Evidenze di Oscillazione del D^0 alle B-factories

Sommario:

- Formalismo delle oscillazioni
- Il caso del charm
- Le misure
  - Oscillazioni di Sapore
  - yCP
  - Analisi di Dalitz
- Interpretazioni e conseguenze

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Formalismo (1)

- Mesoni neutri : autostati di sapore (M^0)
- Evoluzione temporale: interazioni deboli, che inducono oscillazioni e decadimenti

$$i\frac{\partial}{\partial t}\begin{pmatrix}|M^0(t)\rangle \\ |\overline{M}^0(t)\rangle\end{pmatrix} = \left(\mathrm{M} - \frac{i}{2}\Gamma\right)\begin{pmatrix}|M^0(t)\rangle \\ |\overline{M}^0(t)\rangle\end{pmatrix}$$

2x2 hermitian matrices

Mesons decay!

- Autostati di massa :

$$|M_{1,2}\rangle = p|M^0\rangle \pm q|\overline{M}^0\rangle$$

- … si propagano con masse($m_{1,2}$) e larghezze ($\Gamma_{1,2}$) definite

$$|M_{1,2}(t)\rangle = e^{-i(m_{1,2}-i\Gamma_{1,2}/2)t}|M_{1,2}(t=0)\rangle$$

Formalismo (2)

- Evoluzione temporale di uno stato prodotto con sapore definito, M^0, al tempo t=0 :

$$|M^0(t)\rangle = e^{-\bar{\gamma}t/2}\left(\cosh(\Delta\gamma t/2)|M^0\rangle - \frac{q}{p}\sinh(\Delta\gamma t/2)|\overline{M}^0\rangle\right)$$

Comparsa dello stato di sapore opposto, con frequenza $\omega = 2\pi/x$

- ... dove i termini

$$\Delta\gamma = (y + ix)\Gamma$$

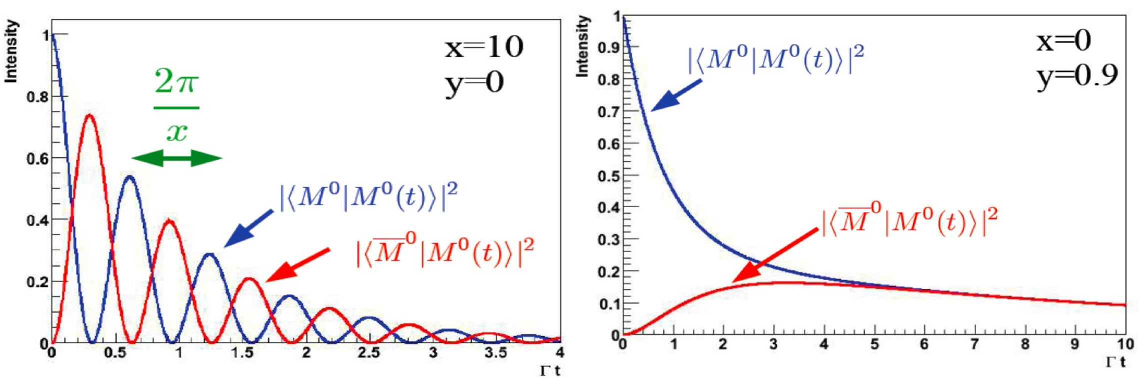
$$\bar{\gamma} = (\Gamma_1 + \Gamma_2)/2 - i(m_1 + m_2)$$

- dipendono dagli osservabili:

