Experimental aspects of the CP violation.

S. Monteil,
LPC – Université Blaise Pascal – in2p3.
[LHCb experiment and CKMfitter group]

Some authoritative literature about the lecture :

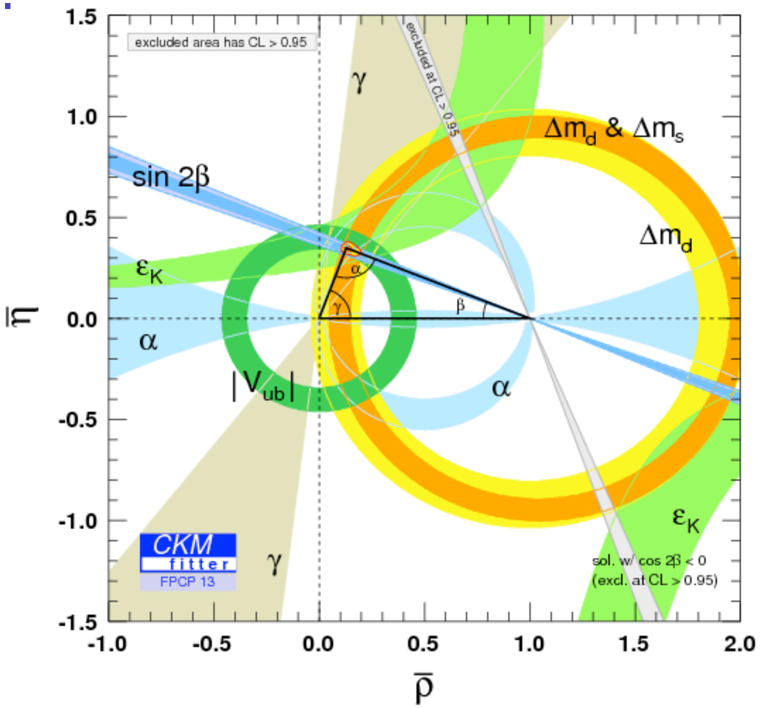
- BaBar physics book: http://www.slac.stanford.edu/pubs/slacreports/slac-r-504.html
- LHCb performance TDR: http://cdsweb.cern.ch/record/630827?ln=en
- A. Höcker and Z. Ligeti: CP Violation and the CKM Matrix. hep-ph/0605217

World Averages and Global Fits:

- Heavy Flavour Averaging Group: http://www.slac.stanford.edu/xorg/hfag/
- CKMfitter: http://ckmfitter.in2p3.fr/
- UTFit: http://www.utfit.org/

Motivation

- In any HEP physics conference summary talk, you will find this plot, stating that (heavy) flavours and CP violation physics is a pillar of the Standard Model.



- One objective of these series of lectures is to undress this plot.

A more detailed outline

1. History and recent past of the parity violation experiments. The discovery of the CP violation.
2. Observables and measurements relevant to study CP violation.
3. The global fit of the SM.
4. Outlook. New Physics exploration with current data: two examples.

3. The Standard Model global fit results

1. Some words about the statistical method.

2. The global picture: fit, detailed view of the constraints, metrology of the SM parameters.

3. Historical perspective.

4. The tensions of the global fit.

3.1 Some words about the statistical method.

- I will present in this chapter the big picture of the global fit of the flavour data to establish the Standard Model CKM profile.
- Though several approaches exist, there are two main groups aiming at establishing CKM profile from flavour data: The UTFit collaboration and the CKMfitter group, which results will be shown in this chapter.
- They differ by their statistical approach to make the metrology of the parameters: bayesian for UTFit and frequentist for CKMfitter.
- They differ also in the treatment of the theoretical uncertainties. The CKMfitter group uses the *R*fit approach.

3.1 Sketch of the statistical method.

- The frequentist approach:

- Use Frequentist Hypothesis testing to build statistical significance(p-value) functions from which estimates of confidence intervals are obtained.

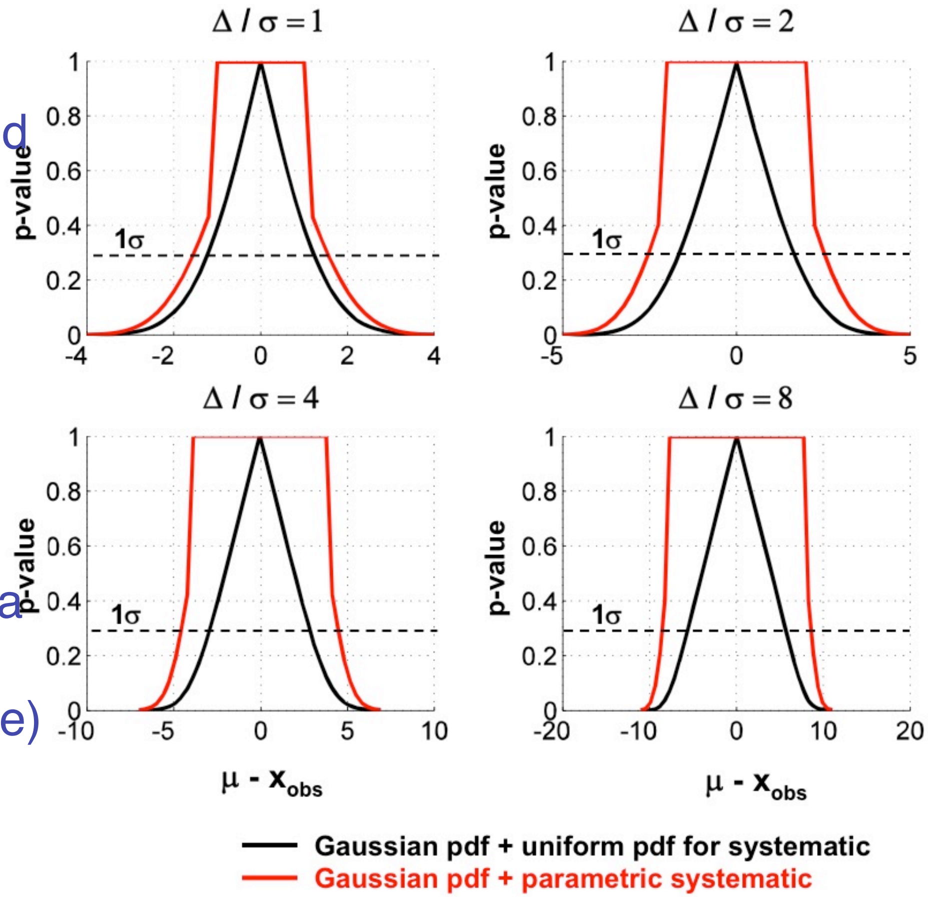
- The statistical test is a Maximum Likelihood Ratio $=\Delta\chi^2$.

- The situation is further complicated by the presence of theoretical uncertainties for which a dedicated scheme is considered: *R*fit.

- When the theoretical uncertainty is not controlled at a satisfactory enough level, the related observable is not considered in the global fit (e.g the ε' measurement – direct CP violation in the kaon system).

3.1 Sketch of the statistical method.

- The *R*fit treatment of theoretical uncertainties:
- Theoretical systematics are considered as additional nuisance parameters bounded over a confidence interval.
- These errors are not statistically distributed.
- This approach yields very different results from what one would get from a statistical modelling of the systematic (example here : uniform over the range)



3.2 The global picture

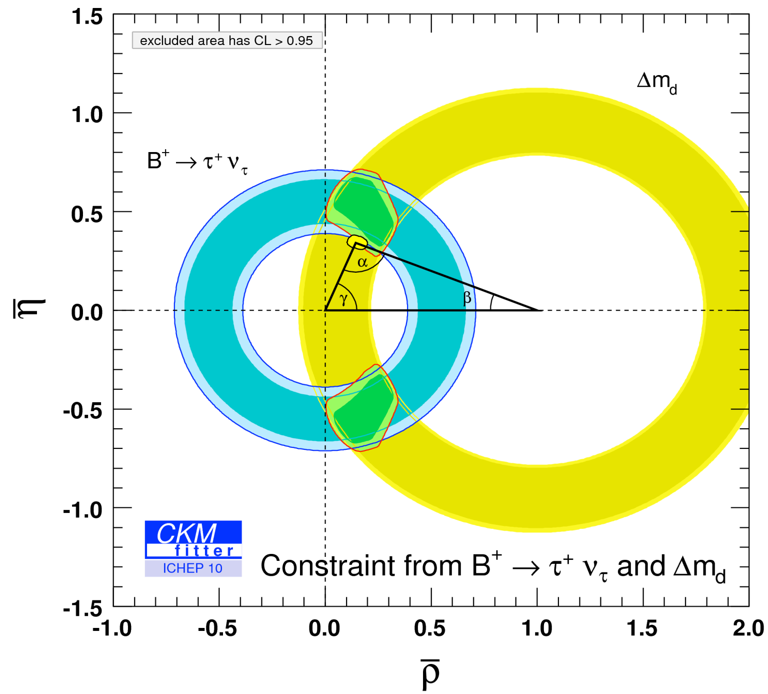
- List of the inputs: in the details.
- The ones we discussed in previous chapter, and:
- α, γ
- Lattice parameters. And ratios.
- The tauonic *B* decay. Deserves a brief description.

Parameter	Value ± Error(s)	Reference	Errors GS	Errors TH
$\lvert V_{ud}\rvert$ (nuclei)	0.97425 ± 0.00022	[1]	⋆	-
$\lvert V_{us}\rvert$ ($K_{\ell 3}$)	0.2254 ± 0.0013	[2]	⋆	-
$\lvert V_{ub}\rvert$	$(3.92 \pm 0.09 \pm 0.45) \times 10^{-3}$	[3, 4]	⋆	⋆
$\lvert V_{cb}\rvert$	$(40.89 \pm 0.38 \pm 0.59) \times 10^{-3}$	[3]	⋆	⋆
$\lvert\varepsilon_K\rvert$	$(2.229 \pm 0.010) \times 10^{-3}$	[5]	⋆	-
Δm_d	(0.507 ± 0.005) ps^{-1}	[3]	⋆	-
Δm_s	(17.77 ± 0.12) ps^{-1}	[6]	⋆	-
$\sin(2\beta)_{[c\bar{c}]}$	0.673 ± 0.023	[3]	⋆	-
$S^{+-}_{\pi\pi}$, $C^{+-}_{\pi\pi}$, $C^{00}_{\pi\pi}$	Inputs to isospin analysis	[3]	⋆	-
$\mathcal{B}_{\pi\pi}$ all charges	Inputs to isospin analysis	[3]	⋆	-
$S^{+-}_{\rho\rho,L}$, $C^{+-}_{\rho\rho,L}$, $S^{00}_{\rho\rho}$, $C^{00}_{\rho\rho}$	Inputs to isospin analysis	[3]	⋆	-
$\mathcal{B}_{\rho\rho,L}$ all charges	Inputs to isospin analysis	[3]	⋆	-
$B^0 \to (\rho\pi)^0 \to 3\pi$	Time-dependent Dalitz analysis	[7, 8]	⋆	-
$B^- \to D^{(*)}K^{(*)-}$	Inputs to GLW analysis	[3]	⋆	-
$B^- \to D^{(*)}K^{(*)-}$	Inputs to ADS analysis	[3]	⋆	-
$B^- \to D^{(*)}K^{(*)-}$	GGSZ Dalitz analysis	[3]	⋆	-
$\mathcal{B}(B^- \to \tau^-\overline{\nu}_\tau)$	$(1.68 \pm 0.31) \times 10^{-4}$	[9]	⋆	-
$\overline{m}_c(m_c)$	$(1.286 \pm 0.013 \pm 0.040)$ GeV	[12]	⋆	⋆
$\overline{m}_t(m_t)$	$(165.02 \pm 1.16 \pm 0.11)$ GeV	[10]	⋆	⋆
B_K	$0.723 \pm 0.004 \pm 0.067$	[16]	⋆	⋆
$\alpha_s(m_Z^2)$	0.1176 ± 0.0020	[5]	-	⋆
η_{cc}	Calculated from $\overline{m}_c(m_c)$ and α_s	[17]	-	⋆
η_{ct}	0.47 ± 0.04	[18]	-	⋆
η_{tt}	0.5765 ± 0.0065	[17, 18]	-	⋆
$\eta_B(\overline{\mathrm{MS}})$	0.551 ± 0.007	[19]	-	⋆
f_{B_s}	$(228 \pm 3 \pm 17)$ MeV	[16]	⋆	⋆
B_s	$1.28 \pm 0.02 \pm 0.03$	[16]	⋆	⋆
f_{B_s}/f_{B_d}	$1.199 \pm 0.008 \pm 0.023$	[16]	⋆	⋆
B_s/B_d	$1.05 \pm 0.01 \pm 0.03$	[16]	⋆	⋆

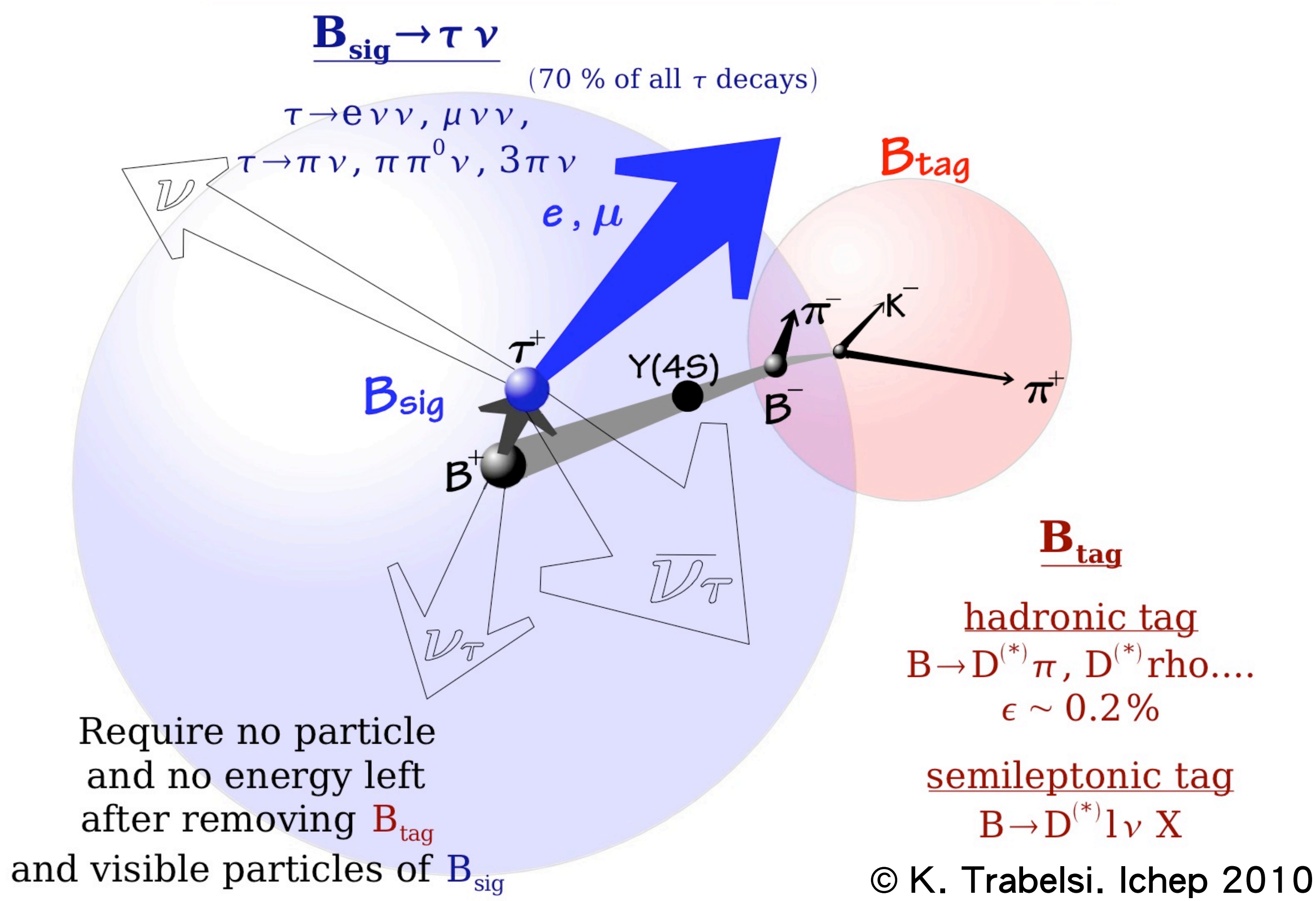
3.2 The global picture. Aparte : Tauonic B decay.

$$\mathcal{B}[M \to \ell\nu] = \frac{G_F^2 m_M m_\ell^2}{8\pi\hbar}\left(1 - \frac{m_\ell^2}{m_M^2}\right)^2 |V_{q_u q_d}|^2 f_M^2 \tau_M (1 + \delta_{\mathrm{em}}^{Ml2})$$

- $B^+ \to \tau^+\nu$ is another way to access the matrix element $|V_{ub}|$. Remember that we have seen in Chapter II that exclusive and inclusive determinations only marginally agrees.
- Actually it's not only $|V_{ub}|$ but the product $f_B|V_{ub}|$.
- The simultaneous treatment of Δm_d and Br[$B^+ \to \tau^+\nu$] allows to get rid of the B decay constant.



