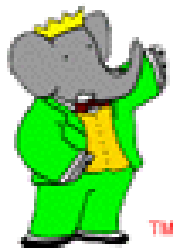




Misure di γ alle B-factory

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Roma 19 Novembre 2004

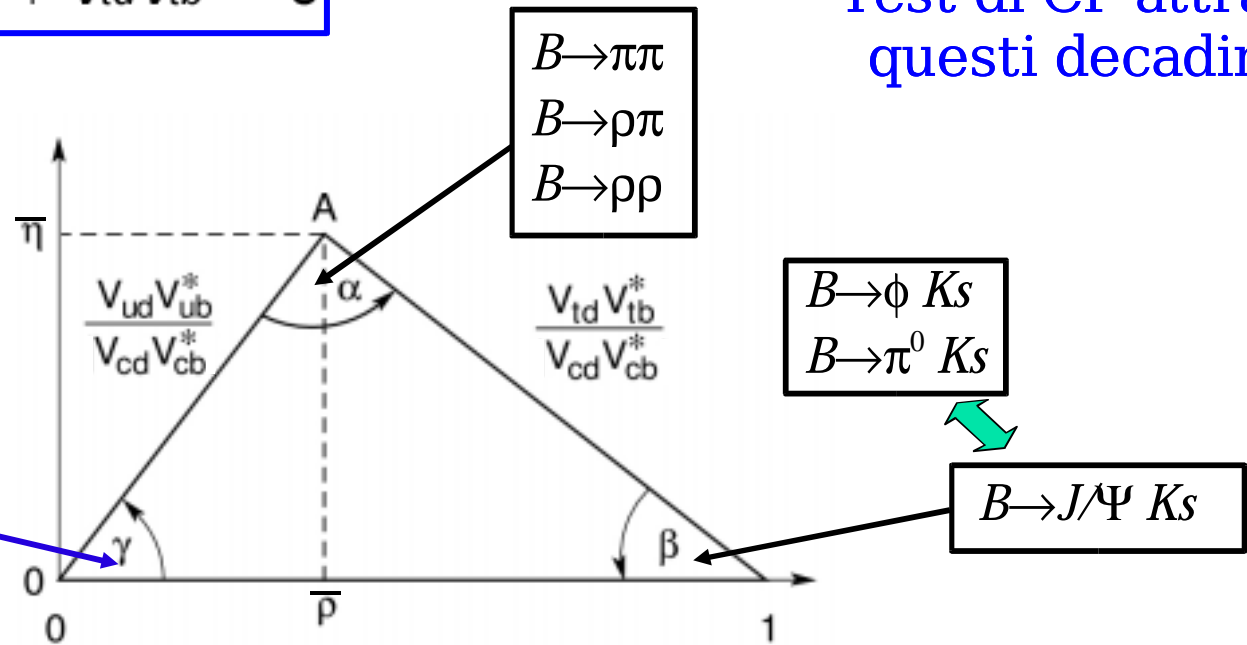
Il triangolo unitario

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

Una sola fase

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

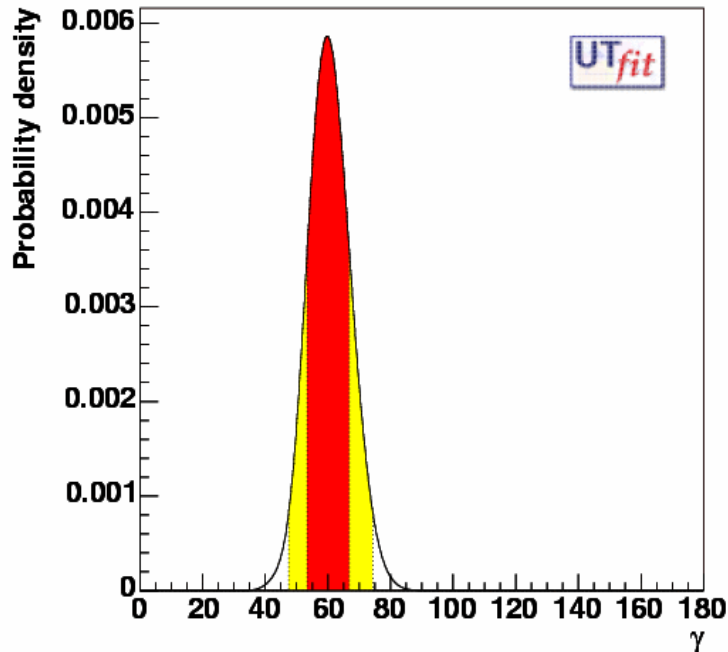
Test di CP attraverso questi decadimenti



Fit del triangolo unitario

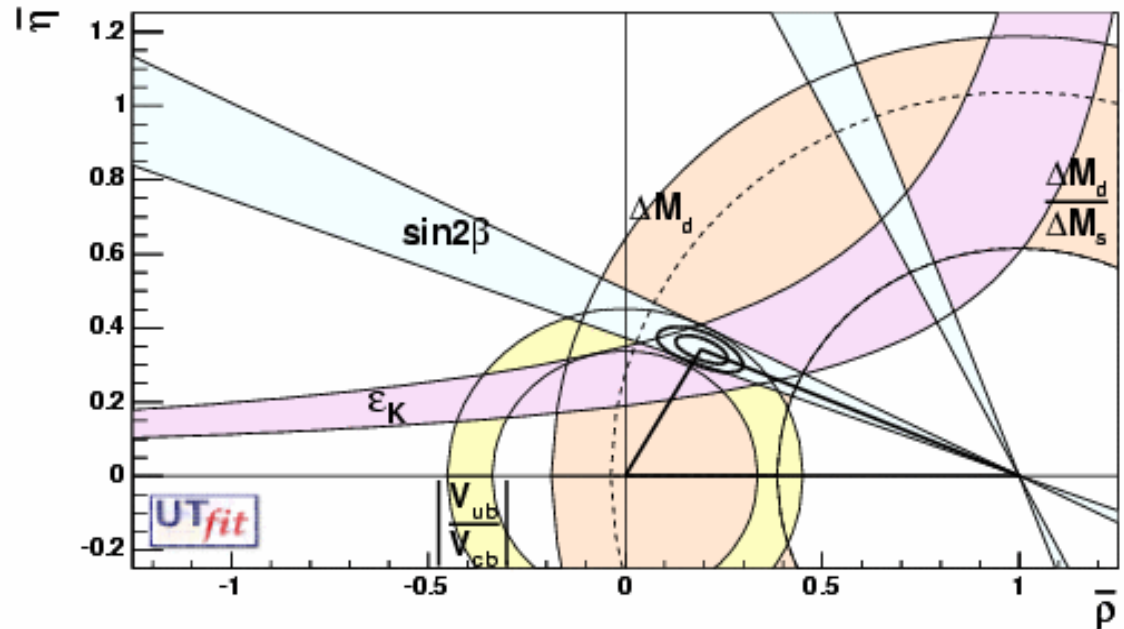
Determinazione
indiretta di γ

$$\gamma = 61.5^\circ \pm 7^\circ$$



68 % C.L.

95 % C.L.



Vincoli utilizzati:

V_{ub}/V_{cb} , ΔM_d , $\Delta M_d/\Delta M_s$, ϵ_K , $\sin 2\beta$

Regione selezionata:

$$\bar{\rho} = 0.172 \pm 0.047$$

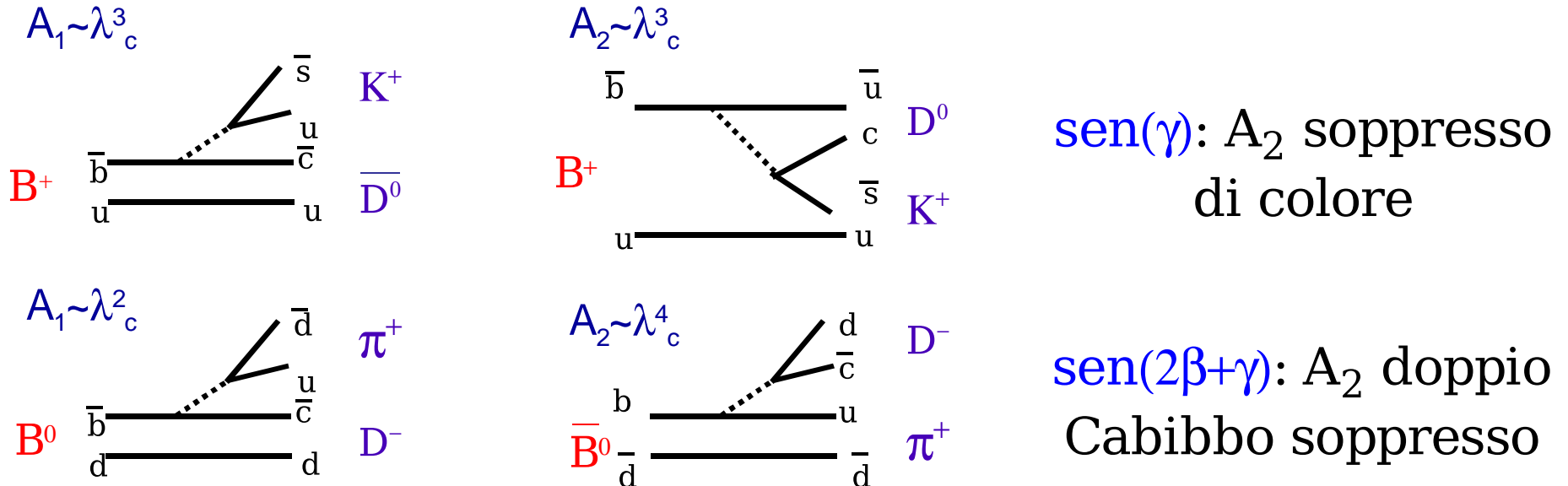
$$\bar{\eta} = 0.348 \pm 0.028$$

Misure di γ

È possibile misurare γ utilizzando **transizioni $b \rightarrow u$**

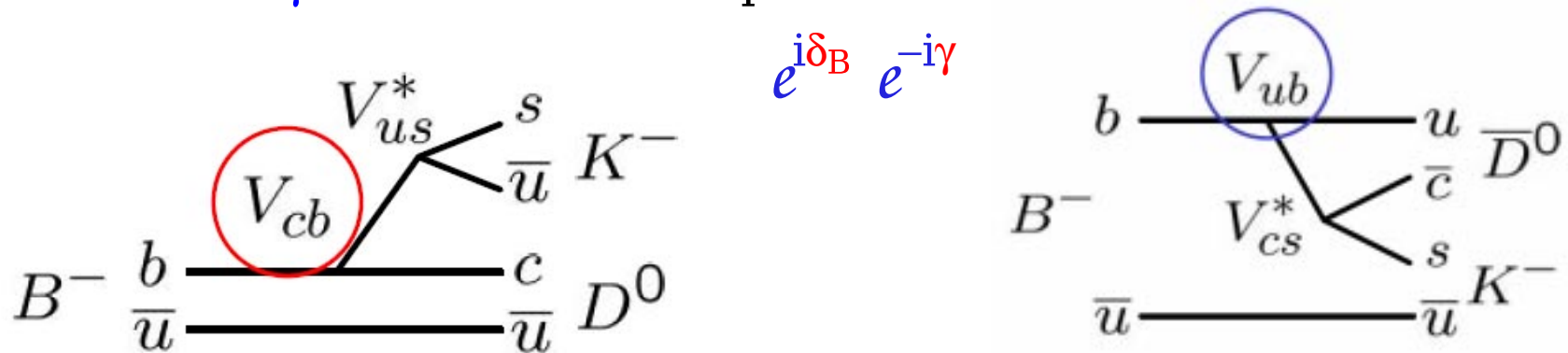
- Misurare γ direttamente nella asimmetria di CP diretta utilizzando i decadimenti del B^+
- Misurare $2\beta + \gamma$ con la violazione di CP nell'interferenza tra mixing e decadimento

Due casi:



Estrazione di γ da decadimenti $B \rightarrow DK$

γ è la fase tra le ampiezze $b \rightarrow u$ e $b \rightarrow c$



Si utilizza l'interferenza tra le ampiezze $B^- \rightarrow D^0 K^-$ e $B^- \rightarrow \bar{D}^0 K^-$ con D^0/\bar{D}^0 che decadono nello stesso stato finale

Il rapporto tra le ampiezze r_B non è ben calcolabile dalla teoria

$$r_B \equiv \frac{|A(B^- \rightarrow \bar{D}^0 K^-)|}{|A(B^- \rightarrow D^0 K^-)|} \sim 0.1 - 0.2$$

Maggiore è il valore di r_B migliore è la precisione su γ

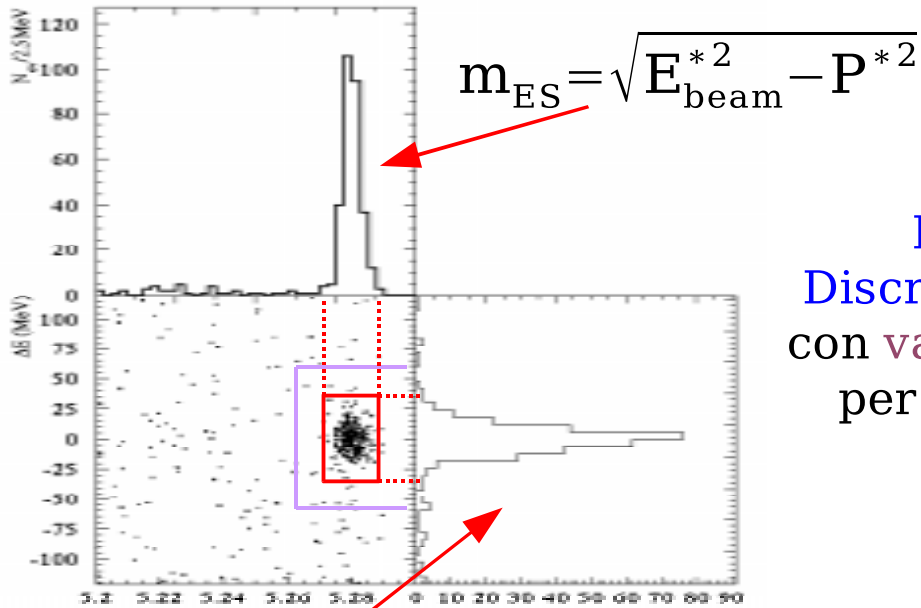
BaBar hep-ex/0402024 : $r_B < 0.22$ (90% C.L.)

Belle hep-ex/0406067 : $r_B = 0.26^{+0.10}_{-0.14} \pm 0.03 \pm 0.04$

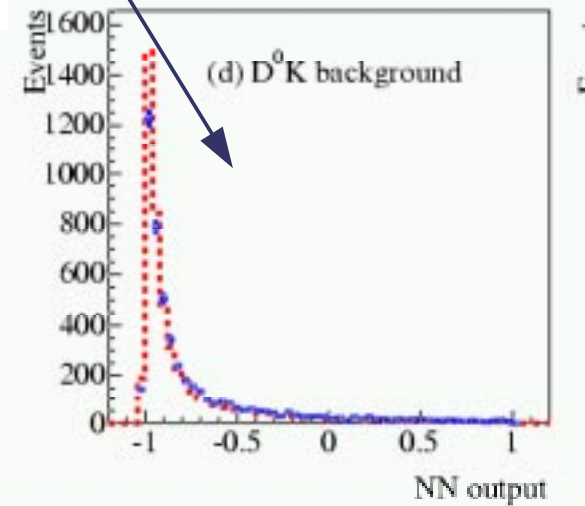
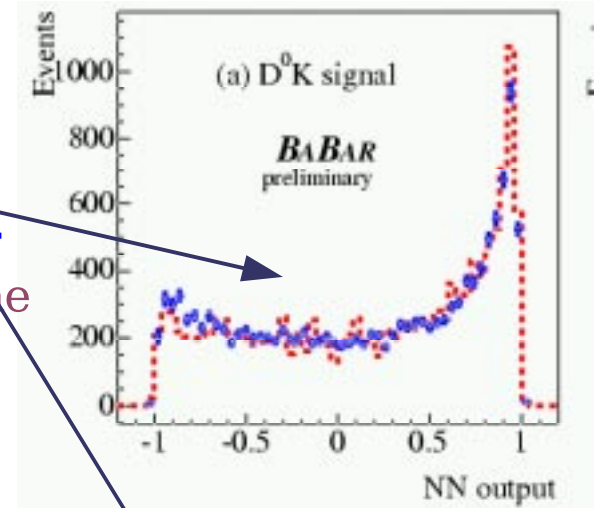
La fase forte relativa δ_B

non è nota

Tecnica di analisi



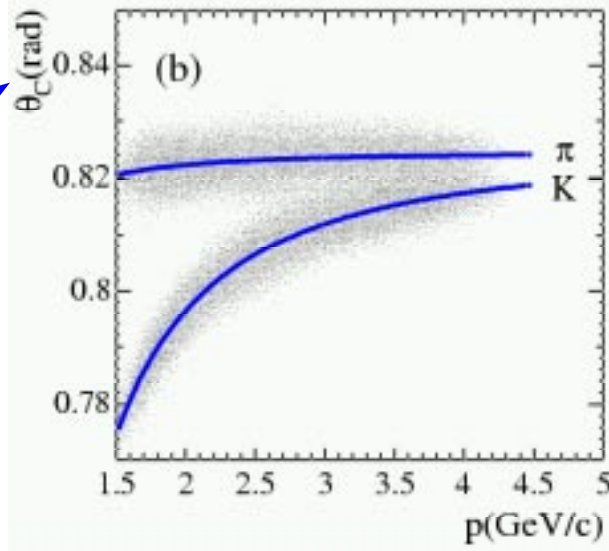
Rete neurale o
Discriminante di Fisher
con variabili topologiche
per separare il fondo
 $e^+e^- \rightarrow q\bar{q}$



$\Delta E = E_B^* - E_{beam}^*$

Angolo Cerenkov

Buona separazione $K^\pm \pi^\pm$
anche per alti impulsi



Il metodo GLW

Gronau-London-Wyler. considerano i decadimenti della D^0 in autostati di CP

Vengono selezionati gli autostati
 pari e dispari di CP

$$D_{CP^\pm}^0 = \frac{D^0 \pm \bar{D}^0}{\sqrt{2}}$$

$$A(CP^+) = \frac{\Gamma(B^+ \rightarrow D_{CP^+}^0 K^+) - \Gamma(B^- \rightarrow D_{CP^+}^0 K^-)}{\Gamma(B^+ \rightarrow D_{CP^+}^0 K^+) + \Gamma(B^- \rightarrow D_{CP^+}^0 K^-)} = 2r_B \sin \gamma \sin \delta_B / R(CP^+)$$

$$A(CP^-) = \frac{\Gamma(B^+ \rightarrow D_{CP^-}^0 K^+) - \Gamma(B^- \rightarrow D_{CP^-}^0 K^-)}{\Gamma(B^+ \rightarrow D_{CP^-}^0 K^+) + \Gamma(B^- \rightarrow D_{CP^-}^0 K^-)} = -2r_B \sin \gamma \sin \delta_B / R(CP^-)$$

$$R(CP^+) = \frac{\Gamma(B^+ \rightarrow D_{CP^+}^0 K^+) + \Gamma(B^- \rightarrow D_{CP^+}^0 K^-)}{\Gamma(B^+ \rightarrow D^0 K^+) + \Gamma(B^- \rightarrow D^0 K^-)} = 1 + r_B^2 + 2r_B \sin \gamma \sin \delta_B$$

$$R(CP^-) = \frac{\Gamma(B^+ \rightarrow D_{CP^-}^0 K^+) + \Gamma(B^- \rightarrow D_{CP^-}^0 K^-)}{\Gamma(B^+ \rightarrow D^0 K^+) + \Gamma(B^- \rightarrow D^0 K^-)} = 1 + r_B^2 - 2r_B \sin \gamma \cos \delta_B$$

