Global Fit to CKM Data

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on behalf of the CKMfitter group

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Parameterisation of the CKM Matrix

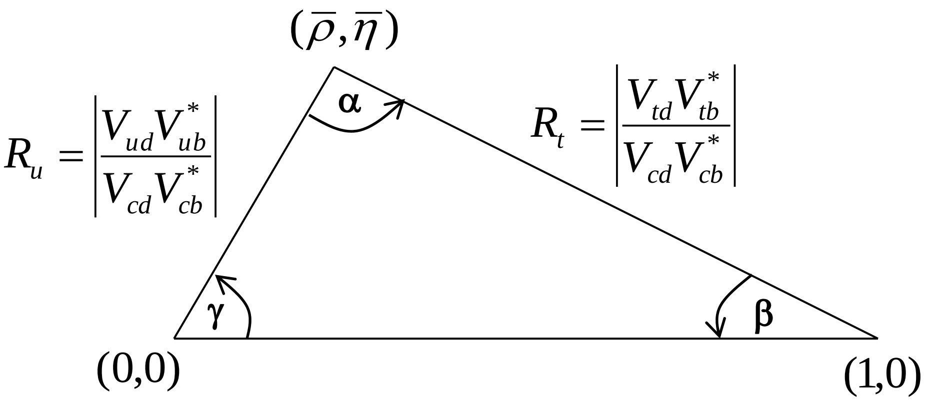
❑ **Phase invariant parameterisation conserving** the CKM matrix **unitarity** at any order in λ.

⇒ Wolfenstein parameterisation with Jarlskog like phase invariants as in Charles *et al.* EPJ C**41**,1-131 (2005). **4 free parameters,** $A, \lambda, \bar{\rho}$ and $\bar{\eta}$ taken as:

$$\lambda = \frac{|V_{us}|}{\sqrt{|V_{ud}|^2 + |V_{us}|^2}}, \quad A\lambda^2 = \frac{|V_{cb}|}{\sqrt{|V_{ud}|^2 + |V_{us}|^2}} \quad \text{and} \quad \bar{\rho} + i\bar{\eta} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}, \text{ with } V_{CKM} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

- λ is measured from $|V_{ud}|$ and $|V_{us}|$ in superallowed nuclear β-decays and (semi)leptonic K decays, resp.
- A is determined from $|V_{cb}|$ and λ.
- $\bar{\rho}+i\bar{\eta}$ is to be determined from angles and sides measurements of the B_d unitarity triangle.

❑ B_d Unitarity Triangle (UT)



$$R_u = \left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right| \qquad R_t = \left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right|$$

Angles

$$\alpha = \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right], \quad \beta = \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right],$$

$$\gamma = \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right], \quad \beta_s = -\arg\left[-\frac{V_{cs}V_{cb}^*}{V_{ts}V_{tb}^*}\right]$$

in B_s

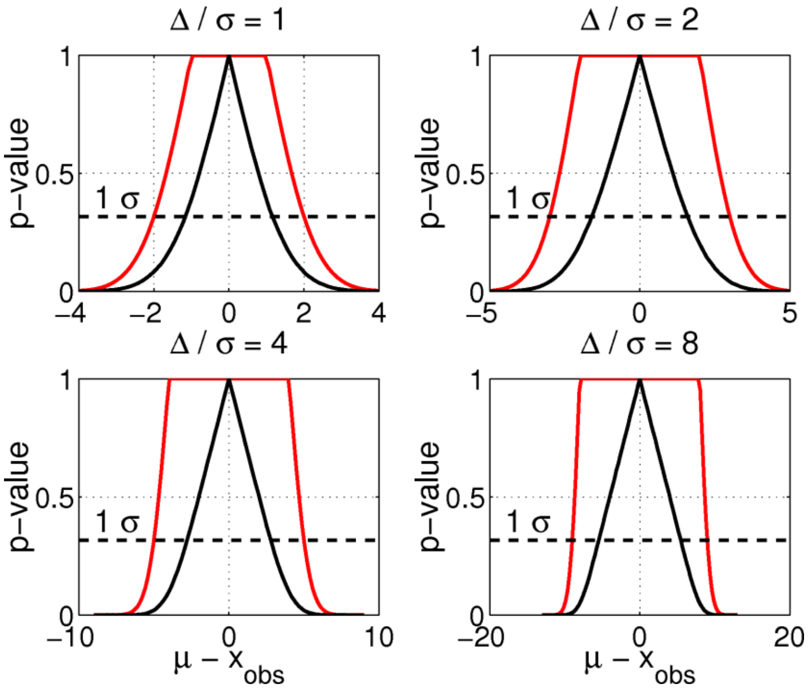
Methodology

■ **Global fit to CKM parameters**

+ Use **Frequentist Hypothesis testing** to build statistical **significance** (p-value) functions from which estimates and **confidence intervals** are obtained; test statistic = Maximum Likelihood Ratio =$\Delta\chi^2$.

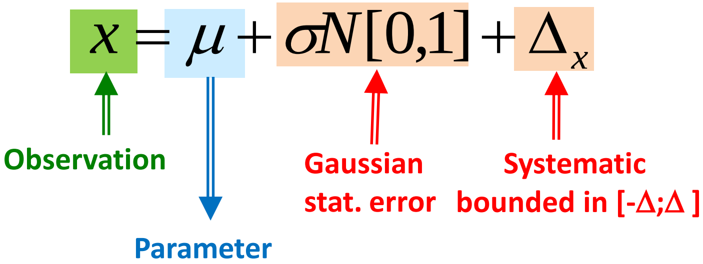
+ Dedicated ***RFit*** scheme for the treatment of theoretical systematics. **Theoretical systematics** are considered as additional **nuisance parameters** .

■ **data = weak ⊗ QCD** ⇒ need for hadronic inputs; **often LQCD** with our own averaging scheme (**OOA**), following an algorithmic scheme with an ‘Educated RFit’ approach.



Illustrative Rfit example

black: Gaussian+flat pdf for syst, red: RFit



$$x = \mu + \sigma N[0,1] + \Delta_x$$

Observables

- **Added leptonic decays observables** with a detailed treatment as in Deschamps *et al.*, PRD**82**, 073012 (2010) ⇒ **Improved** accuracy for **$|V_{us}|$**.
- **Updated γ: inputs for ADS (Belle+CDF) ⊕ improved statistical treatment of γ**; use of a more powerful p-Value to treat nuisances.

CP

A, λ

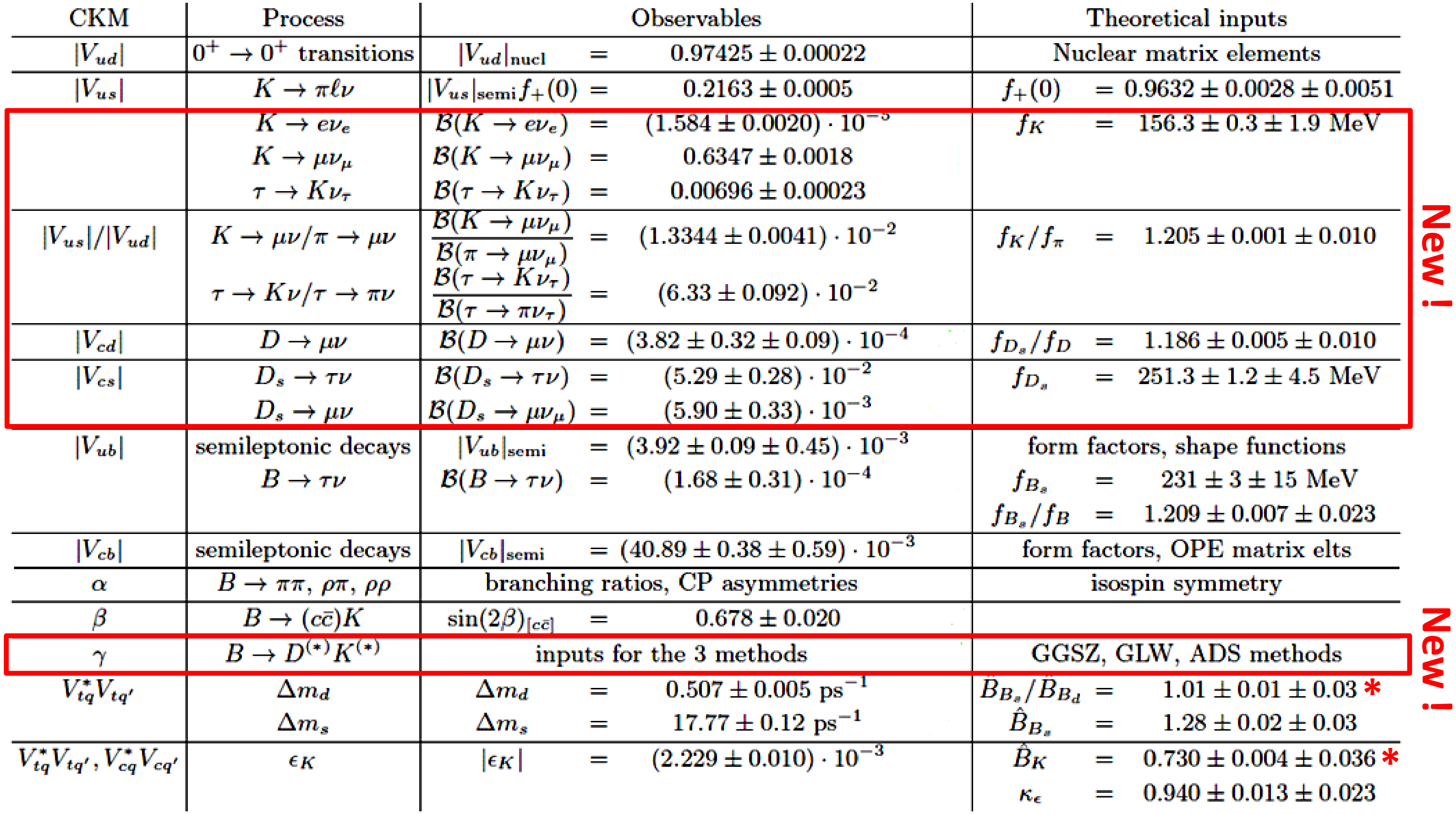
R_u, R_t

Modulus and sides from rates

CP

$\bar{\rho}, \bar{\eta}$

Angles from phases in interferences



CKM	Process	Observables	Theoretical inputs
$\|V_{ud}\|$	$0^+ \to 0^+$ transitions	$\|V_{ud}\|_{\text{nucl}} = 0.97425 \pm 0.00022$	Nuclear matrix elements
$\|V_{us}\|$	$K \to \pi \ell \nu$	$\|V_{us}\|_{\text{semi}} f_+(0) = 0.2163 \pm 0.0005$	$f_+(0) = 0.9632 \pm 0.0028 \pm 0.0051$
	$K \to e \nu_e$	$\mathcal{B}(K \to e \nu_e) = (1.584 \pm 0.0020) \cdot 10^{-5}$	$f_K = 156.3 \pm 0.3 \pm 1.9$ MeV
	$K \to \mu \nu_\mu$	$\mathcal{B}(K \to \mu \nu_\mu) = 0.6347 \pm 0.0018$	
	$\tau \to K \nu_\tau$	$\mathcal{B}(\tau \to K \nu_\tau) = 0.00696 \pm 0.00023$	
$\|V_{us}\|/\|V_{ud}\|$	$K \to \mu\nu / \pi \to \mu\nu$	$\frac{\mathcal{B}(K \to \mu \nu_\mu)}{\mathcal{B}(\pi \to \mu \nu_\mu)} = (1.3344 \pm 0.0041) \cdot 10^{-2}$	$f_K / f_\pi = 1.205 \pm 0.001 \pm 0.010$
	$\tau \to K\nu / \tau \to \pi\nu$	$\frac{\mathcal{B}(\tau \to K \nu_\tau)}{\mathcal{B}(\tau \to \pi \nu_\tau)} = (6.33 \pm 0.092) \cdot 10^{-2}$	
$\|V_{cd}\|$	$D \to \mu\nu$	$\mathcal{B}(D \to \mu\nu) = (3.82 \pm 0.32 \pm 0.09) \cdot 10^{-4}$	$f_{D_s}/f_D = 1.186 \pm 0.005 \pm 0.010$
$\|V_{cs}\|$	$D_s \to \tau\nu$	$\mathcal{B}(D_s \to \tau\nu) = (5.29 \pm 0.28) \cdot 10^{-2}$	$f_{D_s} = 251.3 \pm 1.2 \pm 4.5$ MeV
	$D_s \to \mu\nu$	$\mathcal{B}(D_s \to \mu\nu_\mu) = (5.90 \pm 0.33) \cdot 10^{-3}$	
$\|V_{ub}\|$	semileptonic decays	$\|V_{ub}\|_{\text{semi}} = (3.92 \pm 0.09 \pm 0.45) \cdot 10^{-3}$	form factors, shape functions
	$B \to \tau\nu$	$\mathcal{B}(B \to \tau\nu) = (1.68 \pm 0.31) \cdot 10^{-4}$	$f_{B_s} = 231 \pm 3 \pm 15$ MeV
			$f_{B_s}/f_B = 1.209 \pm 0.007 \pm 0.023$
$\|V_{cb}\|$	semileptonic decays	$\|V_{cb}\|_{\text{semi}} = (40.89 \pm 0.38 \pm 0.59) \cdot 10^{-3}$	form factors, OPE matrix elts
α	$B \to \pi\pi, \rho\pi, \rho\rho$	branching ratios, CP asymmetries	isospin symmetry
β	$B \to (c\bar{c})K$	$\sin(2\beta)_{[c\bar{c}]} = 0.678 \pm 0.020$	
γ	$B \to D^{(*)} K^{(*)}$	inputs for the 3 methods	GGSZ, GLW, ADS methods
$V_{tq}^* V_{tq'}$	Δm_d	$\Delta m_d = 0.507 \pm 0.005$ ps^{-1}	$\hat{B}_{B_s}/\hat{B}_{B_d} = 1.01 \pm 0.01 \pm 0.03$ *
	Δm_s	$\Delta m_s = 17.77 \pm 0.12$ ps^{-1}	$\hat{B}_{B_s} = 1.28 \pm 0.02 \pm 0.03$
$V_{tq}^* V_{tq'}, V_{cq}^* V_{cq'}$	ϵ_K	$\|\epsilon_K\| = (2.229 \pm 0.010) \cdot 10^{-3}$	$\hat{B}_K = 0.730 \pm 0.004 \pm 0.036$ *
			$\kappa_\epsilon = 0.940 \pm 0.013 \pm 0.023$

New !

