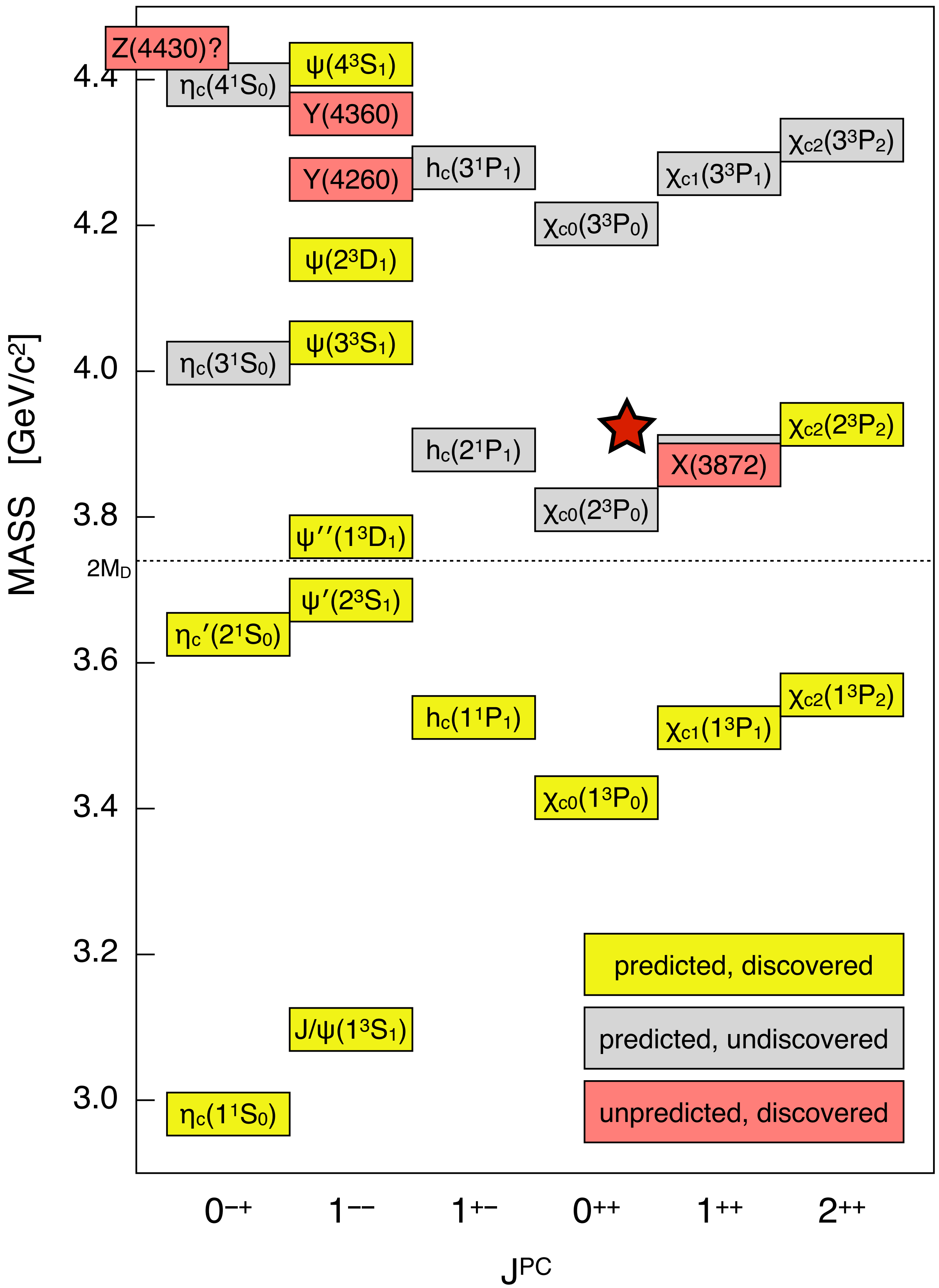
For example in B decays...

$B^\pm \rightarrow K^\pm(\pi^+\pi^- J/\psi)$ at Belle



$M = 3871.68 \pm 0.17$ MeV
$\Gamma < 1.2$ MeV (PDG 2012)

Connecting the XYZ at BESIII



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For example in B decays...

X(3872) Properties:

* very narrow (< 1.2 MeV)
* has $J^{PC} = 1^{++}$ (LHCb)
* too light to be the $\chi_{c1}(2P)$
* confirmed by many experiments
* mass is right at $D^{*0}D^0$ mass

D*D molecule?

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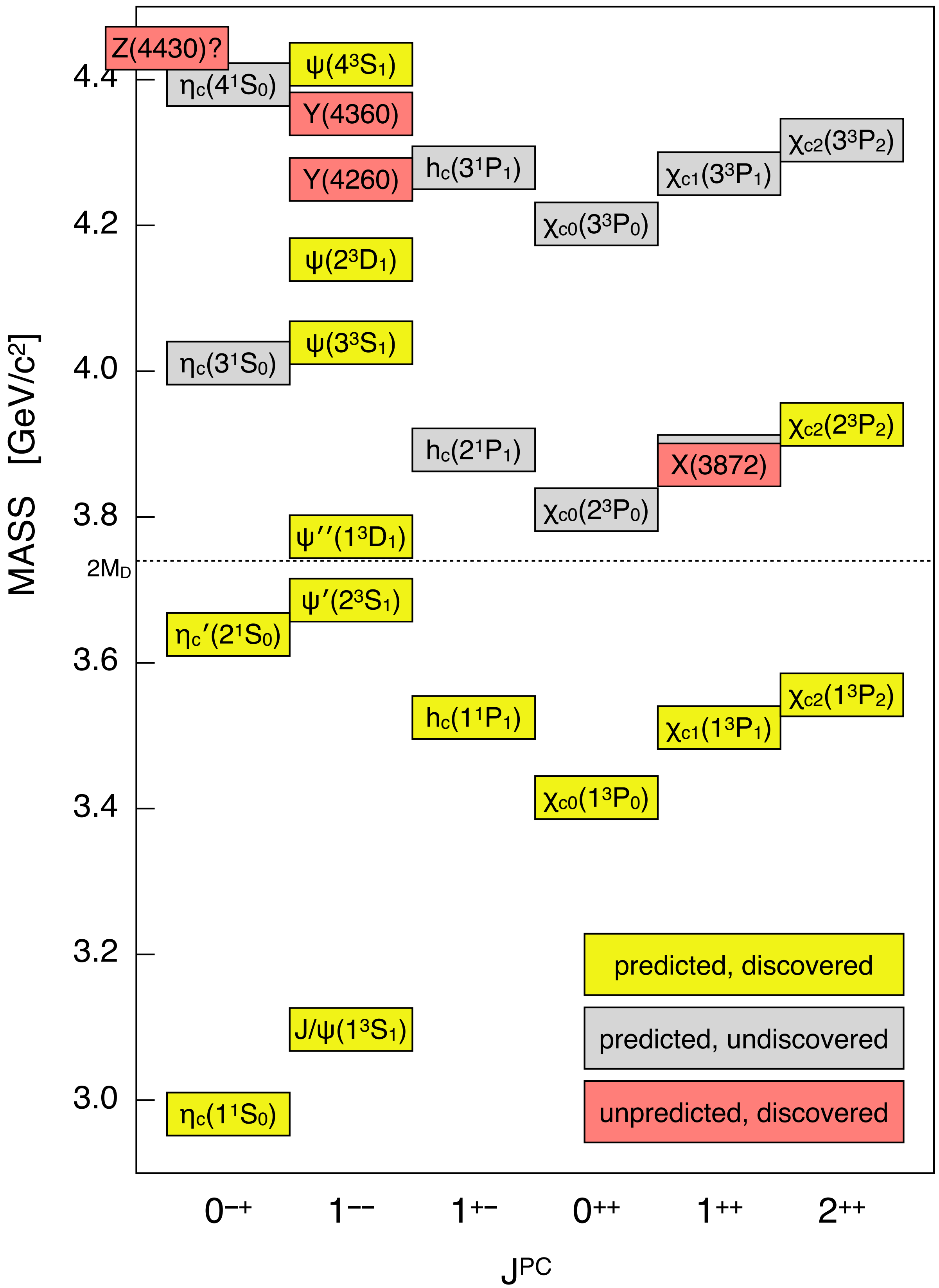

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For example in B decays...

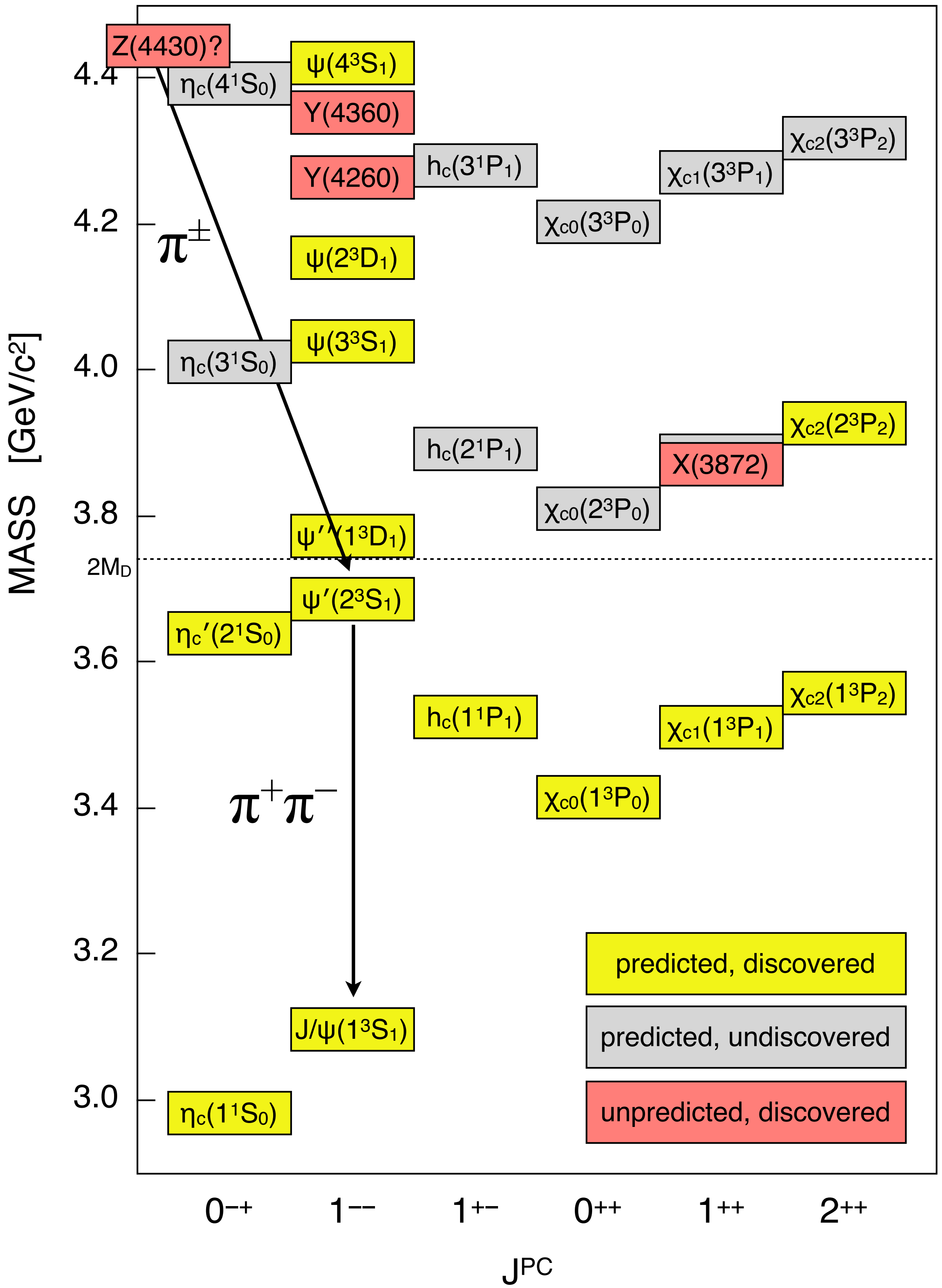
Other B decays:

$B^\pm \to K^\pm(\pi^+\pi^- J/\psi)$

$B \to K(\omega J/\psi)$

$B \to K(\pi^+\chi_{c1}(1P))$

$B \to K(\pi^+\psi(2S))$



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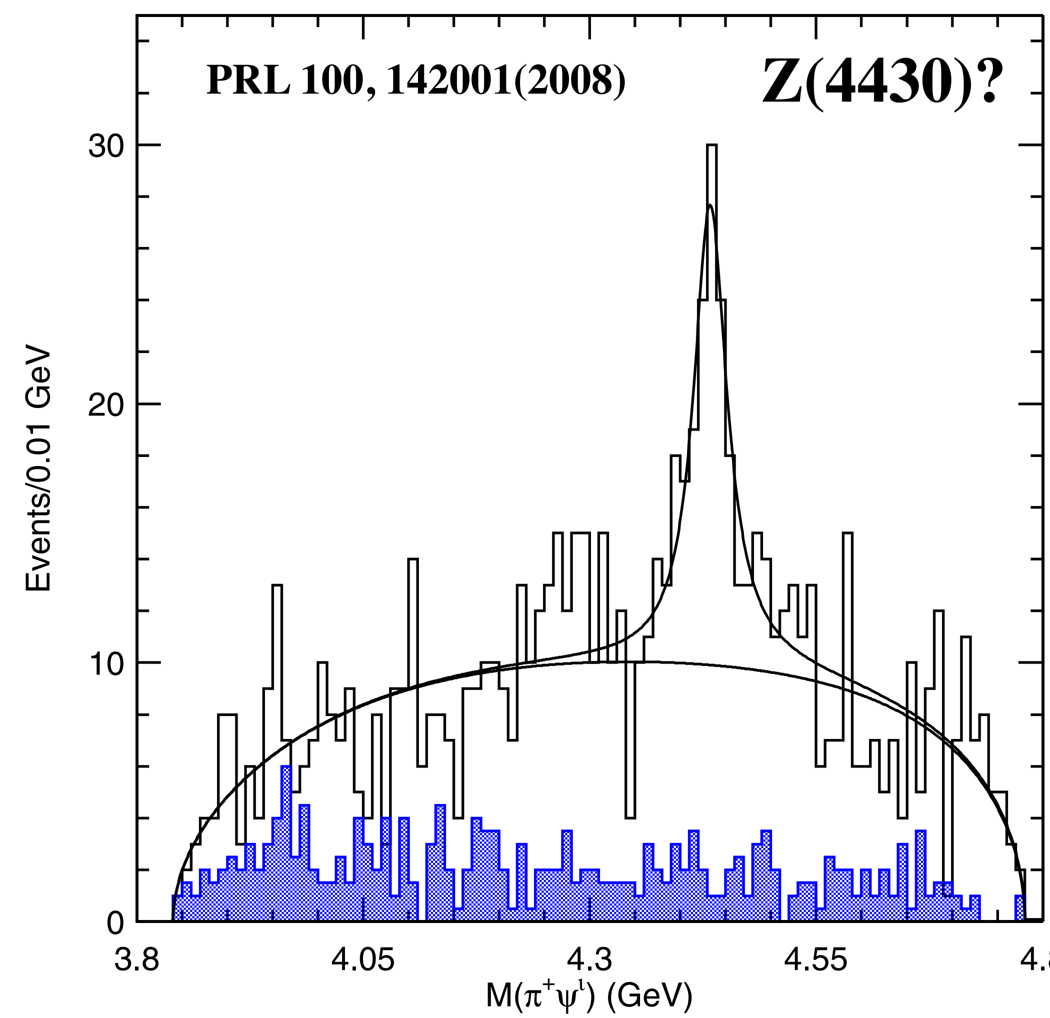
For example in B decays...

$B \to K(\pi^+\psi(2S))$ at Belle



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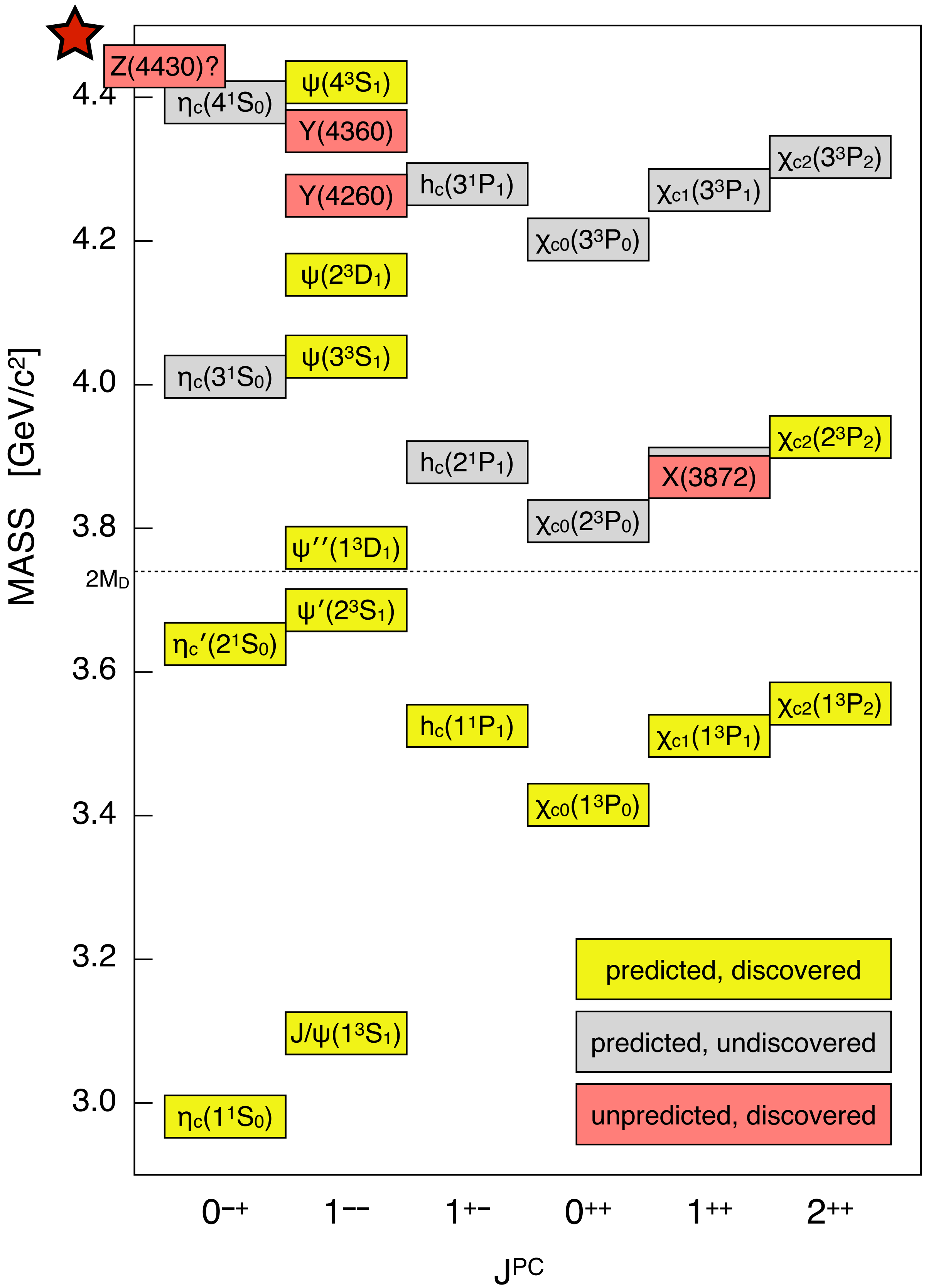

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For example in B decays...

<u>Z(4430) Properties:</u>

* has an electric charge

$\Rightarrow$ **needs at least four quarks!**

* *(not confirmed by BaBar)*

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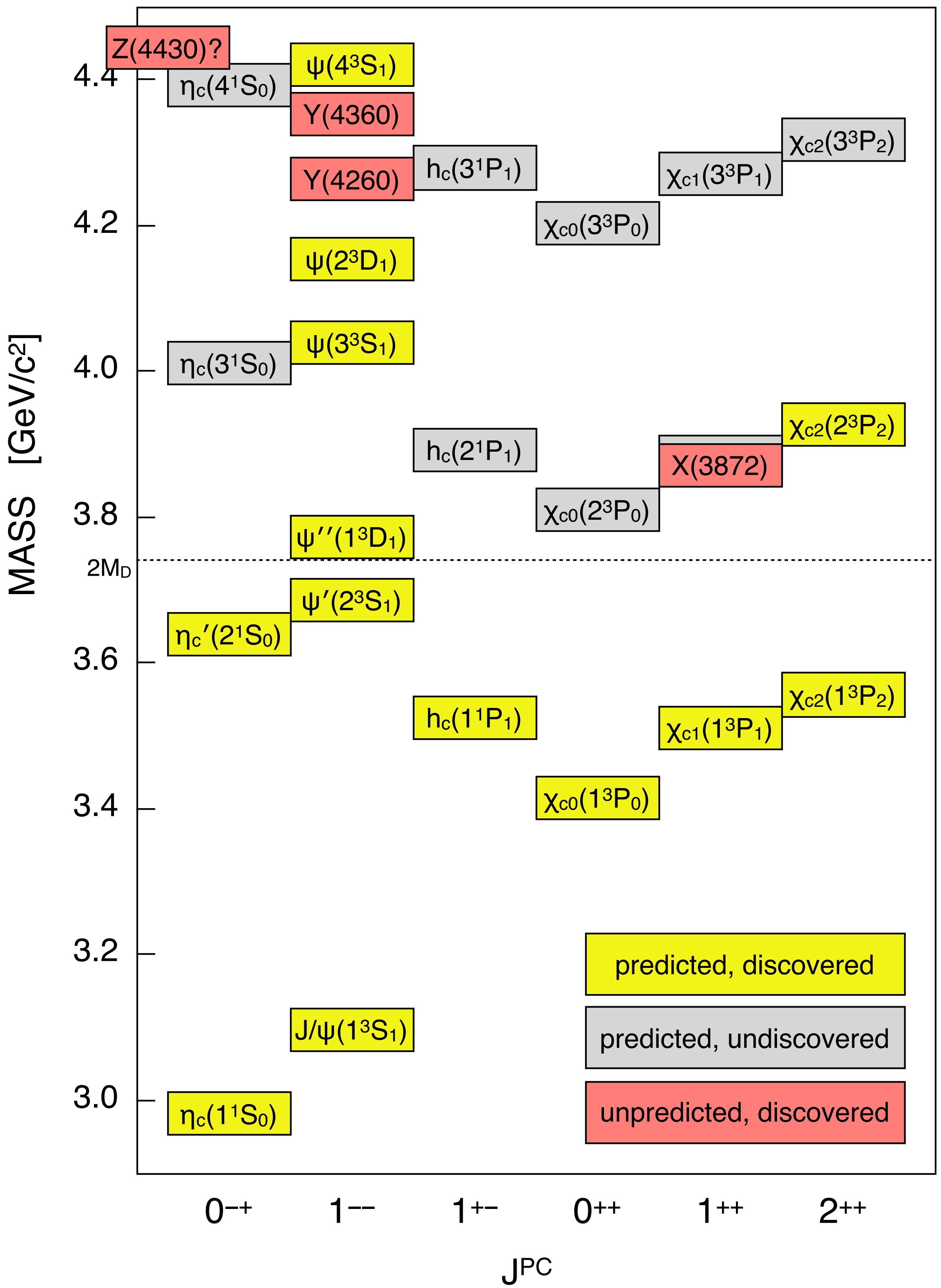

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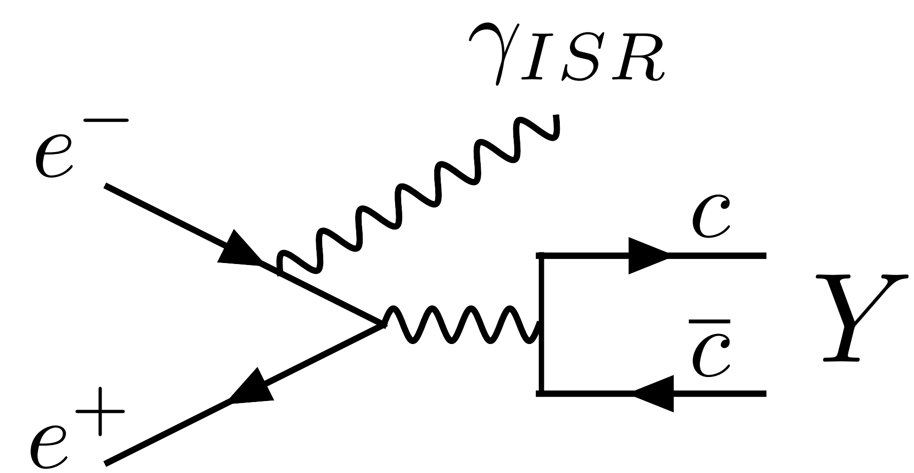
And in Initial State Radiation (ISR)...



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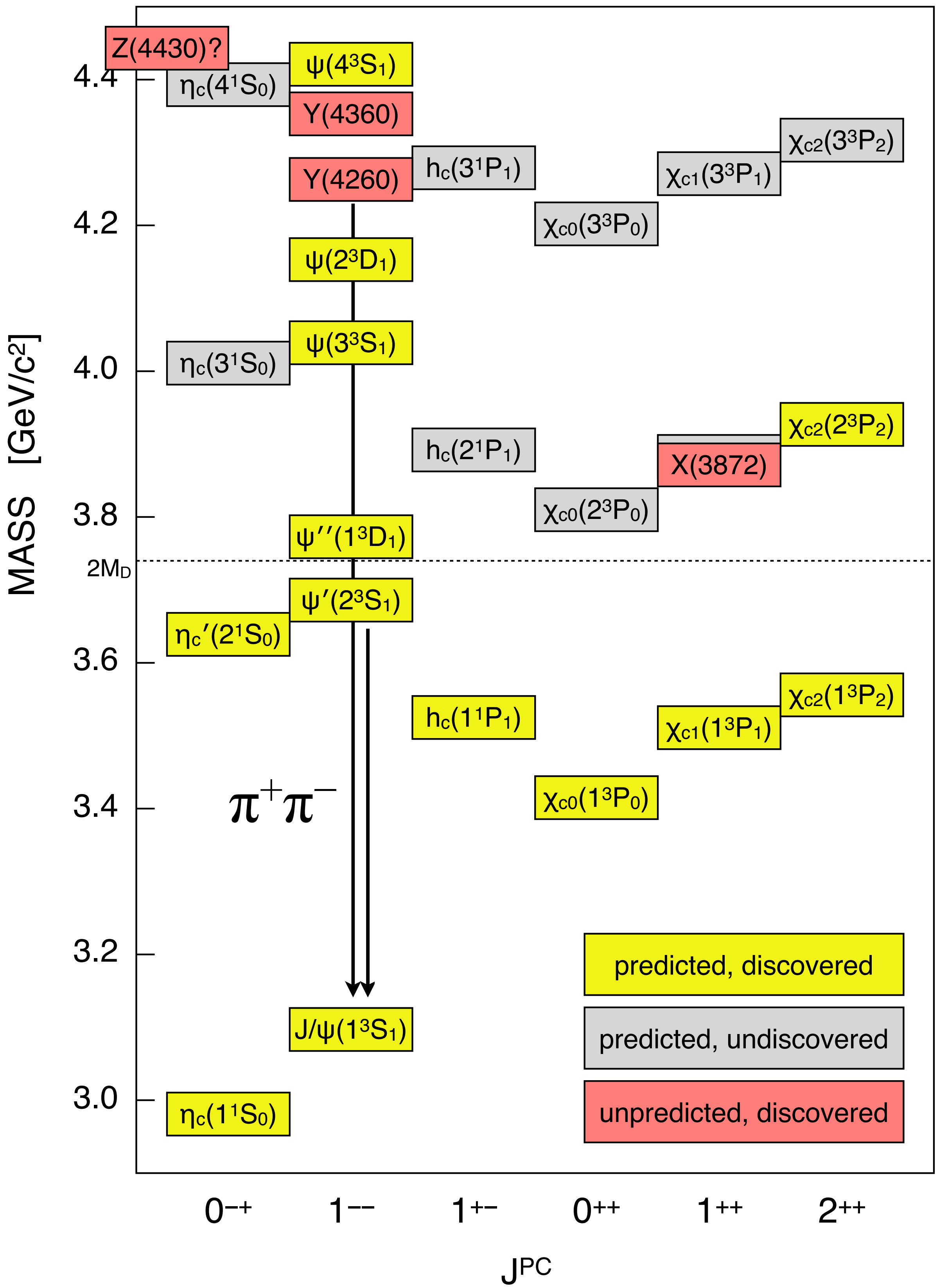

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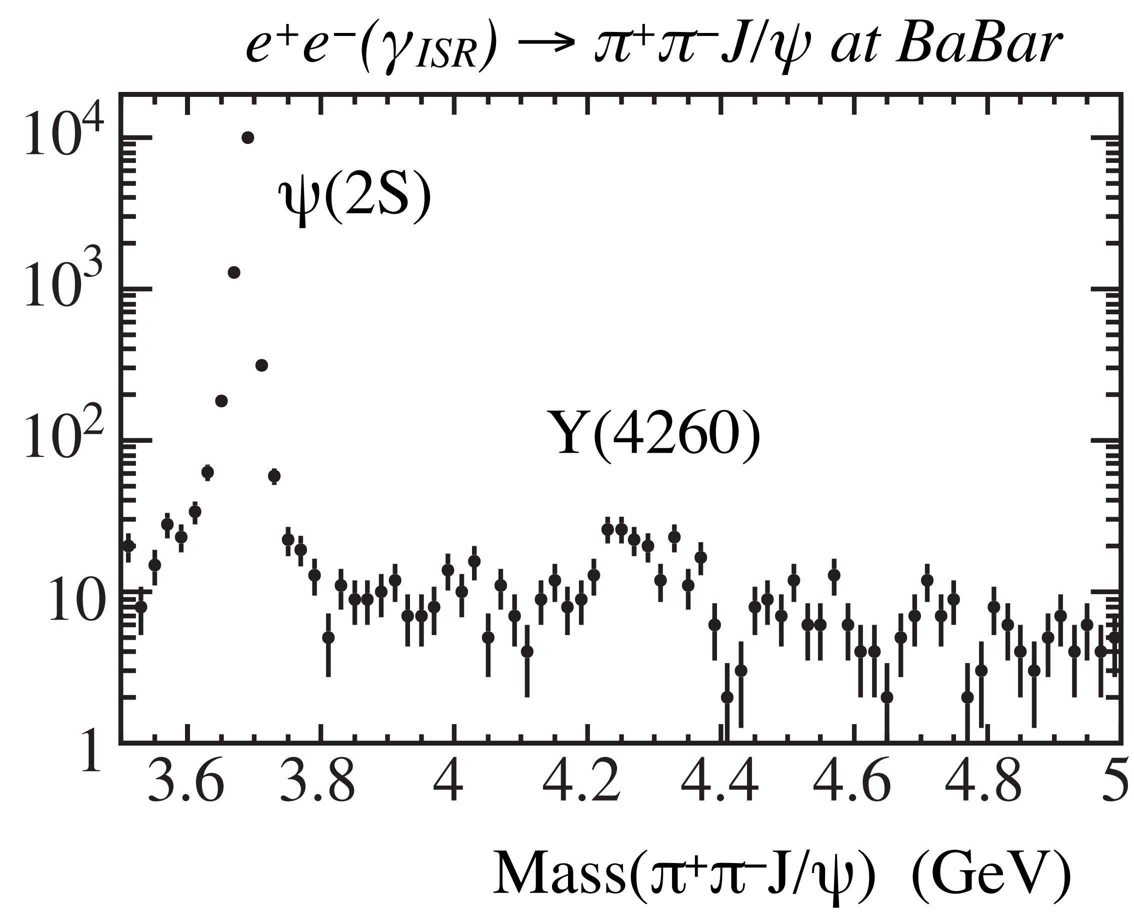

PRL 95, 142001 (2005)

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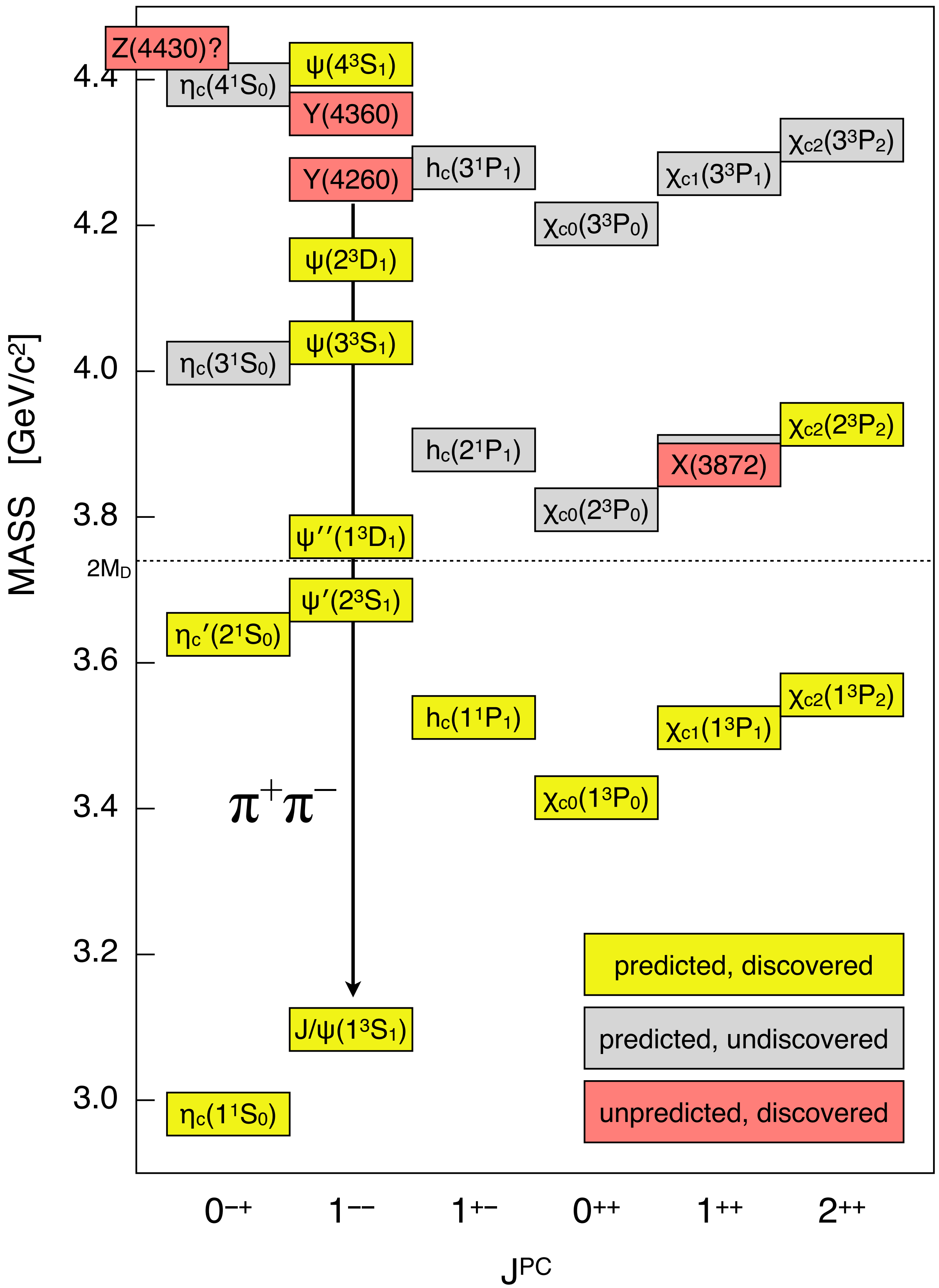

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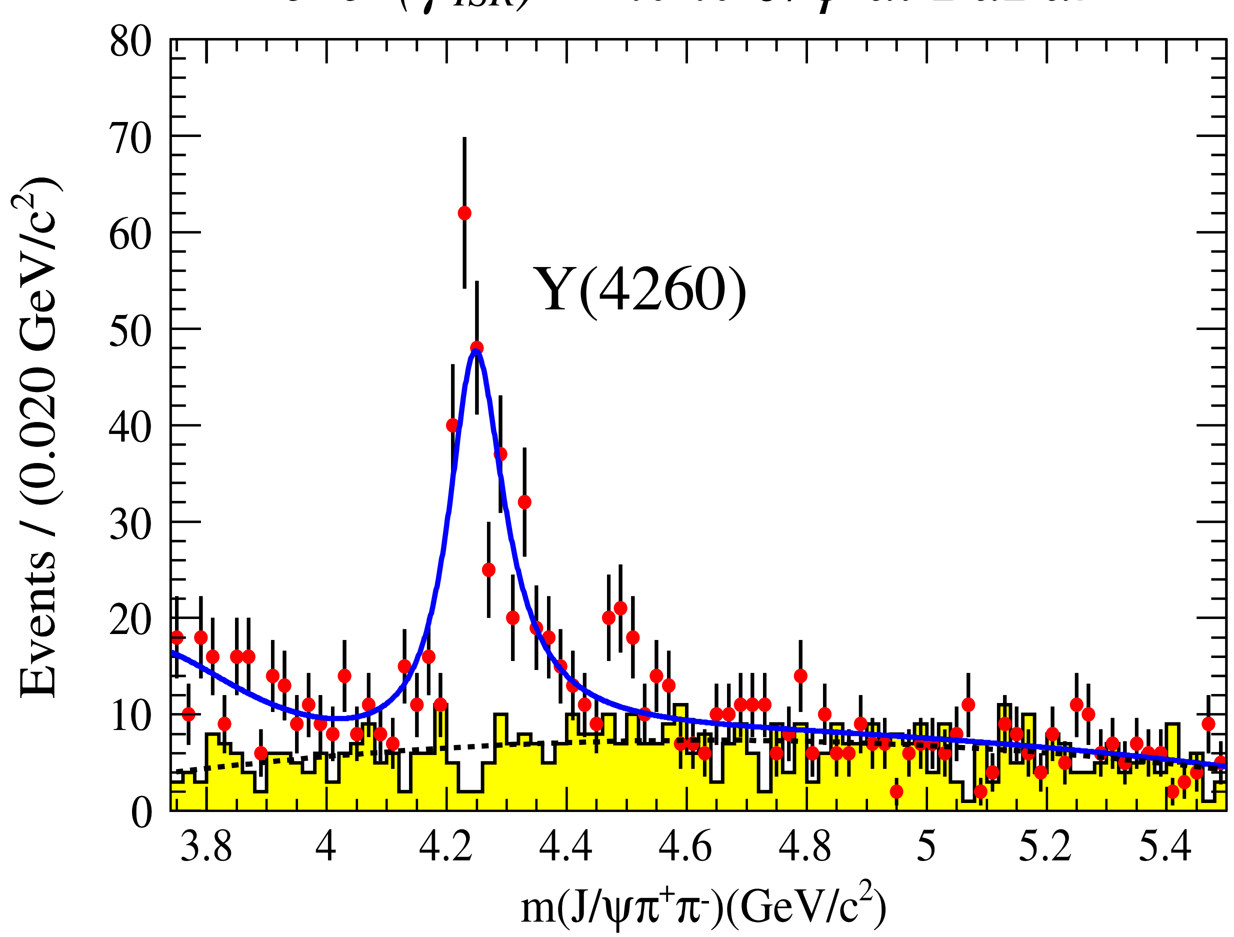
$e^+e^-(\gamma_{ISR}) \rightarrow \pi^+\pi^- J/\psi$ *at BaBar*



PRD 86, 051102(R) (2012)

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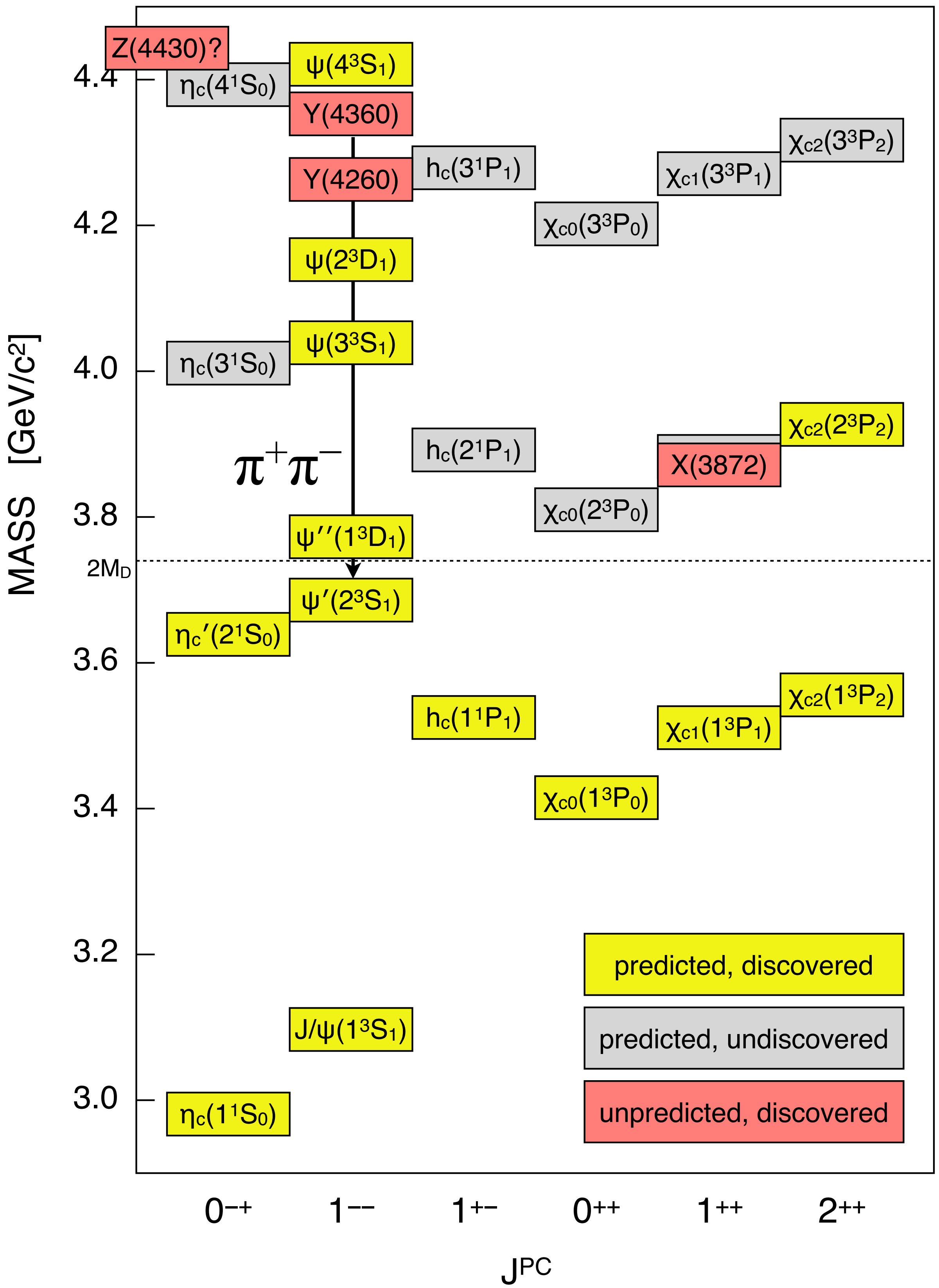

