Rare Hadronic B Decays

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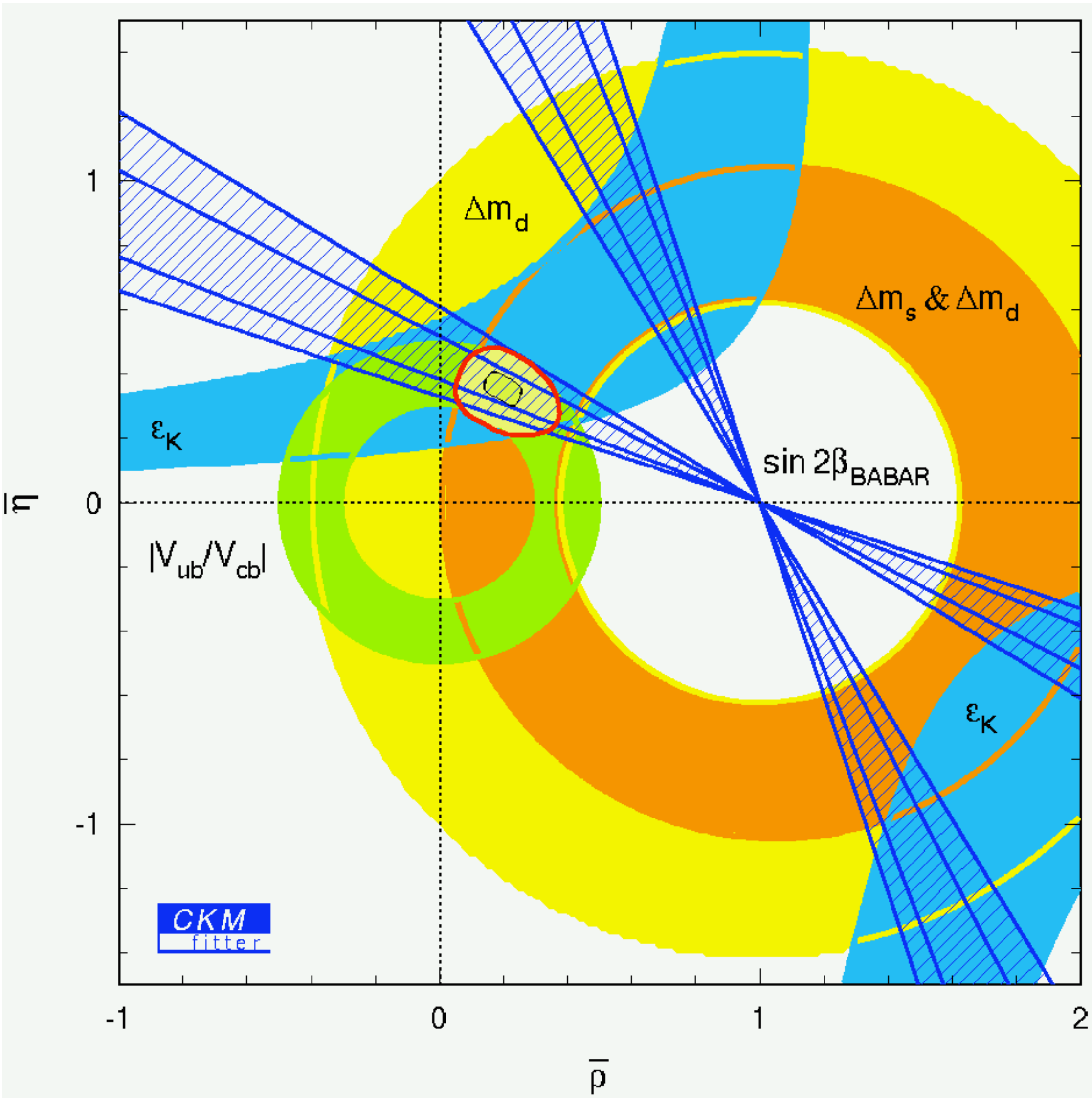
Lepton Photon 2003

Scope of Talk

- To present updated branching fractions (BF) and CP asymmetries (A_{CP}) for rare (charmless) B decay modes
- To show how BF and A_{CP} are used with theoretical models to put constraints on the Standard Model and to search for New Physics.

NB: All results are preliminary unless referenced.

How Good is the Standard Model?



LEP

Coupling Constants

CPLEAR

- $\not{T}$ consistent with $\not{CP}$
- Tight CPT constraint

K [ε_K] and B sectors [Δm_d, $|V_{ub}|$, $|V_{td}|$, Sin (2β)] consistent with each other and SM (theory)

A. Höcker et al, Eur. Phys. Jour. C21 (2001) 225, [hep-ph/0104062]

Motivation for Rare Decays

- **SM is a very good approximation to reality**

  Hence $A^{SM}_{Common} >> A^{NP}$

- **Need to consider processes where A^{SM} is small in order to be sensitive to new physics.**

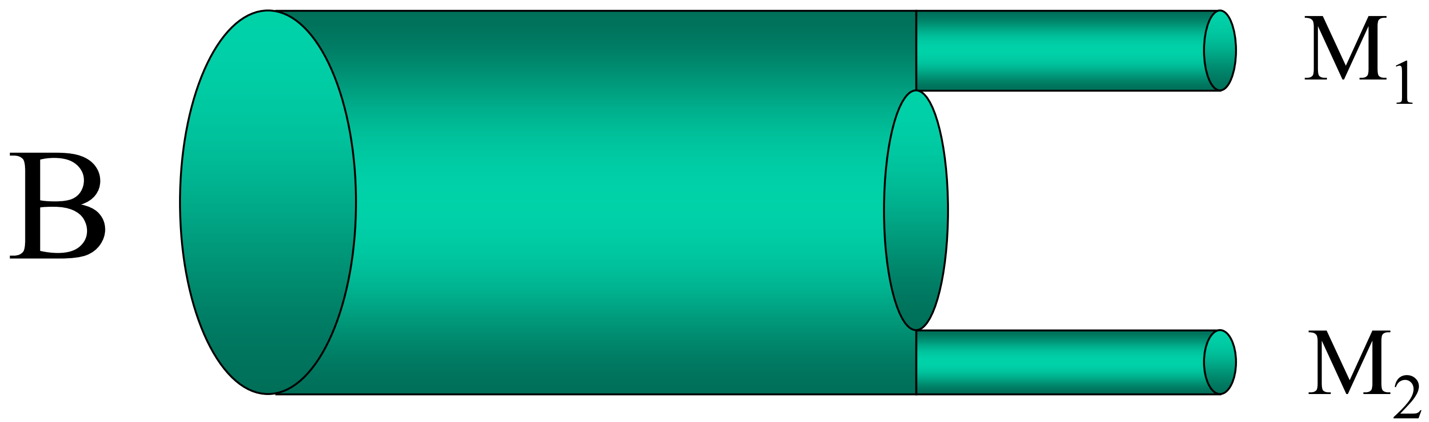
- **Hence processes dominated by penguin loops, or CKM - suppressed decays**

Procedure

- Compare nature (precise, experimental measurements) with SM (theoretical models) for sensitive quantities.
- Agreement gives an alternative route to (□, □) and additional constraints on the unitarity triangle.
- Disagreement means:
  - New Physics …. **OR**
  - Refinements needed to theoretical calculations … ….**AND** Model-independent calculations needed

The (theoretical) Problem

How to go from here …



to branching fractions and CP asymmetry

Classes of theoretical calculations

- **QCD Factorisation** ($m_b >> \Lambda_{QCD}$)

Amps factorise to LO (Λ / m_b), all orders α_S

Naïve factorisation recovered in LO

> Beneke, Buchalla, Neubert & Sachrajda
> Nucl Phys B606 (2001) 245
> Beneka & Neubert Hep-ph / 0308039

- **Phenomenology**

Amplitudes of dominant processes related to measured BF and each other via SU(3)

> Chiang, Rosner Phys Rev D65 074035
> Chiang et al Hep-ph / 0307395
> Lipkin Phys Lett B254 (1991) 247

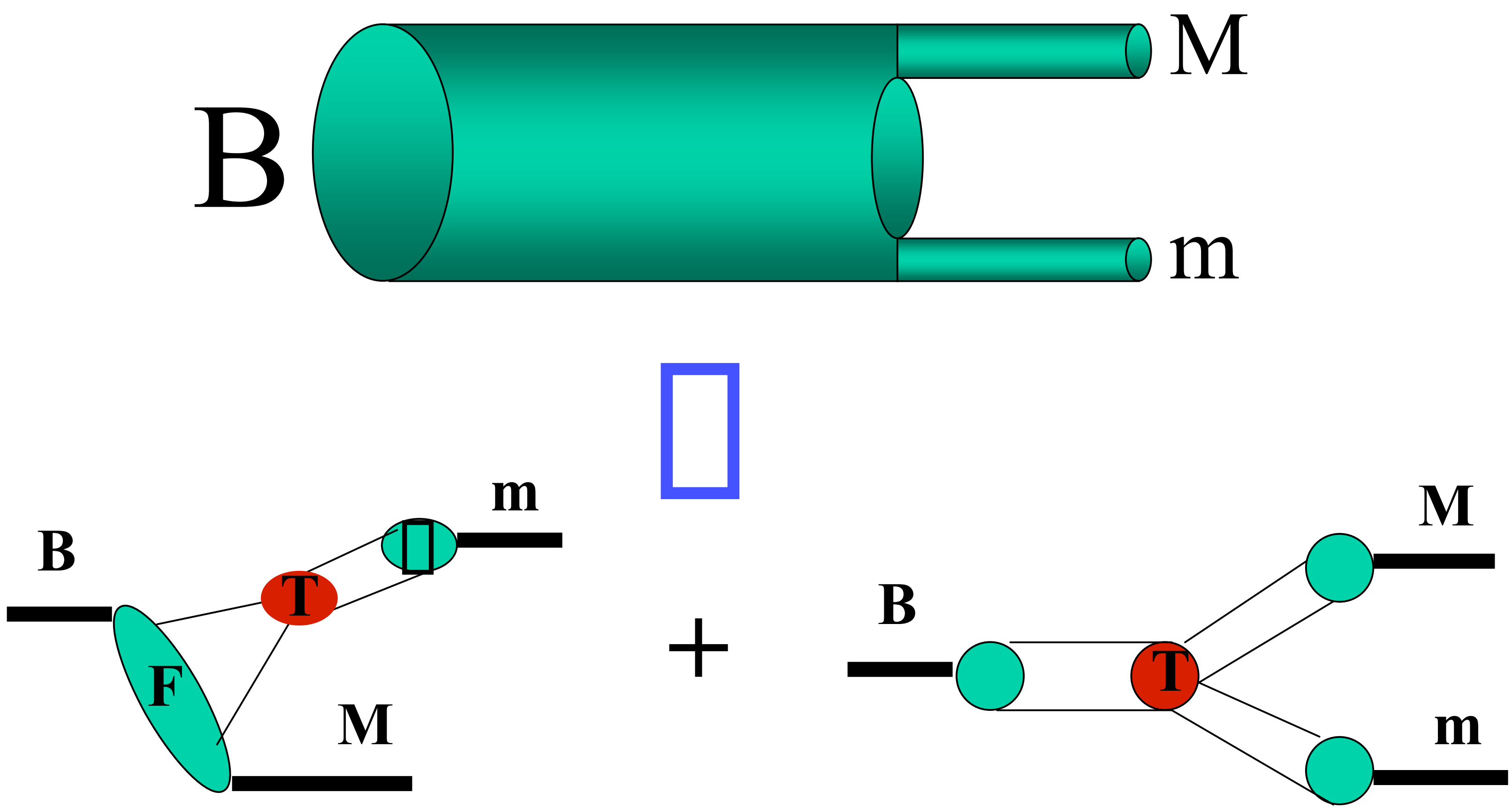
- **Model "Independent"**

Isospin & minimal dynamical assumptions

$\Rightarrow$ bounds on deviations from SM

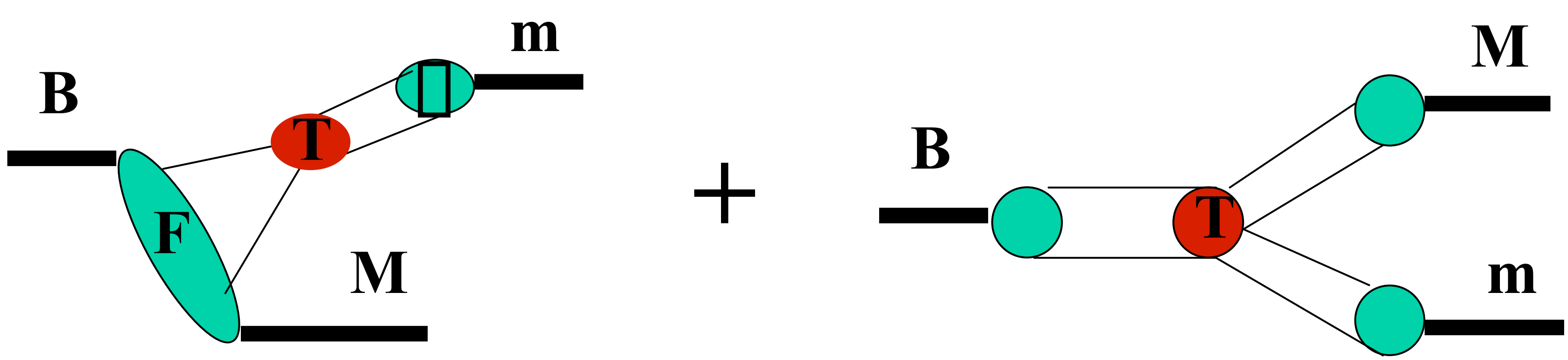
> Grossman, Ligeti, Nir, Quinn
> Hep-ph / 0303171

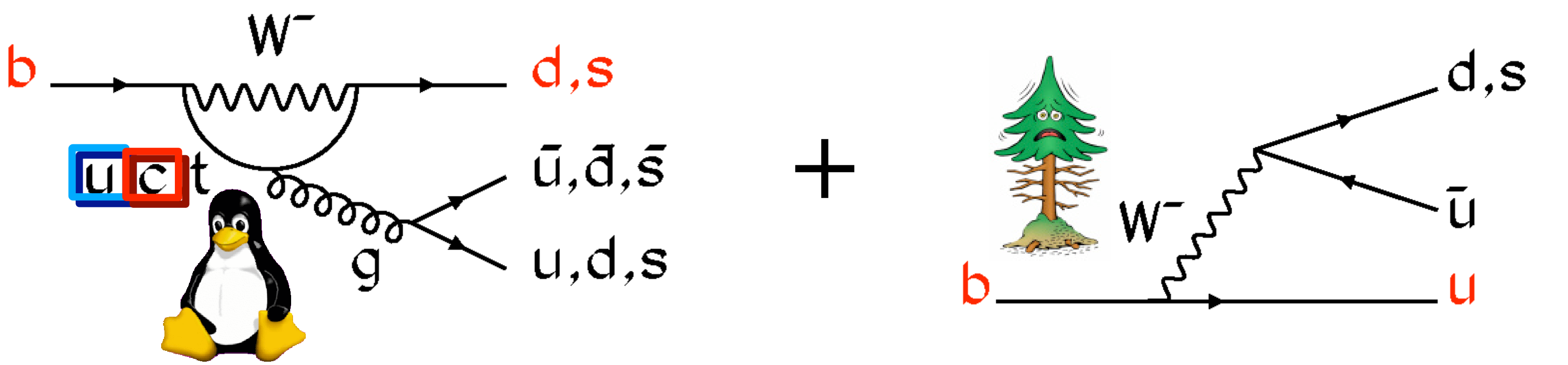
Visualising QCD Factorisation



$$\langle Mm|Q|B\rangle \;=\; F^{B\square\; m}\, T * f_M\, \square_M + F^{B\square\; M}\, T * f_m\, \square_m + T\, f_B\, \square_B * f_M\, \square_M * f_m\, \square_m$$

Pictorial Phenomenology





Leading Order – Naive Factorisation

Direct CP Violation

CP asymmetry occurs if the decay B → f (and its charge conjugate) is mediated by two amplitudes with different strong and weak phases:

$$a_f = a_1 e^{i(\delta_1 + \phi_1)} + a_2 e^{i(\delta_2 + \phi_2)}$$

$$\bar{a}_{\bar{f}} = a_1 e^{i(\delta_1 - \phi_1)} + a_2 e^{i(\delta_2 - \phi_2)}$$

