

Constraining new physics with Unitarity Triangle *fit*

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on behalf of UT*fit* Collaboration

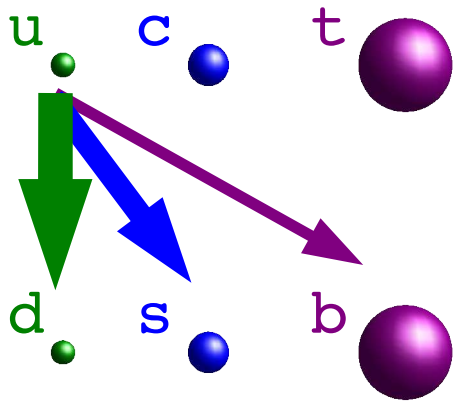
M. Bona, M. Ciuchini, G. D'Agostini,
E. Franco, V. Lubicz, G. Martinelli,
F. Parodi, M. P., P. Roudeau, C. Schiavi,
L. Silvestrini, A. Stocchi

<http://www.utfit.org>



Modello Standard e Violazione CP

Gli **autostati di massa** non sono autostati dell'interazione debole. La Lagrangiana dello Standard Model contiene la **matrice di mescolamento** V_{CKM}



$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\bar{\rho} - i\bar{\eta}) \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1 - \bar{\rho} - i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

L'esistenza delle **tre famiglie** di quark implica la presenza di una **fase non riassorbibile** nella ridefinizione dei quark. La presenza di un elemento complesso porta alla **violazione di CP**



Il Triangolo di unitarietà

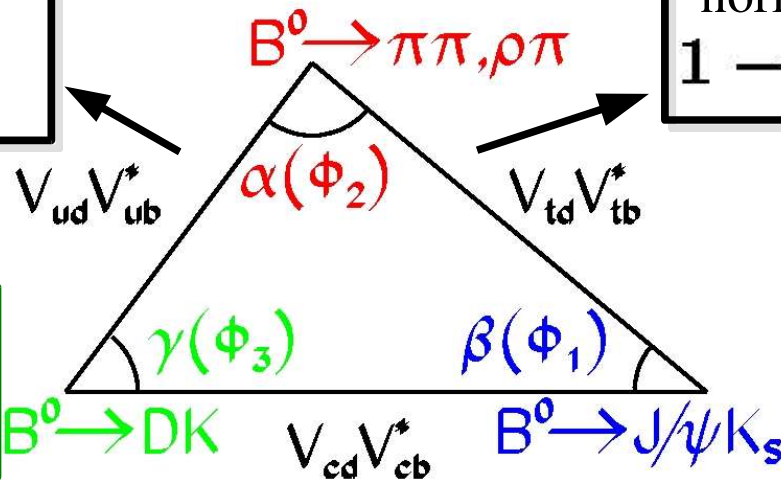
La matrice CKM viene da una **rotazione nella base dei quark**. Conservazione della probabilità \rightarrow **Unitarietà**

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

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

normalized:
 $\bar{\rho} + i\bar{\eta}$

normalized:
 $1 - \bar{\rho} - i\bar{\eta}$

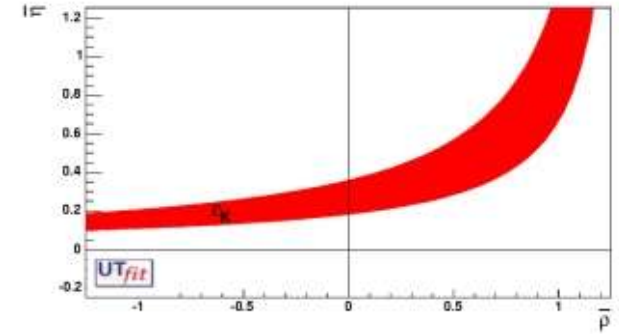
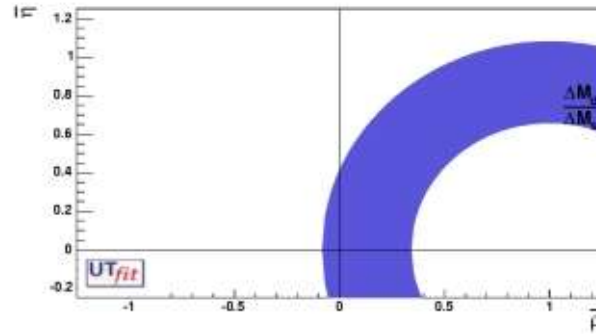
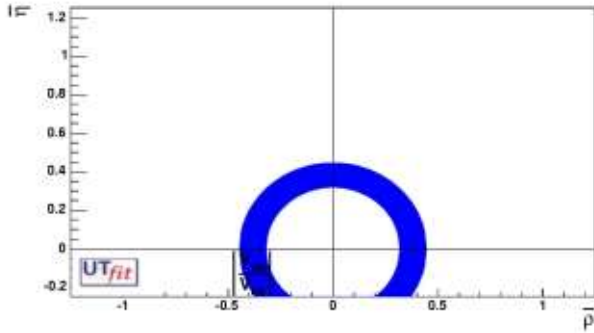


$$\gamma = \text{atan} \left(\frac{\bar{\eta}}{\bar{\rho}} \right)$$

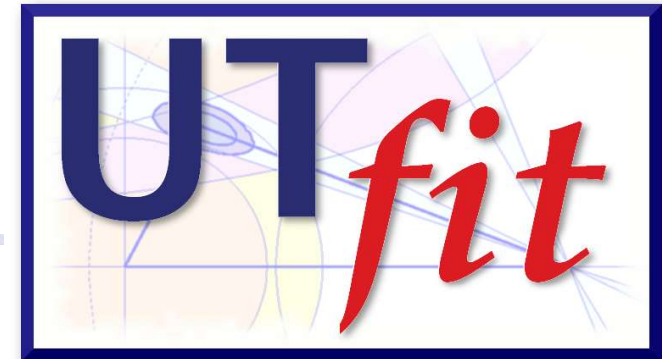
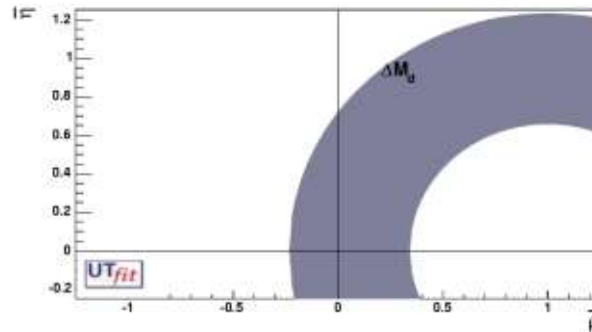
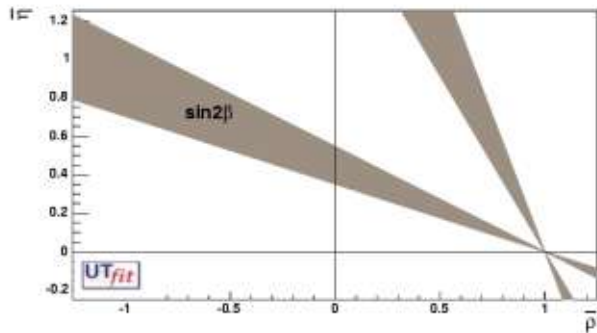
$$\beta = \text{atan} \left(\frac{\bar{\eta}}{(1 - \bar{\rho})} \right)$$

numerose osservabili
funzioni di $\bar{\rho}$ ed $\bar{\eta}$:
overconstraining



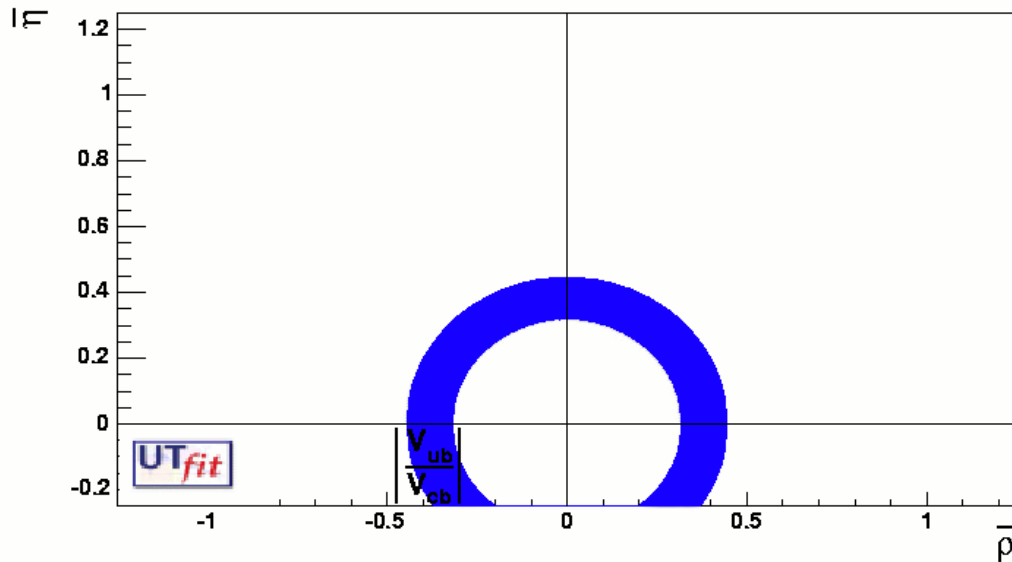
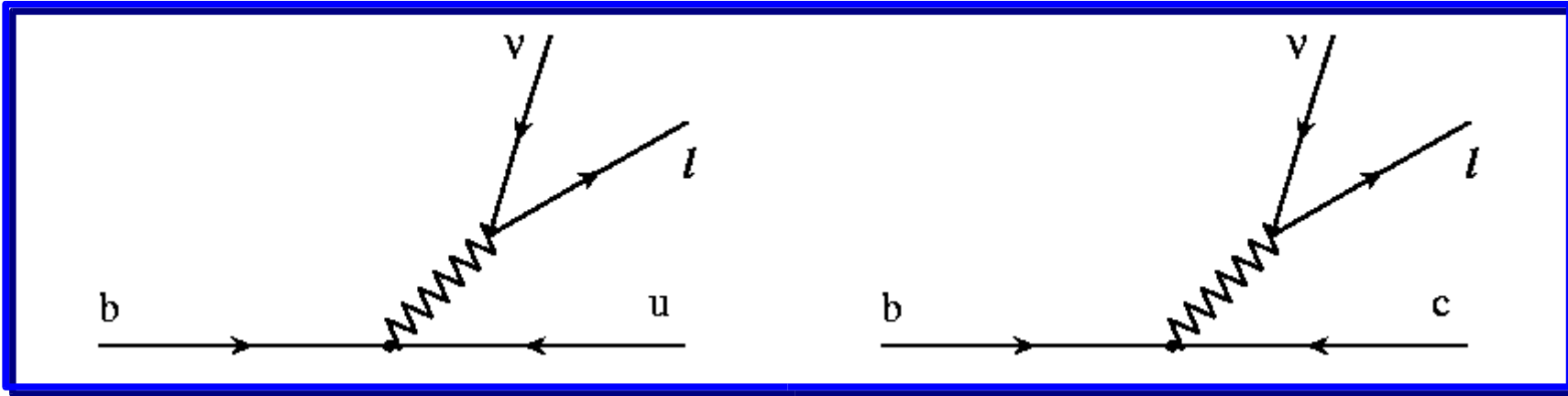


I constraint "Classici"



$$\left| \frac{V_{ub}}{V_{cb}} \right|$$

Processo ad albero → eventuali contributi nuova fisica trascurabili



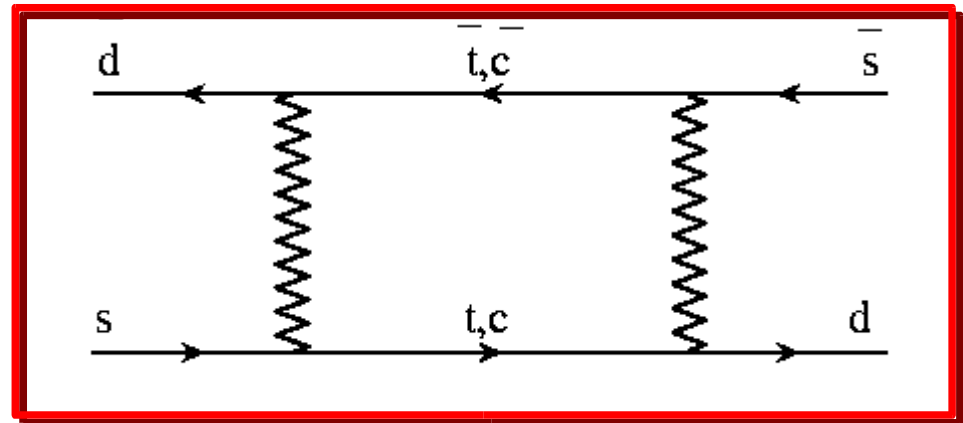
$$\left| \frac{V_{ub}}{V_{cb}} \right| = \frac{\lambda}{1 - \frac{\lambda^2}{2}} \sqrt{\bar{\rho}^2 + \bar{\eta}^2}$$



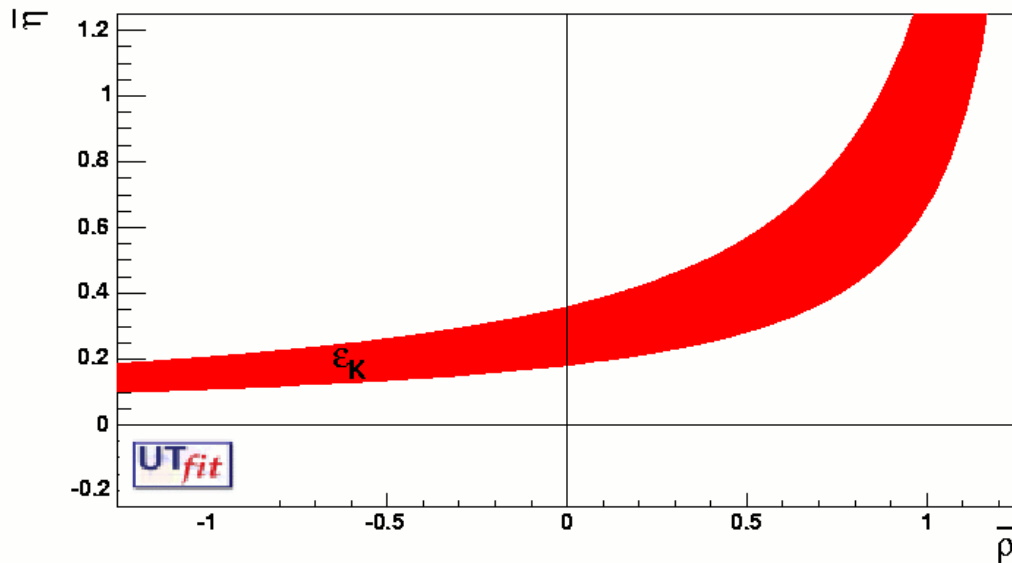
ε_K dal \bar{K} -K mixing

$$B_K = \frac{\langle K | J_\mu J^\mu | \bar{K} \rangle}{\langle K | J_\mu | 0 \rangle \langle 0 | J^\mu | \bar{K} \rangle}$$

da lattice QCD



$$|\varepsilon_K| = C_\varepsilon B_K A^2 \lambda^6 \bar{\eta} \{ -\eta S_0(x_c) (1 - \lambda^2/2) + \eta_3 S_0(x_c, x_t) + \eta_2 S_0(x_t) A^2 \lambda^4 (1 - \bar{\rho}) \}$$

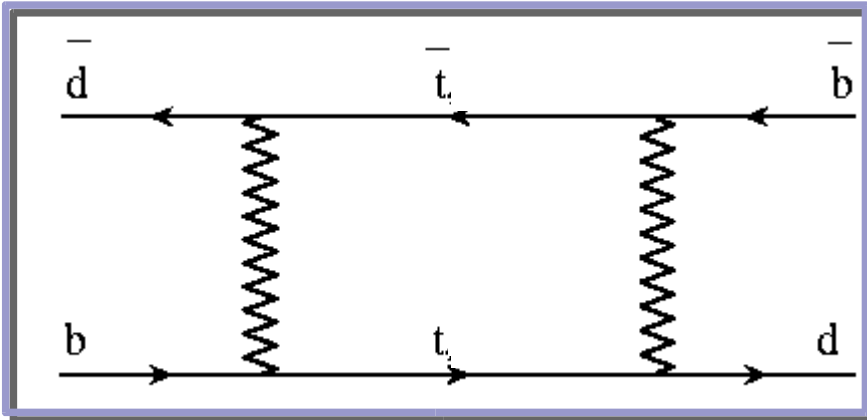


S_0 = Funzioni di Inami Lim
per contributi c-c, c-t, e t-t
(da calcoli perturbativi)