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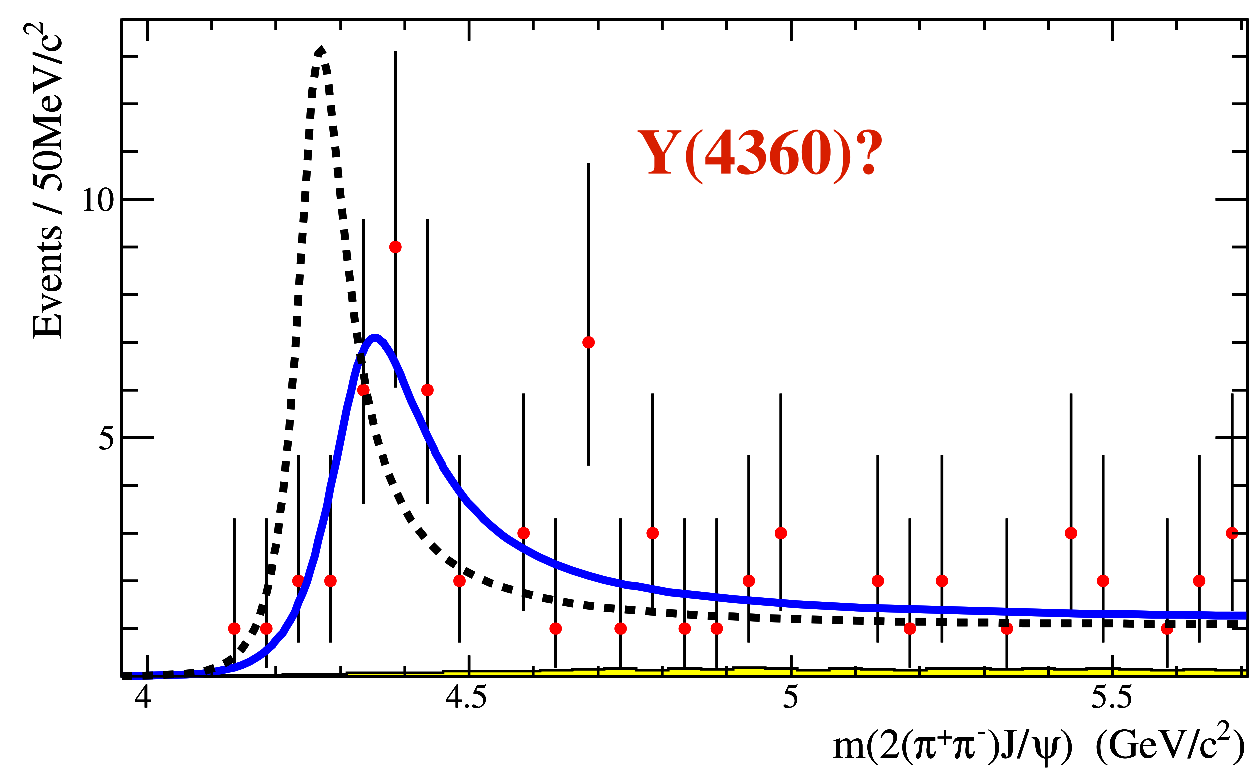

PRL 98, 212001 (2007)

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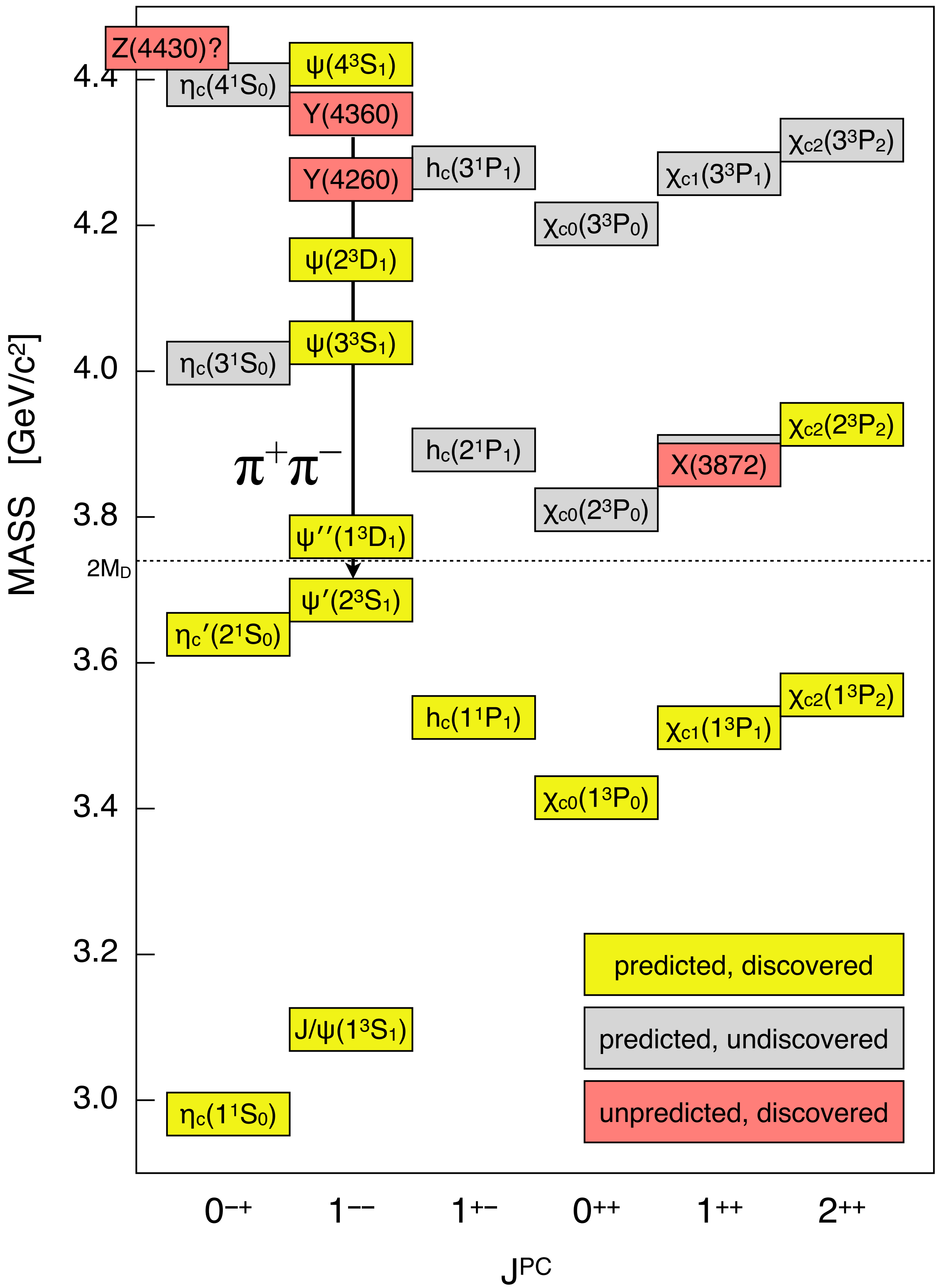

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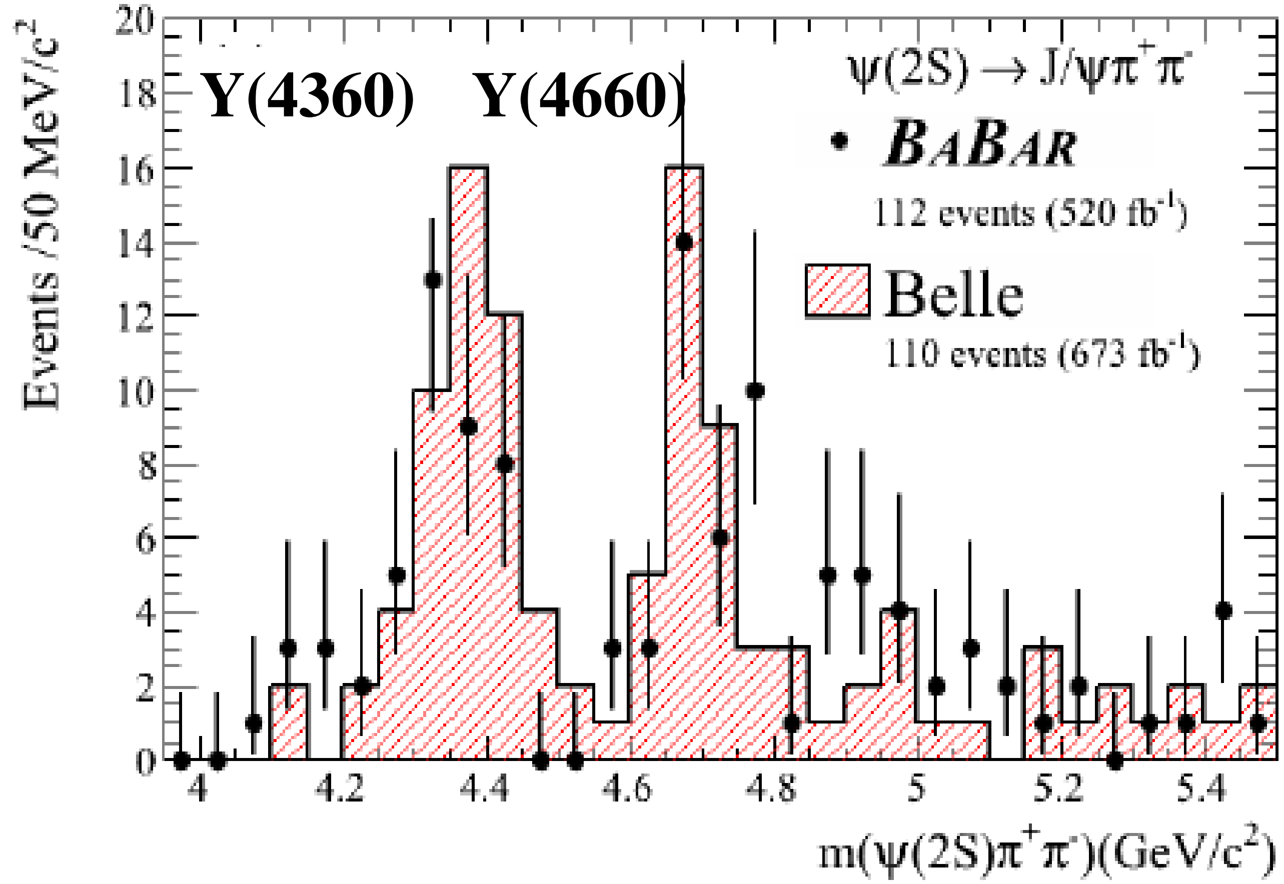

arXiv:1211.6271 and CHARM 2012

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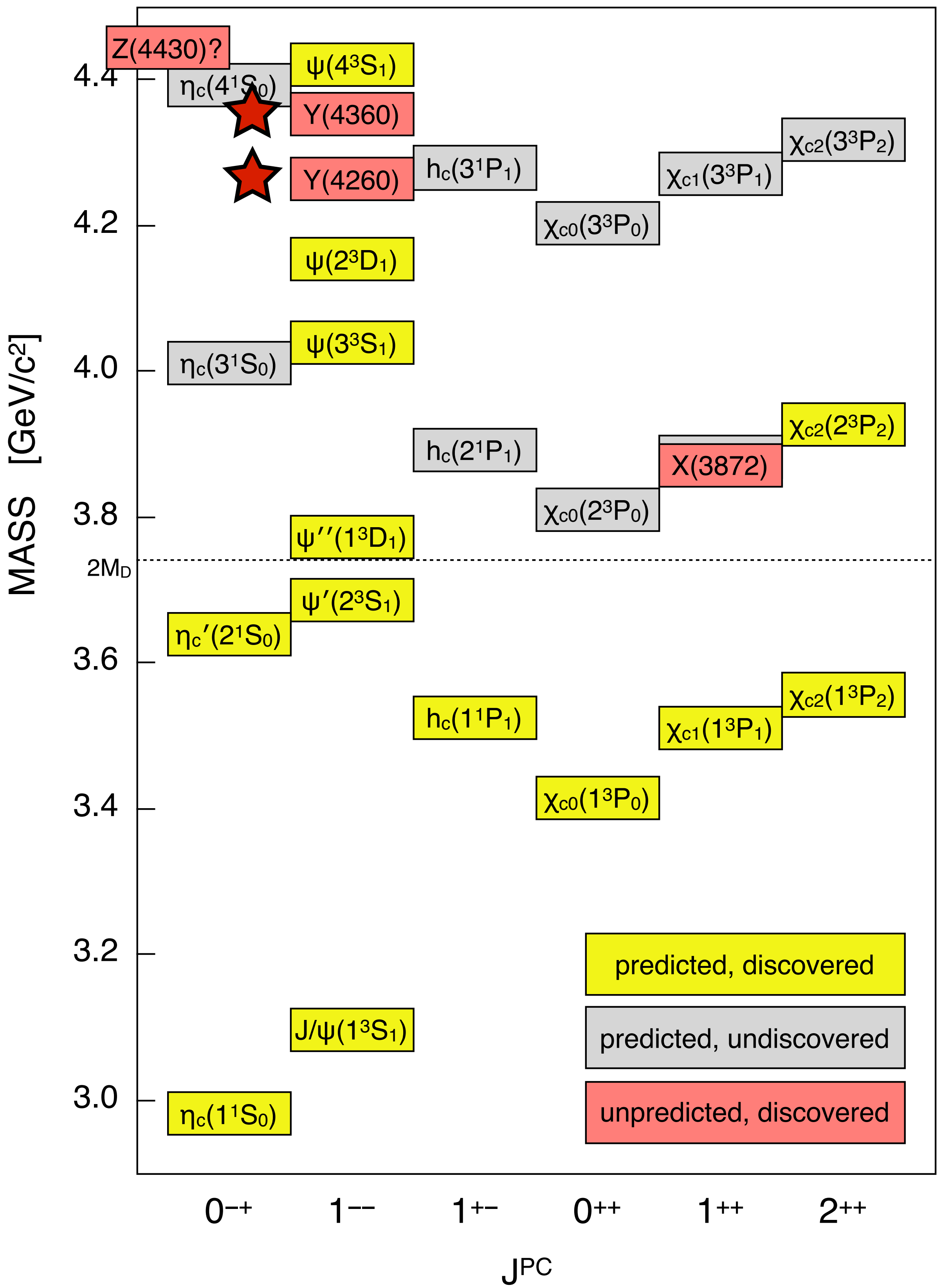


Most XYZ states were discovered at **Belle** and **BaBar** using e^+e^- collisions in the bottomonium region...

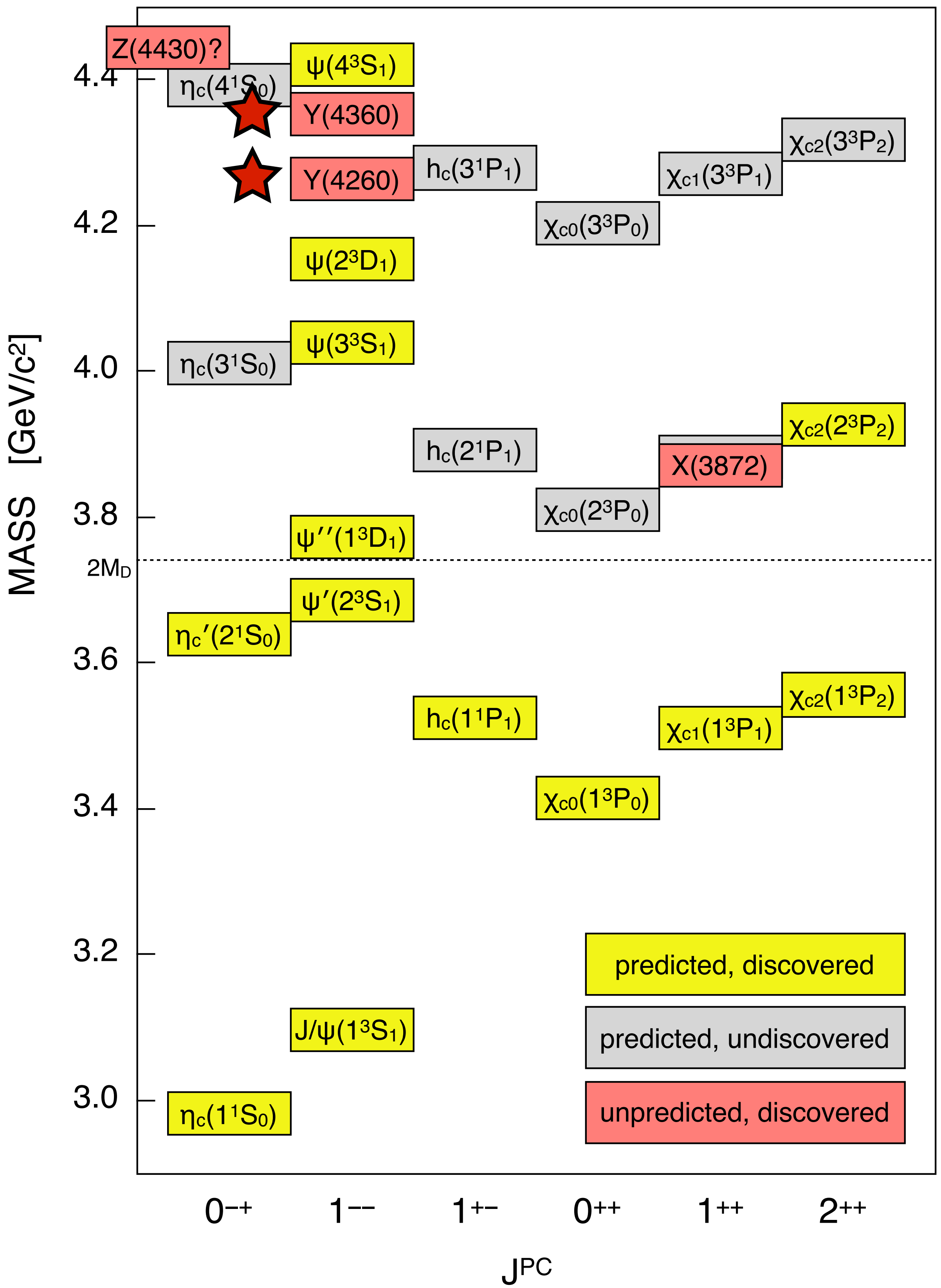
And in Initial State Radiation (ISR)...

<u>Y(4260), Y(4360) Properties:</u>

* not predicted in the quark model

* tight upper limits on open charm decays

Connecting the XYZ at BESIII



<u>Theoretical Ideas on Y(4260), Y(4360):</u>

DD* bound states (Y(4360) = D_sD_s*)

(NPA815, 53 (2009))

J/ψf_0 bound state (with KK → ππ)

(PRD80, 094012 (2009))

Tetraquarks (or two diquarks)

(PRD72, 031502(R) (2005))

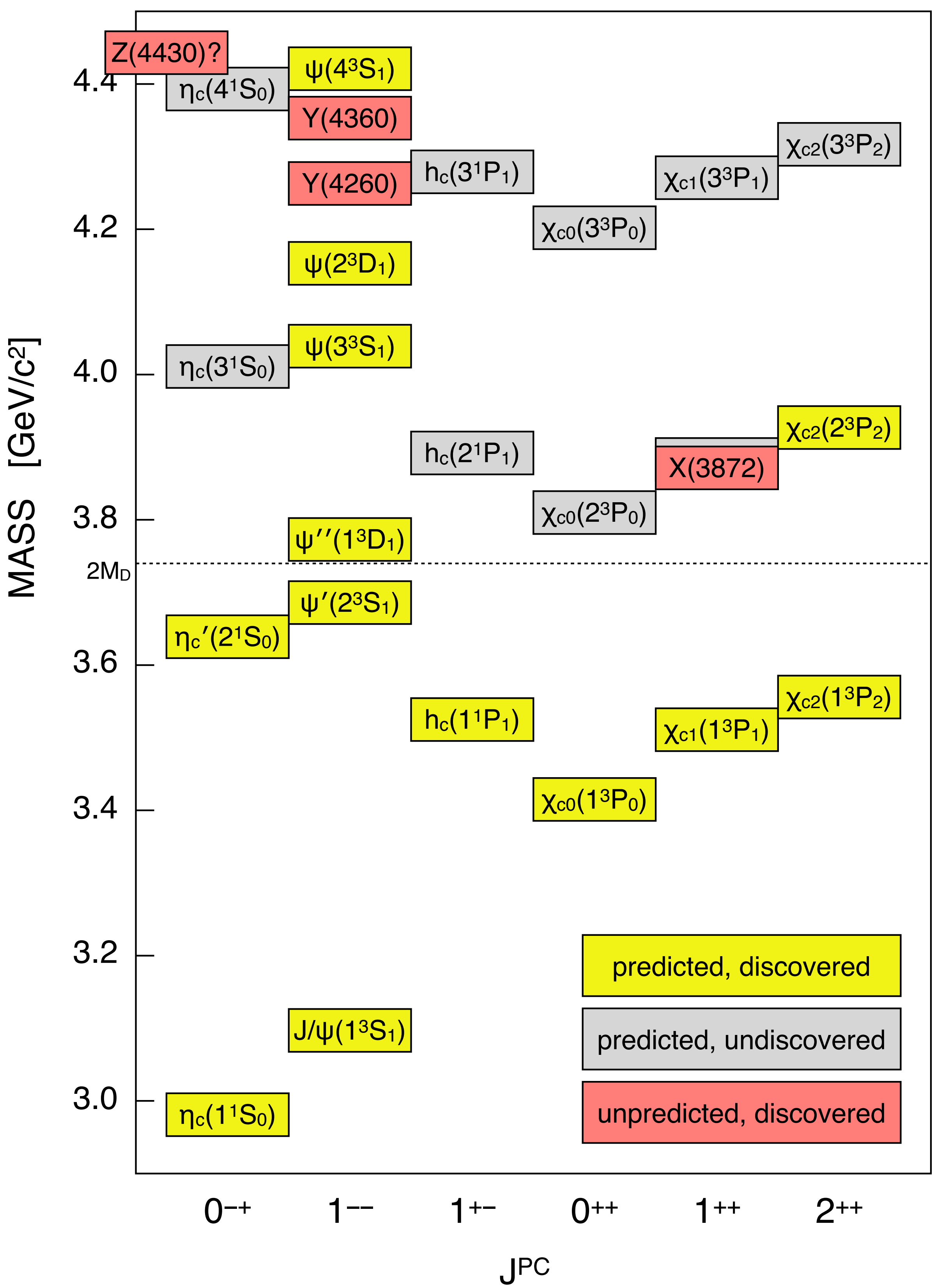
Hadrocharmonium

(PLB666, 344 (2008))

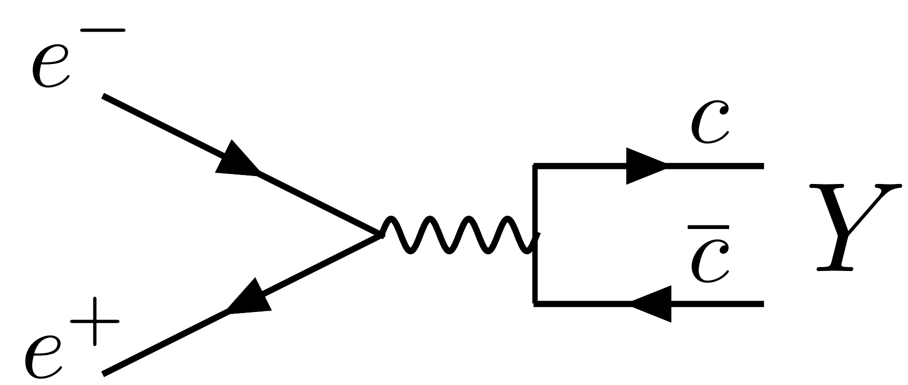
Hybrid Charmonium

(PLB628, 215 (2005), PRD78, 094504 (2008), PLB625, 212 (2005))

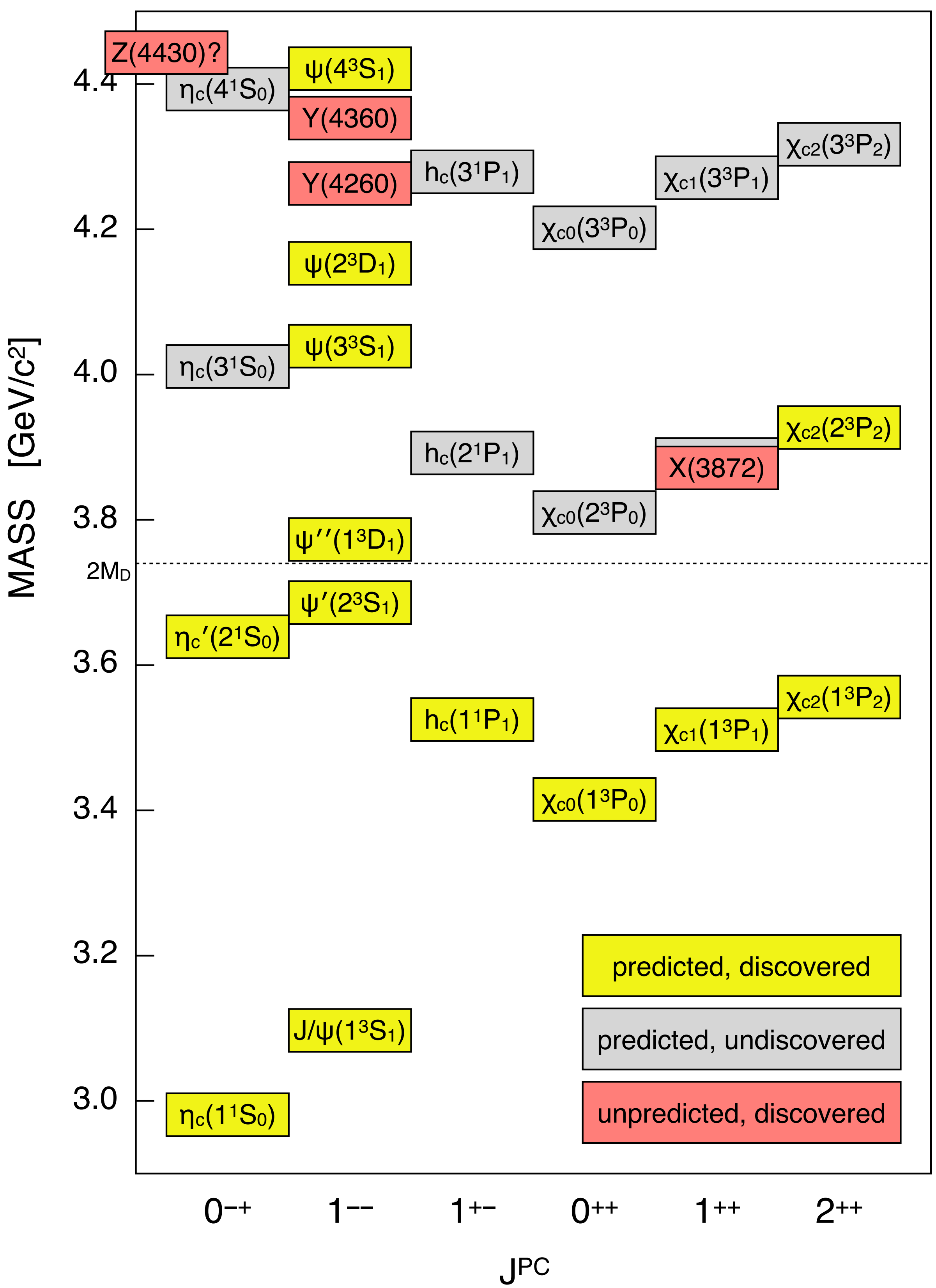
Connecting the XYZ at BESIII



BESIII can produce the **Y(4260)** and **Y(4360)** directly by tuning the BEPCII center of mass energies…

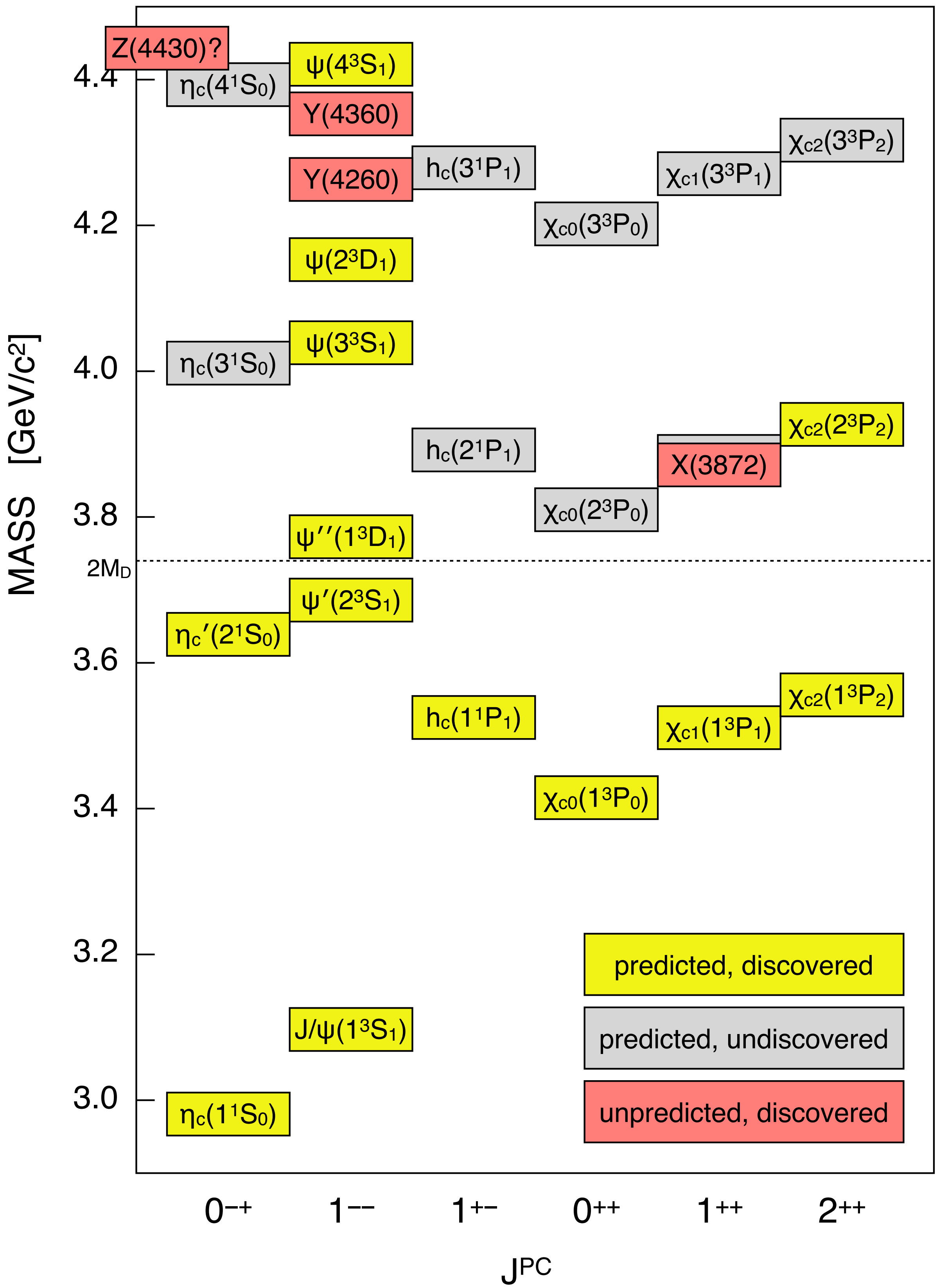


Connecting the X



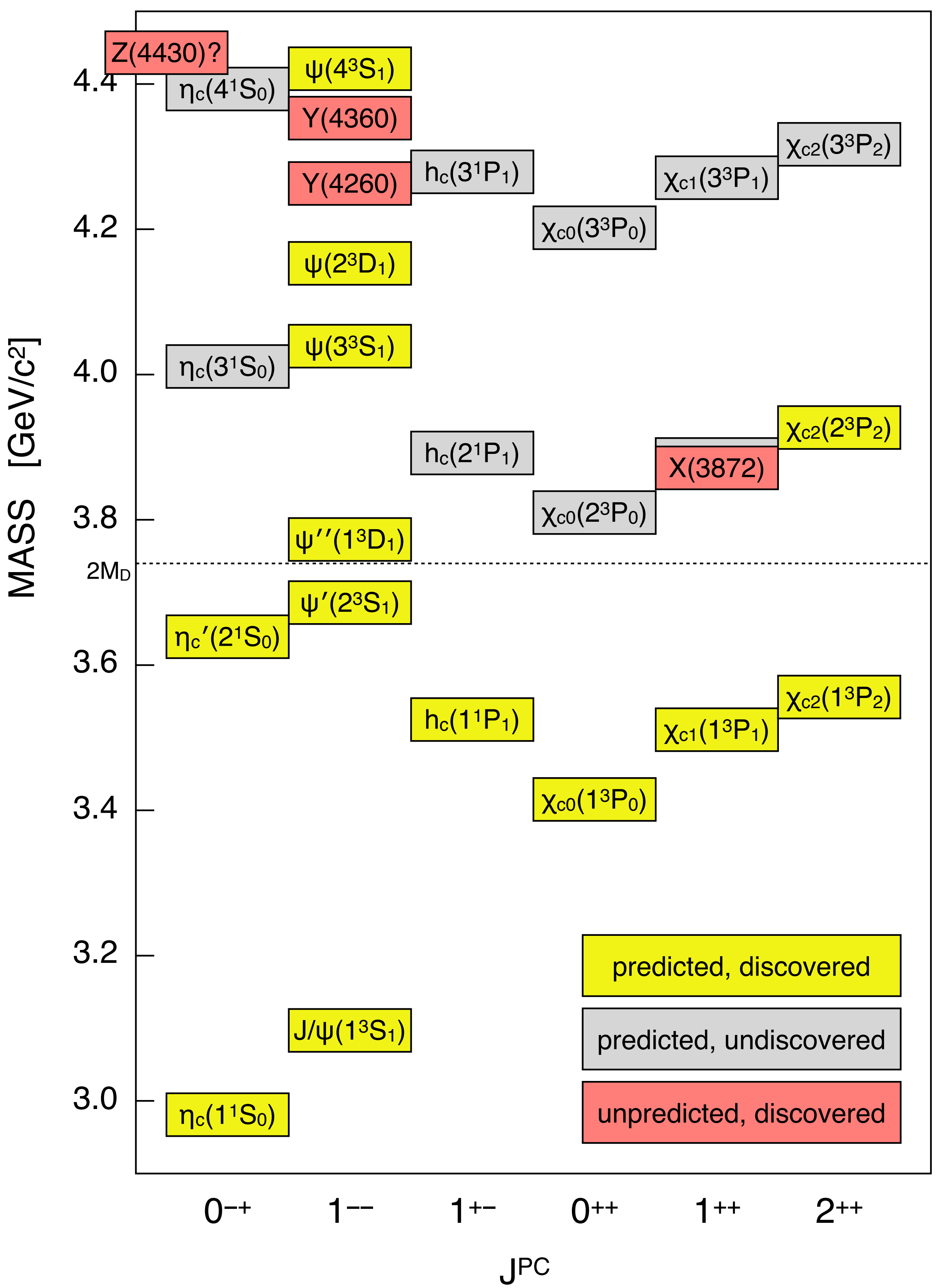
Google satellite image of BEPC-II

Connecting the X



Google satellite image of BEPC-II

Connecting the XYZ at BESIII



Google satellite image of BEPC-II

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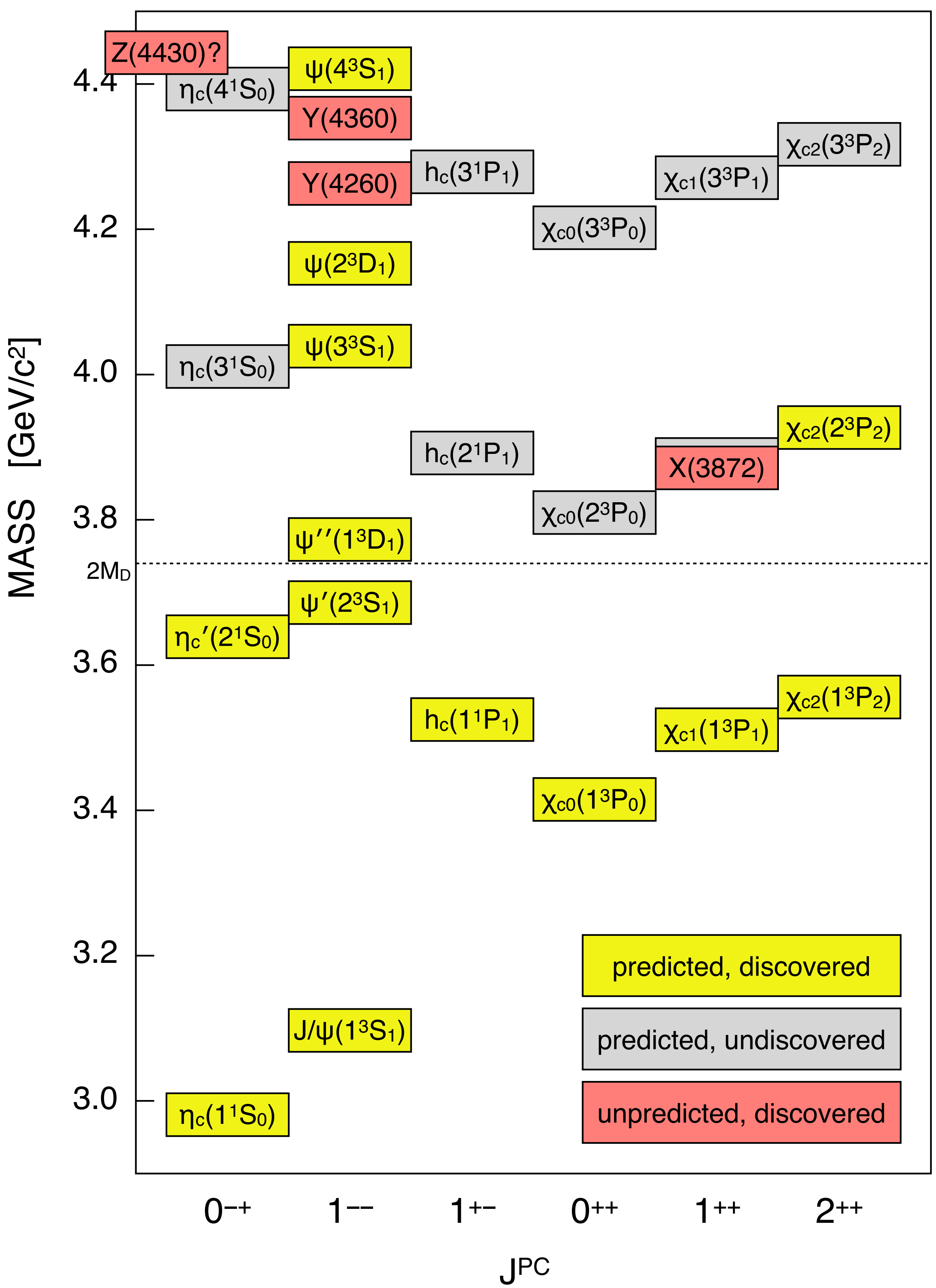

Google satellite image of BEPC-II

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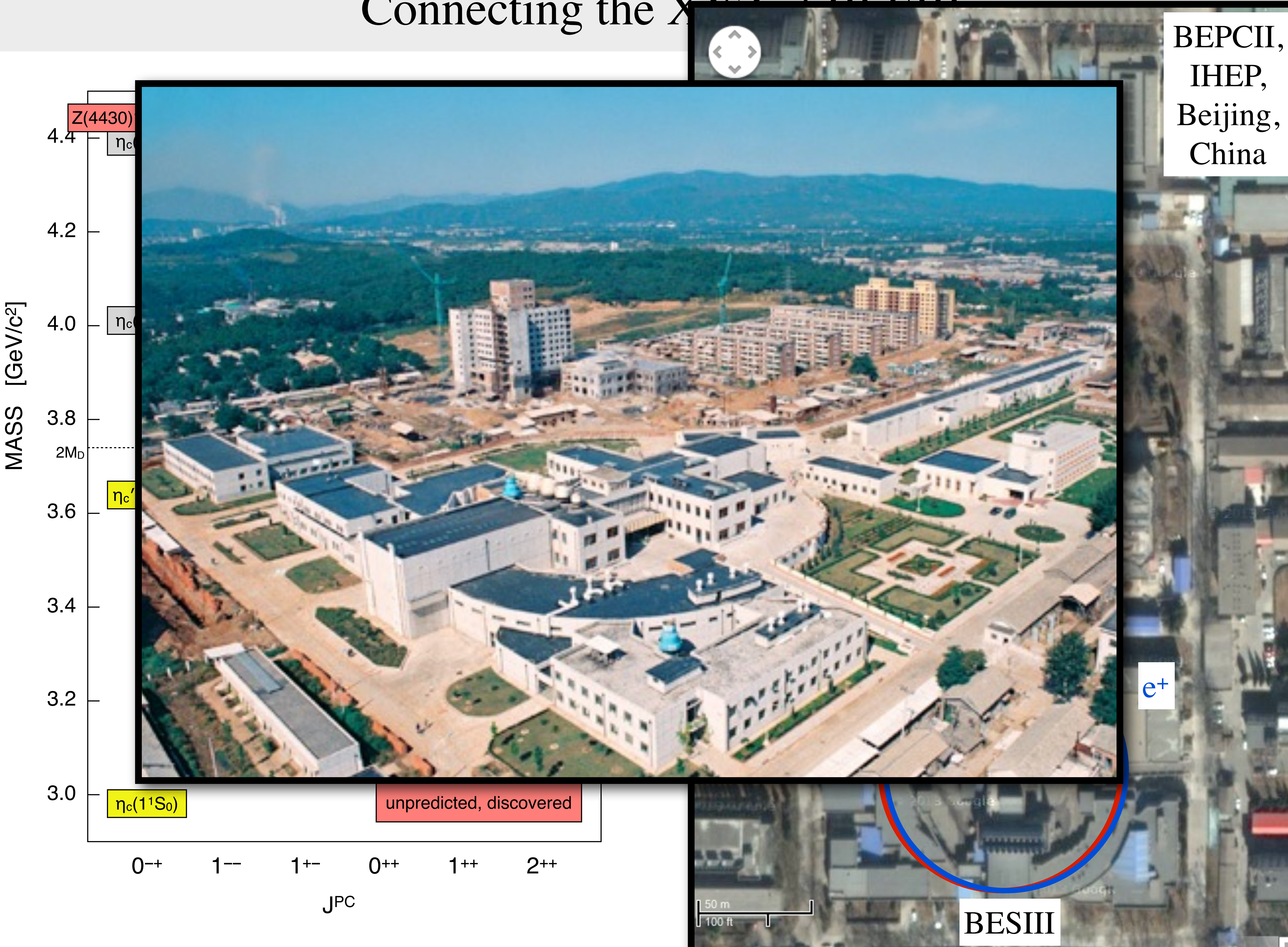


