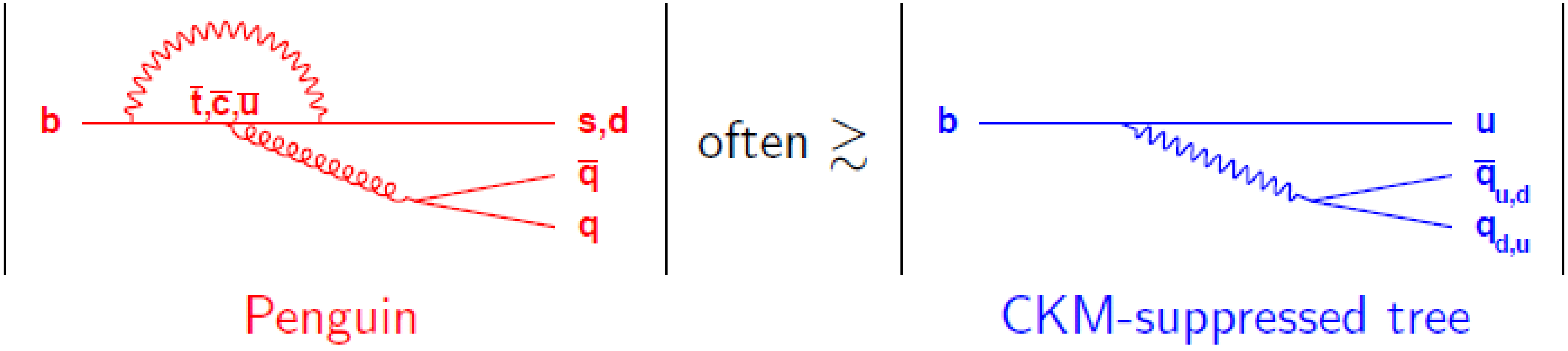
Hadronic rare B decays at Belle and BaBar

2008/06/05 M.Iwasaki (U. Tokyo)
For the Belle Collaboration

Introduction :
Rare hadronic B-decays



Rare hadronic B-decays are rich sources of information

- Indirect CP Violation : Extract CKM parameters
- Direct CP Violation : Interfering SM amplitudes
- Search for new physics effects : study loop processes
- Measured BR, angular correlations

→ Phenomenological test/development of the theoretical models

Introduction

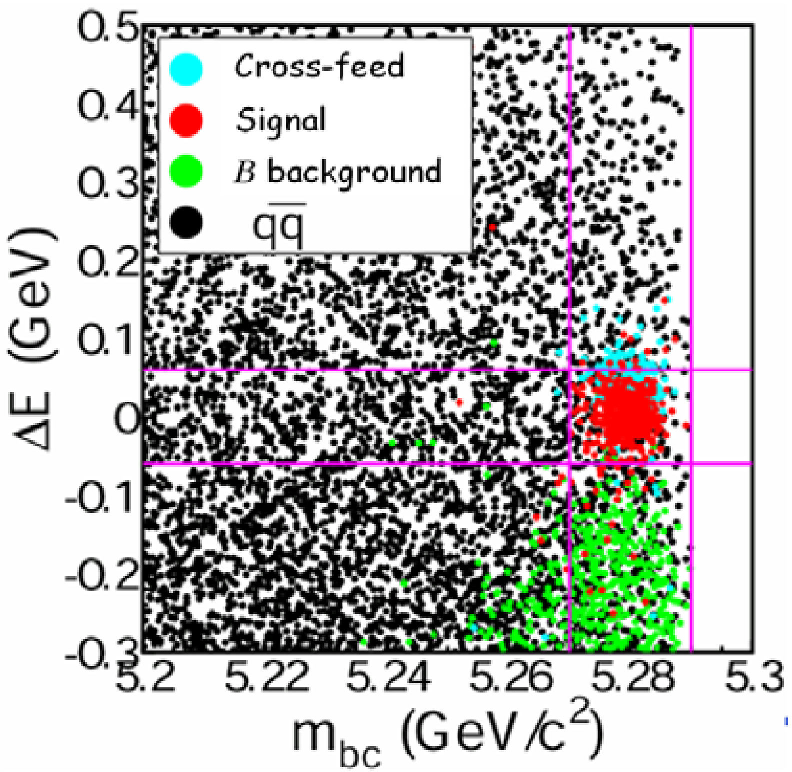
In this talk, we'll cover:

1. Extraction of the angle ϕ_2/α of the UT
   - $B^0 \to \rho^0\rho^0$ with isospin SU(2) (Belle)
   - $B \to a_1 K$ with flavor SU(3) (BaBar)
2. $B \to VV(A)$ polarization : f_L
   - $B^0 \to \omega K^{*0}$ (Belle)
   - $B^0 \to b_1^{\mp}\rho^{\pm}$ (BaBar)
3. Baryonic B-decay : Br, A_{CP}
   - $B \to p\bar{p}K^*$ (Belle)

Analysis methods

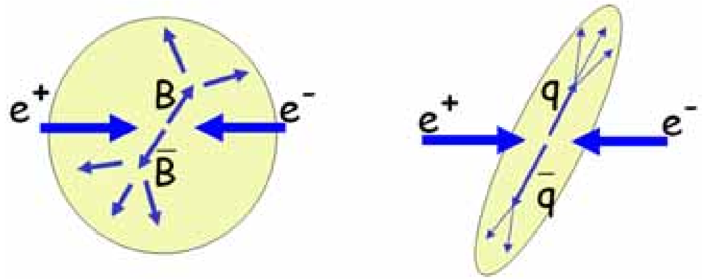
B reconstruction with ΔE and M_{bc}

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



Main background

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



Spherical   Jet-like

- π/K/p separation➔ PID

Signal Extraction

- **Unbinned maximum likelihood fit to ΔE, Mbc. Mass…**

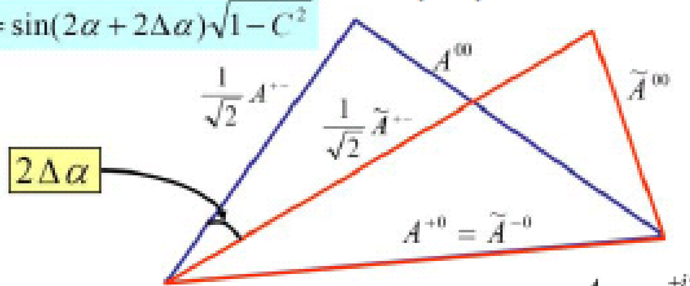
$$\mathcal{L} = \frac{exp(-\sum_j n_j)}{n!} \prod_{i=1}^{n_{cand}} (\sum_j n_j \mathcal{P}_j^i)$$

Extraction of the $\phi_2(\alpha)$ of the UT

- Hadronic B decays from b→uud transitions provide the most direct information about the weak phase ϕ_2 (α).
- The difficulty in extracting ϕ_2 is the presence of subleading penguin amplitudes (P) with a different weak phase than that of the dominant tree amplitudes (T)
- This difficulty can be overcome by using symmetries:
  - isospin SU(2) (PRL 65, 3381(1990), PRD 71, 07401(2005)
  - approximate flavor SU(3) (PRD57, 1783 (1998)

