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Studies of Charmless Hadronic Decays of B Mesons with Belle

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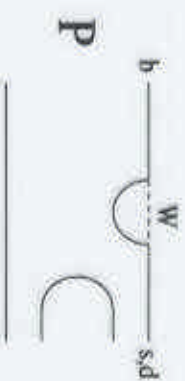
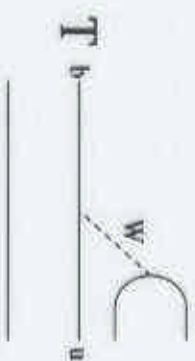
- Motivation
- Data Analysis
- Results
- Conclusions

Contributed papers: Osaka 287, 289, 292

BELLE-CONF-0005, 0006, 0007

Motivation

- **Test the Standard Model**
 - Search for direct CP violation
 - Extract CP violation angle ϕ_2 (α).
 - ◆ $B^0 \rightarrow K^+ \pi^-, \pi^+ \pi^-, \pi^0 \pi^0$
 - ◆ $B^0 \rightarrow \rho^+ \pi^-, \rho^0 \pi^0$
 - Determine the third angle ϕ_3 (γ).
 - ◆ $B \rightarrow K^0 \pi^\pm, K^+ \pi^0$
 - ◆ $B \rightarrow K^0 \pi^\pm, K^\pm \pi^-, \pi^\pm \pi^0$
- **Probe New Physics**
 - Any Channel with an unexpected branching fraction.



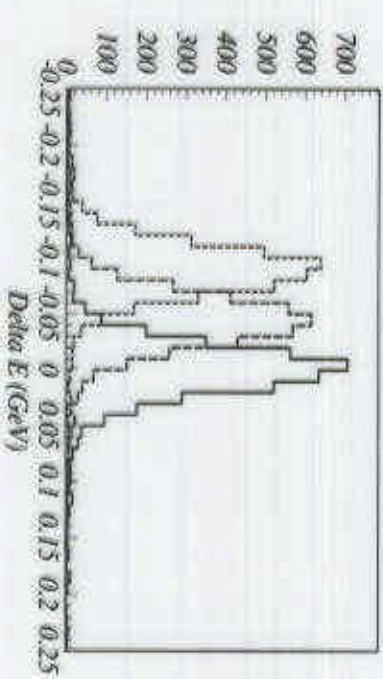
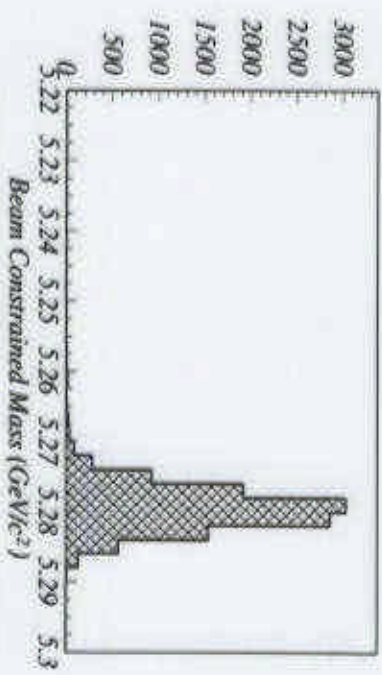
Data Analysis

- Data Sample
 - ~ 5.5 million $B\bar{B}$ events (on $\Upsilon(4S)$ resonance)
 - 600 pb^{-1} off resonance data
- Event Selection

