

Precision tests of the flavor sector of the standard model

Jacques Chauveau

LPNHE

15 Dec 2010

Challenges for Precision Physics at the LHC

Witek's roadmap

- To cover
 - the physics of the CKM,
 - the rare decays of B-mesons and kaons
 - and, if the time allow, a mentioning of the lepton sectors (e.g the last results from PSI).
- To convey a message
 - that the flavour sector tests already put a very stringent limits on the possible extension of the SM.
 - together with the talk on the LEP EW-legacy, better identify
 - the precision challenges for the LHC EW programme
 - the domains where the LHC can be competitive with respect to the previous results.

References

- The data are averaged in
 - PDG [K. Nakamura et al. \(Particle Data Group\), J. Phys. G 37, 075021 \(2010\)](#)
 - HFAG [*D. Asner et al., "Averages of b-hadron, c-hadron, and tau-lepton Properties," arXiv:1010.1589 updates at http://www.slac.stanford.edu/xorg/hfag*](#)
- Ecole de Gif 2010 (Koppenburg, Monteil)
- Excellent reviews (there are more):
 - A. Hoeker, Z. Ligeti [Ann.Rev.Nucl.Part.Sci.56:501-567,2006](#)
 - CKM workshop 2008 book [Physics Reports 494 \(2010\), pp. 197-414](#)
 - G. Isidori, Y. Nir, G. Perez (INP) [*arXiv:1002.0900v2 \[hep-ph\]*](#)
- The global CKM fits
 - CKMfitter (which I use extensively) [*CKMfitter Group \(J. Charles et al.\), Eur. Phys. J. C41, 1-131 \(2005\)* \[hep-ph/0406184\], updates at http://ckmfitter.in2p3.fr](#)
 - UTfit [http://utfit.org/UTfit/](#)

Outline

- Flavor physics
- CKM fits
- Tensions
- Potentially predictive areas
- Perspectives

Flavor Physics

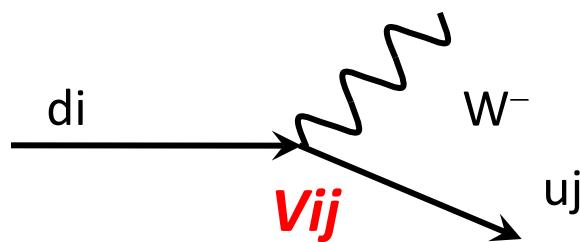
Flavor physics

- Flavor (in the SM)
 - The fermions (Q, U, D, L, E)
 - have mass
 - mix
- Flavor physics: interactions that distinguish flavors
 - Weak and Yukawa
- Flavor change, flavor violation
 - Only the weak CC at tree level in the SM
- FCNC
 - Only in loop processes in the SM

Pattern ??

The CKM mechanism

- The Yukawa interaction is the unique source of flavor physics
- 10 parameters in the quark sector. *Ad Hoc.*
- In the absence of Yukawa couplings: Flavor symmetry
- The Yukawa terms break the Flavor Symmetry bringing quark mixing: **The CKM mechanism**, with the unitary matrix V .



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

- B factory legacy
- “Very likely, Flavor Violation and CP violation in flavor changing processes are dominated by the CKM mechanism” (Nir et al.)*

The CKM matrix

- Falsifiable at low energy:

- 4 parameters measurable in many processes
- 3 mixing angles and one phase: CP violation
- Interference patterns, therefore enhanced sensitivity.

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

- Observed hierarchy inspired the Wolfenstein parameterization

$$V \simeq \begin{pmatrix} 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda + \frac{1}{2}A^2\lambda^5[1 - 2(\rho + i\eta)] & 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4(1 + 4A^2) & A\lambda^2 \\ A\lambda^3[1 - (1 - \frac{1}{2}\lambda^2)(\rho + i\eta)] & -A\lambda^2 + \frac{1}{2}A\lambda^4[1 - 2(\rho + i\eta)] & 1 - \frac{1}{2}A^2\lambda^4 \end{pmatrix}$$

Unitarity triangles

- The kaon triangle

$$0 = \frac{V_{ud}V_{us}^*}{V_{cd}V_{cs}^*} + \frac{V_{cd}V_{cs}^*}{V_{cd}V_{cs}^*} + \frac{V_{td}V_{ts}^*}{V_{cd}V_{cs}^*}$$

- The Bs triangle

$$0 = \frac{V_{us}V_{ub}^*}{V_{cs}V_{cb}^*} + \frac{V_{cs}V_{cb}^*}{V_{cs}V_{cb}^*} + \frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}$$

- The D triangle

$$0 = \frac{V_{ud}V_{cd}^*}{V_{us}V_{cs}^*} + \frac{V_{us}V_{cs}^*}{V_{us}V_{cs}^*} + \frac{V_{ub}V_{cb}^*}{V_{us}V_{cs}^*}$$

- Jarlskog invariant

$$J = A^2 \lambda^6 \eta (1 - \lambda^2/2) \simeq 10^{-5}$$

- The UT

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

CKM: the matrix and the UT

Phase convention independent parameters

$$\lambda^2 = \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2}$$

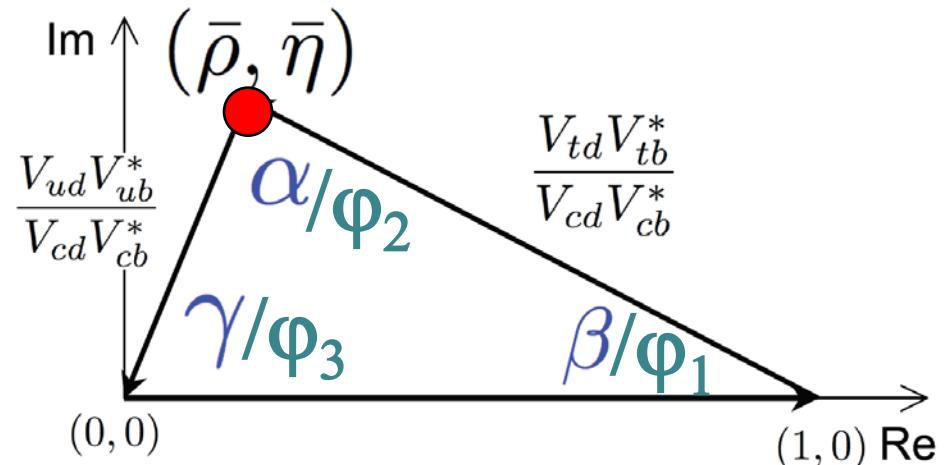
$$A^2 \lambda^4 = \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2}$$

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

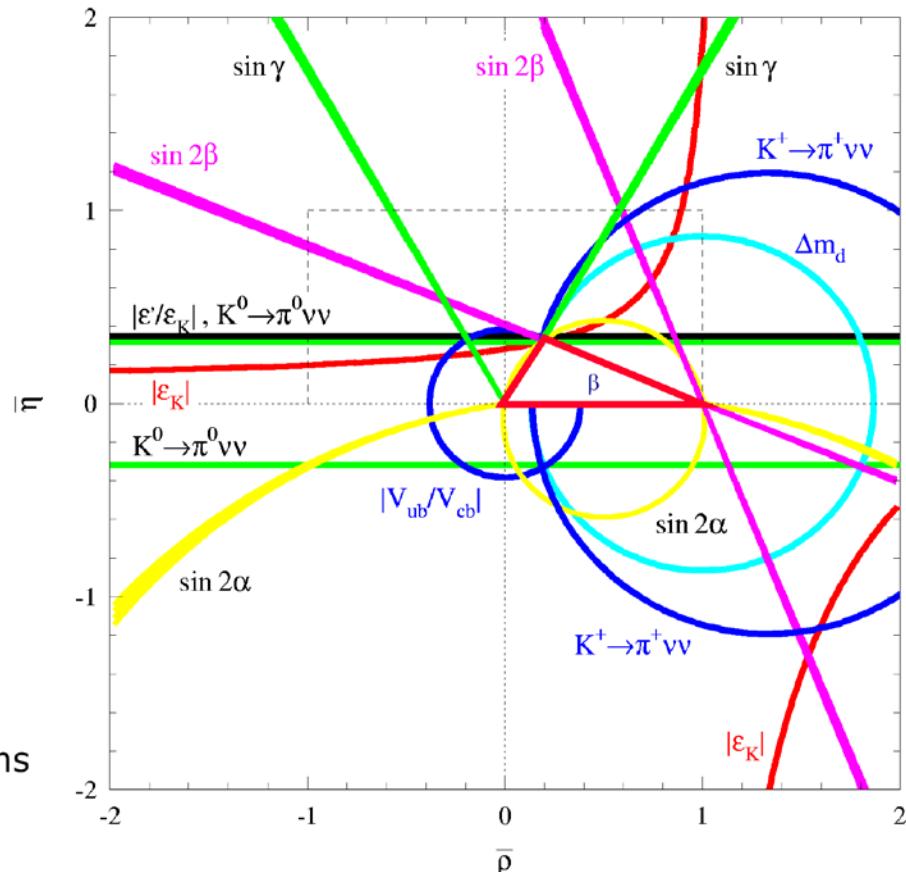
$$\rho + i\eta = \frac{\sqrt{1 - A^2 \lambda^4}(\bar{\rho} + i\bar{\eta})}{\sqrt{1 - \lambda^2}[1 - A^2 \lambda^4(\bar{\rho} + i\bar{\eta})]}$$

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

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



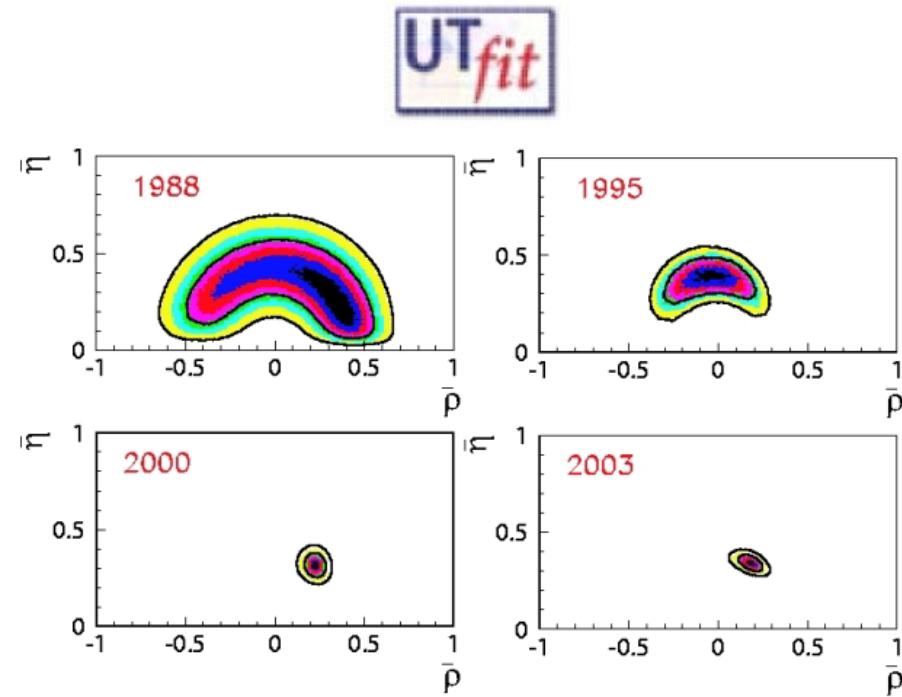
CKM matrix and UT



Falsifiable at low energy:

4 parameters measurable in many processes,

2 realizing that λ is precisely known and A factorizes



My focus

The strategy

- Initial strategy when planning the B factories
 - Test the validity of the Standard Model
 - If there is a discrepancy, look for new physics
- Current version
 - The SM (CKM) is valid: **Precision tests**
 - Look for NP within the uncertainties
 - The CKM fits reveal a few **tensions**
 - New measurements (not precise yet) on the Bs
- There is a new physics flavor problem

Precision flavor tests

Theory to interpret flavor measurements

- $K, (D), B_d$ and B_s
 - Lightest quarks in a generation undergo *rare* (decay, mixing) processes.
- At low energy, integrate out W, Z, t , resulting in 3 (4) or 5 active flavor *effective Hamiltonians* written as an *Operator Product Expansion* (OPE)
 - DeltaF=2
 - DeltaF=1
 - Their interference

$$\mathcal{H}_W^{\Delta F=1} = 4 \frac{G_F}{\sqrt{2}} \sum_i C_i(\mu) Q_i(\mu)$$

Wilson coefficients
Calculated perturbatively

Non perturbative QCD,
the hard part

$\Delta F=1$

$$\begin{aligned} \mathcal{H}_W^{\Delta B=1, \Delta C=0, \Delta S=-1} = 4 \frac{G_F}{\sqrt{2}} & \left(\lambda_c^s (C_1(\mu) Q_1^c(\mu) + C_2(\mu) Q_2^c(\mu)) \right. \\ & \left. + \lambda_u^s (C_1(\mu) Q_1^u(\mu) + C_2(\mu) Q_2^u(\mu)) - \lambda_t^s \sum_{i=3}^{10} C_i(\mu) Q_i(\mu) \right), \end{aligned} \quad (43)$$

where the $\lambda_q^s = V_{qb}^* V_{qs}$ and the operator basis is given by

CA	$Q_1^q = \bar{b}_L^\alpha \gamma^\mu q_L^\alpha \bar{q}_L^\beta \gamma_\mu s_L^\beta$	CS
$Q_3 = \bar{b}_L^\alpha \gamma^\mu s_L^\alpha \sum_q \bar{q}_L^\beta \gamma_\mu q_L^\beta$ $Q_5 = \bar{b}_L^\alpha \gamma^\mu s_L^\alpha \sum_q \bar{q}_R^\beta \gamma_\mu q_R^\beta$		
$Q_7 = \frac{3}{2} \bar{b}_L^\alpha \gamma^\mu s_L^\alpha \sum_q e_q \bar{q}_R^\beta \gamma_\mu q_R^\beta$ $Q_9 = \frac{3}{2} \bar{b}_L^\alpha \gamma^\mu s_L^\alpha \sum_q e_q \bar{q}_L^\beta \gamma_\mu q_L^\beta$		(44)

There are golden modes, and non-golden modes.

