Measurements of J/ψ and $\psi(2S)$ parameters via ISR

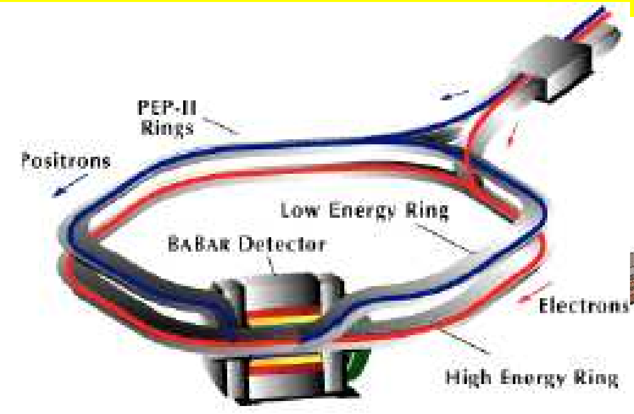
Peter A. Lukin,
BINP, Novosibirsk, Russia and IEKP, Karlsruhe, Germany
(for BaBar Collaboration)

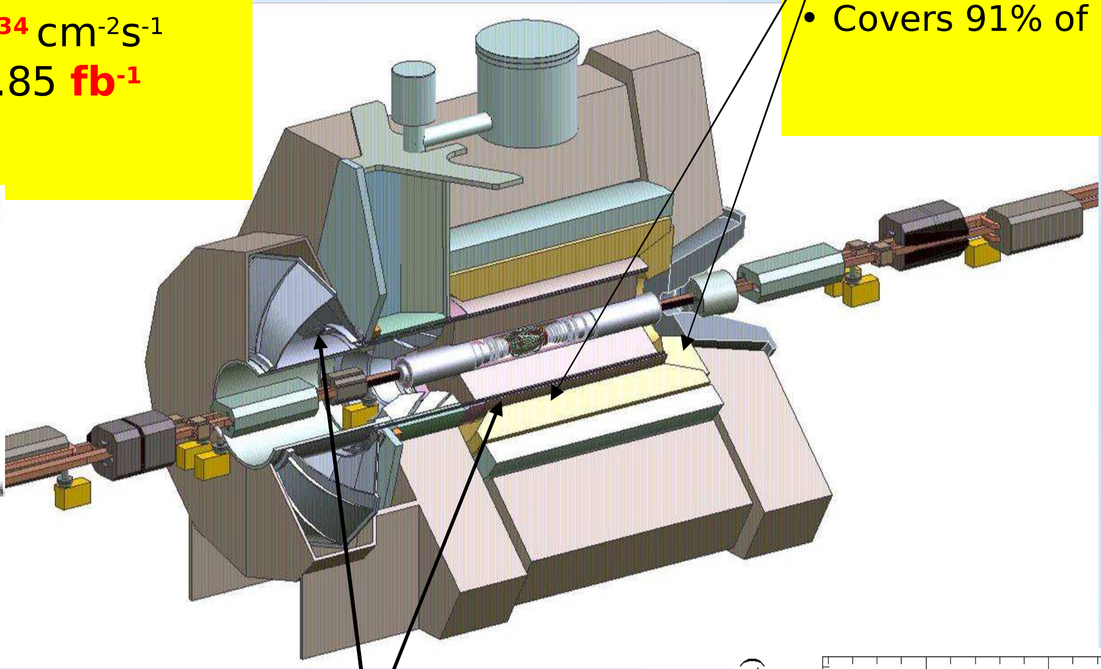
QWG07, DESY, Hamburg, Germany

BaBar/PEP-II

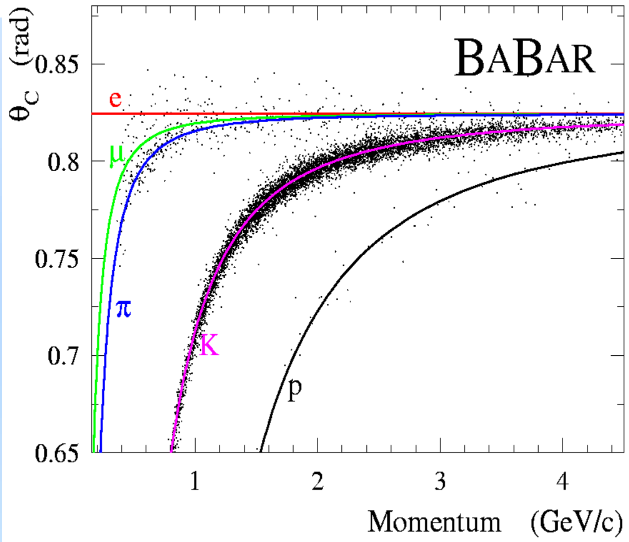
❖**PEP-II** is an asymmetric e^+e^- collider with a CM energy of $\Upsilon(4S)$ =10.58 GeV.
❖Peak luminosity = **1.21 *10^34** $cm^{-2}s^{-1}$
❖Integrated luminosity = 476.85 **fb^{-1}**

BaBar EMC:
- 6580 CsI(Tl) crystals, E resolution ~1-2 % at high E.
- Covers 91% of solid angle.

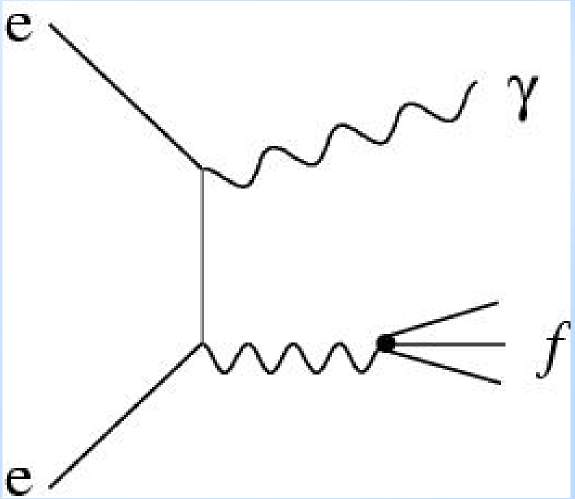




BaBar DIRC
- Covers 80% of solid angle
- Particle ID up to 4-5 GeV/c



The ISR method



Spectrum over invariant mass (m) of hadronic system *f* in the $e^+e^- \rightarrow f\gamma$ reaction is related to cross section of $e^+e^- \rightarrow f$ process according to:

$$\frac{d\sigma_{e^+e^-\rightarrow f\gamma}}{dm} = \frac{2m}{s} W(s,x)\,\sigma_{e^+e^-\rightarrow f}(m), \quad x = \frac{E_\gamma}{\sqrt{s}} = 1 - \frac{m^2}{s},$$

