Other B Physics Results from Belle

(Modes not using B decay times)

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Representing the Belle collaboration

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Plan

There are many topics.
We will loosely categorize them as

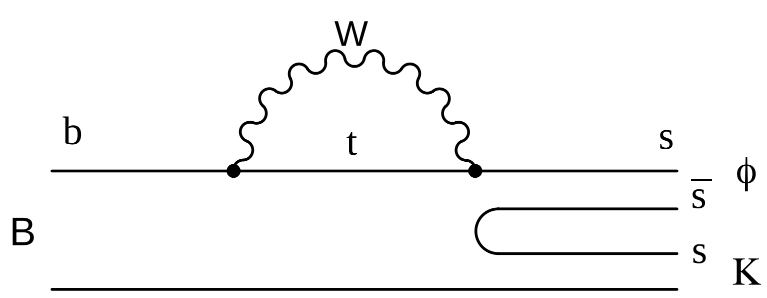
1. Modes useful for ϕ_1
2. Modes useful for ϕ_3 (and ϕ_2)
3. CKM matrix elements
4. Understanding basic B decay mechanisms and long-distance QCD

Modes useful for ϕ_1

Observable: $$\lambda \equiv \frac{q\,Amp(\bar{B}^0 \to f)}{p\,Amp(B^0 \to f)}$$

$$(B_{H,L} = pB^0 \pm q\bar{B}^0)$$

- $b \to s$ penguin process.
  - $\phi K_S\,(CP-)$: $\mathrm{Im}\lambda \sim \sin 2\phi_1$
    pure penguin (short or long-distance)
    may be modified by new physics in $b \to s$.



- $b \to c\bar{c}d(s)$ **tree process**
  ($b \to c\bar{c}d$**: some penguin with** V_{td}**)**

  - $D^+D^-(CP+)$ **(**$b \to c\bar{c}d$**):** $\mathrm{Im}\lambda \sim \sin 2\phi_1$
  - $D^{*+}D^{*-}$**:** **(**$b \to c\bar{c}d$**):** $\mathrm{Im}\lambda \sim \sin 2\phi_1$
    CP**-diluted by polarizations (as in** $J/\Psi K_S^*$**).**

  - $D^{*+}D^-$ **(**$b \to c\bar{c}d$**),** $D^{(*)+}D^{(*)-}K_S$ **(**$b \to c\bar{c}s$**):**
    $\mathrm{Im}\lambda \sim r \sin(2\phi_1 + \delta_{\mathrm{strong}})$
    CP**-diluted.**
    In general, $r \equiv |Amp(\bar{B}^0 \to f)/Amp(B^0 \to f)| \neq 1$**,**
    and the strong phase δ_S **does not cancel out.**

Technique: Full B Reconstruction

(When all B decay products are detected)

(In this talk, all E's and $\vec{P}$'s are in the $\Upsilon 4S$ frame.)

$$B \longrightarrow f_1 \cdots f_n$$

$E_B = 5.28$ GeV and $|\vec{P}_B| = 0.35$ GeV/c are known.

Use energy-momentum conservation:

- $E_{\rm tot} = \Sigma_i^n \, E_i \quad \longrightarrow \Delta E \equiv E_{\rm tot} - E_{\rm beam}$
  (Energy difference)

- $\vec{P}_{\rm tot} = \Sigma_i^n \, \vec{P}_i \quad \longrightarrow M_{bc} \equiv \sqrt{E_{\rm beam}^2 - P_{\rm tot}^2}$
  (beam-constrained mass)

Technique: Continuum Suppression

Most rare modes: background is dominated by continuum $e^+e^- \to q\bar{q}$ 2-jet events.

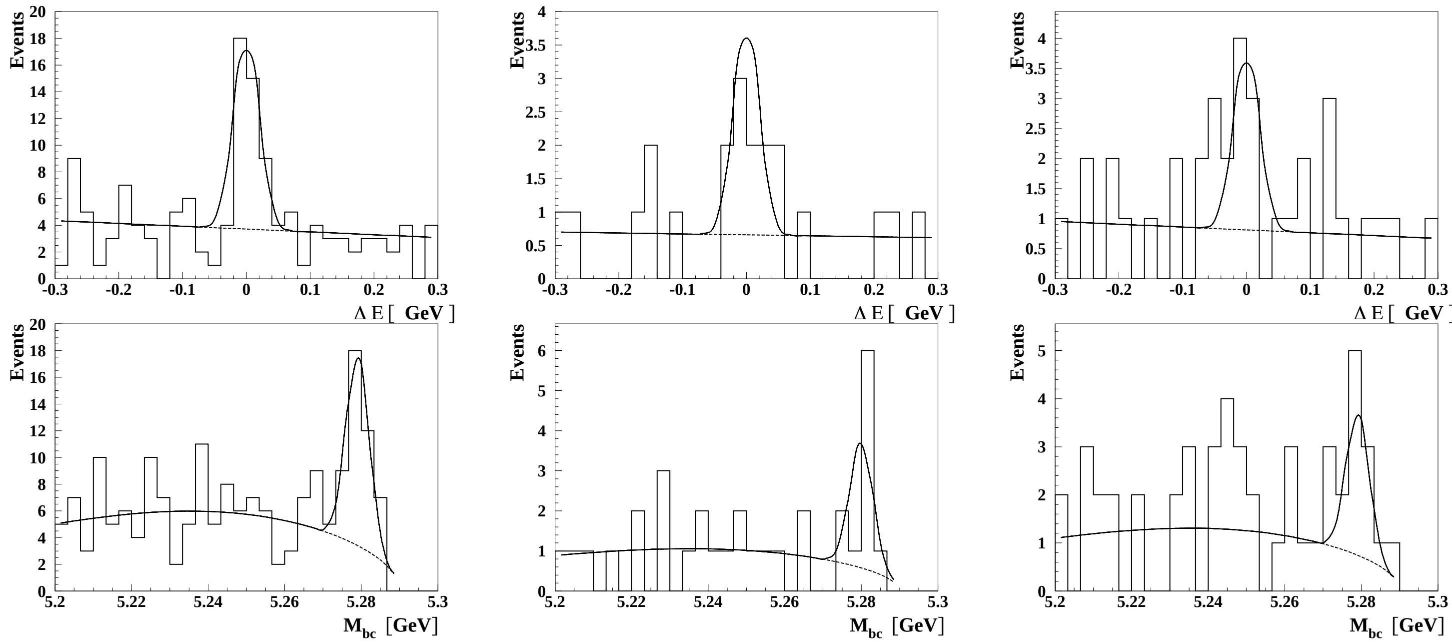
- Event shape variables: Fox-Wolfram R_l, thrust, etc.
  continuum: skinny, $B\bar{B}$: spherical.
- Angle(B candidate axis, axis of the rest)
  continuum: aligned, $B\bar{B}$: uniform.
- Angle(B, beam)
  continuum: $1 + \cos^2\theta$, B: $\sin^2\theta$.
- Fisher: $F = \Sigma_i c_i X_i$ (above+X_i energy flow etc.)
  Adjust c_i to maximize the separation.

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

ϕK^{+} ϕK_S ϕK^{*0}

ΔE

M_{bc}



$$Br(\times 10^{-5}): \quad 1.12^{+0.22}_{-0.20} \pm 0.14 \quad 0.89^{+0.34}_{-0.27} \pm 0.10 \quad 1.30^{+0.64}_{-0.52} \pm 0.21$$