Si misurano A_{CP^\pm} , R_{CP^\pm} e si risolve per δ_B , r_B e γ
 (con un'ambiguità di ordine 8 in γ)

$$\text{Br}(B \rightarrow D K) \approx 10^{-4} \quad \text{Br}(D \rightarrow f) \approx 10^{-2}$$



ricostruire il maggior numero di stati possibile



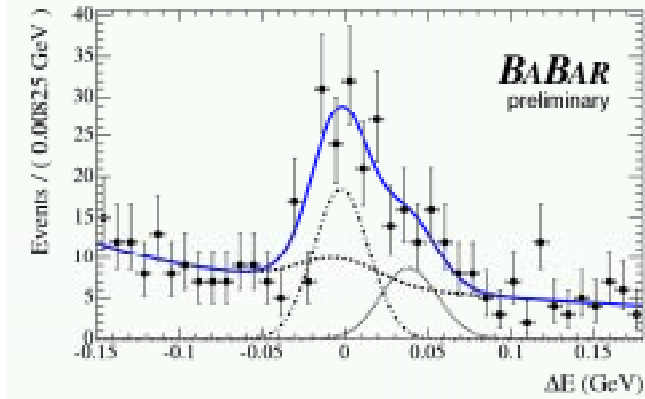
$B^- \rightarrow D_{CP} K^-$: yield

$D_{CP}^0 K^-$

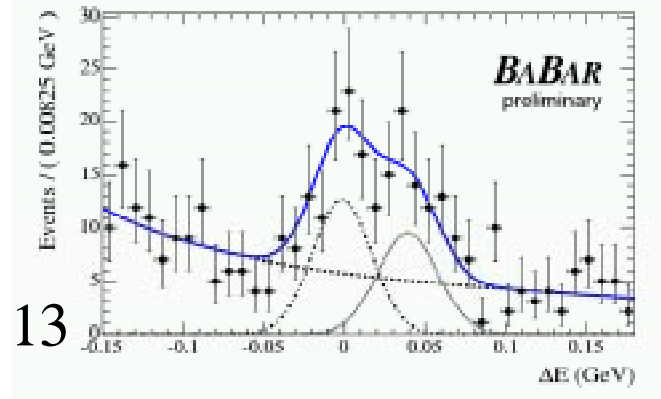
$N_{BB}=214 \cdot 10^6$

$D_+ (\pi^+ \pi^-, K^+ K^-)$

$D_- (K_S \pi^0)$



$K^+ K^-$ 75 ± 13
 $\pi^+ \pi^-$ 18 ± 7

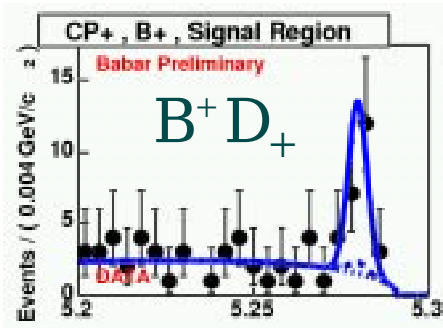


$K_S \pi^0$ 76 ± 13

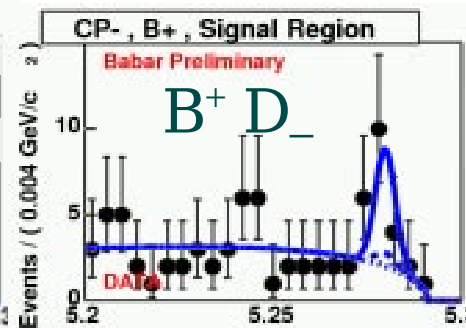
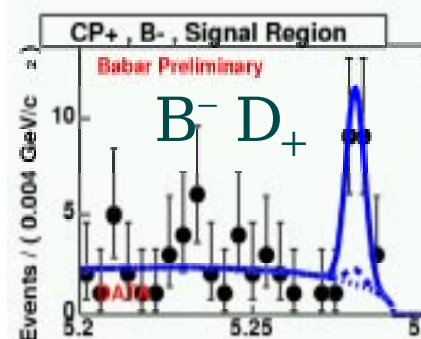
$D_{CP}^0 K^{*-} (K^{*-} \rightarrow K_S \pi^-)$

$N_{BB}=227 \cdot 10^6$

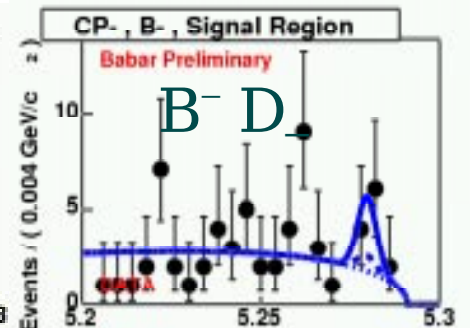
Con $K_S \phi, K_S \omega$



D_+ 33.4 ± 6.9



D_- 15.1 ± 5.8





$B^- \rightarrow D^{(*)0}_{CP} K^{(*)-}$: risultati

$D^0_{CP} K^- \quad N_{BB}=214 \cdot 10^6$

$R_{CP+}=0.87 \pm 0.14 \pm 0.06$

$A_{CP+}=0.40 \pm 0.15 \pm 0.08$

$R_{CP-}=0.80 \pm 0.14 \pm 0.08$

$A_{CP-}=0.21 \pm 0.17 \pm 0.07$

$D^0_{CP} K^{*-} (K^{*-} \rightarrow K_S \pi^-) \quad N_{BB}=227 \cdot 10^6$

$R_{CP+}=1.77 \pm 0.37 \pm 0.12$

$A_{CP+}=-0.09 \pm 0.20 \pm 0.06$

$R_{CP-}=0.76 \pm 0.29 \pm 0.06^{+0.04}_{-0.14}$

$A_{CP-}=-0.33 \pm 0.34 \pm 0.10 \cdot (+1.15 \pm 0.12)(A_{CP-}-A_{CP+})$

Errore sistematico
dovuto al fondo CP_+

$D^{*0}(D^0_{CP} \pi^0)K^- \quad N_{BB}=123 \cdot 10^6$

$R_{CP+}=1.09 \pm 0.26^{+0.10}_{-0.08}$

$A_{CP+}=-0.02 \pm 0.24 \pm 0.05$

$R_{CP+}+R_{CP-}=2(1+\Gamma_B^2)$

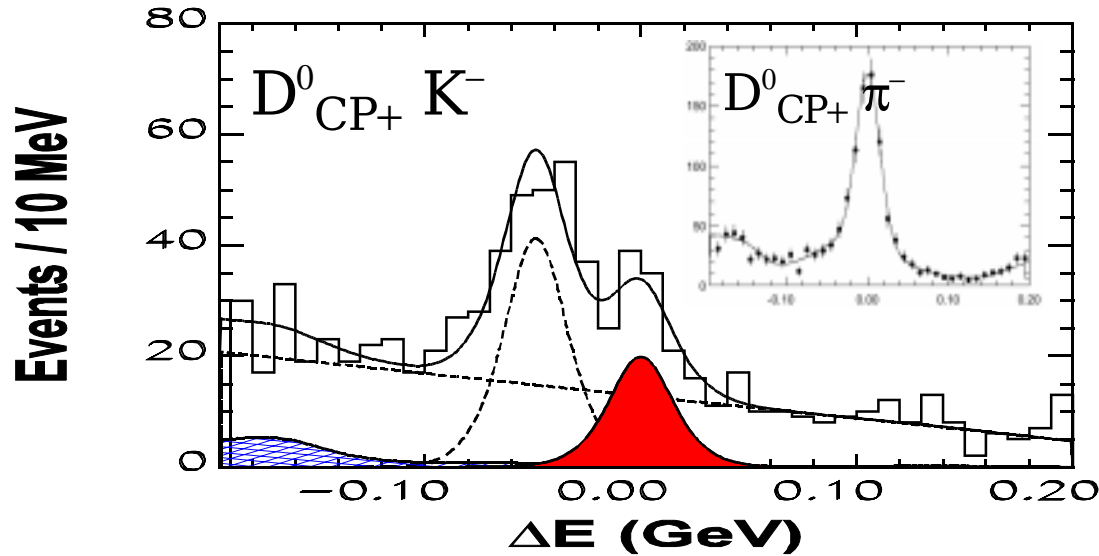
$\Gamma_B=0.23 \pm 0.24$

Ulteriori stati finali autostati di CP ancora da aggiungere



GLW: Belle

$\mathcal{L} = 250 \text{ fb}^{-1}$



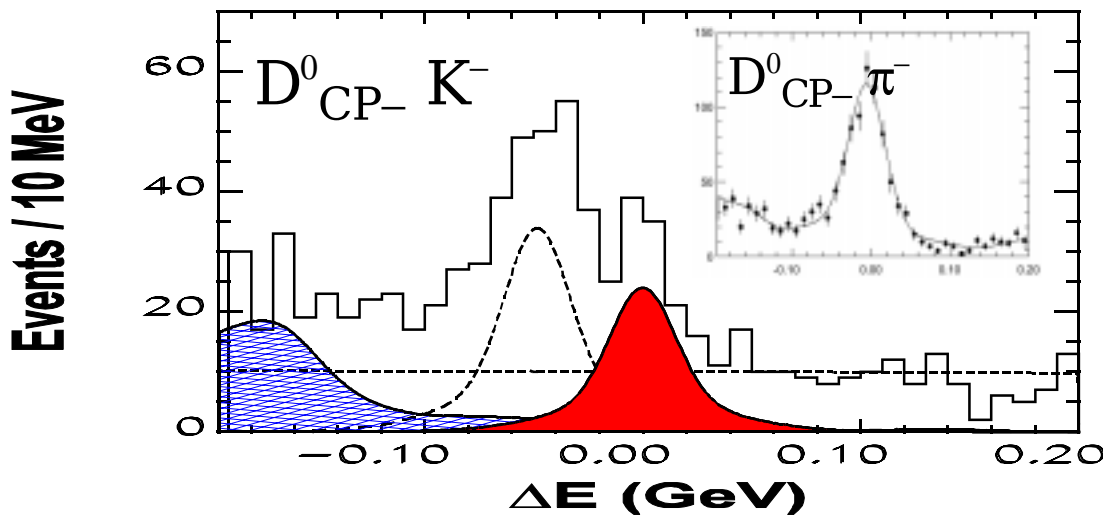
$D^0_{CP} K^-$

$$R_{CP+} = 0.98 \pm 0.14 \pm 0.06$$

$$A_{CP+} = 0.07 \pm 0.14 \pm 0.06$$

$$R_{CP-} = 1.29 \pm 0.16 \pm 0.08$$

$$A_{CP-} = -0.11 \pm 0.14 \pm 0.05$$



$D^{*0}_{CP} K^-$

$$R_{CP+} = 1.43 \pm 0.28 \pm 0.06$$

$$A_{CP+} = -0.27 \pm 0.25 \pm 0.04$$

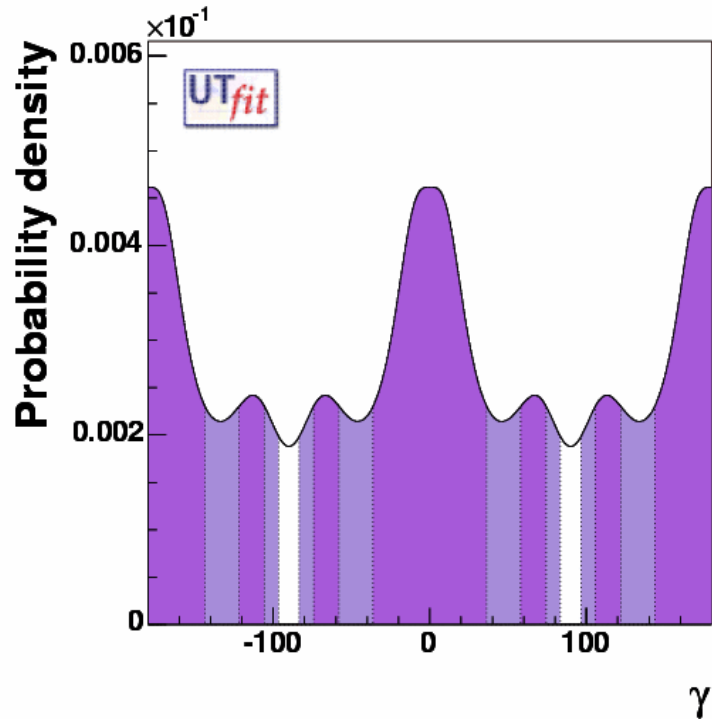
$$R_{CP-} = 0.94 \pm 0.26 \pm 0.03$$

$$A_{CP-} = 0.26 \pm 0.26 \pm 0.03$$

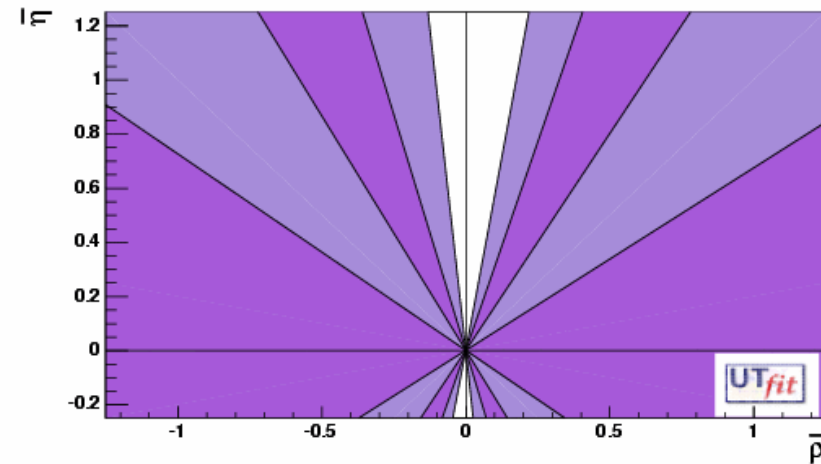
GLW: vincoli sul piano $\bar{\rho}-\bar{\eta}$

Mediando i valori di BaBar e Belle:

DK (GLW)	$A_{CP^+}(DK) = 0.22 \pm 0.11$	$A_{CP^-}(DK) = 0.02 \pm 0.12$	$R_{CP^+}(DK) = 0.91 \pm 0.12$	$R_{CP^-}(DK) = 1.02 \pm 0.12$
D*K (GLW)	$A_{CP^+}(DK) = -0.14 \pm 0.18$	$A_{CP^-}(DK) = 0.26 \pm 0.26$	$R_{CP^+}(DK) = 1.25 \pm 0.20$	$R_{CP^-}(DK) = 0.94 \pm 0.29$
DK* (GLW)	$A_{CP^+}(DK) = -0.07 \pm 0.18$	$A_{CP^-}(DK) = -0.16 \pm 0.29$	$R_{CP^+}(DK) = 1.77 \pm 0.39$	$R_{CP^-}(DK) = 0.76 \pm 0.33$



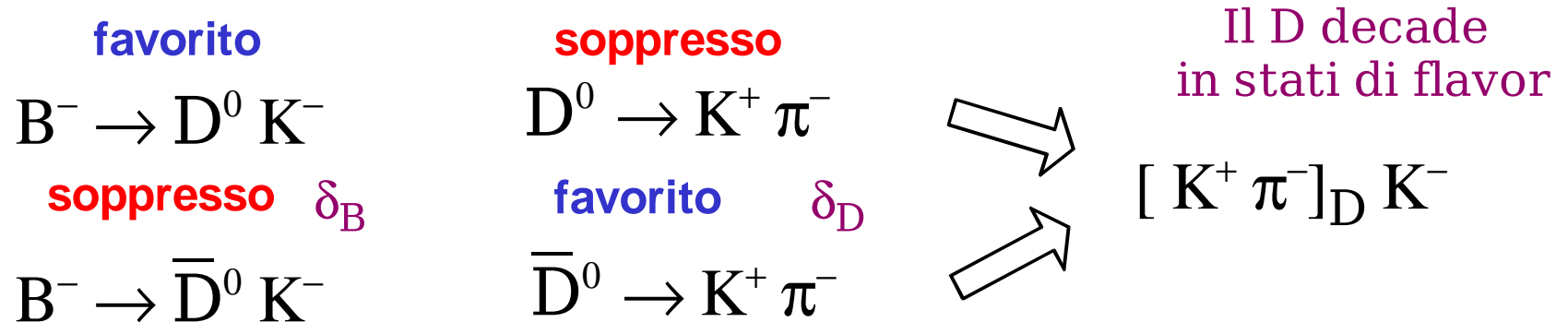
68 % C.L. 95 % C.L.



