UT angles and sides measurement at BaBar

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On behalf of BaBar Collaboration

IFAE 2007 – Napoli – April 11th – 13th 2007

Outline

- Introduction
- UT sides measurements
  - $|V_{cb}|$
  - $|V_{ub}|$
  - $|V_{td}/V_{ts}|$ → See D. Monorchio's talk
- UT angles measurements
  - β
  - γ
  - α
- Conclusions

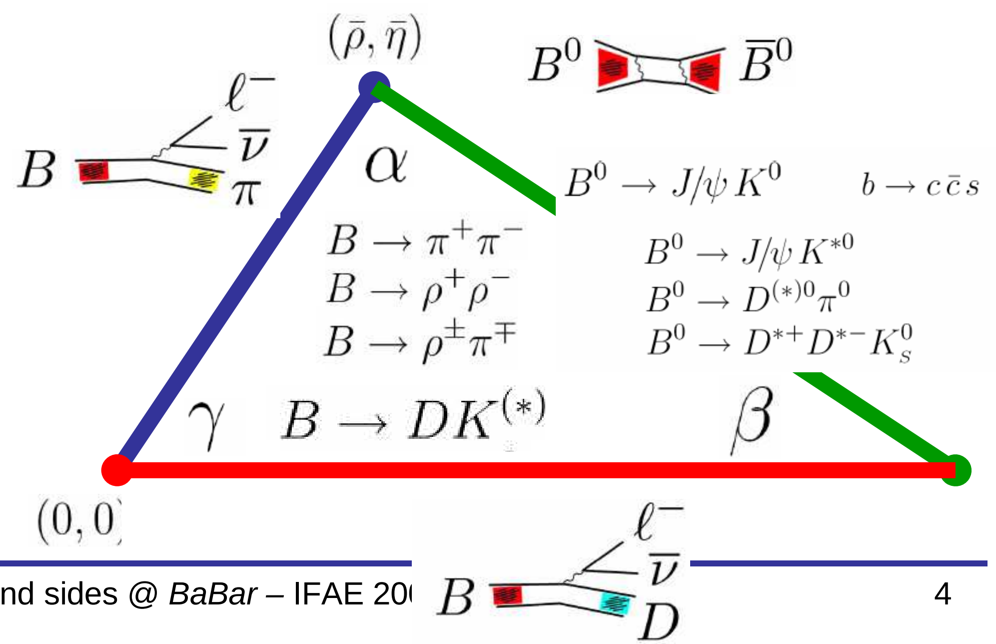
Introduction

Quark mixing matrix

- weak and mass eigenstates of the quarks are not the same
- changes in base are described by unitarity transformations
- Cabibbo Kobayashi Maskawa (CKM) matrix
- with 3 quark families there is an irreducible complex phase in the matrix, responsable of CP Violation in Standard Model (SM)

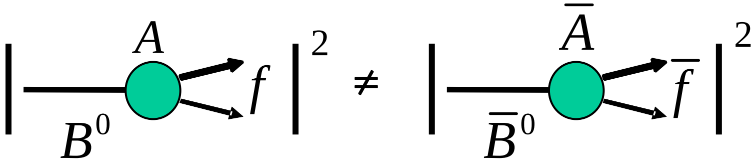
$$\mathbf{V} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

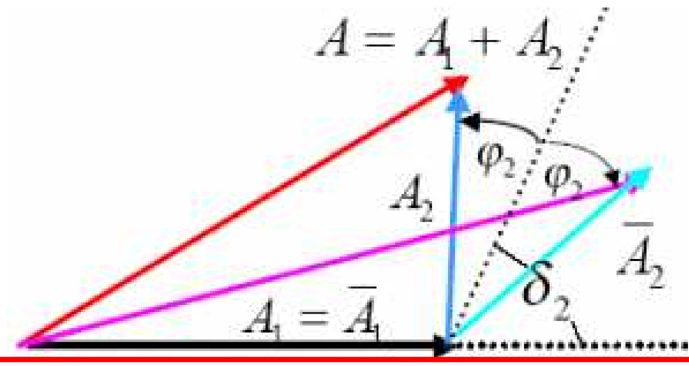
$$\boxed{V_{td}V_{tb}^* + V_{cd}V_{cb}^* + V_{ud}V_{ub}^* \;=\; 0}$$



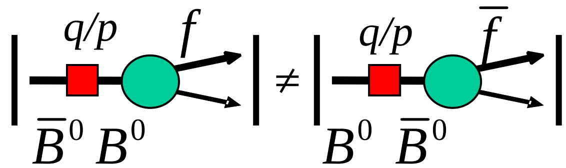
CP Violation: three types

1. Direct CP violation in the decay





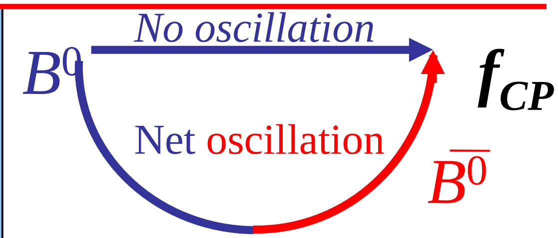
2. CP violation in mixing



$$\boxed{\left|\frac{q}{p}\right| = \left|\sqrt{\frac{(M_{12}^* - i\frac{\Gamma_{12}^*}{2})}{(M_{12} - i\frac{\Gamma_{12}}{2})}}\right| \neq 1}$$

SM predicts: $\left|\frac{q}{p}\right| - 1 \approx 4\pi \frac{m_c^2}{m_t^2} \sin\beta \approx 5\times 10^{-4}$

3. Intereference between mixing & decay



$$C_{f_{CP}} = \frac{1 - |\lambda_{f_{CP}}|^2}{1 + |\lambda_{f_{CP}}|^2}$$

$$\lambda_{f_{CP}} = \frac{q}{p}\frac{\bar{A}}{A}$$

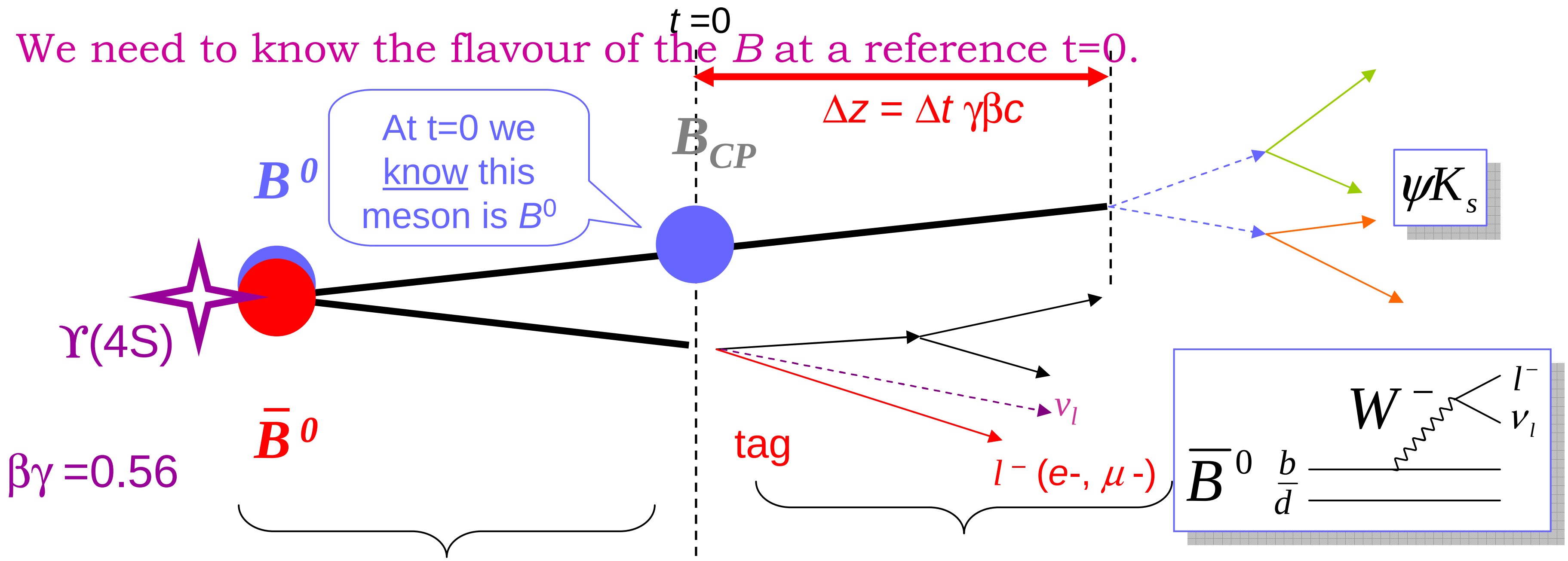
$$S_{f_{CP}} = \frac{-2\,\mathrm{Im}\,\lambda_{f_{CP}}}{1 + |\lambda_{f_{CP}}|^2}$$

$$A_{f_{CP}}(t) = \frac{\Gamma\left(\bar{B}^0_{phys}(t) \to f_{CP}\right) - \Gamma\left(B^0_{phys}(t) \to f_{CP}\right)}{\Gamma\left(B^0_{phys}(t) \to f_{CP}\right) + \Gamma\left(\bar{B}^0_{phys}(t) \to f_{CP}\right)}$$

$$\boxed{A_{f_{CP}} = -C_{f_{CP}} \cos(\Delta m t) + S_{f_{CP}} \sin(\Delta m t)}$$

CPV measurements at B-factories

We need to know the flavour of the B at a reference t=0.



The two mesons oscillate coherently : at any given time, if one is a B^0 the other is necessarily a $\bar{B}^0$

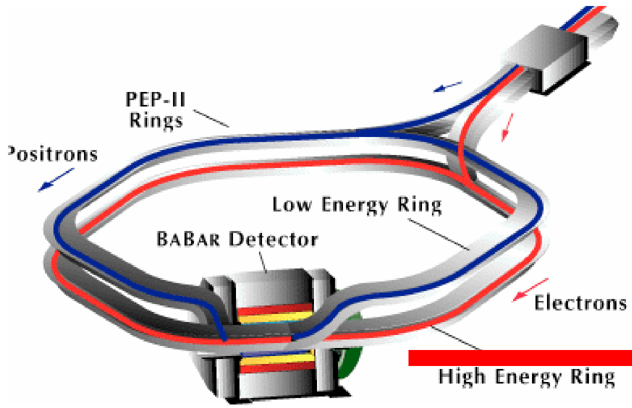
In this example, the tag-side meson decays first. It decays semi-leptonically and the charge of the lepton gives the flavour of the tag-side meson : $l^- = \bar{B}^0 \quad l^+ = B^0$.

(Kaon and pion tags also used)

Δt picoseconds later, the B^0 (or perhaps it is now a $\bar{B}^0$) decays.

BaBar Experiment

PEP-II at SLAC

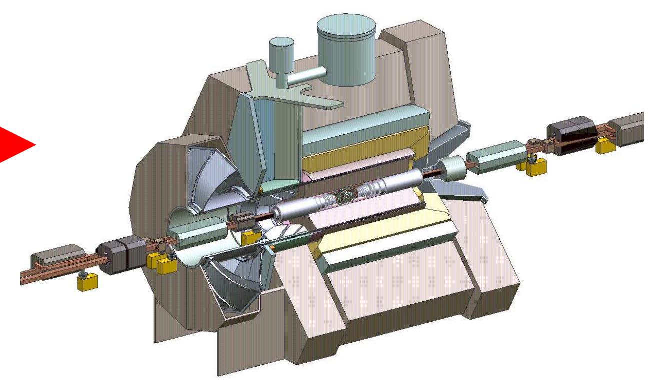


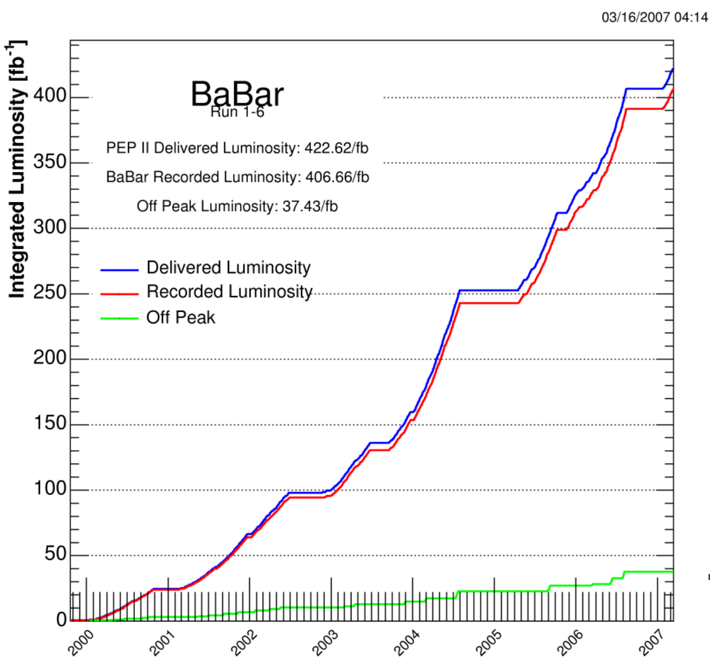
9 GeV (e^-) $\times$ 3.1 GeV (e^+)
peak luminosity:

$$\mathbf{1.2\times10^{34}cm^{-2}s^{-1}}$$

11 nations,
77 institutes,
~600 persons

BaBar

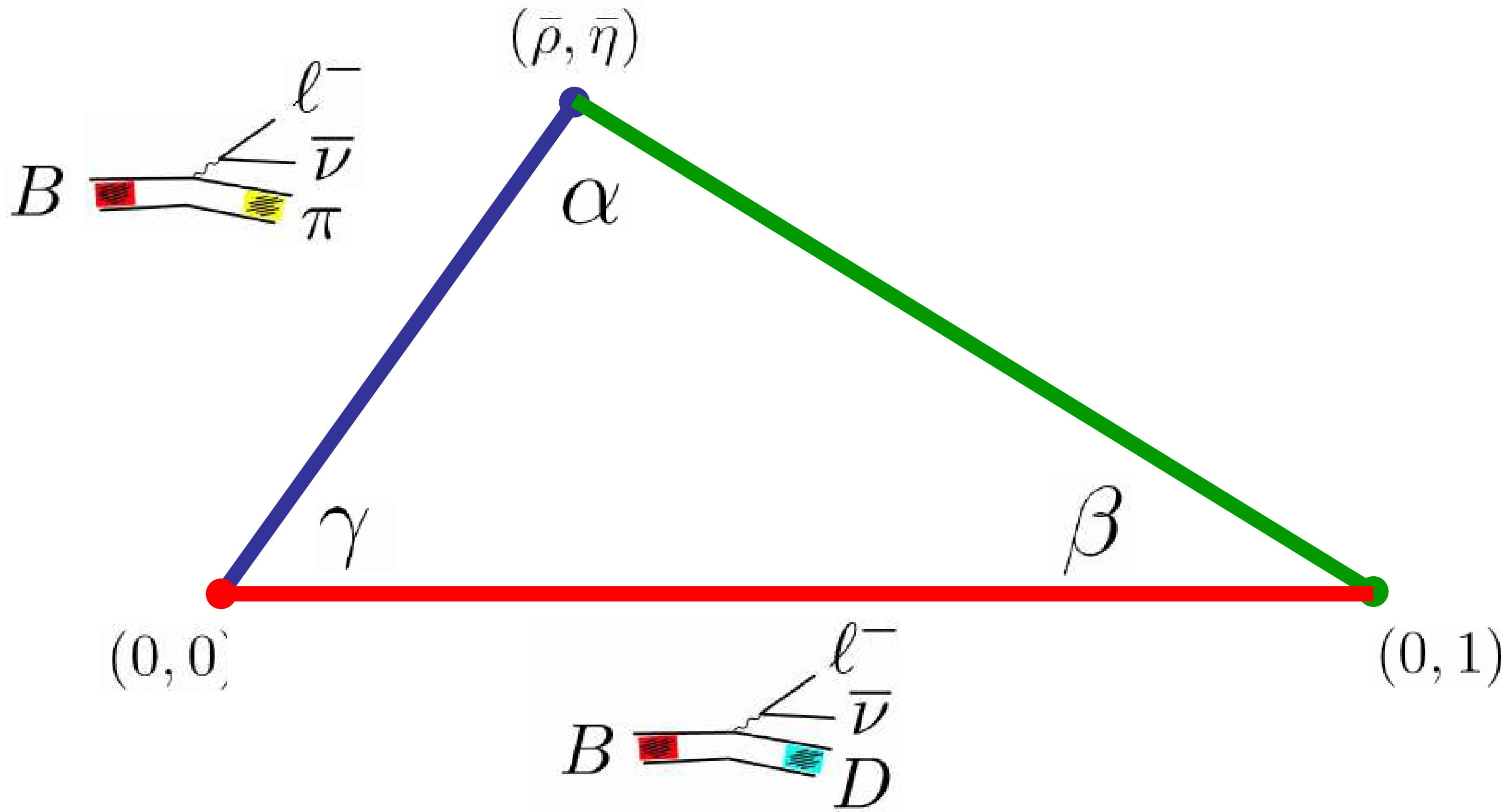




More than 400 fb^{-1}

UT sides measurements

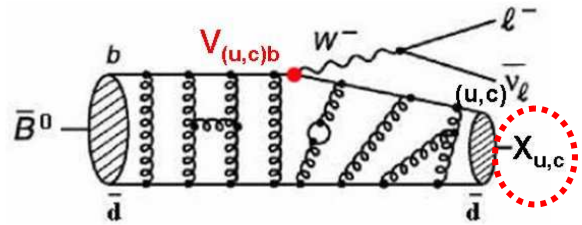
$|V_{cb}|$ & $|V_{ub}|$



$(\bar{\rho}, \bar{\eta})$
ℓ^-
$\overline{\nu}$
B
π
α
γ
β
$(0, 0)$
$(0, 1)$
ℓ^-
$\overline{\nu}$
B
D

$|V_{cb}|$ & $|V_{ub}|$: howto

- $|V_{ub}|$ and $|V_{cb}|$ are measured with semileptonic $b \to u l \nu$ and $b \to c l \nu$ decays.
- Complementary approaches: **inclusive** *Vs* **exclusive**

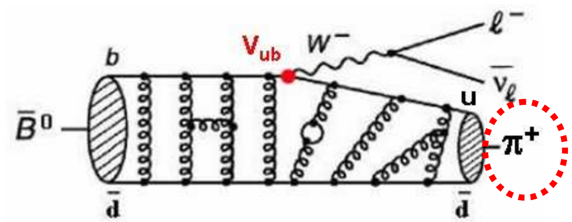


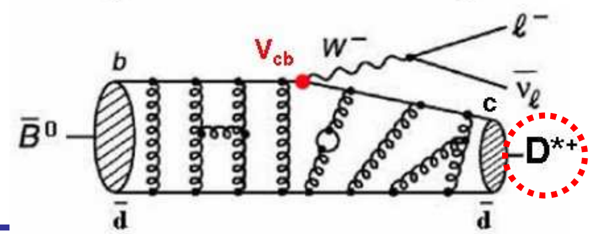
Inclusive:

- calculate $b \to x l \nu$, measure $B \to X l \nu$ for **any** X hadron
- unknown b-quark parameters obtained from measurements of $B \to X_c l \nu$ and $B \to X_s \gamma$ decays

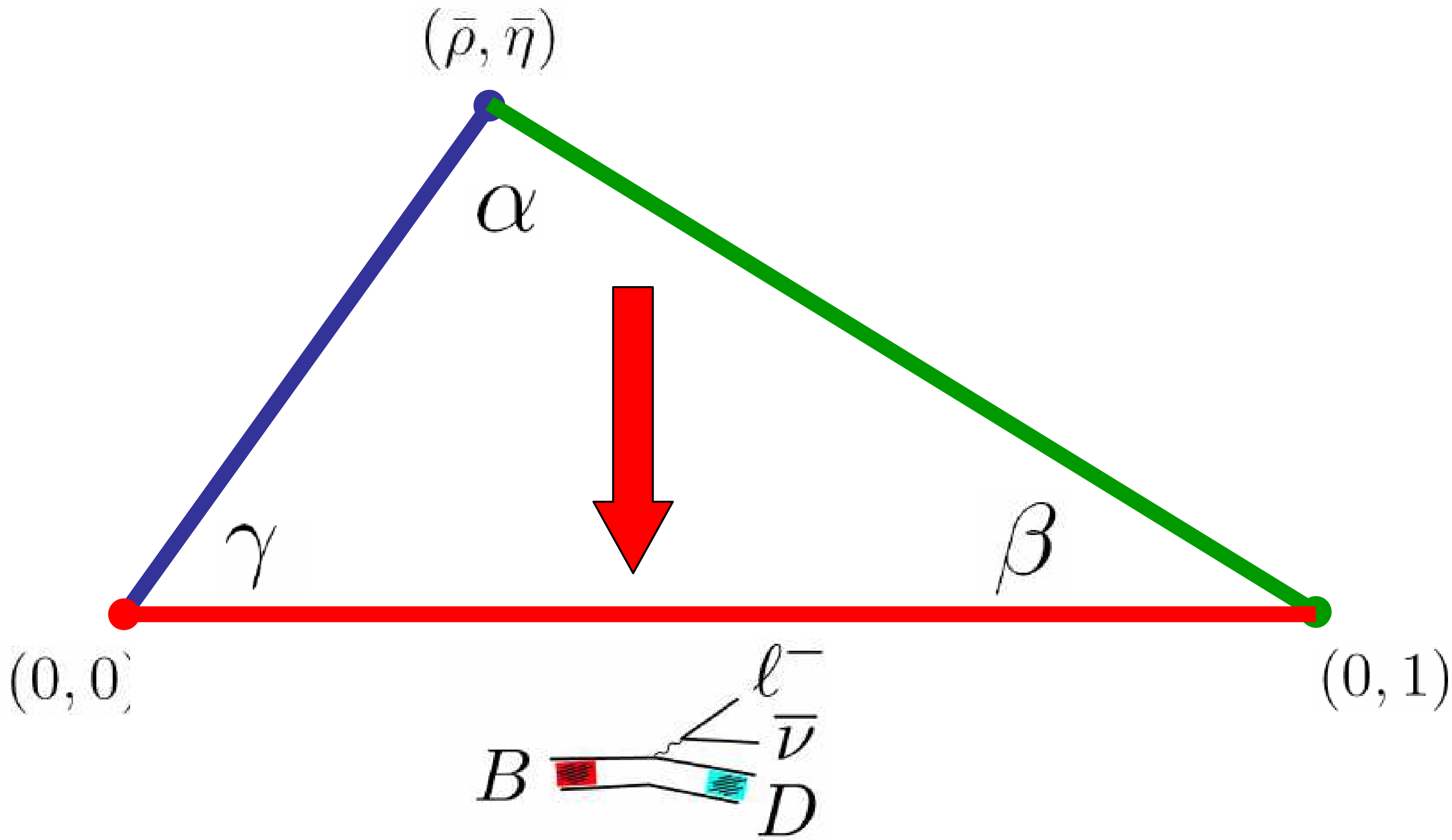
Exclusive:

- calculate and measure $B \to X l \nu$, for **one** hadron
- rely on form factor calculations (which are improving):
  - "unquenched" lattice QCD (HPQCD, Fermilab, …)
  - Light-Cone Sum Rules (Ball & Zwicky, …)
  - quark models (ISGW2, HQET, …)





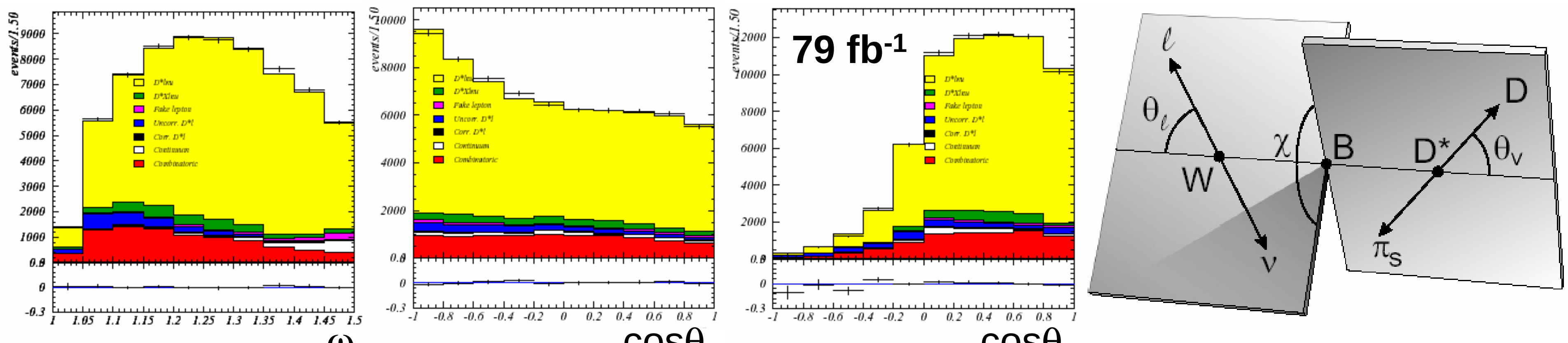
$|V_{cb}|$



Exclusive $|V_{cb}|$

- Simultaneous measurement of $|V_{cb}|$ and the $B^0 \to D^* l \nu$ form factors

hep-ex/0607076



Preliminary

- $B^0 \to D^* l \nu$ form factors parametrized by R_1, R_2 & ρ^2
- $F(1)|V_{cb}|$ & form factors given by fit of ω, cosθ$_V$ & cosθ$_L$ spectra

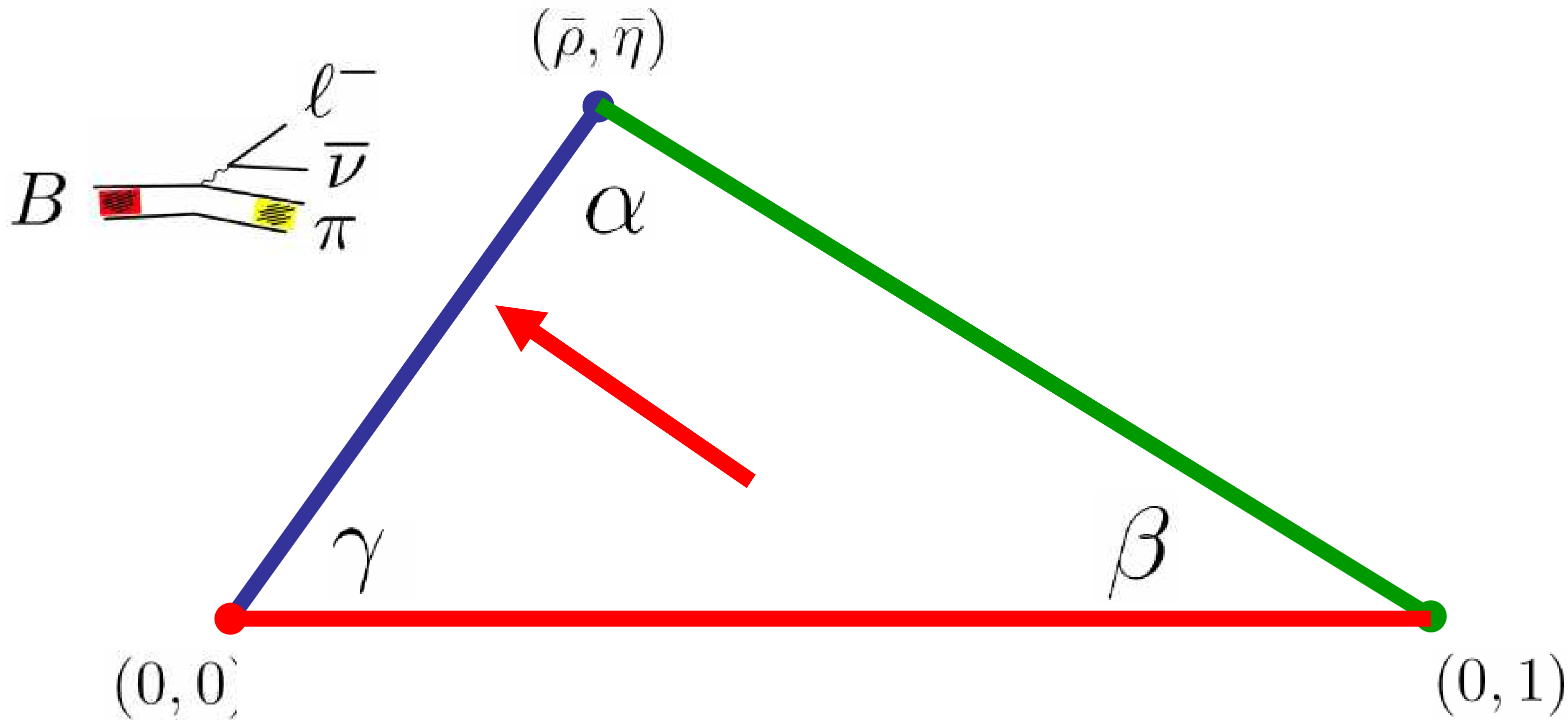
Form factors 5 times more precise than former CLEO results

$$
\begin{aligned}
\mathcal{F}(1)|V_{cb}| &= (34.68 \pm 0.32 \pm 1.15) \times 10^{-3} \\
\rho^2 &= 1.179 \pm 0.048 \pm 0.028 \\
R_1 &= 1.417 \pm 0.061 \pm 0.044 \\
R_2 &= 0.836 \pm 0.037 \pm 0.022.
\end{aligned}
$$

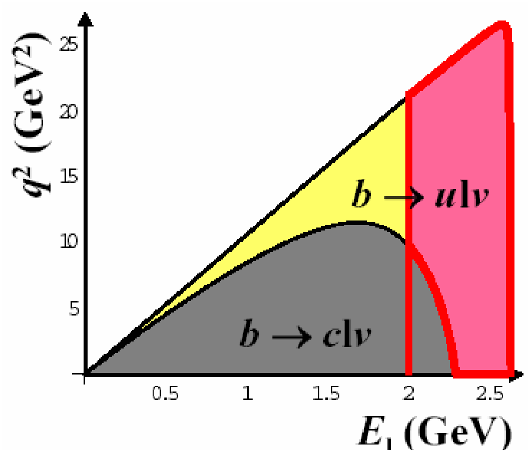
$$|V_{cb}| = (37.6 \pm 0.3 \pm 1.3(+1.5,-1.3)) \times 10^{-3}$$

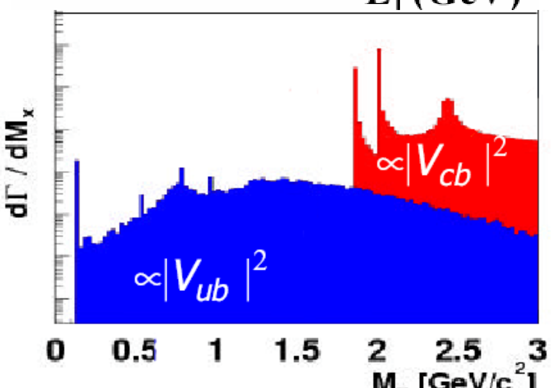
*ρ^2, R_1, R_2 averaged with BaBar's Phys.Rev.**D74**, 092004 (2006)

$|V_{ub}|$

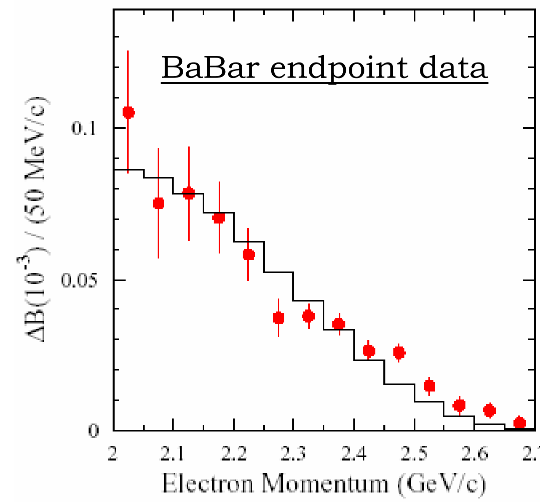


Inclusive $|V_{ub}|$

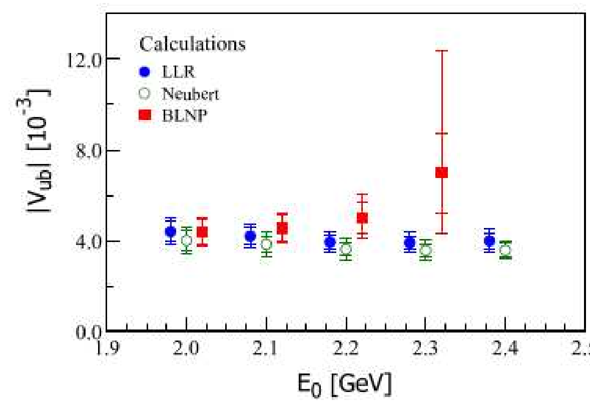




- Problem: $B \to X_c l \nu$ bkg rate ~50x higher than $B \to X_u l \nu$ signal…
- Solution: select $b \to u l \nu$ events with **low M_X**, **high E_{lep}** and/or **high q^2**.



