Charmless Hadronic B Decays at BABAR

- Motivation
- BABAR & PEP-II
- Analysis of two-body and $\phi$ final states
- Results
- Outlook

Paul C. Bloom
University of Colorado

SLAC Experimental Seminar – May 17, 2001
Motivation:
Rare B decays are interesting

- Dominant decay: $b \rightarrow c$ ($V_{cb}$)
  - For example
  - Typical BF $\sim 10^{-3}$
- Charmless decays:
  - $b \rightarrow u$ (Cabibbo-suppressed tree – $V_{ub}$)
  - $b \rightarrow d, s$ (loop/penguin)
What can one learn?

• Tests of theory branching ratio predictions
  – \( \Gamma(B^0 \rightarrow \pi^+\pi^-) / \Gamma(B^0 \rightarrow K^+ \pi^-) \) gives estimate for penguin contribution to \( b \rightarrow u/d \)
  – Measurement of CP phase \( \gamma \) (assumes QCD factorization)

• Direct CP searches
  – Can arise from tree\(\\text{penguin} \) interference

• Time-dependent CP-asymmetries
  – \( \pi^+\pi^- \rightarrow \sin 2\alpha, \phi K^0 \rightarrow \sin 2\beta \)

• New physics lurking in loops!
  But beware:
  – Low rates and large backgrounds
    \( \sigma(q\bar{q})/\sigma(BB) \ast Br \sim 10^5 - 10^6 \)
  – Penguins pollute CKM angle extraction

Charmless Hadronic B Decays at BABAR

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How can we study these decays?

• Charmless B decays are rare! (BF \( \sim 10^{-5} \))
  – Need millions of B’s (i.e. high luminosity)
  – Good efficiency

• Time-dependent CP studies require precision \( \Delta z \) measurement and flavor tagging
  – Asymmetric collider with boosted CM
  – Lepton and kaon ID

• Charmless modes decay to high momentum pions and kaons (which tag the decay as a penguin)
  – \( K/\pi \) separation is crucial
The BABAR detector @ PEP-II

- Asymmetric collider operating at the \( \Upsilon(4S) \) resonance
  - Decays exclusively to \( BB \) pairs in a coherent \( L=1 \) state

<table>
<thead>
<tr>
<th></th>
<th>Goal</th>
<th>Achieved</th>
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<tbody>
<tr>
<td>( nb^{-1}/sec )</td>
<td>3.0</td>
<td>3.28</td>
</tr>
<tr>
<td>( pb^{-1}/day )</td>
<td>135</td>
<td>184</td>
</tr>
<tr>
<td>( fb^{-1}/week )</td>
<td>0.8</td>
<td>1.03</td>
</tr>
<tr>
<td>( fb^{-1}/month )</td>
<td>3.3</td>
<td>3.8</td>
</tr>
</tbody>
</table>

\[ E(e^-) = 9.0 \text{ GeV}, \quad E(e^+) = 3.1 \text{ GeV} \]

\[ \beta\gamma = 0.56 \]

Charmless Hadronic B Decays at BABAR

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1999-2000 Running

- 1999-2000 dataset:
  - 20.7 fb$^{-1}$ on-peak
  - 2.6 fb$^{-1}$ off-peak
  - 22.7 x 10$^6$ BB pairs
It’s a B “factory”

- Close communication between PEP-II and BaBar
  - Automated coordination between detector HV ramping and beam injection
  - Efficient machine operation

- Highly automated online data acquisition system
  ~95% efficiency

Charmless Hadronic B Decays at BABAR

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The BABAR detector

Instrumented Flux Return (IFR) (resistive plate chambers)

Particle ID (DIRC)
- 144 quartz bars
- 11,000 phototube array

Superconducting Coil (1.5T)

Electromagnetic Calorimeter (EMC)
(6580 CsI crystals)

Drift Chamber
(40 layers)

Silicon Vertex Tracker
(5 double-sided layers)