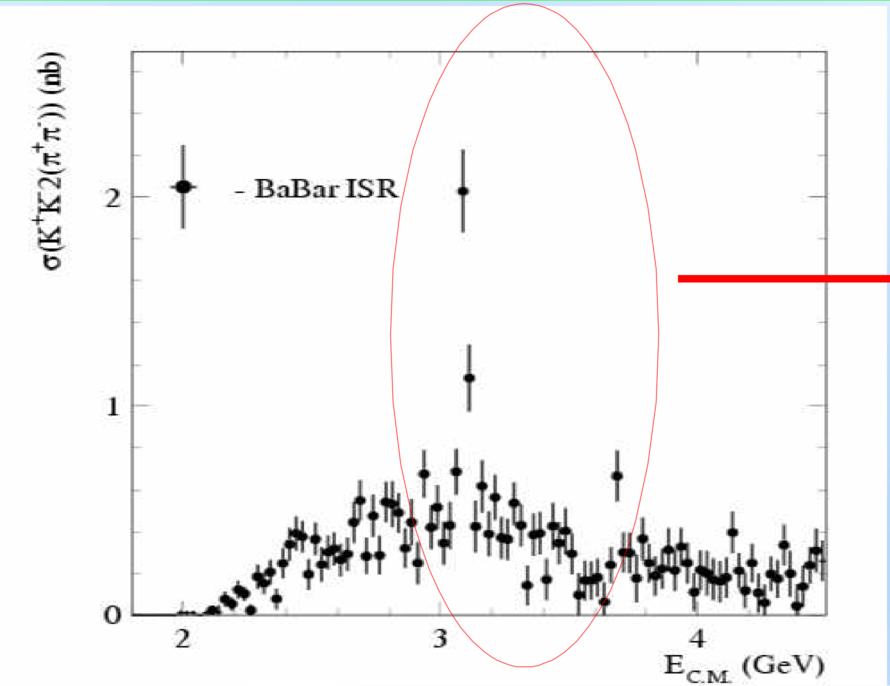
- **Measurement of hadronic cross sections in wide energy range in single experiment**
- **The results were obtained with ISR photon detected**
- **The advantage of the approach with detected photon is the low dependence of the detection efficiency on mass of hadronic system and its internal substructure.**

ISR Experimental Program

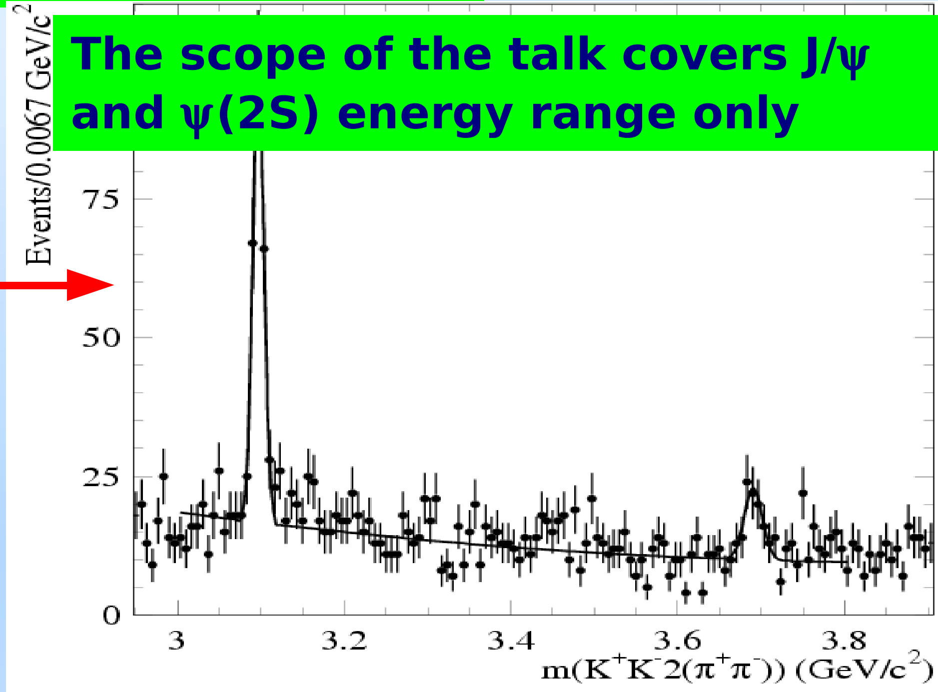
- **Objective :**
  Precise cross section measurements for all significant processes,
  $e^+ e^- \rightarrow f$, from threshold to c.m. energy ~ 4.5-5.0 GeV
- **Purpose :**
  Significantly improve understanding of the spectroscopy of $J^{PC} = 1^{--}$ states, and of their resonant substructure
  Combine the cross section measurements to obtain improved precision on the c.m. energy dependence of R in this region
  Calculation of hadronic contribution to vacuum polarization in measurement of $(g-2)_\mu$
  Calculation of $\alpha(m^2_Z)$
- **Reactions for which results have been published :**
  - $e^+e^- \rightarrow \pi^+\pi^-\pi^0$
  - $e^+e^- \rightarrow 2\pi^+2\pi^-$, $K^+K^-\pi^+\pi^-$, $2K^+2K^-$
  - $e^+e^- \rightarrow 3\pi^+3\pi^-$, $2\pi^+2\pi^-\pi^0\pi^0$, $K^+K^-2\pi^+2\pi^-$
  - $e^+e^- \rightarrow p\bar{p}$
  - $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$, $\phi\pi\pi$, $\phi f^0(980)$
- **New results presented here :**
  $J/\psi \rightarrow 2\pi^+2\pi^-\pi^0$, $K K \pi^0$, $\Lambda \bar{\Lambda}$, $\pi^+\pi^-\pi^0\pi^0$
- **Work in progress on :**
  $\pi^+\pi^-$, K K , $\pi^+\pi^-3(\pi^0)$, d d ,..

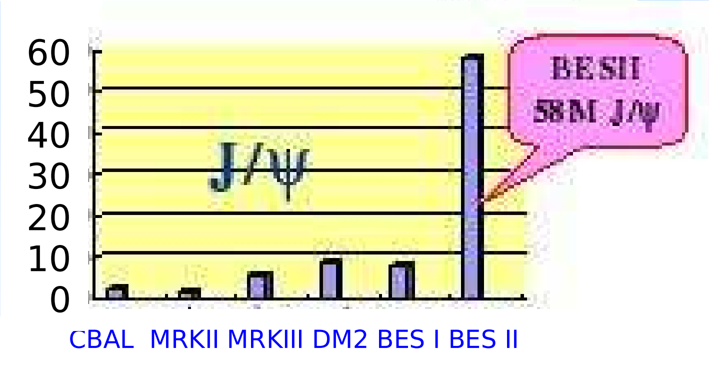
The scope of the talk

The typical Babar ISR experiment goal is to measure cross section of a process in broad energy range



The scope of the talk covers J/ψ and ψ(2S) energy range only





Babar - 8.36M of J/ψ
356.4K of ψ(2S)

Other energy regions will be discussed in M. Davier talk on 20 of October 2007 QWG07 session

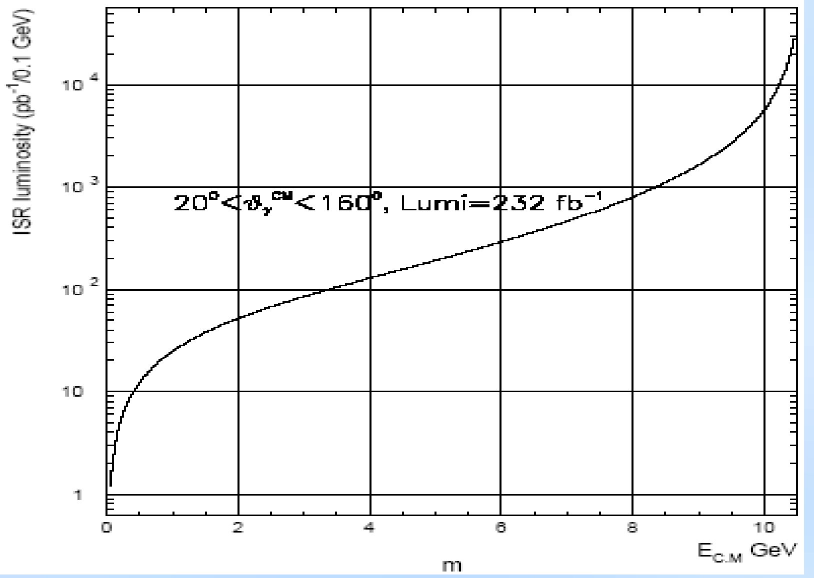
$J/\psi - \psi(2S)$ *region*

We measure:

$$\Gamma_{ee}^{J/\psi} \cdot B_f^{J/\psi} = \frac{N_{J/\psi \to f} M^2_{J/\psi}}{6\pi^2 \cdot dL/dM \cdot \varepsilon(M_{J/\psi}) \cdot C}$$