$$Br(B \rightarrow \phi K^{*+}) < 1.9 \times 10^{-5} \quad (90\%\, C.L.)$$

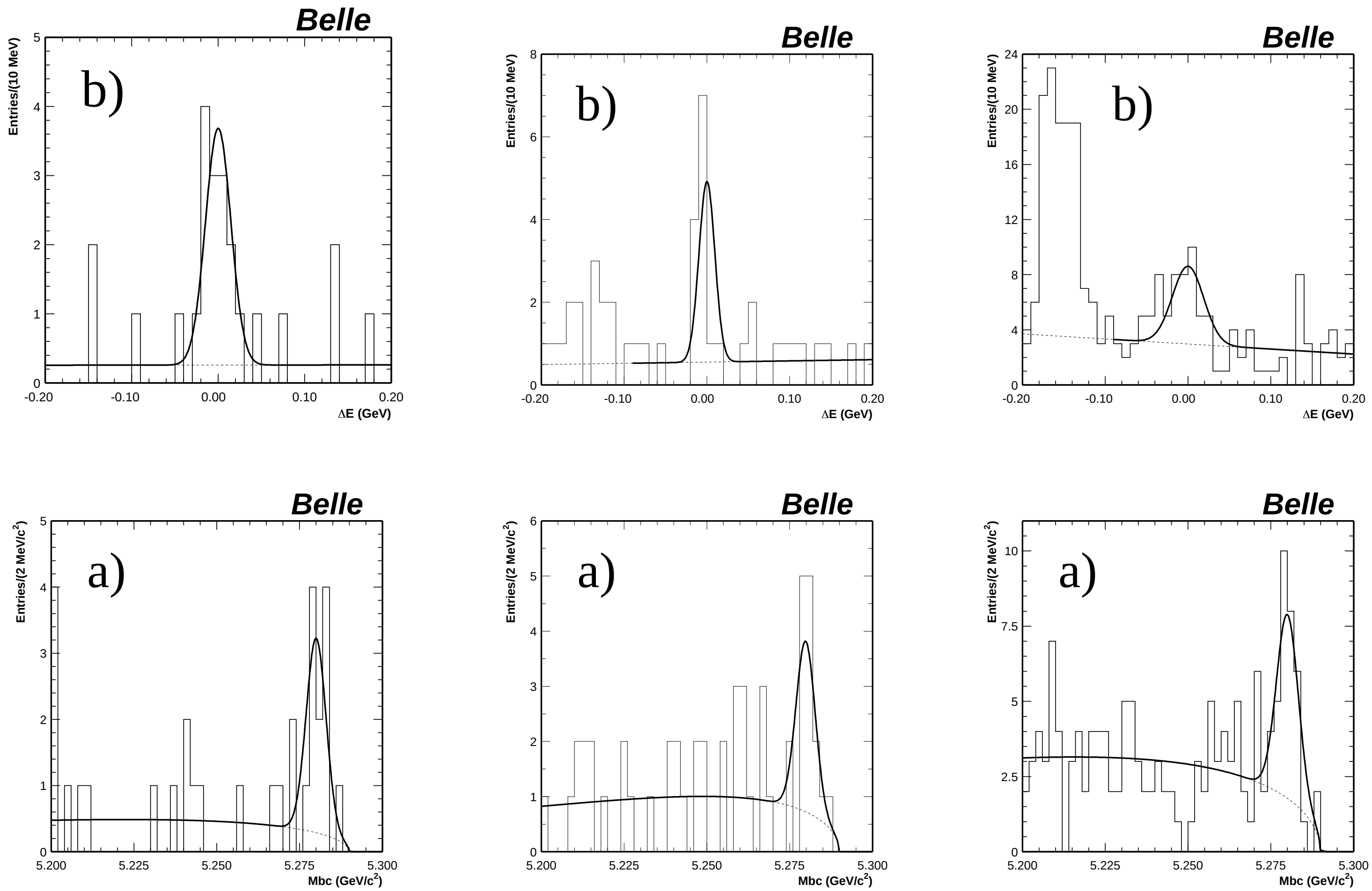
Preliminary

$B \to D^{(*)}\bar{D}^{(*)}(K)$ (exclusive) $(21.6\ fb^{-1})$

$D^{*+}D^{*-}$ | $D^{*+}D^{-} + D^{+}D^{*-}$ | $D^{0}D^{*-}K^{+}$

δE

M_{bc}



$Br(\times 10^{-3})$: $1.21 \pm 0.41 \pm 0.27$ | $1.04 \pm 0.38 \pm 0.22$ | $3.2 \pm 0.8 \pm 0.7$

Preliminary

Partial Reconstruction of $D^{*+}D^{-}$

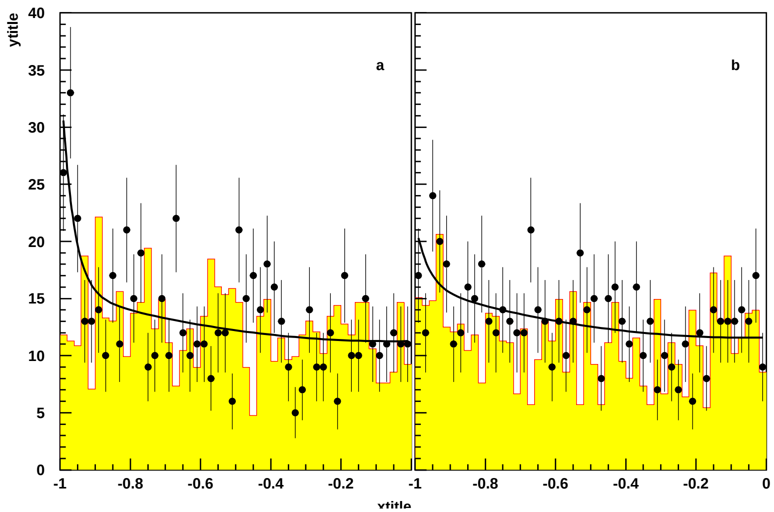
$B^0 \rightarrow D^{*+}D^{-}$, $D^{*+} \rightarrow D^0\pi^+_{slow}$
D^- and $\pi+_{slow}$ back-to-back

No reconstruction of D^0.

θ: helicity angle of D^{*+} decay.
(expect $\cos^2\theta$)
Require $\cos\theta$ is 'physical'
Plot $\cos\theta_{D^- - \pi^+_{slow}}$

Two samples:
w/ and w/o lepton tag.

Lepton-tag



$0.5 < |\cos\theta| < 1.05$ $|\cos\theta| < 0.5$

$$Br(B^0 \rightarrow D^{*+}D^-) + Br(B^0 \rightarrow D^{*-}D^+) = (1.84 \pm 0.43^{+0.68}_{-0.63}) \times 10^{-3}$$

Modes useful for ϕ_3

$$B^- \to D_{CP} K^-$$

$B^- \to D^0 K^- / B^- \to \bar{D}^0 K^-$

Interference

$\sim 10\%$ asymmetry expected.

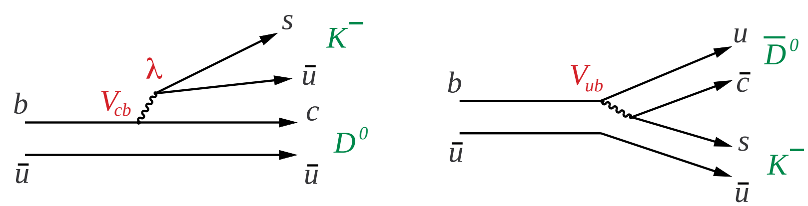
Eventually extract ϕ_3/γ

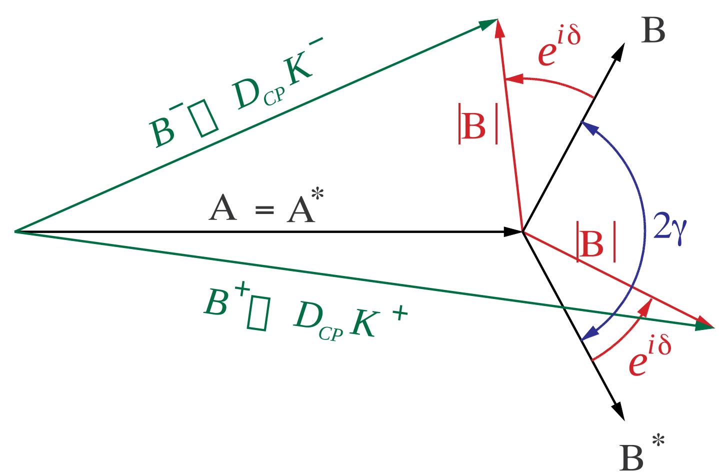
(No penguin polution)

Look for the asymmetry first.

$$A_{CP} \equiv \frac{\Gamma(D_{CP}K^-) - \Gamma(D_{CP}K^+)}{\Gamma(D_{CP}K^-) + \Gamma(D_{CP}K^+)}$$

