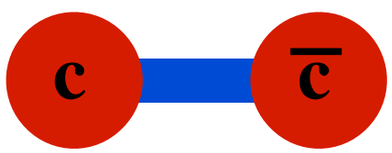
Prospects for Future Studies of the XYZ:

Belle II, BESIII, PANDA, GlueX

Ryan Mitchell
Indiana University
April 2013 APS Meeting

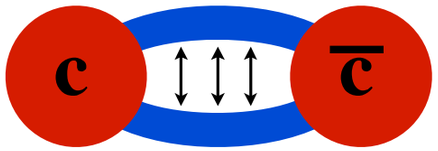
Three Goals of Experimental Meson Spectroscopy

1. Understand quark model states.



CHARMONIUM

2. Investigate new states.



HYBRID CHARMONIUM

3. Explore.

1. Understand quark model states.

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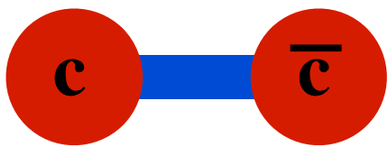

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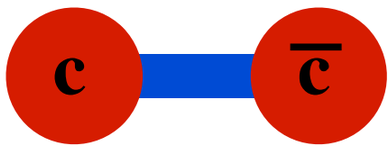

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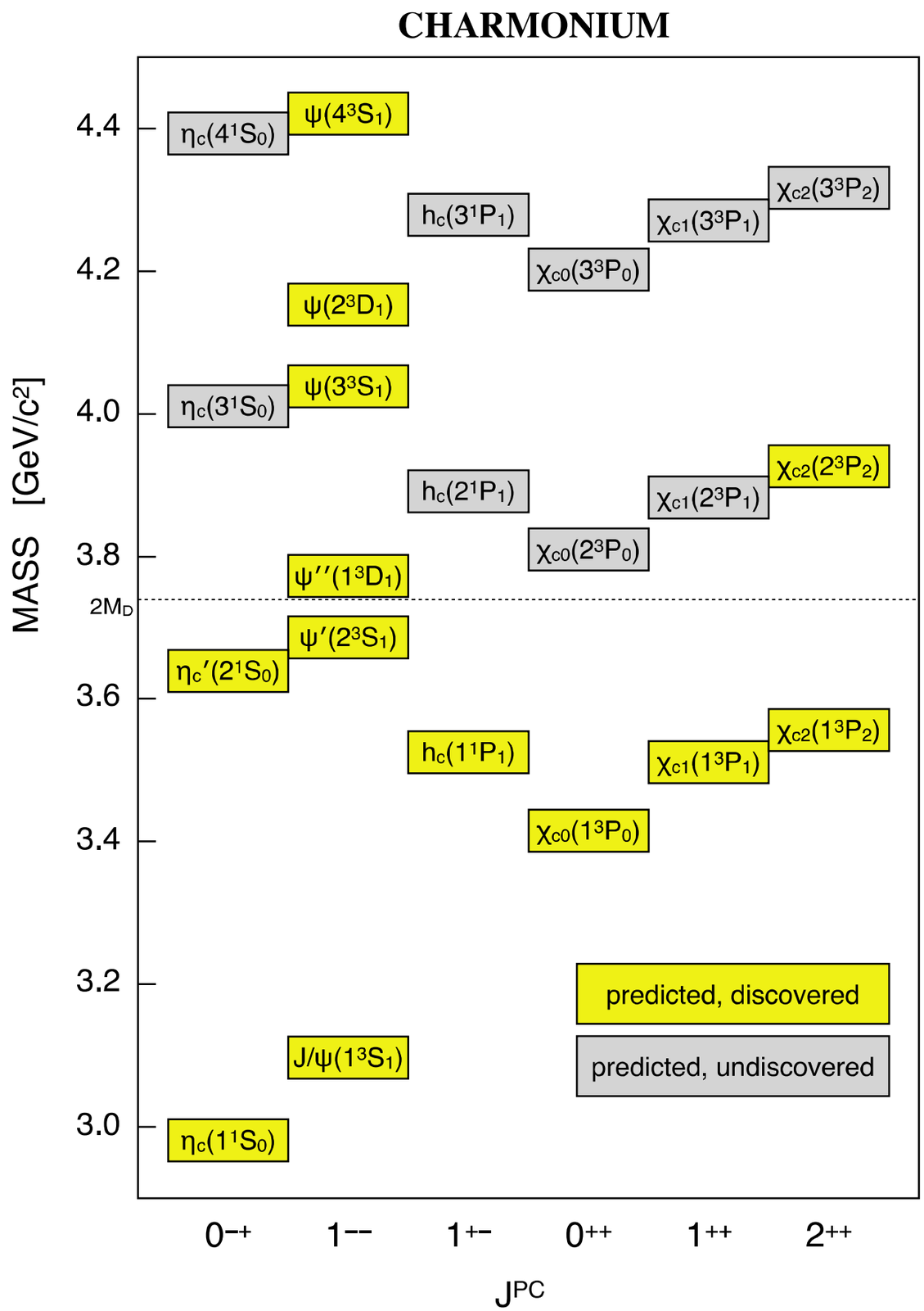

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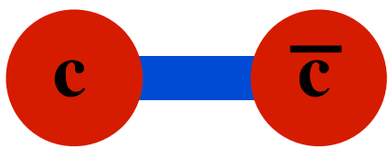

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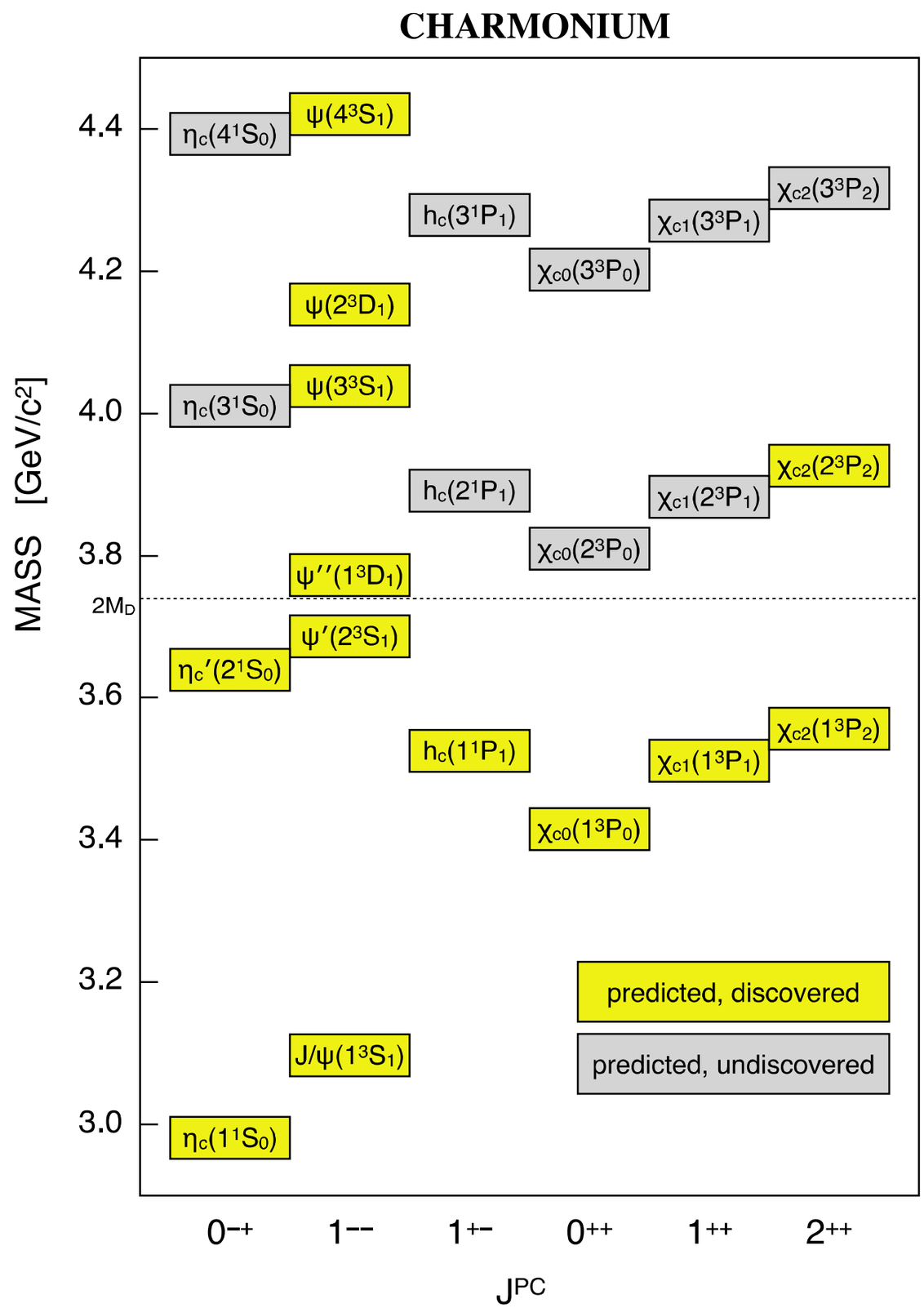

<u>Example:</u>

Use e^+e^- collisions to produce $\psi(2S)$ or J/ψ.

CLEO-c

location: Ithaca, NY, USA
accelerator: CESRc
dates: 2003 - 2008

BESIII

location: Beijing, China
accelerator: BEPC-II
dates: 2008 - present

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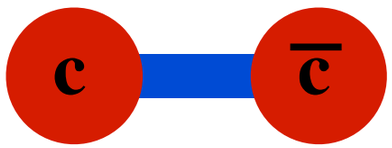

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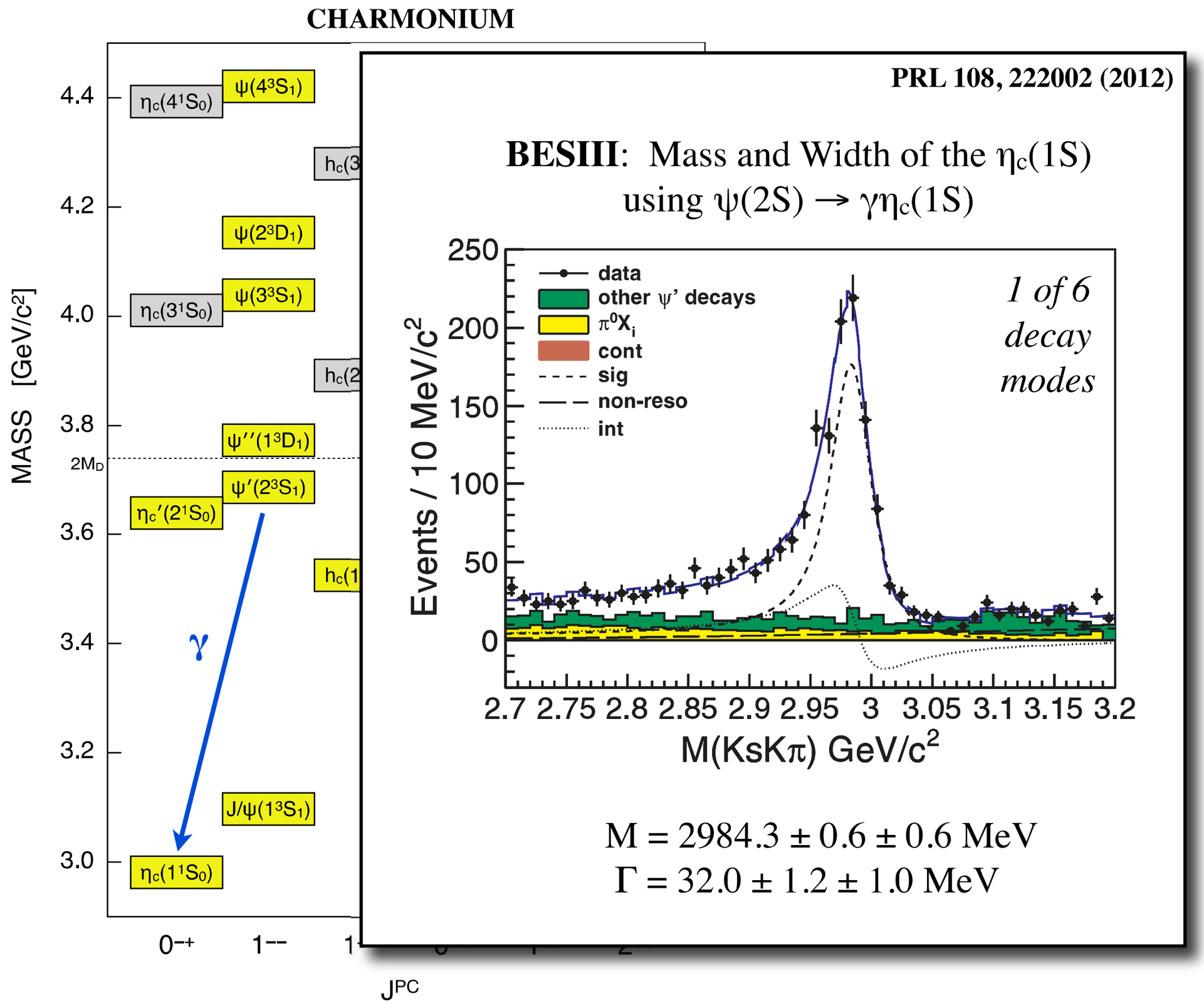

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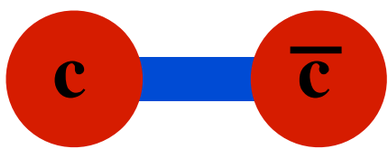

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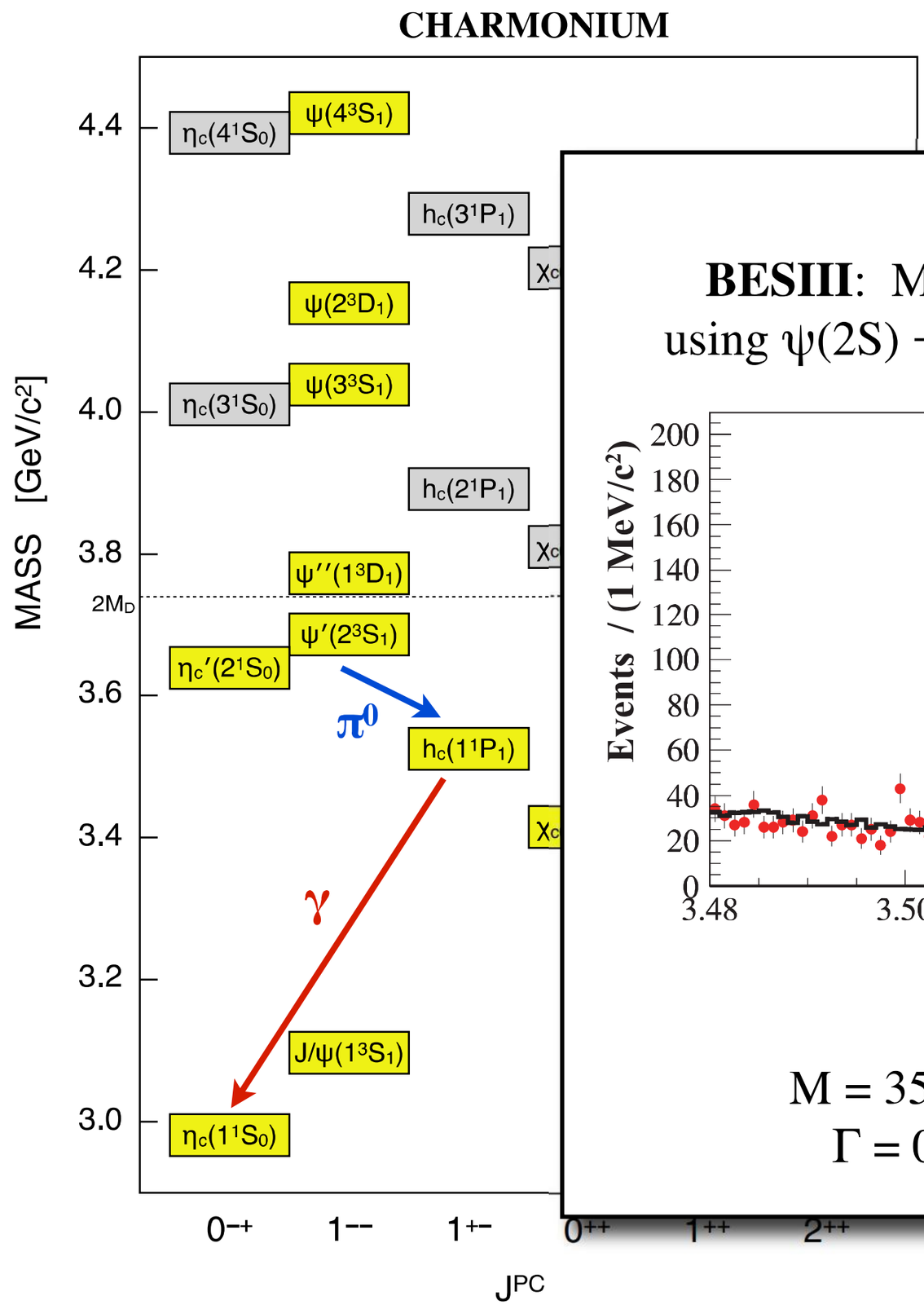
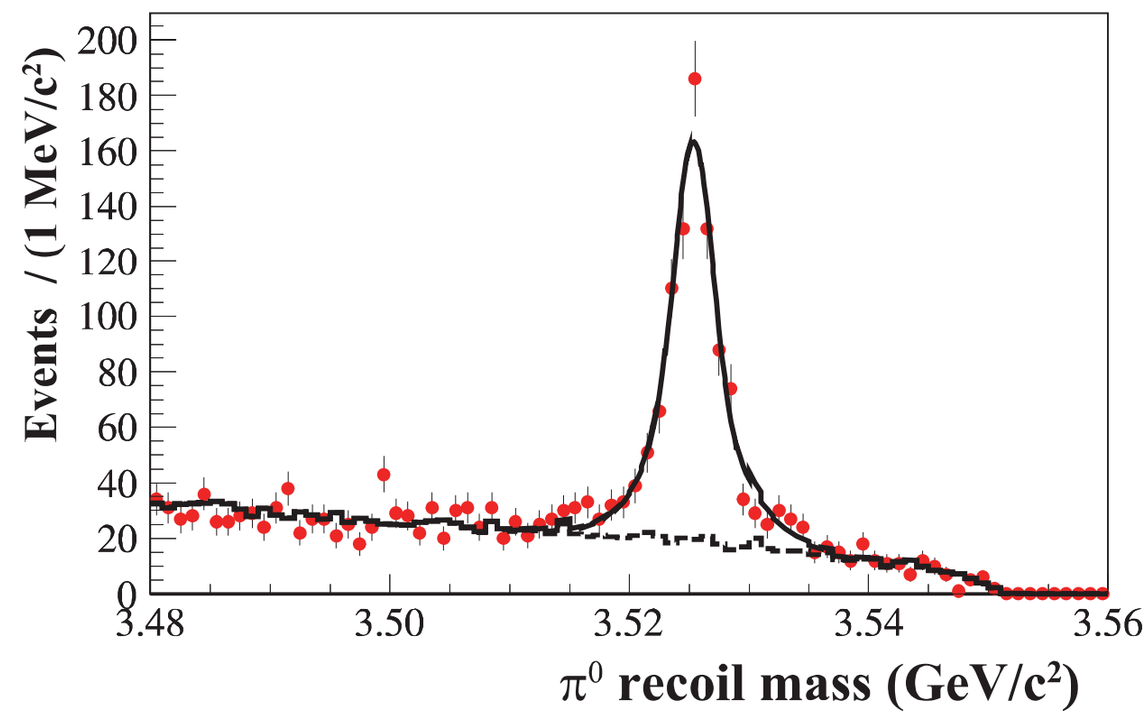


PRD 86, 092009 (2012)

BESIII: Mass and Width of the $h_c(1P)$ using $\psi(2S) \rightarrow \pi^0 h_c(1P)$; $h_c(1P) \rightarrow \gamma\eta_c(1S)$



