CKMfitter summer 2008 updates and studies of new physics in $B_{d,s}$ meson mixing

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The CKM Matrix: The Four Parameters

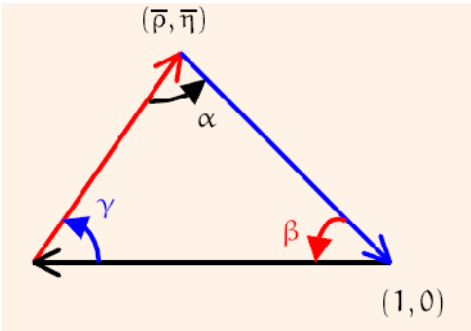
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Consider the Wolfenstein parametrization as in EPJ C41:1-131,2005 :

Unitarity-exact to all order in λ and phase convention independent :

$$\lambda^2 = \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2}, \quad A^2\lambda^4 = \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2} \quad \text{and} \quad \bar{\rho} + i\bar{\eta} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

- λ is measured from $|V_{ud}|$ and $|V_{us}|$ in nuclear decays and semileptonic 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 CKM unitarity triangle.



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

Global CKM fit : the inputs

Standard Model fit

[EPJC21, 225-259]

- Standard χ^2 minimization. Use Rfit method to handle theoretical parameters
- Use all constraints on which we think we have a good theoretical control
- Main inputs :

	observable	Experimental source	Related theory parameters	ICHEP08 update
CP-conserving	Δm_d	Bfact. dominated (last WA)	η_B, B_s, f_{Bs}/f_{Bd} m_t … (CKM2006)	-
	Δm_s	D0/CDF (last WA)	η_B, B_s, f_{Bs} (CKM2006)	-
	$B \to \tau\nu$	Bfact. (last WA)	f_{Bs}, f_{Bs}/f_{Bd} (CKM2006)	BABAR/Belle
	$\lvert V_{ub} \rvert$	Incl.+excl. (own average)	-	*
	$\lvert V_{ud,us,cb} \rvert$		PDG, HFAG, Flavianet	
CP-violating	$\lvert \varepsilon_K \rvert$	KTeV/Kloe	B_K, $\alpha_S(m_Z)$, m_c,m_t … (CKM2006)	PDG07
	$\sin 2\beta$	Bfact : J/PsiK$_s$	-	BABAR
	α	Bfact : $\pi\pi$, $\rho\rho$, $\rho\pi$ BR&A	- SU(2)	BABAR/Belle
	γ	Bfact/CDF : DK	- GLW/ADS/GGSZ	GLW $D^{*0}K^-$

* $|V_{ub}|$ & $|V_{cb}|$: 2008 HFAG update will be in the final CKMfitter summer2008 update

- More details about inputs on :
http://ckmfitter.in2p3.fr/plots_Summer2008/ckmEval_results_summer08.ps

Global CKM fit : the overall picture

Inputs:

$|V_{ub}|$

$B \to \tau\nu$

Δm_d

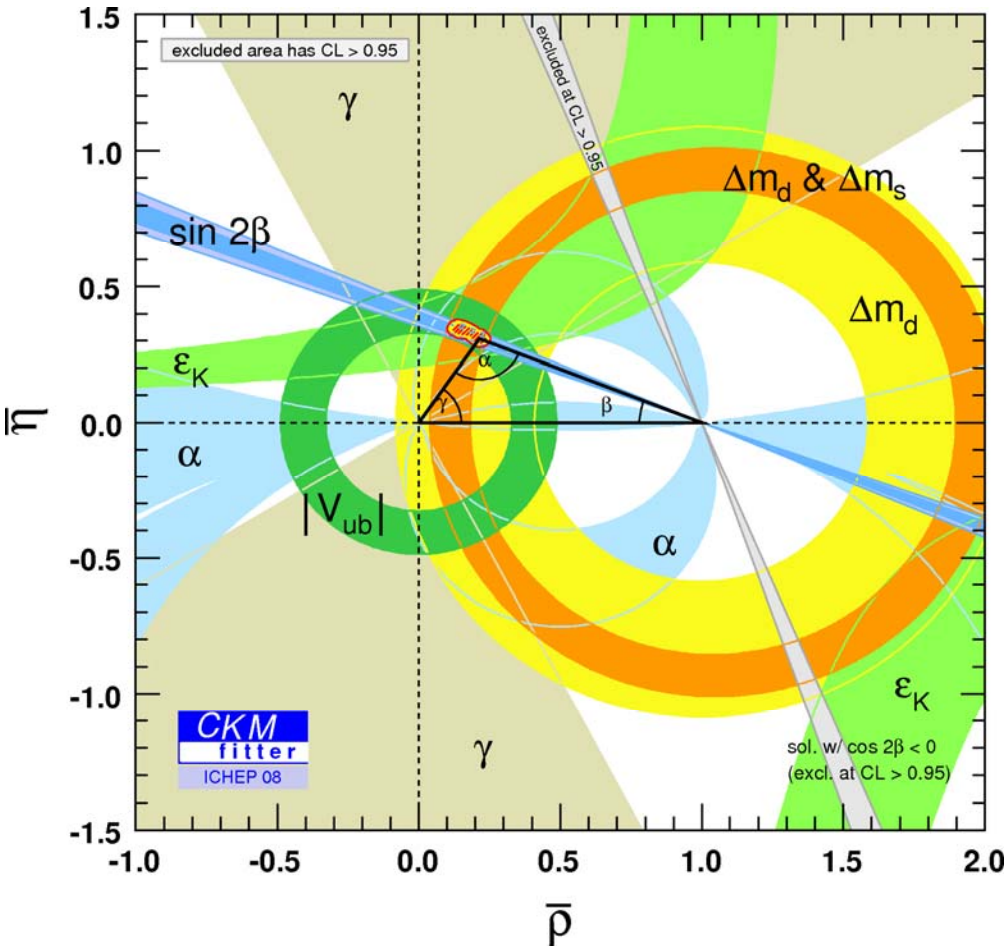
Δm_s

$|\varepsilon_K|$

$\sin 2\beta$

α

γ



Summer 2008 (preliminary)

all constraints together

95% CL interval :

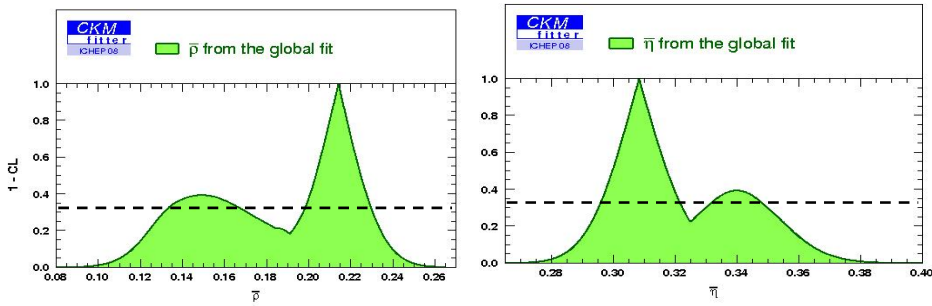
$$(\bar{\rho}, \bar{\eta}) = \left(0.214^{+0.031}_{-0.104}, 0.308^{+0.061}_{-0.025}\right)$$

Nice agreement of all constraints at the 2σ level

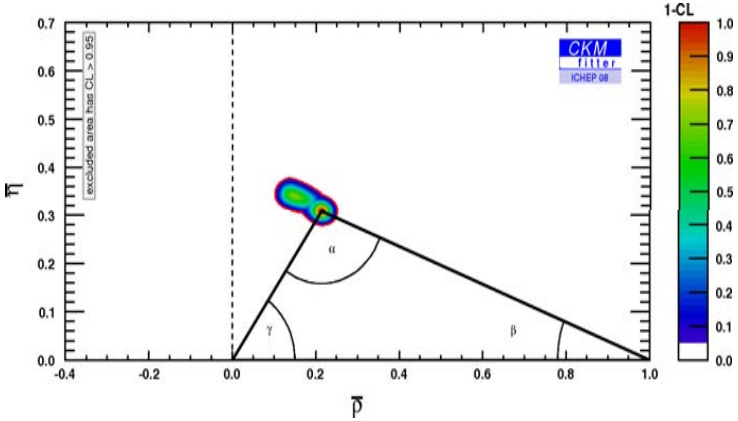
The CKM mechanism IS the dominant source of CP violation in the B system

Global CKM fit : a closer look

A double structure is visible at the 1σ level due to interplay between (lower) sin(2β) , (larger) BR(B→τν) and α (mirror structure)

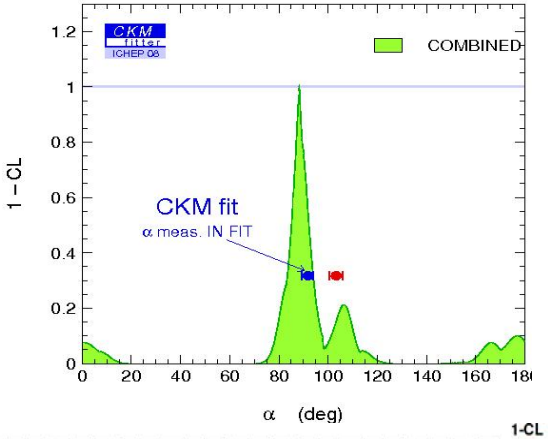


The prefered apex of the global fit matches the highest α value (disfavored w/ α data only)



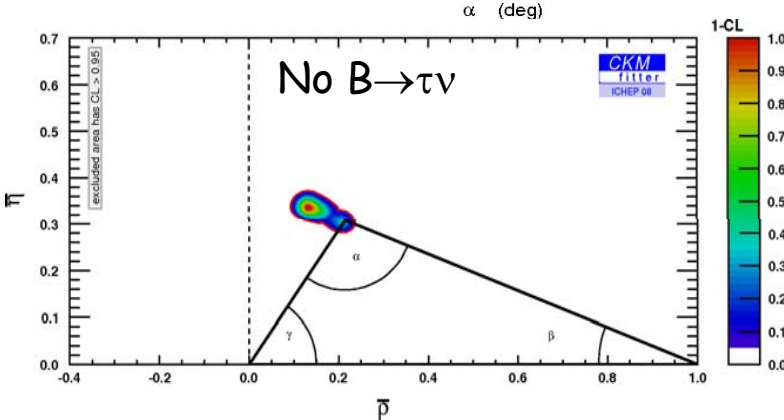
1σ interval

$$(\bar{\rho}, \bar{\eta}) = \left(0.149^{+0.019}_{-0.016}, 0.340^{+0.009}_{-0.009}\right) \cup \left(0.214^{+0.016}_{-0.016}, 0.308^{+0.013}_{-0.013}\right)$$



Removing BR(B→τν)
the other apex solution is prefered

… and the χ^2_{min} of the fit decreases by 2.9 σ



Global CKM fit : testing the CKM paradigm

Inputs:

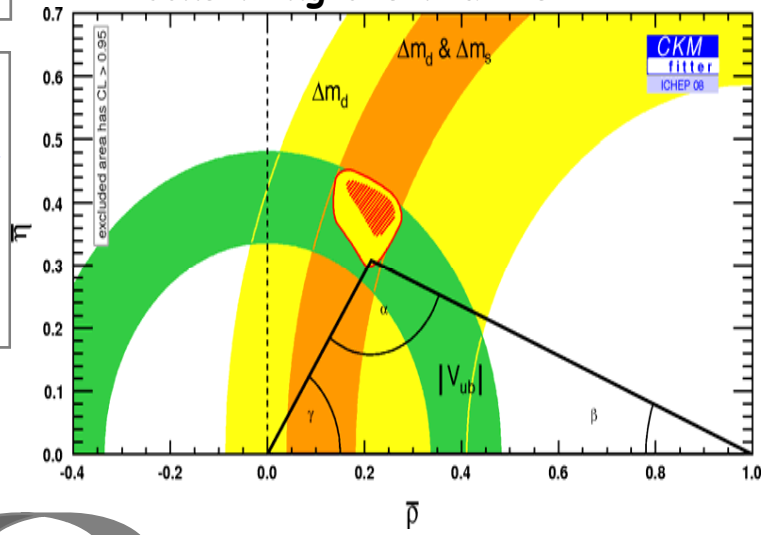
$|V_{ub}|$

$B \to \tau\nu$

Δm_d

Δm_s

CP-conserving observables



Inputs:

