# Unitarity Triangle Fitter Results for CKM Angles

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IN2P3/LAL-Orsay

INFN-Bologna

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# Credits

http://utfit.org/

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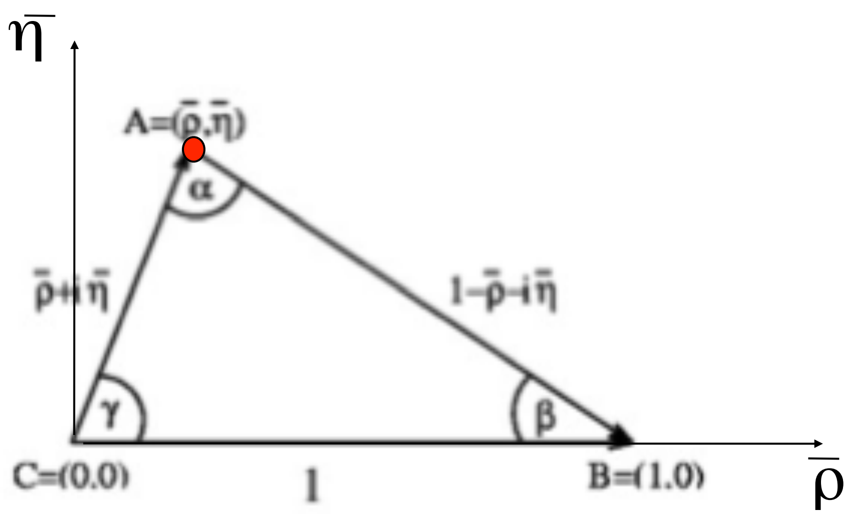
Use the Bayesian statistics to extract the observables. Extract the credibility interval from the fit.

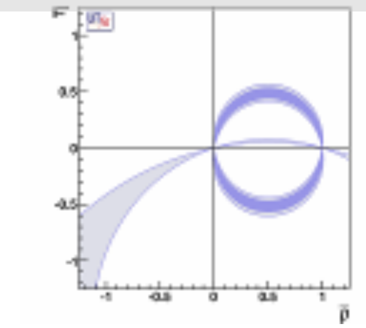
Gaussian PDFs are used to represent statistical and systematic uncertainties.

The results included into this talk are based on experimental studies that were public before this conference.

# Constraints used (angles)

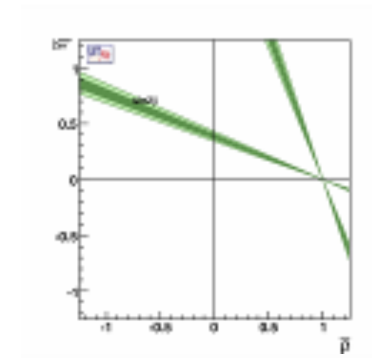



$\alpha$



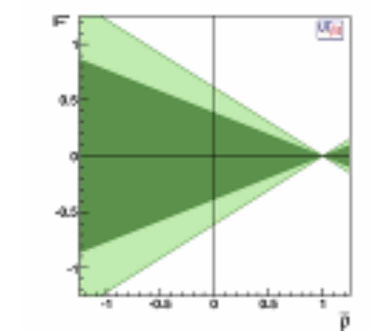
$B \to \pi\pi$, $B \to \rho\rho$, $B \to \rho\pi$

$\sin(2\beta)$



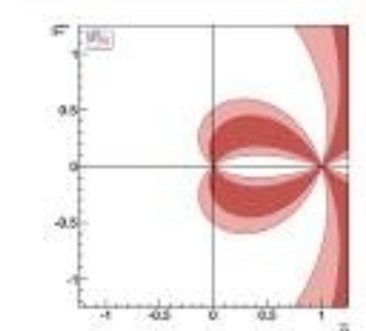
$B \to J/\Psi K$

$\cos(2\beta)$



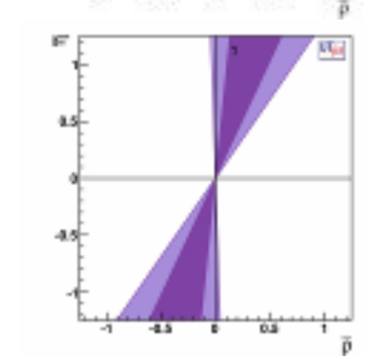
$B \to DK$, $B \to D\pi$

$2\beta+\gamma$

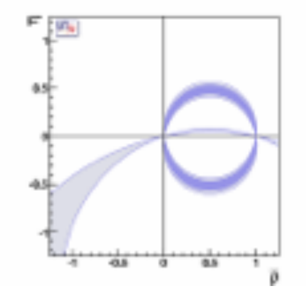


$B \to DK$, $B \to D\pi$

$\gamma$



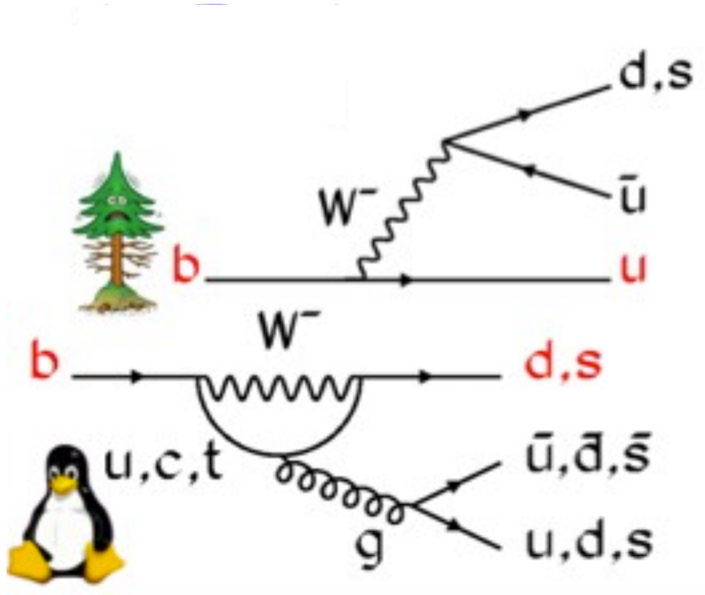
$B \to DK$





## B→ππ, B→ρρ, B→ρπ

One can write the following equations to describe one of the decays mentioned:




$$A^{+-} = -Te^{-i\alpha} + Pe^{i\delta_P}$$
$$A^{+0} = -\frac{1}{\sqrt{2}}\left[e^{-i\alpha}(T + T_c\, e^{i\delta_{T_c}})\right]$$
$$A^{00} = -\frac{1}{\sqrt{2}}\left[e^{-i\alpha}T_c\, e^{i\delta_{T_c}} + P\, e^{i\delta_P}\right]$$

For the $B^0 \to \pi^+\pi^-$

$$a_{f_{CP}}(t) = \frac{\text{Prob}(B^0(t) \to f_{CP}) - \text{Prob}(\overline{B^0}(t) \to f_{CP})}{\text{Prob}(\overline{B^0}(t) \to f_{CP}) + \text{Prob}(B^0(t) \to f_{CP})} = C_f \cos\Delta m_d t + S_f \sin\Delta m_d t$$

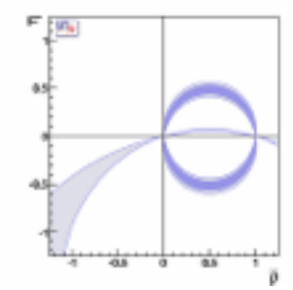
which gives:

$$\lambda_{\pi\pi} = e^{2i\alpha}\frac{1 + |P/T|e^{i\delta}e^{i\gamma}}{1 + |P/T|e^{i\delta}e^{-i\gamma}}$$
$$C_{\pi\pi} \propto \sin(\delta)$$
$$S_{\pi\pi} = \sqrt{1 - C^2_{\pi\pi}}\,\sin(2\alpha_{eff})$$





