CALIBRATION OF: $\theta_C$

Apply $\cos \theta_{\text{polar}}$ angle dependent parameterization of Cherenkov angle ($\theta_C$) systematic offset, resolution and small satellite peaks

$\theta_C(\text{rec.}) = \theta_C(K^\pm)$
for kaons from $D^{*+}$ control sample $\Rightarrow$
MAXIMUM LIKELIHOOD FIT

An 8 parameter, unbinned extended likelihood fit is performed (fitted quantities in red). The PDF for event $i$ reads ($N' \equiv \sum_k N_k$):

$$P_i \left( m_{ES,i}, \Delta E_i, F_i, \theta_{C,i}, \theta_{C,i} \right)$$

$$= N_{\pi\pi} P_{i}^{\pi\pi} + N_{b\pi\pi} P_{i}^{b\pi\pi} + N_{KK} P_{i}^{KK} + N_{bKK} P_{i}^{bKK}$$

$$+ \frac{1}{2} N_{K\pi} (1 + A_{K\pi}) P_{i}^{K+\pi-} + \frac{1}{2} N_{bK\pi} (1 + A_{bK\pi}) P_{i}^{bK+\pi-}$$

$$+ \frac{1}{2} N_{K\pi} (1 - A_{K\pi}) P_{i}^{K-\pi+} + \frac{1}{2} N_{bK\pi} (1 - A_{bK\pi}) P_{i}^{bK-\pi+}$$

with $P^k = P_{mES} P_{\Delta E} P_{F} P_{\theta_C} P_{\theta_C}^k$ and $\mathcal{L}_{tot} = e^{-N'} \prod_{i=1}^{N} P_i$

- $N_{\pi\pi}$: number of $B \rightarrow \pi^+ \pi^-$ decays
- $N_{K\pi}$: number of $B \rightarrow K^+ \pi^-$ decays
- $A_{K\pi}$: asymmetry between $B \rightarrow K^+ \pi^-$ and $B \rightarrow K^- \pi^+$ decays:
  $$(N_{K^+\pi^-} - N_{K^-\pi^+})/(N_{K^+\pi^-} + N_{K^-\pi^+})$$
- $N_{KK}$: number of $B \rightarrow K^+ K^-$ decays
- $N_{b\pi\pi}$: number of background $\pi^+ \pi^-$ candidates
- $N_{bK\pi}$: number of background $K^+ \pi^-$ candidates
- $A_{bK\pi}$: asymmetry between background $K^+ \pi^-$ and $K^- \pi^+$ candidates
- $N_{bKK}$: number of background $K^+ K^-$ candidates
SYSTEMATIC STUDIES

Imperfect Knowledge of PDFs

- Generous variations of PDF shape parameters:
  * within their statistical errors
  * to cover MC-data disagreements
- Use of alternate parameterizations
- PID: no charge asymmetry found in PID performance

→ Dominant systematic errors: Fisher shape (for background), \( m_{ES} \) and \( \Delta E \) (signal peaks and resolution).

Cross Checks

- Validate of the fitting method: toy Monte Carlo studies with known input were performed: no bias has been found in the fit outputs within the toy statistics
- Parallel PID cut-based analysis

Comparison with ICHEP'2000 (Osaka) Results

- Bias was found in background part of previous 6 parameter fit:
  * 2 background parameters: \( N_{\text{bkgd}} \) and \( f_{\pi} \)
  * this implies that background consists of randomly paired tracks, so that:
    \[ f_{\pi\pi} = f_{\pi}^2, \quad f_{K\pi} = 2f_{\pi}(1 - f_{\pi}), \quad f_{KK} = (1 - f_{\pi})^2. \]
  * This is not true. E.g., the 2-body selection criteria prefer to select \( K^{\pm}K^{\mp} \) from both \( ss \) and \( cc \)
  * Refit of Osaka sample (with new, substantially improved selection):
The combined 8 parameters fit yields for 16032 events

\[
[N \pm \sigma \text{(stat)} \pm \sigma \text{(syst)}]
\]

\[
\begin{align*}
N_{\pi\pi} &= 41 \pm 10 \pm 7 \\
N_{K\pi} &= 169 \pm 17^{+12}_{-17} \\
N_{KK} &= 8.2^{+7.8}_{-6.4} \pm 3.3
\end{align*}
\]

(correlations < 15%)

The branching ratios are obtained via \( BR = \frac{N_S}{\epsilon N_{B\bar{B}}} \), with \( N_{B\bar{B}} = 22.5 \times 10^6 \) and \( \epsilon = 0.43 (K^+ K^-) + 0.45 (\pi^+ \pi^-) \).