Δm_d dal $\bar{B}_d - B_d$ mixing

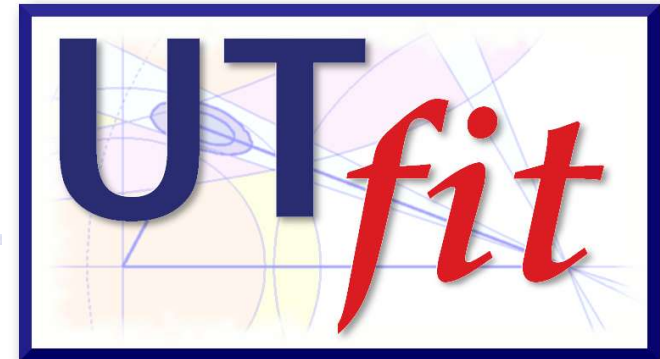
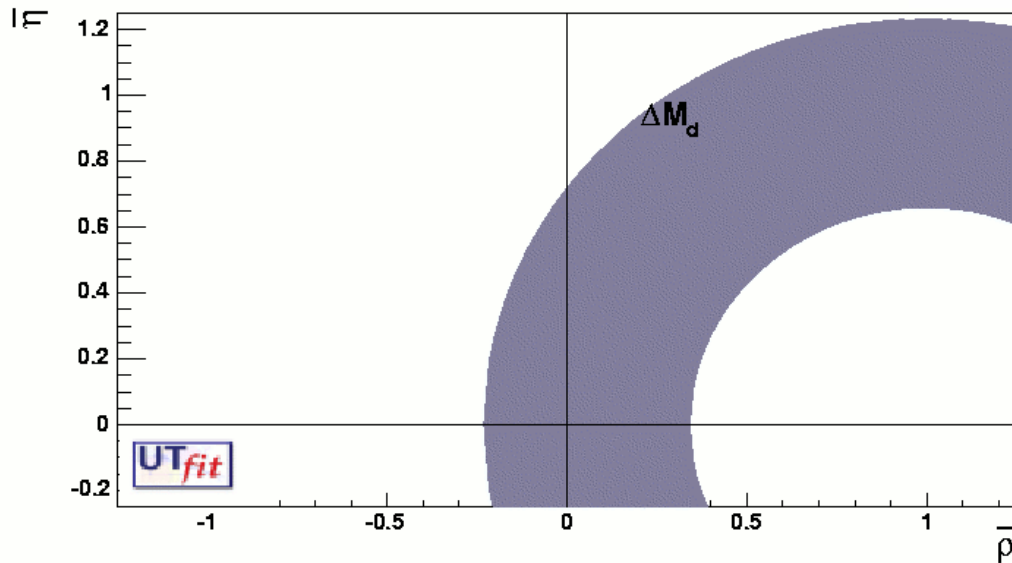
S = Funzione di Inami Lim
per contributo t-t
(da calcoli perturbativi)



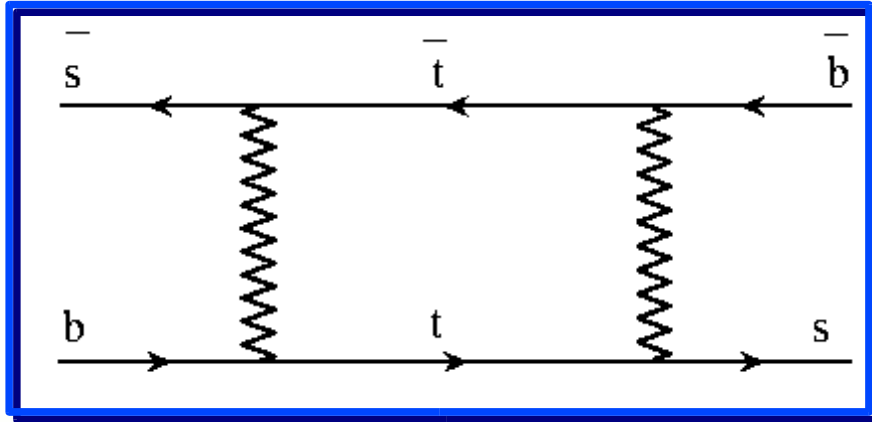
$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_W^2 \eta_b S(x_t) m_{B_d} f_{B_d}^2 \hat{B}_{B_d} |V_{ib}|^2 |V_{td}|^2 =$$

$$= \frac{G_F^2}{6\pi^2} m_W^2 \eta_b S(x_t) m_{B_d} f_{B_d}^2 \hat{B}_{B_d} |V_{cb}|^2 \lambda^2 ((1-\bar{\rho})^2 + \bar{\eta}^2)$$

B_{B_d} e f_{B_d} da lattice QCD

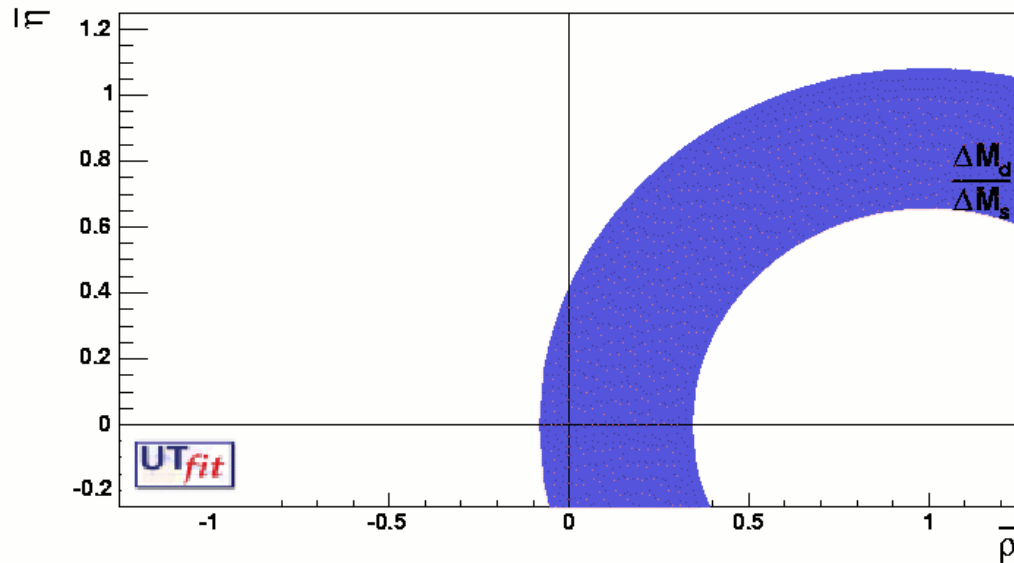


Δm_s dal $\bar{B}_s - B_s$ mixing



$$\Delta m_d \approx [(1-\rho)^2 + \eta^2] \frac{f_{B_s}^2 B_{B_s}}{\xi^2}$$

$$\Delta m_s \approx f_{B_s}^2 B_{B_s}$$



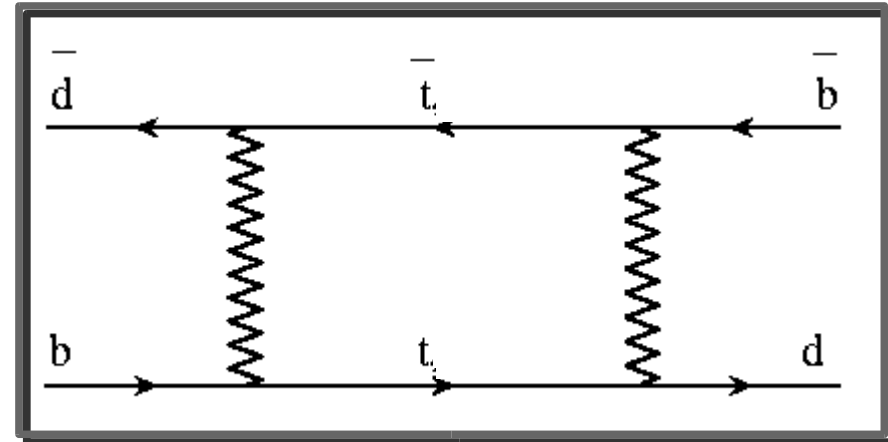
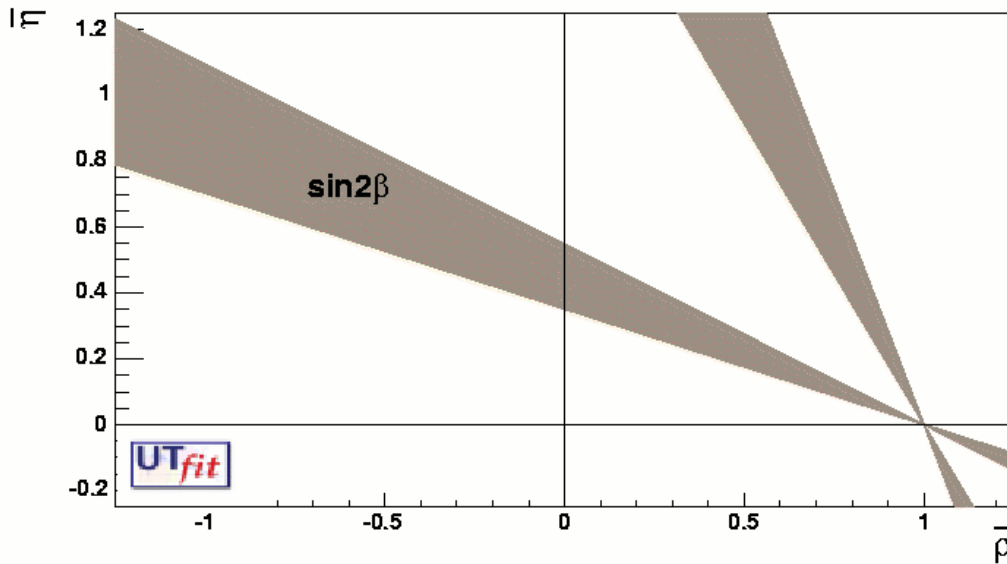
Nessuna dipendenza da $\bar{\rho}$ ed $\bar{\eta}$, ma impatto su Δm_d attraverso ξ e $f_{B_s} B_{B_s}$ (da lattice QCD)



$\sin 2\beta$ da $A_{CP} B^0 \rightarrow J/\psi K^0$

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

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



Il metodo Statistico

Le grandezze misurate, funzioni di $\bar{\rho}$ ed $\bar{\eta}$, sono messe in relazione a $\bar{\rho}$ ed $\bar{\eta}$ tramite il teorema di Bayes

$$f(\bar{\rho}, \bar{\eta}, X | c_1, \dots, c_m) \sim \prod_{j=1, m} f_j(\mathcal{C} | \bar{\rho}, \bar{\eta}, X) *$$

$$X \equiv x_1, \dots, x_n = m_t, B_K, F_B, \dots$$

$$\mathcal{C} \equiv c_1, \dots, c_m = \epsilon, \Delta m_d / \Delta m_s, A_{CP}(J/\psi K_S), \dots$$

$$j=1, m$$

$$\prod_{i=1, N} f_i(x_i) f_0(\bar{\rho}, \bar{\eta})$$

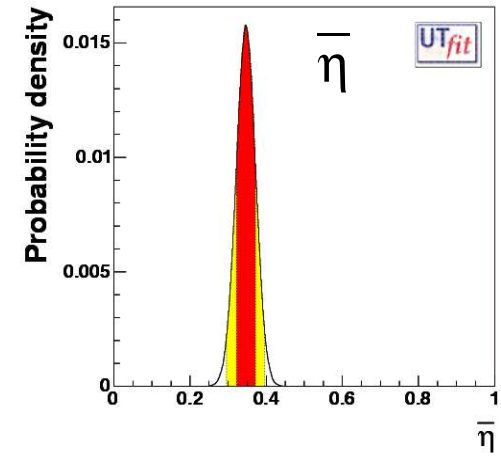
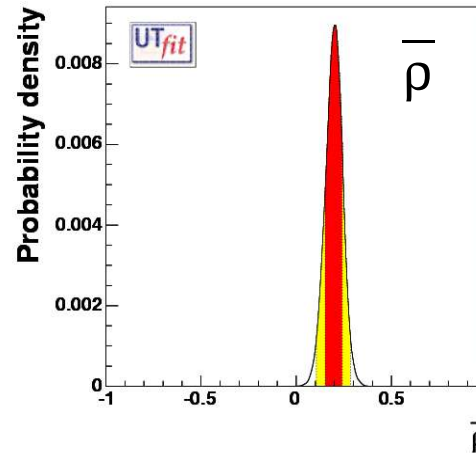
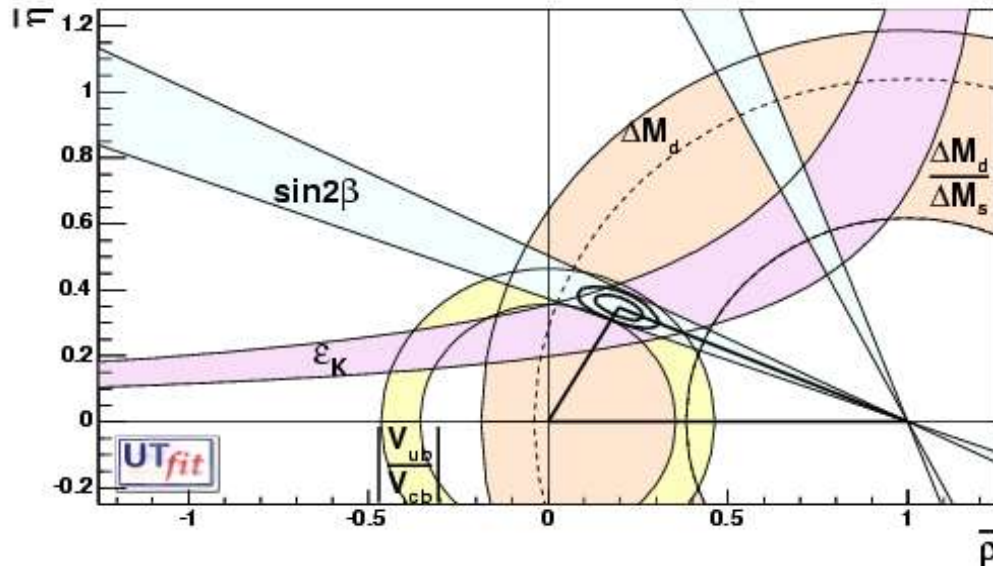
$(b \rightarrow u)/(b \rightarrow c)$	$\bar{\rho}^2 + \bar{\eta}^2$	$\bar{\Lambda}, \lambda_1, F(1), \dots$
ϵ_K	$\bar{\eta}[(1 - \bar{\rho}) + P]$	B_K
Δm_d	$(1 - \bar{\rho})^2 + \bar{\eta}^2$	$f_B^2 B_B$
$\Delta m_d / \Delta m_s$	$(1 - \bar{\rho})^2 + \bar{\eta}^2$	ξ
$A_{CP}(J/\psi K_S)$	$\sin 2\beta$	—