A ***B***

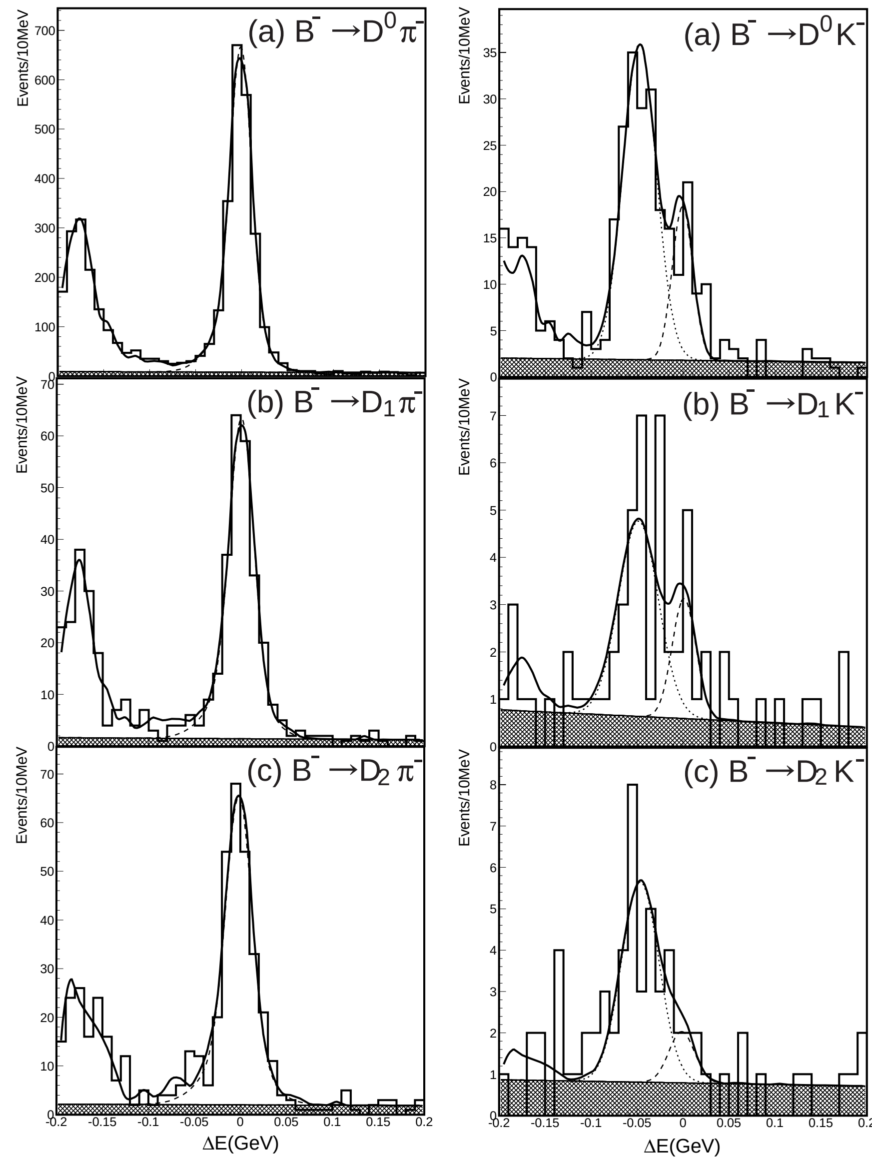




$B^- \to D_{CP} K^-$ (29.1 fb^{-1})

$D^0 h^-$: assign π mass to h^-.
Signal at $\Delta E = -49$ MeV.

CP $+$:
$K^+K^-, \pi^+\pi^-$
CP $-$:
$K_S\pi^0, K_S\omega, K_S\eta, K_S\eta'$



$B^- \to D_{CP} K^-$

Preliminary

	$CP+$	$CP-$
A_{CP}	$A_1 = 0.29^{+0.29}_{-0.24} \pm 0.05$ $-0.14 < A_1 < 0.79$	$A_2 = -0.22^{+0.26}_{-0.22} \pm 0.04$ $-0.60 < A_2 < 0.21$
R_{CP}	$R_1 = 1.38 \pm 0.38 \pm 0.15$	$R_2 = 1.37 \pm 0.36 \pm 0.12$

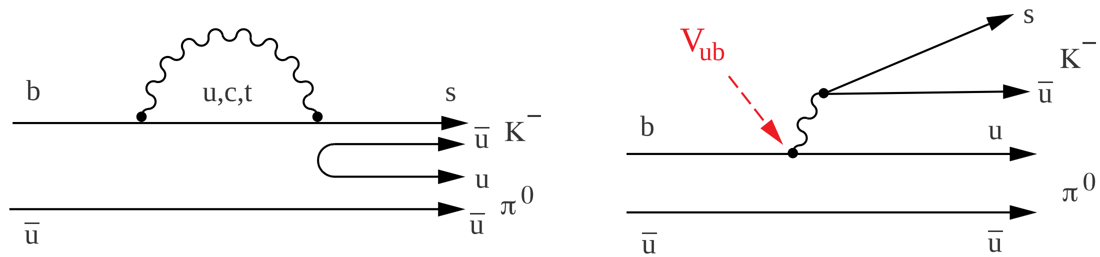
$$R_i \equiv \frac{Br(B^\pm \to D_i K^\pm)/Br(B^\pm \to D_i \pi^\pm)}{Br(B^\pm \to D^0 K^\pm)/Br(B^\pm \to D^0 \pi^\pm)}$$

(Cabibbo suppression factor ratio, D_{CP} vs D^0)

$A_1 = -A_2$ expected. Still consistent with no asymmetry.

$B \to \pi\pi/K\pi/KK$

Direct CPV by tree-penguin interference.

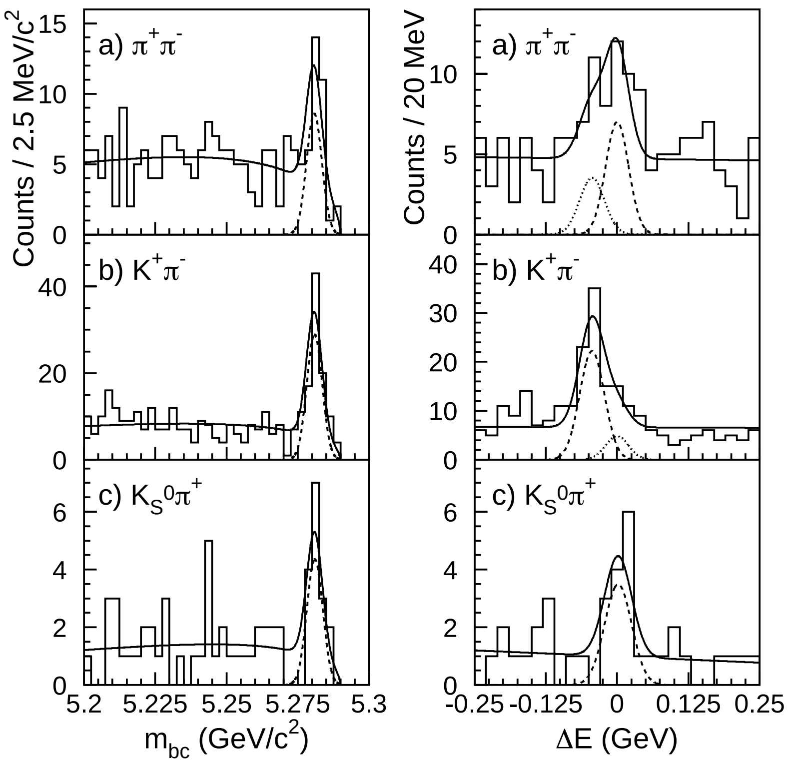


Statistically more favorable than DK modes, but theoretically challenging.

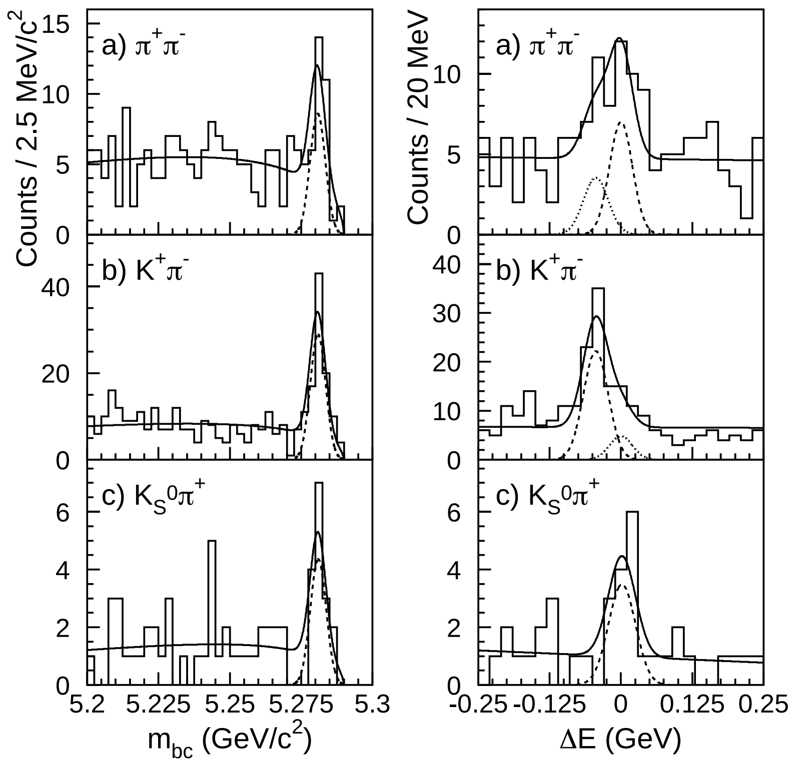
Future: use theoretical expressions (QCD factorization etc.) for multiple modes and perform fit for ϕ_3.

