Results on $B \to VV$ and PV Decays

XXXIXth Rencontres de Moriond: QCD and High Energy Hadronic Interactionss

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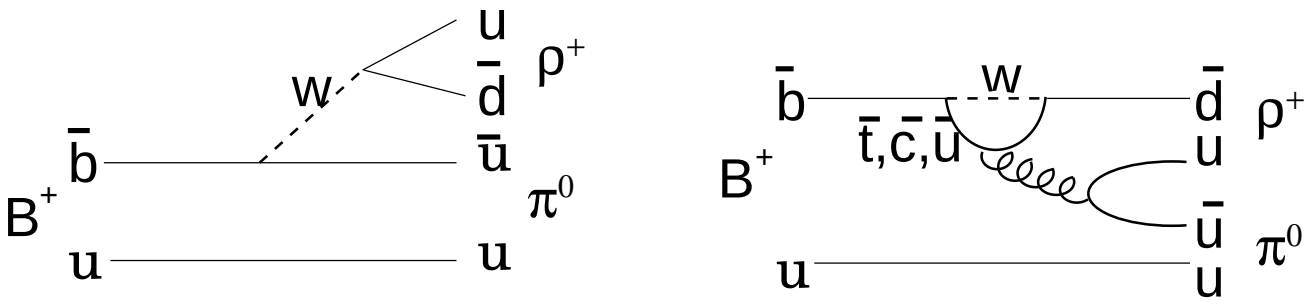
representing the Belle Collabroration

- $B \to \phi K^*$
- $B^+ \to \rho^+ \rho^0$
- $B^+ \to \rho^+ \pi^0$
- $B^0 \to \rho^0 \pi^0$
- Summary

Results are preliminary unless a reference is given

$B \to PV$ modes

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

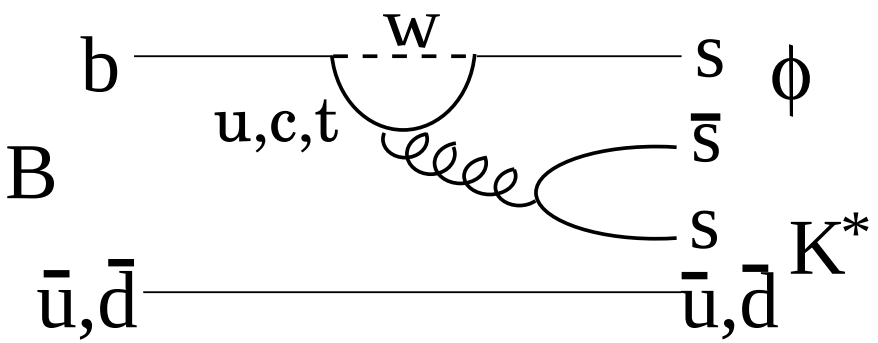


- These decays can occur via tree and penguin. A significant penguin contribution could result in observable direct CP violation.

- An isospin analysis of $B \to \rho\pi$ decays can be used to extract ϕ_2, and eliminate the uncertainties due to the penguin contribution.

$B \to VV$ modes

- $B \to \phi K^*$
  - $B^0 \to \phi K^{*0}$
  - $B^+ \to \phi K^{*+}$



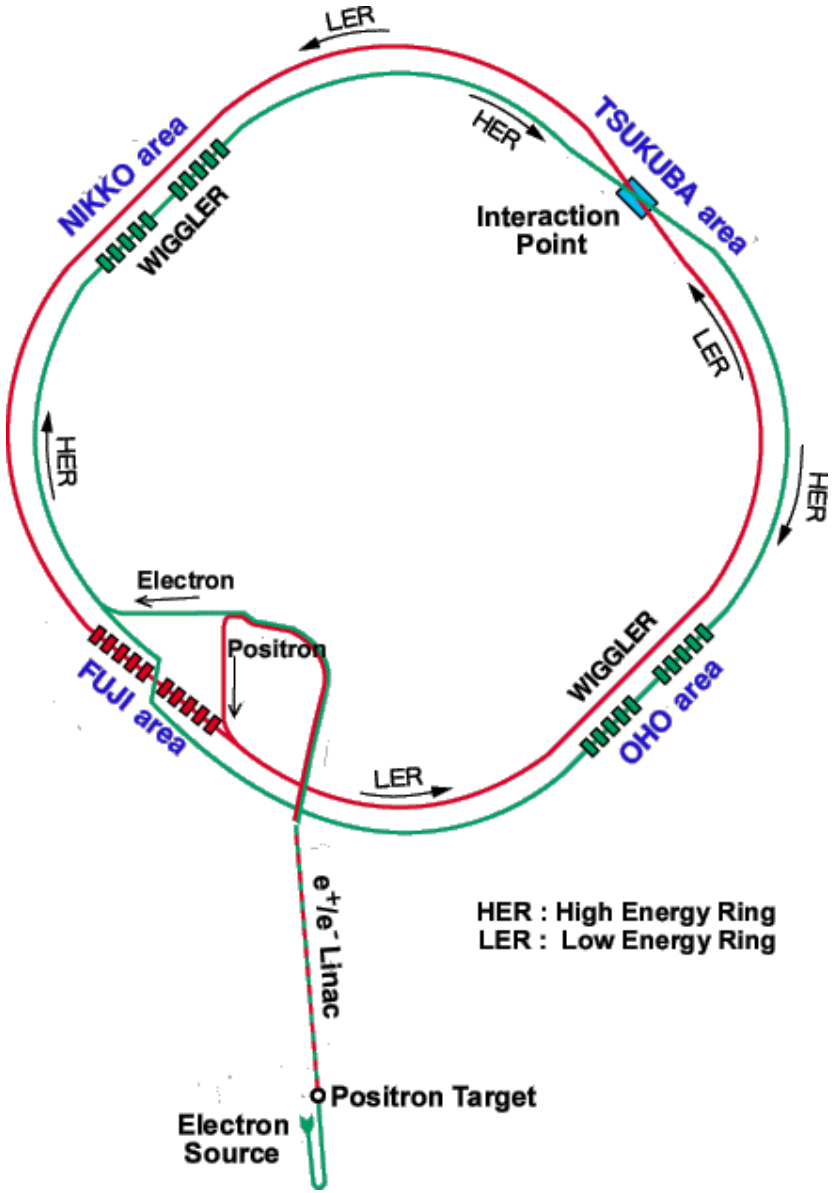
- $B^+ \to \rho^+ \rho^0$

- $B \to VV$ decays provide additional observable for detecting direct CP violation and physics beyond the SM.