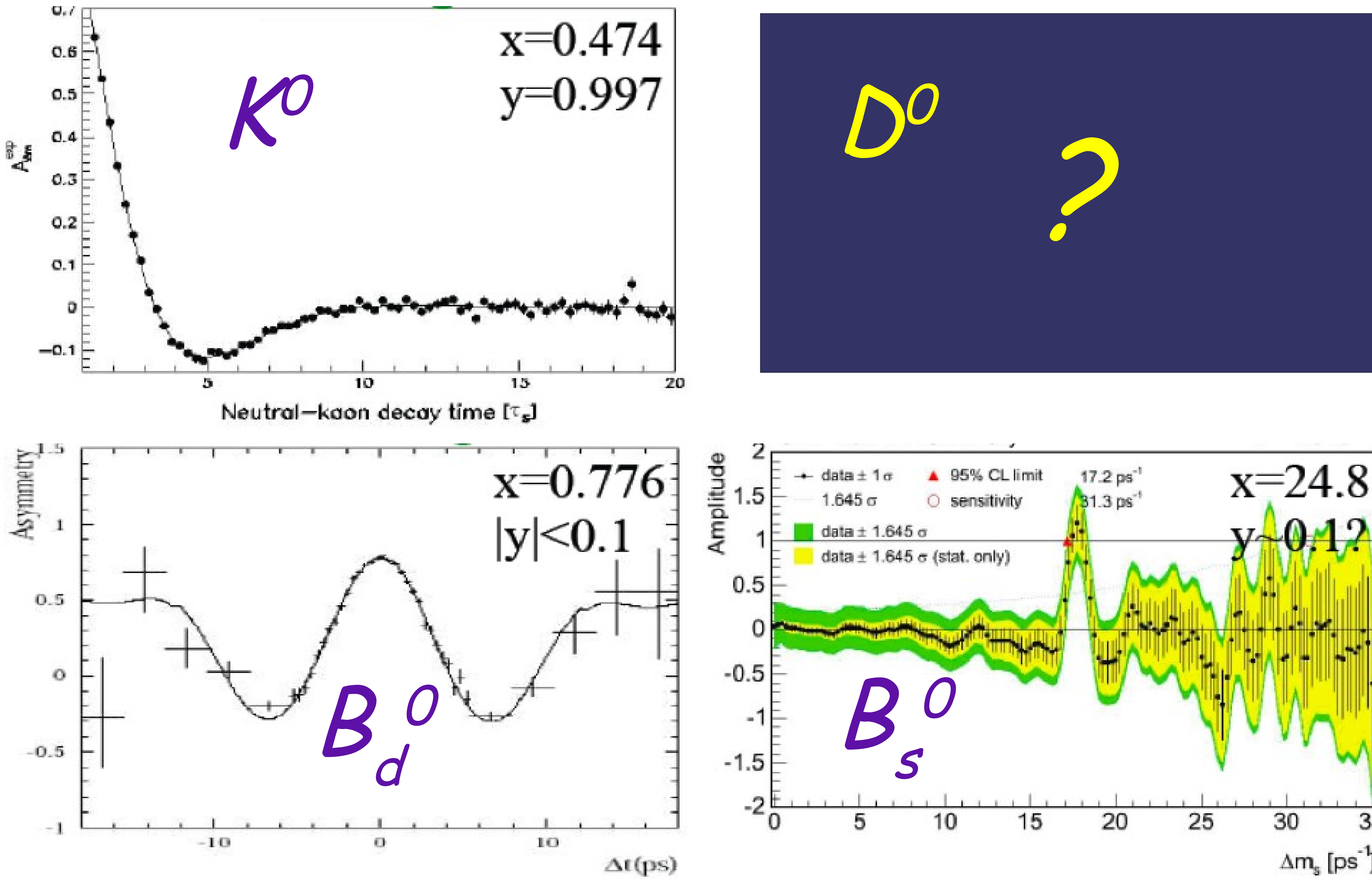
$$\Gamma = \frac{\Gamma_1 + \Gamma_2}{2} = \frac{1}{\tau}$$

