CP Violation and the CKM Matrix

Assessing the impact of the asymmetric *B* Factories

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for the CKMfitter Group

SLAC Experimental Seminar, May 09, 2005

CKM fitter

http://www.slac.stanford.edu/xorg/ckmfitter/ and http://ckmfitter.in2p3.fr/

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Outline

Introductory disclaimer:

this seminar mainly addresses *B*-physics experts

it discusses/condenses parts of the 2004 publication from the CKMfitter Group

Charles *et al.*, EPJ C41, 1–131 (2005) [hep-ph/0406184]

Höcker-Lacker-Laplace-Le Diberder, EPJ C21, 225 (2001)

<u>Themes :</u>

- CKM phase invariance and unitarity
- Statistical issues
- CKM metrology
  - the traditional inputs
  - deep *B* physics : α, β, γ
  - a new star : $B^+ \to \tau^+\nu$
  - the global CKM fit
- Related topics
  - phenomenological discussion of $B \to K\pi$ decays
- Preparing the future

To start with …

1. The Universe is empty* !
2. The Universe is almost empty* !

$$\frac{\Delta n_{\text{baryon}}}{n_\gamma} = \frac{n_{\text{baryon}} - n_{\overline{\text{baryon}}}}{n_\gamma} \sim O\left(10^{-10}\right)$$

Bigi, Sanda, « *CP* Violation » (2000)

- Initial condition ?
- Dynamically generated ?

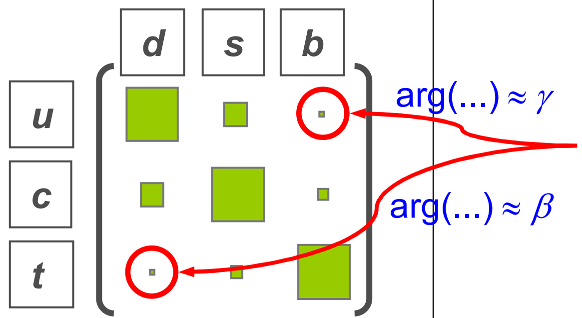
Sakharov rules (1967) to explain Baryogenesis

1. Baryon number violation
2. *CP* violation
3. No thermic equilibrium (non-stationary system)

- So, if we believe to have understood CPV in the quark sector, what does it signify ?
- A sheer accident of nature ?
- and … (less important, but puzzling) is the new physics minimal flavor violating ? If so, why ???

The CKM Matrix and the Unitarity Triangle

$V_{\mathrm{CKM}} =$

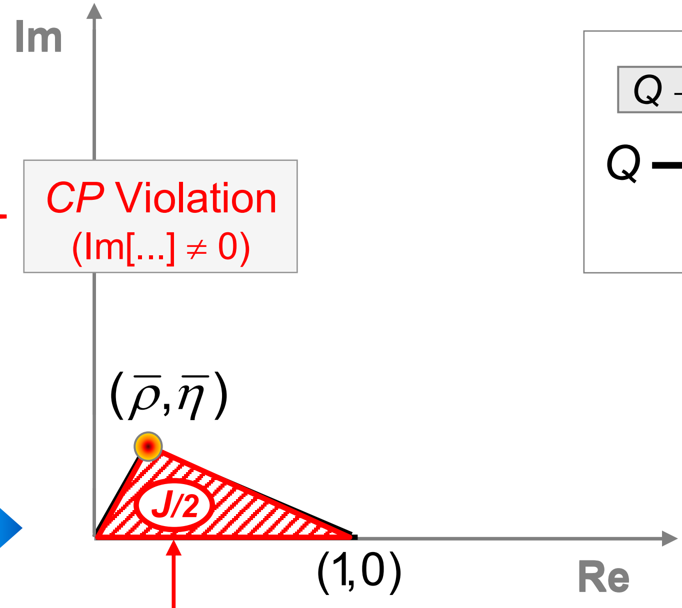


$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

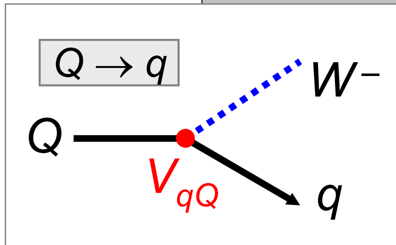
$$\left(\propto A\lambda^3 \propto -A\lambda^3 \propto A\lambda^3\right)$$

$$\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} + 1 + \underbrace{\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}}_{} = 0$$

phase invariant : $\bar{\rho} + i\bar{\eta}$



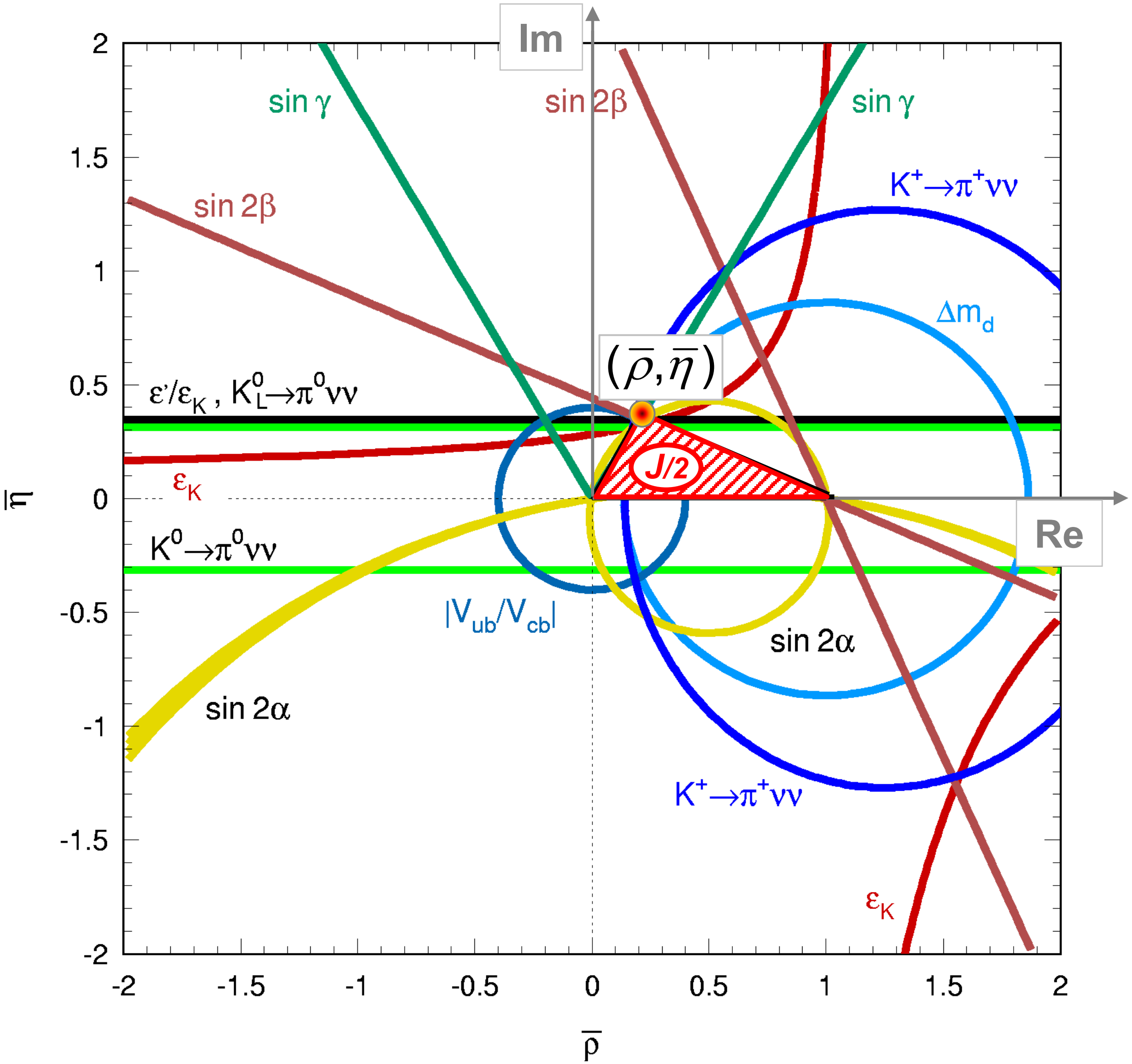
CP Violation
(Im[...] ≠ 0)



Jarlskog invariant
J = 0 ⇔ no VCP

Jarlskog, PRL 55, 1039 (1985)

The CKM Matrix and the Unitarity Triangle



The Unitary Wolfenstein Parameterization

- The standard parameterization uses Euler angles and one CPV phase → unitary !

$$V = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

- Now, define $\boxed{s_{12} \equiv \lambda}$ $\boxed{s_{23} \equiv A\lambda^2}$ $\boxed{s_{13}e^{-i\delta} \equiv A\lambda^3(\rho - i\eta)}$

- And insert into V → V is still unitary ! With this one finds (to all orders in λ) :

$$\rho + i\eta = \frac{\sqrt{1 - A^2\lambda^4}\,(\bar{\rho} + i\bar{\eta})}{\sqrt{1-\lambda^2}\left[1 - A^2\lambda^4(\bar{\rho} + i\bar{\eta})\right]}$$

where: $$\bar{\rho} + i\bar{\eta} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

- If one wishes (not necessary for the analysis), one can Taylor expand in λ and finds :

$$\bar{\rho} = \rho\left(1 - \frac{\lambda^2}{2}\right) + \left(\frac{1}{2}A^2\rho - \frac{1}{8}\rho - A^2\left(\rho^2 - \eta^2\right)\right)\lambda^4 + O(\lambda^6)$$

$$\bar{\eta} = \eta\left(1 - \frac{\lambda^2}{2}\right) + \left(\frac{1}{2}A^2\eta - \frac{1}{8}\eta - 2A^2\rho\eta\right)\lambda^4 + O(\lambda^6)$$

Buras *et al.*,
PRD 50, 3433 (1994)

The CKMfitter Project

- Started development in 2000 with Standard CKM fit – first publication in 2001
- Since then, many additional implementations :
  - $B \to \pi\pi$, $\rho\pi$, $\rho\rho$ isospin analyses, and Dalitz interpretation
  - $B \to \pi\pi$, $K\pi$, KK isospin + SU(3) analyses
  - full QCD Factorization (BBNS) for $B \to PP$, PV
  - $B \to D^{(*)}K^{(*)}$ (ADS, GLW and Dalitz) interpretation
  - rare B decays: $B \to \tau(\mu)\nu$ and $B \to \rho(K^*)\gamma$
  - CPV and mixing in B_s decays
  - rare kaon decays: $K \to \pi\nu\nu$
  - dilepton *CP* asymmetries
  - new physics analyses
- Features 3 statistical approaches :
  - *R*fit (frequentist)
  - 90% CL scan method (frequentist)
  - Bayesian
- Code : ~ 42k lines at present (40k F vs. 2k C++) – re-foundation meeting in June, 2005 to take future technology decision: full rewrite in C++/Root, or with Mathematica

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Date: May 2005
Pages: 1 - 131

CKMfitter Group: from 4 (2000) to 15 (2005) members, mostly experimentalists including BABAR, Belle, LHCb

Code is publicly available :

- under CVS (still needs BABAR account – will eventually move to sourceforge),
- on the web: http://www.slac.stanford.edu/xorg/ckmfitter/

Fitting Approach

Measurement

x_{exp}

Constraints on theoretical parameters

Theoretical predictions

$x_{theo}(y_{model} = y_{theo}, y_{QCD})$

$y_{theo} = (A, \lambda, \rho, \eta, m_t, \theta, \ldots)$

$y_{QCD} = (B_K, f_B, B_{Bd}, \ldots)$

Define: “χ^2” $= -2 \ln \mathcal{L}(y_{model})$

$$\mathcal{L}(y_{model}) = \mathcal{L}_{exp}\left[x_{exp} - x_{theo}(y_{model})\right] \times \mathcal{L}_{theo}(y_{QCD})$$

- experimental likelihood
- if not available: Gaussian errors
  - asymmetric errors
  - correlations between x_{exp}'s

« *Guesstimates* »

Frequentist: *R*fit

Uniform likelihoods: “allowed *ranges*”

Bayesian

Probabilities

Three Step CKM Analysis using *R*fit

CKM fitter

Probing the SM

- Test of "Goodness-of-fit"
- Evaluate global minimum
  $\chi^2_{\min;y_{\mathrm{mod}}}(y_{\text{mod-opt}})$
- Create perfect data set :
  $x_{\text{exp-opt}} = x_{\text{theo}}(y_{\text{mod-opt}})$
  generate $x_{\exp}$ using $\mathcal{L}_{\exp}$
- Perform many toy fits:
  $\chi^2_{\text{min-toy}}(y_{\text{mod-opt}}) \rightarrow F(\chi^2_{\text{min-toy}})$

$$\mathrm{CL(SM)} = \int_0^{\chi^2_{\min;y_{\mathrm{mod}}}} F(\chi^2)\,d\chi^2$$

Metrology

- Define:
  $y_{\mathrm{mod}} = \{a;\ \mu\}$
  $= \{\rho,\ \eta,\ A, \lambda, y_{\mathrm{QCD}}, \ldots\}$
- Set Confidence Levels in $\{a\}$ space, irrespective of the μ values
- Fit with respect to $\{\mu\}$
  $\chi^2_{\min;\ \mu}(a) = \min_\mu \{\chi^2(a,\ \mu)\}$
- $\Delta\chi^2(a) = \chi^2_{\min;\ \mu}(a) - \chi^2_{\min;y_{\mathrm{mod}}}$

$\mathrm{CL}(a) = 1 - \mathrm{Prob}(\Delta\chi^2(a),\ N_{\mathrm{dof}})$
(or toy MC)

Test New Physics

- If CL(SM) good

Obtain limits on New Physics parameters

- If CL(SM) bad

Try some other model

AH-Lacker-Laplace-Le Diberder EPJ C21 (2001) 225, [hep-ph/0104062]

Statistics : Popular Misconceptions

See also R. Faccini's plenary talk at BABAR Collaboration meeting February, 2005

- Use and misuse of Bayesian statistics :
  - Bayes' theorem tells us about the convolution of probability densities (the "*priors*")
  - Bayes did <u>not</u> tell us that we should assign probabilities to all quantities in this world
- Addresses the problem of *Finetuning* :
  - Leaving all y_{model} parameters free to vary in the fit (within defined ranges) is certainly conservative, but does not apply any hierarchy between the solutions
  - If one wishes to introduce a hierarchy to increase the information budget, one has to take care about the origin of the y_{model} parameters :

The y_{QCD} parameters have prior information: all y_{QCD} may hit at their bounds → finetuning scenario ?

↓

use of PDFs for y_{QCD} suppresses these solutions in a controlled way:

- arbitrary suppression strength
- not conservative

The y_{theo} parameters are unknown: → <u>no finetuning scenario</u>

↓

use of PDFs for y_{theo} suppresses (and enh.) solutions in an uncontrolled way:

- arbitrary results (biased)
- not conservative

Popular Misconceptions: Examples (I)

- Famous illustrative example: consider observable T with theory prediction

$$T = \prod_{i=1}^{N} y_i \quad \text{with } y_{\text{model}} \text{ parameters: } y_i \in [-\Delta, +\Delta]$$

a Bayesian approach with *a priori* PDFs $G(y_i)$, generates the *a posteriori* PDF

$$\rho(T) = \int_{-\infty}^{+\infty} \ldots \int_{-\infty}^{+\infty} \prod_{i=1}^{N} dy_i' \; G(y_i') \; \delta\left(T - T(y_1' \ldots y_N')\right)$$

and using uniform *priors* for all x_i leads to : $\boxed{\rho(T) \propto (-\ln T)^{N-1}}$

- Illustration for N=3 and $\Delta=\sqrt{3}$:

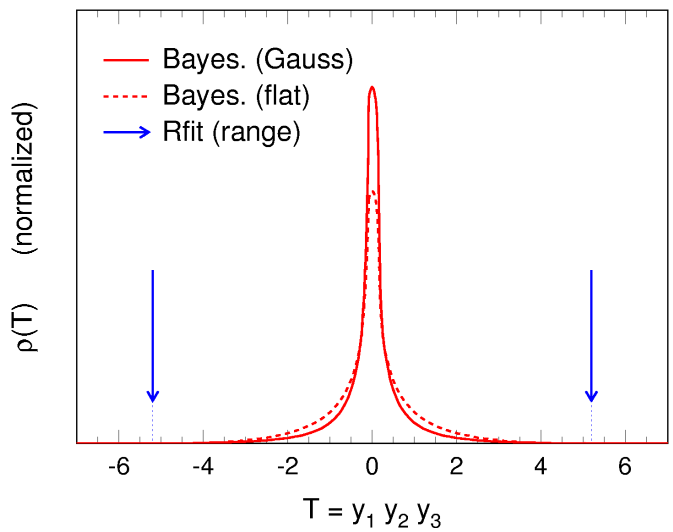
$$T = y_1 \cdot y_2 \cdot y_3$$

  - *R*fit is not weighed within :

$$T_i \in \left[-3\sqrt{3}, +3\sqrt{3}\right]$$

  - Biasian strongly weighs

    see plot



see appendix in: hep-ph/0104062

Popular Misconceptions: Examples (II)

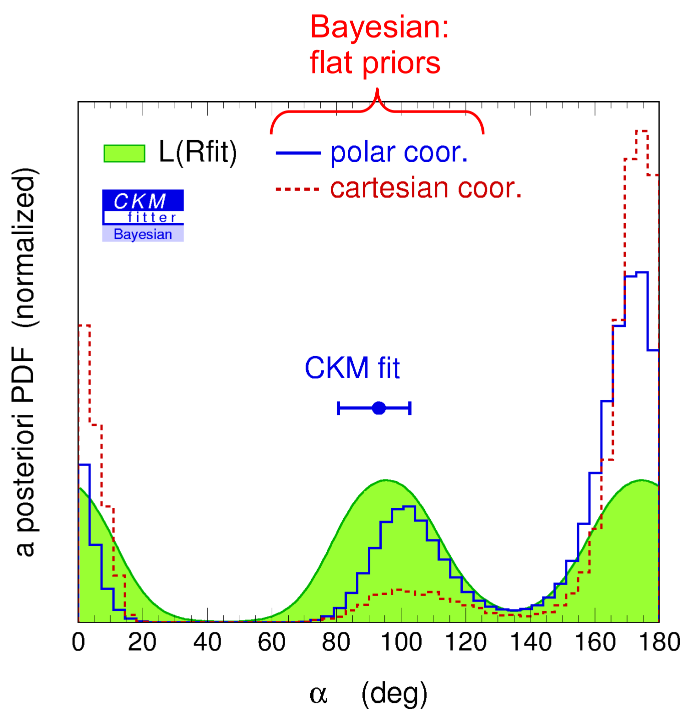
- $B \to \rho\rho$ Gronau-London isospin analysis:

$$\text{Observables: } O_i = f_i\underbrace{(\alpha, \overbrace{T^{+-}, T^{00}, P^{+-}}^{\in \mathbb{C}})}_{y_{\text{theo}}} \quad \forall i = 1,\ldots,6$$

  - there are 8 mirror solutions for $\alpha \in [0,\pi]$, *i.e.*, 8 different values of α give same O_i
  - if penguins → 0 : two sets of 4 solutions merge with 2 solutions left
  - nature cannot distinguish between these solutions ! (because the corresp. observables are degenerate)
  - independent of the param. (polar, cartesian, …)

- The *R*fit analysis (χ^2 fit) reproduces degenerate $\chi^2_{\text{min}}(\alpha)$ at the mirror solutions

- When using PDFs for the y_{theo}, the Bayesian analysis *cannot* in general reproduce the mathematical property of the isospin analysis, since it applies arbitrary input weights



Concluding Remarks

- Is the frequentist analysis without approximations ? In principle yes, but not in practice :
  - Often use Gaussian CL = 1 – Prob($\Delta\chi^2$,N_{dof}) approximation for simplicity
    - full approach would be toy Monte Carlo analysis to determine CL
    - Prob(…) is mostly conservative (tested for sin($2\beta+\gamma$) and $B \to \rho\rho$ analyses)
  - What about the definition of the estimator ? Is this arbitrary ? Source of bias ?
    - the choice of the estimator is arbitrary; in Gaussian case, maximum likelihood is optimal
    - using a bad estimator <u>does not</u> create a bias; however, it will give bad constraints
    - using an optimized estimator is just like optimizing a BABAR data analysis: there is nothing wrong with cut & count, it's just not optimal

- Other comments to Bayesian analyses :
  - In many applications (like, *e.g.*, γ from $B \to DK$) there is no obvious (mathematical) way to see the bias from *priors*
    - however, in most cases it can still be significant
  - Does the *prior* dependence reduce when the measurement is significant ?
    - not true in general (see α from $B \to \rho\rho$)
  - The Bayesian analysis should use *priors* when there is prior information, and leave parameters free, when there is not

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  - Often use Gaussian CL = 1 – Prob($\Delta\chi^2$,N_{dof}) approximation for simplicity
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MUCH LESS TEXT FROM NOW ON !

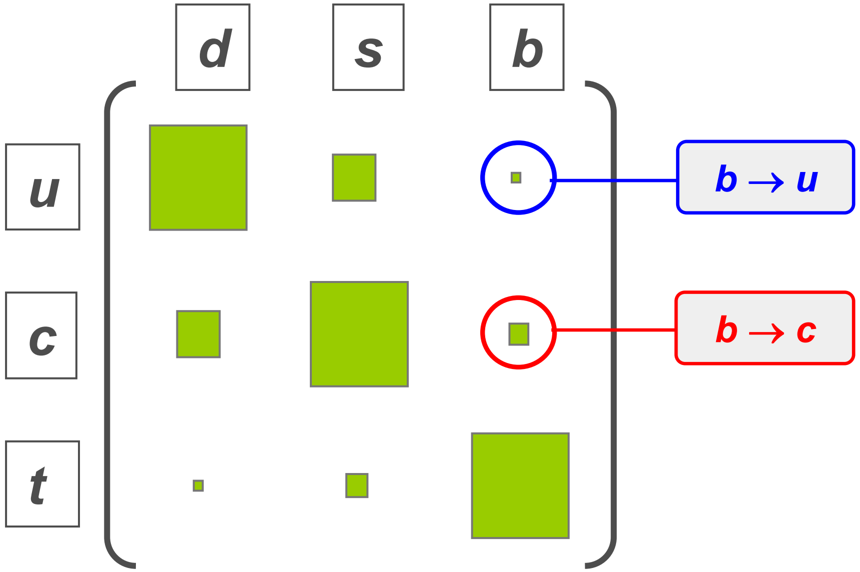
- Other comments to Bayesian analyses :
  - In many applications (like, *e.g.*, γ from $B \to DK$) there is no obvious (mathematical) way to see the bias from priors
    - however, in most cases it can still be significant
  - Does the prior dependence reduces when the measurement is significant ?
    - not true in general (see example for α from $B \to \rho\rho$)
  - A serious Bayesian analysis would use priors when there is prior information, and leave parameters free, when there is not

Inputs to the Global CKM Fit

- $|V_{ud}|$ and $|V_{us}|$ [not discussed here]
- $|V_{ub}|$ and $|V_{cb}|$
- CPV in K^0 mixing
- B_d and B_s mixing
- $\sin 2\beta$
- α :
  - $B \to \pi\pi$
  - $B \to \rho\rho$
  - $B \to \rho\pi$
- γ :
  - ADS, GLW
  - Dalitz
- $B^+ \to \tau^+\nu$

$|V_{cb}|$ and $|V_{ub}|$

- For $|V_{cb}|$ and $|V_{ub}|$ exist exclusive and inclusive semileptonic approaches

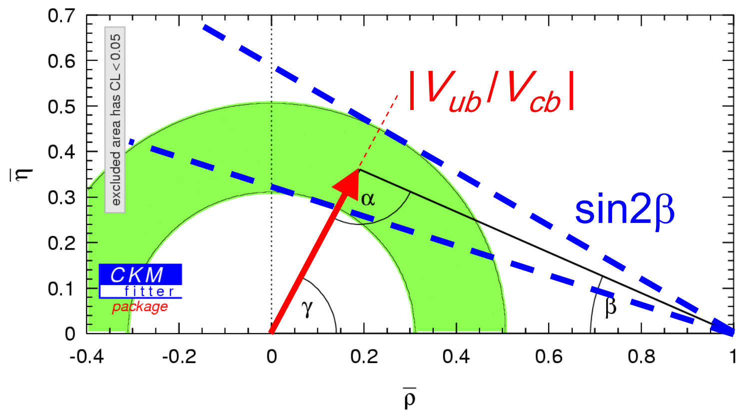


exclusive	inclusive
$B \to \pi \ell \nu$	$B \to X_u \ell \nu$
$B \to D^* \ell \nu$	$B \to X_c \ell \nu$

dominant uncertainties

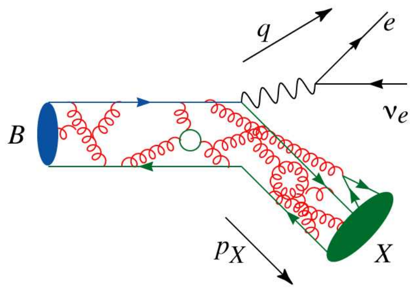
exclusive	inclusive
Form factor	OPE ($\lvert V_{cb,ub}\rvert$) and shape function ($\lvert V_{ub}\rvert$)

- $|V_{ub}|$ ($\to \rho^2 + \eta^2$) is crucial for the SM prediction of $\sin(2\beta)$
- $|V_{cb}|$ ($\to A$) is important in the kaon system (ε_K, BR($K \to \pi\nu\nu$), …)



$|V_{cb}|$ and $|V_{ub}|$

- Inclusive approaches most appealing at present



$$\simeq \frac{d\Gamma}{d(\mathrm{PS})} \sim \left|V_{[u,c]b}\right|^2 \times \left(\overbrace{\text{quark model}}^{\text{free quark decay}} + \overbrace{\sum_n C_n \left(\frac{\Lambda_{\mathrm{QCD}}}{m_b}\right)^n}^{\text{nonperturbative corrections}} \right)$$

- $|V_{cb}|$: moments analyses have 1.5–2% precision !

