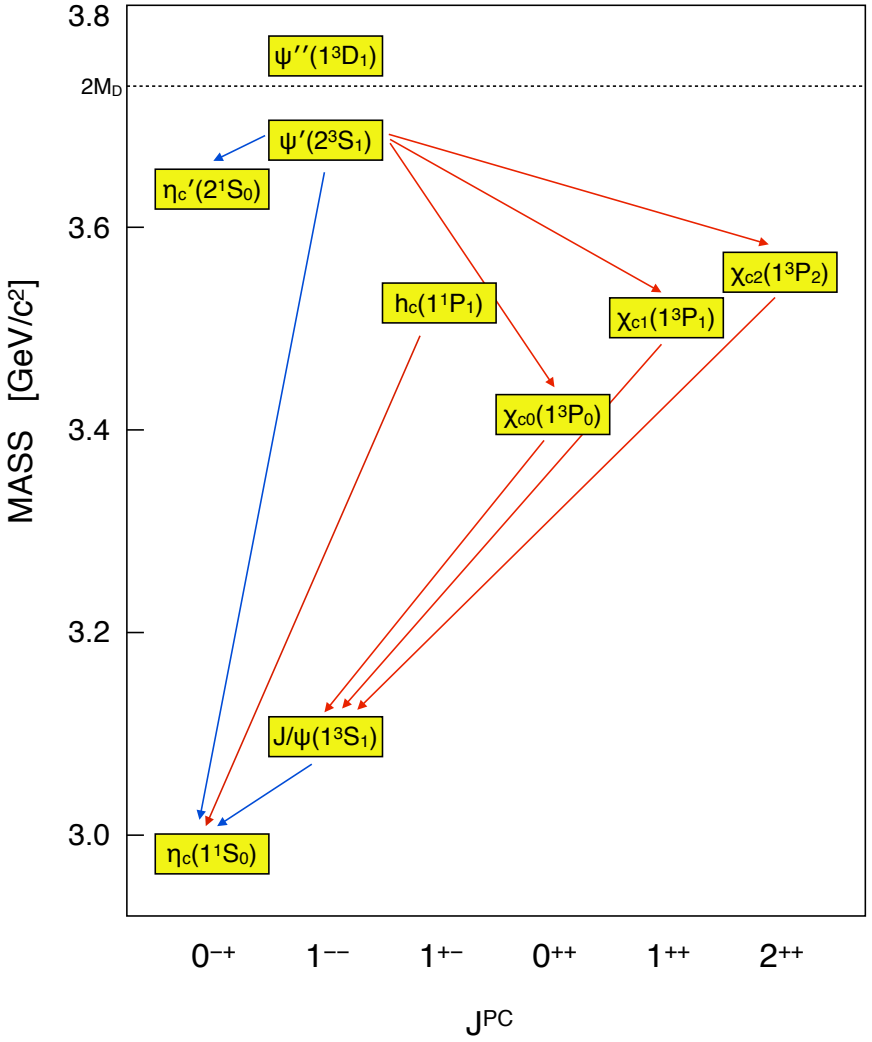
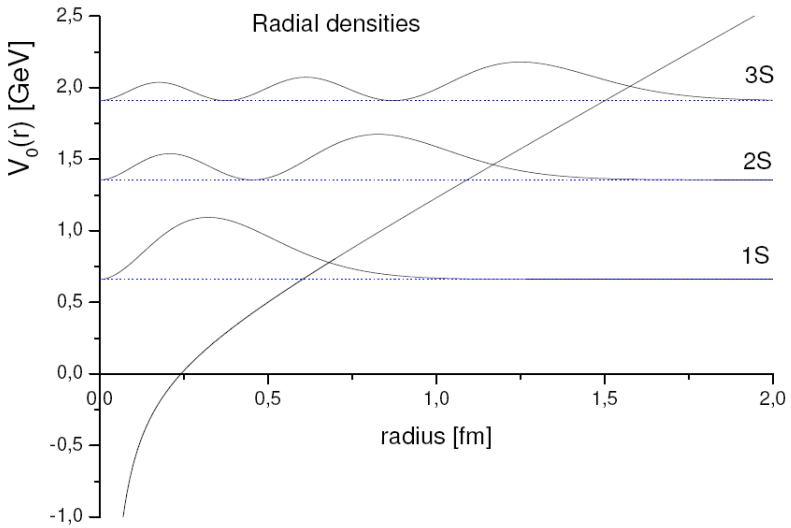
“probing confinement potential”

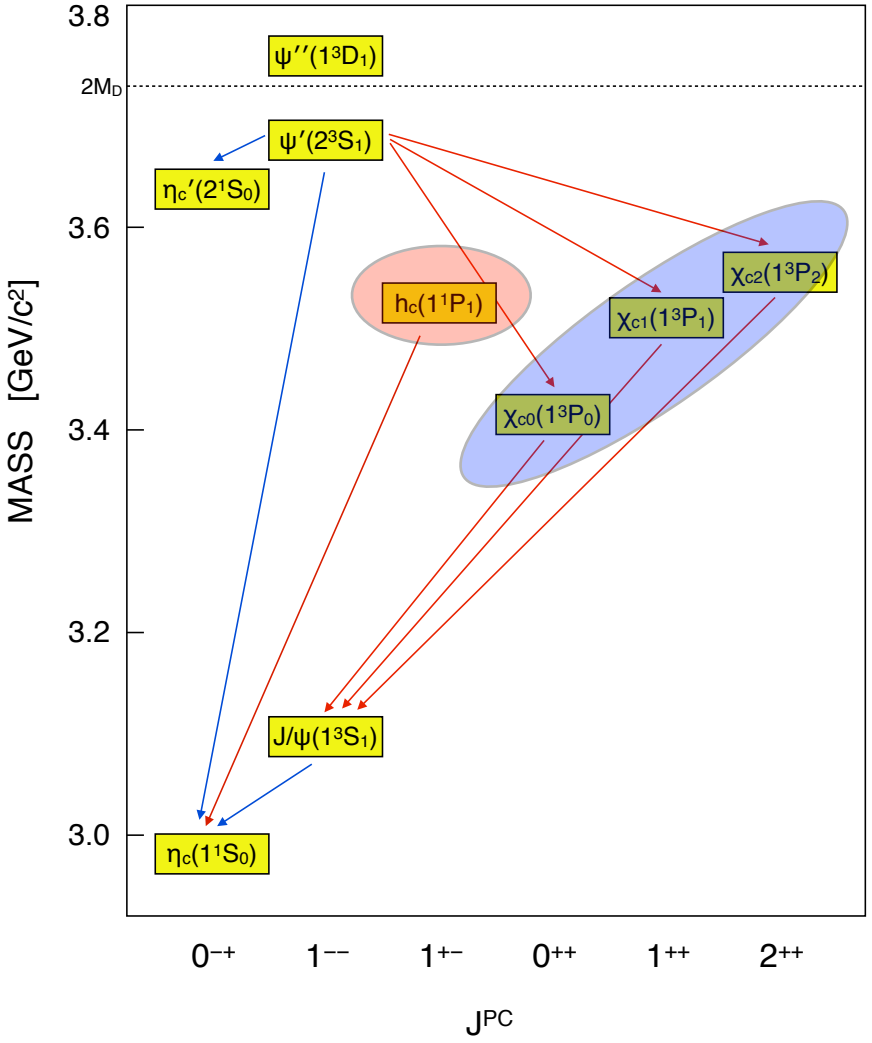
Barnes, Godfrey, Swanson
PRD72, 054026 (2005)

$$
\begin{aligned}
V(r) &= -\frac{4}{3}\frac{\alpha_s}{r} + kr \\
&+ \frac{32\pi\alpha_s}{9m_c^2}\delta_r \vec{S}_c\vec{S}_{\bar{c}} \\
&+ \frac{1}{m_c^2}\left(\frac{2\alpha_s}{r^3} - \frac{k}{2r}\right)\vec{L}\vec{S} \\
&+ \frac{1}{m_c^2}\frac{4\alpha_s}{r^3}\left(\frac{3\vec{S}_c\vec{r}\cdot\vec{S}_{\bar{c}}\vec{r}}{r^2} - \vec{S}_c\vec{S}_{\bar{c}}\right)
\end{aligned}
$$





"probing confinement potential"



Barnes, Godfrey, Swanson
PRD72, 054026 (2005)

$$V(r) = -\frac{4}{3}\frac{\alpha_s}{r} + kr + \frac{32\pi\alpha_s}{9m_c^2}\delta_r \vec{S}_c\vec{S}_{\bar{c}} + \frac{1}{m_c^2}\left(\frac{2\alpha_s}{r^3} - \frac{k}{2r}\right)\vec{L}\vec{S} + \frac{1}{m_c^2}\frac{4\alpha_s}{r^3}\left(\frac{3\vec{S}_c\vec{r}\cdot\vec{S}_{\bar{c}}\vec{r}}{r^2} - \vec{S}_c\vec{S}_{\bar{c}}\right)$$

P-wave hyperfine splitting:

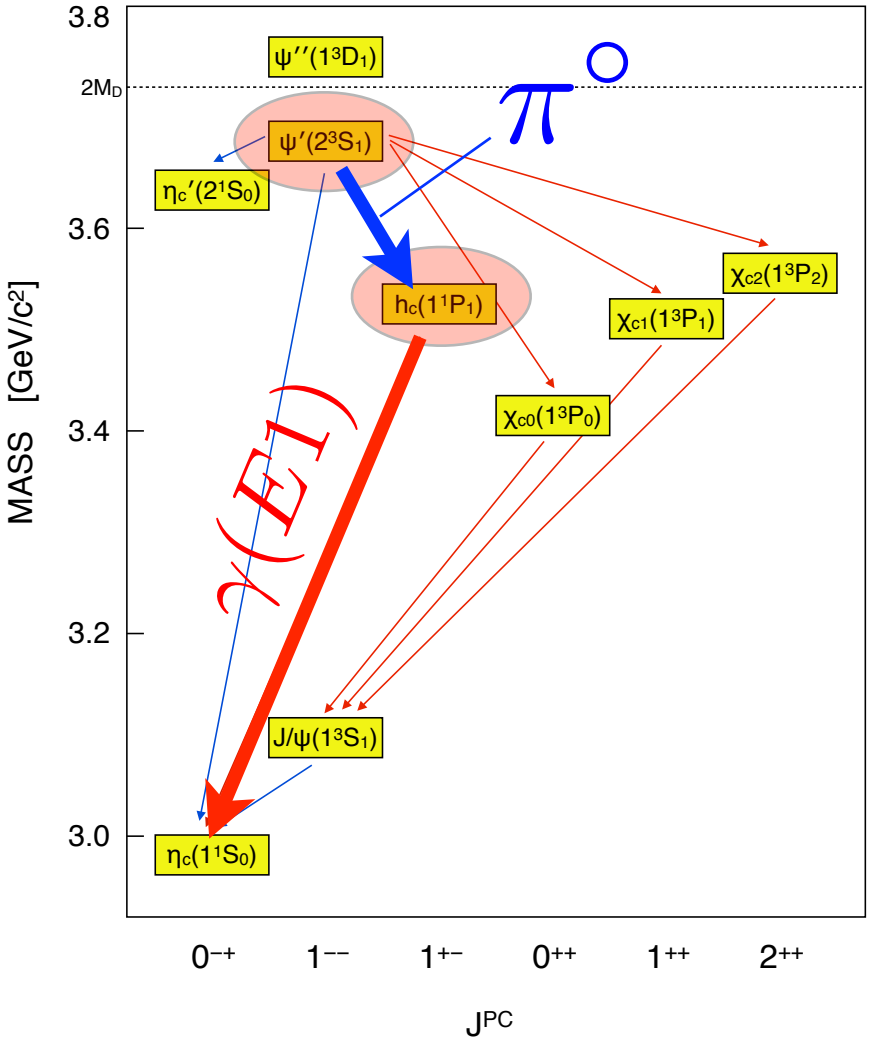
$$\propto |\psi(0)|^2$$

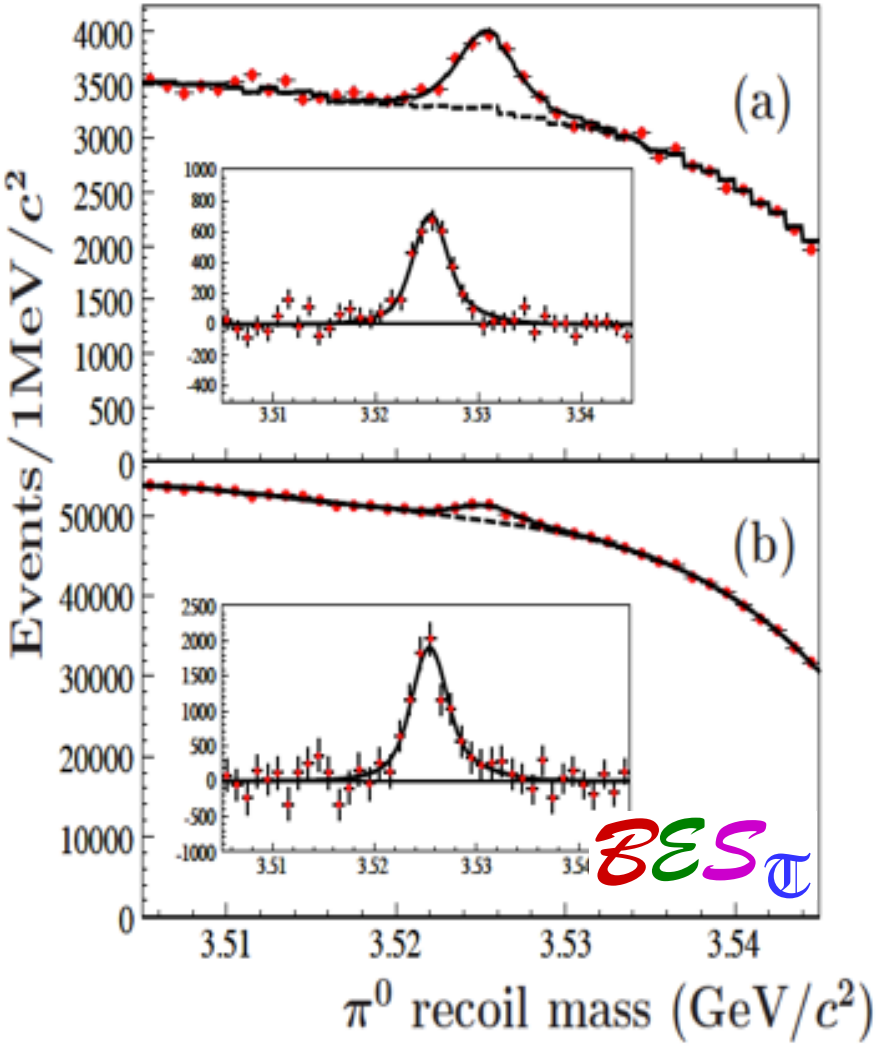
$$m(h_c) \overset{?}{=} \frac{m(\chi_{c0}) + 3\cdot m(\chi_{c1}) + 5\cdot m(\chi_{c2})}{9}$$

$\Delta M_{\rm hf} = m_{h_c} - \bar{m}_{\chi_c}$ deviation from zero?

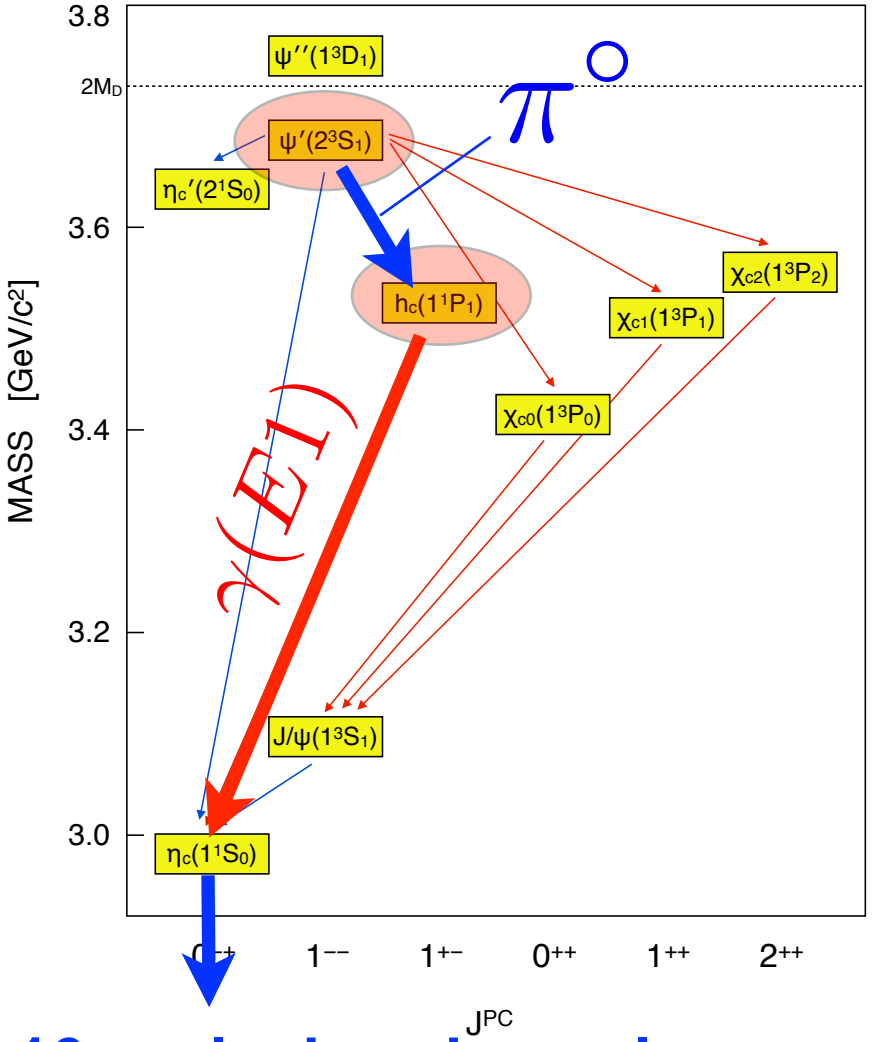
"probing confinement potential"

PRL 104, 132002 (2010)



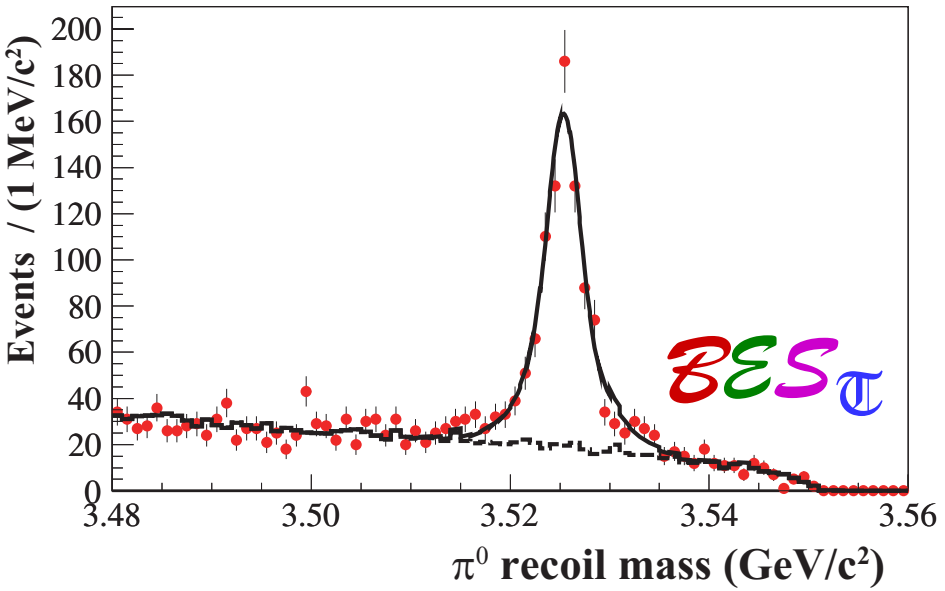


"probing confinement potential"