9.0 GeV e⁻ →

3.1 GeV e⁺ →

Charmless Hadronic B Decays at BABAR
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The DIRC (Detector of Internally Reflected Cherenkov radiation)

- Identification of high momentum kaons crucial for charmless physics.
- DIRC provides excellent K/π discrimination above 1 GeV/c.
Charged Hadron ID

- DIRC provides $>3\sigma$ K/$\pi$ separation out to 3.5 GeV/c
- DCH dE/dx provides good separation at lower momenta
Other detector performance

- Vertexing
  - ~15 μm hit resolution at 0°
  - ~190 μm Δz resolution

- Tracking
  - Combined SVT, DCH covers 92% LAB solid angle
  - ~98% average tracking efficiency
  - σ(p_T)/p_T ~1%

- Calorimetry
  - 7 MeV/c² π⁰ resolution for E_γ > 30 MeV
Analysis strategy

- Select B candidates with initial-state kinematic constraints
  - $\Delta E$, $m_{ES}$
- Make additional pre-selections
  - Event shape, PID, resonance kinematics
- Extract signal using extended maximum likelihood fit
  - Cross check with event counting analysis
Kinematic selection of B candidates

- $e^+e^- \rightarrow BB$
  - $\Rightarrow$ B meson energy given by the beam energy ($\frac{1}{2}\sqrt{s}$)
  - Compare with measured candidate energy
    \[ \Delta E = E_B^* - E_{beam}^* \]
  - Substitute in invariant mass
    \[ m_{ES} = \sqrt{E_{beam}^* - p_B^*} \]
Event shape

- Backgrounds completely dominated by combinatorics from continuum $qq\bar{q}$
- No problems from “feed-down” and “feed-across”.
- Continuum background is “jetty”, signal is spherical
  - exploit event shape to reduce backgrounds
- Fox-Wolfram moments, sphericity, thrust, multivariate techniques can provide effective background suppression.
Event shape variables

• All charmless analyses use a cut on either the thrust or sphericity angle
  – Cosine of the angle between the sphericity (thrust) axis of the B candidate and the rest of the event: $|\cos(\theta_{S(T)})| < 0.9$
  – Results in a background rejection of ~3
More event shape variables

- Primary signal/background separation comes from thrust (sphericity) angle
- Additional separation from
  - B emission angle and B thrust angles (wrt the beam axis)
  - Angular energy flow (wrt the B thrust axis)
Even more on event shape

- For additional background rejection, we can turn to multivariate techniques.
- One straightforward approach is to form a Fisher discriminant: \( F = \sum a_i x_i \)
  - Optimized linear combination.
  - Constants chosen to maximize separation between signal and background.
  - Fisher in \( \phi \) analyses uses angular energy flow along with B emission and thrust.
  - Two-body analyses use only the energy flow.
Particle ID

• For high momentum tracks, we separate kaons from pions by their Cherenkov angle ($\theta_C$)
  – All charged tracks in the two body analysis, and the bachelor in $\phi K^+/\pi^+$
• Use $D^*$-tagged, $D^0 \rightarrow K^-\pi^+$ to calibrate the DIRC response
• measured – expected $\theta_C$ is parameterized by the sum of core and “satellite” Gaussians
  – Resolutions and offsets are functions of polar angle
  – Satellites represent 2(3)% of $\pi(K)$
Average resolution: $\sim 3\,\text{mr}$
More PID

- Charged hadron ID is also important in identifying charged secondaries of B daughter resonances
- Combined system (DRC, DCH, SVT) information in selectors
  - System(s) used depends on track momentum
- Used to select charged daughters of resonances ($D^0 \rightarrow K^+\pi^-$ for example)
Resonance daughter requirements

- Both daughters of the $\phi$ and appropriate $K^*$ daughters must be identified as kaons
  - Average efficiency 96% per kaon in $\phi K^+$
  - Average mis-ID ~4%
- Pion daughters of $K^*$ candidates must not be identified as kaons
- $K^0_S$ – requirements on decay time significance and angle between flight and momentum direction
- $\pi^0$ – photon $\cos\theta^*$ and lateral cluster shape
Resonance Kinematics

- After the application of PID requirements, additional pre-selections are made on resonance candidate invariant masses to remove background.
- In pseudoscalar-vector decays of the B, the $\phi$ is polarized, and its helicity angle follows a $\cos^2\theta_H$ distribution.

