Charmonium and charmonium-like results from *BABAR*

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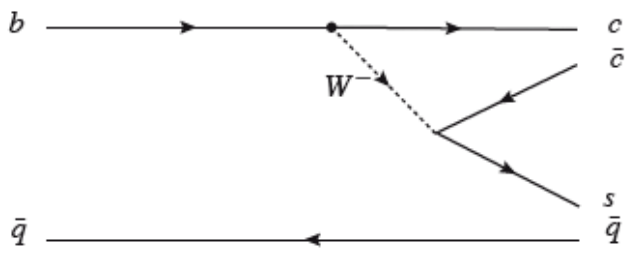
Outline

- Introduction
- Search for the $Z_1(4050)^+$ and $Z_2(4250)^+$ states in $\bar{B}^0 \to \chi_{c1} K^- \pi^+$ and $B^+ \to \chi_{c1} K_s^0 \pi^+$ PRD 85, 052003 (2012)
- Study of the $J/\psi\omega$ final state in two-photon collisions
- Search for resonances decaying into $\eta_c \pi^+ \pi^-$ using two-photon interactions
- Study of the reaction $e^+e^- \to J/\psi\pi^+\pi^-$ via initial-state radiation
- Summary

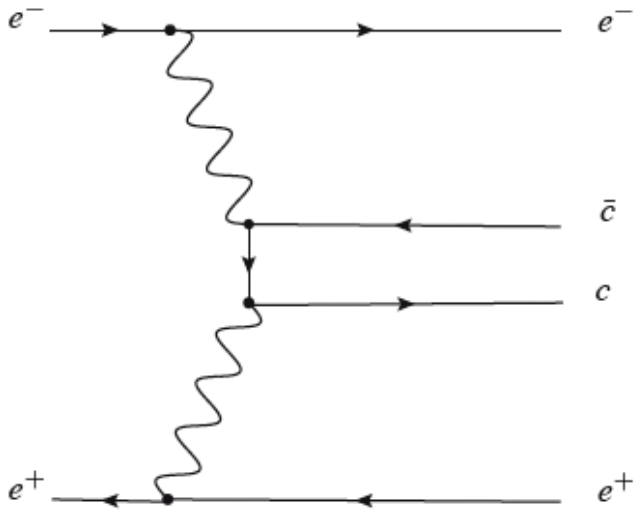
Experimental methods for charmonium production at the B-factories

B meson decays



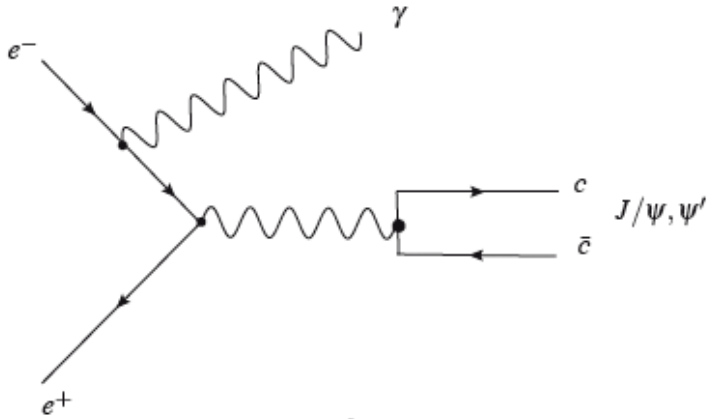
States of any quantum numbers can be produced

Two-photon production



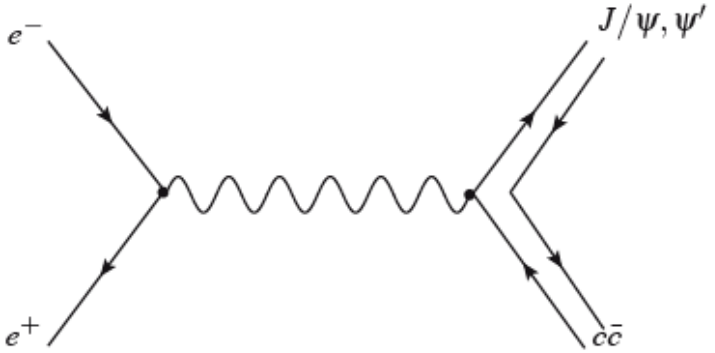
J-even charmonium states can be produced

Initial State Radiation (ISR)



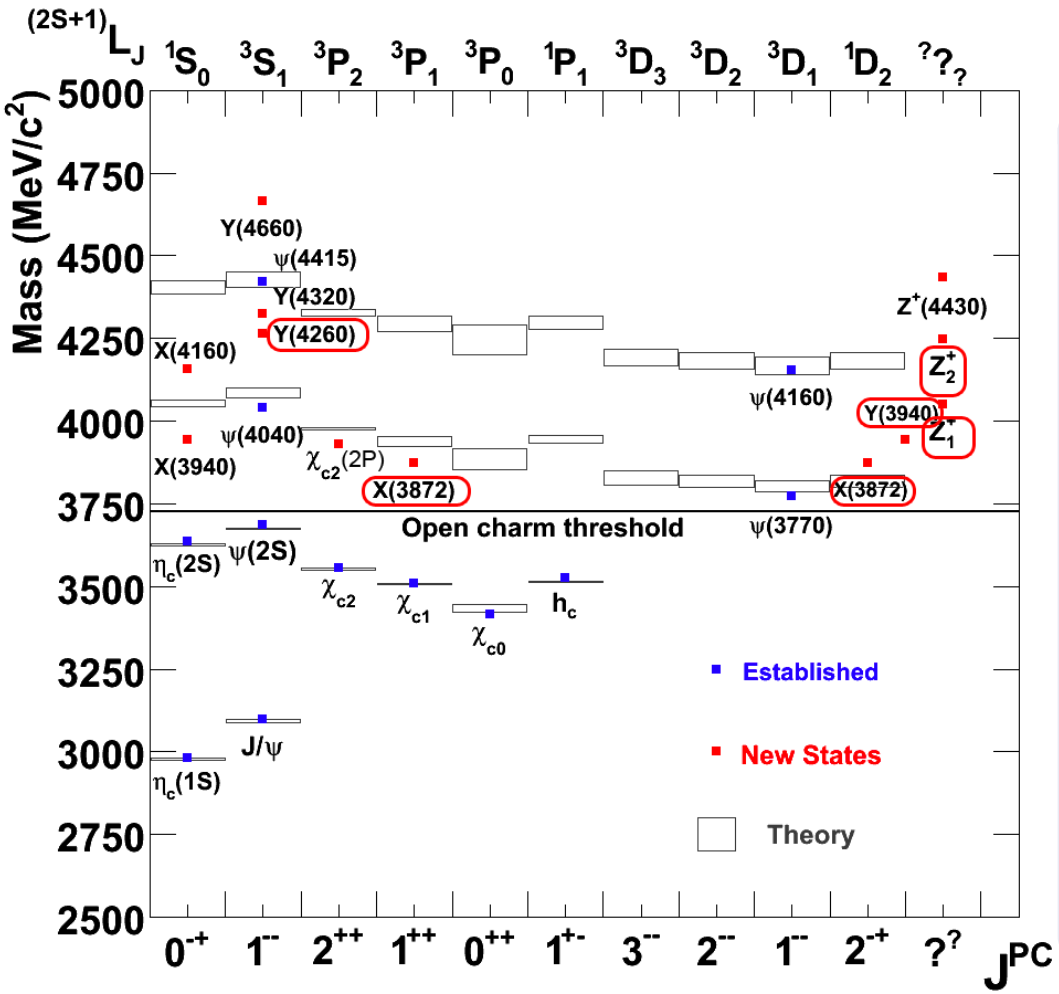
Only states with J^{PC} =1^{--} can be produced

Double charmonium production



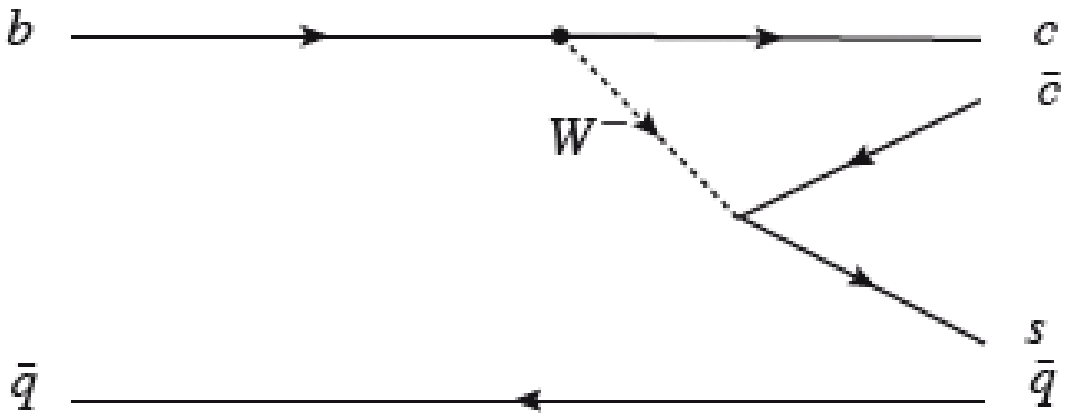
Only charmonium states with C=+1 are allowed to be produced in association with the J/ψ or the ψ(2S)

Charmonium spectrum



- Below the $D\bar{D}$ threshold, all expected states have been observed, with properties in good agreement with theory; there are no additional states.
- Many unexpected states have been reported above the $D\bar{D}$ threshold, seemingly too many with $J^{PC} = 1^{--}$
- These result mainly from Belle and *BABAR* , with significant contributions also from CDF, D0 and CLEO.