Standard Model +
OPE/HQET/
Lattice QCD
to go from
quarks
to hadrons

$$m_t$$



Utilizzando
tutti i vincoli



$\sin 2\beta$ misurato con precisione
confrontabile alla misura "indiretta"

$$\bar{\eta} = 0.341 \pm 0.027$$

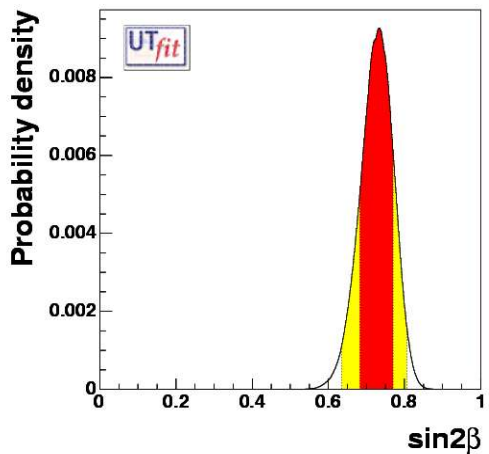
$$\bar{\rho} = 0.204 \pm 0.044$$

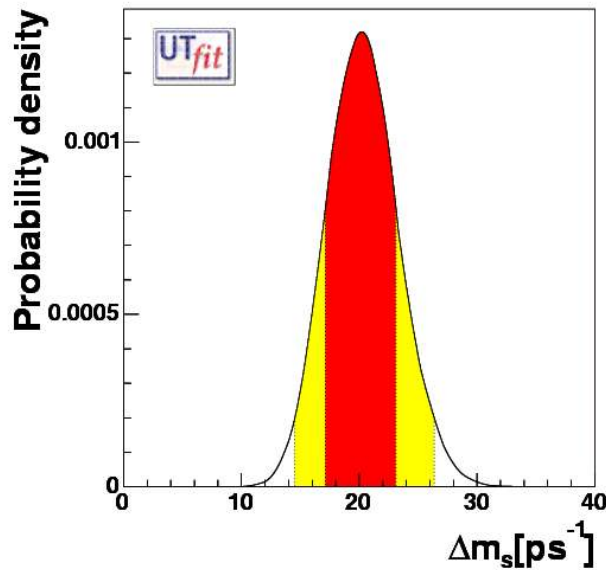
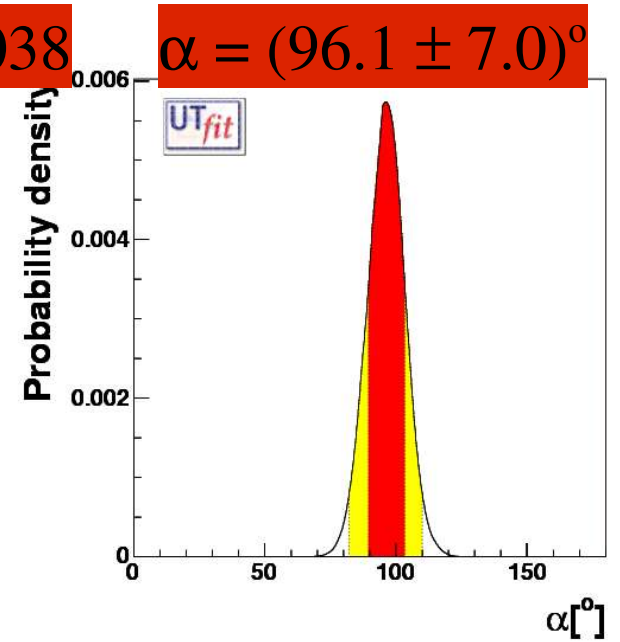
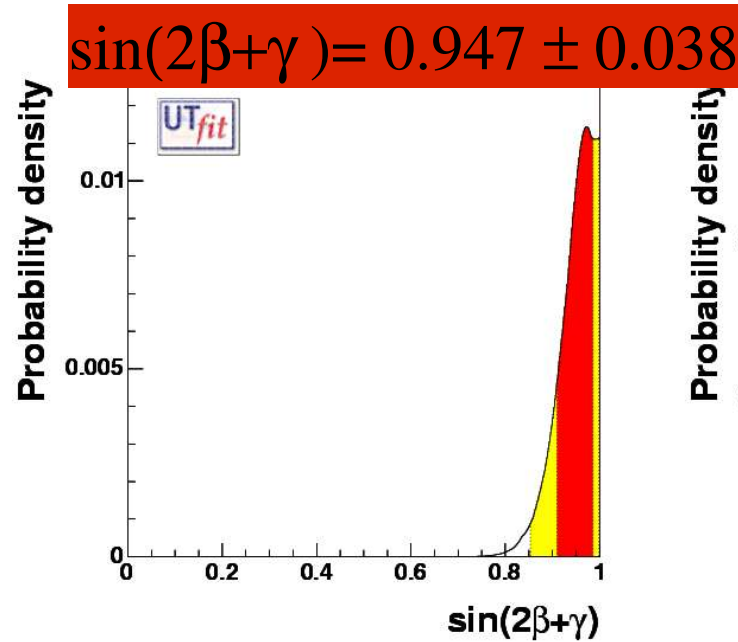
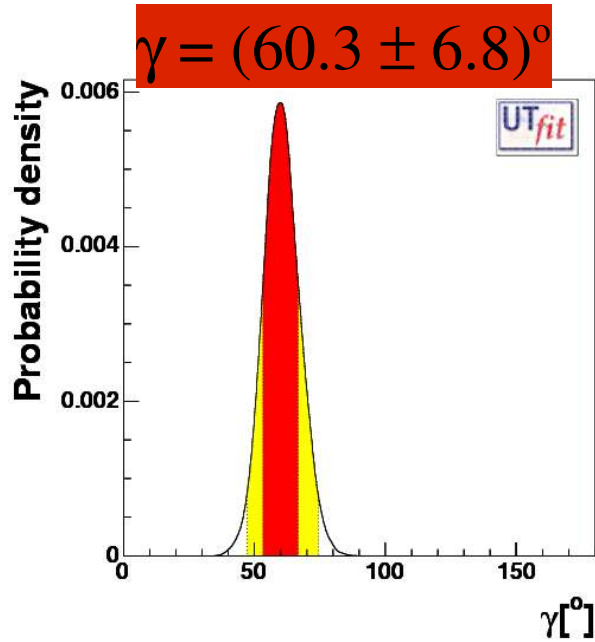
$$\sin 2\beta = 0.725 \pm 0.043$$

(da lati UT + ϵ_K)

$$\sin 2\beta = 0.726 \pm 0.037$$

(da $J/\psi K^0$)

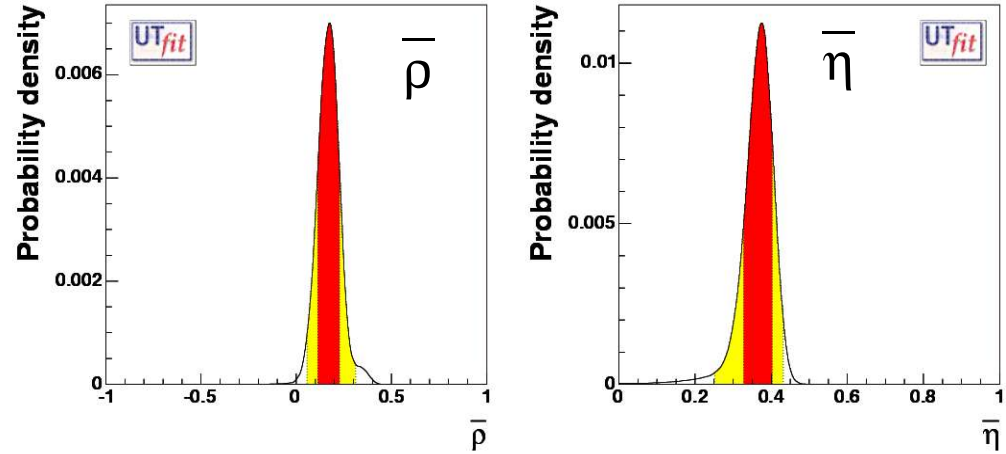
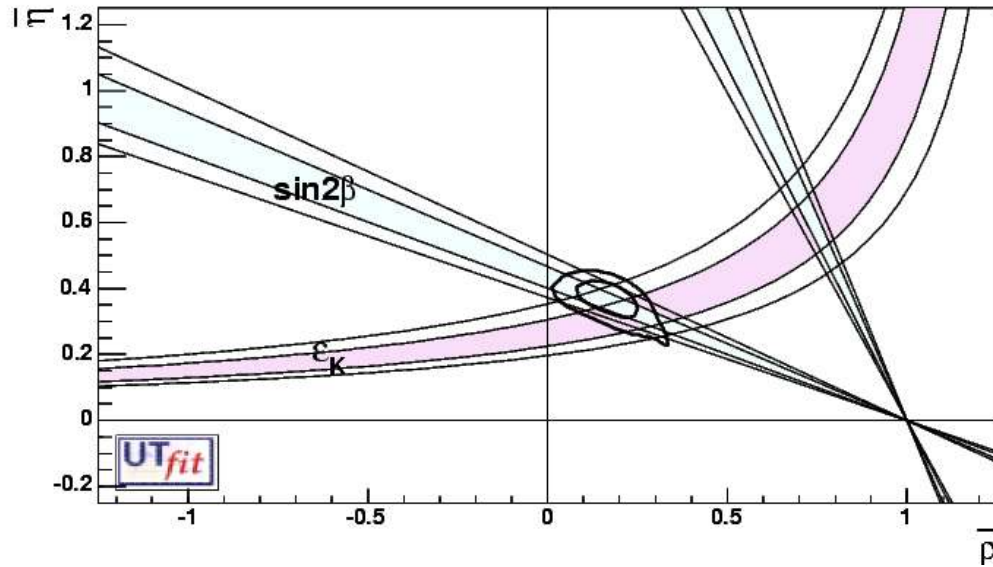




Ignorando il lower
bound su Δm_s

$$\Delta m_s = 21.2 \pm 2.3 \text{ ps}^{-1}$$

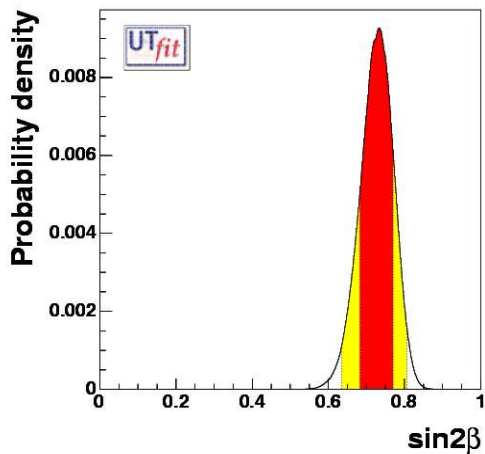
Utilizzando
tutti i vincoli



Violazione di CP con quantità
che conservano CP

$$\bar{\eta} = 0.364 \pm 0.037$$

$$\bar{\rho} = 0.169 \pm 0.057$$

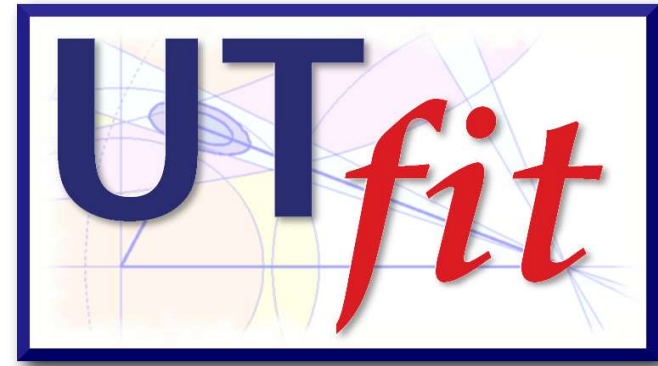


$$\sin 2\beta = 0.734 \pm 0.043$$

(da lati UT)

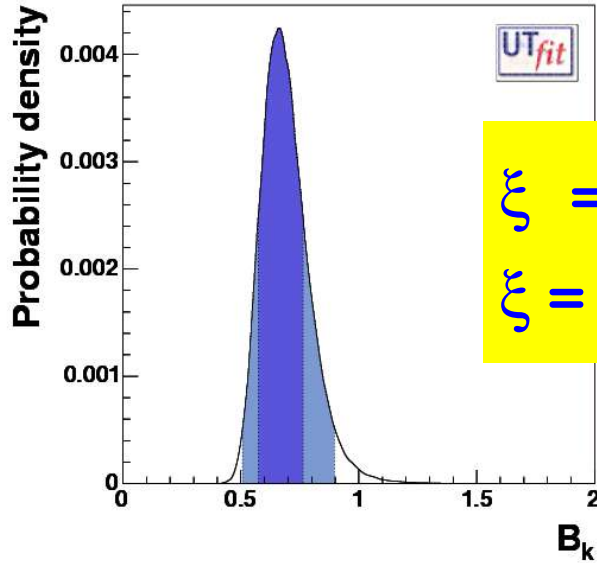
$$\sin 2\beta = 0.726 \pm 0.037$$

(da $J/\psi K^0$)



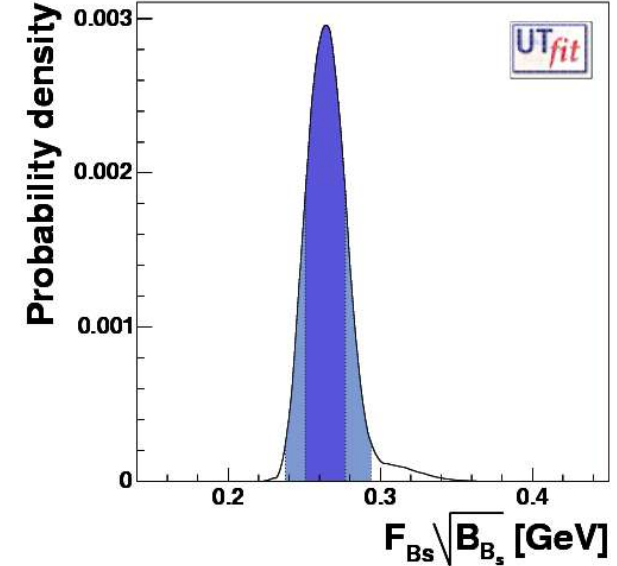
UT_{fit} e predizioni LQCD (I)

E' possibile ottenere predizioni su un parametro di Lattice QCD utilizzando le altre informazioni



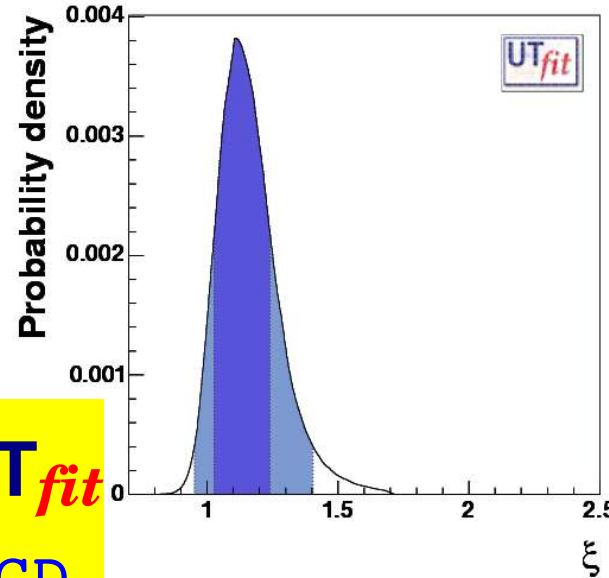
$$\xi = 1.15 \pm 0.11 \text{ UT}_{fit}$$

$$\xi = 1.24 \pm 0.06 \text{ LQCD}$$



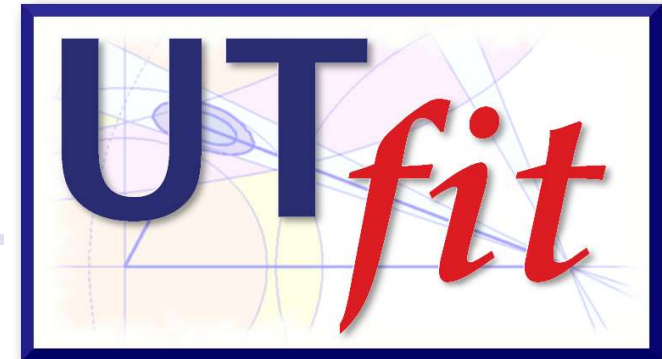
$$f_{B_s} \sqrt{B_{B_s}} = 0.69 \pm 0.10 \text{ UT}_{fit}$$

$$f_{B_s} \sqrt{B_{B_s}} = 0.86 \pm 0.11 \text{ LQCD}$$

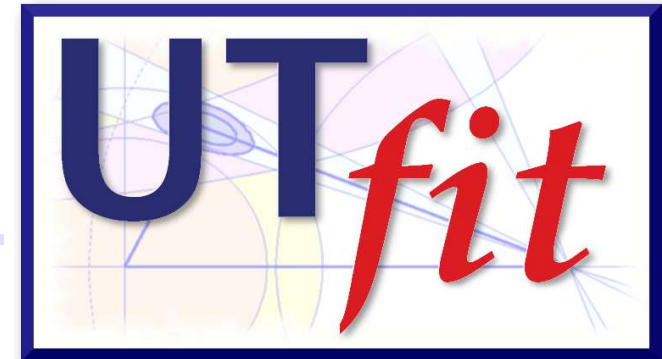
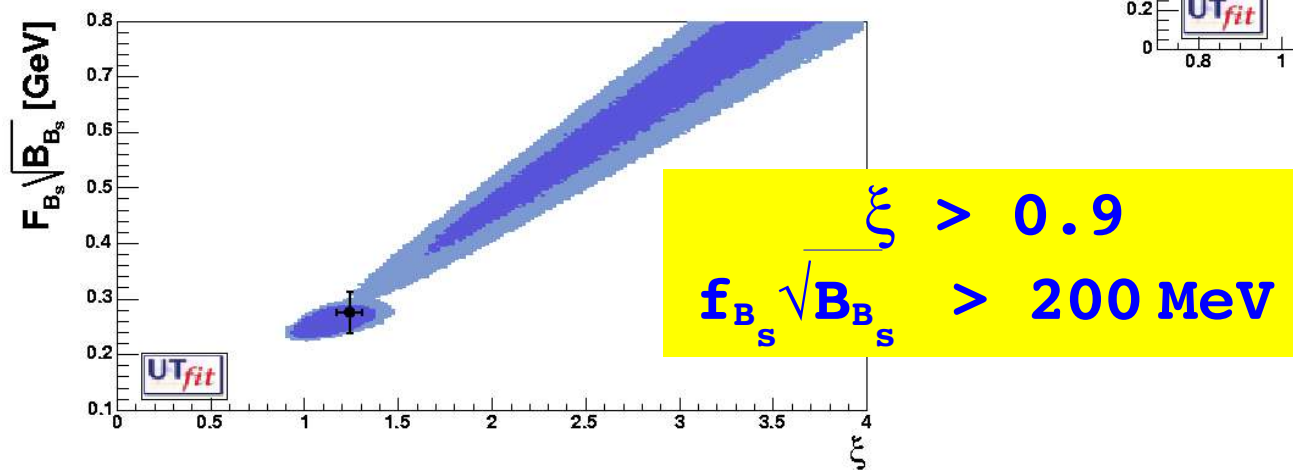
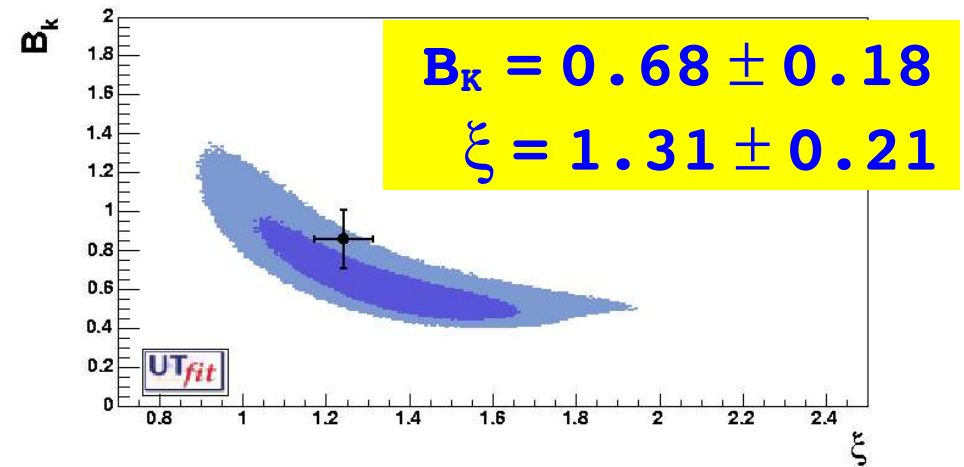
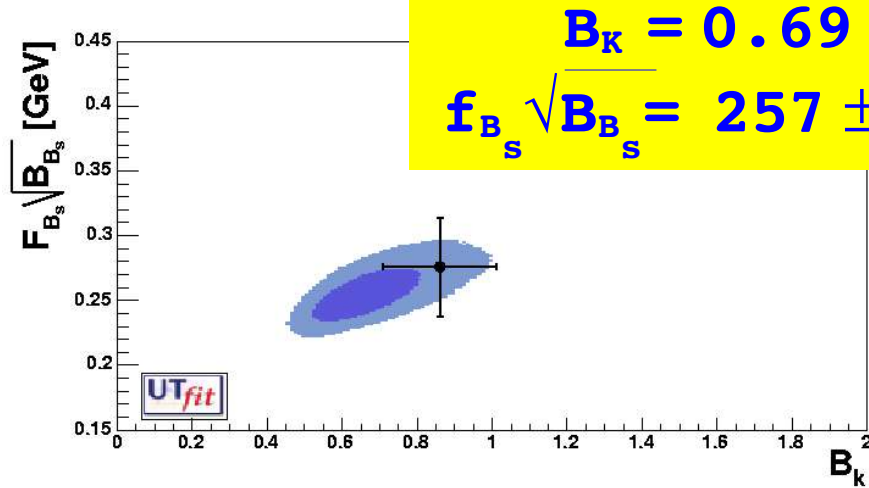