![Graph showing $\phi$ and $K^*$ distributions](image)
Signal extraction

• The primary method for extracting signals is an extended maximum likelihood fit
  – Apply loose preselection (toss things that aren’t signal-like)
  – Determine for every selected event $i$ a signal and background probability $P_{\text{sig}}$ and $P_{\text{bkg}}$, according to probability density functions (PDFs)
    • Getting the PDFs right is the name of the game
Control Samples

• Maximum likelihood analyses require information about signal and background
  – Measure background PDFs from sideband and off-resonance data
  – Deduce signal PDFs from Monte Carlo
    • So, how well does your MC reproduce the data?
    • How can you be sure for a rare mode?

• The answer is control samples
  – Use abundant modes (i.e. charmed) with similar topology to study systematic differences between data and Monte Carlo
More on control samples

• An example: Use $B^- \rightarrow D^0 \pi^-$ ($D^0 \rightarrow K\pi$) to study $B^+ \rightarrow \phi K^+$
  – Study $\Delta E$ and $m_{ES}$ resolutions, means
  – Does the MC reproduce event shape variables?
    • Yes
– Other control modes
  • $D^+ \pi^- (D^+ \rightarrow K^-\pi^+\pi^+)$
  • $D^0 \pi^- (D^0 \rightarrow K_S \pi^+\pi^-)$
  • $D^0 \rho^+ (D^0 \rightarrow K\pi, K_S \pi^+\pi^-)$
Charge asymmetries and $CP$

- CP violation in decay can be observed as an asymmetry between a decay and its charge conjugate.
- We can measure this in “self-tagging” modes like $K^\pm \pi^\mp$ and $K^\pm \pi^0$.
- Direct CP asymmetries can be included directly into the ML fit for these modes.
Back to signal extraction

• Maximize the following likelihood:

\[
L = \frac{e^{-(N_{\text{sig}} + N_{\text{bgr}})}}{N!} \times \prod_{i=1}^{N} \left[ N_{\text{sig}} p_{\text{sig}}(i) + N_{\text{bgr}} p_{\text{bgr}}(i) \right.
\]

\[
+ \frac{1}{2} N_{\text{sig}} (1 + A_{\text{sig}}) p_{\text{sig}}^+(i) + \frac{1}{2} N_{\text{bkg}} (1 + A_{\text{sig}}) p_{\text{bkg}}^+(i)
\]

\[
+ \frac{1}{2} N_{\text{sig}} (1 - A_{\text{bkg}}) p_{\text{sig}}^-(i) + \frac{1}{2} N_{\text{bkg}} (1 - A_{\text{bkg}}) p_{\text{bkg}}^-(i)
\]

\[
p_{\text{sig}}(i) = p_{\text{sig}}(m_{\text{ES}}(i), \Delta E(i), F(i),...) \quad \quad N: \quad \text{total of selected events (observed)}
\]

\[
p_{\text{bkg}}(i) = p_{\text{bkg}}(m_{\text{ES}}(i), \Delta E(i), F(i),...) \quad \quad N_{\text{sig}}: \quad \text{signal events (from fit)}
\]

\[
N_{\text{bgr}}: \quad \text{background events (from fit)}
\]

• In some cases, fit several modes simultaneously

– More signal and background categories
2-Body results $B^0 \rightarrow h^+ h^-$

- 8 parameter ML fit
  - Input: $m_{ES}$, $\Delta E$, $F$, $\theta_C^+$, $\theta_C^-$
  - Output: $N_{\text{sig}}(\pi\pi)$, $N_{\text{sig}}(K\pi)$, $N_{\text{sig}}(KK)$, $N_{\text{bkg}}(\pi\pi)$, $N_{\text{bkg}}(K\pi)$, $N_{\text{bkg}}(KK)$, $A_{\text{sig}}(K\pi)$, $A_{\text{bkg}}(K\pi)$

- Results (all $\times 10^{-6}$ !)