$M = 3525.31 \pm 0.11 \pm 0.14$ MeV

$\Gamma = 0.70 \pm 0.28 \pm 0.22$ MeV

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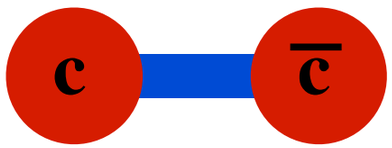

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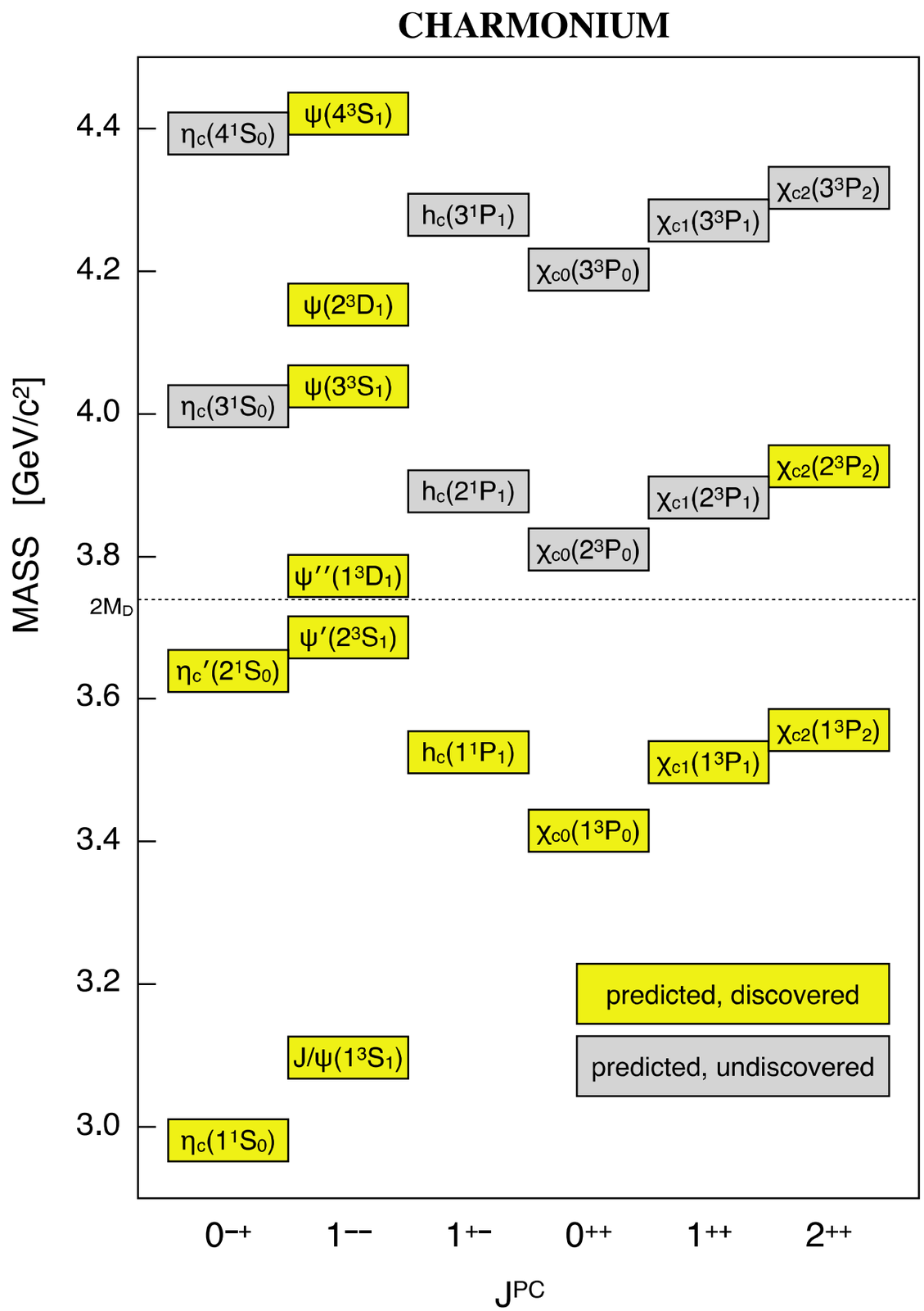

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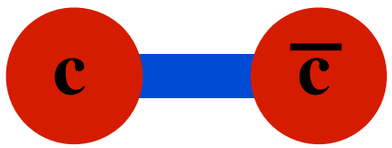

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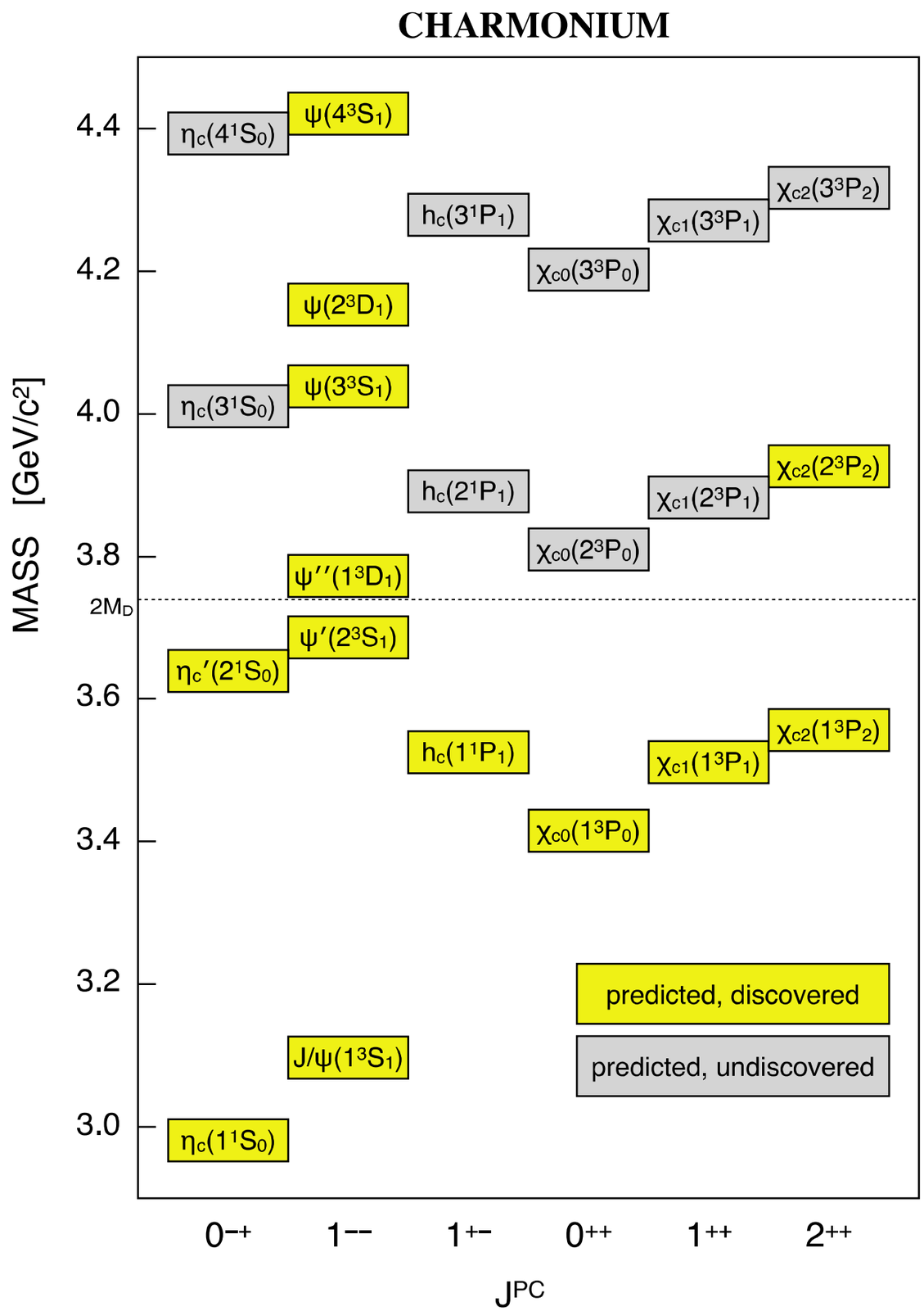

quark model states

$\Upsilon(bb)$

$\psi(cc)$

$\phi(ss)$

$\omega(nn)$
$\varrho(nn)$

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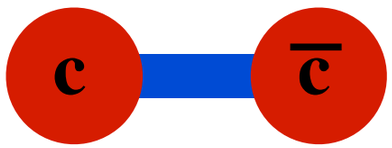

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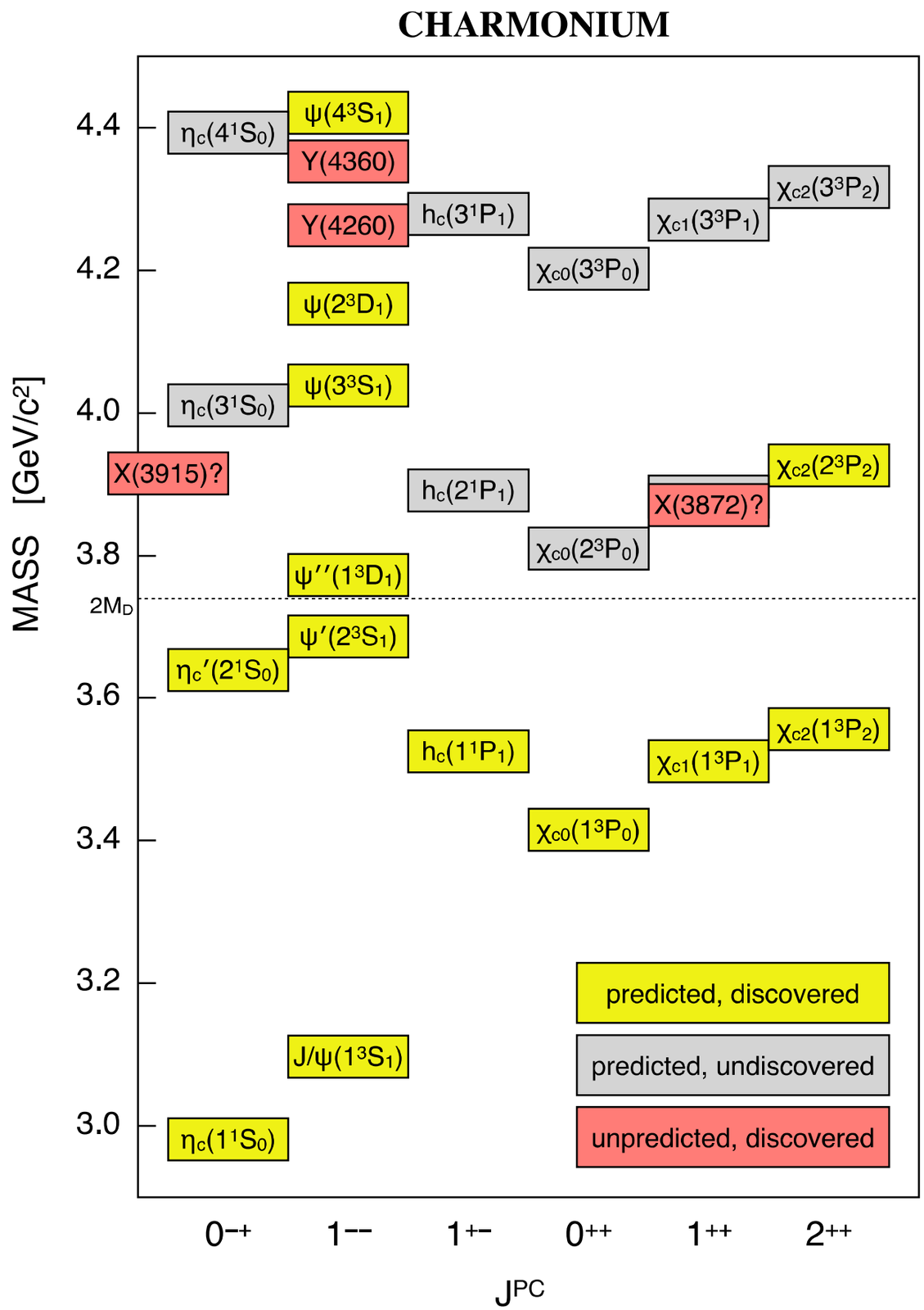

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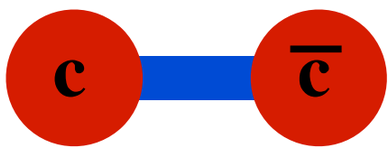

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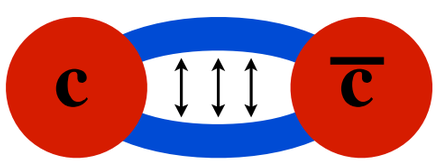

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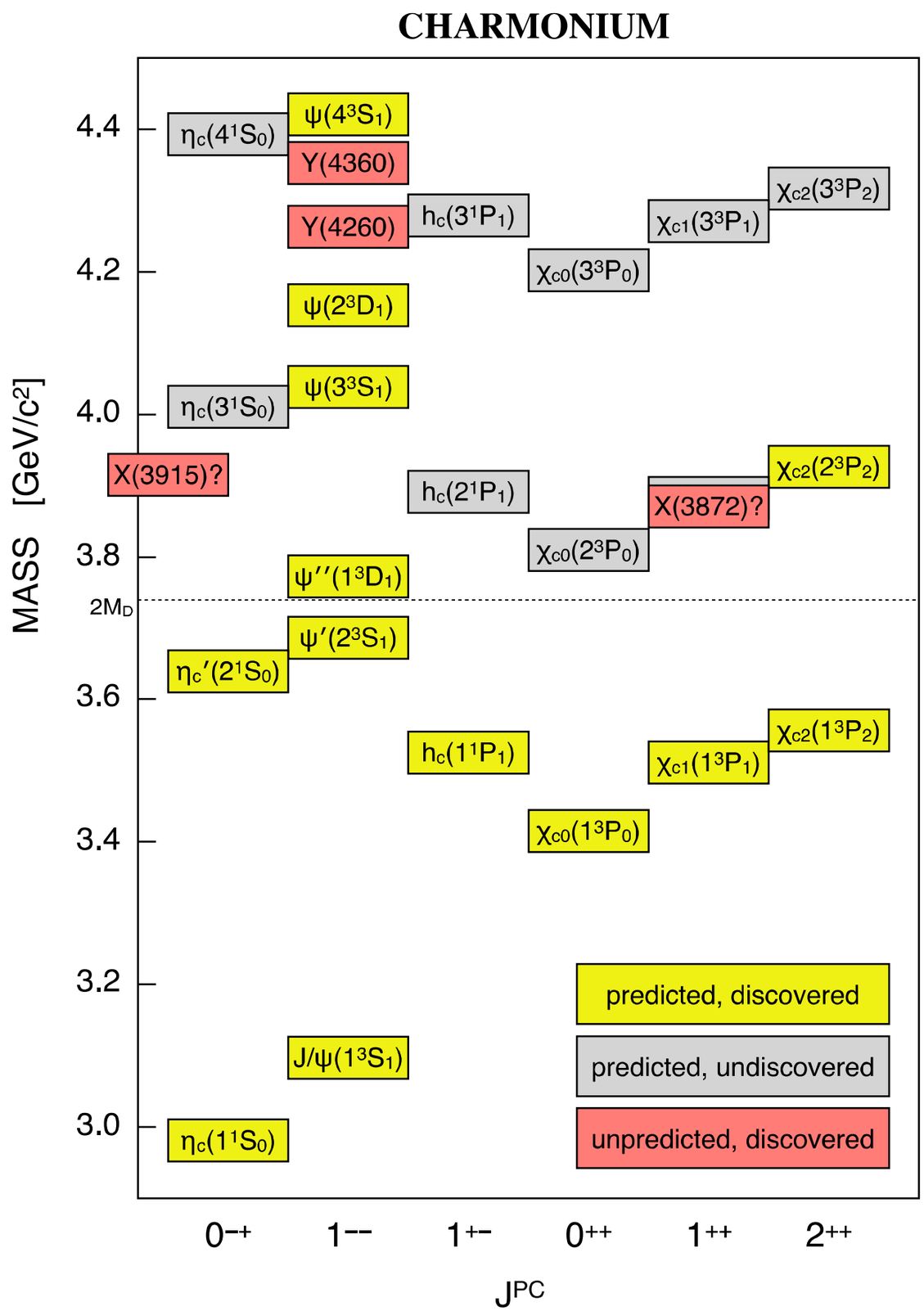

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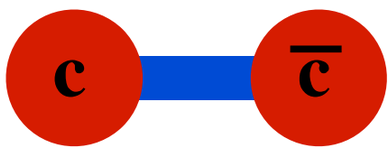

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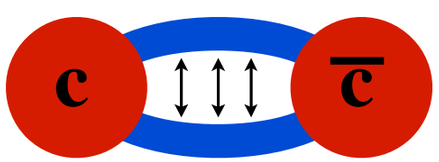

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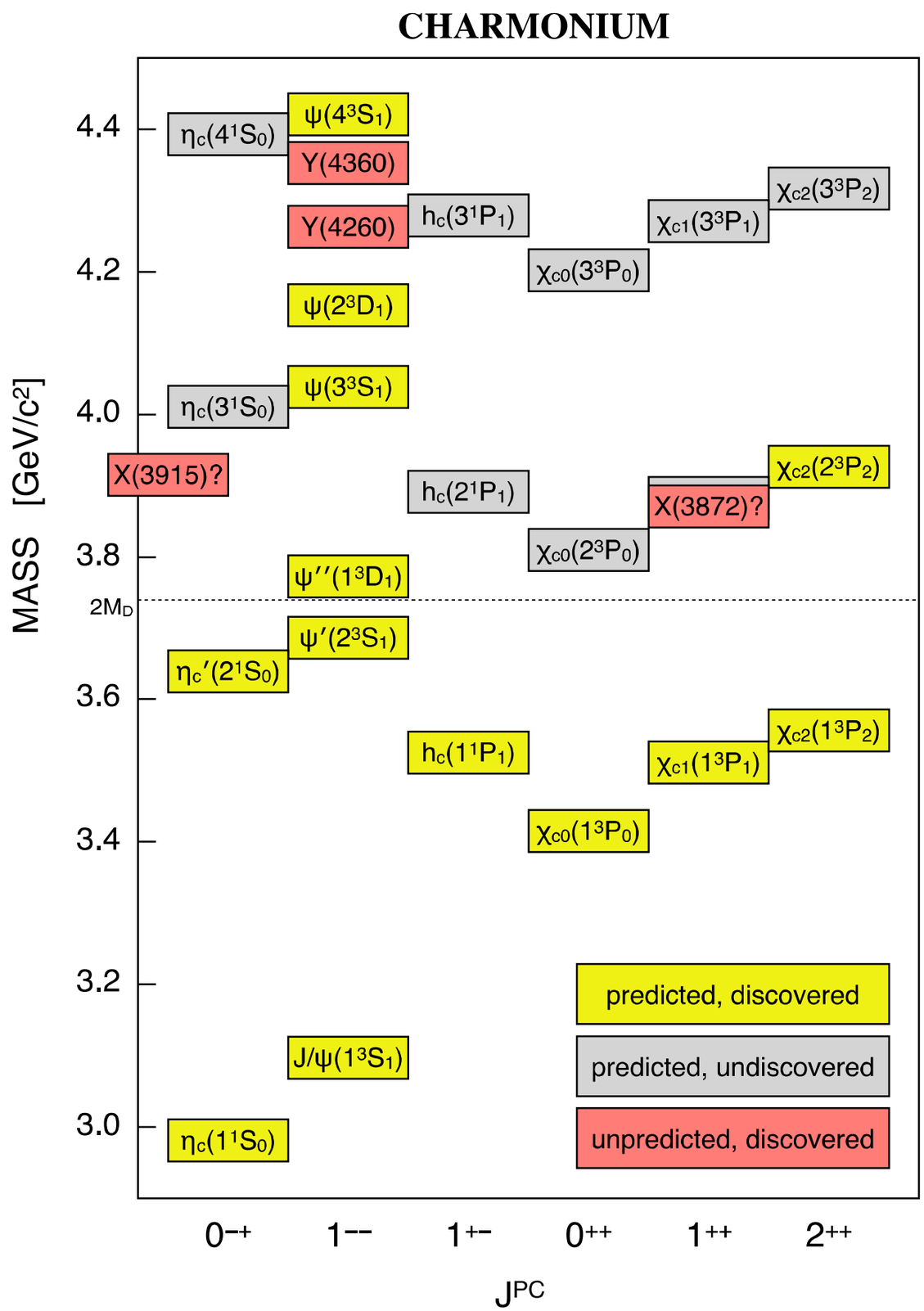

Example:

Use e^+e^- collisions at higher energies.