$\Delta F=1$

For γ , lepton pairs final states, **radiative penguin processes**, remove the quarks EWP, add new (CA) EWP with on shell γ , Z

$$Q_{7\gamma} = \frac{e}{16\pi^2} m_b \bar{b}_L^\alpha \sigma^{\mu\nu} F_{\mu\nu} s_L^\alpha$$

$$Q_{8g} = \frac{g_s}{16\pi^2} m_b \bar{b}_L^\alpha \sigma^{\mu\nu} G_{\mu\nu}^A T^A s_L^\alpha$$

$$Q_{9V} = \frac{1}{2} \bar{b}_L^\alpha \gamma^\mu s_L^\alpha \bar{l} \gamma_\mu l$$

$$Q_{10A} = \frac{1}{2} \bar{b}_L^\alpha \gamma^\mu s_L^\alpha \bar{l} \gamma_\mu \gamma_5 l$$

EWPs (radiative)

$$\begin{aligned} \mathcal{H}_W = -4 \frac{G_F}{\sqrt{2}} \lambda_t^s & \left(\sum_{i=1}^6 C_i(\mu) Q_i(\mu) + C_{7\gamma}(\mu) Q_{7\gamma}(\mu) + C_{8g}(\mu) Q_{8g}(\mu) \right. \\ & \left. + C_{9V}(\mu) Q_{9V}(\mu) + C_{10A}(\mu) Q_{10A}(\mu) \right), \end{aligned} \quad (48)$$

Trouble is at low energy, to compute the matrix elements of the effective operators. Use factorization theorems (QCDF, PQCD, SCET) and Lattice QCD.

$\Delta F=2$, K and B mixing

Easier formalism, only one type of operator, collapsing box diagrams.

$$\mathcal{H}_W^{\Delta S=2} = \frac{G_F^2}{4\pi^2} M_W^2 \left(\lambda_c^2 \eta_1 S_0(x_c) + \lambda_t^2 \eta_2 S_0(x_t) + \lambda_t \lambda_c \eta_3 S_0(x_t, x_c) \right) \hat{Q}_s$$

$$Q_s = \bar{s}_L \gamma_\mu d_L \bar{s}_L \gamma^\mu d_L \quad \hat{B}_K = \frac{\langle \bar{K}^0 | \hat{Q}^{\Delta S=2} | K^0 \rangle}{\frac{8}{3} f_K^2 m_K^2} \quad \text{Bag factor}$$

$$|\varepsilon_K| = \frac{G_F^2 m_W^2 m_K f_K^2}{12\sqrt{2} \pi^2 \Delta m_K} B_K \left\{ \eta_{cc} S(x_c, x_c) \text{Im}[(V_{cs} V_{cd}^*)^2] + \eta_{tt} S(x_t, x_t) \text{Im}[(V_{ts} V_{td}^*)^2] + 2\eta_{ct} S(x_c, x_t) \text{Im}[V_{cs} V_{cd}^* V_{ts} V_{td}^*] \right\},$$

Long distance effects break the OPE. Hence not applicable to Δm_K

$$\Delta m_d = \frac{G_F^2}{6\pi^2} \eta_B m_{B_d} f_{B_d}^2 B_d m_W^2 S(x_t) |V_{td} V_{tb}^*|^2$$

$$\xi = \frac{f_{B_s} \sqrt{B_s}}{f_{B_d} \sqrt{B_d}}$$

$$\Delta m_s = \frac{G_F^2}{6\pi^2} \eta_B m_{B_s} \xi^2 f_{B_d}^2 B_d m_W^2 S(x_t) |V_{ts} V_{tb}^*|^2$$

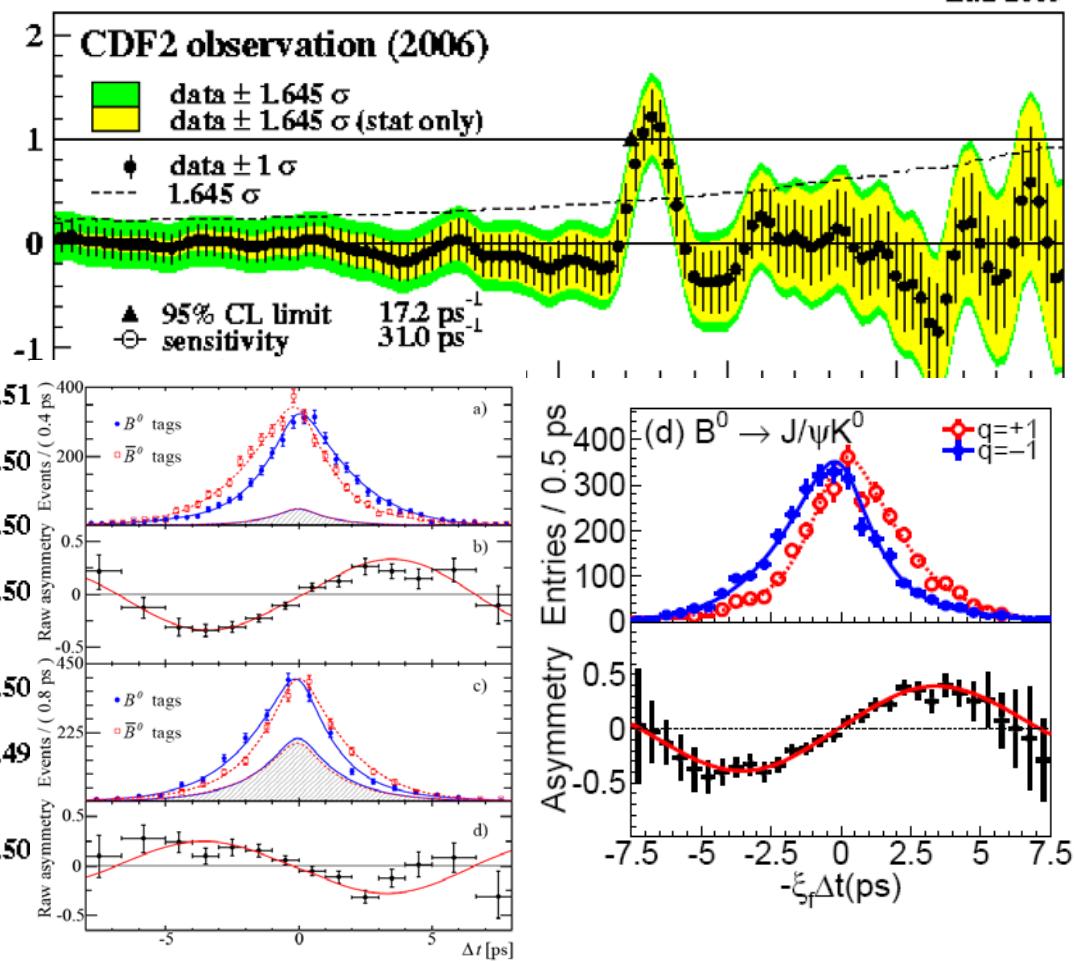
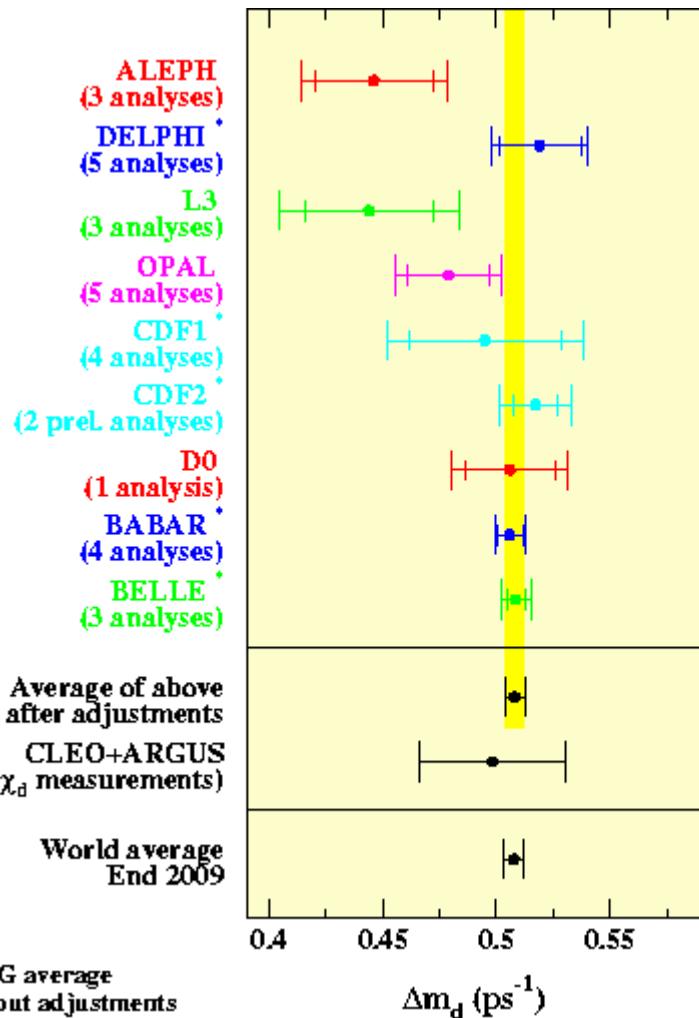
Lattice, cancellation

Input to the CKM fits

- Only take observables with theoretical uncertainty under control.
- Experimental direct determinations of the CKM matrix elements (sides).
- CP violation and mixing observables (angles)
- Theoretical parameters
 - determined from experiment
 - or from theory (LQCD or other)

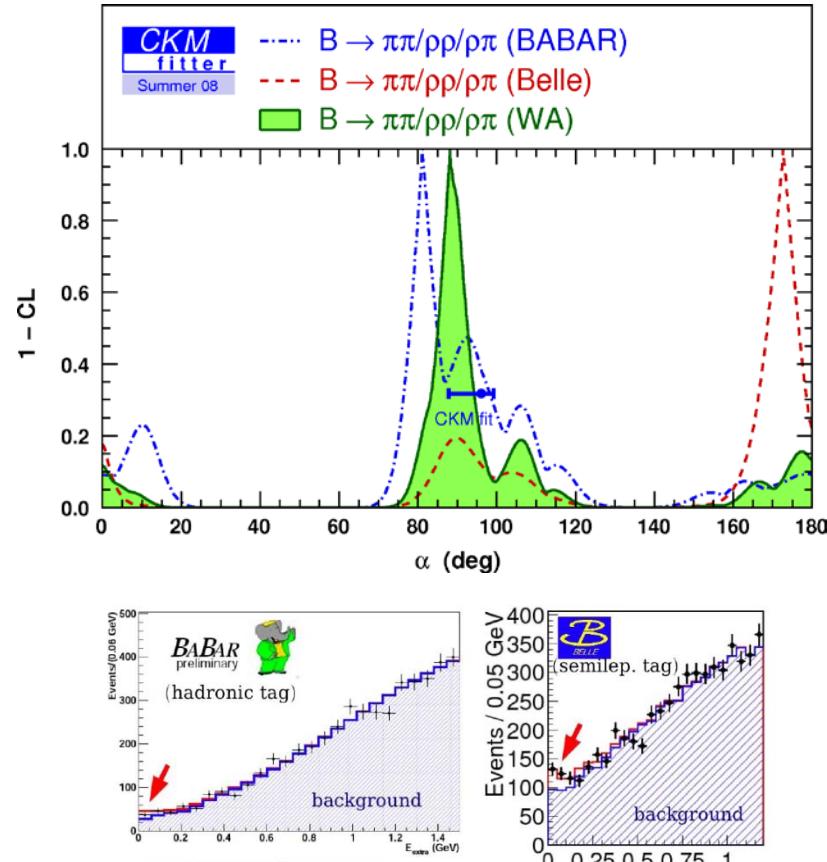
Mixing, $A_{CP}(t)$ in the CKM fit

End 2009



$\alpha, \text{Br}(\text{B} \rightarrow \tau\nu)$

- For α , fight the hadronic uncertainties by using isospin.
Works very well in the $\rho\rho$ system
- skip
 - For γ , combine GLW, ADS, GGSZ methods in $B_u \rightarrow D^{(*)}K^{(*)}$
 - V_{ub}, V_{cb} from the B_d semileptonic inclusive and exclusive decays
- $\text{Br}(\text{B} \rightarrow \tau\nu)$ interesting, points to higher V_{ub} , but see below