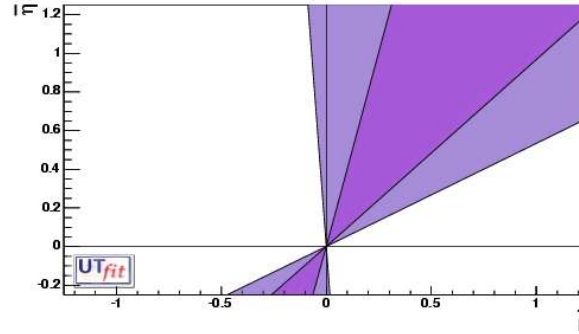
$$B_K = 0.69 \pm 0.10 \text{ UT}_{fit}$$

$$B_K = 0.86 \pm 0.11 \text{ LQCD}$$

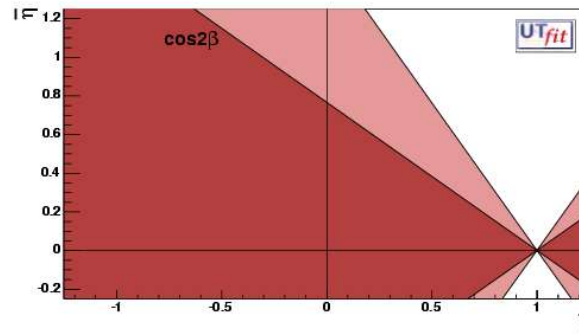
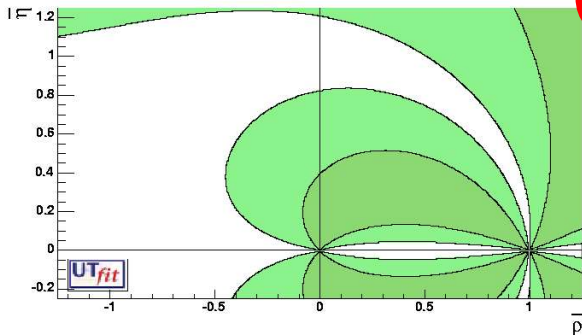


UT_{fit} e predizioni LQCD (II)

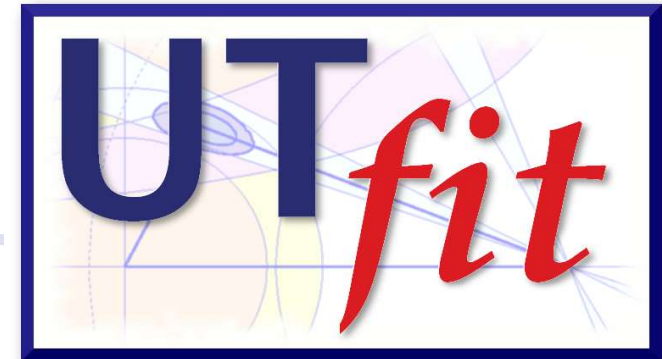
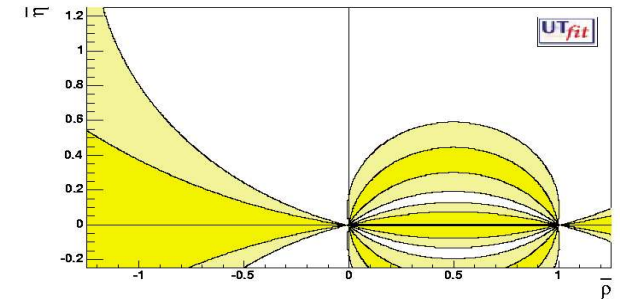




I Nuovi Constraint



K



α da analisi SU(2)

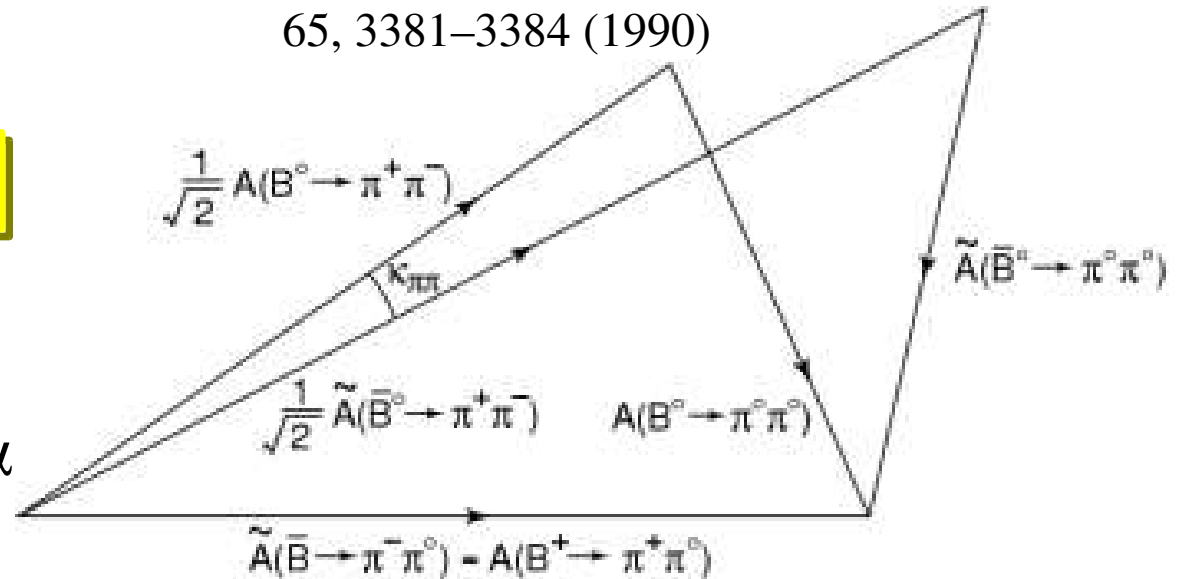
Utilizzando SU(2) per scrivere le ampiezze:

$$A^{+-} = -Te^{-i\alpha} + Pe^{i\delta_P}$$

$$A^{+0} = -1/\sqrt{2} e^{-i\alpha} (T + T_C e^{i\delta_C})$$

$$A^{00} = -1/\sqrt{2} (T_C e^{i\delta_C} e^{-i\alpha} + Pe^{i\delta_P})$$

Gronau-London, Phys. Rev. Lett.
65, 3381–3384 (1990)



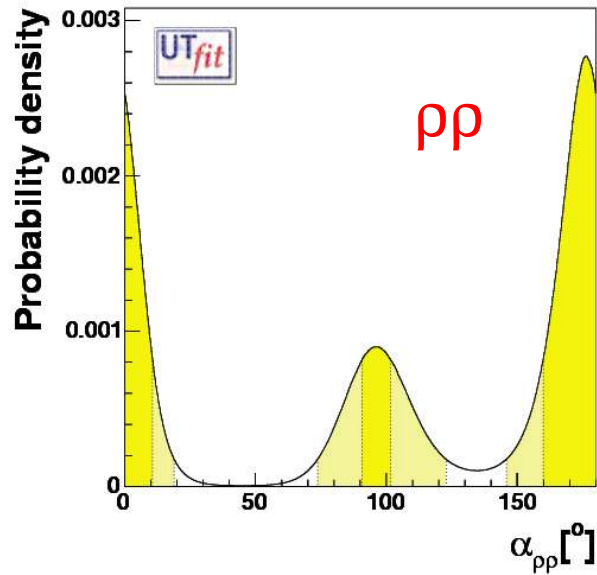
incognite: $T, P, T_C, \delta_P, \delta_{T_C}, \alpha$

osservabili: $3 \times \text{BR}, C_{+-}, S_{+-}$

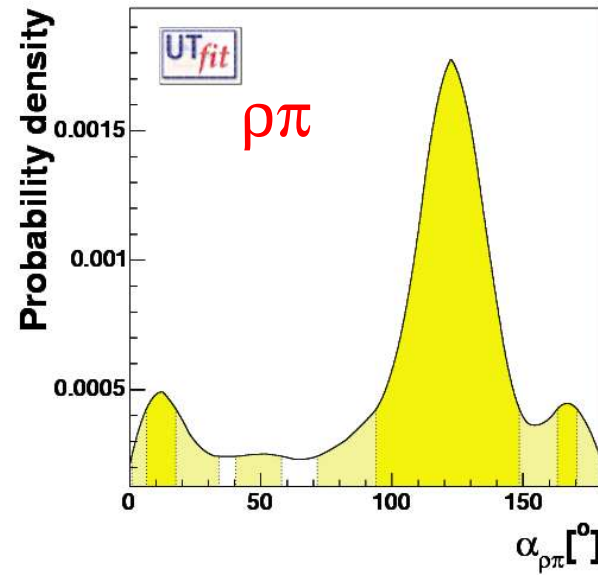
**Simile approccio studiando $(\rho\pi)^0$
sul piano di Dalitz**



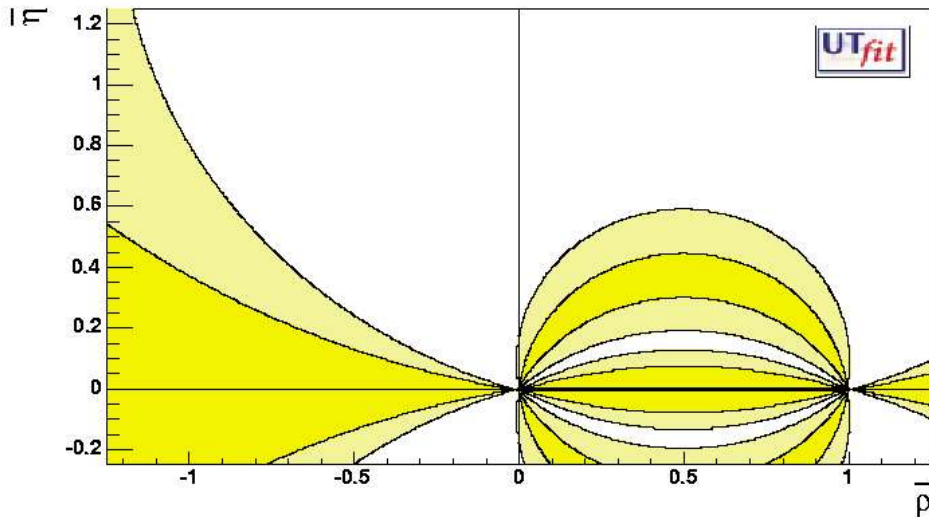
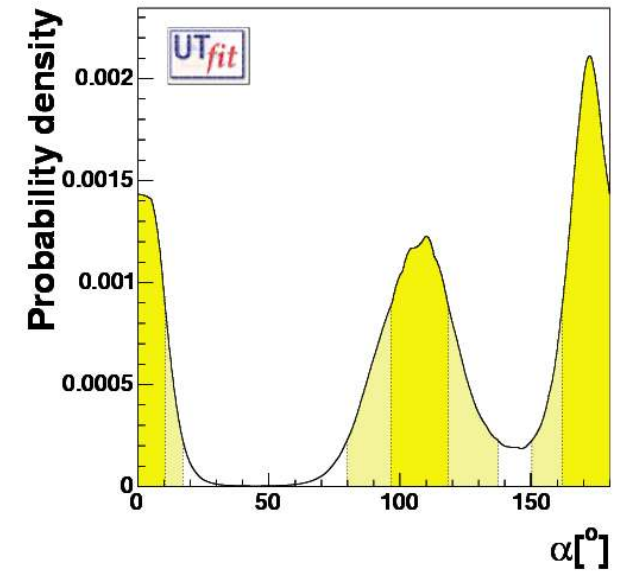
α da analisi SU(2)



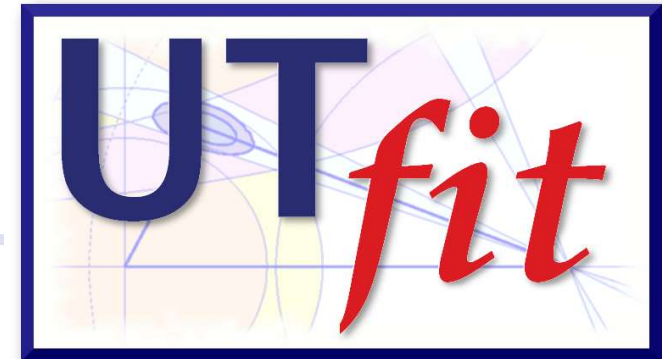
+



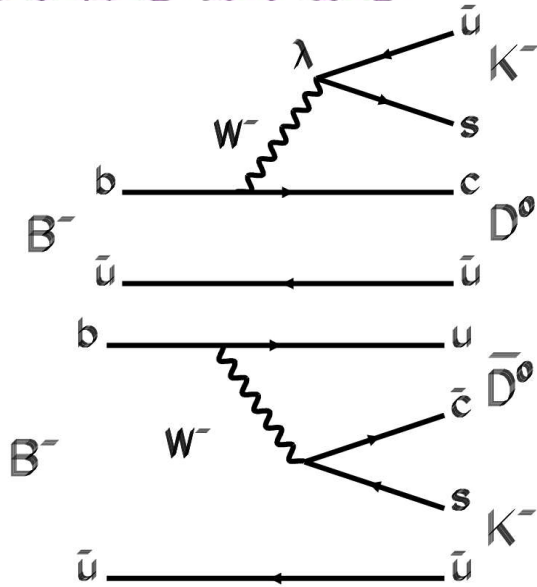
=



$$\alpha = (117 \pm 11)^\circ \text{ U } (176 \pm 14)^\circ$$



γ da $B \rightarrow D^{(*)} K^{(*)}$



$\sim V_{cb}$

$\sim |V_{ub}| e^{-i\gamma}$

$$A(B^- \rightarrow D^0 K^-) = A_B$$

$$A(B^+ \rightarrow \bar{D}^0 K^+) = A_B$$

$$A(B^- \rightarrow \bar{D}^0 K^-) = A_B r_B e^{i(\delta_B - \gamma)}$$

$$A(B^+ \rightarrow D^0 K^+) = A_B r_B e^{i(\delta_B + \gamma)}$$

$r_B =$ rapporto di ampiezze

$\delta_B =$ fase forte relativa

● **GLW (Gronau, Londow, Wyler):** uso di autostati di CP del D, D_{CP}^0

$$R_{CP\pm} = 1 + r_B^2 \pm 2r_B \cos \gamma \cos \delta_B \quad A_{CP\pm} = \frac{\pm 2r_B \sin \gamma \sin \delta_B}{1 + r_B^2 \pm 2r_B \cos \gamma \cos \delta_B}$$