$$M_b = \sqrt{E_{\text{beam}}^{*2} - (\sum \hat{p}_i)^2}$$

$$\Delta E = E_{\text{measured}} - E_{\text{beam}}^*$$

$$E_{\text{beam}}^* \approx 5.29 \text{ GeV}$$



$K^{\pm}K^{\mp}$ $K^{\pm}\pi^{\mp}$ $\pi^{\pm}\pi^{\mp}$

Data Analysis

- K- π Separation

Not used for particles
from 2-body B decays

$$L(h;p) = L^{ACC}(h;p) \times L^{det}(h;p) \times L^{TOF}(h;p)$$

$$PID(K) = \frac{L(K)}{L(K) + L(\pi)}$$

For $P > 2 \text{ GeV}/c$

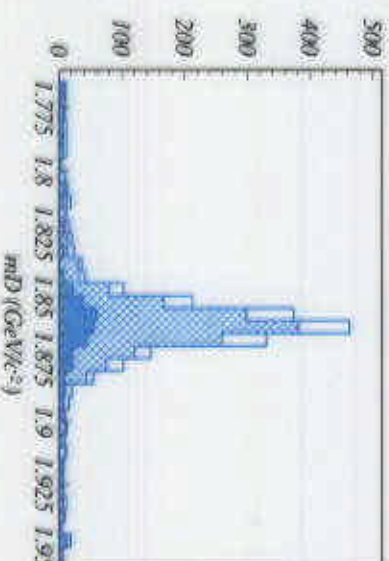
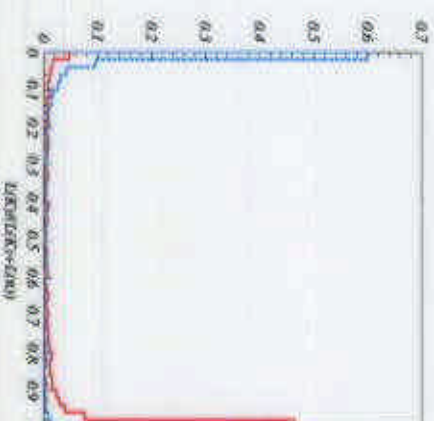
- ◆ PID(K) > 0.6 for kaons
- ◆ PID(K) < 0.4 for pions
- ◆ Efficiency and Fake Rate



EFF (K) = 78%; EFF (π) = 91%

K fakes π rate: 17%

π fakes K rate: 6%



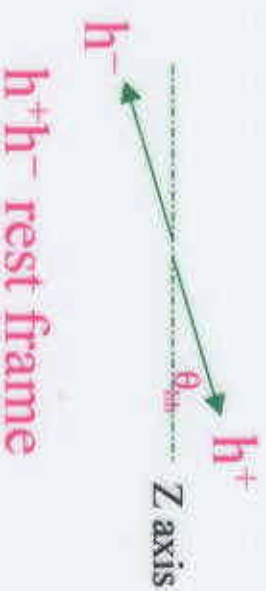
Data Analysis

- Background Suppression

- $\cos(\theta_{\text{thrust}})$;
- $\cos(\theta_B)$;
- $\cos(\theta_{\text{th}})$;

4. Sphericity:
$$\frac{\sum |P_{T,i}|}{\sum |P_i|}$$

Particle i outside the 45° cone
with respect to the thrust axis



5. SFW (Super Fox-Wolfram moment)

$\rightarrow R_l = H_l/H_0$; $H_l = \sum_{ij} |p_i| |p_j| P_l(\cos\theta_{ij})$

$P_l(\cos\theta_{ij})$ is the l th
Legendre polynomial

$\rightarrow R_l = R_l^{SS} + R_l^{SO} + R_l^{OO}$; l ranges from 1 to 4

\rightarrow Remove R_l^{SS} and modify (or not use) R_1^{SO} , R_3^{SO} and R_4^{OO}

Data Analysis

- $K^+\pi^-, \pi^+\pi^-, K^+K^-, K_s^+\pi^+, K_s^+K^+$

→ Form Likelihood ratio from $\cos\theta_B, \cos\theta_{hh},$ and SFW

$$\text{SFW} = \sum \alpha_i R_i^{s^0} + \beta_j R_j^{p^0}$$

$$L(B\bar{B}) = L^{\text{SFW}}(B\bar{B}) \times L^{\cos\theta_B}(B\bar{B}) \times L^{\cos\theta_{hh}}(B\bar{B})$$

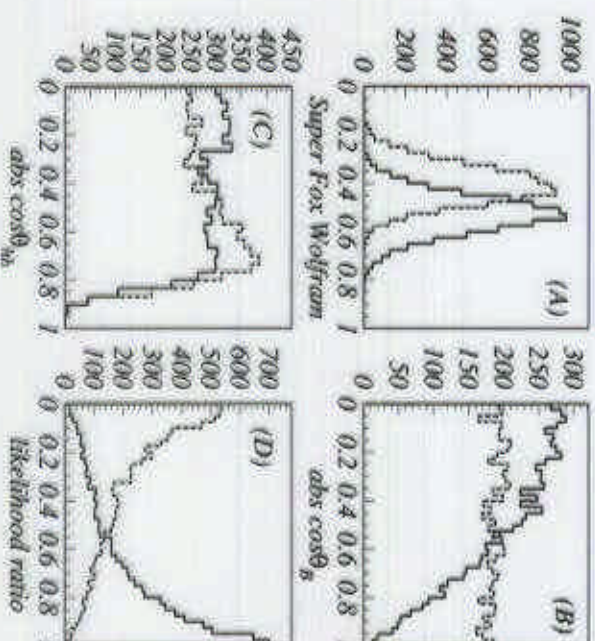
$$\text{LR}(B\bar{B}) = \frac{L(B\bar{B})}{L(B\bar{B}) + L(q\bar{q})}$$