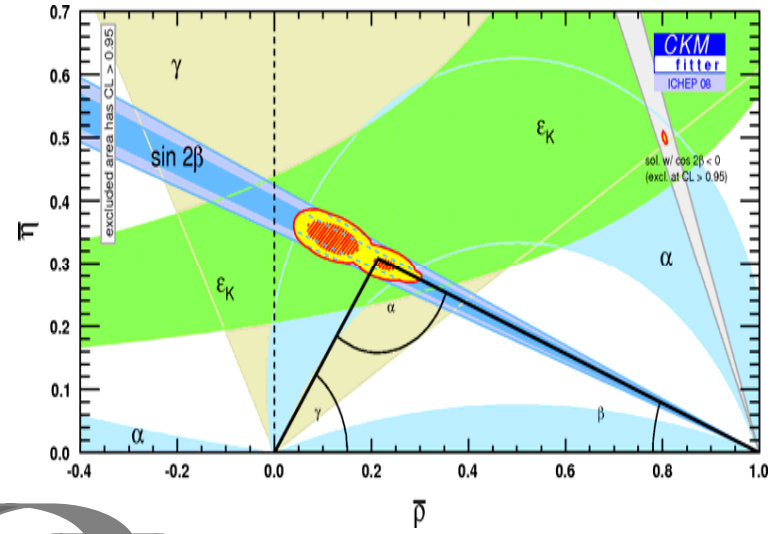
$|\varepsilon_K|$

$\sin 2\beta$

α

γ

CP-violating observables



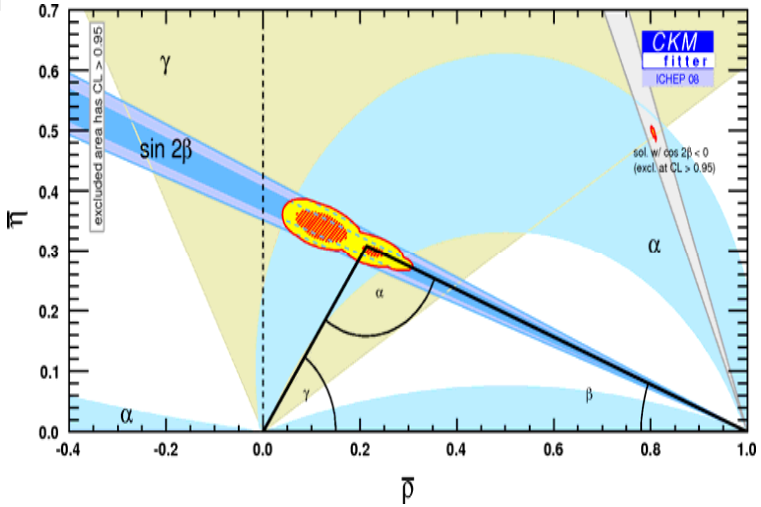
Inputs:

$\sin 2\beta$

α

γ

Angles (small theor. uncertainties)



Inputs:

$|\varepsilon_K|$

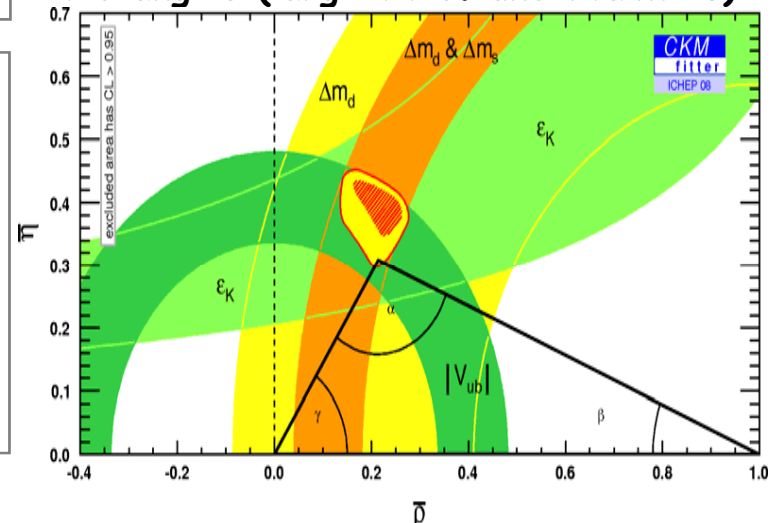
$|V_{ub}|$

$B \to \tau\nu$

Δm_d

Δm_s

No angles (large theo. uncertainties)



Global CKM fit : testing the CKM paradigm

Inputs:

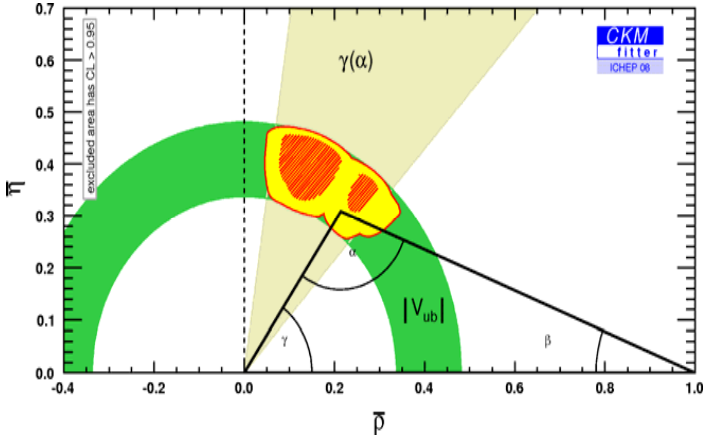
$|V_{ub}|$

$B \to \tau\nu$

γ

$\pi-\alpha-\beta$

Observables w/ "Tree" processes



Inputs:

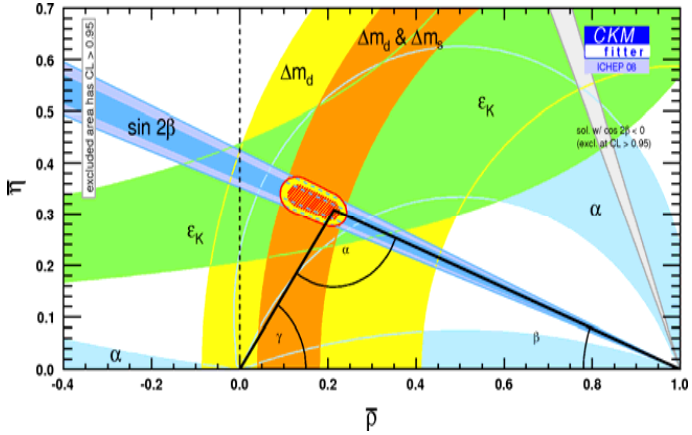
$|\varepsilon_K|$

$\sin 2\beta$

Δm_d

Δm_s

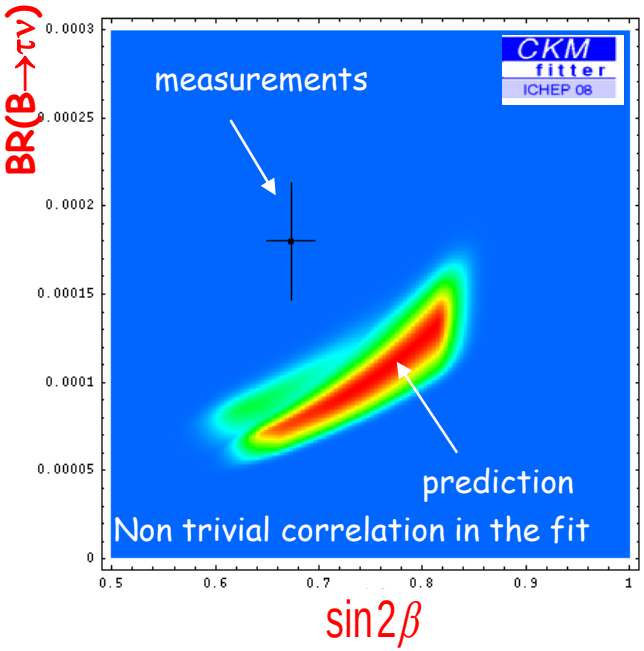
Observables involving Loops



Assuming there is no NP in $\Delta I=3/2$ $b\to d$ EW penguin amplitude.
Use α with β (charmonium) to produce a new γ 'Tree'.

Tension between sin(2β) and BR(B→τν)

- removing sin(2β) from the fit decreases χ^2_{min} by 2.6σ
- removing BR(B→τν) from the fit decreases χ^2_{min} by 2.9σ

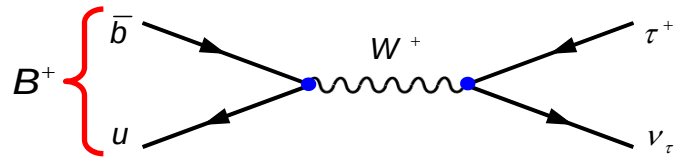


Either due to :

- Fluctuations (of BR(B→τν) and sin(2β))
- Problem with lattice predictions
- Conspiration of all other input against BR(B→τν) & sin(2β)
- New Physics

$B^+ \to \tau^+ \nu_\tau$: experimental inputs

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



- Helicity-suppressed annihilation decay sensitive to $f_B \times |V_{ub}|$

Experimental measurements

	BR(B→τν)x10⁴
Belle (hadronic)	1.79 0.71 [2006]
Belle (semi-leptonic)	1.65 0.52 [ICHEP08]
Belle	**1.70 0.42**
BABAR (hadronic)	1.80 1.00 [2007]
BABAR (semi-leptonic)	1.80 0.81 [CKM08]
BABAR	**1.80 0.63**
World Average	**1.73 ± 0.35**

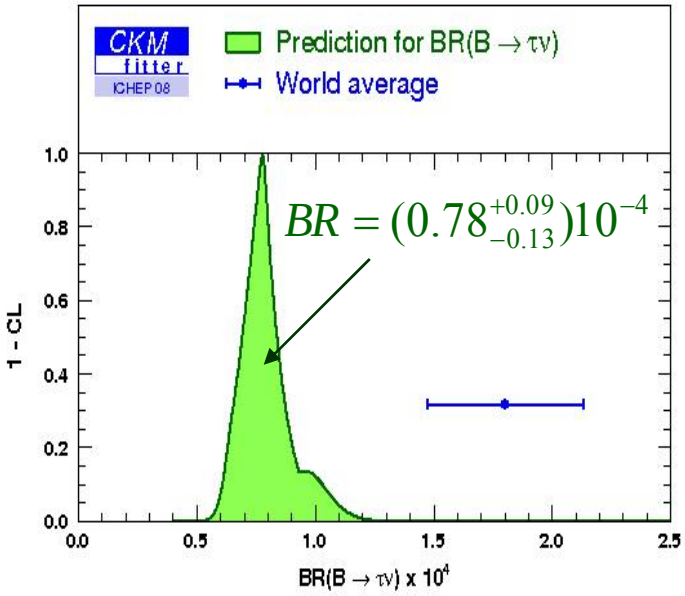
The various measurements are consistent

Inputs:

$|V_{ub}|$
Δm_d
Δm_s
$|\varepsilon_K|$
$\sin 2\beta$
α
γ

[N. Tantalo CKM2006]

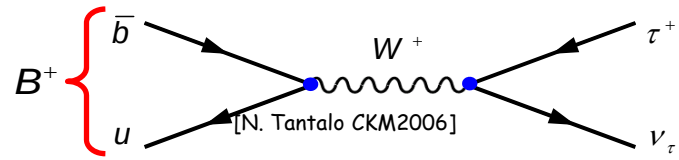
$f_{Bd} = (f_{Bd}/f_{Bs}) \times f_{Bs} = (223\ \ 15\ \ 25)$ MeV



Similar deviation with $D_s \to \tau\nu$

$B^+ \to \tau^+ \nu_\tau$: theoretical inputs

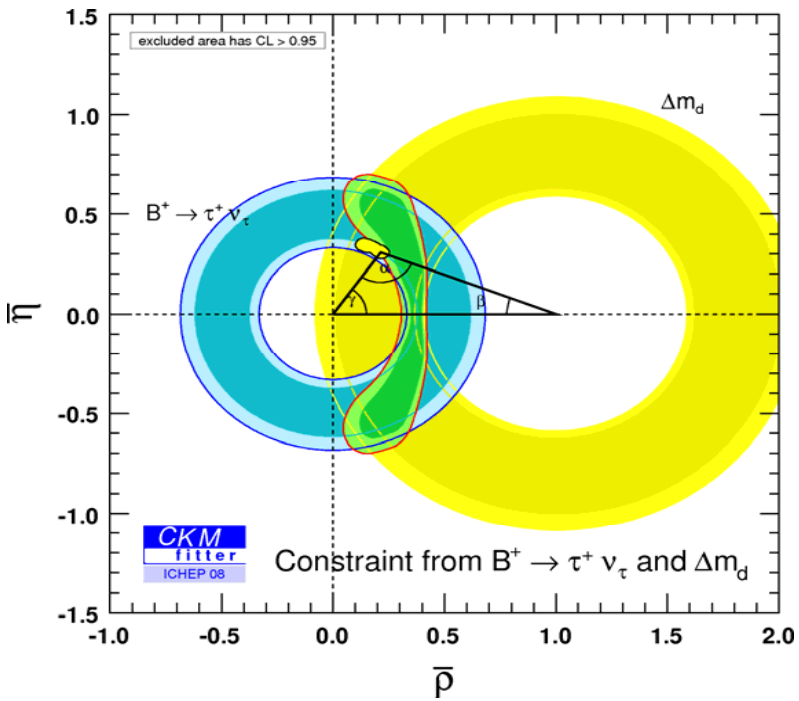
$$\mathrm{BR}(B^+ \to \tau^+\nu) = \frac{G_F^2 m_B \tau_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 \, |V_{ub}|^2$$



