Results on conventional and exotic charmonium at BaBar

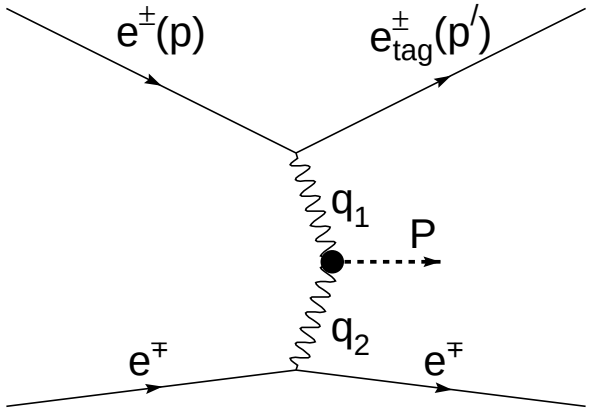
Denis Bernard

On behalf of the BaBar Collaboration

XXI. International Workshop on Deep-Inelastic Scattering and Related Subjects

22-26 April 2013 Marseille, France

Two photon production : 1 : tagged measurements



- One $e^{\pm}$ emits a highly offshell γ, $Q^2 = -q^2$; Electron tag.
  The other $e^{\mp}$ lost in beam tube
- $d\sigma/dQ^2$ depends on form factor $F(Q^2)$
- Excellent signal purity ; Good reconstruction efficiency (≈ 0.2)
- Example : measurement of $\gamma\gamma^* \to \eta_c$ form factor PRD81 (2010) 052010

  No results presented in this talk

Two photon production : 2 : untagged measurements

- Photons quasi-real : allowed J^{PC} are
  - $0^{\pm+}$, $2^{\pm+}$, $4^{\pm+}$ ..
  - 3^{++}, 5^{++} ..

  Angular momentum conservation, P conservation, and C invariance (strong decays)

  $\Rightarrow$ these quantum numbers apply to the final state too.

- Both $e^{\mp}$ lost in beam tube, undetected.

Charmonium in $\gamma\gamma \to J/\psi\,\omega$

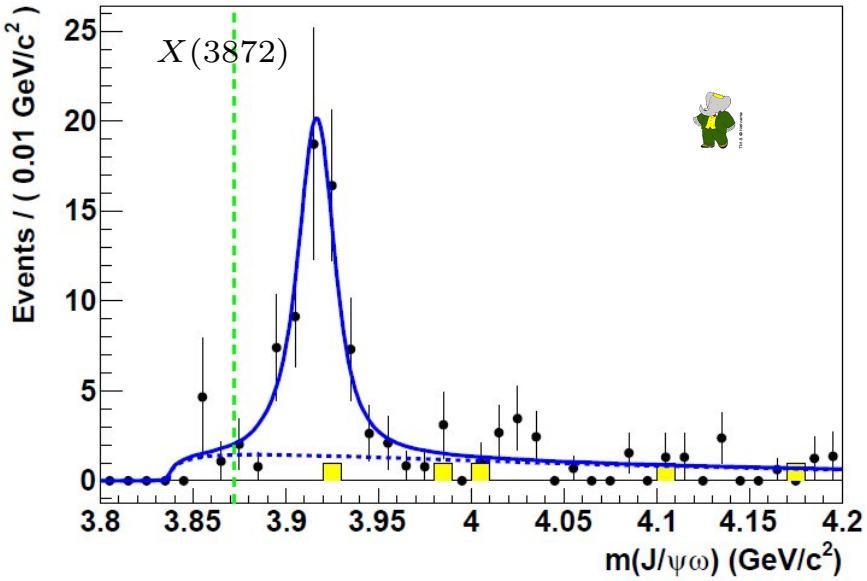
- X(3915)
  - X(3915) observed by Belle in $\gamma\gamma \to J/\psi\,\omega$; $\chi_{c0}(2P)$? $\chi_{c2}(2P)$?
  - Z(3930) observed by Belle, and BaBar, in $\gamma\gamma \to D\overline{D}$. $\chi_c 2(2P)$

  Are X(3915) and Z(3930) the same state ? measure J^{PC} of X(3915) !

- X(3872)
  - discovered in B decays, $X(3872) \to J/\psi\,\pi\pi$, Belle
  - seen in B decays, $J/\psi\,\pi\pi$, $J/\psi\,\omega$, $D^0 D^0 \pi^0$, $J/\psi\,\gamma$ $(C = +)$
  - $J^{PC} = 1^{++}$ or $J^P = 2^{-+}$, angular analysis of $J/\psi\,\pi\pi$ CDF
  - If :
    - $J^P = 2^-$, X(3872) 2-photon production allowed.
    - $J^P = 1^+$, X(3872) 2-photon production NOT allowed.