Signal: MC events

Background: Sideband data

→ Require $\text{LR}(B\bar{B}) > 0.8$

Fit M_b and ΔE distributions





Preliminary Results: $K^+\pi^-$

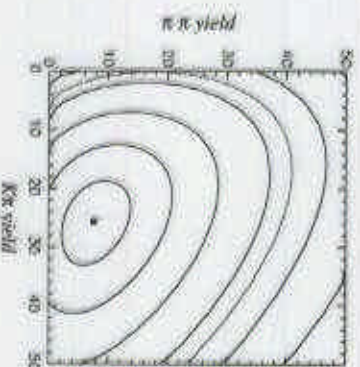
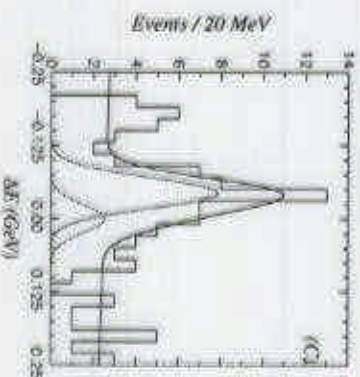
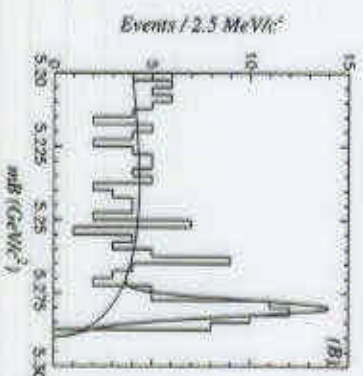
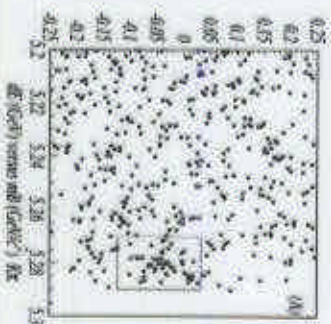
1. One of the tracks with PID(K) > 0.6
2. Fit both $K^+\pi^-$ and $\pi^+\pi^-$ components

Found

$25.6_{-6.8}^{+7.5} K^+\pi^-$ events
and $7.6 \pm 5.8 \pi^+\pi^-$ events

$$\text{Br}(B^0 \rightarrow K^+\pi^-) = 1.74_{-0.46}^{+0.51} \times 10^{-5}$$

Significance 4.4σ





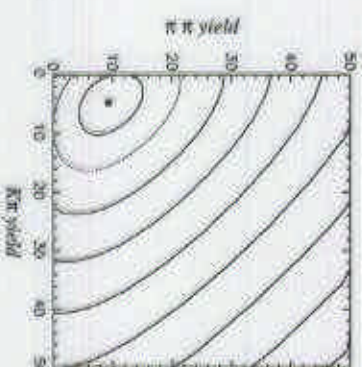
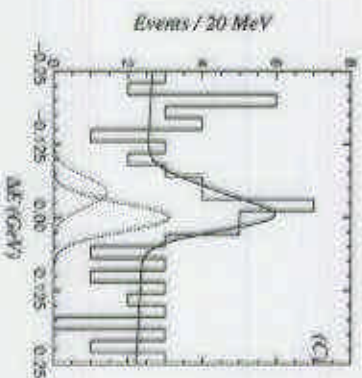
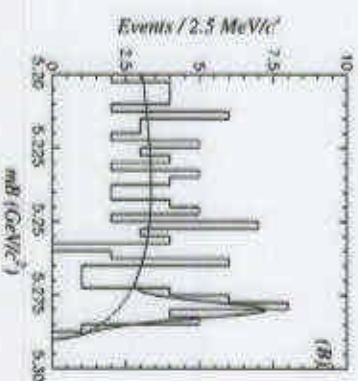
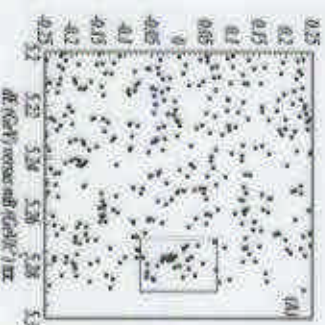
Preliminary Results: $\pi^+\pi^-$

