

# CP Violation in the B system:

## Measurement of $\sin 2\beta = \sin 2\phi_1$

- BaBar and Belle have presented data on tagged  $B_d$  and  $B_{\bar{d}}$  **SMITH** decays to final CP eigenstates,  $f_{CP}$ , to observe the time- **HAZUMI** dependent CP asymmetry
- Both employ the “golden” final state  $J/\psi K_S$  and  $\psi(2S) K_S$  and  $\psi K_L$ . (Belle uses a few other modes) Through the time-dependent asymmetry, these decays all provide a measure of  $\sin 2\beta$  in a theoretically clean way.
- The high-performance subsystems of the detectors all work so as to make the prime measurement for which they were designed.

S. SMITH

(BABAR)

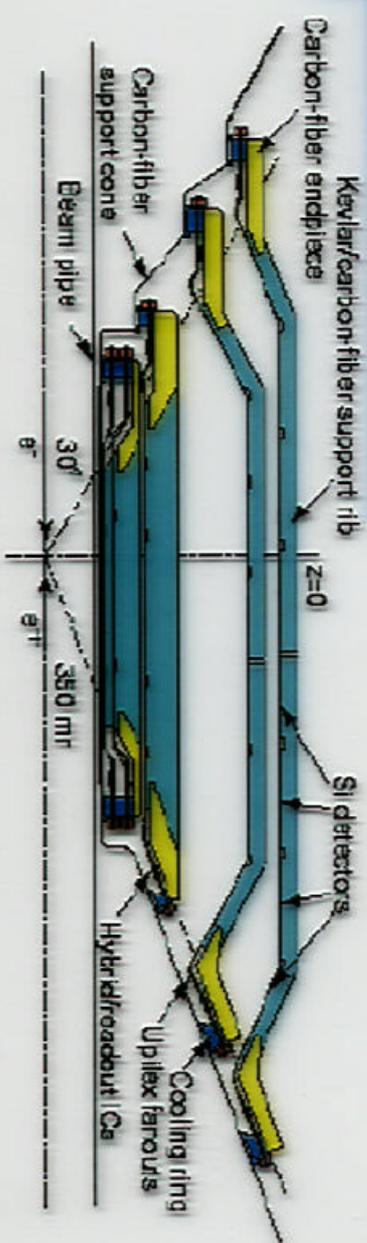
# Crucial Elements in A( $\Delta t$ ) measurement: I. Vertex Resolution

Even at PEP-II, B's don't go very far! ( $\approx 250 \mu\text{m}$ )

$\Rightarrow$  5 Layer Silicon Vertex Tracker

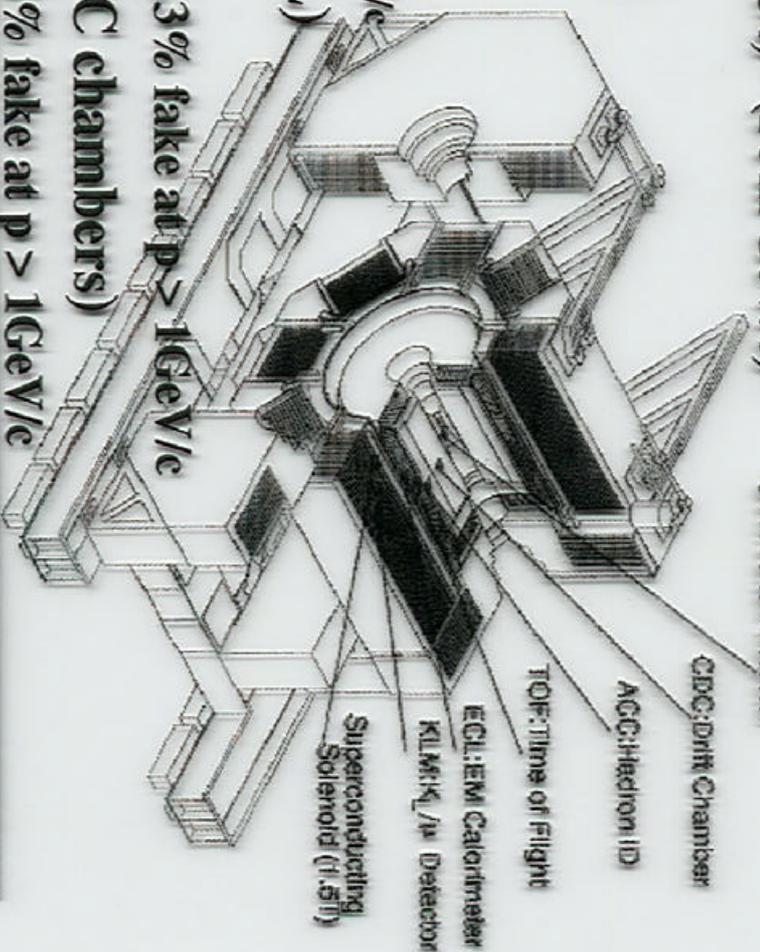


$\sigma_z \approx 70 \mu\text{m}$ : reco'd B  
180  $\mu\text{m}$ : tagging B  
(rms for 99% of events)