Google satellite image of BEPC-II

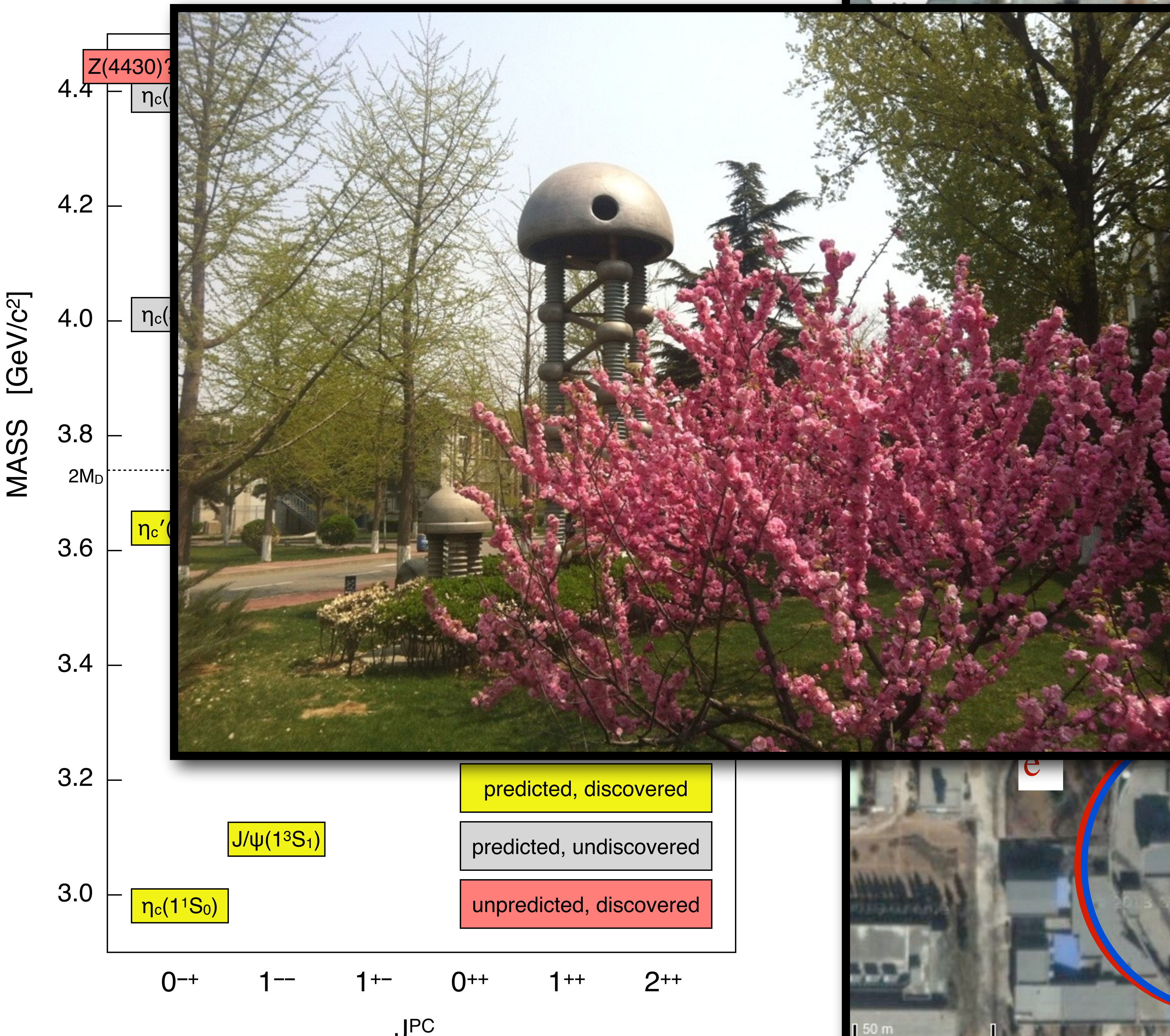
Connecting the XYZ at BESIII

MASS [GeV/c^2]

J^{PC}

Google satellite image of BEPC-II

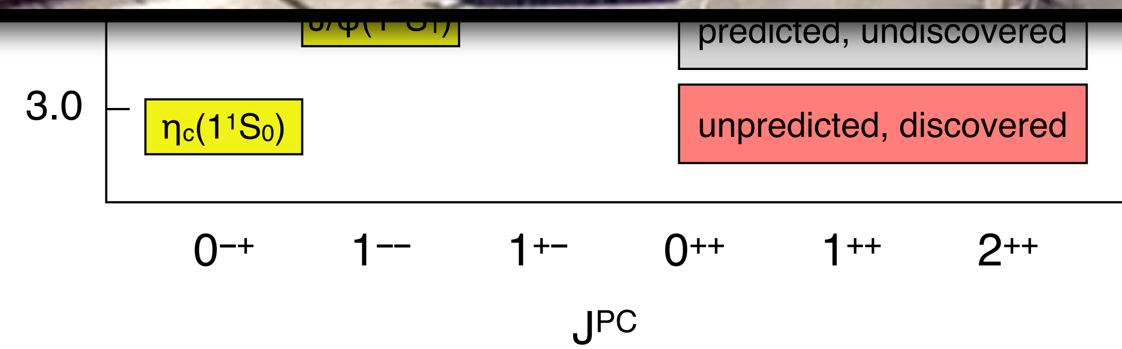
Connecting the XYZ at BESIII



Google satellite image of BEPC-II

Connecting the X

Google satellite image of BEPC-II



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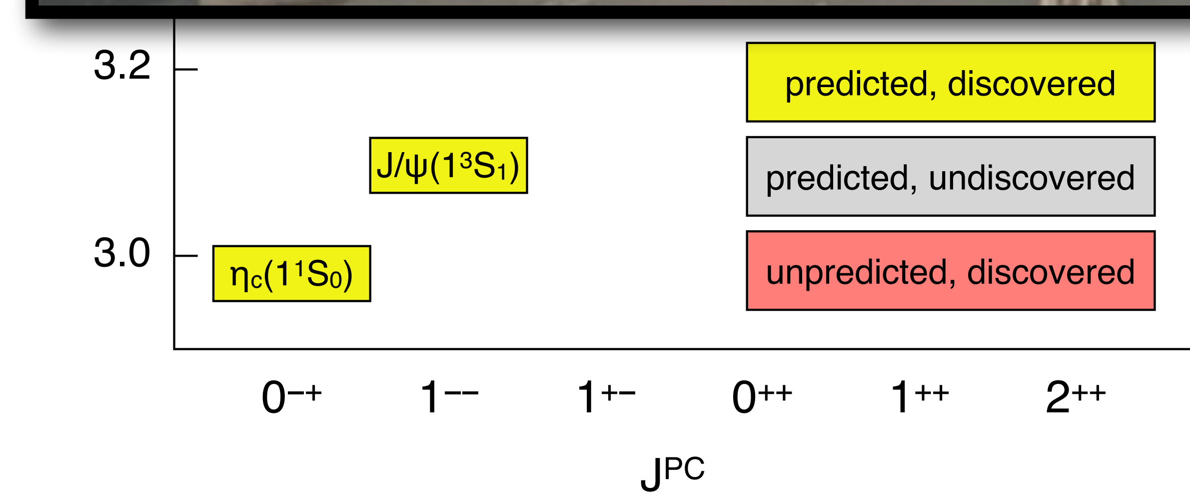

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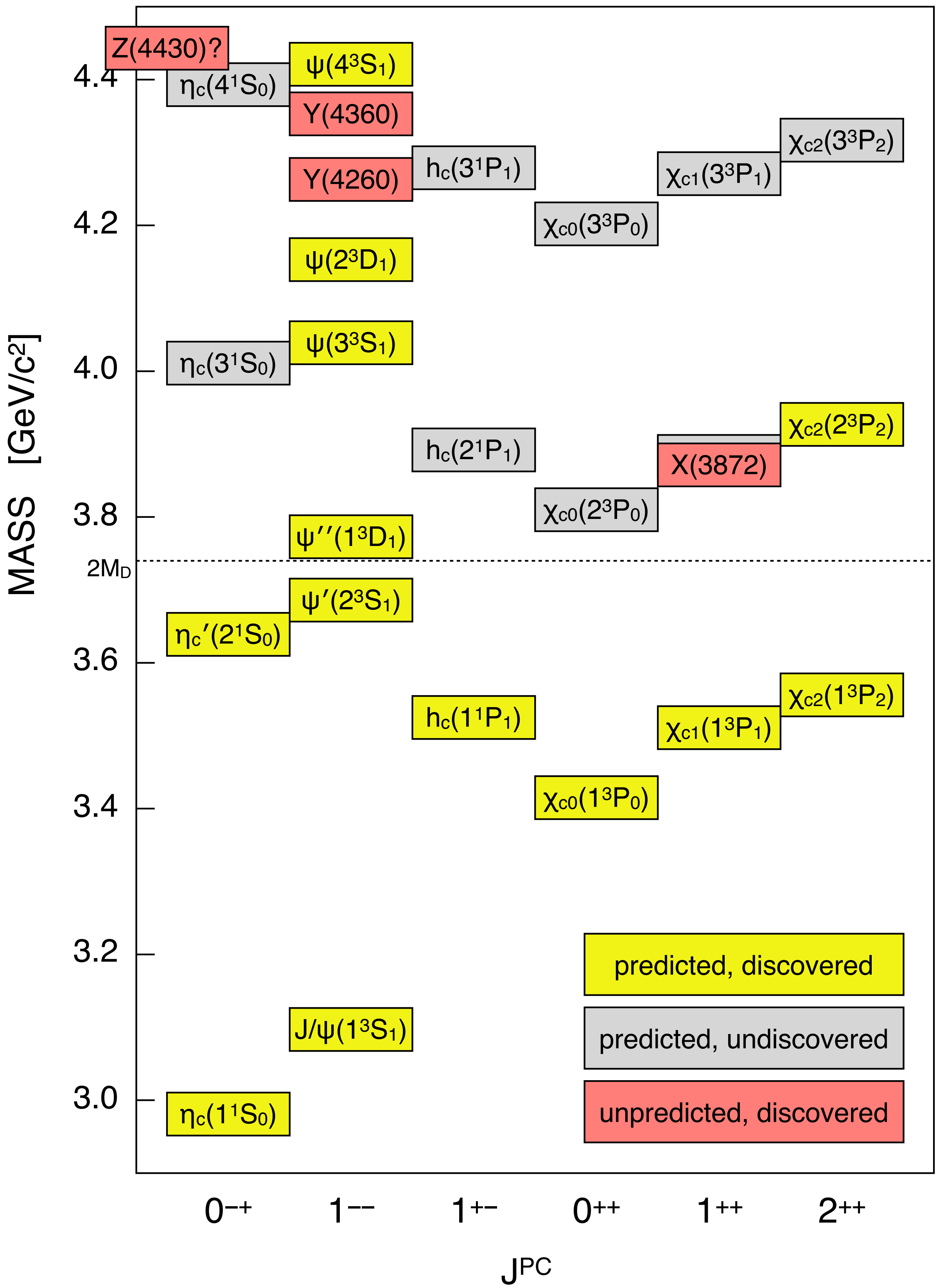

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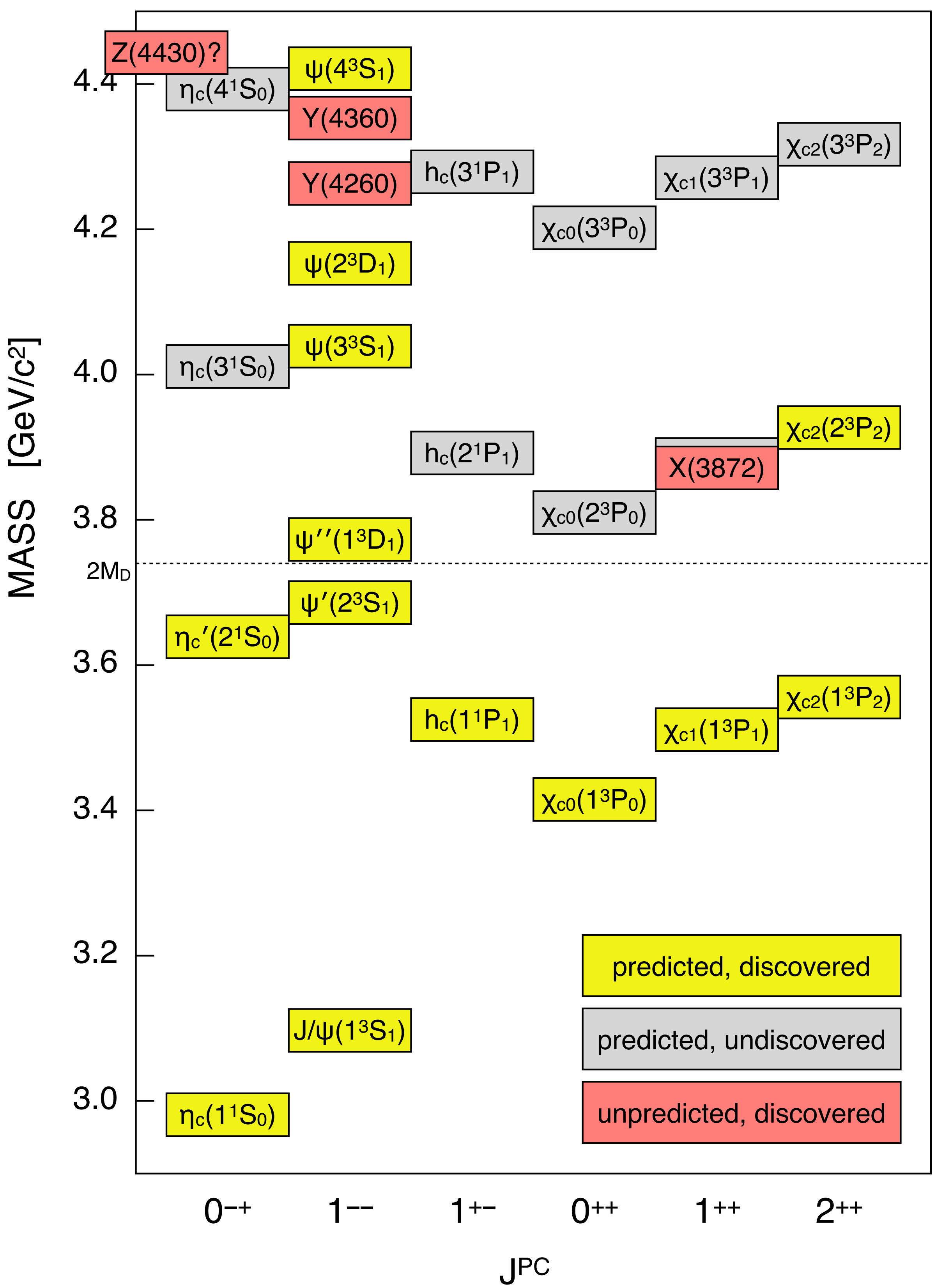
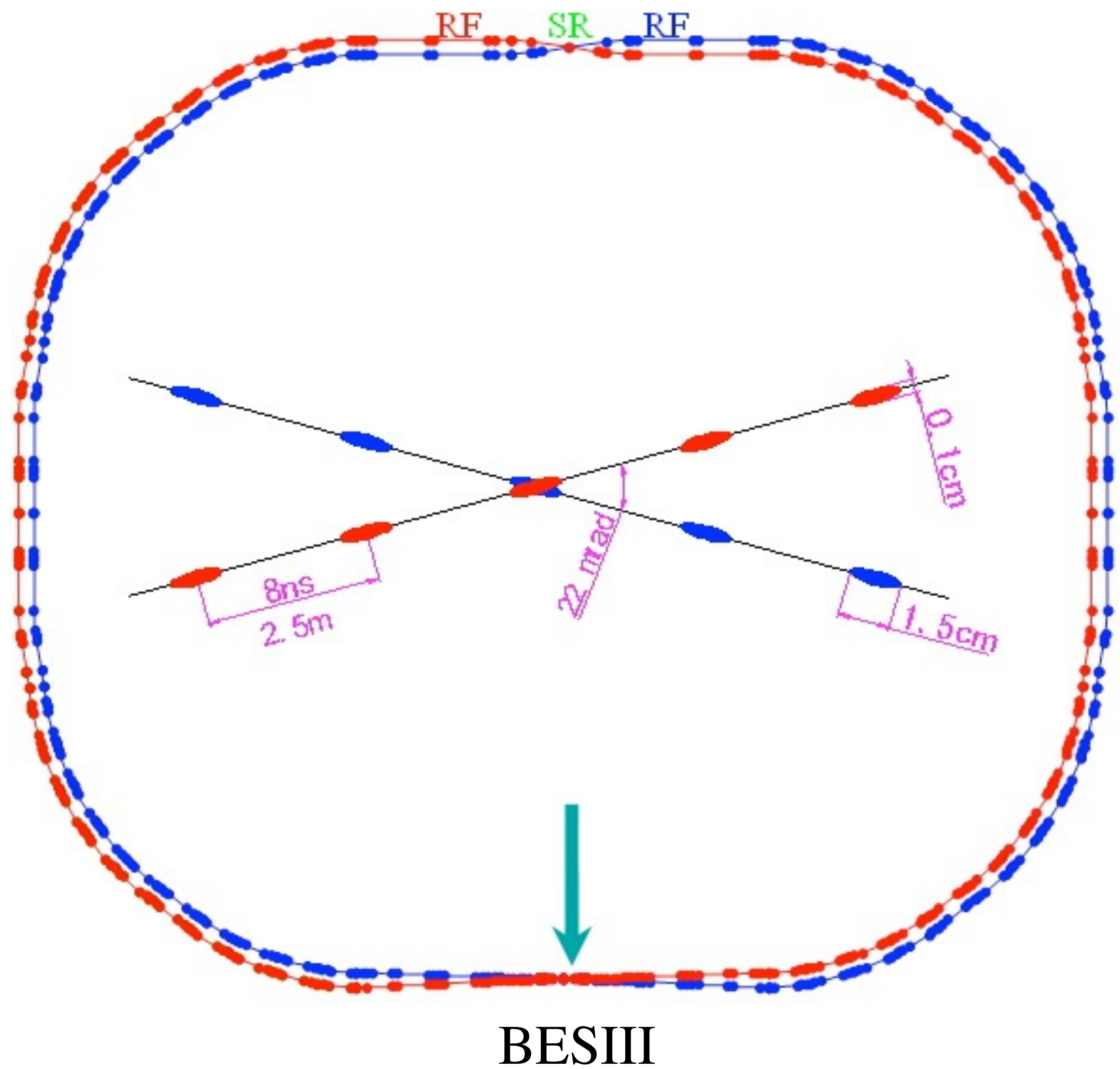
Connecting the XYZ at BESIII



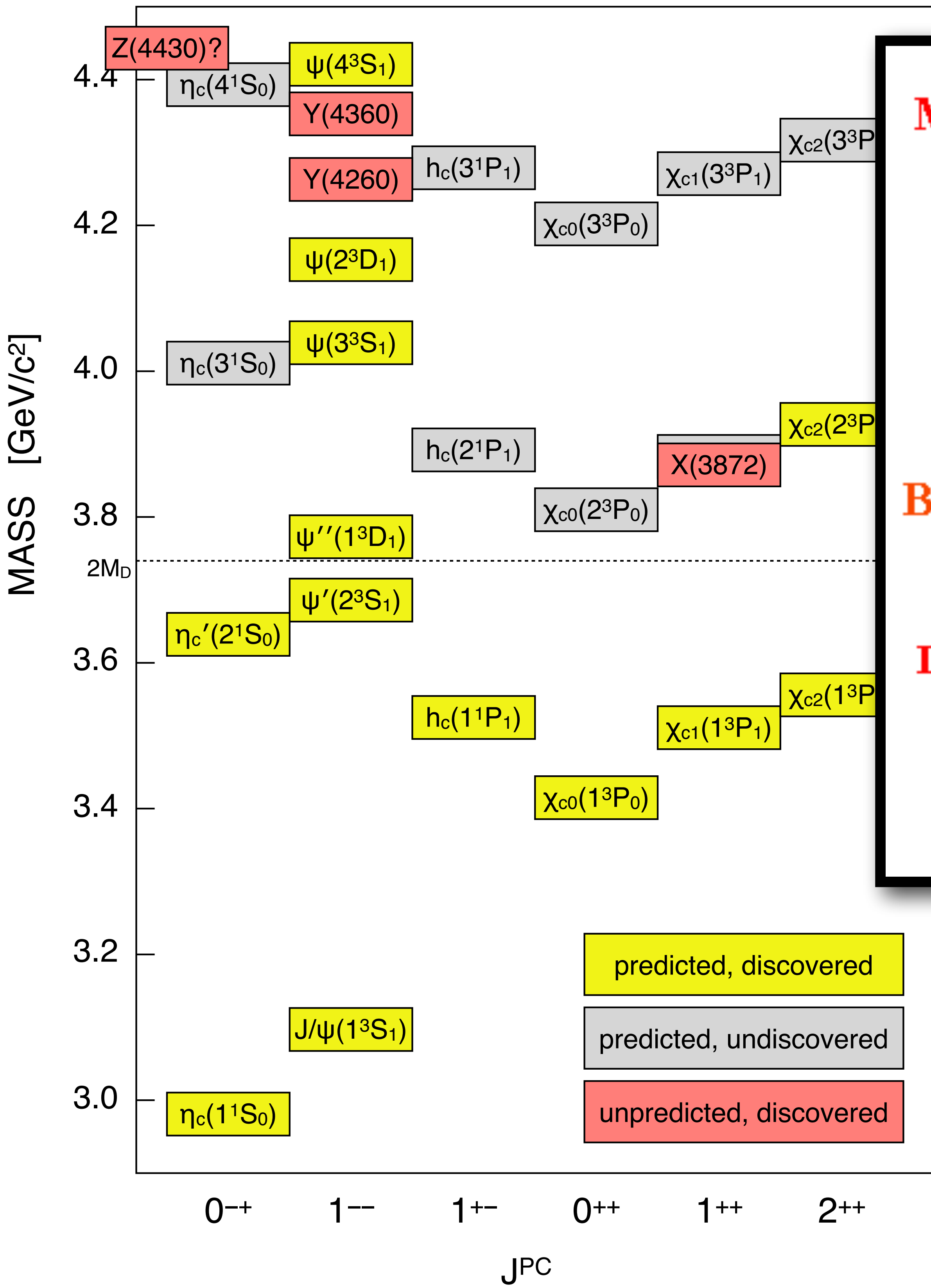
BEPC-II e^+e^- Collider



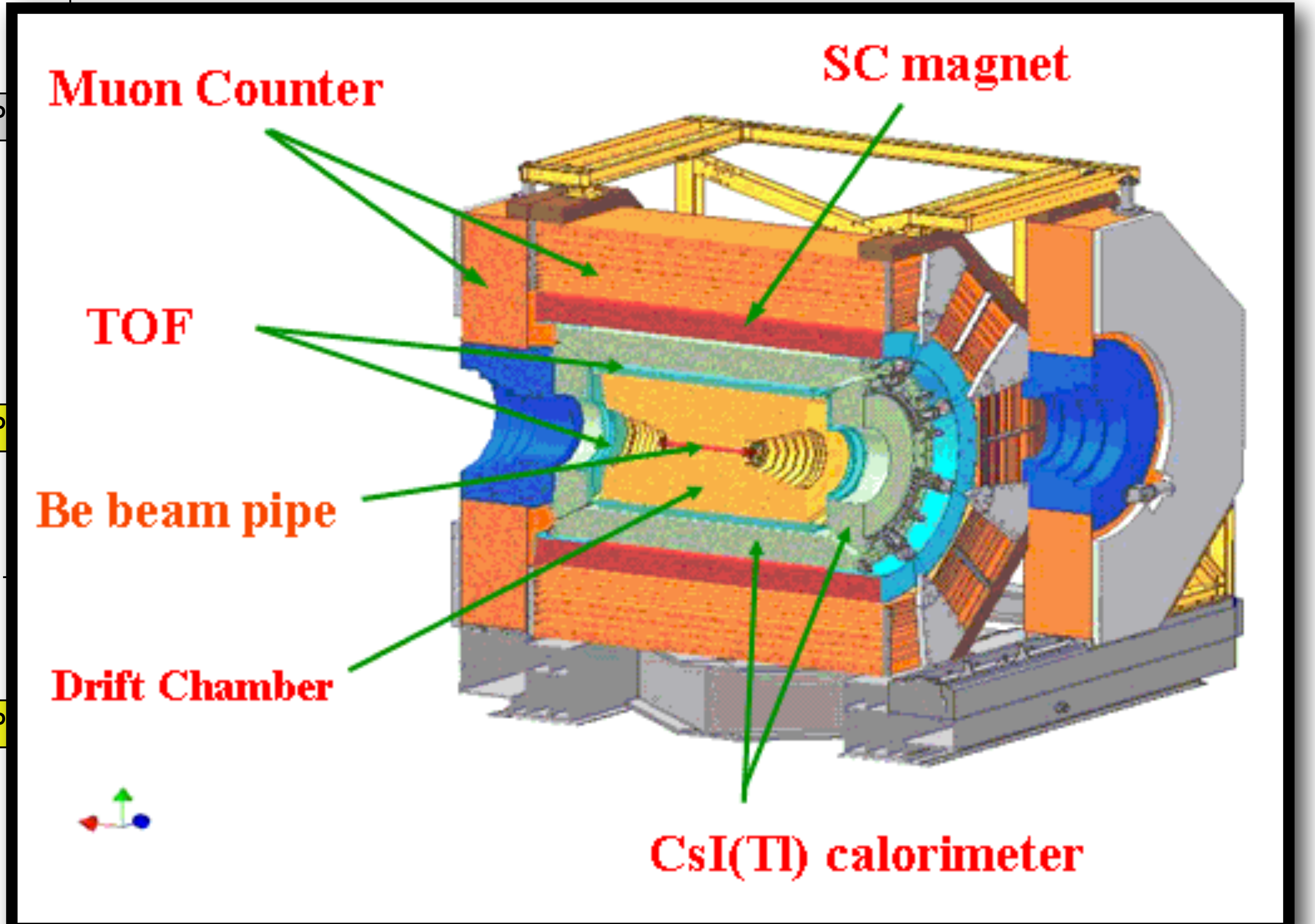
e^+e^- collisions in the charmonium region

(about 2 – 5?? GeV center of mass energies)

Connecting the XYZ at BESIII



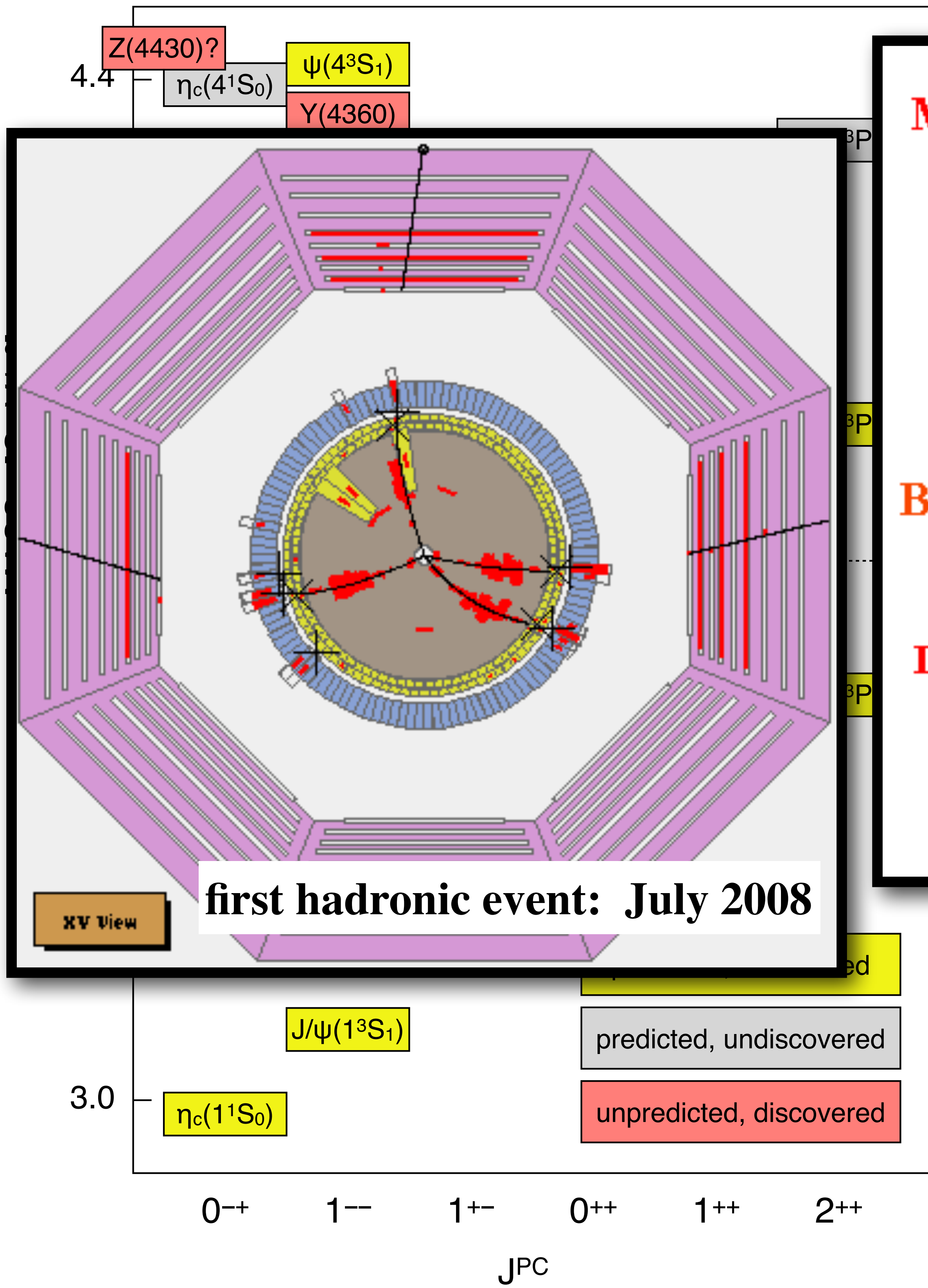
BESIII Detector



<u>**Select data samples (2008-present):**</u>

* more than a billion J/ψ decays
* 106 million $\psi(2S)$ decays (+ more)
* ~2.9 fb^{-1} at ψ''
* ~500 pb^{-1} at 4.009 GeV
* ***XYZ data***

Connecting the XYZ at BESIII



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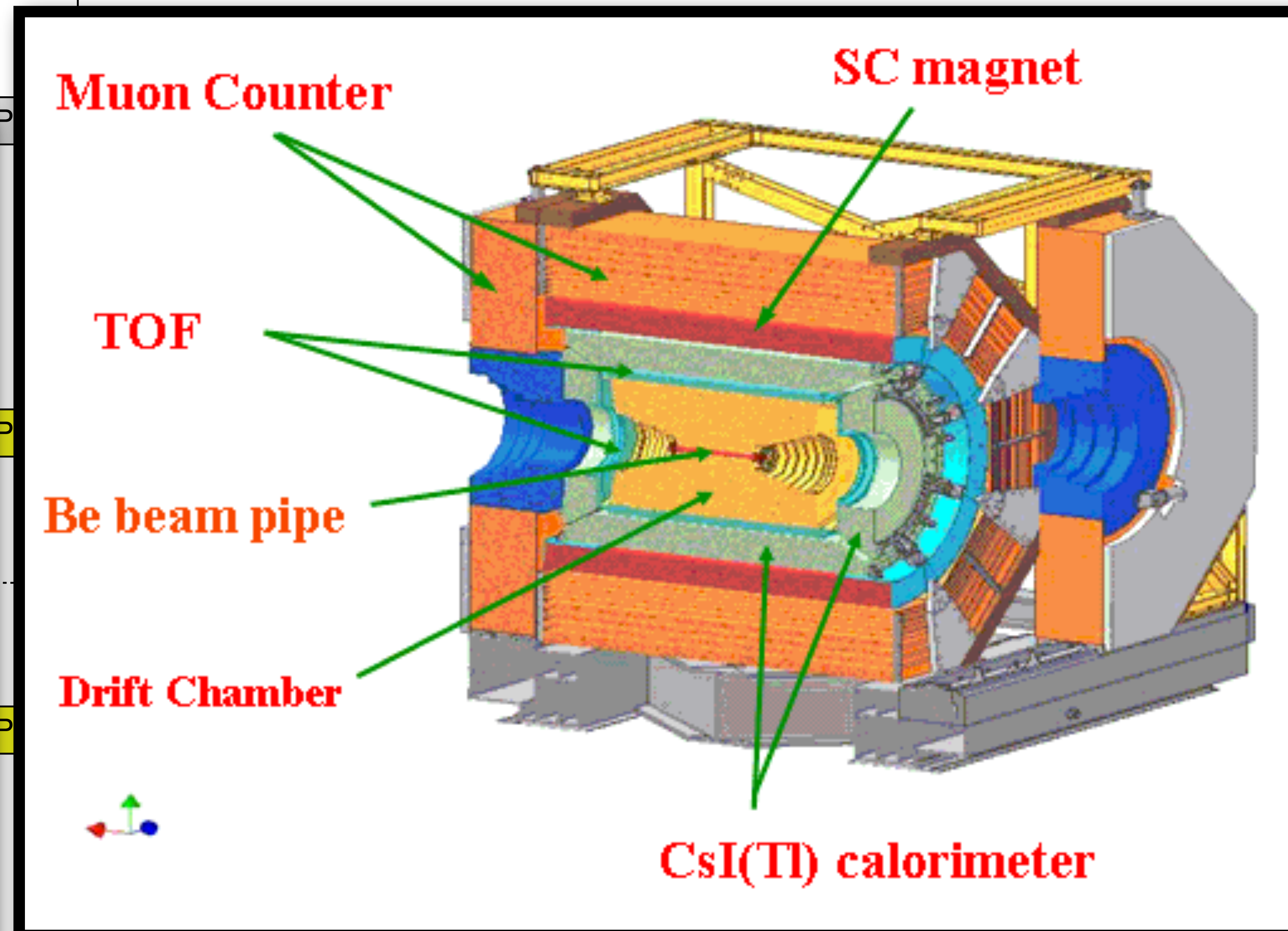

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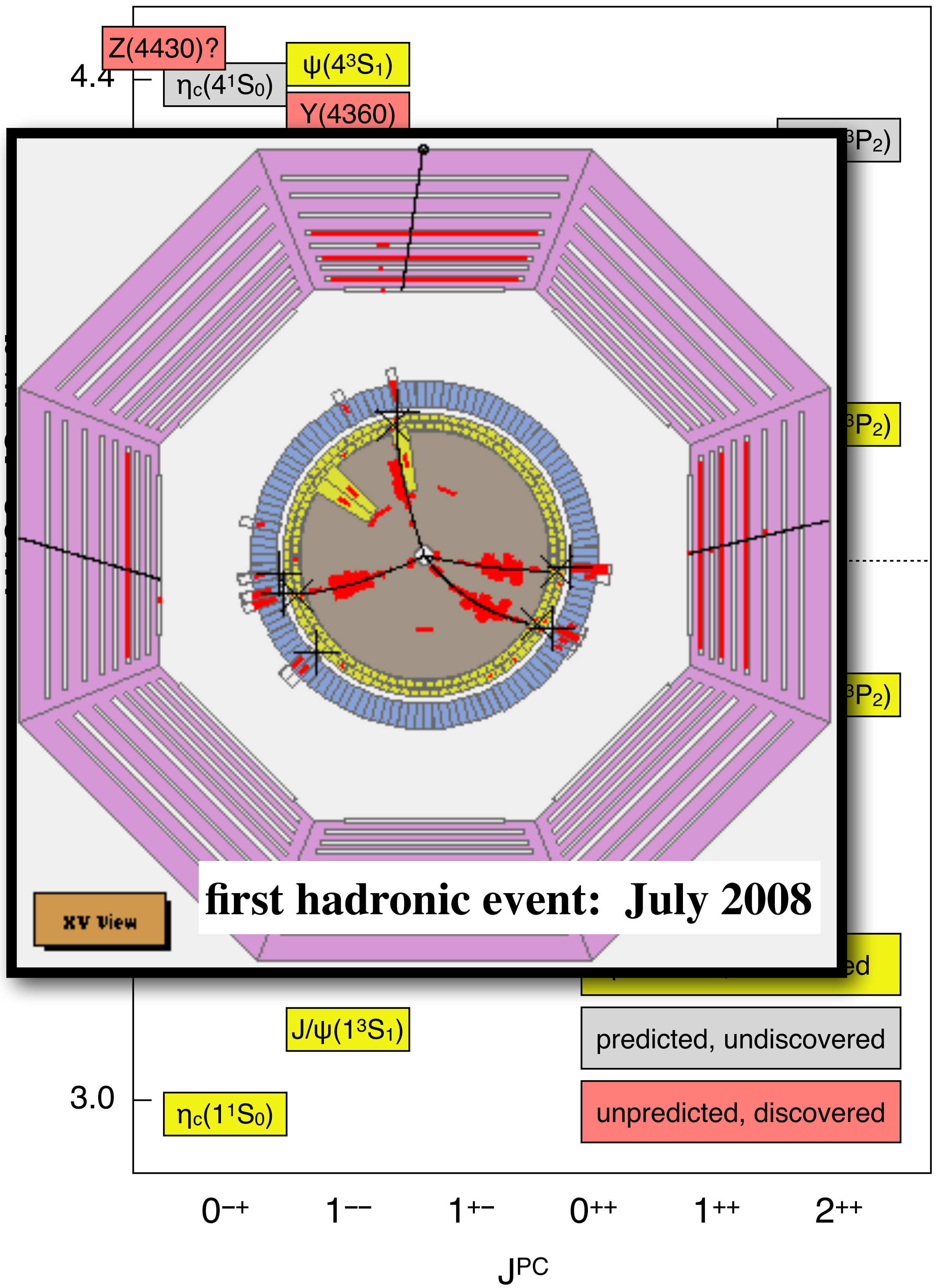


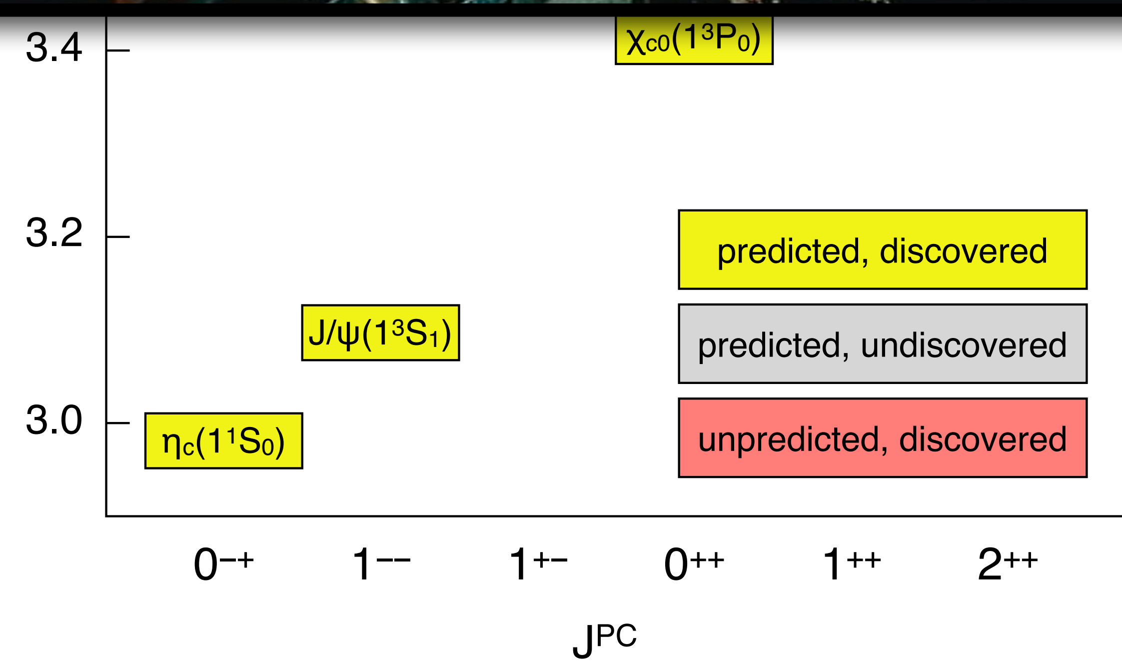
BESIII Detector

Select data samples (2008-present):

- * more than a billion J/ψ decays
- * 106 million $\psi(2S)$ decays (+ more)
- * $\sim 2.9\ \mathrm{fb}^{-1}$ at ψ''
- * $\sim 500\ \mathrm{pb}^{-1}$ at 4.009 GeV
- **** XYZ data***

Connecting the XYZ at BESIII

MARK I Detector



BESIII Detector

<u>Select data samples (2008-present):</u>

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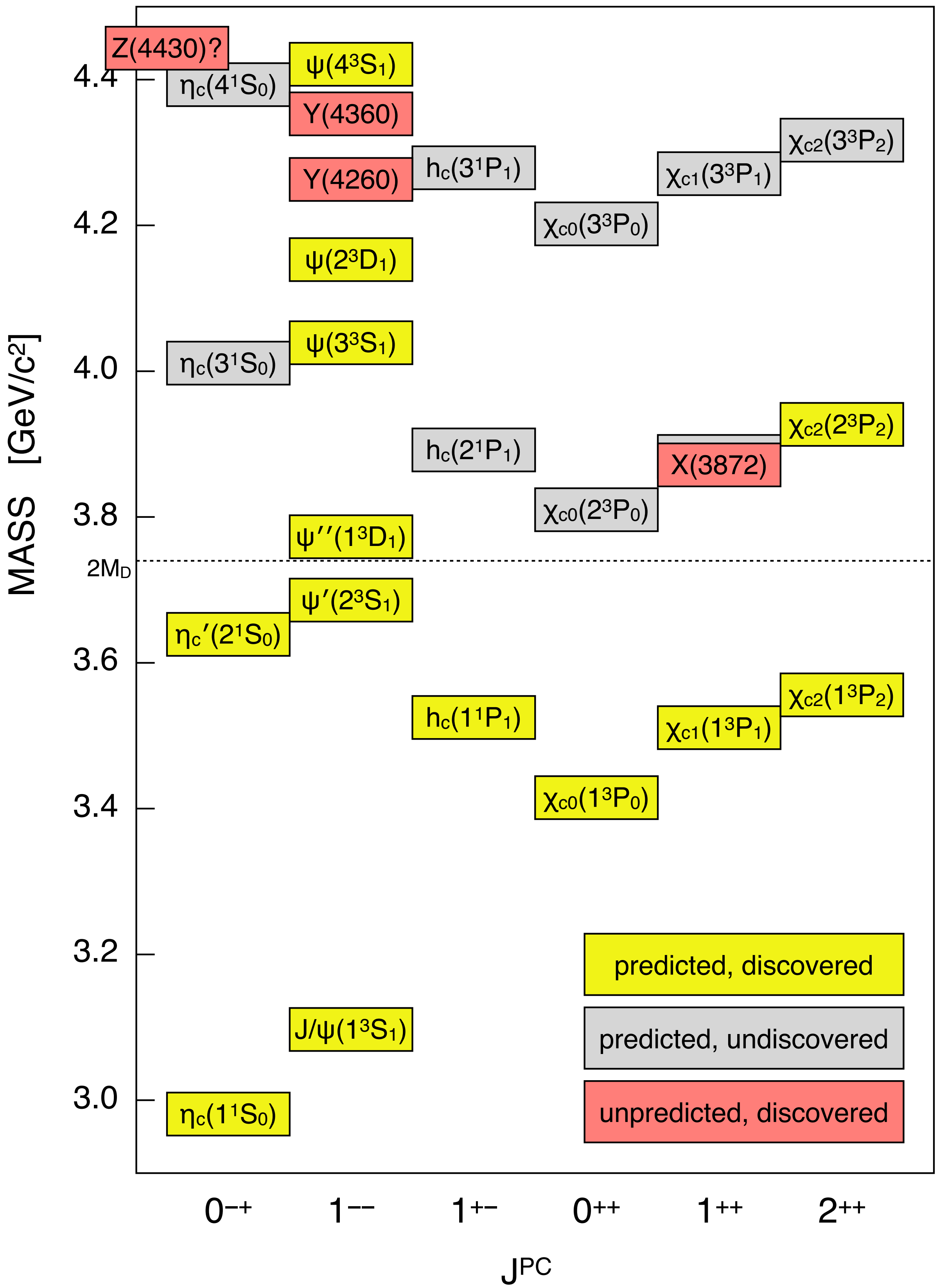
* ~500 pb^{-1} at 4.009 GeV
* ***XYZ data***