1. Both tracks with PID(K) < 0.4
2. Fit both $K^+\pi^-$ and $\pi^+\pi^-$ components

Found

$9.3^{+5.7}_{-5.1} \pi^+\pi^-$ events
and $4.7 \pm 5.2 K^+\pi^-$ events

$\text{Br}(B^0 \rightarrow \pi^+\pi^-) =$
 $0.63^{+0.39}_{-0.35} \times 10^{-5}$
< 1.65×10^{-5} 90% C.L.
Significance 1.9 σ



Preliminary Results: $K_S\pi^+$, $K_S K^+$, K^+K^-

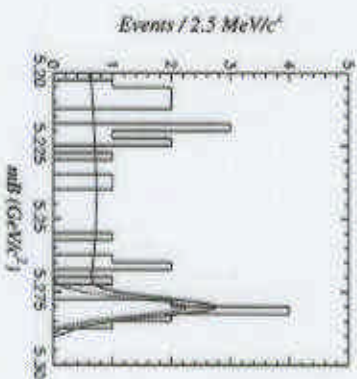
- Found $5.7_{-2.7}^{+3.4} K_S\pi^+$ events

$$\begin{aligned} \text{Br}(B^+ \rightarrow K^0 \pi^+) &= \\ 1.66_{-0.78}^{+0.98} \times 10^{-5} \\ &< 3.4 \times 10^{-5} \quad 90\% \text{ C.L.} \\ \text{Significance} & 2.4 \sigma \end{aligned}$$

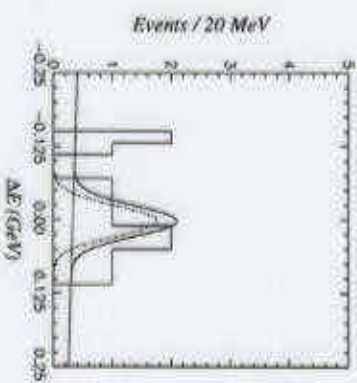
- $0.8_{-0.8}^{+3.1} K^+K^-$ events
- $0.0_{-0.0}^{+0.5} K_S K^+$ events

$$\begin{aligned} \text{Br}(B^0 \rightarrow K^+ K^-) &< 0.6 \times 10^{-5} \\ \text{Br}(B^+ \rightarrow K^0 K^+) &< 0.8 \times 10^{-5} \end{aligned}$$

