Discrepancy in the Unitarity Triangle fit from b ↔ s transitions

arXiv:0803.0659 [hep-ph]

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on behalf of Ut*fit* Collaboration

www.utfit.org

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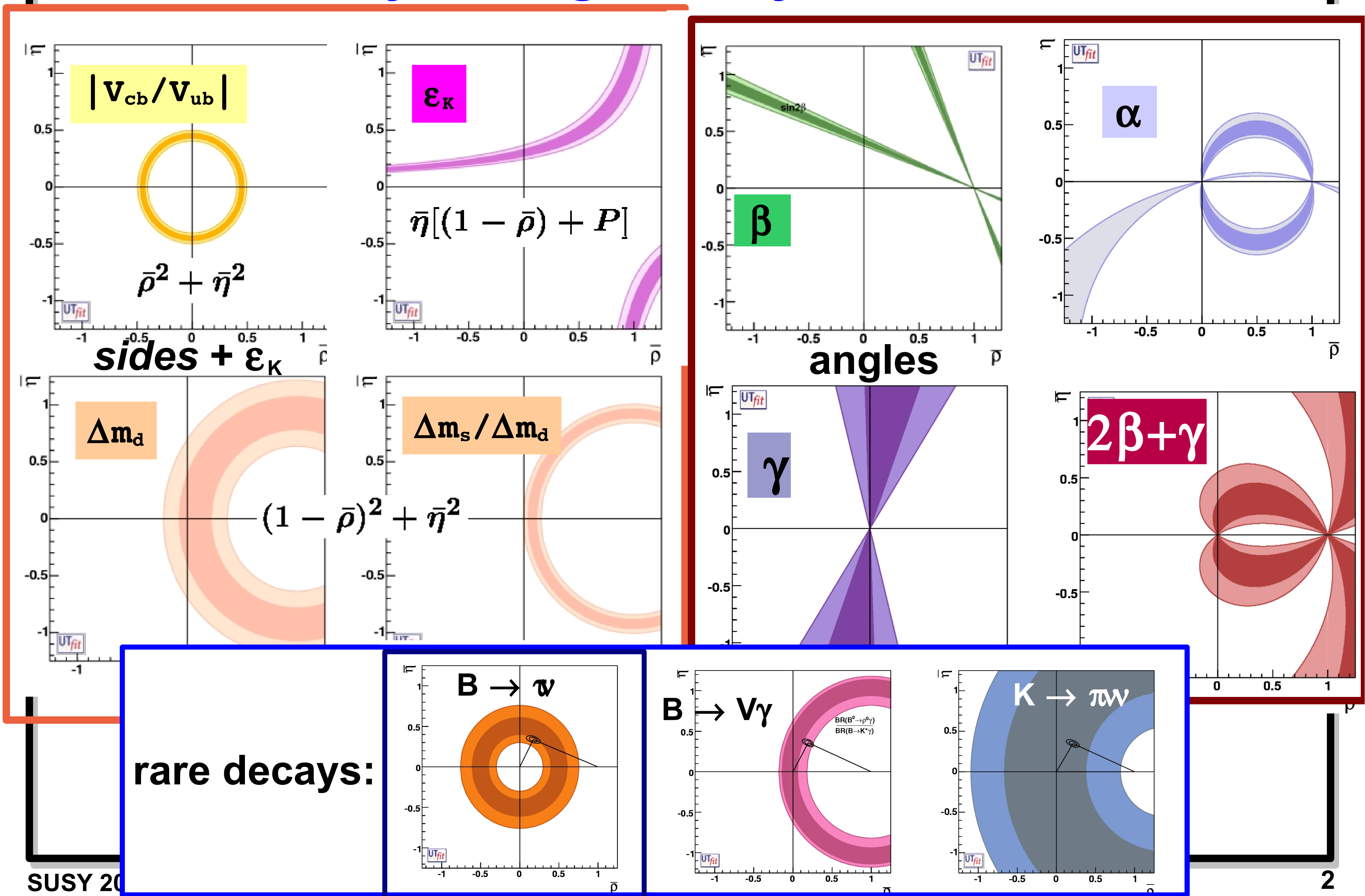
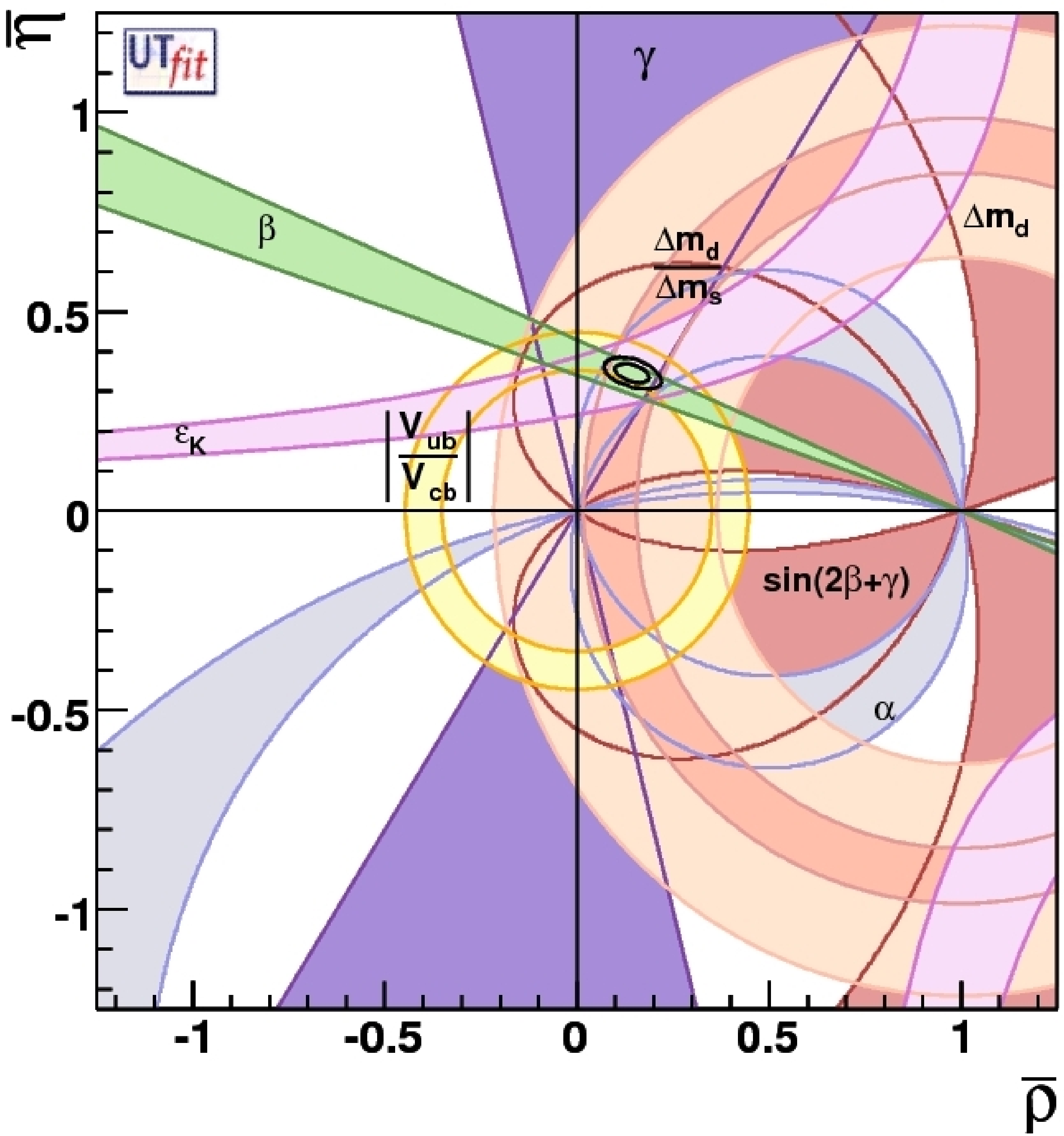
Unitarity Triangle analysis in the SM



Experimental situation (II)



results updated for this conf
web site is still to be updated
- new γ (Moriond08)
- new α (Moriond08)
- new ILQCD (Lubicz, Tarantino)

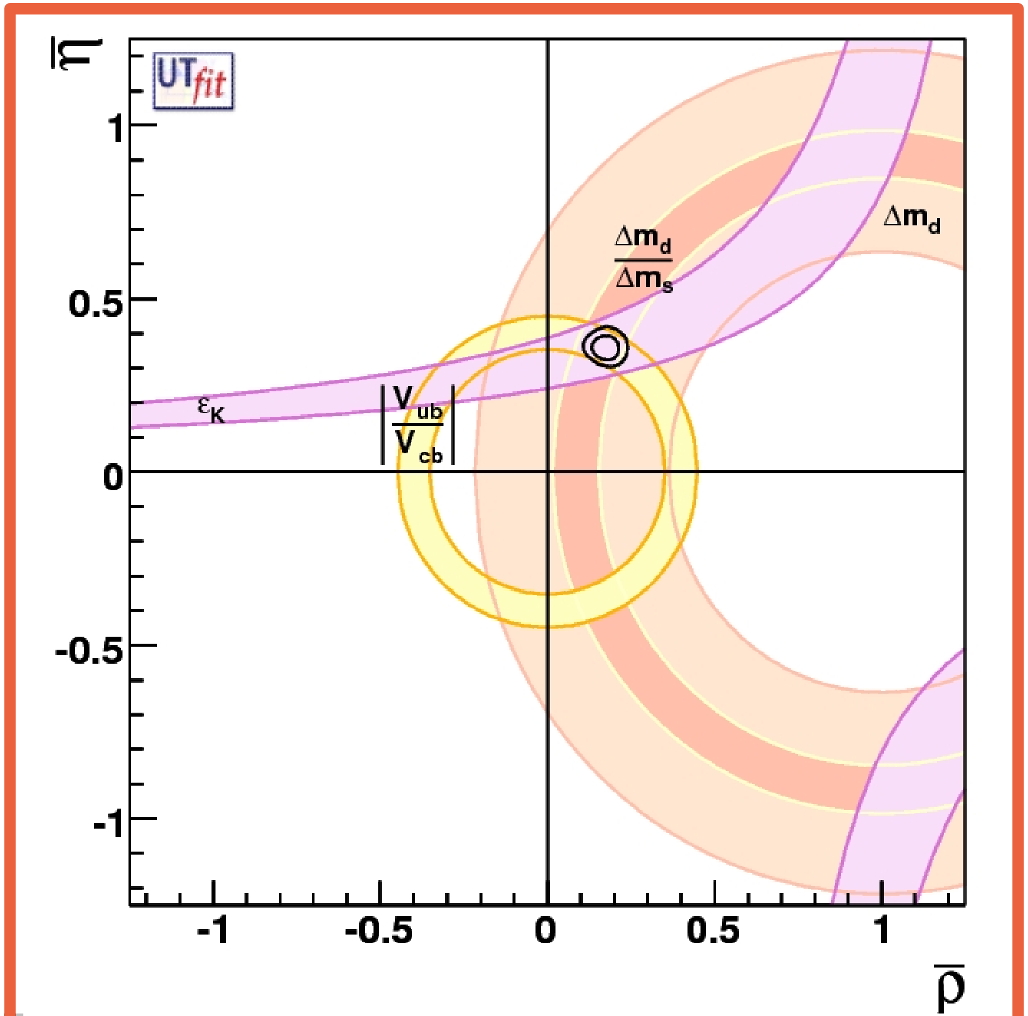
$\bar{\rho} = 0.155 \pm 0.022$

$\bar{\eta} = 0.342 \pm 0.014$

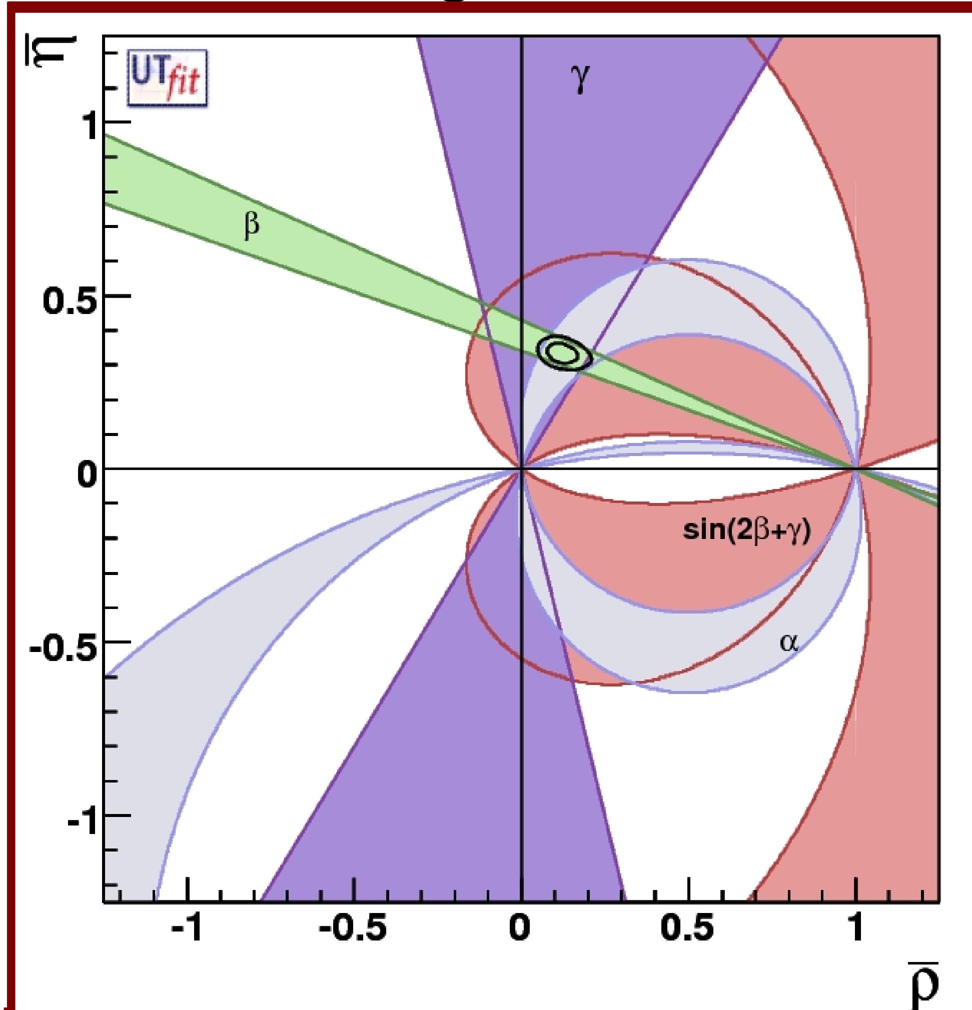
- Theory under control
- Data in agreement
- NP, if any, seems not to introduce additional CP or flavour violation in b ↔ d transitions at current experimental precision

Experimental situation (I)

sides + ε_K



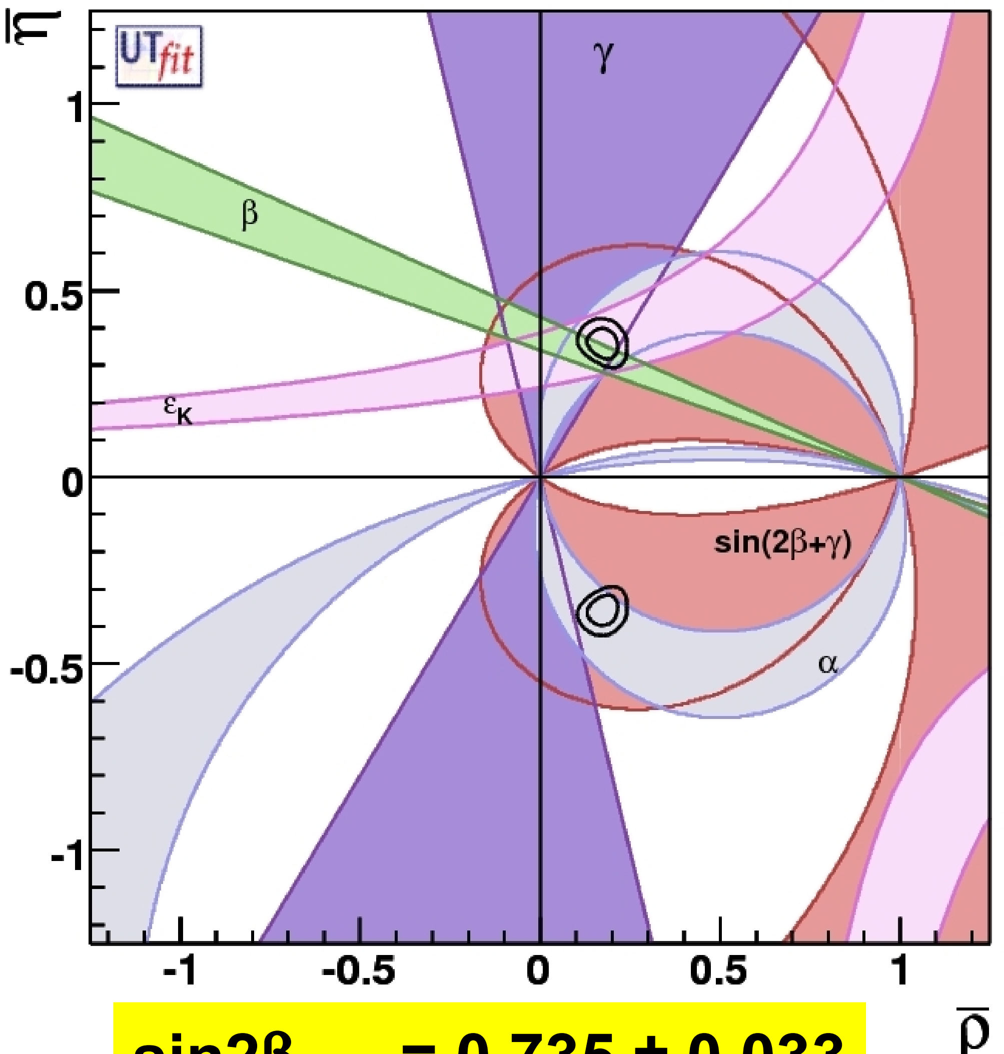
angles



$\bar\rho = 0.175 \pm 0.027$
$\bar\eta = 0.359 \pm 0.023$

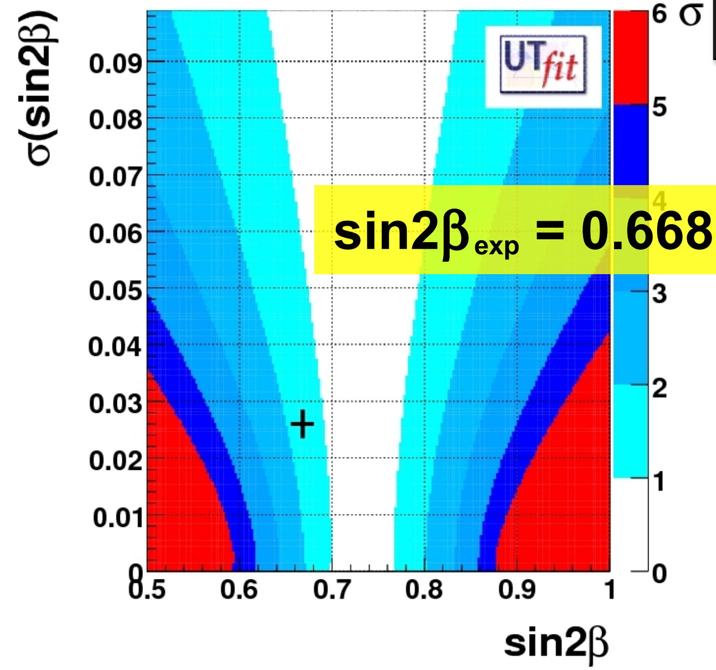
$\bar\rho = 0.124 \pm 0.032$
$\bar\eta = 0.333 \pm 0.014$

