

Charmless Hadronic Rare B Decays by Belle

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KEK

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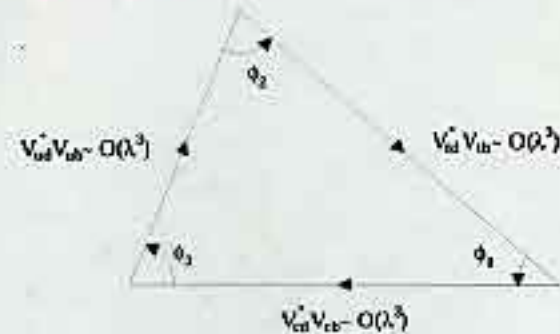
- Introduction
- $B \rightarrow 3$ -body results
- $B \rightarrow$ (quasi) 2-body results
- $B \rightarrow$ baryonic 3-/2-body results
- Summary

— Introduction —

- Goal is the elucidation of CP violation mechanism.
 - In the Standard Model, the Kobayashi-Maskawa (KM) scheme predicts CP violation in B meson system through a **quark mixing containing a complex phase** in the weak interaction.

$$\mathbf{V} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}, \quad \mathbf{V}^\dagger \mathbf{V} = \mathbf{1}.$$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = \delta_{db} = 0$$



$$\phi_1 \equiv \pi - \arg\left(\frac{-V_{tb}^*V_{td}}{-V_{cb}^*V_{cd}}\right) \simeq \arg(-V_{td}), \quad \phi_2 \equiv \arg\left(\frac{V_{tb}^*V_{td}}{-V_{ub}^*V_{ud}}\right) \simeq \arg\left(-\frac{V_{td}}{V_{ub}^*}\right), \quad \phi_3 \equiv \arg\left(\frac{V_{ub}^*V_{ud}}{-V_{cb}^*V_{cd}}\right) \simeq \arg(V_{ub}^*)$$

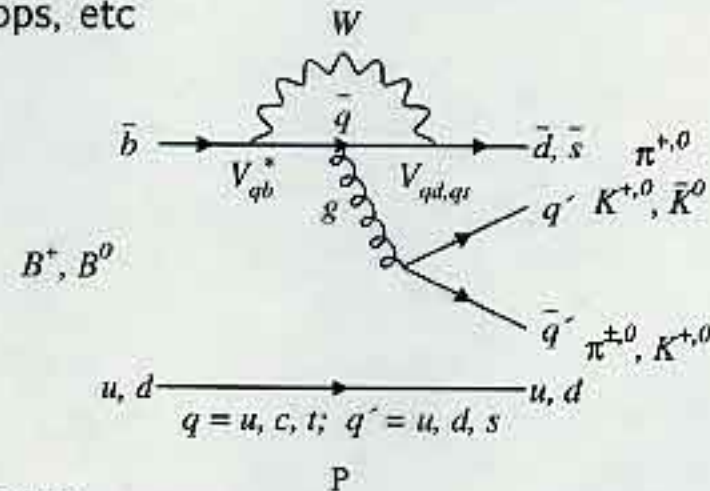
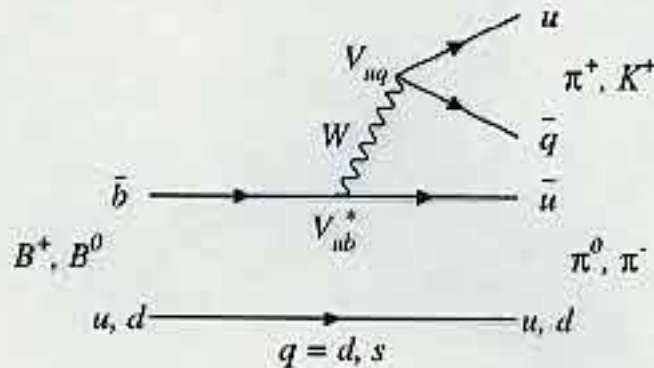
- Now the experimental phase is in the second stage.
 - In the last summer, mixing-induced **"indirect" CP violation** was observed.
 - Next targets are the **precise test of the KM scheme** and **search for a new physics** beyond the SM.

— Charmless hadronic rare B decays —

Providing a rich sample . . .

o to test the KM scheme and probe a new physics

- ϕ_3 measurement through a $b \rightarrow u$ transition
- "direct" CP violation through an interference between "Tree" and "Penguin" diagrams
- new physics beyond the SM through penguin loops, etc

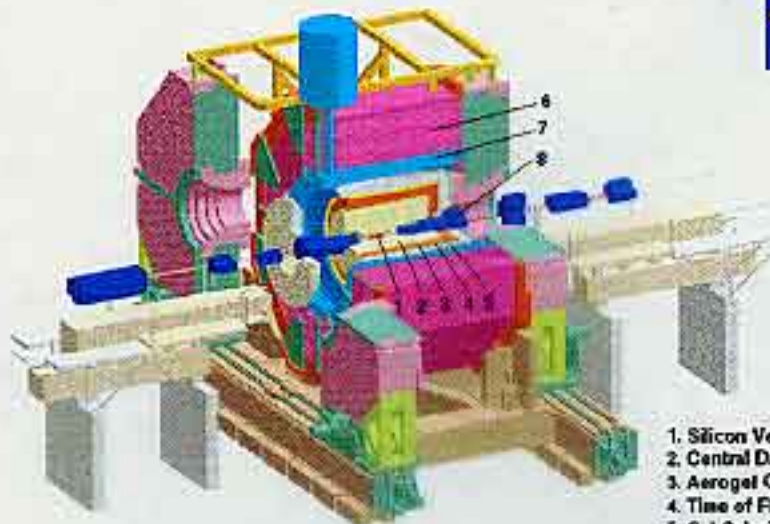


o to understand the detailed nature of B mesons

- 2-body, quasi 2-body, 3-body, . . . (many decay channels)
- (QCD or pQCD)-factorization, isospin/SU(3) symmetries
- Long distance effects, annihilation/exchange diagrams, . . .
- Need a coherent study of various channels.

