Hadronic B Decays with the *BABAR* Detector

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Presented on behalf of *BABAR* Collaboration

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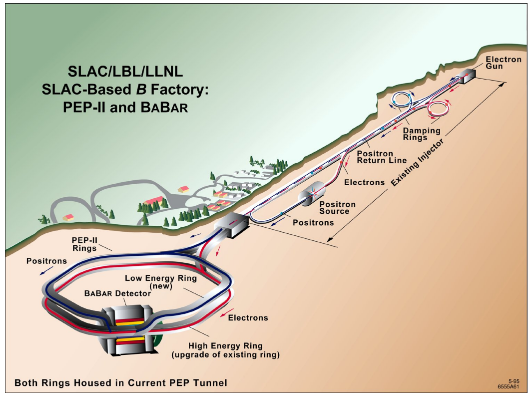
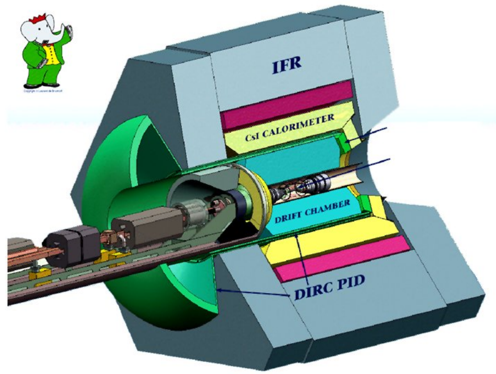
- **Data set**
  - ▷ **Data collected at the $\Upsilon(4S)$ resonance in Y2K**
  - ▷ **Results based on 20.7 fb^{-1} corresponding to 22.7$\times$ 10^6 $B\overline{B}$ pairs**
- **Outline**
  - ▷ **The *BABAR* detector**
  - ▷ **Kinematic variables**
  - ▷ **Measurement of $B \to J/\psi K^*$ decay amplitudes**
  - ▷ **Conclusion**
- **All results are preliminary**





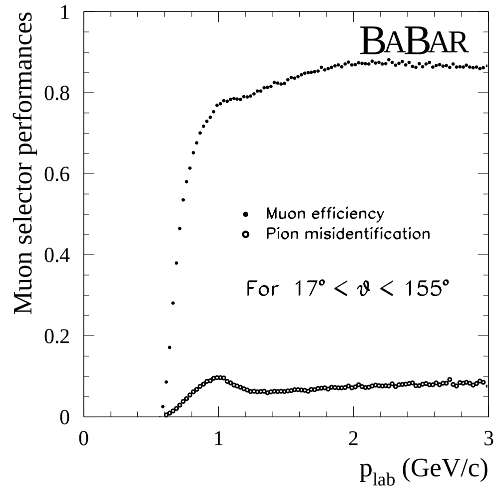
- **Subsystems**
  - ▷ **Tracking:** **5 double-sided layers SVT + 40-layers Drift Chamber (DCH)**

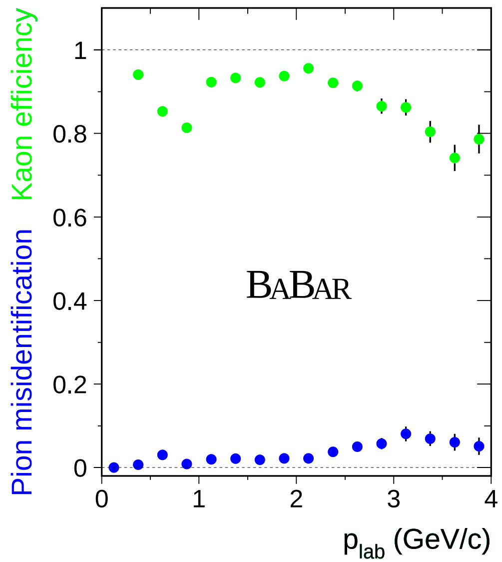
$$\sigma(p_T)/p_T = 0.0019 \cdot (p_T/GeV/c) \oplus 0.0025$$

