Search for $B^0 \rightarrow \rho^0 \rho^0$ Decay

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  - $e^+e^- \rightarrow u,d,s,c$ background suppression
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The Prospect of $B^0 \rightarrow \rho^0 \rho^0$ Mode

- The CP violation in the standard model can be described by the presence of a complex phase in the three generation CKM quark-mixing matrix.
- One of the CKM phase angel $\phi_2$ (or $\alpha$) can be determined by measuring a time-dependent CP asymmetry in charmless $b \rightarrow u\bar{u}d$ decays, such as $B \rightarrow \pi\pi$ or $B \rightarrow \rho\rho$, etc.
- However, most of $B$ decay modes consist of not only pure electroweak amplitude (tree diagram), but also gluonic penguin loop diagrams (penguin diagram).
- To extract pure electroweak amplitude for a precise $\phi_2$ (or $\alpha$) measurement, we need some special skills; one of them is the isospin analysis.
The Prospect of $B^0 \to \rho^0 \rho^0$ Mode

The penguin contribution can be constrained by using isospin relations. This decay mode $B^0 \to \rho^0 \rho^0$ can complete the isospin analysis of $B \to \rho \rho$. (M. Gronau and D. London, PRL 65, 3381 (1990))

$\phi_2^{\text{eff}} = \phi_2 + \Delta \phi_2^{+-}$

Penguin Contribution

Isospin triangles relating the amplitudes of $B \to \rho^+ \rho^-$, $B \to \rho^+ \rho^0$, $B \to \rho^0 \rho^0$ and their charge conjugates for CP-even longitudinal polarization.
Latest Development of $B^0 \rightarrow \rho^0 \rho^0$ Measurement

- BABAR measurement: (B.Aubert et al. PRL 98 111801 (2007))
  $$BF(\rho^0 \rho^0) = (1.07 \pm 0.33 \pm 0.19) \times 10^{-6}, f_L = 0.87 \pm 0.13 \pm 0.04$$
  (with 3.5$\sigma$, 384M $B\bar{B}$)

- BABAR measurement: (B.Aubert et al. arXiv:0708.1630 (2007))
  $$BF(\rho^0 \rho^0) = (0.84 \pm 0.29 \pm 0.17) \times 10^{-6}, f_L = 0.70 \pm 0.14 \pm 0.05$$
  (with 3.6$\sigma$, 427M $BB$)

  $$BF(\rho^0 \rho^0) < 1.6 \times 10^{-6}, \text{assume } f_L = 1$$
  (with 520M $B\bar{B}$)

- BELLE measurement: (2008)
  New Result with 657M $B\bar{B}$
KEKB Asymmetry-Energy $e^+e^-$ Collider

- Two separate rings for $e^+$ and $e^-$
- Energy in CM is 10.58 GeV $\Rightarrow$ Y(4S)
- Ring length 3 Km

Results are based on 657 MBB pairs

Integrated luminosity (fb)

Total L = 766/fb
Reconstruct $B^0$ with four charged pions (good pions):

$$B^0 \rightarrow \rho^0 \rho^0 \rightarrow (\pi^+ \pi^-)(\pi^+ \pi^-)$$

- Four reconstructed variables:
  - Beam-energy constrained mass
    \[ M_{bc} = \sqrt{E_{beam}^2 - P_B^2} \]
  - Energy difference:
    \[ \Delta E = E_B - E_{beam} \]
  - Two $\pi^+\pi^-$ invariant masses:
    \[ M_{\pi^+\pi^-} = \sqrt{E_{\pi^+\pi^-}^2 - P_{\pi^+\pi^-}^2} \]

(Two possible $\pi^+\pi^-$ pairs and the probability of correct combination is considered)

- Veto $B \rightarrow D^0 X$, $D^{\pm} X$, $D_s^{\pm} X$ modes.
- For multiple counting events, we select the best $\chi^2$ of candidate from vertex fit.
The dominant background in $B$ analysis is $e^+e^- \rightarrow u,d,s,c$ “continuum” (~3x BB)

To suppress continuum background, we can use event shape variables.