Phys. Rev. D76 (2007) 014015



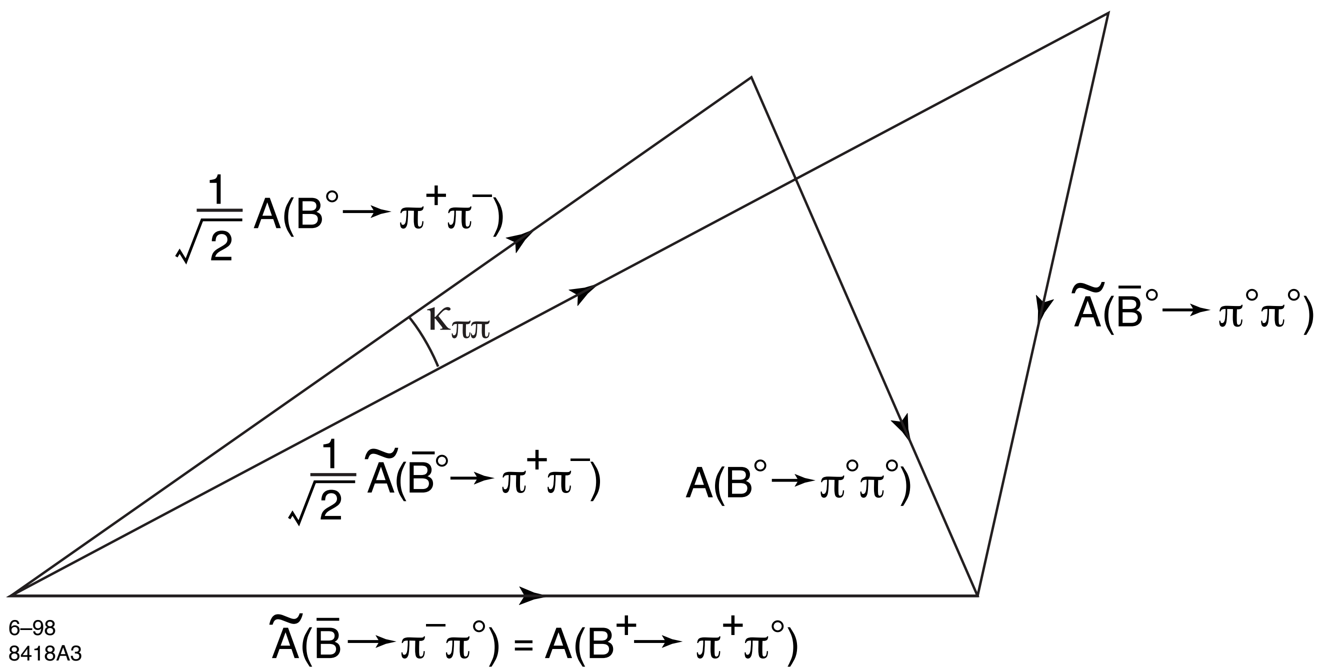
# Alpha from B→ππ

$B\to\pi^+\pi^-$, $B\to\pi^0\pi^0$, $B\to\pi^+\pi^0$ decays are connected from isospin relations. ππ states can have I = 2 or I = 0

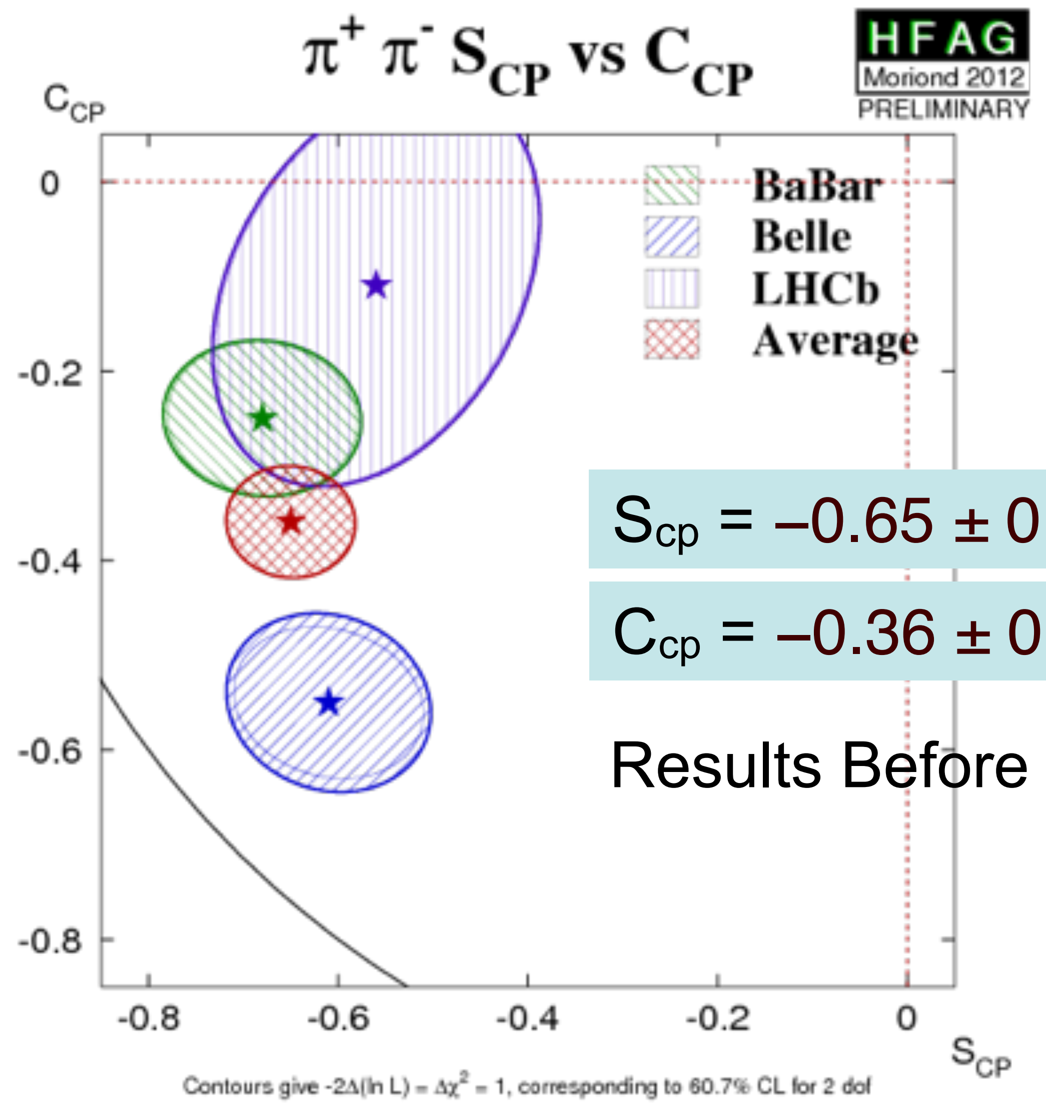
the gluonic penguins contribute only to the I = 0 state (ΔI=1/2)

$\pi^+\pi^0$ is a pure I = 2 state (ΔI = 3/2) and it gets contribution only from the tree diagram

triangular relations allow for the determination of the phase difference induced on α