$B \to \pi\pi/K\pi$ (10.4 fb^{-1})

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



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



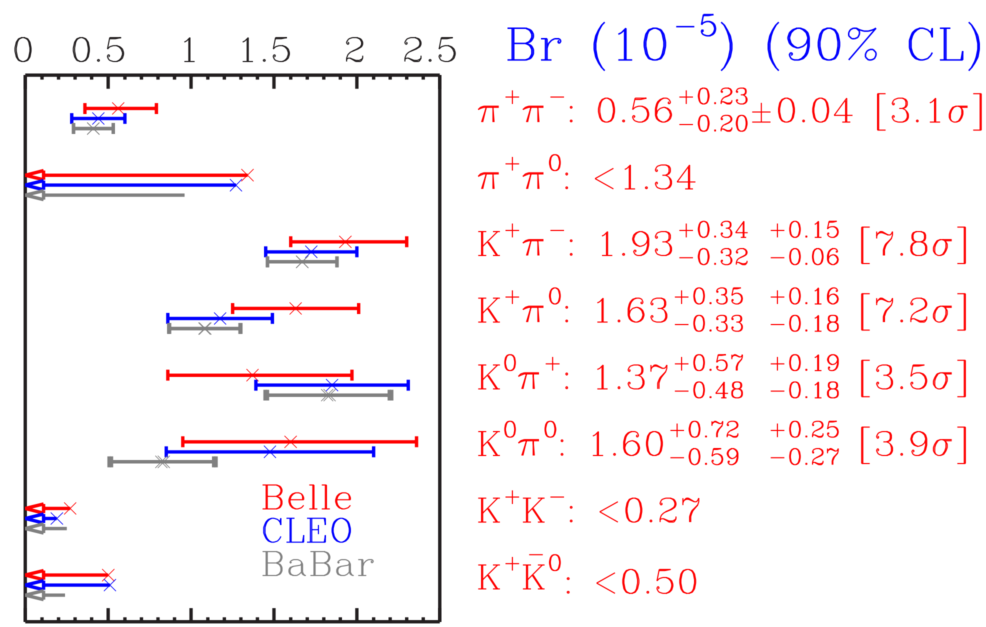
$\pi^\pm/K^\pm$: assigned the π mass; $\Delta E = -44$ MeV for $K^\pm$

$B \to \pi\pi / K\pi / KK$

$K^+\pi^- \gg \pi^+\pi^-$
$\to K^+\pi^-$ **mostly penguin.**
$K^+\pi^- \ll \pi^+\pi^-$
$\to \pi^+\pi^-$ **mostly tree.**

$\pi^+\pi^0$: **tree.**
$K^0\pi^+$: **penguin.**

- $K^+\pi^-$ **mostly penguin?**
- **Large penguin in** $\pi^+\pi^-$**?**
- **No signal in** KK**.**



Direct CP Violation in $K\pi$ (10.4 fb^{-1})

$$A_{CP} \equiv \frac{\Gamma(\bar{B} \to f) - \Gamma(\bar{B} \to f)}{\Gamma(\bar{B} \to f) - \Gamma(\bar{B} \to f)}$$

$K^{\pm}\pi^{\mp}$: assume $B^0 \not\to K^-\pi^+$, $\bar{B}^0 \not\to K^+\pi^-$
$K^{\pm}\pi^0$, $K_S\pi^{\pm}$: self-tagged by charge.

A_{CP}	$Belle$	$(90\%C.L)$	$Ref1$	$Ref2$
$K^{\pm}\pi^{\mp}$	$0.044^{+0.186+0.018}_{-0.167-0.021}$	$-0.25 : 0.37$	0.05 ± 0.10	0.19
$K^{\pm}\pi^0$	$-0.059^{+0.222+0.055}_{-0.196-0.017}$	$-0.40 : 0.36$	0.06 ± 0.10	0.18
$K_S\pi^0$	$0.098^{+0.430+0.020}_{-0.343-0.063}$	$-0.53 : 0.82$	0.01 ± 0.01	0.01

Ref1: Beneke, Buchalla, Neubert, and Sachrajda, 2001
Ref2: Kuem, Li, and Sanda, 2001

- $K_S\pi^+$ is penguin-dominated $\to$ small A_{CP}
- 20% error at 10 fb^{-1} $\to$ 6% error next year.

CKM Matrix Elements

Technique: Neutrino reconstruction

$B \to X\ell\nu$ as an example

$$\vec{P}_\nu = -\sum_i \vec{P}_i\,, \qquad P_\nu = (|\vec{P}_\nu|, \vec{P}_\nu)$$

(i: all detected particles of the event)

Cuts to improve the resolution:
• no other leptons in the event. • $|Q_{\rm tot}| \leq 1$

Consistency cuts (typical):

$$M^2_{miss} = E^2_{miss} - \vec{P}^2_\nu < 2\,\mathrm{GeV}^2 \qquad (E_{miss} = 2E_{beam} - \sum_i E_i)$$

$$|\cos\theta_{B,(X\ell)}| \leq 1\,, \qquad \left(\cos\theta_{B,(X\ell)} = \frac{2E_B E_{X\ell} - M^2_B - M^2_{X\ell}}{2|\vec{P}_B||\vec{P}_{X\ell}|}\right)$$

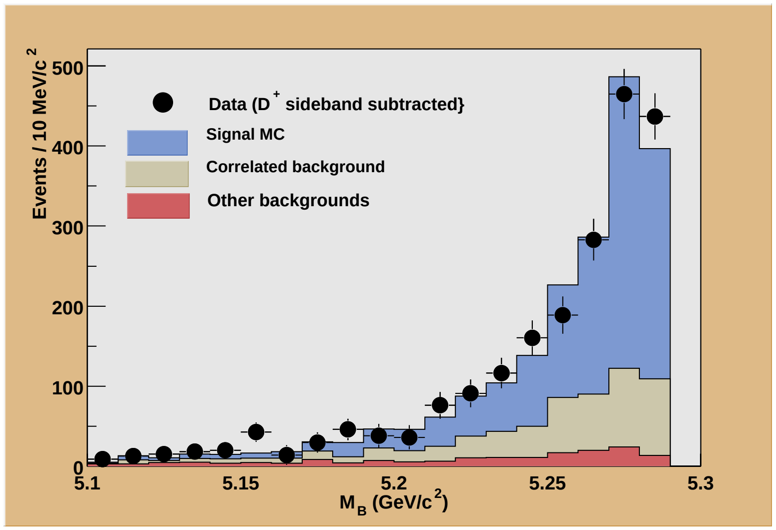
Take P_ν as just another 4-momentum for ΔE and M_{bc}

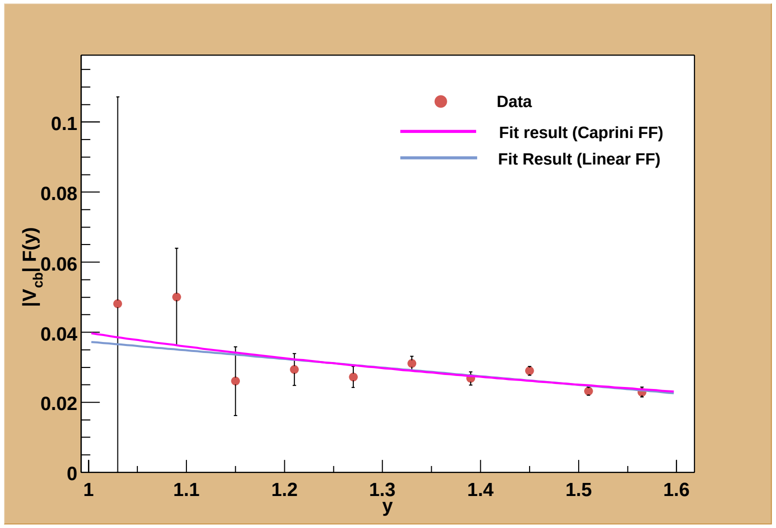
$\bar{B}^0 \to D^+\ell^-\nu$ (10.8 fb^{-1}) ($\ell = e$ or μ)

$$\frac{d\Gamma}{dy} = \frac{G_F^2}{48\pi^3}(m_B + m_D)^3 m_D^3 (y^2 - 1)^{3/2} |V_{cb}|^2 F_D^2(y)$$

$y \equiv v_B \cdot v_D$ (γ factor of D in B frame)

Large correlated background ($D^*/D^{**}\ell\nu$)





$F_D(1) = 1$ in the heavy-quark limit $\to |V_{cb}|$

Need corrections for $F_D(1)$: use $F_D(1) = 0.913 \pm 0.042$

Preliminary ($\sim$10 fb^{-1})

	$D^+\ell\nu$	$D^{*+}\ell\nu$
$\lvert V_{cb}\rvert F(1)(\times 10^{-2})$	$3.73 \pm 0.35 \pm 0.43$	$3.62 \pm 0.15 \pm 0.18$
$F(1)$ used	0.913 ± 0.042	0.98 ± 0.07
$\lvert V_{cb}\rvert(\times 10^{-2})$	$4.06 \pm 0.46 \pm 0.46 (\pm 0.28)$	$3.97 \pm 0.16 \pm 0.20 (\pm 0.19)$
$Br(\%)$	$2.09 \pm 0.11 \pm 0.31$	$4.77 \pm 0.38 \pm 0.40$

$Br(\Upsilon 4S \to B^0 \bar{B}^0) = 0.5,\ \tau_{B^0} = 1.548 \pm 0.032$ ps.

