The Experimental Status of Three-Body Charmless B-Decays

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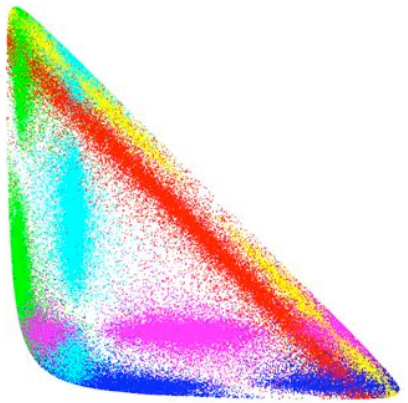


Introduction

- Goal: provide a snapshot of our experimental knowledge of charmless 3-body decays
- 4 different levels of measurement:
  - "unmeasured" → self-explanatory
  - "inclusive" → all resonance structure is disregarded; just measure the total rate to the 3-body final state
  - "Q2B" → 3-body final state is measured in a 2-body way…e.g. $B^0 \rightarrow$ "$\rho^+\pi^-$" $\rightarrow \pi^+\pi^-\pi^0$
    - interference effects are ignored to first order
  - "Dalitz" → full amplitude fit has been performed
- Color code numbers…Inclusive vs. Q2B vs. Dalitz
- I'll show both final and ***preliminary*** results…I'll try to keep with preliminary numbers in bold-italics

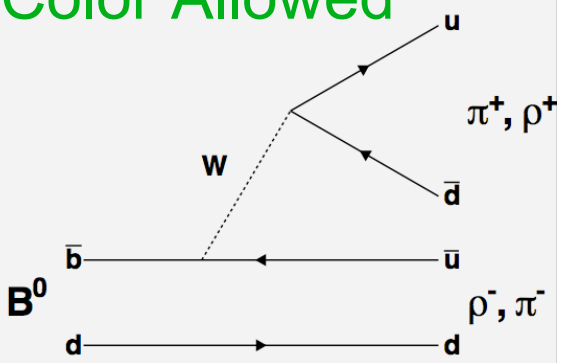
B→ππ**π Decays**

- related to CKM angle α
- involve either a b→u or b→d transition

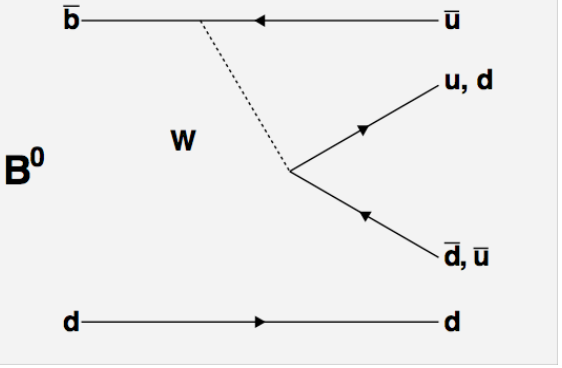
3 diagrams dominate…

- color allowed tree
- color suppressed tree
- b→d penguin

Color Allowed

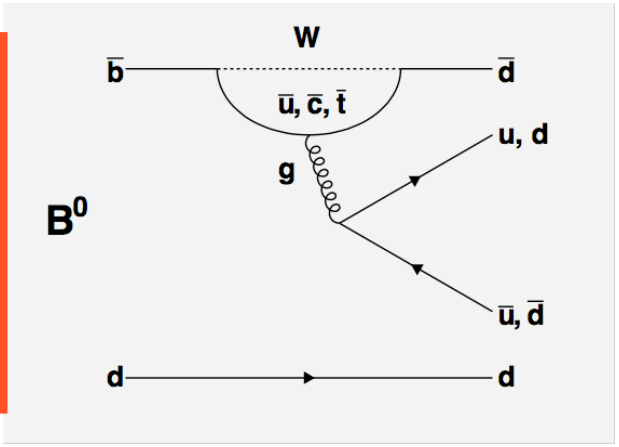


Color Suppressed

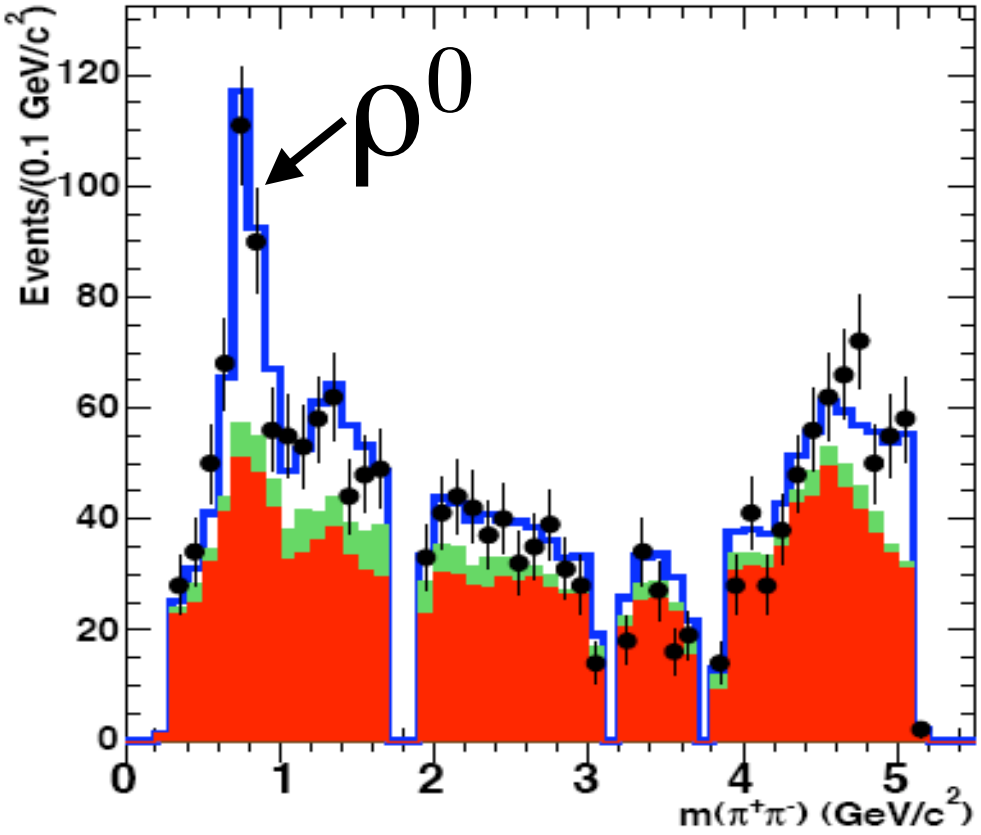


$B^0 \to \rho^0\pi^0$ and $B^+ \to \rho^+\pi^0$ can only go via CS or penguin decays; give us insight into the size of these contributions

Penguin



$B^+ \to \pi^+\pi^-\pi^+$ Dalitz Analysis



The 3π Dalitz plot isn't very busy… mainly just the ρ

- Red → qqbar
- Green → bbbar
- Blue → Signal Model
- Points → Data

$B^+ \to \pi^+\pi^-\pi^+$ Results

Mode	BaBar BR (10^{-6}) A_{CP}	Belle BR (10^{-6}) A_{CP}
Inclusive	16.2 ± 1.2 ± 0.9 -0.01 ± 0.08 ± 0.03	----------
$\rho^0(770)\pi^+$	8.8 ± 1.0 ± 0.8 -0.07 ± 0.12 ± 0.05	8.0 ± 2.2 ± 0.7
$\rho^0(1450)\pi^+$	<2.3	----------
$f_0(980)\pi^+$	<3.0	----------
$f_2(1270)\pi^+$	<3.5	----------
$f_0(1370)\pi^+$	<3.0	----------
NR*	<4.6	----------

BaBar: 210 fb^{-1}
Belle : 29.4 fb^{-1}

BaBar: PRD **72**, 052002, 2005.
Belle : PLB **542**, 183, 2002.

$B^0 \to \pi^+\pi^-\pi^0$ (Q2B) Results

$$f_{Qtag}^{\rho^+\pi^-}(\Delta t) = (1 + A_{CP})\frac{e^{-|\Delta t|/\tau}}{4\tau}\left[1 + Q_{tag}(S + \Delta S)\sin(\Delta m \Delta t) - Q_{tag}(C + \Delta C)\cos(\Delta m \Delta t)\right]$$

$$f_{Qtag}^{\rho^-\pi^+}(\Delta t) = (1 + A_{CP})\frac{e^{-|\Delta t|/\tau}}{4\tau}\left[1 + Q_{tag}(S - \Delta S)\sin(\Delta m \Delta t) - Q_{tag}(C - \Delta C)\cos(\Delta m \Delta t)\right]$$

- Dominated by $B \to \rho\pi$, not a CP state
- 3 additional parameters
- Babar results from a TD Dalitz analysis
  - more info later