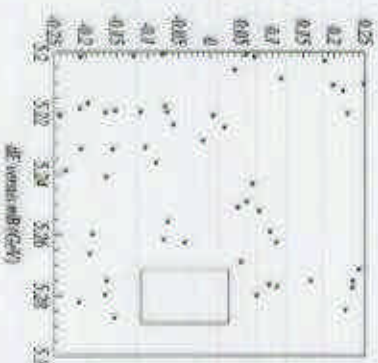
$K_S\pi^+$



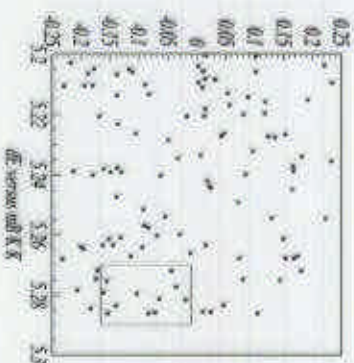
$K_S\pi^+$



$K_S K^+$



K^+K^-





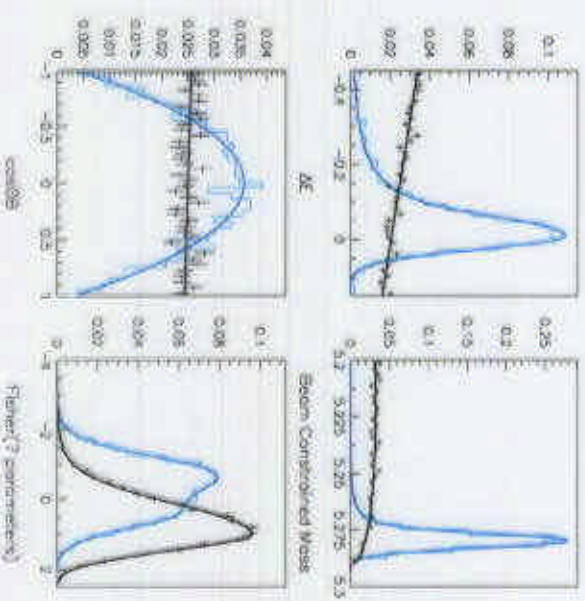
Data Analysis

- $K^+\pi^0$, $\pi^+\pi^0$, and $K_S\pi^0$

➔ Perform likelihood fit on M_b , ΔE , $\cos\theta_B$, Fisher
Fisher contains SFW, $\cos\theta_{\text{thrust}}$, and Sphericity

$$L(f_S) = \prod_i f_S \times P_S(X_i) + (1-f_S) \times P_B(X_i)$$

➔ Use likelihood ratio method
for a consistency check



Data Analysis

- $K^+\pi^0$, $\pi^+\pi^0$, and $K_S\pi^0$

- ◆ Apply π^0 mass constraint

- ◆ Further reduce background

$$|\cos\theta_{\text{thrust}}| < 0.8 \text{ for } K^+\pi^0, K_S\pi^0$$

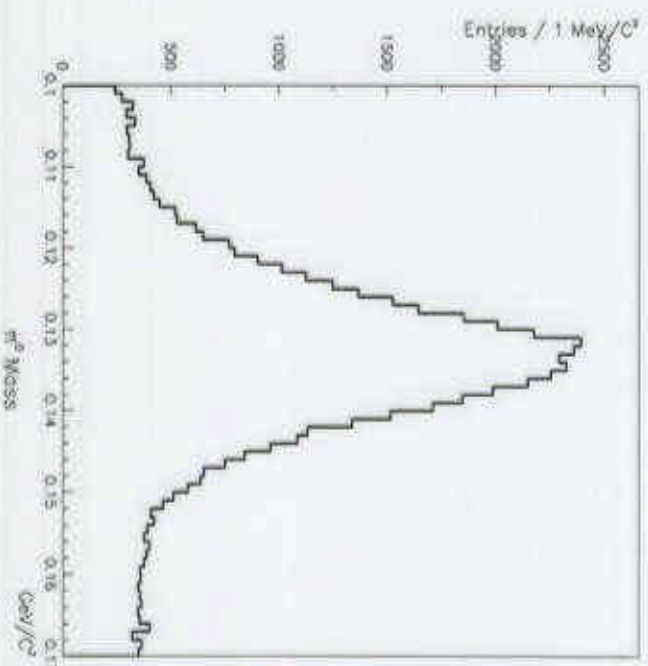
$$|\cos\theta_{\text{thrust}}| < 0.6 \text{ for } \pi^+\pi^0$$