Dominant systematics:

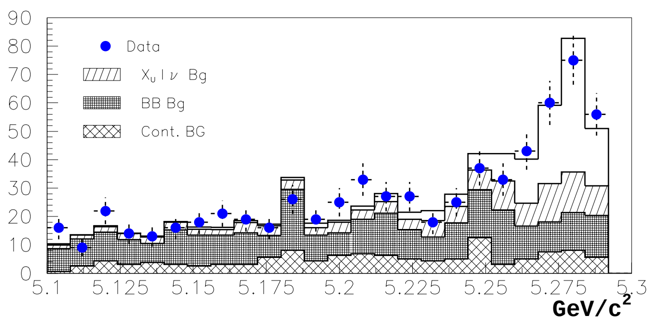
1. ν reconstruction simulation
2. Slow $\pi^\pm$ efficiency (for $D^{*+}\ell^-\nu$)
3. Tracking efficiency

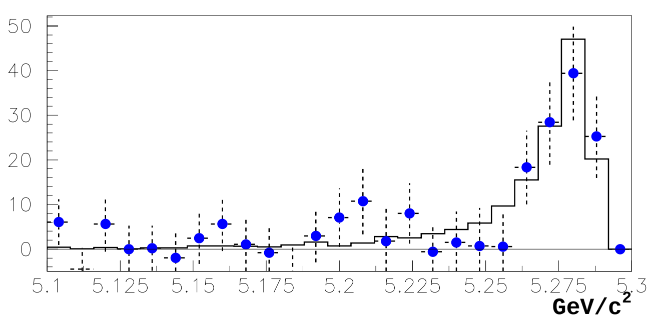
Will hit the systematics limit soon.

$B^0 \to \pi^- \ell^+ \nu$ (21.3 fb^{-1})

$Br(\pi^- \ell^+ \nu)$
$= (1.28 \pm 0.20 \pm 0.26) \times 10^{-4}$

Preliminary





$|V_{cb}|$ to be extracted.
Requires $F_\pi(1)$:
HQ limit cannot be used.
$\to$ large uncertainty.

Recoil mass analysis under way.

Inclusive $B \to X\ell^+\nu$ (5.1 fb^{-1})

Tag a $B\bar{B}$ event with a lepton
(e or μ, $P > 1.4$ GeV)

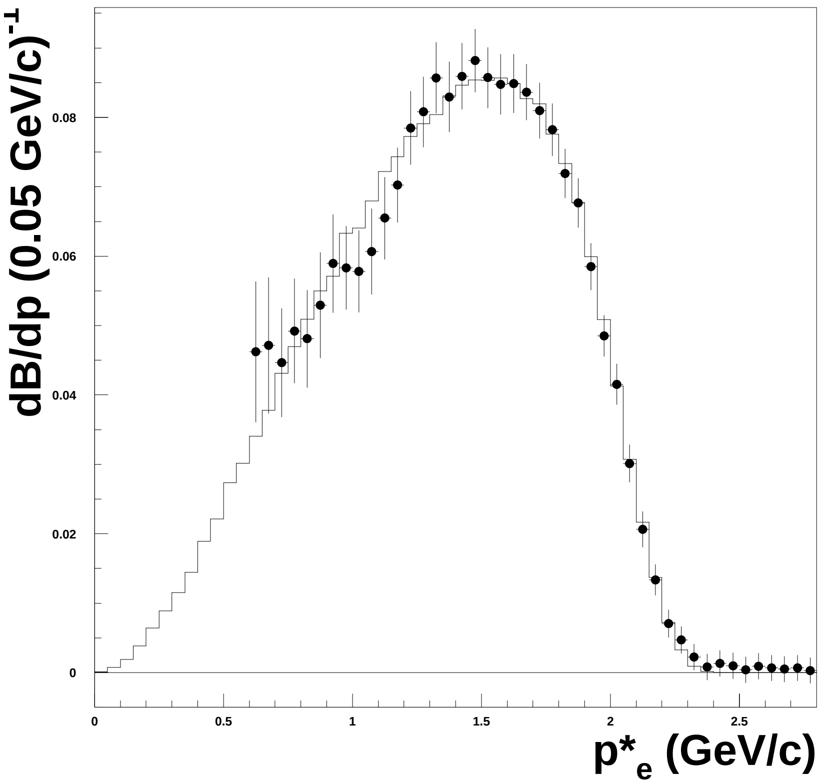
Look for a $e^\pm$ on 'the other side'.

Use the charge correlation to
separate $b \to \ell^-$ and $b \to c \to \ell^+$.

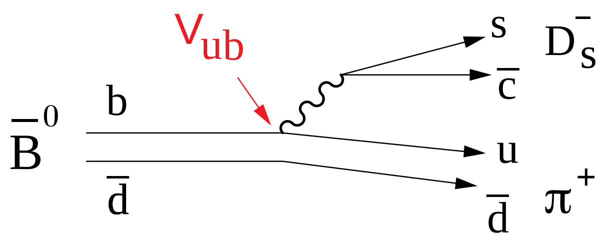
Unfold B^0-$\bar{B}^0$ mixing.

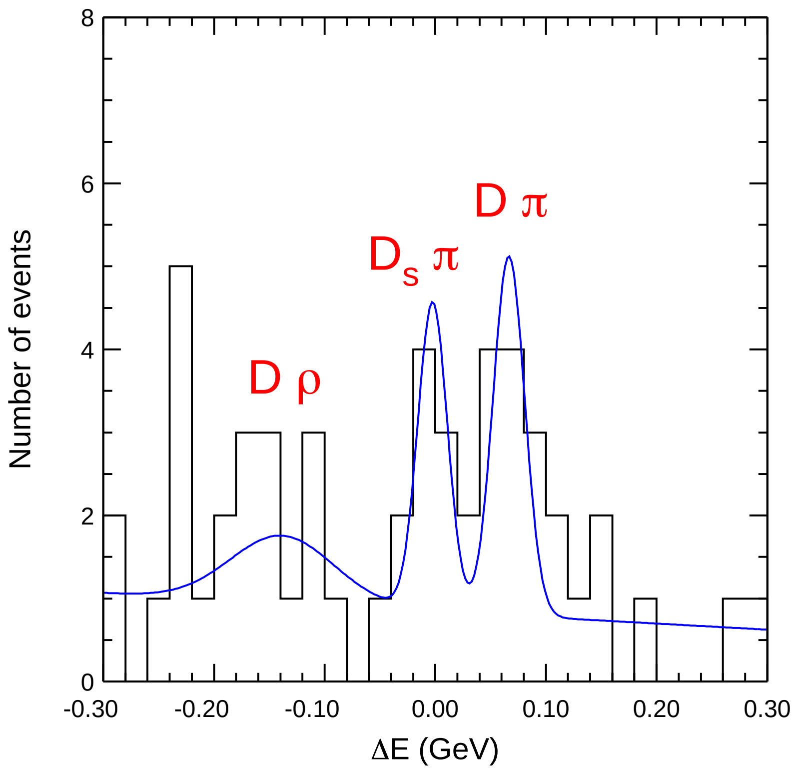
$Br = 10.86 \pm 0.14 \pm 0.47\%$
$|V_{cb}| = 0.040 \pm 0.001 \pm 0.004$
(ISGW model) Preliminary

Systematics limited.
(e detection efficiency)



$$B^0 \to D_S^+ \pi^- \ (21.3\ \mathrm{fb}^{-1})$$
$$(D_S^+ \to \phi\pi^+, K^{*0}K^+, K_S K^+)$$





Extract $|V_{ub}|$

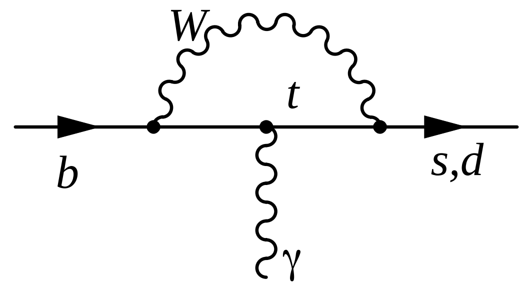
(Need $B \to \pi$ form factor)

$$Br(D_S^+\pi^-) < 1.1 \times 10^{-4}$$
$$Br(D_S^+K^-) < 0.7 \times 10^{-4}$$

(Preliminary)

Radiative Charmless Decays

$$\frac{\Gamma(b \to d\gamma)}{\Gamma(b \to s\gamma)} \propto \left|\frac{V_{td}}{V_{ts}}\right|^2$$



$$|V_{ts}| \sim |V_{cd}| \text{ (unitarity)} \longrightarrow |V_{td}|$$

- Large pQCD correction ($\sim \times 3$) $\longrightarrow$ A good test of pQCD.
- Complete next-to-leading calculation done.
- New physics may enter the loop. (e.g. Higgs replacing W)
- Inclusive $b \to d\gamma$ has a large background from $b \to s\gamma$.
  Try exclusive ($B \to \rho\gamma$ etc.).

Technique: Semi-inclusive Reconstruction

(Continuum suppression for rare inclusive measurements)

$B \to X_s\gamma$ as an example.

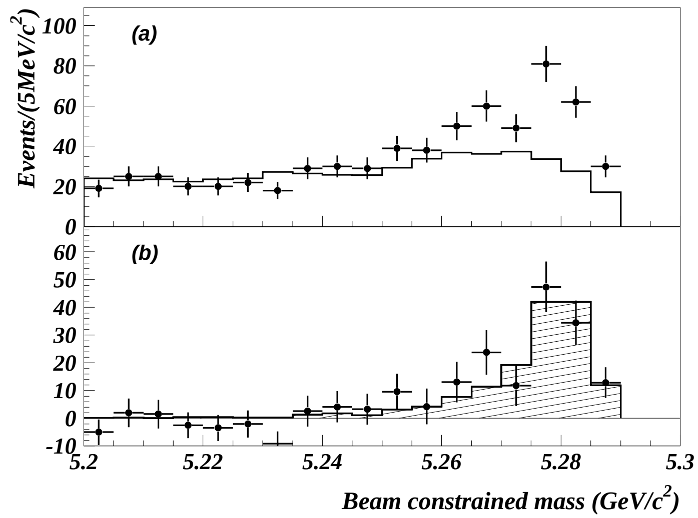
- Select a candidate γ.
- $X_s = K^{\pm}/K_S + n\pi$ $(1 \leq n \leq 4$, upto one $\pi^0)$
  Take all combinations.
- Require that ΔE and M_{bc} of the $X_s\gamma$ system are in the signal region.
- Rquire that X_s and γ are back-to-back.
- Pick one candidate per event by vertex consistency, or if no charged tracks, by the back-to-backness of X_s-γ.