Same relations hold for B→ρρ system

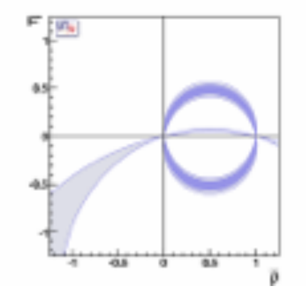



$S_{cp} = -0.65 \pm 0.07$

$C_{cp} = -0.36 \pm 0.06$

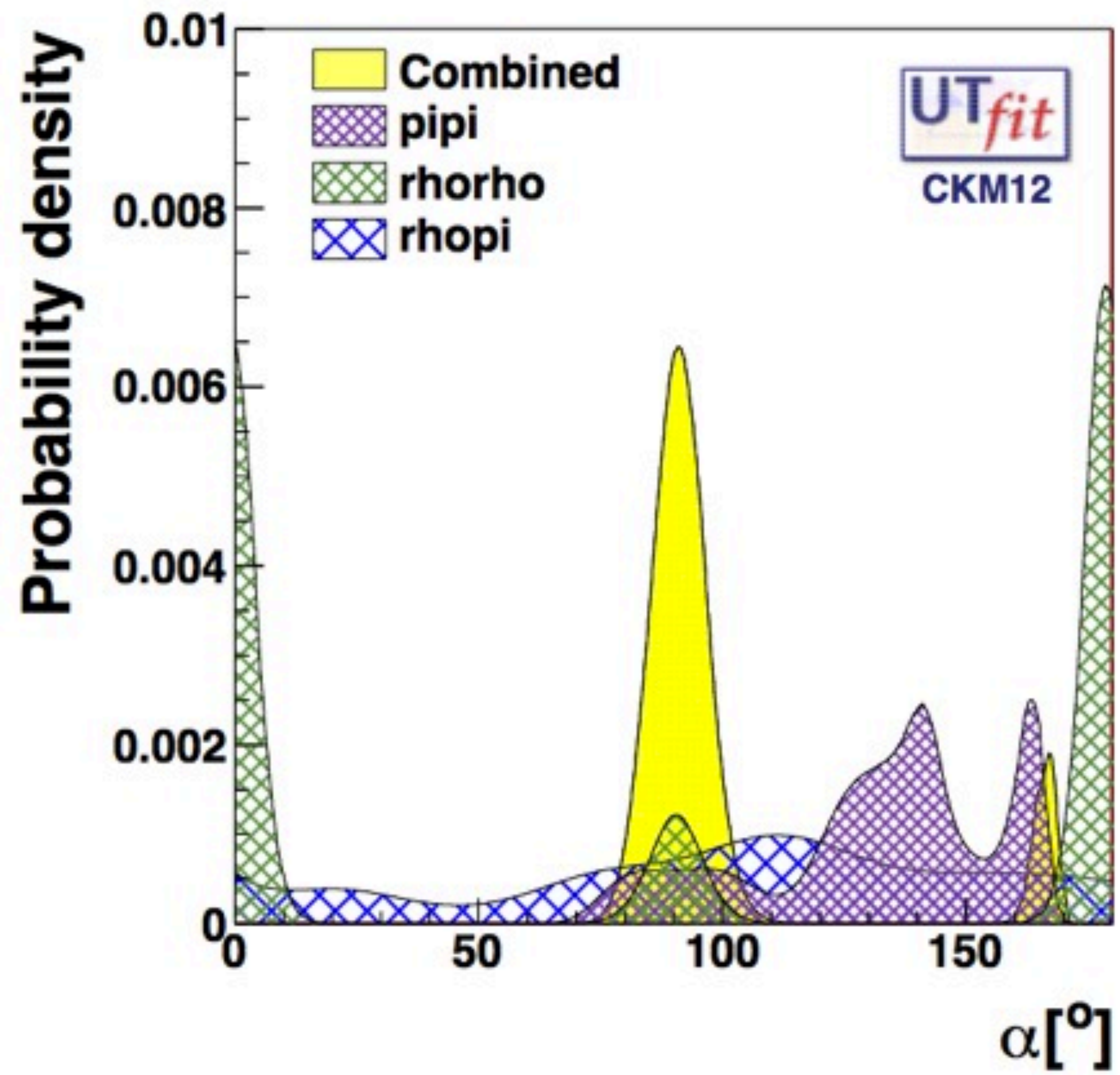
Results Before CKM

M. Gronau and D. London, Phys. Rev. Lett. 65 (1990) 3381



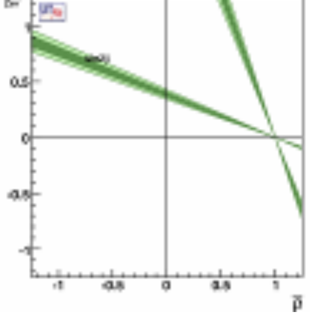
Another point is adding the B→ρπ analysis

This is a completely different analysis: The time-dependent Dalitz plot analysis of the decays of the neutral B allows one to infer the value of α without any dependence on the hadronic parameter.




$$\alpha = (90.6 \pm 6.6)^{\circ}$$

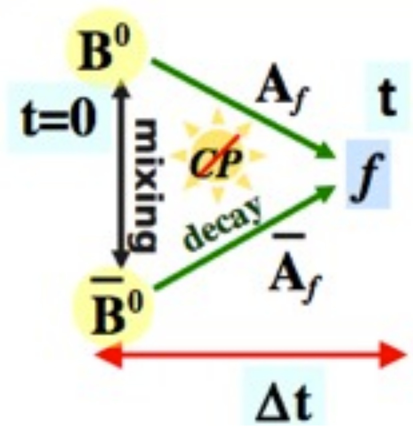
Phys. Rev. D76 (2007) 014015



# Beta results

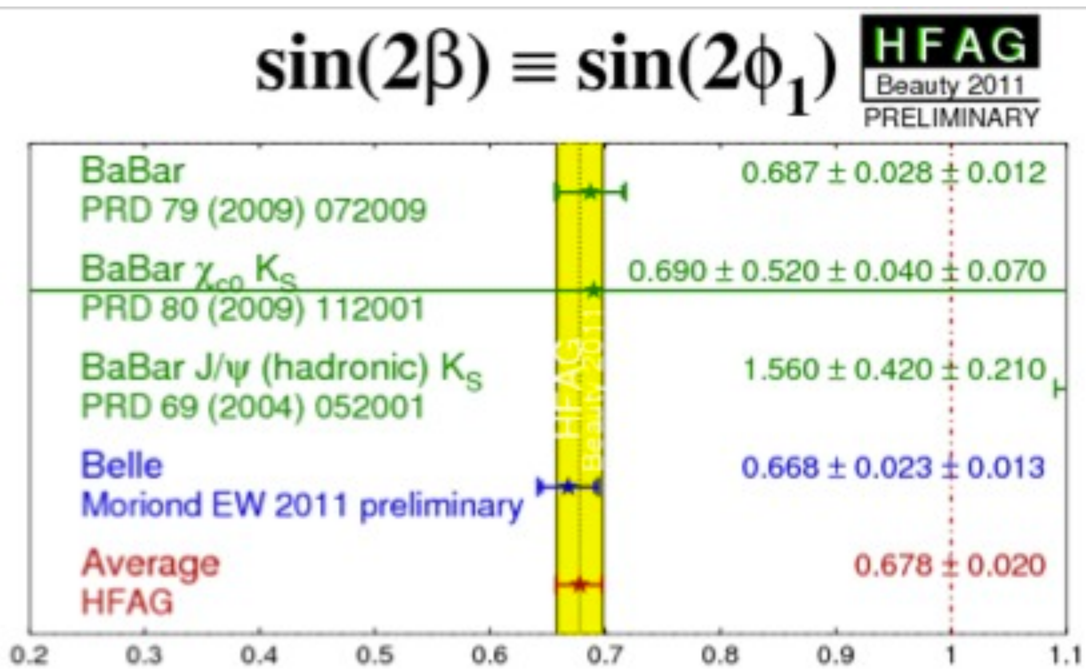
B→J/ΨK

**sin2β from time-dependent $A_{CP}$ in B → J/ψK**




$$a_{f_{CP}}(t) = \frac{\mathrm{Prob}(B^0(t)\to f_{CP}) - \mathrm{Prob}(\overline{B^0}(t)\to f_{CP})}{\mathrm{Prob}(\overline{B^0}(t)\to f_{CP}) + \mathrm{Prob}(B^0(t)\to f_{CP})} = C_f \cos\Delta m_d t \ + \ S_f \sin\Delta m_d t$$