- ◆ $K^+\pi^0 \rightarrow \pi^+\pi^0$ Feed down

1. Estimate the number of feed down events.

2. Add $K^+\pi^0$ fraction f_{SK} with -40 MeV shift on ΔE shape.

3. Fix f_{SK} based on number of $K^+\pi^0$ feed down events.



Preliminary Results

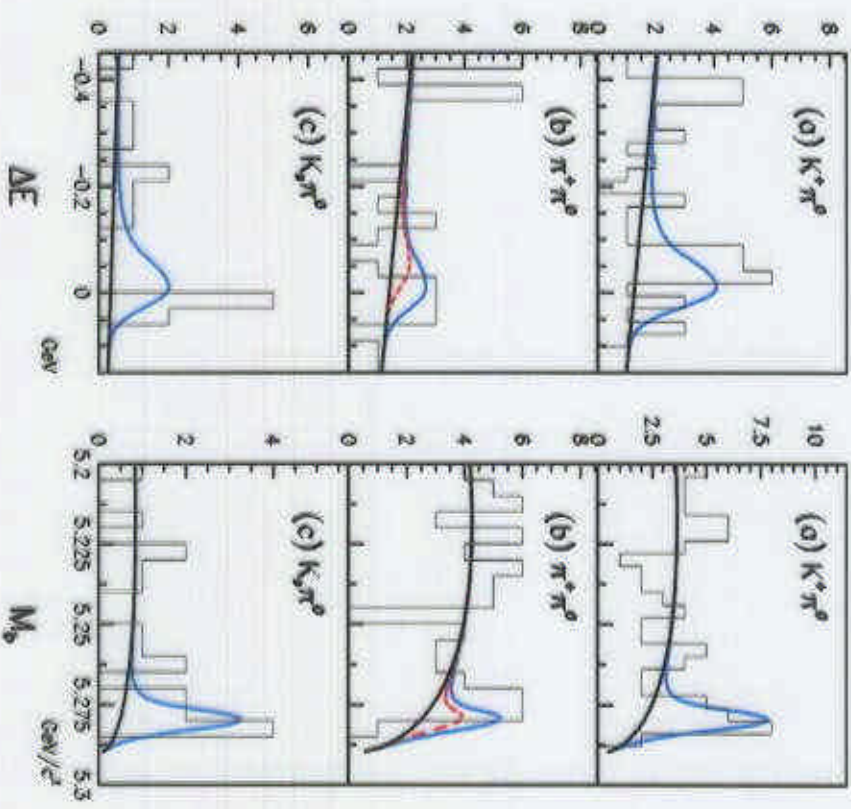
◆ Projection Plots

Signal enriching cuts

$$M_b: -0.15 < \Delta E < 0.05 \text{ GeV}$$

$$\Delta E: M_b > 5.27 \text{ GeV}/c^2$$

$$|\cos\theta_B| < 0.8, \text{ Fisher} < -0.1$$



Red curve in (b) is $K^+\pi^0$ feed down.

Preliminary Results

- ◆ $K^+\pi^0$:

$32.3^{+8.4}_{-8.4}$ events
 $\text{Br}(B^+ \rightarrow K^+\pi^0) =$
 $(1.88^{+0.55}_{-0.49}) \times 10^{-5}$
 Significance 5.0σ

- ◆ $K_S \pi^0$:

$10.8^{+4.8}_{-4.0}$ events
 $\text{Br}(B^0 \rightarrow K^0\pi^0) =$
 $(2.10^{+0.93}_{-0.78}) \times 10^{-5}$
 Significance 3.9σ

- ◆ $\pi^+\pi^0$:

$5.4^{+5.7}_{-4.4}$ events
 $\text{Br}(B^+ \rightarrow \pi^+\pi^0) =$
 $(0.33^{+0.35}_{-0.27}) \times 10^{-5}$
 $< 1.01 \times 10^{-5}$
 Significance 1.3σ

Preliminary Results

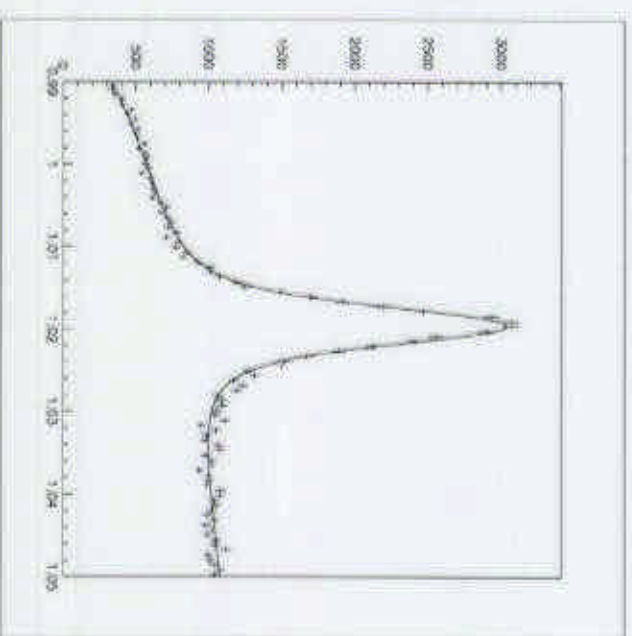
- $\phi K^+, \phi K_S$
 - ◆ $\phi \rightarrow K^+ K^-$ selection
 - Beam position vertex constrained
 - PID(K) > 0.1 (loose cut)
 - $P^* (K^+ K^-) > 2 \text{ GeV}/c$

- ◆ Simple Slice Cuts

$$|\cos\theta_{\text{thrust}}| < 0.8, |\cos\theta_B| < 0.8$$

$$|\cos\theta_H| > 0.5$$

* ϕ from B decays is 100% polarized.