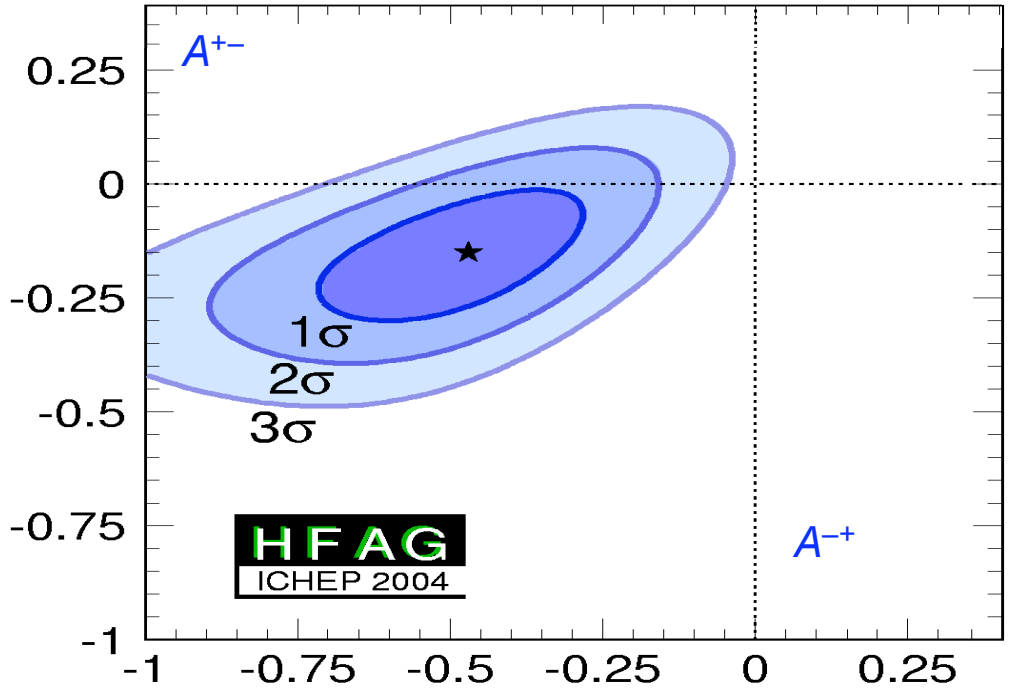
BaBar: 193 fb^{-1}
(except BRs..90fb^{-1})
Belle : 140 fb^{-1}
(except BRs..78 or 350 fb^{-1})

Observ.	BaBar	Belle
BR($\rho^+\pi^-$)	22.6 ± 1.8 ± 2.2	***29.1 ± 5.0 ± 4.0***
S($\rho^+\pi^-$)	***-0.10 ± 0.14 ± 0.04***	-0.28 ± 0.23 ± 0.09
ΔS($\rho^+\pi^-$)	***0.22 ± 0.15 ± 0.03***	-0.30 ± 0.24 ± 0.09
C($\rho^+\pi^-$)	***0.34 ± 0.11 ± 0.05***	0.25 ± 0.17 ± 0.04
ΔC($\rho^+\pi^-$)	***0.15 ± 0.11 ± 0.03***	0.38 ± 0.18 ± 0.03
A($\rho^+\pi^-$)	***-0.09 ± 0.05 ± 0.01***	-0.16 ± 0.10 ± 0.02
BR($\rho^0\pi^0$)	<2.9	***3.1 ± 0.9 ± 0.7***

BaBar: PRL **91**, 201802, 2003, hep-ex/0409099, PRL **93**, 051802, 2004.
Belle : hep-ex/0307077, PRL 94, 121802, 2005, hep-ex/0508077.

Direct CPV in $B^0 \to \pi^+\pi^-\pi^0$?

Preliminary



Combined BaBar and Belle

Some indication of direct CP! In more intuitive parameters:

$$A_{\rho\pi}^{+-} \equiv \frac{A_{\rho\pi} + C + A_{\rho\pi}\Delta C}{1 + \Delta C + A_{\rho\pi} C}$$

$$= -0.15 \pm 0.09$$

$$A_{\rho\pi}^{-+} \equiv \frac{A_{\rho\pi} - C - A_{\rho\pi}\Delta C}{1 - C - A_{\rho\pi}\Delta C}$$

$$= -0.47^{+0.13}_{-0.15}$$

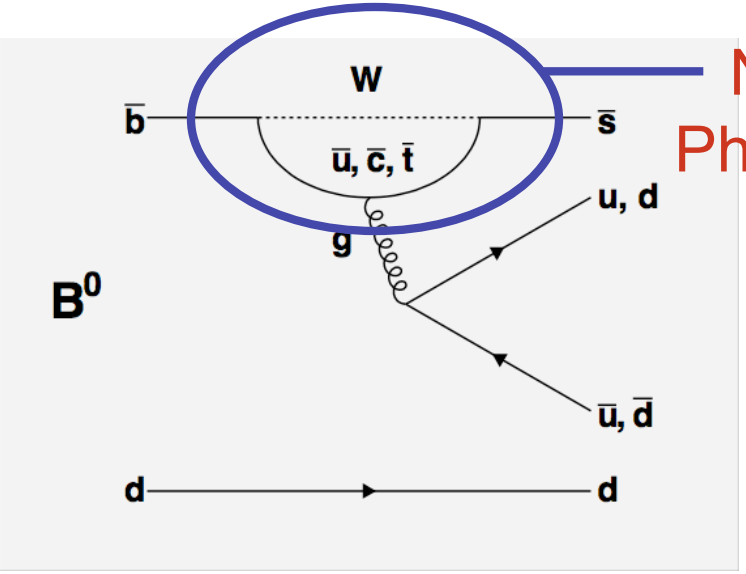
Other $B \to \pi\pi\pi$ Results

- Adding more π^0s is hard…
  - $\rho^+(770)\pi^0$ was measured in a Q2B way
  - no $\pi^0\pi^0\pi^0$ modes (nor inclusive) have been measured
    - could include $f_0\pi^0$, "σ"π^0, etc…
    - is a "Gershon-Hazumi" mode…definite CP eigenstate
    - Very diffcult to measure experimentally

Mode	BaBar BR (10^{-6}) A_{CP}	Belle BR (10^{-6}) A_{CP}
$\rho^+(770)\pi^0$	***10.0 ± 1.4 ± 0.9*** ***-0.01 ± 0.13 ± 0.01***	13.2 ± 2.3 ± 1.7 0.06 ± 0.19 ± 0.05
$\pi^0\pi^0\pi^0$	Unmeasured	

BaBar: hep-ex/0506069
Belle : PRL **94**, 031801, 2004.

B→Kππ Decays

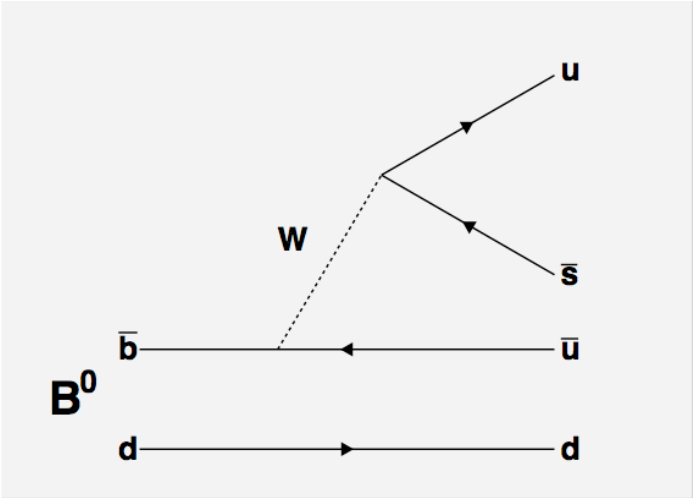


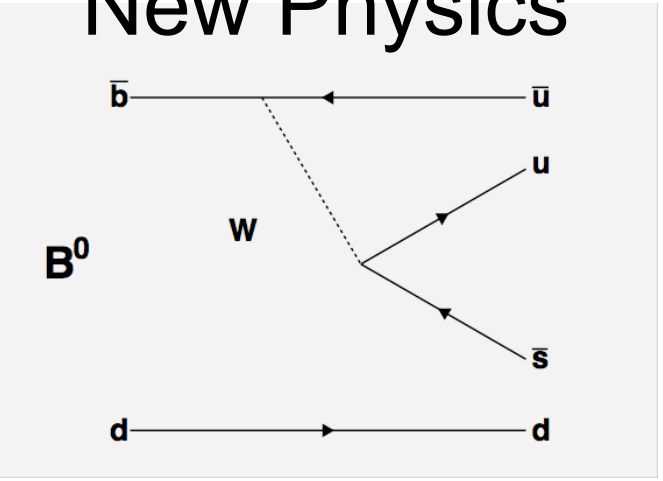
New Physics?

•penguin decays should dominate, since trees are supressed by a factor of b→u.