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	ETORS GS	ETORS TH
$ V_{ud} $ (nuclei)	0.97425 ± 0.00022	[1]	*	-
$ V_{us} $ (K_{l3})	0.2254 ± 0.0013	[2]	*	-
$ V_{ub} $	$(3.92 \pm 0.09 \pm 0.45) \times 10^{-3}$	[3, 4]	*	*
$ V_{cb} $	$(40.89 \pm 0.38 \pm 0.59) \times 10^{-3}$	[3]	*	*
$ \varepsilon_K $	$(2.229 \pm 0.010) \times 10^{-3}$	[5]	*	-
Δm_d	$(0.507 \pm 0.005) \text{ ps}^{-1}$	[3]	*	-
Δm_s	$(17.77 \pm 0.12) \text{ ps}^{-1}$	[6]	*	-
$\sin(2\beta)_{[cc]}$	0.673 ± 0.023	[3]	*	-
$S_{\pi\pi}^{+-}, C_{\pi\pi}^{+-}, C_{\pi\pi}^{00}$ $B_{\pi\pi}$ all charges	Inputs to isospin analysis	[3]	*	-
$S_{\rho\rho,L}^{+-}, C_{\rho\rho,L}^{+-}, S_{\rho\rho}^{00}, C_{\rho\rho}^{00}$ $B_{\rho\rho,L}$ all charges	Inputs to isospin analysis	[3]	*	-
$B^0 \rightarrow (\rho\pi)^0 \rightarrow 3\pi$	Inputs to isospin analysis	[3]	*	-
$B^- \rightarrow D^{(*)} K^{(*)-}$	Inputs to GLW analysis	[3]	*	-
$B^- \rightarrow D^{(*)} K^{(*)-}$	Inputs to ADS analysis	[3]	*	-
$B^- \rightarrow D^{(*)} K^{(*)-}$	GGSZ Dalitz analysis	[3]	*	-
$\mathcal{B}(B^- \rightarrow \tau^- \bar{\nu}_\tau)$	$(1.68 \pm 0.31) \times 10^{-4}$	[9]	*	-
$\overline{m}_c(m_c)$	$(1.286 \pm 0.013 \pm 0.040) \text{ GeV}$	[12]	*	*
$\overline{m}_t(m_t)$	$(165.02 \pm 1.16 \pm 0.11) \text{ GeV}$	[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]	-	*
$\eta_B(\overline{\text{MS}})$	0.551 ± 0.007	[19]	-	*
f_{B_s}	$(228 \pm 3 \pm 17) \text{ MeV}$	[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]	*	*

CKM status

Global fit results described by Frank Porter at ICHEP

$$|V| = \begin{pmatrix} 0.97418 \pm 0.00027 & 0.2253 \pm 0.0008 & 0.00392 \pm 0.00046 \\ 0.230 \pm 0.011 & 1.04 \pm 0.06 & 0.0409 \pm 0.0007 \\ 0.0081 \pm 0.0005 & 0.0387 \pm 0.0023 & 0.88 \pm 0.07 \end{pmatrix}$$

Still plenty of room for a fourth generation.

ICHEP 2010 averages (assuming 3×3 unitarity, SM)

CKMfitter, ICHEP10 UTfit, ICHEP10

A $0.812^{+0.013}_{-0.027}$

λ 0.22543 ± 0.00077

$\bar{\rho}$ 0.144 ± 0.025 0.132 ± 0.020

$\bar{\eta}$ $0.342^{+0.016}_{-0.015}$ 0.358 ± 0.012

$\alpha(^{\circ})$ 91.0 ± 3.9

$\sin 2\beta$ $0.689^{+0.023}_{-0.021}$

$\gamma(^{\circ})$ 67.2 ± 3.9

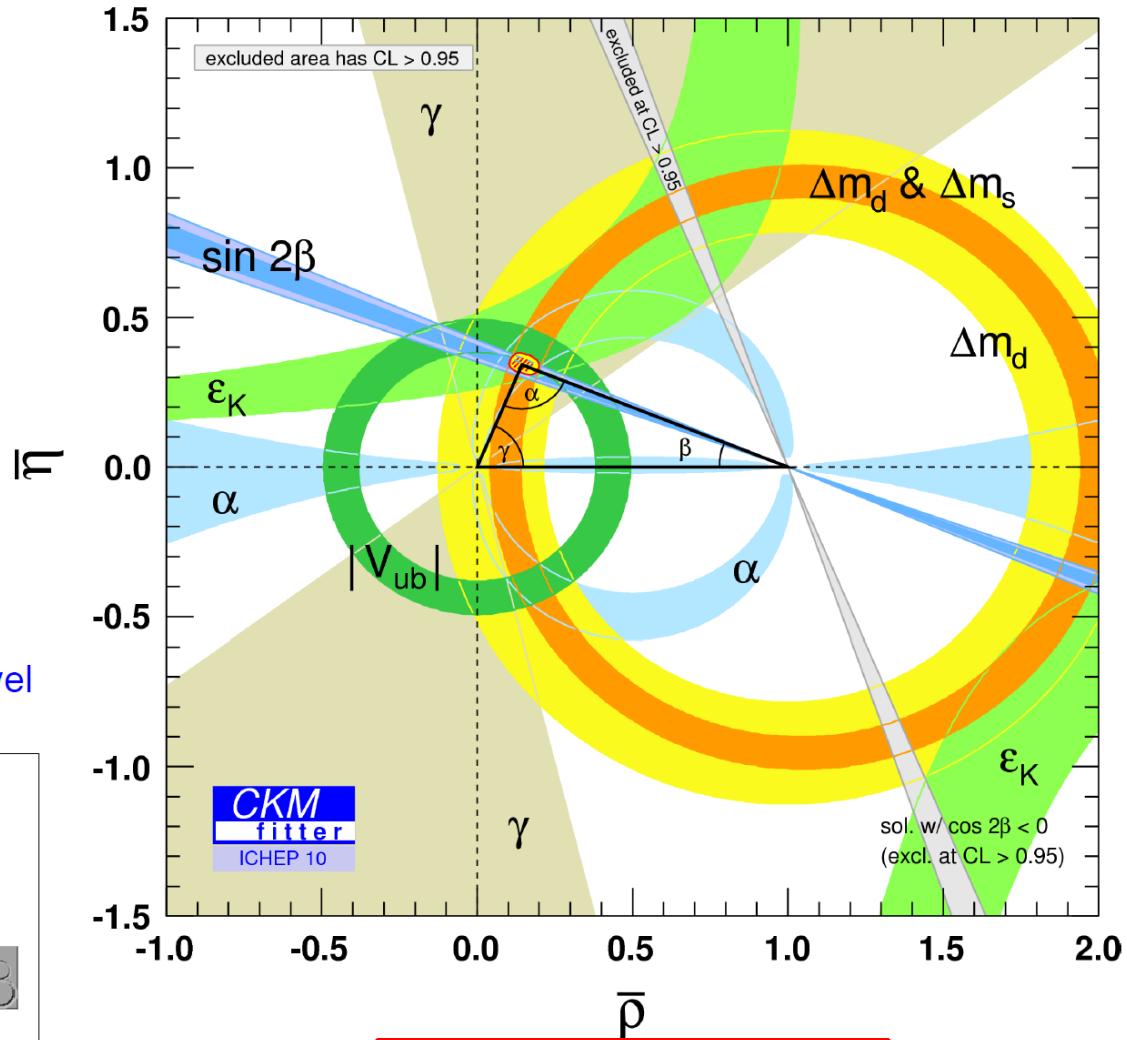
Much less precise than the EWPT

Global fit results

Inputs (theor. uncer. under control (LQCD)):

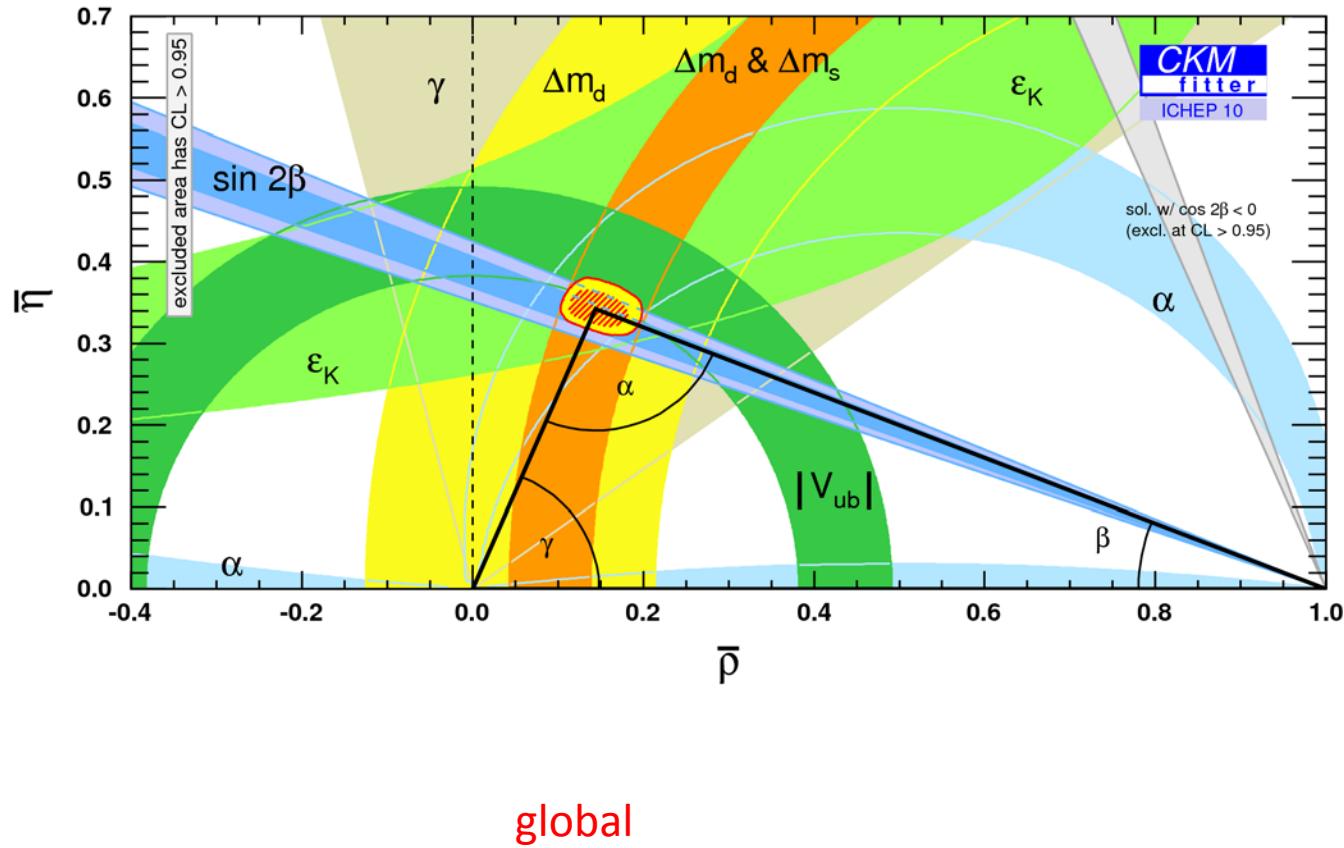
$A, \lambda: |V_{ud}|, |V_{us}|, |V_{cb}|$
 $(\bar{\rho}, \bar{\eta}):$
 → $|V_{ub}|$
 → $B \rightarrow TV$
 → γ
 → Δm_d
 → $\Delta m_d \& \Delta m_s$
 → $|\varepsilon_K|$
 → $\sin 2\beta$
 → α

Overall consistency at 2σ level



Fit variations

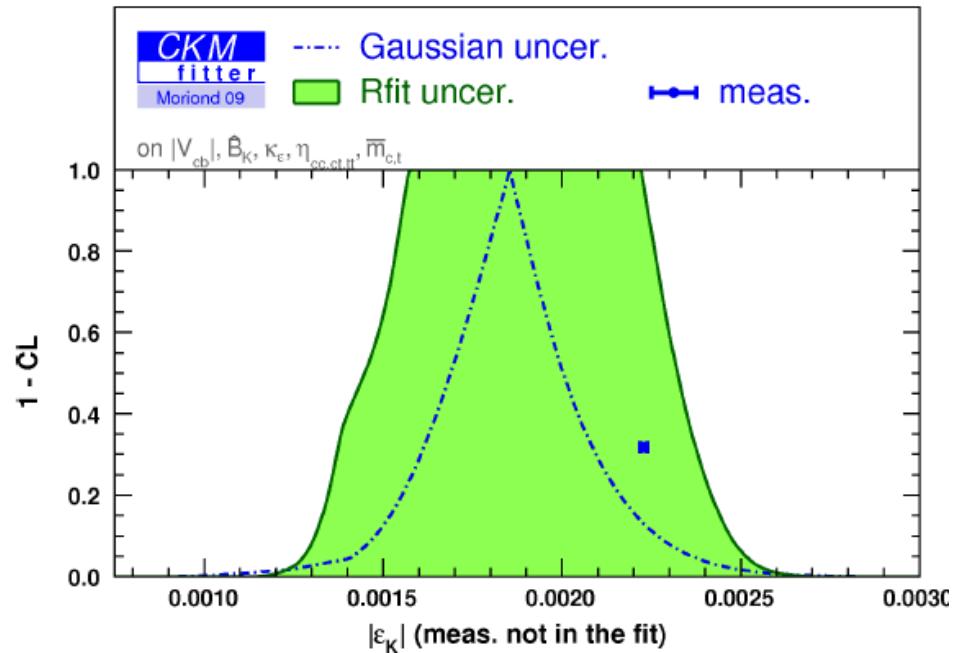
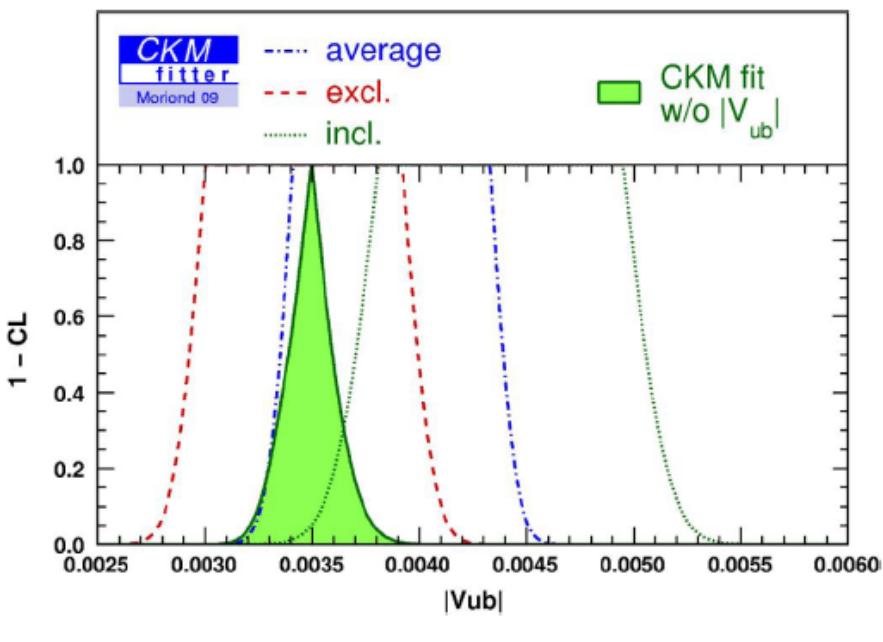
tree
loop
CP cor
CP vio|
w/o τ
w/o $s2\beta$