N – number of events, observed, obtained from the fit of J/ψ with Gaussian describing resolution.
ε (M) – detection efficiency
$C = (h \bullet c/2\pi)^2 = 3.8938{*}10^{11}\ MeV^2 \bullet nb$
dL/dM - ISR luminosity

$$\frac{dL}{dM} = \frac{\alpha}{\pi x}\left(\left(2-2x-2x^2\right)\log\frac{1+\cos\theta_0}{1\text{-}\cos\theta_0} - x^2\cos\theta_0\right)\frac{2M}{s}L$$



L – PEP II integrated luminosity

$\theta_0 = 20^o$ provides 10% of acceptance for ISR photon

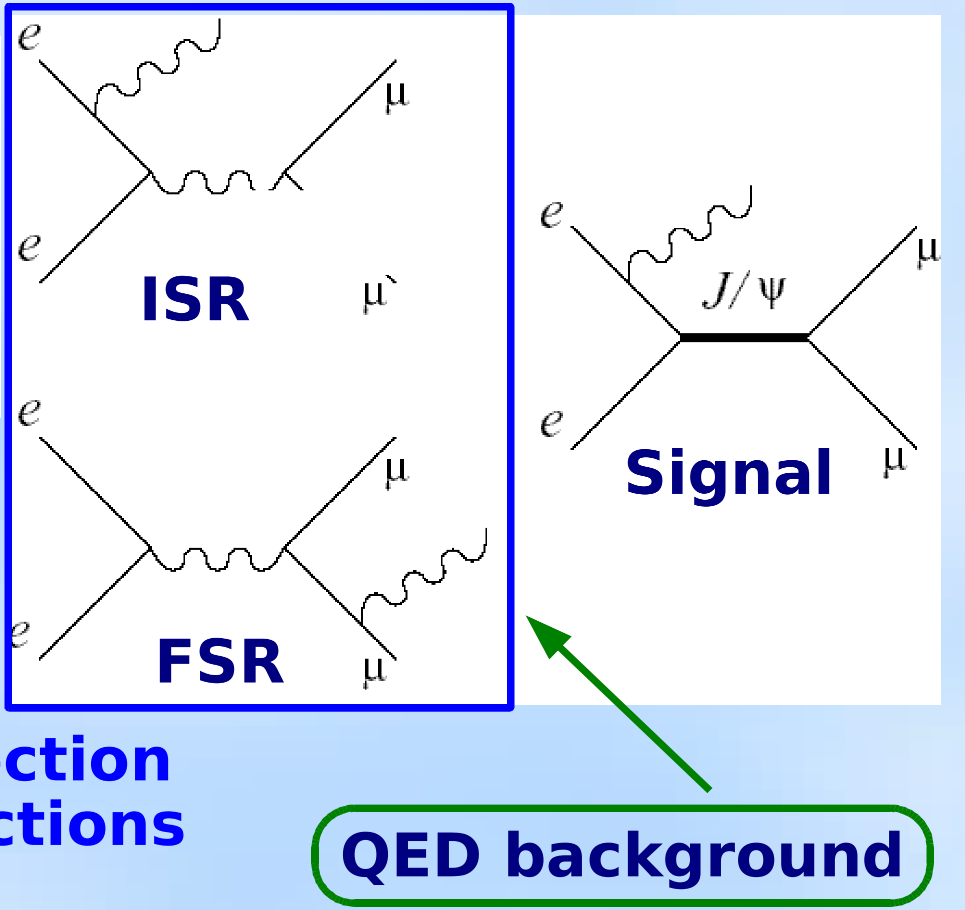
About 6% systematic error from efficiency (3%-5%) and luminosity (3%).
We hope to decrease luminosity systematic error down to 1%
If statistical error < 6% BaBar is competitive with other experiments, if systematic error of the other experiment is greater than 6%

J/ψ Width measurement from J/ψ→μμ. The Method.

We measure the ratio R of J/ψ signal to QED background excluding FSR

$$R = \frac{N_{J/\psi}}{\frac{dN}{dM}\cdot 4\ \mathrm{MeV/c^2}} =$$

$$\frac{\sigma^{Born}_{J/\psi}}{\frac{d\sigma^{Born}_{ISR}}{dM}\cdot 4\ \mathrm{MeV/c^2}}\cdot\frac{1}{K},\quad K = \frac{d\sigma^{vis}_{Total}/dM}{d\sigma^{vis}_{ISR}/dM}$$



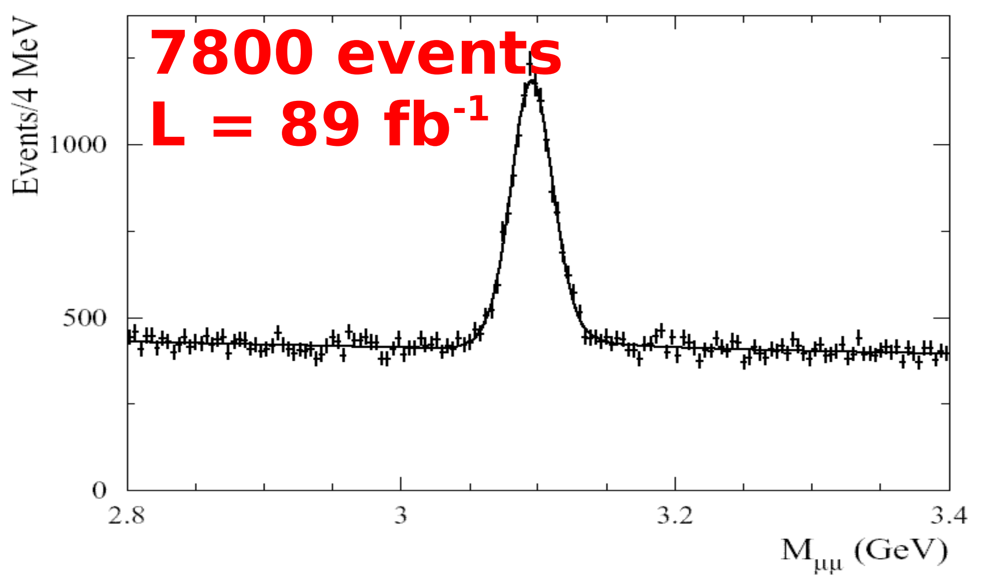
FSR is excluded according to simulation. The FSR correction factor K = 1.08 for our selections procedure