— Belle Detector —

BELLE Detector

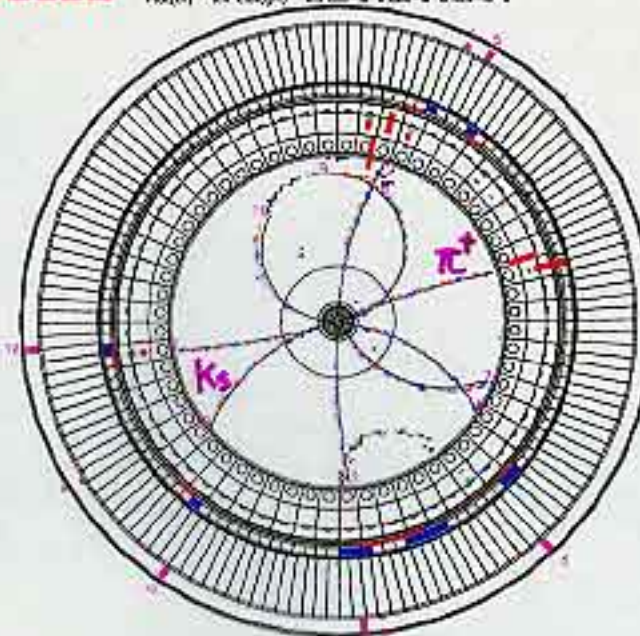


1. Silicon Vertex Detector
2. Central Drift Chamber
3. Aerogel Cherenkov Counter
4. Time of Flight Counter
5. Cal Calorimeter
6. KLM Detector
7. Superconducting Solenoid
8. Superconducting Final Focussing System

- SVD: Vertexing (proper time)
- CDC: Tracking, PID (dE/dx)
- ACC: PID (N_{pe})
- TOF: Trigger, PID (TOF)
- ECL: e, γ detection
- KLM: K_L^0, μ detection

BELLE

Exp. 0 Run 242 Form 2 Rev1 98211
 Date 4.00 Size 3.50 Section 4 041305A 2002
 Type 0 Owner 0 App'd 0 B'Prod 1.00 Display NCR
 Plot(m) 9.4 Evt/Run 2.3 000-M 0.00E-M 0.00E-M 1



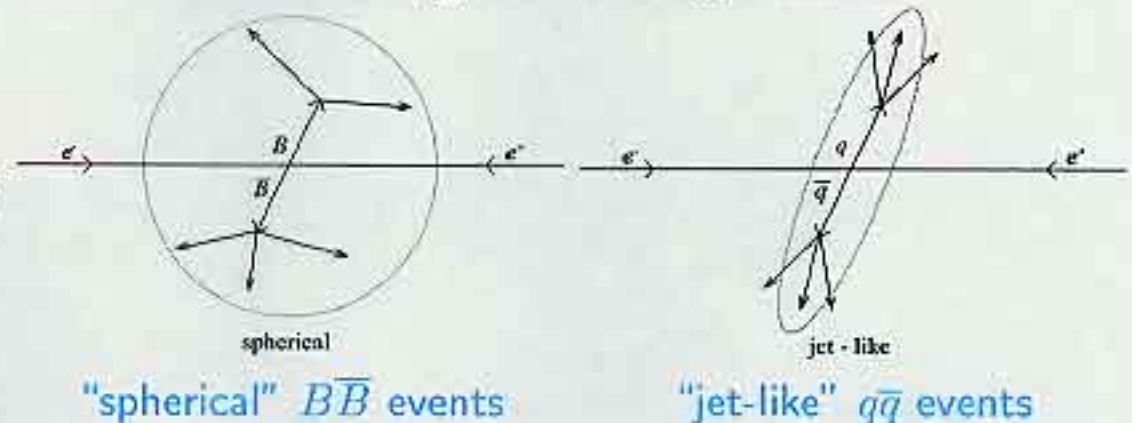
— General analysis procedure —

o B Kinematic Reconstruction

- beam energy constrained mass: $m_{bc} \equiv \sqrt{E_{\text{beam}}^{*2} - p_B^{*2}}$
 - energy difference: $\Delta E \equiv E_B^* - E_{\text{beam}}^*$
- $\sim 5.29 \text{ GeV}$ $\sim 350 \text{ MeV}/c$

o $e^+e^- \rightarrow q\bar{q}$ ($q = u, d, s, c$) continuum background suppression

- event topology
- modified Fox-Wolfram moments
- energy flow, thrust angle, sphericity
- angular distribution
- B flight direction, decay axis
- Fisher discriminant, likelihood ratio



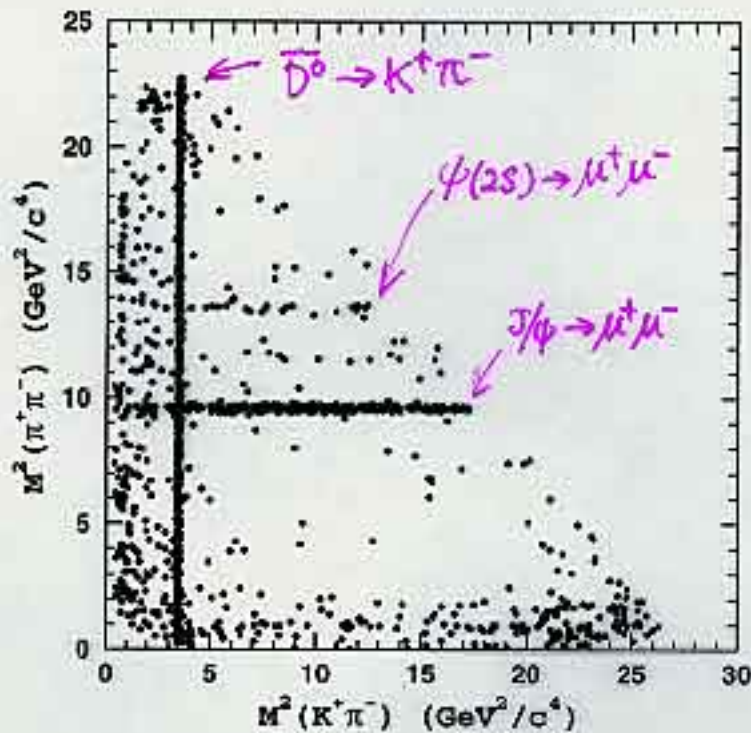
o Particle identification

- dE/dx (CDC), ToF (TOF), $N_{p.e.}$ (ACC)
- combined into a single likelihood variable

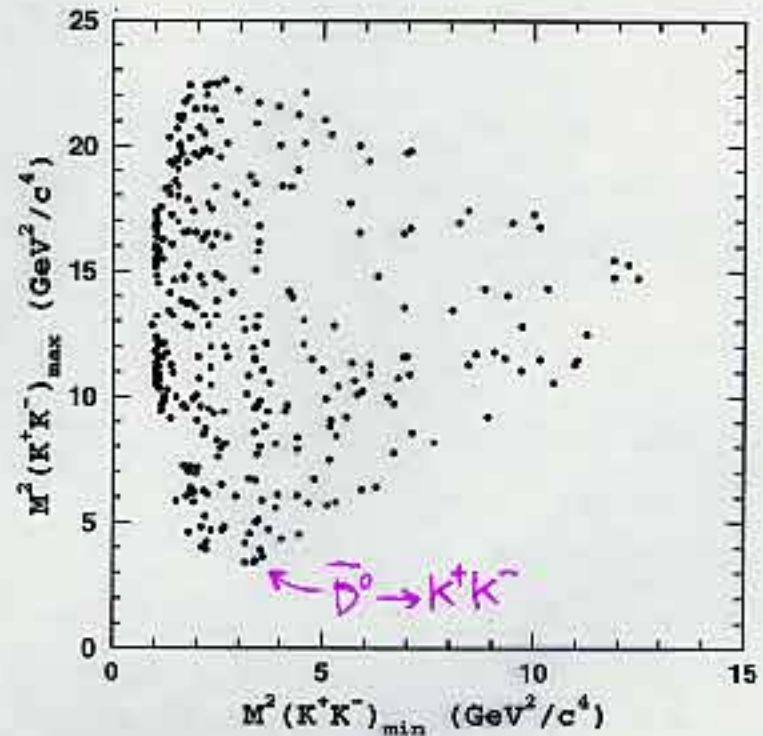
$$P_K = \frac{\mathcal{L}_K}{\mathcal{L}_K + \mathcal{L}_\pi}$$

o Study of three-body decays

- **New results** on $B \rightarrow$ three-body charmless decays!
- Much more decay channels to study.
- Now a Dalitz analysis is possible.

