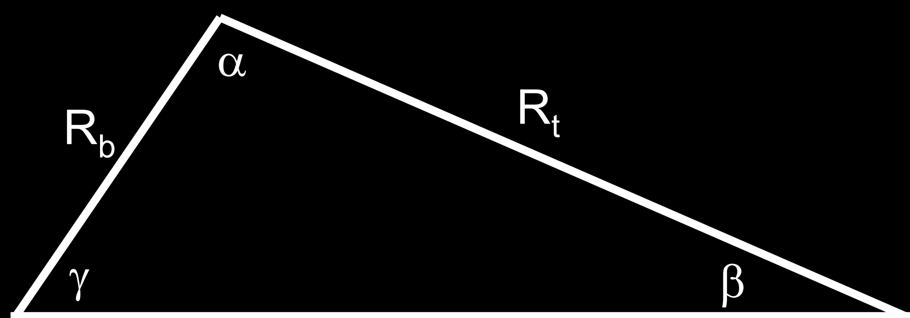
Experimental reach for CKM angles and sides.



Adrian Bevan

UK HEP Forum on Heavy Flavour Physics
Cosener's House,

21-22nd June 2007

Queen Mary
University of London

Outline of the next 45 minutes

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

- Motivation.
- Angles:
  - Standard Model viewpoint of β, α, γ.
  - Looking for New Physics contributions.
- Sides:
  - R_b.
  - R_t.
- Combination of results.
- Unexplored territory.
- Conclusions.

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The unitarity triangle

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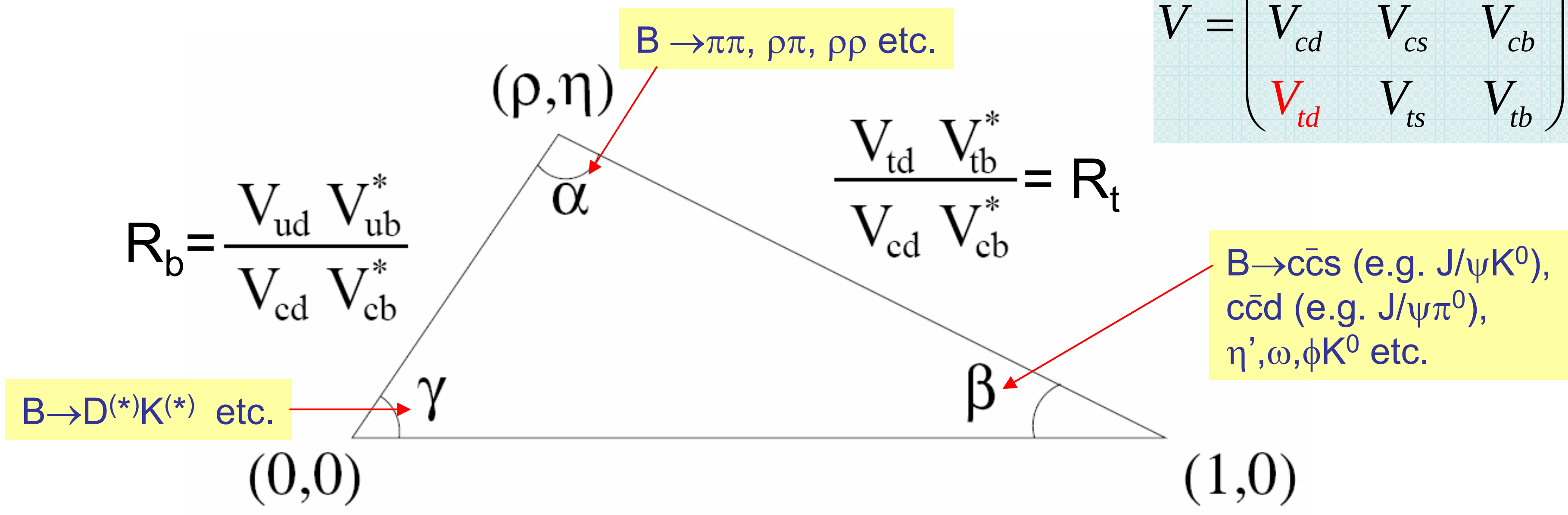

- B-factories have measured β to ~1° in c$\bar{c}$s, and starting to do precision measurements in charmless b→s penguin decays.
- α is measured to 7°.
- Now starting to constrain γ.

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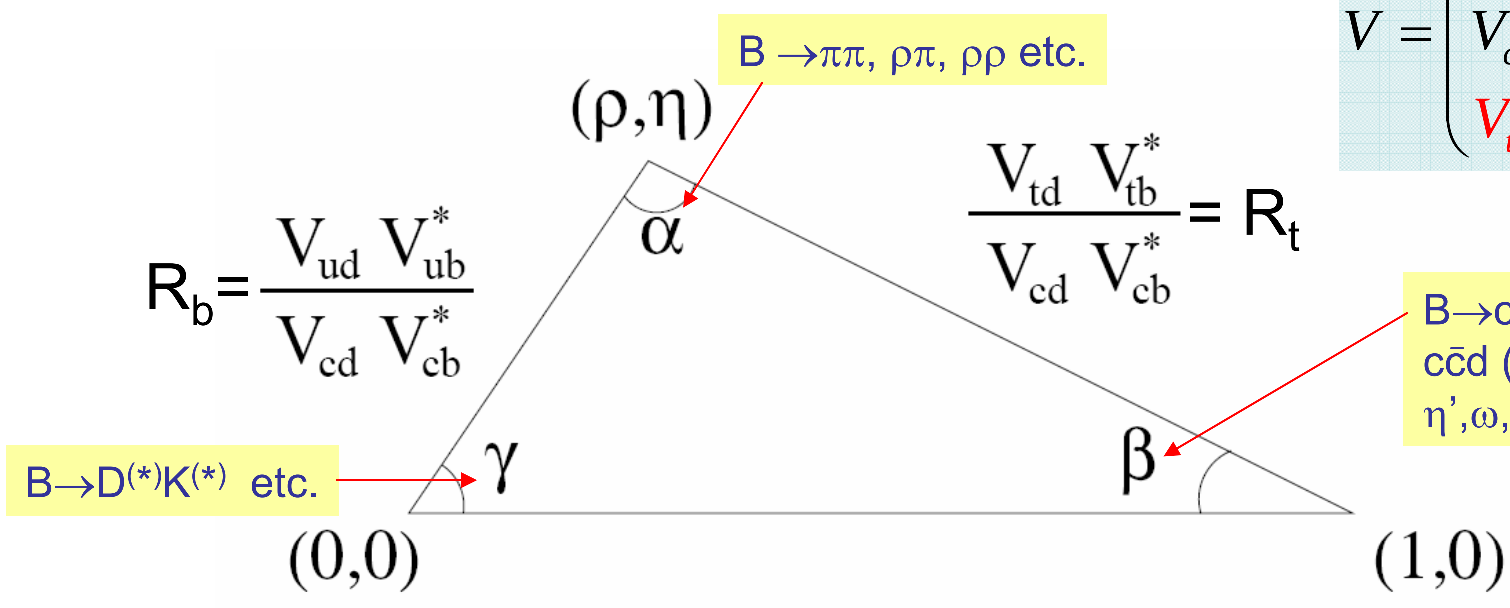

- B-factories have measured β to ~1° in $c\bar{c}s$, and starting to do precision measurements in charmless $b \to s$ penguin decays.
- α is measured to 7°.
- Now starting to constrain γ.

Think of the UT for BaBar and Belle results.
More triangles are studied with B_S decays.
That's LHCb & SuperB's job.

The unitarity triangle

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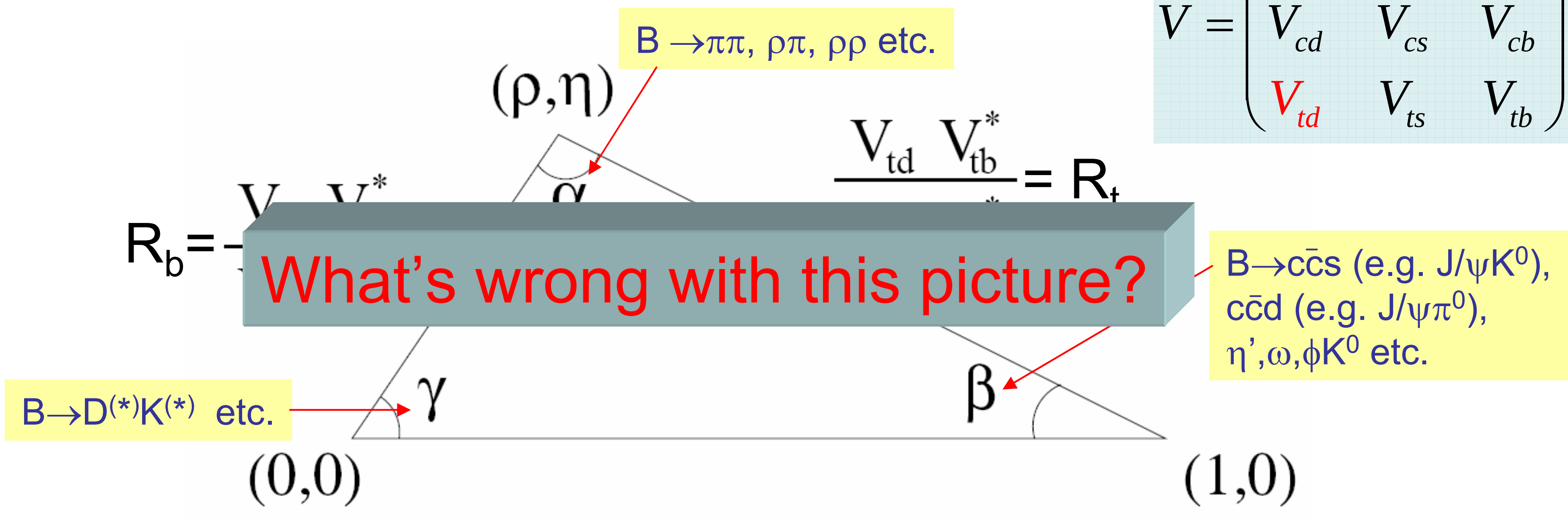

What's wrong with this picture?

- B-factories have measured β to ~1° in cc̄s, and starting to do precision measurements in charmless b→s penguin decays.
- α is measured to 7°.
- Now starting to constrain γ.

Think of the UT for BaBar and Belle results.
More triangles are studied with B_s decays.
That's LHCb & SuperB's job.

Questions still unanswered

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

- Why is the level of CPV described by CKM too small?
  - What makes up the difference?

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- Why is the level of CPV described by CKM too small?
  - What makes up the difference?

- Is the triangle unitary?
  - Over-constraining the CKM matrix is the only way to check this.

Recall that there are 6 triangles that can be used to over-constrain the CKM matrix. We're only concentrating on a few of them with B-physics.

Questions still unanswered

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

- Why is the level of CPV described by CKM too small?
  - What makes up the difference?
- Is the triangle unitary?
  - Over-constraining the CKM matrix is the only way to check this.
- Are tree and higher order angle measurements the same?
  - Are there non-trivial New Physics flavour couplings at TeV energies?

Outline of the next 45 minutes

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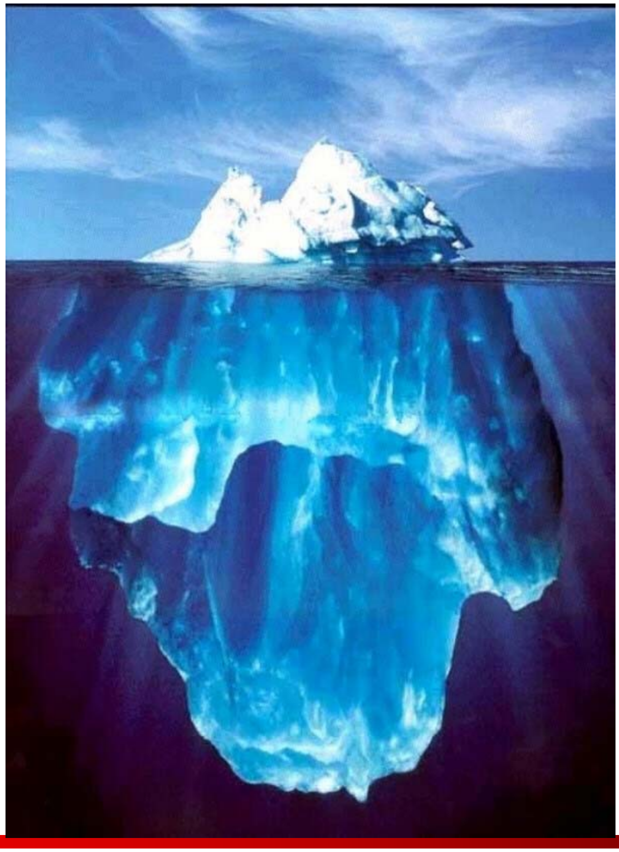
Measuring β

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

- Main goal of the current B-factories.
  - Observation of CP violation in B decays (2001).

- … but this was the tip of the iceberg.



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- Main goal of the current B-factories.
  - Observation of CP violation in B decays (2001).
- … but this was the tip of the iceberg.
- Lots more physics to do.
  - Cross-check tree level with loops.
  - Cross-check different tree/loop processes to compare topologies.
  - Observed CP violation in penguin decays (2006).
  - Control standard model uncertainties on measurements.
  - Search for new physics.

    +…

β from b→cc̄s decays

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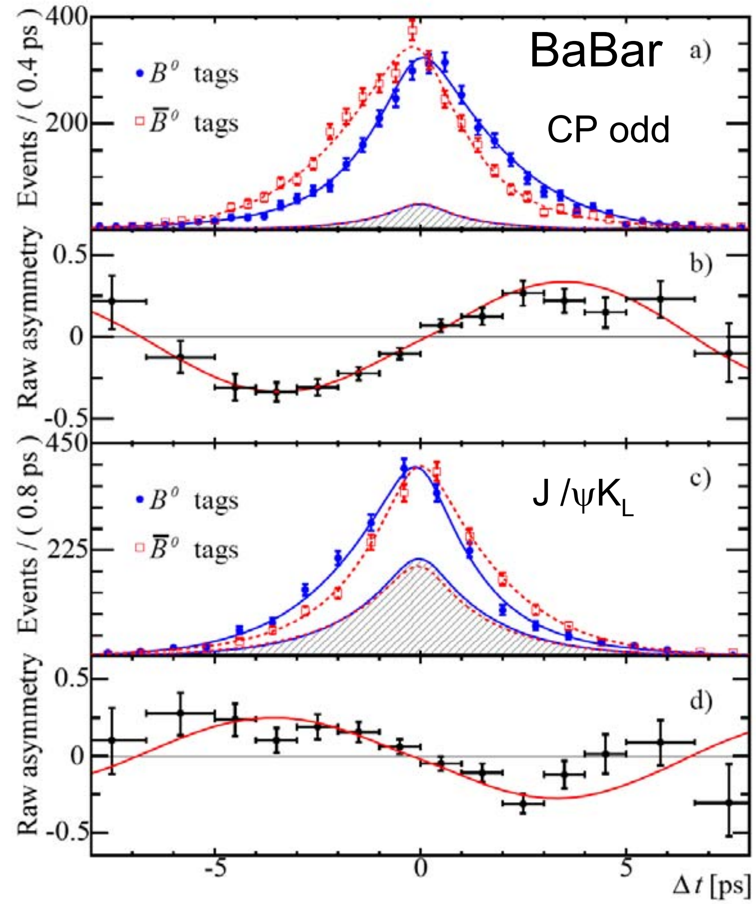
HFAG average of results:

$$\sin(2\beta) = 0.678 \pm 0.022_{STAT} \pm 0.012_{SYST}$$

$$\beta = (21.3 \pm 1.0)^{\circ}$$

- Good agreement in different channels (BaBar results shown) for sin2β.
- 1° precision has been attained.
- This measurement was the raison d'etre of the current B-factories.

Sample	N_{tag}	$P(\%)$	$\sin2\beta$	$\lvert\lambda\rvert$
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



hep-ex/0703021
PRL 98 031802 (2007)

β from b→cc̄s decays

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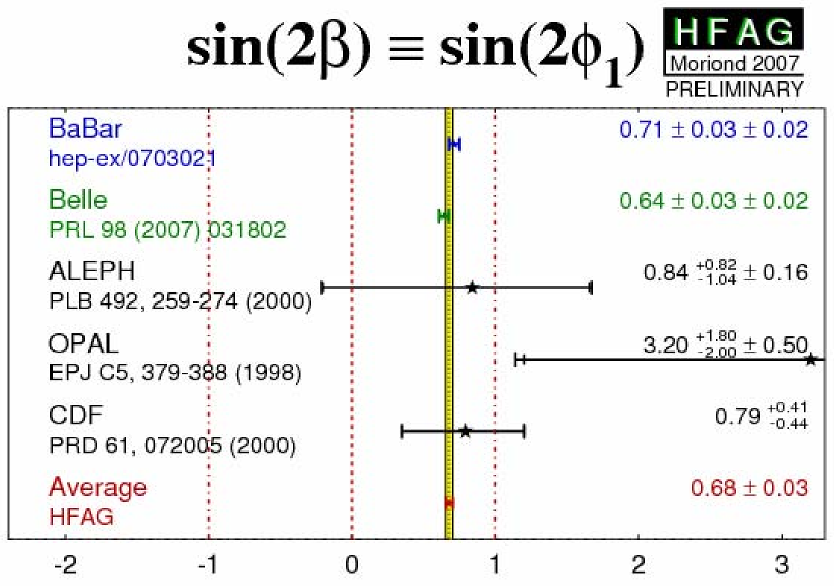
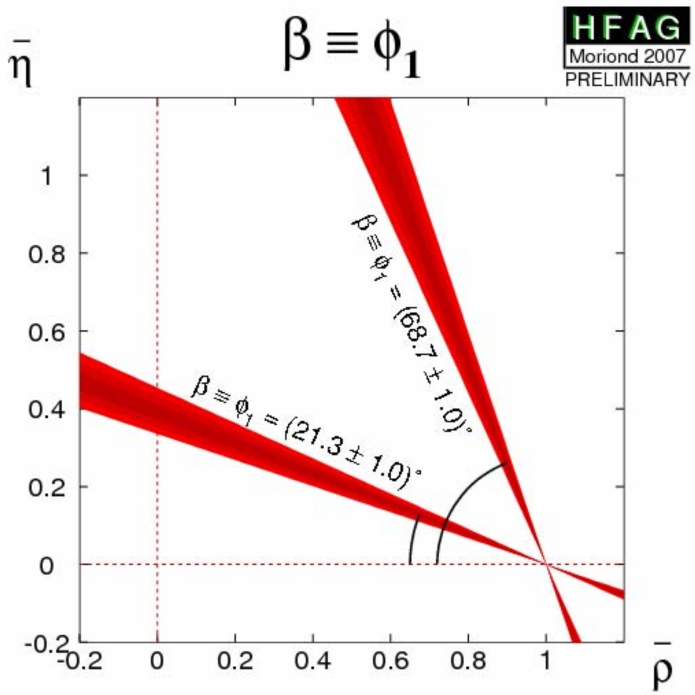


- Experiments agree well.



