Charmonium Production at BaBar

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On behalf of the BABAR™ Collaboration

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Overview

- BaBar detector & PEP-II performance
- η_c measurements in 2 photon events
  - *Measurement of the η_c width*
  - *Observation of $\eta_c(2S)$*
- J/ψ production using ISR events
  - *Measurement of the J/ψ total width*

Preliminary Result!

- Understanding J/ψ production in B decays as a test of non-relativistic QCD:
  - Branching fractions: $B^+ \to J/\psi p \bar{\Lambda}$ *and* $B^0 \to J/\psi \bar{p} p$
- Summary of new exclusive B decays to charmonium

All of the above analyses represent new or newly updated results

BaBar Detector

Detector of Internally Reflected Cherenkov light

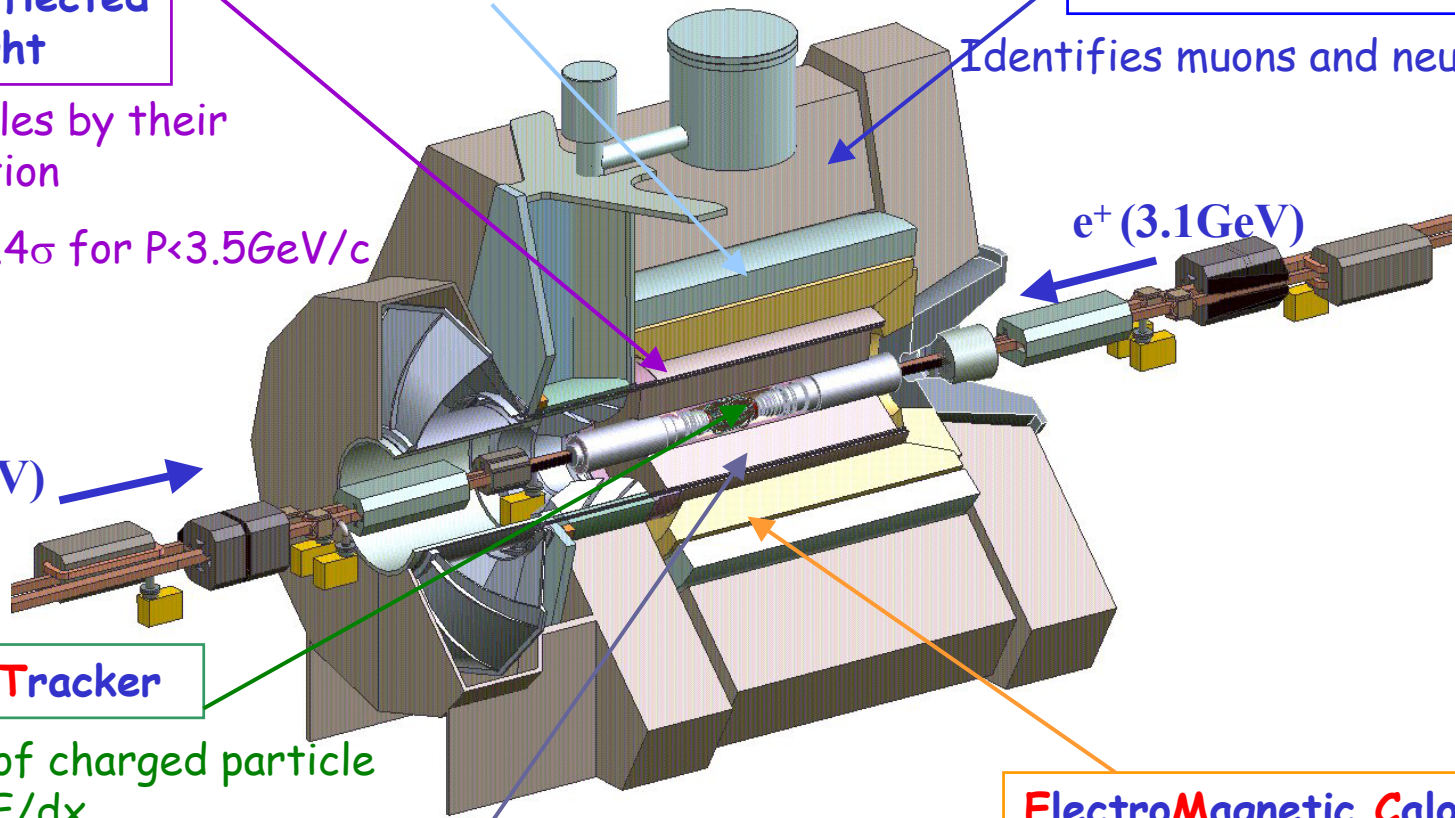
Identifies particles by their Cherenkov radiation

K-π separation>3.4σ for P<3.5GeV/c

1.5T solenoid

Instrumented Flux Return

Identifies muons and neutral hadrons



Silicon Vertex Tracker

Measures origin of charged particle
Trajectories + dE/dx
97% efficiency

Drift CHamber

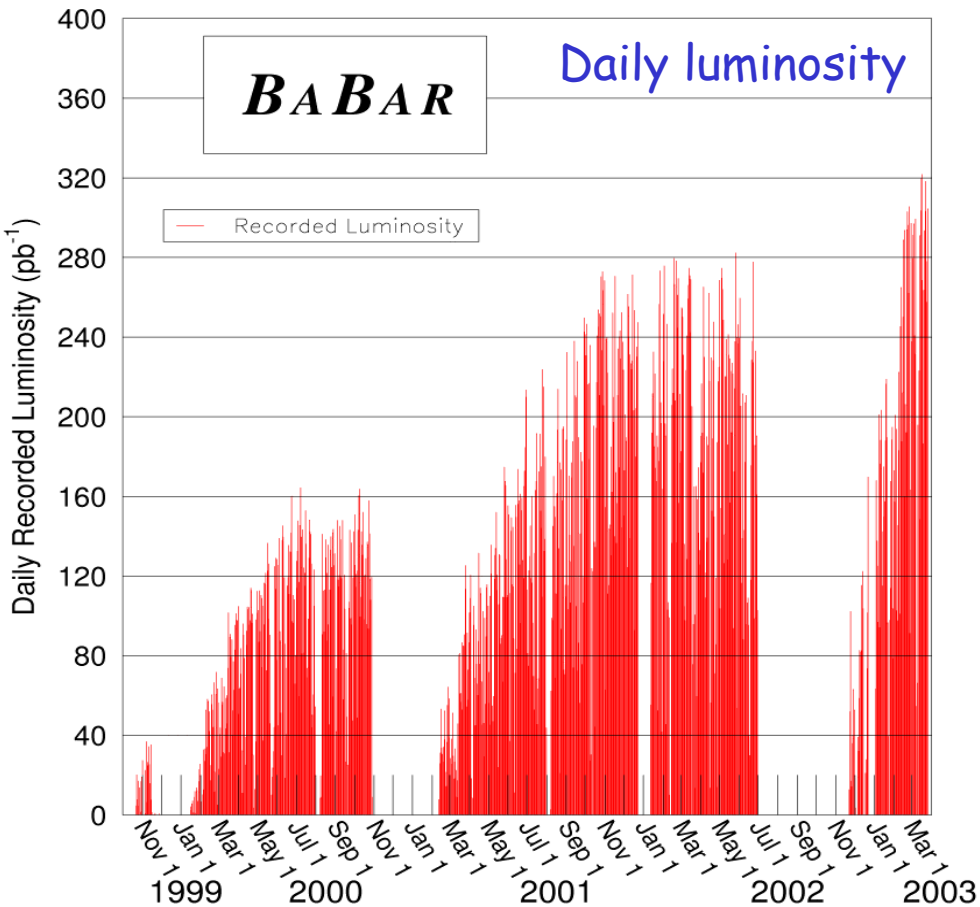
Measures momentum of charged particles + dE/dx
$\sigma(p_T)/P_T=0.13\%P_T\oplus0.45\%$

