The Belle Collaboration

New Measurements of $B \to PV$ & VV Decays at Belle

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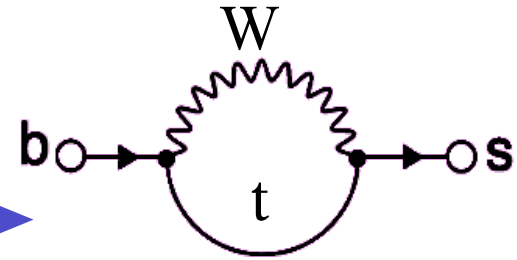
Introduction

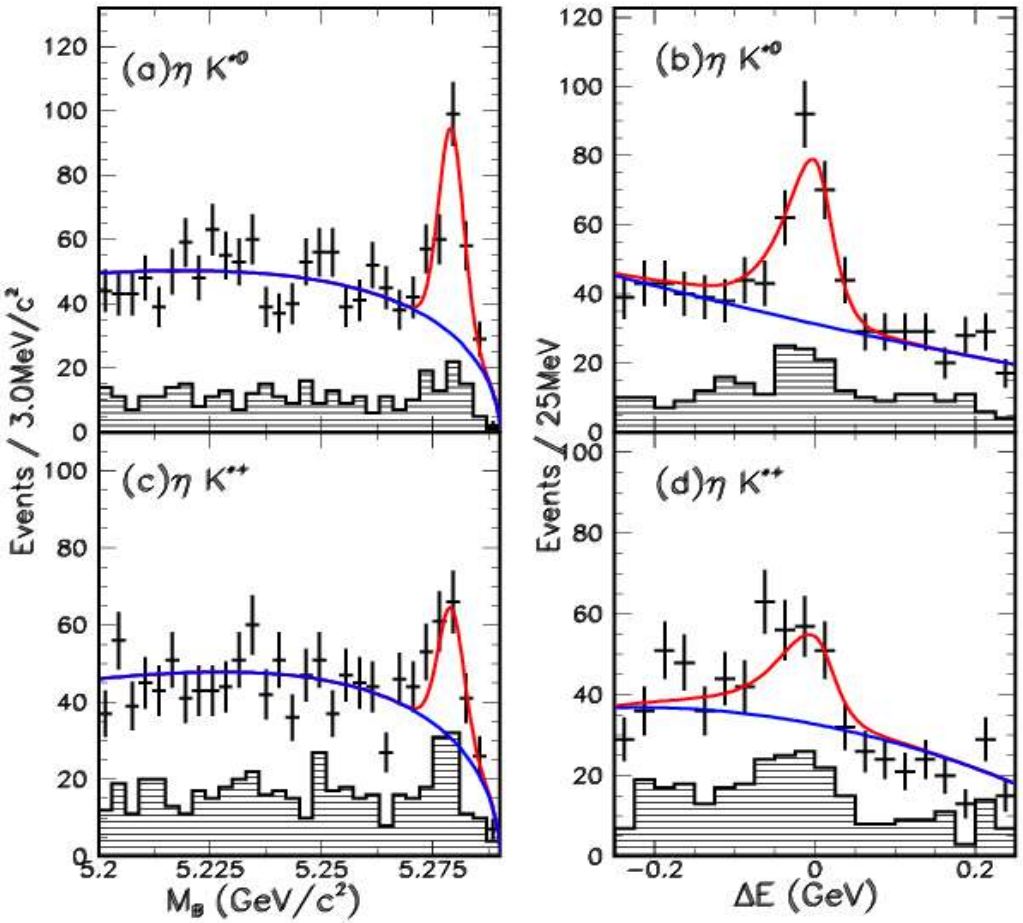
- Results are based on Belle 140/fb data.
- Large penguin contributions in *PV* decays may generate sizable *direct CP violation*.
- $B \to VV$ decays require a sophisticated angular analysis to extract helicity amplitudes, i.e. longitudinal(R_0) and transverse($R_\perp$ & $R_{||}$).
- Unexpected polarization in ϕK^* decay:

Measurement	*Naive SM Prediction*
$R_0 = 0.43 \pm 0.09 \pm 0.04$	$R_0 \gg R_{||} + R_\perp$
$R_\perp = 0.41 \pm 0.10 \pm 0.04$	$R_\perp \approx R_{||}$
[Belle 78/fb, PRL 91, 201801(2003)]	

One of the possible interpretation is *New Physics* in the penguin loop.



Update of $B \to \eta K^*$



- Two η decay channels are included:
  - $\eta \to \gamma\gamma$
  - $\eta \to \pi^+\pi^-\pi^0$
- $B \to \eta K^{*0}$, $K^{*0} \to K^+\pi^-$:

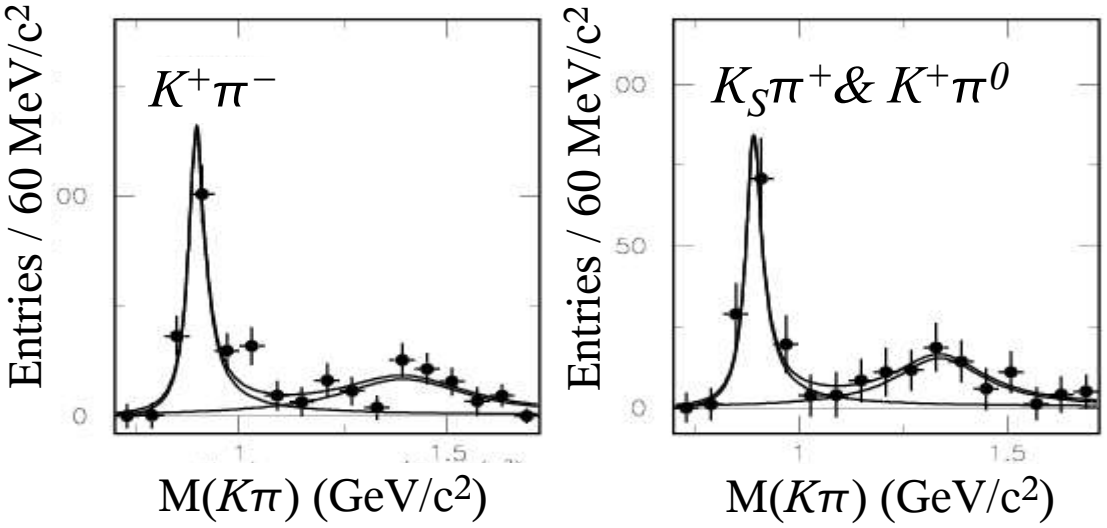
  $N_{\text{signal}} = 175\ ^{+19}_{-18}$
- $B \to \eta K^{*+}$, $K^{*+} \to K^+\pi^0$ & $K^{*+} \to K_S\pi^+$:

  $N_{\text{signal}} = 106\ ^{+18}_{-17}$

Update of $B \to \eta K^*$

Branching Fractions & DCPV

- Consider possible feed-down from higher K* states
- Possible $\eta\rho$ contribution is checked.



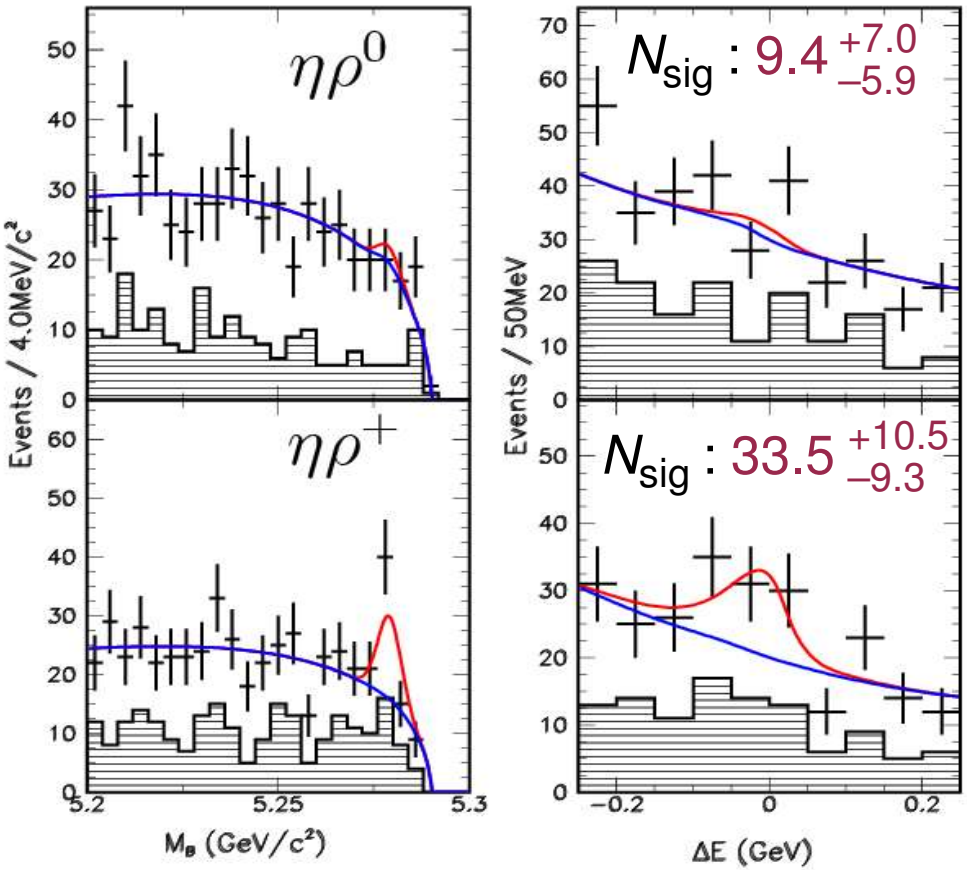
$$\mathcal{B}(B \to \eta K^{*0}) = (19.0^{+2.1}_{-2.0} \pm 1.4) \times 10^{-6}$$

$$\mathcal{B}(B \to \eta K^{*\pm}) = (22.8^{+3.5}_{-3.7} \pm 2.2) \times 10^{-6}$$

$$\mathcal{A}_{CP}(\eta K^{*0}) = -0.04^{+0.11}_{-0.10} \pm 0.01$$

$$\mathcal{A}_{CP}(\eta K^{*\pm}) = -0.09^{+0.16}_{-0.15} \pm 0.01$$

Search for $B \to \eta\rho$

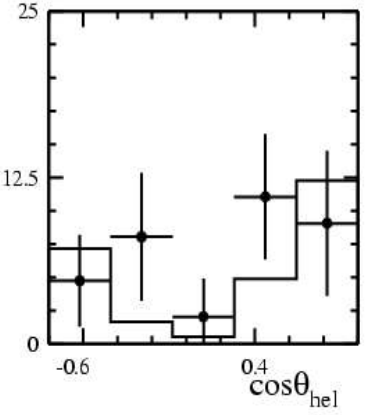


$\mathcal{B}(B \to \eta\rho^0) < 2.7 \times 10^{-6}$

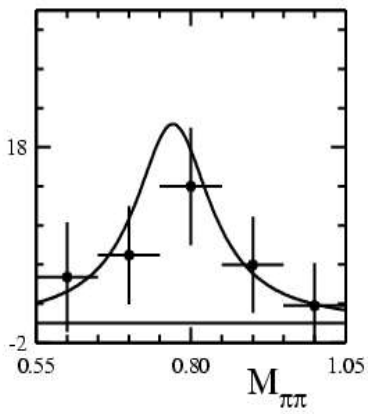
$\mathcal{B}(B \to \eta\rho^\pm) = (8.5^{+2.6}_{-2.4} \pm 1.0) \times 10^{-6}$

