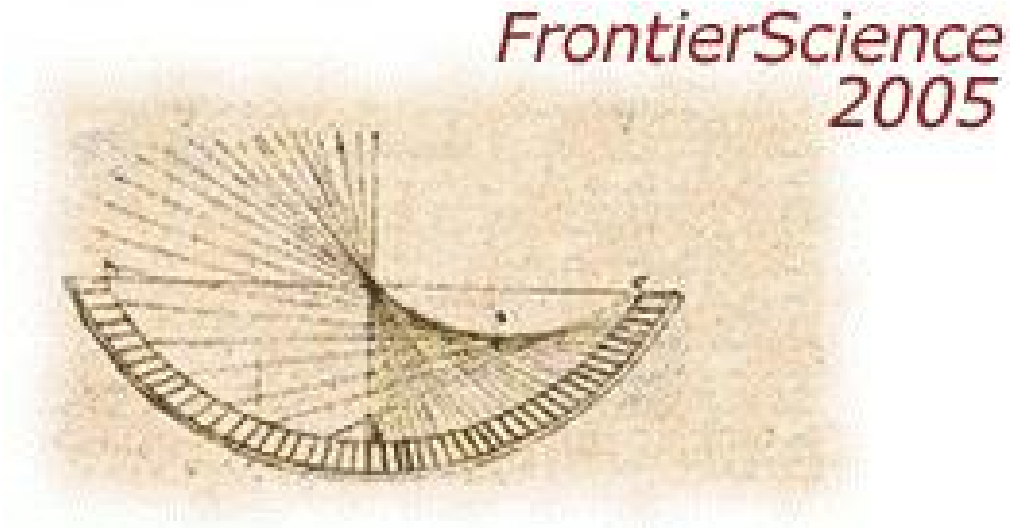
New Hadron Spectroscopy @ BaBar



- X(3872)
- Inclusive charmonia
- $e^+e^- \rightarrow J/\psi\, c\bar{c}$
- Y(4260) New

Gagan Mohanty

University of Warwick

Representing the BaBar collaboration

X(3872): Observation

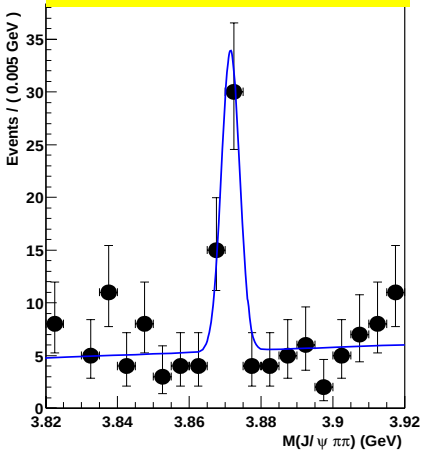
Discovere
$B^{\pm} \rightarrow K^{\pm}X$
X(3872) –
(compatib