$$a_{f_{CP}}(t) = -\eta_{CP} \sin\Delta m_d \Delta t \sin 2\beta$$



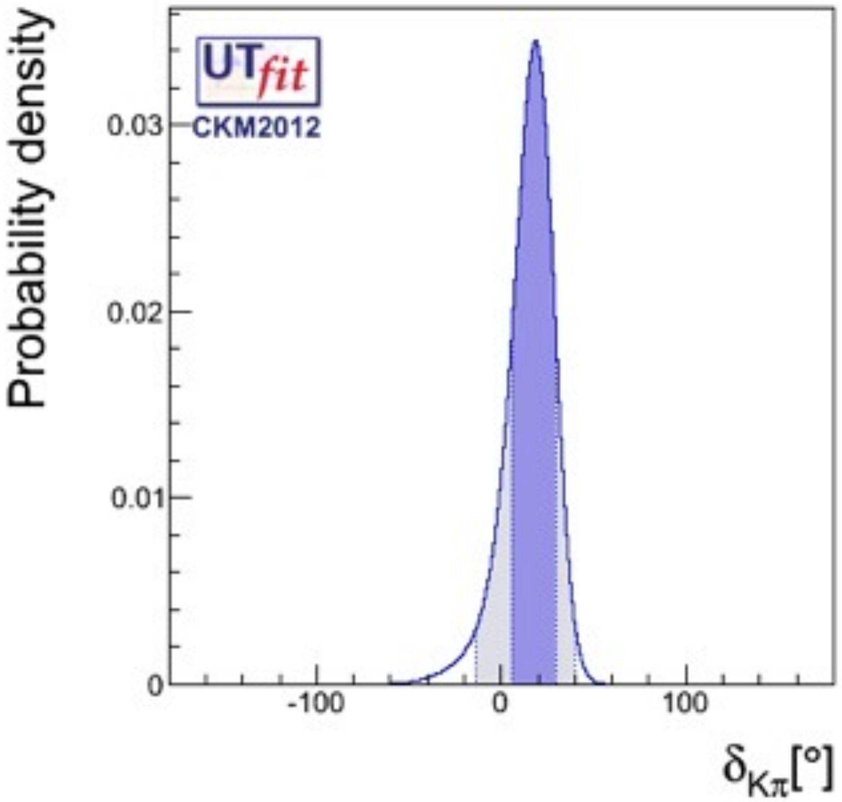

$$\sin(2\beta) = 0.68 \pm 0.023$$

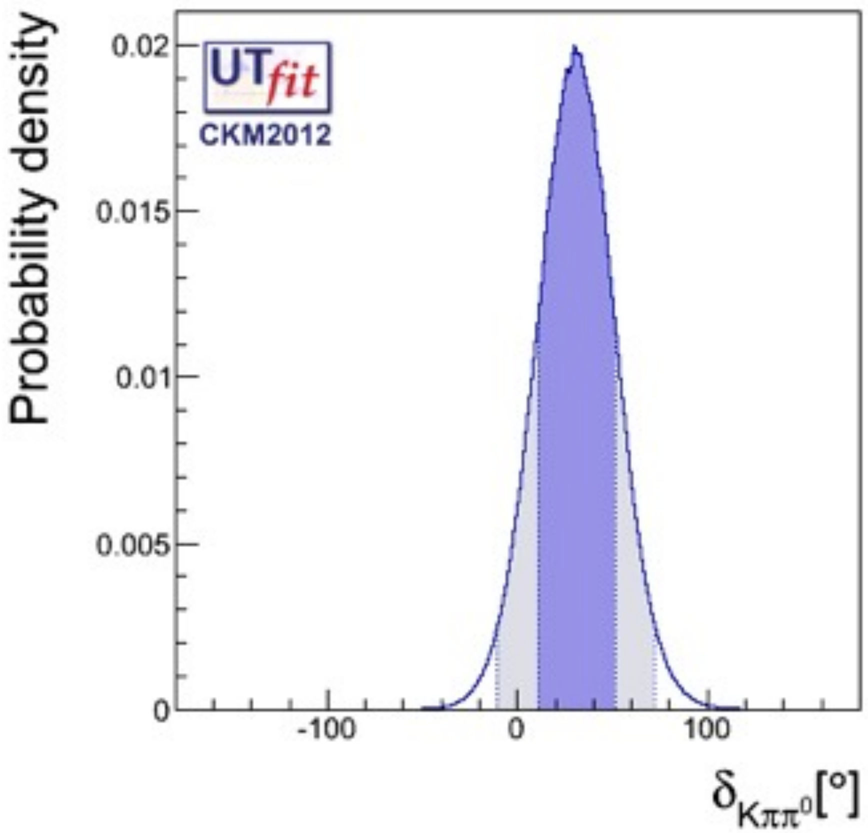
**data-driven theoretical uncertainty**

**ΔS = 0.000 ± 0.012**

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

We perform a fit to the charm sector results allowing for CP violation in the singly-Cabibbo suppressed decays and receive the following results that can be used in the γ reconstruction.



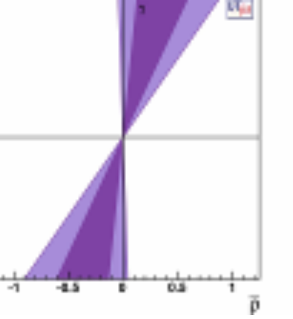

$\delta_{K\pi}\ [^\circ] \quad = \quad (18 \pm 12)$

$\delta_{K\pi\pi^0}\ [^\circ] \quad = \quad (31 \pm 20)$

The obtained results are in agreement with the closest HFAG results.

A. Bevan et al. arXiv:1206.6245, accepted to JHEP

http://www.utfit.org/UTfit/DDbarMixing

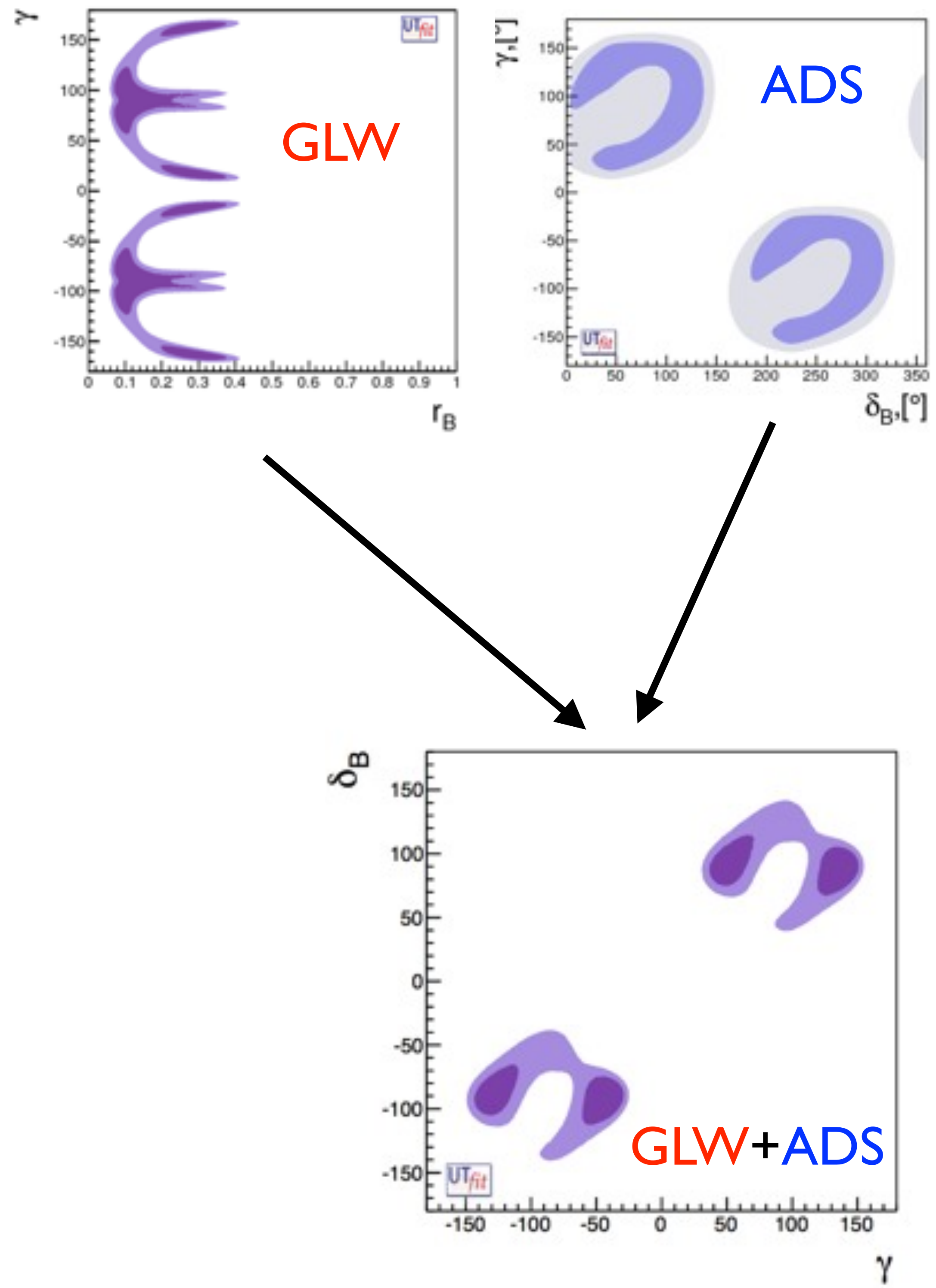


# Gamma inputs

We use the available information coming from the three methods:

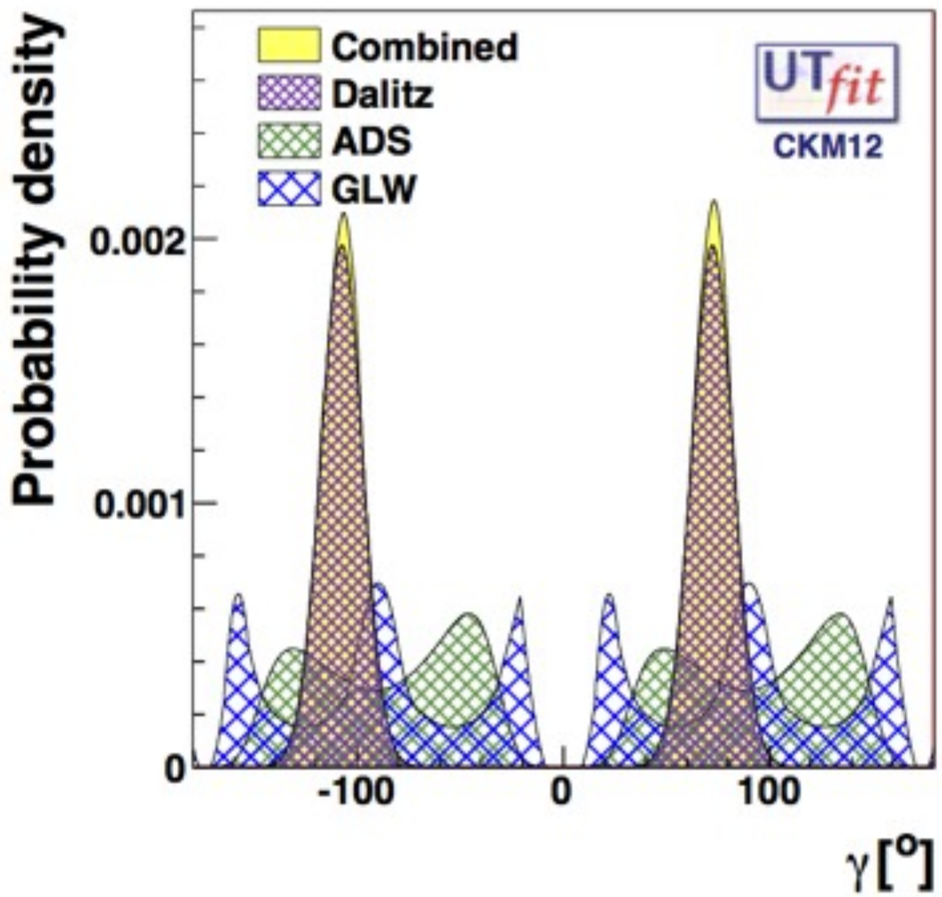
- GLW (M. Gronau, D. London, D. Wyler, PLB253,483 (1991); PLB 265, 172 (1991))
- ADS (D. Atwood, I. Dunietz and A. Soni, PRL 78, 3357 (1997))
- GGSZ (A. Giri, Yu. Grossman, A. Soffer, J. Zupan, PRD 68, 054018(2003))