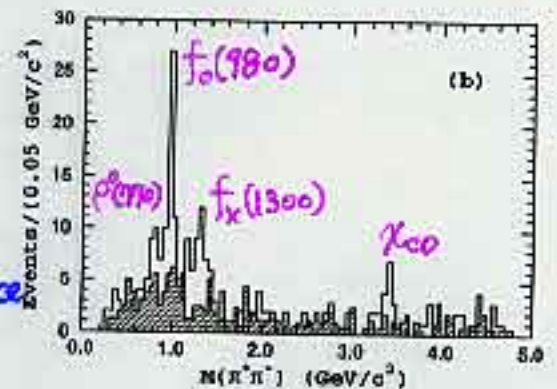
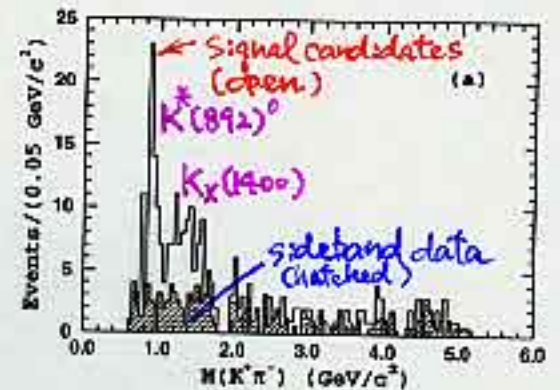
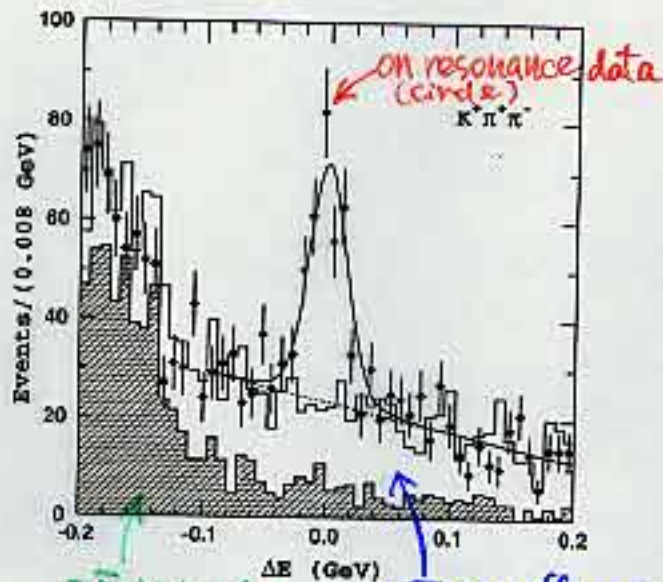
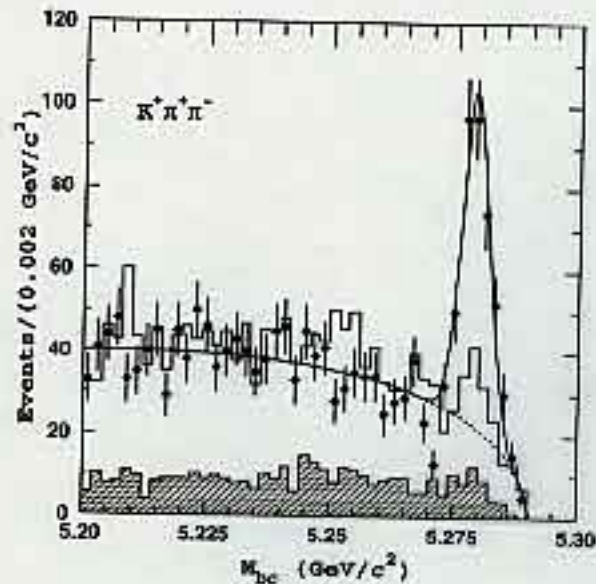


$B^+ \rightarrow K^+ \pi^+ \pi^-$
w/ e veto for semileptonic decay background.



$B^+ \rightarrow K^+ K^+ K^-$
w/ e and $D(\rightarrow K\pi)$ vetoes

o $B^+ \rightarrow K^+ \pi^+ \pi^-$ decays (29.1 fb^{-1})

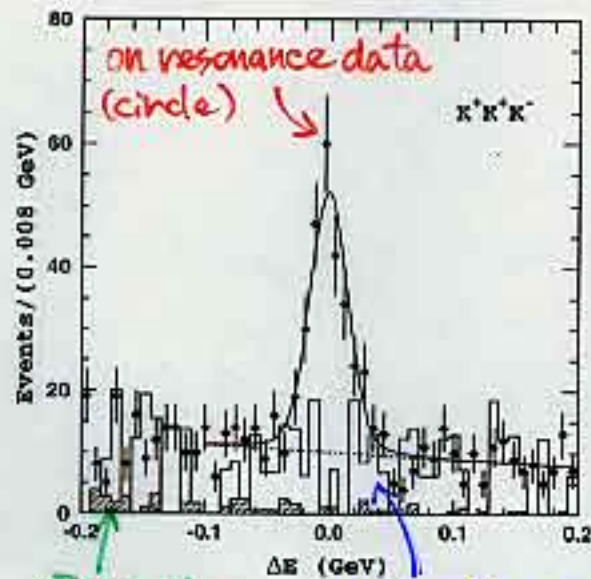
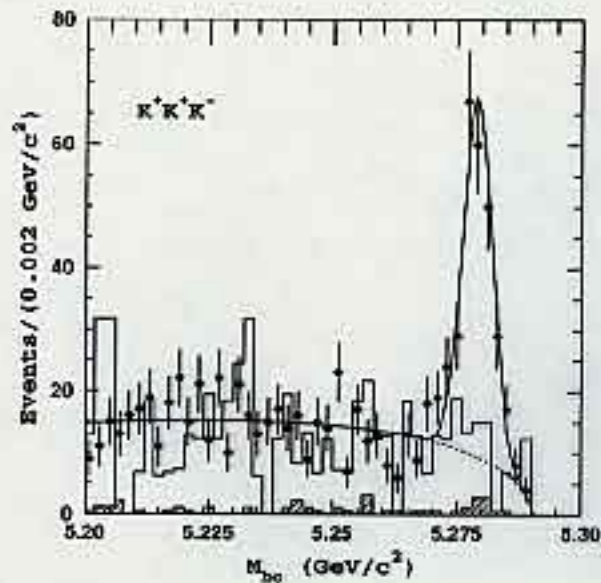