The *tension*

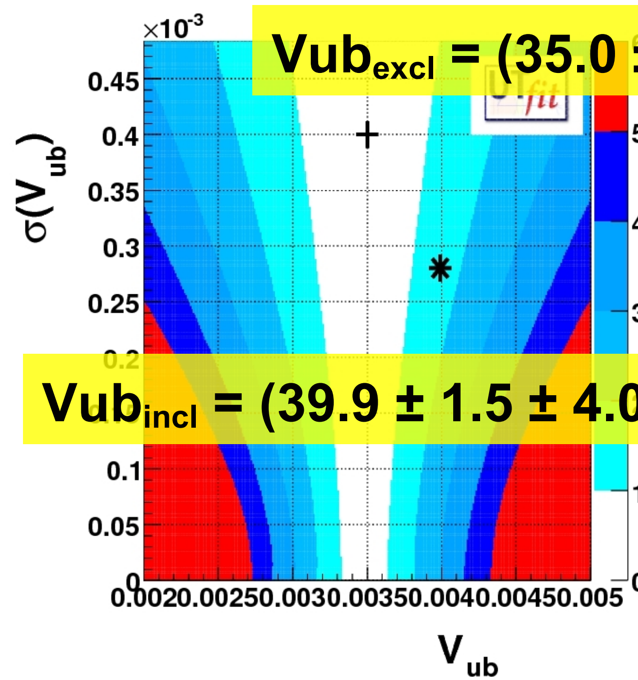


$\sin 2\beta_{UTfit}$ = 0.735 ± 0.033

Vub_{UTfit} = (34.8 ± 1.6) · 10^{-4}



$\sin 2\beta_{exp}$ = 0.668 ± 0.026



Vub_{excl} = (35.0 ± 4.0) · 10^{-4}

Vub_{incl} = (39.9 ± 1.5 ± 4.0[flat]) · 10^{-4}

Experimental Novelties

TEVATRON experiments have started to test the b↔s sector with B_s mixing

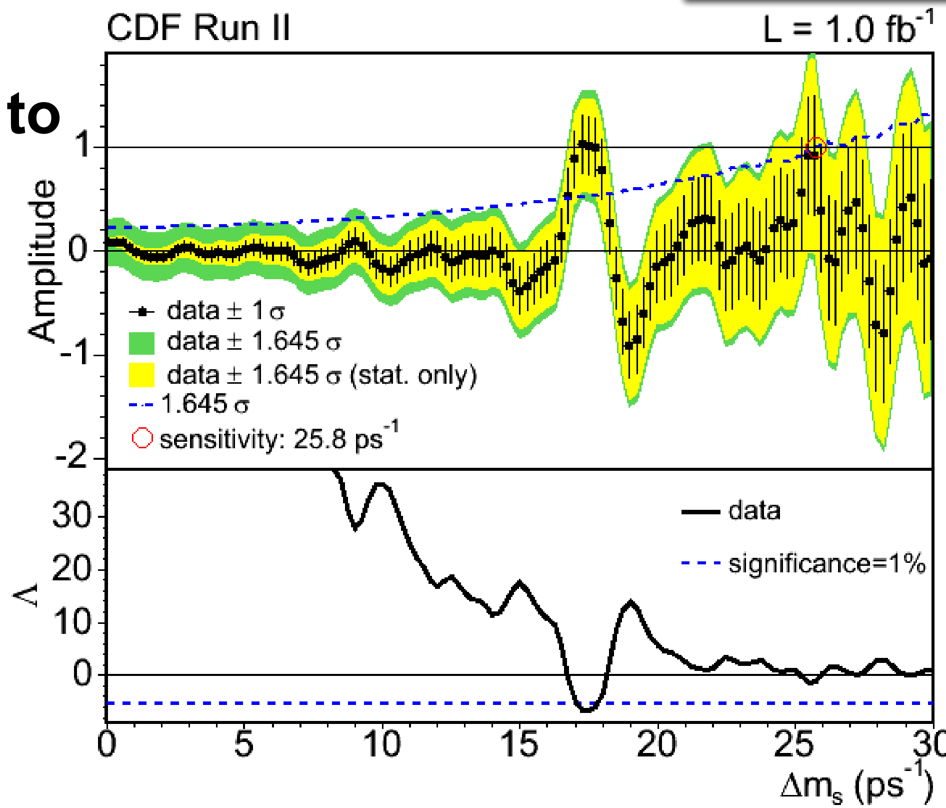
- Measurement of Δm_s

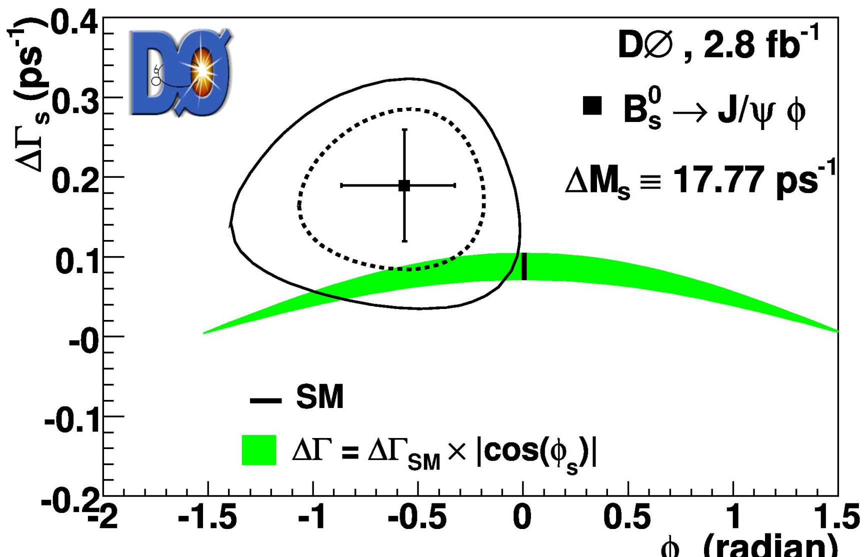
- Measurement of dilepton charge asymmetry
- Semileptonic asymmetry
- Measurement of $\Delta\Gamma_s/\Gamma_s$
- B_s lifetime measurement in flavour specific final states

Indirect constraints on the mixing phase

- 2D bound on β_s vs $\Delta\Gamma$ from tagged angular analysis of $B_s \rightarrow J/\psi\phi$ decays

Some discrepancy with Standard Model observed





$\phi_s = 2\beta_s$ vs $\Delta\Gamma_s$ from $B_s \to J/\psi\phi$ (I)

- Angular analysis as a function of proper time and b-tagging
- Similar to B_d measurement in $B_d \to J/\psi K^*$
- Additional sensitivity from the $\Delta\Gamma_s$ terms (negligible for B_d)

$$\frac{d^4P(t,\vec{w})}{dtd\vec{w}} \propto |A_0|^2 T_+ f_1(\vec{w}) + |A_\parallel|^2 T_+ f_2(\vec{w}) + |A_\perp|^2 T_- f_3(\vec{w}) + |A_\parallel||A_\perp| U_+ f_4(\vec{w}) + |A_0||A_\parallel|\cos(\delta_\parallel) T_+ f_5(\vec{w}) + |A_0||A_\perp| V_+ f_6(\vec{w})$$

$$T_\pm = e^{-\Gamma t} \times [\cosh(\Delta\Gamma t/2) \mp \cos(2\beta_s)\sinh(\Delta\Gamma t/2) \mp \eta \sin(2\beta_s)\sin(\Delta m_s t)],\ \eta = +1(-1) \text{ for } P(\bar{P})$$

$$U_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp - \delta_\parallel)\cos(\Delta m_s t) - \cos(\delta_\perp - \delta_\parallel)\cos(2\beta_s)\sin(\Delta m_s t) \pm \cos(\delta_\perp - \delta_\parallel)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)]$$

$$V_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp)\cos(\Delta m_s t) - \cos(\delta_\perp)\cos(2\beta_s)\sin(\Delta m_s t) \pm \cos(\delta_\perp)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)]$$

Dunietz et al.
Phys.Rev.D63:114015,2001

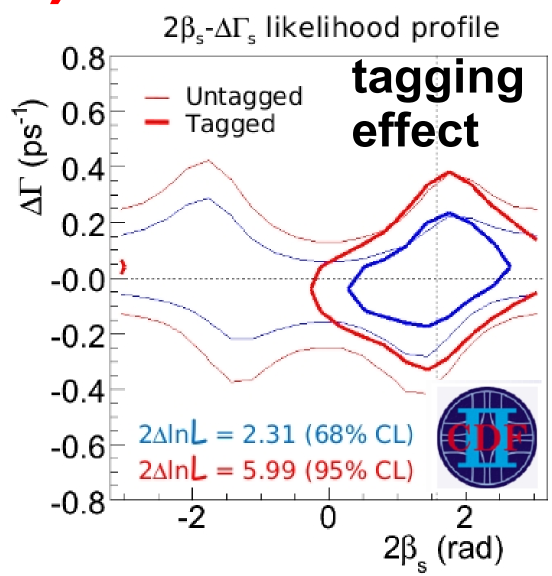
Ambiguities for
$\phi_s \to \pi - \phi_s$,
$\Delta\Gamma_s \to -\Delta\Gamma_s$,
$\cos(\delta_\perp - \delta_\parallel) \to -\cos(\delta_\perp - \delta_\parallel)$

- transversity basis: $W(\theta, \varphi, \psi)$
- θ and φ: direction of the μ^+ from J/ψ decay
- ψ: between the decay planes of J/ψ and ϕ

$\phi_s = 2\beta_s$ vs $\Delta\Gamma_s$ from $B_s \to J/\psi\phi$ (II)

Results from the Tevatron Collaborations:

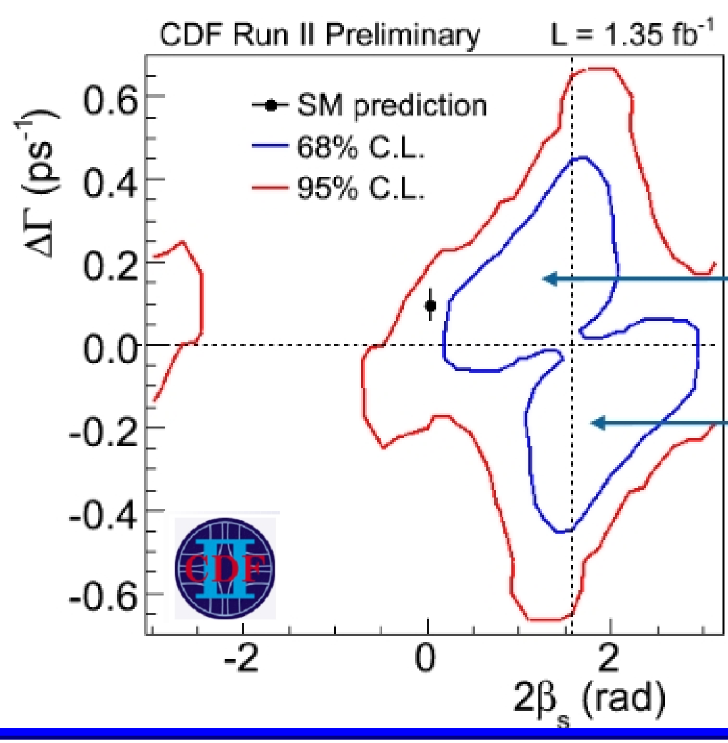
- **D0: arXiv:0802.2255 [hep-ex]**
  - $\tau_s = 1.52 \pm 0.06$ *(stat)* ± 0.01 *(syst)* ps
  - $\Delta\Gamma_s = 0.19 \pm 0.07$ *(stat)* ${}^{+0.02}_{-0.01}$ *(syst)* ps^{-1}
  - $\phi_s = -2\beta_s = -0.57\ {}^{+0.24}_{-0.30}$ *(stat)* ${}^{+0.07}_{-0.02}$ *(syst)* rad
- **CDF: arXiv:0712.2397 [hep-ex]**
  - **Feldman-Cousins likelihood ratio ordering with systematics included**



Standard Model expectations:
(arXiv:hep-ph/0612167)

$\Delta\Gamma_s = 0.096 \pm 0.039$ ps^{-1}
$2\beta_s = 0.04 \pm 0.01$ rad

Standard Model p_{value} = 15% (1.5σ)



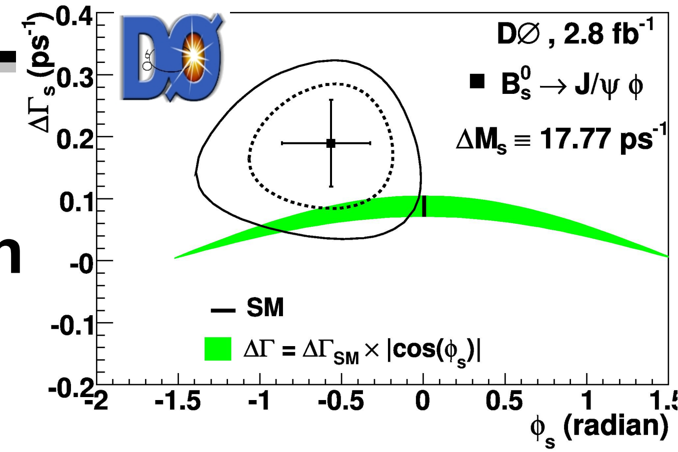
strong phases can separate the two minima

$\cos(\delta_\perp) < 0$
$\cos(\delta_\perp - \delta_\parallel) > 0$

$\cos(\delta_\perp) > 0$
$\cos(\delta_\perp - \delta_\parallel) < 0$

Δm_s constraint to 17.77 ± 0.12 ps^{-1}

G. Gomez-Ceballos



Modeling D0 data (I)

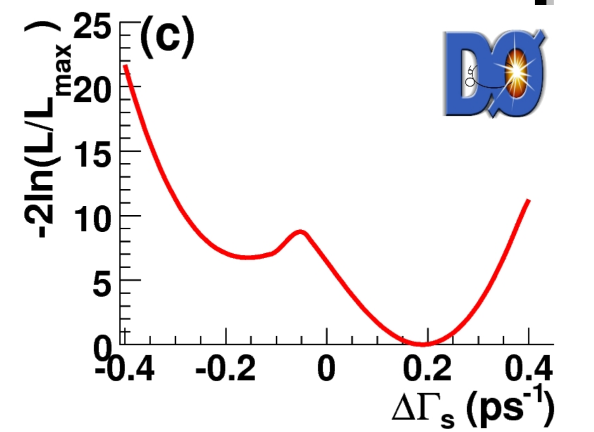
Unlike for CDF, it was not possible to obtain the 2D likelihood from D0.
We use three different approaches:

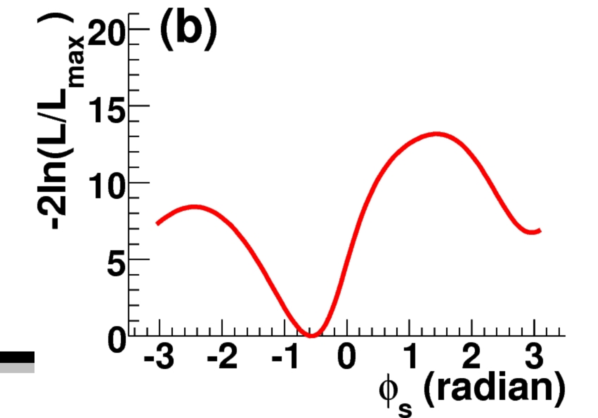
Default result: **take the quoted result + 7x7 correlation matrix and marginalize the 5 nuisance parameters (flat priors used)**

To include non-Gaussian tails:

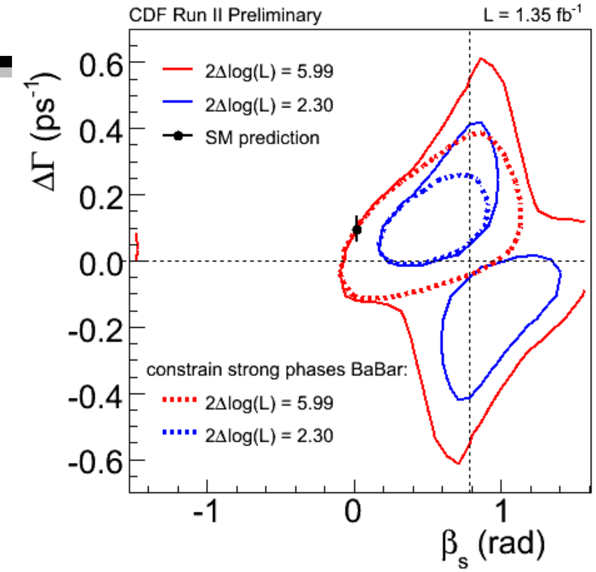
1) scale errors such that they agree with the quoted "2σ" ranges: [-0.06, 1.20] → 0.38
***Pessimistic*: the tail is on the opposite side w.r.t. SM but we extend it on the SM side.**

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**

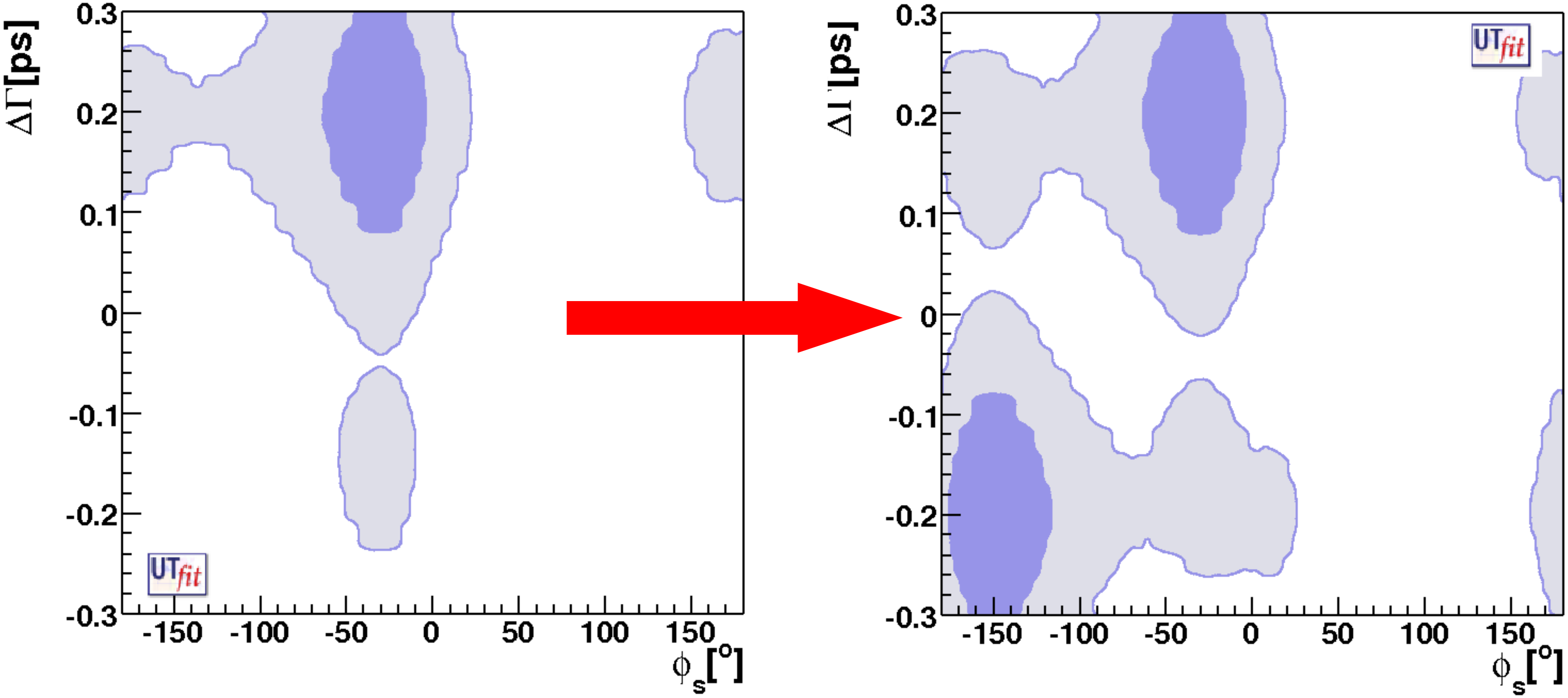




Modeling D0 data (II)