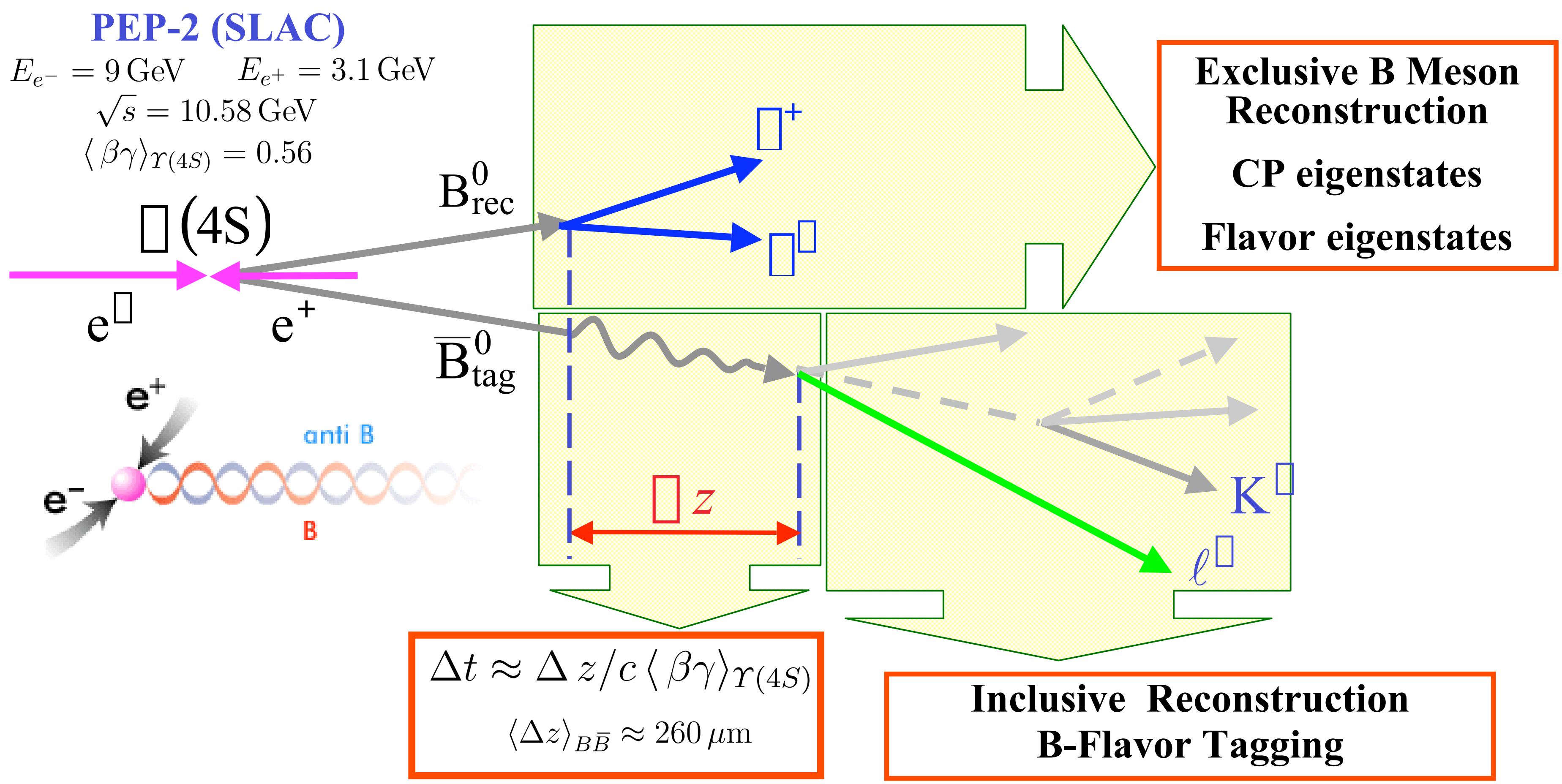
δ: strong phase CP-even
ϕ: weak phase CP-odd

$$A_{CP} = \frac{|\bar{a}_{\bar{f}}|^2 - |a_f|^2}{|\bar{a}_{\bar{f}}|^2 + |a_f|^2} = \frac{2a_1 a_2 \sin(\delta_2 - \delta_1)\sin(\phi_2 - \phi_1)}{a_1^2 + a_2^2 + 2a_1 a_2 \cos(\delta_2 - \delta_1)\cos(\phi_2 - \phi_1)}$$

Naïve Expectation:

A_{CP} small for $K\pi$ ($\pi^0\pi^+$)	Dominant penguin (tree)
A_{CP} large for $\pi^-\pi^+$	Unless dynamically suppressed

Overview of B Production and Decay



B

$B_{rec} = B_{flav}$ Flavor eigenstates → Resolution function and Tagging

$B_{rec} = B_{Signal}$ Signal: → Branching fraction; A_{CP}; CP Analysis

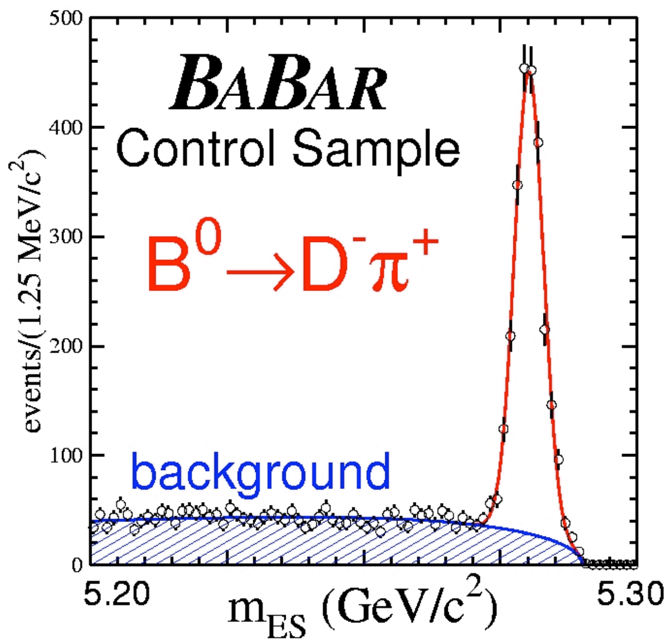
Signal Selection

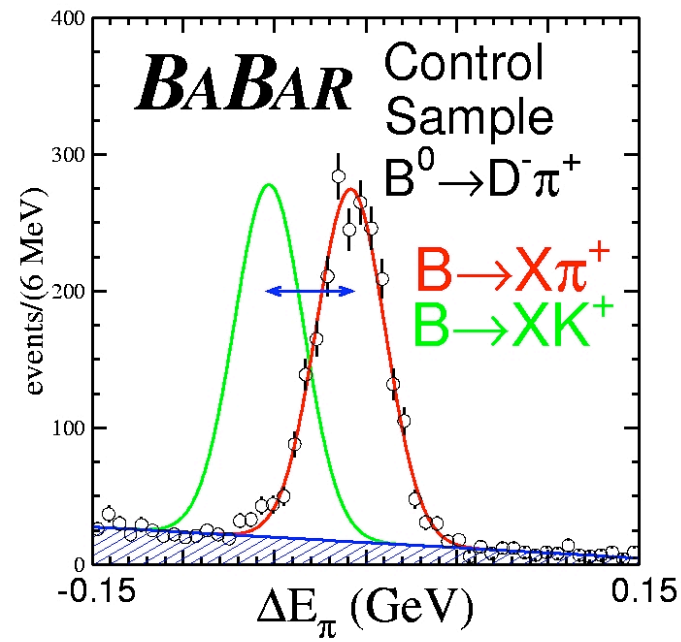
$$m_{\mathrm{ES}} = \sqrt{E^{*2}_{\mathrm{beam}} - p^{*2}_{B}}$$

$$\Delta E = E^{*}_{B} - E^{*}_{\mathrm{beam}}$$

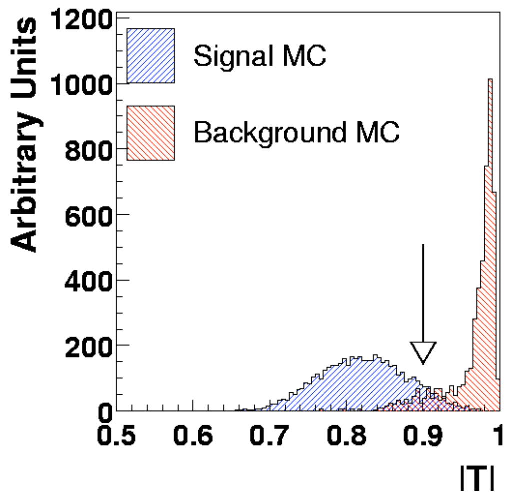
$\sigma(m_{\mathrm{ES}}) \approx 2.6$ MeV/c^2

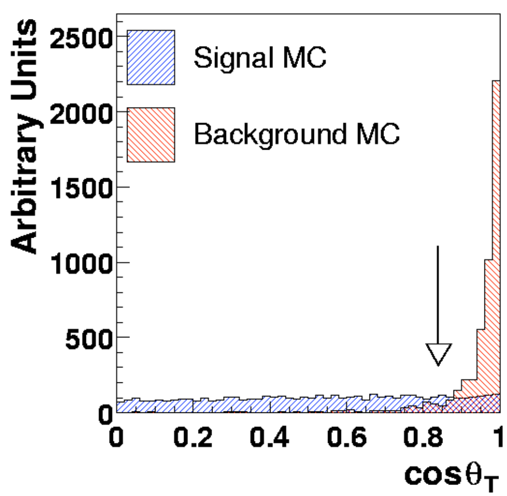
$\sigma(\Delta E) \approx 20$ MeV



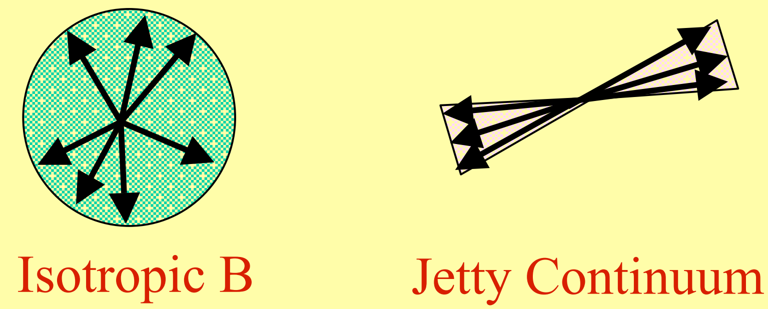


Discrimination of B and Continuum

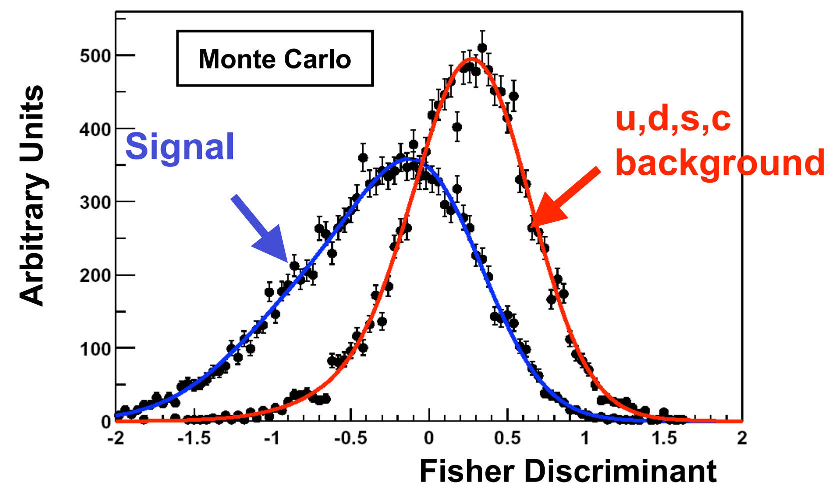




B produced (almost) at rest in Y(4S) frame



Combine into a Fisher (or NN)

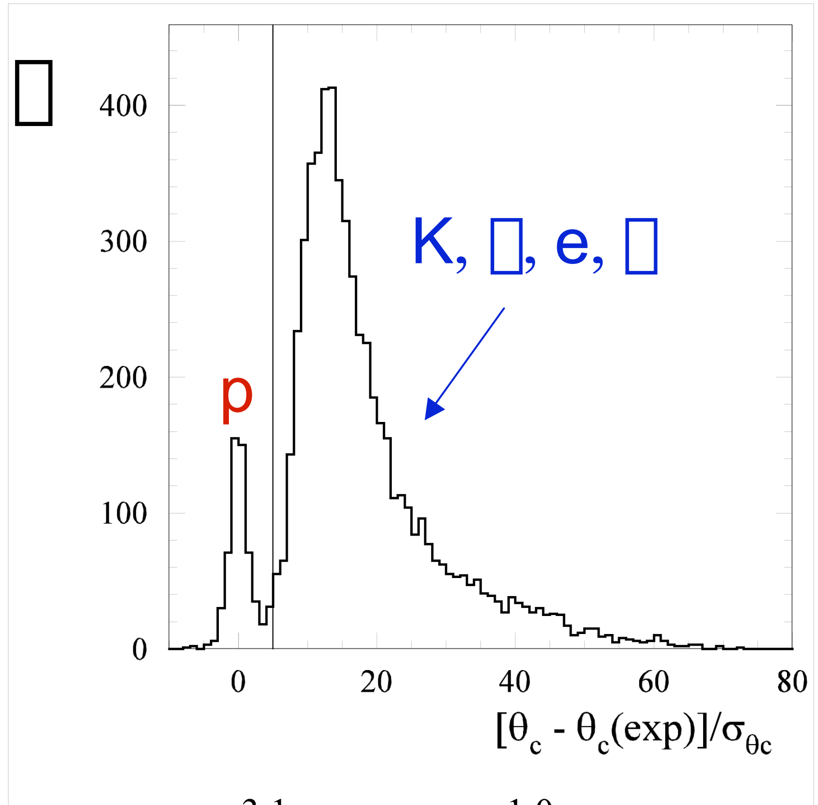


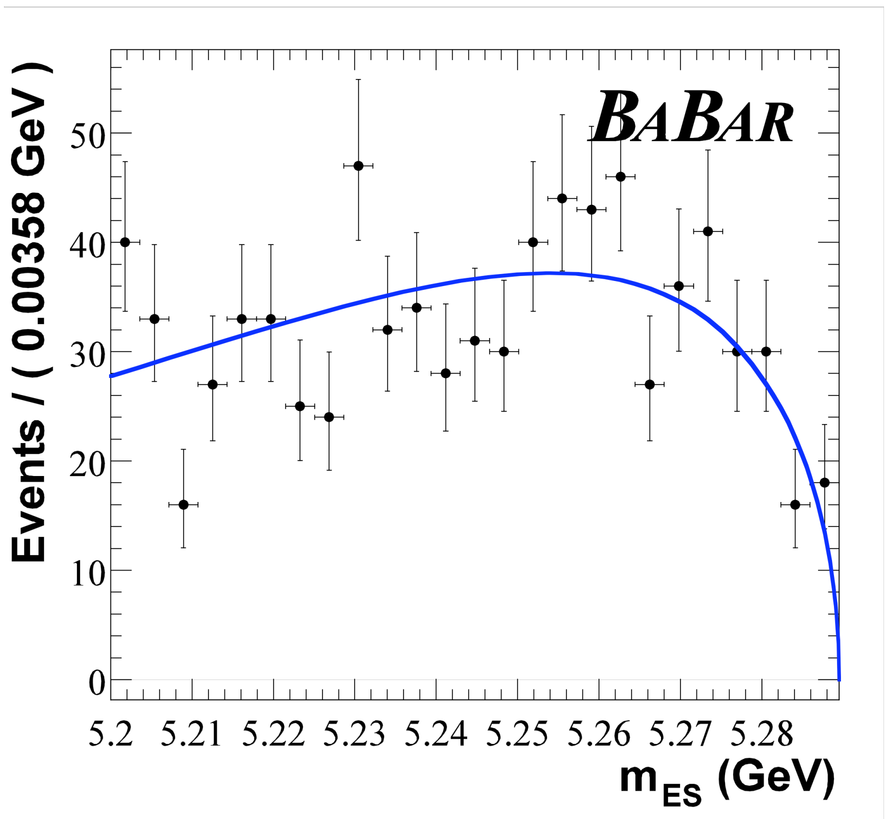
Search for B^0 _ p p_{bar} @ BaBar

Use the DIRC to reject K, □, e, □

Signal Eff = 91%
Background Eff = 3%

Total signal efficiency = 37%





$$N_S = □0.3^{+3.1}_{□2.0}\,(\mathrm{stat}) \pm^{+1.0}_{□1.2}\,(\mathrm{syst})$$

$$< 7.5\,(90\%\ \mathrm{C.L.})$$

$$□r(B^0 □\ p\bar{p}) < 2.7□10^{□7}\ (90\%\ \mathrm{C.L.})$$

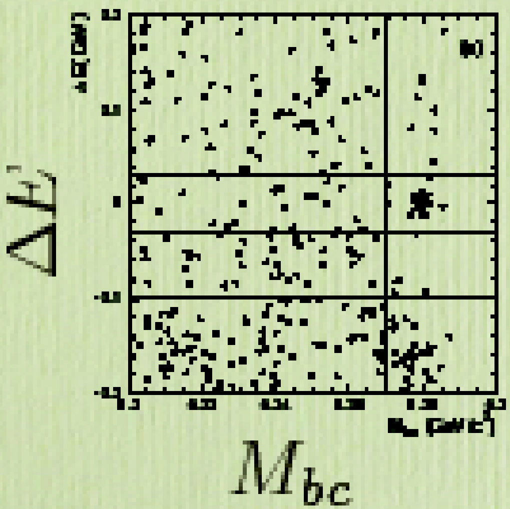
Smallest upper-limit
BF in $B^0/B^{\pm}$ decays!

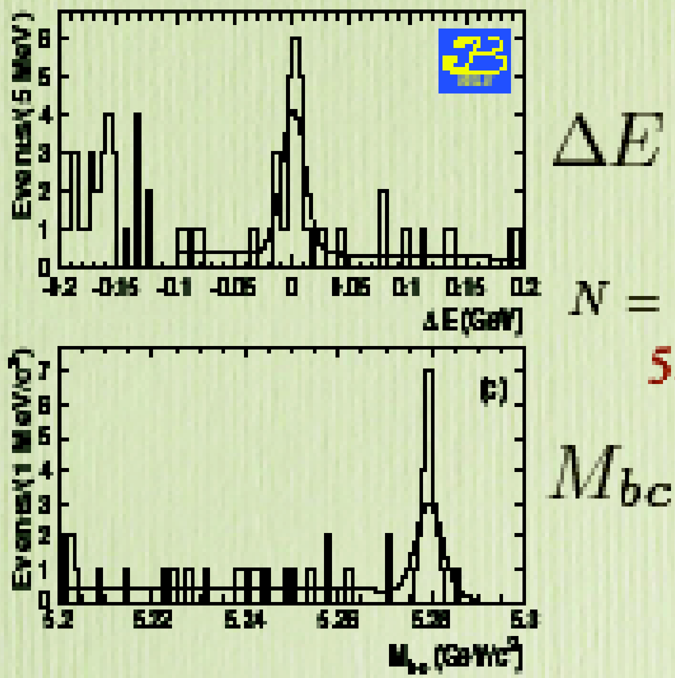
$\overline{B}^0 \to \Lambda_c^+ \overline{p}$

1st two-body baryonic B decay!