New !

Compilation of numerical input values available at:
http://ckmfitter.in2p3.fr

Improved Treatment of $|V_{us}|$

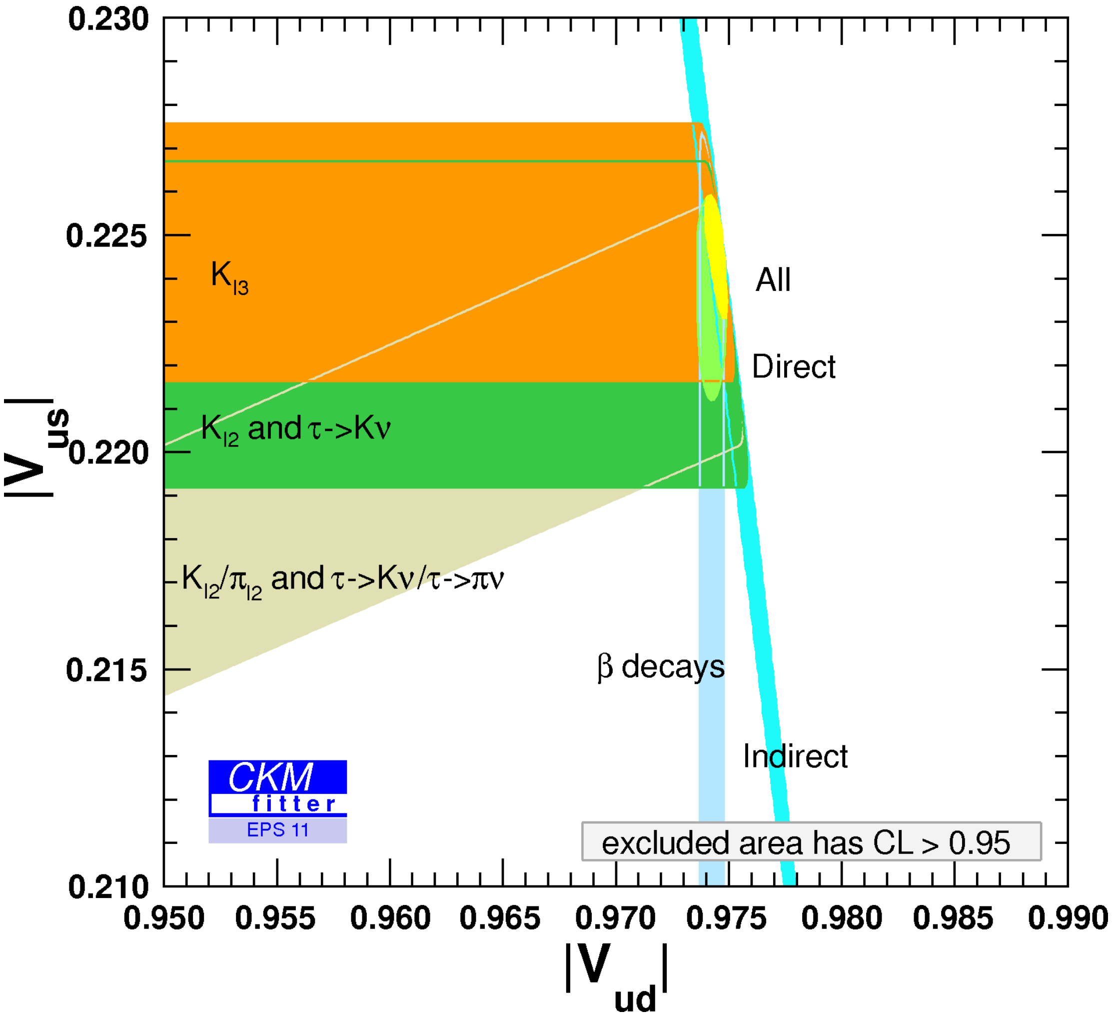
- **Combining constraints** from leptonic decays **improves accuracy on $|V_{us}|$** by ~50% hence on the CKM parameters λ (50%) and A (25%). Little impact on UT $(\bar{\rho},\bar{\eta})$ which is normalised.

- **Direct constraints** from leptonic decays are **in good agreement** with other **indirect observables** (B's, ε_K).

Global fit results (all):

$$A = 0.816^{+0.011}_{-0.021}, \quad \lambda = 0.22518^{+0.00036}_{-0.00077}$$

(1 σ interval)

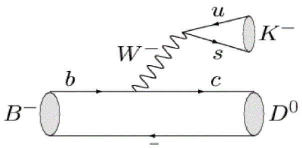


Improved Treatment of γ

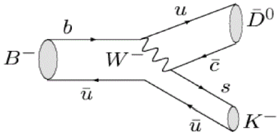
- **γ from interferences** between $B^- \to D^0 K^-$ and $B^- \to \bar{D}^0 K^-$. 3 methods with different D final states: GLW (CP eigenstates), ADS (Kπ, 2 Cabibbo supp.) & GGSZ (3 body, Dalitz).

- **Fit simultaneously γ and hadronic quantities**: phases δ_B, suppression ratios, r_B. The accuracy on γ **depends critically on rB** ⊂ [0.1;0.2]

⇒ nuisance treated within a full frequentist /conservative scheme.



colour allowed
$A\lambda^3$



colour suppressed
$A\lambda^3(\rho + i\eta)$

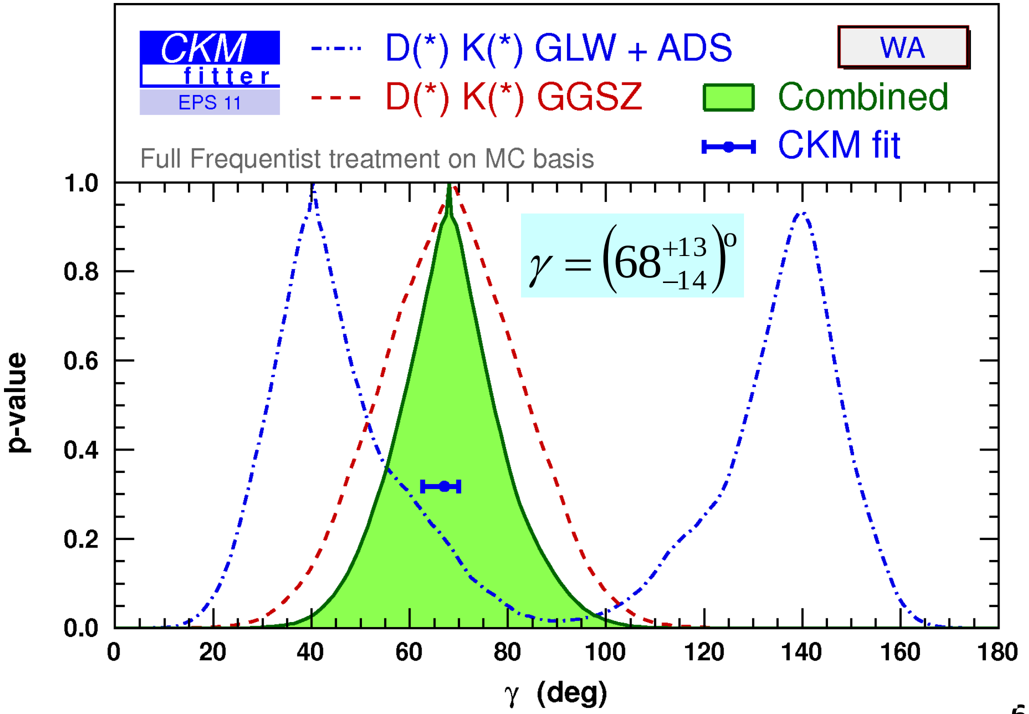
$$r_B = \frac{|A_{\text{suppressed}}|}{|A_{\text{favoured}}|} \approx \left|\frac{V_{ub}V_{cs}^*}{V_{cb}V_{us}^*}\right| \times [\text{colour supp}]$$

- **Updated ADS (D(Kπ)K) inputs :**

 - **Belle**, PRL **106**, 231803 (2011)
 - **CDF** , P@LHC2011

 ⇒ **better rejection of small r_B values**

- **Changed** from the supremum, p_{sup}, p-Value **to the Berger-Boos, p_β, p-Value** [JASA 89, 427 (1994)] : **better control over nuisance parameters** from an auxiliary test; nuisances are constrained to a 3.3 σ confidence interval based on their Likelihood.



Global Fit of the UT

Observables

$|V_{ud}|, |V_{us}|$

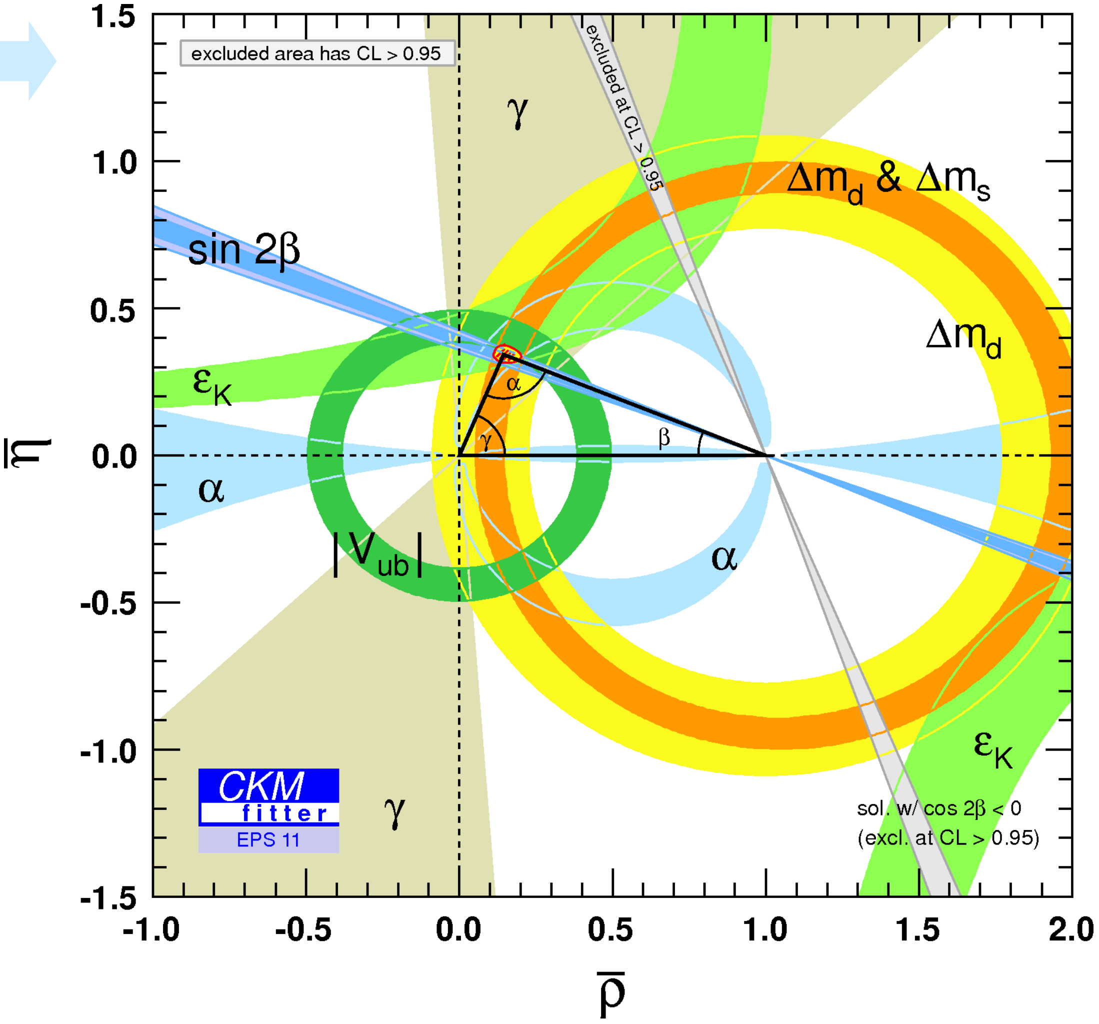
$|V_{cb}|, |V_{ub}|$

$\mathcal{B}[B \to \tau \nu]$

$\Delta m_d, \Delta m_s$

$|\varepsilon_K|$

$\alpha, \sin(2\beta_{cc}), \gamma$



Fit of UT apex is dominated by **sin(2β), $\Delta m_d/\Delta m_s$** and **α**. Excellent agreement between these 3 inputs.