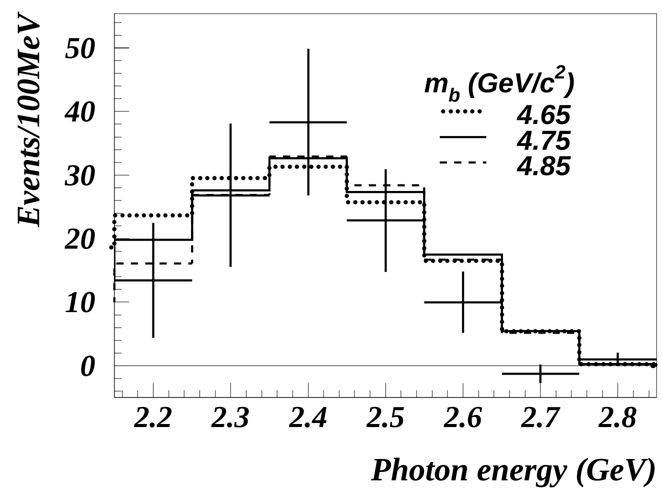
$B \to X_s\gamma$ Semi-inclusive (5.8 fb^{-1})

$Br(B \to X_s\gamma) =$
$(3.36 \pm 0.53 \pm 0.42^{+0.50}_{-0.54}) \times 10^{-4}$

SM theory: $(3.28 \pm 0.33) \times 10^{-4}$

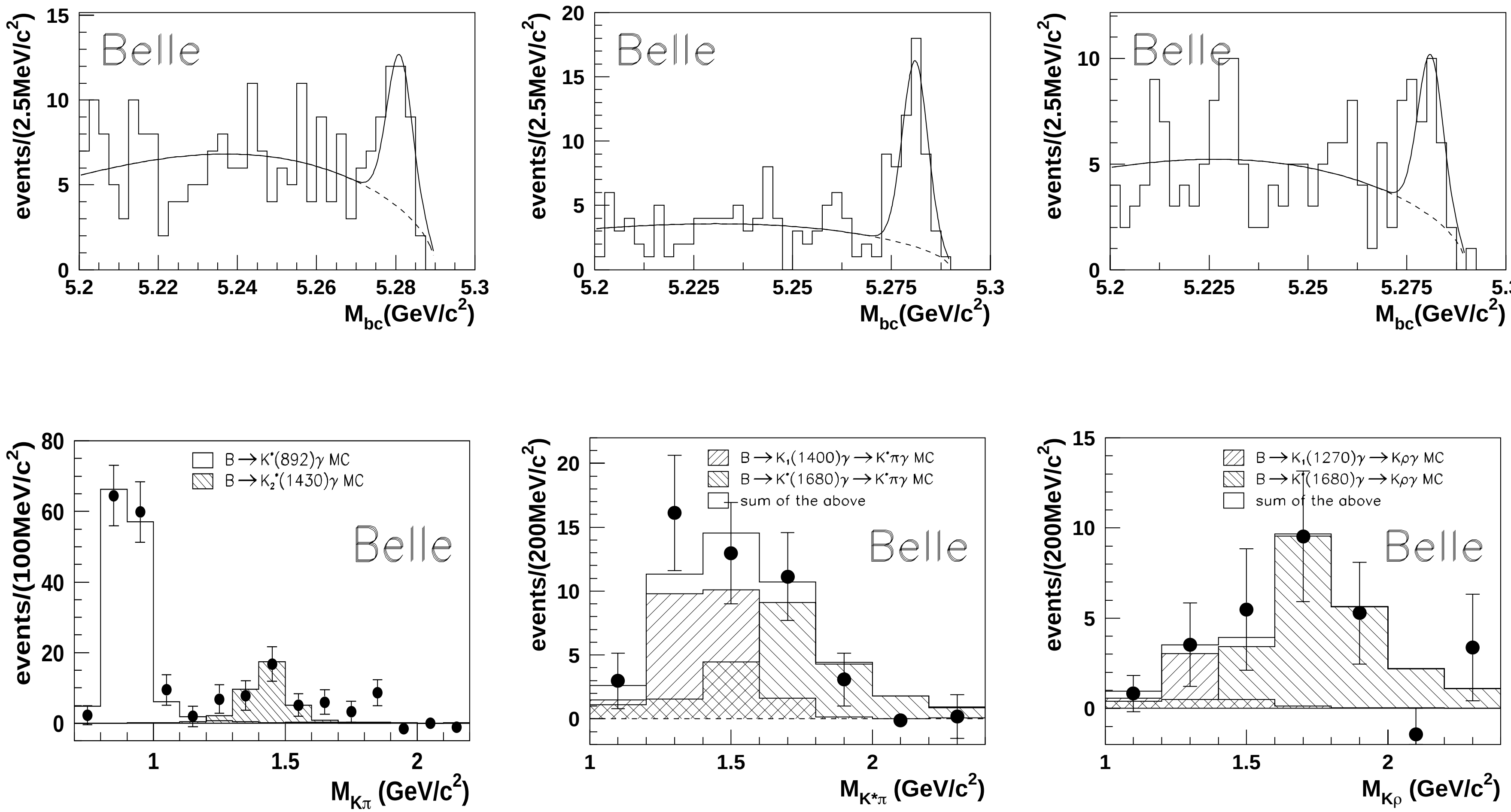
- Triumph of SM and pQCD!
- Photon spectrum agree also.
  (Kagan and Neubert, 1999.)





Exclusive $B \to X_s\gamma$ (21.3 fb^{-1})

$K_2^*(1430)\gamma$ $K^{*0}\pi^+\gamma$ $K^+\rho^0\gamma$



Exclusive $B \to X_s\gamma$

Preliminary

	$Br(\times 10^{-5})$
$K^{*0}\gamma$	$4.96 \pm 0.67 \pm 0.45$
$K^{*+}\gamma$	$3.89 \pm 0.93 \pm 0.41$
$K_2^{*0}(1430)\gamma$	$1.26 \pm 0.66 \pm 0.10$
$K^{*0}\pi^+\gamma$	$5.6 \pm 1.1 \pm 0.9$
$K^+\rho^0\gamma$	$6.5 \pm 1.7 \pm 1.1$

A large fraction of $X_s\gamma$ inclusive is accounted for.

$B \to \rho\gamma$ is not seen yet (10.4 fb^{-1}):

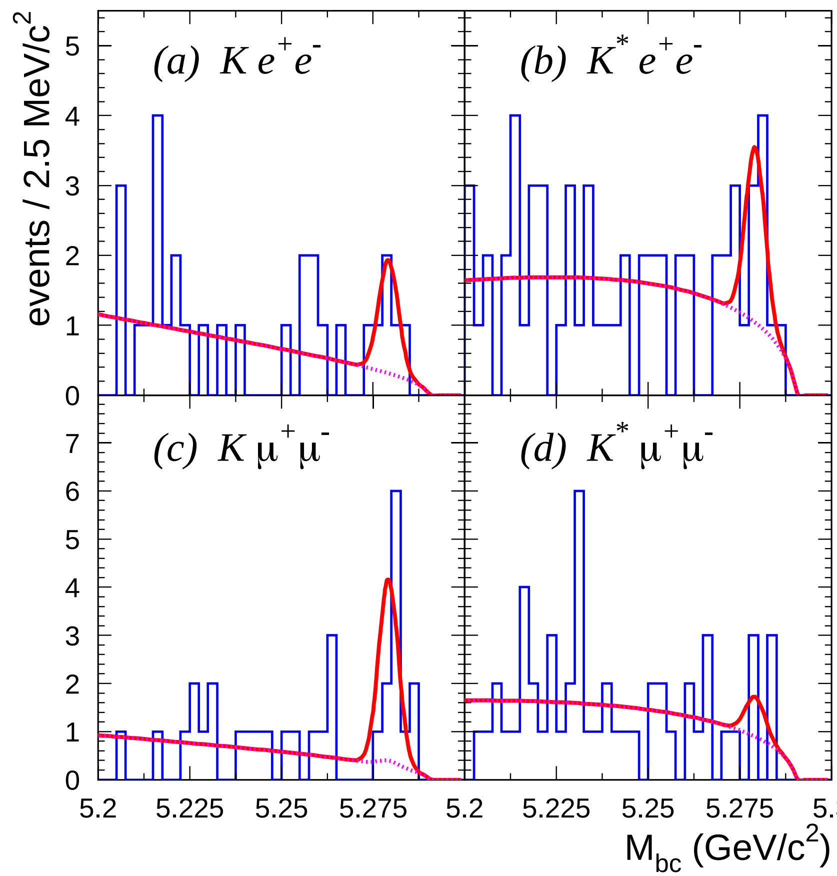
$$\frac{Br(\rho\gamma)}{Br(K^*\gamma)} < 0.19 \text{ (90\% C.L.)}$$