<table>
<thead>
<tr>
<th>Mode</th>
<th>$\varepsilon$ (%)</th>
<th>$N_S$</th>
<th>$S\sigma$</th>
<th>$B(10^{-6})$</th>
<th>$A$</th>
<th>$A_{90%\text{ C.L.}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+\pi^-$</td>
<td>45</td>
<td>$41 \pm 10 \pm 7$</td>
<td>4.7</td>
<td>$4.1 \pm 1.0 \pm 0.7$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$K^+\pi^-$</td>
<td>45</td>
<td>$169 \pm 17 \pm 13$</td>
<td>15.8</td>
<td>$16.7 \pm 1.6 \pm 1.3$</td>
<td>$-0.19 \pm 0.10 \pm 0.03$</td>
<td>$[-0.35, -0.03]$</td>
</tr>
<tr>
<td>$K^+K^-$</td>
<td>43</td>
<td>$8.2^{+7.8}_{-6.4} \pm 3.5$</td>
<td>1.3</td>
<td>$&lt; 2.5 (90%\text{ C.L.})$</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Other 2-body results

<table>
<thead>
<tr>
<th>Mode</th>
<th>$\varepsilon$ (1%)</th>
<th>$N_0$</th>
<th>$S$ ($\sigma$)</th>
<th>$B(10^{-6})$</th>
<th>$A$</th>
<th>$A$ 90% C.L.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+\pi^0$</td>
<td>32</td>
<td>$37 \pm 14 \pm 5.8$</td>
<td>3.4</td>
<td>$&lt; 9.6$ (90% C.L.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K^+\pi^0$</td>
<td>31</td>
<td>$75 \pm 14 \pm 7.5$</td>
<td>8.0</td>
<td>$10.8^{+2.1}_{-1.0}$</td>
<td>$0.00 \pm 0.18 \pm 0.04$</td>
<td>$[-0.30, +0.30]$</td>
</tr>
<tr>
<td>$K^0\pi^+$</td>
<td>14</td>
<td>$39^{+11}_{-10} \pm 6$</td>
<td>9.8</td>
<td>$18.2^{+3.3}_{-3.0}$</td>
<td>$-0.21 \pm 0.18 \pm 0.03$</td>
<td>$[-0.51, +0.09]$</td>
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<tr>
<td>$\bar{K}^0K^+$</td>
<td>14</td>
<td>$0.0^{+3.4}_{-0}$</td>
<td>0</td>
<td>$&lt; 2.5$ (90% C.L.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K^0\pi^0$</td>
<td>9.6</td>
<td>$17.9^{+6.8}_{-5.8} \pm 1.9$</td>
<td>4.5</td>
<td>$8.2^{+3.1}_{-2.1}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Statistically significant results in all modes except $K^+K^-$, $\pi^+\pi^0$ and $K^0K^+$
- Asymmetries consistent with zero
  - But the sensitivity is starting to get interesting
2-body projections \( h^+h^- \)

- Cut on likelihood, overlay fit result

\[
\begin{align*}
K^+\pi^- & \quad 10 \\
\pi^+\pi^- & \quad 0 \\
\end{align*}
\]

\( m_{ES} \) ranges from 5.2 to 5.3 GeV/c\(^2\)
More 2-body projections

$m_{ES}$ ranges from 5.2 to 5.3 GeV/c$^2$

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2-body cross checks and systematics

• Cross-checks
  – Correlation between $\pi\pi$ and $K\pi$ yields < 15%
  – The likelihood fit shows no significant bias in toy Monte Carlo studies
  – Cherenkov angle satellite peaks were varied over a conservative range with no significant effect
  – Cut-based analyses based on PID selectors give consistent results

• Dominant systematics
  – Resolution on $\Delta E$ (10%)
  – Fisher discriminant shape (5-10%)
  – PID contributes a negligible amount
Comparison of 2-body results

- How do those “other” experiments do?