BB MC only
(hatched)

BB MC + off resonance
data

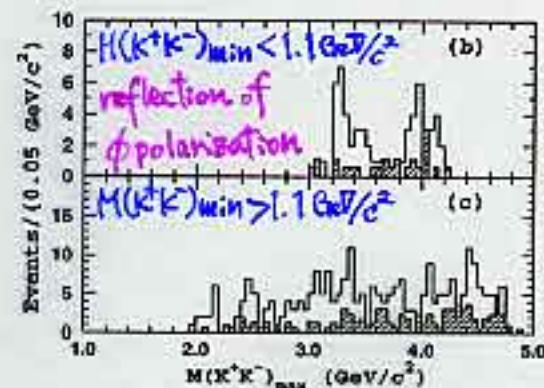
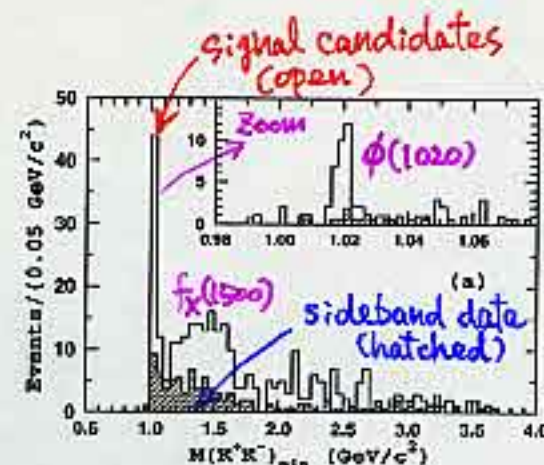
- Intermediate resonances, $K_X(1400)$, $f_X(1300)$? (opened)
- First inclusive measurement — $\mathcal{B}(B^+ \rightarrow K^+ \pi^+ \pi^-) = (55.6 \pm 5.8 \pm 7.7) \times 10^{-6}$
- First S+P channel — $\mathcal{B}(B^+ \rightarrow f_0(980)K^+) \times \mathcal{B}(f_0(980) \rightarrow \pi^+ \pi^-) = (9.6^{+2.4+1.5+3.4}_{-2.3-1.5-0.8}) \times 10^{-6}$
- First observation — $\mathcal{B}(B^+ \rightarrow K^*(892)^0 \pi^+) = (19.4^{+4.2+2.1+3.5}_{-3.9-2.1-6.8}) \times 10^{-6}$

○ $B^+ \rightarrow K^+ K^+ K^-$ decays (29.1 fb^{-1})



$\bar{B}\bar{B}$ MC only
(hatched)

$\bar{B}\bar{B}$ MC + off resonance
data
(open)

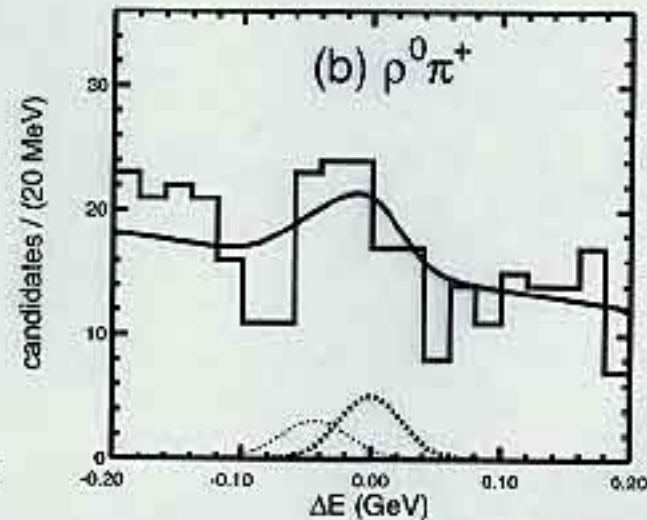
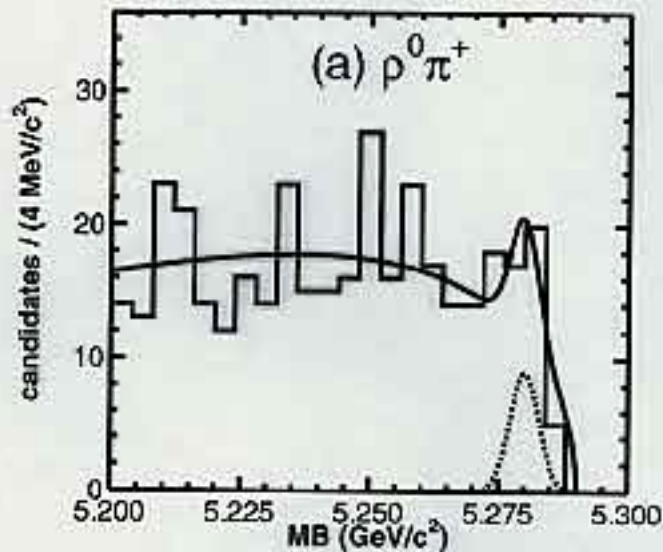


- Intermediate resonances, $f_X(1500)$?
- First inclusive measurement — $\mathcal{B}(B^+ \rightarrow K^+ K^+ K^-) = (35.3 \pm 3.7 \pm 4.5) \times 10^{-6}$

○ $B \rightarrow \pi^+ \pi^- \pi^+$ decays (23.1 fb^{-1})

Background contamination is more severe.