Overall consistent picture

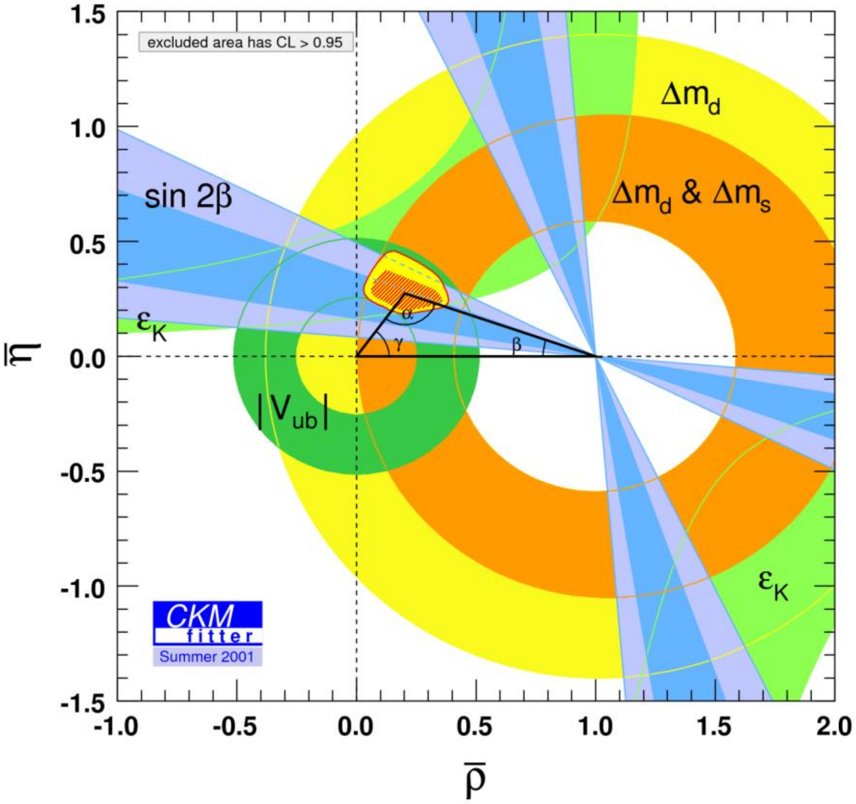
The KM mechanism is the dominant source of $\not{C}\!\not{P}$ in B's

$$\bar{\rho} = 0.144^{+0.027}_{-0.018}, \quad \bar{\eta} = 0.343^{+0.014}_{-0.014}.$$

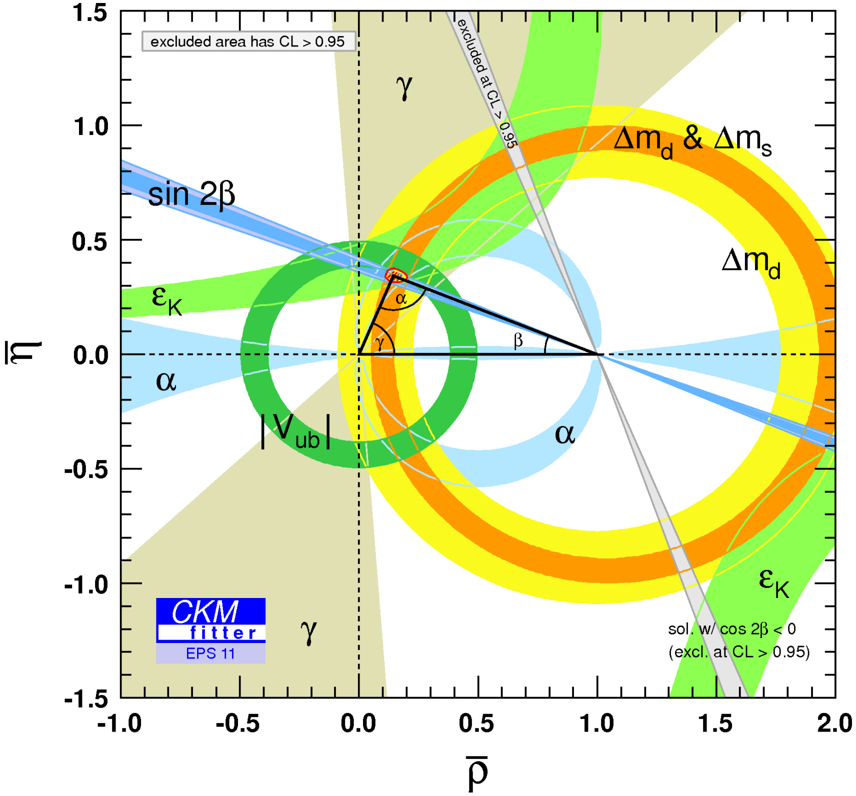
(1 σ interval)

From EPS 2001 to EPS 2011

EPS 2001



EPS 2011



Metrology and Prophecies

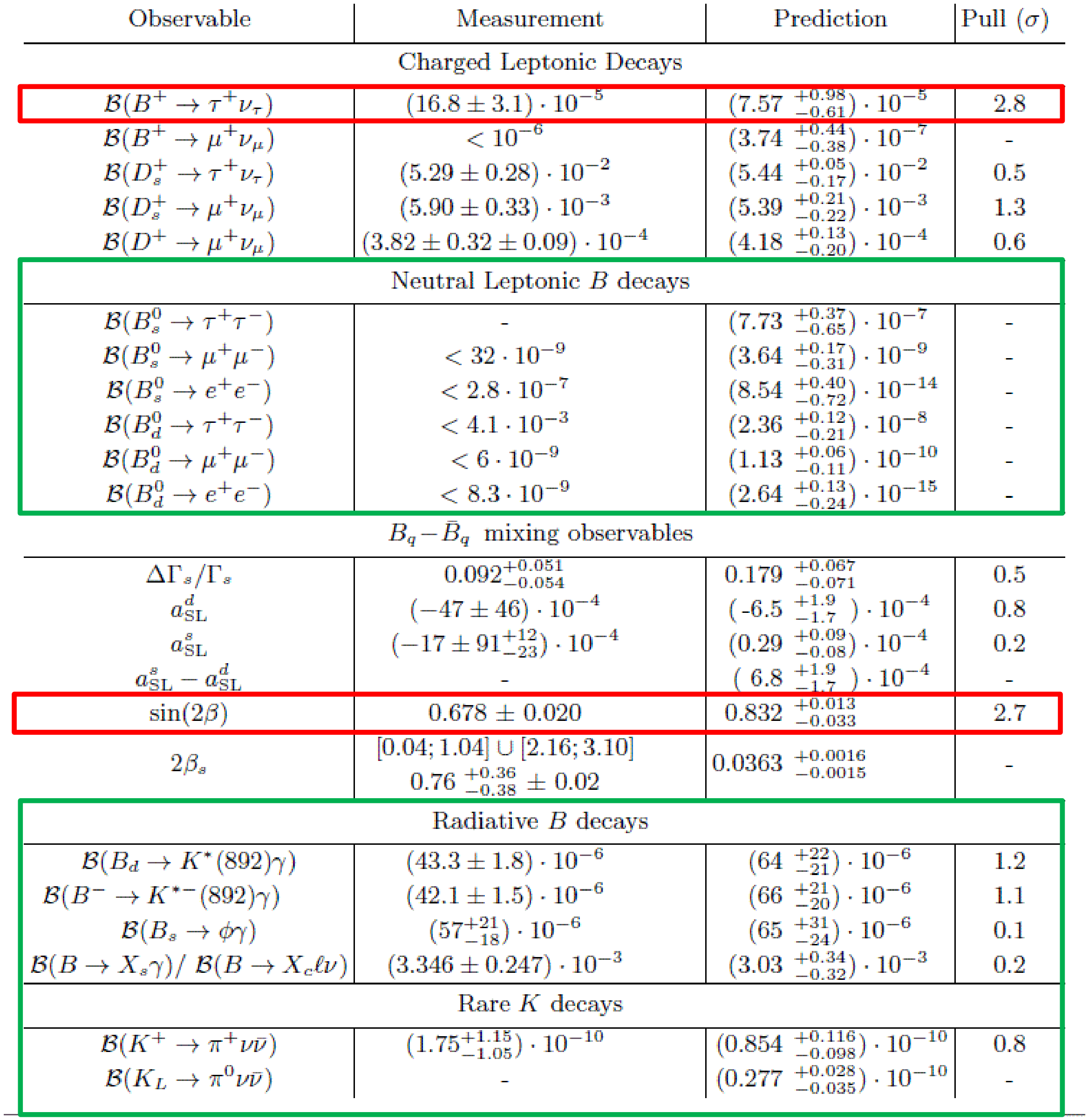
- **Predictions of selected flavour observables within the Standard Model** *Charles et al.*, arXiv:1106.4041 [hep-ph] (to appear in PRD).

- Treatment for the predictions of **neutral B meson leptonic decays** to NLO.

- **Included** CKM predictions for **radiative B meson decays** and **rare Kaon decays**.

- **Overall consistency but …** **Ongoing discrepancy that reduces to a disagreement between BR[B→τν] and sin(2β_{cc})**

Taking one of these two observables out of the fit, the χ^2_{min} drops by 2.6 σ.