$X_s \ell^+ \ell^-$

Preliminary

	$Br(\times 10^{-6})$
$K\mu^+\mu^-$	$1.01^{+0.39}_{-0.32} \pm 0.11$
Ke^+e^-	< 1.2
$K^*\mu^+\mu^-$	3.0
$K^*e^+e^-$	5.1
$X_s\mu^=\mu^-$	19.1
$X_s e^+e^-$	10.1

$K\mu^+\mu^-$ is seen (4.7σ)

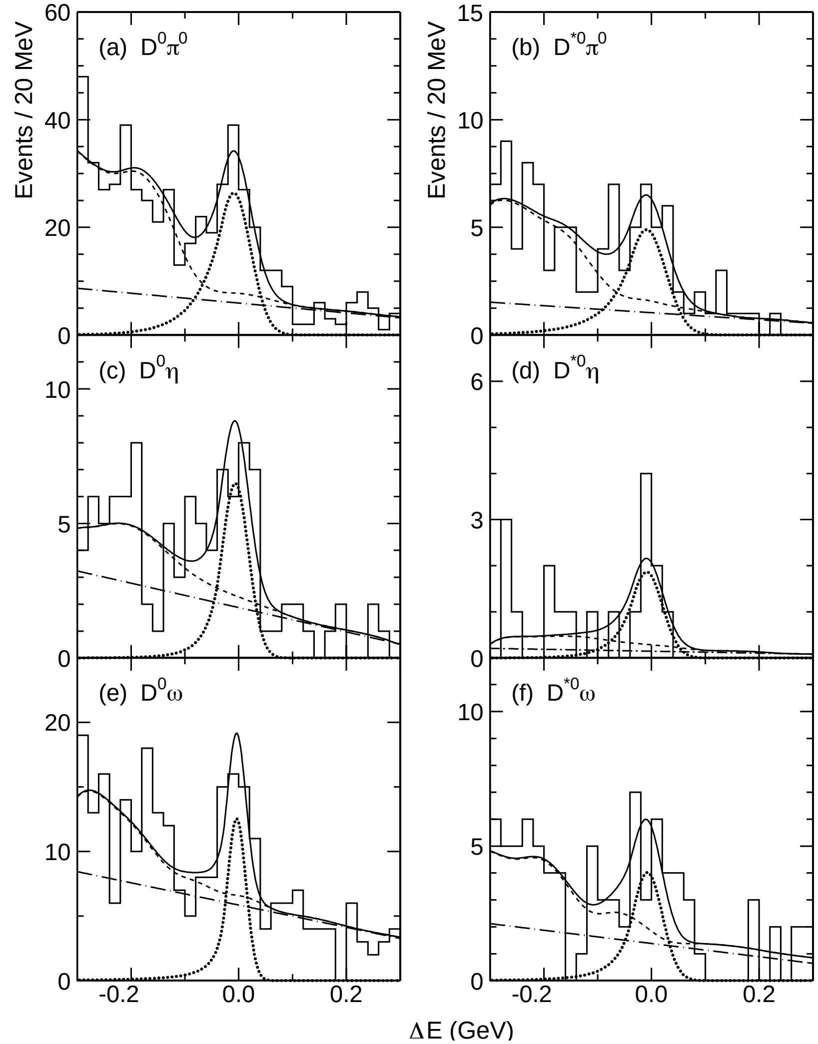


Understanding Basic Decay Mechanisms

- Color-suppressed $b \longrightarrow c\bar{u}d$. (factorization)
- $B^+ \longrightarrow \chi_{c0}K^+$. (factorization)
- $B \longrightarrow \chi_{c2}X$. (factorization)
- $B^+ \longrightarrow p\bar{p}K^+$ (baryon in rare modes)
- Other rare modes
- Flavor-tagged $K^\pm$. (overall accounting)

Color-suppressed $b \to c\bar{u}d$ Modes

$Br(\times 10^{-4})$	Belle	Th.Model
$D^0\pi^0$	$3.1 \pm 0.4 \pm 0.5$	0.7
$D^{*0}\pi^0$	$2.7^{+0.8+0.5}_{-0.70.6}$	1.0
$D^0\eta$	$1.4^{+0.5}_{-0.4} \pm 0.3$	0.5
$D^{*0}\eta$	$2.0^{+0.9}_{-0.8} \pm 0.4$	1.0
$D^0\omega$	$1.8 \pm 0.5^{+0.4}_{-0.3}$	0.7
$D^{*0}\omega$	$3.1^{+1.3}_{-1.1} \pm 0.8$	1.7



Consistently larger than
the factorization model.

FSI rescattering from D^+X^-?

$B^+ \to \chi_{c0} K^+$

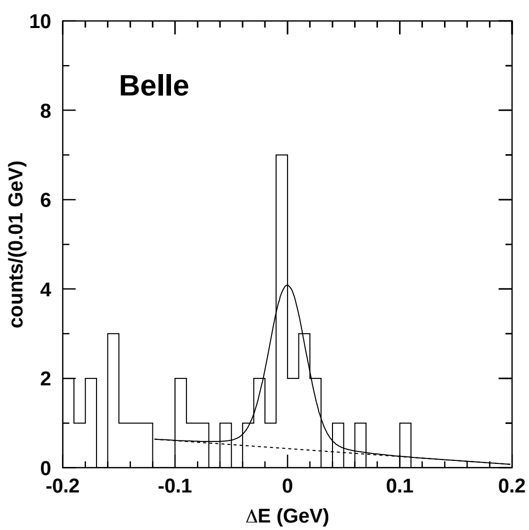
Prohibitted in naive factorization: $\langle \chi_{c0} | (\bar{c}c)^{\mu}_{V-A} | 0 \rangle = 0$

(P and C conservation. Conserved vector current also is relevant.)

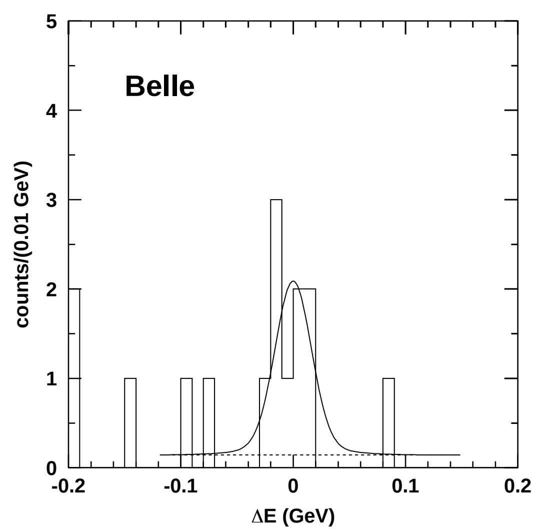
$$Br(B^+ \to \chi_{c0} K^+) = (8.0^{+2.7}_{-2.4} \pm 1.0 \pm 1.1[Br]) \times 10^4$$