  - ▷ **DIRC:** **kaon id up to 3.1 GeV with** $> 3\sigma$
  - ▷ **CsI(Tl) Electromagnetic Calorimeter :**

$$\sigma(E)/E = 0.023 \cdot (E/GeV)^{-1/4} \oplus 0.019$$

  - ▷ **IFR:** **18 layers of resistive plate chambers for muon identification.**
- **Particle Identification**
  - ▷ **e/μ:** **based on EMC and IFR**
  - ▷ **Kaon:** **based on DIRC and** dE/dx **information in DCH**





Kinematic Variables

- **Energy difference**

$$\Delta E = E_B^* - E_{beam}^*$$

  - **Gaussian signal**
  - **Linear background**

- **Energy-substituted mass**

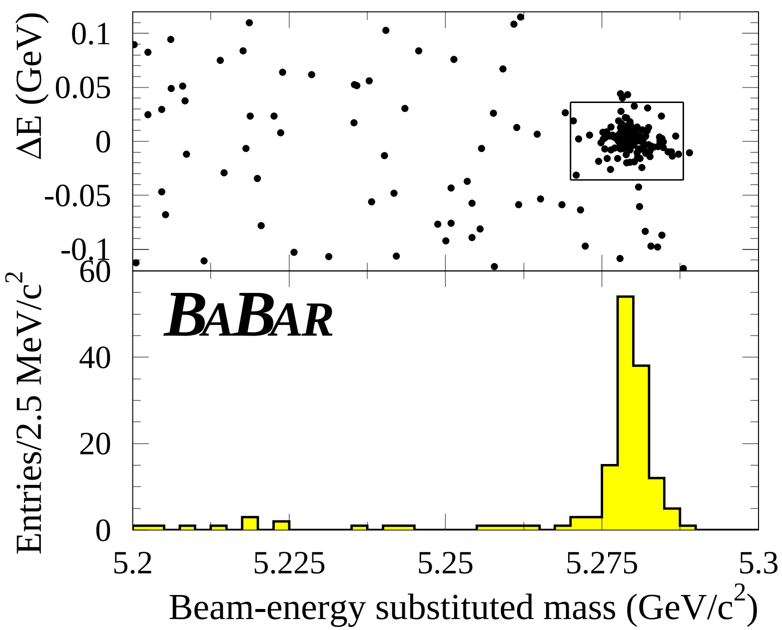
$$M_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$$