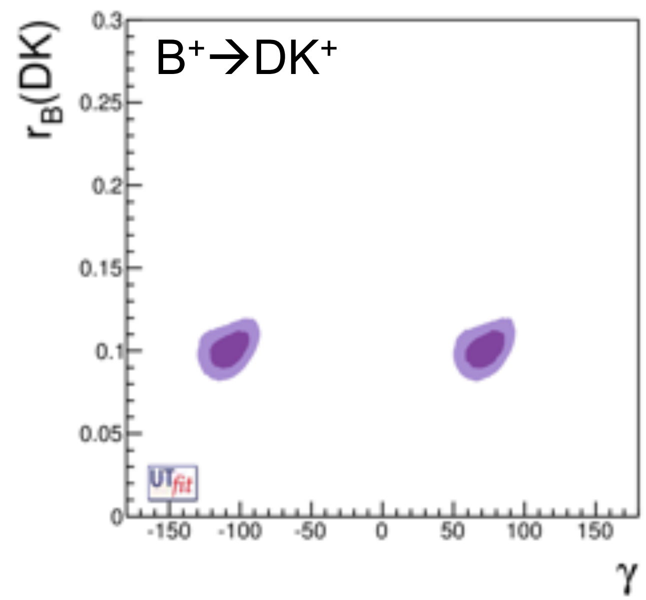
For the decays: $B^+ \rightarrow D^{(*)}K^{(*)+}$ and $B^0 \rightarrow D^{(*)}K^{(*)0}$

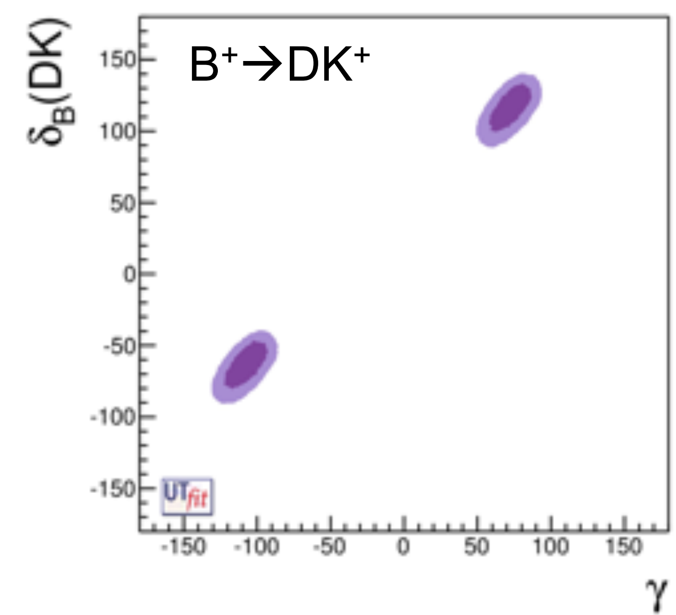



The combination is performed starting from the HFAG averages. The main problem is treatment of the nontrivial likelihoods for {$\gamma$, $\delta_B$, $r_B$} observables.

# Results of Combination



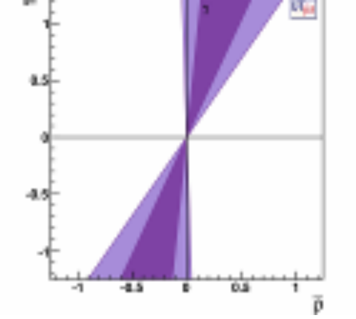




With new results in $B^0$ system, we are able to have the combined value more than 4 sigmas away from 0.

$\gamma_{all} = (72.3 \pm 9.3)°$

| | $DK^+$ | $D^*K^+$ | $DK^{*+}$ | $DK^{*0}$ |
|---|---|---|---|---|
| $\delta_B$ | (117±11)° | (-51±14)° | (124±35)° | (124 ±46)° |
| $r_B$ | (0.101±0.007) | (0.12±0.02) | (0.12±0.06) | (0.26±0.06) |

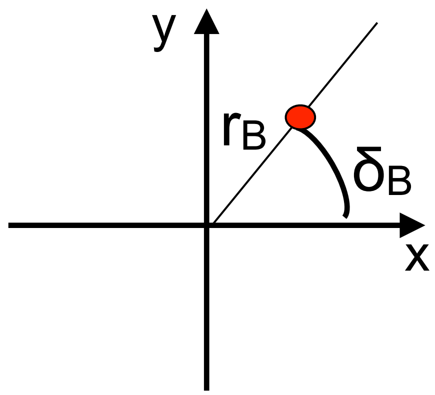
https://www.utfit.org/foswiki/bin/view/UTfit/GammaFromTrees



# Gamma combination: prior studies and strong phases

We have tested the behavior of the gamma average for different priors including:

- Flat cartesian coordinates {x;y}:

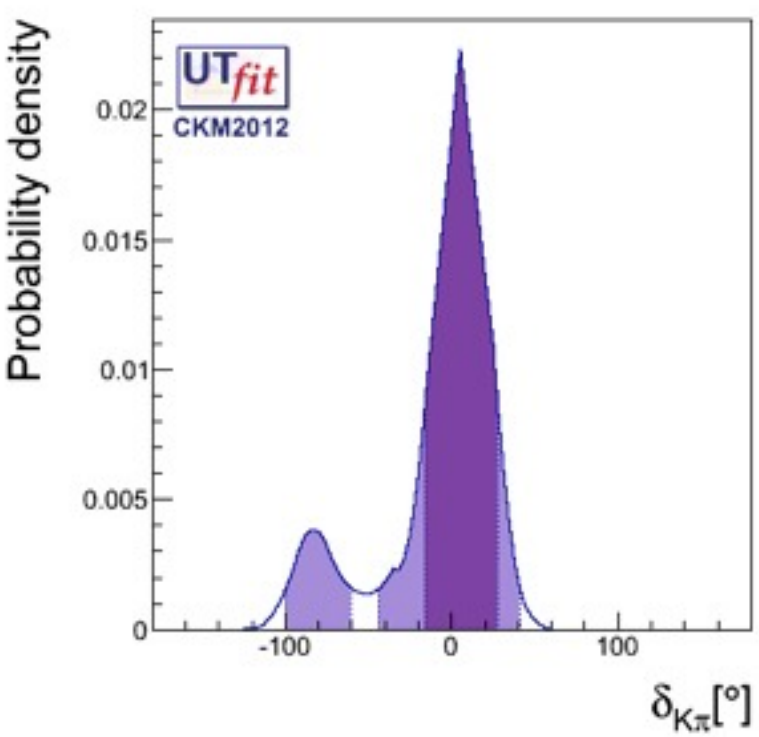


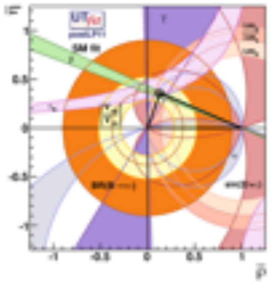

- Jeffreys prior on $r_B$ (weight ~ $1/\sqrt{r_B}$ )

The results are stable against all the reasonable priors and do not give more than 2 degrees difference.

Another important result is that we are able to measure the strong mixing phase $\delta_{D \to K\pi}$. The results are consistent with our mixing studies.

