Constraining new physics with the Unitarity triangle

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on behalf of UTfit Collaboration

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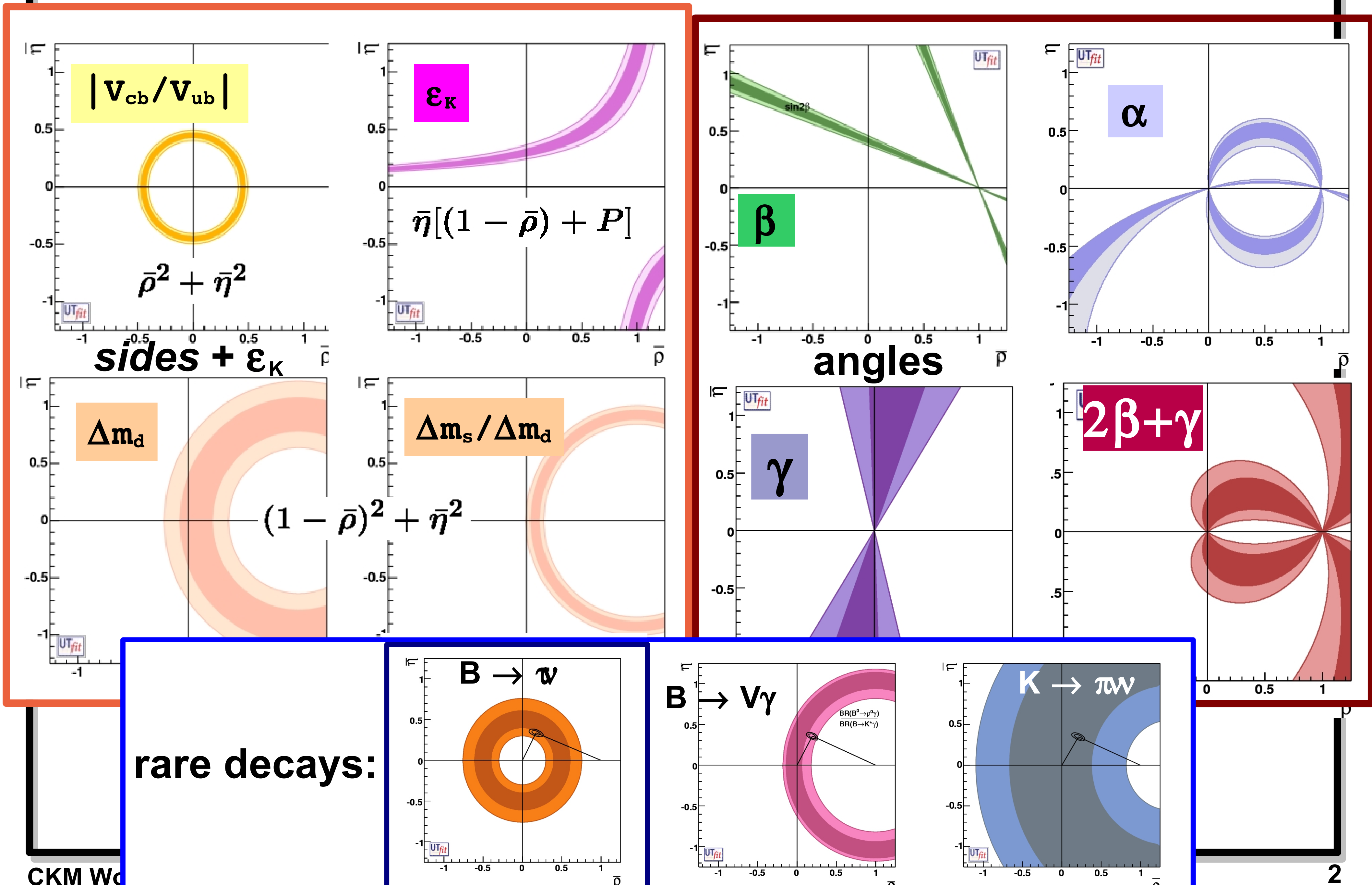
www.utfit.org

Unitarity Triangle analysis in the SM



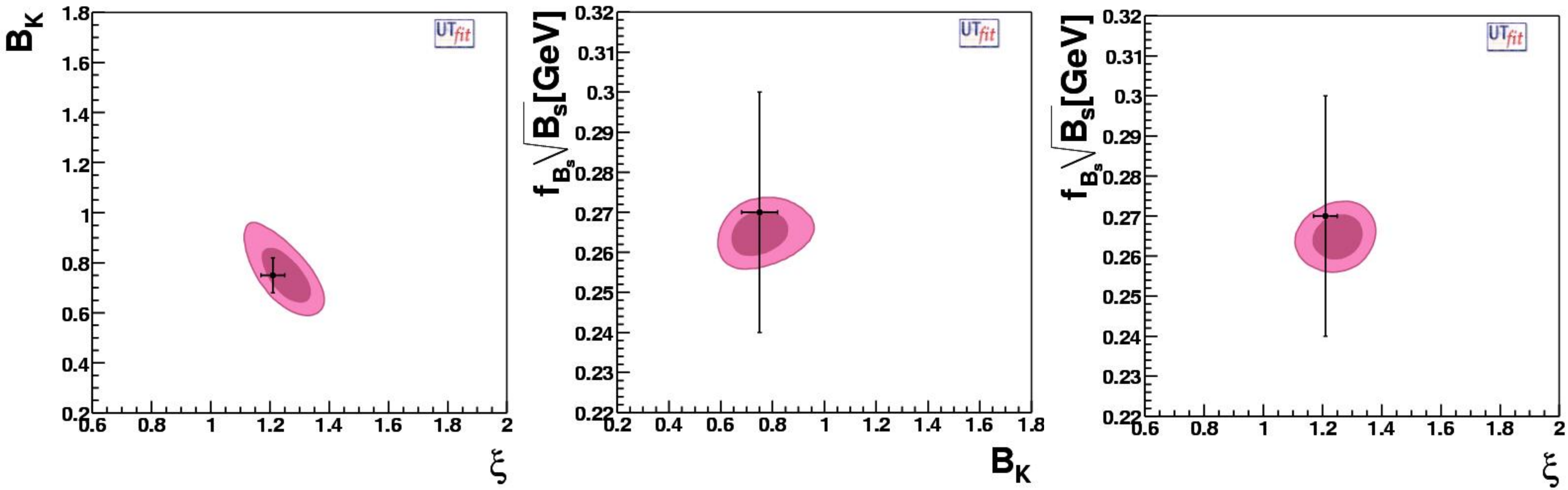
New inputs for Summer '08: LQCD

- We updated our inputs from lattice QCD to new calculations
- Through the Standard Model Unitarity Triangle analysis, without using the lattice inputs, we also obtain the updated values of the predictions for the lattice parameters

$$B_K^{UT} = 0.75 \pm 0.07$$
$$f_{Bs}\sqrt{B_{Bs}}^{UT} = 265 \pm 4 \text{ MeV}$$
$$\xi^{UT} = 1.25 \pm 0.06$$

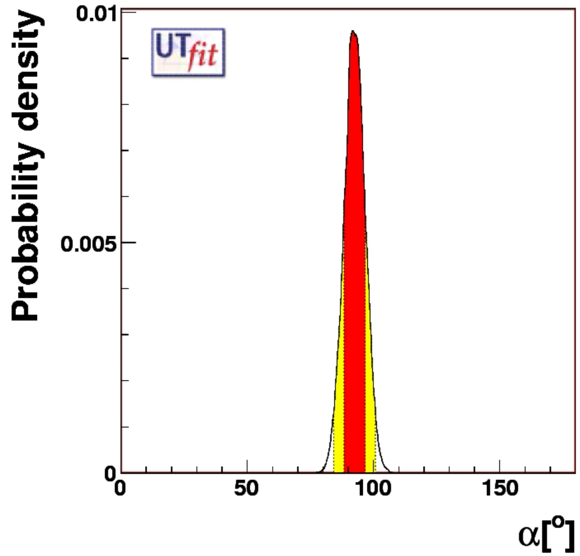
$$B_K^{lat} = 0.75 \pm 0.07$$
$$f_{Bs}\sqrt{B_{Bs}}^{lat} = 270 \pm 30 \text{ MeV}$$
$$\xi^{lat} = 1.21 \pm 0.04$$

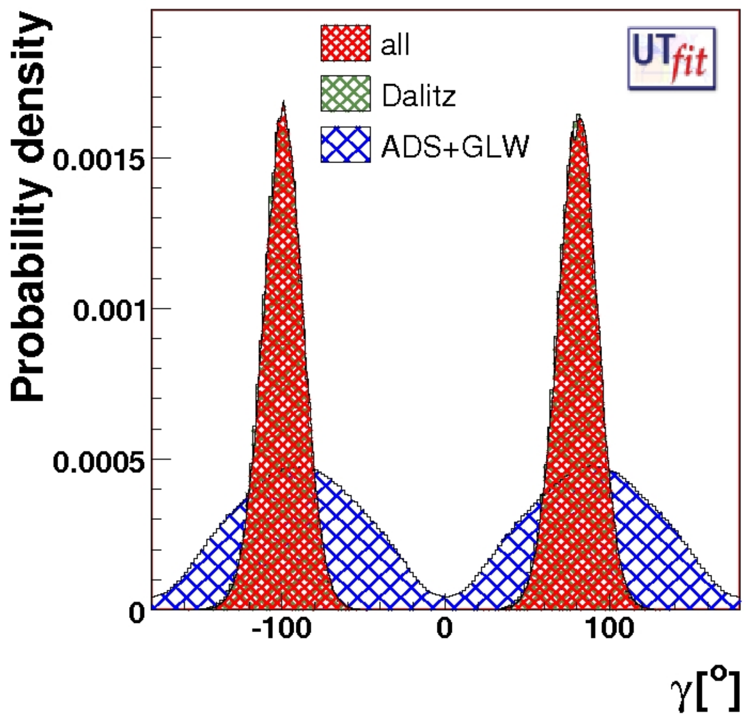
Averages by Utfit: V. Lubicz, C. Tarantino)

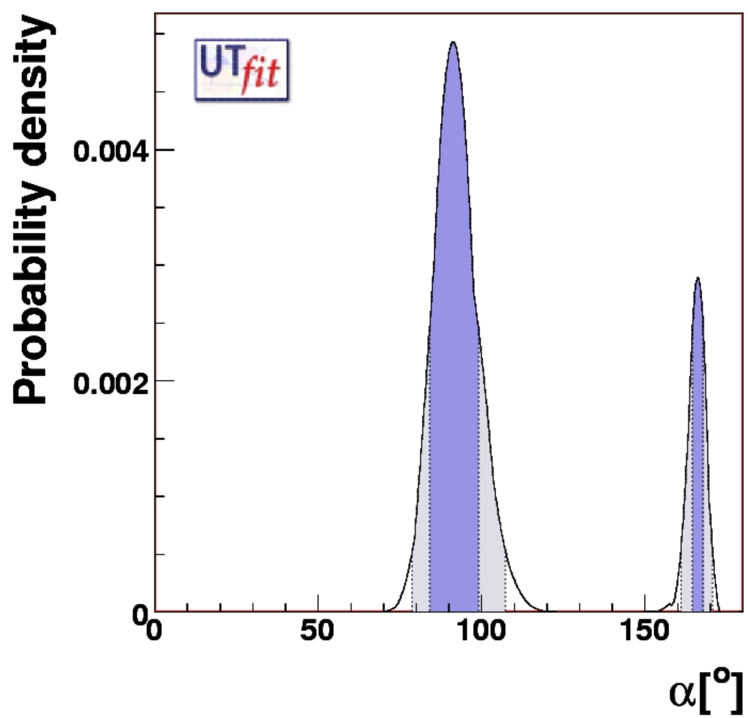


New inputs for Summer '08: angles

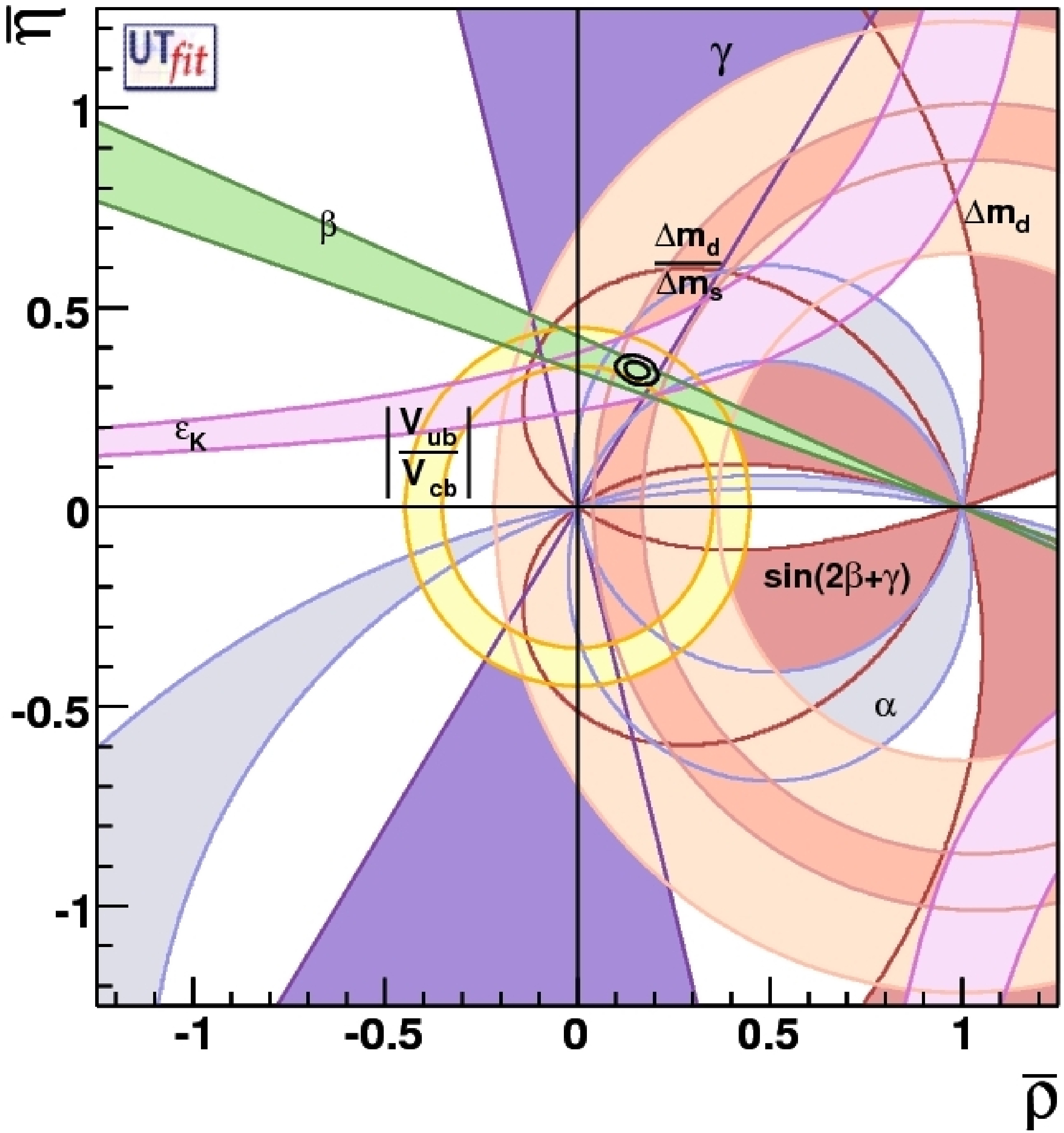
- γ: $(81 \pm 13)°$ @ 68% Prob. [mod. 90°]
  [56, 105]° @ 95% Prob. [mod. 90°]
  from the rest of the UTfit
  $\gamma^{UT} = (64 \pm 3)°$
- α: $(92 \pm 7)°$ U $(166 \pm 2)°$ @ 68% Prob.
  [79 ± 107]° U [161,171]° @ 95% Prob.
  from the rest of the UTfit
  $\alpha^{UT} = (92 \pm 4)°$







Experimental situation (I)



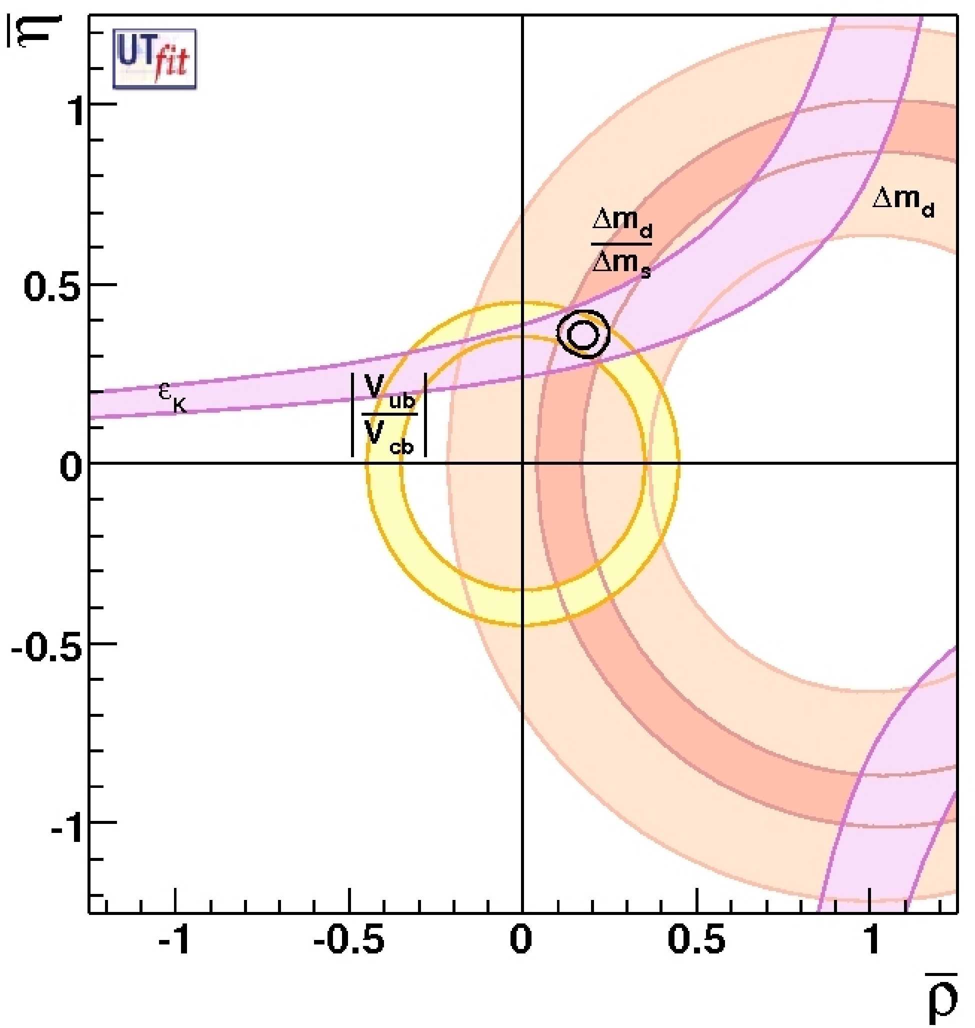
results updated in summer 2008
- new γ (ICHEP08)
- new α (ICHEP08)
- new ILQCD (Lubicz, Tarantino)

$\bar\rho = 0.155 \pm 0.022$
$\bar\eta = 0.342 \pm 0.014$

- Theory under control
- Data in agreement
- NP, if any, seems not to introduce additional CP or flavour violation in $b \leftrightarrow d$ transitions at current experimental precision

Experimental situation (II)