- The pure penguin decays $B \to \phi K^*$ provide information on $\mathbf{V_{ts}}$, and is sensitive to new physics.

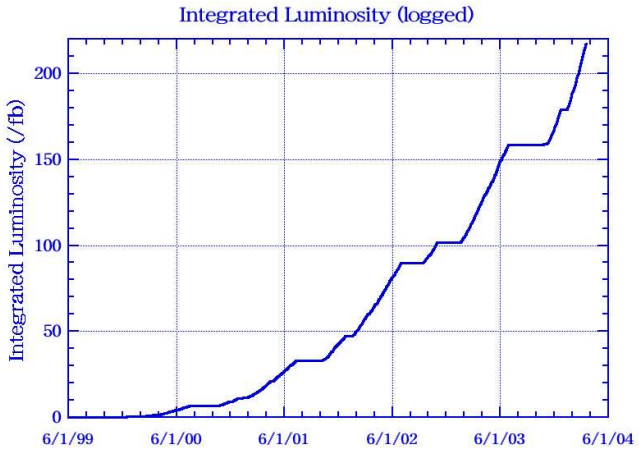
- $B^+ \to \rho^+ \rho^0$ can be used to extract ϕ_2 from an $B \to \rho\rho$ isospin analysis.

Belle at KEKB



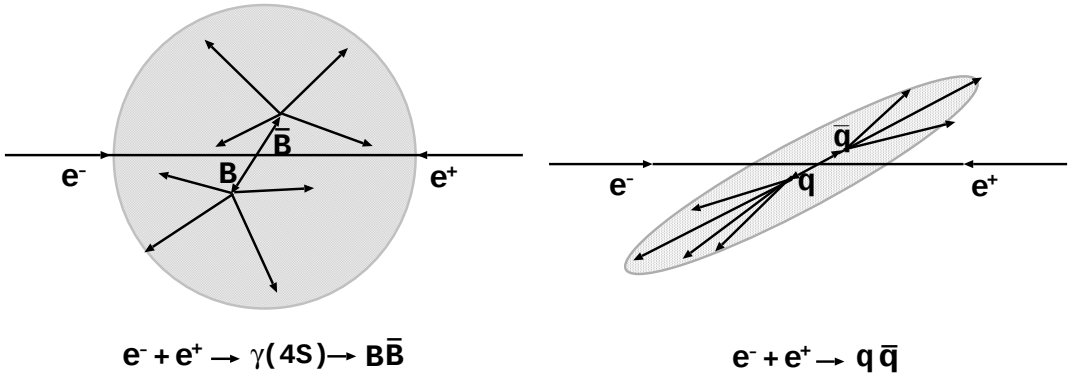
- $e^+e^- \to \Upsilon(4S) \to B\bar{B}$
- e^+: 3.5 GeV; e^-: 8.0 GeV
- $\sqrt{s} = 10.58$ GeV at $\Upsilon(4S)$

- Peak: $1.2 \times 10^{34}\mathrm{cm}^{-2}s^{-1}$
- $\int \mathcal{L}dt = 219\mathrm{fb}^{-1}$ on Mar.30, 2004.



Data Selection

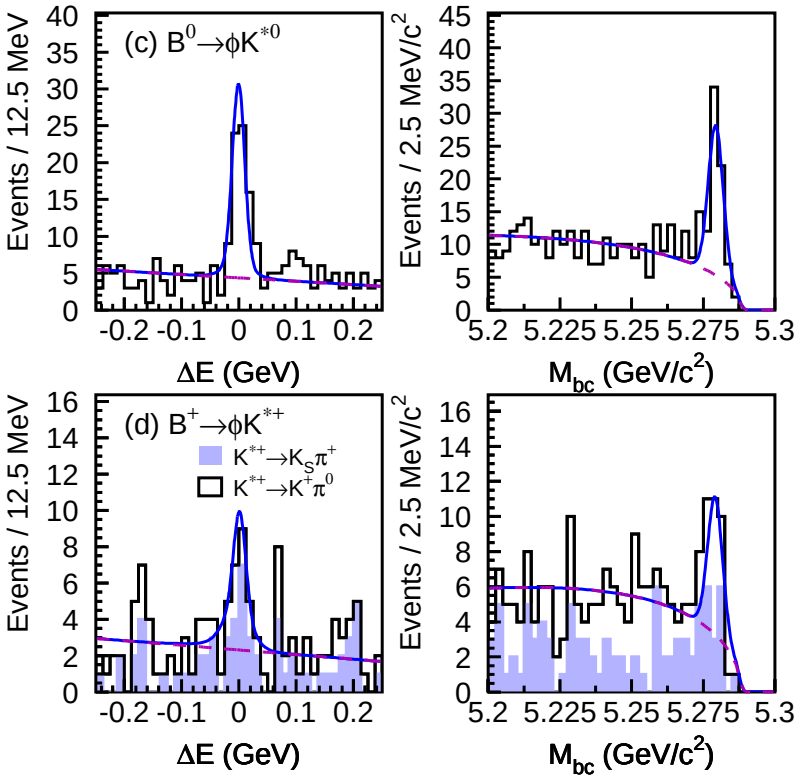
- Kinematic Reconstruction
  - beam energy constrained mass, $M_{\rm bc} \equiv \sqrt{(E^*_{\rm beam})^2 - (p^*_B)^2}$
  - energy difference, $\Delta E \equiv E^*_B - E^*_{\rm beam}$
- Continuum suppression via event shape and production angle



