

Studies of B Meson Rare Decays at Belle

Toru Iijima / KEK
for
Belle Collaboration



February 20, 2001
BCP4, International Workshop on B Physics & CP Violation
Ise, Japan



Belle Collaboration



BELLE Collaboration

Aomori University
Budker Institute of Nuclear Physics
Chiba University
Chuo University
University of Cincinnati
Frankfurt University
Gyeongsang National University
University of Hawaii
Hiroshima Institute of Technology
Hiroshima College of Maritime Tech.
IHEP, Beijing
ITEP, Moscow
Joint Crystal Collaboration Group
Kanagawa University
KEK
Korea University
Krakow Institute of Nuclear Physics
Kyoto University
University of Melbourne
Mindanao State University
Nagasaki Institute of Applied Science
Nagoya University
Nara Woman's University
National Central University
National Kaoshiung University

National Lien-Ho College of Tech. and Commerce
National Taiwan University
Nihon Dental College
Niigata University
Osaka University
Osaka City University
Panjab University
Princeton University
Saga University
Seoul National University
University of Science and Tech. of China
Sugiyama Woman's College
Sungkyunkwan University
University of Sydney
Toho University
Tohoku University
Tohoku-gakuin University
University of Tokyo
Tokyo Institute of Technology
Tokyo Metropolitan University
Tokyo University of Agriculture and Technology
Toyama National College of Maritime Technology
University of Tsukuba
Utkal University
Virginia Polytechnic Institute and State University
Yonsei University



Talk Contents

- Brief Introduction
- Analysis Features
- Results based on **10.5fb⁻¹ (11.1M B \bar{B})**
 \Leftrightarrow 5.1fb⁻¹ at ICHEP2000
 - Cabibbo suppressed decays
 $B \rightarrow D^{(*)} K^{(*)}$
 - Charmless two-body decays
 $B \rightarrow \pi\pi / K\pi / KK$
 $B \rightarrow \eta' h$ (h=K⁺, π^+ , K⁰)
 - EW penguin decays
 $B \rightarrow K^{(*)} \ell \ell$ search
- Summary

Note: All results are preliminary !



B Rare Decays and the Unitarity Triangle

- B Meson rare decays for determination of the unitarity triangle...

Vub measurement
 $B \rightarrow D_s \pi$
 $b \rightarrow ulv (\pi lv, \rho lv, \dots)$

$B \rightarrow \pi\pi$
 $B \rightarrow \rho\pi$

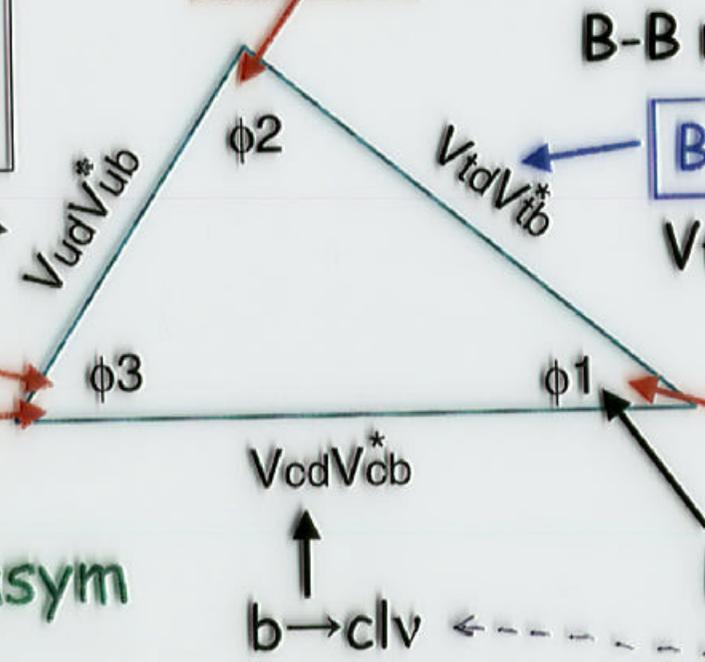
Time-dependent CP asym.
 (Indirect CPV)

Atwood
ronau

$B \rightarrow DK$

$B \rightarrow \pi\pi / K\pi$
 & Other charmless decays

"Partial rate asym
 (Direct CPV)"



B-B mixing

$B \rightarrow \rho\gamma / B \rightarrow K^*\gamma$

V_{td}/V_{ts}

$B \rightarrow \phi K$

$B \rightarrow J/\psi K_s$

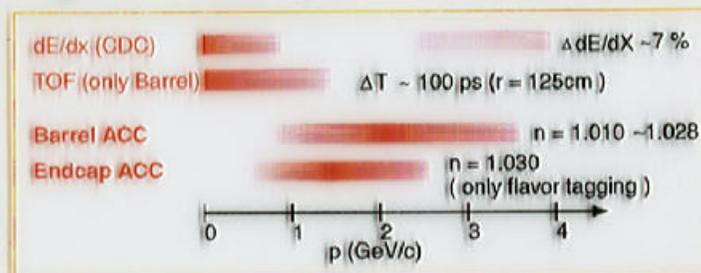
E.H. Thorndike
yesterday



Particle Identification

- Clear K/ π separation is essential to distinguish decays.

