Measurements of charmonium states inclusive production in the two body decays $B \rightarrow X_{cc} + K$, and more.

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on behalf of the BABAR Collaboration

Fully reconstructing a $\bar{B}$ in $e^+e^- \rightarrow \Upsilon(4S)$ allows one to study the recoil (missing mass) spectrum of $B \rightarrow K,X$ decays (charge conjugation implicit). This provides measurements absolute $B \rightarrow (K,\text{charmonium})$ branching fractions. In addition to probing charmonium production, the same technique allows one to study exclusive $B \rightarrow K,D^{(*)}$ production. Results from BaBar's 424 fb$^{-1}$ sample are reported. In particular, we observe production of a $D^{**0}(2680)$ resonance.
Feynmann Diagrams for the Amplitudes

$B^+ \rightarrow b W^+ c \rightarrow K^+ u s u$  

$B^+ \rightarrow b W^+ u \rightarrow D^{(*)} c d$  

$B_d \rightarrow b c \rightarrow D^{(*)} d$  

$J/\psi, \eta_c, \chi_c, \psi', \eta'_c, X(3872), \cdots$
Some Key Ideas

• Recoil (missing mass) spectra measure “inclusive” $B \rightarrow K,X$ branching fractions. They are democratic as they do not depend on the decays of their daughters.

• Alternatively, exclusive $B \rightarrow K,X$ final states can be fully reconstructed for specific decays, including specific final states for the daughter states. For example $X = X(3872) \rightarrow J/\psi,\pi^-,\pi^+$.

• $B \rightarrow K,X$ daughter kaons characteristically differ from $B \rightarrow D,X; D \rightarrow K,Y$ kaons:
Inclusive $B^+$ Sample

- $1.67 \ M \pm 4230 \ B^\pm$

- Train a neural net to accept 80% of signal, remove 90% of bkgd.

- Remaining sample is $\sim 1.3 \ M \ B^\pm$ (shown on left)

\[ m_{ES} = \sqrt{E_{CM}^2/4 - p_B^2} \]
Selecting Kaons from $B \rightarrow K, X$

- Most kaons produced in $B$-decays are daughters of $D$-mesons, not daughters of the $B$-mesons themselves.
- Another neural net is trained to discriminate between daughter and grand-daughter kaons:
  - Use MC to avoid bias;
  - Train separately for $1 \text{ GeV} < p_K < 1.5 \text{ GeV}$ and for $1.5 \text{ GeV} < p_K < 2.0 \text{ GeV};$
  - 15 discriminating variables chosen carefully not to depend on particular decay topology of recoil system.
“Combination” Neural Nets

- The separate B and K neural nets are combined to further optimize $S^2/(S+B)$

- This “super-NN” is trained separately for $1.5 \text{ GeV} < p_K < 1.8 \text{ GeV}$ and for $1.2 \text{ GeV} < p_K < 1.5 \text{ GeV}$ (higher charmonium mass)

- These optimized super-NNs retain 55% of signal and reject background 3x in the $X(3872)$ region, 2.5x in the $J/\psi$ region.
$B^- \rightarrow K^-, X^0$

Lower Mass Charmonium Region

$p(K^-)$ from $B^- \rightarrow K^-, X^0$

$B \rightarrow K^-, \eta_c$ BF not sensitive to unknown $\eta_c$ decay BFs.
$B^- \rightarrow K^-, X^0$

Lower Mass Charmonium Region

$p(K^-)$ from $B^- \rightarrow K^-, X^0$

$B \rightarrow K^-, \eta_c$ BF not sensitive to unknown $\eta_c$ decay BF.
B\(^-\) \rightarrow K^-, X^0

Higher Mass Charmonium Region

Spectrum is fit with PDG widths convoluted with detector resolution for 8 signal peaks [that labeled $\chi_1$ is a combination of $\chi_{c1}$ and $h_c$] and a third degree polynomial background shape.
Higher Mass Charmonium Region

Spectrum is fit with PDG widths convoluted with detector resolution for 8 signal peaks [that labeled $\chi_1$ is a combination of $\chi_{c1}$ and $h_c$] and a third degree polynomial background shape.

No $X(3872)$ seen
$\text{B}^- \rightarrow \text{K}^- , X^0$

**Full Charmonium Mass Region**

$X(3872)$ $\psi '$ $\eta_c$ $\chi_2$ $\chi_1$ $\chi_0$ $J/\psi$ $\eta_c$

$p(K^-)$ from $\text{B}^- \rightarrow \text{K}^- , X^0$

Spectrum is fit with PDG widths convoluted with detector resolution for 10 signal peaks, after background subtraction. (BF tables will be presented later.)
B\(^-\) \rightarrow K^- , X^0

**Lower Mass, Neutral D\((\ast)\), Recoil Region**

The statistical significance of the D\(^{**\ast}0\)(2680) \(\sim 3.3\sigma\). Its mass is measured to be \((2.680 \pm 0.003)\) GeV. The K\(^-\), D\(^0\) and K\(^-\), D\(^{\ast\ast}0\) branching fractions are consistent with PDG 2014 values.
Very High Mass Charmonium Region

$p(K^-)$ from $B^- \rightarrow K^-, X^0$

Sensitive to narrow peaks ($\Gamma < 20$ MeV). The only structure “observed” ($p_K = 1.0425$ GeV, $m_{\text{recoil}} = 3.990$ GeV) has a statistical significance $< 3\sigma$ when considering the “look elsewhere” effect. Not sensitive to $Y(4260)$ due to its width ($\Gamma \sim 100$ MeV)
B^0 \to K^-, X^+