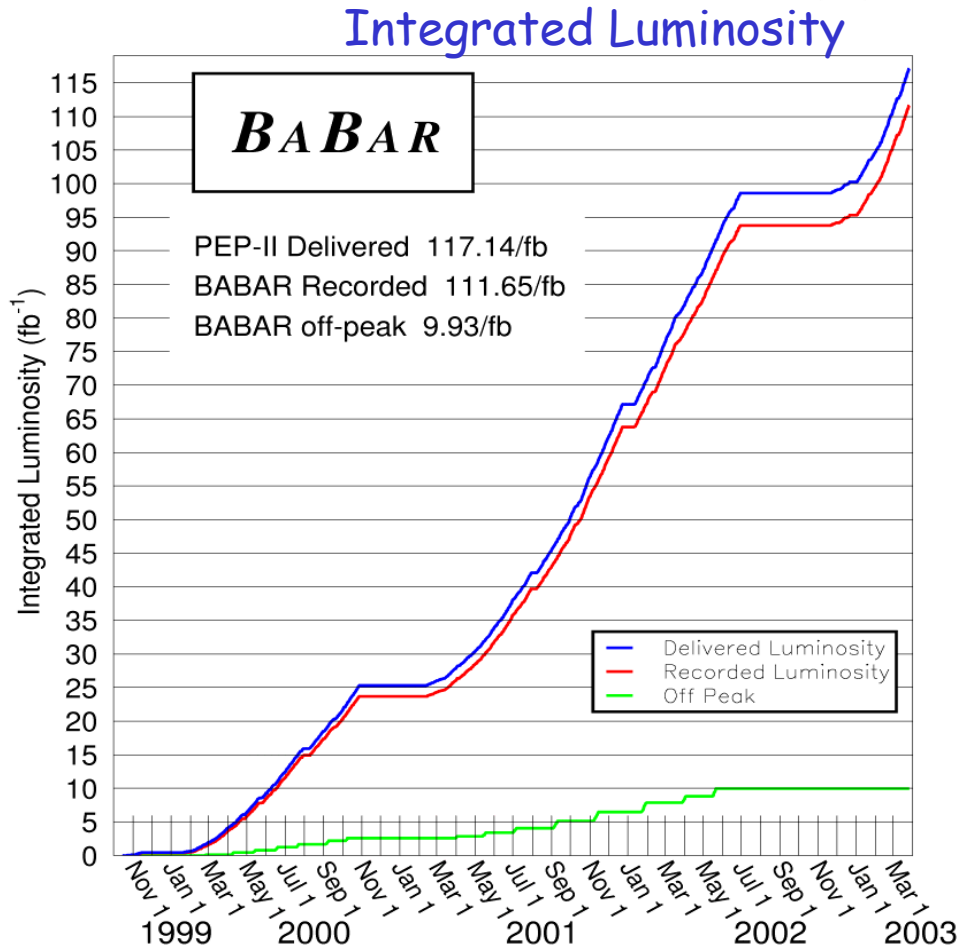
ElectroMagnetic Calorimeter

Measures energy of electrons and photons
$\sigma(E)/E=1.33\%E^{-1/4}\oplus2.1\%$

PEP-II Performance

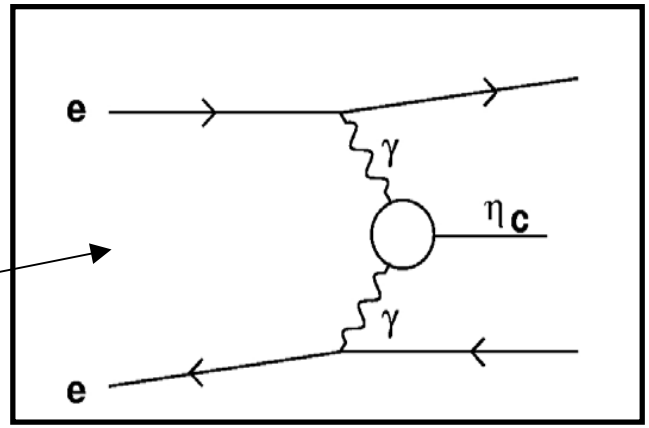
PEP-II has provided 100fb^{-1} to date exceeding design specifications





η_c production in 2γ events

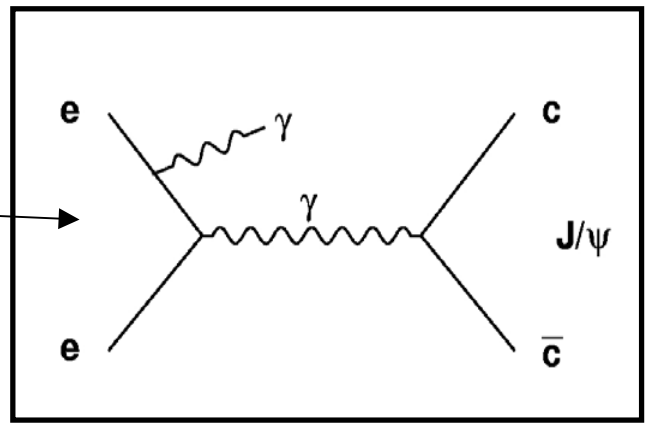
- η_c lowest lying charmonium state
- η_c width poorly determined
- New Babar result using 1715 ± 70 signal events



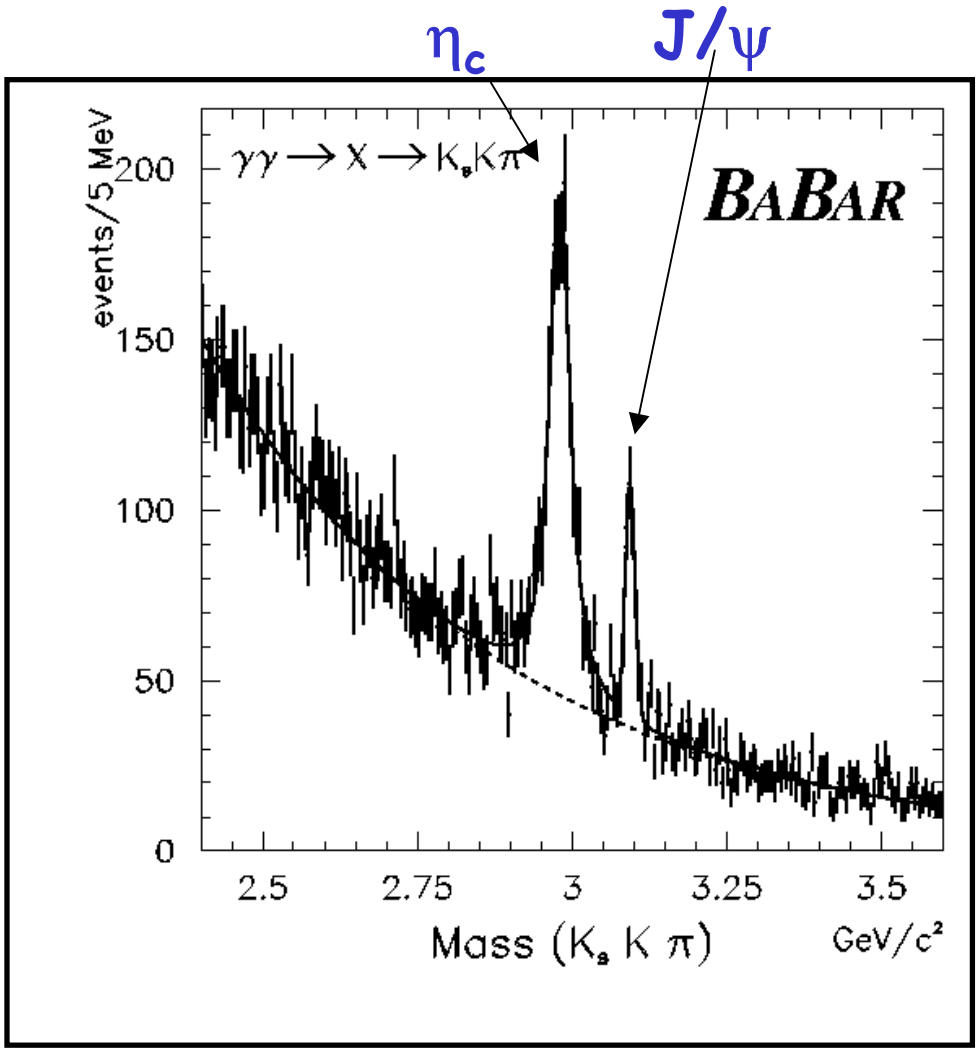
$$e^+e^- \rightarrow e^+e^-\eta_C$$

$$\eta_C \rightarrow K_S^0 K^+ \pi^-$$

- Use J/ψ ISR events as cross check of the detector resolution model
- Don't detect the electrons



η_c production in 2γ events - Analysis strategy



Spectrum fitted with:

J/ψ: Gaussian

η_c: Gaussian $\otimes$ Breit-Wigner

Bkg.:Exponential

Free parameters:

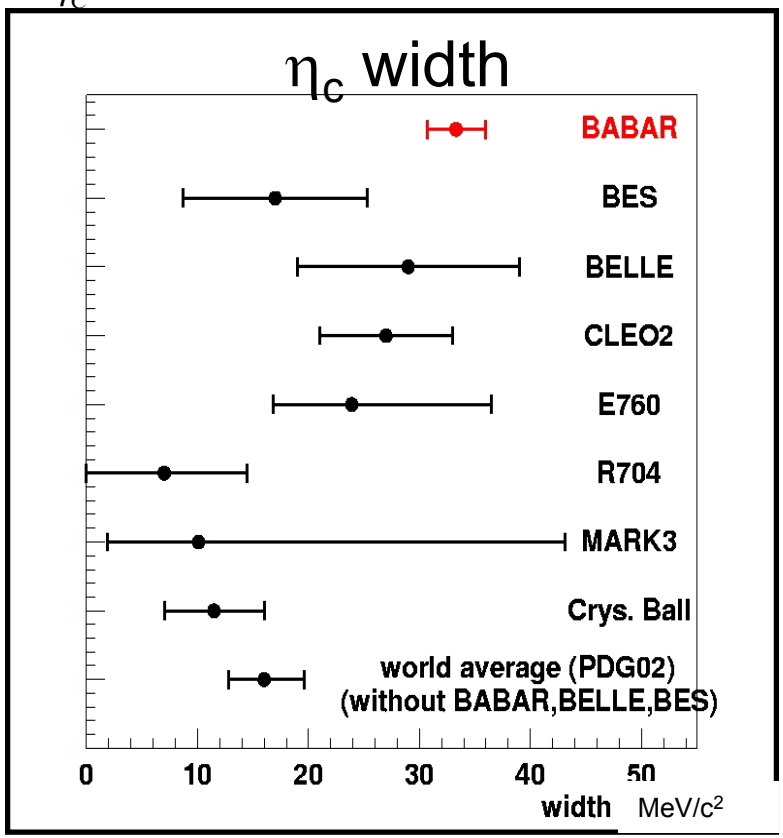
$$M_{J/\psi},\ M_{J/\psi} - M_{\eta_c},\ \sigma_{J/\psi},\ \Gamma^{tot}_{\eta_c},\ (\text{bkgr.})$$

$$M_{\eta_c} = M^{PDG}_{J/\psi} - (M_{J/\psi} - M_{\eta_c})_{fit}$$

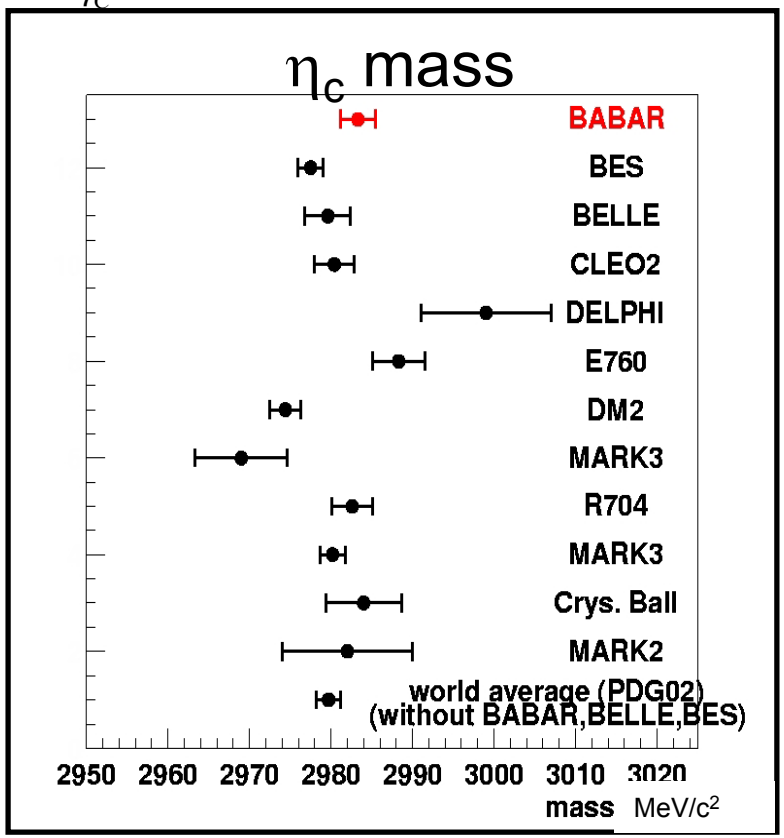
$$\sigma_{\eta_c} = \sigma_{J/\psi} - 0.8\,\text{MeV} \quad \text{from MC}$$

η_c production in 2γ events - Results

$\Gamma_{\eta_C}^{TOT} = 33.3 \pm 2.5 \pm 0.8 \mathrm{MeV/c^2}$



$M_{\eta_C} = 2983.3 \pm 1.2 \pm 1.8 \mathrm{MeV/c^2}$

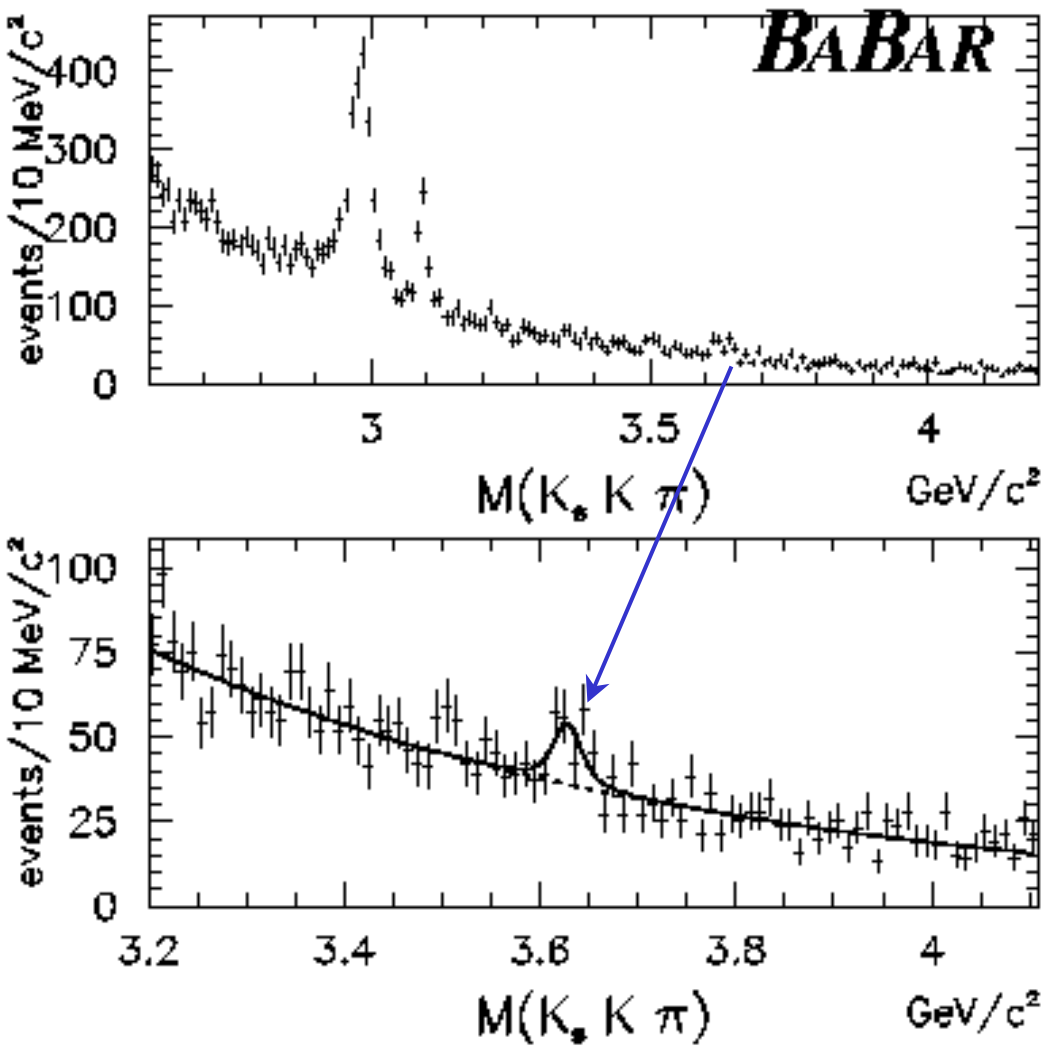


Dominant Syst errors:

for $M_{\eta c}$ uncertainty on mass scale $M_{J/\psi}^{FIT} - M_{J/\psi}^{PDG} = -1.8 \mathrm{MeV/c^2}$

for $\Gamma_{\eta c}$ uncertainty in background parameterization (0.7MeV/c²)