•In decays like B→R^0K^0, the tree is also color suppressed…TDCP should measure sin2β

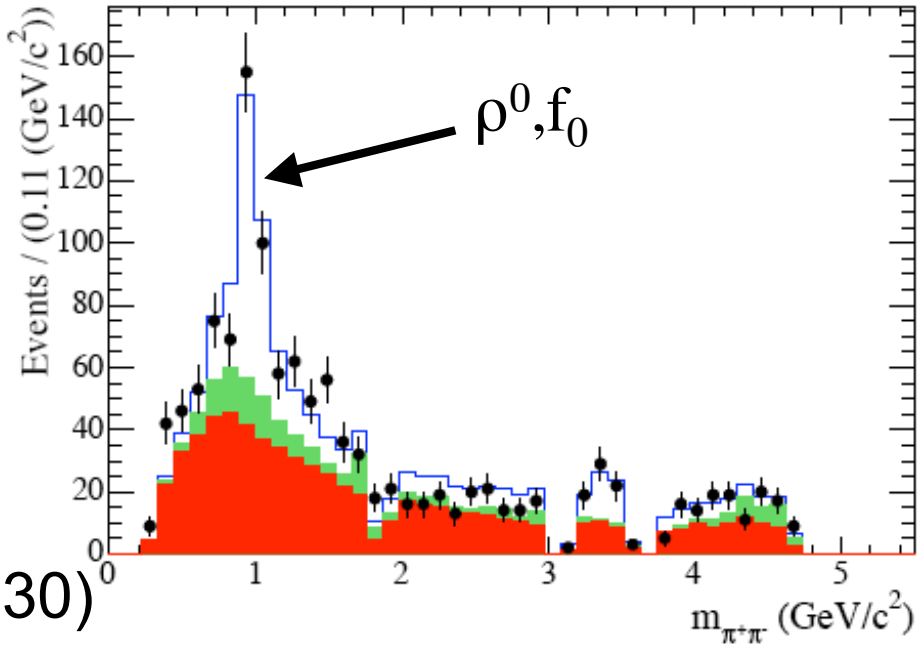
•Good place to look for New Physics

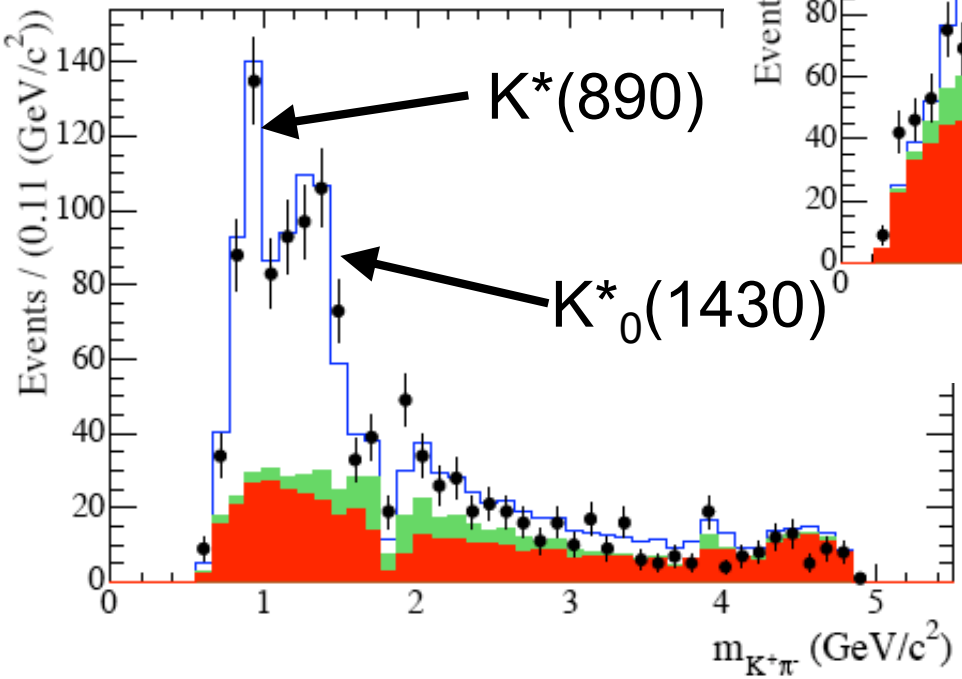




$B^+ \to K^+\pi^-\pi^+$ Dalitz Analysis

BaBar: 210 fb^{-1}

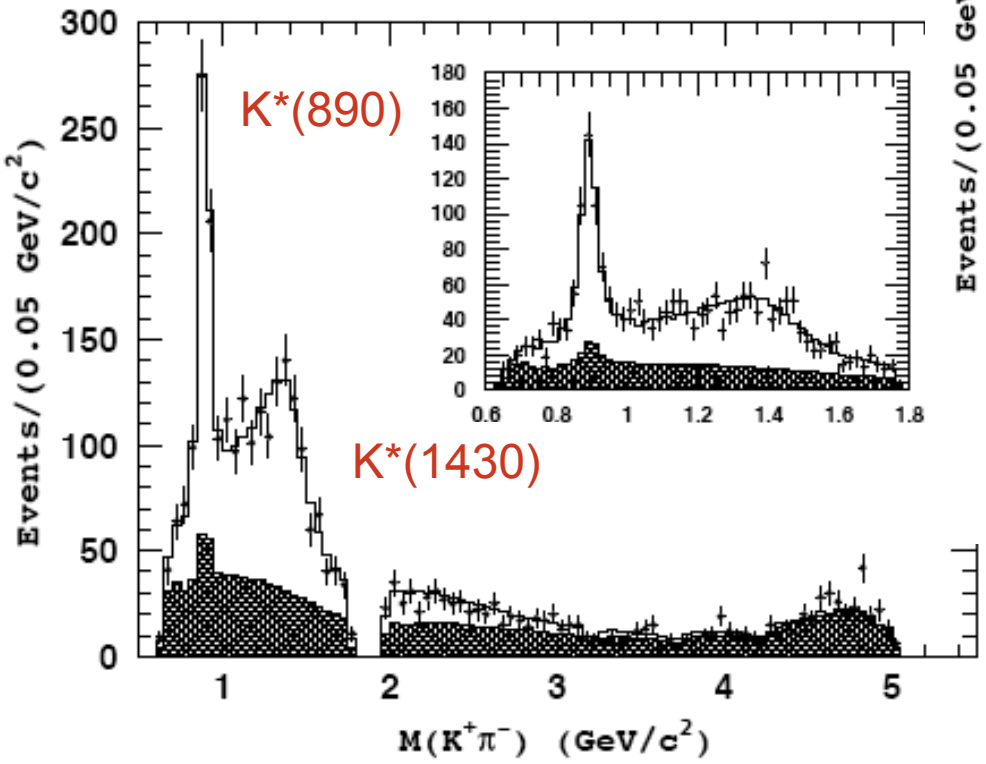


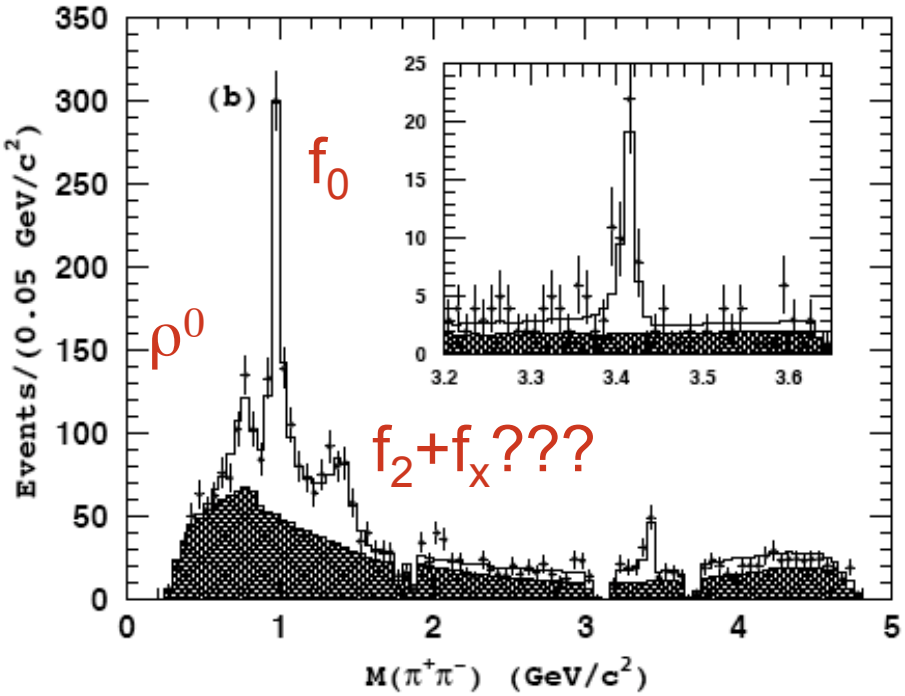


$B^+ \to K^+\pi^-\pi^+$ Dalitz Analysis

Preliminary

Belle : 357 fb^{-1}





f_x looks like a broad scalar at ~ 1450 MeV

$B^+ \to K^+\pi^-\pi^+$ Comparisons

- Difficult to do direct comparison between Belle and BaBar because they use different signal models
- Main differences are in K(1430) and non-resonance models
- BaBar: LASS for the 1430, flat NR
- Belle : Relativistic BW for the 1430, sum of exponentials for NR

$B^+ \to K^+\pi^-\pi^+$ Results

Mode	BaBar BR (10^{-6}) A_{CP}	Belle BR (10^{-6}) A_{CP}
Inclusive	64.1 ± 2.4 ± 4.0 -0.01 ± 0.04 ± 0.01	***48.8 ± 1.1 ± 3.6*** ***0.05 ± 0.03 ± 0.03***
$K^*(890)^0\pi^+$	9.0 ± 0.8 ± 0.6 0.07 ± 0.08 ± 0.07	***6.5 ± 0.4 ± 0.6*** ***-0.14 ± 0.06 ± 0.03***
$K^*(1430)^0\pi^+$	34.0 ± 1.7 ± 2.1 -0.06 ± 0.03 ± 0.03	***32.6 ± 1.0 ± 2.8*** ***0.08 ± 0.04 ± 0.04***
$\rho(770)^0K^+$	5.1 ± 0.8 ± 0.7 0.32 ± 0.13 ± 0.09	***3.9 ± 0.5 ± 0.4*** $***0.30 \pm 0.11^{+0.11}_{-0.04}$
$f_0(980)K^+$	9.5 ± 1.0 ± 0.8 0.09 ± 0.1 ± 0.07	***8.8 ± 0.8 ± 1.2*** ***-0.08 ± 0.07 ± 0.05***
$f_2(1270)K^+$	<8.9	***0.8 ± 0.2 ± 0.2*** ***-0.59 ± 0.22 ± 0.04***
NR*	2.85 ± 0.6 ± 0.7	***16.9 ± 1.3 ± 1.6***