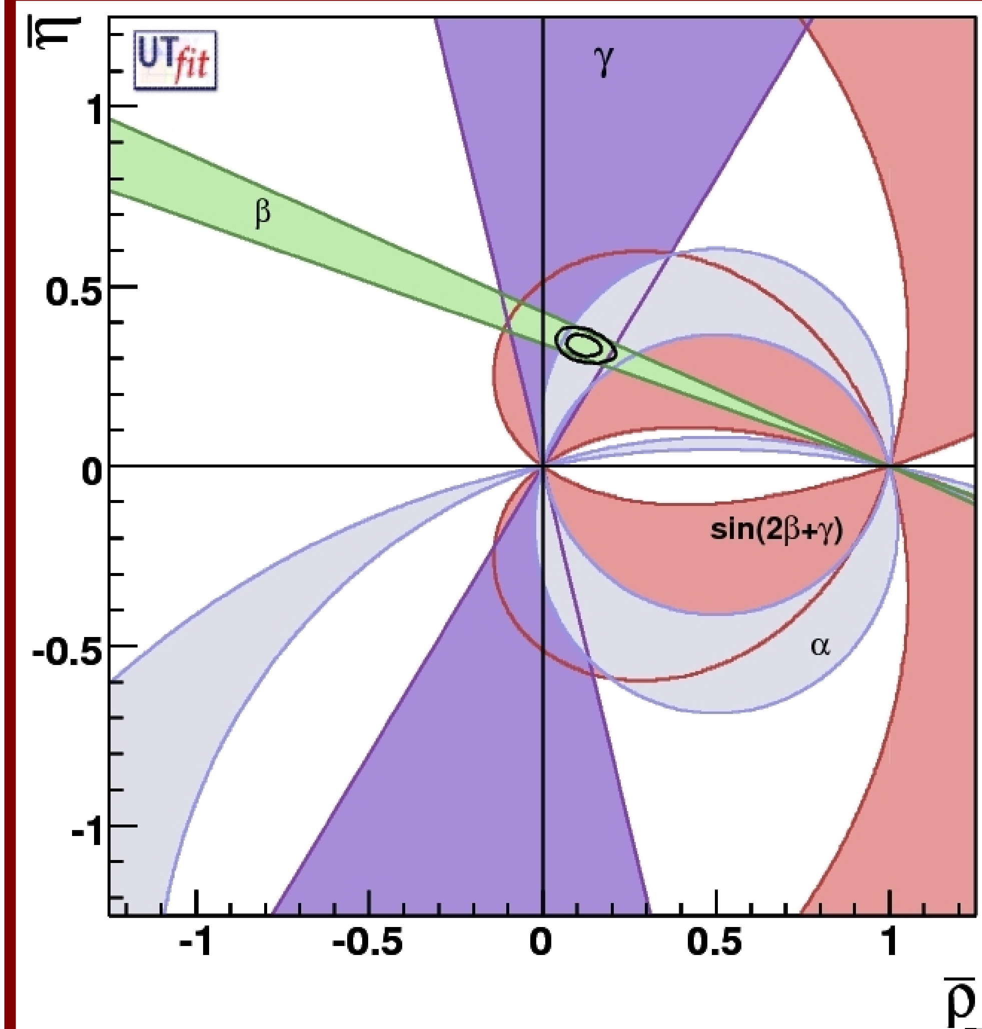
sides + ε_K



$\bar{\rho} = 0.175 \pm 0.027$

$\bar{\eta} = 0.360 \pm 0.023$

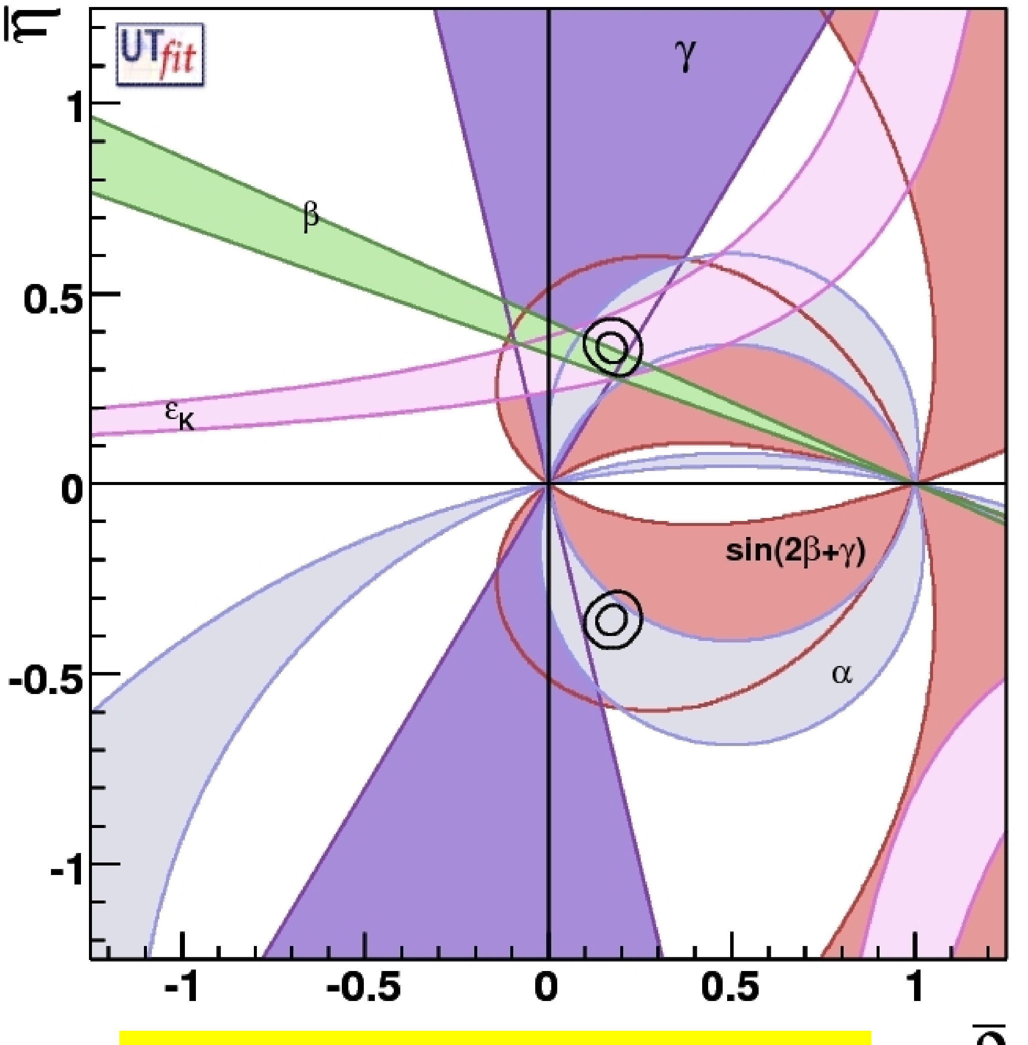
angles

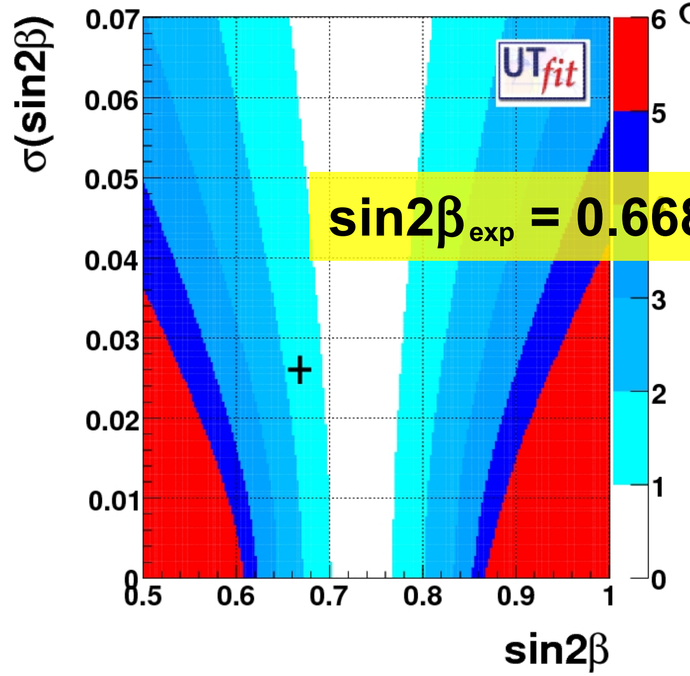


$\bar{\rho} = 0.120 \pm 0.034$

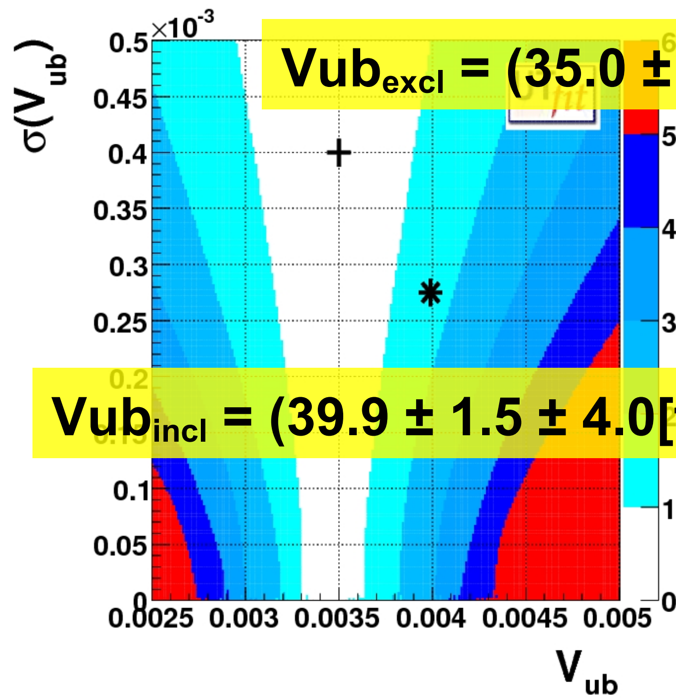
$\bar{\eta} = 0.335 \pm 0.020$

The *tension*





$\sin 2\beta_{exp} = 0.668 \pm 0.026$



$Vub_{excl} = (35.0 \pm 4.0) \cdot 10^{-4}$

$Vub_{incl} = (39.9 \pm 1.5 \pm 4.0[flat]) \cdot 10^{-4}$

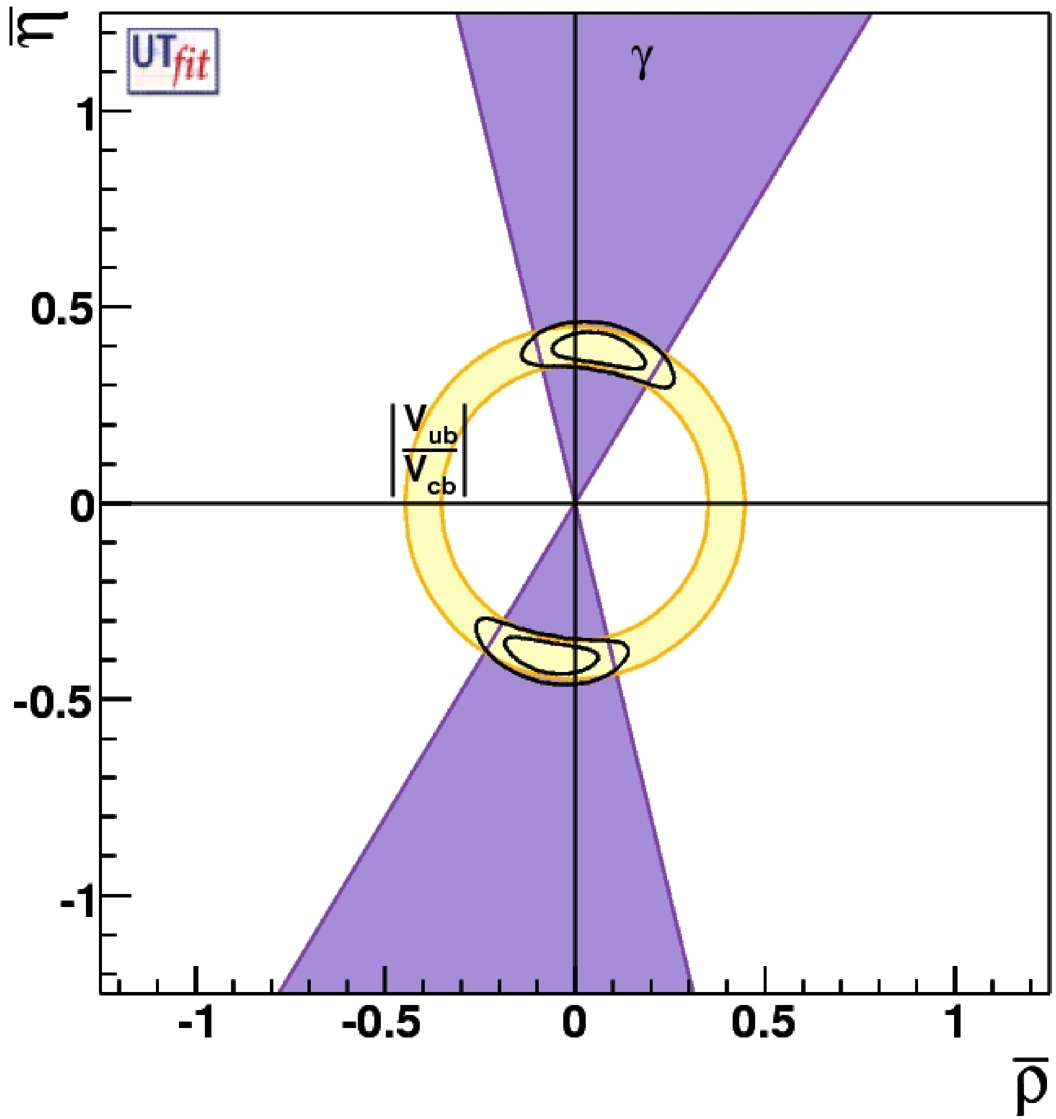
$\sin 2\beta_{UTfit} = 0.736 \pm 0.034$

$Vub_{UTfit} = (34.8 \pm 1.6) \cdot 10^{-4}$

“Tree level” fit

B factories are constraining the UT with tree-level processes

Assuming no NP at tree level
(the effect of the $\bar{D}^0$-D^0 mixing to γ are small wrt the present error and can be accounted for in the future)



We can determine $\bar{\rho}$ and $\bar{\eta}$ regardless of NP

$$\bar{\rho} = \pm\, 0.06 \pm 0.08$$
$$\bar{\eta} = \pm\, 0.39 \pm 0.03$$

Values in agreement with SM within the errors

Including NP in UT analysis

M. Bona *et al.* (UTfit)
Phys.Rev.Lett.97:151803,2006

	ρ, η	C_{Bd}, ϕ_{Bd}	$C_{\varepsilon K}$	C_{Bs}, ϕ_{Bs}
V_{ub}/V_{cb}	X			
γ (DK)	X			
ε_K	X		X	
sin2β	X	X		
Δm_d	X	X		
α ($\rho\rho$,$\rho\pi$,$\pi\pi$)	X	X		
A_{SL} B_d	X	X X		
$\Delta\Gamma_d/\Gamma_d$	X	X X		
$\Delta\Gamma_s/\Gamma_s$	X			X X
Δm_s				X
A_{CH}	X	X X		X X

model independent assumptions

SM → **SM+NP**

tree level

$(V_{ub}/V_{cb})^{SM}$ → $(V_{ub}/V_{cb})^{SM}$
γ^{SM} → γ^{SM}

Bd Mixing

β^{SM} → $\beta^{SM}+\phi_{Bd}$
α^{SM} → $\alpha^{SM}-\phi_{Bd}$
Δm_d → $C_{Bd}\Delta m_d$

Bs Mixing

Δm_s^{SM} → $C_{Bs}\Delta m_s^{SM}$
β_s^{SM} → $\beta_s^{SM}+\phi_{Bs}$

K Mixing

ε_K^{SM} → $C_{\varepsilon K}\varepsilon_K^{SM}$

General parameterization of NP

Consider for example Bs mixing process.
Given the SM amplitude, we can define

$$C_{B_s} e^{-2i\phi_{B_s}} = \frac{\langle \overline{B}_s | H_{eff}^{SM} + H_{eff}^{NP} | B_s \rangle}{\langle \overline{B}_s | H_{eff}^{SM} | B_s \rangle} = 1 + \frac{A_{NP} e^{-2i\phi_{NP}}}{A_{SM} e^{-2i\beta_s}}$$

All NP effects can be parameterized in terms of one complex parameter for each meson system.

C_{pen} and ϕ_{pen} are parameterize possible NP contributions from $b \to s$ penguins

B meson mixing matrix element NLO calculation
Ciuchini et al. JHEP 0308:031,2003.

$$\frac{\Gamma_{12}^q}{A_q^{\rm full}} = -2\frac{\kappa}{C_{B_q}}\left\{ e^{2\phi_{B_q}}\left(n_1 + \frac{n_6 B_2 + n_{11}}{B_1}\right) - \frac{e^{(\phi_q^{\rm SM}+2\phi_{B_q})}}{R_t^q}\left(n_2 + \frac{n_7 B_2 + n_{12}}{B_1}\right)\right.$$
$$+\frac{e^{2(\phi_q^{\rm SM}+\phi_{B_q})}}{R_t^{q^2}}\left(n_3 + \frac{n_8 B_2 + n_{13}}{B_1}\right) + e^{(\phi_q^{\rm Pen}+2\phi_{B_q})} C_q^{\rm Pen}\left(n_4 + n_9\frac{B_2}{B_1}\right)$$
$$\left. - e^{(\phi_q^{\rm SM}+\phi_q^{\rm Pen}+2\phi_{B_q})}\frac{C_q^{\rm Pen}}{R_t^q}\left(n_5 + n_{10}\frac{B_2}{B_1}\right)\right\}$$

NP-specific and B_s constraints (I)

$$\boxed{\Delta m_s = |A_s^{\text{full}}| = C_{B_s} (\Delta m_s)^{\text{SM}}}$$

experimenal laikelihood used in the fit

$$\boxed{2\phi_s = -\arg A_s^{\text{full}} = 2(\beta_s - \phi_{B_s})}$$

see M. Ciuchini's talk or my back-up slides :)

SM contribution

Sin $2\beta_s$= 0.037 ± 0.002 (SM or MFV)

ϕ_s and $\Delta\Gamma_s$: 2D experimental likelihood from CDF and our different threatments for D0

- $\Delta\Gamma$ for B_d and B_s
  - on B_d not effective: experimental error x10 the precision of the fit
  - the experimental measurement of $\Delta\Gamma_s$ actually measures $\Delta\Gamma_s \cos(\beta_s+\phi_{Bs})$

  NP can only decrease the experimental result wrt the SM value

  experimental WA > SM expectation (NP suppressed)

$$\boxed{\frac{\Delta\Gamma_s}{\Delta m_s} = \text{Re}\left(\frac{\Gamma_{12}^s}{A_s^{\text{full}}}\right)}$$

$\Delta\Gamma_s/\Gamma_s$ = 0.10 ± 0.06

Ciuchini et al. JHEP 0308:031,2003.