3.2 The global picture. Aparte : Tauonic B decay reconstruction.



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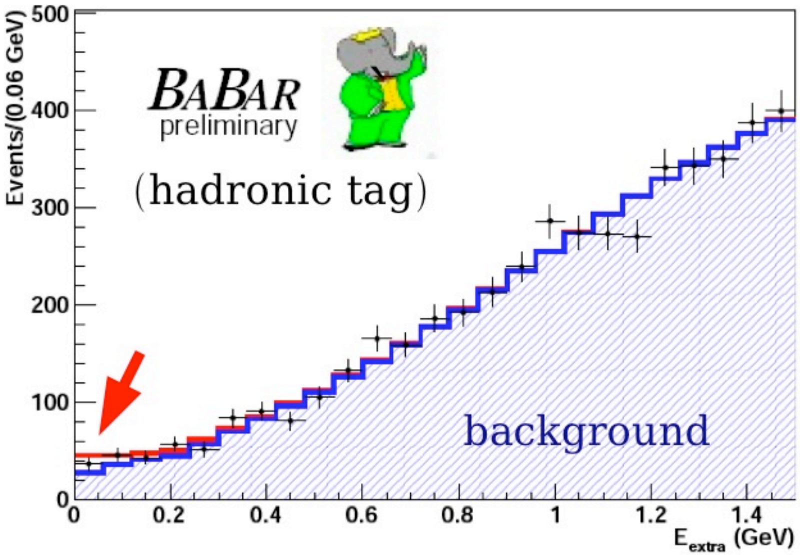
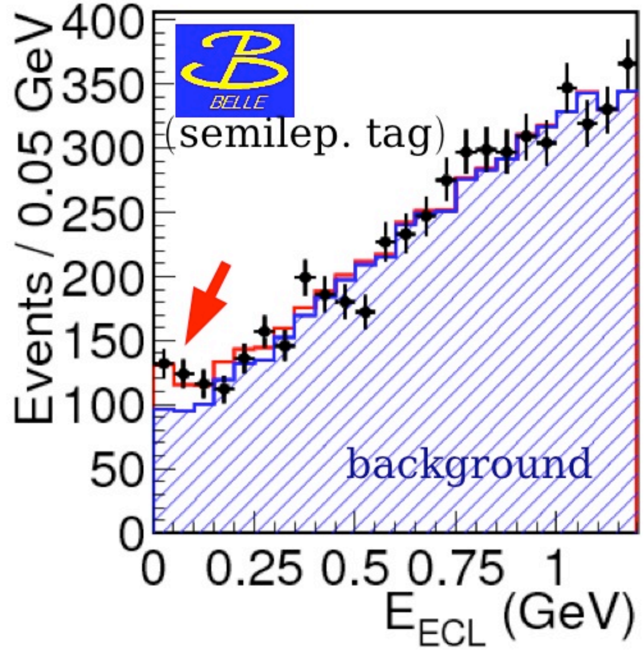


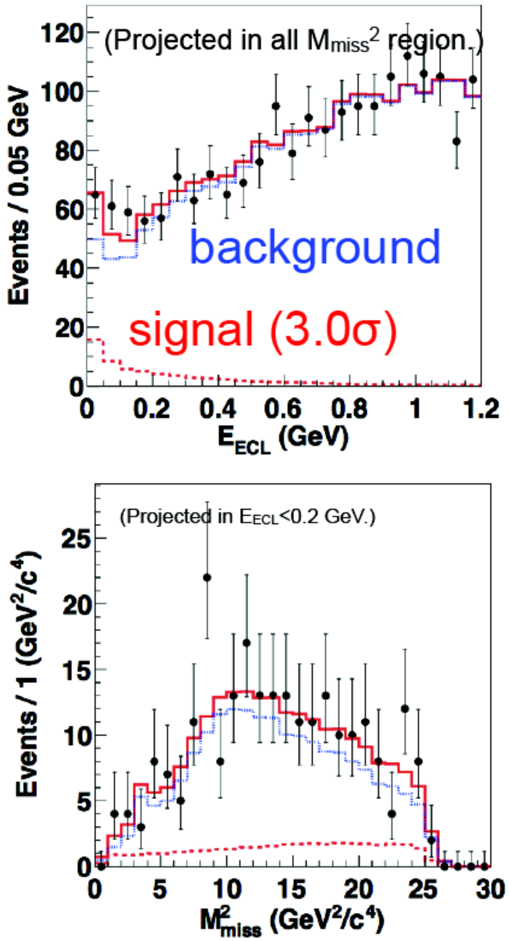


	tag	BF(→τν)[10^-4]
BaBar	SL (459M)	1.70±0.82
	Had (467M)	1.80±0.61 *NEW*
	Average	1.76±0.49
Belle	SL (657M)	1.54±0.48 *NEW*
	Had (449M)	1.79±0.71
	Average	1.62±0.40
World Average		1.68±0.31

- ECL/Extra = extra calorimeter energy
- SM prediction:

$$B(B^+ \to \tau^+ \nu_\tau) = (0.763^{+0.114}_{-0.061}) \cdot 10^{-4}$$

3.2 The global picture. Aparte : Tauonic B decay reconstruction.



- New measurement (well, more an evidence of) from Belle experiment with hadronic tag.

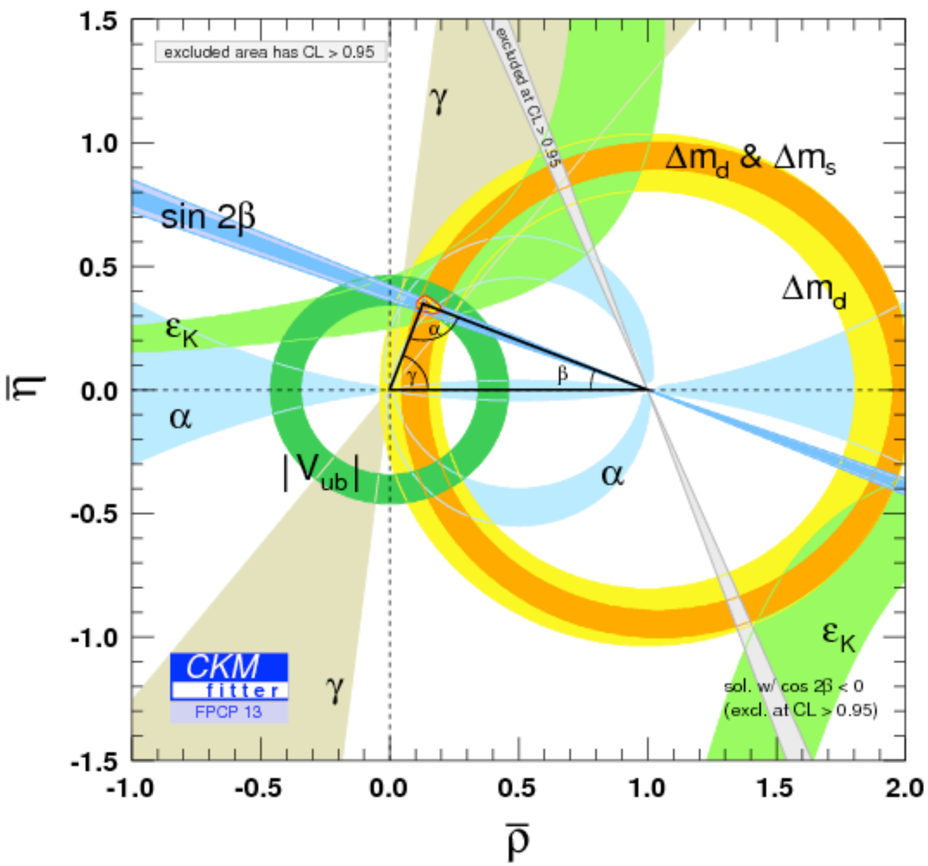
Belle

- based on 772 M $B\bar{B}$ (full data sample),
- four τ decay channels: $e\nu\nu$, $\mu\nu\nu$, $\pi\nu$, $\rho\nu$;
- improved tracking,
- improved tagging (NeuroBayes),
- K_L veto added,
- better understanding of the peaking background,
- signal extracted from 2D fit in ($E_{\rm ECL}$, $M^2_{\rm miss}$),
- $\mathcal{B} = (0.72^{+0.27}_{-0.25} \pm 0.11) \times 10^{-4}$.

- Much more consistent w/ SM expectation. Strong implications, see later.

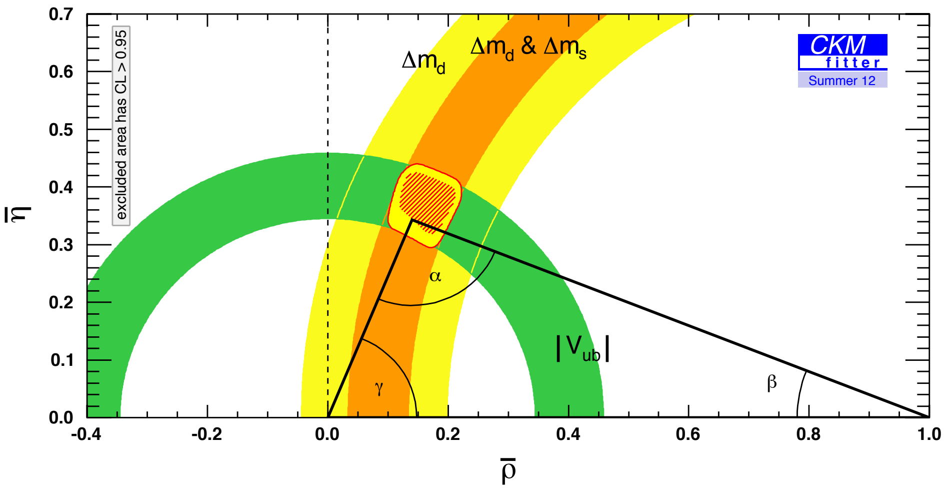
3.2 Standard Model: the CKM profile

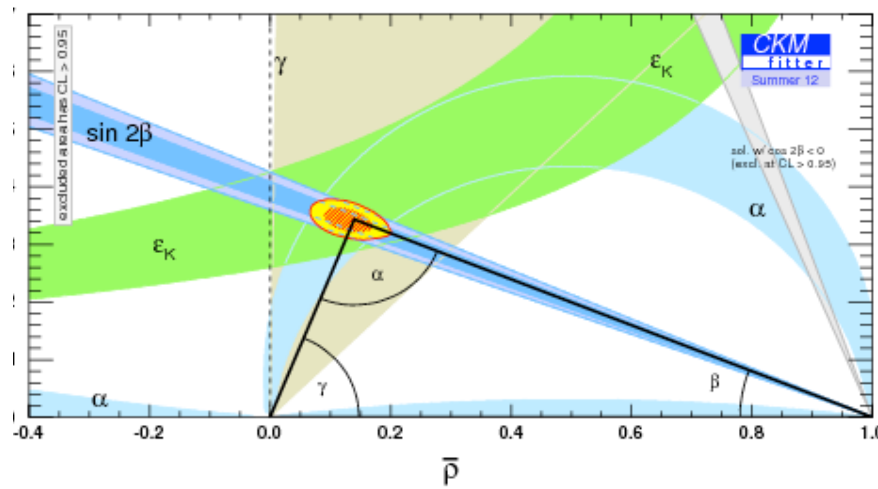
- The global picture:
- Notice to read the picture: regions outside the coloured area are excluded at 95 % Confidence Level.
- There is a region of Wolfenstein parameter space which is common to all the constraints.
- In other terms, there is a remarkable consistency between all of the observables at the 95 % CL.



3.2 Standard Model: the CKM profile

- The global picture: comparison of observables constraints.
- CP-conserving against CP violating.

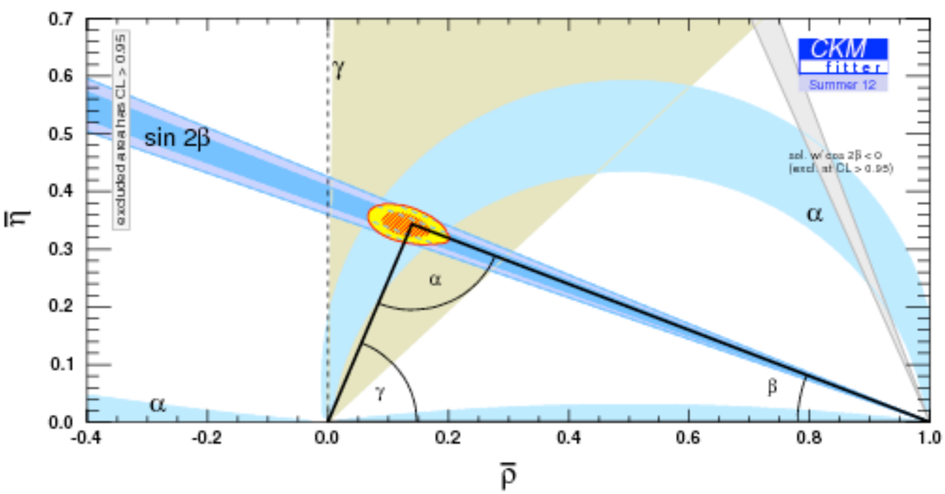


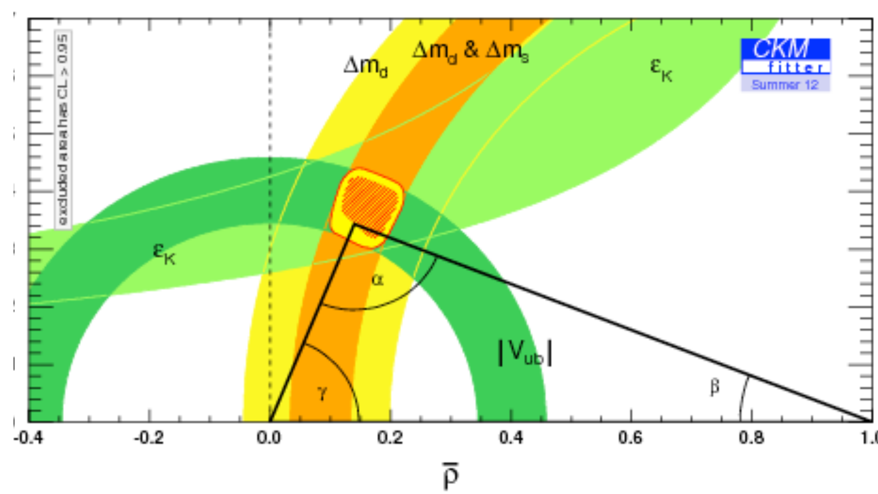


- Correct agreement. CP-conserving observables can quantify CP violation.