- Helicity-suppressed annihilation decay sensitive to $f_B \times |V_{ub}|$
- Powerful <u>together</u> with Δm_d : removes f_B dependence

$$\frac{BR(B^+ \to \tau^+\upsilon)}{\Delta m_d} = \frac{3\pi}{4} \frac{m_\tau^2 \tau_{B^+}}{m_W^2 S(x_t)} (1 - \frac{m_\tau^2}{m_B^2})^2 \frac{\sin^2(\beta)}{\sin^2(\gamma)} \frac{1}{|V_{ud}|^2 B_{B_d}}$$

$f_{Bd}=(f_{Bd}/f_{Bs})\times f_{Bs}$ =(223 15 25) MeV
$B_{Bd}=(B_{Bd}/B_{Bs})\times B_{Bs}$=1.29 0.06 0.09



Inputs:

Δm_d

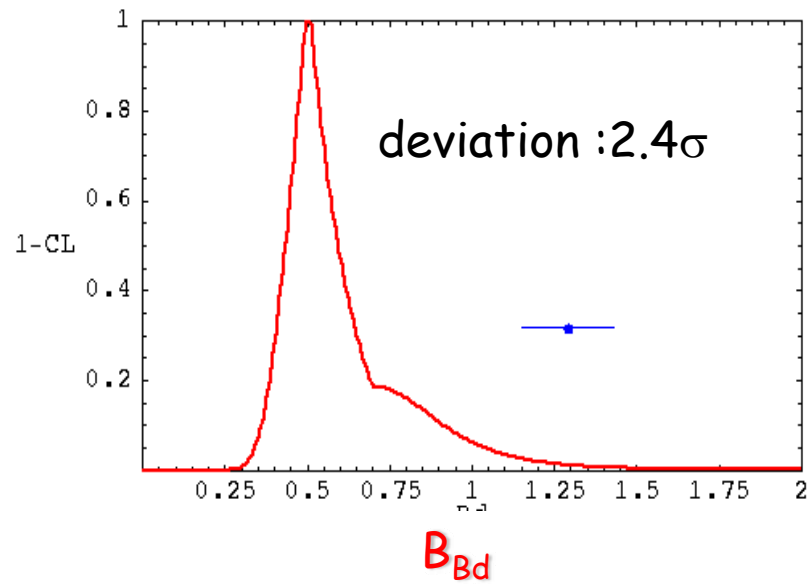
$B \to \tau\nu$

$\gamma(=\pi-\beta-\alpha)$

$\sin 2\beta$

$|V_{ud}|$

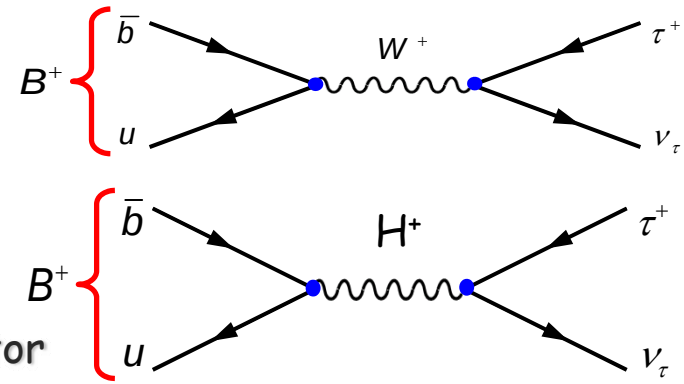
Theory free prediction for B_{Bd}



The tension is not driven by V_{ub} (SL) nor f_{Bd} (nor ε_K)

$B^+ \to \tau^+ \nu_\tau$ & charged higgs

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

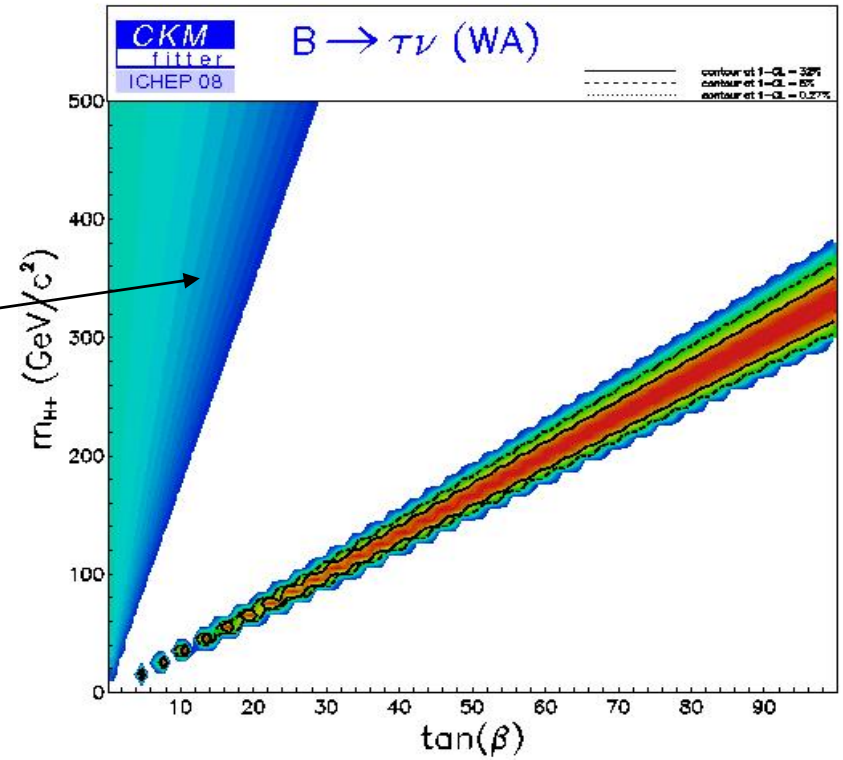


- Helicity-suppressed annihilation decay sensitive to $f_B \times |V_{ub}|$
- Powerful <u>together</u> with Δm_d : removes f_B dependence
- Sensitive to charged Higgs replacing the W propagator

e.g : 2HDM type II

$$BR(B^+ \to \tau^+ \nu_\tau) = BR^{SM} \times (1 - \frac{m_B^2}{m_H^2} \tan^2 \beta)^2$$

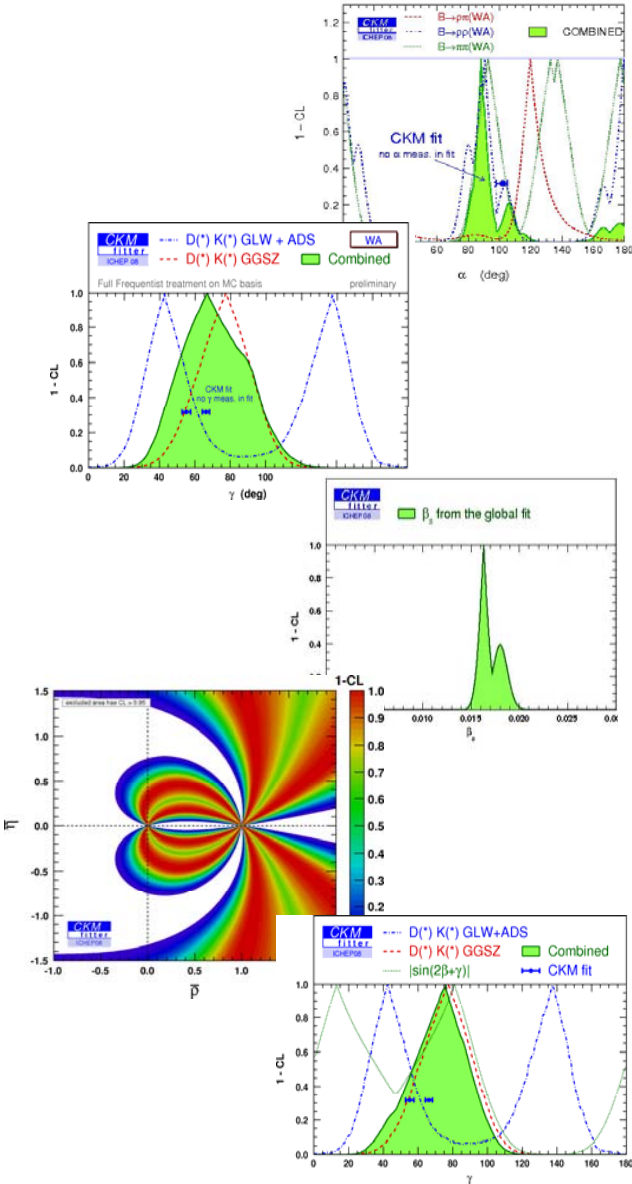
Disfavoured region
$BR/BR^{SM} < 1$



Global CKM fit : the numerical results

- Selection of CKM fit numerical results:

Observable	Central ± 1 σ
A	0.796 [+0.024 -0.017]
λ	0.2253 [+0.0008 -0.0008]
J [10^{-5}]	2.55 [+0.44 -0.16]
α (deg) (meas. not in the fit)	102.1 [+3.0 -4.0]
β (deg) (meas. not in the fit)	27.45 [+0.74 -1.18]
γ (deg) (meas. not in the fit)	55.1 [+2.5 -2.3] U 66.3[+2.0,2.1]
β_s(deg) (meas. not in the fit)	0.93 [+0.041 -0.038] U 1.03 [+0.027 -0.028]
Δm_s [ps^{-1}] (meas. not in the fit)	22.4[+4.9 -3.5]
$\lvert V_{ub}\rvert$ (meas. not in the fit)	0.0035 [+0.00019 -0.00016]
B(B->τν) [10^{-4}] (meas. not in the fit)	0.78 [+0.09 -0.13]
B(B->$\mu^+\mu^-$) [10^{-11}]	9.44 [+0.50 -0.65]
B(B_s->$\mu^+\mu^-$) [10^{-9}]	3.13 [+0.15 -0.21]



- Results and plots are available on :

http://ckmfitter.in2p3.fr/plots_Summer2008/

New Physics in $B_{d,s}$ mesons mixing

- Assume that tree-level processes are not affected by NP (SM4FC)
- Assume that NP only affects the short distance physics in $\Delta F=2$ transisitons

Model-independent parametrisation

$$\left\langle B_q^0 \left| M_{12}^{SM+NP} \right| \overline{B}_q^0 \right\rangle \equiv \Delta_q^{NP} . \left\langle B_q^0 \left| M_{12}^{SM} \right| \overline{B}_q^0 \right\rangle$$

$$\Delta_q^{NP} = \mathrm{Re}(\Delta_q) + i\ \mathrm{Im}(\Delta_q) = |\Delta_q| e^{i\phi^{\Delta_q}} = r_q^2 e^{2i\theta_q} = 1 + h_q e^{2i\sigma_q}$$

→ Observables affected by NP in mixing :

$\Delta m_q \rightarrow \lvert\Delta_q\rvert \Delta m_q(SM)$	Oscillations
$2\beta \rightarrow 2\beta^{SM} + \phi^{\Delta_d}$ $2\alpha \rightarrow 2\pi - 2\gamma - 2\beta^{SM} - \phi^{\Delta_d}$ $-2\beta_s \rightarrow -2\beta_s^{SM} + \phi^{\Delta_s}$ $\phi_s = Arg\left[-\frac{M_{12}^s}{\Gamma_{12}^s}\right] \rightarrow \phi_s^{SM} + \phi^{\Delta_s}$	Phases
$A_{SL}^q \rightarrow \left\lvert\frac{\Gamma_{12}^q}{M_{12}^{q,SM}}\right\rvert . \frac{\sin(\phi_q^{SM} + \phi_q^{\Delta})}{\lvert\Delta_q\rvert}$	SL asymmetries
$\Delta\Gamma_q \rightarrow 2\lvert\Gamma_{12}^q\rvert . \cos(\phi_q^{SM} + \phi_q^{\Delta})$	Lifetime diff.