NP-specific constraints (II)

$$A_{\mathrm{SL}}^{s} \equiv \frac{\Gamma(\bar{B}_s \to \ell^+ X) - \Gamma(B_s \to \ell^- X)}{\Gamma(\bar{B}_s \to \ell^+ X) + \Gamma(B_s \to \ell^- X)} = \mathrm{Im}\left(\frac{\Gamma_{12}^{s}}{A_s^{\mathrm{full}}}\right)$$

- **semileptonic asymmetry A_{SL}:**
  sensitive to NP effect on both size and phase of B mixing

Laplace et al. Phys.Rev.D 65: 094040,2002

$$A_{\mathrm{SL}}^{s} \times 10^2 = -0.20 \pm 1.19$$

D0 ICHEP08

- **same-side dilepton charge asymmetry A_{CH}:**
  admixture of B_d and B_s dependent on $\bar{\rho}$ and $\bar{\eta}$ and on NP effects

$$A_{\mathrm{SL}}^{\mu\mu} \times 10^3 = -4.3 \pm 3.0$$

$$A_{\mathrm{SL}}^{\mu\mu} = \frac{f_d \chi_{d0} A_{\mathrm{SL}}^{d} + f_s \chi_{s0} A_{\mathrm{SL}}^{s}}{f_d \chi_{d0} + f_s \chi_{s0}}$$

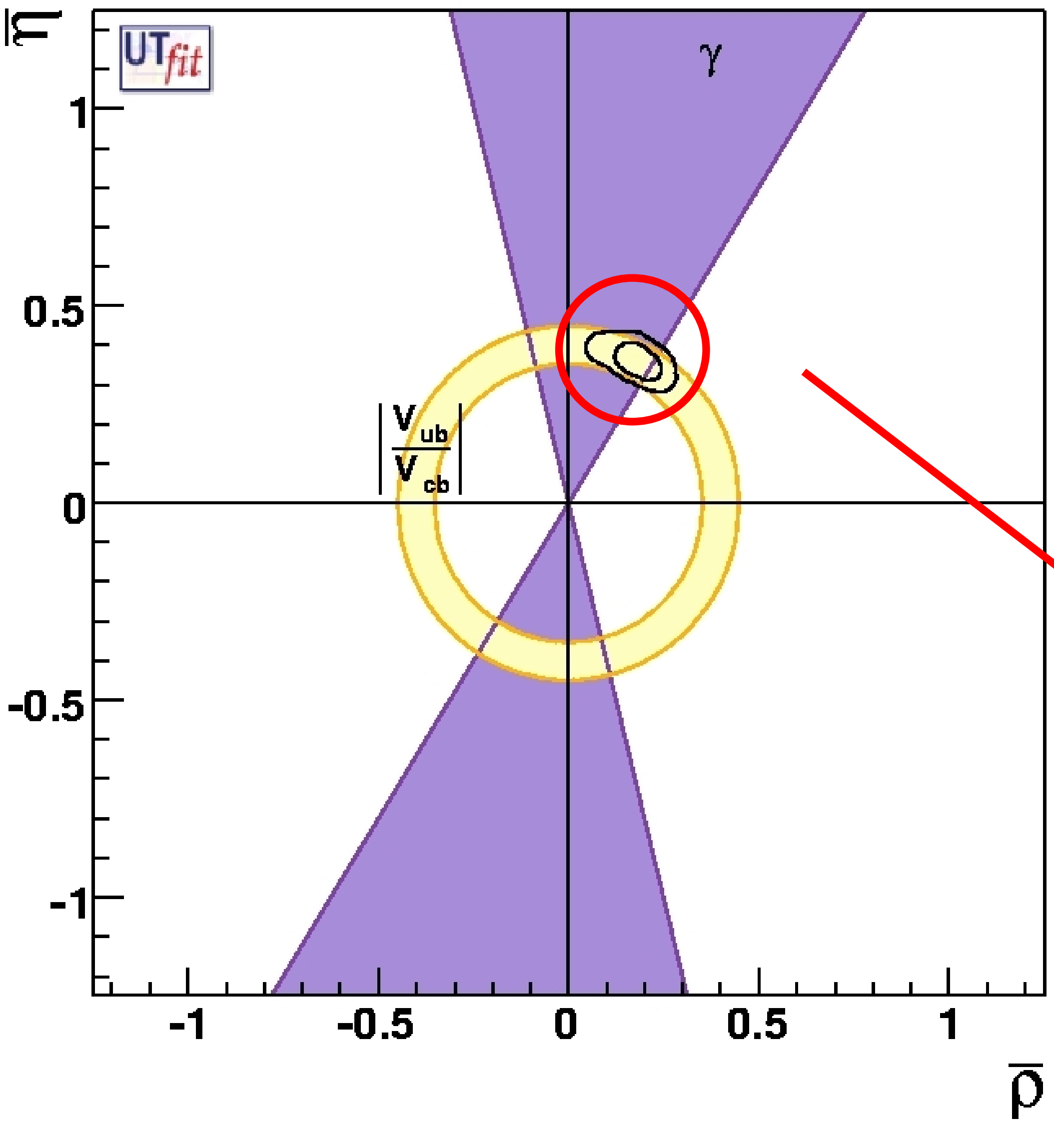
- **lifetime τ_s in flavour-specific final states:**
  fit for a single exponential for B_s and $\bar{B}_s$ the average lifetime is a function of the width and width difference

$$\tau_{B_s}^{\mathrm{FS}}\ [\mathrm{ps}] = 1.461 \pm 0.032$$

$$\tau_{B_s}^{FS} = \frac{1}{\Gamma_s} \frac{1 - \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1 + \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$$

Dunietz et al., hep-ph 0012219

The UT*fit* beyond the SM



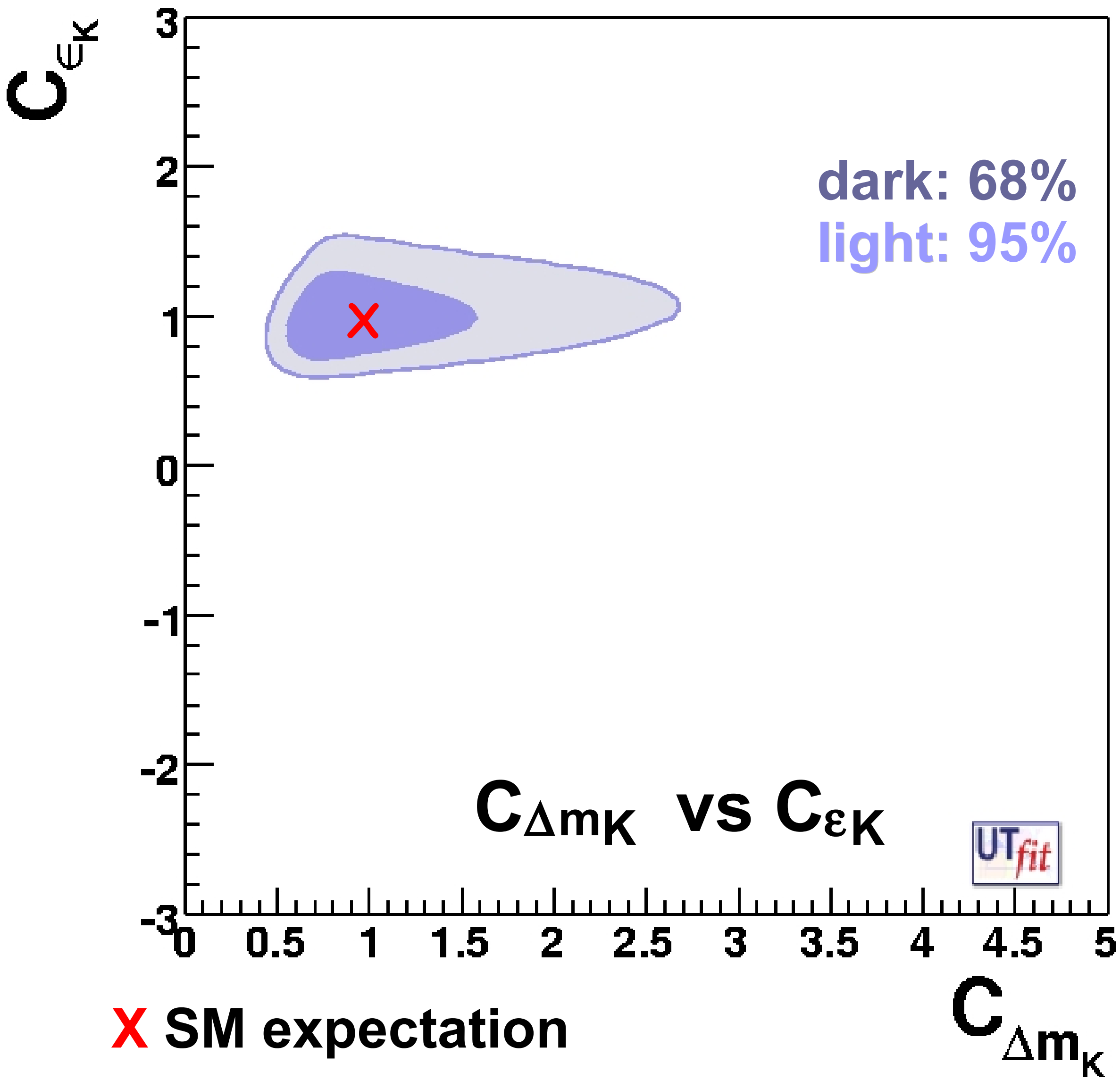
$\bar{\rho} = 0.177 \pm 0.044$
$\bar{\eta} = 0.360 \pm 0.031$

Allowing for NP we go back to the SM solution

$\bar{\rho} = 0.155 \pm 0.022$
$\bar{\eta} = 0.342 \pm 0.014$

This is the crucial starting point and what boosted the precision of this analysis: the uncertainty on CKM parameters with NP was the limiting factor. great success of the B factories program

New Physics in K sectors



X SM expectation

$$\mathrm{Im}\,A_K = C_\varepsilon \,\mathrm{Im}\,A_K^{SM}$$
$$\mathrm{Re}\,A_K = C_{\Delta m_K} \,\mathrm{Re}\,A_K^{SM}$$

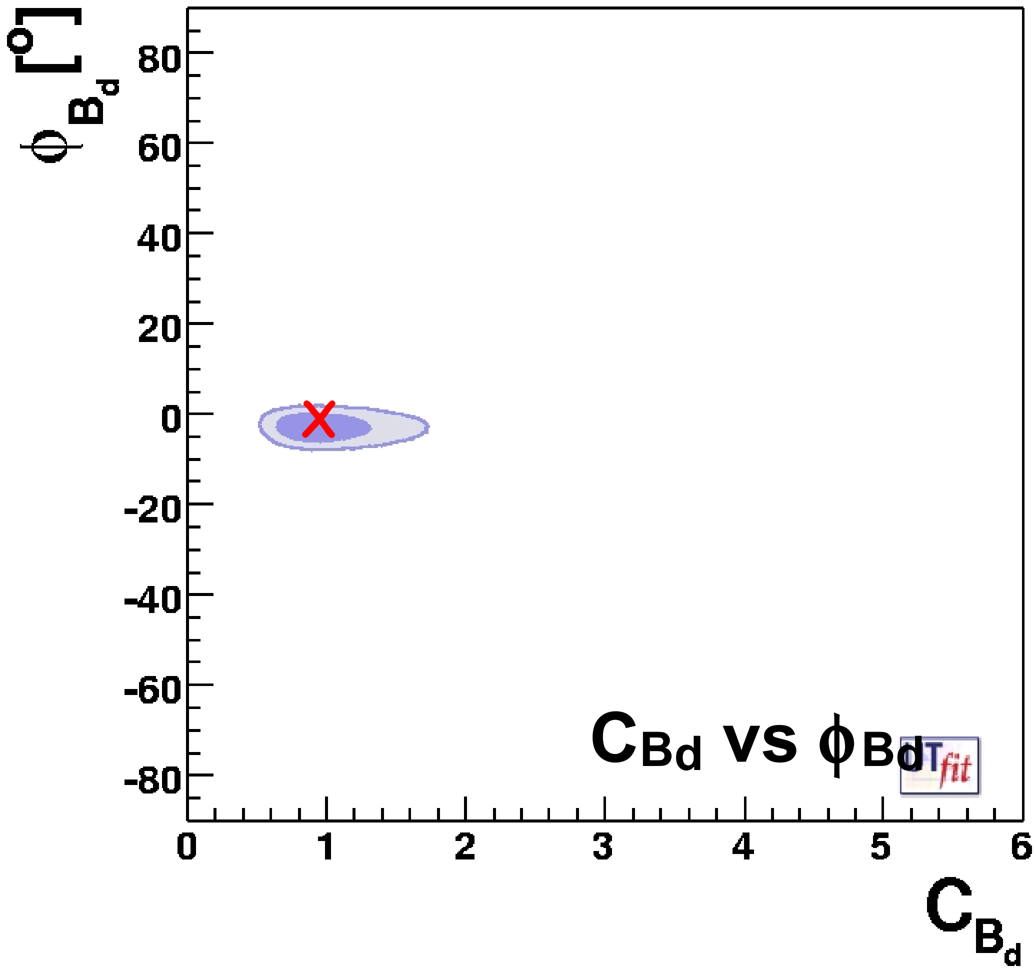
$$\Delta m_K = C_{\Delta m_K} (\Delta m_K)^{SM}$$
$$\varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$

$C_{\varepsilon K} = 0.99 \pm 0.16$

$C_{\Delta mK} = 0.96. \pm 0.34$

New Physics in B_d sectors

$$C_{B_s} e^{-2i\phi_{B_s}} = \frac{\langle \overline{B}_s | H_{eff}^{SM} + H_{eff}^{NP} | B_s \rangle}{\langle \overline{B}_s | H_{eff}^{SM} | B_s \rangle} = 1 + \frac{A_{NP} e^{-2i\phi_{NP}}}{A_{SM} e^{-2i\beta_s}}$$

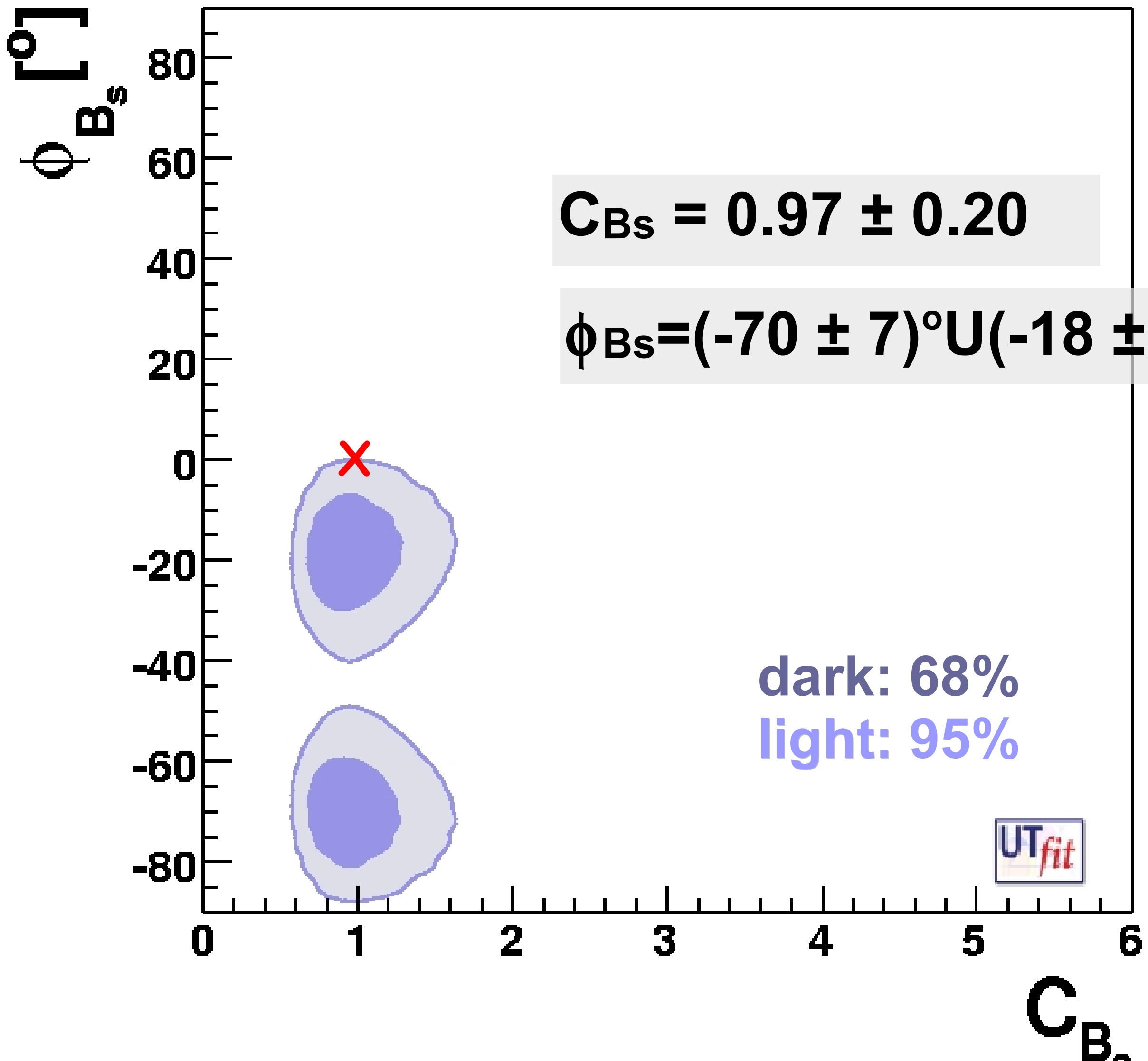


$C_{Bd} = 0.96 \pm 0.23$

$\phi_{Bd} = (-2.9 \pm 1.9)°$

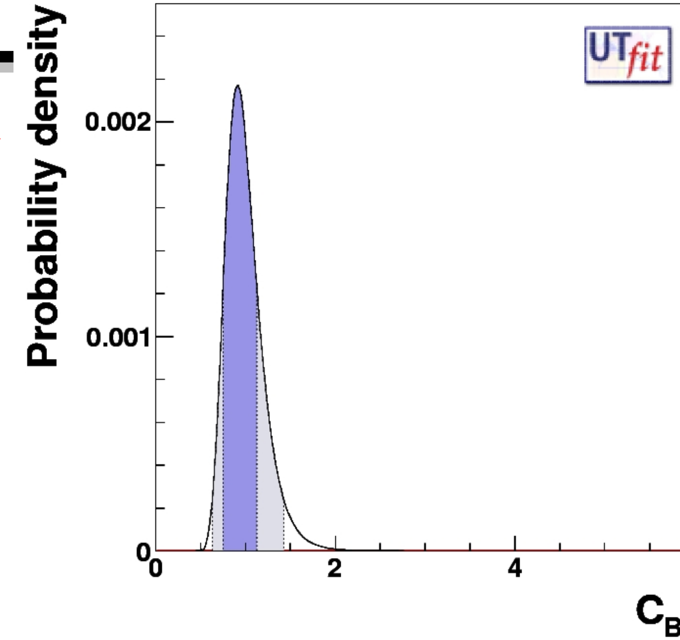
New Physics in the B_s sector

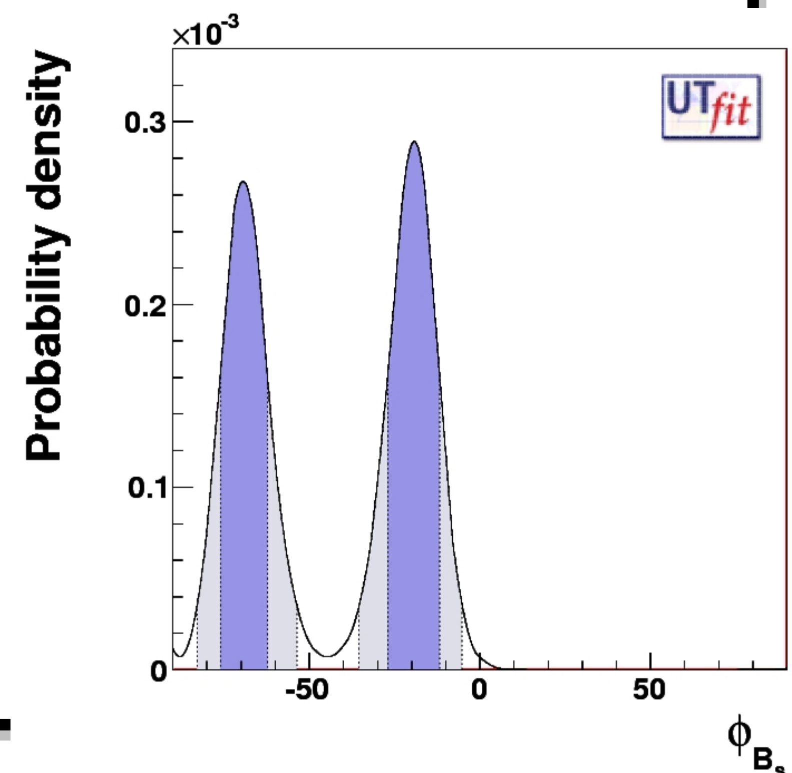
X SM expectation



$C_{Bs} = 0.97 \pm 0.20$

$\phi_{Bs} = (-70 \pm 7)° \cup (-18 \pm 7)°$





Testing the TeV scale

R G E

At the high scale

new physics enters according to its specific features

At the low scale

use OPE to write the most general effective Hamiltonian.
the operators have different chiralities than the SM

NP effects are in the Wilson Coefficients C

$$\mathcal{H}_{\rm eff}^{\Delta B=2} = \sum_{i=1}^{5} C_i Q_i^{bq} + \sum_{i=1}^{3} \tilde{C}_i \tilde{Q}_i^{bq}$$

$$\begin{aligned}
Q_1^{q_i q_j} &= \bar{q}_{jL}^{\alpha}\gamma_\mu q_{iL}^{\alpha}\bar{q}_{jL}^{\beta}\gamma^\mu q_{iL}^{\beta} \,, \\
Q_2^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha}\bar{q}_{jR}^{\beta} q_{iL}^{\beta} \,, \\
Q_3^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\beta}\bar{q}_{jR}^{\beta} q_{iL}^{\alpha} \,, \\
Q_4^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha}\bar{q}_{jL}^{\beta} q_{iR}^{\beta} \,, \\
Q_5^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\beta}\bar{q}_{jL}^{\beta} q_{iR}^{\alpha} \,.
\end{aligned}$$

NP effects are enhanced

- up to a **factor 10** by the values of the matrix elements especially for transitions among quarks of different chiralities
- up to a **factor 8** by RGE

M. Bona *et al.* (UTfit)
JHEP 0803:049,2008
arXiv:0707.0636

Testing the TeV scale (II)

"magic numbers" (see arXiv:0707.0636) $\eta = \alpha_s(\Lambda)/\alpha_s(m_t)$

Lattice QCD

$$\langle \bar{B}_q | \mathcal{H}_{\mathrm{eff}}^{\Delta B=2} | B_q \rangle_i = \sum_{j=1}^{5} \sum_{r=1}^{5} \left(b_j^{(r,i)} + \eta\, c_j^{(r,i)} \right) \eta^{a_j} C_i(\Lambda) \boxed{\langle \bar{B}_q | Q_r^{bq} | B_q \rangle}$$

The dependence of C on Λ changes on flavor structure:

- **Generic**: $C(\Lambda) = \alpha/\Lambda^2$ with arbitrary phase
- **NMFV**: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$ with arbitrary phase
- **MFV**: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$ with SM phase

α is the coupling among NP and SM

- $\alpha \sim 1$ for strongly coupled NP
- $\alpha \sim \alpha_W$ (α_s) in case of loop coupling through weak (strong) interactions

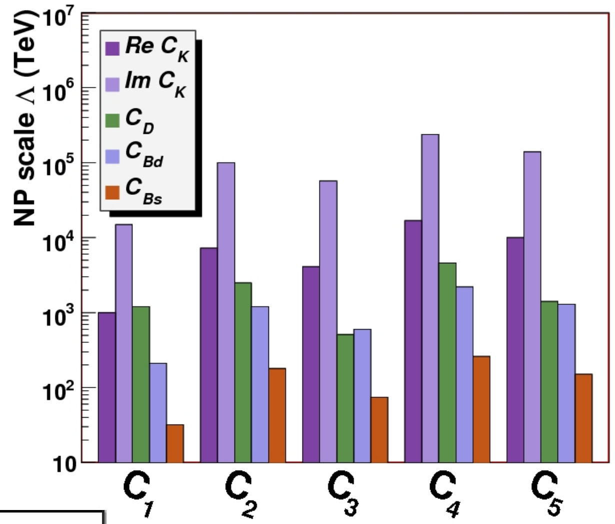
F_{SM} is the combination of CKM factors for the considered process

If no NP effect is seen lower bound on NP scale Λ
if NP is seen upper bound on NP scale Λ

Upper and lower bound on the scale

Lower bounds on NP scale from K and B_d physics (in TeV at 95% prob.)