BaBar

location: Palo Alto, CA, USA
accelerator: PEP-II
dates: 1999 - 2008

Belle

location: Tsukuba, Japan
accelerator: KEKB
dates: 1999 - 2010

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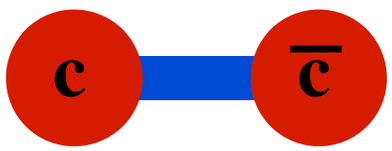

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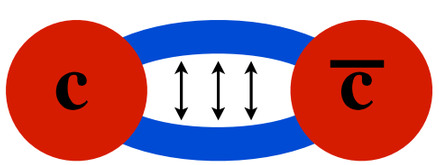

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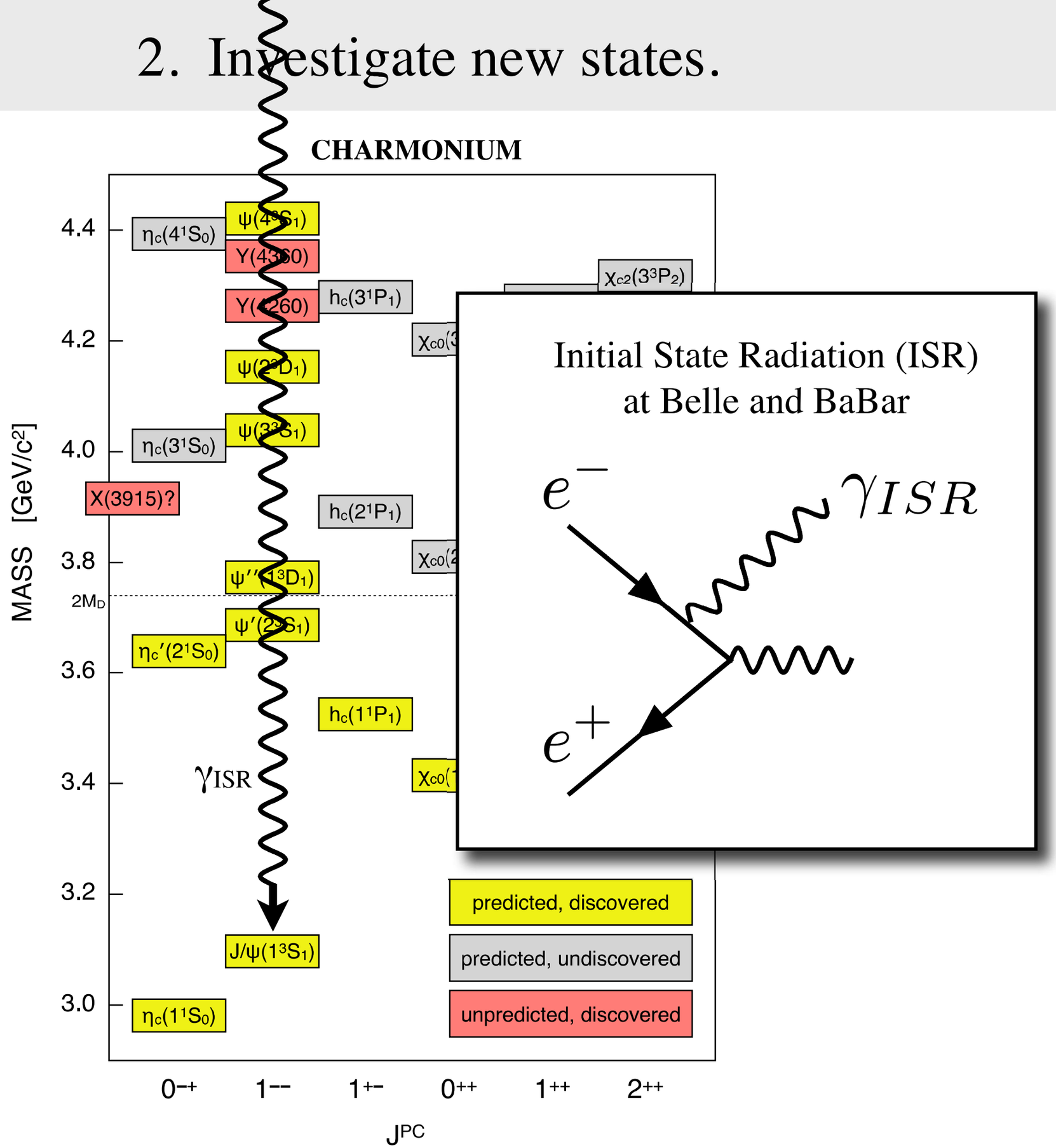

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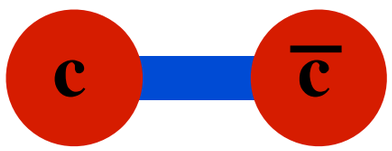

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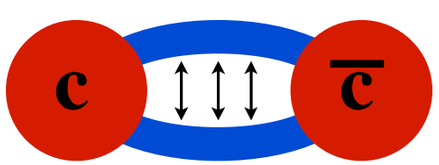

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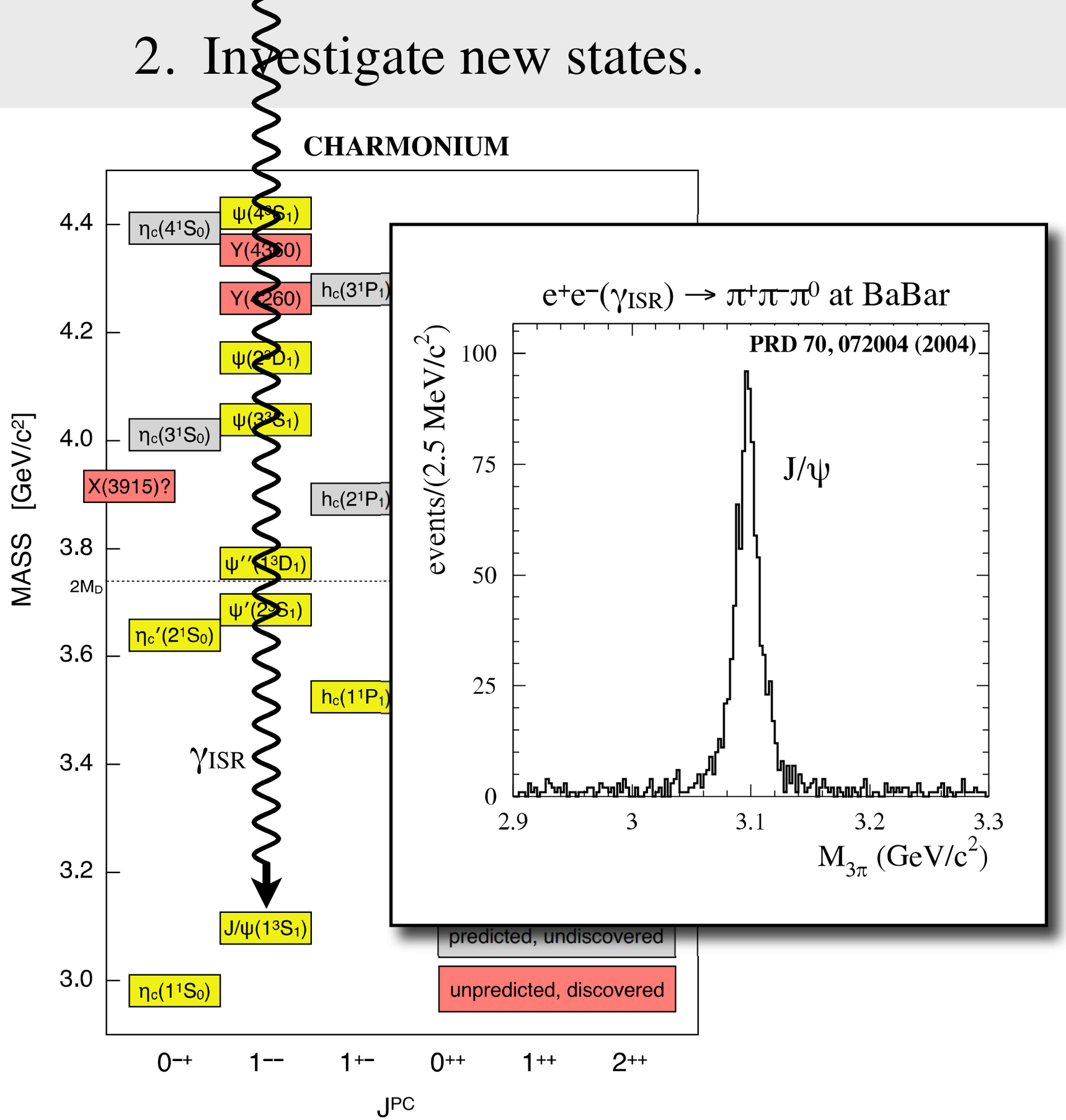

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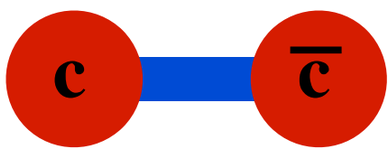

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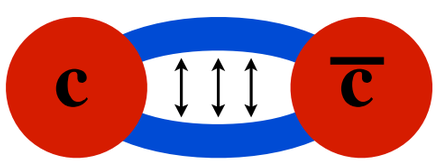

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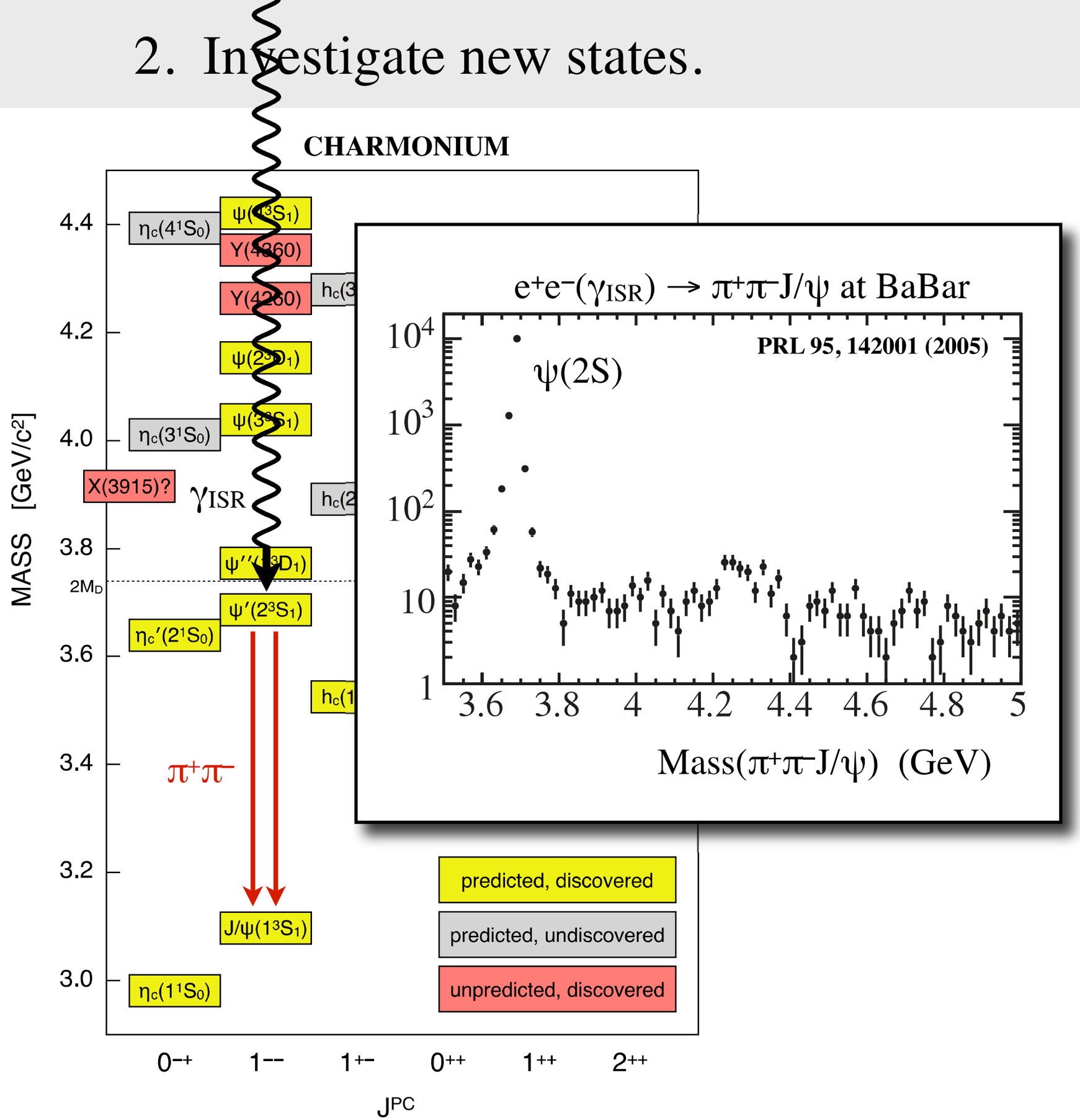

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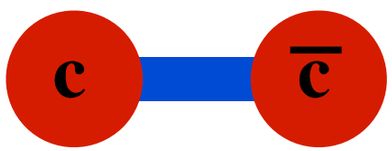

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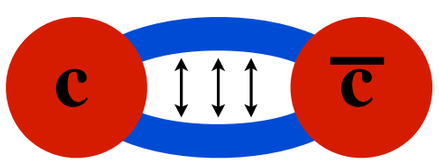

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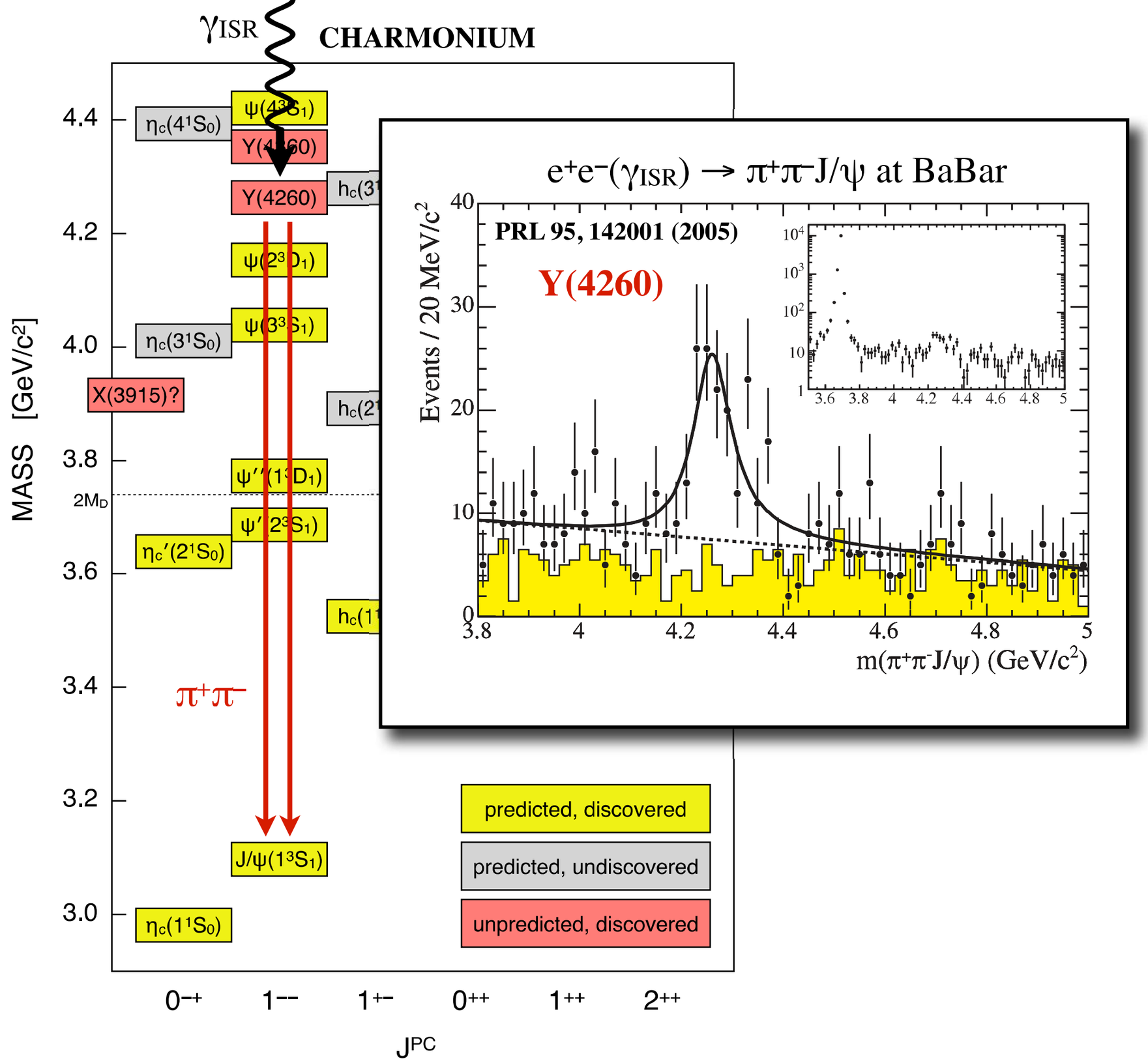

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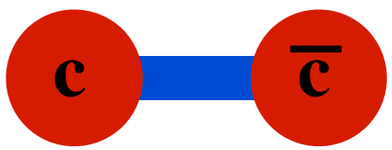

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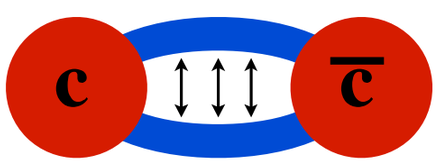

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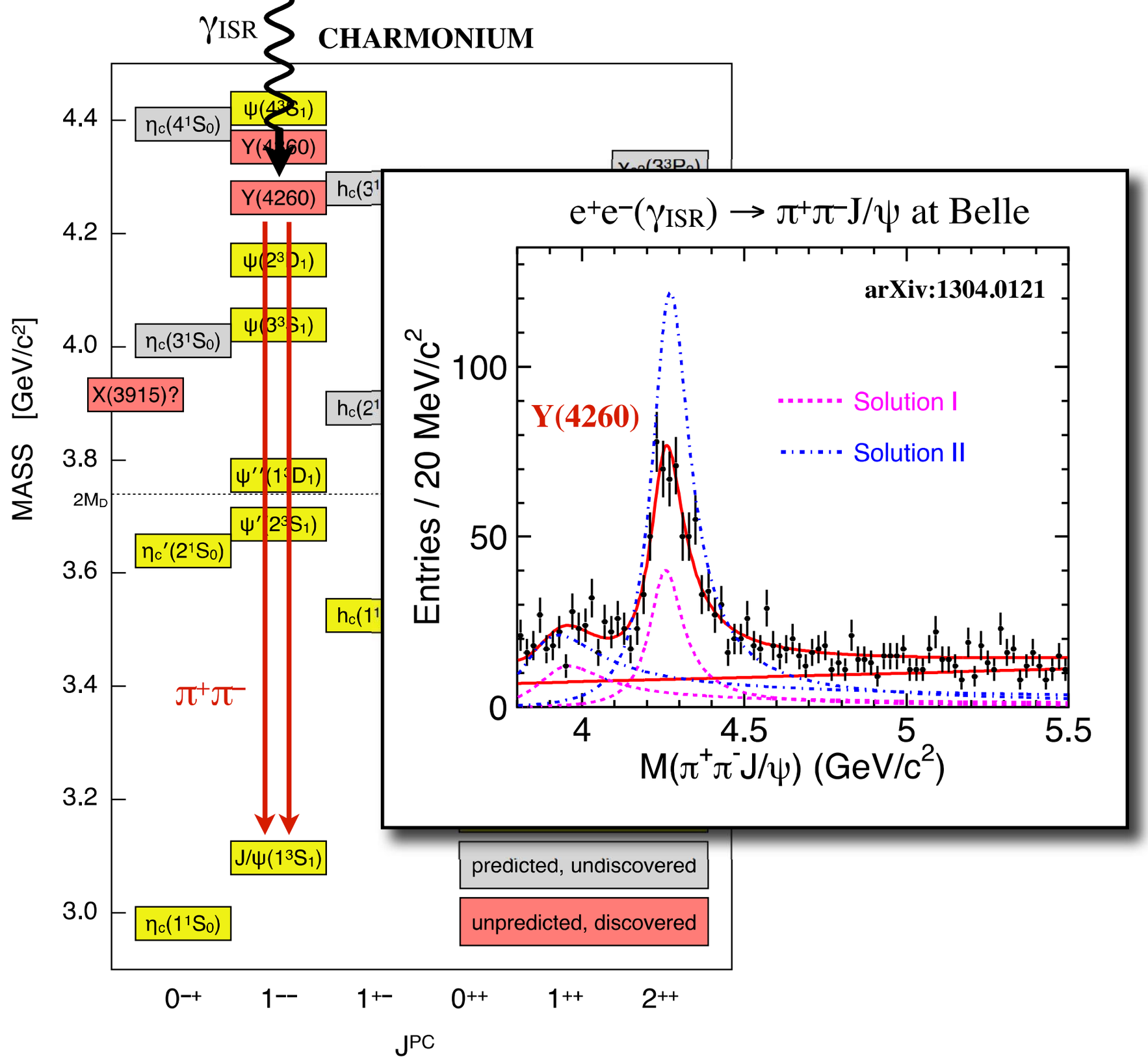