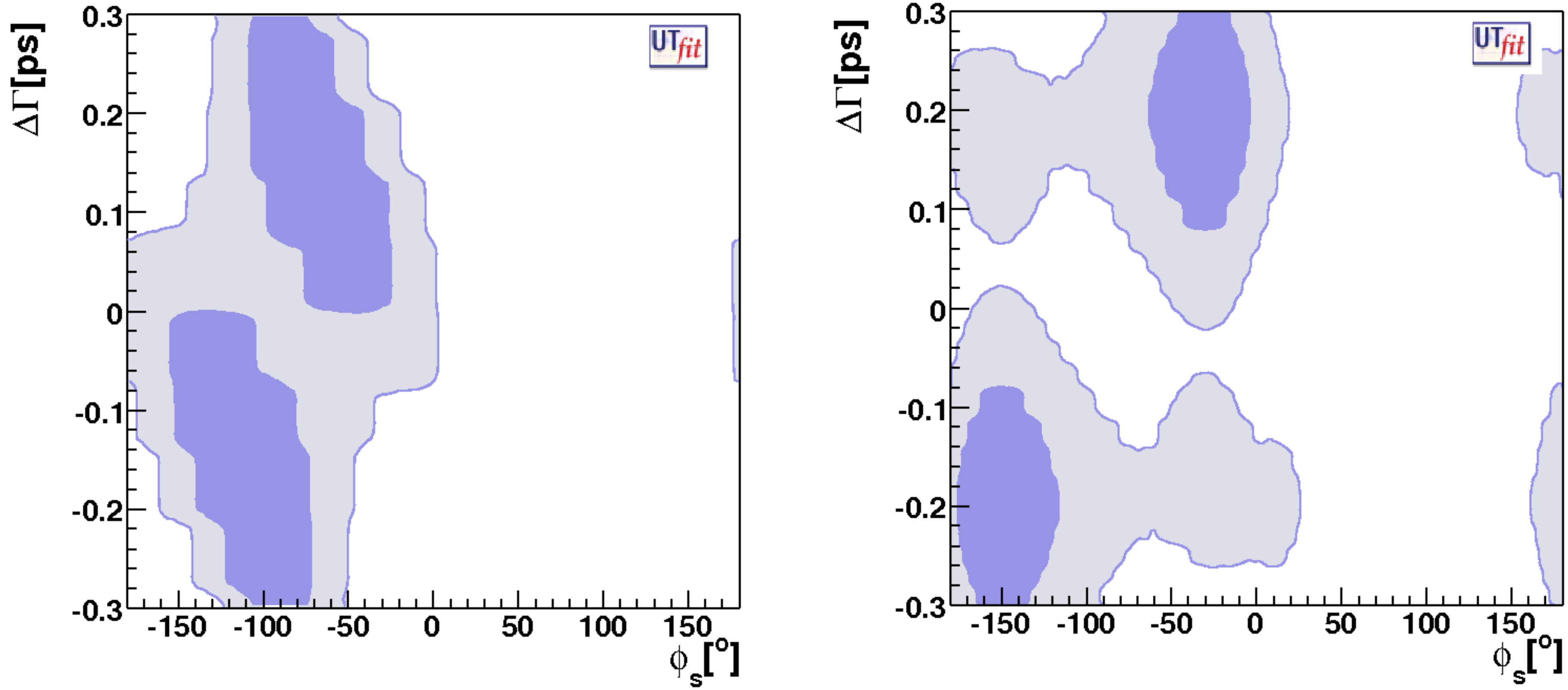


- Strong phase from $B_d \to J\psi K^*$ + SU(3) (consistent with naive factorization)
- The phase better determined by the fit than by the assumption. But the ambiguity is lost
- **The problem:** the ϕ singlet component is ignored
- To be conservative, we put it back in the data by **mirroring the likelihood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

"Tree level" fit

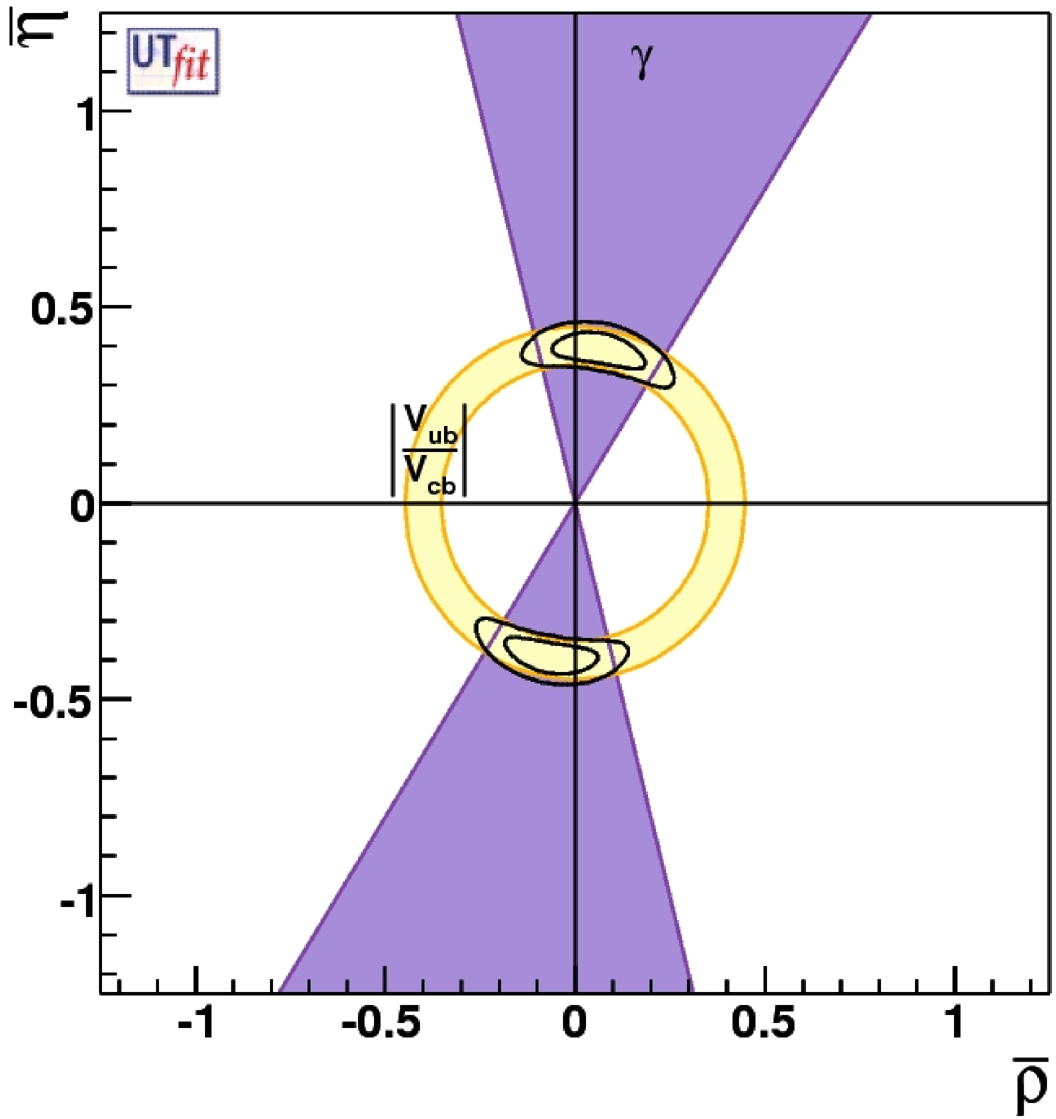
B factories are constraining the UT with tree-level processes

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



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.

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

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

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

UTfit

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 (ρρ,ρπ,ππ)	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

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

Bd Mixing

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

Bs Mixing

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

K Mixing

SM	SM+NP
ε_K^{SM}	$C_{\varepsilon K}\varepsilon_K^{SM}$

NP-specific and B_s constraints (I)

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

experimenal laikelihood used in the fit

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

SM contribution

$\sin 2\beta_s = 0.037 \pm 0.002$ (SM or MFV)

ϕ_s and $\Delta\Gamma_s$: 2D experimenal 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)

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

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

Ciuchini et al. JHEP 0308:031,2003.

NP-specific constraints (II)

$$A^s_{\rm SL} \equiv \frac{\Gamma(\bar{B}_s \to \ell^+ X) - \Gamma(B_s \to \ell^- X)}{\Gamma(\bar{B}_s \to \ell^+ X) + \Gamma(B_s \to \ell^- X)} = {\rm Im}\left(\frac{\Gamma^s_{12}}{A^{\rm full}_s}\right)$$

- **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

$$A^s_{\rm SL} \times 10^2 = 2.45 \pm 1.96$$

- **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

$$A^{\mu\mu}_{\rm SL} \times 10^3 = -4.3 \pm 3.0$$

$$A^{\mu\mu}_{\rm SL} = \frac{f_d \chi_{d0} A^d_{\rm SL} + f_s \chi_{s0} A^s_{\rm SL}}{f_d \chi_{d0} + f_s \chi_{s0}}$$

- **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

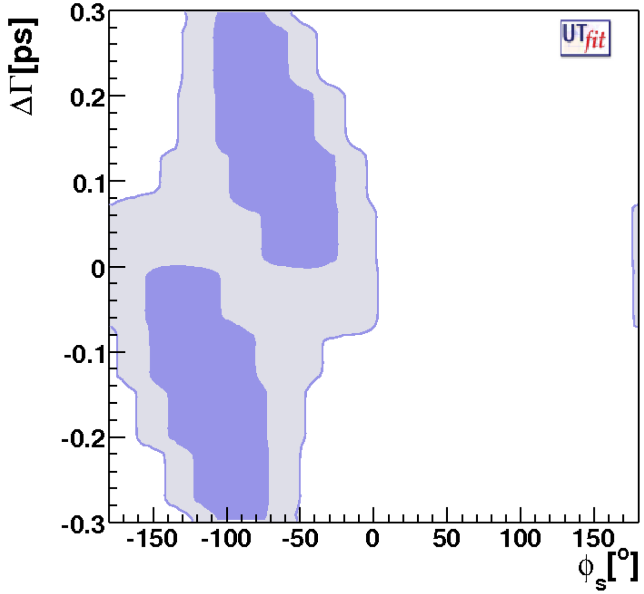
$$\tau^{\rm FS}_{B_s}\ [\rm ps] = 1.461 \pm 0.032$$

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

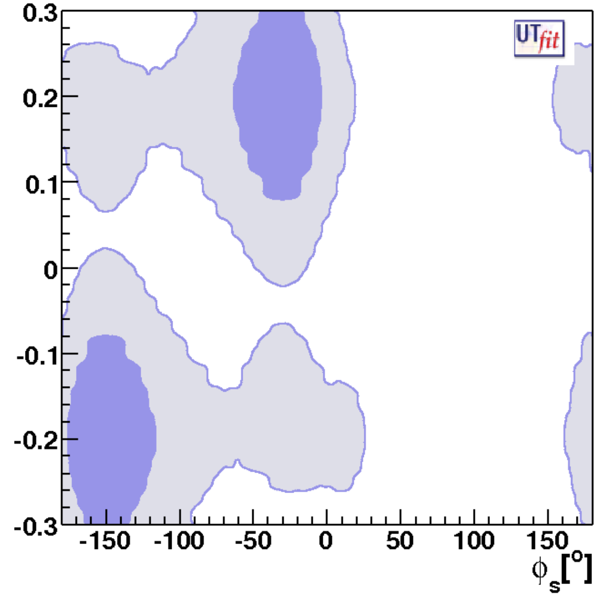
Dunietz et al., hep-ph 0012219

More than two measurements (I)

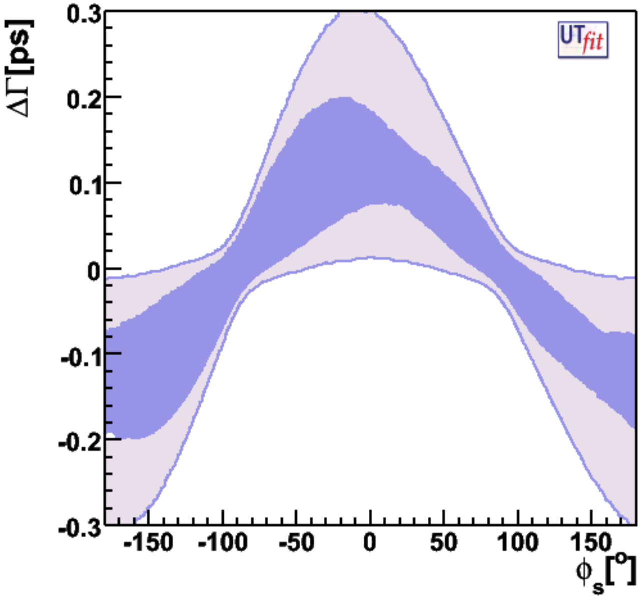
CDF tagged measurement



D0 tagged measurement



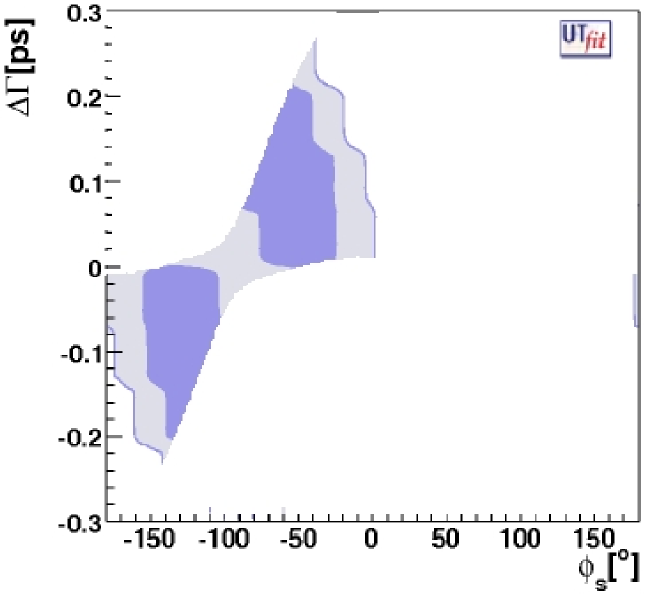
Our analysis (using A_{SL}, A_{CH}, τ_{Bs})



- **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**

More than two measurements (II)

CDF tagged measurement



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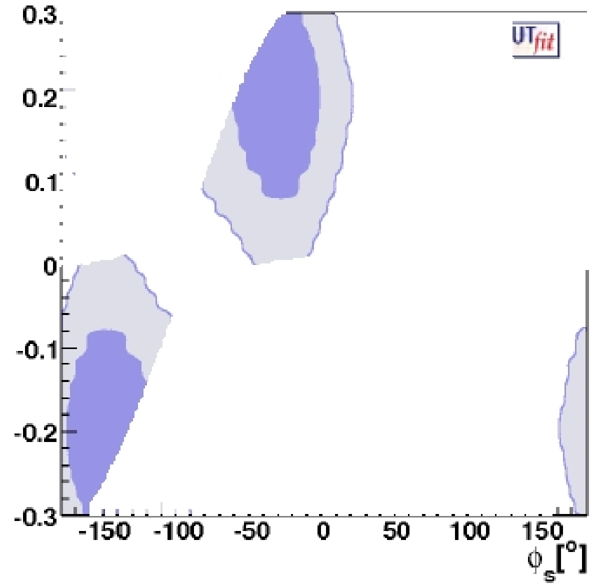

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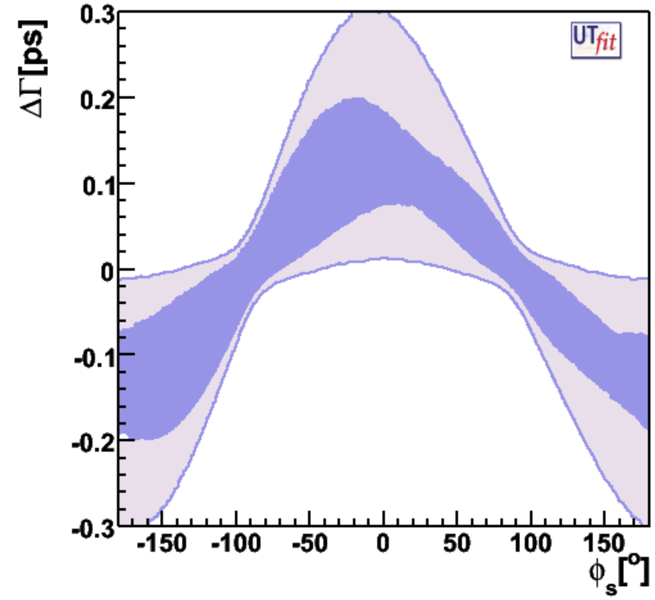