PRL **90**, 121802 (2003)

- $\Lambda_c^+ \to p K^- \pi^+$





$N = 19.6^{+5.0}_{-4.4}$

$5.8\,\sigma$

$$\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p}) = (2.19^{+0.56}_{-0.49} \pm 0.32 \pm 0.57) \times 10^{-5}$$

Heavy Flavor Averaging Group
August 2003

Compilation of B^+ Baryonic Branching Fractions

All branching fractions are in units of 10^{-6}

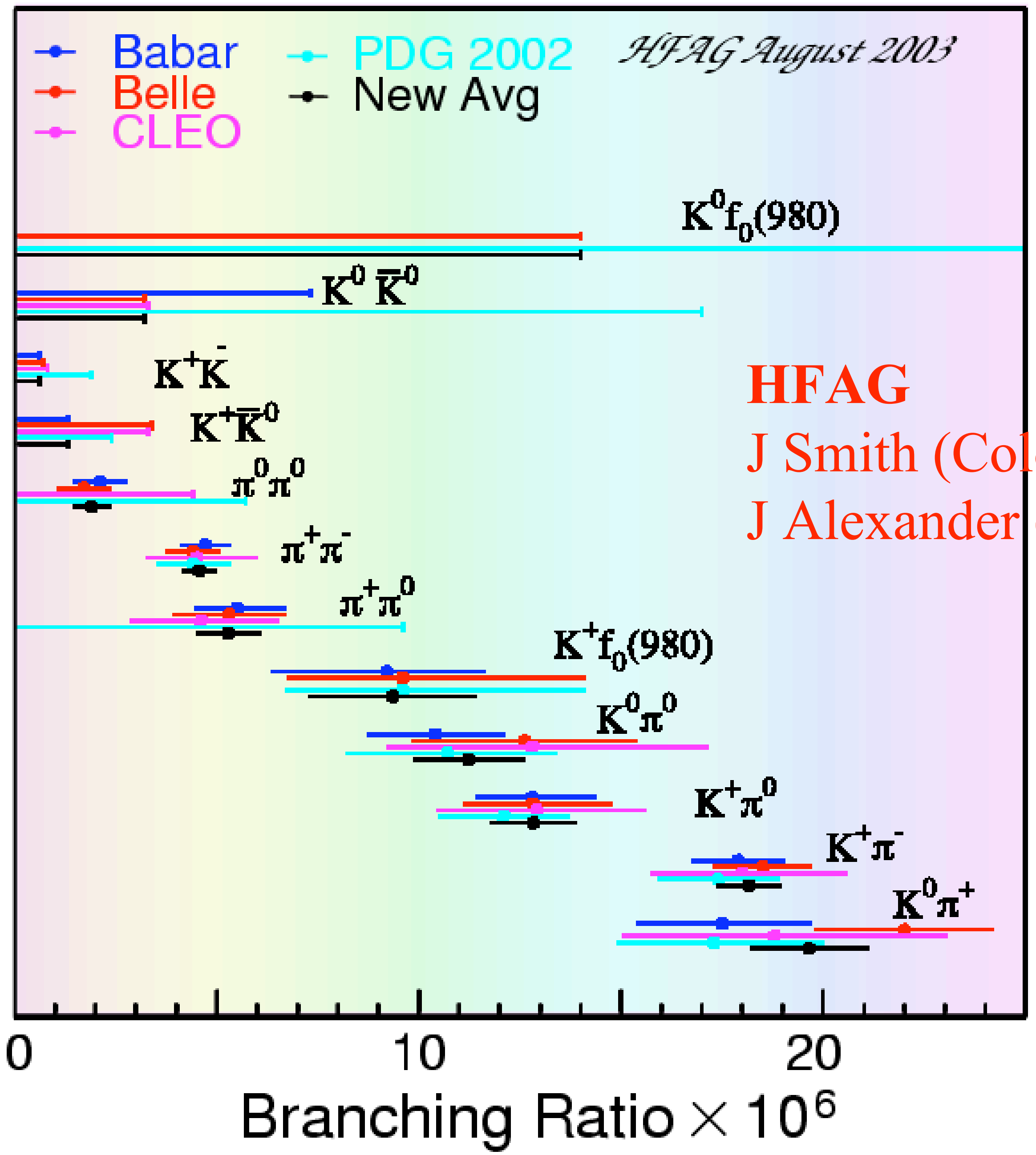
In PDG2002 New since PDG2002 (preliminary) New since PDG2002 (published)

RPP#	Mode	PDG2002 Avg.	BABAR	Belle	CLEO	New Avg.
159	$p\bar{p}\pi^+$	< 160		$3.06^{+0.73}_{-0.62} \pm 0.37$	< 160	3.06 ± 0.82
–	$p\bar{p}K^+$	New		$5.66^{+0.67}_{-0.57} \pm 0.62$		5.66 ± 0.91
–	$p\bar{p}K^{*+}$	New		$10.31^{+3.62+1.34}_{-2.77-1.65}$		10.3 ± 3.9
163	$p\bar{\Lambda}$	< 2.6		< 2.2	< 1.5	< 1.5
167	$\Lambda_c^- p\pi^+$	620 ± 270		$187^{+43}_{-40} \pm 56$	$240 \pm 60^{+63}_{-62}$	208 ± 54
–	$\overline{\Sigma}_c^0(2455)p$	New		< 93	< 80	< 80
–	$\overline{\Sigma}_c^0(2520)p$	New		< 46		< 46
168	$\Lambda_c^- p\pi^+\pi^0$	< 3120			$1810 \pm 290^{+520}_{-500}$	1810 ± 595
–	$\overline{\Sigma}_c^0(2455)p\pi^0$	New			$420 \pm 130 \pm 170$	420 ± 214
169	$\Lambda_c^- p\pi^+\pi^+\pi^-$	< 1460			$2250 \pm 250^{+630}_{-610}$	2250 ± 678
–	$\overline{\Sigma}_c^0(2455)p\pi^+\pi^-$	New			$440 \pm 120 \pm 120$	440 ± 170
–	$\overline{\Sigma}_c^{--}(2455)p\pi^+\pi^+$	New			$280 \pm 90 \pm 90$	280 ± 127
–	$\overline{\Lambda}_c^-(2593)p\pi^+$	New			< 190	< 190

Summary of BF (10^{-6}) for $K\pi$, $\pi\pi$ and KK

Mode	BaBar	Belle	CLEO	Average
$K^+\pi^-$	17.9 ± 0.9 ± 0.7	18.5 ± 1.0 ± 0.7	18.0 ± 2.3 ± 1.2	18.1 ± 0.8
$K^0\pi^+$	17.5 ± 1.8 ± 1.3	22.0 ± 1.9 ± 1.1	18.8 ± 3.7 ± 2.1	19.6 ± 1.5
$K^+\pi^0$	12.8 ± 1.2 ± 1.0	12.8 ± 1.4 ± 1.2	12.9 ± 2.4 ± 1.2	12.8 ± 1.1
$K^0\pi^0$	10.4 ± 1.5 ± 0.8	12.6 ± 2.4 ± 1.4	12.8 ± 4.0 ± 1.7	11.2 ± 1.4
$\pi^+\pi^-$	4.7 ± 0.6 ± 0.2	4.4 ± 0.6 ± 0.3	4.5 ± 1.4 ± 0.5	4.6 ± 0.4
$\pi^+\pi^0$	5.5 ± 1.0 ± 0.6	5.3 ± 1.3 ± 0.5	4.6 ± 1.8 ± 0.7	5.3 ± 0.8
$\pi^0\pi^0$	2.1 ± 0.6 ± 0.3	1.7 ± 0.6 ± 0.3	< 4.4	1.90 ± 0.47
K^+K^-	< 0.6	< 0.7	< 0.8	< 0.6
K^+K^0	< 1.3	< 3.4	< 3.3	< 1.3
K^0K^0	< 1.6	< 3.2	< 3.3	< 3.2

$B \rightarrow K\pi, \pi\pi, KK$

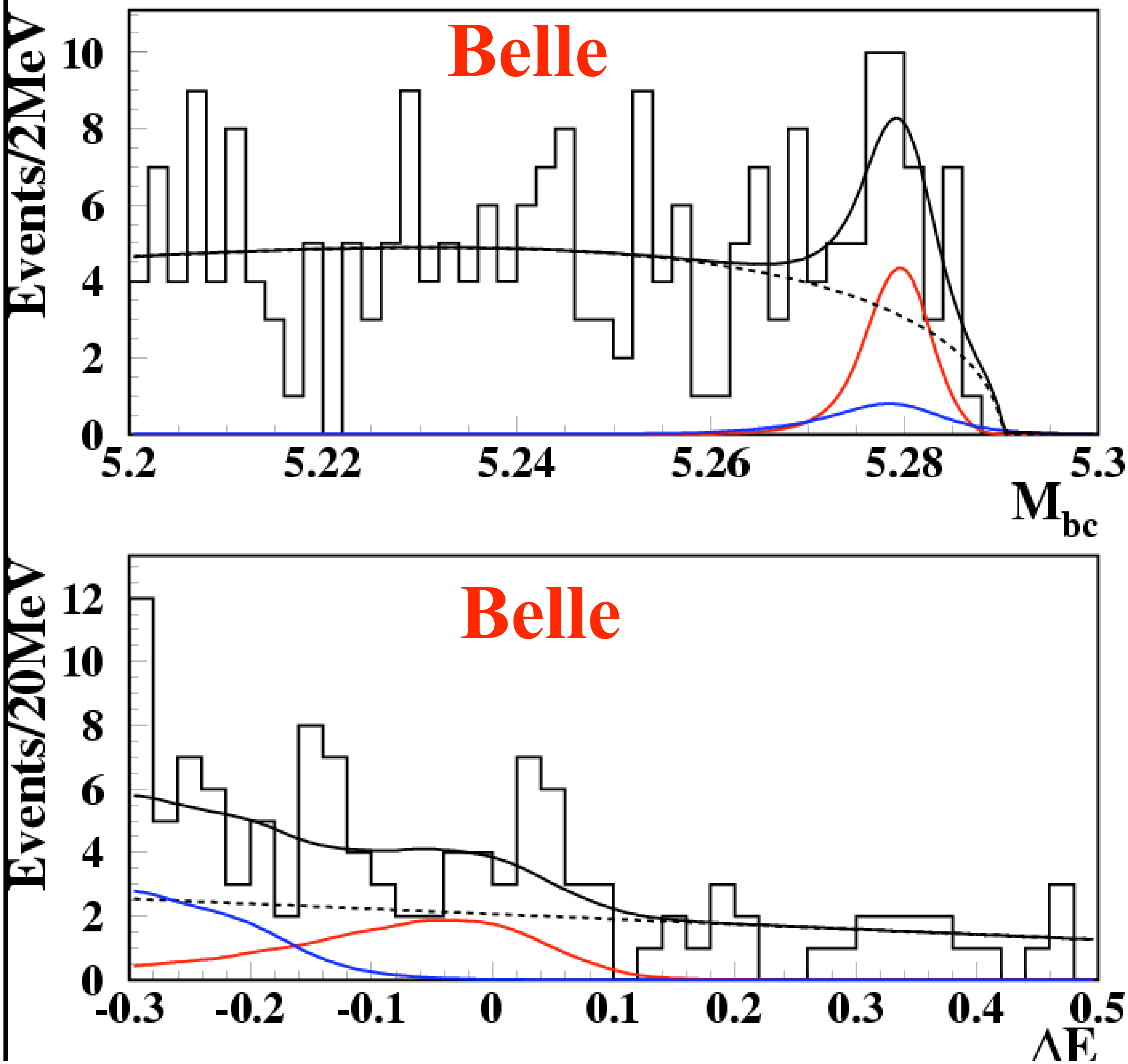


HFAG

J Smith (Colorado)

J Alexander (Cornell)

$B^0 \to \pi^0 \pi^0$



Belle

$152\ 10^6$ BB

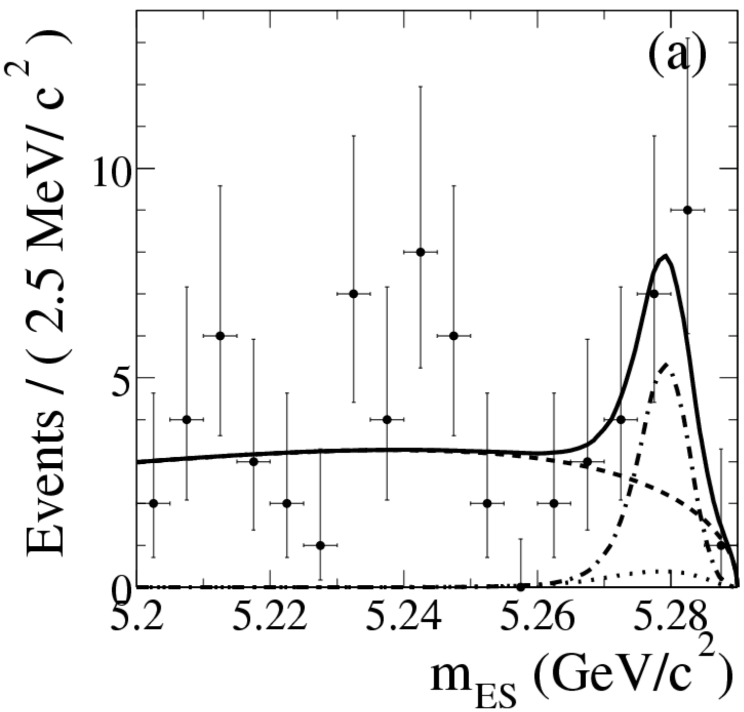
140 fb^{-1}

Signal 3.4

$25.6^{+9.3}_{-8.4}$

BF (10^{-6})