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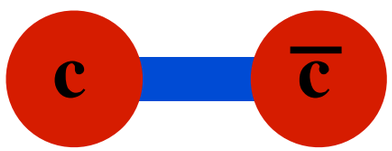

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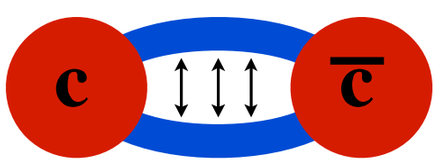

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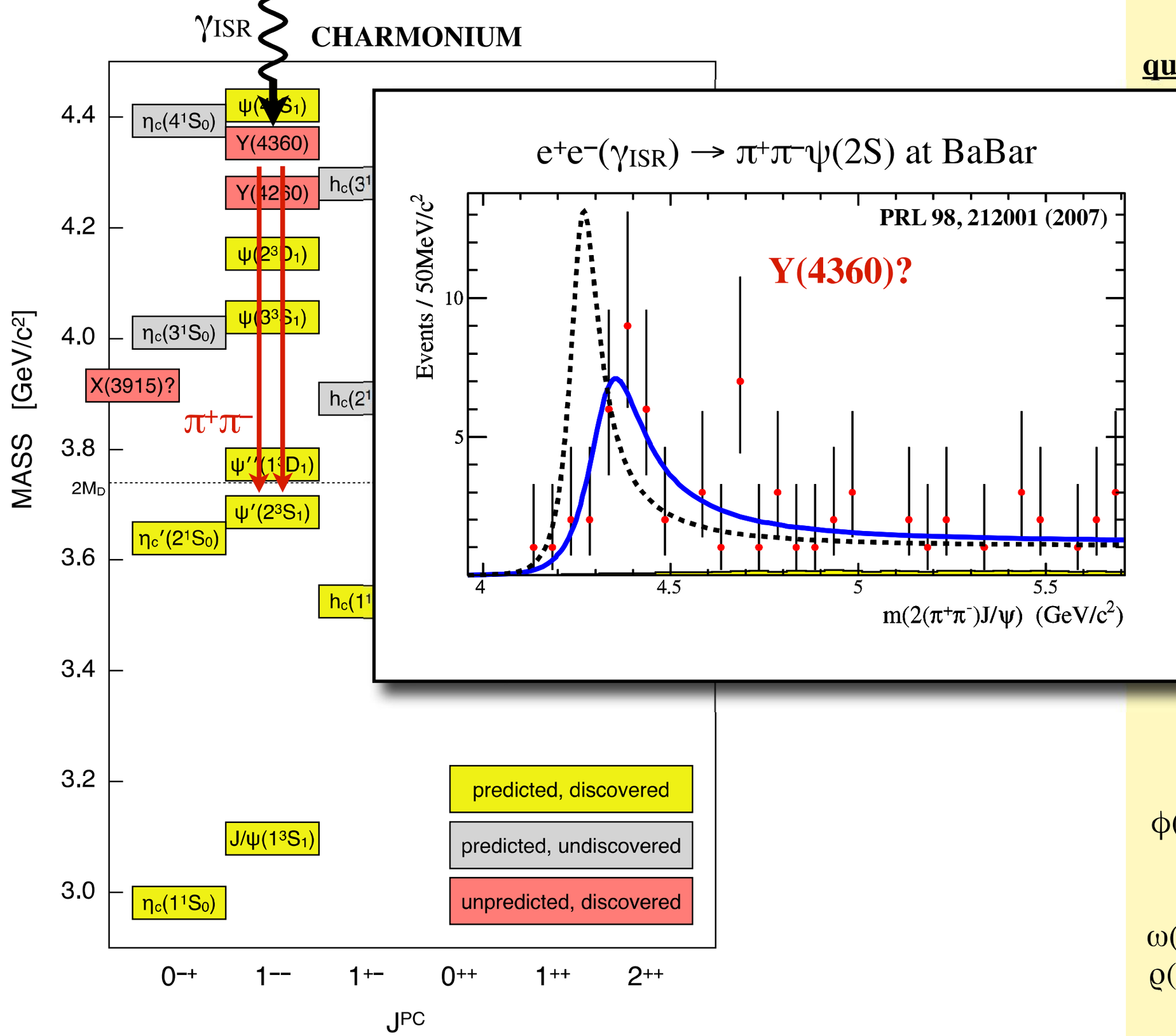

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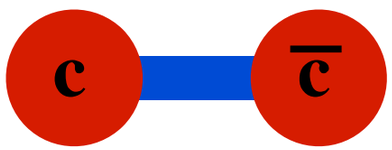

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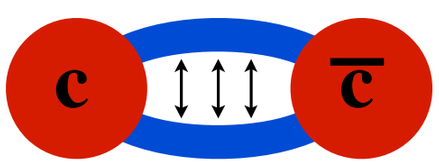

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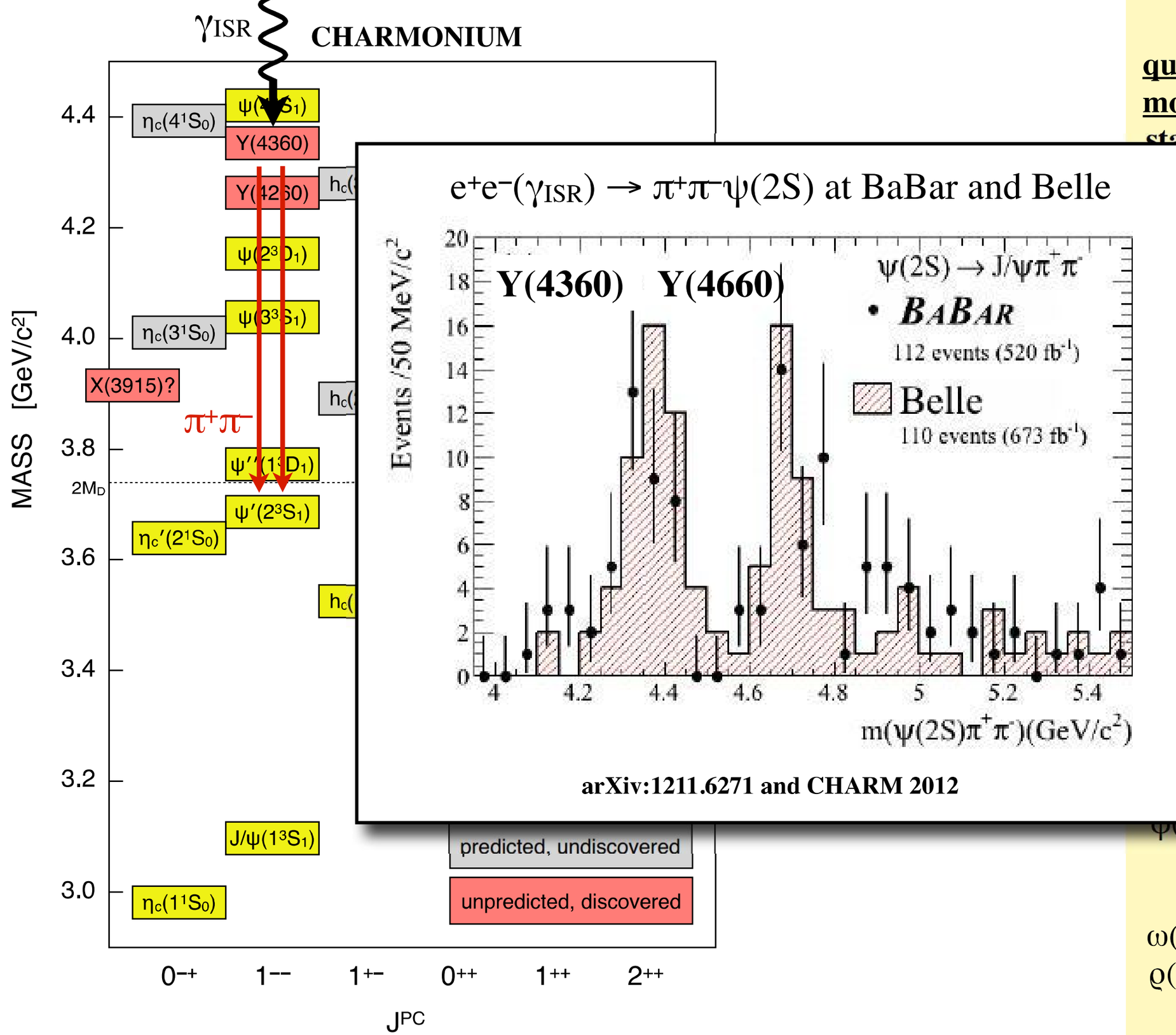

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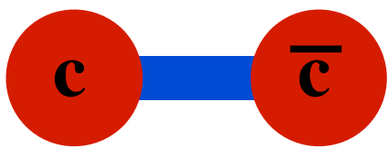

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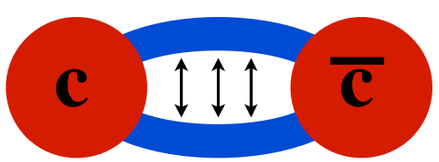

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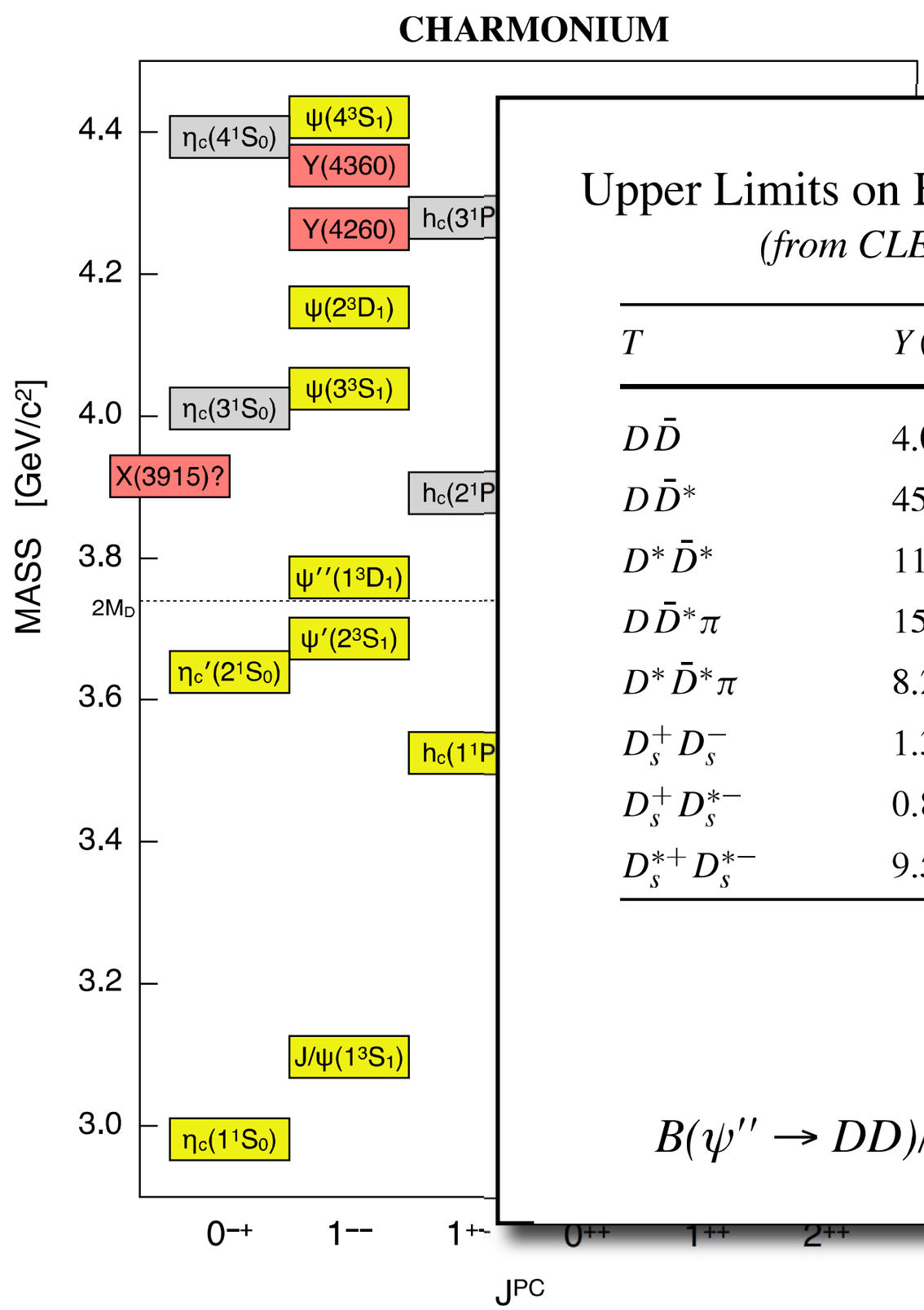

Upper Limits on B(Y → DD) / B(Y → ππψ)

(from CLEO, BaBar, and Belle)

T	$Y(4260)$	$Y(4360)$
$D\bar{D}$	4.0 [16], 7.6 [27]	
$D\bar{D}^*$	45 [16], 34 [28]	
$D^*\bar{D}^*$	11 [16], 40 [28]	
$D\bar{D}^*\pi$	15 [16], 9 [22]	8 [22]
$D^*\bar{D}^*\pi$	8.2 [16]	
$D_s^+D_s^-$	1.3 [16], 0.7 [29]	
$D_s^+D_s^{*-}$	0.8 [16], 44 [29]	
$D_s^{*+}D_s^{*-}$	9.5 [16]	

EPJ C71, 1534 (2011)

$$B(\psi'' \to DD)/B(\psi'' \to \pi\pi\psi) \approx 500$$

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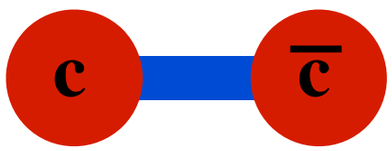

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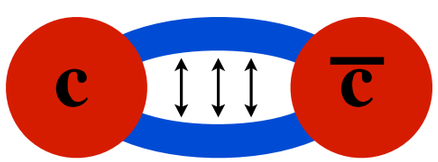
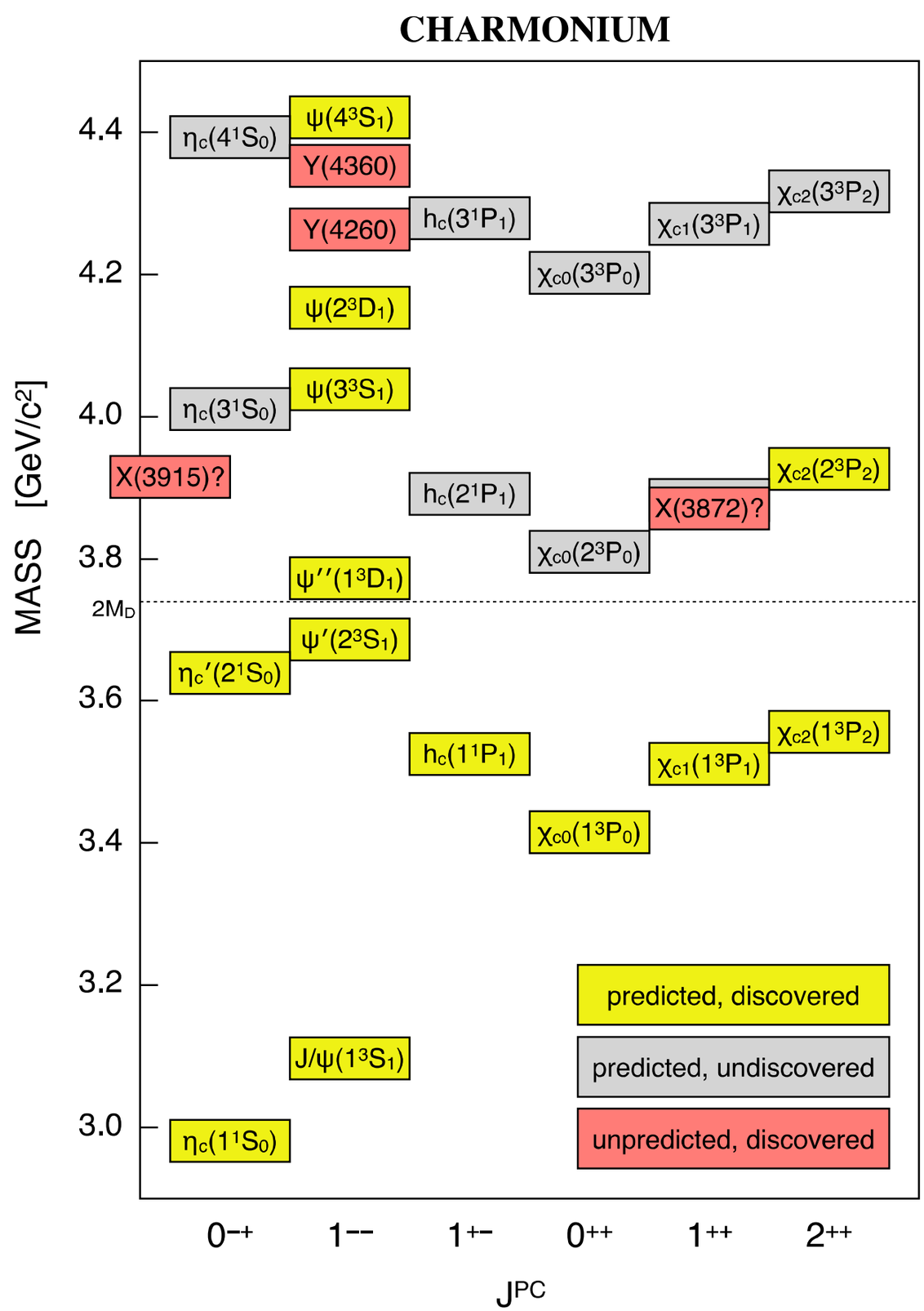


HYBRID CHARMONIUM



quark model states

ϒ(bb)

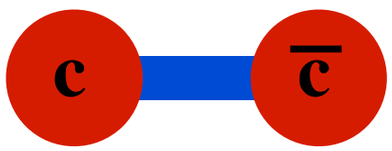
ψ(cc)

ϕ(ss)

ω(nn)
ϱ(nn)

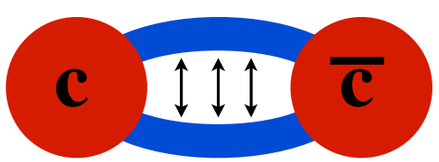
2. Investigate new states.