$$x = \frac{\Delta m}{\Gamma}$$

$$y = \frac{\Delta \Gamma}{2\Gamma}$$

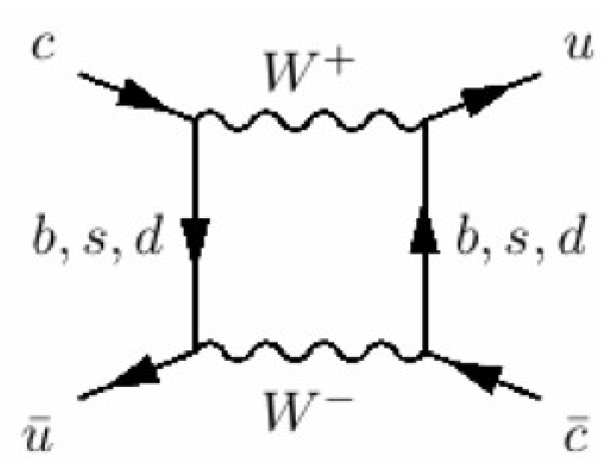


L'Anello Mancante (pre-Moriond)



D-mixing : teoria

- Contributi a "corto-raggio" (quark-like)



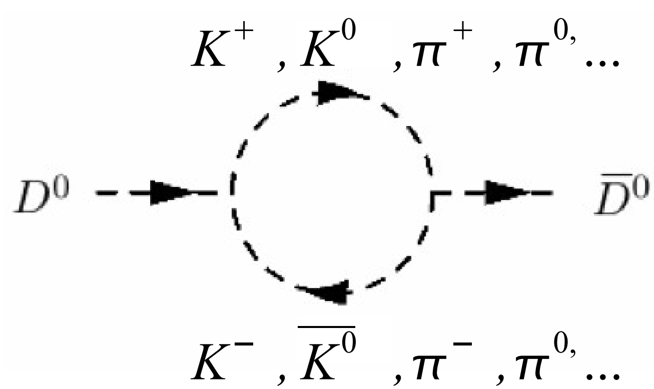
Soppressione Cabibbo

Soppressione GIM

$$H \propto \cos^2\theta_c \sin^2\theta_c \frac{(m_s^2 - m_d^2)^2}{m_c^2}$$

Stati Virtuali: contribuiscono solo a x

- Contributi a "lungo-raggio" (hadron-like)



Stati Reali (Comuni): contribuiscono a x e y

$$\Sigma_i \Gamma_i(comuni) \ll \Gamma(tot)$$

Soppressione di fatto

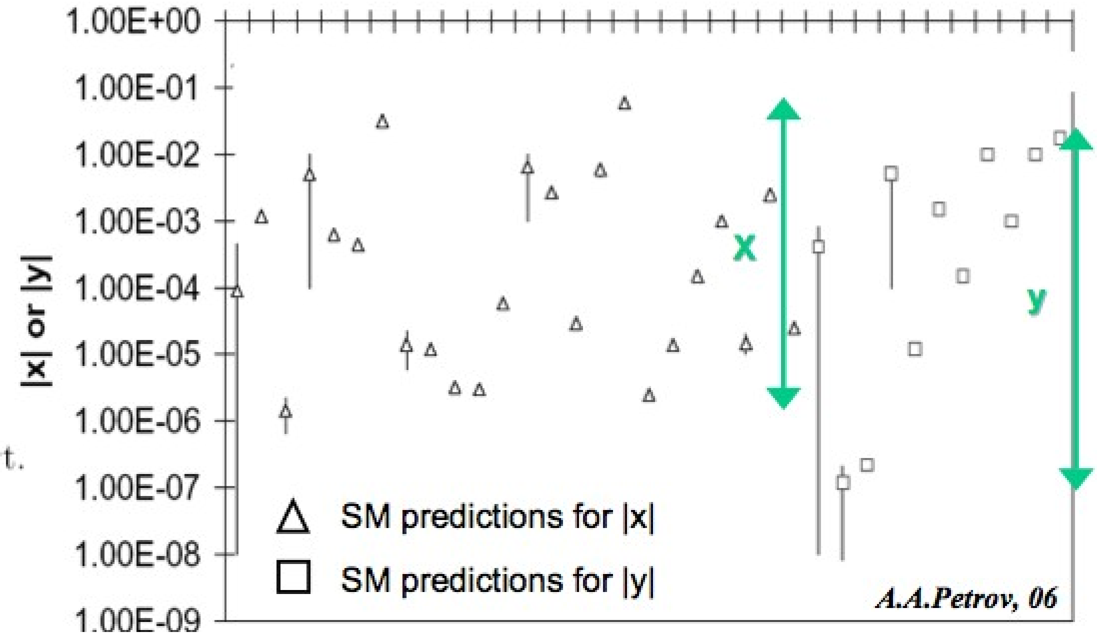
D-mixing: Predizioni ?