η_c production in 2γ events - $\eta_c(2S)$



BaBar preliminary results:

$$N(\eta_c(2S)) = 86 \pm 23$$

$$\Gamma^{tot}_{\eta_C(2S)} = 20 \pm 10 \pm 4 \ \text{MeV/c}^2$$

$$M_{\eta_C(2S)} = 3632.2 \pm 5.0 \pm 1.8 \ \text{MeV/c}^2$$

Theory:

$$3583 < M_{\eta_c(2S)} < 3640 \ \text{MeV/c}^2$$

Ebert et al., Phys. Rev. D62, 034014 (2000)
Eichten, Quigg, Phys. Rev. D49,5845 (1994)
Lahde, Riska, hep-ph/0112131

Belle: (in excl. B decays):

$$M_{\eta_c(2S)} = 3654 \pm 6 \pm 8 \ \text{MeV/c}^2$$

$$\Gamma^{tot}_{\eta_c(2S)} < 55 \ \text{MeV/c}^2$$

Crystal Ball: (in ψ(2s) decays)

$$M_{\eta_c(2S)} = 3594 \pm 5 \ \text{MeV/c}^2$$

$$\Gamma^{tot}_{\eta_c(2S)} < 8.0 \ \text{MeV/c}^2$$

J/ψ production in ISR events

- Study ISR $e^+ e^- \to \gamma \mu^+\mu^-$ events in the $\mu^+\mu^-$ mass range around the J/ψ mass (2.8 – 3.2GeV/c^2)
- Fit to the J/ψ mass spectrum to measure J/ψ parameters
- ~10% of ISR events have a photon which falls in the detector acceptance
- High statistics due to large luminosity so fully reconstruct both muons **and** photon
- Event selection
  - $E\gamma^* > 3GeV$
  - Muon ID $E_\mu(EMC) < 0.4GeV$, $p_\mu > 0.5GeV/c$
  - Kinematic cuts $|E_{total} - E_{beams}| < 1.5GeV$, $\Delta\phi < 0.07rad$
- 1C Kinematic fit – mass of the recoil against the di-muon system constrained to be 0 (photon hypothesis)

J/ψ production in ISR events – Method

In ISR $$\frac{d\sigma_{J/\psi}(s,x)}{dx} = W(s,x).\sigma_0(s(1-x))$$

Probability that ISR photon has energy fraction *x*

Integrating and adding in J/ψ lineshape:

$$\sigma_{J/\psi}(s) = \frac{12\pi\Gamma_{ee}\Gamma_{\mu\mu}}{m.s.\Gamma_{tot}}.W(s,x_0);\ x_0 = (1-\frac{m^2}{s})$$

Measuring total cross section gives:

$$\frac{\Gamma_{ee}\Gamma_{\mu\mu}}{\Gamma_{tot}} = \Gamma_{ee}B_{\mu\mu}$$

Substituting in PDG values for $B_{\mu\mu}$ and B_{ee} allows measurement of Γ_{ee} and Γ_{tot}

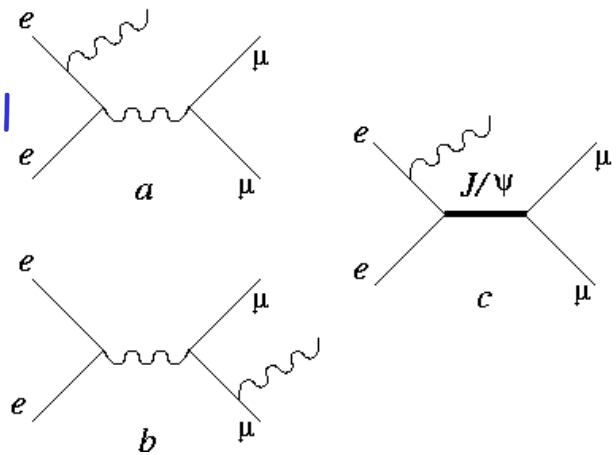
$$B_{ee} = \frac{\Gamma_{ee}}{\Gamma_{tot}}$$

J/ψ production in ISR events - Method

Fit the di-muon mass spectrum with:

2nd order polynomial (from simulation)

$$f(m) = c[R \cdot H(m; M_{J/\psi}, \sigma_G) + NR_{PDF}(m)]$$



J/ψ lineshape (from simulation) convoluted with Gaussian (detector resolution)

main fit parameter

Obtain total cross section from R

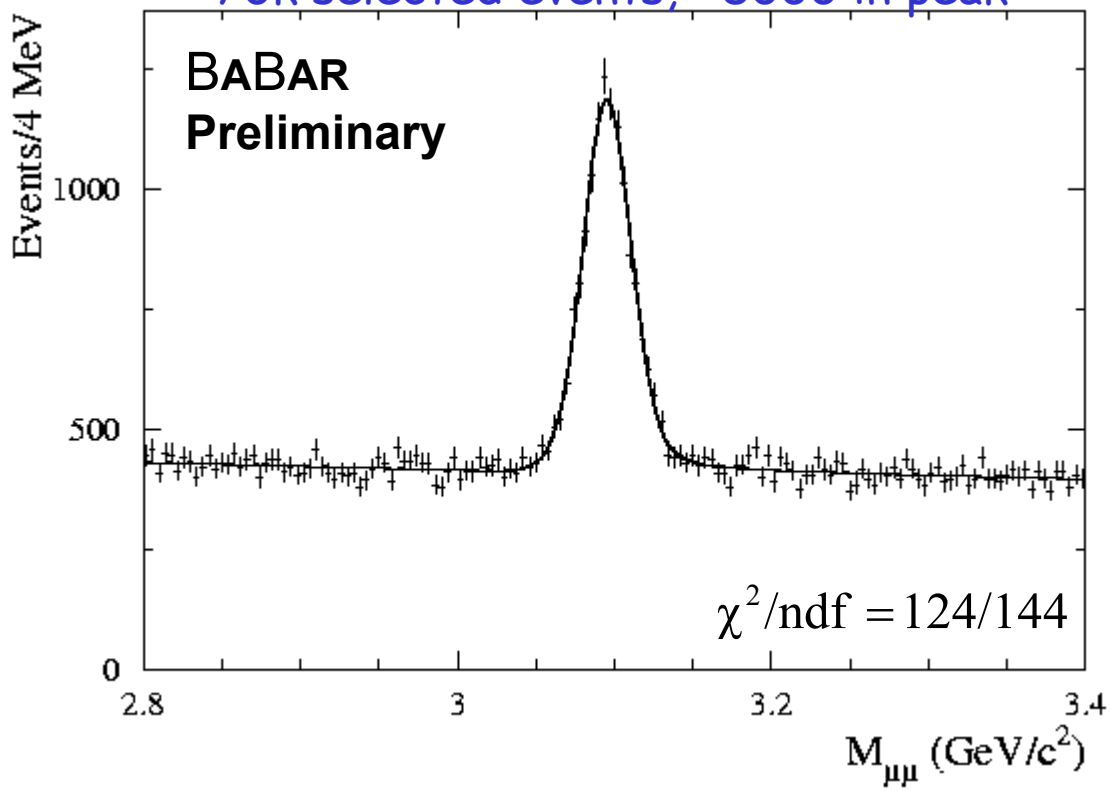
$$R = \frac{\sigma^{Born}_{J/\psi}}{\sigma^{Born}_{ISR}} \cdot \frac{1}{K} \qquad K = \frac{d\sigma^{vis}_{Total}/dM}{d\sigma^{vis}_{ISR}/dM}$$

K corrects for FSR Processes = 1.11±0.01 (from simulation)

