Measurement of $\mathcal{B}(\Upsilon(4S) \rightarrow B^0 \bar{B}^0)$

Romulus Godang
The University of Mississippi

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BABAR Collaboration Meeting

On behalf of
D. Summers, L. Cremaldi, R. Kroeger

- Motivation
- Reconstruction Method
- Analysis Technique
- Systematic Errors
- Summary
Motivation

\( f_{00} \equiv \mathcal{B}(\Upsilon(4S) \to B^0 \bar{B}^0) \)

- First direct measurement of \( f_{00} \)
- Important for normalizing all \( B \) branching fractions
- Mostly published papers assume \( \mathcal{B}(\Upsilon(4S) \to B \bar{B}) \approx 100\% \)
- Enhance our knowledge of isospin violation effects in \( \Upsilon(4S) \) decays

Semileptonic \( B \) Decay

A good place to measure \( f_{00} \):
- Largest \( \mathcal{B} \) of any exclusive \( B \) decay
- Simplest \( B \) decay transition
  (External spectator)
- Lepton current (weak interaction)
  (Understood and calculable)
Partial Reconstruction:

- \( \bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell \) (\( D^{*+} \rightarrow D^0 \pi^+ \))
- \( D^{*+} \) is identified by soft \( \pi^+ \) only
- Undetected neutrino is inferred by conservation of mom. and energy

\[
\mathcal{M}_\nu^2 \equiv (E_{\text{beam}} - \bar{E}_{D^*} - E_\ell)^2 - (\vec{p}_{D^*} + \vec{p}_\ell)^2
\]

- 1.5 GeV/c < \( p_\ell \) < 2.5 GeV/c
- 60 MeV/c < \( p_\pi \) < 200 MeV/c

If the decay has been properly reconstructed, \( \mathcal{M}_\nu^2 \) will peak \( \sim \) zero

Theoretical Predictions

- Precise \( f_{00} \) is a sensitive probe to isospin violation in \( \Upsilon(4S) \) decays

\[
\frac{f_{+-}}{f_{00}} \equiv \frac{\Gamma(\Upsilon(4S)\rightarrow B^+ B^-)}{\Gamma(\Upsilon(4S)\rightarrow B^0 B^0)} \sim 1.03 - 1.25
\]

<table>
<thead>
<tr>
<th>Authors</th>
<th>( R^{+}/0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atwood et al. (1990)</td>
<td>( \sim 1.18 )</td>
</tr>
<tr>
<td>Byers et al. (1990)</td>
<td>1.05 - 1.10</td>
</tr>
<tr>
<td>Lepage (1990)</td>
<td>1.03 - 1.14</td>
</tr>
<tr>
<td>Kaiser et al. (2003)</td>
<td>1.04 - 1.25</td>
</tr>
<tr>
<td>Voloshin (2003)</td>
<td>( \sim 1.19 )</td>
</tr>
</tbody>
</table>

The fact: \( \beta_B \sim 0.065 \) (small)

- Non-relativistic process
- Coulomb correction is needed
Experimental Results

The previous measurements of $R^{+/0}$:

<table>
<thead>
<tr>
<th>$R^{+/0}$</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.006 \pm 0.036 \pm 0.031$</td>
<td>BABAR</td>
</tr>
<tr>
<td>$1.058 \pm 0.084 \pm 0.136$</td>
<td>CLEO</td>
</tr>
<tr>
<td>$1.10 \pm 0.06 \pm 0.05$</td>
<td>BABAR</td>
</tr>
<tr>
<td>$1.04 \pm 0.07 \pm 0.04$</td>
<td>CLEO</td>
</tr>
<tr>
<td>$1.04 \pm 0.13 \pm 0.12$</td>
<td>CLEO</td>
</tr>
</tbody>
</table>

$R^{+/0}$ values are consistent with unity and depends on:

- the ratio of $B^+$ and $B^0$ lifetime
- the assumption of isospin symmetry

Previous results has shown P.R. is a powerful tools in its statistical error

Data Sample

Reconstructing $(\ell^\pm - \pi^\mp)$ of opposite charge with $\ell = e, \mu$

- Run1+Run2: 2000-2001-2002:
  - $\Upsilon(4S)$-resonance: $82 \text{ fb}^{-1}$
  - Off-resonance: $10 \text{ fb}^{-1}$
  - $B^0\bar{B}^0$: $190 \text{ fb}^{-1}$
  - $B^+B^-$: $190 \text{ fb}^{-1}$