● **ADS (Atwood, Dunietz, Soni):** B^0 and \bar{B}^0 nello stesso stato finale

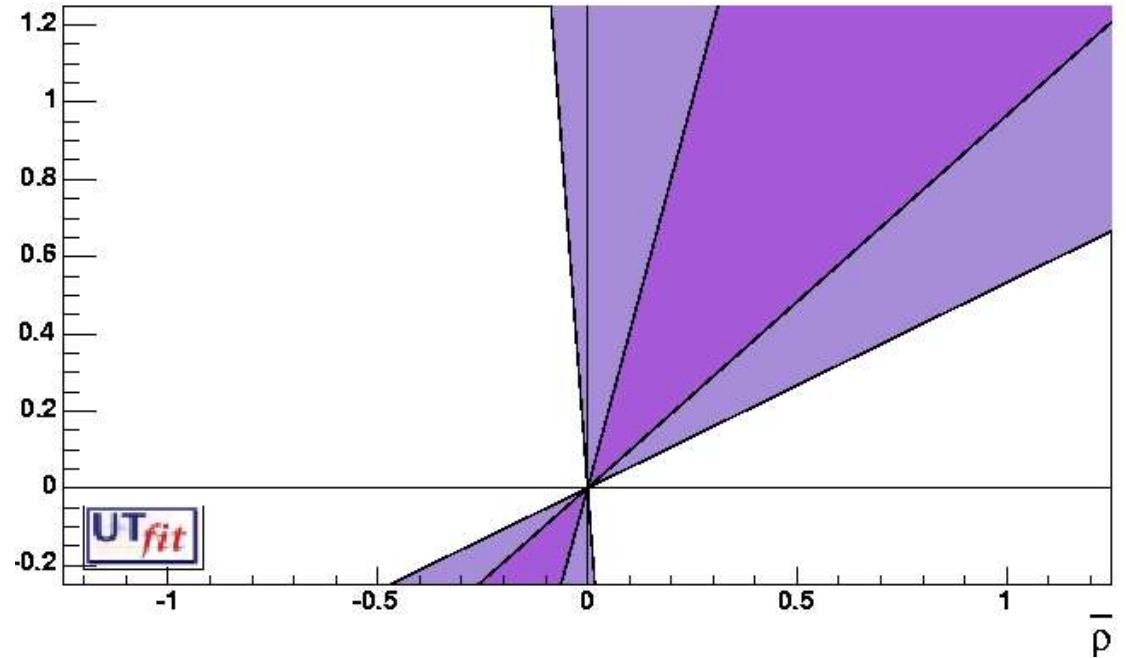
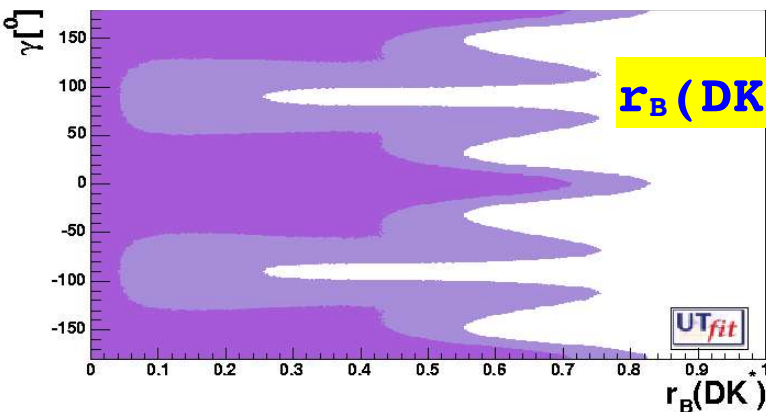
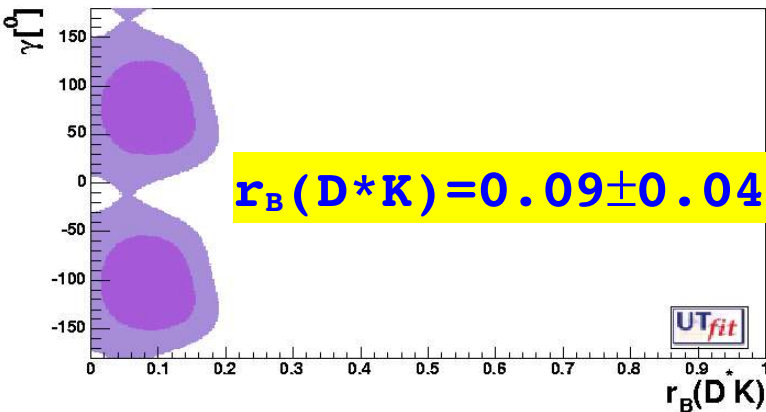
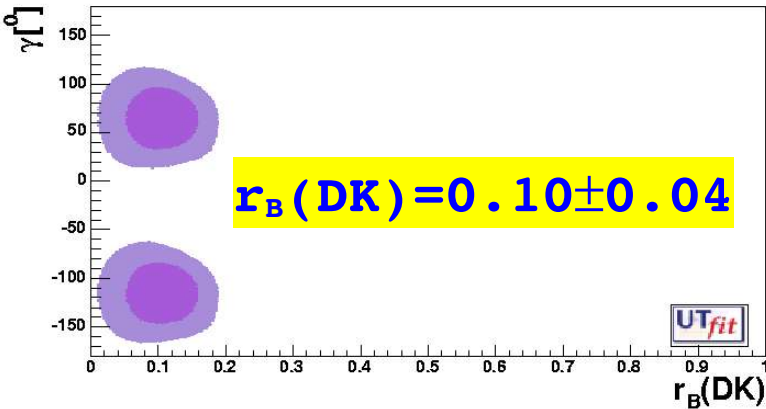
$$R_{ADS} = r_B^2 + r_{DCS}^2 + 2r_B r_{DCS} \cos \gamma \cos(\delta_B + \delta_D)$$

● **Analisi Dalitz plot in 3 corpi:**
ad esempio $D^0 \rightarrow K_S \pi^+ \pi^-$



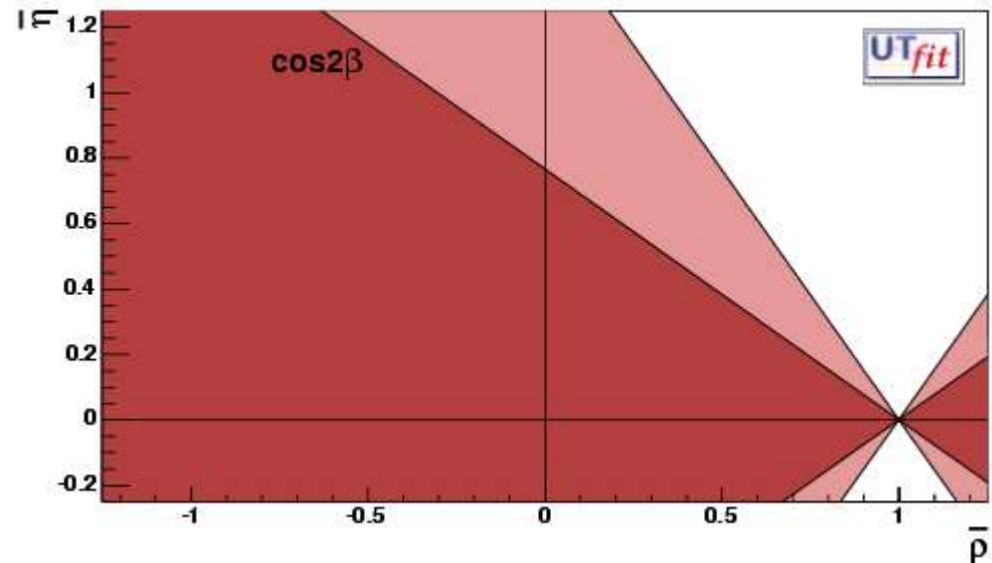
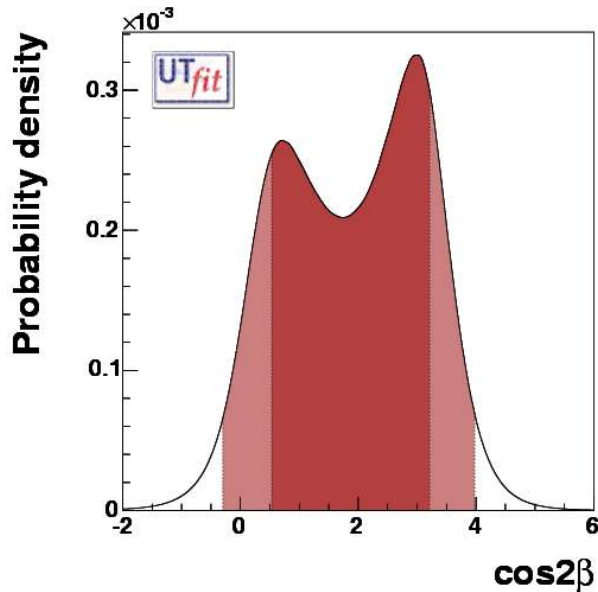
γ da $B \rightarrow D^{(*)} K^{(*)}$

$$\gamma = (59.1 \pm 16.7)^\circ \text{ U } (-120.3 \pm 17.2)^\circ$$



$\cos 2\beta$ da $B \rightarrow J/\psi K^{*0}$

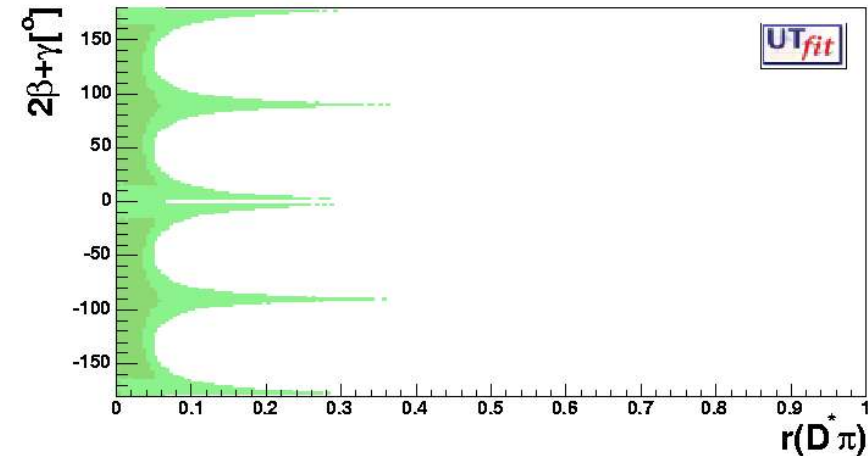
Combinazione scettica dei
risultati di BaBar e Belle
 $\cos 2\beta = 1.9 \pm 1.3$
> 0 @ 87% Probabilità



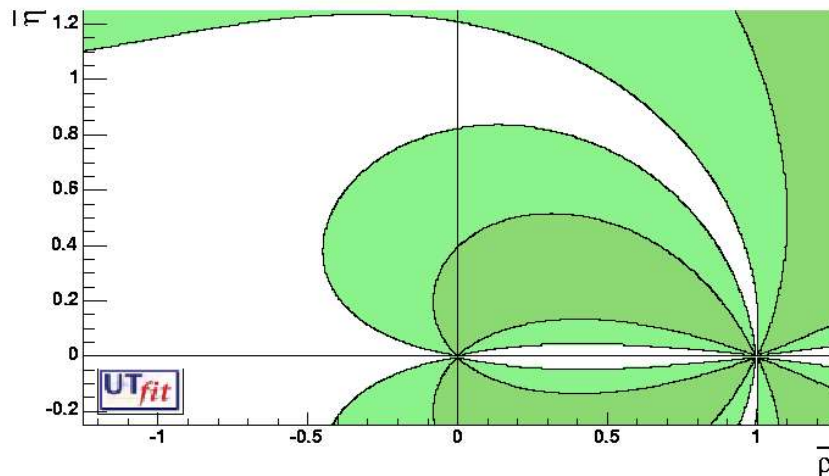
**Rimossa ambiguità
associata a $\sin 2\beta$**



$\sin 2\beta + \gamma$ da $B \rightarrow D^{(*)} \pi(\rho)$



- Interferenza $b \rightarrow u$ vs $b \rightarrow c$ come per DK
- Sistema aperto (2 osservabili per $2\beta + \gamma$, r e δ)
- Solo conoscendo r si può estrarre $2\beta + \gamma$

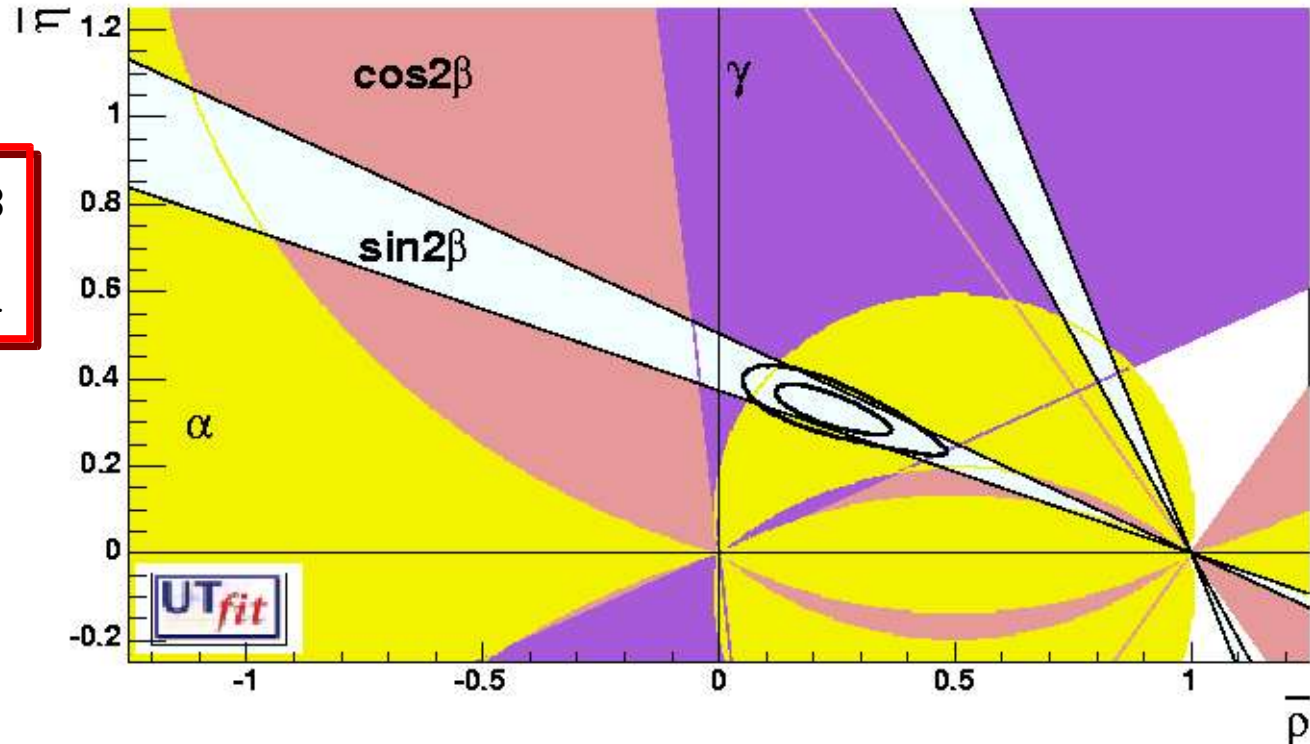


- ◆ Estrazione di r da $B \rightarrow D_s \pi$
- ◆ Errore teorico 30% (guessed)
- ◆ Incertezza fuori controllo, **non incluso nel fit**



