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

**Les Rencontres de Physique de la Vallée d'Aoste**

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# *Outline*

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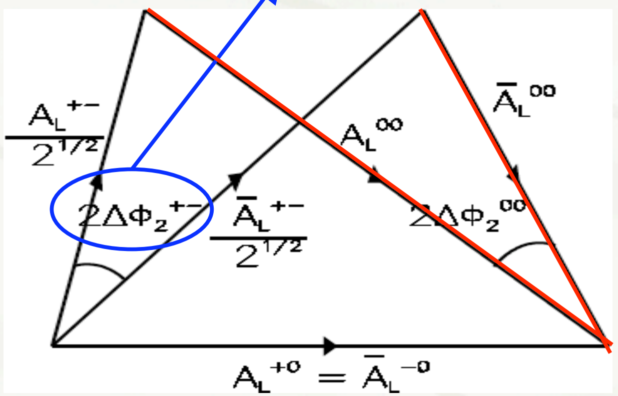
# *The Prospect of $B^0 \to \rho^0 \rho^0$ Mode*

- 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 $b \to u\bar{u}d$ decays, such as $B \to \pi\pi$ or $B \to \rho\rho$, *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))

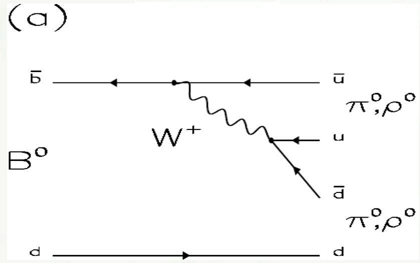
$\phi_2^{eff} = \phi_2 + \Delta\phi_2^{+-}$ **Penguin Contribution**



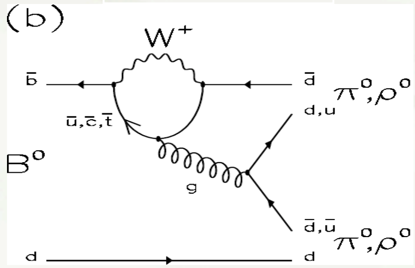

$$A_L^{+-} = BF(B^0 \to \rho^+\rho^-)$$
$$\bar{A}_L^{+-} = BF(\bar{B}^0 \to \rho^+\rho^-)$$
$$A_L^{+0} = BF(B^+ \to \rho^+\rho^0)$$
$$\bar{A}_L^{-0} = BF(\bar{B}^- \to \rho^-\rho^0)$$
$$A_L^{00} = BF(B^0 \to \rho^0\rho^0)$$
$$\bar{A}_L^{00} = BF(\bar{B}^0 \to \rho^0\rho^0)$$

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.

