# Charmless B meson decays at Belle

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(For the Belle Collaboration)

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- ☑ Introduction
- ☑ Experiment /Analysis Overview
- ☑ $B^0 \to \rho^0\rho^0$
- ☑ $B \to p\bar{p}K^*$
- ☑ Summary

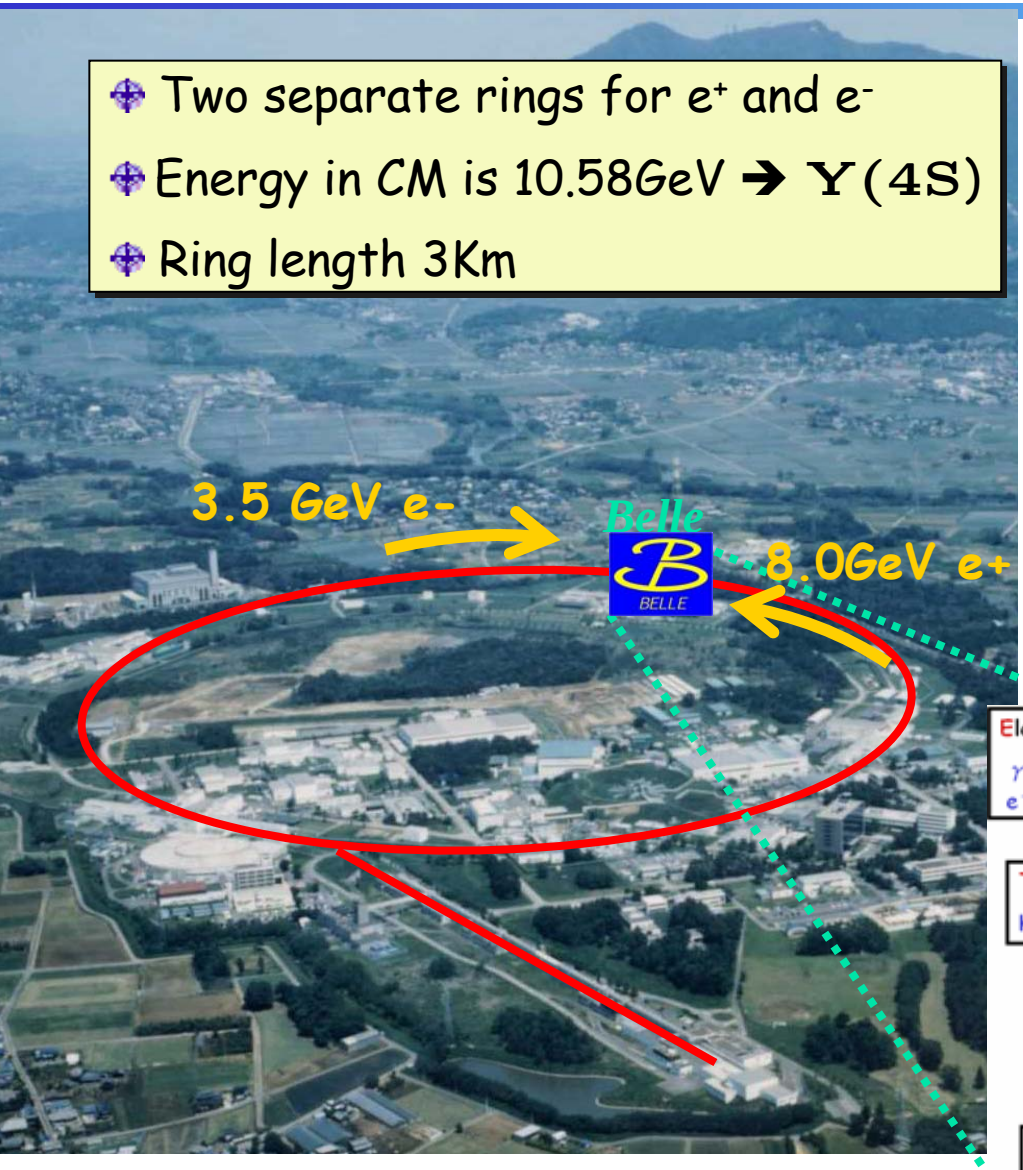
# Introduction

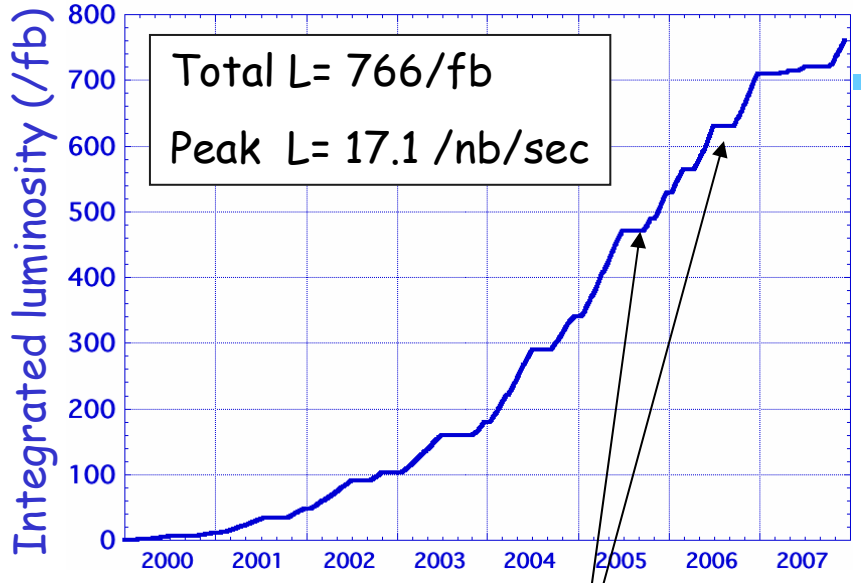
- Rich physics outputs from charmless B decays
  - CPV, CKM angles, Vxx, B decay mechanism, new physics, …
- Many activities on charmless B decays at Belle
- **Mesonic**/**Baryonic**/Radiative/Leptonic/…decays