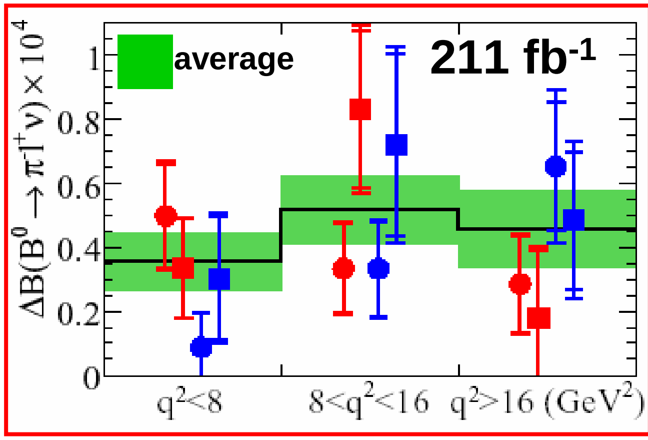
New interpretation of BaBar endpoint: **hep-ph/0702072**



Four BaBar measurements using ~82 fb^{-1} so far:
- Tagged "SF free" (M_X): PRL **96**, 221801 (2006)
- Untagged endpoint: Phys. Rev. **D73**, 012006 (2006)
- Untagged E_e-q^2: PRL **97**, 019903 (2006)
- Tagged M_X-q^2: hep-ex/0507017

$$|V_{ub}| = (4.40 \pm 0.30 \pm 0.41 \pm 0.23) \times 10^{-3} \text{ (BLNP)}$$

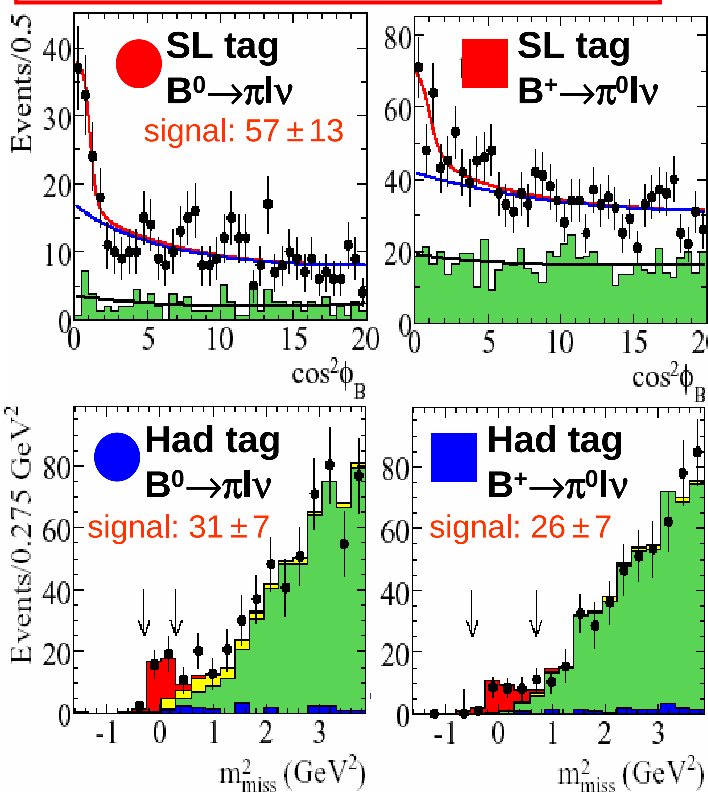
Exclusive $|V_{ub}|$ (tagged)



Measurement of $|V_{ub}|$ from tagged $B\to\pi l\nu$ decays

Phys. Rev. Lett. **97**, 211801 (2006)

- Tagged $B\to\pi l\nu$ reconstruction in 3 q^2 bins
- Combination of semileptonic and hadronic tags

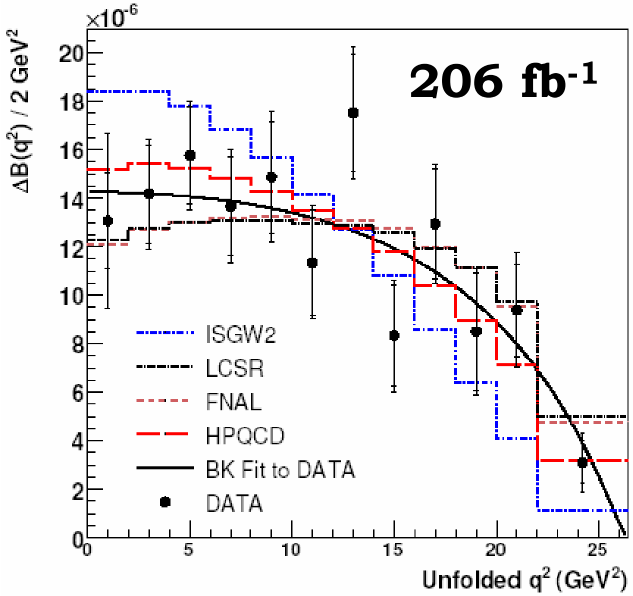


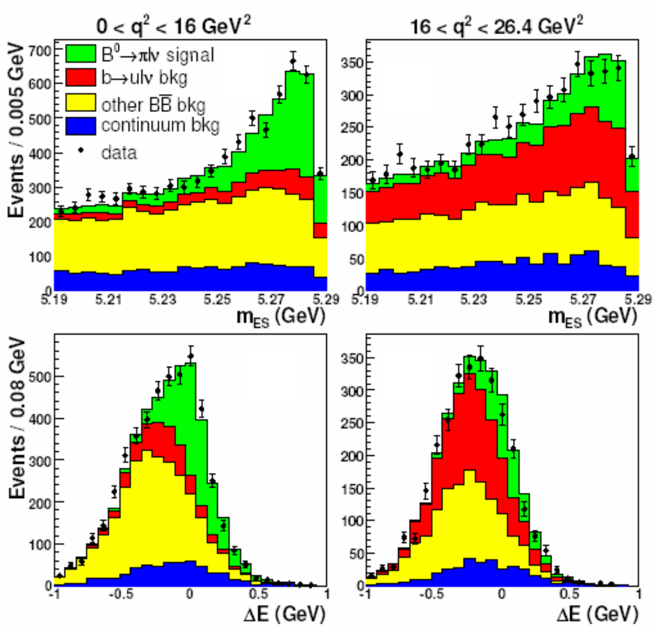
$$BF(B^0 \to \pi\ell\nu) = (1.33 \pm 0.17_{stat} \pm 0.11_{syst}) \times 10^{-4}$$

$$|V_{ub}| = (4.5 \pm 0.5_{stat} \pm 0.7_{syst}{}^{+0.7}_{-0.5\,FF}) \times 10^{-3} \quad \text{(HPQCD)}$$

- Statistically limited!!!
- Very promising with increasing BaBar dataset!!!

Exclusive $|V_{ub}|$ (untagged)





Measurement of $|V_{ub}|$ and $B^0 \to \pi l \nu$ form-factor shape with a loose neutrino reconstruction technique

hep-ex/0612020 (accepted by Phys. Rev. Lett.)

- Reconstruct ~5000 signal events
- Signal & bkgd yields by a multi-parameter fit
- test QCD calculations:
  - →LQCD & LCSR compatible
  - →ISGW2 incompatible

$$BF(B^0 \to \pi \ell \nu) = (1.46 \pm 0.07_{stat} \pm 0.08_{syst}) \times 10^{-4}$$

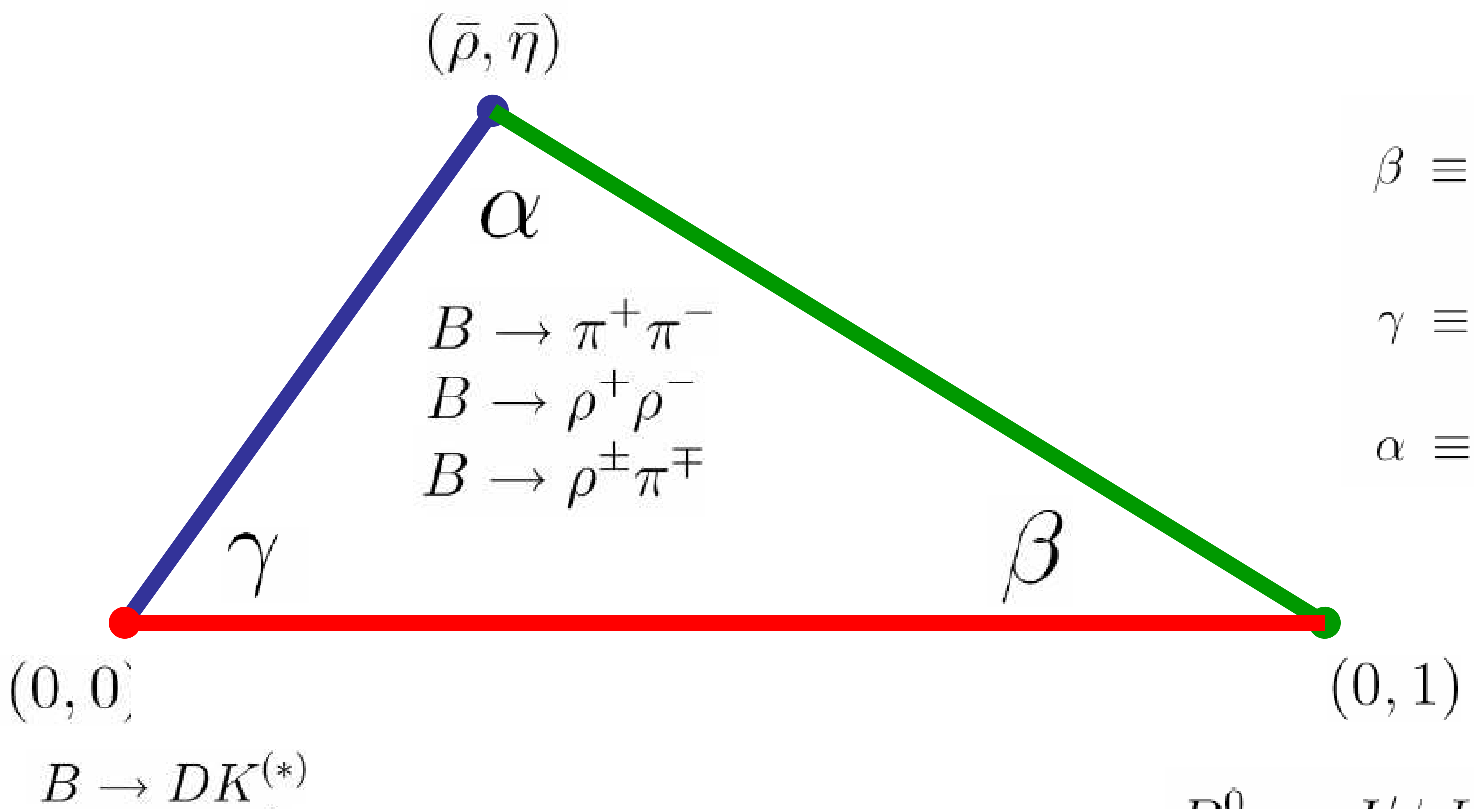
$$|V_{ub} f_+(0)| = (9.6 \pm 0.3_{stat} \pm 0.2_{syst}) \times 10^{-4}$$

$$|V_{ub}| = (4.1 \pm 0.2_{stat} \pm 0.2_{syst}{}^{+0.6}_{-0.4\,FF}) \times 10^{-3} \quad \text{(HPQCD)}$$

Smallest statistical & systematic uncertainties of all individual $B \to \pi l \nu$ measurements to date!!!

UT angles measurements

α, β & γ



$$\beta \equiv \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right]$$

$$\gamma \equiv \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]$$

$$\alpha \equiv \pi - \beta - \gamma$$

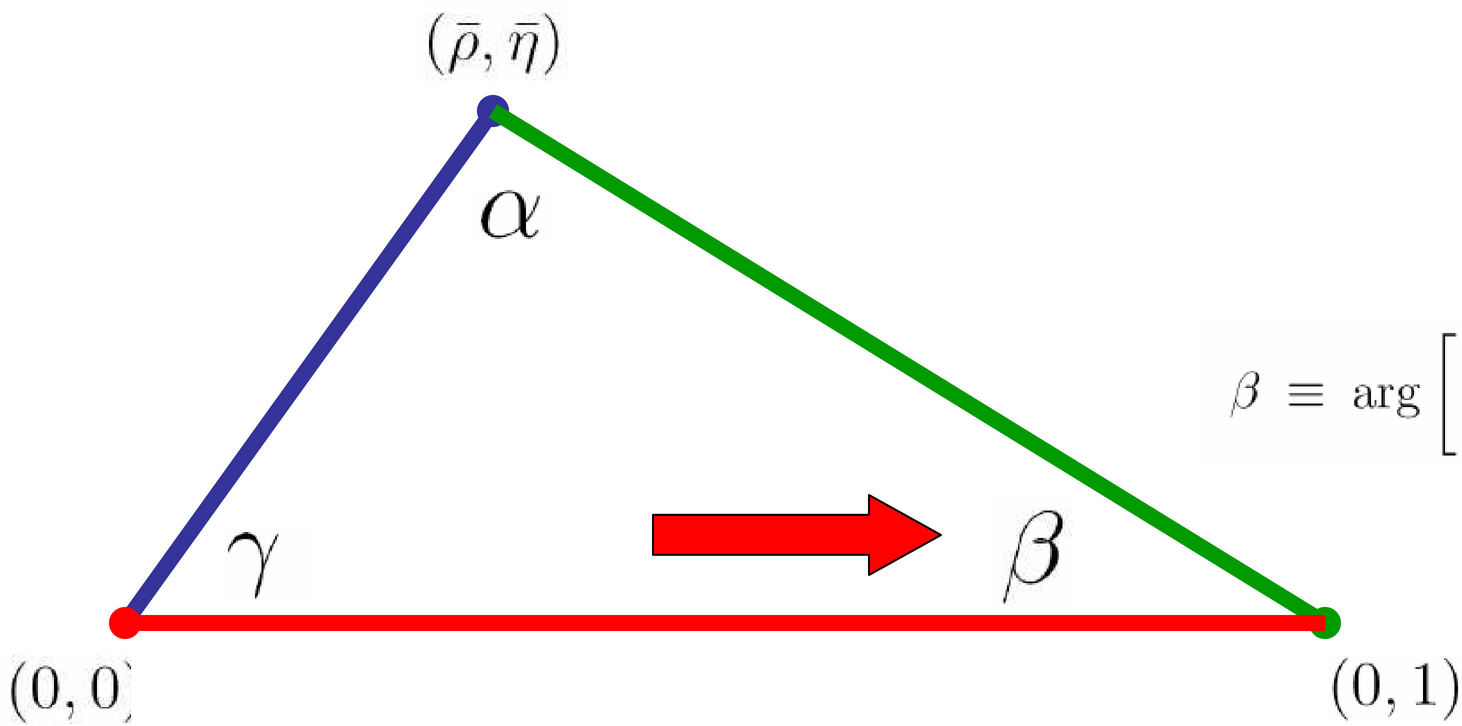
$B^0 \to J/\psi\, K^0 \qquad b \to c\,\bar{c}\,s$

$B^0 \to J/\psi\, K^{*0}$

$B^0 \to D^{(*)0}\pi^0$

$B^0 \to D^{*+}D^{*-}K_S^0$

β



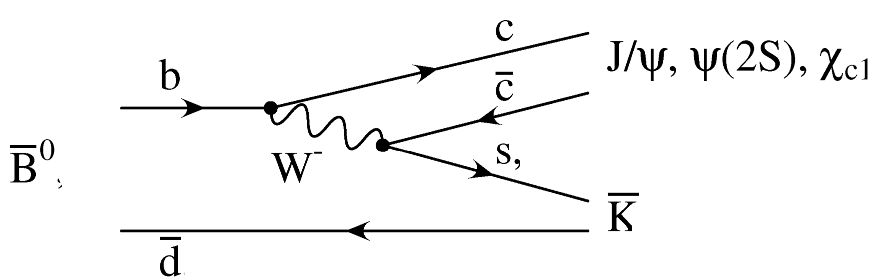
$$\beta \equiv \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right]$$

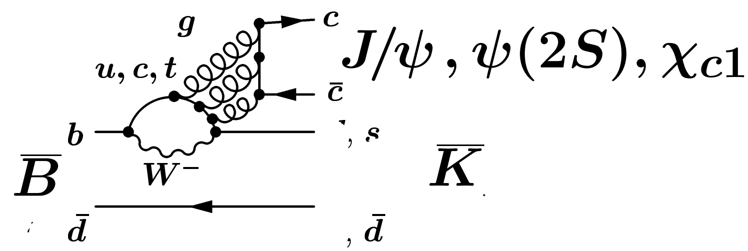
$$B^0 \to J/\psi\, K^0 \qquad b \to c\,\bar{c}\,s$$

$$B^0 \to J/\psi\, K^{*0}$$
$$B^0 \to D^{(*)0}\pi^0$$
$$B^0 \to D^{*+}D^{*-}K_S^0$$

Charmonium K^0 modes

"Golden" modes: tree diagrams dominate; the *t*-quark penguin has the same weak phase as the tree, so the measured SM quantity is sin2β





SM prediction: $C_f=0 \rightarrow A_{CP}(\Delta t) = S_f \sin(\Delta m \Delta t)$

Experimentally very clean!
Many accessible decay modes with (relatively) large BFs

$B\rightarrow J/\psi K^0 \sim 8.5 \times 10^{-4}$
$B\rightarrow J/\psi K^{*0} \sim 1.3 \times 10^{-3}$
$B\rightarrow \psi(2S) K^0 \sim 6.2 \times 10^{-4}$
$B\rightarrow x_{c1} K^0 \sim 4 \times 10^{-4}$
$B\rightarrow \eta_c K^0 \sim 1.2 \times 10^{-3}$

Charmonium K^0 modes

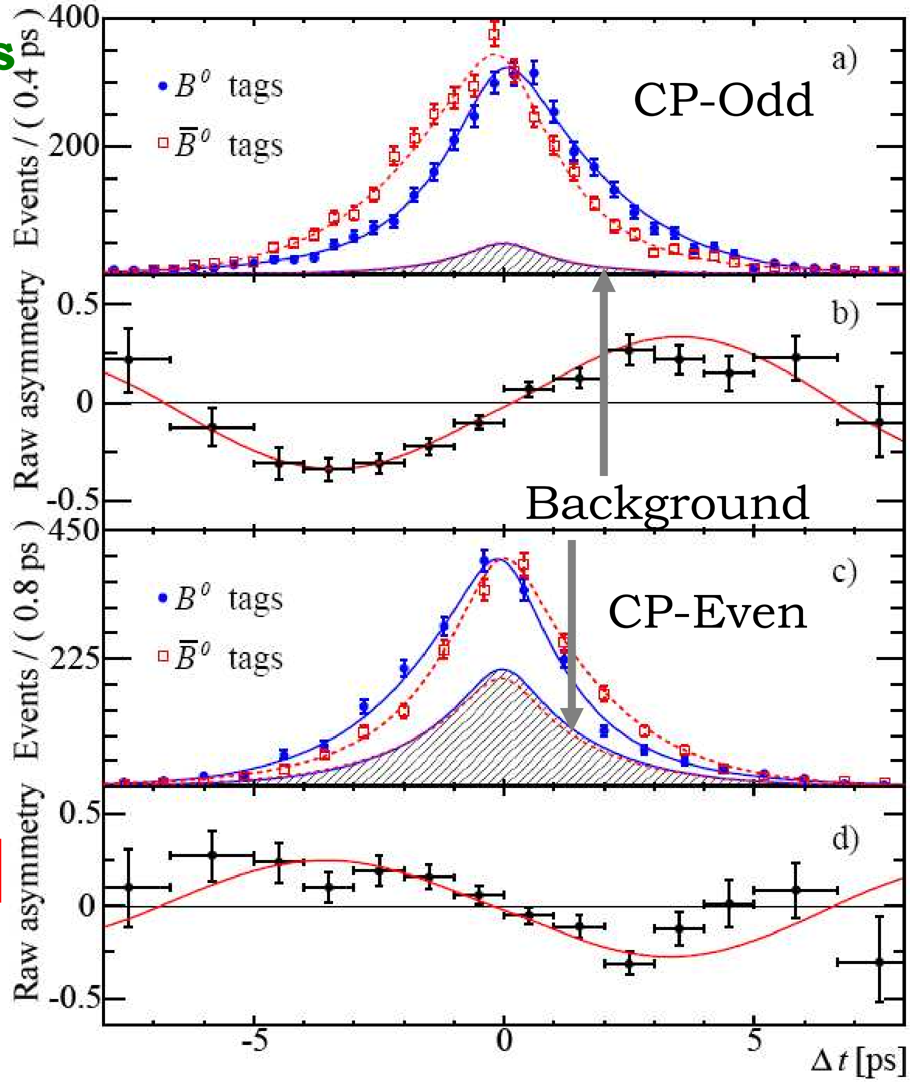
hep-ex/0703021, submitted to PRL

384 M BB pairs

Sample	N_{tag}	$P(\%)$	$\sin 2\beta$	$\vert\lambda\vert$
Full CP sample	12677	75	0.714 ± 0.032	0.952 ± 0.022
$J/\psi K^0_S (\pi^+\pi^-)$	4459	96	0.702 ± 0.042	0.976 ± 0.030
$J/\psi K^0_S (\pi^0\pi^0)$	1086	88	0.617 ± 0.103	0.812 ± 0.058
$\psi(2S) K^0_S$	687	83	0.947 ± 0.112	0.867 ± 0.079
$\chi_{c1} K^0_S$	313	89	0.759 ± 0.170	0.804 ± 0.102
$\eta_c K^0_S$	328	69	0.778 ± 0.195	0.948 ± 0.141
$J/\psi K^0_L$	4748	55	0.734 ± 0.074	1.061 ± 0.063
$J/\psi K^{*0}$	1056	66	0.477 ± 0.271	0.954 ± 0.083
$J/\psi K^0$	10275	76	0.697 ± 0.035	0.966 ± 0.025
$J/\psi K^0_S$	5547	94	0.686 ± 0.039	0.950 ± 0.027
$\eta_f = -1$	6873	92	0.711 ± 0.036	0.935 ± 0.024
1999-2002 data	3084	79	0.735 ± 0.063	0.987 ± 0.045
2003-2004 data	4850	77	0.728 ± 0.052	0.940 ± 0.035
2005-2006 data	4725	74	0.681 ± 0.054	0.940 ± 0.037

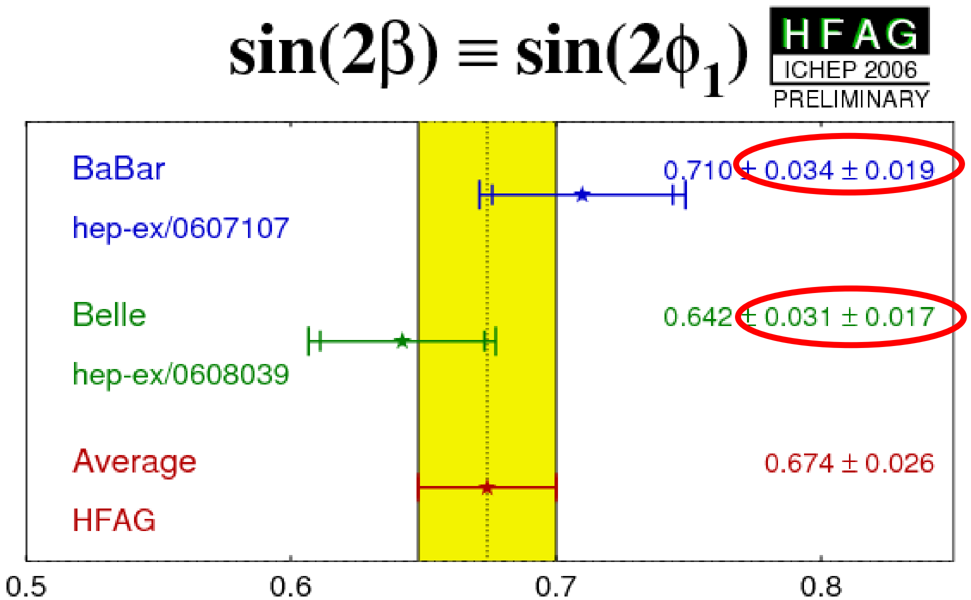
$$\boxed{\sin 2\beta = 0.714 \pm 0.032\,(\text{stat}) \pm 0.018\,(\text{syst})}$$

$$\boxed{|\lambda| = 0.952 \pm 0.022\,(\text{stat}) \pm 0.017\,(\text{syst})}$$

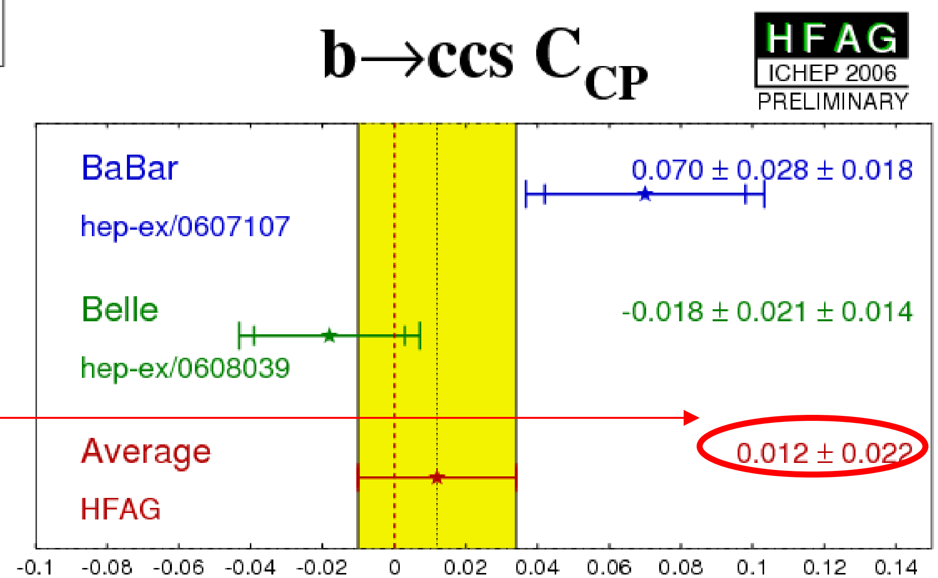


Sin2β averages

Heavy Flavors Averaging Group
E.Barberio et al., hep-ex/0603003



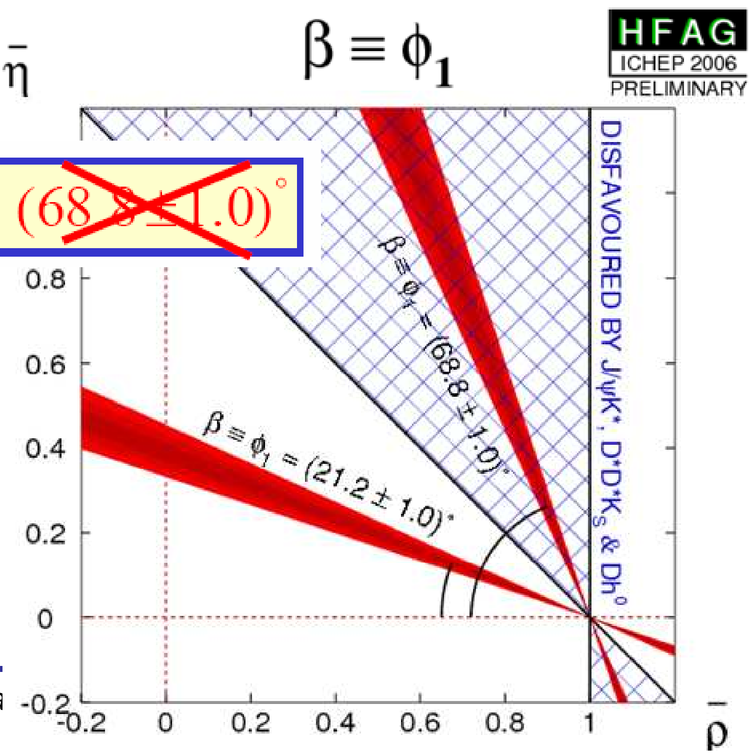
still statistically limited



Consistent with zero: no evidence for NP in tree decay

All the cos(2β) world

- Resolve the geometric ambiguity on β in the measurement of cos 2β
  1. TD analysis of VV $J/\Psi\ K^{*0}$ decays
  2. TD Dalitz fit of $D\rightarrow K_S\pi^+\pi^-$ in $B^0\rightarrow D^0h^0$
  3. TD study of $B^0\rightarrow D^*D^*K_S$



$$\boxed{\beta = (21.2 \pm 1.0)^\circ \ \text{ or } \ \cancel{(68.8 \pm 1.0)^\circ}}$$