Connecting the XYZ at BESIII



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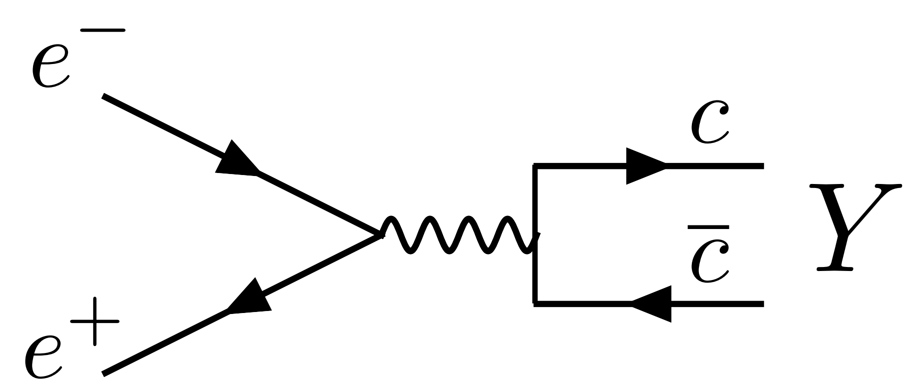
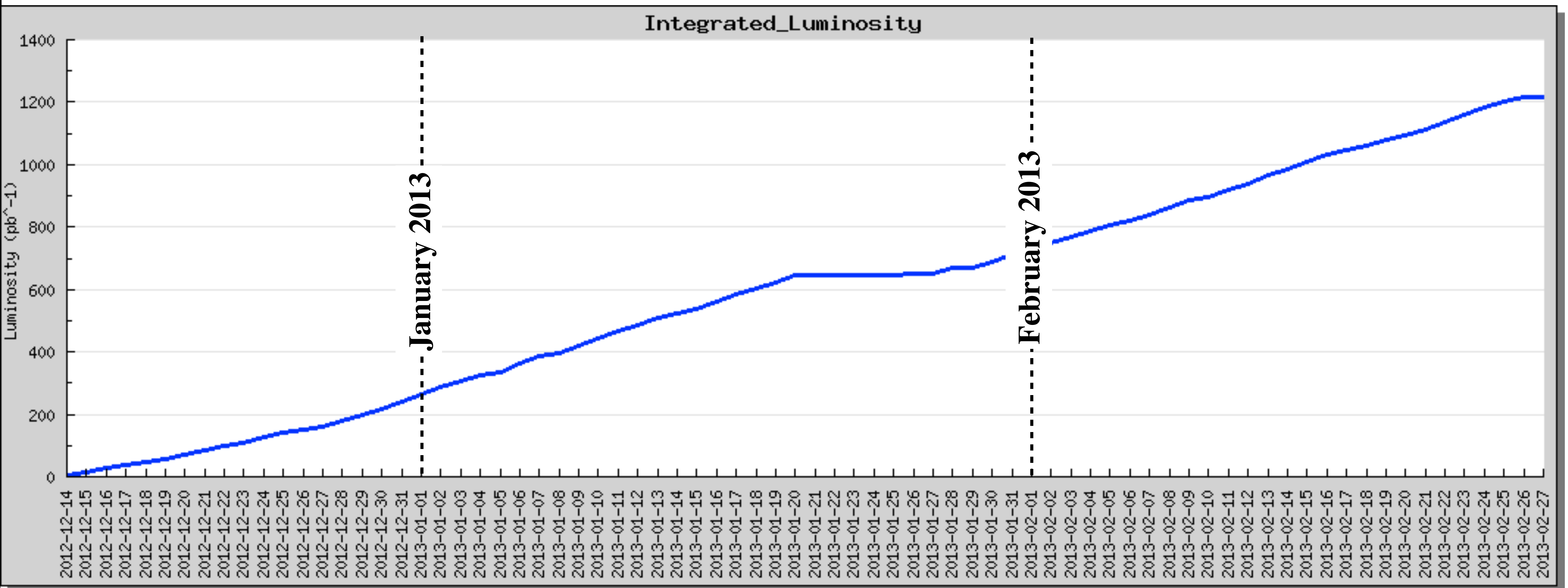


BESIII Initial Round of Data-taking



4260 (515 pb^{-1})
(world's largest sample of Y(4260) by ~2×)

4190 (42 pb^{-1})
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4360 (523 pb^{-1})
(world's largest sample of Y(4360) by ~4×)

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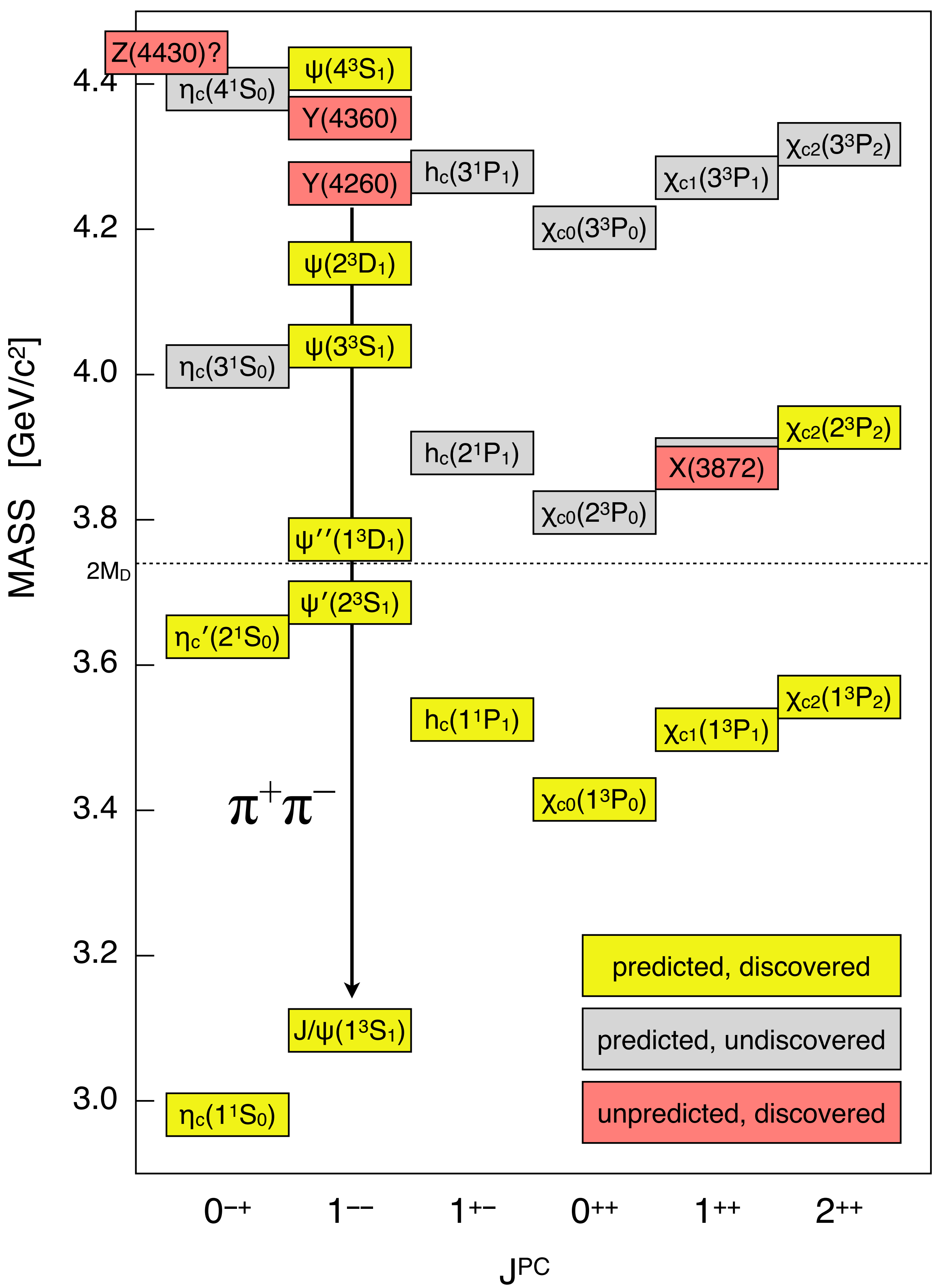
4420 (43 pb^{-1})

BESIII Initial Round of Data-taking

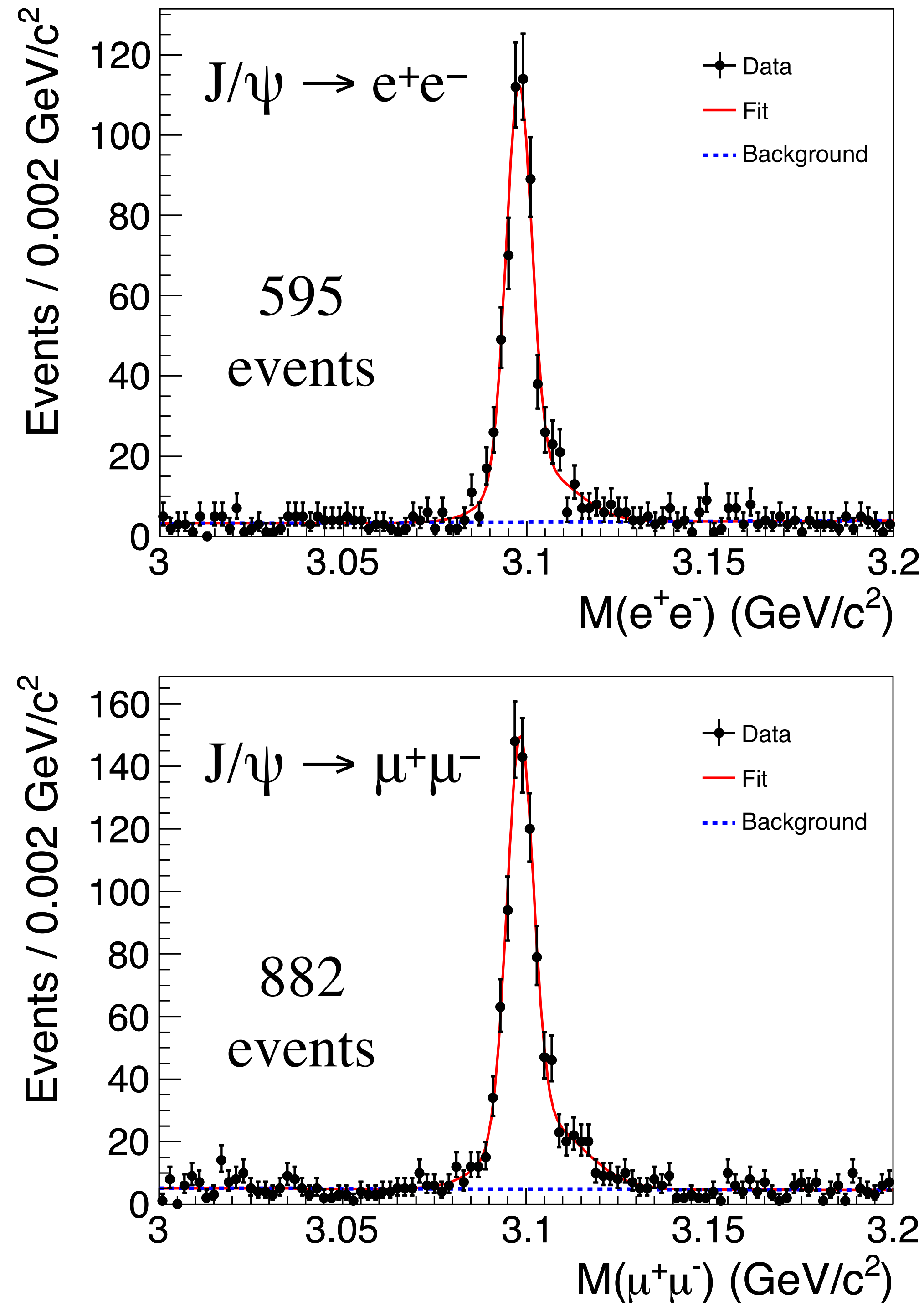
53 pb^{-1})

43 pb^{-1})

Connecting the XYZ at BESIII



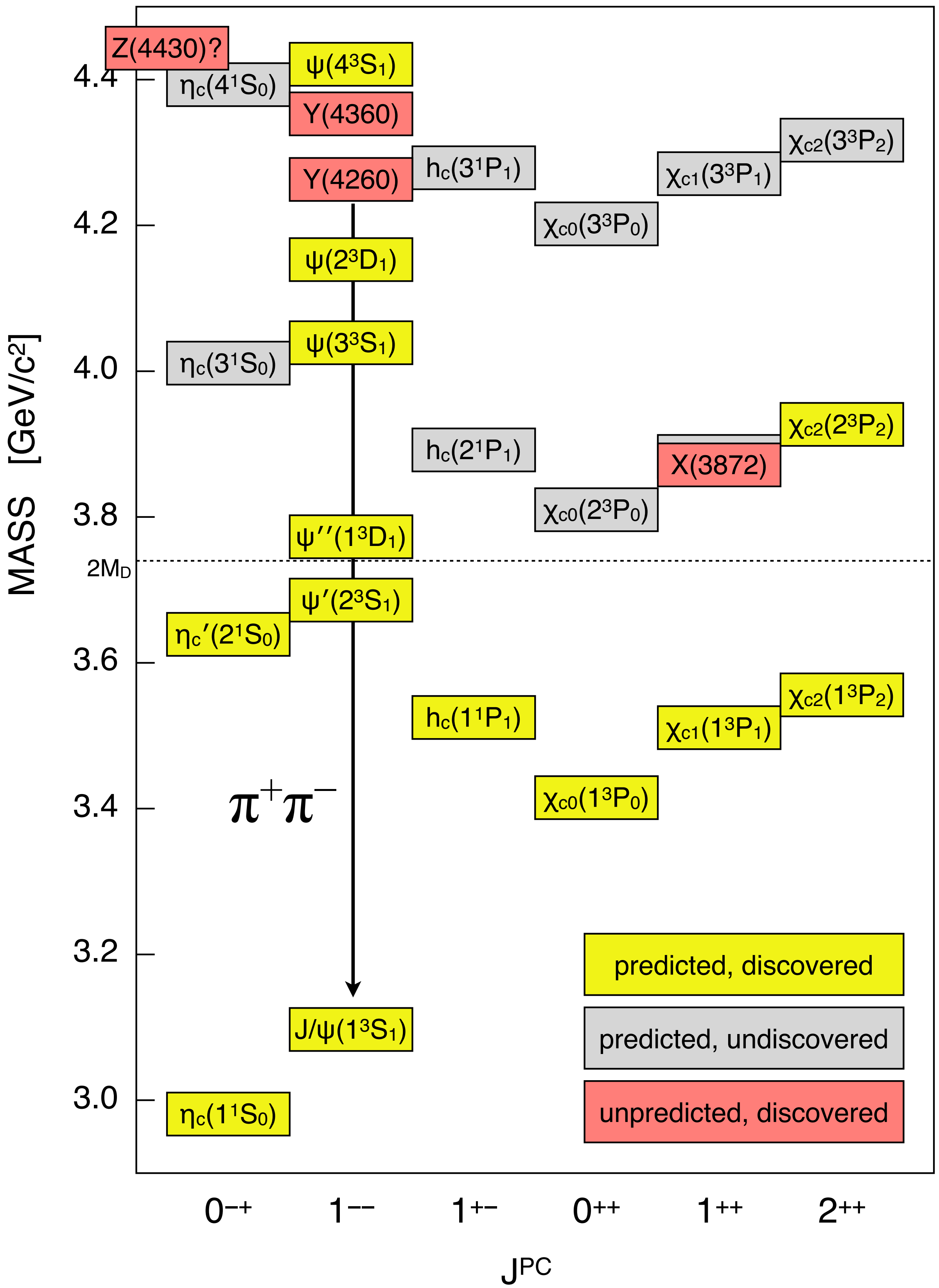
e^+e^- (at 4260 MeV) $\to \pi^+\pi^- J/\psi$ at BESIII

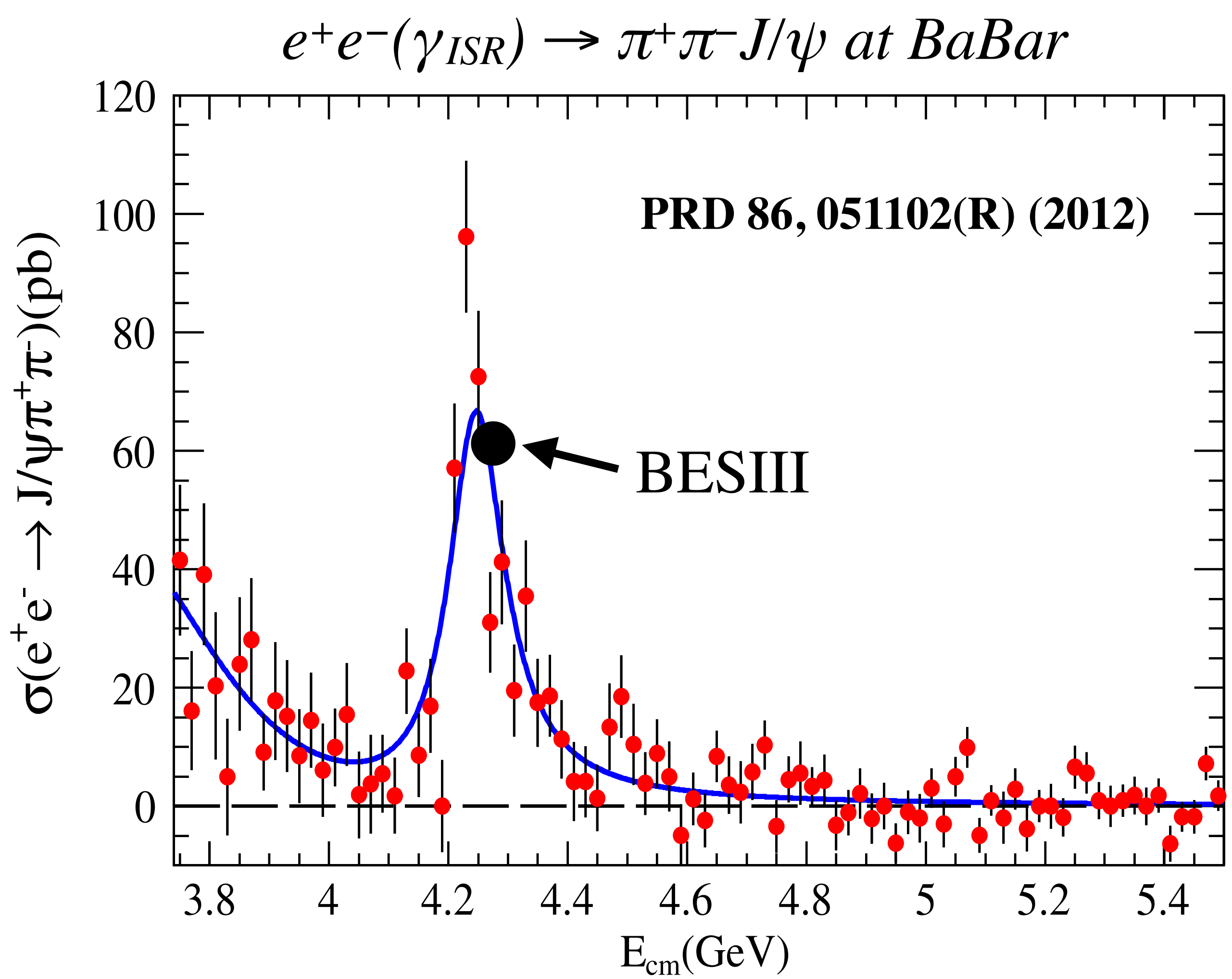


PRL 110, 252001 (2013)

(cross section consistent with Belle and BaBar)

Connecting the XYZ at BESIII





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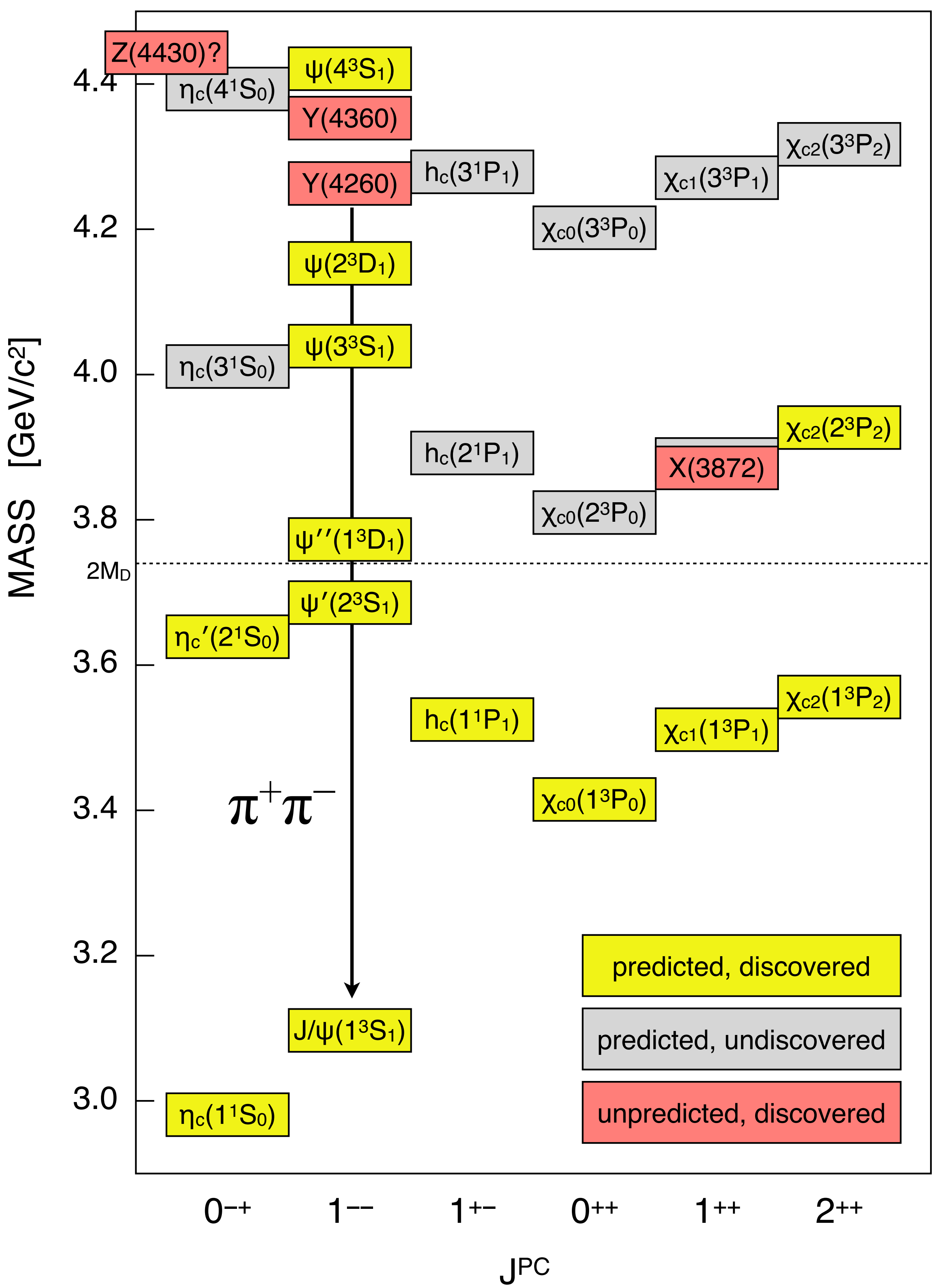
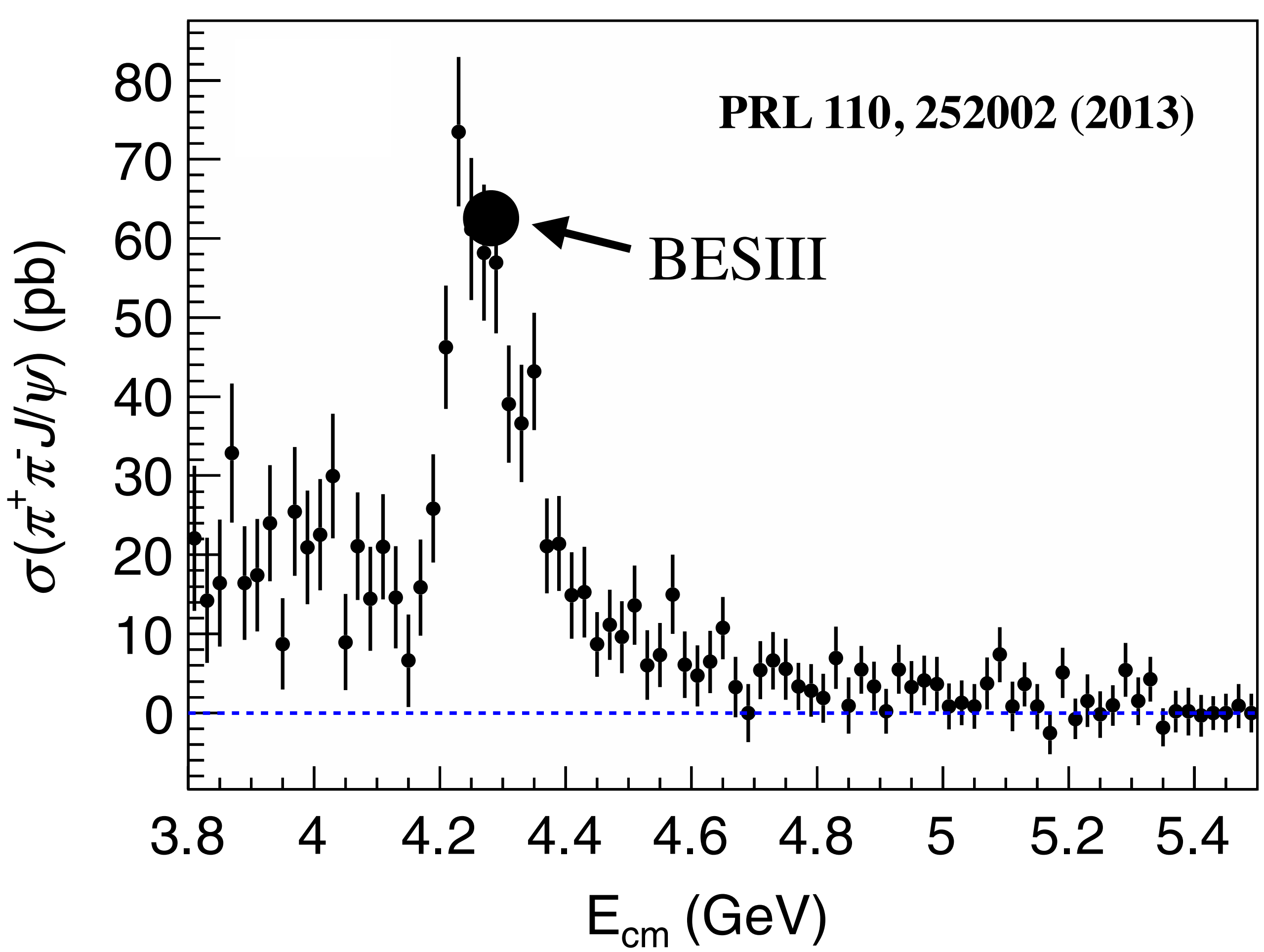
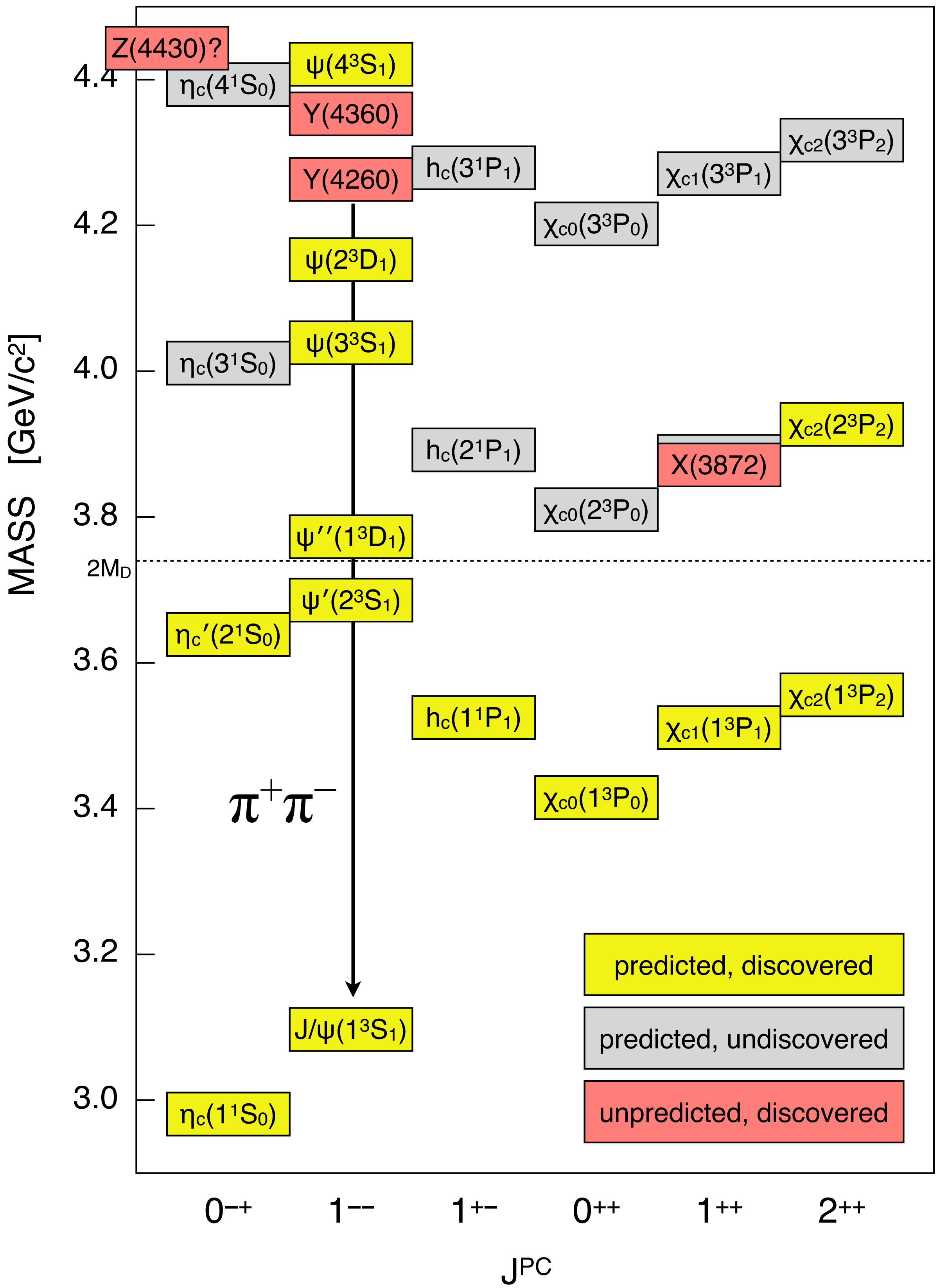


$e^+e^-(\gamma_{ISR}) \rightarrow \pi^+\pi^- J/\psi$ at Belle

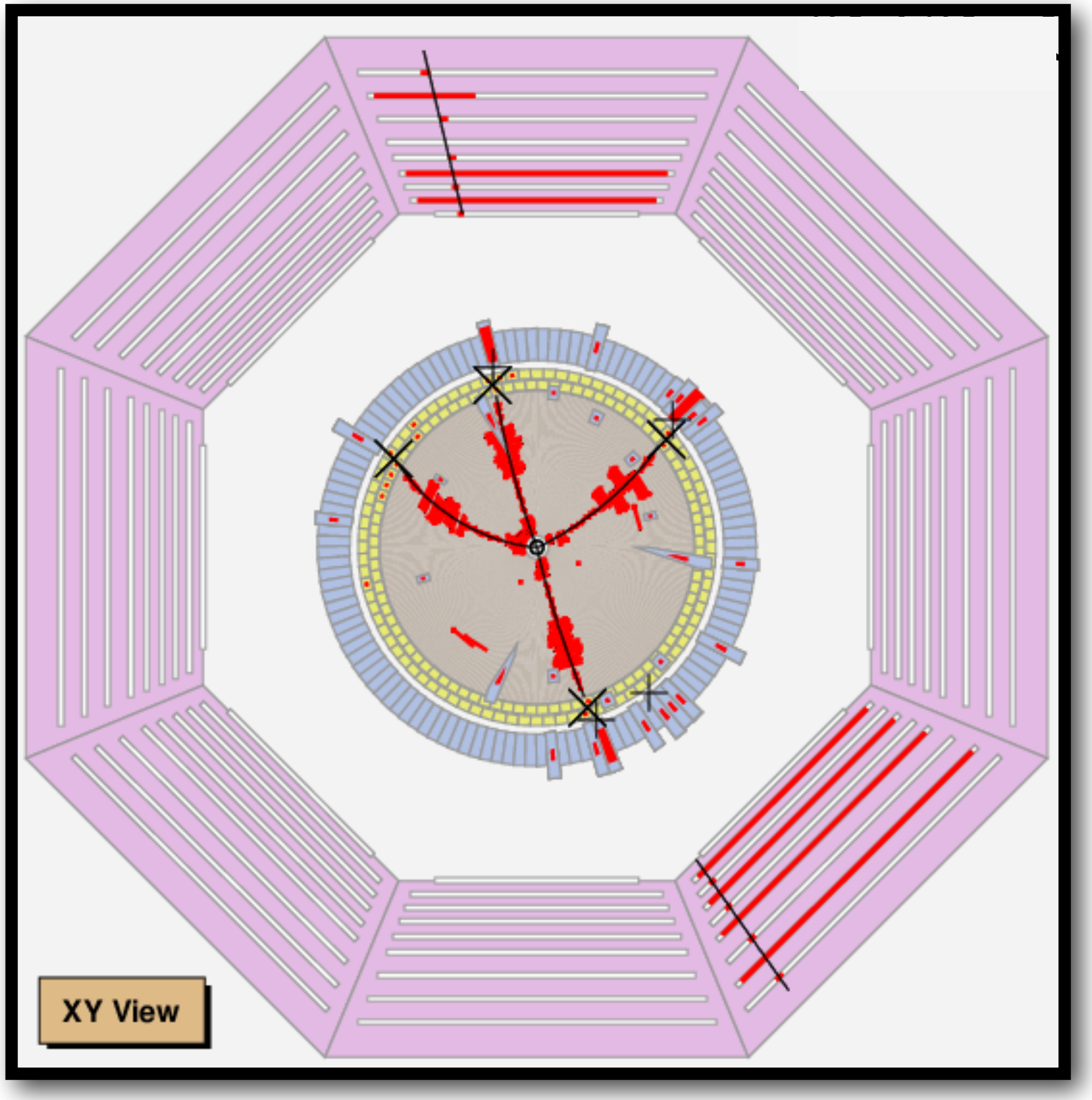


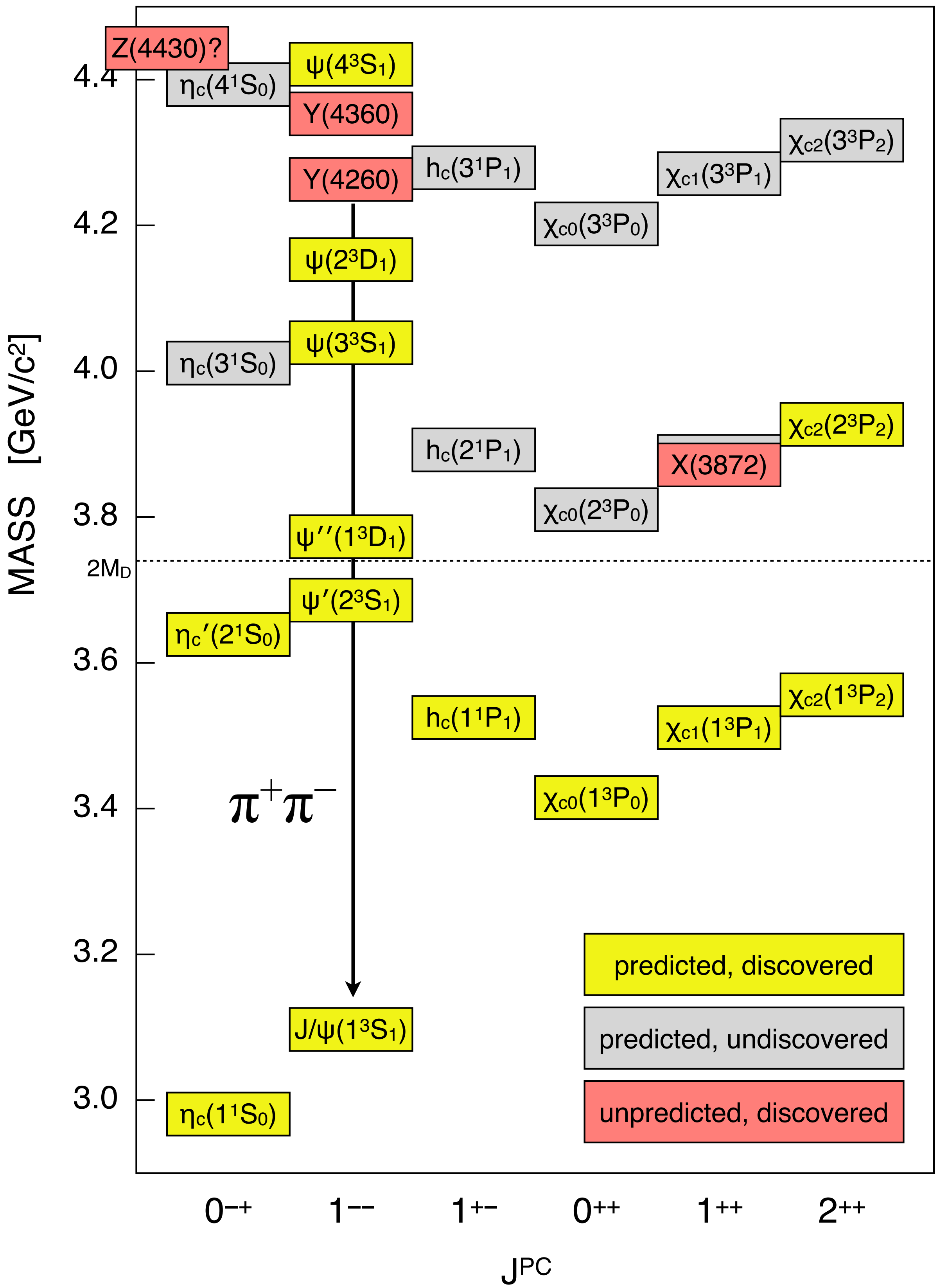
(cross section consistent with Belle and BaBar)