  - **Gaussian signal (2.5-3 MeV/c^2)**
  - **ARGUS background function :**

$$B = \alpha y \sqrt{1-y^2} exp(s_f(1-y^2)),$$

where $y = M_{ES}/E_{beam}^*$

$B^0 \to J/\psi K_S, K_S \to \pi^+\pi^-$



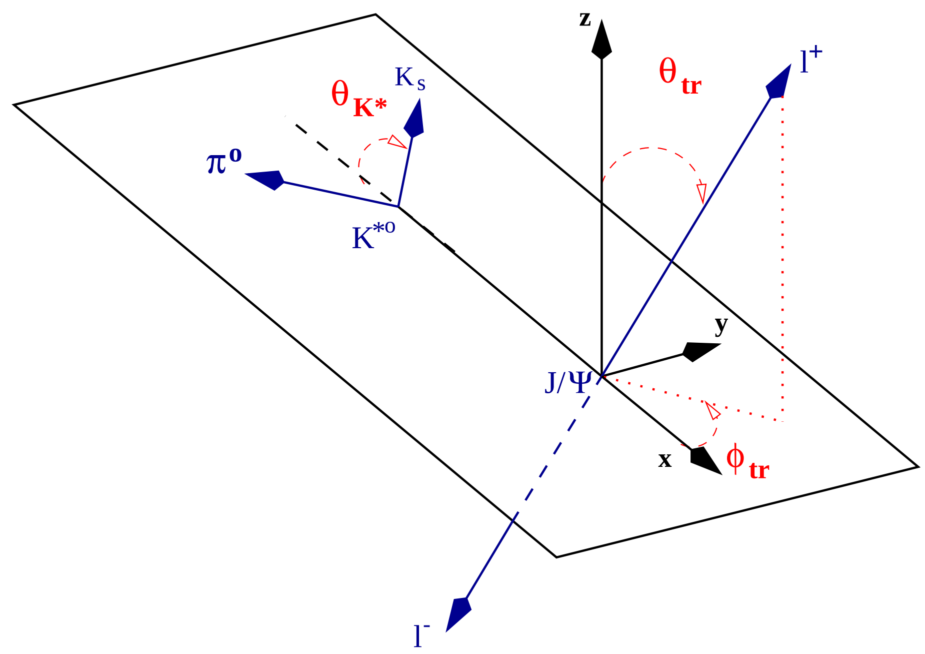
MOTIVATION

- **Measurement of CP-violation in $B^0 \to J/\psi(K_s^0\pi^0)^{*0}$**
  - ▷ $B^0 \to J/\psi(K_s^0\pi^0)^{*0}$ **is a mixture of CP-odd and CP-even states**
  - ▷ **Time dependence can be used, as for the Golden Mode $B^0 \to J/\psi K_s$ to provide a measurement of $sin2\beta$.**
  - ▷ **Dilution knowledge is necessary for CP-violation measurement.**
  - ▷ **P→VV decay structure implies L=0,1,2 between J/ψ and K*.**
  - ▷ **R$_\perp$ - fraction of CP-odd (P-wave) eigenstate $\Rightarrow D_\perp = 1 - 2R_\perp$.**
- **Test of factorization with $B \to J/\psi K^*$**
  - ▷ **Implies the relative phases 0 or π**
  - ▷ **A recent CDF measurement indicates a deviation of $\sim 2\sigma$.**
- **$\Delta I = 0$ for weak decay $\Rightarrow$ all $K^* \to K\pi$ modes can be used**

$B \to J/\psi K^*$

TRANSVERSITY FRAME

- The transversity frame is defined in J/ψ rest frame
  - ▷ K^* direction is -x axis.
  - ▷ $K\pi$ plane is (x, y) plane
  - ▷ z direction provides right handed (x, y, z) frame
- Transversity angles θ_{tr} and ϕ_{tr} are defined as polar and azimuthal angles of the l^+
- K^* helicity angle is an angle between K direction and direction opposite J/ψ in the K^* rest frame

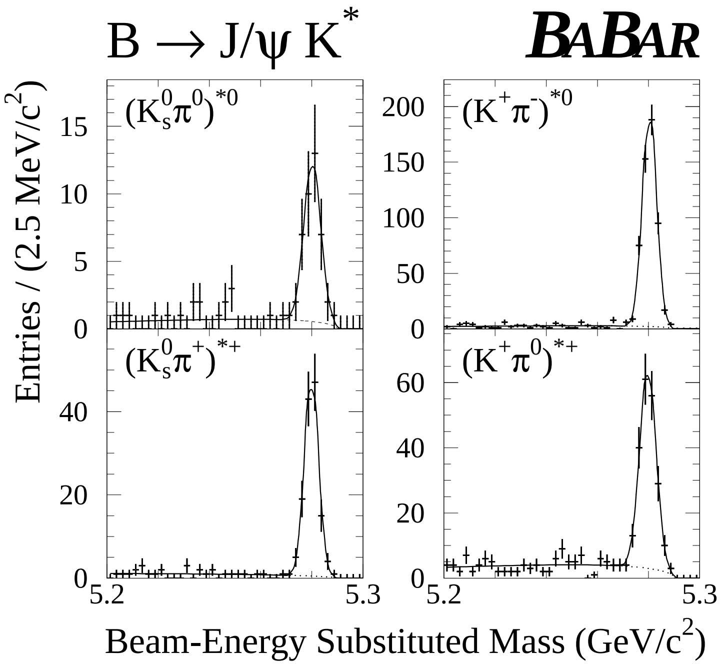


- Decay amplitudes
  - ▷ $A_0 = \sqrt{\frac{2}{3}}D - \sqrt{\frac{1}{3}}S$ — CP-even
  - ▷ $A_\parallel = \sqrt{\frac{1}{3}}D + \sqrt{\frac{2}{3}}S$ — CP-even
  - ▷ $A_\perp = P$ — CP-odd
- $|A_0|^2 = \Gamma_L/\Gamma$, $R_\perp = |A_\perp|^2$