Fit solo Angoli

$$\sin 2\beta + \cos 2\beta + \gamma + \alpha$$



$$\bar{\eta} = 0.328 \pm 0.038$$

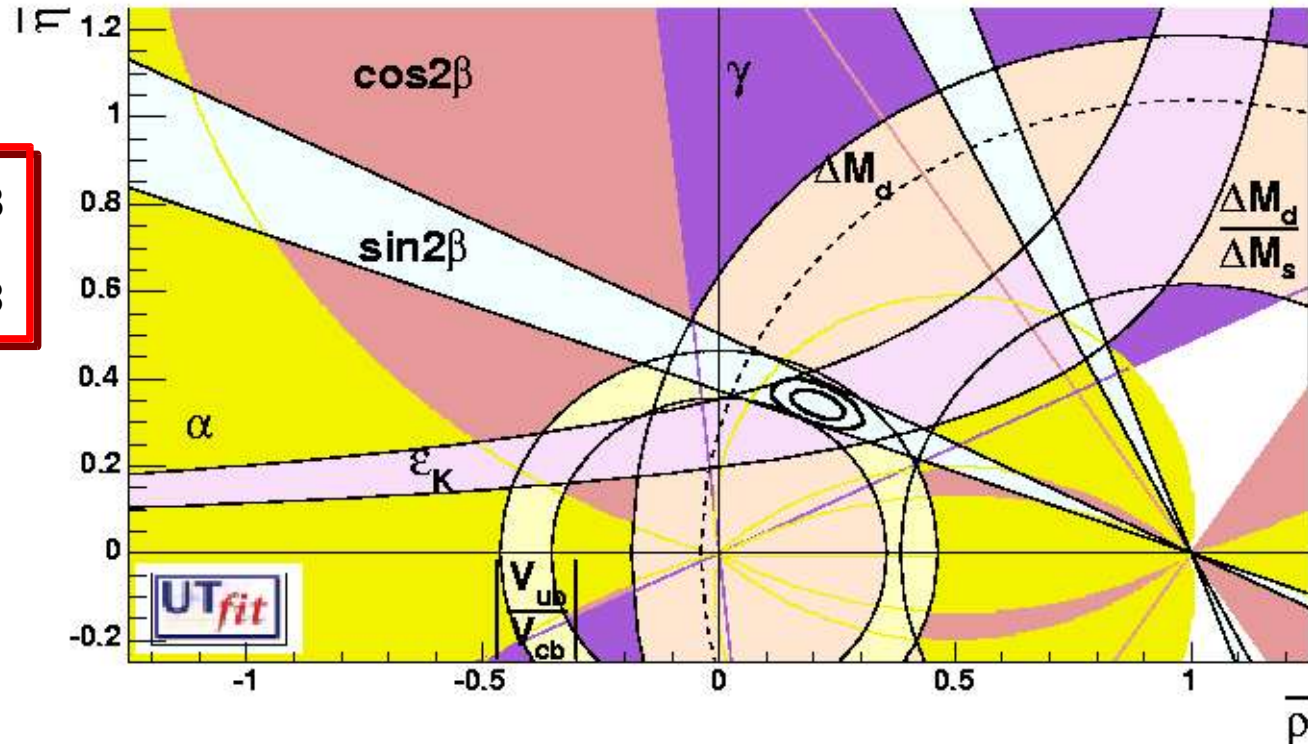
$$\bar{\rho} = 0.241 \pm 0.081$$

Precisione comparabile a quella
dell'analisi nell'era pre B factory



Fit da tutte le info

Analisi Standard + $\cos 2\beta$ + γ + α



$$\bar{\eta} = 0.341 \pm 0.023$$

$$\bar{\rho} = 0.207 \pm 0.038$$

Perfetto accordo tra le nuove misure
e l'analisi: meccanismo CKM
spiega la violazione di CP



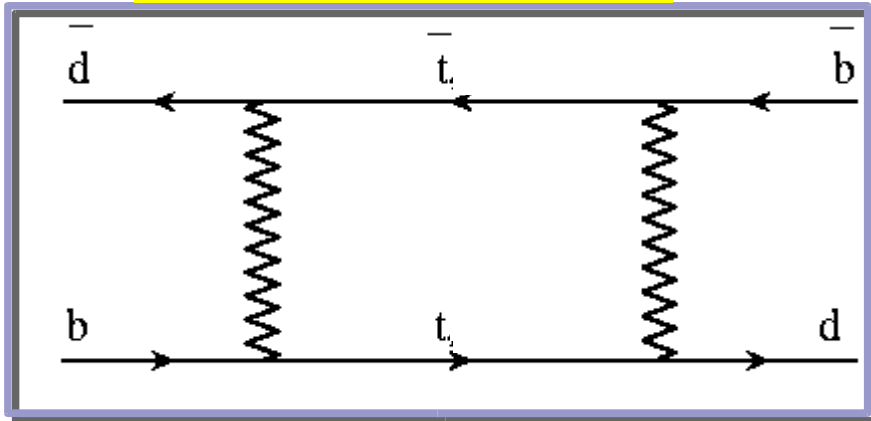
Generalizzazione alla Nuova Fisica



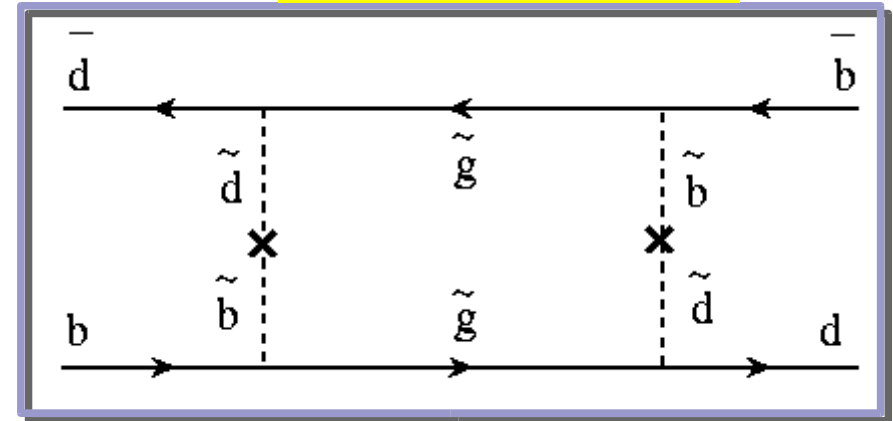
Generalizzazione

Ammettiamo che esista della nuova fisica e parametrizziamo in modo generale il modo in cui dovrebbe intervenire nelle misure considerate

Standard Model



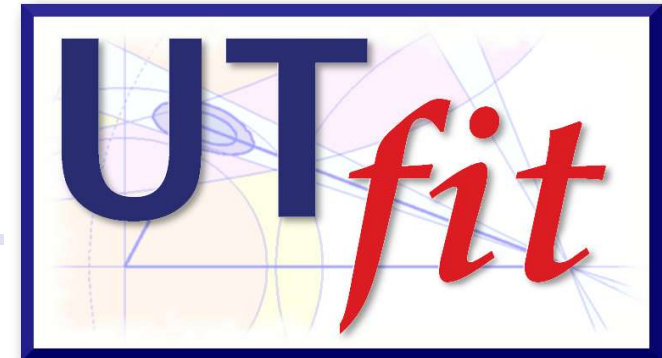
Nuova Fisica



+

- ◆ $|\epsilon_K|^{\text{EXP}} = C_\epsilon \cdot |\epsilon_K|^{\text{SM}}$
- ◆ $\Delta m_d^{\text{EXP}} = C_{Bd} \cdot \Delta m_d^{\text{SM}}$
- ◆ $A_{\text{CP}}(J/\psi K^0) = \sin(2\beta + 2\phi_{Bd})$
- ◆ $\alpha(\rho\rho)^{\text{EXP}} = \alpha^{\text{SM}} - \phi_{Bd}$

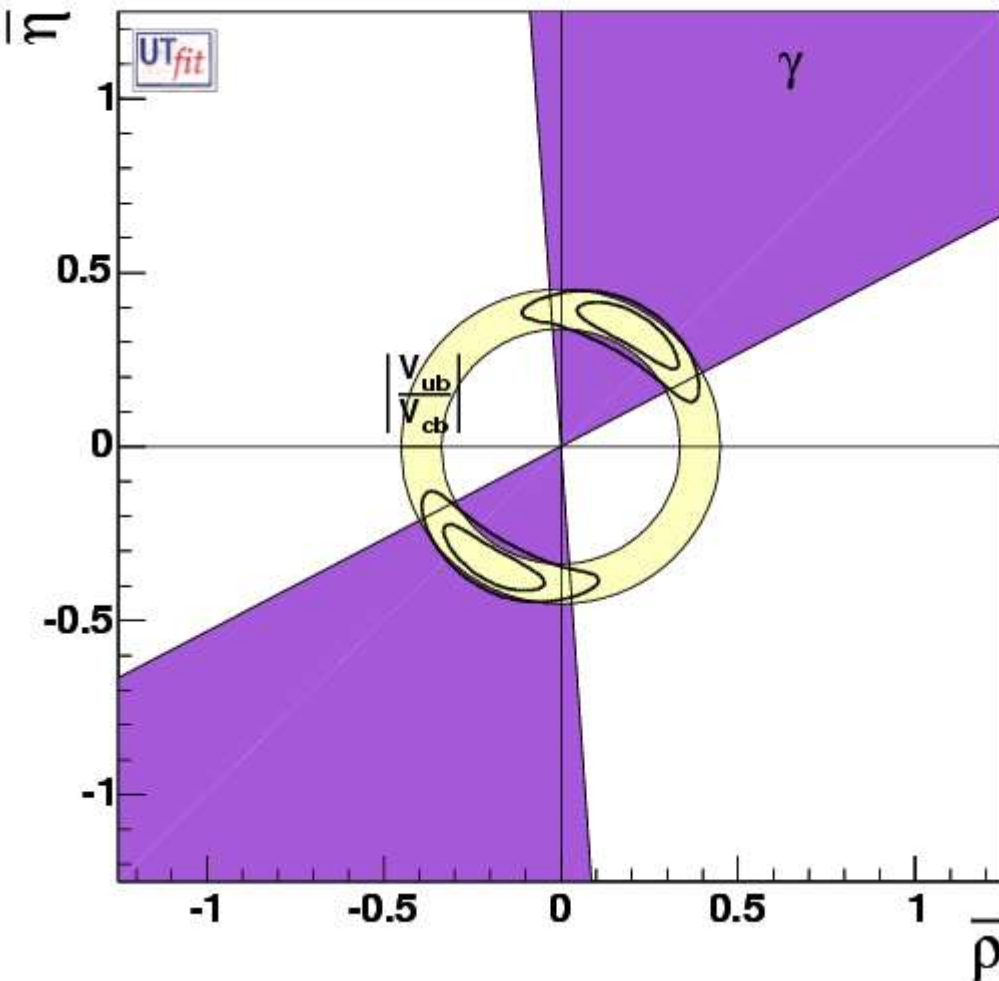
I processi ad albero non vengono influenzati dalla ridefinizione



Ciò che la NP non cambia

$|V_{ub}/V_{cb}|$ e g non vengono alterati. L'area che selezionano:

- Stabilisce l'esistenza della violazione CP
- Crea un paradigma che tutti i modelli di Nuova Fisica devono rispettare



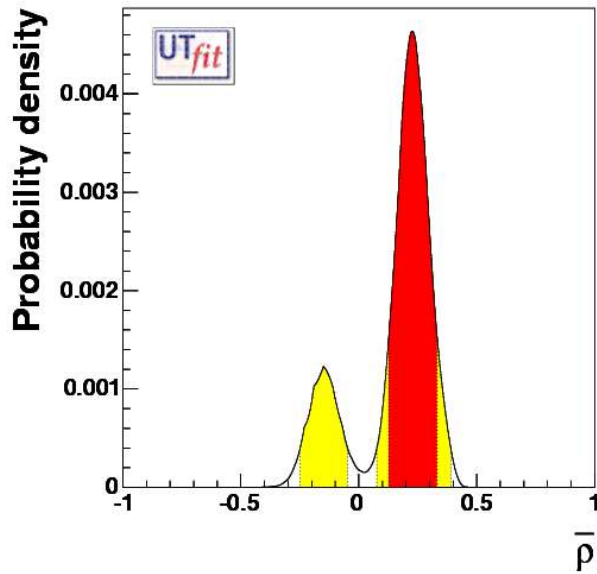
$$\bar{\eta} = \pm 0.21 \pm 0.10$$

$$\bar{\rho} = \pm 0.36 \pm 0.06$$



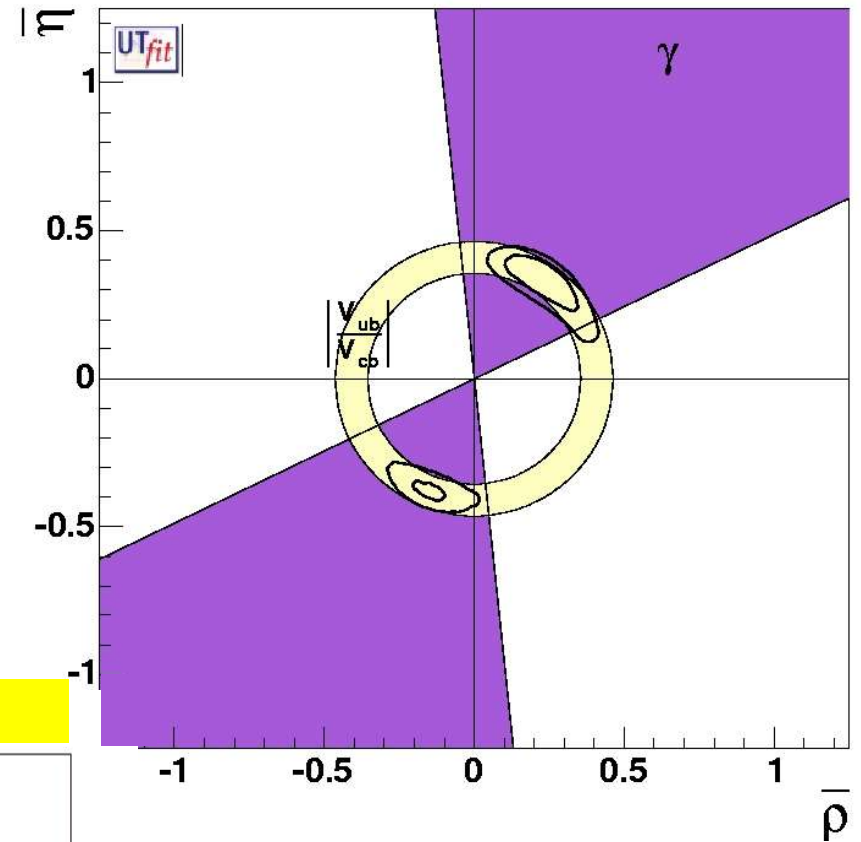
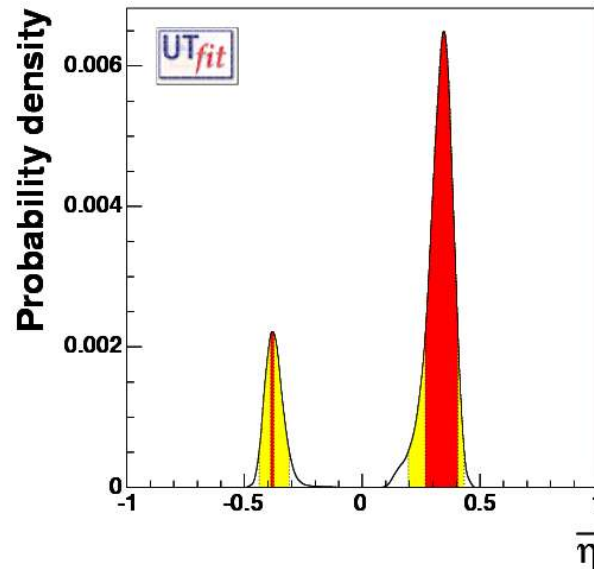
Accendendo la NP

Esiste una seconda soluzione ($\phi_{Bd} \sim 40^\circ$)
 Il significato delle osservabili
 sensibili a NP viene reinterpretato
 Il settore $b \rightarrow s$ completamente libero