3.2 Standard Model: the CKM profile

- The global picture: comparison of observables constraints.
- Angles (No theory) against No angles (Hadronic uncert.).

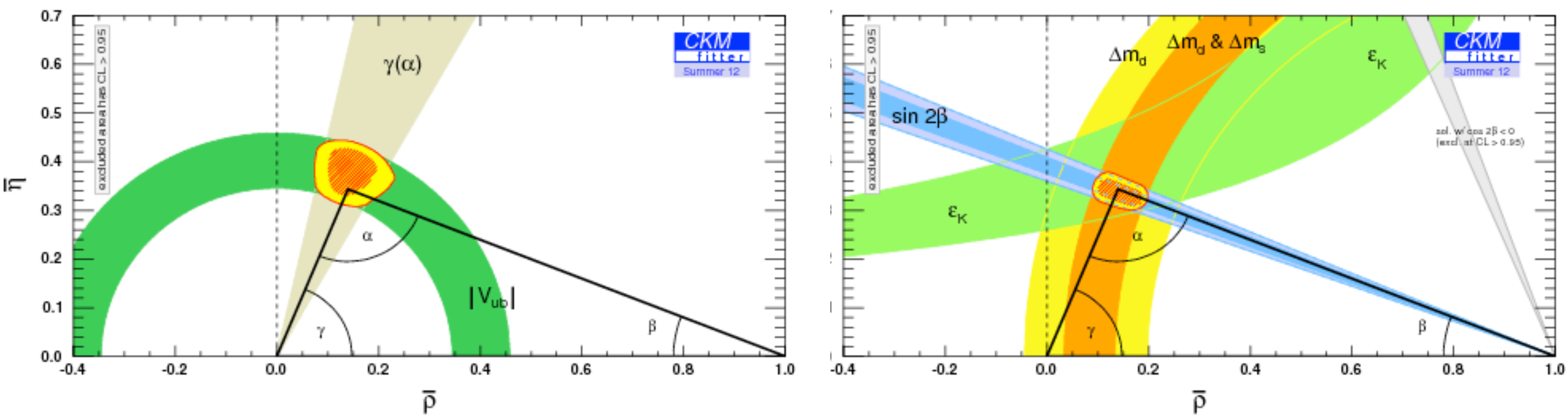




- Correct agreement. Remember that only observables with a good theoretical control are considered in the global fit.

3.2 Standard Model: the CKM profile

- The global picture: comparison of observables constraints.
- Trees against Loops.



- Trees are thought to be pure SM. Loops could exhibit New Physics. Fair agreement.

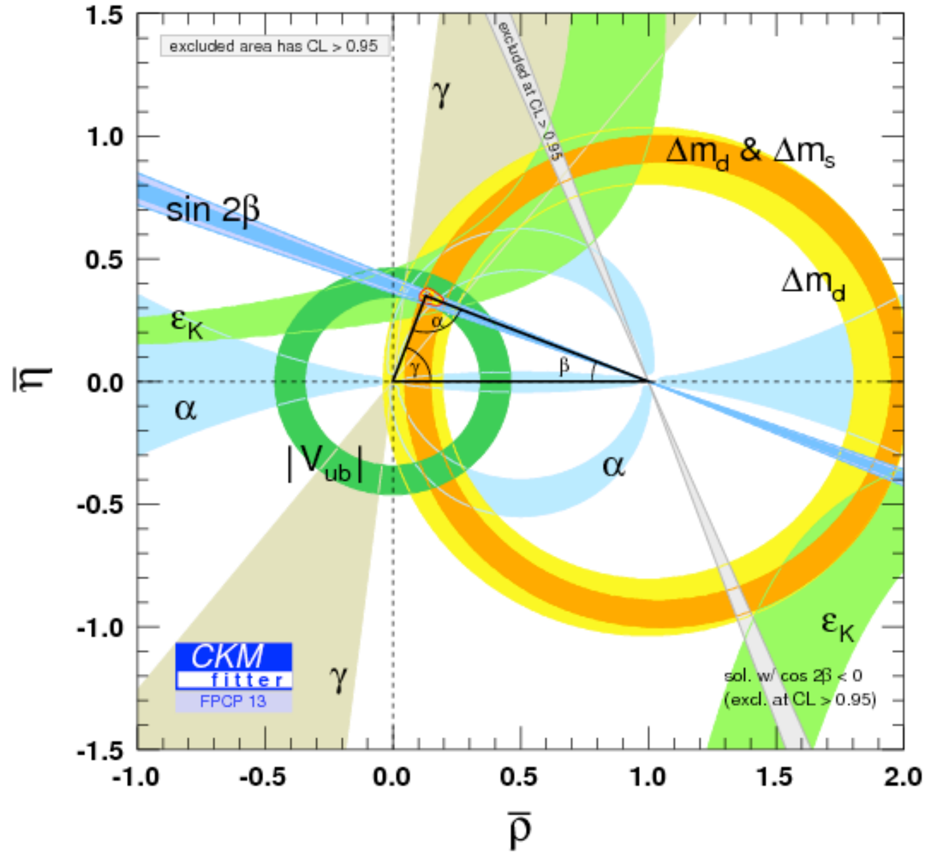
3.2 Standard Model: the CKM profile.

- The global picture:

- This is a tremendous success of the Standard Model and especially the Kobayashi-Maskawa mechanism. This is simultaneously an outstanding experimental achievement by the B factories.

- CKM is at work in weak charged current.

- The KM phase IS the dominant source of CP violation in K and B system.



3.3 Back to the future .

- Recreational Homework. Find the break through measurements along ages.

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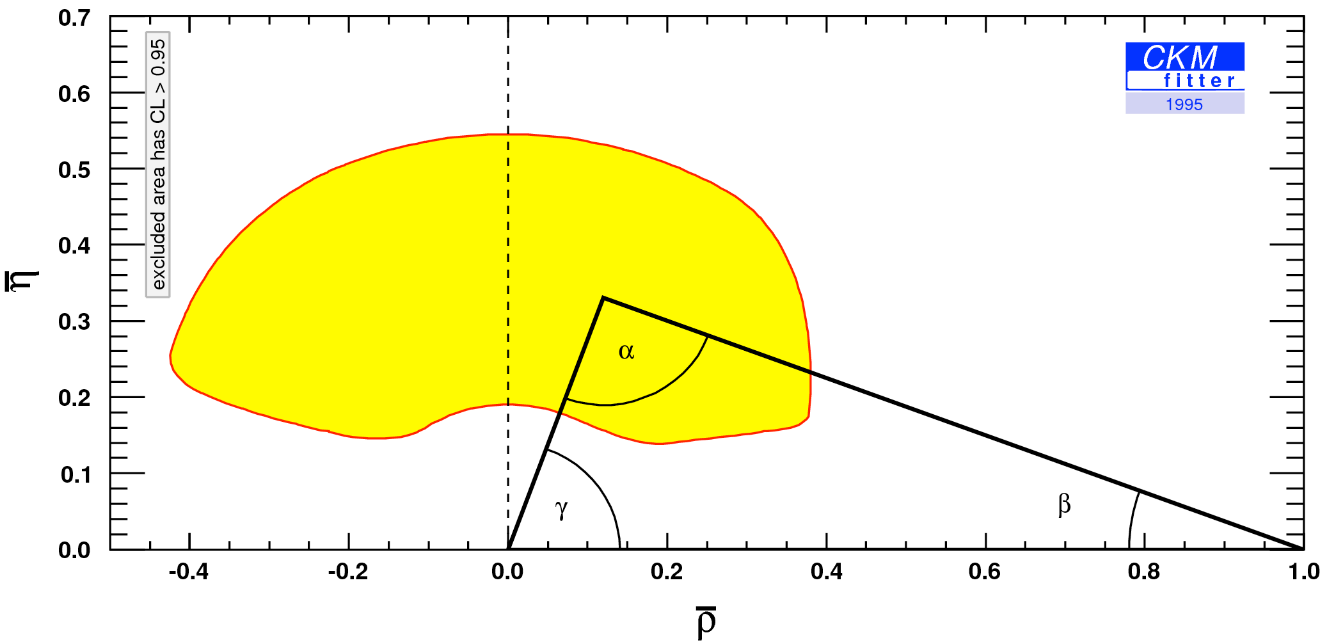

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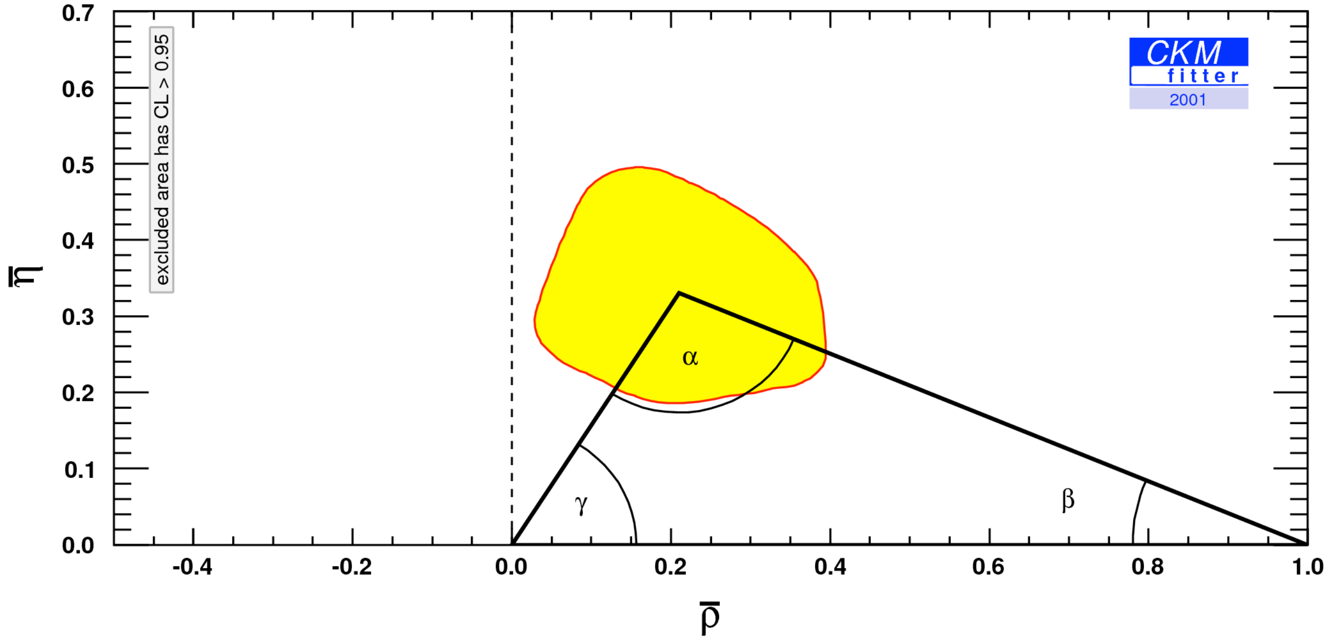

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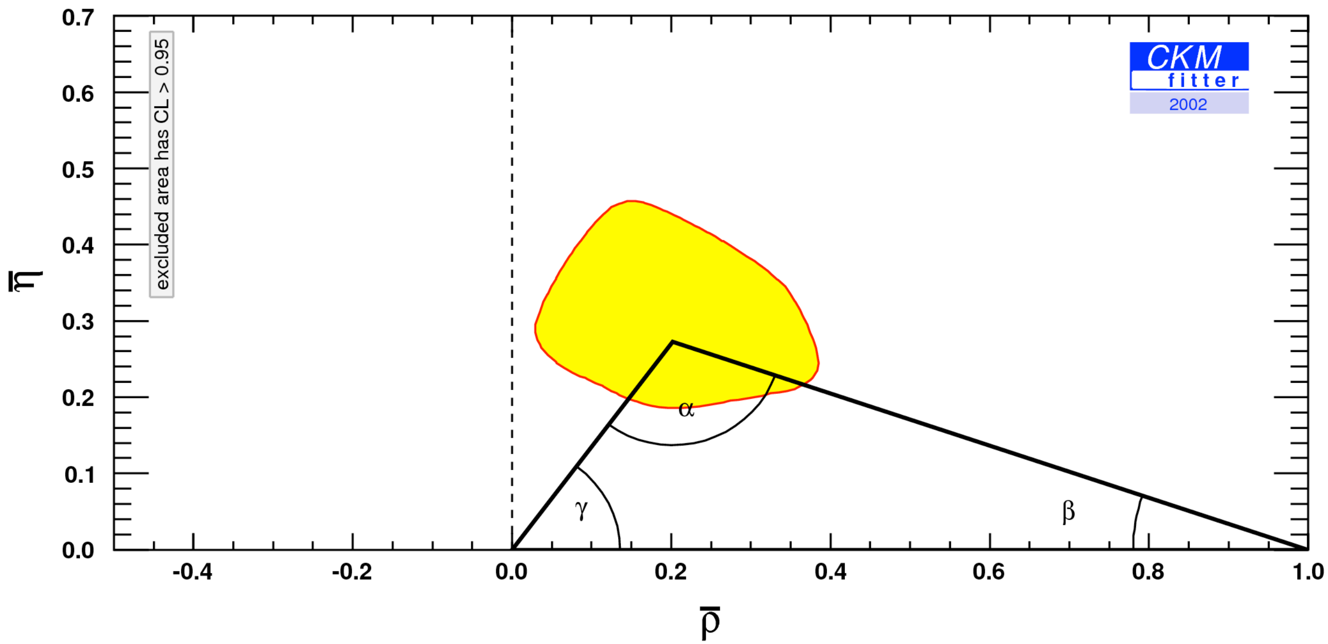

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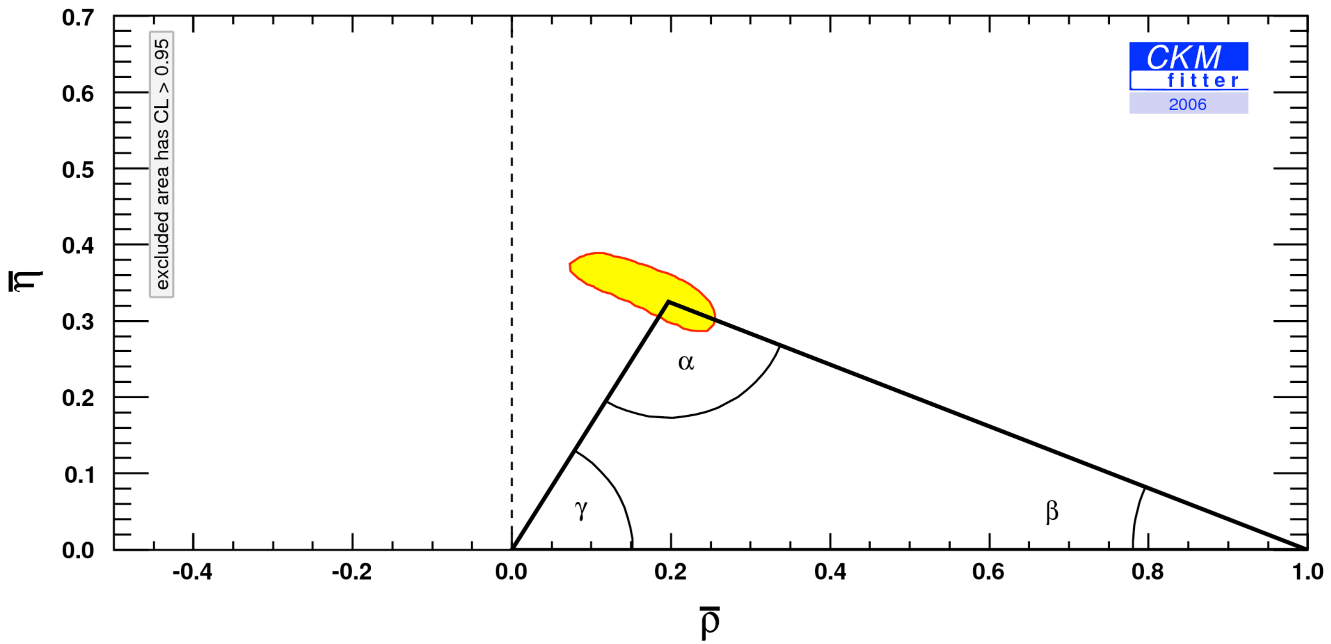