1. Understand quark model states.

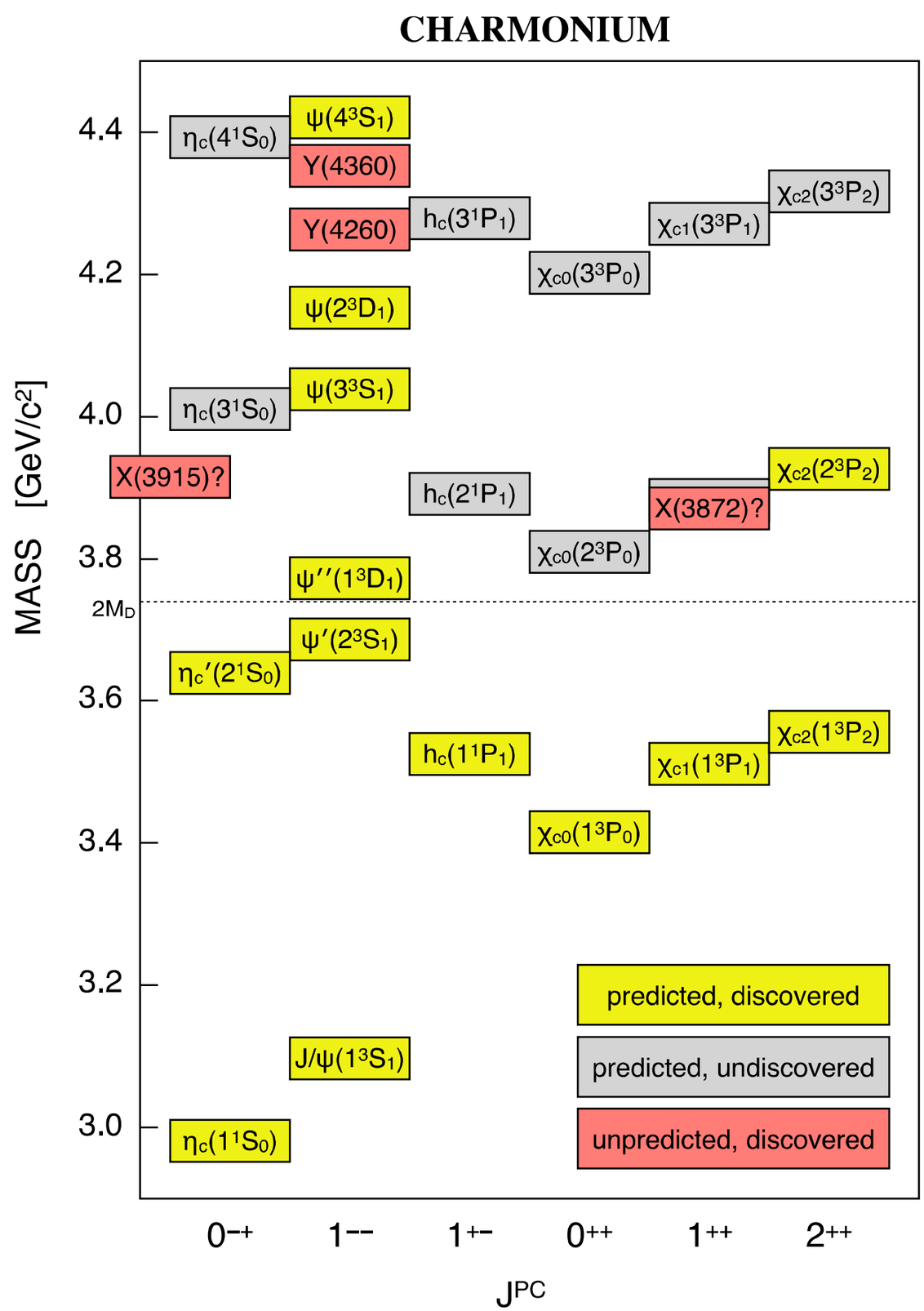


CHARMONIUM

2. Investigate new states.



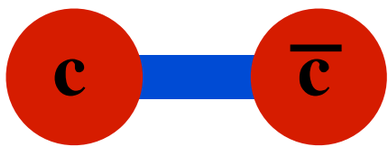
HYBRID CHARMONIUM



"beyond" quark model states	**quark model states**
$Y_b(10890)$	$\Upsilon(bb)$
$Y(4260)$	
$X(3872)$	
	$\psi(cc)$
$Y_s(2175)$	
$\pi_1(1600)$	
	$\phi(ss)$
	$\omega(nn)$
	$\varrho(nn)$

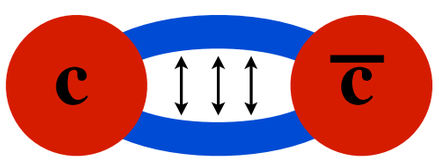
2. Investigate new states.

1. Understand quark model states.



CHARMONIUM

2. Investigate new states.



HYBRID CHARMONIUM

How can we learn more?

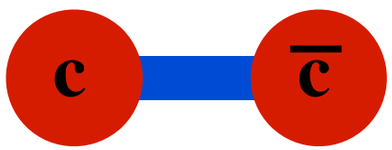
Measure properties more precisely.

Find new decays.

"beyond" quark model states	**quark model states**
$Y_b(10890)$	$\Upsilon(bb)$
$Y(4260)$	
$X(3872)$	
	$\psi(cc)$
$Y_s(2175)$	
$\pi_1(1600)$	
	$\phi(ss)$
	$\omega(nn)$
	$\varrho(nn)$

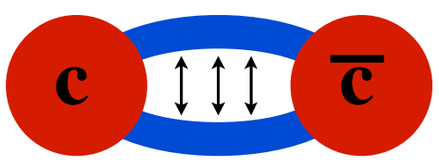
2. Investigate new states.

1. Understand quark model states.



CHARMONIUM

2. Investigate new states.



HYBRID CHARMONIUM

How can we learn more?

Measure properties more precisely.

Find new decays.

future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$\Upsilon_b(10890)$	$\Upsilon(bb)$
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PANDA	$X(3872)$	
GlueX	$Y_s(2175)$	$\psi(cc)$
	$\pi_1(1600)$	$\phi(ss)$
		$\omega(nn)$ $\varrho(nn)$

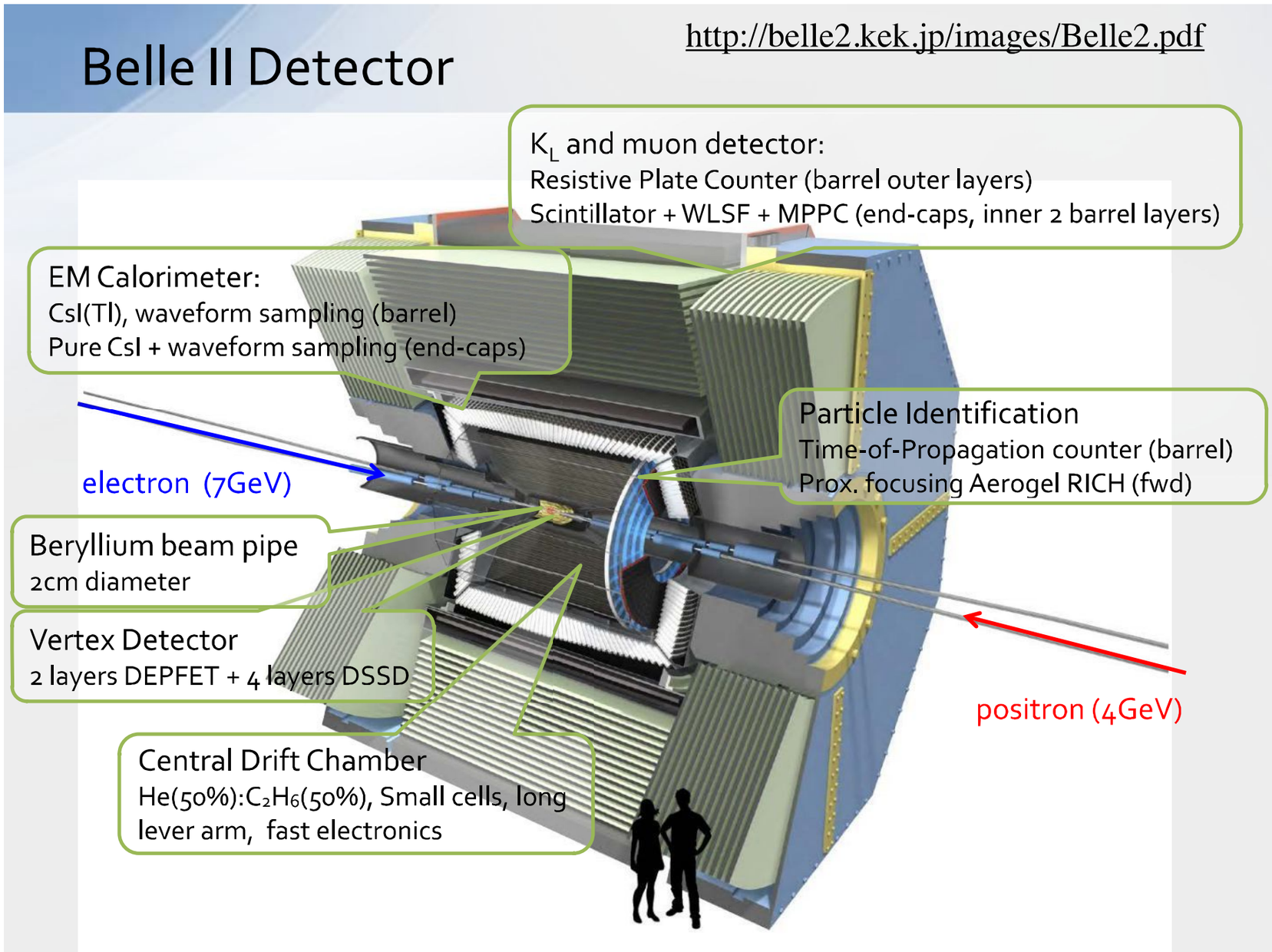
2A. Investigate new states with Belle II

Belle II
(e^+e^- collisions in the Υ(nS) region)

location: Tsukuba, Japan
accelerator: superKEKB
dates: ~2017 – ?

future and ongoing experiments	**"beyond" quark model states**	**quark model states**
Belle II	$Y_b(10890)$	$\Upsilon(bb)$
BESIII	Y(4260)	
PANDA	X(3872)	$\psi(cc)$
GlueX	$Y_s(2175)$ $\pi_1(1600)$	$\phi(ss)$ $\omega(nn)$ $\varrho(nn)$

2A. Investigate new states with Belle II

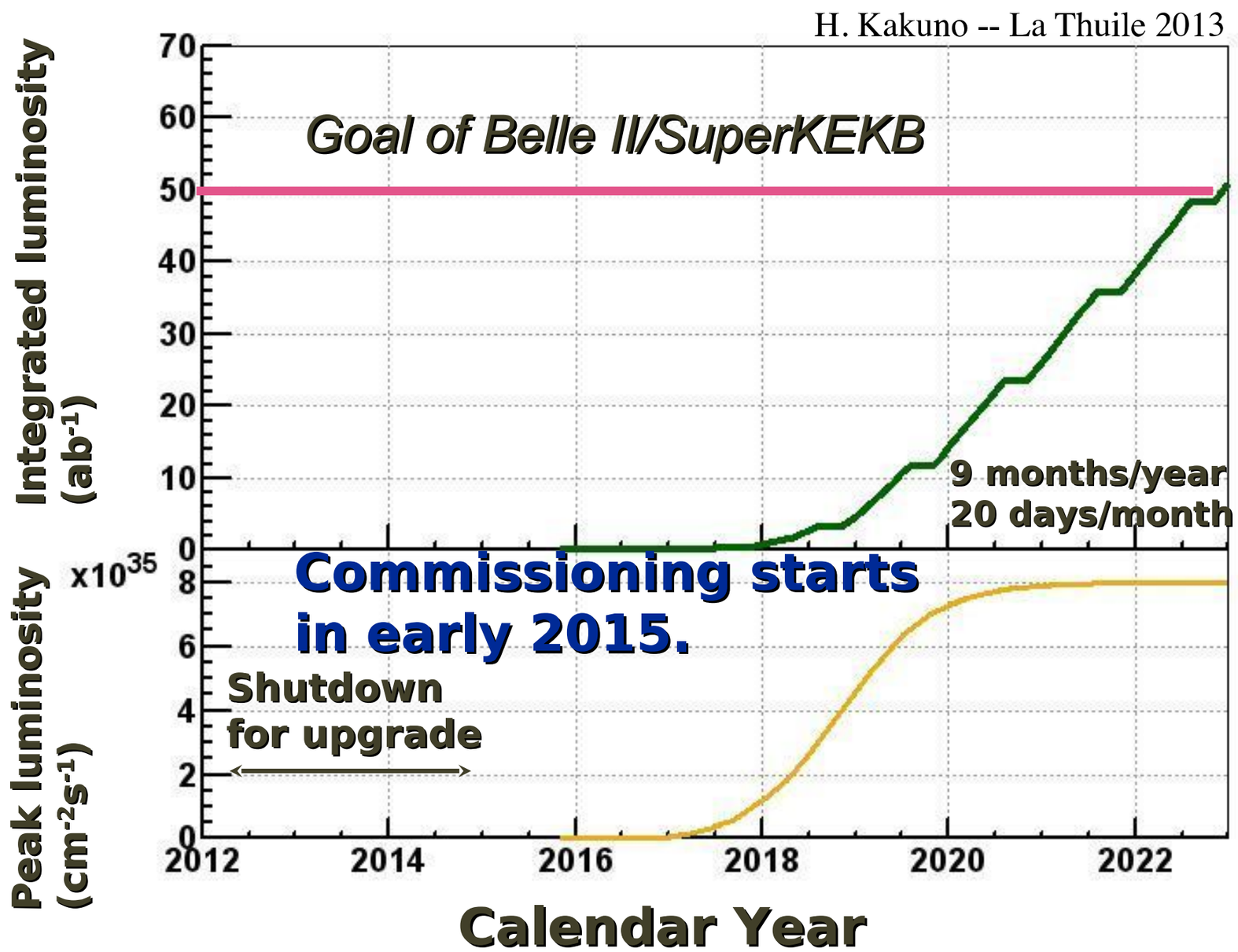


e^+e^- collisions in the Υ(nS) region

future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$\Upsilon_b(10890)$	$\Upsilon(bb)$
BESIII	$Y(4260)$	
PANDA	$X(3872)$	$\psi(cc)$
GlueX	$Y_s(2175)$ $\pi_1(1600)$	$\phi(ss)$ $\omega(nn)$ $\varrho(nn)$

2A. Investigate new states with Belle II

40× luminosity of KEKB



future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$Y_b(10890)$	$\Upsilon(bb)$
BESIII	$Y(4260)$	
PANDA	$X(3872)$	
		$\psi(cc)$
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	$\pi_1(1600)$	
GlueX		$\phi(ss)$
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2A. Investigate new states with Belle II

Imagine Belle and BaBar results with ×40 statistics...

future and ongoing experiments	**"beyond" quark model states**	**quark model states**
Belle II	$\Upsilon_b(10890)$	$\Upsilon(bb)$
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Imagine Belle and BaBar results with ×40 statistics...

* directly produce the $\Upsilon_b(10890)$...

future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	**$\Upsilon_b(10890)$**	$\Upsilon(bb)$
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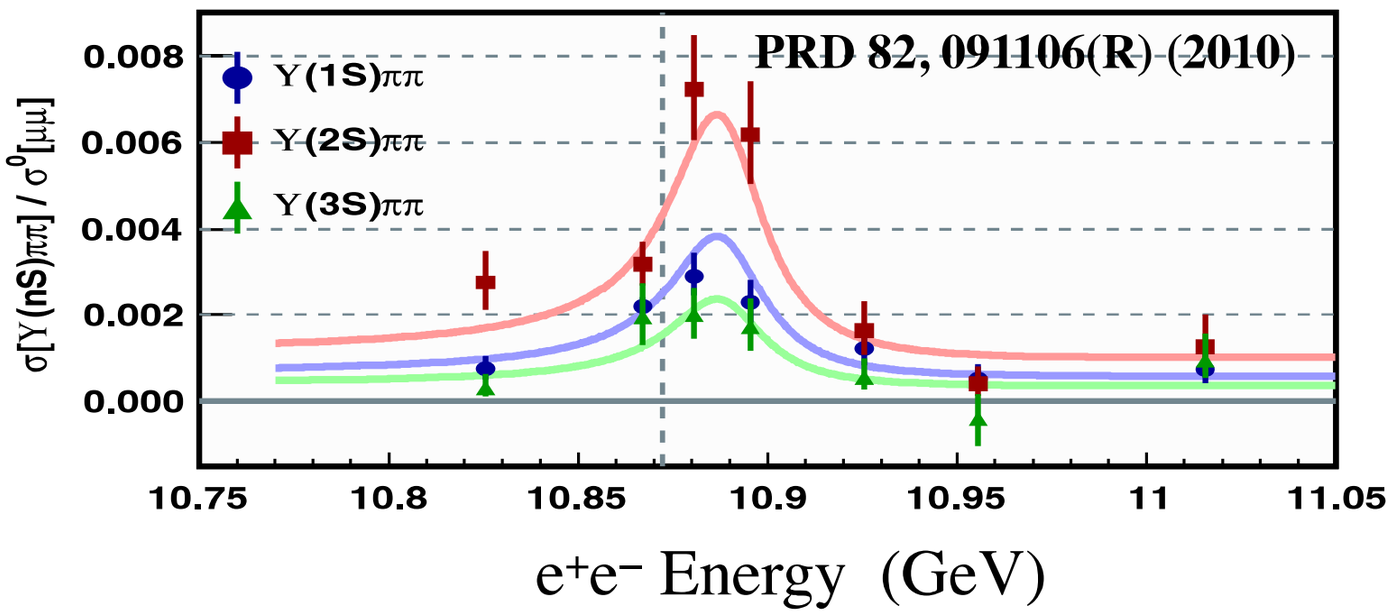
		$\omega(nn)$ $\varrho(nn)$

2A. Investigate new states with Belle II

Imagine Belle and BaBar results with ×40 statistics...

* directly produce the $\Upsilon_b(10890)$...

$e^+e^- \to \pi^+\pi^-\Upsilon(1S,2S,3S)$ at Belle



$$\Gamma(\Upsilon_b(10890) \to \pi\pi\Upsilon(nS)) \sim 100 \times \Gamma(\Upsilon(mS) \to \pi\pi\Upsilon(nS))$$

Discovery of the $\Upsilon_b(10890)$.