Inclusive B^0 Sample

- 372,597 \pm 775 B^0
- Only very clean tagging B^0-decays, and tighter cuts than for B^\pm, so fewer events and better S:B.

\[
m_{ES} = \sqrt{E_{CM}^2/4 - p_B^2}
\]
$B^0 \rightarrow K^-, X^+$

Lower Mass, Charged D($^*$), Recoil Region

No evidence for a D$^{**\ast}(2680)$ although D$^+$, D$^{*\ast}$, and D$^{**\ast}$ signals are seen. The $K^-, D^+$ and $K^-, D^{*\ast}$ branching fractions are consistent with PDG 2014 values.
Higher Mass, Charged Recoil Region

\[ B^0 \rightarrow K^- , X^+ \]

Sensitive to narrow peaks ($\Gamma < 20 \text{ MeV}$).
No structures evident. Sensitivity to BF's
$\sim (3 - 5) \times 10^{-4}$. 

May 18, 2015
Michael D Sokoloff
Charmonium Results

Results from the fits of the K momentum spectrum in the charmonium mass region for 1.67 M reconstructed B± events. (Peak positions and widths in MeV; upper limits are 90% CL)

<table>
<thead>
<tr>
<th>Particle</th>
<th>Yield</th>
<th>Peak Position</th>
<th>Width</th>
<th>BF(10⁻⁴)</th>
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</thead>
<tbody>
<tr>
<td>J/ψ</td>
<td>516±67</td>
<td>2982±5</td>
<td>&lt;43</td>
<td>9.6±1.2(stat)±0.8(sys)</td>
</tr>
<tr>
<td>ηc</td>
<td>655±77</td>
<td></td>
<td></td>
<td>13.3±1.8(stat)±0.4(sys)±0.3(ref)</td>
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<tr>
<td>χc0</td>
<td>218±76</td>
<td>3632 ± 7</td>
<td>&lt;33</td>
<td>4.4±0.9</td>
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<tr>
<td>χc1</td>
<td>192±35</td>
<td></td>
<td></td>
<td>7.0±1.3(stat)±1.0(sys)</td>
</tr>
<tr>
<td>χc2</td>
<td>0±32</td>
<td></td>
<td></td>
<td>&lt;1.2</td>
</tr>
<tr>
<td>ηc (2S)</td>
<td>283±94</td>
<td></td>
<td></td>
<td>6.0±2.1(stat)±0.4(sys)</td>
</tr>
<tr>
<td>Ψ'</td>
<td>293±90</td>
<td></td>
<td></td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>Ψ(3770)</td>
<td>0±49</td>
<td></td>
<td></td>
<td>1.4±1.5 or &lt; 4.4</td>
</tr>
<tr>
<td>X(3872)</td>
<td>75±81</td>
<td></td>
<td></td>
<td></td>
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</table>

May 18, 2015      Michael D Sokoloff
D-meson Results

BABAR Preliminary

<table>
<thead>
<tr>
<th>Particle</th>
<th>Yield</th>
<th>Peak Position</th>
<th>BF(10^{-4})</th>
<th>PDG 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>D^0</td>
<td>126±20</td>
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<td>3.5±0.5(stat)±0.3(sys)</td>
<td>3.7±0.17</td>
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<tr>
<td>D^*0</td>
<td>126±21</td>
<td></td>
<td>3.5±0.5(stat)±0.3(sys)</td>
<td>4.2±0.34</td>
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<tr>
<td>D^{**0}</td>
<td>97±25</td>
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<td>2.1±0.5(stat)±0.3(sys)</td>
<td>-</td>
</tr>
<tr>
<td>D^{**0}(2680)</td>
<td>95±29</td>
<td>2.68±0.003</td>
<td>2.1±0.6(stat)±0.3(sys)</td>
<td>-</td>
</tr>
<tr>
<td>D^±</td>
<td>44±10</td>
<td></td>
<td>3.3±0.8(stat)±0.3(sys)</td>
<td>2.0±0.21</td>
</tr>
<tr>
<td>D^{*±}</td>
<td>40±10</td>
<td></td>
<td>3.0±0.8(stat)±0.3(sys)</td>
<td>2.1±0.16</td>
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<tr>
<td>D^{**}(2420)^±</td>
<td>52±13</td>
<td></td>
<td>3.9±1.0(stat)±0.3(sys)</td>
<td>-</td>
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</table>

Results from the fits of the K momentum spectra in the D region mass, performed for B^± and B^0 samples of 1.67 M and 0.8 M reconstructed B events, respectively. (Peak position reported in GeV)
Summary and Outlook

• **BABAR** has measured exclusive $B \rightarrow K, X$ final state branching fractions for a series of $X =$ charmonium and $D(\ast)$ channels.

• Because these measurements are inclusive, they can be used in conjunction with exclusive final state measurements to determine absolute charmonium and $D(\ast)$ branching fractions, particularly for the $\eta_c$ and $\eta_c(2S)$. They also provide lower bounds for observed $X(3872)$ modes. With the 100x statistics anticipated from Belle-II, the precision of BF measurements will become a few percent.

• We observe a new $D^{**0}$ at a mass of $(2680 \pm 3)$ MeV with $3.3\sigma$ significance. We do not observe the charged analogue.