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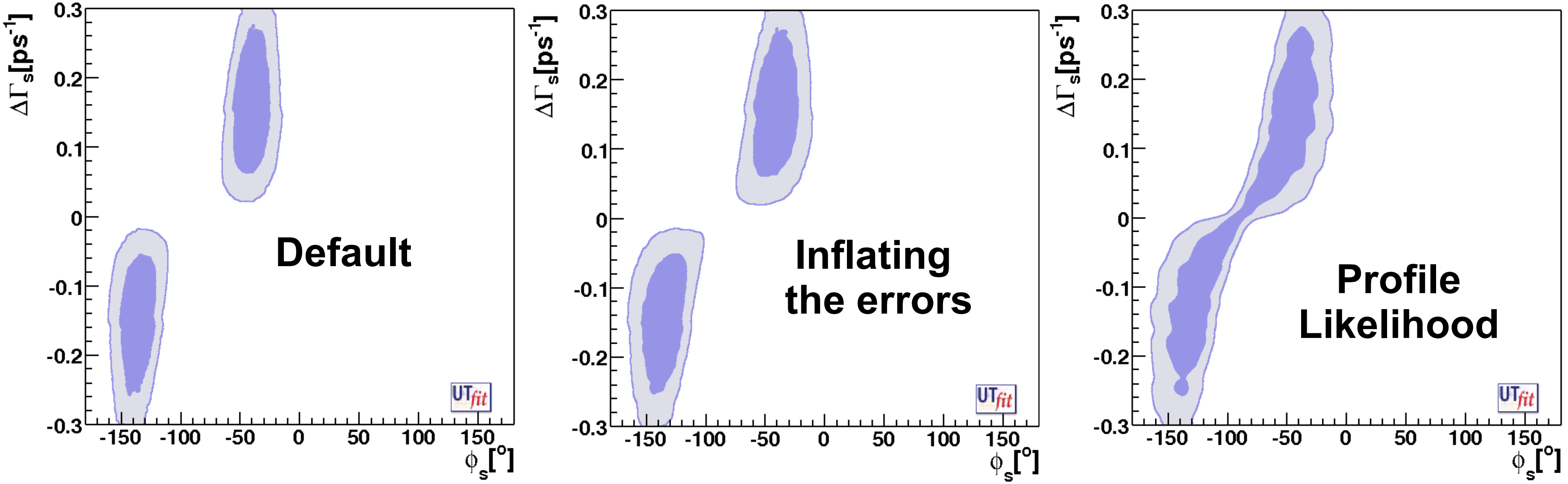
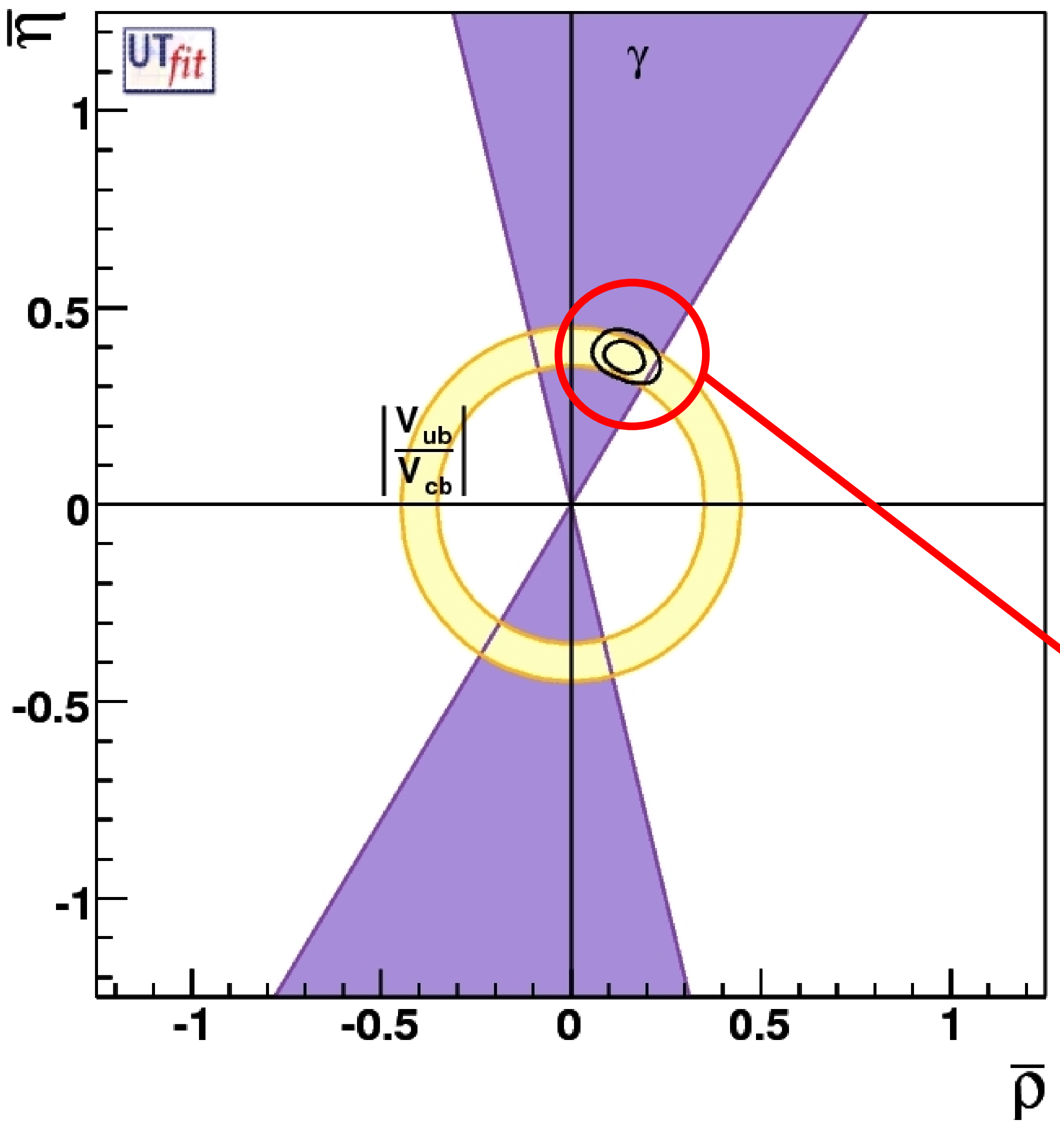
Dependence on the D0 data model

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 profile likelihood approach

The UT$_{fit}$ beyond the SM



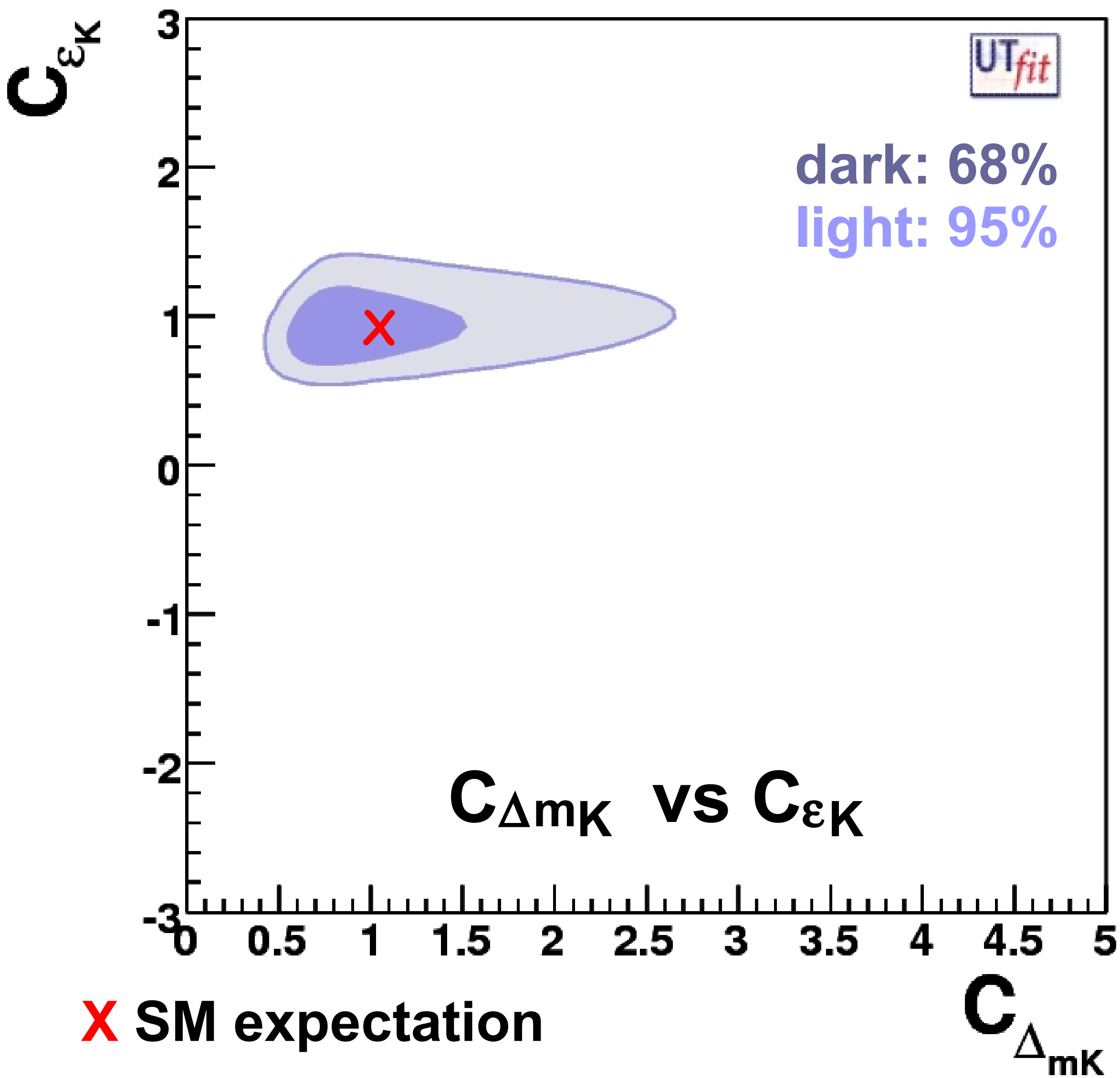
$\bar{\rho}$ = 0.141 ± 0.036
$\bar{\eta}$ = 0.373 ± 0.028

Allowing for NP we go back to the SM solution

$\bar{\rho}$ = 0.155 ± 0.022
$\bar{\eta}$ = 0.342 ± 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

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

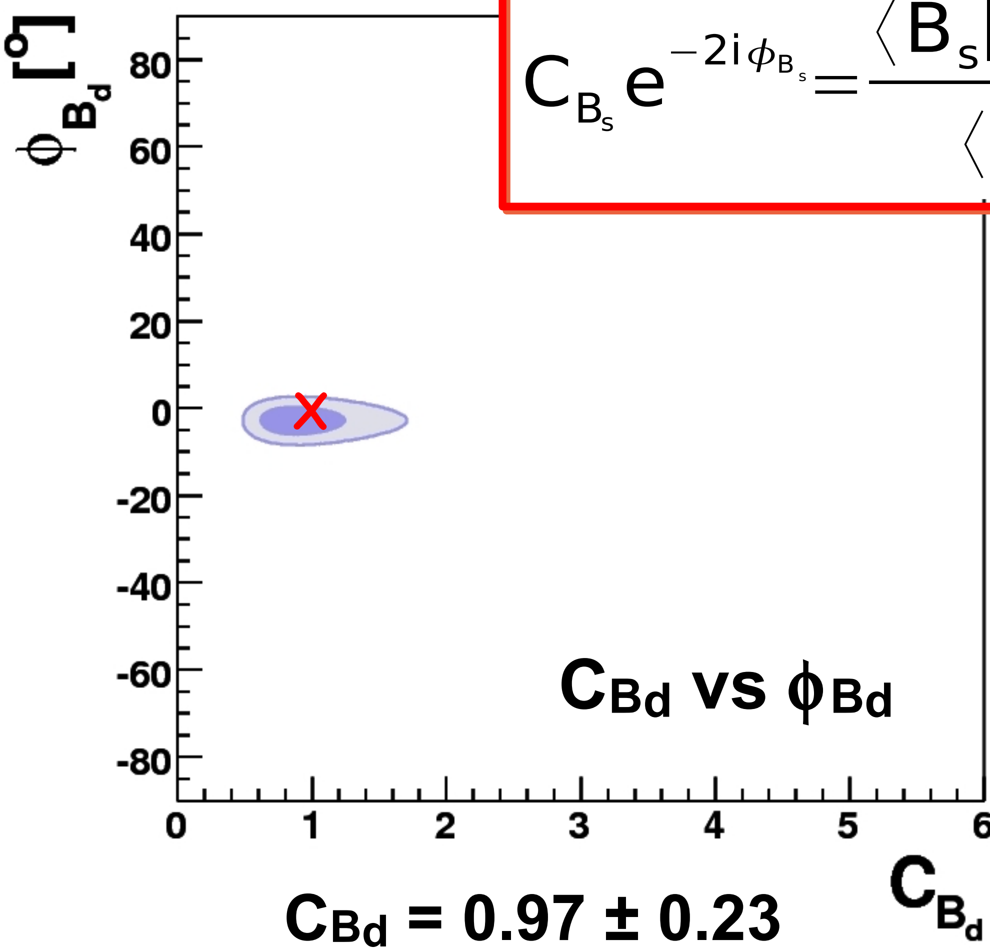
$$\Delta m_K = C_{\Delta m_K} (\Delta m_K)^{SM}$$
$$\varepsilon_K = C_\varepsilon\,\varepsilon_K^{SM}$$

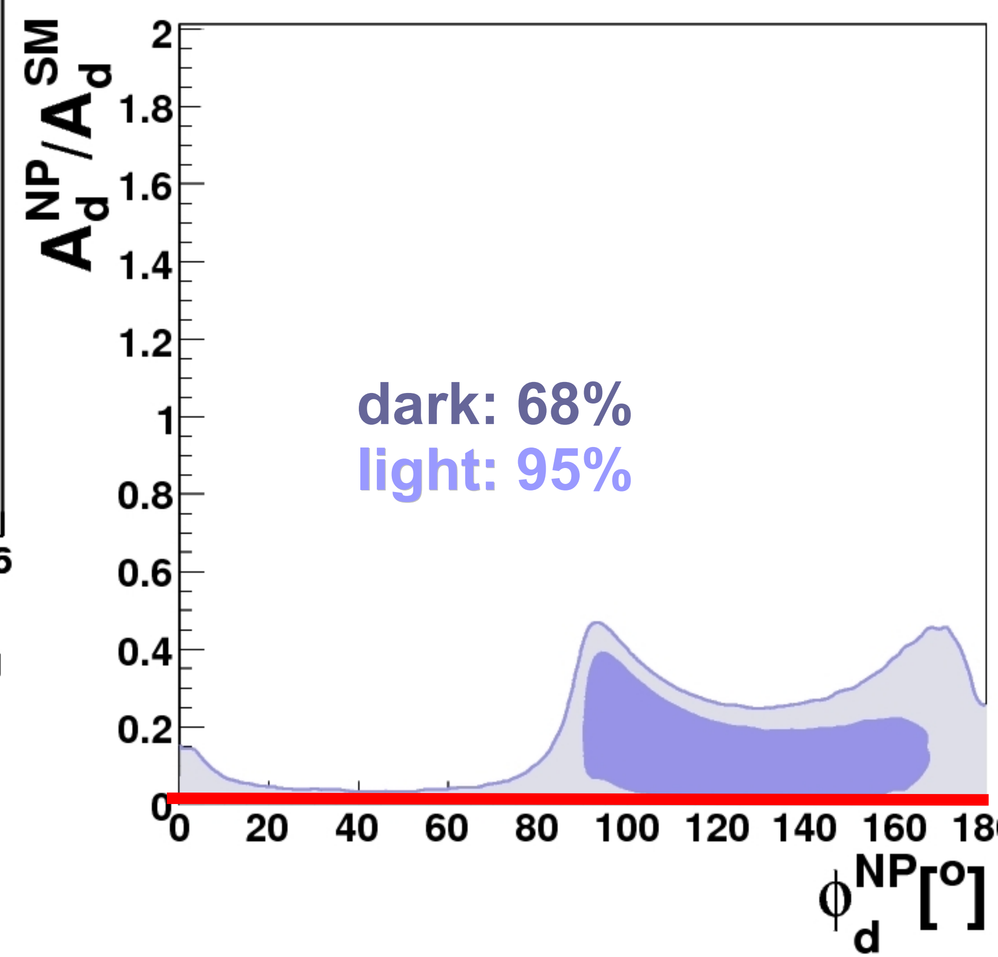
$C_{\varepsilon K} = 0.95 \pm 0.13$
[0.70,1.25] @ 95% Prob.

$C_{\Delta mK} = 1.16 \pm 0.42$
[0.60,2.42] @ 95% Prob.

New Physics in B_d sectors

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

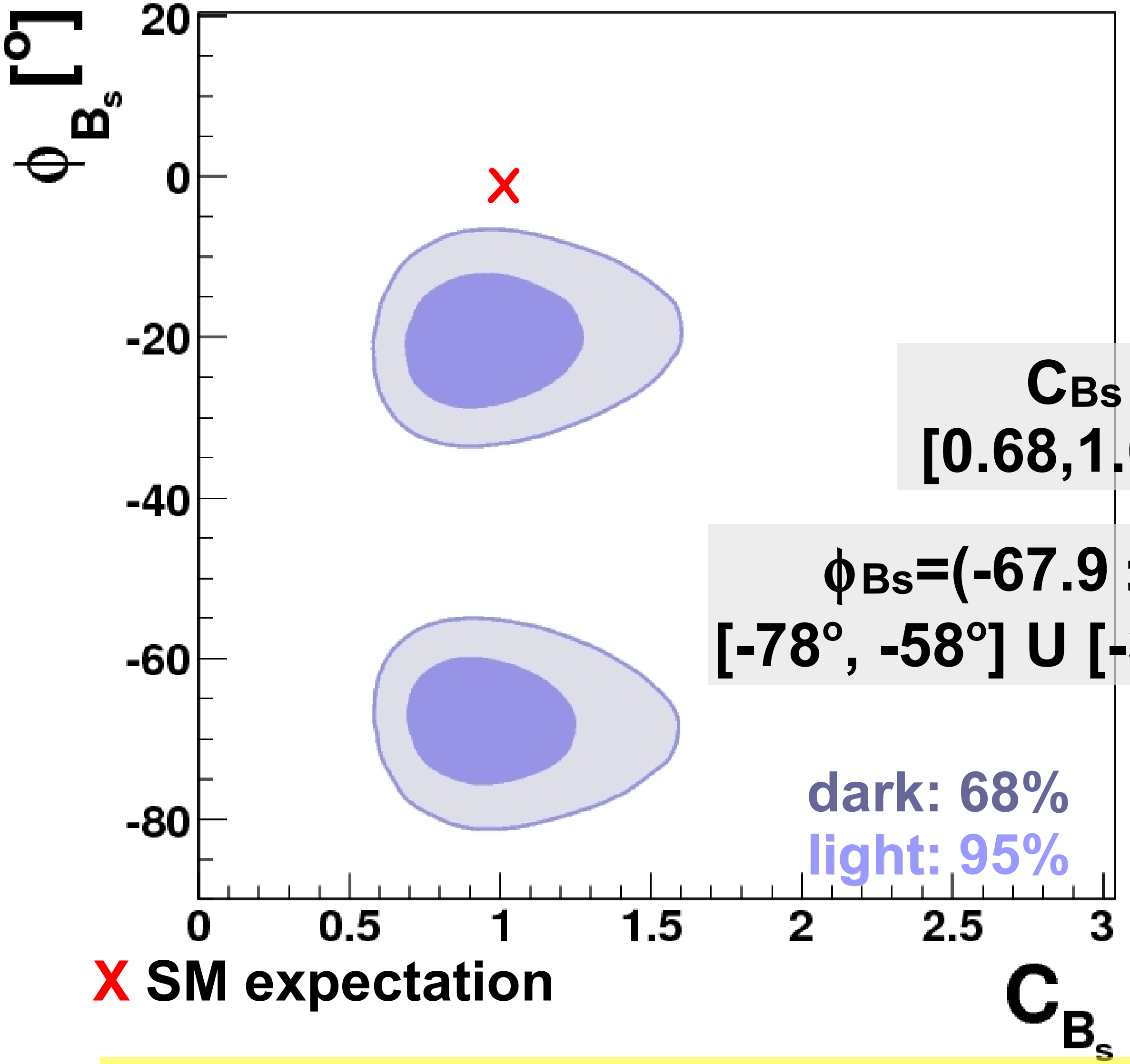




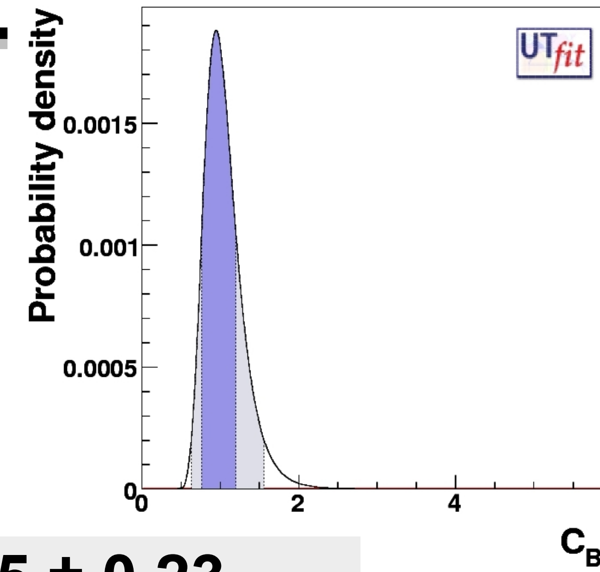
$C_{Bd} = 0.97 \pm 0.23$
[0.59,1.59] @ 95% Prob.

$\phi_{Bd} = (-2.8 \pm 1.9)°$
[-6.5°, 1.1°] @ 95% Prob.