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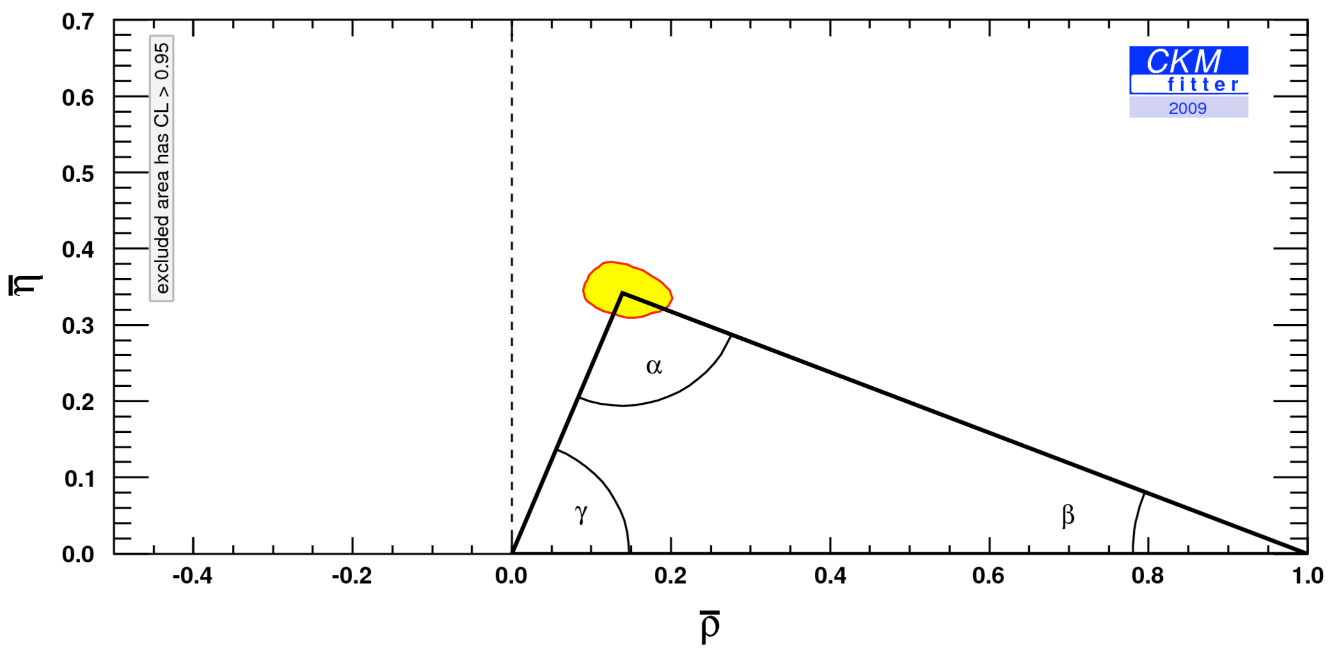

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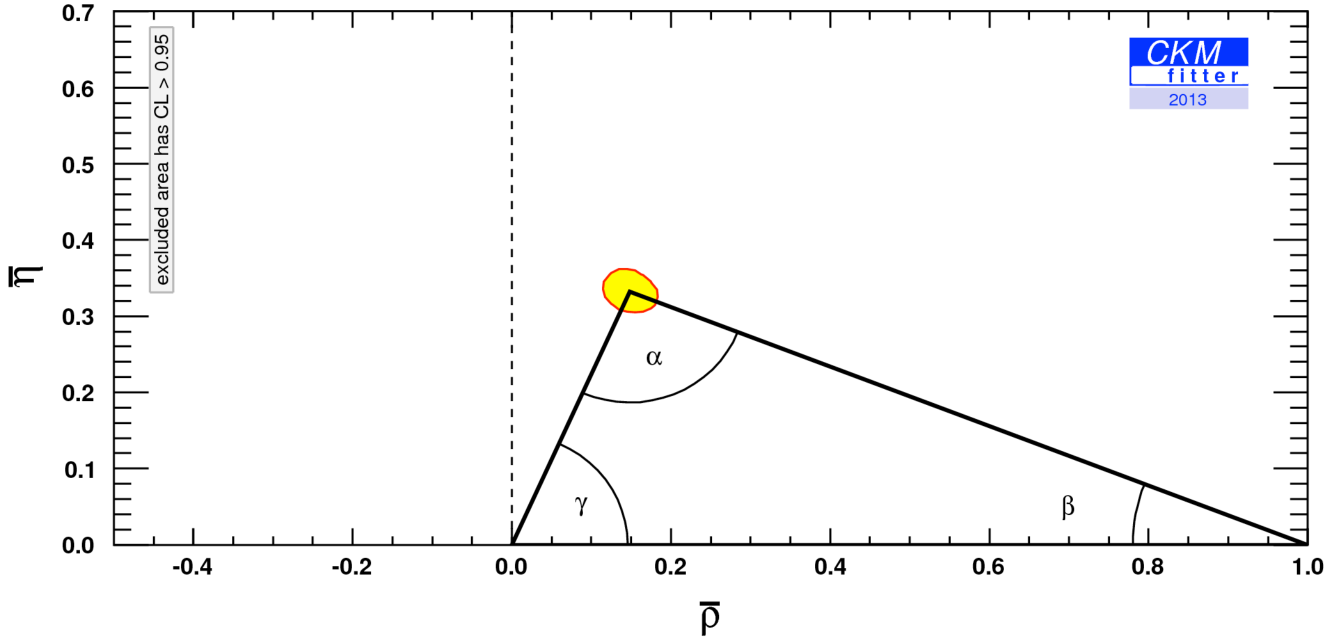

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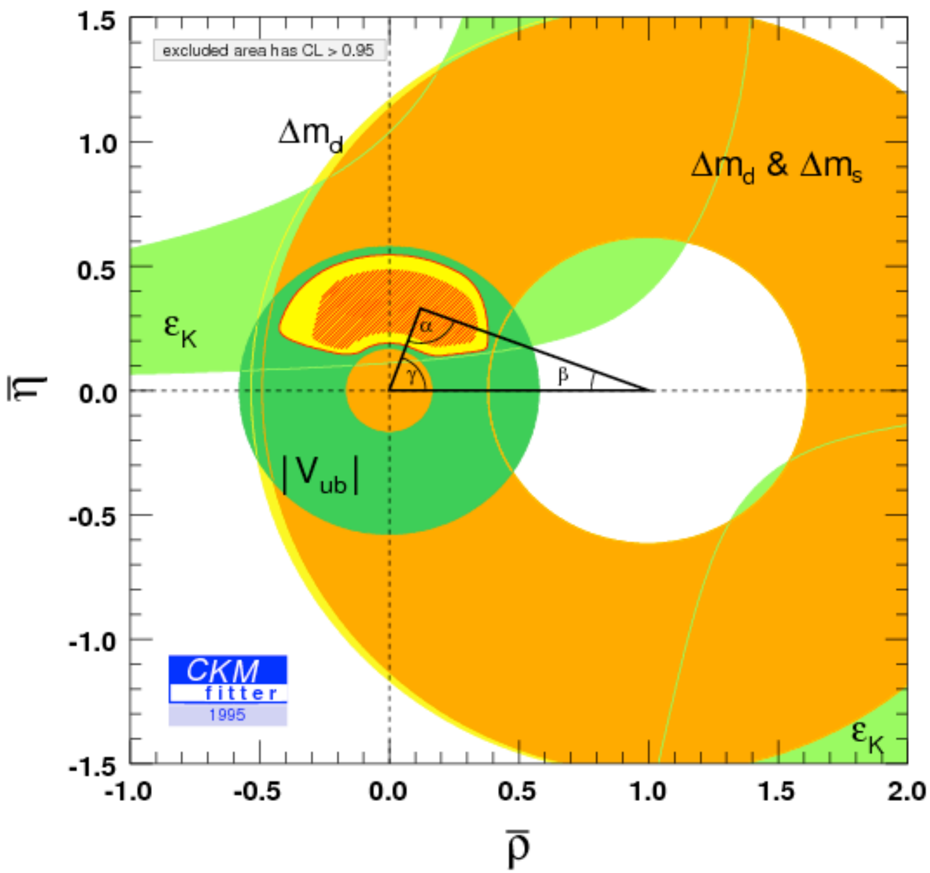

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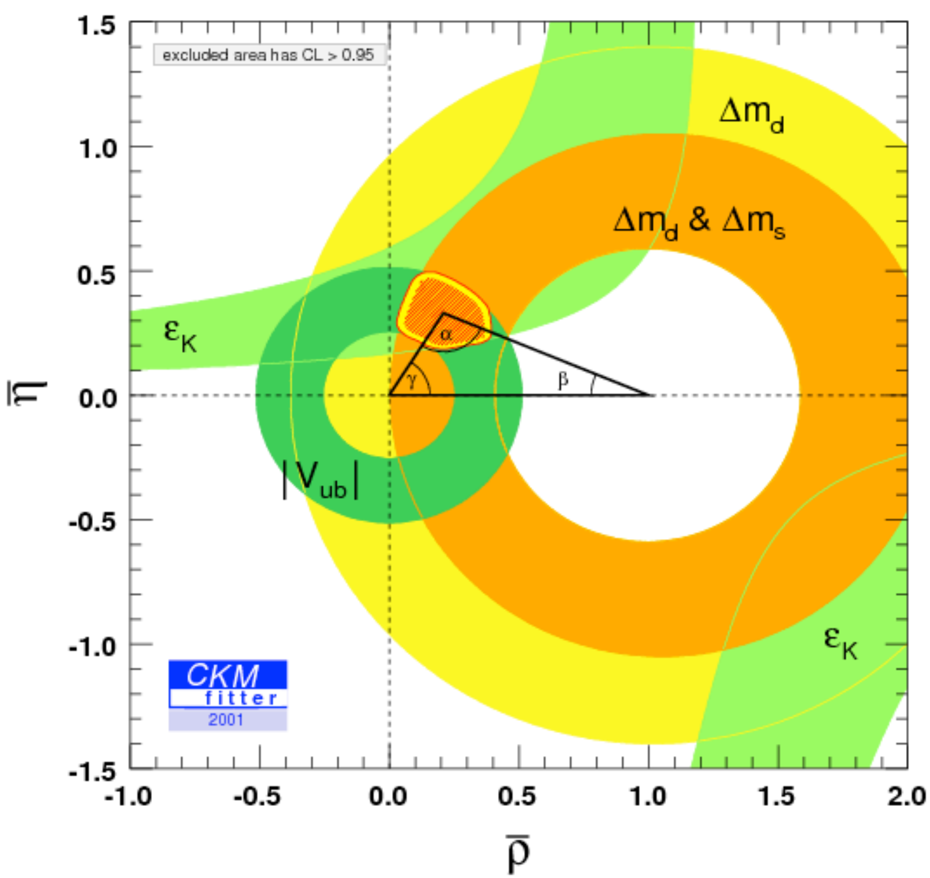

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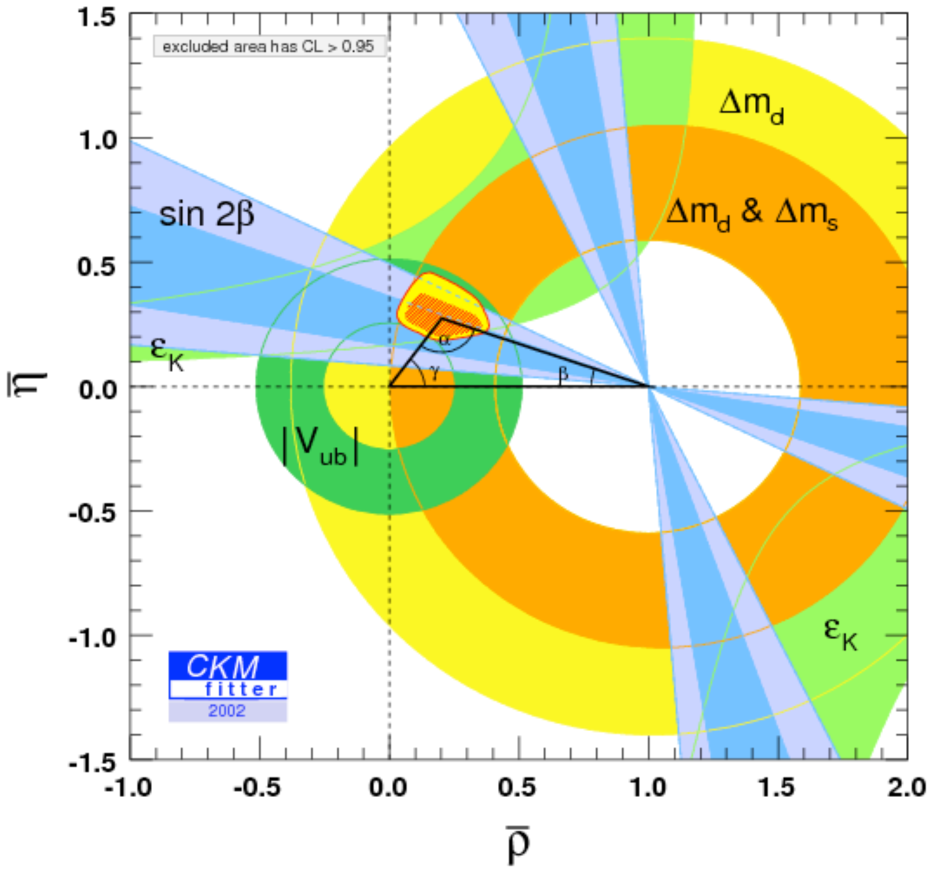

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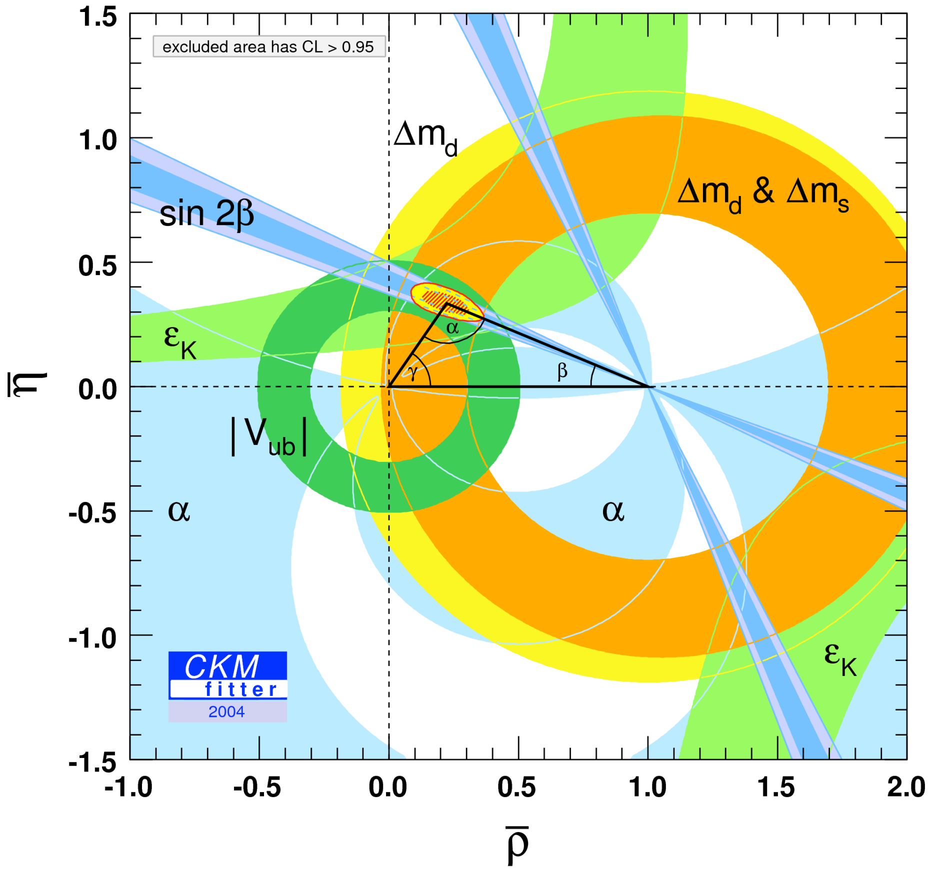