SU(2)

$S = \sin(2\alpha + 2\Delta\alpha)\sqrt{1-C^2}$



Neglecting EW penguins, ±0 is a pure tree mode and so the two triangles share a common side:

$$A(B^+ \to h^+h^0) = \tilde{A}(B^- \to h^-h^0)$$

$$A_{hh} = e^{+i\gamma}T + e^{-i\beta}P$$

$$\tilde{A}_{hh} = e^{-i\gamma}T + e^{+i\beta}P$$

SU(3)

in $\Delta S=0$ decays: $T \sim V_{ub}V^*_{ud}$ and $P \sim V_{cb}V^*_{cd}$

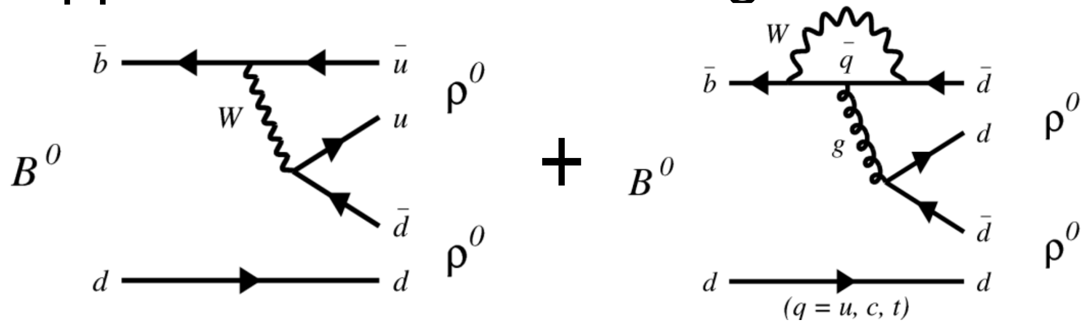
in $\Delta S=1$ decays: $T' \sim V_{ub}V^*_{us}$ and $P' \sim V_{cb}V^*_{cs}$

thus P'/T' is $1/\lambda^2$ enhanced over P/T

$\Rightarrow$ can be used to bound P/T

Search for $B^0 \to \rho^0\rho^0$

- Color-suppressed Tree and Penguin

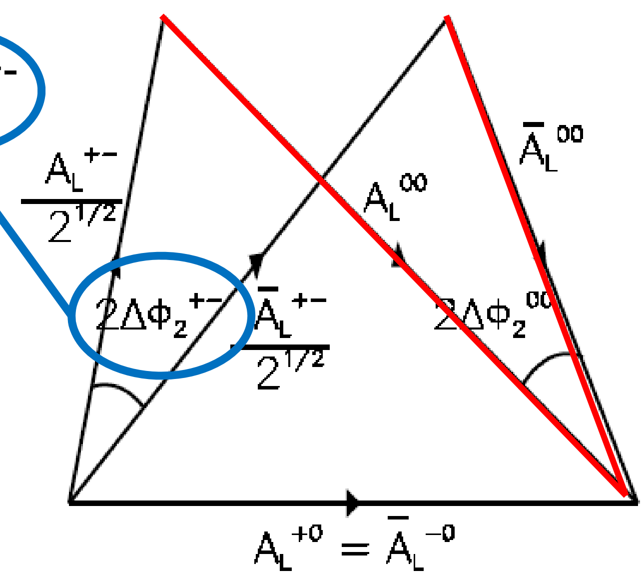


→ Small branching fraction (~ 1×10^{-6})

- This decay can complete the isospin analysis to constrain the penguin contribution in the extraction of ϕ_2

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

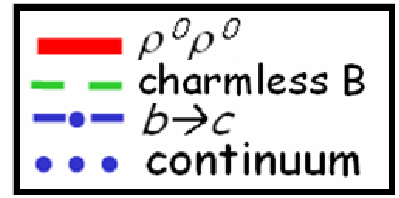
Penguin contribution

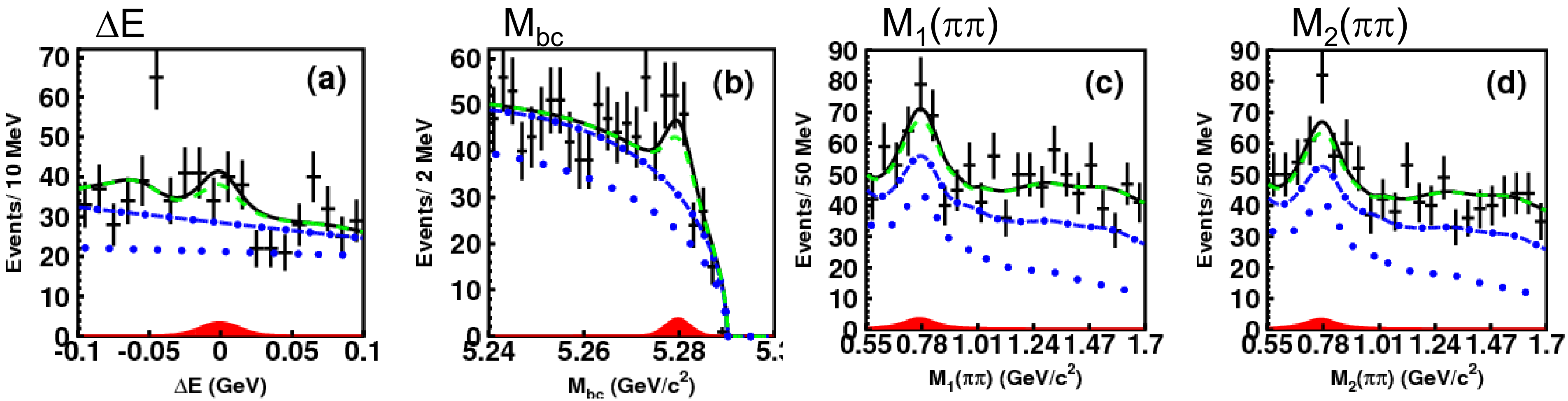


$$A_L^{+-} = BF(B^0 \to \rho^+\rho^-)$$
$$\bar{A}_L^{+-} = BF(\bar{B}^0 \to \rho^+\rho^-)$$
$$A_L^{+0} = BF(B^+ \to \rho^+\rho^0)$$
$$\bar{A}_L^{-0} = BF(\bar{B}^- \to \rho^-\rho^0)$$
$$A_L^{00} = BF(B^0 \to \rho^0\rho^0)$$
$$\bar{A}_L^{00} = BF(\bar{B}^0 \to \rho^0\rho^0)$$

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

Belle 657MBB preliminary





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
4π	$161.2^{+61.2+26.0}_{-59.4-28.5}$	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 $f_L = 1$ (100% longitudinal polarization)

$\rho^0\pi\pi$, 4π excess are seen

UL consistent with BaBar : Br($\rho^0\rho^0$) = $(0.84 \pm 0.29 \pm 0.17) \times 10^{-6}$ arXiv:0708.1630