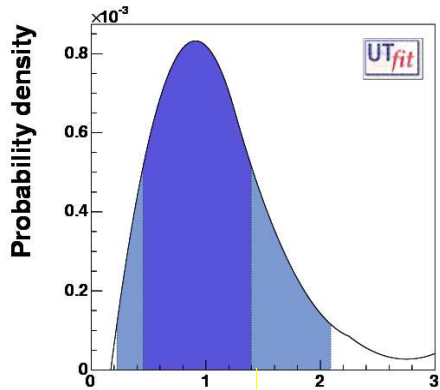


$$\bar{\rho} = 0.23 \pm 0.10$$

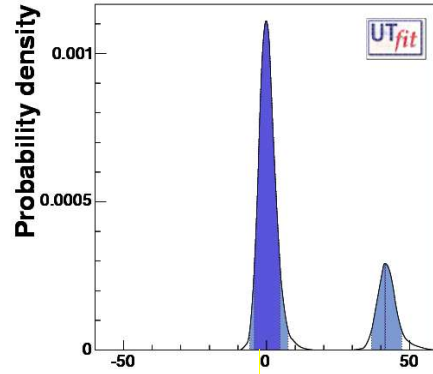
$$\bar{\eta} = 0.34 \pm 0.07$$



Accendendo la NP

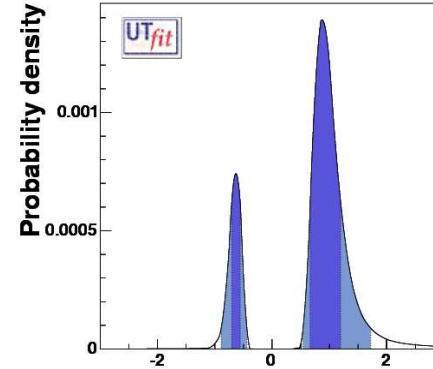


$$C_{B_d} = 0.93 \pm 0.47$$



$$\phi_{B_d} = [-5.9, 7.6]$$

$$U [36-7, 47.3]$$

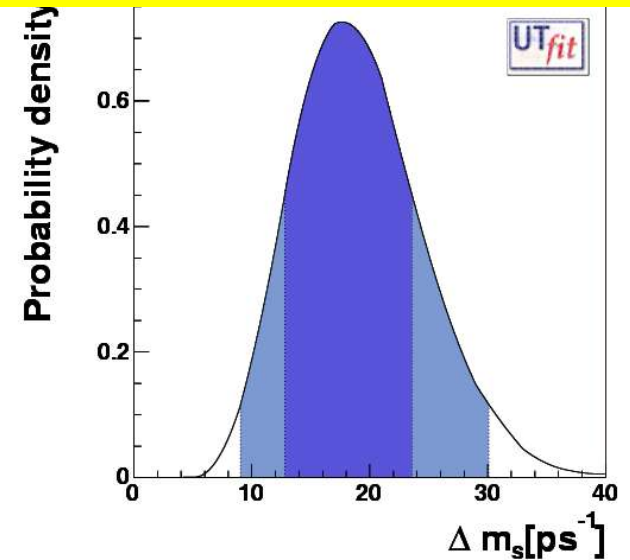
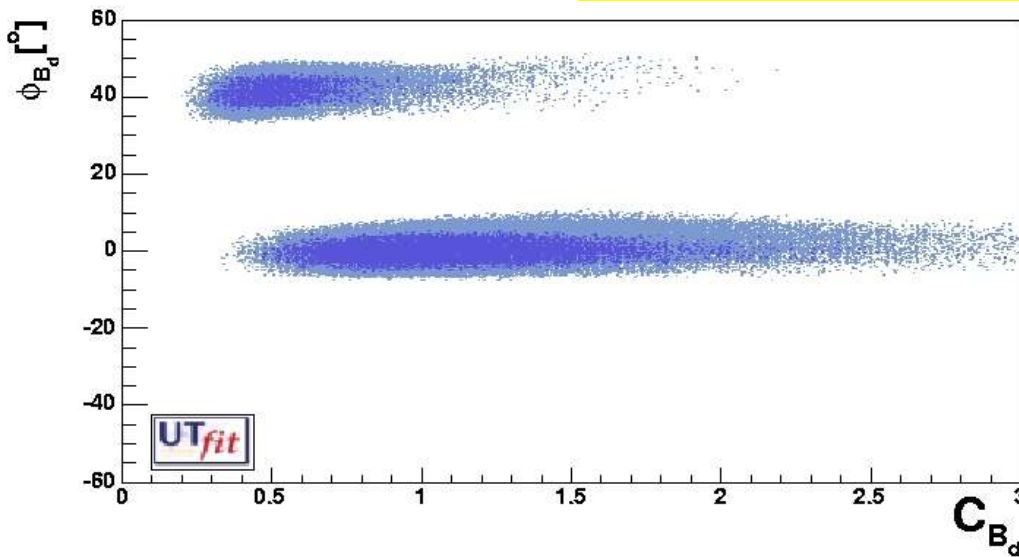


$$C_{\epsilon_K} = 0.93 \pm 0.07$$

$$U -0.63 \pm 0.07$$

$$\Delta m_s = 18.2 \pm 5.4$$

(analisi standard 21.2 ± 2.3)



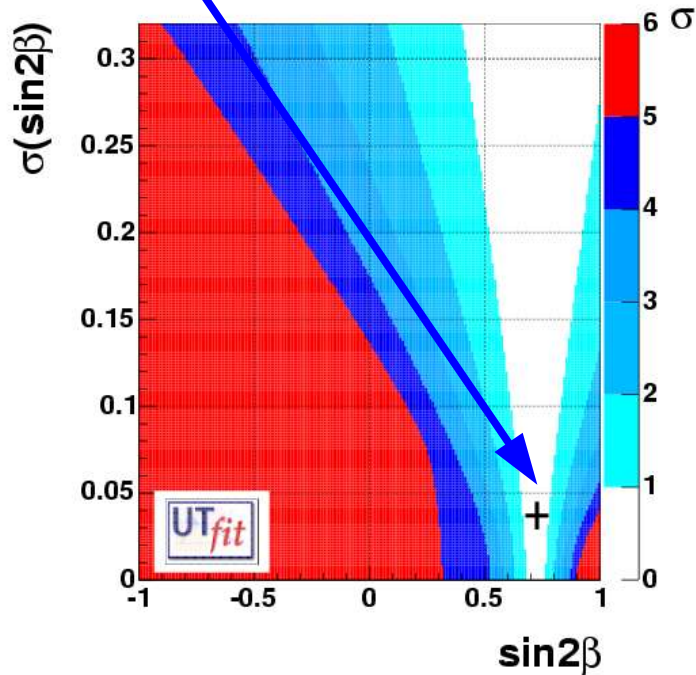
La ricerca della Nuova Fisica

Data la misura diretta di X , $X_{\text{DIR}} \pm \sigma_{\text{DIR}}$ e la determinazione indiretta $X_{\text{IND}} \pm \sigma_{\text{IND}}$, la distribuzione della variabile $X_{\text{DIR}} - X_{\text{IND}}$ quantifica la discrepanza tra la singola misurata ed il resto dell'analisi. Lo studio della discrepanza in funzione di X_{DIR} dà la sensibilità dei vari constraint alla NP



$\sin 2\beta$

$\sin 2$ ($J/\psi K^0$)

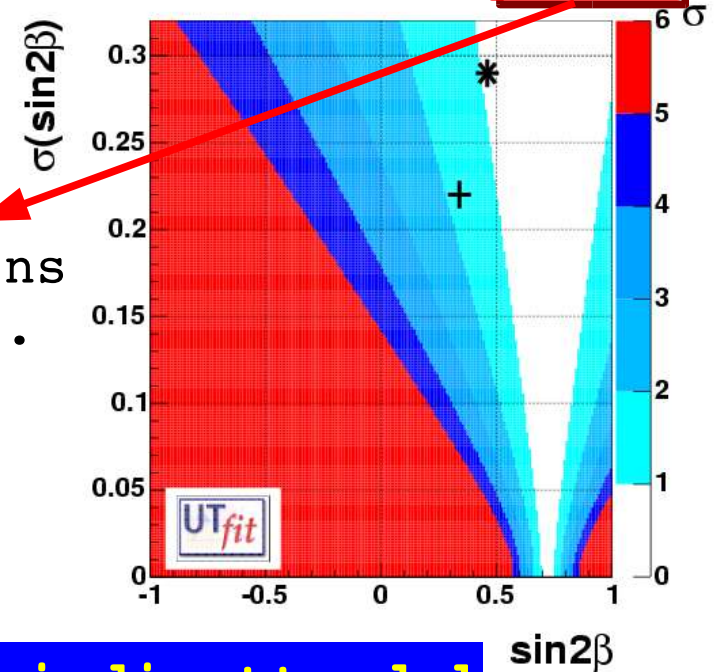


$\sin 2$ indiretto dal resto del fit standard

$\sin 2\beta$ da ϕK_S

$\sin 2\beta = 0.34 \pm 0.20 \pm 0.08$ HFAG
 $\sin 2\beta = 0.46 \pm 0.28 \pm 0.08$ Skep

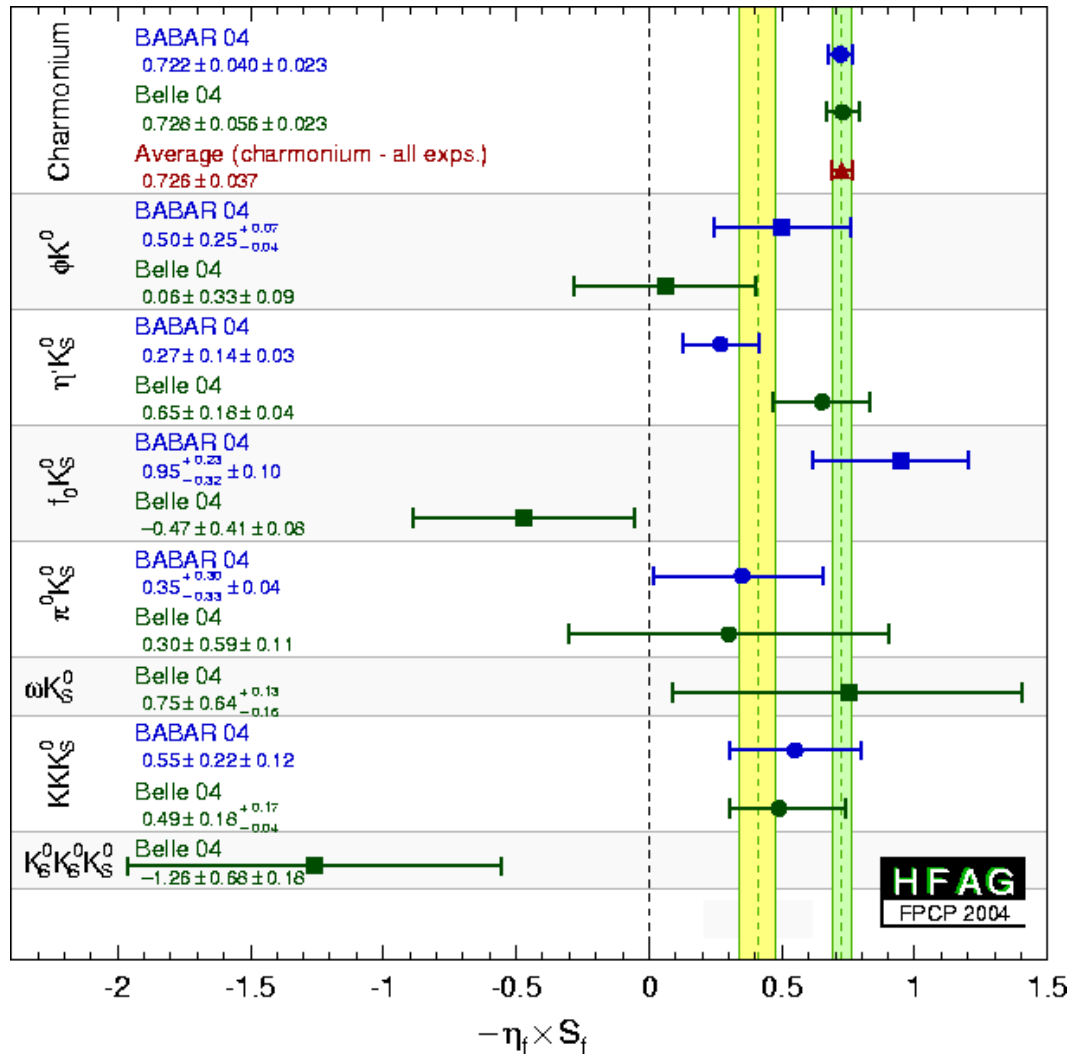
Correzioni adroniche dai Charming Penguins (Ciuchini et al. in preparation)



$\sin 2$ indiretto dal fit standard



$\sin 2\beta$ da altri canali?



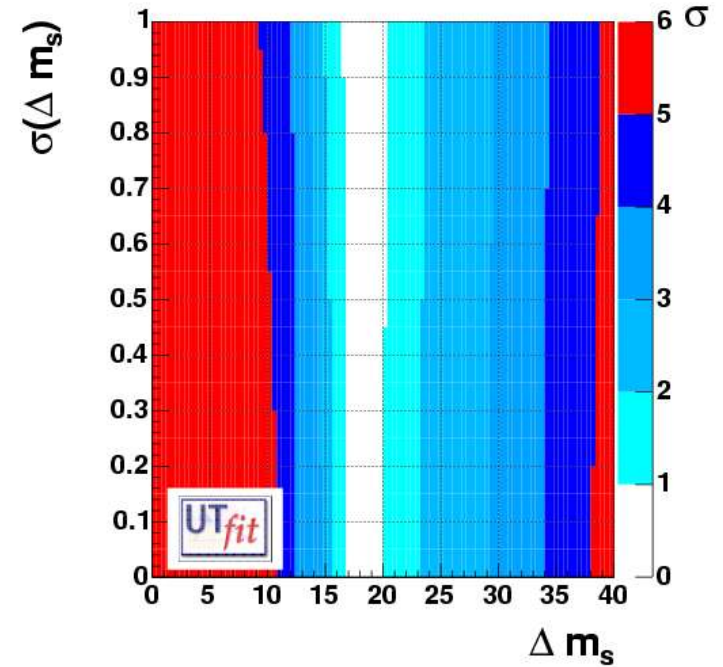
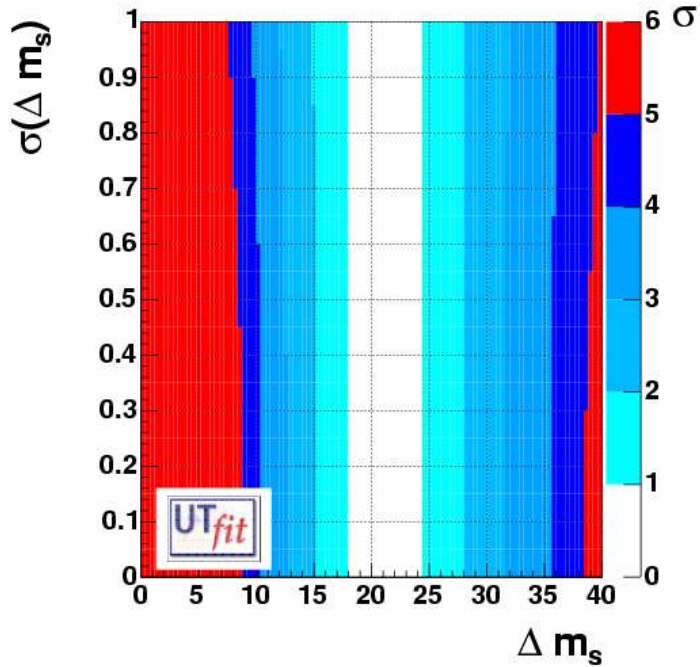
In linea di principio altri canali offrono la stessa fisica.

Le correzioni adroniche dipendono dai singoli canali.

- Mediare non è corretto
- Bisogna essere sicuri di controllare gli effetti adronici prima di dire che si sta testando il Modello Standard



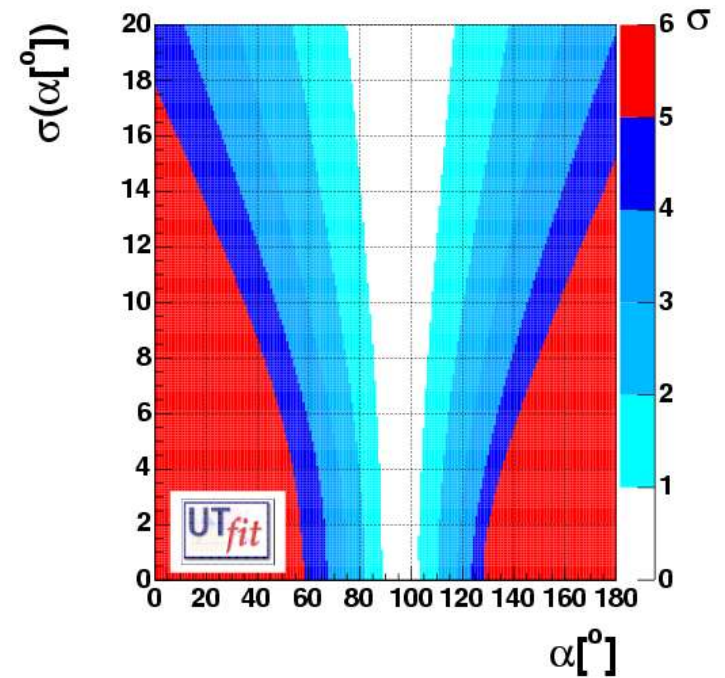
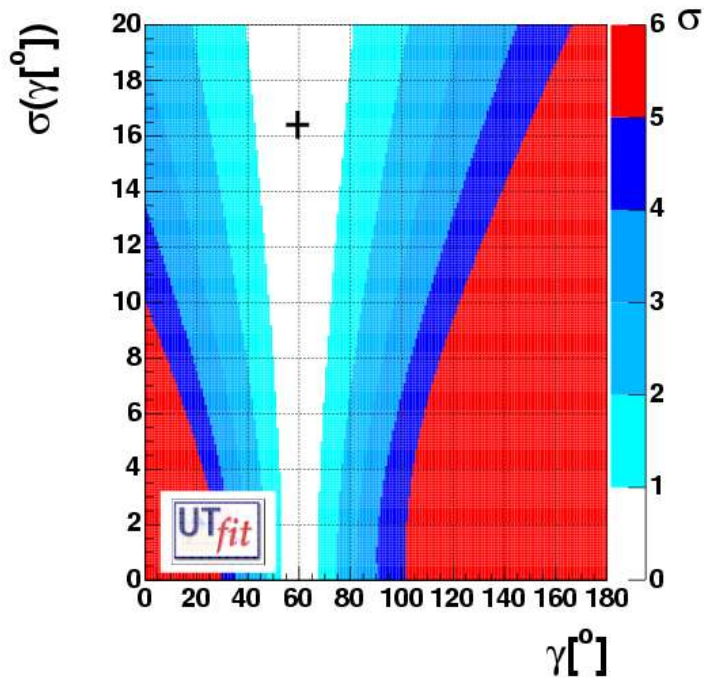
Δm_s indiretto dal fit standard