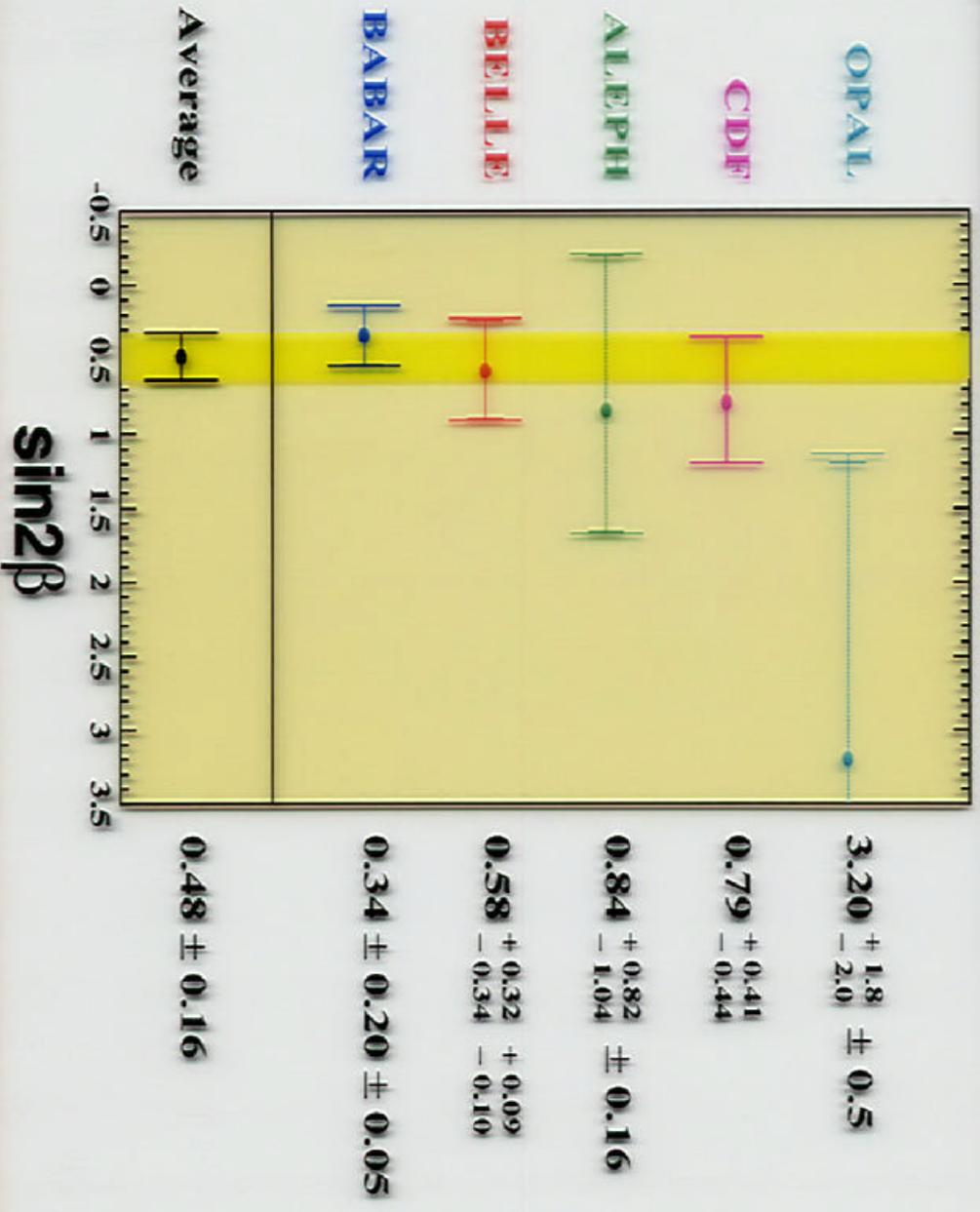


12A

- ◆ Silicon Vertex Detector (SVD)
  - ◆ Impact parameter resolution :  $55\mu\text{m}$  for  $p=1\text{GeV}/c$  at normal incidence
- ◆ Central Drift Chamber (CDC)
  - ◆  $(\sigma_{Rt}/Pt)^2 = (0.0019Pt)^2 + (0.0034)^2$  (Pt in  $\text{GeV}/c$ )<sup>2</sup>
- ◆ K/ $\pi$  separation with
  - ◆  $dE/dx$  in CDC ( $\sigma_{dE/dx} = 6.9\%$ )
  - ◆ TOF ( $\sigma_{\text{TOF}} = 95\text{ps}$ )
  - ◆ Aerogel Cerenkov (ACC)
    - ◆ Efficiency =  $\sim 85\%$ ,  
Fake rate =  $\sim 10\%$  up to  $3.5\text{GeV}/c$
- ◆  $\gamma, e^\pm$  with CsI crystals (ECL)
  - ◆  $\sigma_E \sim 1.5\%$  for  $E=1\text{GeV}$
  - ◆  $e^\pm$  : efficiency  $> 90\%$  with  $\sim 0.3\%$  fake at  $p > 1\text{GeV}/c$
- ◆ KL and  $\mu^\pm$  with KLM (RPC chambers)