  - event shape: a Fisher discriminant $\mathcal{F}$ formed from modified Fox-Wolfram moments.
  - production angle: θ_B between B flight direction and beam axis
  - likelihoods: $\mathcal{L}_{sig}$ for signal and $\mathcal{L}_{cont}$ for continuum
  - normalized likelihood ratio: $\mathcal{LR} = \frac{\mathcal{L}_\pi}{\mathcal{L}_\pi + \mathcal{L}_K}$

$$B \to VV$$

$B \to \phi K^*$ (78 fb^{-1}) – branching fraction



- 2D unbinned maximum LH fit in $M_{\rm bc} - \Delta E$
  - $N_s(\phi K^{*0}(K^+\pi^-)) = 58.5^{+9.1}_{-8.1}$
  - $N_s(\phi K^{*+}(K_S\pi^+)) = 11.3^{+4.5}_{-3.8}$
  - $N_s(\phi K^{*+}(K^+\pi^0)) = 8.0^{+4.3}_{-3.5}$
- the KKK^* contributions are estimated from high ϕ-mass sideband data.

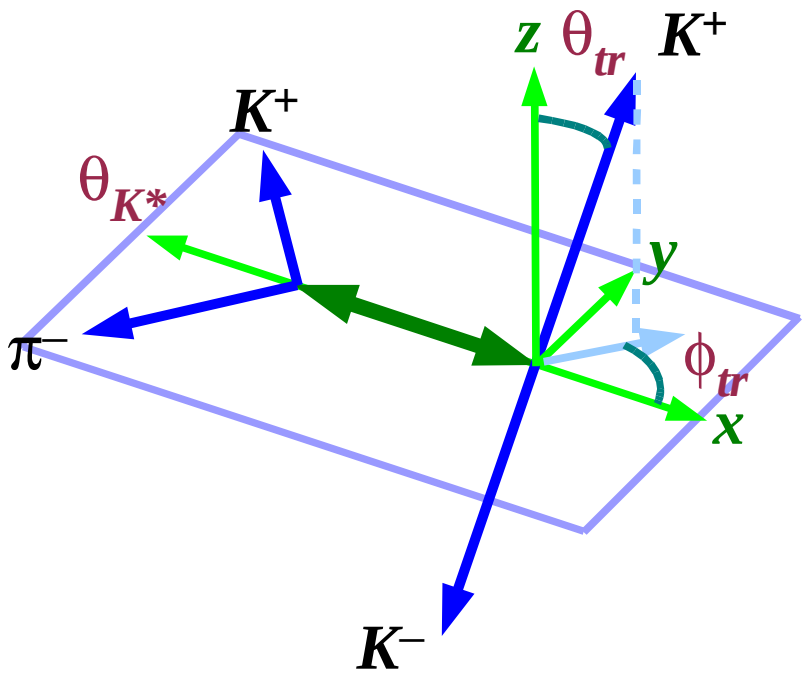
$$\mathcal{B}(\mathrm{B} \to \phi \mathrm{K}^{*0}) = (10.0^{+1.6\ +0.7}_{-1.5\ -0.8}) \times 10^{-6}, \quad \mathcal{A}_{\mathrm{CP}}(\mathrm{B} \to \phi \mathrm{K}^{*0}) = 0.07 \pm 0.15^{+0.05}_{-0.03},$$

$$\mathcal{B}(\mathrm{B} \to \phi \mathrm{K}^{*+}) = (6.7^{+2.1\ +0.7}_{-1.9\ -1.0}) \times 10^{-6}, \quad \mathcal{A}_{\mathrm{CP}}(\mathrm{B} \to \phi \mathrm{K}^{*+}) = -0.13 \pm 0.29^{+0.08}_{-0.11}.$$

$B \to \phi K^*$ –angular distribution in the transversity basis

$$\frac{d^3\Gamma(\phi_{\rm tr}, \cos\theta_{\rm tr}, \cos\theta_{K^*})}{d\phi_{\rm tr} d\cos\theta_{\rm tr} d\ cos\theta_{K^*}} = \frac{9}{32\pi}[|A_\perp|^2 2\cos^2\theta_{\rm tr}\sin^2\theta_{K^*}$$
$$+|A_\parallel|^2 2\sin^2\theta_{\rm tr}\sin^2\phi_{\rm tr}\sin^2\theta_{K^*}$$
$$+|A_0|^2 4\sin^2\theta_{\rm tr}\cos^2\phi_{\rm tr}\cos^2\theta_{K^*}$$
$$+\sqrt{2}{\rm Re}(A_\parallel^* A_0)\sin^2\theta_{\rm tr}\sin 2\phi_{\rm tr}\sin 2\theta_{K^*}$$
$$-\eta\sqrt{2}{\rm Im}(A_0{}^* A_\perp)\sin 2\theta_{\rm tr}\cos\phi_{\rm tr}\sin 2\theta_{K^*}$$
$$-2\eta{\rm Im}(A_\parallel^* A_\perp)\sin 2\theta_{\rm tr}\sin\phi_{\rm tr}\sin^2\theta_{K^*}] \ ,$$

($\eta = 1$ for $\bar{b}$ or -1 for b)



$$\frac{\Gamma_L}{\Gamma} = \frac{|A_0|^2}{|A_0|^2+|A_\parallel|^2+|A_\perp|^2}$$