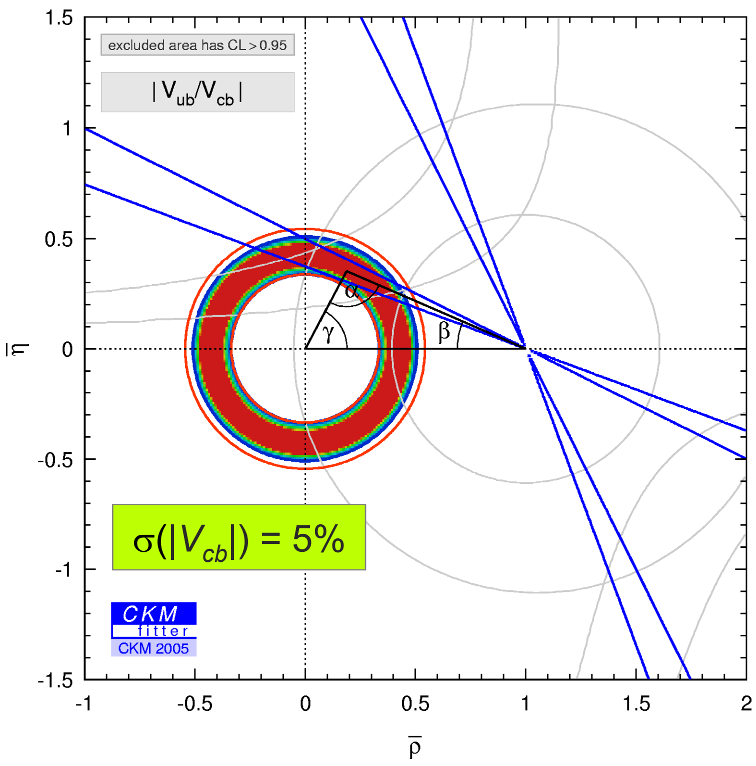
CKM-05

$$\left|V_{cb}\right|_{\text{inclusive}} = \left(42.0 \pm 0.6_{\text{exp}} \pm 0.8_{\text{theo}}\right) \times 10^{-3}$$
$$\left|V_{cb}\right|_{\text{exclusive}} = \left(40.2 \pm 2.1_{\text{exp}} \pm 1.8_{\text{theo}}\right) \times 10^{-3}$$

- $|V_{ub}|$: reduced conflict between excl. and incl.
  - SF params. from $b \to c l \nu$, OPE from Bosch *et al.*
  - reduction of central value $4.6 \to 4.1 \times 10^{-3}$
  - $\pi \ell \nu$ result goes up with Lattice FF (unquenched)

our average

$$\left|V_{ub}\right|_{\text{average}} = \left(4.05 \pm 0.13_{\text{exp}} \pm 0.50_{\text{theo}}\right) \times 10^{-3}$$



$|V_{cb}|$ and $|V_{ub}|$

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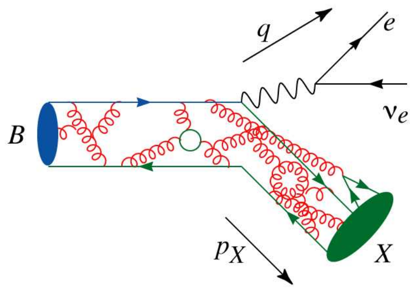

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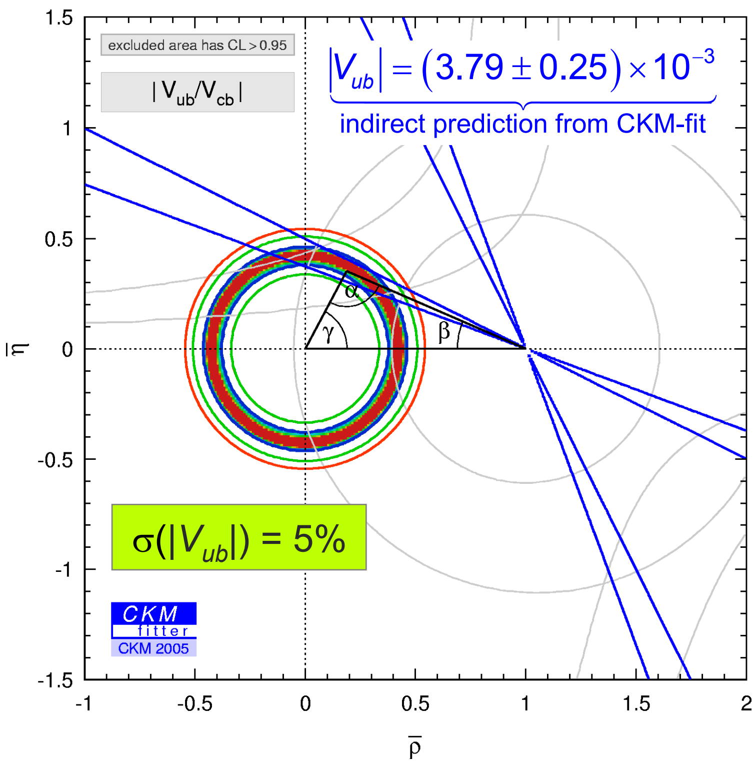


CPV in the Kaon System

effective matrix element

- Neutral kaon mixing mediated by box diagrams

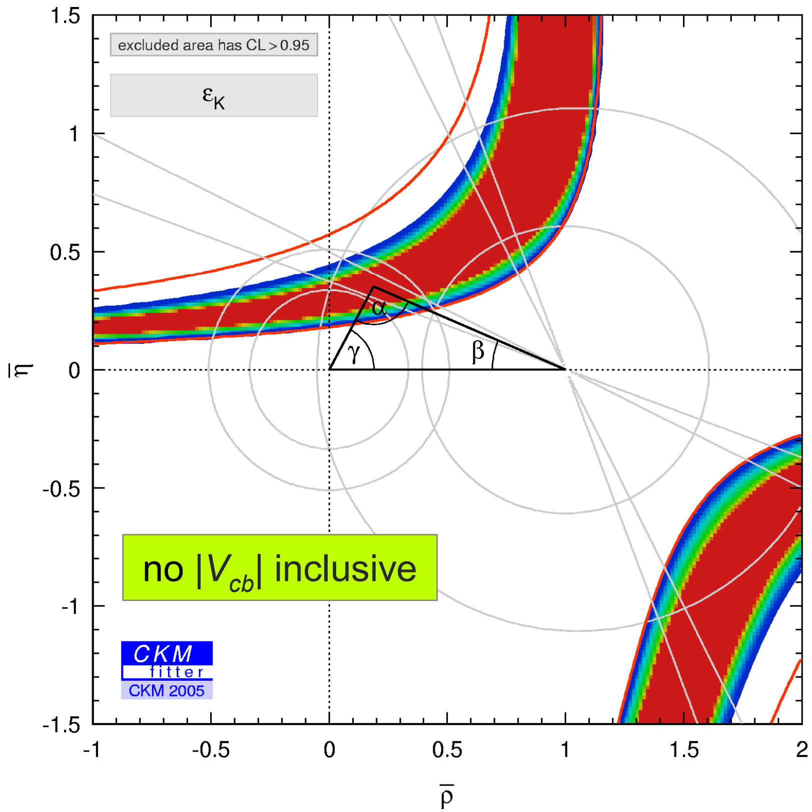
$$\langle \bar{K}^0 | (\bar{s}\gamma^\mu(1-\gamma^5)d)^2 | K^0 \rangle = \frac{8}{3} m_K^2 f_K^2 B_K$$

- Most precise results from amplitude ratio of K_L to K_S decays to $\pi^+\pi^-$ and $\pi^0\pi^0$

$$|\varepsilon_K| = \left| \frac{2}{3}\eta_{+-} + \frac{1}{3}\eta_{00} \right| = (2.282 \pm 0.017) \times 10^{-3}$$

$$\propto f_K^2 B_K \sum_{ij=cc,ct,tt} \eta_{ij} S(x_i, x_j) \underbrace{\mathrm{Im}\left[V_{is}V_{id}^* \cdot V_{js}V_{jd}^*\right]}_{\bar{\rho},\bar{\eta}\ \text{dependence}}$$

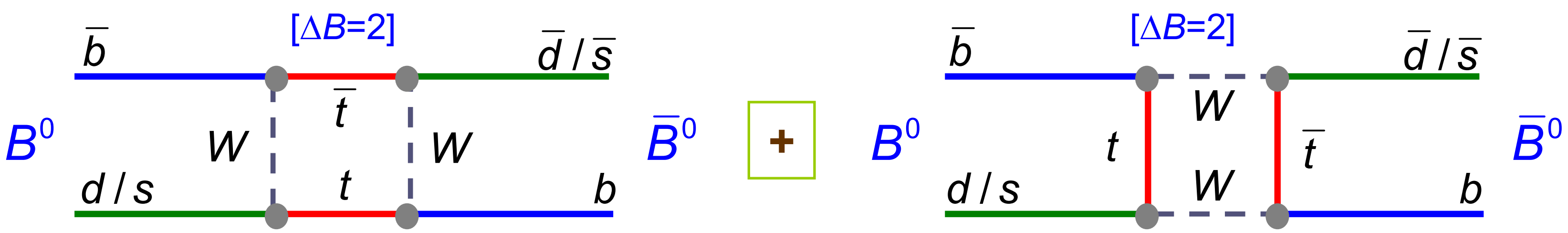
  - η_{ij} from perturbative QCD
  - significant improvement on B_K from Lattice QCD reported at CKM-05 : 0.79 ± 0.04 ± 0.09



- Direct CPV (ε') theory not yet mature for use in CKM fit (→ same problem in *B* physics)

B^0 Mixing

- Effective FCNC Processes (*CP* conserving — top loop dominates in box diagram):



Perturbative QCD

CKM Matrix Elements

$$\Delta m_q = \frac{G_F^2}{6\pi^2} m_{B_q} m_W^2 \, \eta_B \, S(x_t) \, f_{B_q}^2 B_q \, \left|V_{tq}V_{tb}^*\right|^2 \quad (\text{for } q = d,s)$$

Loop integral
(top loop dominates)

Non-perturbative: Lattice
(eff. 4 fermion operator)

- Dominant theoretical uncertainties : $\sigma_{\text{rel}}\left(f_{B_{d/s}}^2 B_{d/s}\right) \simeq 36\%$
- Improved error indirect via Δm_s : $\sigma_{\text{rel}}\left(\xi^2 = f_{B_s}^2 B_s / f_{B_d}^2 B_d\right) \simeq 10\%$

[SU(3) breaking correction]

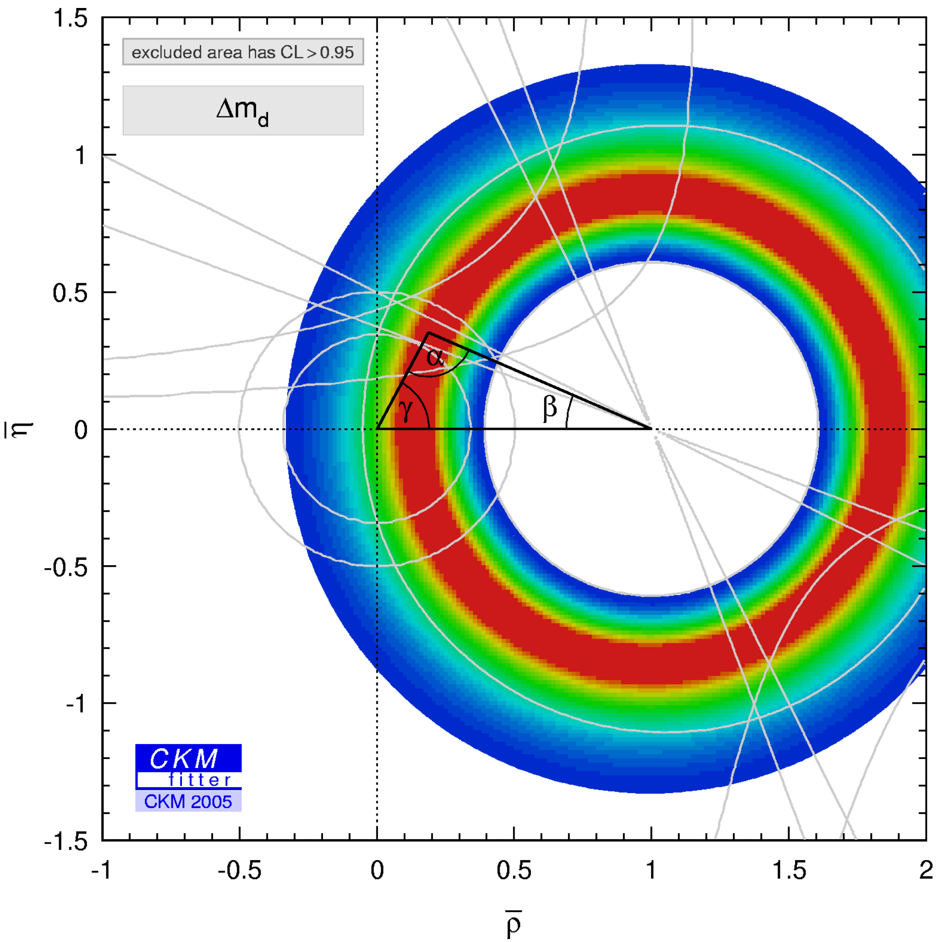
consider in fit that Lattice results are correlated !

B^0 Mixing

- Δm_d = (0.510 ± 0.005) ps^{-1} HFAG – Winter 2005

[CKM constraint dominated by theory error]

CKM fit predicts : $\Delta m_d = 0.47\,^{+0.23}_{-0.12}$ ps^{-1}



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CKM fit predicts : $\Delta m_d = 0.47\,^{+0.23}_{-0.12}$ ps^{-1}

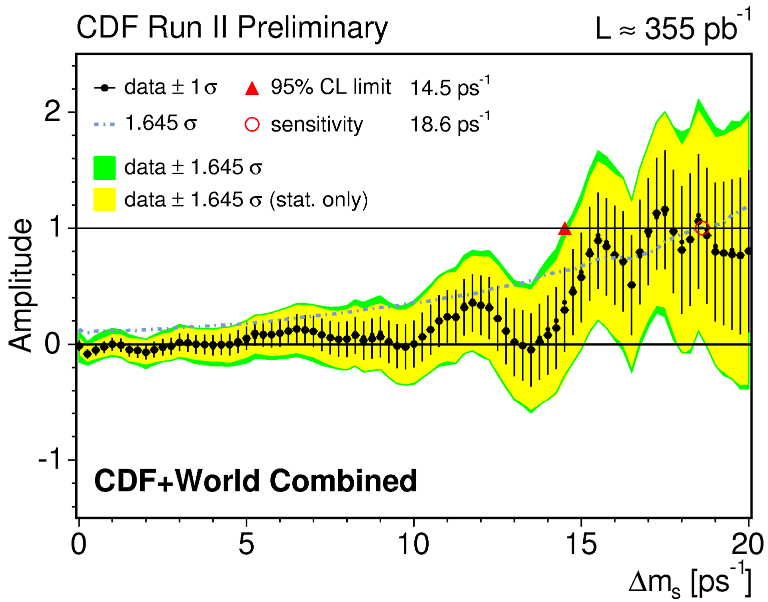
CKM fit predicts : $\Delta m_d = 18.3\,^{+6.5}_{-2.3}$ ps^{-1}

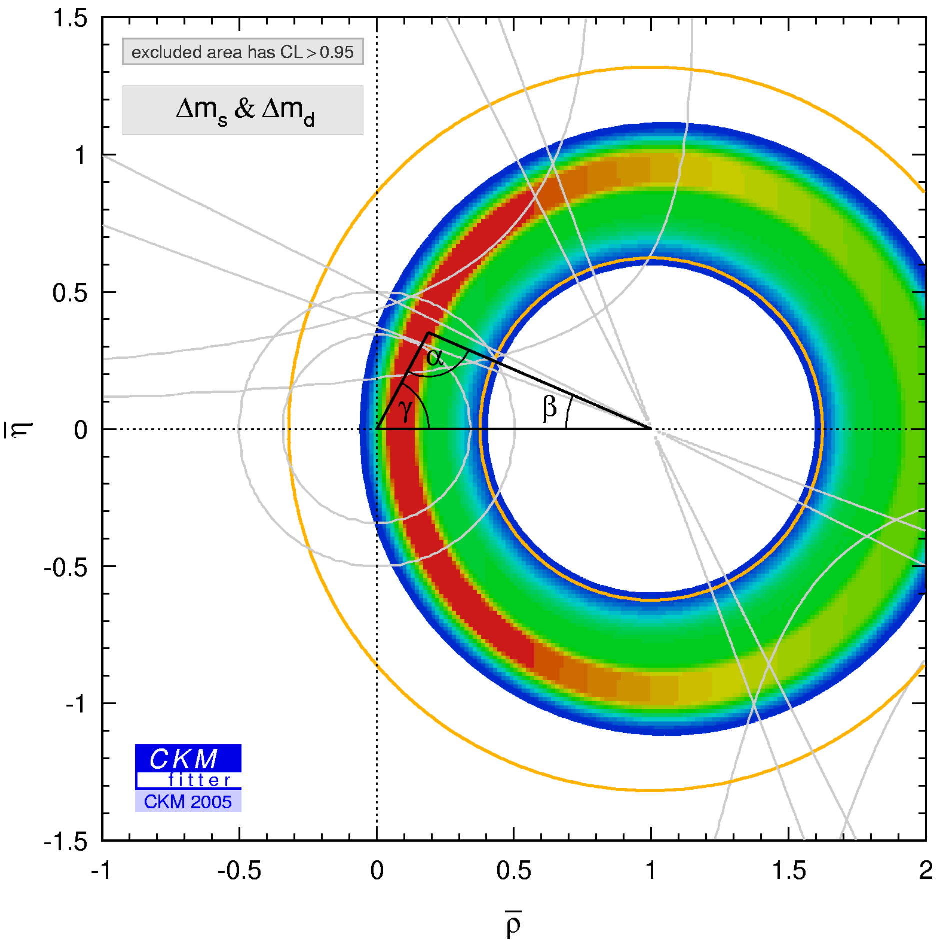
- No signal yet for Δm_s → upper limit :

  Δm_s > 14.5 ps^{-1} at 95% CL

  [CDF: WA sensitivity 18.1 → 18.6 ps^{-1}]

$$P_{B^0 \to B^0(\bar{B}^0)} \propto e^{-t/\tau}\left(1 \pm A \cos \Delta m t\right)$$





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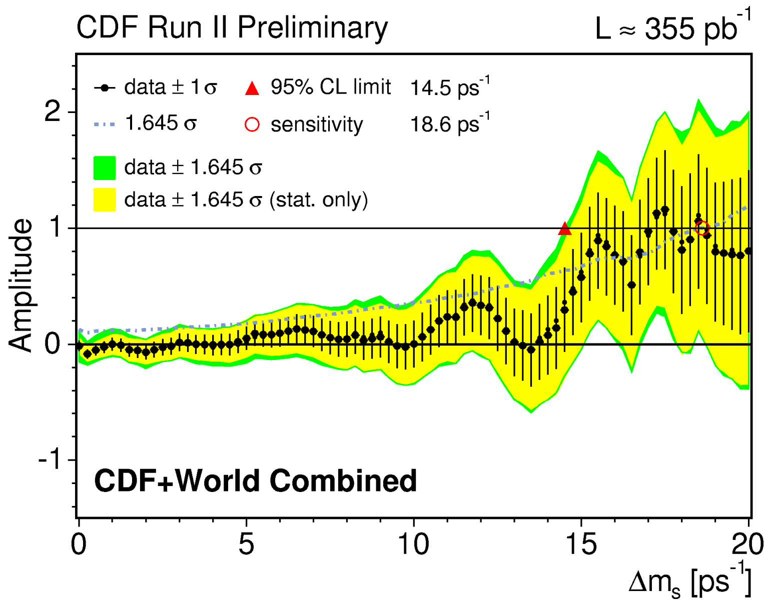
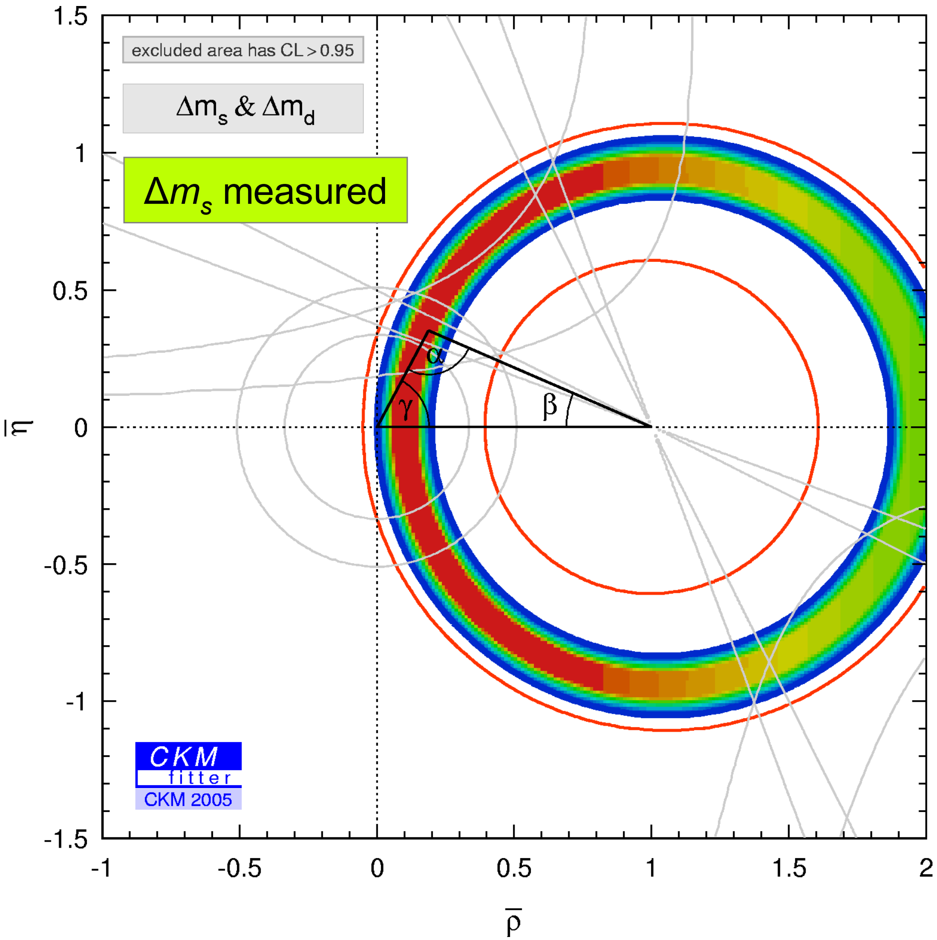
$$P_{B^0\to B^0(\bar{B}^0)} \propto e^{-t/\tau}\left(1 \pm A\cos\Delta m t\right)$$





$\sin 2\beta$ [first UT input that is not theory limited !]