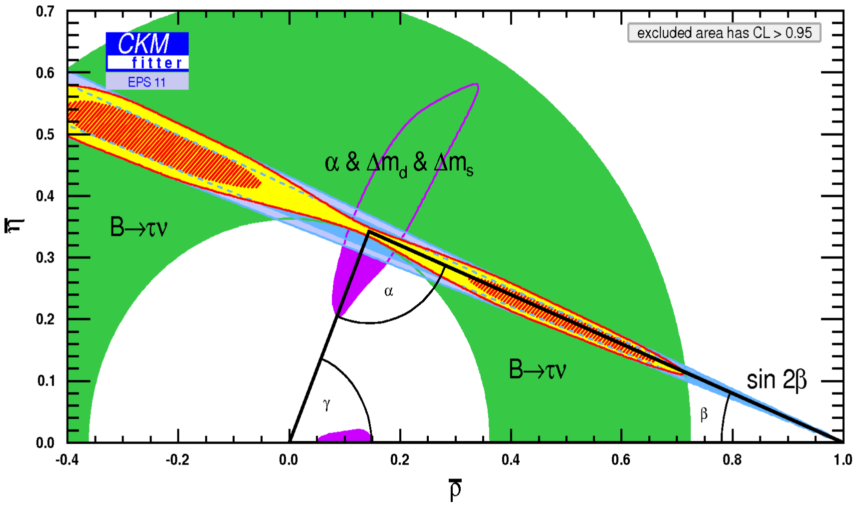


Observable	Measurement	Prediction	Pull (σ)
Charged Leptonic Decays			
$\mathcal{B}(B^+ \to \tau^+\nu_\tau)$	$(16.8 \pm 3.1) \cdot 10^{-5}$	$(7.57\ ^{+0.98}_{-0.61}) \cdot 10^{-5}$	2.8
$\mathcal{B}(B^+ \to \mu^+\nu_\mu)$	$< 10^{-6}$	$(3.74\ ^{+0.44}_{-0.38}) \cdot 10^{-7}$	-
$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$	$(5.29 \pm 0.28) \cdot 10^{-2}$	$(5.44\ ^{+0.05}_{-0.17}) \cdot 10^{-2}$	0.5
$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)$	$(5.90 \pm 0.33) \cdot 10^{-3}$	$(5.39\ ^{+0.21}_{-0.22}) \cdot 10^{-3}$	1.3
$\mathcal{B}(D^+ \to \mu^+\nu_\mu)$	$(3.82 \pm 0.32 \pm 0.09) \cdot 10^{-4}$	$(4.18\ ^{+0.13}_{-0.20}) \cdot 10^{-4}$	0.6
Neutral Leptonic B decays			
$\mathcal{B}(B_s^0 \to \tau^+\tau^-)$	-	$(7.73\ ^{+0.37}_{-0.65}) \cdot 10^{-7}$	-
$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	$< 32 \cdot 10^{-9}$	$(3.64\ ^{+0.17}_{-0.31}) \cdot 10^{-9}$	-
$\mathcal{B}(B_s^0 \to e^+e^-)$	$< 2.8 \cdot 10^{-7}$	$(8.54\ ^{+0.40}_{-0.72}) \cdot 10^{-14}$	-
$\mathcal{B}(B_d^0 \to \tau^+\tau^-)$	$< 4.1 \cdot 10^{-3}$	$(2.36\ ^{+0.12}_{-0.21}) \cdot 10^{-8}$	-
$\mathcal{B}(B_d^0 \to \mu^+\mu^-)$	$< 6 \cdot 10^{-9}$	$(1.13\ ^{+0.06}_{-0.11}) \cdot 10^{-10}$	-
$\mathcal{B}(B_d^0 \to e^+e^-)$	$< 8.3 \cdot 10^{-9}$	$(2.64\ ^{+0.13}_{-0.24}) \cdot 10^{-15}$	-
$B_q - \bar{B}_q$ mixing observables			
$\Delta\Gamma_s/\Gamma_s$	$0.092^{+0.051}_{-0.054}$	$0.179\ ^{+0.067}_{-0.071}$	0.5
a^d_{SL}	$(-47 \pm 46) \cdot 10^{-4}$	$(-6.5\ ^{+1.9}_{-1.7}\ ) \cdot 10^{-4}$	0.8
a^s_{SL}	$(-17 \pm 91^{+12}_{-23}) \cdot 10^{-4}$	$(0.29\ ^{+0.09}_{-0.08}) \cdot 10^{-4}$	0.2
$a^s_{\mathrm{SL}} - a^d_{\mathrm{SL}}$	-	$(\ 6.8\ ^{+1.9}_{-1.7}\ ) \cdot 10^{-4}$	-
$\sin(2\beta)$	0.678 ± 0.020	$0.832\ ^{+0.013}_{-0.033}$	2.7
$2\beta_s$	$[0.04; 1.04] \cup [2.16; 3.10]$ $0.76\ ^{+0.36}_{-0.38} \pm 0.02$	$0.0363\ ^{+0.0016}_{-0.0015}$	-
Radiative B decays			
$\mathcal{B}(B_d \to K^*(892)\gamma)$	$(43.3 \pm 1.8) \cdot 10^{-6}$	$(64\ ^{+22}_{-21}) \cdot 10^{-6}$	1.2
$\mathcal{B}(B^- \to K^{*-}(892)\gamma)$	$(42.1 \pm 1.5) \cdot 10^{-6}$	$(66\ ^{+21}_{-20}) \cdot 10^{-6}$	1.1
$\mathcal{B}(B_s \to \phi\gamma)$	$(57^{+21}_{-18}) \cdot 10^{-6}$	$(65\ ^{+31}_{-24}) \cdot 10^{-6}$	0.1
$\mathcal{B}(B \to X_s\gamma)/\ \mathcal{B}(B \to X_c\ell\nu)$	$(3.346 \pm 0.247) \cdot 10^{-3}$	$(3.03\ ^{+0.34}_{-0.32}) \cdot 10^{-3}$	0.2
Rare K decays			
$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})$	$(1.75^{+1.15}_{-1.05}) \cdot 10^{-10}$	$(0.854\ ^{+0.116}_{-0.098}) \cdot 10^{-10}$	0.8
$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu})$	-	$(0.277\ ^{+0.028}_{-0.035}) \cdot 10^{-10}$	-

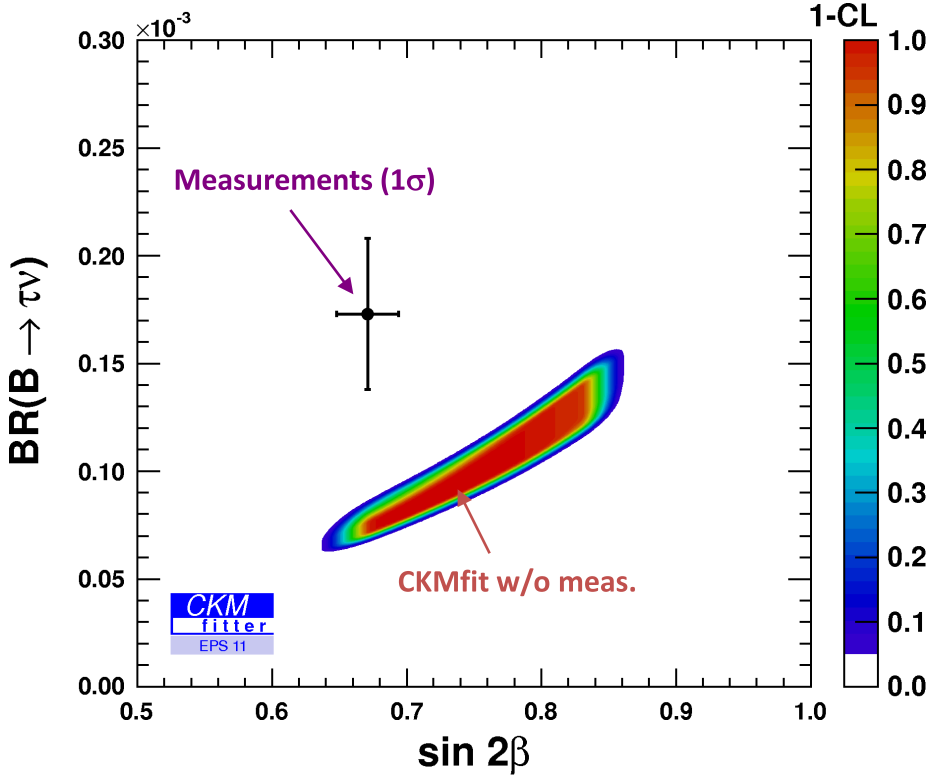
$\sin(2\beta_{cc})$ vs BR[B → τ ν]

- **The combination $\sin(2\beta_{cc})$ and BR[$B\to\tau\nu$] favours 2 solutions in contradiction with other inputs**:

⇒ Within the SM, either the observed BR[$B\to\tau\nu$] is too high either $\sin(2\beta_{cc})$ is too low ...



Yellow area: 95% CL for combined fit with $\sin(2\beta_{cc})$ and BR[$B\to\tau\nu$]. The orange dashed area indicates the 1 σ confidence level.



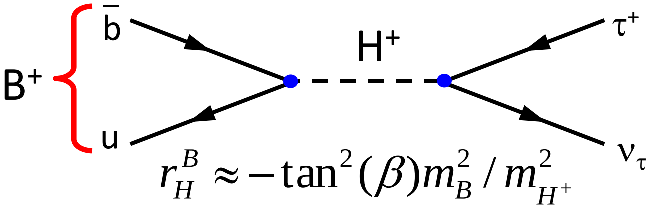
- **Measurements are consistent** between BaBar and Belle & different tags.

- **LQCD** prediction for the mixing term $f_{Bd}^2 \times B_{Bd}$ is **in perfect agreement** with observation. Would require both decay constant, f_{Bd}, and bag parameter, B_{Bd}, to be severely off in order to accommodate measurements ...

New Physics: 2HDM Type II

- **Charged higgs** contribution can modify BR[B→τν] as a multiplicative term in **2HDM Type II** model. Note that one would need $r_H^B \approx -2.5$ to fit BR[B→τν] ⇒ **fine tuned solution to m_B**.

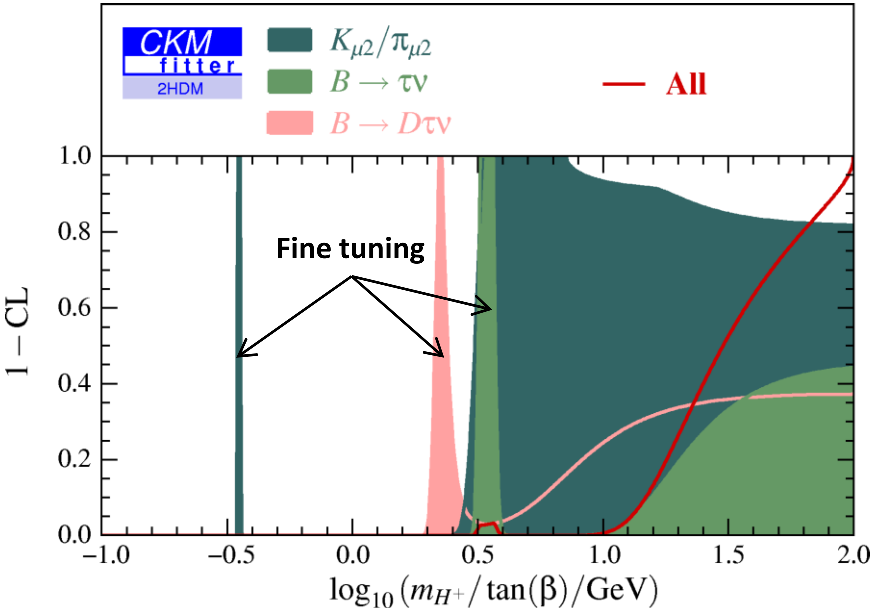
$$\mathrm{BR}(B^+ \to \tau^+ \nu) = \frac{G_F^2 m_B \tau_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_{B_d}^2 \left|V_{ub}\right|^2 \times (1+r_H^B)^2$$

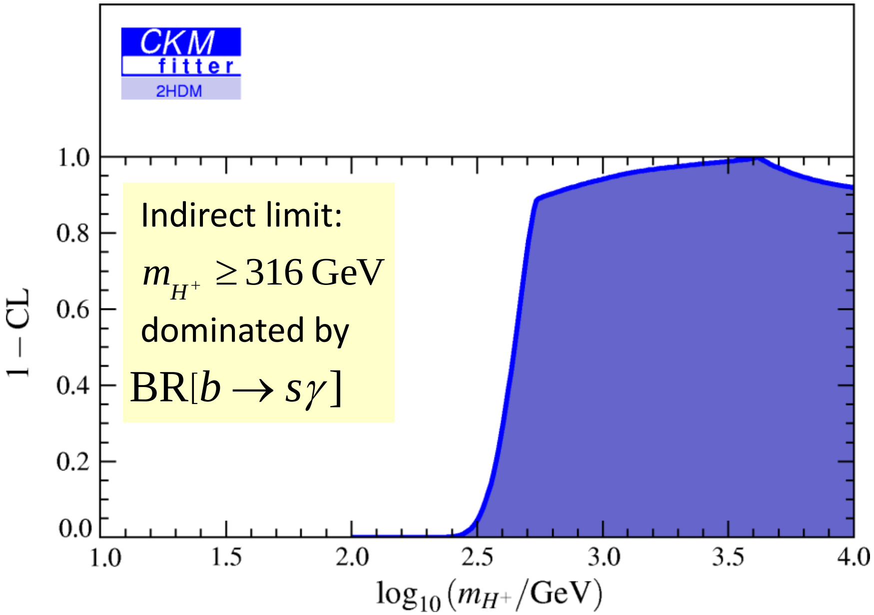


$$r_H^B \approx -\tan^2(\beta) m_B^2 / m_{H^+}^2$$

- **Combined 2HDM(II) analysis** within CKMfitter including modified constraints from mesons leptonic and semileptonic tree decays, loop radiative b → sγ decays, B-B̄ mixing and Z → bb̄ partial width: Deschamps *et al.*, PRD**82**, 073012 (2010).

⇒ **Fine tuned solution ruled out at 95% CL** from BR[B→Dτν] and BR[K→μν]/BR[π→μν] constraints mostly. **No indications in favour of a Type II charged Higgs**.





Indirect limit:
$m_{H^+} \geq 316\ \mathrm{GeV}$
dominated by
$\mathrm{BR}[b \to s\gamma]$

New Physics in B’s Mixing

- **Assume** that **NP only** affects shorts distance Physics in **$|\Delta B| = 2$** $\Rightarrow$ Only the dispersive mixing term, M_{12}^{q}, is modified by NP. **Model independent parameterisation**: Lenz & Nierste JHEP 706 (2007) 72. Generic study within CKMfitter: Charles *et al.*, PRD**34**, 717-731 (2011) (restrict to ‘scenario I’ here: general case with $\Delta_s \neq \Delta_d$).

$$\frac{M_{12}^{q}}{M_{12}^{SM,q}} = \left(\mathrm{Re}[\Delta_q] + i\,\mathrm{Im}[\Delta_q]\right) = |\Delta_q| e^{2i\Phi_q^{NP}}$$

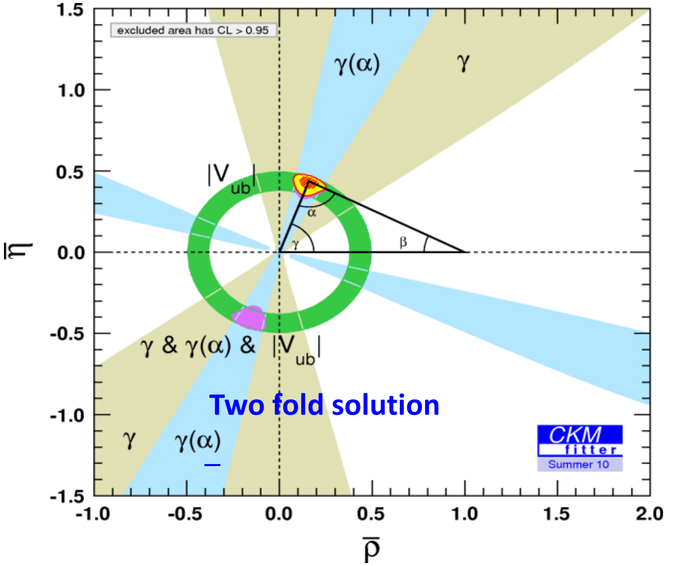
Predictions modified by NP:

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

$\Rightarrow$ **2 new phases** (+2 moduli) to accommodate discrepancies.

CKM parameters are constrained by a fit to unaffected observables:

$$|V_{ud}|, |V_{us}|, |V_{cb}|, |V_{ub}|_{SL+B\to\tau\nu}, \gamma, \gamma(\alpha) = \pi - \alpha - \beta_{cc}$$



$\Rightarrow$ γ and “α + β_{cc}” not modified by NP

New Physics in B_d Mixing

- **A single additional** negative **NP phase** in B_d mixing could accommodate a too low $\sin(2\beta_{cc})$ (2.7σ). From the global fit we find: $\Phi_d^{NP} = (-12.9^{+3.8}_{-2.7})^{o}$.