→ SM parameters are fixed by :

$|V_{ub}|$, $|V_{cb}|$, $|V_{ud}|$, $|V_{us}|$, γ, $\gamma(\alpha)=\pi-\beta-\alpha$

Inputs:

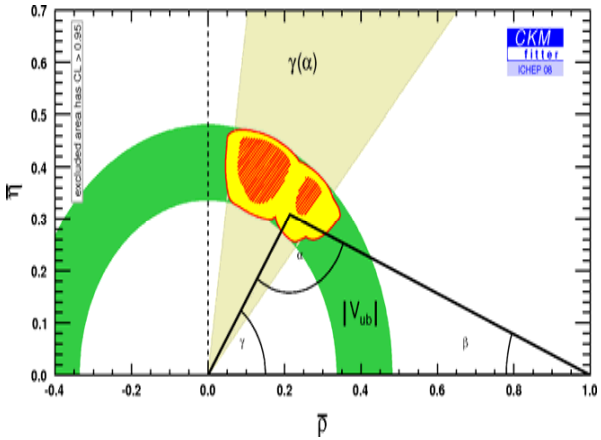
$|V_{ub}|$

$B \rightarrow \tau\nu$

γ

$\pi-\alpha-\beta$

Observables w/ "Tree" processes



New Physics in mixing : the B_d case

Using 'ICHEP08 updated' inputs (except new D0 A_{SL}^{s} value presented yesterday morning [T. Moulik])

Inputs:

Δm_d

Δm_s

$\sin(2\beta)$

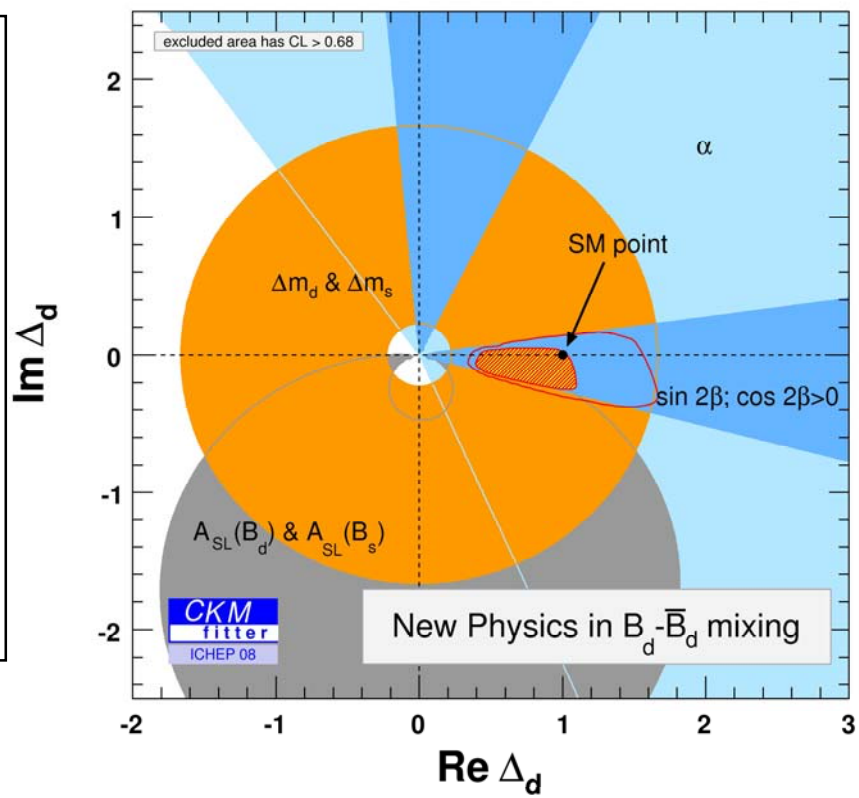
α

$\Delta\Gamma_d$

$A_{SL}^{B_d}$

$A_{SL}^{B_s}$

Warning : only 68% CL regions are shown



BR(B→τν) not included

Dominant constraint from β and Δm_d. Both agrees with SM.

Agreement with SM :

	hypothesis	deviation
(1D) :	$\phi^{\Delta_d}=0$	0.9 σ
(2D) :	$\Delta_d = 1$	0.9σ

The cartesian parametrization $\Delta_d^{NP} = \mathrm{Re}(\Delta_d) + i\,\mathrm{Im}(\Delta_d)$ allows for a simple geometrical interpretation of each individual constraints.

New Physics in mixing : the B_d case

Including BR($B \to \tau\nu$)

Inputs:

Δm_d

Δm_s

$\sin(2\beta)$

α

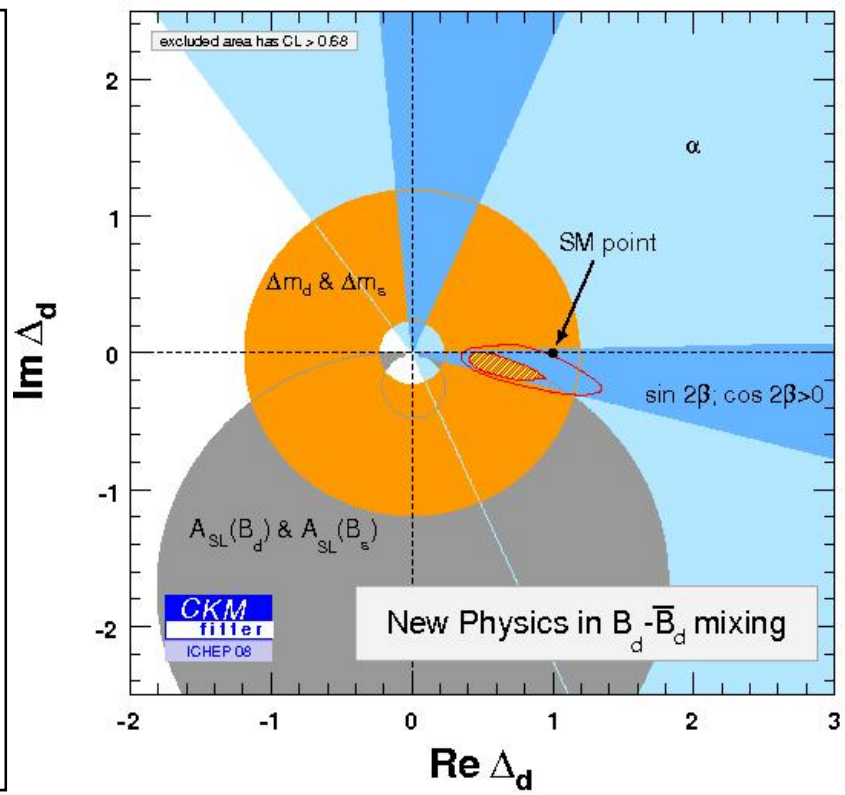
$\Delta\Gamma_d$

$A_{SL}^{B_d}$

$A_{SL}^{B_s}$

$B \to \tau\nu$

Warning : only 68% CL regions are shown



Agreement with SM :

	hypothesis	deviation
(1D) :	$\phi^{\Delta_d}=0$	1.5 σ
(2D) :	$\Delta_d = 1$	2.1 σ

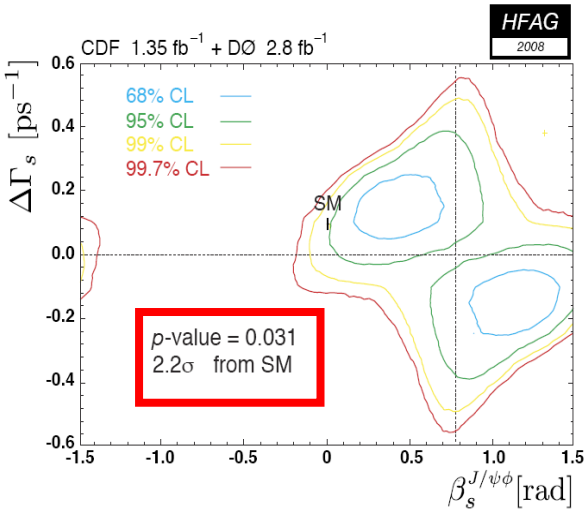
New Physics in mixing : the B_s case

- **Direct constraint on NP phase in B_s mixing**

The CDF/D0 measurement of $(2\beta_s, \Delta\Gamma_s)$ from the time-dependent angular analysis of the $B_s \to J/\psi\phi$ provides a direct constraint on $\phi^{\Delta s}$

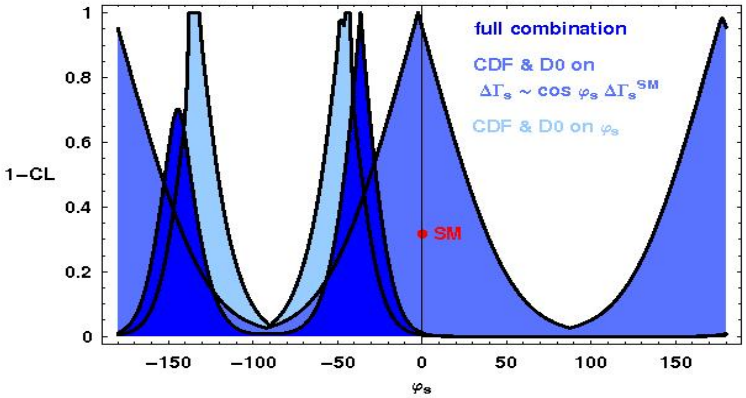
Using the HFAG combination of CDF and D0 likelihood :

Prefered value : $(\beta_s, \Delta\Gamma_s) / (\pi - \beta_s, -\Delta\Gamma_s) = \left(-45^{+14}_{-21}\,\mathrm{deg}, 0.150^{+0.67}_{-0.55}\,ps^{-1}\right)$



- **Other constraints**

  - Δm_s : consistent with SM expectation
  - $A_{SL}(B_s)$: large error wrt SM prediction
  - τ^{FS} : weak constraint on $\Delta\Gamma$
  - NP relation $\Delta\Gamma_s \approx \Delta\Gamma_s^{SM} \cos(\phi^{\Delta_s})$ [Lenz,Nierste]
    - $\Delta\Gamma_s^{SM} = (0.090^{+0.019}_{-0.022})\,ps$
    - tends to push the NP phase $\phi^{\Delta s}$ towards SM.



Clean analysis : all theoretical uncertainties are in the $\Delta\Gamma^{SM}$ prediction but…

… it cannot tell much more on $\phi^{\Delta s}$ than the direct Tevatron measurement

New Physics in mixing : the B_s case

- **Constraint in the $(\phi_s, \Delta\Gamma_s)$ plane**

Agreement with SM :

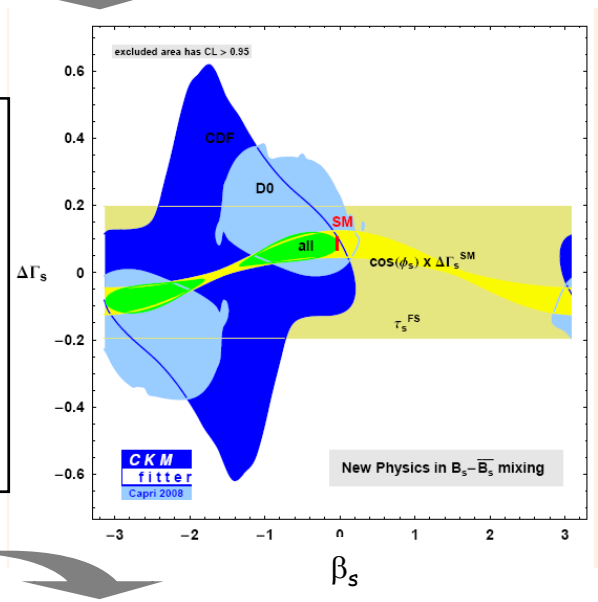
hypothesis	deviation
(1D) : $\beta_s = \beta_s^{SM}$	2.4 σ
(2D) : $(\beta_s, \Delta\Gamma_s) = (\beta_s^{SM}, \Delta\Gamma_s^{SM})$	1.9 σ

Inputs:

$$\phi_s$$

$$\Delta\Gamma_s = \Delta\Gamma_s^{SM} \cos(\phi_s)$$

$$\tau_s^{FS}$$



Warning : only 68% CL regions are shown

- **Full SM+NP fit**

Dominant constraint from Δm and ϕ_s

Agreement with SM :

hypothesis	deviation
(1D) : $\phi^{\Delta_s} = 0$	2.5 σ
(2D) : $\Delta_s = 1$	2.1 σ

Inputs:

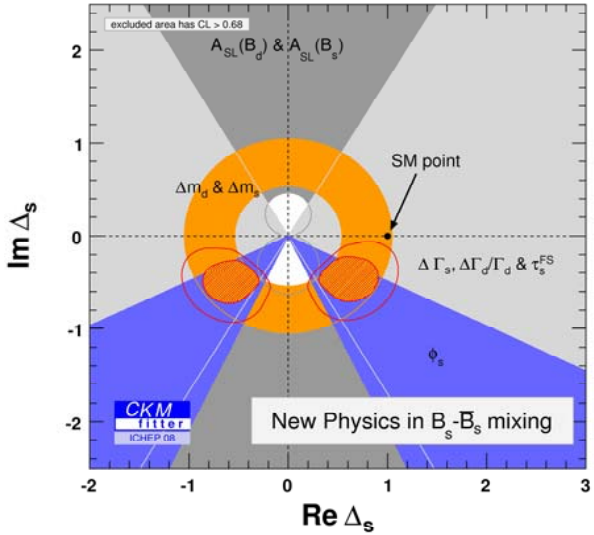
$$\phi_s$$

$$\Delta m_s \ \& \ \Delta m_d$$

$$A_{SL}^{B_d} \ \& \ A_{SL}^{B_s}$$

$$\Delta\Gamma_s \ \& \ \tau_s^{FS}$$

$$B \to \tau\nu$$



Summary

- Standard Model CKM fit
  - (preliminary) summer 2008 results
  - tension between sin(2β) and BR(B→τν)
    - removing BR(B→τν) decreases χ^2_{min} by 2.9σ

95% CL interval :

$$(\bar{\rho},\bar{\eta}) = \left(0.214^{+0.031}_{-0.104}, 0.308^{+0.061}_{-0.025}\right)$$

- SM + New Physics fit
  - (preliminary) update of NP fit in $B_{d,s}$ mesons mixing
    - 2.1σ deviations from SM in B_d mixing (0.9 without B→τν)
      - something happens with BR(B→τν)
        - observable fluctuation ?
        - problem with lattice predictions ?
        - conspiration of all other inputs ?
        - new physics ?
    - 2.1σ deviations from SM in B_s mixing
      - the bulk is the direct Tevatron ϕ_s measurement

Agreement with SM :

Hypothesis	Deviation
$\Delta_d = 1$	2.1 σ
$\Delta_s = 1$	2.1 σ
$\Delta_d = \Delta_s = 1$	2.9 σ

- Preliminary summer 2008 SM & NP fit results available on :

http://ckmfitter.in2p3.fr/plots_Summer2008/

Many thanks to Christian Kaufhold

SPARES

A bit more about the tension …

χ^2_{min} reduction by 2.6σ

Inputs:

$|V_{ub}|$

$B \to \tau\nu$

Δm_d

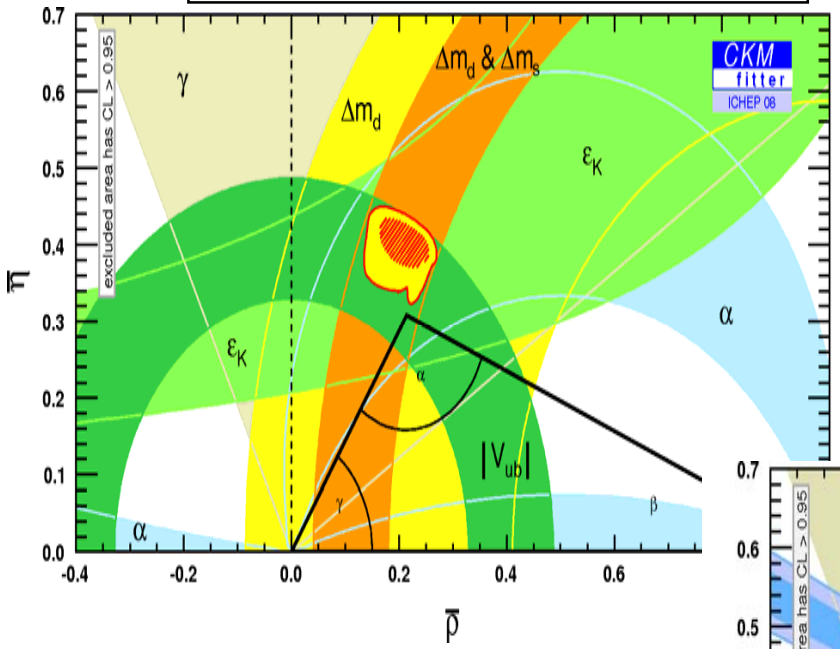
Δm_s

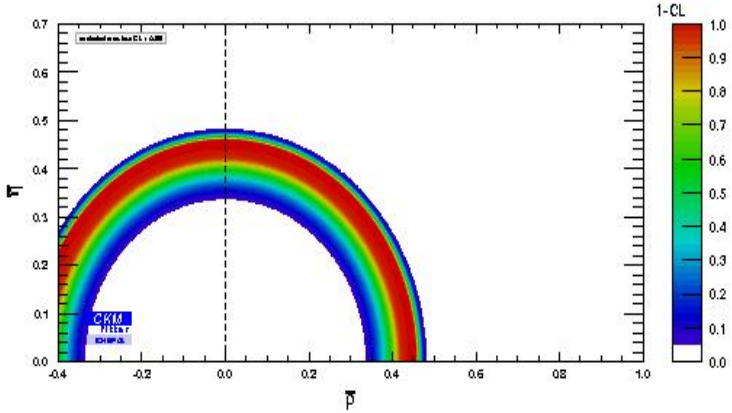
$|\varepsilon_K|$

~~$\sin 2\beta$~~

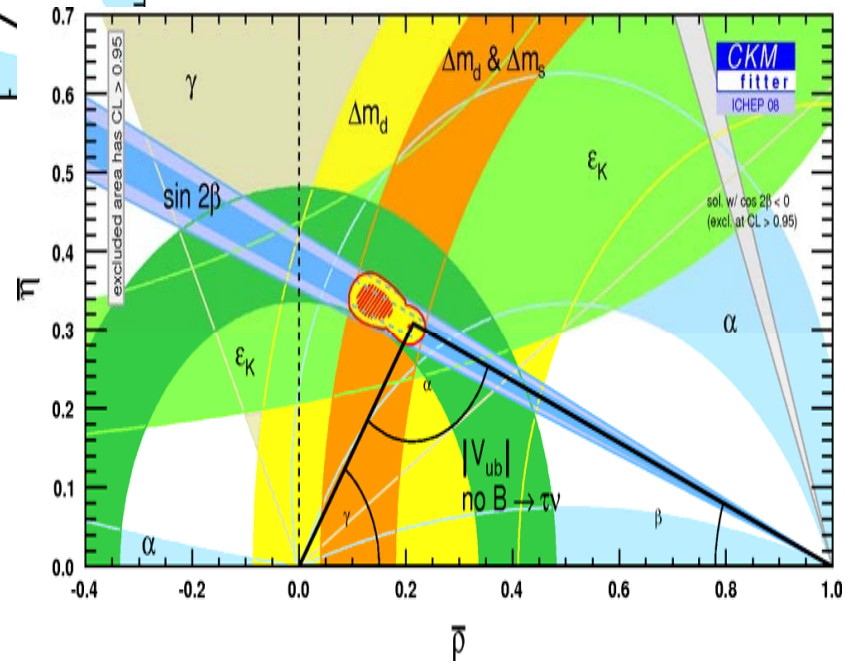
α

γ





χ^2_{min} reduction by 2.9σ



Inputs:

$|V_{ub}|$

~~$B \to \tau\nu$~~

Δm_d

Δm_s

$|\varepsilon_K|$

$\sin 2\beta$

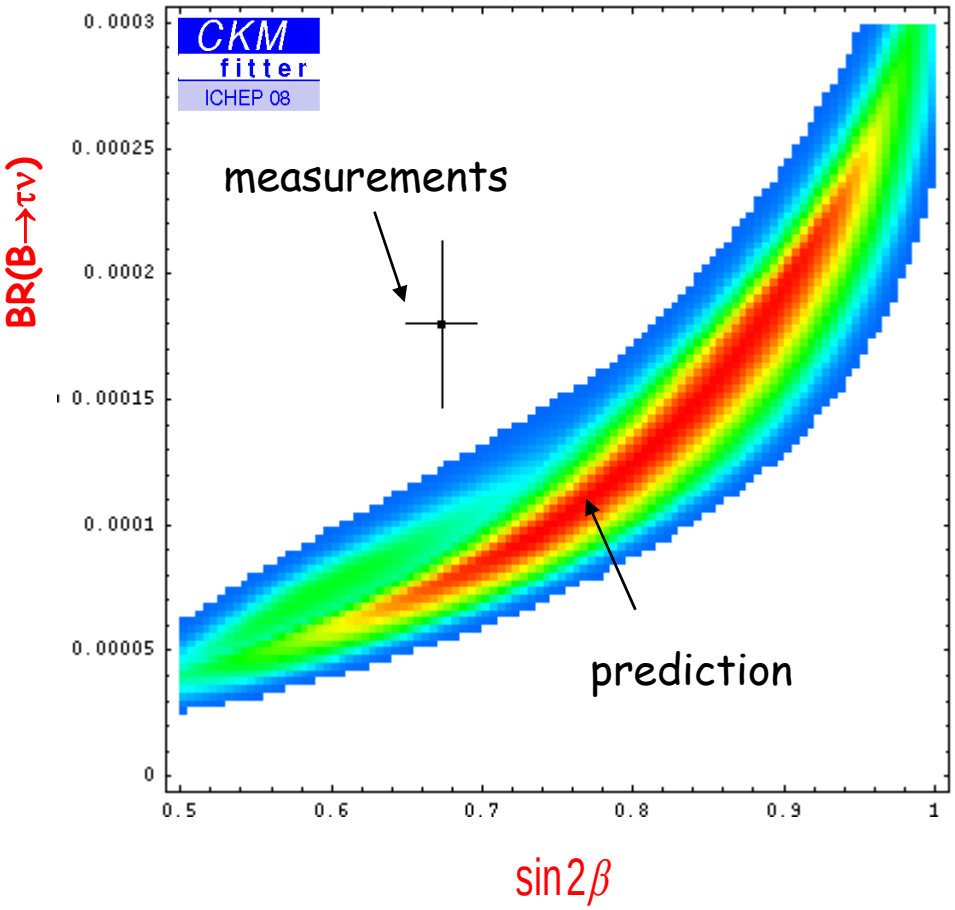
α

γ

A bit more about the tension …

Tension between sin(2β) and BR(B→τν)

'Semi-leptonic' |Vub| not included

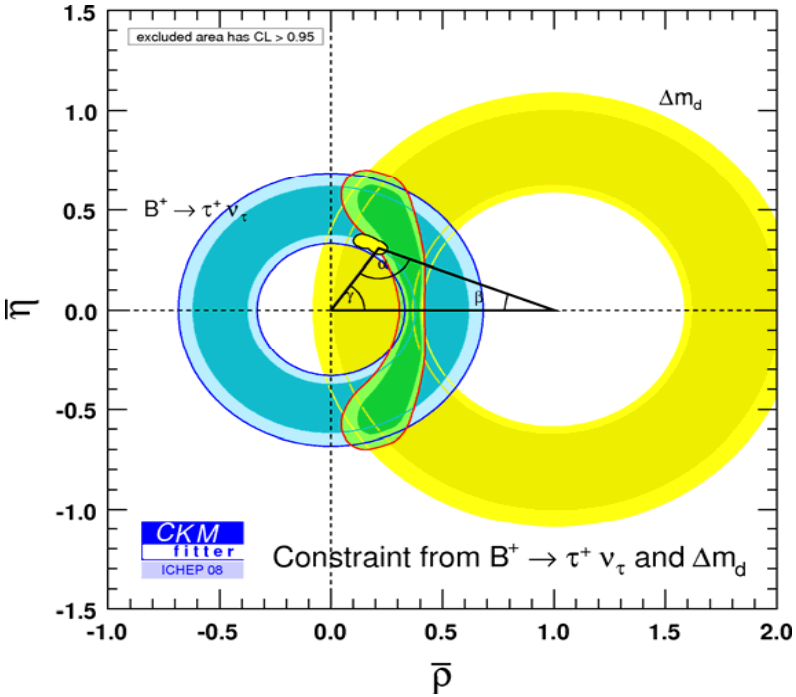


A bit more about the tension & LQCD

Tantalo [hep-ph/0703241]
Becirevic [hep-ph/0310072]

$$f_{B_s} = (268 \pm 17 \pm 20) MeV$$
$$f_{B_s} / f_{B_d} = (1.20 \pm 0.02 \pm 0.05)$$
$$B_{B_s} = (1.29 \pm 0.05 \pm 0.08)$$
$$B_{B_s} / B_{B_d} = (1.00 \pm 0.02)$$