Connecting the XYZ at BESIII

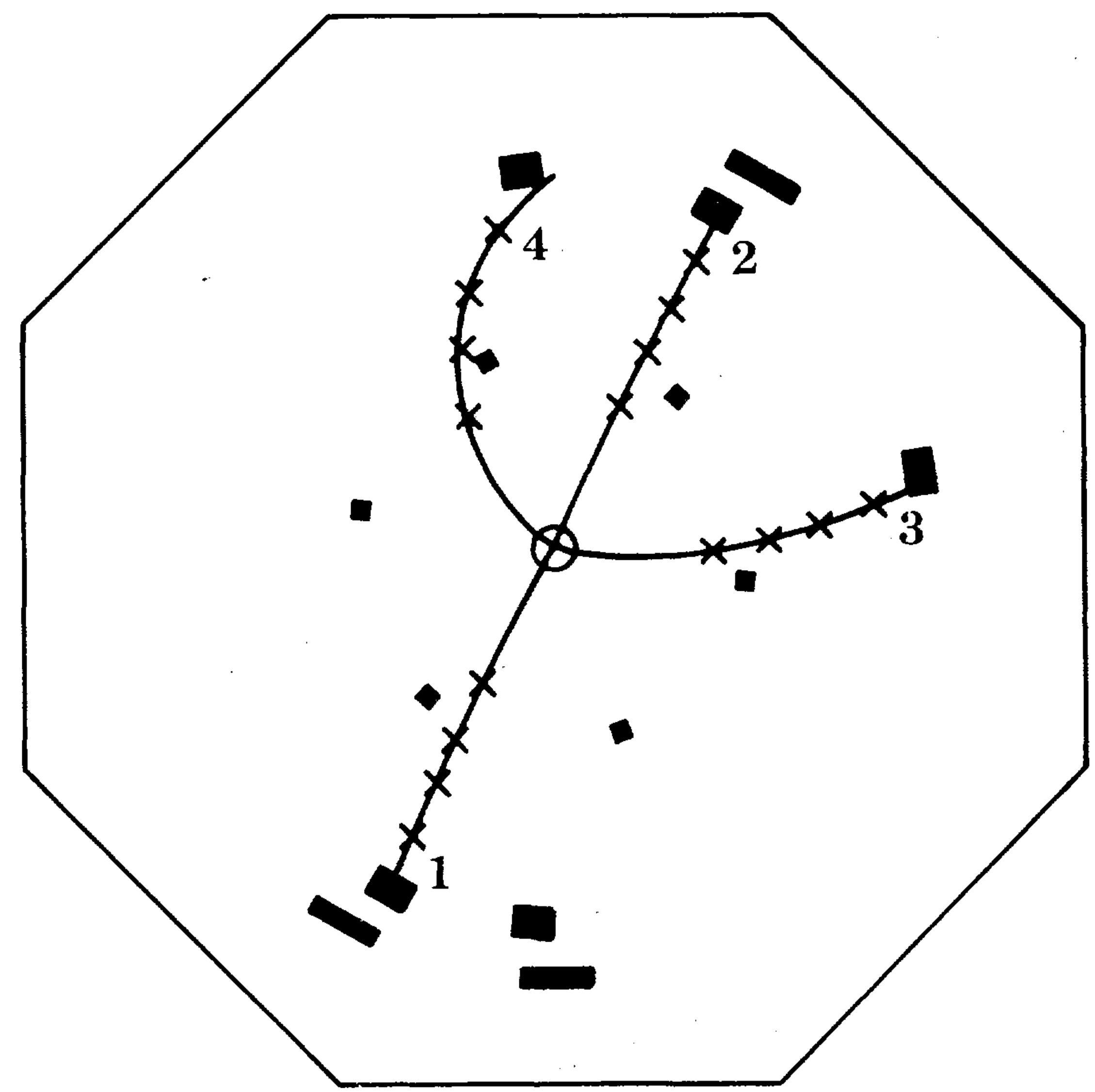


e^+e^- (at 4260 MeV) $\to \pi^+\pi^- J/\psi$ at BESIII

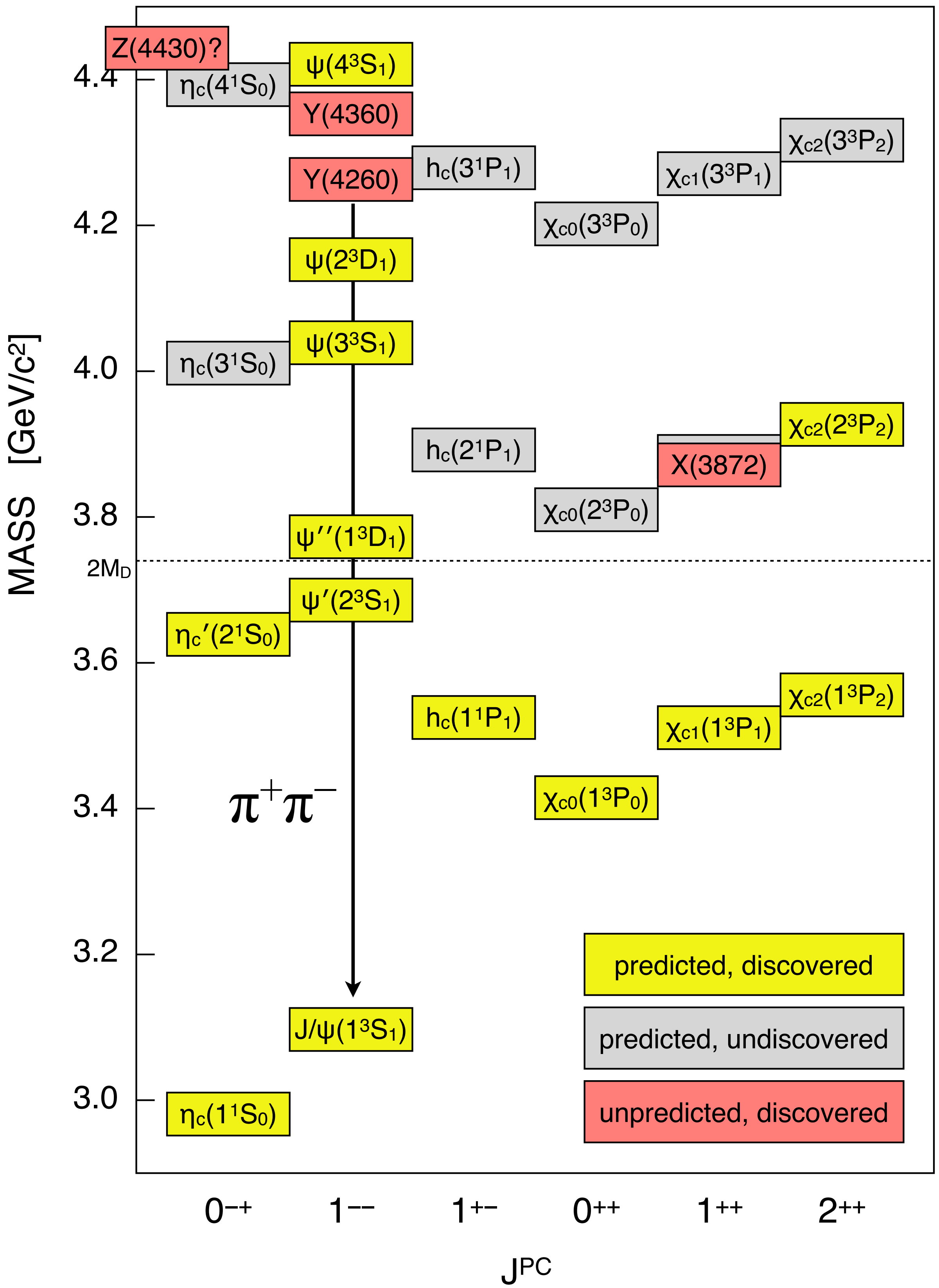




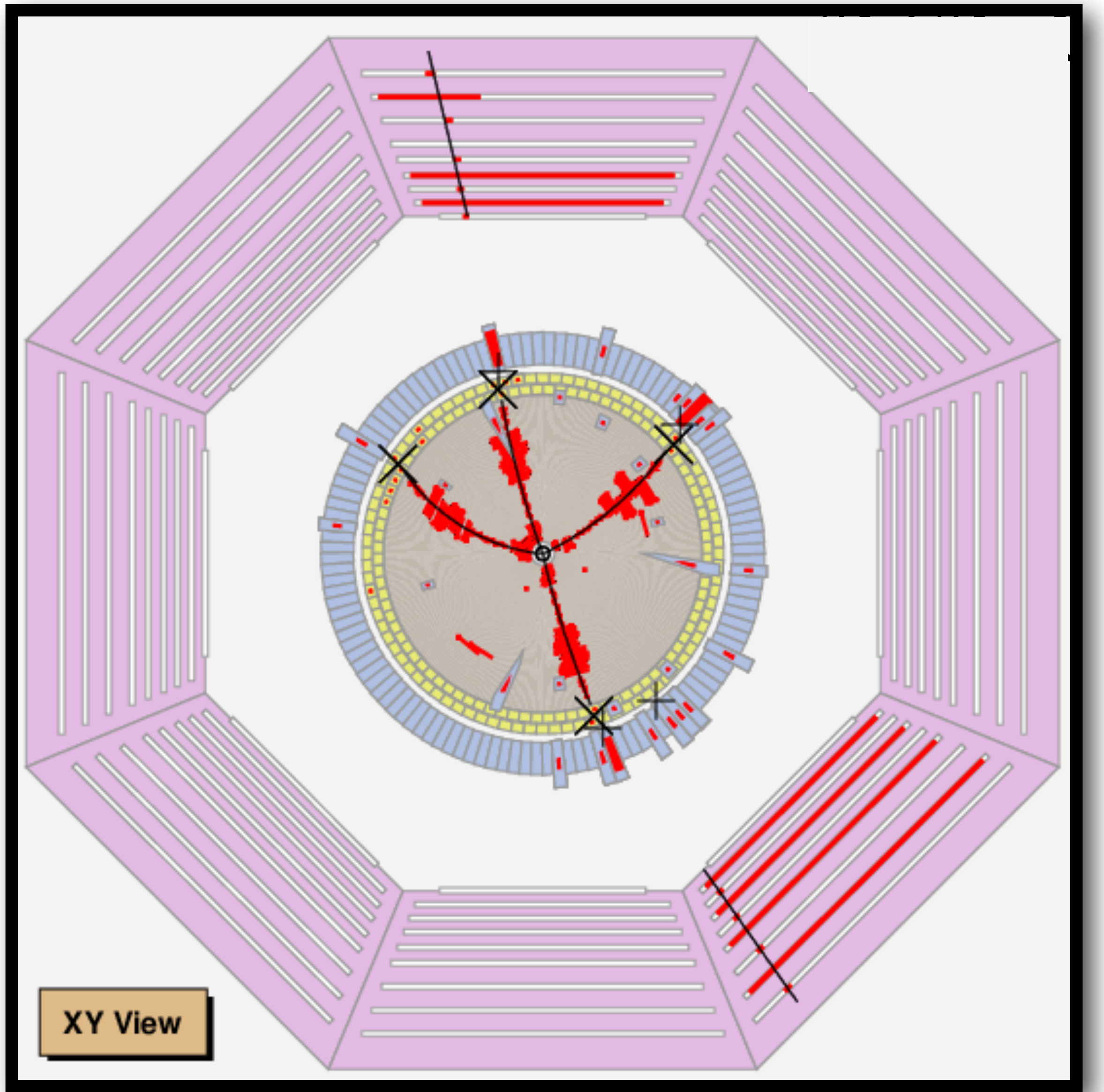
$\psi(2S) \to \pi^+\pi^- J/\psi$
at SLAC



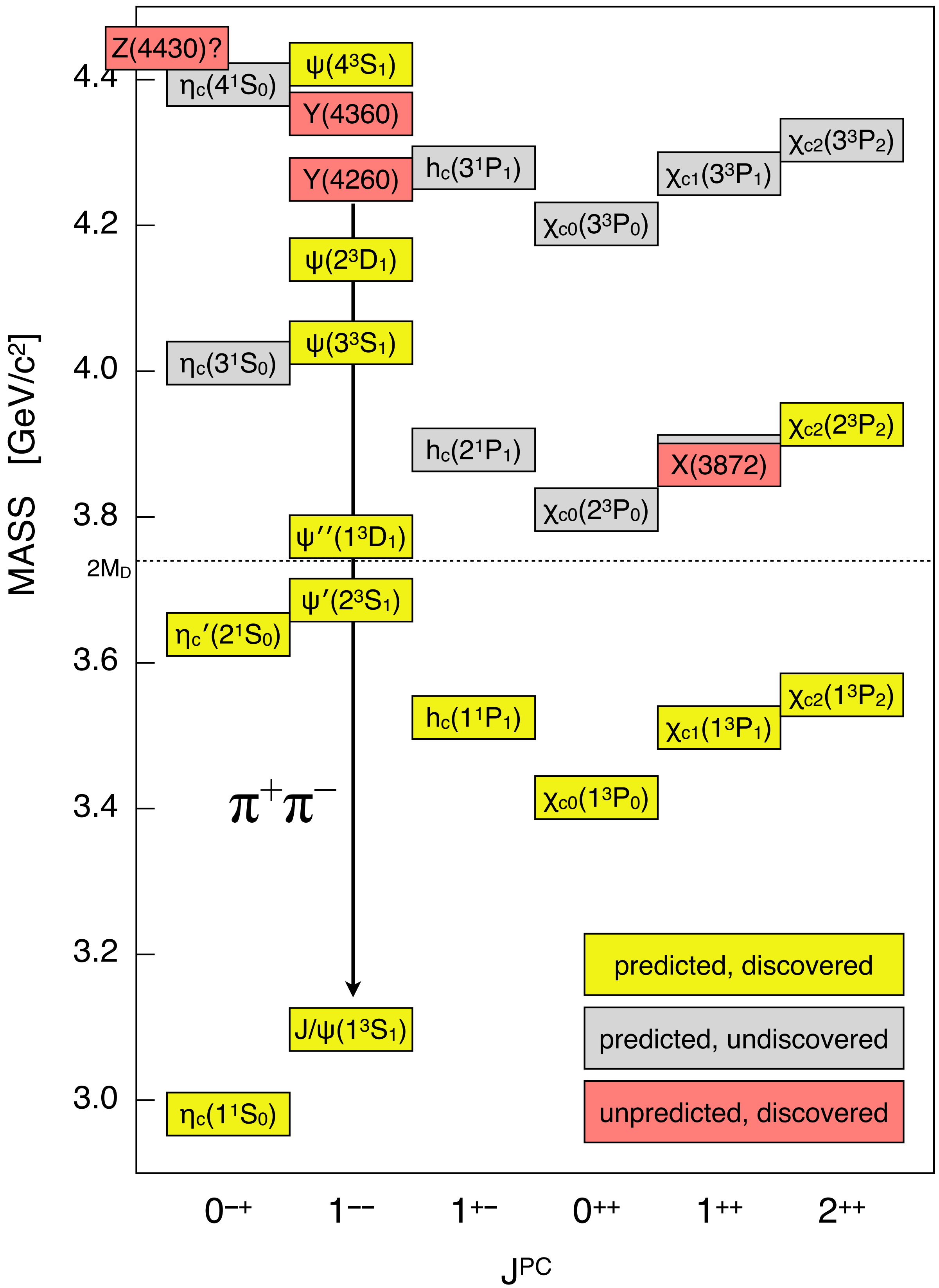
PRL34, 1181 (1975)



e^+e^- (at 4260 MeV) → $\pi^+\pi^- J/\psi$ at BESIII



Connecting the XYZ at BESIII



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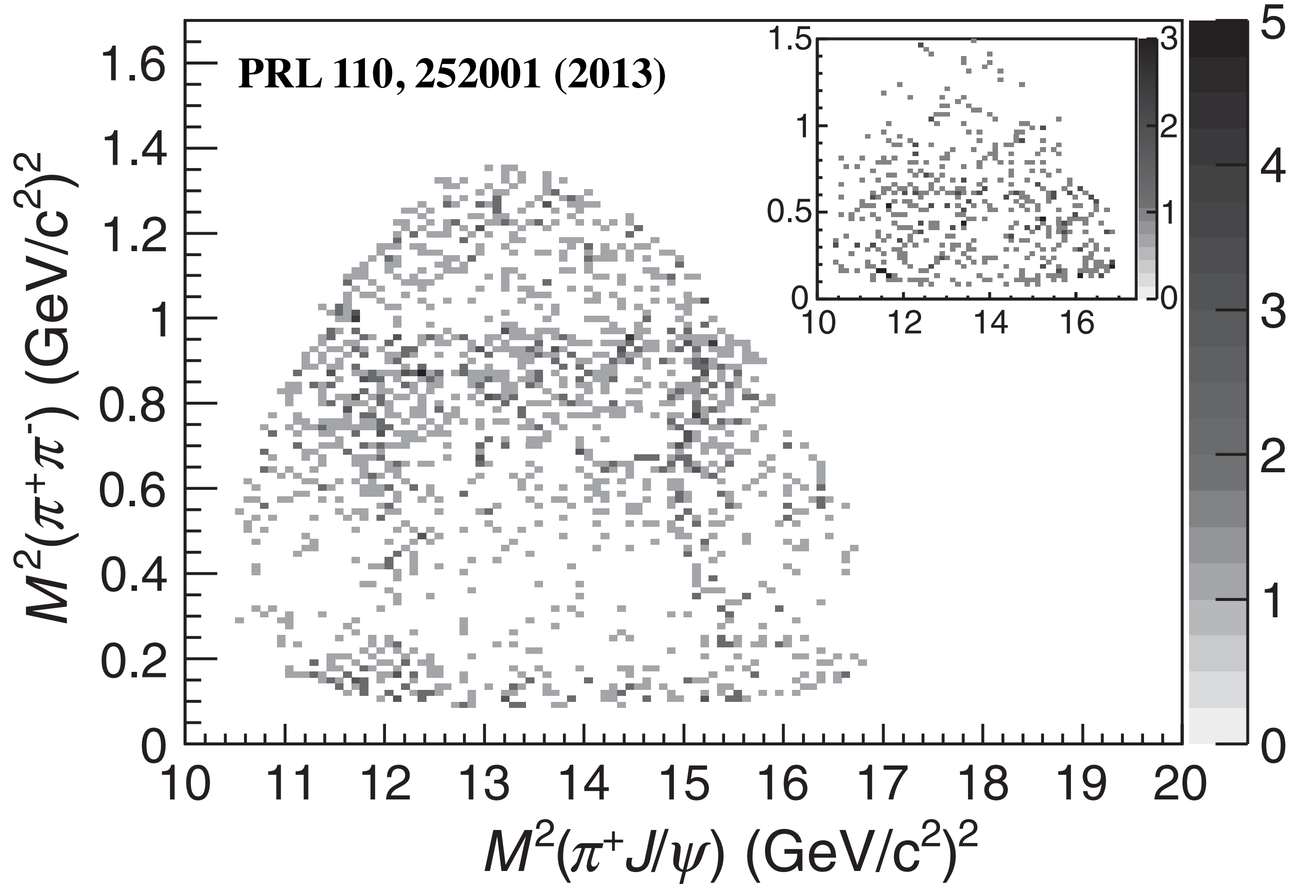
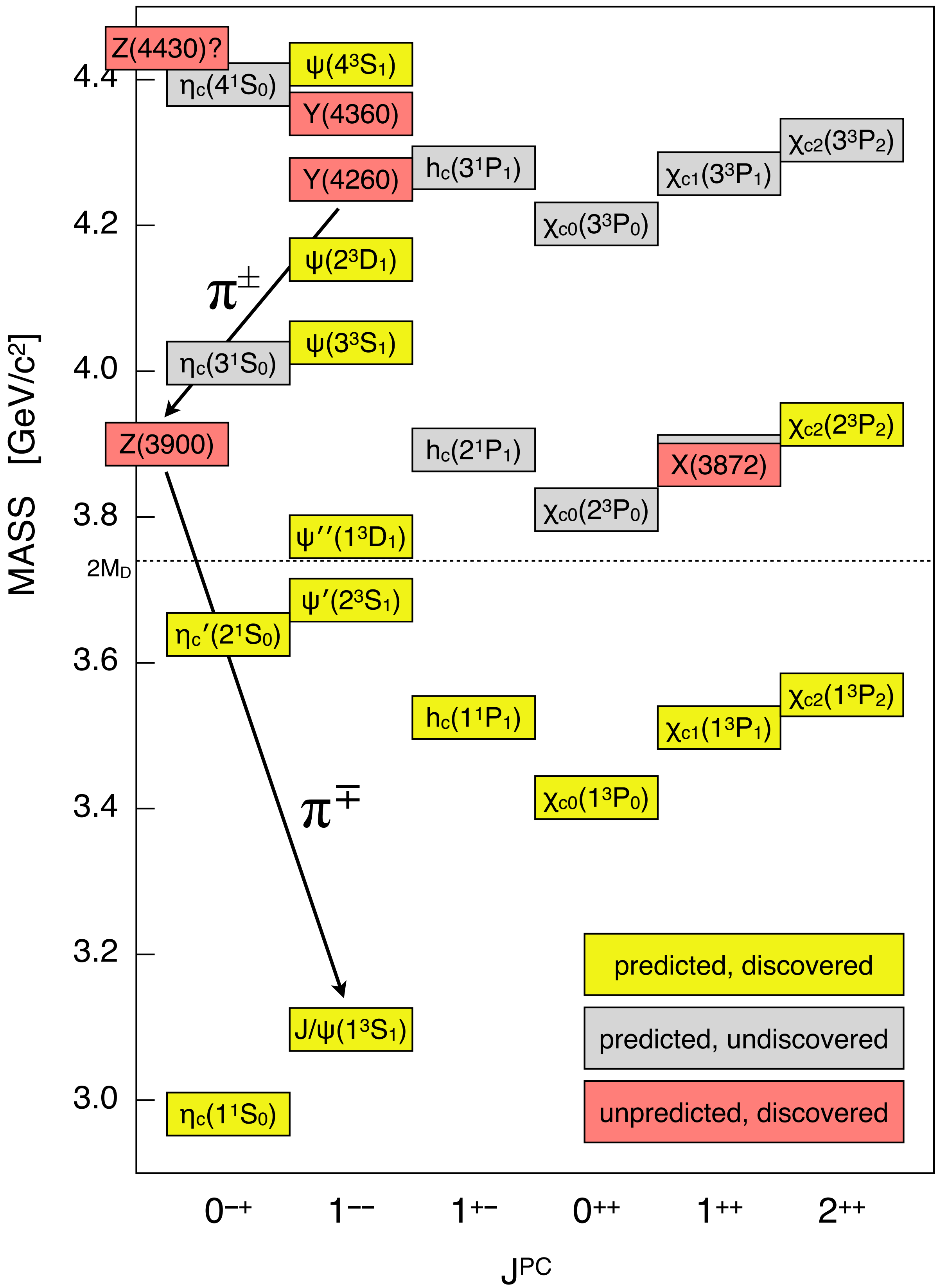


non-trivial substructure in $\pi^+\pi^- J/\psi$

Connecting the XYZ at BESIII



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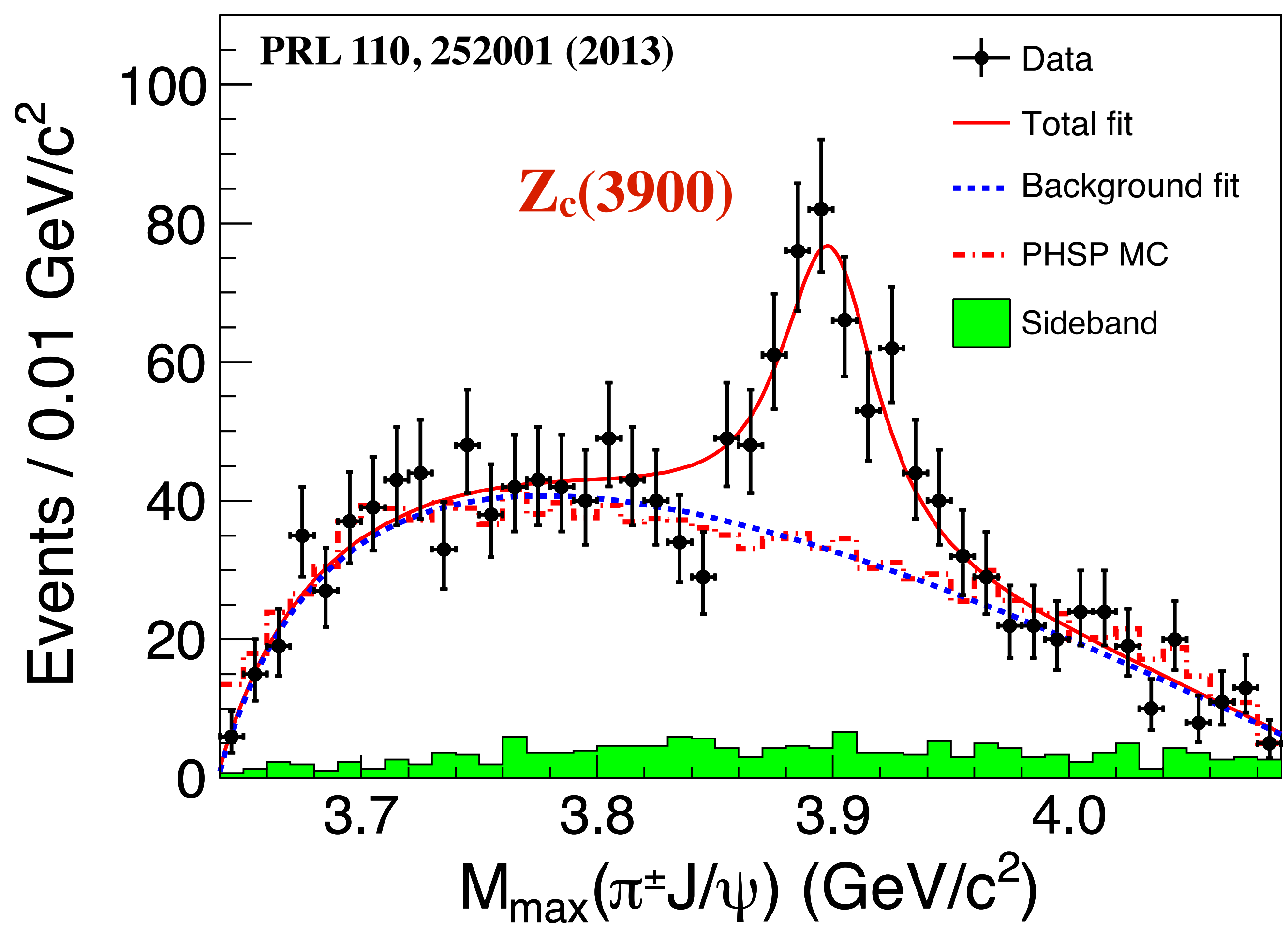


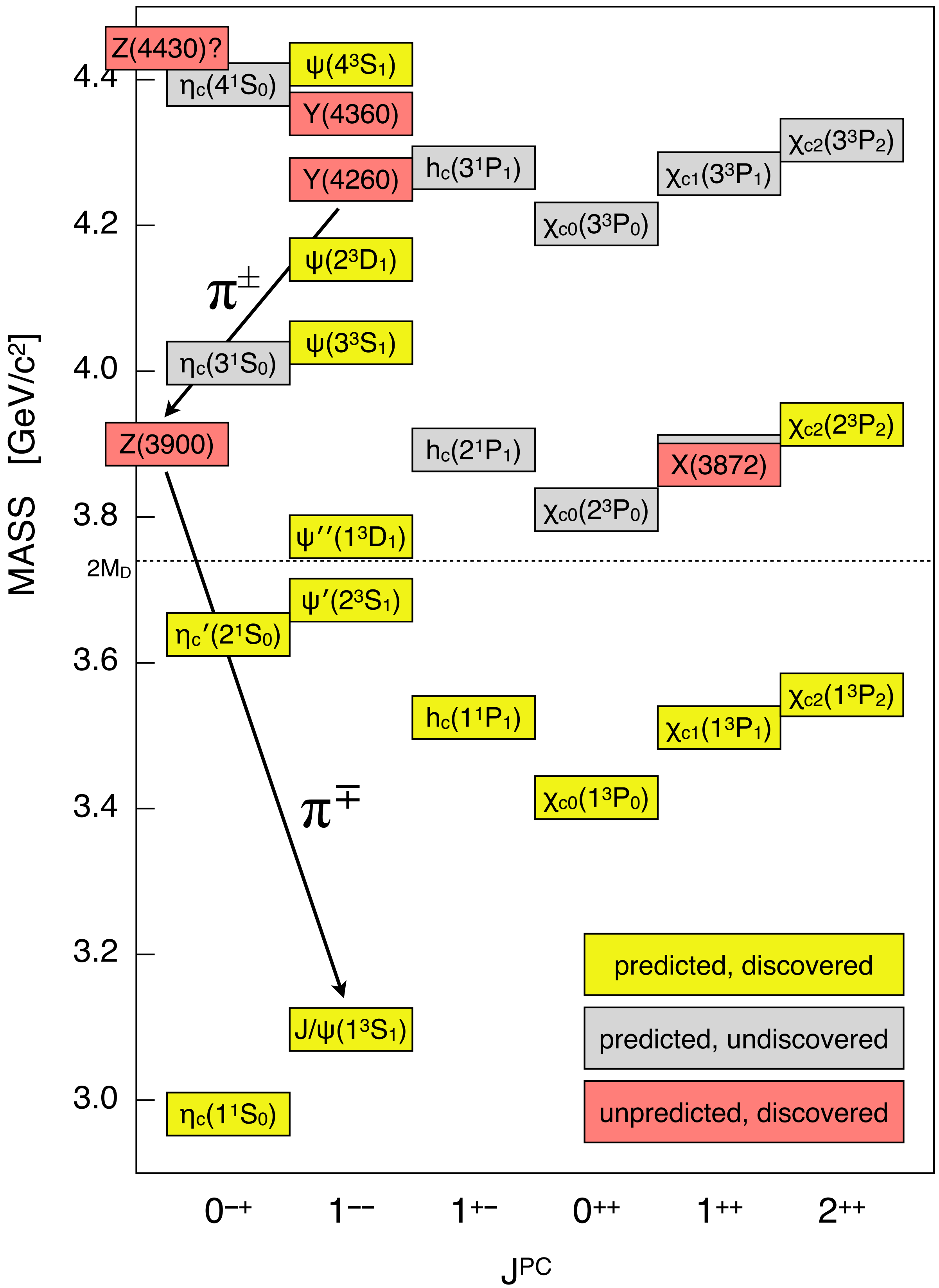
$M = 3899.0 \pm 3.6 \pm 4.9$ MeV
$\Gamma = 46 \pm 10 \pm 20$ MeV

$\Rightarrow$ "Charged Charmoniumlike Structure"

(Confirmed by Belle and CLEO data.)

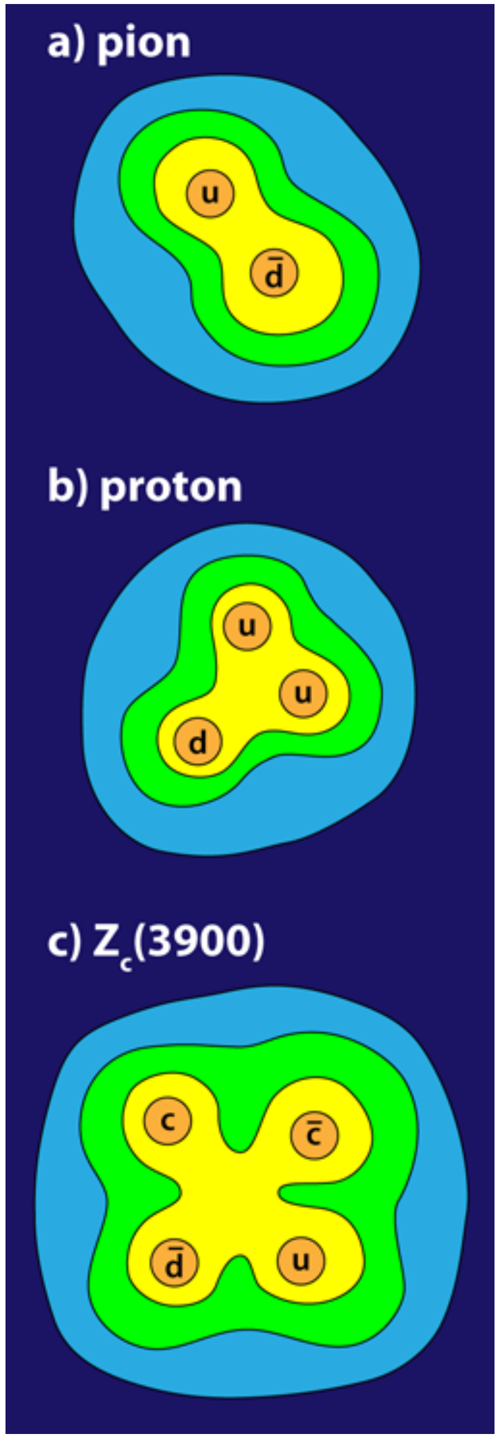
(Many theoretical ideas -- close to D^*D threshold.)

Connecting the XYZ at BESIII

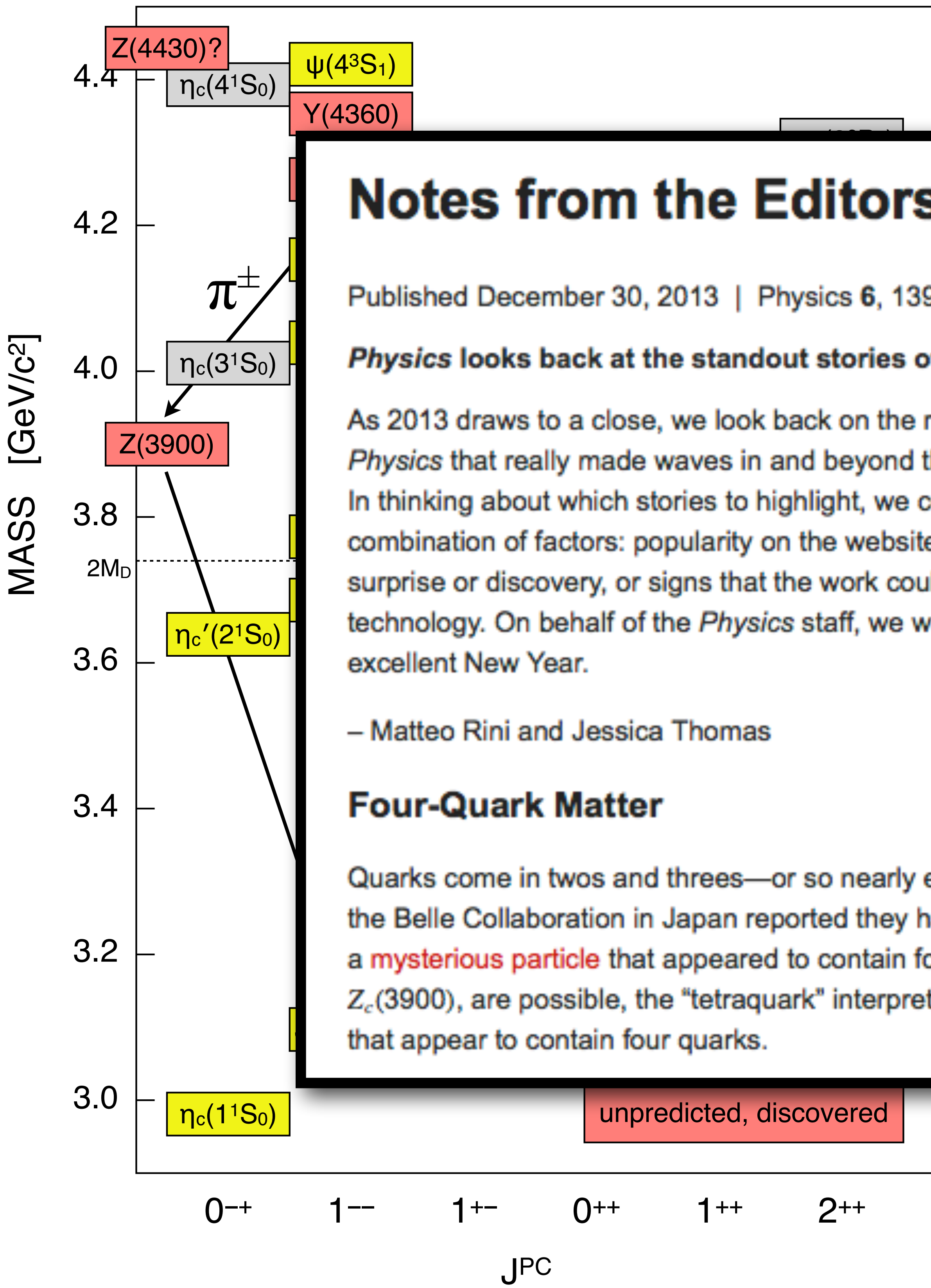


Viewpoint: New Particle Hints at Four-Quark Matter

Eric Swanson, University of Pittsburgh, Pittsburgh, PA 15260, USA
Published June 17, 2013 | Physics **6**, 69 (2013) | DOI: 10.1103/Physics.6.69



Connecting the XYZ at BESIII



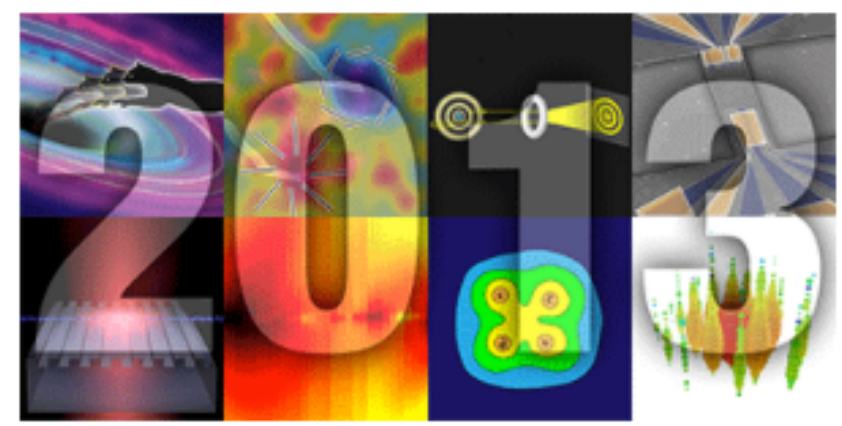
Notes from the Editors: Highlights of the Year

Published December 30, 2013 | Physics **6**, 139 (2013) | DOI: 10.1103/Physics.6.139

Physics **looks back at the standout stories of 2013.**

As 2013 draws to a close, we look back on the research covered in *Physics* that really made waves in and beyond the physics community. In thinking about which stories to highlight, we considered a combination of factors: popularity on the website, a clear element of surprise or discovery, or signs that the work could lead to better technology. On behalf of the *Physics* staff, we wish everyone an excellent New Year.

– Matteo Rini and Jessica Thomas

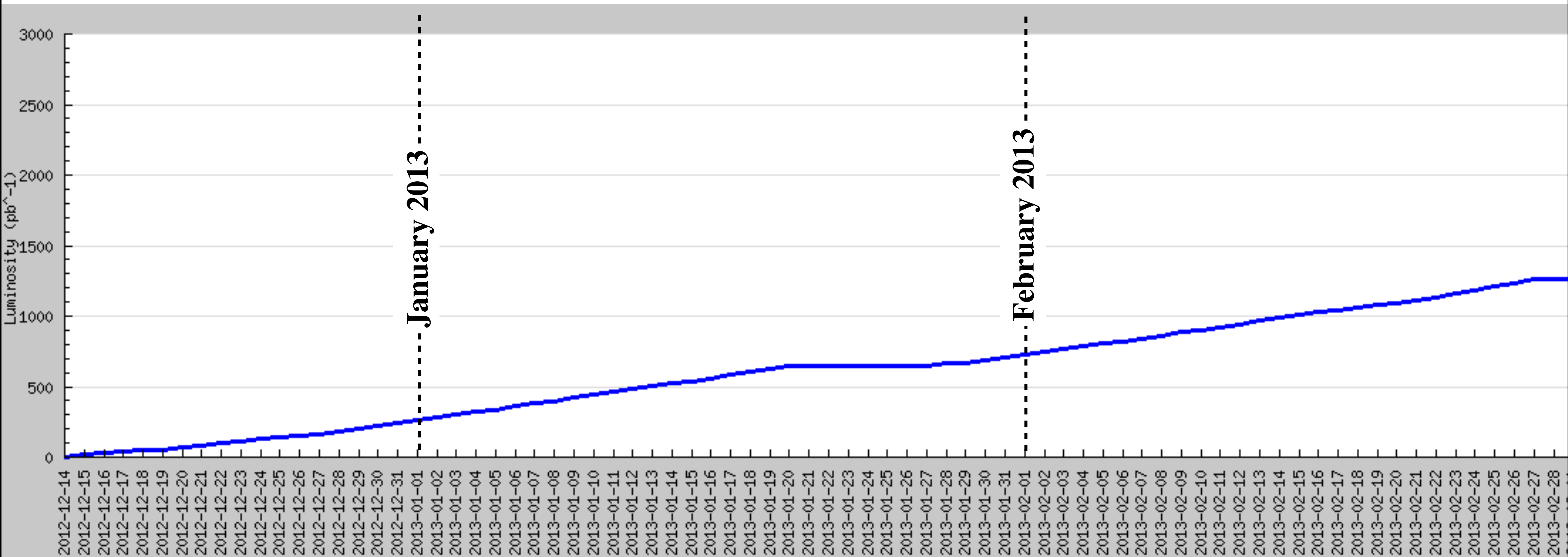


Images from popular *Physics* stories in 2013.

Four-Quark Matter

Quarks come in twos and threes—or so nearly every experiment has told us. This summer, the BESIII Collaboration in China and the Belle Collaboration in Japan reported they had sorted through the debris of high-energy electron-positron collisions and seen a mysterious particle that appeared to contain four quarks. Though other explanations for the nature of the particle, dubbed $Z_c(3900)$, are possible, the "tetraquark" interpretation may be gaining traction: BESIII has since seen a series of other particles that appear to contain four quarks.