New Physics in the B_s sector

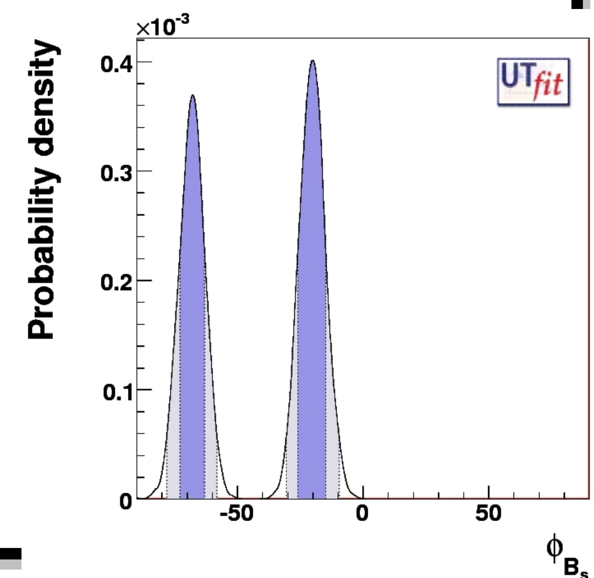


X SM expectation



C_{Bs} = 1.05 ± 0.23
[0.68,1.66] @ 95% Prob.

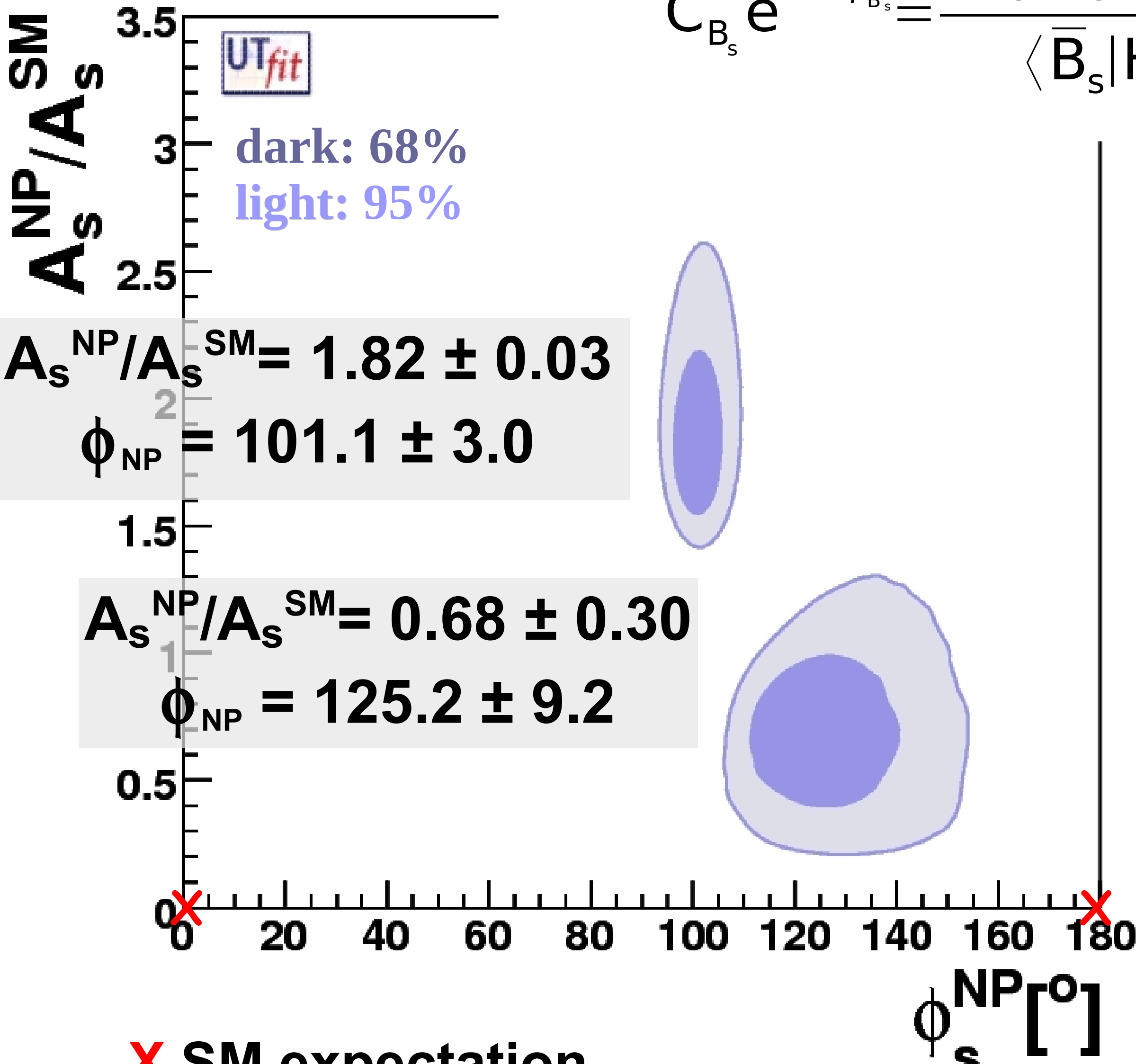
ϕ_{Bs}=(-67.9 ± 4.8)°U(-20.4 ± 5.5)°
[-78°, -58°] U [-31°, -10.°] @ 95% Prob.



ϕ_{Bs}<0 @ 99.7% probability
(equivalent to the Gaussian 3σ threshold)
for any approach we tried on D0 data

The NP Amplitude

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



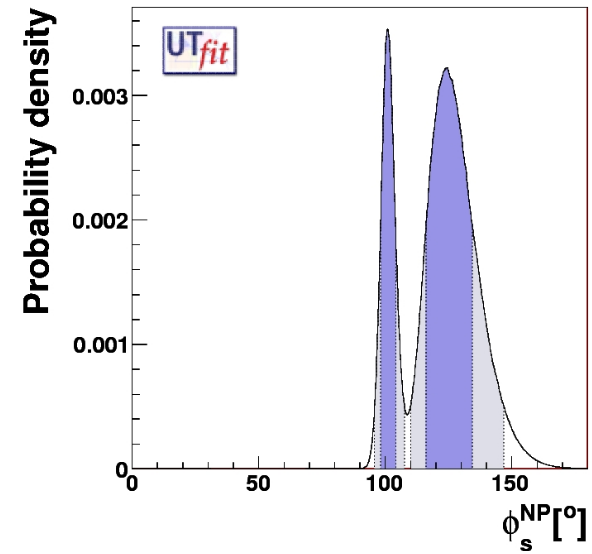
$A_s^{NP}/A_s^{SM} = 1.82 \pm 0.03$

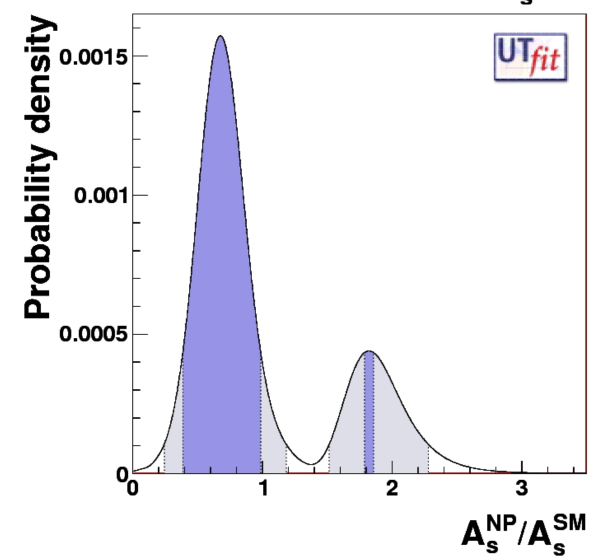
$\phi_{NP} = 101.1 \pm 3.0$

$A_s^{NP}/A_s^{SM} = 0.68 \pm 0.30$

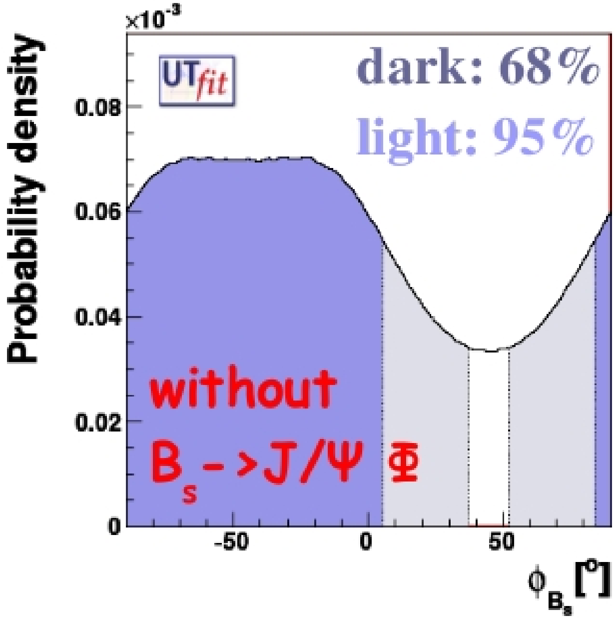
$\phi_{NP} = 125.2 \pm 9.2$

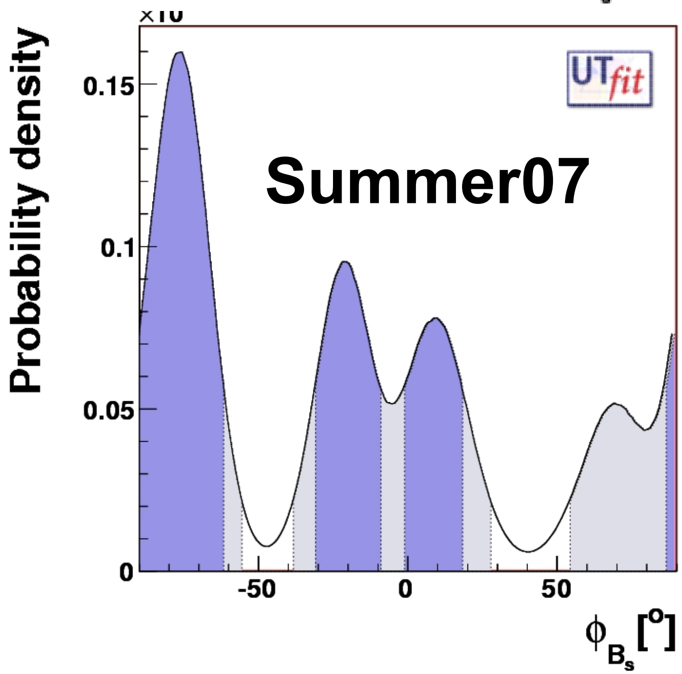
X SM expectation

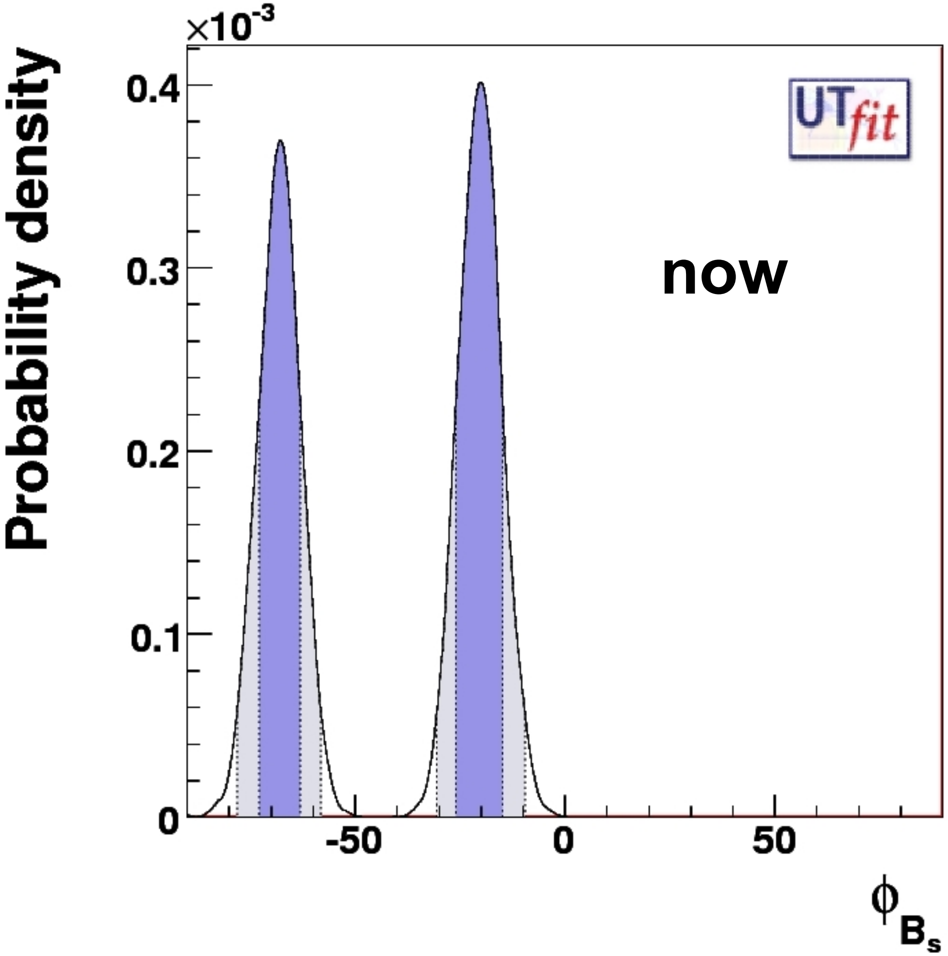




Did the result move by a lot?

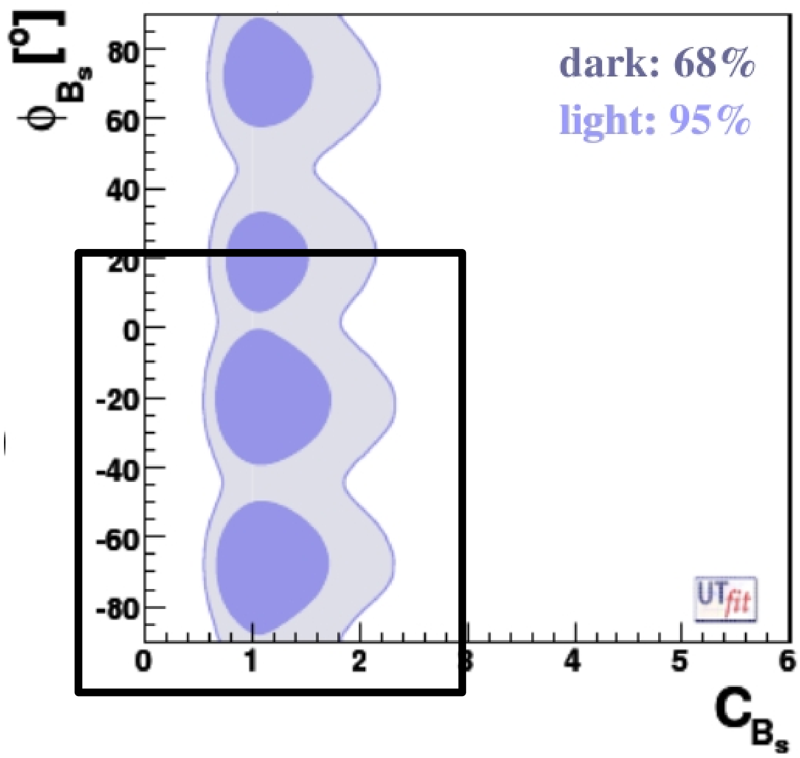


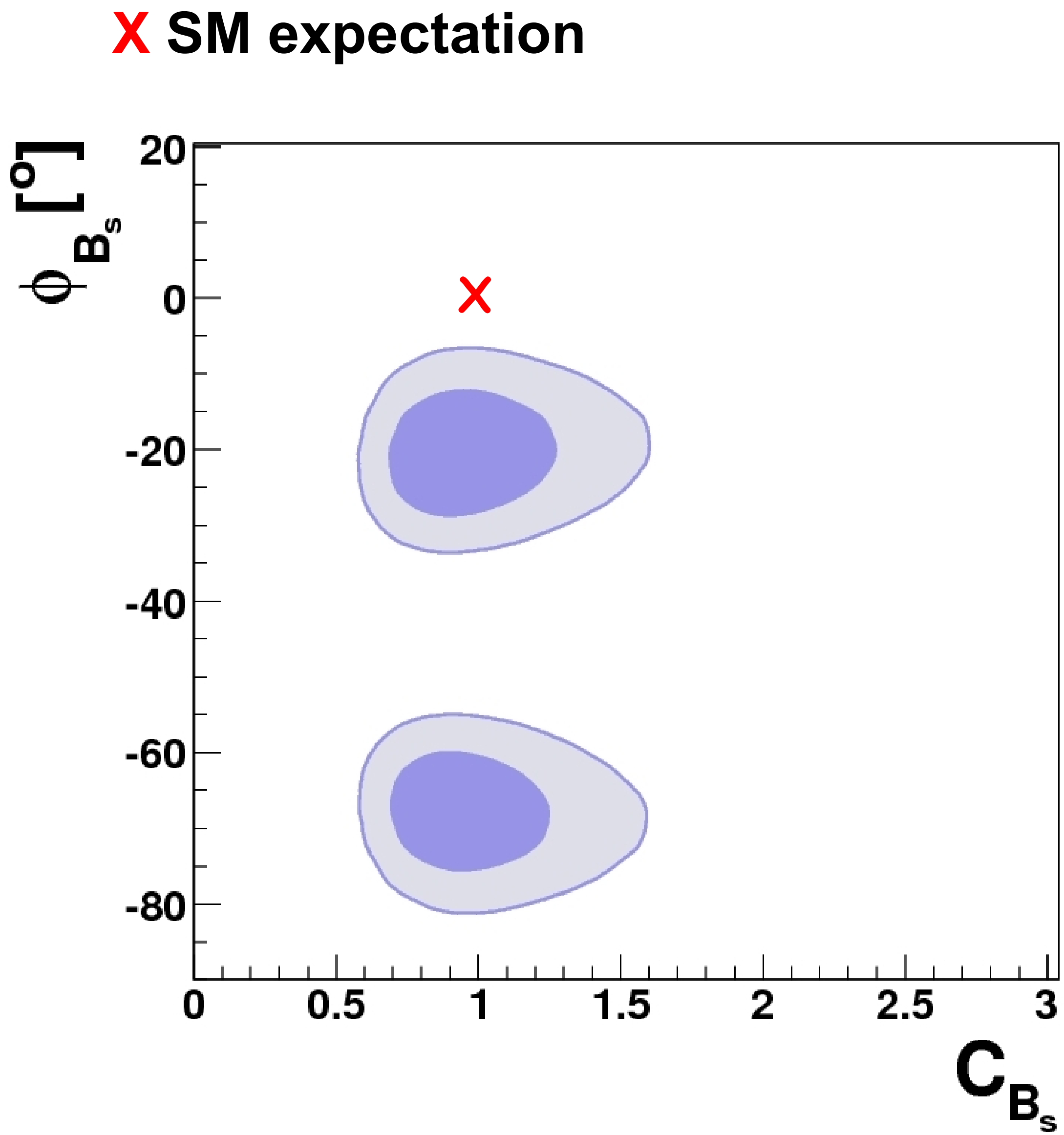




The two most probable peaks last summer are those that survived.