BaBar: 210 fb^{-1}
Belle : 357 fb^{-1}

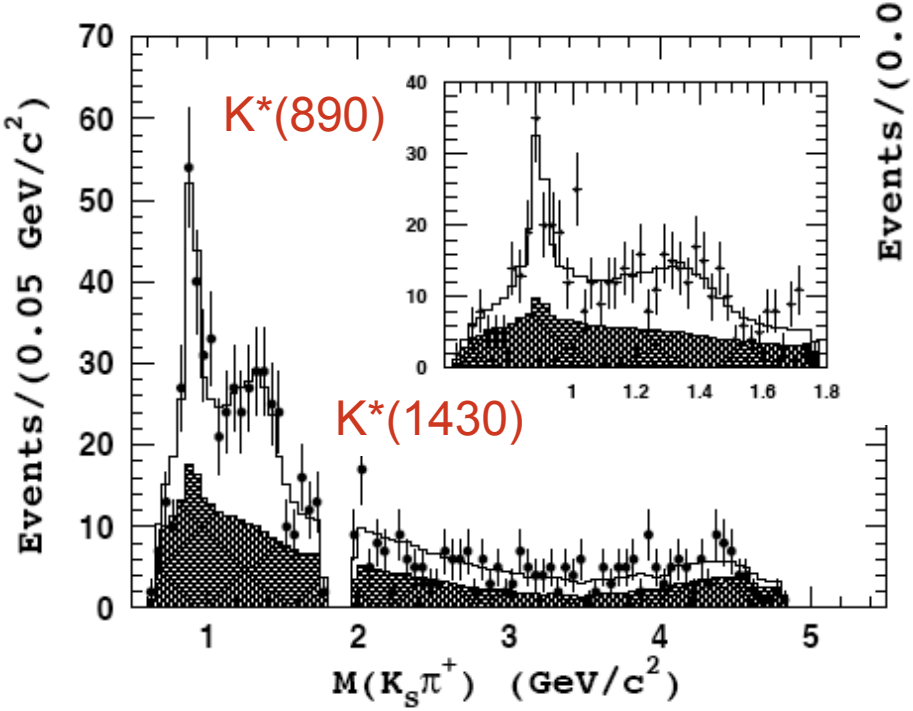
BaBar: PRD **72**, 072003, 2005.
Belle : hep-ex/0509001.

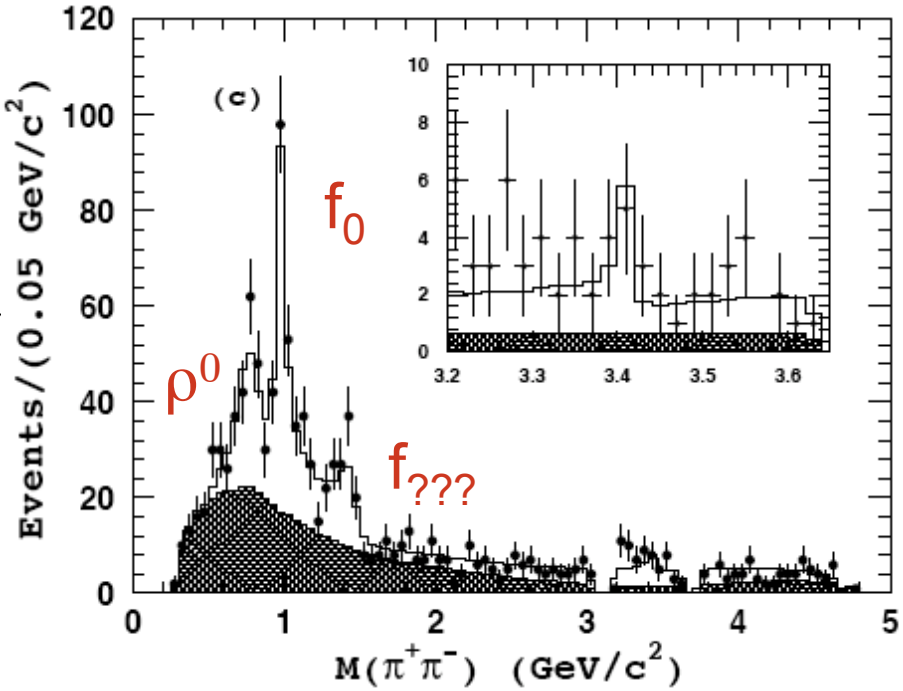
All BRs are
$BR(B \to Rh \to K^+\pi^-\pi^+)$

*** 3.9σ significance for direct CPV in ρK^+ (including phase)

$B^0 \to K_s \pi^- \pi^+$ Dalitz Analysis

Preliminary





$f_{???}$--not the $f_2(1270)$?
Fits better to $f_0(1370)$ but still not perfect.
Same as what's in $K^+\pi^-\pi^+$?

$B^0 \to K_s \pi^- \pi^+$ Results

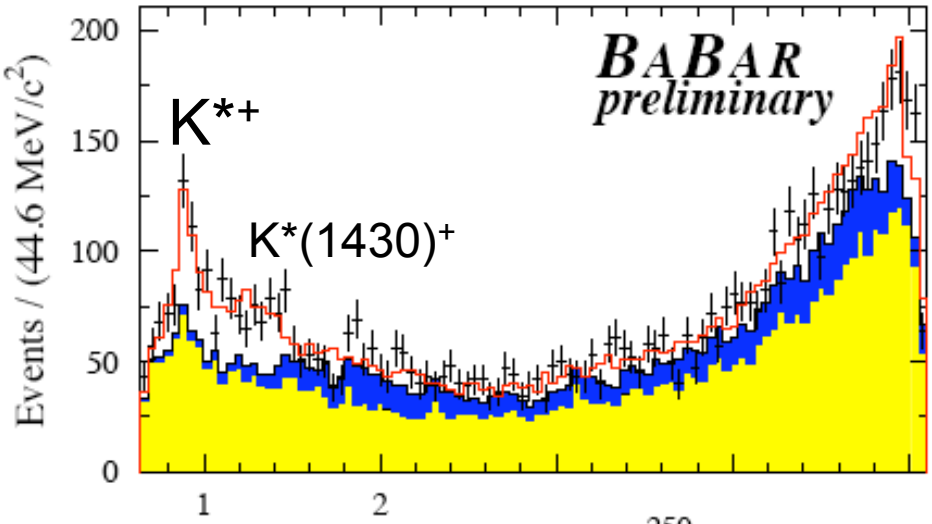
Mode	BaBar BR (10^{-6}) A_{CP}	Belle BR (10^{-6}) A_{CP}
Inclusive	43 ± 2.3 ± 2.3	***47.5 ± 2.4 ± 3.7***
$K^*(890)^+\pi^-$	7.3 ± 1.0 ± 1.0 -0.11 ± 0.14 ± 0.05	***5.6 ± 0.7 ± 0.9***
$K^*(1430)^+\pi^-$	----------	***30.8 ± 2.4 ± 3.1***
$\rho(770)K^0$	***5.1 ± 1.0 ± 1.2***	***6.1 ± 1.0 ± 1.1***
$f_0(980)K^0$	5.5 ± 0.7 ± 0.7 ***S=0.95 ± 0.27 ± 0.10*** ***C=-0.24 ± 0.31 ± 0.15***	***7.6 ± 1.7 ± 0.8*** ***S=0.47 ± 0.36 ± 0.08*** ***C=0.23 ± 0.23 ± 0.13***
NR*	---------	***19.9 ± 2.5 ± 1.8***

BaBar: 210 fb^{-1}
Belle : 357 fb^{-1}

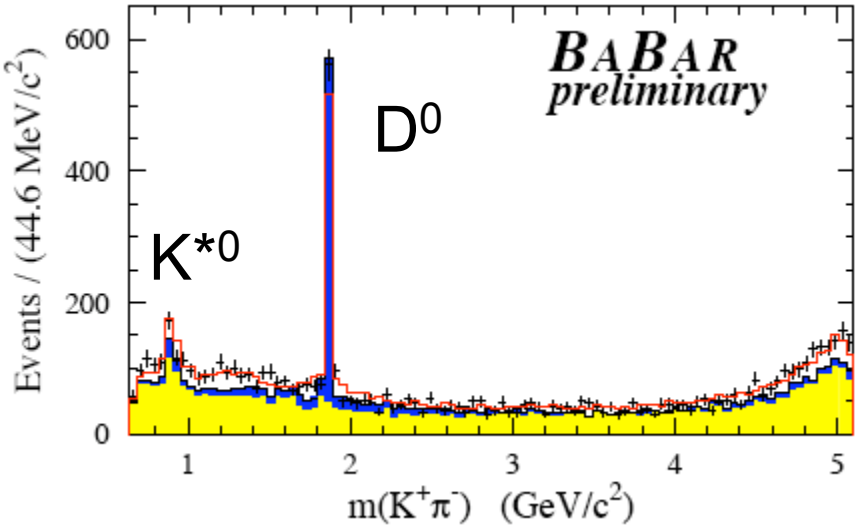
All BRs are $BR(B \to Rh \to K^0\pi^-\pi^+)$