Eur. Phys. J.C71, 1534 (2011)



Search for the $Z_1(4050)^+$ and $Z_2(4250)^+$ states in $\bar{B}^0 \to \chi_{c1} K^- \pi^+$ and $B^+ \to \chi_{c1} K_s^0 \pi^+$ (429 fb^{-1})

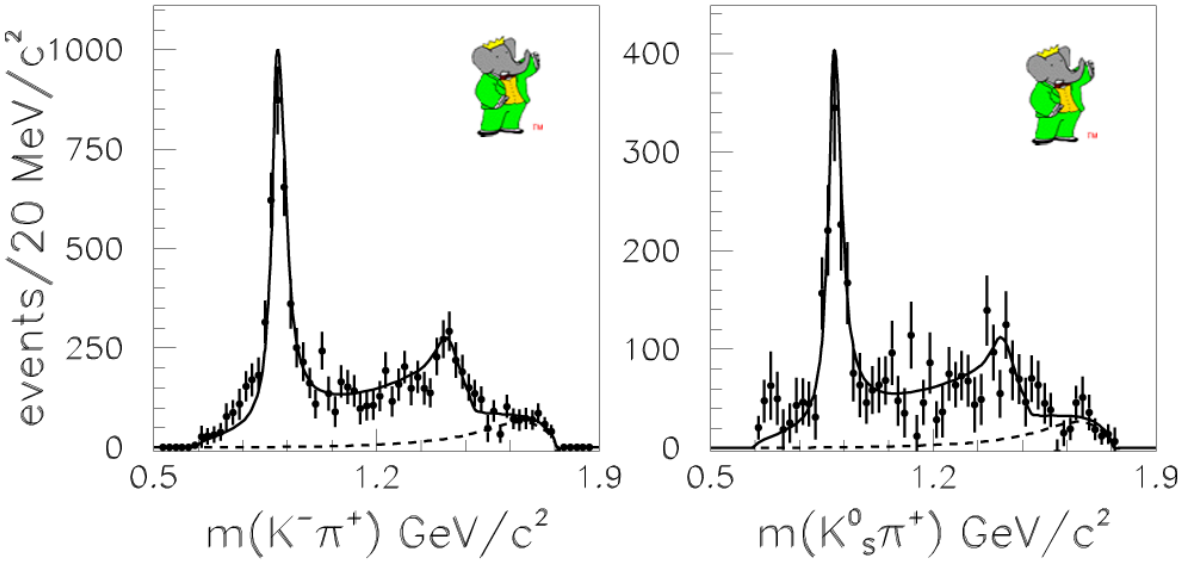
PRD 85, 052003 (2012)

Search for the $Z_1(4050)^+$ and $Z_2(4250)^+$ - Motivation

- Belle reported $Z_1(4050)^+$ and $Z_2(4250)^+$ decay to $\chi_{c1}\pi^+$ in $\bar{B}^0 \to \chi_{c1}K^-\pi^+$ (PRD 78, 072004 (2008))
- Belle reports of $Z(4430)^- \to \psi(2S)\pi^-$ in $B^{-,0} \to \psi(2S)\pi^- K^{0,+}$ (PRL 100, 142001 (2008), PRD 80, 031104(R) (2009)) were not confirmed by *BABAR* (PRD 79, 112001 (2009)); in the latter, no structure was observed in the $J/\psi\pi^-$ system for the corresponding $B^{-,0} \to J/\psi\pi^- K^{0,+}$ decay processes.
- These reports have generated much theoretical, and experimental, discussion since such charged charmonium-like states must have four-quark content at minimum.

- As a consequence, we search for $Z_1(4050)^+$ and $Z_2(4250)^+$ decay to $\chi_{c1}\pi^+$ in $\bar{B}^0 \to \chi_{c1}K^-\pi^+$ and also in $B^+ \to K_s^0\chi_{c1}\pi^+$ where $\chi_{c1} \to J/\psi\gamma$
- We project the $K\pi$ mass distribution and its Legendre polynomial angular dependence in terms of S-, P-, and D-wave amplitudes onto the $\chi_{c1}\pi^+$ mass distribution and search for corroboration of the Belle report of additional resonant structure(s).

Search for the $Z_1(4050)^+$ and $Z_2(4250)^+$ - Analysis procedure I



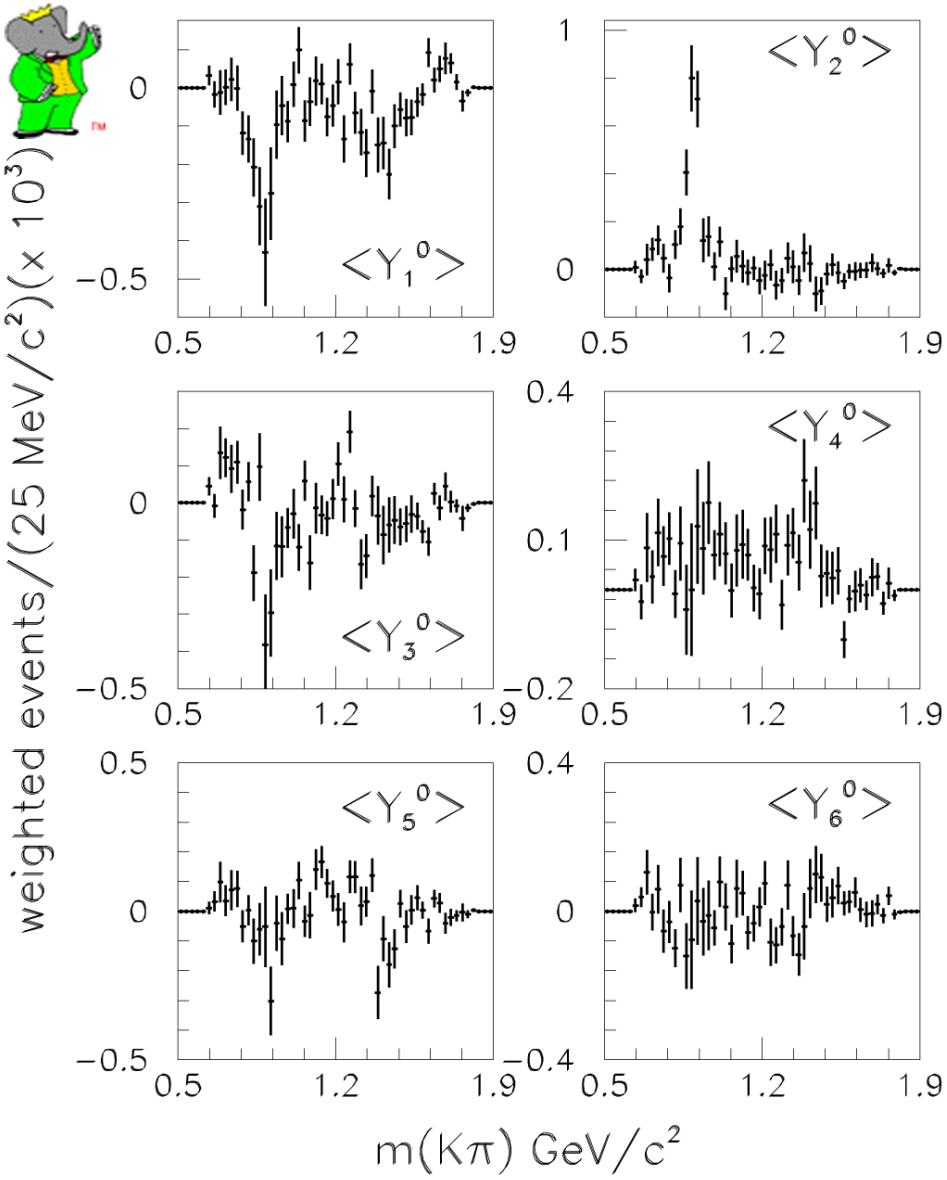
- The $K\pi$ data are background-subtracted and efficiency-corrected $\rightarrow$ interference terms absent from mass projection.
- Fit with a sum of S-, P-, and D-wave intensity contributions.

Channel	S-wave	P-wave	D-wave	χ^2/NDF
$\overline{B}^0 \to \chi_{c1} K^- \pi^+$	40.4 ± 2.2	37.9 ± 1.3	11.4 ± 2.0	58/54
		10.3 ± 1.5		
$B^+ \to \chi_{c1} K^0_S \pi^+$	42.4 ± 3.5	37.1 ± 3.2	10.1 ± 3.1	55/54
		10.4 ± 2.5		

- Very good agreement between the $\bar{B}^0$ and B^+ fractions.
- Much larger S-wave contribution than for J/ψ and $\psi(2S)$
- Fits improved by the inclusion of a $K_1^*(1680)$ contribution (2nd row in P-wave column); not present for J/ψ and $\psi(2S)$

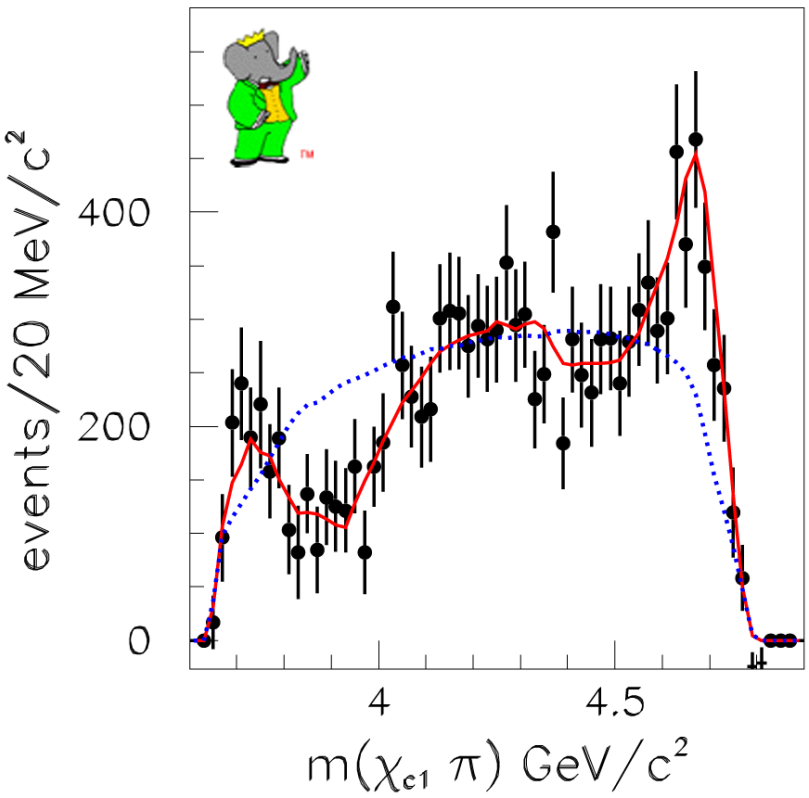
Search for the $Z_1(4050)^+$ and $Z_2(4250)^+$ - Analysis procedure I

- The moments are background-subtracted and efficiency-corrected
- The moments are for $\bar{B}^0$ and B^+ data combined since the intensity fractions agree and the $\bar{B}^0$ and B^+ moments are consistent
- The combined data sample contains about the same number of events as the Belle χ_{c1} sample from $\bar{B}^0$ decay
- The $< Y_L^0 >$ moments for L$\geq$6 are consistent with zero; the presence of narrow structure(s) in the $\chi_{c1}\pi^+$ mass distribution would be expected to result in higher $< Y_L^0 >$ moment contributions (from MC studies).