<table>
<thead>
<tr>
<th>Mode</th>
<th>BABAR</th>
<th>CLEO</th>
<th>BELLE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20.7 fb⁻¹</td>
<td>9.3 fb⁻¹</td>
<td>10.4 fb⁻¹</td>
</tr>
<tr>
<td></td>
<td>2001</td>
<td>2001</td>
<td>2001</td>
</tr>
<tr>
<td>π⁺π⁻</td>
<td>4.1 ± 1.0 ± 0.6</td>
<td>4.3 +1.6 ± 0.5</td>
<td>5.6 +2.2 ± 0.4</td>
</tr>
<tr>
<td>K⁻π⁻</td>
<td>16.7 ± 1.6 +1.2</td>
<td>17.2 +2.3 ± 1.2</td>
<td>19.3 +2.4 ± 1.1</td>
</tr>
<tr>
<td>K⁻K⁻</td>
<td>&lt; 2.5</td>
<td>&lt; 1.9</td>
<td>&lt; 2.7</td>
</tr>
</tbody>
</table>
More 2-body comparisons

<table>
<thead>
<tr>
<th>Mode</th>
<th>BABAR 20.7 fb$^{-1}$</th>
<th>CLEO 9.3 fb$^{-1}$</th>
<th>BELLE 10.4 fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+\pi^0$</td>
<td>$&lt; 9.0$</td>
<td>$&lt; 12.7$</td>
<td>$&lt; 13.4$</td>
</tr>
<tr>
<td>$K^-\pi^0$</td>
<td>$10.8^{+2.1+1.0}_{-1.9-1.2}$</td>
<td>$-$</td>
<td>$16.3^{+3.3+1.6}_{-3.2-1.8}$</td>
</tr>
<tr>
<td>$K^0\pi^0$</td>
<td>$8.2^{+3.1+1.1}_{-2.7-1.2}$</td>
<td>$14.6^{+3.9+2.4}_{-3.1-3.2}$</td>
<td>$16.0^{+5.7+2.5}_{-5.9-2.7}$</td>
</tr>
<tr>
<td>$K^0\pi^+$</td>
<td>$18.2^{+3.8+1.6}_{-3.0-2.0}$</td>
<td>$11.6^{+2.0+1.4}_{-2.7-2.2}$</td>
<td>$13.7^{+5.7+1.9}_{-4.8-1.8}$</td>
</tr>
<tr>
<td>$K^0\bar{K}^+$</td>
<td>$&lt; 2.6$</td>
<td>$&lt; 5.1$</td>
<td>$&lt; 5.0$</td>
</tr>
</tbody>
</table>
Results for $\phi K$, $\phi K^*$

- 2 parameter ML fit (4 for $\phi K^+/\pi^+$)
  - Inputs: $m_{ES}$, $\Delta E$, $M_{KK}$ (all modes) $M_{K\pi}$ ($K^*$ modes), $\theta_H$ (PV modes), $\theta_C$ ($\phi K^+/\pi^+$), $F$ (all modes except $\phi K_S$), $\theta_T$ and $\theta_B$ ($\phi K_S$)
  - Output: $N_{\text{sig}}$, $N_{\text{bkg}}$

- Results:

