Studies of X(3872) and Y(4260) at *BABAR*

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Representing the BaBar collaboration

APS-DPF2006 + JPS2006

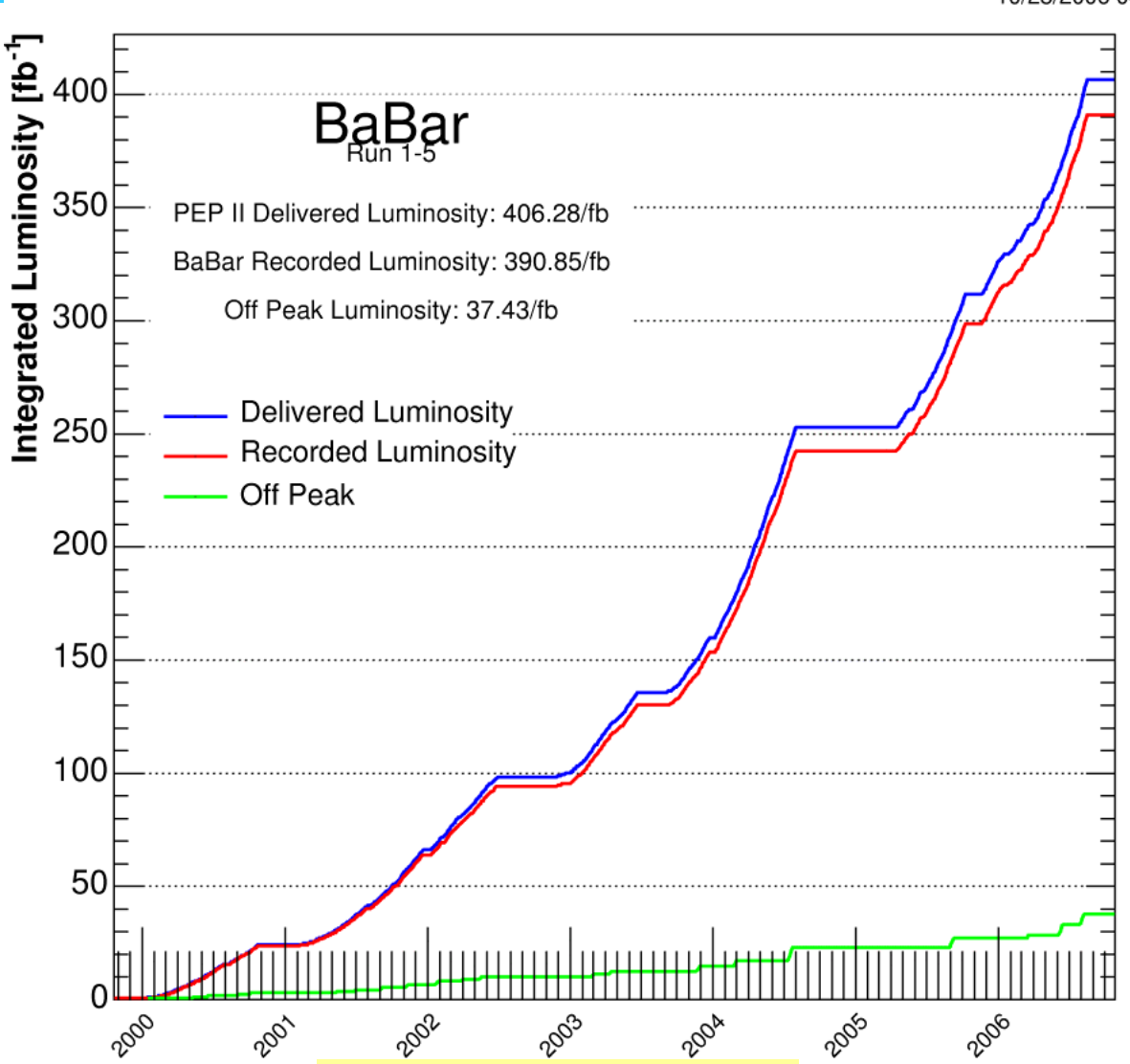
October 31, 2006

BABAR

Outline

- **X(3872)**
- **Y(4260)**
- A **structure** observed in **ISR** $\pi^+\pi^-\psi(2S)$

BABAR Data



(as of Oct 28, 2006)

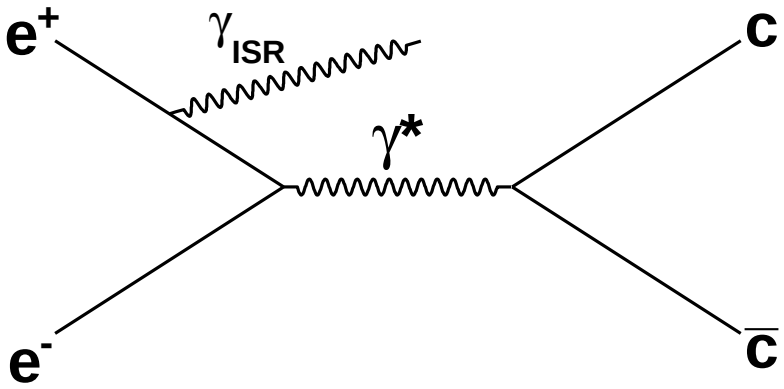
- **Peak Luminosity:**
  $1.21 \times 10^{34}\ cm^{-2}\ sec^{-1}$
- **Recorded:** 391 fb^{-1}
- **This talk based on up to 298 fb^{-1}**

Data taking will resume in Jan 2007

Charmonium Production at BABAR

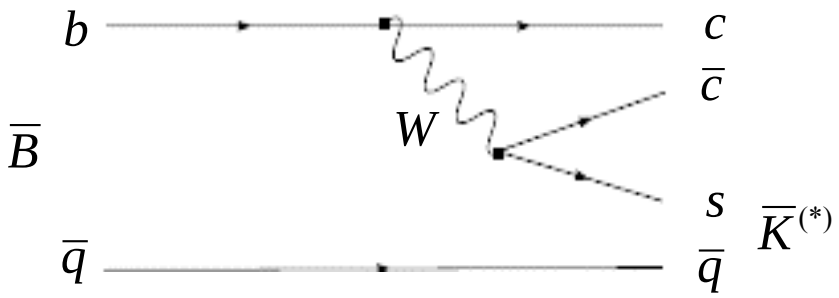
B-factory is also a **charmonium** factory

- Continuum production
  - **ISR: $J^{PC}=1^{--}$**



  - two-photon, double $c\bar{c}$, others

- Production in B decay
  - **b→c transition: $\overline{B}\to(c\bar{c})\overline{K}^{(*)}$**



300 fb^{-1} data can produce

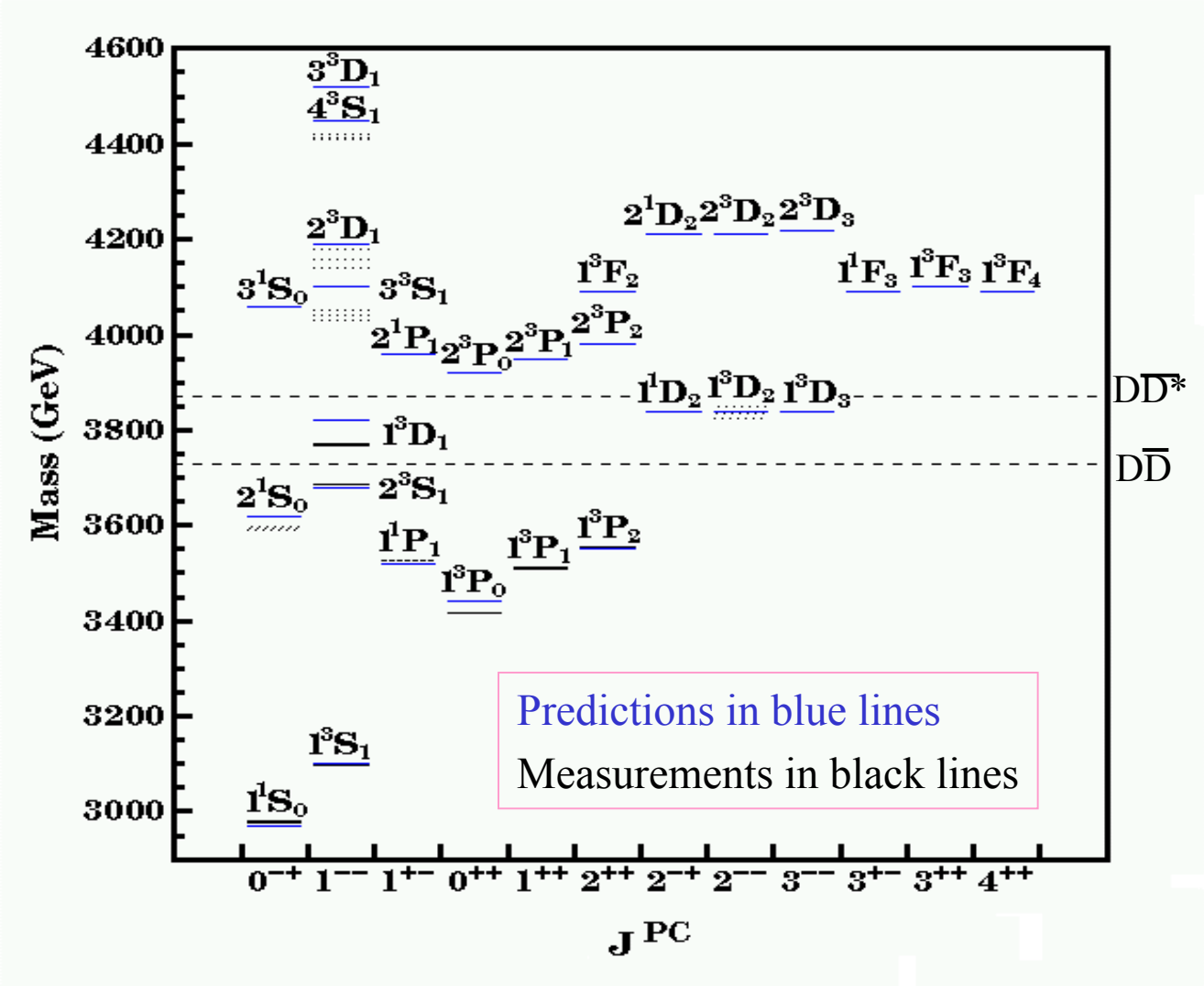
- **11M J/ψ, 4M ψ(2S) in ISR**
- **6M J/ψ, 2M ψ(2S) in B decay**