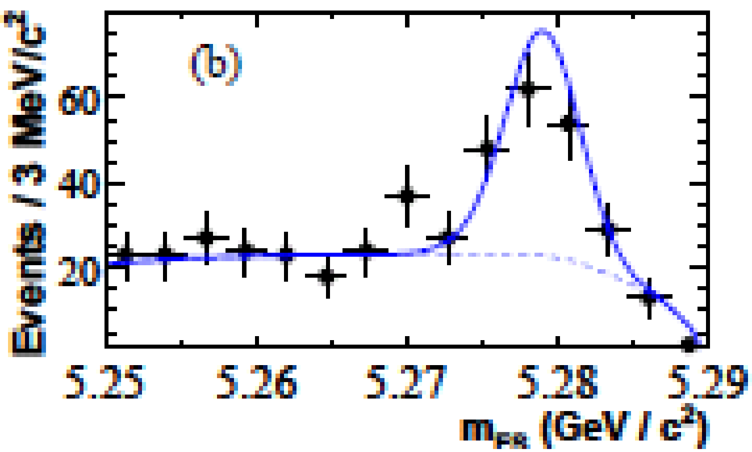
Observation of B→a_1(1260)K

- Time-dependent CPV $B^0 \rightarrow a_1(1260)\pi$ can be used to extract the effective ϕ_2 : $\phi_2^{eff} = \phi_2 + \Delta\phi_2$
- Using SU(3) related modes such as $B \rightarrow K_1\pi$ and $B \rightarrow a_1K$, it is possible to bound $\Delta\phi_2$
- $B \rightarrow K_1\pi$ has been measured

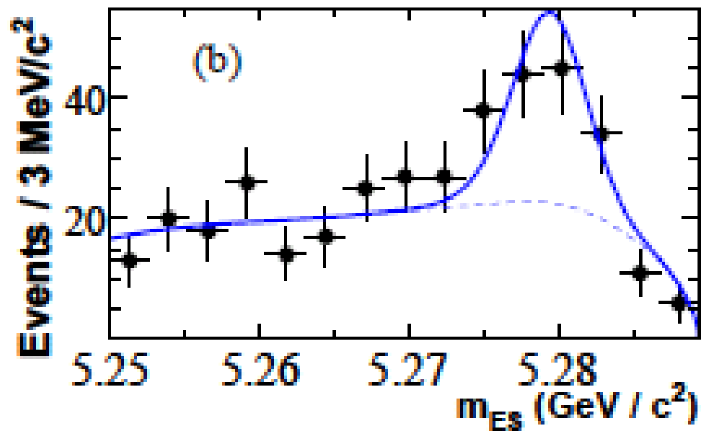
BaBar 383MBB

PRL100, 51803(2008)

$B^+ \rightarrow a_1^+(1260)K$



$B^0 \rightarrow a_1^-(1260)K$



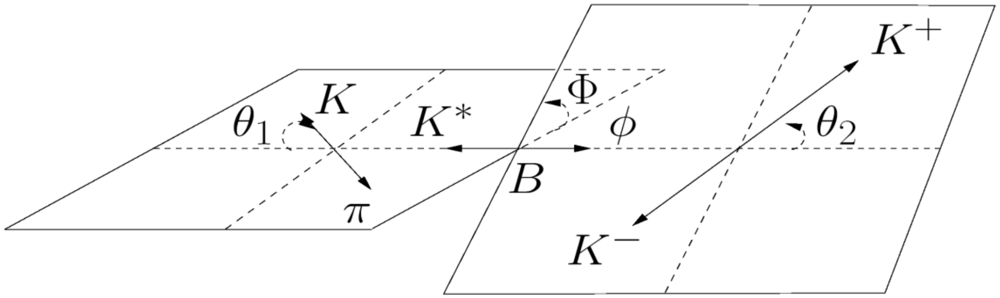
$\mathcal{B}(B^0 \rightarrow a_1^- K^+) \cdot \mathcal{B}(a_1^- \rightarrow \pi^+\pi^-\pi^-) = (8.2 \pm 1.5 \pm 1.2) \cdot 10^{-6}$ (5.1 σ)

$A_{ch}(B^0 \rightarrow a_1^- K^+) = -0.16 \pm 0.12 \pm 0.01$

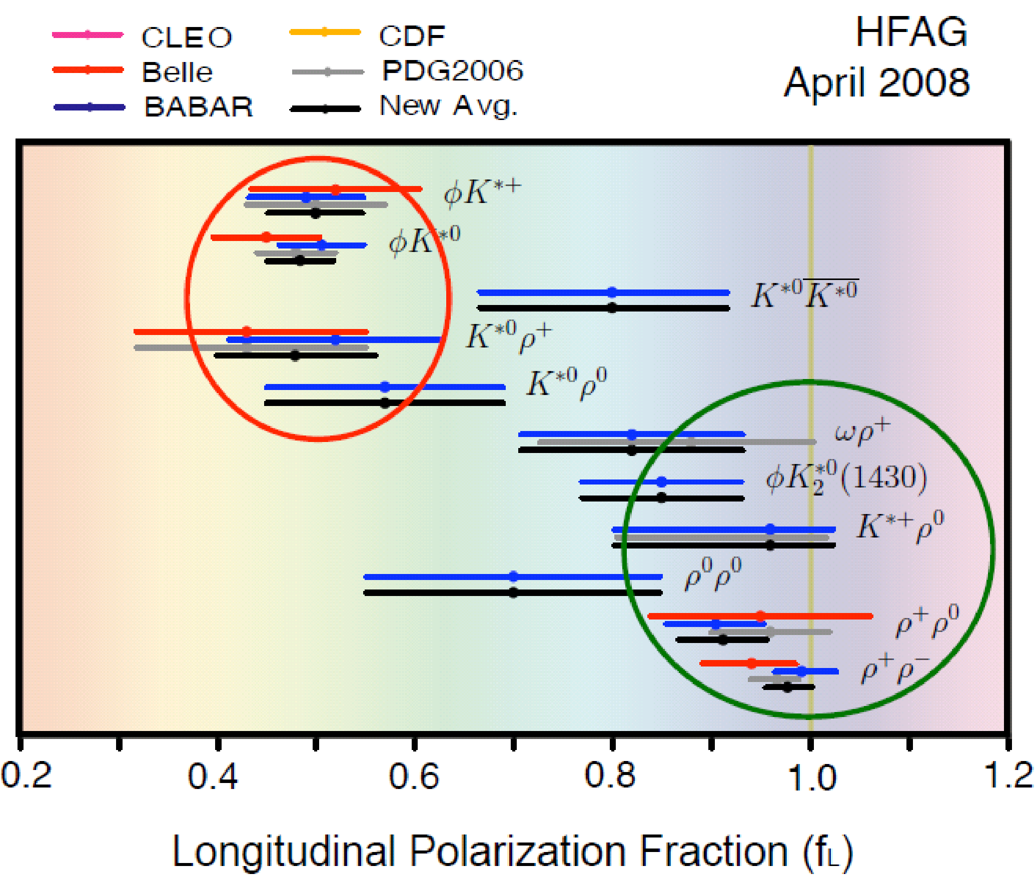
$\mathcal{B}(B^+ \rightarrow a_1^+ K^0) \cdot \mathcal{B}(a_1^+ \rightarrow \pi^+\pi^+\pi^-) = (17.4 \pm 2.5 \pm 2.2) \cdot 10^{-6}$ (6.2 σ)