Amplitude Extraction — an unbinned maximum LH fit

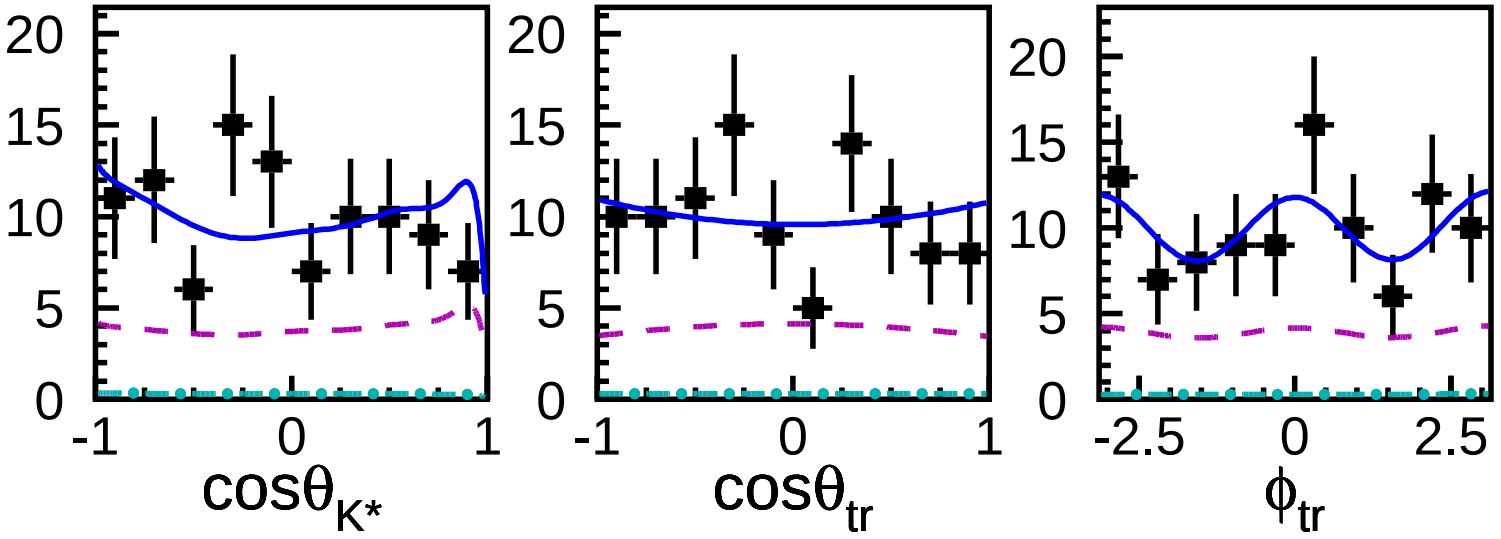
$$\mathcal{L} = \prod_i^N \epsilon(\theta_{K^*}, \theta_{\rm tr}, \phi_{\rm tr})[f_{\phi K^{*0}} \cdot \Gamma(\theta_{K^*}, \theta_{\rm tr}, \phi_{\rm tr}) + f_{q\bar{q}} \cdot P_{q\bar{q}}(\theta_{K^*}, \theta_{\rm tr}, \phi_{\rm tr})$$
$$+ f_{KKK^{*0}} \cdot P_{KKK^{*0}}(\theta_{K^*}, \theta_{\rm tr}, \phi_{\rm tr})] \ ,$$

normalization: $|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2 = 1$;
phase convention: take A_0 real

- efficiency correction ϵ is a function of $(\theta_{K^*}, \theta_{\rm tr}, \phi_{\rm tr})$, determined from MC.
- the PDF for continuum $P_{q\bar{q}}$ is obtained from sideband data.
- the PDF for KKK^* $P_{KKK^{*0}}$ is flat $\times\ \epsilon$.
- fractions $f_{\phi K^{*0}}$, $f_{q\bar{q}}$, $f_{KKK^{*0}}$ are functions of $M_{\rm bc}$ and ΔE.

Results of Angular Analysis For $B^0 \to \phi K^{*0}$

$$|A_0|^2 = 0.43 \pm 0.09 \pm 0.04,$$
$$|A_\perp|^2 = 0.41 \pm 0.10 \pm 0.04,$$
$$\arg(A_\parallel) = -2.57 \pm 0.39 \pm 0.09 \ (\textit{cf.}\ -\pi)$$
$$\arg(A_\perp) = 0.48 \pm 0.32 \pm 0.06 \ (\textit{cf.}\ 0)$$

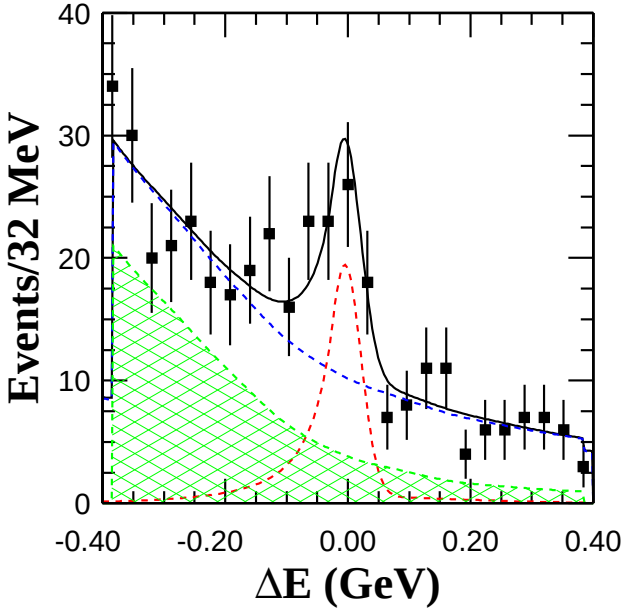


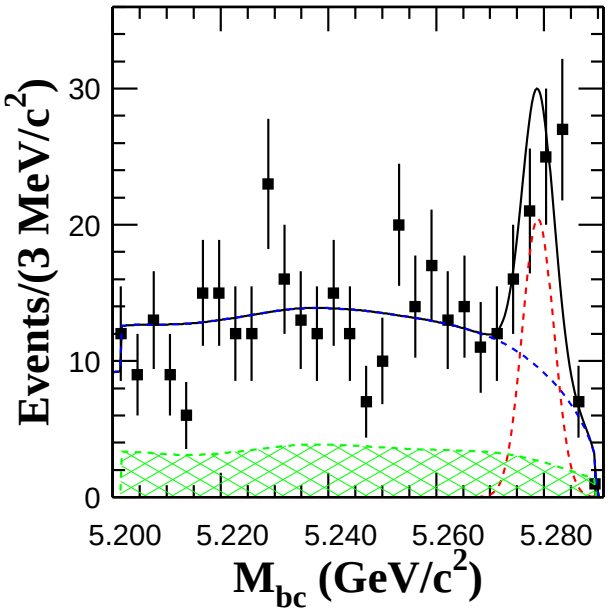
[PRL 91, 201801(2003)]