QED background

J/ψ Width measurement from J/ψ→μμ
The result. (PRD69,011103,(2004))

$$K \cdot R = 21.03 \pm 0.49 \pm 0.46$$

$$\sigma_{J/\psi} = (2124 \pm 49 \pm 47)\ \mathrm{fb}$$



$$\Gamma_{ee} \cdot B_{\mu\mu} = 0.3301 \pm 0.0077 \pm 0.0073\ \mathrm{keV}$$

Using from PDG $B_{\mu\mu} = (5.88 \pm 0.10)\%$ $B_{ee} = (5.93 \pm 0.10)\%$

we obtain

Babar

Γ_{ee} = 5.61 ± 0.20 keV,

Γ = 94.7 ± 4.4 keV

To be compared with

PDG(2006)

Γ_{ee} = 5.55 ± 0.14 ± 0.02 keV,

Γ = 93.4 ± 2.1 keV

The PDG(2006) value includes BaBar and CLEO results

J/ψ results already published

Decay	Babar	PDG(2004)	Reference
$B(J/\psi \to \pi^+\pi^-\pi^0)$	$(2.18\pm0.19) \times 10^{-2}$	$(1.50\pm0.20) \times 10^{-2}$	PRD70,072004,2004
$B(J/\psi \to \pi^+\pi^-\pi^+\pi^-)$	$(3.61\pm0.37) \times 10^{-3}$	$(4.0\pm1.0) \times 10^{-3}$	PRD71,052001,2005
$B(J/\psi \to K^+K^-\pi^+\pi^-)$	$(6.09\pm0.73) \times 10^{-3}$	$(7.2\pm2.3) \times 10^{-3}$	PRD71,052001,2005
$B(J/\psi \to K^+K^-K^+K^-)$	$(6.7\pm1.5) \times 10^{-4}$	No entry	PRD71,052001,2005
$B(J/\psi \to 3\pi^+3\pi^-)$	$(4.40 \pm 0.41) \times 10^{-2}$	$(4.0 \pm 2.0) \times 10^{-2}$	PRD73,052003,2006
$B(J/\psi \to 2\pi^+2\pi^-2\pi^0)$	$(1.65 \pm 0.21) \times 10^{-2}$	No entry	PRD73,052003,2006
$B(J/\psi \to \omega\eta)$	$(1.47\pm 0.44) \times 10^{-3}$	$(1.58 \pm 0.16) \times 10^{-3}$	PRD73,052003,2006
$B(J/\psi \to K^+K^-2\pi^+2\pi^-)$	$(5.09\pm 0.45) \times 10^{-3}$	$(3.1 \pm 1.3) \times 10^{-3}$	PRD73,052003,2006
$B(J/\psi \to \phi 2\pi^+2\pi^-)$	$(1.77\pm 0.37) \times 10^{-3}$	$(1.60 \pm 0.32) \times 10^{-3}$	PRD73,052003,2006
$B(J/\psi \to pp)$	$(2.22\pm 0.16) \times 10^{-3}$	$(2.18\pm 0.08) \times 10^{-3}$	PRD73,012005,2006

better

worse

ψ(2S) *results already published*

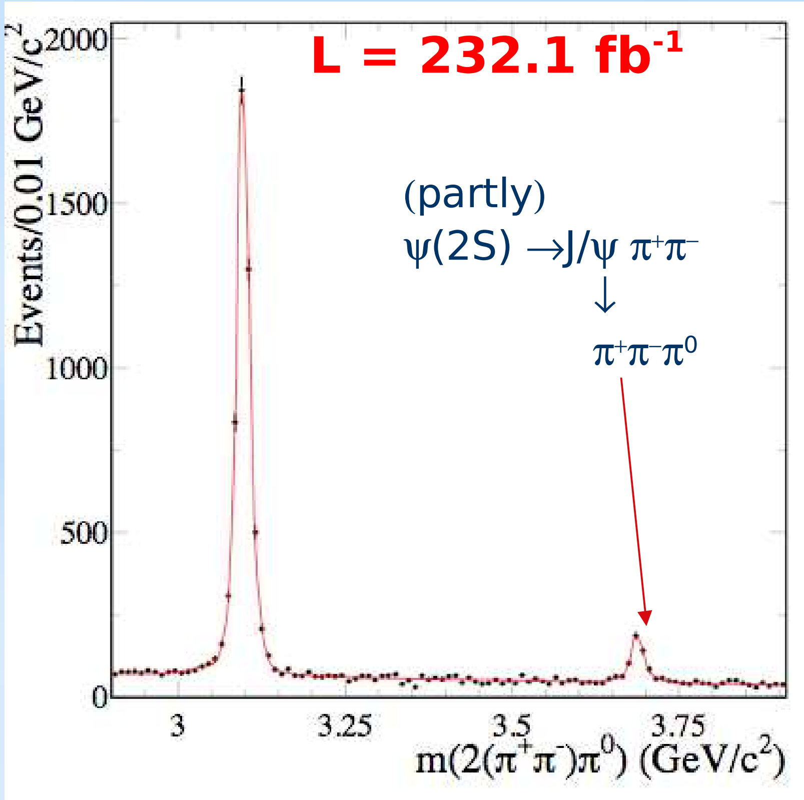
Decay	Babar	PDG(2004)	Reference
$B(\psi(2S) \to 2\pi^+2\pi^-2\pi^0)$	(5.3 ± 1.7) x10^{-3}	No entry	PRD73,052003,2006
$B(\psi(2S) \to K^+K^-2\pi^+2\pi^-)$	(2.1 ± 1.0) x10^{-3}	No entry	PRD73,052003,2006
$B(\psi(2S) \to pp)$	(3.3± 0.9) x10^{-4}	(2.36± 0.24) x10^{-4}	PRD73,012005,2006

better

worse

J/ψ region for $2(\pi^+\pi^-)\pi^0$

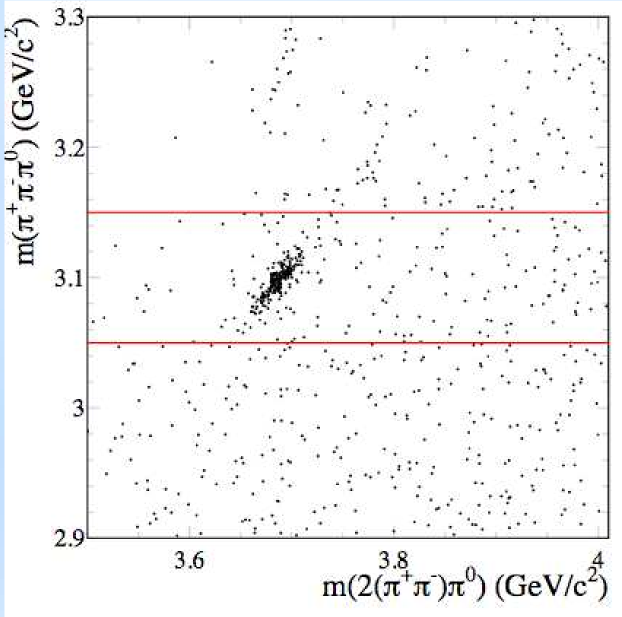
	N	ε	dL/dE, nb^{-1}/MeV	$\Gamma_{ee}B_{5\pi}$, keV
J/ψ	4990±79	0.1045	65.6	$(3.03\pm0.05\pm0.18)\times10^{-1}$
$\psi(2S)$	410±30	0.0965	84.0	$(2.97\pm0.22\pm0.18)\times10^{-2}$



	Babar	PDG(2006)
$B(J/\psi\to5\pi)\times10^{-2}$	5.46±0.09±0.34	3.37±0.26
$B(\psi(2S)\to5\pi)\times10^{-2}$	1.20±0.09±0.07	0.266±0.029