  - ◆  $\mu^\pm$  : efficiency  $> 90\%$  with  $\sim 2\%$  fake at  $p > 1\text{GeV}/c$



# Time evolution of $\sin 2\beta$



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## Measurement of $\sin 2\beta$ (con't)

- The results for  $\sin 2\beta$  are

0.34	$\pm 0.20$	$\pm 0.05$	BaBar
0.58	$+0.32/-0.34$	$+0.09/-0.10$	Belle
- These results are consistent with each other and with previous, less accurate measurements.  
The present “world average” for  $\sin 2\beta$  is  
 $0.48 \pm 0.16$
- These results are also consistent with the Standard Model and a single phase in the CKM matrix as the origin of CP violation, in which  $\sin 2\beta$  is in the range 0.5 to 0.9.

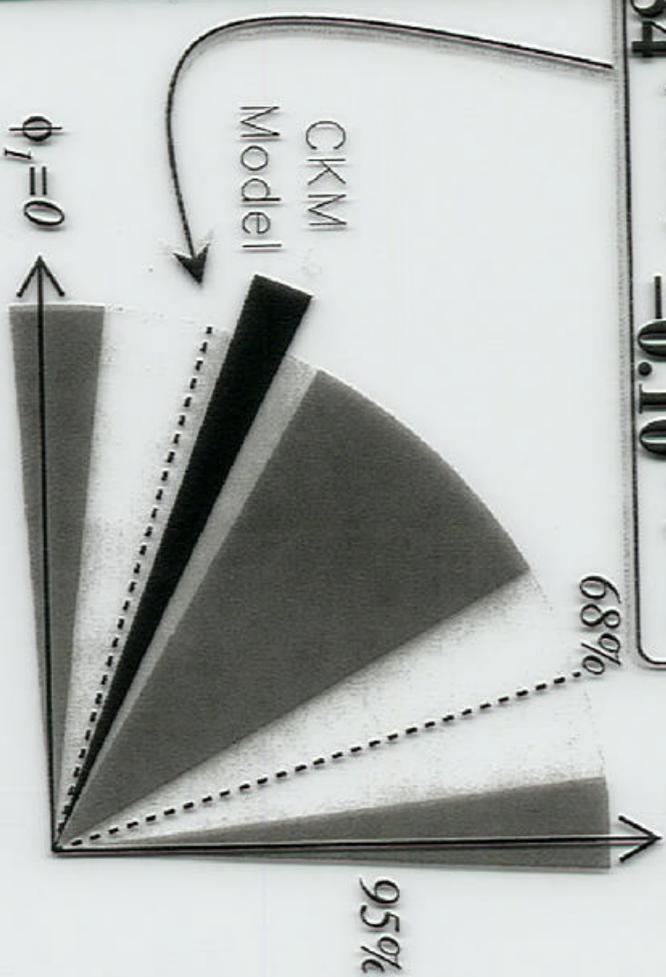
# CP fit : Significance



$$\sin 2\phi_1 = 0.58^{+0.32}_{-0.34} \text{ (stat)} \quad +0.09^{+0.09}_{-0.10} \text{ (syst)}$$