$B^+ \to \rho^+\rho^0$(78 fb^{-1}) –branching fraction

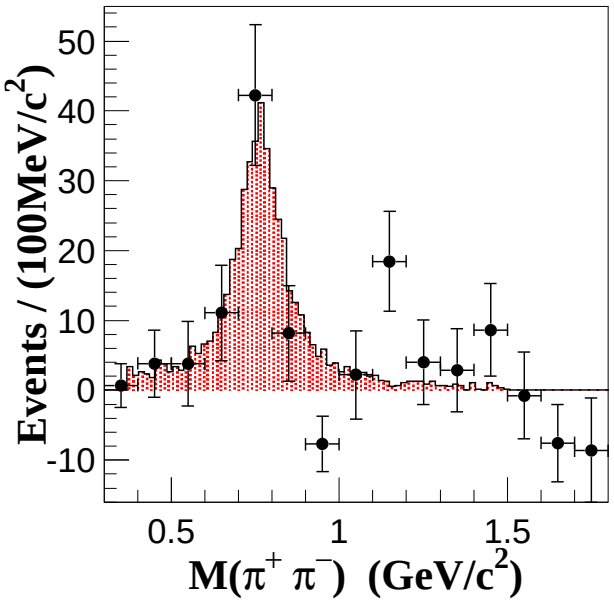
- 1D binned maximum likelihood fit
- from ΔE fit

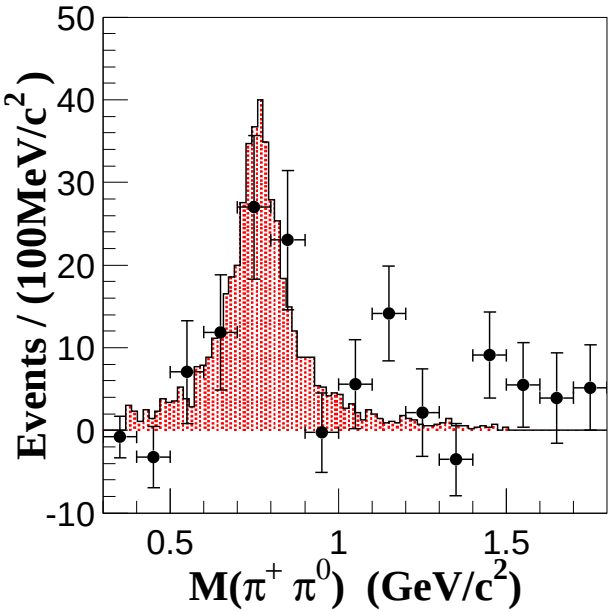
$$N_s = 58.7 \pm 13.2$$
$$S = 5.3\sigma$$
$$\epsilon = 2.1\% \text{ (longi.)}$$





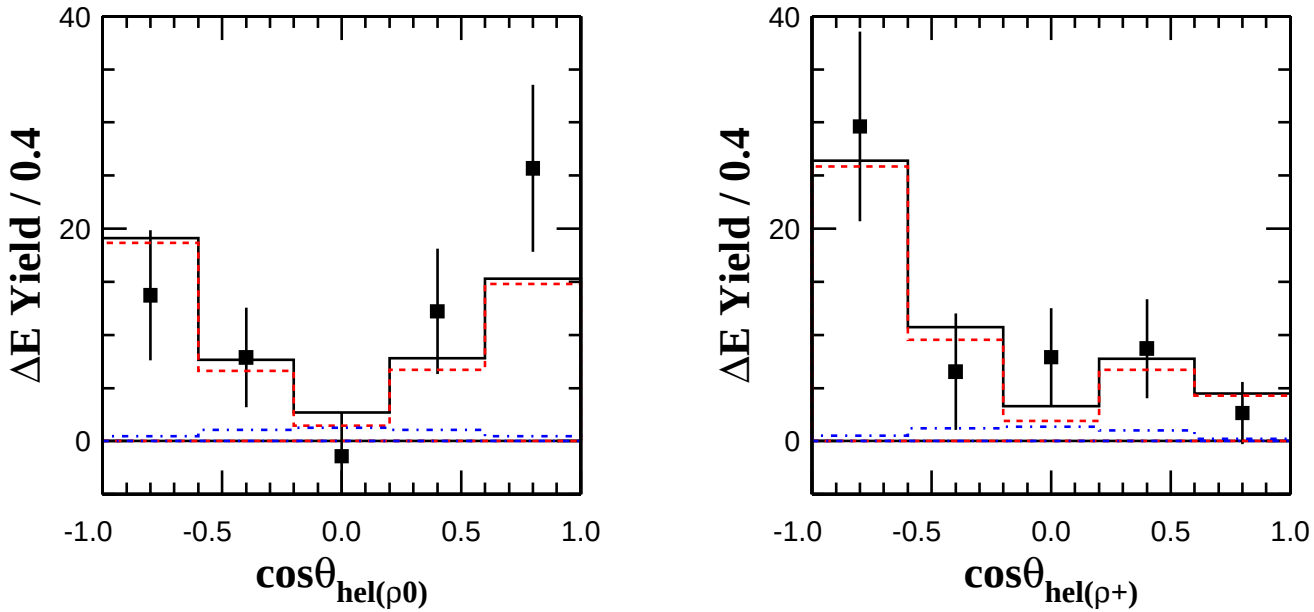
- good agreement between background-subtracted data and $B^+ \to \rho^+\rho^0$ simulation