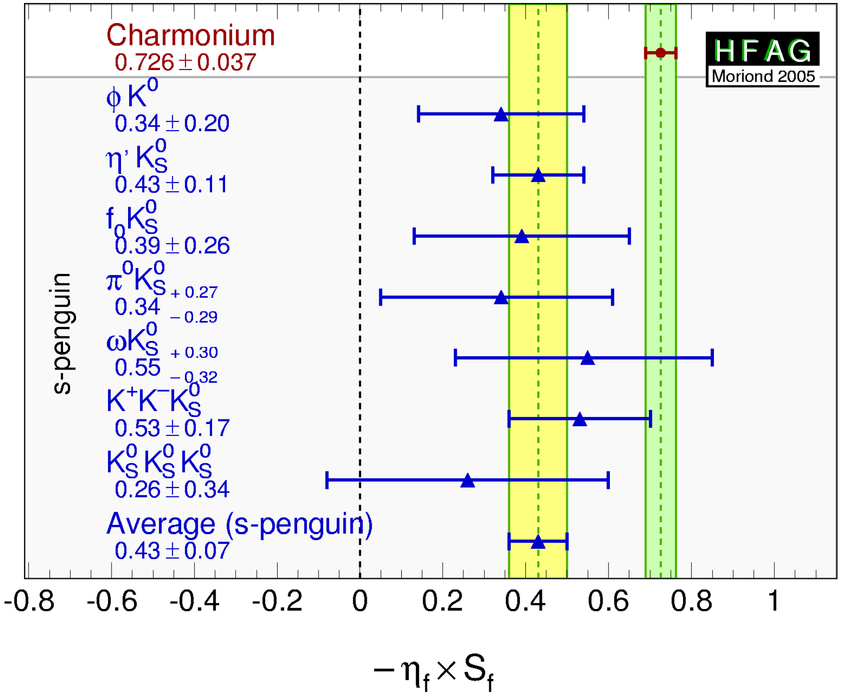
- "The" *raison d'être* of the *B* factories :
  $$\sin 2\beta = \begin{cases} 0.722 \pm 0.040 \pm 0.023 & \text{[BABAR]} \\ 0.728 \pm 0.056 \pm 0.023 & \text{[Belle]} \end{cases}$$
  $$= 0.725 \pm \underbrace{0.037}_{0.033\text{[stat-only]}}$$
  HFAG – Winter 2005

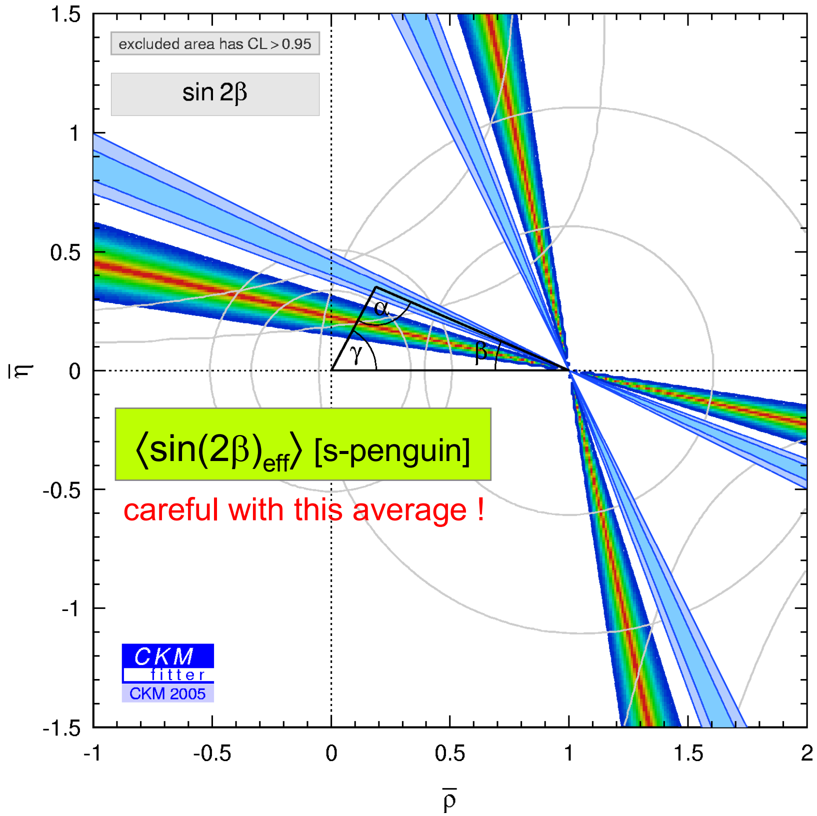
  Theory uncertainty ? Mannel at CKM 2005

  $$\Delta S_\beta \equiv \sin 2\beta_{\text{eff}} - \sin 2\beta = (-2.2 \pm 2.2) \times 10^{-4}$$

- Conflict with $\sin 2\beta_{\text{eff}}$ from *s*-penguin modes ?

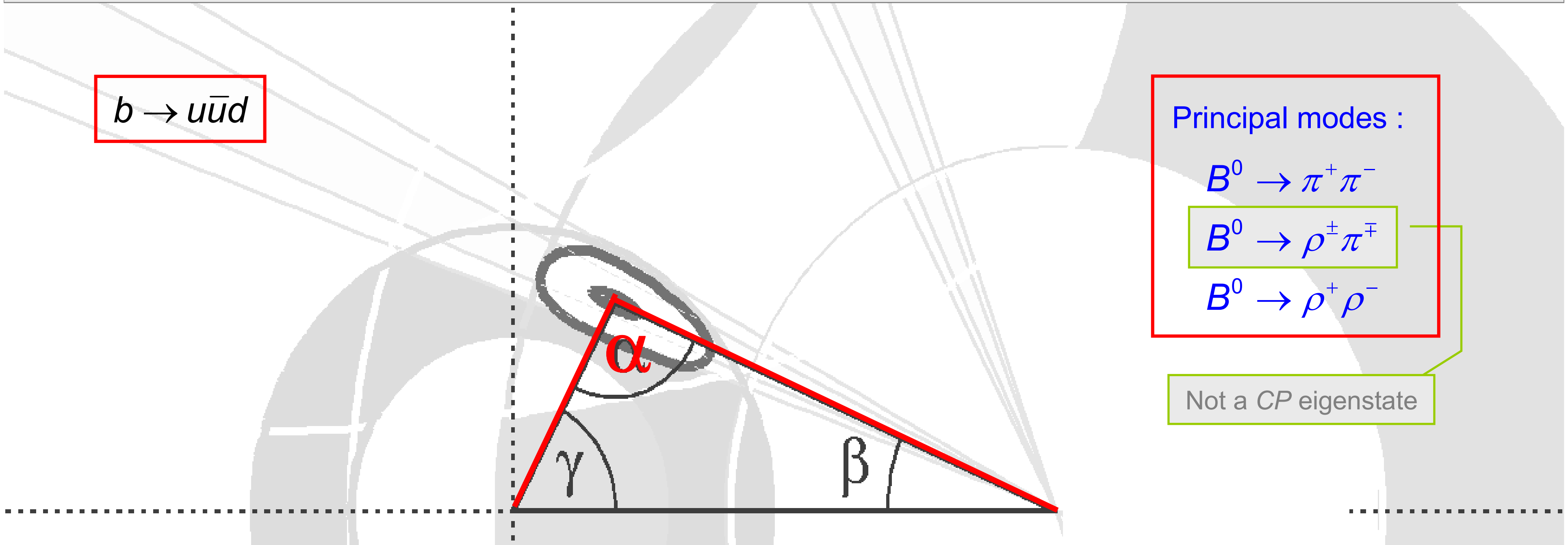
  what is ΔS_β ? positive ? WG4 at CKM 2005





α [next UT input that is not theory limited]

$b \to u\bar{u}d$



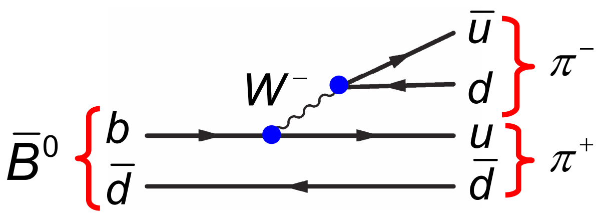
Principal modes :

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

$B^0 \to \rho^{\pm}\pi^{\mp}$

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

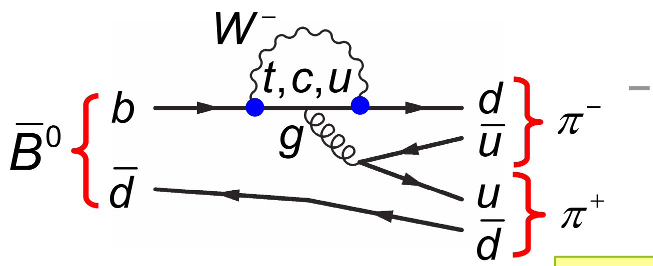
Not a *CP* eigenstate



$\propto V_{ub}V_{ud}^*$

$\propto \lambda^3$

Tree : dominant



$\propto V_{tb}V_{td}^*$

$\propto \lambda^3$

Penguin : competitive ?

Charmless $b \to u$ Decays : realistic case

- "*T*" and "*P*" are of the same order of magnitude :
  [Note that *T* and *P* are *complex* amplitudes !]

$$\lambda_{h^+h^-} = \eta_{h^+h^-} \left(\frac{q}{p}\right)_B \left(\frac{e^{-i\gamma} T^{+-} + e^{+i\beta} P^{+-}}{e^{+i\gamma} T^{+-} + e^{-i\beta} P^{+-}}\right)$$

$$= \eta_{h^+h^-} e^{2i\alpha} \left(\frac{1 - |P^{+-}/T^{+-}| e^{-i(\alpha - \delta_{+-})}}{1 - |P^{+-}/T^{+-}| e^{+i(\alpha + \delta_{+-})}}\right)$$

$$\equiv \left|\lambda_{h^+h^-}\right| e^{2i\alpha_{\text{eff}}}$$

where $\delta_{+-} \equiv \theta_{P^{+-}} - \theta_{T^{+-}}$
is the relative strong phase

Direct *CP* violation can occur :

$$|\lambda_{h^+h^-}| \neq 1$$

$$C_{f_{CP}} = \frac{1 - |\lambda_{h^+h^-}|^2}{1 + |\lambda_{h^+h^-}|^2} \overset{!}{\neq} 0$$

- Time-dependent CP observable :

realistic scenario

$$A_{h^+h^-}(t) = S_{h^+h^-} \sin(\Delta m_d t) - C_{h^+h^-} \cos(\Delta m_d t)$$

$$= \sqrt{1 - C^2_{h^+h^-}} \sin(2\alpha_{\text{eff}}) \cdot \sin(\Delta m_d t) - C_{h^+h^-} \cos(\Delta m_d t)$$

digression: what is the meaning of "*T*" and "*P*" ?

- Example :

$$A(B^0 \to \pi^+\pi^-) = V_{ud}V_{ub}^*(T + P_u) + V_{cd}V_{cb}^*P_c + V_{td}V_{tb}^*P_t$$

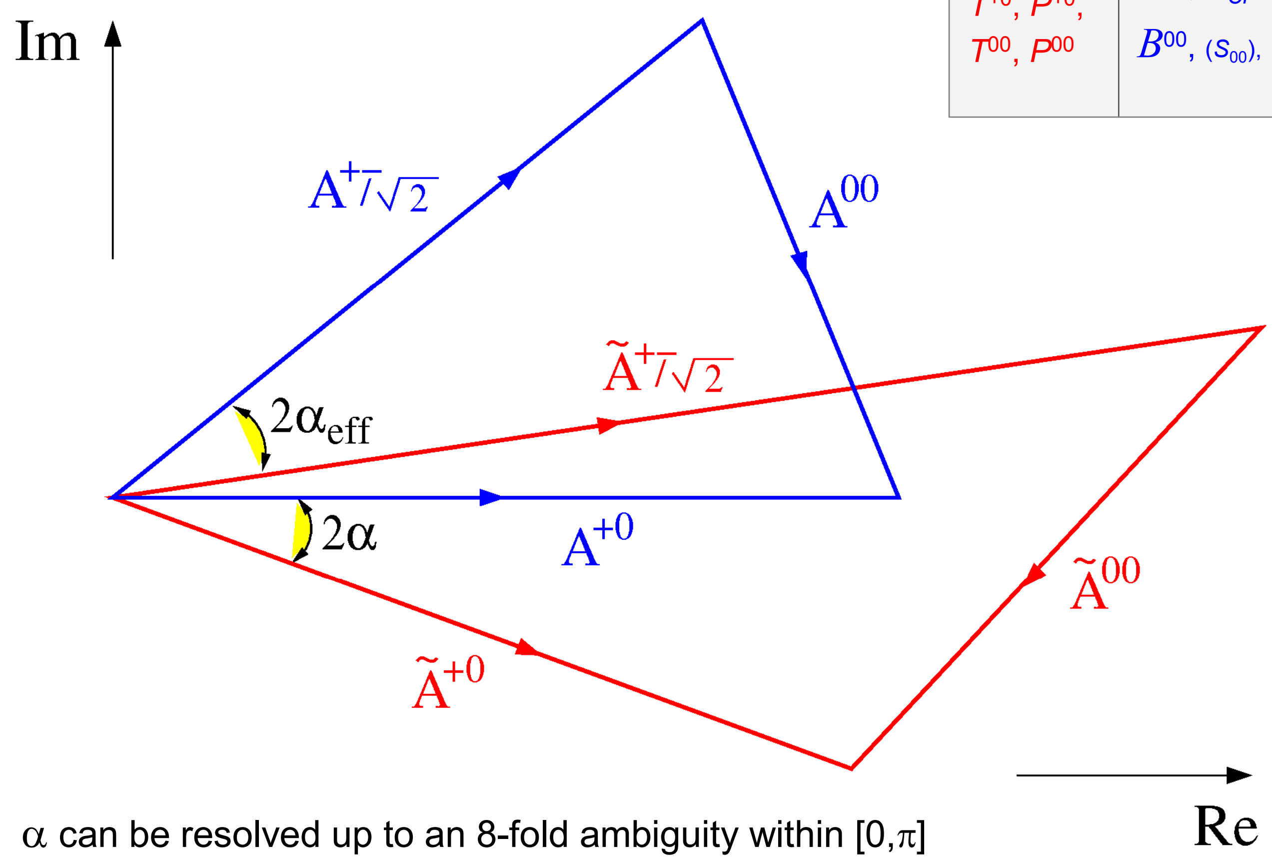
$$\text{unitarity} \;= \begin{cases} V_{cd}V_{cb}^*(P_c - P_u - T) + V_{td}V_{tb}^*(P_t - P_u - T) & \text{U - convention} \\ V_{ud}V_{ub}^*(T + P_u - P_c) + V_{td}V_{tb}^*(P_t - P_c) & \text{C - convention} \\ V_{ud}V_{ub}^*(T + P_u - P_t) + V_{cd}V_{cb}^*(P_c - P_t) & \text{T - convention} \end{cases}$$

"Tree" "Penguin"

→ The "tree" in the (most popular) C - and T - conventions has penguin contributions !

Isospin Analysis for $B \to \pi\pi,\ \rho\rho$

Unknowns	Observables	Constraints	Account
α, T^{+-}, P^{+-}, T^{+0}, P^{+0}, T^{00}, P^{00}	B^{+-}, $S_{\pi\pi}$, $C_{\pi\pi}$ B^{+0}, A_{CP} B^{00}, (S_{00}), C_{00}	2 isospin triangles and one common side	13 unknowns – 7 observ. – 5 constraints – 1 glob. phase = 0 ☺



α can be resolved up to an 8-fold ambiguity within $[0,\pi]$

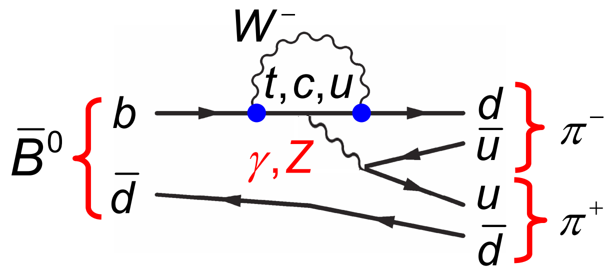
Assumptions:

- neglect EW penguins (shifts α by ~ +2°) penguins
- neglect SU(2) breaking
- in $\rho\rho$: Q2B approx. (neglect interference)

Refs. for SU(2) analyses : Gronau-London, PRL, 65, 3381 (1990), Lipkin *et al.*, PRD 44, 1454 (1991), a.o.

digression: Electroweak (EW) Penguins

- EW penguins can mediate $\Delta I = 3/2$ transitions and hence violate the SU(2) relations



$\propto V_{tb}V_{td}^*$
$\propto \lambda^3$

- Use "Fiertz" trick : the effective weak Hamiltonian of the decay $B \to \pi\pi$ reads:

$$H_{\text{eff}} = \frac{G_F}{\sqrt{2}}\left[V_{ub}V_{ud}^*\left(c_1O_1 + c_2O_2\right) - \sum_{i=3}^{10} V_{tb}V_{td}^* c_i O_i\right] + \text{h.c.}$$

where O_1 and O_2 are $(V\text{–}A)\times(V\text{–}A)$ tree operators and $O_{7\text{-}10}$ EW penguins operators

O_7 and O_8 have Lorentz structure $(V\text{–}A)\times(V\text{+}A)$ while O_9 and O_{10} are $(V\text{–}A)\times(V\text{–}A)$

but: $c_7, c_8 \ll c_9, c_{10}$ so that one can Fiertz-relate the EW O_9, O_{10} to the tree O_1, O_2 :

$$P_{EW}^{+-} = \left(T^{+-}/\sqrt{2} + T^{00}\right)\left|V_{tb}^*V_{td}/V_{ub}^*V_{ud}\right| \cdot f\left(\frac{c_9 + c_{10}}{c_1 + c_2}\right)$$

Neubert-Rosner,
PLB 441, 403 (1998)
PRL 81, 5076 (1998)

- Hence, if $f(\ldots)$ real, $A_{CP}(\pi^+\pi^0)$ not sensitive to P_{EW} !

CP Results for $B^0 \to \pi^+\pi^-$

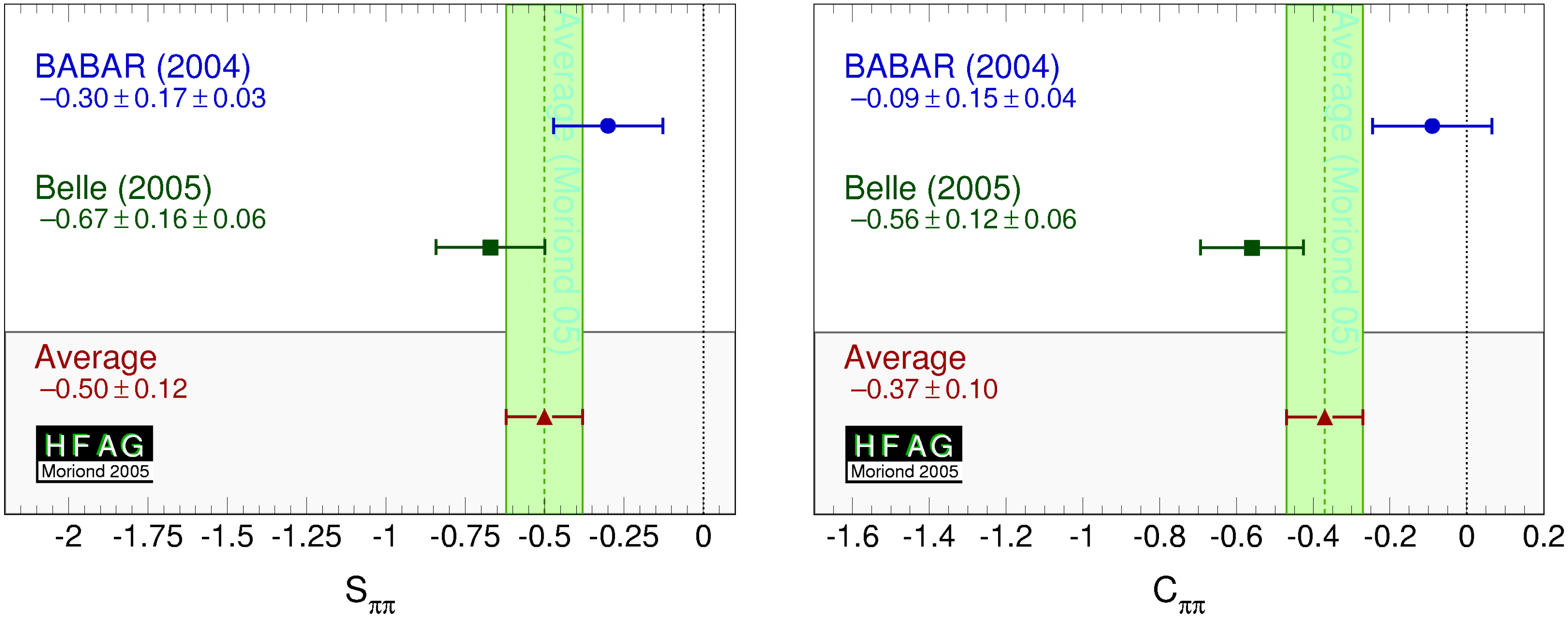
- Results for the time-dependent analysis :

	BABAR (227m)	Belle (275m)	Average
$S_{\pi\pi}$	$-0.30 \pm 0.17 \pm 0.03$	$-0.67 \pm 0.16 \pm 0.06$	-0.50 ± 0.12
$C_{\pi\pi}$	$-0.09 \pm 0.15 \pm 0.04$	$-0.56 \pm 0.12 \pm 0.06$	-0.37 ± 0.10

BABAR, hep-ex/0501071
Belle, hep-ex/0502035

Mediocre (but improved) agreement :

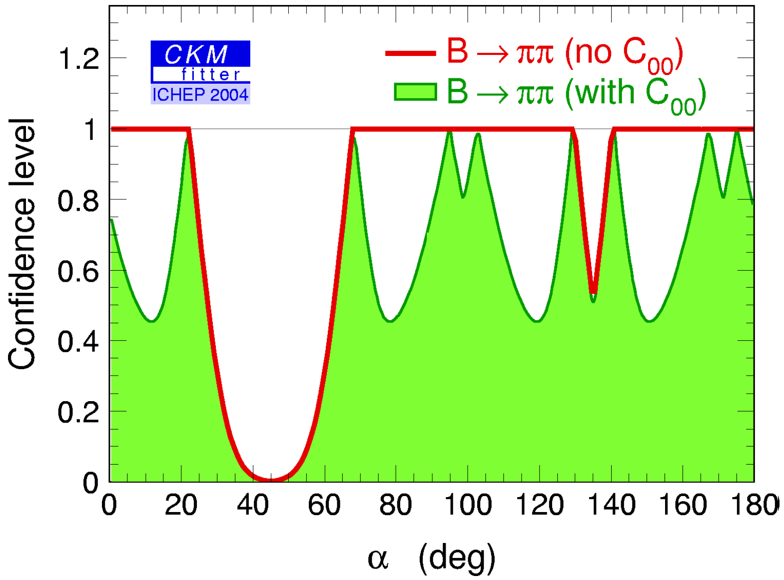
$\chi^2 = 7.9$ (CL = 0.019 $\Rightarrow$ 2.3σ)



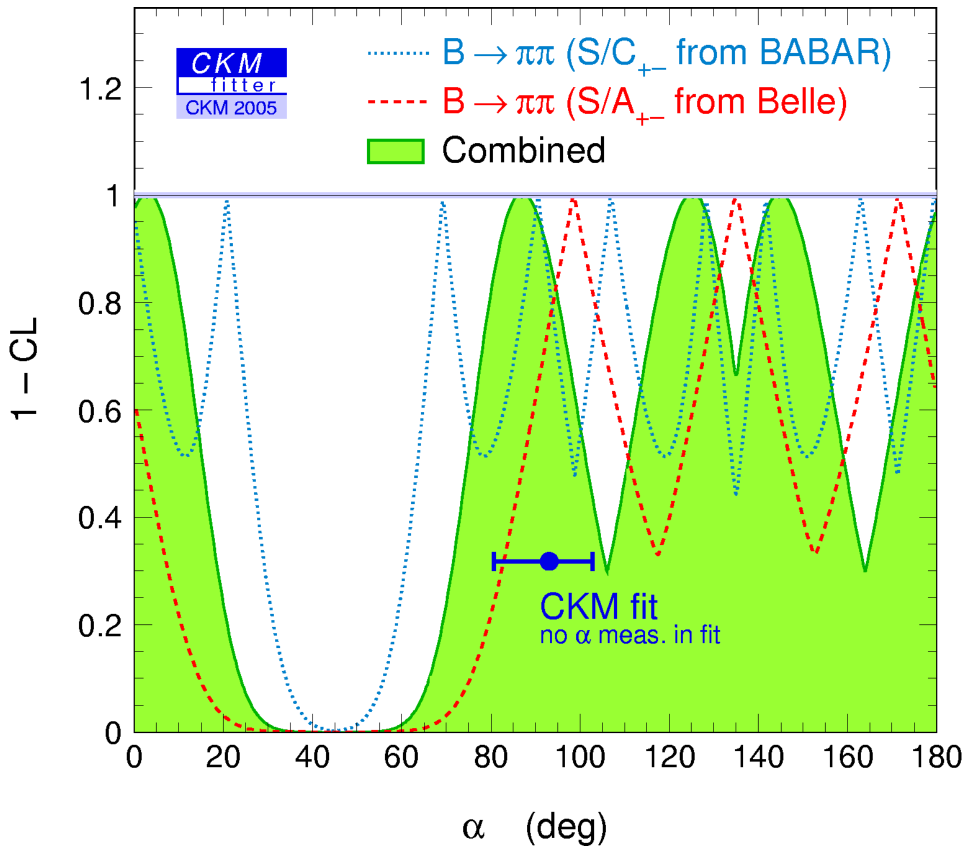
$B \to \pi\pi$ Isospin Analysis

- χ^2 fit of isospin relations to observables: $|\alpha - \alpha_{\rm eff}| < 38^\circ$ (90% CL)