confirm ✓

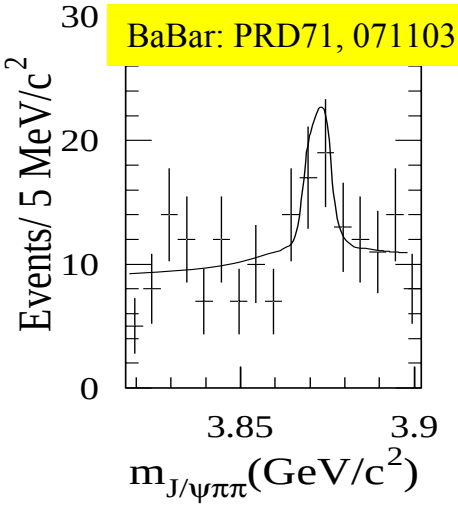
✓

✓ BaBar in 107 fb^{-1}

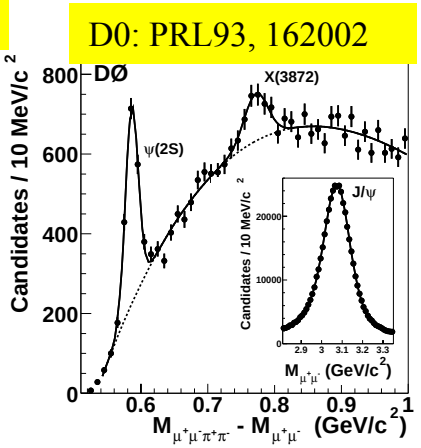
Belle: PRL91, 262001



BaBar: PRD71, 071103



D0: PRL93, 162002

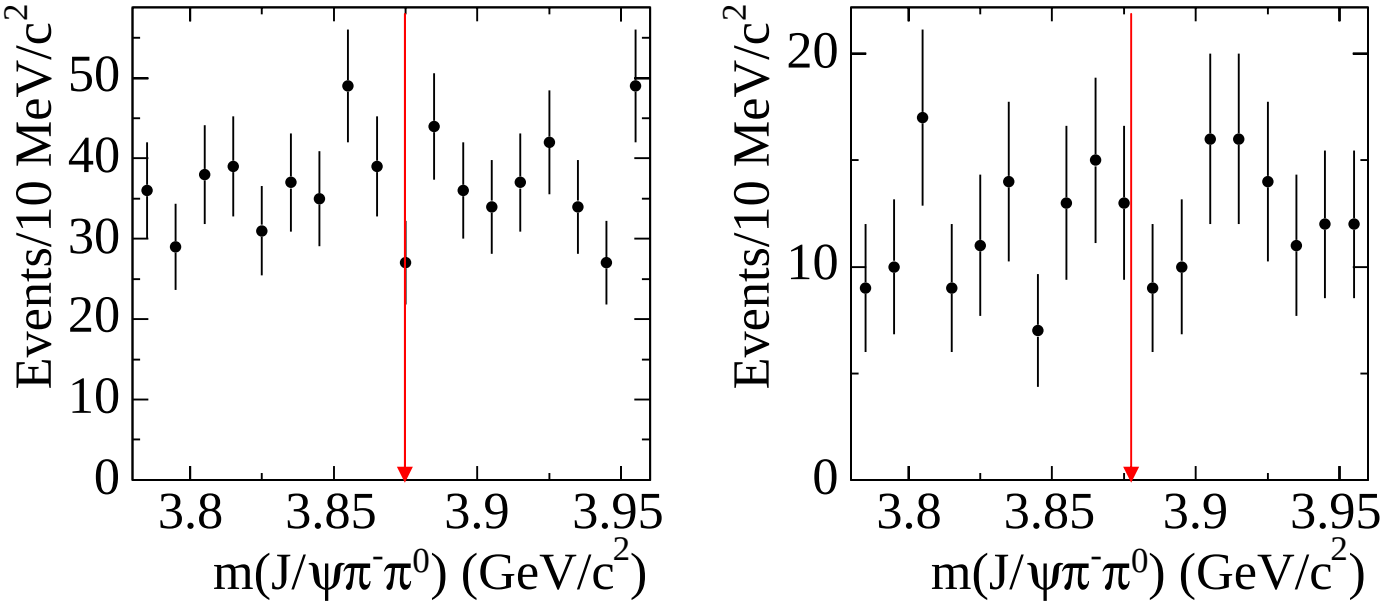


$M_X = 3871.9 \pm 0.5$ MeV/c^2
$\Gamma_X < 2.3$ MeV @ 90% C.L.
Close to $D^0\overline{D}^{*0}$ threshold,
Study other properties

X(3872): charged partner

If X(3872) were an isovector object, then $B(B \to KX^-) \sim 2.B(B \to KX^0)$

$B^0 \to J/\psi\pi^-\pi^0 K^+$ $\quad$ $B^- \to J/\psi\pi^-\pi^0 K^0_S$



BaBar: PRD 71, 031501 on 212 fb^{-1}

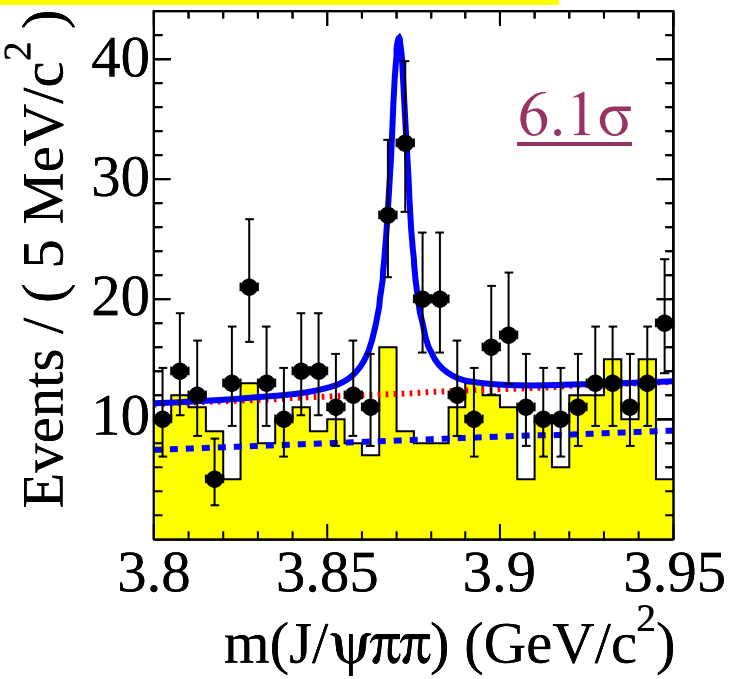
Hypothesis is ruled out @ 10^{-4} confidence level