- $B^0 \to \rho^0\rho^0$ (with 657M$B\bar{B}$ updated from 520M$B\bar{B}$ @ LP07)
  - ➢ $\phi_2 (= \alpha)$ constraint
- $B \to p\bar{p}K^*$ (with 535M$B\bar{B}$ updated from 85M$B\bar{B}$)
  - ➢ baryonic B decay mechanism

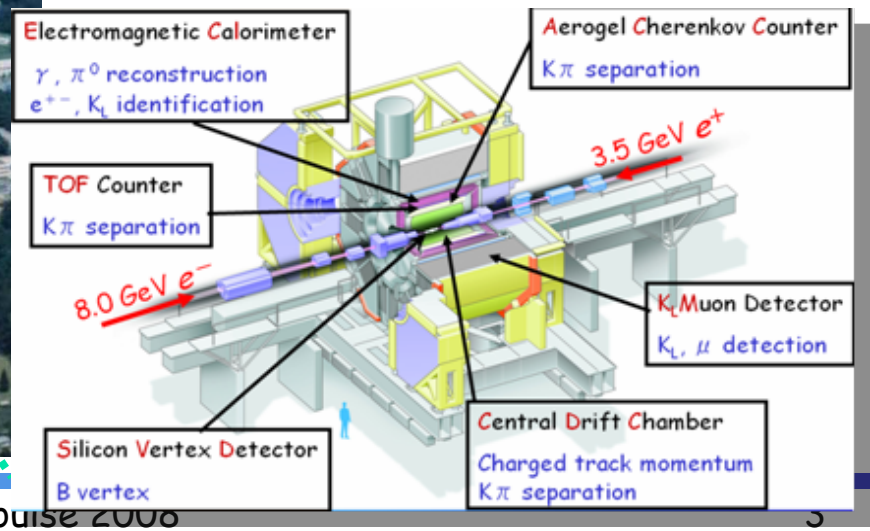
# KEKB accelerator

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



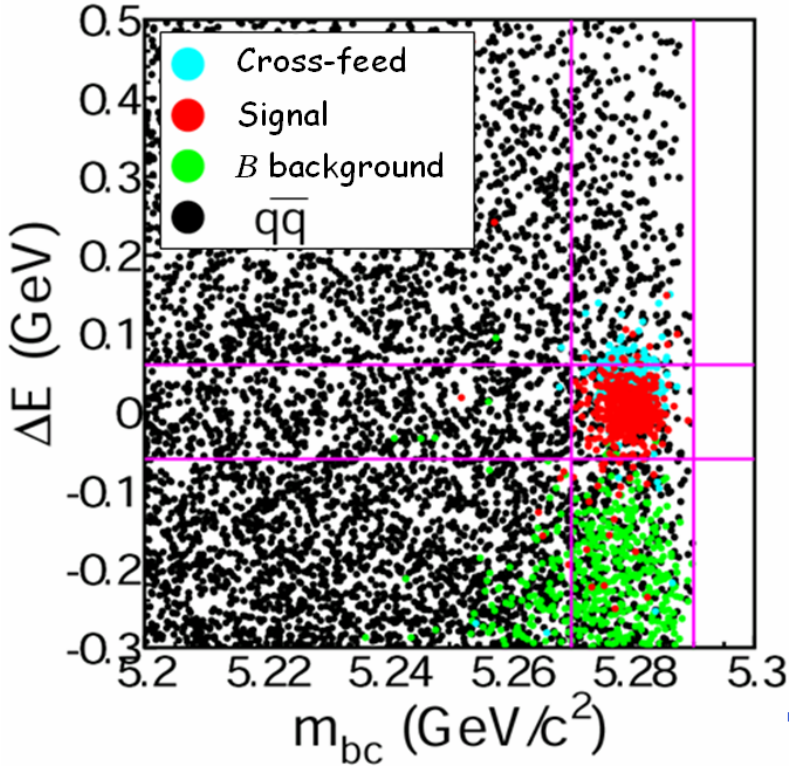

Results are based on
535 or 657 MB$\bar{B}$ pairs



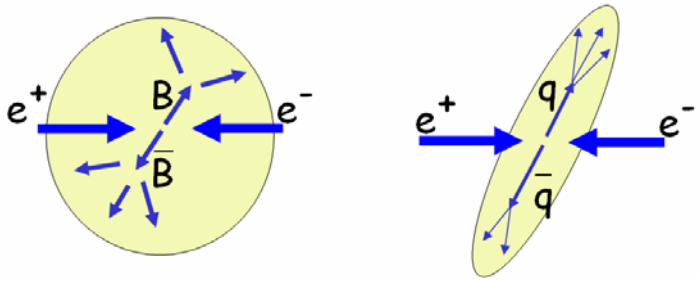
# Analysis Overview

- **B reconstruction with $\Delta E$ and $m_{bc}$**

$$\Delta E \equiv E_B^* - E_{\rm beam}^*$$
$$m_{bc} \equiv \sqrt{E_{\rm beam}^{*2} - p_B^{*2}}$$




- **Main background**
  - $e^+e^- \rightarrow q\bar{q}(q=u,d,s,c)$ ➔ event topology



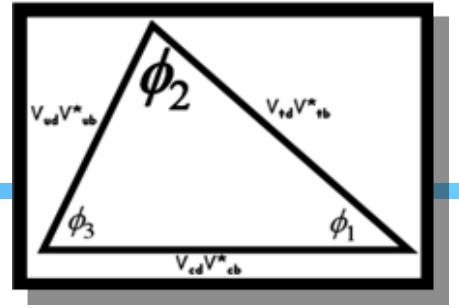

Spherical Jet-like

  - $\pi$ /K/p separation➔ PID

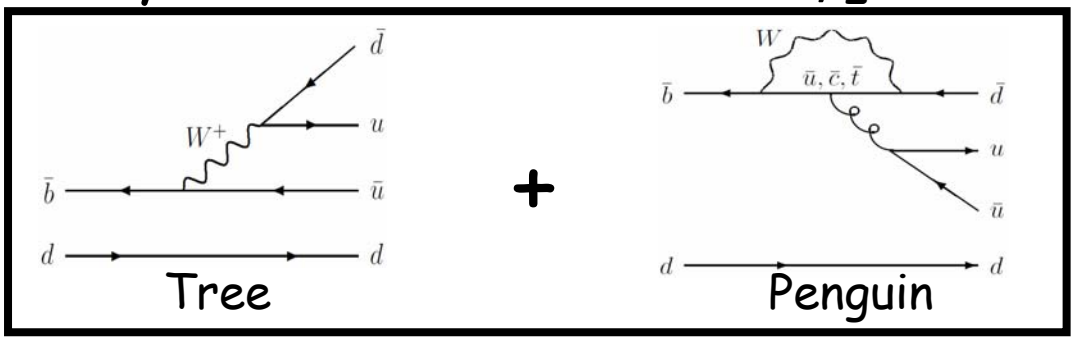
- **Signal extraction**
  - Unbinned maximum likelihood fit on $\Delta E$, $m_{bc}$, Mass…

$$\mathcal{L} = \frac{exp(-\sum_j n_j)}{n!} \prod_{i=1}^{n_{cand}} (\sum_j n_j \mathcal{P}_j^i)$$