Serve maggiore statistica
per determinare γ

$B^- \rightarrow [K^+ \pi^-]_D K^-$: metodo ADS

Atwood-Dunietz-Soni: considerano l'interferenza tra le ampiezze



Si contano i **candidati B** con un **K** di segno opposto

$$R_{\text{ADS}} = \frac{\text{Br}([K^+ \pi^-]K^-) + \text{Br}([K^- \pi^+]K^+)}{\text{Br}([K^- \pi^+]K^-) + \text{Br}([K^+ \pi^-]K^+)} = r_D^2 + r_B^2 + 2r_B r_D \cos(\delta_D + \delta_B) \cos(\gamma)$$

$$A_{\text{ADS}} = \frac{\text{Br}([K^+ \pi^-]K^-) - \text{Br}([K^- \pi^+]K^+)}{\text{Br}([K^+ \pi^-]K^-) + \text{Br}([K^- \pi^+]K^+)} = 2r_B r_D \sin(\delta_D + \delta_B) \sin(\gamma) / R_{\text{ADS}}$$

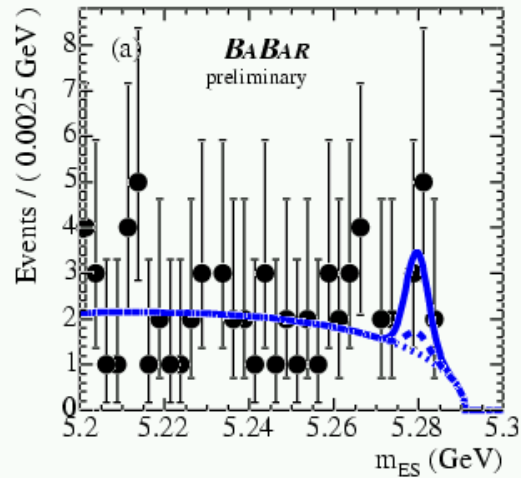
Input: $r_D = \frac{|A(D^0 \rightarrow K^+ \pi^-)|}{|A(D^0 \rightarrow K^- \pi^+)|} = 0.060 \pm 0.003$
Phys.Rev.Lett.91:171801,2003

Fase forte δ_D **non nota**

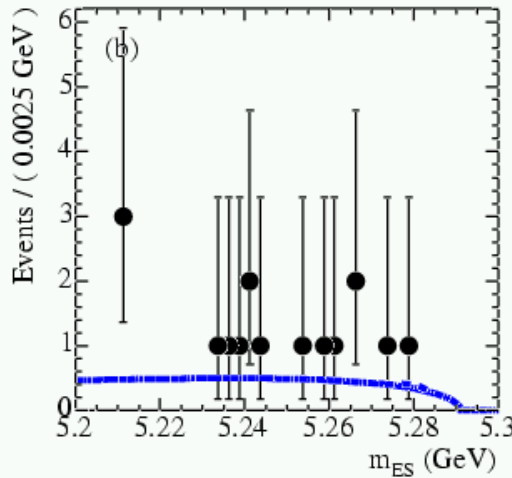


ADS: risultati

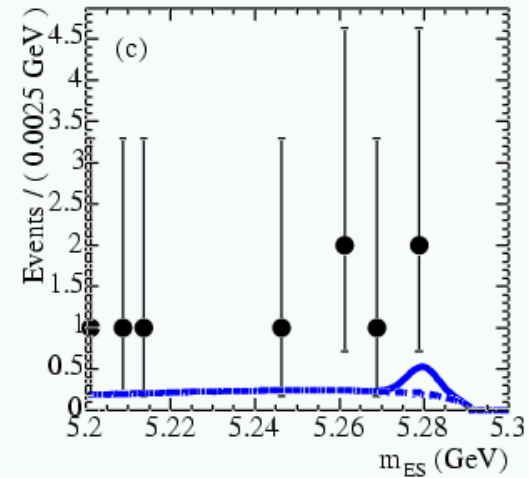
$D^0 K$



$D^{*0}(D^0 \pi^0)K$



$D^{*0}(D^0 \gamma)K$



$$N([\text{K}^\pm \pi^\mp]_D \text{K}^\mp) = 4.7^{+4.0}_{-3.2}$$

$$N([\text{K}^\pm \pi^\mp]_{D^*(D\pi)} \text{K}^\mp) = -0.2^{+1.3}_{-0.8}$$

$$N([\text{K}^\pm \pi^\mp]_{D^*(D\gamma)} \text{K}^\mp) = 1.2^{+2.1}_{-1.4}$$

$$N_{\text{BB}} = 227 \cdot 10^6$$

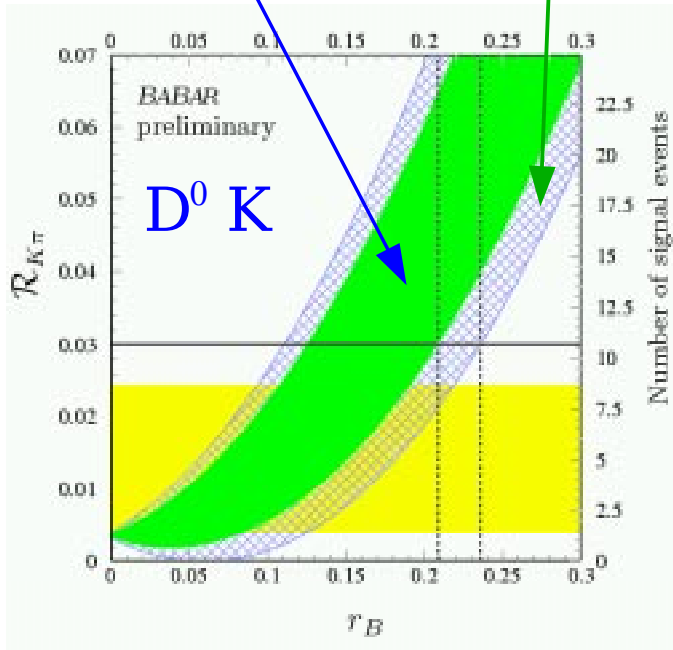
Nessuna evidenza di segnale
nel campione attuale



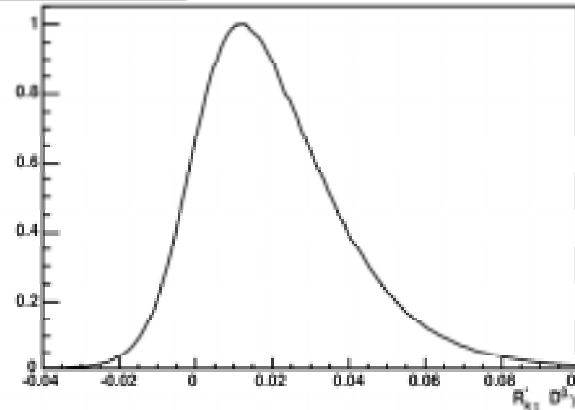
r_B dal metodo ADS

any δ_D
 $r_D \pm 1\sigma$
 $48^\circ < \gamma < 73^\circ$

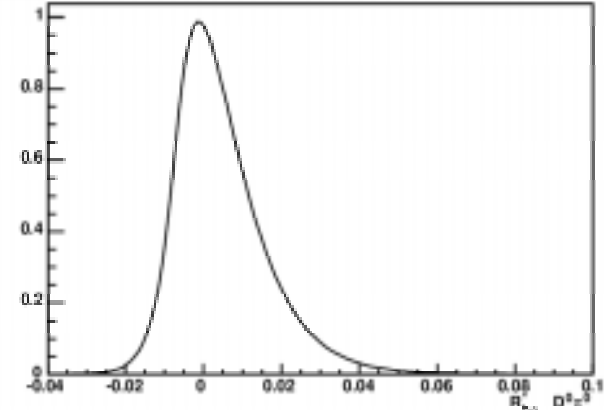
any γ



Likelihood for $D^0 \gamma$



Likelihood for $D^0 \pi^0$



$$r_B^{*2} = \frac{\mathcal{R}_{K\pi, D\pi^0}^* + \mathcal{R}_{K\pi, D\gamma}^*}{2} - r_D^2$$

Utilizzando un metodo bayesiano con una prior uniforme:

$$R_{ADS} < 0.030 \text{ @ } 90\% \text{ CL}$$

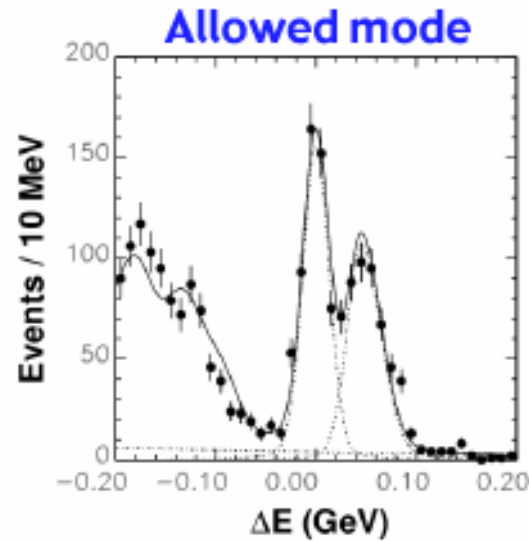
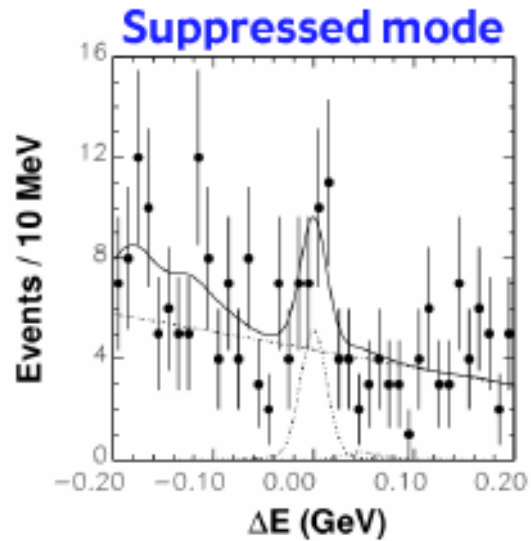
$$r_B < 0.23 \text{ @ } 90\% \text{ CL}$$

$$r_B^* < 0.16 \text{ @ } 90\% \text{ CL}$$

A_{ADS} non misurato



ADS: Belle



$$\mathcal{L} = 250 \text{ fb}^{-1}$$



Yield da fit in ΔE

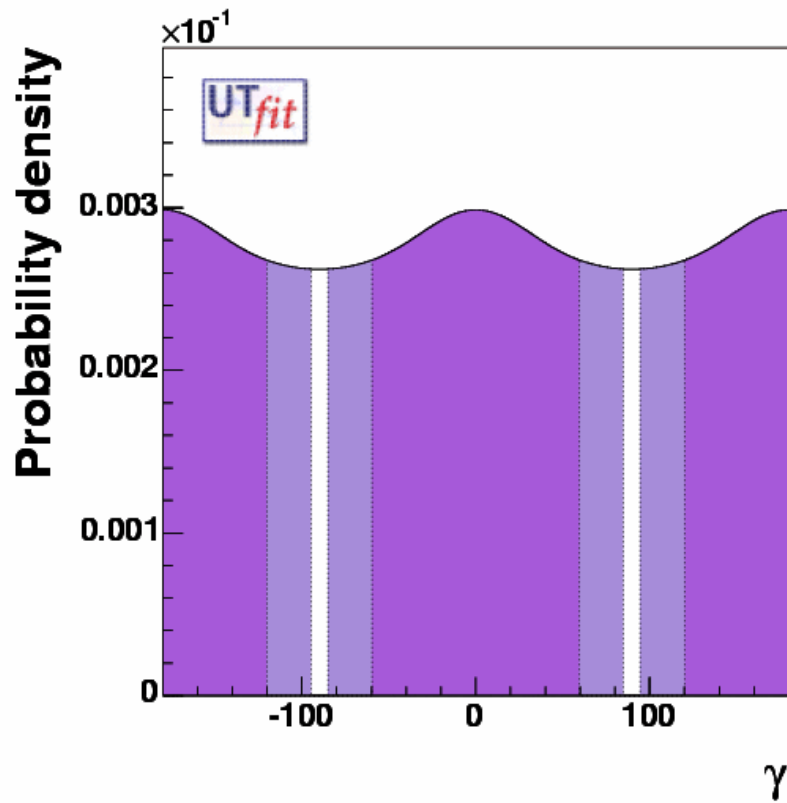
$$N([K^+ \pi^+]_D K^+) = 14.7 \pm 7.6$$

$$r_B < 0.28 \text{ @ } 90\% \text{ CL}$$

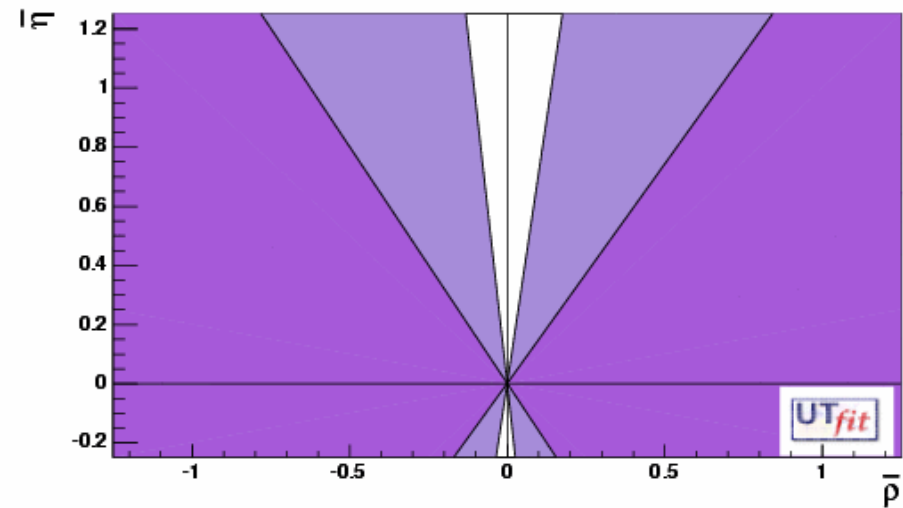
$$R_{\text{ADS}} < 0.047 \text{ @ } 90\% \text{ CL}$$

ADS: vincoli sul piano $\bar{\rho}-\bar{\eta}$

Combinando i risultati di BaBar e Belle:



68 % C.L. 95 % C.L.



Questo metodo è **fortemente limitato dalla statistica**
(molto sensibile al valore di r_B)

D⁰ → 3 corpi: analisi di Dalitz

hep-ph/0303187

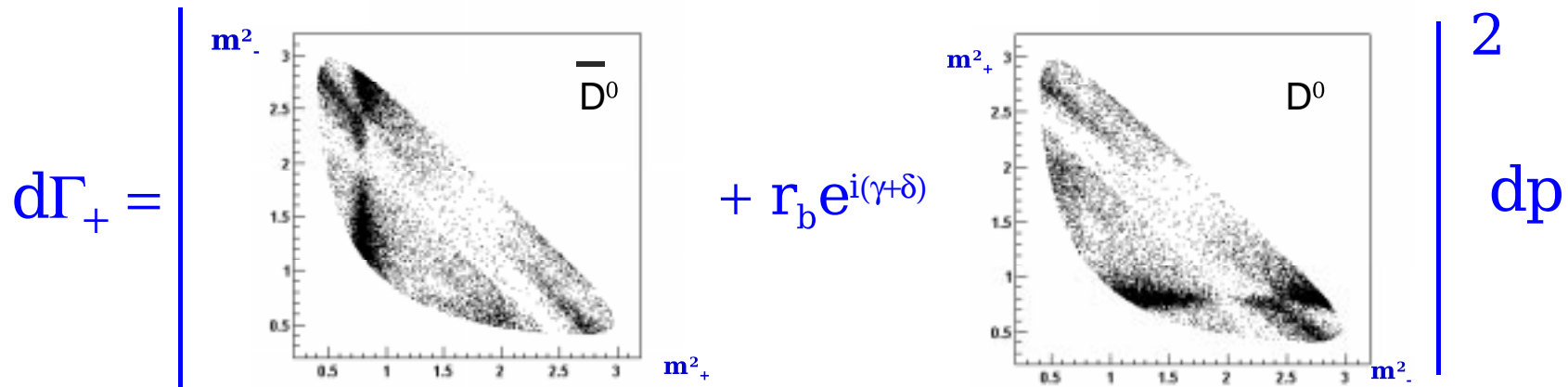
Interferenza nel Dalitz plot di $B^- \rightarrow D^0 K^-$ con $D^0/\bar{D}^0 \rightarrow K_S \pi^+ \pi^-$

$$M_-(m_-^2, m_+^2) = |\mathcal{A}(B^- \rightarrow D^0 K^-)| \left[f(m_-^2, m_+^2) + r_B e^{i(\delta_B - \gamma)} f(m_+^2, m_-^2) \right]$$

$$M_+(m_-^2, m_+^2) = |\mathcal{A}(B^+ \rightarrow \bar{D}^0 K^+)| \left[f(m_+^2, m_-^2) + r_B e^{i(\delta_B + \gamma)} f(m_-^2, m_+^2) \right]$$

f = ampiezza per i decadimenti del D⁰

m_{\pm} = massa(K_S π[±])



Dipendenza dal modello

$$d\hat{\Gamma}(B^- \rightarrow (K_S \pi^- \pi^+)_D K^-) = \left(A_{12,13}^2 + r_B^2 A_{13,12}^2 + 2r_B \mathcal{R}e \left[A_D(s_{12}, s_{13}) A_D^*(s_{13}, s_{12}) e^{-i(\delta_B - \gamma)} \right] \right) dp$$

A_D = ampiezza per i decadimenti del D^0

s_{ij} = massa($K_S \pi^\pm$)

A_D = somma di risonanze determinate da un campione di controllo ($D^{*+} \rightarrow D^0 \pi^+$ ad alta statistica)

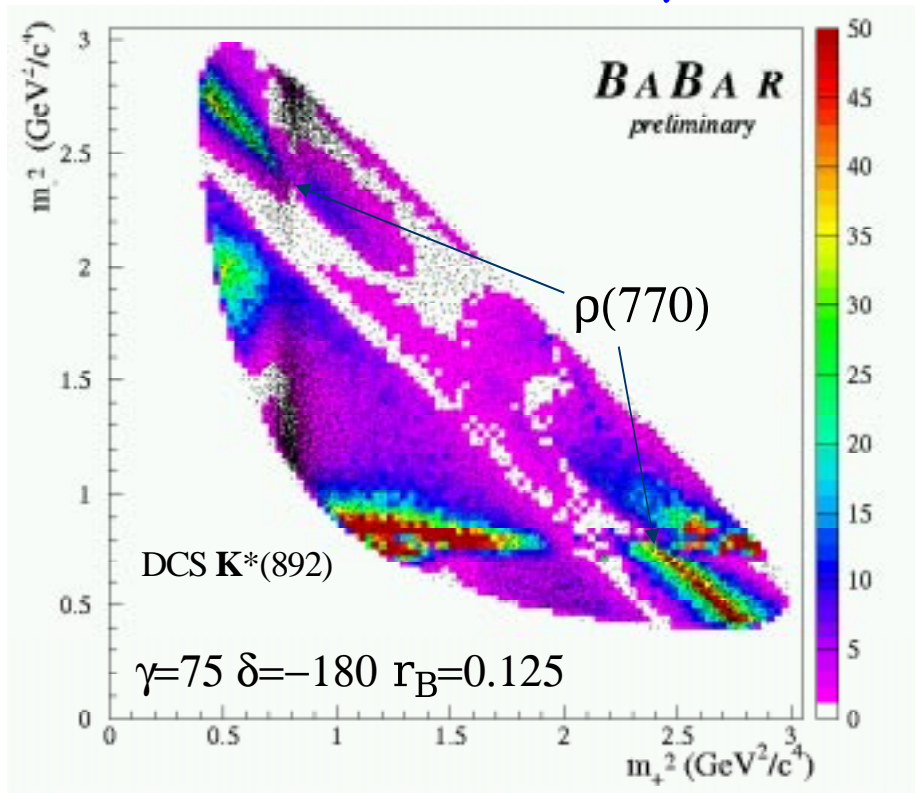
L' estrazione di γ è limitata asintoticamente dall' errore sistematico dovuto all' incertezza del modello per il Dalitz plot