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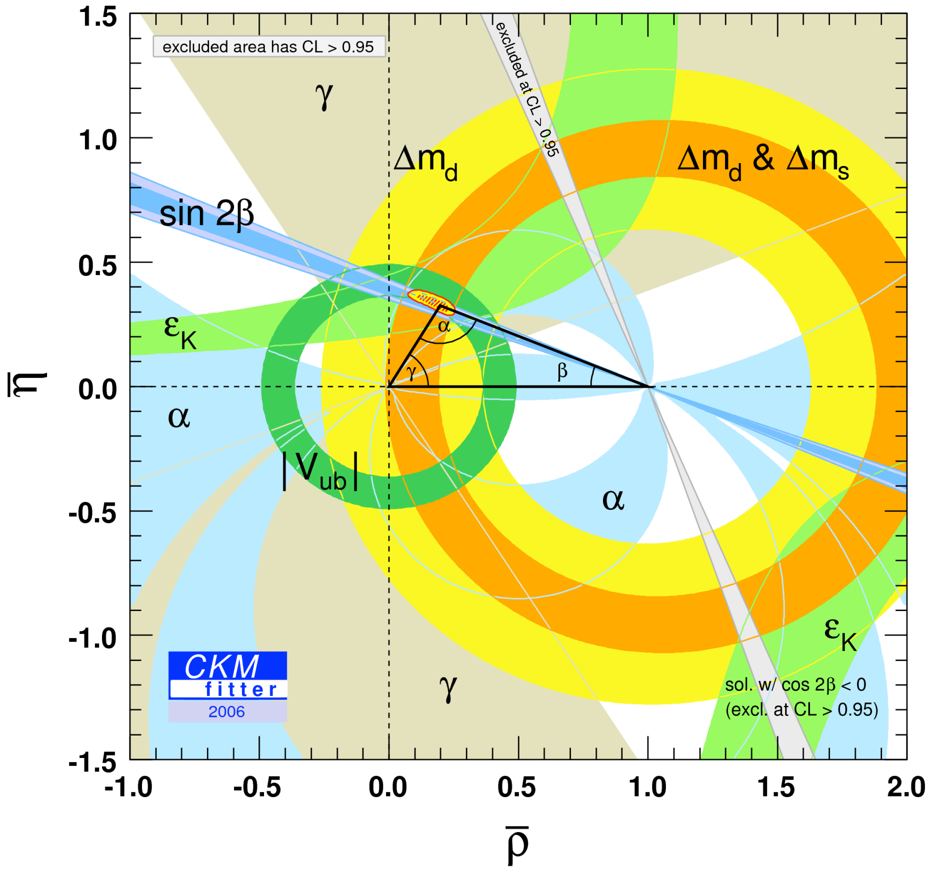

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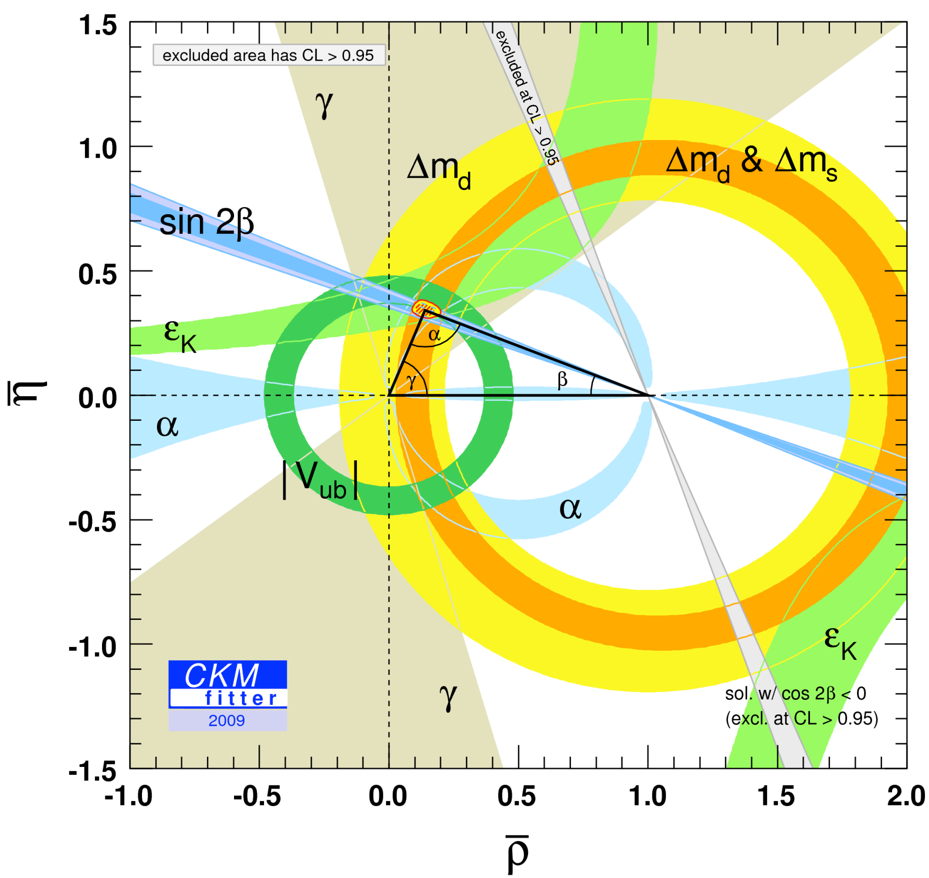

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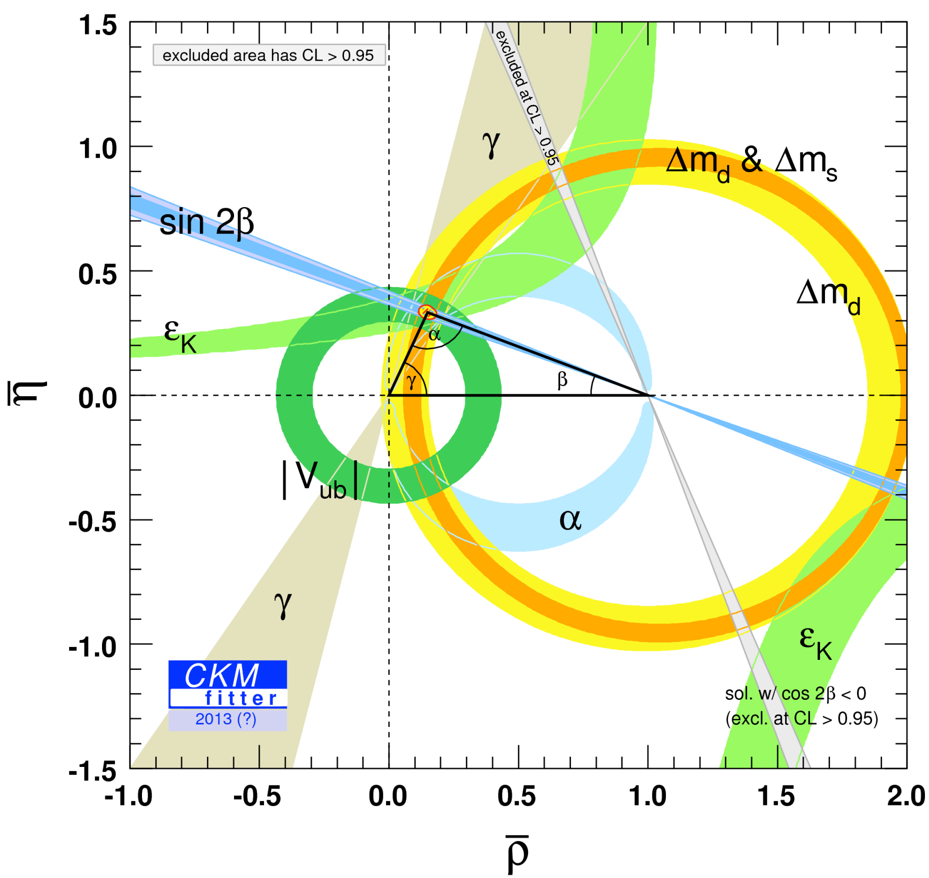

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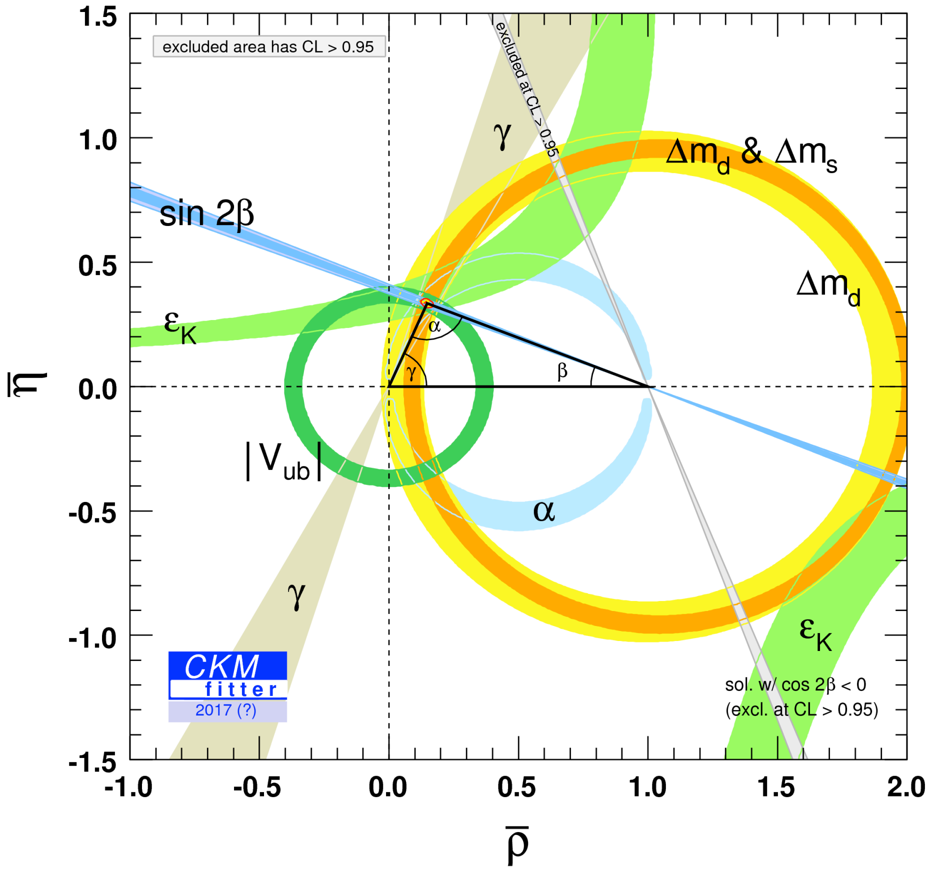


3.3 Back to the future .

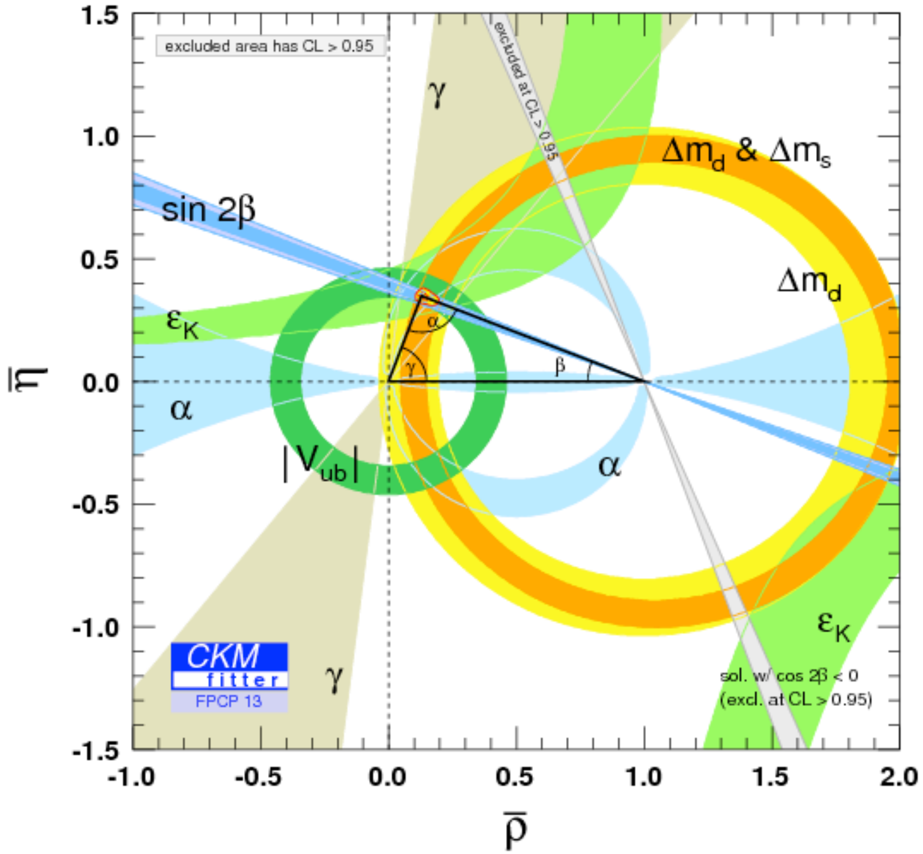
- 1995: starting point given by the top quark mass measurement. K and B mixings can be predicted.
- 2001: pre-Bfactories era. LEP/CLEO based UT. Comparison with kaon mixing gives a consistency check.
- 2002: CP violation in the interference between decay and mixing is observed. This is the first true consistency test of the Standard Model.
- 2004: alpha is measured.
- 2006: Δm_s (and gamma)
- 2013: LHCb dominating the gamma measurement.
- 2017: Super Flavour Factory (SuperKEKB) and LHCb (upgrade): additionally LQCD improvement.

3.3 Standard Model Predictions from the global fit.

- Now that the Standard Model hypothesis is validated [Validated does not mean that the SM is THE theory: it means that it passed the statistical test !!!] it's relevant to make the metrology of the CKM parameters.

- Additonally, perform consistency checks. Exclude the meas. of the observable you want to predict from the global fit and … compare !

- Please pick your favourite around here: http://ckmfitter.in2p3.fr.