Efficiency systematics cancel in this ratio

J/ψ production in ISR events - Results

~70k selected events, ~8000 in peak



Background:
< 0.1% in peak
< 0.3% in NR region

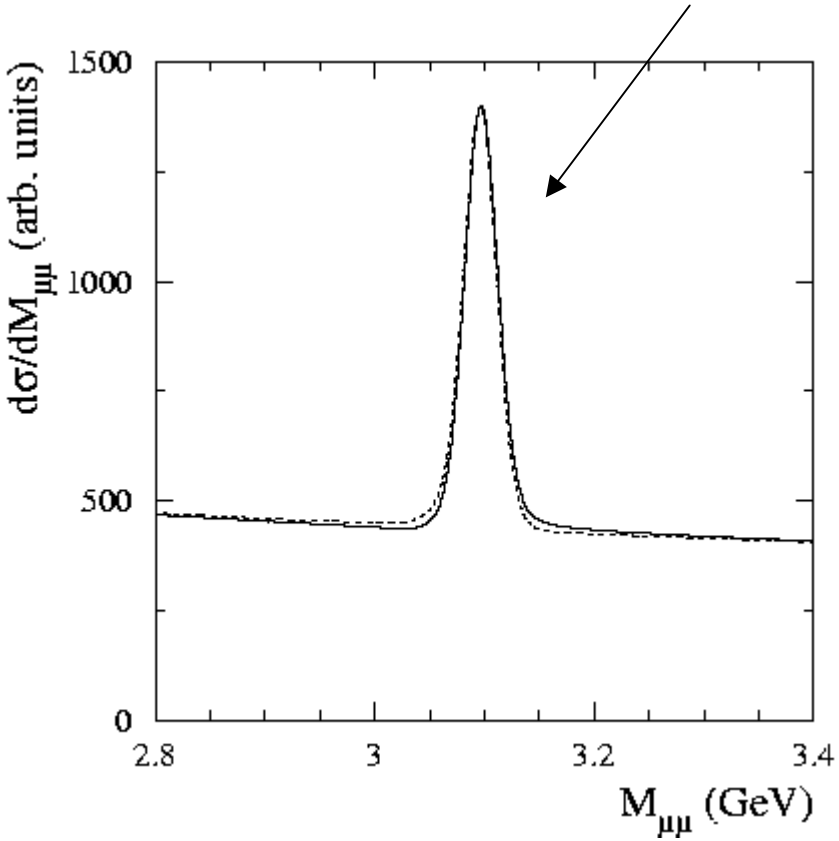
Preliminary results: $\Gamma^{Total}_{J/\psi} = 94.7 \pm 4.4 \mathrm{keV/c^2}$ $\Gamma^{ee}_{J/\psi} = 5.61 \pm 0.20 \mathrm{keV/c^2}$

PDG: $\Gamma^{Total}_{J/\psi} = 87 \pm 5 \mathrm{keV/c^2}$ $\Gamma^{ee}_{J/\psi} = 5.26 \pm 0.37 \mathrm{keV/c^2}$

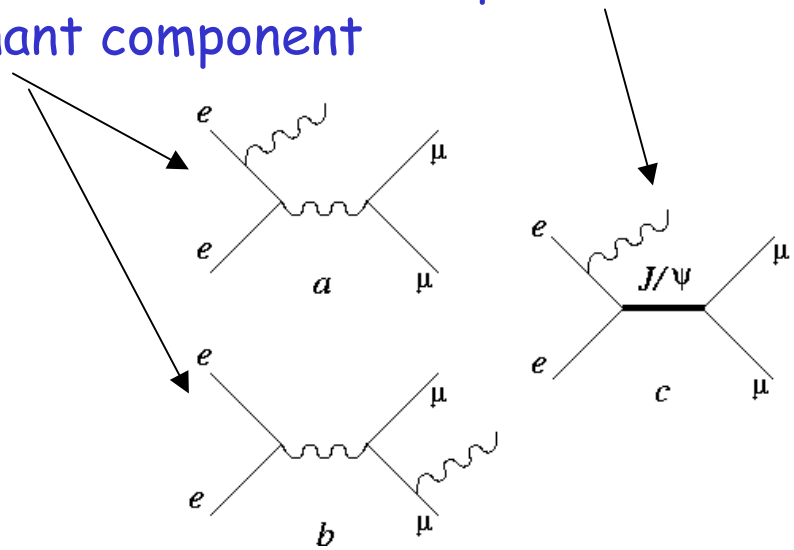
(Dominant systematic is error on K from FSR, and uncertainty on J/ψ lineshape)

J/ψ production in ISR events - Interference

Line shape with/without interference convoluted with detector resolution



•Interference between J/Ψ production and non-resonant component



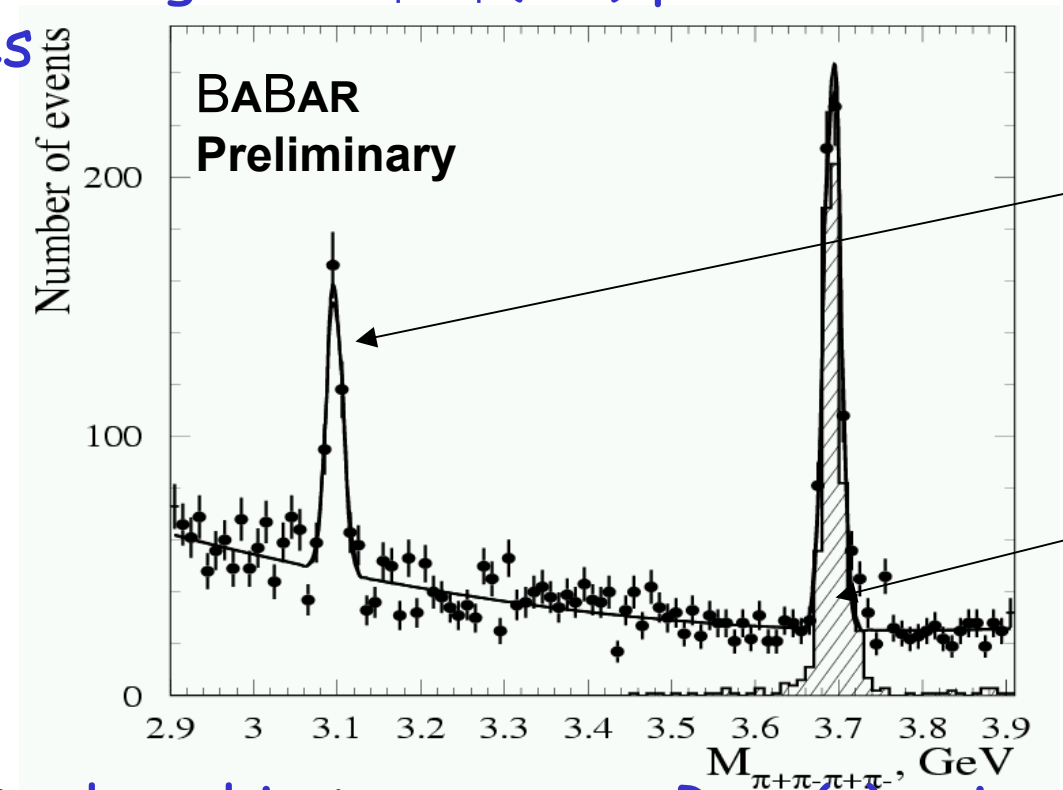
•Effects the shape of the distribution but has very little effect on the total cross section

•Taken into account as a systematic error (0.3%)

J/ψ production in ISR events – the future…

This is just the beginning for charmonium production in ISR at BaBar

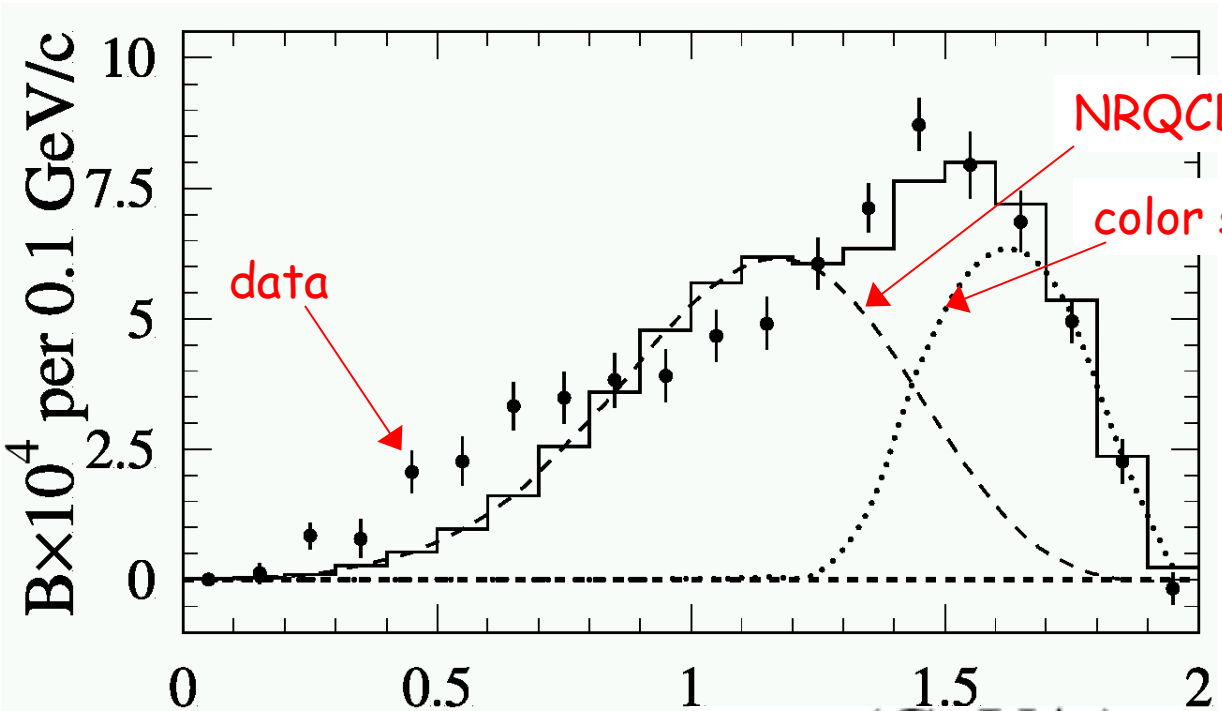
Also looking at J/ψ, ψ(2S) production in hadron decays modes