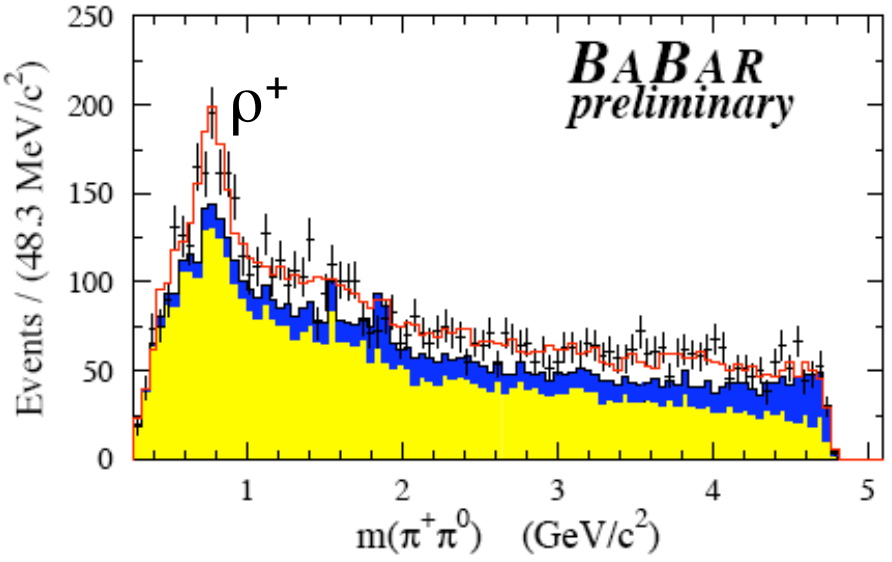
BaBar: hep-ex/0408095, hep-ex/0408079, hep-ex/0508013 (accepted by PRD-RC)
Belle : hep-ex/0507057, hep-ex/0509047.

$B^0 \to K^+\pi^-\pi^0$ Dalitz Analysis



Preliminary





$B^0 \to K^+\pi^-\pi^0$ Results

Mode	BaBar BR (10^{-6}) A_{CP}	Belle BR (10^{-6}) A_{CP}
Inclusive	***34.9 ± 1.0 ± 1.0***	36.6 ± 4.2 ± 3.0
$K^*(890)^+\pi^-$	***10.9 ± 2.3 ± 1.5*** ***-0.25 ± 0.17 ± 0.03***	14.8 ± 4.5 ± 2.3
$K^*(1430)^+\pi^-$	***11.2 ± 1.5 ± 3.5*** ***-0.07 ± 0.12 ± 0.08***	----------
$K^*(890)^0\pi^0$	***3.0 ± 0.9 ± 0.5*** ***-0.01 ± 0.23 ± 0.13***	<3.5
$K^*(1430)^0\pi^0$	***7.9 ± 1.5 ± 2.7*** ***-0.34 ± 0.15 ± 0.11***	----------
$\rho(770)^-K^+$	***8.6 ± 1.4 ± 1.0*** ***-0.13 ± 0.15 ± 0.14***	15.1 ± 3.4 ± 2.5
NR*	***<4.6***	<9.4

BaBar: 210 fb^{-1}
Belle : 78 fb^{-1}

BaBar: hep-ex/0408073
Belle : PLB **599**, 148, 2004.

All BRs are have been corrected for secondary BFs

Other $B \to K\pi\pi$ Results

The "other" $K\pi\pi$ modes are either highly suppressed (wrong sign) or are are more difficult experimentally

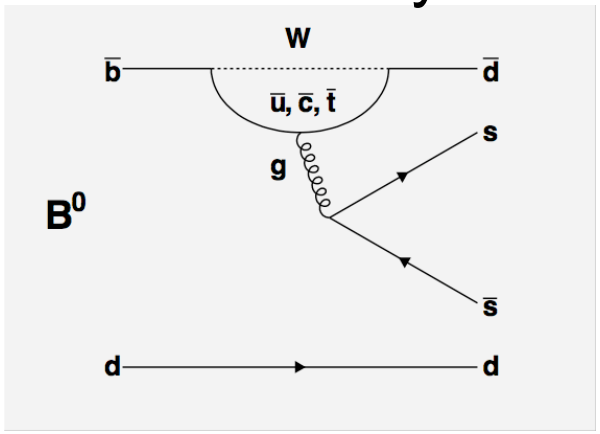
Mode	BaBar BR (10^{-6}) A_{CP}	Belle BR (10^{-6}) A_{CP}
$K_s\pi^0\pi^0$	***----------*** ***S=-0.84 ± 0.71 ± 0.08*** ***C=0.27 ± 0.52 ± 0.13***	***----------***
$K_s\pi^+\pi^0$	***<66 (CLEO)***	
$K_L\pi\pi$	***No Measurements***	
$K^-\pi^+\pi^+$	***<1.8***	***<4.5***
$K^-\pi^+\pi^+$	***Unmeasured (and highly suppressed)***	
$K^-\pi^0\pi^0$		

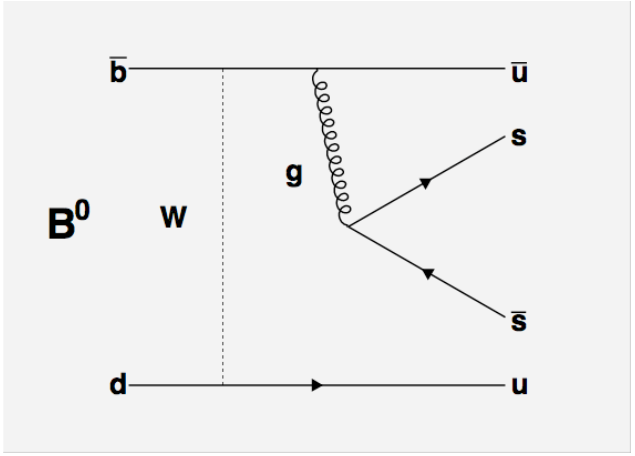
Babar: hep-ex/050817

$B \to KK\pi$ **Results**

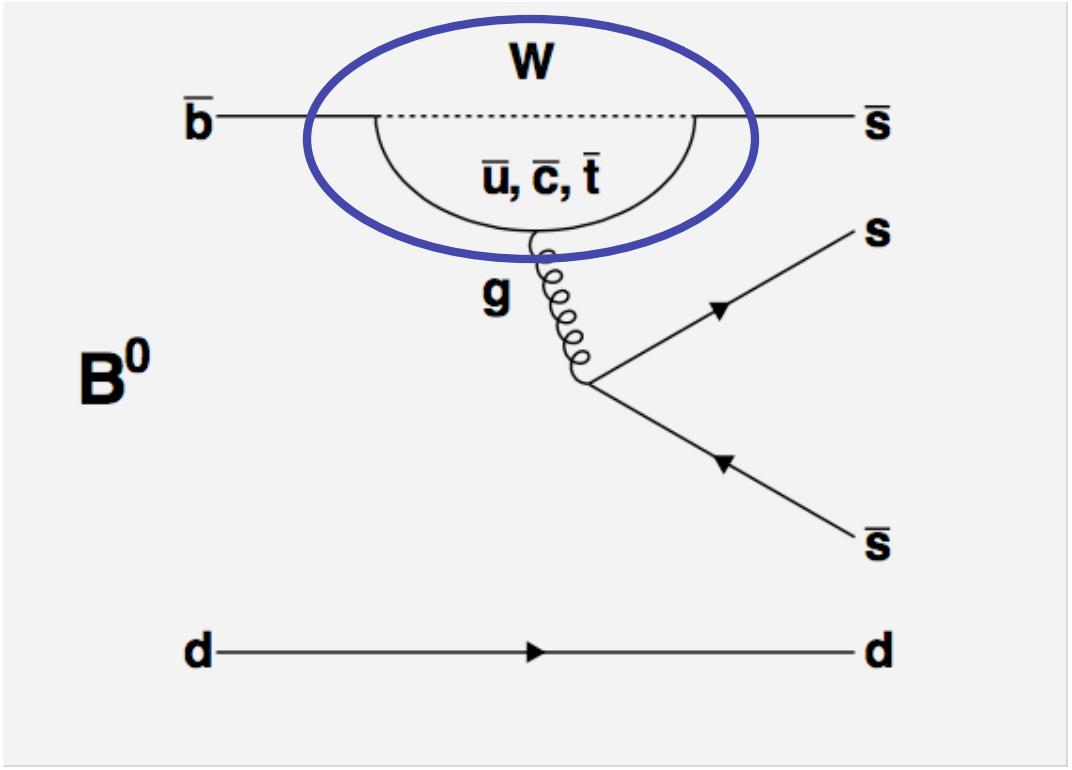
Modes with two Kaons (even number of s-quarks) are suppressed. No 3-body modes have been observed yet.