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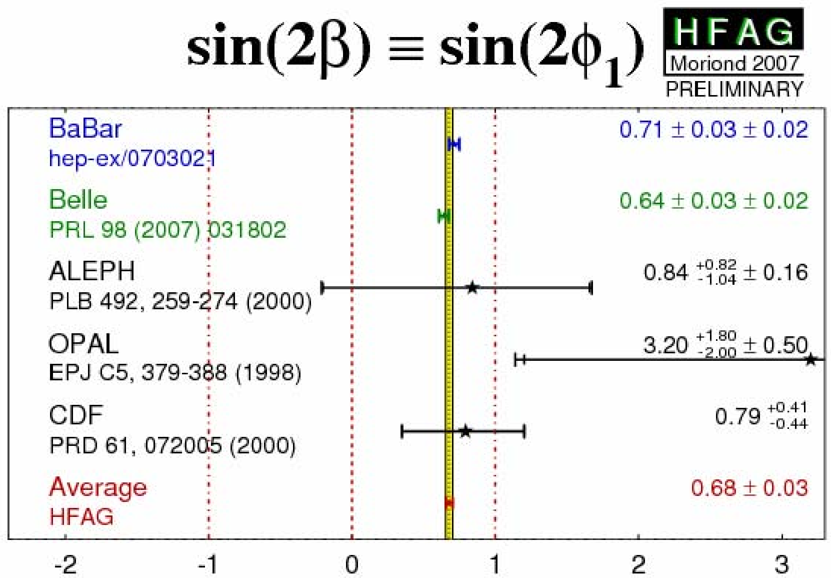
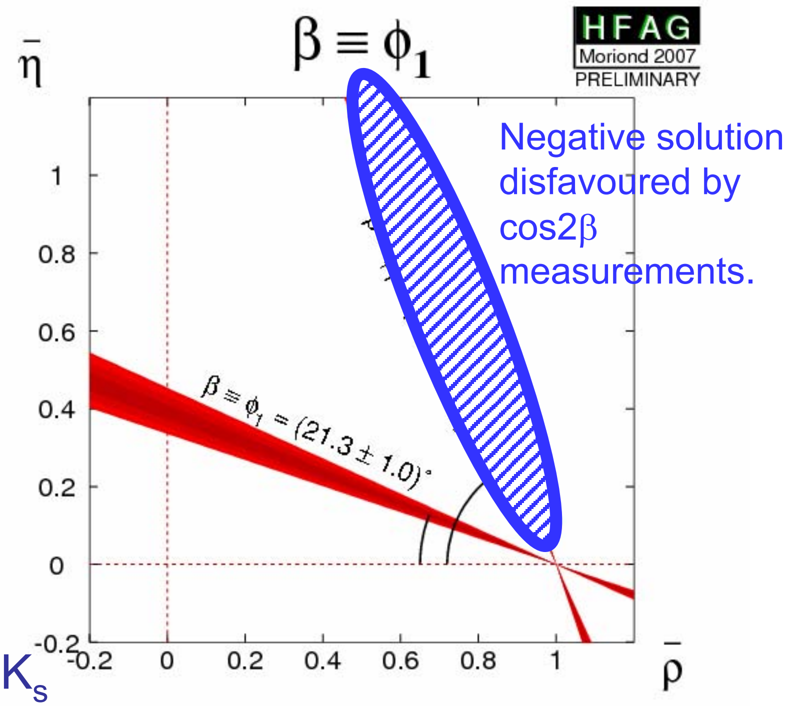




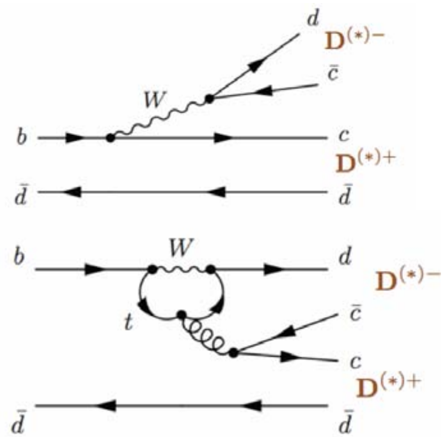
- Experiments agree well.
- $\cos 2\beta$ from $J/\psi K^*$, $K^+K^-K^0$, $D^0(K_s\pi^+\pi^-)h^0$ $D^{*+}D^{*-}K_s$ favours β=21.3° over β=68.7°.
- Expect
  - LHCb: 0.3° measurement (stat) ($10fb^{-1}$)
  - Super LHCb: 0.1° measurement (stat) ($100fb^{-1}$)
  - Super B: 0.2° measurement ($75ab^{-1}$)

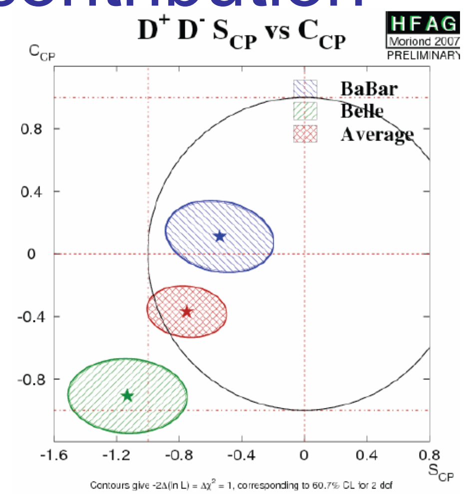
hep-ex/0703021
PRL 98 031802 (2007)

β from $b \to c\bar{c}d$ decays

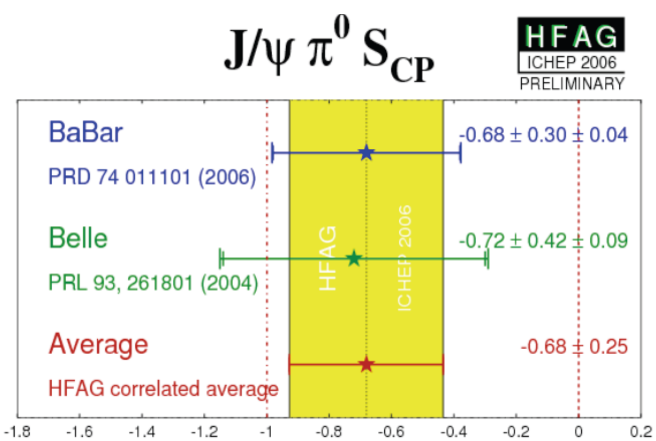
$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- Tree dominated decays, perhaps with some penguin contribution





- Same tree topology as $c\bar{c}s$ – just replace the 's' quark for a 'd' quark.
- Sizable deviation from β in $c\bar{c}s$ decays would indicate New Physics
  - Measurements are consistent with tree level expectation.



- $B^0 \to J/\psi\pi^0$ can be used to estimate SM uncertainty to $c\bar{c}s$ β calculation at the level of 10^{-2}.

β from b→s penguins

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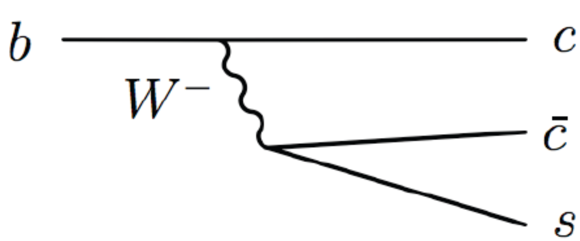
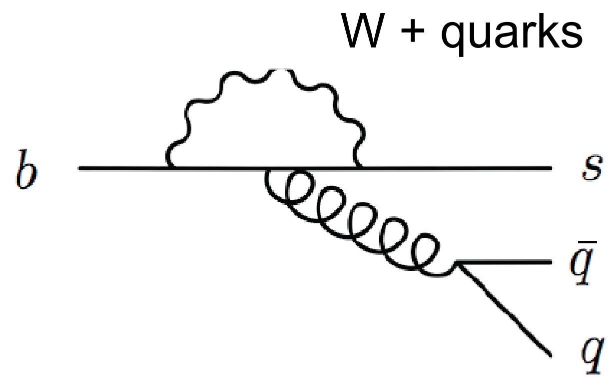
- Tree level β is known to 1°.
- What is β measured in loop processes?



TREE



LOOP

β from b→s penguins

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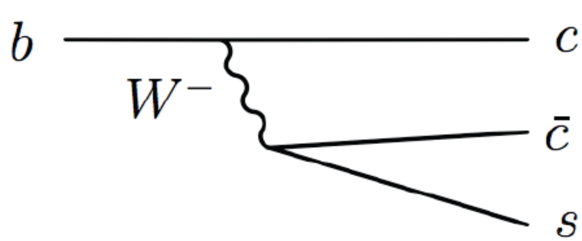
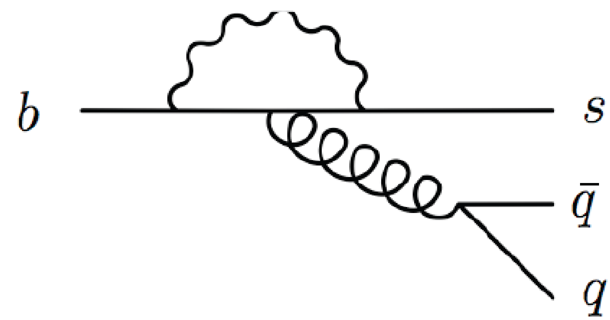


TREE

H + quarks?



LOOP

β from b→s penguins

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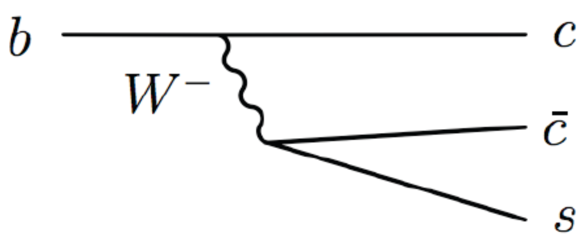
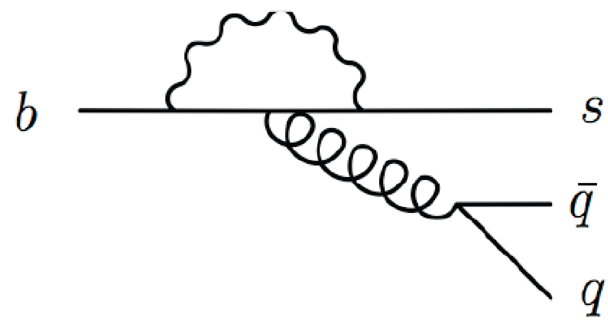


TREE

SUSY particles?



LOOP

- This would result in different:
  - rate measurements.
  - CP asymmetries (i.e. $\sin 2\beta_{TREE} \neq \sin 2\beta_{LOOP}$).

β from b→s penguins

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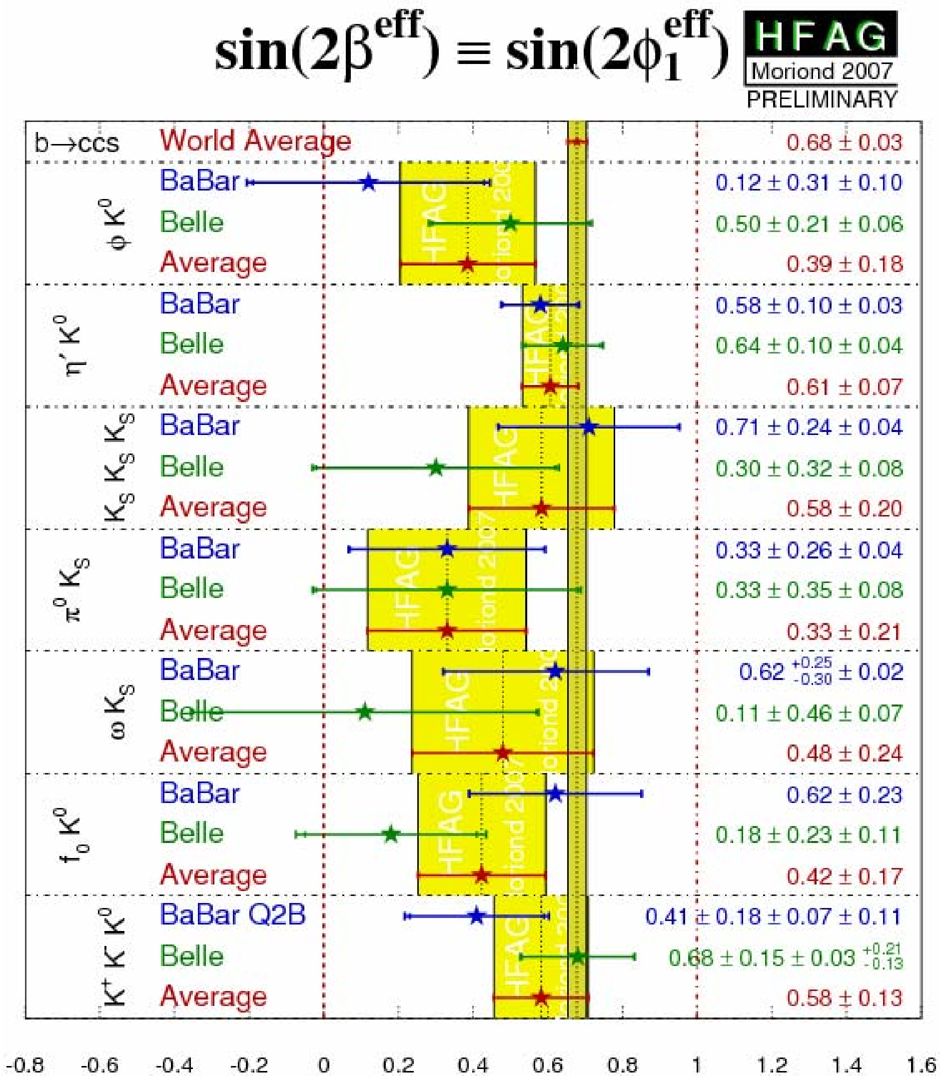
- Naive average is 2.6σ different from the tree level β measurement.



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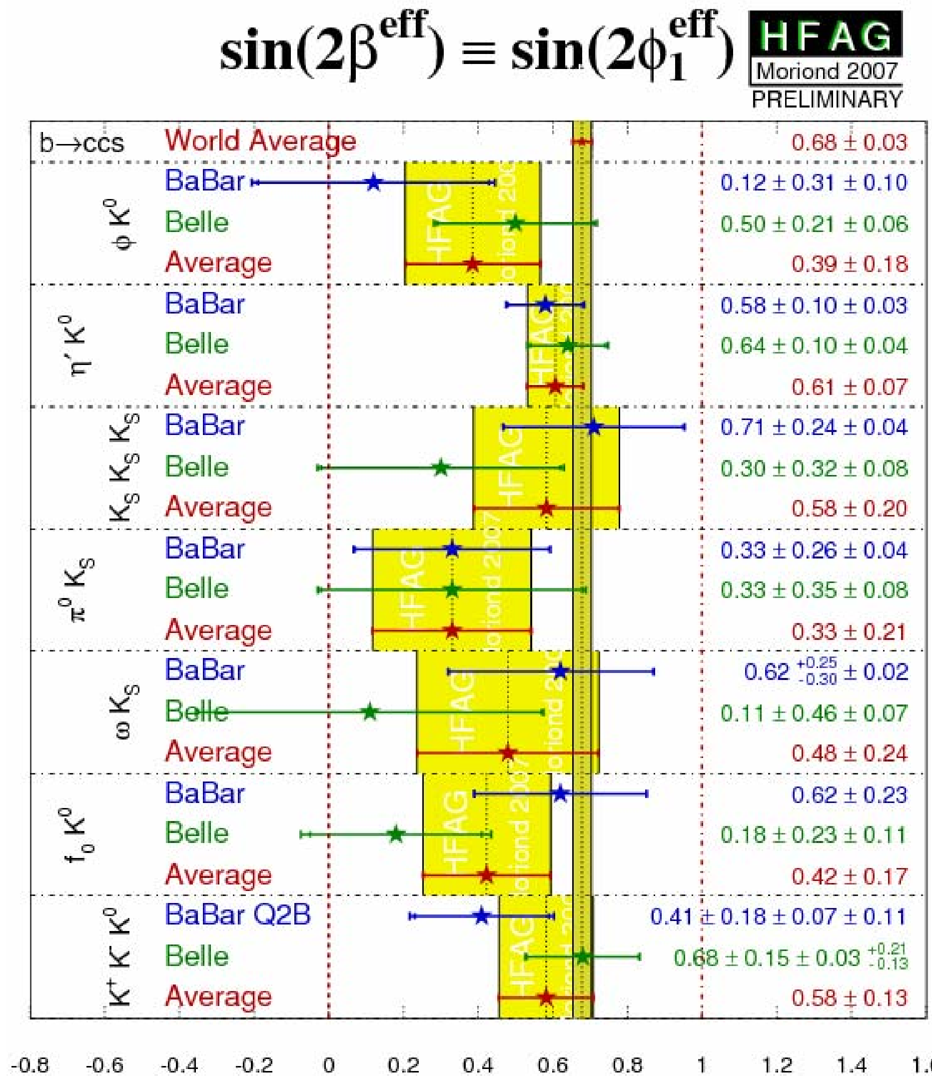
- Different channels have different theoretical uncertainties.

ΔS_f	QCDF	pQCD	SCET
ϕK_S	0.02 ± 0.01	$0.020^{+0.005}_{-0.008}$	
ωK_S	0.13 ± 0.08		
$\rho^0 K_S$	$-0.08^{+0.08}_{-0.12}$		
$\eta' K_S$	0.01 ± 0.01		-0.02 ± 0.01 -0.01 ± 0.01
ηK_S	$0.10^{+0.11}_{-0.07}$		-0.03 ± 0.17 $+0.07 \pm 0.14$
$\pi^0 K_S$	$0.07^{+0.05}_{-0.04}$	$0.06^{+0.02}_{-0.03}$	0.08 ± 0.03
$f_0 K_S$	0.02 ± 0.00		
$a_0 K_S$	0.02 ± 0.01		
$\bar{K}_0^{*0}\pi^0$	$0.00^{+0.03}_{-0.05}$ $0.02^{+0.00}_{-0.02}$		

Chua hep-ph/0605301



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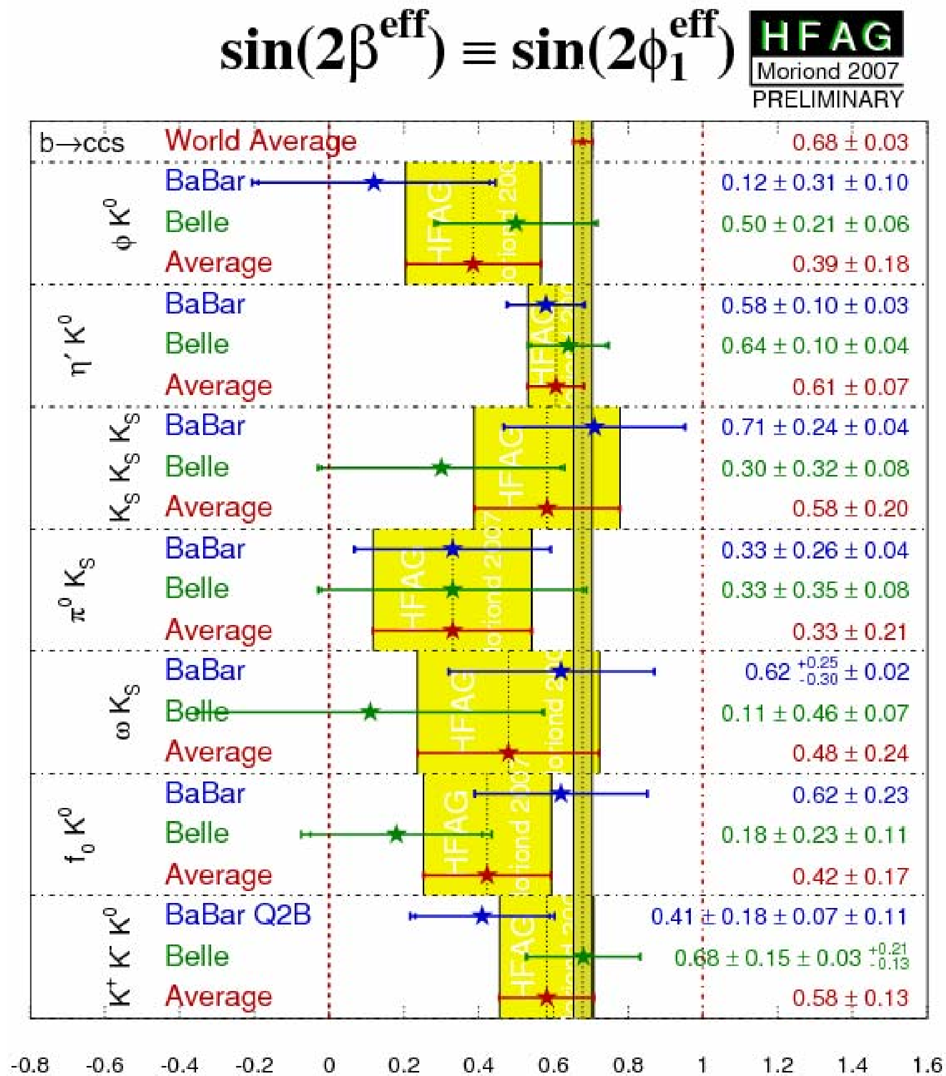
- Need to compare each mode with the tree level value.
  - Can't do this with the current statistics.
  - Need to wait for the next generation machines.



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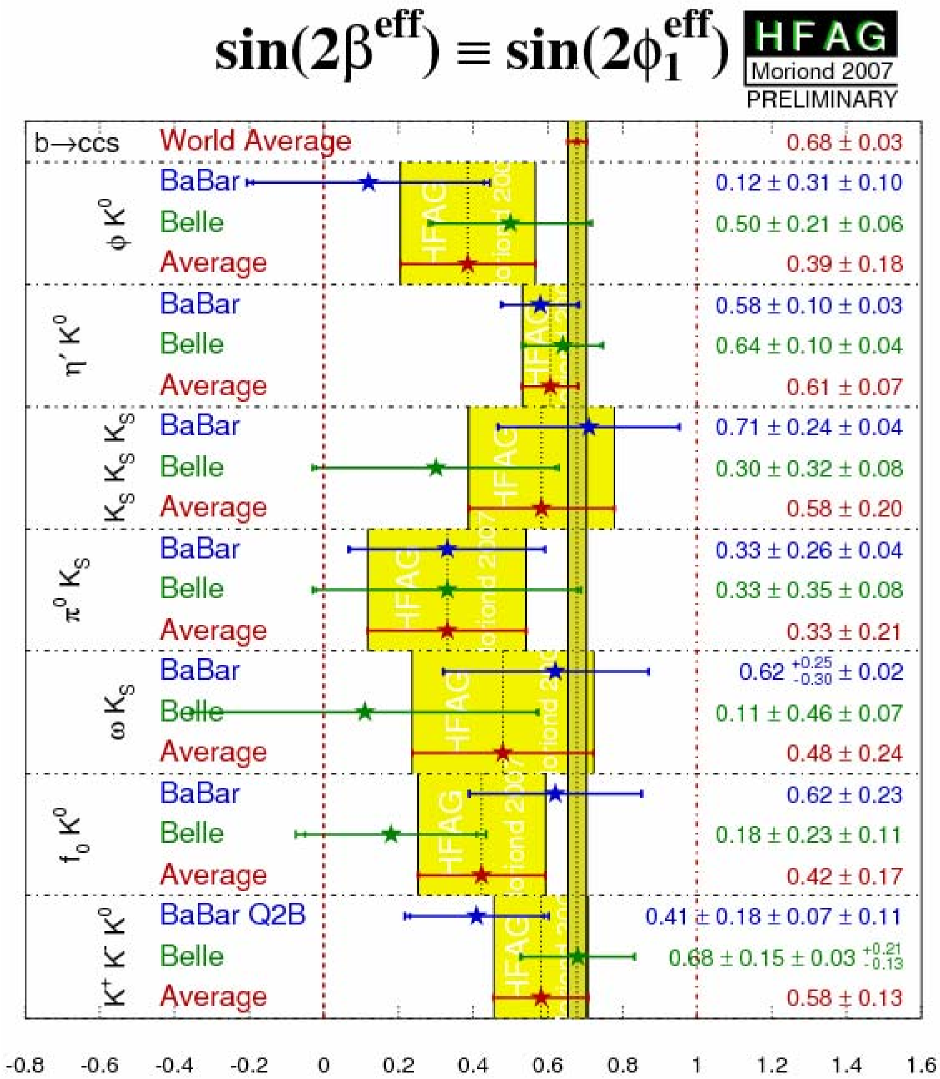
- Different channels have different theoretical uncertainties.
- Need to compare each mode with the tree level value.
  - Can't do this with the current statistics.
  - Need to wait for the next generation machines.
  - LHCb can do $B_d \to \phi K_s$ and B_s equivalent decays.
  - Super LHCb might be re-optimised to do other B_d channels.
  - Super B would compliment the range of measurements that one has from LHCb.