BABAR



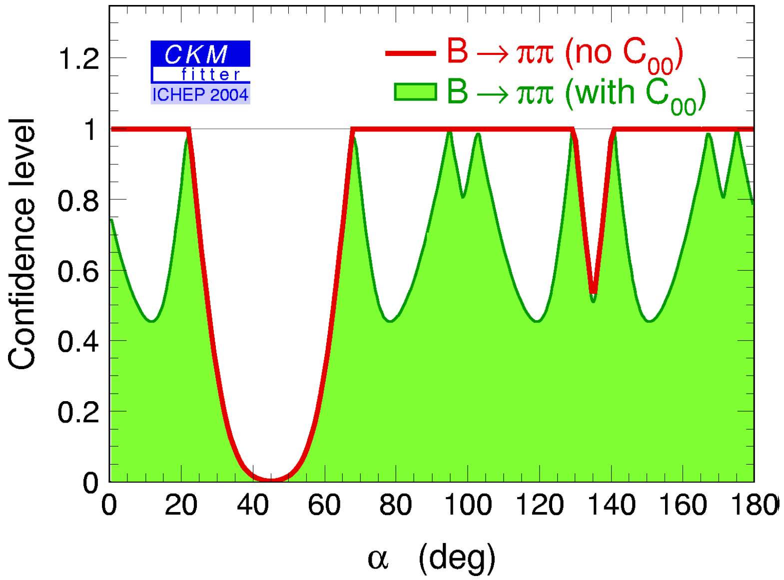
BABAR & Belle



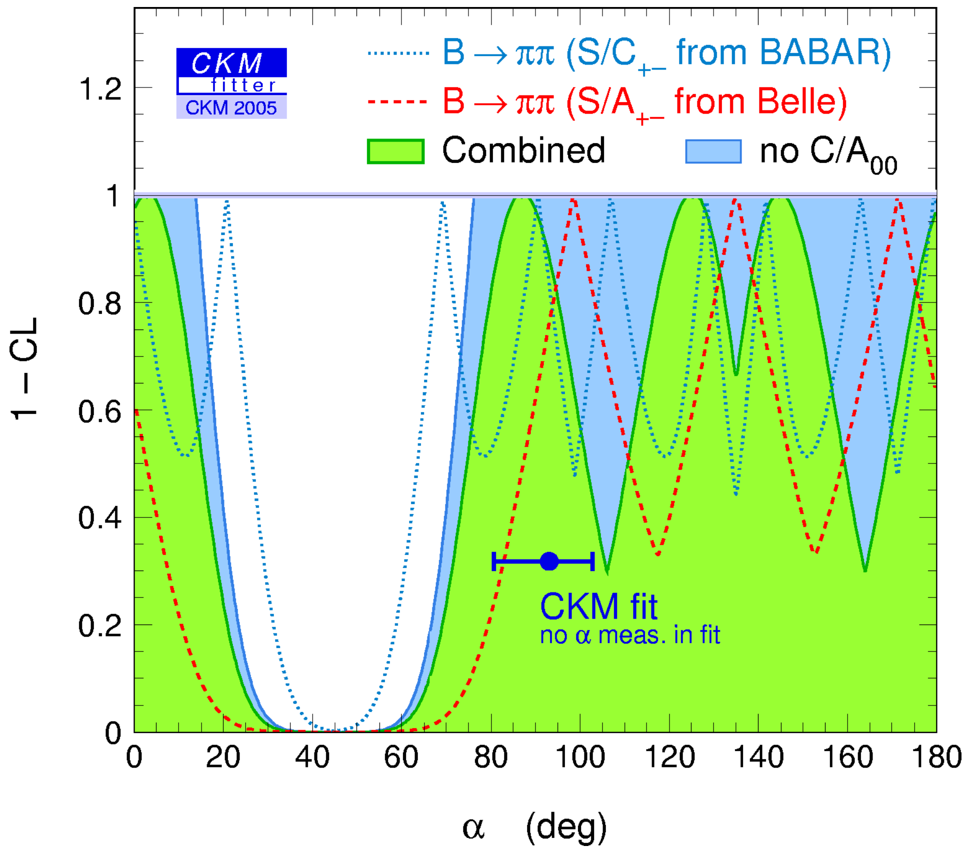
$B \to \pi\pi$ Isospin Analysis

- χ^2 fit of isospin relations to observables: $|\alpha - \alpha_{\text{eff}}| < 38^\circ$ (90% CL)

BABAR



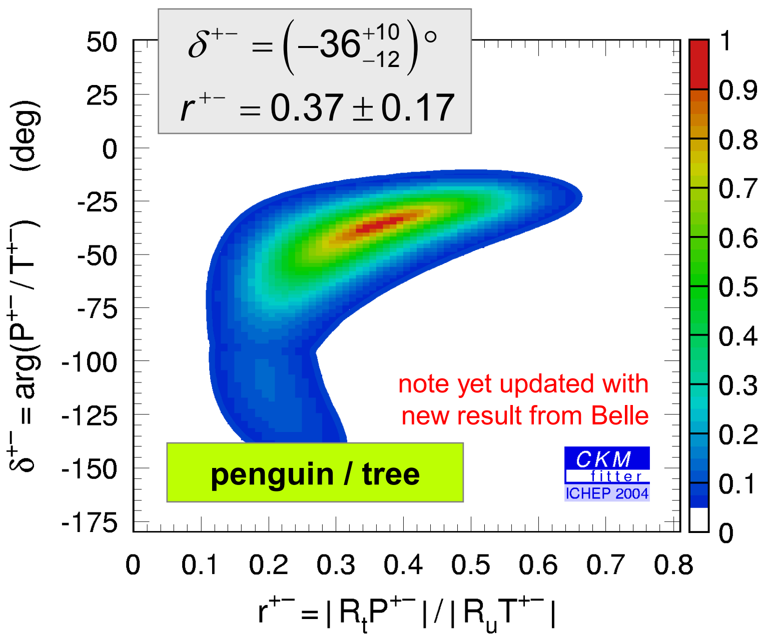
BABAR & Belle



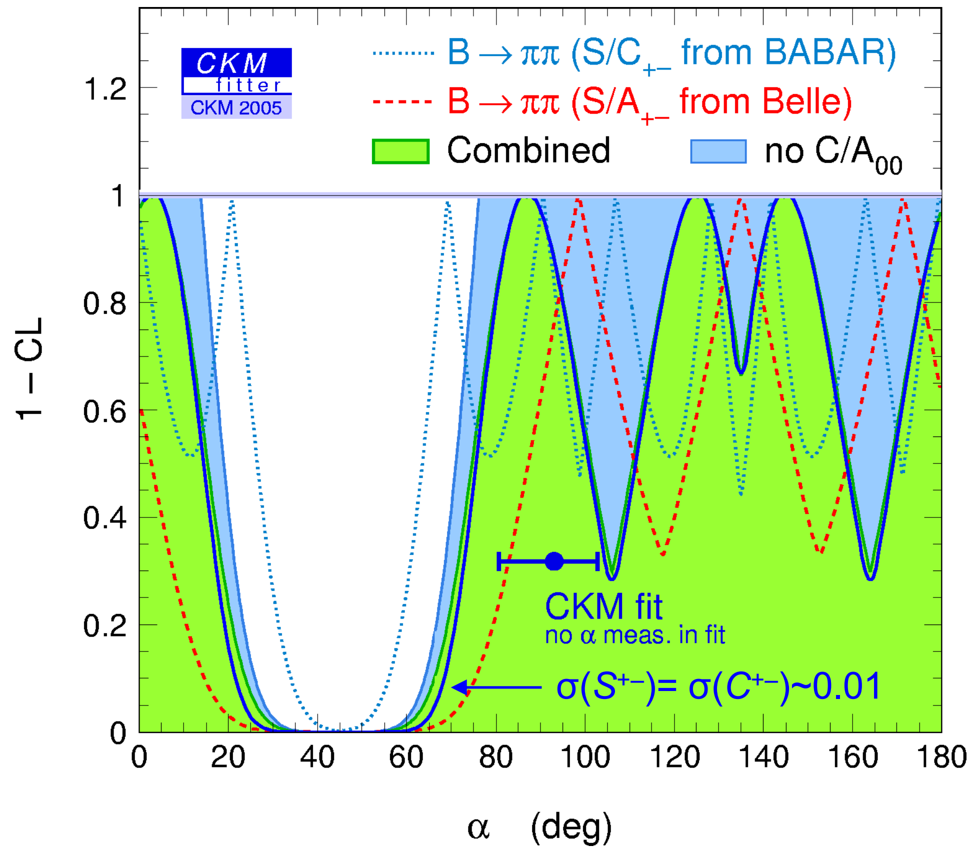
$B \rightarrow \pi\pi$ Isospin Analysis

- χ^2 fit of isospin relations to observables: $|\alpha - \alpha_{eff}| < 38°$ (90% CL)

BABAR & Belle



BABAR & Belle



- Study decay dynamics ...

A "surprise" : $B \to \rho\rho$

- Nature's great present : longitudinal polarization dominates ➡ almost no *CP* dilution
- Branching fractions for the $B \to \rho\rho$ system :

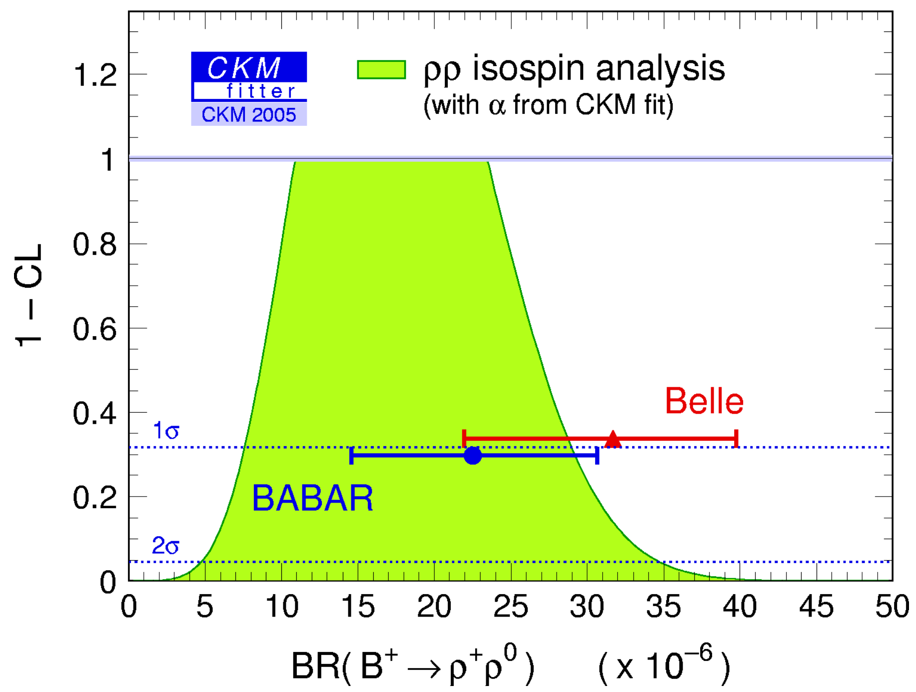
$$\mathcal{B}^{+-} = (30 \pm 6)\times10^{-6}\,,\ \ \mathcal{B}^{+0} = (26.4\,^{+6.1}_{-6.4})\times10^{-6}\,,\ \ \mathcal{B}^{00} < 1.1\times10^{-6} \text{ at } 90\% \text{ CL}$$

BABAR, hep-ex/0412067

- Small $\mathcal{B}^{00}/\mathcal{B}^{+0}$ ratio requires small penguins !
- But: $P^{+-} = 0$ would mean that : $\mathcal{B}^{+-}/\mathcal{B}^{+0} \to 2$
- Test : input α from CKM fit, and solve isospin analysis without $\mathcal{B}^{+0}$ in fit :

$$8\times10^{-6} < \mathcal{B}^{+0} < 29\times10^{-6}$$

[1σ region]



$B \to \rho\rho$ Isospin Analysis

- Results from *CP* fit : BABAR, hep-ex/0503049

	BABAR (232m)
f_L	$0.978 \pm 0.014\,^{+0.021}_{-0.029}$
$S_{\rho\rho,L}$	$-0.33 \pm 0.24\,^{+0.08}_{-0.14}$
$C_{\rho\rho,L}$	$-0.03 \pm 0.18 \pm 0.09$

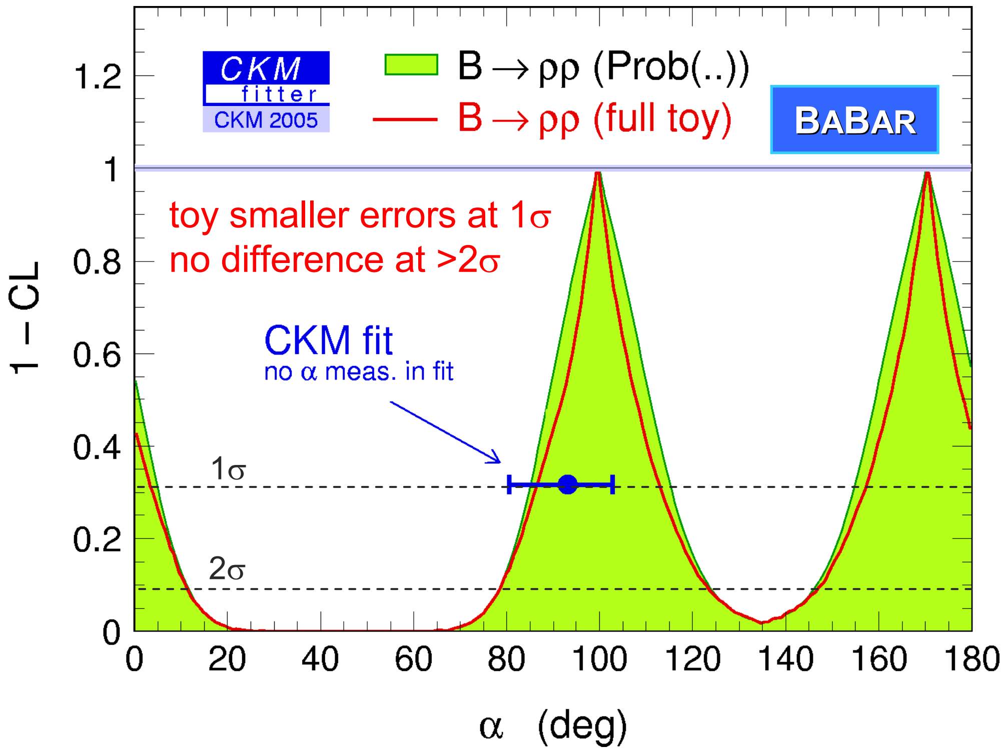
- Isospin analysis :

$$\left|\alpha - \alpha_{\text{eff}}\right| < 14^\circ \quad (90\%\ \text{CL})$$

full toy

$$\alpha = (100 \pm 13)^\circ$$

of which 11° is due to penguins



penguin / tree
$\delta^{+-} = (\ldots)^\circ$
$r^{+-} = 0.07^{+0.14}_{-0.07}$

As expected: much smaller than in $B \to \pi\pi$

$B \to \rho\rho$ Isospin Analysis

- Results from *CP* fit : BABAR, hep-ex/0503049

	BABAR (232m)
f_L	$0.978 \pm 0.014\ ^{+0.021}_{-0.029}$
$S_{\rho\rho,L}$	$-0.33 \pm 0.24\ ^{+0.08}_{-0.14}$
$C_{\rho\rho,L}$	$-0.03 \pm 0.18 \pm 0.09$

- Isospin analysis :

$$|\alpha - \alpha_{\text{eff}}| < 14^\circ \quad (90\%\ \text{CL})$$

full toy

$$\alpha = (100 \pm 13)^\circ$$

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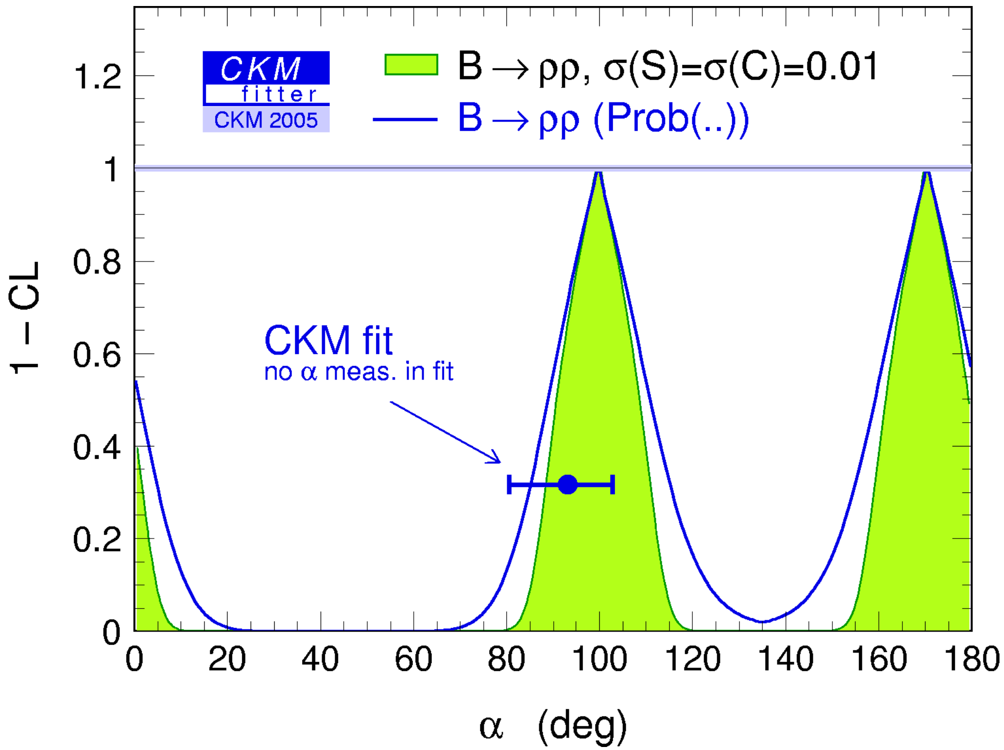


penguin / tree

$$\delta^{+-} = (\ldots)^\circ$$
$$r^{+-} = 0.07^{+0.14}_{-0.07}$$

As expected: much smaller than in $B \to \pi\pi$

The $B \to \rho\pi$ System

- Dominant mode $\rho^+\pi^-$ is not a *CP* eigenstate

  Aleksan *et al*, NP B361, 141 (1991)

- Q2B Isospin analysis requires to constrain pentagon

  Lipkin *et al.*, PRD 44, 1454 (1991)

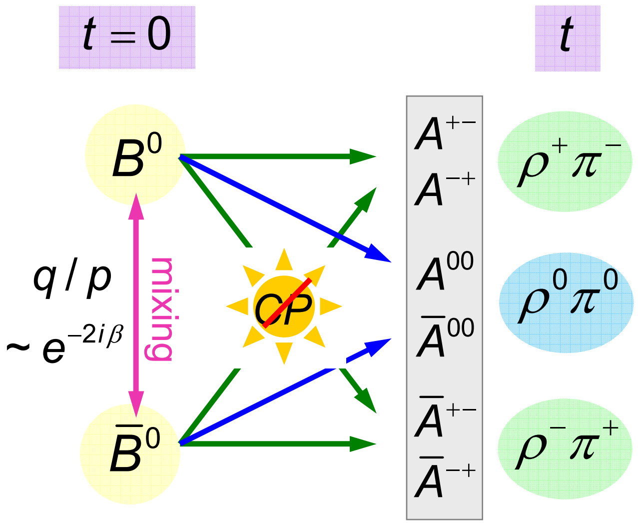
  - 13 observables vs 12 unknowns ☺
  - needs statistics of Super-*B* ☹ [systematics?]

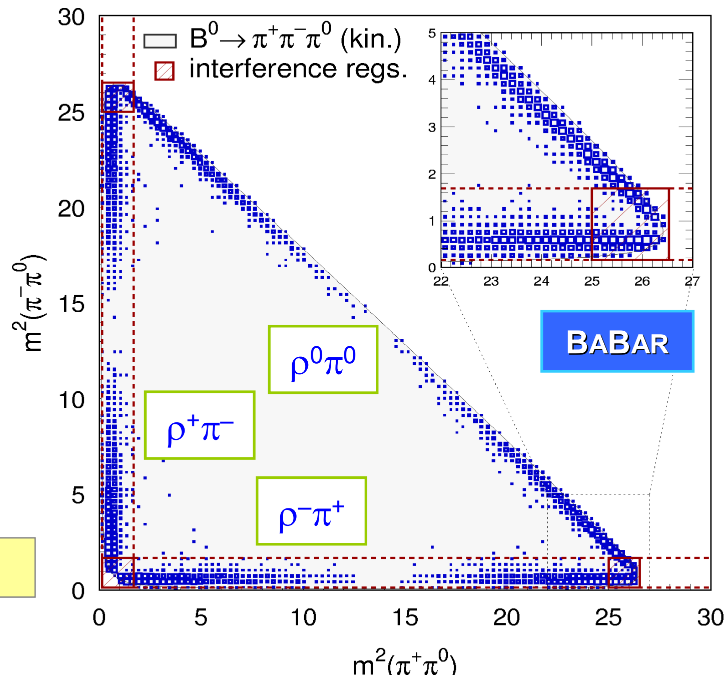
- Better: exploit amplitude interference in Dalitz plot

  Snyder-Quinn, PRD 48, 2139 (1993)

  - simultaneous fit of α and strong phases
  - BABAR determines 16 (27) FF coefficients
  - correlated χ^2 fit to determine physics quantities

BABAR, hep-ex/0408099





Results of $B^0 \to (\rho\pi)^0 \to \pi^+\pi^-\pi^0$ Dalitz analysis

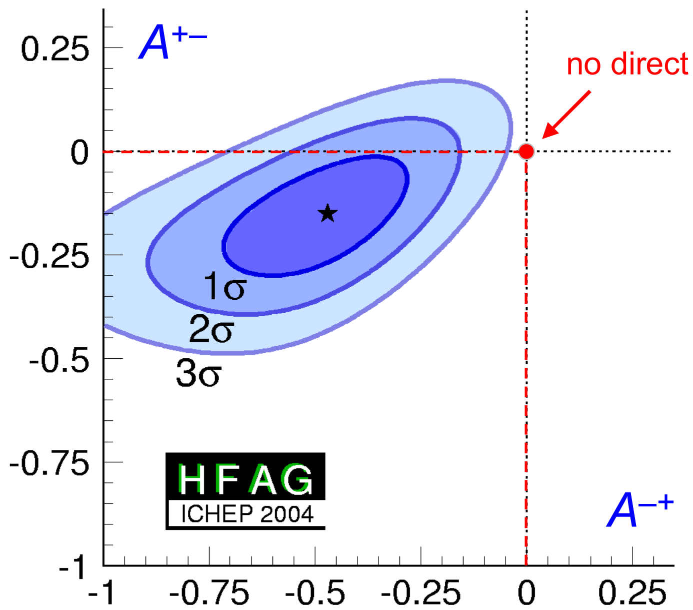
- From the 16 FF coefficients one determines the physical parameters :

Direct *CP* violation ?

Average : BABAR (213m) & Belle (152m)

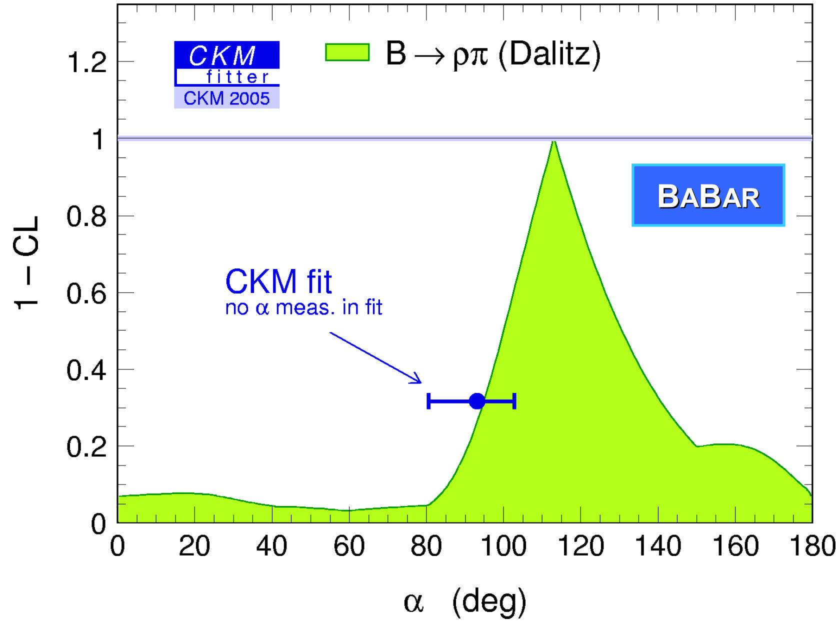
A^{+-} -0.15 ± 0.09	A^{-+} $-0.47^{+0.13}_{-0.14}$

$\Delta\chi^2$(no direct CPV) = 14.5 (CL = 0.00070 $\Rightarrow$ 3.4σ)



Parameters : α, $|T^{+-}|, T^{-+}, T^{00}, P^{+-}, P^{-+}$

Scan in α using the bilinears :

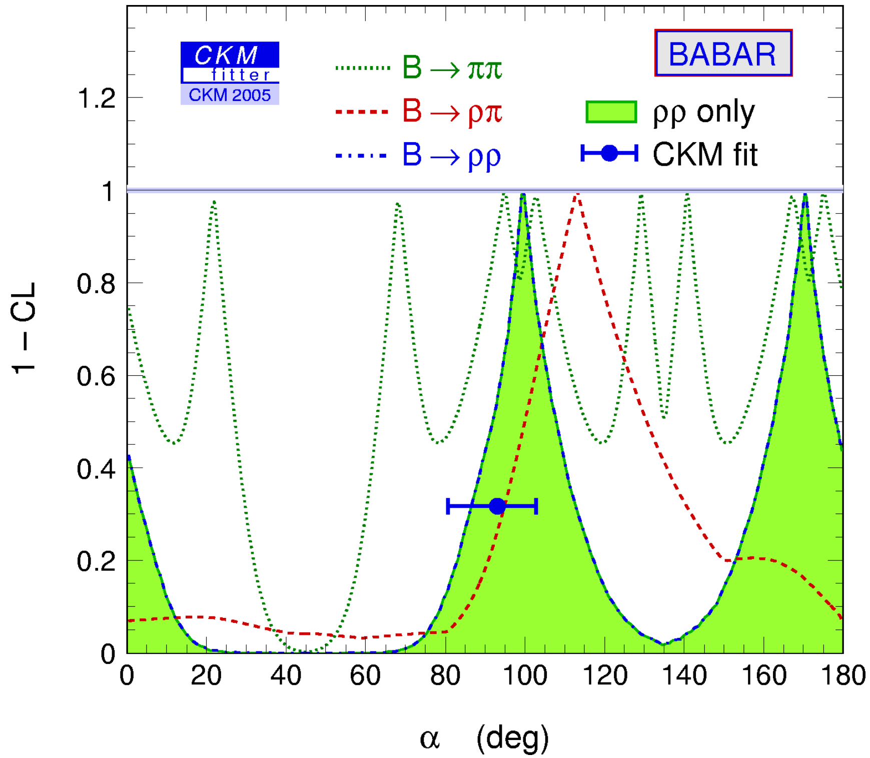


BABAR, hep-ex/0408099

Combination of $\pi\pi$, $\rho\pi$, $\rho\rho$: first measurement of α

- Combining the three analyses ($B \to \rho\rho$ best single measurement) :
  - mirror solution disfavored
  - for the SM solution we find :