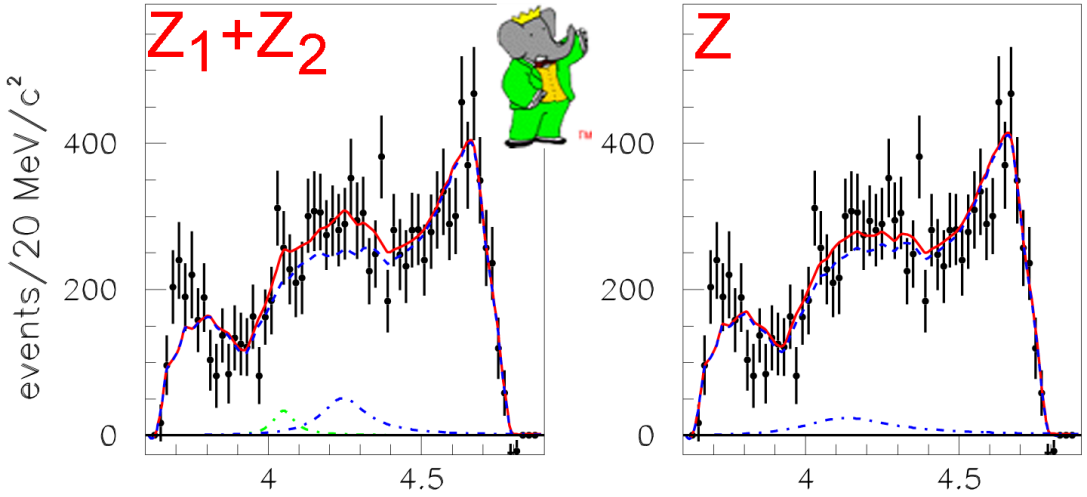
Search for the $Z_1(4050)^+$ and $Z_2(4250)^+$ - Analysis procedure II

We use a linear interpolation of the $< Y_L^0 >$ moments for L$\leq$5 to describe the $K\pi$ angular structure and, in conjunction with the fit to the $K\pi$ mass distribution, create the reflection onto the $\chi_{c1}\pi^+$ mass distribution.



- The dashed curve indicates the projection for a flat $K\pi$ angular distribution
- The solid curve is obtained by using the interpolation of the moments up to $< Y_5^0 >$; the excellent description of the data indicates that there is no need for additional narrow structure(s) in the mass distribution
- We quantify the latter by adding Z_1 and Z_2 Breit-Wigner intensity contributions (or a Z BW intensity contribution) to our unnormalized $K\pi$ reflection, in a fit to the data; the Z parameter values are fixed to those in the Belle paper.

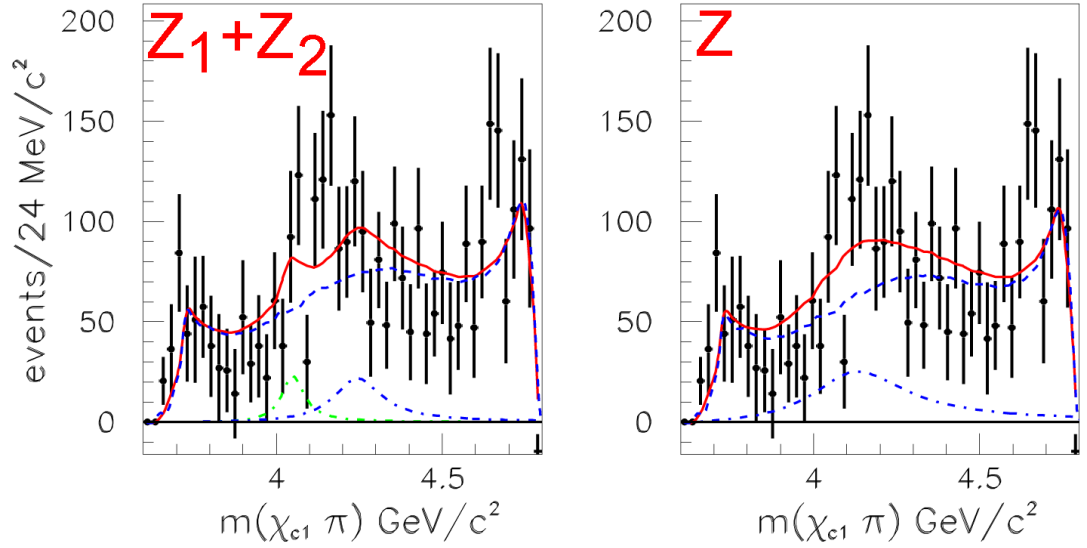
Search for the $Z_1(4050)^+$ and $Z_2(4250)^+$ - Results



Data	Resonance	N_σ	Fraction (%)	χ^2/NDF
a) Total	$Z_1(4050)^+$	1.1	1.6 ± 1.4	57/57
	$Z_2(4250)^+$	2.0	4.8 ± 2.4	
b) Total	$Z(4150)^+$	1.1	4.0 ± 3.8	61/58
c) Window	$Z_1(4050)^+$	1.2	3.5 ± 3.0	53/46
	$Z_2(4250)^+$	1.3	6.7 ± 5.1	
d) Window	$Z(4150)^+$	1.7	13.7 ± 8.0	53/47

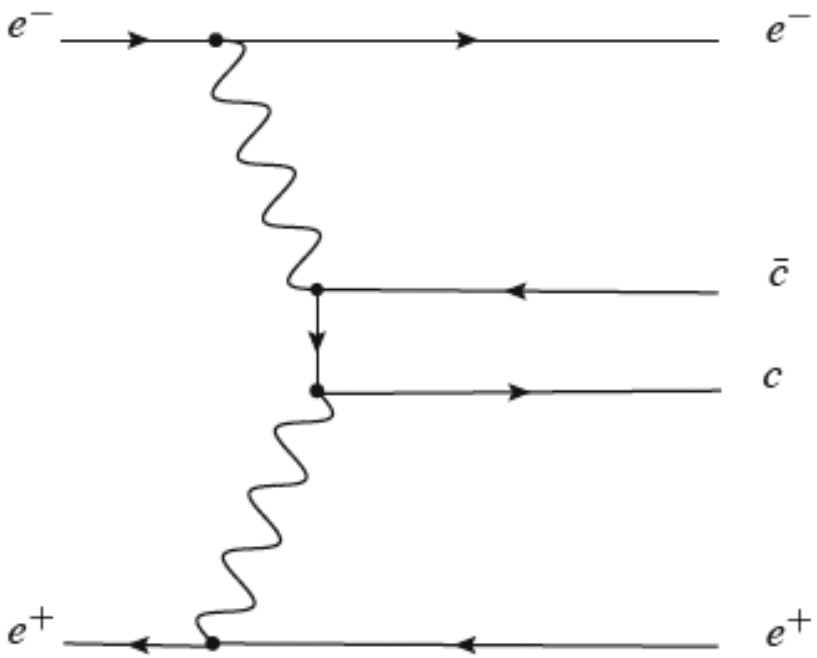
In every case, low ($\leq 2\sigma$) significance is obtained.

Window: $1.0 < m^2(K\pi) < 1.75\ \mathrm{GeV}^2/c^4$



Upper limits at 90% C.L.

$$B(\bar{B}^0 \to Z_1^+ K^-) x (B(Z_1^+ \to \chi_{c1}\pi^+) < 1.8 \times 10^{-5}$$
$$B(\bar{B}^0 \to Z_2^+ K^-) x (B(Z_2^+ \to \chi_{c1}\pi^+) < 4.0 \times 10^{-5}$$
$$B(\bar{B}^0 \to Z^+ K^-) x (B(Z^+ \to \chi_{c1}\pi^+) < 4.7 \times 10^{-5}$$



Study of the $J/\psi\ \omega$ final state in two-photon collisions (519 fb^{-1})

$\gamma\gamma \to J/\psi\ \omega$ - Motivation

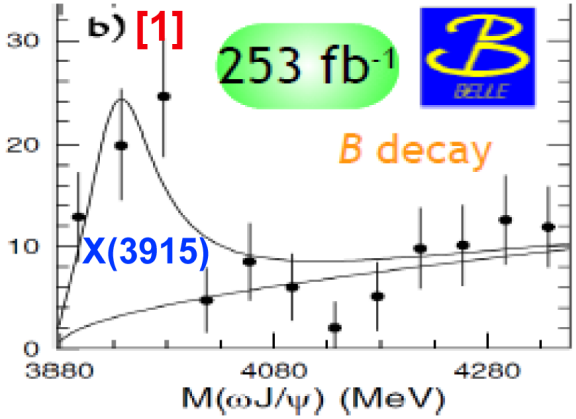
Confirm the X(3915) and search for the X(3872).

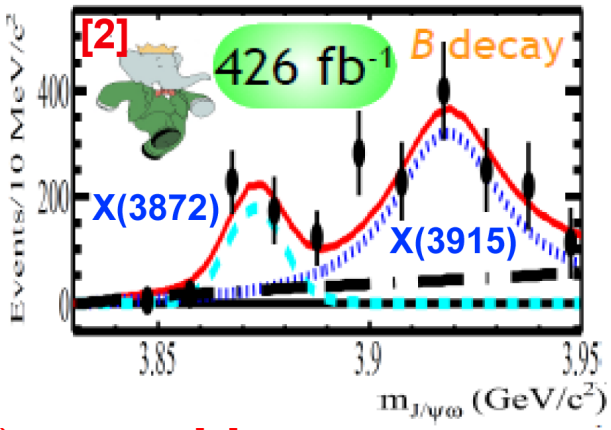
X(3915)

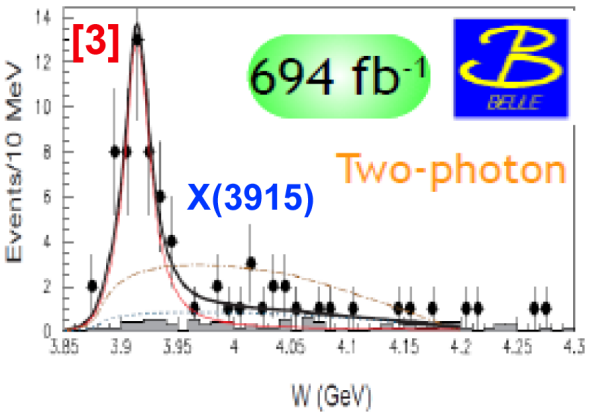
- The X(3915) was seen by both Belle [1] and [2] in $B \to X(3915)K$, with X(3915)$\to J/\psi\ \omega$
- Belle also observed the X(3915) in $\gamma\gamma \to X(3915) \to J/\psi\ \omega$ [3]
- Interpretation of X(3915) as the $\chi_{c0}(2P)$ or $\chi_{c2}(2P)$ state has been suggested.