- DK/D π
- K π / $\pi\pi$ /KK etc.
- K* γ / $\rho\gamma$

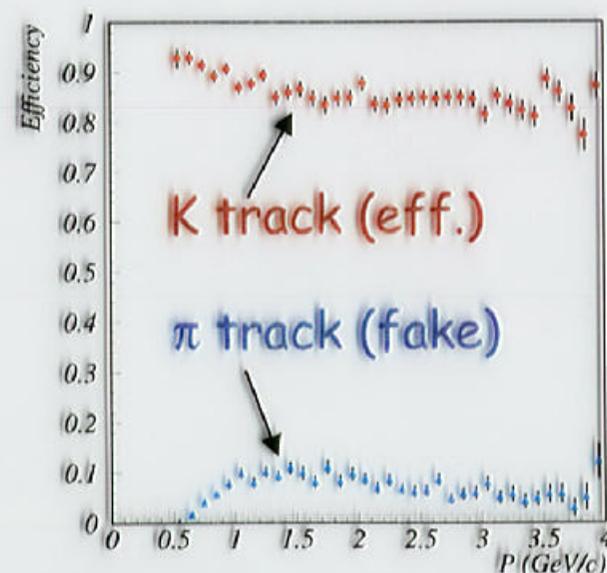


- Belle use **dE/dx + ToF + ACC**

- Wide momentum coverage
- ACC: Aerogel Cherenkov
- Combined into likelihood;

$$\text{PID}(K) = \frac{L(K)}{L(K) + L(\pi)} \quad \begin{array}{l} \sim 1 \text{ for } K \\ \sim 0 \text{ for } \pi \end{array}$$

- Calibration with $D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+$





Continuum Suppression

- Event shape: "spherical B events" \Leftrightarrow "jetty qq events"
- Newly developed shape variable **"Super Fox Wolfram"**

$$R_i^{so} = \frac{\sum_{i,s} |p_i| \cdot |p_s| \cdot P_i(\cos\theta_{is})}{\sum_{i,s} |p_i| \cdot |p_s|} \quad (\text{signal-other})$$

$$R_i^{oo} = \frac{\sum_{i,j} |p_i| \cdot |p_j| \cdot P_i(\cos\theta_{ij})}{\sum_{i,j} |p_i| \cdot |p_j|} \quad (\text{other-other})$$

$i: 1 \sim 4$

$s: B$ cand. track, $i, j: \text{non-B}$

$$\Rightarrow F_{\text{SFW}} = \sum_{i=1,4} [\alpha_i \cdot R_i^{so} + \beta_i \cdot R_i^{oo}]$$

Fisher discriminants

- + $\cos\theta_B, \cos\theta_{hh}, \cos\theta_{H, \dots}$

\Rightarrow Likelihood ratio (LR)

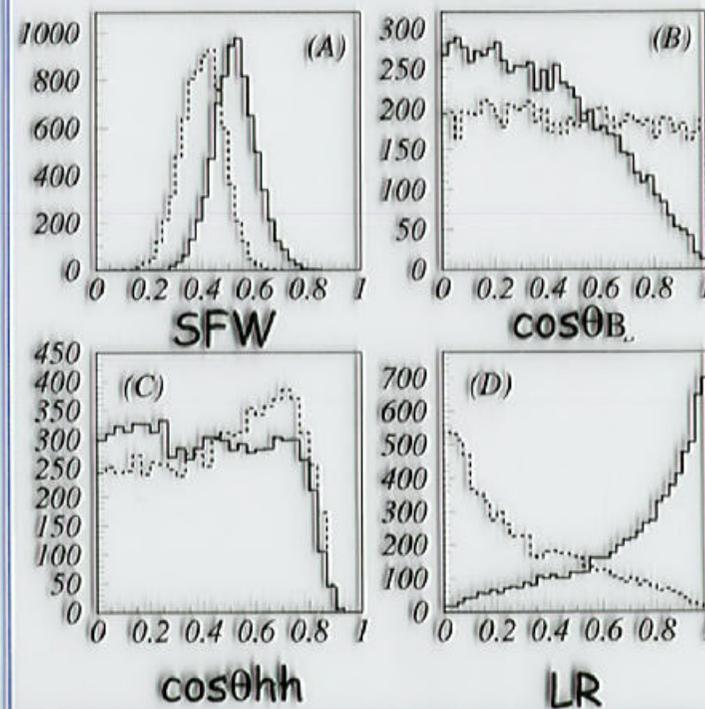
$$L(\overline{B\overline{B}}) = L_{\overline{B\overline{B}}}^{\text{SFW}} \times L_{\overline{B\overline{B}}}^{\cos\theta_B} \times L_{\overline{B\overline{B}}}^{\cos\theta_{hh}} \times \dots$$