1. Phys.Rev.D71 (2005) 032005

2. hep-ex/0607105

3. Phys.Rev. D74 (2006) 091101

Colour suppressed decays

TD analysis of $D^0 \to CP$ in $B^0 \to D^{(*)0} h^0$

348 fb^{-1}

$\eta_f = +1$ (CP even)			$\eta_f = -1$ (CP odd)		
Mode	D_{CP}	N_{signal}	Mode	D_{CP}	N_{signal}
$D^0_{K^0_S\omega}\pi^0$	$-$	26.2 ± 6.3	$D^0_{KK}\pi^0$	$+$	104 ± 17
$D^0_{K^0_S\pi^0}\omega$	$-$	40.0 ± 8.0	$D^0_{KK}\eta_{\gamma\gamma}$	$+$	28.9 ± 6.5
$D^0_{K^0_S\omega}\omega$	$-$	23.2 ± 6.8	$D^0_{KK}\eta_{3\pi}$	$+$	14.2 ± 4.7
$D^{*0}_{KK}\pi^0$	$+$	23.2 ± 6.3	$D^0_{KK}\omega$	$+$	51.2 ± 8.5
$D^{*0}_{KK}\eta_{\gamma\gamma}$	$+$	9.8 ± 3.5	$D^{*0}_{K^0_S\omega}\pi^0$	$-$	5.5 ± 3.3
$D^{*0}_{KK}\eta_{3\pi}$	$+$	6.8 ± 2.9			
Combined		131 ± 16			209 ± 23
Total					340 ± 32

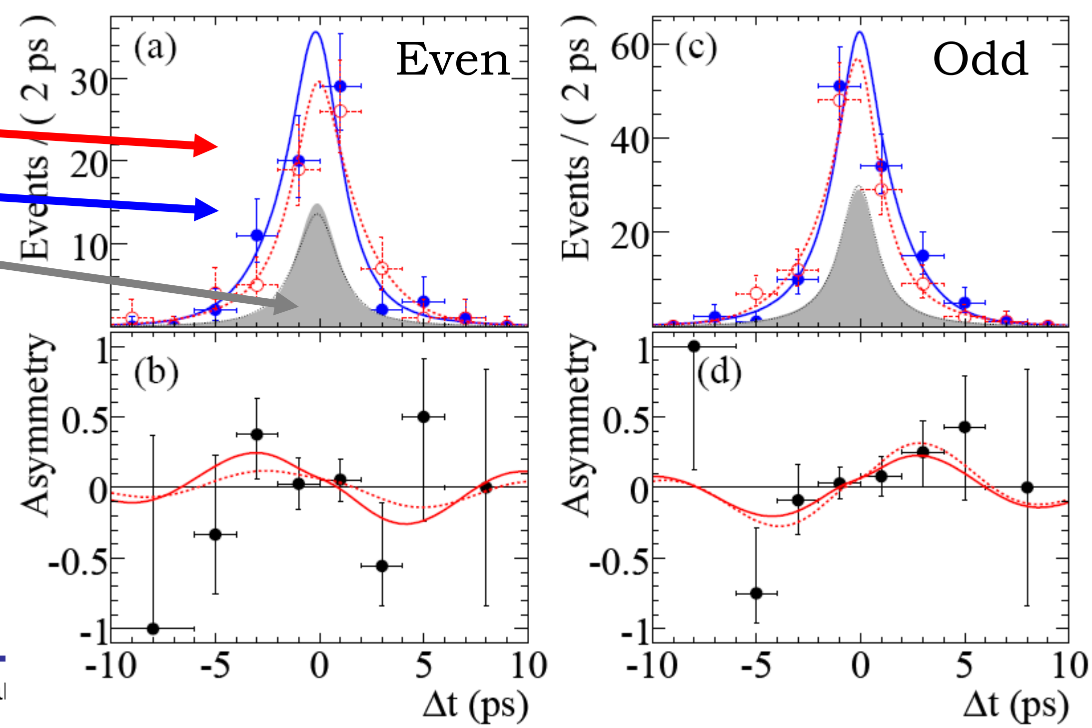
tree level dominated

small SM unceratainty

Δt for $\overline{B}^0$ tag

Δt for B^0 tag

Background

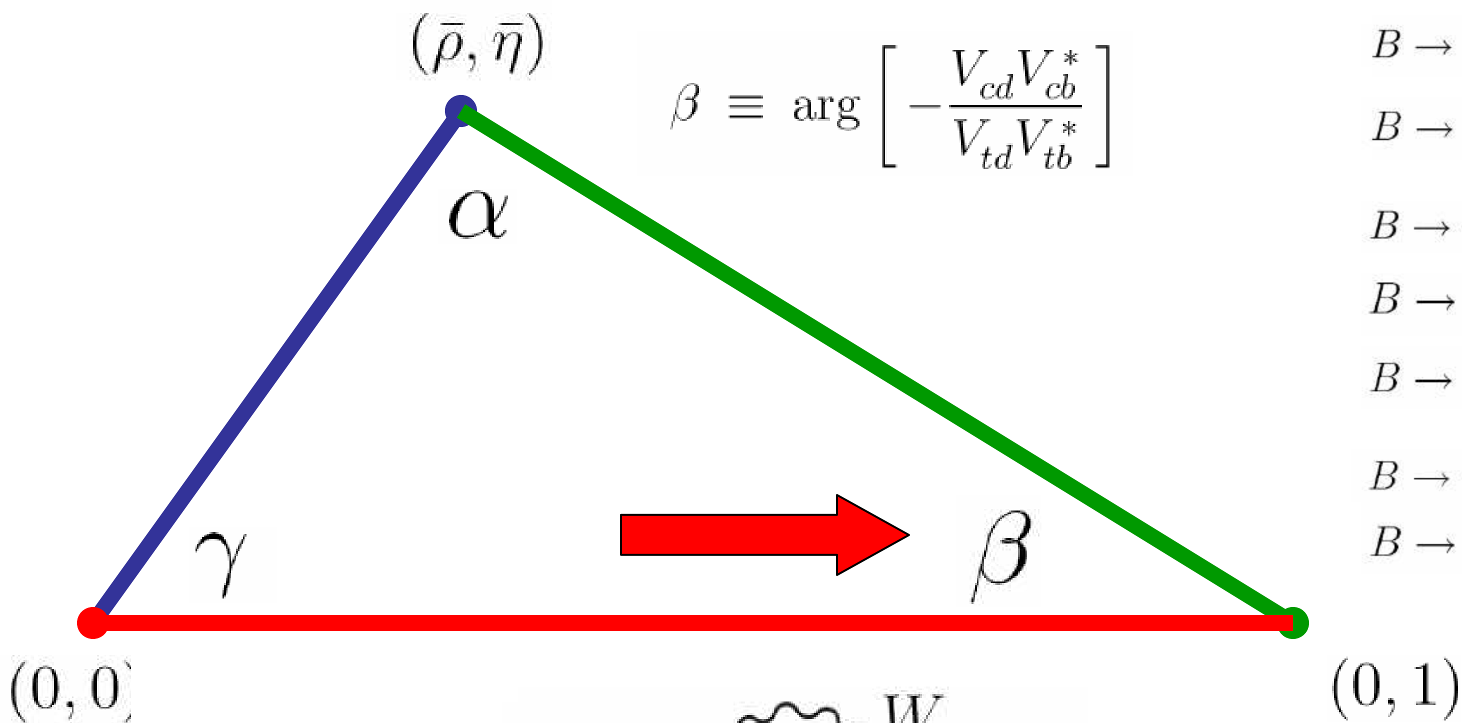


$$\boxed{\mathcal{S} = -0.56 \pm 0.23 \pm 0.05}$$

$$\boxed{\mathcal{C} = -0.23 \pm 0.16 \pm 0.04}$$

First measurement of sin2β in these modes!

β: penguin modes



$$\beta \equiv \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right]$$

$B \to \phi K_S^0$

$B \to K_S^0 K_S^0 K_S^0$

$b \to s\,\bar{s}\,s$

$B \to \eta' K_S^0$

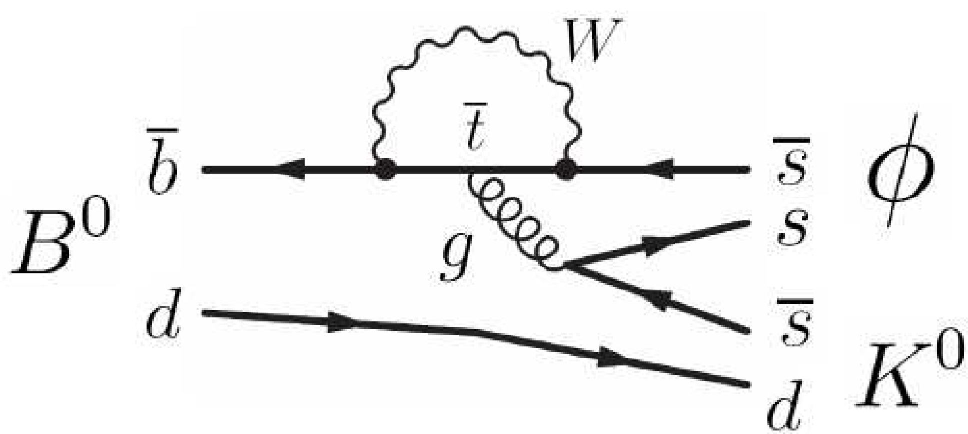
$B \to f_0 K_S^0$

$B \to K K K_S^0$

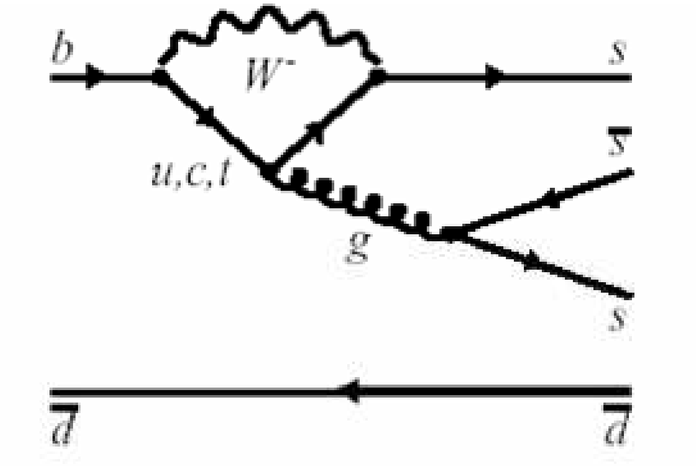
$B \to \pi^0 K_S^0$

$B \to \omega K_S^0$

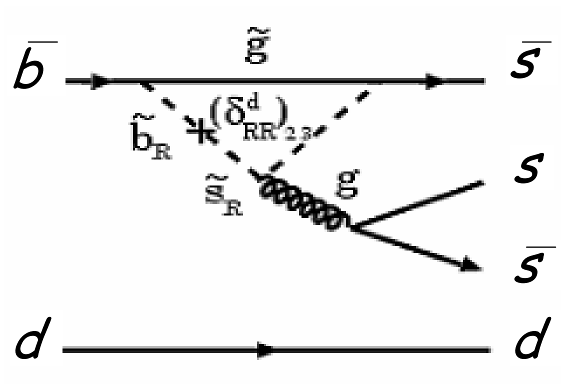
$b \to q\bar{q}s$



Sin2β with penguins

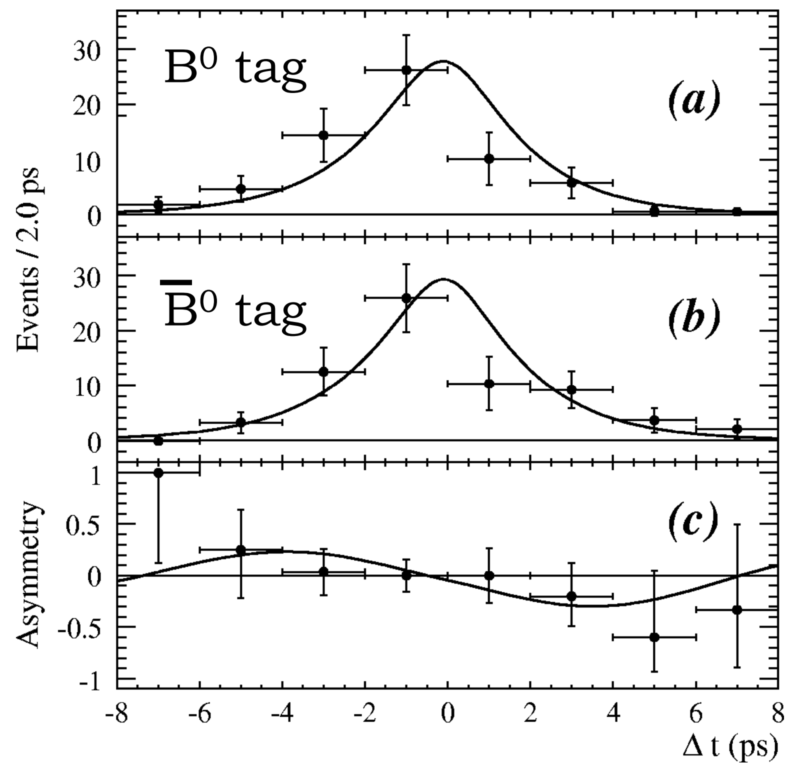


NP in the loop?



$B^0 \rightarrow K_S K_S K_S$

384 M BB

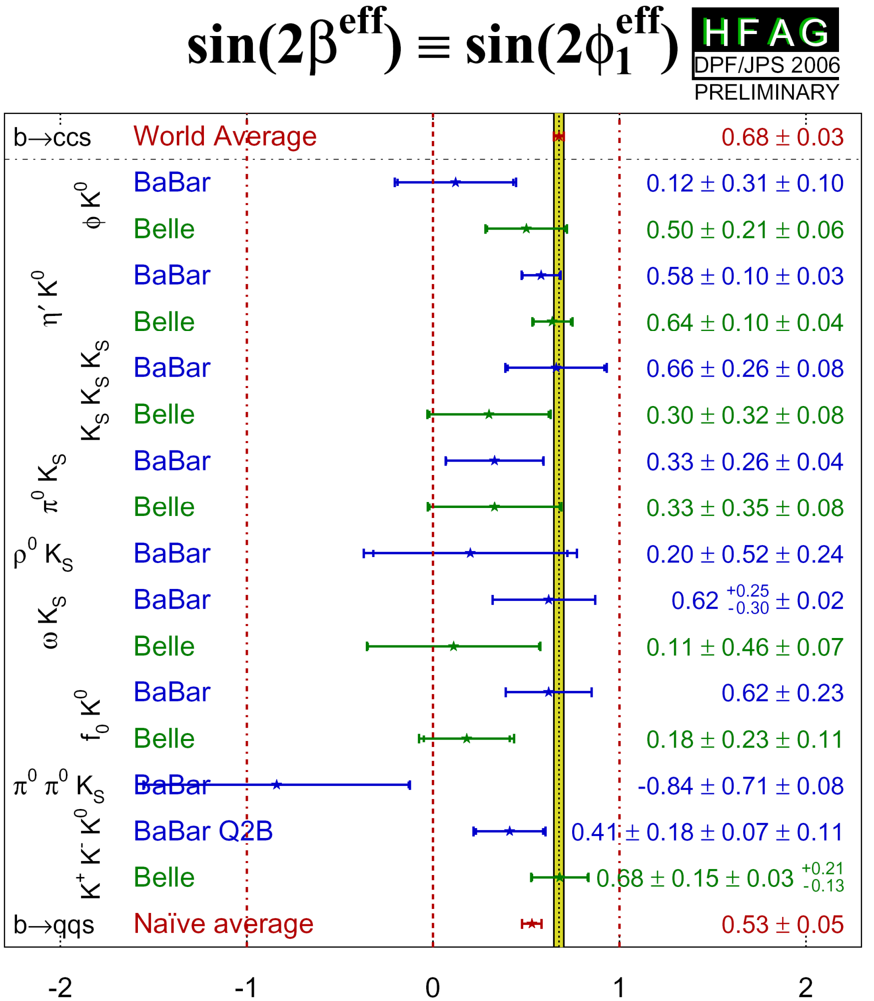


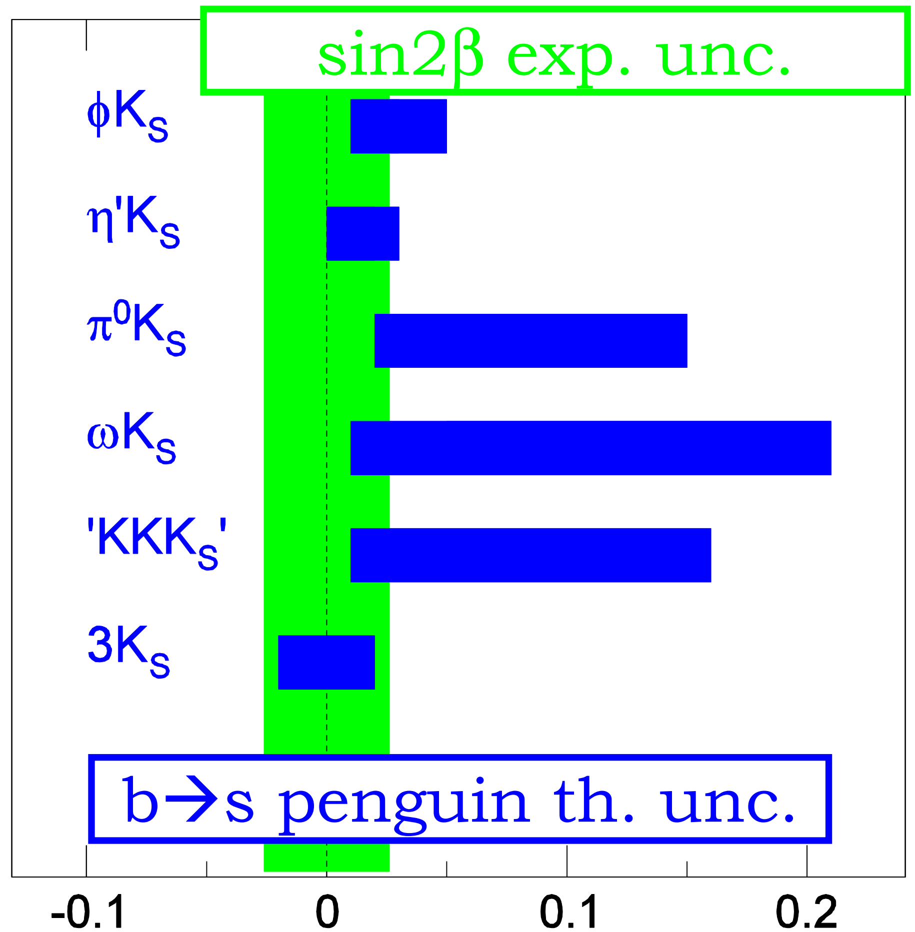
hep-ex/0702046 (submitted to PRL)

$$S = +0.71 \pm 0.24 \pm 0.04$$
$$C = +0.02 \pm 0.21 \pm 0.05$$

Sin2β with penguins

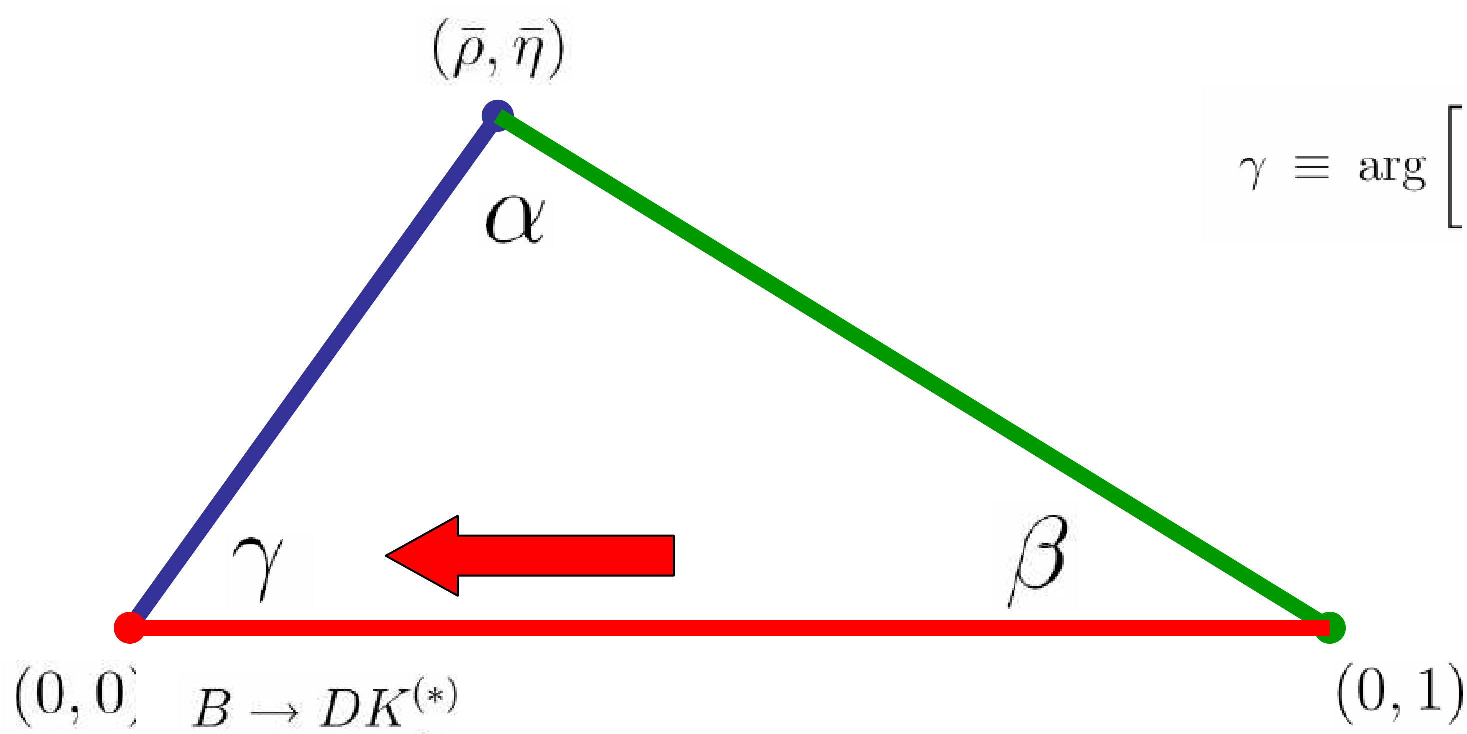
$\sin 2\beta_{eff}$ points towards values lower than $\sin 2\beta$





$\Delta\sin 2\beta = \sin 2\beta_{eff} - \sin 2\beta$

γ

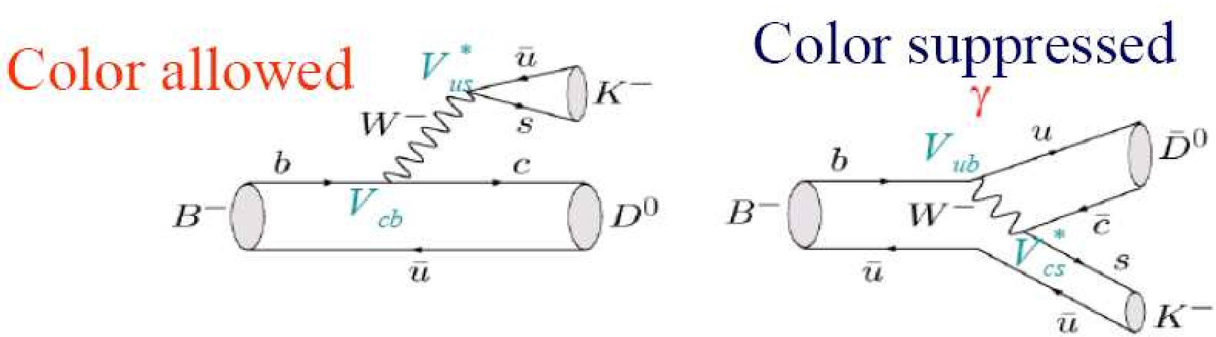


$$\gamma \equiv \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]$$

$B^+ \to D^0 K^+$

only tree diagrams: no issue with New Physics in loops

- Interference between:
  1. ($b \to c$) $B^+ \to \overline{D}^0 K^+$
  2. CKM-and color-suppressed ($b \to u$) $B^+ \to D^0 K^+$,
- D^0 and the $\overline{D}^0$ decay to a common final state f
  1. GLW : f is a CP eigenstate
     - KK, $\pi\pi$, $K_s\omega$, $K_s\phi$, $K_s\pi$
  2. ADS : f is doubly Cabibbo suppressed
     - $K\pi$, $K\pi\pi^0$
  3. GGSZ : f is a 3 body decay (Dalitz)
     - $K_s\pi\pi$, $\pi\pi\pi^0$

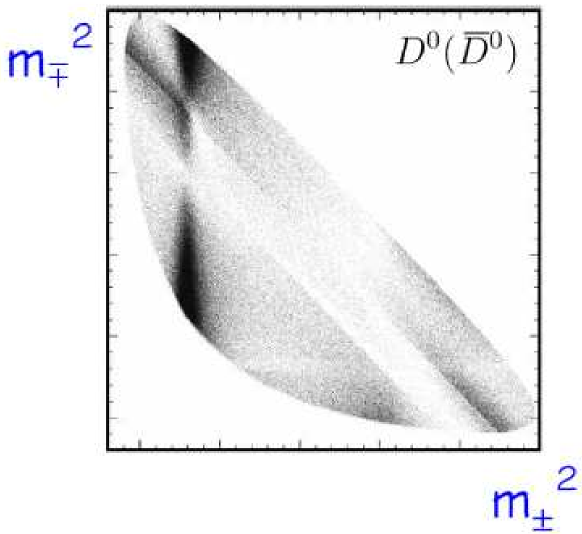


$B^+ \rightarrow D^{(*)0}[K_s\pi\pi]\, K^+$: GGSZ (Dalitz)

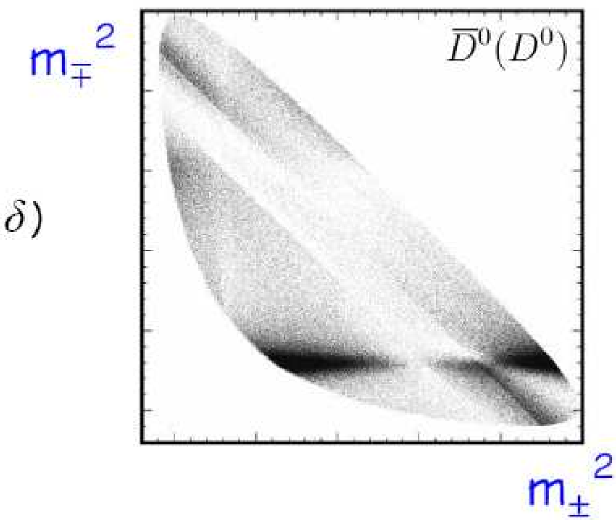
$B \rightarrow D[K_s\pi\pi]K$

Idea: fit $K_s\pi\pi$ Dalitz structure

$$|A_{\mp}|^2 = \Bigg|$$



$$+\, r_B\, e^{i(\gamma\pm\delta)}$$



$$\Bigg|^2$$

$$CP \begin{cases} \Gamma(B^-) \propto |f_-|^2 + r_b^2 |f_+|^2 + \boxed{2x_-}\, \mathrm{Re}\left(f_- f_+^*\right) + 2y_-\, \mathrm{Im}\left(f_- f_+^*\right) \\ \Gamma(B^+) \propto |f_+|^2 + r_b^2 |f_-|^2 + \boxed{2x_+}\, \mathrm{Re}\left(f_+ f_-^*\right) + 2y_+\, \mathrm{Im}\left(f_+ f_-^*\right) \end{cases}$$

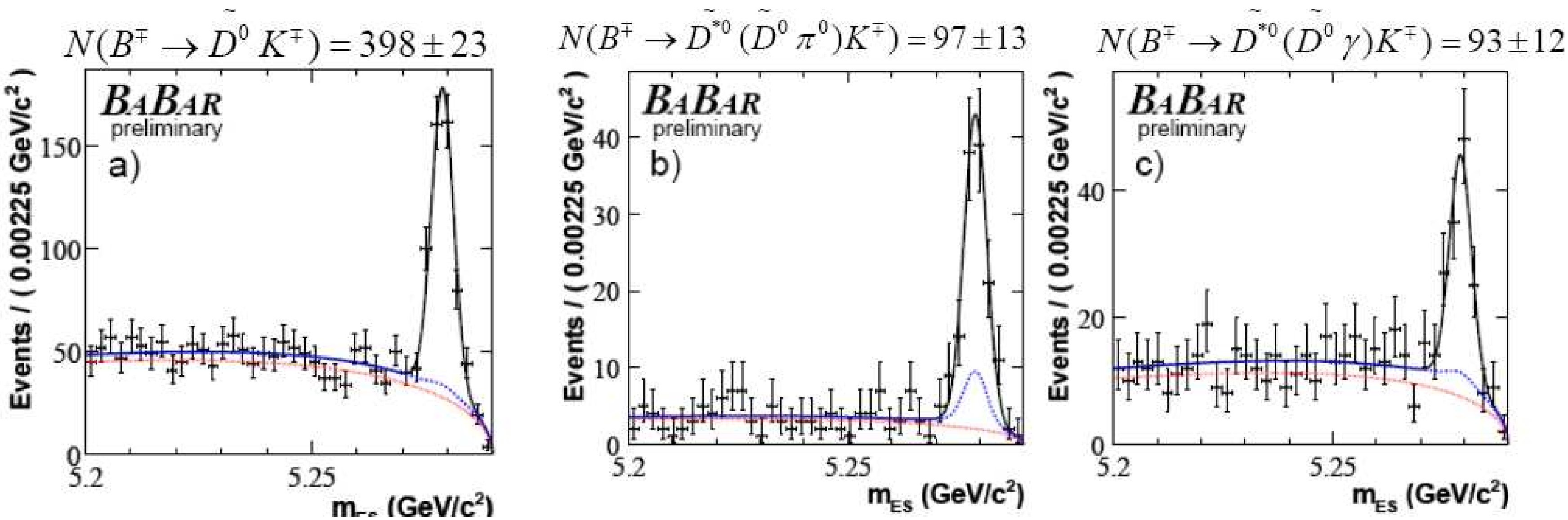
$$f_{\mp} \equiv f(m_{\mp}^2, m_{\pm}^2)$$

From a large D^0 control sample

$$r_B = \left|\frac{A(b \rightarrow u)}{A(b \rightarrow c)}\right|$$

$$\boxed{\begin{aligned} x_{\mp} &= r_b \cos(\delta \mp \gamma) \\ y_{\mp} &= r_b \sin(\delta \mp \gamma) \end{aligned}}$$

$B^+ \to D^{(*)0} K^+$: GGSZ (Dalitz)



$$\gamma = (92 \pm \underset{\text{(stat)}}{41} \pm \underset{\text{(syst)}}{11} \pm \underset{\text{(Dalitz)}}{12})^\circ$$

$$\delta_B = (118 \pm 63 \pm 19 \pm 36)^\circ$$

$$\delta_B^* = (-62 \pm 59 \pm 18 \pm 10)^\circ$$

$$0.00 < r_B < 0.140$$
$$0.017 < r_B^* < 0.203$$

one standard deviations constraints

hep-ex/0607104

$347 \times 10^6 \, B\overline{B}$ pairs

$B^+ \rightarrow D^{(*)0}[\pi\pi\pi^0]\ K^+$: GGSZ (Dalitz)