$\mathcal{A}_{CP}(\eta\rho^\pm) = -0.17^{+0.32}_{-0.28} \pm 0.02$

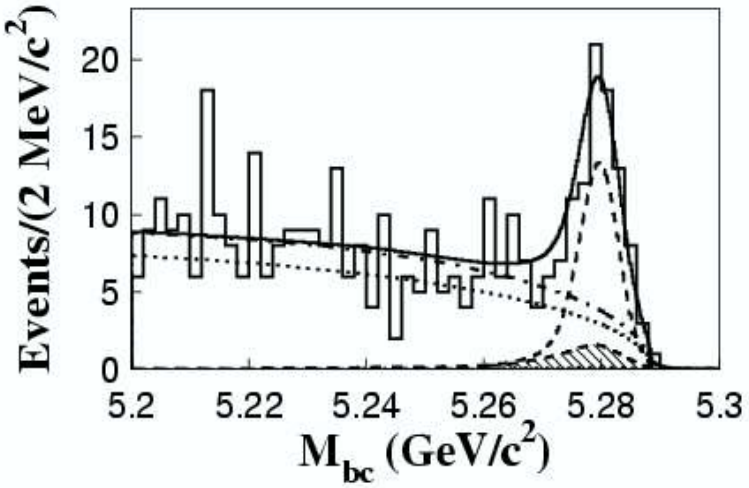
$\rho^\pm$ helicity angle

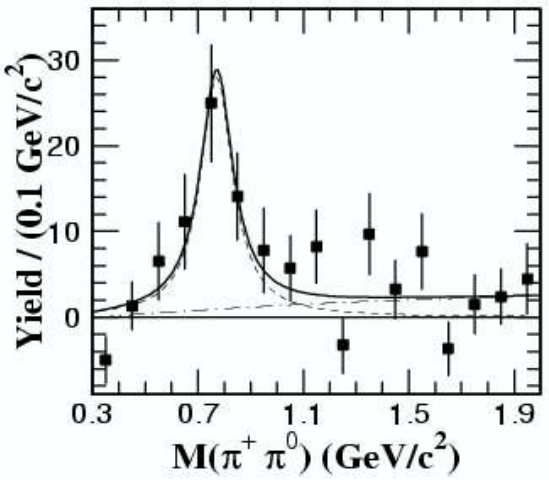


$M(\pi^\pm\pi^0)$

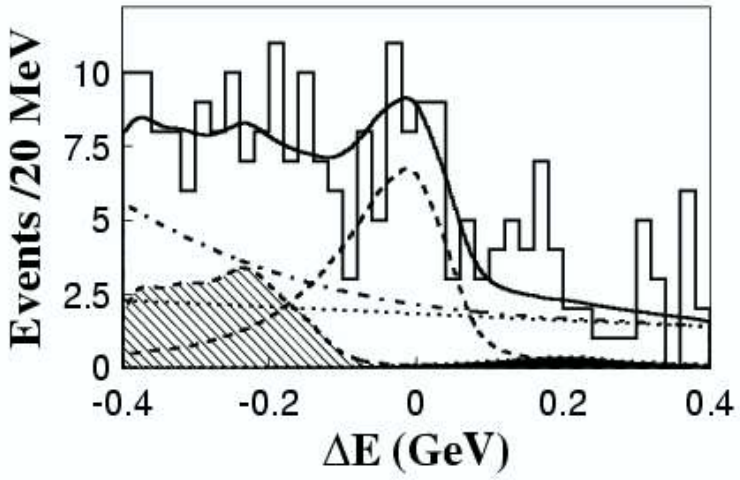


Measurement of $B \to \rho^+\pi^0$





Fraction of non-resonant: 5.8±4.8%



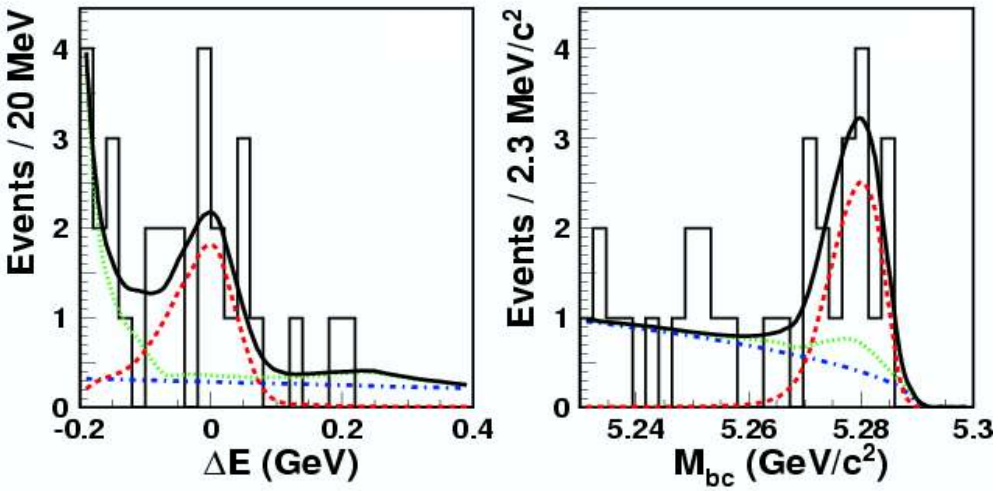
N_{sig} = 87±17, Significance = 8.1σ

$\mathcal{B}(B \to \rho^{\pm}\pi^0) = (13.2 \pm 2.3^{+1.4}_{-1.9}) \times 10^{-6}$