- **Dominant constraints are sin(2β) and Δm_d**. A_{SL}'s help to exclude the CKM symmetric solution with $\eta < 0$.

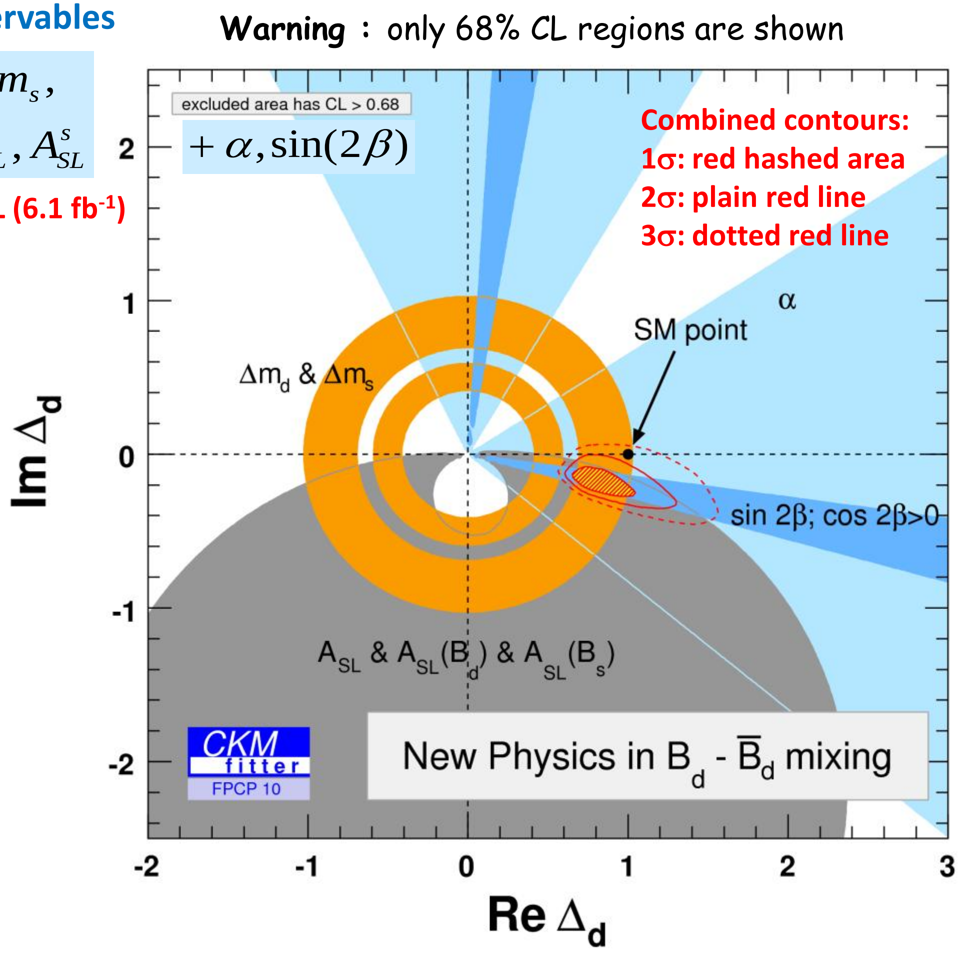
- The **observed shift traduces the tension** between BR[B→τν] and $\sin(2\beta_{cc})$. The **SM hypothesis is disfavoured at 2.5σ**. If to take out BR[B→τν] one recovers agreement at 1.1 σ.

NP Observables

$\Delta m_d, \Delta m_s,$

$A_{SL}, A_{SL}^d, A_{SL}^s$

'Old' D0 ASL (6.1 fb^{-1})



Combined contours:
1σ: red hashed area
2σ: plain red line
3σ: dotted red line

New Physics in B_s Mixing

- **Deviations in** A_{SL} and ϕ_s could sign **an additional NP phase** in B_s mixing.

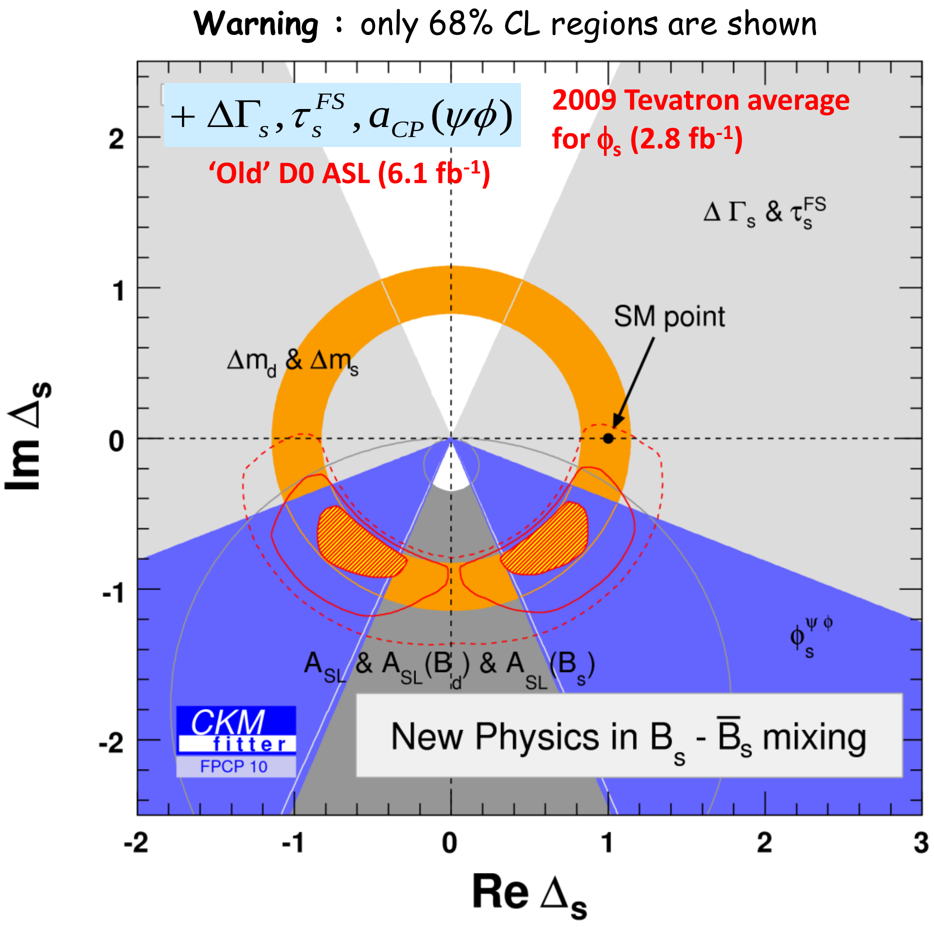
- **The dominant constraints** in the fit come from **A_{SL}**, (**ϕ_s = -2β_s**, $\Delta\Gamma_s$) and **Δm_s**.

- With **2009 Tevatron average for ϕ_s (2.8 fb^{-1})** and **old D0 (6.1 fb^{-1}) A_{SL}**. The **SM** 2D **hypothesis Δ_s = 1** was **disfavoured at 2.7 σ** with or without B→τν. Note that:

- **Taking out A_{SL}(DØ)** the discrepancy was only **1.9 σ**.

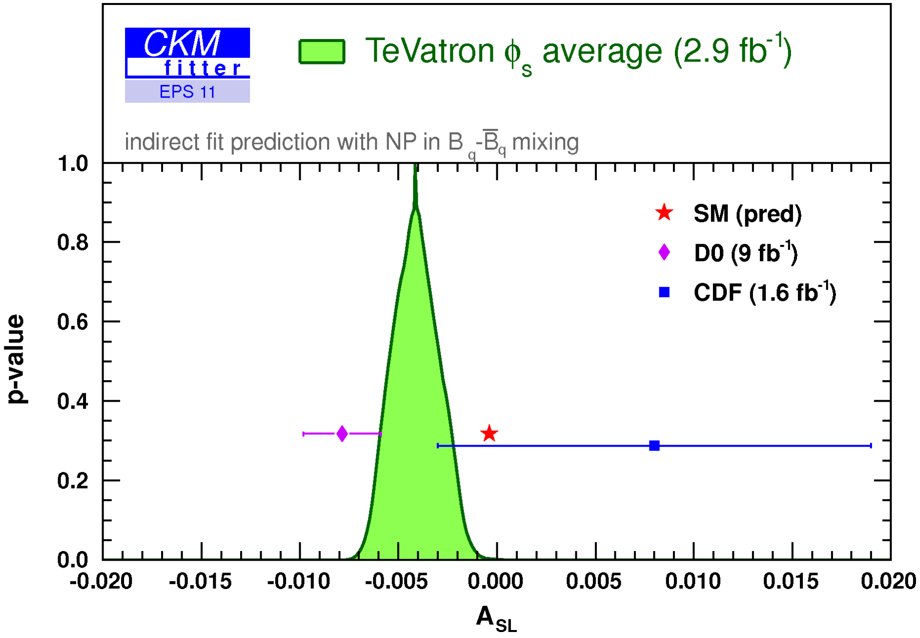
- The disagreement with the SM is driven in the same direction by ϕ_s and A_{SL}.

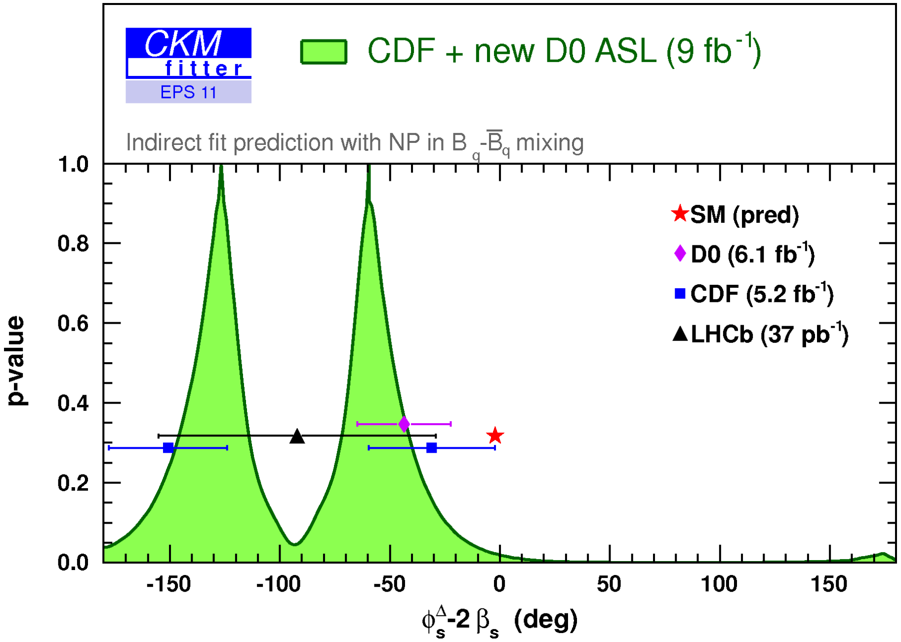
- **Δm_s agrees with the SM** which further constraints **$|\Delta_s|$ to ~1**.



NP in B_s Mixing : and with Updated A_{SL}?

- **The observed deviation in** A_{SL} (3.9σ, D0 9 fb^{-1}) might indicate **an additional** negative **NP phase** in B_s mixing. From the fit w/o ϕ_s we expect: $\Phi_s^{NP} = (-59^{+18}_{-12} \cup -127^{+12}_{-19})^o$. It agrees with 2009 Tevatron average (2.8 fb^{-1}) for ϕ_s and latest observations. **Eagerly waiting from updated Tevatron average and results from LHCb!**



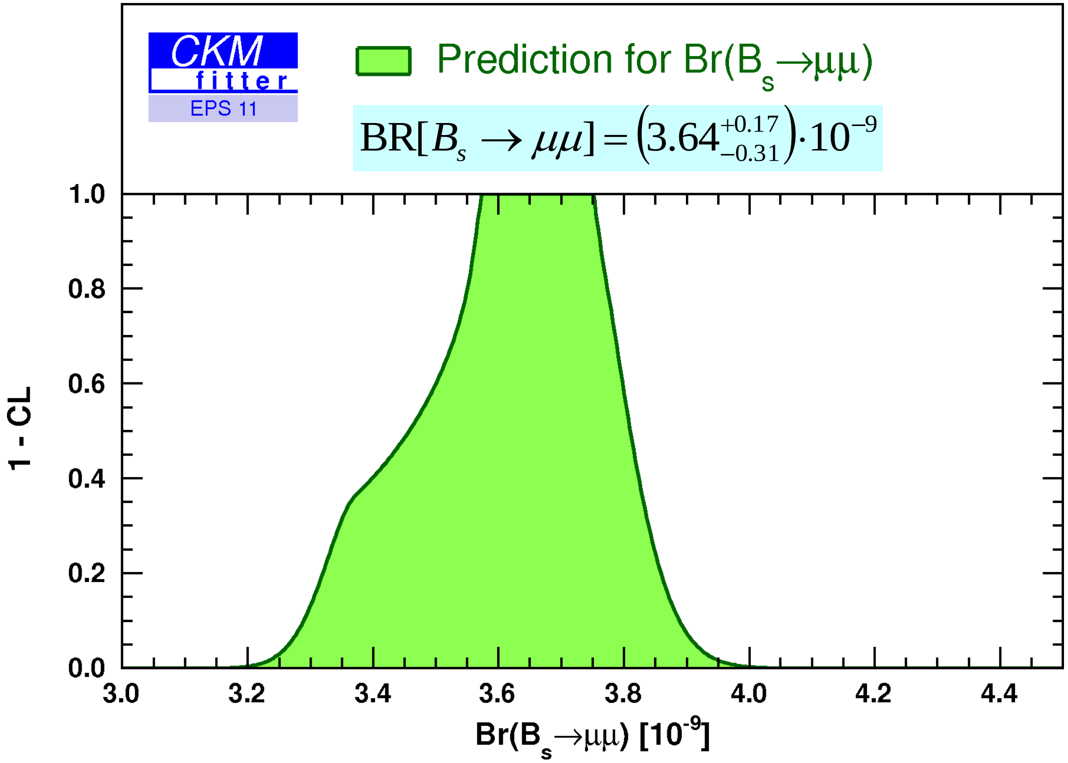


Conclusion and Outlooks

■ **The KM mechanism** is obviously **at work** at O(0.1) but there is **still room for New Physics** in the mixing of both B_d and B_s mesons.