Scenario	strong/tree	α_s loop	α_W loop
MFV	5.5	0.5	0.2
NMFV	62	6.2	2
General	24000	2400	800



Upper bounds on NP scale from B_s:

Scenario	strong/tree	α_s loop	α_W loop
NMFV	35	4	2
General	800	80	30

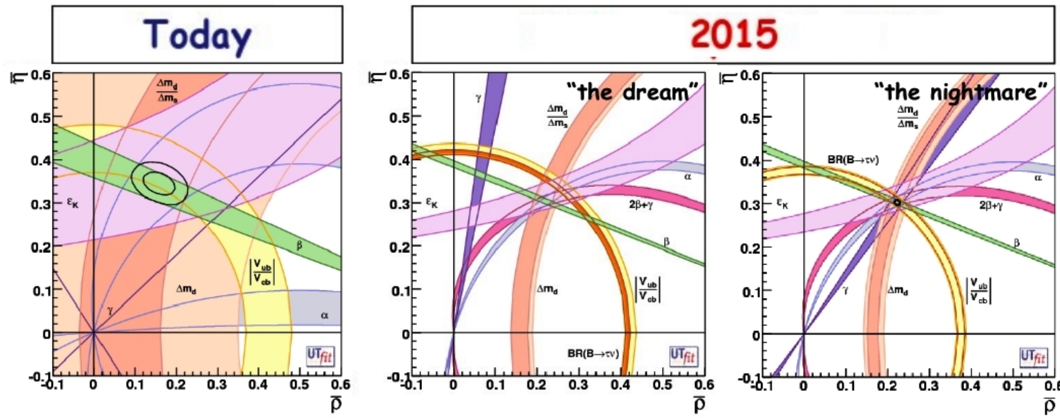
- the general case was already problematic (well known flavour puzzle)
- NMFV has problems with the size of the B_s effect vs the (insufficient) suppression in B_d and (in particular) K mixing
- MFV is OK for the size of the effects, but the B_s phase cannot be generated

Data suggest some hierarchy in NP mixing which is stronger than the SM one

Some conclusions

- Tevatron data show a hint of discrepancy wrt SM
- we are looking forward to be able to use the updated results (CDF likelihood still not available) or even better the combined likelihood (w/o frequentistic assumptions :)

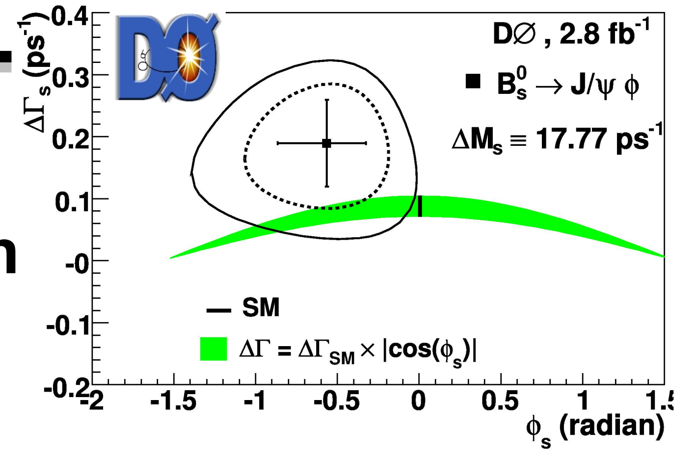
- In any case, LHCb (and a superB!) will reach better precision and provide additional measurements (e.g. $\gamma+2\beta_s$ from $B_s \to D_s K$)



- If confirmed, this result changes our perspective for LHC: NP seen in flavour means that we don't need anymore the NP scale to be at 1000 TeV
- the challenge is for theory
  - MFV disfavoured
  - flavour hierarchy needs to be stronger than the CKM λ expansion

Back-up slides

Modeling D0 data (I)

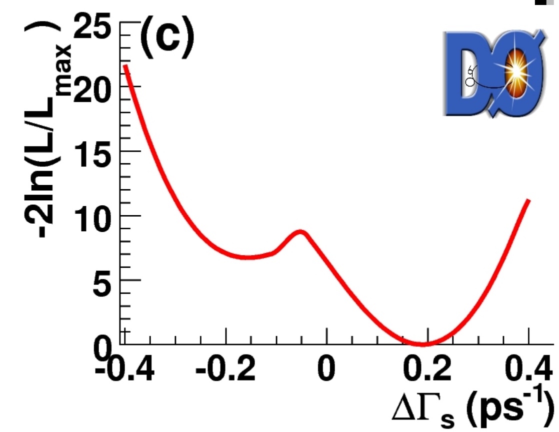


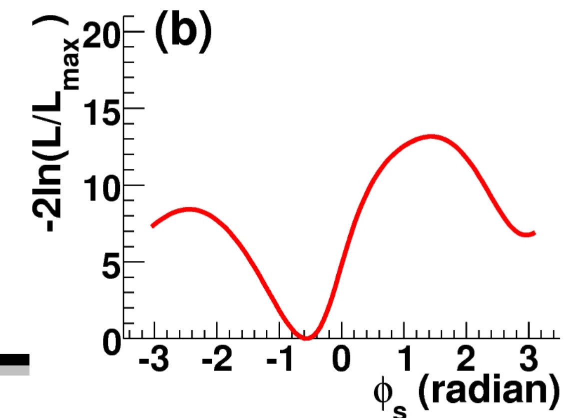
Unlike for CDF, it was not possible to obtain the 2D likelihood from D0.
We use three different approaches:

Default result: take the quoted result + 7x7 correlation matrix and marginalize the 5 nuisance parameters (flat priors used)

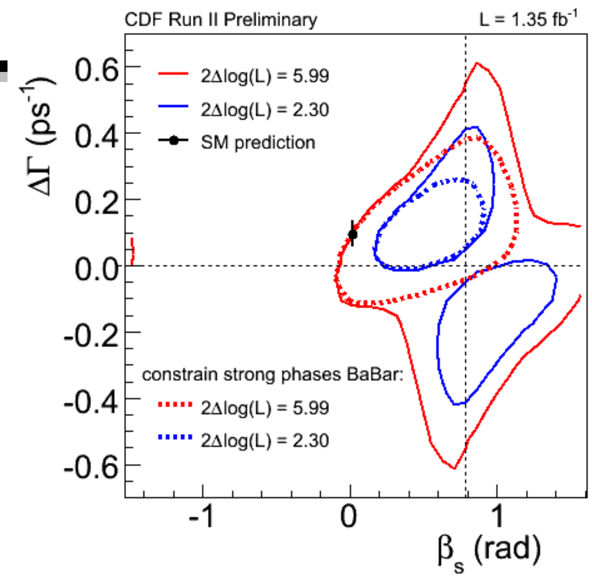
To include non-Gaussian tails:

1) **scale errors such that they agree with the quoted "2σ" ranges: [-0.06, 1.20] → 0.38**
   ***Pessimistic*: the tail is on the opposite side w.r.t. SM but we extend it on the SM side.**
2) **use the 1D profile likelihood given by D0.**
   ***Conservative*: the uncertainty on ϕ_s enters on ϕ_s likelihood directly, as well as in the $\Delta\Gamma$ one (as a nuisance parameter) and vice versa**

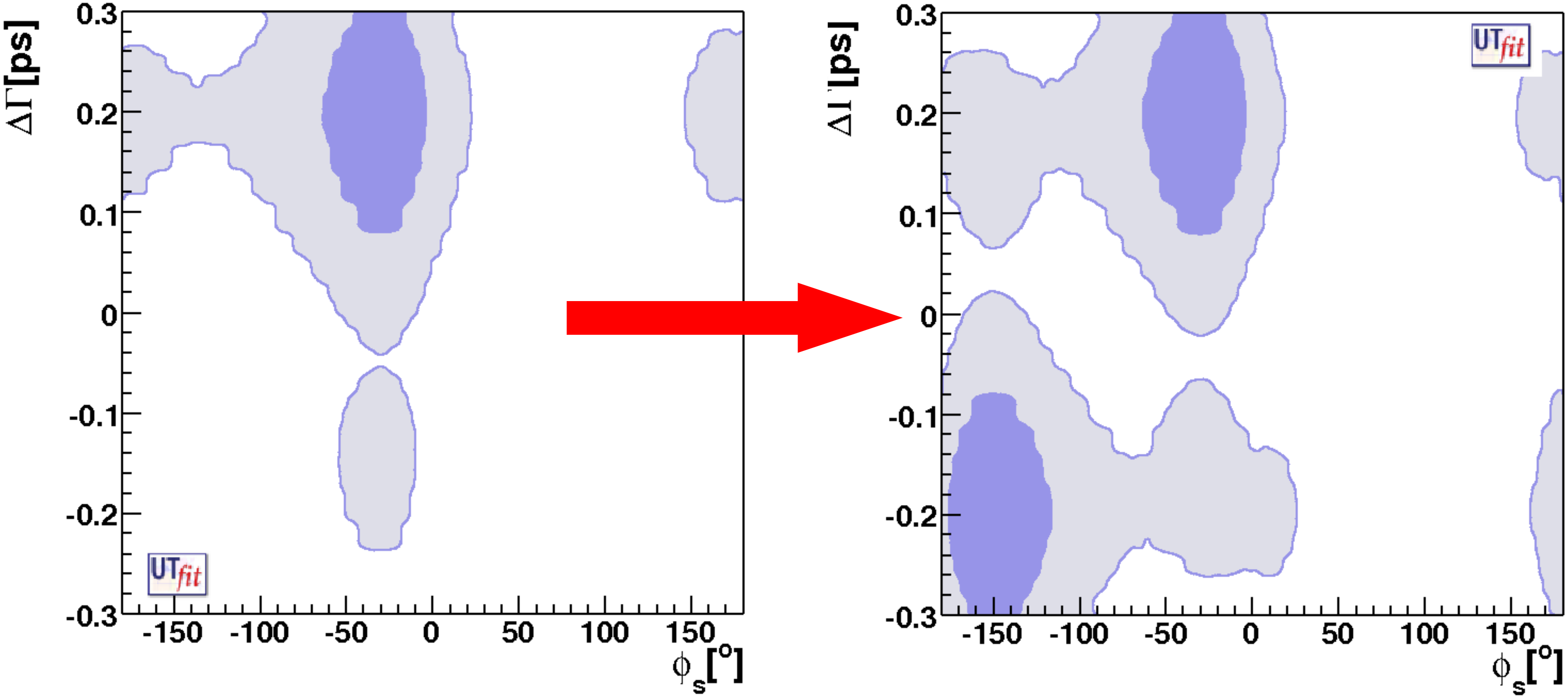




Modeling D0 data (II)

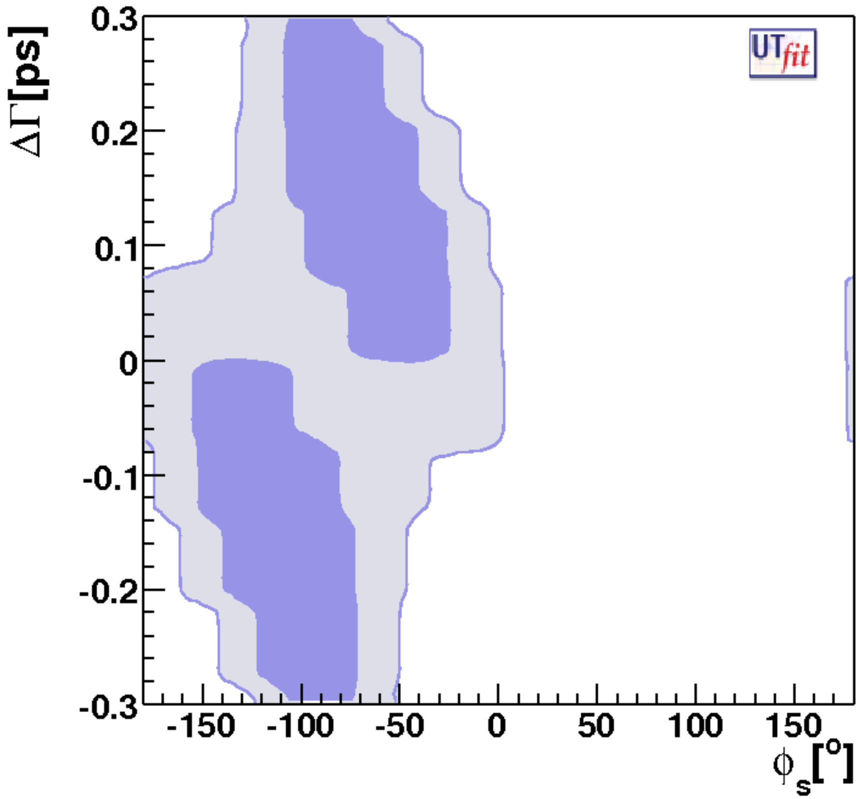


- Strong phase from $B_d \rightarrow J\psi K^*$ + SU(3) (consistent with naive factorization)
- The phase better determined by the fit than by the assumption. But the ambiguity is lost
- The problem: the ϕ singlet component is ignored
- To be conservative, we put it back in the data by mirroring the likelihood before marginalizing for the nuisance parameters

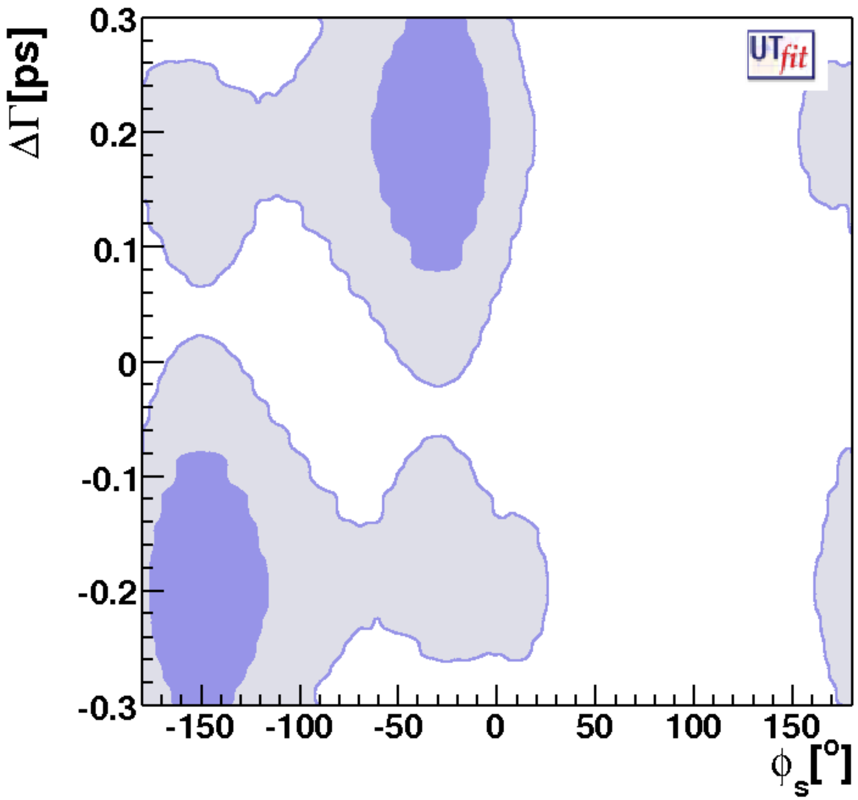


Comparing the measurements

CDF tagged measurement



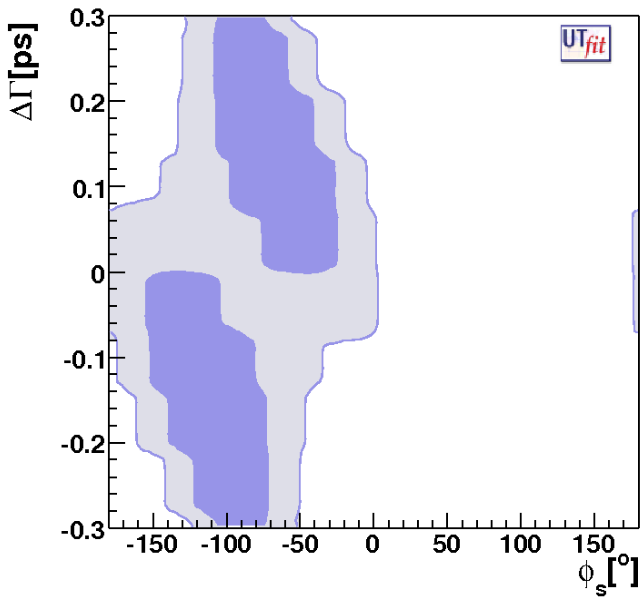
D0 tagged measurement



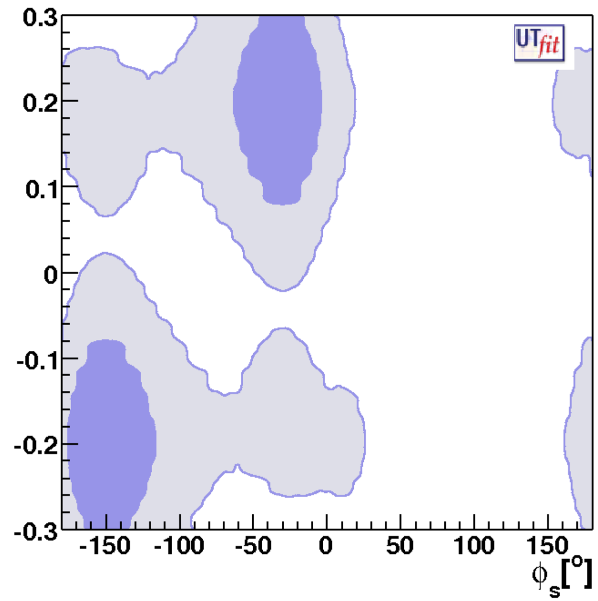
- CDF bound directly provided by the experiment
- D0 bound obtained from the 7 dimensional result as previously explained (profile likelihood case shown here)
- The two measurements are in very good agreement

More than two measurements (I)