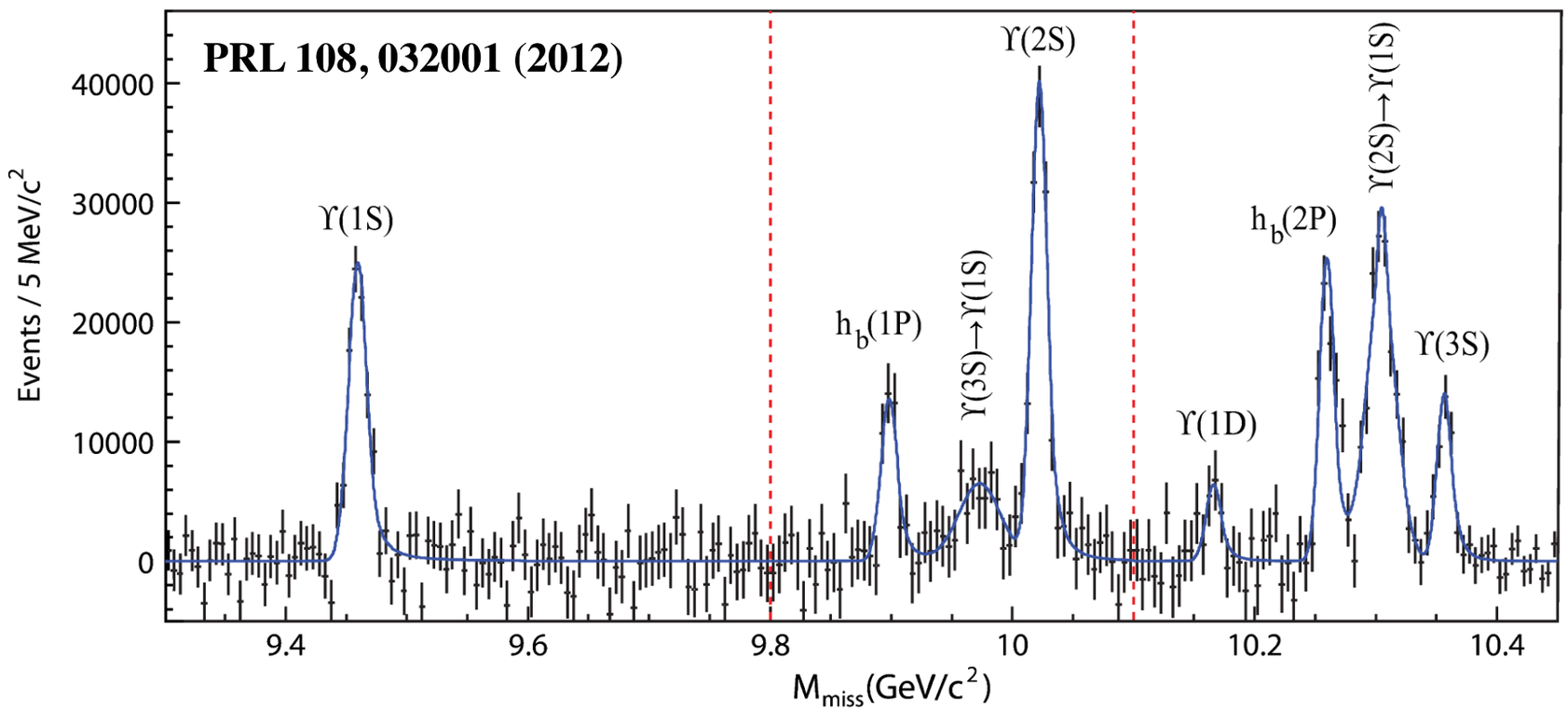
future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	**$\Upsilon_b(10890)$**	$\Upsilon(bb)$
BESIII	$Y(4260)$	
PANDA	$X(3872)$	$\psi(cc)$
GlueX	$Y_s(2175)$ $\pi_1(1600)$	$\phi(ss)$ $\omega(nn)$ $\varrho(nn)$

2A. Investigate new states with Belle II

Imagine Belle and BaBar results with ×40 statistics...

* directly produce the $Y_b(10890)$...

$Y_b(10890) \rightarrow \pi^+\pi^- X$ at Belle



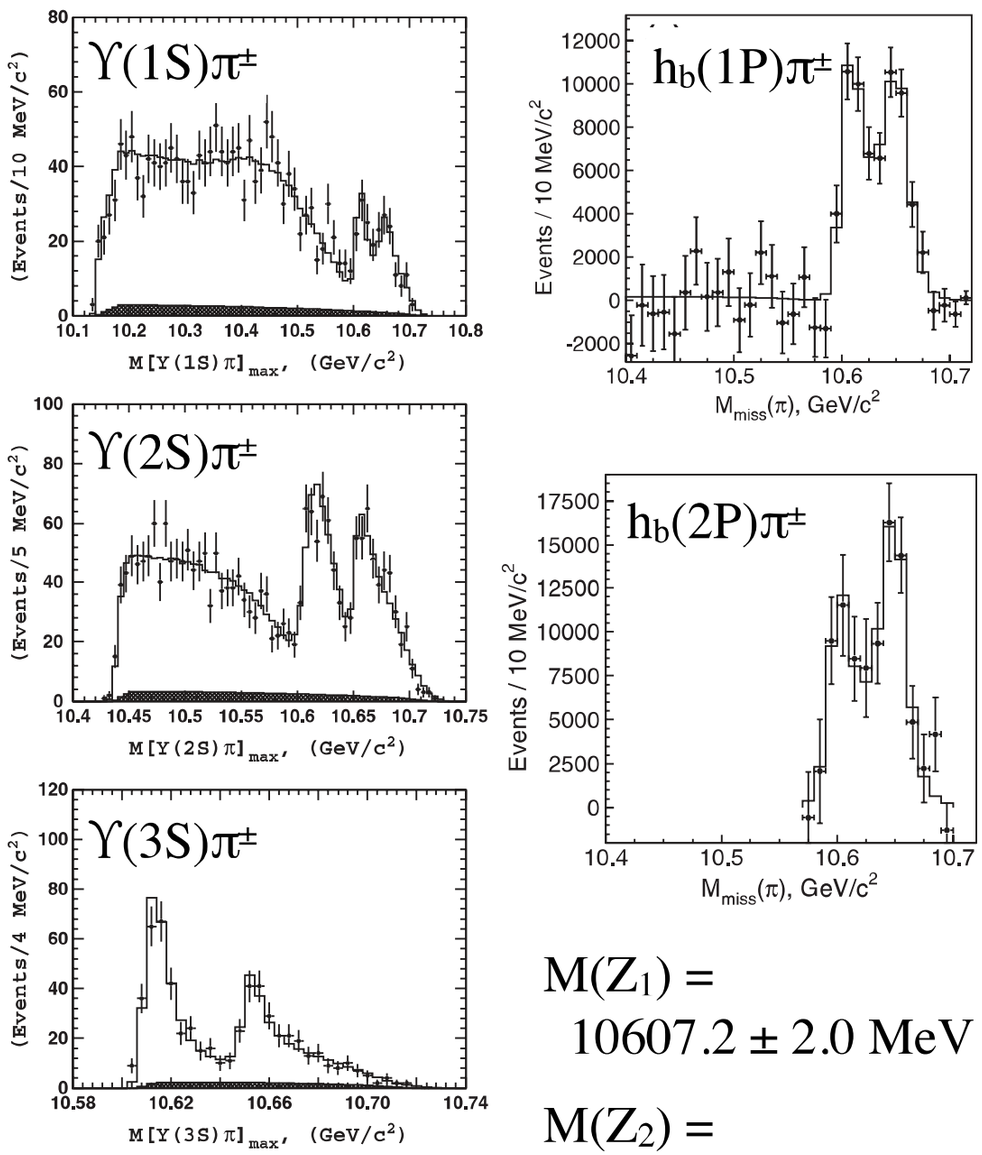
Discovery of the $h_b(1P,2P)$.

future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	**$Y_b(10890)$**	
		ϒ(bb)
BESIII	Y(4260)	
PANDA	X(3872)	
		ψ(cc)
	$Y_s(2175)$	
	$\pi_1(1600)$	
GlueX		ϕ(ss)
		ω(nn)
		ϱ(nn)

2A. Investigate new states with Belle II

Imagine Belle and BaBar results with ×40 statistics...

* directly produce the $\Upsilon_b(10890)$...



$M(Z_1) =$
10607.2 ± 2.0 MeV

$M(Z_2) =$
10652.2 ± 1.5 MeV

PRL 108, 122001 (2012)

Discovery of the Z_b states.

future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	**$\Upsilon_b(10890)$**	$\Upsilon(bb)$
BESIII	Y(4260)	
PANDA	X(3872)	$\psi(cc)$
GlueX	$Y_s(2175)$ $\pi_1(1600)$	$\phi(ss)$ $\omega(nn)$ $\varrho(nn)$

2A. Investigate new states with Belle II

Imagine Belle and BaBar results with ×40 statistics...

* directly produce the $Y_b(10890)$...
* produce the Y(4260) via ISR...

future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$Y_b(10890)$	$\Upsilon(bb)$
BESIII	**Y(4260)**	
PANDA	X(3872)	
GlueX	$Y_s(2175)$ $\pi_1(1600)$	$\psi(cc)$ $\phi(ss)$ $\omega(nn)$ $\varrho(nn)$

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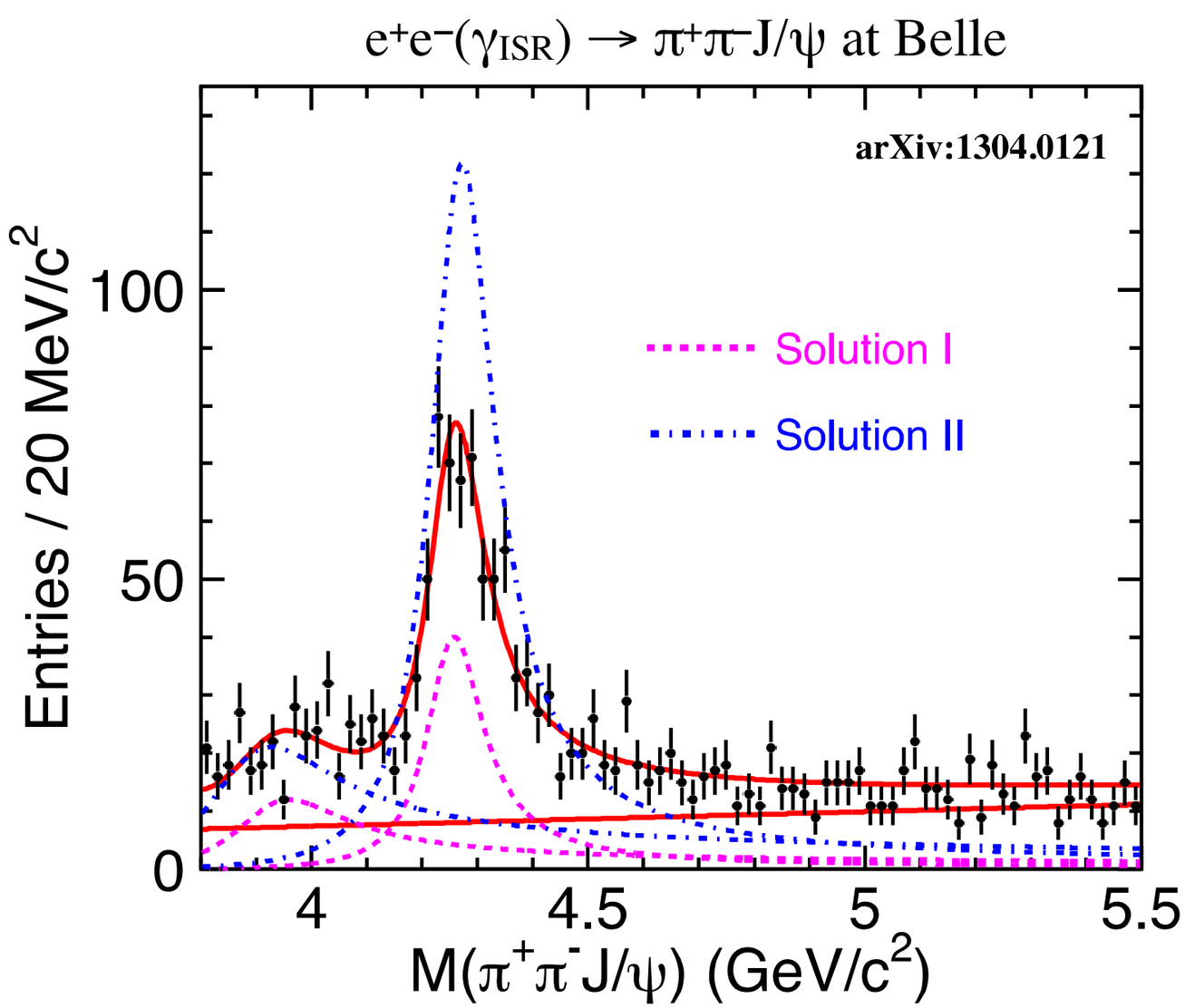


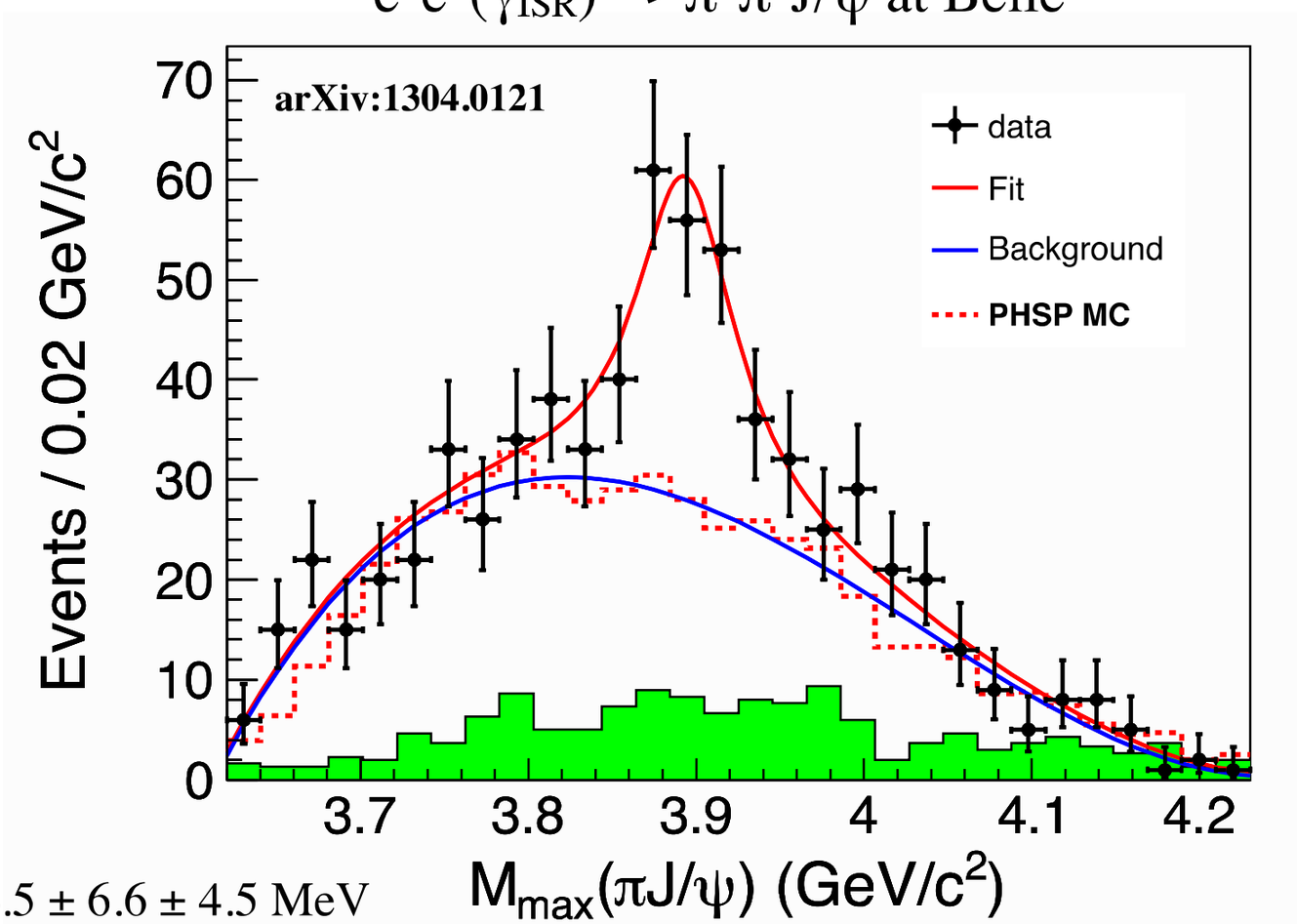
future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$\Upsilon_b(10890)$	$\Upsilon(bb)$
BESIII	**Y(4260)**	
PANDA	X(3872)	
		$\psi(cc)$
	$Y_s(2175)$	
GlueX	$\pi_1(1600)$	$\phi(ss)$
		$\omega(nn)$ $\varrho(nn)$

2A. Investigate new states with Belle II

Imagine Belle and BaBar results with ×40 statistics...

* directly produce the $\Upsilon_b(10890)$...
* produce the Y(4260) via ISR...

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



$M = 3894.5 \pm 6.6 \pm 4.5$ MeV

$\Gamma = 63 \pm 24 \pm 26$ MeV

Observation of a $Z_c(3900)$ state.

future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$\Upsilon_b(10890)$	$\Upsilon(bb)$
BESIII	**Y(4260)**	
PANDA	X(3872)	$\psi(cc)$
GlueX	$Y_s(2175)$ $\pi_1(1600)$	$\phi(ss)$ $\omega(nn)$ $\varrho(nn)$

2A. Investigate new states with Belle II

Imagine Belle and BaBar results with ×40 statistics...

* directly produce the $Y_b(10890)$...
* produce the Y(4260) via ISR...
* produce the X(3872) via B decays...

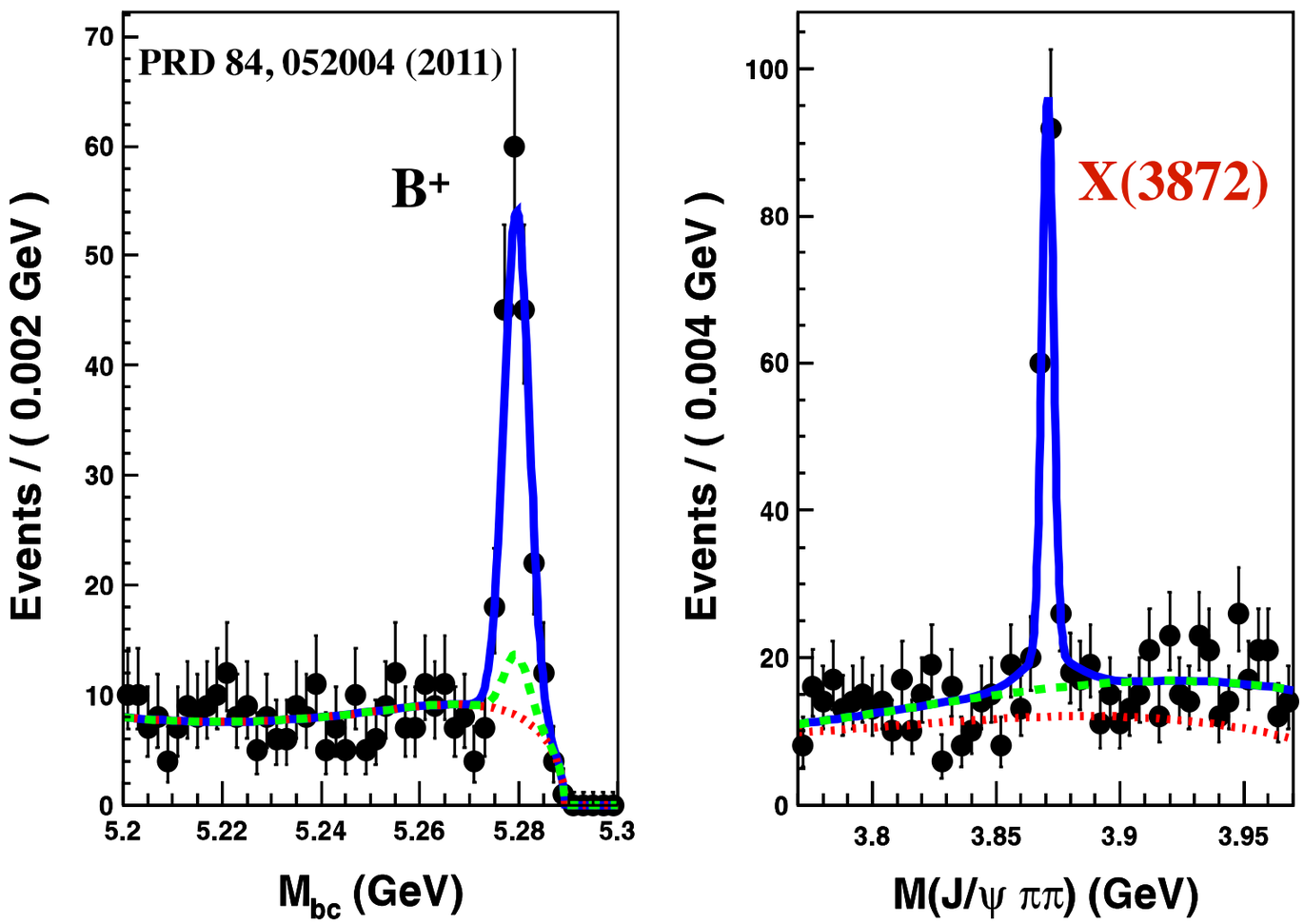
future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$Y_b(10890)$	$\Upsilon(bb)$
BESIII	Y(4260)	
PANDA	**X(3872)**	
		$\psi(cc)$
GlueX	$Y_s(2175)$	
	$\pi_1(1600)$	$\phi(ss)$
		$\omega(nn)$ $\varrho(nn)$

2A. Investigate new states with Belle II

Imagine Belle and BaBar results with ×40 statistics...