**Tree**




**Penguin**

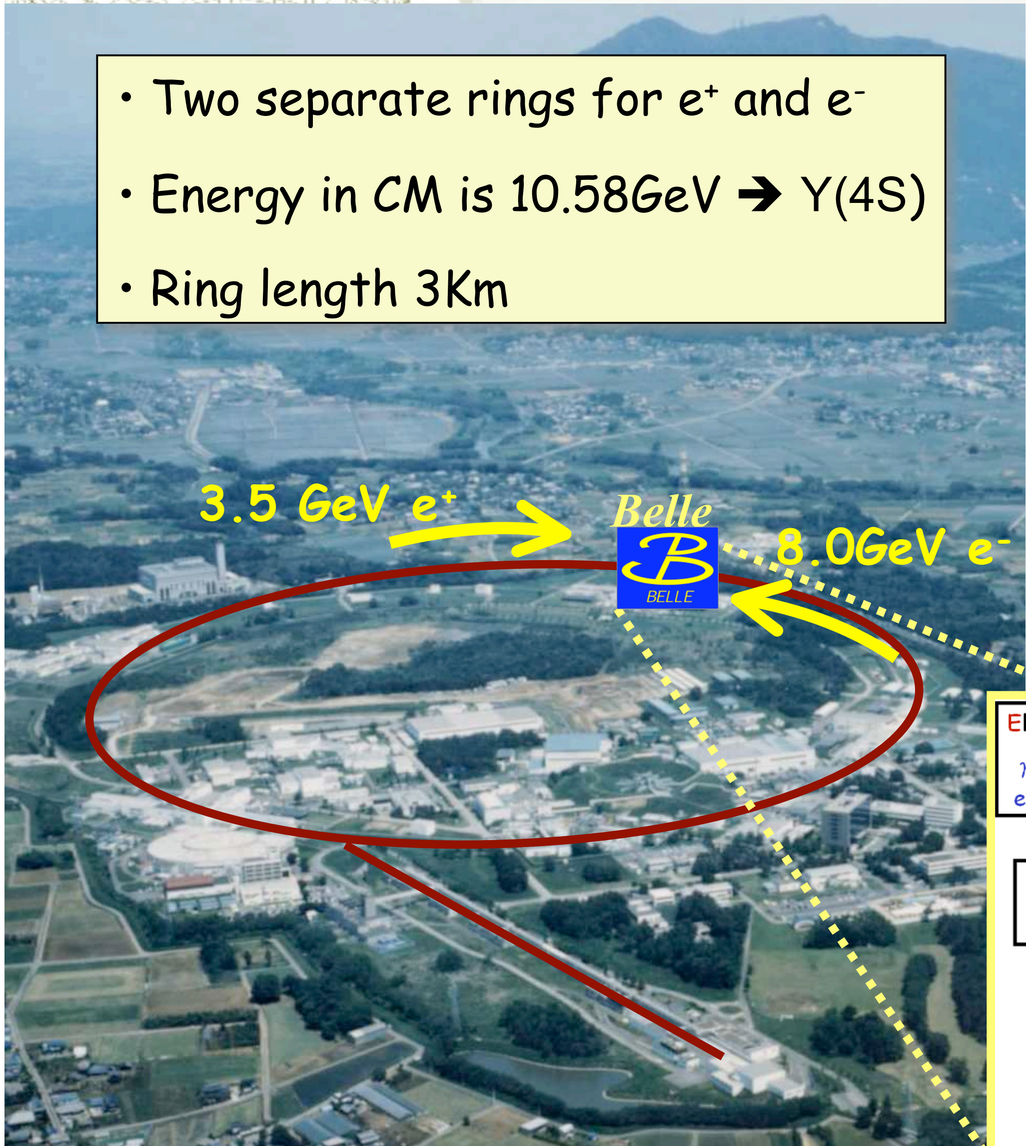


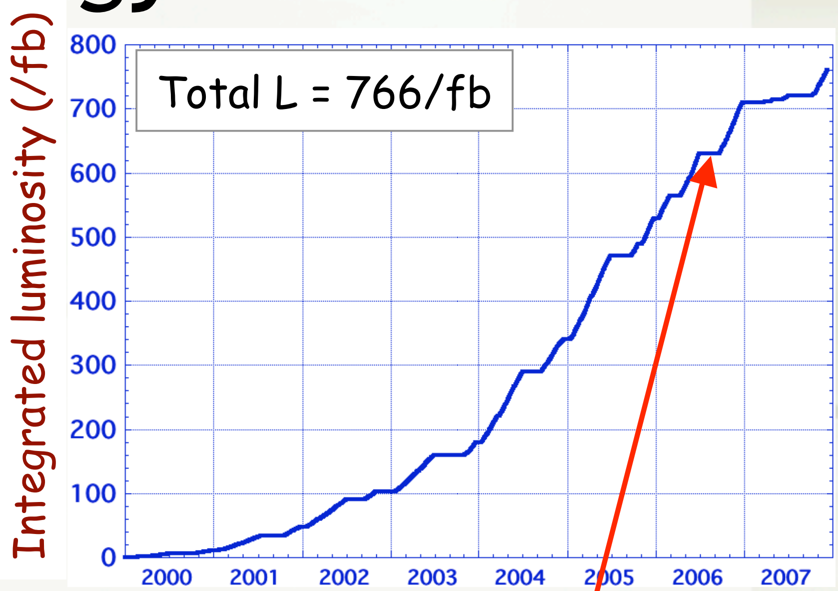
# *Latest Development of* $B^0 \to \rho^0 \rho^0$ *Measurement*

- 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 $B\bar{B}$)
- BELLE measurement: (K.Abe et al., arXiv:0708.2006 (2007))
  $BF(\rho^0\rho^0) < 1.6 \times 10^{-6}$, assume $f_L = 1$
  (with 520M $B\bar{B}$)
- BELLE measurement: (2008)
  New Result with 657M $B\bar{B}$