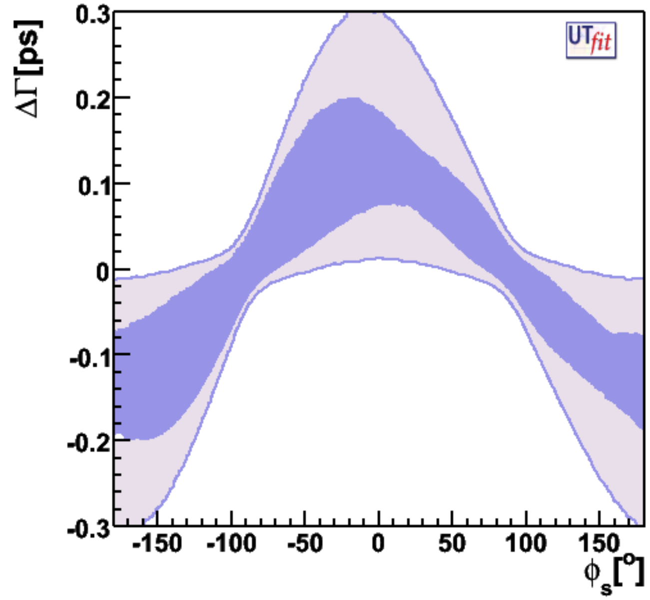
CDF tagged measurement



D0 tagged measurement



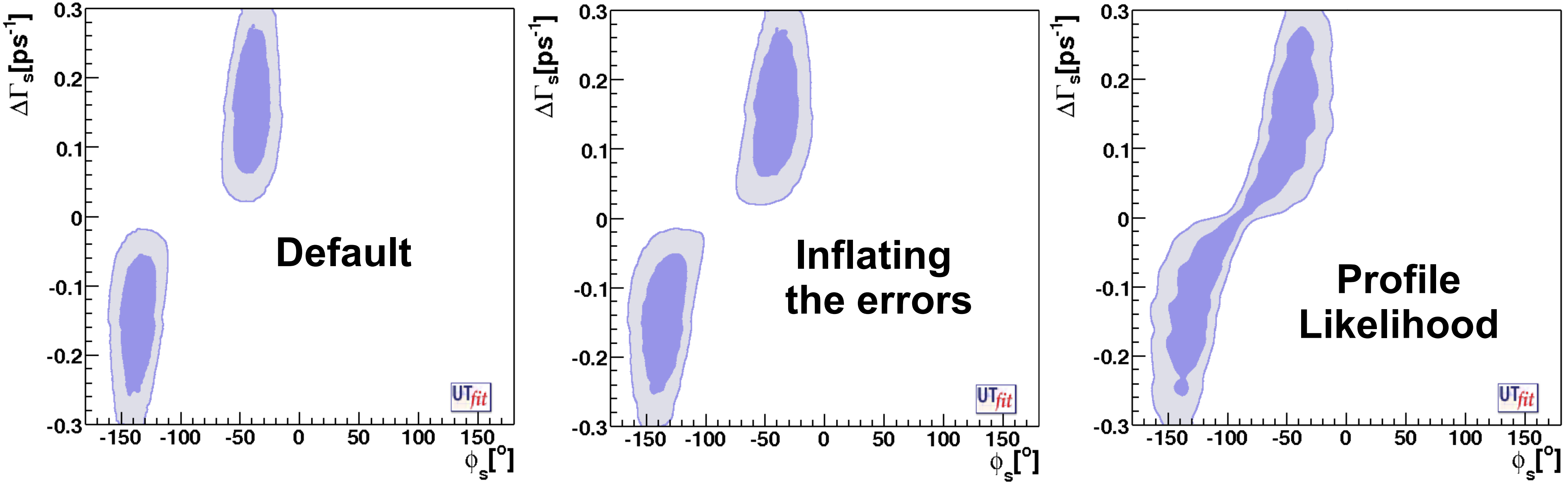
Our analysis (using A_{SL}, A_{CH}, τ_{Bs}, $\Delta\Gamma/\Gamma$)



- CDF and D0 measurements consider $\Delta\Gamma$ and β_s as uncorrelated parameters
- In our analysis, we enforce the dependence of $\Delta\Gamma$ from SM and NP parameters
- There is more physics information in our fit than in a simple combination of the two experimental results

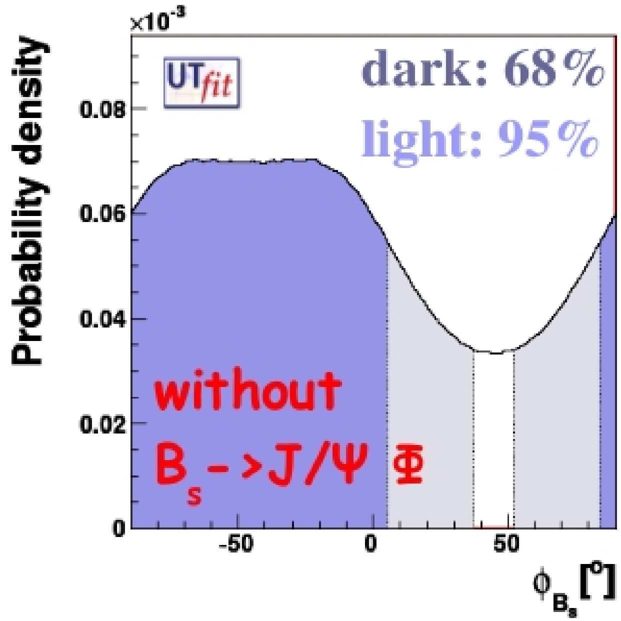
Dependence on the D0 data model

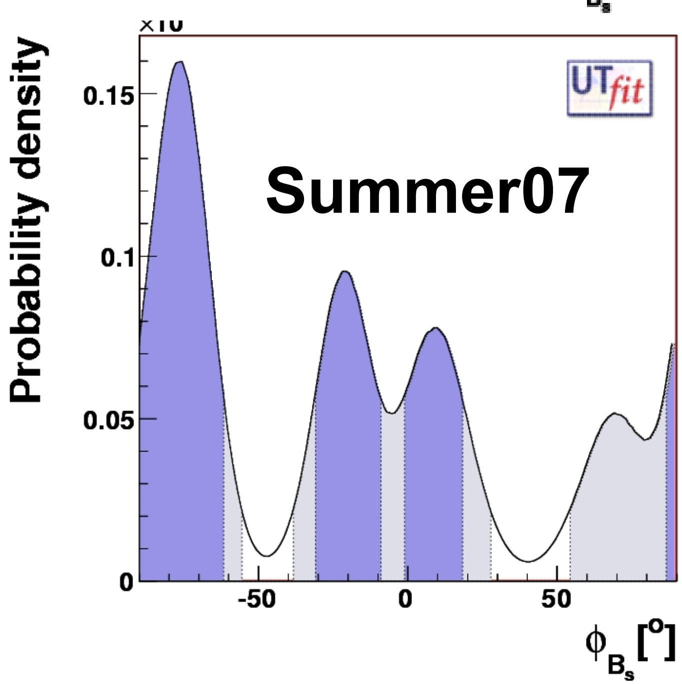
results from all constraints: only the D0 data treatment is changing

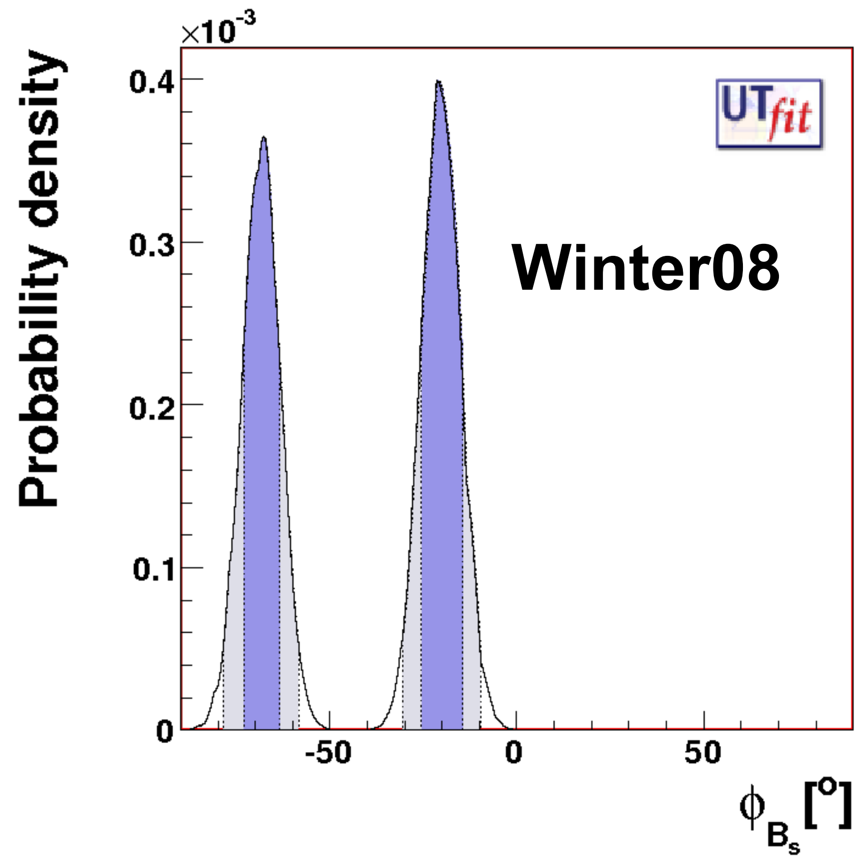


- The details on how we model D0 are crucial on the side opposite to the SM prediction
- The distance from the SM value depends on the approach, but not by O(1) effects
- A reduction of the significance is expected when going from the default to the conservative approaches

Did the result move by a lot?

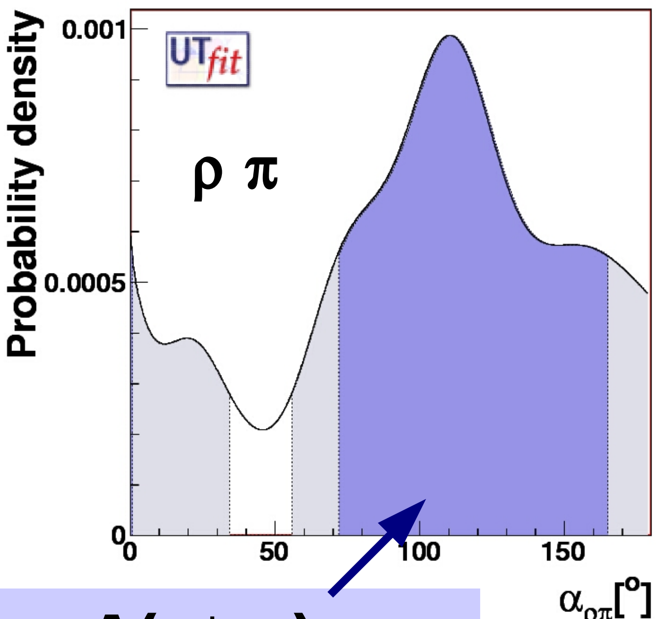


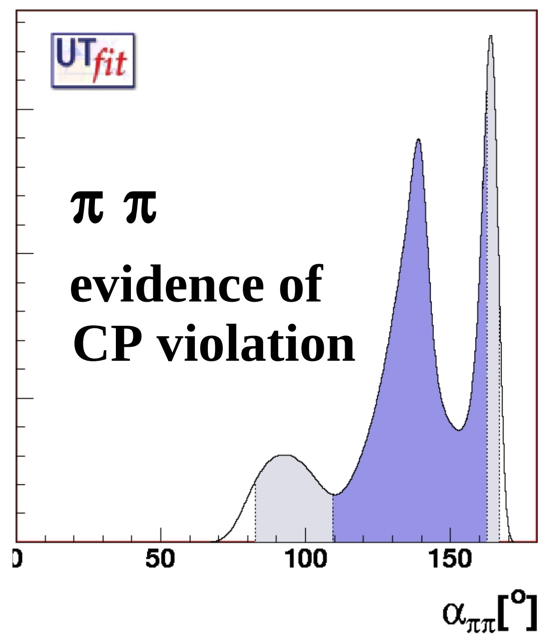


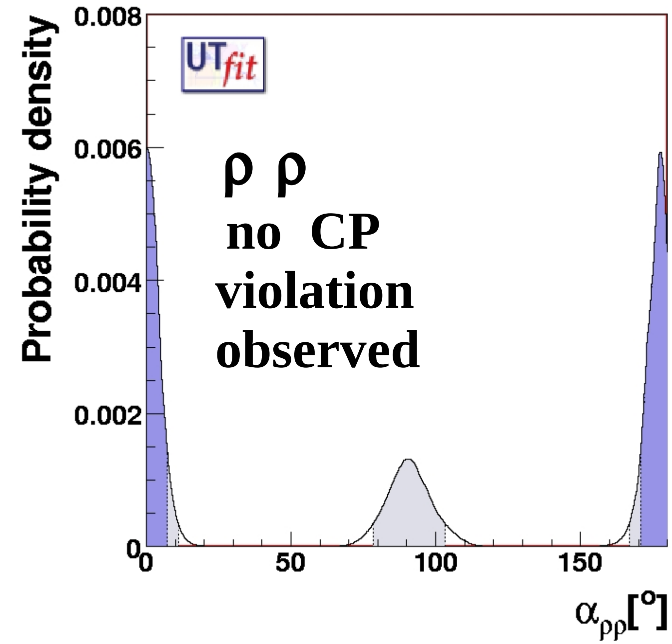


The two most probable peaks last summer are those that survived.

α extraction from the three analyses



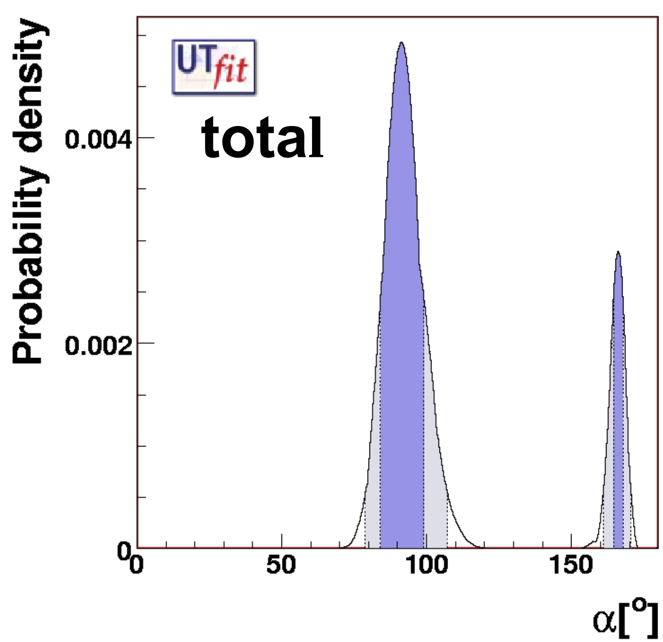


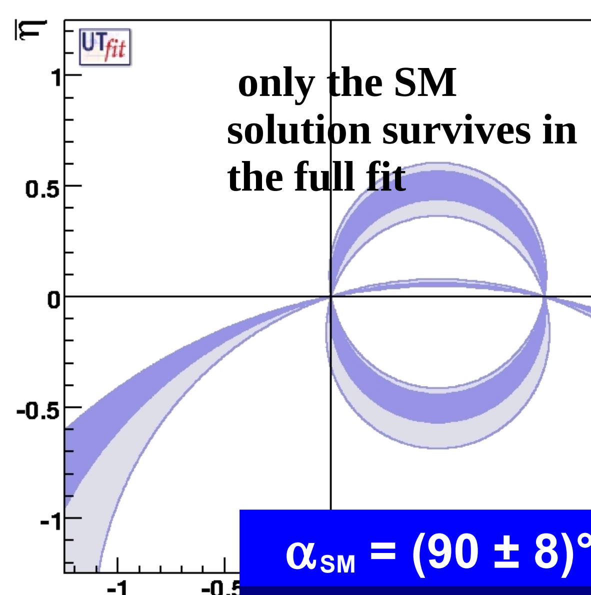


$A = A(\rho^+\pi^-)$
$+A(\rho^-\pi^+)$
$+2A(\rho^0\pi^0)$
$= (T^{+-} + T^{-+}$
$+ 2T^{00})\, e^{2i\alpha}$

$\rightarrow \quad R = \bar{A}/A$
$= e^{2i\alpha}$

no paramete-rization involved

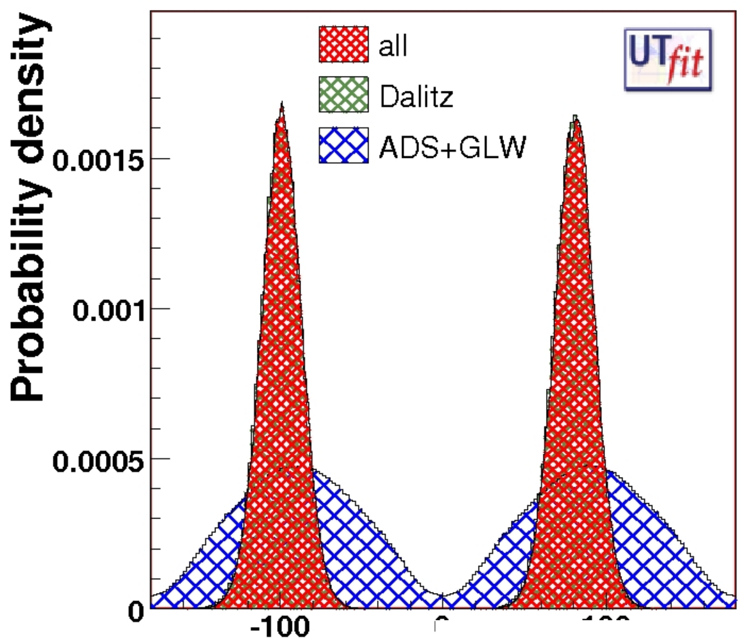


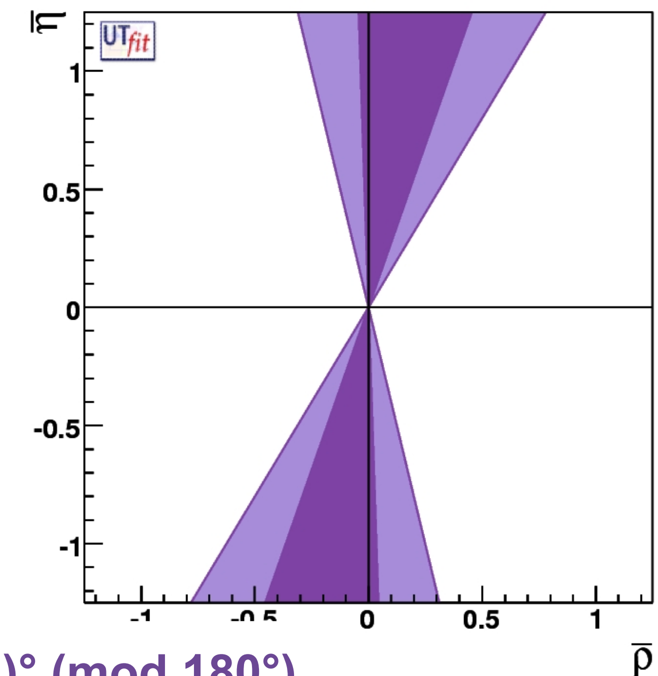


$\alpha_{SM} = (90 \pm 8)°$

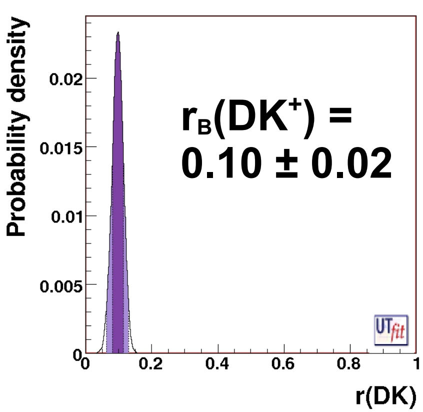
$\alpha_{UTfit} = (92 \pm 4)°$

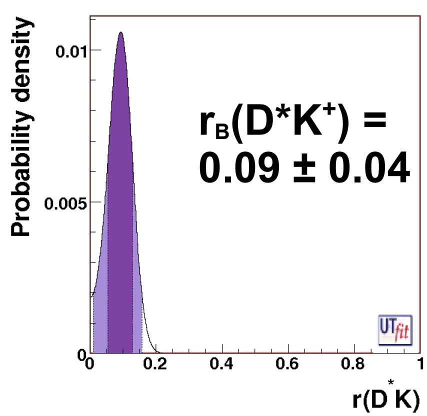
Combining the methods for γ

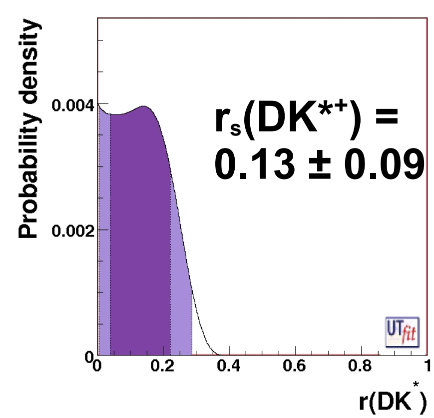




$\gamma = (80 \pm 13)^\circ$ (mod.180°)