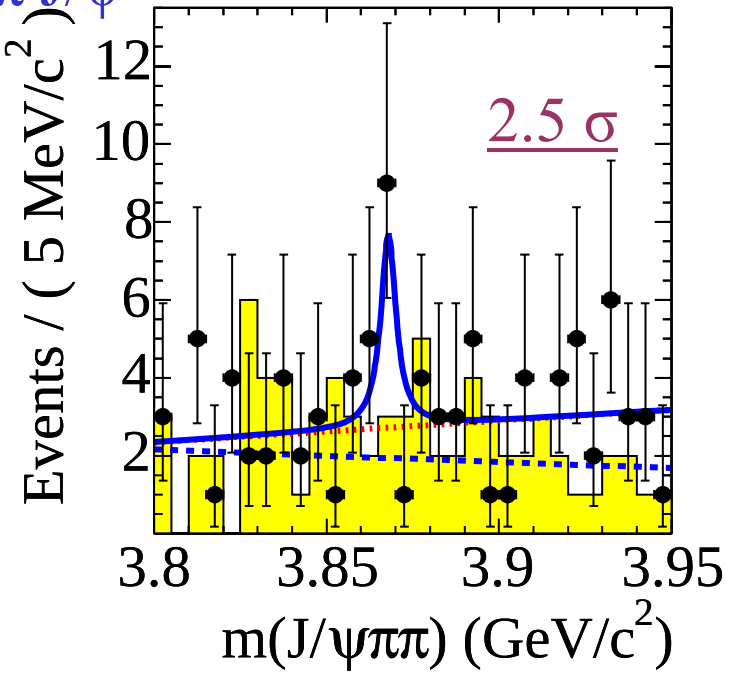
X(3872): Exclusive B decays

$B^{\pm} \rightarrow X(3872) K^{\pm}$ $\quad$ $B^{0} \rightarrow X(3872) K_S$

$\pi^+\pi^- J/\psi$

BaBar update: hep-ex/0507090 on 211 fb^{-1}





$N = 61.2 \pm 15.3$, $M_X = 3871.3 \pm 0.6 \pm 0.1$ MeV/c^2

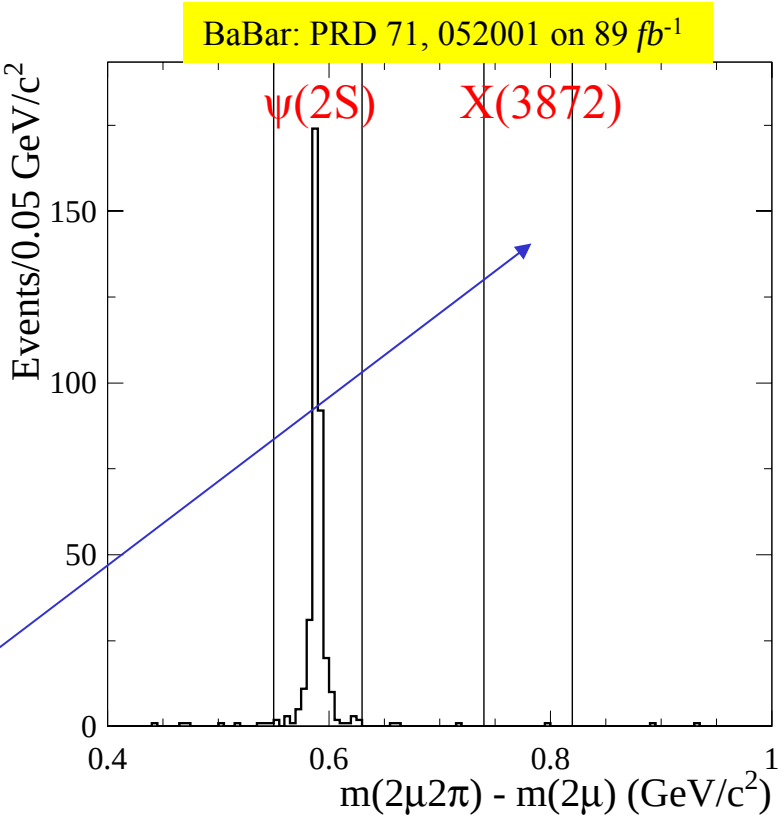
$N = 8.3 \pm 4.5$, $M_X = 3868.6 \pm 1.2 \pm 0.2$ MeV/c^2