$$\phi_1 = \pi/2$$

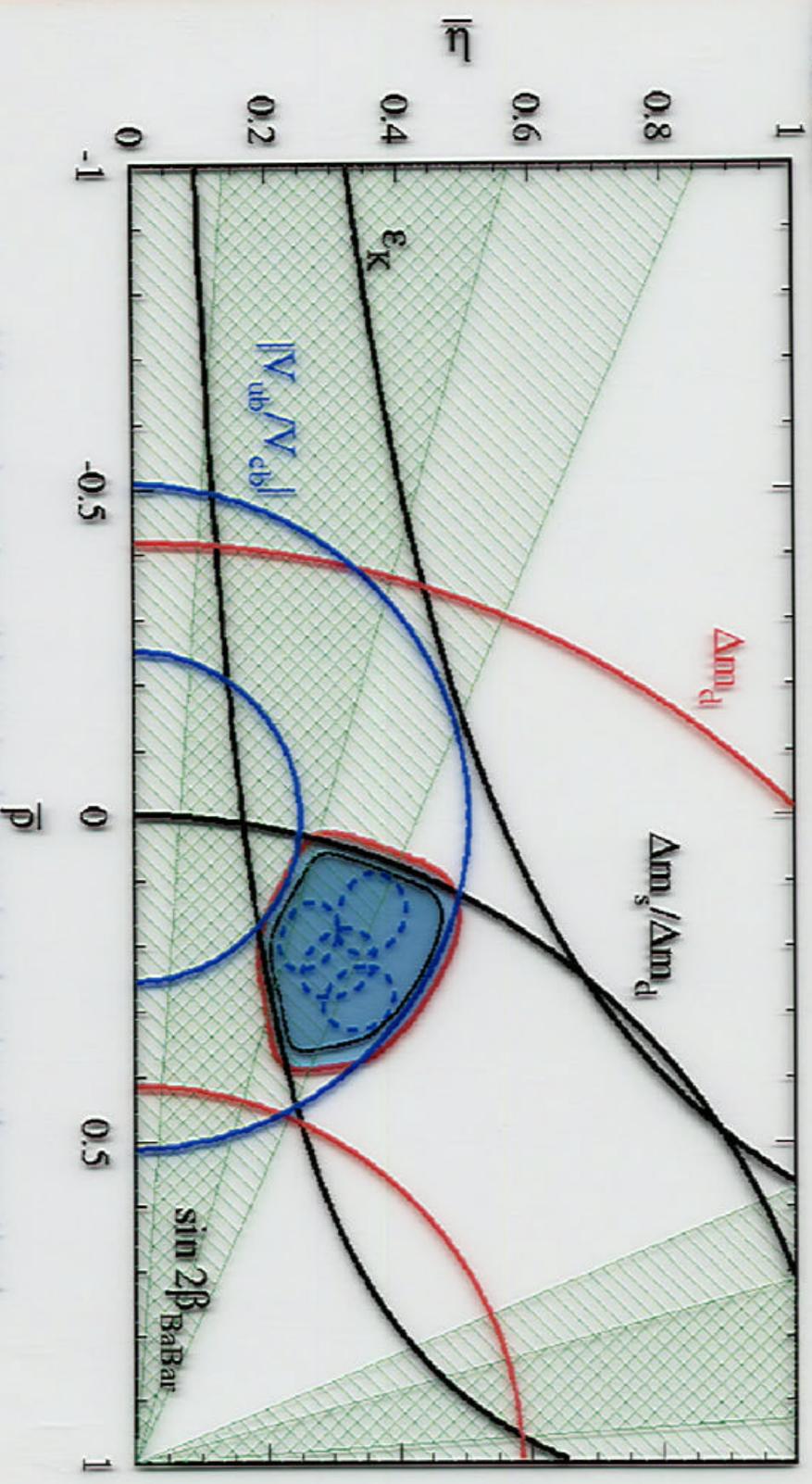
1) Probability of observing  $\sin 2\phi_1 > 0.58$  if CP is conserved is **4.9%**.



2) Feldman-Cousins confidence interval

Poster presentation by  
Dr. D. J. Jackson  
for more information !

# Constraints on Unitarity Triangle



Allowed region (blue) is determined using theoretical inputs and fitting many experimental measurements

## Measurement of $\sin 2\beta$ (con't)

- These are great results and we can now see getting to the goal of errors of 0.1 or less for the “golden” mode,  $J/\psi K_S$ , and confirmatory measurements in several other modes. At present, the asymmetry data for  $J/\psi K_S$  with  $K_S$  decaying to  $\pi^+ \pi^-$  are (statistical errors only)

0.25	+/- 0.26	BaBar
1.21	+ .40/- .47	Belle

# Measurement of the Other Angles

- For  $\sin 2\alpha = \sin 2\phi_2$ , the original prime mode was  $B \rightarrow \pi^+ \pi^-$ , but it was soon realized that in addition to the tree amplitude, penguin diagrams with a different weak phase enter. Theory using isospin allows using other  $\pi \pi$  modes to remove the “penguin pollution”, but BR’s are low. Modes like  $\pi \rho$  could help.