$B^+ \to \rho^+\rho^0$ – helicity amplitudes

- longitudinally polarized ($\lambda = 0$): 48.3 ± 10.8 events
- transversely polarized ($\lambda = \pm 1$): 4.3 ± 8.7 events



$$\frac{\Gamma_L}{\Gamma} = (94.8 \pm 10.6 \pm 2.1)\%,$$

$$\mathcal{B}(B^+ \to \rho^+\rho^0) = (31.7 \pm 7.1^{+3.8}_{-6.7}) \times 10^{-6}.$$

[PRL 91, 221801(2003)]

(Note: detection efficiency is strongly dependent on polarization)

Polarization in $B \to VV$

- Theory predicts that longitudinal polarization dominates.
- $B^+ \to \rho^+\rho^0$ ($b \to u$ tree transition):

$$\frac{\mathbf{\Gamma_L}}{\mathbf{\Gamma}} = (\mathbf{94.8 \pm 10.6(stat) \pm 2.1(sys)})\%$$

  longitudinally polarized.

- $B \to \phi K^*$ ($b \to s$ penguin transition):

$$\frac{\mathbf{\Gamma_L}}{\mathbf{\Gamma}} = (\mathbf{43 \pm 9 \pm 4})\%$$

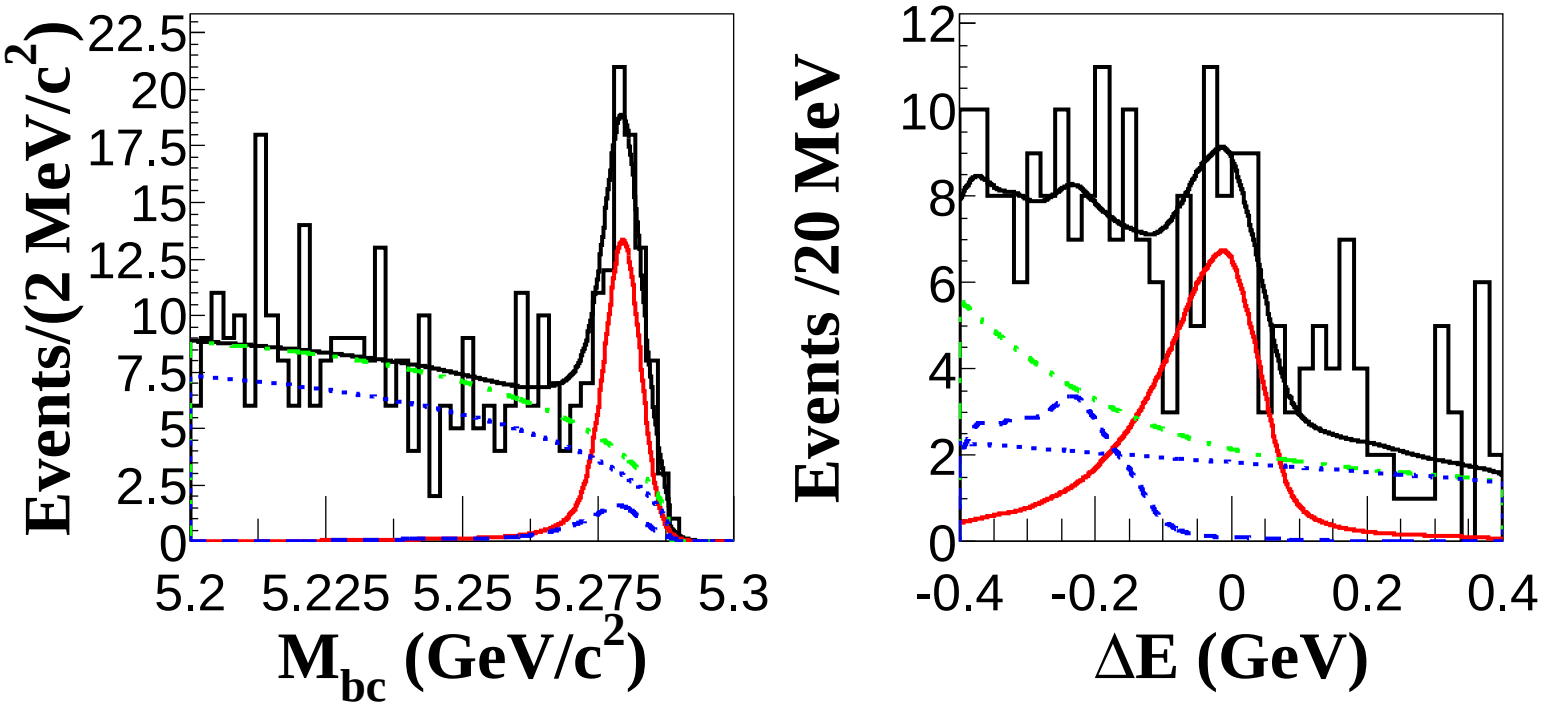
NP in penguin loop ???!

ref. Y. Grossman hep-ph/0310229

- Need analysis of more VV channels, e.g. $B \to K^*\rho$

$$B \to PV$$

Observation of $B^+ \to \rho^+\pi^0$ (140 fb^{-1})