Parametrizzazione del Dalitz

Parametrizzazione del Dalitz plot all'interno del formalismo isobarico

Sensibilità in γ



$$f = a_{nr} e^{i\phi_{nr}} + \sum a_r e^{i\phi_r} A(K_S \pi^- \pi^+ | r)$$

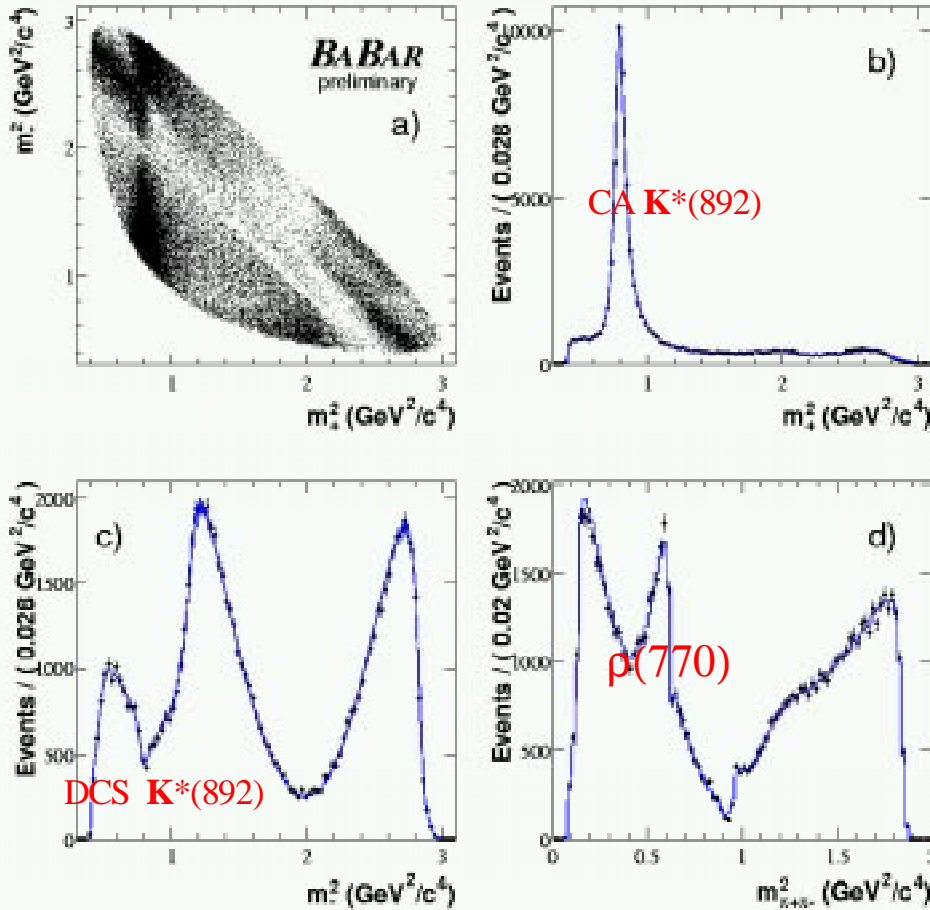
$A = \text{Breit-Wigner} \times \text{fattore di spin}$

Il Dalitz plot viene parametrizzato utilizzando un campione ad alta statistica di eventi





$D^0 \rightarrow K_S \pi^+ \pi^-$: Modello del Dalitz



Resonance	Amplitude	Phase (degrees)	Fraction (%)
$K^*(892)$	1.777 ± 0.018	131.0 ± 0.81	58.51
$\rho^0(770)$	1 (fixed)	0 (fixed)	22.33
$K^*(892)$ DCS	0.1789 ± 0.0080	-44.0 ± 2.4	0.59
$\omega(782)$	0.0391 ± 0.0016	114.8 ± 2.5	0.56
$f_0(980)$	0.469 ± 0.011	213.4 ± 2.2	5.81
$f_0(1370)$	2.32 ± 0.31	114.1 ± 4.4	3.39
$f_2(1270)$	0.915 ± 0.041	-22.0 ± 2.9	2.95
$K_0^*(1430)$	2.454 ± 0.074	-7.9 ± 2.0	8.37
$K_0^*(1430)$ DCS	0.350 ± 0.069	$-344. \pm 10.$	0.60
$K_2^*(1430)$	1.045 ± 0.045	-53.1 ± 2.6	2.70
$K_2^*(1430)$ DCS	0.074 ± 0.038	-98 ± 30	0.01
$K^*(1410)$	0.524 ± 0.073	-157 ± 10	0.39
$K^*(1680)$	0.99 ± 0.31	-144 ± 18	0.35
$\rho(1450)$	0.554 ± 0.097	$35 \pm 12.$	0.28
σ_1	1.346 ± 0.044	-177.5 ± 2.5	9.11
σ_2	0.292 ± 0.025	-206.8 ± 4.3	0.98
Non resonant	3.41 ± 0.48	-233.9 ± 5.0	6.82

σ_1 ($m=484 \pm 9$ MeV, $\Gamma=383 \pm 14$ MeV) e σ_2 ($m=1014 \pm 7$ MeV, $\Gamma=88 \pm 13$ MeV)

non presenti nel p.d.g. 2004

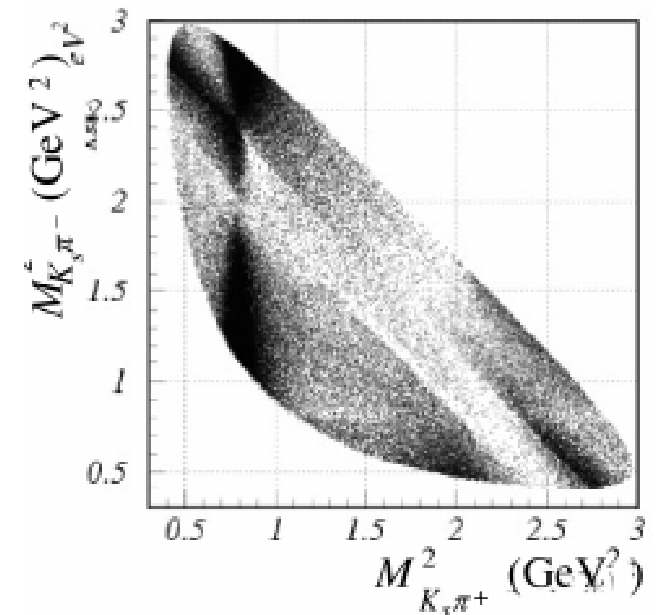
D – mixing e \mathcal{CP} nei decadimenti del D trascurati



$D^0 \rightarrow K_S \pi^+ \pi^-$: Belle

Resonance	Our fit		
	Amplitude	Phase, °	Fit fraction
$\sigma_1 K_S$	1.66 ± 0.11	218.0 ± 3.8	11%
$\rho(770) K_S$	1	0	21%
ωK_S	$(3.30 \pm 1.13) \cdot 10^{-2}$	114.3 ± 2.3	0.4%
$f_0(980) K_S$	0.405 ± 0.008	212.9 ± 2.3	4.8%
$\sigma_2 K_S$	0.31 ± 0.05	236 ± 11	0.9%
$f_2(1270) K_S$	1.36 ± 0.06	352 ± 3	1.5%
$f_0(1370) K_S$	0.82 ± 0.10	308 ± 8	0.9%
$K^*(892) \pi^+$	1.656 ± 0.012	137.6 ± 0.6	60%
$K^*(892) \pi^-$	0.149 ± 0.007	325.2 ± 2.2	0.5%
$K^*_0(1430) \pi^+$	1.96 ± 0.04	357.3 ± 1.5	5.8%
$K^*_0(1430) \pi^-$	0.30 ± 0.05	128 ± 8	0.1%
$K^*_2(1430) \pi^+$	1.32 ± 0.03	313.5 ± 1.8	2.8%
$K^*_2(1430) \pi^-$	0.21 ± 0.03	281.5 ± 9	0.07%
$K^*(1680) \pi^-$	2.56 ± 0.22	70 ± 6	0.4%
$K^*(1680) \pi^+$	1.02 ± 0.22	102 ± 11	0.07%
Non resonant	6.1 ± 0.3	146 ± 3	24%

parametrizzazione
all'interno del
formalismo isobarico



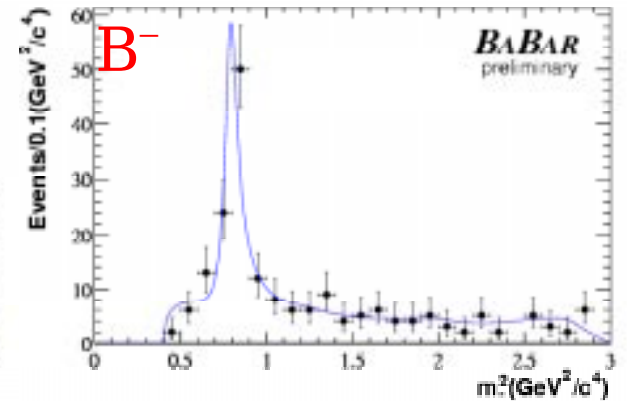
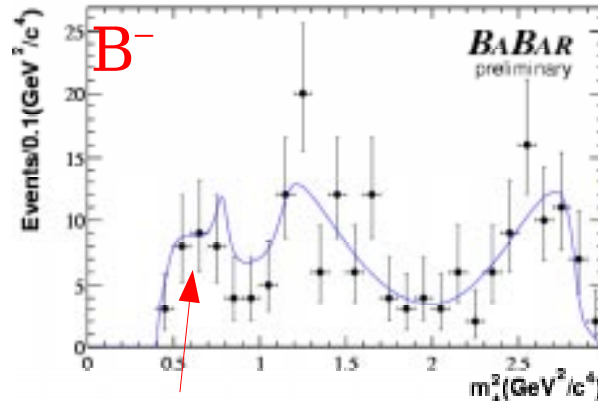
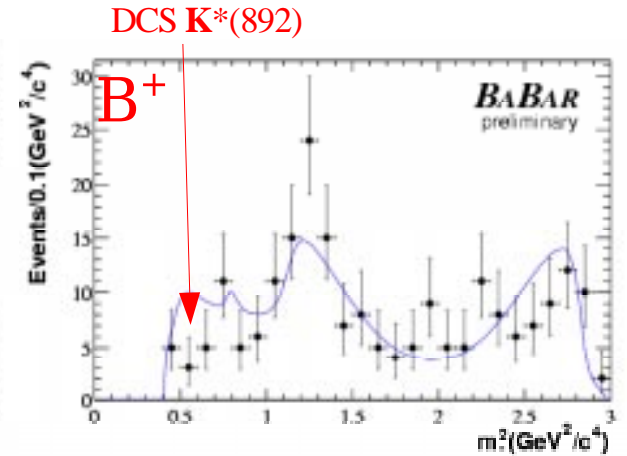
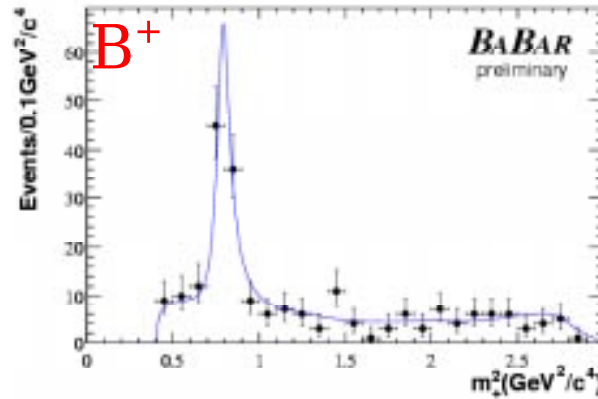
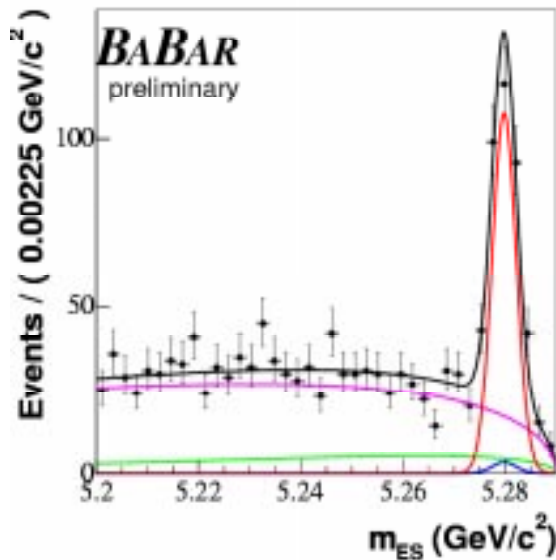


Proiezioni del Dalitz

Proiezioni del Dalitz plot per eventi con $m_{ES} > 5.272 \text{ GeV}/c^2$

$$N(BB) = 227 \times 10^6$$

$$N(B \rightarrow DK) = 292 \pm 21$$



$$N(B \rightarrow [D\pi^0]_{D^*} K) = 94 \pm 11$$

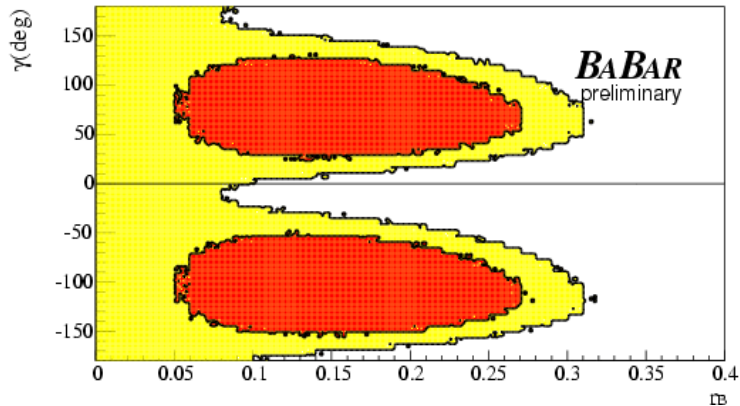
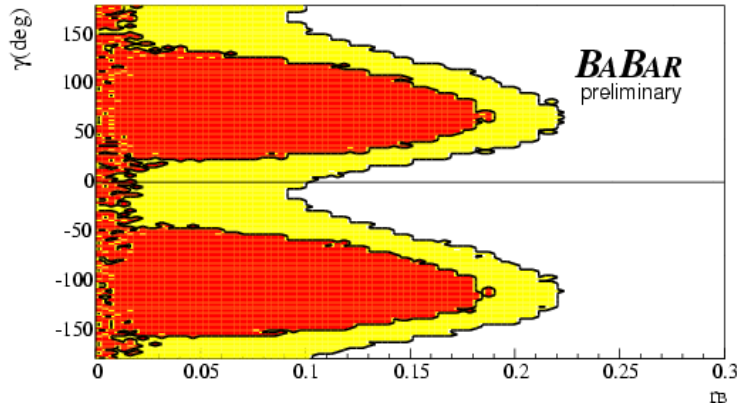
$$N(B \rightarrow [D\gamma^0]_{D^*} K) = 42 \pm 9$$

DCS $K^*(892)$

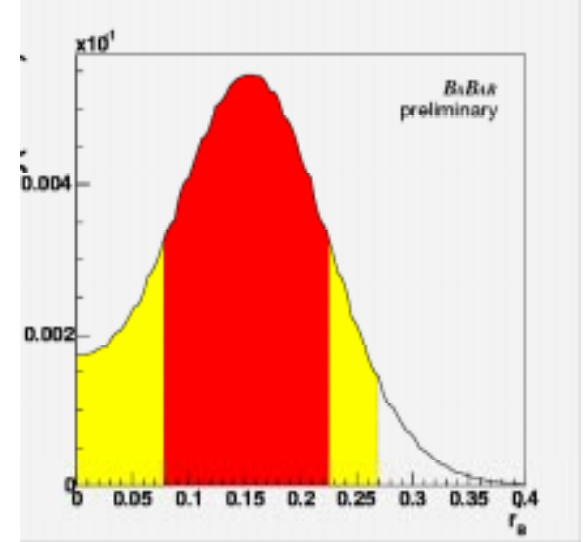
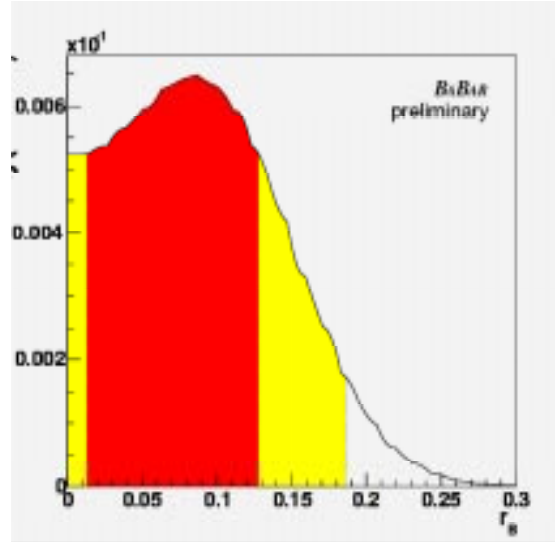
PDF di segnale + fondo



D⁰ Dalitz: r^(*)_B



PDF a posteriori con una prior uniforme



$$r_B^* = 0.155^{+0.070}_{-0.077}(\text{stat.}) \pm 0.020(\text{syst.}) \pm 0.040(\text{Dalitz model})$$

Includendo le incertezze sistematiche

$$r_B < 0.19 \text{ @ } 90 \% \text{ C.L.}$$

Regione di confidenza bayesiana

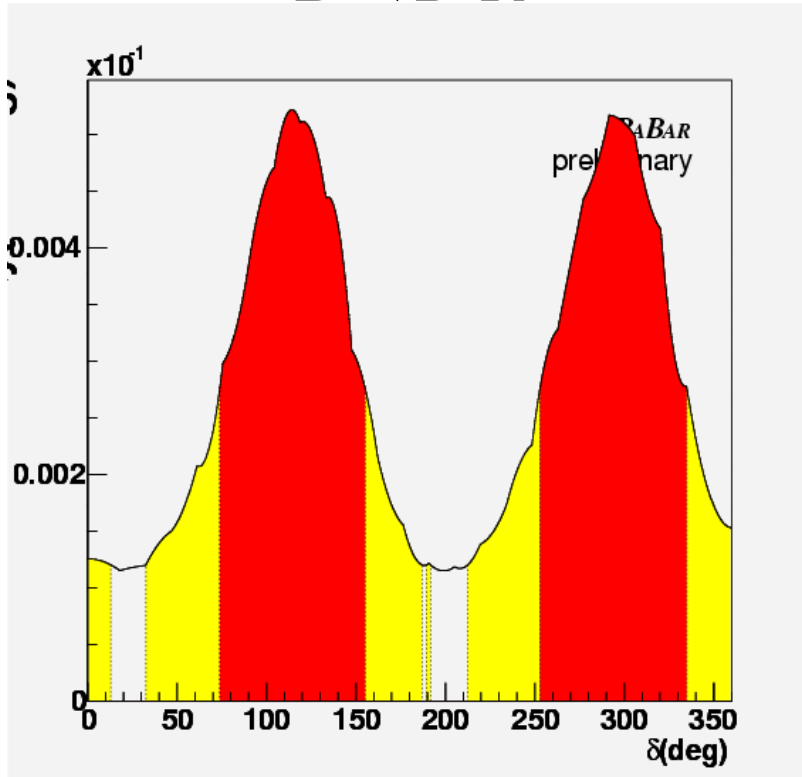
68 % C.L.