$R = B(B^0 \rightarrow X(3872) K_S) / B(B^{\pm} \rightarrow X(3872) K^{\pm}) = 0.5 \pm 0.3 \pm 0.05$

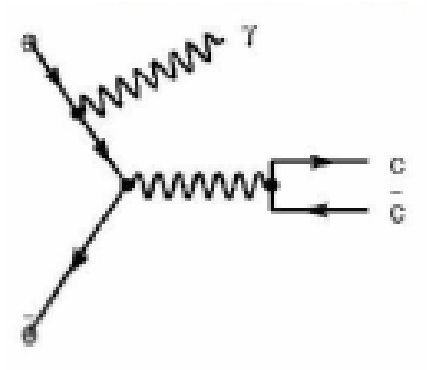
$\Delta M = 2.7 \pm 1.3 \pm 0.2$ MeV/c^2

X(3872): ISR production

Search for $e^+e^- \rightarrow X(3872)\gamma_{ISR}$
$X(3872) \rightarrow J/\psi\,\pi^+\pi^-$, $J/\psi \rightarrow \mu^+\mu^-$
(γ_{ISR} is tagged in this sample)



Only possible, if $J^{PC} = 1^{--}$



No signal observed

$$\mathcal{B}(X(3872) \rightarrow J/\psi\pi\pi) \times \Gamma^X_{ee} < 6.2\,\text{eV}@\,90\%\ \text{C.L.}$$

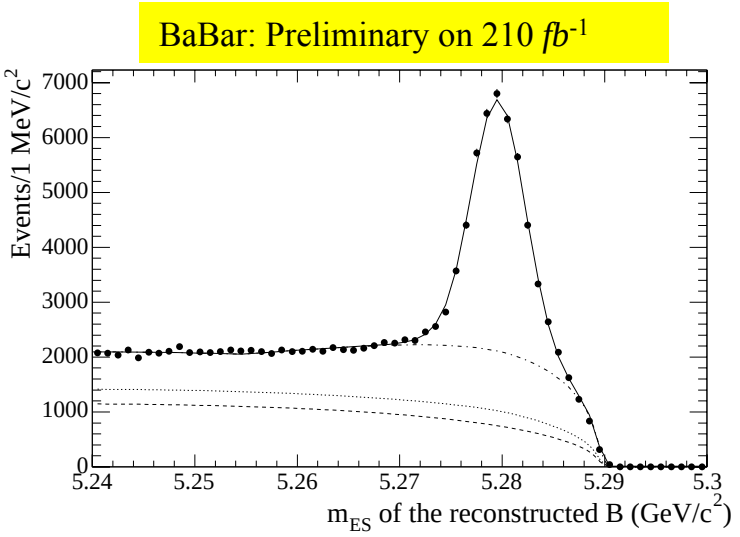
WARWICK

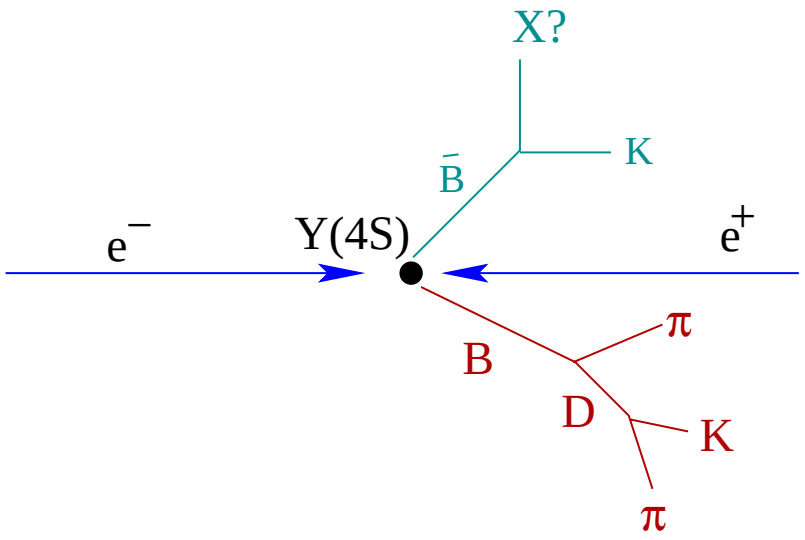
X(3872): Interpretation

- ρJ/ψ mode stands against the charmonium assignment (an isospin violating decay)
- Standard quarkonium theory needs to be improved, if we want it to fit in correctly
- Mass being right at $D^0\overline{D}^{*0}$ threshold may be possibly due to
  - D^0D^{*0} molecule formation – $R \sim 10^{-1}$ Braaten *et. al.*: PRD 71, 074005
  - Diquark-antidiquark (X_u=cu-$\overline{cu}$ or X_d=cd-$\overline{cd}$) state – $\Delta M \sim 7\pm2$ MeV/c^2 Maiani *et. al.*: PRD 71, 014028
- Need more data to convincingly discriminate the models