$$LR = \frac{L(\overline{B\overline{B}})}{L(\overline{B\overline{B}}) + L(q\overline{q})} \quad \Rightarrow \text{Slice cut}$$

- Systematic checked with
 - $B \rightarrow D\pi$ data for signals
 - Side-band data for background

— signal ···· $q\overline{q}$ background

ex.) $B \rightarrow hh$ analysis





Cabibbo Suppressed Decays

- Extraction of ϕ_3 using direct CP violation through interference between $b \rightarrow c$ and $b \rightarrow u$ transitions.

- Cabibbo suppressed $B^- \rightarrow D^0 K^-$

Gronau & Wyler, PLB265, 172 (1991)

Dunietz, PLB270, 75 (1991)

- Doubly Cabibbo suppressed $B \rightarrow D^{(*)+} \pi^-$

Atwood, Dunietz and Soni, PRL78, 3257 (1997)

Dunietz, PLB427, 179 (1998)

- The first step is to establish the Cabibbo suppressed decays!

Naive expectation:

$$R_c \equiv \frac{\text{Br}(B \rightarrow D^{(*)} K^-)}{\text{Br}(B \rightarrow D^{(*)} \pi^-)} \sim \tan^2 \theta_c (f_K / f_\pi)^2 \sim 0.074$$

$$\begin{aligned} R_{c'} &\equiv \frac{\text{Br}(B^- \rightarrow D^0 K^{*-})}{\text{Br}(B^- \rightarrow D^0 \pi^-)} = \frac{\text{Br}(B^- \rightarrow D^0 K^{*-})}{\text{Br}(B^- \rightarrow D^0 K^-)} \cdot \frac{\text{Br}(B^- \rightarrow D^0 K^-)}{\text{Br}(B^- \rightarrow D^0 \pi^-)} \\ &\sim \frac{\text{Br}(B^- \rightarrow D^0 \rho^-)}{\text{Br}(B^- \rightarrow D^0 \pi^-)} \cdot \frac{\text{Br}(B^- \rightarrow D^0 K^-)}{\text{Br}(B^- \rightarrow D^0 \pi^-)} \sim 0.19 \end{aligned}$$