BESIII Initial Round of Data-taking



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(world's largest sample of Y(4260) by ~2×)

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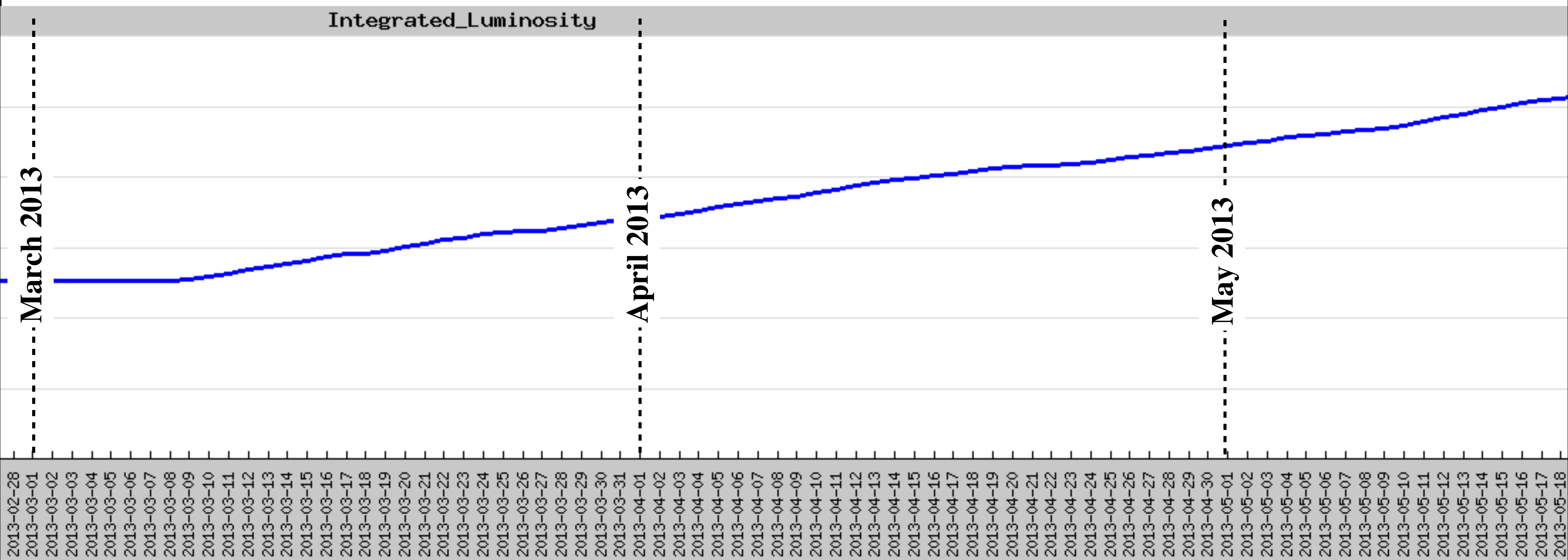
BESIII Additional Round of Data-taking



BESIII meeting

4260 (291 pb^{-1})

4230 (1011 pb^{-1})

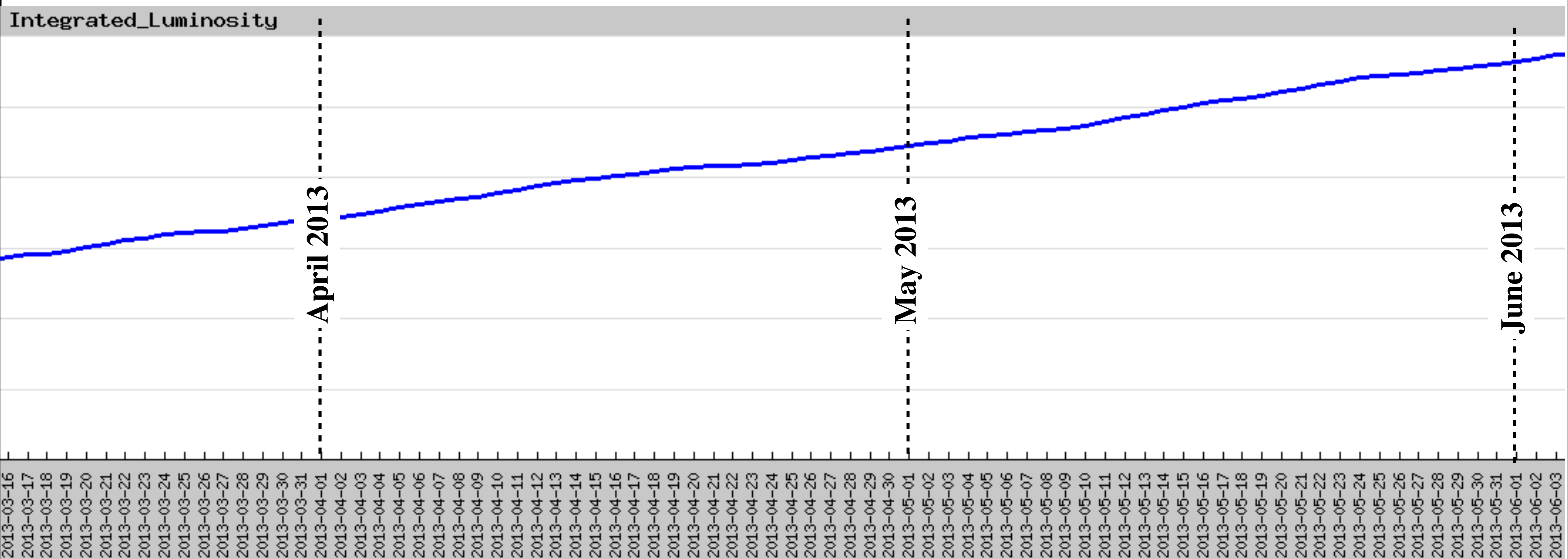
4210 (52 pb^{-1})

4220 (52 pb^{-1})

4245 (53 pb^{-1})

Connecting the XYZ at BESIII

BESIII Additional Round of Data-taking



91 pb^{-1})

4230 (1011 pb^{-1})

4210 (52 pb^{-1})

4220 (52 pb^{-1})

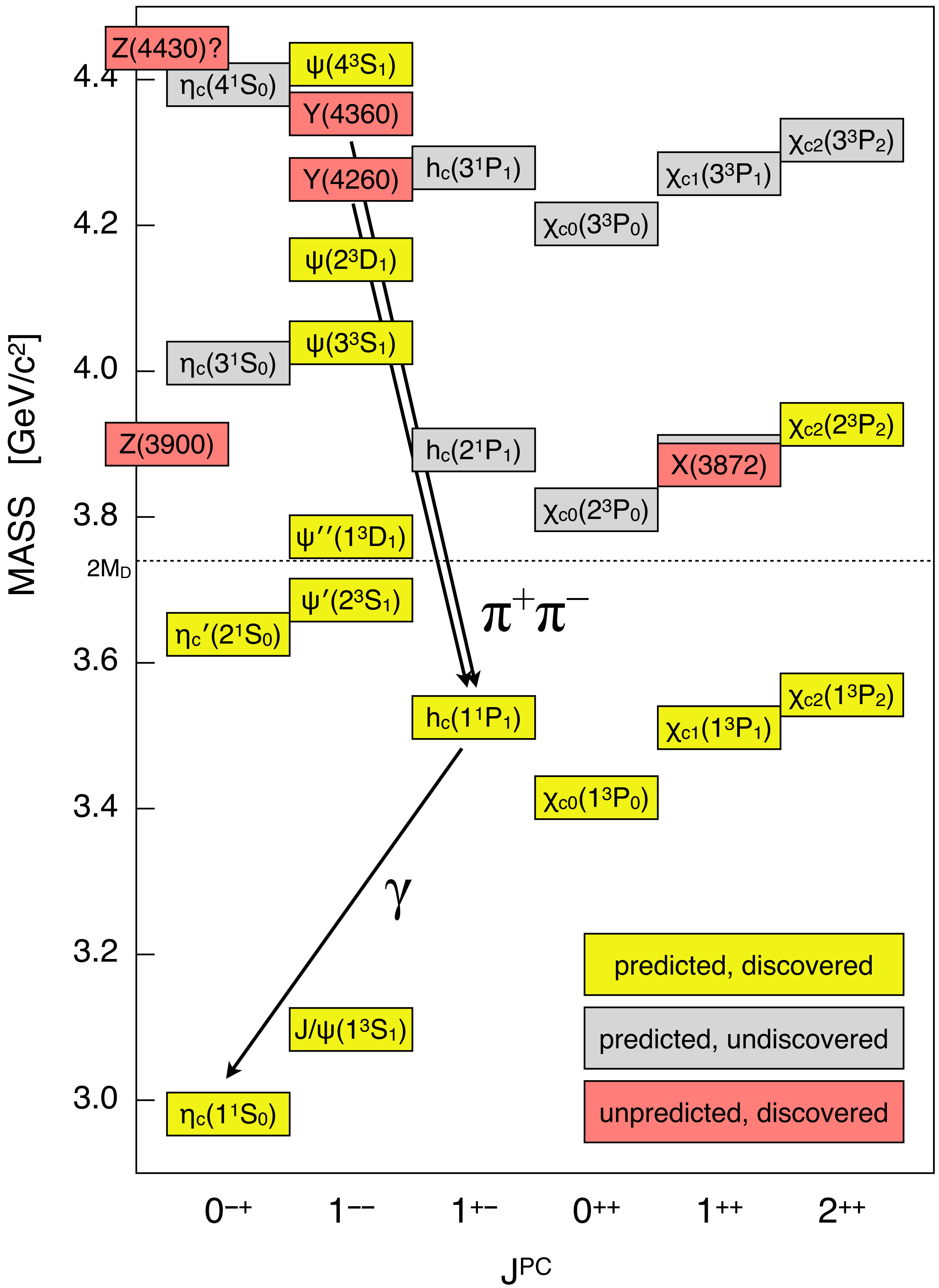
4245 (53 pb^{-1})

3810 (48 pb^{-1})

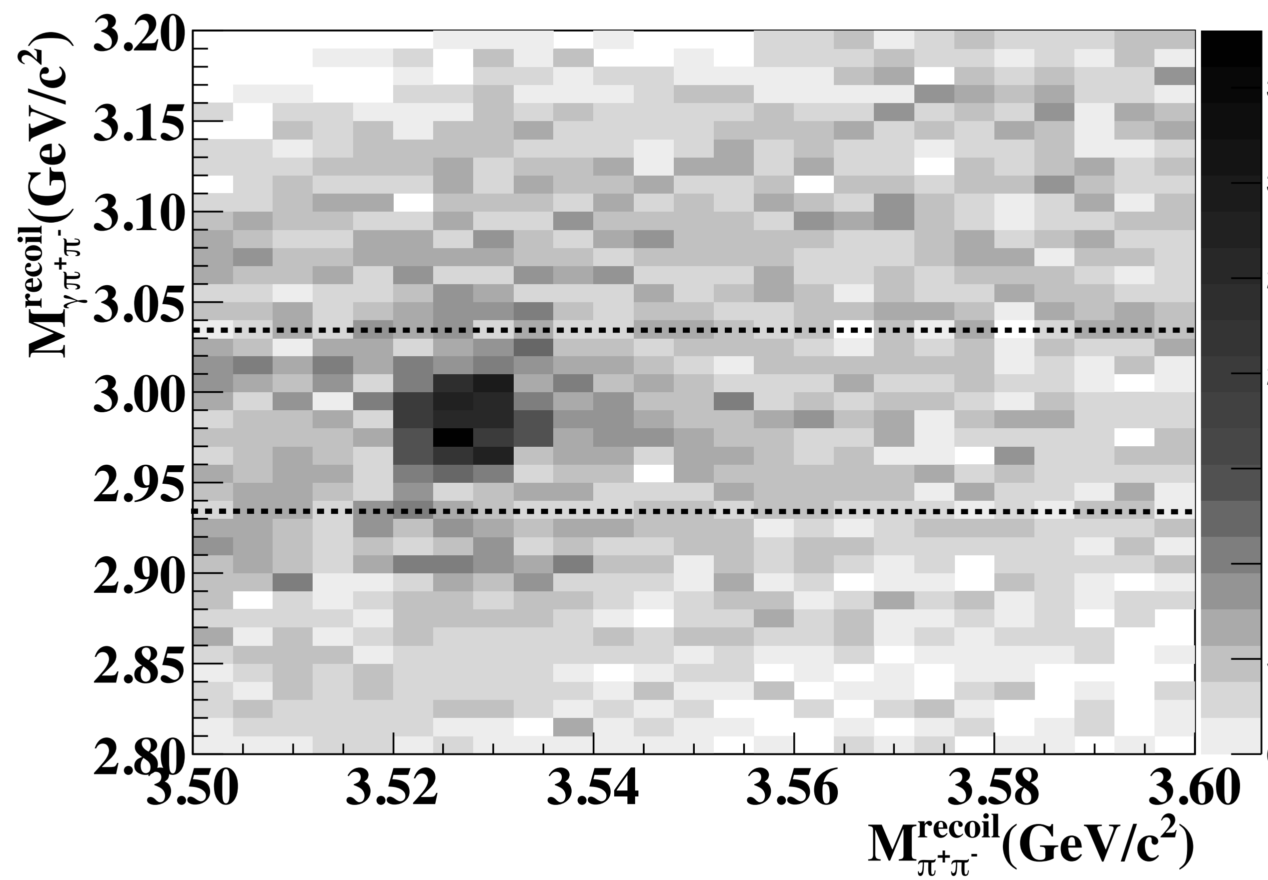
3900 (50 pb^{-1})

4090 (50 pb^{-1})

Connecting the XYZ at BESIII



e^+e^- (at 4260 MeV) $\rightarrow \pi^+\pi^- h_c(1P)$ at BESIII



PRL 111, 242001 (2013)

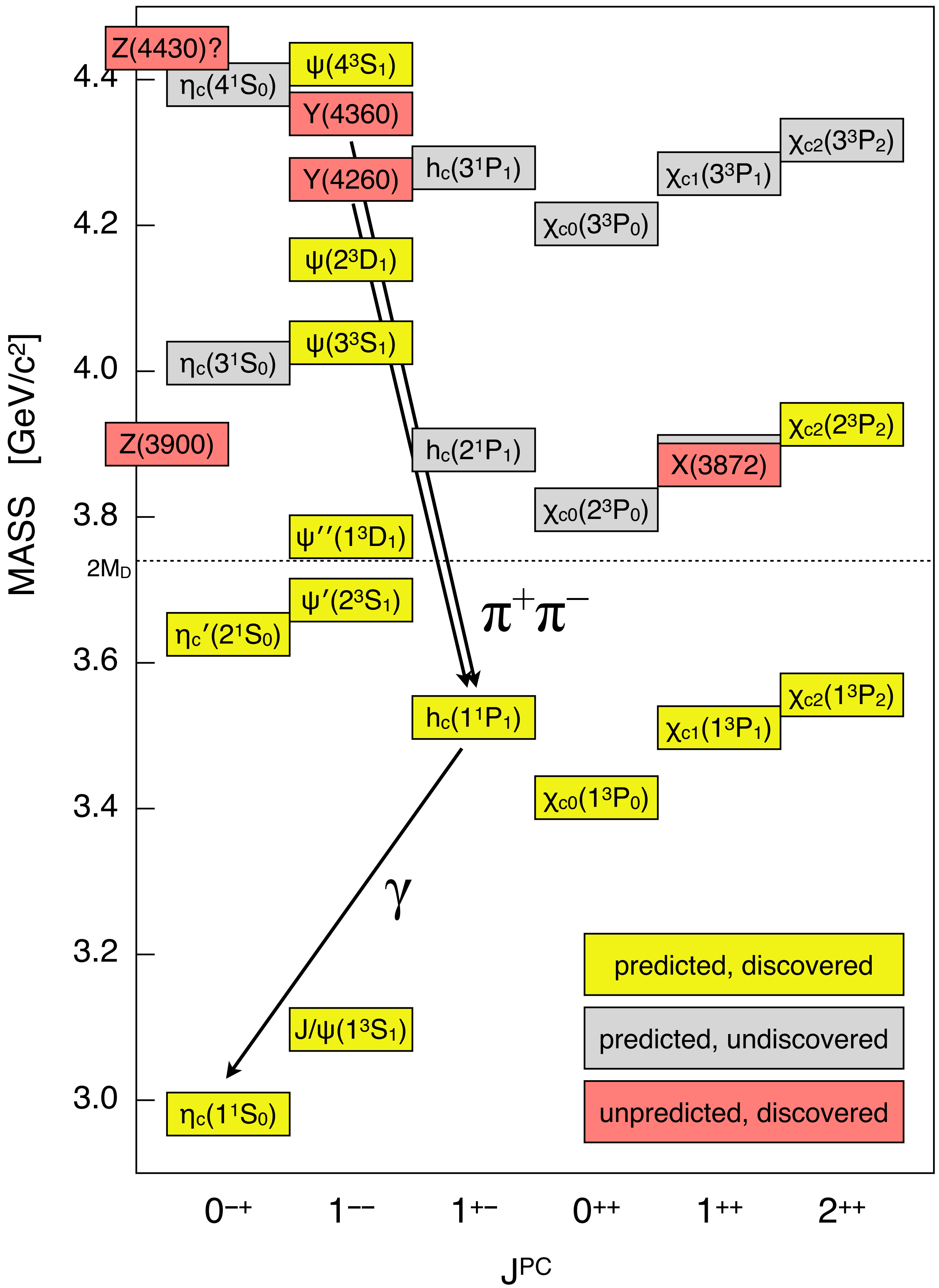
Exclusively reconstruct the process:

$e^+e^- \rightarrow \pi^+\pi^- h_c(1P)$

$h_c(1P) \rightarrow \gamma\eta_c(1S)$

$\eta_c(1S) \rightarrow$ **16 decay channels**

Connecting the XYZ at BESIII



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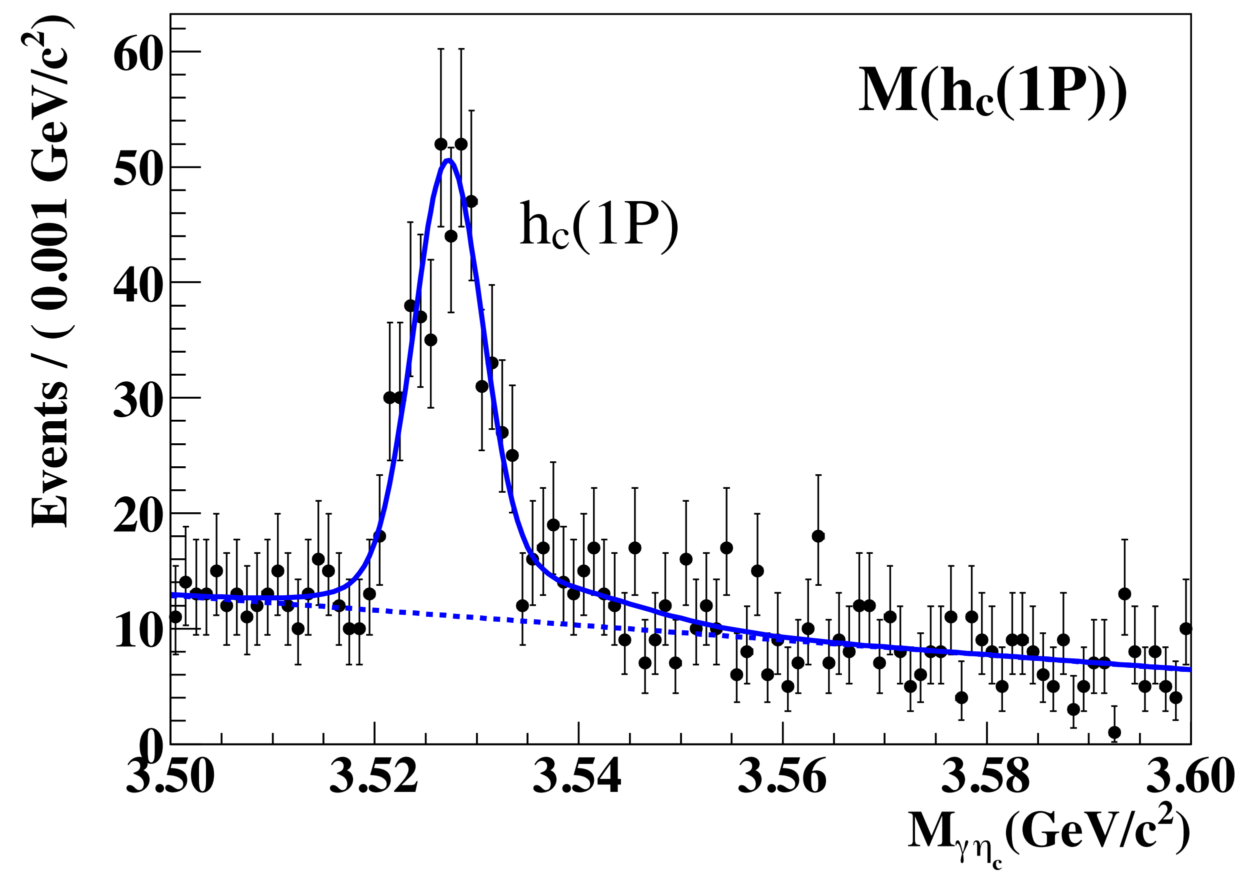


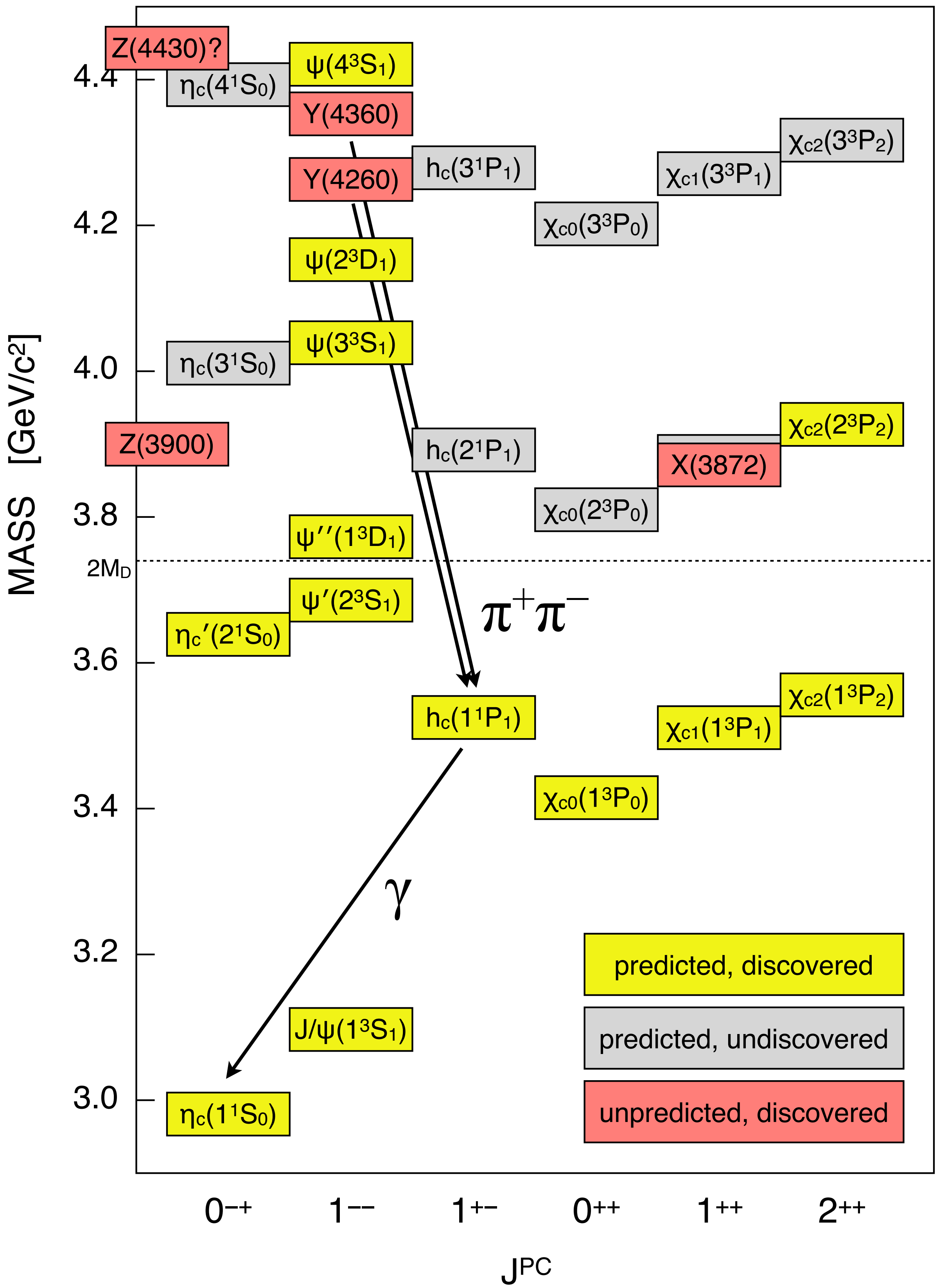
PRL 111, 242001 (2013)

Exclusively reconstruct the process:

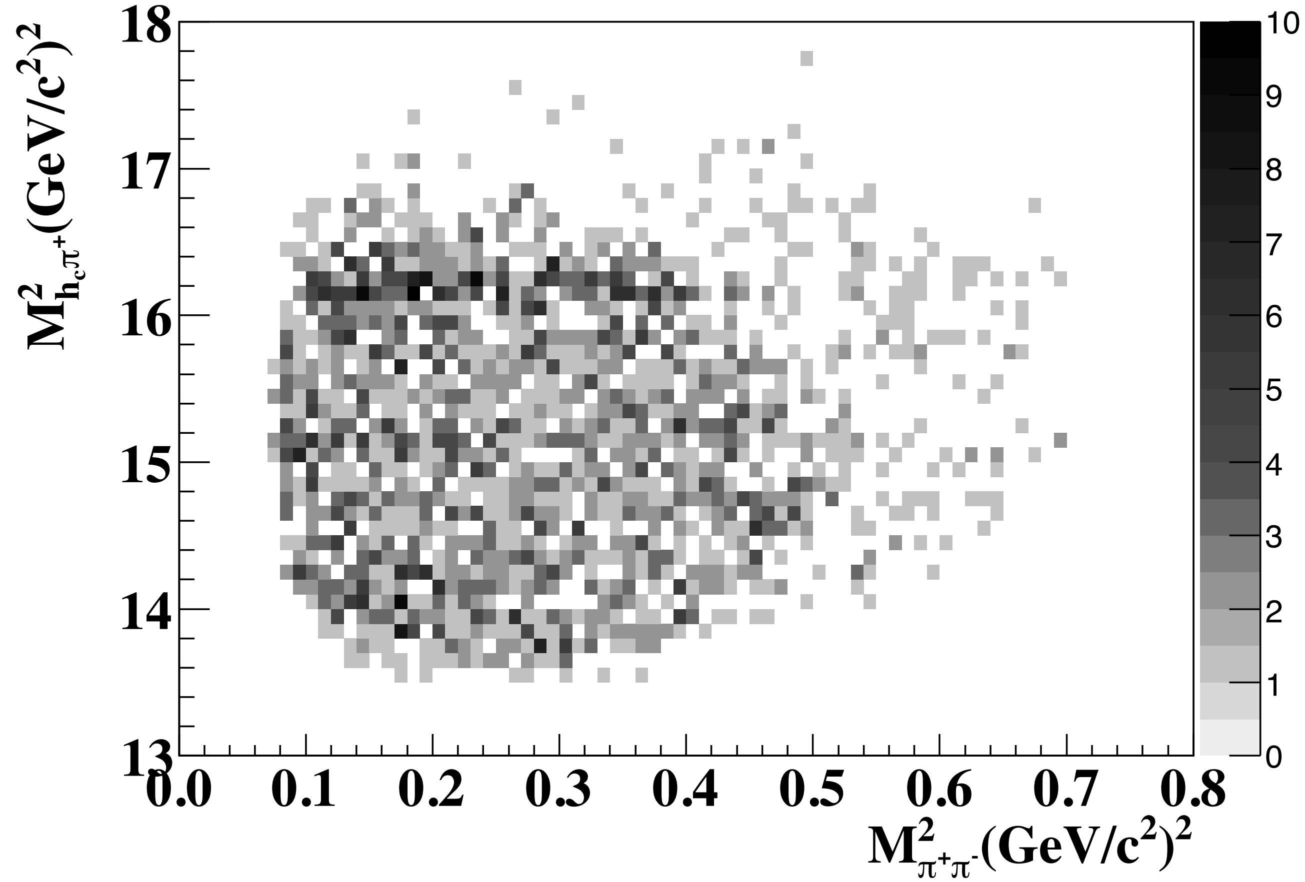
$e^+e^- \rightarrow$ **$\pi^+\pi^-$** $h_c(1P)$

$h_c(1P) \rightarrow$ **γ** $\eta_c(1S)$

$\eta_c(1S) \rightarrow$ **16 decay channels**



$e^+e^- \to \pi^+\pi^- h_c(1P)$ at BESIII



PRL 111, 242001 (2013)

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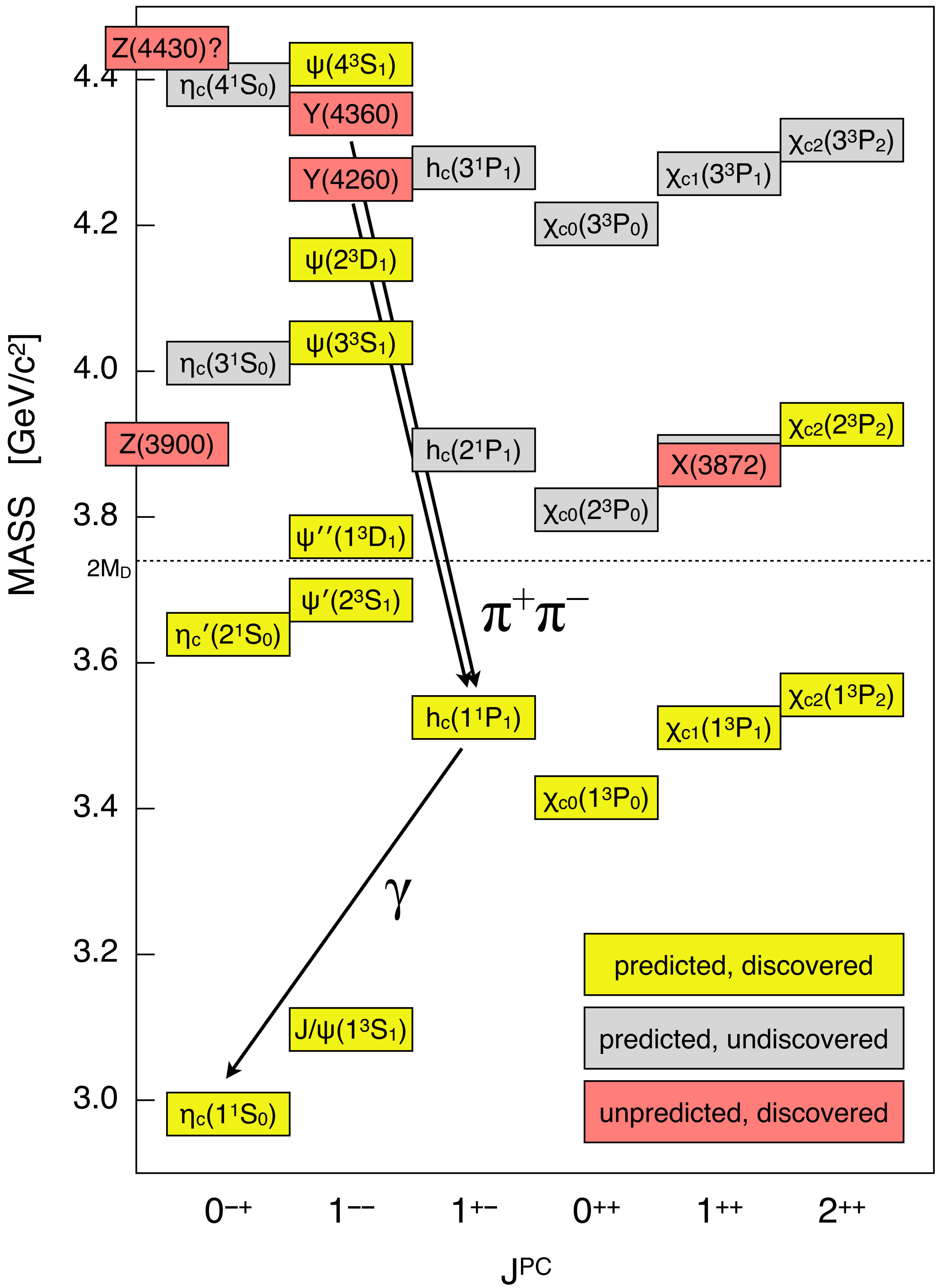
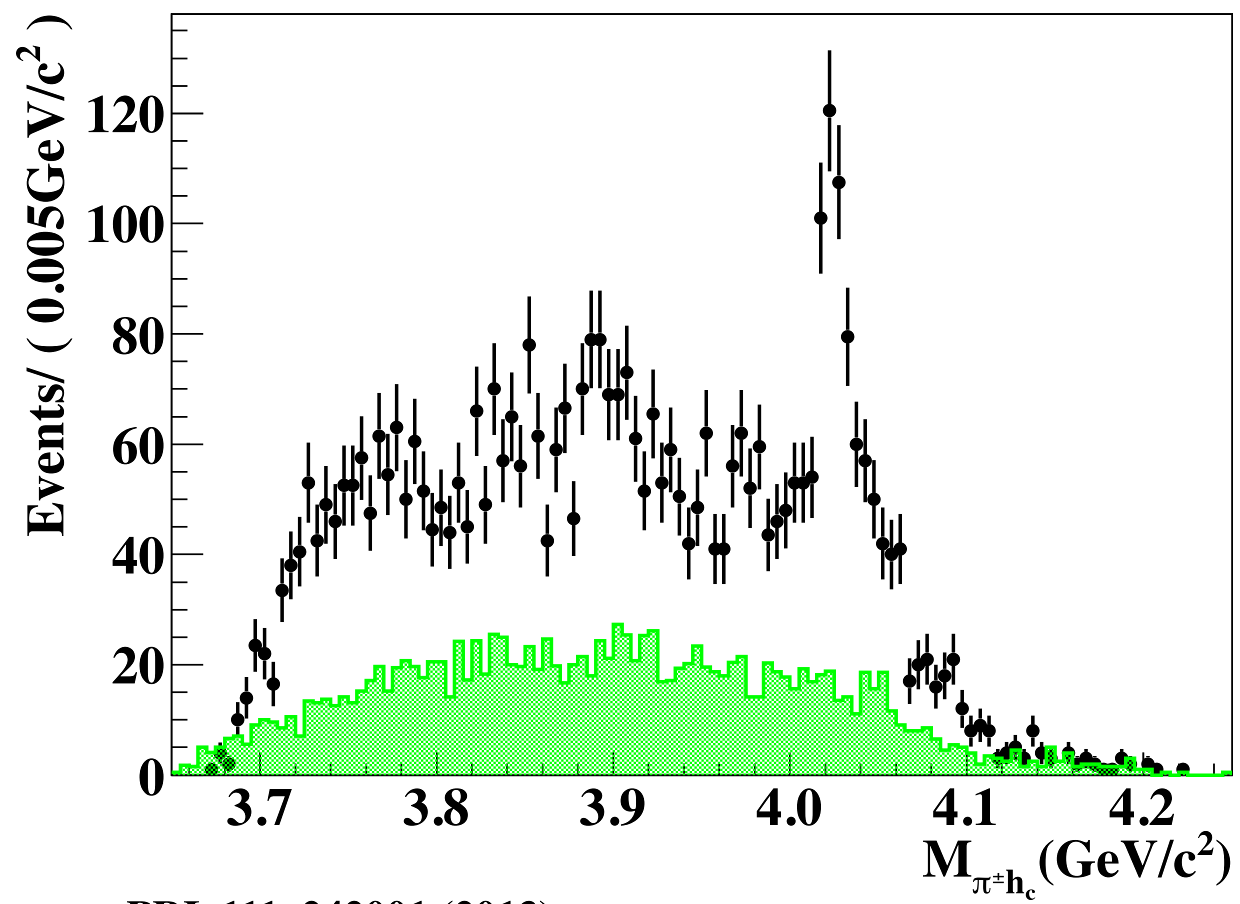
$\eta_c(1S) \to$ **16 decay channels**

Connecting the XYZ at BESIII



$e^+e^- \rightarrow \pi^+\pi^- h_c(1P)$ at BESIII



PRL 111, 242001 (2013)

Exclusively reconstruct the process:

$e^+e^- \rightarrow$ **$\pi^+\pi^-$** $h_c(1P)$

$h_c(1P) \rightarrow$ **γ** $\eta_c(1S)$

$\eta_c(1S) \rightarrow$ **16 decay channels**

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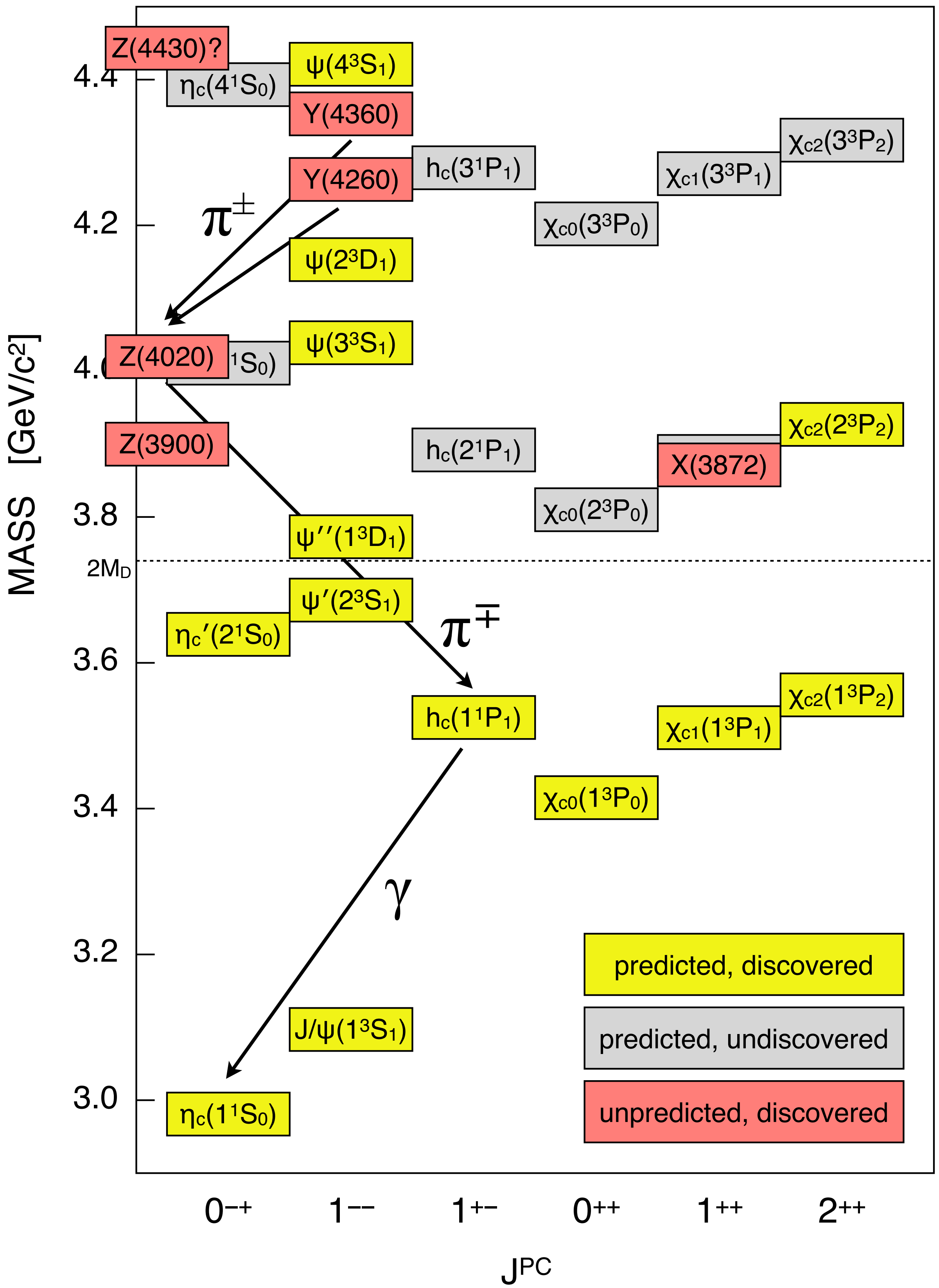

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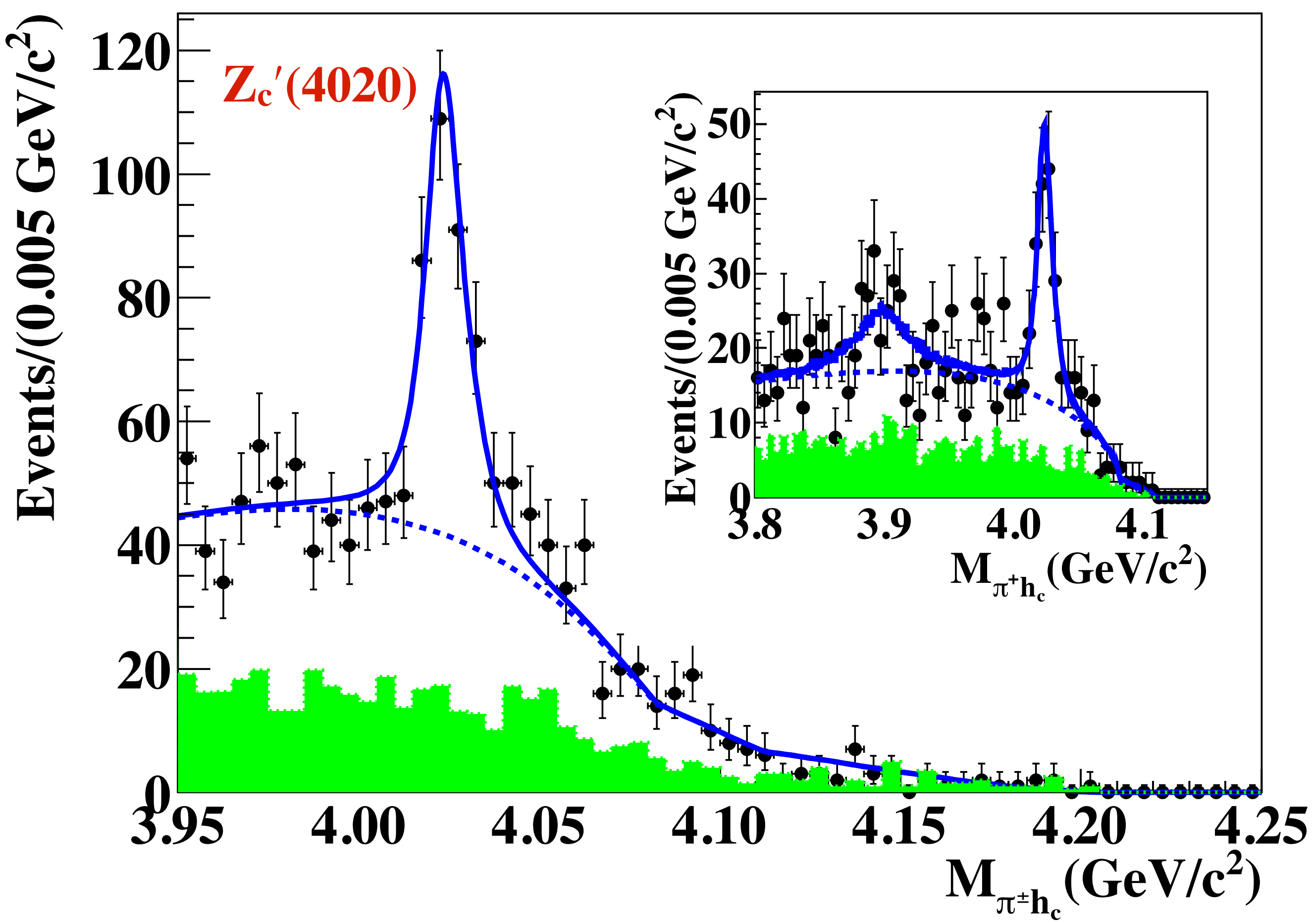

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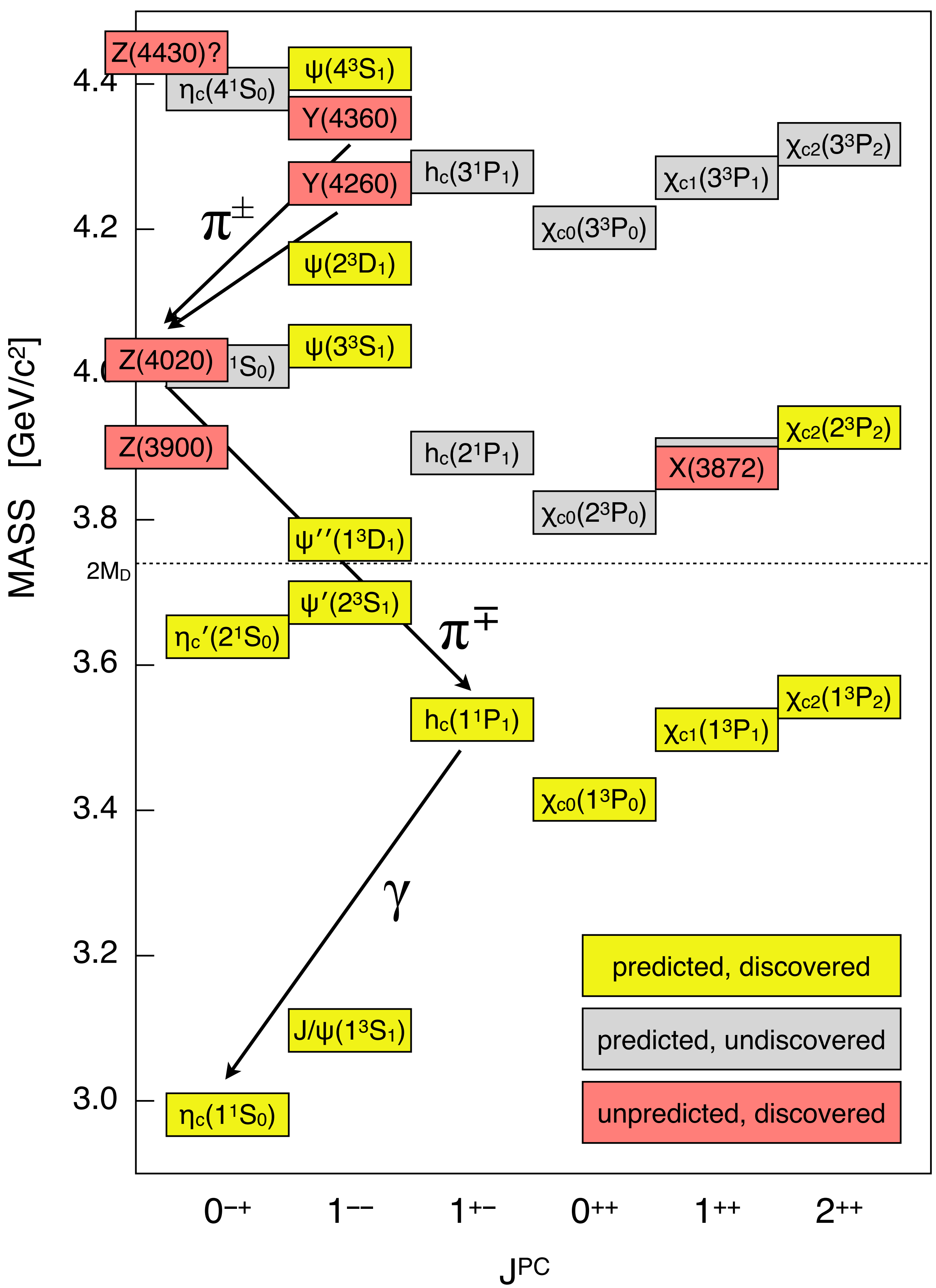
⇒ **"Charged Charmoniumlike Structure"**

(this time close to D^*D^* threshold)

$$M = 4022.9 \pm 0.8 \pm 2.7 \text{ MeV}$$

$$\Gamma = 7.9 \pm 2.7 \pm 2.6 \text{ MeV}$$

Connecting the XYZ at BESIII



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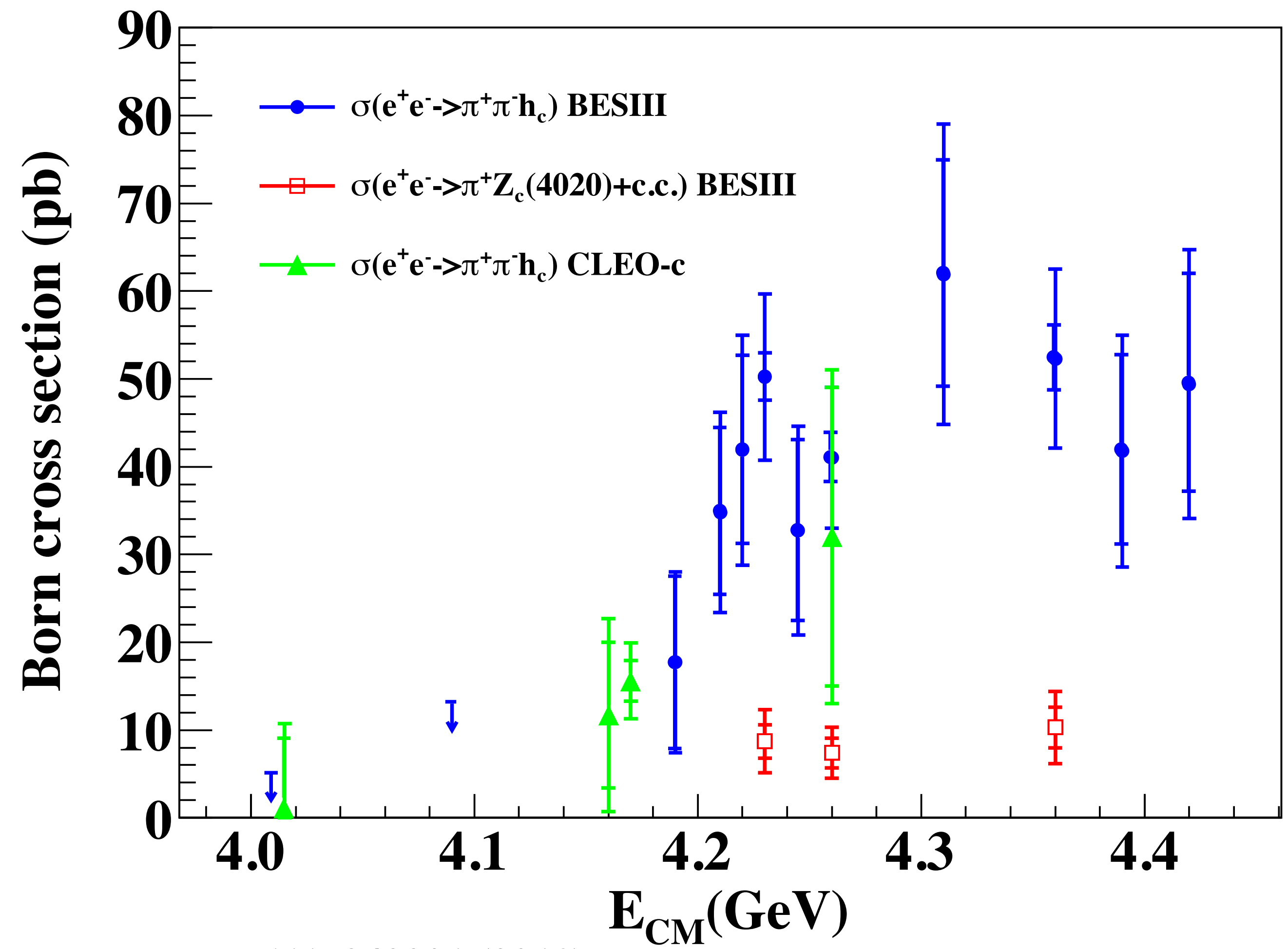

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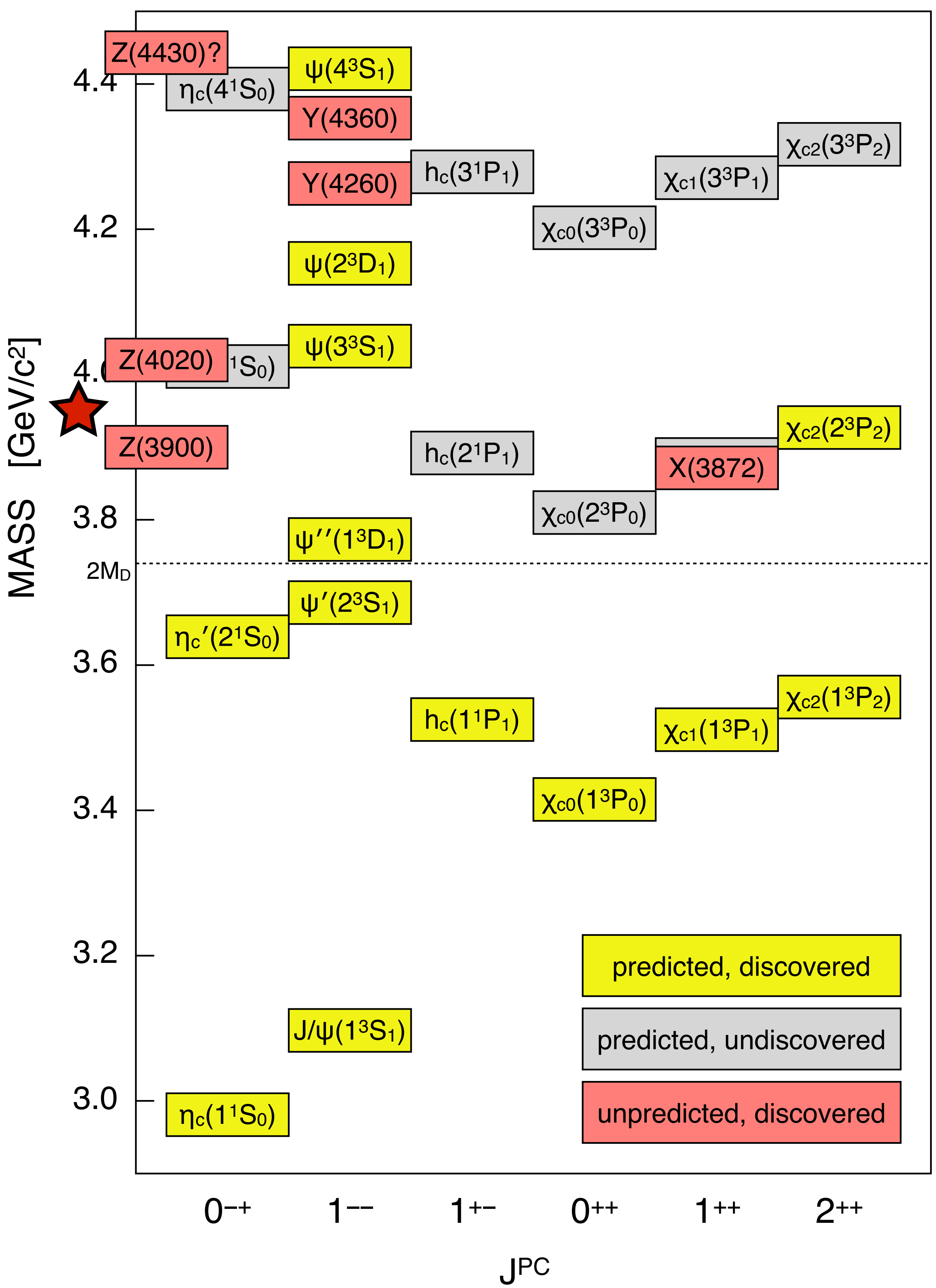
The cross section shape requires more data…

Is it a combination of the **Y(4260)** and **Y(4360)**?