16 exclusive channels

PRD 86, 092009 (2012)

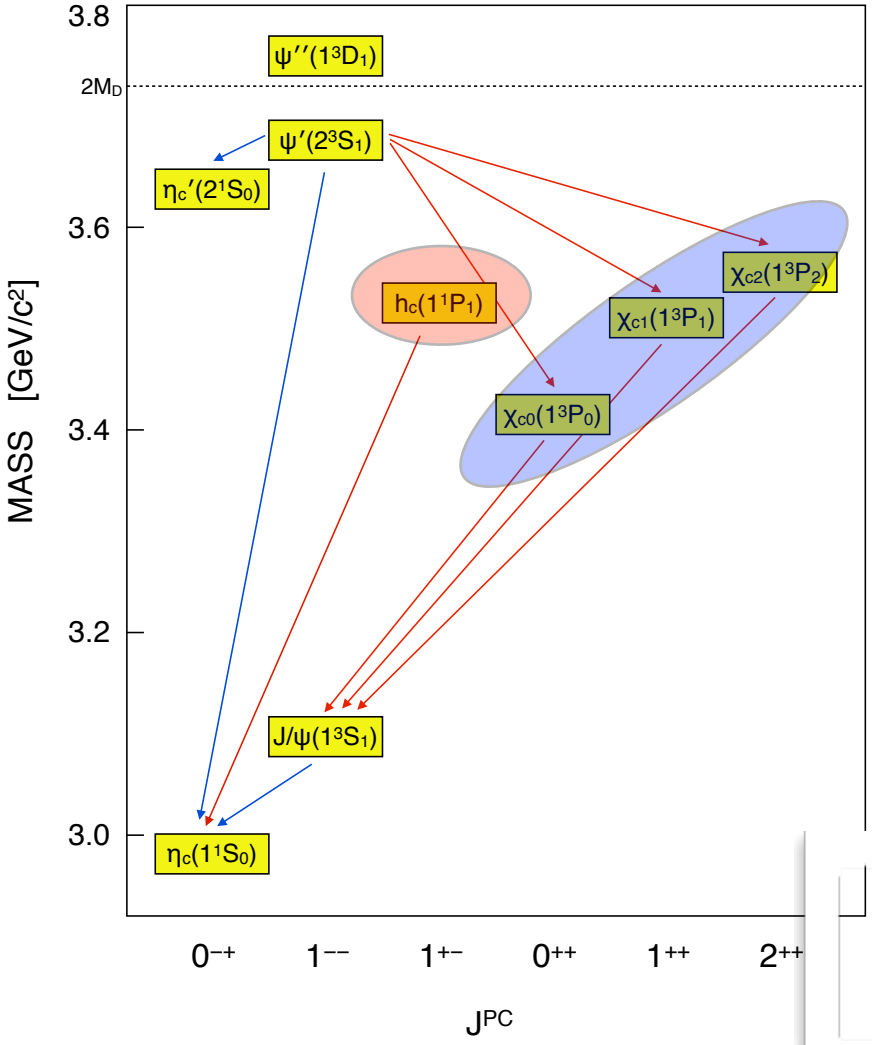


Precision!

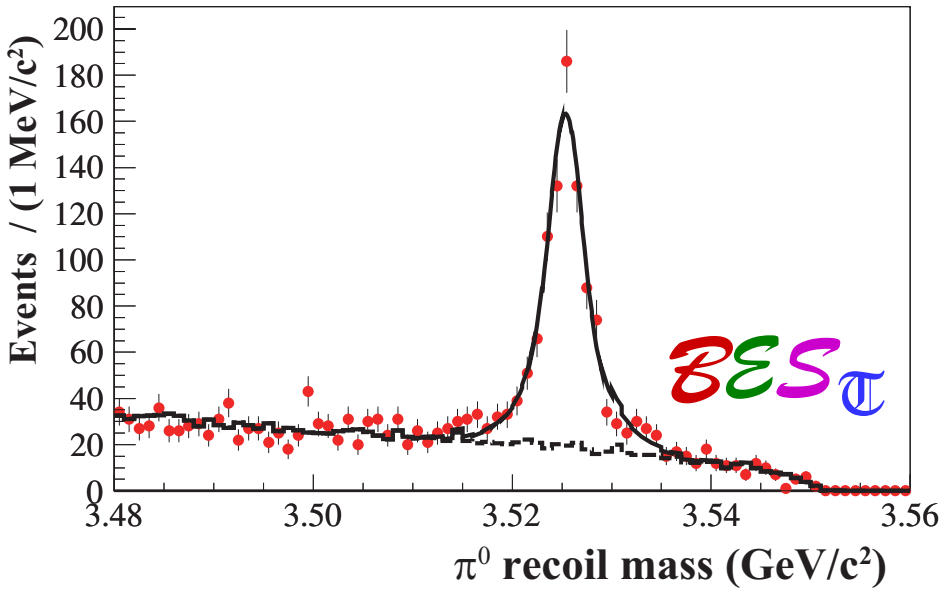
$$M = 3525.31 \pm 0.11 \pm 0.14 \text{ MeV}$$

$$\Gamma = 0.70 \pm 0.28 \pm 0.22 \text{ MeV}$$

"probing confinement potential"



PRD 86, 092009 (2012)



$$\Delta M_{hf} \equiv \langle M(1^3P)\rangle - M(1^1P_1)$$
$$= -0.01 \pm 0.11(\text{stat}) \pm 0.15(\text{syst})\ \text{MeV}/c^2$$

"exploiting isospin breaking"

breaking of
isospin symmetry: u <-> d

probe the ratio m_u/m_d

$$\frac{m_u}{m_d} \Leftrightarrow R = \frac{B\left(\Psi' \to \pi^0 J/\psi\right)}{B\left(\Psi' \to \eta J/\psi\right)}$$

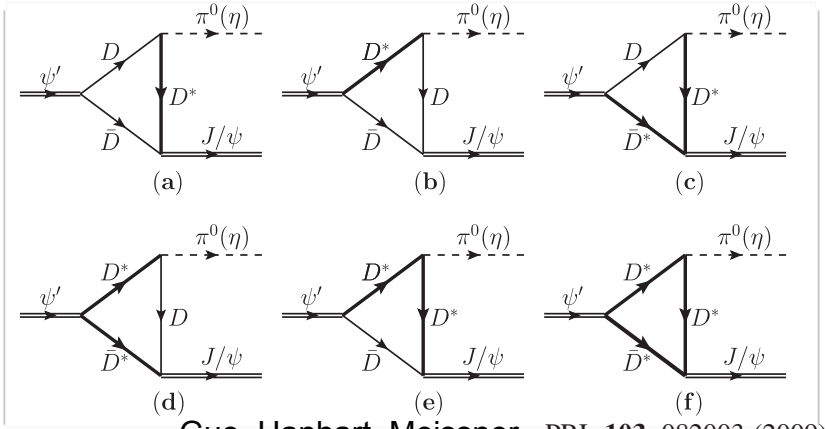
"exploiting isospin breaking"

breaking of
isospin symmetry: u <-> d

probe the ratio m_u/m_d

size of hadronic loops in charmonium

$$\frac{m_u}{m_d} \Leftrightarrow R = \frac{B(\Psi' \to \pi^0 J/\psi)}{B(\Psi' \to \eta J/\psi)} + loops\,!$$



Guo, Hanhart, Meissner PRL **103,** 082003 (2009)