- SU(3) esatto : $x = y = 0$
- Difficile il calcolo delle correzioni a SU(3)
- Effetti maggiori su y ?

$x <\sim 10^{-3}$,

$y <\sim 10^{-2}$

G. Burdman and I. Shipsey, Ann. Rev. Nucl. and Part. Sci. **53**, 431 (2003).

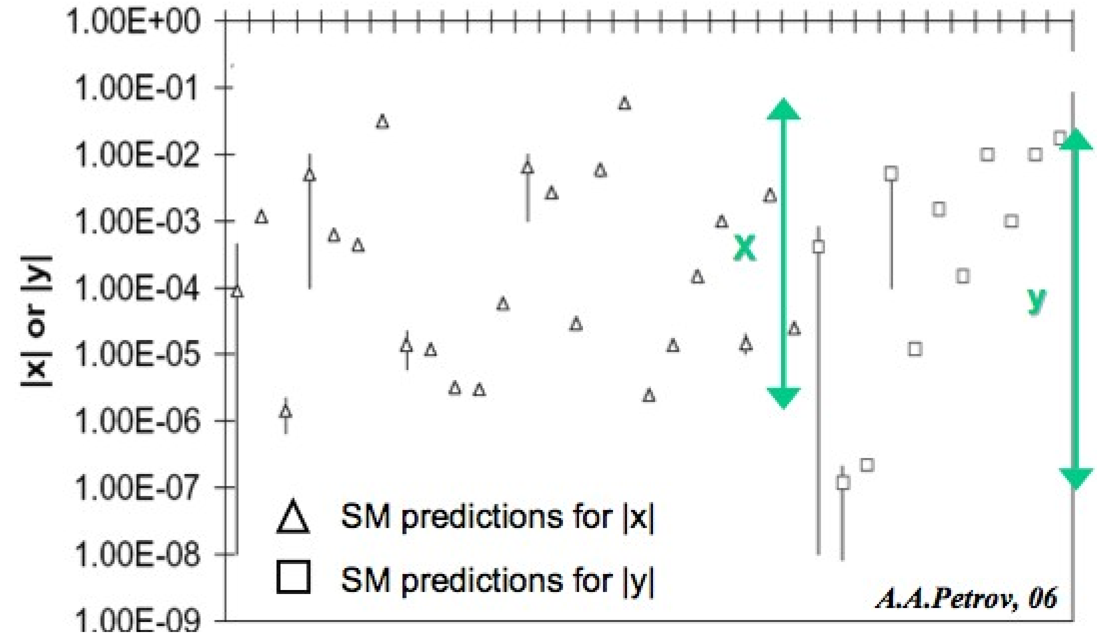


D-mixing: Predizioni ?