$B \rightarrow D^{(*)} K^-$ Analysis

Reconstructed B decays

$$B^- \rightarrow D^0 h^-, D^{*0} h^-$$

$$B^0 \rightarrow D^+ h^-, D^{*+} h^-$$

Charm Reconstruction

$$D^{*+} \rightarrow D^0 \pi^+, D^+ \pi^0, D^{*0} \rightarrow D^0 \pi^0$$

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

$$D^0 \rightarrow K^- \pi^+, K^- \pi^+ \pi^0, K^- \pi^+ \pi^+ \pi^-$$

PID cut

K from D

$$\text{PID}(K) > 0.3 \text{ for } D^0 \rightarrow K^- \pi^+$$

$$D^{*+} \rightarrow D^0 \pi^+$$

$$\text{PID}(K) > 0.7 \text{ for others}$$

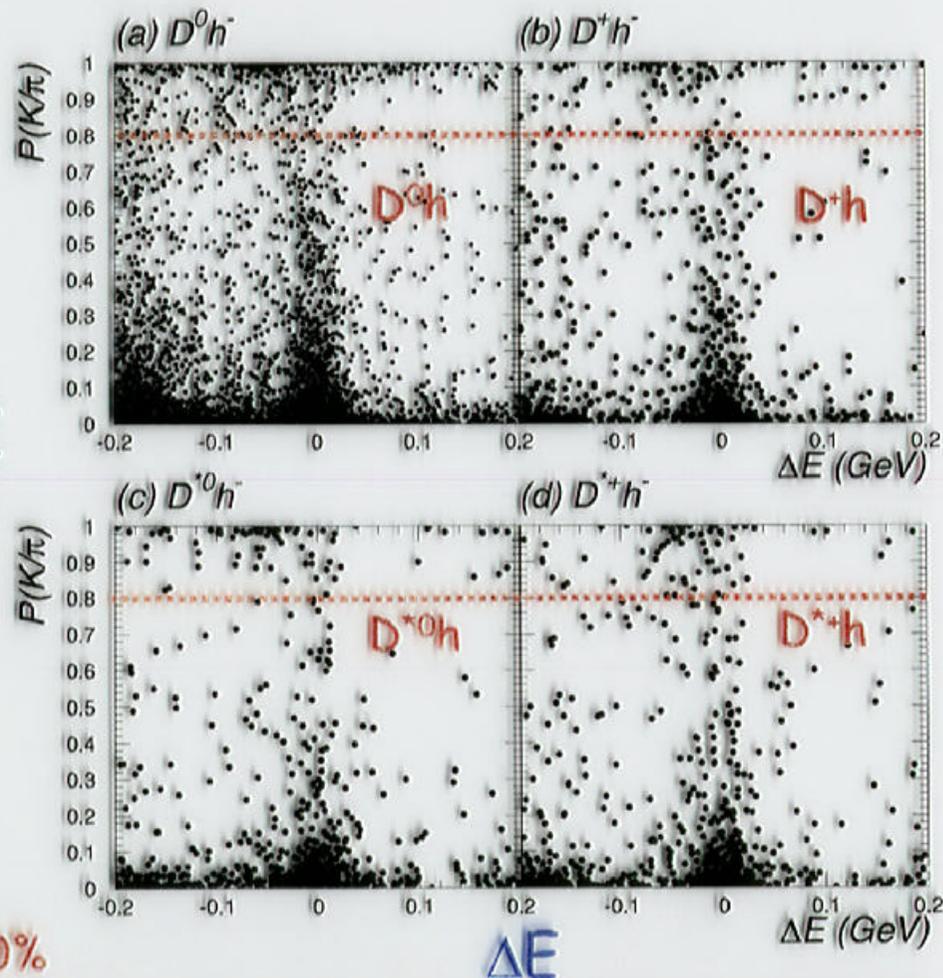
Prompt K/ π from B

$$\text{PID}(K) > 0.8 \text{ for } B \rightarrow D^{(*)} K^-$$

$$\text{PID}(K) < 0.8 \text{ for } B \rightarrow D^{(*)} \pi^-$$

$$\Rightarrow K \text{ eff.} = 76.5\% / \pi \text{ fake} = 2.0\%$$

PID(K)