95 % C.L.

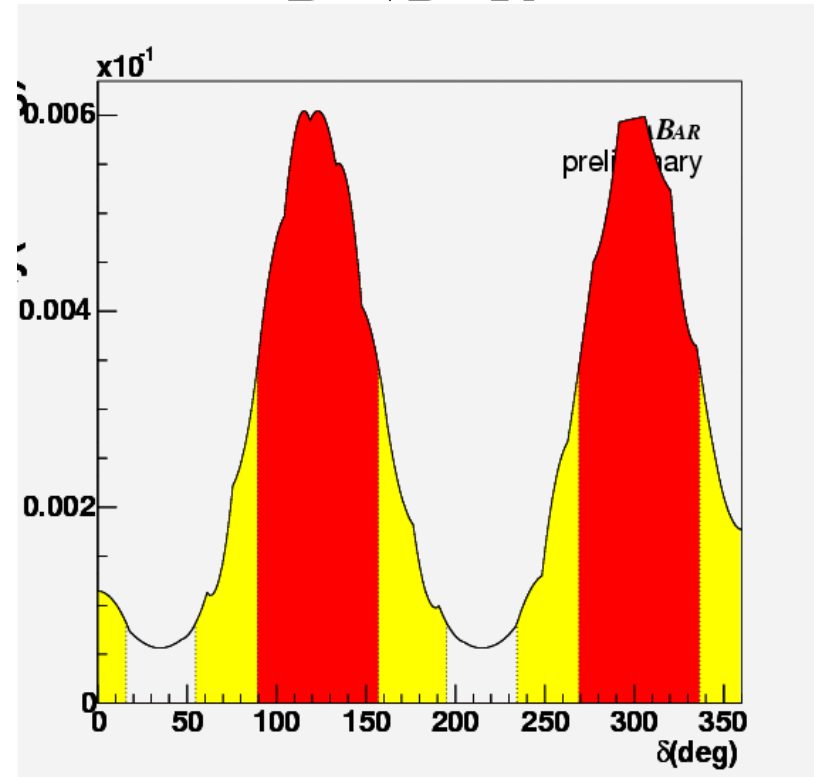


D⁰ Dalitz: $\delta^{(*)}_B$

B → D K



B → D* K



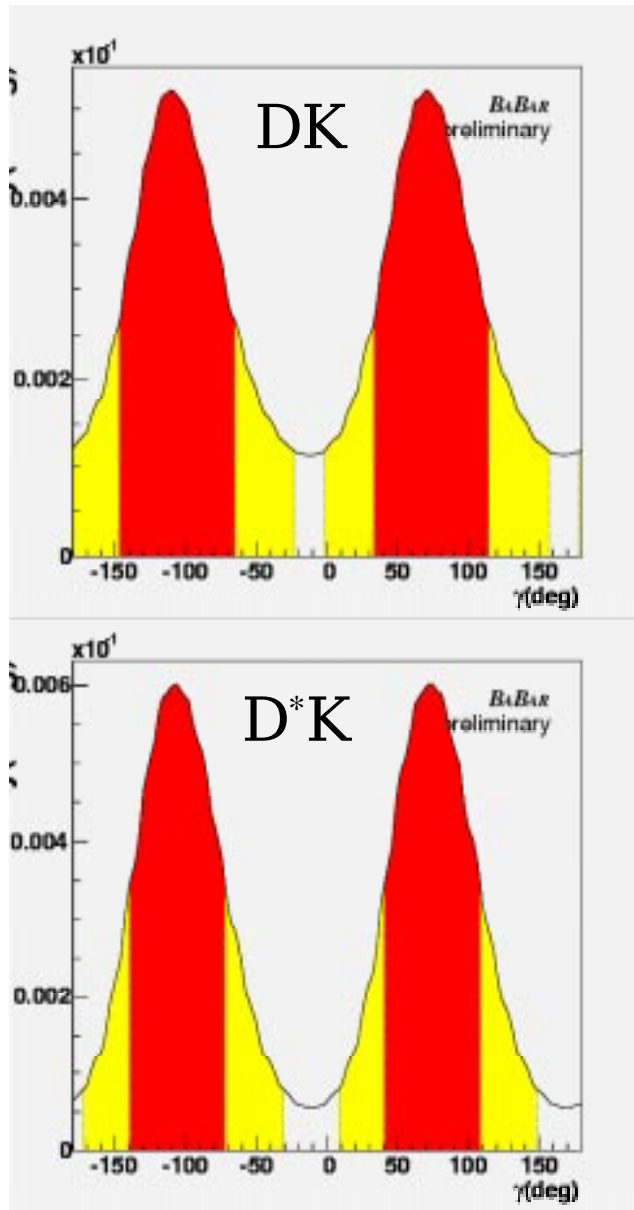
Intervalli disgiunti a causa dell'ambiguità $\gamma \rightarrow \gamma + \pi$, $\delta_B \rightarrow \delta_B + \pi$

$$\delta = 114^\circ \pm 41^\circ(\text{stat.}) \pm 8^\circ(\text{syst.}) \pm 10^\circ(\text{Dalitz Model})$$

$$\delta^* = 303^\circ \pm 34^\circ(\text{stat.}) \pm 14^\circ(\text{syst.}) \pm 10^\circ(\text{Dalitz Model})$$

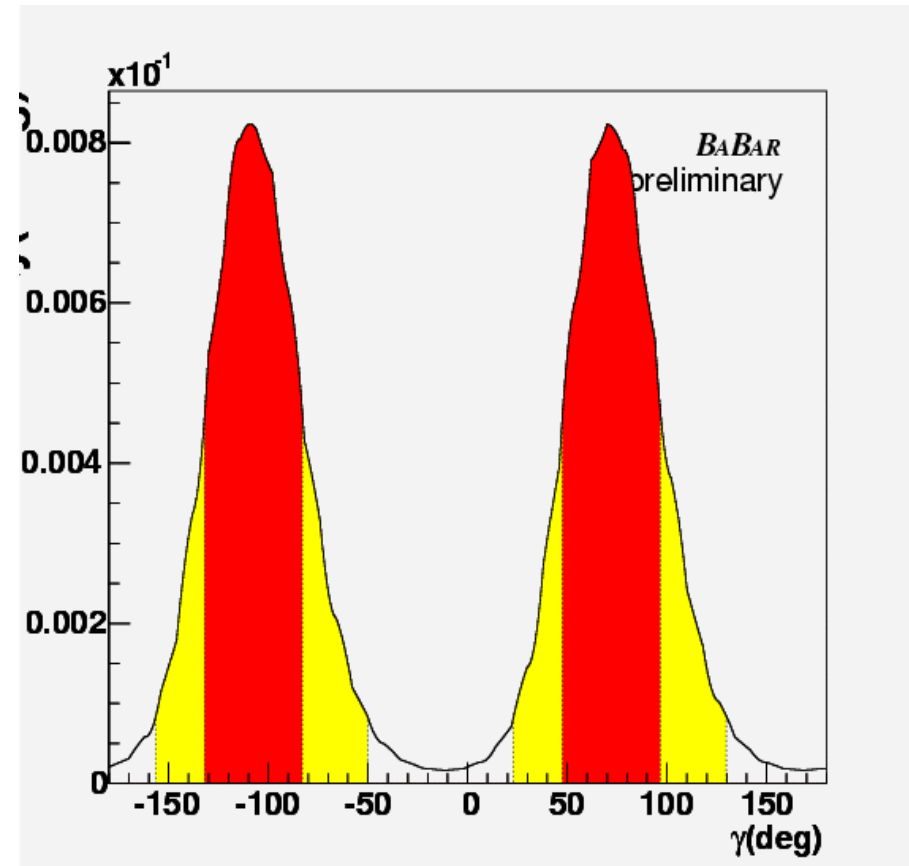


D⁰ Dalitz: γ



68 % C.L.

95 % C.L.

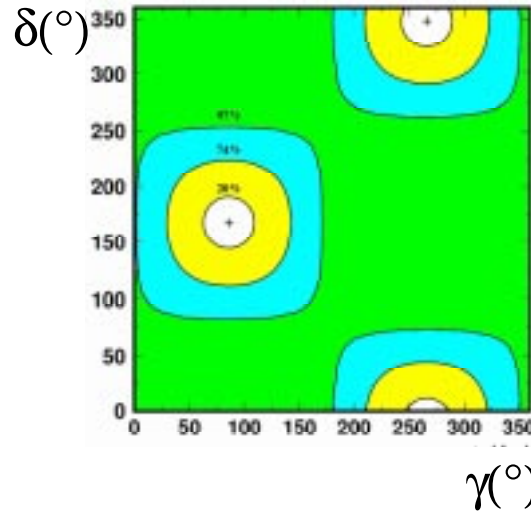
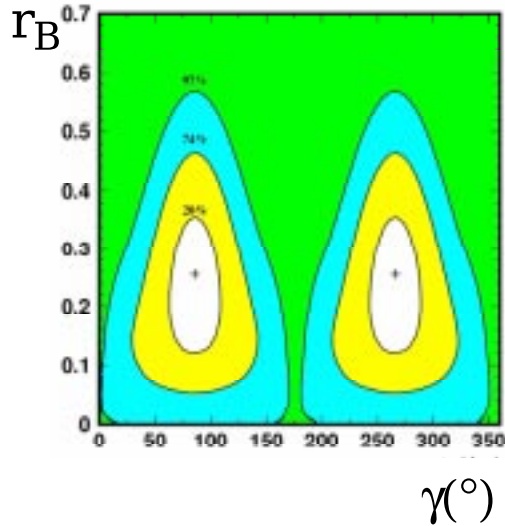


$$\gamma = 70^\circ \pm 26^\circ(\text{stat.}) \pm 10^\circ(\text{syst.}) \pm 10^\circ(\text{Dalitz model})$$



D⁰ Dalitz: Belle

$\mathcal{L} = 140 \text{ fb}^{-1}$



Errori stimati
utilizzando toy MC
ed un approccio
frequentista

$$\Gamma_B = 0.26^{+0.10}_{-0.14}(\text{stat.}) \pm 0.03(\text{syst.}) \pm 0.04(\text{Dalitz Model})$$

$$\Gamma_B^* = 0.20^{+0.19}_{-0.17}(\text{stat.}) \pm 0.02(\text{syst.}) \pm 0.04(\text{Dalitz Model})$$

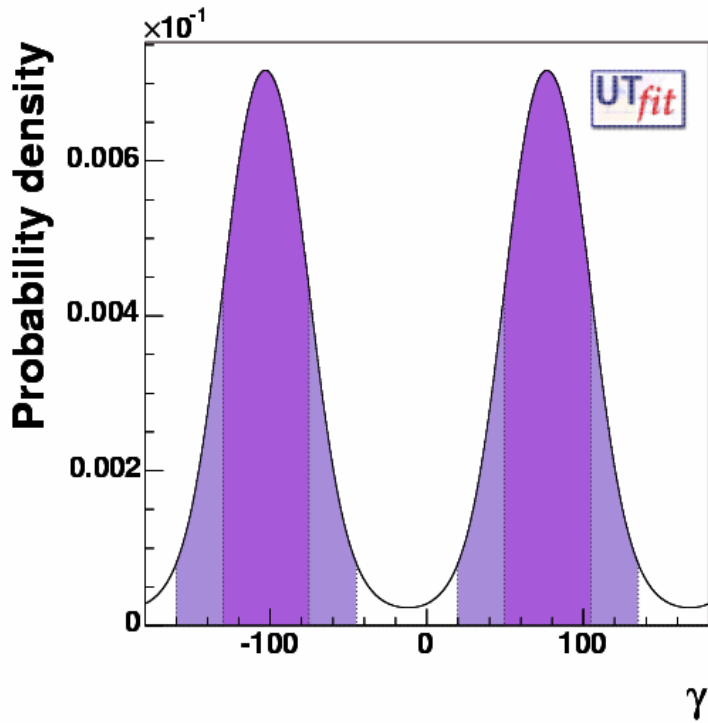
$$\delta = 168^\circ \pm 23^\circ(\text{stat.}) \pm 11^\circ(\text{syst.}) \pm 21^\circ(\text{Dalitz Model})$$

$$\delta^* = 302^\circ \pm 46^\circ(\text{stat.}) \pm 11^\circ(\text{syst.}) \pm 21^\circ(\text{Dalitz Model})$$

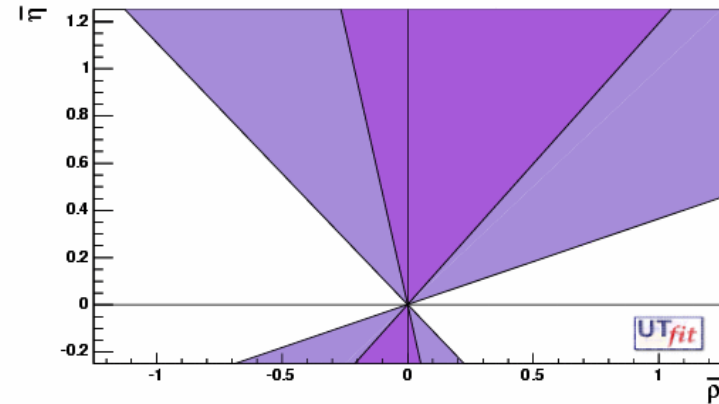
$$\gamma = 77^\circ \text{ }^{+17^\circ}_{-19^\circ}(\text{stat.}) \pm 13^\circ(\text{syst.}) \pm 11^\circ(\text{Dalitz model})$$

D⁰ Dalitz: vincoli sul piano $\bar{\rho}-\bar{\eta}$

Combinando i risultati di BaBar (solo D K) e Belle (D K e D* K):



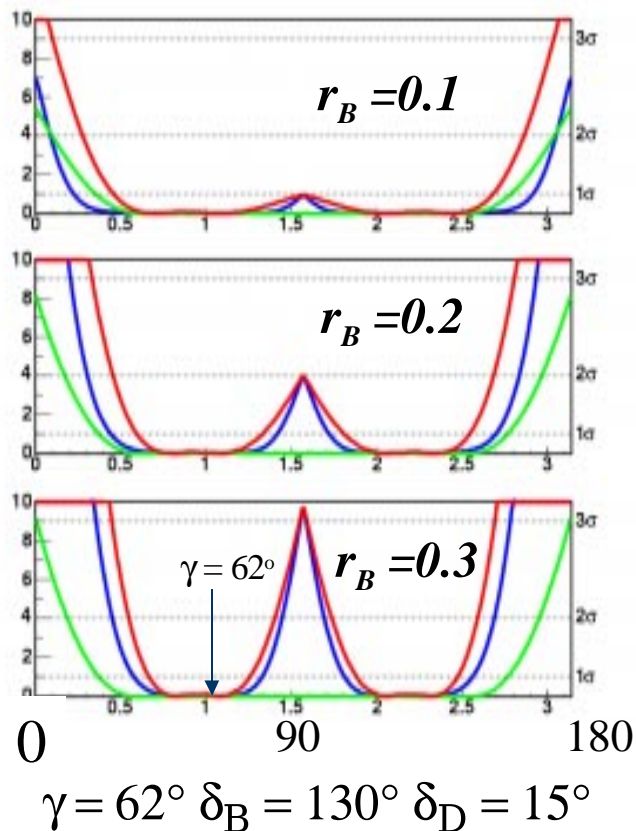
68 % C.L. 95 % C.L.



Questo metodo fornisce una
prima misura di γ

Il ruolo di r_B

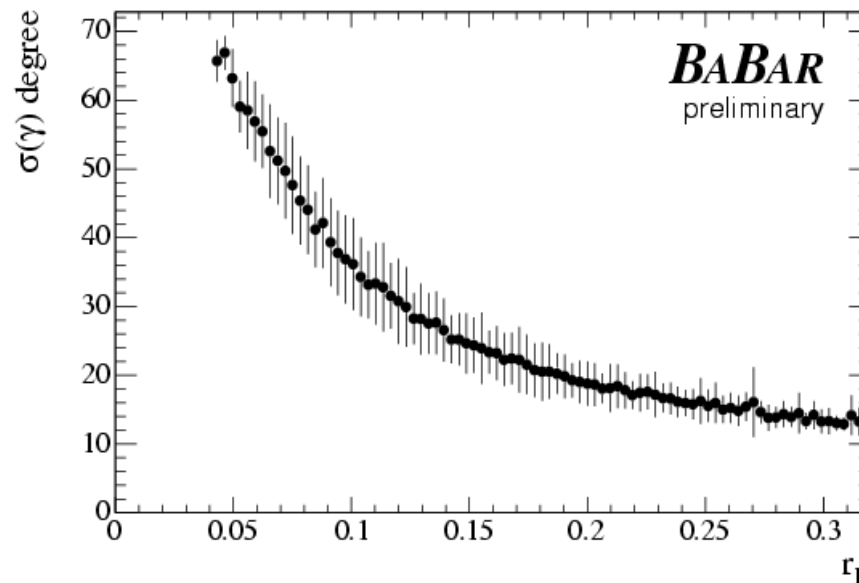
Sensibilità in γ con 500 fb^{-1}
(per un solo canale)