$X(3872)$ and $X(3915)$ in $\gamma\gamma \to J/\psi\,\omega$

- Untagged, $p_T < 0.2\,\mathrm{GeV}/c$, $E_{EMC,extra} < 0.3\,\mathrm{GeV}$, $\psi(2S)$ veto
- ISR background rejected by $m^2_{miss} = (p_{e^+e^-} - p_{rec})^2 > 2(\,\mathrm{GeV}/c^2)^2$

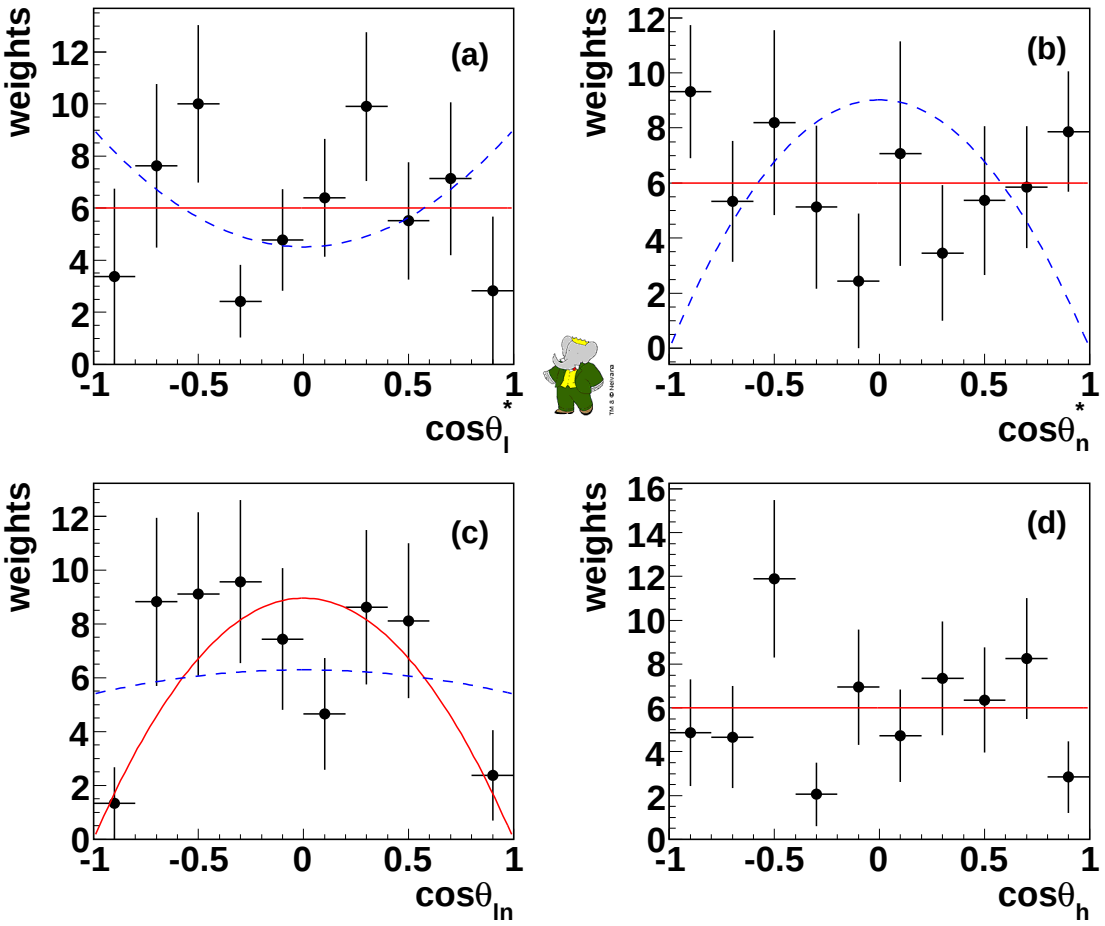


		$m(\,\mathrm{MeV}/c^2)$	$\Gamma(\,\mathrm{MeV})$	$\Gamma_{\gamma\gamma} \times \mathcal{B}(J/\psi\,\omega)$ (eV)
X(3915)	7.6σ	$3919.4 \pm 2.2 \pm 1.6$	$13 \pm 6 \pm 3$	$52 \pm 10 \pm 3$ $(J=0)$ $10.5 \pm 1.9 \pm 0.6$ $(J=2)$
X(3872)	not seen : disfavors 2^-			< 1.7