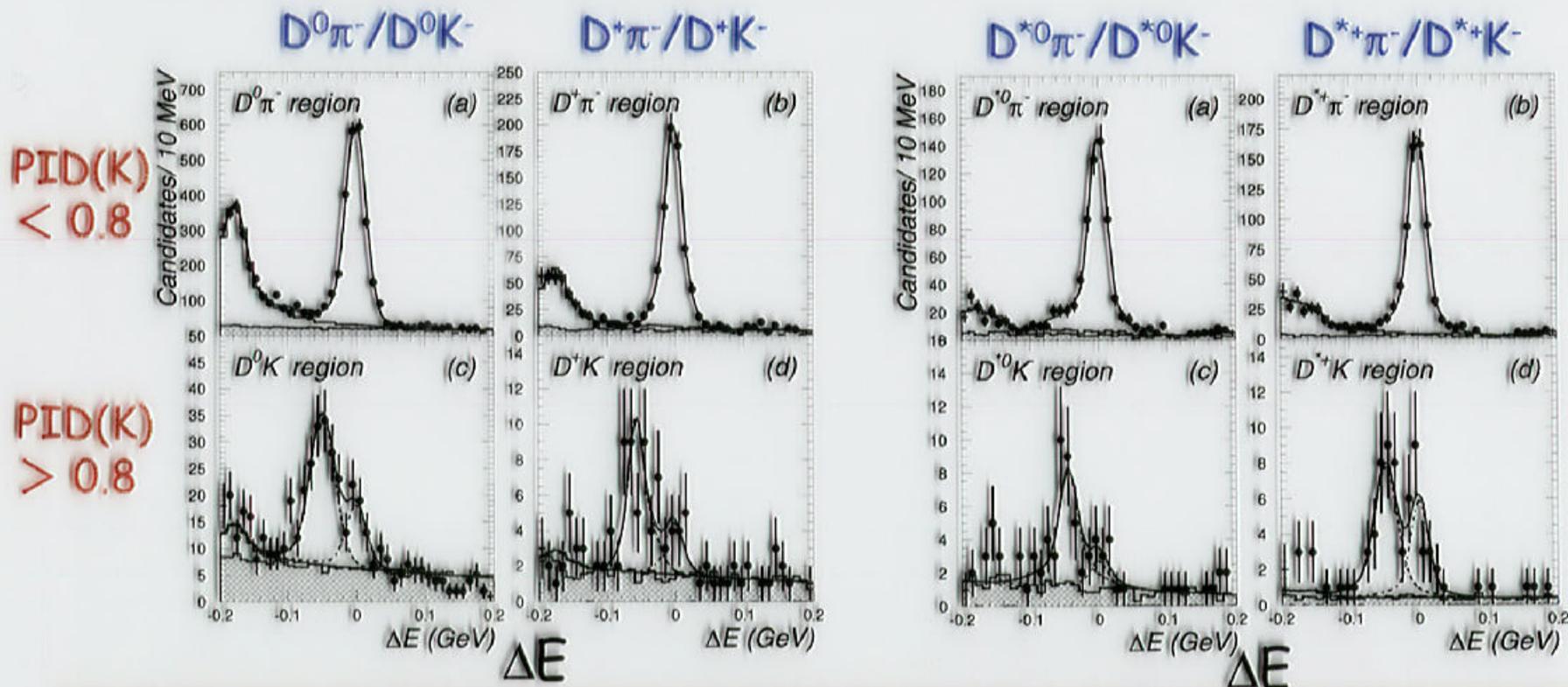




$B \rightarrow D^{(*)}K^-$ Signals

ΔE distribution after PID selection

- $D^{(*)} \pi$ events; $\Delta E \sim 0$ MeV
- $D^{(*)} K$ events; $\Delta E \sim -49$ MeV





$B \rightarrow D^{(*)}K^- / D^{(*)}\pi^-$ Ratio

Results with 11.1M $B\bar{B}$

	PID(K)<0.8	PID(K)>0.8		Σ Signif.	Br(DK)/Br(D π)
	N(D π)	N(DK)	N(D π)		
D 0 h $^-$	2402.8 \pm 97.8	135.7 \pm 15.6	49.0 \pm 11.3	11.3	0.0770 \pm 0.0094 \pm 0.0058
D $^+$ h $^-$	681.9 \pm 32.1	32.9 \pm 7.3	10.1 \pm 4.9	6.0	0.066 \pm 0.015 \pm 0.007
D *0 h $^-$	584.8 \pm 32.4	32.3 \pm 7.7	6.5 \pm 4.9	5.7	0.076 \pm 0.019 \pm 0.009
D $^{*+}$ h $^-$	640.9 \pm 30.8	35.4 \pm 7.1	20.6 \pm 5.7	7.5	0.072 \pm 0.015 \pm 0.006

- ▶ Many systematics cancel in the ratio
- ▶ Results agree with the expected ratio, $R_c \sim 0.074$

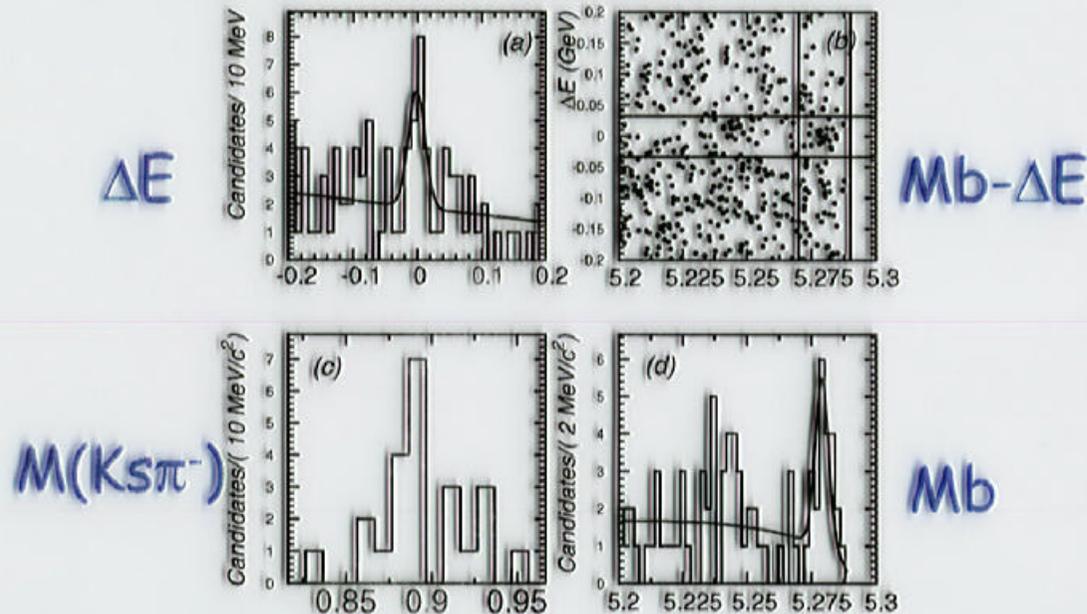
\Leftrightarrow CLEO w/ 3.3MBB, $\text{Br}(D^0K^-)/\text{Br}(D^0\pi^-) = 0.055 \pm 0.015 \pm 0.005$