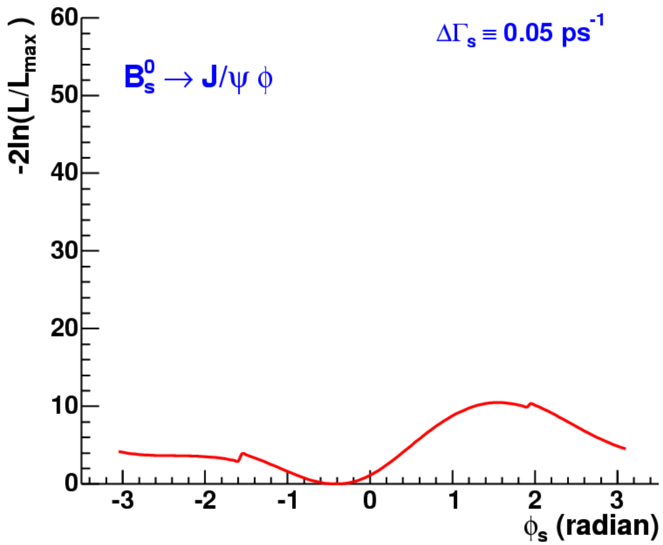
Did the result move by a lot? 2D

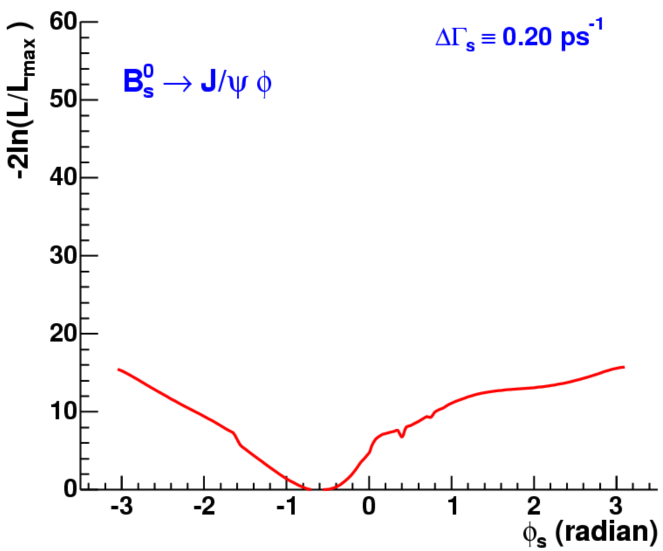




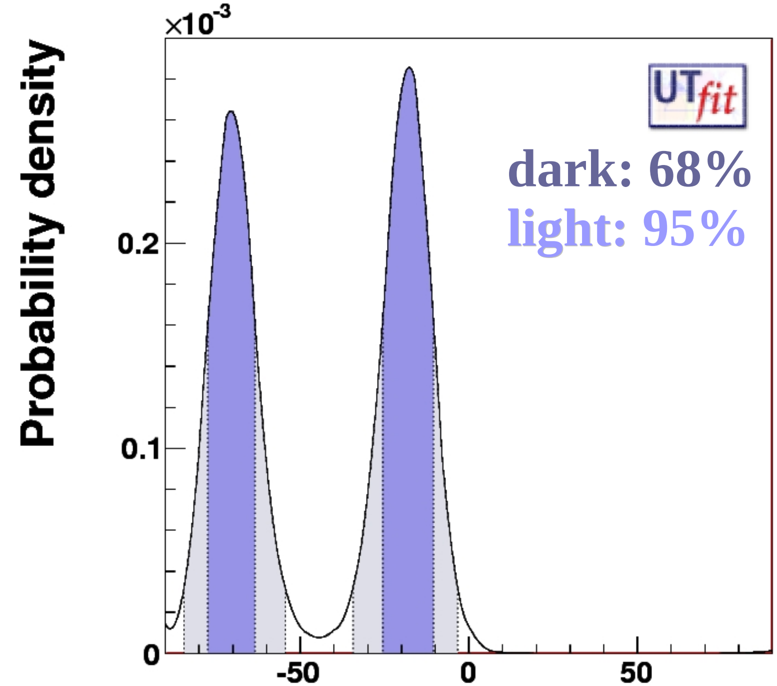
A new 2D likelihood scan from D0

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





We reran the analysis and the significance of the D0-only result drops down to ~1σ:
the full fit gives ~2.5σ

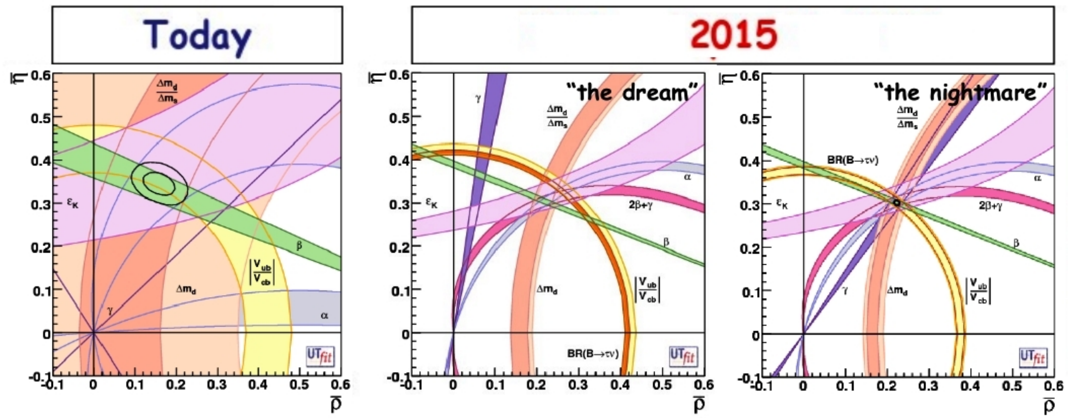


ϕ_{Bs}=(-70.4 ± 7.0)°U(-18.0 ± 7.6)°
[-84°, -54°] U [-34°, -3°] @ 95% Prob.

Some conclusions

- Tevatron data show a hint of discrepancy wrt SM
- we are looking forward to the updates of the analyses and possibly to an averaged likelihood from CDF+D0

- 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
  - NP models need a (not fine tuned) mechanism to produce effects in $b \to s$ inducing $\leq 10\%$ effects in $b \to d$ and K

Back-up slides

Update of the LQCD parameters

Lubicz, Tarantino
for UTfit

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

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

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

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

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

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

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

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

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

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

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

If this evidence is confirmed...

M.Ciuchini
CERN 08

* 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	SuperB
	10/fb (5 years)	1/ab (1 month at Υ(5S))
Δm_s	0.07%(+0.5%)	no
A^s_{SL}	?	0.006
ϕ_s (J/ψ ϕ)	0.01+syst	0.14
		75/ab (5 years)
sin2β (J/ψ 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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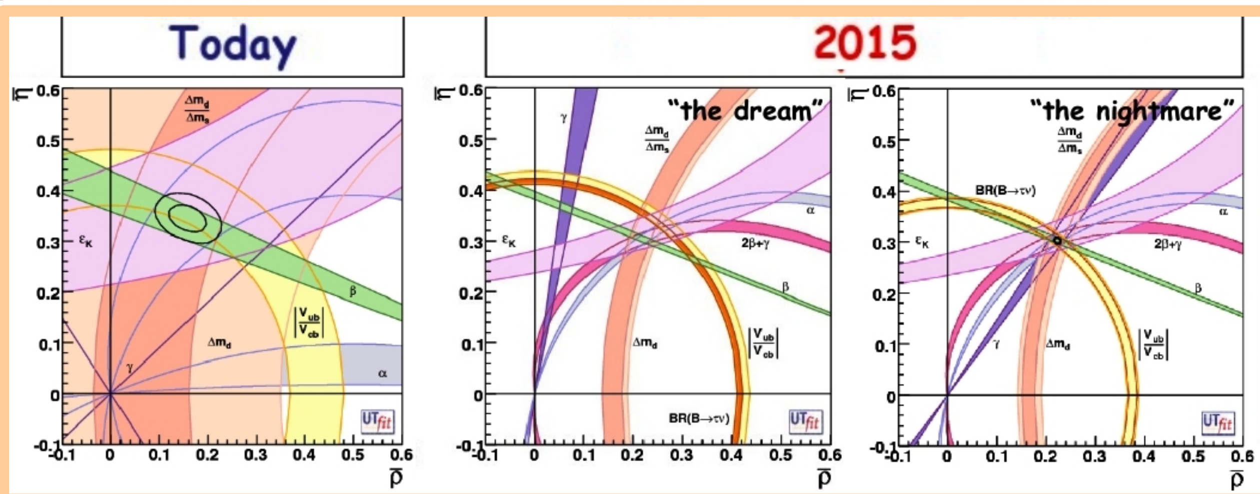
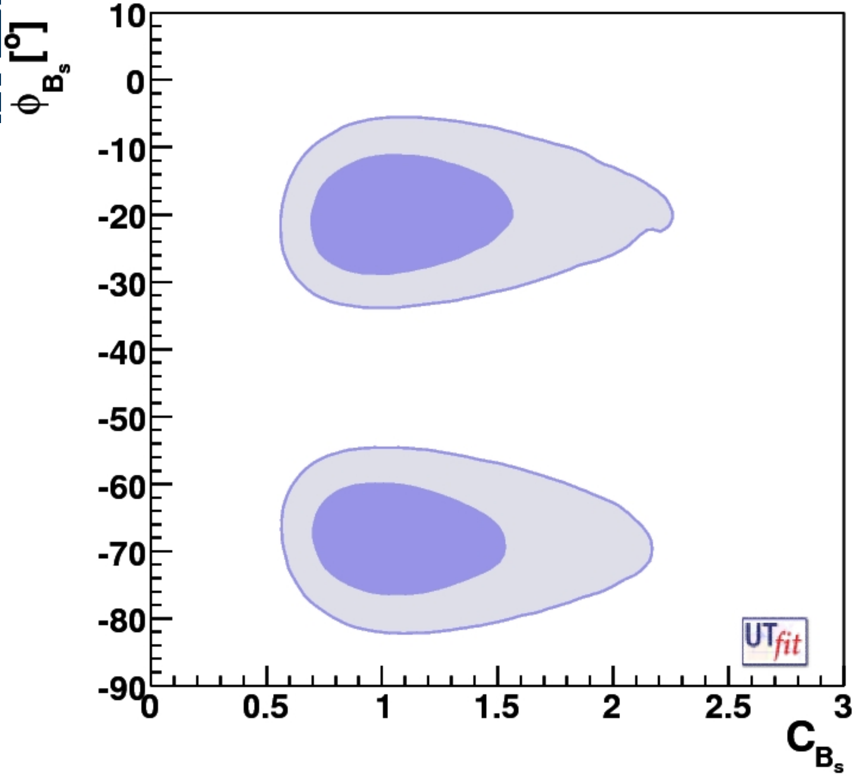
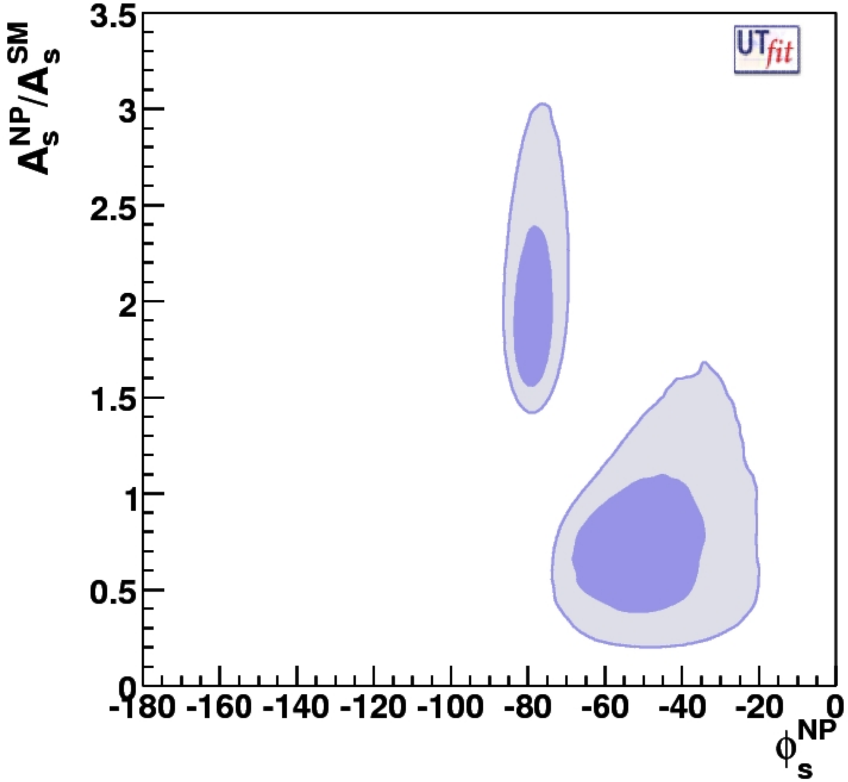
Hadronic matrix element	Current lattice error	60 TFlop Year [2011 LHCb]	1-10 PFlop Year [2015 SuperB]
$f_+^{K\pi}(0)$	0.9% (22% on 1-f_+)	0.4% (10% on 1-f_+)	< 0.1% (2.4% on 1-f_+)
$\hat{B}_K$	11%	3%	1%
f_B	14%	2.5 - 4.0%	1 – 1.5%
$f_{B_s}B_{B_s}^{1/2}$	13%	3 - 4%	1 – 1.5%
ξ	5% (26% on ξ-1)	1.5 - 2 % (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%

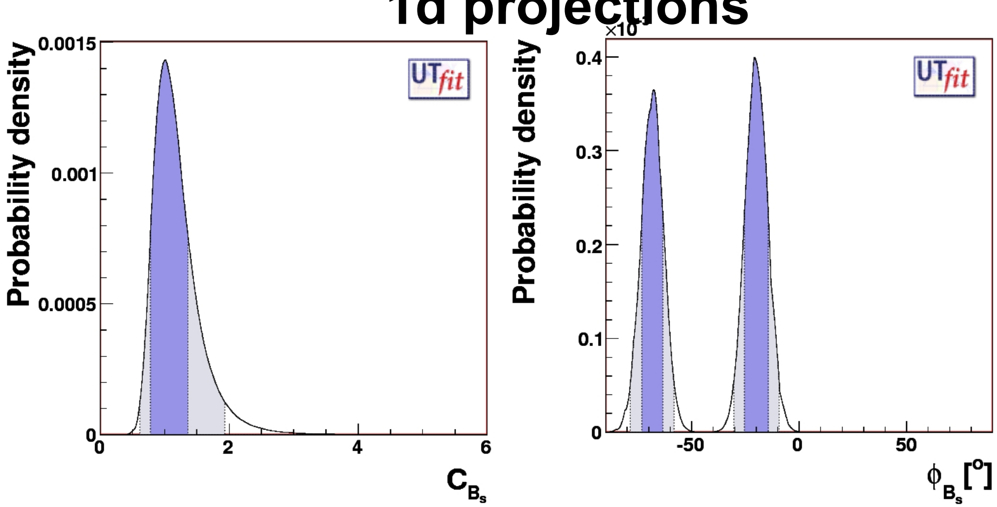
S.Sharpe @ Lattice QCD: Present and Future, Orsay, 2004
and report of the U.S. Lattice QCD Executive Committee



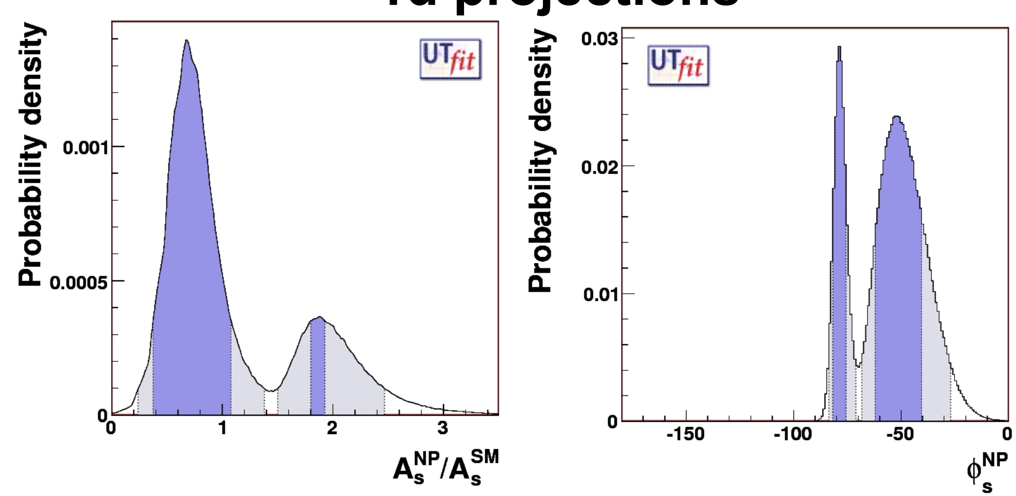




1d projections

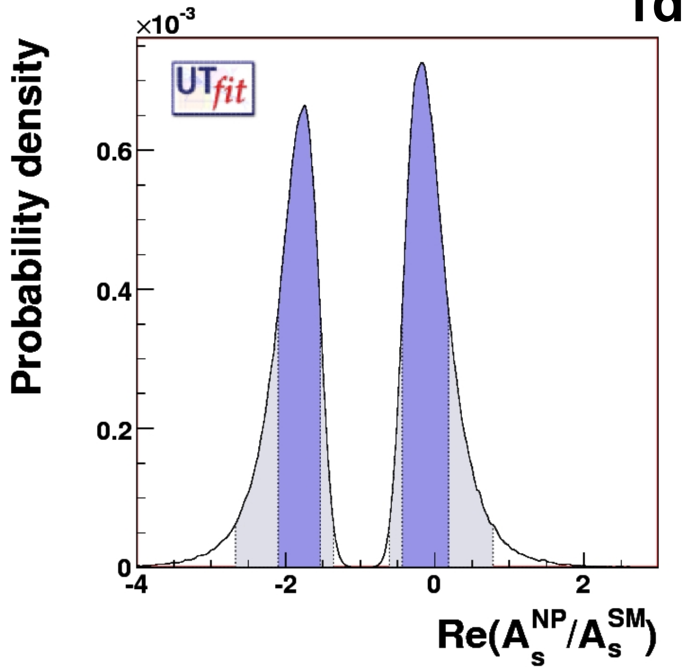


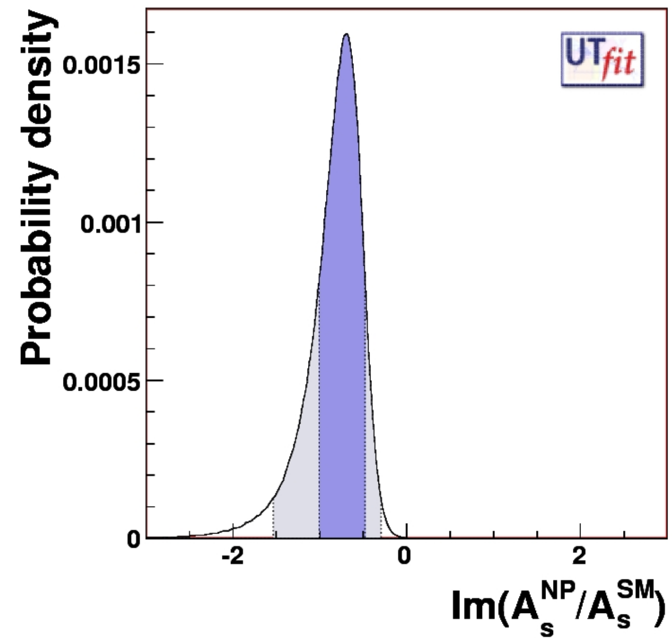
1d projections

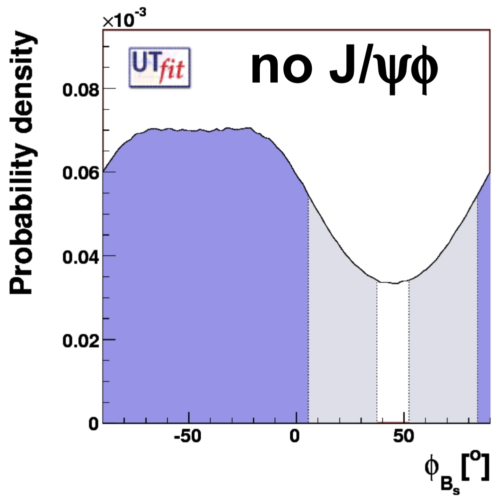


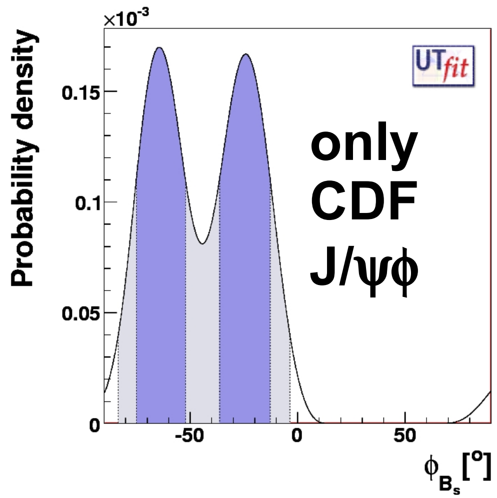
plots from: arXiv:0803.0659 [hep-ph]