Tensions

- Some measurements are difficult
 - V_{ub} and V_{cb} in semileptonic B decays
 - $\sin 2\beta_{\text{eff}}$
- Variations of the fit reveal some inconsistencies
 - $\text{BR}(B \rightarrow \tau\nu)$, $\sin 2\beta_{cc}$, $[\varepsilon_K]$
- The new B_s measurements
 - ϕ_s , semimuonic asymmetry A_{sl}^s

V_{ub} and ε_K



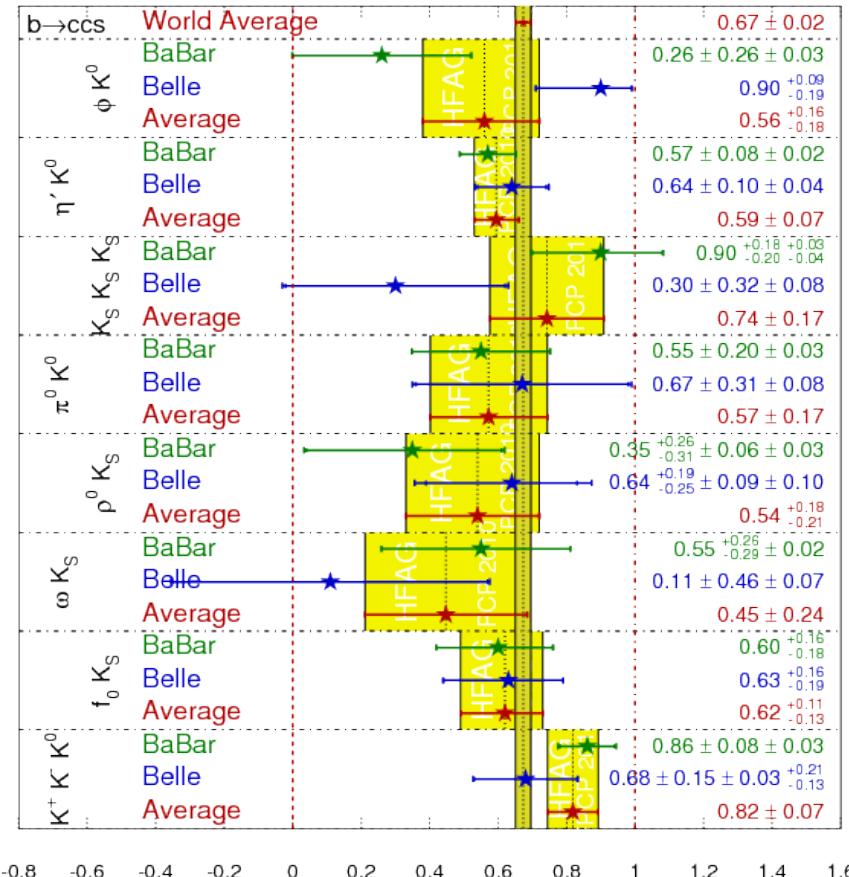
$\sin 2\beta_{\text{eff}}$

$$\sin(2\beta^{\text{eff}}) \equiv \sin(2\phi_1^{\text{eff}})$$

HFAG

FPCP 2010

PRELIMINARY



$\sin 2\beta$ and $\text{BR}(B \rightarrow \tau \nu)$

Wolfenstein parameters: (relative precision: 2.5%, 0.4%, 17% and 5%)

$A = 0.812^{+0.013}_{-0.027}$	$\lambda = 0.22543 \pm 0.00077$	$\bar{\rho} = 0.144 \pm 0.025$	$\bar{\eta} = 0.342^{+0.016}_{-0.015}$
-------------------------------	---------------------------------	--------------------------------	--

Sides and angles:

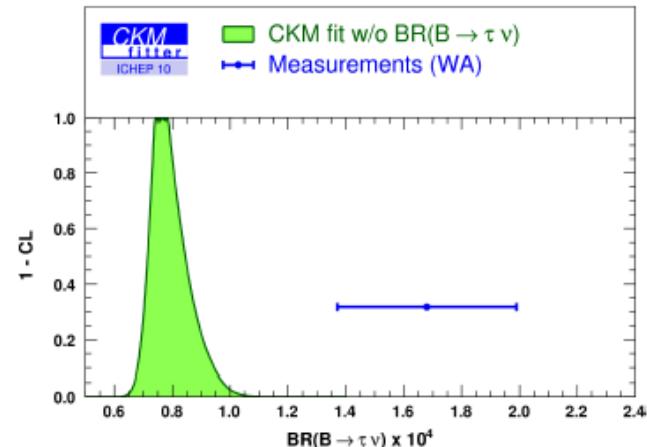
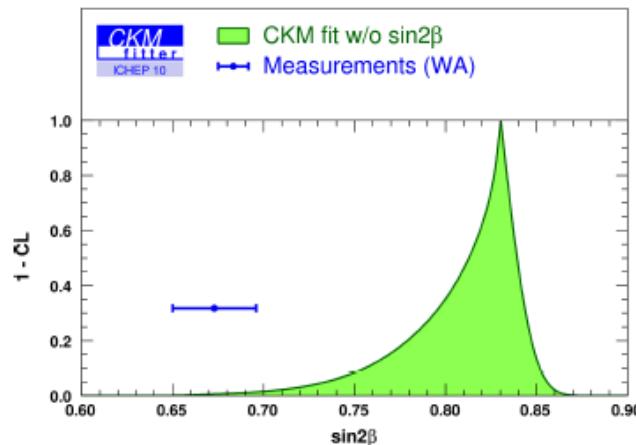
$R_u = 0.371^{+0.015}_{-0.013}$	$R_t = 0.922^{+0.025}_{-0.026}$	$\alpha = (91.0 \pm 3.9)^\circ$	$\beta = (21.76^{+0.92}_{-0.82})^\circ$	$\gamma = (67.2 \pm 3.9)^\circ$
---------------------------------	---------------------------------	---------------------------------	---	---------------------------------

B_s system

$\beta_s = (1.041^{+0.050}_{-0.048})^\circ$	$\text{BF}(B_s \rightarrow \mu \mu)[10^{-9}] = 3.073^{+0.070}_{-0.190}$
---	---

St. t'J @ ICHEP10

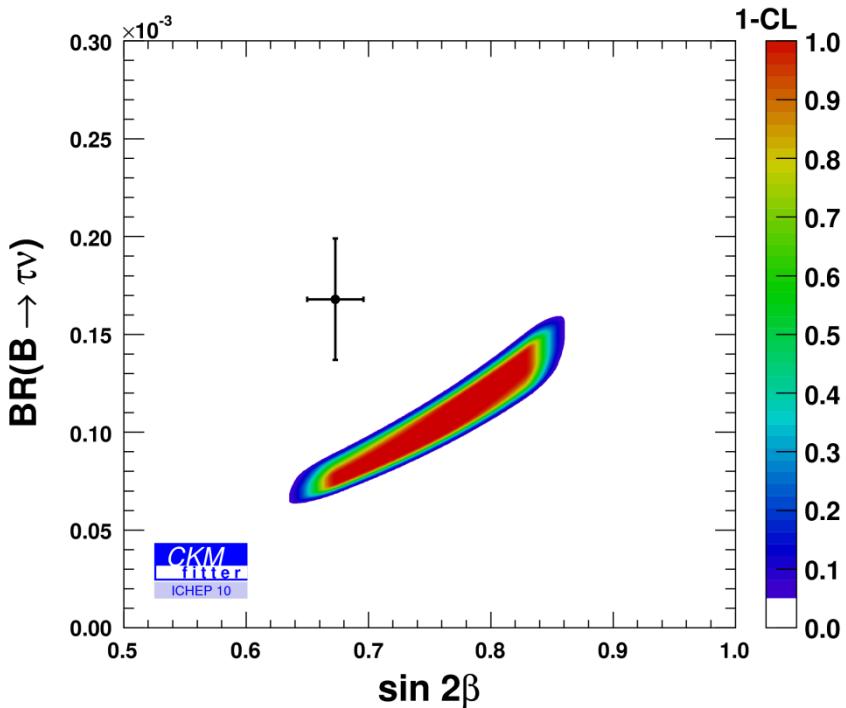
All measurements consistent with their predictions within $\pm 1\sigma$ except
 $\sin 2\beta$: 2.6σ and $B \rightarrow \tau \nu$: 2.8σ



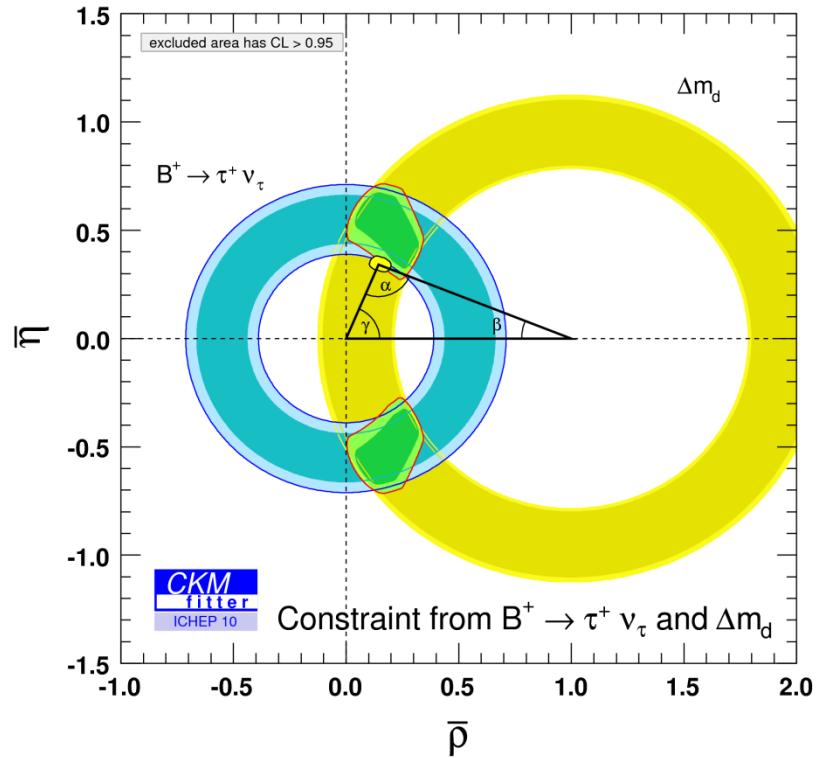
$\sin 2\beta$ and $\text{BR}(B \rightarrow \tau v)$

$$\Gamma(M^- \rightarrow \ell^-\bar{\nu}_\ell) = \frac{G_F^2}{8\pi} |V_{q_u q_d}|^2 f_M^2 m_M m_\ell^2 \left(1 - \frac{m_\ell^2}{m_M^2}\right)^2$$