First observation of the $B \rightarrow D^+K^-$, $D^{*0}K^-$ and $D^{*+}K^-$



■ First observation of $B^- \rightarrow D^0 K^{*-}$!

- K^{*-} reconstructed w/ $K\pi^-$ (clean mode)



$N_s = 15.0 \pm 4.6$
 Signif. = 4.7σ

■ $\text{Br}(B^- \rightarrow D^0 K^{*-}) / \text{Br}(B^- \rightarrow D^0 \pi^-) = 0.116 \pm 0.036 \pm 0.015$
 $\Leftrightarrow R_{c'} \sim \text{Br}(D^0 K^-) / \text{Br}(D^0 \pi^-) \times \text{Br}(D^0 \rho^-) / \text{Br}(D^0 \pi^-) \sim 0.19$



Charmless Two-body Decays

- Extraction of ϕ_2 angle
 - $B^0 \rightarrow \pi\pi$
 - $B^0 \rightarrow \rho\pi$
- Search for direct CP violation
 - Tree and Penguin interference
 $\propto \sin\phi_3 \cdot \sin(\delta_p - \delta_T)$
- Constraint on ϕ_3 angle using ratios of CP averaged $\text{Br}(K\pi)$ and $\text{Br}(\pi\pi)$.
 - Fleischer et al (hep-ph/0003323)
 - Neubert et al (hep-ph/0008072)
"QCD factorization"
and others... (M. Gronau's talk, yesterday)
- Probing New Physics
 - Any channel with an unexpected branching fraction

$$\frac{\text{Br}(\pi^+\pi^-)}{\text{Br}(K^+\pi^-)} \quad \frac{\text{Br}(K^+\pi^+)}{2\text{Br}(K^0\pi^0)}$$
$$\frac{2\text{Br}(K^+\pi^0)}{\text{Br}(K^0\pi^+)} \quad \frac{\tau_{B^+} \text{Br}(K^+\pi^+)}{\tau_{B^0} \text{Br}(K^0\pi^+)}$$



$B^0 \rightarrow K^+ \pi^-$ Signals

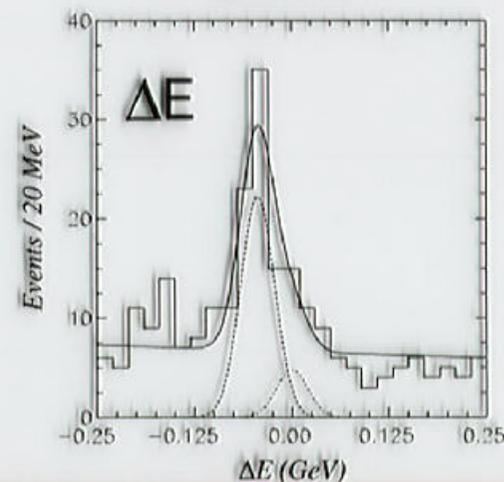
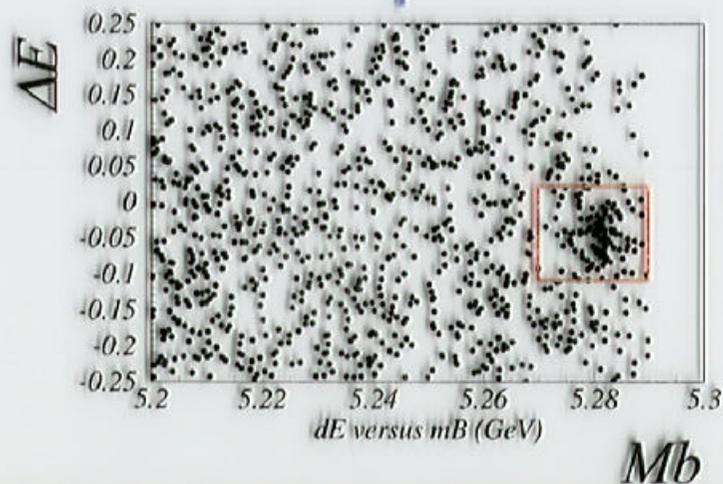
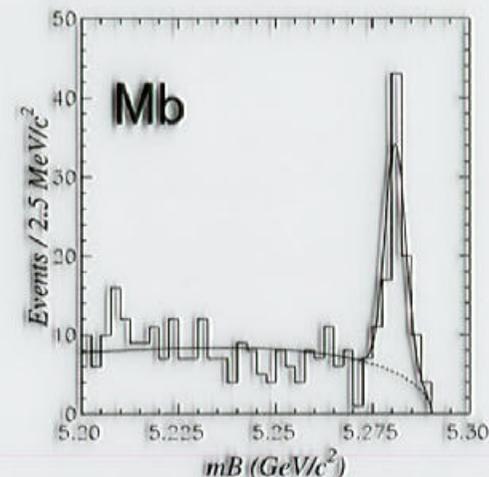
- $PID(K) > 0.6$ for one of the two tracks.