β_s @ the next generation

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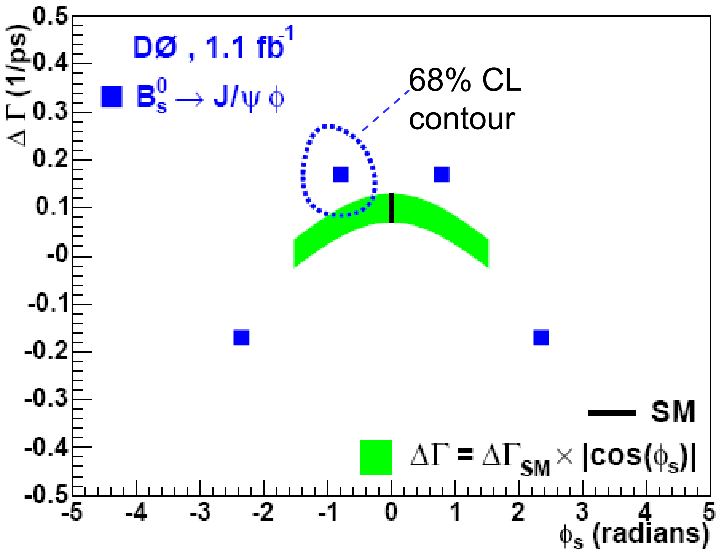
- LHCb + Super LHCb:
  - Improve upon knowledge of β to 0.1°.
  - Open up the study of ϕ_s in B_s decays.
    - 0.003 (10 %) measurement in $B_s \to J/\psi\phi$ decays.
    - 0.014 measurement in $B_s \to \phi\phi$ decays.
    - Search for NP in B_s sector.

} @ 100fb^{-1}

GW LHCb upgrade WS, Jan 07



hep-ex/0701012

- Tevatron starting to constrain ϕ_s

$$\phi_s(D\emptyset) = -0.79 \pm 0.56^{+0.14}_{-0.01}$$

β_s @ the next generation

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    - 0.014 measurement in $B_s \rightarrow \phi\phi$ decays.
    - } @ $100 fb^{-1}$
    - Search for NP in B_s sector.

GW LHCb upgrade WS, Jan 07

- Super B:
  - Comparable β measurement ~0.2°.
  - Complementary measurements of $b \rightarrow s$ decays from B_d.
  - ~3° measurement of β_s from $B_s \rightarrow J/\psi\phi$ with $30 ab^{-1}$ at Y(5S).
    - Use the sign of Δt to measure Re(λ) and Im(λ).

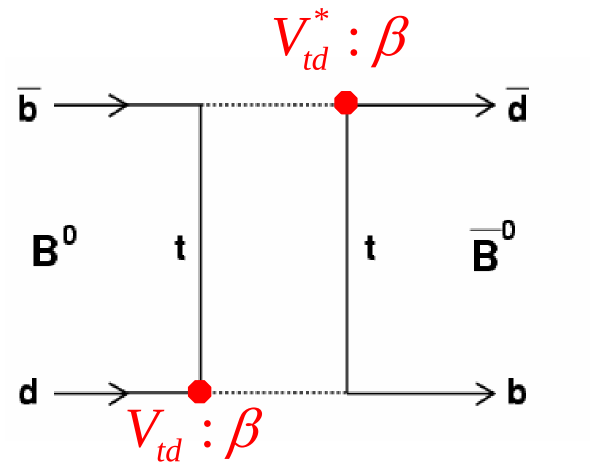
hep-ph/0703258

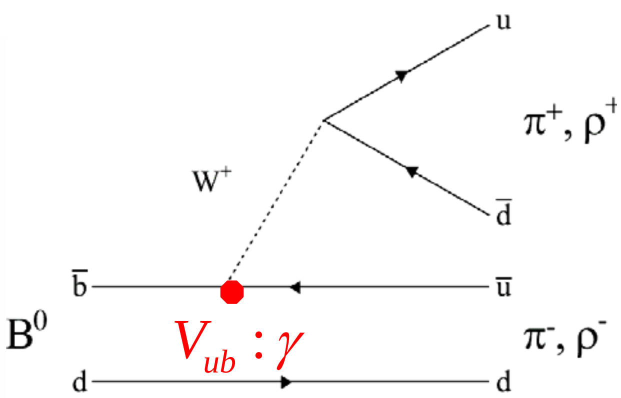
Measuring α

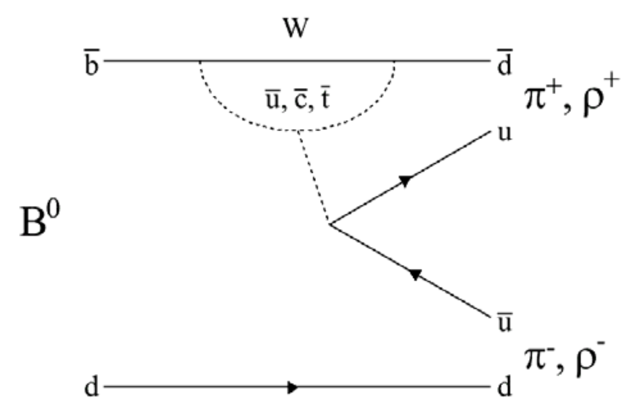
$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- **CP violation in $B^0 \to h^+h^-$, $h=\pi,\rho,a_1$**

+Loops (penguins)







$$C_{hh} = 0$$

$$S_{hh} = \sin(2\alpha)$$

$$C_{hh} \propto \sin(\delta)$$

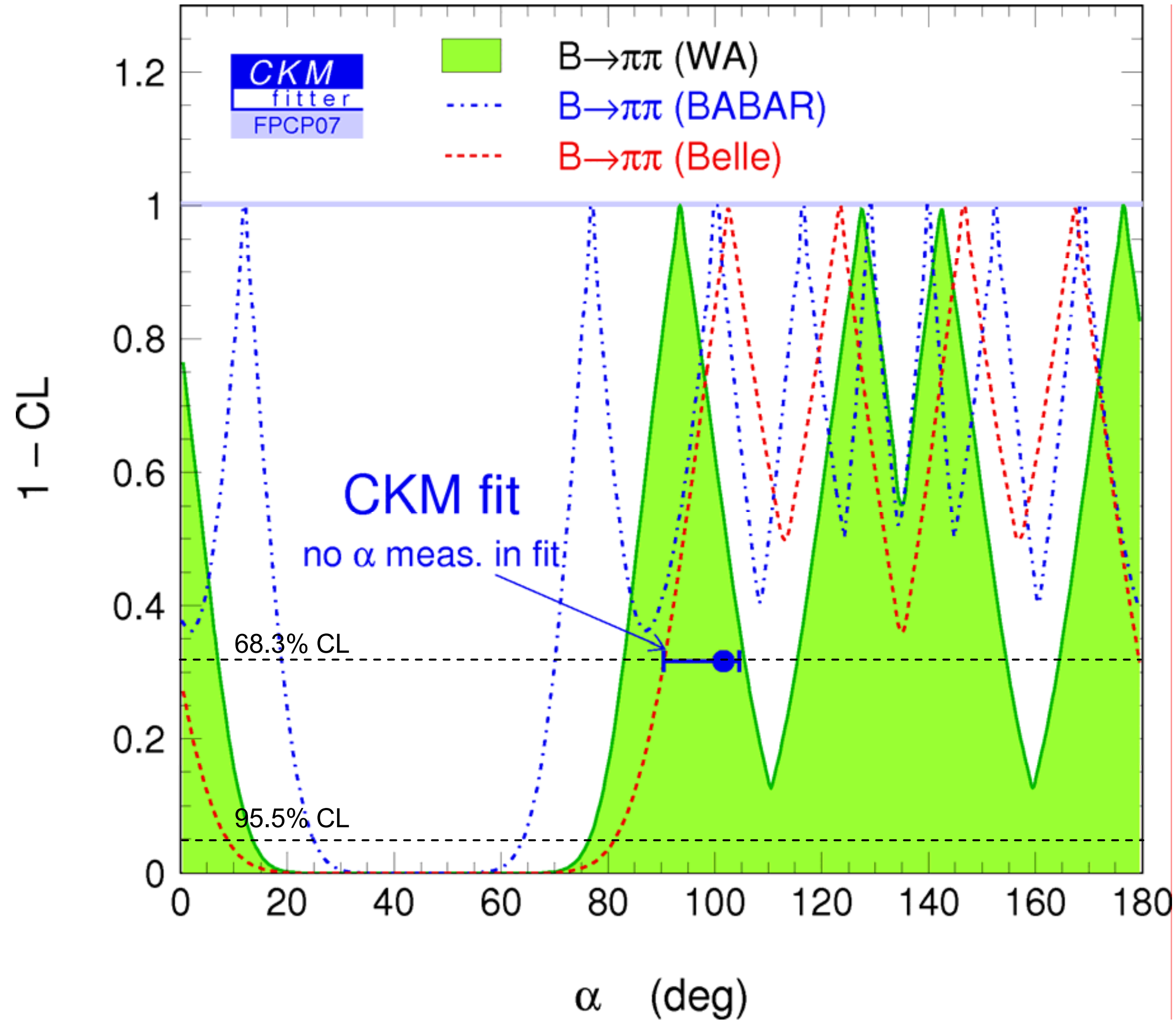
$$S_{hh} = \sqrt{1 - C_{hh}^2}\,\sin(2\alpha_{\text{eff}})$$

$$\delta = \delta_P - \delta_T$$

- Measure α_{eff}.
- Need to bound $|\alpha_{\text{eff}} - \alpha|$ (shift from loops).
- Different |Penguin/Tree| for different decays.
- More complicated for non-CP eigenstates like ρπ.

B→ππ isospin analysis

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

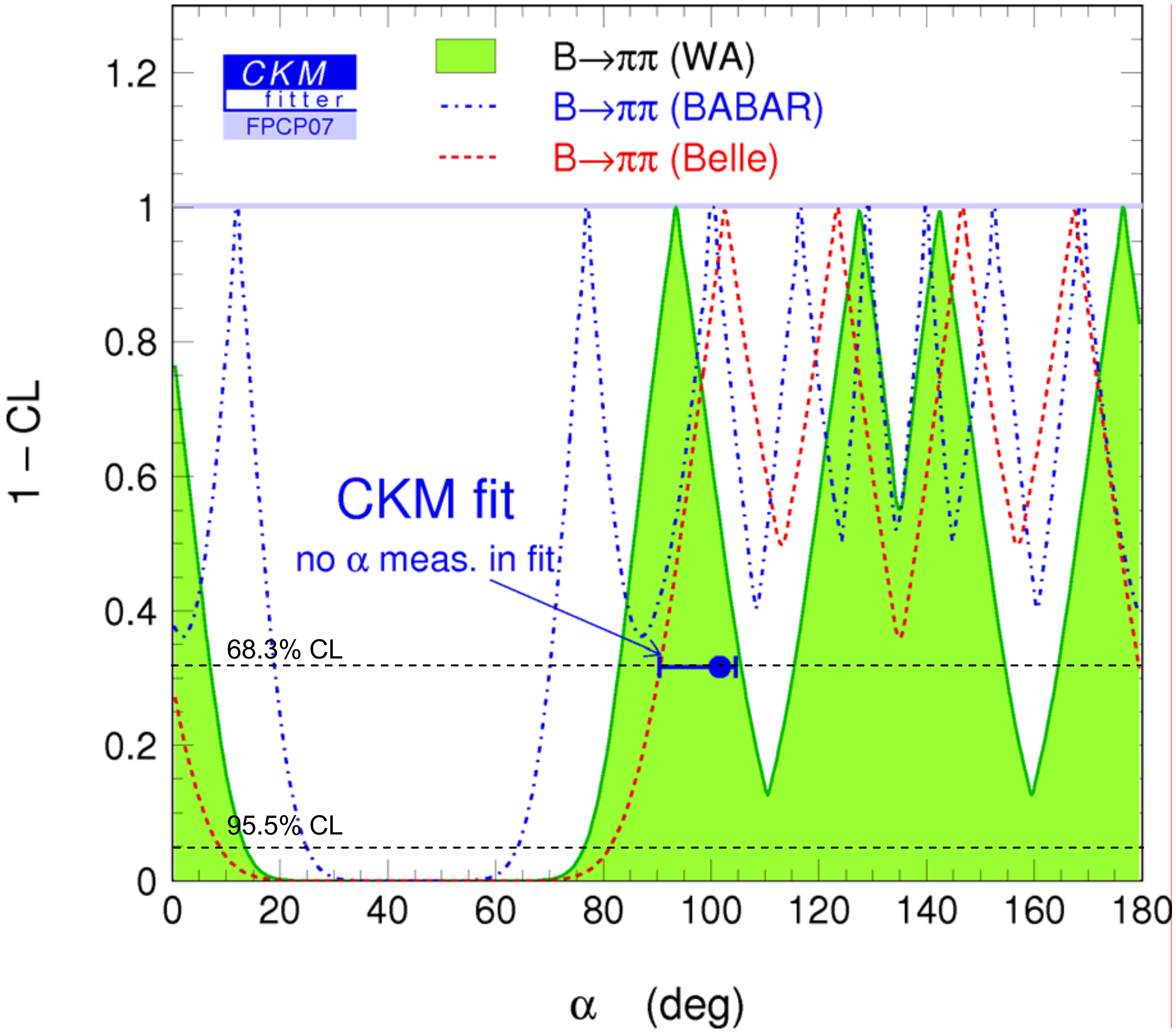


- α~50° excluded.
- Several ambiguities to resolve between solutions.
- Difference between BaBar and Belle constraints on α is driven by the different values of C obtained by each experiment.

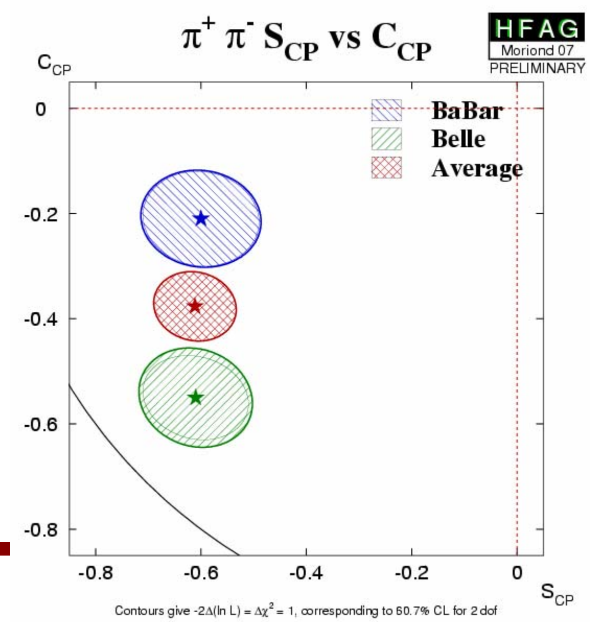
hep-ex/0703016
PRL **98** 211801 (2007)

B→ππ isospin analysis

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

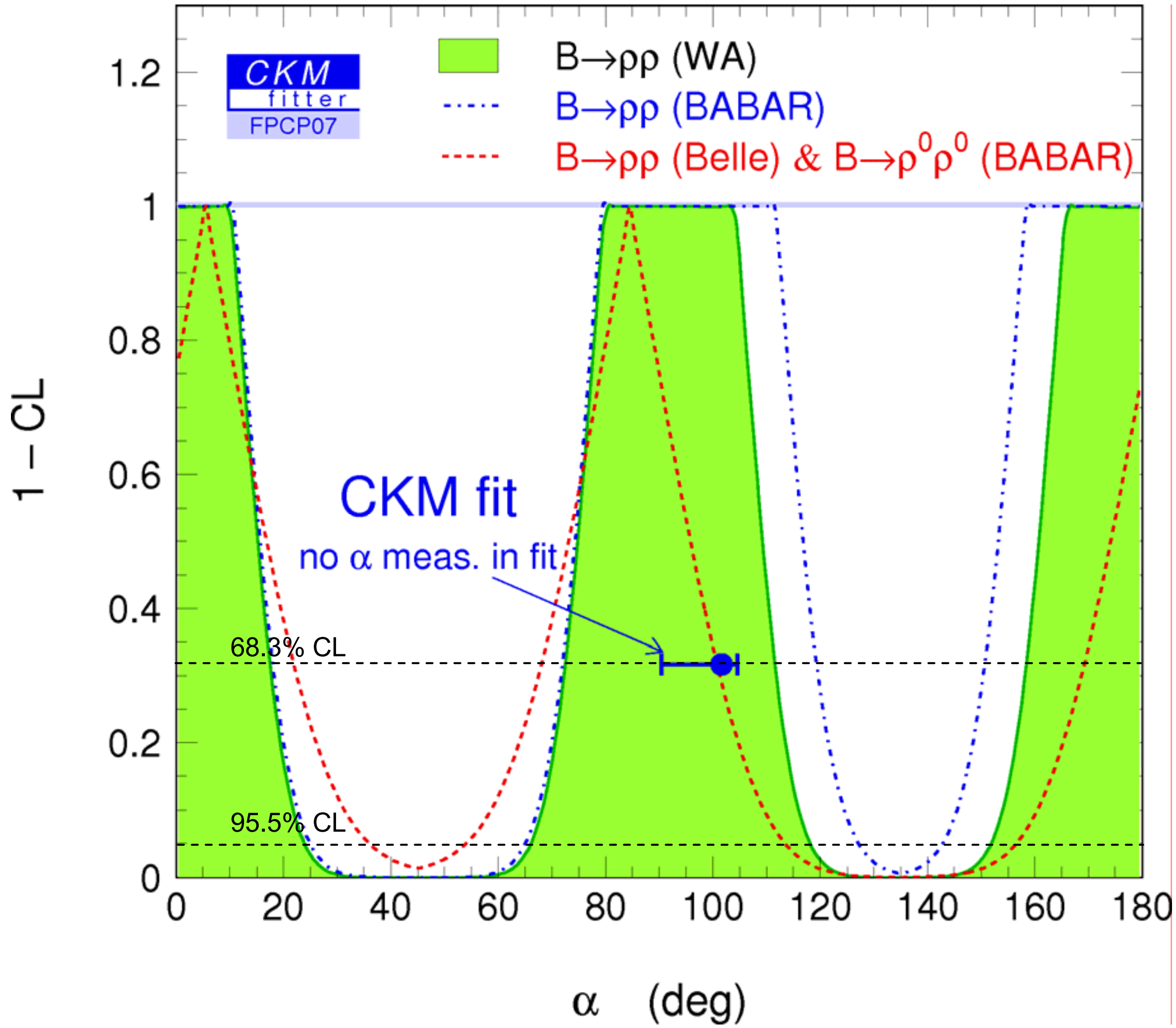


- α~50° excluded.
- Several ambiguities to resolve between solutions.
- Difference between BaBar and Belle constraints on α is driven by the different values of C obtained by each experiment.