<table>
<thead>
<tr>
<th>Mode</th>
<th>$\varepsilon$</th>
<th>$\varepsilon_{\text{int}}$</th>
<th>$N$</th>
<th>$N_{\text{sig}}$</th>
<th>$S$</th>
<th>$B(10^{-6})$</th>
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</thead>
<tbody>
<tr>
<td>$\phi K^{-}^+$</td>
<td>36.4</td>
<td>17.9</td>
<td>4202</td>
<td>31.4+6.7</td>
<td>10.5</td>
<td>7.7+1.6 ± 0.8</td>
</tr>
<tr>
<td>$\phi K^{0}$</td>
<td>37.4</td>
<td>6.1</td>
<td>351</td>
<td>10.8+4.1</td>
<td>6.4</td>
<td>8.1+2.1 ± 0.8</td>
</tr>
<tr>
<td>$\phi K^{0+}$</td>
<td>-</td>
<td>4.9</td>
<td>-</td>
<td>-</td>
<td>4.5</td>
<td>9.7+1.3 ± 1.7</td>
</tr>
<tr>
<td>$\phi K^{0+}$</td>
<td>15.1</td>
<td>2.5</td>
<td>781</td>
<td>7.1+4.2</td>
<td>2.7</td>
<td>12.8+7.7 ± 3.2</td>
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<tr>
<td>$\phi K^{0+}$</td>
<td>21.5</td>
<td>2.4</td>
<td>381</td>
<td>4.4+3.7</td>
<td>3.6</td>
<td>8.0+5.0 ± 1.3</td>
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<tr>
<td>$\phi K^{0+}$</td>
<td>26.3</td>
<td>8.6</td>
<td>2517</td>
<td>16.9+5.3</td>
<td>6.6</td>
<td>8.6+3.8 ± 1.1</td>
</tr>
<tr>
<td>$\phi K^{0}$</td>
<td>38.9</td>
<td>19.1</td>
<td>4202</td>
<td>0.9+3.1</td>
<td>0.6</td>
<td>&lt; 1.4 (90% CL)</td>
</tr>
</tbody>
</table>

Charged and neutral mode BF’s consistent with Isospin invariance
\( \phi \) projection plots

- Cut on likelihood, overlay the fit result:
More $\phi$ projection plots

$\phi K^+$

$\phi$ helicity behaves as expected – we have conservation of angular momentum!

$\cos\theta_H$

$\phi K^0$

Clear $\phi$ and $K^*$ signals

$M_{KK}$ (GeV/c$^2$)

$M_{K\pi}$ (GeV/c$^2$)

Fisher discriminates between signal and background

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Cross checks and systematics for the $\phi$ modes

• Cross Checks
  – Correlations between fit variables < 10%
  – Toy MC studies show no bias in the fit and reproduce the measured event yield, significance and fit $\chi^2$
  – Event counting analyses reproduce fit results

• Dominant Systematics
  – Variation of PDF parameterizations (4-17%)
  – Selector PID (2% per track)
  – Polarization in Vector-Vector decay modes
## Comparison of $\phi$ results with BELLE and CLEO

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>$\phi K^+$</td>
<td>7–16</td>
<td>5.5^{+2.1}_{-1.8} ± 0.6</td>
<td>13.9^{+8.7}<em>{-8.8}^{+1.1}</em>{-2.4}</td>
<td>7.7^{+1.6}_{-1.4} ± 0.8</td>
</tr>
<tr>
<td>$\phi K^0$</td>
<td>7–13</td>
<td>&lt; 12.3</td>
<td>&lt; 16</td>
<td>8.1^{+3.1}_{-2.3} ± 0.8</td>
</tr>
<tr>
<td>$\phi K^{*-}$</td>
<td>0.2–31</td>
<td>&lt; 22.5</td>
<td>&lt; 36</td>
<td>9.7^{+4.7}_{-3.4} ± 1.7</td>
</tr>
<tr>
<td>$\phi K^{*0}$</td>
<td>0.2–31</td>
<td>11.5^{+2.5}_{-3.1} ± 1.7</td>
<td>15^{+8}_{-6} ± 9</td>
<td>8.6^{+3.8}_{-2.4} ± 1.1</td>
</tr>
<tr>
<td>$\phi \pi^+$</td>
<td>≪ 1</td>
<td>&lt; 4.0</td>
<td>&lt; 1.4</td>
<td>&lt; 1.4</td>
</tr>
<tr>
<td>$\phi \pi^0$</td>
<td>≪ 1</td>
<td>&lt; 5.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Other charmless results