- X(3915) : Confirms Belle's observation (PRL 104 (2010) 092001)
- X(3872) : Not seen

Phys. Rev. D 86, 072002 (2012) 519 fb^{-1}

$X(3915)$ in $\gamma\gamma \to J/\psi\omega$: Angular Analysis : Step 1



p_{χ^2} for θ_n^*

$J^P = 0^\pm$ $p_{\chi^2} = 64.7\ \%$

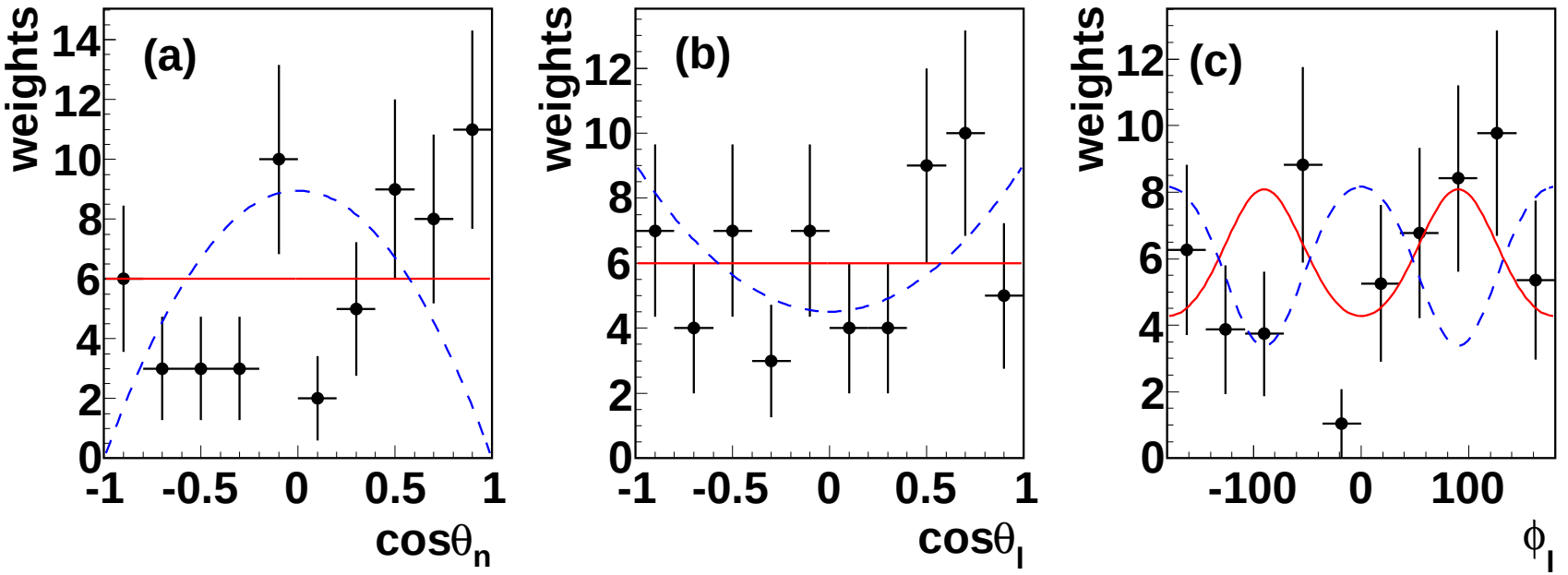
$J^P = 2^+$ $p_{\chi^2} = 9.6 \times 10^{-9}$

$J^P = 0^\pm$ preferred

Phys. Rev. D 86, 072002 (2012)

519 fb^{-1}

$X(3915)$ in $\gamma\gamma \to J/\psi\omega$: Angular Analysis : Step 2



p_{χ^2} for θ_n :

- $J^P = 0^+$ $p_{\chi^2} = 6.1\ \%$
- $J^P = 0^-$ $p_{\chi^2} = 4.8 \times 10^{-11}$

$J^P = 0^+$ preferred ; $\chi_{c0}(2P)$? ?