* directly produce the $\Upsilon_b(10890)$...
* produce the $\Upsilon(4260)$ via ISR...
* produce the X(3872) via B decays...

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



future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$\Upsilon_b(10890)$	$\Upsilon(bb)$
BESIII	$\Upsilon(4260)$	
PANDA	X(3872)	$\psi(cc)$
GlueX	$\Upsilon_s(2175)$ $\pi_1(1600)$	$\phi(ss)$ $\omega(nn)$ $\varrho(nn)$

2A. Investigate new states with Belle II

Imagine Belle and BaBar results with ×40 statistics...

* directly produce the $Y_b(10890)$...
* produce the Y(4260) via ISR...
* produce the X(3872) via B decays...
* produce the $Y_s(2175)$ via ISR...

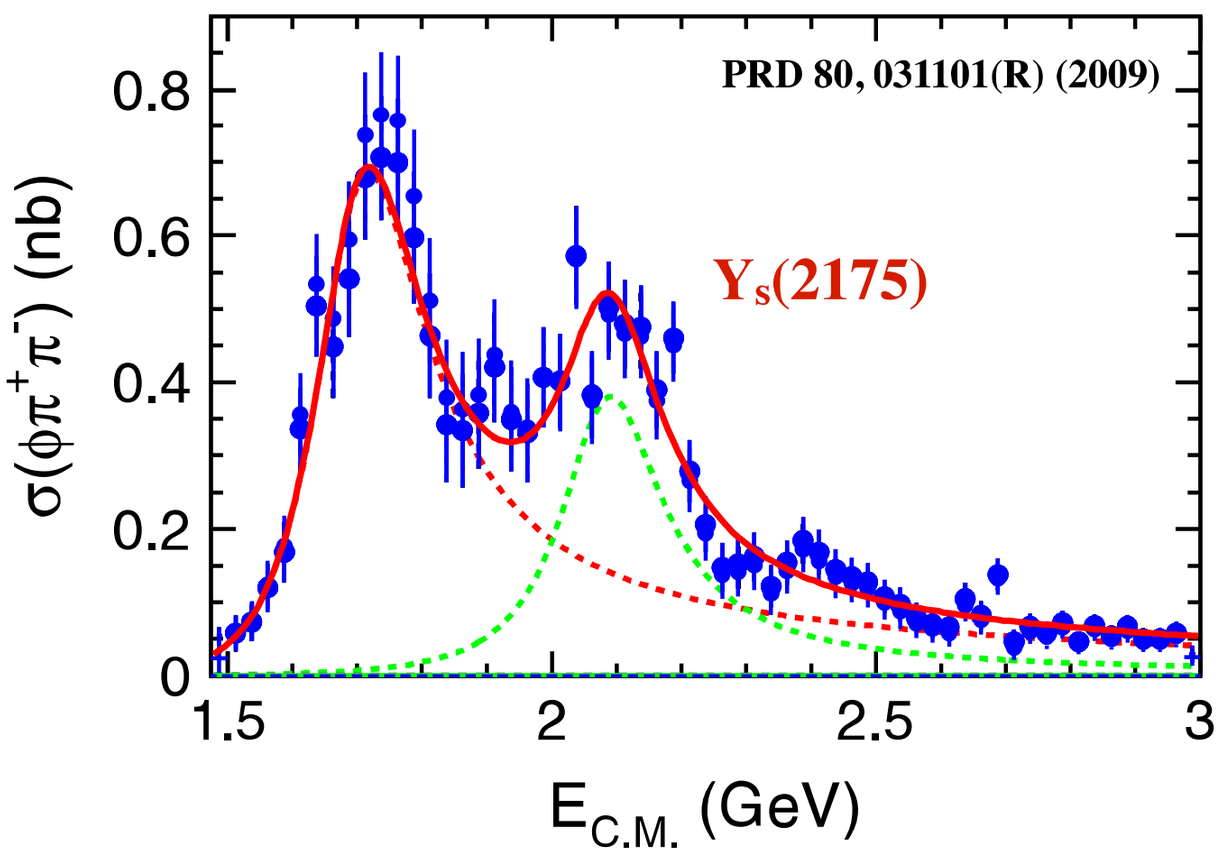
future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$Y_b(10890)$	$\Upsilon(bb)$
BESIII	Y(4260)	
PANDA	X(3872)	
GlueX	**$Y_s(2175)$** $\pi_1(1600)$	$\psi(cc)$ $\phi(ss)$ $\omega(nn)$ $\varrho(nn)$

2A. Investigate new states with Belle II

Imagine Belle and BaBar results with ×40 statistics...

* directly produce the $Y_b(10890)$...
* produce the Y(4260) via ISR...
* produce the X(3872) via B decays...
* produce the $Y_s(2175)$ via ISR...

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



future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$Y_b(10890)$	$\Upsilon(bb)$
BESIII	Y(4260)	
PANDA	X(3872)	$\psi(cc)$
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2A. Investigate new states with Belle II

Imagine Belle and BaBar results with ×40 statistics...

* directly produce the $Y_b(10890)$...
* produce the Y(4260) via ISR...
* produce the X(3872) via B decays...
* produce the $Y_s(2175)$ via ISR...

future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$Y_b(10890)$	$\Upsilon(bb)$
BESIII	Y(4260)	
PANDA	X(3872)	
GlueX	$Y_s(2175)$ $\pi_1(1600)$	$\psi(cc)$ $\phi(ss)$ $\omega(nn)$ $\varrho(nn)$

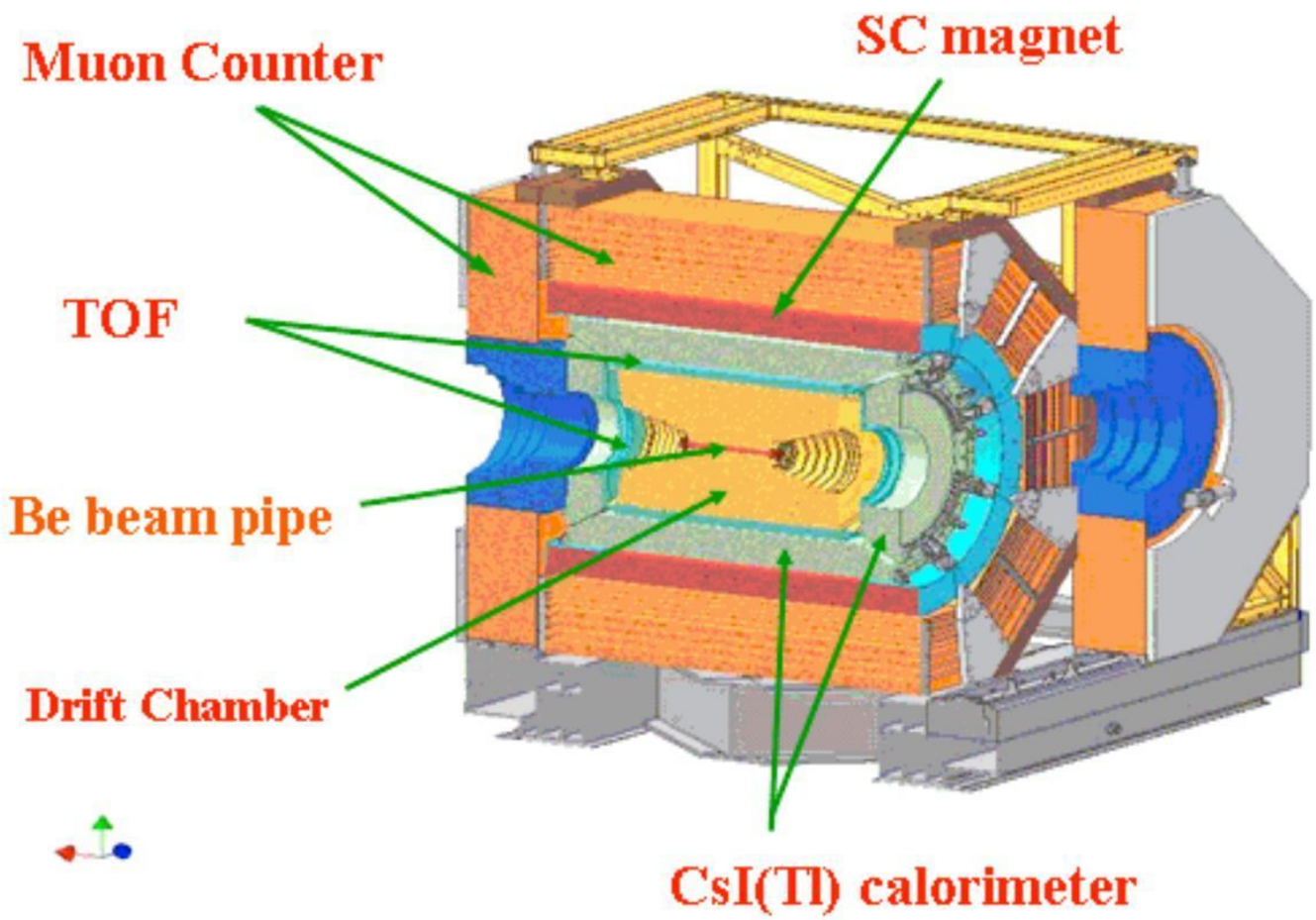
2B. Investigate new states with BESIII

BESIII
(e^+e^- collisions in the charmonium region)

location: Beijing, China
accelerator: BEPC-II
dates: 2008 – ?

future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$Y_b(10890)$	$\Upsilon(bb)$
BESIII	$Y(4260)$	
PANDA	$X(3872)$	
		$\psi(cc)$
	$Y_s(2175)$	
GlueX	$\pi_1(1600)$	$\phi(ss)$
		$\omega(nn)$ $\varrho(nn)$

2B. Investigate new states with BESIII



e^+e^- collisions in the charmonium region

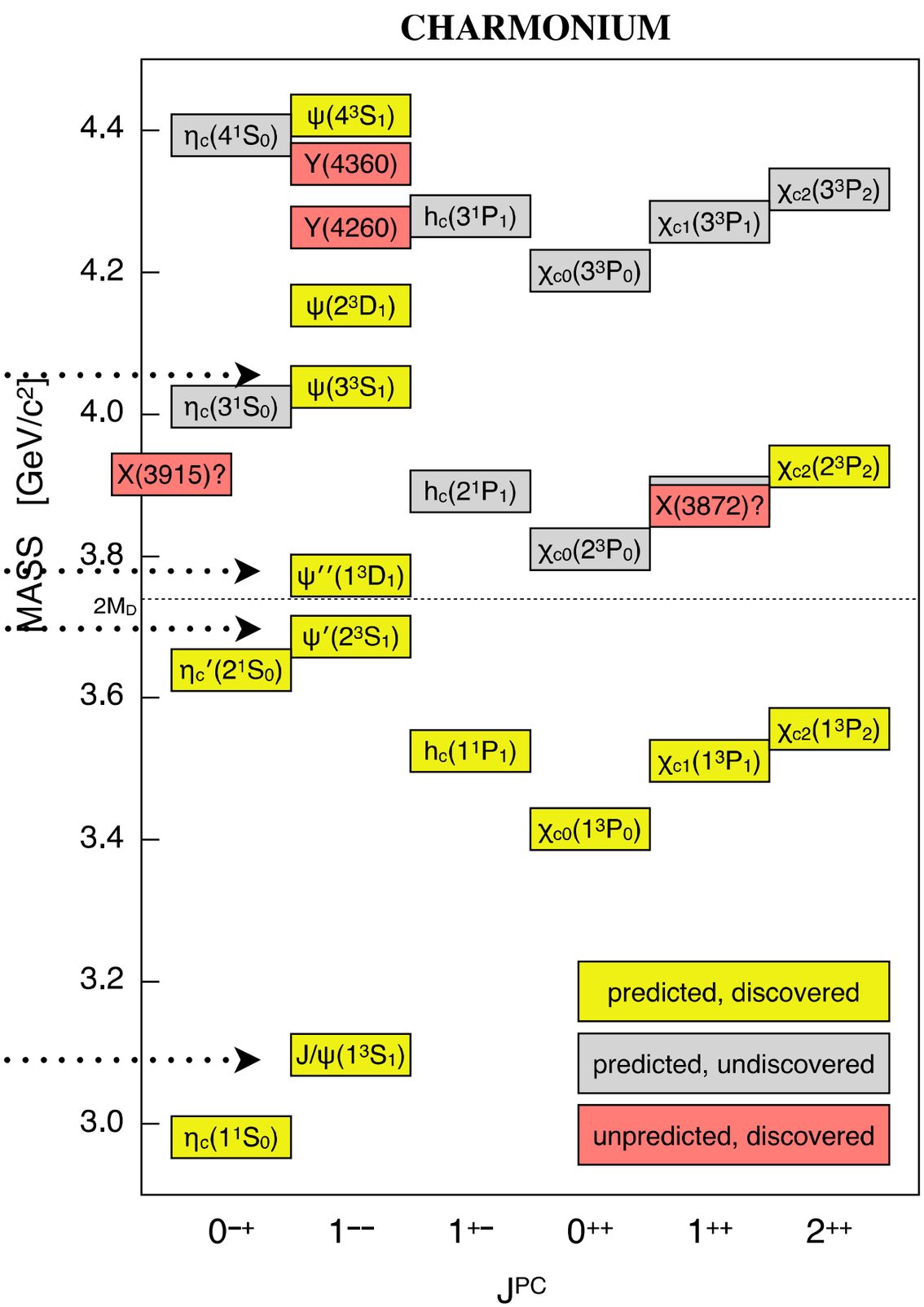
future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$Y_b(10890)$	$\Upsilon(bb)$
BESIII	$Y(4260)$	
PANDA	$X(3872)$	
		$\psi(cc)$
	$Y_s(2175)$	
	$\pi_1(1600)$	
GlueX		$\phi(ss)$
		$\omega(nn)$
		$\varrho(nn)$

2B. Investigate new states with BESIII

future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$\Upsilon_b(10890)$	$\Upsilon(bb)$
BESIII	$Y(4260)$	
PANDA	$X(3872)$	$\psi(cc)$
GlueX	$Y_s(2175)$ $\pi_1(1600)$	$\phi(ss)$ $\omega(nn)$ $\varrho(nn)$

2B. Investigate new states with BESIII

* ~500 pb^{-1} at **4.009 GeV**
* ~2.9 fb^{-1} at **ψ″**
* ~100M **ψ(2S)** (+ more)
* >1B **J/ψ** decays



future and ongoing experiments	**"beyond" quark model states**	**quark model states**
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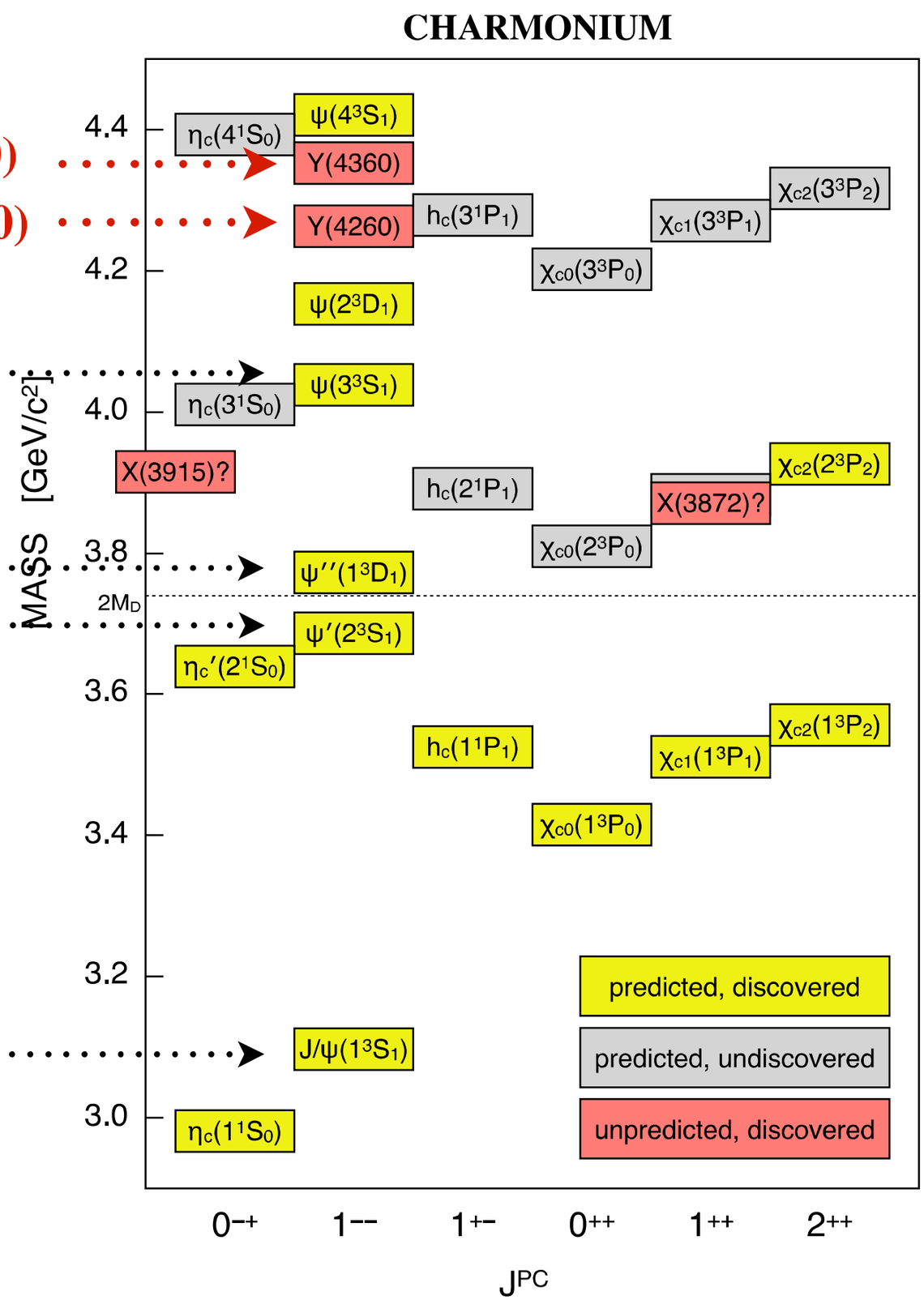
BESIII	Y(4260)	
PANDA	X(3872)	
		ψ(cc)
GlueX	$Y_s(2175)$	
	$\pi_1(1600)$	
		ϕ(ss)
		ω(nn)
		ϱ(nn)

2B. Investigate new states with BESIII

NEW!