Mode	BaBar BR (10^{-6}) A_{CP}	Belle BR (10^{-6}) A_{CP}
$K^+K^-\pi^+$	***<6.3***	***<13***
$\phi\pi^+$	***<0.41***	***----------***
$K^{*0}K^+$	***<5.3 (CLEO)***	
$K^+K^0\pi^-$	***---------***	***<18***
$K^+K^-\pi^0$	***<19 (CLEO)***	
$\phi\pi^0$	***<1.0***	***----------***
$K_sK_s\pi^+$	***----------***	***<3.2***
$K^+K^0\pi^0$	***<24 (CLEO)***	
$K^+K^+\pi^-$	***<1.3***	***<2.4***



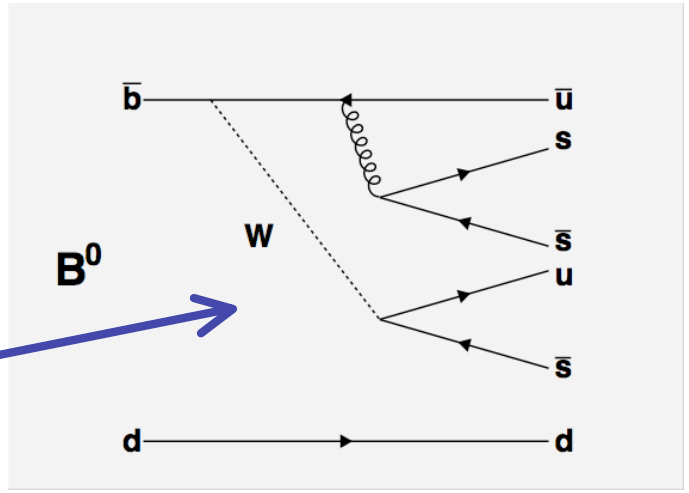


B→KKK **Decays**

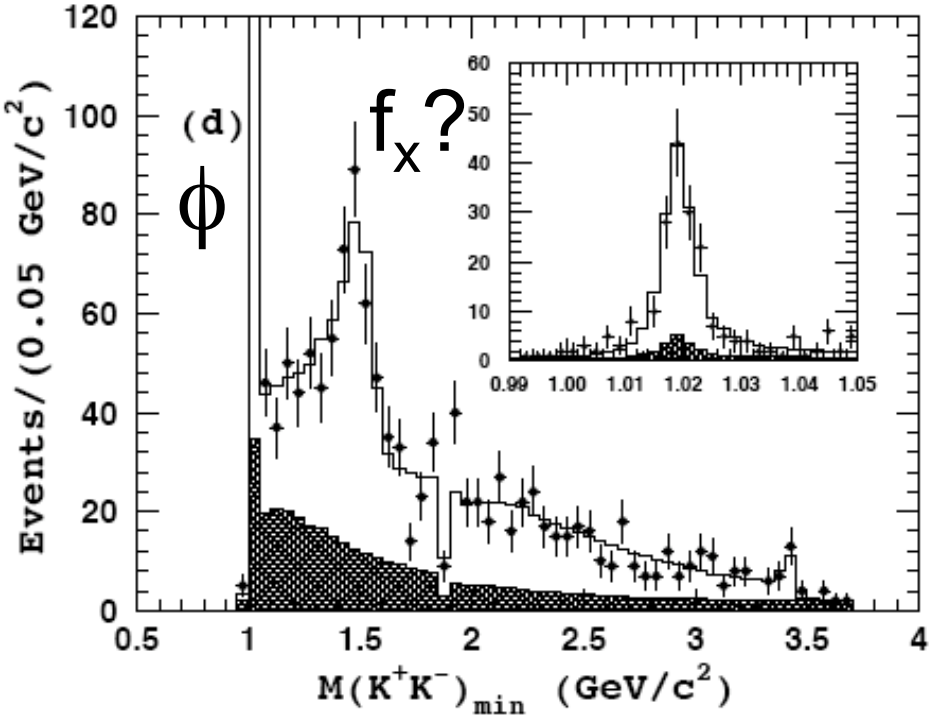


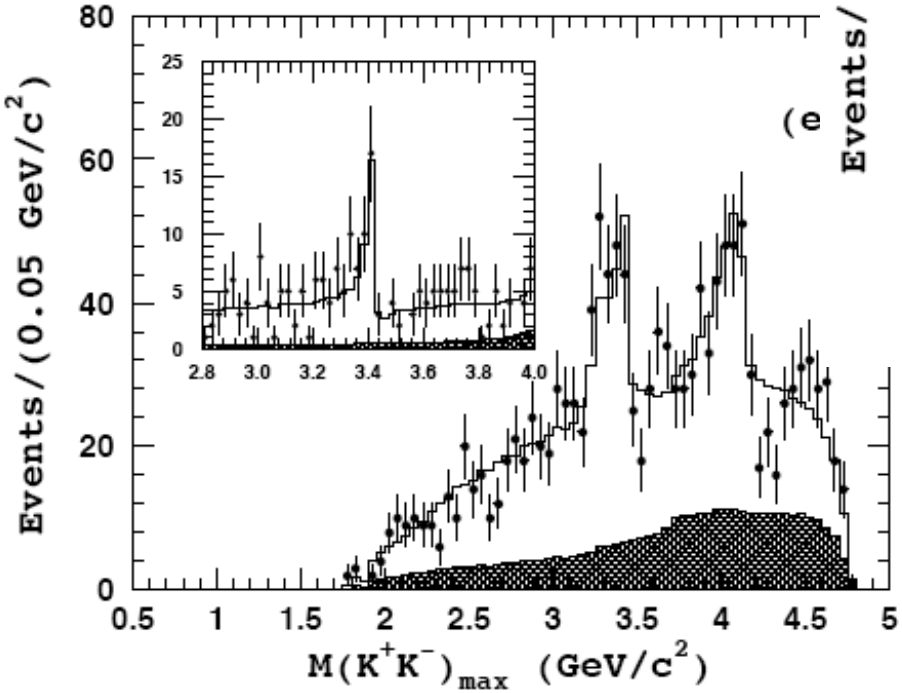
These decays include ϕK_s, $K^+K^-K_s$, and $K_sK_sK_s$…(almost) exclusively b→s penguin decays!

… $K^+K^-K_s$ does have this tree conribution



$B^+ \to K^+K^-K^+$ **Dalitz Analysis**





The fx state looks like a scalar…
M~1500MeV, Γ~140 MeV

$B^+ \to K^+K^-K^+$ **Results**

Mode	BaBar BR (10^{-6}) A_{CP}	Belle BR (10^{-6}) A_{CP}
Inclusive	29.6 ± 2.1 ± 1.6 0.02 ± 0.07 ± 0.03	30.6 ± 1.2 ± 2.3
ϕK^+	10.0 ± 0.9 ± 0.5 ***0.05 ± 0.06 ± 0.01***	9.6 ± 0.9 ± 0.9 0.01 ± 0.12 ± 0.05
NR*	----------	24 ± 1.5 ± 3.5

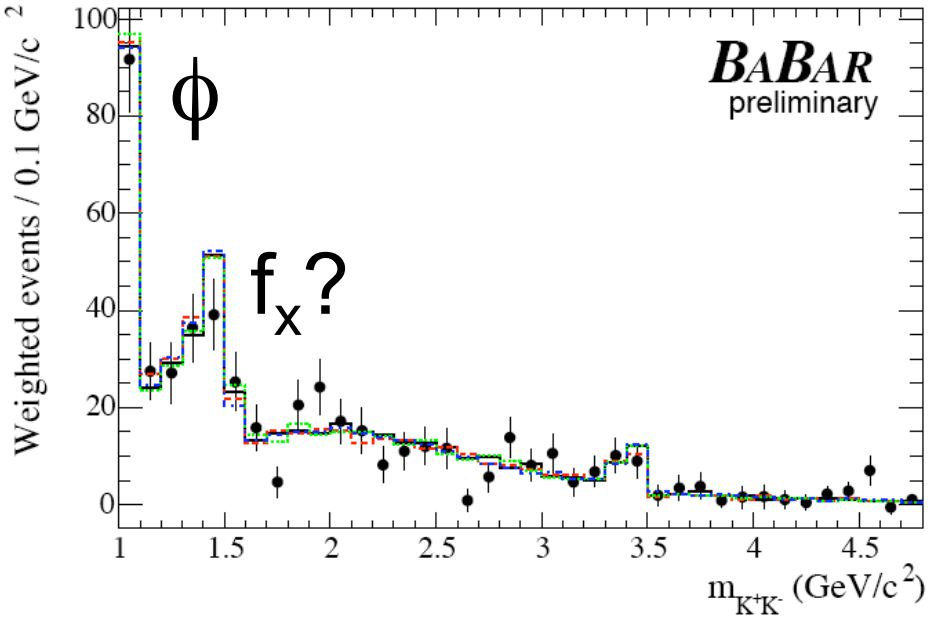
BaBar: 82, and 210 fb^{-1}
Belle : 140 fb^{-1}

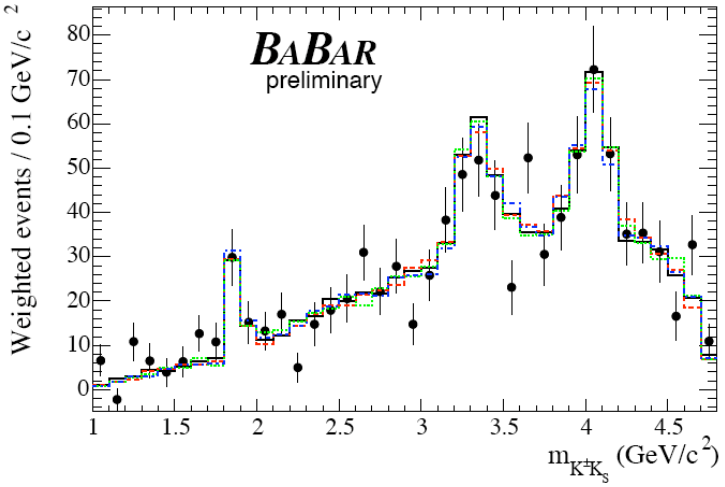
BaBar: PRL **91**, 051801, 2003. hep-ex/0408072.
Belle : PRL 91, 201801, 2003. PRD **71**, 092003, 2005.