$B \to J/\psi K^*$

B SELECTION

- $B^0 \to J/\psi K^{*0}$ **and** $B^+ \to J/\psi K^{*+}$ **with** K^* **identified in the** $K_s^0\pi^0, K^+\pi^-$ **and** $K_s^0\pi^+, K^+\pi^0$**, respectively.**
- $J/\psi \to e^+e^-, \mu^+\mu^-$
- $-70 < \Delta E < 50$ **MeV for the modes with a** π^0 **and** $|\Delta E| < 30$ **MeV for the others.**
- **Cross Feed due to** $J/\psi(K\pi)$ **with either a lost** π^+**, or a wrongly reconstructed** π^0
- $Cos\theta_{K^*}$ **<0.667 for** π^0 **modes**



Mode	N_{events}	ϵ, [%]	CrossFeed Contam.,[%]
$B^0 \to J/\psi(K_s^0\pi^0)^{*0}$	39.6±6	9.9	15.8
$B^0 \to J/\psi(K^+\pi^-)^{*0}$	530±32	23.9	2.4
$B^+ \to J/\psi(K_s^0\pi^+)^{*+}$	131±12	17.2	3.0
$B^+ \to J/\psi(K^+\pi^0)^{*+}$	195±15	13.8	15.7

ANGULAR DISTRIBUTIONS

- **Defining**

$$
\begin{aligned}
f_1 &= +\ 9/(32\pi) \cdot 2\cos^2\theta_{K^*}(1-\sin^2\theta_{tr}\cos^2\phi_{tr}) \\
f_2 &= +\ 9/(32\pi) \cdot \sin^2\theta_{K^*}(1-\sin^2\theta_{tr}\sin^2\phi_{tr}) \\
f_3 &= +\ 9/(32\pi) \cdot \sin^2\theta_{K^*}\sin^2\theta_{tr} \\
f_4 &= +\ 9/(32\pi) \cdot \sin^2\theta_{K^*}\sin 2\theta_{tr}\sin\phi_{tr}\cdot\zeta \\
f_5 &= -\ 9/(32\pi) \cdot 1/\sqrt{2}\cdot\sin 2\theta_{K^*}\sin^2\theta_{tr}\sin 2\phi_{tr} \\
f_6 &= +\ 9/(32\pi) \cdot 1/\sqrt{2}\cdot\sin 2\theta_{K^*}\sin 2\theta_{tr}\cos\phi_{tr}\cdot\zeta
\end{aligned}
$$

- $\zeta = +1$ **for** B^+ **and** B^0**;** $\zeta = -1$ **for** B^- **and** $\overline{B}^0$
  $\zeta = 0$ **for the CP mode (average of** $\zeta = \pm 1/(1+x_d^2)$**,** $x_d = \Delta m_{B_d}/\Gamma_{B_b}$**)**
- **The angular distribution** $g(\cos\theta_{tr}, \cos\theta_{K^*}, \phi_{tr})$

$$
g = \frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_{\mathrm{tr}}\ \mathrm{d}\cos\theta_{\mathrm{K^*}}\ \mathrm{d}\phi_{\mathrm{tr}}} = \sum_{i=1}^{6} A_i^2 f_i
$$

where $A_i^2 (i = 1, 6)$ **are** $|A_0|^2$, $|A_\parallel|^2$, $|A_\perp|^2$, $\mathrm{Im}(A_\parallel^* A_\perp)$, $\mathrm{Re}(A_0^* A_\parallel)$ $\mathrm{Im}(A_0^* A_\perp)$