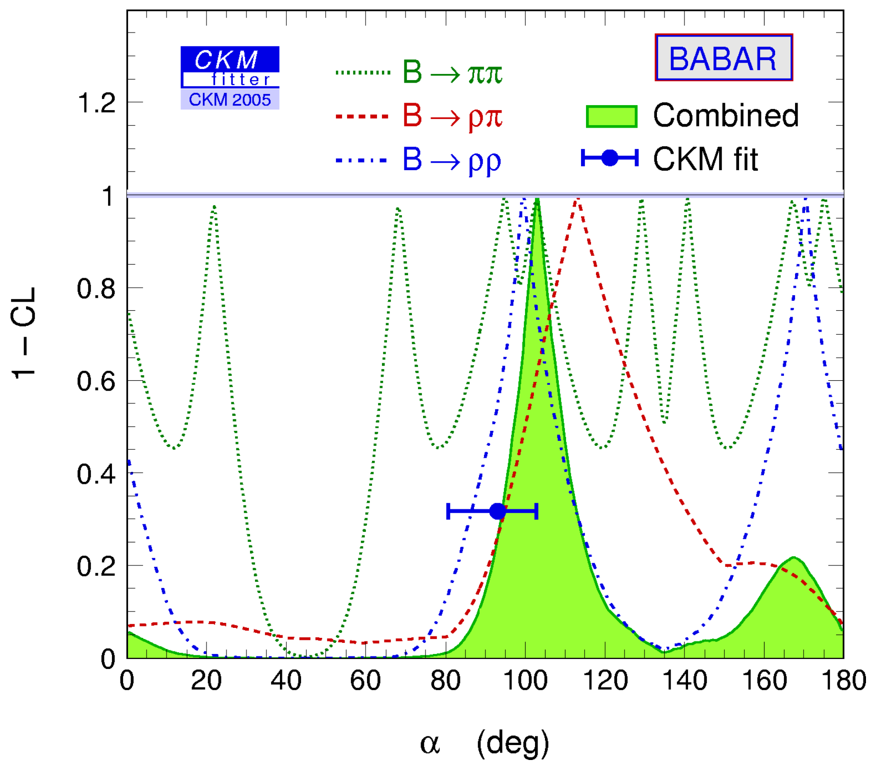
$$\alpha_{\rho\rho} = [100 \pm 13]^\circ$$



Combination of $\pi\pi$, $\rho\pi$, $\rho\rho$: first measurement of α

- Combining the three analyses ($B \to \rho\rho$ best single measurement) :
  - mirror solution disfavored
  - for the SM solution we find :

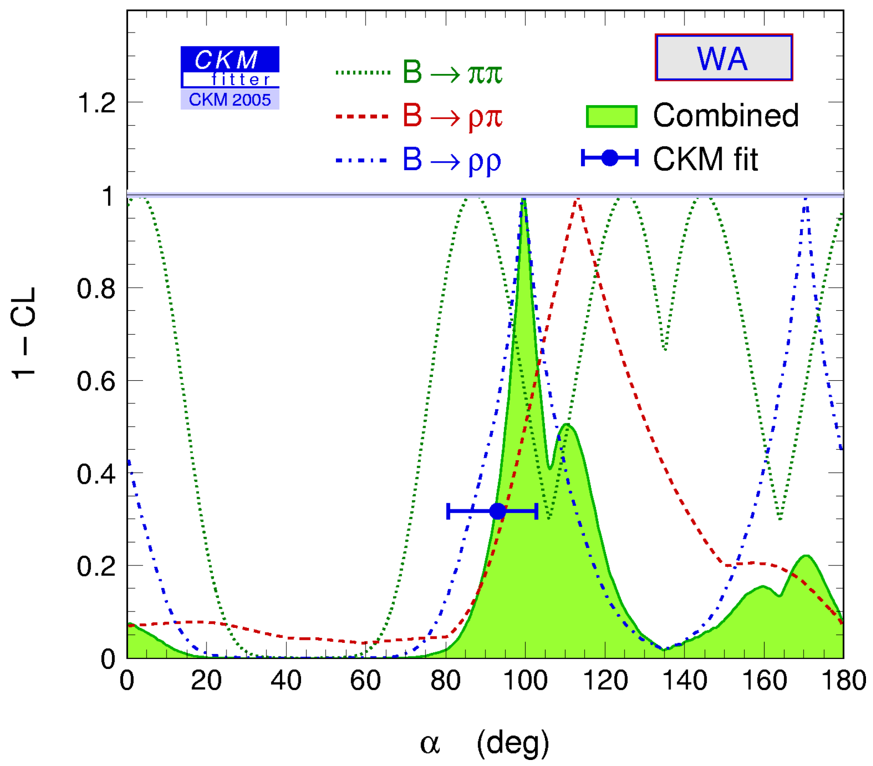
$$\alpha_{\pi\pi\text{-BABAR}} = \left[103\,^{+10}_{-9}\right]^{\circ}$$

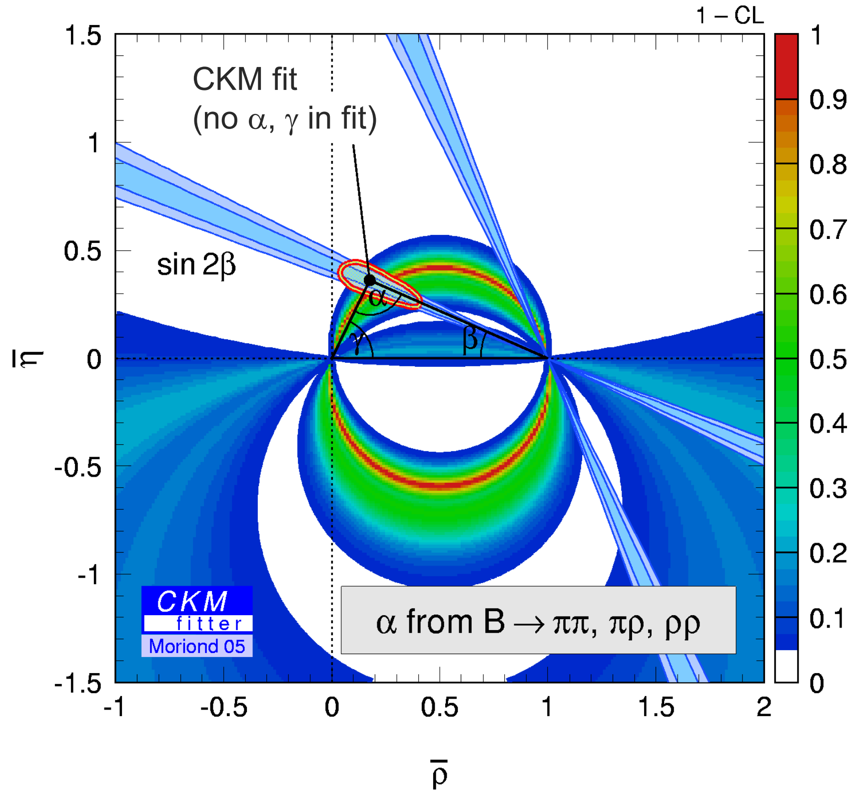


Combination of $\pi\pi$, $\rho\pi$, $\rho\rho$: first measurement of α

- Combining the three analyses ($B \to \rho\rho$ best single measurement) :
  - mirror solution disfavored
  - for the SM solution we find :
  - similar precision as CKM fit :

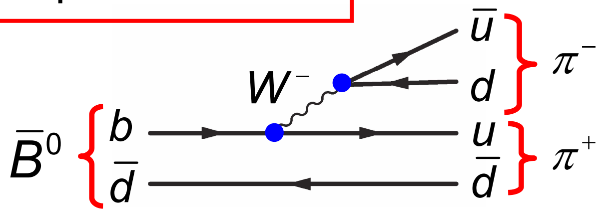
$$\alpha_{B\text{-Factories}} = \left[101\,^{+16}_{-9}\right]^\circ \quad \Rightarrow \quad \alpha_{\text{CKM}} = \left[93\,^{+10}_{-13}\right]^\circ$$

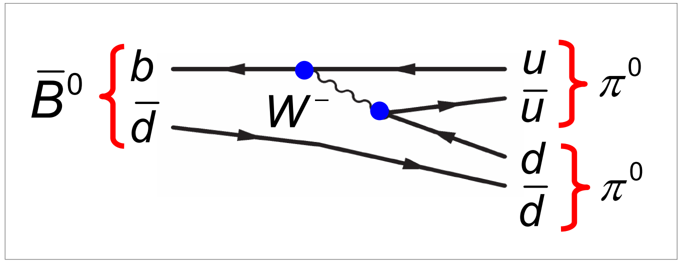




digression : “Color-Suppressed” Amplitudes

Example : $b \to u\bar{u}d$





Famous modes :

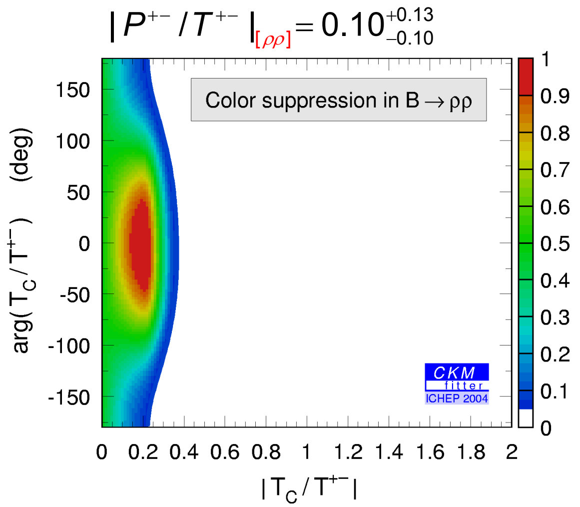
$B^0 \to \pi^0\pi^0$

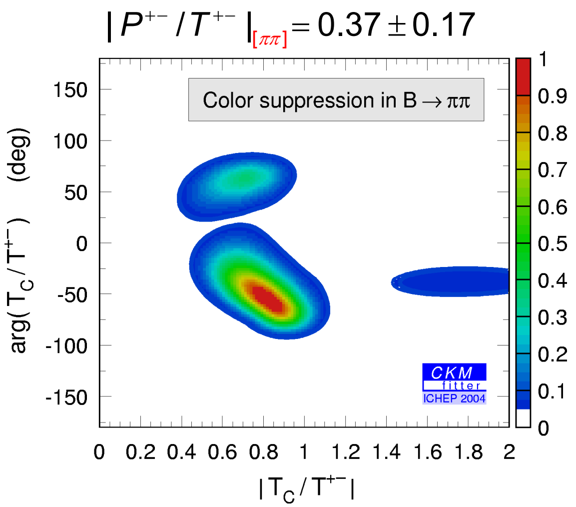
$B^0 \to \rho^0\pi^0$

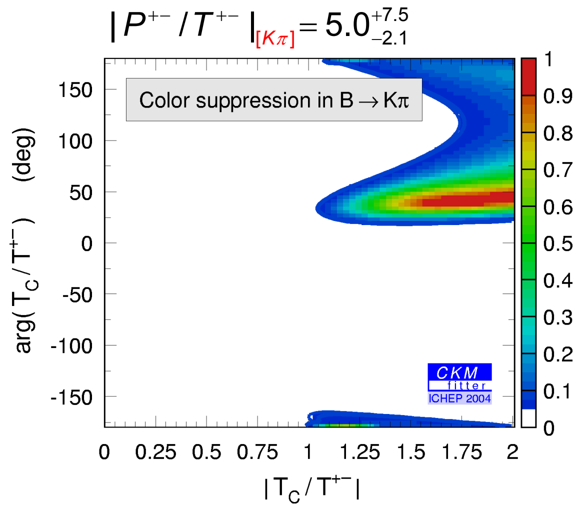
$B^0 \to \rho^0\rho^0$

- The color of the quarks emitted by the virtual W must correspond to the external quark lines to produce color-singlets ➡ suppression by ~$1/N_c$ (naïve!)

[Suppression ≈ verified in $\mathcal{B}(B^0 \to D^0\pi^0)/\mathcal{B}(B^0 \to D^-\pi^+) = (1/10.4)_{\rm exp} \approx (1/N_c)^2$]







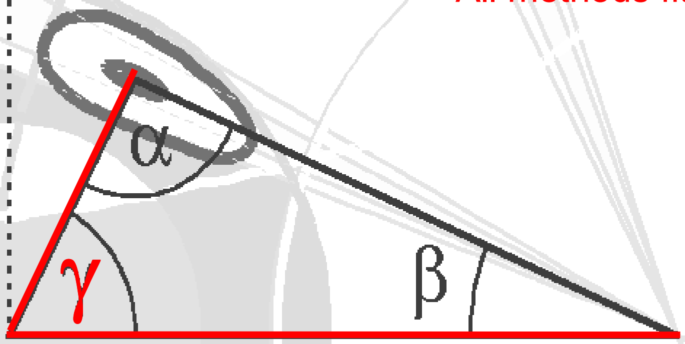
➡ important non-factorizable contributions when large penguins ? Large *u*-penguins ?

γ [next UT input that is not theory limited]

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

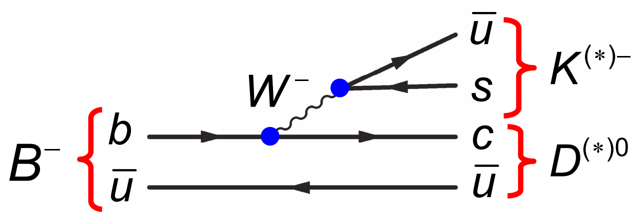
the million dollar Q:

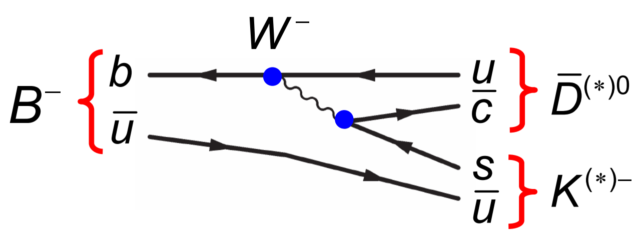
$\left.\begin{array}{l} r_B \\ r_B^* \end{array}\right\}$ how small ?



- GLW : D^0 decays into *CP* eigenstate
- ADS : D^0 decays to $K^-\pi^+$ (favored) and $K^+\pi^-$ (suppressed)
- GGSZ : D^0 decays to $K_S\pi^+\pi^-$ (interference in Dalitz plot)
  - All methods fit simultaneously: γ, r_B and θ

Gronau-London, PL B253, 483 (1991); Gronau-Wyler, PL B265, 172 (1991)
Atwood-Dunietz-Soni, PRL 78, 3257 (1997)
Giri *et al*, PRD 68, 054018 (2003)





No Penguins ☺

Tree: dominant $\propto V_{cb}V_{us}^*$ $\propto \lambda^3$

Tree: color-suppressed $\propto V_{ub}V_{cs}^*$ $\propto \lambda^3\sqrt{\rho^2+\eta^2}$

relative CKM phase : γ

“ADS+GLW” : Constraint on γ

- BABAR and Belle have measured the observables for GLW and ADS in the modes $B^- \to D^0K^-$, $D^{*0}K^-$, D^0K^{*-}

  not yes used

  - No significant measurement of suppressed amplitude yet $\Rightarrow$ limit : $r_B^{(*)} \lesssim 0.2$

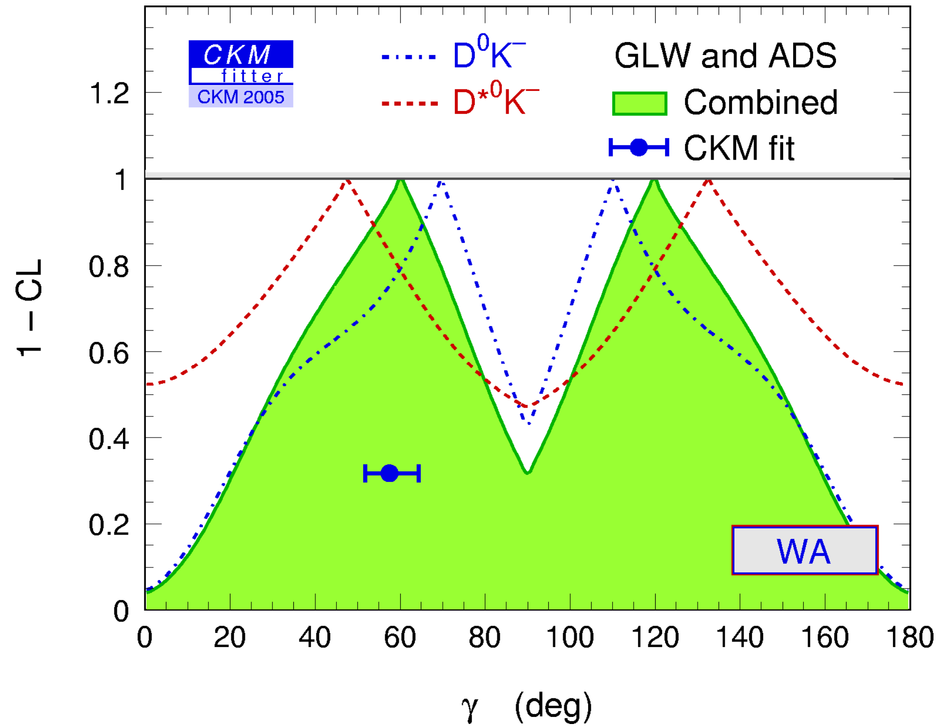
BABAR, hep-ex/0408082, hep-ex/0408060
hep-ex/0408069, hep-ex/0408028

Belle, Belle-CONF-0443, hep-ex/0307074
hep-ex/0408129

  - for the SM solution :

$$\gamma_{meas} = \left[60\,^{+30}_{-39}\right]^\circ$$

$$\gamma_{CKM} = \left[58\,^{+7}_{-5}\right]^\circ$$

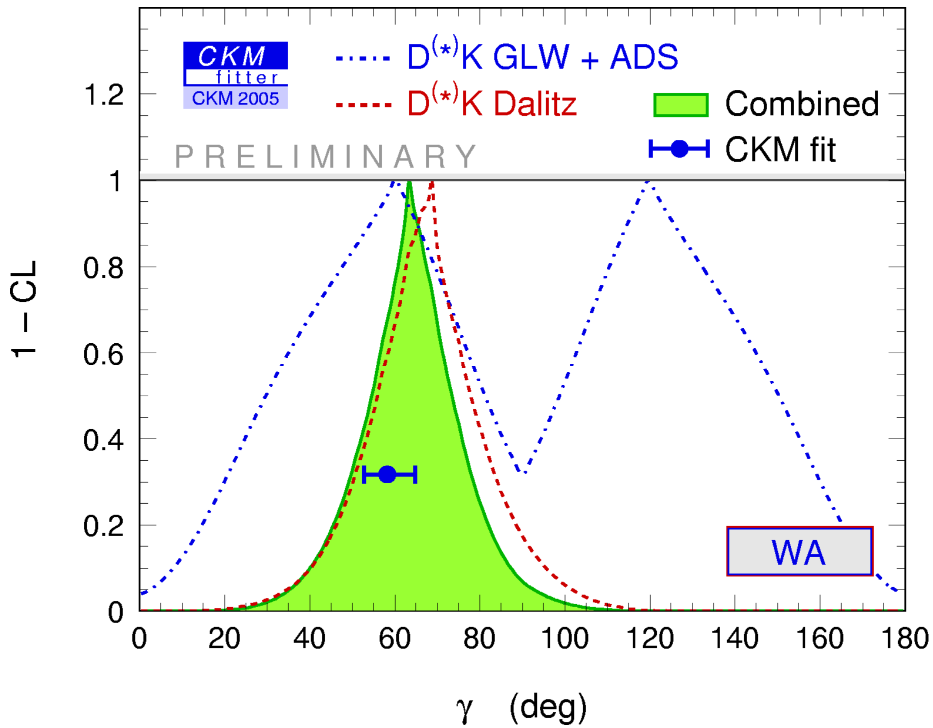


  - not yet competitive with CKM fit

"GGSZ" : Constraint on γ

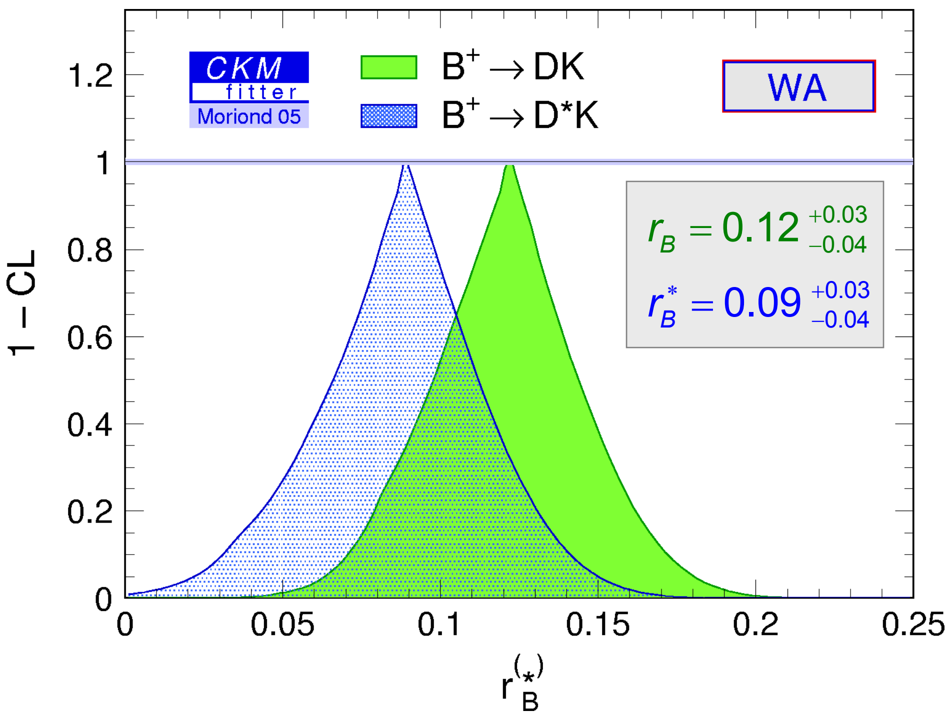
- Promising : Increase *B* decay interference through *D* decay Dalitz plot with $D^0 \rightarrow K_S \pi^+ \pi^-$
  - huge number of resonances to model: $K^*(892)$, $\rho(770)$, $\omega(782)$, $f_0(980{,}1370)$, $K_0^*(1430)$, ... ☹
  - amplitudes of Dalitz plot measured in charm control sample ☺

$$\gamma_{\text{meas}} = \left[63\,^{+15}_{-13}\right]^\circ$$



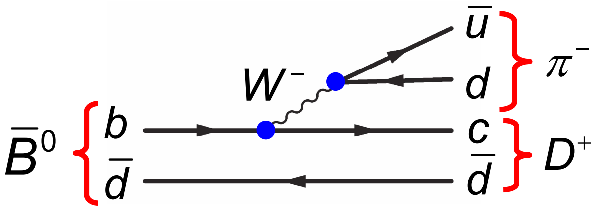
Measurement of amplitude ratio:

[no improved constraint when adding γ from CKM fit]



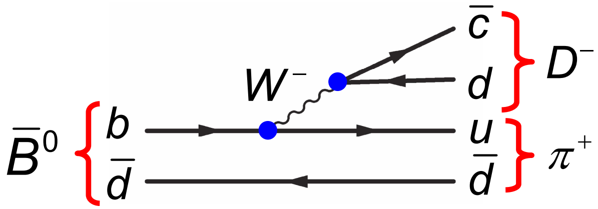
$b \to c\bar{u}d, u\bar{c}d$

"sin(2β + γ)"



Tree: dominant

$\propto V_{cb}V_{ud}^*$
$\propto \lambda^2$



Tree: doubly CKM-suppressed

$\propto V_{ub}V_{cd}^*$
$\propto \lambda^4$

Similarly: $B_s^0(\bar{B}_s^0) \to D_s^- K^+$
golden γ mode at LHCb

- Relative weak phase 2β + γ

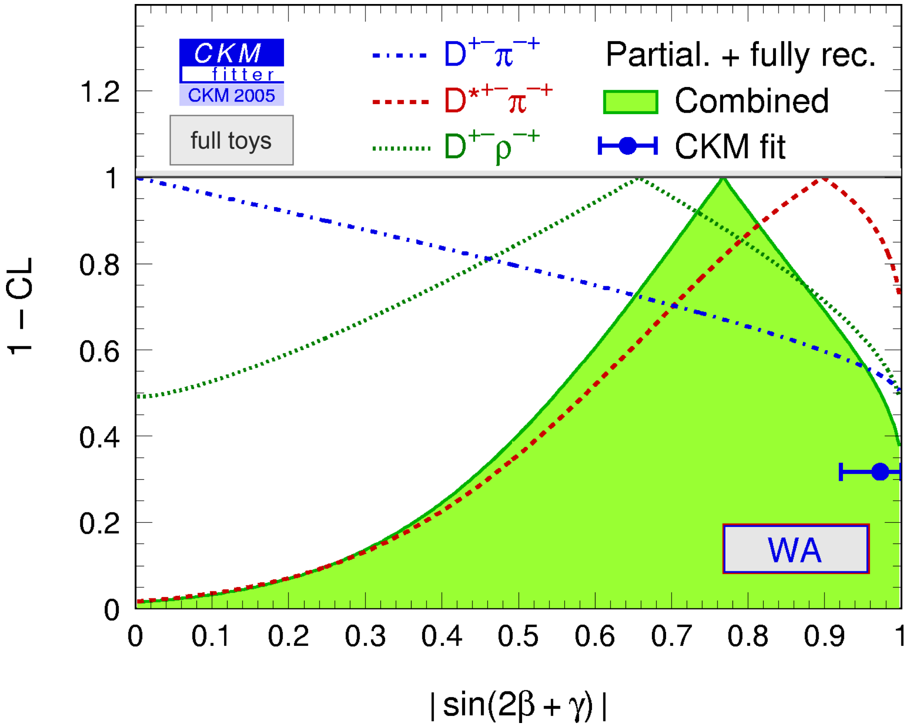
but : γ dependence of the order of $O(10^{-4})$

- Huge statistics, but small *CP* asymmetry
- Unknowns : r_{B0}, γ and δ $\Rightarrow$ needs external input
- Use SU(3) to estimate $r_{B0}^{(*)}$ (theory error: 30%)

therefore not used in global CKM fit

BABAR, hep-ex/0408038, hep-ex/0408059

Belle, hep-ex/0408106, PRL 93 (2004) 031802; Erratum-ibid. 93 (2004) 059901

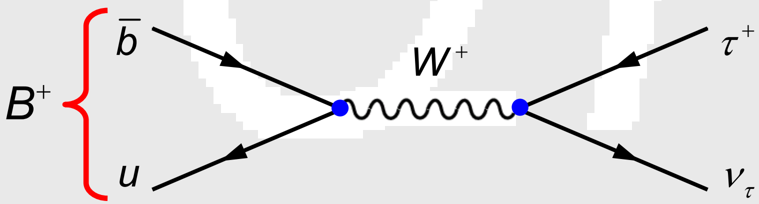


$B^+ \to \tau^+\nu_\tau$

- A new star at the horizon; helicity-suppressed annihilation decay sensitive to $f_B \times |V_{ub}|$
- Powerful <u>together</u> with Δm_d : removes f_B dependence

<u>not</u> to be used as a measurement of f_B !