- $B^+ \rightarrow \bar{D}^0 (\rightarrow h^+ \pi^-) \pi^+$, $B^+ \rightarrow J/\psi (\psi(2S)) (\rightarrow l^+ l^-) h^+$
- $B \rightarrow K \pi \pi$, $B \rightarrow \pi \pi$, $K \pi$, $B \rightarrow \rho \rho$



$B^+ \rightarrow \rho^0 \pi^+$

- Need more detailed study: $\mathcal{B}(B^+ \rightarrow \rho^0 \pi^+) < 14.5 \times 10^{-6}$

Preliminary

Summary of $B^+ \rightarrow h^+h^+h$ decays

Mode	ϵ [%]	N_s [events]	S [σ]	\mathcal{B} [10^{-6}]
$\pi^+\pi^-\pi^+$				
$\rho^0\pi^+$	11.1	$15.5^{+11.8}_{-11.0}$	1.9	< 14.5
$K^+\pi^+\pi^-$	17.3	237 ± 23		$55.6 \pm 5.8 \pm 7.7$
$K^*(892)^0\pi^+$	18.9	60^{+13}_{-12}	6.2	$12.9^{+2.8+1.4+2.3}_{-2.6-1.4-4.5}$
$K_X(1400)\pi^+$	16.2	58^{+14}_{-13}	4.9	$14.5^{+3.5+1.8+3.3}_{-3.3-1.8-6.5}$
$\rho^0(770)K^+$	15.1	9^{+13}_{-12}	0.8	< 12
$f_0(980)K^+$	17.8	42^{+11}_{-10}	5.0	$9.6^{+2.5+1.5+3.4}_{-2.3-1.5-0.8}$
$f_X(1300)K^+$	16.9	46^{+14}_{-13}	3.9	$11.1^{+3.4+1.4+7.2}_{-3.1-1.4-2.9}$
$K^-\pi^+\pi^+$	16.2	12 ± 9		< 7.0
$K^+\pi^-\pi^0$	12.8	$105.2^{+23.9}_{-22.9} \pm 15.3$	4.8	$35.6^{+8.1}_{-7.7} \pm 5.2$
$K^*(892)^0\pi^0$	5.8	$5.5^{+4.2+0.9}_{-3.5-1.0}$	1.7	< 9.6
$K^*(892)^+\pi^-$	2.2	$13.1 \pm 4.2 \pm 1.5$	4.3	$26.0 \pm 8.3 \pm 3.5$
ρ^-K^+	6.0	$21.9^{+7.1+2.4}_{-6.4-4.2}$	4.2	$15.8^{+5.1+1.7}_{-4.6-3.0}$
$\rho^0\pi^0$	9.0	$0.0^{+1.8}_{-0.0}$		< 2.8
$K^+K^+\pi^-$	14.2	2.0 ± 5.3		< 3.2
$K^+K^-\pi^+$	14.6	26 ± 12		< 12
$K^+K^+K^-$	24.0	210 ± 21		$35.3 \pm 3.7 \pm 4.5$
$\phi(1020)K^+$	23.6	$42^{+8.7}_{-7.9}$	7.2	$7.2^{+1.5+0.9+0.4}_{-1.4-0.9-0.4}$
$f_X(1500)K^+$	21.3	146^{+17}_{-17}	12	$27.6^{+3.2+3.5+1.4}_{-3.2-3.5-1.4}$

o Study of (quasi) two-body decays

Many decay channels have been observed.

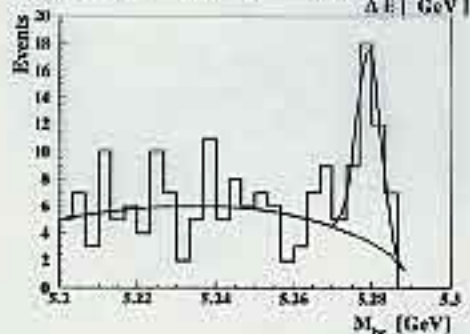
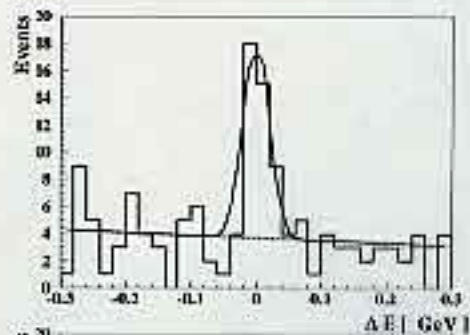
Next targets are getting available.

- more precise measurement
→ increased statistics, feed back from three-body decay studies ...
- CP violation study
→ "direct" CP violation search, ϕ_3 extraction/constraint

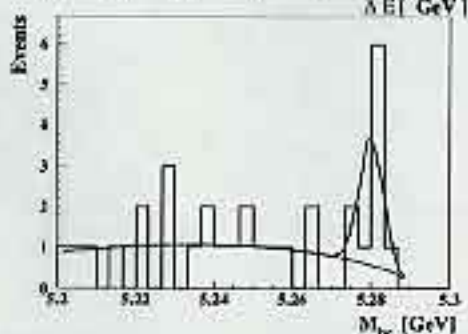
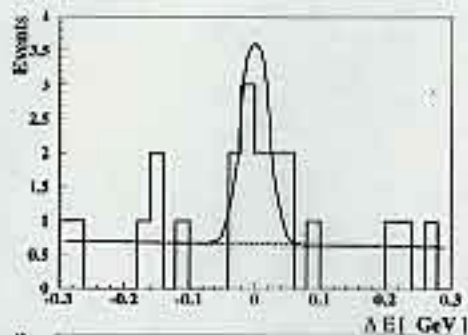
$$\begin{aligned} \mathcal{A}_{CP} &= \frac{\Gamma(\bar{B} \rightarrow \bar{f}) - \Gamma(B \rightarrow f)}{\Gamma(\bar{B} \rightarrow \bar{f}) + \Gamma(B \rightarrow f)} \quad (\text{ex. } f = K^+\pi^-), \\ &= \frac{2|T||P| \sin \Delta\delta \sin \phi_3}{|T|^2 + |P|^2 + 2|T||P| \cos \Delta\delta \cos \phi_3} \end{aligned}$$

○ $B \rightarrow \phi K^{(*)}$ decays (21.6 fb^{-1})

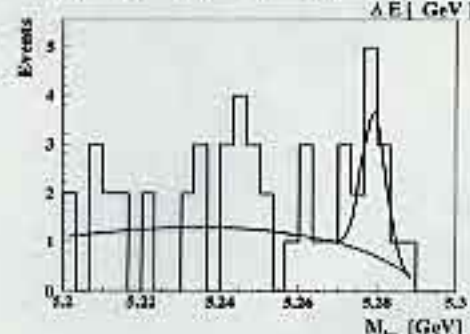
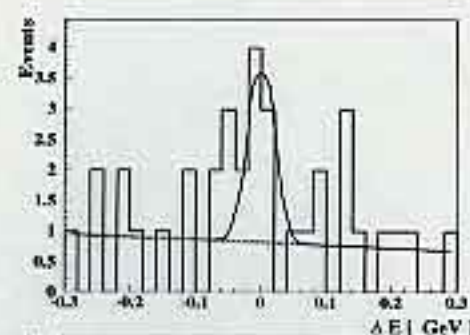
- New physics search via $b \rightarrow s\bar{s}s$ Penguin
- $\sin 2\phi_1$ measurement in $B^0 \rightarrow \phi K_S^0$