Inclusive charmonia: technique

- Fully reconstruct one of the B's (robust NN to enhance S/B ratio)
- Find a recoiling K & calculate its momentum in the other B rest frame ⇒ calculate m_X



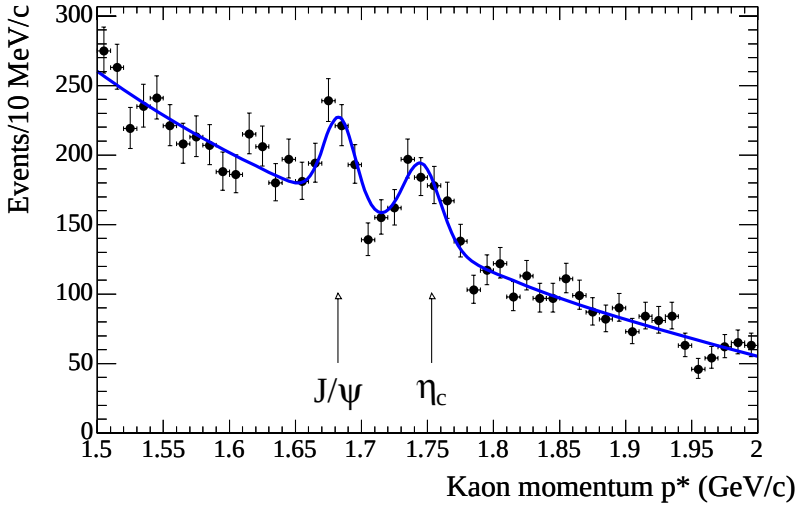


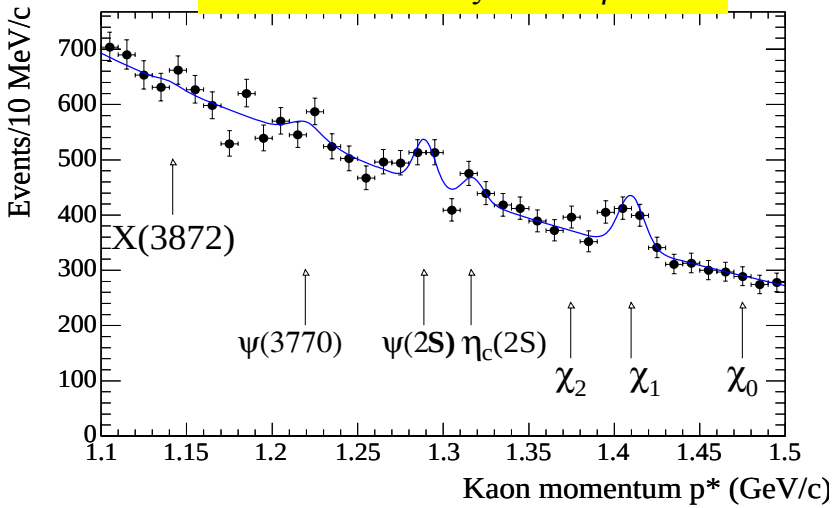
$$m_X = \sqrt{m_B^2 + m_K^2 - 2E_K^\star \cdot m_B}$$

Can measure the absolute B of X

Inclusive charmonia: Results

BaBar: Preliminary on 210 fb^{-1}





- Clear J/ψ, η_c (~7σ) and χ_{c1} (6σ) signal peaks
- Indication for ψ(2S) (3σ), ψ(3770) (1.4σ) and η_c(2S) (~2σ)
- No signature of X(3872), 90% UL on $B(B^{\pm}\rightarrow K^{\pm}X) < 3.2\times10^{-4}$
- Using world average value of $B(B^{\pm}\rightarrow K^{\pm}X(3872).(X\rightarrow J/\psi\,\pi\pi))$, we derive $B(X(3872)\rightarrow J/\psi\,\pi^{+}\pi^{-}) > 4.2\%$ at 90% CL