3.3 Standard Model Predictions from the global fit. An example out of the global fit as it used to be in 2010.

- CKM parameters:

$$A = 0.812^{+0.013}_{-0.027}$$
$$\lambda = 0.22543 \pm 0.00077$$
$$\bar{\rho} = 0.144 \pm 0.025$$
$$\bar{\eta} = 0.342^{+0.016}_{-0.015}$$
$$J = (2.96^{+0.18}_{-0.17})10^{-5}$$

- Rare decays:

$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = (0.763^{+0.114}_{-0.061})10^{-4}$$
$$\mathcal{B}(B^+ \to \mu^+ \nu_\mu) = (0.387^{+0.045}_{-0.043})10^{-6}$$
$$\mathcal{B}(B_s \to \mu^+ \mu^-) = (3.073^{+0.070}_{-0.190})10^{-9}$$
$$\mathcal{B}(B_s \to \mu^+ \mu^-) = (9.87^{+0.25}_{-0.67})10^{-11}$$

- Matrix element / angles (including Bs system)

$$|V_{ub}| = 0.00354^{+0.00016}_{-0.00020}$$
$$\sin 2\beta = 0.830^{+0.013}_{-0.034}$$
$$\sin 2\beta_s = 0.0363 \pm 0.0017$$

- Lattice parameters (!)

$$B_K = 0.83^{+0.26}_{-0.15}$$
$$\xi = 1.195^{+0.053}_{-0.044}$$
$$f_{B_s} = 235.8 \pm 8.9 \text{ MeV}$$

3.3 The consistency check in details. Is it that good ?

- Yes it is !
- Predictions can be made on single observables not present in the global fit but depending on the CKM parameters.
- Here is an example of such predictions Phys.Rev. D84 (2011) 033005
- LHCb can measure some of these observables: null test of the SM hypothesis (See Yasmine's seminar LHC).

Charged Leptonic Decays				
$\mathcal{B}(B^+ \to \tau^+\nu_\tau)$	$(16.8 \pm 3.1)\cdot 10^{-5}$	[4]	$(7.57\ ^{+0.98}_{-0.61})\cdot 10^{-5}$	2.8
$\mathcal{B}(B^+ \to \mu^+\nu_\mu)$	$< 10^{-6}$	[10]	$(3.74\ ^{+0.44}_{-0.38})\cdot 10^{-7}$	-
$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$	$(5.29 \pm 0.28)\cdot 10^{-2}$	[10]	$(5.44\ ^{+0.05}_{-0.17})\cdot 10^{-2}$	0.5
$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)$	$(5.90 \pm 0.33)\cdot 10^{-3}$	[10]	$(5.39\ ^{+0.21}_{-0.22})\cdot 10^{-3}$	1.3
$\mathcal{B}(D^+ \to \mu^+\nu_\mu)$	$(3.82 \pm 0.32 \pm 0.09)\cdot 10^{-4}$	[9]	$(4.18\ ^{+0.13}_{-0.20})\cdot 10^{-4}$	0.6
Neutral Leptonic B decays				
$\mathcal{B}(B_s^0 \to \tau^+\tau^-)$	-		$(7.73\ ^{+0.37}_{[illegible]})\cdot 10^{-7}$	-
$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	$< 32\cdot 10^{-9}$	[10]	$(3.64\ ^{+0.17}_{-0.31})\cdot 10^{-9}$	-
$\mathcal{B}(B_s^0 \to e^+e^-)$	$< 2.8\cdot 10^{-7}$	[10]	$(8.54\ ^{[illegible]}_{-0.72})\cdot 10^{-14}$	-
$\mathcal{B}(B_d^0 \to \tau^+\tau^-)$	$< 4.1\cdot 10^{-3}$	[10]	$(2.36\ ^{+0.12}_{-0.21})\cdot 10^{-8}$	-
$\mathcal{B}(B_d^0 \to \mu^+\mu^-)$	$< 6\cdot 10^{-9}$	[10]	$(1.13\ ^{+0.06}_{-0.11})\cdot 10^{-10}$	-
$\mathcal{B}(B_d^0 \to e^+e^-)$	$< 8.3\cdot 10^{-9}$	[10]	$(2.64\ ^{+0.13}_{-0.24})\cdot 10^{-15}$	-
$B_q - \bar{B}_q$ mixing observables				
$\Delta\Gamma_s/\Gamma_s$	$0.092^{+0.051}_{-0.054}$	[10]	$0.179\ ^{+0.067}_{-0.071}$	0.5
$a^d_{\rm SL}$	$(-47 \pm 46)\cdot 10^{-4}$	[10]	$(-6.5\ ^{+1.9}_{-1.7})\cdot 10^{-4}$	0.8
$a^s_{\rm SL}$	$(-17 \pm 91^{+12}_{-23})\cdot 10^{-4}$	[26]	$(0.29\ ^{+0.09}_{-0.08})\cdot 10^{-4}$	0.2
$a^s_{\rm SL} - a^d_{\rm SL}$	-		$(6.8\ ^{+1.9}_{-1.7})\cdot 10^{-4}$	-
$\sin(2\beta)$	0.678 ± 0.020	[10]	$0.832\ ^{[illegible]}_{-0.033}$	2.7
$2\beta_s$	$[0.04; 1.04] \cup [2.16; 3.10]$	[27]	$0.0363\ ^{+0.0016}_{-0.0015}$	-
	$0.76\ ^{+0.36}_{-0.38} \pm 0.02$	[28]		
Radiative B decays				
$\mathcal{B}(B_d \to K^*(892)\gamma)$	$(43.3 \pm 1.8)\cdot 10^{-6}$	[10]	$(64\ ^{+22}_{-21})\cdot 10^{-6}$	1.2
$\mathcal{B}(B^- \to K^{*-}(892)\gamma)$	$(42.1 \pm 1.5)\cdot 10^{-6}$	[10]	$(66\ ^{+21}_{-20})\cdot 10^{-6}$	1.1
$\mathcal{B}(B_s \to \phi\gamma)$	$(57^{+21}_{-18})\cdot 10^{-6}$	[10]	$(65\ ^{+31}_{-24})\cdot 10^{-6}$	0.1
$\mathcal{B}(B \to X_s\gamma)/\ \mathcal{B}(B \to X_c\ell\nu)$	$(3.346 \pm 0.247)\cdot 10^{-3}$	[10]	$(3.03\ ^{+0.34}_{-0.32})\cdot 10^{-3}$	0.2
Rare K decays				
$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})$	$(1.75^{+1.15}_{-1.05})\cdot 10^{-10}$	[29]	$(0.854\ ^{+0.116}_{-0.098})\cdot 10^{-10}$	0.8
$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu})$	-		$(0.[illegible])\cdot 10^{-10}$	

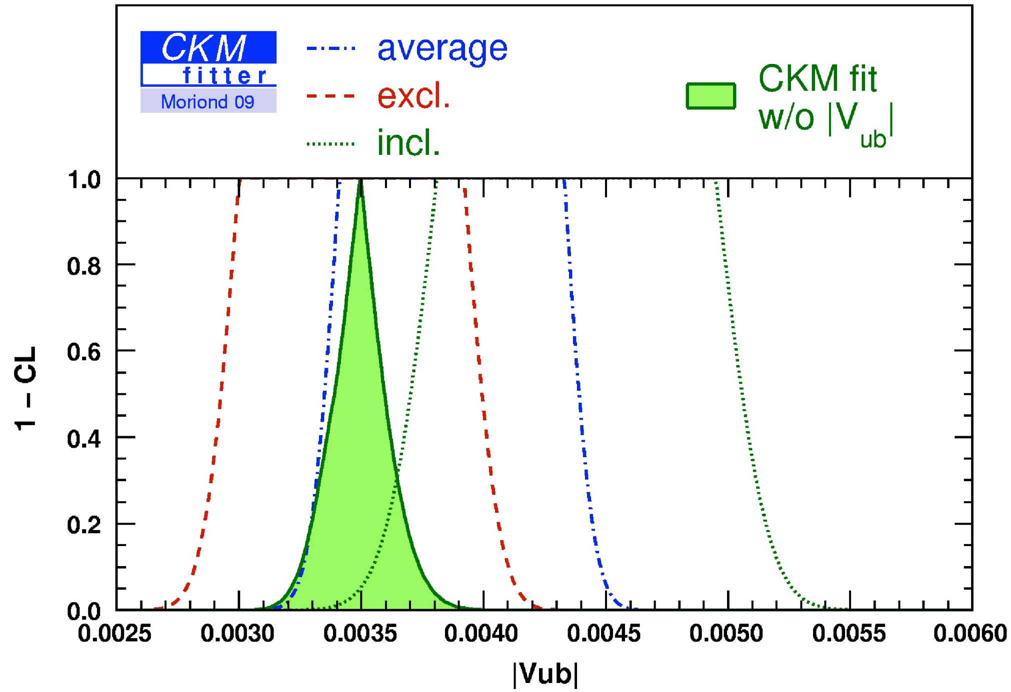
3.4 The tensions in the global fit.

- Among the consistency checks, we find some marginal agreement.
- We will review what could be possible hints of New Physics as indicated by the big picture.
- The most significant one is the marginal agreement of tauonic B decay branching ratio and sin 2β.
- The outlook will de dedicated to specific New Physics analyses which can accomodate the observed discrepancy. I will consider the most discrepant picture along time to make my point.

3.4 The tensions in the global fit.

3.4.1 $|V_{ub}|$ vs $\sin 2\beta$?

- It is actually more a $|V_{ub}|$ vs $|V_{ub}|$ tension.
- We are living with a significant difference between exclusive and inclusive measurements: a longstanding issue.
- The $\sin 2\beta$ measurement prefers the exclusive value (if SM is correct).

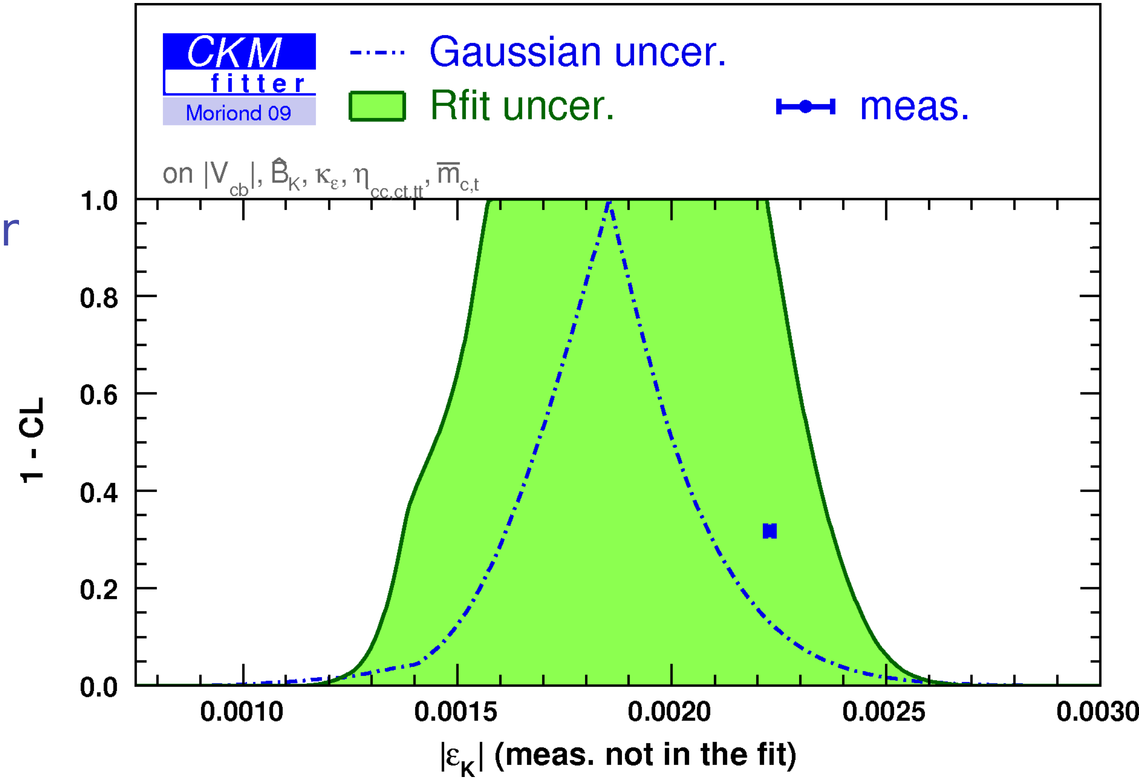


3.4 The tensions in the global fit.

3.4.2 $|\varepsilon_K|$ vs $\sin 2\beta$?

Buras & Guadagnoli recently advocated necessity of an additior parameter in the SM lowering the prediction.

A possible tension $|\varepsilon_K|$ vs $\sin 2\beta$ was mentioned and received appealing explanations (Soni & Lunghi).

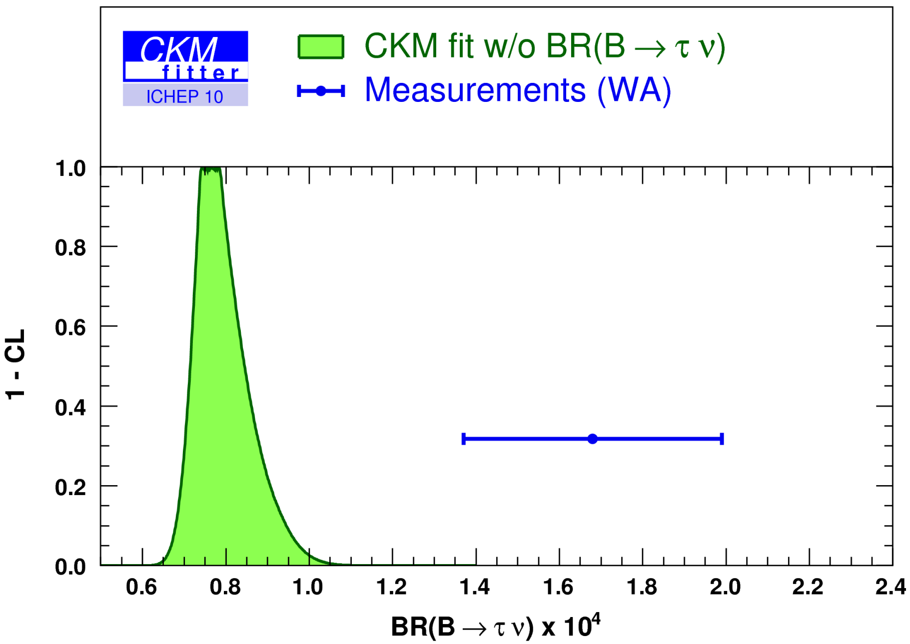


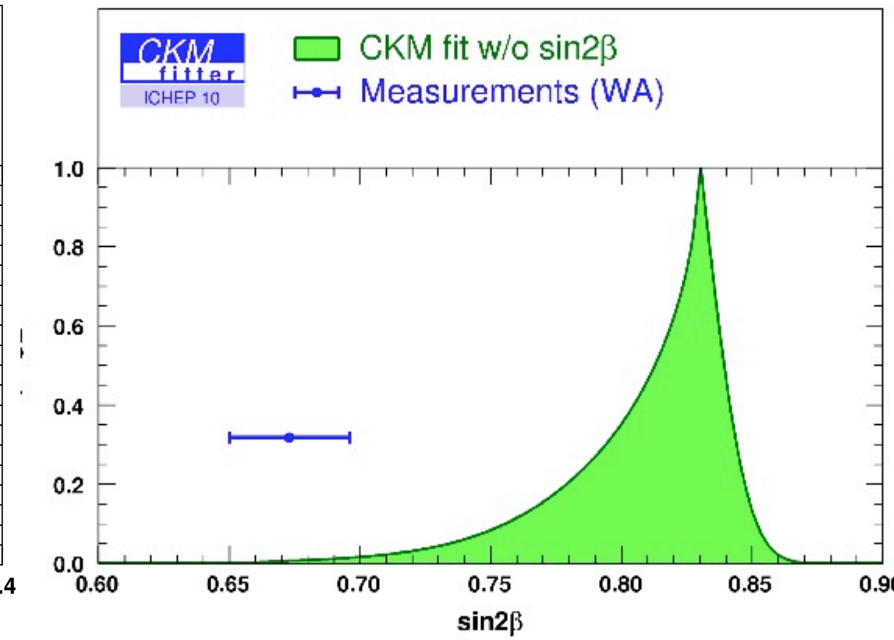
A tension arises only if all the uncertainties on QCD parameters are Gaussian.

3.4 The tensions in the global fit.

3.4.3 $B^+ \to \tau^+ \nu$ vs $\sin 2\beta$?