$A_{ch}(B^+ \rightarrow a_1^+ K^0) = 0.12 \pm 0.11 \pm 0.02$

B→VV(A) polarization



- Helicity amplitudes
  A_0 (longitudinal), $A_{\pm 1}$ (transverse)
- $f_L = A_0/(A_0+A_{+1}+A_{-1})$
- Naively predict $f_L = 1-(m_V/m_B)^2 \sim 1$



Message:

- Tree dominated decays: $f_L \sim 1$
- Penguin dominated decays: $f_L \sim 0.5$

Theoretical explanation:

- Penguin annihilation (Kagan)
- Non-factorizable vertex corrections, hard spectator scattering (Beneke, Rohrer, D.S.Yang; Cheng, K.C.Yang)

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

arXiv:0707.2462

Belle 520MBB

$B \to VV$

$b \to s$ penguin dominates

4D fit after continuum suppression

ΔE, M_{bc}, $M(K\pi)$ and $M(3\pi)$

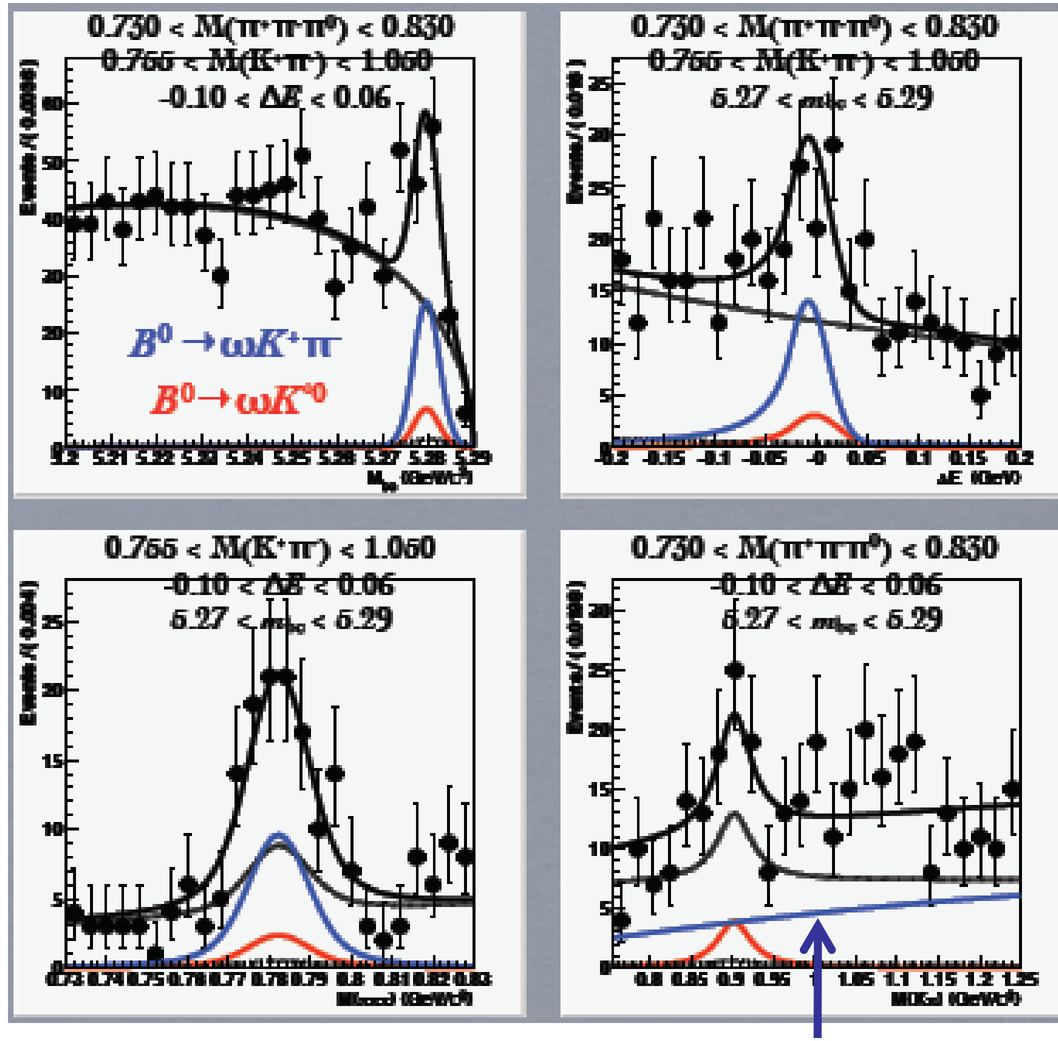
Yield = $15.1^{+11.1}_{-10.0}$

Br = $(1.2^{+0.9}_{-0.8} \pm 0.2) \times 10^{-6}$

$< 2.7 \times 10^{-6}$

Significance = $1.6\,\sigma$

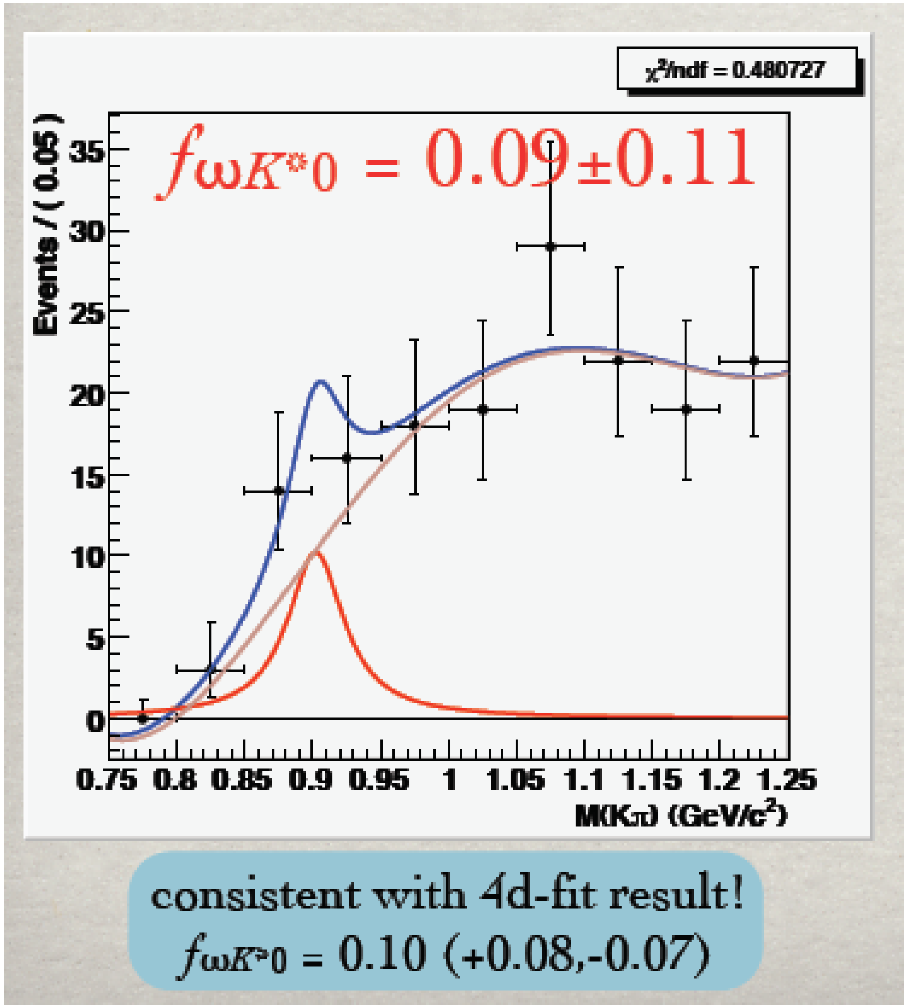
Preliminary



Large non-resonant $K\pi$ contribution

$B^0 \to \omega K^{*0}$ continue

Bkg subtracted distribution



Belle 520MBB Preliminary

Both methods give the similar $f_{\omega K^*}$

(ωK^* signal fraction) of ~10%

→ Large non-resonant

$B \to \omega K^*$ measurement from Belle

… Will update soon

Search for $B^0 \to b_1^{\mp}\rho^{\pm}$

$B \to VA$

Tree dominant channels

Dominant b_1 decay: $b_1 \to \omega\pi$

- New experimental search for $B \to b_1^{\mp}\rho^{\pm}$ modes

- New theory predictions for $B \to b_1 V$ modes

- Predicted $Br(B^0 \to b_1^- \rho^+)$ is about $\times 3$ $Br(B^0 \to b_1^- \pi^+)$