- Sensitive to charged Higgs replacing the *W* propagator



$$\mathrm{BR}(B^+ \to \tau^+\nu) = \frac{G_F^2 m_B \tau_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 \, |V_{ub}|^2$$

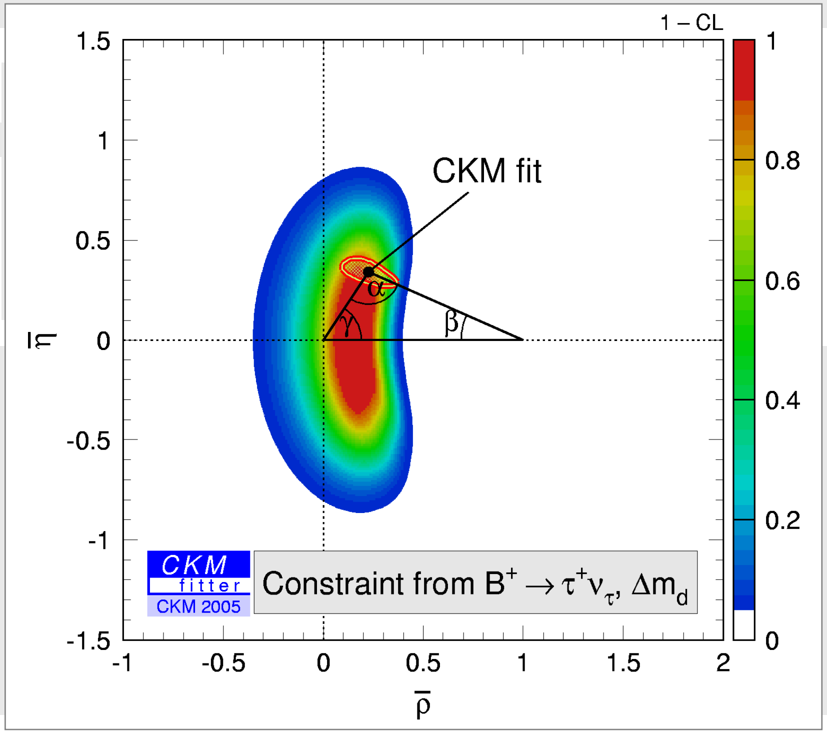
- Best current limit from BABAR :

$$\mathrm{BR}(B^+ \to \tau^+\nu) = 13\,^{+10}_{-9} \times 10^{-5}$$
$$< 26 \times 10^{-5} \text{ at } 90\% \text{ CL}$$

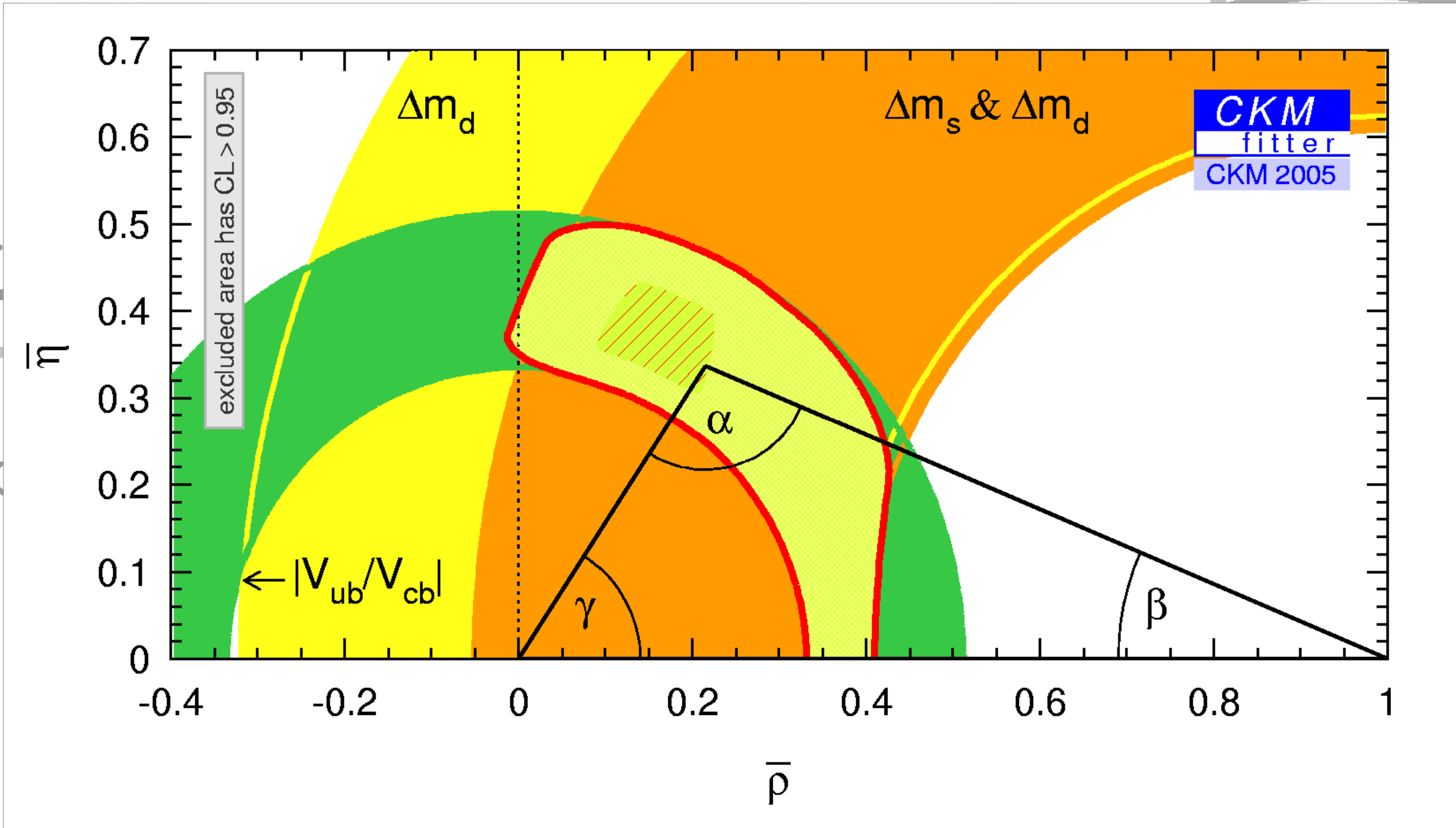
Datta, SLAC seminar 2005

- Prediction from global CKM fit :

$$\mathrm{BR}(B^+ \to \tau^+\nu) = 8.9\,^{+3.9}_{-1.7} \times 10^{-5}$$



Putting it all together — the global CKM fit



Inputs:

$\left|\frac{V_{ub}}{V_{cb}}\right|$

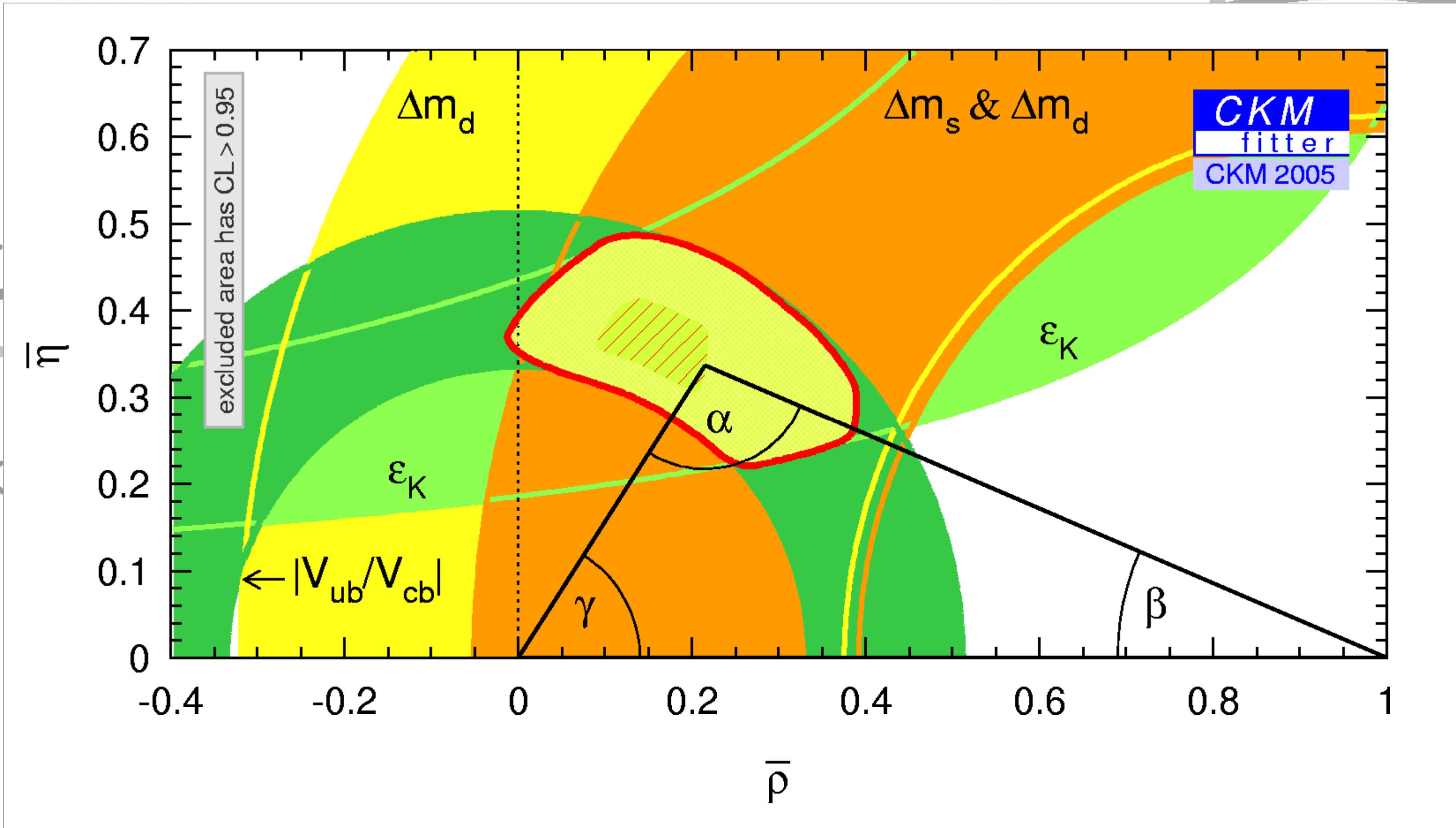
Δm_d

Δm_s

$B \to \tau\nu$

Perfect agreement … if it weren't for the *s*-penguin decays

Putting it all together — the global CKM fit



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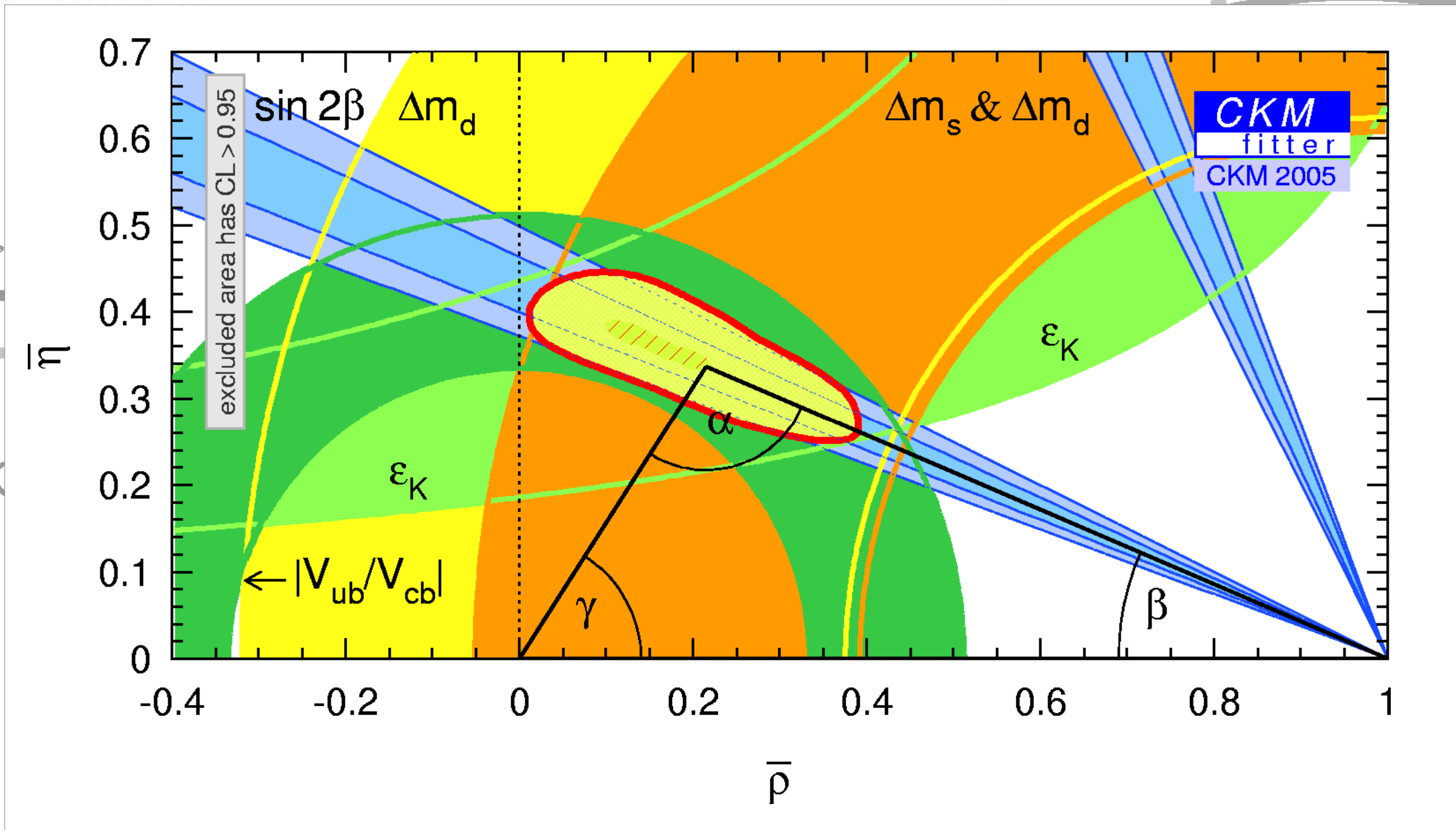

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Δm_s

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$|\varepsilon_K|$

$\sin 2\beta$

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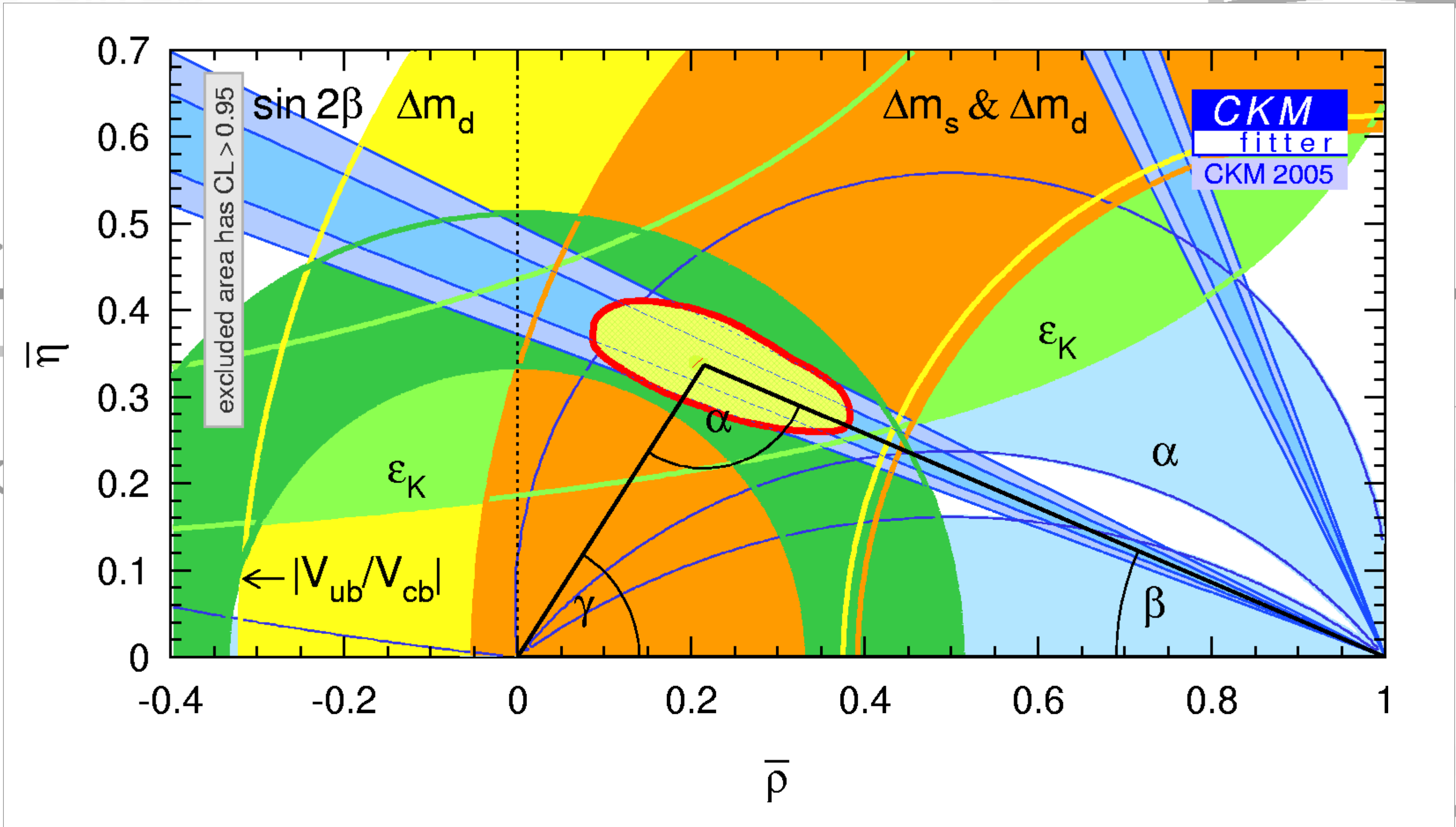


Inputs:

$\left|\frac{V_{ub}}{V_{cb}}\right|$

Δm_d

Δm_s

$B \to \tau\nu$

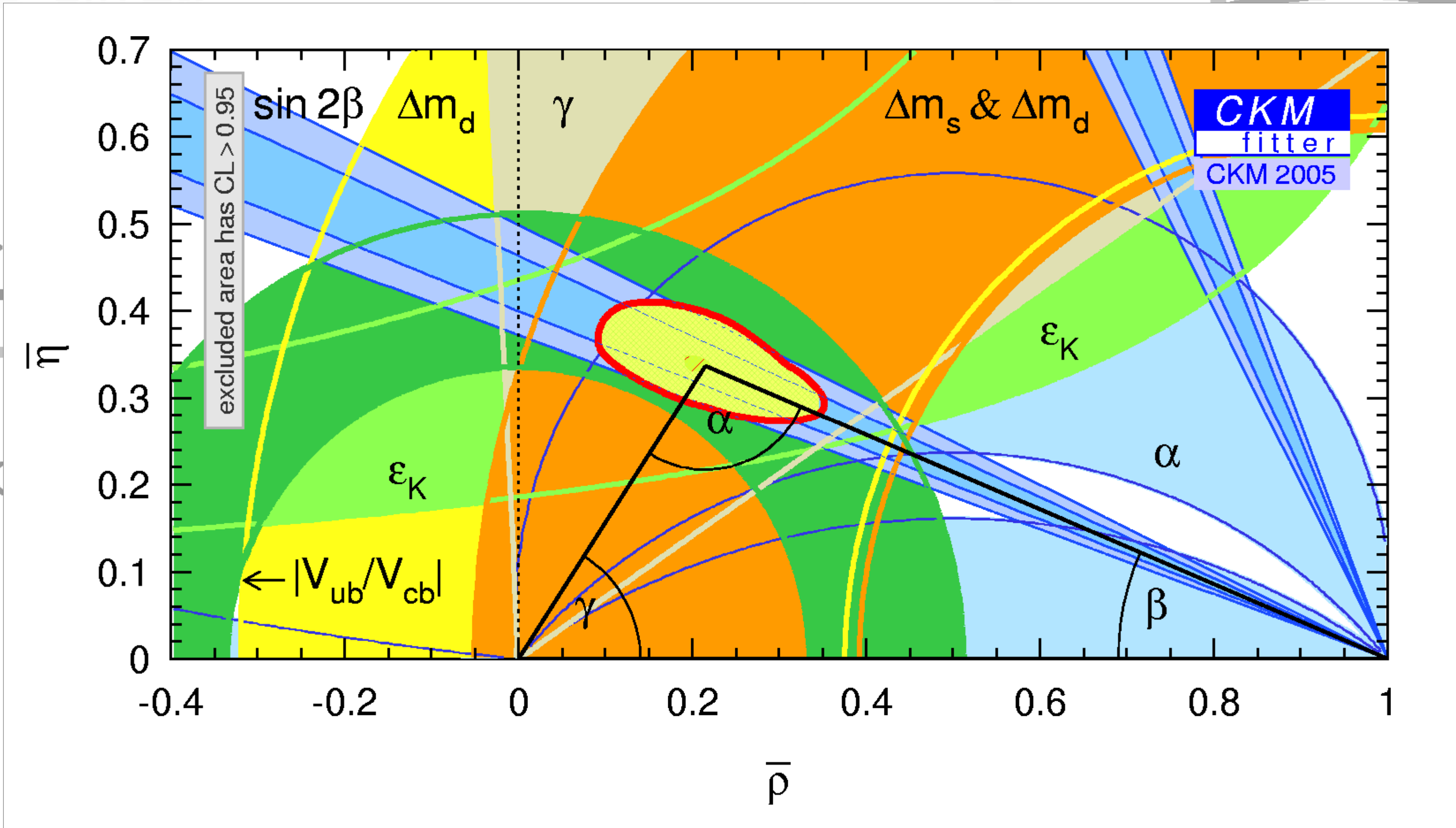
$|\varepsilon_K|$

$\sin 2\beta$

α

Perfect agreement … if it weren't for the *s*-penguin decays

Putting it all together — the global CKM fit



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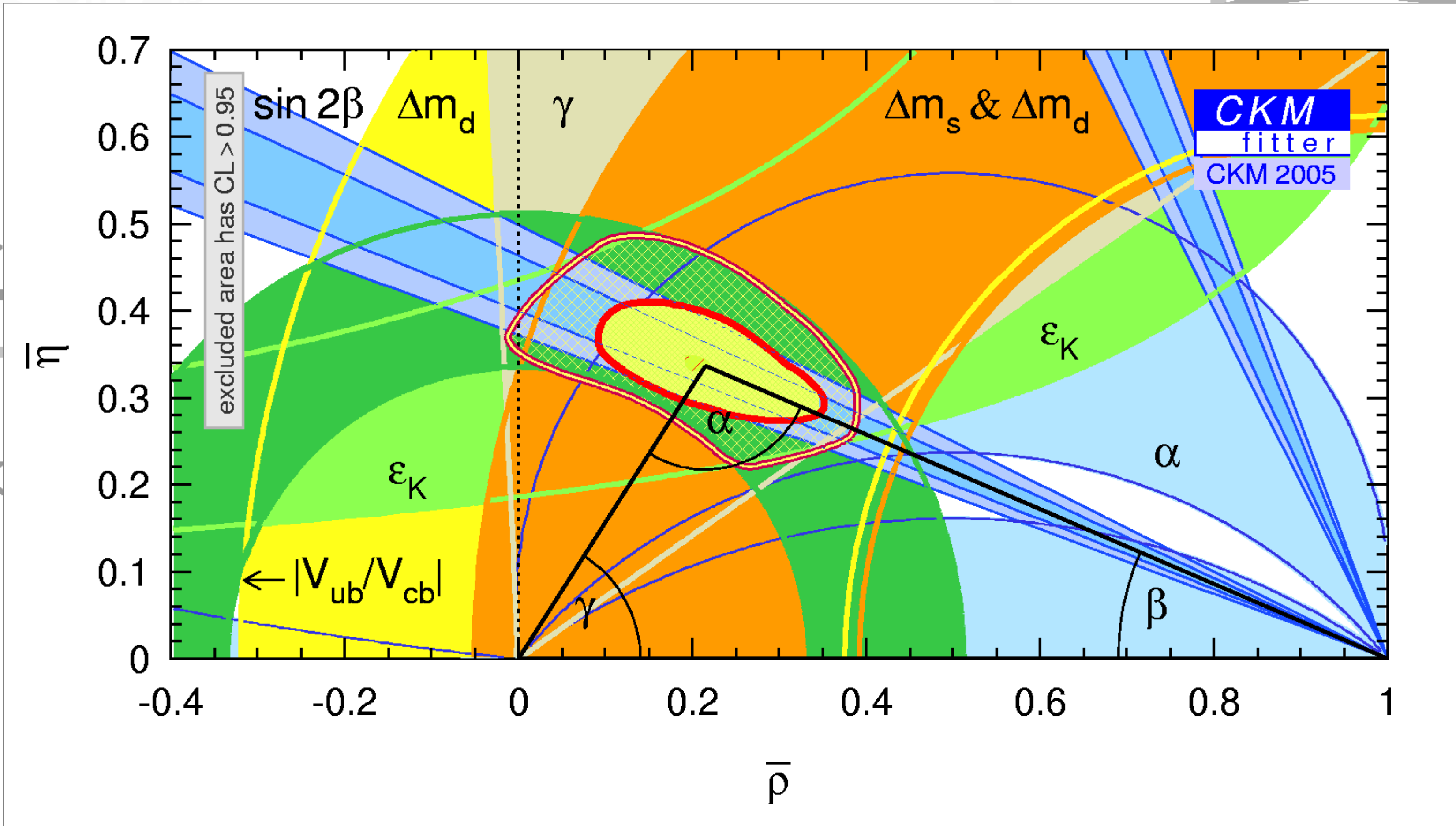
$\sin 2\beta$