Phys. Rev. D 86, 072002 (2012)

519 fb^{-1}

Search for resonances in $\gamma\gamma \to \eta_c \pi^+ \pi^-$

Predictions :

- $\Gamma(\eta_c(2S) \to \eta_c \pi^+ \pi^-)/\Gamma(\psi(2S) \to J/\psi\, \pi^+ \pi^-) = 2.9$
  That is $\mathcal{B}(\eta_c(2S) \to \eta_c \pi^+ \pi^-) = (2.2^{+1.6}_{-0.6})\%$
  M.B. Voloshin, Mod. Phys. Lett. A 17 (2002) 1533

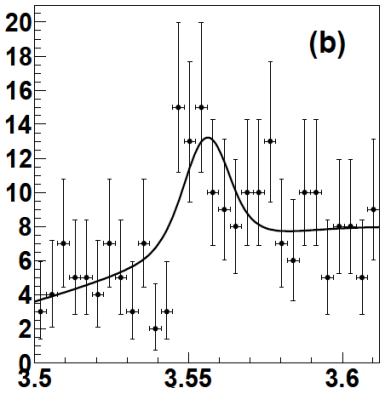
- Then
  - If $X(3872) \equiv \eta_{c2}$ $(1^1D_2,\ J^{PC} = 2^{-+})$,
  - $\mathcal{B}(X(3872) \to \eta_c \pi^+ \pi^-) > \mathcal{B}(X(3872) \to J/\psi\, \pi^+ \pi^-) > 2.6\%$[PDG]
    (isospin conserving) (isospin violating)
    S. Olsen et al., (Int J. Mod. Phys A 20 240 (2005))

If $J^{PC} = 2^{-+}$, X(3872) 2-photon production would be allowed, and $\mathcal{B}(X(3872) \to \eta_c \pi^+ \pi^-)$ could be sizable.

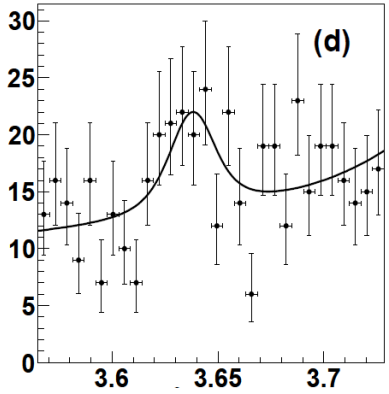
Search for resonances in $\gamma\gamma \to \eta_c \pi^+ \pi^-$

- Untagged $\eta_c \to K^0_S K^+ \pi^-$ 473.9 fb^{-1} Phys. Rev. D 86, 092005 (2012)

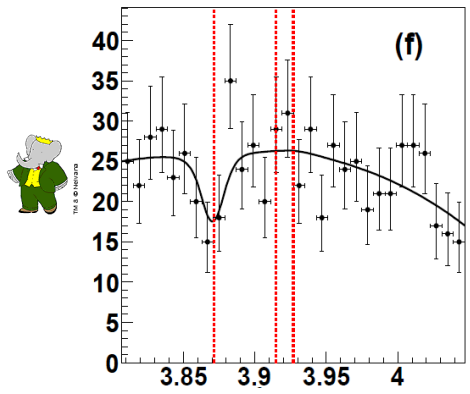
$\chi_{c2}(1P)$



$\eta_c(2S)$



$X(3872)$, $X(3915)$, $\chi_{c2}(2P)$



$m_{K^0_S K^+ \pi^- \pi^+ \pi^-}$

$$\frac{\mathcal{B}(\chi_{c2}(1P)\to\eta_c\pi^+\pi^-)}{\mathcal{B}(\chi_{c2}(1P)\to K^0_S K^+\pi^-)} = 14.5^{+10.9}_{-8.9} \pm 7.3 \pm 2.5 \qquad \mathcal{B}(\chi_{c2}(1P) \to \eta_c\pi^+\pi^-) < 2.2\%$$

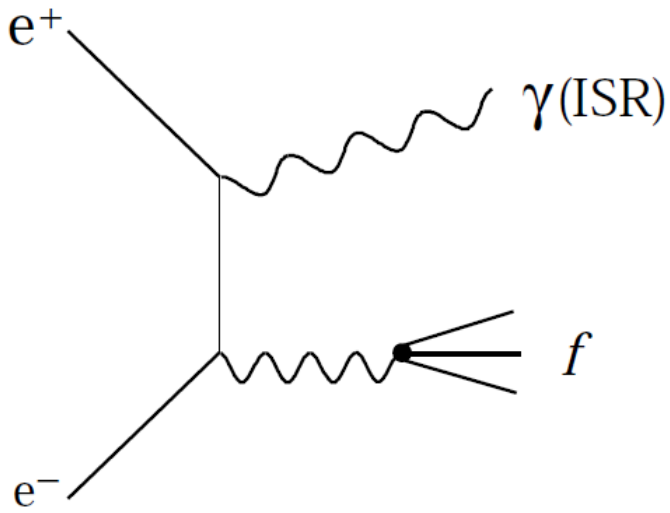
$$\frac{\mathcal{B}(\eta_c(2S)\to\eta_c\pi^+\pi^-)}{\mathcal{B}(\eta_c(2S)\to K^0_S K^+\pi^-)} = 4.9^{+3.5}_{-3.3} \pm 1.3 \pm 0.8 \qquad \mathcal{B}(\eta_c(2S) \to \eta_c\pi^+\pi^-) < 7.4\%$$