- Correlation $\text{BR}(\tau v)$ and Δm_d



Also sensitive to charged Higgs



Recent TeVatron measurements

$$\mathcal{A}_{\text{SL}}^d = \frac{N(\overline{B}^0(t) \rightarrow \ell^+ \nu_\ell X) - N(B^0(t) \rightarrow \ell^- \bar{\nu}_\ell X)}{N(\overline{B}^0(t) \rightarrow \ell^+ \nu_\ell X) + N(B^0(t) \rightarrow \ell^- \bar{\nu}_\ell X)} = \frac{|p/q|_d^2 - |q/p|_d^2}{|p/q|_d^2 + |q/p|_d^2}$$

$$\mathcal{A}_{\text{SL}}^d = -0.0047 \pm 0.0046 \quad (\text{B factories})$$

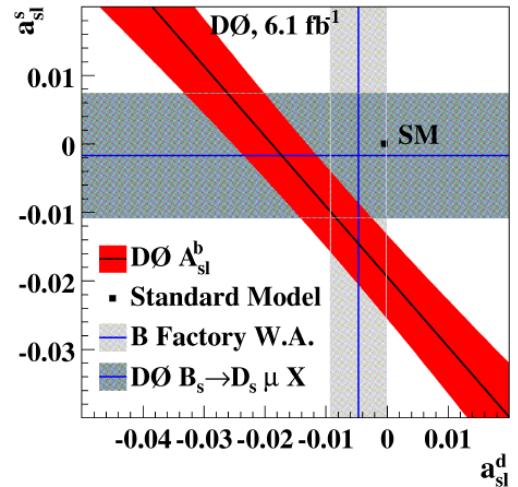
$$\mathcal{A}_{\text{SL}}^b = -0.00957 \pm 0.00251(\text{stat}) \pm 0.00146(\text{syst})$$

$$\mathcal{A}_{\text{SL}}^b(\text{SM}) = (-2.3^{+0.5}_{-0.6}) \times 10^{-4} \quad \textcolor{red}{3.2 \sigma}$$

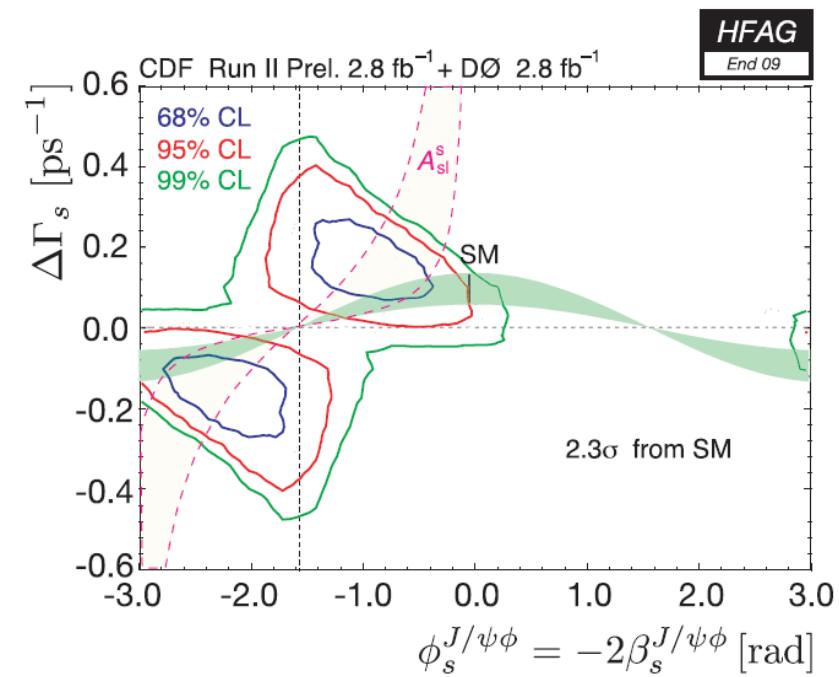
$$\phi_s = \arg [-M_{12}/\Gamma_{12}]$$

$$2\beta_s^{SM} = 2 \arg [-(V_{ts}V_{tb}^*) / (V_{cs}V_{cb}^*)] = 0.037 \pm 0.002 \approx 0.04.$$

$$\mathcal{A}_{\text{SL}}^s = \frac{|\Gamma_s^{12}|}{|M_s^{12}|} \sin \phi_s \quad \Delta \Gamma_s = \Gamma_L^s - \Gamma_H^s = 2 |\Gamma_{12}^s| \cos \phi_s$$

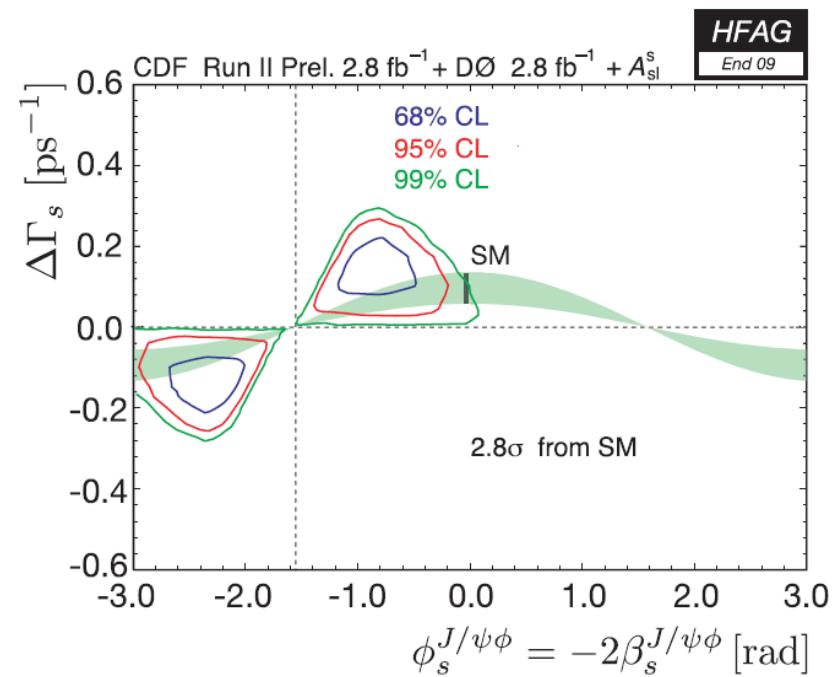


HFAG accounting of TeVatron



plot

$$\frac{\Delta\Gamma_s}{\Delta M_s} \tan\phi_s$$



include

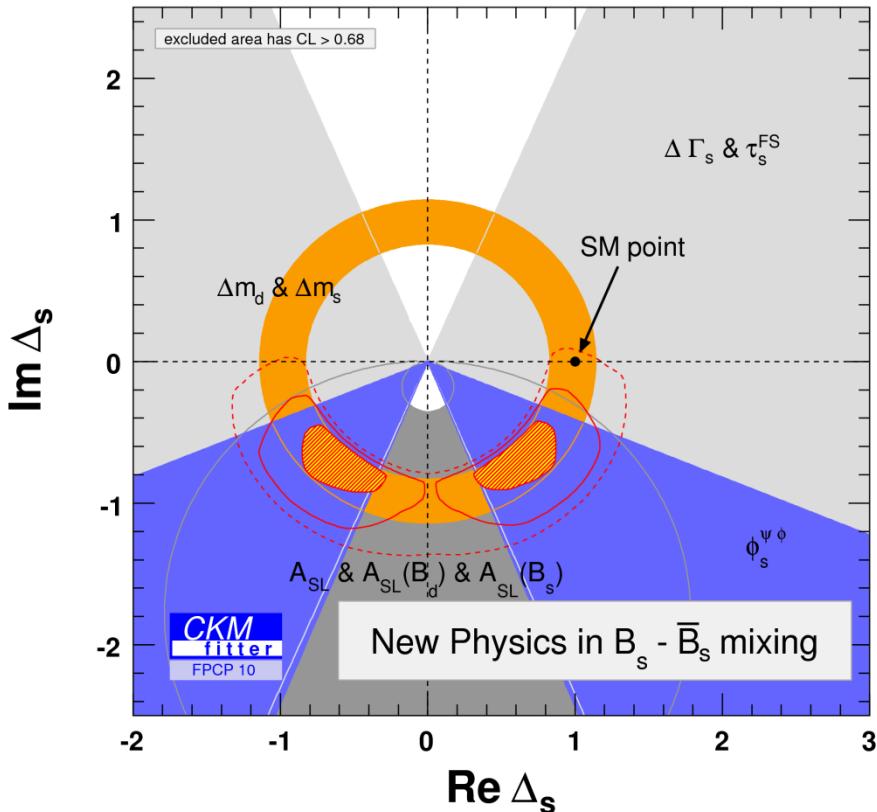
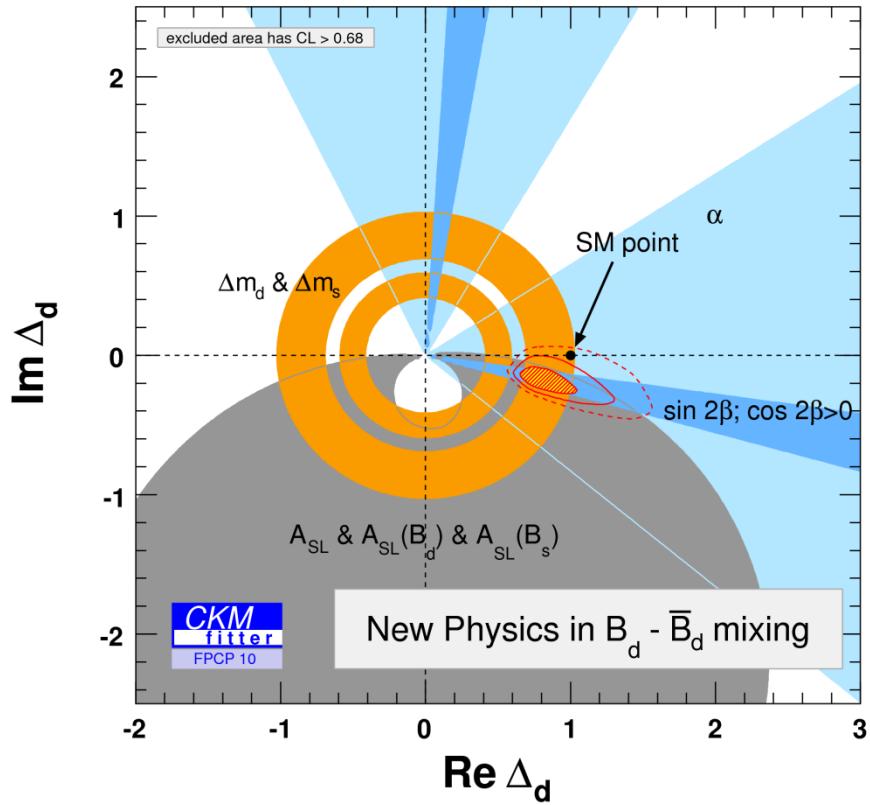
Potentially predictive areas

- The SM test passed with flying colors (2σ consistency)
- Learn from the past looking glass?
 - charm existence (GIM) and mass (K mixing)
 - 3rd Generation (KM)
 - Top mass (Bd mixing)
- New physics in loops → fit CKM parameters with trees, compare to loops.
- EDM constraints
- The flavor structure of 1 TeV scale New physics is non generic
 - The MFV scenario
 - Other approaches
- Phenomenological attempts
 - Generic effective theory (Fermi)
 - Specific models

CKM fitter generic searches

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

[arXiv:1008.1593v2](https://arxiv.org/abs/1008.1593v2) [hep-ph]



Phenomenological strategies

- The SM as a low energy effective theory
 - what are the new energy scales?
 - what are the new interactions and symmetries?
- EWP arguments favor $\Lambda \sim 1$ TeV (Andreas' talk)
- Two main strategies (see e.g CKM08)
 1. Model independent a la Fermi
 - DF=2 strongly constrained unless selection rules (symmetry) imposed
 - MFV is an example
 2. Explicit high energy models
 - SUSY e.g. Mass insertion approximation in general MSSM
 - Or non SUSY

Model independent approach

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \sum \frac{c_i^{(d)}}{\Lambda^{(d-4)}} O_i^{(d)} (\text{SM fields}).$$

- For instance assume no NP affecting the CKM fit in processes with SM tree.
- Generic $\Delta F=2$ NF
- flavor problem $\Lambda > \frac{4.4 \text{ TeV}}{|V_{ti}^* V_{tj}| / |c_{ij}|^{1/2}} \sim \begin{cases} 1.3 \times 10^4 \text{ TeV} \times |c_{sd}|^{1/2} \\ 5.1 \times 10^2 \text{ TeV} \times |c_{bd}|^{1/2} \\ 1.1 \times 10^2 \text{ TeV} \times |c_{bs}|^{1/2} \end{cases}$
- weak constraint
- MFV (minimal flavor violation)
 - A symmetry (the non Yukawa SM flavor symmetry)
 - Symmetry breaking only by the SM Yu and Yd
 - Generated scale above but not far from 1 TeV
 - Some predictions, not spectacular

$$B \rightarrow X_s \gamma, B \rightarrow X_s \ell^+ \ell^-$$
$$\epsilon_K, \Delta m_{B_d}, \Delta m_{B_s}$$
$$B_s \rightarrow \mu^+ \mu^-$$

Explicit high energy models

W. Altmannshofer, A. J. Buras, S. Gori, P. Paradisi, and D. M. Straub, Nucl. Phys. B830, 17 (2010), 0909.1333.

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{CP}(B \rightarrow X_s \gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \rightarrow K^* \mu^+ \mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \rightarrow K^* \mu^+ \mu^-)$	★	★	★	★	★	★	?
$B \rightarrow K^{(*)} \nu \bar{\nu}$	★	★	★	★	★	★	★
$B_s \rightarrow \mu^+ \mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \rightarrow \pi^0 \nu \bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \rightarrow e \gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \rightarrow \mu \gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \rightarrow e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

Table 8: “DNA” of flavour physics effects for the most interesting observables in a selection of SUSY and non-SUSY models. ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