Charmonium Spectroscopy

Properties are pretty well understood up to (including) ψ(3770)

Good agreement between experimental data and theoretical prediction until X(3872) and Y(4260), etc

In principle, states like ψ(3770) above open-charm are not narrow, and dominantly decay to open-charm channel

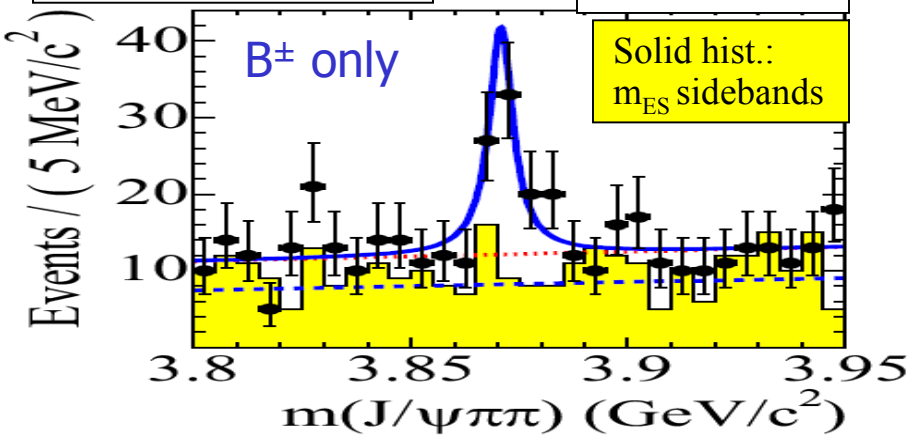


X(3872)

Update on X(3872)→ $\pi^+\pi^-$J/ψ

Discovered by **Belle** in $B^{\pm} \to K^{\pm} X(\pi^+\pi^- J/\psi)$, *PRL 91, 262001 (2003)*
Soon confirmed by **CDF** (*PRL 93, 072001 (2004)*) and **D0** (*PRL 93, 162002 (2004)*)
and ***BABAR*** (*PRD 71, 071103 (2005)*)

BABAR: 232M $B\bar{B}$
PRD 73, 011101 (2006)



$\mathcal{B}(B^{\pm} \to K^{\pm} X(3872), X(3872) \to \pi^+\pi^- J/\psi)$
$= (10.1 \pm 2.5 \pm 1.0) \times 10^{-6}$

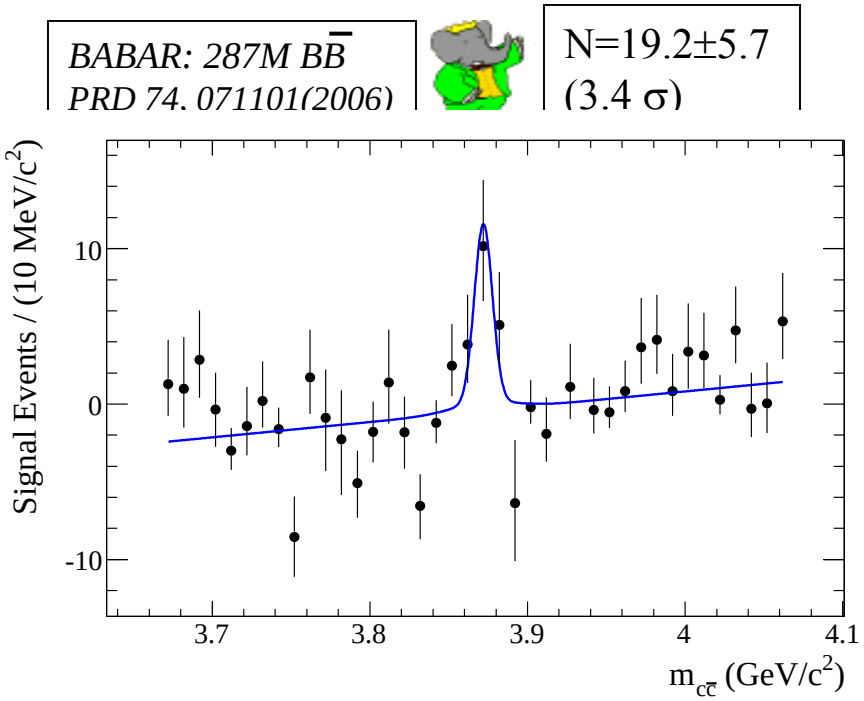
Combined results:

m_X = (3871.2 ±0.5) MeV/c^2

Narrow! $\Gamma_X < 2.3$ MeV @ 90% CL

Very close to **$m(D^0)+m(D^{*0})$=(3871.8 ±0.5) MeV/c^2 !**

Confirmation of X(3872)→ γJ/ψ ➔ C(X)=+1



$\mathcal{B}(B^{\pm}\to K^{\pm}X(3872), X(3872)\to\gamma J/\psi)$
$= (3.3\pm1.0\pm0.3)\times10^{-6}$

- Confirm Belle's observation

Belle/*BABAR* average:

$$\frac{\mathcal{B}(X\to\gamma\, J/\psi)}{\mathcal{B}(X\to\pi^+\pi^- J/\psi)} = 0.19\pm0.07$$

Establish C = +1, and hence it forbids
- $\pi^0\pi^0 J/\psi$, $\pi^0 J/\psi$, $\eta J/\psi$, $\gamma\chi_c$ or $\gamma\eta_c$

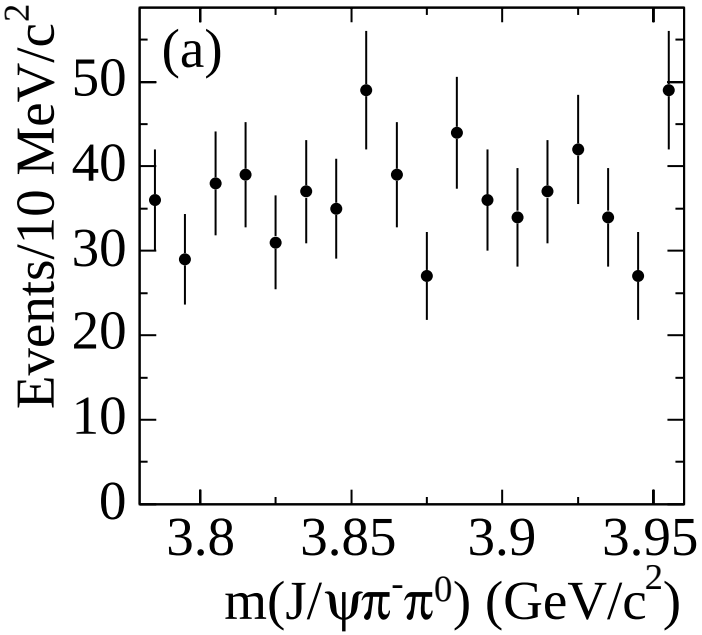
- C = +1 ➔ C = -1 for $\pi^+\pi^-$ ➔ **I=1**
- C = +1 ➔ **odd L** for $\pi^+\pi^-$
  Consistent with ρ-like $\pi^+\pi^-$ in $X\to\pi^+\pi^- J/\psi$