B→ρρ isospin analysis

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

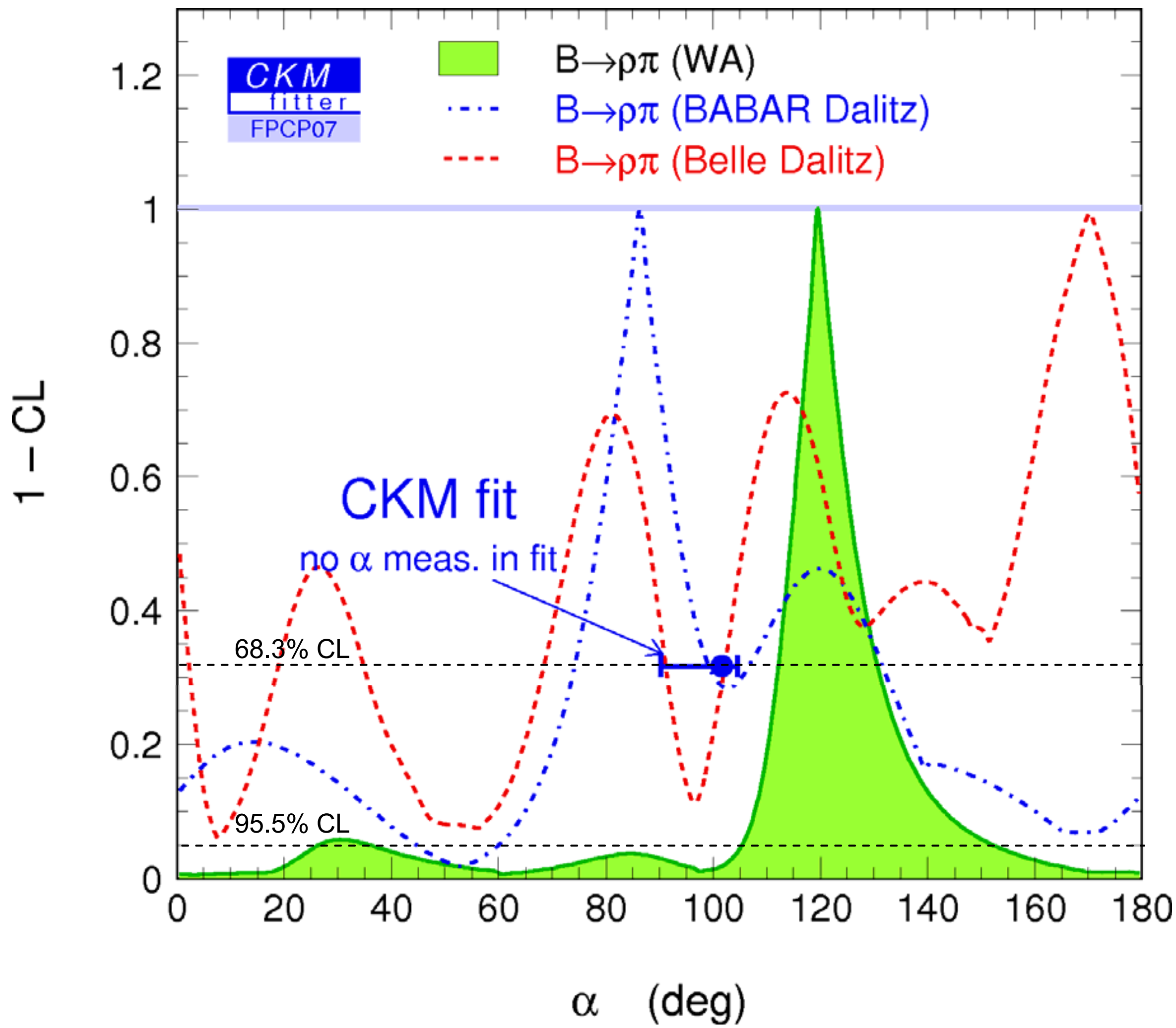


- α~50°, 130° excluded.
- Several ambiguities to resolve between solutions.
- Difference between BaBar and Belle constraints on α is driven by the different values of C obtained by each experiment.

arXiv:0705.2157
hep-ex/0702009

B→ρπ Dalitz analysis

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

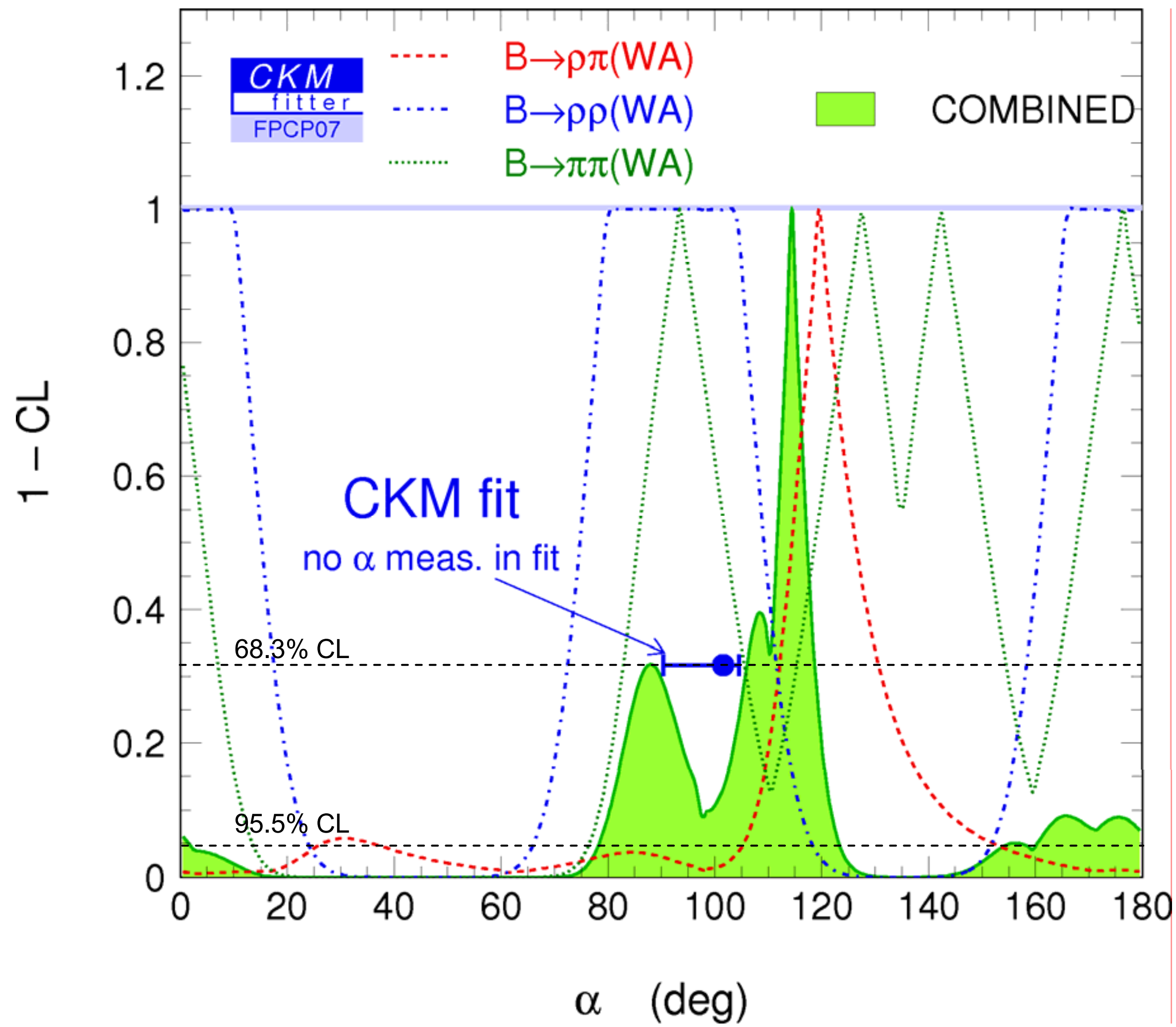


- Constraint on α is weak at the 3σ level.
- Several ambiguities to resolve between solutions.
- Difference between BaBar and Belle constraints on α is driven by statistical fluctuations between the two samples.

hep-ex/0703008
PRL **98** 221602 (2007)

Overall

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



- α~50°, 130° excluded.
- Ambiguities to resolve between solutions.
- Combining different measurements gives us a measurement of α compatible with the Standard Model at almost 2σ.
- Need more statistics to
  - Rule out incompatibilities.
  - Compare the value of α measured with individual channels.

α @ The next generation

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

- LHCb
  - $\sigma(\alpha)$ from $\rho\pi$ will be 4.5° with $10fb^{-1}$.
  - SU(3) methods can be used with $\pi^+\pi^-/K\pi$ to obtain α/γ.
  - S and C measurements from $\rho^0\rho^0$ will help a lot.
  - $a_1\pi$ the jury is still out on how useful these modes will be.
- Super LHCb
  - Upgrade to accumulate $100fb^{-1}$ σ~1.4° from $\pi^+\pi^-\pi^0$.
- SuperB
  - $75ab^{-1}$ accumulated at the Υ(4S).
    - $\sigma(\alpha)$ ~ 0.75° using $\rho\rho$ decays
    - $\sigma(\alpha)$ ~ 1-2° using $\pi\pi$ decays
    - See AB at the 5th Super B Workshop in Paris ***http://events.lal.in2p3.fr/conferences/SuperBFactory/index.html*** for more details.

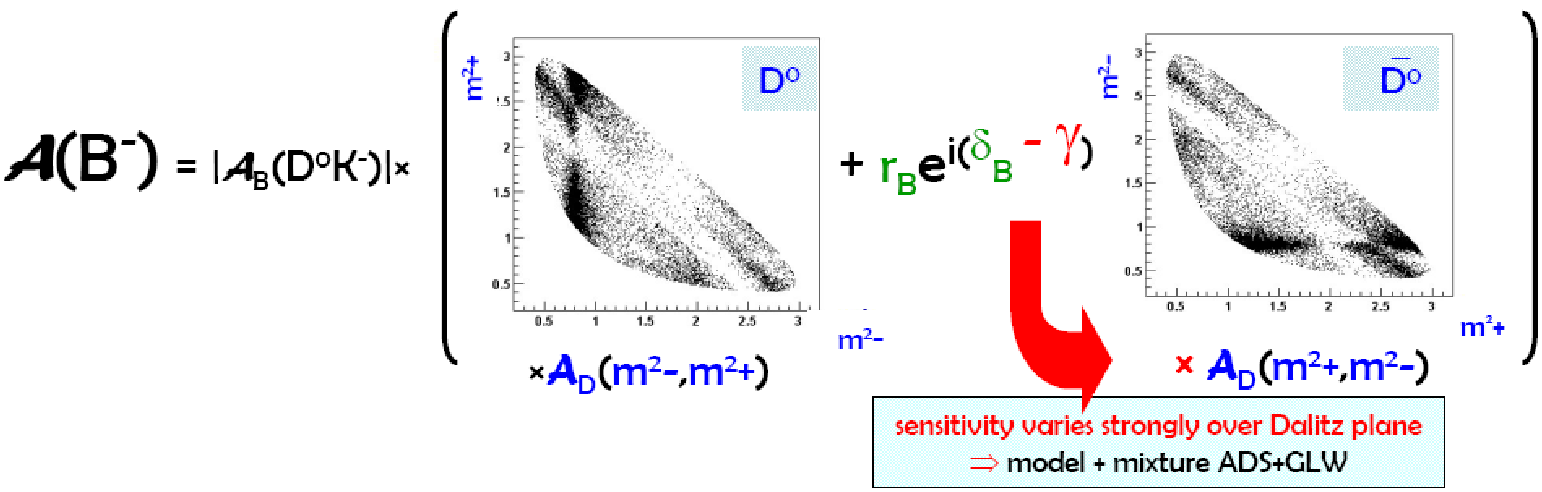
Measuring γ

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

- Gives an over-constraint of the triangle.
- Least well known of UT angles.
- Need LHCb to give a precision measurement.
- γ: safety in numbers.
  - No single channel will dominate precision.
    - γ: $B \to DK$ etc.,
    - $2\beta+\gamma$: $D^*\pi$ etc.
  - Need to average many methods to obtain ultimate precision.
  - Use $\pi\pi/K\pi$ or $\rho\rho/K^*\rho$ with SU(3) as cross-check.

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

- GGSZ:
  - Structure of Dalitz plot gives access to γ, r_B, δ_B.
  - $D^0 \to K_s \pi^+ \pi^-$ final state is accessible through many different decays.



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

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

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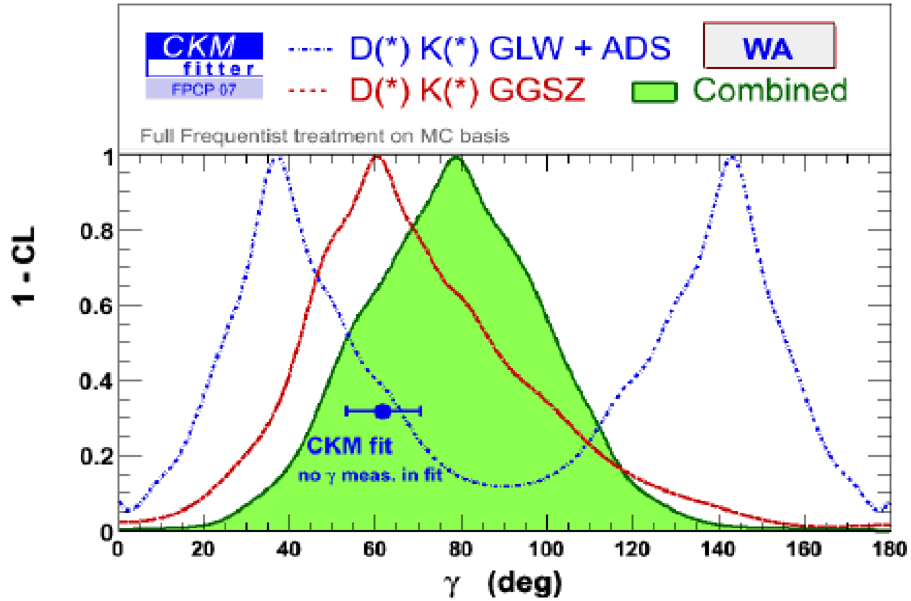


$\phi_3/\gamma = (77 \pm 31)^\circ$

CKM-Fitter@1σ: [52.8,70.1]°

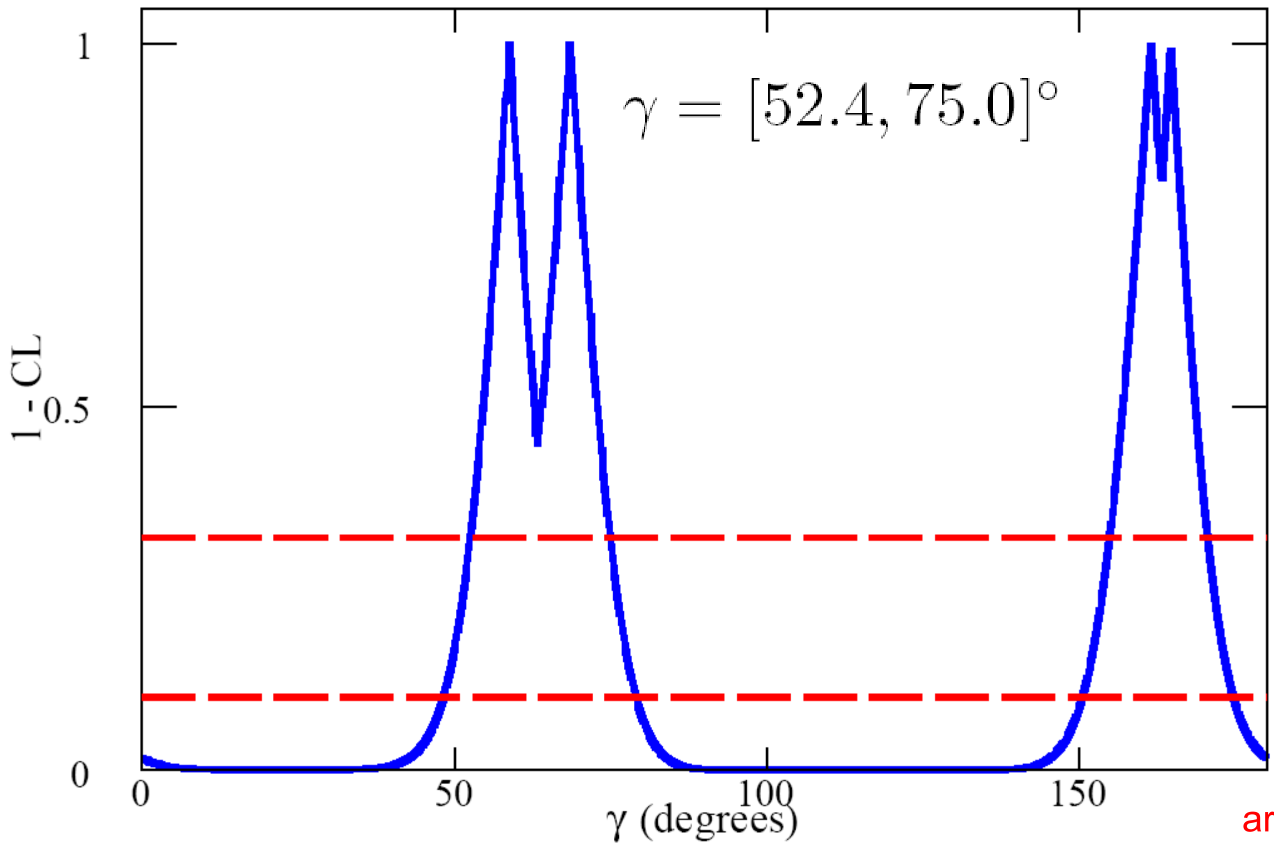
$r_B(DK)<0.13$, $r_B(D^*K)<0.13$, $r_B(DK^*)<0.27$ @ 90% C.L.

$B \rightarrow \rho\rho$ SU(3) analysis

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

- Relate $K^{*0}\rho^+$ to the penguin amplitude in $\rho^+\rho^-$ and use $S_{\rho+\rho-}$ and $C_{\rho+\rho-}$ to constrain γ.

$$\mathcal{A}(B^0 \rightarrow \rho^+\rho^-) = Te^{i\gamma} + Pe^{i\delta_{TP}}$$



- Introduce theory uncertainty of a few degrees.
- Reduced experimental uncertainty on penguin contamination.
- Uses β from charmonium to extract γ.
- With small δ,

$$\gamma = (68.5^{+6.4}_{-7.0})^\circ$$

arXiv:0705.2157
Beneke et al., PLB **638** p68 (2006)

B→ππ SU(3) analysis

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

- The analogous method to constrain γ using ππ decays uses B→Kπ to contain the penguin.

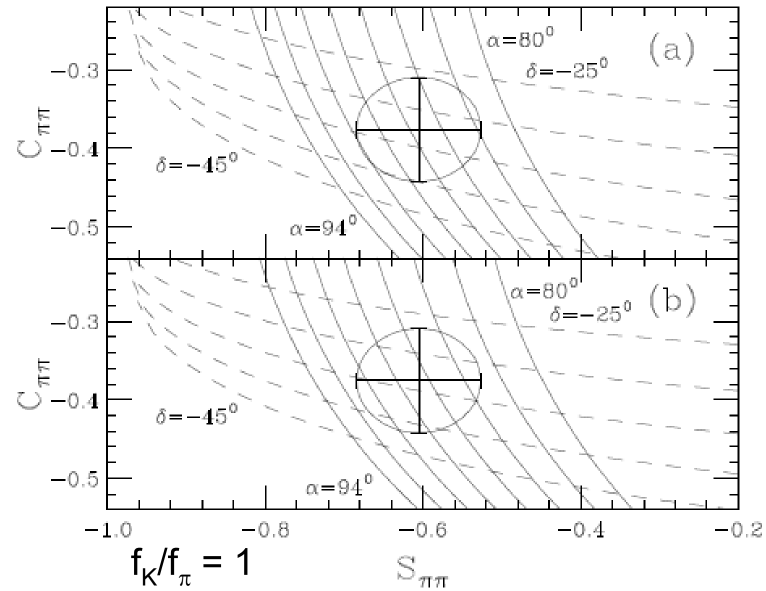
$$A(B^0 \to \pi^+\pi^-) = Te^{i\gamma} + Pe^{i\delta}$$

$$C_{\pi\pi} = \frac{2r\sin\delta\sin(\beta+\alpha)}{R_{\pi\pi}},$$

$$S_{\pi\pi} = \frac{\sin 2\alpha + 2r\cos\delta\sin(\beta-\alpha) - r^2\sin 2\beta}{R_{\pi\pi}},$$

$$R_{\pi\pi} \equiv 1 - 2r\cos\delta\cos(\beta+\alpha) + r^2,$$

- Can relate C and S to values of γ, r and δ
  - N.B. β is input from ccs decays, so the only angle left to determine is γ in this convention.
- Uncertainties are larger than ρρ case, but this provides a good cross-check.



$f_K/f_\pi = 1$

$$\gamma = (74 \pm 4^{+10}_{-8})^\circ$$

Gronau & Rosner arXiv:0704.3459

γ @ The next generation

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

- The difficulty in measuring γ comes from the small value of r_B.
  - Need larger data sets to do precision measurements.
  - Need to combine many channels to reach the ultimate precision.

γ @ The next generation

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

γ from $B^0 \to DK^{*0}$, $B^\pm \to DK^\pm$ & $B_s^0 \to D_s^\mp K^\pm$

LHCb

- **LHCb goals for measuring CKM angle γ**
  - $B^0 \to D^0K^{*0}$, $B^\pm \to D^0K^\pm$
    Two interfering tree processes in neutral or charged B decay
  - Use decays common to D^0 and anti-D^0
    Cabbibo favoured self-conjugate D decays
    e.g. $D^0 \to K_S\pi\pi$, K_SKK, $KK\pi\pi$ Dalitz analysis
    Cabbibo favoured, single & doubly Cabbibo suppressed D decays
    e.g. $D^0 \to K\pi$, KK, $K\pi\pi\pi$ ADS (GLW) method
  - $B_s \to D_s^\mp K^\pm$ - two tree decays ($b \to c$ and $b \to u$) of $O(\lambda^3)$
    Interference via B_s mixing
- **γ Sensitivity**
  - Expected precision for ADS and Dalitz $\sigma(\gamma) \sim 5° -15°$ in 2 fb^{-1}
- **Motivation for LHCb Upgrade**
  - Theoretical error in SM is very small < 1°
  - Large statistics helps to reduce systematic error to similar level
  - With 100 fb^{-1} estimate precision $\sigma(\gamma) \sim 1°$
  - Requires **1st level detached vertex trigger** for hadronic decays

Beauty 2006 | Oxford, 29 Sept 2006 | F. Muheim | 13

c.f. Super B precision ~1-2 ° @75ab^{-1}

Looking for new physics: summary

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

- β
  - Standard model (tree level) reference point from $c\bar{c}s$ decays.
  - Many crosschecks that are loop dominated, or have loop contributions. These can be used for NP searches.
  - β_s measurements – B_s decay equivalents.
- α
  - 3 comparable measurements: cross-checks.
  - … more if SU(3) based approaches are used.
- γ
  - Several channels to compare and combine. $2\beta+\gamma$ measurements provide useful constraints on the $\bar{\rho}$-$\bar{\eta}$ plane.
- These angle measurements over-constrain the triangle.
  - Inconsistencies can indicate NP.