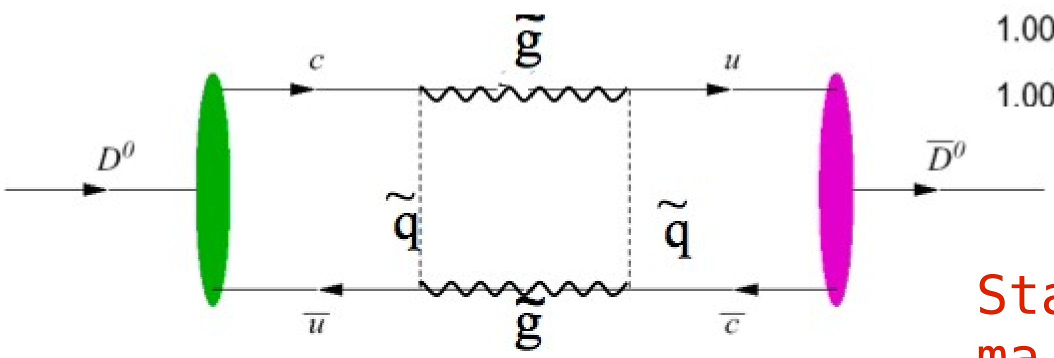
- SU(3) esatto : $x = y = 0$
- Difficile il calcolo delle correzioni a SU(3)
- Effetti maggiori su y ?

$x \lesssim 10^{-3}$,

$y \lesssim 10^{-2}$



- Nuova Fisica:



Stati Virtuali: correzioni a x, ma difficili da quantificare

Risultati Sperimentali

Molti esperimenti in passato hanno studiato il fenomeno

- Nessuna evidenza

Prime evidenze da B-factories : Moriond 2007

- alta sezione d'urto

$$\sigma(e^+ e^-) \rightarrow c\bar{c} = 1.3 \quad nb \quad @ \quad \sqrt{s} \simeq 10.5 \quad GeV$$

- alta luminosita'

$$BABAR: \int L\,dt \simeq 380\, fb^{-1}, \quad \Rightarrow \quad 5 \times 10^8 (D\bar{D})$$

$$Belle: \quad \int L\,dt \simeq 540\, fb^{-1}, \quad \Rightarrow 7 \times 10^8 (D\bar{D})$$

- boost “naturale”

$$\beta \gamma c \tau \simeq 100\, \mu m$$

Le Evidenze Sperimentali

Oscillazione di Sapore

$$D^0 \Leftrightarrow \overline{D}^0$$

- BABAR NEW hep-ex/0703020
- Belle PRL 96 151801 (2006)

Autostati di Massa

$$D^0 / \overline{D}^0 \to K^+ \; K^- \; , \pi^+ \; \pi^-$$

- BABAR PRL 91 121801 (2003)
- Belle NEW hep-ex/0703036

Analisi di Dalitz

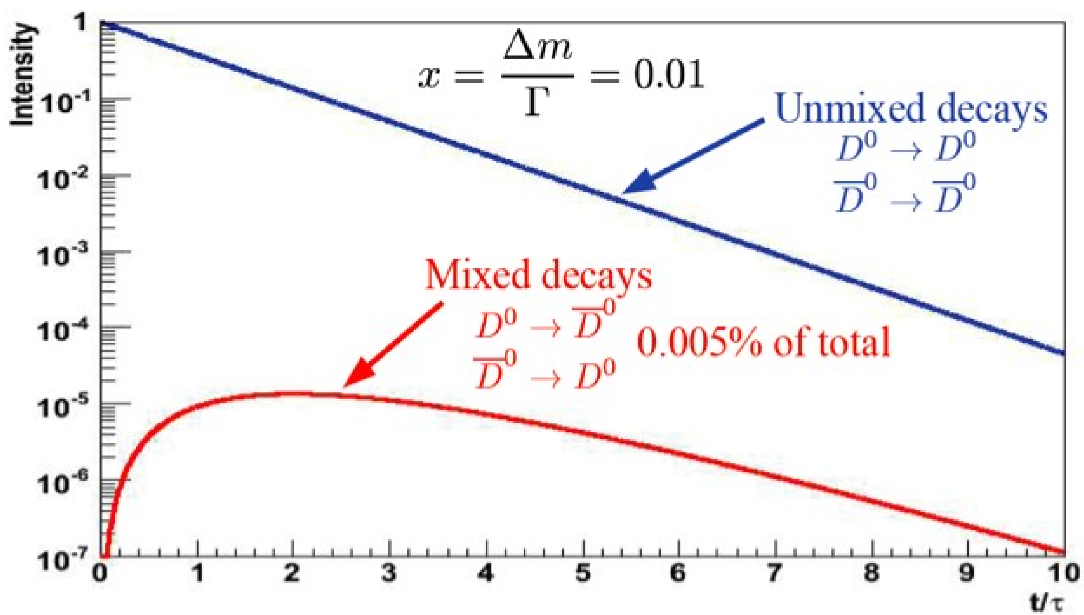
- BABAR PRL 97 221803 (2006) $D^0 / \overline{D}^0 \to K^- \; \pi^+ \; \pi^0 \;\; , K\,3\pi$
- Belle NEW hep-ex/07041000 $D^0 / \overline{D}^0 \to K_s \;\; \pi^+ \; \pi^-$