# $B^0 \to \rho^0\rho^0$ (introduction)

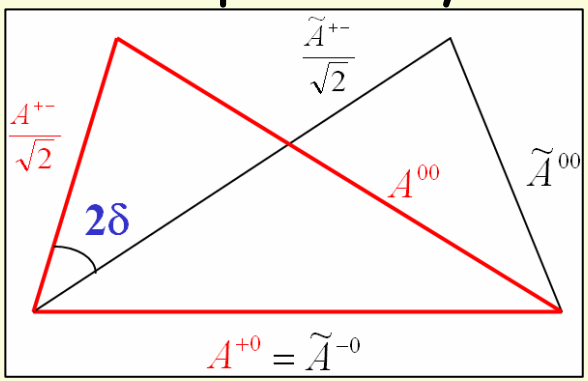



- $\phi_2(=\alpha)$ measurement is essential to test SM
- 3 decay channels to measure $\phi_2$ : $B \to \pi\pi, \rho\pi, \rho\rho$




- Penguin pollution $\delta$: $\mathcal{S}_{\rho\rho} = \sqrt{1-\mathcal{A}_{\rho\rho}}\ \sin(2\phi_2^{\rm eff}) \qquad \phi_2^{\rm eff} = \phi_2 + \delta$

- Isospin analysis (PRL,65,3381(1990))

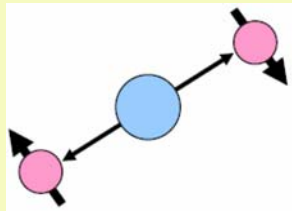



$A^{+-} = A(B^0 \to \rho^+\rho^-)$
$\widetilde{A}^{+-} = A(\overline{B}^0 \to \rho^+\rho^-)$
$A^{00} = A(B^0 \to \rho^0\rho^0)$
$\widetilde{A}^{00} = A(\overline{B}^0 \to \rho^0\rho^0)$
$A^{+0} = A(B^+ \to \rho^+\rho^0)$
$\widetilde{A}^{-0} = A(B^- \to \rho^-\rho^0)$

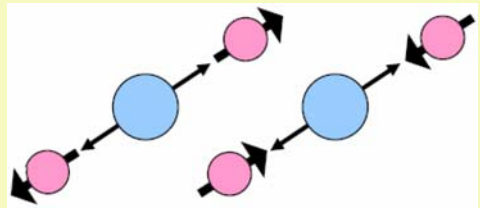
➔ Have to measure all BRs of $B \to \rho\rho$

- Polarization measurement

3 polarization states with diff. CP



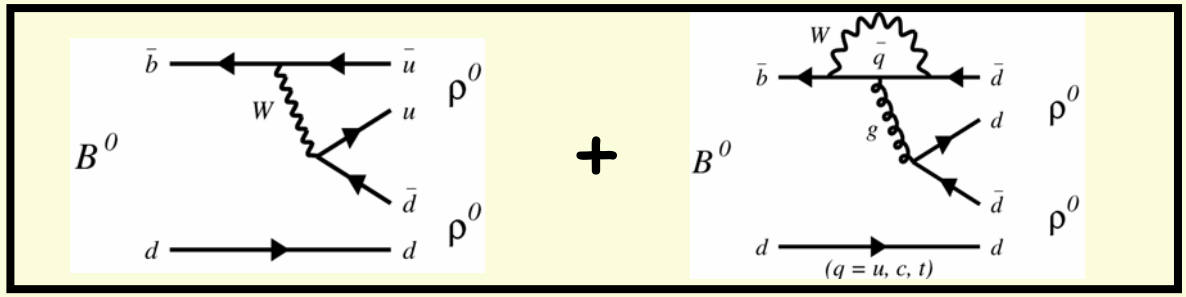
Longitudinal(CP even)



Transverse(CP even + odd)