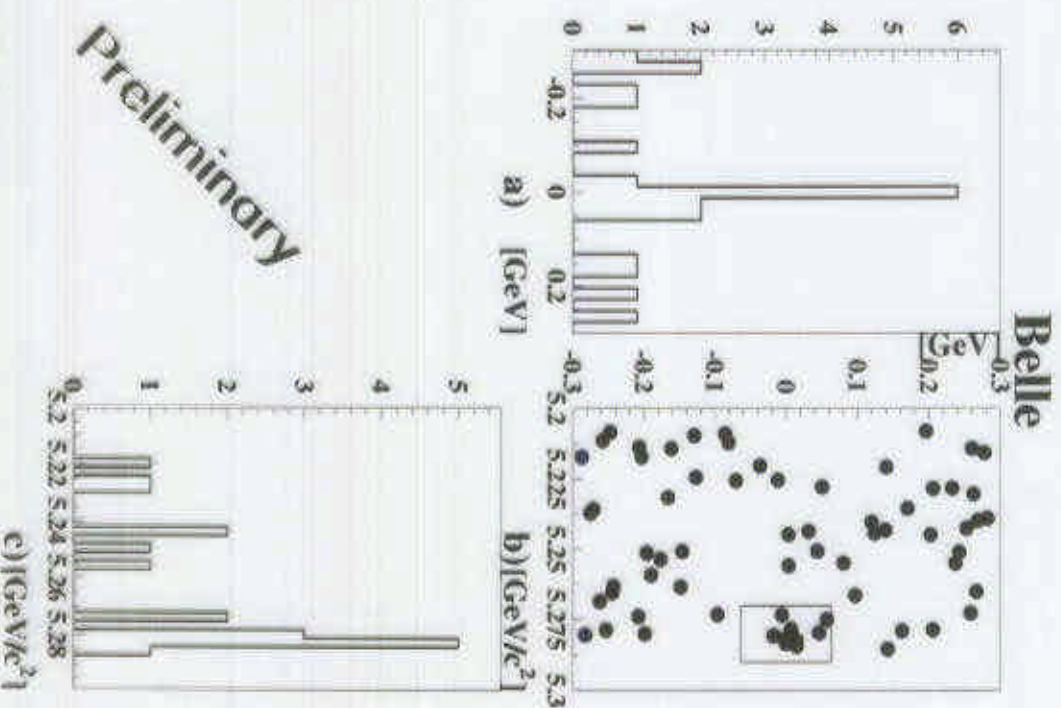


Preliminary Results: ϕK^+

$9.2_{-2.8}^{+3.6}$ events
 $\text{Br} = (1.72_{-0.54}^{+0.67}) \times 10^{-5}$
 significance 5.4σ
 Lower limit: 0.71×10^{-5}
 Upper limit: 3.0×10^{-5}