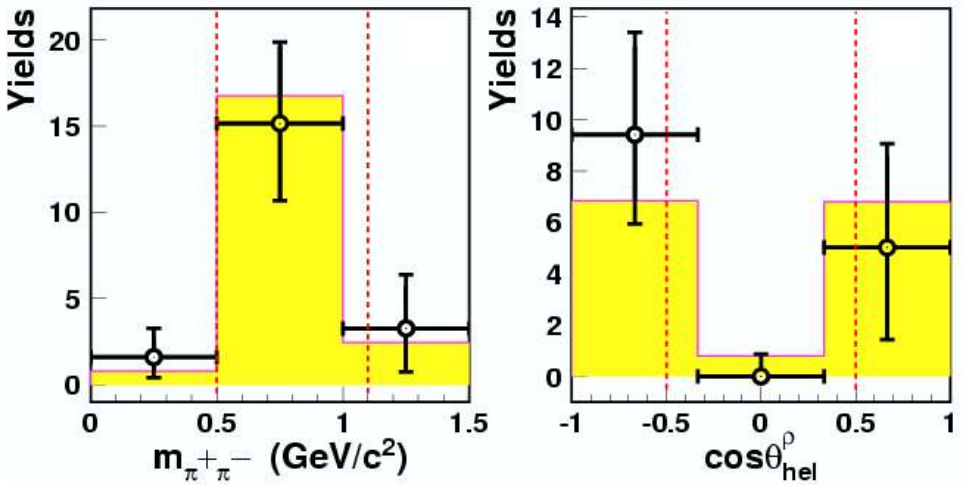
$\mathcal{A}_{CP}(\rho^{\pm}\pi^0) = 0.06 \pm 0.19^{+0.04}_{-0.06}$

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

Projections of ΔE & M_{bc} fit



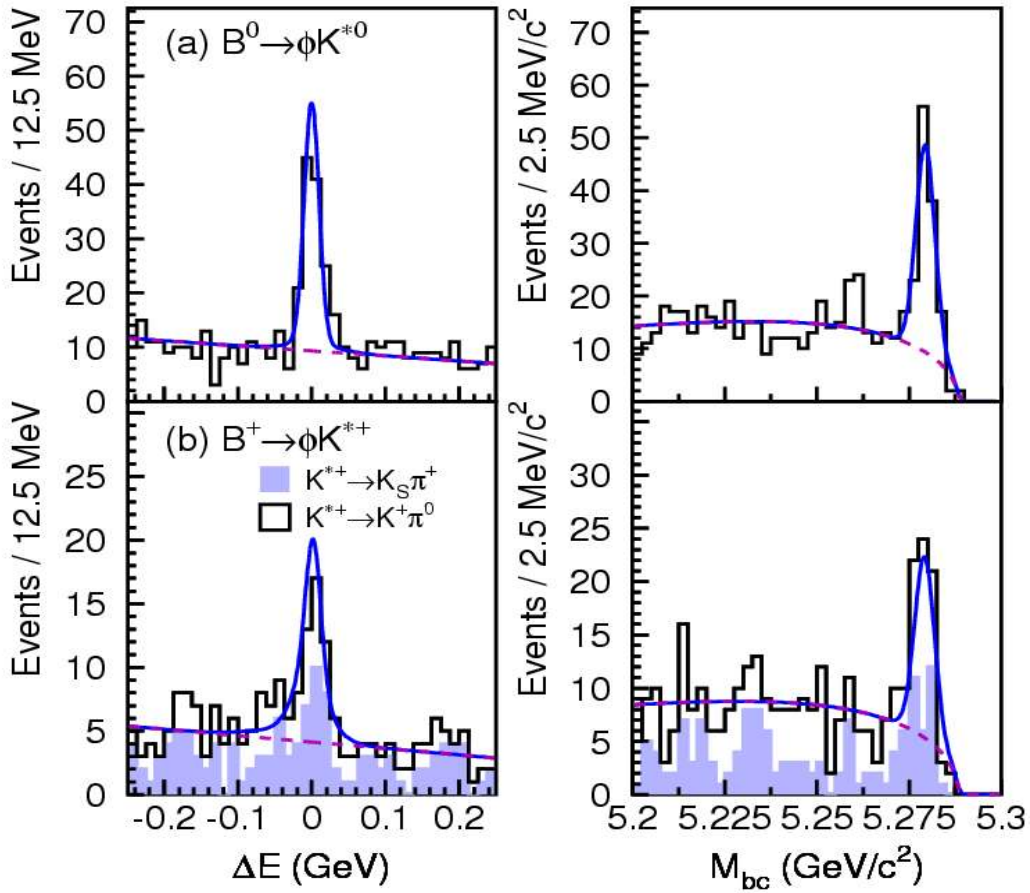
Signal yields versus M($\pi\pi$) & cos(θ_{hel})