- For  $\sin 2\gamma = \sin 2\phi_3$ , many methods have been proposed. Where will the first rough measurement come from? Probably interference of penguin and tree amplitudes in  $B \rightarrow K \pi$  decays. A “precise” value should come from  $B_u \rightarrow D^0 K$  rates or  $B_s(t) \rightarrow D_s K$  hadron colliders.

FALK

ATWOOD

TAYLOR

BERGER

TOMMS

NAKADA

# Rare B Decays

- The measurement of many branching ratios for  $B \rightarrow PP, PV, \text{ and } VV$  to the  $10^{-5}$  level and below is proceeding apace from BaBar, Belle, and CLEO. Exclusive and inclusive  $b \rightarrow s \gamma$  radiative decays are becoming standard measurements and we are headed toward measurements of  $b \rightarrow s \mu^+ \mu^-$ .
- Important theoretical progress is being made as well, especially in understanding where and how factorization applies, how penguin amplitudes fit into the picture, and where and how we might see indications of physics beyond the Standard Model. Precise data from both electron-positron and hadron collider experiments will be needed in the interplay of theory and experiment.

KAWASAKI  
 LYON  
 IITIMA  
 HÖCKER  
 USHIKODA  
 BOZEK  
 GARMASH  
 MANNEN  
 LI  
 KEUM  
 SILVERSMAN  
 MASIERO  
 LONDON  
 HOV  
 LIPKIN  
 BRODSKY  
 BHATTACHARYA  
 KOU, SINHA, ...

# B → Kπ, KK, ππ

## Results

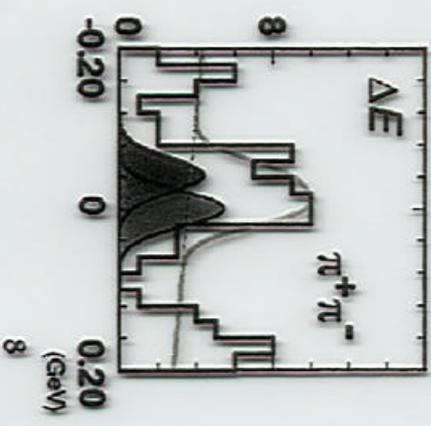
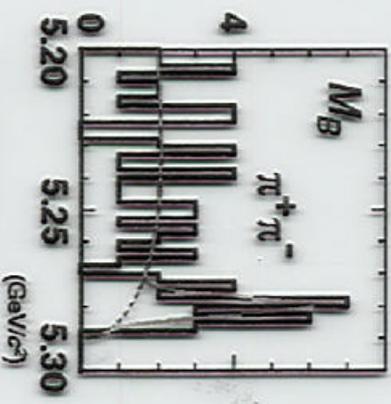
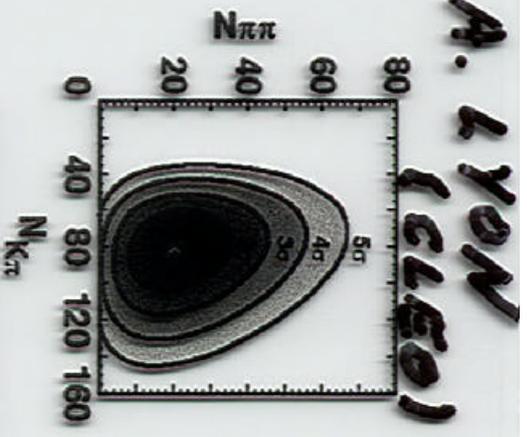
CLEO Kπ, PRL 85, 515 (2000)  
 Babar/Belle ICHEP2000