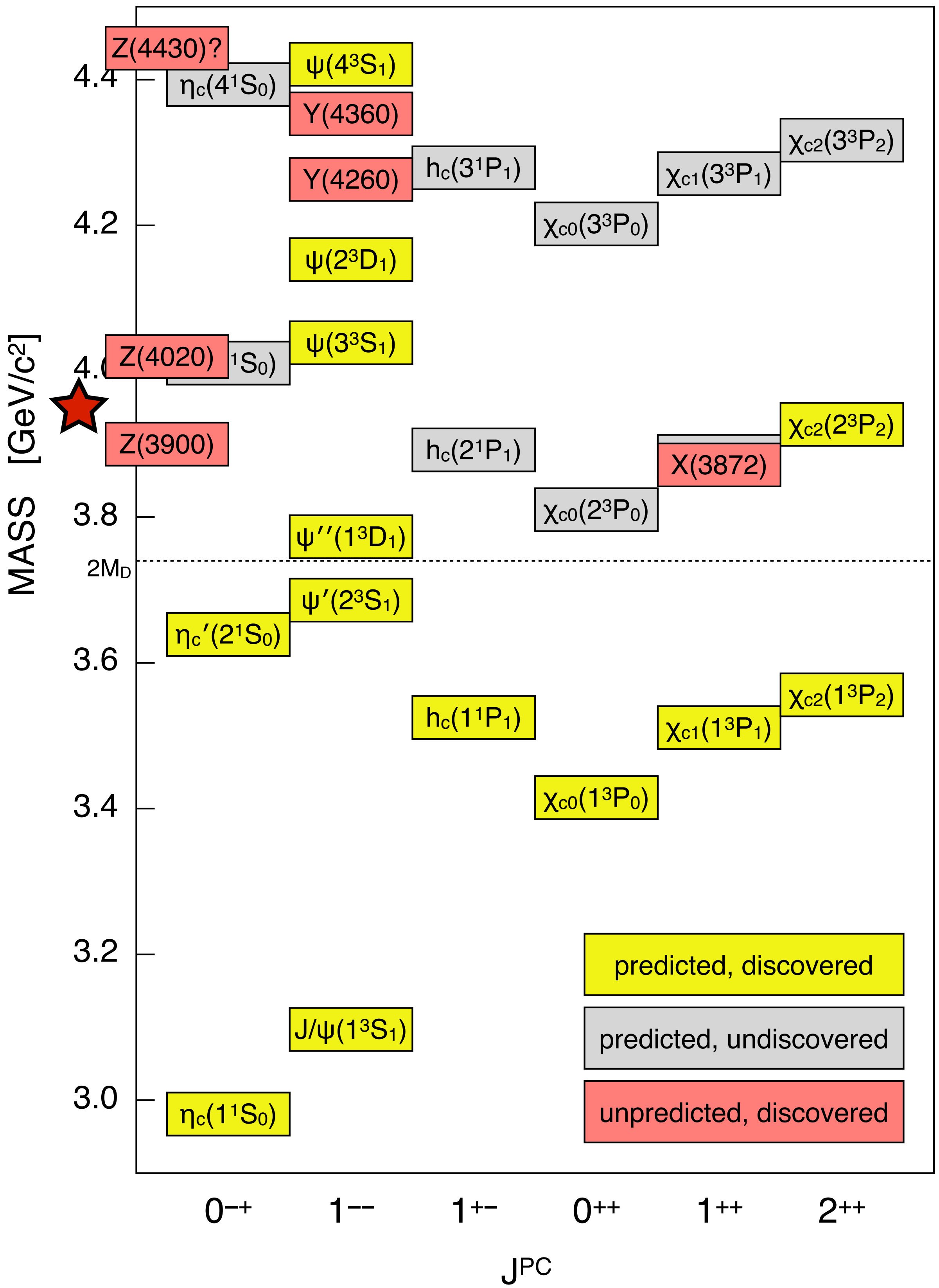
Or something completely different?

Connecting the XYZ at BESIII



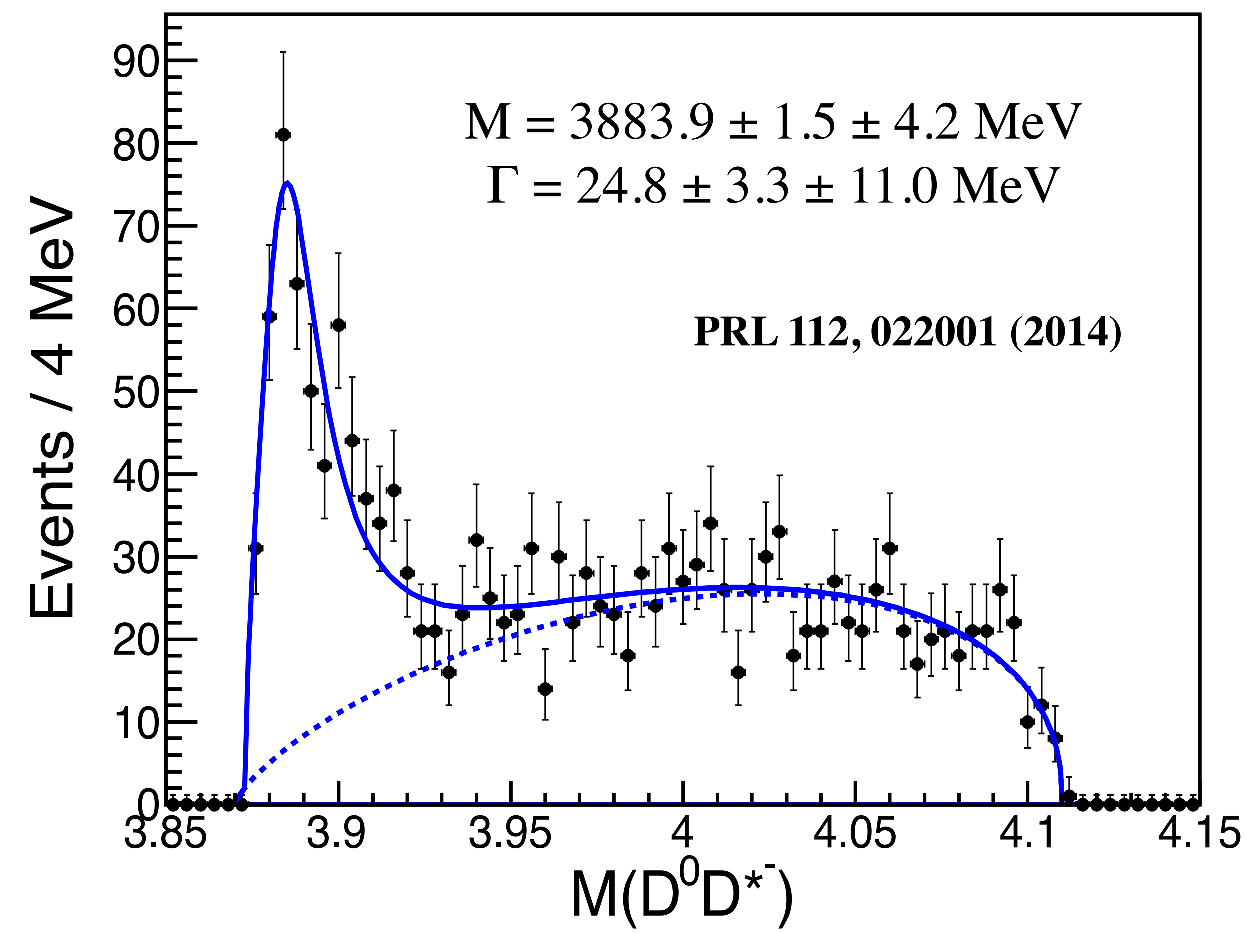
The $Z_c(3900)$ is close to DD^* threshold...

Connecting the XYZ at BESIII



The $Z_c(3900)$ is close to DD^* threshold…

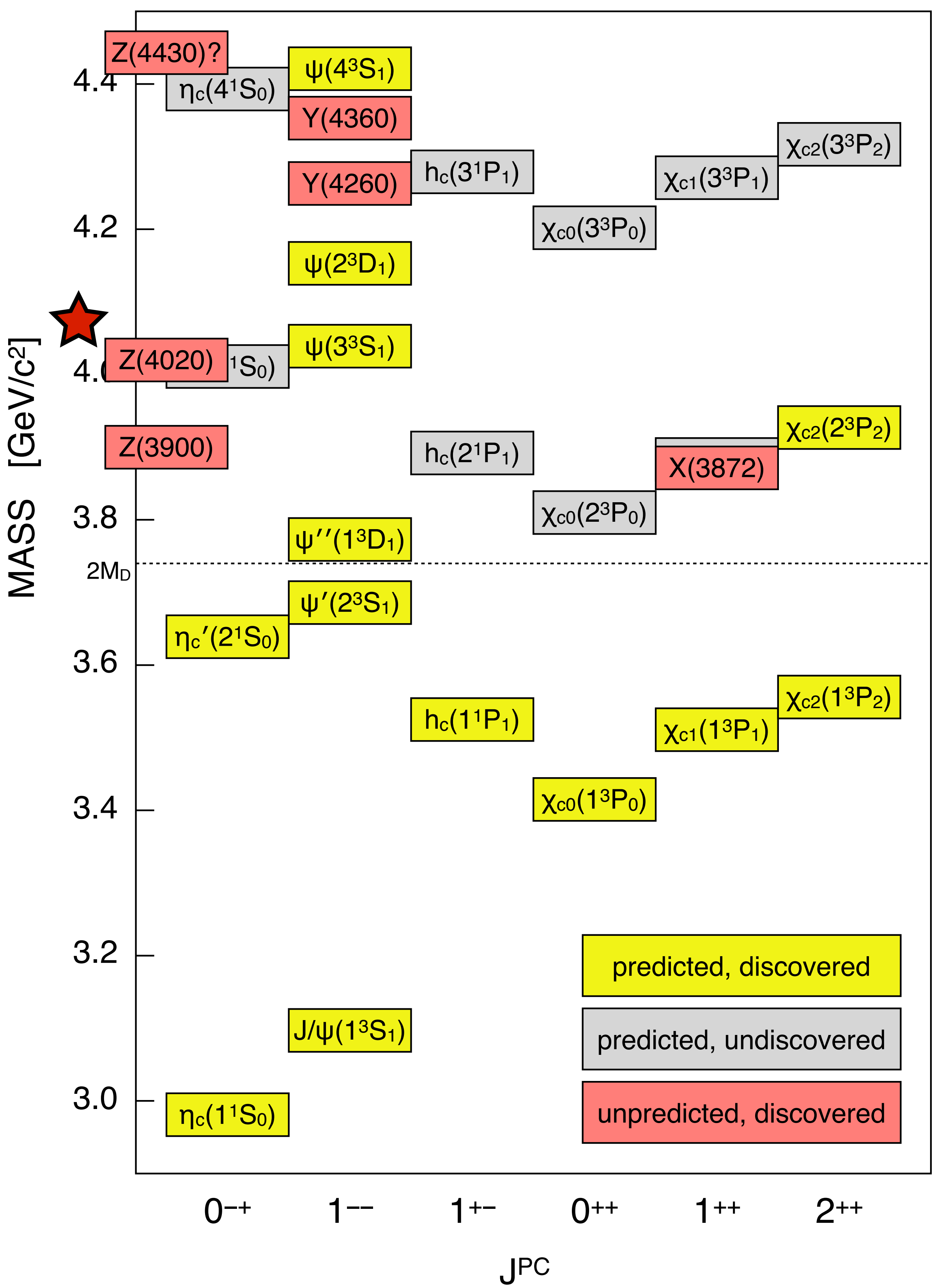
e^+e^- (at 4.26 GeV) $\rightarrow \pi^+D^0D^{*-}$ at BESIII



… and BESIII sees structure in DD^*.

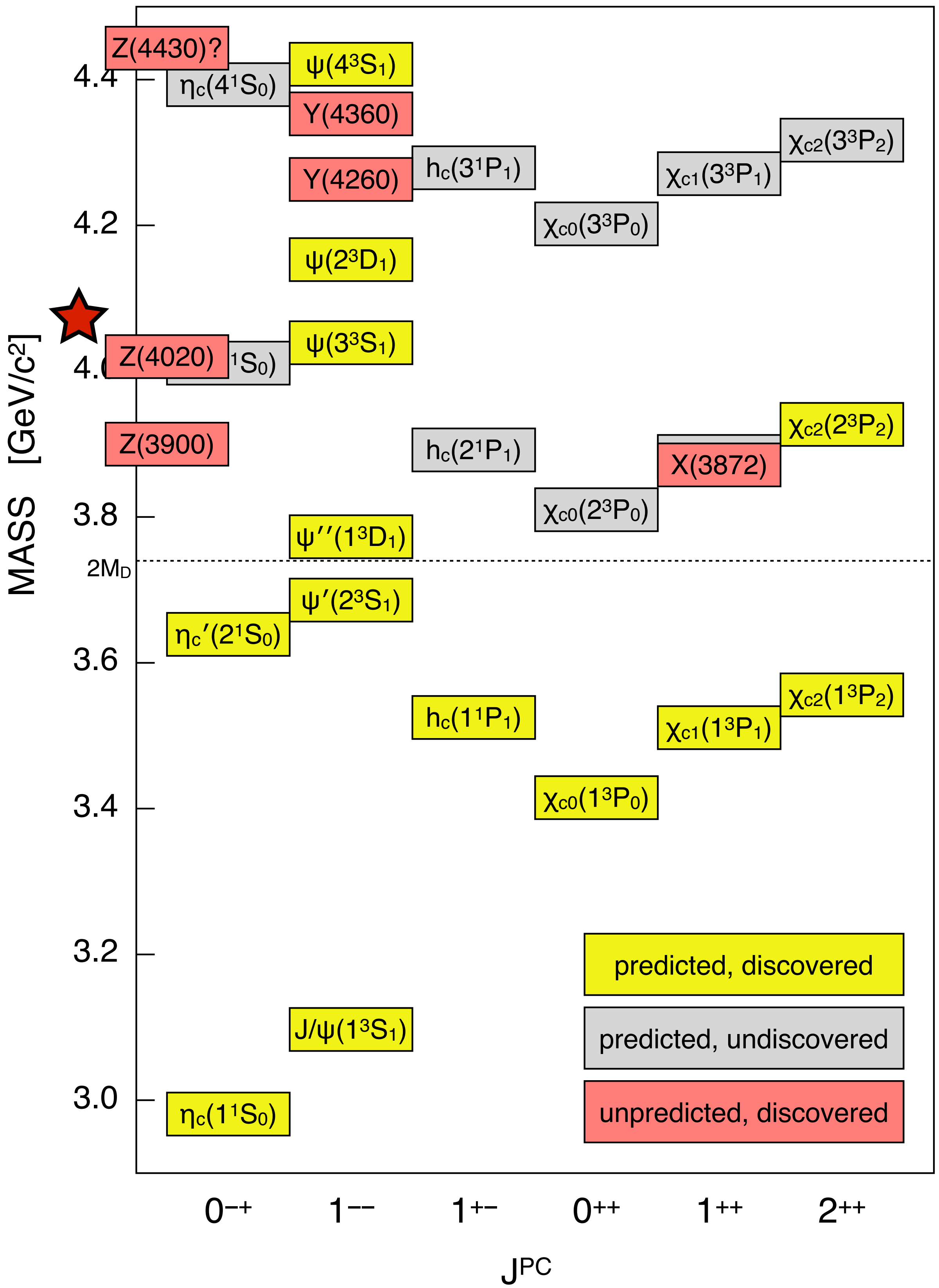
Reconstruct the π^+ and $D^0 \rightarrow K^-\pi^+$ and infer the D^{*-}.
(Also analyze $\pi^+D^-D^{*0}$ with the same method.)

Connecting the XYZ at BESIII



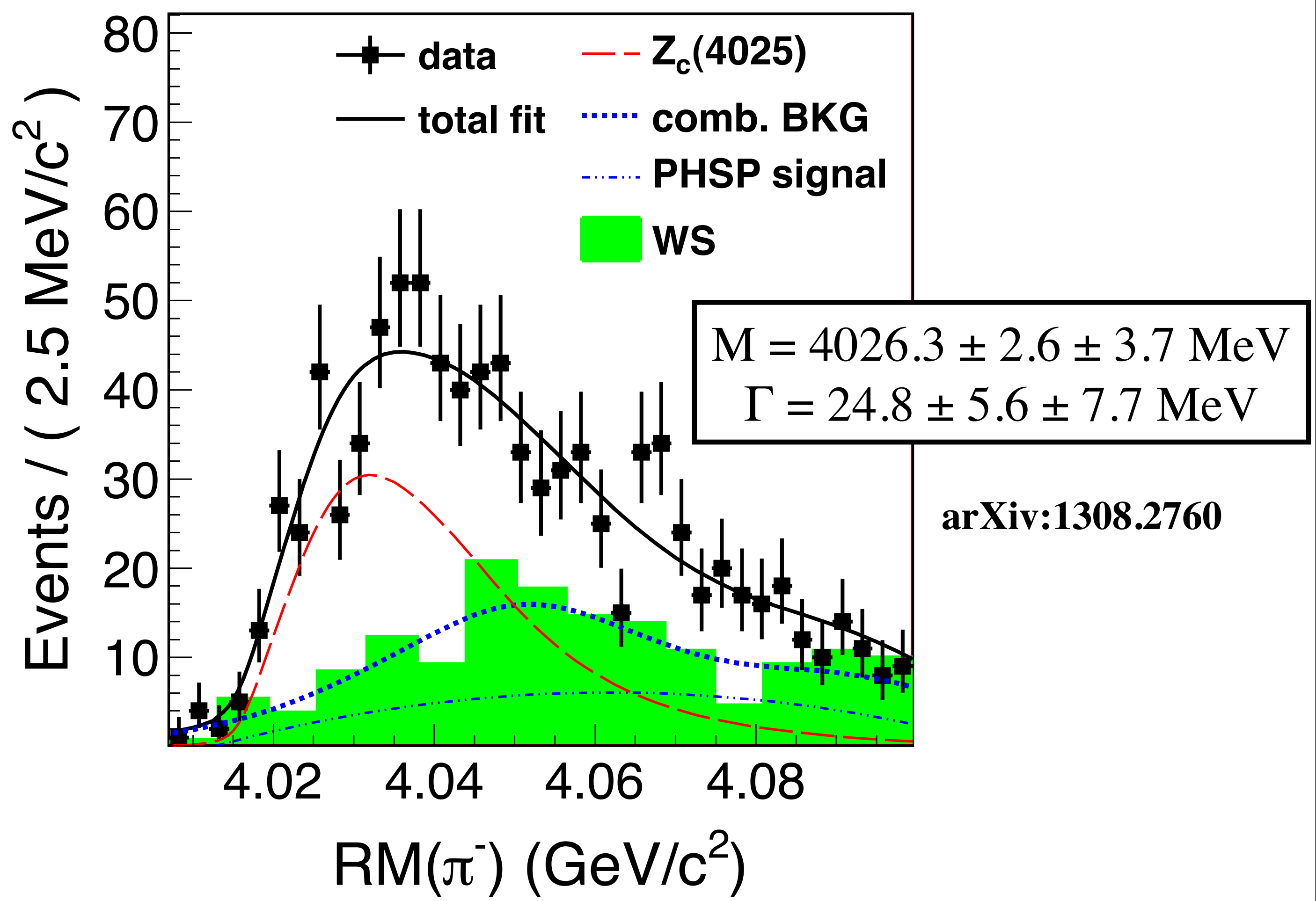
The $Z_c'(4020)$ is close to D^*D^* threshold...

Connecting the XYZ at BESIII



The $Z_c'(4020)$ is close to D^*D^* threshold...

e^+e^- (at 4.26 GeV) $\rightarrow \pi^\pm(D^*D^*)^\mp$ at BESIII

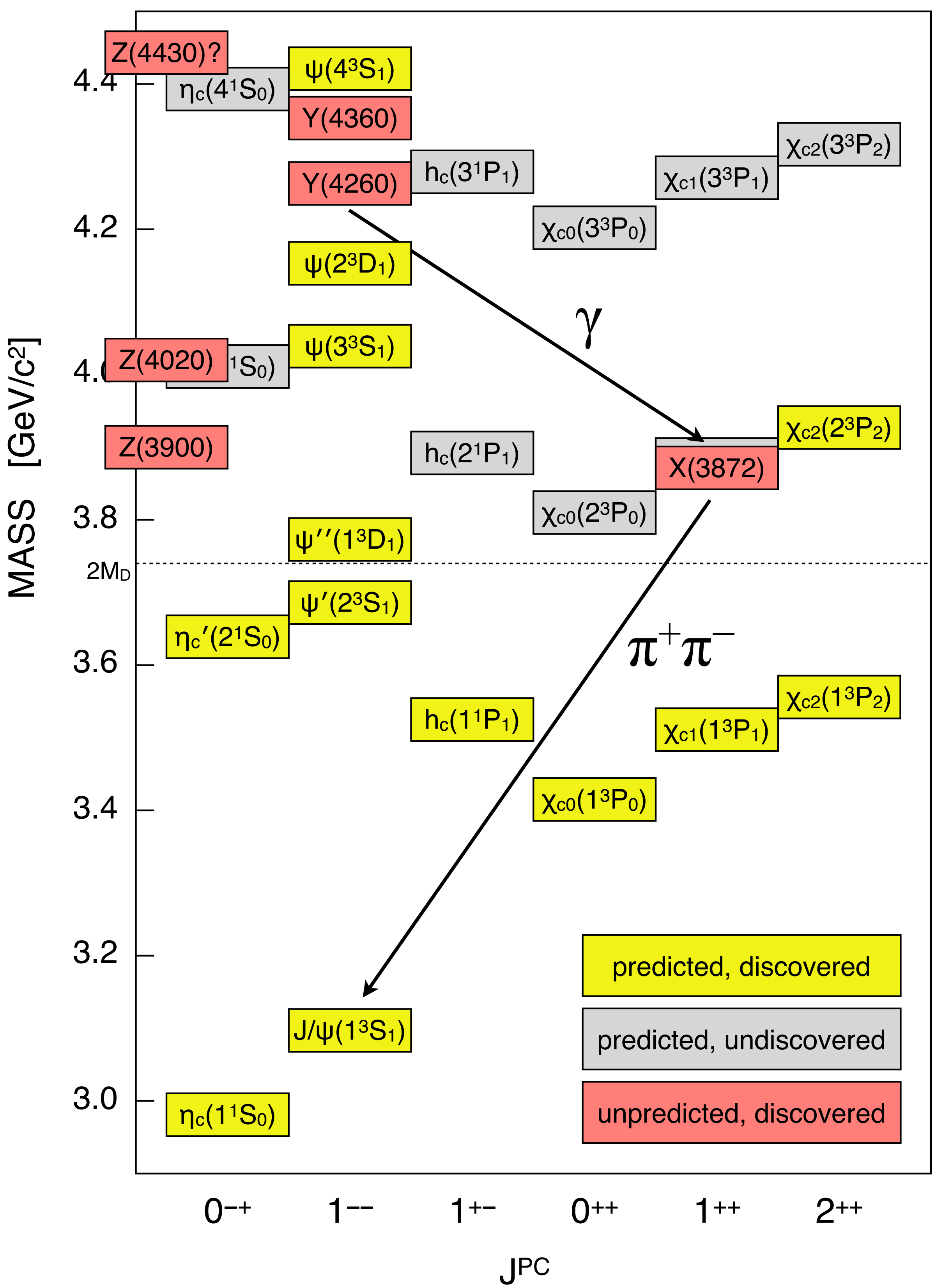


arXiv:1308.2760

... and BESIII sees structure in D^*D^*.

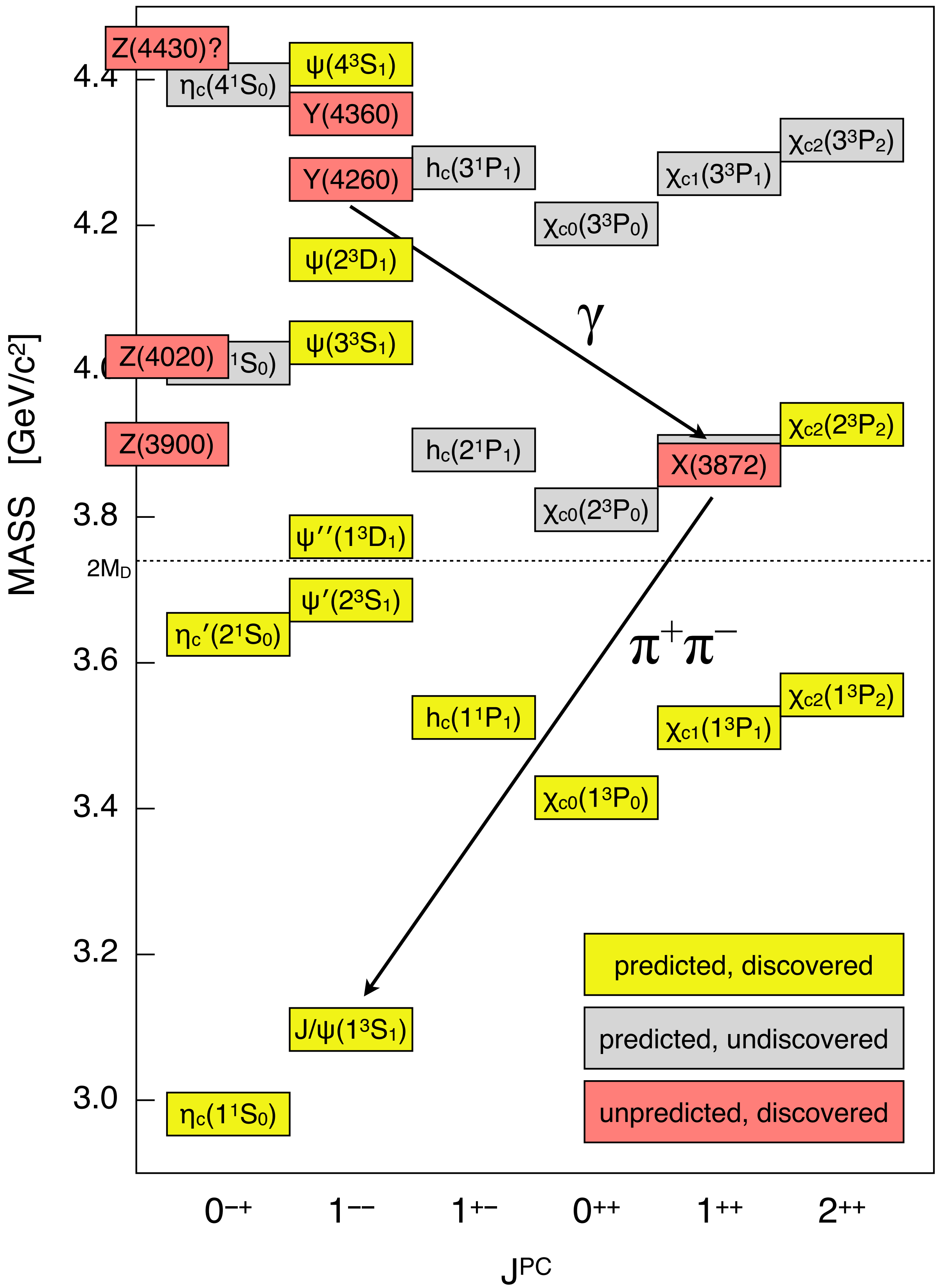
Reconstruct the π^-, a $D^+ \rightarrow K^-\pi^+\pi^+$, and a π^0 from a D^*.

Connecting the XYZ at BESIII

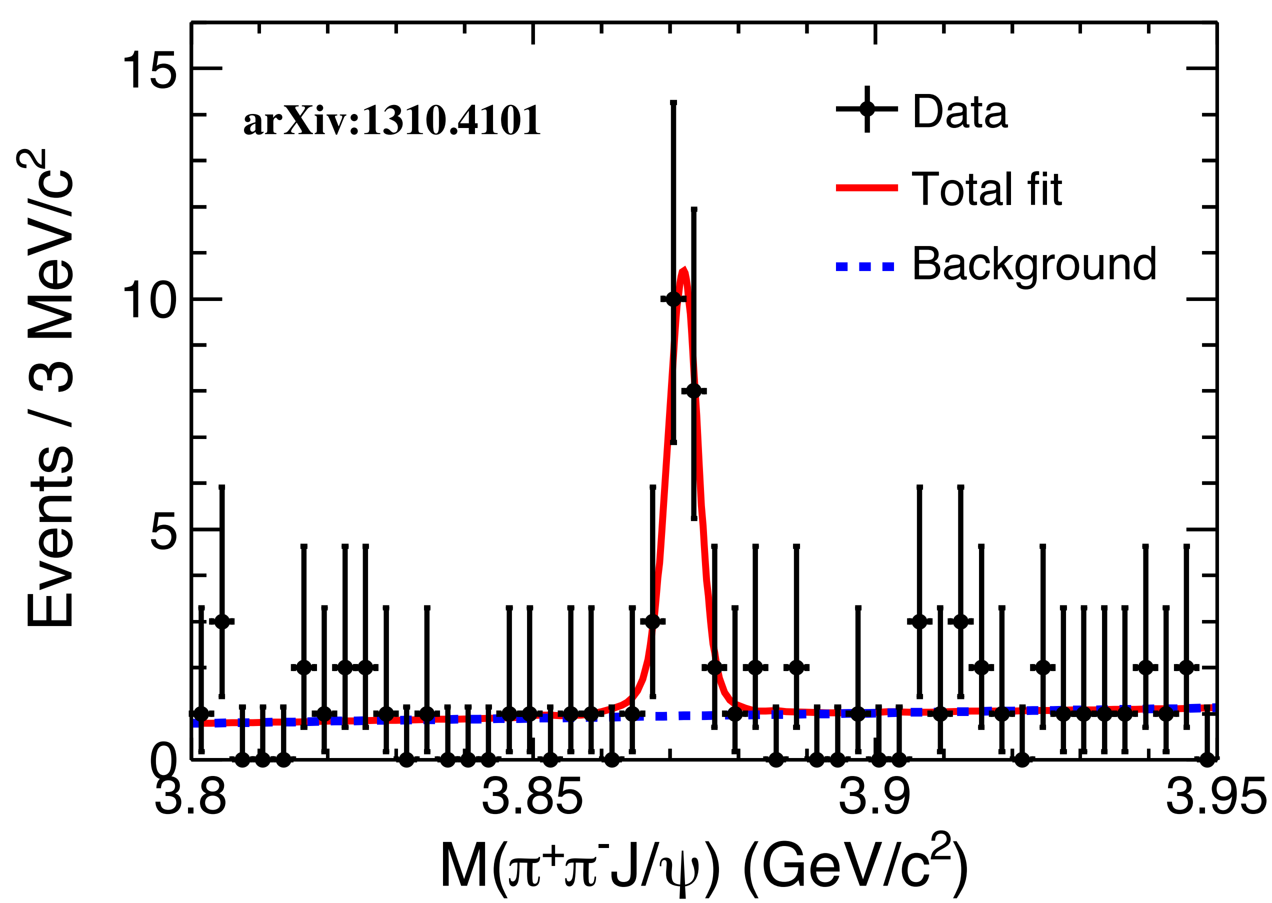


Search for $Y(4260) \to \gamma X(3872)$...

Connecting the XYZ at BESIII



$e^+e^- \rightarrow \gamma(\pi^+\pi^- J/\psi)$ at BESIII



⇒ **"Observation of the X(3872)"**

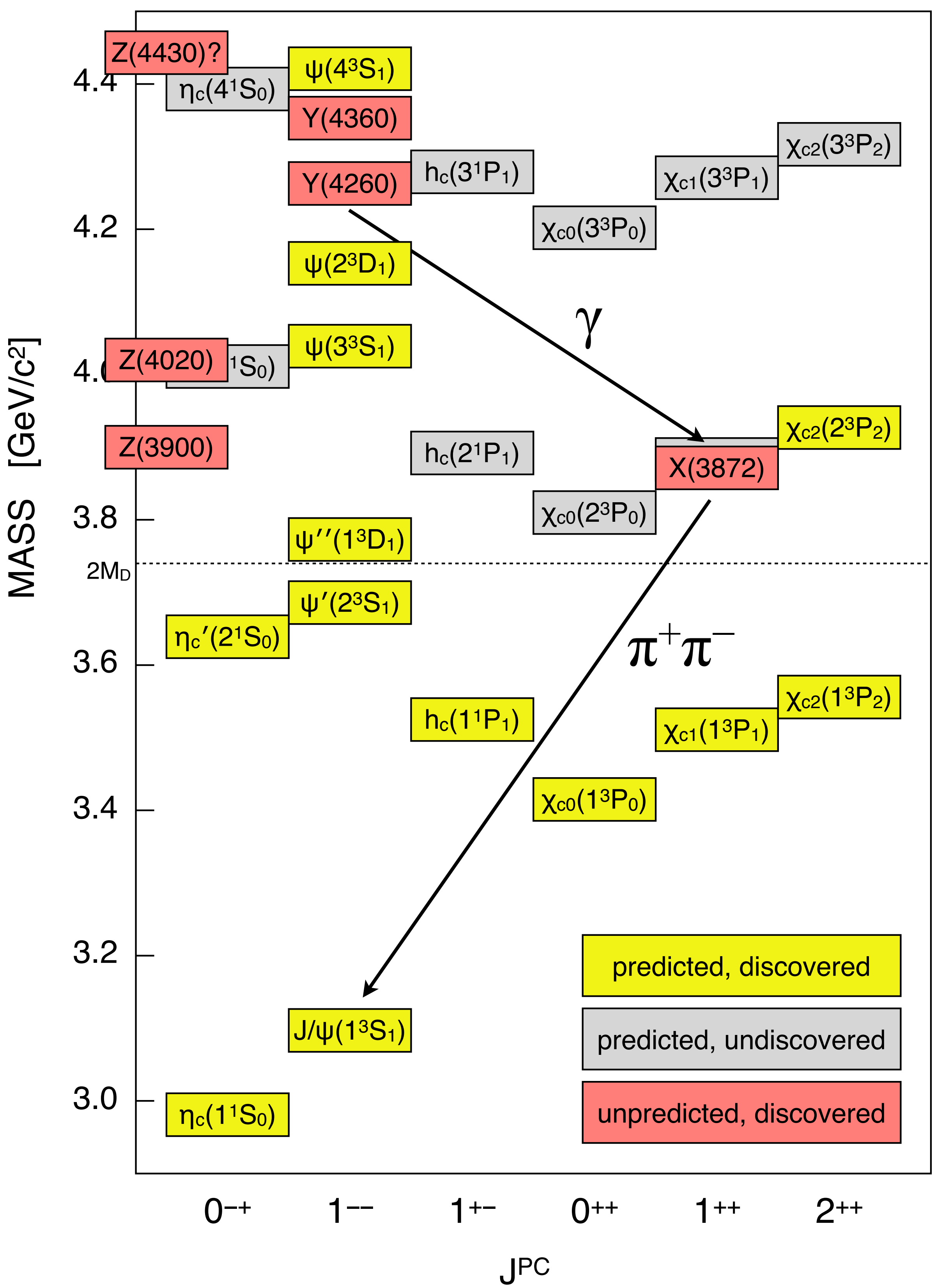
significance = 6.3σ

N = 20.1 ± 4.5 events

M = 3871.9 ± 0.7 ± 0.2 MeV

Γ consistent with resolution

Connecting the XYZ at BESIII



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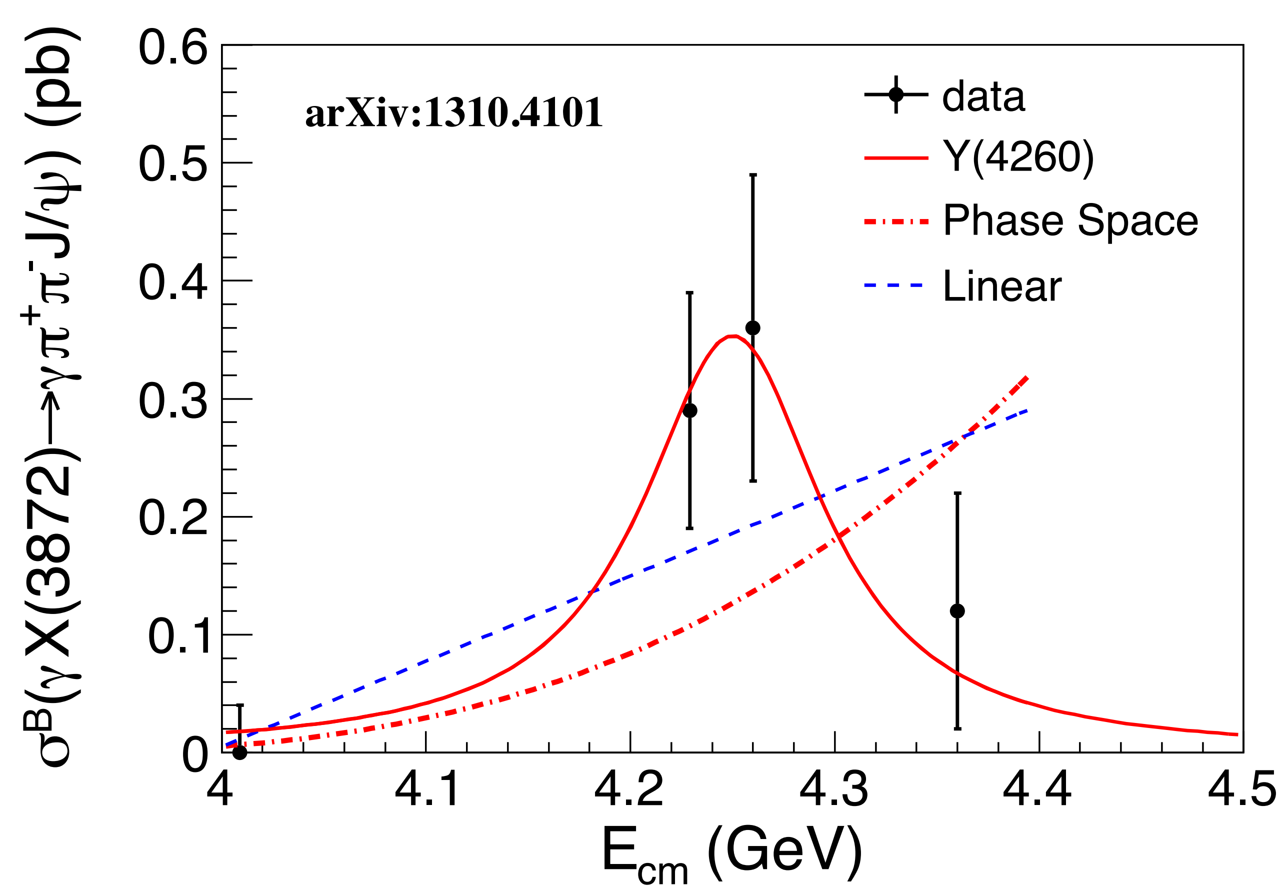
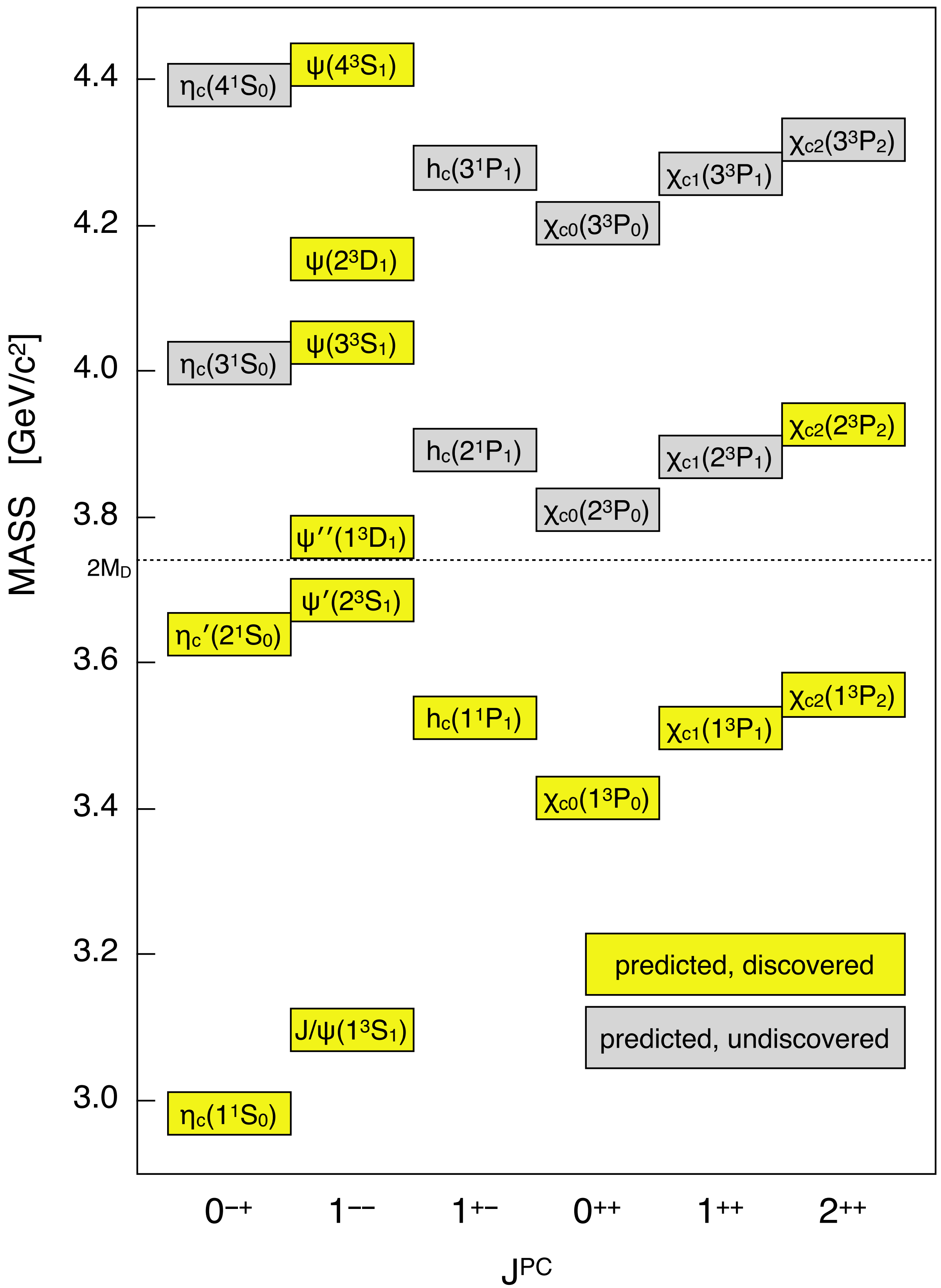


Hints that this is Y(4260) → γX(3872)!?