Outline of the next 45 minutes

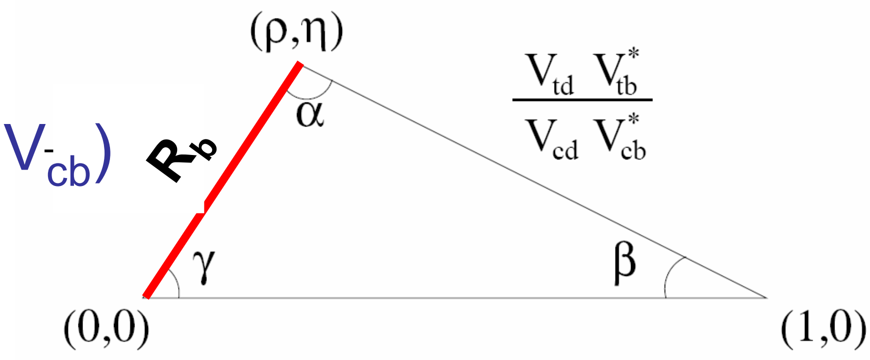
$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- Motivation.
- Angles:
  - Standard Model viewpoint of β, α, γ.
  - Looking for New Physics contributions.
- Sides:
  - R_b.
  - R_t.
- Combination of results.
- Unexplored territory.
- Conclusions.

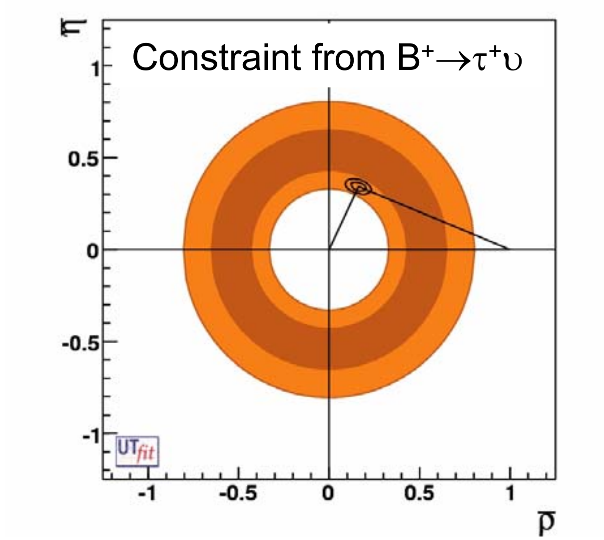
R_b

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

- Compliment the angles.
  - Semileptonic decays (V_{ub}, V_{cb}) using $X_{u/c} l \nu$.
  - Rare decays $B^+ \to l^+ \nu$
  - … + ε_K, $K \to \pi \nu \bar{\nu}$ tell us about R_b and R_t. *[G. Isidori tomorrow]*



- Any Inconsistencies with other constraints indicate new physics.
- Alternatively search for new physics using $\tau^+ \upsilon$, $\mathcal{B}$, A_{CP} in $b \to s\gamma$.

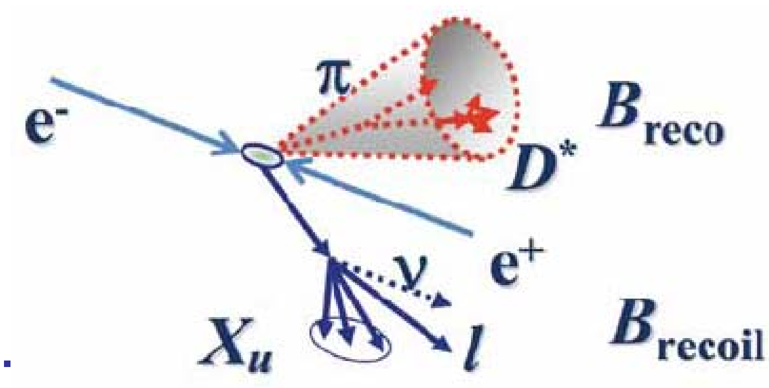


V_{ub}

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

- $|V_{ub}|^2 \propto \mathcal{B}(B \rightarrow X_u l \nu)$ in a limited region of phase space.

- Reconstruct other B in the event & $X_u l \nu$ signal using the other B + beam information to *reconstruct* ν.

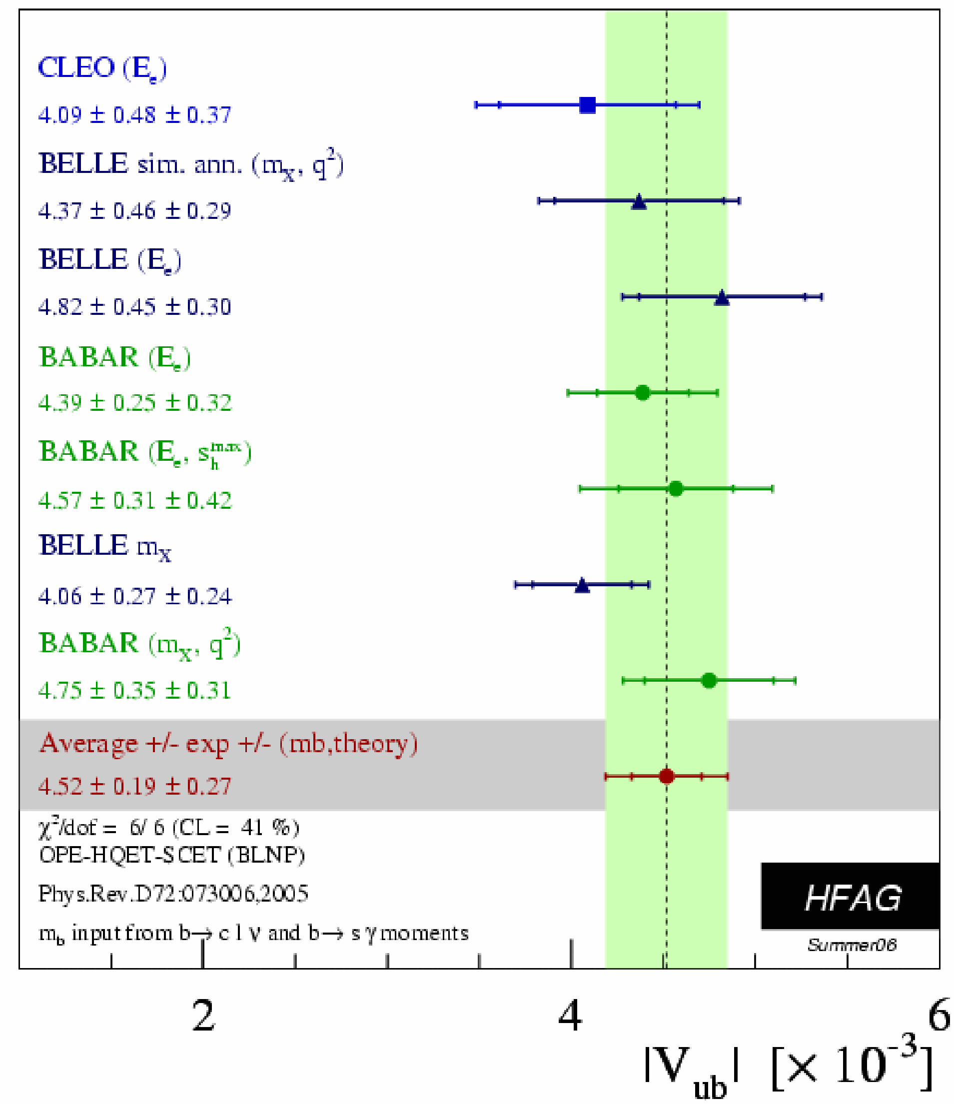


- Measure $\mathcal{B}$ as a function of q^2 ($l\nu$), m_X or lepton energy.

- Need theory to interpret result in terms of $|V_{ub}|$.
  - Several models on the market: BLNP, BLL, DGE.
  - Significant theoretical uncertainty on average.

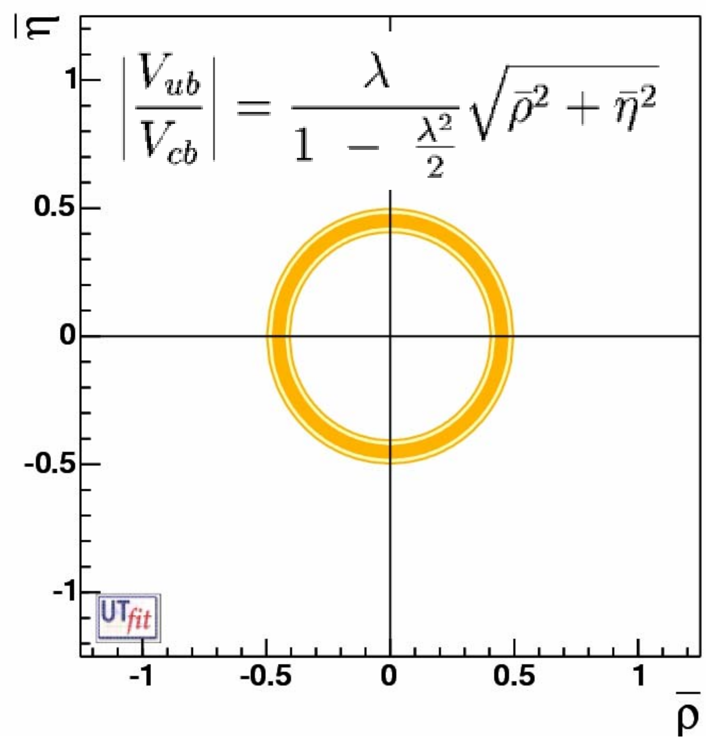
Inclusive V_{ub} : $b \to u l \nu$

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



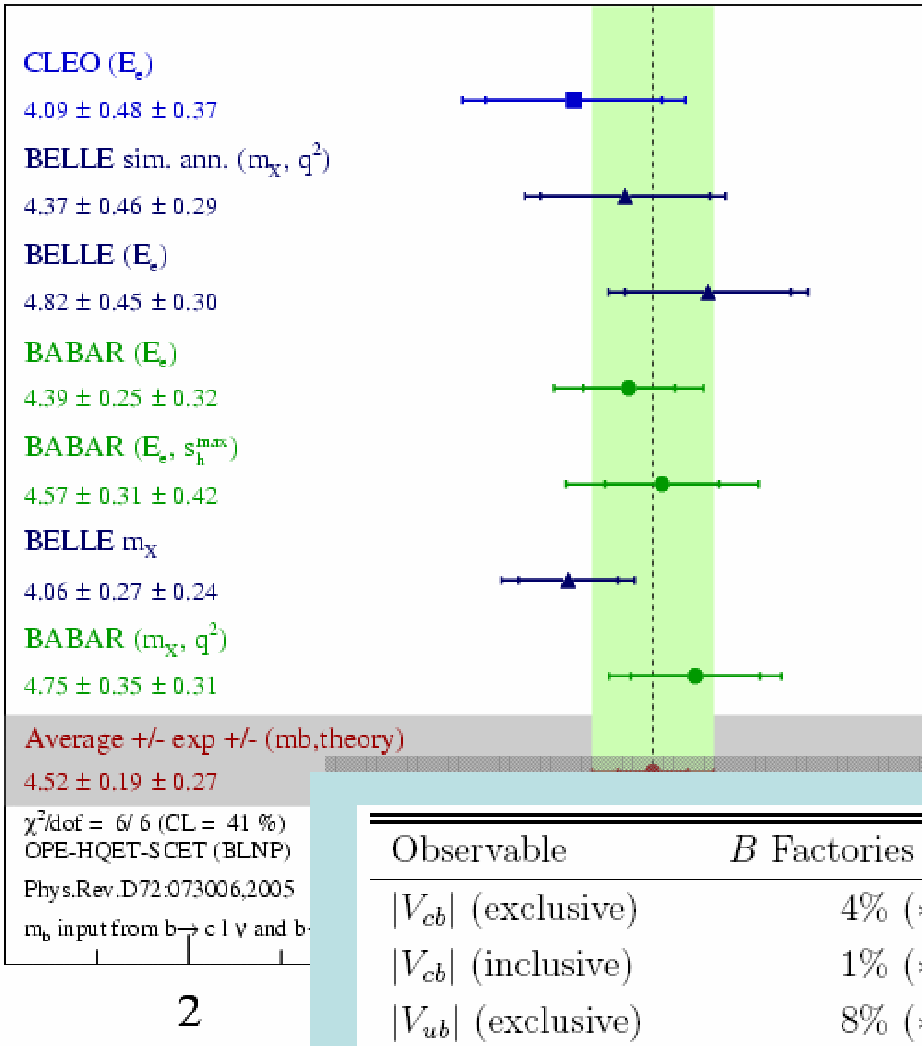
- Take BLNP as an example scheme.

$$|V_{ub}|_{incl} = (4.52 \pm 0.19 \pm 0.27) \times 10^{-3}$$



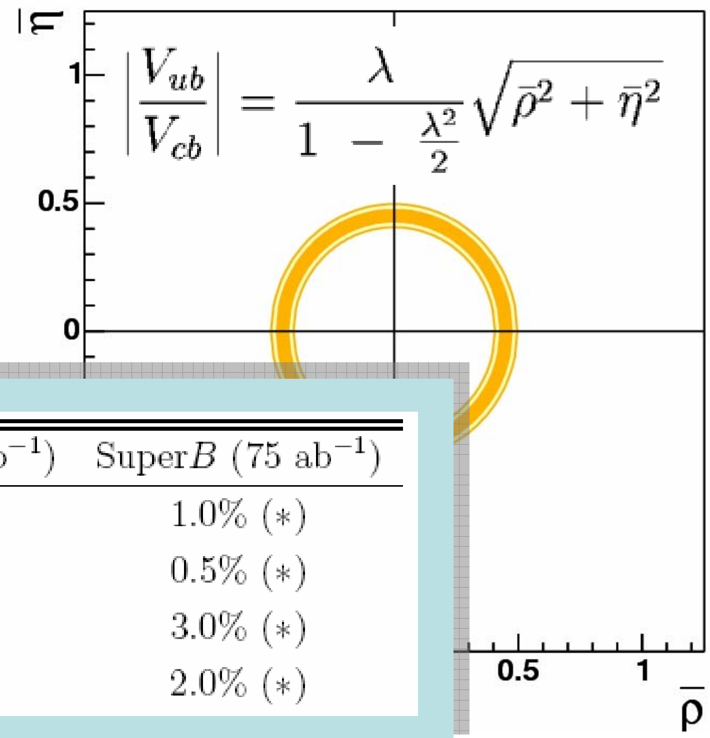
Inclusive V_{ub} : $b \to u l \nu$

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



- Take BLNP as an example scheme.

$|V_{ub}|_{incl} = (4.52 \pm 0.19 \pm 0.27) \times 10^{-3}$

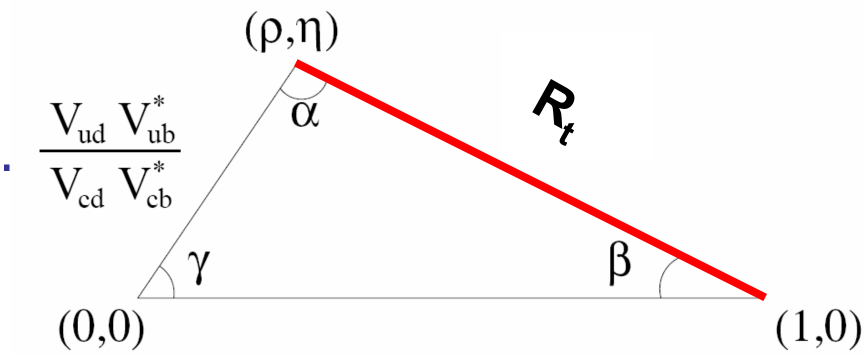


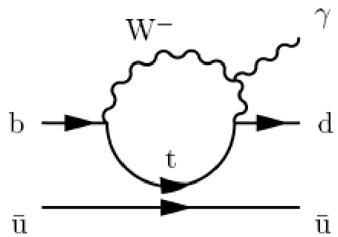
Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\lvert V_{cb}\rvert$ (exclusive)	4% (∗)	1.0% (∗)
$\lvert V_{cb}\rvert$ (inclusive)	1% (∗)	0.5% (∗)
$\lvert V_{ub}\rvert$ (exclusive)	8% (∗)	3.0% (∗)
$\lvert V_{ub}\rvert$ (inclusive)	8% (∗)	2.0% (∗)

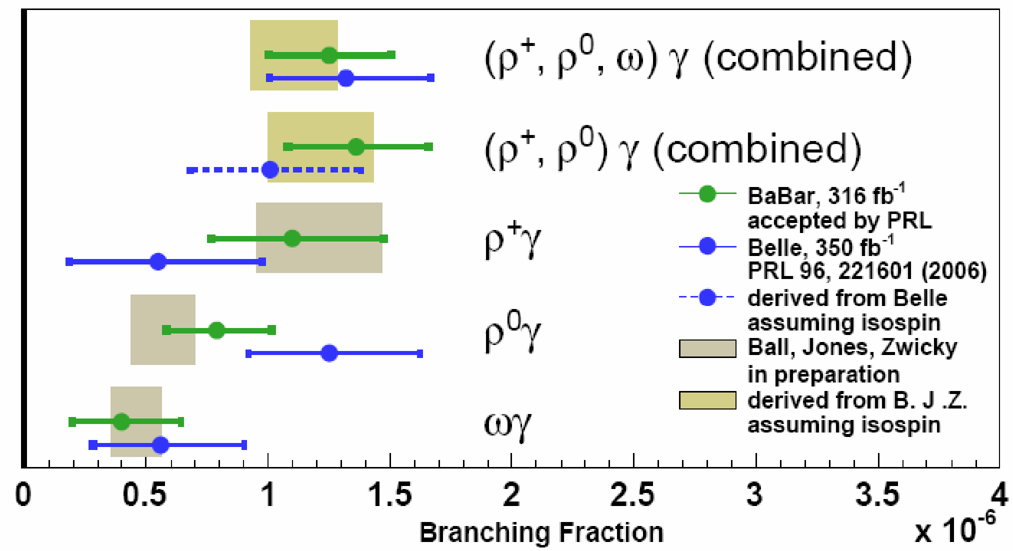
R_t

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

- Compliment the angles.
  - $b \to d\gamma / s\gamma$ to extract $|V_{td}/V_{ts}|$.







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

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

$O(0)$ — $(1+\Delta R)$

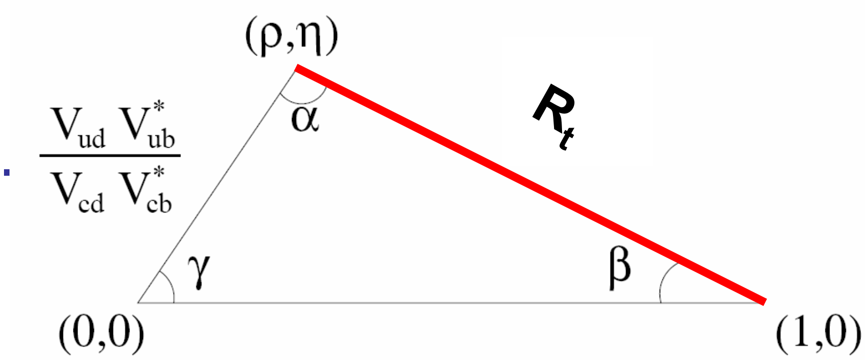
$O(1)$ — $\left(\frac{T^\rho(0)}{T^{K^*}(0)}\right)^2$

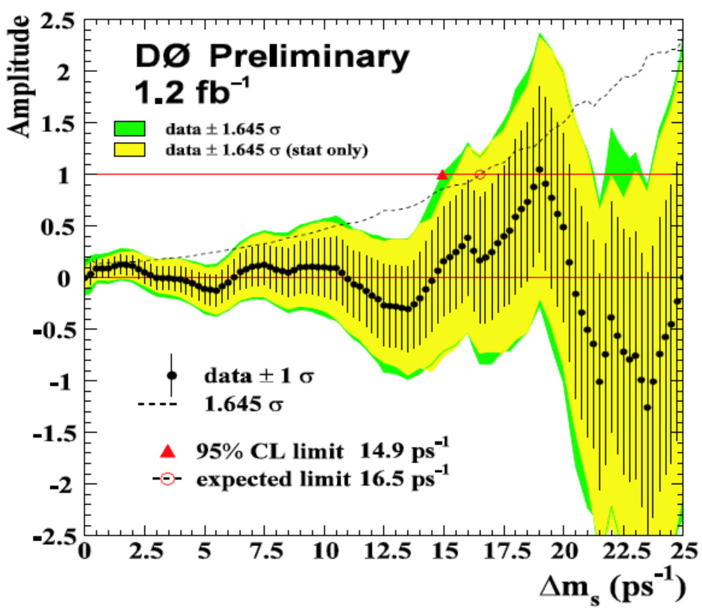
hep-ex/0612017
PRL 96 221601 (2006)

Aart Heijboer @ Moriond EW,
D0: PRL **97** 061802 (2006)
CDF: PRL **97** 242003 (2006)

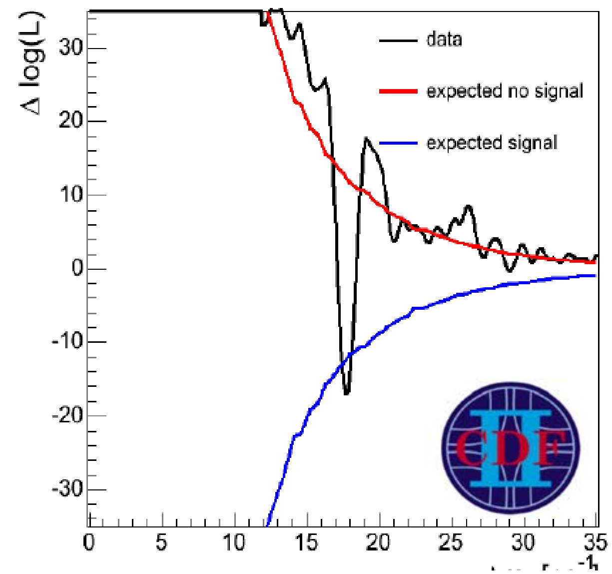
R_t

- Compliment the angles.
  - $b \to d\gamma / s\gamma$ to extract $|V_{td}/V_{ts}|$.
  - Δm_s from the Tevatron.