Double Charmonium Production

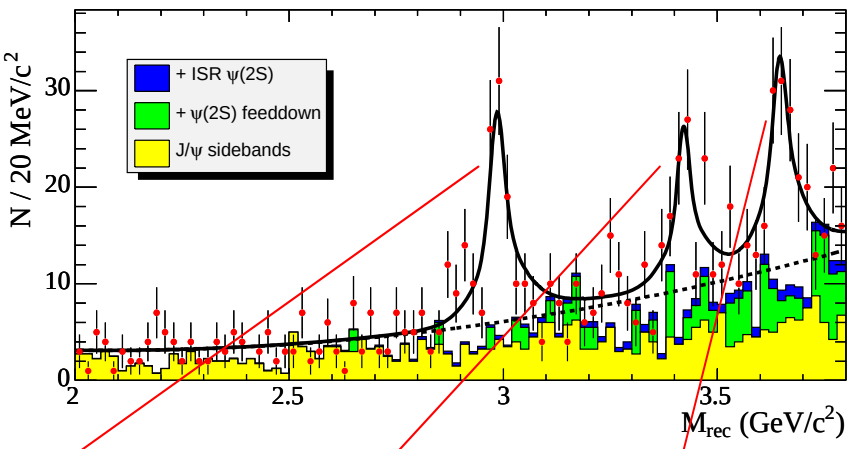
Aim:

Study $e^+e^- \rightarrow J/\psi\, c\bar{c}$

Technique:

- Reconstruct a J/ψ cand.
- Compute its recoil mass

BaBar: PRD 72, 031101 on 124 fb^{-1}



$J/\psi\, c\bar{c}(\rightarrow >)$ 2 tracks	η_c	χ_{c0}	$\eta_c(2S)$
N(signals)	126 ± 20	81 ± 20	120 ± 27
Mass (MeV/c^2)	$2984.8 \pm 4.0^{+4.5}_{-5.0}$	$3420.5 \pm 4.8^{+11.5}_{-9.5}$	$3645.0 \pm 5.5^{+4.9}_{-7.8}$
Efficiency (%)	29.5 ± 0.7	32.2 ± 0.7	30.2 ± 0.8
Born cross section (fb)	$17.6 \pm 2.8^{+1.5}_{-2.1}$	$10.3 \pm 2.5^{+1.4}_{-1.8}$	$16.4 \pm 3.7^{+2.4}_{-3.0}$

Double Charmonium Production (Theory *vs.* Experiment)

$\sigma(J/\psi\, c\bar{c})[fb]$	η_c	χ_{c0}	$\eta_c(2S)$
BaBar	$17.6 \pm 2.8^{+1.5}_{-2.1}$	$10.3 \pm 2.5^{+1.4}_{-1.8}$	$16.4 \pm 3.7^{+2.4}_{-3.0}$
Belle	$25.6 \pm 2.8 \pm 3.4$	$6.4 \pm 1.7 \pm 1.0$	$16.5 \pm 3.0 \pm 2.4$
NRQCD1	2.31 ± 1.09	2.28 ± 1.03	0.96 ± 0.45
NRQCD2	5.5	6.9	3.7

PRL 88, 052001

PRD 67, 054007

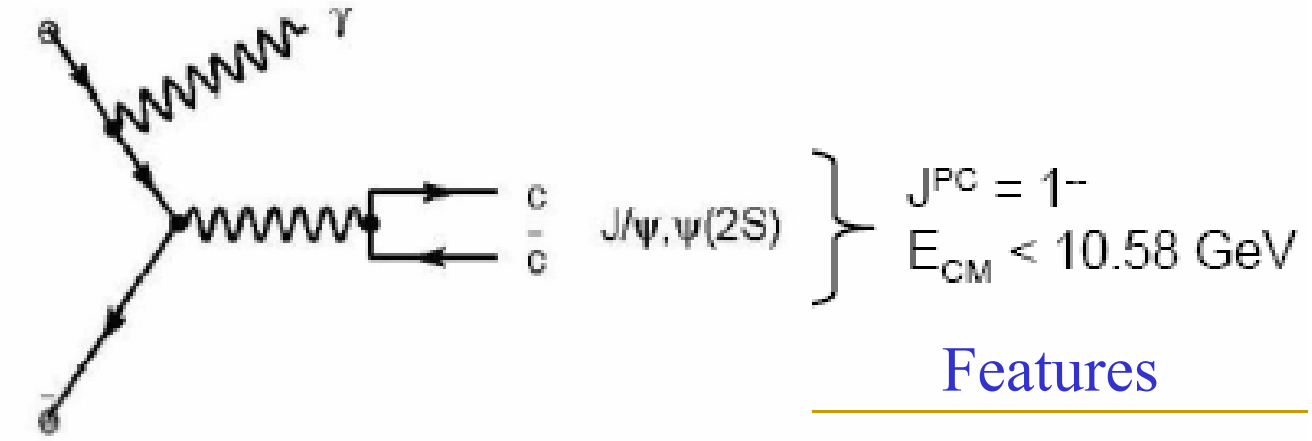
hep-ph/0408141

} don't include the B(→ > 2 tracks) factor

- Measured cross sections significantly differ from the theoretical predictions
- Recent works incorporating charm quark dynamics seem to resolve the conflict hep-ph/0412335 hep-ph/0506076