X(3872)

- The $X(3872) \to J/\psi\ \omega$ was seen in B decays by both *BABAR* and Belle experiment.
- The possible X(3872) quantum numbers could be J^{PC}=1^{++} or J^{PC}=2^{-+} [4].
- $\gamma\gamma \to X(3872)$ would imply $J^{PC} = 2^{-+}$
- $\gamma\gamma \to X(3872)$ is not seen in Belle's spectrum.

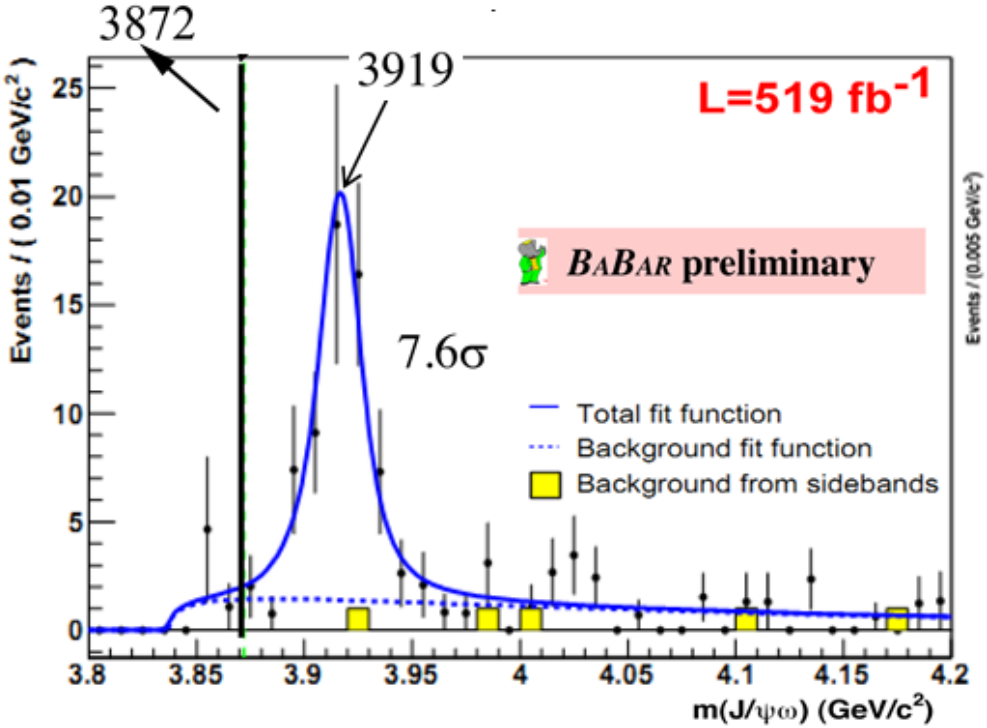


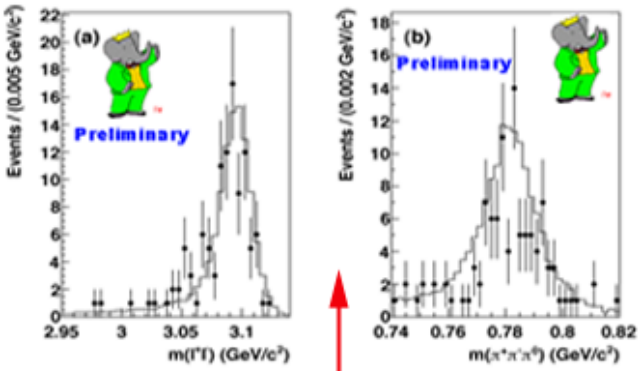




[1] Belle PRL 94,182002 (2005)
[2] *BABAR* PRD 82,011101(R) (2010)
[3] Belle PRL 104,092001 (2010)
[4] CDF PRL 98,132002 (2007)

$\gamma\gamma \to J/\psi\ \omega$ - Results





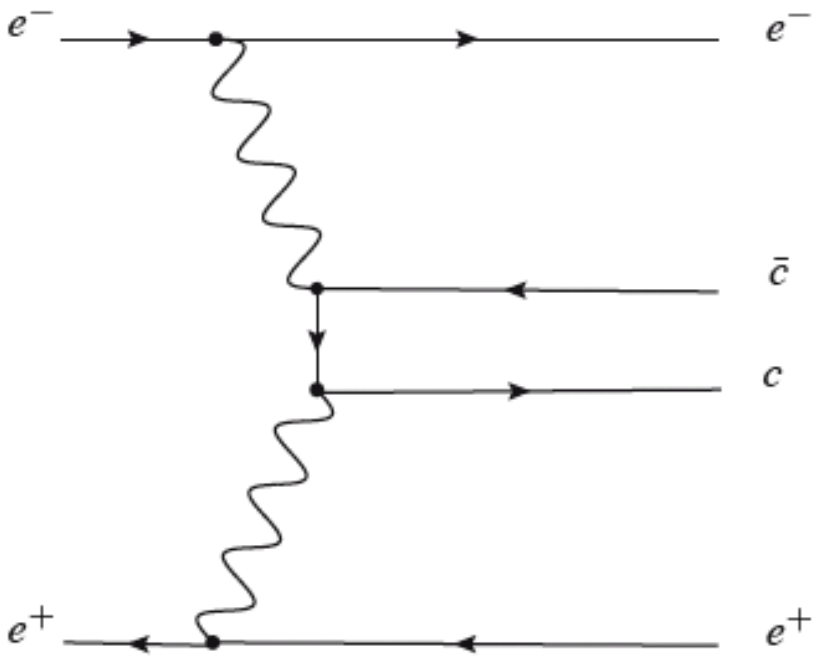
After the event selection, clear J/ψ and ω signal, with negligible background

Results are consistent with Belle's: (PRL 104, 092001 (2010))

	BABAR	Belle
Mass (MeV/c^2)	$3919.4 \pm 2.2 \pm 1.6$	$3915 \pm 3 \pm 2$
Width (MeV)	$13 \pm 6 \pm 3$	$17 \pm 10 \pm 3$
$\Gamma_{\gamma\gamma} \times \mathcal{B}$ (J=0) (eV)	$52 \pm 10 \pm 3$	$61 \pm 17 \pm 8$
$\Gamma_{\gamma\gamma} \times \mathcal{B}$ (J=2) (eV)	$10.5 \pm 1.9 \pm 0.6$	$18 \pm 5 \pm 2$

New limit: $\Gamma_{\gamma\gamma}(X(3872)) \times B(X(3872) \to J/\psi\ \omega)(J=2) < 1.7$ eV

The mass and width values are slightly smaller than those obtained by Belle and *BABAR* for the $\chi_{c2}(2P)$ from $\gamma\gamma \to D\bar{D}$



Search for resonances decaying into $\eta_c\pi^+\pi^-$ using two-photon interactions (474 fb^{-1})

$\gamma\gamma \to \eta_c \pi^+\pi^-$ - Motivation

- Look for the process $\gamma\gamma \to X \to \eta_c(1S)\pi^+\pi^-$ where X stands for one of the resonances $\chi_{c2}(1P)$, $\eta_c(2S)$, X(3872), X(3915) or $\chi_{c2}(2P)$, where $\eta_c(1S) \to K_s^0 K^\pm \pi^\mp$ and $K_s^0 \to \pi^+\pi^-$

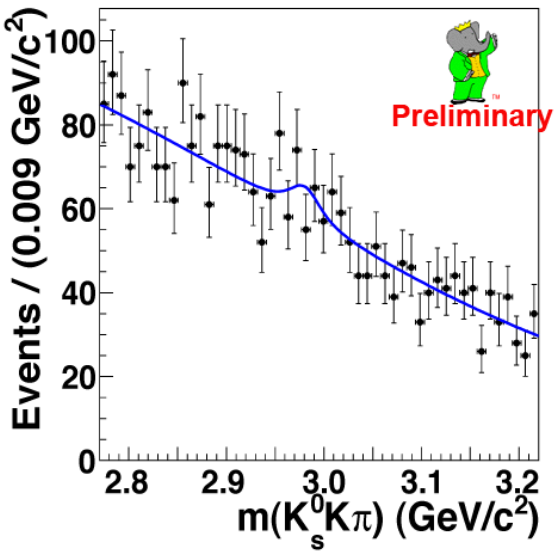
- Measure branching fractions for the decay of the states $\chi_{c2}(1P)$, $\eta_c(2S)$, X(3872), X(3915) and $\chi_{c2}(2P)$ to $\eta_c(1S)\pi^+\pi^-$

- Prediction for $B(\eta_c(2S) \to \eta_c(1S)\pi^+\pi^-) \sim 2.2\%$ obtained from $\Gamma(\eta_c(2S) \to \eta_c(1S)\pi^+\pi^-)/\Gamma(\psi(2S) \to J/\psi\pi^+\pi^-) \sim 2.9$ (M.B.Voloshin Mod.Phys.Lett A 17, 1533 (2002))

$\gamma\gamma \to \eta_c \pi^+\pi^-$ - Analysis procedure

- The extraction of the signal yield proceeds in two steps:

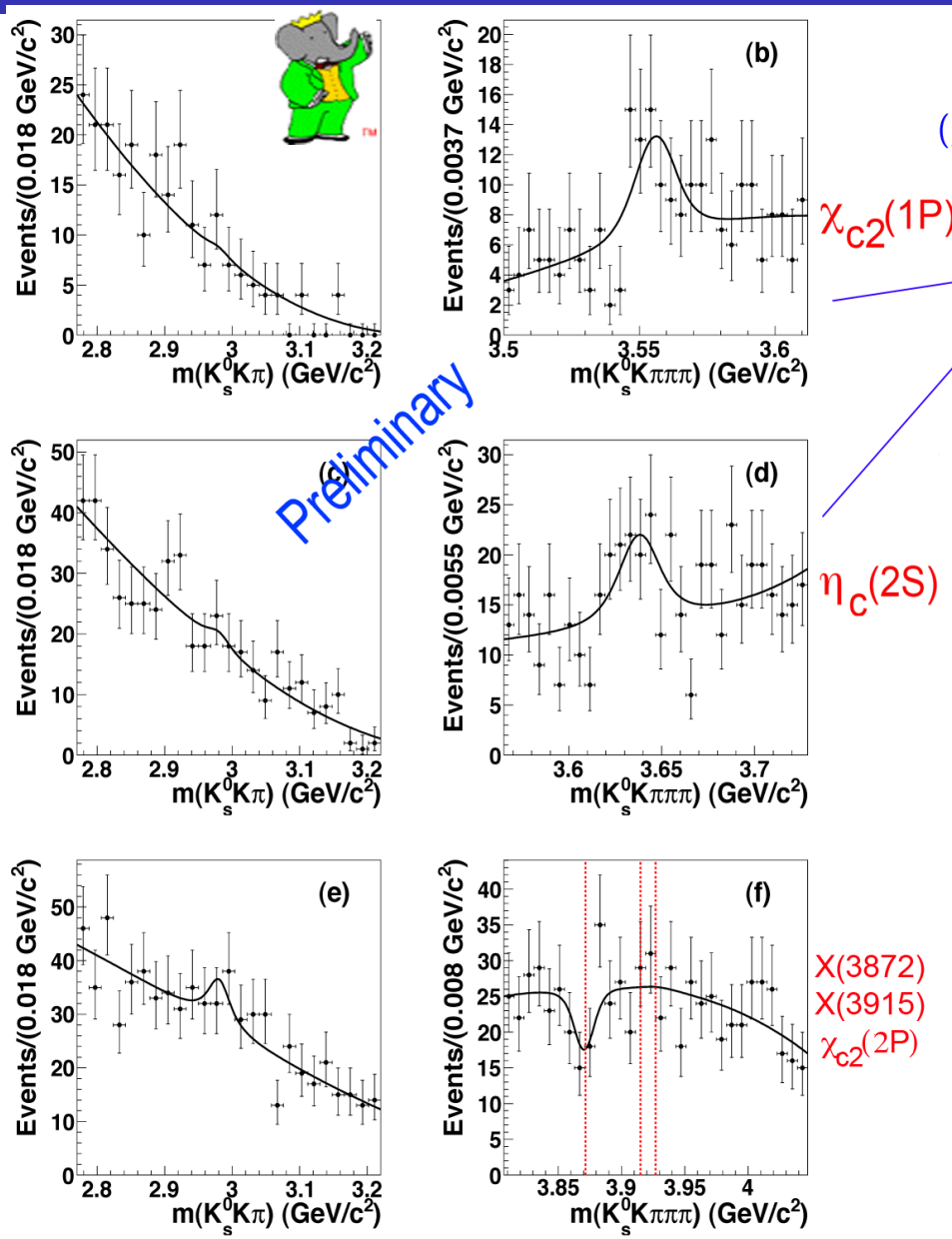
- Step 1: determine the values of the m($K_s^0 K^\pm \pi^\mp$) distribution parameters for the combinatoric background from a one-dimensional fit to m($K_s^0 K^\pm \pi^\mp$)



- Step2: perform a two-dimensional fit in $m(K_s^0 K^\pm \pi^\mp)$ and $m(K_s^0 K^\pm \pi^\mp \pi^+ \pi^-)$ in a window around each resonance of interest.

- Event types in 2D fit:
  - Signal (i.e. decay to $\eta_c(1S)\pi^+\pi^-$)
  - Combinatoric background
  - Direct decay (i.e. signal in $m(K_s^0 K^\pm \pi^\mp \pi^+ \pi^-)$, but $K_s^0 K^\pm \pi^\mp$ not from $\eta_c(1S)$ decay)
  - η_c-peaking background (peaks in $m(K_s^0 K^\pm \pi^\mp)$ but no 5-body signal)

$\gamma\gamma \to \eta_c \pi^+ \pi^-$ - Results



The two-dimensional fit is carried out separately in the region of each X state ($\chi_{c2}(1P)$, $\eta_c(2S)$, X(3872), X(3915), $\chi_{c2}(1P)$)

See contribution from non-resonant $\gamma\gamma \to X \to K_s^0 K^\pm \pi^\mp \pi^+ \pi^-$

Resonance	$\Gamma_{\gamma\gamma}\mathcal{B}$(eV)	
	Central value	UL
$\chi_{c2}(1P)$	$7.2^{+5.5}_{-4.4} \pm 2.9$	15.7
$\eta_c(2S)$	$65^{+47}_{-44} \pm 18$	133
$X(3872)$	$-4.5^{+7.7}_{-6.7} \pm 2.9$	11.1
$X(3915)$	$-13^{+12}_{-12} \pm 8$	16
$\chi_{c2}(2P)$	$-16^{+15}_{-14} \pm 6$	19

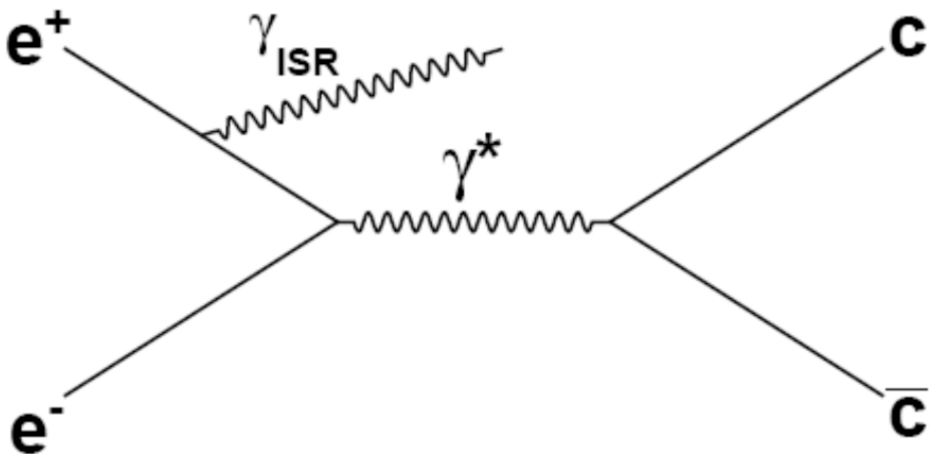
Using $B(\chi_{c2}(1P) \to K_s^0 K^\pm \pi^\mp)$ and $B(\eta_c(2S) \to K_s^0 K^\pm \pi^\mp)$ we obtain:

$B(\chi_{c2}(1P) \to \eta_c(1S)\pi\pi)$ <2.2% @90%CL

$B(\eta_c(2S) \to \eta_c(1S)\pi\pi)$ <7.4% @90%CL

(consistent with the 2.2% prediction)

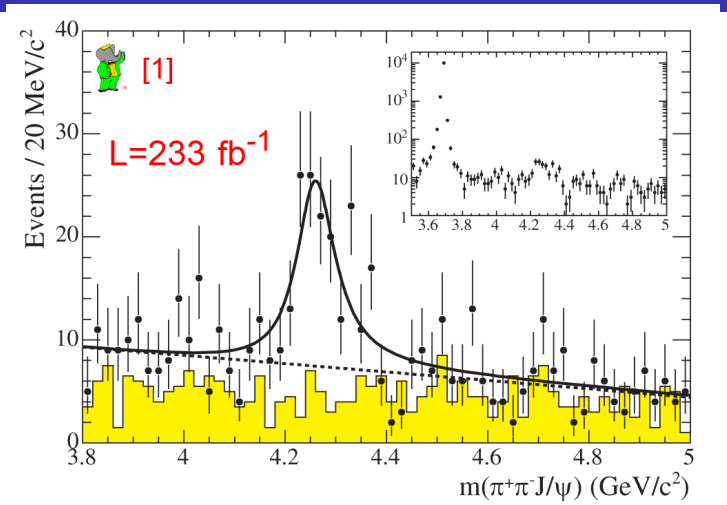
Study of the reaction $e^+e^- \to J/\psi\pi^+\pi^-$ via initial-state radiation

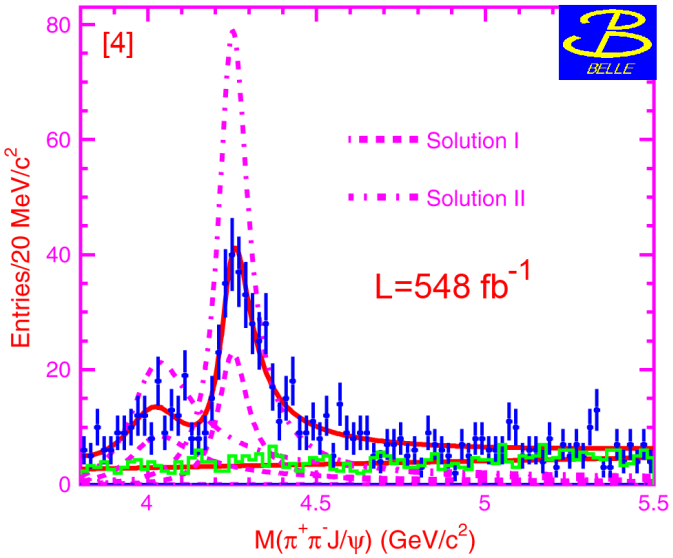


Study of the reaction $e^+e^- \to J/\psi\pi^+\pi^-$ via initial-state radiation (454 fb^{-1})

$e^+e^- \to \gamma J/\psi\pi^+\pi^-$ - Motivation

- *BABAR* discovered the Y(4260) in ISR production of $J/\psi\pi^+\pi^-$ [1]; implies $J^{PC} = 1^{--}$
- Confirmation from CLEO-c [2], CLEO-III [3] and Belle [4] with some spread in the resonance parameter values.
- Belle confirmed the Y(4260) in ISR production, and also suggested the existence of the Y(4008) [4].
- All the 1^{--} slots in the charmonium spectrum are already filled. The nature of the Y(4260) is still unclear.