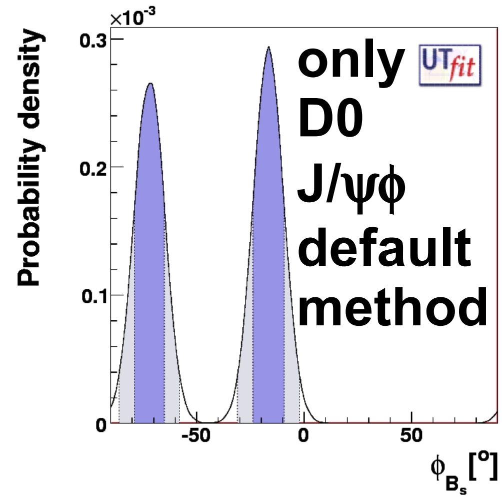
1d projections

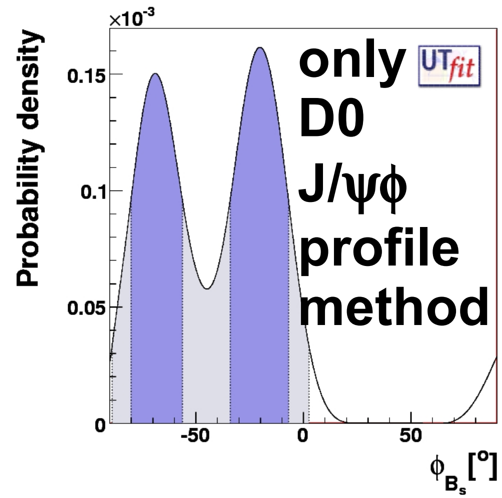






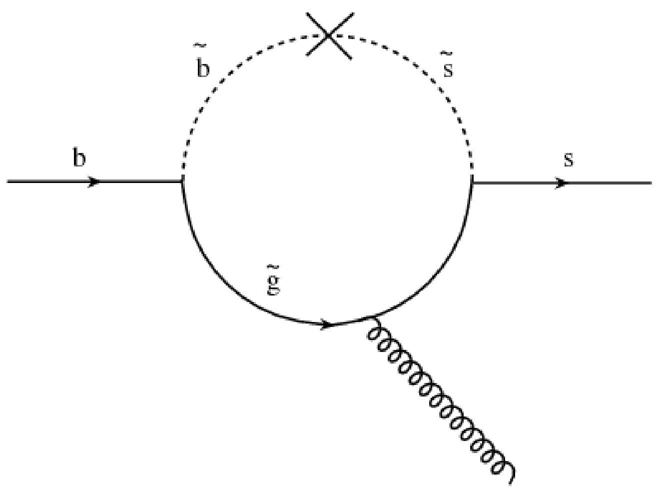


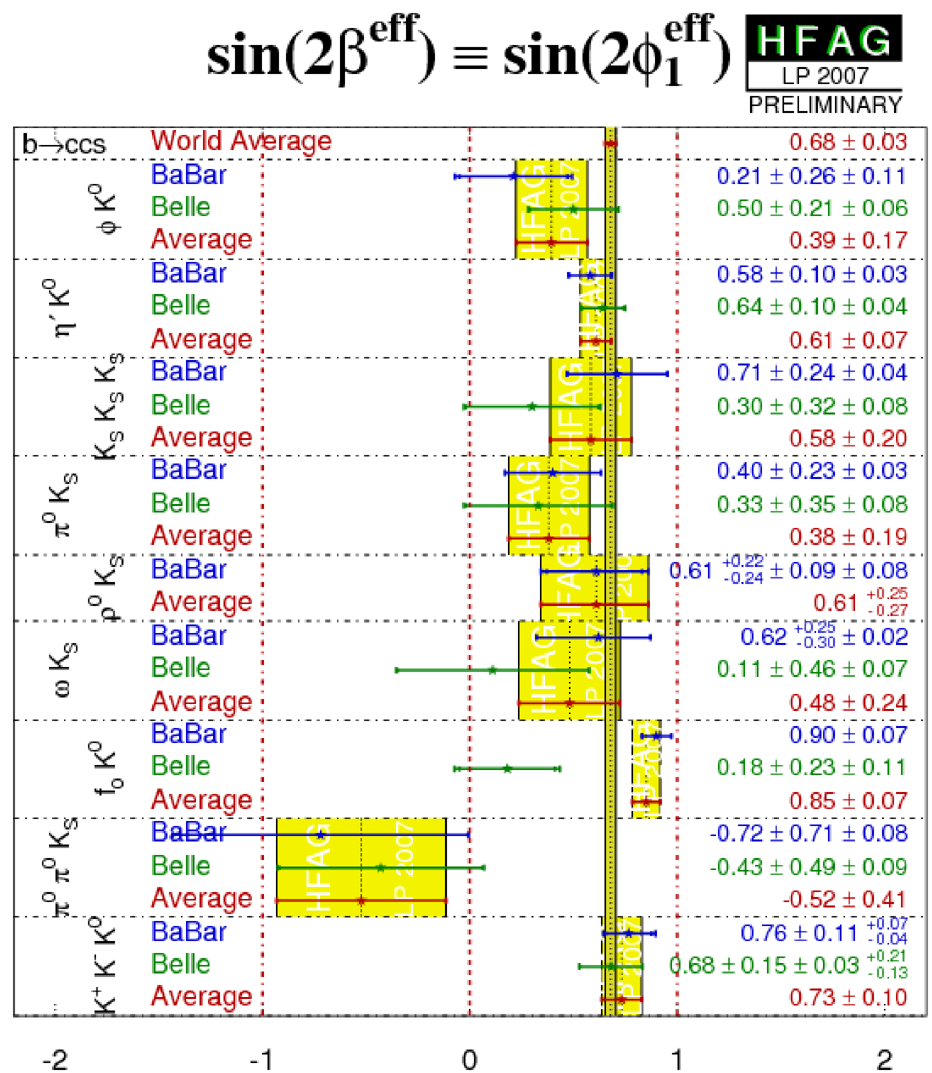




plots from: arXiv:0803.0659 [hep-ph]

$b \rightarrow s$ penguins





- Extra sources of FCNC: investigation looking at $b \leftrightarrow s$ penguin decays
- Some "hints" seen on $\sin 2\beta$ in penguin decays
- Difficult interpretation due to theoretical issues (but SM hadron corrections are expected to induce positive shifts)

Semileptonic Asymmetry A_{SL}

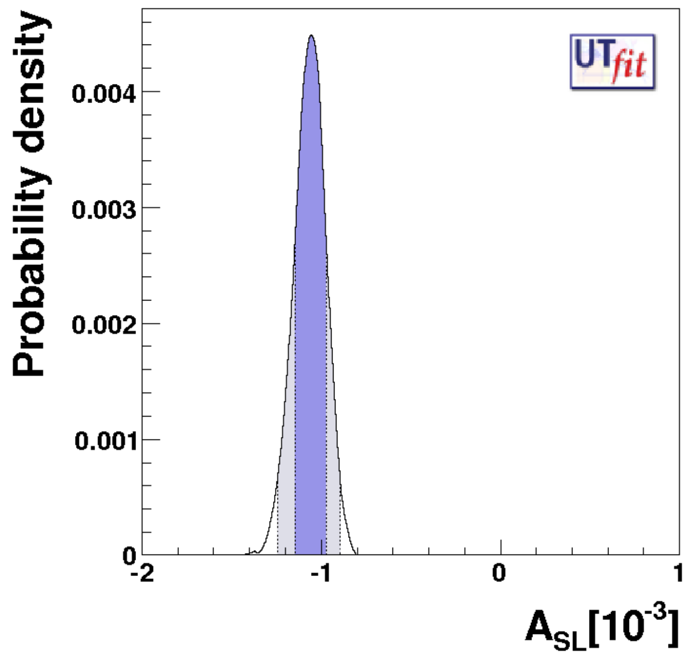
$$A_{\rm SL} \equiv \frac{\Gamma(\bar{B}^0 \to \ell^+ X) - \Gamma(B^0 \to \ell^- X)}{\Gamma(\bar{B}^0 \to \ell^+ X) + \Gamma(B^0 \to \ell^- X)}$$

$$= -{\rm Re}\left(\frac{\Gamma_{12}}{M_{12}}\right)^{\rm SM} \frac{\sin 2\phi_{B_d}}{C_{B_d}} + {\rm Im}\left(\frac{\Gamma_{12}}{M_{12}}\right)^{\rm SM} \frac{\cos 2\phi_{B_d}}{C_{B_d}}$$

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

$$\frac{\Delta\Gamma_q}{\Delta m_q} = -2\frac{\kappa}{C_{B_q}}\left\{\cos\left(2\phi_{B_q}\right)\left(n_1 + \frac{n_6 B_2 + n_{11}}{B_1}\right) - \frac{\cos\left(\phi_q^{\rm SM} + 2\phi_{B_q}\right)}{R_t^q}\left(n_2 + \frac{n_7 B_2 + n_{12}}{B_1}\right) + \frac{\cos\left(2(\phi_q^{\rm SM} + \phi_{B_q})\right)}{R_t^{q^2}}\right.$$

$$\left.\left(n_3 + \frac{n_8 B_2 + n_{13}}{B_1}\right) + \cos\left(\phi_q^{\rm Pen} + 2\phi_{B_q}\right) C_q^{\rm Pen}\left(n_4 + n_9\frac{B_2}{B_1}\right) - \cos\left(\phi_q^{\rm SM} + \phi_q^{\rm Pen} + 2\phi_{B_q}\right)\frac{C_q^{\rm Pen}}{R_t^q}\left(n_5 + n_{10}\frac{B_2}{B_1}\right)\right\}$$

- 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 $\bar{B}_s$ 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*
$(\pi-\phi_s, -\Delta\Gamma_s, \pi-\delta_{1,2})$	$(\pi+\phi_s, -\Delta\Gamma_s, \pm\delta_{1,2})$
	$(-\phi_s, \Delta\Gamma_s, \pm(\pi-\delta_{1,2}))$
	$(\pi-\phi_s, -\Delta\Gamma_s, \pm(\pi-\delta_{1,2}))$

$$\frac{d^4\Gamma}{dt\,d\cos\theta\,d\varphi\,d\cos\psi} \propto$$

Dunietz, Fleischer, Nierste
hep-ph/0012219

$$\begin{aligned}
&2\cos^2\psi(1-\sin^2\theta\cos^2\varphi)|A_0(t)|^2\\
&+\sin^2\psi(1-\sin^2\theta\sin^2\varphi)|A_\parallel(t)|^2\\
&+\sin^2\psi\sin^2\theta|A_\perp(t)|^2\\
&+(1/\sqrt{2})\sin 2\psi\sin^2\theta\sin 2\varphi\,\mathrm{Re}(A_0^*(t)A_\parallel(t))\\
&+\ (1/\sqrt{2})\sin 2\psi\sin 2\theta\cos\varphi\,\mathrm{Im}(A_0^*(t)A_\perp(t))\\
&-\ \sin^2\psi\sin 2\theta\sin\varphi\,\mathrm{Im}(A_\parallel^*(t)A_\perp(t)).
\end{aligned}$$

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

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

$$\mathrm{Im}\{A_0^*(t)A_\perp(t)\} = |A_0(0)|\,|A_\perp(0)|\,e^{-\Gamma t}$$

$$\times\left[\sin\delta_2\cos(\Delta m\,t) - \cos\delta_2\cos\phi\,\sin(\Delta m\,t) - \cos\delta_2\sin\phi\,\sinh\frac{\Delta\Gamma\,t}{2}\right]$$

$$\mathrm{Im}\{\overline{A}_0^*(t)\overline{A}_\perp(t)\} = |A_0(0)|\,|A_\perp(0)|\,e^{-\Gamma t}$$

$$\times\left[-\sin\delta_2\cos(\Delta m\,t) + \cos\delta_2\cos\phi\,\sin(\Delta m\,t) - \cos\delta_2\sin\phi\,\sinh\frac{\Delta\Gamma\,t}{2}\right]$$

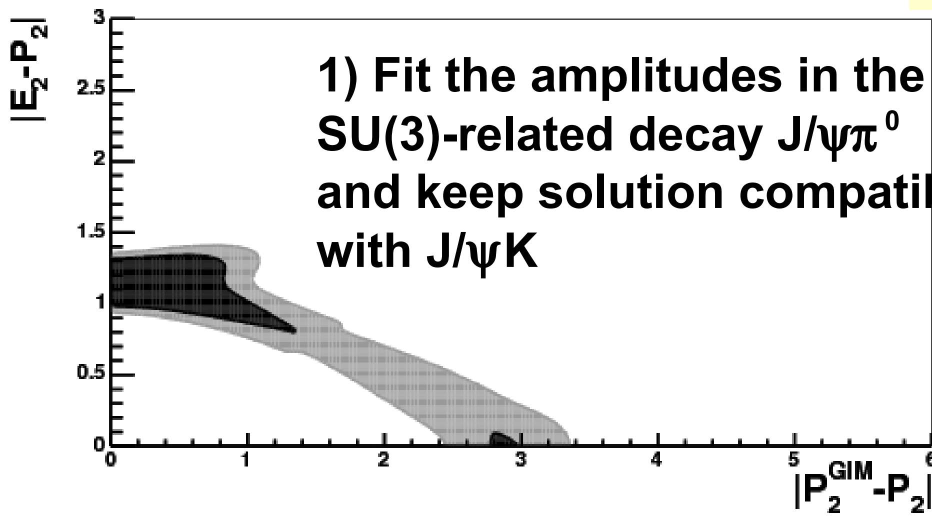
Theory error on sin2β

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

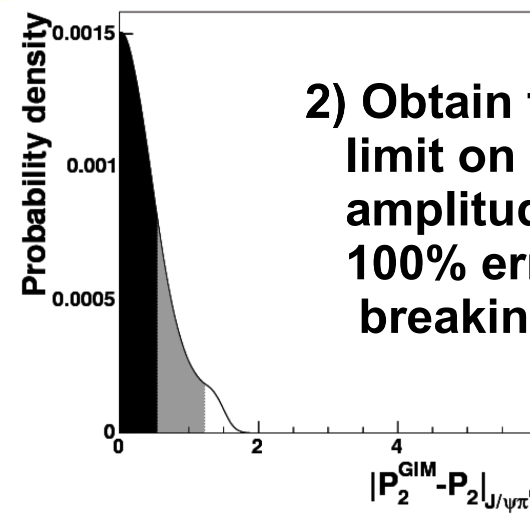
Channel	Cl.	E_1 1	E_2 $\frac{1}{N}$	EA_2 $\frac{1}{N^2}$	A_2 $\frac{1}{N}$	P_1 $\frac{1}{N}$	P_2 $\frac{1}{N^2}$	P_3 1	P_1^{GIM} 1	P_2^{GIM} $\frac{1}{N^2}$	P_3^{GIM} 1	P_4 1	P_4^{GIM} $\frac{1}{N^3}$
$B_d \to J/\psi K^0$			λ^2	–	–	–	λ^2			λ^4			–
$B_d \to \pi^0 J/\psi$	D	–	λ^3	λ^3	–	–	λ^3	–	–	λ^3	–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

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

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

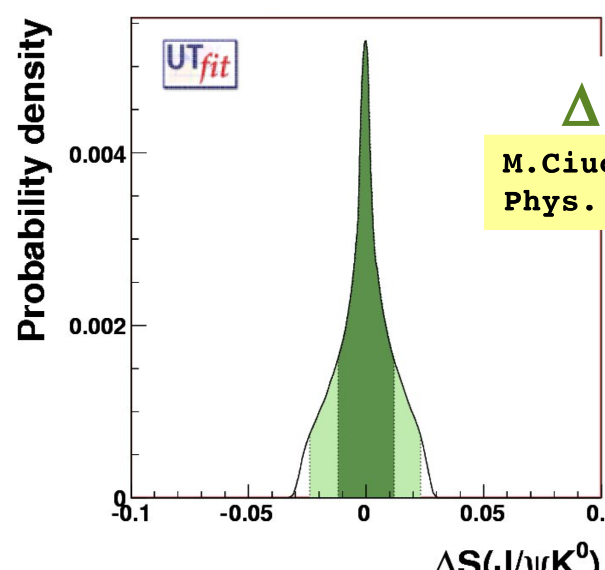


1) Fit the amplitudes in the SU(3)-related decay $J/\psi\pi^0$ and keep solution compatible with $J/\psi K$



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

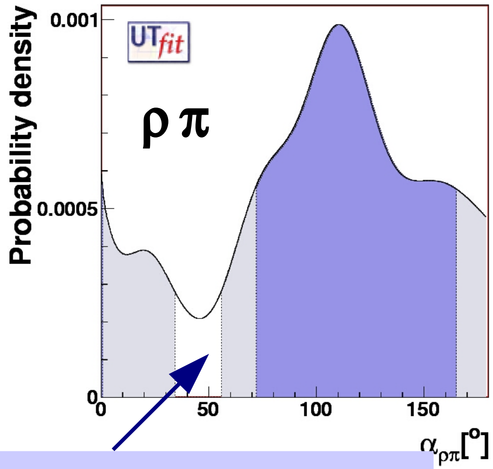
3) Fit the amplitudes in $J/\psi K^0$ imposing the upper bound on the CKM suppressed amplitude and extract the error on sin2β