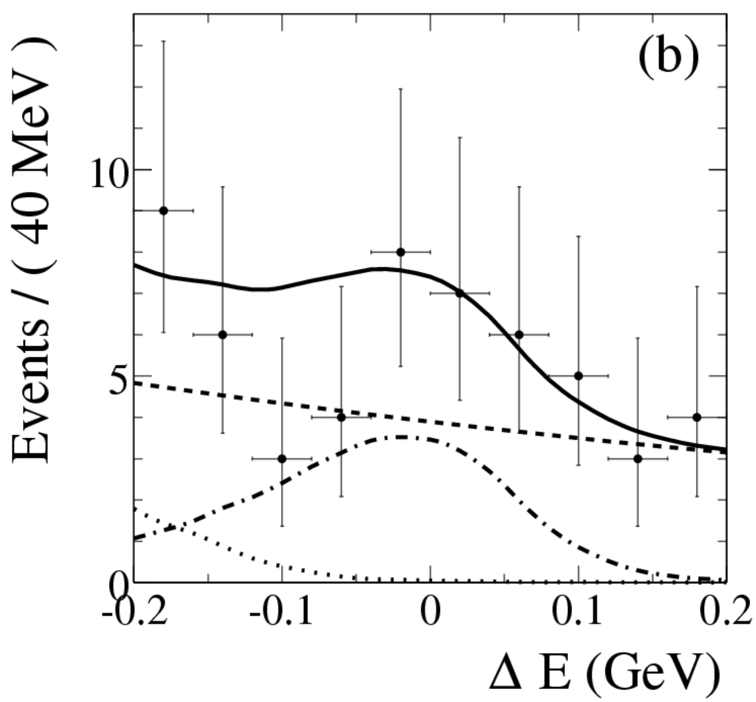
$1.7 \pm 0.6 \pm 0.2$



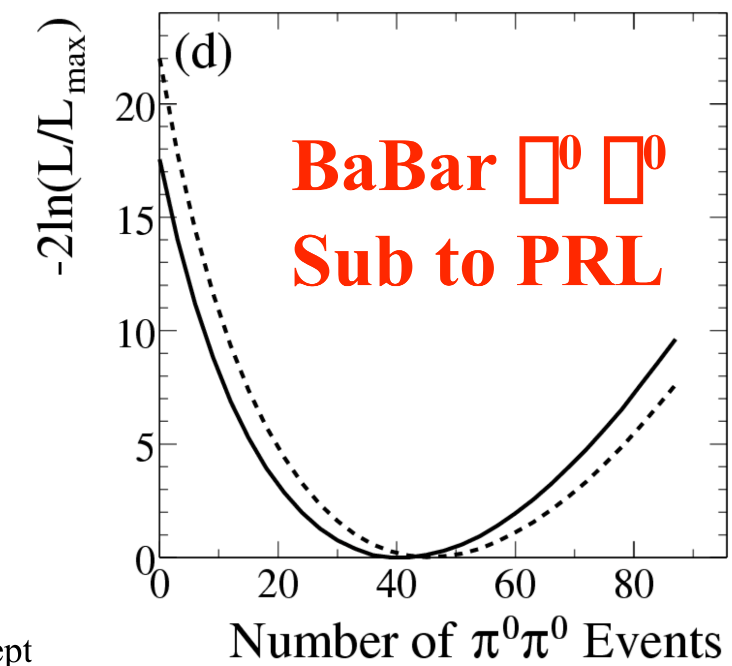
BaBar
$124\ 10^6$ BB
113 fb^{-1}

Signal 4.2 □
46 ± 13 ± 3

BF (10^{-6})
2.1 ± 0.6 ± 0.3



Lept



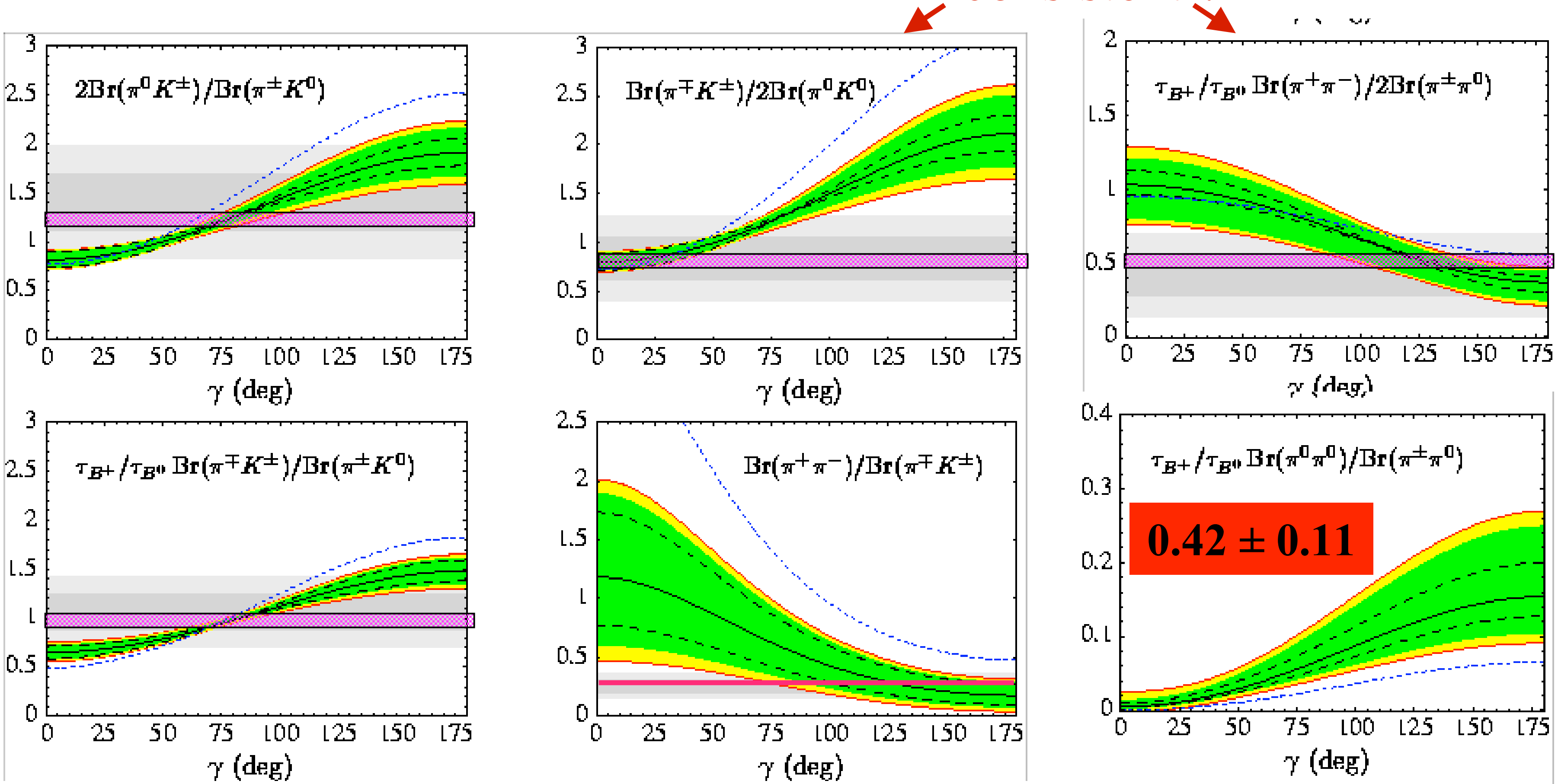
QCD_F: Ratios of ππ & Kπ BF's

Data (2001)

Data (2003)

BBNS NPB606 (2001) 245

Inconsistent ?



Comparison of BF and A_{CP} with Theory‡

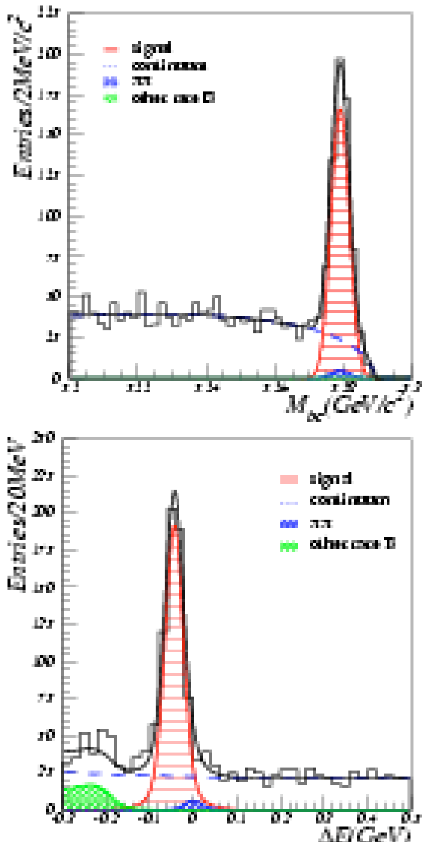
Mode	BF_{Exp} (10^{-6})	BF pQCD (10^{-6})	A_{CP} Expt (%)	A_{CP} pQCD (%)	A_{CP} QCDF (%)
$K^+\pi^-$	18.2 ± 0.8	13 – 19	-9 ± 3†	-13 – -22	$+5 \pm 10$
$K^0\pi^+$	19.6 ± 1.5	14 – 26	-1 ± 6	-0.6 – -1.5	0 ± 1
$K^+\pi^0$	12.8 ± 1.1	8 – 14	0 ± 7	-10 – -17	$+7 \pm 10$
$K^0\pi^0$	11.2 ± 1.4	8 – 14	3 ± 37		-3 ± 4
$\pi^+\pi^-$	4.55 ± 0.44	6 – 11		16 – 30	-6 ± 13
$\pi^+\pi^0$	5.3 ± 0.8	2.7 – 4.8	-7 ± 14	0	-2 ± 5
$\pi^0\pi^0$	1.90 ± 0.47	0.33 – 0.65			45 ± 60

† Belle: $-8.8 \pm 3.5 \pm 1.8$
BaBar $-10.7 \pm 4.1 \pm 1.2$

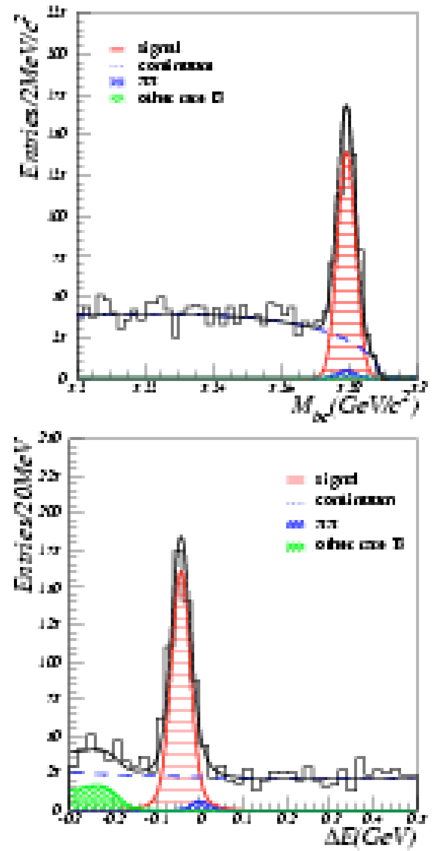
‡ Keum and Sanda hep-ph/0306004
Beneke and Neubert hep-ph/0308039

$B \to K^{\pm}\pi^{\mp}$ A_{CP} **Belle**

- $B \to K^{+}\pi^{-}$
  $N_{sig} = 559.2 \pm 26.3$



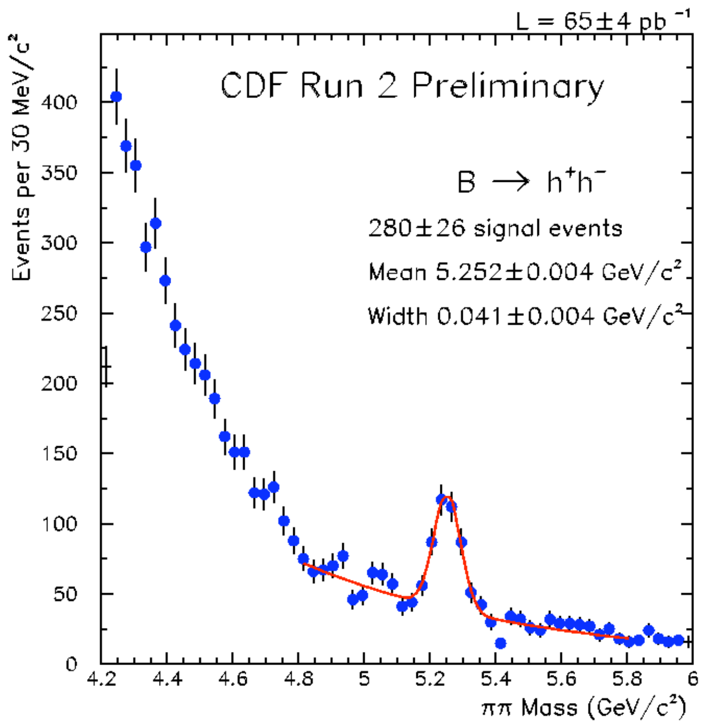
- $B \to K^{-}\pi^{+}$
  $N_{sig} = 470.6 \pm 24.2$



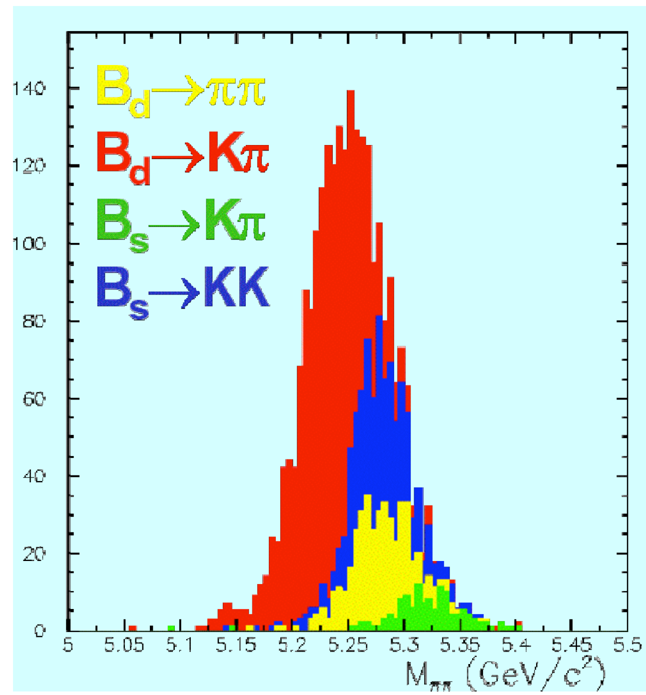
Disentangling the B□h+h- contributions (I)

B □ h±h- from hadronic trigger
Includes B_d □□□, B_s□KK, B_s□K □, and B_d□ K□

Monte-Carlo plot below shows:
B_d □ □+□□,Bs □ K+K- B_s □ K± □±,
& B_d □ K± □± (From Monte-Carlo)
all pile up in the same region



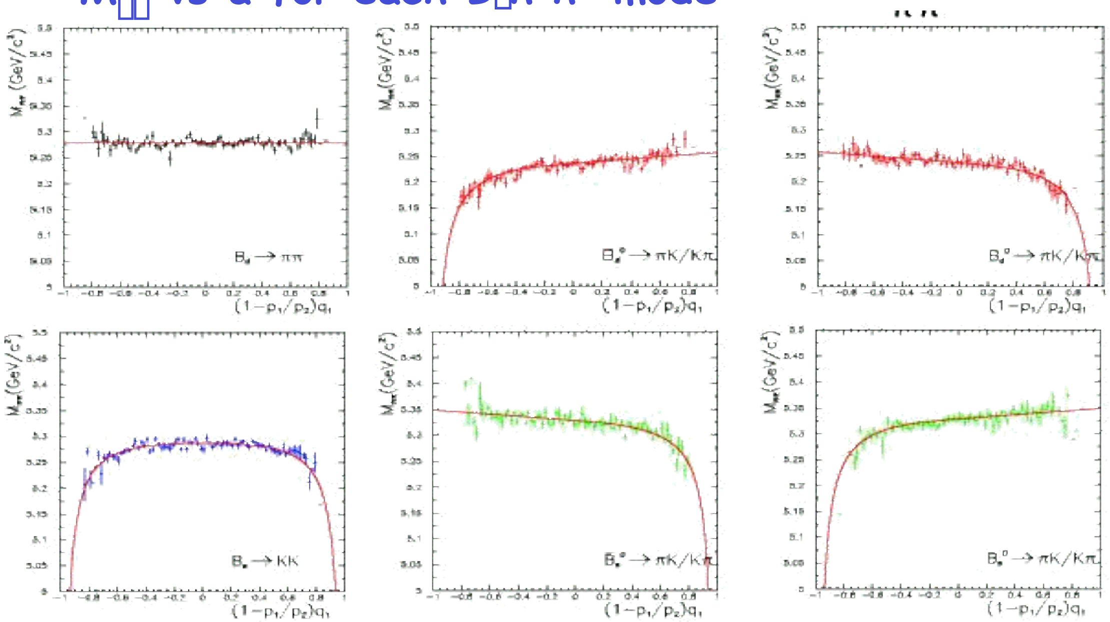
CDF



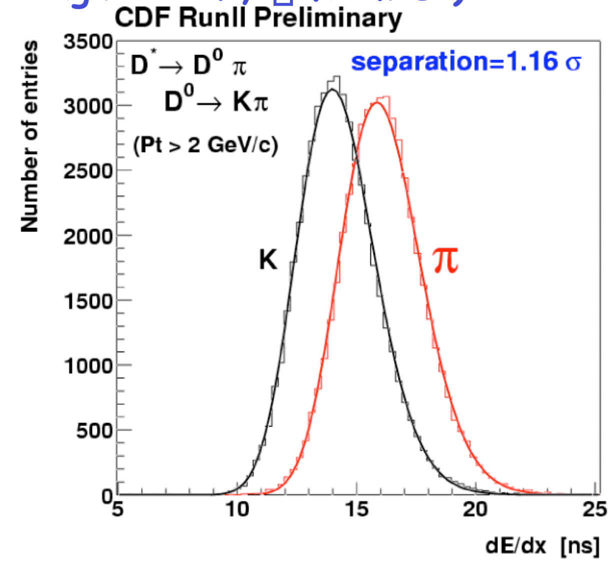
Must disentangle contributions from each mode
To do this we use:
-Kinematical variable separation $M_{□□}$ vs □=(1-p_1/p_2)·q_1
-dE/dx based K and □ identification

Disentangling the $B \to h^+h^-$ contributions (II)

$M_{\pi\pi}$ vs a for each $B \to h^+h^-$ mode



dE/dx calibration using $D^{*\pm} \to D^0\pi^\pm$, $D^0 \to K^\pm\pi^\pm$ (π from D^* unambiguously distinguishes K, π from D^0)



Sanity check: Measure Ratio of Branching Ratios

CDF : $\Gamma(B_d \to \pi^+\pi^-)/\Gamma(B_d \to K^+\pi^-) = 0.26 \pm 0.11 \pm 0.055$, PDG:

Yield for each mode:

$B_d \to \pi^+\pi^-$ 148±17

$B_d \to K^\pm \pi^\pm$ 39±14

$B_s \to K^\pm \pi^\pm$ 3±11

$B_s \to K^+K^-$ 90±17(stat) ±17(stat)

First observation !

CDF

Method works ! Confirmed by Sanity check against ratio of branching ratios

Have first observation of $B_s \to K^+K^-$

Its a CP Eigenstate: Can use this To measure γ_s as well !!

Disentangling the $B \to h^+h^-$ contributions (Blessed CDF results)

- $ACP(B_d \to K\pi) = 0.02 \pm 0.15(stat) \pm 0.017(syst)$

- $BR(B_d \to \pi\pi)/BR(B_d \to K\pi) =$

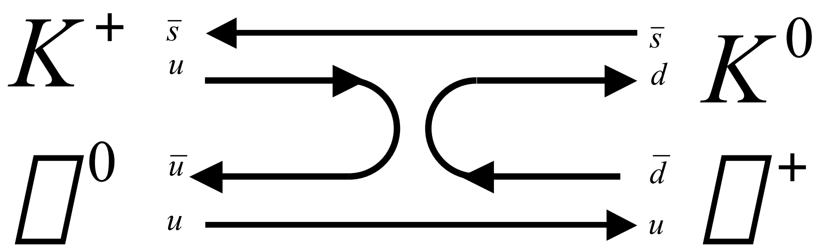
  $0.26 \pm 0.11(stat) \pm 0.055(syst)$

- $fs \times BR(B_s \to KK)/fd \times BR(B_d \to K\pi) =$

  $0.74 \pm 0.20(stat) \pm 0.22(syst)$

- Yield of $B_s \to KK = 90 \pm 17(stat) \pm 17(syst)$

Is Rescattering Important?