$\gamma(4S)$

$\bar{B}B$ (Spherical)
Extract Signals By 4-D Un-binned ML Fit \([\Delta E, M_{bc}, M_1(\pi\pi), M_2(\pi\pi)]\)

Likelihood function :

\[ L = \exp\left(-\sum n_j \prod_{i=1}^{N_{cand}} \left( \sum n_j P_j^i \right) \right) \]

where \( P_j^i = P_{\text{Smoothed}}(\Delta E^i, M_{bc}^i) \times P_{\text{Smoothed}}(M_1^i, M_2^i) \rangle \)

\((j = \text{event type category for signals or backgrounds})\)

For signal PDFs:

\[ P_{\text{Signal}}^i = (1 - f_{SCF}) \times P_{\text{Right}}^i + f_{SCF} \times P_{\text{SCF}}^i \]

For continuum and Generic B PDFs :

\[ P_{q\bar{q},BB}^i = P_{\text{Chebyshev}}(\Delta E^i) \times P_{\text{ARGUS}}(M_{bc}^i) \times P_{\text{Smoothed}}(M_1^i, M_2^i) \]
\[ [M_1(\pi\pi), M_2(\pi\pi)] \text{ Variables Are Used To Distinguish Signal Modes} \]

\[ B^0 \rightarrow \rho^0 \rho^0 \]
\[ B^0 \rightarrow \rho^0 \pi\pi \]
\[ B^0 \rightarrow \alpha_1 \pi \]
\[ B^0 \rightarrow \pi\pi\pi\pi \]

Use 4-D fit to a grand \( M_1(\pi\pi) \) v.s. \( M_2(\pi\pi) \) region:
\[ M_{1,2}(\pi\pi) \in (0.55, 1.7) \text{ GeV/c}^2 \]
Measurement Results

<table>
<thead>
<tr>
<th>Mode</th>
<th>Yield</th>
<th>Eff. (%)</th>
<th>$\Sigma$</th>
<th>BF (x10^{-6})</th>
<th>UL (x10^{-6})</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho^0\rho^0$</td>
<td>$24.5^{+23.6+9.7}_{-22.1-9.9}$</td>
<td>9.16</td>
<td>1.0</td>
<td>$0.4 \pm 0.4 \pm 0.2$</td>
<td>$&lt;1.0$ (assume $f_L=1$)</td>
</tr>
<tr>
<td>$\rho^0\pi\pi$</td>
<td>$161.2^{+61.2+26.0}_{-59.4-28.5}$</td>
<td>2.90</td>
<td>1.3</td>
<td>$5.9^{+3.5+2.7}_{-3.4-2.8}$</td>
<td>$&lt;11.9$</td>
</tr>
<tr>
<td>$4\pi$</td>
<td>$112.5^{+67.4+51.5}_{-65.6-53.7}$</td>
<td>1.98</td>
<td>2.5</td>
<td>$12.4^{+4.7+2.0}_{-4.6-2.2}$</td>
<td>$&lt;19.0$</td>
</tr>
<tr>
<td>$\rho^0f_0$</td>
<td>$-11.8^{+14.3+4.9}_{-12.9-3.6}$</td>
<td>5.10</td>
<td>0.0</td>
<td>0.0</td>
<td>$&lt;0.6$</td>
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<tr>
<td>$f_0f_0$</td>
<td>$-7.7^{+4.7+3.0}_{-3.5-2.9}$</td>
<td>2.75</td>
<td>0.0</td>
<td>0.0</td>
<td>$&lt;0.4$</td>
</tr>
<tr>
<td>$f_0\pi\pi$</td>
<td>$6.3^{+37.0+18.0}_{-34.7-18.1}$</td>
<td>1.55</td>
<td>0.0</td>
<td>$0.6^{+3.6}_{-3.4} \pm 1.8$</td>
<td>$&lt;7.3$</td>
</tr>
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</table>