Babar value of $B(\psi(2S)\to 5\pi)$ includes transition $\psi(2S)\to J/\psi\ \pi\pi$, $J/\psi\to3\pi$

The $\psi(2S) \to J/\psi\ \pi^+\pi^- \to 2(\pi^+\pi^-)\pi^0$

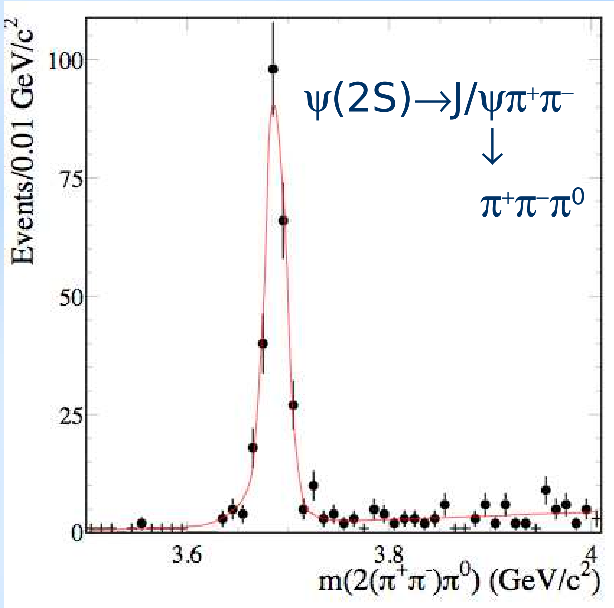


$N_{\psi(2s)}$ = 256 ± 17 ε = 0.0965 dL/dE = 84.0 nb^{-1}/MeV

$\Gamma_{ee} \bullet B_{J/\psi\pi\pi} \bullet B_{J/\psi\to3\pi}$ = (1.86 ± 0.12 ± 0.11) × 10^{-2} keV

Γ_{ee} = 2.48 ± 0.06 keV, $B_{J/\psi\pi\pi}$ = 0.318 ± 0.006 PDG2006

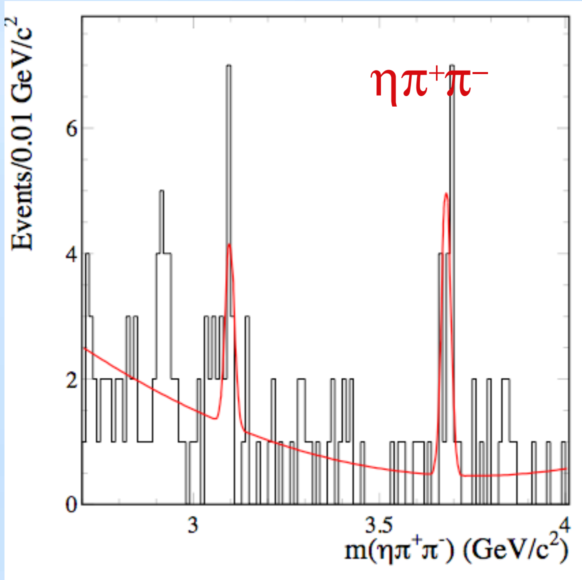
$B_{J/\psi\to3\pi}$ = (2.36 ± 0.16 ± 0.16) × 10^{-2}



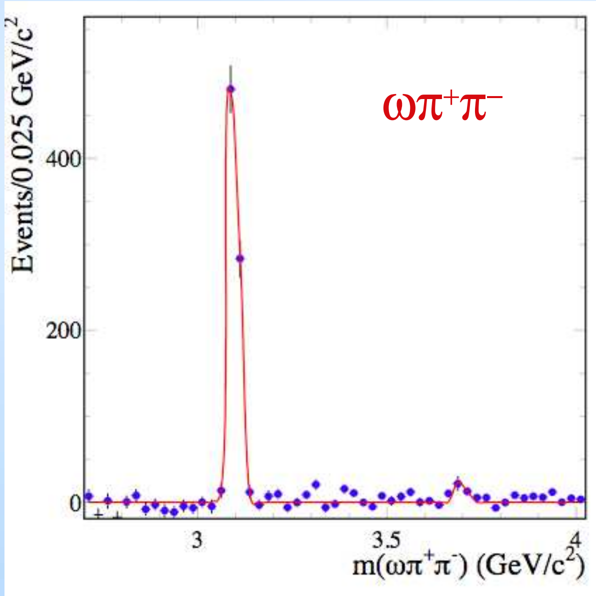
$B_{J/\psi\to3\pi}$ = (2.02 ± 0.14)×10^{-2}	S=1.7	PDG2006
$B_{J/\psi\to3\pi}$ = (2.18 ± 0.19)×10^{-2}		BaBar 2004
$B_{J/\psi\to3\pi}$ = (2.18 ± 0.20)×10^{-2}		BES 2004
$B_{J/\psi\to3\pi}$ = (2.09 ± 0.12)×10^{-2}		BES 2004
$B_{J/\psi\to3\pi}$ = (1.42 ± 0.19)×10^{-2}		MARK3 1988

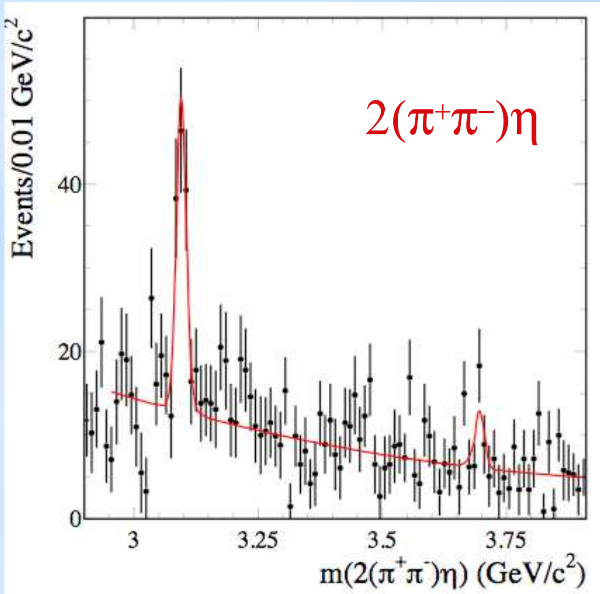
We are in agreement with BaBar and BES !

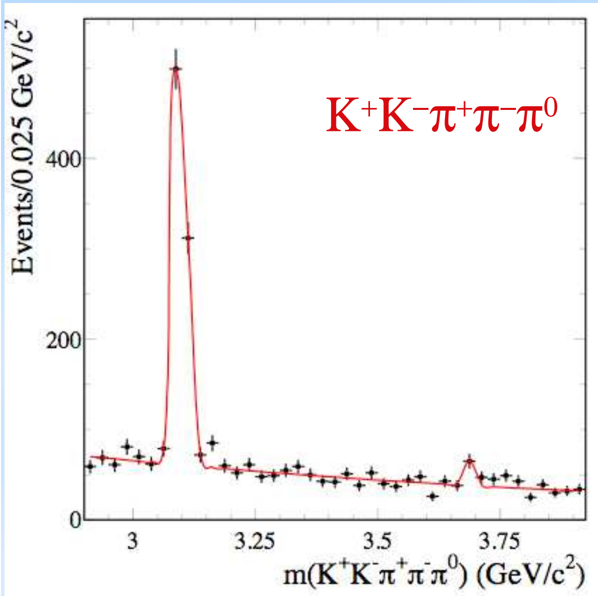
$J/\psi - \psi(2S)$ region for other decays into 5 hadrons