$$N_{sig} = 87 \pm 15$$

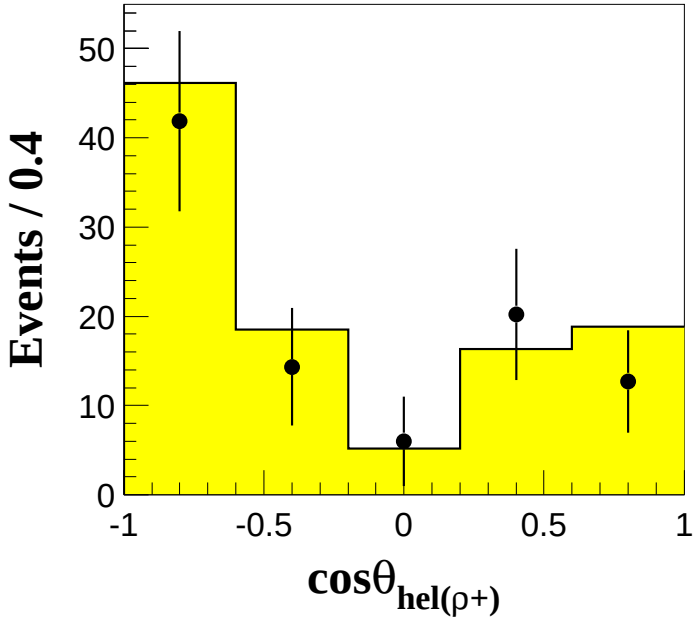
$$S = 8.1\sigma$$

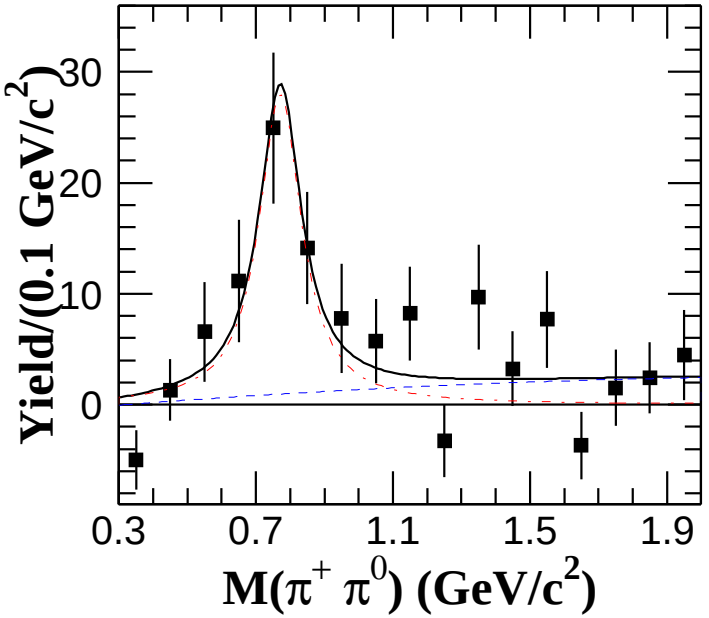
$$\epsilon = 4.4\%$$

$$\mathcal{B}(\mathbf{B^+ \to \rho^+\pi^0}) = (\mathbf{13.2 \pm 2.3^{+1.4}_{-1.5}}) \times \mathbf{10^{-6}}$$

Additional continuum suppression by b-flavor tagging information.

- Helicity $\cos\theta_{\mathrm{hel}(\rho)}$ and $M(\pi^+\pi^0)$ distributions



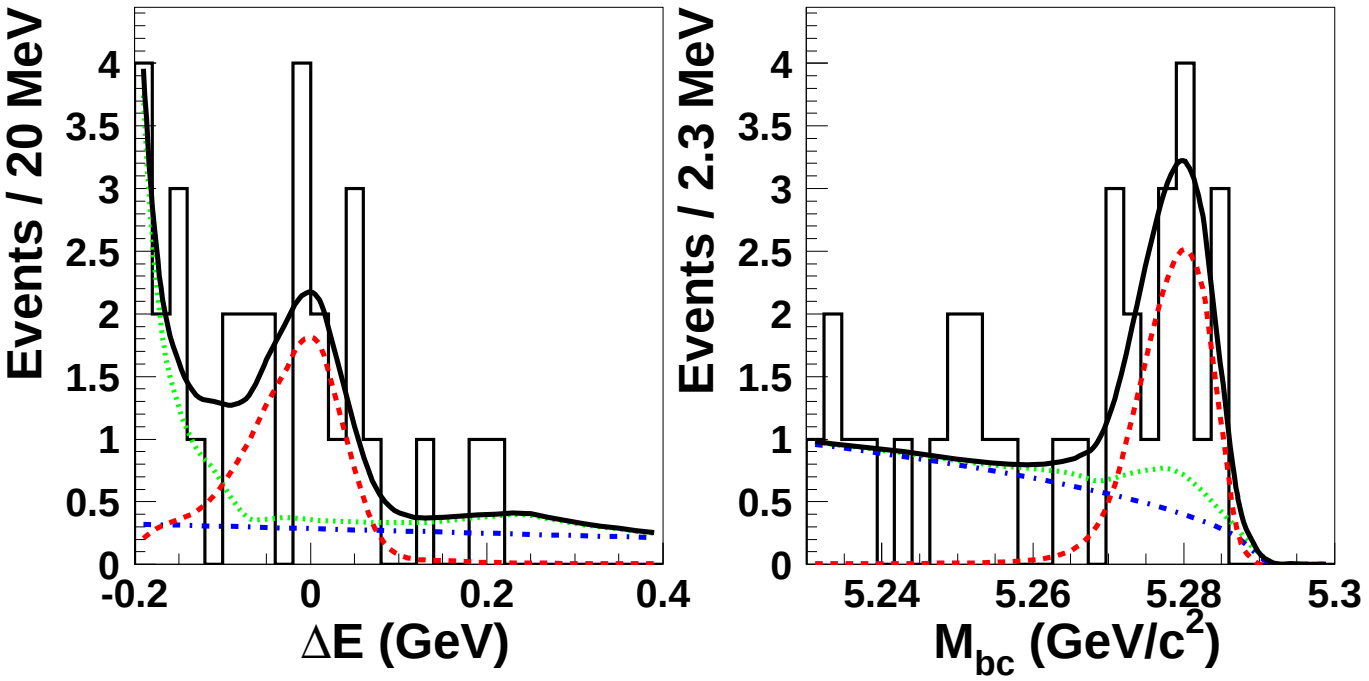


  - good agreement between background-subtracted data and MC simulation.
  - Breit-Wigner: 46.4 ± 9.5
  - Non-resonant: 2.8 ± 1.6