GLW ADS GLW+ADS

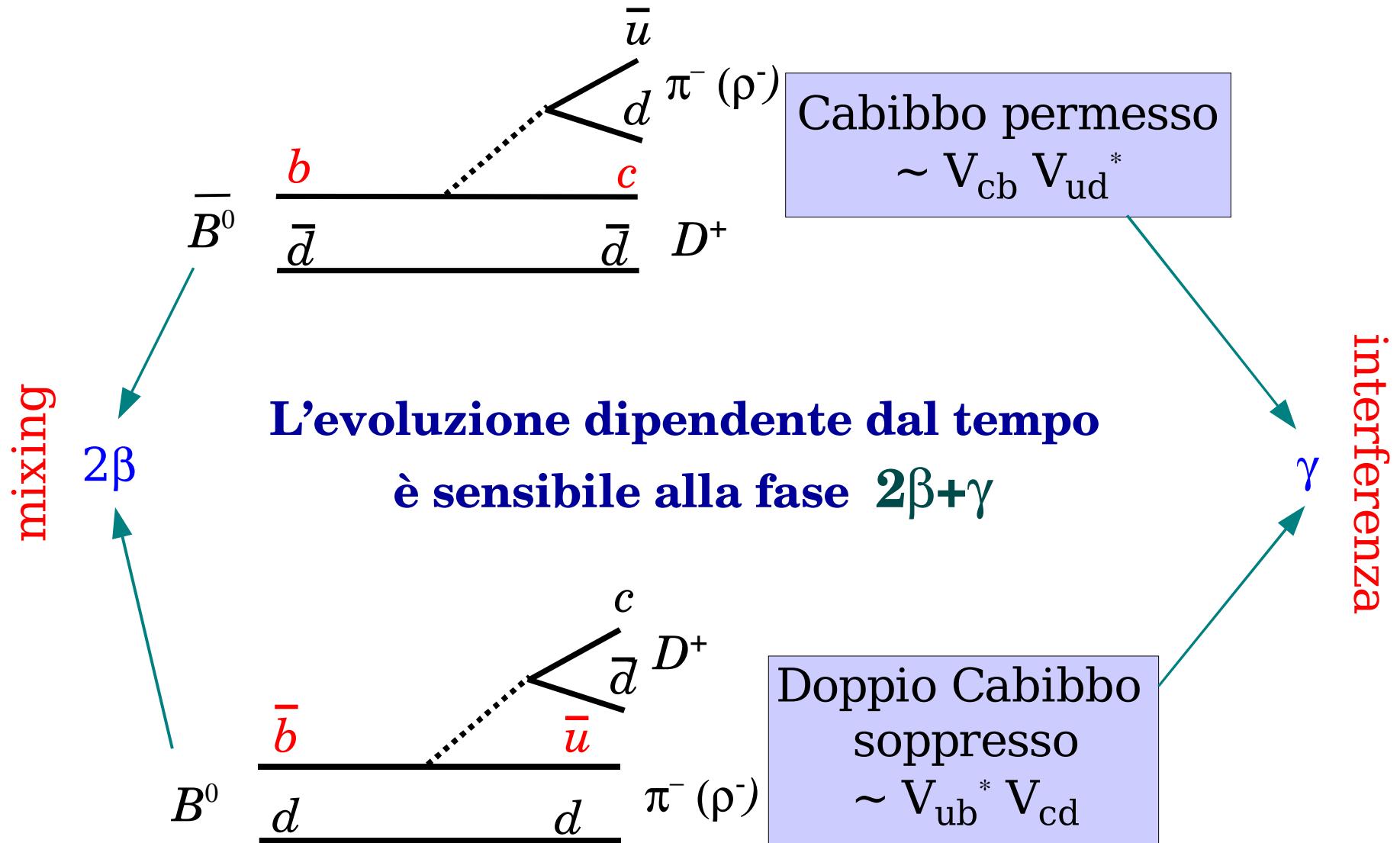
GLW $R_{\pm} \approx 1 + r_B$ $A_{\pm} \approx r_B$
 ADS $R_{\text{ADS}} \approx r_B^2$ $A_{\text{ADS}} \approx 1$

D^0 Dalitz



La misura di γ può essere
ottenuta dalla **combinazione**
di molti modi

La fase $(2\beta+\gamma)$ in $B \rightarrow D^{(*)}\pi(\rho)$



Assunzioni teoriche

- Lo stato finale non è autostato di CP. Due stati finali: $A_{D^-\pi^+(\rho)}(t)$ e $A_{D^+\pi^-(\rho)}(t)$.
- Si deve valutare il parametro:

$$\lambda = r e^{-i(2\beta+\gamma-\delta)} = \frac{A(B^0 \rightarrow D^{(*)+} \pi^-(\rho))}{A(\overline{B^0} \rightarrow D^{(*)+} \pi^-(\rho))} e^{-i2\beta}$$

$$r \approx \left| \frac{V_{ub}^* V_{cd}}{V_{ud}^* V_{cb}} \right| \approx 0.02$$



Piccola asimmetria di CP

- Il canale doppio Cabibbo soppresso (e quindi r) non è misurabile. Si utilizza quindi il canale $B^0 \rightarrow D_s^+ \pi^-(\rho^-)$ assumendo che:

Valga la simmetria SU(3)

I diagrammi con scambio di W siano trascurabili

Il ruolo di $B^0 \rightarrow D_S^{(*)} \pi$

$B^0 \rightarrow D^{(*)+} \pi^-$

Diagramma ad albero

Diagramma con scambio di W

SU(3)

$B^0 \rightarrow D_S^{(*)+} \pi^-$

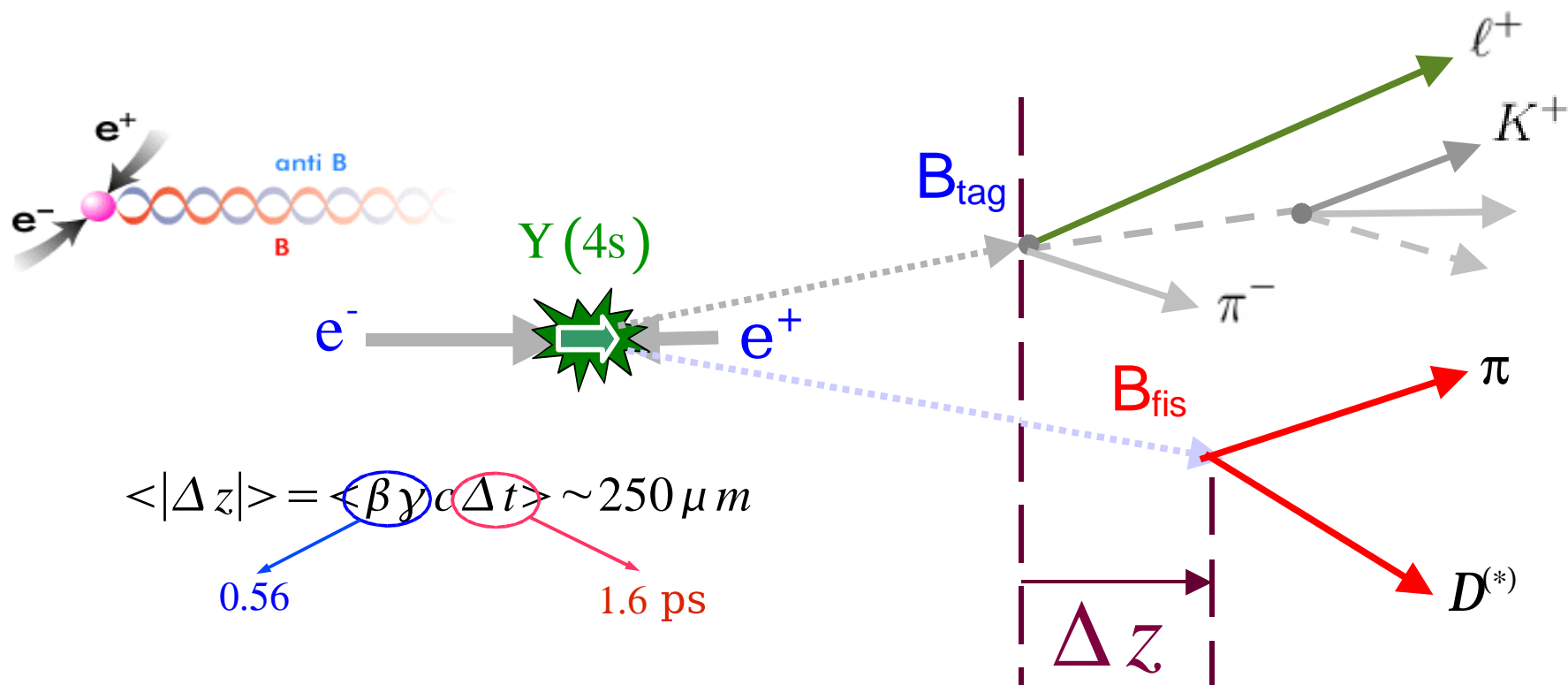
Solo diagramma ad albero

$$r^{(*)} = \sqrt{\frac{\text{Br}(B^0 \rightarrow D_S^{(*)+} \pi^-) f_{D^{(*)}}}{\text{Br}(B^0 \rightarrow D_S^{(*)-} \pi^+) f_{D_S^{(*)}}}}$$

$r = 0.019 \pm 0.004$
 $r^* = 0.017^{+0.005}_{-0.007}$

Si assume un **errore teorico** del **30%**

Analisi dipendente dal tempo



Viene identificato il flavor di uno dei due B (B_{tag}) con una ricostruzione parziale diverse categorie in base agli elementi dei prodotti di decadimento:

- Un leptone: categoria leptonica
- Un kaone: categoria kaonica
- Inclusivo: categoria other

Parametrizzazione

O.Long, M.Baak, R.N. Cahn, D.Kirkby
SLAC-PUB-9687, hep-ex/0303030

La rate di decadimento dipendente dal tempo:

$$\Gamma(B \rightarrow D^{(*)} \pi) \propto 1 + \xi_m \cos(\Delta m \Delta t) - [\xi_1 a + \xi_m c + \xi_1 \xi_m b] \sin(\Delta m \Delta t)$$

$\xi_m = 1(-1)$ per i canali Cabibbo favoriti (doppio Cabibbo soppressi)

$\xi_1 = 1(-1)$ per B_{tag} identificati come B^0 (\bar{B}^0)

$$a = 2r \sin(2\beta + \gamma) \cos \delta$$

$$b = 2r' \sin(2\beta + \gamma) \cos \delta'$$

$$c = 2 \cos(2\beta + \gamma) (r \sin \delta - r' \sin \delta')$$

$\xi_m = 1$	$\xi_m = -1$
$B^0 \rightarrow D^- \pi^+$	$B^0 \rightarrow D^+ \pi^-$
$\bar{B}^0 \rightarrow D^+ \pi^-$	$\bar{B}^0 \rightarrow D^- \pi^+$

r' , δ' sono il rapporto e la differenza fra le ampiezze $b \rightarrow u$ e $b \rightarrow c$ nel decadimento del B_{tag}

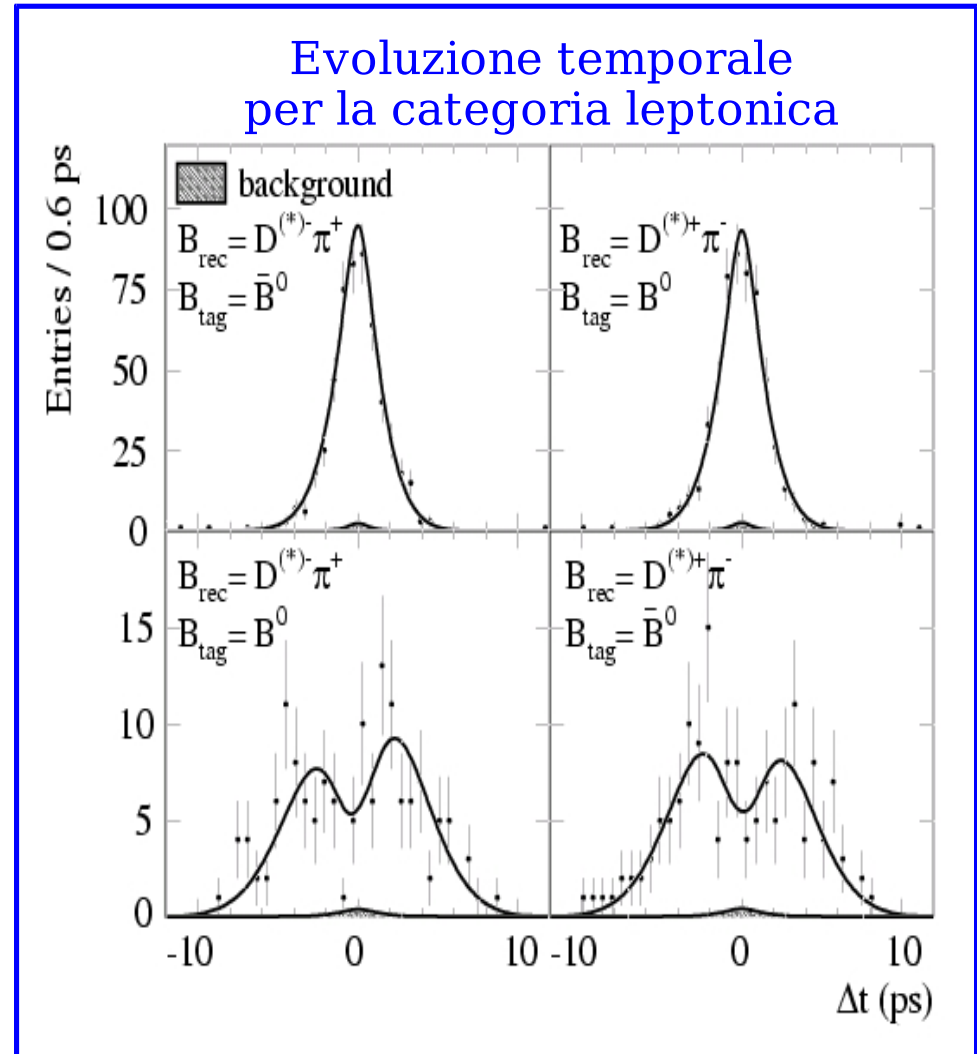
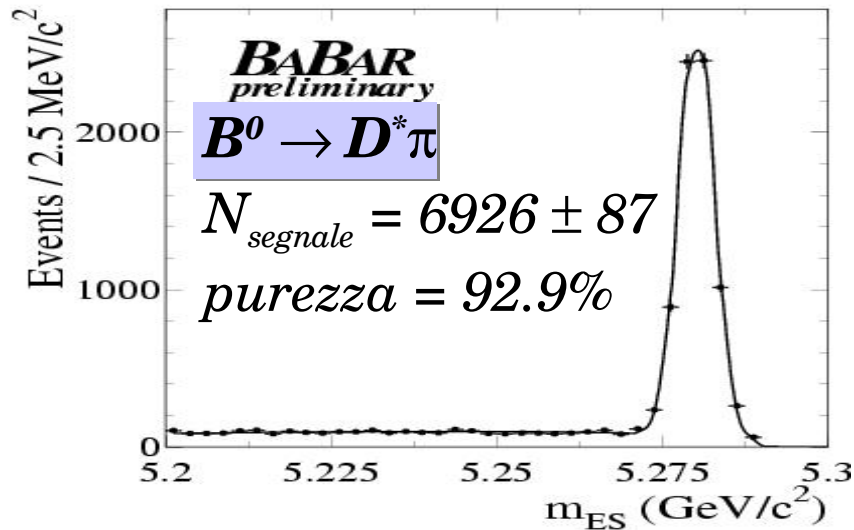
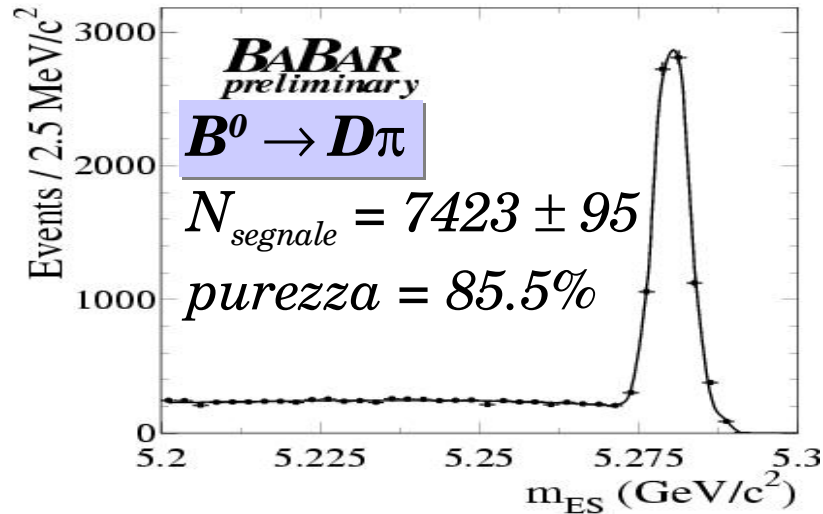
$r' = 0$ negli eventi con tag leptonic
(per i quali non esiste l'ampiezza soppressa).

Per la misura di $\sin(2\beta + \gamma)$ si utilizzano soltanto a e c_{lep} (categoria leptonica)



Ricostruzione esclusiva

$\mathcal{L}=105 \text{ fb}^{-1}$



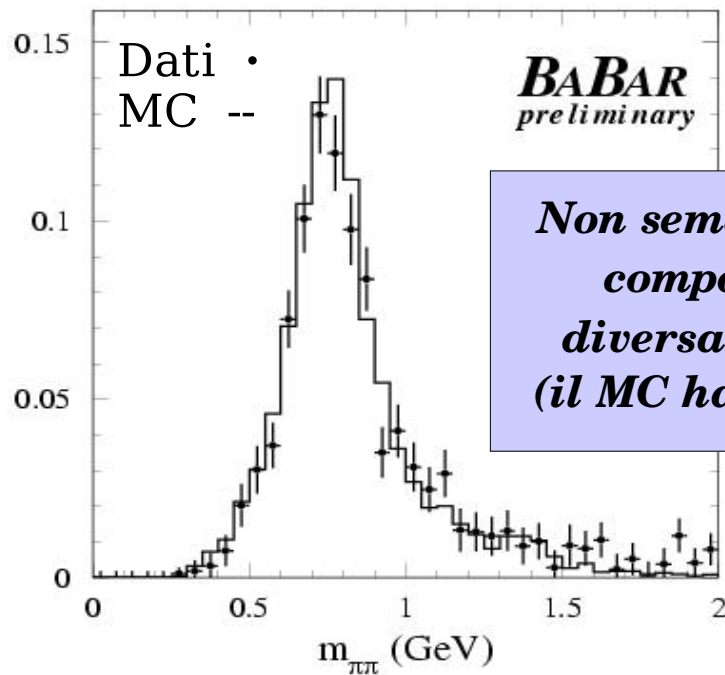


$\sin(2\beta+\gamma)$ da $B \rightarrow D \rho$

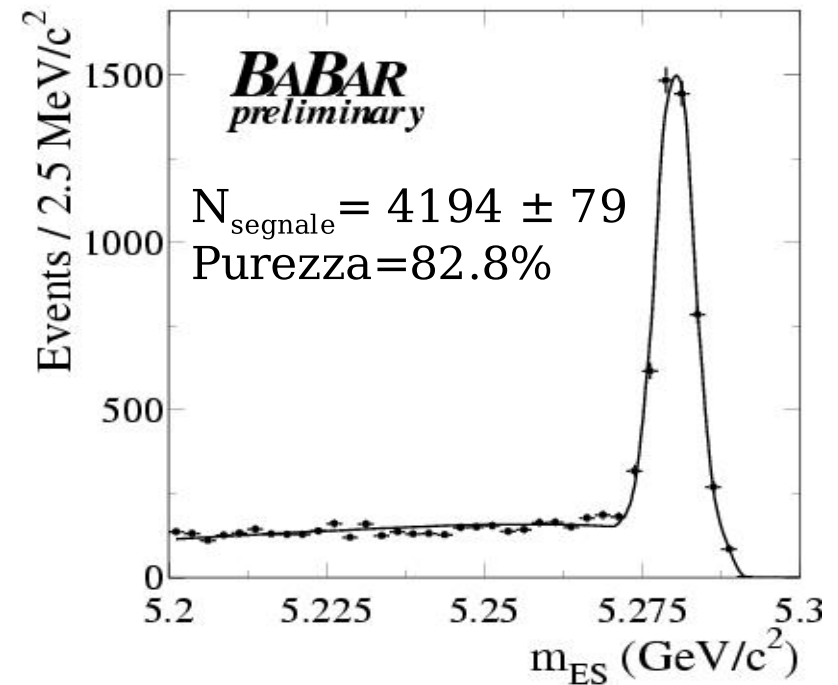
$\lambda = r e^{-i(2\beta+\gamma-\delta)}$ dipende dalla struttura della massa invariante $\pi\pi^0$