FITTING METHOD

- **All B candidates in the range 5.2 $< M_{ES} <$ 5.3 GeV/c^2 are used in an unbinned maximum likelihood fit.**
- **The angular and M_{ES} information is used to produce a *pdf* with x the fraction of signal events, and (1-x) the fraction of non $B \to J/\psi K^*$ background:**

$$pdf = x \times g_A \times G(M_{ES}) + (1 - x) \times g_B \times B(M_{ES})$$

where $G(M_{ES})$ is a Gaussian and $B(M_{ES})$ is a Argus function.

- **The observed angular distributions are biased due to $\epsilon(\cos\theta_{tr}\ , \cos\theta_{K^*}\ , \phi_{tr})$**
- **A 3D efficiency/acceptance map in $(\cos\theta_{tr}\ , \cos\theta_{K^*}\ , \phi_{tr})$ space $\Rightarrow$ source of systematic uncertainty due to Monte Carlo statistics.**
- **Only the projections of ϵ on the f_i basis functions are needed in order to perform the acceptance corrections**

CORRECTIONS

- **Acceptance corrections**
  - ▷ **Signal events are described by the *pdf* function:**

$$g_{obs} = g(\vec{\omega}_j) \times \epsilon(\vec{\omega}_j)/<\epsilon>, \quad \vec{\omega}_j = (\cos\theta_{tr}\ , \cos\theta_{K^*}\ , \phi_{tr})$$

  - ▷ **The mean efficiency $<\epsilon>$**

$$<\epsilon>= \int g \times \epsilon = \sum_{i=1}^{6} A_i^2 \xi_i, \qquad \xi_i = \int f_i \times \epsilon$$

  - ▷ ξ_i **($\epsilon \to f_i$) are amplitude independent. They are extracted using a detailed simulation of the detector.**
  - ▷ **The likelihood for the signal is:**

$$\mathcal{L}_{signal} = \sum_{j=1}^{N_{obs}} \log(g(\vec{\omega}_j)) + \sum_{j=1}^{N_{obs}} \log(\epsilon(\vec{\omega}_j)) - N_{obs} \times \log(\sum_{i=1}^{6} A_i^2 \xi_i)$$

  - ▷ **Knowledge of the acceptance probability for each event is not necessary:**
    $\Sigma_{j=1}^{N_{obs}} \log(\epsilon(\vec{\omega}_j))$ **may be excluded from the log of the likelihood function since it is a constant for the sample being analyzed.**

Log Likelihood

- **Background corrections**
  - ▷ **The** *pdf* **of the non** $B \to J/\psi K^*$ **background:**
    $g_B^{obs}(\vec{\omega}_j) = g_B(\vec{\omega}_j) \times \epsilon(\vec{\omega}_j)/\langle\epsilon\rangle \Rightarrow B_i^2 (i = 1, 6)$
  - ▷ **Corrections due to Cross Feed by a modification** $\tilde{\xi}_i$ **of the** ξ_i **values.**
  - ▷ $\tilde{\xi}_i$ **depend on amplitude (**$\tilde{\xi}_i(A_i) \sim \mathcal{O}(10^{-3})$**).**
- **The complete log likelihood has the form:**

$$\mathcal{L} = \sum_{j=1}^{N_{obs}} \log\Big(x \cdot G(M_{ES_j}) \cdot g(\vec{\omega}_j) + (1-x) \cdot B(M_{ES_j}) \cdot g_B(\vec{\omega}_j) \Big) - N_{obs} \log\left(\sum_{i=1}^{6} \tilde{\xi}_i \cdot (x \cdot A_i^2 + (1-x) \cdot B_i^2) \right) - \mathcal{N}$$