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>[BR ± σ(stat) ± σ(syst)] ( \times 10^{-6} )</th>
<th>BaBar</th>
<th>CLEO</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \pi^+ \pi^- )</td>
<td>4.1 ± 1.0 ± 0.7</td>
<td>4.3 ± 1.6 ± 0.5</td>
<td></td>
</tr>
<tr>
<td>( K^+ \pi^- )</td>
<td>16.7 ± 1.6 ( ^{+1.2}_{-1.7} )</td>
<td>17.2 ( ^{+2.5}_{-2.4} ) ± 1.2</td>
<td></td>
</tr>
<tr>
<td>( K^+ K^- )</td>
<td>&lt; 2.5 (90% CL)</td>
<td>&lt; 1.9 (90% CL)</td>
<td></td>
</tr>
</tbody>
</table>
Parallel cut & dice analysis and binned likelihood fit of the $m_{ES}$ distribution finds consistent results
MEASUREMENT OF THE $B \rightarrow J/\psi K^*$ 
DECAY AMPLITUDES

Properties of $B \rightarrow J/\psi K^*$ Decays:

- Decay $P \rightarrow VV$: $J^P(J/\psi) = 1^-$ and $J^P(K^*) = 1^-$
  $L = 0, 1, 2$ between the 2 vector mesons
- Final state $K_S^0 \pi^0$ is not a pure CP eigenstate
- Parameter $R_\perp$ measures CP$^-$ fraction

Motivation for the Analysis:

- CP measurement using $B \rightarrow J/\psi K^{*0} \rightarrow (\ell^+\ell^-)(K_S^0 \pi^0)$. For $R_\perp \equiv 0, 1$, $J/\psi K^{*0}(K_S^0 \pi^0)$ is a golden CP channel
- Test of factorization hypothesis: zero FSI implies zero or $\pi$ phase shifts between amplitudes

Analysis Framework:

- Considered are the $K^*$ final states:
  $(K_S^0 \pi^0)^*, (K^\mp \pi^\pm)^*, (K_S^0 \pi^\mp)^*, (K^\pm \pi^0)^*$
- Assuming $\Delta I = 0$: all $K \pi$ final states have same amplitudes
- Using Transversity Basis: amplitudes are CP eigenstates
ANGULAR DISTRIBUTION

The Transversity Basis (defined in $J/\psi$ rest frame):

- Define 3 amplitudes ($\sum |A_i|^2 = 1$):
  - $A_\parallel$: both vector mesons have parallel polarization: CP = +1
  - $A_0$: both vector mesons have longitudinal polarization: CP = +1
  - $A_\perp$: both vector mesons have perpendicular polarization: CP = -1.
    In particular: $|A_\perp|^2 \equiv R_\perp$.

- After removal of global phase, 2 phases left: $\phi_\parallel$, $\phi_\perp$

Angular distribution:

$$g(\cos \theta_{tr}, \cos \theta_{K^*}, \phi_{tr})$$

$$= f_1 |A_0|^2 + f_2 |A_\parallel|^2 + f_3 |A_\perp|^2$$
$$+ f_4 \xi \text{Im}[A^*_\parallel A_\perp] + f_5 \text{Re}[A^*_0 A_\parallel]$$
$$+ f_6 \xi \text{Im}[A^*_0 A_\perp]$$

$\xi = +1$ (-1) for $B^+$, $B^0$ ($B^-$, $B^0$)
$\xi = 0$ for CP mode without initial flavor tagging
**B → J/ψ K^* CANDIDATE SELECTION**

- **J/ψ → ℓ⁺ ℓ⁻**: vertex two identified leptons and apply mass cut
- **K_S^0**: vertex 2 tracks, apply mass cut, require minimum flight length and that the K_S^0 origins from the interaction point
- **K^***: formed from K π combinations within K^* mass cut
- **B → J/ψ K^***: apply cut on K^* helicity angle, \(\cos \theta_{K^*}\), (reducing (self) cross feed) and energy difference \(\Delta E\)

### Selection Efficiencies:

<table>
<thead>
<tr>
<th>Selection</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>J/ψ(K_S^0 π^0)⁺⁰</td>
<td>9.9%</td>
</tr>
<tr>
<td>J/ψ(K_π^± π^±)⁺⁰</td>
<td>23.9%</td>
</tr>
<tr>
<td>J/ψ(K_S^0 π^±)⁺±</td>
<td>17.2%</td>
</tr>
<tr>
<td>J/ψ(K_π^± π^0)⁺±</td>
<td>13.8%</td>
</tr>
</tbody>
</table>

- K π feed thru: \(<2.0\%\)
- Self feed thru: \(<13.7\%\)
$K^*$ MASS SPECTRUM

Signal contributions may arise from the heavier $K^*$ excitations $K_0^*(1430)$, $K_2^*(1430)$, and non-resonant $K\pi$ production.