Using RFit errors

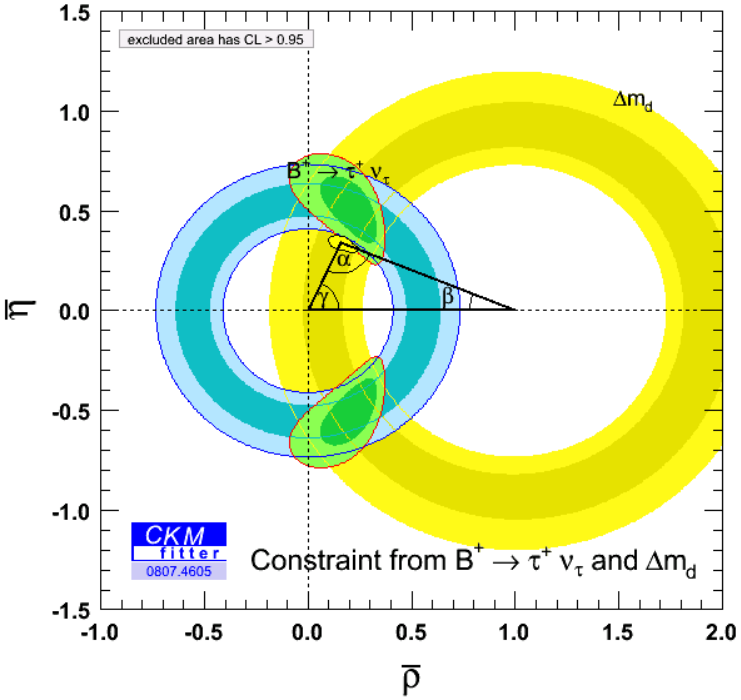


[arXiv:0807.4605]

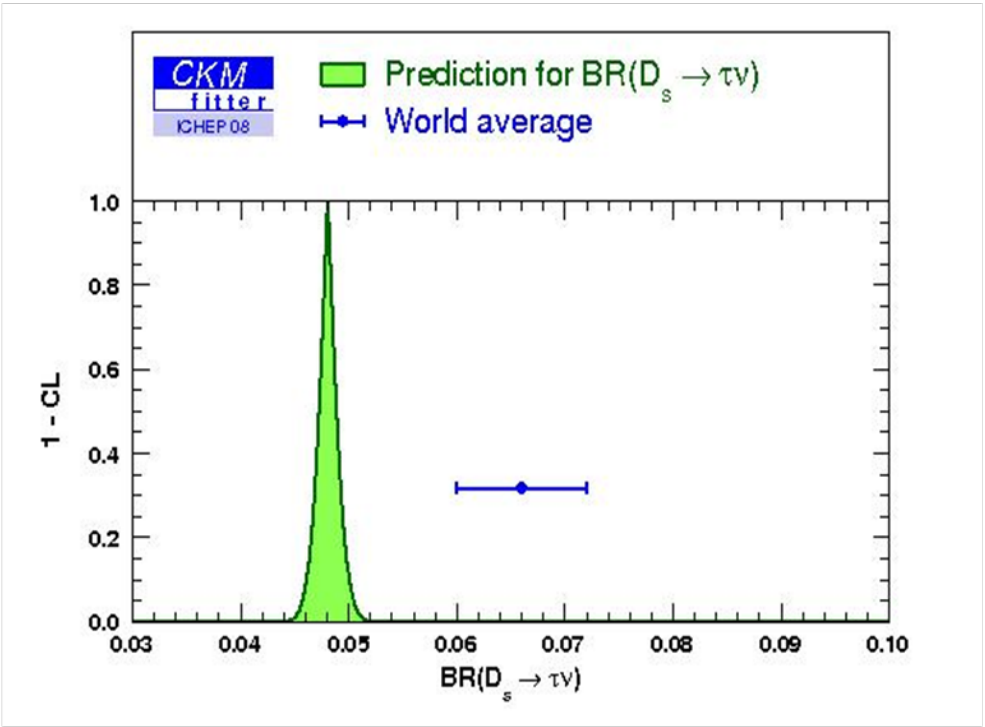
V. Lubicz and C. Tarantino (2008)

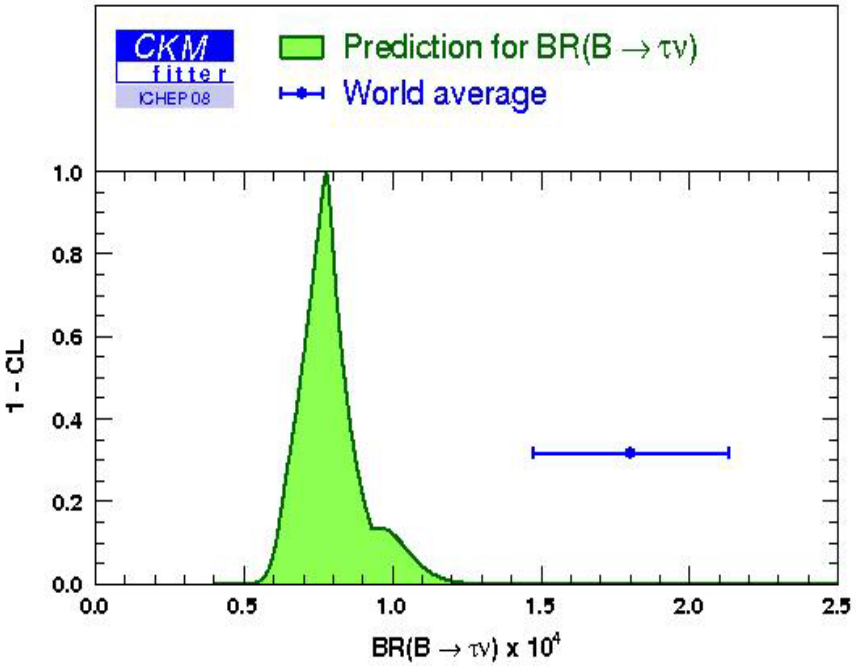
$$f_{B_s} = (245 \pm 25) MeV$$
$$f_{B_s} / f_{B_d} = (1.21 \pm 0.04)$$
$$B_{B_s} = (1.22 \pm 0.12)$$
$$B_{B_s} / B_{B_d} = (1.00 \pm 0.03)$$

Using Gaussian errors



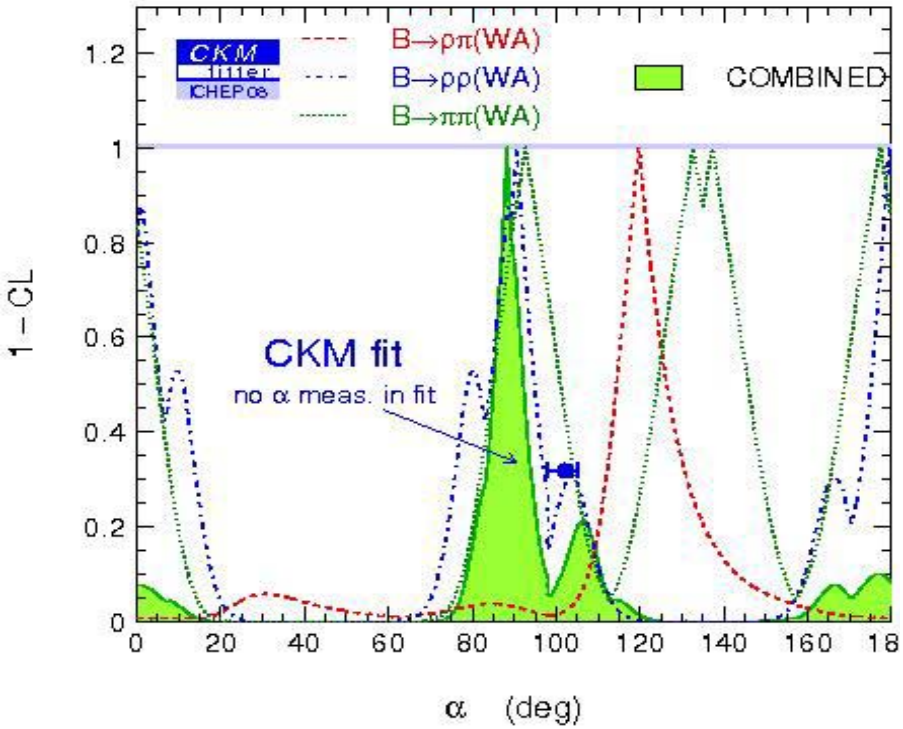
Leptonic decays

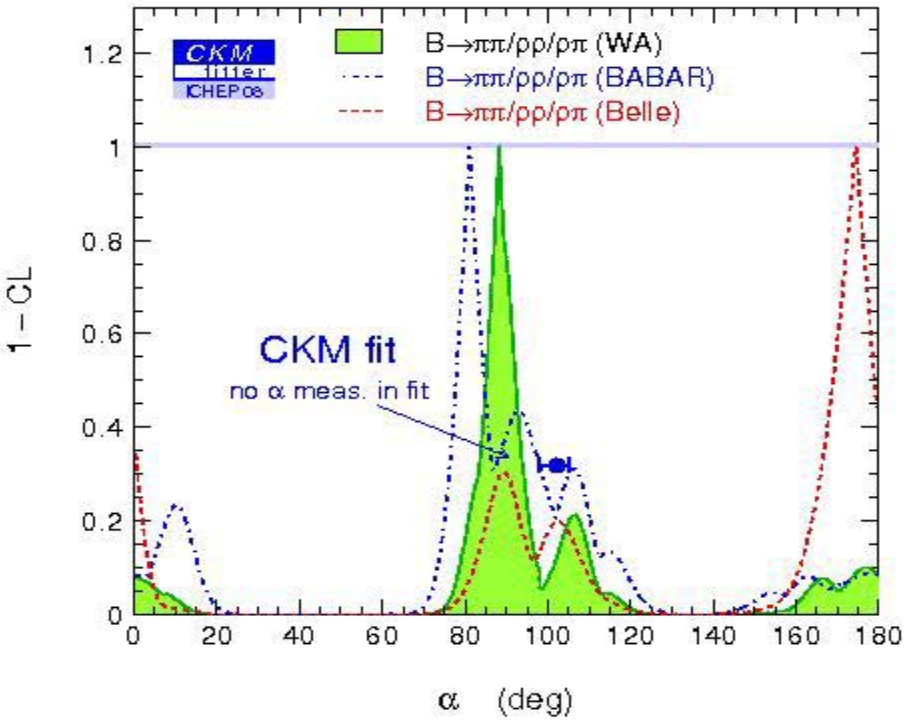


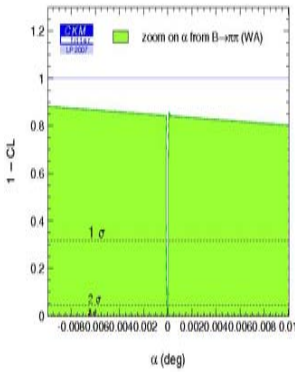


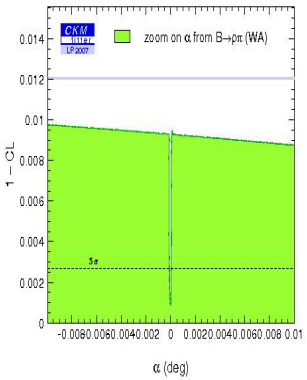
Is there a common origin ?