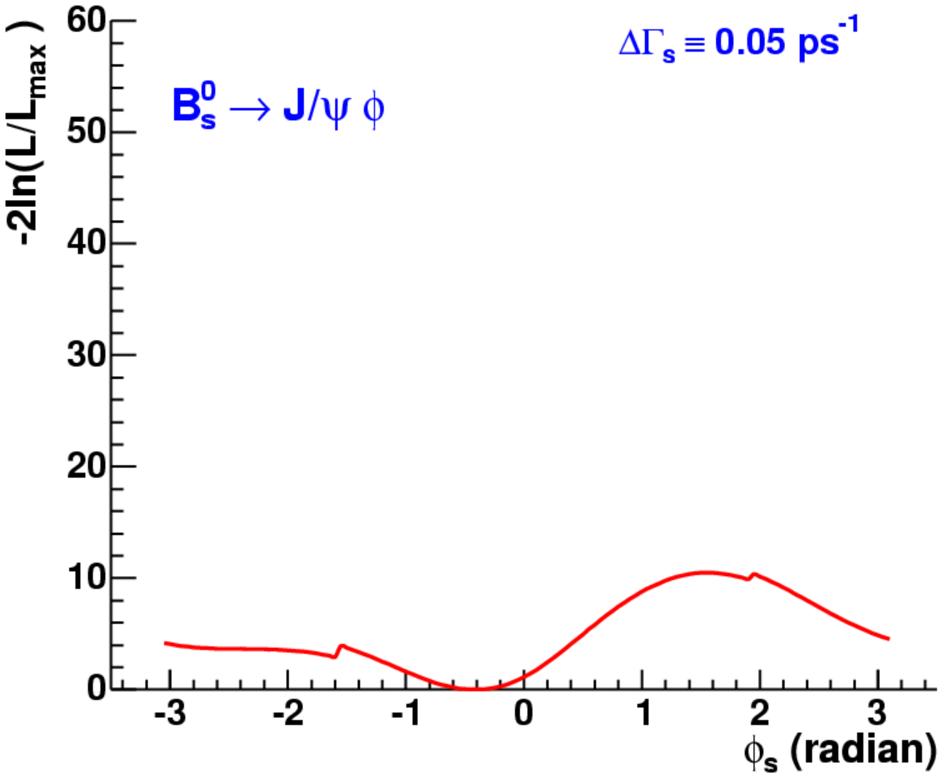


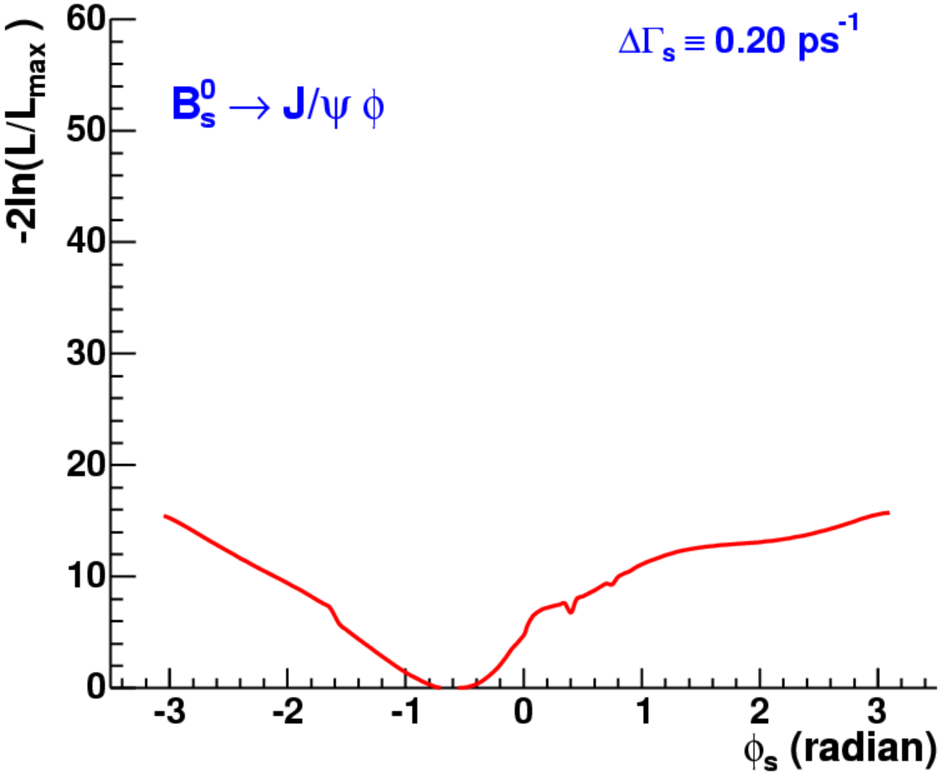




A new 2D likelihood scan from D0

Appeared two weeks ago on the D0 web-site
it hasn't the SU(3) assumption
but the fit looks preliminary:





Update of the LQCD parameters

Lubicz, Tarantino
for UTfit

$$\boxed{\hat{B}_K = 0.75 \pm 0.07},$$

$$f_{B_s} = 245 \pm 25 \text{ MeV} \quad , \quad f_B = 200 \pm 20 \text{ MeV} \quad , \quad f_{B_s}/f_B = 1.21 \pm 0.04 \, ,$$

$$\boxed{f_{B_s}\sqrt{\hat{B}_{B_s}} = 270 \pm 30 \text{ MeV}} \quad , \quad f_B\sqrt{\hat{B}_{B_d}} = 225 \pm 25 \text{ MeV} \quad , \quad \boxed{\xi = 1.21 \pm 0.04},$$

$$\boxed{\hat{B}_{B_d} = \hat{B}_{B_s} = 1.22 \pm 0.12}, \quad \hat{B}_{B_s}/\hat{B}_{B_d} = 1.00 \pm 0.03 \, ,$$

$$\boxed{|V_{cb}| \text{ (excl.)} = (39.2 \pm 1.1) \cdot 10^{-3}} \quad , \quad \boxed{|V_{ub}| \text{ (excl.)} = (35.0 \pm 4.0) \cdot 10^{-4}}.$$

These averages can be compared with the previous ones used by UTfit

$$\hat{B}_K = 0.79 \pm 0.04 \pm 0.08 \, ,$$

$$f_{B_s} = 230 \pm 30 \text{ MeV} \quad , \quad f_B = 189 \pm 27 \text{ MeV} \quad , \quad f_{B_s}/f_B = 1.22^{+0.05}_{-0.06} \, ,$$

$$\boxed{f_{B_s}\sqrt{\hat{B}_{B_s}} = 262 \pm 35 \text{ MeV}} \quad , \quad f_B\sqrt{\hat{B}_{B_d}} = 214 \pm 38 \text{ MeV} \quad , \quad \boxed{\xi = 1.23 \pm 0.06},$$

$$\hat{B}_{B_d} = 1.28 \pm 0.05 \pm 0.09 \quad , \quad \hat{B}_{B_s}/\hat{B}_{B_d} = 1.02 \pm 0.02^{+0.06}_{-0.02} \, ,$$

$$|V_{cb}| \text{ (excl.)} = (39.1 \pm 0.6 \pm 1.7) \cdot 10^{-3} \quad , \quad |V_{ub}| \text{ (excl.)} = (34.0 \pm 4.0) \cdot 10^{-4} \, .$$

M.Ciuchini
CERN 08

If this evidence is confirmed...

- MFV models are ruled out, including the simplest realizations of the MSSM
- the following pattern of flavour violation in NP emerges:

  1 <-> 2: strong suppression
  1 <-> 3: $\lesssim O(10\%)$
  2 <-> 3: $O(1)$

  this pattern is not unexpected in flavour models and SUSY-GUTs
- In progress: (i) update of the $\Delta F=2$ operator analysis, (ii) correlations with $\Delta F=1$ in MSSM

Marco Ciuchini IFAE - Bologna, 28 March 2008 Page 23

A^{NP}_d/A^{SM}_d~0.1 and A^{NP}_s/A^{SM}_s~0.7 correspond to $A^{NP}_d/A^{NP}_s \sim \lambda^2$ i.e. to an additional λ suppression.

L.Silvestrini
Capri 08

- Lower bounds on NP scale from K and B_d physics: (in TeV at 95% probability)

Scenario	strong/tree	α_s loop	α_W loop
MFV	5.5	0.5	0.2
NMFV	62	6.2	2
General	24000	2400	800

- Upper bounds on NP scale from ϕ_s:

Scenario	strong/tree	α_s loop	α_W loop
NMFV	35	4	2
General	800	80	30

- Need a flavour structure, but not NMFV!

Silvestrini Capri, 16/6/2008

- Large NP contributions to $b \leftrightarrow s$ transitions are natural in nonabelian flavour models, given the large breaking of flavour SU(3) due to the top quark mass

Pomarol, Tommasini; Barbieri, Dvali, Hall; Barbieri, Hall; Barbieri, Hall, Romanino; Berezhiani, Rossi; Masiero et al; …

- GUTs can naturally connect the large mixing in ν oscillations with a large $b \leftrightarrow s$ mixing Baek et al.; Moroi; Akama et al.; Chang, Masiero, Murayama; Hisano, Shimizu; Goto et al.; …

- In a given model expect correlation between $b \leftrightarrow s$ (B_s mixing) and $b \to s$ (penguin decays) transitions
- This correlation is welcome given the large room for NP in $b \to s$ hadronic penguins (S_{peng}, $A_{K\pi}$, ...) Beneke; Buchalla et al.; Buras et al.; London et al.; Hou et al.; Lunghi & Soni; Feldmann et al.; ...
- The correlation is however affected by large hadronic uncertainties

The future of CKM fits

LHCb reach from: O. Schneider, 1st LHCb Collaboration Upgrade Workshop

SuperB reach from: SuperB Conceptual Design Report, arXiv:0709.0451

	LHCb 2015 10/fb (5 years)	SuperB 1/ab (1 month at Υ(5S))
Δm_s	0.07%(+0.5%)	no
A^s_{SL}	?	0.006
ϕ_s ($J/\psi\ \phi$)	0.01+syst	0.14
		75/ab (5 years)
$\sin 2\beta$ ($J/\psi\ K_s$)	0.010	0.005
γ (all methods)	2.4°	1-2°
α (all methods)	4.5°	1-2°
$\lvert V_{cb}\rvert$ (all methods)	no	< 1%
$\lvert V_{ub}\rvert$ (all methods)	no	1-2%

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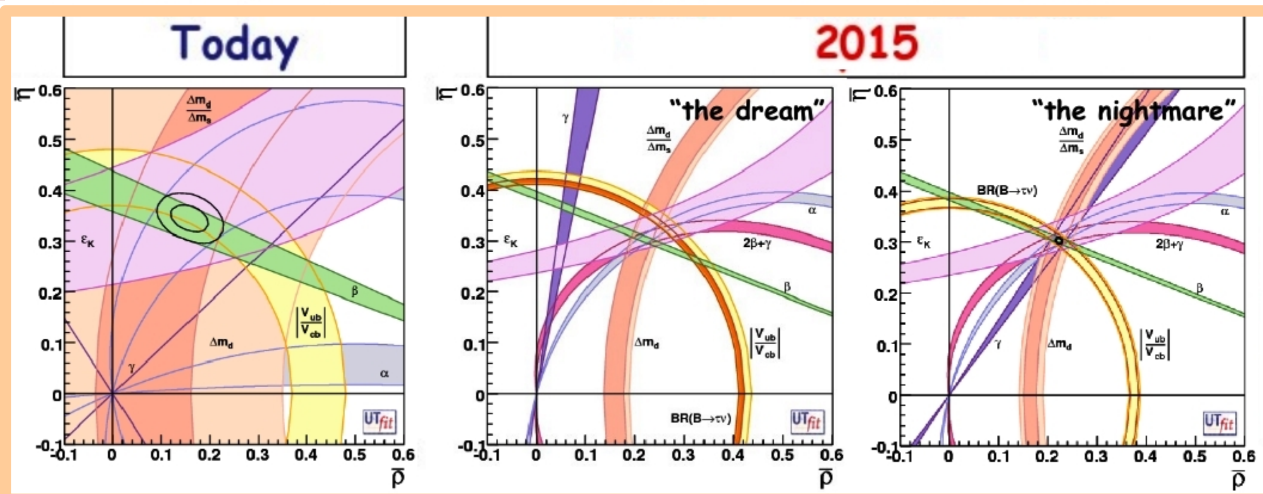
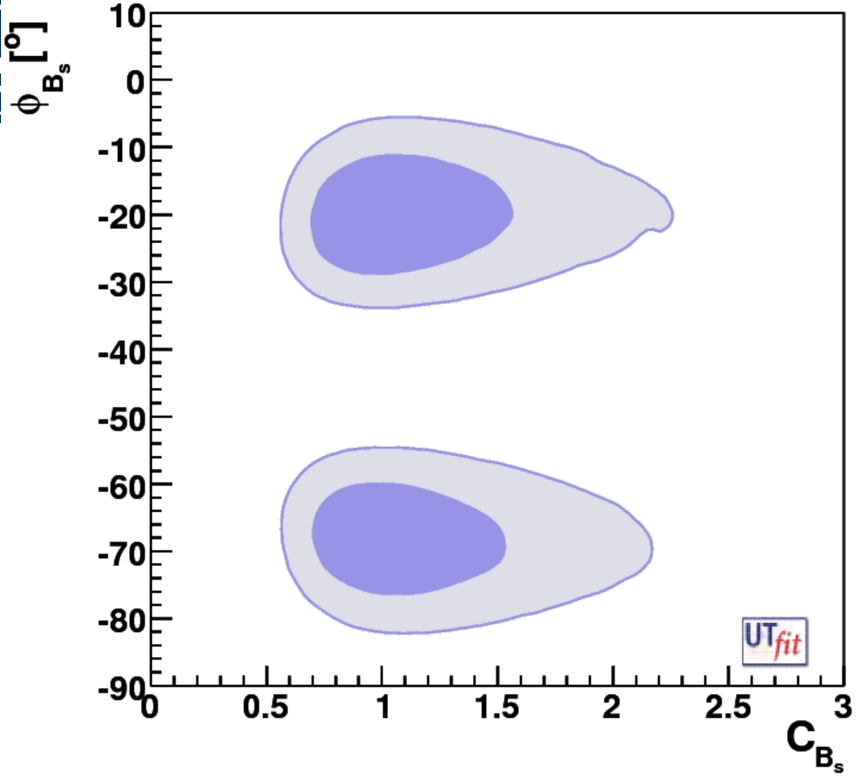
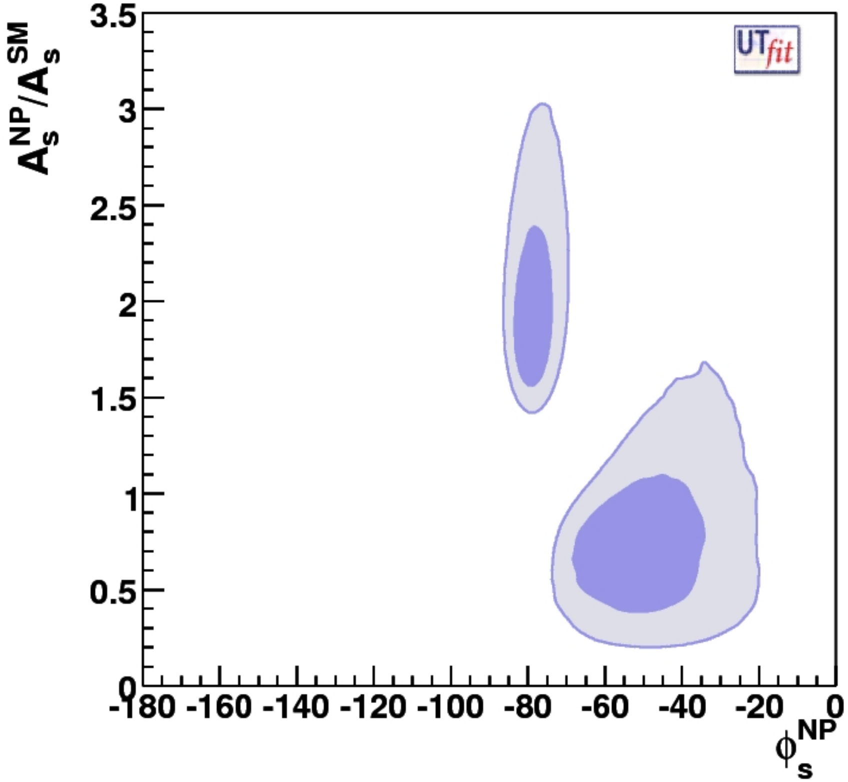
Hadronic matrix element	Current lattice error	60 TFlop Year [2011 LHCb]	1-10 PFlop Year [2015 SuperB]
$f_+^{K\pi}(0)$	0.9% (22% on 1-f_+)	0.4% (10% on 1-f_+)	< 0.1% (2.4% on 1-f_+)
$\hat{B}_K$	11%	3%	1%
f_B	14%	2.5 - 4.0%	1 – 1.5%
$f_{B_s} B_{B_s}^{1/2}$	13%	3 - 4%	1 – 1.5%
ξ	5% (26% on ξ-1)	1.5 - 2 % (9-12% on ξ-1)	0.5 – 0.8 % (3-4% on ξ-1)
$\mathcal{F}_{B\to D/D^* l\nu}$	4% (40% on 1-$\mathcal{F}$)	1.2% (13% on 1-$\mathcal{F}$)	0.5% (5% on 1-$\mathcal{F}$)
$f_+^{B\pi}, \ldots$	11%	4 - 5%	2 – 3%
$T_1^{B\to K^*/\rho}$	13%	----	3 – 4%

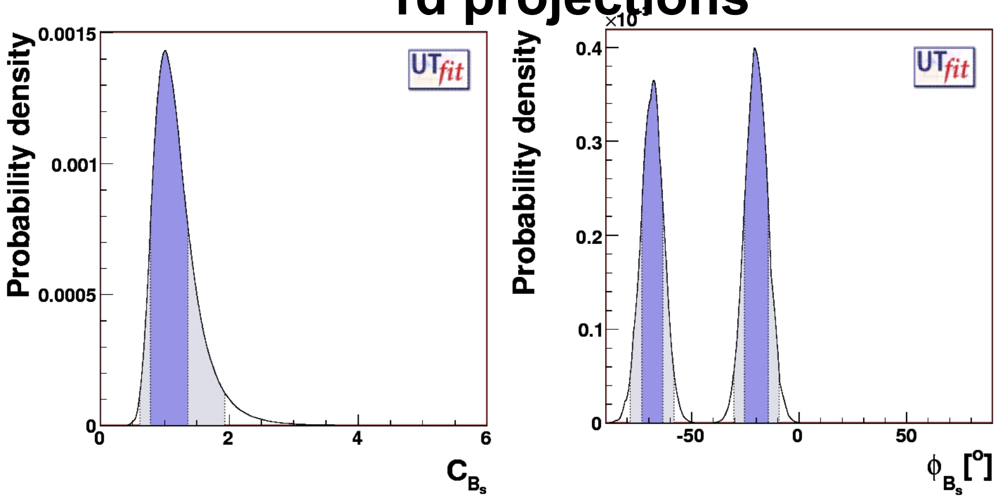
S.Sharpe @ Lattice QCD: Present and Future, Orsay, 2004 and report of the U.S. Lattice QCD Executive Committee