# $B^0 \to \rho^0\rho^0$ (introduction)

- Color-suppressed Tree and Penguin



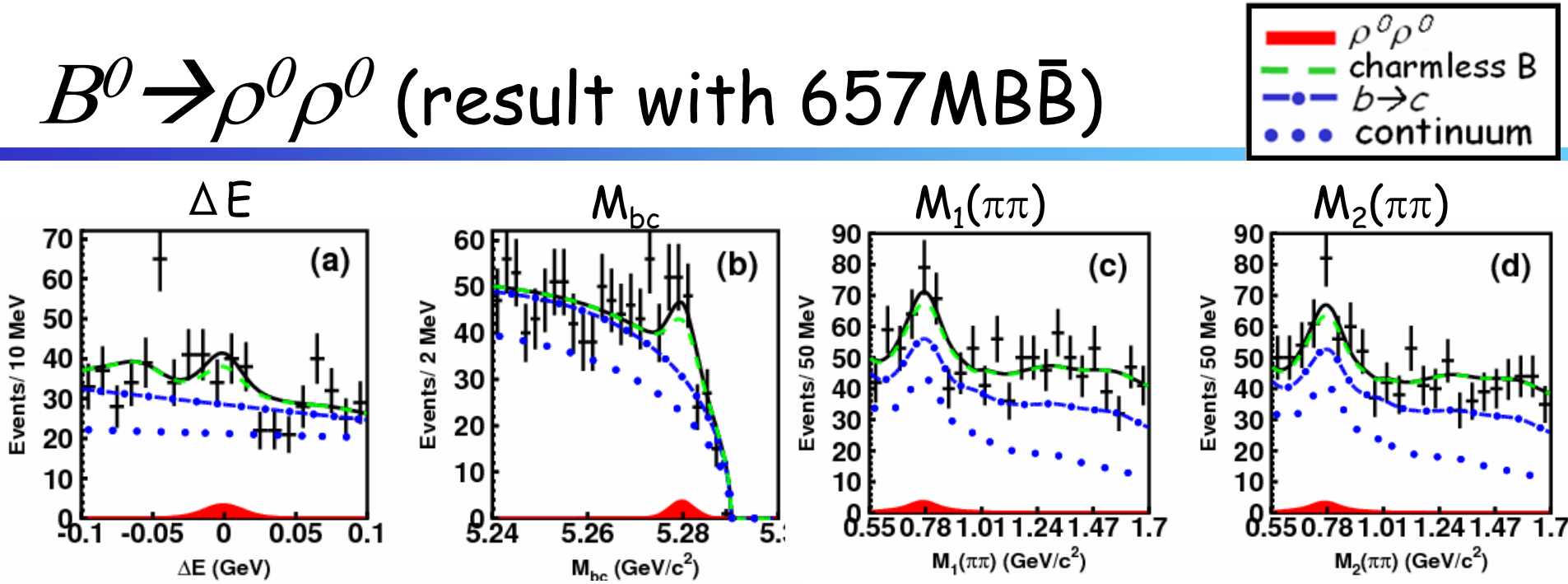

  - Small branching fraction (~ 1x10$^{-6}$)
  - Strong limit can be set to δ ➔ $\rho^0\rho^0$ is crucial

- Measure 6 modes: $B^0 \to \rho^0\rho^0,\ \rho^0\pi\pi,\ 4\pi,\ \rho^0 f_0,\ f_0 f_0,\ f_0\pi\pi$
  - Unbinned maximum likelihood fit on ΔE, mbc, M1(ππ), M2(ππ)

$$\mathcal{L} = \frac{exp(-\sum_j n_j)}{n!} \prod_{i=1}^{n_{cand}} (\sum_j n_j \mathcal{P}_j^i) \qquad \mathcal{P}_j^i = P_j(M_{bc}^i, \Delta E^i, M_1^i, M_2^i)$$

    - Fix $B^0 \to a_1^+\pi^-$, $B^+ \to \rho^+\rho^0$ to the expected value
    - Assume $\rho^0\rho^0$ 100% longitudinal polarized

# $B^0 \to \rho^0\rho^0$ (result with 657MB$\bar{B}$)




$$\mathcal{B}(B^0 \to \rho^0\rho^0) < 1.0 \times 10^{-6}$$

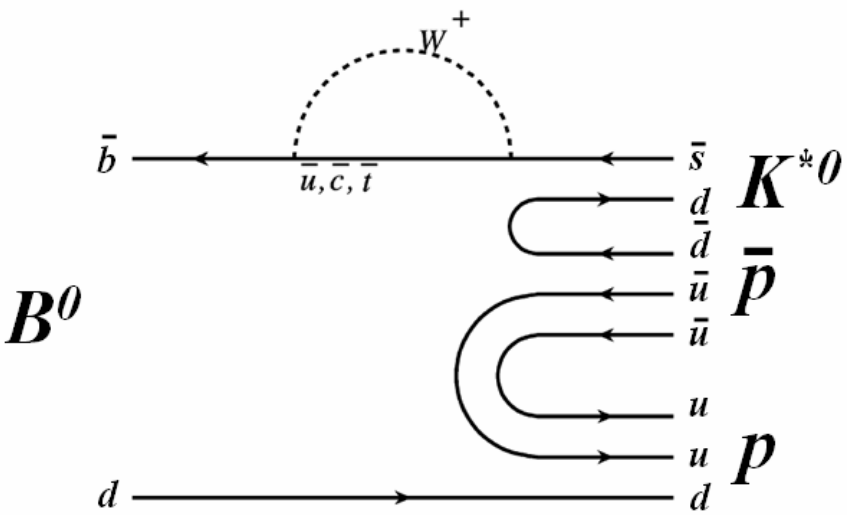
| Mode | Yield | Eff.(%) | $\mathcal{S}$ | $\mathcal{B}(\times 10^{-6})$ | UL$(\times 10^{-6})$ |
|---|---|---|---|---|---|
| $\rho^0\rho^0$ | $24.5^{+23.6+9.7}_{-22.1-9.9}$ | 9.16 | 1.0 | $0.4 \pm 0.4 \pm 0.2$ | $< 1.0$ |
| $\rho^0\pi\pi$ | $112.5^{+67.4+51.5}_{-65.6-53.7}$ | 2.90 | 1.3 | $5.9^{+3.5+2.7}_{-3.4-2.8}$ | $< 11.9$ |
| $4\pi$ | $161.2^{+61.2+26.0}_{-59.4-28.5}$ | 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 | $0.6^{+3.6}_{-3.4} \pm 1.8$ | $< 7.3$ |

- Assume $f_L = 1$
- $\mathcal{S}$ includes systematics
- $\rho^0\pi\pi$, $4\pi$ excess are seen
- Consistent with BABAR

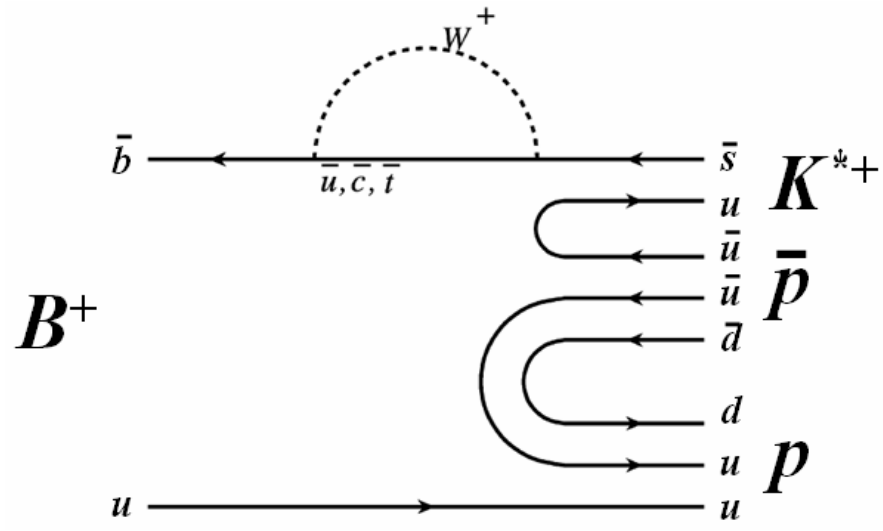
  Br($\rho^0\rho^0$)=(1.07±0.33±0.19)x10$^{-6}$