Eventual goal is to measure $R_{HAD}(s)$ using ISR at BaBar

B→J/ψX experimental observation

An excess at low momentum in the inclusive production of charmonium mesons in B decay at the Υ(4S) has been observed compared to the non-relativistic QCD prediction (excess corresponds to a branching fraction ~10^{-4})



Phys.Rev. D67, 032002 (2003)

Possible source includes:

- intrinsic charm component of B
- production of $s\bar{q}g$ hybrid with J/ψ
- Rate enhanced due to B decay to J/ψ baryon-antibaryon

$B^+ \to J/\psi p\bar{\Lambda}$ and $B^0 \to J/\psi p\bar{p}$ analysis

These processes can be enhanced by exotic QCD resonances in intermediate states e.g. (**baryonium**, **pentaquark**, **nuclear-bound quarkonium**)

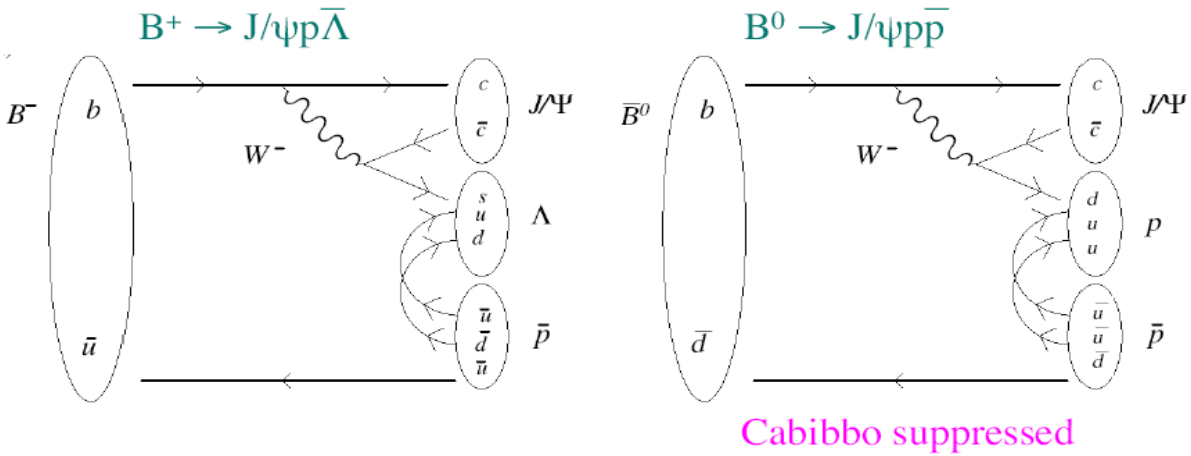
$B^+ \to J/\psi p\bar{\Lambda}$

$\to p\pi$

$\to l^+l^-, l=\mu, e$

$B^0 \to J/\psi p\bar{p}$

$\to l^+l^-, l=\mu, e$

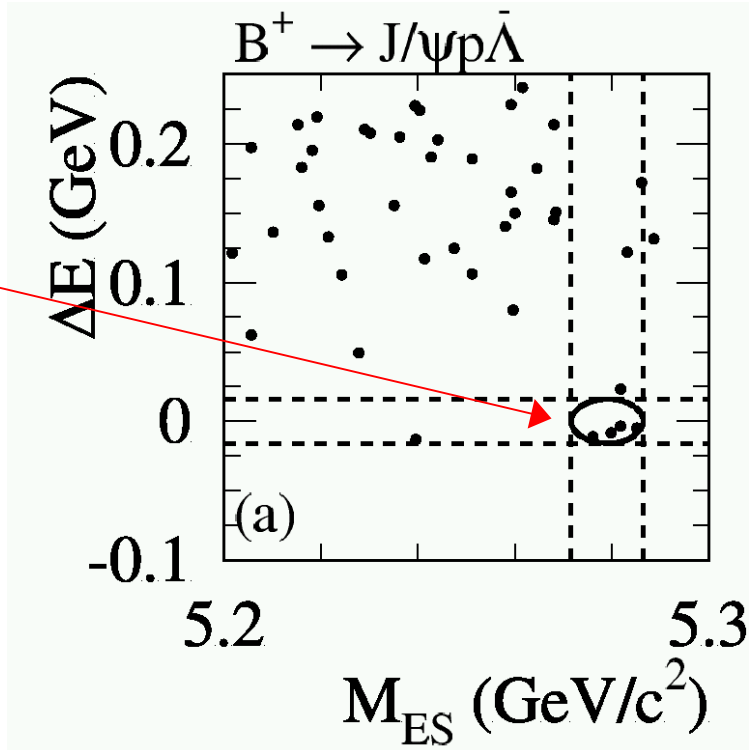


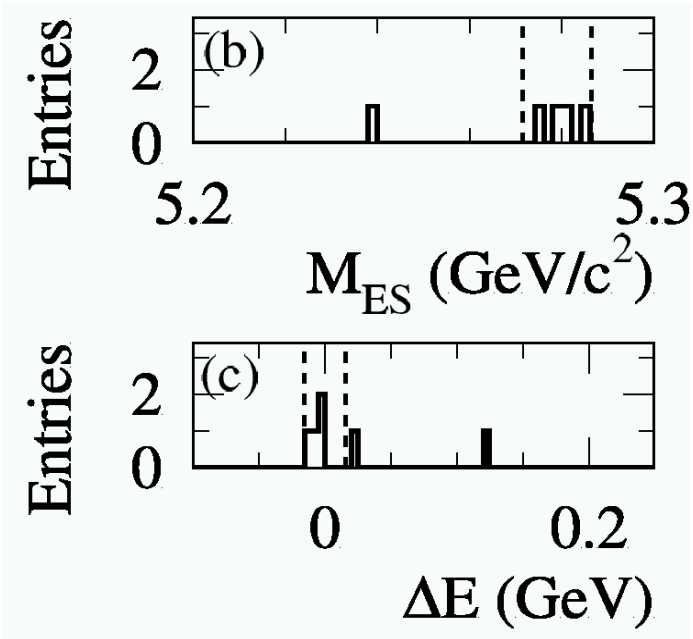
Cabibbo suppressed

Key elements of the analysis are the separation of low momentum protons from Kaons (DIRC, dE/dx) - 98 % efficiency, less than 1% misidentification

$B^+ \to J/\psi\, p\bar{\Lambda}$ results

4 events in signal region with an expected background of 0.21±0.14





Prob.(≥4, expecting 0.21 ±0.14) is equal to 2.5×10^{-4} (3.5 σ)