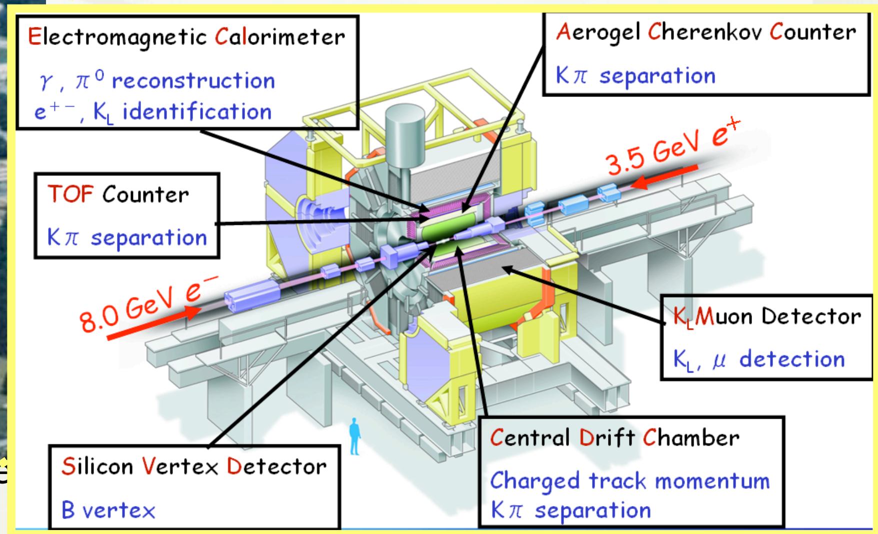
# *KEKB Asymmetry-Energy $e^+e^-$ Collider*

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




Results are based on 657 $MB\bar{B}$ pairs



# *Analysis Method*

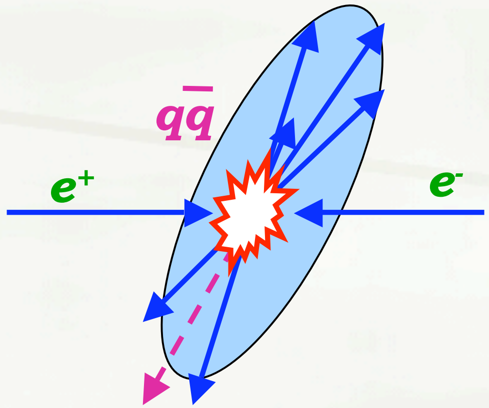
- Reconstruct $B^0$ with four charged pions (good pions) :
  $B^0 \to \rho^0\rho^0 \to (\pi^+\pi^-)(\pi^+\pi^-)$
- Four reconstructed variables :
  - Beam-energy constrained mass $M_{bc} = \sqrt{E_{beam}^2 - P_B^2}$
  - Energy difference : $\Delta E = E_B - E_{beam}$
  - Two $\pi^+\pi^-$ invariant masses : $M_{\pi^+\pi^-} = \sqrt{E_{\pi^+\pi^-}^2 - P_{\pi^+\pi^-}^2}$

  (Two possible $\pi^+\pi^-$ pairs and the probability of correct combination is considered)
- Veto $B \to D^0X$, $D^{\pm}X$, $D_s^{\pm}X$ modes.
- For multiple counting events, we select the best $\chi^2$ of candidate from vertex fit.

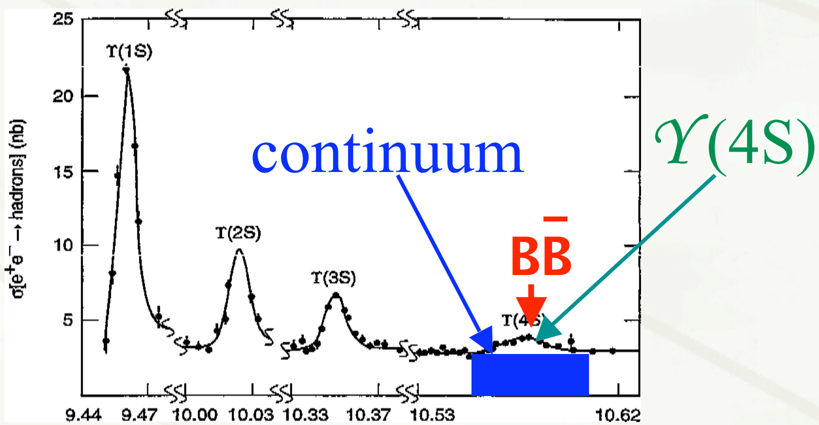
# $e^+e^- \to u,d,s,c$ Background Suppression