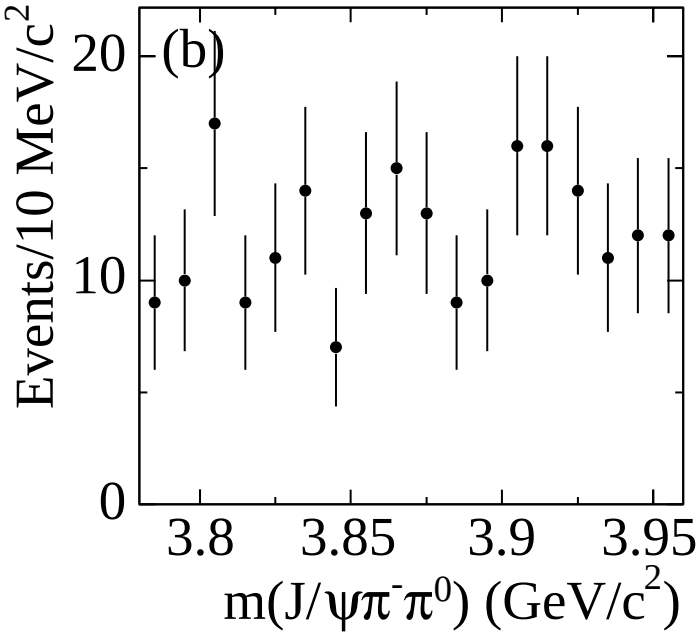
Search for X Charged-Partners

Search for $\mathbf{X^-(3872)\to\pi^-\pi^0 J/\psi}$ in

$B^0\to K^+X^-(3872)$ and $B^-\to K_sX^-(3872)$

BABAR: 287M $B\bar{B}$
PRD 71, 031501(2005)





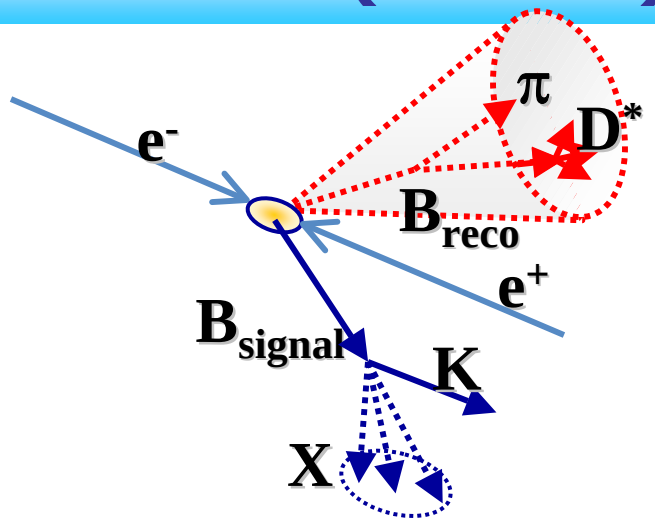
$\mathcal{B}(B^0\to K^+X^-(3872), X^-(3872)\to\pi^-\pi^0 J/\psi)$
$< 5.4\times10^{-6}$ @ 90% CL

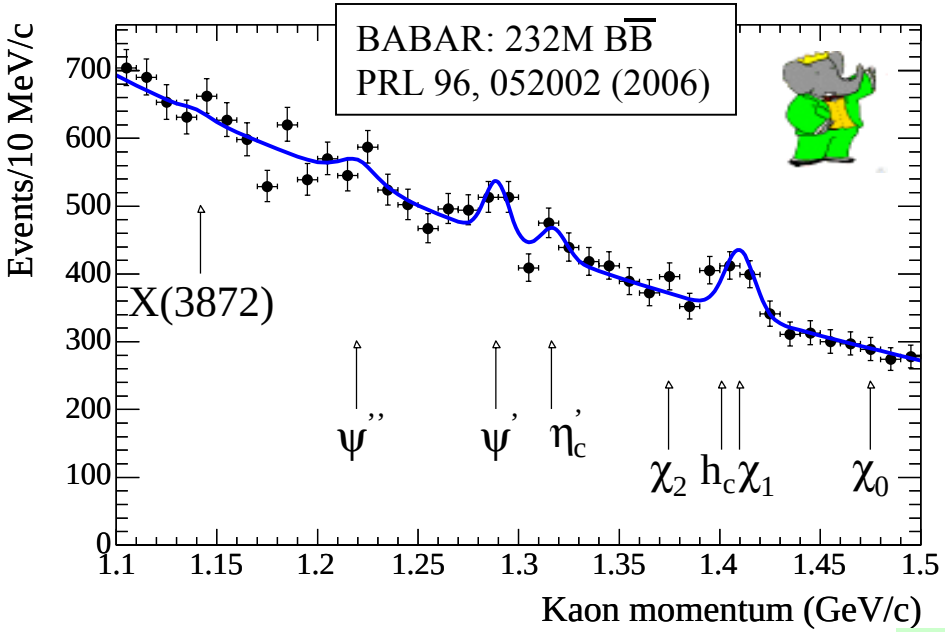
$\mathcal{B}(B^-\to KsX^-(3872), X^-(3872)\to\pi^-\pi^0 J/\psi)$
$< 22\times10^{-6}$ @ 90% CL

No evidence found: ➔**I=0** for X, **isospin violation** in $X\to\pi^+\pi^- J/\psi$

Inclusive Search for B→ K X(3872)

- Fully reconstruct one B
- Measure p(K) in the other B frame
- Calculate m(X) based on p(K)





$\mathcal{B}(B^{\pm}\to K^{\pm}c\bar{c})$ are consistent with PDG values for known charmonia

No charged X(3872) observed

$\mathcal{B}(B^0 \to K^{\mp} X^{\pm}(3872)) < 5\times10^{-4}$ @ 90% CL

Determined upper/lower limits on **absolute BFs**

$\mathcal{B}(B^{\pm}\to K^{\pm}X(3872))<3.2\times10^{-4}$ @ 90% CL

$\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)>4.2\%$ @ 90% CL

Y(4260)

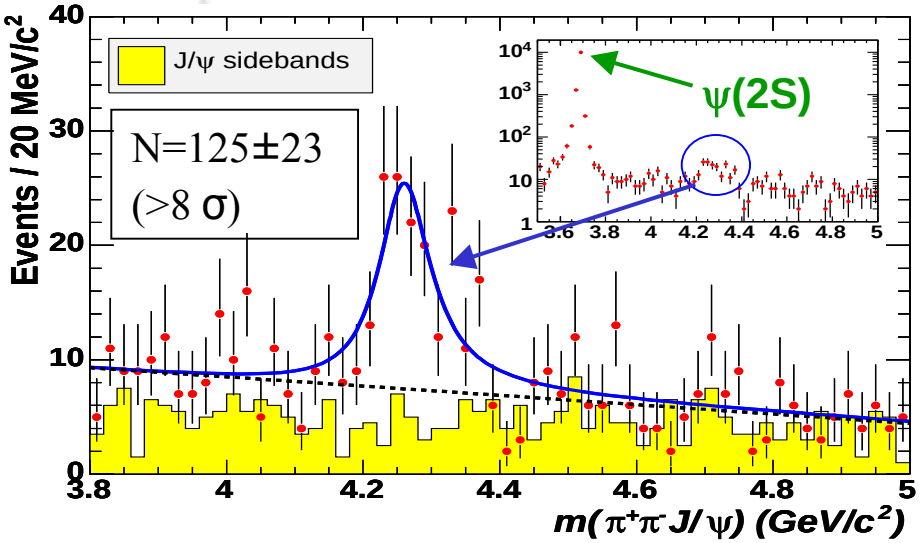
Discovery of the Y(4260)→ $\pi^+\pi^-$J/ψ

Observed in ISR events (γ_{ISR} detection **not** required) ➔ $J^{PC} = 1^{--}$

ISR ψ(2S) as good benchmark

BABAR: 233 fb^{-1}
PRL 95, 142001 (2005)

Peak cross section: $\sigma(e^+e^- \to Y, Y \to \pi^+\pi^- J/\psi) = (51 \pm 12)$ pb