- ‘Osaka’ results, based on 7.7 fb\(^{-1}\)
- Event counting analysis only

Observations

\[
\begin{align*}
\text{Br}(B^0 \rightarrow \bar{\tau}^- p^+) &= (49 \pm 13^{+6}_{-5}) \times 10^{-6} \\
\text{Br}(B^+ \rightarrow \bar{\tau} K^+) &= (62 \pm 18 \pm 8) \times 10^{-6}
\end{align*}
\]

Upper limits (90% CL)

\[
\begin{align*}
\text{Br}(B^0 \rightarrow p^+ p^- p^+) &< 22 \times 10^{-6} \\
\text{Br}(B^0 \rightarrow K^+ p^- p^+) &< 54 \times 10^{-6} \\
\text{Br}(B^+ \rightarrow K^{*0} p^+) &< 28 \times 10^{-6} \\
\text{Br}(B^+ \rightarrow \bar{\tau}^0 K^+) &< 29 \times 10^{-6} \\
\text{Br}(B^+ \rightarrow \bar{\tau}^0 p^+) &< 39 \times 10^{-6} \\
\text{Br}(B^+ \rightarrow \bar{\tau} h^+) &< 24 \times 10^{-6} \\
\text{Br}(B^+ \rightarrow \bar{\tau} K^0) &< 14 \times 10^{-6} \\
\text{Br}(B^+ \rightarrow \bar{\tau} K^0) &< 112 \times 10^{-6}
\end{align*}
\]
Operational outlook

- 2001 run began Feb 1
- Quick turn-on
  - $1.5 \times 10^{33}$ by Feb 15
- Rather painful since then 😞
  - Still managed to record $>6.0$ fb\(^{-1}\) so far
- Run through July 2002
- Expect $\sim 100$ fb\(^{-1}\) total by shutdown
Analysis outlook

- Many analyses nearing maturity
- Expect updates on all ‘Osaka’ charmless analyses soon
- New analyses not far off
  - Including direct CP studies of established modes and Dalitz analyses of 3-body decays
- Expect updates on two-body modes late this summer
  - Will include first time-dependent $B \rightarrow \pi\pi$ measurement!
Long-term outlook

<table>
<thead>
<tr>
<th>Year</th>
<th>Yearly Lumi</th>
<th>Cumulative Lumi</th>
<th>Peak Lumi</th>
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<tbody>
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<td>1999</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2000</td>
<td>23</td>
<td>25</td>
<td>2</td>
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<tr>
<td>2001</td>
<td>40</td>
<td>65</td>
<td>5</td>
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<td>2002</td>
<td>70</td>
<td>135</td>
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<td>240</td>
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<td>2004</td>
<td>130</td>
<td>370</td>
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<tr>
<td>2005</td>
<td>175</td>
<td>545</td>
<td>17</td>
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</tbody>
</table>

Charmless Hadronic B Decays at BABAR

Paul C. Bloom
Summary

• PEP-II and BABAR have been operating at or better than design since ~18 months after turn-on
• Excellent program of charmless physics underway
  – Two body, including $B \rightarrow \pi\pi$ ($\sin 2\alpha$)
  – $\phi$ modes ($\phi K_S$ and $\phi K^{*+}$ are first observations)
  – Many other results in the pipeline
• Continued luminosity improvements/upgrades $\rightarrow$ expect $\sim 1/2 \text{ ab}^{-1}$ by 2005
  – We are embarking on a program which may go far in helping us understand the physics of flavor
More on resonances

**K^0_S**

<table>
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<tr>
<th>Events / 0.75 MeV/c^2</th>
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<tbody>
<tr>
<td>1000</td>
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<tr>
<td>750</td>
</tr>
<tr>
<td>500</td>
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<td>250</td>
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**π^0**

<table>
<thead>
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<th>Candidates per 1 MeV/c^2</th>
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<tbody>
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<td>800</td>
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<td>400</td>
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<tr>
<td>200</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

**BABAR**

±10 MeV/c^2 window

±15 MeV/c^2 window

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• PDFs for $\phi K^*$ for example

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