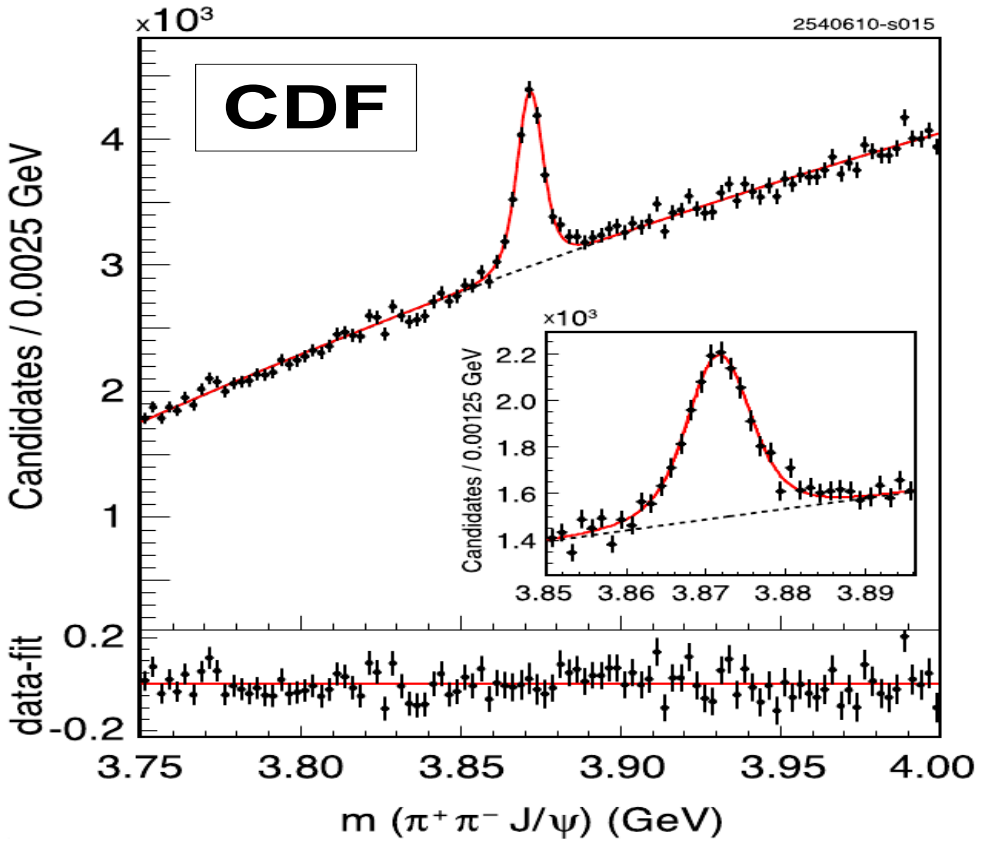
"exploiting isospin breaking"

breaking of
isospin symmetry: u <-> d

probe the ratio m_u/m_d

size of hadronic loops in charmonium

understand nature of the X(3872) state



"exploiting isospin breaking"

breaking of
isospin symmetry: u <-> d

probe the ratio m_u/m_d

size of hadronic loops in charmonium

understand nature of the X(3872) state

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

Experiment	
CDF 2	3871.61 ± 0.16 ± 0.19 MeV
BaBar (B^+)	3871.4 ± 0.6 ± 0.1 MeV
BaBar (B^0)	3868.7 ± 1.5 ± 0.4 MeV
D0	3871.8 ± 3.1 ± 3.0 MeV
Belle	3871.84 ± 0.27 ± 0.19 MeV
LHCb	3871.96 ± 0.46 ± 0.10 MeV
World Average	**3871.67 ± 0.17 MeV**
$M(D^0)+M(D^{*0})$ PDG2010	3871.79 ± 0.30 MeV

$\Gamma < 1.2$ MeV

$\Delta m = -0.12 \pm 0.35$ MeV

"exploiting isospin breaking"

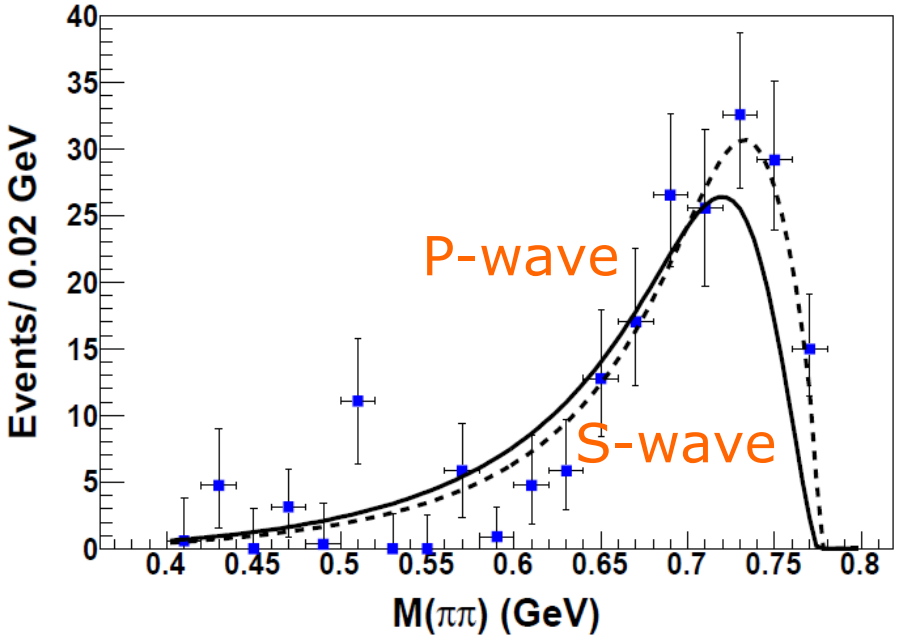
breaking of
isospin symmetry: u <-> d

probe the ratio m_u/m_d

size of hadronic loops in charmonium

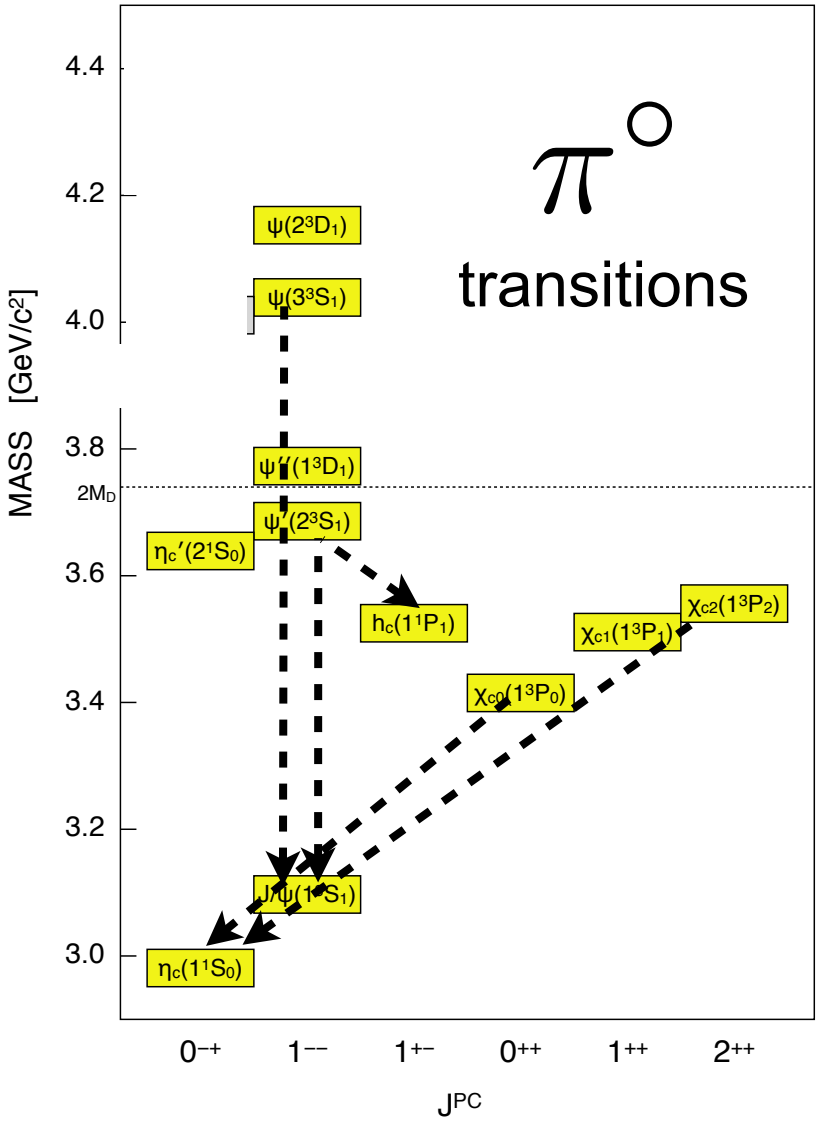
understand nature of the X(3872) state

$$X(3872) \to J/\Psi\rho$$



Isospin breaking enhanced for X(3872)

"exploiting isospin breaking"



BESⅢ

$B(\psi(4010) \rightarrow \pi^0 J/\psi) < 2.8 \cdot 10^{-4}$

Phys. Rev. D 86, 071101(R) (2012)

$B(\psi' \rightarrow \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \cdot 10^{-4}$

PRL 104, 132002 (2010)

$B(\psi' \rightarrow \pi^0 J/\psi)/B(\psi' \rightarrow \eta J/\psi) = (3.74 \pm 0.06 \pm 0.04) \cdot 10^{-2}$

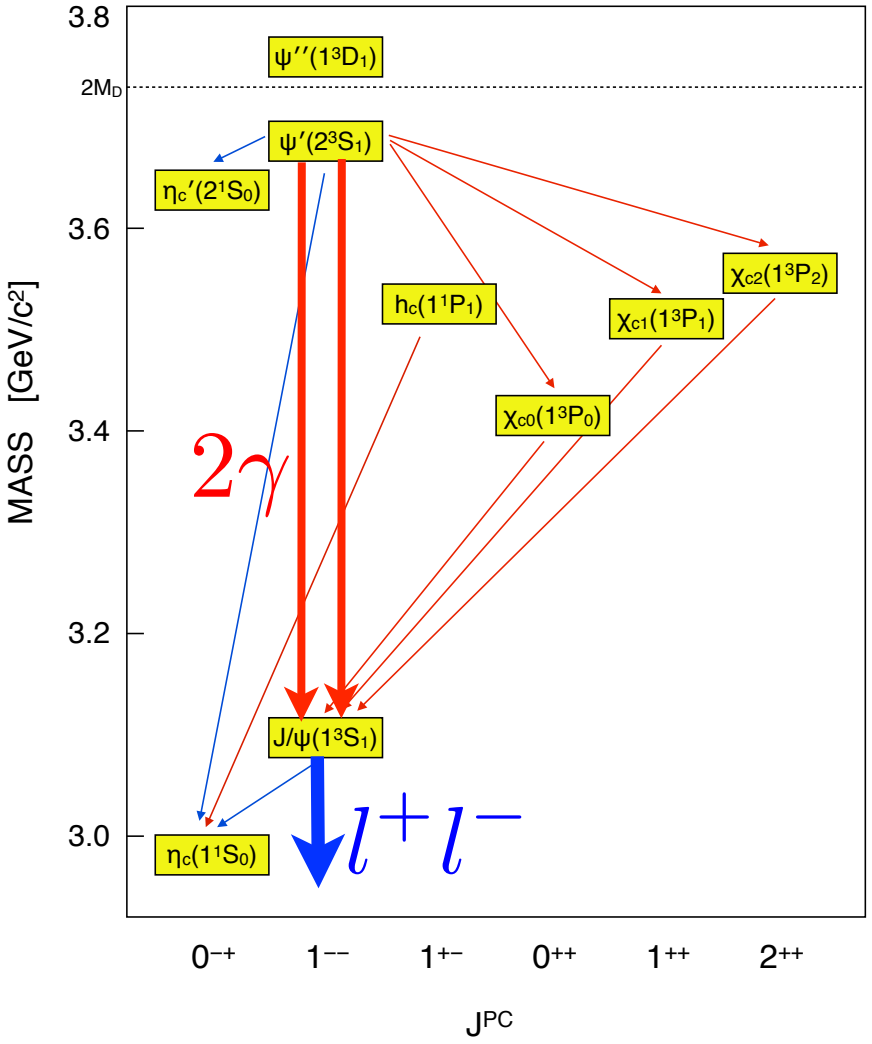
PRD 86, 092008 (2012)