■ **Intriguing discrepancies** are pointing out requiring updated/crosschecked inputs … Some of those are just around the corner: ϕ_s, A_{SL}, …, $B_s \to \mu\mu$, $B_d \to K^* \mu\mu$?!

⇒ Eagerly waiting from updated results from the Tevatron and LHC experiments !



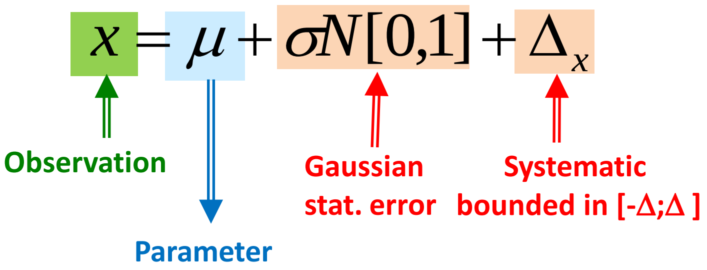
More on RFit and P-Values

- **Theoretical systematics** are considered as additional ***nuisance parameters*** bounded over a confident enough range. On the latter interval the significance is flat.

Note that this result is very different from what one would get from a statistical modelling of the systematic (ex: uniform over the range)

- **In most cases the p-value is derived using Wilks' theorem**, assuming asymptotic regime. **Some cases** where **nuisance parameters** are of prime importance, like gamma, deserve a full computation of the p-Value.

Simple illustrative example allowing analytical resolution:



$$x = \mu + \sigma N[0,1] + \Delta_x$$

Observation

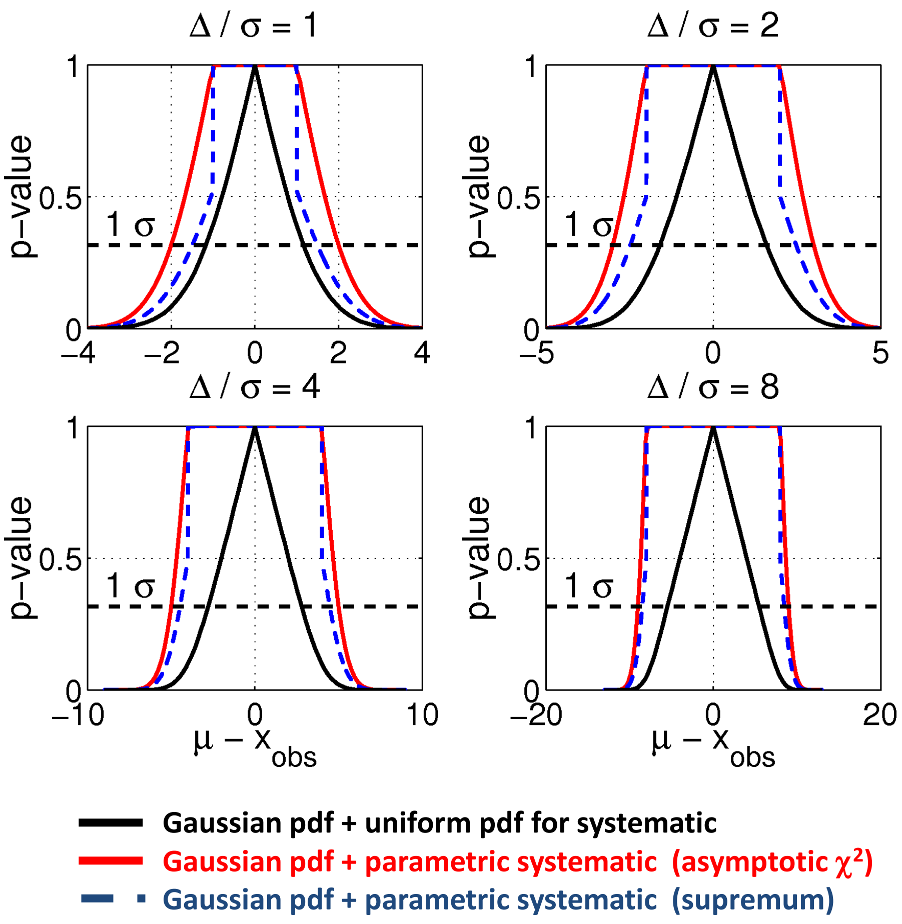
Parameter

Gaussian stat. error

Systematic bounded in [-Δ;Δ]

$$\text{p-value} = \begin{cases} 1 & \text{if} \quad x-\mu \in [-\Delta;\Delta] \\ \frac{1}{2}(\text{erfc}[\frac{|x-\mu|+\Delta}{\sqrt{2}\sigma}] + \text{erfc}[\frac{|x-\mu|-\Delta}{\sqrt{2}\sigma}]) & \text{elsewhere} \end{cases}$$

(supremum)



More on LQCD Averages

■ More and more **accurate theoretical predictions** **(ex:** f_{Bs}/f_{Bd} ~2-3%) but various methods, results and error estimates depending on collaborations. **Need to combine these results**; several methods also ...

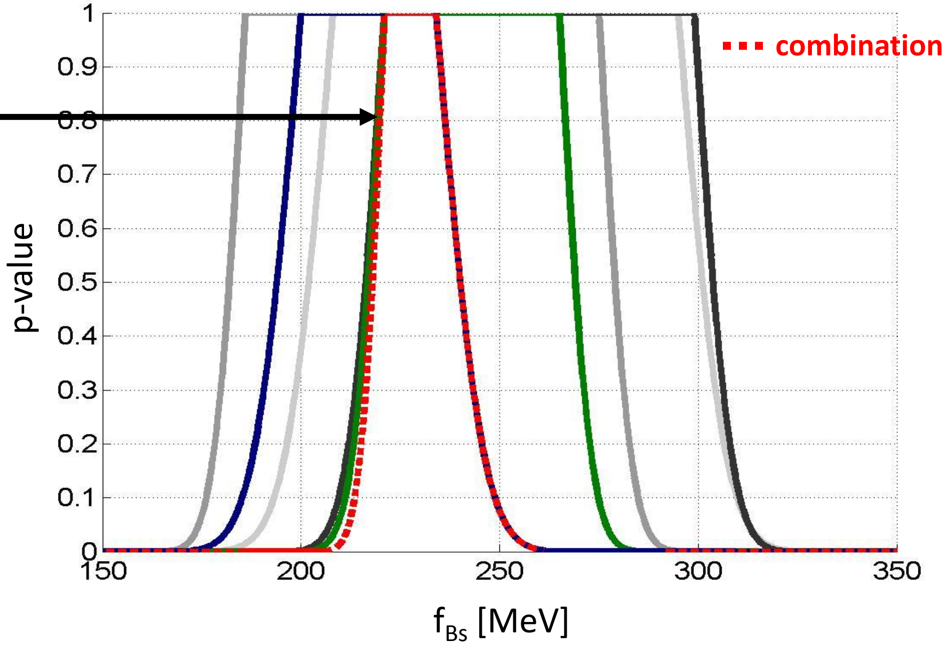
⇒ For now we perform **our own average** using an **algorithmic procedure** with only unquenched 2 and 2+1 LQCD results.

■ Our Own Average: Educated *RFit* scheme illustrated here with f_{Bs}

1) From selected LQCD results estimate f_{Bs} **central value in the *RFit* scheme**, distinguishing statistic and systematic contributions to uncertainties.

2) Perform and **educated combination of uncertainties**; Not more nor less accurate than the most precise individual LQCD prediction.

$$\Rightarrow\ f_{B_s} = 231 \pm 3 \pm 15\ \text{MeV}$$



For more details:

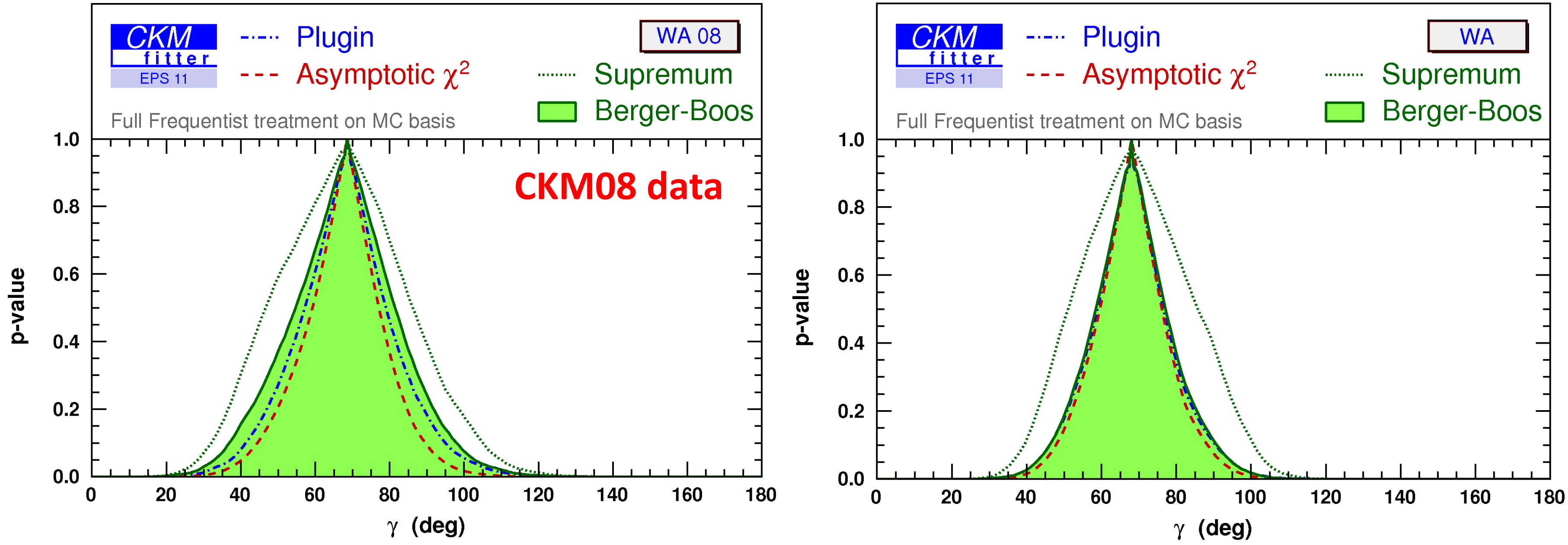
- **+ V. Tisserand (CKMfitter Group), Moriond EW 2009 proceedings [arXiv:0905.1572];**
- **+ S. Descotes-Genon (CKMfitter Group), *IP3 workshop: Lattice meets Phenomenology, 2010, Durham* http://conference.ippp.dur.ac.uk/getFile.py/access?contribId=6&sessionId=2&resId=0&materialId=slides&confId=294**

Gamma and the Berger-Boos *p* value

- **The Berger-Boos, p_β, p-Value** [JASA 89, 427 (1994)] makes a more powerful use of the data than the supremum *p* value, p_{sup}, by providing **control over the nuisance parameters, θ**. It is a valid / conservative *p* value defined as: $p_\beta = \sup_{\theta \subset C_\beta} p(\theta) + \beta$, where C_β is a level 1-β confidence set for the nuisance θ.

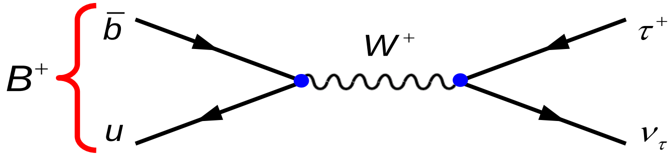
  ⇒ we use the **Likelihood** under the null hypothesis to infer the **confidence region C_β**.

- The **very increased accuracy on γ not only** comes **from the new statistical treatment**, **but also from more accurate measurements**, which help constraining the nuisance, r_B. This is illustrated below by re-playing various stat. treatment with CKM08 data.