**Need more data...**

$B^0 \to p\bar{p}K^{*0}$



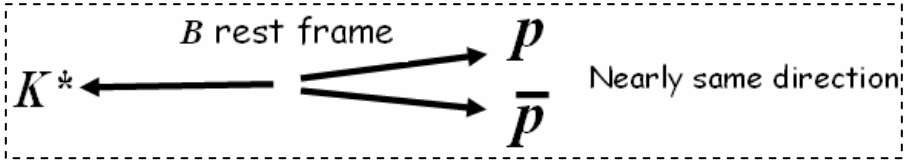

$B^+ \to p\bar{p}K^{*+}$




***Belle collaboration, arXiv:0802.0336v1***

# $B \to p\bar{p}K^*$ (introduction)

- Threshold enhancement of the baryon pair mass(m1+m2) spectra
  - $B \to p\bar{p}K^+, p\bar{p}K^0, p\bar{p}\pi^+, p\bar{p}K^{*+}, p\bar{\Lambda}\pi^-, p\bar{\Lambda}\pi^0, p\bar{\Lambda}\gamma, \Lambda\bar{\Lambda}K^+$




  - 2-body counterpart is not found
  - No enhancement in $p\bar{p}K^{*0}$ by BABAR(PRD76,092004,2007)
  - Enhancement in $p\bar{p}K^{*0}$ is predicted(PRD75,094013,2007)

- $\mathcal{B}(p\bar{p}K^+) > \mathcal{B}(p\bar{p}K^{*+}) > \mathcal{B}(p\bar{p}K^{*0})$ (PRD66,014020)
- Large DCPV prediction: Acp($B^+ \to p\bar{p}K^{*+}$) ~20% (PRD75,094013,2007)
- Angular distributions → help to understand decay mechanisms

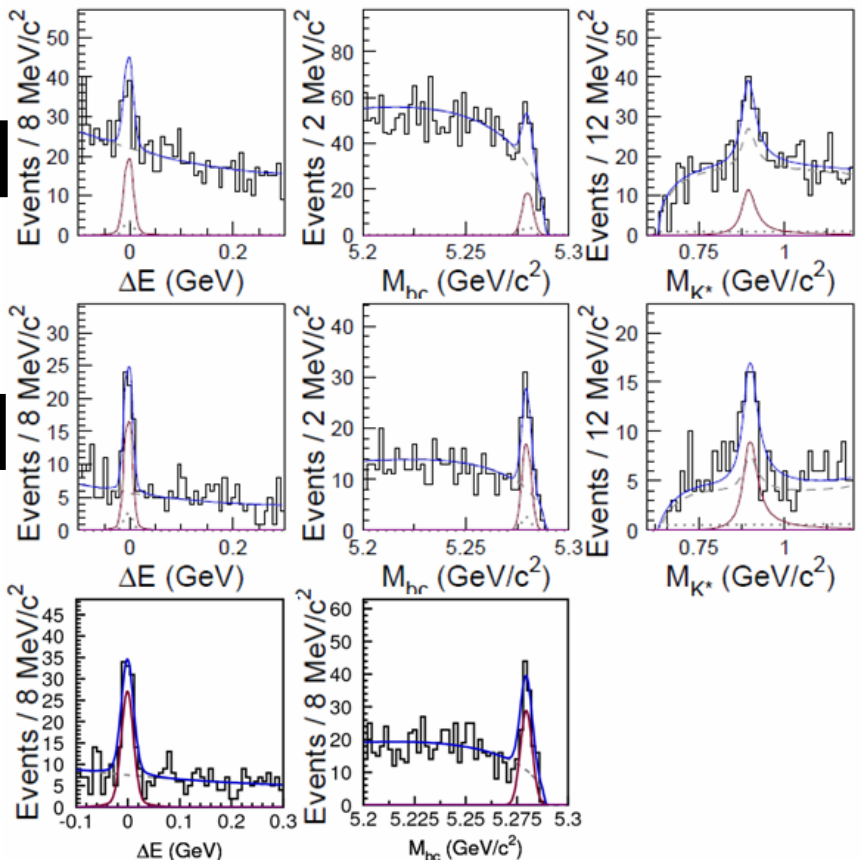
Update $B \to p\bar{p}K^{*0}$, $p\bar{p}K^{*+}$, $p\bar{p}K^0$ with 535MB$\bar{B}$(>6 x last data)

# $B \to p\bar{p}K^*$ (result with 535MBB̄)

$p\bar{p}K^{*0}$

$p\bar{p}K^{*+}$

$p\bar{p}K^{0}$




- Unbinned maximum likelihood fit

$$\mathcal{L} = \frac{exp(-\sum_j n_j)}{n!} \prod_{i-1}^{n_{cand}} (\sum_j n_j \mathcal{P}_j^i)$$

$$\mathcal{P}_j^i = P_j(M_{bc}^i, \Delta E^i, M_{K^*}^i)$$

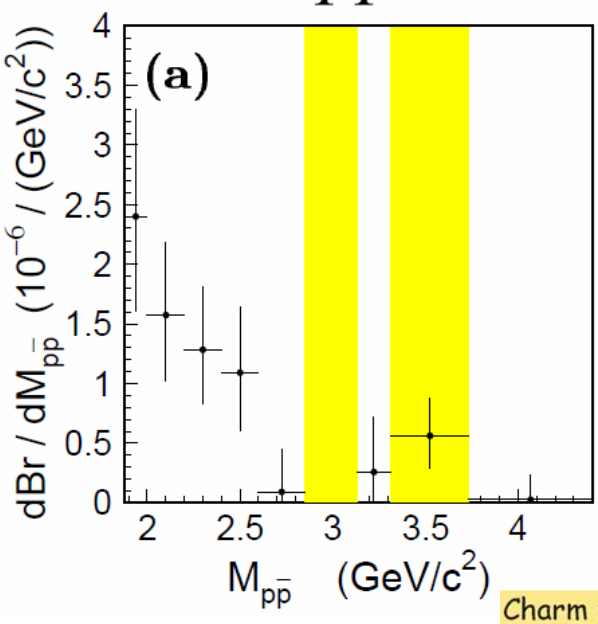
- $M(p\bar{p}) < 2.85 GeV/c^2$

- First observation of $B^0 \to p\bar{p}K^{*0}$
- Consistent with the theor. prediction
  - $\mathcal{B}(p\bar{p}K^+) > \mathcal{B}(p\bar{p}K^{*+}) > \mathcal{B}(p\bar{p}K^{*0})$
- No significant $A_{CP}$