$B(\chi_{c0,2} \rightarrow \pi^0 \eta_c) < ?$

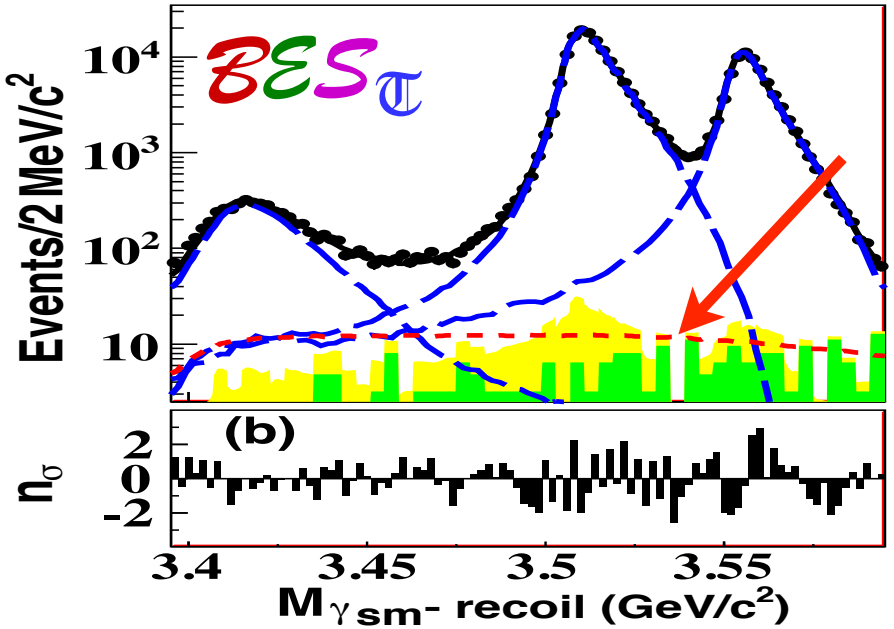
In Progress

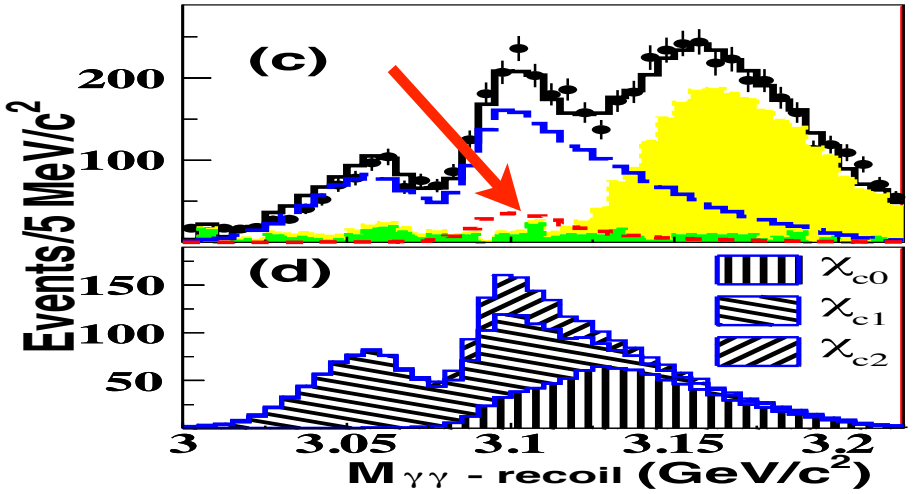
valuable input to EFT approaches (low-energy QCD expansion)

"two-photon transitions"



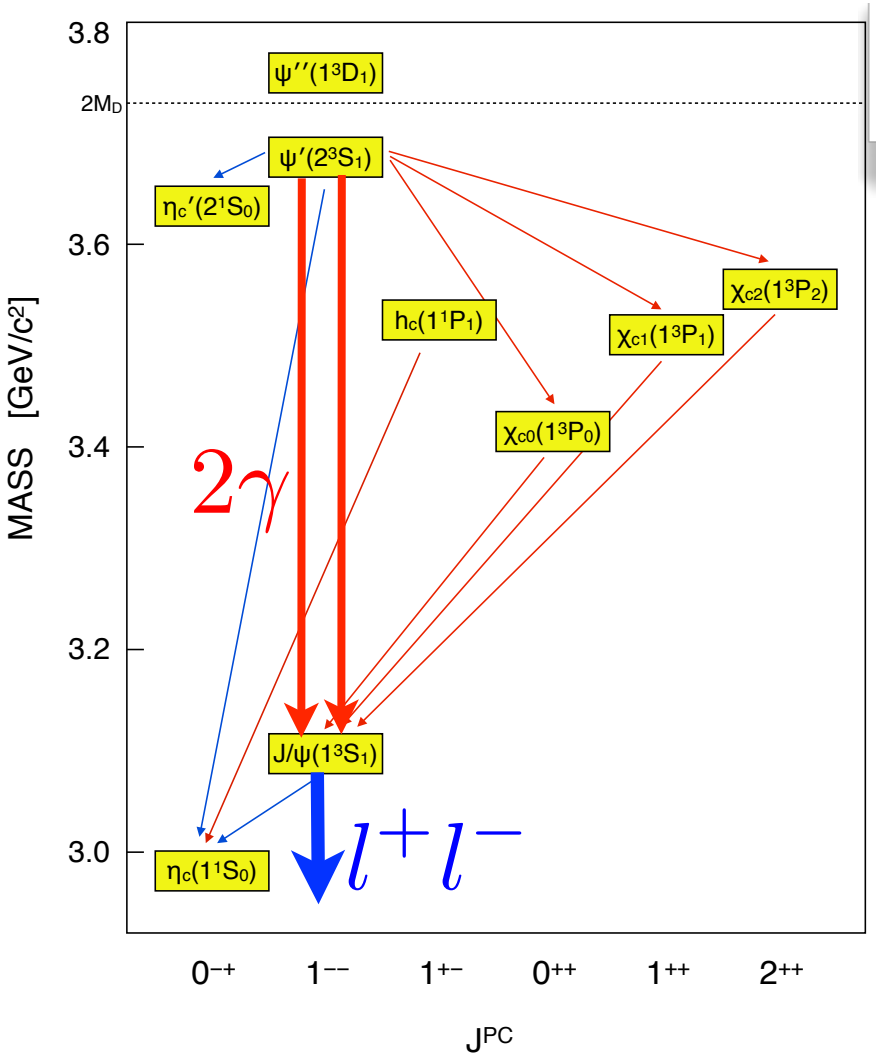
Phys. Rev. Lett 109, 172002 (2012)





"two-photon transitions"

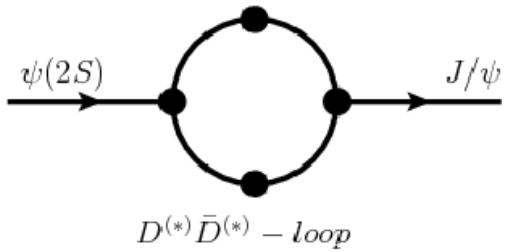
Phys. Rev. Lett 109, 172002 (2012)