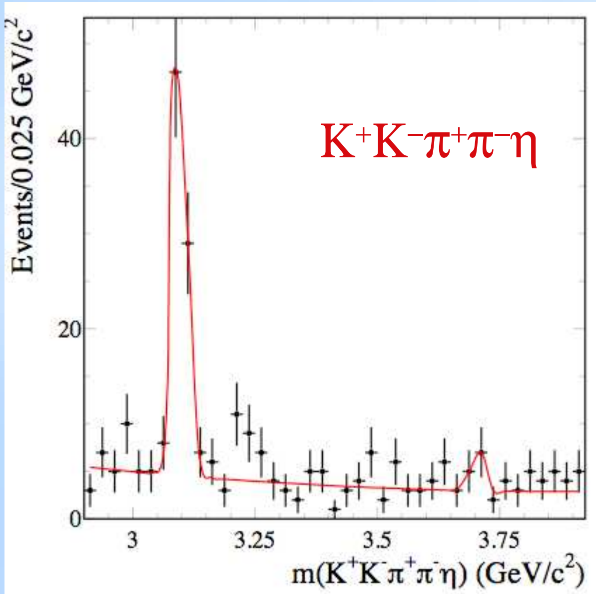


L = 232.1 fb⁻¹

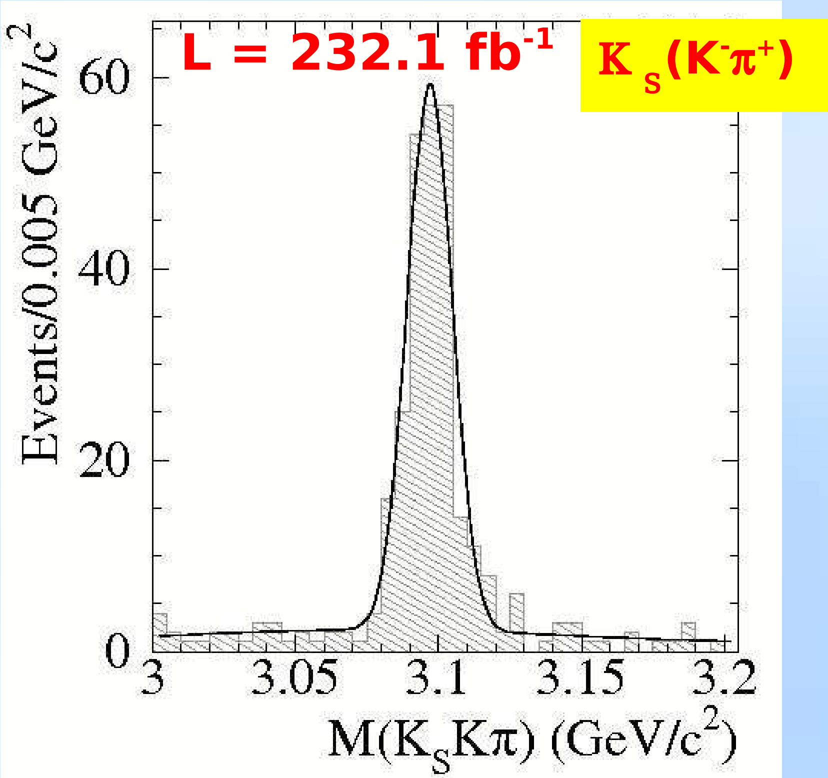








$J/\psi \to K(892)^{*0} K^0$ *(preliminary)*

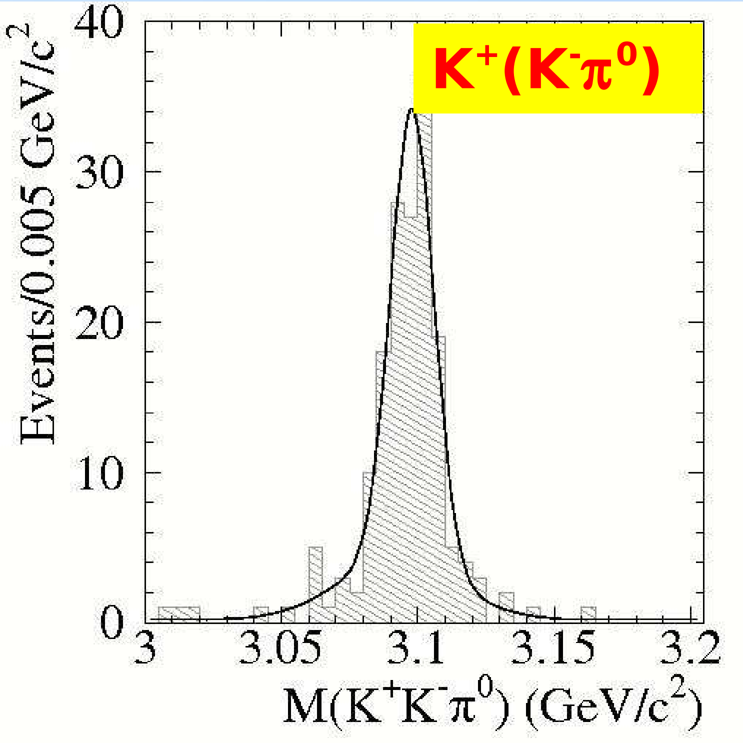


	N	ε	$\Gamma_{ee}B$, eV	Bx10^{-3}
$J/\psi \to K_S(K^-\pi^+)$	94±9	0.09	8.51±0.85±0.50	1.57±0.16±0.09

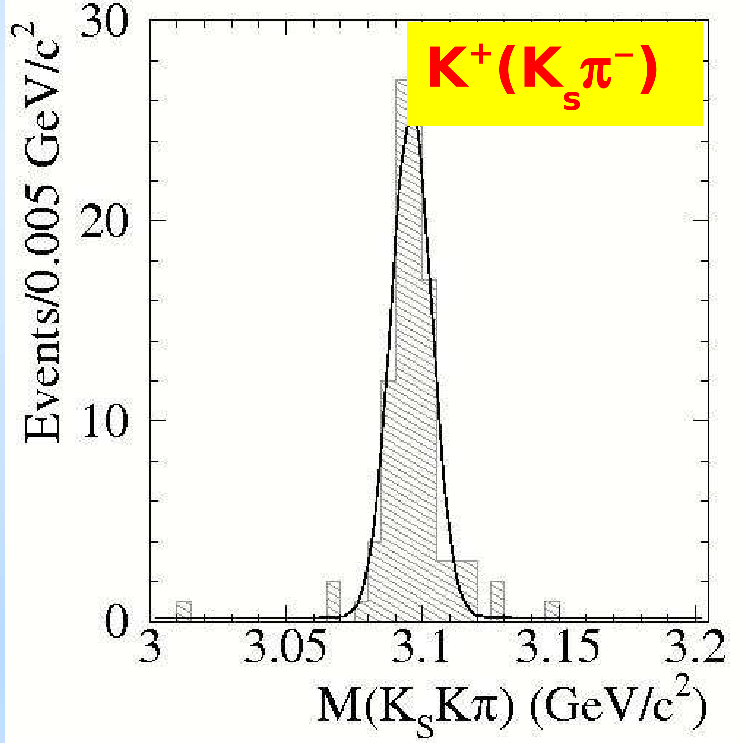
Using Γ_{ee} = (5.55±0.14) keV (PDG 2006):