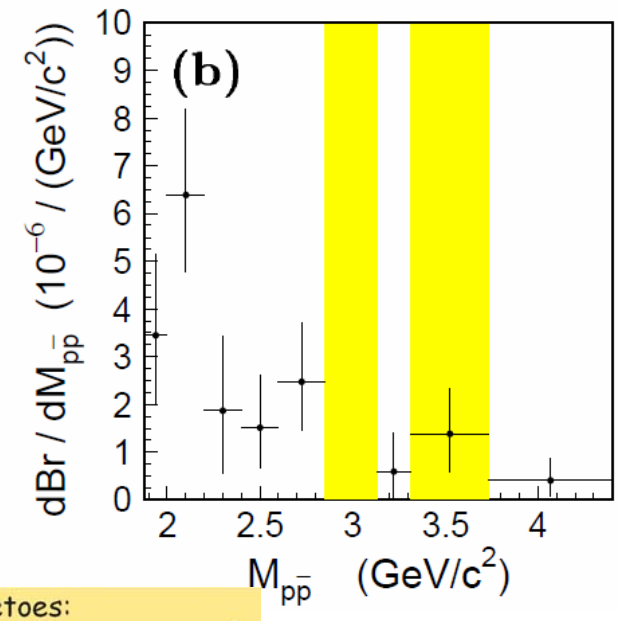
| Mode | $N_S$ | $\mathcal{S}$ | $\mathcal{B}(\times 10^{-6})$ | $\mathcal{A}_{CP}$ |
|---|---|---|---|---|
| $B^0 \to p\bar{p}K^{*0}$ | $70.1^{+14.8}_{-13.9}$ | 7.2 | $1.18^{+0.29}_{-0.25} \pm 0.11$ | $-0.08 \pm 0.20 \pm 0.02$ |
| $B^+ \to p\bar{p}K^{*+}$ | $54.2^{+10.9}_{-10.1}$ | 8.8 | $3.38^{+0.73}_{-0.60} \pm 0.39$ | $-0.01 \pm 0.19 \pm 0.02$ |
| $B^0 \to p\bar{p}K^{0}$ | $107.8^{+12.5}_{-11.8}$ | 14.8 | $2.51^{+0.35}_{-0.29} \pm 0.21$ | — |