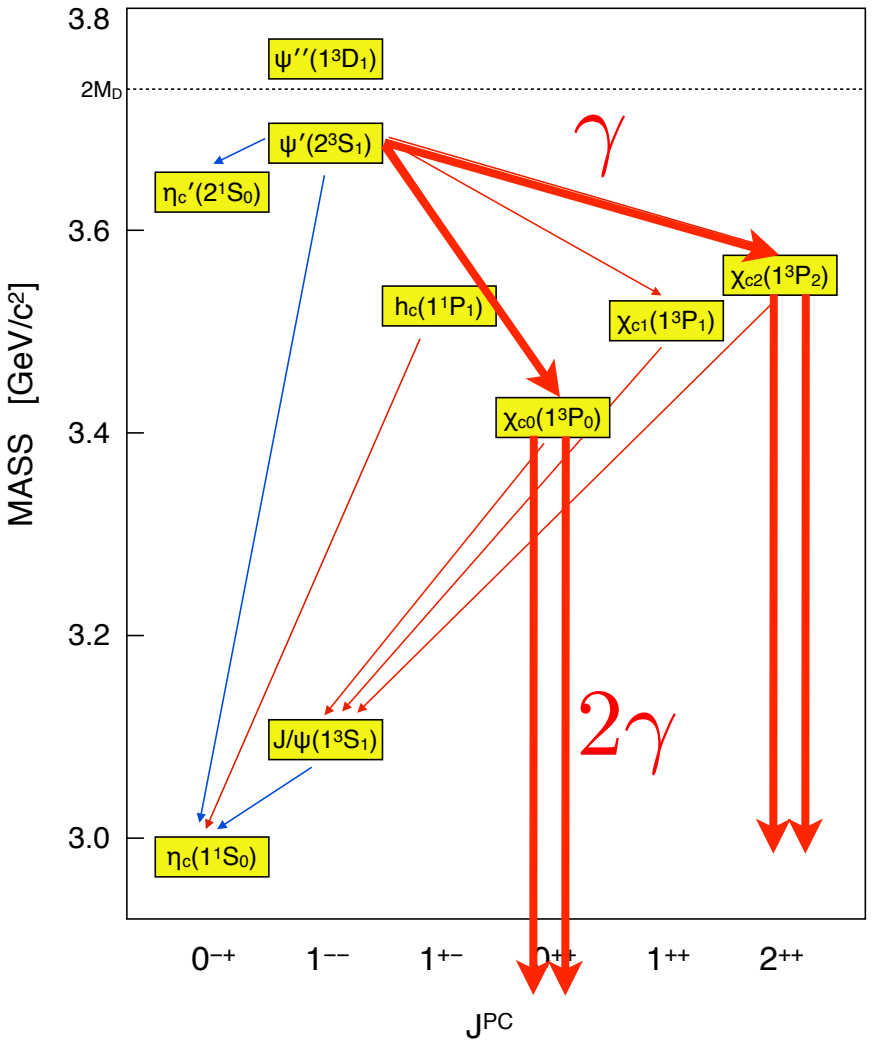
$$B(\psi' \rightarrow \gamma\gamma J/\psi) = (3.1 \pm 0.6_{(stat)} {}^{+0.8}_{-1.0}{}_{(syst)})\times 10^{-4}$$

milestone demonstrating the potential of BESIII

physics: sensitive probe to hadronic loop effects!



"two-photon decays"

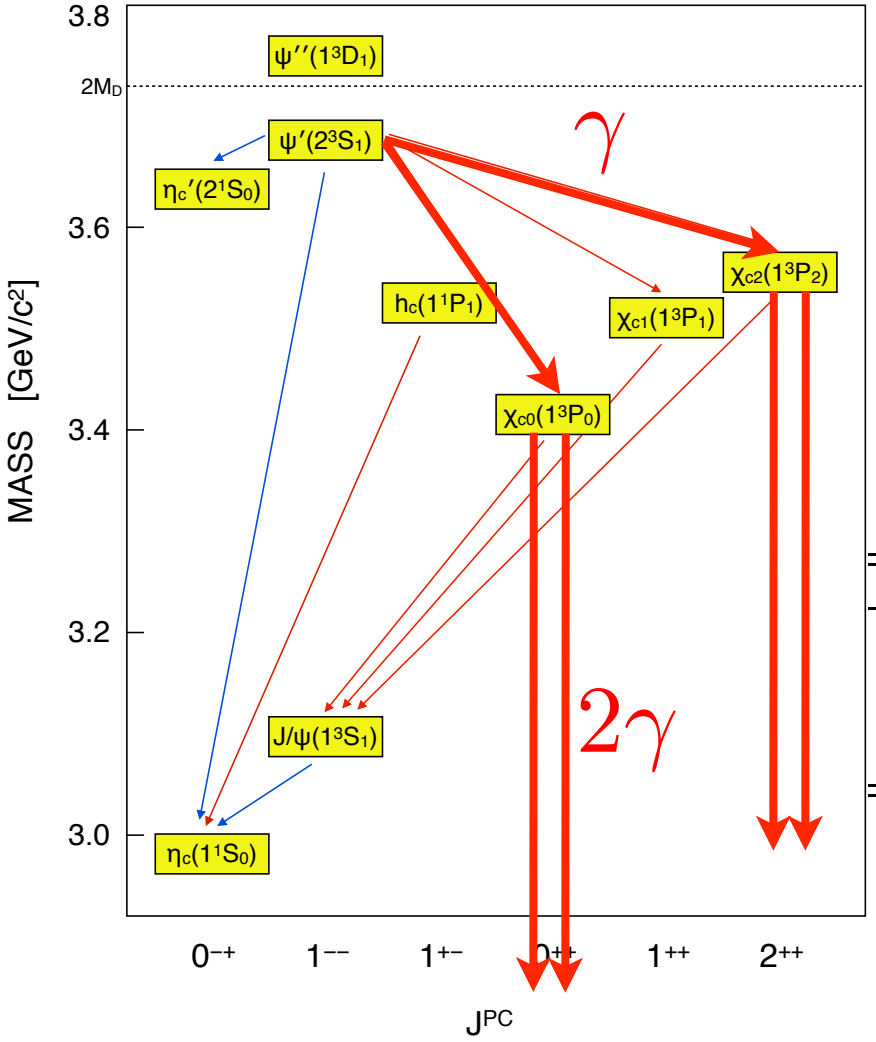


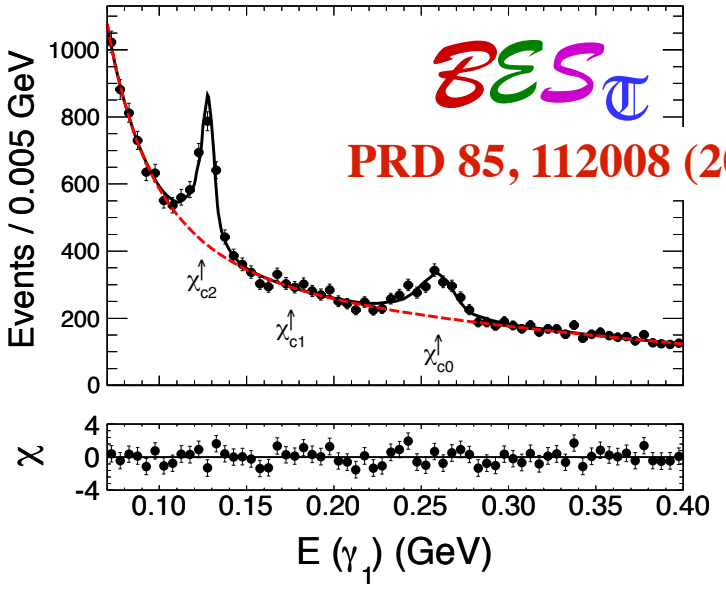
ideal probe to test validity of perturbative QCD

analog to P-wave triplet states in positronium, in lowest order:

$$R_{th}^{(0)} = \frac{\Gamma(^3P_2 \to \gamma\gamma)}{\Gamma(^3P_0 \to \gamma\gamma)} = 4/15 \approx 0.27$$

"two-photon decays"





Quantity	χ_{c0}	χ_{c2}
$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^5$	2.17±0.17±0.12	2.81±0.17±0.15
$\mathcal{B}_2 \times 10^4$	2.24±0.19±0.12±0.08	3.21±0.18±0.17±0.13
$\Gamma_{\gamma\gamma}$ (keV)	2.33±0.20±0.13±0.17	0.63±0.04±0.04±0.04
$\mathcal{R}$	0.271±0.029±0.013±0.027	

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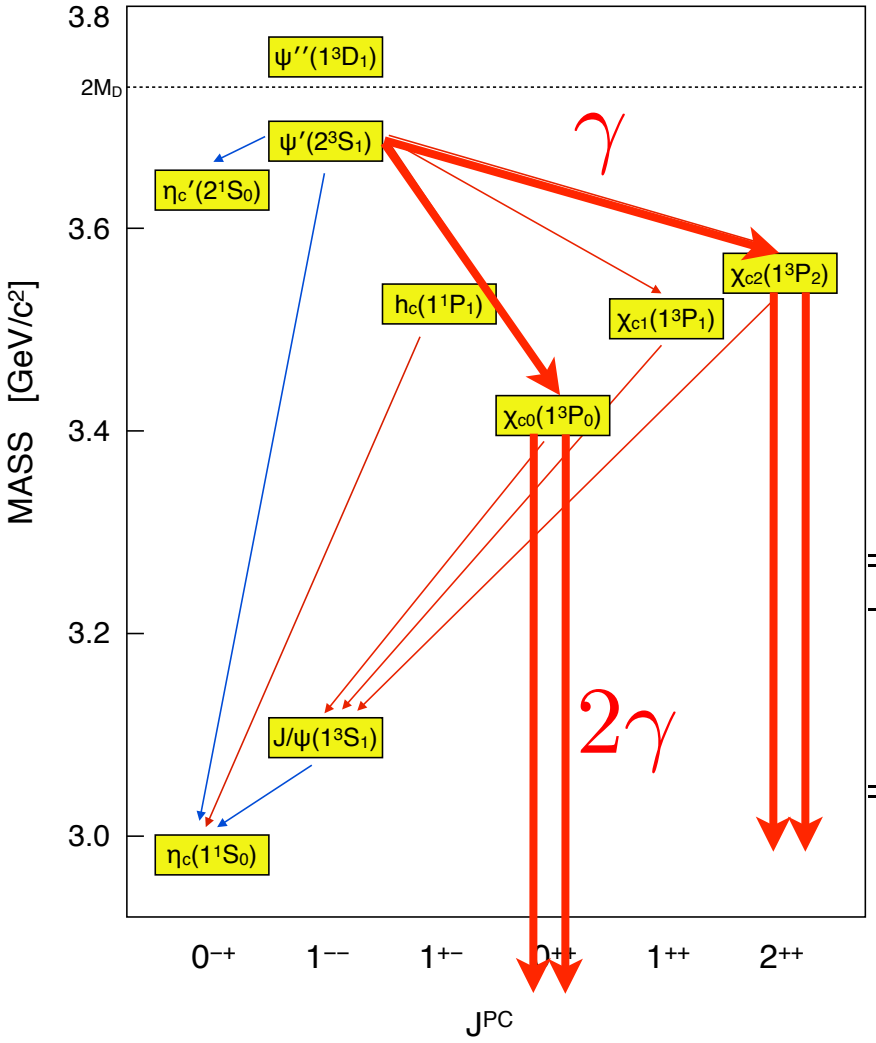
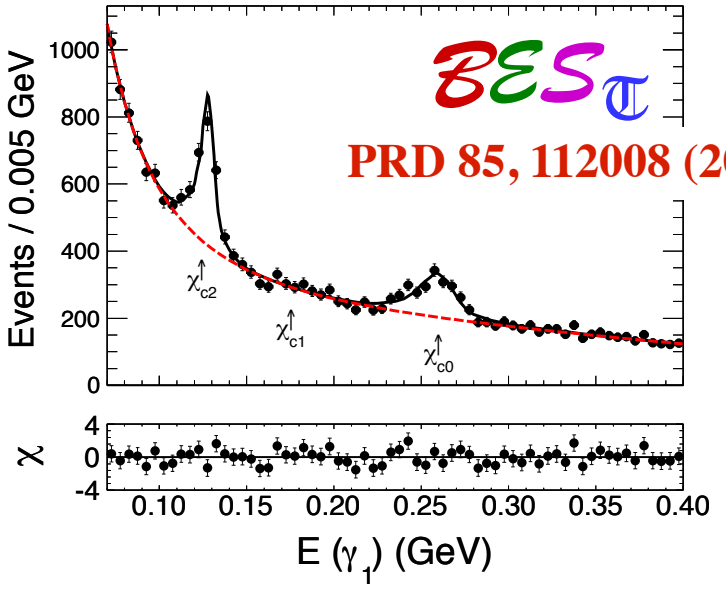
"two-photon decays"