	Babar	PDG(2006)
$B(J/\psi \to K(892)^{*0} K^0) \times 10^3$	4.2±0.5±0.3	4.8±0.4

$J/\psi \rightarrow K(892)^{*+}K^{-}$ *(preliminary)*



L= 232.1 fb^{-1}

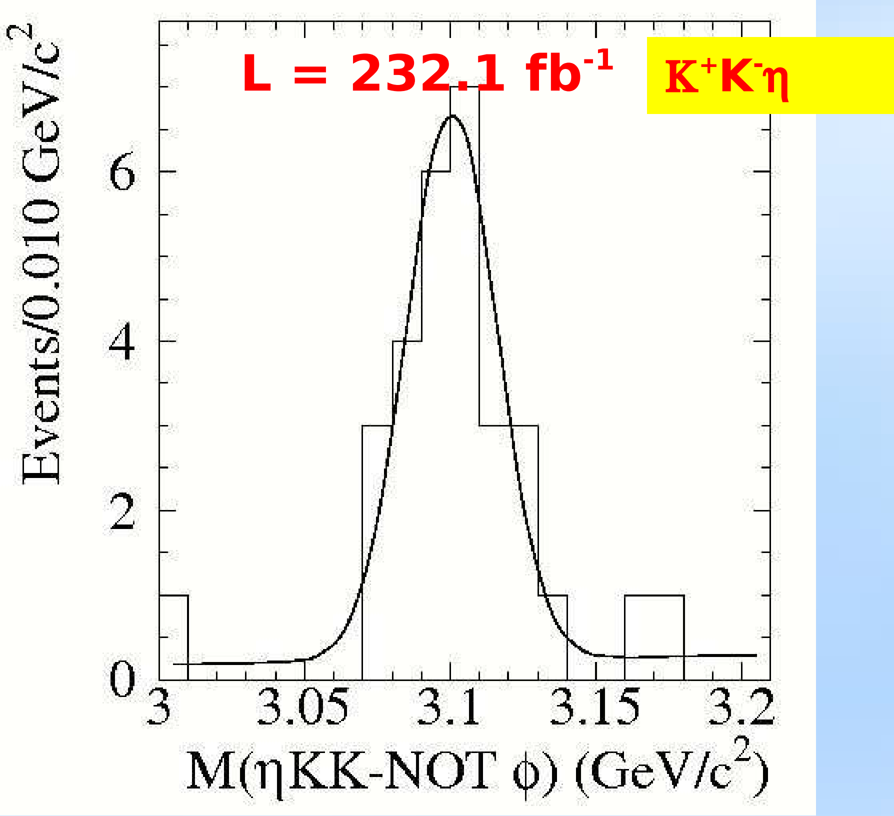


	N	ε	$\Gamma_{ee}B$, eV	$B \times 10^{-3}$
$J/\psi \rightarrow K^+(K^-\pi^0)$	155±12	0.09	10.96±0.85±0.70	1.97±0.16±0.09
$J/\psi \rightarrow K^+(K_s\pi^-)$	89±9	0.09	8.38±0.85±0.50	1.51±0.16±0.09

Using Γ_{ee} = (5.55±0.14) keV (PDG 2006):

	Babar	PDG(2006)
$B(J/\psi \rightarrow K(892)^{*+}K^-) \times 10^3$	5.2±0.3±0.2	5.0±0.4

$J/\psi \to K^+K^-\eta$ *(preliminary)*

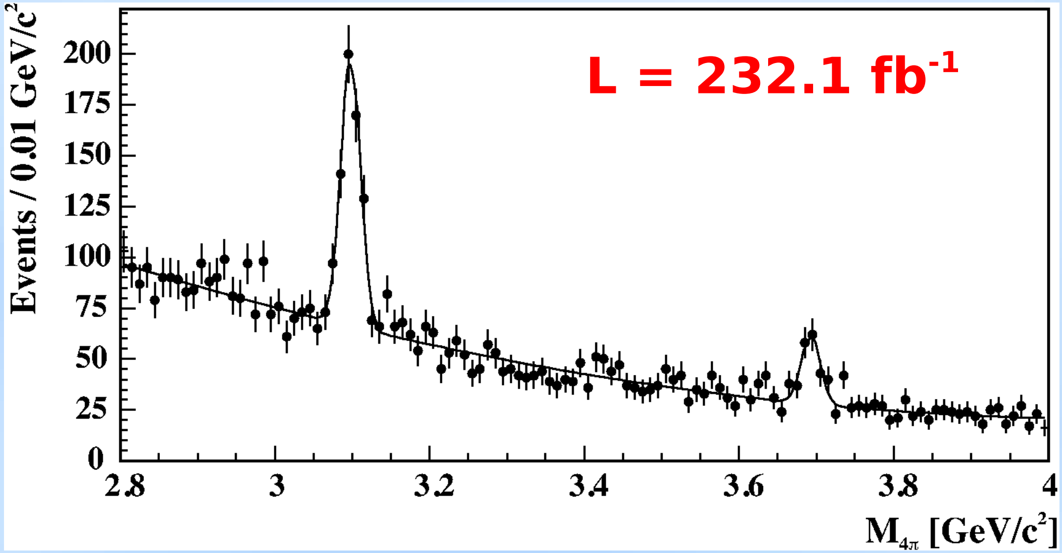


	N	ε	$\Gamma_{ee}B$, eV
$J/\psi \to K^-K^+\eta$	21±3	0.03	4.8±0.7±0.3

Using Γ_{ee} = (5.55±0.14) keV (PDG 2006):

	Babar	PDG(2006)
$B(J/\psi \to K^+K^-\eta)\times10^4$	8.7±1.3±0.7	No entry

J/ψ *and* $\psi(2S) \to \pi^+\pi^-\pi^0\pi^0$ *(preliminary)*



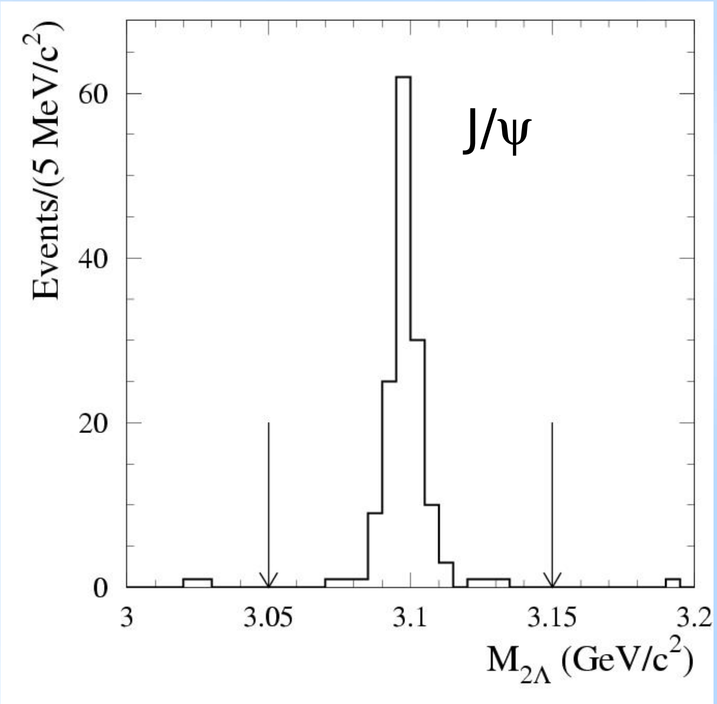
	N	ε	$\Gamma_{ee}B\mathrm{x}10^{-2}$, keV
$J/\psi \to 2\pi 2\pi^0$	438±41	0.087	3.19±0.40