Background subtracted $m_{K^\pm \pi^\mp}$ spectrum:
THE AMPLITUDE FIT

Unbinned Maximum Likelihood Fit exploiting $m_{ES}$ and the angular information of the event.

AMPLITUDES: SIGNAL

Acceptance corrected, normalized signal PDF for event $i$:

$$g_{obs}(\bar{\omega}_i) = \frac{g(\bar{\omega}_i) \cdot \epsilon(\bar{\omega}_i)}{\langle \epsilon \rangle}$$

$\epsilon(i)$: event efficiency
$\langle \epsilon \rangle$: efficiency averaged over angular space

$$\langle \epsilon \rangle = \int g \cdot \epsilon = \sum_{j=1}^{6} A_j^2 \eta_j \quad (\eta_j = \int f_j \cdot \epsilon)$$

$\eta_j$: obtained from MC simulation (channel dependent)

AMPLITUDES: BACKGROUND (BG)

- Non $B \rightarrow J/\psi K^*$ BG: define "projected" $g_B(\bar{\omega}_i)$, similar to $g_{obs}(\bar{\omega}_i)$, with $B_i$ the background amplitudes
- (S)CF BG is amplitude dependent: correct the $\eta_i$ for this bias

$B$ - MASS

The PDFs for $m_{ES}$ are a Gaussian for signal and the ARGUS function for background.
THE COMPLETE LIKELIHOOD

The final log likelihood ($x$ is signal fraction within $5.2 \leq m_{ES} \leq 5.3$):

$$ \log L = \sum_{i=1}^{N_{obs}} \log \left( x \cdot \text{Gauss}(m_{ES,i}) \cdot g_i(\bar{\omega}) + (1 - x) \cdot \text{ARGUS}(m_{ES,i}) \cdot g_{B,i}(\bar{\omega}) \right) $$

$$ - N_{obs} \log \left( \sum_{i=1}^{6} \eta_i \left[ xA_i^2 + (1 - x)B_i^2 \right] \right) = \mathcal{N} $$

The likelihood is extended by the normalization condition:

$$ \mathcal{N} = N_{obs} \left( |A_0|^2 + |A_|||^2 + |A_\perp|^2 \right) $$

Illustration only:
Acceptance corrected 1D projections of the 3 angles & fit results
Top: without $\pi^0$
Bottom: with $\pi^0$
SYSTEMATIC EFFECTS

Systematics are dominated by

- Heavy $K^*$ excitations (shifts observed when including higher mass region in the fit)
- MC statistics.

Smaller systematics arise from background, model, tracking, PID.

\[ |A_{||}|^2 = 1 \]

- (a) Non-corrected fit
- (b) Acceptance corrected fit
- (c) Acceptance & BG corrected fit
- (d) Acceptance & BG & (S)FA corrected fit

\[ |A_0|^2 = 1 \]

\[ |A_\perp|^2 = 1 \]
RESULTS

Signal Amplitudes \((\pm \sigma_{stat} \pm \sigma_{sys})\):

\[
\begin{align*}
|A_0|^2 &= 0.597 \pm 0.028 \pm 0.008 \\
|A_\perp|^2 &= 0.160 \pm 0.032 \pm 0.036 \\
|A_\parallel|^2 &= 0.243 \pm 0.034 \pm 0.033 \\
\phi_\perp &= (-0.17 \pm 0.16 \pm 0.06) \text{ rad} \\
\phi_\parallel &= (2.50 \pm 0.20 \pm 0.07) \text{ rad} \quad (\Rightarrow \text{ FSI ?})
\end{align*}
\]

Dominant longitudinal component. Small \(P\) wave. For \(\sin 2\beta\) with \(J/\psi (K_S^0 \pi^0)^{*0}\), the dilution is: \(D_\perp = (1 - 2|A_\perp|^2) = 0.68 \pm 0.10\)
CONCLUSIONS

- **BABAR** advances towards the finalization of the analyses using the full RUN 1999-2000 data set of 21 fb$^{-1}$

- The data quality has been found within the design requirements

- First, preliminary results have been presented on the
  - Measurement of the branching fractions of $B^0 \rightarrow h^+h'^-$ final states ($h = \pi, K$)
  - Measurement of the $B \rightarrow J/\psi K^*$ decay amplitudes

- The results obtained are in agreement with published values, though the precision dominates the previous measurements on all above quantities

- We are looking forward to the forthcoming unblinding of the remaining rich variety of charmless $B$ decays