Δm_s indiretto dal resto del fit standard



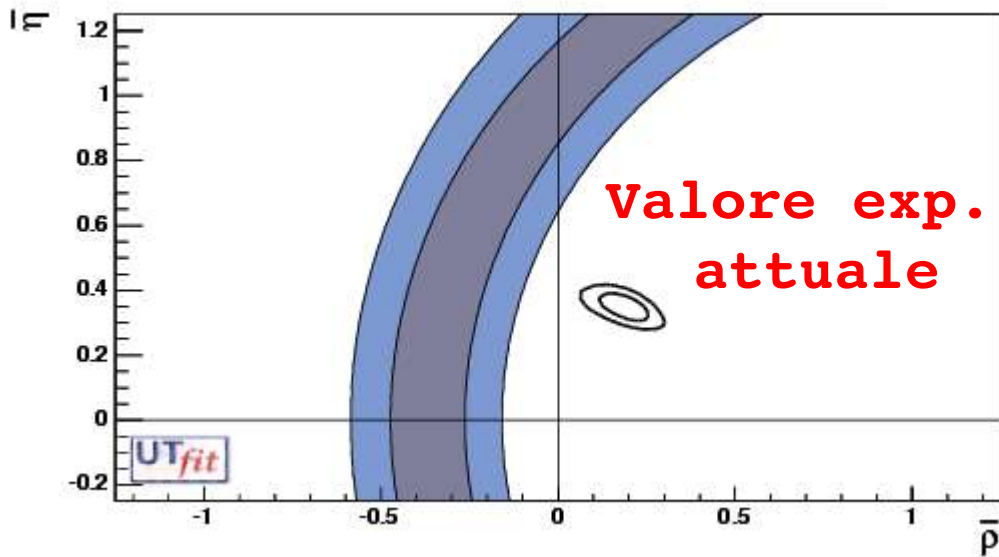
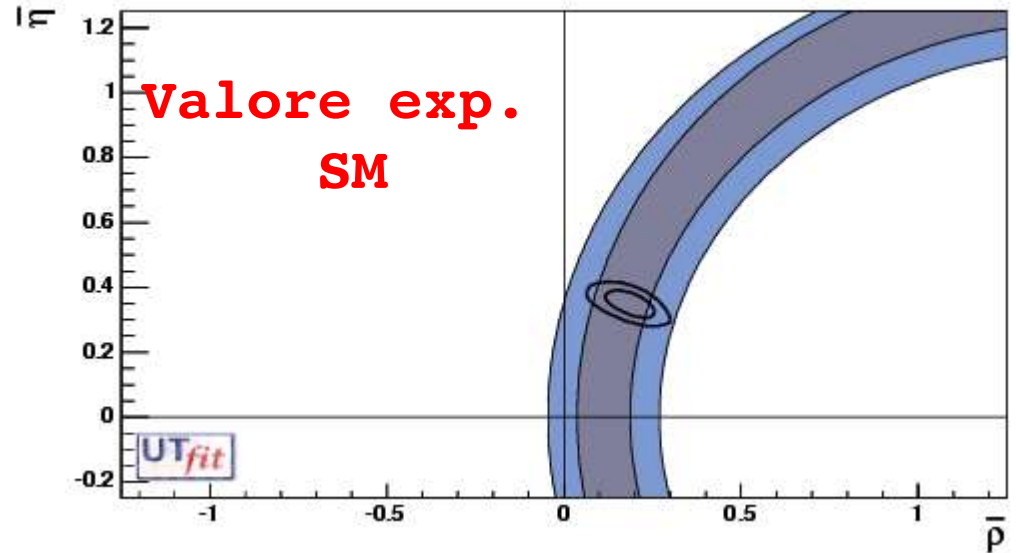
Misure indirette dal fit standard



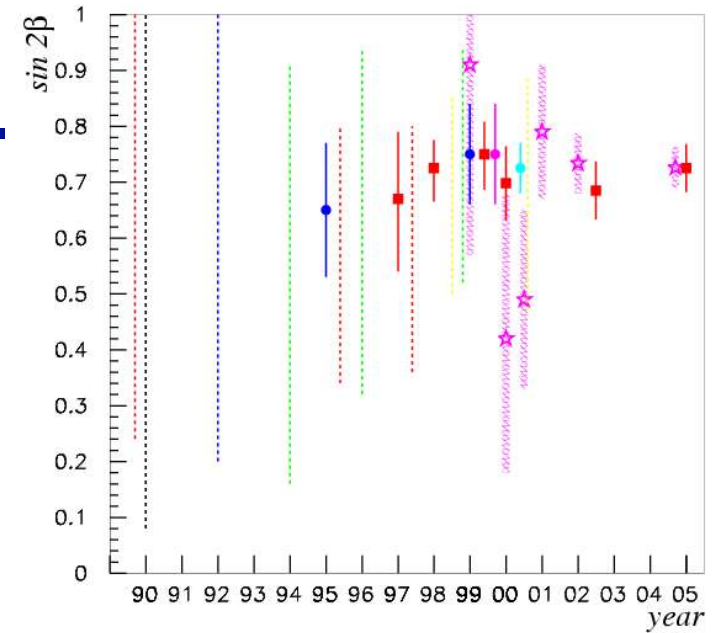
Difficilmente queste grandezze
potranno fornire discrepanze evidenti
(a meno di misure charmless di γ)



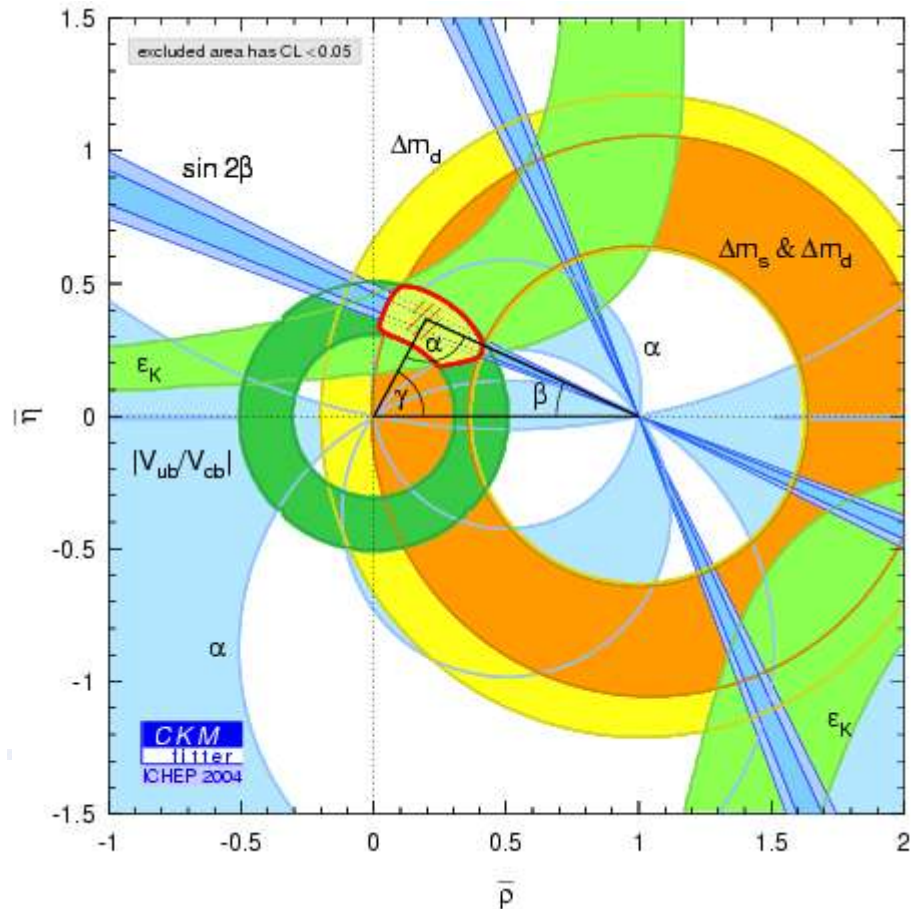
Scenario NA48/3
per $K \rightarrow \pi \nu \bar{\nu}$:
misura al 10% e
miglioramenti
teorici



Diffidate delle



imitazioni



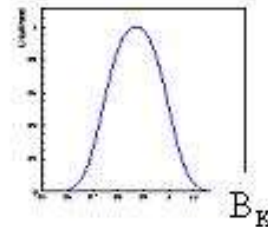
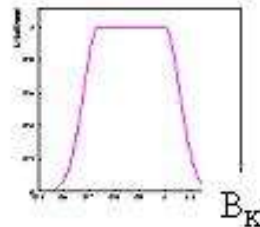
Differenza nel metodo

Ex : $B_K = 0.87 \pm 0.06$ (gaus) ± 0.13 (theo.)

Rfit

Bayesian

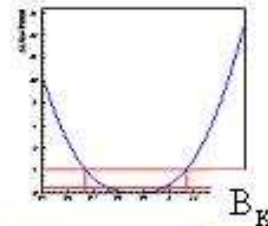
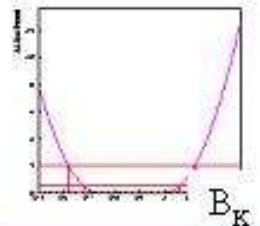
Likelihood obtained
summing linearly
the two errors



p.d.f.
from convolution
(sum in quadrature)

Likelihood
From inversion of p.d.f

Delta Likelihood

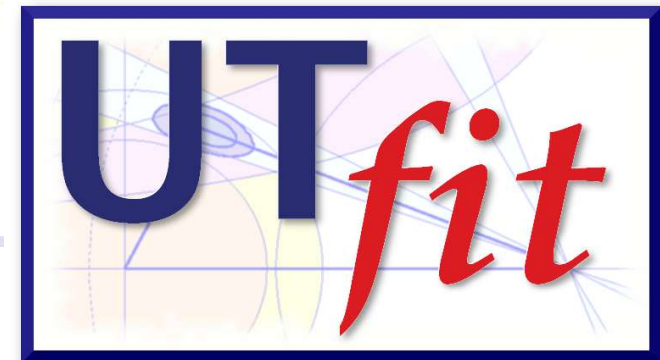


Delta Likelihood

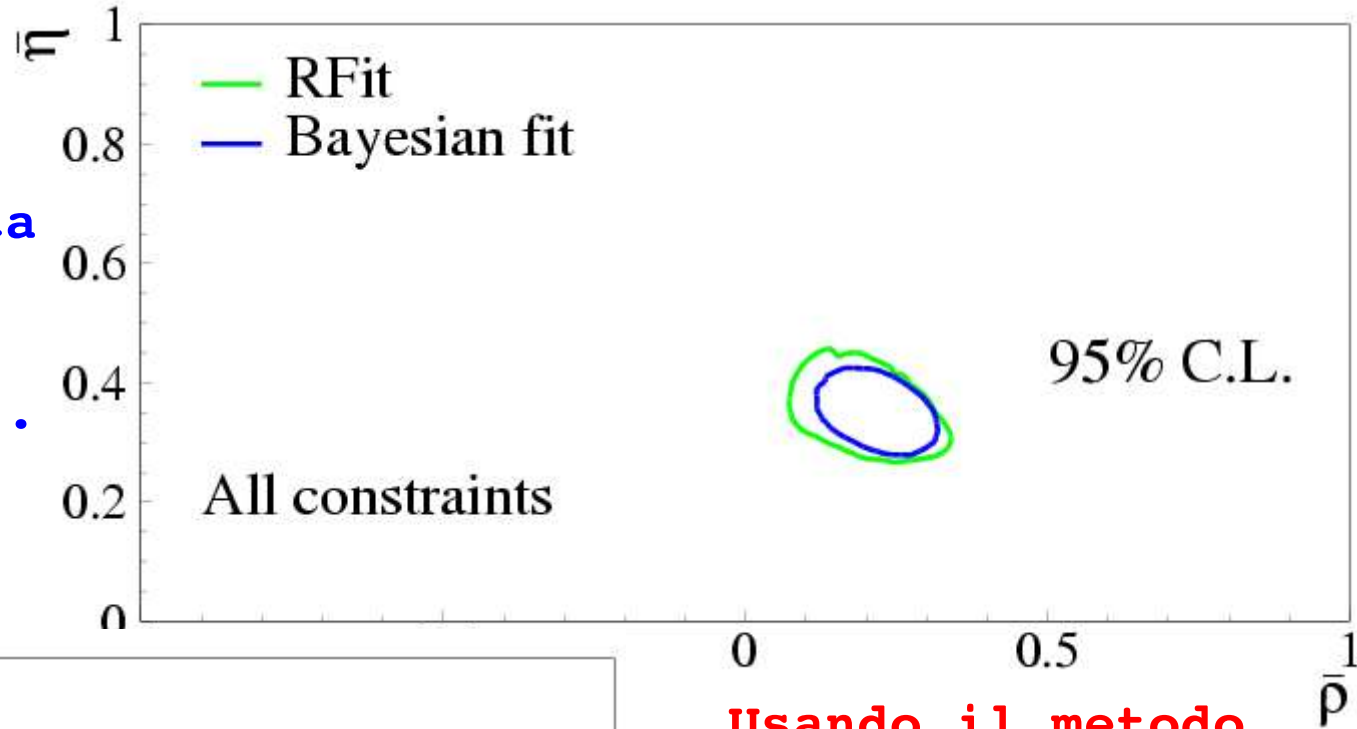
At 68% CL

[0.68-1.06]

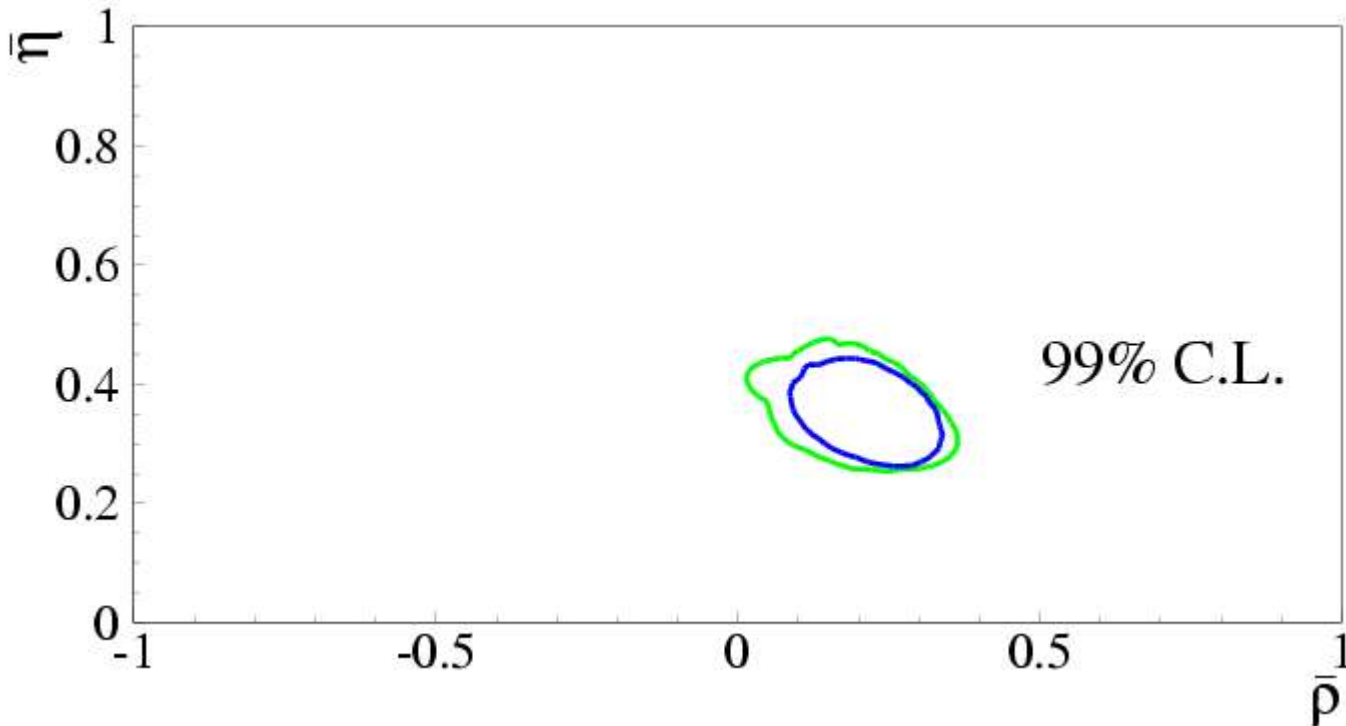
[0.76-0.98]



La differenza sta tutta
negli input di LQCD.
Chi ha i teorici li
consulta, gli altri...



Usando il metodo
frequentista
con l'input bayesiano
e viceversa



Conclusioni

- ◆ L'analisi di Triangolo Unitario dimostra la solidità del Modello Standard
- ◆ Il metodo statistico permette di controllare i progressi teorici (LQCD) con le misure
- ◆ Le nuove misure dalle B factory confermano questo scenario
- ◆ L'estensione alla Nuova Fisica non esclude ancora tutte le sorprese
- ◆ Alcune misure particolarmente utili in questo senso:
 - pinguini $b \rightarrow s$ in canali $B \rightarrow f_{CP}$
 - misura di Δm_s



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