A new generation of experiments

- LHCb
- Super Flavor factories
- Rare kaon decay experiments

Observable	SM prediction	Theory error	Present result	Future error	Future Facility
$ V_{us} $ [$K \rightarrow \pi \ell \nu$]	input	$0.5\% \rightarrow 0.1\%_{\text{Latt}}$	0.2246 ± 0.0012	0.1%	K factory
$ V_{cb} $ [$B \rightarrow X_c \ell \nu$]	input	1%	$(41.54 \pm 0.73) \times 10^{-3}$	1%	Super- B
$ V_{ub} $ [$B \rightarrow \pi \ell \nu$]	input	$10\% \rightarrow 5\%_{\text{Latt}}$	$(3.38 \pm 0.36) \times 10^{-3}$	4%	Super- B
γ [$B \rightarrow DK$]	input	$< 1^\circ$	$(70^{+27}_{-30})^\circ$	3°	LHCb
$S_{B_d \rightarrow \psi K}$	$\sin(2\beta)$	$\lesssim 0.01$	0.671 ± 0.023	0.01	LHCb
$S_{B_s \rightarrow \psi \phi}$	0.036	$\lesssim 0.01$	$0.81^{+0.12}_{-0.32}$	0.01	LHCb
$S_{B_d \rightarrow \phi K}$	$\sin(2\beta)$	$\lesssim 0.05$	0.44 ± 0.18	0.1	LHCb
$S_{B_s \rightarrow \phi \phi}$	0.036	$\lesssim 0.05$	—	0.05	LHCb
$S_{B_d \rightarrow K^* \gamma}$	$\text{few} \times 0.01$	0.01	-0.16 ± 0.22	0.03	Super- B
$S_{B_s \rightarrow \phi \gamma}$	$\text{few} \times 0.01$	0.01	—	0.05	LHCb
A_{SL}^d	-5×10^{-4}	10^{-4}	$-(5.8 \pm 3.4) \times 10^{-3}$	10^{-3}	LHCb
A_{SL}^s	2×10^{-5}	$< 10^{-5}$	***	10^{-3}	LHCb
$A_{CP}(b \rightarrow s \gamma)$	< 0.01	< 0.01	-0.012 ± 0.028	0.005	Super- B
$\mathcal{B}(B \rightarrow \tau \nu)$	1×10^{-4}	$20\% \rightarrow 5\%_{\text{Latt}}$	$(1.73 \pm 0.35) \times 10^{-4}$	5%	Super- B
$\mathcal{B}(B \rightarrow \mu \nu)$	4×10^{-7}	$20\% \rightarrow 5\%_{\text{Latt}}$	$< 1.3 \times 10^{-6}$	6%	Super- B
$\mathcal{B}(B_s \rightarrow \mu^+ \mu^-)$	3×10^{-9}	$20\% \rightarrow 5\%_{\text{Latt}}$	$< 5 \times 10^{-8}$	10%	LHCb
$\mathcal{B}(B_d \rightarrow \mu^+ \mu^-)$	1×10^{-10}	$20\% \rightarrow 5\%_{\text{Latt}}$	$< 1.5 \times 10^{-8}$	[?]	LHCb
$A_{\text{FB}}(B \rightarrow K^* \mu^+ \mu^-)_{q_0^2}$	0	0.05	(0.2 ± 0.2)	0.05	LHCb
$B \rightarrow K \nu \bar{\nu}$	4×10^{-6}	$20\% \rightarrow 10\%_{\text{Latt}}$	$< 1.4 \times 10^{-5}$	20%	Super- B

INP compilation

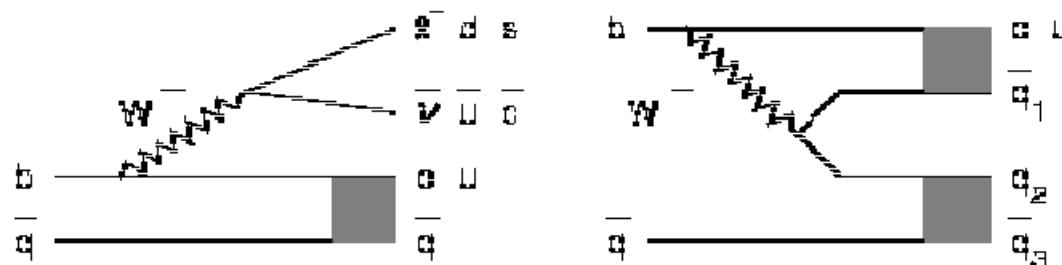
$ q/p _{D\text{-mixing}}$	1	$< 10^{-3}$	$(0.86^{+0.18}_{-0.15})$	0.03	Super- <i>B</i>
ϕ_D	0	$< 10^{-3}$	$(9.6^{+8.3}_{-9.5})^\circ$	2°	Super- <i>B</i>
$\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$	8.5×10^{-11}	8%	$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$	10%	<i>K</i> factory
$\mathcal{B}(K_L \rightarrow \pi^0 \nu \bar{\nu})$	2.6×10^{-11}	10%	$< 2.6 \times 10^{-8}$	[?]	<i>K</i> factory
$R^{(e/\mu)}(K \rightarrow \pi \ell \nu)$	2.477×10^{-5}	0.04%	$(2.498 \pm 0.014) \times 10^{-5}$	0.1%	<i>K</i> factory
$\mathcal{B}(t \rightarrow c Z, \gamma)$	$\mathcal{O}(10^{-13})$	$\mathcal{O}(10^{-13})$	$< 0.6 \times 10^{-2}$	$\mathcal{O}(10^{-5})$	LHC (100 fb^{-1})

TABLE VIII: Status and prospects of selected $B_{s,d}$, D , K and t observables (based on information from Ref. [46, 91, 92]). In the third column “Latt” refer to improvements in Lattice QCD expected in the next 5 years. In the fourth column the bounds are 90% CL. The errors in the fifth column refer to 10 fb^{-1} at LHCb, 50 ab^{-1} at Super-*B*, and two years at NA62 (“*K* factory”). In the third and fifth column the errors followed by “%” are relative errors, whil the others are absolute errors. For entries marked “[?]” we have not found a reliable estimate of the future experimental prospects.

Outlook

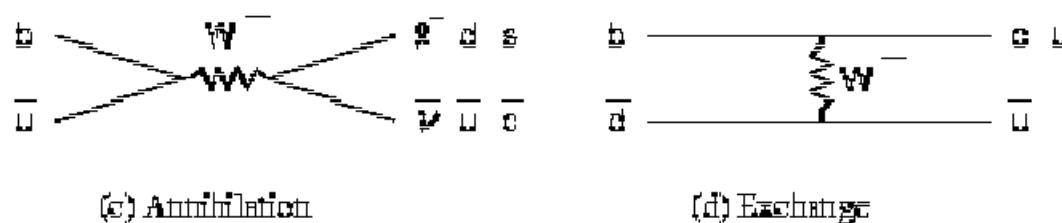
- SM test passed (2σ consistency).
- The precision is much less than for the EWPT
- Next generation of experiments can improve.
- Also in the lepton sector (PSI experiments): G_F , LFV.
- Lattice must match the experimental projected precision.
- There is room for a fourth family of fermions.
- $\sim 2\text{-}3 \sigma$ discrepancies in the CKM fits to be watched.
- How much can we hope to learn about the NP flavor problem from low energy measurements?
- If new particles seen at the LHC, flavor measurements to tell the couplings.
- Still no clue to “who ordered that?”, the BAU.

BACKUP



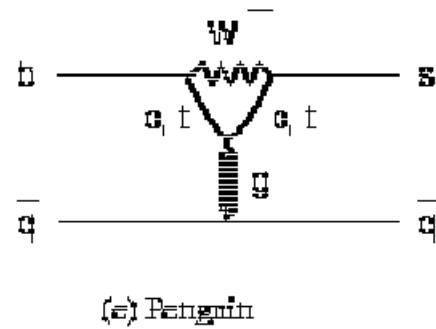
(a) Spectator

(b) Color Mixed



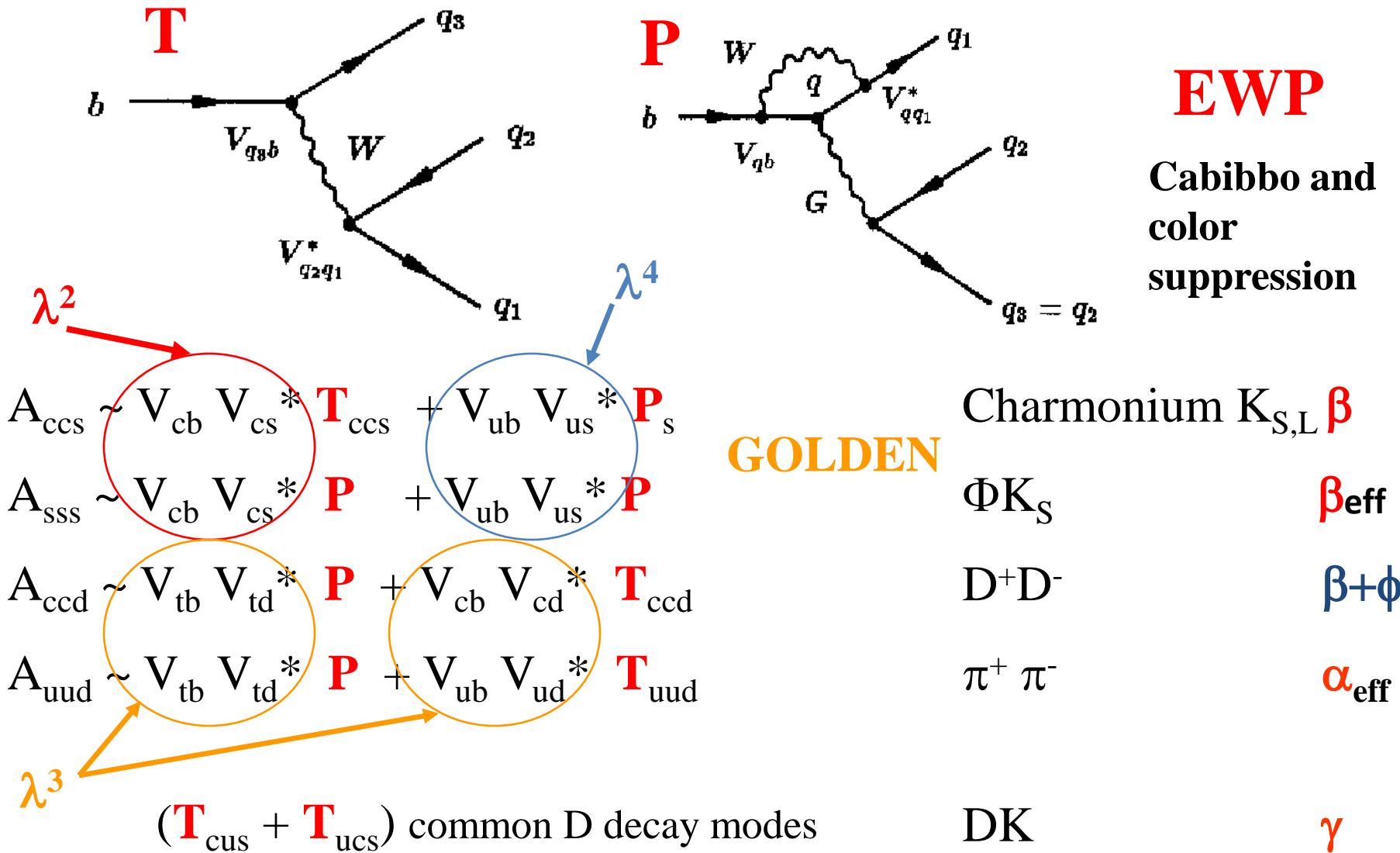
(c) Annihilation

(d) Exchange



(e) Parton

Amplitude structure in the SM



Model independent $\Delta F=2$ detailed

Operator	Bounds on Λ in TeV ($c_{ij} = 1$)		Bounds on c_{ij} ($\Lambda = 1$ TeV)		Observables
	Re	Im	Re	Im	
$(\bar{s}_L \gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	$\Delta m_K; \epsilon_K$
$(\bar{s}_R d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	$\Delta m_K; \epsilon_K$
$(\bar{c}_L \gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	$\Delta m_D; q/p , \phi_D$
$(\bar{c}_R u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	$\Delta m_D; q/p , \phi_D$
$(\bar{b}_L \gamma^\mu d_L)^2$	5.1×10^2	9.3×10^2	3.3×10^{-6}	1.0×10^{-6}	$\Delta m_{B_d}; S_{\psi K_S}$
$(\bar{b}_R d_L)(\bar{b}_L d_R)$	1.9×10^3	3.6×10^3	5.6×10^{-7}	1.7×10^{-7}	$\Delta m_{B_d}; S_{\psi K_S}$
$(\bar{b}_L \gamma^\mu s_L)^2$		1.1×10^2		7.6×10^{-5}	Δm_{B_s}
$(\bar{b}_R s_L)(\bar{b}_L s_R)$		3.7×10^2		1.3×10^{-5}	Δm_{B_s}

TABLE I: Bounds on representative dimension-six $\Delta F = 2$ operators. Bounds on Λ are quoted assuming an effective coupling $1/\Lambda^2$, or, alternatively, the bounds on the respective c_{ij} 's assuming $\Lambda = 1$ TeV. Observables related to CPV are separated from the CP conserving ones with semicolons. In the B_s system we only quote a bound on the modulo of the NP amplitude derived from Δm_{B_s} (see text). For the definition of the CPV observables in the D system see Ref. [15].