All measurements (2010) were consistent with their predictions within one standard deviation apart Br($B^+ \to \tau^+ \nu$) [2.8 σ] and $\sin 2\beta$ [2.6 σ]

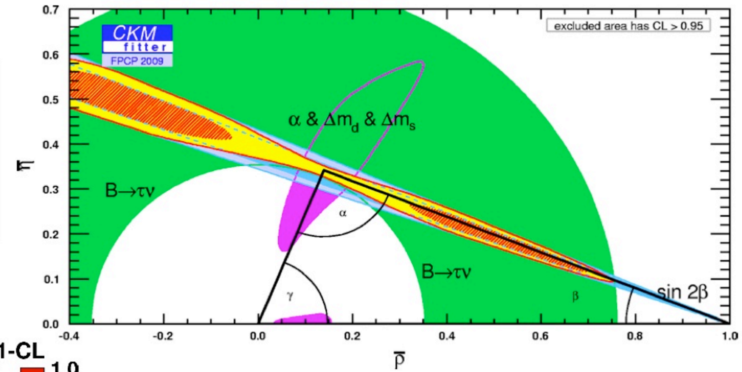


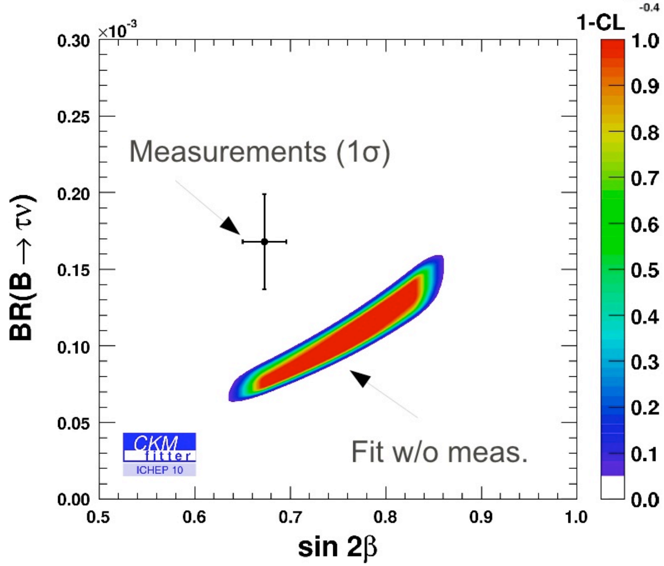


3.4 The tensions in the global fit.

3.4.3 $B^+ \to \tau^+ \nu$ vs $\sin 2\beta$?

- The combination sin2β and B →τν favors 2 solutions in contradictions with other inputs.
- One cannot accommodate both inputs simultaneously in the global fit.





Non-trivial correlation of indirect constraints on sin2β and B →τν.

The low value of the prediction of B →τν is mainly driven by the measured value of sin2β

Sources of discrepancies:
1) Measurements (stat. fluctuations)?
2) Lattice estimate of f_B?
3) New Physics in B→τν and/or sin2β?

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4. Outlook and conclusions.

1. Analysis of mixing processes. Which room left for new physics. A bottom-up approach (model-independent)

2. A top-down appproach (dedicated model testing): the Two Higgs Doublet (Type II).

3. Conclusion remarks.

4.1 Bottom-Up: NP in ΔF=2 processes

Aim at investigating in a model-independent manner the space left to NP contributions by the current data. Only two additional parameters added. Several equivalent parametrisations exist:

$$\langle B_q | \mathcal{H}^{\rm SM+NP}_{\Delta B=2} | \bar{B}_q \rangle \equiv \langle B_q | \mathcal{H}^{\rm SM}_{\Delta B=2} | \bar{B}_q \rangle \times ({\rm Re}(\Delta_q) + i\,{\rm Im}(\Delta_q))$$

$${\rm Re}(\Delta_q) + i{\rm Im}(\Delta_q) = r_q^2 e^{i2\theta_q} = 1 + h_q e^{i\sigma_q}$$

Soares & Wolfenstein, PRD 47, 1021 (1993)
Deshpande, Dutta & Oh, PRL77, 4499 (1996)
Silva & Wolfenstein, PRD 55, 5331 (1997)
Cohen et al., PRL78, 2300 (1997)
Grossman, Nir & Worah, PLB 407, 307 (1997)

Goto et al., PRD 53, 6662 (1996)

Hypotheses:

- Only the short distance part of the mixing processes might receive NP contributions.
- Unitary 3X3 CKM matrix.
- Tree-level processes are not affected by NP (so-called SM4FC: $b \to q_i q_j q_k$ ($i \neq j \neq k$)). As a consequence, the quantities which do not receive NP contributions in that scenario **are:**

$$|V_{ud}|,\ |V_{us}|,\ |V_{ub}|,\ |V_{cb}|,\ B^+ \to \tau^+ \nu_\tau \text{ and } \gamma$$

4.1 NP in ΔF=2 processes

Following the cartesian coordinates parameterisation proposed by Lenz and Nierste (JHEP0706:072,2007)

$$\Delta_q = |\Delta_q| e^{i2\Phi_q^{\mathrm{NP}}}$$

The predictions of the observables sensitive to NP contributions are modified as:

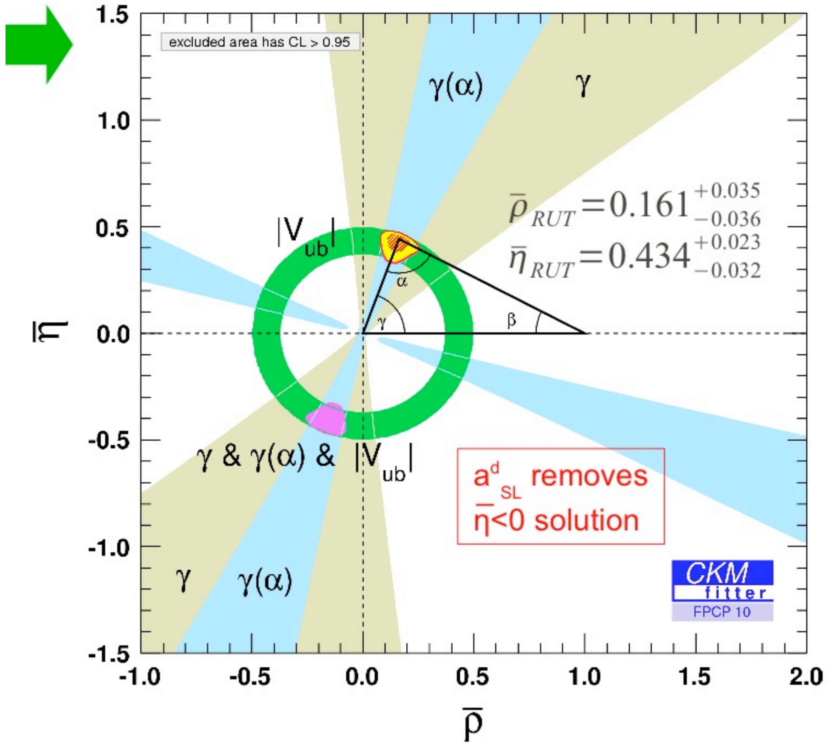
parameter	prediction in the presence of NP
Δm_q	$\lvert\Delta_q^{\mathrm{NP}}\rvert \times \Delta m_q^{\mathrm{SM}}$
2β	$2\beta^{\mathrm{SM}} + \Phi_d^{\mathrm{NP}}$
$2\beta_s$	$2\beta_s^{\mathrm{SM}} - \Phi_s^{\mathrm{NP}}$
2α	$2(\pi - \beta^{\mathrm{SM}} - \gamma) - \Phi_d^{\mathrm{NP}}$
$\Phi_{12,q} = \mathrm{Arg}[-\frac{M_{12,q}}{\Gamma_{12,q}}]$	$\Phi_{12,q}^{\mathrm{SM}} + \Phi_q^{\mathrm{NP}}$
A_{SL}^q	$\frac{\Gamma_{12,q}}{M_{12,q}^{\mathrm{SM}}} \times \frac{\sin(\Phi_{12,q}^{\mathrm{SM}} + \Phi_q^{\mathrm{NP}})}{\lvert\Delta_q^{\mathrm{NP}}\rvert}$
$\Delta\Gamma_q$	$2\lvert\Gamma_{12,q}\rvert \times \cos(\Phi_{12,q}^{\mathrm{SM}} + \Phi_q^{\mathrm{NP}})$

4.1 NP in ΔF=2 processes

Hypotheses:

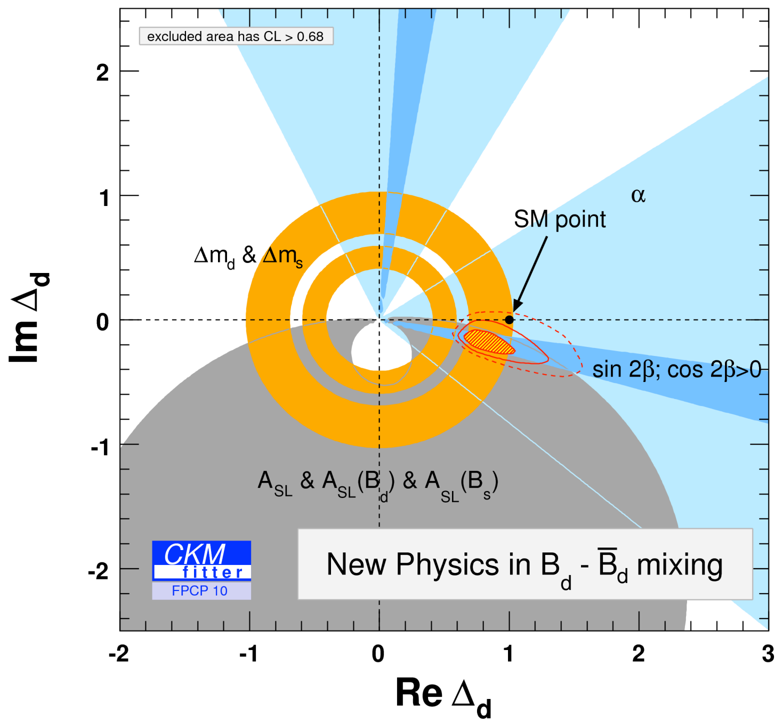
• tree-level processes are not affected by NP (so-called SM4FC: $b \to q_i q_j q_k$ ($i \neq j \neq k$)). As a consequence, the quantities which do not receive NP contributions in that scenario are:

$$|V_{ud}|,\ |V_{us}|,\ |V_{ub}|,\ |V_{cb}|,\ B^+ \to \tau^+\nu_\tau \text{ and } \gamma$$



- They fix the apex of the UT.
- α and β receives the same additional phase with opposite sign and hence can be interpreted as γ tree.
- The second (symmetric) solution is disfavored by the semileptonic charge asymmetry.

4.1 NP in $\Delta F=2$ processes

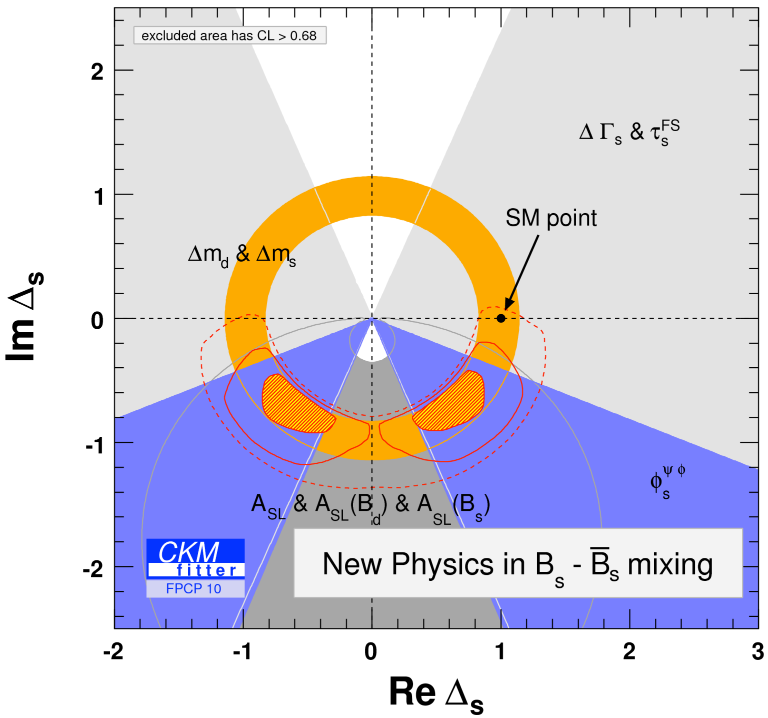


- β and A_{SL} are both favouring the negative imaginary part.
- SM hypothesis (2D): 2.5σ

1. Sizeable NP contributions allowed in the Bd mixing.

2. A new phase in the Bd mixing accomodates the $B^+ \to \tau^+ \nu$ vs $\sin 2\beta$ discrepancy of the SM global fit

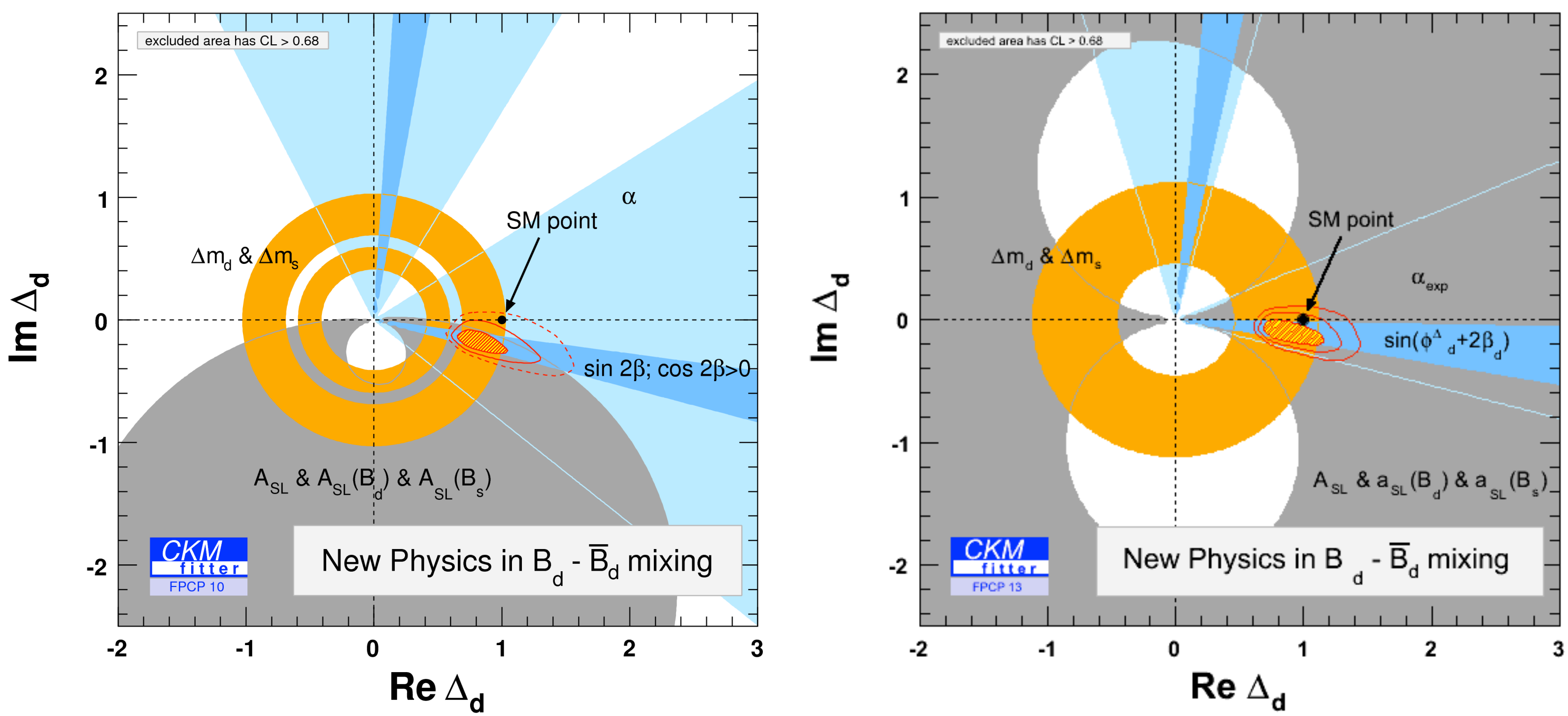
4.1 NP in $\Delta F=2$ processes



- β_s and A_{SL} are both favouring the negative imaginary part.
- SM hypothesis (2D): 2.7σ

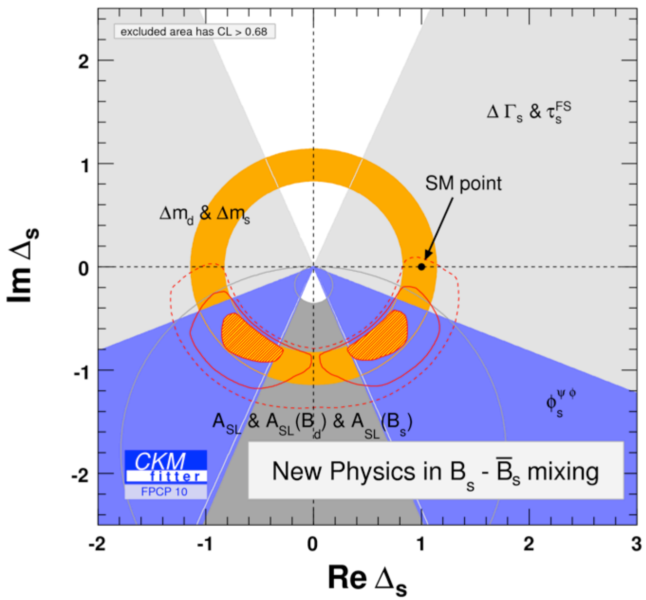
1. Sizeable NP contributions allowed in the Bs mixing.
2. LHCb contribution should be decisive.