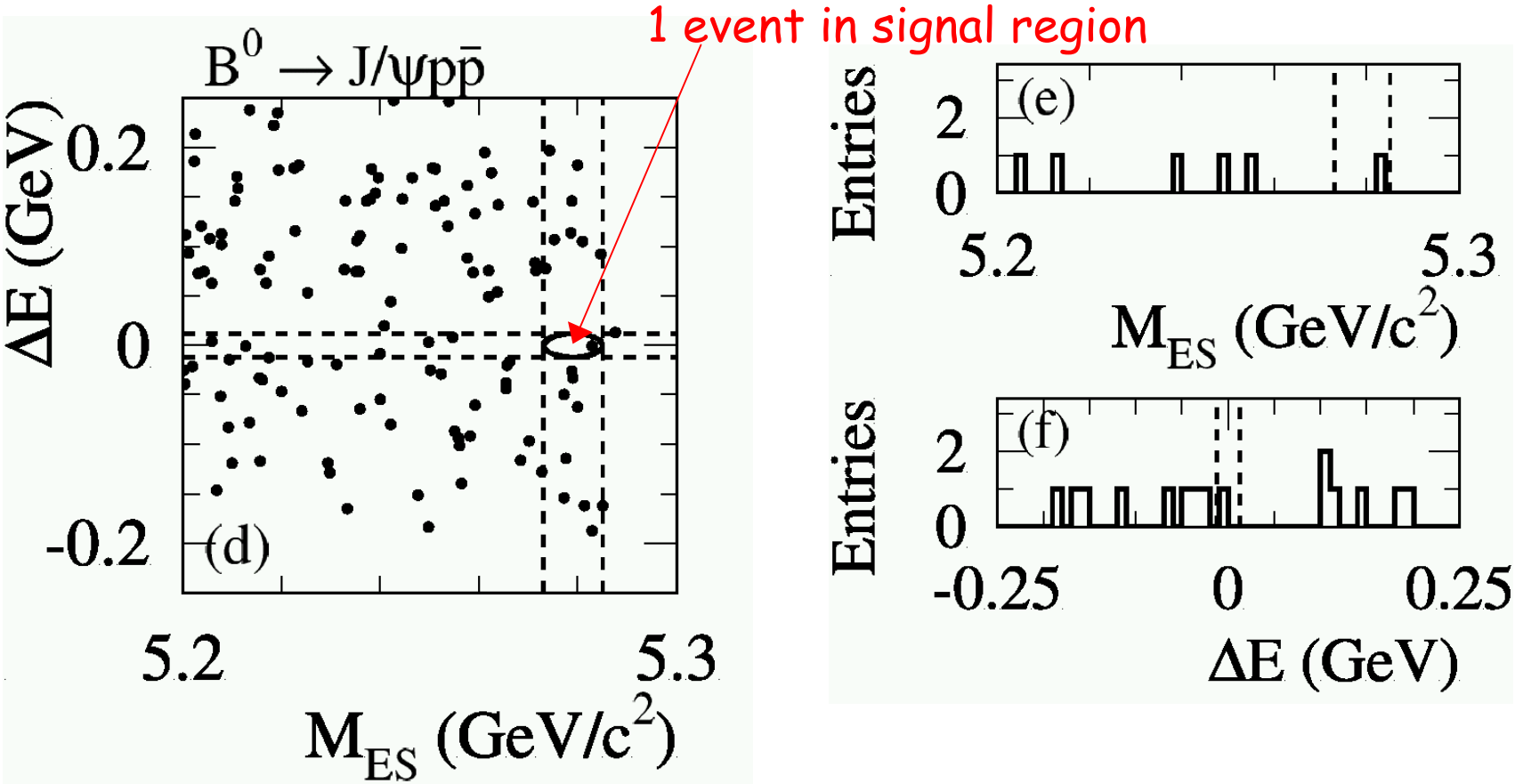
Bayesian analysis, uniform prior ≥0 gives:

$\mathcal{B}(B^+ \to J/\psi\, p\bar{\Lambda}) = (12\ ^{+9}_{-6})\times10^{-6}$ 90% CL upper limit 26×10^{-6}

Efficiency uncertainty is dominant systematic

Submitted to PRL
hep-ex/0303036

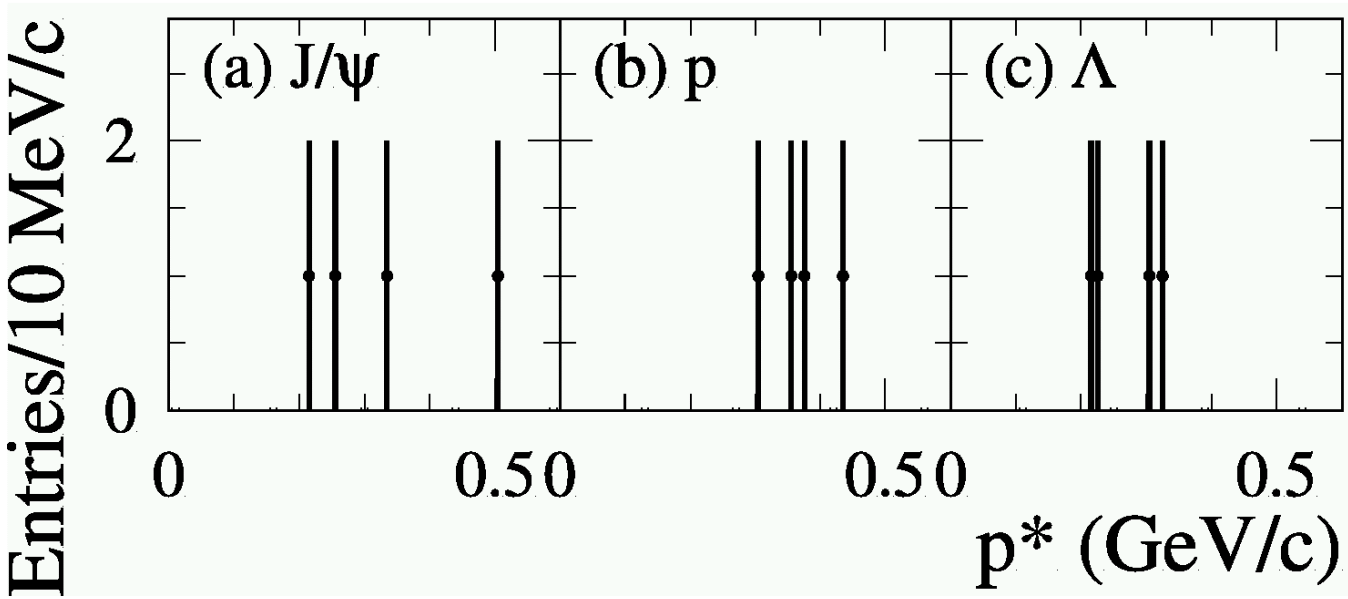
$B^0 \to J/\psi\, p\bar{p}$ results



Expected 0.64±0.17 background events, one observed.
90% CL upper limit 1.9×10^{-6}

This is not an explanation of the excess

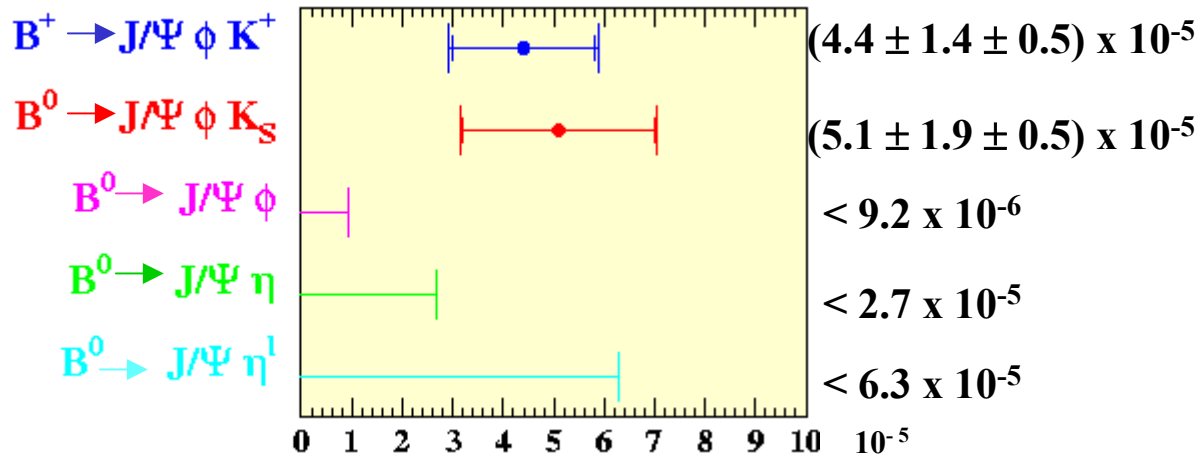
- Measured branching fractions order of magnitude too low to explain excess
- Each of the possible QCD exotic resonances (baryonium, pentaquark, nuclear-bound quarkonium) that could be involved foresee a monoenergetic particle (J/ψ , p, Λ) in the B frame