BR[B→τν] vs sin(2β) : Experimental Side

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



- Helicity-suppressed annihilation decay sensitive to **$(f_{Bd}\times|V_{ub}|)^2$**

Experimental measurements

	$\mathcal{B}[B\to\tau\nu]\times10^4$
Belle (hadronic)	1.79±0.71
Belle (semi-leptonic)	1.54±0.48 [New]
Belle	**1.62±0.40**
BABAR (hadronic)	1.80±0.61 [New]
BABAR (semi-leptonic)	1.70±0.82
BABAR	**1.76±0.49**
World Average	**1.68 ± 0.31**

The various measurements for B → τν look consistent; we combine them using a weighted mean and assume Gaussian distributions. The p-value for this hypothesis is 11% (1.6 σ).

CKMfit prediction: $(0.757^{+0.098}_{-0.061})\times10^{-4}$
(1σ, without meas.)

- **sin(2β) from HFAG charmonium WA**: $\sin(2\beta_{cc}) = 0.673(23)$, **no obvious tension**.

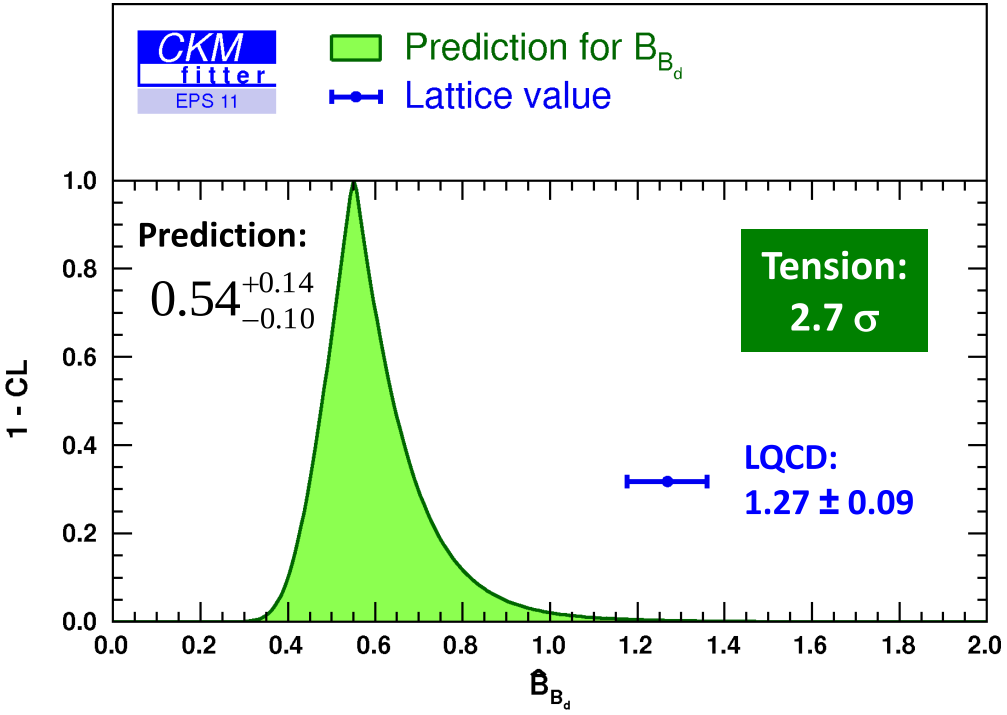
There is an overall experimental agreement that either $\mathcal{B}$[B → τν] is too high or sin(2β_{cc}) too low

BR[B→τν] vs sin(2β) : LQCD Side

- The bag parameter B_{Bd} can be measured from the ratio of B → τν to Δm_d eliminating the dependency to f_{Bd}, as:

$$\frac{\mathcal{B}[B\to\tau\nu]}{\Delta m_d}=\frac{3\pi}{4}\frac{m_\tau^2\tau_B}{m_W^2\eta_B S[x_t]}(1-\frac{m_\tau^2}{m_B^2})^2\frac{\sin^2(\beta)}{\sin^2(\alpha+\beta)}\frac{1}{|V_{ud}|^2 B_{B_d}}$$

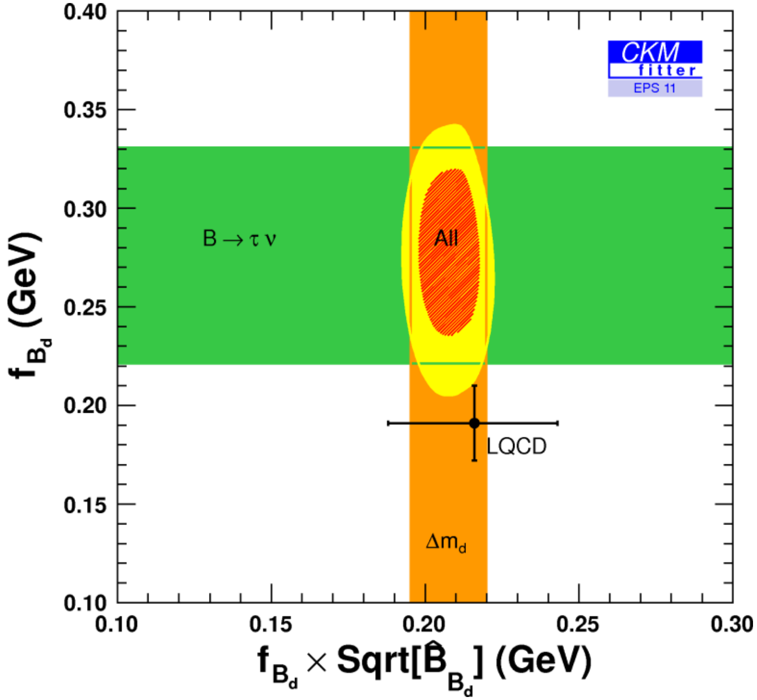
The tension is still there at ~ 2.7 σ! But a factor of 2 off on B_{Bd} while keeping f_{Bd} wouldn't work in the global fit …



- Let's let f_{Bd} and B_{Bd} be completely free and fit them from all observables. What do we get?

⇒ No more tension / no more constraints

⇒ The global fit is accommodated keeping $f_{Bd}^2 \times B_{Bd} \approx$ const to fit Δm_d while increasing f_{Bd} to fit B → τν



Would require significant change on LQCD f_{Bd} while keeping the product $f_{Bd} \times \mathrm{sqrt}[B_{Bd}]$

Something Rotten in ε_K ?

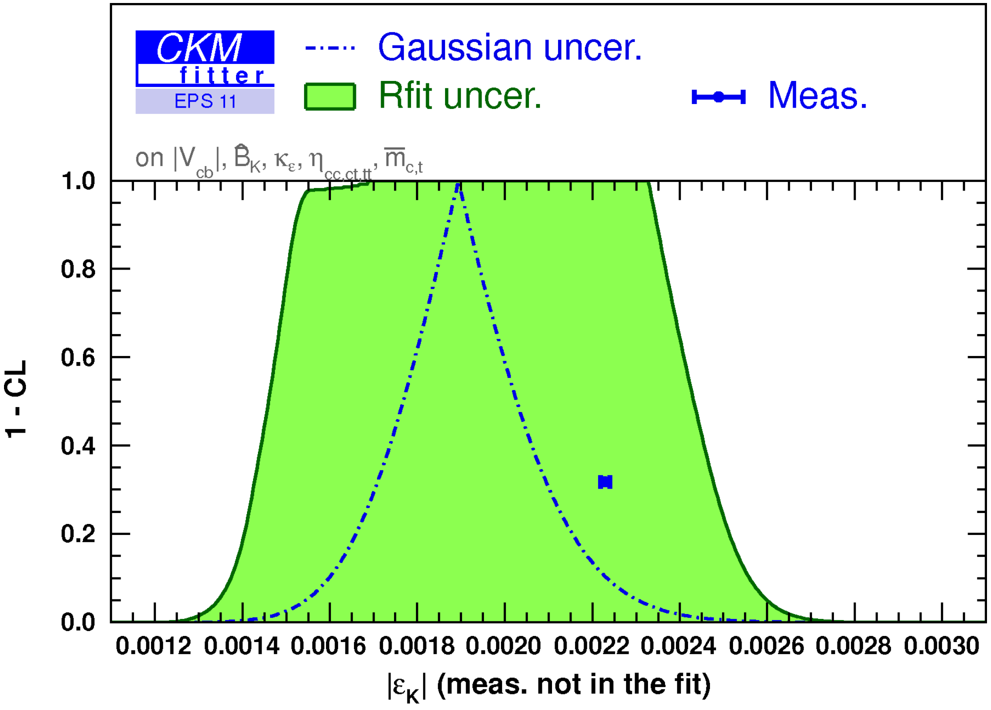
- Reminder from Buras & Guadagnoli (Phys. Rev. D78, 033005 (2008)): there is an **additional suppression factor,** κ_{ε}, to $|\varepsilon_K|$. We use $\kappa_{\varepsilon} = 0.940 \pm 0.013 \pm 0.023$ [Charles *et al.*, PRD**34**, 717-731 (2011)]; consistent with other estimates.

  ⇒ **κ_{ε} does not spoil the prediction for $|\varepsilon_K|$** dominated by other uncertainties: **$|V_{cb}|^4$ ~ 7%** , **B_K ~5%**.

- **Any tension between direct measurement of $|\varepsilon_K|$ and indirect measurement from the global fit, through $\sin(2\beta_{cc})$?**

⇒ Using **Gaussian distributions** for systematic uncertainties and including the factor κ_{ε} we get **1.6 σ** deviation

⇒ With our ***Educated RFit*** treatment of systematics **no deviation is seen**. The measurement is compatible with our fit best guess considering **uncertainties** on CKM parameters (through **$|V_{cb}|^4$** mainly and hadronic uncertainties from **B_K ~5%**).



$|V_{ub}|$: Inclusive vs Exclusive

■ Similar treatment to LQCD inputs -***Educated RFit*** scheme- to combine the two methods for |Vub|:

- Inclusive: b → ulν + Operator Product Expansion
- Exclusive: B → πlν + Form Factors

■ **Inputs:** (first 2 from HFAG)

$|V_{ub}|_{incl.} = 4.32(+21,-24)(45)\ 10^{-3}$

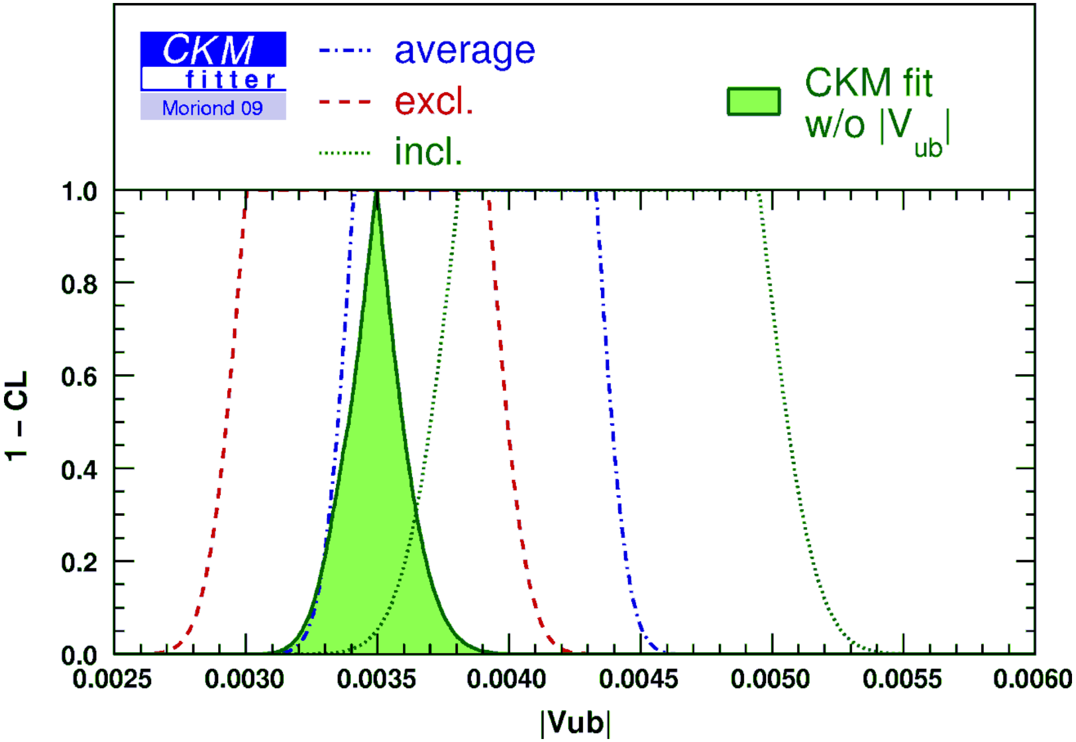
$|V_{ub}|_{excl.} = 3.51(10)(46)\ 10^{-3}$

$\mathbf{|V_{ub}| = 3.92(9)(45)\ 10^{-3}}$

Δ|Vub| = 0.81, consistent with error budget

■ **Output of the global fit:** (w/o |Vub|)

$\mathbf{|V_{ub}| = 3.49(13)\ 10^{-3}}$

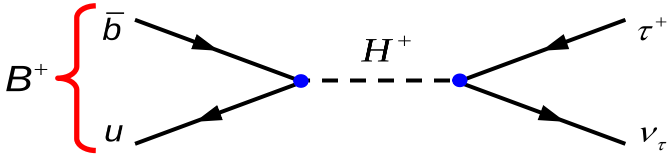


The discrepancy between Incl/Excl depends on the statistical treatment

2HDM : Fine Tuned Solution

■ **Charged Higgs contributions can increase $\mathcal{B}[B\to\tau\nu]$** prediction but only **in a fine tuned scenario**.