$B^+ \rightarrow \phi K^+$



$B^+ \rightarrow \phi K_S^0$



$B^+ \rightarrow \phi K^{*0}$

- $B(B^+ \rightarrow \phi K^+) = (1.12_{-0.20}^{+0.22} \pm 0.14) \times 10^{-5}$
- $B(B^0 \rightarrow \phi K^0) = (1.12_{-0.20}^{+0.22} \pm 0.14) \times 10^{-5}$
- $B(B^0 \rightarrow \phi K^{*0}) = (1.30_{-0.52}^{+0.64} \pm 0.21) \times 10^{-5}$

Preliminary

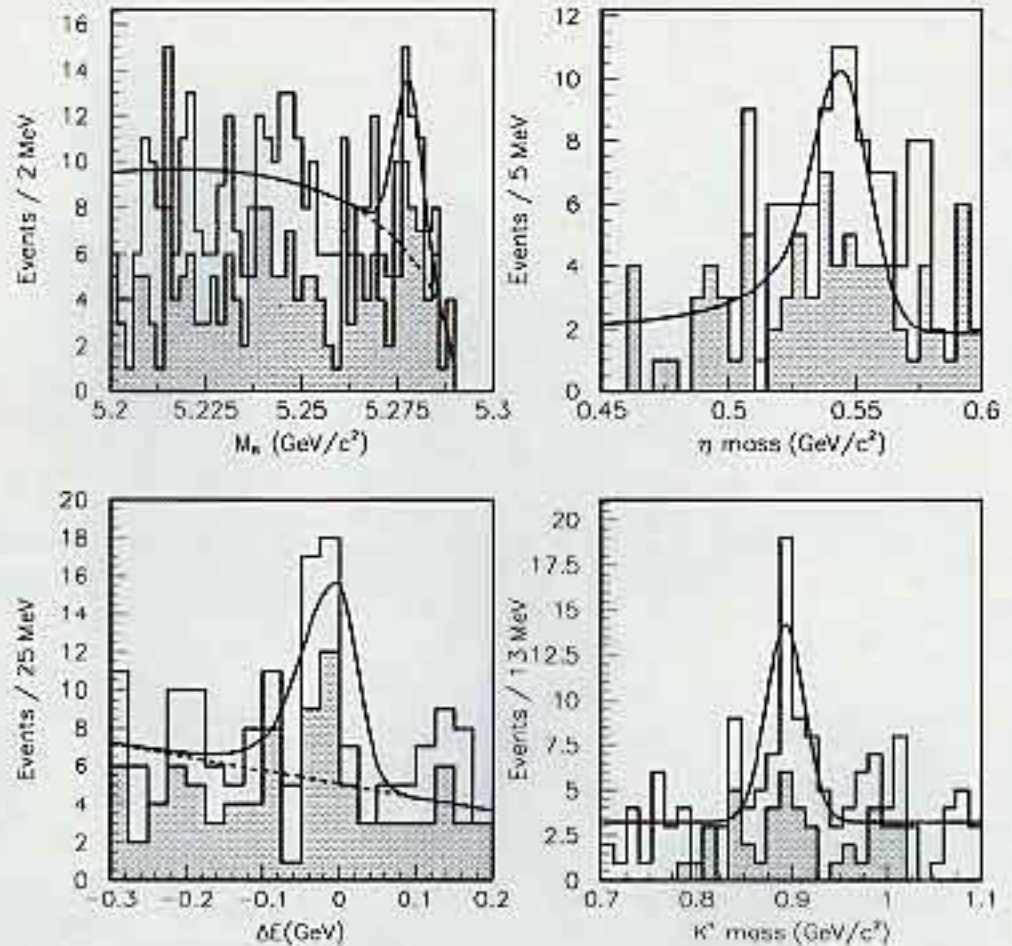
○ $B \rightarrow \eta K^*, \eta' K$ decays
 (21.3 fb^{-1}) (10.4 fb^{-1})

● Unexpectedly large \mathcal{B} 's
 → new physics?

Preliminary

- $\mathcal{B}(B^0 \rightarrow \eta K^{*0}) = (21.2^{+5.4}_{-4.7} \pm 2.0) \times 10^{-6}$
 theory: $\mathcal{B} = 2.0 \sim 8.2 \times 10^{-6}$
- $\mathcal{B}(B^+ \rightarrow \eta' K^+) = (79^{+12}_{-11} \pm 9) \times 10^{-6}$
 theory: $\mathcal{B} = 21 \sim 53 \times 10^{-6}$
- $\mathcal{B}(B^+ \rightarrow \eta' K^0) = (55^{+19}_{-16} \pm 8) \times 10^{-6}$
 theory: $\mathcal{B} = 20 \sim 50 \times 10^{-6}$

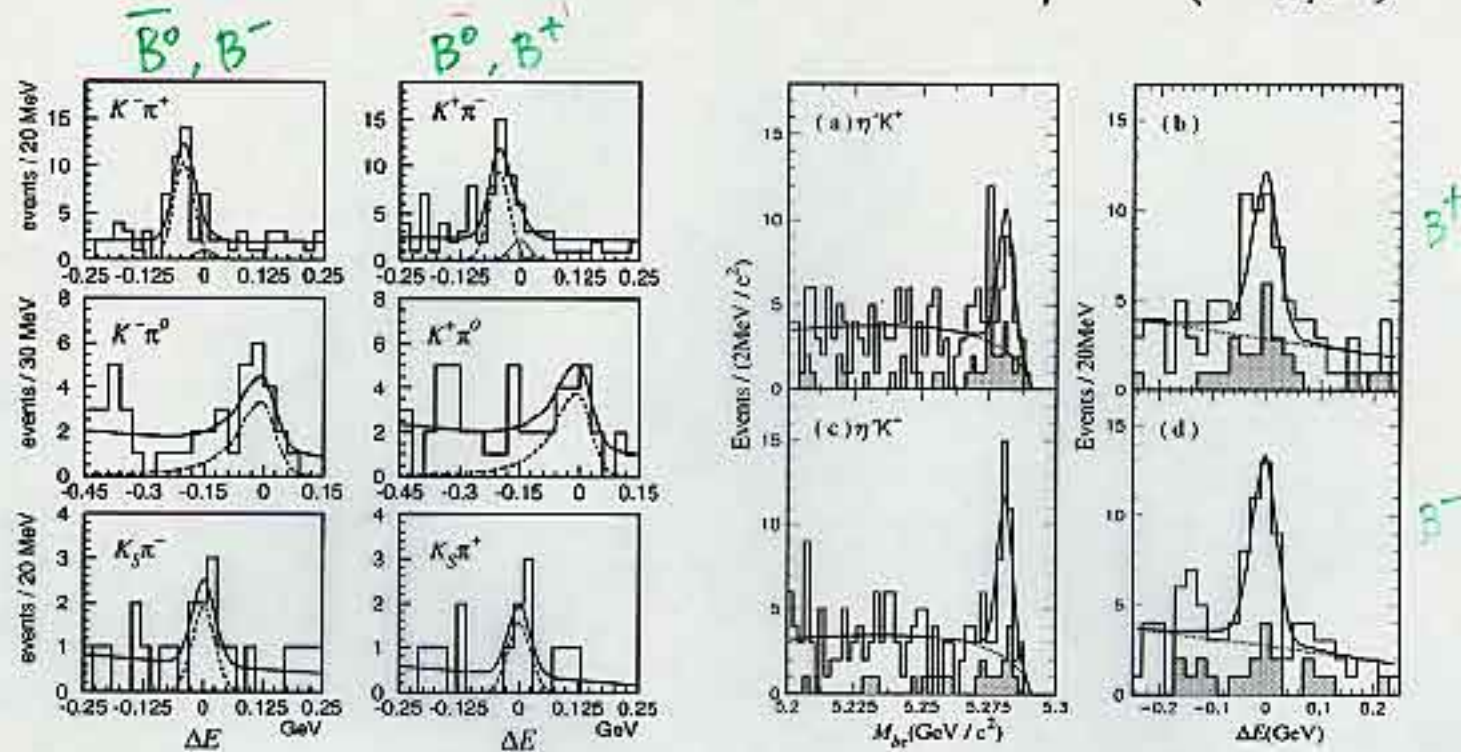
→ PLB 517, 309 (2001)