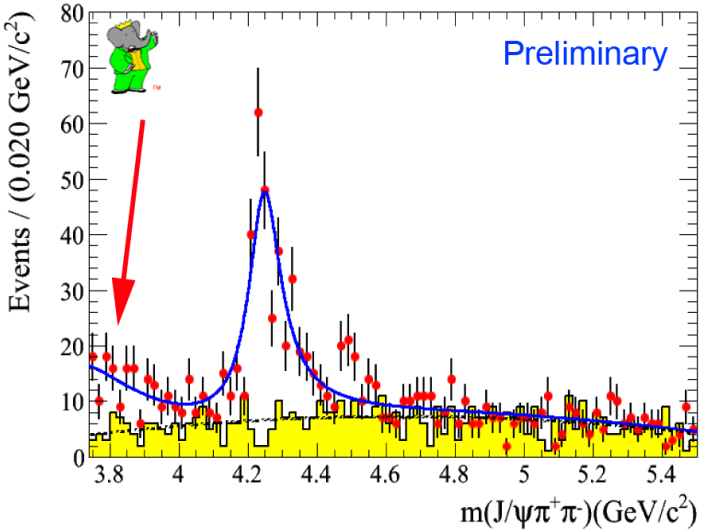
[1] *BABAR* PRL 95,142001 (2005)

[2] CLEO-c PRL 96,162003 (2006)

[3] CLEO-III PR 74,091104(R) (2006)

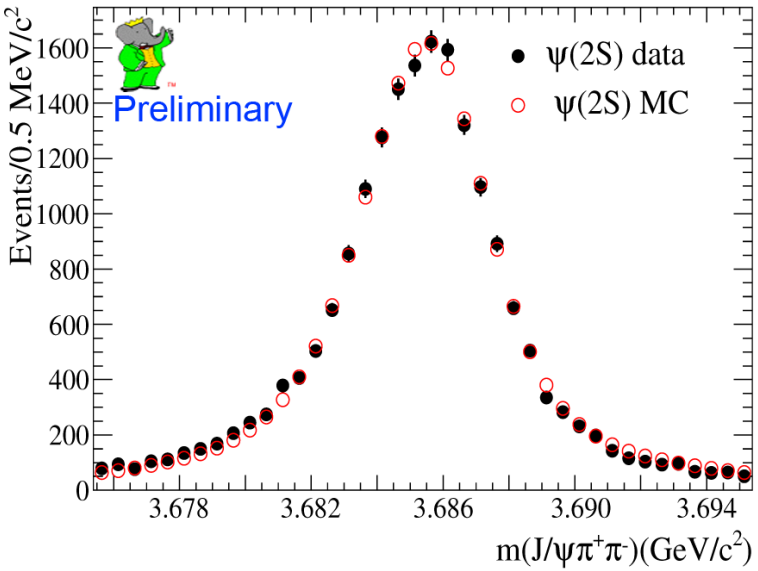
[4] Belle PRL 99,182004 (2007)

$e^+e^- \to \gamma J/\psi\pi^+\pi^-$ - $\psi(2S)$ region (3.5-4 GeV/c^2)



The region below 4 GeV/c^2 ($\psi(2S)$ and $\psi(3770)$ region) in the $J/\psi\pi^+\pi^-$ mass region is investigated in detail for the first time.

- In order to understand a possible contribution coming from the $\psi(2S)$ tail a detailed study of the $\psi(2S)$ lineshape has been performed.
- Note that BES (Phys.Lett.B 605,63(2005)) and CLEO (Phys.Lett.96 082004(2006)) reported the decay of the $\psi(3770)$ to $J/\psi\pi^+\pi^-$.



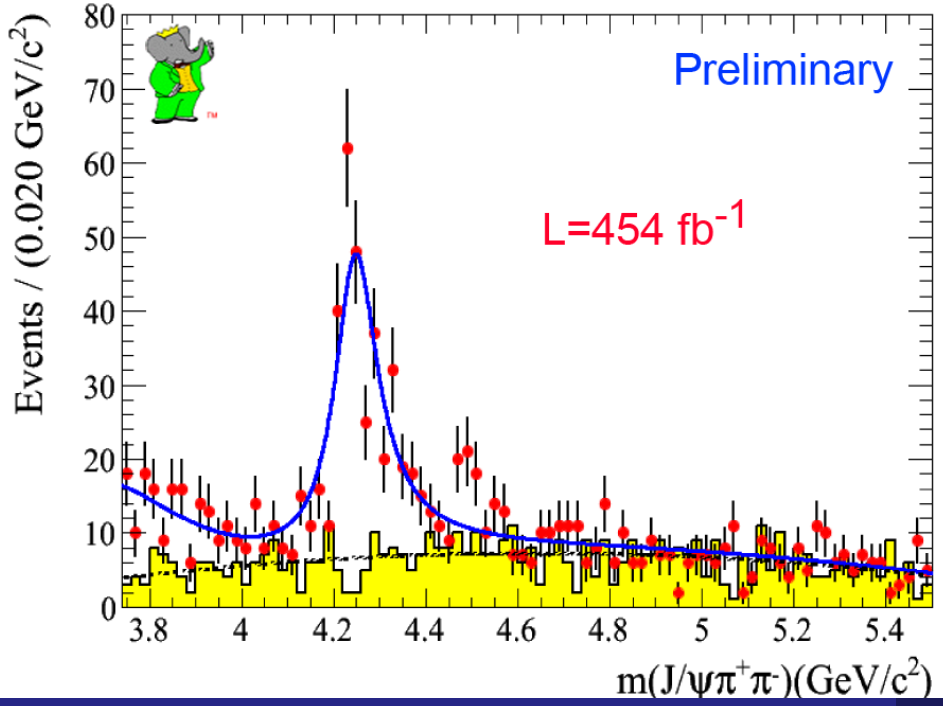
$\sigma(e^+e^- \to \psi(2S))$=14.5±0.7 pb

$\Gamma(\psi(2S) \to e^+e^-)$=2.29±0.05 KeV

We conclude that we cannot discount the possibility of a contribution from an $e^+e^- \to J/\psi\pi^+\pi^-$ continuum cross section in this region.

$e^+e^- \to \gamma J/\psi\pi^+\pi^-$ - Up to 5.5 GeV/c^2

- A extendend-maximum-likelihood fit is performed to the signal region $J/\psi\pi^+\pi^-$ distribution and simultaneously to the background distribution in the region 3.74-5.5 GeV/c^2.
- The fit function incorporates the mass-dependence of efficiency and luminosity, and uses a relativistic BW for the Y(4260), a third-order polynomial to describe the background from the J/ψ sideband regions (yellow histogram and dashed curve); an empirical exponential function describes the excess of events below 4 GeV/c^2, which may result from the $\psi(2S)$ tail and a possible $J/\psi\pi^+\pi^-$ nonresonant contribution.



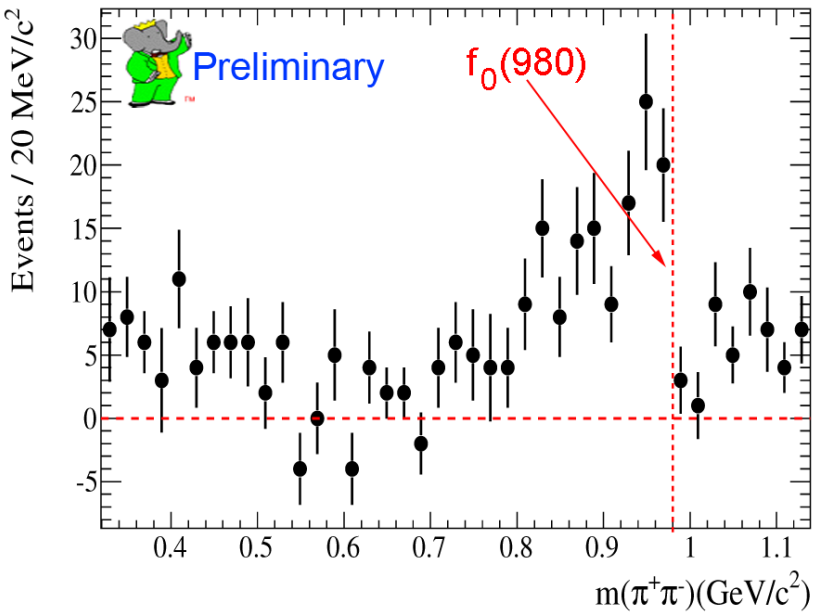
Mass (Y(4260)) = 4244±5±4 MeV/c^2

Γ(Y(4260))=114^{+16}_{-15}±7 MeV

$\Gamma_{e^+e^-} \times B(J/\psi\pi^+\pi^-)$=9.2±0.8±0.7 eV

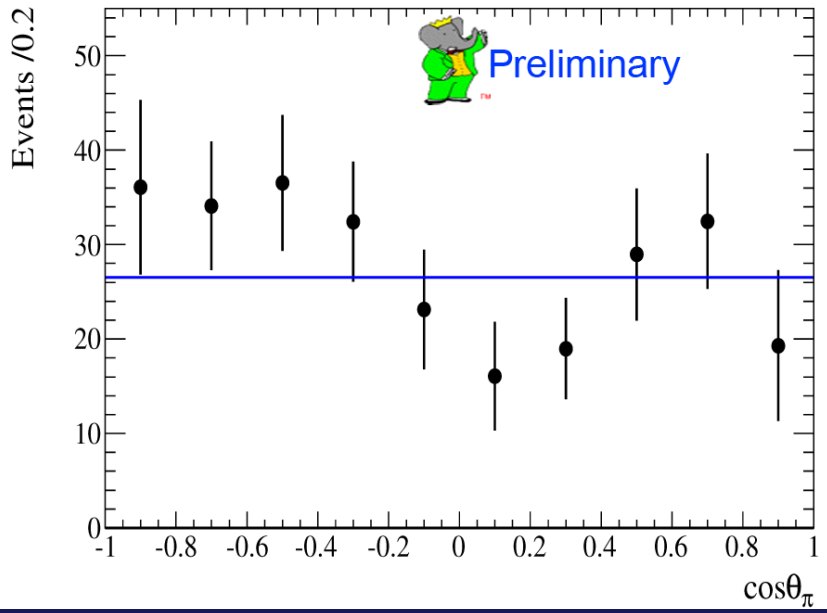
We see no evidence for the state at ~4GeV/c^2 reported by Belle.

$\pi^+\pi^-$ Invariant mass distribution in the Y(4260) decay



- For $4.15 \leq m(J/\psi\pi^+\pi^-) \leq 4.45$ GeV/c^2
- The distribution seems to peak around the $f_0(980)$ mass; however the peak is displaced from the indicated $f_0(980)$ position.
- The fact that the peak is displaced suggests possible interference between the $f_0(980)$ and an $m(\pi^+\pi^-)$ continuum.