90% CL limit $17 < \Delta m_s < 21$ ps^{-1}



$$\Delta m_s = 17.77 \pm 0.10(\text{stat}) \pm 0.07(\text{syst})$$

$$\frac{|V_{td}|}{|V_{ts}|} = 0.2060 \pm 0.0007(\text{exp}) \,^{+0.0081}_{-0.0060}(\text{theo})$$

- LHCb will do a precision measurement of Δm_s

Impact on ρ-η

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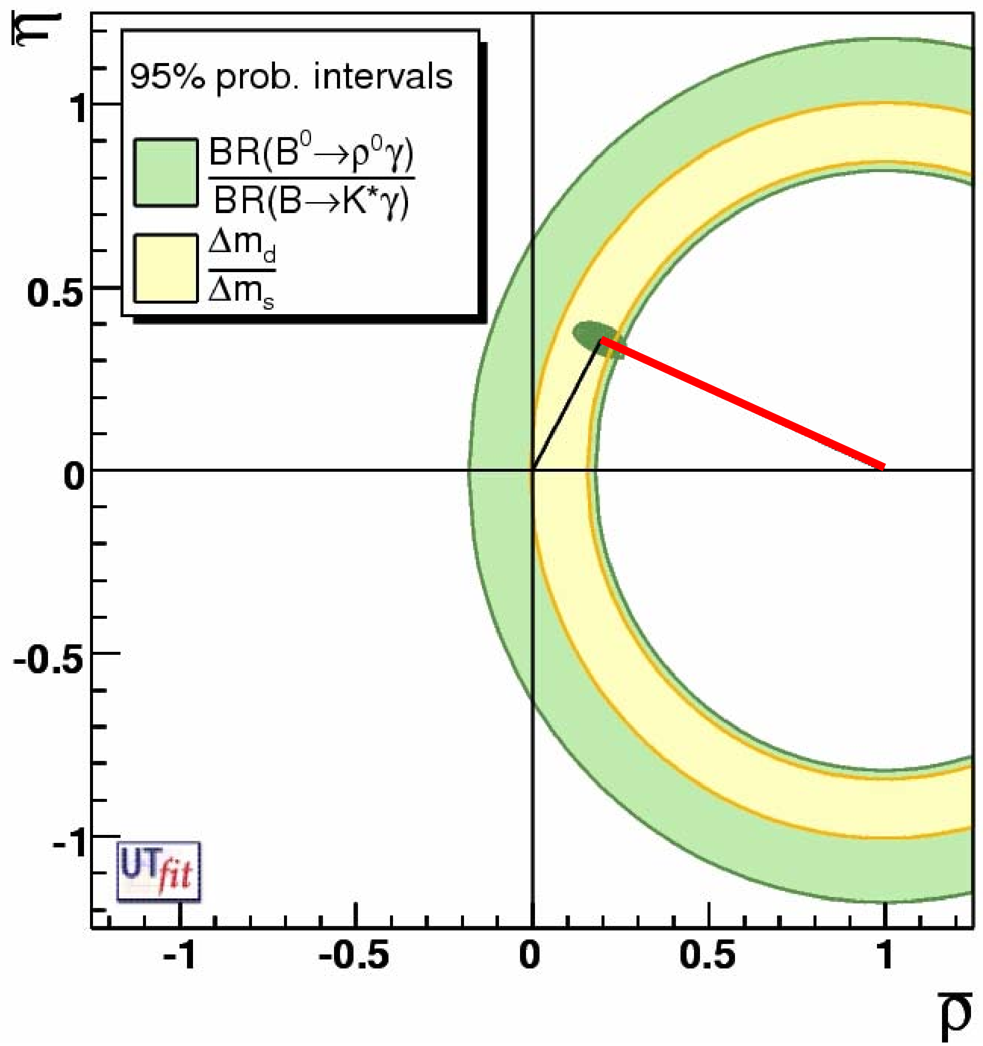


Outline of the next 45 minutes

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

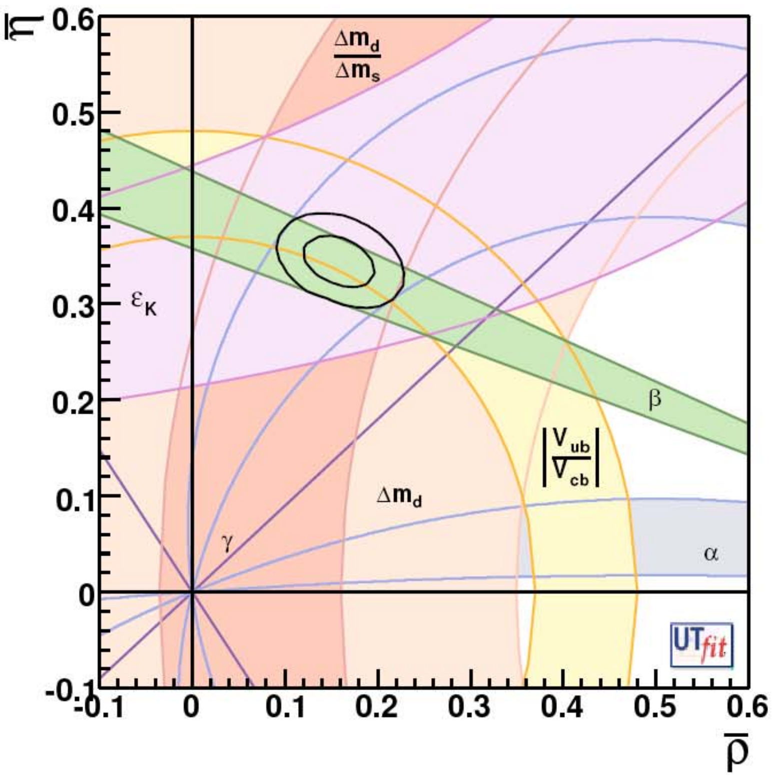
- Motivation.
- Angles:
  - Standard Model viewpoint of β, α, γ.
  - Looking for New Physics contributions.
- Sides:
  - R_b.
  - R_t.
- **Combination of results.**
- Unexplored territory.
- Conclusions.

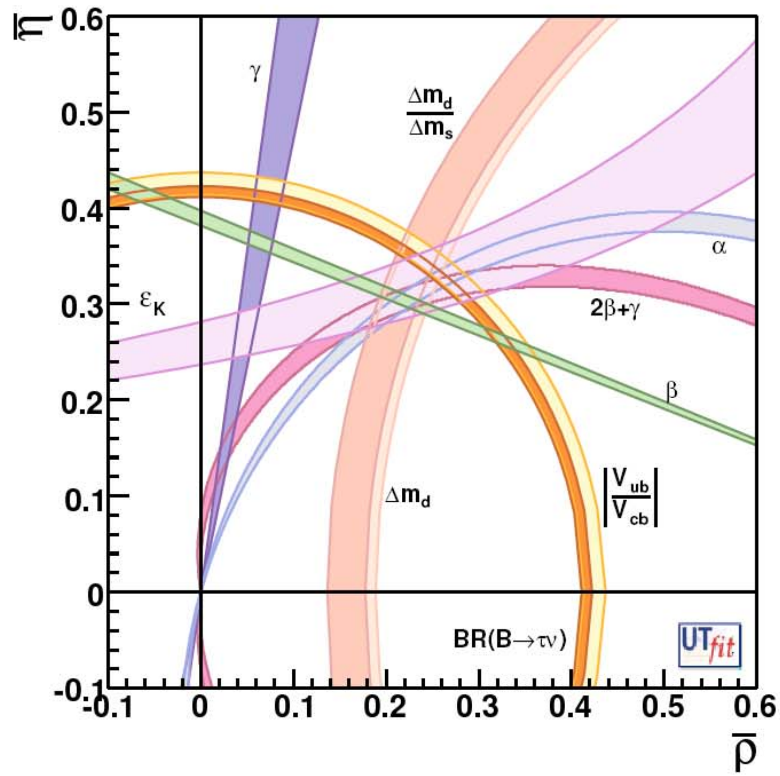
Combination of results.

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

- *[See talk by M. Bona in this session]*

Current Precision with all constraints.





Extrapolating existing measurements to Super LHCb / super-B luminosity.

Outline of the next 45 minutes

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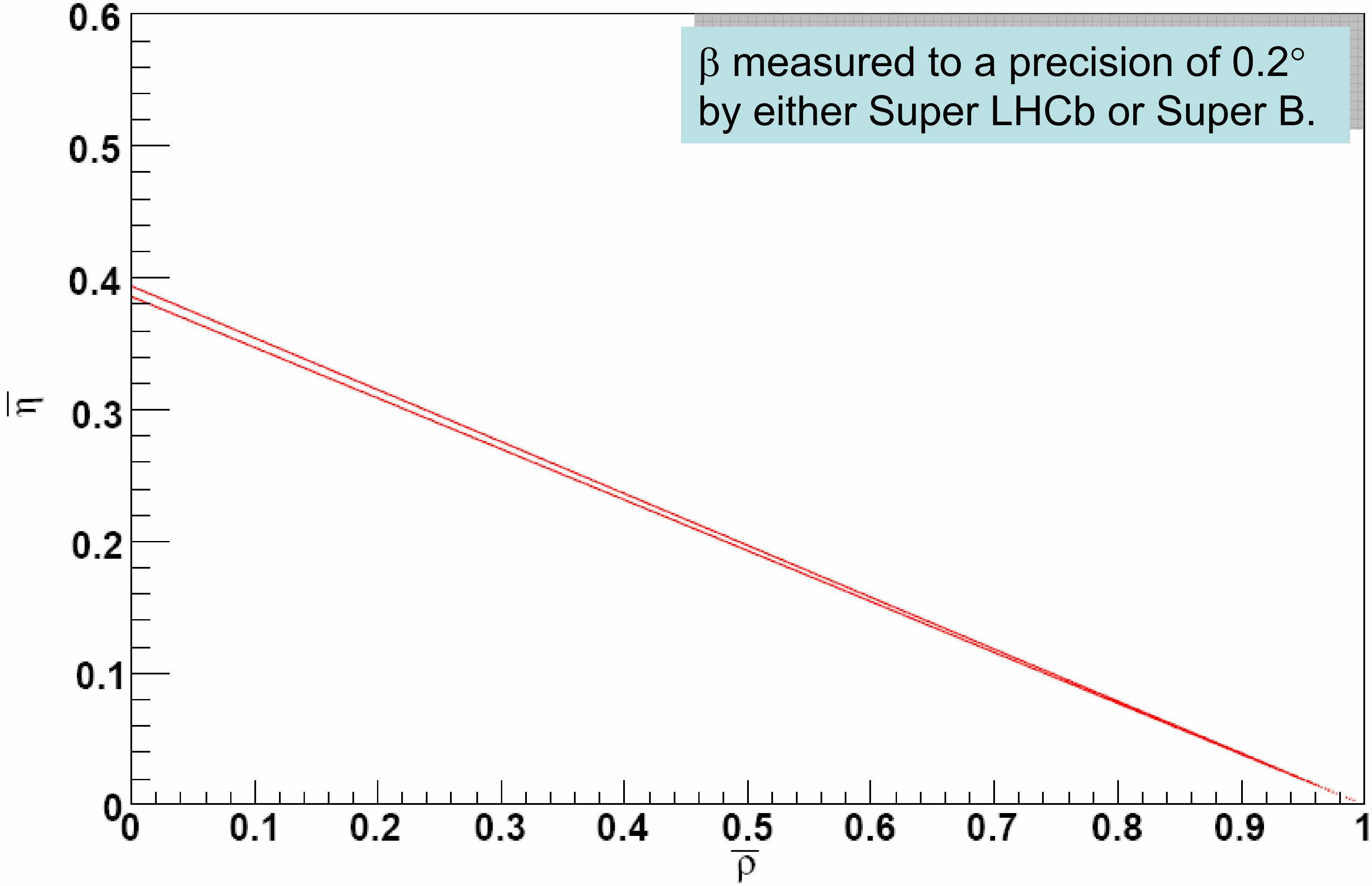
Prediction for 2020?

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



Prediction for 2020?

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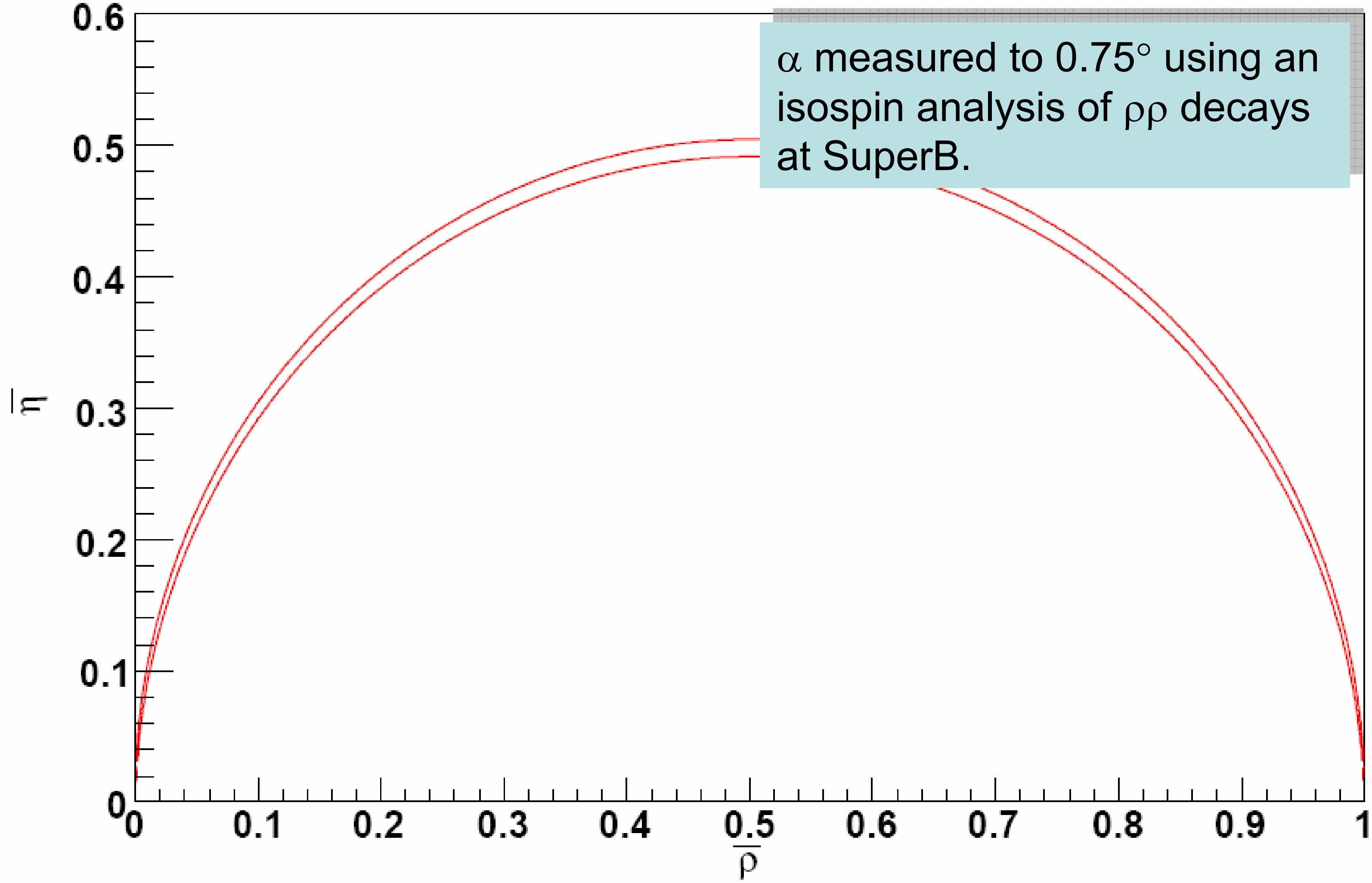

Prediction for 2020?

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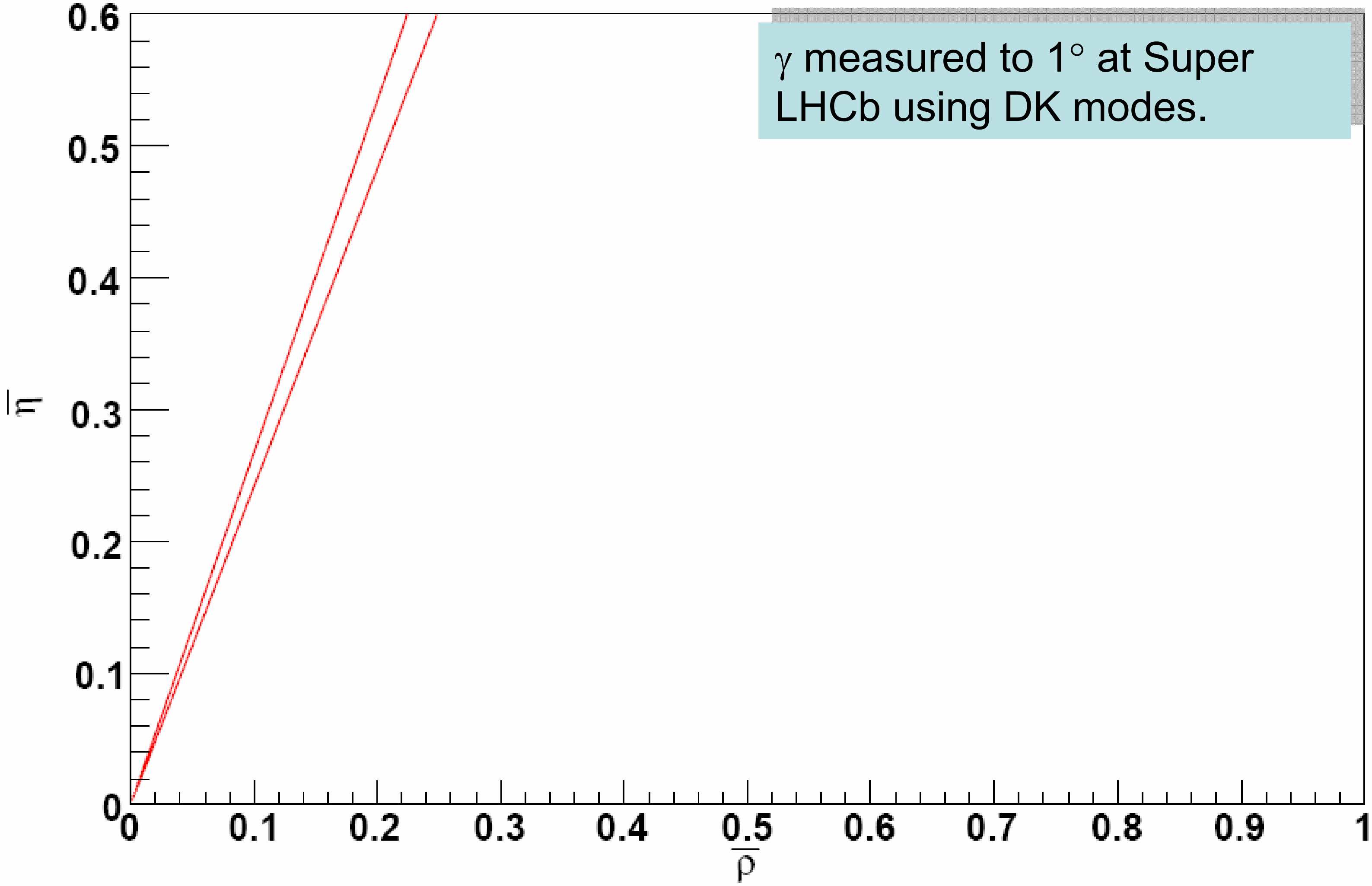

Prediction for 2020?