Exploring ISR production

[Recap from page# 5]



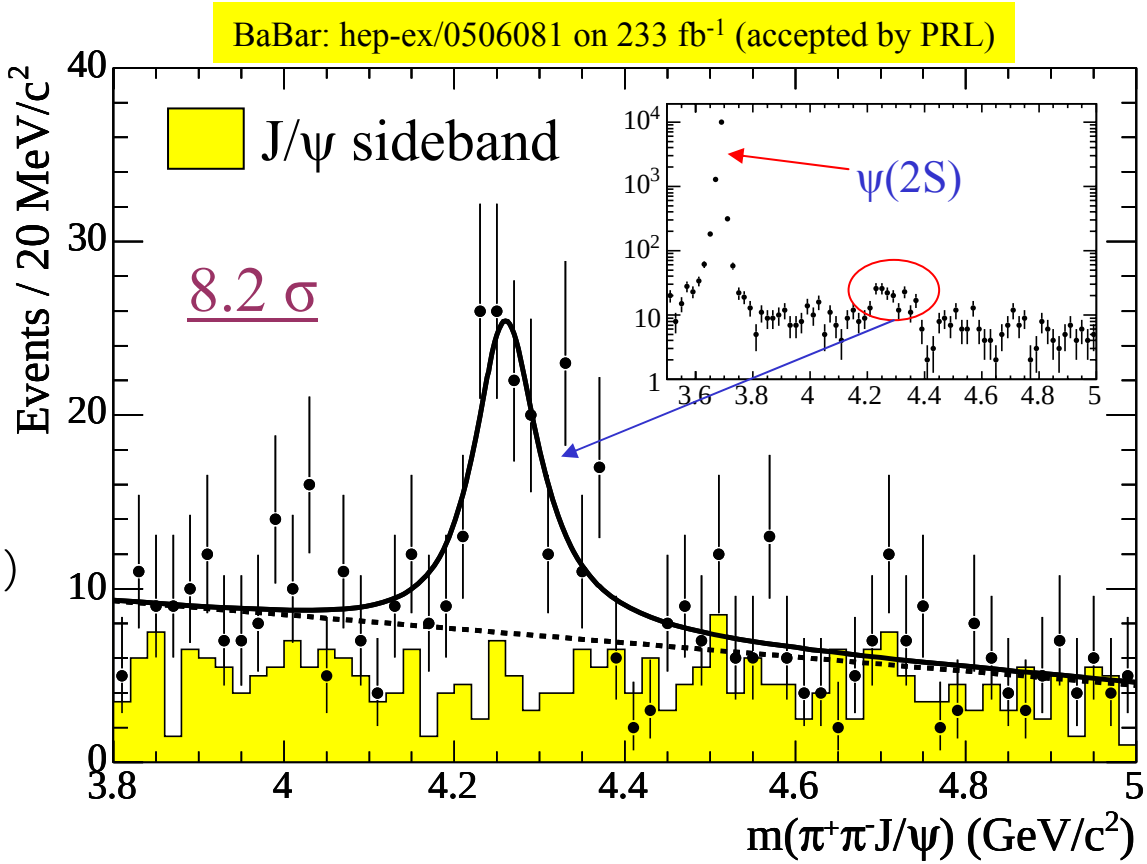
- Photon from initial $e^{+/-}$ states (mostly lost in beampipe)
- Small recoil mass against the final state & low missing p_T
- Well known benchmark channels *e.g.* J/ψ, ψ(2S)…

Y(4260): ISR production

- No X(3872)
- Observed Y(4260)

From single-resonance fit:

- $N = 125 \pm 23$
- $M = 4259 \pm 8^{+2}_{-6}\ \mathrm{MeV}/c^2$
- $\Gamma = 88 \pm 23^{+6}_{-4}\ \mathrm{MeV}$
- $\Gamma(Y \to e^+e^-) \cdot \mathcal{B}(Y \to J/\psi\pi^+\pi^-) = 5.5 \pm 1.0^{+0.8}_{-0.7}$ eV
- $J^{PC} = 1^{--}$ (ISR production)