Connecting the XYZ at BESIII



(I) The quark model describes most of charmonium remarkably well. $(c\bar{c})$

(II) But the "*XYZ*" states point beyond the quark model. $(c\bar{c}g, c\bar{q}q\bar{c}, (c\bar{q})(q\bar{c}), c\bar{c}\pi\pi)$

(III) Most of the XYZ states were discovered by Belle and BaBar.

(IV) But BESIII can directly produce the **Y(4260)** and **Y(4360)** in e^+e^- annihilation.

(V) BESIII has observed "charged charmoniumlike structures" — the **Z_c(3900)** and the **Z_c'(4020)**.

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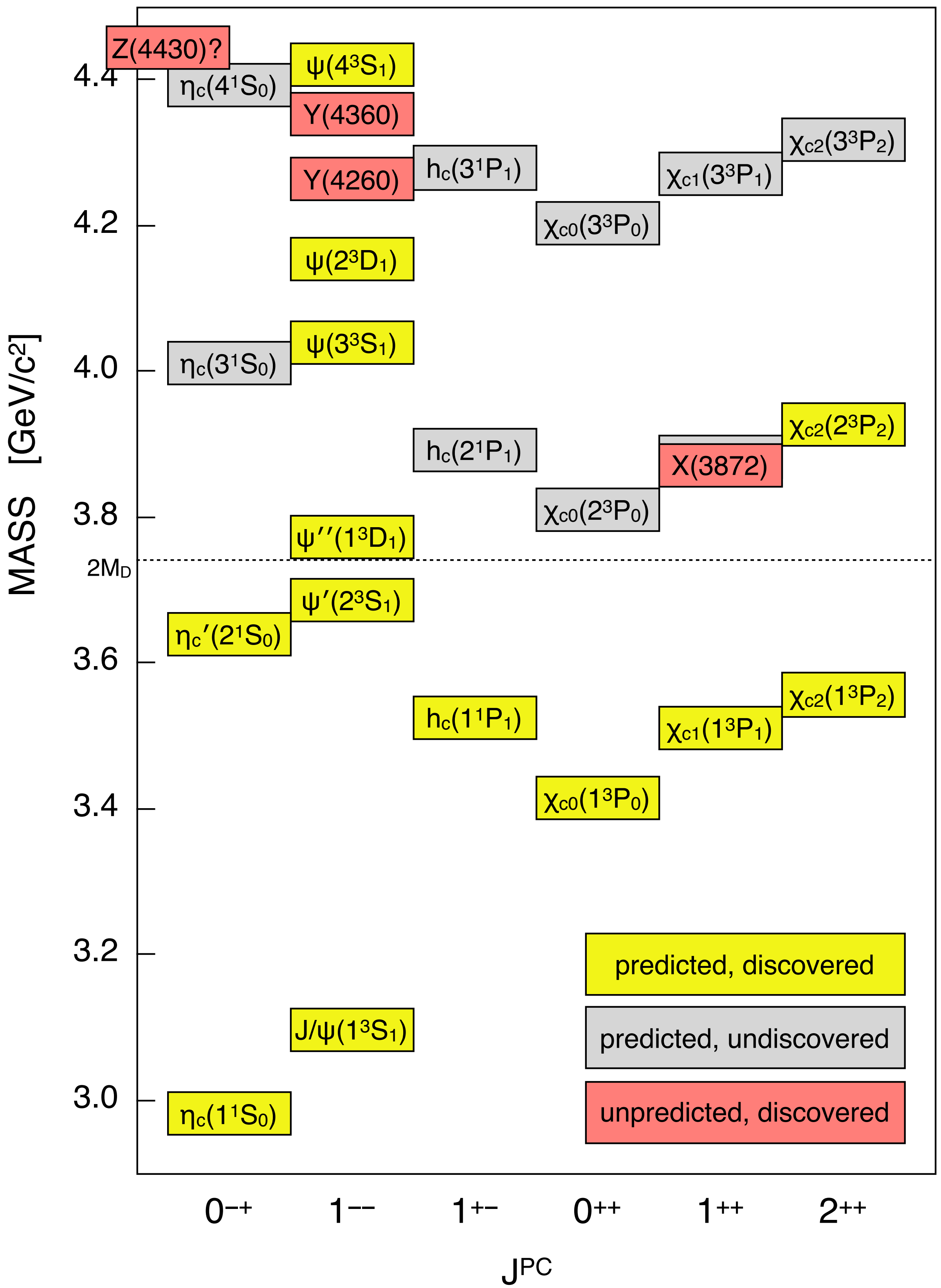
(VII) We are building connections.

Connecting the XYZ at BESIII



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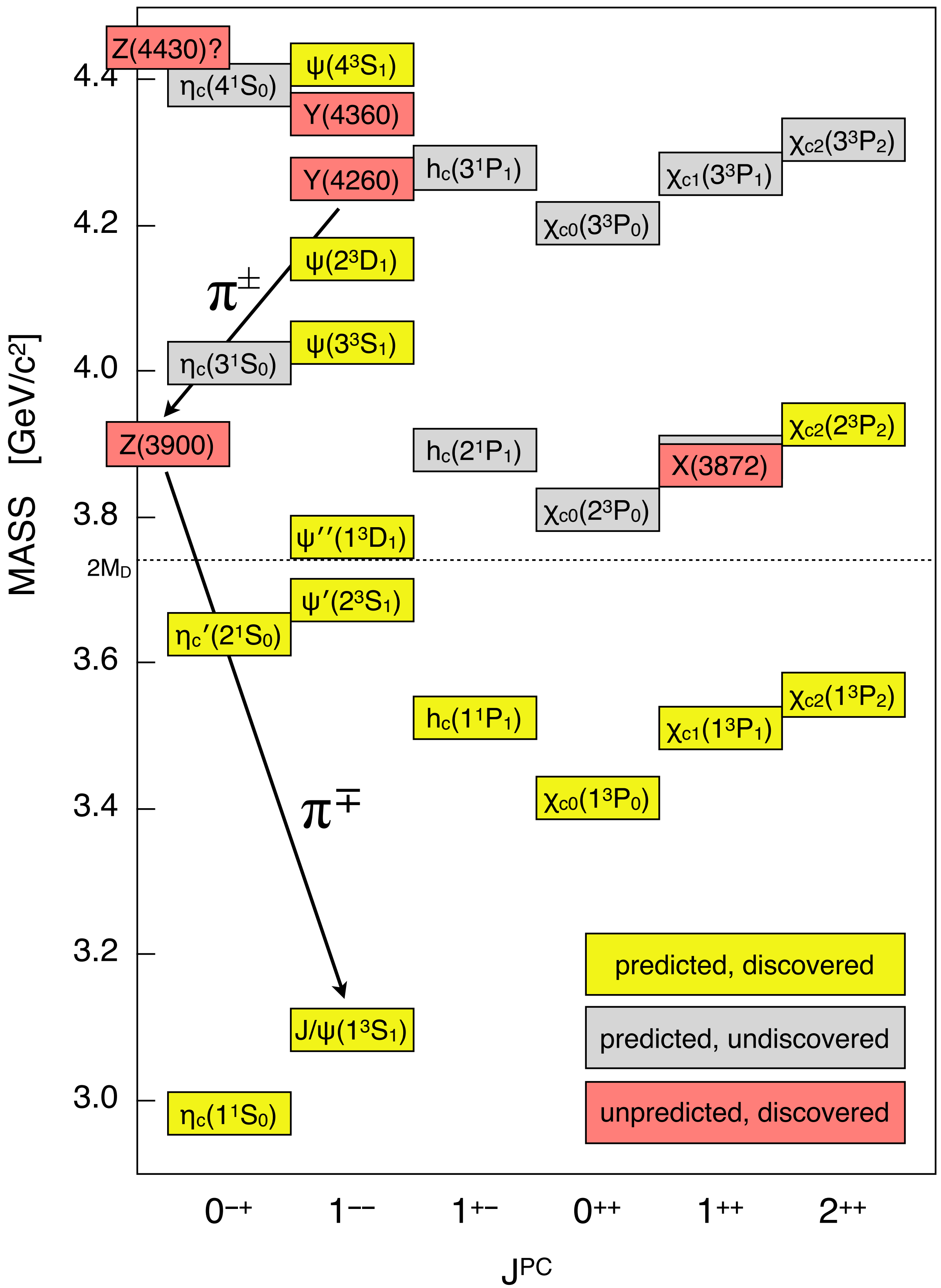

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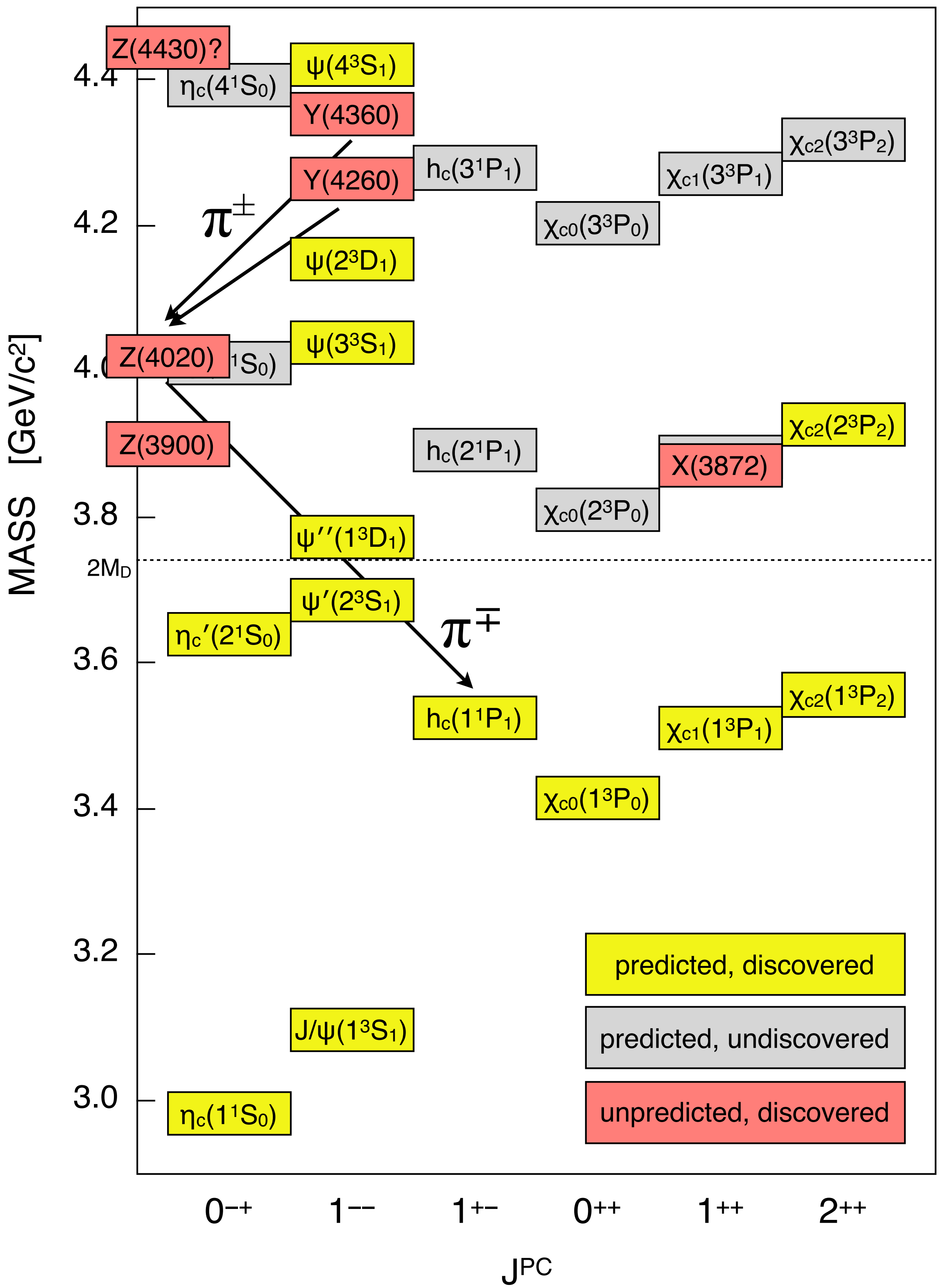

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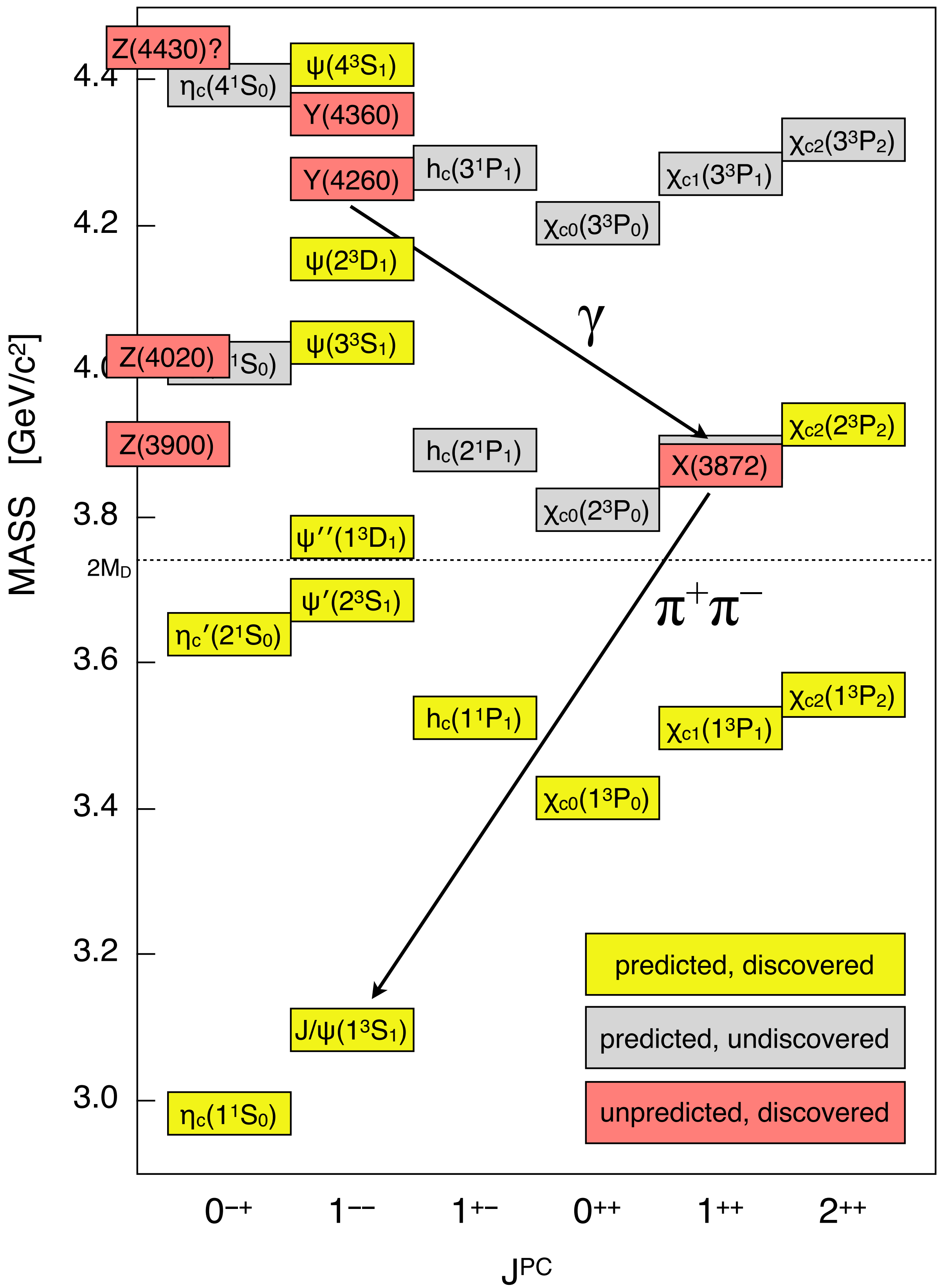

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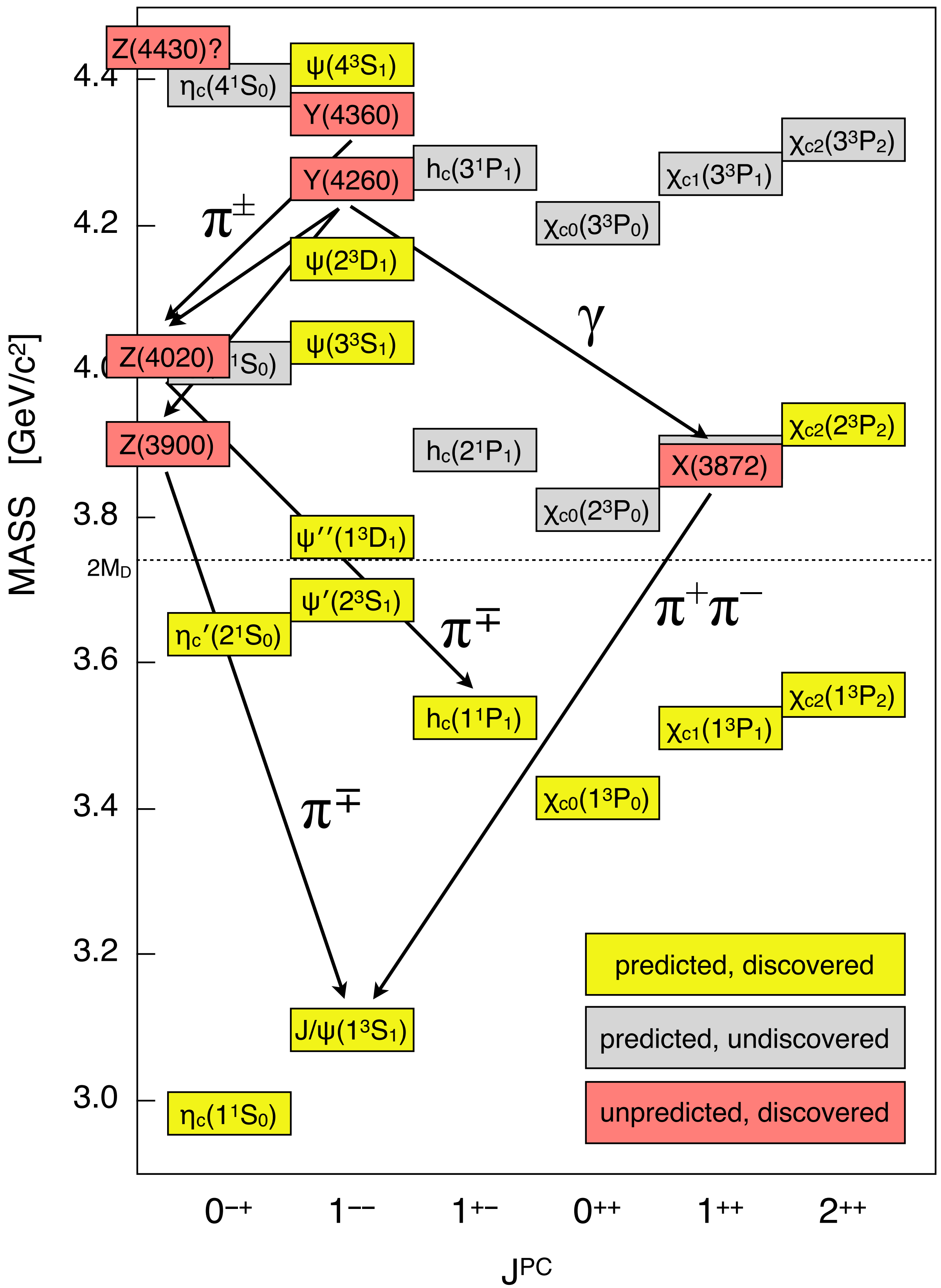

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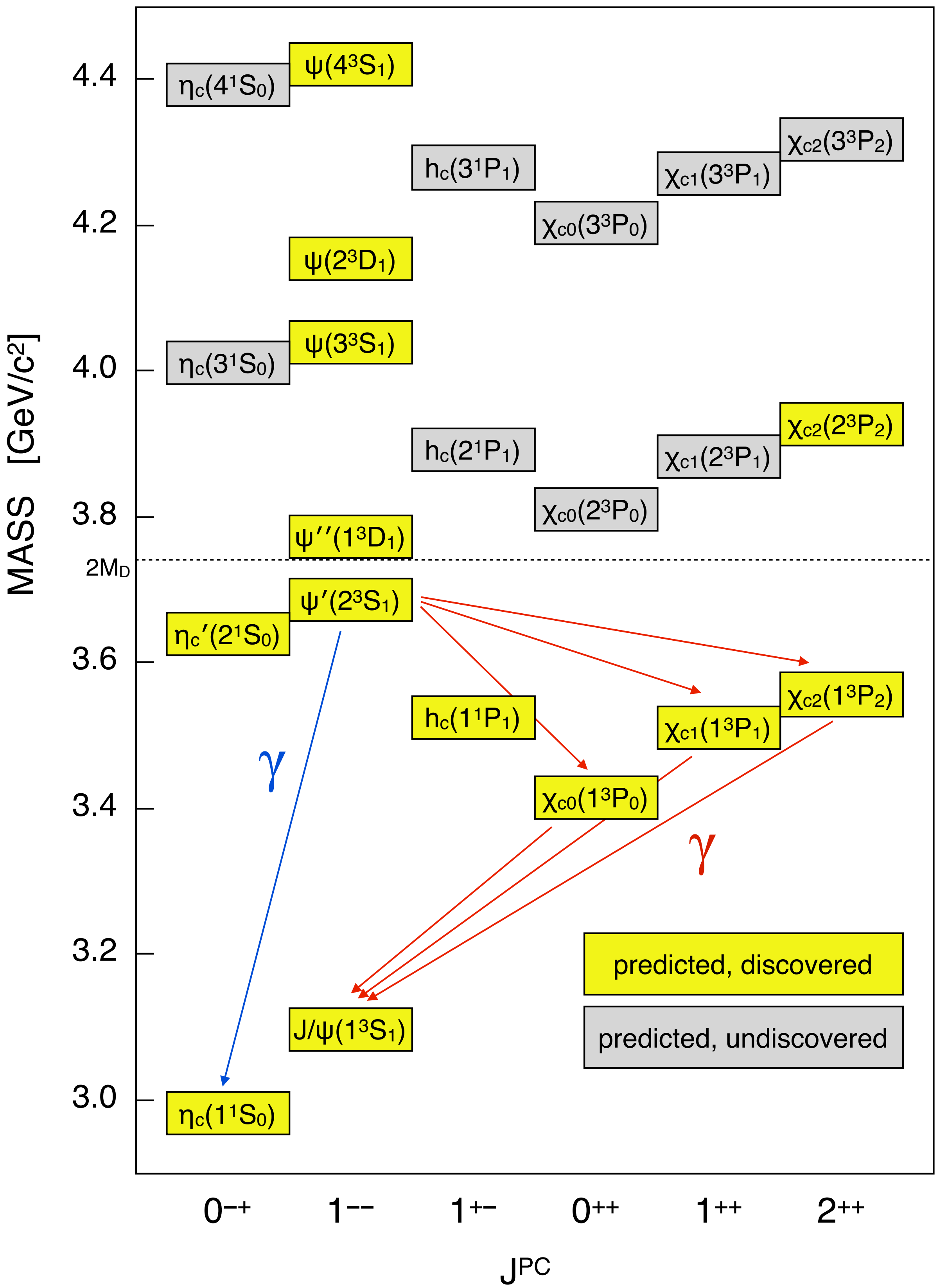

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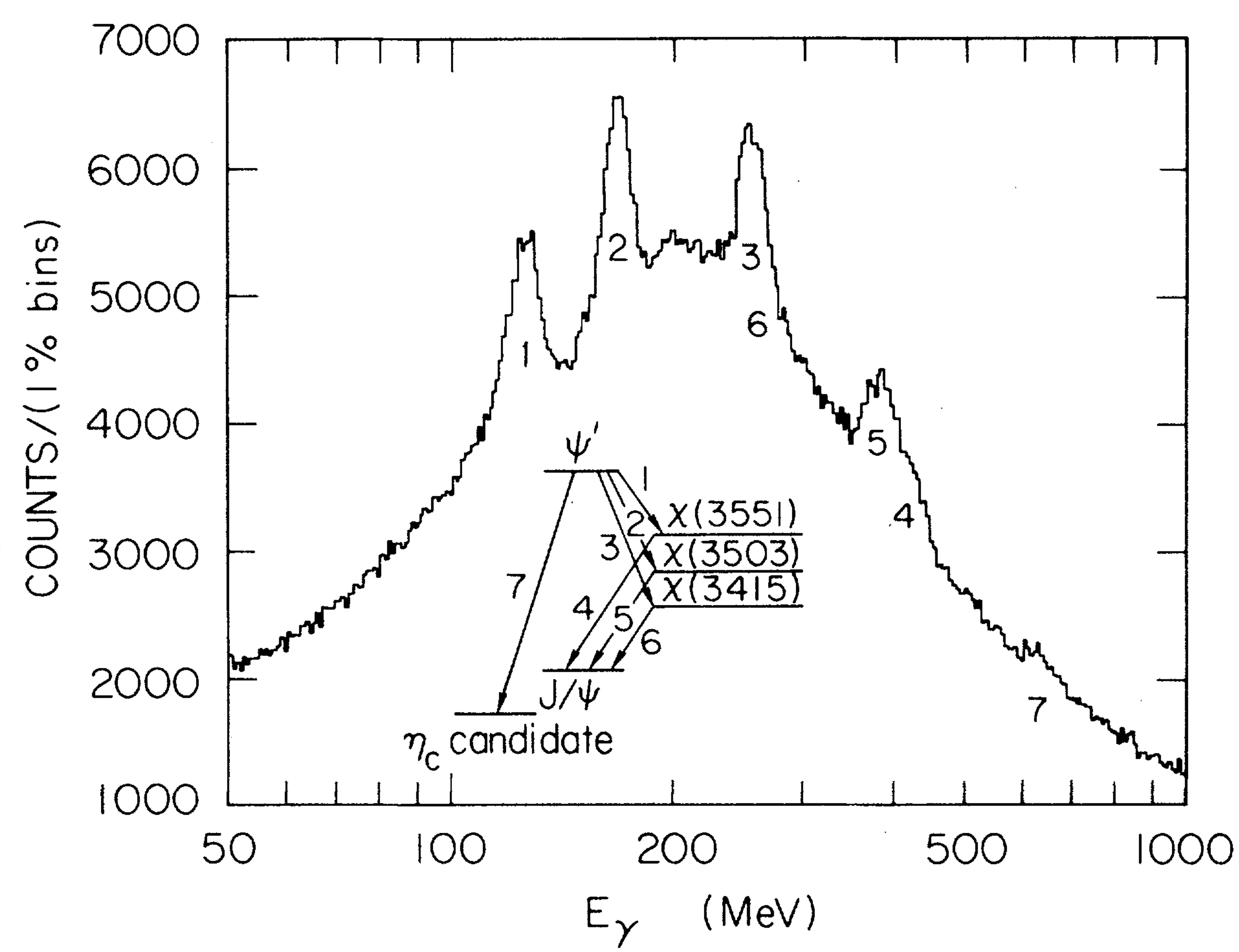
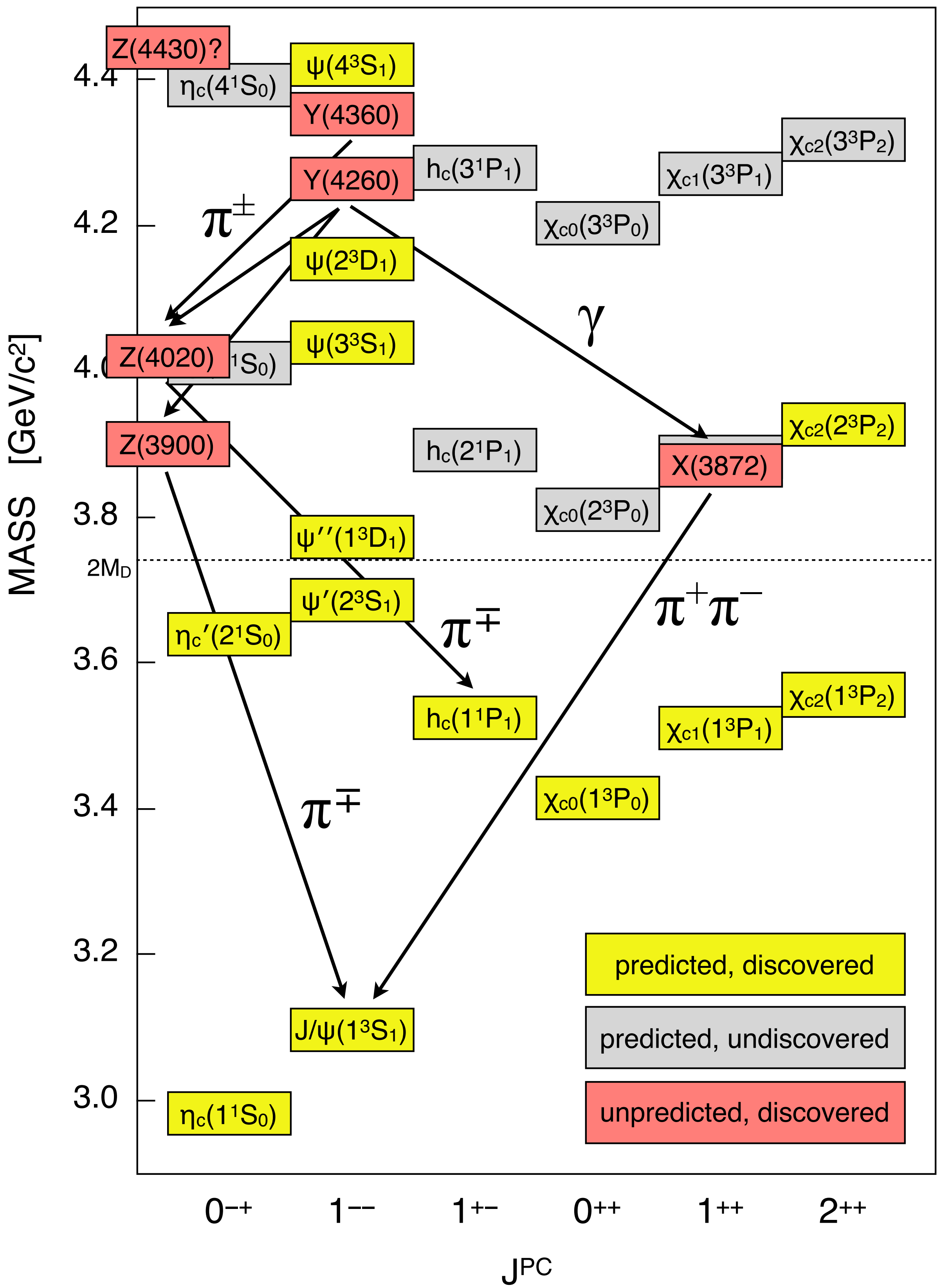
Crystal Ball at SLAC
(discovery of η_c)



PRL45, 1150 (1980)

Connecting the XYZ at BESIII



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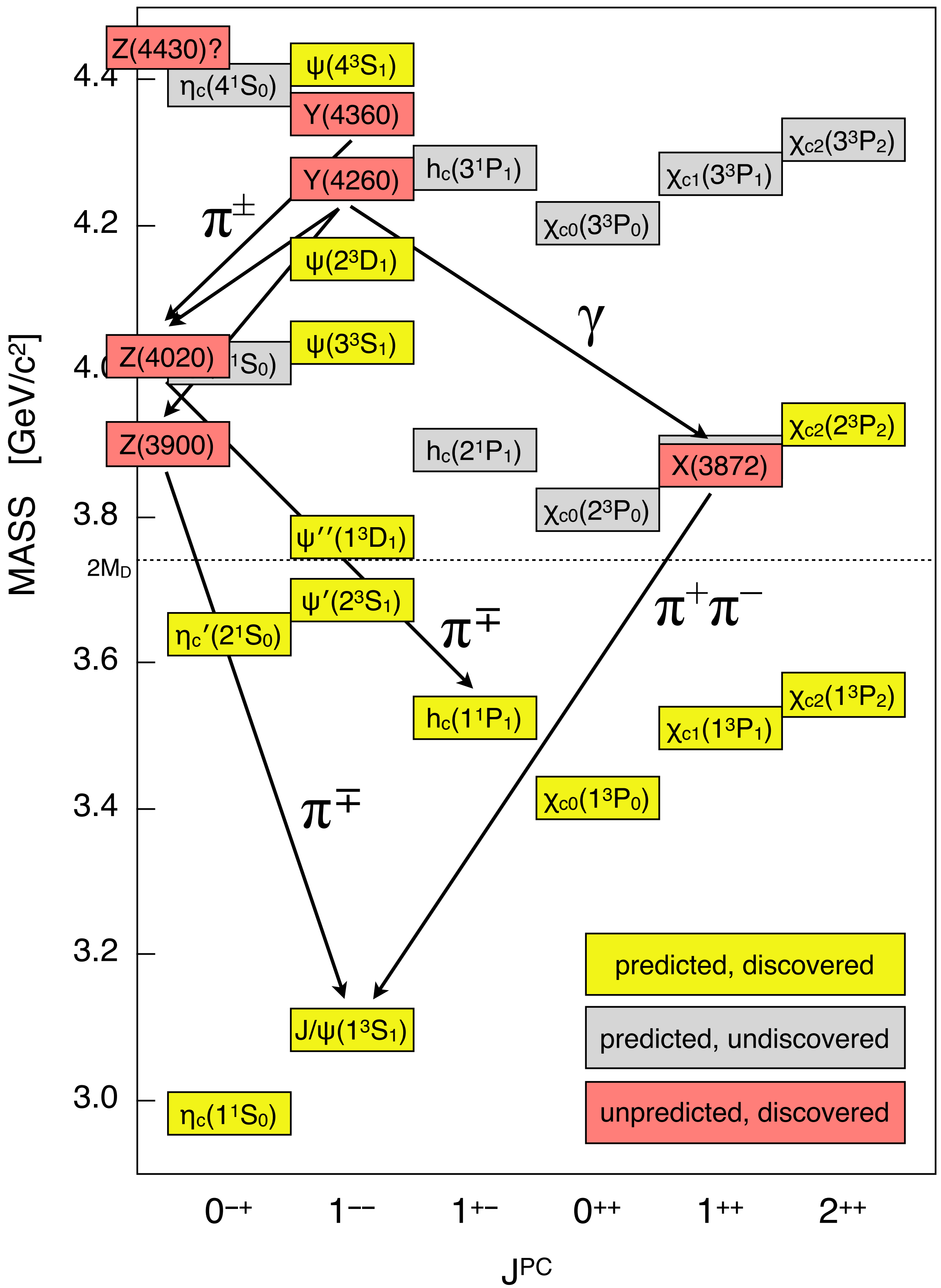

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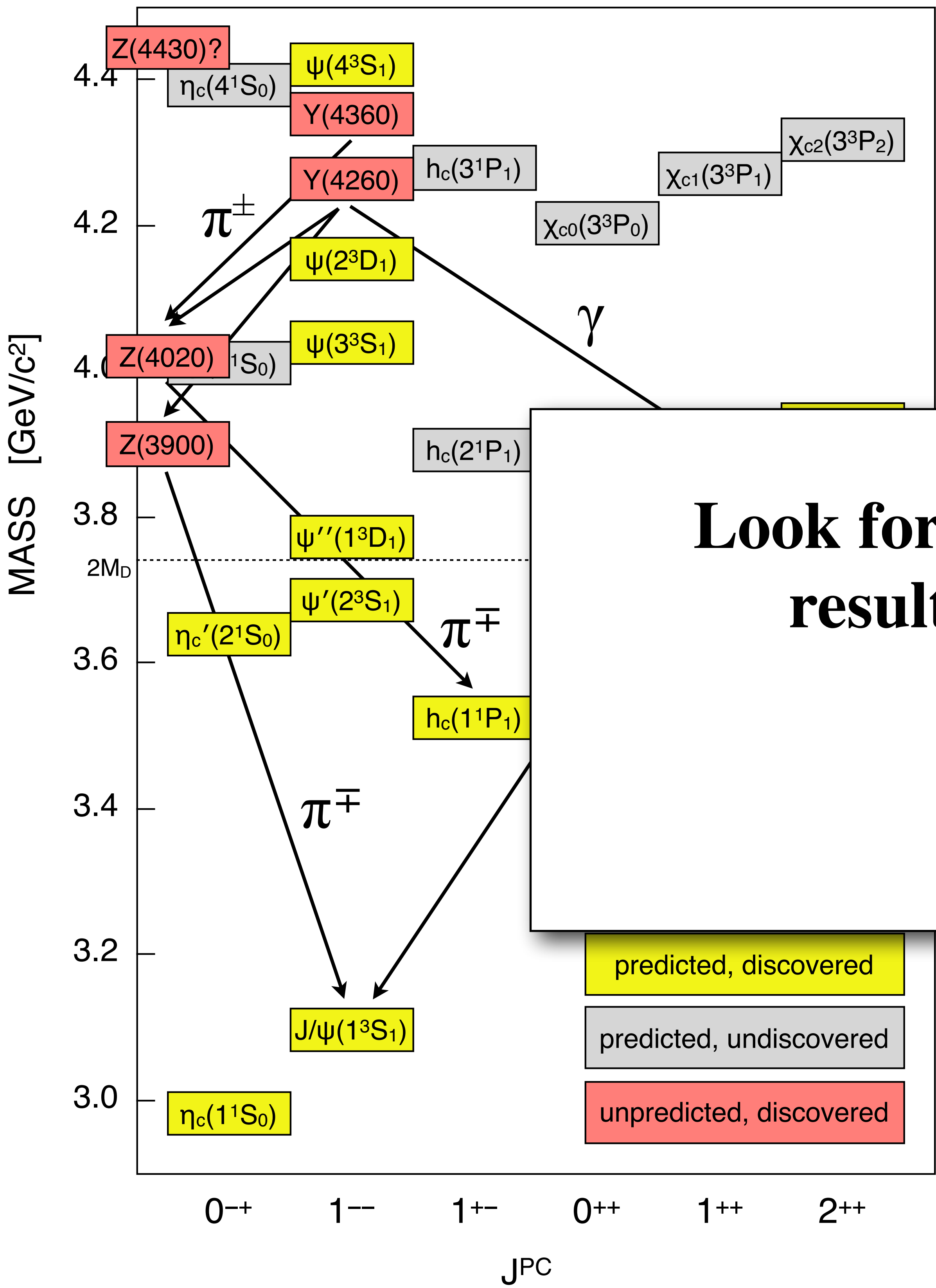

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Look forward to many new results from BESIII!

Thanks!