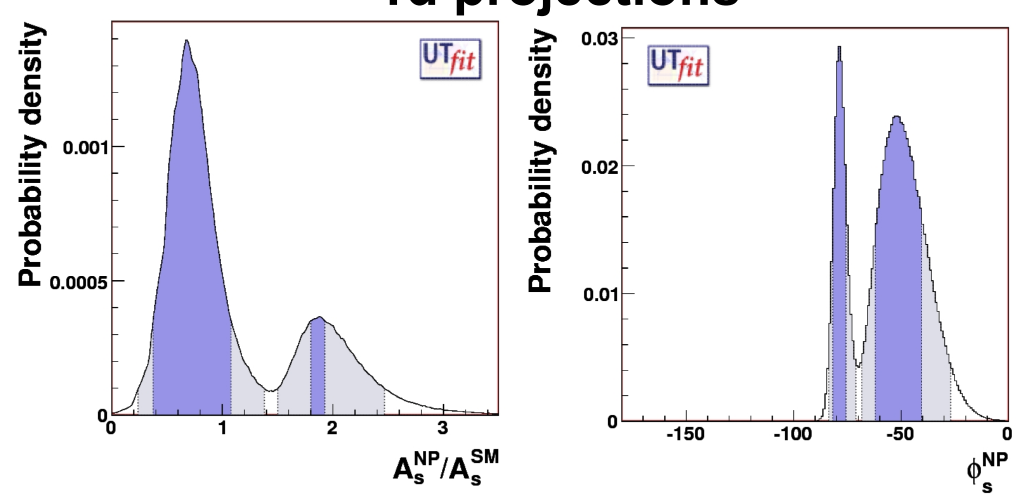




1d projections

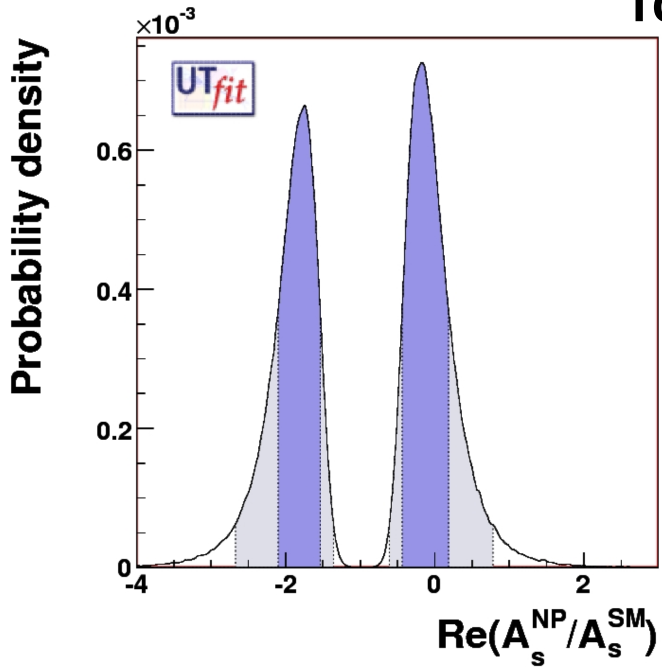


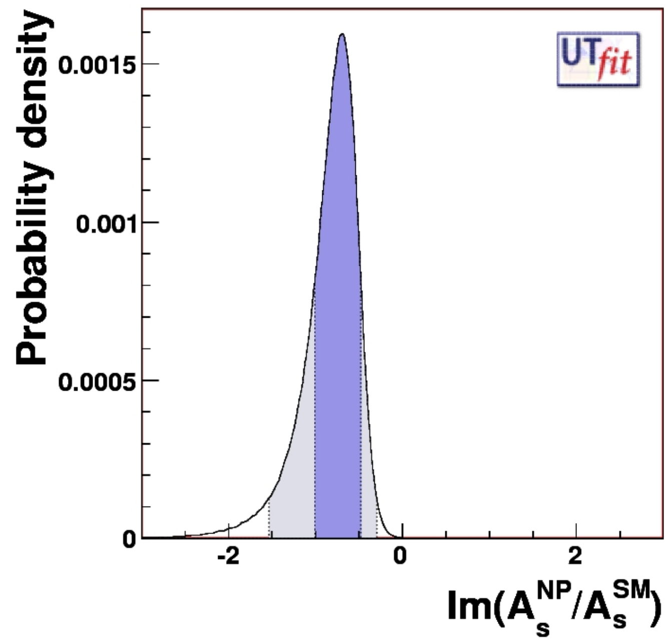
1d projections

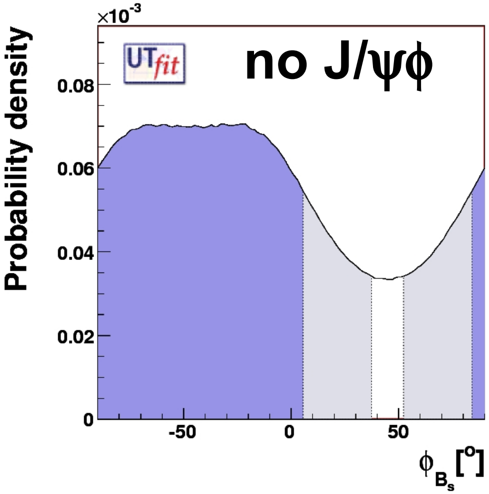


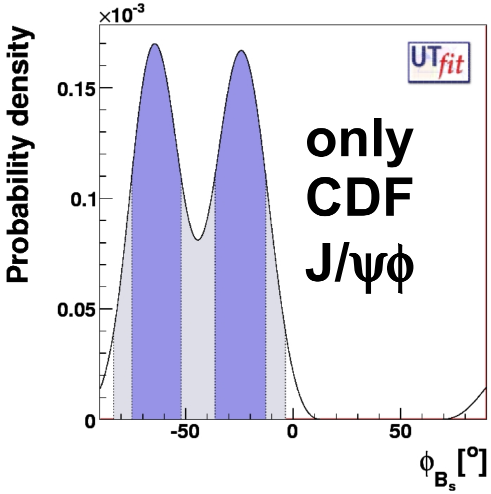
plots from: arXiv:0803.0659 [hep-ph]

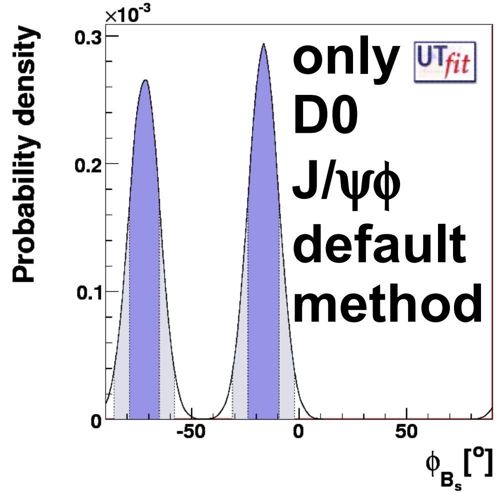
1d projections

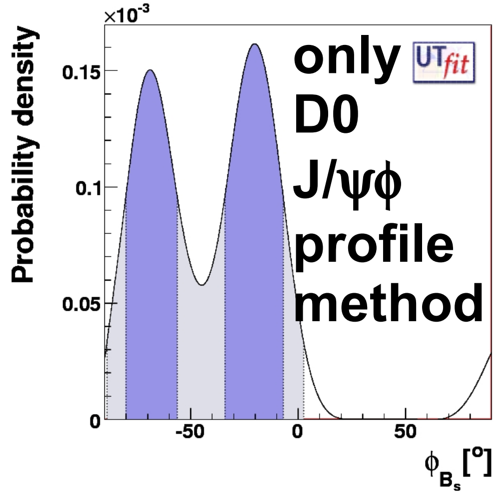






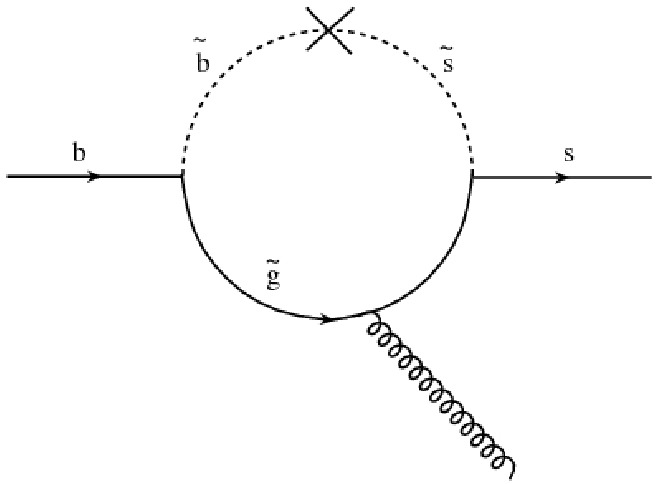


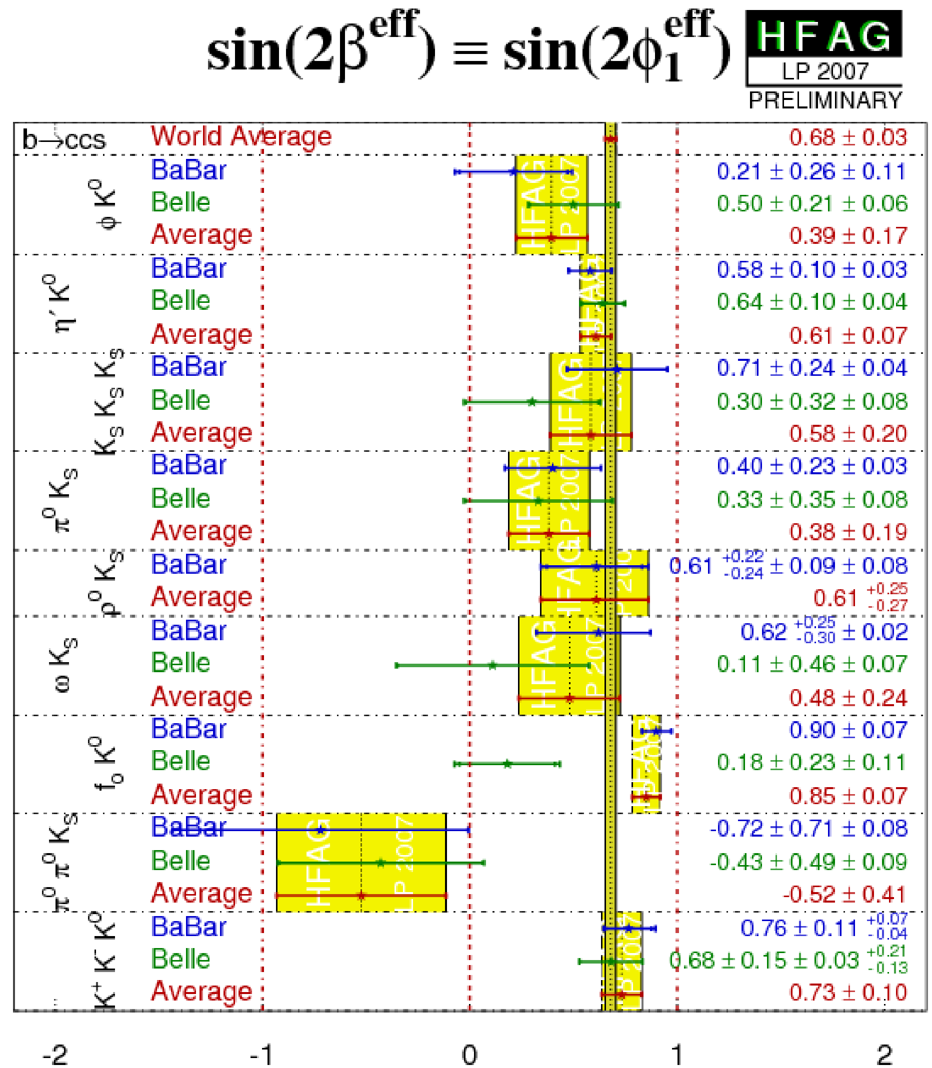




plots from: arXiv:0803.0659 [hep-ph]

b → s penguins





- ◉ **Extra sources of FCNC: investigation looking at b ↔ s penguin decays**
- ◉ **Some “hints” seen on sin2β in penguin decays**
- ◉ **Difficult interpretation due to theoretical issues (but SM hadron corrections are expected to induce positive shifts)**

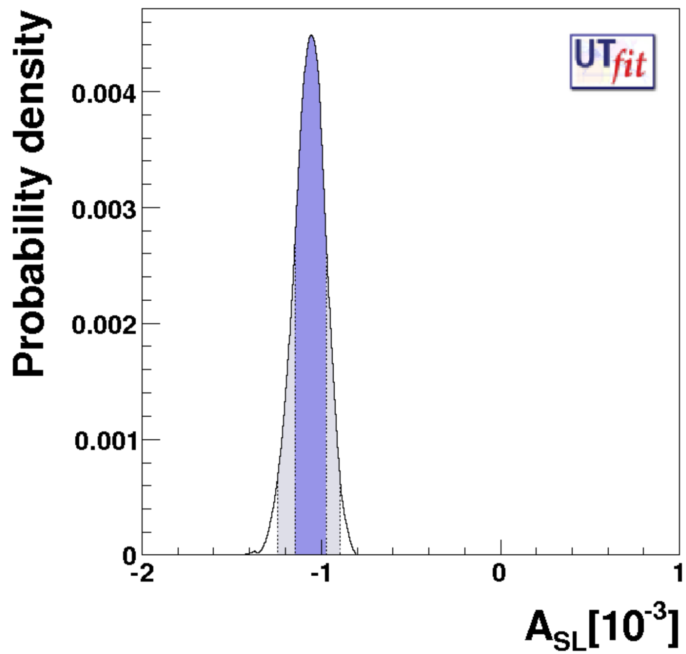
Semileptonic Asymmetry A_{SL}

$$A_{\rm SL} \equiv \frac{\Gamma(\bar{B}^0 \to \ell^+ X) - \Gamma(B^0 \to \ell^- X)}{\Gamma(\bar{B}^0 \to \ell^+ X) + \Gamma(B^0 \to \ell^- X)}$$
$$= -{\rm Re}\left(\frac{\Gamma_{12}}{M_{12}}\right)^{\rm SM} \frac{\sin 2\phi_{B_d}}{C_{B_d}} + {\rm Im}\left(\frac{\Gamma_{12}}{M_{12}}\right)^{\rm SM} \frac{\cos 2\phi_{B_d}}{C_{B_d}}$$

SM prediction $(-1.06\pm0.09)10^{-3}$

Direct measurement $(-0.3\pm5.0)10^{-3}$

Laplace, Ligeti, Nir and Perez Phys.Rev.D 65:094040,2002



Similar constraint available both Bs decays

$\Delta\Gamma$ for B_d and B_s

$$\frac{\Delta\Gamma_q}{\Delta m_q} = -2\frac{\kappa}{C_{B_q}}\left\{\cos(2\phi_{B_q})\left(n_1 + \frac{n_6 B_2 + n_{11}}{B_1}\right) - \frac{\cos(\phi_q^{SM} + 2\phi_{B_q})}{R_t^q}\left(n_2 + \frac{n_7 B_2 + n_{12}}{B_1}\right) + \frac{\cos(2(\phi_q^{SM} + \phi_{B_q}))}{R_t^{q^2}}\right.$$
$$\left.\left(n_3 + \frac{n_8 B_2 + n_{13}}{B_1}\right) + \cos(\phi_q^{Pen} + 2\phi_{B_q})\, C_q^{Pen}\left(n_4 + n_9\frac{B_2}{B_1}\right) - \cos(\phi_q^{SM} + \phi_q^{Pen} + 2\phi_{B_q})\frac{C_q^{Pen}}{R_t^q}\left(n_5 + n_{10}\frac{B_2}{B_1}\right)\right\}$$

- The constraint on B_d is not effective (experimental error~ 10 times the precision from the rest of the fit)

	SM	SM+NP	exp
$10^3\,\Delta\Gamma_d/\Gamma_d$	2.8 ± 2.7	2.0 ± 1.8	9 ± 37
$\Delta\Gamma_s/\Gamma_s$	0.10 ± 0.06	0.00 ± 0.08	0.25 ± 0.09

- The experimental measurement of $\Delta\Gamma_s$ actually measures $\Delta\Gamma_s \cos(\beta_s + \phi_{Bs})$ (Dunietz et al., hep-ph/0012219)
- NP can only decrease the experimental result wrt the SM value
- Experimental WA > SM expectation (NP suppressed)

NLO calculation of the matrix element of B meson mixing

Ciuchini et al. JHEP 0308:031,2003.

Same Sign dilepton charge asymmetry

Ratio of B_d and B_s production at Tevatron

Semileptonic asymmetries of Bd and Bs mesons

$$A_{CH} = \frac{1}{4}\left(A^d_{\mathrm{SL}} + \frac{f_s \chi_{s0}}{f_d \chi_{d0}} A^s_{\mathrm{SL}}\right)$$

$$\overset{(-)}{\chi}_q = \frac{\frac{\Delta\Gamma_q}{\Gamma_q}^2 + 4\frac{\Delta m_q}{\Gamma_q}^2}{\frac{\Delta\Gamma_q}{\Gamma_q}^2(\overset{(-)}{z}_q - 1) + 4(2\overset{(-)}{z}_q + \frac{\Delta m_q}{\Gamma_q}^2(1 + \overset{(-)}{z}_q))}$$

With $z = |q/p|^2$ and $\bar{z} = |p/q|^2$

From NLO calculation of the B meson mixing

τ_{Bs} in Flavor Specific final states

- B_s and $\overline{B}_s$ lifetime difference induced by $\Delta\Gamma_s$
- Experimental fit done with a single exponential rather than two exponentials
- The "average" lifetime is a function of the width and width difference

τ_{Bs} in Flavor Specific final states

$$\tau_{B_s}^{FS} = \frac{1}{\Gamma_s} \frac{1 - \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1 + \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$$

Time-dependent angular analysis

TAGGED	UNTAGGED
2-fold ambiguity	*4-fold ambiguity*
$(\pi-\phi_s, -\Delta\Gamma_s, \pi-\delta_{1,2})$	$(\pi+\phi_s, -\Delta\Gamma_s, \pm\delta_{1,2})$
	$(-\phi_s, \Delta\Gamma_s, \pm(\pi-\delta_{1,2}))$
	$(\pi-\phi_s, -\Delta\Gamma_s, \pm(\pi-\delta_{1,2}))$

Dunietz, Fleischer, Nierste
hep-ph/0012219

$$\frac{d^4\Gamma}{dt\,d\cos\theta\,d\varphi\,d\cos\psi} \propto$$
$$2\cos^2\psi(1-\sin^2\theta\cos^2\varphi)|A_0(t)|^2$$
$$+\sin^2\psi(1-\sin^2\theta\sin^2\varphi)|A_{\|}(t)|^2$$
$$+\sin^2\psi\sin^2\theta|A_\perp(t)|^2$$
$$+(1/\sqrt{2})\sin 2\psi\sin^2\theta\sin 2\varphi \mathrm{Re}(A_0^*(t)A_{\|}(t))$$
$$+\ (1/\sqrt{2})\sin 2\psi\sin 2\theta\cos\varphi \mathrm{Im}(A_0^*(t)A_\perp(t))$$
$$-\ \sin^2\psi\sin 2\theta\sin\varphi \mathrm{Im}(A_{\|}^*(t)A_\perp(t)).$$

$$|A_0(t)|^2 = |A_0(0)|^2 e^{-\Gamma t}\left[\cosh\frac{\Delta\Gamma\, t}{2} - |\cos\phi|\sinh\frac{|\Delta\Gamma|\, t}{2} + \sin\phi\,\sin(\Delta m\, t)\right]$$

$$|\overline{A}_0(t)|^2 = |A_0(0)|^2 e^{-\Gamma t}\left[\cosh\frac{\Delta\Gamma\, t}{2} - |\cos\phi|\sinh\frac{|\Delta\Gamma|\, t}{2} - \sin\phi\,\sin(\Delta m\, t)\right]$$

$$\mathrm{Im}\{A_0^*(t)A_\perp(t)\} = |A_0(0)|\,|A_\perp(0)|\,e^{-\Gamma t}$$
$$\times\left[\sin\delta_2\,\cos(\Delta m\, t) - \cos\delta_2\,\cos\phi\,\sin(\Delta m\, t) - \cos\delta_2\,\sin\phi\,\sinh\frac{\Delta\Gamma\, t}{2}\right]$$

$$\mathrm{Im}\{\overline{A}_0^*(t)\overline{A}_\perp(t)\} = |A_0(0)|\,|A_\perp(0)|\,e^{-\Gamma t}$$
$$\times\left[-\sin\delta_2\,\cos(\Delta m\, t) + \cos\delta_2\,\cos\phi\,\sin(\Delta m\, t) - \cos\delta_2\,\sin\phi\,\sinh\frac{\Delta\Gamma\, t}{2}\right]$$

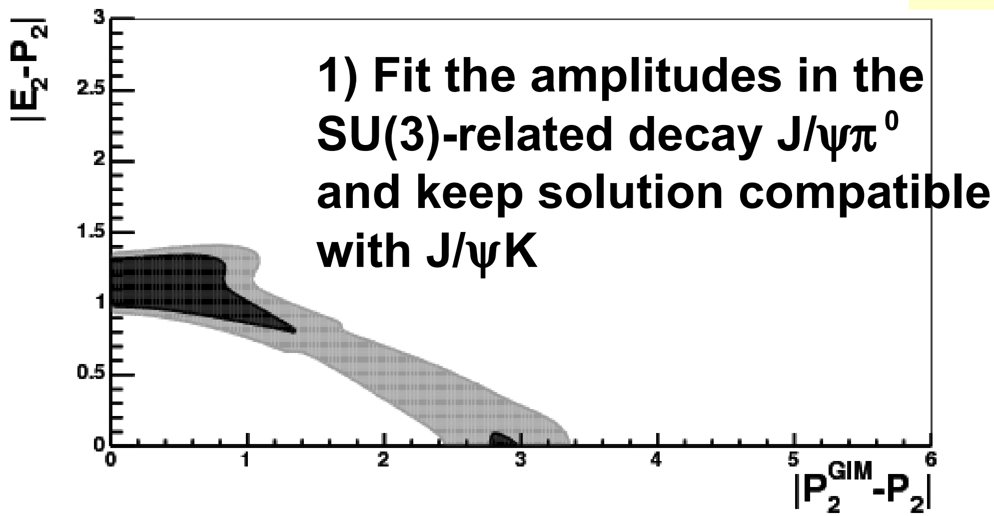
Theory error on sin2β

A.Buras, L.Silvestrini
Nucl.Phys.B569:3-52(2000)