$N_s = 60.3^{+10.6}_{-9.9}$ $K^+ \pi^-$ signals

12 ± 7 $\pi^+ \pi^-$ background

$$Br(B^0 \rightarrow K^+ \pi^-) = (1.87^{+0.33}_{-0.31}) \times 10^{-5}$$

Signif. = 7.8σ





$B^0 \rightarrow \pi^+ \pi^-$ Signals

- PID(K) < 0.4 for both tracks.

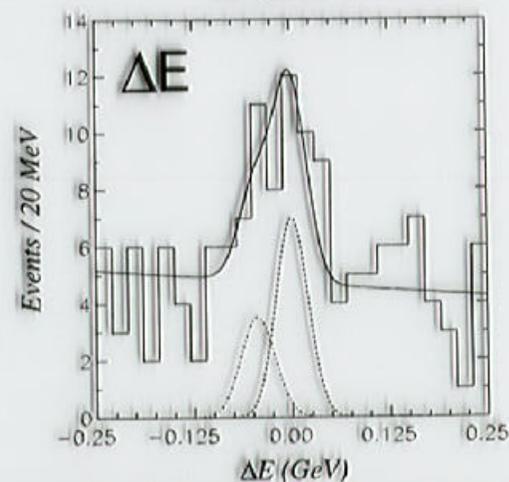
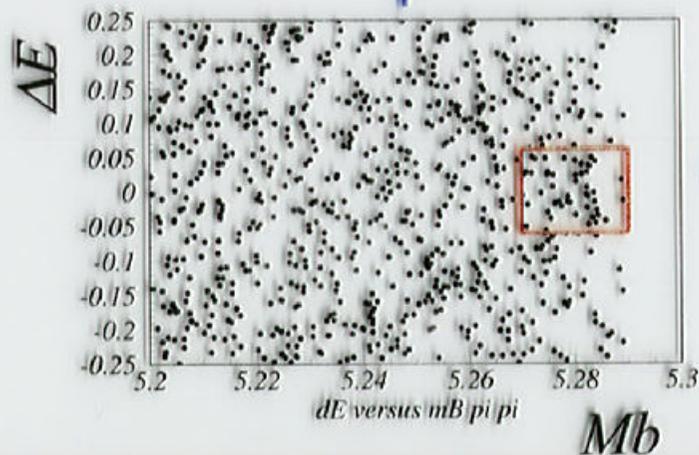
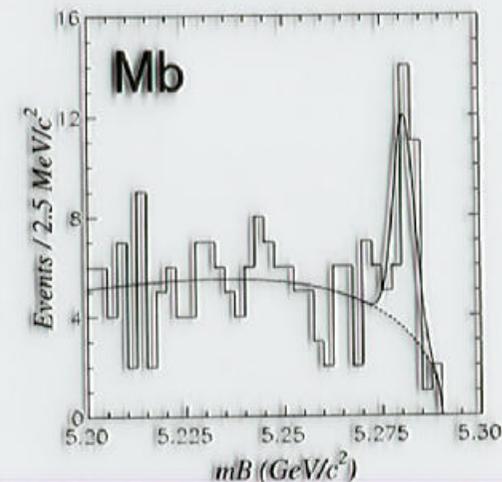
$$N_s = 17.7^{+7.1}_{-6.4} \pi^+ \pi^- \text{ signals}$$