$B^0 \rightarrow \eta K^{*0}, \eta \rightarrow \gamma\gamma$ (shaded)
 $\eta \rightarrow \pi^+ \pi^- \pi^0$ (open)

o Direct CP Violation Search in $B \rightarrow K\pi$ and $\eta'K^+$ (10.4 fb^{-1})

Belle



PRL 87, 101801
(2001)

PRD 64, 071101
(2001)

Mode	$N(B)$	$N(B)$	A_{CP}	90% C.L.
$K^\mp \pi^\pm$	$27.7^{+6.8}_{-6.1}$	$25.4^{+7.0}_{-6.3}$	$0.044^{+0.186}_{-0.167} \pm 0.018$	$[-0.25, 0.37]$
$K^\mp \pi^0$	$16.5^{+5.3}_{-4.7}$	$18.6^{+5.7}_{-5.0}$	$-0.059^{+0.222}_{-0.196} \pm 0.055$	$[-0.40, 0.36]$
$K^0 \pi^\mp$	$5.6^{+3.4}_{-2.7}$	$4.6^{+2.8}_{-2.2}$	$0.098^{+0.430}_{-0.343} \pm 0.020$	$[-0.53, 0.82]$
$\eta' K^\pm$	450^{+98}_{-88}	398^{+90}_{-80}	$0.06 \pm 0.15 \pm 0.01$	$[-0.20, 0.32]$

→ corrected by ϵ, Br

Summary of $B \rightarrow$ charmless (quasi) two-body decays

Belle

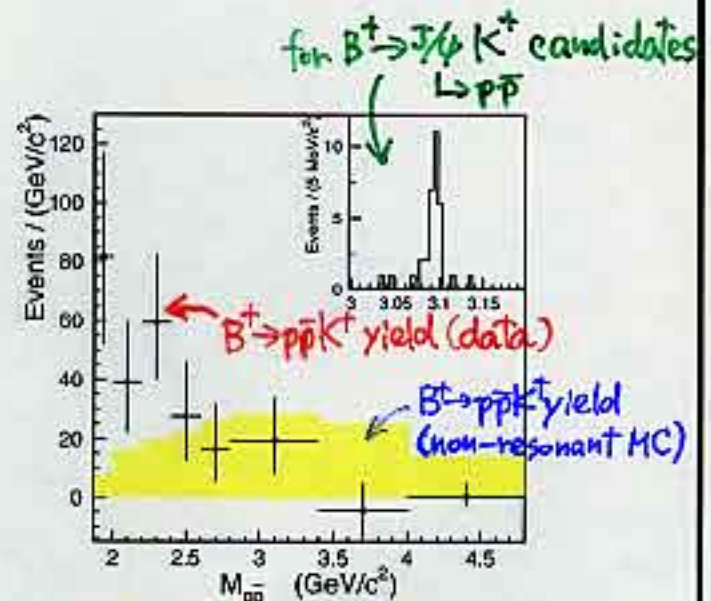
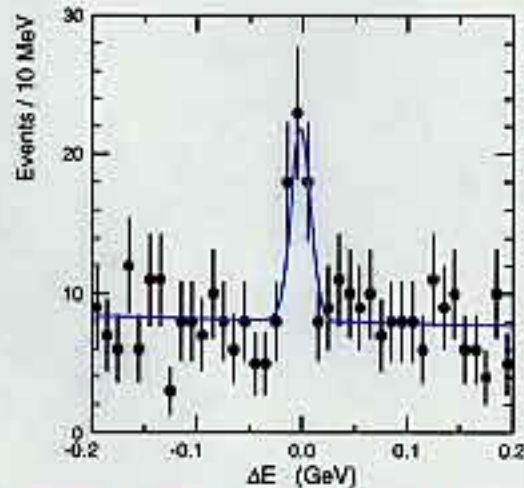
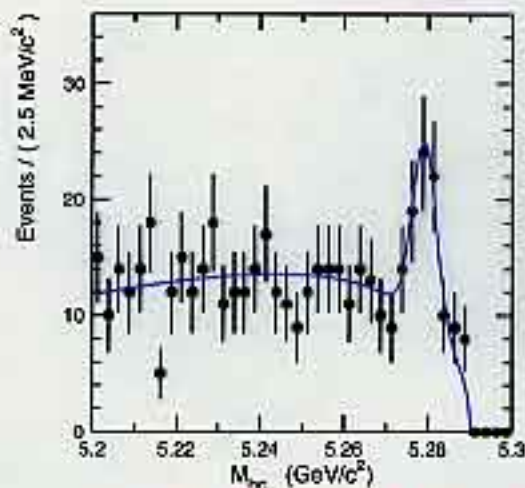
Mode	N_s [events]	S [σ]	ϵ [%]	\mathcal{B} [10^{-5}]
$\pi^+\pi^-$	$17.7^{+7.1}_{-6.4}^{+0.3}_{-1.1}$	3.1	28.1	$0.56^{+0.23}_{-0.20} \pm 0.04$
$\pi^+\pi^0$	$10.4^{+5.1}_{-4.3}^{+1.2}_{-1.6}$	2.7	12.0	< 1.34
$K^+\pi^-$	$60.3^{+10.6}_{-9.9}^{+2.7}_{-1.1}$	7.8	28.0	$1.93^{+0.34}_{-0.32}^{+0.15}_{-0.06}$
$K^+\pi^0$	$34.9^{+7.6}_{-7.0}^{+0.6}_{-2.0}$	7.2	19.2	$1.63^{+0.35}_{-0.33}^{+0.16}_{-0.18}$
$K^0\pi^+$	$10.3^{+4.3}_{-3.6}^{+0.4}_{-0.1}$	3.5	13.5	$1.37^{+0.57}_{-0.48}^{+0.19}_{-0.18}$
$K^0\pi^0$	$8.4^{+3.8}_{-3.1}^{+0.4}_{-0.6}$	3.9	9.4	$1.60^{+0.72}_{-0.59}^{+0.25}_{-0.27}$
K^+K^-	$0.2^{+3.8}_{-0.2}$	-	24.0	< 0.27
$K^+\bar{K}^0$	$0.0^{+0.9}_{-0.0}$	-	12.1	< 0.50
ηK^{*0}	5.1			$2.12^{+0.54}_{-0.47} \pm 0.20$
ηK^{*+}	2.9			< 4.99
$\eta\rho^0$	0.0			< 0.55
$\eta\rho^+$	0.0			< 0.68
$\eta'\pi^+$	0.0			< 0.7
$\eta'K^+$	12.0			$7.9^{+1.2}_{-1.1} \pm 0.9$
$\eta'K^0$	5.4			$5.5^{+1.9}_{-1.6} \pm 0.8$
ϕK^+	$36.1^{+7.2}_{-6.5}$	8.5	14.0	$1.12^{+0.22}_{-0.20} \pm 0.14$
ϕK^0	$8.0^{+3.5}_{-2.8}$	4.2	3.9	$0.89^{+0.34}_{-0.27} \pm 0.10$
ϕK^{*0}	$7.5^{+3.7}_{-3.0}$	3.6	2.5	$1.30^{+0.64}_{-0.52} \pm 0.21$
ϕK^{*+}	0.6 ± 1.0	0.0	0.9	< 1.9