(compatible with prediction 2.2%)

$\Gamma_{\gamma\gamma}(X) \times \mathcal{B}(X \to \eta_c\pi^+\pi^-)$	$X(3872)$	$X(3915)$	$\chi_{c2}(2P)$
	< 11.1 eV	< 16 eV	< 19 eV

- No evidence for $\gamma\gamma$ production of $X(3872)$, $X(3915)$ nor $\chi_{c2}(2P)$

Initial State Radiation Production



- Here selecting final state with $J^{PC} = 1^{--}$

ISR : Older BaBar Results

A vigorous campaign that is still in progress

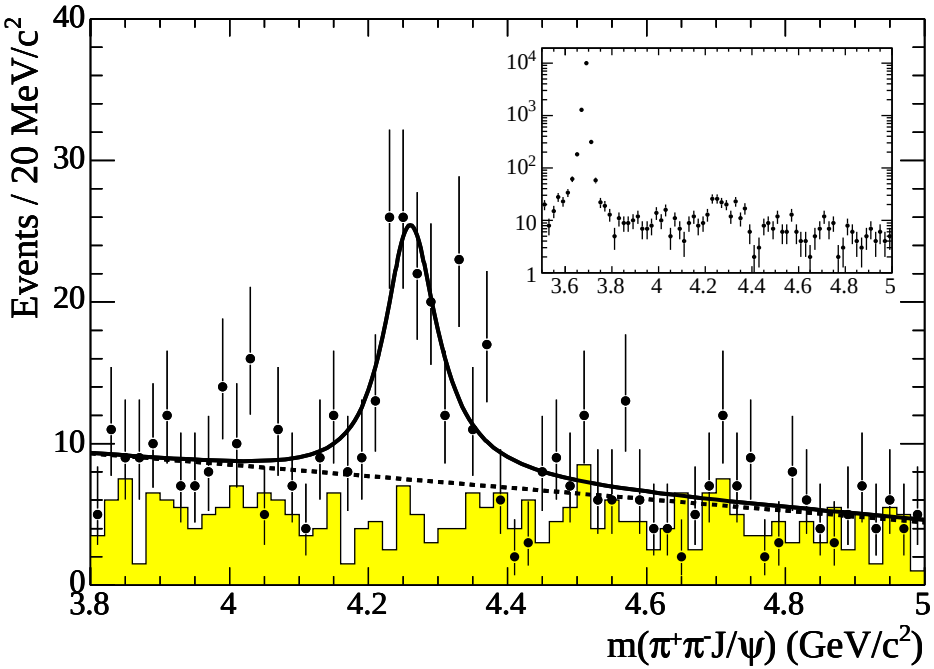
K^+K^-	in preparation
$K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$, $K^+K^-K^+K^-$	Phys. Rev.D86, 012008, 2012
$\pi^+\pi^-\pi^+\pi^-$	Phys. Rev.D85, 112009, 2012
$\pi^+\pi^-$	Phys. Rev.D86, 032013, 2012
$K^+K^-\eta$, $K^+K^-\pi^0$, $K^0K^\pm\pi^\mp$	Phys.Rev.D77 :092002,2008.
$2(\pi^+\pi^-)\pi^0$, $2(\pi^+\pi^-)\eta$, $K^+K^-\pi^+\pi^-\pi^0$, $K^+K^-\pi^+\pi^-\eta$	Phys.Rev.D76 :092005,2007.
$K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$, $K^+K^-K^+K^-$	Phys.Rev.D76 :012008,2007.
$3(\pi^+\pi^-)$, $2(\pi^+\pi^-\pi^0)$, $K^+K^-2(\pi^+\pi^-)$	Phys.Rev.D73 :052003,2006.
$\overline{p}p$	Phys.Rev.D73 :012005,2006.
$2(\pi^+\pi^-)$, $K^+K^-\pi^+\pi^-$, $K^+K^-K^+K^-$	Phys.Rev.D71 :052001,2005.
$\pi^+\pi^-\pi^0$	Phys.Rev.D70 :072004,2004.