- The $\pi^+\pi^-$ system has C=+1 and hence even angular momentum.
- Define θ_π as the angle between the π^+ direction and that of the recoil J/ψ both in the dipion rest frame.
- The distribution, which must be symmetric, is consistent with S-wave behaviour ($\chi^2/NDF = 12.3/9$; probability=19.7%).



$\pi^+\pi^-$ Invariant mass distribution in the Y(4260) decay

We use a simple model to describe the $\pi^+\pi^-$ mass distribution, namely the square of an amplitude consisting of the coherent sum of a nonresonant component motivated by a QCD multipole expansion and an $f_0(980)$ amplitude; the relative strength and phase of these components are free to vary in the fit to the data.

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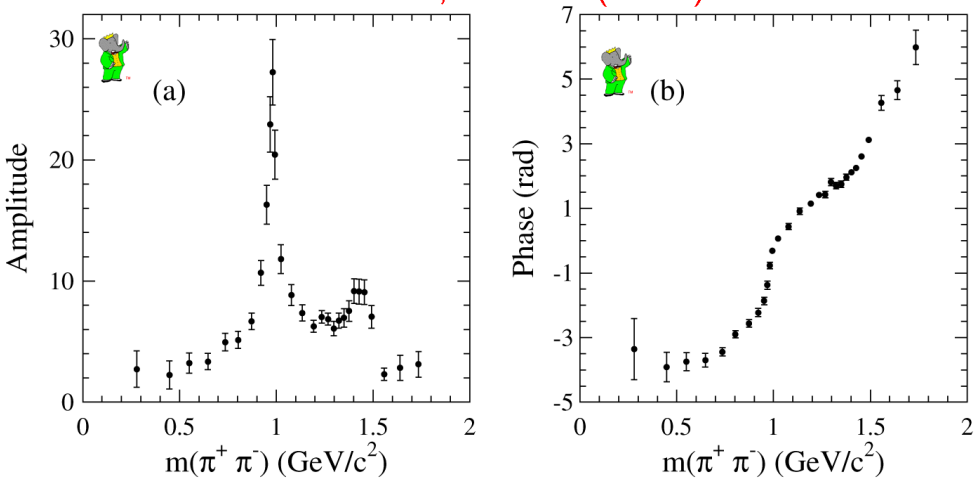
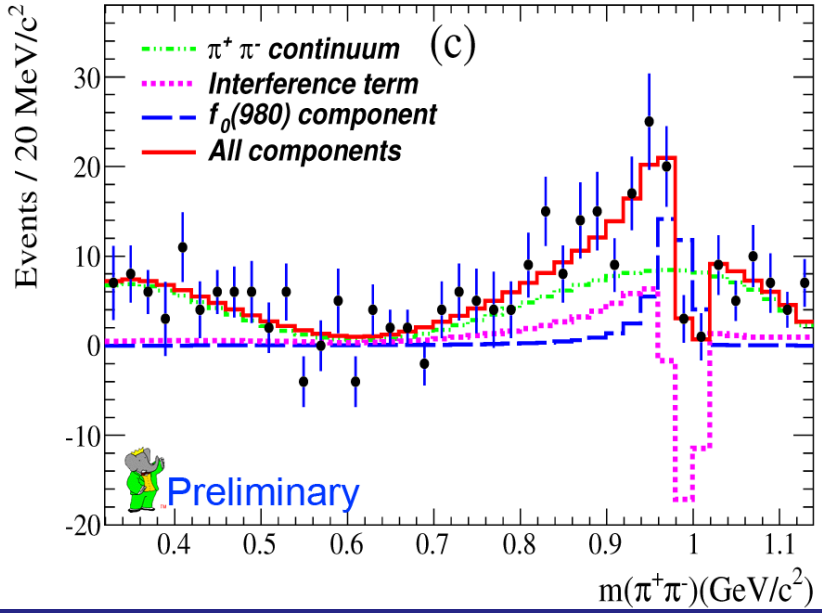


The mass-dependence of the $f_0(980)$ amplitude and phase is from the *BABAR* analysis of the decay $D_s^+ \to \pi^+\pi^-\pi^+$



A good description of the $\pi^+\pi^-$ mass distribution is obtained.
This indicates that there is an $f_0(980)$ contribution to the decay of the Y(4260) to $J/\psi\pi^+\pi^-$ but that contribution is not dominant.

$$\frac{B(Y_{4260}\to J/\psi f_0(980), f_0(980)\to\pi^+\pi^-)}{B(Y_{4260}\to J/\psi\pi^+\pi^-)} = (17\pm13)\%$$

Summary I

Search for the $Z_1(4050)^+$ and $Z_2(4250)^+$ states in $\bar{B}^0 \to \chi_{c1} K^- \pi^+$ and $B^+ \to \chi_{c1} K_s^0 \pi^+$

PRD 85, 052003 (2012)

$B(\bar{B}^0 \to Z_1^+ K^-) x (B(Z_1^+ \to \chi_{c1}\pi^+)$ <1.8 x 10^{-5} No significant signal observed.

$B(\bar{B}^0 \to Z_2^+ K^-) x (B(Z_2^+ \to \chi_{c1}\pi^+)$ <4.0 x 10^{-5} No significant signal observed.

$B(\bar{B}^0 \to Z^+ K^-) x (B(Z^+ \to \chi_{c1}\pi^+)$ <4.7 x 10^{-5} No significant signal observed.

Study of the $J/\psi\ \omega$ final state in two-photon collisions:

Confirm Belle's results for $\gamma\gamma \to X(3915) \to J/\psi\ \omega$:

$\Gamma_{\gamma\gamma}(X(3915))B(X(3915) \to J/\psi\ \omega)(J=0)) = (52 \pm 10 \pm 3)$ eV

$\Gamma_{\gamma\gamma}(X(3915))B(X(3915) \to J/\psi\ \omega)(J=2)) = (10.5 \pm 1.9 \pm 0.6)$ eV

BABAR determines a limit on $\gamma\gamma \to X(3872) \to J/\psi\ \omega$:

$\Gamma(X(3872)) x B(X(3872) \to J/\psi\ \omega)$ <1.7 eV @ 90% CL

Summary II

Search for resonances decaying into $\eta_c\pi^+\pi^-$ using two-photon interactions:

New limits on decays to $\eta_c\pi^+\pi^-$:

- $B(\chi_{c2}(1P) \to \eta_c(1S)\pi\pi)$ <2.2% @90% CL No significant signal observed.

- $B(\eta_c(2S) \to \eta_c(1S)\pi\pi)$ <7.4% @90% CL No significant signal observed.

Study of the reaction $e^+e^- \to J/\psi\pi^+\pi^-$ via initial state radiation:

- $\sigma(e^+e^- \to \psi(2S))$=14.5±0.7 pb

- $\Gamma(\psi(2S) \to e^+e^-)$ =2.29±0.05 keV

- Improved precision on the Y(4260) parameter values

- $\Gamma_{e^+e^-} xB(J/\psi\pi^+\pi^-)$ =9.2±0.8±0.7 eV

- $\pi^+\pi^-$ invariant mass distribution: $\frac{B(Y_{4260}\to J/\psi f_0(980), f_0(980)\to\pi^+\pi^-)}{B(Y_{4260}\to J/\psi\pi^+\pi^-)}$=(17±13)%

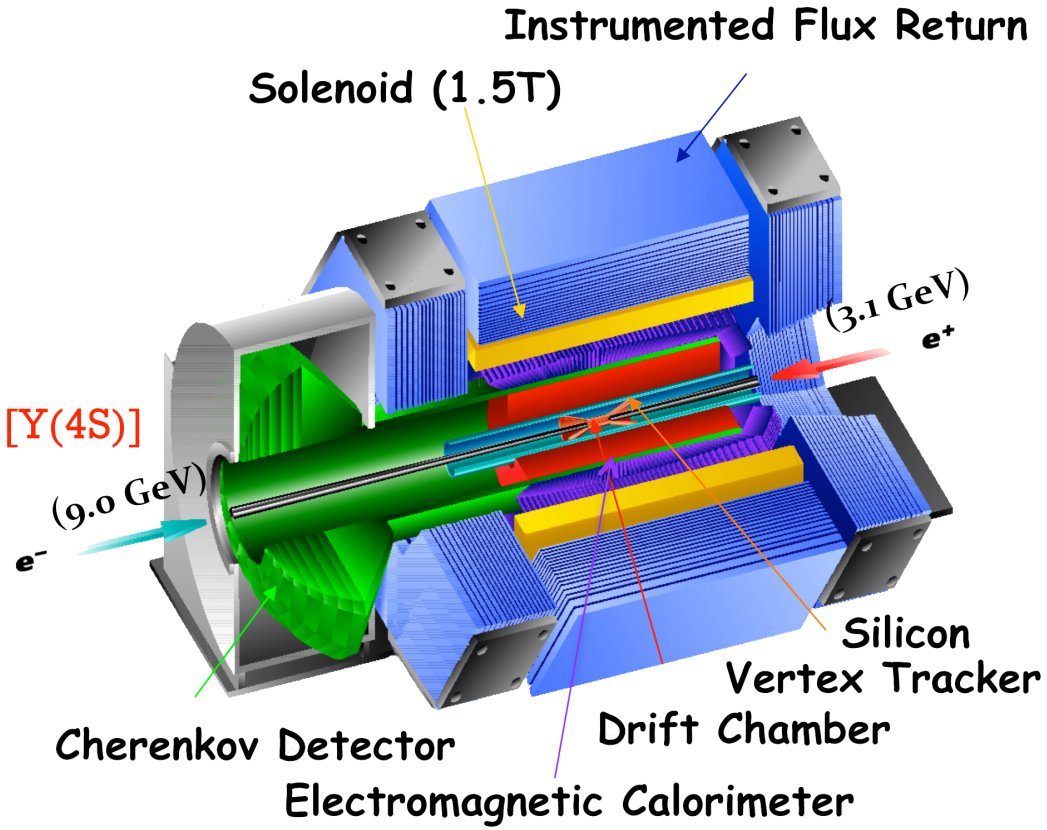
Ongoing *BABAR* charmonium analyses

- B decay:
  - $B \to KJ/\psi\phi$
- ISR production:
  - $e^+e^- \to \psi(2S)\pi^+\pi^-$
  - $e^+e^- \to J/\psi K^+K^-$
- $\gamma\gamma$ interactions:
  - $\gamma\gamma \to K\bar{K}\pi$
  - $\gamma\gamma \to \eta K\bar{K}$
- Inclusive $c\bar{c}$
  - $e^+e^- \to J/\psi c\bar{c}$
  - $e^+e^- \to \psi(2S)c\bar{c}$

A lot of interesting results have been obtained, but much more data are required for a better understanding of the charmonium spectrum.

