Search for $B^0 \rightarrow \ell^+ \ell^-$ at Belle

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DPF, August 4, 2015
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The Belle Collaboration has accumulated 772 million events at the $\Upsilon(4S)$ resonance.

Data-taking ended in 2010 and was reprocessed with better tracking in 2011. Analysis of these data is on-going.

$\sqrt{s} = 10.58\text{GeV} \rightarrow \text{e}^+\text{e}^- \rightarrow \Upsilon(4S) \rightarrow \text{B}\bar{\text{B}}$

Peak luminosity = $2.1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

Integrated luminosity $\approx 1000 \text{ fb}^{-1}$

KEKB instantaneous luminosity: $\mathcal{L} = 2.1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
SVD measures B\bar{B} vertices.

The Silicon Vertex Detector provides vertex reconstruction resolution of better than 100 μm.
CDC provides tracking data.

The Central Drift Chamber provides:
- 3D trajectories and momentum vectors
- Measurement of charged particle energy loss in the chamber gas (dE/dx) for particle identification
ECL identifies electrons.

The electromagnetic calorimeter is the main sub-detector for electron identification.

The ECL also detects photons.
KLM identifies muons.

The $K_{\text{Long}}$-μ detector identifies muons and $K_L$ particles over a large momentum range.
The sub-detectors combine for efficient particle identification.
The standard model allows for $B^0 \to e^+ e^-$ and $B^0 \to \mu^+ \mu^-$ but not $B^0 \to e^\pm \mu^\mp$.

$B^0 \to e^+ e^-$ and $B^0 \to \mu^+ \mu^-$ proceed through flavor changing weak current.

$B^0 \to \ell^+ \ell^-$ is a helicity suppressed decay. Either the lepton or anti-lepton must be in a suppressed state.
Extensions of the standard model could allow $B^0 \rightarrow e^\pm \mu^{\mp}$ to occur.

Neutrino Oscillation ($\approx 10^{-60}$)

Hypothetical particles like leptoquarks

Any observation of $B^0 \rightarrow e^\pm \mu^{\mp}$ would indicate new physics.
Previous studies have set upper limits on branching fractions.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Standard Model Prediction</th>
<th>Measured Branching fraction</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \to e^+e^-$</td>
<td>$2.3 \times 10^{-15}$</td>
<td>$&lt; 8.3 \times 10^{-8}$</td>
<td>CDF</td>
</tr>
<tr>
<td>$B \to \mu^+\mu^-$</td>
<td>$1.0 \times 10^{-10}$</td>
<td>$&lt; 6.3 \times 10^{-10}$</td>
<td>LHCb</td>
</tr>
<tr>
<td>$B \to e^\pm\mu^\mp$</td>
<td>0</td>
<td>$&lt; 2.8 \times 10^{-9}$</td>
<td>LHCb</td>
</tr>
</tbody>
</table>

LHCb measured

$\mathcal{B}(B_s \to \mu^+\mu^-) = [3.1 \pm 0.7] \times 10^{-9}$

Skimming requirements

- Uses one positive and one negative track to form a B candidate.
- Skim pass range
  - $-1.0 \text{ GeV} \leq \Delta E \leq 0.5 \text{ GeV}$
  - $5.20 \text{ GeV}/c^2 \leq M_{BC} \leq 5.30 \text{ GeV}/c^2$
- Skimmed data are written to ROOT files for analysis.

$\Delta E$ has an asymmetric range to allow for electron bremsstrahlung.

$B^0 \rightarrow e^+e^-$
Continuum suppression variables: Event shape

\[ e^+ e^- \rightarrow Y(4S) \rightarrow B \bar{B} \]  
(Spherical)

\[ e^+ e^- \rightarrow q \bar{q} \]  
(Jet-like)
Continuum suppression variables: $\cos \theta_B$
Continuum suppression variables: $\Delta z$
Continuum suppression variables are combined into a single likelihood ratio.
Around 10% of events have no $\Delta z$.  

- These are otherwise good events but with a failed vertex reconstruction.  
- These events are treated separately.  
- All events are recombined into one data set at the end of analysis.
A cut on \( N_{\text{track}} \geq 5 \) helped reduce continuum and tau-pair bkg.s.

Number of events expected for one stream of data across full fit region
\((5.2 \leq M_{\text{BC}} \leq 5.3 \text{ GeV/c}^2 \text{ and } |\Delta E| \leq 0.5 \text{ GeV})\)
A cut on the pion ID reduces \( B \rightarrow K \pi \) background.

\[
\mathcal{L}_{\pi/K} = \frac{\mathcal{L}_\pi}{\mathcal{L}_\pi + \mathcal{L}_K}
\]

- Cut is placed at \( \mathcal{L}_{\pi/K} \geq 0.5 \).
- Reduces \( B \rightarrow K \pi \) by a factor of 10 and \( B \rightarrow KK \) by a factor of 100.
- Signal modes reduced by 0% - 3%.
A sensitivity study found the best expected upper limit.

- Use null signal and the expected number of background events.
- Generate 10,000 toy MC sets.
- Fit toy MC to PDFs of signal and background.
- Extract signal yield.
- Optimize cuts on continuum suppression to get best sensitivity on branching fraction.

$$BF_{UL} = \frac{UL90}{\epsilon_{sig} N_{events}}$$
Linearity study: Previous method used standard ROOT fits.

- Gives negative bias for $\#\text{signal}_{\text{gen}} < 5$
- Negative bias is caused by a low tail in number of fitted signal yield distribution
Linearity study: Previous method used basic ROOT fits.

Near -18 signal events found

$B \rightarrow \mu\mu$

0 signal events generated

$M_{bc}$

$\Delta E$
Linearity Study: New method uses multiple initial guesses.

- Good for $\#signal_{\text{gen}} > 0$.
- $\#signal_{\text{gen}} = 0$ values show improvement but still low ($-0.7 \rightarrow -0.8$).
Summary and Plan

SUMMARY
- Skimmed data
- Optimized cuts
- Completed sensitivity and linearity studies

PLAN
- Unblind the study
- Calculate systematic errors
- Publish results