Mode	CLEO (9.7M $\bar{B}\bar{B}$ )			Theory BF × 10 <sup>-6</sup>	Belle (ICHEP2000) [5.5M $\bar{B}\bar{B}$ ] BF × 10 <sup>-6</sup>	Babar (ICHEP2000) [8.6M $\bar{B}\bar{B}$ ] BF × 10 <sup>-6</sup>
	N <sub>sig</sub>	Signif.	Eff (%)			
$\pi^+\pi^+$	20.0 $^{+1.6}_{-6.5}$	4.2 $\sigma$	48	4.3 $^{+1.6}_{-1.4} \pm 0.5$	8-26	8-26
$\pi^+\pi^0$	21.3 $^{+9.7}_{-8.5}$	3.2 $\sigma$	39	< 12.7	3-20	< 10.1
$\pi^0\pi^0$	6.2 $^{+4.8}_{-3.7}$	2.0 $\sigma$	29	< 5.7	0.3-4.6	
$K^+\pi^-$	80.2 $^{+11.8}_{-11.0}$	11.7 $\sigma$	48	17.2 $^{+2.5}_{-2.4} \pm 1.2$	7-24	17.4 $^{+3.1}_{-4.6} \pm 3.4$
$K^0\pi^+$	25.2 $^{+6.4}_{-5.6}$	7.6 $\sigma$	14	18.2 $^{+4.6}_{-4.0} \pm 1.6$	3-15	< 34
$K^+\pi^0$	42.1 $^{+10.9}_{-9.9}$	6.1 $\sigma$	38	11.6 $^{+3.0}_{-2.7} \pm 1.4$	8-26	18.8 $^{+3.5}_{-4.9} \pm 2.3$
$K^0\pi^0$	16.1 $^{+5.9}_{-5.0}$	4.9 $\sigma$	11	14.6 $^{+5.9}_{-5.1} \pm 2.4$	3-9	21.0 $^{+3.3}_{-7.8} \pm 2.5$
$K^+K^-$	0.7 $^{+3.4}_{-0.7}$	0 $\sigma$	48	< 1.9	< 6	< 6.6
$K^+K^0$	1.4 $^{+2.3}_{-1.3}$	1.1 $\sigma$	14	< 5.1	< 5	1.9 $^{+0.6}_{-0.5} \pm 0.2$
$K^0\bar{K}^0$	0	0 $\sigma$	5	< 17		2.1 $^{+0.9}_{-0.8} \pm 0.2$

- ◆ Good agreement with theory
- ◆ Small rate and limit for  $\pi\pi$  modes
- ❖ No strong phase enhancement
- ❖ Large gluonic penguins