BF(10^{-6})

	BaBar	P_QCD*
K^+K^-	<0.6	0.05
K^+K^0	<2.2	1.7
$K^0\overline{K}^0$	<1.6	1.8

*Chen and Li, Phys. Rev D63, 014003 (2000)

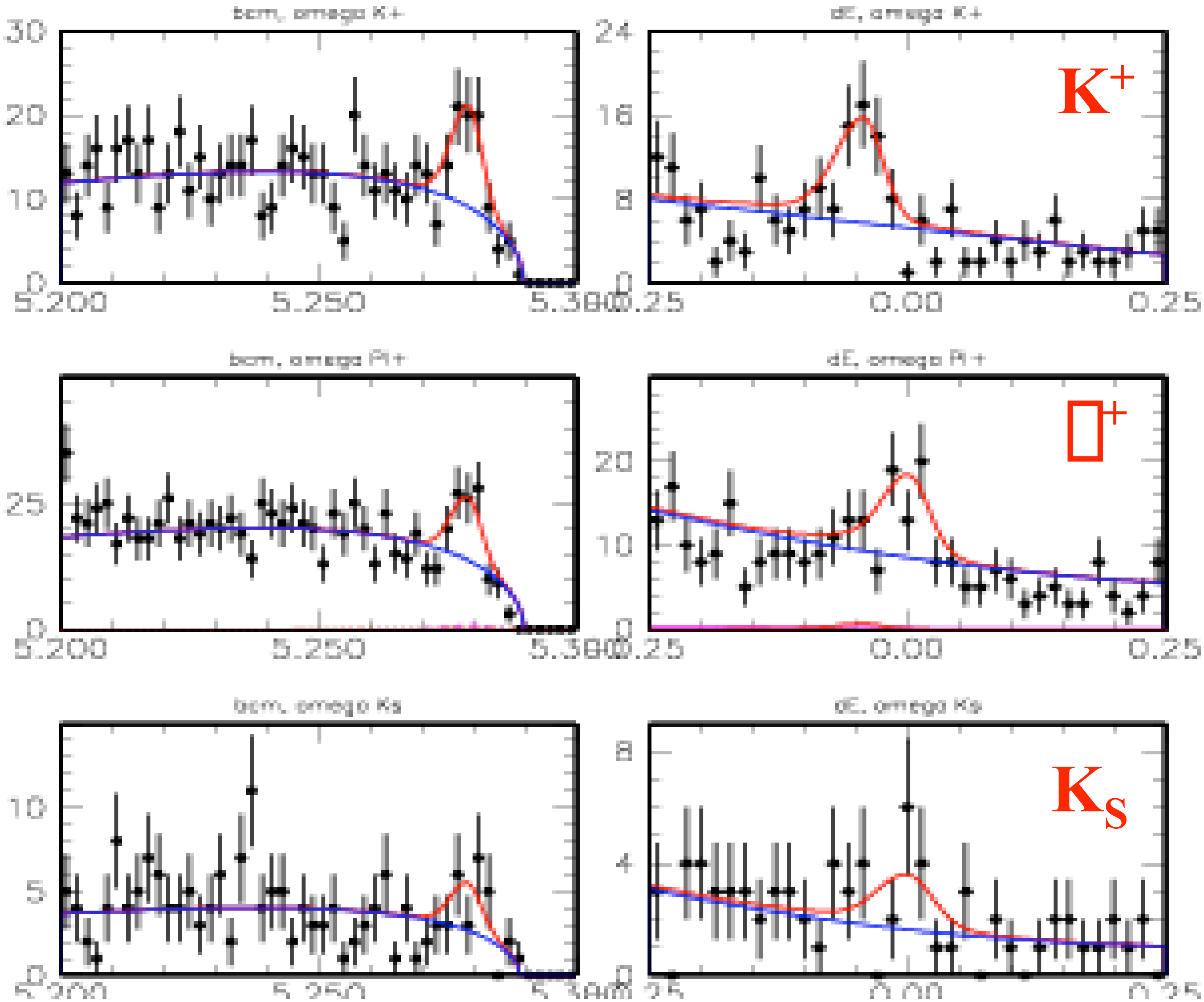
- Could modify branching fractions and CP asymmetries in □□ and K□ decays, complicating extraction of □ and □
- KK decays are more sensitive to rescattering
  - Could have significant enhancement through (for example) DD or □□ intermediate states

No sign of rescattering (FSI) yet

BF & A_{CP} for B □ □□, □K, □□, □K

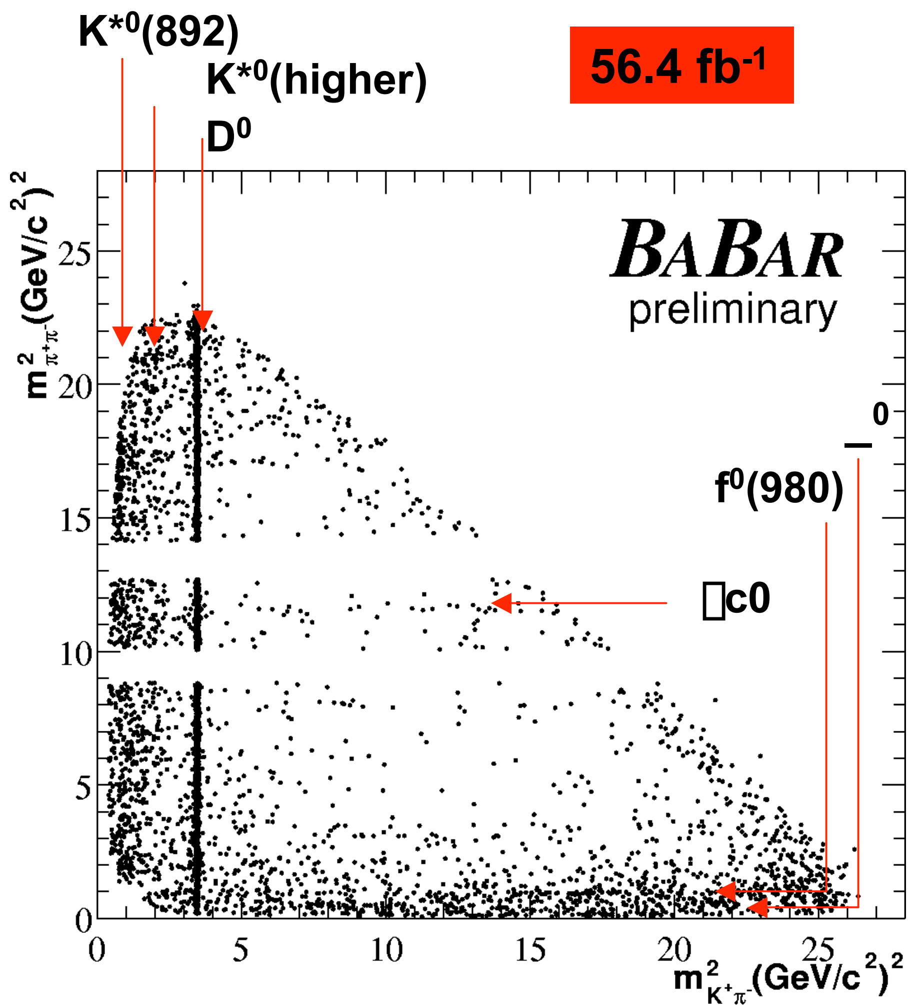
Mode	BF (10^{-6}) (BaBar)	BF (10^{-6}) (Belle)	A_{CP} % (BaBar)	A_{CP} % (Belle)
B^0 __ __$^+$ π^-	**22.6 ± 2.8**	**29.1 ± 6.4**	**-11 ± 7**	**-38 ± 21**
B^0 __ __$^+$ K^-	**7.3 ± 1.8**	**15.1 ± 4.1**	**19 ± 18**	**22 ± 23**
B^0 __ __^{0} π^0	**< 2.5**	**6.0 ± 3.1**		
B^+ __ __$^+$ π^0	**11.0 ± 2.7**		**23 ± 17**	
B^+ __ __^{0} π^+	**9.3 ± 1.3**	**8.0 ± 2.3**	**-17 ± 11**	
B^+ __ __^{0} K^+	**< 6.2**	**< 12**		
B^0 __ __ K^0	**5.3 ± 1.4**	**< 7.6**		
B^+ __ __ K^+	**5.0 ± 1.1**	**6.7 ± 1.4**	**-5 ± 16**	**6 ± 20**
B^0 __ __ π^0	**< 3**			
B^+ __ __ π^+	**5.4 ± 1.1**	**5.9 ± 1.5**	**4 ± 17**	**48 ± 23**

Belle B □ □ □, K



bcm, omega K+
dE, omega K+
bcm, omega Pi+
dE, omega Pi+
bcm, omega Ks
dE, omega Ks
K+
□+
KS
5.200
5.250
0.00
0.25

BaBar: B □ K□□ Dalitz Plot



Branching Fractions 10^{-6}

B+ □ K*0(892)□+, K*0□ K+ □-	$10.3 \pm 1.2^{+1.0}_{-2.7}$
B+ □ f0(980)K+, f0 □ □+□	$9.2 \pm 1.2^{+2.1}_{-2.6}$
B+ □ □c0 K+, □c0 □ □+□	1.46±0.35±0.12
B+ □ D0□+, D0 □ K+ □-	184.6±3.2±9.7
B+□ higher K*0□+, K*0□ K+□-	$25.1 \pm 2.0 +^{11.0}_{-5.7}$
B+ □ □0(770)K+, □0 □ □+□	< 6.2
B+ □ K+ □- □+ (non resonant)	< 17
B+ □ higher fK+, f □ □+□	<12

Belle: Dalitz Plot Amplitude Analysis

140 fb^{-1} $B^+ \to K^+K^+K^-$ (Signal 1400) and $K^+\pi^+\pi^-$ (Signal 2584)

Resonances:

$K^+\pi^+\pi^-$ $K^*(890)$, $K^*(1430)$, $\rho(770)$, $\chi_{c0}(3400)$, $f_0(980)$, X(1350)

$K^+K^+K^-$ $\phi(1020)$, $\chi_{C0}(3400)$, X(1500)

Background parameterisation – fitted with large (7*) sideband sample

$$A_{BG} = \sum_k \alpha_k e^{-\beta s_{ij}} + BW(K^*) + BW(\rho)$$

Signal parameterisation – fix masses, widths except X, f_0

$$A_{Signal} = \sum_R a_R e^{i\delta_R} + \left[\frac{a_1}{s_{12}^p} e^{\phi_1} + \frac{a_2}{s_{23}^p} e^{\phi_2} \right]_{NonRes}$$

Fit to signal + background and determine amplitudes and phases

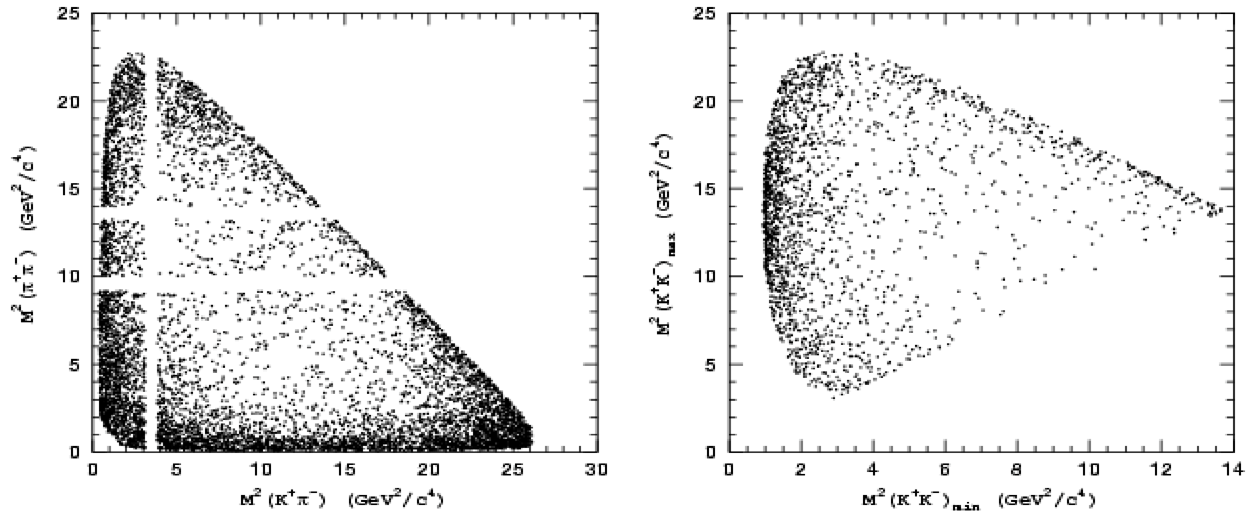


FIG. 7: Dalitz plots for events in the $\Delta E - M_{\rm bc}$ sidebands for the $K^+\pi^+\pi^-$ (left) and $K^+K^+K^-$ (right) final states.

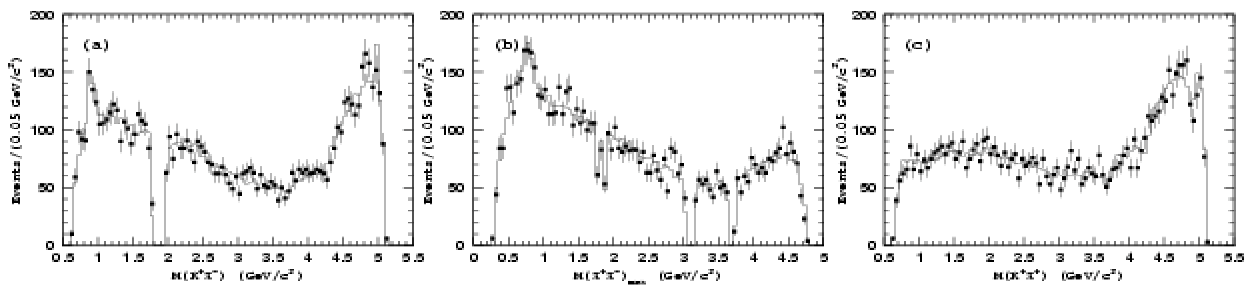


FIG. 8: Results of the best fit to the $K^+\pi^+\pi^-$ events in the $\Delta E - M_{\rm bc}$ sidebands shown as projections onto two-particle invariant mass squared variables. Points with error bars are data, histograms are fit results.

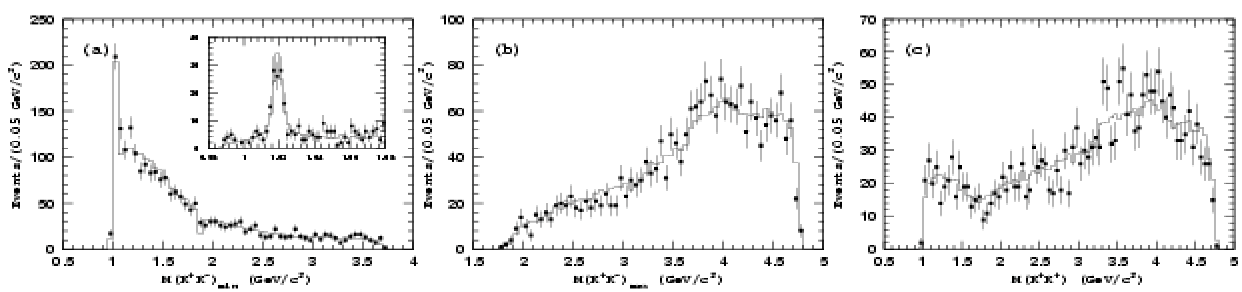
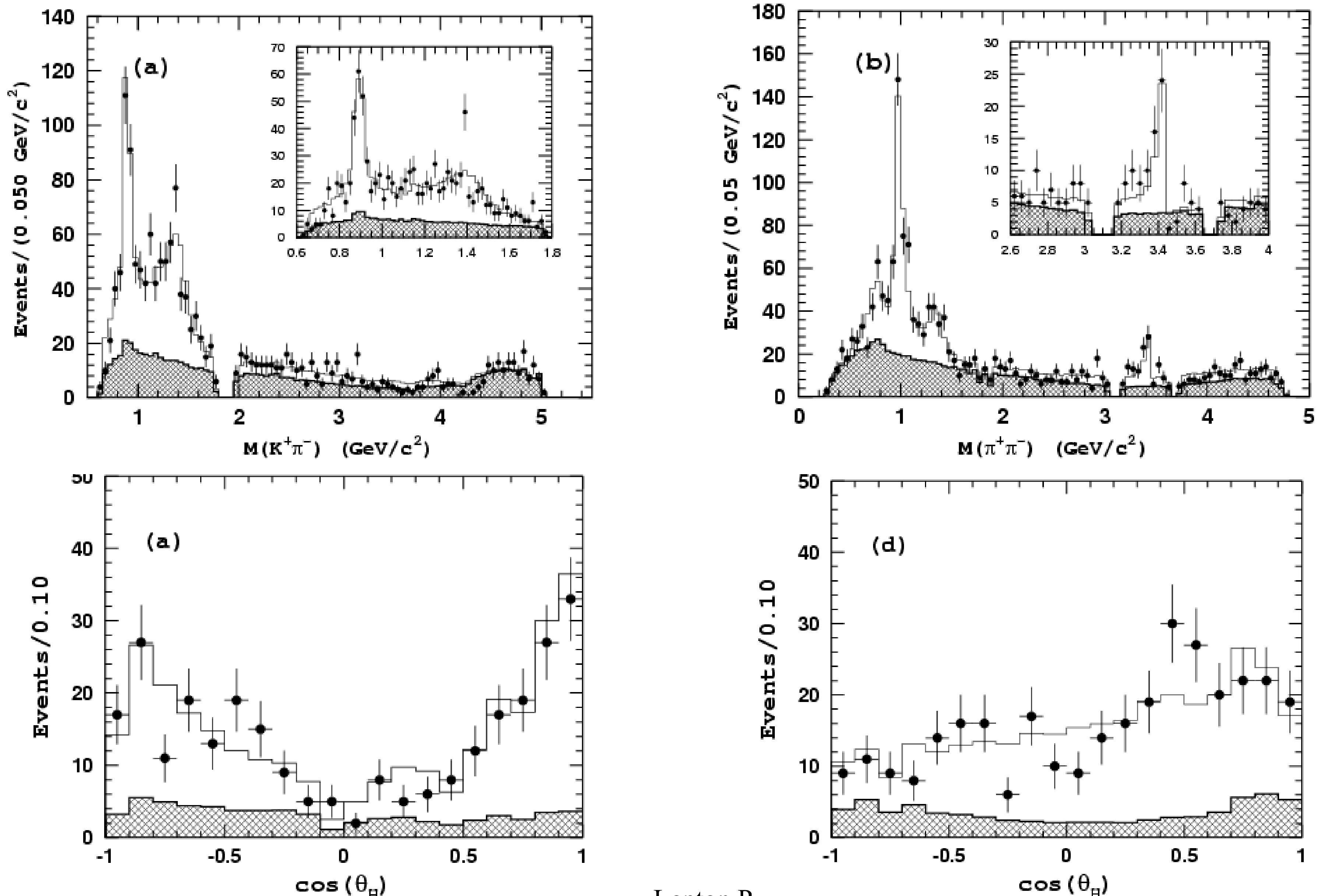


FIG. 9: Results of the best fit to the $K^+K^+K^-$ events in the $\Delta E - M_{\rm bc}$ sidebands shown as projections onto two-particle invariant mass squared variables. Points with error bars are data, histograms are fit results. The inset in (a) shows the $\phi(1020)$ mass region in 4 MeV^2/c^4 bins.