	Br(10^{-6})	f_L	Br(10^{-6})
Mode	Cheng, Yang		CMV
$\overline{B}^0 \to b_1^+ \rho^-$	$32.1^{+16.5+12.0}_{-14.7-\ 4.7}$	$(0.96^{+0.01}_{-0.02})$	1.6
$\overline{B}^0 \to b_1^- \rho^+$	$0.6^{+0.6+1.8}_{-0.3-0.2}$	$(0.98^{+0.00}_{-0.32})$	0.55
$\overline{B}^0 \to b_1^0 \rho^0$	$0.4^{+0.4+21.3}_{-0.2-0}$	$(0.82^{+0.16}_{-0.51})$	0.002
$B^- \to b_1^0 \rho^-$	$29.0^{+16.2+5.4}_{-10.6-5.8}$	$(0.96^{+0.01}_{-0.06})$	0.86
$B^- \to b_1^- \rho^0$	$0.9^{+1.7+2.6}_{-0.6-0.5}$	$(0.90^{+0.06}_{-0.33})$	0.36
$\overline{B}^0 \to b_1^0 \omega$	$0.1^{+0.2+1.4}_{-0.0-0.0}$	$(0.10^{+1.04}_{-0.01})$	0.004
$B^- \to b_1^- \omega$	$0.9^{+1.4+2.7}_{-0.5-0.3}$	$(0.91^{+0.07}_{-0.33})$	0.38
$\overline{B}^0 \to b_1^0 \phi$	$0.01^{+0.01+0.01}_{-0.00-0.00}$	$(0.98^{+0.01}_{-0.33})$	0.0002
$B^- \to b_1^- \phi$	$0.02^{+0.02+0.03}_{-0.01-0.00}$	$(0.98^{+0.01}_{-0.33})$	0.0004
$\overline{B}^0 \to b_1^+ K^{*-}$	$7.6^{+3.3+40.7}_{-2.4-\ 7.1}$	$(0.71^{+0.17}_{-0.66})$	0.32
$\overline{B}^0 \to b_1^0 \overline{K}^{*0}$	$3.0^{+1.1+4.6}_{-0.7-2.1}$	$(0.80^{+0.20}_{-0.70})$	0.15
$B^- \to b_1^- \overline{K}^{*0}$	$12.1^{+4.4+21.2}_{-3.2-\ 2.7}$	$(0.80^{+0.20}_{-0.70})$	0.18
$B^- \to b_1^0 K^{*-}$	$6.8^{+2.4+12.5}_{-1.8-\ 4.4}$	$(0.84^{+0.15}_{-0.29})$	0.12

Cheng & Yang, arXiv:0805.0329

Search for $B^0 \to b_1^{\mp} \rho^{\pm}$

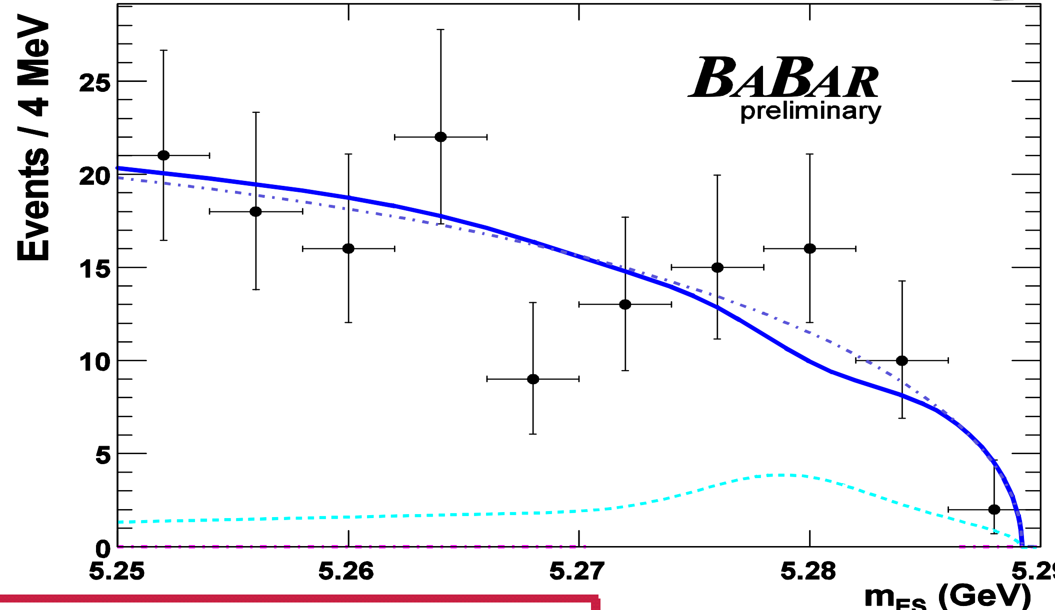
Preliminary
(First Presented at FPCP08)

- Should be > $b_1^- \pi^+$?
- 2nd-class current rule →

  $B^0 \to b_1^{\mp}\rho^{\pm} \gg B^0 \to b_1^{\pm}\rho^{\mp}$

  (expt. Doesn't distinguish)

-Find no excess.