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## Systematic Uncertainties

<table>
<thead>
<tr>
<th>Source</th>
<th>$\rho^0\rho^0$</th>
<th>$\rho^0\pi\pi$</th>
<th>$4\pi$</th>
<th>$\rho^0f_0$</th>
<th>$f_0f_0$</th>
<th>$f_0\pi\pi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fitting PDF</td>
<td>±10.2</td>
<td>±29.8</td>
<td>±12.2</td>
<td>±18.6</td>
<td>±31.2</td>
<td>±269.8</td>
</tr>
<tr>
<td>N(a$_1\pi$)</td>
<td>±21.6</td>
<td>±33.5</td>
<td>±2.7</td>
<td>±17.8</td>
<td>±1.3</td>
<td>±39.7</td>
</tr>
<tr>
<td>N(ρ₀ρ⁺)</td>
<td>±0.0</td>
<td>±0.7</td>
<td>±0.2</td>
<td>±0.0</td>
<td>±0.0</td>
<td>±1.6</td>
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<tr>
<td>f$_{SCF}$</td>
<td>-17.6</td>
<td>+13.5</td>
<td>-10.3</td>
<td>-8.5</td>
<td>+9.1</td>
<td>-34.9</td>
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<tr>
<td>Fitting Bias</td>
<td>±16.3</td>
<td>+6.4</td>
<td>+7.8</td>
<td>+30.5</td>
<td>±20.8</td>
<td>±82.5</td>
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<tr>
<td>Interference</td>
<td>+25.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Tracking</td>
<td>±5.3</td>
<td>±4.6</td>
<td>±4.4</td>
<td>±5.0</td>
<td>±4.8</td>
<td>±4.5</td>
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<tr>
<td>PID</td>
<td>±4.8</td>
<td>±3.5</td>
<td>±3.2</td>
<td>±4.4</td>
<td>±3.9</td>
<td>±3.4</td>
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<tr>
<td>LR cut</td>
<td>±3.2</td>
<td>±3.2</td>
<td>±3.2</td>
<td>±3.2</td>
<td>±3.2</td>
<td>±3.2</td>
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<tr>
<td>N(BBar)</td>
<td>±1.3</td>
<td>±1.3</td>
<td>±1.3</td>
<td>±1.3</td>
<td>±1.3</td>
<td>±1.3</td>
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<tr>
<td><strong>Sum (%)</strong></td>
<td><strong>+39.5</strong></td>
<td><strong>+45.8</strong></td>
<td><strong>+16.1</strong></td>
<td><strong>+41.5</strong></td>
<td><strong>+39.3</strong></td>
<td><strong>+285.0</strong></td>
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<tr>
<td></td>
<td><strong>-40.5</strong></td>
<td><strong>-47.7</strong></td>
<td><strong>-17.7</strong></td>
<td><strong>-30.4</strong></td>
<td><strong>-38.2</strong></td>
<td><strong>-287.1</strong></td>
</tr>
</tbody>
</table>
Systematic on Interference for $B^0 \rightarrow \rho^0 \rho^0$ mode

- We test the possible interference between $B^0 \rightarrow a_1 \pi$, non-resonant $4\pi$, $\rho^0 \pi \pi$ and $\rho^0 \rho^0$ by Toy MC.
- Assume the interference term due to the amplitudes for these modes is constant in the $B^0 \rightarrow \rho^0 \rho^0$ signal region; we uniformly vary interference amplitude and phase angle, and then perform a fit in each case to measure the deviations as the systematic uncertainties.

$$\left| \frac{1}{m^2 - m_0^2 + im_0 \Gamma} + Ae^{-i\delta} \right|^2 = A^2 + 2A \left[ \frac{(m^2 - m_0^2) \cos \delta - \Gamma m_0 \sin \delta}{(m^2 - m_0^2)^2 + (\Gamma m_0)^2} \right] + \frac{1}{(m^2 - m_0^2)^2 + (\Gamma m_0)^2}$$

Include this interference term in Toy MC generation and perform a fit to measure the deviation.
Conclusion

- We measure the branching fraction of $B^0 \rightarrow \rho^0 \rho^0$ to be $(0.4 \pm 0.4 \pm 0.2) \times 10^{-6}$ with 1.0σ significance, assume $f_L = 1$, the 90% confidence level upper limit is $<1.0 \times 10^{-6}$. This is the new result with 657M $B\bar{B}$ data sample.

- Basically it is consistent with BABAR measurement. However we find excesses in non-resonant $B^0 \rightarrow 4\pi$ and $B^0 \rightarrow \rho^0 \pi \pi$ decays; BABAR did not find significant evidence for them. Since we consider larger $M(\pi\pi)$ area for the fit, which would make a better measurement for non-resonant feeddown modes.

- We also float the $B^0 \rightarrow a_1 \pi$ yield in the fit; the fit result is $BF(B^0 \rightarrow a_1 \pi) = (33.8 \pm 12.8) \times 10^{-6}$, which is consistent with the assumed value.

- For the yields of $B^0 \rightarrow \rho^0 f_0$, $B^0 \rightarrow f_0 f_0$ and $B^0 \rightarrow f_0 \pi \pi$ decays are not significant, so the corresponding upper limits are also calculated.