Belle DP Mass and Helicity Projections K



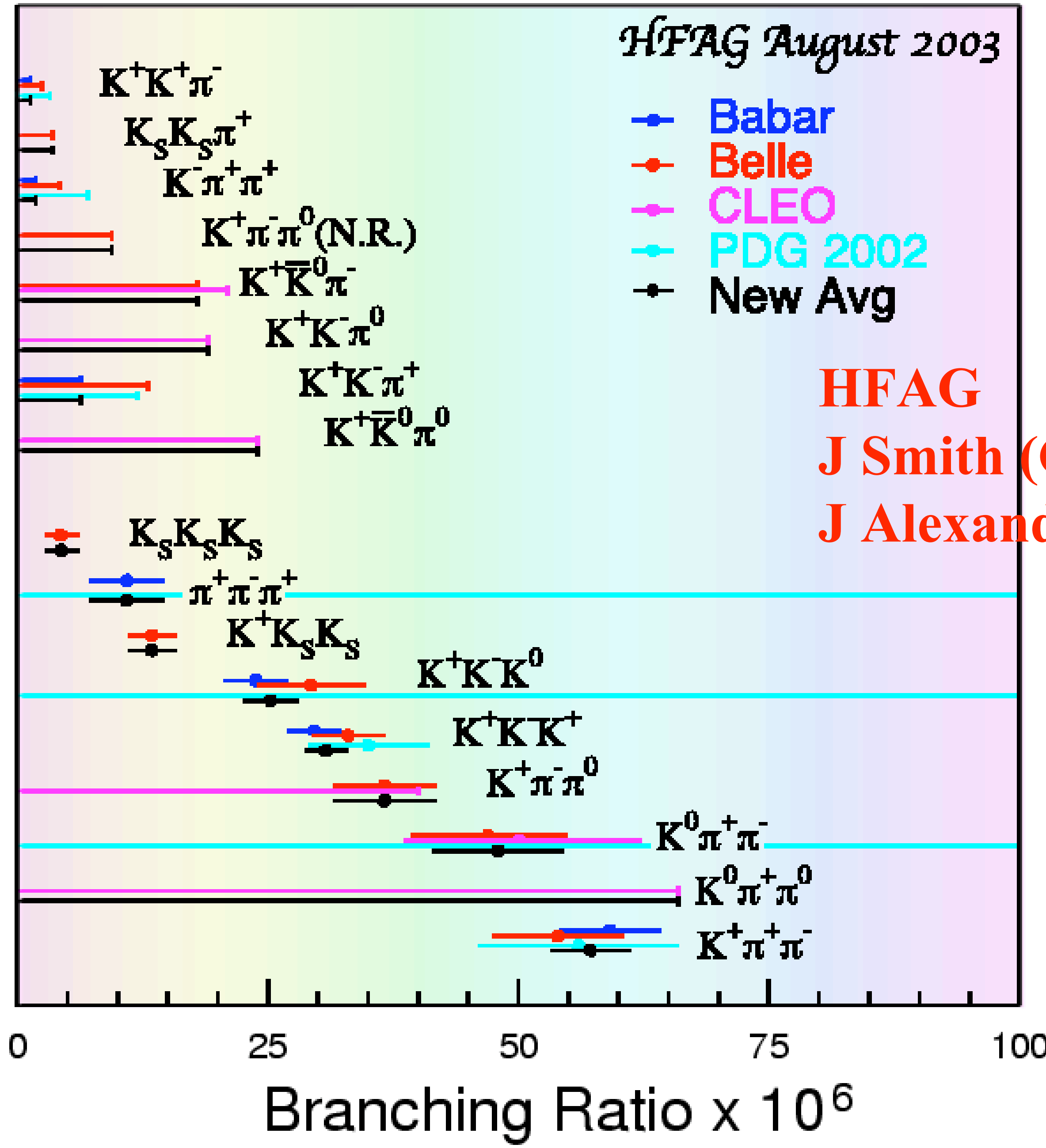
Lepton P

Belle Branching Fractions from Dalitz Plot

Table 7: Summary of branching fraction results. The first quoted error is statistical, the second is systematic and the third is the model error.

Mode	$\mathcal{B}(B^+ \to Rh^+) \times \mathcal{B}(R \to h^+h^-) \times 10^6$
$K^+\pi^+\pi^-$ charmless total	$45.5 \pm 2.1^{+4.4+0.5}_{-3.8-0.2}$
$K^*(892)^0\pi^+$, $K^*(892)^0 \to K^+\pi^-$	$5.67 \pm 0.60^{+0.54+0.56}_{-0.46-0.33}$
$K_0^*(1430)\pi^+$, $K_0^*(1430) \to K^+\pi^-$	$25.0 \pm 1.6^{+2.4+0.0}_{-2.1-1.5}$
	$(6.00 \pm 0.84^{+0.58+0.??}_{-0.52-0.??})$
$K^*(1680)\pi^+$, $K^*(1680) \to K^+\pi^-$	< 5.3
$K_2^*(1430)\pi^+$, $K_2^*(1430) \to K^+\pi^-$	< 3.4
$\rho^0(770)K^+$, $\rho^0(770) \to \pi^+\pi^-$	$3.94 \pm 0.61^{+0.37+0.70}_{-0.32-0.23}$
$f_0(980)K^+$, $f_0(980) \to \pi^+\pi^-$	$10.3 \pm 1.1^{+1.0+0.2}_{-0.9-1.9}$
$f_2(1270)K^+$, $f_2(1270) \to \pi^+\pi^-$	< 3.5
Non-resonant	$13.5 \pm 1.7^{+1.3+6.3}_{-1.1-0.6}$
$K^+K^+K^-$ charmless total	$29.4 \pm 1.1^{+2.1+0.2}_{-2.1-0.0}$
ϕK^+, $\phi \to K^+K^-$	$4.24 \pm 0.37^{+0.31+0.00}_{-0.31-0.15}$
$f_2'(1525)K^+$, $f_2'(1525) \to K^+K^-$	$<?.?$
Non-resonant	$22.5 \pm 2.1^{+1.6+4.1}_{-1.6-0.9}$
$\chi_{c0}K^+$, $\chi_{c0} \to \pi^+\pi^-$	$1.17 \pm 0.29^{+0.11+0.25}_{-0.10-0.28}$
$\chi_{c0}K^+$, $\chi_{c0} \to K^+K^-$	$0.85 \pm 0.24^{+0.06+0.15}_{-0.06-0.00}$

B → 3 body, charmless



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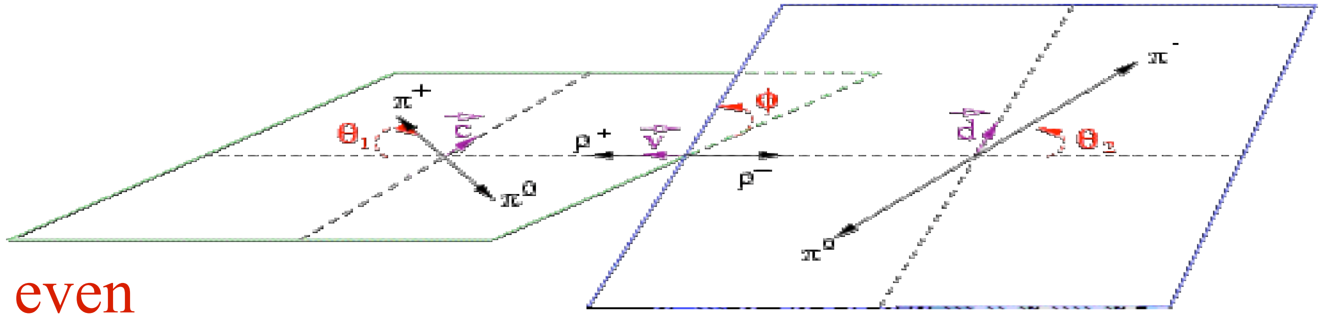
Longitudinal Polarisation B _ V V

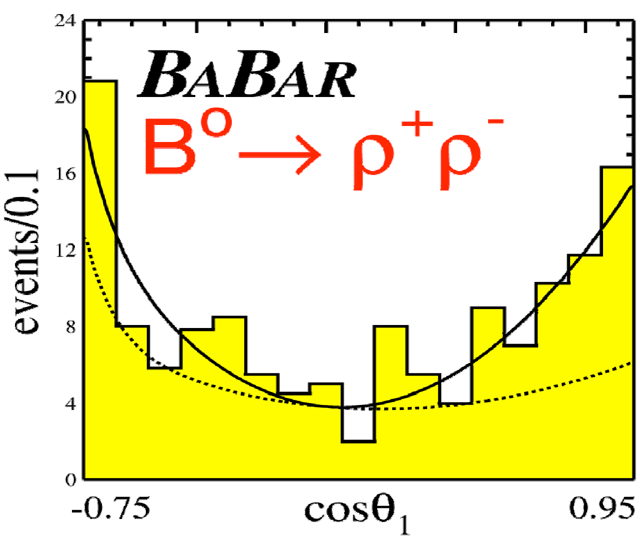
f_L = □$_L$ / □



100% Pol □ CP even

Expect: $f_L \sim 1 - O(M^2_V/M^2_B)$

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta_1 d\cos\theta_2} = \frac{9}{4}\left\{\frac{1}{4}(1-f_L)\sin^2\theta_1\sin^2\theta_2 + f_L\cos^2\theta_1\cos^2\theta_2\right\}$$



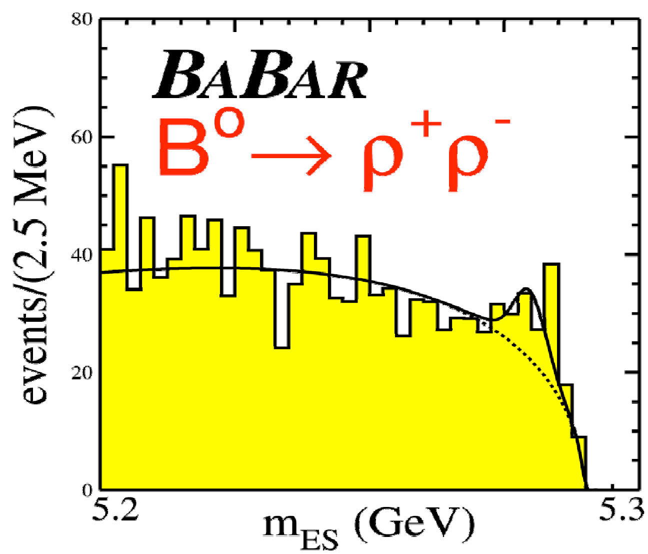
B^0 □ □$^+$ □$^-$

N_S = 93 ±22±9

BaBar [> 5□]

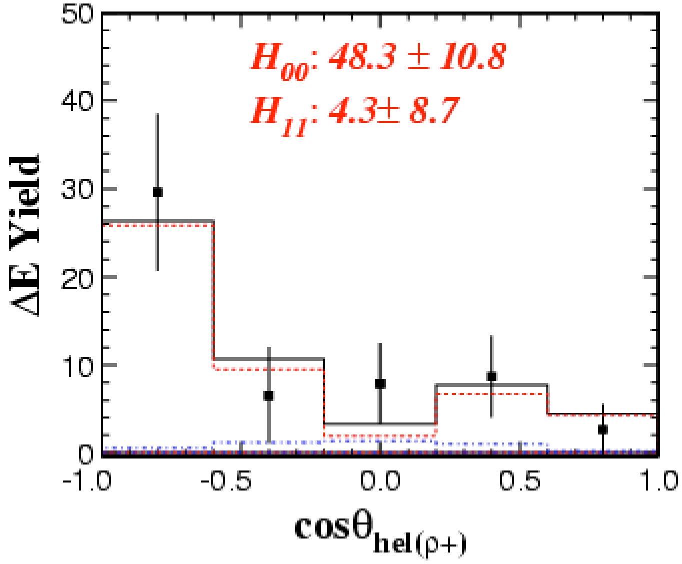
Cos(□$_1$) **M$_{ES}$**

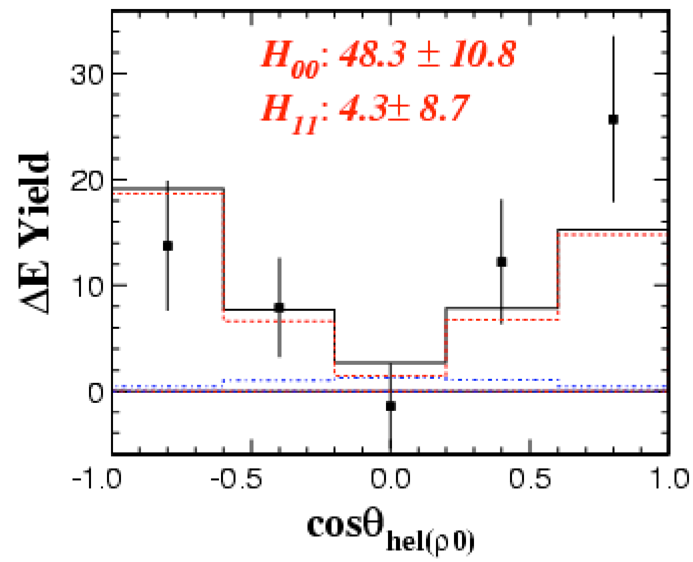
□ □

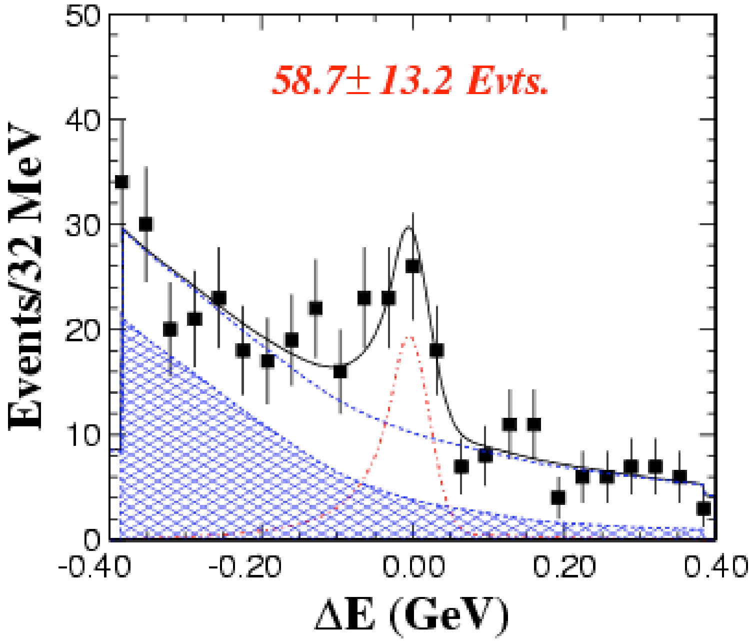


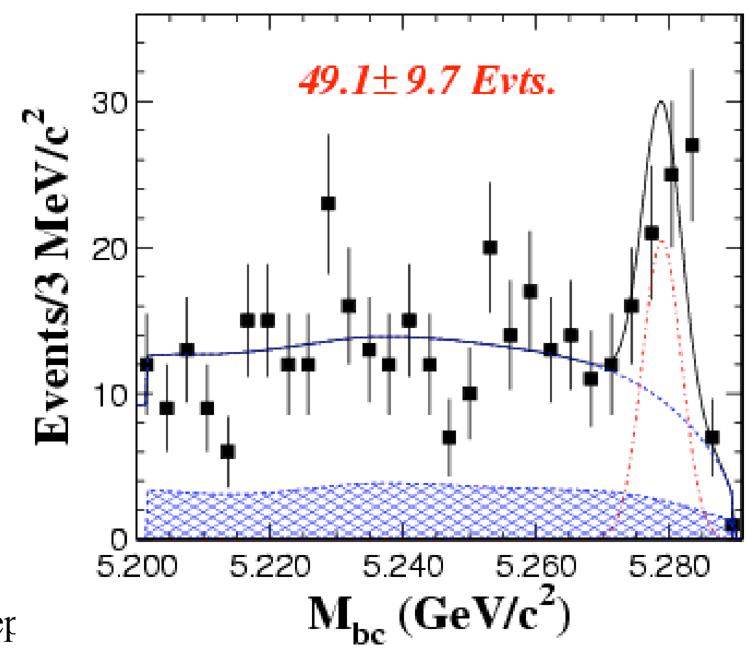
Belle

$B \to \rho^+ \rho^0$









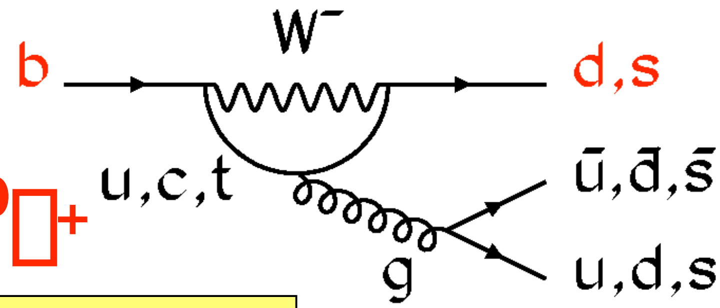
Lep

B _ _ _ and _ K^* [BaBar & Belle]