$B^0 \to K^+K^-K_s$ Dalitz Analysis

In the model: ϕ, $f_x(1500)^{***}$, χ_0, $f_0(980)$
Non-Resonant--$\exp(\beta M_{K+K-})$

No P-wave (other than ϕ)





Two solutions…switch of NR-f_x phase. Large difference in f_x amplitude depending on solution

***$M(f_x)$~1500 MeV; $\Gamma(f_x)$~100 MeV; it's a scalar
Probably the same as what is seen in $K^+K^-K^+$

$B \to KKK^0$ Branching Fraction Results

Mode	BaBar	Belle
ϕK^0	$8.4 \pm 1.4 \pm 0.5$	$9.0 \pm 2.0 \pm 0.7$
$K^+K^-K^0$	$23.8 \pm 2.0 \pm 1.6$	$28.3 \pm 3.3 \pm 4.0$
$K^+K_sK_s$	$10.7 \pm 1.2 \pm 1.0$	$13.4 \pm 1.9 \pm 1.5$
$K_sK_sK_s$	$6.9 \pm 0.9 \pm 0.6$	$4.2 \pm 1.6 \pm 0.8$
$K_sK_sK_L$	Unmeasured	
$K^+K_sK_L$	Unmeasured	

BaBar: PRD **93**, 181805, 2004. PRD **69**, 011102, 2004. PRL **93**, 181805, 2004. PRL **95**, 011801, 2005.
Belle : PRD **69**, 012001, 2004. PRL **91**, 201801, 2003. PRD **69**, 012001, 2004.

$B^0 \to KKK^0$ **TD-CPV Results**

Mode	BaBar $\sin 2\beta_{eff}$ C	Belle $\sin 2\beta_{eff}$ C
ϕK^0	0.50 ± 0.25 ± 0.06 0.00 ± 0.23 ± 0.05	***0.44 ± 0.27 ± 0.05*** ***-0.14 ± 0.17 ± 0.07***
$*K^+K^-K^0$	***0.41 ± 0.18 ± 0.13***** ***0.23 ± 0.13****	***0.60 ± 0.53 ± 0.14*** ***0.06 ± 0.11 ± 0.07***
$K_sK_sK_s$	0.63 ± 0.30 ± 0.04 -0.10 ± 0.25 ± 0.05	***0.58 ± 0.36 ± 0.86*** ***-0.50 ± 0.23 ± 0.06***

BaBar: 210 fb^{-1}
Belle : 357 fb^{-1}

$*\phi$ region is vetoed
**Includes $K^+K^-K_L$

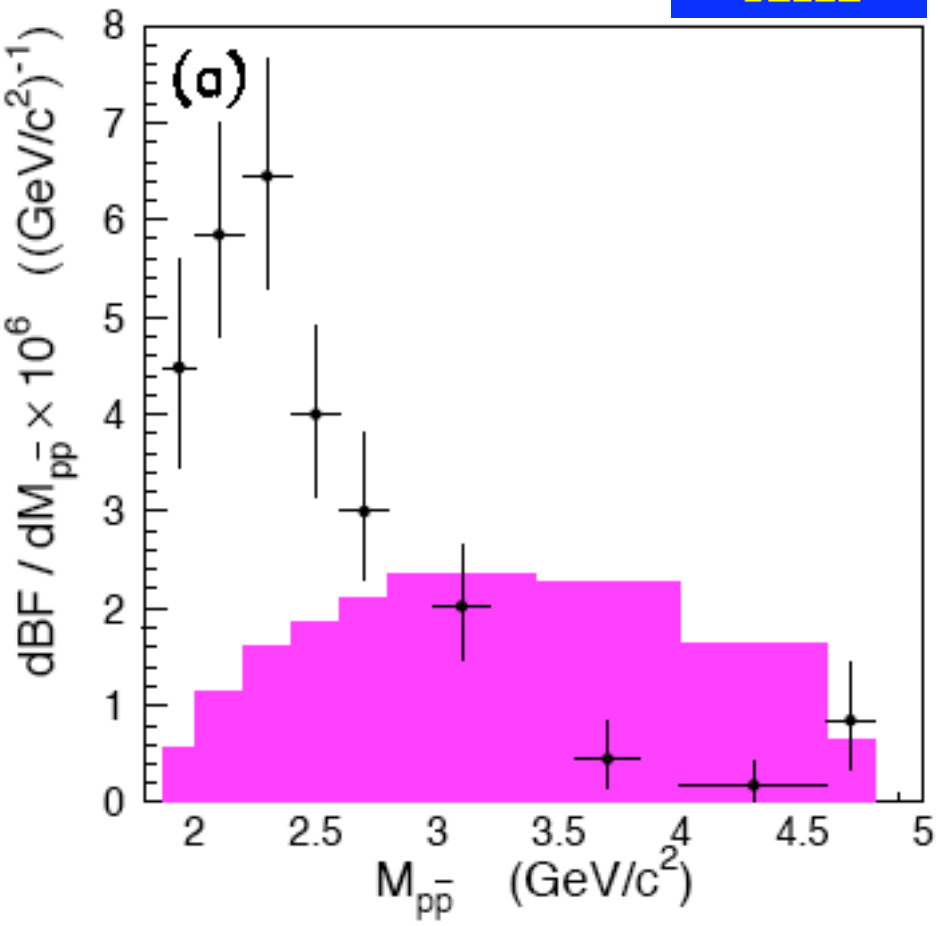
BaBar: PRD 71, 091102, 2005. hep-ex/0507052.
Belle : hep-ex/0507037

Baryonic B-decays

Study of charmless baryonic decays has lagged behind the meson decays…they are quite a bit more complicated theoretically.

A few things we know:

- preference to many body final states…$p\bar{p}<p\bar{p}\pi<?p\bar{p}\pi\pi$
- enhancement at low $p\bar{p}$ mass is observed in all modes
  - similarly seen in $p\bar{\Lambda}$



Baryonic Results

Mode	BaBar	Belle
$p\bar{p}\pi^+$	----------	$3.1 \pm 0.7 \pm 0.4$
$p\bar{p}\pi^0$	----------	----------
$p\bar{p}K^+$	$6.7 \pm 0.5 \pm 0.4$	$5.3 \pm 0.4 \pm 0.6$
$p\bar{p}K^0$	----------	$1.2 \pm 0.3 \pm 0.1$
$p\bar{p}K^{*+}$	----------	$10.3 \pm 3.0 \pm 1.5$
$p\bar{p}K^{*0}$	----------	<7.6
$p\bar{\Lambda}\pi^-$	----------	$3.3 \pm 0.6 \pm 0.4$
$p\bar{\Lambda}K^-$	----------	<0.82
$p\bar{\Sigma}^0\pi^-$	----------	<3.8
$\Lambda\bar{\Lambda}\pi^+$	----------	<2.8
$\Lambda\bar{\Lambda}K^+$	----------	$2.9 \pm 0.8 \pm 0.4$