The dominant background in *B* analysis is
$e^+e^- \to u,d,s,c$ "continuum"
(~3x BB)

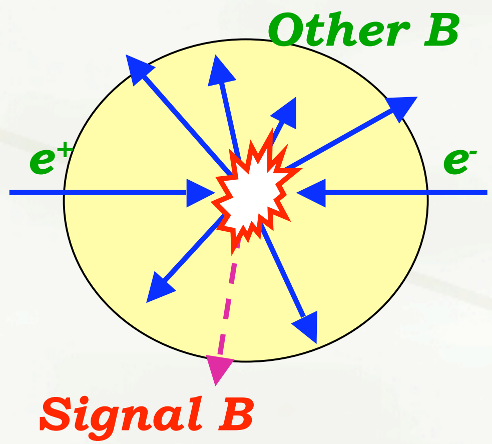
continuum
(Jet-like)




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




$B\bar{B}$
(Spherical)



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

**Likelihood function :**

$$L = \exp\left(-\sum_j n_j\right)\prod_{i=1}^{N_{cand}}\left(\sum_j n_j P_j^i\right)$$

where $P_j^i = p_{Smoothed}(\Delta E^i, M_{bc}^i)_j \times p_{Smoothed}(M_1^i, M_2^i)_j$

( j = event type category for signals or backgrounds)

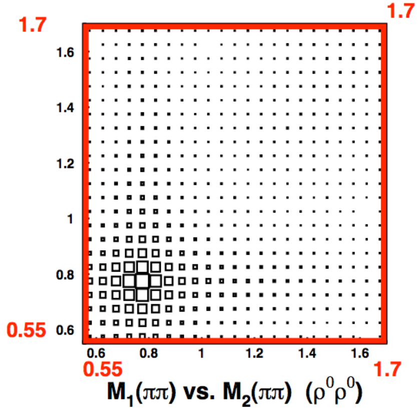
**For signal PDFs:**

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

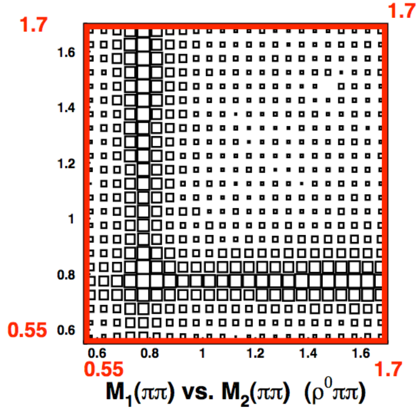
**For continuum and Generic *B* PDFs :**

$$P_{q\bar{q},B\bar{B}}^i = p_{Chebyshev}(\Delta E^i) \times p_{ARGUS}(M_{bc}^i) \times p_{Smoothed}(M_1^i, M_2^i)$$

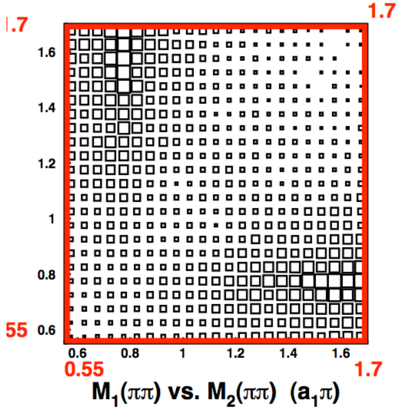
# $[M_1(\pi\pi), M_2(\pi\pi)]$ Variables Are Used To Distinguish Signal Modes