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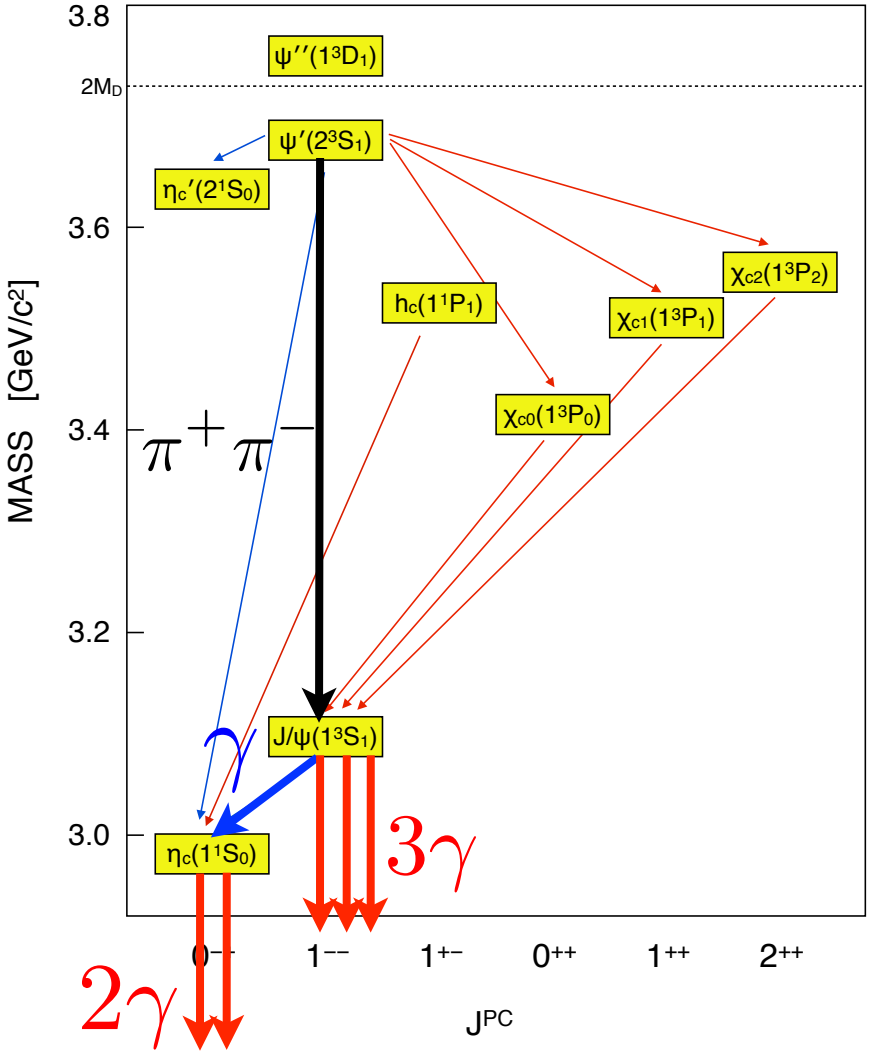
$\mathcal{R}$	0.271±0.029±0.013±0.027	

+radiative corrections

$$R_{th}^{(1)} = 0.116 \pm 0.010$$

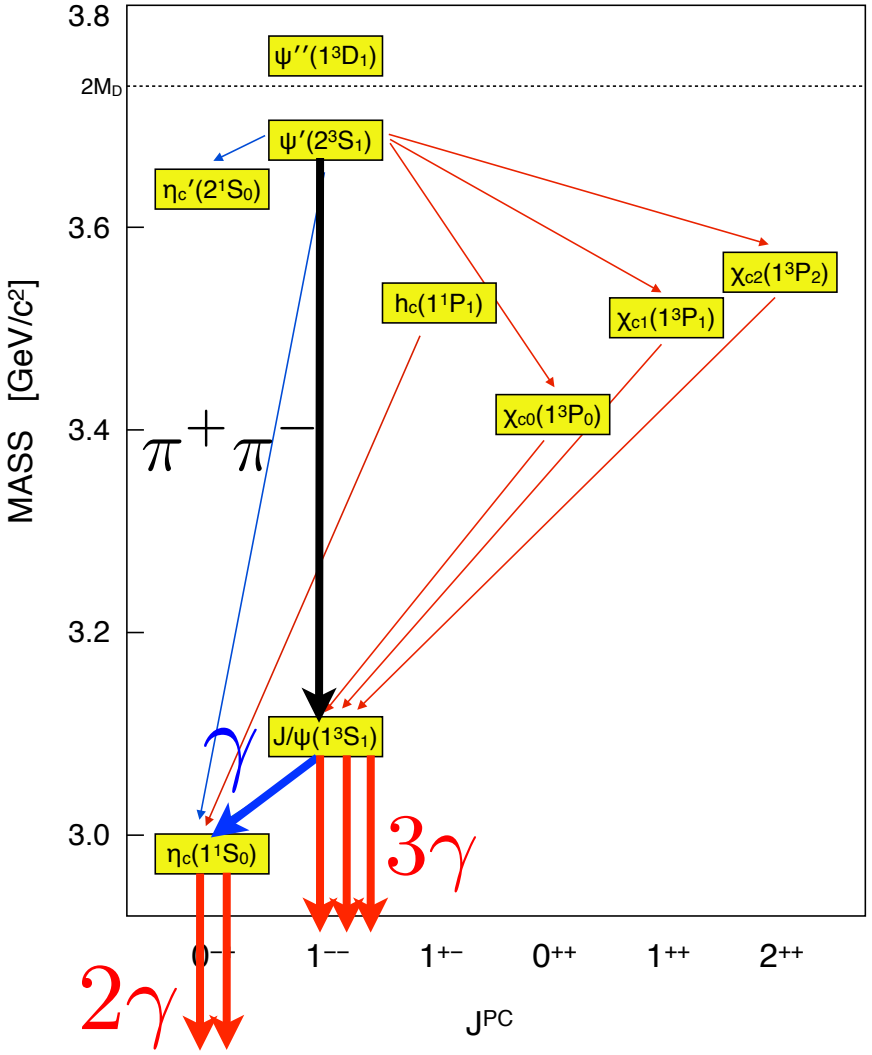
M. B. Voloshin, Prog. Part. Nucl. Phys. **61**, 2, 455 (2008).