Assuming single resonance

$$\Gamma_{ee}^{Y} \times \mathcal{B}(Y(4260) \to \pi^+\pi^- J/\psi) = (5.5 \pm 1.0^{+0.8}_{-0.7})\ \text{eV}$$

$$m_Y = (4259 \pm 8^{+2}_{-6})\ \text{MeV/c}^2$$
$$\Gamma_Y = (88 \pm 23^{+6}_{-4})\ \text{MeV}$$

Confirmations from CLEO-c, CLEO-III and Belle

ISR $\pi^+\pi^-J/\psi$	BaBar	CLEO-III	Belle (Preliminary)
Yield	125 ± 23 (>8σ)	$14.1^{+5.2}_{-4.2}$ (4.9σ)	165 ± 24 (>7σ)
Mass(MeV/c^2)	$4259 \pm 8^{+2}_{-6}$	$4283^{+17}_{-16} \pm 4$	$4295 \pm 10^{+11}_{-5}$
Width(MeV)	$88 \pm 23^{+6}_{-4}$	$70^{+40}_{-25} \pm 5$	$133 \pm 26^{+13}_{-6}$

M($\pi^+\pi^-$) Spectrum in Y(4260)$\rightarrow\pi^+\pi^-$J/ψ

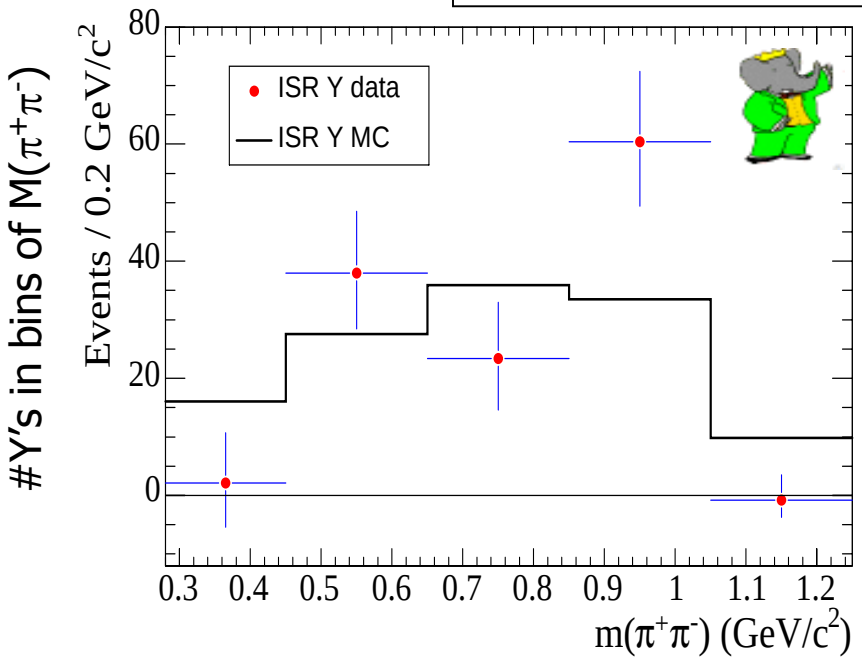
CLEO-c: $\mathcal{B}(\Upsilon\rightarrow\pi^0\pi^0 J/\psi)/\mathcal{B}(\Upsilon\rightarrow\pi^+\pi^- J/\psi) \approx 0.5$ ➔ **I=0**

Hence, possible quantum number for the $\pi^+\pi^-$ system

- $I^G = 0^+$
- $J^{PC} = 0^{++}$ or 2^{++}

BABAR: 233 fb^{-1}
PRL 95, 142001 (2005)

Solid hist:
$\pi^+\pi^-$ phase space
for S-wave $\pi^+\pi^- J/\psi$

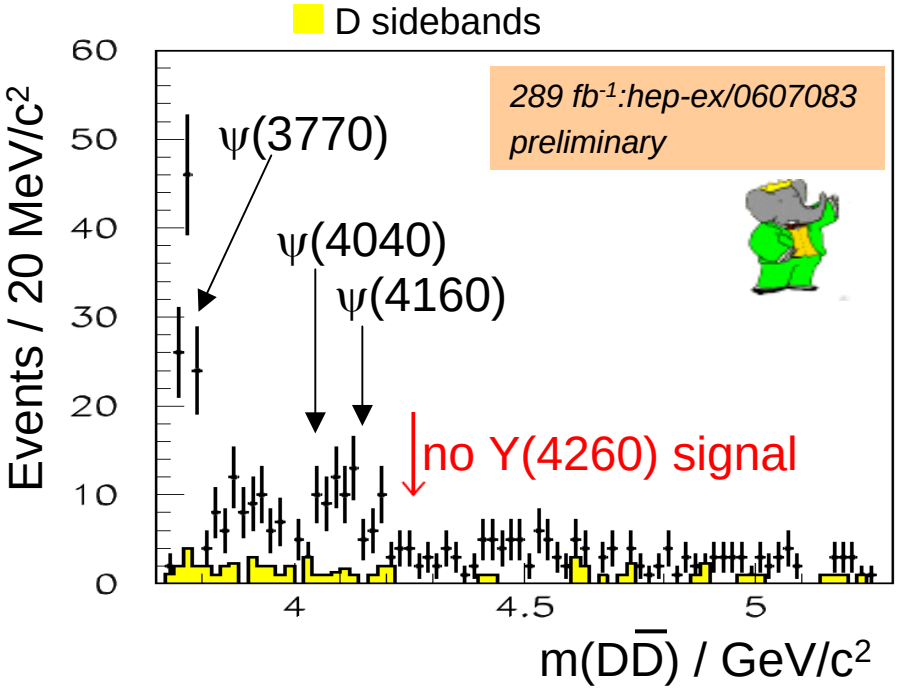


$\pi^+\pi^-$ invariant mass spectrum inconclusive

Search for **Other Y(4260) Decays** (I)

- $e^+e^- \to \gamma_{ISR}(D\bar{D})$ (γ_{ISR} detection **not** required)

Motivation: In principle, charmonium states like ψ(3770) above open-charm should dominantly decay to open-charm channels



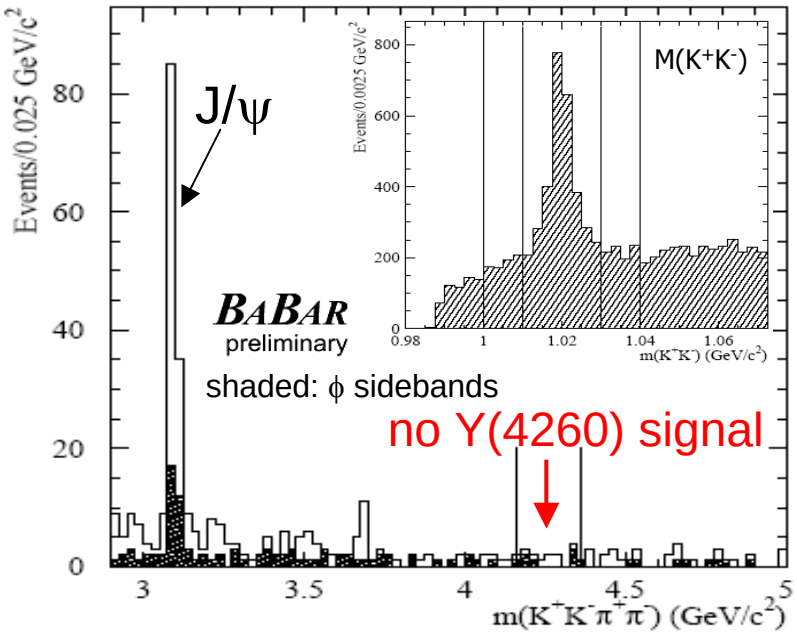
No evidence found

$$\frac{\mathcal{B}(Y(4260) \to D\bar{D})}{\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-)} < 7.6 \ \ (95\%\ \mathrm{CL})$$

This ratio is ~500 for ψ(3770) where $D\bar{D}$ is dominant

Search for **Other Y(4260) Decays** (II)

- $e^+e^- \to \gamma_{ISR}(\phi\pi^+\pi^-)$ (γ_{ISR} detection required)



232 fb^{-1}: hep-ex/0610018

$$\Gamma_{ee}^{Y} \times \mathcal{B}(Y(4260) \to \phi\pi^+\pi^-) < 0.4 \text{ eV (90\% CL)}$$

NB:

$$\Gamma_{ee}^{Y} \times \mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-) = 5.5 \pm 1.0^{+0.8}_{-0.7} \text{ eV}$$

➔ **Rule out glueball interpretation**

- $e^+e^- \to \gamma_{ISR}(p\bar{p})$ (γ_{ISR} detection required)

$$\frac{\mathcal{B}(Y(4260) \to p\bar{p})}{\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-)} < 0.13 \text{ (90\% CL)}$$