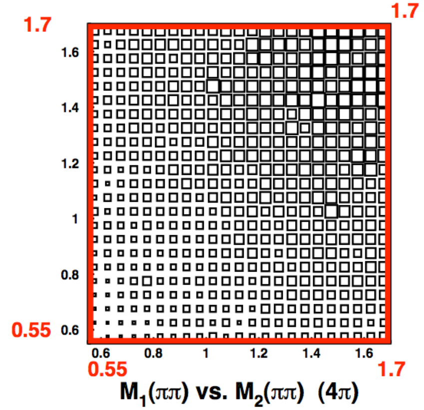

$B^0 \to \rho^0\rho^0$



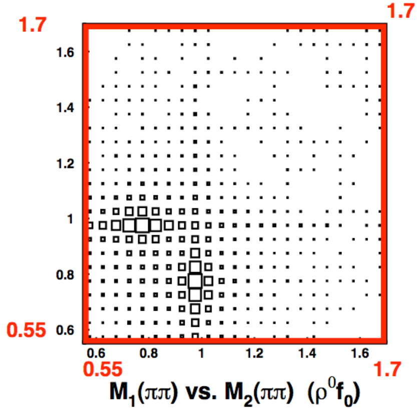

$B^0 \to \rho^0\pi\pi$



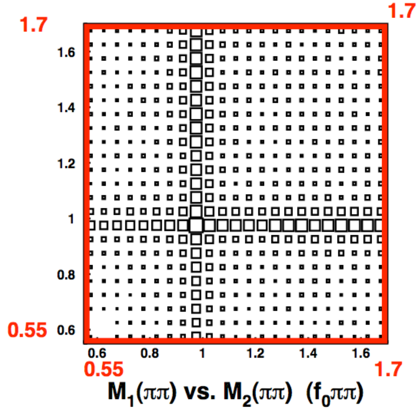

$B^0 \to a_1\pi$



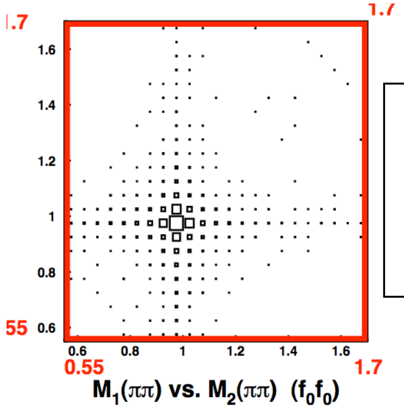

$B^0 \to \pi\pi\pi\pi$




$B^0 \to \rho^0 f_0$



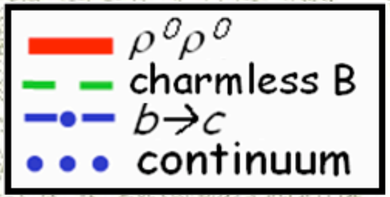

$B^0 \to f_0\pi\pi$



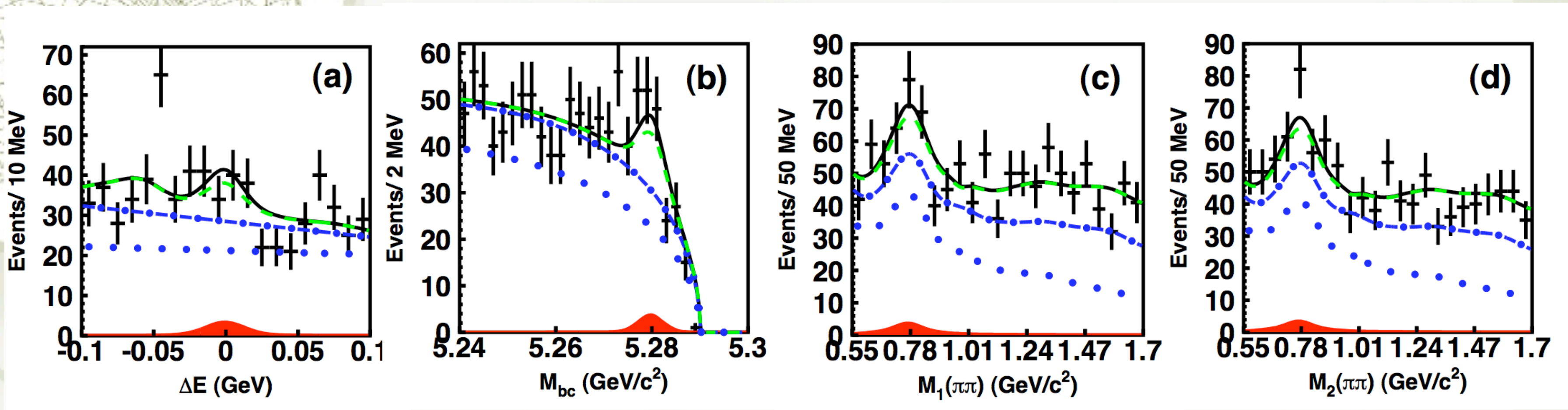

$B^0 \to f_0 f_0$

Use 4-D fit to a grand $M_1(\pi\pi)$ v.s. $M_2(\pi\pi)$ region:

$M_{1,2}(\pi\pi) \in (0.55, 1.7)$ GeV/$c^2$




# *Measurement Results*




| Mode | Yield | Eff.(%) | Σ | BF (x10$^{-6}$) | UL (x10$^{-6}$) |
|---|---|---|---|---|---|
| $\rho^0\rho^0$ | $24.5^{+23.6+9.7}_{-22.1-9.9}$ | 9.16 | 1.0 | 0.4 ± 0.4 ± 0.2 | <1.0 (assume $f_L$=1) |
| $\rho^0\pi\pi$ | $161.2^{+61.2+26.0}_{-59.4-28.5}$ | 2.90 | 1.3 | $5.9^{+3.5+2.7}_{-3.4-2.8}$ | <11.9 |
| $4\pi$ | $112.5^{+67.4+51.5}_{-65.6-53.7}$ | 1.98 | 2.5 | $12.4^{+4.7+2.0}_{-4.6-2.2}$ | <19.0 |
| $\rho^0 f_0$ | $-11.8^{+14.5+4.9}_{-12.9-3.6}$ | 5.10 | 0.0 | 0.0 | <0.6 |
| $f_0 f_0$ | $-7.7^{+4.7+3.0}_{-3.5-2.9}$ | 2.75 | 0.0 | 0.0 | <0.4 |
| $f_0\pi\pi$ | $6.3^{+37.0+18.0}_{-34.7-18.1}$ | 1.55 | 0.0 | $0.6^{+3.6}_{-3.4} \pm 1.8$ | <7.3 |

# Systematic Uncertainties

| Source | $\rho^0\rho^0$ | $\rho^0\pi\pi$ | $4\pi$ | $\rho^0 f_0$ | $f_0 f_0$ | $f_0\pi\pi$ |
|---|---|---|---|---|---|---|
| Fitting PDF | ±10.2 | ±29.8 | ±12.2 | ±18.6 | ±31.2 | ±269.8 |
| $N(a_1\pi)$ | ±21.6 | ±33.5 | ±2.7 | ±17.8 | ±1.3 | ±39.7 |
| $N(\rho^0\rho^+)$ | ±0.0 | ±0.7 | ±0.2 | ±0.0 | ±0.0 | ±1.6 |
| $f_{SCF}$ | -17.6 | +13.5 | -10.3 | -8.5 | +9.1 | -34.9 |
| Fitting Bias | ±16.3 | +6.4 -5.7 | +7.8 -3.3 | +30.5 -14.4 | ±20.8 | ±82.5 |
| Interference | +25.7 -20.8 | - | - | - | - | - |
| Tracking | ±5.3 | ±4.6 | ±4.4 | ±5.0 | ±4.8 | ±4.5 |
| PID | ±4.8 | ±3.5 | ±3.2 | ±4.4 | ±3.9 | ±3.4 |
| LR cut | ±3.2 | ±3.2 | ±3.2 | ±3.2 | ±3.2 | ±3.2 |
| N(BBar) | ±1.3 | ±1.3 | ±1.3 | ±1.3 | ±1.3 | ±1.3 |
| **Sum (%)** | +39.5 -40.5 | +45.8 -47.7 | +16.1 -17.7 | +41.5 -30.4 | +39.3 -38.2 | +285.0 -287.1 |

# Systematic on Interference for $B^0 \to \rho^0 \rho^0$ mode

- We test the possible interference between $B^0 \to a_1 \pi$, 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 $B^0 \to \rho^0 \rho^0$ 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.

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

$\rho^0$ mass

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

# Conclusion

- We measure the branching fraction of $B^0 \to \rho^0\rho^0$ to be $(0.4 \pm 0.4 \pm 0.2) \times 10^{-6}$ with $1.0\sigma$ significance, assume $f_L = 1$, the 90% confidence level upper limit is $< 1.0 \times 10^{-6}$. This is the new result with 657M $B\overline{B}$ *data sample*.
- Basically it is consistent with BABAR measurement. However we find excesses in non-resonant $B^0 \to 4\pi$ and $B^0 \to \rho^0\pi\pi$ 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 $B^0 \to a_1\pi$ yield in the fit; the fit result is $BF(B^0 \to a_1\pi) = (33.8 \pm 12.8) \times 10^{-6}$, which is consistent with the assumed value.
- For the yields of $B^0 \to \rho^0 f_0$, $B^0 \to f_0 f_0$ and $B^0 \to f_0\pi\pi$ decays are not significant, so the corresponding upper limits are also calculated.