Se è presente **soltanto la componente ρ** nella regione della massa invariante $\pi\pi^0$ selezionata:

- Stessa evoluzione temporale degli stati $D^{(*)}\pi$ (sensibile a $\sin(2\beta+\gamma)$)
- Stessa tecnica di analisi



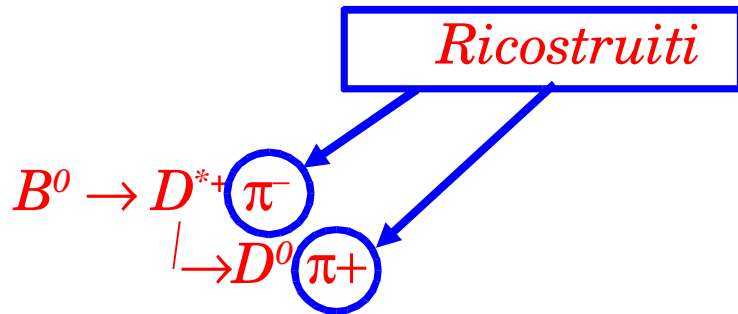
*Non sembra ci sia
componente
diversa dalla ρ
(il MC ha solo la ρ)*





Ricostruzione parziale

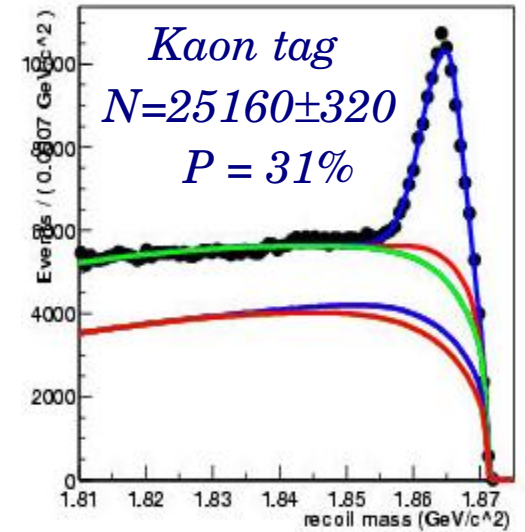
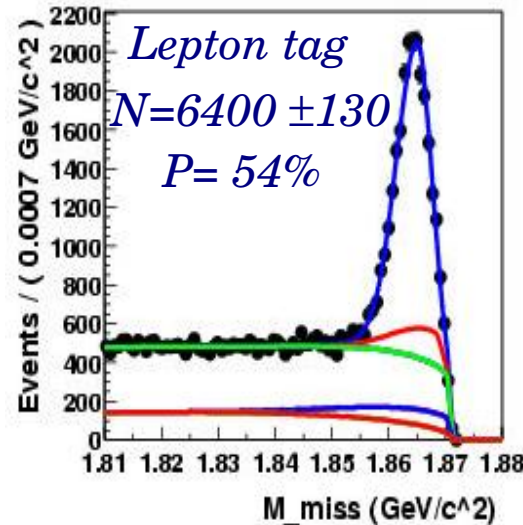
$\mathcal{L}=166 \text{ fb}^{-1}$
([hep-ex/0408038](#))



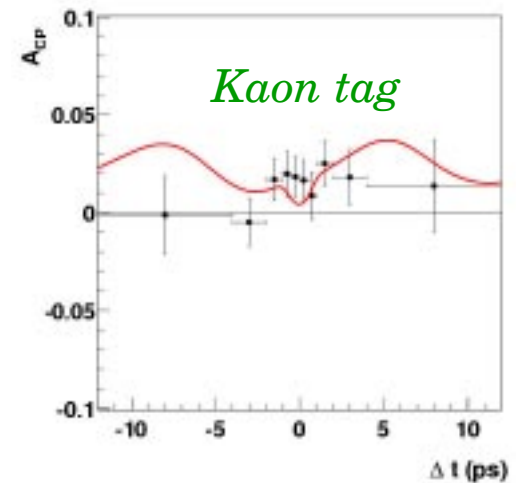
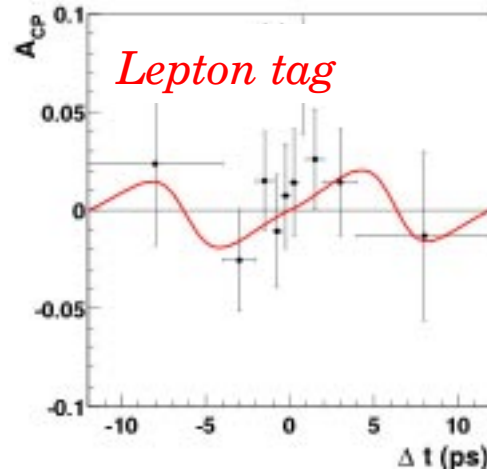
Vantaggio: non si perde efficienza per la ricostruzione del D^0

m_{miss} = massa invariante del D

$$A_{CP} = \frac{N_{B_{tag}^0} - N_{\bar{B}_{tag}^0}}{N_{B_{tag}^0} + N_{\bar{B}_{tag}^0}}$$



$D^* \rho$ Combinatorial BB Peaking BB Continuum





$\sin(2\beta+\gamma)$: risultati

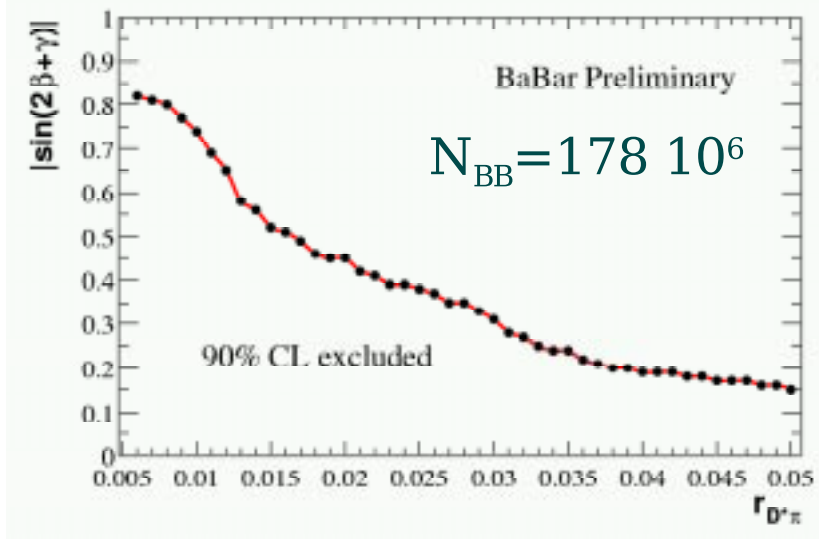
Ricostruzione esclusiva di $D^-\rho^+, D^-\pi^+, D^{*-}\pi^+$

$N_{\text{BB}} = 110 \cdot 10^6$

$$\begin{array}{ll}
 a^{D\pi} = -0.032 \pm 0.031 \text{ (stat.)} \pm 0.020 \text{ (syst.)} & c_{lep}^{D\pi} = -0.059 \pm 0.055 \text{ (stat.)} \pm 0.033 \text{ (syst.)} \\
 a^{D^*\pi} = -0.049 \pm 0.031 \text{ (stat.)} \pm 0.020 \text{ (syst.)} & c_{lep}^{D^*\pi} = +0.044 \pm 0.054 \text{ (stat.)} \pm 0.033 \text{ (syst.)} \\
 a^{D\rho} = -0.005 \pm 0.044 \text{ (stat.)} \pm 0.021 \text{ (syst.)} & c_{lep}^{D\rho} = -0.147 \pm 0.074 \text{ (stat.)} \pm 0.035 \text{ (syst.)}
 \end{array}$$

Risonanze $\pi\pi$ diverse dalla ρ sono incluse nell'errore sistematico.

Ricostruzione parziale di $D^{*-}\pi^+$



$$\begin{array}{l}
 a^\mu = 2r^\mu \sin(2\beta + \gamma) \cos \delta^\mu \\
 c_{lep}^\mu = 2 \cos(2\beta + \gamma) (r^\mu \sin \delta^\mu - r'_{lep} \sin \delta'_{lep})
 \end{array}$$



La sensibilità è data dal parametro

$$r = \frac{|A(\bar{B}^0 \rightarrow \bar{D}^{(*)0} \bar{K}^0)|}{|A(\bar{B}^0 \rightarrow D^{(*)0} \bar{K}^0)|}$$

Ricerca della **transizione $b \rightarrow u$**
(canale self-tagging)

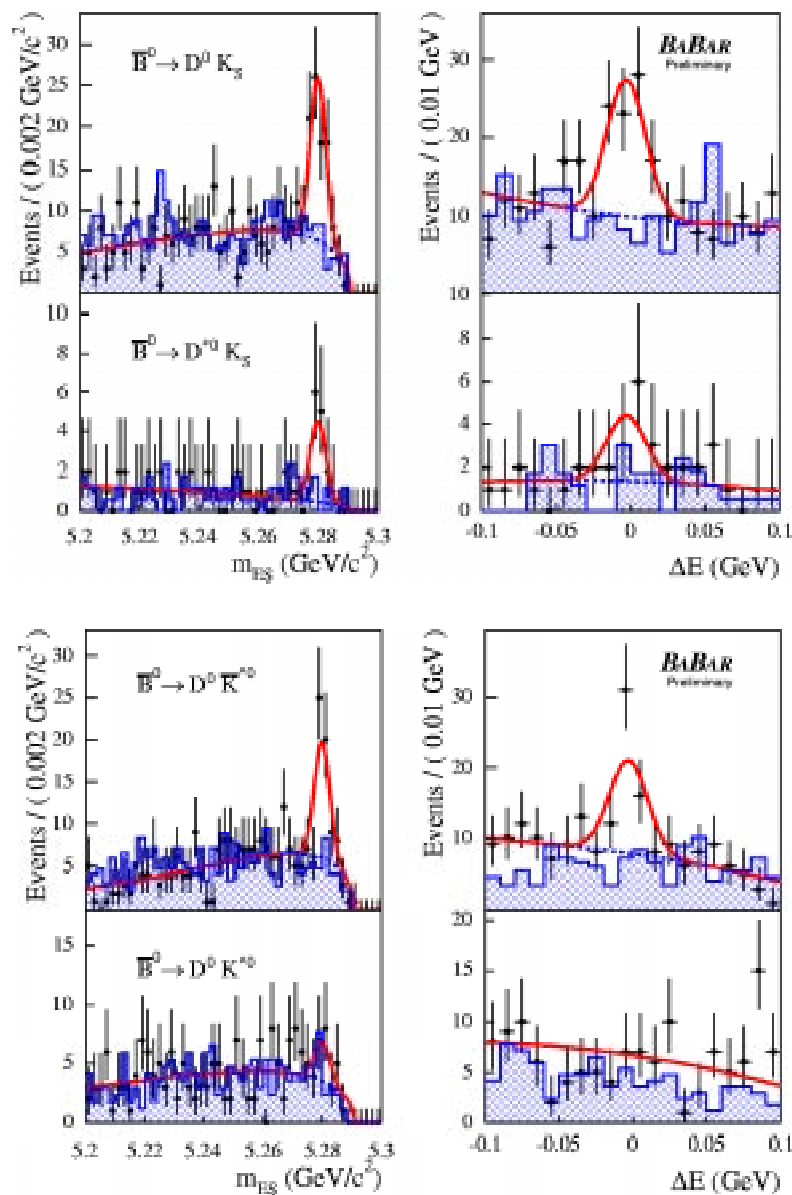


Lo scopo finale è estrarre **$\sin(2\beta+\gamma)$**
attraverso un'analisi **time-dependent**

$$\begin{aligned} \mathcal{B}(B \rightarrow D^0 \bar{K}^0) &= (6.2 \pm 1.2 \pm 0.4) \times 10^{-5} \\ \mathcal{B}(B \rightarrow D^{*0} \bar{K}^0) &= (4.5 \pm 1.9 \pm 0.5) \times 10^{-5} \\ \mathcal{B}(\bar{B}^0 \rightarrow D^0 \bar{K}^{*0}) &= (6.2 \pm 1.4 \pm 0.6) \times 10^{-5} \\ \mathcal{B}(\bar{B}^0 \rightarrow \bar{D}^0 \bar{K}^{*0}) &= (1.1 \pm 1.1 \pm 1.2) \times 10^{-5} \end{aligned}$$

$$\text{Br}(\bar{B}^0 \rightarrow \bar{D}^0 \bar{K}^{*0}) < 4.1 \cdot 10^{-5} @ 90\% \text{ C.L.}$$

Assenza di segnale





$\sin(2\beta+\gamma)$: Belle

Lepton tag

$$\mathcal{L} = 250 \text{ fb}^{-1}$$

$$\begin{aligned}
P(B^0 \rightarrow D^{(*)+}\pi^-) &= \frac{1}{8\tau_{B^0}} e^{-|\Delta t|/\tau_{B^0}} [1 - C \cos(\Delta m \Delta t) - S^+ \sin(\Delta m \Delta t)] \\
P(B^0 \rightarrow D^{(*)-}\pi^+) &= \frac{1}{8\tau_{B^0}} e^{-|\Delta t|/\tau_{B^0}} [1 + C \cos(\Delta m \Delta t) - S^- \sin(\Delta m \Delta t)] \\
P(\bar{B}^0 \rightarrow D^{(*)+}\pi^-) &= \frac{1}{8\tau_{B^0}} e^{-|\Delta t|/\tau_{B^0}} [1 + C \cos(\Delta m \Delta t) + S^+ \sin(\Delta m \Delta t)] \\
P(\bar{B}^0 \rightarrow D^{(*)-}\pi^+) &= \frac{1}{8\tau_{B^0}} e^{-|\Delta t|/\tau_{B^0}} [1 - C \cos(\Delta m \Delta t) + S^- \sin(\Delta m \Delta t)]
\end{aligned}$$

- $C = (1 - R_{D^{*\pi}}^2)/(1 + R_{D^{*\pi}}^2) \simeq 1$
- $S^\pm = -2R_{D^{*\pi}} \sin(2\phi_1 + \phi_3 \pm \delta_{D^{*\pi}})$
- $R_{D^{*\pi}} = \frac{|\text{suppressed}|}{|\text{favoured}|} \sim 0.02$

Per **estrarre** il valore di S^\pm si **fissano** i valori di τ_B e Δm_B ai valori delle **medie mondiali**.

$$S^+ = 0.035 \pm 0.041 \pm 0.018$$

$$S^- = 0.026 \pm 0.040 \pm 0.018$$

Assumendo $\delta=0$ o π :

$$2 R_{D^{*\pi}} \sin(2\beta+\gamma) = 0.031 \pm 0.028 \pm 0.013$$

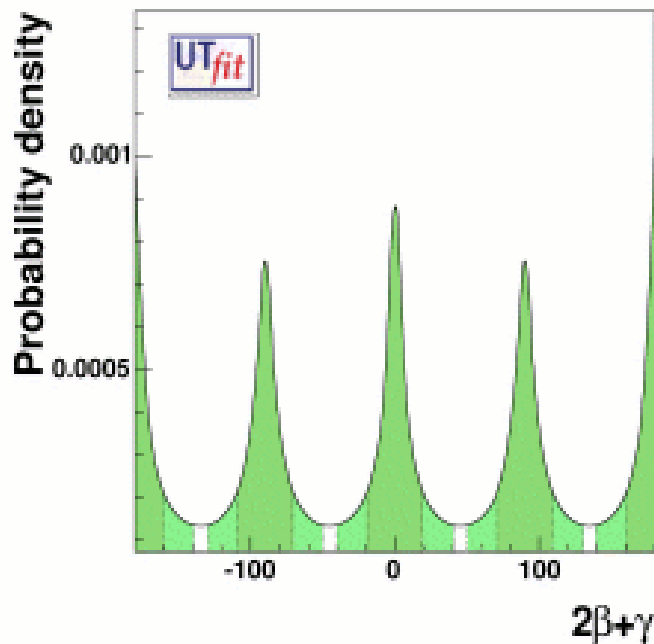
$\sin(2\beta+\gamma)$: vincoli sul piano $\bar{\rho}-\bar{\eta}$

Da $B^0 \rightarrow D^{\pm(*)} \pi^\mp$

$$a^{(*)} = 2r^{(*)} \sin(2\beta+\gamma) \cos(\delta^{(*)})$$

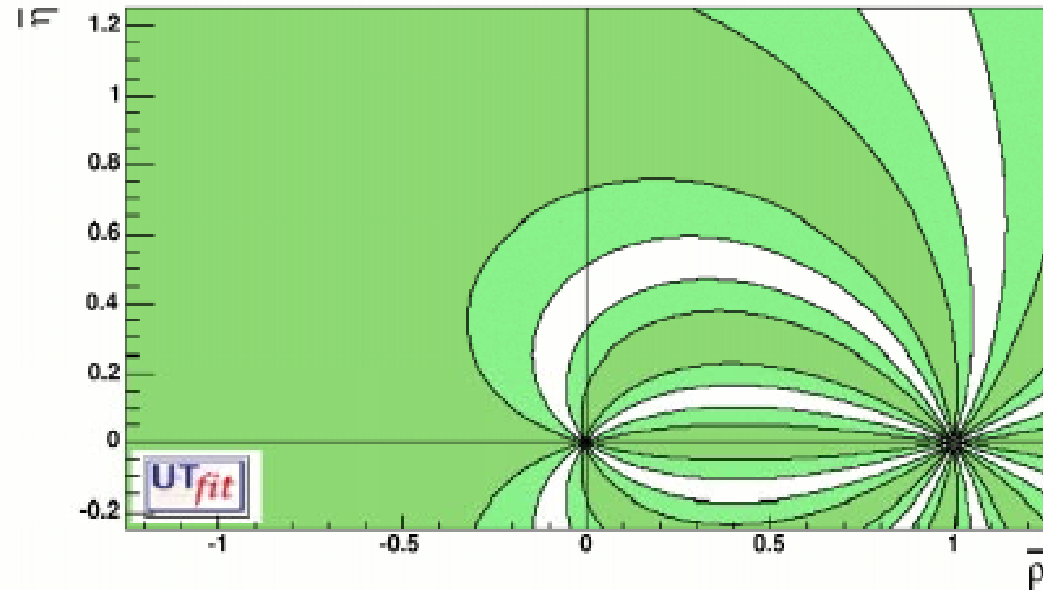
$$c^{(*)} = 2r^{(*)} \cos(2\beta+\gamma) \sin(\delta^{(*)})$$