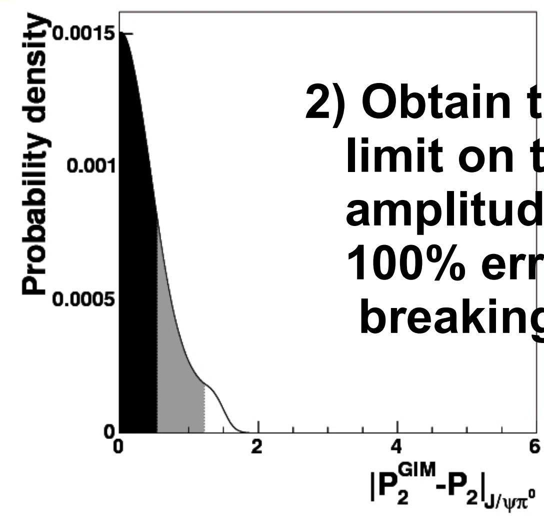
Channel	Cl.	E_1	E_2	EA_2	A_2	P_1	P_2	P_3	P_1^{GIM}	P_2^{GIM}	P_3^{GIM}	P_4	P_4^{GIM}
		1	$\frac{1}{N}$	$\frac{1}{N^2}$	$\frac{1}{N}$	$\frac{1}{N}$	$\frac{1}{N^2}$?	1	1	$\frac{1}{N^2}$?	1	1	$\frac{1}{N^3}$
$B_d \to J/\psi K^0$			λ^2	–	–	–	λ^2			λ^4			–
$B_d \to \pi^0 J/\psi$	D	–	λ^3	λ^3	–	–	λ^3	–	–	λ^3	–	$[\lambda^3]$	$[\lambda^3]$

$V^*_{cb}V_{cs}$ $V^*_{tb}V_{ts}$ $V^*_{ub}V_{us}$

$V^*_{cb}V_{cd}$ $V^*_{tb}V_{td}$ $V^*_{ub}V_{ud}$

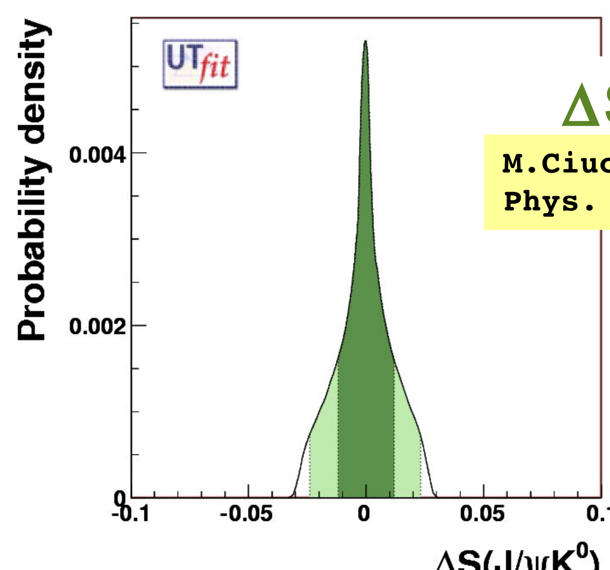


1) Fit the amplitudes in the SU(3)-related decay $J/\psi\pi^0$ and keep solution compatible with $J/\psi K$



2) Obtain the upper limit on the penguin amplitude and add 100% error for SU(3) breaking

3) Fit the amplitudes in $J/\psi K^0$ imposing the upper bound on the CKM suppressed amplitude and extract the error on sin2β

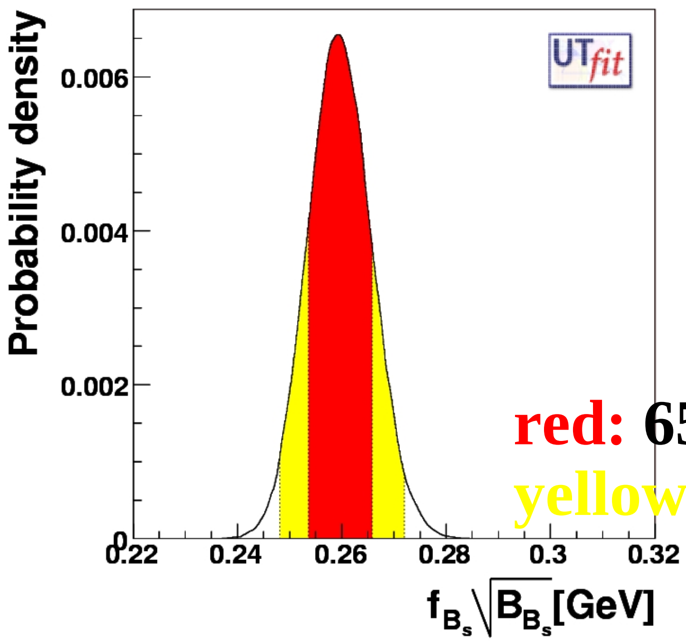


$\Delta S = 0.000 \pm 0.012$

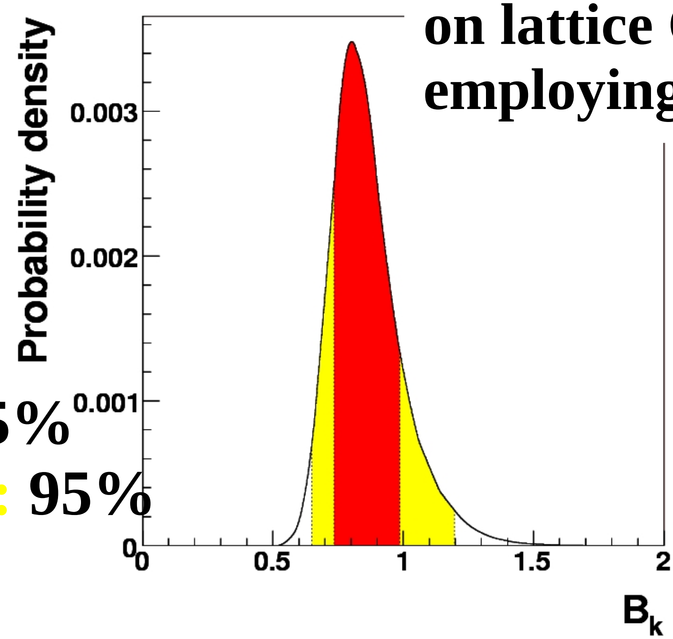
M.Ciuchini, M.Pierini, L.Silvestrini
Phys. Rev. Lett. 95, 221804 (2005)

LQCD predictions

It is possible to obtain predictions on lattice QCD parameters employing all the other inputs

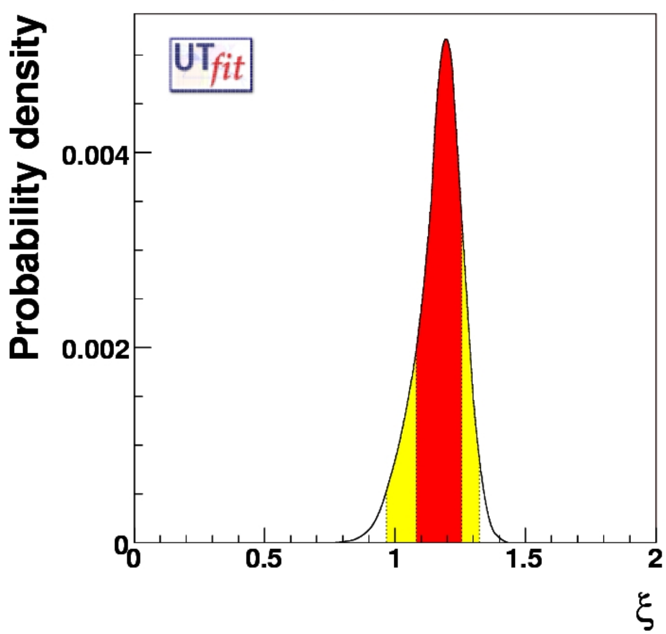


red: 65%
yellow: 95%



$f_{B_s}\sqrt{B_{B_s}} = 259 \pm 6$

$f_{B_s}\sqrt{B_{B_s}} = 276 \pm 38$ LQCD



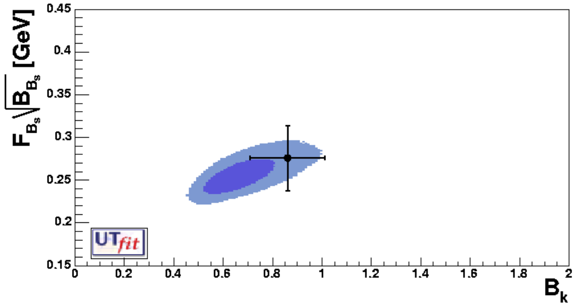
$B_K = 0.86 \pm 0.13$

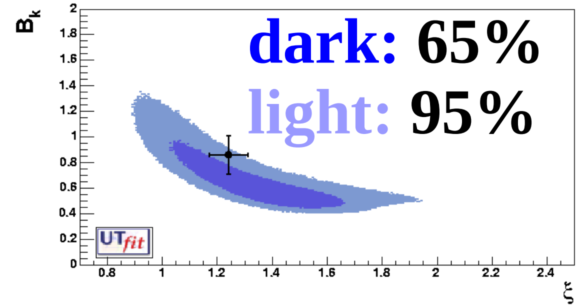
$B_K = 0.79 \pm 0.04 \pm 0.09$ LQCD

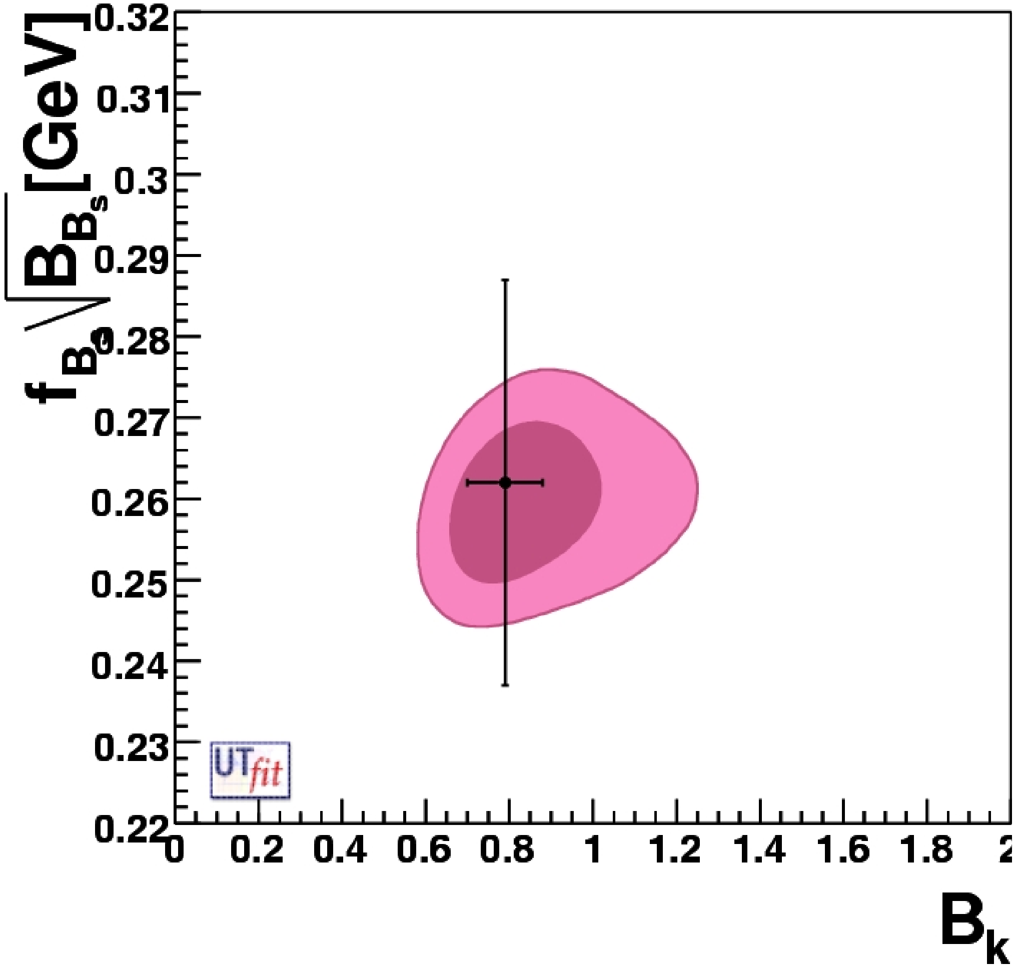
$\xi = 1.17 \pm 0.08$

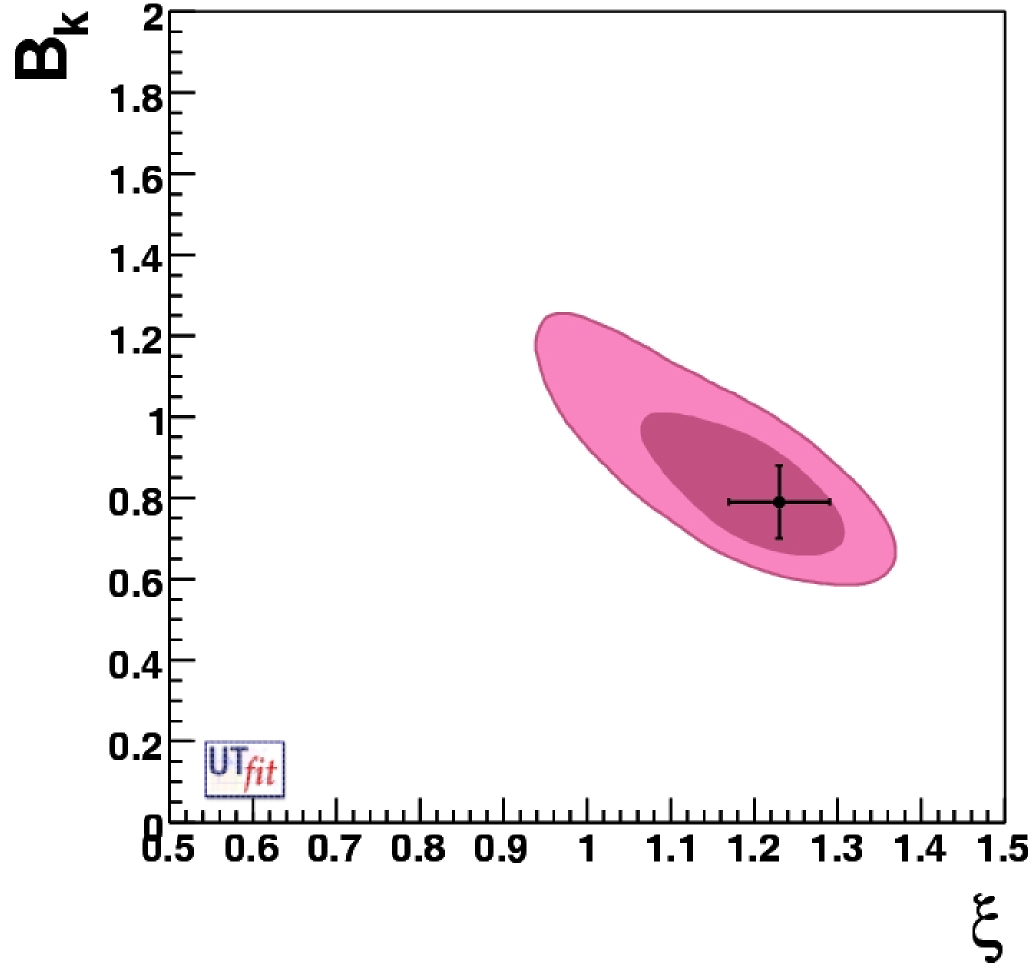
$\xi = 1.24 \pm 0.04 \pm 0.06$ LQCD

LQCD predictions (II)

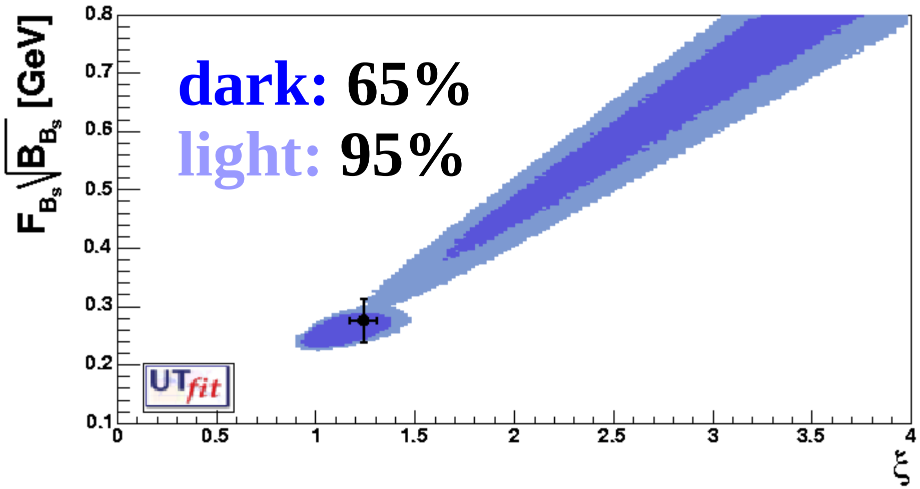


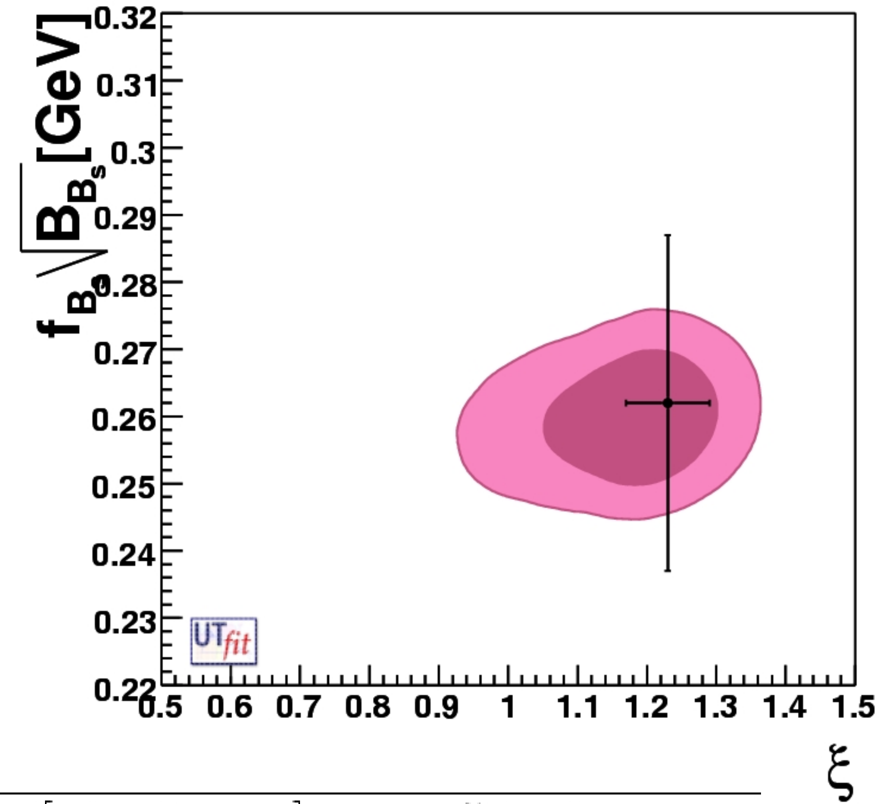






LQCD predictions (II)





Parameter	All	All[no semilep]	Lattice
$\hat{B}_K$	0.91 ± 0.18	0.86 ± 0.13	$0.79 \pm 0.04 \pm 0.09$
$f_{B_s}\,\hat{B}_{B_s}^{1/2}$ (MeV)	258 ± 6	259 ± 6	262 ± 35
ξ	1.11 ± 0.11	1.17 ± 0.08	1.23 ± 0.06