- First measurement of CP parameters with this channel
- Signal yield: 170±29 on ~324x10^6 $B\bar{B}$ pairs

NEW

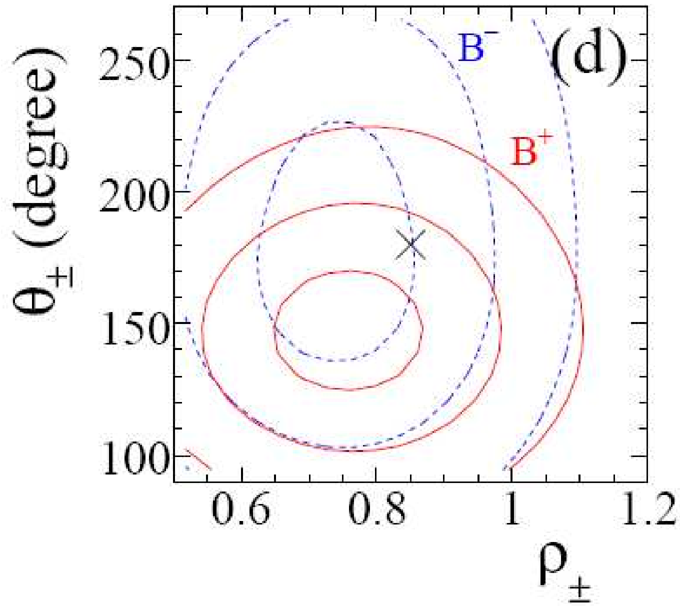
$$x_\pm = \rho_\pm \cos\vartheta_\pm + x^0$$
$$y_\pm = \rho_\pm \sin\vartheta_\pm$$

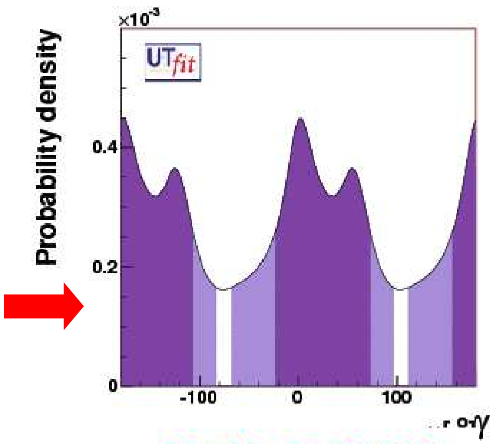
$$x_0 \equiv -\int \mathrm{Re}\left(f(m_+^2, m_-^2), f^*(m_-^2, m_+^2)\right) dm_+^2\, dm_-^2$$

f= D Dalitz amplitude

hep-ex/0703037

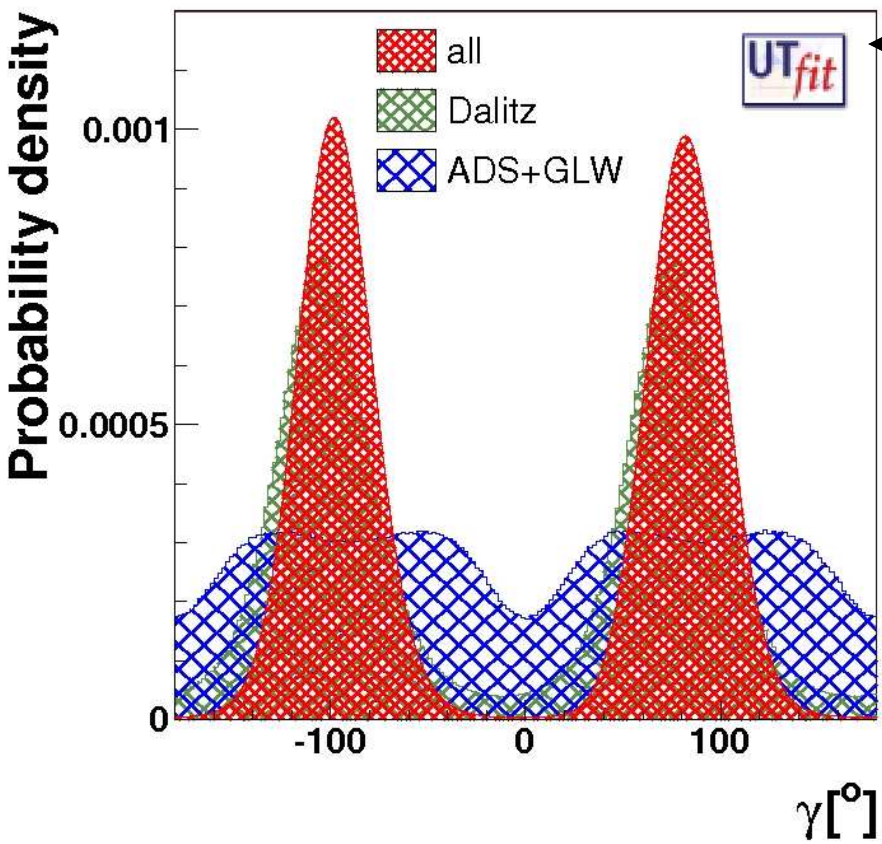
- $\rho^- = 0.72 \pm 0.11 \pm 0.06$
- $\vartheta^- = (173 \pm 42 \pm 19)°$
- $\rho^+ = 0.75 \pm 0.11 \pm 0.06$
- $\vartheta^+ = (147 \pm 23 \pm 16)°$





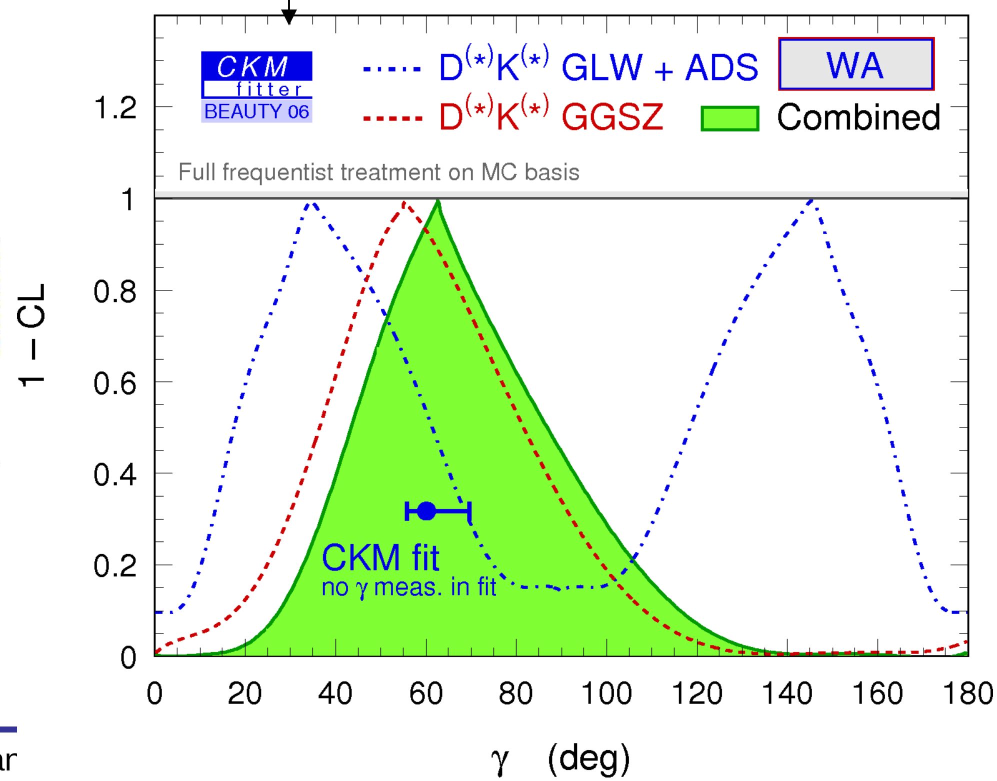
γ = 25±48 @ 68%CL
γ =[-67,97] @ 90% CL

γ : results

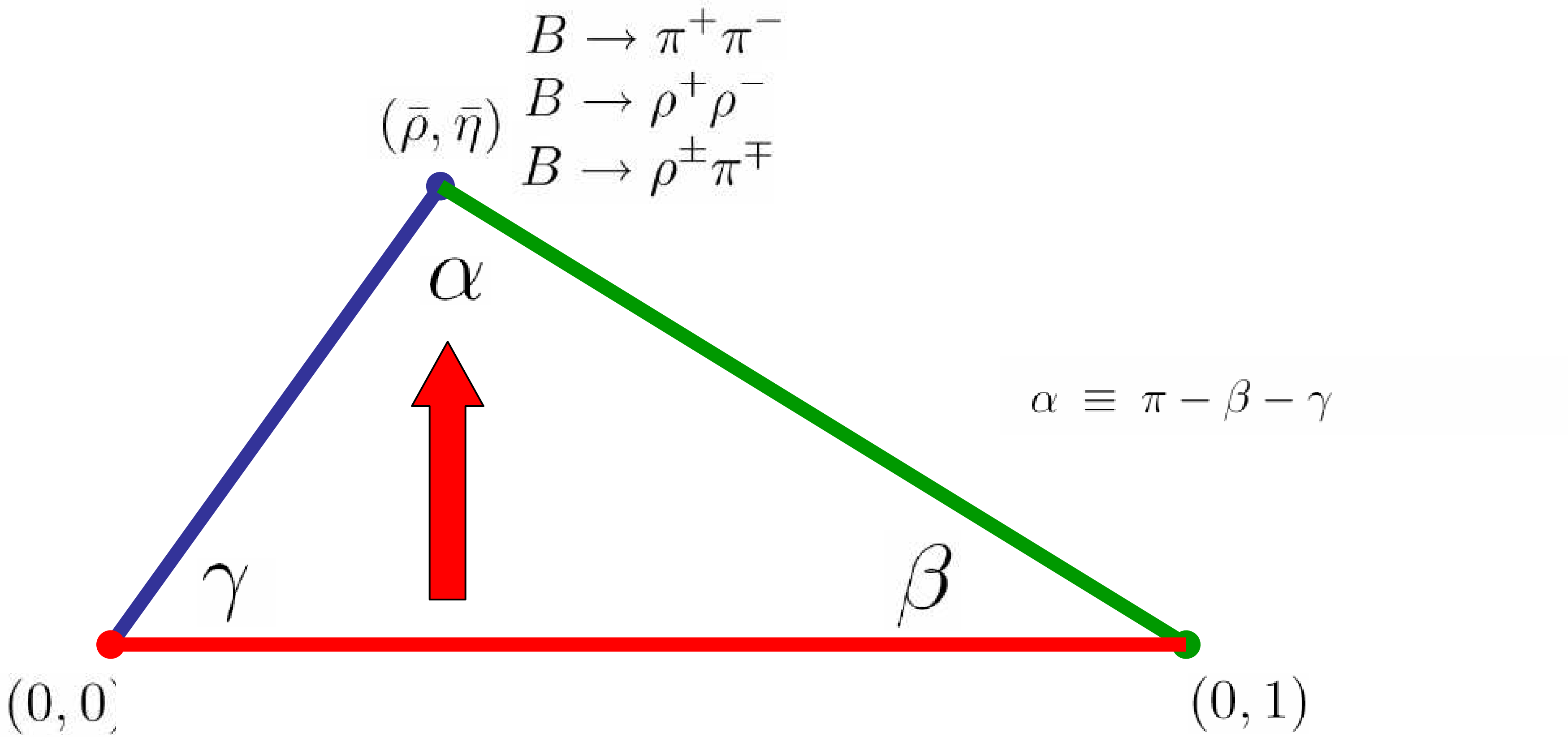


UT$_{fit}$: = $(82 \pm 19)^o$

CKMfitter: = $(62^{+38}_{-24})^o$



α

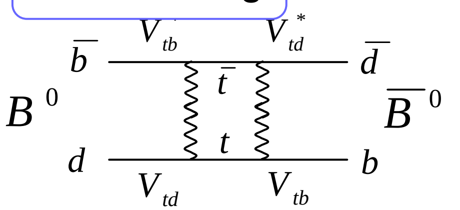


$B \to \pi^+\pi^-$
$B \to \rho^+\rho^-$
$B \to \rho^\pm\pi^\mp$
$(\bar{\rho},\bar{\eta})$
α
$\alpha \equiv \pi - \beta - \gamma$
γ
β
$(0,0)$
$(0,1)$

α: howto

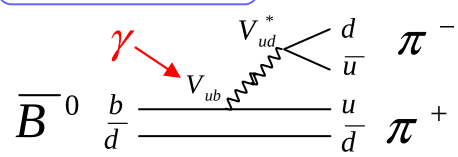
- Access to α from the interference of a $b \to u$ decay (γ) with $B^0 \bar{B}^0$ mixing (β)

$B^0\bar{B}^0$ mixing



$q/p \propto V^*_{tb}V_{td}/V_{tb}V^*_{td}$

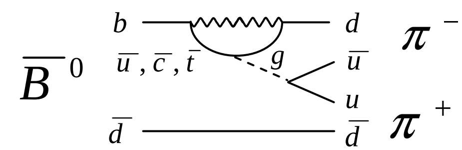
Tree decay



$A \propto V^*_{ud}V_{ub}$

$\oplus$

Penguin decay



$A \approx V^*_{td}V_{tb}$

$$\lambda = \frac{q}{p}\frac{\bar{A}}{A} = e^{-i2\beta}e^{-i2\gamma} = e^{i2\alpha}$$

$S = \sin(2\alpha)$

$C = 0$

Inc. penguin contribution

$$\lambda = e^{i2\alpha}\frac{T + P\,e^{+i\gamma}e^{i\delta}}{T + P\,e^{-i\gamma}e^{i\delta}}$$

$S = \sqrt{1-C^2}\,\sin(2\alpha_{eff})$

$C \propto \sin\delta$

How can we obtain α from α_{eff}?

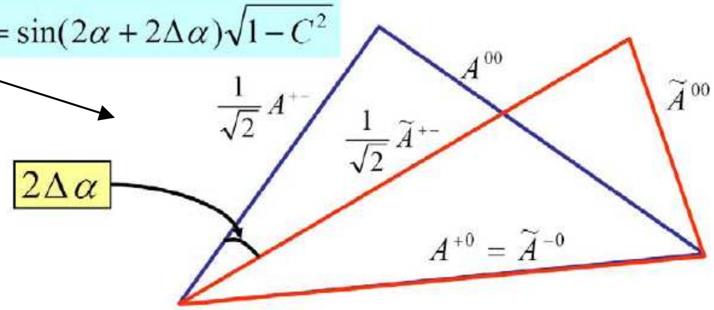
Time-dep. asymmetry : $A_{\pi\pi}(\Delta t) = S_{\pi\pi}\sin(\Delta m_d \Delta t) - C_{\pi\pi}\cos(\Delta m_d \Delta t)$

Use SU(2) to relate different *hh* final states

$$\begin{aligned}
A^{+-} &= A(B^0 \to \pi^+\pi^-)\\
\tilde{A}^{+-} &= A(\bar{B}^0 \to \pi^+\pi^-)\\
A^{00} &= A(B^0 \to \pi^0\pi^0)\\
\tilde{A}^{00} &= A(\bar{B}^0 \to \pi^0\pi^0)\\
A^{+0} &= A(B^+ \to \pi^+\pi^0)\\
\tilde{A}^{-0} &= A(B^- \to \pi^-\pi^0)
\end{aligned}$$

$$A_{hh} = e^{+i\gamma}T + e^{-i\beta}P$$
$$\tilde{A}_{hh} = e^{-i\gamma}T + e^{+i\beta}P$$

$S = \sin(2\alpha + 2\Delta\alpha)\sqrt{1-C^2}$



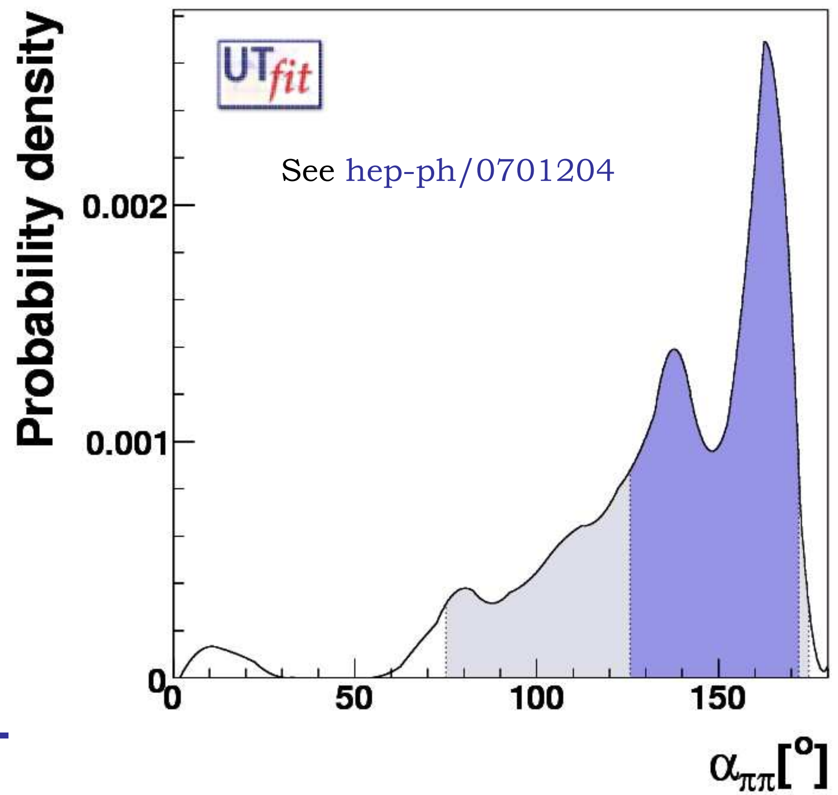
$B^0 \to \pi^+\pi^-$

Using isospin relations

$BR(B^0 \to \pi^+\pi^-) = 5.2 \pm 0.2$ HFAG (10^{-6}) -

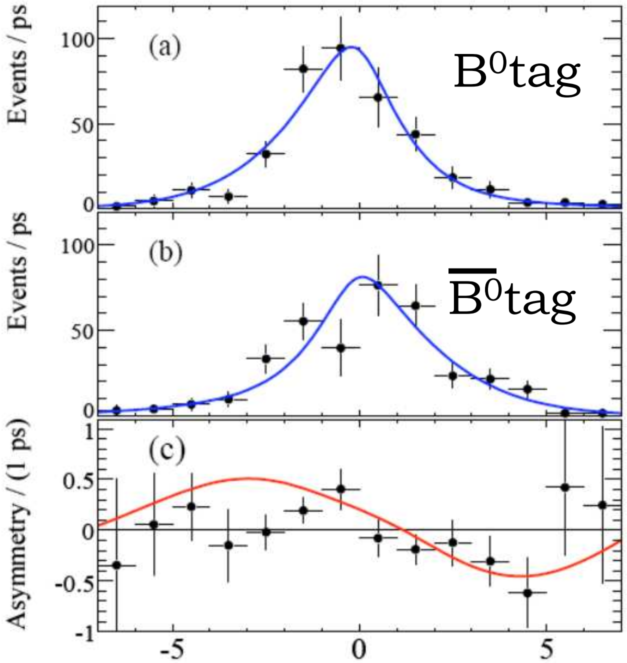
$BR(B^+ \to \pi^+\pi^0) = 5.7 \pm 0.4$ $A_{CP}(B^+ \to \pi^+\pi^0) = 0.04 \pm 0.05$

$BR(B^0 \to \pi^0\pi^0) = 1.3 \pm 0.2$ $A_{CP}(B^0 \to \pi^0\pi^0) = 0.36\,^{+0.33}_{-0.31}$

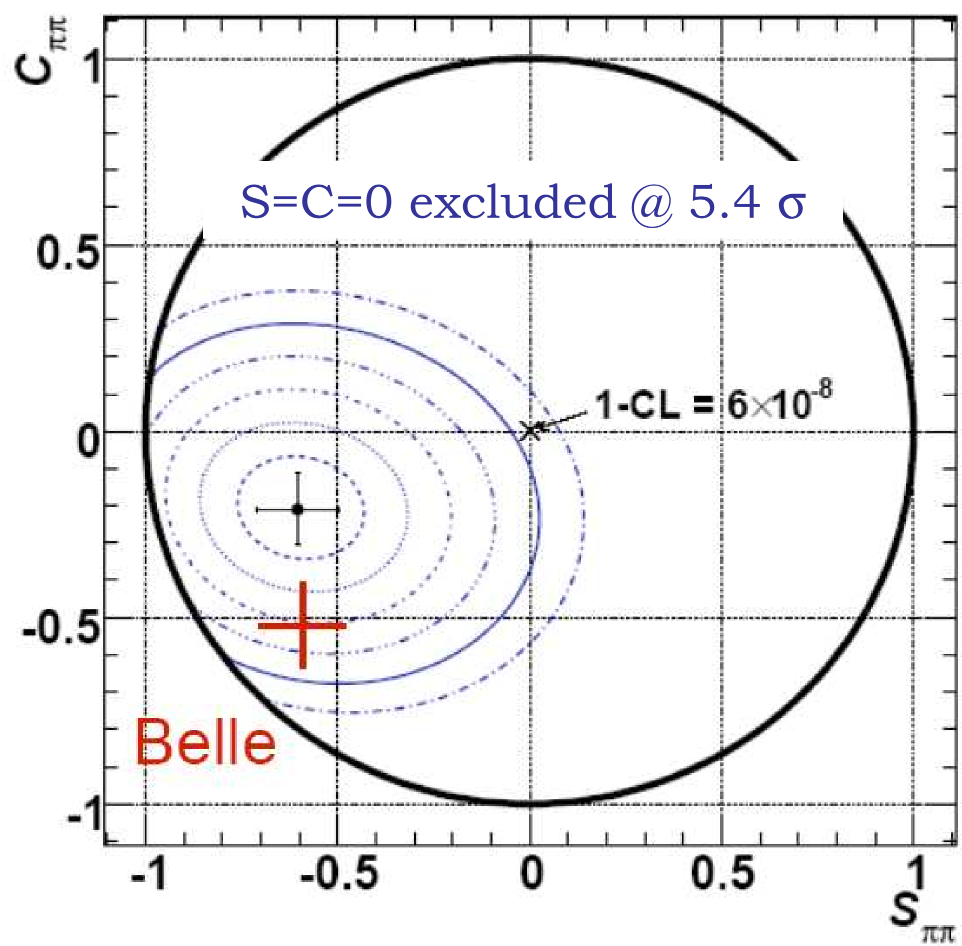


$B^0 \to \pi^+\pi^-$ & $B^0 \to K^+\pi^-$

NEW



383 M BB pairs; hep-ex/0703016



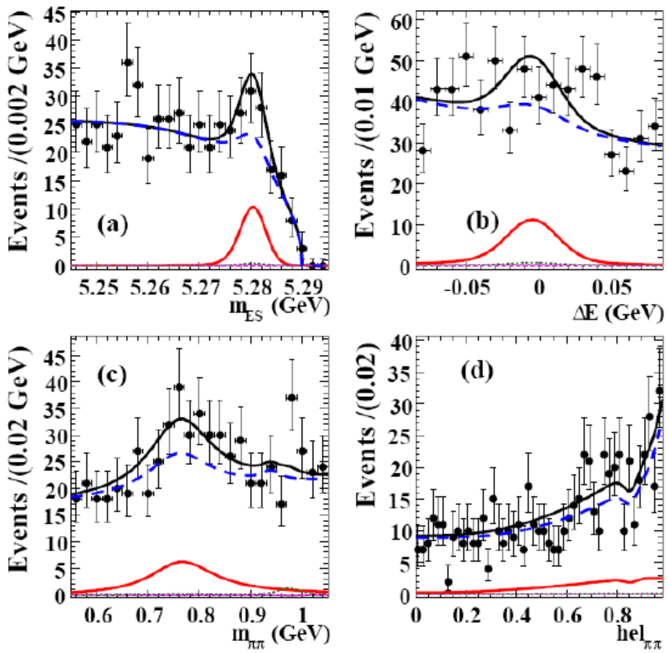
$$N_{\pi\pi} = 1139 \pm 49$$
$$N_{K\pi} = 4372 \pm 82$$

$$S_{\pi\pi} = -0.60 \pm 0.11 \pm 0.03\,(5.2\sigma)$$
$$C_{\pi\pi} = -0.21 \pm 0.09 \pm 0.02\,(2.2\sigma)$$
$$A_{K\pi} = -0.107 \pm 0.018\,^{+0.007}_{-0.004}\,(5.5\sigma)$$

hep-ex/0612021
PRL accepted

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

$384 \times 10^6\, B\bar{B}$ pairs



$N_{\rho^0\rho^0} = 100 \pm 32 \pm 17$

3.5σ evidence for $B \to \rho^0\rho^0$

$f_L(B^0 \to \rho^0\rho^0) = 0.87 \pm 0.13 \pm 0.04$

$Br\,(B^0 \to \rho^0\rho^0) = (1.07 \pm 0.33 \pm 0.19)\cdot 10^{-6}$

Small $\rho^0\rho^0$ BF $\Rightarrow$ small penguin pollution

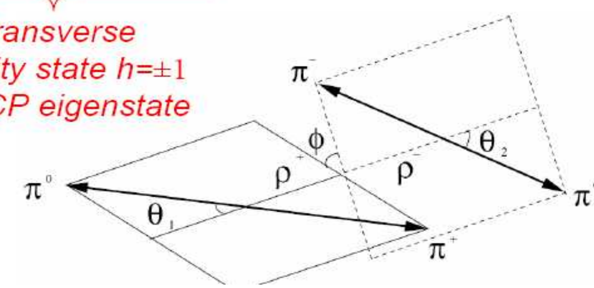
$B^0 \to \rho^+\rho^-$

hep-ex/0607097

$347 \times 10^6\, B\bar{B}$ pairs

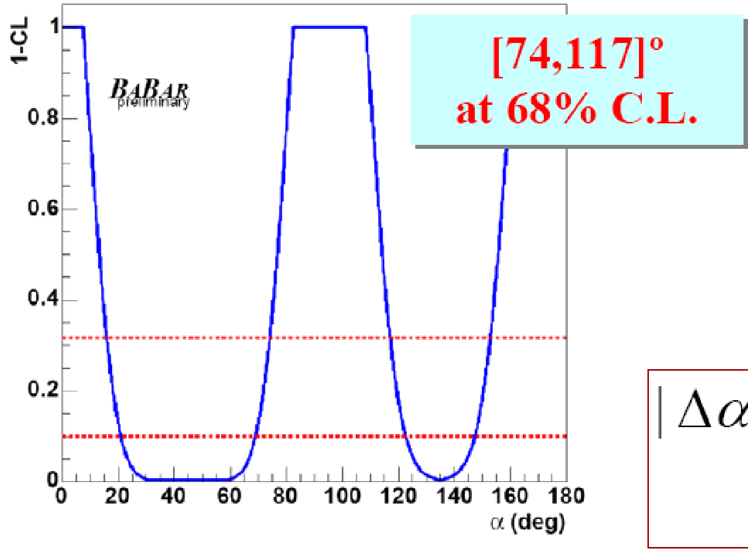
$$\frac{d^2N}{d\cos\theta_1 d\cos\theta_2} \propto \underbrace{f_L \cos^2\theta_1 \cos^2\theta_2}_{\text{Longitudinal Helicity state } h=0 \text{ CP+1 eigenstate}} + \underbrace{\tfrac{1}{4}(1-f_L)\sin^2\theta_1 \sin^2\theta_2}_{\text{Transverse Helicity state } h=\pm1 \text{ non-CP eigenstate}}$$

$f_L = 0.977 \pm 0.024\,^{+0.015}_{-0.013}$



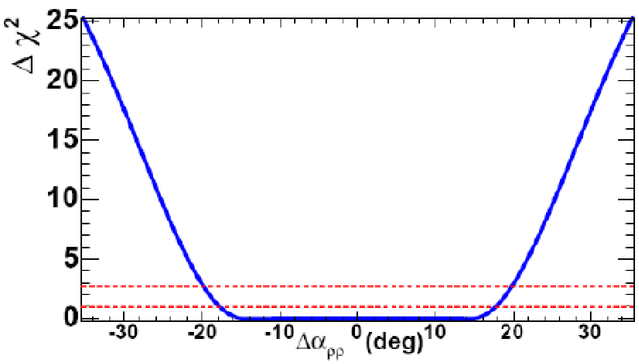
All B→ρρ together

- Isospin analysis of ρρ as for ππ



Constraint on α worse than previous result becouse of:
- smaller $\mathcal{B}(B^{\pm} \to \rho^{\pm} \rho^{0})$
- larger $\mathcal{B}(B^{0} \to \rho^{0} \rho^{0})$

$$|\Delta\alpha| \equiv |\alpha - \alpha_{eff}| < 18° @ 68\%CL$$
$$< 20° @ 90\% \text{ CL}$$



(previous result 11° @ 68% CL)

Still most promising decay to measure α

More α: B→πππ^0 (Dalitz)

- describe the $\pi^+\pi^-\pi^0$ final state as sum of interfering $\rho^+\pi^-$, $\rho^-\pi^+$, $\rho^0\pi^0$ Snyder & Quinn, PRD48, 2139 (1993)
- measure the time-dependent and Dalitz Plot-dependent decay rate

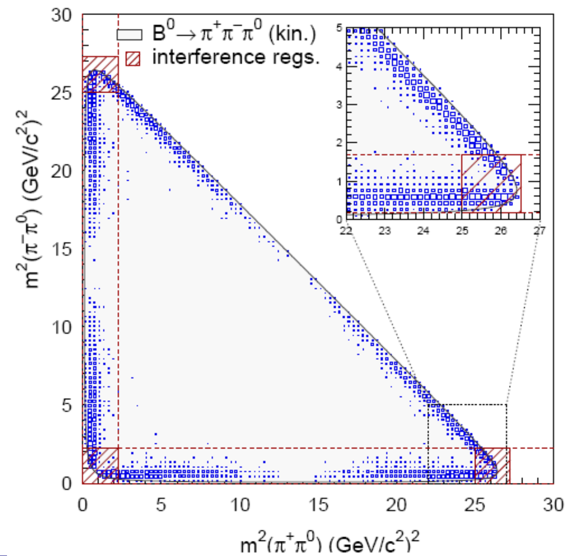
$$|\mathcal{A}_{3\pi}^{\pm}(\Delta t)|^2 = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left[|A_{3\pi}|^2+|\overline{A}_{3\pi}|^2\mp(|A_{3\pi}|^2-|\overline{A}_{3\pi}|^2)\cos(\Delta m_d\Delta t)\pm 2\mathrm{Im}\left[\overline{A}_{3\pi}A_{3\pi}^*\right]\sin(\Delta m_d\Delta t)\right]$$

$$\begin{aligned} A_{3\pi} &= f_+ A^+ + f_- A^- + f_0 A^0 \\ \overline{A}_{3\pi} &= f_+ \overline{A}^+ + f_- \overline{A}^- + f_0 \overline{A}^0 \end{aligned}$$

charge of ρ

Dalitz Model
$f_i(m^2_{\pi^+\pi^0}, m^2_{\pi^-\pi^0})$

strong and weak phases
$$\begin{aligned} A^\kappa &= T^\kappa e^{-i\alpha} + P^\kappa \\ \overline{A}^\kappa &= T^{\overline{\kappa}} e^{+i\alpha} + P^{\overline{\kappa}} \end{aligned}$$