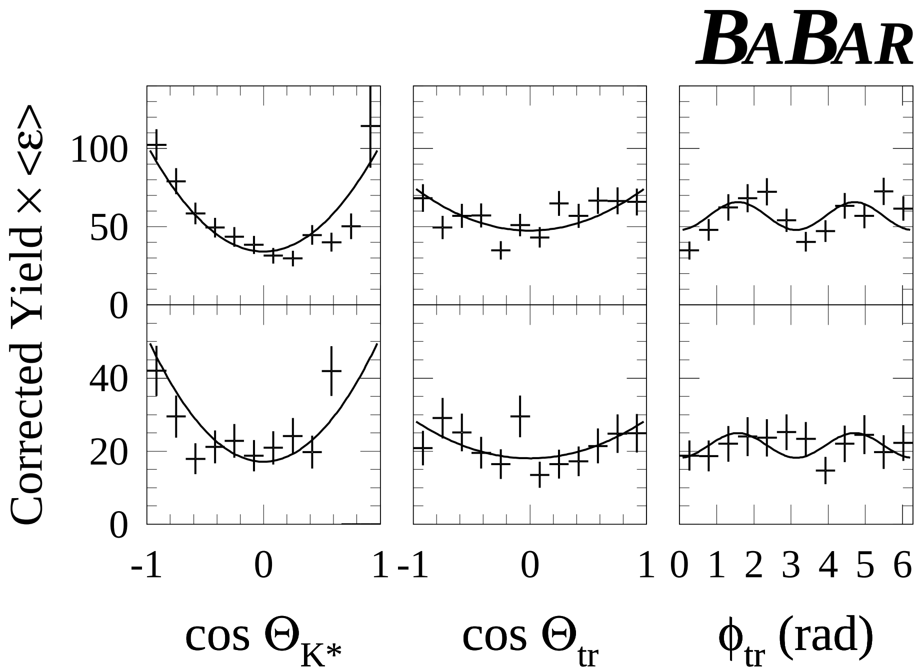
- **The normalization of the amplitudes :** $\mathcal{N} = N_{obs}(|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2)$ **(extended likelihood method)**

$B \to J/\psi K^*$

RESULTS

non- π^0 modes ⇒

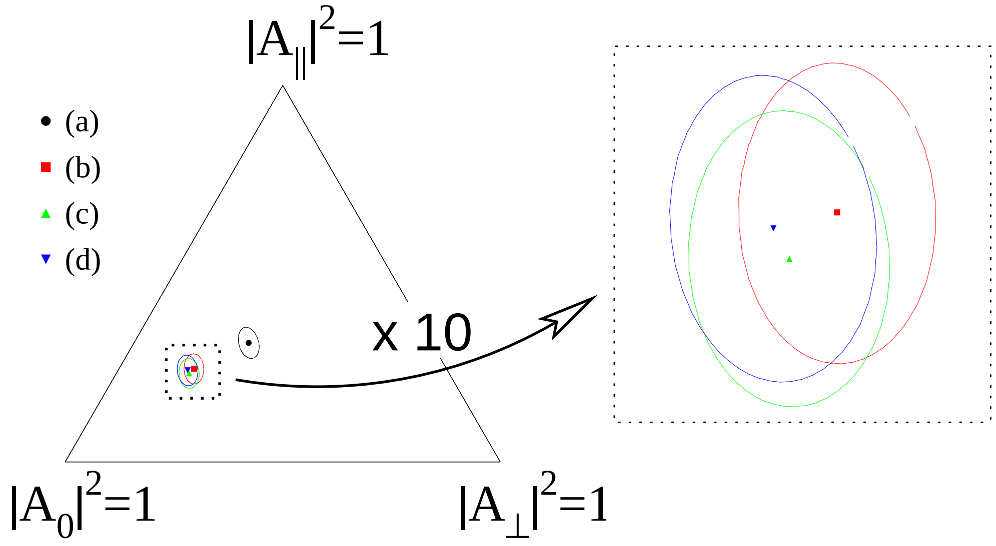
π^0 modes ⇒



Quantity	Value
$\|A_0\|^2$	**0.597±0.028±0.008**
$\|A_\perp\|^2$	**0.160±0.032±0.036**
$\|A_\parallel\|^2$	**0.243±0.034±0.033**
$\phi_\perp = arg(A_\perp/A_0)$	**-0.17±0.16±0.06**
$\phi_\parallel = arg(A_\parallel/A_0)$	**2.50±0.20±0.07**