○ Study of baryonic rare decays

- New results on $B \rightarrow$ baryonic charmless decays!
- Broaden the study of B physics and CP violation.

○ $B^+ \rightarrow p\bar{p}K^+$ decay (29.4 fb^{-1})

- First observation of $b \rightarrow s$ baryonic decay!



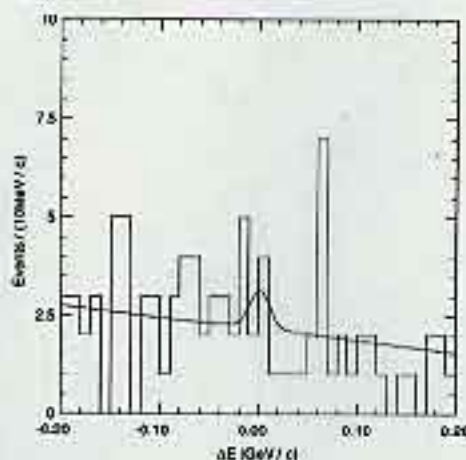
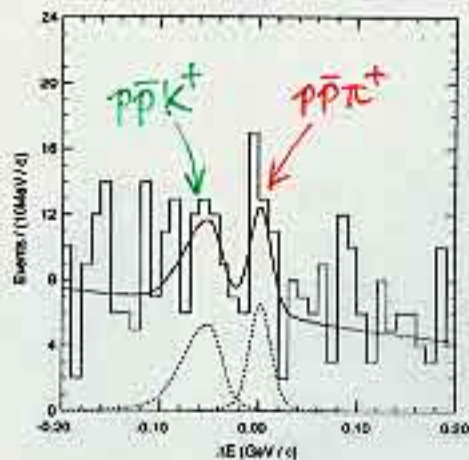
$$N_s(B^+ \rightarrow p\bar{p}K^+) = 42.8_{-9.6}^{+10.8}, \quad \mathcal{B}(B^+ \rightarrow p\bar{p}K^+) = (4.3_{-0.9}^{+1.1} \pm 0.5) \times 10^{-6}$$

Preliminary

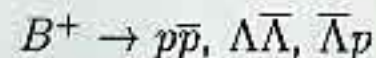
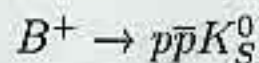
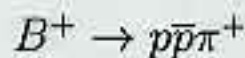
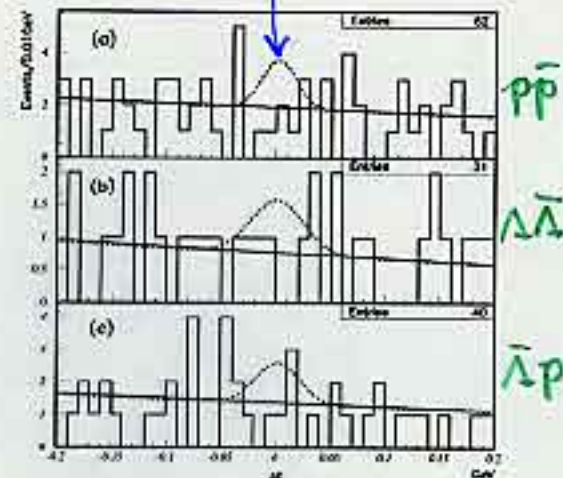
- Very clear signal (5.6σ) (charmonia $\rightarrow p\bar{p}$ are vetoed)
- $m_{p\bar{p}}$ spectrum is inconsistent with phase space.

o $B \rightarrow p\bar{p}h, p\bar{p}$ decays

- Three-body decays are seen.
- What's happen on two-body decays?



fixed at 90 % C.L. upper limit



Mode	ϵ [%]	N_s [events]	S [σ]	B [10^{-6}]
$p\bar{p}\pi^+$		$16.2^{+8.6}_{-8.0}$	2.1	< 3.7
$p\bar{p}K^+$		$42.8^{+10.8}_{-9.6}$	5.6	$4.3^{+1.1}_{-0.9} \pm 0.5$
$p\bar{p}K^0$		$6.4^{+4.4}_{-3.7}$		< 7.2
$p\bar{p}$	27.5 ± 2.3	$0.0^{+0.7}_{-0.0}$		< 1.6
$\Lambda\bar{\Lambda}$	13.2 ± 1.6	$0.0^{+4.9}_{-0.0}$		< 2.3
$\bar{\Lambda}p$	18.0 ± 1.7	$0.0^{+6.1}_{-0.0}$		< 2.1

Preliminary

— Summary —

- Three-body rare decays are observed.
 - Large amount of data and good understanding of background components give new results.
 - $B^+ \rightarrow K^+\pi^+\pi^-$, $f_0(980)K^+$, $K^*(892)^0\pi^+$, $K^+K^+K^+$
 - $B^+ \rightarrow p\bar{p}K^+$
 - Window of B physics study is significantly broadened.
 - detailed nature of B meson, CP violation, KM scheme, ...
- Two-body decays are in precise measurements.
 - Various channels have already been observed.
 - Increased statistics and feed back from study of three-body decays give more precise measurements.
 - direct CP violation search, new physics search, ...

Charmless hadronic rare B decays keep providing a new information of B physics!