- First observations 454 2 fb^{-1}, 232 fb^{-1}, 89 fb^{-1} @ 10.6 GeV
- Unprecedented accuracy on contributions to a_μ

Not covered in this talk ;

Study of ISR-produced resonances decaying to $\psi\pi^+\pi^-$

- Y(4260) discovered by BaBar in $J/\psi\pi^+\pi^-$ ISR production PRL 95 (2005) 142001

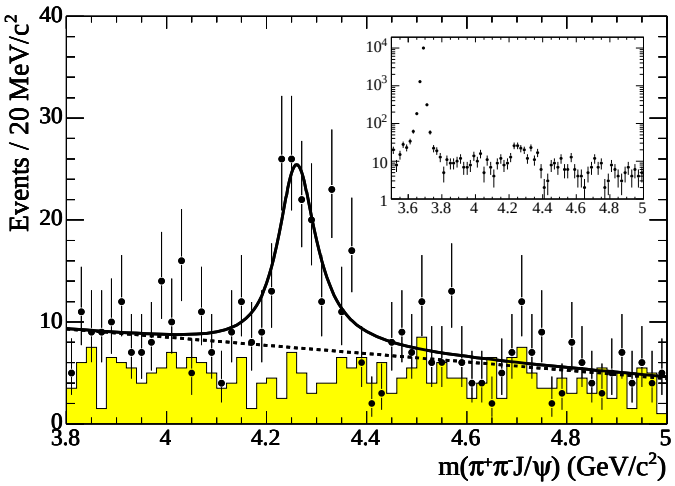


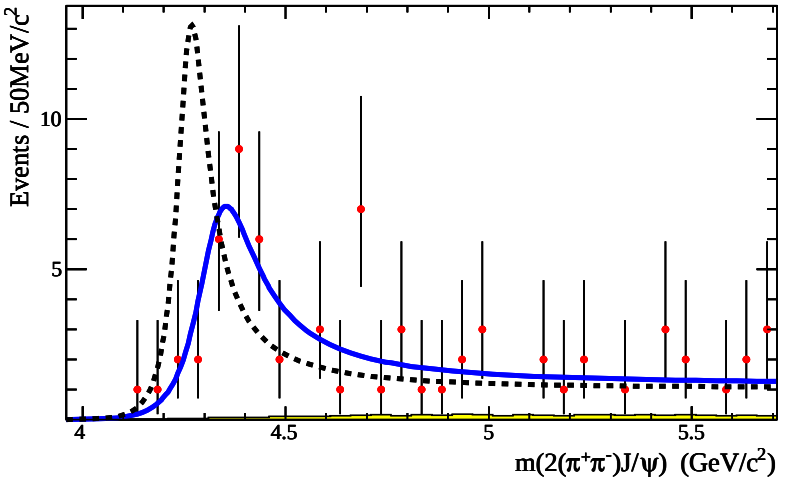
- Decays to $D\overline{D}$, $D\overline{D}^*$, $D^*\overline{D}^*$, $D_s^+D_s^-$, $D_s^{*+}D_s^-$, $D_s^{*+}D_s^{*-}$, are not seen (CLEO, Belle, BaBar) : most likely NOT a charmonium meson.
- Most likely NOT a four-quark system as not seen in $D_s^+D_s^-$ Maiani et al., Phys.Rev. D72 (2005) 031502
- hybrid charmonium meson ? Zhu, Phys.Lett. B625 (2005) 212