* ~500 pb^{-1} at **Y(4360)**
* > 500 pb^{-1} at **Y(4260)**
* ~500 pb^{-1} at **4.009 GeV**
* ~2.9 fb^{-1} at **ψ″**
* ~100M **ψ(2S)** (+ more)
* >1B **J/ψ** decays



future and ongoing experiments	"beyond" quark model states	quark model states
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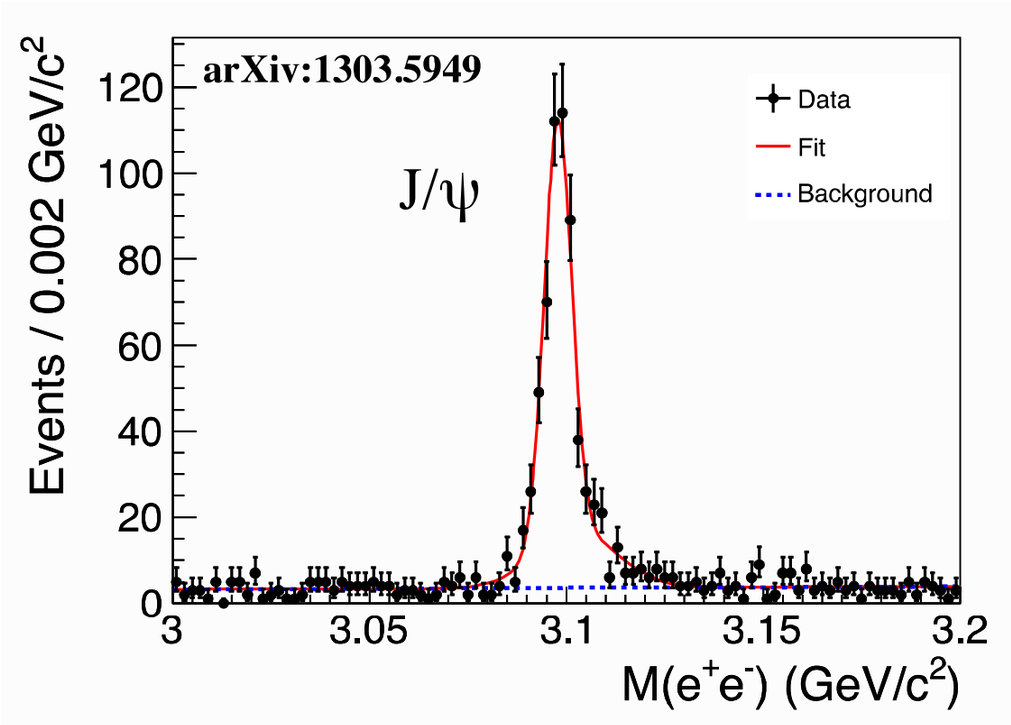
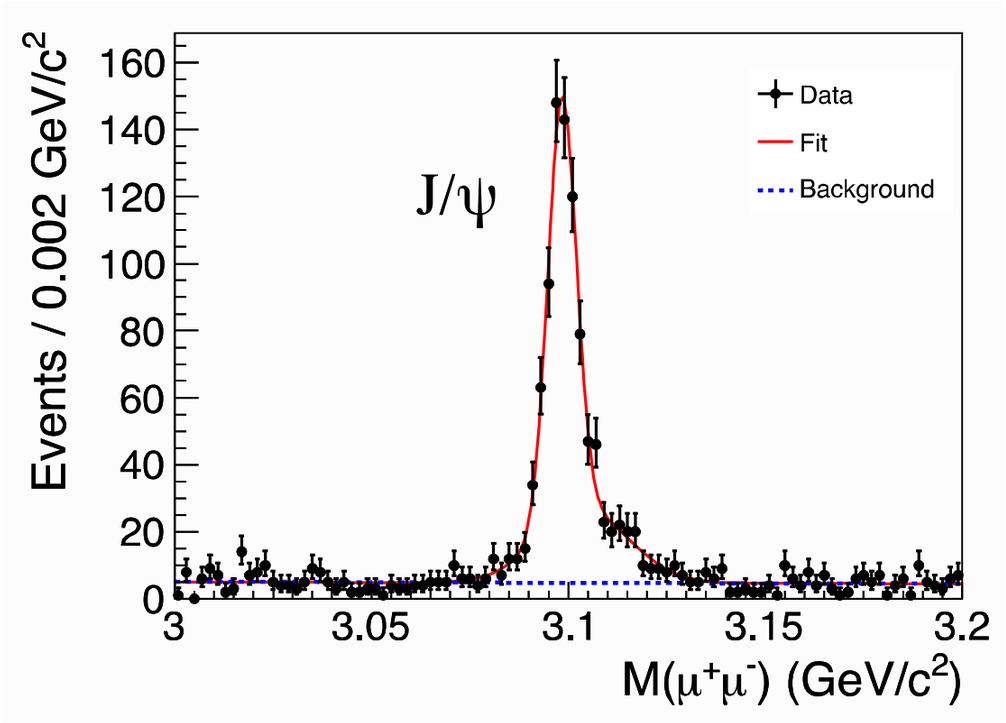
BESIII	**Y(4260)**	
PANDA	X(3872)	
		ψ(cc)
GlueX	$Y_s(2175)$	
	$\pi_1(1600)$	
		ϕ(ss)
		ω(nn)
		ϱ(nn)

2B. Investigate new states with BESIII

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





future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$\Upsilon_b(10890)$	$\Upsilon(bb)$
BESIII	**Y(4260)**	
PANDA	X(3872)	$\psi(cc)$
GlueX	$Y_s(2175)$ $\pi_1(1600)$	$\phi(ss)$ $\omega(nn)$ $\varrho(nn)$

2B. Investigate new states with BESIII

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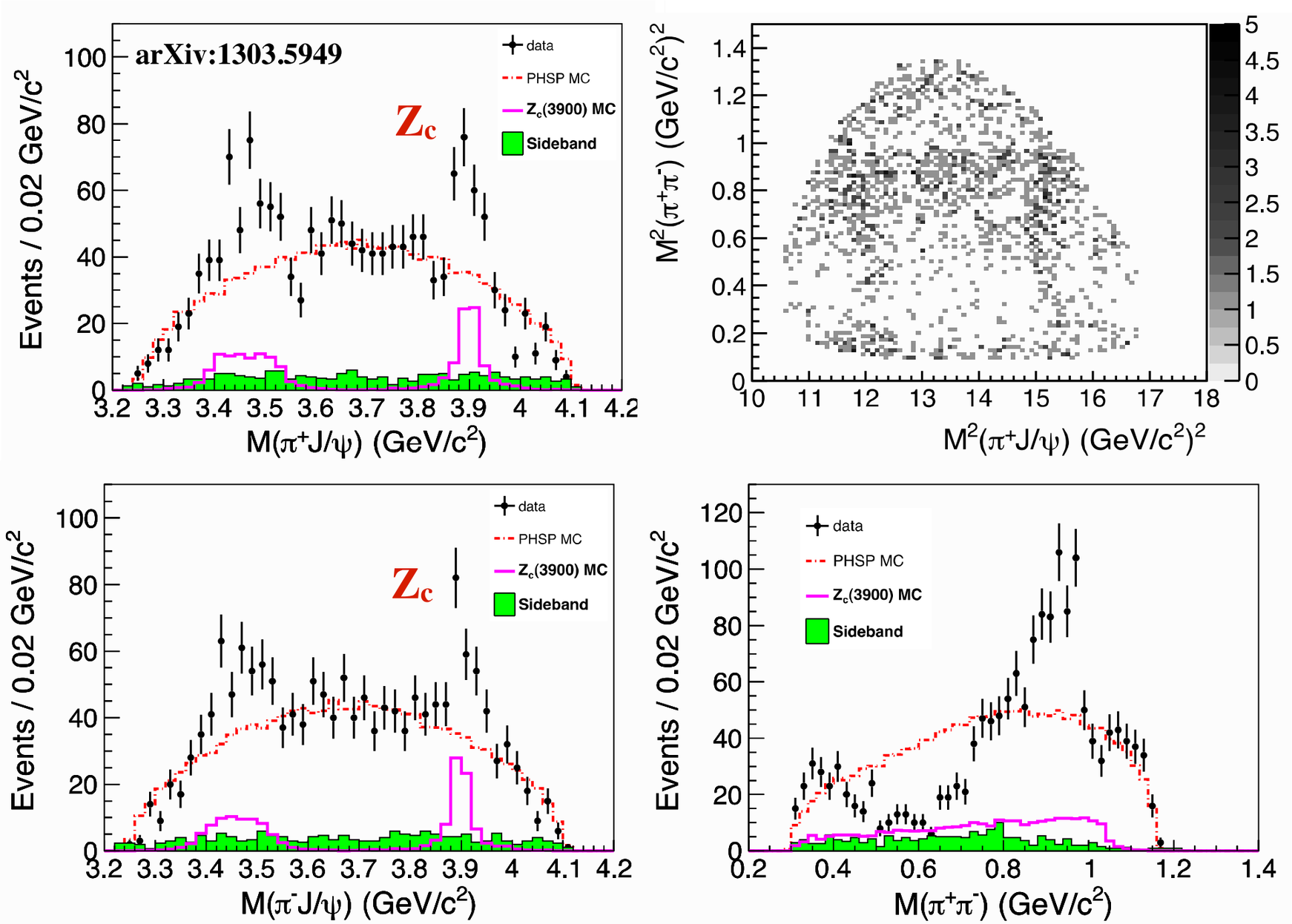
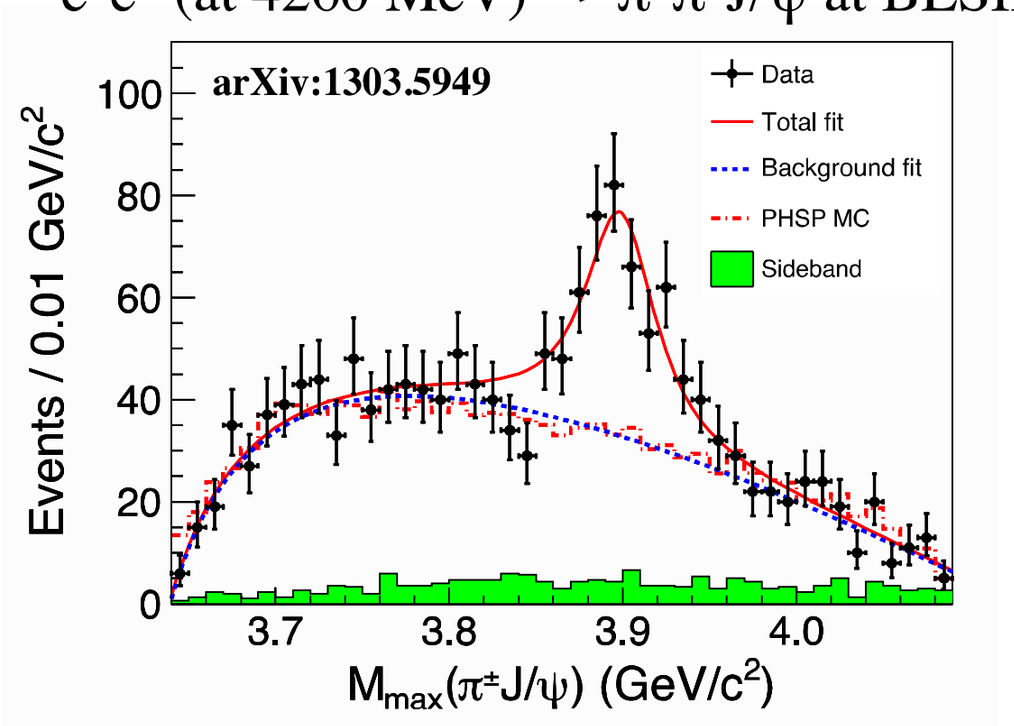


Observation of a $Z_c(3900)$ state.

future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$\Upsilon_b(10890)$	$\Upsilon(bb)$
BESIII	**Y(4260)**	
PANDA	X(3872)	
		$\psi(cc)$
GlueX	$Y_s(2175)$	
	$\pi_1(1600)$	$\phi(ss)$
		$\omega(nn)$
		$\varrho(nn)$

2B. Investigate new states with BESIII

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

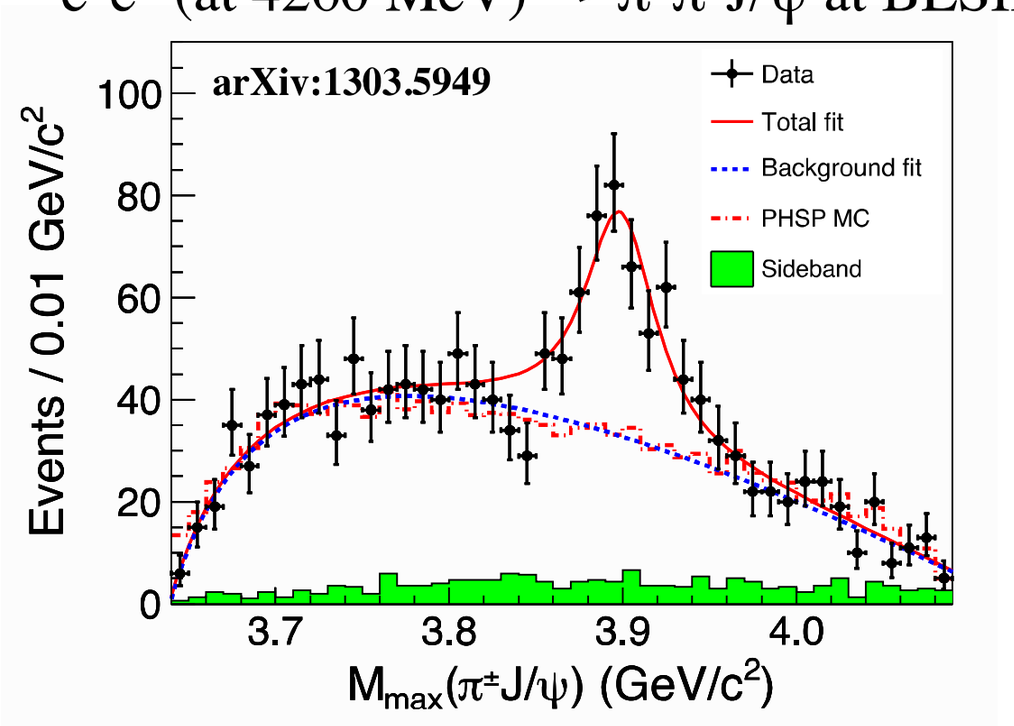


$M = 3899.0 \pm 3.6 \pm 4.9$ MeV
$\Gamma = 46 \pm 10 \pm 20$ MeV

future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$Y_b(10890)$	$\Upsilon(bb)$
BESIII	**Y(4260)**	
PANDA	X(3872)	
		$\psi(cc)$
GlueX	$Y_s(2175)$	
	$\pi_1(1600)$	$\phi(ss)$
		$\omega(nn)$ $\varrho(nn)$

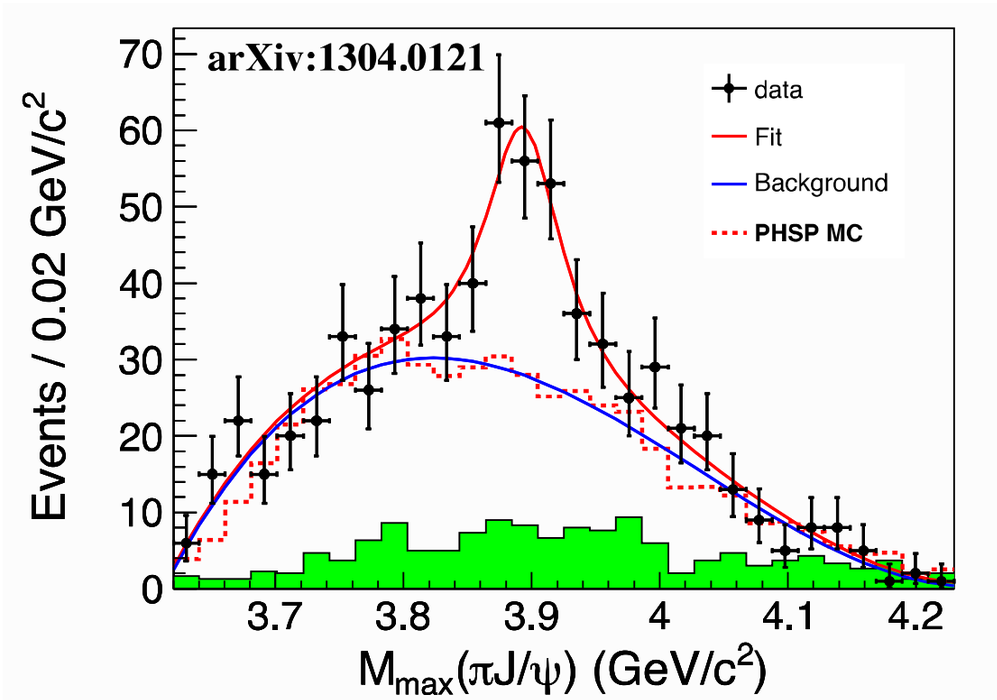
2B. Investigate new states with BESIII

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



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

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



$M = 3894.5 \pm 6.6 \pm 4.5$ MeV
$\Gamma = 63 \pm 24 \pm 26$ MeV

future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$Y_b(10890)$	$\Upsilon(bb)$
BESIII	**Y(4260)**	
PANDA	X(3872)	
		$\psi(cc)$
GlueX	$Y_s(2175)$	
	$\pi_1(1600)$	$\phi(ss)$
		$\omega(nn)$ $\varrho(nn)$

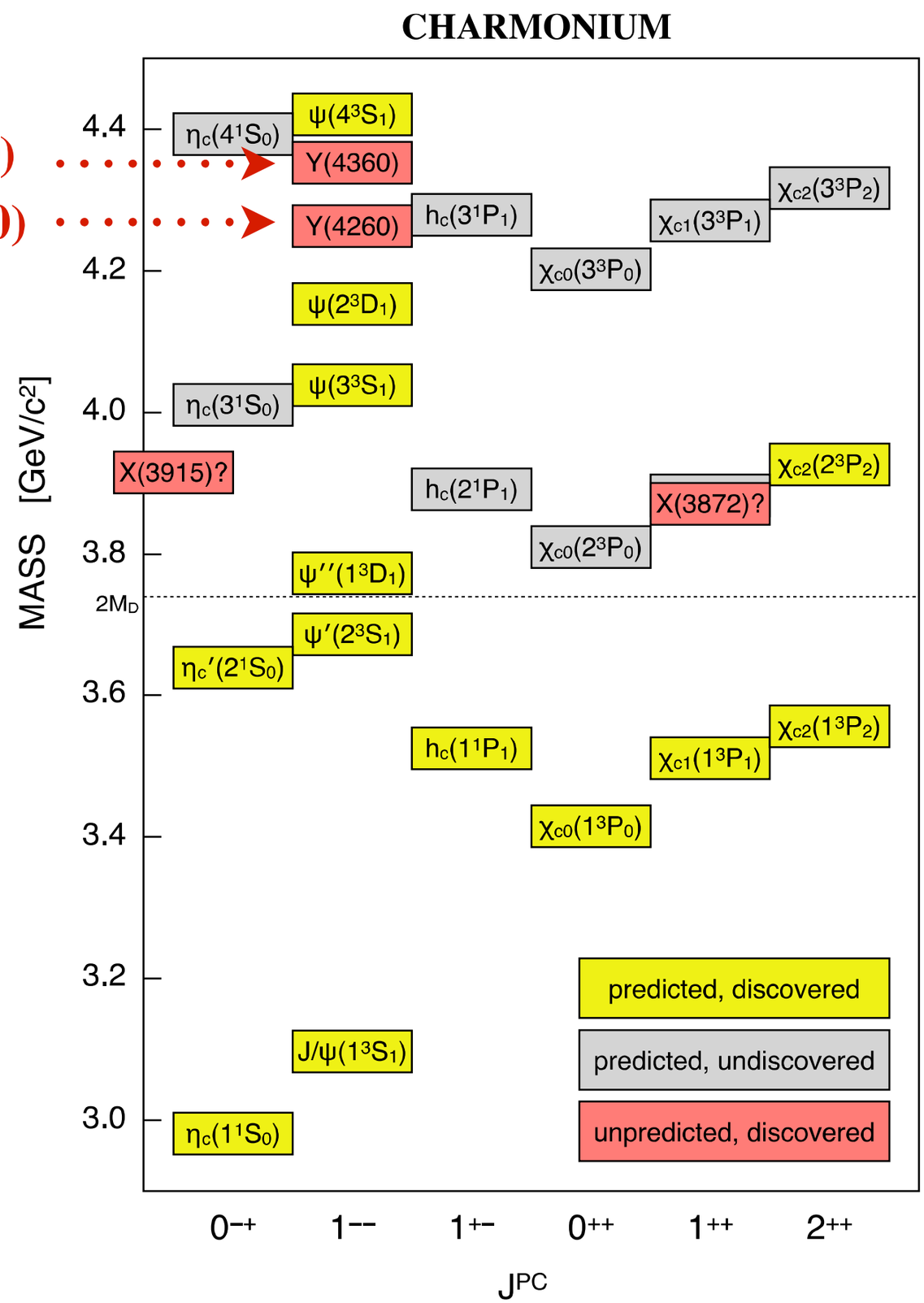
2B. Investigate new states with BESIII

NEW!

* ~500 pb^{-1} at **Y(4360)**
* > 500 pb^{-1} at **Y(4260)**

This data is less than two months old...

Expect many new results soon!



future and ongoing experiments	"beyond" quark model states	quark model states
Belle II	$Y_b(10890)$	$\Upsilon(bb)$
BESIII	**Y(4260)**	
PANDA	X(3872)	$\psi(cc)$
GlueX	$Y_s(2175)$ $\pi_1(1600)$	$\phi(ss)$ $\omega(nn)$ $\varrho(nn)$