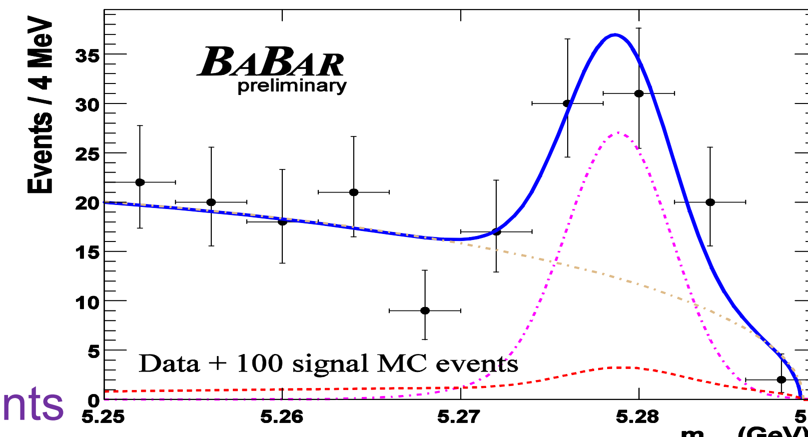


$$\mathcal{B}(B^0 \to b_1^{\mp}\rho^{\pm}) = (-0.1 \pm 0.9 \pm 0.7) \times 10^{-6}$$
$$(< 1.7 \times 10^{-6},\ 90\%\ \text{C.L.})$$

BaBar 465MBB

- Rather puzzling lack of agreement with the theoretical estimate.

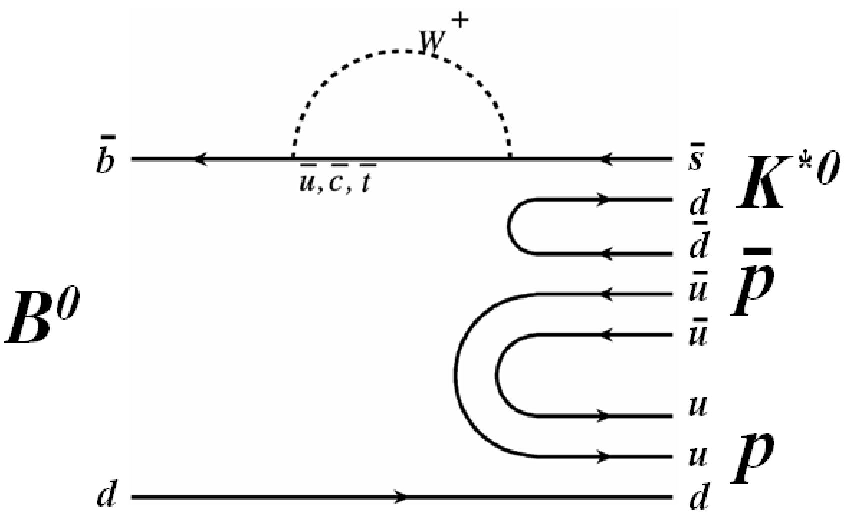
Test: add 100
Signal MC events

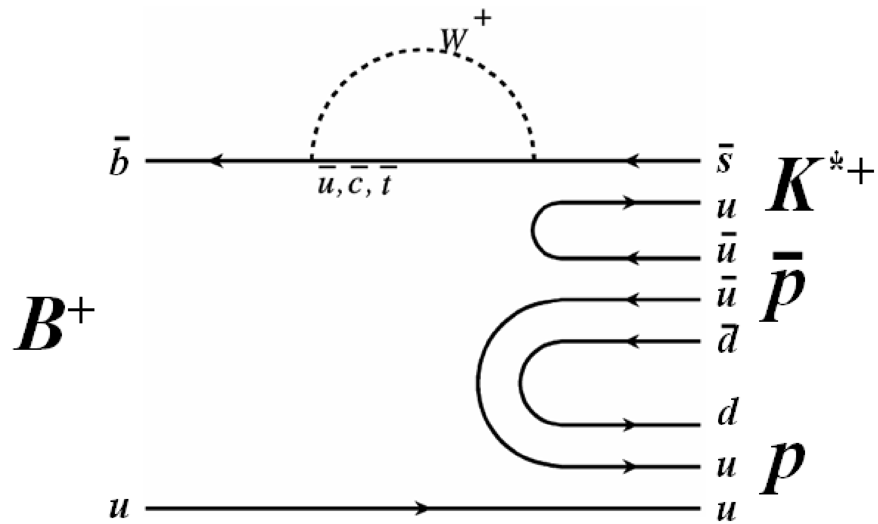


Baryonic B decays

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

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

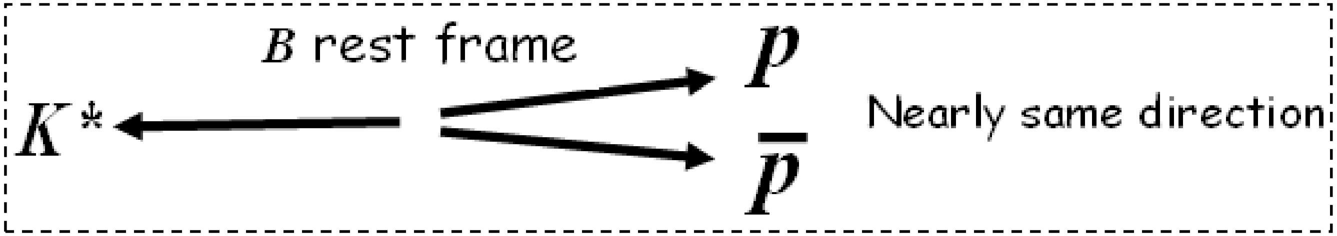




$B \rightarrow p\bar{p}K^*$ (introduction)

Threshold enhancement of the baryon pair mass(m1+m2) spectra

$B \rightarrow p\bar{p}K^+$, $p\bar{p}K^0$, $p\bar{p}\pi^+$, $p\bar{p}K^{*+}$, $p\bar{\Lambda}\pi^-$, $p\bar{\Lambda}\pi^0$, $p\bar{\Lambda}\gamma$, $\Lambda\bar{\Lambda}K^+$



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)