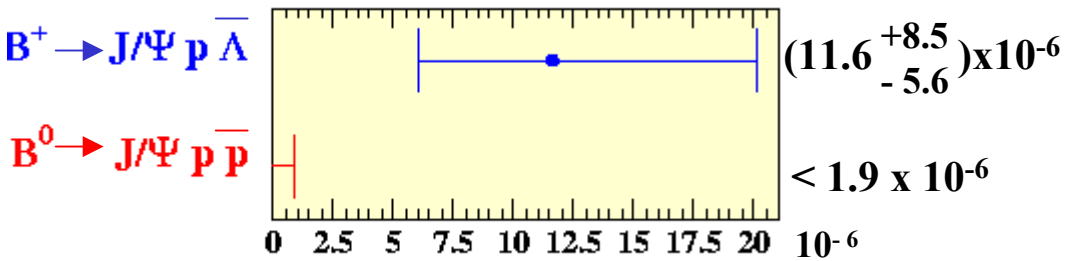


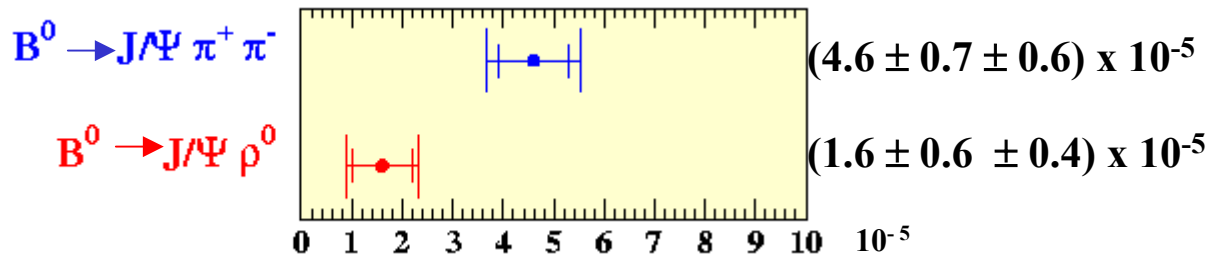
No evidence for Exotic resonance production

Summary of exclusive B decays to Charmonium

Measured Branching fractions And Upper Limits at 90% CL







Phys.Rev.Lett. 90, 091801 (2003)

Summary

- **New measurement of the η_c width**
  - *Agrees with large width measurements by Belle*
    $\Gamma_{\eta_C}^{TOT} = 33.3 \pm 2.5 \pm 0.8 \mathrm{MeV/c^2}$
  - *Observation of the $\eta_c(2S)$*
- **J/ψ production in ISR events**
  - *Preliminary measurement of the total J/ψ width*
    $\Gamma_{J/\psi}^{Total} = 94.7 \pm 4.4 \mathrm{keV/c^2}$
  - *Preliminary measurement of the e^+e^- J/ψ width*
    $\Gamma_{J/\psi}^{ee} = 5.61 \pm 0.20 \mathrm{keV/c^2}$
- **New Exclusive B decays to charmonium**
  - *J/ψ Baryon anti-Baryon processes cannot explain the excess of J/ψ production at low p* in B decays*

BACK UP SLIDES…

What is Mes and DeltaE

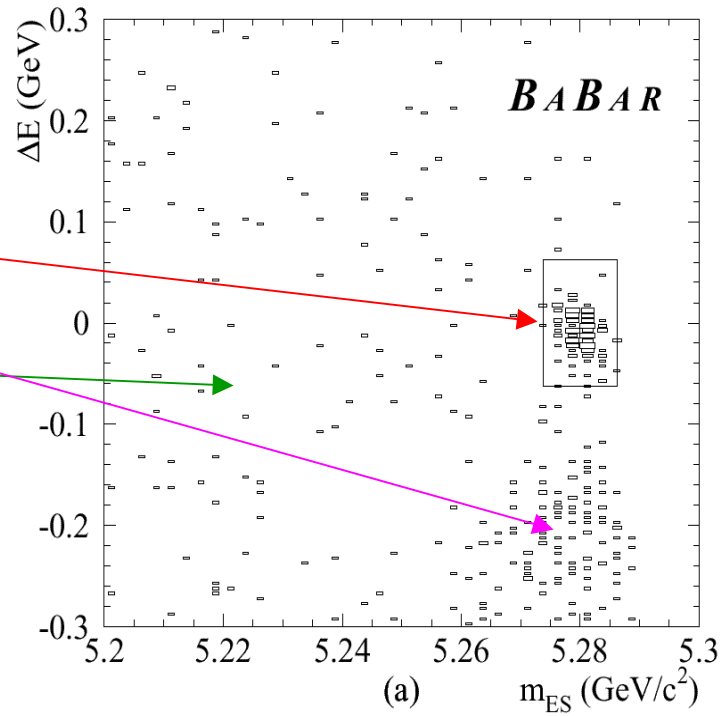
etaC event selection

Systematics on ISR J/ψ widths

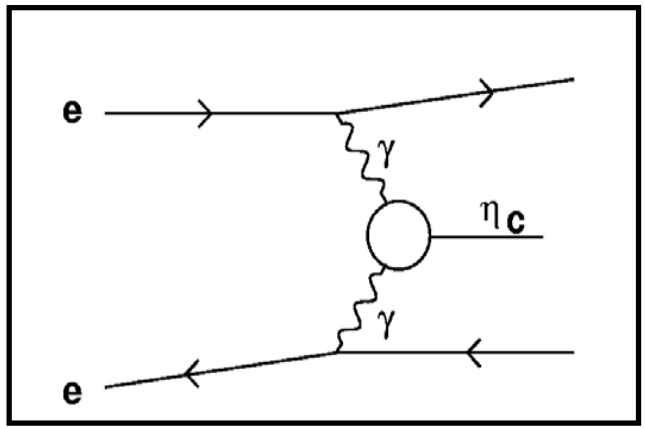
J/ψ baryon anti-baryon event selection

Exclusive B reconstruction variables

- The variables M_{ES} and ΔE
  - ΔE is the difference between the B candidate energy and the expected energy $\Delta E = E_B^* - E_{beam}^*$
  - M_{ES} is the B candidate mass with the beam energy used as the candidates energy $M_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$
  - Nearly uncorrelated
  - Very useful for distinguishing signal from, background (continuum & B background)



η_c production in 2γ events – Event Selection



- Do not reconstruct the e^+e^-
- Select 2 photon events
  - E^{tot}(lab) <9GeV (suppresses B decays)
  - Σp_T <0.5GeV/c
- Fully reconstruct the $\eta_C(K_S K^+\pi^-)$
  - Ks ->$\pi+\pi-$
    - 0.491<M($\pi+\pi-$)<0.503 GeV/c^2
    - Cos θ(Ks) > 0.99
  - Apply Particle Id on charged K candidate (dE/dX & DIRC)
  - Fit the $K_S K^+\pi^-$ vertex (prob(χ2)>0.01)

J/ψ production in ISR events – Systematic Errors

Summary of the systematic errors on the J/ψ parameters

Statistical error on K factor	0.9%
Systematic error on K factor (Varying cut values)	1.3%
Background uncertainty (MC / varying background cuts)	0.5%
Simulation of J/ψ lineshape (fit with or without muon bremsstrahlung)	1.4%
Interference (see slide 13)	0.3%
Total	**2.2%**

B -> J/Ψ Baryon anti-Baryon – Event Selection

- Reconstruct J/ψ -> e+e- or μ+μ-
- $2.95 < M_{ee} < 3.13$ GeV/c^2 or $3.06 < M_{\mu\mu} < 3.13$ GeV/c^2
  - Particle Id on the electron candidates (EMC, dE/dX, DIRC) and muon candidates (EMC, IFR)
- Particle Id on Proton candidates (dE/dX, DIRC)
- Lambda candidates reconstructed in Λ-> p+π- mode
  - $1.10 < M_{p\pi} < 1.13$ GeV/c^2
  - Λ vertex >2mm from J/ψ vertex
- Cut on difference between expected B energy and B candidate energy (ΔE) & Mes (B-mass with the beam energy used to improve the resolution)
- Efficiencies
  - $4.9 \pm 0.9\%$ ($B^+ \to J/\psi\, \bar{\Lambda} p$), $18.4 \pm 2.4\%$ ($B^0 \to J/\psi\, \bar{p}p$)