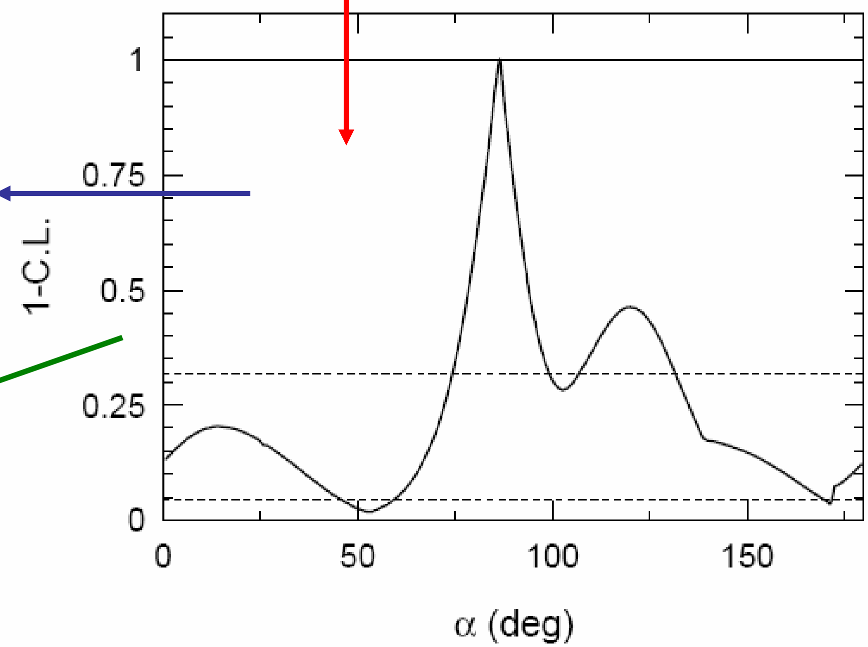
Extracting α from $B\rightarrow\pi\pi\pi^0$

hep-ex/0703008

375M BB

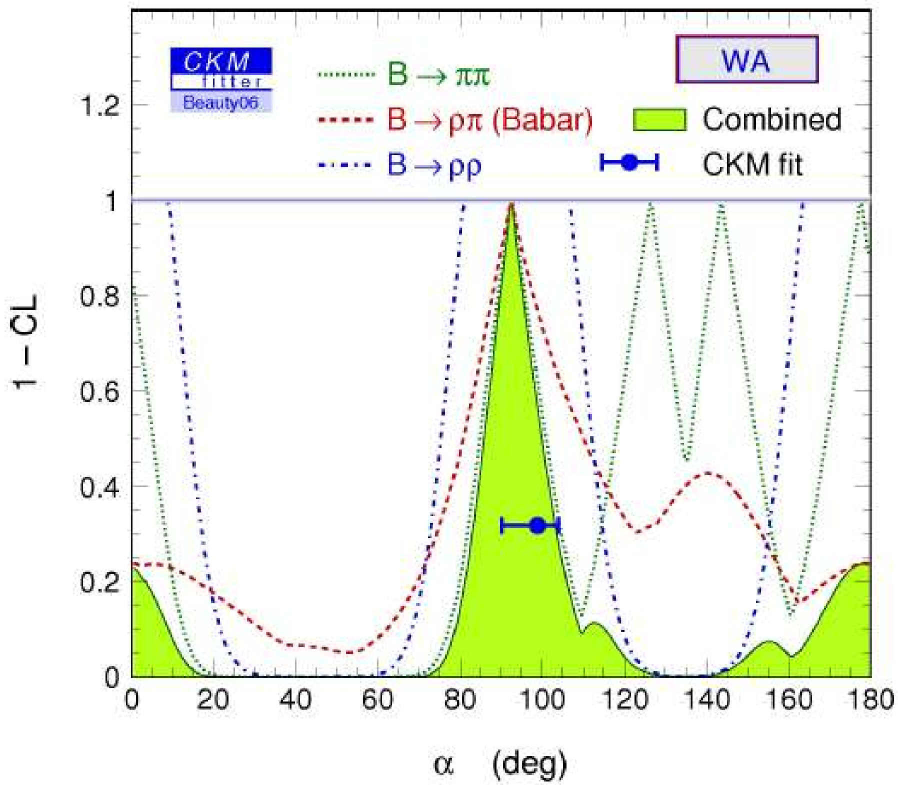
- use frequentist procedure to extract a CL for α from the 26 parameters
  - The method extracts without ambiguities in $[0,180]^{o}$

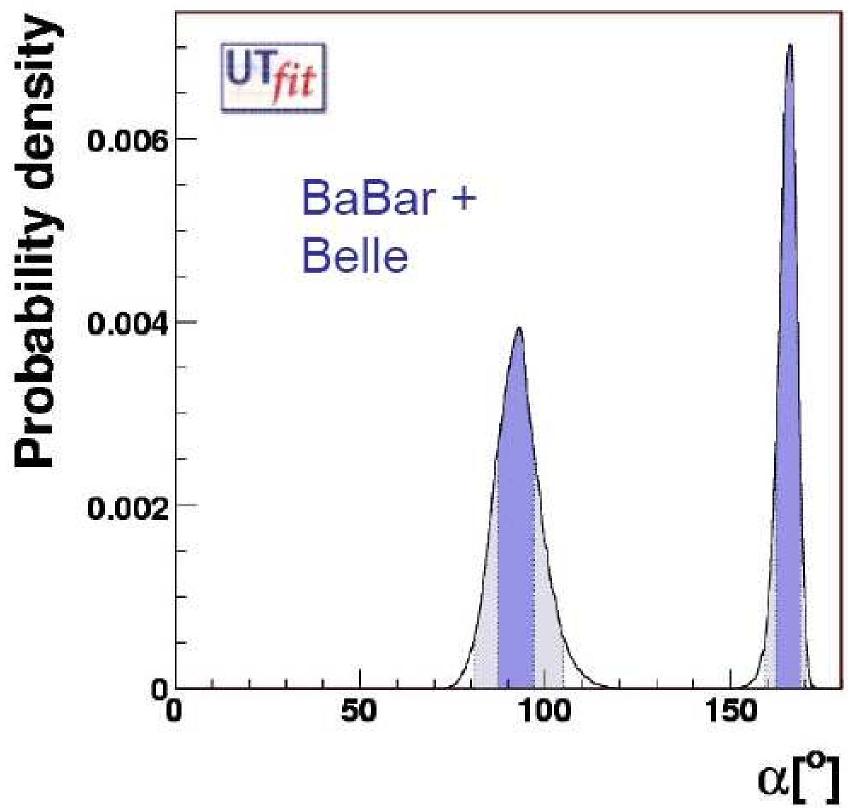
Result consistent with SM



Need more data to set a constraint at 90% C.L.

α: the whole picture





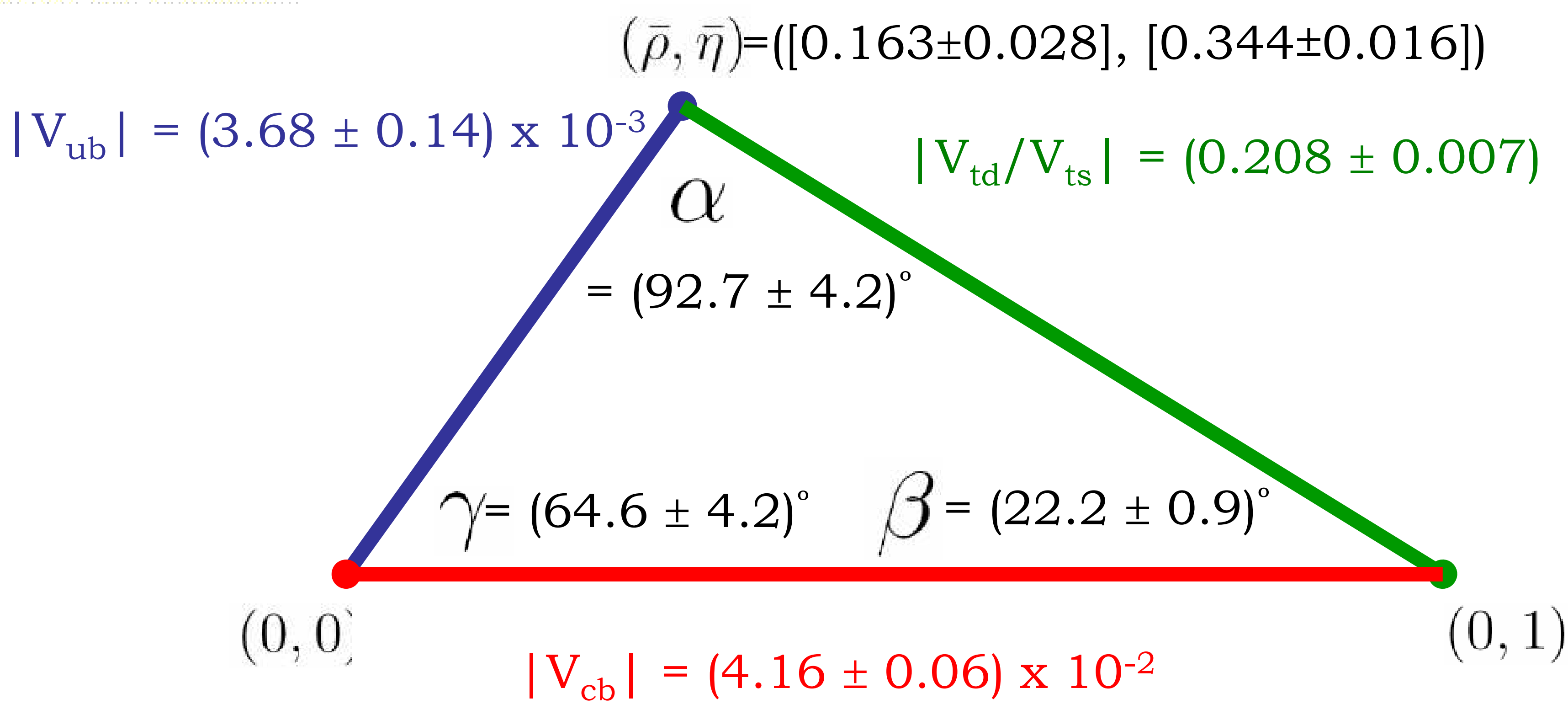
$$\alpha_{WA,CKMfitter} = (93^{+11}_{-9})^{\circ}$$

$$\alpha_{WA,UTfit} = [81,105]^{\circ} \cup [159,171]^{\circ} \ @95\%CL$$

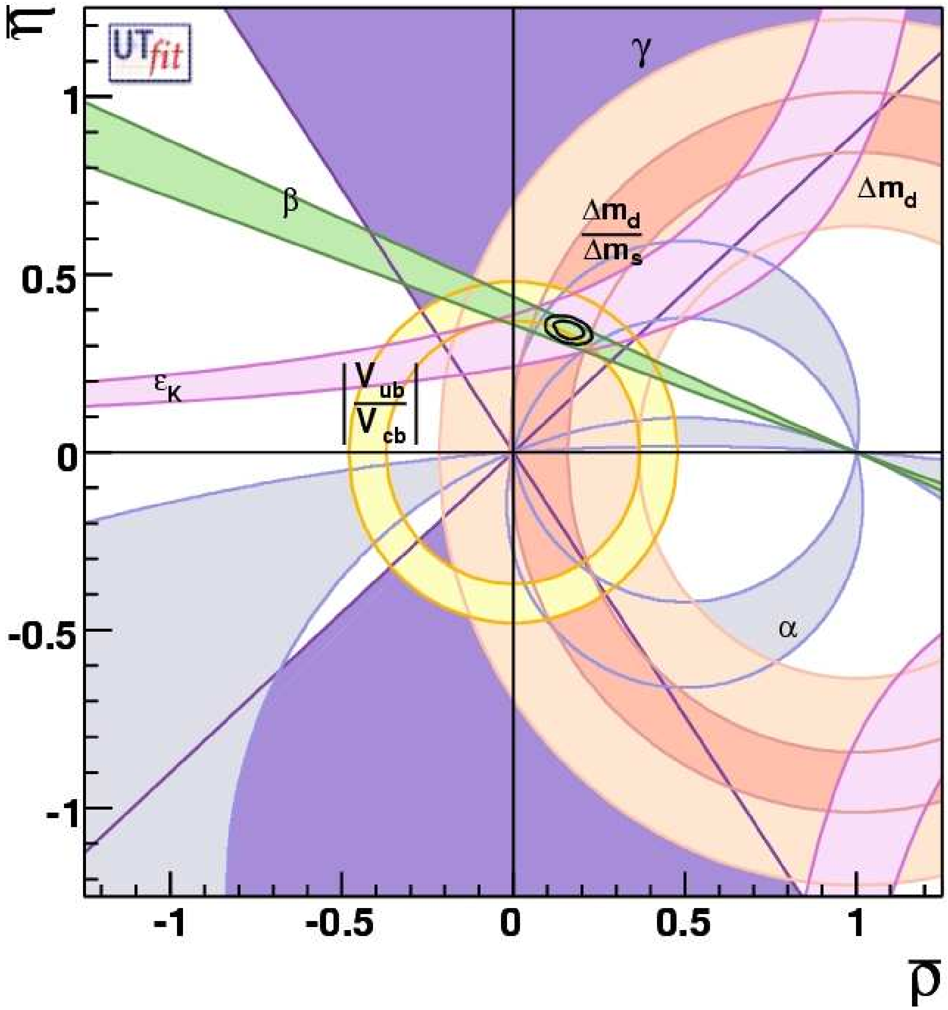
Conclusions

UTfit™ : global fit

http://utfit.roma1.infn.it



CKM: it works!



- **CKM is now a tested theory**
- **Great success for the Standard Model**

$\alpha = (93^{+11}_{-9})^o$
$\beta = (21.2 \pm 1.0)^o$
$\gamma = (62^{+38}_{-24})^o$

$|V_{cb}| = (4.15 \pm 0.07) \times 10^{-2}$
$|V_{ub}| = (4.09 \pm 0.26) \times 10^{-3}$
$|V_{td}/V_{ts}| = 0.202 \pm 0.021$

BaBar massively contributed to this great success!!!

The end

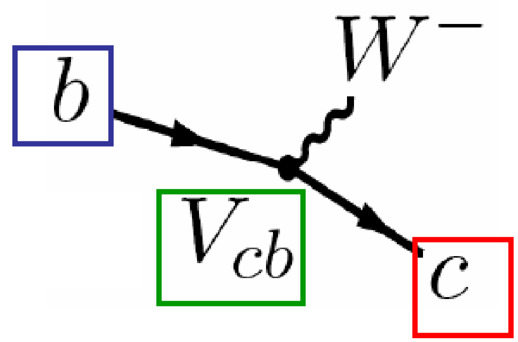
Backup slides

Quark mixing matrix

- weak and mass eigenstates of the quarks are not the same
- changes in base are described by unitarity transformations
- Cabibbo Kobayashi Maskawa (CKM) matrix

$$\mathbf{V} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

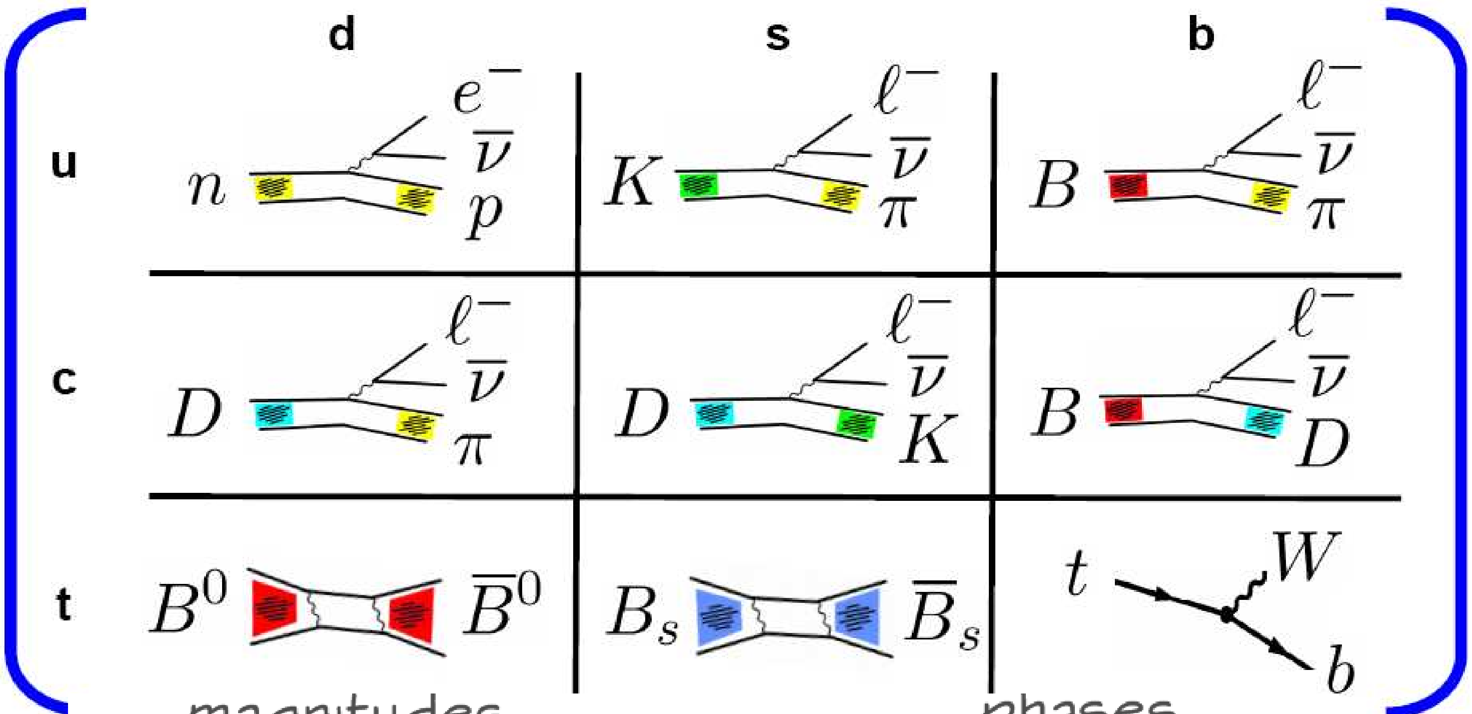
CKM elements: "weak couplings" between Down-type and Up-type quarks



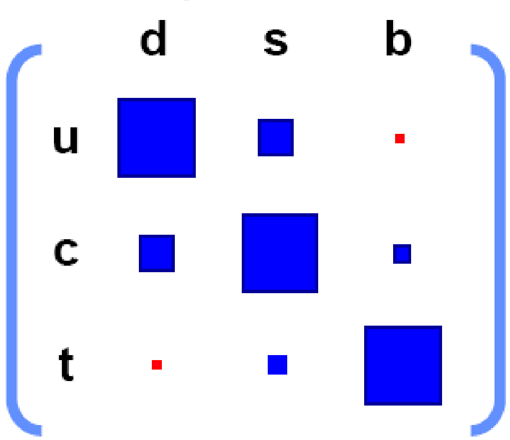
- with 3 quark families there is an irreducible complex phase in the matrix
- This is responsable of CP Violation in Standard Model (SM)

CKM matrix

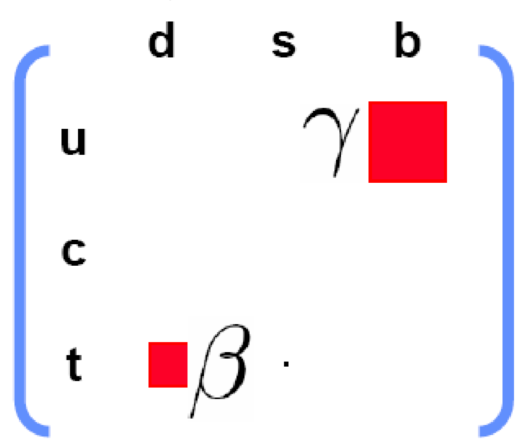
V =



magnitudes

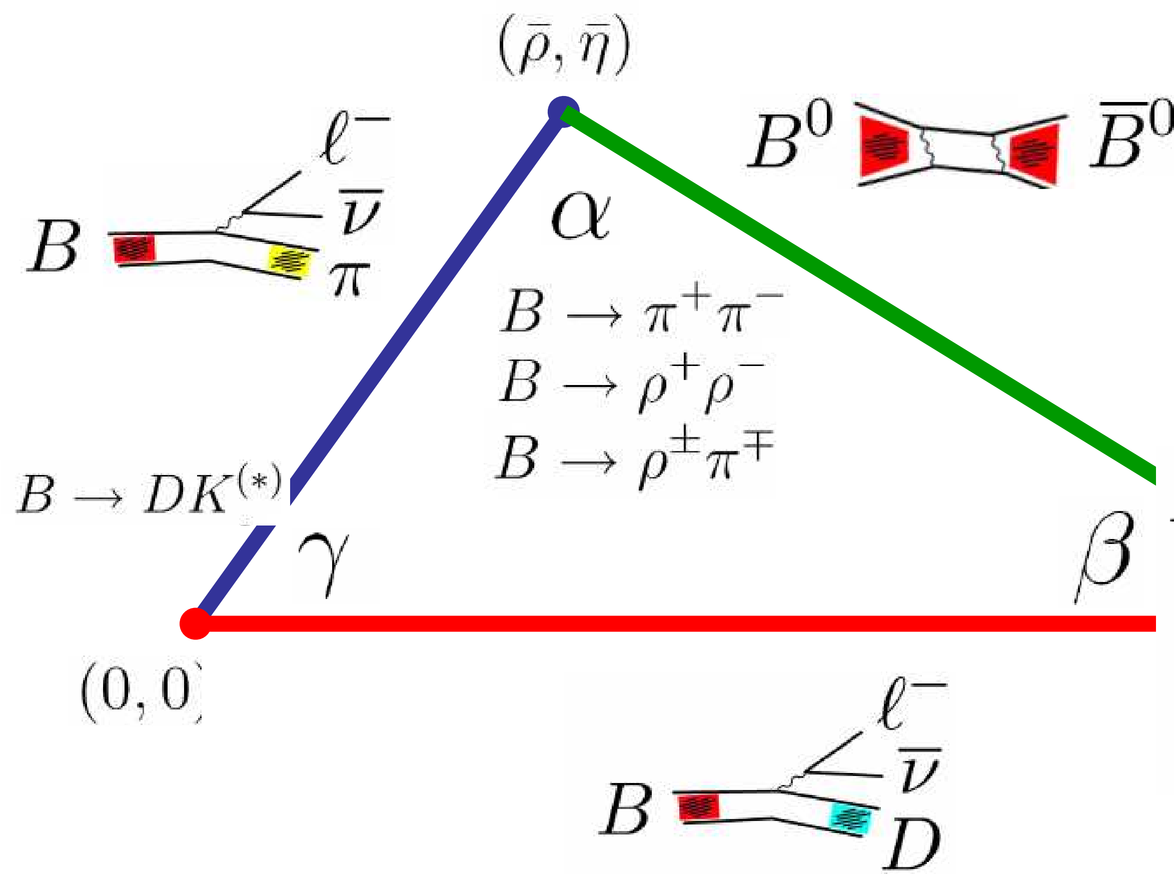


phases



The Unitarity Triangle (UT)

$$\boxed{V_{td}V_{tb}^* + V_{cd}V_{cb}^* + V_{ud}V_{ub}^* \;=\; 0}$$



$$\beta \equiv \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right] \sim 21°$$

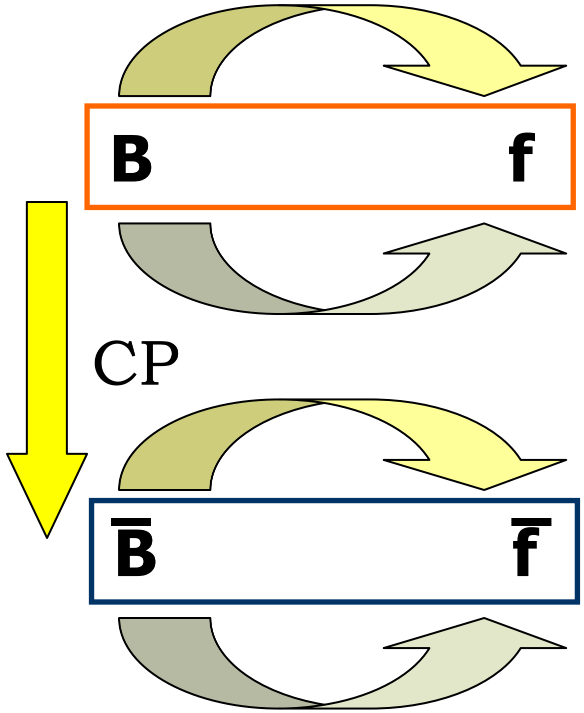
$$\gamma \equiv \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right] \sim 62°$$

$$\alpha \equiv \pi - \beta - \gamma$$

$B^0 \to J/\psi\, K^0 \qquad b \to c\,\bar{c}\,s$

$B^0 \to J/\psi\, K^{*0}$
$B^0 \to D^{(*)0}\pi^0$
$B^0 \to D^{*+}D^{*-}K_S^0$

CP violation in B mesons (I)

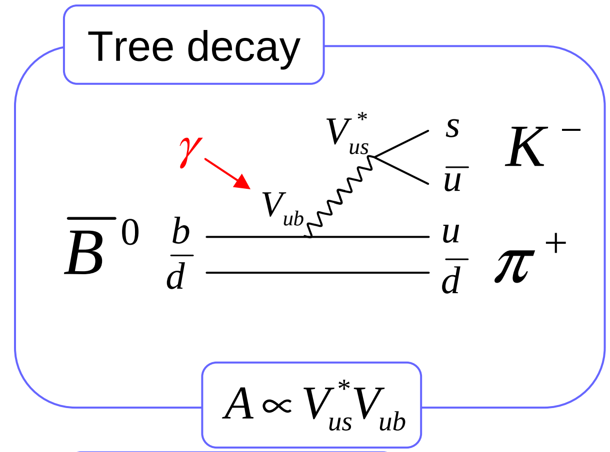


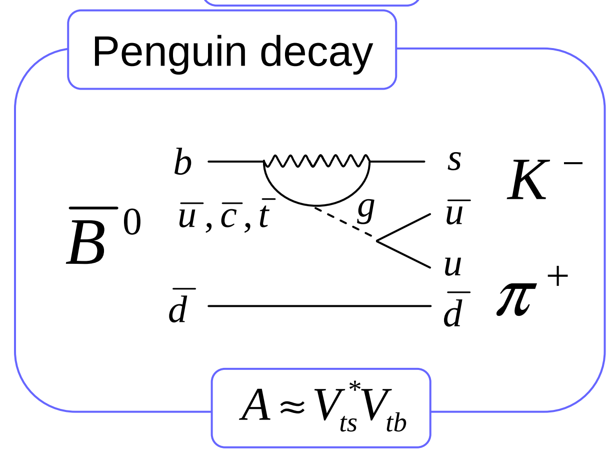
$$A_1 = a_1\, e^{i\phi_1}\, e^{i\delta_1}$$

$$A_2 = a_2\, e^{i\phi_2}\, e^{i\delta_2}$$

$$\bar{A}_1 = a_1\, e^{-i\phi_1}\, e^{i\delta_1}$$

$$\bar{A}_2 = a_2\, e^{-i\phi_2}\, e^{i\delta_2}$$

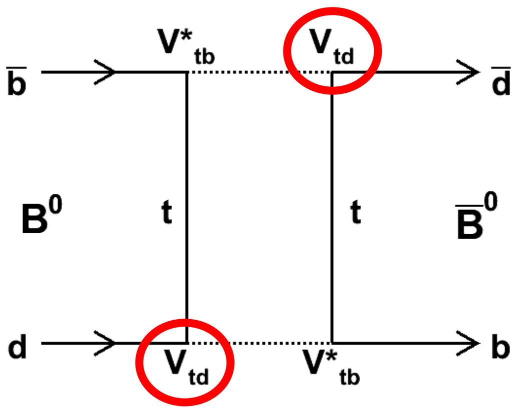


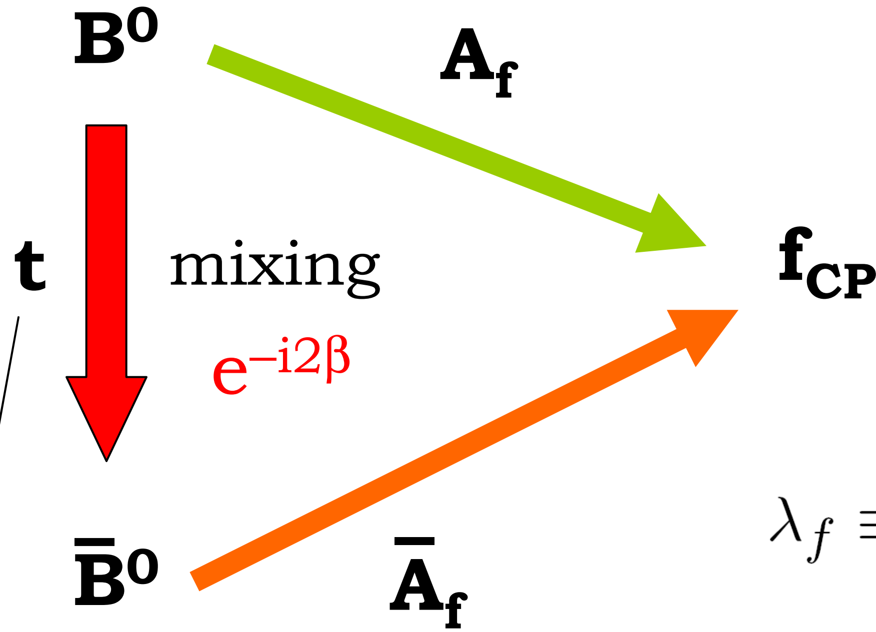


Interference $\rightarrow (A_1+A_2)^2 \neq (\bar{A}_1+\bar{A}_2)^2$

$$\textbf{Asymmetry} = \frac{\Gamma(B)-\Gamma(\bar{B})}{\Gamma(B)+\Gamma(\bar{B})} = \frac{|A|^2-|\bar{A}|^2}{|A|^2+|\bar{A}|^2} \sim 2\sin(\phi_1-\phi_2)\sin(\delta_1-\delta_2)$$

CP violation in B mesons (II)