MFV bounds

Operator	Bound on Λ	Observables
$H^\dagger (\overline{D}_R Y^{d\dagger} Y^u Y^{u\dagger} \sigma_{\mu\nu} Q_L) (e F_{\mu\nu})$	6.1 TeV	$B \rightarrow X_s \gamma, B \rightarrow X_s \ell^+ \ell^-$
$\frac{1}{2} (\overline{Q}_L Y^u Y^{u\dagger} \gamma_\mu Q_L)^2$	5.9 TeV	$\epsilon_K, \Delta m_{B_d}, \Delta m_{B_s}$
$H_D^\dagger (\overline{D}_R Y^{d\dagger} Y^u Y^{u\dagger} \sigma_{\mu\nu} T^a Q_L) (g_s G_{\mu\nu}^a)$	3.4 TeV	$B \rightarrow X_s \gamma, B \rightarrow X_s \ell^+ \ell^-$
$(\overline{Q}_L Y^u Y^{u\dagger} \gamma_\mu Q_L) (\overline{E}_R \gamma_\mu E_R)$	2.7 TeV	$B \rightarrow X_s \ell^+ \ell^-, B_s \rightarrow \mu^+ \mu^-$
$i (\overline{Q}_L Y^u Y^{u\dagger} \gamma_\mu Q_L) H_U^\dagger D_\mu H_U$	2.3 TeV	$B \rightarrow X_s \ell^+ \ell^-, B_s \rightarrow \mu^+ \mu^-$
$(\overline{Q}_L Y^u Y^{u\dagger} \gamma_\mu Q_L) (\overline{L}_L \gamma_\mu L_L)$	1.7 TeV	$B \rightarrow X_s \ell^+ \ell^-, B_s \rightarrow \mu^+ \mu^-$
$(\overline{Q}_L Y^u Y^{u\dagger} \gamma_\mu Q_L) (e D_\mu F_{\mu\nu})$	1.5 TeV	$B \rightarrow X_s \ell^+ \ell^-$

TABLE II: Bounds on the scale of new physics (at 95% C.L.) for some representative $\Delta F = 1$ [27] and $\Delta F = 2$ [12] MFV operators (assuming effective coupling $\pm 1/\Lambda^2$), and corresponding observables used to set the bounds.

Rare B decays

3.3 Standard Model Predictions from the global fit.

- CKM parameters:

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

- Rare decays:

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

- Matrix element / angles (including Bs system)

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

- Lattice parameters (!)

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

SuperB

B Physics @ Y(4S)

	ab^{-1}	SuperB (75 ab^{-1})
$\sin(2\beta) (J/\psi K^0)$	0.018	0.005 (\dagger)
$\cos(2\beta) (J/\psi K^{*0})$	0.30	0.05
$\sin(2\beta) (D h^0)$	0.10	0.02
$\cos(2\beta) (D h^0)$	0.20	0.04
$\beta(J/\psi \pi^0)$	0.10	0.02
$S(D^+ D^-)$	0.20	0.03
$S(\phi K^0)$	0.13	0.02 (\star)
$S(\eta' K^0)$	0.05	0.01 (\star)
$S(K_s^0 K_s^0 K_s^0)$	0.15	0.02 (\star)
$S(K_s^0 \pi^0)$	0.15	0.02 (\star)
$S(\omega K_s^0)$	0.17	0.03 (\star)
$S(f_0 K_s^0)$	0.12	0.02 (\star)
$\gamma (B \rightarrow DK, D \rightarrow \text{CP eigenstates})$	$\sim 15^\circ$	2.5°
$\gamma (B \rightarrow DK, D \rightarrow \text{suppressed states})$	$\sim 12^\circ$	2.0°
$\gamma (B \rightarrow DK, D \rightarrow \text{multibody states})$	$\sim 9^\circ$	1.5°
$\gamma (B \rightarrow DK, \text{combined})$	$\sim 6^\circ$	$1-2^\circ$
$\gamma (B \rightarrow \pi\pi)$	$\sim 16^\circ$	3°
$\gamma (B \rightarrow \rho\rho)$	$\sim 7^\circ$	$1-2^\circ$ (\star)
$\gamma (B \rightarrow \rho\pi)$	$\sim 12^\circ$	2°
$\gamma (\text{combined})$	$\sim 6^\circ$	$1-2^\circ$ (\star)
$2\beta + \gamma (D^{(\star)\pm} \pi^\mp, D^\pm K_s^0 \pi^\mp)$	20°	5°

Observable	B Factories (2 ab^{-1})	SuperB (75 ab^{-1})
$ V_{cb} $ (exclusive)	4% (\star)	1.0% (\star)
$ V_{cb} $ (inclusive)	1% (\star)	0.5% (\star)
$ V_{ub} $ (exclusive)	8% (\star)	3.0% (\star)
$ V_{ub} $ (inclusive)	8% (\star)	2.0% (\star)
$\mathcal{B}(B \rightarrow \tau\nu)$	20%	4% (\dagger)
$\mathcal{B}(B \rightarrow \mu\nu)$	visible	5%
$\mathcal{B}(B \rightarrow D\tau\nu)$	10%	2%
$\mathcal{B}(B \rightarrow \rho\gamma)$	18%	3% (\dagger)
$\mathcal{B}(B \rightarrow \omega\gamma)$	30%	5%
$A_{CP}(B \rightarrow K^*\gamma)$	0.007 (\dagger)	0.004 (\star)
$A_{CP}(B \rightarrow \rho\gamma)$	~ 0.20	0.05
$A_{CP}(b \rightarrow s\gamma)$	0.012 (\dagger)	0.004 (\dagger)
$A_{CP}(b \rightarrow (s+d)\gamma)$	0.03	0.006 (\dagger)
$S(K_s^0 \pi^0 \gamma)$	0.15	0.02 (\star)
$S(\rho^0 \gamma)$	possible	0.10
$A_{CP}(B \rightarrow K^*\ell\ell)$	7%	1%
$A^{FB}(B \rightarrow K^*\ell\ell)s_0$	25%	9%
$A^{FB}(B \rightarrow X,\ell\ell)s_0$	35%	5%
$\mathcal{B}(B \rightarrow K\nu\bar{\nu})$	visible	20%
$\mathcal{B}(B \rightarrow \pi\nu\bar{\nu})$	-	possible

Charm mixing and CP

Mode	Observable	$\Upsilon(4S)$ (75 ab^{-1})	$\psi(3770)$ (300 fb^{-1})
$D^0 \rightarrow K^+ \pi^-$	x'^2	3×10^{-5}	
	y'	7×10^{-4}	
$D^0 \rightarrow K^+ K^-$	y_{CP}	5×10^{-4}	
$D^0 \rightarrow K_S^0 \pi^+ \pi^-$	x	4.9×10^{-4}	
	y	3.5×10^{-4}	
	$ q/p $	3×10^{-2}	
$\psi(3770) \rightarrow D^0 \bar{D}^0$	x^2		$(1-2) \times 10^{-5}$
	y		$(1-2) \times 10^{-3}$
	$\cos \delta$		$(0.01-0.02)$

Charm FCNC

	Sensitivity
$D^0 \rightarrow e^+ e^-$, $D^0 \rightarrow \mu^+ \mu^-$	1×10^{-8}
$D^0 \rightarrow \pi^0 e^+ e^-$, $D^0 \rightarrow \pi^0 \mu^+ \mu^-$	2×10^{-8}
$D^0 \rightarrow \eta e^+ e^-$, $D^0 \rightarrow \eta \mu^+ \mu^-$	3×10^{-8}
$D^0 \rightarrow K_S^0 e^+ e^-$, $D^0 \rightarrow K_S^0 \mu^+ \mu^-$	3×10^{-8}
$D^+ \rightarrow \pi^+ e^+ e^-$, $D^+ \rightarrow \pi^+ \mu^+ \mu^-$	1×10^{-8}

τ Physics

Sensitivity

$\mathcal{B}(\tau \rightarrow \mu\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \rightarrow e\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \rightarrow \mu\mu\mu)$	2×10^{-10}
$\mathcal{B}(\tau \rightarrow eee)$	2×10^{-10}
$\mathcal{B}(\tau \rightarrow \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \rightarrow en)$	6×10^{-10}

B_s Physics @ Y(5S)

Observable	Error with 1 ab^{-1}	Error with 30 ab^{-1}
$\Delta\Gamma$	0.16 ps^{-1}	0.03 ps^{-1}
Γ	0.07 ps^{-1}	0.01 ps^{-1}
β_s from angular analysis	20°	8°
A_{SL}^s	0.006	0.004
A_{CH}^s	0.004	0.004
$\mathcal{B}(B_s \rightarrow \mu^+ \mu^-)$	-	$< 8 \times 10^{-9}$
$ V_{tb}/V_{ts} $	0.08	0.017
$\mathcal{B}(B_s \rightarrow \gamma\gamma)$	38%	7%
β_s from $J/\psi\phi$	10°	3°
β_s from $B_s \rightarrow K^0 \bar{K}^0$	24°	11°

Rare B decays

	$B_s \rightarrow \mu^+ \mu^-$	$K_L \rightarrow \pi^0 \nu \bar{\nu}$	$K_L \rightarrow \mu e$	$\mu \rightarrow e \gamma$	d_n
SM	$3 \cdot 10^{-9}$	$3 \cdot 10^{-11}$	10^{-40}	10^{-54}	10^{-32} e cm.
Exp Bound	$4 \cdot 10^{-8}$	$6 \cdot 10^{-8}$	10^{-12}	10^{-11}	$5 \cdot 10^{-26}$ e cm.

Table I. Approximate SM values and experimental upper bounds for selected branching ratios and the neutron electric dipole moment d_n .

Rare kaon decays

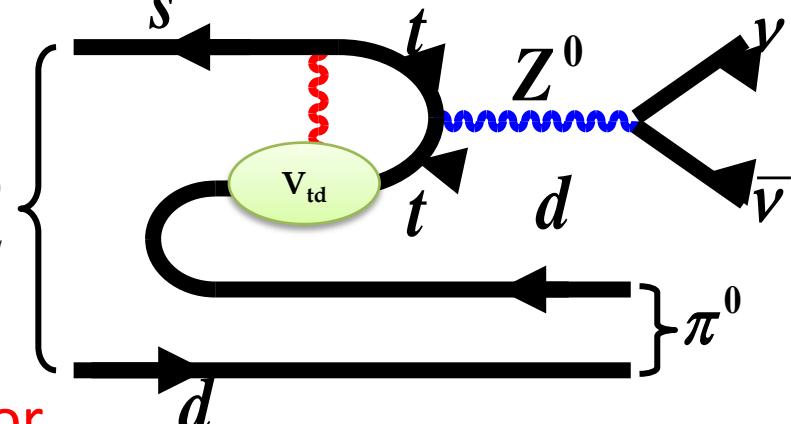
- $K \rightarrow \pi \nu \bar{\nu}$

$$\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = r_{K^+} \frac{3\alpha^2 \mathcal{B}(K^+ \rightarrow \pi^0 e^+ \nu)}{2\pi^2 |V_{us}|^2 \sin^4 \theta_W} \left| X(x_t) V_{td} V_{ts}^* + X_c V_{cd} V_{cs}^* \right|^2$$

$$\mathcal{B}(K_L^0 \rightarrow \pi^0 \nu \bar{\nu}) = \kappa_L \left[\frac{\text{Im}(V_{td} V_{ts}^*)}{\lambda^5} X(x_t) \right]^2 = \kappa_L A^4 \bar{\eta}^2 X^2(x_t) + \mathcal{O}(\lambda^4)$$

Measurement of $\text{Br}(K_L \rightarrow \pi^0 \bar{\nu} \nu)$

$$\begin{aligned} A(K_L \rightarrow \pi^0 \bar{\nu} \nu) &\propto V_{td}^* V_{ts} - V_{ts}^* V_{td} \\ &= 2 \times V_{ts} \times \text{Im}(V_{td}) \\ &\propto \eta \end{aligned}$$



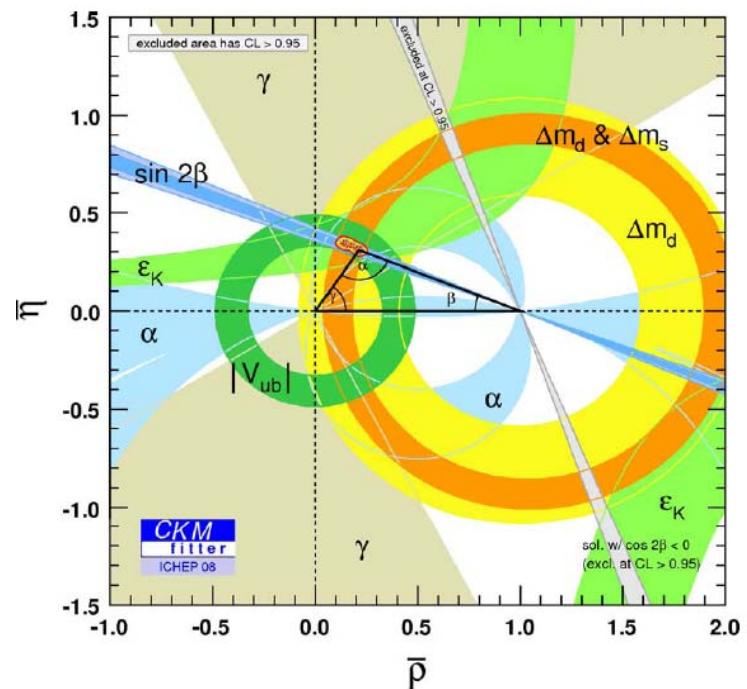
Amplitude of CP-violation in Quark Sector.