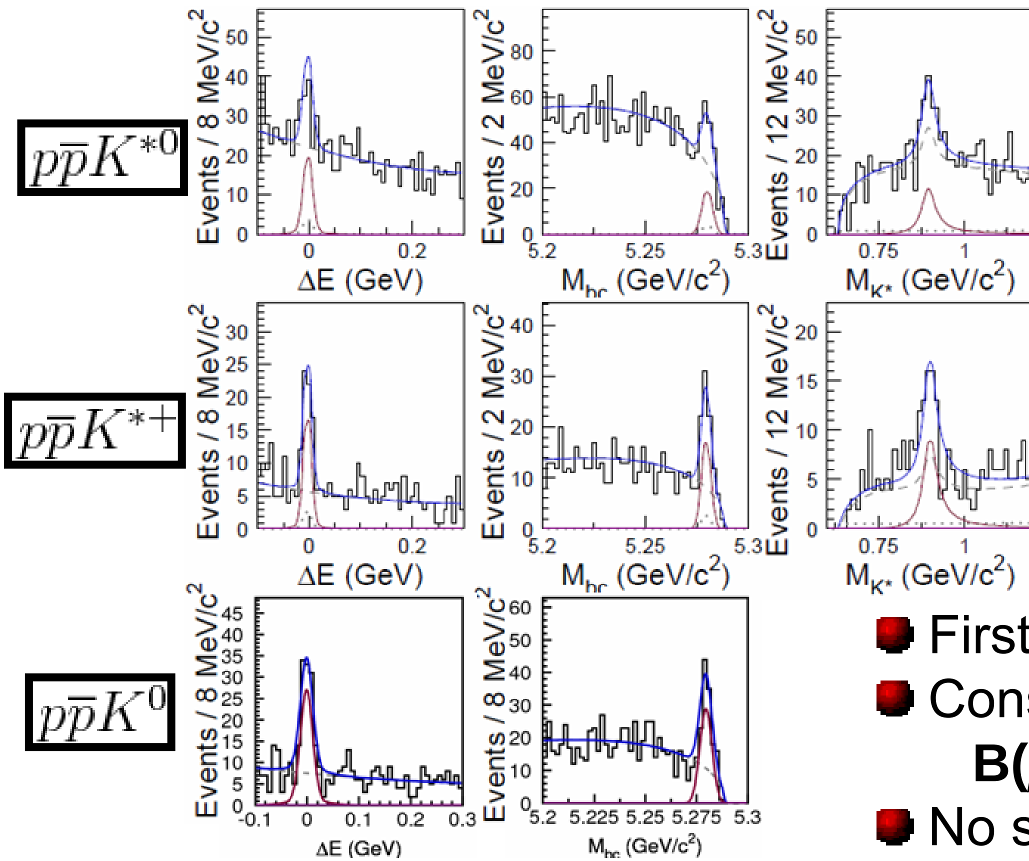
$B(p\bar{p}K^+) > B(p\bar{p}K^{*+}) > B(p\bar{p}K^{*0})$ (PRD66,014020)

Large DCPV prediction $A_{cp}(B^+ \rightarrow p\bar{p}K^{*+})$ ~20% (PRD75,094013,2007)

Angular distributions → help to understand decay mechanisms

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

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



arXiv:0802.0336
To be published in PRL

Belle 535MBB

- Unbinned maximum likelihood fit

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

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

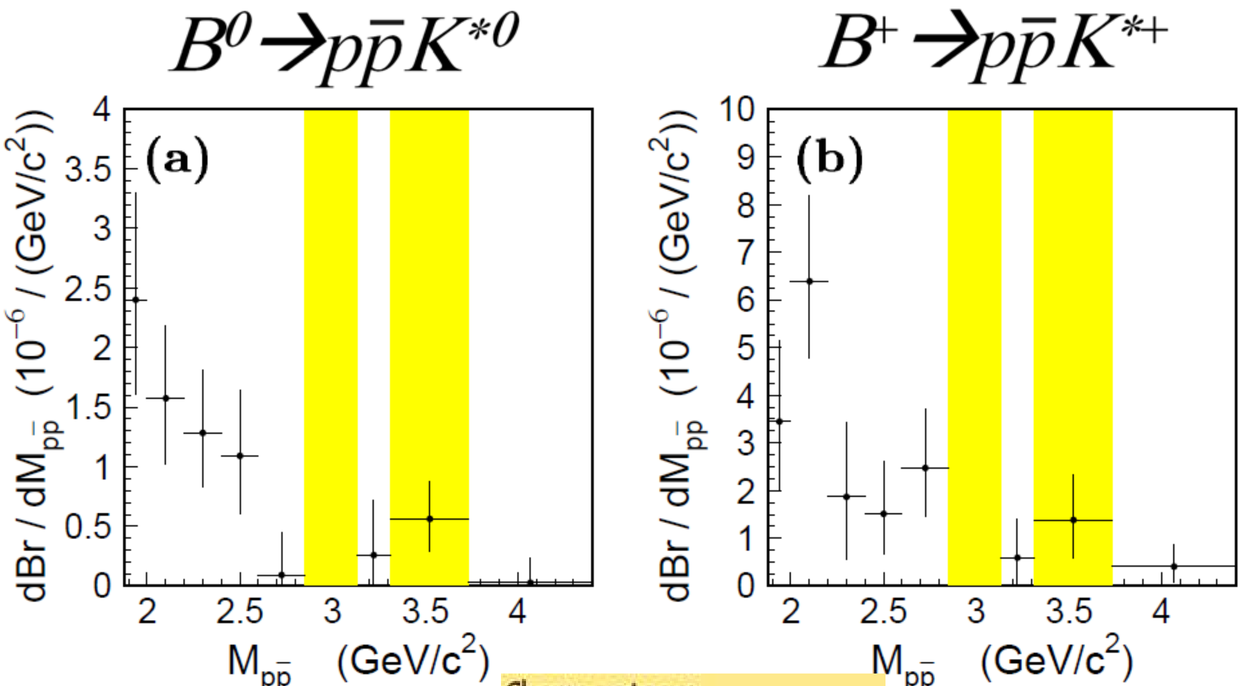
- $M(\bar{p}p)$<2.85GeV/c^2

- First observation of $B^0 \to p\bar{p}K^{*0}$
- Consistent with the theoretical prediction
  $B(p\bar{p}K^+) > B(p\bar{p}K^{*+}) > B(p\bar{p}K^{*0})$
- 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	$2.51^{+0.35}_{-0.29} \pm 0.21$	—

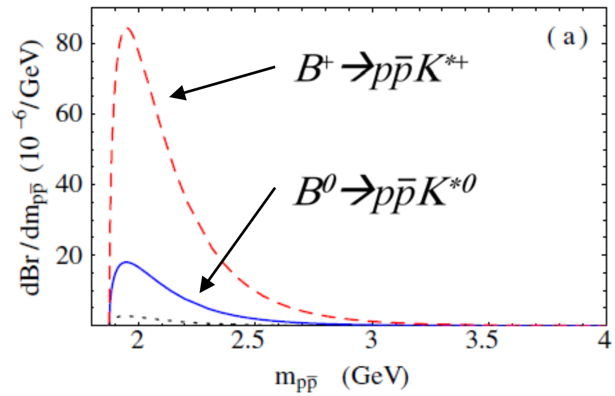
$B \to p\bar{p}K^*$ (threshold enhancement)