A. Lyon (CLEO) - 2001

**Data** ———  
**Fit Proj** ———  
**Continuum** .....  
 **$\pi\pi$  signal**   
 **$K\pi$  bkg** 



A. LYON (CLEO)

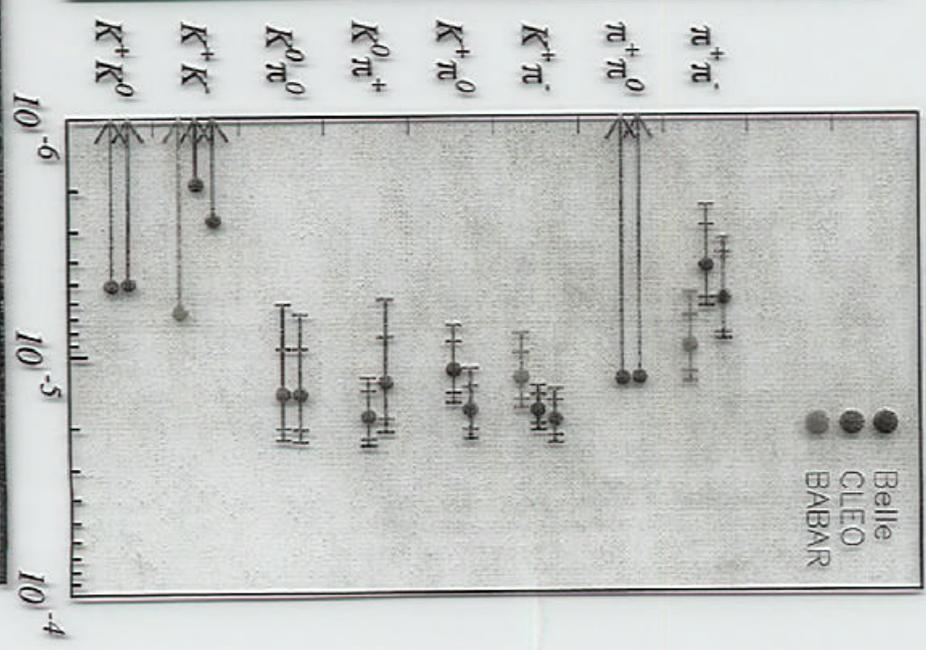


# T. IIZUMI (BELLE)

## Results w/ 11.1M BB

Mode	Ns	$\Sigma$	Eff (%)	Br( $10^{-5}$ )	U.L. ( $10^{-5}$ )
$B^0 \rightarrow \pi^+ \pi^-$	$17.7^{+7.1}_{-6.4}$	3.1	28	$0.59^{+0.24}_{-0.21} \pm 0.05$	-
$B^+ \rightarrow \pi^+ \pi^0$	$9.4^{+4.8}_{-4.0}$	2.9	12	$0.71^{+0.36}_{-0.30} \pm 0.09$	1.26
$B^0 \rightarrow K^+ \pi^-$	$60.3^{+10.6}_{-9.9}$	7.8	29	$1.87^{+0.33}_{-0.30} \pm 0.16$	-
$B^+ \rightarrow K^+ \pi^0$	$35.8^{+7.7}_{-7.0}$	7.5	19	$1.70^{+0.37}_{-0.33} \pm 0.20$	-
$B^+ \rightarrow K^0 \pi^+$	$10.3^{+4.3}_{-3.6}$	3.5	13	$1.31^{+0.55}_{-0.46} \pm 0.26$	-
$B^0 \rightarrow K^0 \pi^0$	$8.8^{+3.7}_{-3.1}$	4.2	11	$1.46^{+0.61}_{-0.51} \pm 0.27$	-
$B^0 \rightarrow K^+ K^-$	$0.2^{+3.8}_{-0.2}$	-	24	-	0.27
$B^+ \rightarrow K^+ K^0$	$0.0^{+0.9}_{-0.0}$	-	13	-	0.50

- Belle (BCP4)
- CLEO (PRL85,515(2000))
- BABAR (ICHEP2000)



February 20, 2001

“Studies on B Meson Rare Decays at Belle”, Toru Iizumi for Belle Collaboration @ BCP4

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**BRANCHING RATIOS FOR  $B^0 \rightarrow h^+h'^-$**   
**PRELIMINARY**

The combined 8 parameters fit yields for 16 032 events

$$[N \pm \sigma(\text{stat}) \pm \sigma(\text{syst})]$$

$N_{\pi\pi}$	$=$	$41 \pm 10 \pm 7$
$N_{K\pi}$	$=$	$169 \pm 17^{+12}_{-17}$
$N_{KK}$	$=$	$8.2^{+7.8}_{-6.4} \pm 3.3$

(correlations < 15%)

The branching ratios are obtained via  $BR = N_S / \epsilon N_{B\bar{B}}$ , with  $N_{B\bar{B}} = 22.5 \times 10^6$  and  $\epsilon = 0.43 (K^+K^-) - 0.45 (\pi^+\pi^-)$ .

Decay Mode	[BR $\pm$ $\sigma(\text{stat}) \pm \sigma(\text{syst})$ ] ( $\times 10^{-6}$ )	
	BABAR	CLEO
$\pi^+\pi^-$	$4.1 \pm 1.0 \pm 0.7$	$4.3^{+1.6}_{-1.4} \pm 0.5$
$K^+\pi^-$	$16.7 \pm 1.6^{+1.2}_{-1.7}$	$17.2^{+2.5}_{-2.4} \pm 1.2$
$K^+K^-$	$< 2.5$ (90% CL)	$< 1.9$ (90% CL)





T. IIZUMA

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

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

	PID(K) $<0.8$		PID(K) $>0.8$		$\Sigma$ Signif.	Br(DK)/Br(D $\pi$ )
	N(D $\pi$ )	N(DK)	N(D $\pi$ )			
D $^0h^-$	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,  $R_C \sim 0.074$ 
  - ⇒ CLEO w/ 3.3M  $B\bar{B}$ ,  $Br(D^0K^-)/Br(D^0\pi^-) = 0.055 \pm 0.015 \pm 0.005$

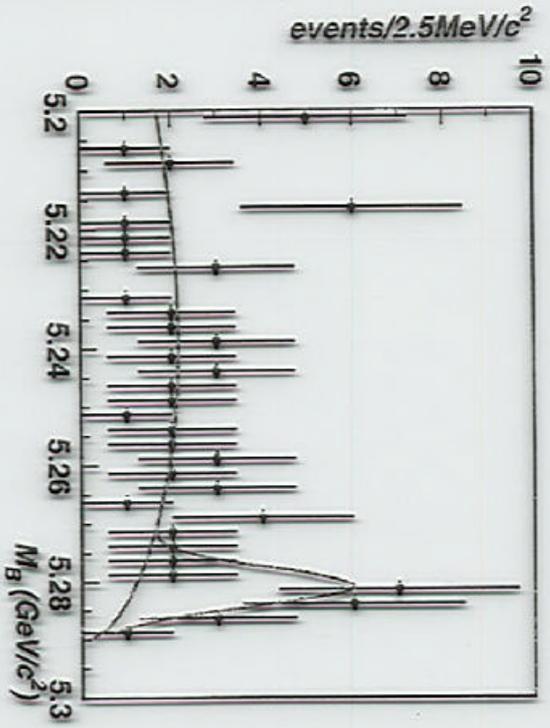
First observation of the  $B \rightarrow D^+K^-$ ,  $D^{*0}K^-$  and  $D^{*+}K^-$