Oscillazioni $D^0 \Leftrightarrow \overline{D^0}$

- Identifica sapore (D/anti-D) in produzione ($t_0 = 0$)
- Identifica sapore (D/anti-D) al decadimento (t)
- Determina x,y dalla frazione (time-dependent) di eventi oscillati:

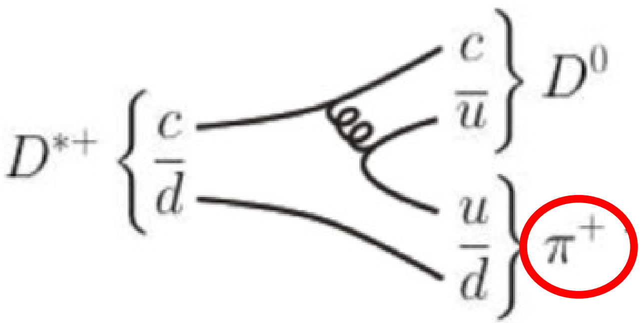
$$r(t) = \frac{N\left(D^0(0) \rightarrow \overline{D^0}(t)\right)}{N\left(D^0(0)\right)}$$

(e complesso coniugato)



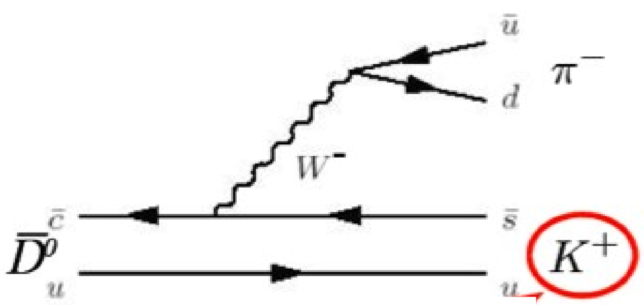
Identificazione di Sapore

- Produzione: D⁰ dal decadimento $D^{*+} \rightarrow \pi^{+} D^{0} \;\; (e \;\; c.c.)$



la carica del π identifica
il sapore del D⁰

- Decadimento : $D^{0} \rightarrow K^{-} \pi^{+} \;\; (e \;\; c.c.)$



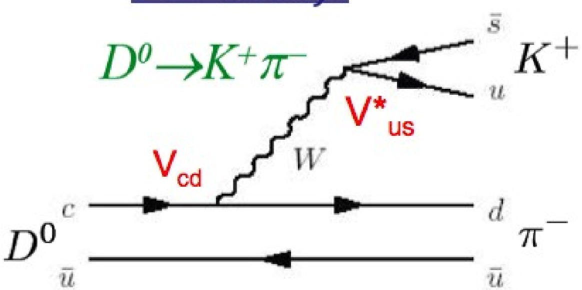
la carica del K identifica
il sapore del D⁰