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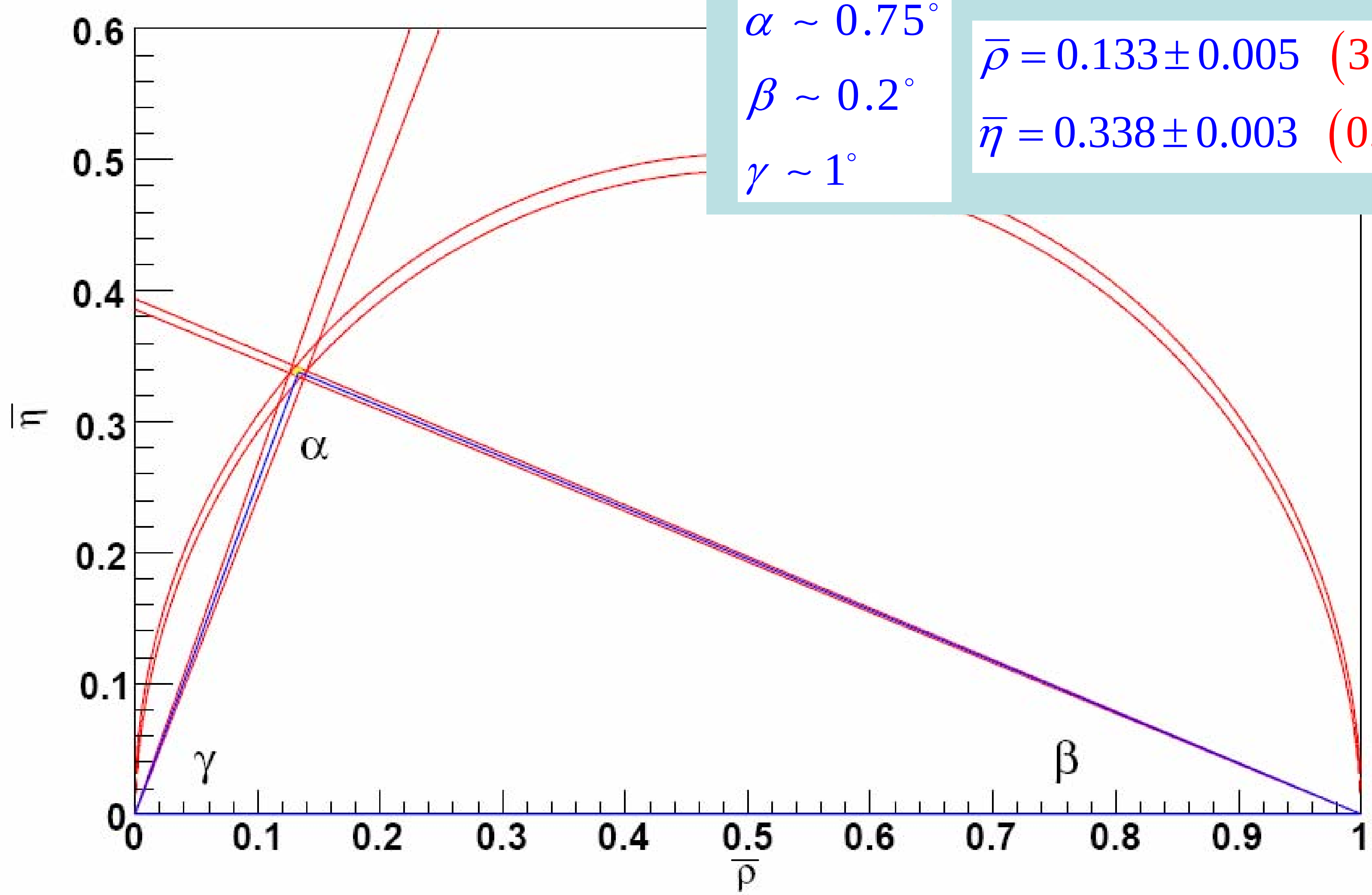


$\alpha \sim 0.75^\circ$

$\beta \sim 0.2^\circ$

$\gamma \sim 1^\circ$

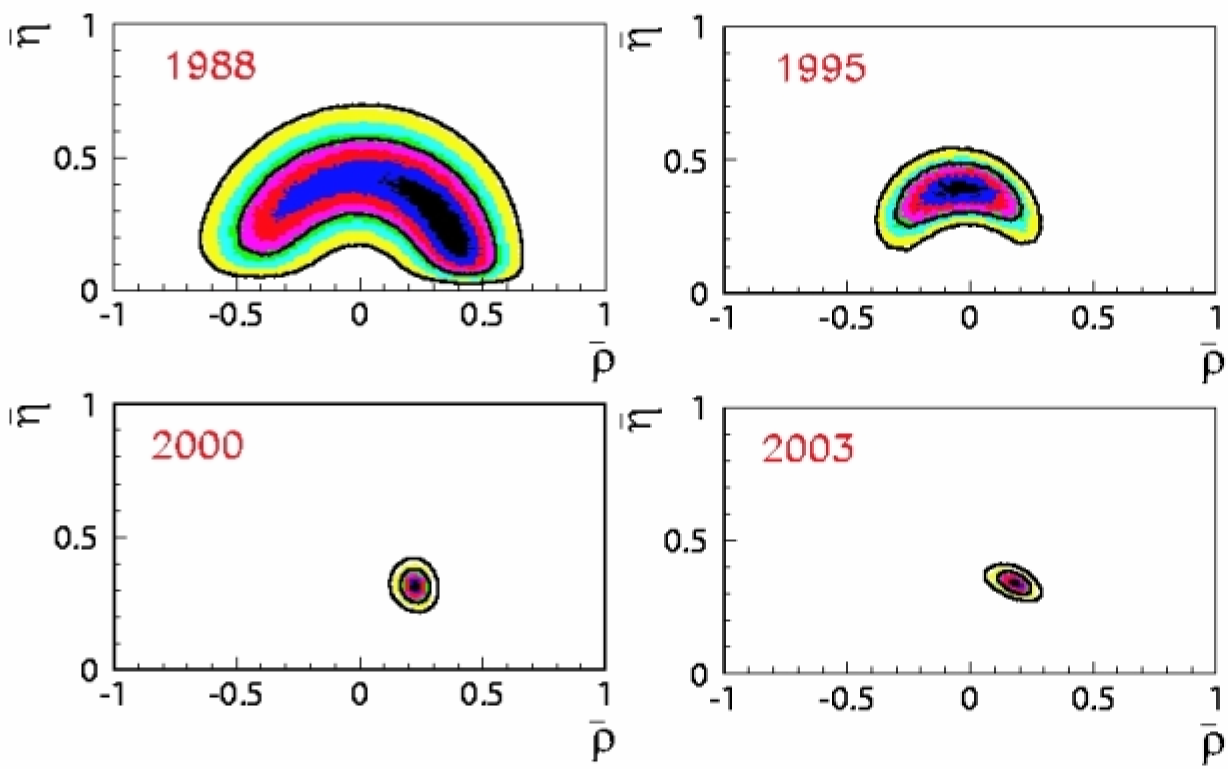
$\bar{\rho} = 0.133 \pm 0.005 \quad (3.8\%)$

$\bar{\eta} = 0.338 \pm 0.003 \quad (0.9\%)$

Past evolution

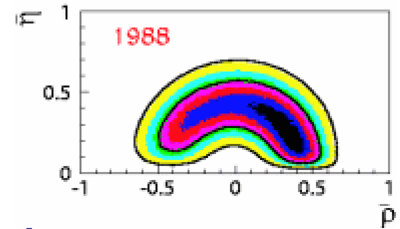
$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- UT fit's evolution of the measurement of the unitarity triangle:
  - All available information from indirect and direct constraints.

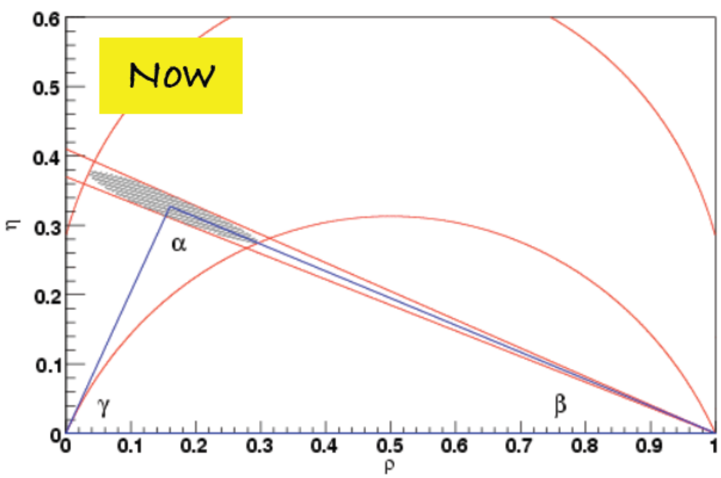


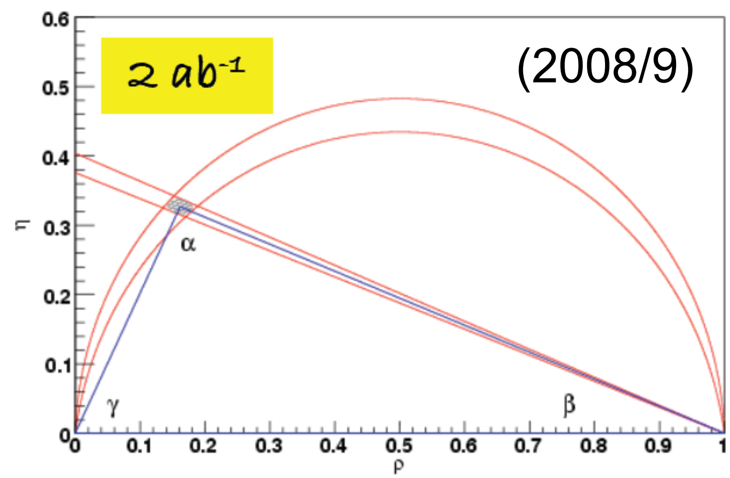
The next 13 years?

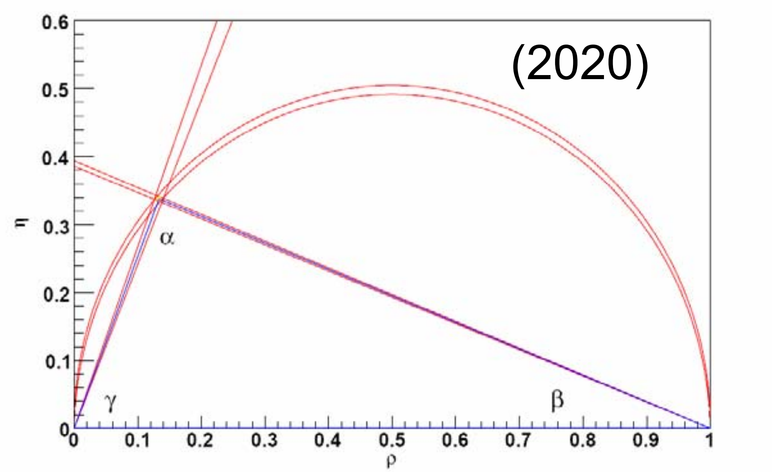
$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



- My prediction of the evolution of the measurement of the unitarity triangle:
  - Using only α (ρρ isospin) and β measurements.







Unexplored territory

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

- Go back and look at the BaBar physics book…
  - You won't correctly identify the best methods to measure α and γ (and a number of other observables).
  - With data in hand, the current B-factories have appreciated how to do the job better than was thought 10-15 years ago. *History usually repeats itself…*
  - Having two collaborations helped keep up the momentum and exchange of ideas.
  - We're just beginning to study B_s in detail at the Tevatron.
  - We can look forward to results from LHCb complementing the existing measurements (2008?).
  - Hopefully we will also see Super B augmenting the flavour programme (2015?).

Outline of the next 45 minutes

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

- Motivation.
- Angles:
  - Standard Model viewpoint of β, α, γ.
  - Looking for New Physics contributions.
- Sides:
  - V_{ub}.
  - V_{td}.
- Combination of results.
- Undiscovered territory.
- Conclusions.

Conclusions

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

- Using 1ab^{-1} of data from the B-factories have established:
  - CP Violation in B decays (indirect and direct).
  - 7° test of the closure of the unitarity triangle.
  - Observe some tension at the 1.5σ level between constraints.
  - Seen evidence for D mixing.
  - *… and done a lot of other things in the meantime.*
- The B-factories will push ahead to collect up to 2ab^{-1}.
- The next generations of experiment will take up the challenge soon:
  - LHC(b): Initial impact in γ and B_s+ lots of other physics. *[See J. Libby on Friday]* *http://lhcb.web.cern.ch/lhcb/*
  - SuperB: Same program as BaBar and Belle + B_S etc. *[See T. Gershon on Friday]* *http://www.pi.infn.it/SuperB/*

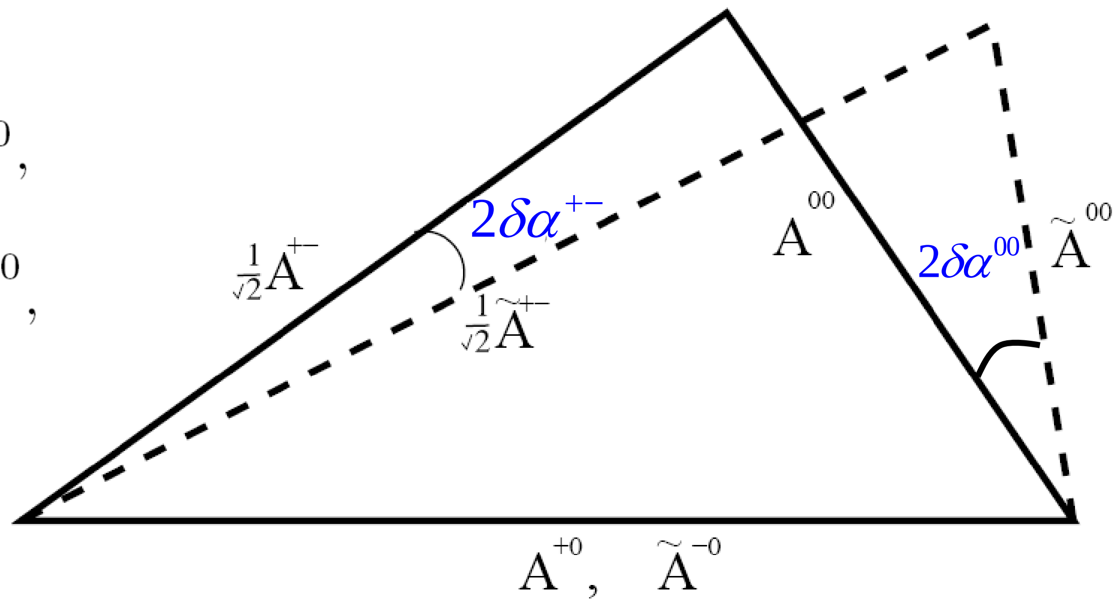
Additional material

SU(2) based methods.

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

- SU(2) isospin relates the different B→hh' amplitudes (h, h' = π, ρ): Gronau London (**GL**) method.

$$\frac{1}{\sqrt{2}} A^{+-} = A^{+0} - A^{00},$$
$$\frac{1}{\sqrt{2}} \overline{A}^{+-} = \overline{A}^{+0} - \overline{A}^{00},$$
$$|A^{+0}| = |\overline{A}^{+0}|$$



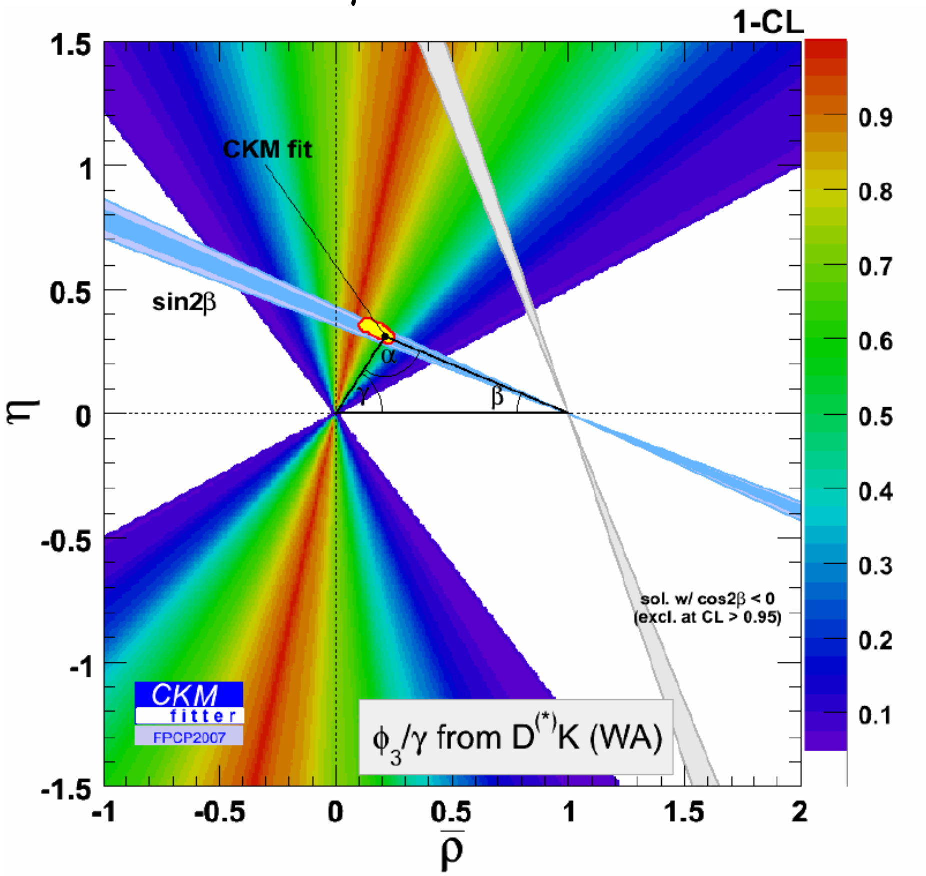
- $\delta\alpha^{ij} = \alpha^{ij}_{eff} - \alpha$ parameterise penguin pollution in +– and 00 charged final states.
- Relationship to S and C:

$$\sin(2\alpha^{+-}_{eff}) = \frac{S^{+-}}{\sqrt{1-(C^{+-})^2}},$$
$$\sin(2\alpha^{00}_{eff}) = \frac{S^{00}}{\sqrt{1-(C^{00})^2}},$$

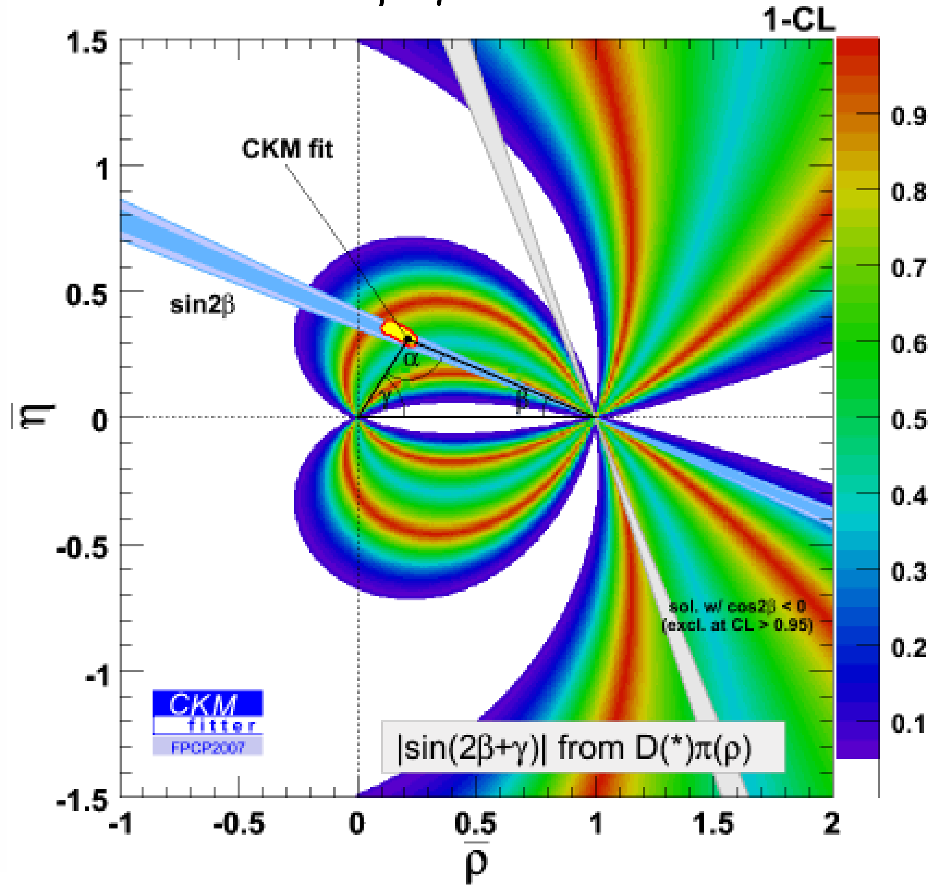
Impact on $\bar{\rho}$ and $\bar{\eta}$

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

From γ measurements



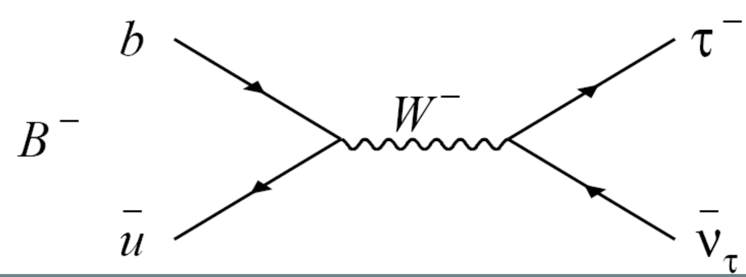
From 2β+γ measurements



$B^+ \to \tau^+ \nu$

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

- Suppressed by V_{ub}

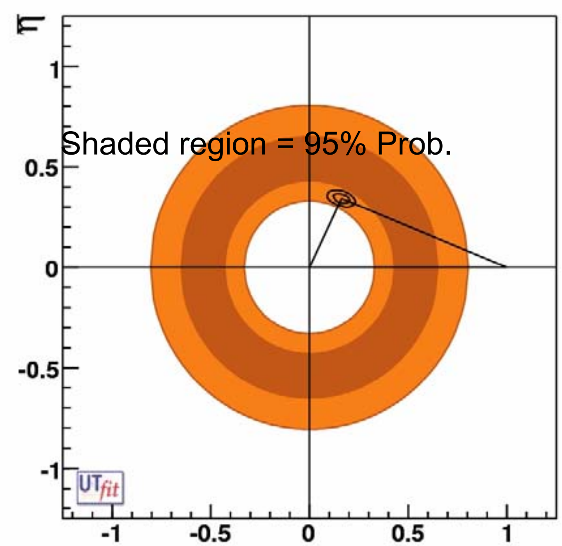


SM prediction
$(1.59 \pm 0.40) \times 10^{-4}$

$$\mathcal{B}_{SM}(B^+ \to l^+ \upsilon_l) = \frac{G_F^2 m_B m_l^2}{8\pi}\left(1 - \frac{m_l^2}{m_B^2}\right) f_B^2 \, |V_{ub}|^2 \, \tau_B$$

- Within the SM, this measurement can be used to constrain f_B.