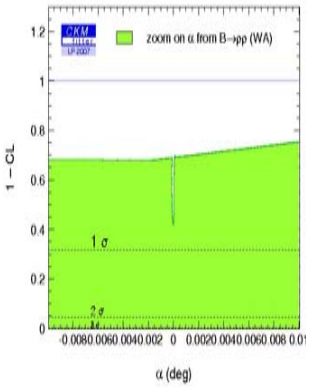
A bit more about α ...











$$\alpha = (88.4^{+5.6}_{-4.9})^\circ \quad \text{[direct]}$$

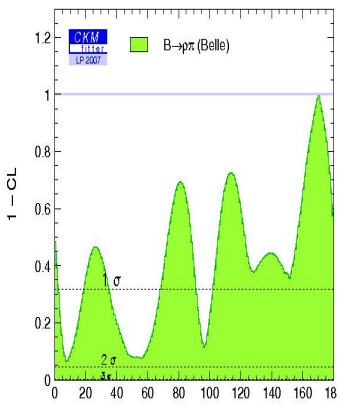
$$\alpha = (102.1^{+3.0}_{-4.0})^\circ \quad \text{[indirect]}$$

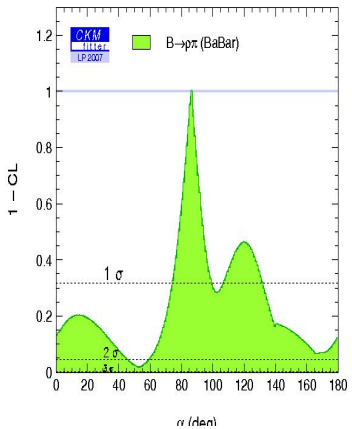
$$\alpha = (91.9^{+2.9}_{-2.6})^\circ \cup (103.4^{+2.6}_{-2.7})^\circ \quad \text{[all]}$$

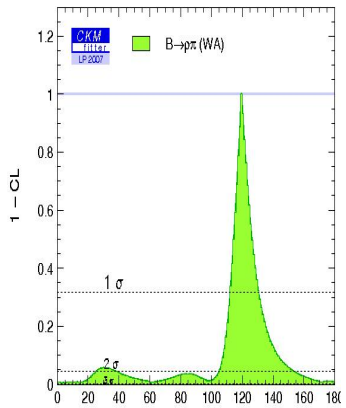
A bit more about α from ρπ …

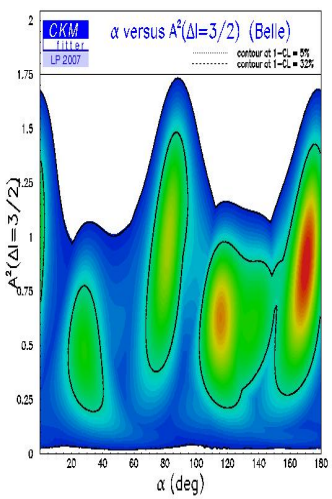
Babar/Belle non intuitive combination is clear in the 2D (α ,$A_{3/2}$) plane

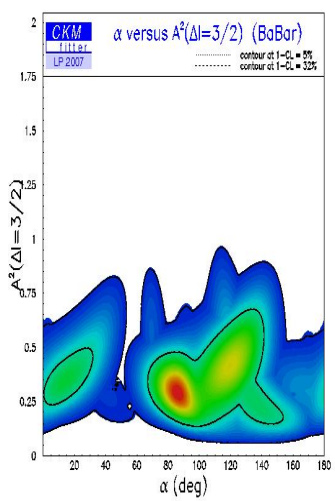
Alpha versus $A^2(\Delta I=3/2)$

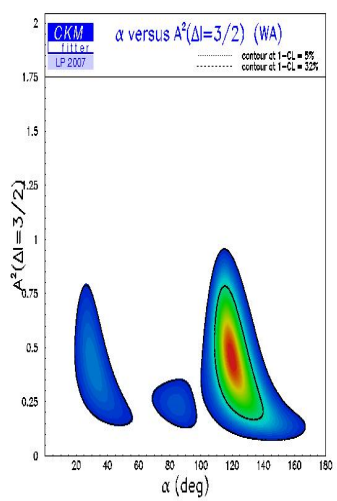


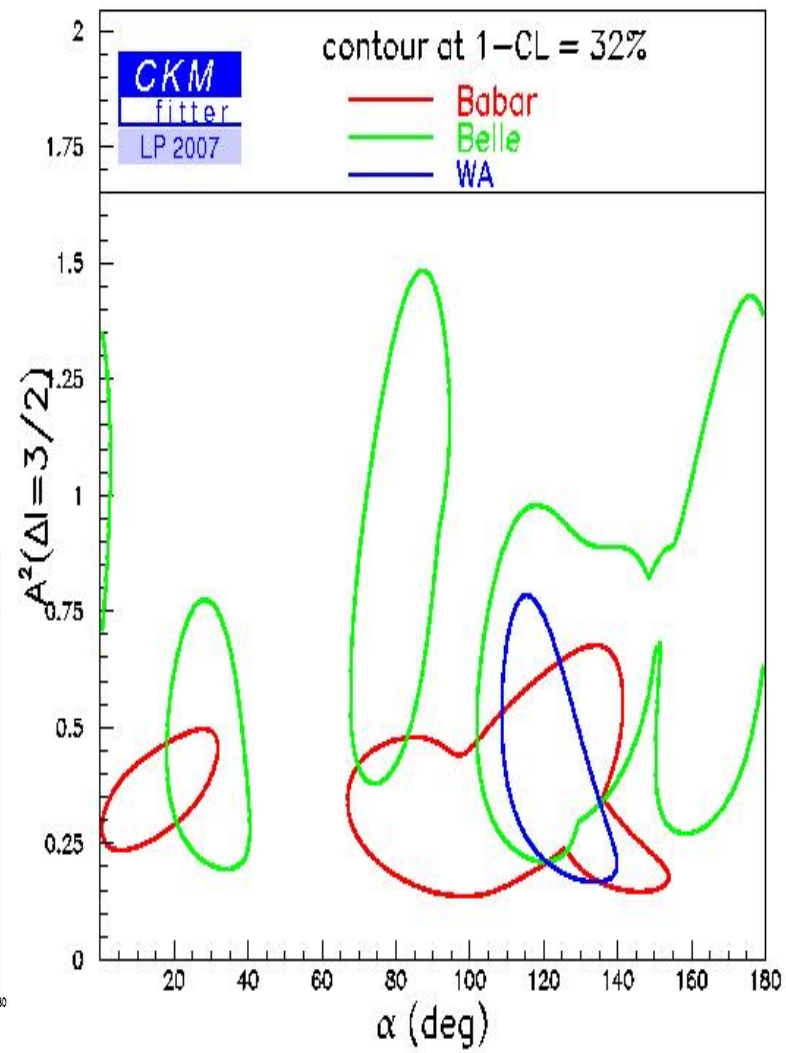




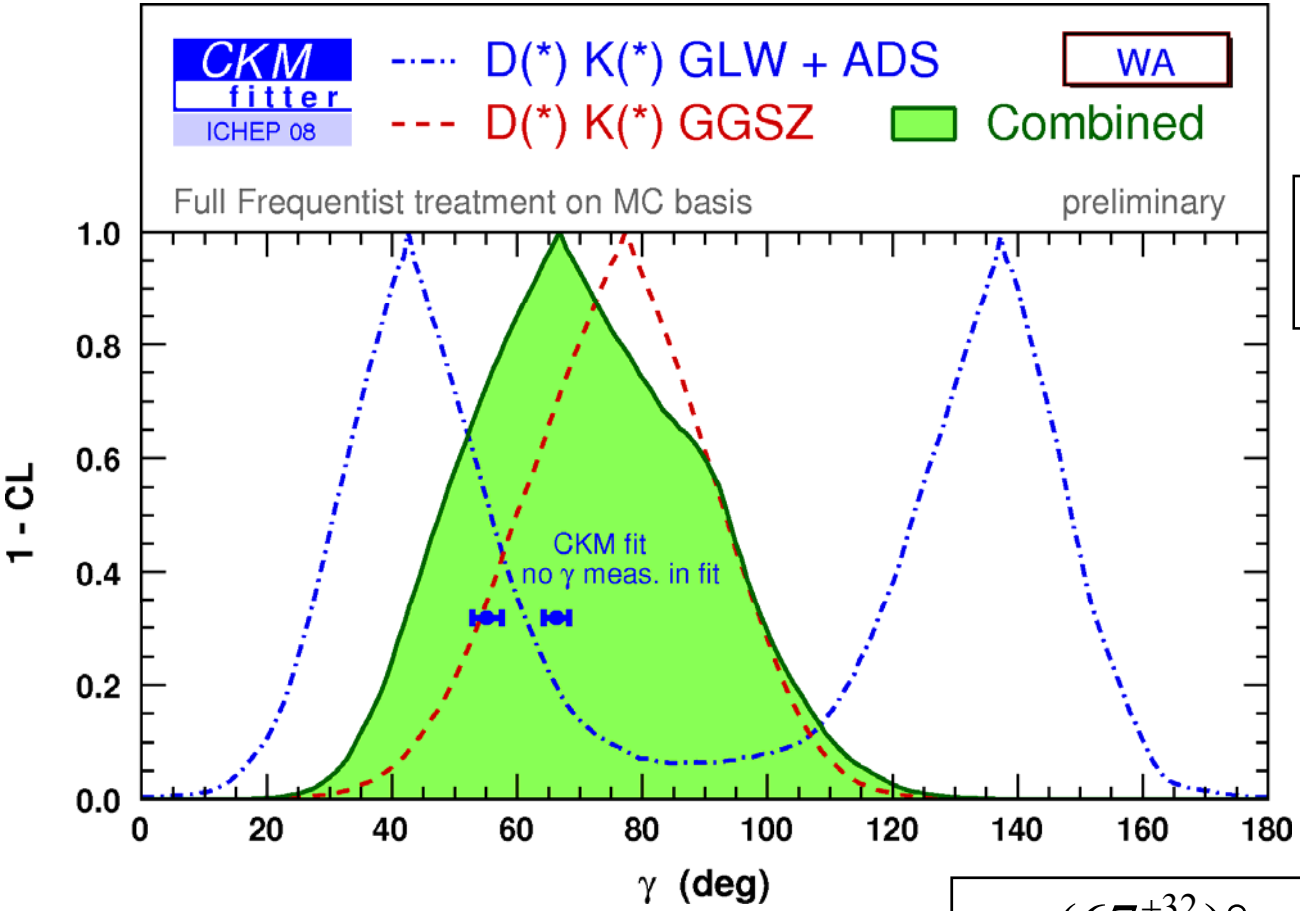








A bit more about γ ...



$$\gamma_{GLW/ADS} = (42^{+19}_{-16})^\circ + mirror$$

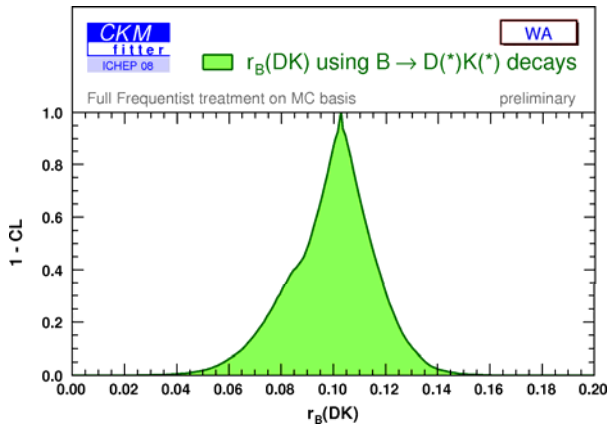
$$\gamma_{GGSZ} = (77^{+22}_{-23})^\circ$$

$$\gamma = (67^{+32}_{-25})^\circ \quad \text{[direct]}$$

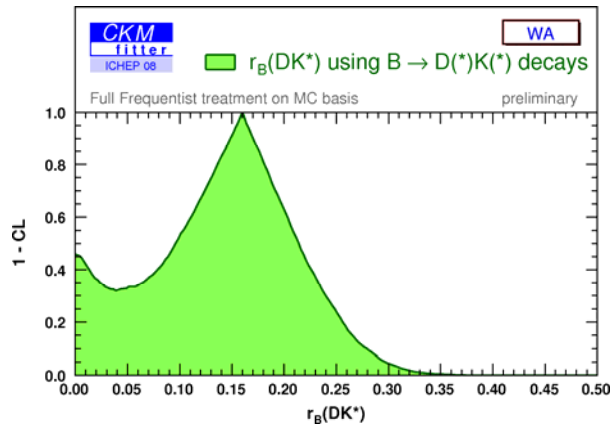
$$\gamma = (55.1^{+2.5}_{-2.3})^\circ \cup (66.3^{+2.0}_{-2.1})^\circ \quad \text{[indirect]}$$

$$\gamma = (55.2^{+2.5}_{-2.3})^\circ \cup (66.3^{+2.6}_{-3.0})^\circ \quad \text{[all]}$$

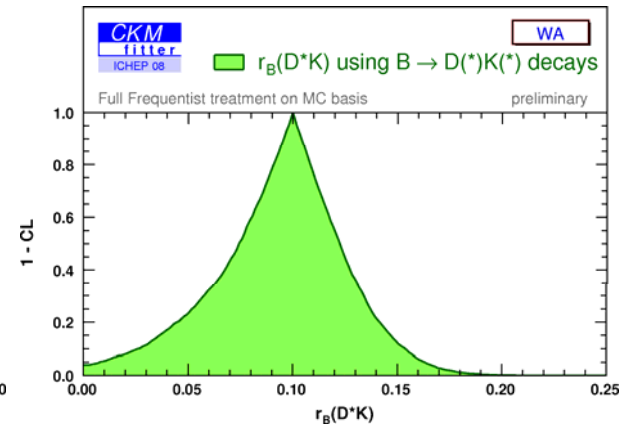
A bit more about γ ...