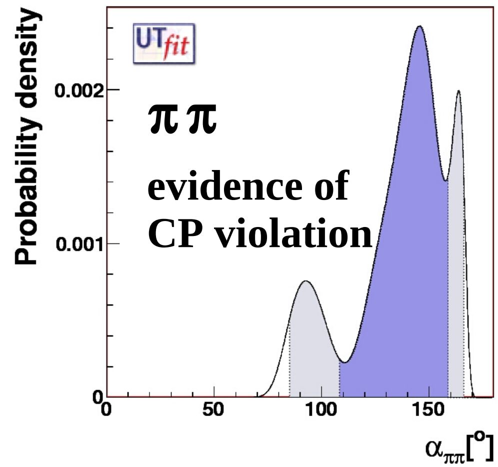


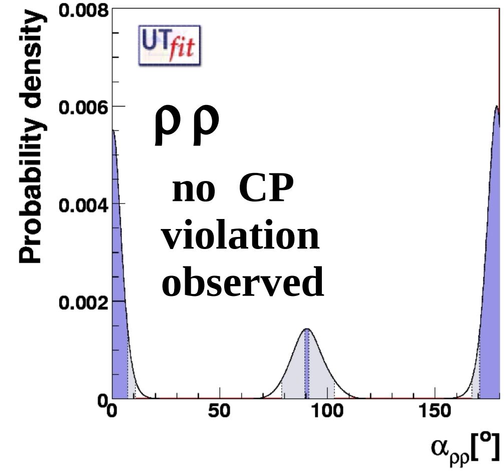
$\Delta S = 0.000 \pm 0.012$

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

α extraction from the three analyses

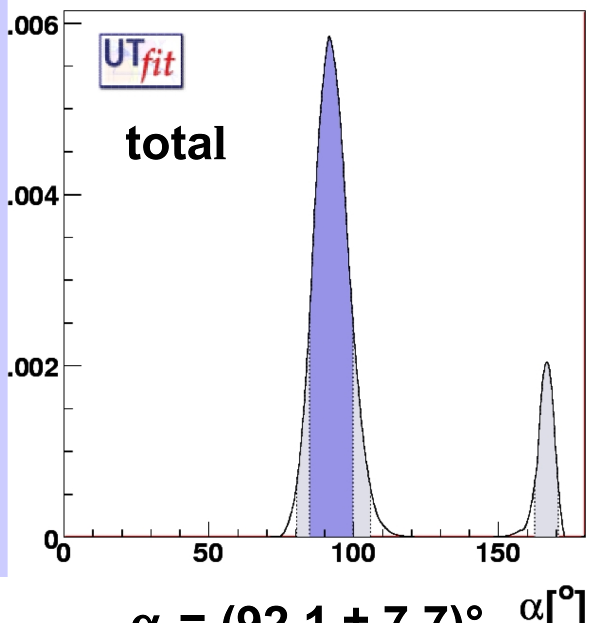




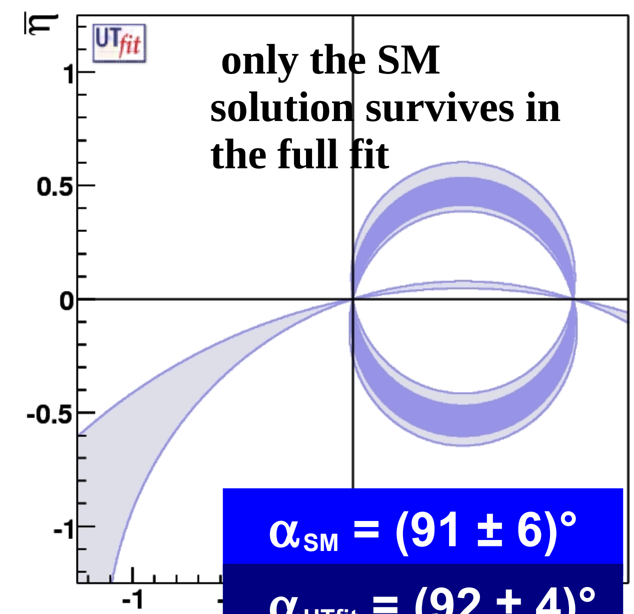


$$A = A(\rho^+\pi^-) + A(\rho^-\pi^+) + 2A(\rho^0\pi^0)$$
$$= (T^{+-} + T^{-+} + 2T^{00})\, e^{2i\alpha}$$
$$\rightarrow \quad R = \bar{A}/A = e^{2i\alpha}$$

no paramete-rization involved



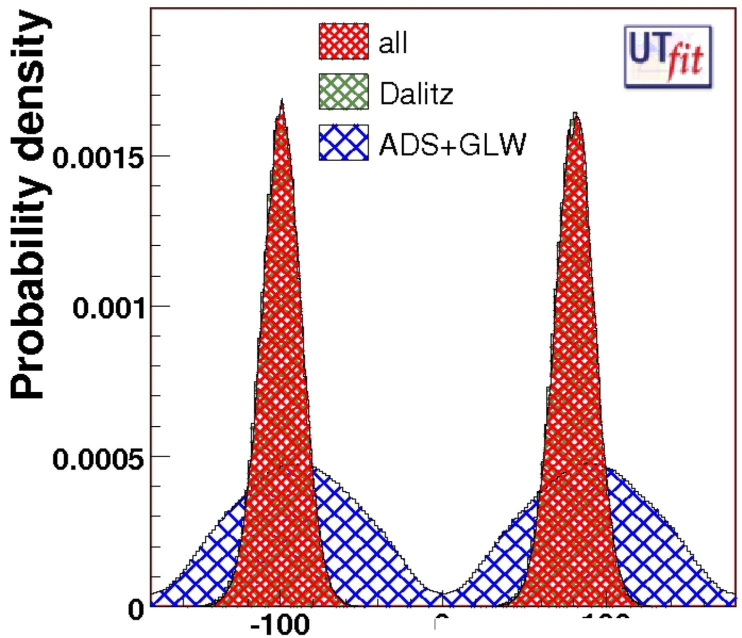
$\alpha = (92.1 \pm 7.7)°$

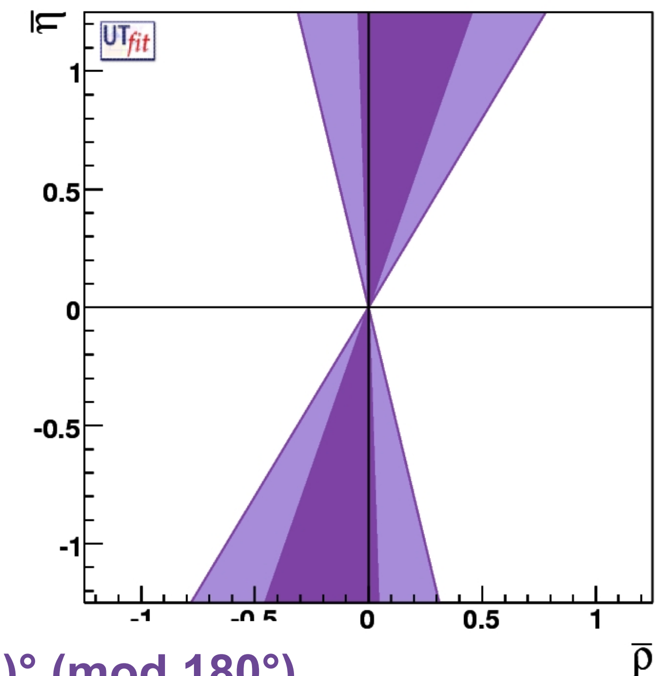


$\alpha_{SM} = (91 \pm 6)°$

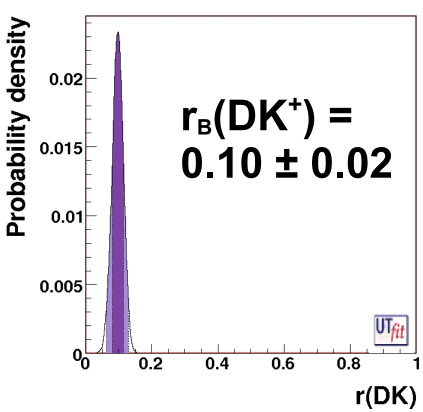
$\alpha_{UTfit} = (92 \pm 4)°$

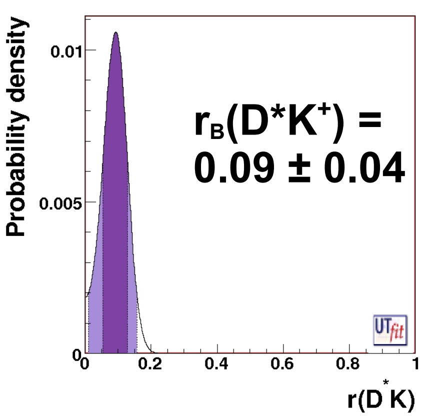
Combining the methods for γ

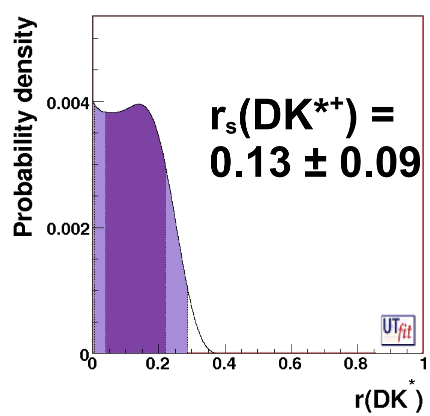




γ = (80 ± 13)° (mod.180°)

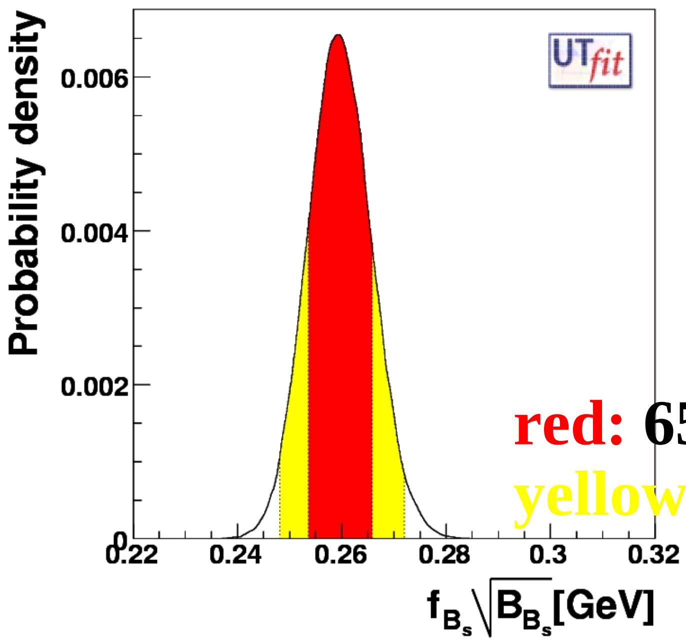




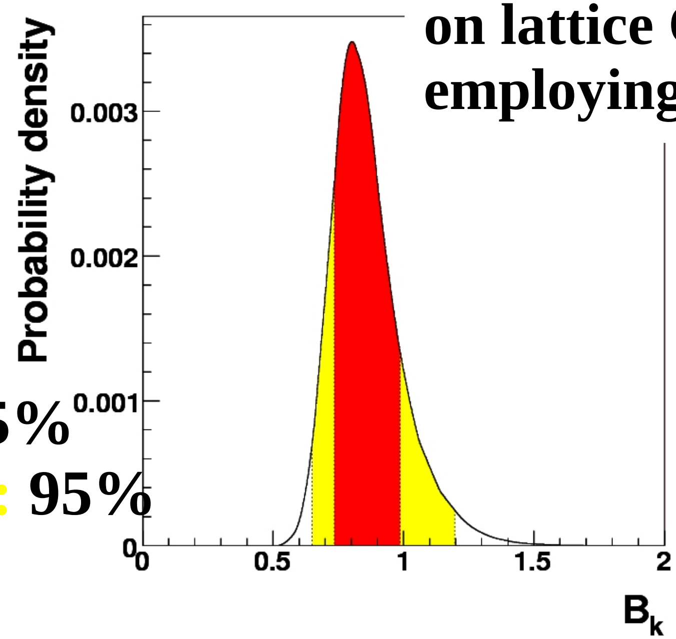


LQCD predictions

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

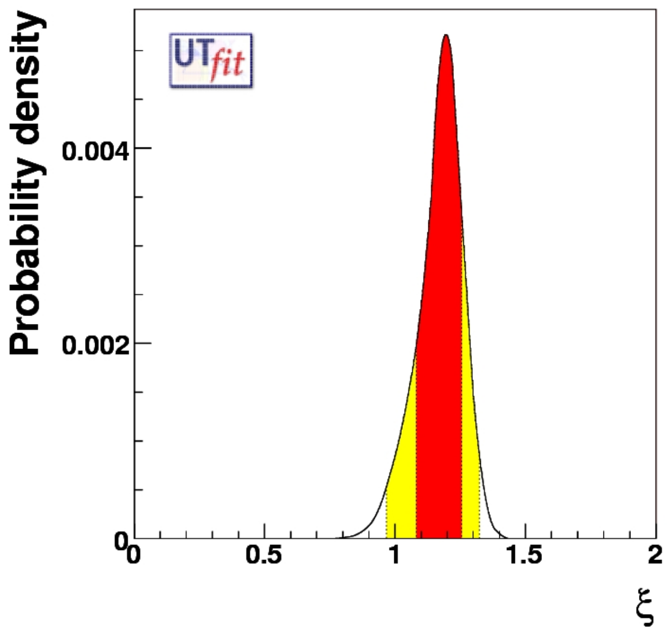


red: 65%
yellow: 95%



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

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



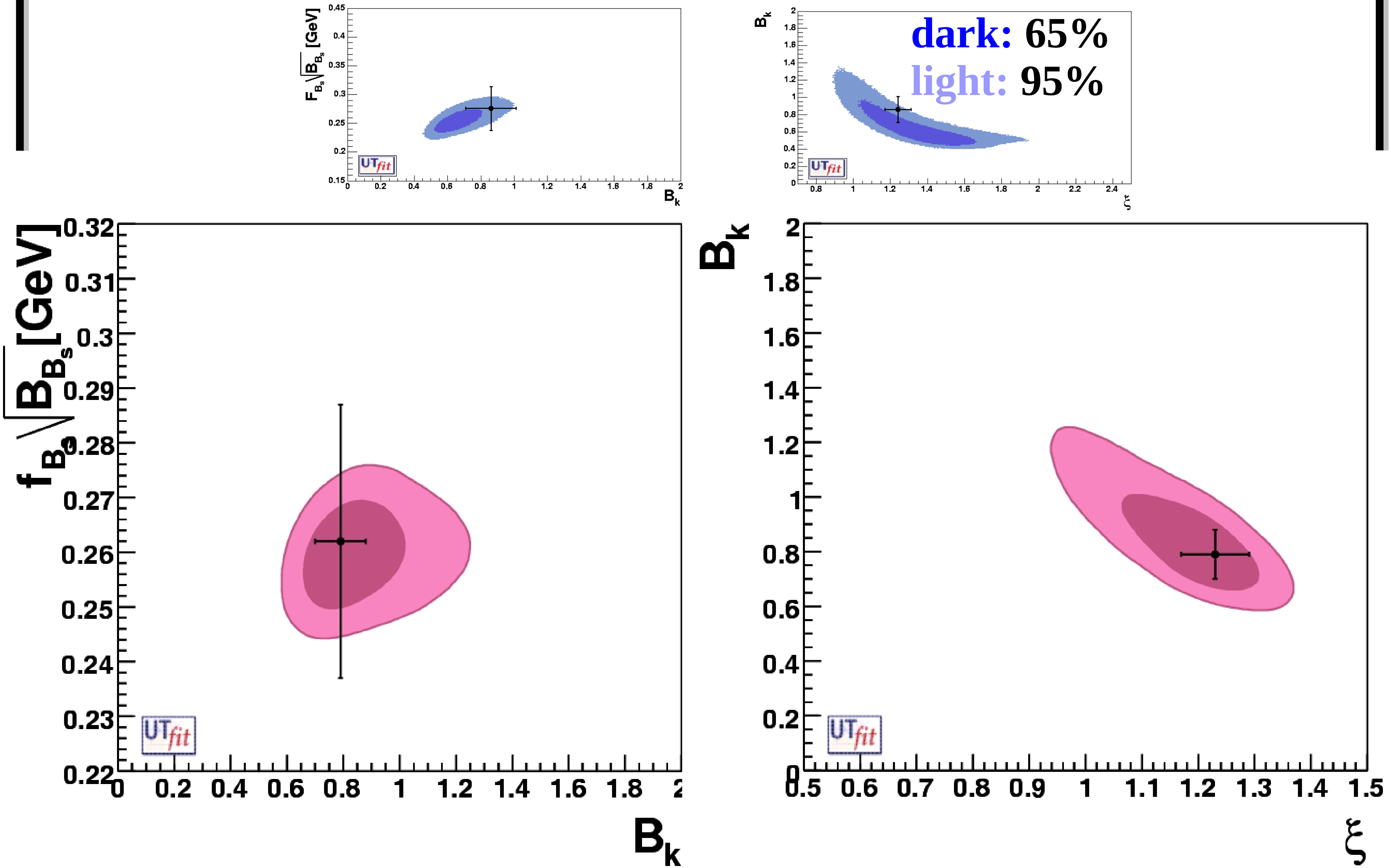
$B_K = 0.86 \pm 0.13$

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

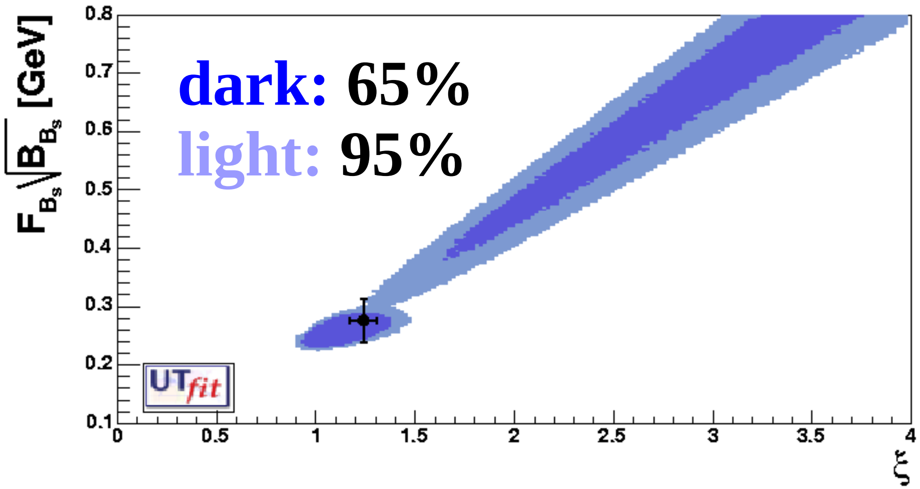
$\xi = 1.17 \pm 0.08$

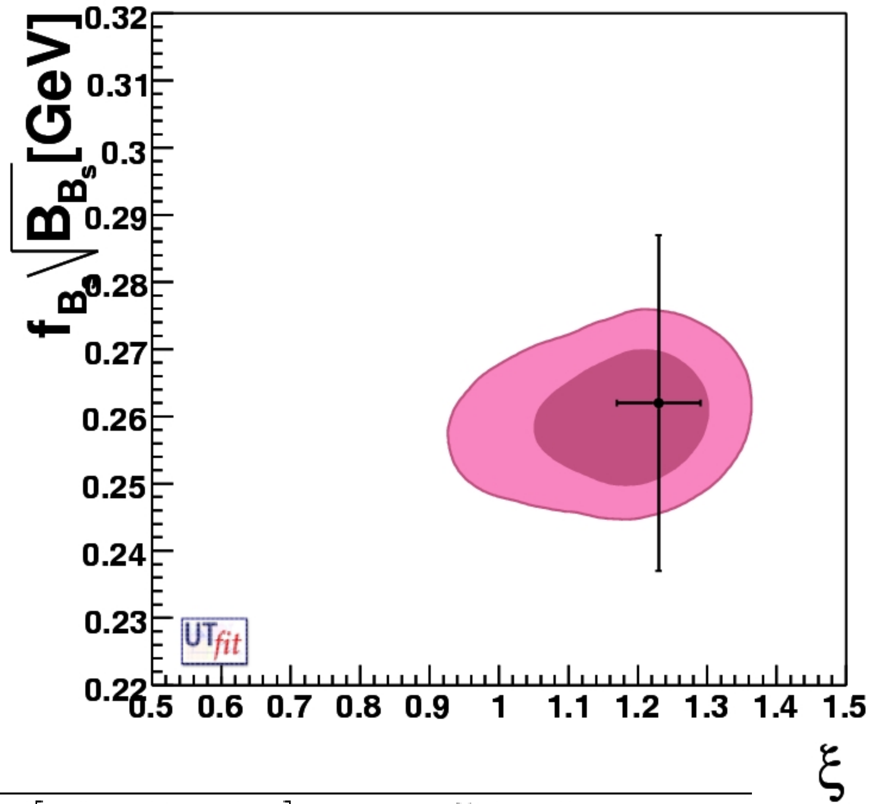
$\xi = 1.24 \pm 0.04 \pm 0.06$ LQCD

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