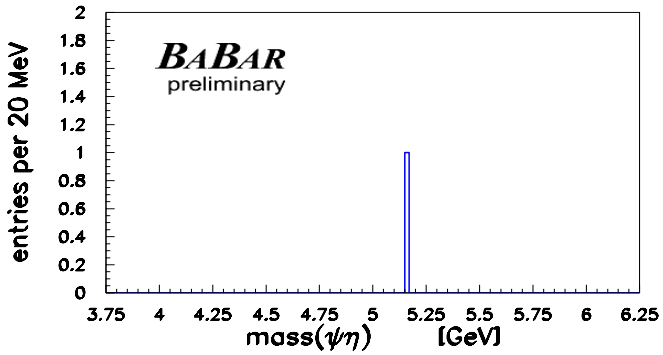
BABAR: 232 fb^{-1}
PRD 73, 012005 (2006)

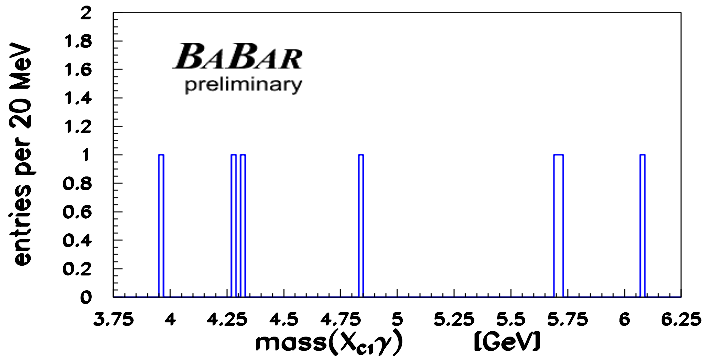
Search for **Other Y(4260) Decays** (III)

- $e^+e^- \to \gamma_{ISR}(J/\psi\ \gamma\ \gamma)$ (γ_{ISR} detection required)

230 fb^{-1}: hep-ex/0608004

Search for **$Y(4260) \to J/\psi\eta$, $J/\psi\pi^0$ and $Y(4260) \to \chi_{c1}\gamma$, $\chi_{c2}\gamma$**





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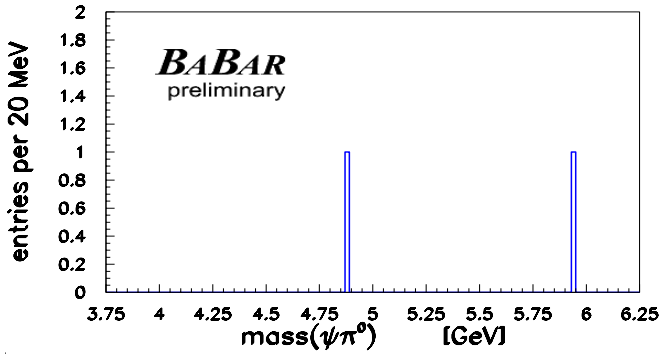
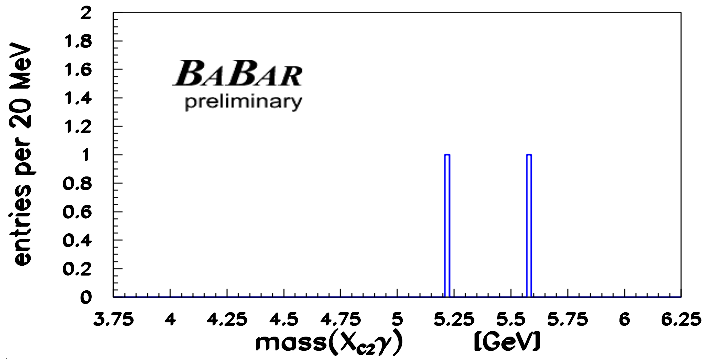




No evidence found, set upper limits (90% CL)

Channel (X)	$J/\psi\eta$	$J/\psi\pi^0$	$\chi_{c1}\gamma$	$\chi_{c2}\gamma$	$J/\psi\gamma\gamma$
$\mathcal{B}(Y \to X)/\mathcal{B}(Y \to \pi^+\pi^- J/\psi)$	**< 1.4**	**< 0.6**	**< 3.6**	**< 2.6**	**<1.2**

Y(4260) Properties (I)

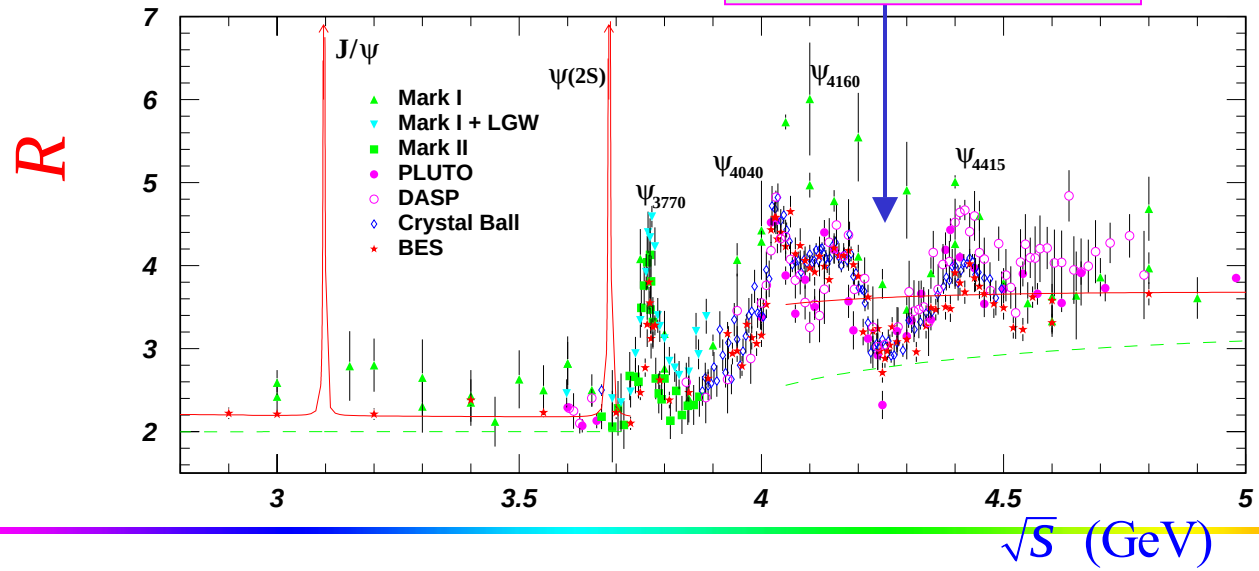
- **CLEO-c**: $\mathcal{B}(\Upsilon\to\pi^0\pi^0 J/\psi)/\mathcal{B}(\Upsilon\to\pi^+\pi^- J/\psi) \approx 0.5$ ➔ **I=0**
- A local mininum in $e^+e^-\to$hadrons cross section at 4.26 GeV
- **Large partial width Y(4260)$\to\pi^+\pi^-$ J/ψ :**

	ψ(2S)	ψ(3770)	Y(4260)
$\Gamma(\to\pi^+\pi^- J/\psi)$	**89 keV**	**45 keV (CLEO)**	**>1 MeV (by Bob Cahn)**

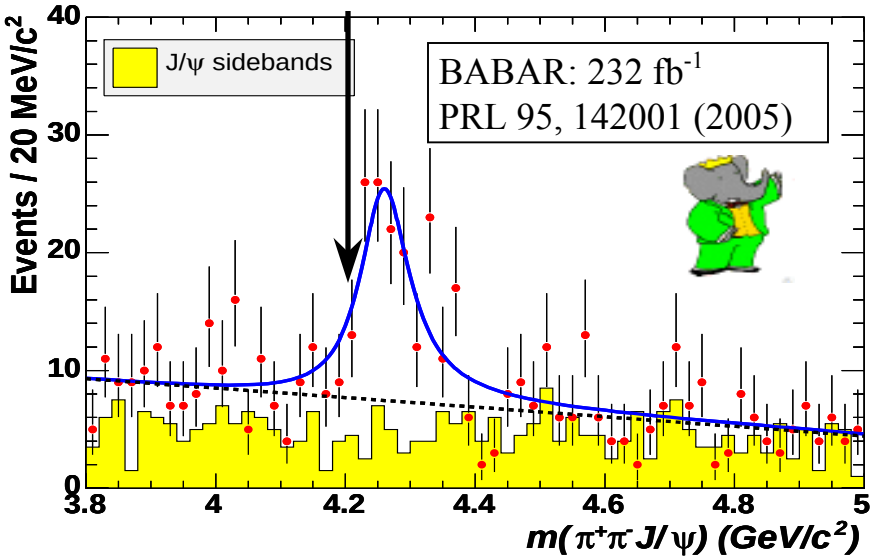
Assuming $\Delta R<1/2$ ➔ $\Gamma_{Y\to ee}$(min)