Using Γ_{ee} = (5.55±0.14) keV (PDG 2006):

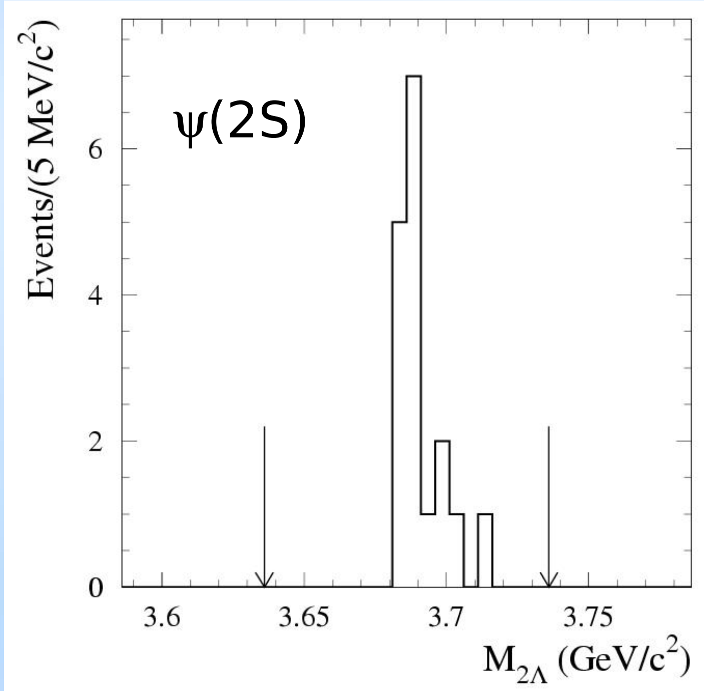
	Babar	PDG(2006)
$B(J/\psi \to 2\pi 2\pi^0)\mathrm{x}10^{-3}$	5.74±0.74	No entry

$\psi(2S)$: All events correspond to $\psi(2S) \to J/\psi\ \pi^0\pi^0 \to \mu^+\mu^-\pi^0\pi^0$

J/ψ and $\psi(2S)$ to $\Lambda\Lambda$ (preliminary)



L = 232.1 fb^{-1}



	N	ε	Γ_{ee}B, eV
J/ψ	142±12	0.062	10.7±0.9±0.7
$\psi(2S)$	17±4	0.059	1.5±0.4±0.1

Using Γ_{ee} = (5.55±0.14) keV (PDG 2006):

	Babar	PDG(2006)	BES
$B(J/\psi \to \Lambda\Lambda) \times 10^{-3}$	1.92±0.21	1.54±0.19	2.03±0.11
$B(\psi(2S) \to \Lambda\Lambda) \times 10^{-4}$	6.0±1.5	2.5±0.7	3.3±0.25

Summary table for newly measured J/ψ decays

better

differ

prelim

Decay	Babar	PDG(2006)
$J/\psi \to 2(\pi^+\pi^-)\pi^0$	$(5.46 \pm 0.09 \pm 0.34) \times 10^{-2}$	$(3.37 \pm 0.26) \times 10^{-2}$
$J/\psi \to \pi^+\pi^-\pi^0$	$(2.36 \pm 0.16 \pm 0.16) \times 10^{-2}$	$(2.02 \pm 0.14) \times 10^{-2}$
$J/\psi \to \omega\pi^+\pi^-$	$(9.7 \pm 0.6 \pm 0.6) \times 10^{-3}$	$(7.2 \pm 1.0) \times 10^{-3}$
$J/\psi \to \eta\pi^+\pi^-$	$(4.0 \pm 1.7 \pm 0.3) \times 10^{-4}$	$(1.93 \pm 0.23) \times 10^{-4}$
$J/\psi \to 2(\pi^+\pi^-)\eta$	$(2.35 \pm 1.7 \pm 0.3) \times 10^{-3}$	$(2.26 \pm 0.28) \times 10^{-3}$
$J/\psi \to \phi\eta$	$(14.0 \pm 6.0 \pm 1.0) \times 10^{-4}$	$(7.4 \pm 0.8) \times 10^{-4}$
$J/\psi \to K^+K^-\pi^+\pi^-\pi^0$	$(1.92 \pm 0.08 \pm 0.15) \times 10^{-2}$	$(1.20 \pm 0.30) \times 10^{-2}$
$J/\psi \to K^+K^-\pi^+\pi^-\eta$	$(4.7 \pm 0.6 \pm 0.3) \times 10^{-3}$	no entry
$J/\psi \to \omega K^+K^-$	$(1.36 \pm 0.5 \pm 0.1) \times 10^{-3}$	$(1.9 \pm 0.4) \times 10^{-3}$
$J/\psi \to K(892)^{*+}K^-$	$(5.2 \pm 0.3 \pm 0.2) \times 10^{-3}$	$(5.0 \pm 0.4) \times 10^{-3}$
$J/\psi \to K^+K^-\eta$	$(8.7 \pm 1.3 \pm 0.7) \times 10^{-4}$	no entry
$J/\psi \to K(892)^{*0}K^0$	$(4.8 \pm 0.5 \pm 0.3) \times 10^{-3}$	$(4.2 \pm 0.4) \times 10^{-3}$
$J/\psi \to \pi^+\pi^-\pi^0\pi^0$	$(5.74 \pm 0.74) \times 10^{-3}$	no entry
$J/\psi \to \Lambda\Lambda$	$(1.92 \pm 0.21) \times 10^{-3}$	$(1.54 \pm 0.19) \times 10^{-3}$

Summary of new results on $\psi(2S)$ decays

Decay	Babar	PDG(2006)
$\psi(2S)\to 2(\pi^+\pi^-)\pi^0$	$(1.2\pm0.09\pm0.07)\text{x}10^{-2}$	$(0.226\pm0.029)\text{x}10^{-2}$
$\psi(2S)\to J/\psi\eta$	$(3.3 \pm 1.0 \pm 0.2)\text{x}10^{-2}$	$(3.09\pm0.08)\text{x}10^{-2}$
$\psi(2S)\to\omega\pi^+\pi^-$	$(1.22\pm0.33\pm0.07)\text{x}10^{-3}$	$(0.66\pm0.17)\text{x}10^{-3}$
$\psi(2S)\to 2(\pi^+\pi^-)\eta$	$(1.2 \pm 0.6 \pm 0.1)\text{x}10^{-3}$	no entry
$\psi(2S)\to K^+K^-\pi^+\pi^-\pi^0$	$(1.8 \pm 0.5 \pm 0.1)\text{x}10^{-3}$	$(1.24\pm0.10)\text{x}10^{-3}$
$\psi(2S)\to K^+K^-\pi^+\pi^-\eta$	$(1.3 \pm 0.7 \pm 0.1)\text{x}10^{-3}$	no entry
$\psi(2S)\to\Lambda\Lambda$	$(6.0 \pm 1.5)\text{x}10^{-4}$	$(2.5 \pm 0.7)\text{x}10^{-4}$

better **differ** **prelim**

Conclusion

- **ISR is a powerful method to measure a lot of J/ψ and ψ(2S) decays modes (even rare) with competative precision, even having less J/ψ and ψ(2S) statistics than BES**

- **Some of the results, based on 232.1 fb^{-1} collected by BaBar and processed to the moment, have been already published or submitted for publication**

- **New and updated results on J/ψ and ψ(2S) decays are coming soon.**