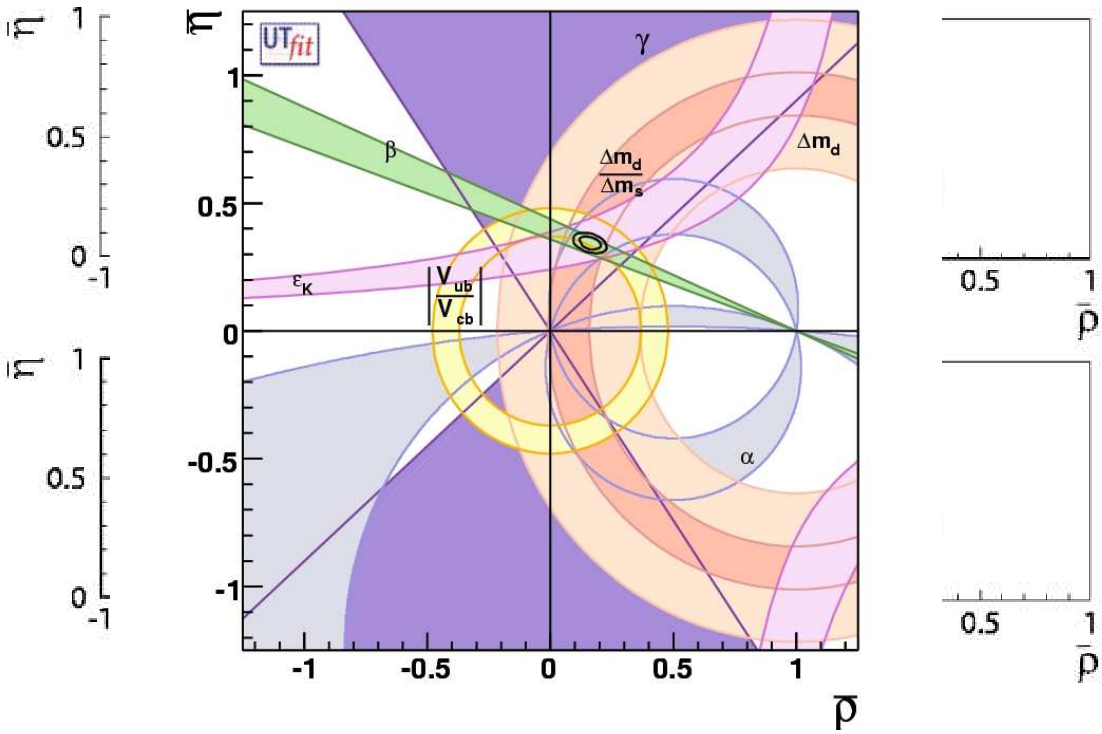


$$\lambda_f \equiv \frac{q}{p}\frac{\overline{A}_f}{A_f}$$

$$A_{CP} = \frac{\Gamma(\overline{B^0}(t) \to f) - \Gamma(B^0(t) \to f)}{\Gamma(\overline{B^0}(t) \to f) + \Gamma(B^0(t) \to f)} = \underbrace{\frac{1-|\lambda|^2}{1+|\lambda|^2}}_{C}\cos(\Delta m \cdot t) + \underbrace{\frac{2\,\mathrm{Im}(\lambda)}{1+|\lambda|^2}}_{S}\sin(\Delta m \cdot t)$$

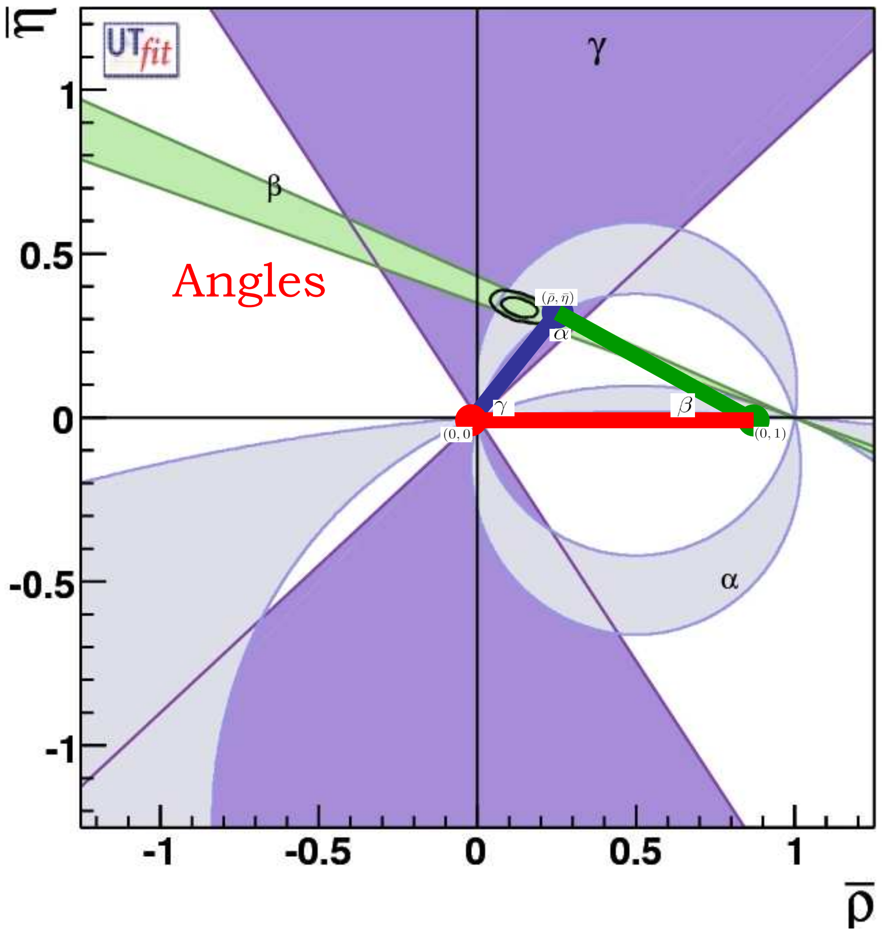
Idea: overconstrain UT

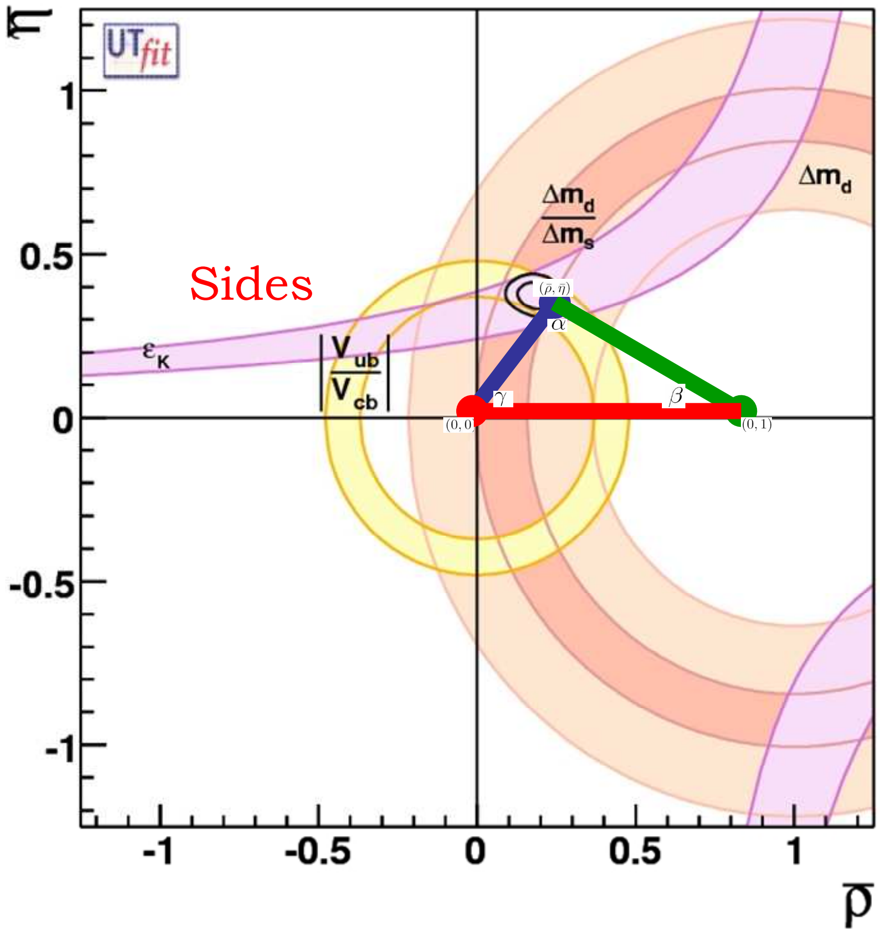
- Measuring different B decays, all UT parameters can be determined
- There are several independent constraints available



UT & CP violation

- UT area $\neq 0 \Leftrightarrow$ CP violation





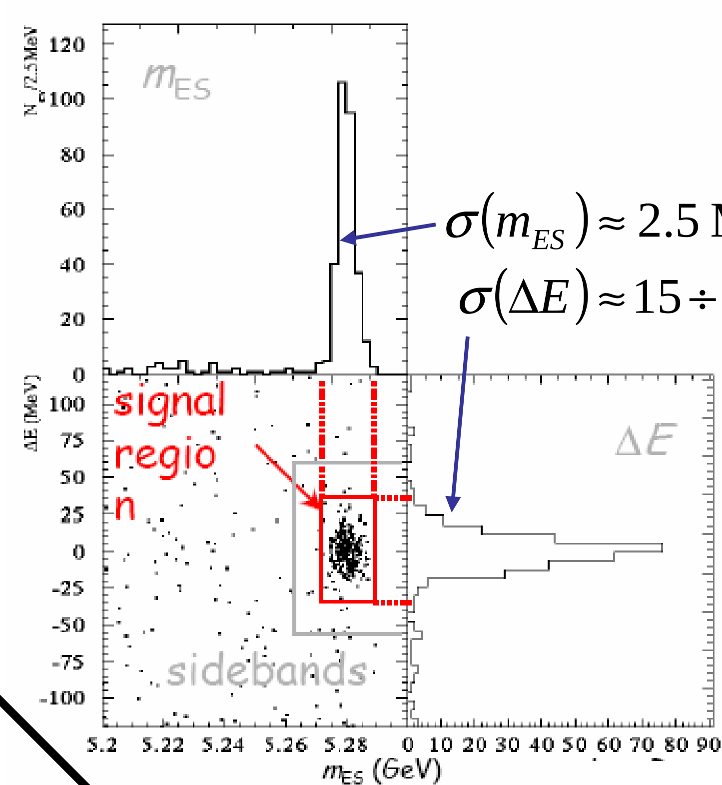
Exclusive B decay reconstruction

- **Likelihood fits with discriminating variables:**
  - **Kinematics:**

$$m_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$$

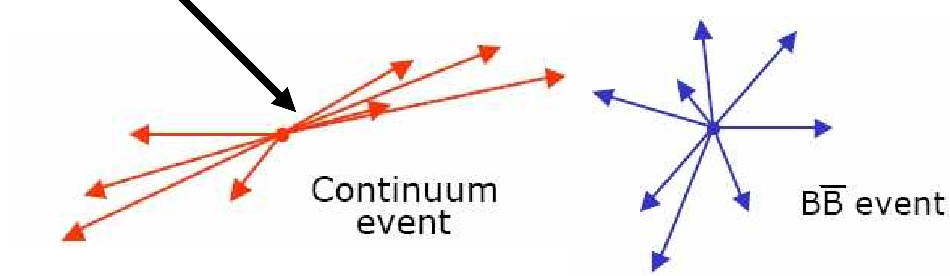
$$\Delta E = E_B^* - E_{beam}^*$$

  - **Particle ID: π, K, e, μ, ...**
  - **Event shape variables, to separate the continuum bkgd (use "off-resonance" data as control sample!!!)**
- **Efficiency**
  - **Typically $\varepsilon \approx$ 15÷40%**
- **Purity**
  - **Up to 97% (for $J/\psi K_S$)**



$\sigma(m_{ES}) \approx 2.5\ \mathrm{MeV}$

$\sigma(\Delta E) \approx 15 \div 30\ \mathrm{MeV}$



Resolutions

Variables that reflect energy and momentum conservation:
peaking for fully reconstructed *B* decays, smooth for combinatorial background

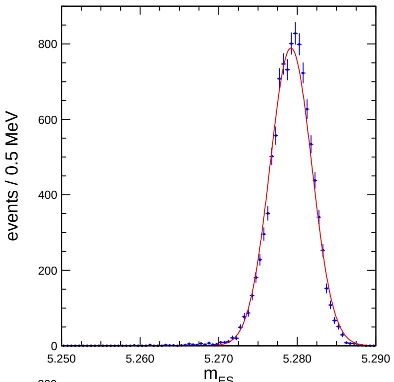
$$m_{\text{ES}} \equiv \sqrt{E^2{}_{\text{CM beam}} - p^2_{\text{CM }B}} = m_B$$

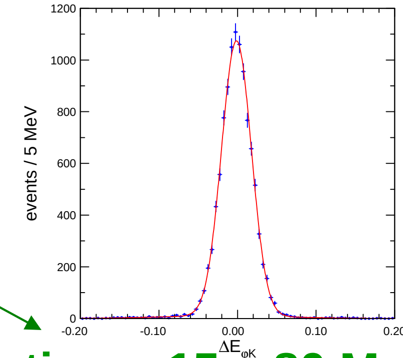
$$\Delta E \equiv E_{\text{CM }B} - E_{\text{CM beam}} = 0$$

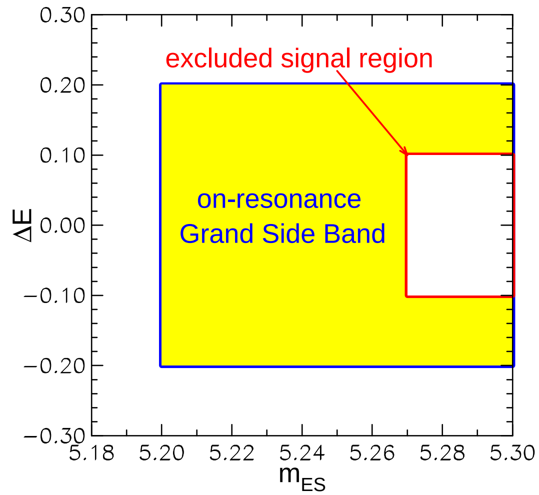
resolution ~ 2.5 – 3.0 MeV

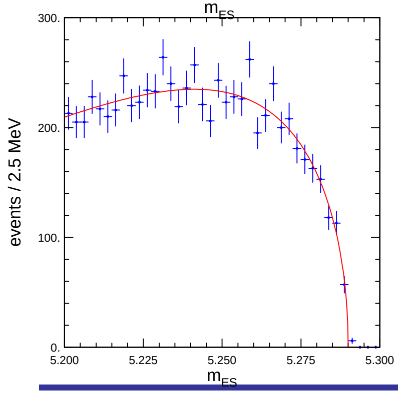
depending on presence of neutrals in the final state

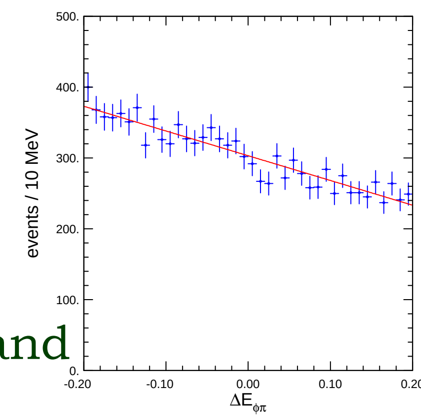
resolution ~ 15 – 80 MeV











continuum background in the Grand Side Band

Tagging: efficiency and effects

The figure of merit for tagging is the
effective tagging efficiency $Q \equiv \Sigma_i \, \varepsilon_i (1 - 2w_i)^2 = (30.4 \pm 0.3)\%$

Category	ε (%)	w (%)	Δw (%)	Q (%)
Lepton	8.67 ± 0.08	3.0 ± 0.3	-0.2 ± 0.6	7.67 ± 0.13
Kaon I	10.96 ± 0.09	5.3 ± 0.4	-0.6 ± 0.7	8.74 ± 0.16
Kaon II	17.21 ± 0.11	15.5 ± 0.4	-0.4 ± 0.7	8.21 ± 0.19
Kaon-Pion	13.77 ± 0.10	23.5 ± 0.5	-2.4 ± 0.8	3.87 ± 0.14
Pion	14.38 ± 0.10	33.0 ± 0.5	5.2 ± 0.8	1.67 ± 0.10
Other	9.61 ± 0.08	41.9 ± 0.6	4.6 ± 0.9	0.25 ± 0.04
All	74.60 ± 0.12			30.4 ± 0.3

$$f_{\pm}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left\{ (1 \mp \Delta\omega) \pm (1 - 2\omega) \times \left[\frac{2\,\mathcal{I}m\,\lambda}{1+|\lambda|^2} \sin(\Delta m_d \Delta t) - \frac{1-|\lambda|^2}{1+|\lambda|^2} \cos(\Delta m_d \Delta t) \right] \right\}$$

$|V_{ub}|$: untagged Vs tagged

- Complementary experimental approaches
  - different systematic errors
  - statistically independent samples

Tagged:

- reconstruct non-signal B to select $\Upsilon(4S)\rightarrow B_{tag}B_{sig}$ events
- B_{tag} reconstructed via hadronic or semileptonic decays

✓ high signal purity for almost all phase space

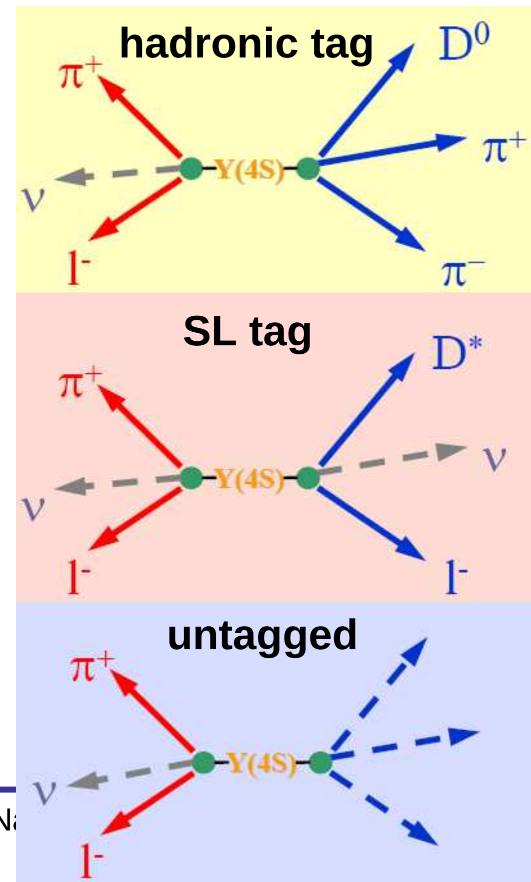
✖ low signal efficiency

Untagged:

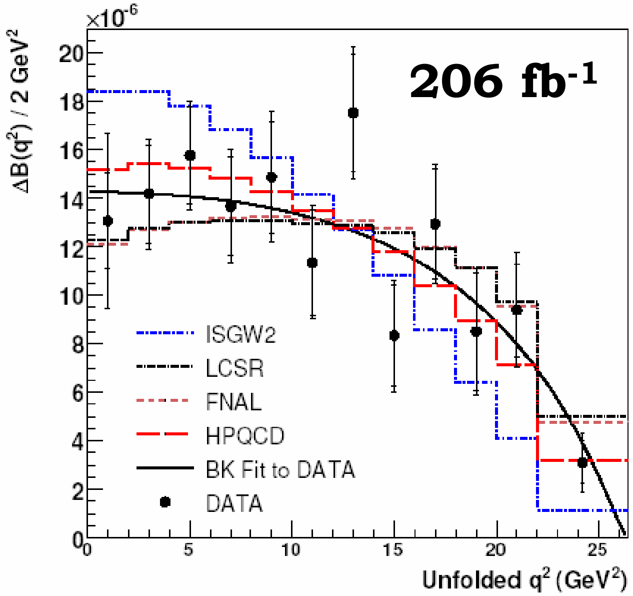
- reconstruct $B_{sig}\rightarrow X l \nu$ only
- ν reconstruction using event's P_{miss}

✖ lower signal purity and restricted phase space

✓ high signal efficiency



Exclusive $|V_{ub}|$ (untagged)



Measurement of $|V_{ub}|$ and $B^0 \to \pi l \nu$ form-factor shape with a loose neutrino reconstruction technique

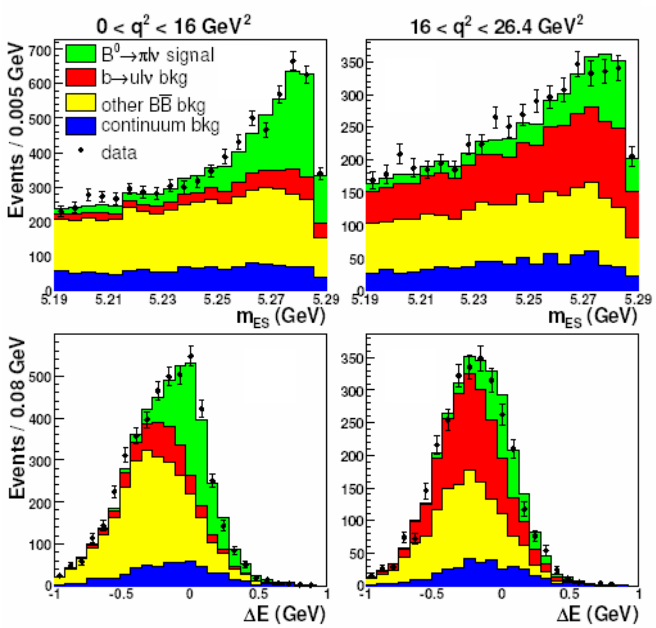
hep-ex/0612020 (accepted by Phys. Rev. Lett.)

- Reconstruct ~5000 signal events, in 12 q^2 bins
- Signal & bkgd yields by a multi-parameter fit (m_{ES}:ΔE,q^2)

•test QCD calculations:

→LQCD and LCSR compatible with our data

→ISGW2 quark-model incompatible (Prob<0.06%).



$$BF(B^0 \to \pi \ell \nu) = (1.46 \pm 0.07_{stat} \pm 0.08_{syst}) \times 10^{-4}$$

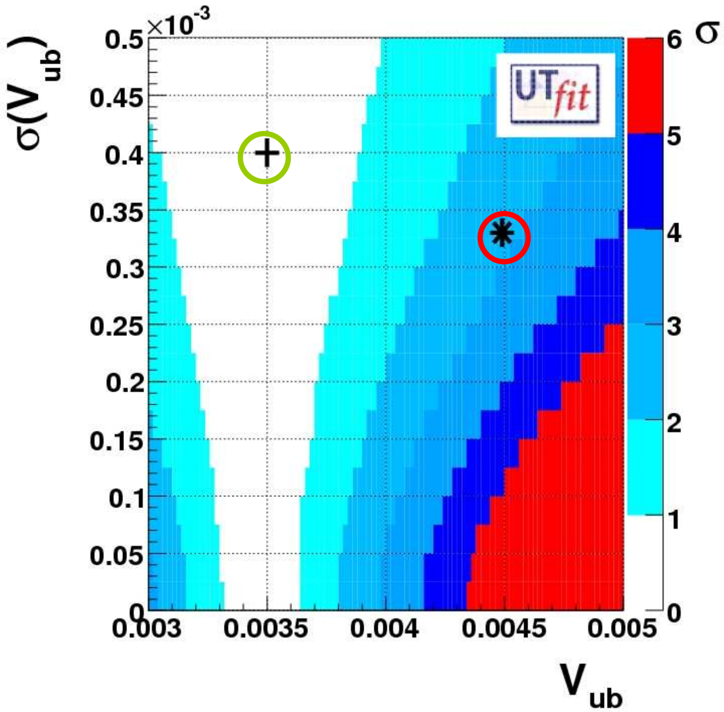
$$|V_{ub} f_+(0)| = (9.6 \pm 0.3_{stat} \pm 0.2_{syst}) \times 10^{-4}$$

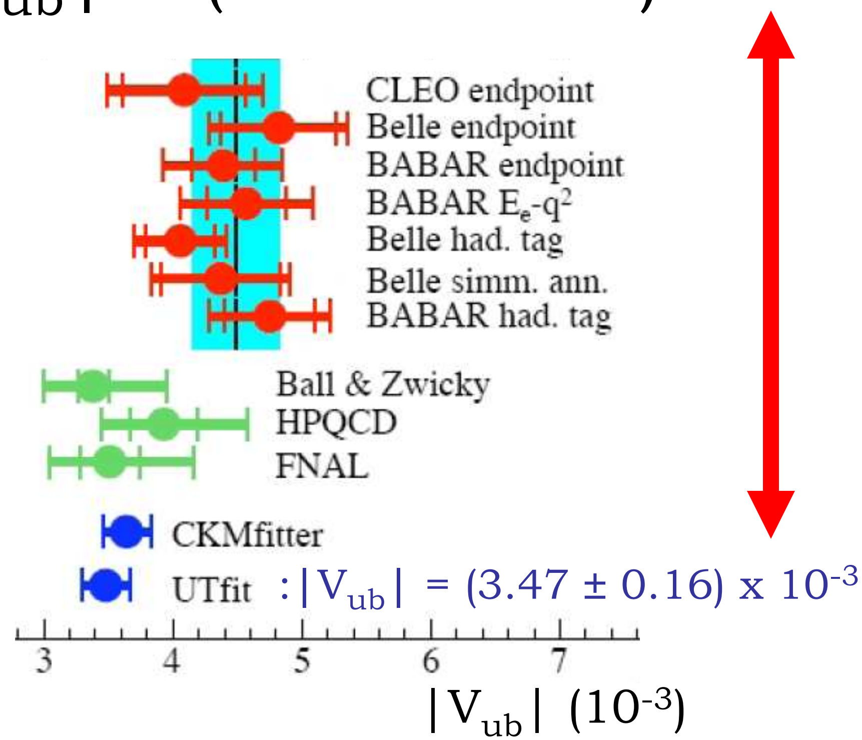
$$|V_{ub}| = (4.1 \pm 0.2_{stat} \pm 0.2_{syst}{}^{+0.6}_{-0.4}{}_{FF}) \times 10^{-3} \quad \text{(HPQCD)}$$

Smallest statistical & systematic uncertainties of all individual $B \to \pi l \nu$ measurements to date!!!

The $|V_{ub}|$ puzzle

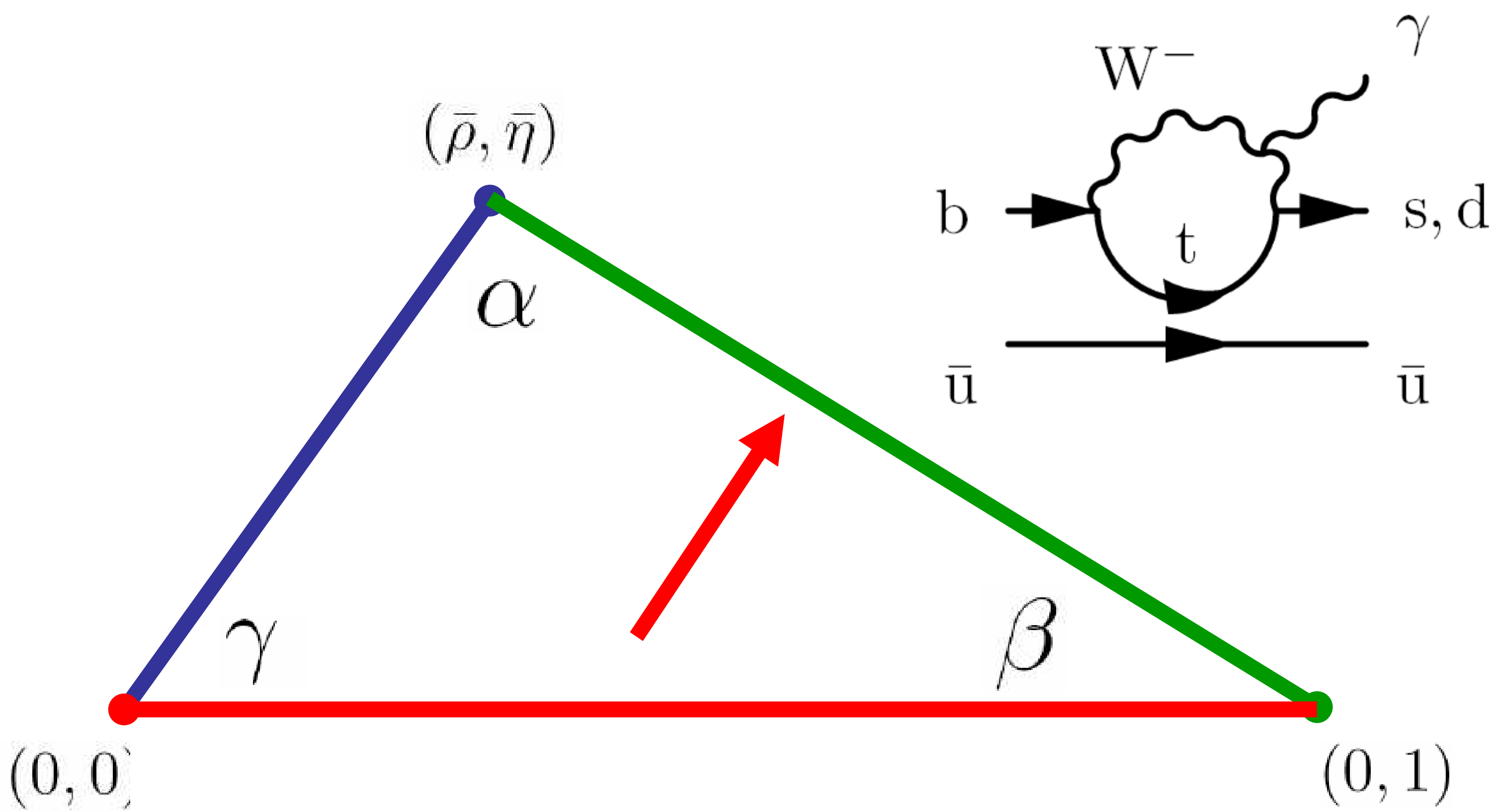
Direct measurement: $|V_{ub}| = (4.09 \pm 0.26) \times 10^{-3}$



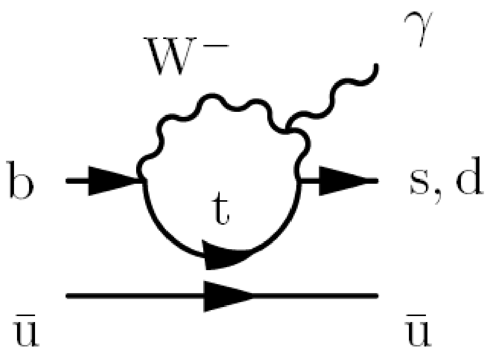


- 2-3 sigmas difference between inclusive $|V_{ub}|$ measurements and global CKM fits
- exclusive $|V_{ub}|$ measurements seem to agree better…