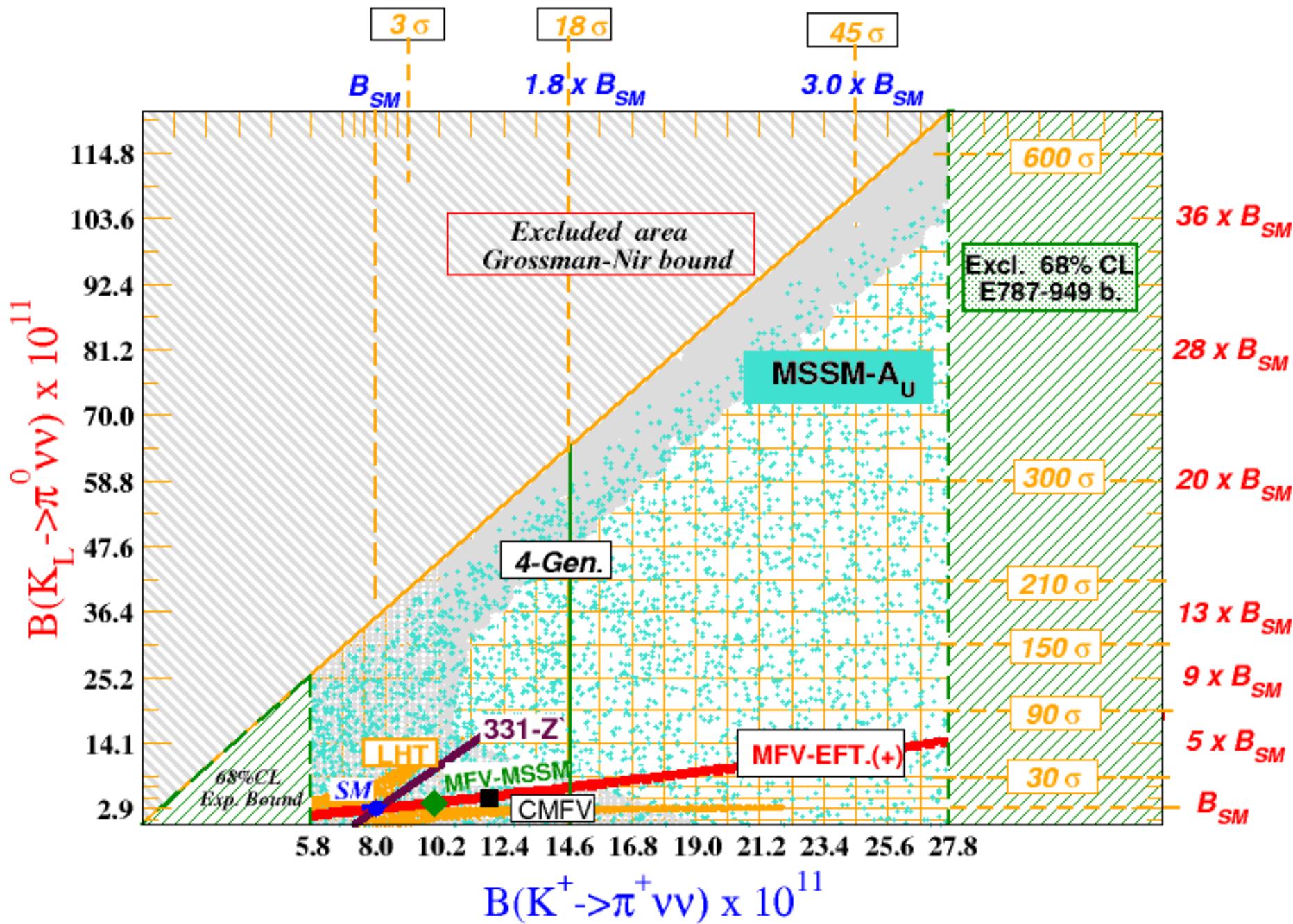
$$\text{Br}(K_L \rightarrow \pi^0 \bar{\nu} \nu)_{SM} = (2.5 \pm 0.4) \times 10^{-11}$$

✓ The clean process :

1~2 % theoretical uncertainty

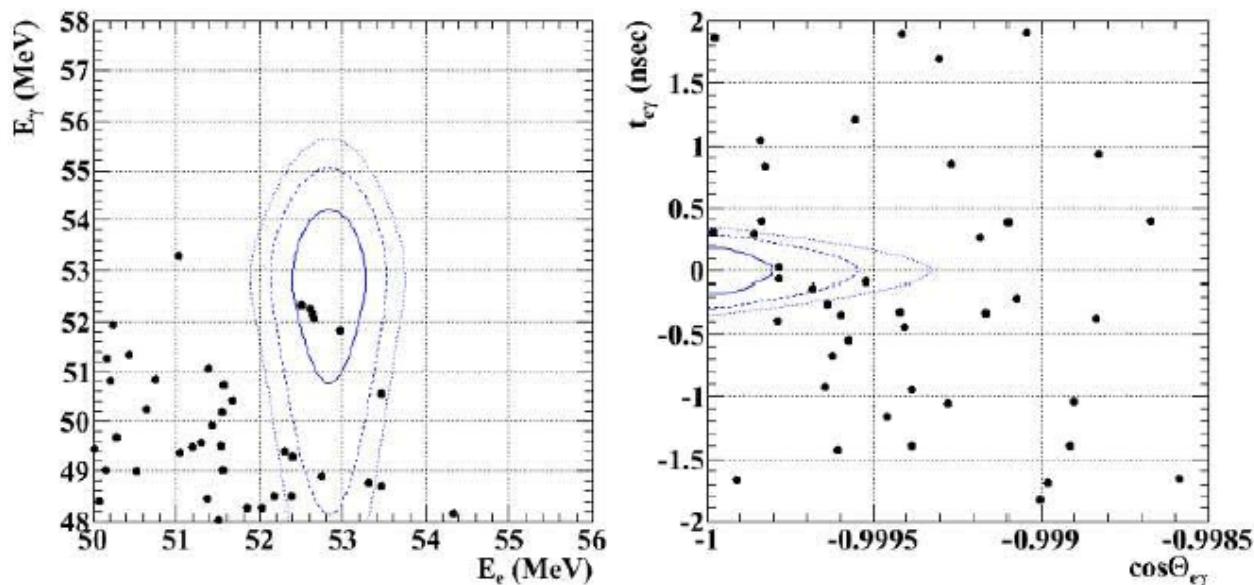
✓ Sensitive to New Physics.





MEG (2)

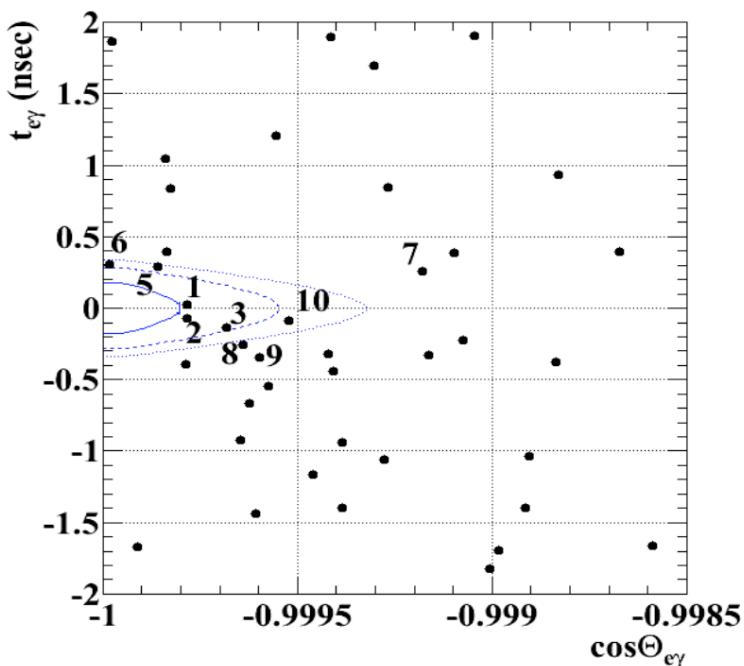
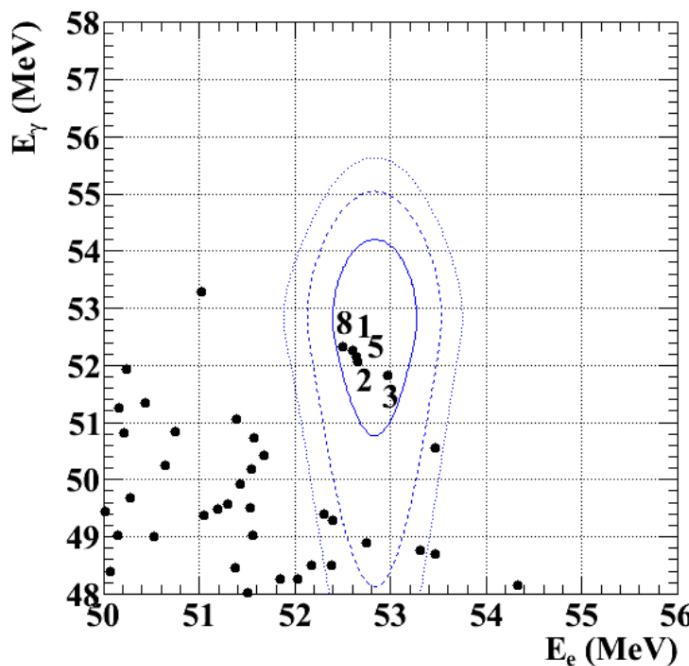
Event distribution after unblinding



Blue lines are 1(39.3 % included inside the region w.r.t. analysis window), 1.64(74.2%) and 2(86.5%) sigma regions.
For each plot, cut on other variables for roughly 90% window is applied.

MEG (3)

Event distribution after unblinding



Blue lines are 1(39.3 % included inside the region w.r.t. analysis window), 1.64(74.2%) and 2(86.5%) sigma regions.

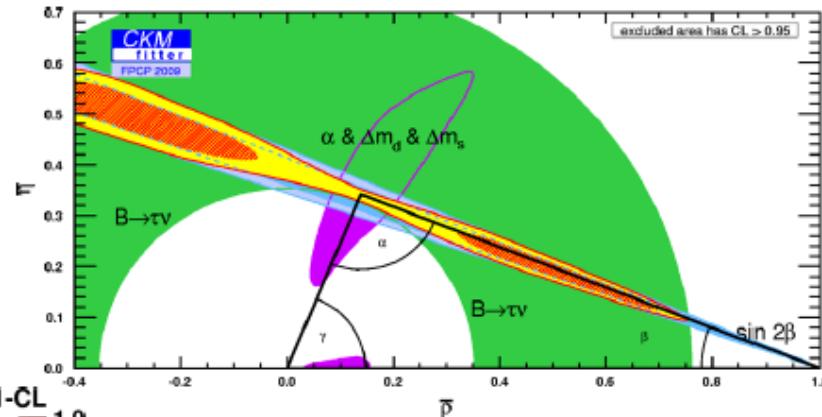
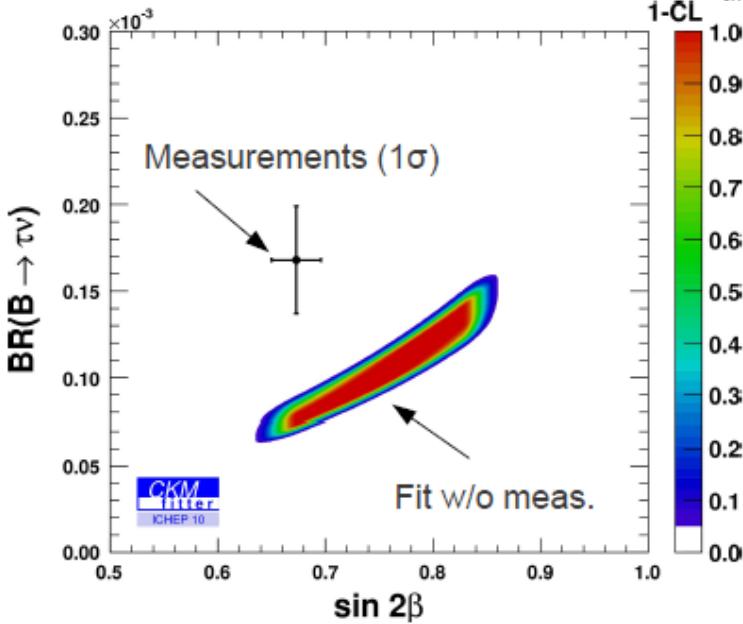
For each plot, cut on other variables for roughly 90% window is applied.

Numbers in figures are ranking by $L_{\text{sig}}/(L_{\text{RMD}}+L_{\text{BG}})$. Same numbered dots in the right and the left figure are an identical event.

CKM (2)

Sin2 β and $B \rightarrow \tau\nu$ discrepancies

- The combination $\sin 2\beta$ and $B \rightarrow \tau\nu$ favors 2 solutions in contradiction with other inputs.
- One cannot accommodate both inputs simultaneously in the global fit.



Non-trivial correlation of indirect constraints on $\sin 2\beta$ and $B \rightarrow \tau\nu$.

The low value of the prediction of $B \rightarrow \tau\nu$ is mainly driven by the measured value of $\sin 2\beta$

Sources of discrepancies:

- 1) Measurements (stat. fluctuations)?
- 2) Lattice estimate of f_B ?
- 3) New Physics in $B \rightarrow \tau\nu$ and/or $\sin 2\beta$?