N_{sig} = 15.1±4.8, Significance = 3.6σ

$\mathcal{B}\,(B \to \rho^0\pi^0)$ = (5.1 ±1.6 ±0.9) x 10^{-6}

Signal Extraction of $B \to \phi K^*$



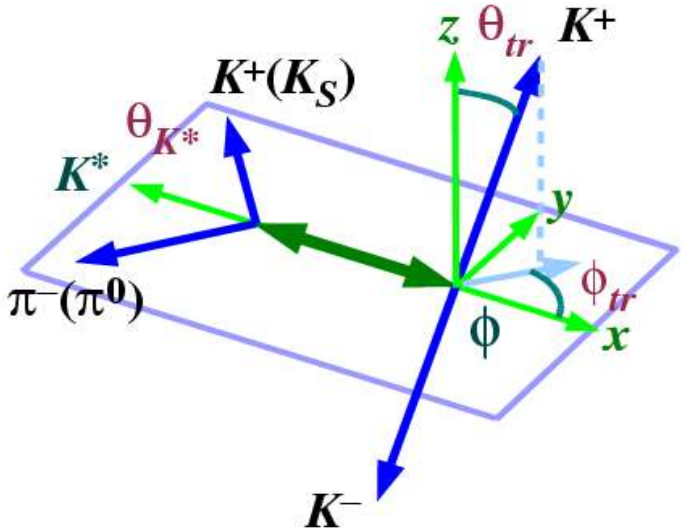
- Signal yield are extracted by fits to ΔE and M_{bc} :
  - $B \to \phi K^{*0}\,(K^+\pi^-)$: 97^{+12}_{-11}
  - $B \to \phi K^{*+}\,(K_S\pi^+)$: $20.4^{+5.9}_{-5.2}$
  - $B \to \phi K^{*+}\,(K^+\pi^0)$: $25.9^{+7.0}_{-6.3}$
- Non-resonant KKK^* contribution is estimated by ϕ mass sideband

Angular Analysis of $B \to \phi K^*$

Transversity Basis

Longitudinal Polarization

$$R_0 = \frac{|A_0|^2}{|A_0|^2 + |A_\perp|^2 + |A_\parallel|^2}$$



Signal PDF

$$\frac{d^3\Gamma(\phi_{tr}, \theta_{tr}, \psi)}{d\phi_{tr}\, d\cos\theta_{tr}\, d\cos\psi} = \frac{9}{32\pi}\Big(|A_\parallel|^2 2\sin^2\theta_{tr}\sin^2\phi_{tr}\sin^2\psi$$
$$+ |A_\perp|^2 2\cos^2\theta_{tr}\sin^2\psi + |A_0|^2 4\sin^2\theta_{tr}\cos^2\phi_{tr}\cos^2\psi$$
$$+ \sqrt{2}\Re(A_\parallel^* A_0)\sin^2\theta_{tr}\sin 2\phi_{tr}\sin 2\psi \pm \sqrt{2}\Im(A_0^* A_\perp)\sin 2\theta_{tr}\cos\phi_{tr}\sin 2\psi$$
$$\pm 2\Im(A_\parallel^* A_\perp)\sin 2\theta_{tr}\sin\phi_{tr}\sin^2\psi\Big)$$

$-$: B
$+$: $\overline{B}$

Angular Analysis of $B \to \phi K^*$

Combined Likelihood

Event fractions (functions of ΔE & M_{bc})

$$L = \prod_i^N \{ f_{sig} \cdot \epsilon \cdot \Gamma(\phi_{tr}, \cos(\theta_{tr}), \cos(\psi)) + f_{qq} \cdot P_{qq} + f_{KKK^*} \cdot P_{KKK^*} \}$$

Signal PDF

Efficiency correction (determined by MC)

Continuum PDF (from sideband data)

KKK* PDF(= flat x ε)

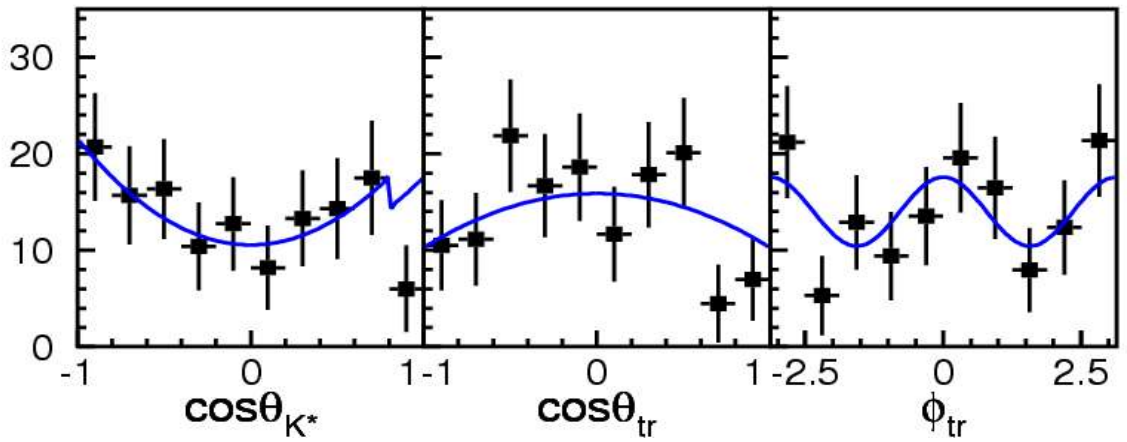
Normalization	$\lvert A_0\rvert^2 + \lvert A_\perp\rvert^2 + \lvert A_\parallel\rvert^2 = 1$
Phase convention	Take A_0 real