Plane $(|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2) = 1 \Rightarrow$

BABAR



All K* decay modes

(a) Angular fit without any corrections

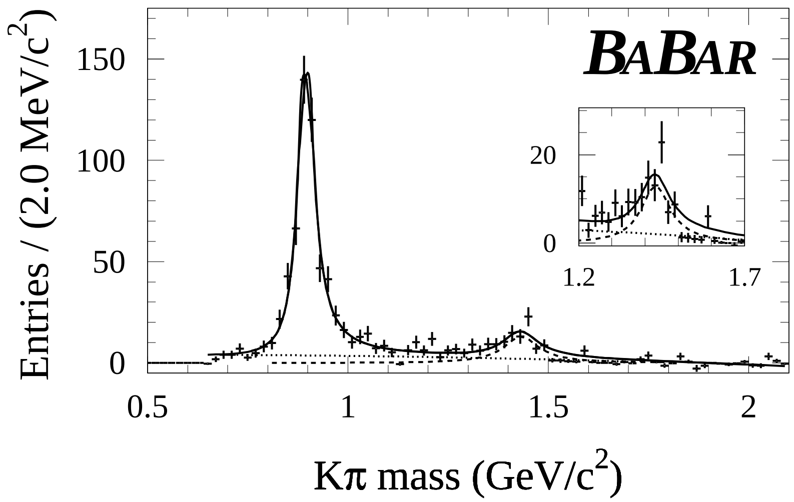
(b) Acceptance corrections

(c) M_{ES} **corrections**

(d) Cross Feed corrections

SYSTEMATIC ERRORS

- **Other $K\pi$ contributions in $B \to J/\psi K\pi$**
- **Resonant contribution around 1430 MeV (K_2^*)**
- **Systematic error due to heavy K^* : fit including $1.1 < m_{K\pi} < 1.3\ GeV/c^2$ events**



	$\lvert A_0\rvert^2$	$\lvert A_\perp\rvert^2$	$\lvert A_\parallel\rvert^2$	$\phi_\perp$	$\phi_\parallel$
Monte Carlo stat.	**0.006**	**0.006**	**0.007**	**0.04**	**0.06**
Backgrounds	**0.002**	**0.005**	**0.006**	**0.01**	**0.00**
Tracking and PID	**0.002**	**0.006**	**0.004**	**0.00**	**0.02**
Heavy K^*	**0.005**	**0.035**	**0.031**	**0.04**	**0.02**
Total	**0.008**	**0.036**	**0.033**	**0.06**	**0.07**

- **Measurements of $B \rightarrow J/\psi K^*$ decay amplitudes have been performed using Y2K (20.7 fb^{-1}) BABAR data.**
- **Comparison with other experiments**

	$\|A_0\|^2$	$\|A_\perp\|^2$	$\phi_\perp$	$\phi_\parallel$
CLEO	0.52 ± 0.08	0.16 ± 0.09	-0.11 ± 0.46	3.00 ± 0.37
CDF	0.59 ± 0.06	$0.13^{+0.13}_{-0.11}$	-0.6 ± 0.5	2.2 ± 0.5
BELLE	-	0.27 ± 0.12	-	-
This result	0.60 ± 0.03	0.16 ± 0.05	-0.17 ± 0.17	2.50 ± 0.21

- Γ_L/Γ **= 0.60±0.03**
- $|A_\perp|^2 = 0.16 \pm 0.05$
  - ▷ **Dilution** $D_\perp = 0.68 \pm 0.10$ **(**$sin2\beta$**)**
- $\phi_\parallel = 2.50 \pm 0.21$ **- Deviation of relative phase (3 σ) from π**
- **Many others *BABAR* results are coming**