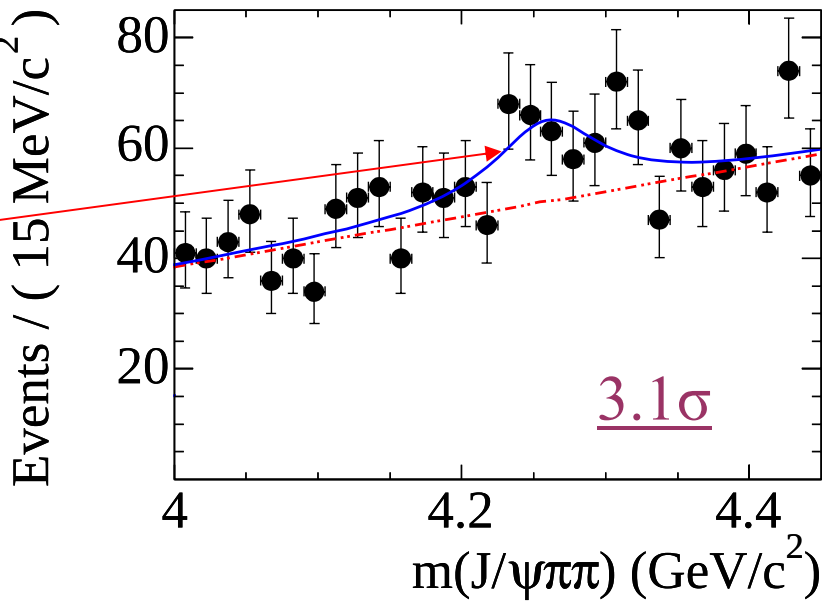


- However, current dataset does not allow a statistically significant discrimination between single- and multi-resonance hypothesis

Y(4260): Exclusive B decays

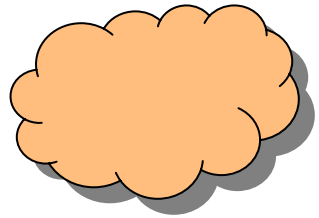
BaBar: hep-ex/0507090 on 211 fb^{-1} (page# 4)

- Observed an excess of $J/\psi\pi^+\pi^-$ events with mass just above 4.2 GeV/c^2
- Fixing M and Γ of this peak to the values from ISR analysis:
  - ✓ N = 128±42
  - ✓ $B(B^- \to Y(4260)K^-).B(Y \to J/\psi\,\pi^+\pi^-) = (2.0\pm0.7\pm0.2)\times10^{-5}$



Summary

❑ Hadron spectroscopy is one of most exciting & pursued areas within BaBar (B factories in general)



❖ I've selected only a few topics here:

- ✓ X(3872) is not fully understood (beg for more fb^{-1})
- ✓ Novel technique employed in inclusive charmonia
- ✓ Theory is catching up with experiment in J/ψ $c\bar{c}$
- ✓ Y(4260) is just observed & hunt-work continues

➢ These recent discoveries have created a renewed interest in the charmonium sector

Back-up Slides

Inclusive charmonia: Table

Particle	Yield	$\mathcal{B}(10^{-4})$	Significance (σ)
η_c	273 ± 43	$8.4 \pm 1.3 \pm 0.8$	7.3
J/ψ	259 ± 41	$8.1 \pm 1.3 \pm 0.7$	6.9
χ_{c0}	9 ± 21	< 1.8	–
$\chi_{c1} + h_c$	227 ± 40	$8.0 \pm 1.4 \pm 0.7$	6.0
χ_{c2}	0 ± 36	< 2.0	–
$\eta_c(2S)$	98 ± 52	$3.4 \pm 1.8 \pm 0.3$	1.8
$\psi(2S)$	139 ± 44	$4.9 \pm 1.6 \pm 0.4$	3.2
$\psi(3770)$	99 ± 69	$3.5 \pm 2.5 \pm 0.3$	1.4
X(3872)	15 ± 39	< 3.2	–

Y(4260): Interpretation

- Charmonium state?
- Molecule of [Ds^{*+} Ds^{*-}] – Y(4260) is just above threshold, 4225 MeV/c^2 and no evidence for Y(4260) → K^+K^- J/ψ
- Molecule of [D^0 $\overline{D}^{*0}(2420)$] (threshold = 4287 MeV/c^2)
- Hybrid ($c\bar{c}g$)?
- Others?

Maiani *et. al.*: PRD 72, 031502

Llanes-Estrada.: hep-ph/0507035

Zhu: hep-ph/0507025