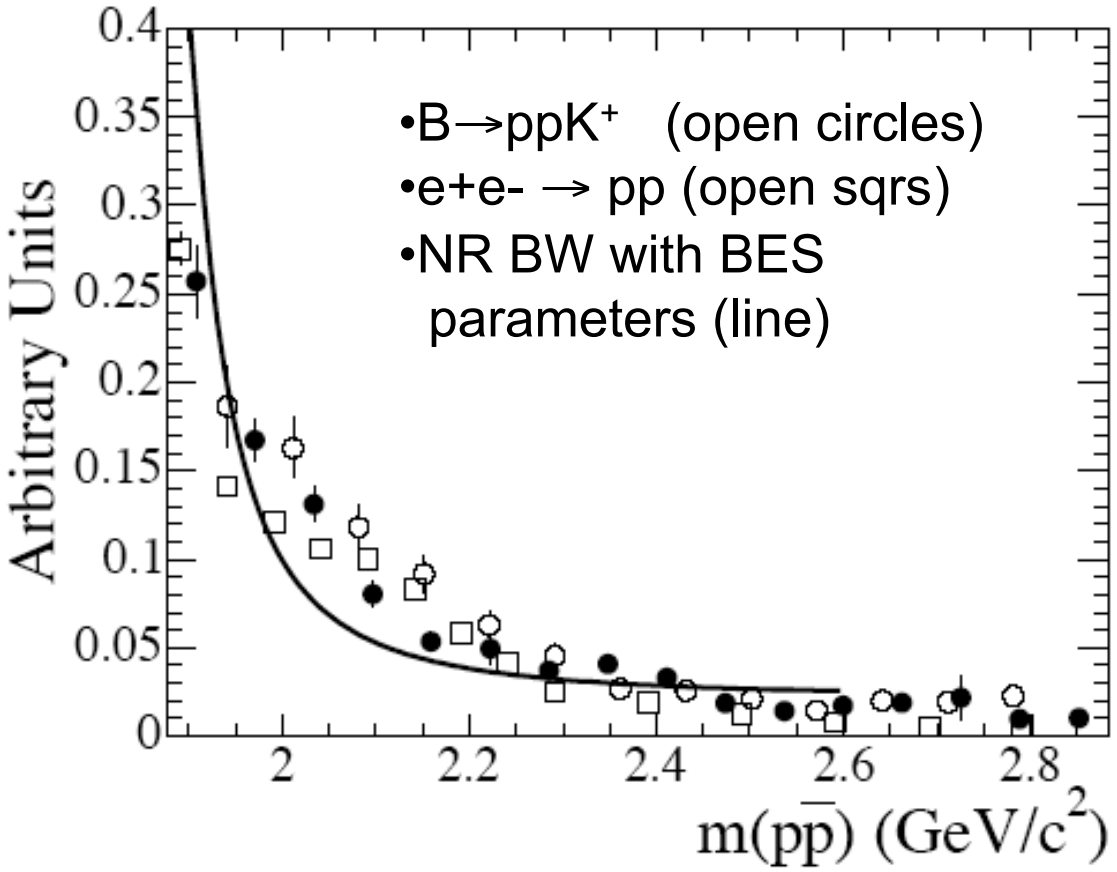
Babar: 210 fb^{-1}
Belle: varies

These BFs are roughly 5-10 times smaller than the mesonic decays

BaBar has some work to do…

Babar: PRD 72, 051101, 2005.
Belle: PRL 64, 131801, 2004. PLB 617, 141, 2005. PRL 90 201812, 2003.

The pp Enhancement: a Resonance?

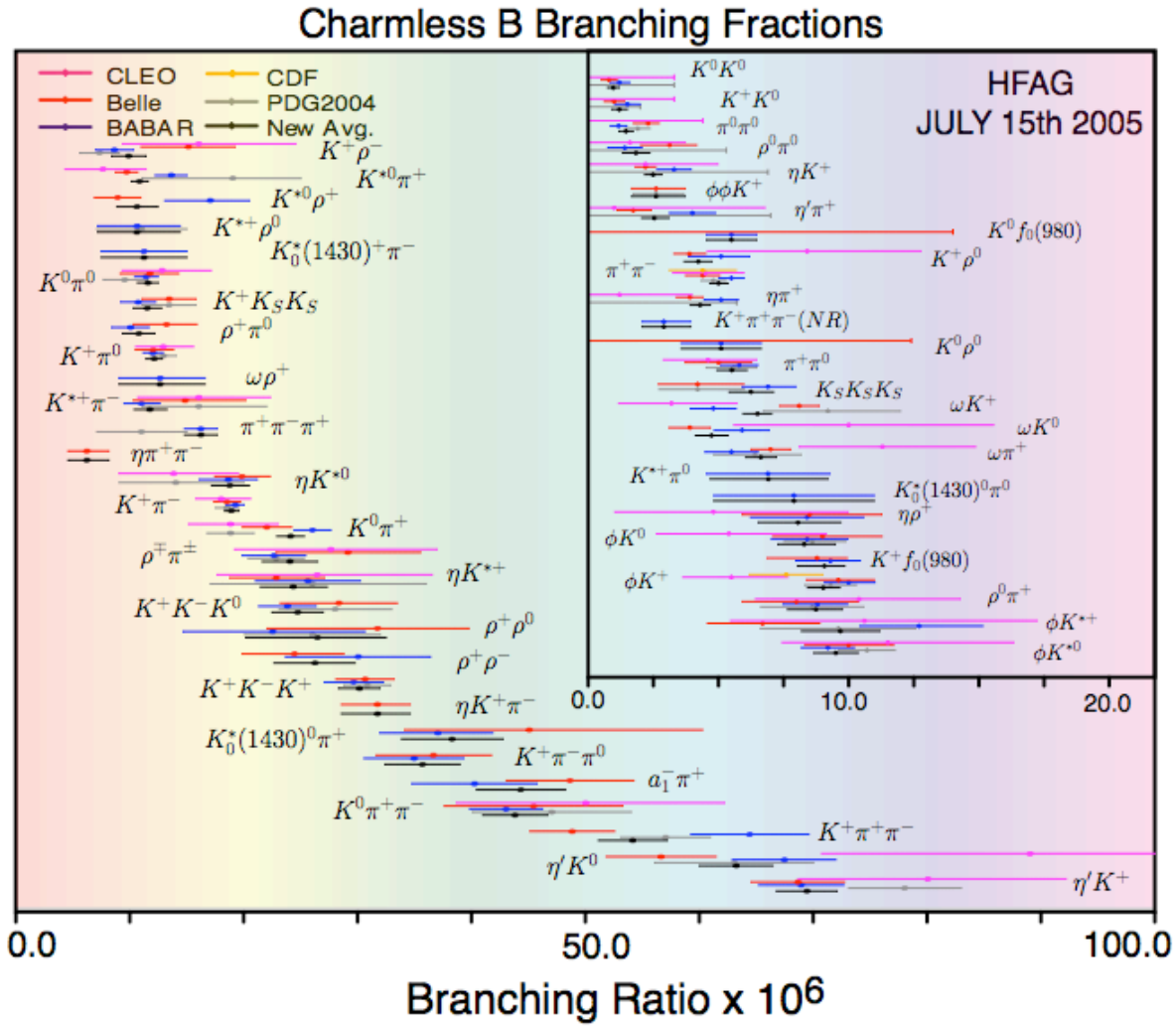


pay no attention to the closed circles ;)

BES has associated a resonance decaying to $\pi\pi\eta'$ with this enhancement…
M=1834 MeV
Γ=69 MeV

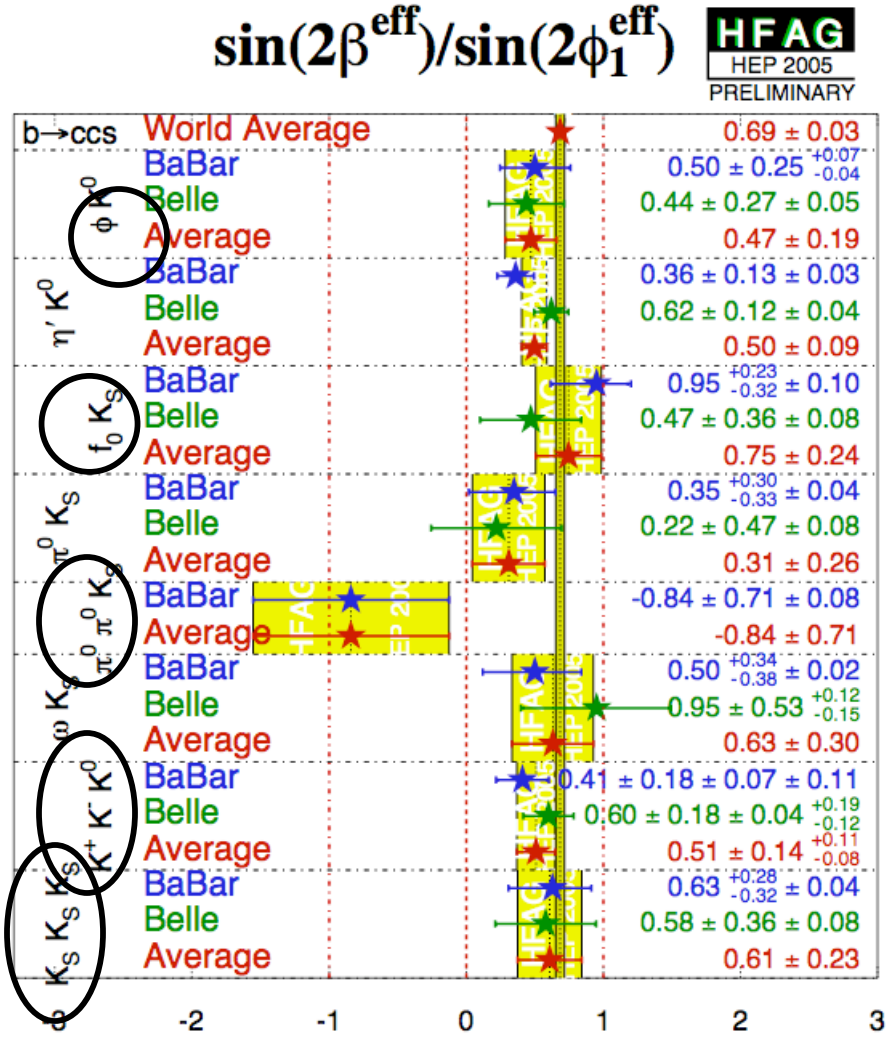
The pp spectrum from ppK^+ and pp form factor look quite similar…not great agreement with the resonance though

The Big Picture (of branching fractions)



Lots of numbers…
most make sense

Status of $\sin 2\beta_{eff}$



The 3-body groups supply most of these very important measurements

…still a hint of deviation from the SM?

Summary

- There's a lot of variety of physics involved with 3-body charmless decays
  - CKM angles…α (and γ)
  - New Physics search through s-penguins
  - Spectroscopy
- Come a long way, but still work to do
- We'd like to do away with the Q2B analysis
  - A Dalitz analysis is the right tool and it should be used…we have the technology, even for TD-CP!
- With more data:
  - Dalitz analysis will become feasible for more modes
  - some of the current measurements can become "precision" measurements
  - we should start to see some of the very rare decays
  - the baryonic decays may start to become more interesting