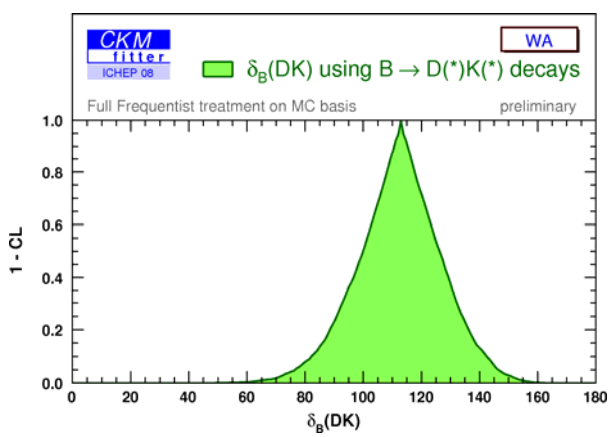
$$r_B(DK) = (0.103^{+0.017}_{-0.023})^\circ$$



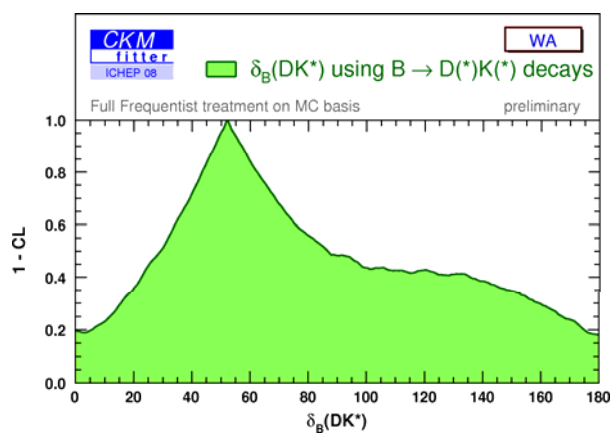
$$r_B(D^*K) = (0.160^{+0.077}_{-0.115})^\circ$$



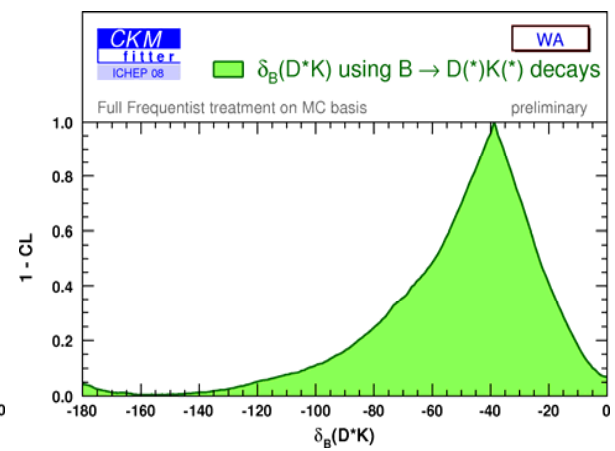
$$r_B(D^*K) = (0.100^{+0.033}_{-0.041})^\circ$$



$$\delta(DK) = (113^{+19}_{-20})^\circ$$



$$\delta(D^*K) = (52^{+104}_{-36})^\circ$$

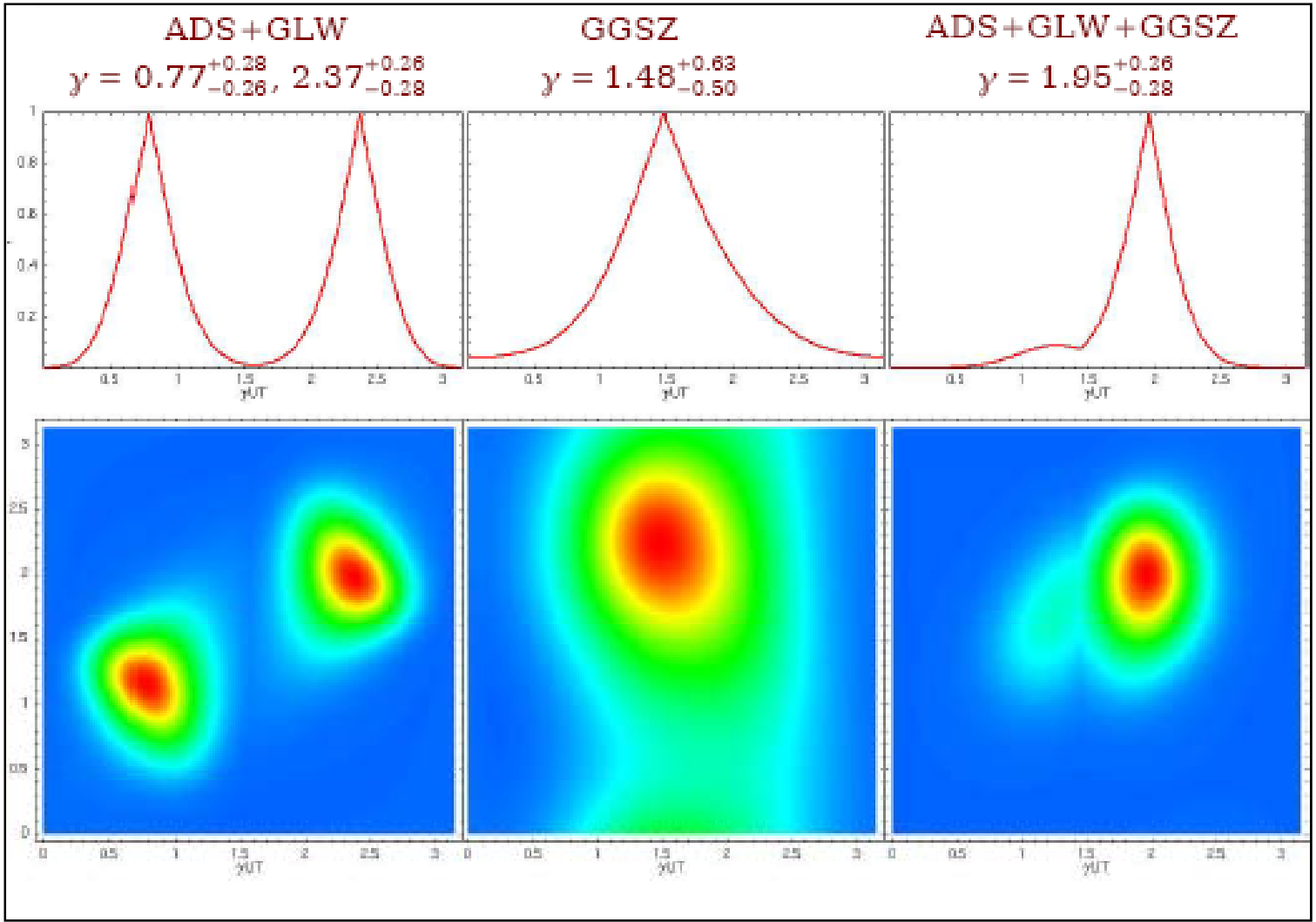


$$\delta(D^*K) = (-39^{+22}_{-35})^\circ$$

A bit more about γ ...

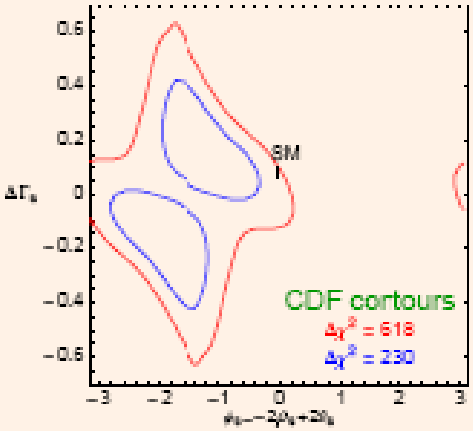
ADS+GLW/GGSZ non intuitive combination is clear in the 2D (γ , δ_{DK}) plane

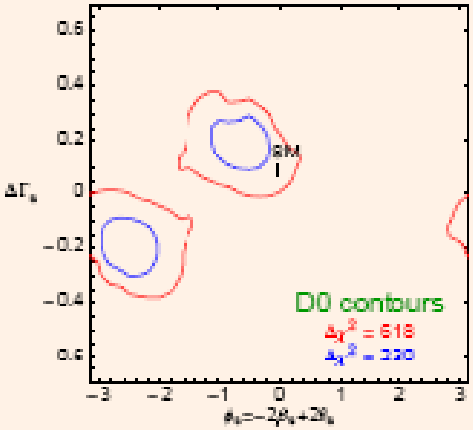
Summer 07 data : for illustration purpose only



A bit more about D0/CDF averaging

A closer look at the Tevatron data and their interpretation





these are the *preliminary* SU(3)-free profile log-likelihood contours in the $(\phi_s, \Delta\Gamma_s)$ plane

blue and red contours would correspond to 68.3% and 95.5% CL in the asymptotic Gaussian regim

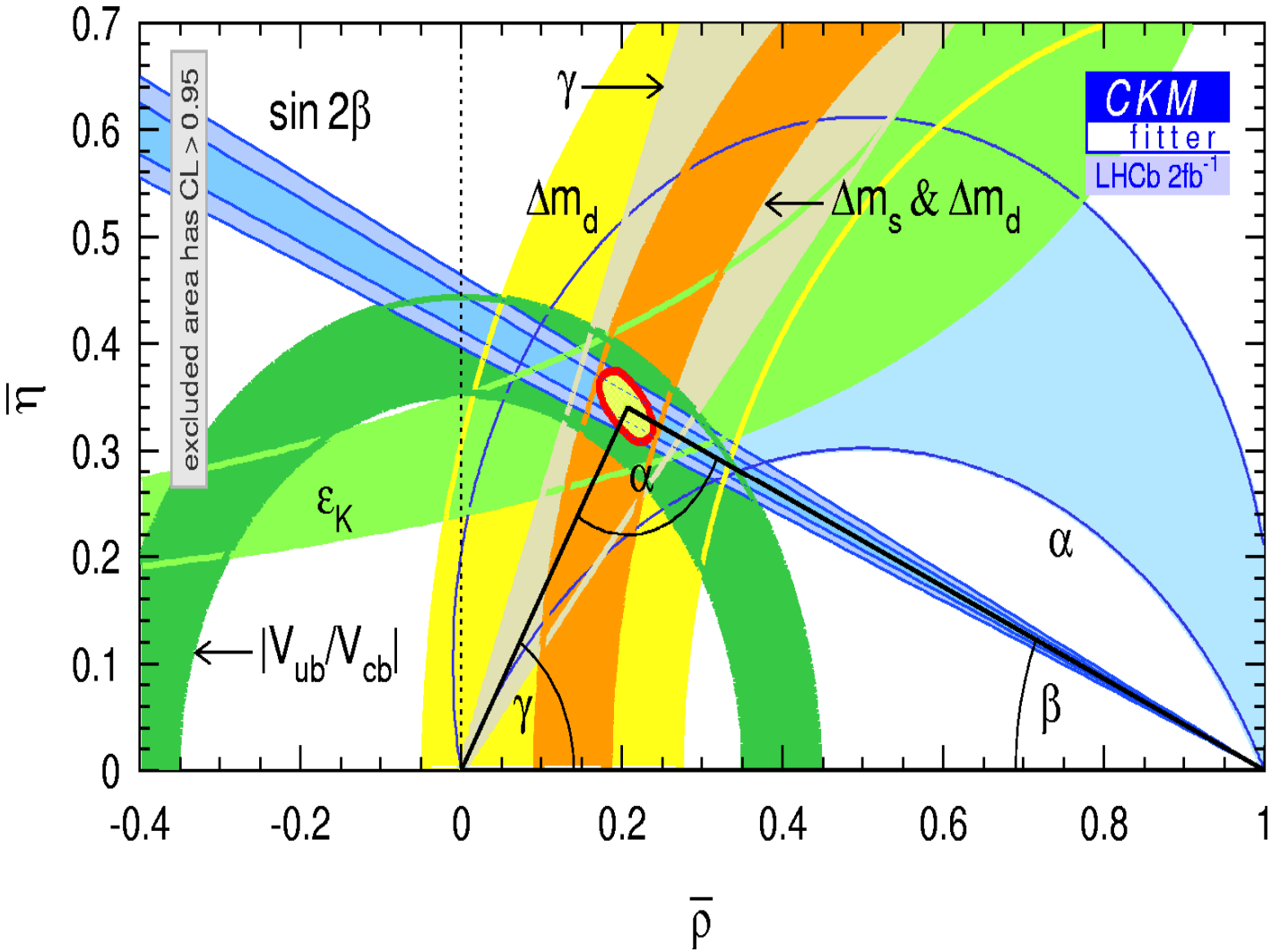
however CDF finds a significant bias towards smaller error values (possible explanation: the untagged analysis is insensitive to ϕ_s when $\Delta\Gamma_s = 0$); CDF corrects for this bias by a full Feldman-Cousins frequentist analysis

in principle one should do the same for D0 data and for the combination; this requires the knowledge of the experimental PDF's

in this talk just assume asymptotic Gaussian regime, i.e. assume that the log-likelihood is χ^2-distributed among many similar experiments

it is known that this simplification is *not conservative*: it tends to underestimate the errors

LHCb end of 2009 ?



Assumptions:
LHCb TDR

$\sigma(\Delta m_s)=0.01$

$\sigma(\sin 2\beta)=0.02$

$\sigma(\alpha) = 10^o$

$\sigma(\gamma) = 5^o$