As in 2007 : Not that simple

$J/\psi\,\pi^+\pi^-$ $\qquad$ $\psi(2S)\pi^+\pi^-$

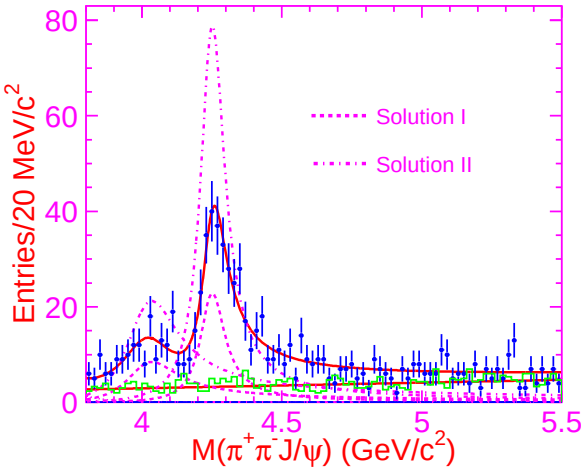
BaBar

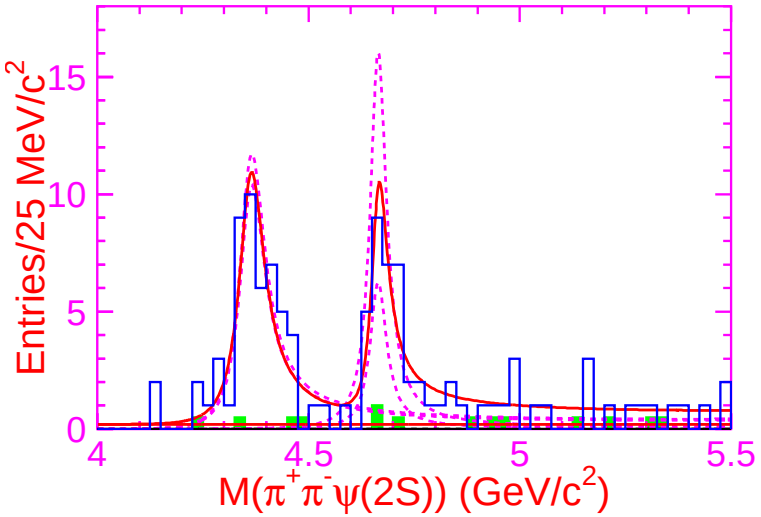




4.26 GeV PRL 95 (2005) 142001 211 fb^{-1} $\qquad$ 4.32 GeV PRL 98 (2007) 212001 298 fb^{-1}

Belle



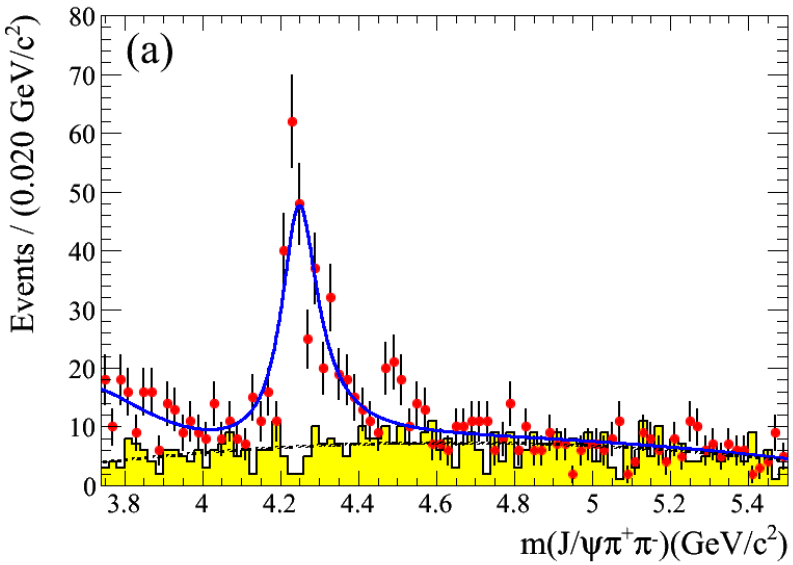


4.05, 4.25 GeV, PRL 99 (2007) 182004 548 fb^{-1} $\qquad$ 4.36, 4.66 GeV, PRL 99 (2007) 142002 673 fb^{-1}

Study of ISR-produced resonances decaying to $\psi\pi^+\pi^-$

- no photon tagging

$Y \to J/\psi\,\pi^+\pi^-$ 454 fb^{-1}



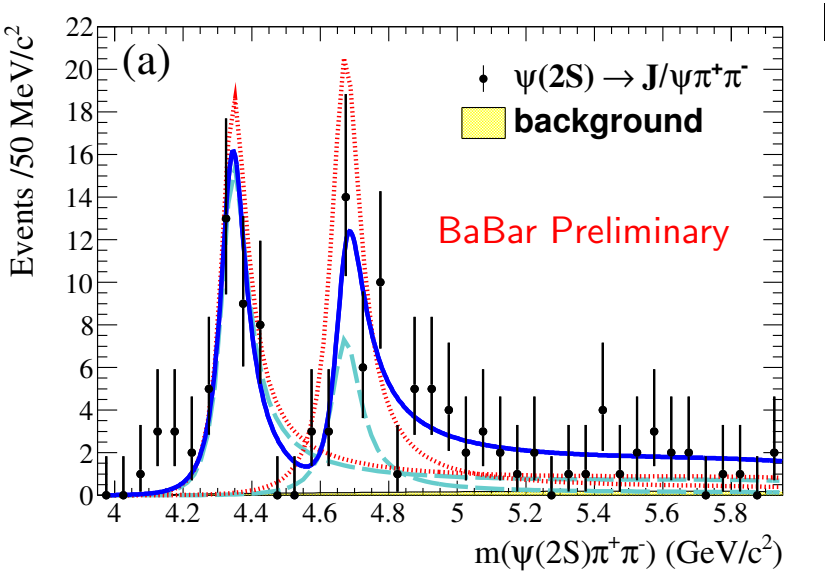
$m(Y(4260)) = 4245 \pm 5 \pm 4\,\mathrm{MeV}/c^2$