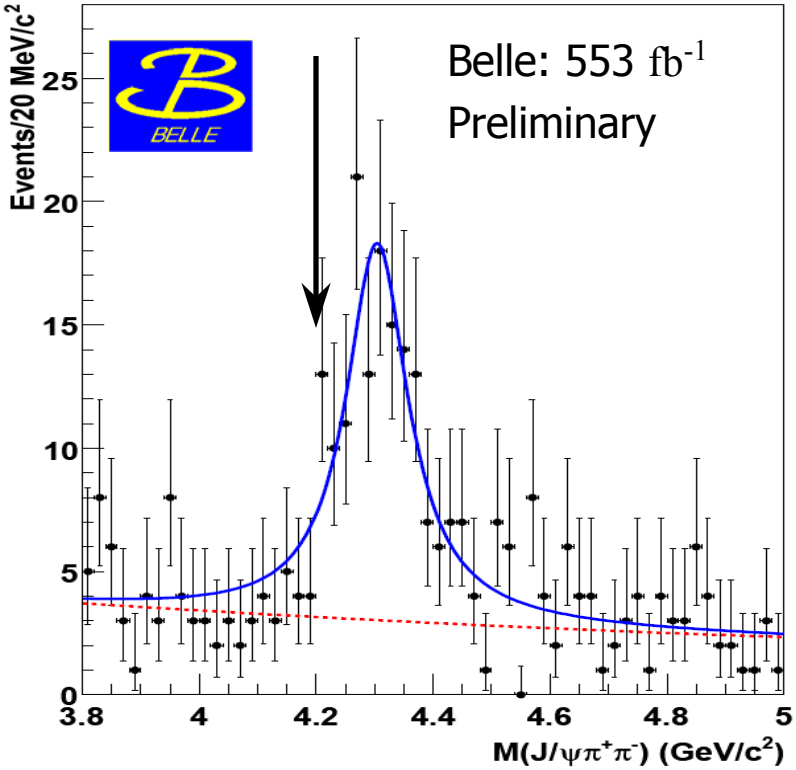
Difficult to interpret as a conventional charmonium state

Dip at 4.26GeV



Y(4260) Properties (II)





Seems a jump around 4.2 GeV/c^2 in Y(4260) structure**?**

And what can we learn from it?

Search for ISR $Y(4260)\to\pi^+\pi^-\psi(2S)$

Motivation:

- **Search for $Y(4260)\to\pi^+\pi^-\psi(2S)$ in ISR**

Observe a **structure, but …**

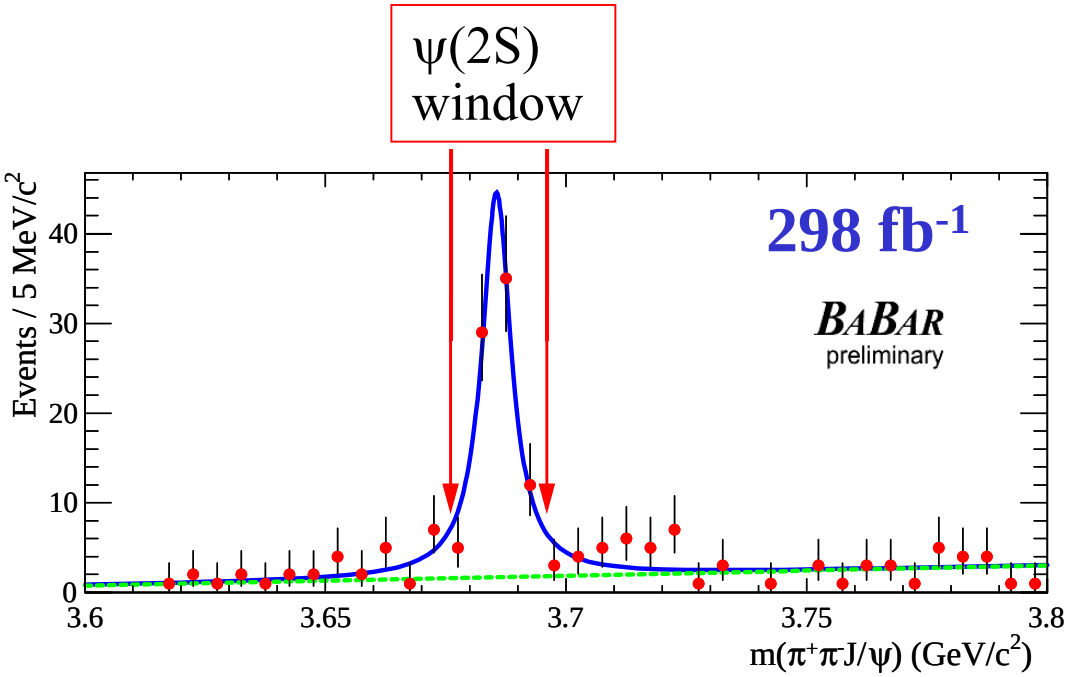
Clean $\pi^+\pi^-\psi(2S)$ Signal

ISR $\pi^+\pi^-\psi(2S)$, $\psi(2S)\to\pi^+\pi^- J/\psi$, $J/\psi\to l^+l^-$ (γ_{ISR} detection **not** required)

4 combinations: $\pi^+\pi^-(\pi^+\pi^- J/\psi)$, $\pi^+\pi^-(\pi^+\pi^- J/\psi)$, $\pi^+\pi^-(\pi^+\pi^- J/\psi)$, $\pi^+\pi^-(\pi^+\pi^- J/\psi)$

All $\pi^+\pi^- J/\psi$ combinations:

- **Clean $\psi(2S)$** signal
- **Half** of entries in sidebands are due to **self-combination** within $\psi(2S)$ signal events
- **3.8 ±1.1** non-$\psi(2S)$ bkg within $\psi(2S)$ window (78 events in total)



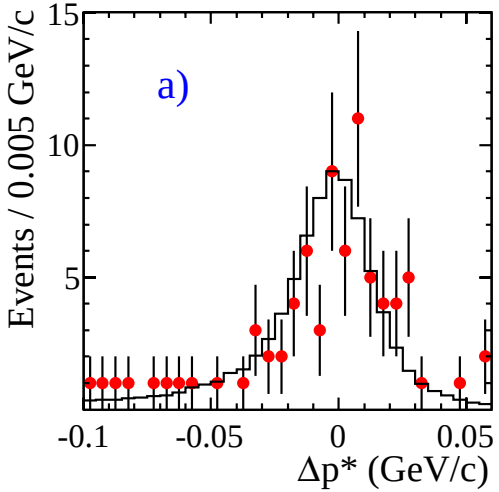
Genuine ISR !

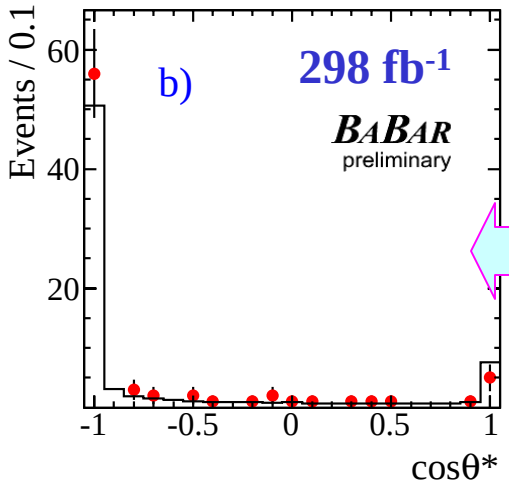
$\Delta p^* = p^*(2\pi^+2\pi^-J/\psi) - (E_{cm}^2 - m(2\pi^+2\pi^-J/\psi)^2)/(2E_{cm})$

momentum difference from expectation for ISR $2\pi^+2\pi^-J/\psi$ events

Points: data in $\psi(2S)$ window

Hist: ISR signal MC





ISR Evts:

$\theta^*(2\pi^+2\pi^-J/\psi)$ **peaks along beam directions**

Data are consistent with ISR signal Monte Carlo

Estimated number of non-ISR $\pi^+\pi^-\psi(2S)$ bkg events

< 1

Cross Section of $e^+e^- \to \pi^+\pi^-\psi(2S)$

$\sigma(e^+e^- \to \pi^+\pi^-\psi(2S))$ from threshold up to 8 GeV is calculated by

$$\frac{d\sigma(s,x)}{dx} = W(s,x)\,\sigma(s(1-x))$$

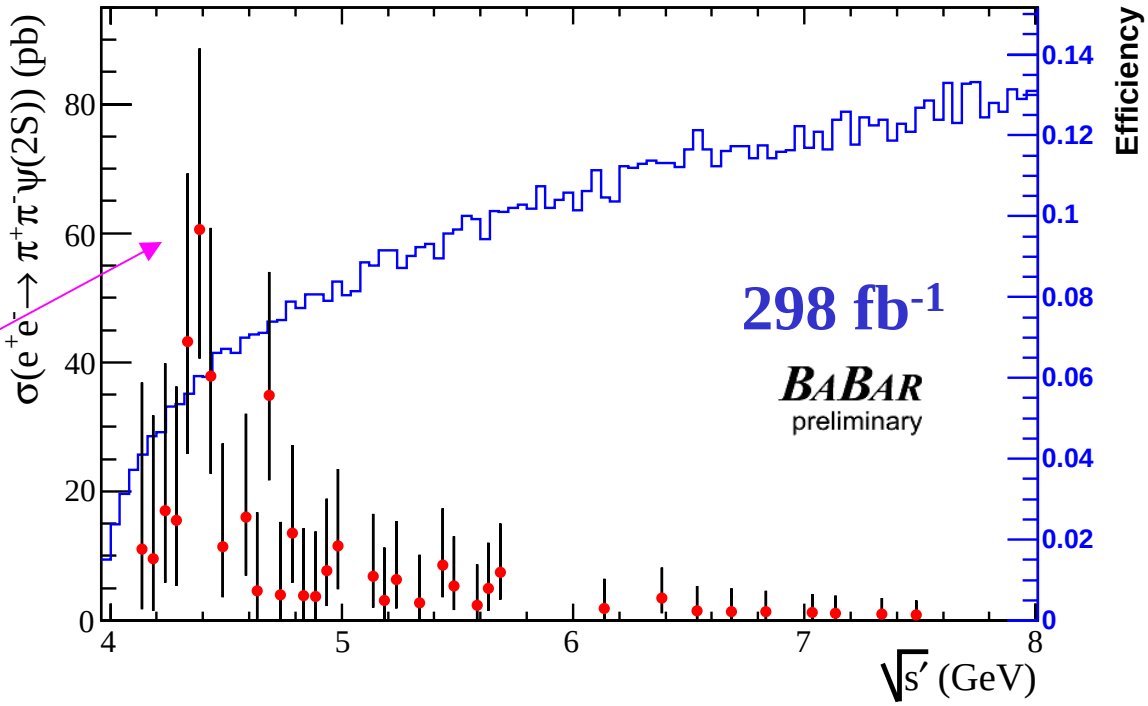
$x \equiv 2E_\gamma^*/\sqrt{s}$; $s' = s(1-x)$;

$W(s,x)$: ISR photon emission probability;

w/ bkg subtraction

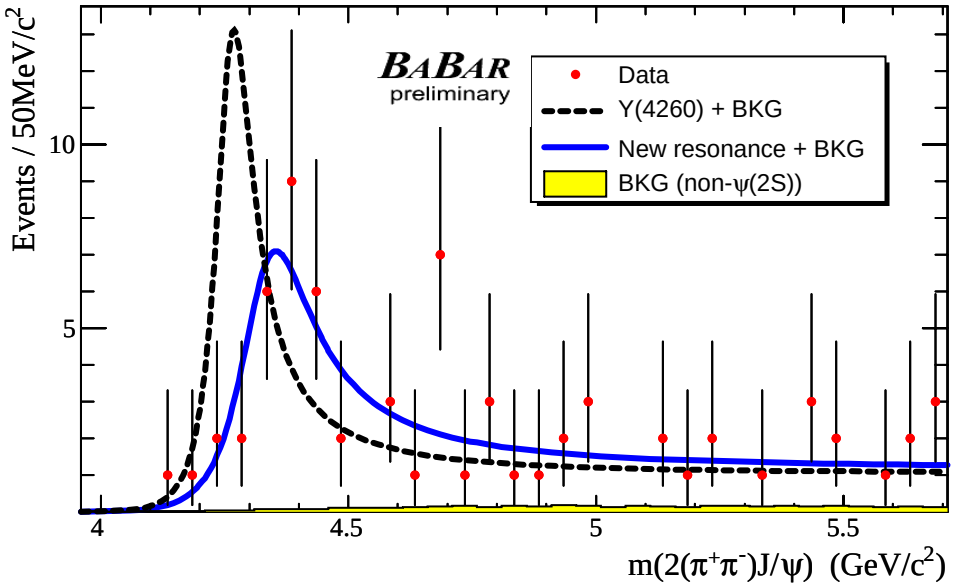
The maximum cross section is about **60 pb around 4.35 GeV**

A structure!



Is it compatible with the Y(4260)?

Fit to m(2($\pi^+\pi^-$)J/ψ) to avoid combinatorics.



298 fb^{-1}: hep-ex/0610057

Nevt = 68 (<5.7 GeV/c^2)

Nbkg = 3.1 ±1.0

Mass resolution ~7 MeV

Incompatible with **ψ(4415), nor well described by Y(4260)**

A single resonance can describe the structure (<5.7 GeV/c^2) well

⇒ **mass=(4324±24) MeV/c^2, Γ=(172±33) MeV** (statistical errors only)

χ^2-prob	< 5.7 GeV/c^2
Y(4260)	**6.5 ×10^{-3}**
ψ(4415)	**1.2 ×10^{-13}**
Y(4320)	**29%**

$\Delta(\log(L_{max}))$ = 5.4 between simultaneous fits of

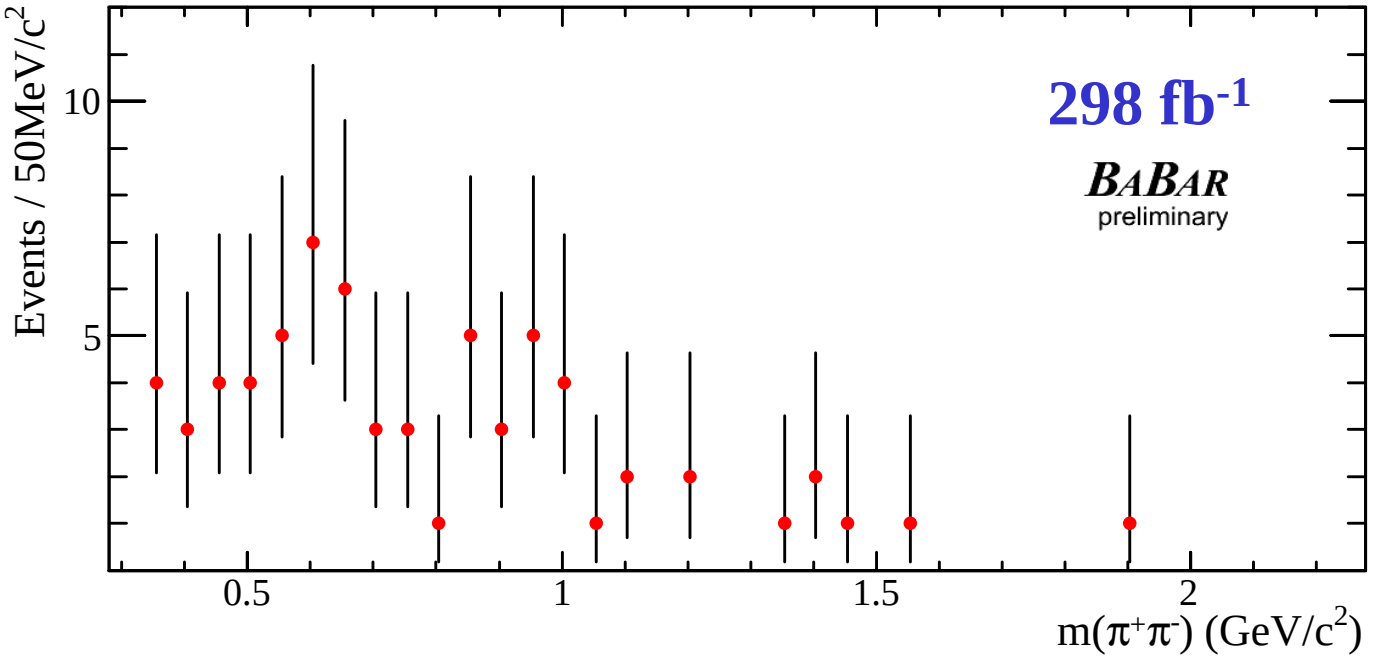
one common resonance and **two independent resonances**

to **this structure** and **$\pi^+\pi^-$J/ψ structure** (*PRL 95, 142001 (2005)*)

➔ Indicates that the two structures are different

M($\pi^+\pi^-$) Spectrum in ISR $\pi^+\pi^-\psi$(2S)

Primary dipion (not from ψ(2S)) invariant mass spectrum for the **m($\pi^+\pi^-\psi$(2S)) range**: [threshold, 5.7 GeV/c^2]



m($\pi^+\pi^-$) is correlated with m($\pi^+\pi^-\psi$(2S)).