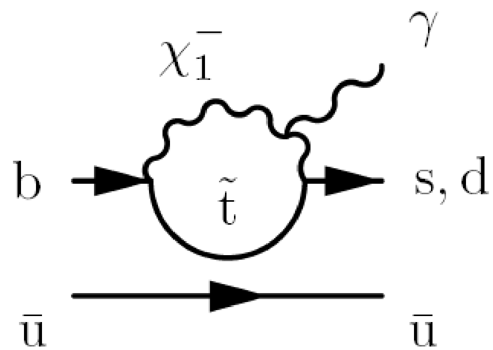
$|V_{td}/V_{ts}|$



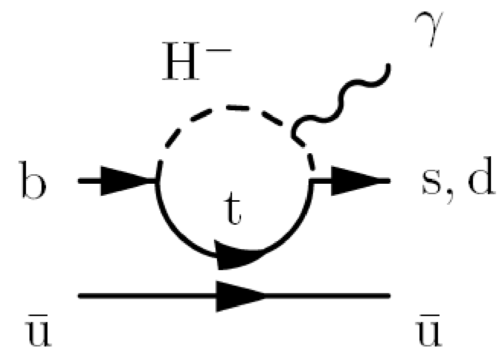
$|V_{td}/V_{ts}|$: radiative penguins



SM radiative penguin



SUSY penguin



SUSY or 2HDM penguin

- Possibility to measure $|V_{td}|/|V_{ts}|$ independently of $\Delta m_d/\Delta m_s$

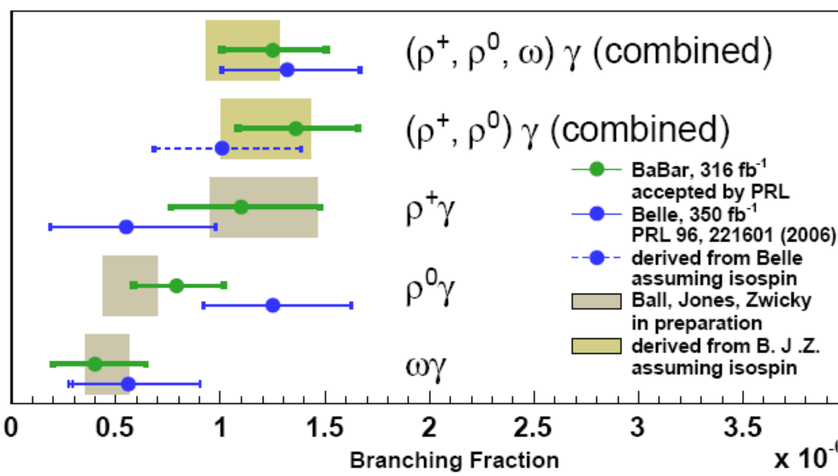
$$\frac{\Gamma(B\to\rho\gamma)}{\Gamma(B\to K^*\gamma)} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \frac{(m_B-m_\rho)^3}{(m_B-m_{K^*})^3}\left(\frac{T^\rho(0)}{T^{K^*}(0)}\right)^2(1+\Delta R)$$

$\Delta R = 0.1 \pm 0.1$ **Ali, Lunghi, Parkhomenko, PLB595, 323 (2004),**

$\left(\frac{T^\rho(0)}{T^{K^*}(0)}\right)^{-1} = 1.17 \pm 0.09$ **Ball,Zwicky JHEP0604, 046 (2006), hep-ph/0603232**

$|V_{td}/V_{ts}|$: radiative penguins

- BaBar results (10^{-6}):
  - hep-ex/0612017, accepted by PRL
- $(\rho^0\gamma)$: $0.79\ ^{+0.22}_{-0.20} \pm 0.06$ (4.9σ)
- $(\rho^\pm\gamma)$: $1.1\ ^{+0.37}_{-0.33} \pm 0.09$ (3.8σ): 1st evidence!
- $B(\omega\gamma)$: $0.40\ ^{+0.24}_{-0.20} \pm 0.05$ (2.2σ)
- $B((\rho/\omega)\gamma)$: $1.25\ ^{+0.25}_{-0.24} \pm 0.09$ (6.4σ)

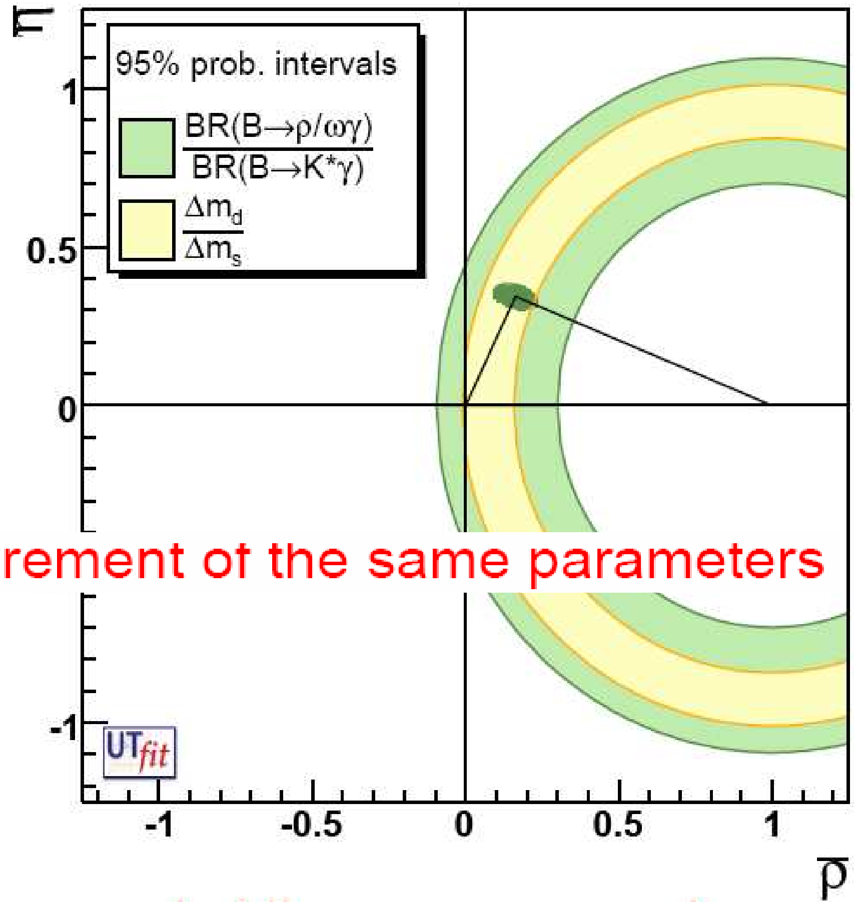


Measure $|V_{td}|/|V_{ts}|$ indep. of $\Delta m_d/\Delta m_s$

$$\mathcal{B}(B \to \rho/\omega\gamma)(10^{-6}): \quad \underbrace{1.25^{+0.25}_{-0.24} \pm 0.09}_{\text{BaBar}} \quad \underbrace{1.32^{+0.34+0.10}_{-0.31-0.09}}_{\text{Belle}} \quad \underbrace{1.28^{+0.20}_{-0.19} \pm 0.06}_{\text{Average}}$$

$$\left|\frac{V_{td}}{V_{ts}}\right|_{\rho/\omega\gamma} = 0.202 \underbrace{{}^{+0.017}_{-0.016}}_{8.2\,\%} \pm \underbrace{0.015}_{7.4\,\%}$$

Ball, Jones, Zwicky hep-ph/0612081



Different diagrams: independent measurement of the same parameters

$$\left|\frac{V_{td}}{V_{ts}}\right|_{\Delta m_d/\Delta m_s} = 0.2060 \pm 0.0007^{+0.0081}_{-0.0060}$$

CDF Phys.Rev.Lett.97:242003 (2006)

Charmonium K^0: details

- B_{CP} sample
- $B \to J/\psi K^0$
  - $J/\psi \to e\ e,\ \mu\ \mu$
  - $K_s^0 \to \pi\ \pi$
  - K_L^0 : cluster
- $B \to \psi(2S) K^0$
  - $\psi(2S) \to e\ e,\ \mu\ \mu,\ J/\psi\ \gamma$
- $B \to x_{c1} K^0$
  - $x_{c1} \to J/\psi\ \gamma$
- $B \to \eta_c K^0$
  - $\eta_c \to K^0 K^+ \pi^-$

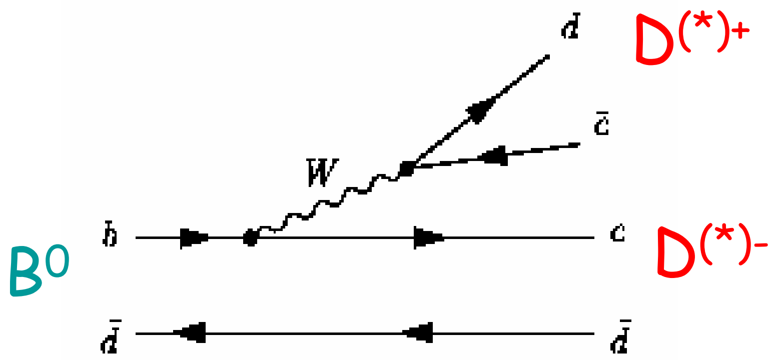
- B_{flav} sample
  - $B \to D^{*-}\ \pi^+$
  - $B \to D^{*-}\ \rho^+$
  - $B \to D^{*-}\ a_1^+$
  - $B \to D^-\ \pi^+$
  - $B \to J/\psi K^{*0} (K^{*0} \to K^+ \pi^-)$

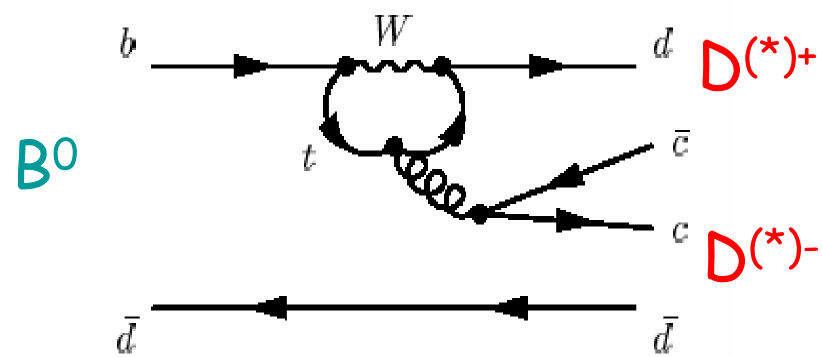
For tagging performance and resolution studies

- B^- sample
  - $B^- \to D^0\ \pi^-$
  - $B^- \to D^{*0}\ \pi^-$
  - $B^- \to J/\psi K^-$
  - $B^- \to \psi(2S) K^-$
  - $B^- \to x_{c1} K^-$
  - $B^- \to J/\psi K^{*-} (K^{*-} \to K^- \pi^0)$

Control sample

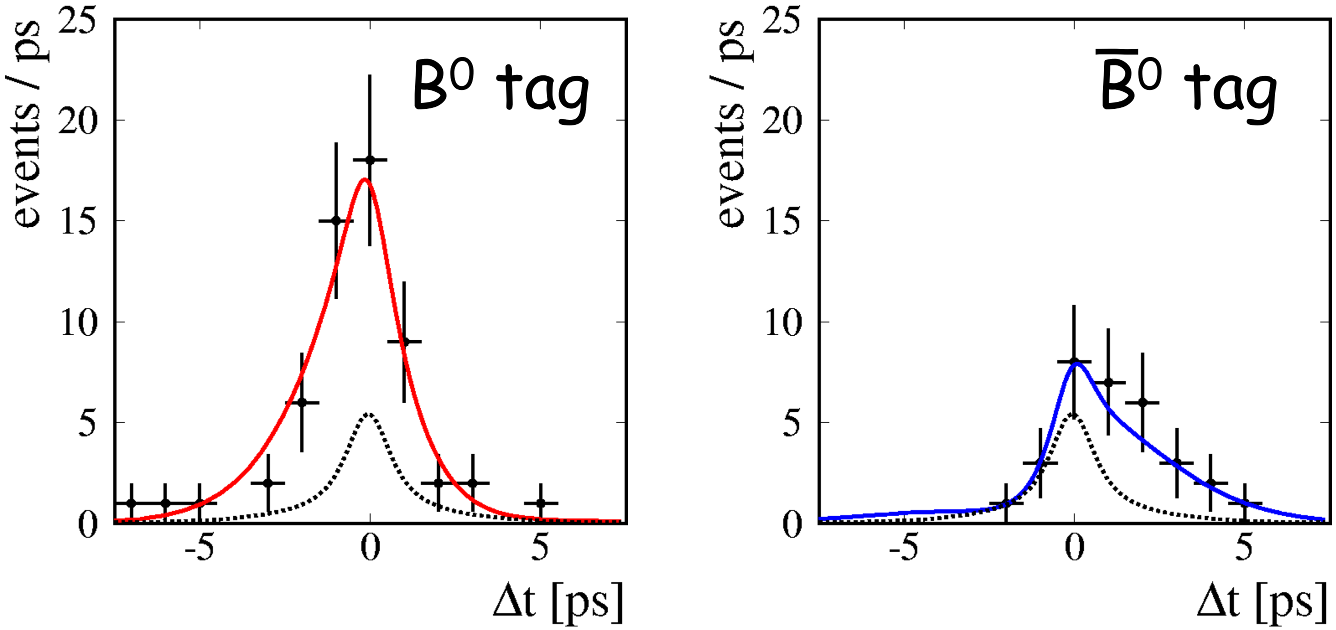
CP Violation in $B \rightarrow D^{(*)}D^{(*)}$ decays





- TD asymmetry ~$\sin 2\beta$: $B \rightarrow D^+D^-$: C=0, S=-$\sin 2\beta$
- Penguin contribution expected to be minimal
  - 2-10% [Phys.Rev.D61:014010,2000]
- Sensitive to new physics in loops

Belle: Evidence for large CPV in $B \rightarrow D^+D^-$



535 M BB

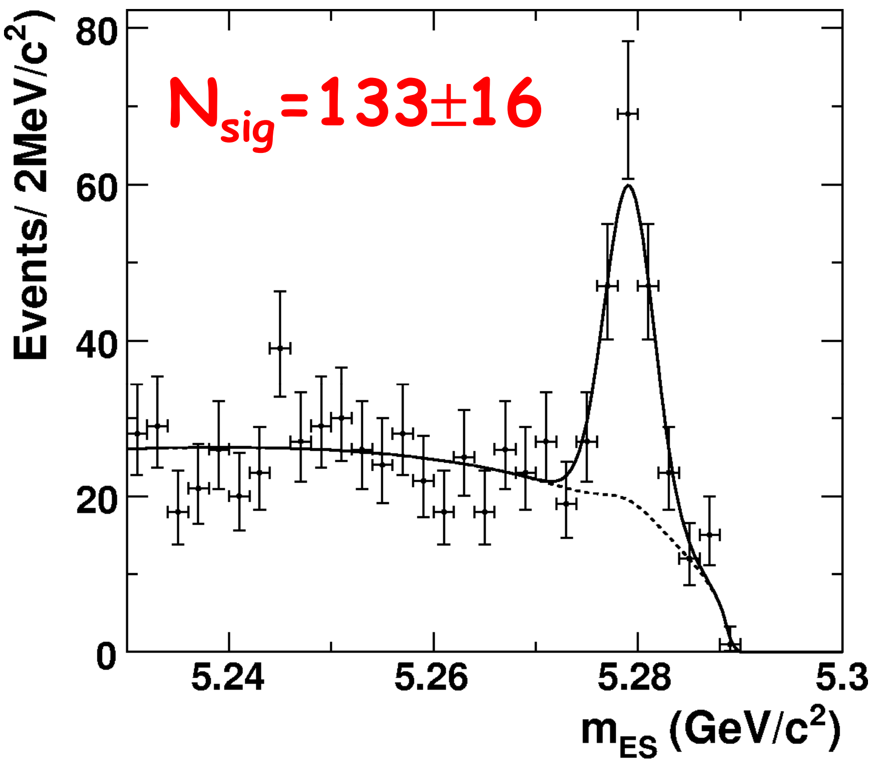
$$\begin{aligned} \sin 2\beta &= +1.13 \pm 0.37 \pm 0.09 \\ C &= -0.91 \pm 0.23 \pm 0.06 \end{aligned}$$

- (sin2β, C) = (0,0) point excluded at 4.1σ confidence

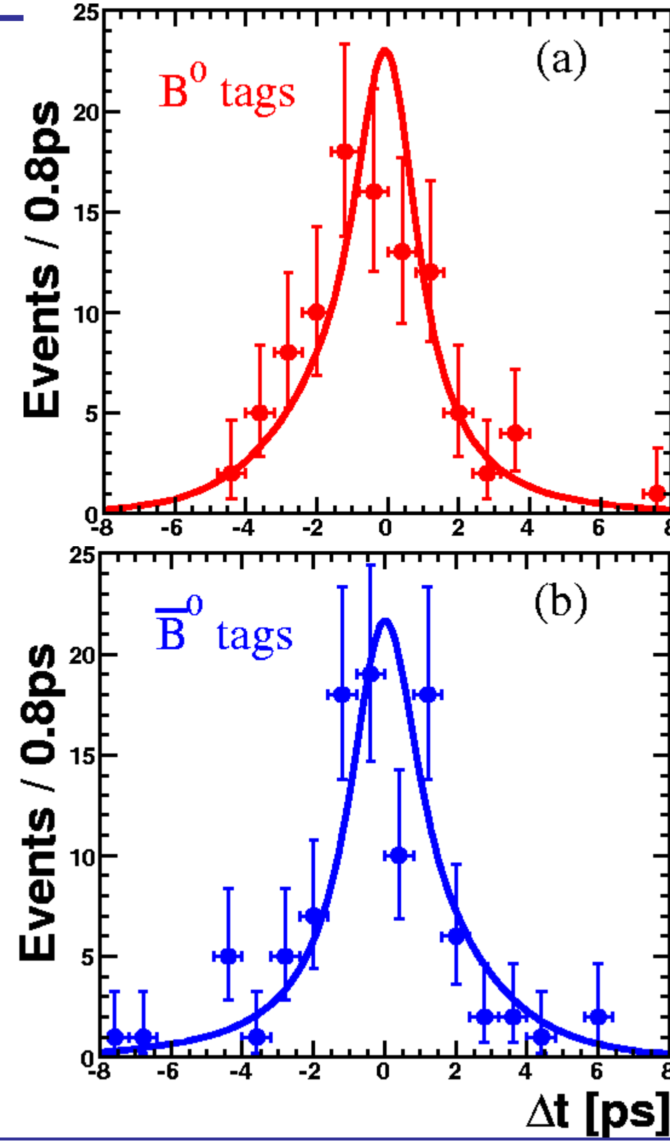
hep-ex/0702031, Submitted to PRL

BABAR does not confirm the large CP violation observed by Belle

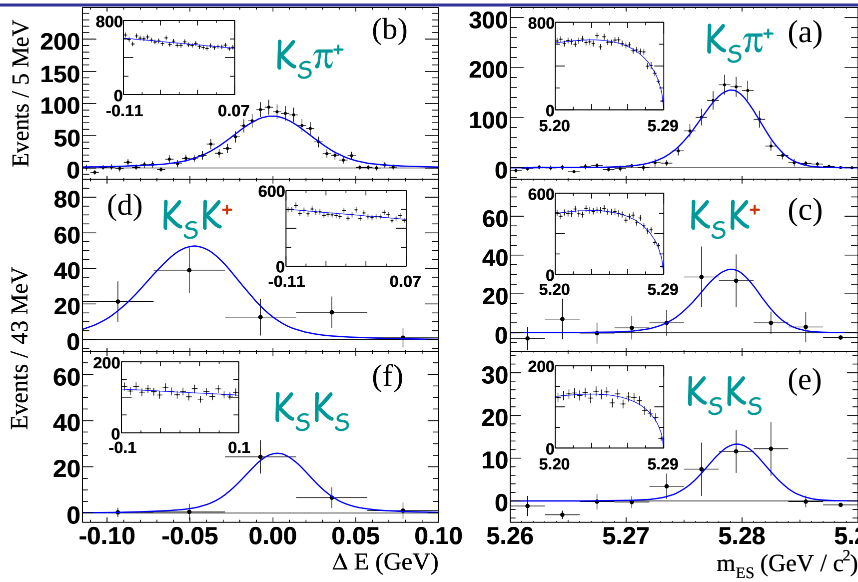
364 M BB

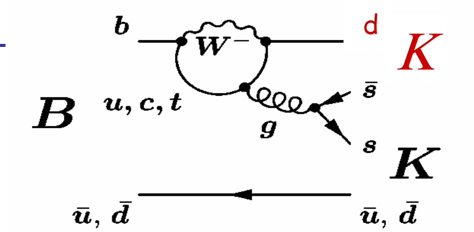


$$
\begin{aligned}
\sin\beta &= +0.54 \pm 0.34 \pm 0.06 \\
C &= \quad 0.11 \pm 0.22 \pm 0.07
\end{aligned}
$$



$B \to K\bar{K}$: Observation of b→dg Penguins





$$\frac{\Gamma(b \to d)}{\Gamma(b \to s)} \sim \frac{|V_{td}|^2}{|V_{ts}|^2} \sim 4\%$$

$$\mathrm{Br}(B^0 \to K^0\overline{K}^0) = (1.08 \pm 0.28 \pm 0.11) \times 10^{-6}\ (7.3\sigma)$$

$$\mathrm{Br}(B^+ \to \overline{K}^0 K^+) = (1.61 \pm 0.44 \pm 0.09) \times 10^{-6}\ (5.3\sigma)$$

$$\mathrm{Br}(B^0 \to K^+K^-) < 0.5 \times 10^{-6}\ \ (90\%\ C.L.)$$

PRL 97: 171805, 2006

347 M BB

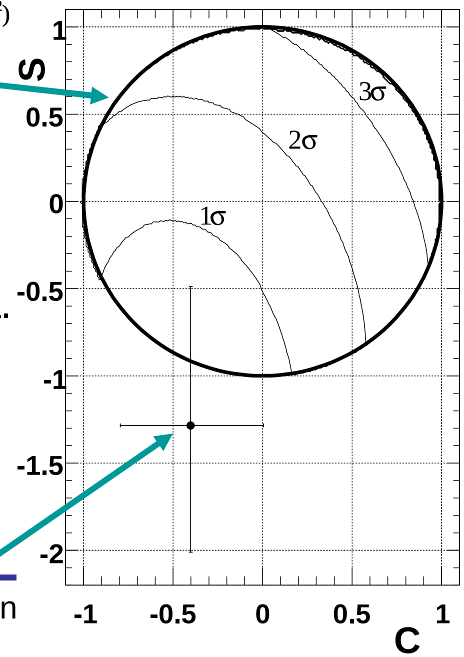
$$A_{CP} \equiv \frac{\Gamma(\overline{B}^0 \to f_{CP}) - \Gamma(B^0 \to f_{CP})}{\Gamma(\overline{B}^0 \to f_{CP}) + \Gamma(B^0 \to f_{CP})}$$
$$= \underbrace{S_{f_{CP}} \sin(\Delta m \Delta t)}_{\text{Indirect CPV}} - \underbrace{C_{f_{CP}} \cos(\Delta m \Delta t)}_{\text{Direct CPV}}$$

physical region

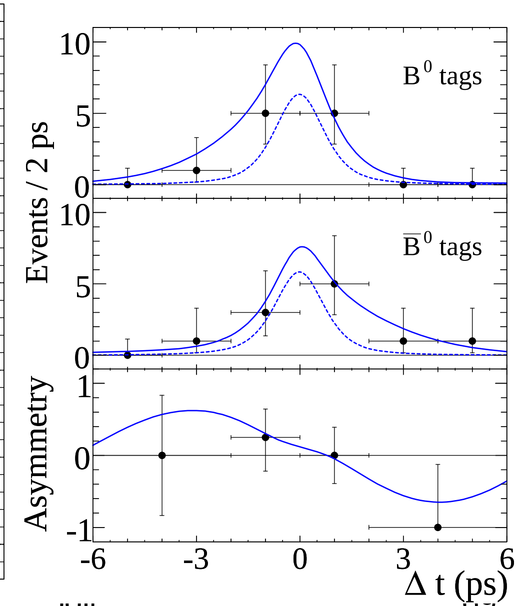
1σ = 68% 2-D C.L.

2σ = 95% 2-D C.L.

3σ = 99.7% 2-D C.L.



fit result



$$S(K^0_S K^0_S) = -1.28^{+0.80}_{-0.73}\ {}^{+0.11}_{-0.16}$$

$$C(K^0_S K^0_S) = -0.40 \pm 0.41 \pm 0.06$$

$$A_{K^0_S K^+} = 0.10 \pm 0.26 \pm 0.03$$

$B^+ \to D^0 K^+$: GLW

- $B \to D_{CP}K$

$$R_{CP\pm} = \frac{\Gamma(B^- \to D^0_{CP\pm}K^-) + \Gamma(B^+ \to D^0_{CP\pm}K^+)}{[\Gamma(B^- \to D^0 K^-) + \Gamma(B^+ \to \overline{D}^0 K^+)]/2}$$

$$A_{CP\pm} = \frac{\Gamma(B^- \to D^0_{CP\pm}K^-) - \Gamma(B^+ \to D^0_{CP\pm}K^+)}{\Gamma(B^- \to D^0_{CP\pm}K^-) + \Gamma(B^+ \to D^0_{CP\pm}K^+)}$$

$$R_{CP\pm} = 1 + r^2 \pm 2r\cos\underline{\delta}\cos\gamma$$

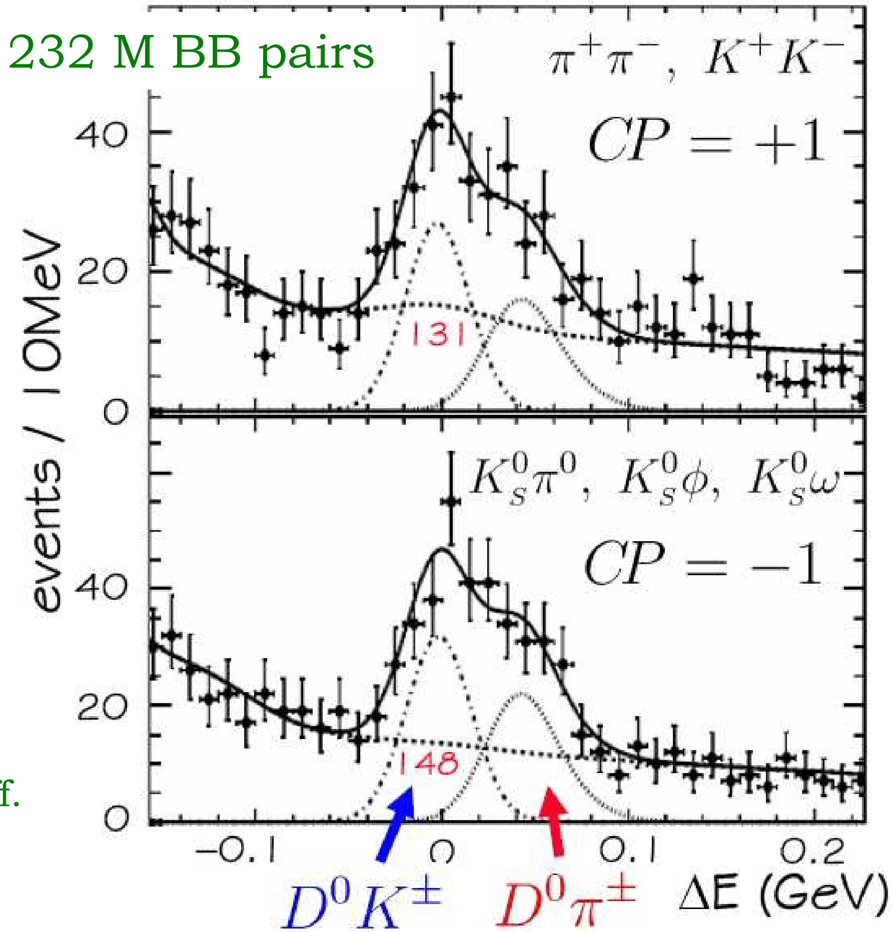
$$A_{CP\pm} = \pm 2r\sin\underline{\delta}\sin\gamma / R_{CP\pm}$$

$$x_\pm = \frac{R_{CP+}(1 \mp A_{CP+}) - R_{CP-}(1 \mp A_{CP-})}{4}$$

$$r^2 = x_\pm^2 + y_\pm^2 = \frac{R_{CP+} + R_{CP-} - 2}{2},$$

δ strong phase diff.

$$x_+ = -0.082 \pm 0.053(\text{stat}) \pm 0.018(\text{syst}),$$
$$x_- = +0.102 \pm 0.062(\text{stat}) \pm 0.022(\text{syst}),$$
$$r^2 = -0.12 \pm 0.08(\text{stat}) \pm 0.03(\text{syst}).$$



BaBar, PRD 73, 051105 (2006)

$B^+ \rightarrow D^0 K^+$: ADS

$B \rightarrow D[K\pi\pi^0]K$

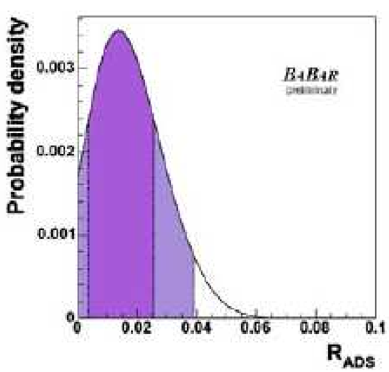
$$R_{ADS} \equiv \frac{\Gamma([K^+\pi^-\pi^0]_D K^-) + \Gamma([K^-\pi^+\pi^0]_D K^+)}{\Gamma([K^+\pi^-\pi^0]_D K^+) + \Gamma([K^-\pi^+\pi^0]_D K^-)} = r_B^2 + r_D^2 + 2r_B r_D C \cos\gamma$$