$\Gamma(Y(4260)) = 114^{+16}_{-15} \pm 7\,\mathrm{MeV}/c^2$

Don't confirm Belle's Y(4.01)

Phys. Rev. D 86, 051102(R) (2012)

$Y \to \psi(2S)\pi^+\pi^-$ 520 fb^{-1}



$m(Y(4360)) = 4340 \pm 16 \pm 9\,\mathrm{MeV}/c^2$,
$m(Y(4660)) = 4669 \pm 21 \pm 3\,\mathrm{MeV}/c^2$
$\Gamma(Y(4360)) = 94 \pm 32 \pm 13\,\mathrm{MeV}$,
$\Gamma(Y(4660)) = 104 \pm 48 \pm 10\,\mathrm{MeV}$

Do confirm Belle's Y(4.66)

Preliminary arXiv :1211.6271

Conclusion

– $\gamma\gamma$

- confirmation of $X(3915) \to J/\psi\omega$; angular analysis favors $J^P = 0^+$: $\chi_{c0}(2P)$?
- $X(3872) \to J/\psi\omega$ is not seen : $J^P = 2^-$ disfavored.
- $X(3872) \to \eta_c\pi^+\pi^-$ is not seen : $J^P = 2^-$ disfavored.

  Together with LHCb's preliminary result arXiv :1302.6269 , points to $J^{PC} = 1^{++}$

– ISR

- $J^{PC} = 1^{--}$ resonances decaying to charmonium,
  $Y(4260) \to J/\psi\pi^+\pi^-$, confirmed
  $Y(4010) \to J/\psi\pi^+\pi^-$, not confirmed
  $Y(4360) \to \psi(2S)\pi^+\pi^-$, confirmed
  $Y(4660) \to \psi(2S)\pi^+\pi^-$ confirmed

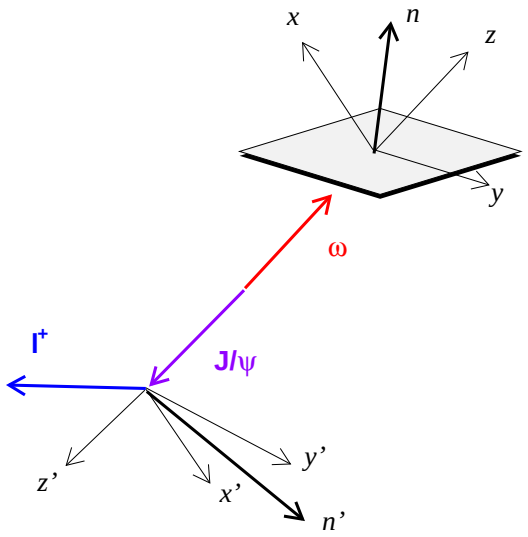
  A hybrid meson spectroscopy ?

Je vous remercie de votre attention

Back up slide

$J/\psi\omega$ angular analysis

- θ^*_ℓ is the angle between the direction of the positively charged lepton from J/ψ decay (ℓ^+) and the beam axis in the $J/\psi\omega$ rest frame.
- θ^*_n is the angle between the normal to the decay plane of the ω ($\vec{n}$) and the two-photon axis,
- θ_{ln} is the angle between the lepton ℓ^+ from J/ψ decay and the ω decay normal



- θ_h is the angle formed by the J/ψ momentum in the $J/\psi\omega$ rest frame with respect to the $J/\psi\omega$ direction in the laboratory frame.
- In the $J/\psi\omega$ rest frame : θ_n is the angle between the normal to the ω decay plane $\vec{n}$ and the ω direction in the $J/\psi\omega$ rest frame.
- θ_l ; first boost the ℓ^+ to the J/ψ rest frame. θ_l is the angle between the ℓ^+ and the direction of the J/ψ in the $J/\psi\omega$ frame.
- ϕ_l as the angle between the J/ψ and ω decay plane normals.