- Partial rate asymmetry

$$\mathcal{A}_{\mathbf{CP}}(\mathbf{B}^{\mp} \to \rho^{\mp}\pi^{\mathbf{0}}) = \frac{\mathbf{N}_{(\rho^-\pi^{\mathbf{0}})} - \mathbf{N}_{(\rho^+\pi^{\mathbf{0}})}}{\mathbf{N}_{(\rho^-\pi^{\mathbf{0}})} + \mathbf{N}_{(\rho^+\pi^{\mathbf{0}})}} = \mathbf{0.06 \pm 0.19 \pm 0.04}$$

First Evidence for $B^0 \to \rho^0\pi^0$ (140 fb^{-1})



$$N_{sig} = 15.1 \pm 4.8$$

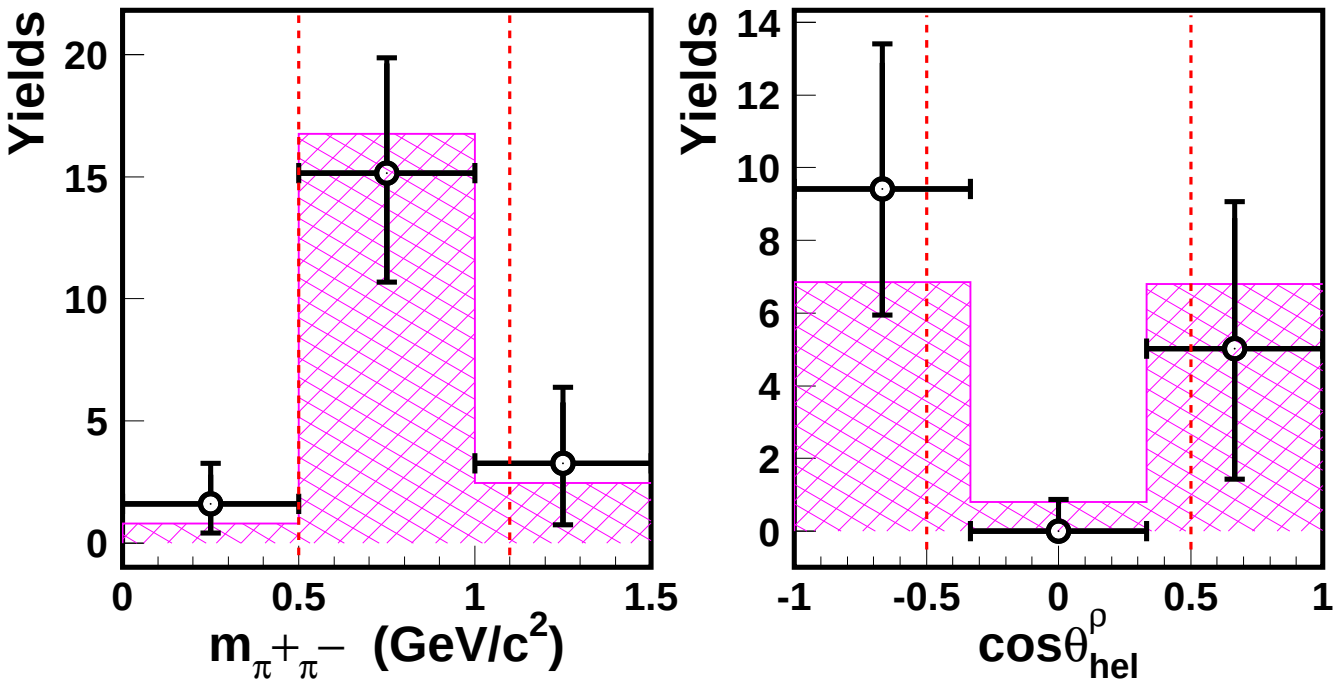
$$S = 3.6\sigma(\text{incl. sys.})$$

$$\epsilon = 1.91\%$$

$$\mathcal{B}(\mathbf{B^0 \to \rho^0\pi^0}) = (\mathbf{5.1 \pm 1.6 \pm 0.8}) \times \mathbf{10^{-6}}.$$

predictions: $\mathcal{O}(10^{-6})$

$B^0 \to \rho^0\pi^0$: $M(\pi\pi)$ and helicity distributions



- Good agreement between background-subtracted data and MC.
- $|\cos\theta_{\rm hel}| > 0.3$
- $0.5 < M(\pi\pi) < 1.1$ GeV/c^2

Summary of $B \to PV$ Results

- Measured the branching fractions and CP asymmetries for $B^+ \to \rho^+\pi^0$,

$$\mathcal{B}(\mathbf{B^+ \to \rho^+\pi^0}) = (\mathbf{13.2 \pm 2.3^{+1.4}_{-1.5}}) \times \mathbf{10^{-6}},$$

$$\mathcal{A}_{\mathbf{CP}}(\mathbf{B^\mp \to \rho^\mp\pi^0}) = \mathbf{0.06 \pm 0.19 \pm 0.04}.$$

- First evidence of $B^0 \to \rho^0\pi^0$, the measured branching fraction

$$\mathcal{B}(\mathbf{B^0 \to \rho^0\pi^0}) = (\mathbf{5.1 \pm 1.6 \pm 0.8}) \times \mathbf{10^{-6}}.$$

- We have now seen all the $B \to \rho\pi$ final states in Belle.

Summary of $B \to VV$ Results

- $b \to s$ penguin: measured $B \to \phi K^*$ branching fractions and performed a three-dimensional angular analysis with 78 fb^{-1}

$$\frac{\Gamma_L}{\Gamma} = (43 \pm 9 \pm 4)\%,$$

Indication of new physics in $b \to s$??
Problem with B decay models ???

- $b \to u$ tree: measured the $B \to \rho^+\rho^0$ branching fraction, and find the longitudinal state is dominant,

$$\frac{\Gamma_L}{\Gamma} = (94.8 \pm 10.6 \pm 2.1)\%.$$