N.B. Lower limit higher than *central Belle* upper limit from CLEO

The first evidence of $b \rightarrow s\bar{s}$ transition

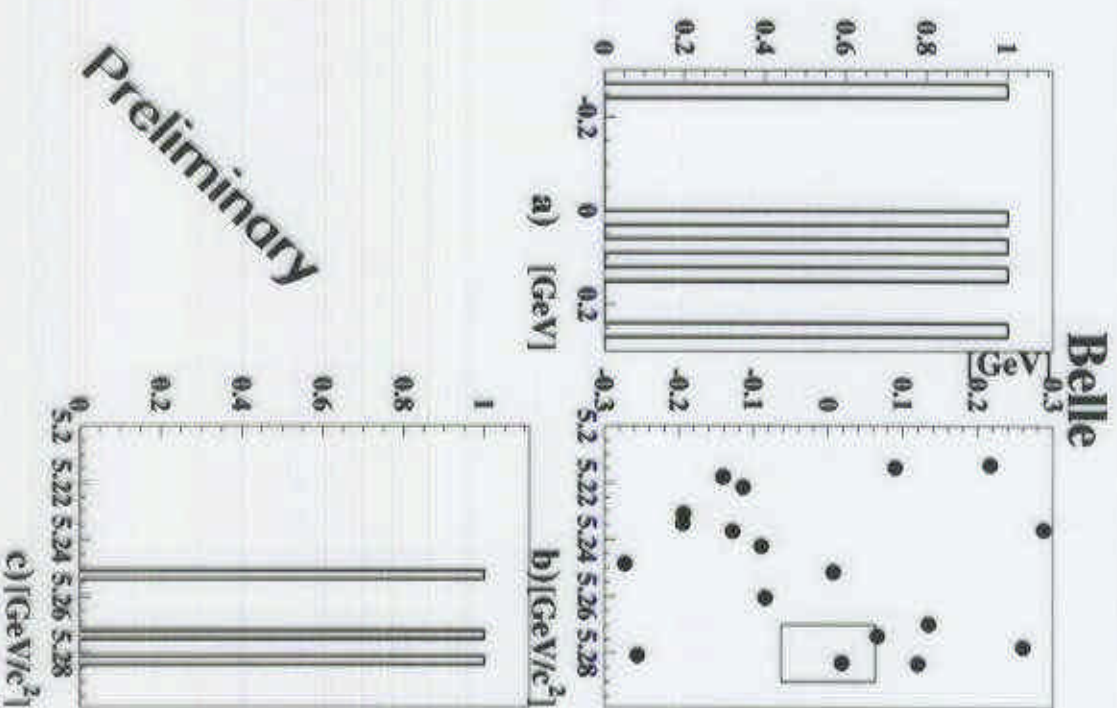


Preliminary



Preliminary Results: ϕK_S

- No significant signal found.
- Expect to see 2.4 ± 0.7 events based on isospin invariance and the number of measured ϕK^+ events.





Summary

Mode	Yield	Sign.	Eff. (%)	Br($\times 10^{-5}$)	UL.(10^{-5})	CLEO($\times 10^{-5}$)
$K^+ \pi^-$	$25.6^{+7.5}_{-6.8} \pm 3.8$	4.4	28	$1.74^{+0.51}_{-0.46} \pm 0.34$	-	$1.72^{+0.25}_{-0.24} \pm 0.12$
$\pi^+ \pi^-$	$9.3^{+5.3}_{-5.1} \pm 2.0$	1.9	28	$0.63^{+0.39}_{-0.35} \pm 0.16$	1.65	$0.43^{+0.16}_{-0.14} \pm 0.05$
$K^+ K^-$	$0.8^{+3.1}_{-0.8}$	-	20	-	0.6	< 0.19
$K^0 \pi^\pm$	$5.7^{+3.4}_{-2.7} \pm 0.6$	2.4	13	$1.66^{+0.98+0.22}_{-0.78-0.24}$	3.4	$1.82^{+0.46}_{-0.40} \pm 0.16$
$K^0 K^\pm$	$0.0^{+0.5}_{-0.0}$	-	11	-	0.8	< 0.51
$K^+ \pi^0$	$32.3^{+9.4+2.4}_{-8.4-2.2}$	5.0	31	$1.88^{+0.55}_{-0.49} \pm 0.23$	-	$1.12^{+0.30+0.14}_{-0.27-0.13}$
$\pi^+ \pi^0$	$5.4^{+5.7+1.0}_{-4.4-1.1}$	1.3	30	$0.33^{+0.35}_{-0.27} \pm 0.07$	1.01	< 1.27
$K^0 \pi^0$	$10.8^{+1.8+0.7}_{-4.0-0.5}$	3.9	19	$2.10^{+0.93+0.25}_{-0.78-0.23}$	-	$1.46^{+0.59+0.24}_{-0.51-0.33}$
ϕK^+	$9.2^{+3.6}_{-2.9} \pm 0.8$	5.4	10	$1.72^{+0.67}_{-0.54} \pm 0.18$	-	< 0.59

* The systematic uncertainty includes the systematic errors of the fit and the reconstruction efficiency.

Conclusions

- Belle measurements on branching fractions of $B \rightarrow K\pi$ and $\pi\pi$ decays are consistent with CLEO
 - Confirm $\text{Br}(B \rightarrow K\pi) > \text{Br}(B \rightarrow \pi\pi)$
 - $\text{Br}(B \rightarrow K^0\pi^0)$ larger than theoretical predictions
- We observe evidence for $B^+ \rightarrow \phi K^+$ decays.
- Other rare decay searches are on-going.
- Looking forward to measuring direct CP violations and the angles ϕ_2 and ϕ_3 .