BACKUP SLIDES

The *BABAR* experiment and data sample



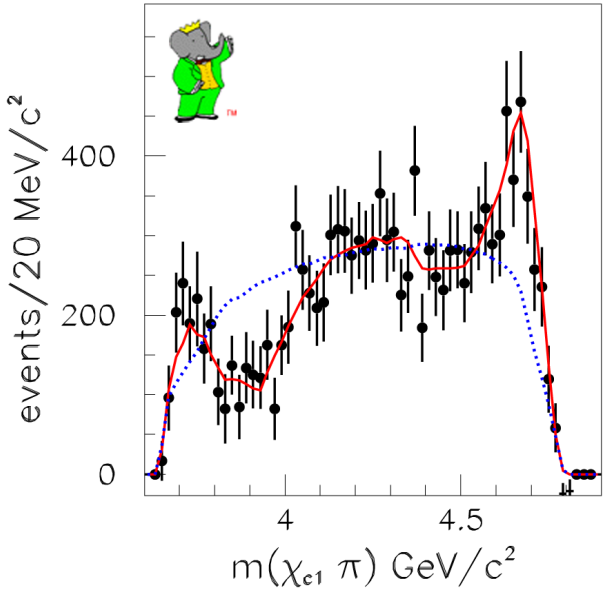
Features

- Asymmetric beams energies: E_{e^-}=9 GeV, E_{e^+}=3.1 GeV; β=0.56 in the CM frame. For $\sqrt{s}$=10.58 GeV, the $\Upsilon(4S)$ mass
- Integrated luminosity: 431 fb^{-1} at $\Upsilon(4S)$ resonance (On-Peak), 45 fb^{-1} 40 MeV below (Off-Peak).
- Data taken also at the $\Upsilon(3S)$ [30 fb^{-1}] $\Upsilon(2S)$ [14 fb^{-1}]
- Data taken period: 1999-2008

BABAR is a B factory: 467 million $B\bar{B}$ pairs in the total data sample.
BABAR is also a c factory: 1.3 million charm events per fb^{-1}.

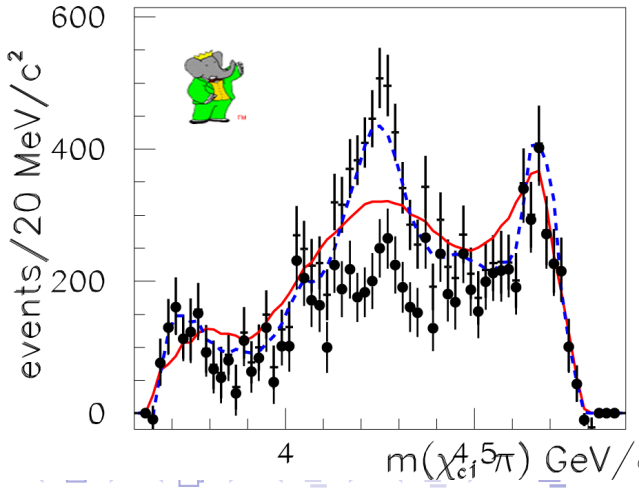
Search for the $Z_1(4050)^+$ and $Z_2(4250)^+$ - Analysis procedure II

Using the information from the $K\pi$ system a description of the $\chi_{c1}\pi$ mass distribution is studied. A MC simulation for $B \to \chi_{c1}K\pi$ has been performed. The best χ^2/NDF obtained is for $L_{max} = 5$.



The result of the simulation with $L_{max} = 5$ is superimposed on the data.
The excellent description of the data indicates that the angular information from the $K\pi$ channel with $L_{max} = 5$ is able to account for the structures observed in the $\chi_{c1}\pi$ projection.
This indicates the absence of significant structure in the exotic $\chi_{c1}\pi^+$ channel.

A 25% contribution of $Z_2^+(4250)$ in the $\bar{B}^0 \to \pi^+K^-\chi_{c1}$ is added on a MC simulation.
The Legendre polynomial moments is then computed.
The resulting MC simulation does not describe the MC data well.



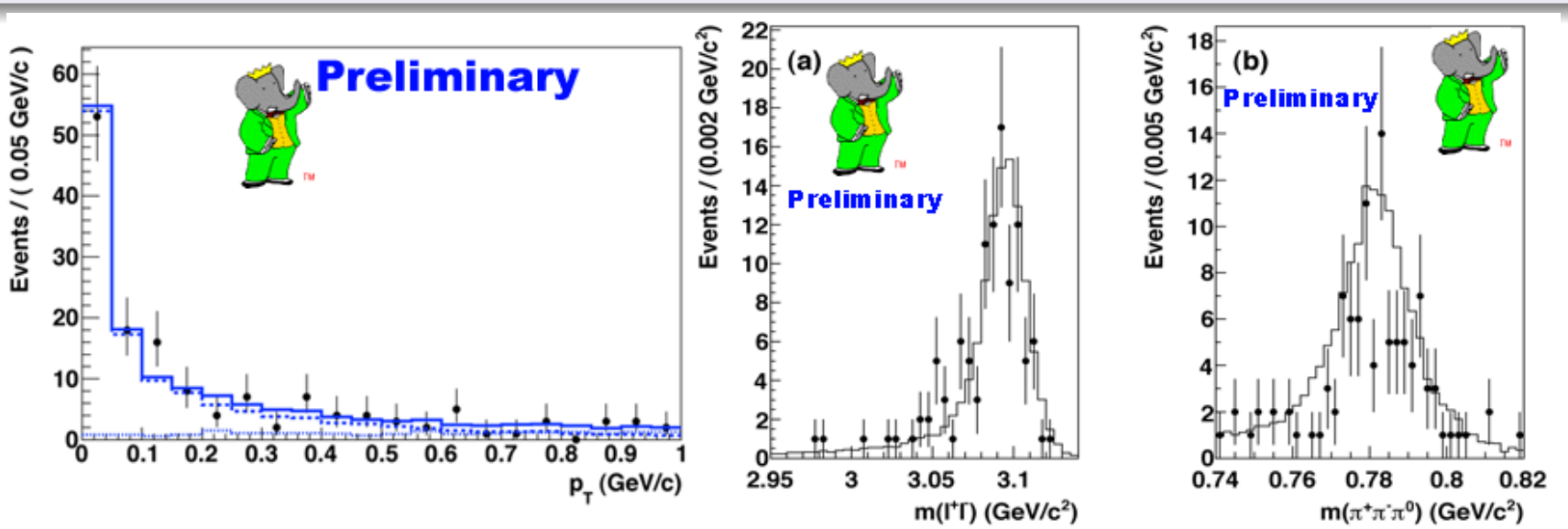
$\gamma\gamma \to J/\psi\omega$ - Event selection

Reconstruction

- $J/\psi \to \ell^+\ell^-$ (ℓ=e,μ); $\omega \to \pi^+\pi^-\pi^0$, $\pi^0 \to \gamma\gamma$
- $m(e^+e^-) \in$[2.95,3.14]; $m(\mu^+\mu^-) \in$[3.05,3.14]; $m(\pi^+\pi^-\pi^0) \in$[0.74,0.82] GeV/c^2

Main event selection

- Four charged tracks
- $M^2_{miss} = (p_{e^+e^-} - p_{J/\psi\omega})^2 > 2(GeV/c^2)^2$
- p_T<0.2 GeV/c
- E_{extra} (EMC energy not associated with the final state particles) <0.3 GeV



After the event selection, clear ω and J/ψ signal, with negligible background.

$\gamma\gamma \to \eta_c \pi^+\pi^-$ - Event selection

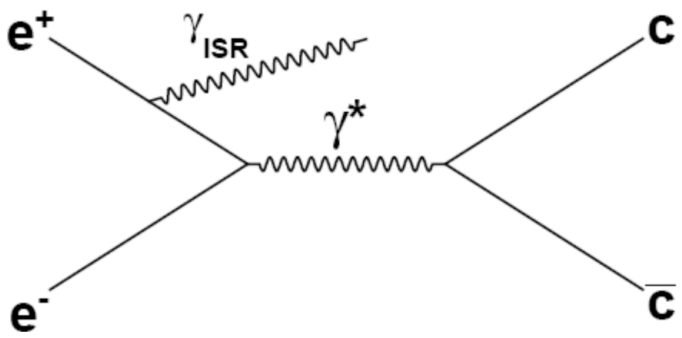
Reconstruction

- $\eta_c \to K_s^0 K^\pm \pi^\mp$; $K_s^0 \to \pi^+\pi^-$
- $m(K_s^0 K^\pm \pi^\mp) \in$[2.77,3.22];
- The sample used to search for the process $\gamma\gamma \to X \to \eta_c \pi^+\pi^-$ is referred to as the "main sample".
- Properties of the η_c and its decay into $K_s^0 K^\pm \pi^\mp$ are studied with a separate "control sample" of $\gamma\gamma \to \eta_c \to K_s^0 K^\pm \pi^\mp$ events.

Main event selection

- Six charged tracks
- $M^2_{miss} = (p_{e^+e^-} - p_X)^2 > 10(GeV/c^2)^2$
- p_T<1.5 GeV/c
- E_{extra} (EMC energy not associated with the final state particles) <0.8GeV
- Study of the η_c Dalitz Plots to select the signal region.
- Neural Network studies in order to remore additional backgrounds, with inputs: p_T; E_{extra}; K and π ID.

$e^+e^- \to \gamma J/\psi\pi^+\pi^-$ - Event selection



The goal is to study the final state $J/\psi\pi^+\pi^-$ after initial state radiation

Reconstruction

- J/ψ candidates is reconstructed via its decay to $\mu^+\mu^-$ or to e^+e^-.
- $m(e^+e^-) - m(J/\psi) \in$[-75,+55] MeV/c^2; $m(\mu^+\mu^-) - m(J/\psi) \in$[-55,+55] MeV/c^2
- The background is estimated using the J/ψ sidebands.

Main event selection

- Four charged tracks
- To select ISR events:
  - $M^2_{miss} = (p_{e^+e^-} - p_{J/\psi\pi^+\pi^-})^2 \in [-0.50, +0.75](GeV/c^2)^2$
  - $p_{T_{miss}}$<2.25 GeV/c