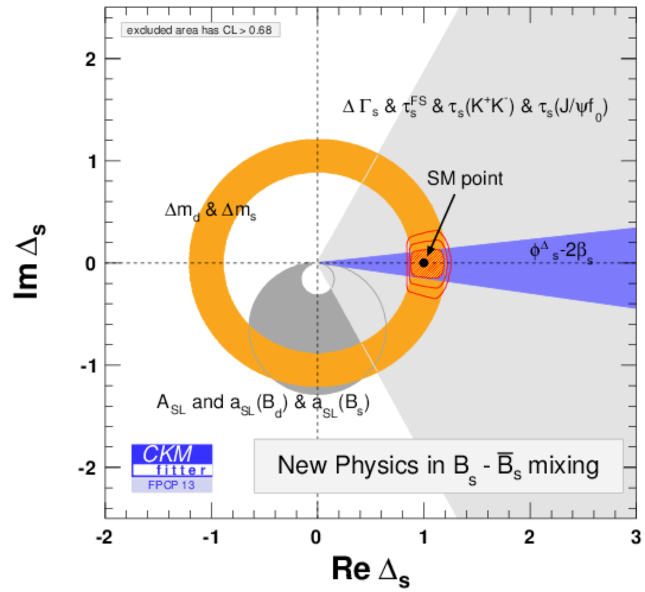
4.1 NP in ΔF=2 processes. After new Belle Results.



- Damned, SM strikes back.

4.1 NP in ΔF=2 processes. After LHCb 1/fb.





- The 2D SM hypothesis is: 0.2 σ (used to be ~ 3 σ)

- But don't infer a wrong statement: sizeable NP is still allowed by the LHCb constraint in both Bd and Bs mixing.

4.1 NP in ΔF=2 processes. Conclusion.

Message Number #:

A single evidence almost smashed the SM. If NP is there, I believe it would come as naturally as in the example I chose.

4.2 Two Higgs Doublets Model (Top-Down)

• Charged Higgs transition is something we immediately imagine for BF($B^+ \to \tau^+ \nu$). What the flavour data say on a 2HDM model?

• Motivations: it is a simple and predictive extension of the Standard Model. Same structure for the quark sector but new flavour changing charged interactions mediated by a charged Higgs.

• Track charged Higgs contributions into tree or loop decays. Redefinition of the SM expression through corrections implying only 2 additionnal parameters:

$$M_{H^+}, \tan\beta = \frac{v_2}{v_1}$$

• 2HDM is embedded into supersymmetric models (MSSM).

• Note: There are of course neutral higgses in 2HDM, which do not enter the processes under consideration in this study.

4.2 Two Higgs Doublets Model (Top-Down)

- All inputs are potentially subjected to receive charged Higgs contributions.

- Yet, we neglected charged Higgs contribution for the following inputs, hence used to determine the apex of the unitarity triangle. Driven by (m_light/m_heavy)² couplings → $|V_{ud}|$, $|V_{ub}|$, $|V_{cb}|$ and $\gamma(\alpha+\beta)$.

- We consider several observables subjected to receive Higgs contributions:

  - Leptonic decays → { $\Gamma[K \to \mu\nu]/\Gamma[\pi \to \mu\nu]$, $\mathcal{B}[D \to \mu\nu]$, $\mathcal{B}[D_s \to \mu\nu]$, $\mathcal{B}[D_s \to \tau\nu]$ and $\mathcal{B}[B \to \tau\nu]$

  - Semileptonic decays → $\mathcal{B}(B \to D\tau\nu)$ and $\mathcal{B}(K \to \pi\ell\nu)$

  - The partial width of Z to bb (used to be a hint of NP!) [consider B mixing also]

  - $b \to s\gamma$

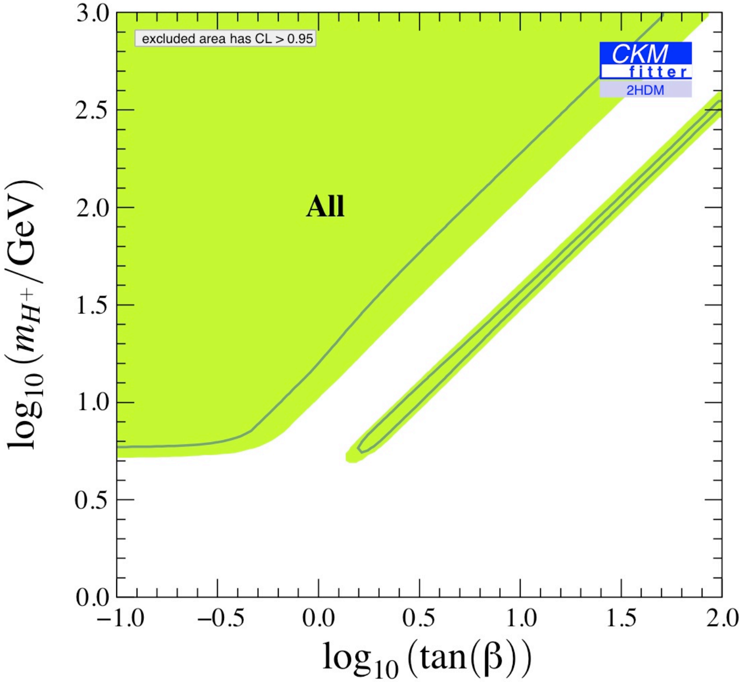
4.2 Two Higgs Doublets Model (Top-Down)

- Leptonic constraints:

$$\mathcal{B}[M \to \ell\nu] = \frac{G_F^2 m_M m_\ell^2}{8\pi\hbar}(1 - \frac{m_\ell^2}{m_M^2})^2 |V_{q_u q_d}|^2 f_M^2 \tau_M (1 + \delta_{\rm em}^{Ml2})$$

$$\mathcal{B}[M \to l\nu] = \mathcal{B}[M \to l\nu]_{SM}(1 + r_H^{Ml2}) \text{ where}$$

$$r_H^{Ml2} = (\frac{m_{q_u} - m_{q_d}\tan^2\beta}{m_{q_u} + m_{q_d}})(\frac{m_M}{m_{H^+}})^2$$



- Most of the individual fined-tuned solutions are removed at 95% CL

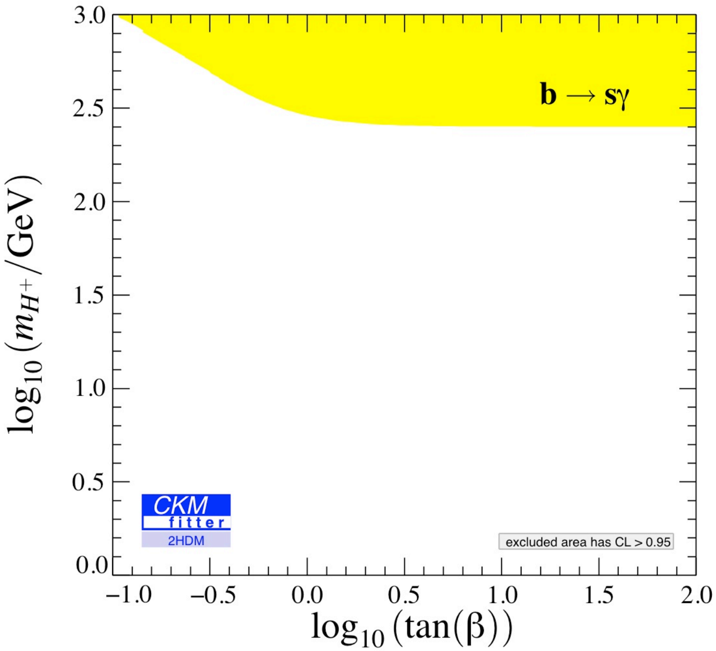
- Large tan β are excluded at small Higgs masses.

4.2 Two Higgs Doublets Model (Top-Down)

- Radiative decay

$$\mathcal{R}_{b\to s\gamma} = \frac{\mathcal{B}[\bar{B}\to X_s\gamma]}{\mathcal{B}[\bar{B}\to X_c l\bar{\nu}]} = \left|\frac{V_{ts}^{\star}V_{tb}}{V_{cb}}\right|^2 \frac{6\alpha_{\rm em}}{\pi C}(P+N)$$

$$P+N = (C_{7,SM}^{{\rm eff},(0)} + B\Delta C_{7,H^+}^{{\rm eff},(0)})^2 + A$$



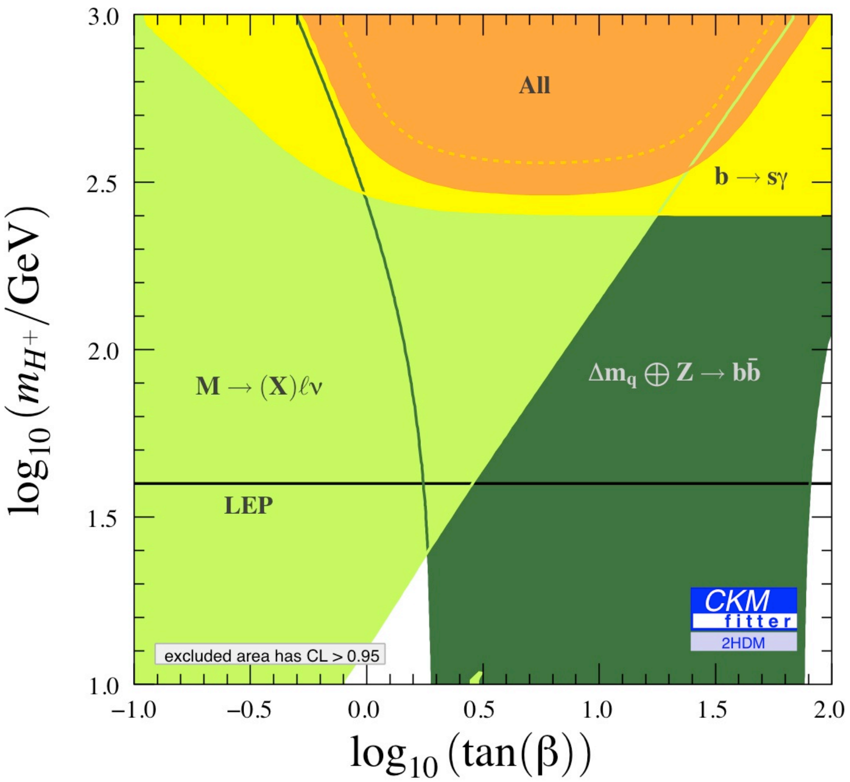
Widely investigated in the literature.

- A.J. Buras, M.Misiak, M.Munz, S. Pokorski, Nucl Phys. B424
- K. Chetyrkin, M. Misiak, M. Munz, Phys. Lett. B400.
- P. Gambino, M.Misiak Nucl., Phys. B611.
- M.Misiak, M. Steinhauser Nucl. Phys. B764.
- C. Degrassi, P. Gambino, P. Slavich, CERN/2007-265
- T. Besmer, C. Greub, T. Hurth, Nucl. Phys. B 609.

- Almost unidimensionnal constraint on the charged Higgs mass. Weak tanβ dependance at large values, where leptonic decays ARE constraining.

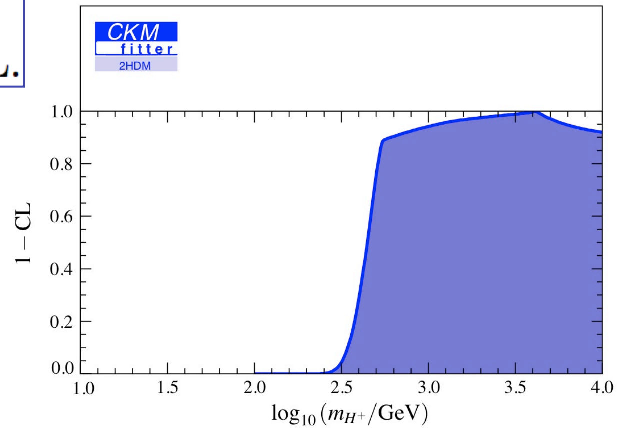
4.2 Two Higgs Doublets Model (Top-Down)

- Combined constraints:



- Leptonic decays (mainly $BR(B^+ \to \tau^+\nu)$) constrain the parameter space at large tanβ.
- unidimensionnal constraint (orange) on M_{H+} mostly by $b \to s\gamma$.
- 2HDM(II) does not perform better than the SM.

$$M_{H+} > 310\ \mathrm{GeV/c^2}$$ at 95% CL.



- CKM mechanism is at work for describing quark flavor transitions.
- KM phase likely to be dominant in B's.

- Triumph of the SM and the B factories.

- Still, sizeable NP contributions still allowed in both Bd and Bs systems.

- We are not yet at the level of precision achieved for Z pole EW fits. For instance, the CKM unitarity triangle is not much constrained:

$$\alpha + \beta + \gamma = (174.8 \pm 9.4)^\circ .$$

- Hunt for rare decays where significant BSM contributions might occur.

- Improve the UT consistency test: measure the gamma angle.

- This is the physics case of the LHCb experiment and super KEKB programs ! Exciting times ahead.

Concluding remarks to trigger some discussions

- Symmetries in Physics are beautiful and powerful.

- Symmetry violations and breaking are not less beautiful.

- The SM has been raised legitimately to a theory of Nature.

- But it's still an effective model. Strong experimental evidences (mostly cosmological) that we need beyond SM CP-violating phases and dark matter. On top of that, neutrino sector still to be understood. Particle Physics's job.

- Particle Physics is orphan now of the LHC no-loose theorem.

- We need to find the way but we have the tools to write the maps:

    - Precision measurements (flavour physics for near future).

    - Direct searches (LHC Run II for near future).