Angular Analysis of $B \to \phi K^*$

Results of the fit

	ϕK^{*0}	ϕK^{*+}	Combined
$\|A_0\|^2$	$0.52 \pm 0.07 \pm 0.05$	$0.49 \pm 0.13 \pm 0.05$	$0.51 \pm 0.06 \pm 0.04$
$\|A_\perp\|^2$	$0.30 \pm 0.07 \pm 0.03$	$0.12\ ^{+0.11}_{-0.08} \pm 0.03$	$0.24 \pm 0.06 \pm 0.03$
$\arg(A_\parallel)$	$-2.30 \pm 0.28 \pm 0.04$	$-2.07 \pm 0.34 \pm 0.07$	$-2.21 \pm 0.22 \pm 0.05$
$\arg(A_\perp)$	$0.64 \pm 0.26 \pm 0.05$	$0.72\ ^{+0.55}_{-0.39} \pm 0.12$	$0.72 \pm 0.21 \pm 0.06$

Projections after background subtraction & efficiency correction ⇨



Triple Product Correlations in $B \to \phi K^*$

- Two *T*-odd quantities are suggested by A.Datta & D.London:

$$A_T^0 = \frac{Im\left(A_\perp A_0^*\right)}{|A_0|^2+|A_\perp|^2+|A_\parallel|^2} \qquad A_T^\parallel = \frac{Im\left(A_\perp A_\parallel^*\right)}{|A_0|^2+|A_\perp|^2+|A_\parallel|^2}$$

T-violation :

$A_T^0 \neq \overline{A_T^0}$ or $A_T^\parallel \neq \overline{A_T^\parallel}$

	B ($\phi K^{*0}/\phi K^{*+}$)	$\bar{B}$ ($\phi \bar{K}^{*0}/\phi K^{*-}$)
$\lvert A_0\rvert^2$	0.41 ±0.10 ±0.03	0.59 ±0.08 ±0.06
$\lvert A_\perp\rvert^2$	0.24 ±0.10 ±0.02	0.26 ±0.08 ±0.04
$\arg(A_\parallel)$	–2.29 ±0.35 ±0.13	–2.05 ±0.31 ±0.04
$\arg(A_\perp)$	0.74 ±0.31 ±0.10	0.64 ±0.31 ±0.06
A_T^0	0.21 ±0.08 ±0.03	0.28 ±0.09 ±0.05
$A_T^\parallel$	0.04 ±0.08 ±0.02	0.06 ±0.06 ±0.02

⇦ No significance difference between B and $\bar{B}$

NP Sensitive Observables of $B \to \phi K^*$

- More observables are suggested by D.London, N. Sinha, R. Sinha:

$$\Lambda_{\lambda\lambda} = \frac{1}{2}(|A_\lambda|^2 + |\overline{A}_\lambda|^2) \qquad \boxed{\Sigma_{\lambda\lambda}} = \frac{1}{2}(|A_\lambda|^2 - |\overline{A}_\lambda|^2)$$

$$\boxed{\Lambda_{\perp i}} = -\mathrm{Im}(A_\perp A_i^* - \overline{A}_\perp \overline{A}_i^*) \qquad \Sigma_{\perp i} = -\mathrm{Im}(A_\perp A_i^* + \overline{A}_\perp \overline{A}_i^*)$$

$$\Lambda_{\|0} = \mathrm{Re}(A_\| A_0^* + \overline{A}_\| \overline{A}_0^*) \qquad \boxed{\Sigma_{\|0}} = \mathrm{Re}(A_\| A_0^* - \overline{A}_\| \overline{A}_0^*)$$

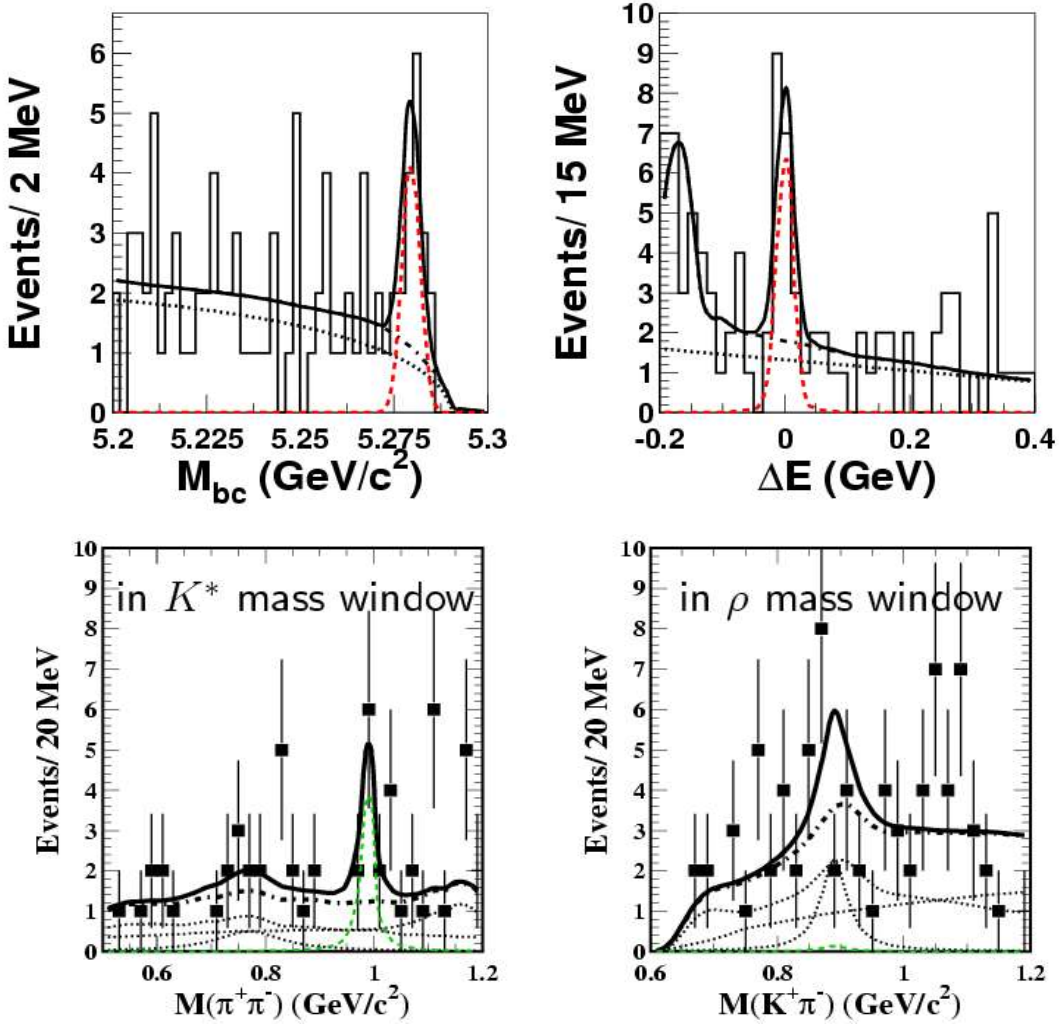
If no New Physics:

$\Sigma_{\lambda\lambda}=0/\Sigma_{\|0}=0/\Lambda_{\perp i}=0$

$(\lambda\in\{0,\perp,\|\}, i\in\{0,\|\})$

Λ_{00}	0.50 ±0.06 ±0.04	Σ_{00}	–0.09 ±0.06 ±0.02
$\Lambda_{\|\|}$	0.25 ±0.06 ±0.02	$\Sigma_{\|\|}$	0.10 ±0.06 ±0.02
$\Lambda_{\perp\perp}$	0.25 ±0.06 ±0.03	$\Sigma_{\perp\perp}$	–0.01 ±0.06 ±0.02
$\Lambda_{\perp 0}(=\overline{A_T^0}-A_T^0)$	0.07 ±0.11 ±0.04	$\Sigma_{\perp 0}$	–0.49 ±0.12 ±0.07
$\Lambda_{\perp\|}(=\overline{A_T^\|}-A_T^\|)$	0.02 ±0.10 ±0.03	$\Sigma_{\perp\|}$	–0.09 ±0.10 ±0.02
$\Lambda_{\|0}$	–0.39 ±0.13 ±0.06	$\Sigma_{\|0}$	–0.11 ±0.13 ±0.04

Search for $B \to \rho^0 K^{*0}$



- Signal yield is extracted by a fit to ΔE and M_{bc} :

$$N(K^{\pm}\pi^{\mp}\pi^{\pm}\pi^{\mp}) = 14.5^{+4.9}_{-4.2}$$

- Check M($K^{\pm}\pi^{\mp}$) and M($\pi^{\pm}\pi^{\mp}$) in the signal window:

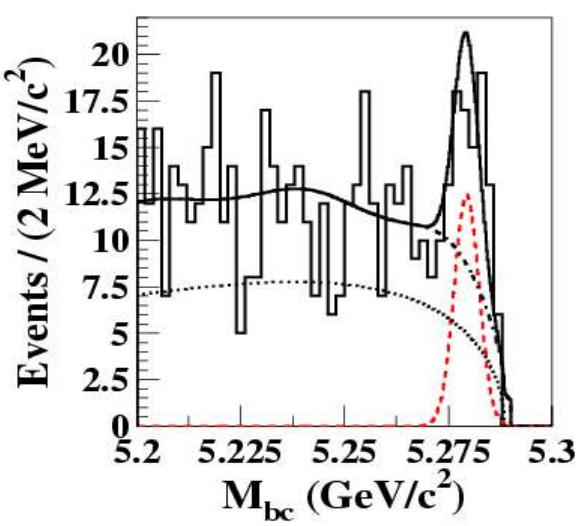
$$N(\rho^0 K^{*0}) = 0 \pm 5.2$$

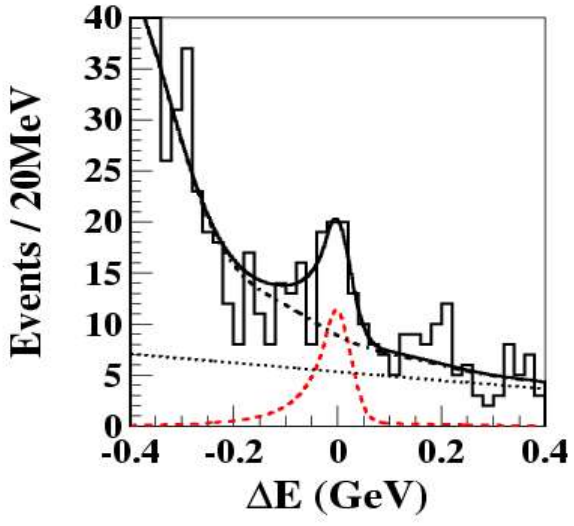
$$N(f_0(980) K^{*0}) = 10.2^{+5.3}_{-4.4}$$