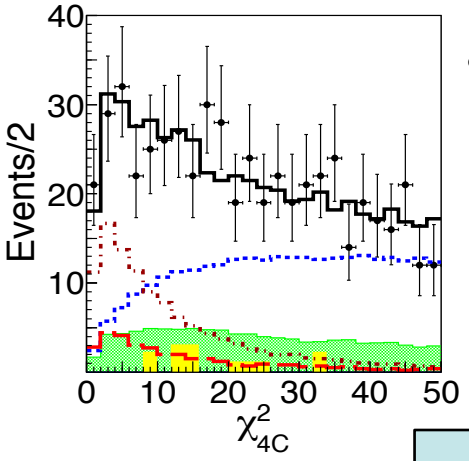
"two and three-photon decays"

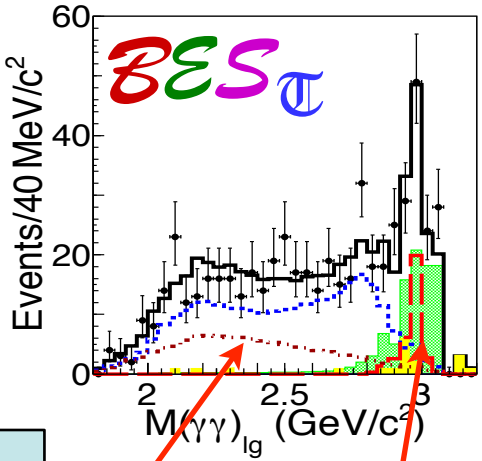


"two and three-photon decays"

arXiv:1208.1461v2



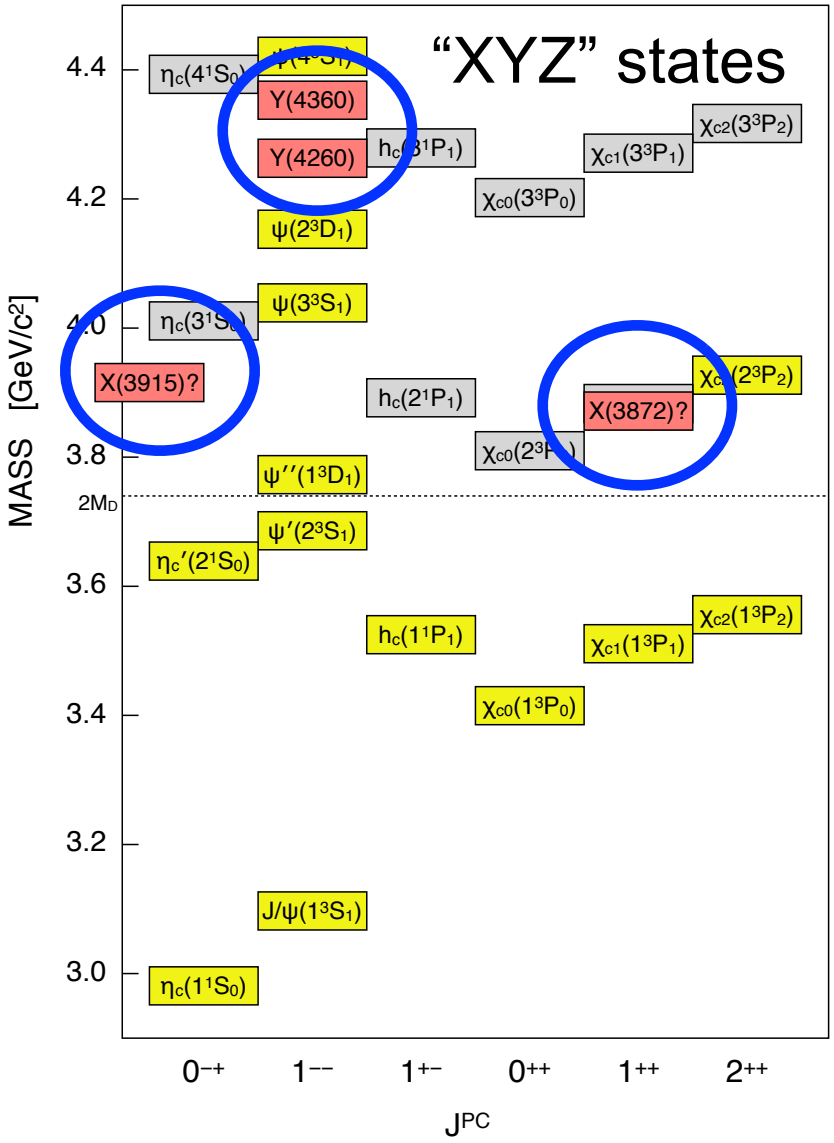




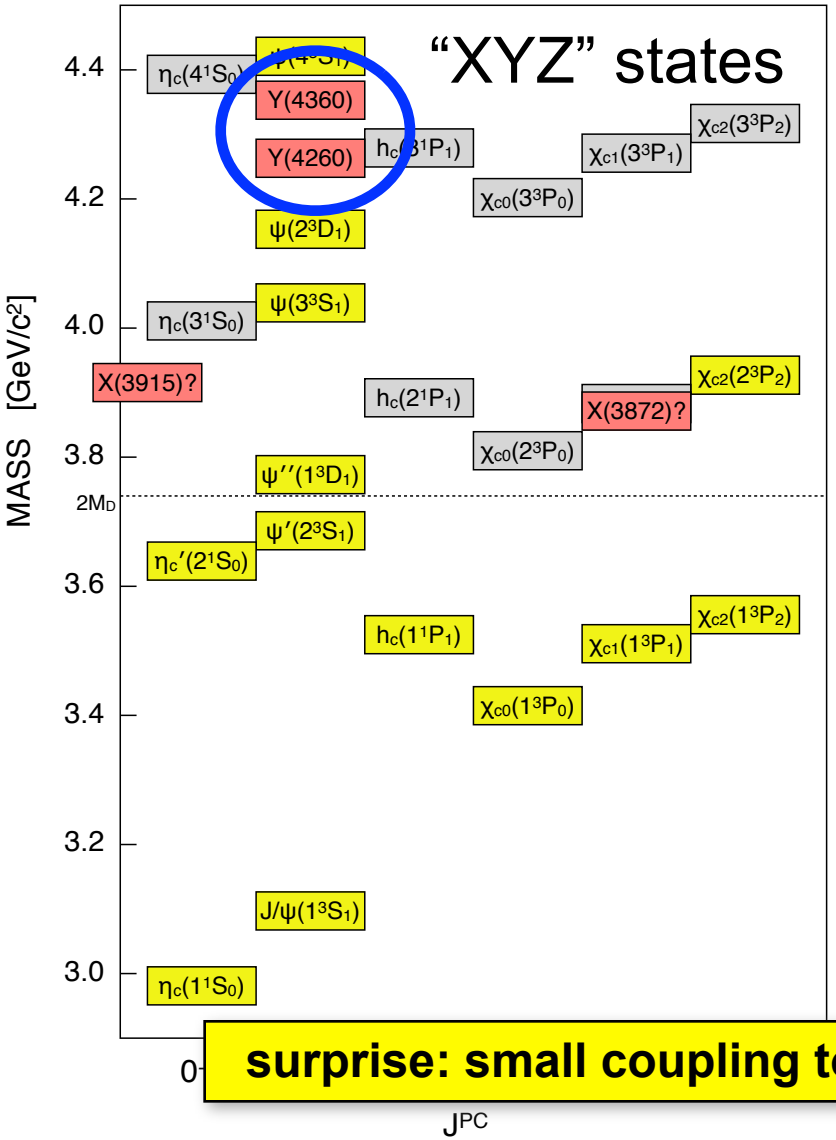
modes	$J/\psi \to 3\gamma$	$J/\psi \to \gamma\eta_c \to 3\gamma$
ϵ (%)	27.9 ± 0.1	20.7 ± 0.2
yields	113.4 ± 18.1	33.2 ± 9.5
significance	$8.3(7.3)\sigma$	$4.1(3.7)\sigma$
$\mathcal{B}(\times 10^{-6})$	$11.3 \pm 1.8 \pm 2.0$	$4.5 \pm 1.2 \pm 0.6$

Preliminary

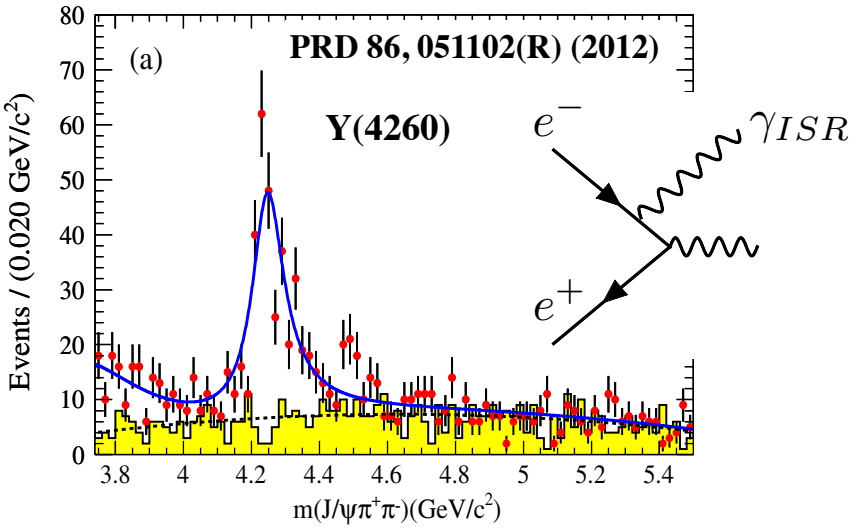
terra incognita: QCD exotics?



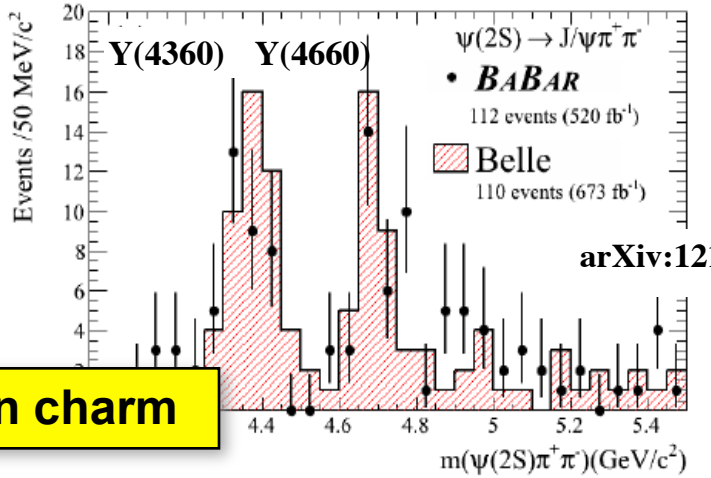
terra incognita: QCD exotics?



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



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



arXiv:1211.6271

surprise: small coupling to open charm

terra incognita: QCD exotics?