Belle 535MBB



Charm vetoes:
η_c, J/ψ, ψ', χ_{c0}, χ_{c1}, h_c

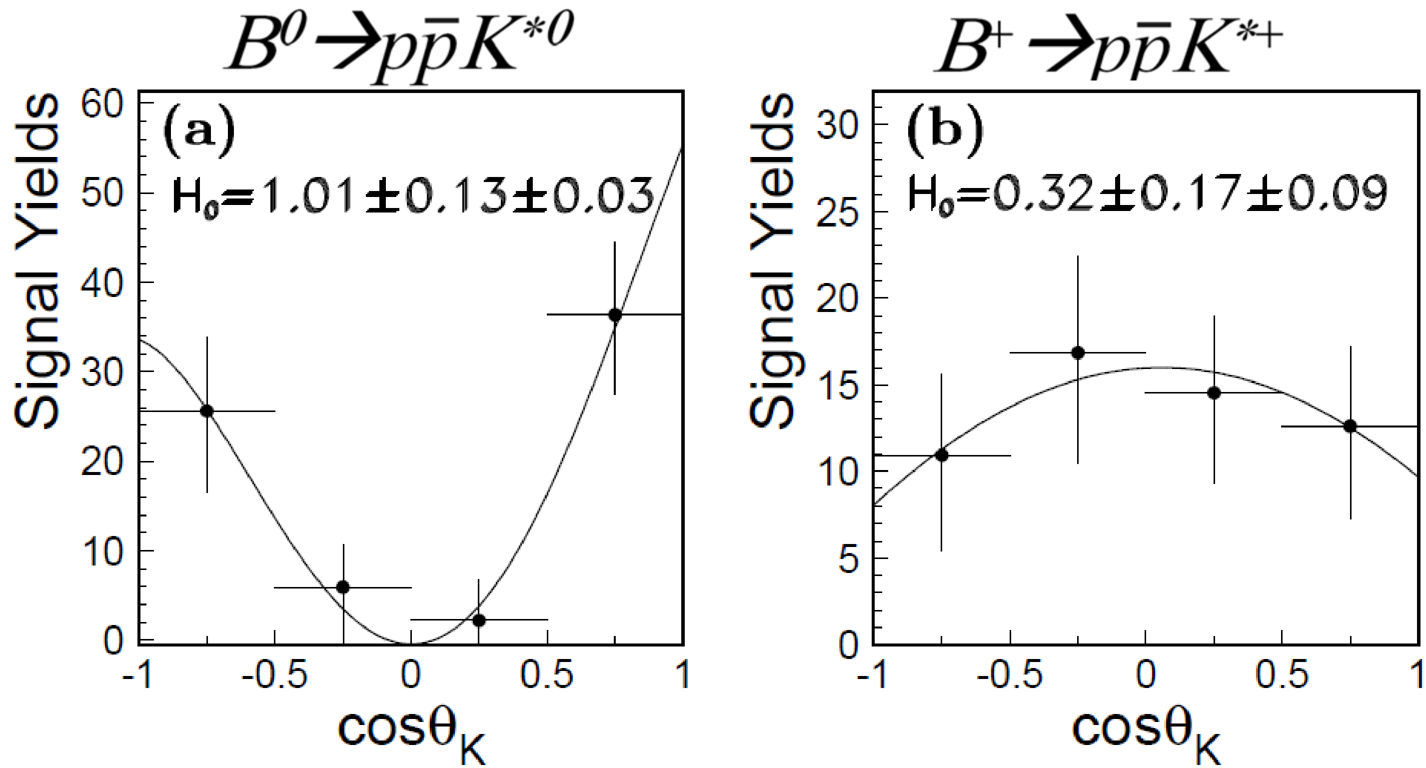
Theoretical expectation
PRD75,094013,2007



$p\bar{p}$ mass enhancement near threshold can be seen
Features similar to the theoretical prediction

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

Belle 535MBB



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

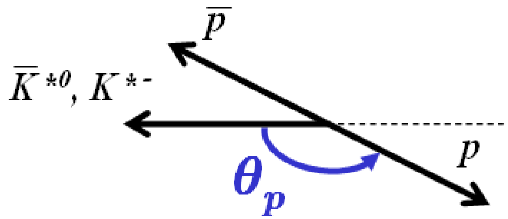
$H_0(K^{*0})$ = 101±13±3 %

$H_0(K^{*+})$ = 32±17±9 %

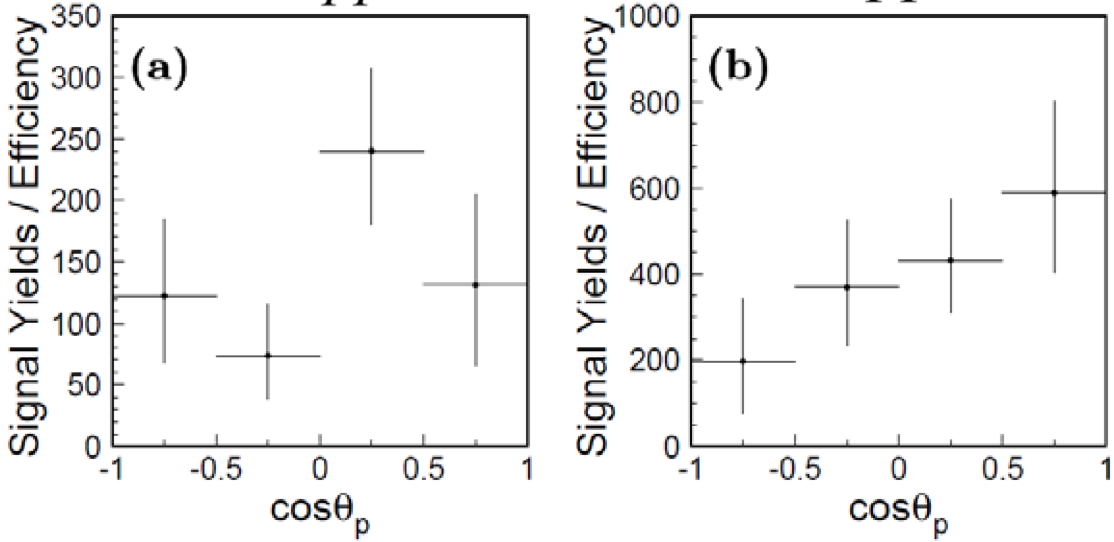
Large K* polarization, consistent with $b \to s$ penguin dominance

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

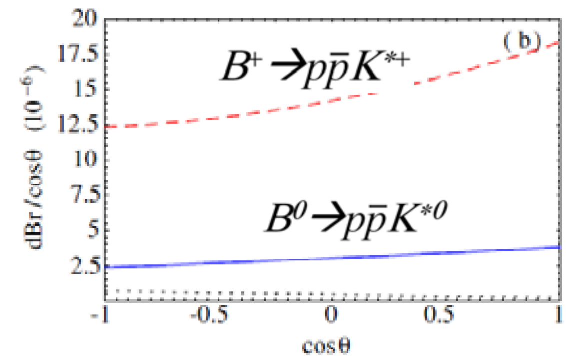
Belle 535MBB



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



Theoretical prediction
PRD75,094013,2007



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

Summary

Rare Hadronic B-decays provide many observables

1. The measurements to constrain the Unitarity Triangle angles:
   Updated BF of $B^0 \rightarrow \rho^0\rho^0$, two observations for $a_1(1260)K$

2. f_L measurements and study of angular correlations in $B \rightarrow VV(A)$ to probe new physics effects:
   Search for $B^0 \rightarrow \omega K^{*0}$, $B^0 \rightarrow b_1^{\mp}\rho^{\pm}$

3. Measurement of the dibaryon systems from B:
   Observation of $B^0 \rightarrow p\bar{p}K^{*0}$
   Threshold enhancement / large K^{*0} polarization