(Errors approximated)	BF (10^{-6})	A_{CP} %	Long. Poln %
B^0_ _^{0} _^{0}	< **2.1** (90 % CL)		
B^0_ _$^+$ _$^-$	**27 ± 7 ± 6**		**99 ± 7 ± 3**
B^+_ _$^+$ _^{0}	**22.5 ± 5.7 ± 5.8**	**-19 ± 23 ± 3**	**97 ± 7 ± 4**
Belle	**31.7 ± 7.1 ± 6.7**	**0 ± 22 ± 3**	**95 ± 11 ± 2**
B^+_ _^{0} K^{*+}	**10.6 ± 3.0 ± 2.4**	**20 ± 32 ± 4**	**96 ± 15 ± 4**

- CP asymmetries consistent with zero
- Polarisation in agreement with expectation

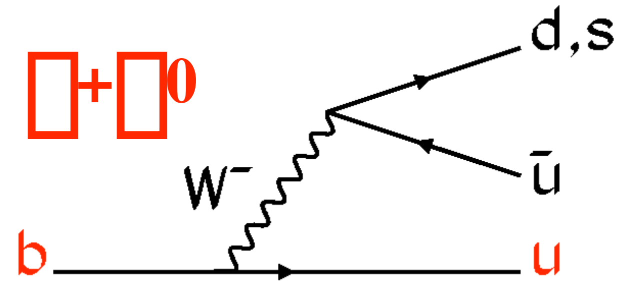
Why we need Theorists



K⁰□+

$V_{cb}^{*} V_{cs} \sim \square^2$

□+□0



$V_{ub}^{*} V_{ud} \sim \square^3$

Mode	CKM	$(f_{decay})^2$	Ratio	Exp Ratio	BF (10^{-6})
$K^0\square^+$	1	1	1	1	19.6
$K^{*0}\square^+$	1	1.85	1.85	0.65	12.7
$\square^+\square^0$	$\square^2$	0.66	0.03	0.27	5.3
$\square^+\square^0$	$\square^2$	1.71	0.085	0.46	9.1
$\square^+\square^0$	$\square^2$	2.9	0.145	1.35	26.4

The VPSTE effect (Form factor corrections at 40% level)

The unique decays B → $\pi^0\pi^0$ and $\rho^0\rho^0$

BF give model-independent limits to the CP angle α

Grossman Quinn bound
PRD 58 (1998) 017504

$$\sin^2(\alpha-\alpha_{Eff}) < \frac{BF(B^0\to\pi^0\pi^0)}{BF(B^0\to\pi^+\pi^-)};\ or < \frac{BF(B^0\to\rho^0\rho^0)}{BF(B^0\to\rho^+\rho^-)}$$

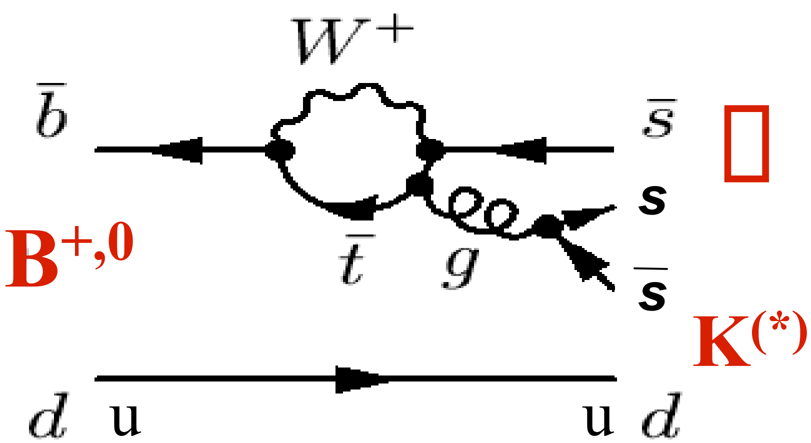
$$\sin^2(\alpha-\alpha_{Eff})_{\pi\pi} < \frac{1.9\pm0.45}{4.55\pm0.45} \approx 0.55(90\%CL)$$

$$\sin^2(\alpha-\alpha_{Eff})_{\rho\rho} < \frac{<2.1}{27\pm8} \approx 0.10(90\%CL)$$

$|\alpha - \alpha_{Eff}| < 50^o$ (ππ) and $< 20^o$ (ρρ) at 90% CL

$\rho^+\rho^-$ is dominantly longitudinal polarised, CP-even final state

B □ □K$^{(*)}$ BaBar & Belle

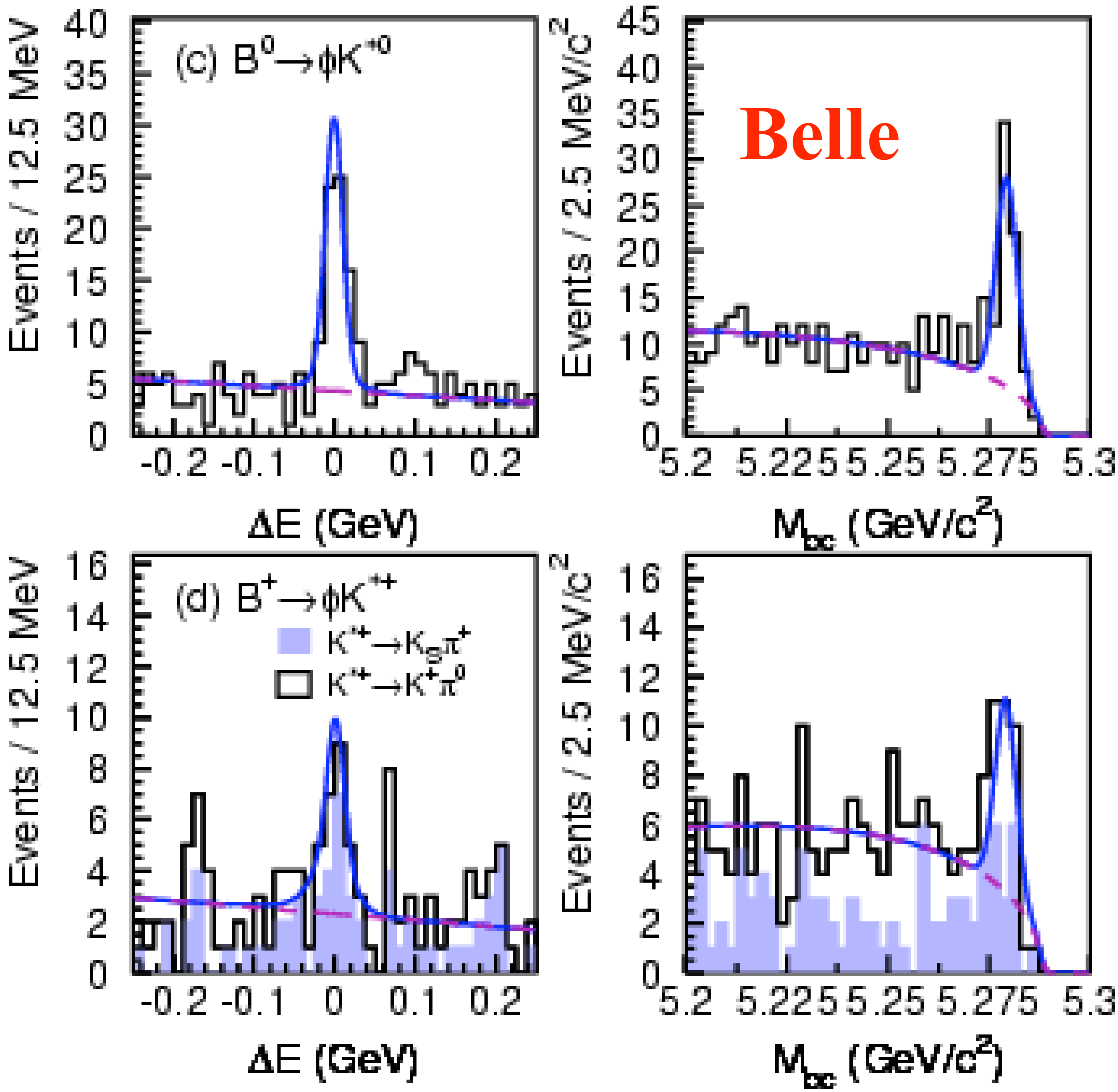


- Expect similar BF all modes
- BF(□□$^+$) < 4 10^{-7} [90% CL]

No indication for rescattering – as KK

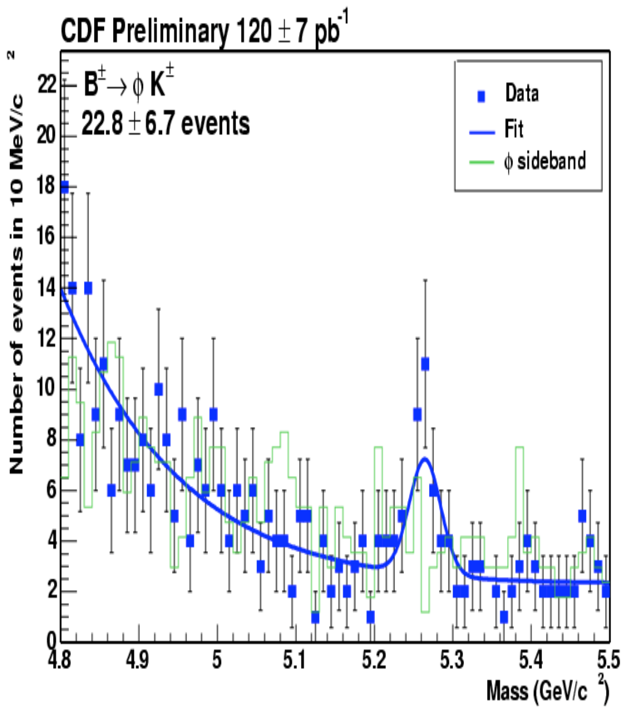
- Polarisation unexpectedly small

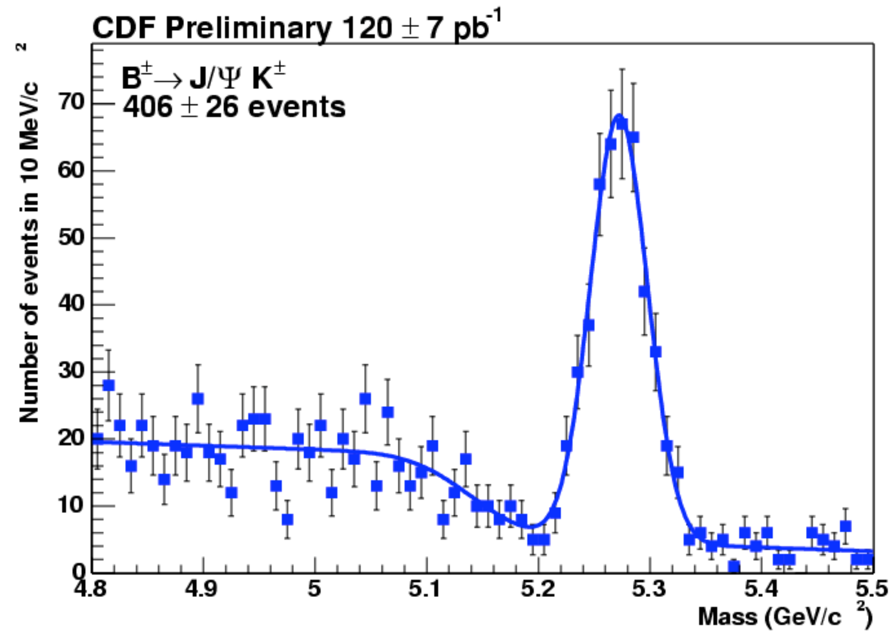
Mode	BF (10^{-6})	A_{CP} (%)	Polarisation %
□K^0	7.6 ± 1.4 9.0 ± 2.2		
□K$^+$	10.0 ± 1.0 9.4 ± 1.3	4 ± 9 1 ± 13	
□K^{*0}	11.2 ± 1.5 10.0 ± 1.8	4 ± 12 7 ± 16	65 ± 7 43 ± 10
□K^{*+}	12.7 ± 2.4 6.7 ± 2.2	16 ± 17 -13 ± 31	46 ± 12



(c) B⁰→φK*⁰
Belle
Events / 12.5 MeV
Events / 2.5 MeV/c²
ΔE (GeV)
M_bc (GeV/c²)
(d) B⁺→φK*⁺
K*⁺→K_Sπ⁺
K*⁺→K⁺π⁰
-0.2 -0.1 0 0.1 0.2
5.2 5.225 5.25 5.275 5.3

BR($B^{\pm}\rightarrow \phi K^{\pm}$) at CDF





- BR($B^{\pm}\rightarrow \phi K^{\pm}$) /BR($B^{\pm}\rightarrow J/\psi\ K^{\pm}$) = 0.0068 ±0.0021 (*stat.*) ± 0.0007 (*syst.*)

Using PDG 2002 for BR($B^{\pm}\rightarrow J/\psi\ K^{\pm}$):

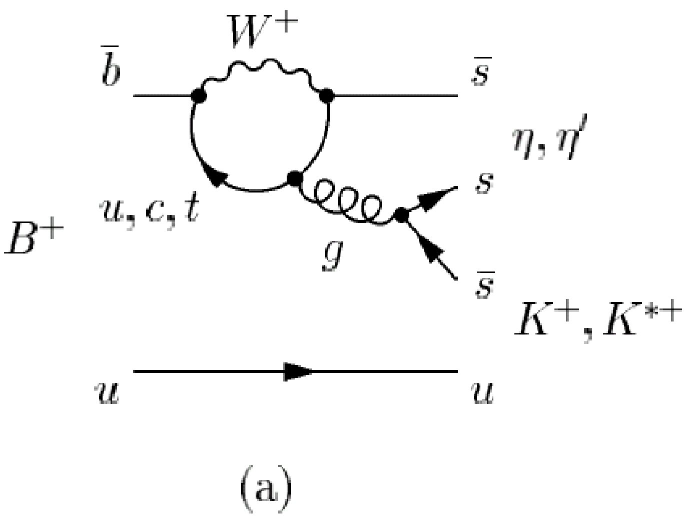
- BR($B^{\pm}\rightarrow \phi K^{\pm}$) = (6.9 ± 2.1 (*stat.*) ± 0.8 (*syst.*)) x 10^{-6}

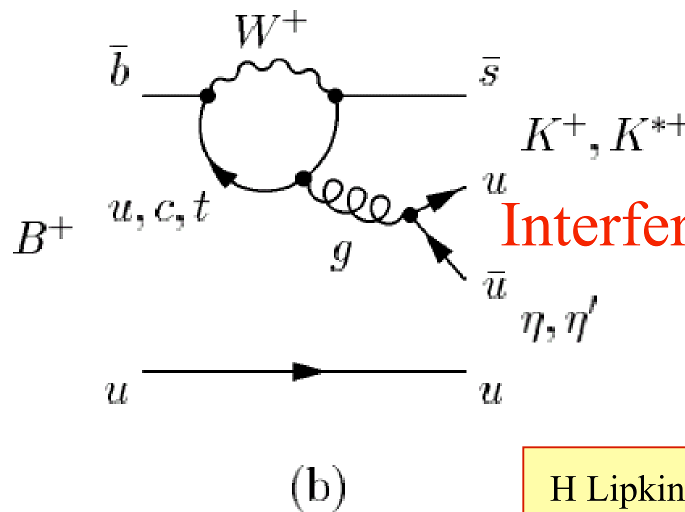
B □ □$^{(')}$K$^{(*)}$ and □$^{(')}$□, □ BaBar and Belle

Mode	BF (10^{-6}) Belle	BF (10^{-6}) BaBar
□ K^+	5.3 ± 1.9	2.8 ± 0.8
□ K^0		< 4.6
□' K^+	78 ± 11	76.9 ± 5.6
□' K^0	68 ± 13	55.4 ± 6.6
□ □$^+$	5.4 ± 2.1	4.2 ± 1.0
□' □$^+$	< 7	2.8 ± 1.3 3.4 □
□ □^{0}	< 5.5	