9.6 ± 6 $K^+ \pi^-$ background

(expected $K\pi$ feeddown = 6.9 ± 2.9)

$$\text{Br}(B^0 \rightarrow \pi^+ \pi^-) = (0.59^{+0.24}_{-0.21}) \times 10^{-5}$$

Signif. = 3.1σ





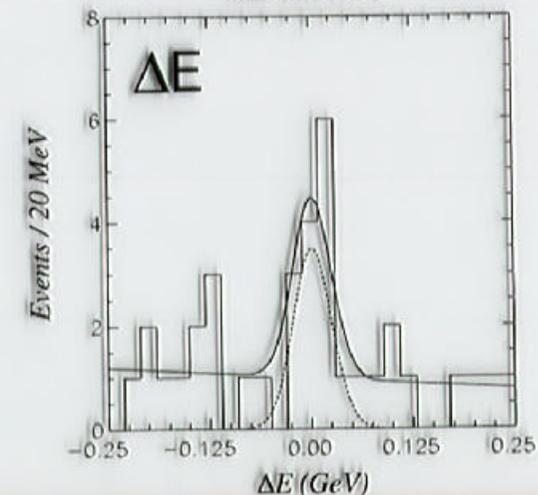
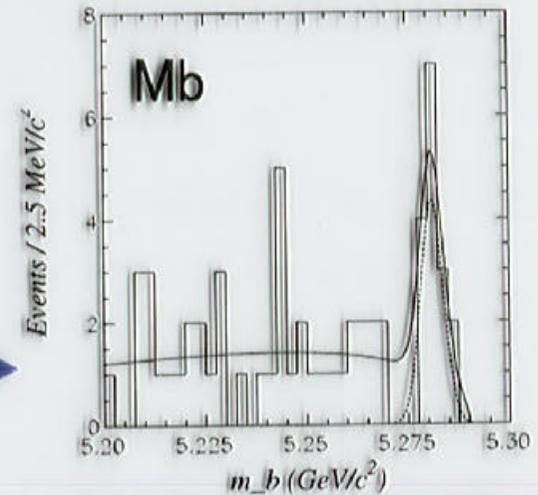
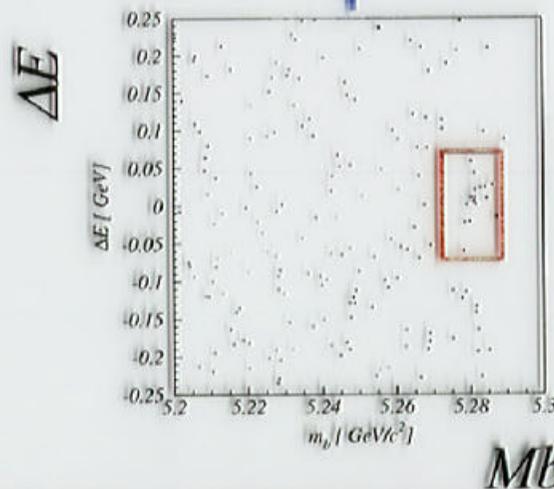
$B^+ \rightarrow K^0 \pi^+$ Signals

- K^0 reconstructed w/ $K_S \rightarrow \pi^+ \pi^-$
- $\text{PID}(K) < 0.4$ for prompt π

$$N_s = 10.3^{+4.3}_{-3.6}$$

$$\text{Br}(B^+ \rightarrow K^0 \pi^+) = (1.31^{+0.55}_{-0.45}) \times 10^{-5}$$

Signif. = 3.5σ





$B \rightarrow h\pi^0$ ($h=K^+, \pi^+, K^0$) Signals

$K^+\pi^0$

$N_s = 34.1^{+7.7}_{-7.0}$ events

$$\text{Br}(B^+ \rightarrow K^+\pi^0) = (1.68^{+0.36}_{-0.33}) \times 10^{-5}$$

Signif. = 7.5σ

$\pi^+\pi^0$

$N_s = 8.4^{+4.8}_{-4.0}$ events

$$\text{Br}(B^+ \rightarrow \pi^+\pi^0) = (0.64^{+0.37}_{-0.30}) \times 10^{-5}$$

$< 1.26 \times 10^{-5}$ @90% C.L.

Signif. = 2.9σ

$K^0\pi^0$

$N_s = 8.2^{+3.7}_{-3.1}$ events

$$\text{Br}(B^0 \rightarrow K^0\pi^0) = (1.37^{+0.62}_{-0.52}) \times 10^{-5}$$

Signif. = 4.2σ

$M_b - \Delta E$ 2D-fit
Projection

M_b

ΔE