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



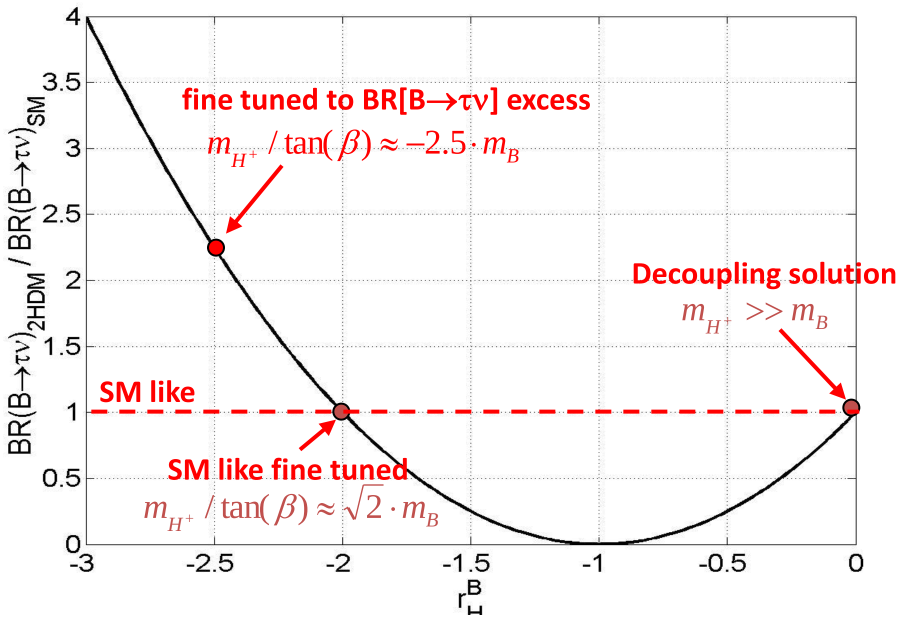
■ **Charged higgs** contribution can modify $\mathcal{B}[B\to\tau\nu]$ as a multiplicative term: $r_H^B \approx -\tan^2(\beta)m_B^2/m_{H^+}^2$ in **2HDM Type II** model. Note that one would need $r_H^B \approx -2.5$ to fit $\mathcal{B}[B\to\tau\nu]$ (fine tuned solution).

⇒ **Requires a global analysis with other observables to check implications.**

Agreement with the SM can be recovered 2 ways:

- $r_H^B \to 0 \Rightarrow m_{H+}/m_B \to \infty$ irrespective tan(β). This is the **decoupling solution.**
- $r_H^B = -2 \Rightarrow m_{H^+}/\tan(\beta)\approx\sqrt{2}\cdot m_B$; requires a **fine tuning of m_{H+}/tan(β) to the meson mass**.

Here fine tuning to adjust BR[B→τν] excess



fine tuned to BR[B→τν] excess
$m_{H^+}/\tan(\beta)\approx -2.5\cdot m_B$

Decoupling solution
$m_{H^+} >> m_B$

SM like

SM like fine tuned
$m_{H^+}/\tan(\beta)\approx\sqrt{2}\cdot m_B$

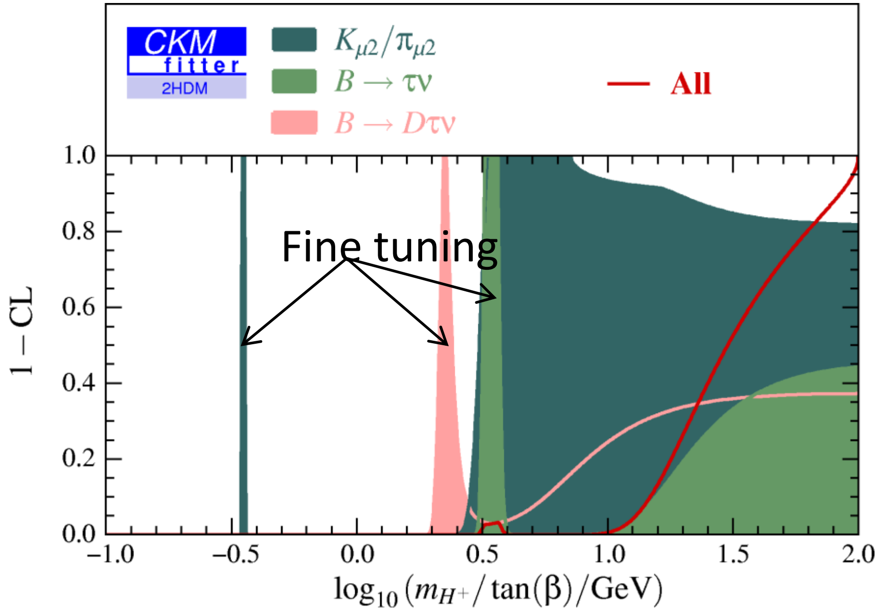
2HDM : Global Fit

- **Combined 2HDM(II) analysis** within CKMfitter including modified constraints from mesons leptonic and semileptonic tree decays and loop radiative b → sγ decays and Z → $b\bar{b}$ partial width [Deschamps *et al.*, PRD**82**, 073012 (2010)].

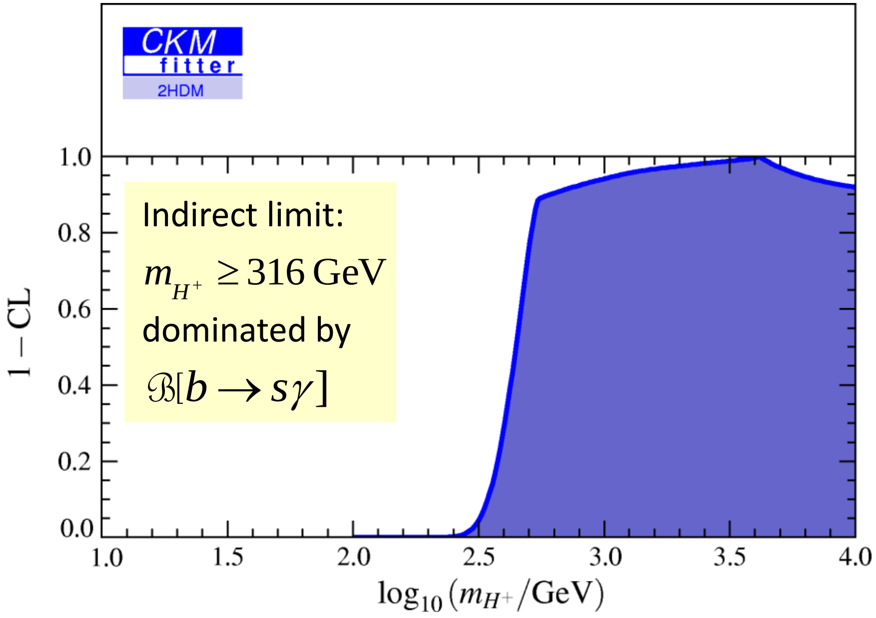
Observables

$$\mathcal{B}[B\to\tau\nu], \mathcal{B}[D\to\mu\nu], \mathcal{B}[D_s\to\mu\nu], \mathcal{B}[D_s\to\tau\nu], \mathcal{B}[K\to\mu\nu]/\mathcal{B}[\pi\to\mu\nu]$$

$$\mathcal{B}[B\to D\tau\nu], \mathcal{B}[K\to\pi\ell\nu], \mathcal{B}[b\to s\gamma], \Delta m_d, \Delta m_s, \Gamma[Z\to b\bar{b}]/\Gamma[Z\to \text{hadrons}]$$



Fine tuning



Indirect limit:
$m_{H^+} \geq 316\,\text{GeV}$
dominated by
$\mathcal{B}[b\to s\gamma]$

- **Combined Fine tuned solution ruled out at 95% CL**, mostly from $\mathcal{B}$[B→Dτν] and $\mathcal{B}$[K→μν]/$\mathcal{B}$[π→μν] constraints.

- **Only marginal improvement of the χ^2_{min}** when going from SM to 2HDM(II), $\Delta\chi^2_{min}$ = 0.02 which corresponds to a p-value of 89%, **0.1 σ effect**, from a toy Monte-Carlo study.

⇒ **We see no particular indication for a charged Higgs effect in a 2HDM Type II scheme**

NP in $\Delta F=2$: Scenario III

Further assume Minimum Flavour Violation (MFV) with large bottom Yukawa coupling

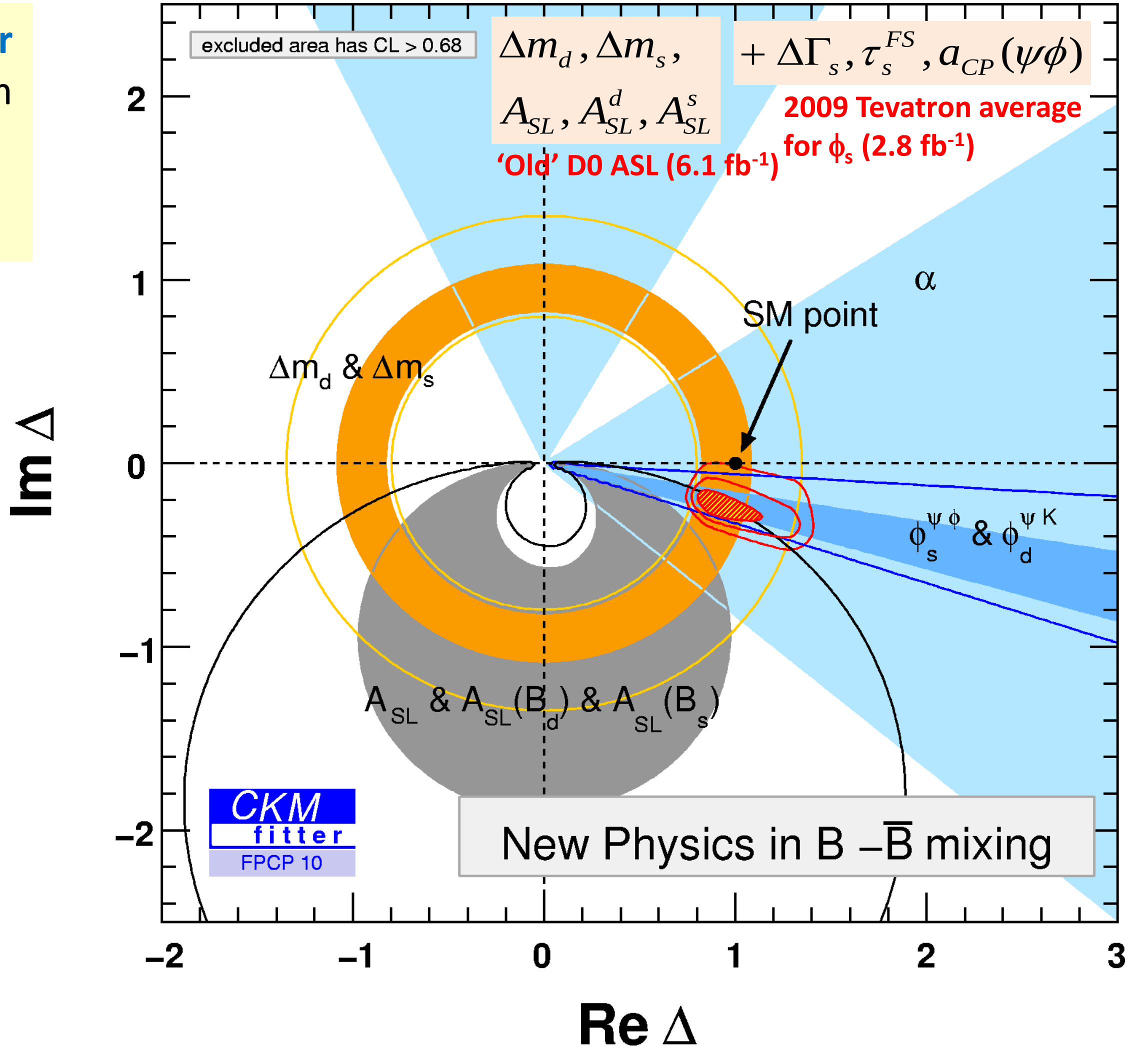
$\Rightarrow \Delta_d = \Delta_s$

- **Dominant constraints** come from **A_{SL}, (ϕ_s = -2β_s,** $\Delta\Gamma_s$) and **sin(2β)**.

All 3 measurements prefer a negative phase arg(Δ) though not with the same magnitude.

- With **2009 Tevatron average for ϕ_s (2.8 fb^{-1}) old D0 (6.1 fb^{-1}) A_{SL}**, the **SM hypothesis (Δ = 1) was disfavoured at 3.1 σ**, from the combination of all 3 discrepancies.

NP Observables



$\Delta m_d, \Delta m_s,$
$A_{SL}, A_{SL}^d, A_{SL}^s$

'Old' D0 ASL (6.1 fb^{-1})

$+ \Delta\Gamma_s, \tau_s^{FS}, a_{CP}(\psi\phi)$

2009 Tevatron average for ϕ_s (2.8 fb^{-1})

NP in ΔF=2 : Scenario I, various Input Sets