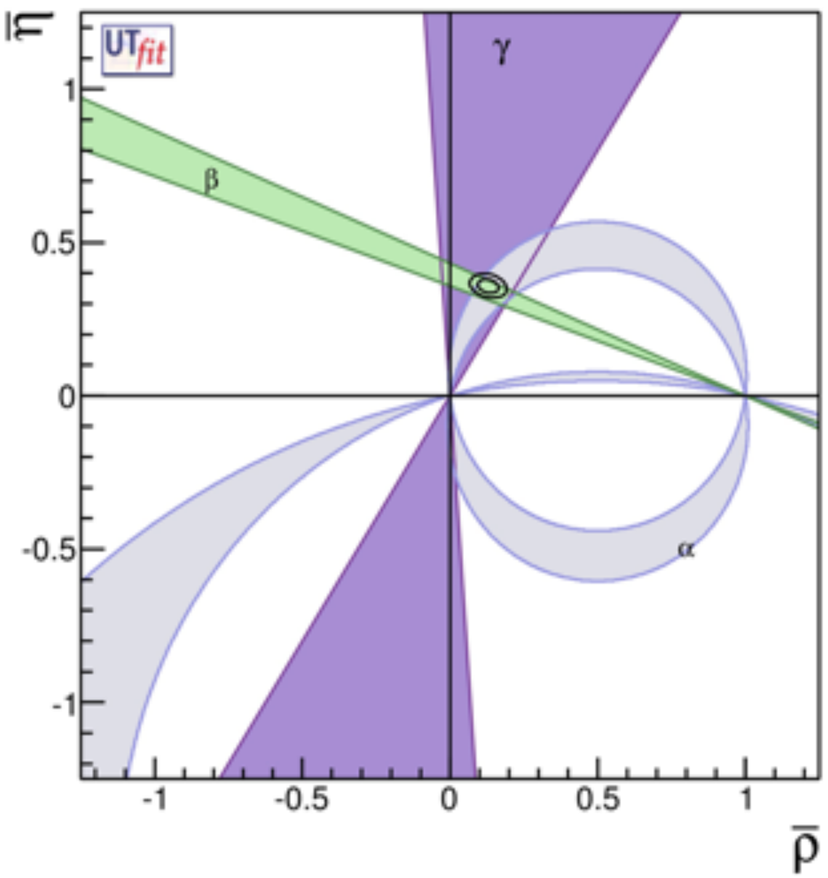
at 68.27% prob [-16,27]
at 95.45% prob [-100,-61] [-43,41]



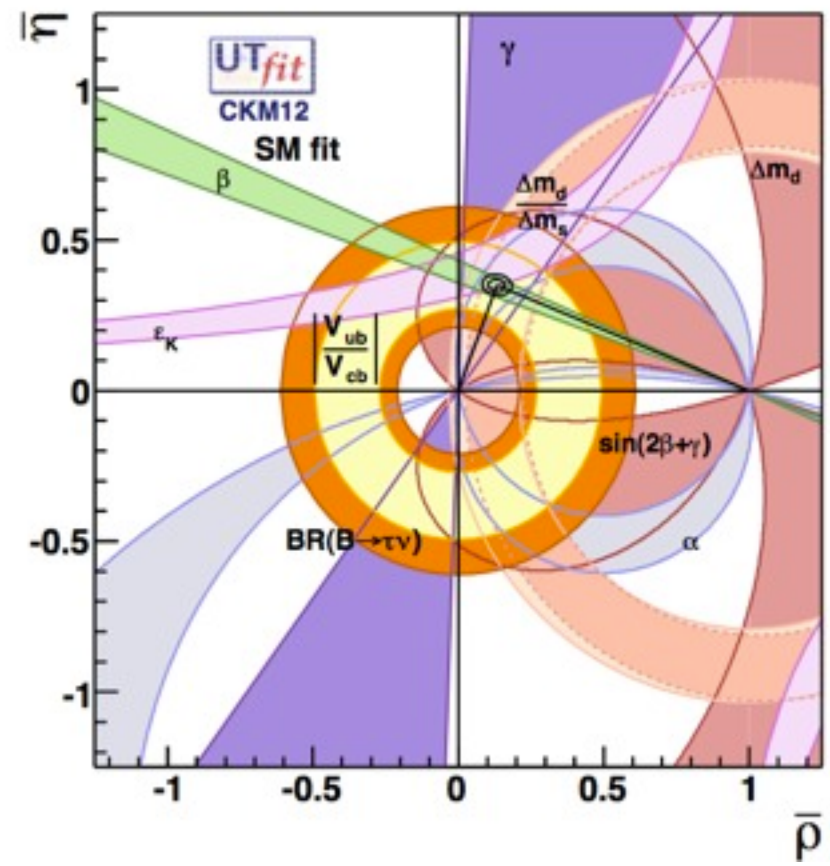


# Standard Model fits

Having only angles we are already able to constrain the CKM triangle



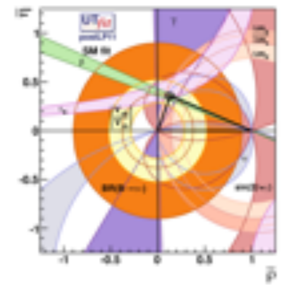

However, adding more input parameters to the fit is very useful, also




$$\bar{\rho} = 0.132 \pm 0.021$$

$$\bar{\eta} = 0.348 \pm 0.015$$

This kind of fit can give the predictions for the angle values.



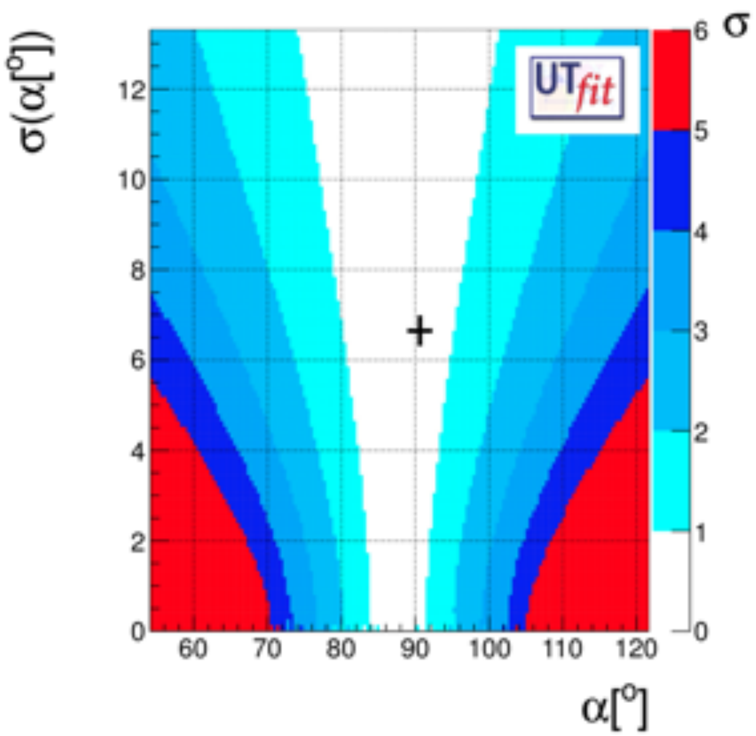


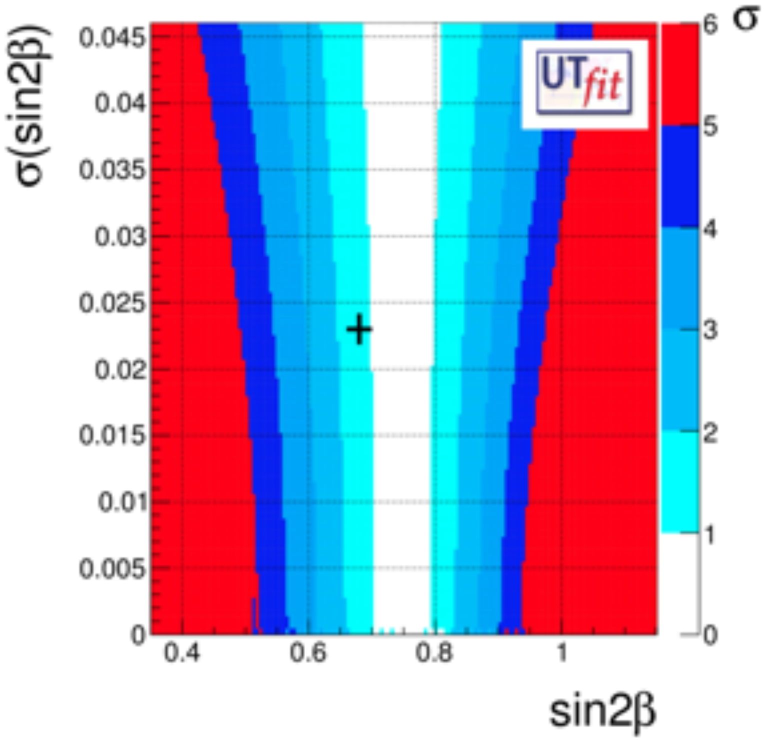
Measurements:

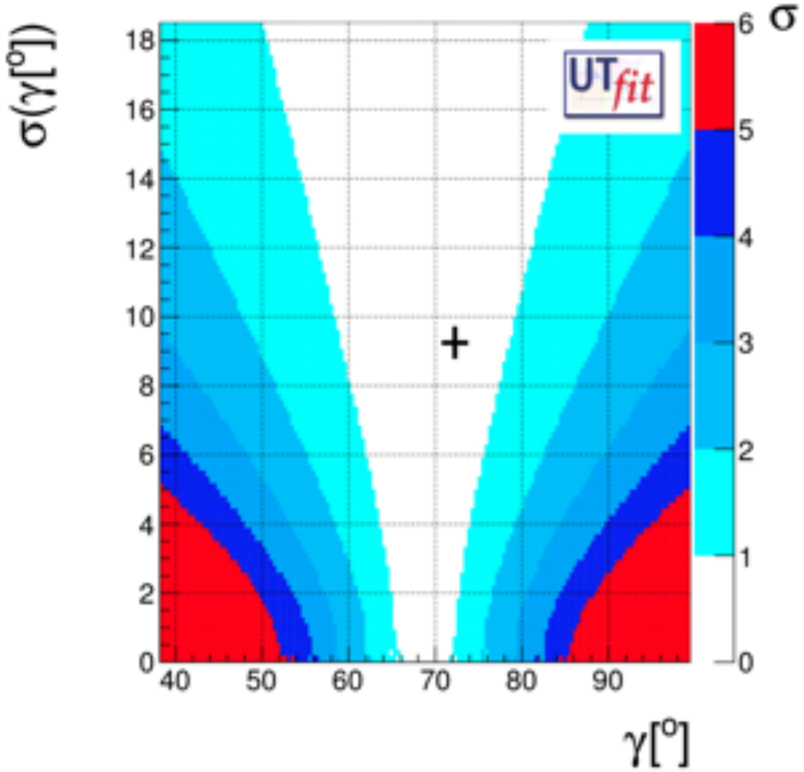
$$\alpha = (90.6 \pm 6.6)^\circ$$

$$\sin(2\beta) = 0.68 \pm 0.023$$

$$\gamma = (72.3 \pm 9.3)^\circ$$



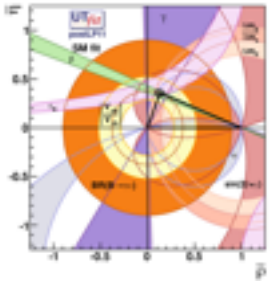

Predictions:

$$\alpha = 87.8 \pm 3.7$$

$$\sin(2\beta) = 0.75 \pm 0.045$$

$$\gamma = 68.8 \pm 3.4$$

No tension except the small one in β



# Full results

## Situation before CKM2012

| | Prediction | Measurement | Pull, $\sigma$ |
|---|---|---|---|
| $\alpha$, ° | (87.8±3.7) | (90.6±6.8) | <1 |
| $\sin(2\beta)$ | (0.75±0.05) | (0.679±0.024) | -1,4 |
| $\gamma$ , ° | (68.8±3.4) | (72.2±9.2) | <1 |
| $V_{ub}$, $10^{-3}$ | (3.63±0.13) | (3.8±0.6) | <1 |
| $V_{cb}$, $10^{-3}$ | (42.3±0.9) | (41.±1.) | <1 |
| $\varepsilon_K$,$10^{-3}$ | (1.96±0.2) | (2.229±0.010) | +1.3 |
| $\Delta m_s$, $ps^{-1}$ | (17.5±1.3) | (17.69±0.08) | <1 |
| $B(B\rightarrow\tau\nu)$,$10^{-4}$ | (0.822±0.008) | (0.99±0.25) | <1 |
| $\beta_s$, rad* | (0.01876±0.0008) | (0.01±0.05) | |
| $B(B_s\rightarrow ll)$,$10^{-9}$* | (3.47±0.27) | <4.5 | |

* Not included into the SM fit

# Generic NP parameterization

Since the fit is over constrained, we can introduce new parameters added in order to parameterize generic NP ΔF=2 processes in all sectors

**$B_d$ and $B_s$ mixing amplitudes (2+2 real parameters):**

$$A_q e^{2i\phi_q} = C_{B_q} e^{2i\phi_{B_q}} A_q^{SM} e^{2i\phi_q^{SM}} = \left(1+\frac{A_q^{NP}}{A_q^{SM}} e^{2i(\phi_q^{NP}-\phi_q^{SM})}\right) A_q^{SM} e^{2i\phi_q^{SM}}$$

In case of absence of NP effects, $C_i=1$, $\varphi_i=0$

**Observables:**

$$\Delta m_{q/K} = C_{B_q/\Delta m_K} (\Delta m_{q/K})^{SM} \qquad \varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$

$$A_{CP}^{B_d\to J/\psi K_s} = \sin 2(\beta + \phi_{B_d}) \qquad A_{CP}^{B_s\to J/\psi\phi} \sim \sin 2(-\beta_s + \phi_{B_s})$$

$$A_{SL}^q = \mathrm{Im}(\Gamma_{12}^q / A_q) \qquad \Delta\Gamma^q / \Delta m_q = \mathrm{Re}(\Gamma_{12}^q / A_q)$$

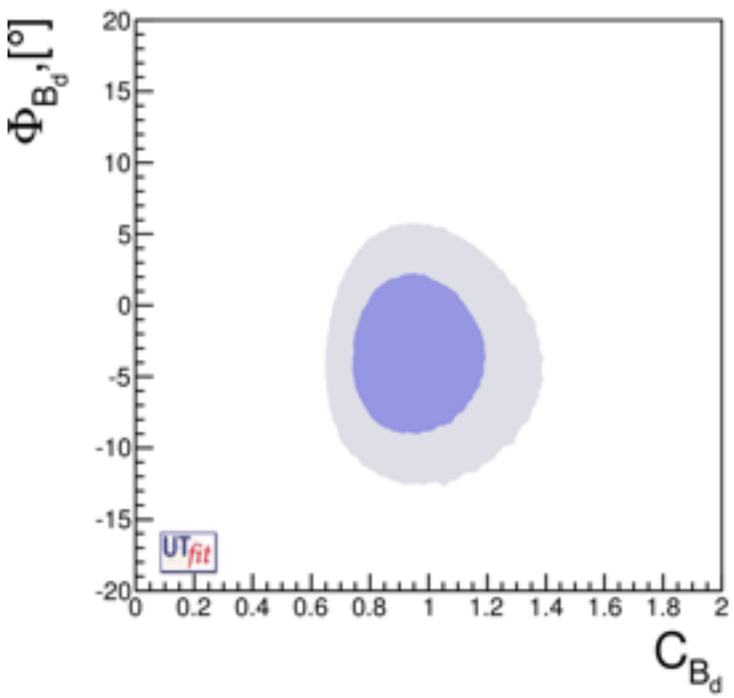
SM:

$$\bar\rho = 0.132 \pm 0.021$$
$$\bar\eta = 0.348 \pm 0.015$$

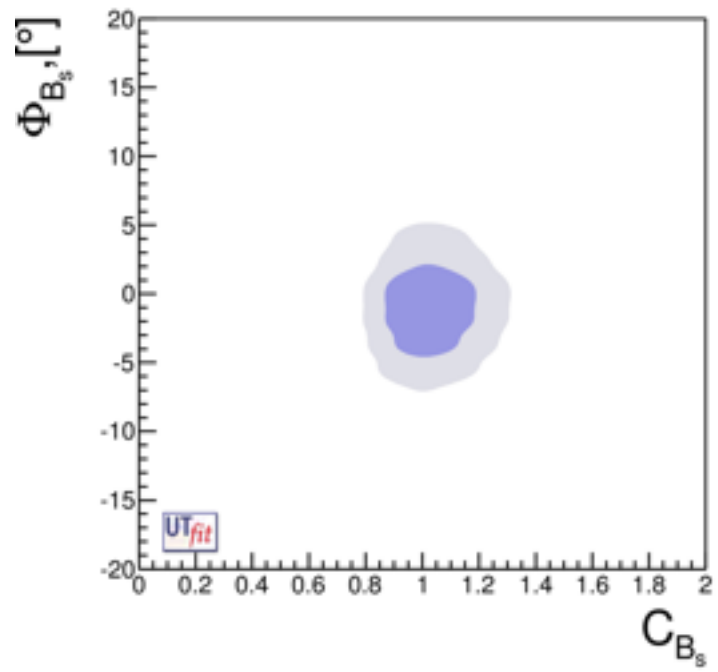
NP:

$$\bar\rho = 0.142 \pm 0.050$$
$$\bar\eta = 0.393 \pm 0.058$$

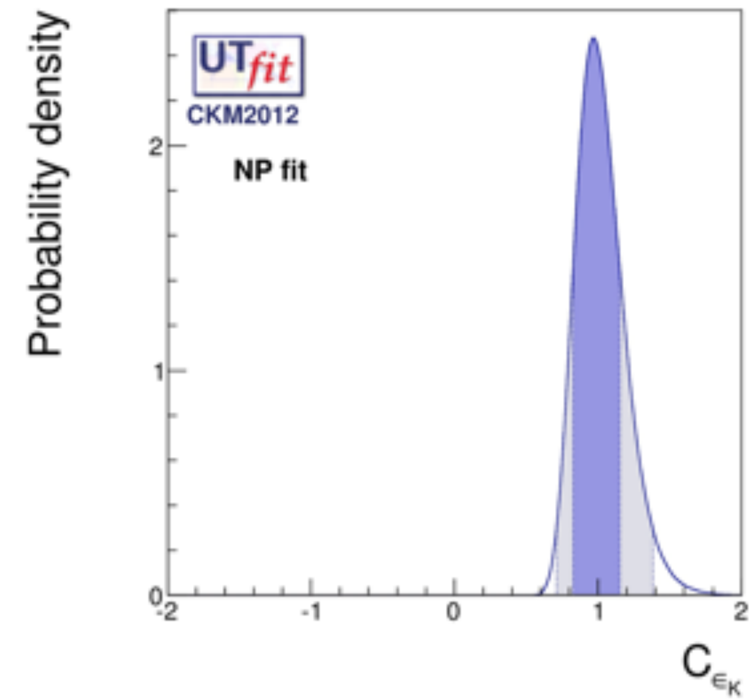
| | | $\rho,\eta$ | $C_d$ | $\varphi_d$ | $C_s$ | $\varphi_s$ | $C_{\varepsilon K}$ |
|---|---|---|---|---|---|---|---|
| Tree processes | γ (DK) | X | | | | | |
| | $V_{ub}/V_{cb}$ | X | | | | | |
| 1↔3 family | $\Delta m_d$ | X | X | | | | |
| | ACP (J/Ψ K) | X | | X | | | |
| | ACP (Dπ(ρ),DKπ) | X | | X | | | |
| | $A_{SL}$ | | X | X | | | |
| | α (ρρ,ρπ,ππ) | X | | X | | | |
| | $A_{CH}$ | | X | X | X | X | |
| 2↔3 family | τ(Bs), $\Delta\Gamma_s/\Gamma_s$ | | | | X | X | |
| | $\Delta m_s$ | | | | X | | |
| | ASL(Bs) | | | | X | X | |
| | ACP (J/Ψ ϕ) | ~X | | | | X | |
| 1↔2 familiy | $\varepsilon_K$ | X | | | | | X |




$$C_{B_d} = 0.95 \pm 0.15$$
$$\Phi_{B_d} = (-3.5 \pm 3.7)^\circ$$




$$C_{B_s} = 1.02 \pm 0.1$$
$$\Phi_{B_s} = (-1.3 \pm 2.2)^\circ$$



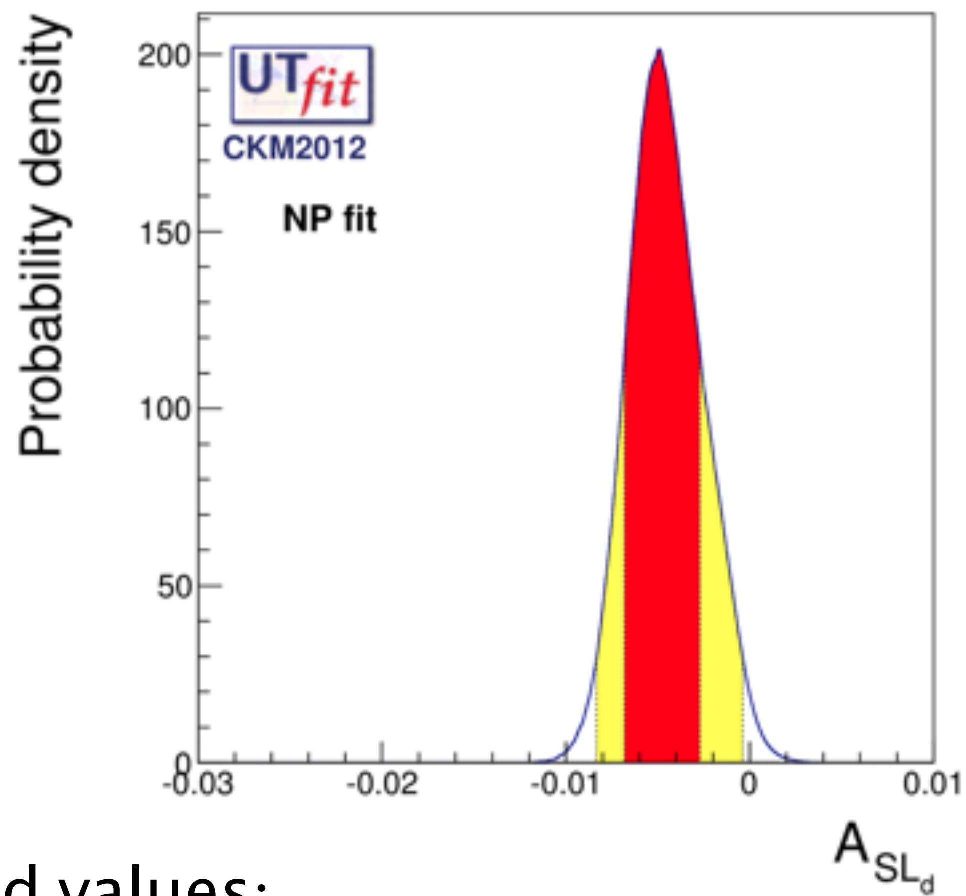

$$C_K = 0.99 \pm 0.16$$

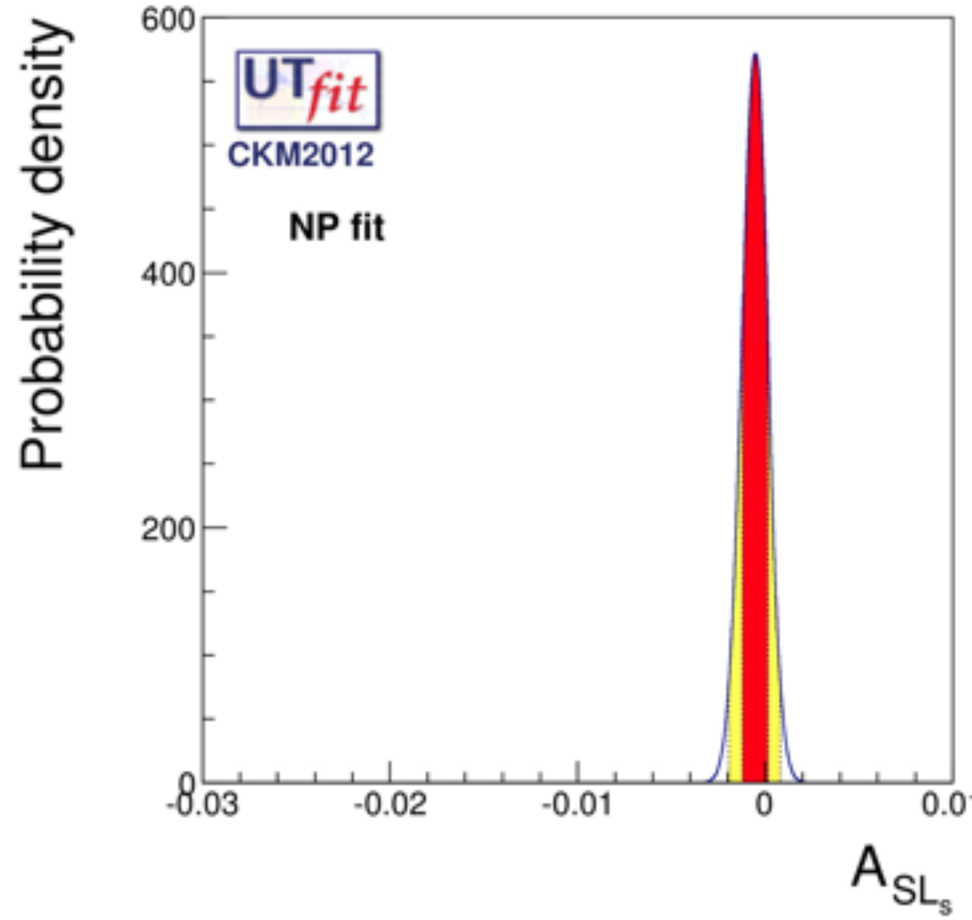
No signs of new physics effects...

Input values:

$$A_{\mathrm{SL}_d} = -0.0005 \pm 0.0056$$

$$A_{\mathrm{SL}_s} = -0.0051 \pm 0.0032$$




Fitted values:

$$A_{\mathrm{SL}_d} = -0.0047 \pm 0.002$$

$$A_{\mathrm{SL}_s} = -0.00053 \pm 0.00068$$

# Conclusions

- The angles measurements are consistent with the SM prediction.
- The updated UTfit combination is overall consistent. No new tensions were found.
- More results are expected after this conference.