Special thanks to:
F. Simonetto, M. Rotondo (Padova) for using their sample
Analysis Technique

Tags Selection

Single and double tag samples:

- **Single tags** $(\mathcal{M}_\nu^2)$ → at least one neutral $B$ partially reconstructed

- Its total yield is denoted by $N_s$

- **Double tags** $(\mathcal{M}_\nu^2)$ → both neutral $B$ partially reconstructed

- Its total yield is denoted by $N_d$

- **In the double-tagged sample:**
  
  - $1^{st}$ candidate is labeled as $\mathcal{M}_\nu^1$
  
  - $2^{nd}$ candidate is labeled as $\mathcal{M}_\nu^2$
  
  - $\mathcal{M}_\nu^1$ and $\mathcal{M}_\nu^2$ are randomly labeled

**$f_{00}$ Determination**

The correlation of $N_s$ and $N_d$ to branching fractions:

$$N_s = 2 \ N_{B\bar{B}} \ f_{00} \ \epsilon_s \ \mathcal{B}(\bar{B}^0 \to D^*+\ell^-\bar{\nu}_\ell)$$

$$N_d = N_{B\bar{B}} \ f_{00} \ \epsilon_d \ \mathcal{B}(\bar{B}^0 \to D^*+\ell^-\bar{\nu}_\ell)^2$$

where:

- $N_{B\bar{B}}$ is the total of $B\bar{B}$ events

- $\epsilon_s(\epsilon_d)$ = reconstruction efficiencies of the single(the double) tags

- Defined $C = \epsilon_d/\epsilon_s^2$ and solve $f_{00}$:

$$f_{00} = \frac{CN_s^2}{4N_dN_{B\bar{B}}}$$
Sanity Check

$\mathcal{M}_1^2$ vs $\mathcal{M}_2^2$ (with all $\mathcal{M}_1^2$ events)

$\mathcal{M}_2^2$ Additional Cut

- In the double tags, the first candidate fall into the signal region
  - Signal region: $\mathcal{M}_2^2 > -2.0 \text{ GeV}^2/c^4$
  - Sideband: $-8 < \mathcal{M}_2^2 < -4 \text{ GeV}^2/c^4$

- Efficiency correlation between single tags and double tags

- First row: 1) data  2) Continuum
- Second row: 1) $B^0 \overline{B}^0$  2) $B^+B^-$
**Backgrounds**

- Single & double tag backgrounds:
  - Continuum: $e^+e^- \rightarrow \gamma^* \rightarrow q\bar{q}$
  - Combinatoric: random combinations of leptons and soft pions
  - Peaking: $B \rightarrow D^*(n\pi)\ell\bar{\nu}_\ell$ decays, $D^*(n\pi)$ may (may not) from $D^{**}$
- Additional backgrounds for double tags
  - $\mathcal{M}^{1\nu}_1$ Combinatoric:
    1\textsuperscript{st} candidate is combinatoric & 2\textsuperscript{nd} candidate is signal
  - $\mathcal{M}^{1\nu}_2$ Peaking:
    1\textsuperscript{st} candidate is a peaking & 2\textsuperscript{nd} candidate is signal

**Wrong Sign Combination**

Monte Carlo simulation is validated by the wrong sign combination: $(\ell^\pm - \pi^\pm)$

Wrong Sign Combination

- No signal is expected for both tags
## Summary of Fitting Results

### Data/MC of the Wrong Sign Combination

<table>
<thead>
<tr>
<th>RG</th>
<th>Source</th>
<th>Single Tags</th>
<th>Double Tags</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data-MC</td>
<td>$\Delta$</td>
<td>$-1346 \pm 2140$</td>
<td>$-80 \pm 82$</td>
</tr>
<tr>
<td>SG</td>
<td>C.L.(%)</td>
<td>69</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>$\chi^2/d.o.f$</td>
<td>17/19</td>
<td>13/16</td>
</tr>
<tr>
<td>Data-MC</td>
<td>$\Delta$</td>
<td>$-816 \pm 2086$</td>
<td>$78 \pm 80$</td>
</tr>
<tr>
<td>SB</td>
<td>C.L.(%)</td>
<td>98</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>$\chi^2/d.o.f$</td>
<td>11/21</td>
<td>9/21</td>
</tr>
<tr>
<td>Data-MC</td>
<td>$\Delta$</td>
<td>$709 \pm 2995$</td>
<td>$71 \pm 84$</td>
</tr>
<tr>
<td>All</td>
<td>C.L.(%)</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>$\chi^2/d.o.f$</td>
<td>41/55</td>
<td>40/53</td>
</tr>
</tbody>
</table>