# $B \to p\bar{p}K^*$ (threshold enhancement)

$B^0 \to p\bar{p}K^{*0}$



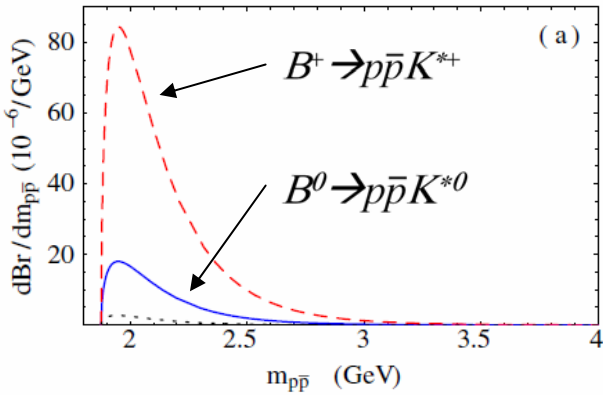

$B^+ \to p\bar{p}K^{*+}$




Charm vetoes:
$\eta_c$, $J/\psi$, $\psi'$, $\chi_{c0}$, $\chi_{c1}$, $h_c$

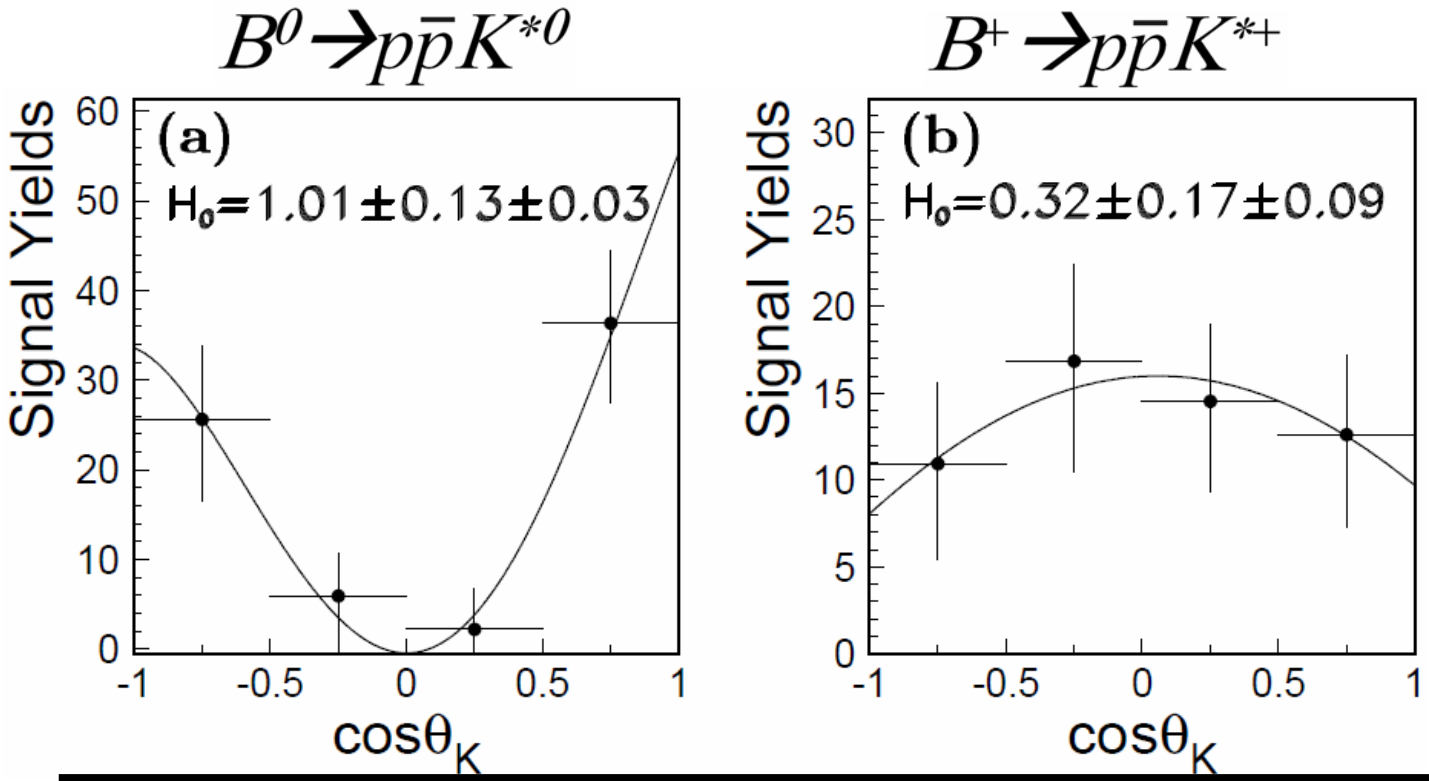
Theoretical expectation

PRD75,094013,2007



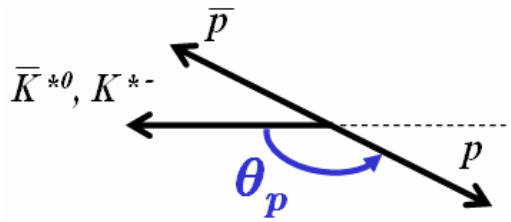

- $p\bar{p}$ mass enhancement near threshold can be seen
- Similar feature to theoretical prediction

# $B \to p\bar{p}K^*$ ($K^*$ angular distribution)

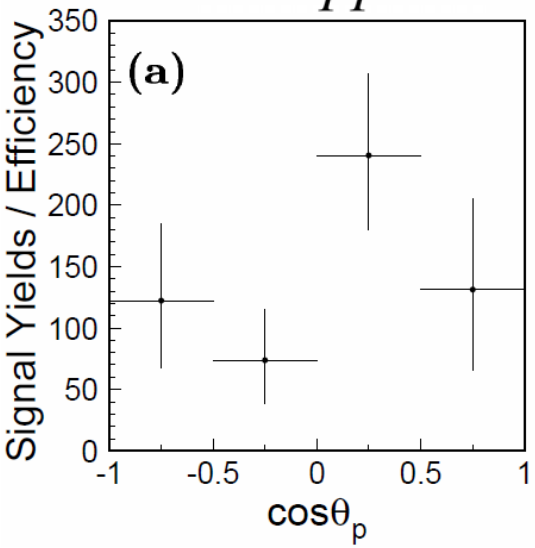



- Efficiency corrected helicity(0,±1) PDFs are applied
- $M(p\bar{p}) < 2.85 GeV/c^2$
- $H_0(K^{*0})$ = 101±13±3 %
- $H_0(K^{*+})$ = 32±17±9 %

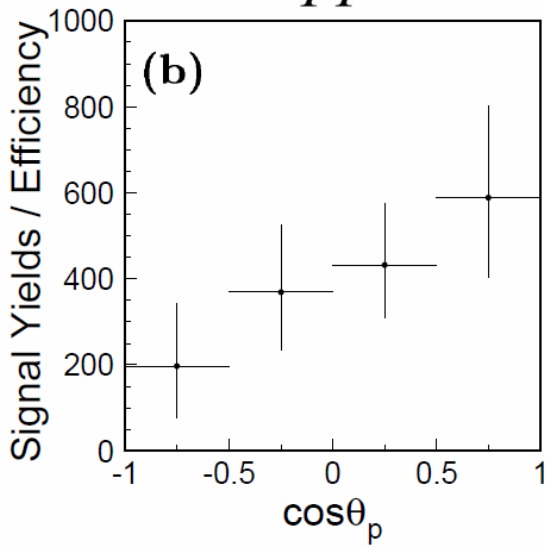
# $B \to p\bar{p}K^*$ (proton angular distribution)




$B^0 \to p\bar{p}K^{*0}$

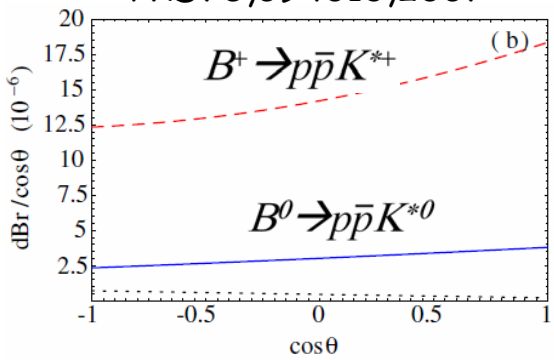



$B^+ \to p\bar{p}K^{*+}$




Theoretical prediction

PRD75,094013,2007




**$p\bar{p}K^{*+}$ is similar to theoretical expectation and $p\bar{p}K^+$**

# Summary

- $B^0 \to \rho^0\rho^0$ with 657MB$\bar{B}$
  - No significant signal $\to$ Br($\rho^0\rho^0$) $< 1.0\times10^{-6}$ (90% C.L.)
  - Upper limits on $B^0 \to \rho^0\pi\pi$ / $4\pi$ / $\rho^0 f_0$ / $f_0 f_0$ / $f_0\pi\pi$