α

γ

Perfect agreement … if it weren't for the *s*-penguin decays

Putting it all together — the global CKM fit



Inputs:

$\left|\frac{V_{ub}}{V_{cb}}\right|$

Δm_d

Δm_s

$B \to \tau\nu$

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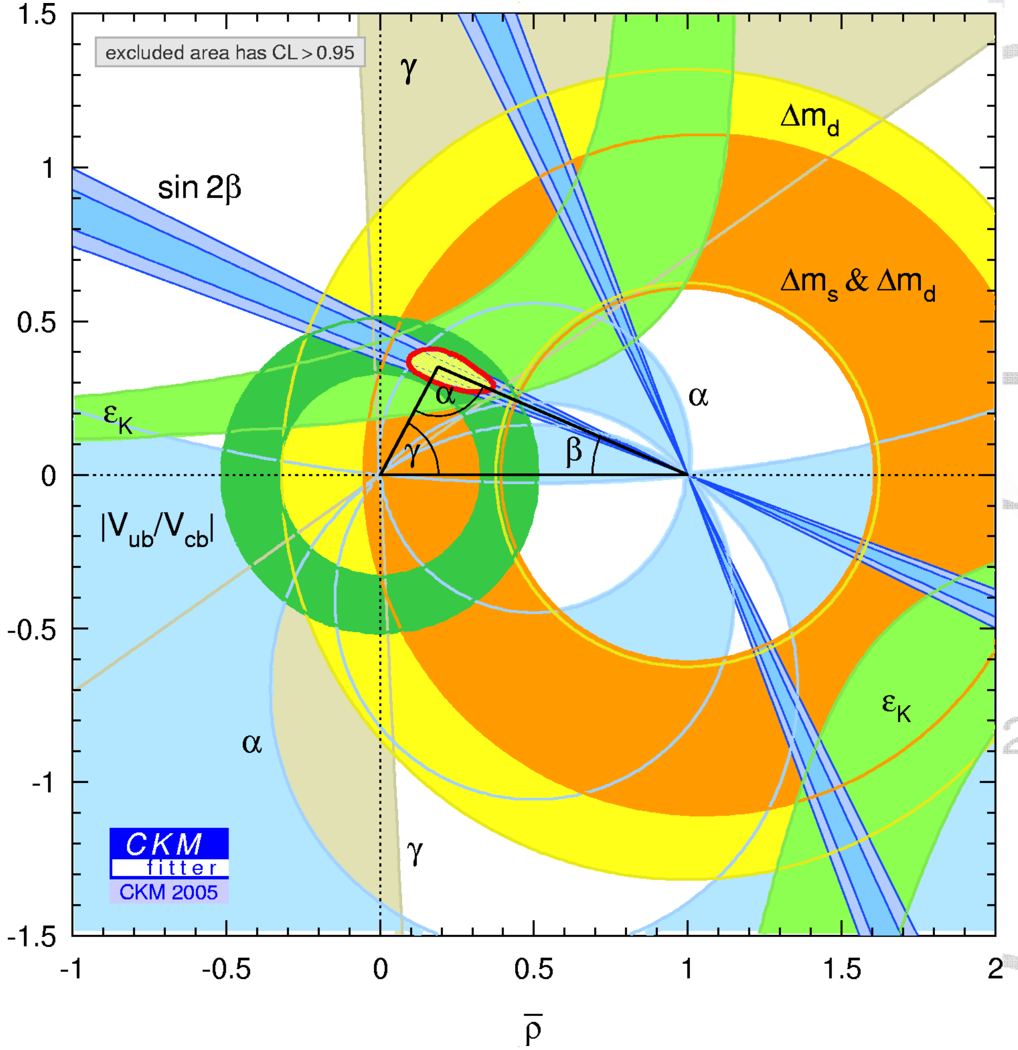
α

γ

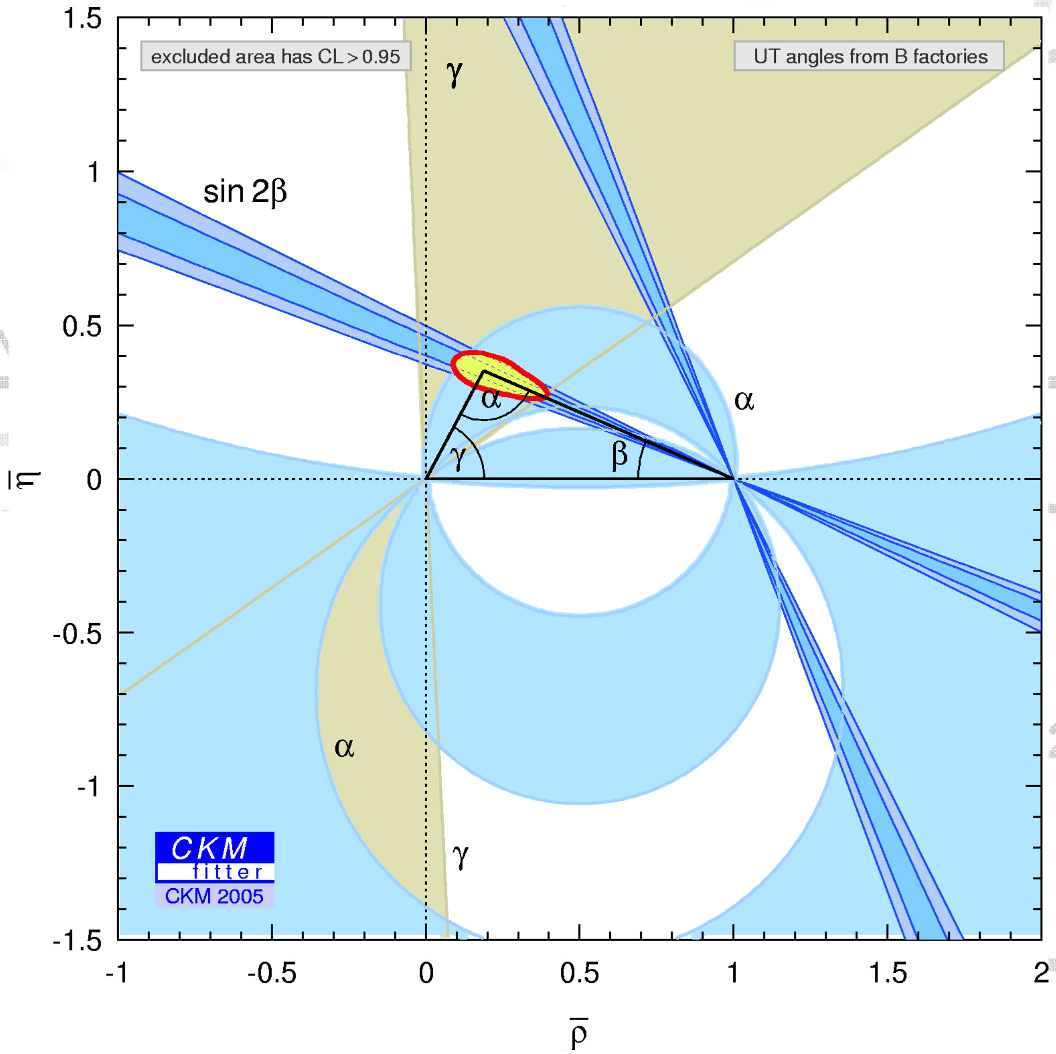
Perfect agreement … if it weren't for the *s*-penguin decays

Putting it all together
the impact of the unitarity triangle angles



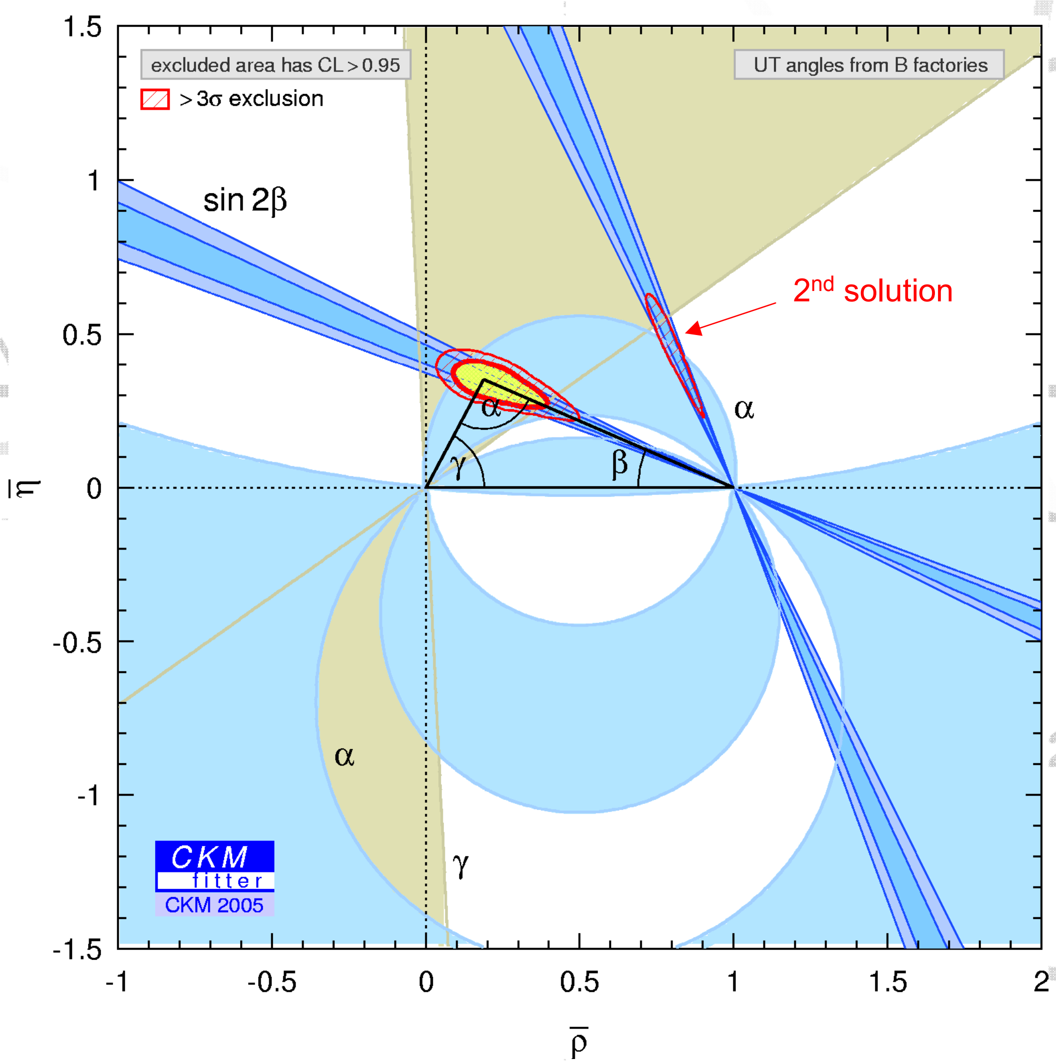
The angle measurements dominate !

Putting it all together — the impact of the unitarity triangle angles



The angle measurements dominate !

Putting it all together — the impact of the unitarity triangle angles



The angle measurements dominate !

Consistent Predictions of all CKM-related Observables

Quantity	Central value ± error at given CL: CL = 0.32	CL = 0.05	CL = 0.003
$\mathcal{B}(K^0_L \to \pi^0\nu\overline{\nu})$ $[10^{-11}]$	$2.89^{+0.84}_{-0.69}$	$^{+1.71}_{-1.24}$	$^{+2.41}_{-1.52}$
$\mathcal{B}(K^+ \to \pi^+\nu\overline{\nu})$ $[10^{-11}]$	$6.7^{+2.8}_{-2.7}$	$^{+3.7}_{-3.2}$	$^{+4.6}_{-3.6}$
$\mathcal{B}(B^+ \to \tau^+\nu_\mu)$ $[10^{-5}]$	$11.9^{+4.5}_{-5.7}$	$^{+10.4}_{-8.2}$	$^{+17.9}_{-10.1}$
$\mathcal{B}(B^+ \to \mu^+\nu_\mu)$ $[10^{-7}]$	$4.7^{+2.3}_{-1.7}$	$^{+4.6}_{-2.7}$	$^{+7.6}_{-3.5}$
$\|V_{ud}\|$	$0.97400^{+0.00054}_{-0.00058}$	$^{+0.00094}_{-0.00095}$	$^{+0.00106}_{-0.00106}$
$\|V_{us}\|$	$0.2265^{+0.0025}_{-0.0023}$	$^{+0.0040}_{-0.0041}$	$^{+0.0045}_{-0.0046}$
$\|V_{ub}\|$ $[10^{-3}]$	$3.87^{+0.35}_{-0.30}$	$^{+0.73}_{-0.60}$	$^{+0.73}_{-0.76}$
$\|V_{ub}\|$ $[10^{-3}]$ (meas. not in fit)	$3.87^{+0.34}_{-0.31}$	$^{+0.81}_{-0.61}$	$^{+1.27}_{-0.88}$
$\|V_{cd}\|$	$0.2264^{+0.0025}_{-0.0023}$	$^{+0.0040}_{-0.0041}$	$^{+0.0045}_{-0.0046}$
$\|V_{cs}\|$	$0.97317^{+0.00053}_{-0.00059}$	$^{+0.00094}_{-0.00097}$	$^{+0.00106}_{-0.00112}$
$\|V_{cb}\|$ $[10^{-3}]$	$41.13^{+1.36}_{-0.58}$	$^{+2.43}_{-1.16}$	$^{+3.08}_{-1.73}$
$\|V_{cb}\|$ $[10^{-3}]$ (meas. not in fit)	$41.2^{+5.1}_{-5.7}$	$^{+7.9}_{-5.8}$	$^{+9.9}_{-5.8}$
$\|V_{td}\|$ $[10^{-3}]$	$8.26^{+0.72}_{-0.86}$	$^{+1.23}_{-1.79}$	$^{+1.64}_{-2.25}$
$\|V_{ts}\|$ $[10^{-3}]$	$40.47^{+1.39}_{-0.62}$	$^{+2.42}_{-1.21}$	$^{+3.17}_{-1.78}$
$\|V_{tb}\|$	$0.999146^{+0.000024}_{-0.000058}$	$^{+0.000047}_{-0.000104}$	$^{+0.000070}_{-0.000133}$
$\|V_{ud}V^*_{ub}\|$ $[10^{-3}]$	$3.77^{+0.34}_{-0.30}$	$^{+0.71}_{-0.59}$	$^{+0.71}_{-0.75}$
$\arg[V_{ud}V^*_{ub}]$ (deg)	62^{+10}_{-12}	$^{+16}_{-24}$	$^{+22}_{-31}$
$\|V_{cd}V^*_{cb}\|$ $[10^{-3}]$	$9.31^{+0.31}_{-0.15}$	$^{+0.62}_{-0.34}$	$^{+0.80}_{-0.49}$
$\arg[V_{cd}V^*_{cb}]$ (deg)	$-179.9653^{+0.0047}_{-0.0042}$	$^{+0.0091}_{-0.0084}$	$^{+0.0122}_{-0.0107}$
$\|V_{td}V^*_{tb}\|$ $[10^{-3}]$	$8.24^{+0.73}_{-0.85}$	$^{+1.24}_{-1.78}$	$^{+1.64}_{-2.24}$
$\arg[V_{td}V^*_{tb}]$ (deg)	$-23.8^{+2.0}_{-2.1}$	$^{+3.8}_{-4.5}$	$^{+5.3}_{-6.0}$
$\|V_{td}/V_{ts}\|$	$0.204^{+0.018}_{-0.022}$	$^{+0.029}_{-0.046}$	$^{+0.039}_{-0.058}$
$\mathrm{Re}\lambda_c$	$-0.2204^{+0.0022}_{-0.0023}$	$^{+0.0038}_{-0.0037}$	$^{+0.0043}_{-0.0041}$
$\mathrm{Im}\lambda_c$ $[10^{-4}]$	$-1.41^{+0.18}_{-0.18}$	$^{+0.34}_{-0.36}$	$^{+0.44}_{-0.48}$
$\mathrm{Re}\lambda_t$ $[10^{-4}]$	$-3.04^{+0.32}_{-0.31}$	$^{+0.67}_{-0.60}$	$^{+0.86}_{-0.80}$
$\mathrm{Im}\lambda_t$ $[10^{-4}]$	$1.41^{+0.19}_{-0.17}$	$^{+0.37}_{-0.34}$	$^{+0.48}_{-0.44}$

Quantity	Central value ± error at given CL: CL = 0.32	CL = 0.05	CL = 0.003
λ	$0.2265^{+0.0025}_{-0.0023}$	$^{+0.0040}_{-0.0041}$	$^{+0.0045}_{-0.0046}$
A	$0.801^{+0.029}_{-0.020}$	$^{+0.066}_{-0.041}$	$^{+0.084}_{-0.054}$
$\overline{\rho}$	$0.189^{+0.088}_{-0.070}$	$^{+0.182}_{-0.114}$	$^{+0.221}_{-0.156}$
$\overline{\eta}$	$0.358^{+0.046}_{-0.042}$	$^{+0.086}_{-0.085}$	$^{+0.118}_{-0.118}$
J $[10^{-5}]$	$3.10^{+0.43}_{-0.37}$	$^{+0.82}_{-0.74}$	$^{+1.08}_{-0.96}$
$\sin 2\alpha$	$-0.14^{+0.37}_{-0.41}$	$^{+0.57}_{-0.71}$	$^{+0.74}_{-0.82}$
$\sin 2\alpha$ (meas. not in fit)	$-0.29^{+0.56}_{-0.46}$	$^{+0.77}_{-0.65}$	$^{+0.93}_{-0.70}$
$\sin 2\beta$	$0.739^{+0.048}_{-0.048}$	$^{+0.096}_{-0.095}$	$^{+0.124}_{-0.137}$
$\sin 2\beta$ (meas. not in fit)	$0.817^{+0.037}_{-0.222}$	$^{+0.053}_{-0.279}$	$^{+0.067}_{-0.334}$
α (deg)	94^{+12}_{-10}	$^{+24}_{-16}$	$^{+32}_{-22}$
α (deg) (meas. not in fit)	98^{+15}_{-16}	$^{+26}_{-22}$	$^{+31}_{-28}$
β (deg)	$23.8^{+2.1}_{-2.0}$	$^{+4.5}_{-3.8}$	$^{+6.0}_{-5.3}$
β (deg) (meas. not in fit)	$27.4^{+1.9}_{-9.2}$	$^{+2.8}_{-11.1}$	$^{+3.7}_{-13.0}$
$\gamma \simeq \delta$ (deg)	62^{+10}_{-12}	$^{+17}_{-24}$	$^{+23}_{-30}$
$\sin\theta_{12}$	$0.2266^{+0.0025}_{-0.0023}$	$^{+0.0040}_{-0.0041}$	$^{+0.0045}_{-0.0046}$
$\sin\theta_{13}$ $[10^{-3}]$	$3.87^{+0.35}_{-0.30}$	$^{+0.35}_{-0.60}$	$^{+0.35}_{-0.76}$
$\sin\theta_{23}$ $[10^{-3}]$	$41.13^{+1.37}_{-0.58}$	$^{+2.43}_{-1.16}$	$^{+3.08}_{-1.73}$
R_u	$0.405^{+0.035}_{-0.032}$	$^{+0.077}_{-0.062}$	$^{+0.093}_{-0.083}$
R_t	$0.889^{+0.073}_{-0.095}$	$^{+0.118}_{-0.196}$	$^{+0.161}_{-0.243}$
Δm_d (ps^{-1}) (meas. not in fit)	$0.54^{+0.26}_{-0.21}$	$^{+0.62}_{-0.31}$	$^{+0.94}_{-0.34}$
Δm_s (ps^{-1})	$17.8^{+6.7}_{-1.6}$	$^{+15.2}_{-2.7}$	$^{+22.1}_{-3.7}$
Δm_s (ps^{-1}) (meas. not in fit)	$16.5^{+10.5}_{-3.4}$	$^{+17.7}_{-5.7}$	$^{+23.9}_{-7.2}$
ε_K $[10^{-3}]$ (meas. not in fit)	$2.5^{+1.6}_{-1.1}$	$^{+2.4}_{-1.4}$	$^{+3.1}_{-1.6}$
$f_{B_d}\sqrt{B_d}$ (MeV) (theor. value not in fit)	215^{+28}_{-21}	$^{+79}_{-31}$	$^{+79}_{-39}$
B_K (theor. value not in fit)	$0.86^{+0.26}_{-0.30}$	$^{+0.57}_{-0.39}$	$^{+0.90}_{-0.45}$
$\overline{m}_t(m_t)$ (GeV/c^2) (meas. not in fit)	165^{+48}_{-47}	$^{+124}_{-64}$	$^{+194}_{-77}$

FOR UPTODATE RESULTS CHECK THE CKMFITTER WEB

CKM fitter

numerical results at: http://www.slac.stanford.edu/xorg/ckmfitter/ and http://ckmfitter.in2p3.fr/ (mirror)

What Else ?