Valori medi di HFAG

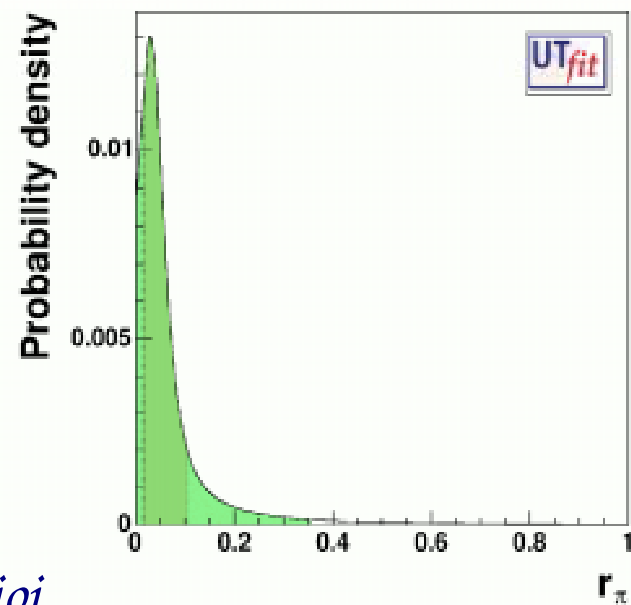


$$\sin(2\beta+\gamma) = ((0, 90, 180) \pm 19)^\circ$$

Nessuna assunzione su r, r^*, r_ρ



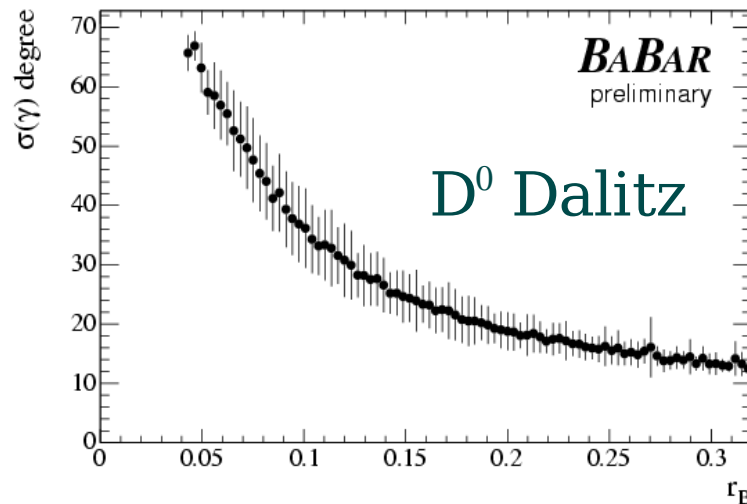
68 % C.L.
95 % C.L.



Conclusioni ...

- Esistono **molte metodi** per l'estrazione di γ che utilizzano i canali $B \rightarrow D^0 K$: **GLW, ADS, D⁰ Dalitz**.
- Il metodo **D⁰ Dalitz** è essere quello con un'incertezza statistica **minore**.
- **Limiti** sulle ampiezze **b→u** dei decadimenti $B \rightarrow D^0 K$ forniscono evidenza che il valore di r_B è **piccolo**.

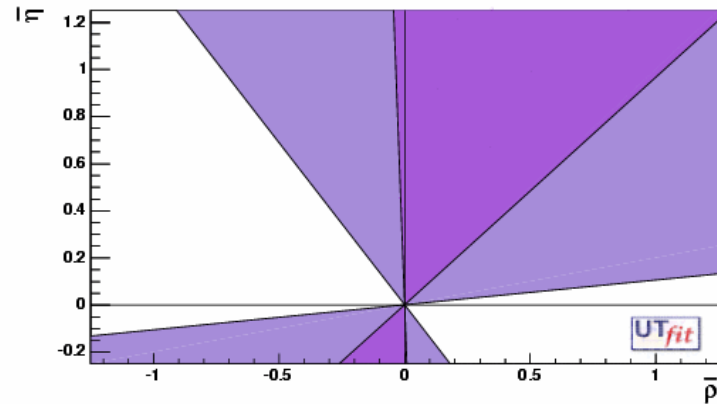
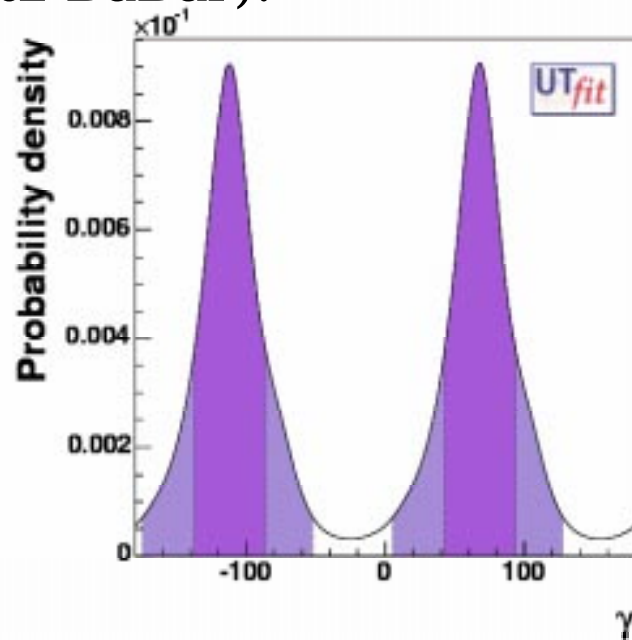
$$r_B = \frac{|A(b \rightarrow u)|}{|A(b \rightarrow c)|}$$



- La **sensibilità** in γ dipende fortemente dal **valore di r_B**
- γ può essere estratto **combinando molti modi**

... e prospettive

- Combinando tutte le misure dirette di BaBar e Belle (eccetto D^{*0} K Dalitz BaBar):



$$\gamma = 68^\circ \pm 26^\circ$$



In ottimo **accordo** con la **determinazione indiretta**: $\gamma = 61.5^\circ \pm 7^\circ$

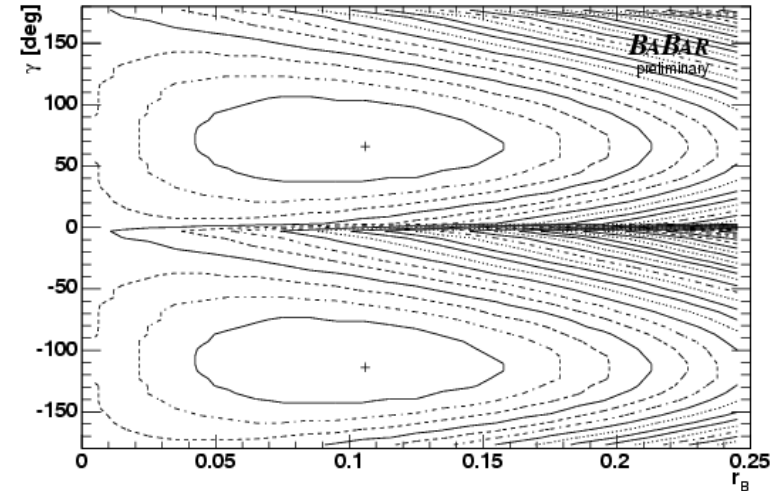
- Le misure di γ sono ancora tutte **dominate dalle incertezze statistiche**.
- Il valore dell'**incertezza statistica**, con l'aumentare della luminosità integrata raccolta dalle B-factory, **dipenderà** principalmente dal valore a cui tenderà il parametro r_B .

Backup slides



Intervalli di confidenza

- La **likelihood** ha un **andamento non gaussiano**
- Utilizzo di una **tecnica bayesiana** per l'estrazione dei parametri
- Scelta di una **prior uniforme** per i **tre parametri** (r_B , δ , γ)



Curve di livello della likelihood nel piano $\gamma - r_B$

Definizione degli **intervalli di confidenza**:

$$\frac{\int_{D(C)} dr_B d\gamma \int_0^{2\pi} d\delta_B \mathcal{L}(r_B, \gamma, \delta_B)}{\int_0^1 dr_B \int_{-\pi}^{\pi} d\gamma \int_0^{2\pi} d\delta_B \mathcal{L}(r_B, \gamma, \delta_B)} = C$$

Intervallo bidimensionale ($D(C)$)

$$\frac{\int_{I(C)} dr_B \int_{-\pi}^{+\pi} d\gamma \int_0^{2\pi} d\delta_B \mathcal{L}(r_B, \gamma, \delta_B)}{\int_0^1 dr_B \int_{-\pi}^{\pi} d\gamma \int_0^{2\pi} d\delta_B \mathcal{L}(r_B, \gamma, \delta_B) dr_B} = C$$

Intervallo unidimensionale ($I(C)$)

C = **livello di confidenza**

Approccio indipendente dal modello

L'approccio indipendente dal modello richiede la divisione in bin del Dalitz plot. Il numero di bin deve essere $n \geq 2$ in quanto:

- $4n$ osservabili: $\#B^+$, $\#B^-$ in i, \bar{i}
- $2n+3$ incognite: $c_i, s_i, r_B, \delta, \gamma$

$$\hat{\Gamma}_i^- \equiv \int_i d\hat{\Gamma}(B^- \rightarrow (K_S \pi^- \pi^+)_D K^-) = T_i + r_B^2 T_i + 2r_B [\cos(\delta_B - \gamma)c_i + \sin(\delta_B - \gamma)s_i]$$

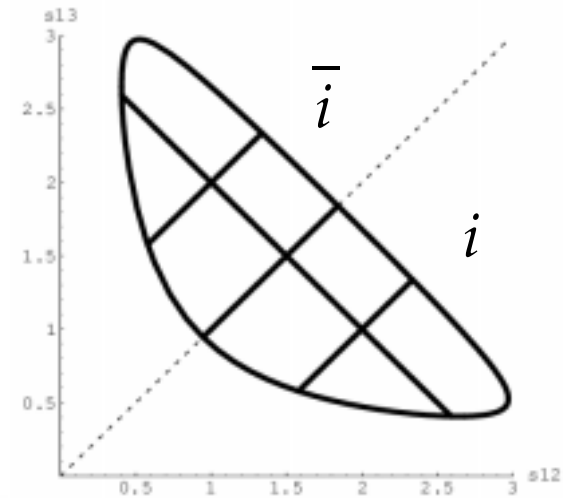
$$\hat{\Gamma}_{\bar{i}}^- \equiv \int_{\bar{i}} d\hat{\Gamma}(B^- \rightarrow (K_S \pi^- \pi^+)_D K^-) = T_i + r_B^2 T_i + 2r_B [\cos(\delta_B - \gamma)c_i - \sin(\delta_B - \gamma)s_i]$$

$$\hat{\Gamma}_i^+ \equiv \int_i d\hat{\Gamma}(B^+ \rightarrow (K_S \pi^- \pi^+)_D K^+) = T_i + r_B^2 T_i + 2r_B [\cos(\delta_B + \gamma)c_i - \sin(\delta_B + \gamma)s_i]$$

$$\hat{\Gamma}_{\bar{i}}^+ \equiv \int_{\bar{i}} d\hat{\Gamma}(B^+ \rightarrow (K_S \pi^- \pi^+)_D K^+) = T_i + r_B^2 T_i + 2r_B [\cos(\delta_B + \gamma)c_i + \sin(\delta_B + \gamma)s_i]$$

c_i ed s_i estratti dal campione di dati

← Incertezza statistica maggiore



$$c_i \equiv \int_i dp A_{12,13} A_{13,12} \cos(\delta_{12,13} - \delta_{13,12})$$

$$s_i \equiv \int_i dp A_{12,13} A_{13,12} \sin(\delta_{12,13} - \delta_{13,12})$$

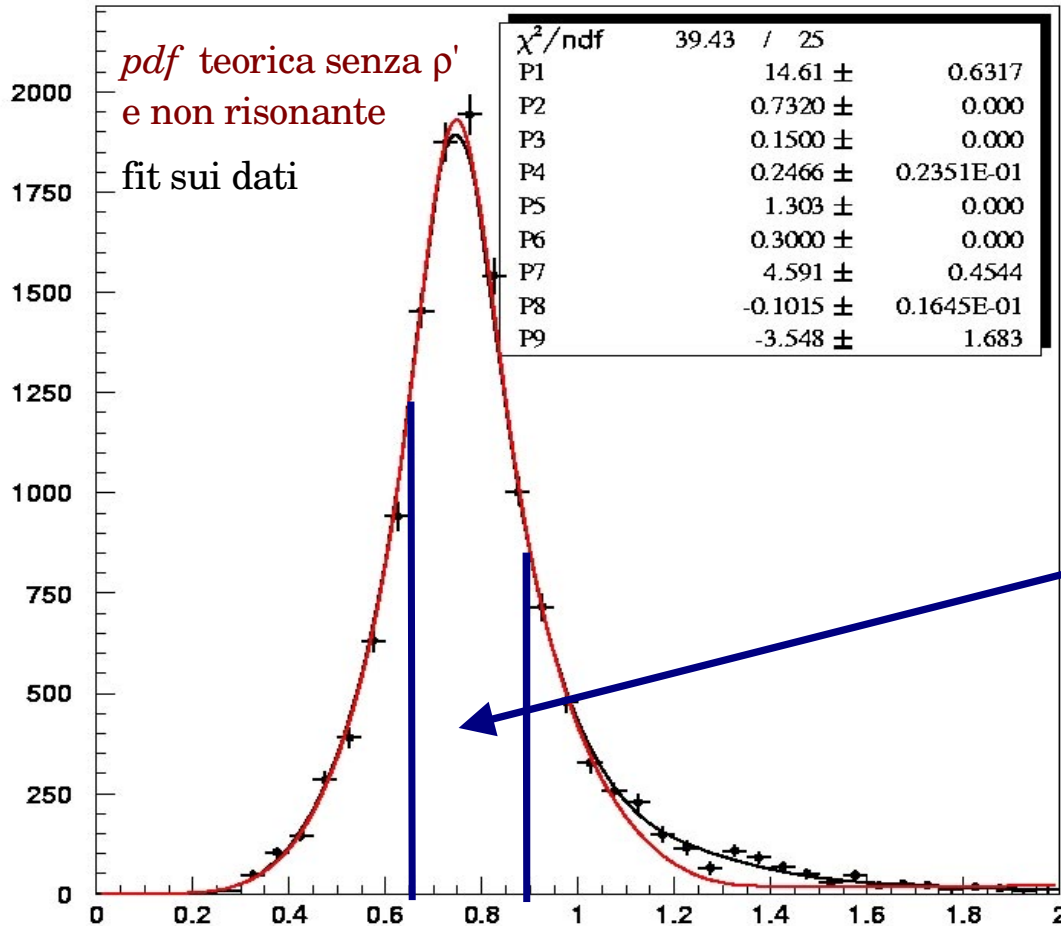
$$T_i \equiv \int_i dp A_{12,13}^2$$

T_i da un campione di D^0 di flavor selezionato



$\sin(2\beta+\gamma)$: massa invariante $\pi\pi$

2004/04/30 10.03



Parametri fissati:

$M_\rho = 732 \text{ MeV}$ $\Gamma_\rho = 150 \text{ MeV}$
 $M_{\rho'} = 1303 \text{ MeV}$ $\Gamma_{\rho'} = 300 \text{ MeV}$

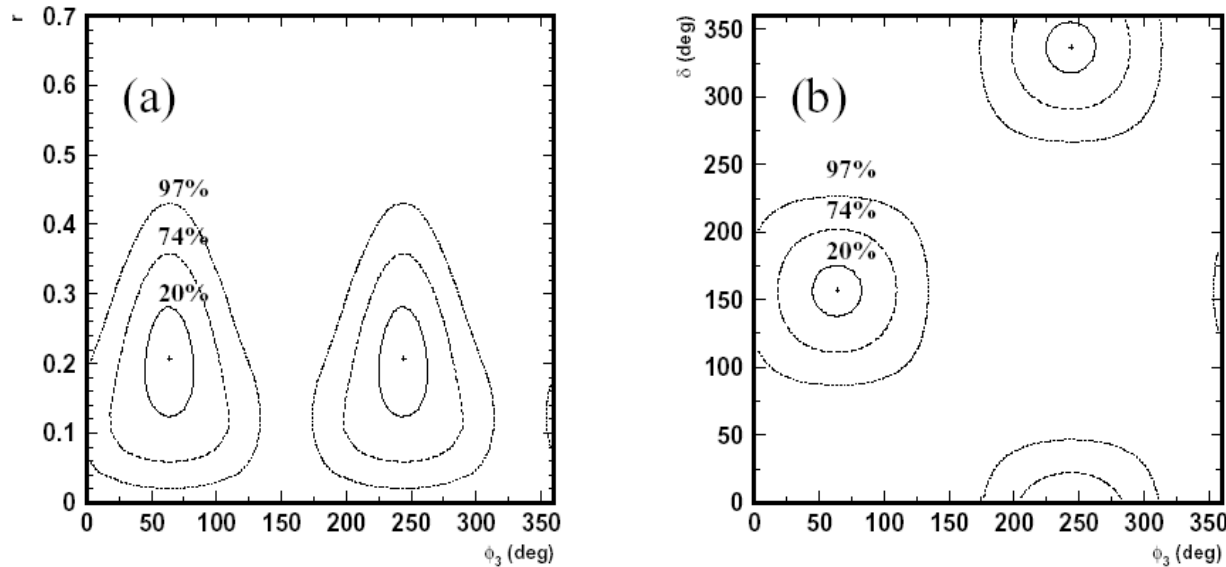
From: A.Bertin et al.[ObelixCollaboration]
 Phys.Lett.B408:476-486,1997

L'impatto nella regione di interesse è minimo.

Frazione di ρ' :
 $f(\rho'+nonres) = (0.9 \pm 7.5) \%$



D⁰ Dalitz: Belle update



$\mathcal{L} = 253 \text{ fb}^{-1}$

$$\Gamma_B = 0.21 \pm 0.08(\text{stat.}) \pm 0.03(\text{syst.}) \pm 0.04(\text{Dalitz Model})$$

$$\Gamma_B^* = 0.12^{+0.16}_{-0.11}(\text{stat.}) \pm 0.02(\text{syst.}) \pm 0.04(\text{Dalitz Model})$$

$$\delta = 157^\circ \pm 19^\circ(\text{stat.}) \pm 11^\circ(\text{syst.}) \pm 21^\circ(\text{Dalitz Model})$$

$$\delta^* = 321^\circ \pm 57^\circ(\text{stat.}) \pm 11^\circ(\text{syst.}) \pm 21^\circ(\text{Dalitz Model})$$

$$\gamma = 68^\circ \pm 15^\circ_{-14^\circ}(\text{stat.}) \pm 13^\circ(\text{syst.}) \pm 11^\circ(\text{Dalitz model})$$