- It shows the Monte Carlo is working well both for single and double tag samples.
1. Data with continuum
2. Continuum subtracted
3. Combinatoric background
4. Data with combinatoric

1. Data with continuum, $M_{1\nu}^2$ bkg
2. Cont. and $M_{1\nu}^2$ bkg subtracted
3. Combinatoric background
4. Data with combinatoric
Counting Procedure

Single Tags

Double Tags

Measurement of $\mathcal{B}(\Upsilon(4S) \rightarrow \bar{B}^0 B^0)$ (page 11)
Results

$\chi^2$ Binned Fit:

<table>
<thead>
<tr>
<th>Source</th>
<th>Single Tags</th>
<th>Double Tags</th>
</tr>
</thead>
<tbody>
<tr>
<td>$BB$ comb.</td>
<td>$558089 \pm 756$</td>
<td>$1522 \pm 41$</td>
</tr>
<tr>
<td>$BB$ pkg</td>
<td>$68168 \pm 261$</td>
<td>$300 \pm 17$</td>
</tr>
<tr>
<td>Signal</td>
<td>$786266 \pm 1948$</td>
<td>$3563 \pm 75$</td>
</tr>
<tr>
<td>Continuum</td>
<td>$238504 \pm 1330$</td>
<td>$162 \pm 37$</td>
</tr>
<tr>
<td>$M1_\nu^2$ comb.</td>
<td>—</td>
<td>$183 \pm 14$</td>
</tr>
<tr>
<td>$M1_\nu^2$ pkg</td>
<td>—</td>
<td>$62 \pm 8$</td>
</tr>
<tr>
<td>$\chi^2$/d.o.f</td>
<td>$41/56$</td>
<td>$48/56$</td>
</tr>
<tr>
<td>C.L.</td>
<td>$93%$</td>
<td>$75%$</td>
</tr>
</tbody>
</table>

- **Counting procedure:**
  - Single tags: $787469 \pm 2013$
  - Double tags: $3550 \pm 96$

- **Both results are agreed well**

- **Total $B\bar{B}$ events: $88725728 \pm 22640$**
**Systematics Error**

**Summary of Systematics Error**

<table>
<thead>
<tr>
<th>Source</th>
<th>$\frac{\delta(f_{00})}{f_{00}}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{M}1^{2}$ peaking</td>
<td>0.1</td>
</tr>
<tr>
<td>Monte Carlo modeling</td>
<td>0.5</td>
</tr>
<tr>
<td>Peaking background</td>
<td>0.8</td>
</tr>
<tr>
<td>$B$ counting</td>
<td>1.2</td>
</tr>
<tr>
<td>Efficiency bias</td>
<td>0.4</td>
</tr>
<tr>
<td>Other type of signal</td>
<td>0.1</td>
</tr>
<tr>
<td>Monte Carlo shape</td>
<td>0.6</td>
</tr>
<tr>
<td>Simulation sample</td>
<td>1.0</td>
</tr>
<tr>
<td>Total</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**Precise $f_{00}$ Measurement**

By combining the yields of the signal tags, double tags and total $B\bar{B}$, we found $f_{00}$:

$$f_{00} = 0.486 \pm 0.010(stat.) \pm 0.010(sys.)$$

- This is a model-independent analysis
- The complete note for $f_{00}$ analysis:
  - BAD # 553, 675, 731
    → supporting documents
  - BAD # 827 → PRL draft

- Syst. error on $B$ counting: 1.2%
  including the effect of 2% of $\mathcal{B}(\Upsilon(4S) \rightarrow non-B\bar{B})$

- We will validate the Red ones
We report the first direct measurement of $f_{00}$:

$$f_{00} = 0.486 \pm 0.010 (\text{stat.}) \pm 0.010 (\text{sys.})$$

This $f_{00}$ measurement is independent of:

- $\bar{B}^0$-lifetime
- $D^{*-}$-branching fraction

Precision measurement of $f_{00}$ is important value for normalizing all $B$ branching fractions

This $f_{00}$ measurement is important to understand the isospin violation effect in $\Upsilon(4S)$ decays

Thanks to A. Soffer, S. Ganzhur, M. Zito, F. Simonetto for their helps!