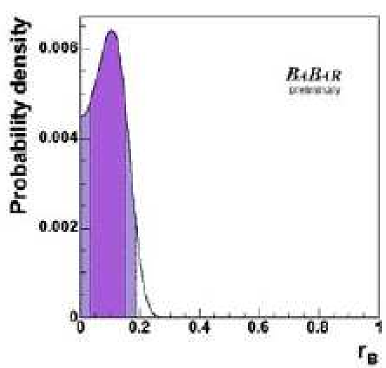
$$A_{ADS} \equiv \frac{\Gamma([K^+\pi^-\pi^0]_D K^-) - \Gamma([K^-\pi^+\pi^0]_D K^+)}{\Gamma([K^+\pi^-\pi^0]_D K^-) + \Gamma([K^-\pi^+\pi^0]_D K^+)} = 2r_B r_D S \sin\gamma / R_{ADS}$$

$$r_B \equiv \left| \frac{A(B^- \rightarrow \bar{D}^0 K^-)}{A(B^- \rightarrow D^0 K^-)} \right|, \quad r_D^2 \equiv \frac{\mathcal{B}(D^0 \rightarrow K^+\pi^-\pi^0)}{\mathcal{B}(D^0 \rightarrow K^-\pi^+\pi^0)}$$

hep-ex/0607065

$226 \times 10^6\ B\bar{B}$ pairs



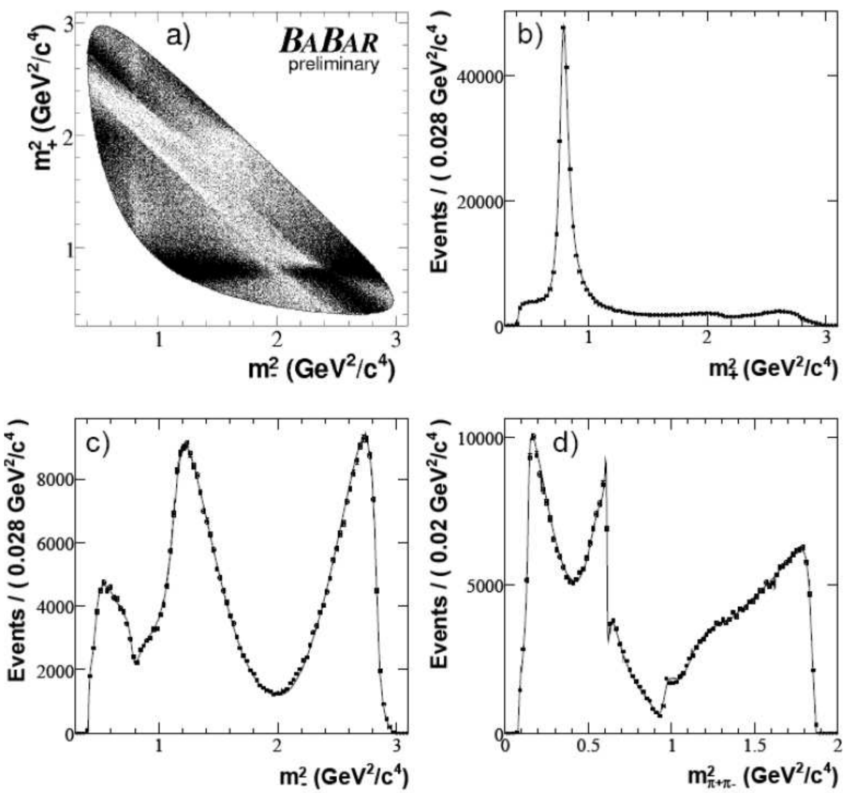


$$\boxed{R_{ADS} = 0.012^{+0.012}_{-0.010}(stat)^{+0.010}_{-0.007}(syst)}$$

$$\boxed{r_B = 0.091 \pm 0.059}$$

$B^+ \to D^{(*)0}[K_S\pi\pi]\, K^+$: GGSZ (Dalitz)

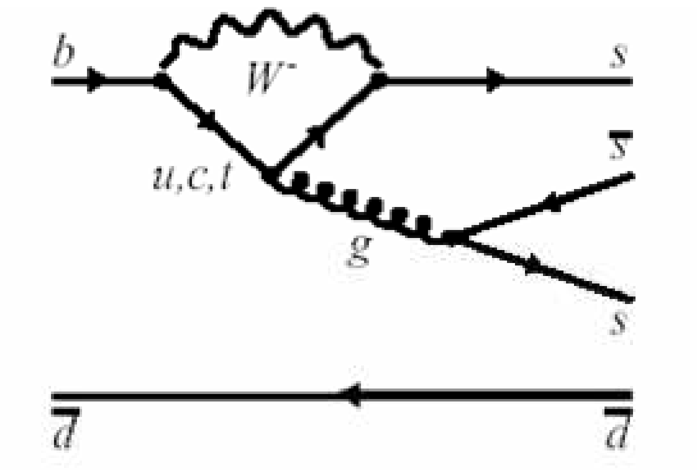
Fit large and pure sample of flavor-tagged D^0K_s to determine the parameters of the Dalitz model $f_\pm$ (Isobar model used by both BaBar and Belle)



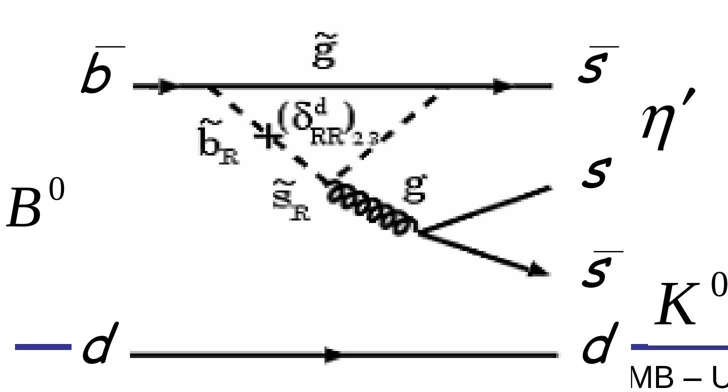
Component	$Re\{a_r e^{i\phi_r}\}$	$Im\{a_r e^{i\phi_r}\}$	Fit fraction (%)
$K^*(892)^-$	-1.223 ± 0.011	1.3461 ± 0.0096	58.1
$K_0^*(1430)^-$	-1.698 ± 0.022	-0.576 ± 0.024	6.7
$K_2^*(1430)^-$	-0.834 ± 0.021	0.931 ± 0.022	[illegible]
$K^*(1410)^-$	-0.248 ± 0.038	-0.108 ± 0.031	0.1
$K^*(1680)^-$	-1.285 ± 0.014	0.205 ± 0.013	0.6
$K^*(892)^+$	0.0997 ± 0.0036	-0.1271 ± 0.0034	0.5
$K_0^*(1430)^+$	-0.027 ± 0.016	[illegible] ± 0.017	0.0
$K_2^*(1430)^+$	0.019 ± 0.017	0.177 ± 0.018	0.1
$\rho(770)$	1	0	21.6
$\omega(782)$	-0.02194 ± 0.00099	0.03942 ± 0.00066	0.7
$f_2(1270)$	-0.699 ± 0.018	0.387 ± 0.018	2.1
$\rho(1450)$	0.253 ± 0.038	0.036 ± 0.055	0.1
Non-resonant	-0.99 ± 0.19	3.82 ± 0.13	8.5
$f_0(980)$	0.4465 ± 0.0057	0.2572 ± 0.0081	6.4
$f_0(1370)$	0.95 ± 0.11	-1.619 ± 0.011	2.0
σ	1.28 ± 0.02	0.273 ± 0.024	7.6
σ'	0.290 ± 0.010	-0.0655 ± 0.0098	0.9

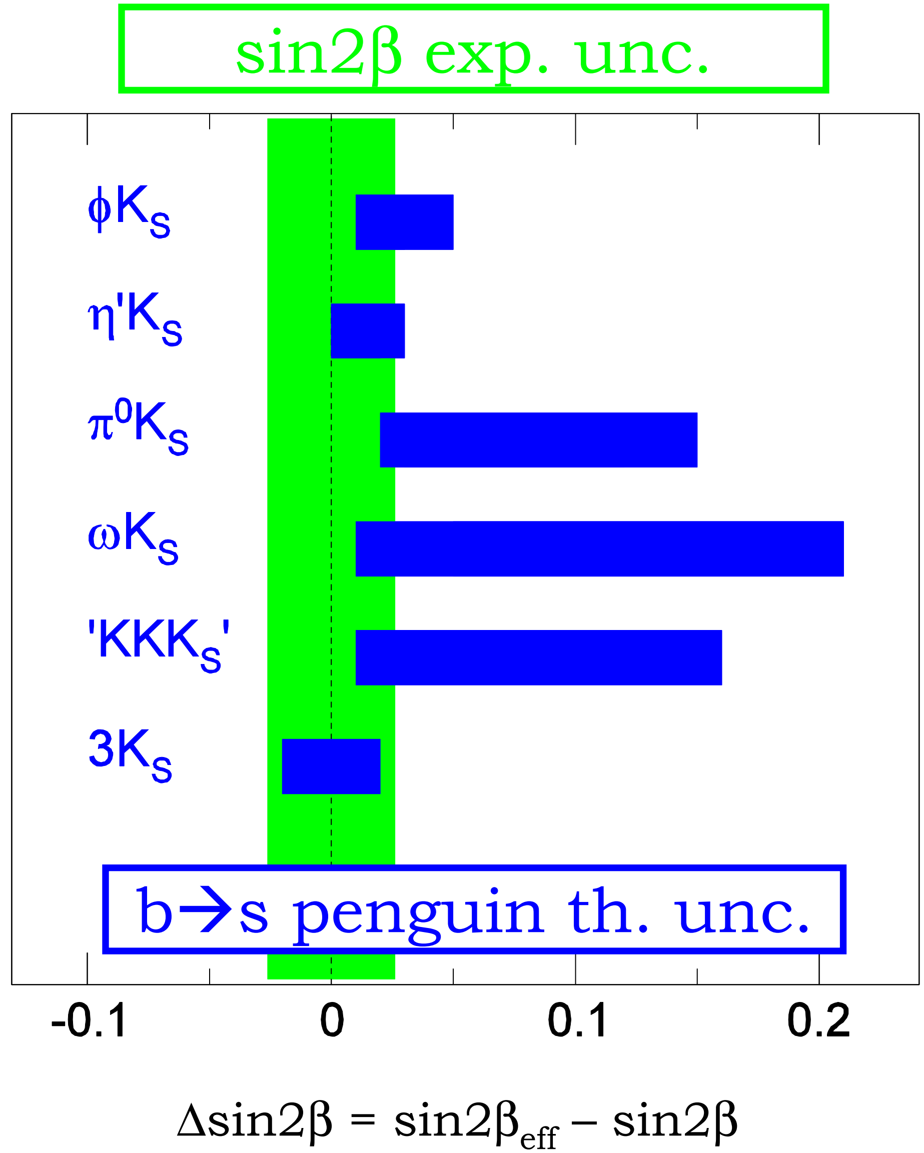
16 Breit-Wigner + constant term

Sin2β with penguins



Beneke PLB 620 143 (2005)
Mishima, Sanda PRD 72 114005 (2005)
Williamson, Zupan PRD 74 014003 (2006)
Cheng, Chua, Soni PRD 014006 (2005)



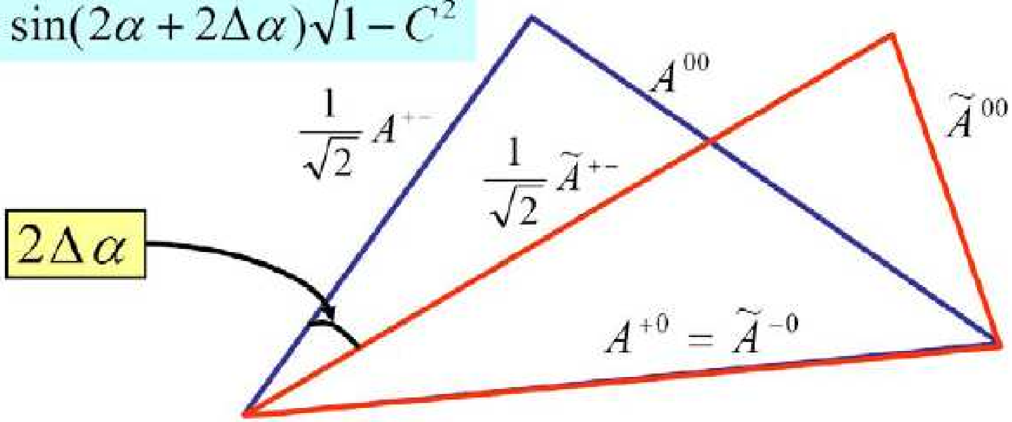


MB – UT angles

$|\alpha - \alpha_{eff}|$: Isospin analysis

- Use SU(2) to relate different *hh* final states

$$S = \sin(2\alpha + 2\Delta\alpha)\sqrt{1 - C^2}$$



$$A_{hh} = e^{+i\gamma}T + e^{-i\beta}P$$
$$\widetilde{A}_{hh} = e^{-i\gamma}T + e^{+i\beta}P$$

$$A^{+0} = \frac{1}{\sqrt{2}} A^{+-} + A^{00}$$
$$\widetilde{A}^{-0} = \frac{1}{\sqrt{2}} \widetilde{A}^{+-} + \widetilde{A}^{00}$$

$$A^{+-} = A(B^0 \to \pi^+\pi^-)$$
$$\widetilde{A}^{+-} = A(\overline{B}^0 \to \pi^+\pi^-)$$
$$A^{00} = A(B^0 \to \pi^0\pi^0)$$
$$\widetilde{A}^{00} = A(\overline{B}^0 \to \pi^0\pi^0)$$
$$A^{+0} = A(B^+ \to \pi^+\pi^0)$$
$$\widetilde{A}^{-0} = A(B^- \to \pi^-\pi^0)$$

Gronau, London : PRL**65**, 3381 (1990)

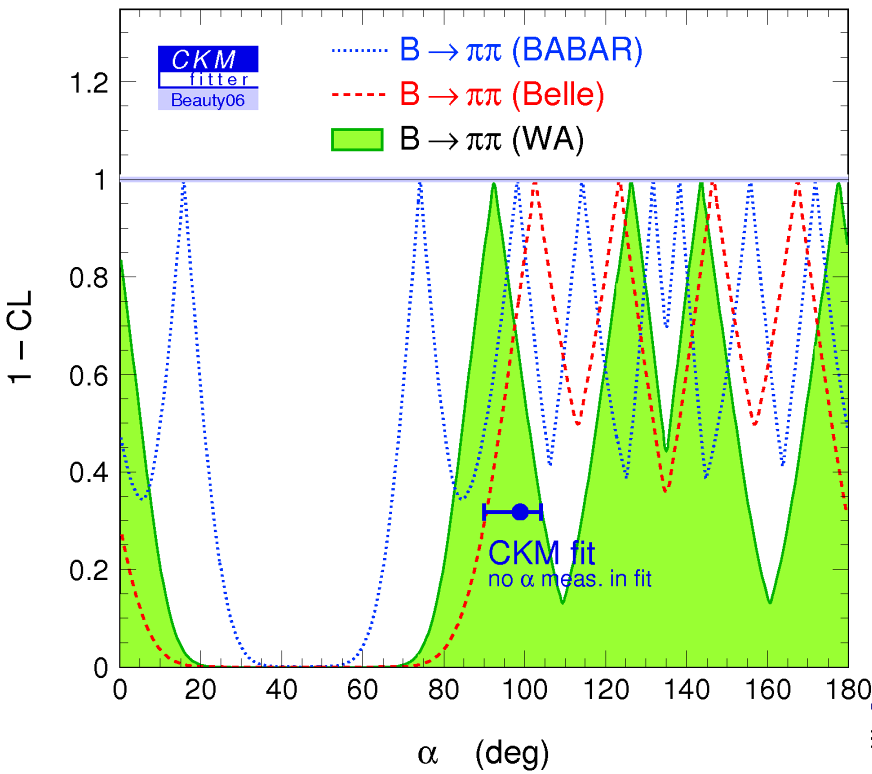
$B^0 \rightarrow \pi^+\pi^-$

Using isospin relations

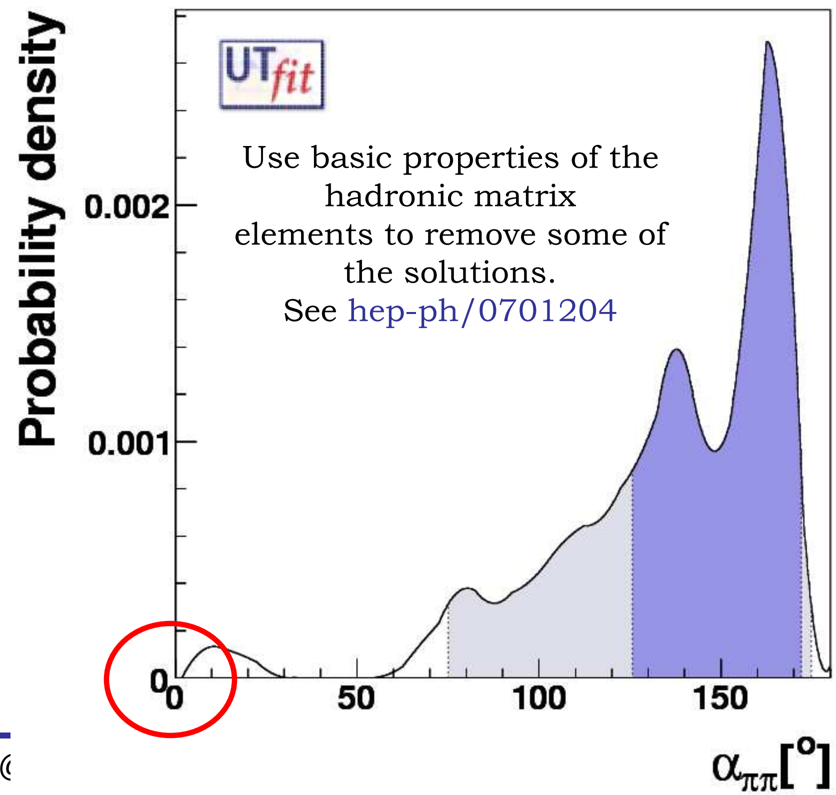
$BR(B^0 \rightarrow \pi^+\pi^-) = 5.2 \pm 0.2$ HFAG (10^{-6}) -

$BR(B^+ \rightarrow \pi^+\pi^0) = 5.7 \pm 0.4$ $A_{CP}(B^+ \rightarrow \pi^+\pi^0) = 0.04 \pm 0.05$

$BR(B^0 \rightarrow \pi^0\pi^0) = 1.3 \pm 0.2$ $A_{CP}(B^0 \rightarrow \pi^0\pi^0) = 0.36^{+0.33}_{-0.31}$



s and sides (

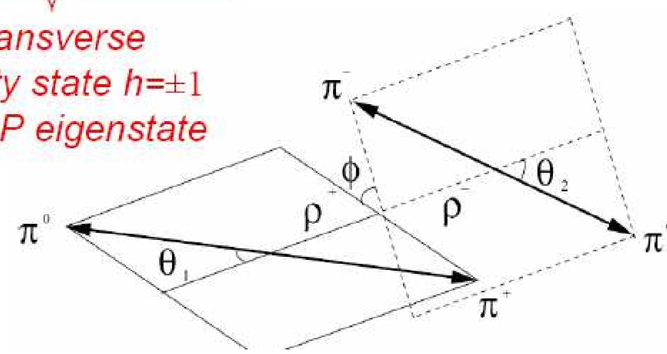


hep-ex/0607097 $B^0 \to \rho^+\rho^-$ $347 \times 10^6 B\overline{B}$ pairs

- Extraction of α follows the same logic as for the B→ππ system
- ρρ is a VV state with 3 possible polarizations (L: A^0; T: A^+ & A^-)
- Angular analysis needed to determine CP content

$$\frac{d^2N}{d\cos\theta_1 d\cos\theta_2} \propto \underbrace{f_L \cos^2\theta_1 \cos^2\theta_2}_{\substack{\text{Longitudinal} \\ \text{Helicity state } h=0 \\ \text{CP+1 eigenstate}}} + \underbrace{\tfrac{1}{4}(1-f_L)\sin^2\theta_1 \sin^2\theta_2}_{\substack{\text{Transverse} \\ \text{Helicity state } h=\pm 1 \\ \text{non-CP eigenstate}}}$$

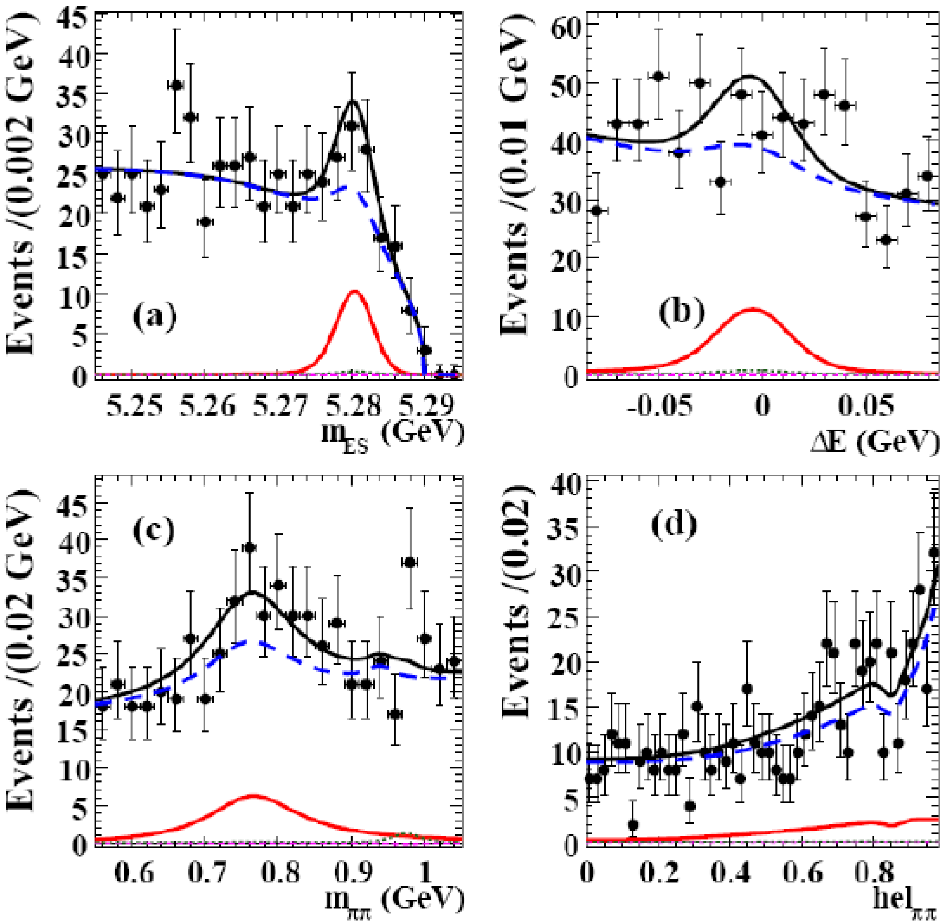
$$\boxed{f_L = 0.977 \pm 0.024 \,{}^{+0.015}_{-0.013}}$$



hep-ex/0612021
PRL accepted

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

$384 \times 10^6\ B\overline{B}$ pairs



$$N_{\rho^0\rho^0} = 100 \pm 32 \pm 17$$

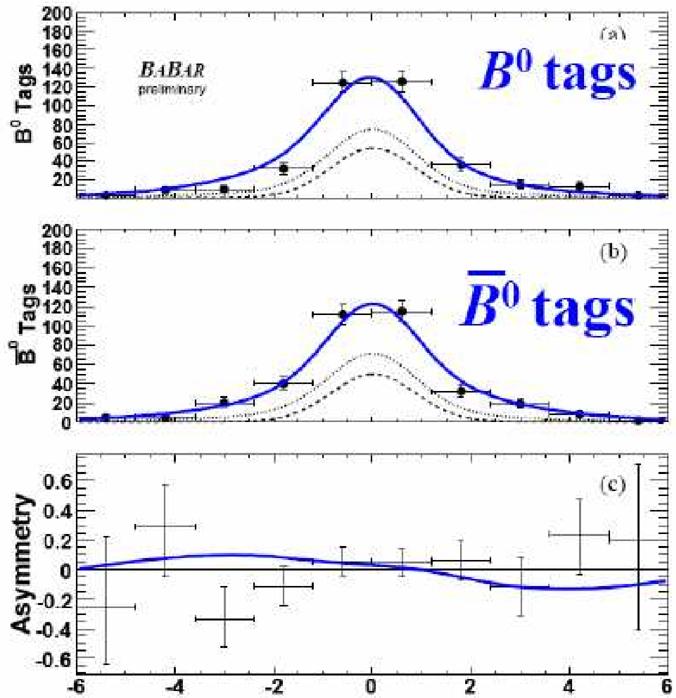
3.5σ evidence for $B \to \rho^0\rho^0$

$$f_L(B^0 \to \rho^0\rho^0) = 0.87 \pm 0.13 \pm 0.04$$

$$Br\ (B^0 \to \rho^0\rho^0) = (1.07 \pm 0.33 \pm 0.19) \cdot 10^{-6}$$

Small $\rho^0\rho^0$ BF $\Rightarrow$ small penguin pollution

$B^{0(\pm)} \to \rho^{0(\pm)} \rho^0$



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

$$S_{long} = -0.19 \pm 0.21^{+0.05}_{-0.07}$$

$$C_{long} = -0.07 \pm 0.15 \pm 0.06$$

$$\alpha_{eff} = (95.5\ ^{+6.9}_{-6.2})^\circ$$

$$Br\,(B^0 \to \rho\rho) = (23.5 \pm 2.2 \pm 4.1) \cdot 10^{-6}$$

$B^\pm \to \rho^\pm\rho^0$

hep-ex/0607092

$$Br\,(B^\pm \to \rho^\pm\rho^0) = (16.8 \pm 2.2 \pm 2.3) \cdot 10^{-6}$$

$$A_{CP}(B^\pm \to \rho^\pm\rho^0) = -0.12 \pm 0.13 \pm 0.10$$

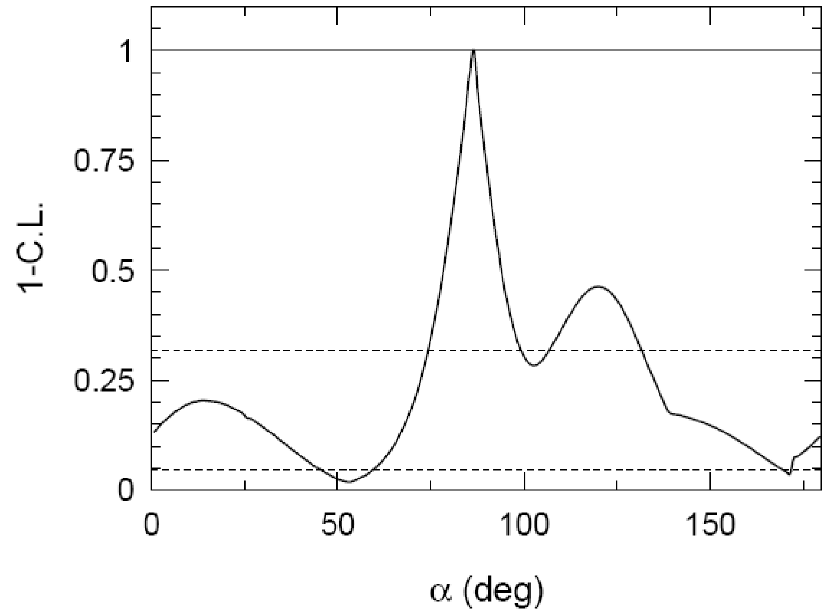
$$f_L(B^\pm \to \rho^\pm\rho^0) = 0.905 \pm 0.042^{+0.023}_{-0.027}$$

$B \to \pi\pi\pi^0$: Dalitz fit to α

- α from a fit to 26 parameters
- The method extracts α without ambiguities in $[0^o, 180^o]$

hep-ex/0703008

375M BB



$$\alpha = (87^{+45}_{-13})^{\circ}$$

- results consistent with SM result (~ 90^o)

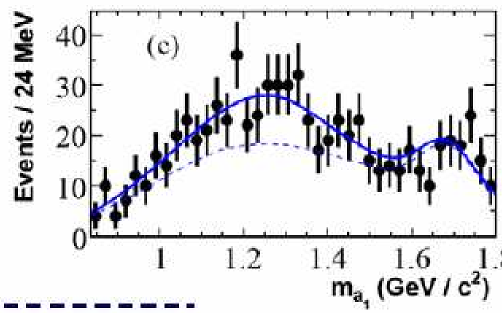
$B \to a_1 \pi$: α_{eff} and…

Phys.Rev.Lett, **97**, 051802 (2006)

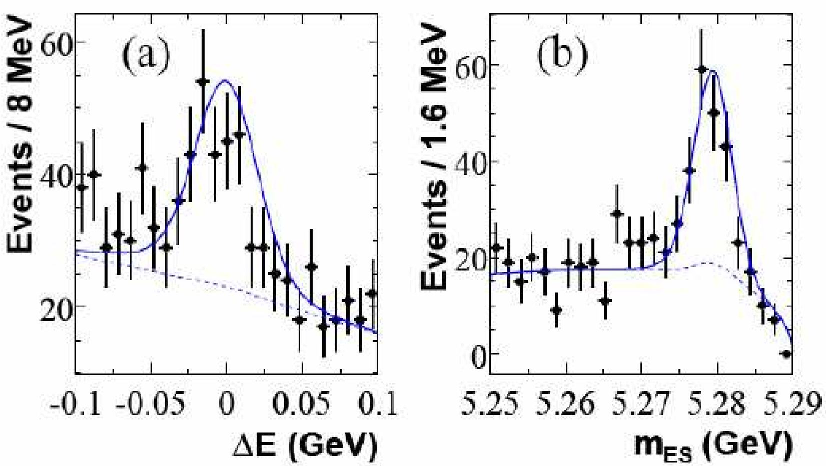
- First BF observation, significance 9.2 σ

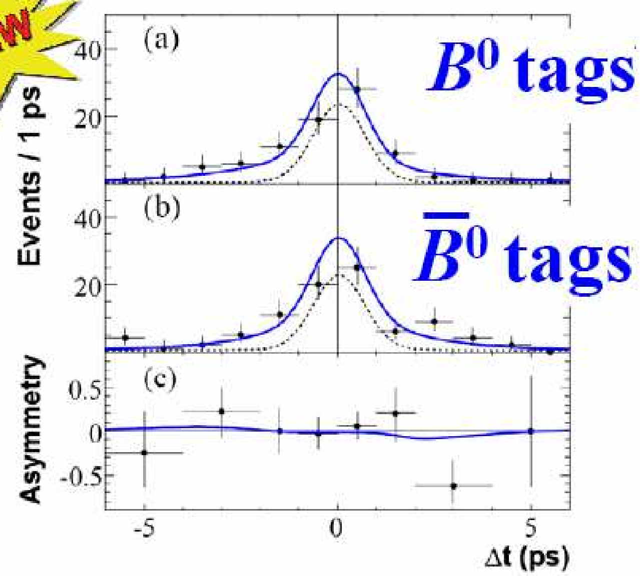
$\mathcal{B}r(B^0 \to a_1(1260)\,\pi) = (33.2 \pm 3.8 \pm 3.0) \cdot 10^{-6}$

Reconstructed a_1 (1260) $\to$ 3 charged pions
Quasi-two body approximation



- First Time Dependent CPV analysis





$B \to a_1\pi$: α_{eff} and SU(3)

$$\begin{aligned} S_{a_1\pi} &= 0.37 \pm 0.21 \pm 0.07 \\ C_{a_1\pi} &= -0.10 \pm 0.15 \pm 0.09 \\ A_{CP} &= -0.07 \pm 0.07 \pm 0.02 \end{aligned}$$

$$\begin{aligned} \Delta S_{a_1\pi} &= -0.14 \pm 0.21 \pm 0.06 \\ \Delta C_{a_1\pi} &= 0.26 \pm 0.15 \pm 0.07 \end{aligned}$$

Using the measured CP parameters we determine the angle α_{eff} and one of the four solutions is compatible with the result of SM-based fits:

Gronau-Zupan
PRD 73, 057502 (2006)

$$\alpha_{eff} = 78.6^o \pm 7.3^o$$

SU(3) related modes

$a_1^+ K^-$ **OR** $a_1^+ K^0_S$ + ($K_1^-(1270)\,\pi^+$ and $K_1^-(1400)\,\pi^+$) OR ($K_1^0(1270)\,\pi^+$ and $K_1^0(1400)\,\pi^+$)

... in progress!