Mode	BF (10^{-6}) Belle	BF (10^{-6}) BaBar
□ K^{*+}	26.5 ± 8.4	25.7 ± 4.2
□ K^{*0}	16.5 ± 4.8	19.0 ± 2.6
□' K^{*+}	< 90	< 12
□' K^{*0}	< 20	< 6.4
□ □$^+$	< 6.2	10.5 ± 3.4 4.8 □
□' □$^+$		14.0 ± 5.4 3.8 □
□' □^{0}	< 14	

Theoretical background: □$^{(')}$ K, K^* modes





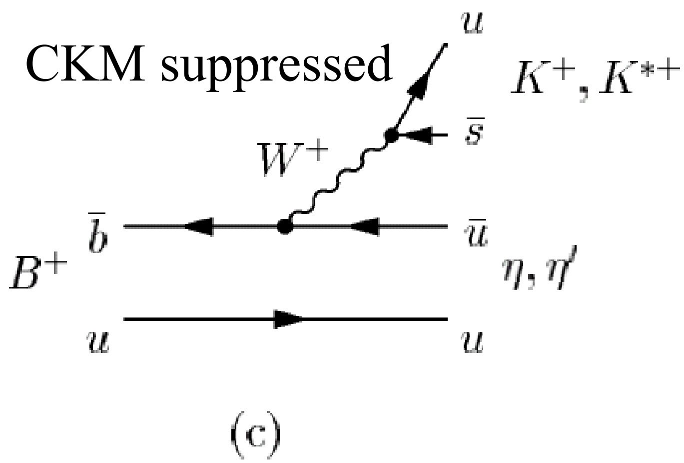
Interference □

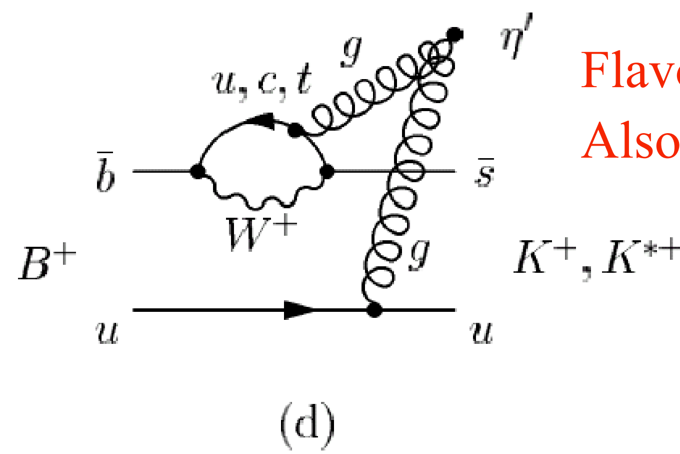
□□K, □$K*$ enhanced

□K, □□$K*$ suppressed

H Lipkin Phys Lett B254 (1991) 247

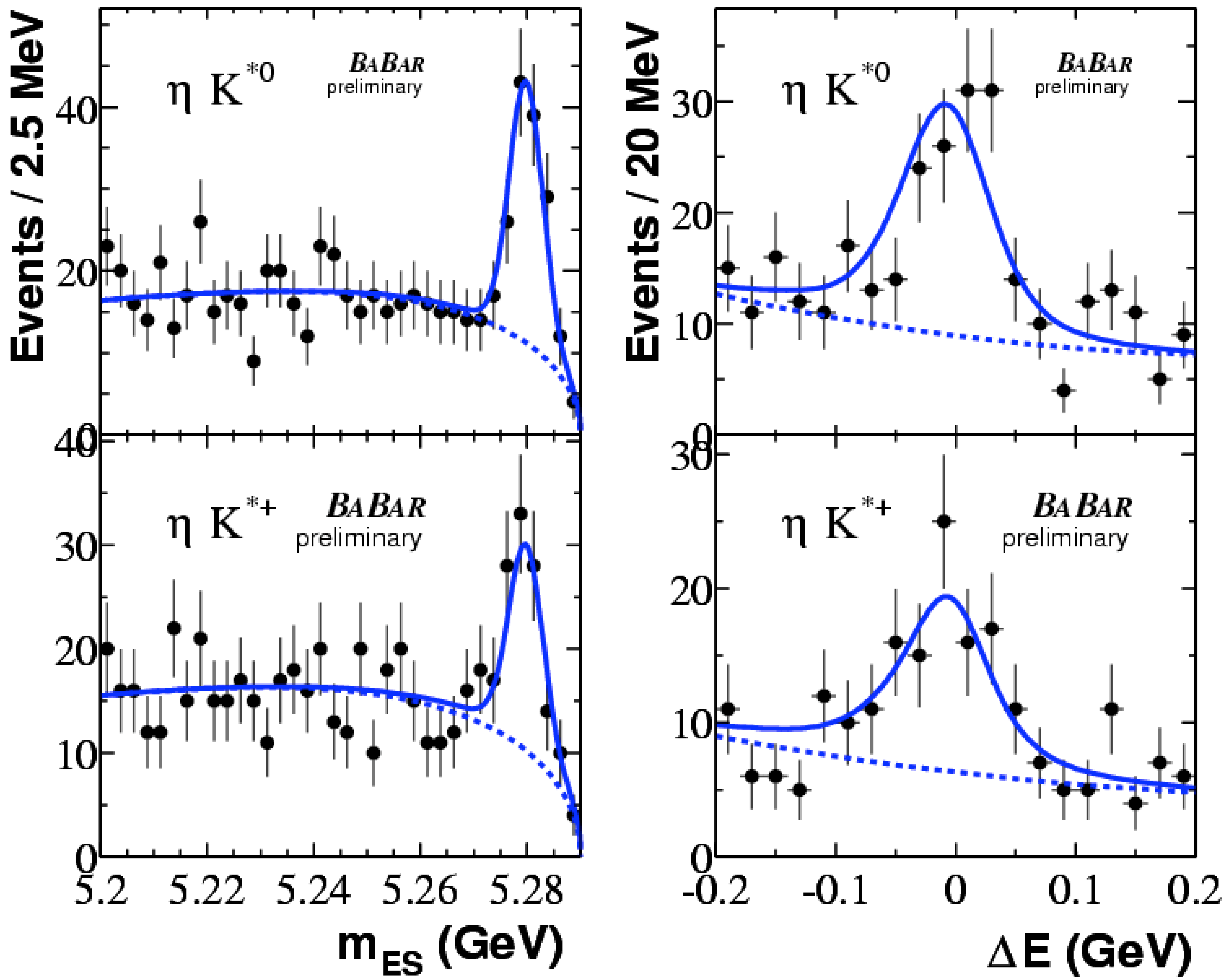
CKM suppressed





Flavour singlet diagram:
Also important for □□$K*$

Similarly for K^0, K^{*0} except no external tree


η K*0
BABAR
preliminary
η K*+
BABAR
preliminary
Events / 2.5 MeV
Events / 20 MeV
m_ES (GeV)
ΔE (GeV)
5.2
5.22
5.24
5.26
5.28
-0.2
-0.1
0
0.1
0.2
0
10
20
30
40

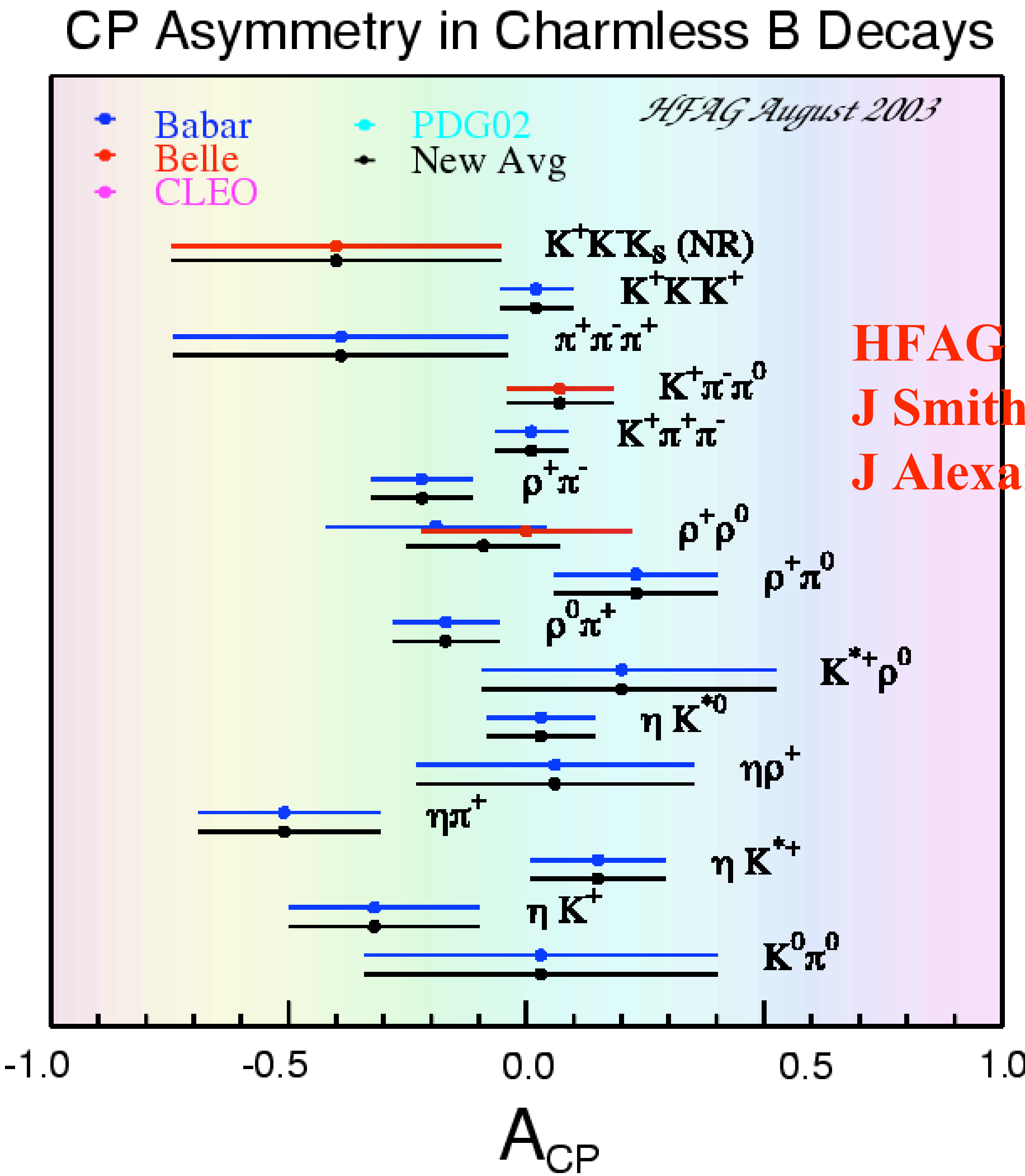
B □ □$^{(')}$K$^{(*)}$ and □□, □□ BaBar and Belle

Mode	A_{CP} (%) Belle	A_{CP} (%) BaBar
□ K^+		-32 ± 22
□ K^0		
□' K^+	-2 ± 7	4 ± 5
□' K^0		
□ □$^+$		-51 ± 20

Mode	A_{CP} (%) Belle	A_{CP} (%) BaBar
□ K^{*+}		15 ± 14
□ K^{*0}		3 ± 11
□' K^{*+}		
□' K^{*0}		
□ □$^+$		6 ± 29

Large asymmetry predicted for □□$^+$, small for □□$^+$

Chiang, Gronau, Luo, Rosner and Suprun [hep-ph/0307395]



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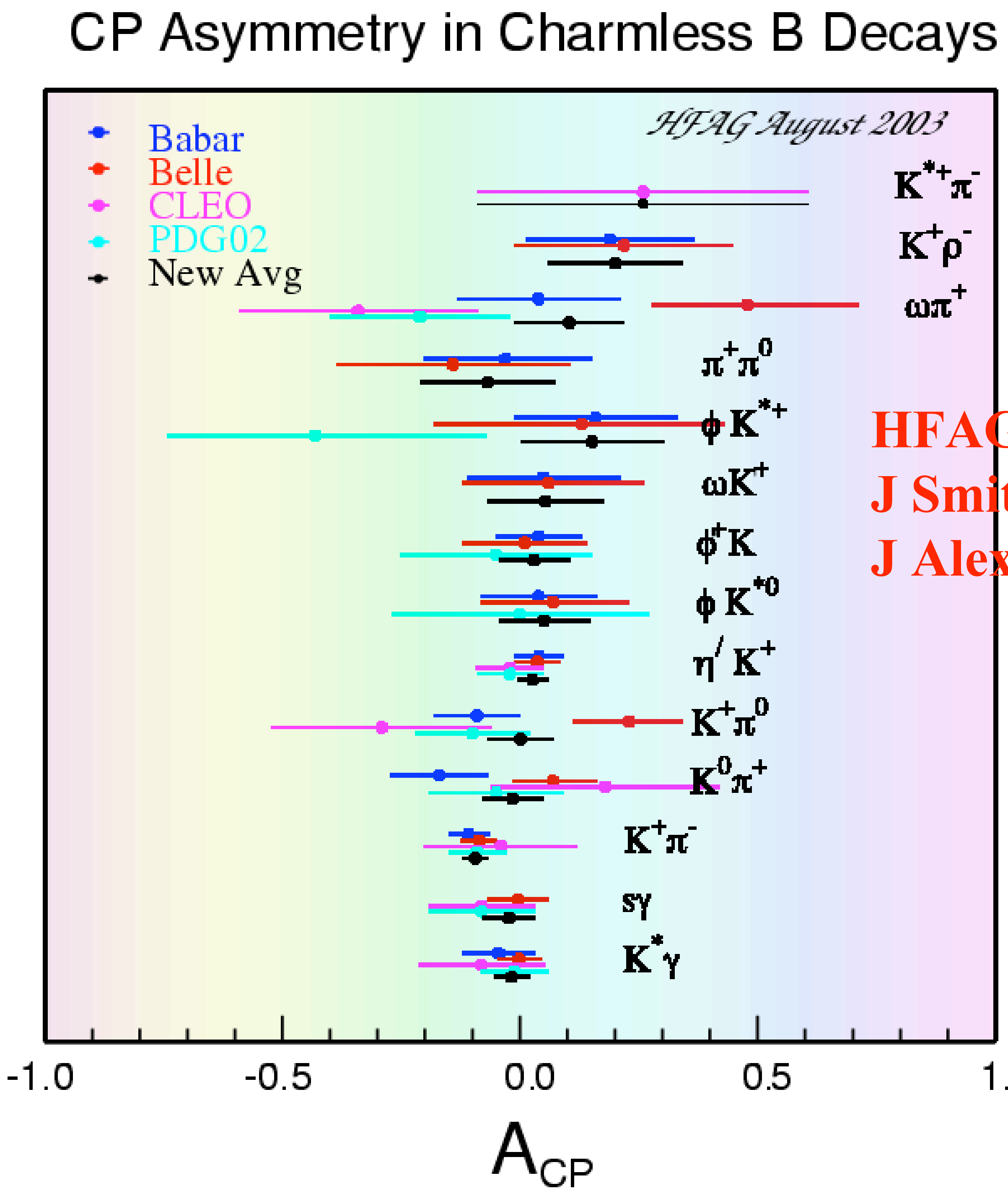

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How does theory stack up?

- Good phenomenological understanding of Branching Fractions for 2-body PP and PV decays
  [Chiang et al hep-ph/0307395; Beneke et al hep-ph/0308039; Keum et al hep-ph/0306004]

- Factorisation models give insight into dynamics, but:
  - BF for $\pi^0 \pi^0$ looks to be in disagreement with all predictions
  - BF for ηK, $\eta' K$, ηK^* final states underestimated in QCDF

  [Annihilation contribution may be too large Aleksan et al, hep-ph/0301165]

- Asymmetry data is not yet precise enough to test models

- There is still a considerable role for model-independent theoretical calculations

When is it safe to claim New Physics?

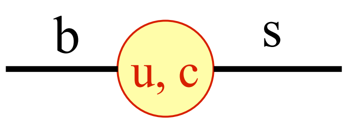
For B^0 □ □K_S, □'K_S, $K^+K^-K_S$ we expect to measure:

S = sin(2□) + □, C = □, where □ = O (□^{2})

If S and C are measured precisely (□S, □C << □^{2} = 0.05)

Claim new physics if: |C| > 5□, or |S- sin(2□)| > 5□

□ might be enhanced:



$$□ \; □ \frac{V_{ub}^{*}V_{us}}{V_{cb}^{*}V_{cs}} \frac{a^u}{a^c} = O(□^2)$$

u-amplitude might be large

Grossman bounds □ using isospin relations and ratios of BFs.

□($K^+K^-K_S$) □ 0.2, □(□'K_S) □ 0.5

GLNQ Hep-ph / 0303171

Must measure □ 20 BFs precisely to improver the limit on □!

Summary – What have we learned?

- Precision measurements of branching fractions are testing factorisation models – to destruction??
- Precise measts of A_{CP} will enable further tests of models. Is there a hint of a signal in K^+□$^-$?
- B □ □K, □K^*, □'K, □'K^* are now almost understood, but polarisation << 100% in □K^* is a puzzle
- Measuring the BF for □^{0} □^{0} is a triumph, but the value is surprisingly high. Increased focus on □^{0}□^{0} for |□ - □$_{eff}$|
- Measurement of many more decay modes is needed to make model-independent tests of NP meaningful
- The expected increase in luminosity of the B Factories promises a continuing, rich harvest of physics