- $B \to p\bar{p}K^*$ with 535MB$\bar{B}$
  - Observation of $B^0 \to p\bar{p}K^{*0}$

| Mode | $N_S$ | $\mathcal{S}$ | $\mathcal{B}(\times10^{-6})$ | $\mathcal{A}_{CP}$ |
|---|---|---|---|---|
| $B^0 \to p\bar{p}K^{*0}$ | $70.1^{+14.8}_{-13.9}$ | 7.2 | $1.18^{+0.29}_{-0.25} \pm 0.11$ | $-0.08 \pm 0.20 \pm 0.02$ |
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| $B^0 \to p\bar{p}K^0$ | $107.8^{+12.5}_{-11.8}$ | 14.8 | $2.51^{+0.35}_{-0.29} \pm 0.21$ | — |

  - Threshold enhancement in $p\bar{p}K^{*0}$ and $p\bar{p}K^{*+}$
  - Large $K^{*0}$ polarization
    - $H_0(K^{*0})$ = 101±13±3 %
    - $H_0(K^{*+})$ = 32±17±9 %

# Backup slides

# Belle Collaboration

BINP
Chiba U.
U. of Cincinnati
Ewha Womans U.
Fu-Jen Catholic U.
U. of Giessen
Gyeongsang Nat'l U.
Hanyang U.
U. of Hawaii
Hiroshima Tech.
IHEP, Beijing
IHEP, Moscow
IHEP, Vienna
ITEP
Kanagawa U.
KEK
Korea U.
Krakow Inst. of Nucl. Phys.
Kyoto U.
Kyungpook Nat'l U.
EPF Lausanne
Jozef Stefan Inst. / U. of Ljubljana / U. of Maribor
U. of Melbourne
Nagoya U.
Nara Women's U.
National Central U.
National Taiwan U.
National United U.
Nihon Dental College
Niigata U.
Nova Gorica
Osaka U.
Osaka City U.
Panjab U.
Peking U.
Princeton U.
Riken
Saga U.
USTC
Seoul National U.
Shinshu U.
Sungkyunkwan U.
U. of Sydney
Tata Institute
Toho U.
Tohoku U.
Tohuku Gakuin U.
U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
INFN Torino
Toyama Nat'l College
VPI
Yonsei U.

**14 countries**
**55 institutes**
**~400 collaborators**

# $B^0 \to \rho^0\rho^0$ (systematics)

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

- Test possible interference between $\rho^0\rho^0$ and $a_1\pi$, $4\pi$, $\rho^0\pi\pi$ by Toy MC
- Simple interference model modified from a relativistic Breit-Wigner

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

(A and $\delta$ are interference amplitude and phase)

- Re-fit with parameters A and $\delta$ which are uniformly varied
- Mean deviation from the incoherent case

# $B \to p\bar{p}K^*$ (Br systematics)

| Source | $p\bar{p}K^{*0}$ | $p\bar{p}K^{*+}$ | $p\bar{p}K^0$ |
|---|---|---|---|
| Number of $B\bar{B}$ Pairs | 1.3% | 1.3% | 1.3% |
| Tracking | 4.4% | 5.4% | 4.1% |
| Proton ID | 4.2% | 4.2% | 4.2% |
| Charged Kaon(Pion) ID | 2.0% | 1.0% | - |
| $K^0_S$ Reconstruction | - | 4.1% | 4.1% |
| $\mathcal{R}$ Selection | 2.3% | 2.3% | 2.3% |
| Multiple Counting | 2.0% | 3.5% | 2.0% |
| MC Statistic | 2.9% | 2.8% | 2.1% |
| Fitting | 5.2% | 5.2% | 1.0% |
| Helicity Distribution | 2.4% | 4.0% | - |
| Total | 9.7% | 11.6% | 8.2% |

# $B \to p\bar{p}K^*$ (Threshold enhancement)

| $M_{p\bar{p}}$ (GeV) | Yield | $\mathcal{B}$ $(10^{-6})$ | Yield | $\mathcal{B}$ $(10^{-6})$ |
|---|---|---|---|---|
| $< 2.0$ | $21.4^{+8.0}_{-7.1}$ | $0.30^{+0.11}_{-0.10}$ | $9.0^{+4.4}_{-3.7}$ | $0.43^{+0.21}_{-0.18}$ |
| $2.0 - 2.2$ | $21.5^{+8.4}_{-7.5}$ | $0.31^{+0.12}_{-0.11}$ | $25.1^{+7.1}_{-6.3}$ | $1.28^{+0.36}_{-0.32}$ |
| $2.2 - 2.4$ | $15.7^{+6.4}_{-5.6}$ | $0.26^{+0.10}_{-0.09}$ | $6.4^{+5.4}_{-4.5}$ | $0.37^{+0.31}_{-0.26}$ |
| $2.4 - 2.6$ | $12.3^{+6.2}_{-5.4}$ | $0.22^{+0.11}_{-0.10}$ | $4.5^{+3.3}_{-2.5}$ | $0.30^{+0.22}_{-0.17}$ |
| $2.6 - 2.85$ | $1.2^{+4.9}_{-3.9}$ | $0.02^{+0.09}_{-0.07}$ | $9.6^{+4.8}_{-3.9}$ | $0.62^{+0.31}_{-0.25}$ |
| $2.85 - 3.128$(veto) | $224.2^{+18.2}_{-17.6}$ | $4.12^{+0.34}_{-0.32}$ | $55.7^{+9.8}_{-9.0}$ | $3.66^{+0.65}_{-0.59}$ |
| $3.128 - 3.315$ | $2.6^{+4.7}_{-3.5}$ | $0.05^{+0.09}_{-0.06}$ | $1.5^{+2.1}_{-1.5}$ | $0.11^{+0.15}_{-0.11}$ |
| $3.315 - 3.735$(veto) | $11.9^{+6.6}_{-5.6}$ | $0.24^{+0.13}_{-0.11}$ | $7.1^{+4.8}_{-4.1}$ | $0.58^{+0.40}_{-0.34}$ |
| $> 3.735$ | $0.7^{+5.5}_{-4.4}$ | $0.02^{+0.14}_{-0.11}$ | $2.5^{+2.9}_{-2.0}$ | $0.27^{+0.31}_{-0.22}$ |
| Charmless | $75.4^{+17.1}_{-14.7}$ | $1.18^{+0.29}_{-0.25}$ | $58.7^{+12.1}_{-10.1}$ | $3.38^{+0.73}_{-0.60}$ |