- Can constrain the apex of the unitarity triangle using this measurement
  - Complements the angle measurements

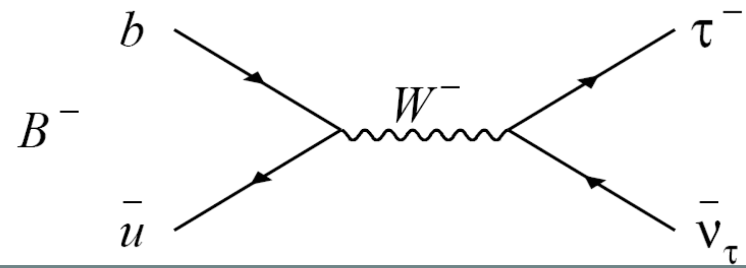


http://utfit.roma1.infn.it/

$B^+ \to \tau^+ \nu$

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

- Suppressed by V_{ub}



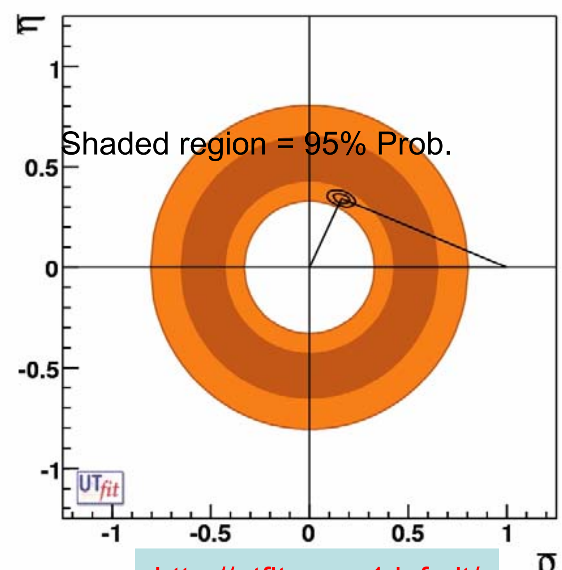
SM prediction
$(1.59 \pm 0.40) \times 10^{-4}$

$$\mathcal{B}_{SM}(B^+ \to l^+ \upsilon_l) = \frac{G_F^2 m_B m_l^2}{8\pi}\left(1 - \frac{m_l^2}{m_B^2}\right) f_B^2 \, |V_{ub}|^2 \, \tau_B$$

- Can replace W^+ with H^+
- $\mathcal{B}$ can be suppressed or enhanced by a factor of r_H.

$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

2HDM: W.S. Hou, PRD **48**, 2342 (1993).



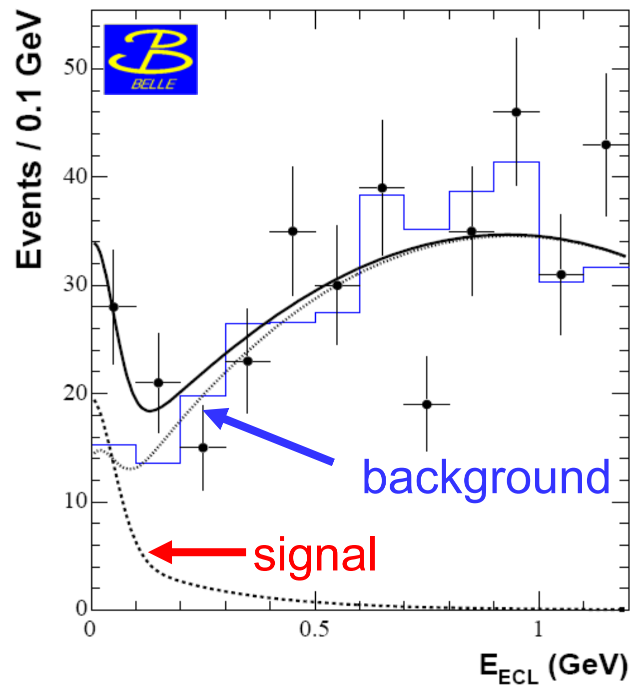
http://utfit.roma1.infn.it/

$B^+ \to \tau^+ \nu$

$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \end{pmatrix}$

hep-ex/0608019
PRL **97** (2006) 251802

- Reconstruct signal decay.
- and other B in the event:
  - Belle: fully reconstruct B mesons in 180 channels.
  - BaBar: Tag with $B \to D^{(*)} l \upsilon$.
- Look at the remaining energy in the calorimeter: signal peaks at $E_{ECL/extra}=0$.



BELLE

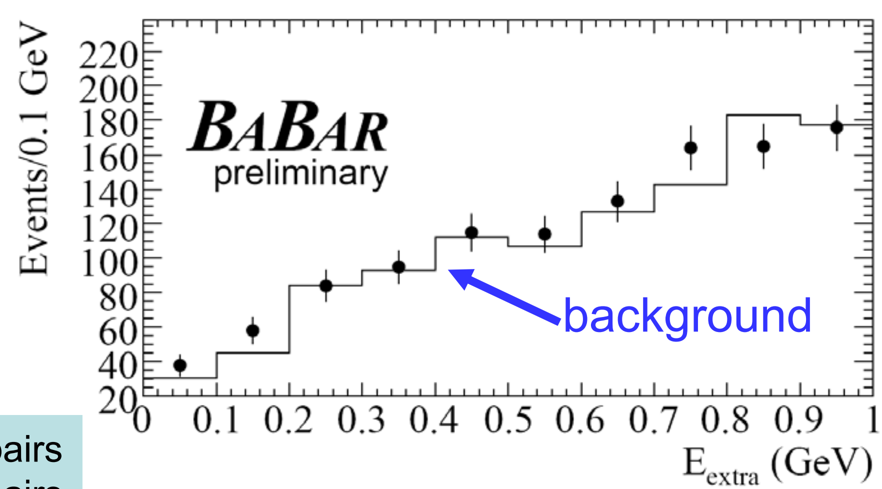
$$\mathcal{B} = (1.79^{+0.56+0.39}_{-0.49-0.46}) \times 10^{-4}$$

(revised). 3.5 σ significance

BABAR

$$\mathcal{B} = (0.88^{+0.68}_{-0.67} \pm 0.11) \times 10^{-4}$$

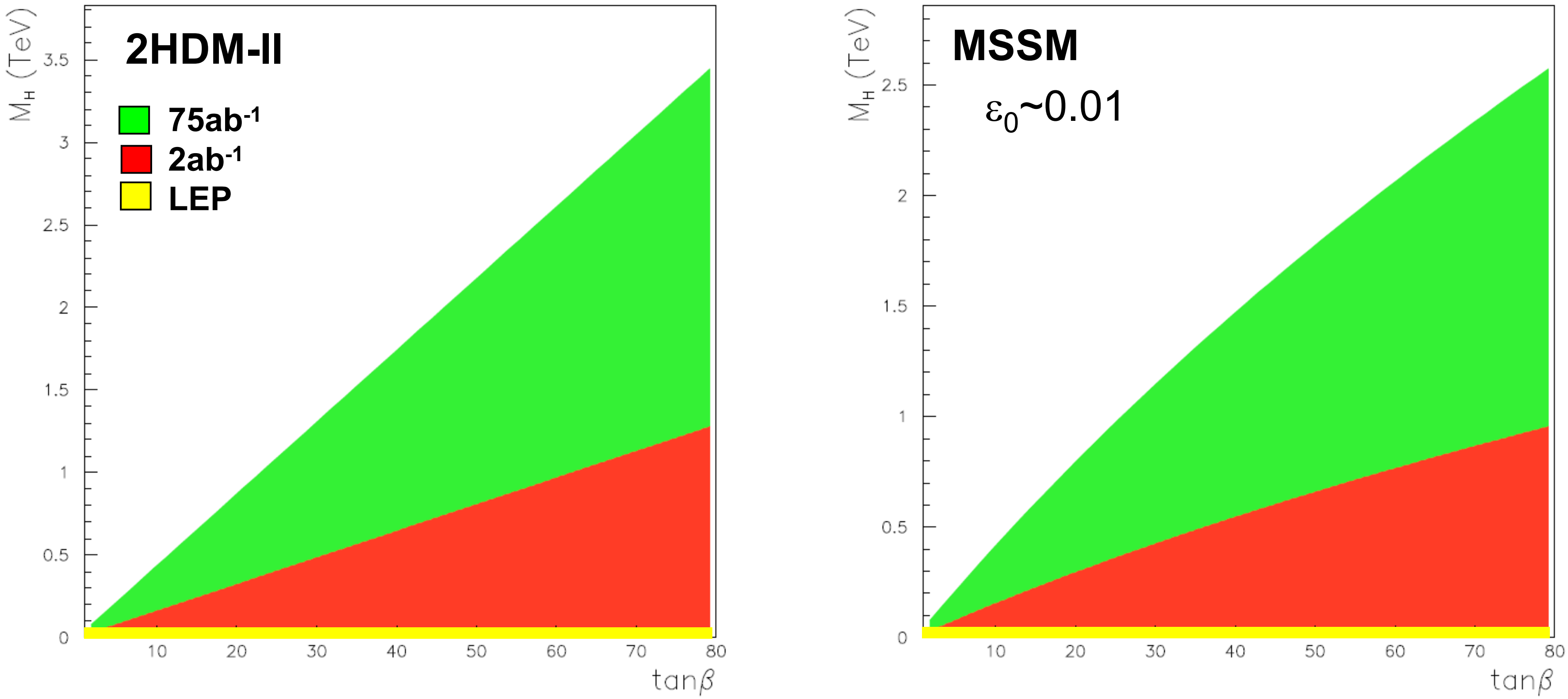
$BF < 1.80 \times 10^{-4}$ @90%CL



BaBar: 320×10^6 B pairs
Belle: 449×10^6 B pairs

$B^+ \to \tau^+ \nu$

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



- Multi TeV search capability for large tanβ.

$$r_H = \left(1 - \tan^2\beta \frac{m_B^2}{m_H^2}\right)^2$$

$$r_H = \left(1 - \frac{\tan^2\beta}{1+\varepsilon_0 \tan\beta} \frac{m_B^2}{m_H^2}\right)^2$$

Charm equivalent: $D_s^+ \to \mu^+\nu, \tau^+\nu$

$B^+ \to e^+\nu, \mu^+\nu$

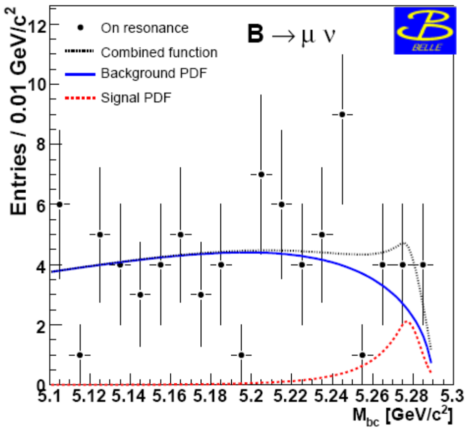
$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \end{pmatrix}$

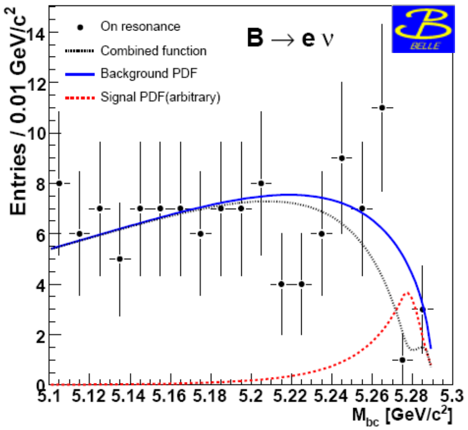
hep-ex/0607110
hep-ex/0611045

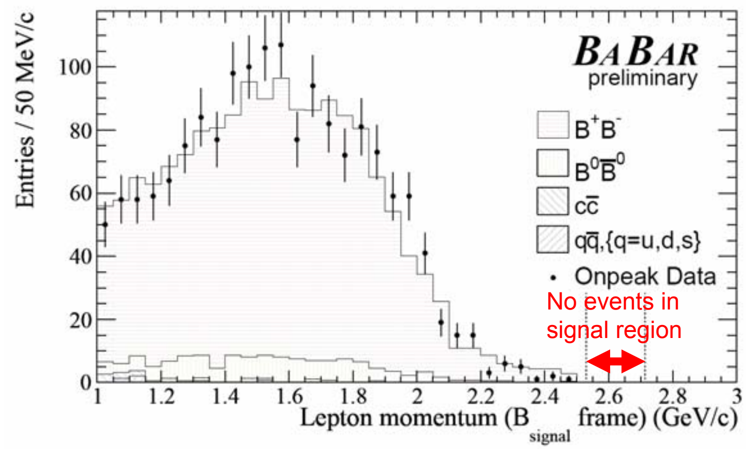
- Same physics motivation as $\tau^+\nu$.

BaBar: 229×10^6 B pairs
Belle: 277×10^6 B pairs

$$\mathcal{B}_{SM}(B^+ \to l^+\upsilon_l) = \frac{G_F^2 m_B m_l^2}{8\pi}\left(1-\frac{m_l^2}{m_B^2}\right) f_B^2 |V_{ub}|^2 \tau_B$$







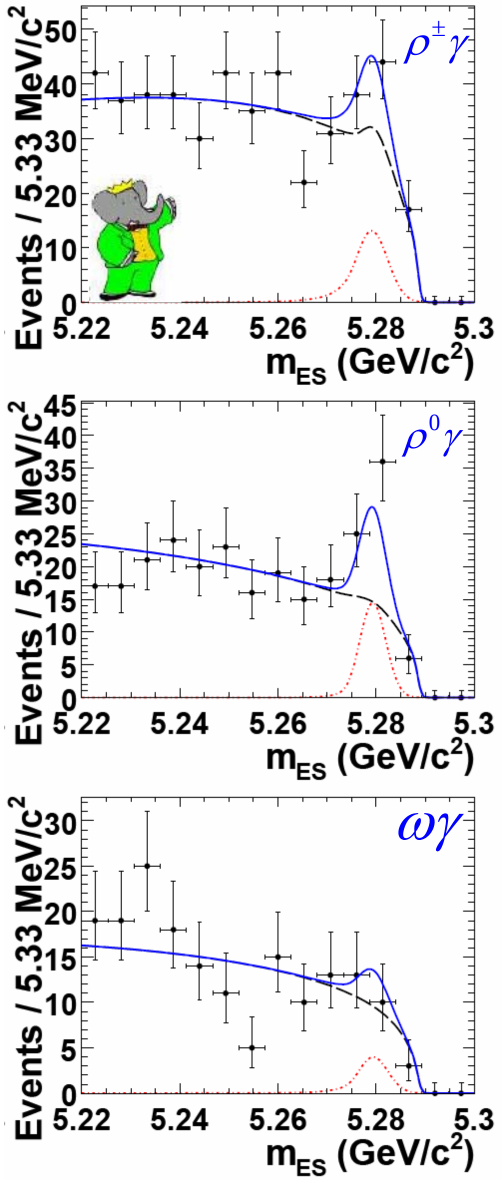
- These searches give null results. Upper limits are shown for **BaBar** and **Belle**.
- Consistent with SM.
- Best limits within a factor of 2 of SM

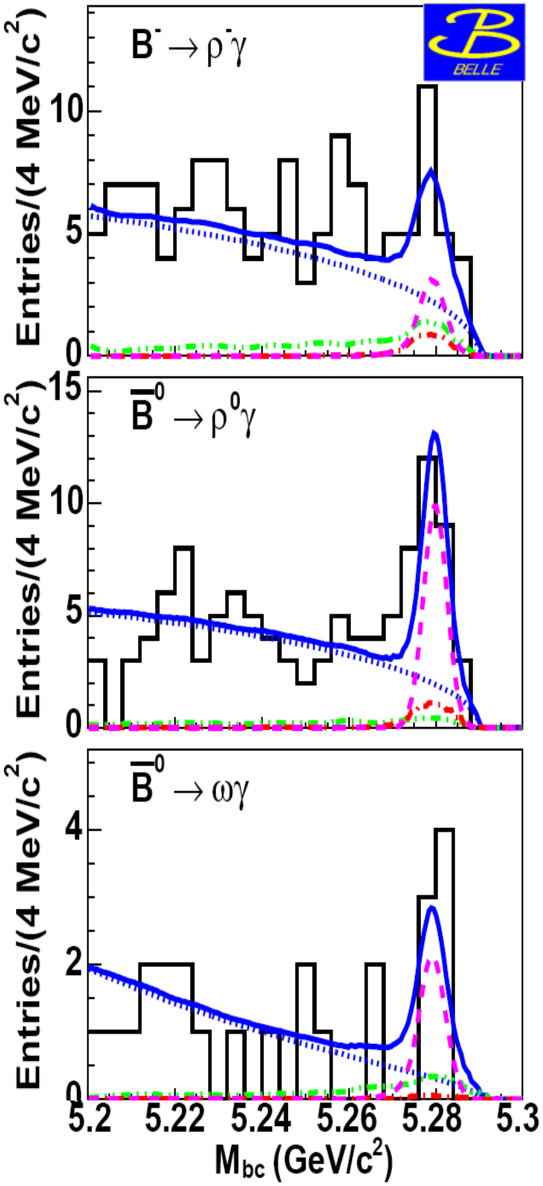
$$\mathcal{B}(B^+ \to e^+\upsilon_e) < 7.9\times10^{-6} \text{ (90\% CL)}$$
$$\mathcal{B}(B^+ \to e^+\upsilon_e) < 9.8\times10^{-7} \text{ (90\% CL)}$$
$$\mathcal{B}(B^+ \to \mu^+\upsilon_\mu) < 6.2\times10^{-6} \text{ (90\% CL)}$$
$$\mathcal{B}(B^+ \to \mu^+\upsilon_\mu) < 1.7\times10^{-6} \text{ (90\% CL)}$$

B→dγ transitions: ωγ, ργ

$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \end{pmatrix}$

RPL**96** (2006) 221601
hep-ex/0612017





BaBar: 347×10^6 B pairs
Belle: 386×10^6 B pairs

- Both experiments observe b→dγ decays.
- With very consistent results.

$$\mathcal{B}(B\to\rho\gamma,\omega\gamma) = (1.25\pm0.25\pm0.09)\times10^{-6}$$

$$\frac{\mathcal{B}(B\to\rho\gamma,\omega\gamma)}{\mathcal{B}(B\to K^{*}\gamma)} = 0.030\pm0.006$$

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.200\pm0.020\pm0.015$$

$$\mathcal{B}(B\to\rho\gamma,\omega\gamma) = (1.32^{+0.34}_{-0.31}\pm0.10)\times10^{-6}$$

$$\frac{\mathcal{B}(B\to\rho\gamma,\omega\gamma)}{\mathcal{B}(B\to K^{*}\gamma)} = 0.032\pm0.006\pm0.002$$

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.199\pm0.026^{+0.018}_{-0.015}$$

B→dγ transitions: ωγ, ργ

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

- Can constrain the unitarity triangle using $B \to K^* \gamma$
  - Orthogonal to constraint from $B^+ \to \tau^+ \upsilon$
  - Compliments angle measurements (Y.J. Kwon's talk @ KEKTC6 Feb 2007)