- Other CKM-related topic not discussed in this seminar :
  - super rare kaon decays : $K \to \pi\nu\nu$
    - charged decay already seen by E787, E949)
    - $\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu})[\mathrm{exp}] = 15\,^{+13}_{-9} \times 10^{-11} \quad \Leftrightarrow \quad [\mathrm{theo} \propto |V_{td}|] = (6.7 \pm 2.8) \times 10^{-11}$
  - radiative decays : $B \to \rho\gamma$, $B \to K^*\gamma$, $b \to s\gamma$, …
  - model-independent analysis of new physics in mixing and decay

E787, PRL 88, 041803 (2002)
E949, PRL 93, 031801 (2004)

→ Charles *et al.*, EPJ C41, 1–131 (2005) [hep-ph/0406184]

- Dynamical analysis of $B \to \pi\pi$, $K\pi$, KK decays under different hypotheses

Most simple charmless B decays; theory understanding must start here

  - SU(2) → done for $\pi\pi$, not fruitful for $K\pi$ at present
  - SU(3)
  - QCD Factorization

→ next pages

Puzzle ? $$R_n = \frac{1}{2}\frac{\mathrm{BR}(B^0 \to \pi^- K^+)}{\mathrm{BR}(B^0 \to \pi^0 K^0)} = 0.79 \pm 0.08, \text{ whereas } \mathrm{R}_n > 1 \text{ in SM (?)}$$

Radiative Penguin Decays

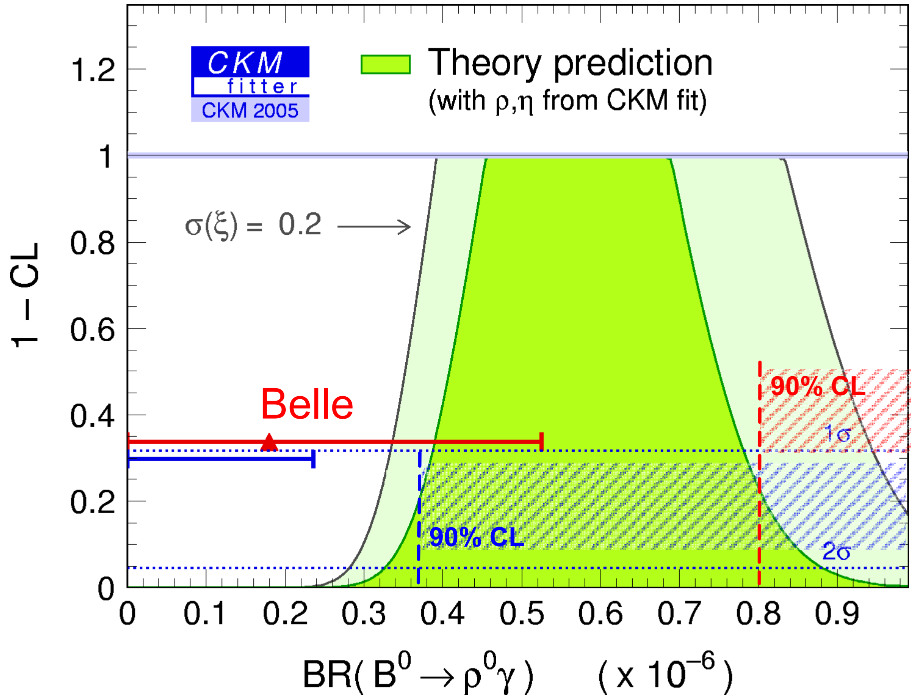
- Radiative penguin decays $B \to \rho\gamma$ ($\propto |V_{td}|^2$) and $B \to K^*\gamma$ ($\propto |V_{ts}|^2$) sensitive to New Physics
- Ratio of BRs predicted more cleanly than the individual rates: SU(3) breaking correction

$$\frac{\mathrm{BR}(B^0 \to \rho^0\gamma)}{\mathrm{BR}(B^0 \to K^{*0}\gamma)} \propto \frac{1}{2}\left|\frac{V_{td}}{V_{ts}}\right|^2 \xi^{-2}(1+\Delta)$$

$$\underbrace{\xi = 1.2 \pm 0.1}_{\text{SU(3) breaking}}\ ,\quad \underbrace{\Delta < 0.04}_{\text{NP contrib.}}$$

Ali, Parkhomenko, EPJ C23 (2002) 89
Bosch, Buchalla, NP B621 (2002) 459
(and later papers); errors from CKM 05

$B \to \rho\gamma$ observation should be imminent!



- So far only upper limit for $B \to \rho\gamma$

$$\mathrm{BR}\left(B^0 \to \rho^0\gamma\right) = \left(0.06\,^{+0.19}_{-0.14}\right)\times 10^{-6}$$

$$\mathrm{BR}\left(B^0 \to K^{*0}\gamma\right) = \left(40.1 \pm 2.0\right)\times 10^{-6}$$

BABAR, PRL 94, 011801 (2005)
Belle, hep-ex/0408137 (prelim.)

Charged modes larger limit: $\mathrm{BR}(B^+ \to \rho^+\gamma) = \left(1.0 \pm 0.4\right)\times 10^{-6}$, but less theoretically clean

Radiative Penguin Decays

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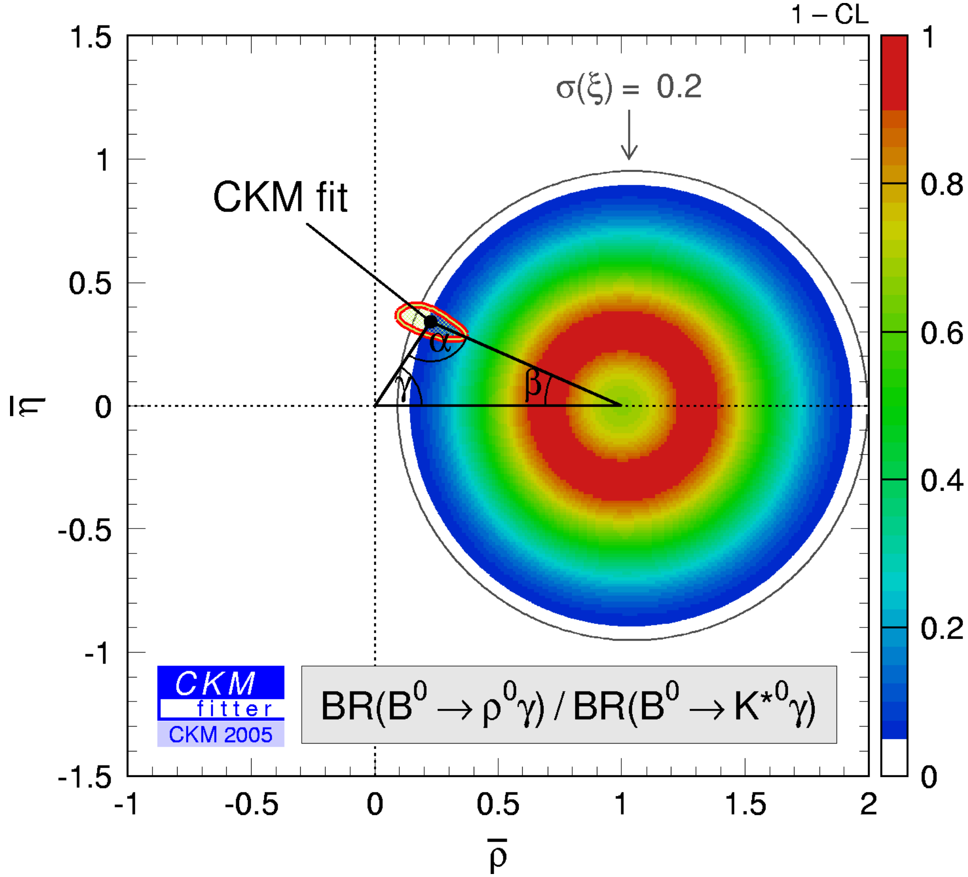

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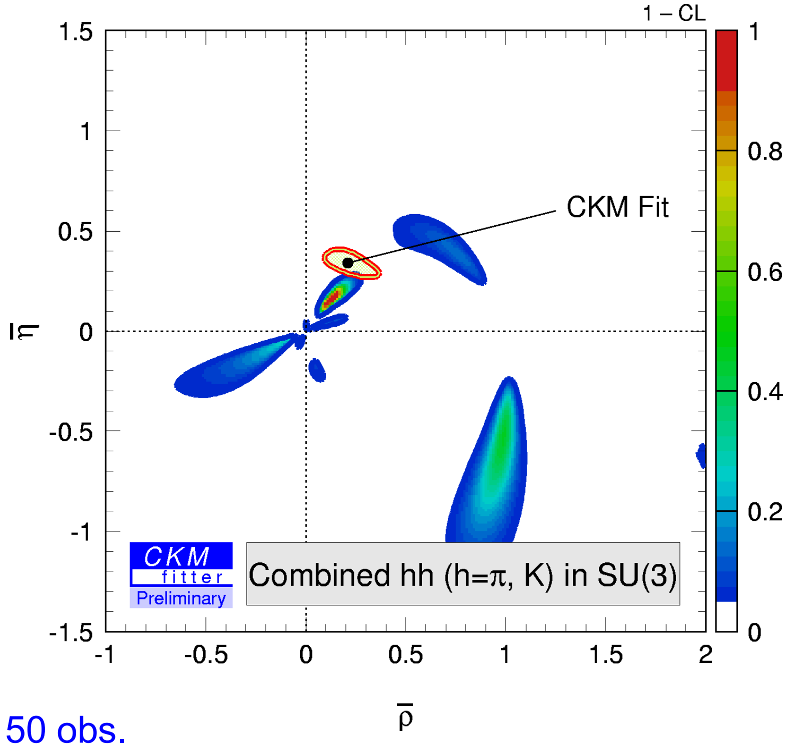
Puzzling $B \to \pi\pi$, $K\pi$, KK Decays : SU(3)

- Many analyses use assumptions beyond SU(3)
  - are annihilation graphs and $P_{EW,C}$ negligible ?
- Are there puzzles ?
  - there is a $\pi\pi$ puzzle: why are "color-suppressed" terms so large ?
  - there is no $K\pi$ puzzle using SU(2) [quadrilateral system not constraining enough – 9 params vs. 9 obs]
  - there seems to be a $K\pi$ puzzle using SU(3) when neglecting annihilation terms and $P_{EW,C}$
- Our analysis: add annihilation and $P_{EW,C}$ (via Fierz)
  - the only analysis so far in strict SU(3) limit
  - "α" from $B \to \pi^+\pi^-$, $K^+\pi^-$, K^+K^-
  - "β" from $B \to \pi^0\pi^0$, $K^0\pi^0$, K^+K^-
  - interesting combined constraint in (ρ,η) plane
- Global analyses:
  - at present: 13 parameters vs. 19 observables
  - when everything is measured (incl. B_s) : 15 par. vs. ~ 50 obs.

Silva-Wolfenstein, 1993
Buras *et al.* (BFRS), EPJ C32, 45 (2003)
Chiang *et al*, PRD D70, 034020 (2004)
Wu-Zhou, hep-ph/0503077
Charles *et al.*, EPJ C21, 225 (2001)
Charles-Malclès-Ocariz-AH, in preparation
… apologies to the many other interesting works !



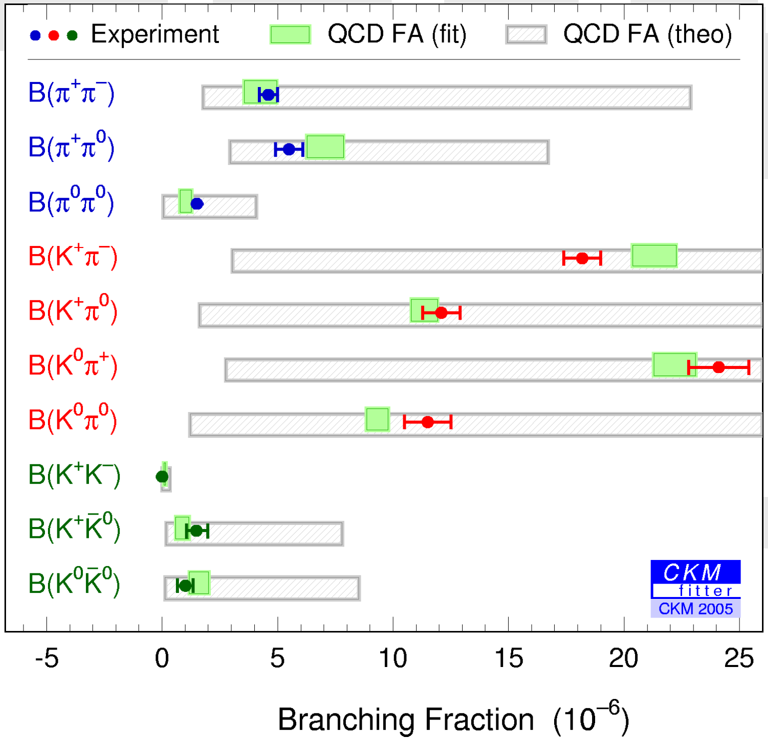
Puzzling $B \to \pi\pi$, $K\pi$, KK Decays : QCDF

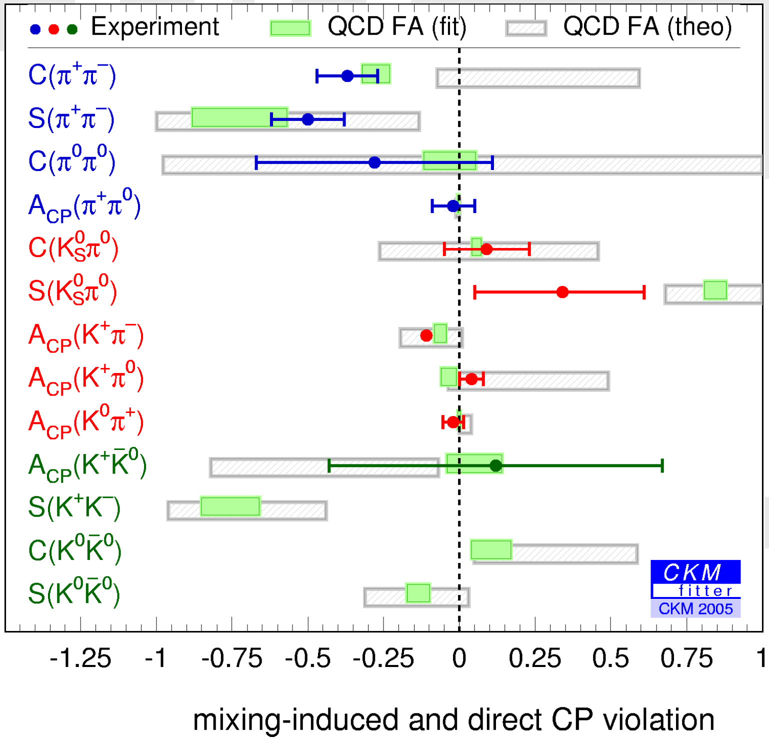
- Several theoretical tools exist for nonleptonic *B* decays. All are based on the concept of *Factorization*

  ➡ "Color Transparency"

- QCD FA — Beneke *et al*, PRL 83, 1914 (1999); NP B675, 333 (03)
- pQCD — Keum *et al*, PLB 504, 6 (2001); PRD 67, 054009 (03)
- SCET — Bauer *et al*, PRD 63, 114020 (2001)

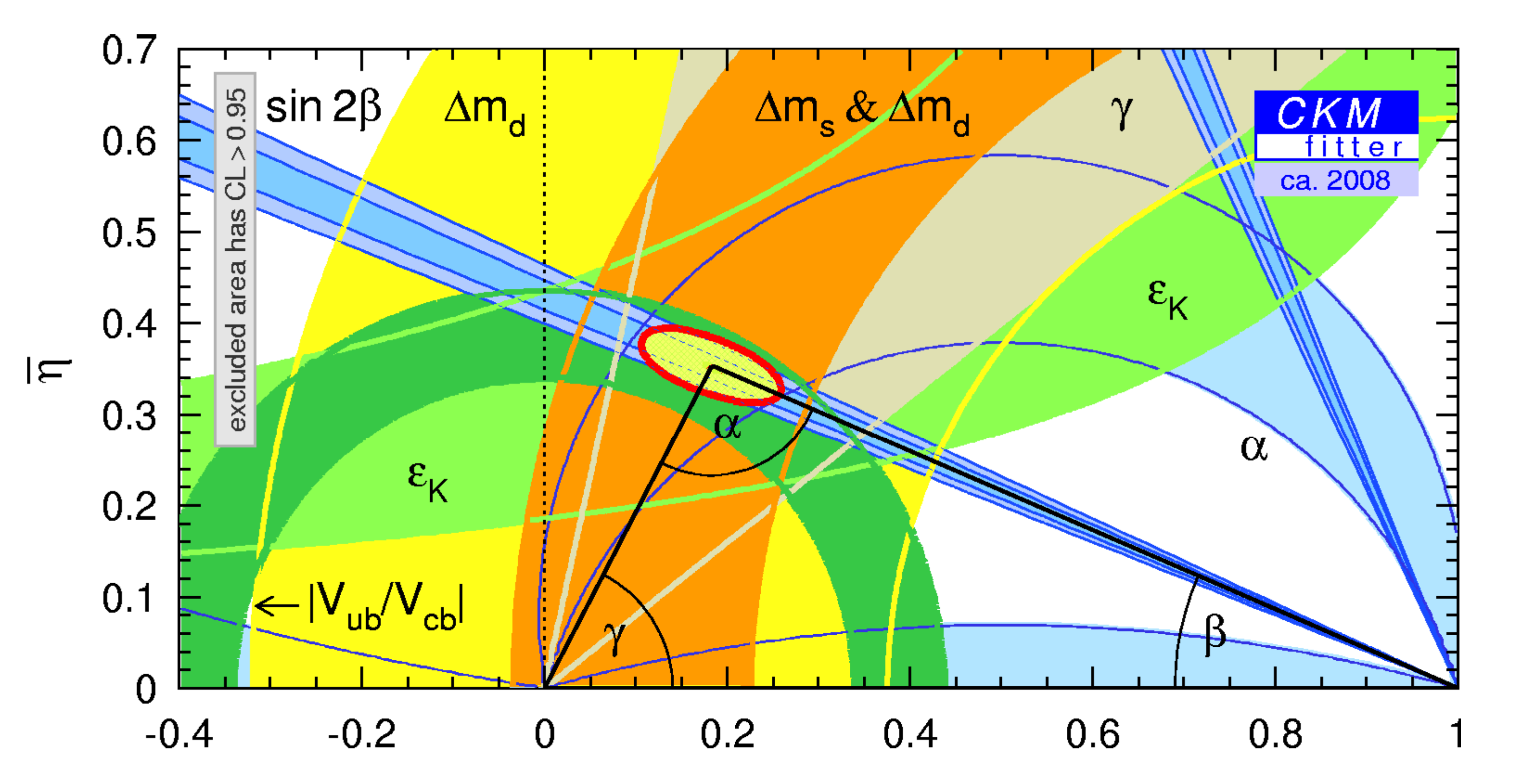
including the treatment of charming penguins by Ciuchini et al.





- With conservative error treatment, only a data-driven fit is predictive ➡ Is there a puzzle ?

And the near Future ? the global CKM fit in 2008



note: Lattice QCD is expected to improve significantly as well !

Inputs:

$\left|\frac{V_{ub}}{V_{cb}}\right|$

Δm_d

Δm_s

$B \to \tau\nu$

$|\varepsilon_K|$

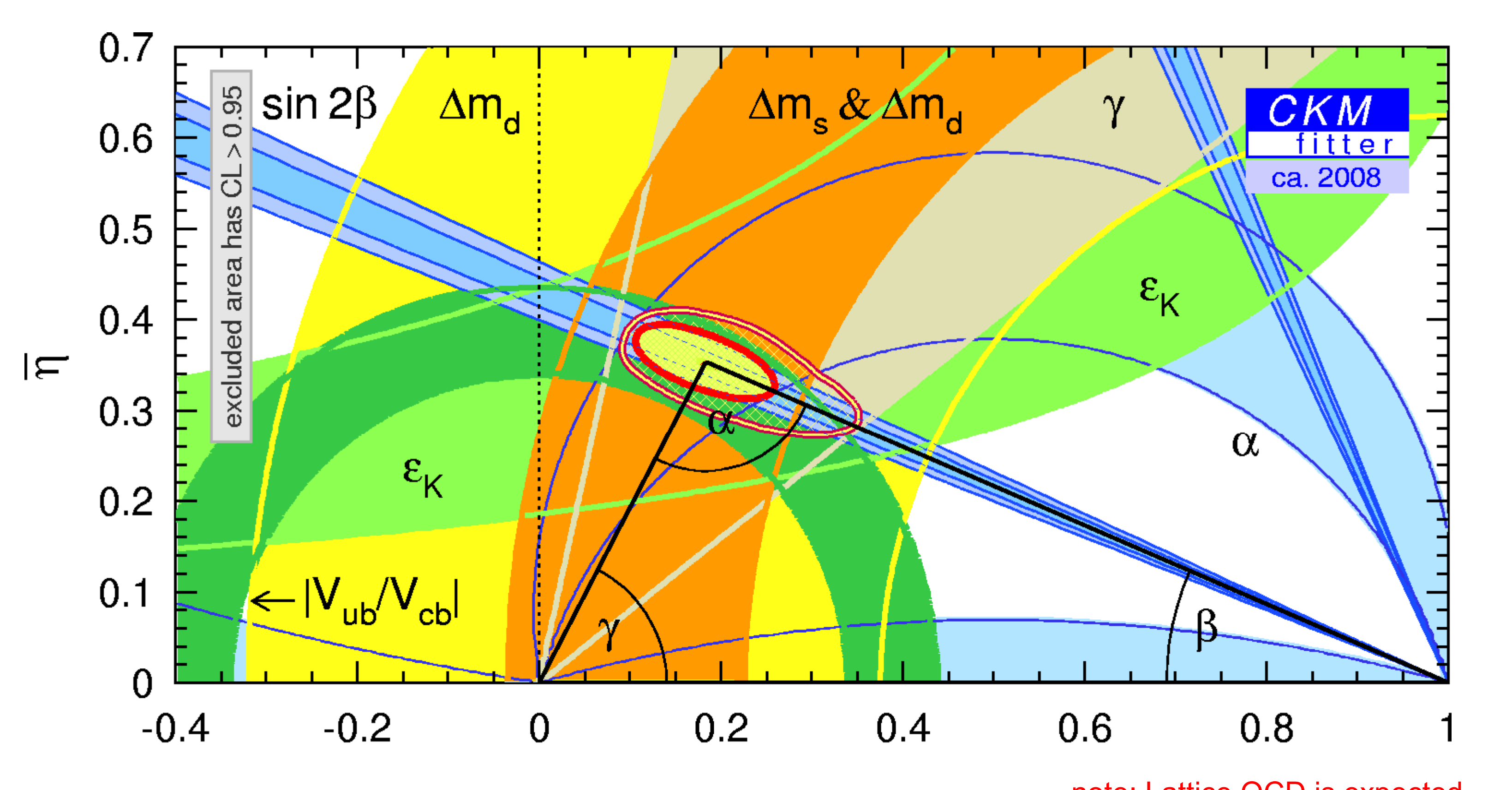
$\sin 2\beta$

α

γ

assumptions: $\sigma(V_{ub}) \sim 8\%$ | $\sigma(\Delta m_s) \sim 5\%$ | $\sigma(\sin 2\beta) \sim 0.019$ | $\sigma(\alpha) \sim 6^\circ$ | $\sigma(\gamma) \sim 10^\circ$

And the near Future ? the global CKM fit in 2008



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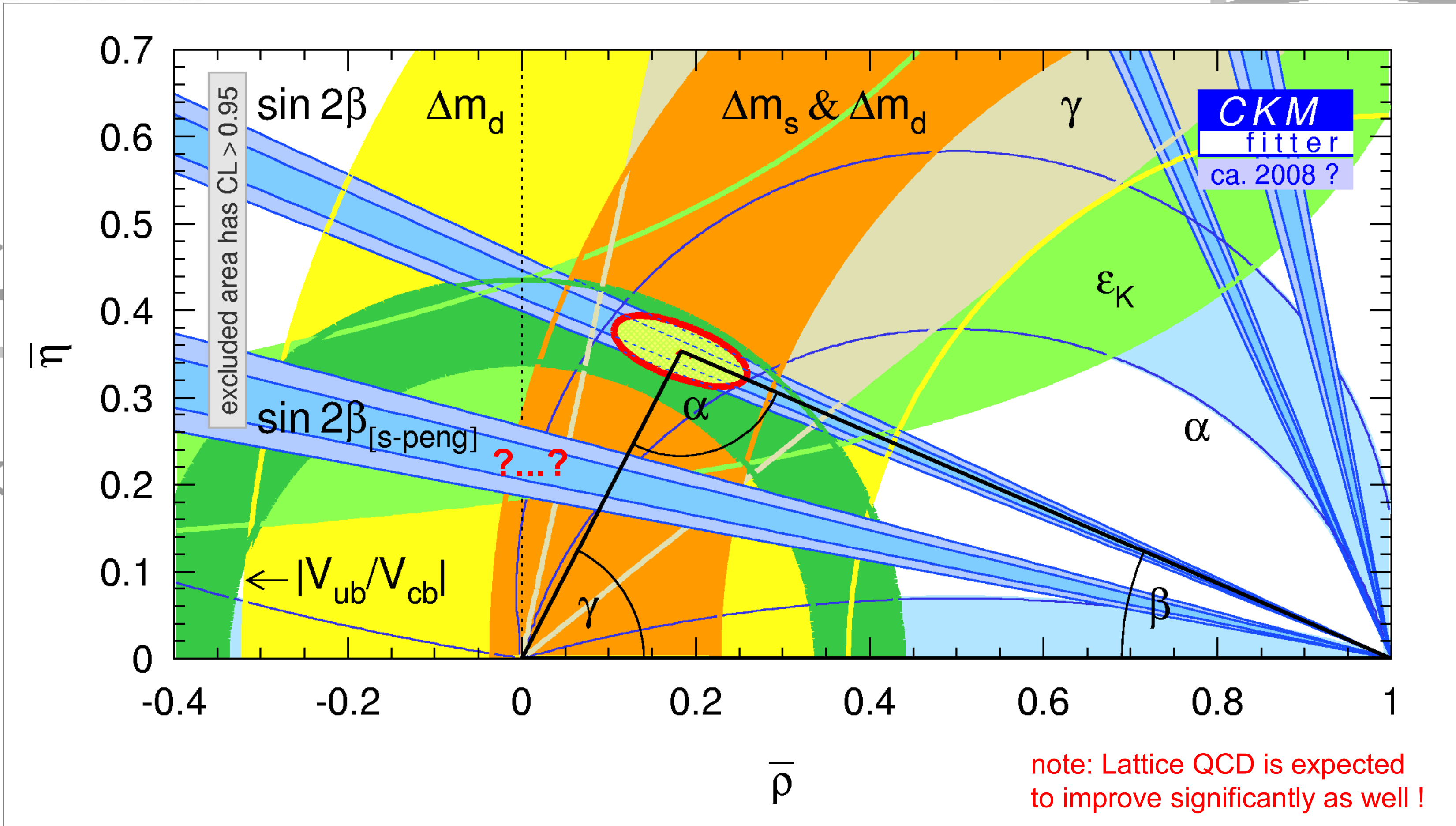
And the near Future ? the global CKM fit in 2008



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			$\sigma(\sin 2\beta) \sim 0.035$	?...?	

the far ...

FUTURE?

INSPIRED

Zfitter

CKMfitter

MNSfitter

Sfitter

GUTfitter

HEPfitter ⟷ COSMOfitter

thank you

appendix
appendix

none
none