Most of the events are NOT $\rho^0 K^{*0}$ ⇩

$$\mathcal{B}(B \to \rho^0 K^{*0}) < 2.6 \times 10^{-6} \text{ @ 90\% CL}$$

Measurement of $B \to \rho^+ K^{*0}$





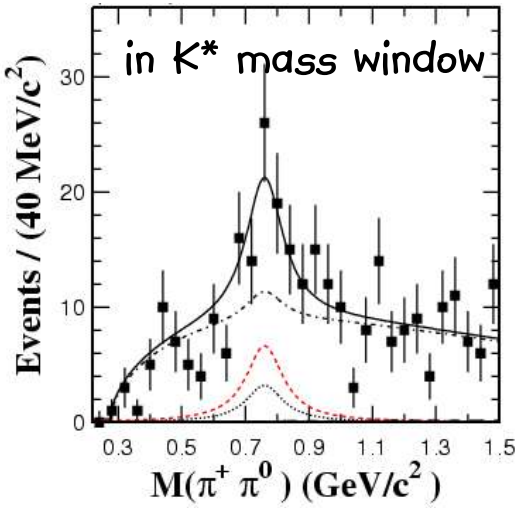
- Signal yield is extracted by a fit to ΔE and M_{bc} :

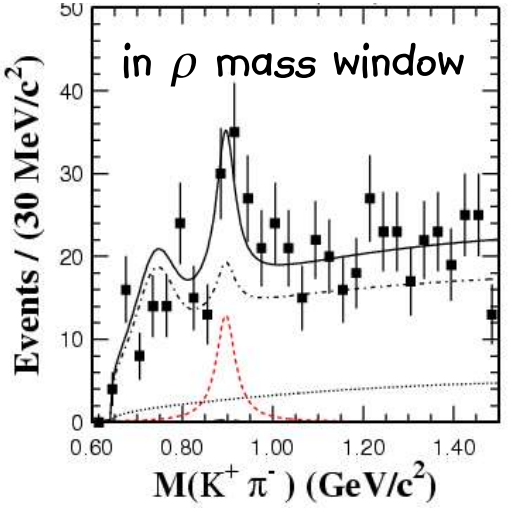
  $N(K^{\pm}\pi^{\mp}\pi^{\pm}\pi^0) = 56.5 \pm 11.6$

- Check M($K^{\pm}\pi^{\mp}$) and M($\pi^{\pm}\pi^0$) in the signal window:

  $N(\rho^{\pm}K^{*0}) = 26.6 \pm 8.7$

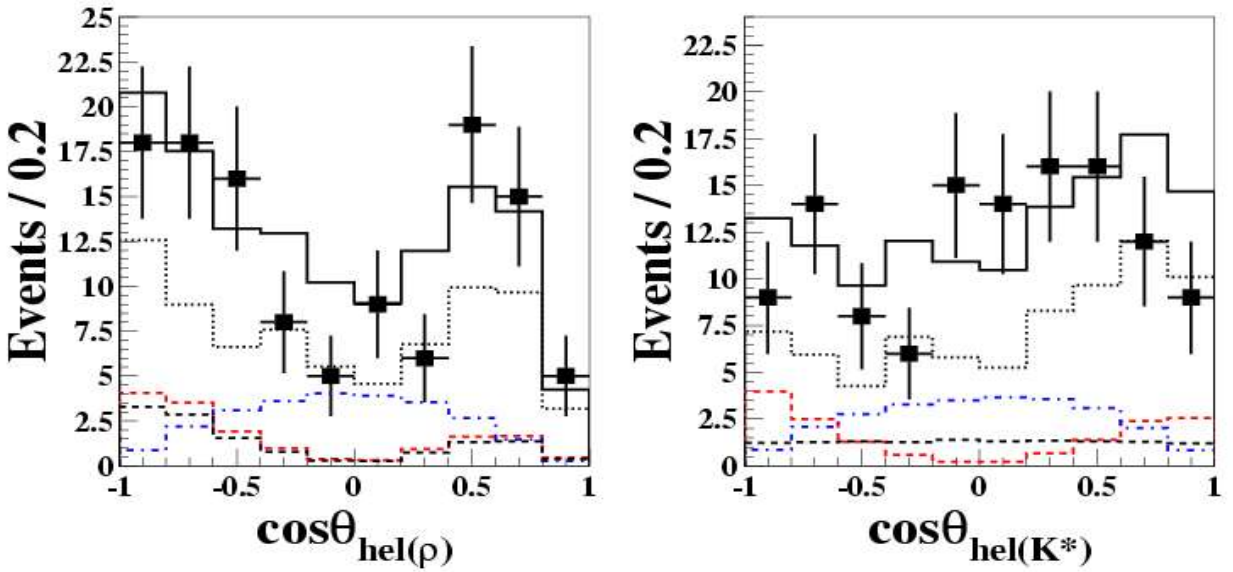
  (Significance = 3.2σ)





Measurement of $B \to \rho^+ K^{*0}$

Polarization & Branching Fraction



- Fit to the two helicity angles ($\rho^\pm$ & K^{*0}):

$$R_0 = 0.50 \pm 0.19^{+0.05}_{-0.07}$$

(3.2σ away from 100%)

- Branching fraction (efficiency is dependent on the polarization):

$$\mathcal{B}(B \to \rho^\pm K^{*0}) = (6.6 \pm 2.2 \pm 0.8) \times 10^{-6}$$

SUMMARY

$B \to PV$

- Branching fractions of $B \to \eta K^*$, $B \to \eta\rho^0$, $B \to \rho\pi^0$ are measured; while no significant signal found in $B \to \eta\rho^0$, an upper limit is given instead.
- No direct CP violation found in our data.

$B \to VV$

- The polarization study of ϕK^* is updated. The fraction of longitudinal component (R_0) still differ from 1.
- *T*-violating asymmetry is measured through triple-product correlations. The results are consistent with zero.
- No clear signal found in $B \to \rho^0 K^*$ decay; an upper limit is provided.
- The polarization and branching fraction of $B \to \rho^+ K^*$ are measured.