$B \rightarrow K_2^*(1430)\gamma$

$B(B \rightarrow K_2^*(1430)\gamma)$

Y. USHIRODA  
(BELLE)

- 11M  $B\bar{B}$  events
- Exclusive reconstruction  
 $K^\pm\pi^\pm, K_S^0\pi^0, K_S^0\pi^\pm, K^\pm\pi^0$   
 $|M_{K\pi} - M_{K_2^*(1430)}| < 100 \text{ MeV}/c^2$



Signal Yield

$$15.6 \pm 4.6^{+0.6}_{-0.7} \text{ events}$$

Assuming all are  $K_2^*(1430)\gamma$ , Branching Fraction

$$B(K_2^*(1430)\gamma) = (18.9 \pm 5.6 \pm 1.8) \times 10^{-6}$$

Preliminary

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## CONCLUSIONS

L. SILVERSTRIM

- ① CHARMING PENGUINS IN  $B \rightarrow K\pi$  DECAYS ARE DOUBLY CABIBBO ENHANCED CORRECTIONS TO BBNS FACTORIZATION  $\rightarrow$  NUMERICALLY DOMINANT (RELEVANT)
- ② A (TOO) SIMPLIFIED ANALYSIS SHOWS THAT:
  - \* FOR  $\gamma = 55^\circ$  AS GIVEN BY UT FITS AND VALUES OF ORDER  $\frac{\Delta}{m_b}$  FOR CHARMING PENGUINS, CAN REPRODUCE EXP. VALUES FOR  $B \rightarrow K\pi$  DECAYS (WITH "PENGUIN" PATTERN  $\pi^0 \bar{K}^0 \simeq \pi^0 K^- \simeq \frac{\pi^- \bar{K}^0}{2} \simeq \frac{\pi^+ K^-}{2}$ )
  - \* FACTORIZATION WITH NO CHARMING PENGUINS GIVES A MUCH WORSE FIT TO  $B \rightarrow K\pi$ , EVEN FOR VERY LARGE  $\gamma$
- ③ FULL ANALYSIS IN PROGRESS...

# Charm and Kaon Physics

- Charm acts as a staging area, both experimentally and theoretically, for the assault on B physics **BIG1**
- In addition, it may yet give us some surprises of its own as we push on the measurements of  $x = \Delta M / \Gamma$  and  $y = \Delta \Gamma / (2 \Gamma)$  in the neutral D system and on CP violating asymmetries to the few percent level and smaller. **SMITH, TANAKA**
- Kaon experiments continue to provide alternate theoretically clean measurements the CKM parameters. The next generation of planned experiments aims at BR's at the  $10^{-11}$  level. **NGUYEN, ARBON, KOCH**

+ LEPTONS: **COM, DUONG**  
μ: **g-r!**

# Conclusions

A. SMITH  
(CLEO)

- Best measurement of the  $D^{*+}$  width:

$$\Gamma(D^{*+}) = 96 \pm 4 \text{ (stat)} \pm 22 \text{ (syst)} \text{ keV}$$

- First measurement of “wrong sign” rate in  $D^0 \rightarrow K^+ \pi^- \pi^0$ :

$$R_{WS} = (0.43^{+0.11}_{-0.10} \text{ (stat.)} \pm 0.07 \text{ (syst.)})\%$$

– Combined proper time/Dalitz fit under study -- stay tuned!

- New direct CP violation search results

$$A(K_S^0 \pi^0) = (+0.1 \pm 1.3 \text{ (stat + syst)})\%$$

$$A(\pi^0 \pi^0) = (+0.1 \pm 4.8 \text{ (stat + syst)})\%$$

$$A(K_S^0 K_S^0) = (-23 \pm 19 \text{ (stat + syst)})\%$$

$$A(K^+ K^-) = 0.0005 \pm 0.0218 \text{ (stat)} \pm 0.0084 \text{ (syst)}$$

$$A(\pi^+ \pi^-) = 0.0195 \pm 0.0322 \text{ (stat)} \pm 0.0084 \text{ (syst)}$$

- New  $\gamma$  measurement:

$$\gamma = -0.011 \pm 0.025 \text{ (stat)} \pm 0.014 \text{ (syst)}$$

# Conclusion

- We have reached the time where the colliders, detectors, and experimental collaborations are in place to carry out the long-planned exploration of CP violation in the B system. Theory has made considerable progress as well in understanding how to relate the measurements made to fundamental parameters and other routes to them.
- Early results on  $\sin 2\beta$  have been presented, and we can see decisive measurements of the angles of the unitarity triangle being made in the next few years to confirm the Standard Model picture or point beyond it.
- The B-Factory and hadron collider experiments are also exploring a host of related issues from mixing to rare decays and direct CP violation.
- Prepare for enormous amounts of data and great physics!