And the m($\pi^+\pi^-$) structure is unclear.

What is the Structure at **4.32** GeV/c^2

- **Could it still be the Y(4260)? But current data does not support, then**
- **Could it be a threshold effect due to a low-mass resonance?**

  But there are just a few known vector charmonium states below the threshold:

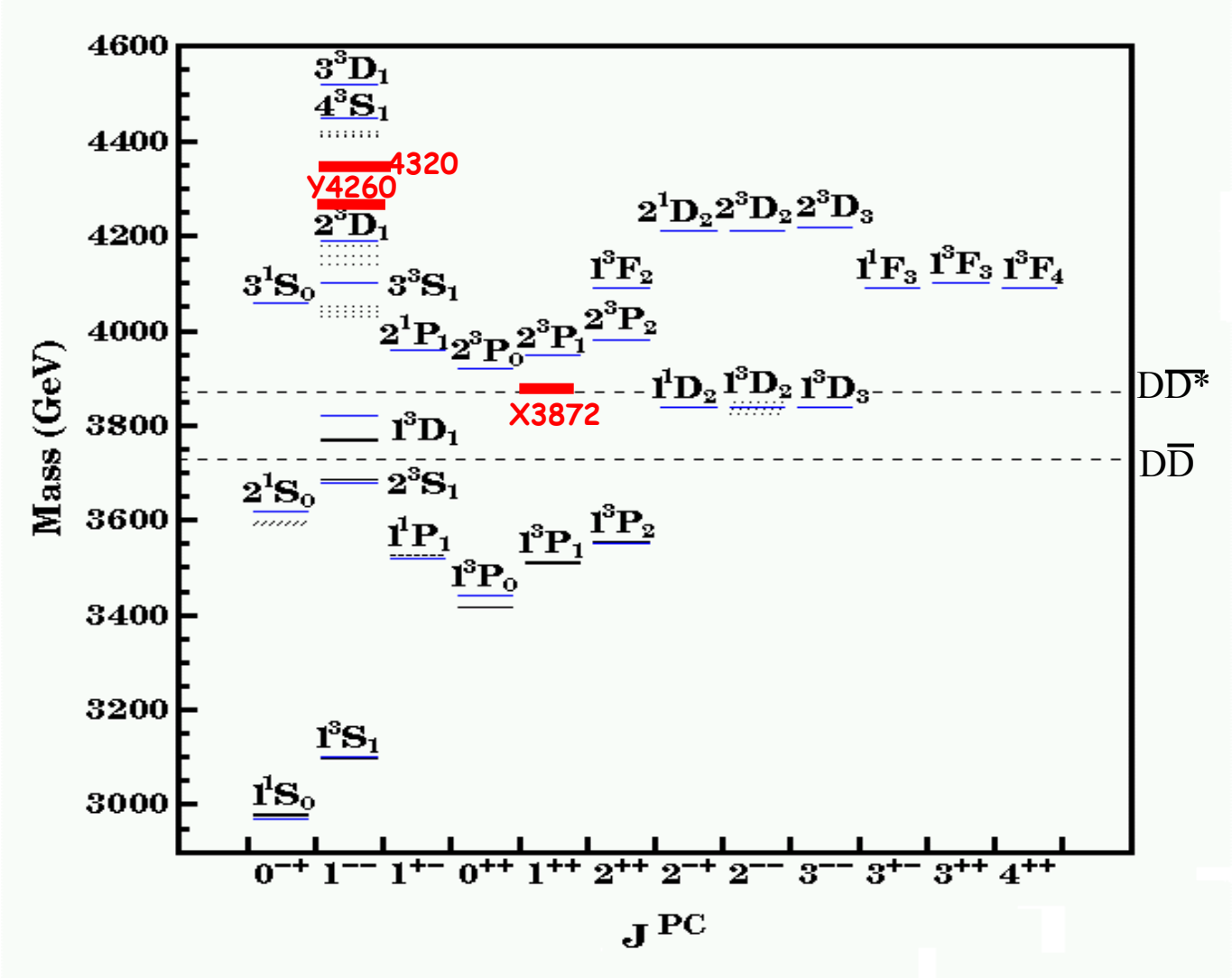
  J/ψ, $\psi(2S)$, $\psi(3770)$, $\psi(4040)$ and $\psi(4160)$
- **Coupled-channel effect?**
- **A new resonance?**
- …

Summary: What are X(3872), Y(4260), 4320?

Are X(3872) and Y(4260) charmonia?

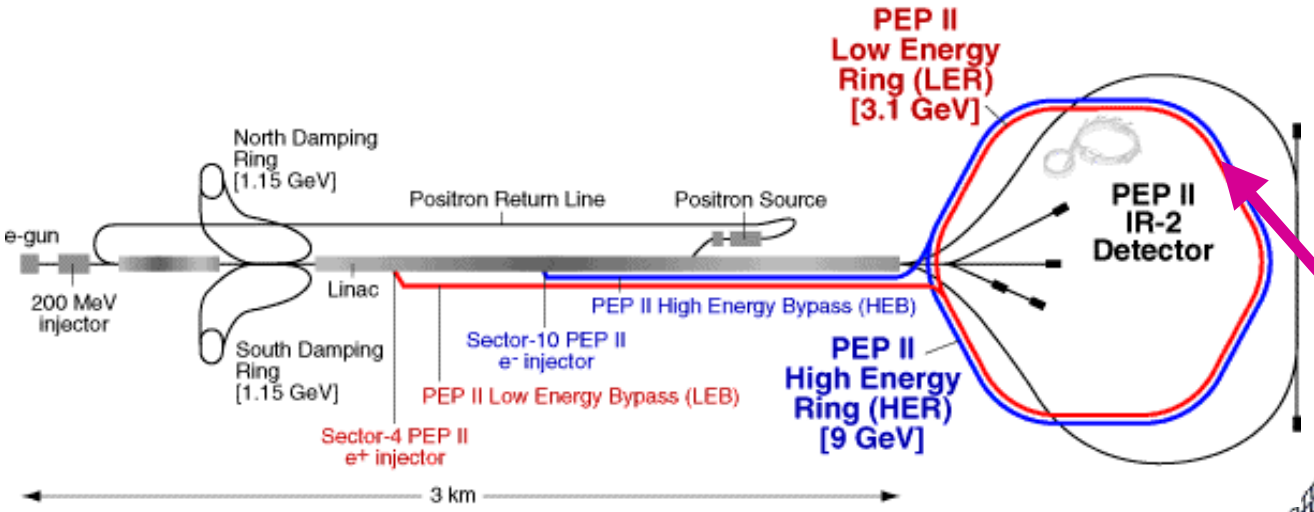
How about the new structure at 4320?

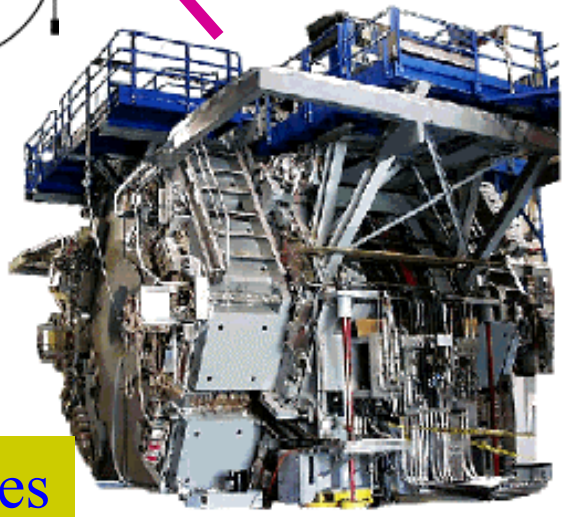
How reliable are the model predictions for mass region above ψ(3770)?



Backup slides

The *BABAR* Experiment at SLAC





$E_{e+} = 3.1\ \mathrm{GeV},\ E_{e-} = 9\ \mathrm{GeV}$ **βγ=0.56, βγcτ~250 μm**

$\sqrt{s} \approx M_{\Upsilon(4S)} = 10.58\ \mathrm{GeV}$ $e^+e^- \to \Upsilon(4S) \to B\overline{B}$

~600 physicists from 80 institutions in 11 countries

BABAR Detector