$$Br(\chi_{c0} K^+)/Br(J/\Psi K^+) = 0.77^{+0.27}_{-0.23} \pm 0.11$$

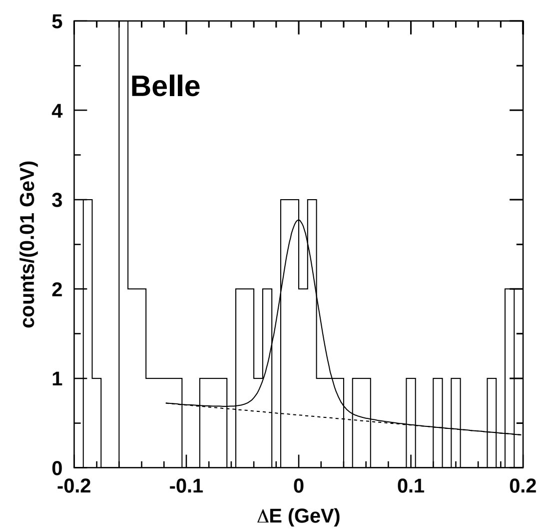
$\chi_{c0} \to \pi^+ \pi^-$



$\chi_{c0} \to K^+ K^-$



$\chi_{c0} \to K^{*0} K^+ \pi^-$



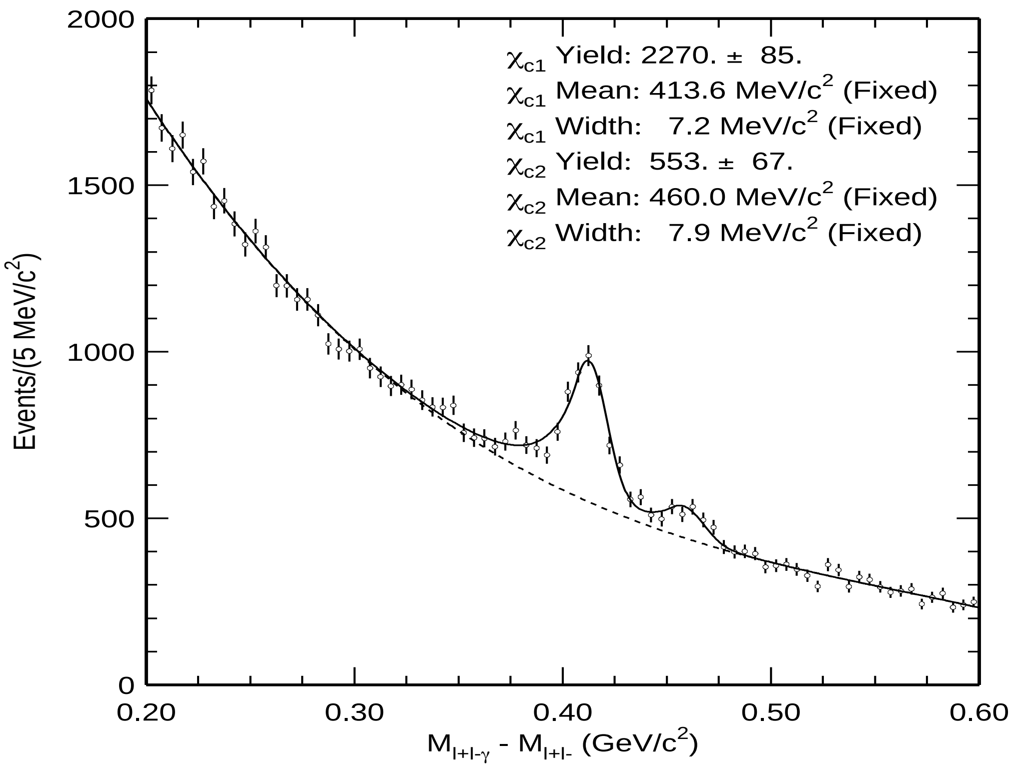
Inclusive χ_{c2} Productions

Prohibitted in naive factorization:

$$\langle \chi_{c2} | (\bar{c}c)^{\mu}_{V-A} | 0 \rangle = 0$$

$$\chi_{c1,2} \rightarrow J/\Psi\gamma, \; J/\Psi \rightarrow \ell^+\ell^-$$

$$Br(B \rightarrow \chi_{c2}X) = (1.22 \pm 0.24 \pm 0.25) \times 10^{-2}$$
$$Br(B \rightarrow \chi_{c1}X) = (3.14 \pm 0.16 \pm 0.29) \times 10^{-2}$$



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

Baryon production in charmless modes.

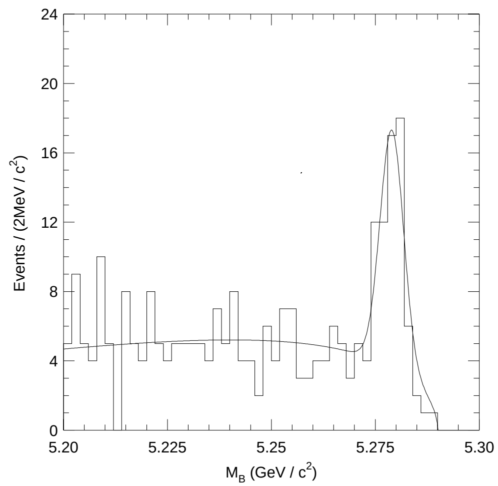
Reject charmonia$\to p\bar{p}$.

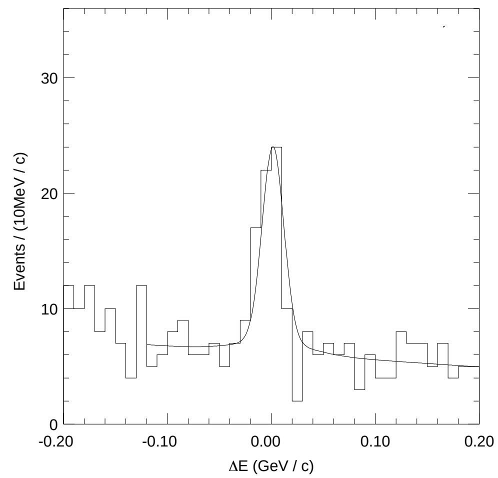
Preliminary

	$Br(\times 10^{-6})$
$p\bar{p}K^+$	$4.2 \pm 0.8 \pm 0.6$ $(M_{p\bar{p}} < 3.4\text{GeV})$
$p\bar{p}$	< 1.6
$\Lambda\bar{\Lambda}$	< 2.3
$\bar{\Lambda}p$	< 2.1

Why not 2-body modes?

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





mode	$Br(\times 10^{-5})$
$\eta' K^+$	$7.9^{+1.2}_{-1.1} \pm 0.9$
$\eta' K^0$	$5.5^{+1.9}_{-1.6} \pm 0.8$
$\eta' \pi^+$	< 7
ηK^{*0}	$2.12^{+0.54}_{-0.47} \pm 0.20$
ηK^{*+}	< 4.99
$\eta \rho^0$	< 0.55
$\eta \rho^+$	< 0.68
$K^{*+}\pi^-$	$2.60 \pm 0.83 \pm 0.35$
$\rho^- K^+$	$1.58^{+0.51+0.17}_{-0.46-0.30}$
$K^+\pi^-\pi^0$	$3.56^{+0.81}_{-0.77} \pm 0.52$

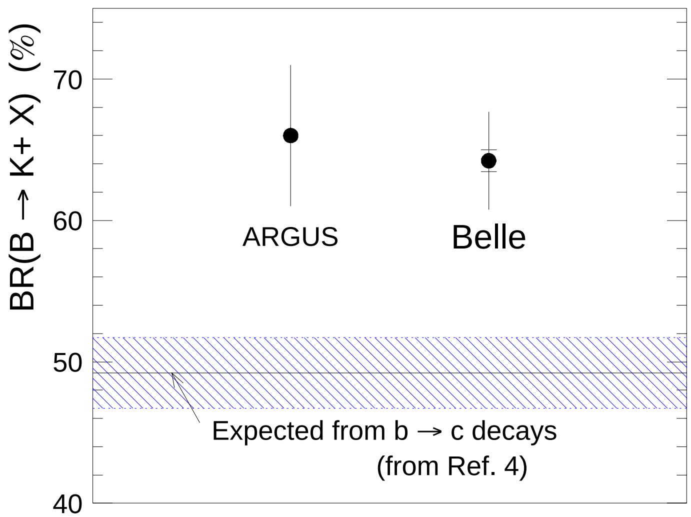
$-0.20 < A_{CP}(\eta' K^\pm) < 0.32$

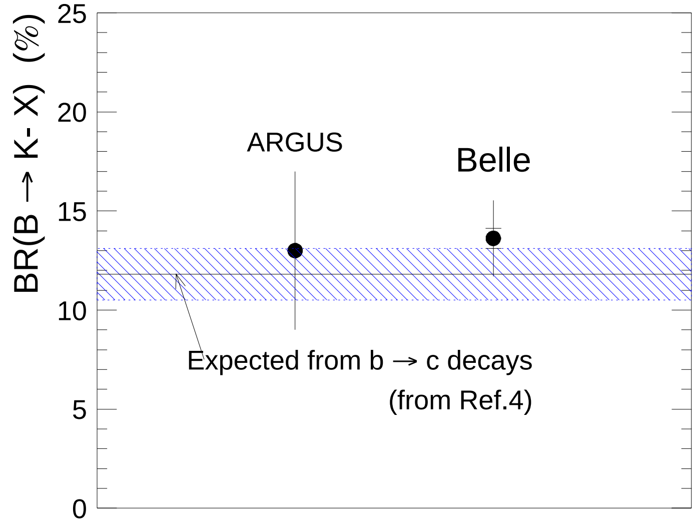
mode	$Br(\times 10^{-5})$
$K^+\pi^-\pi^+$	$5.85 \pm 0.71 \pm 0.88$
$K^+K^-K^+$	$3.70 \pm 0.39 \pm 0.44$
$K^{*0}\pi^+$	$1.67^{+0.37+0.21+0.30}_{-0.34-0.21 0.59}$
$f_0(980)K^+$	$1.17^{+0.25+0.15+0.41}_{-0.27-0.15 0.10}$
$K^-\pi^+\pi^+$	< 0.77
$K^+K^+\pi^-$	< 0.60
$K^+K^-\pi^+$	< 0.21

4th error: model dependence
(interferences)

Flavor-tagged inclusive $K^{\pm}$

Tag the other B by a high-P lepton.





Ref4: Kagan, 1998.

Summary

- Many new modes have been observed with up to $\int L dt \sim 30$ fb^{-1}.
- Some are useful for measuring ϕ_3 or performing further tests in measuring ϕ_1.
- Direct CP asymmetry measurements are closing in on theoretical estimations.
- Measurements of $|V_{ub}|$ steadily improving, including $b \to u D_s^+$.
- Many new analyses are becoming possible on a regular basis.