- Schema naive: $\pi^{\pm}K^{\mp}$: un-mixed ("Right Sign")
  $\pi^{\pm}K^{\pm}$: mixed ("Wrong Sign")

Complicazioni : DCS

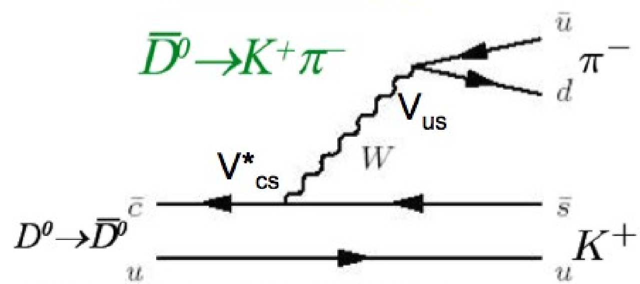
- Decadimenti Doppio Cabibbo Soppressi : falso segnale di oscillazione

DCS decay:



Relative rate ~0.3%

Mixed decay:



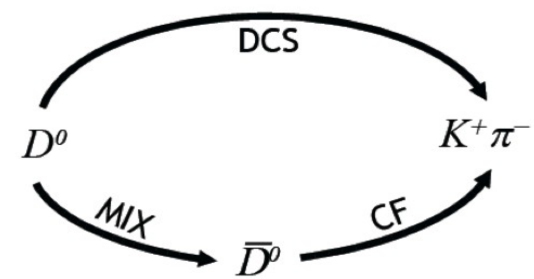
Relative rate: 0.005% (for x=0.01)

☹ **Rate confrontabile col segnale**

☺ **Nessuna struttura temporale**

- Interferiscono col segnale ☺

- Introducono una fase forte (ignota) ☹



$$\frac{A_{DCS}}{A_{CF}} = -\sqrt{R_D}\, e^{-i\delta} \qquad \begin{cases} x' = x\cos\delta + y\sin\delta \\ y' = -x\sin\delta + y\cos\delta \end{cases}$$

misuriamo dei parametri efficaci !

L'evoluzione temporale

- Includendo gli effetti di interferenza e sviluppando per i piccoli valori di x',y' :

Interferenza

$$r(t)=\bar{r}(t) \simeq e^{-\Gamma t}\left(R_D+\sqrt{R_D}\,y'\,\Gamma t+\frac{(x'^2+y'^2)}{4}\Gamma^2 t^2+\ldots\right)$$

DCS

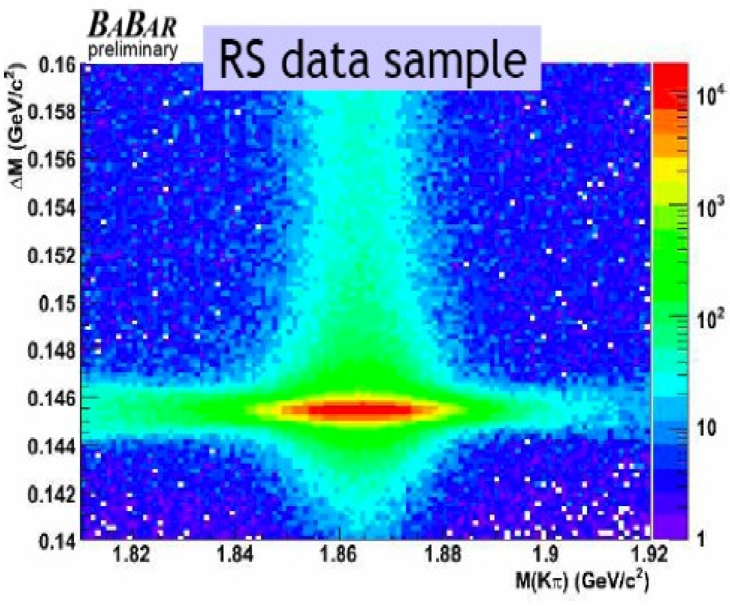
Mix

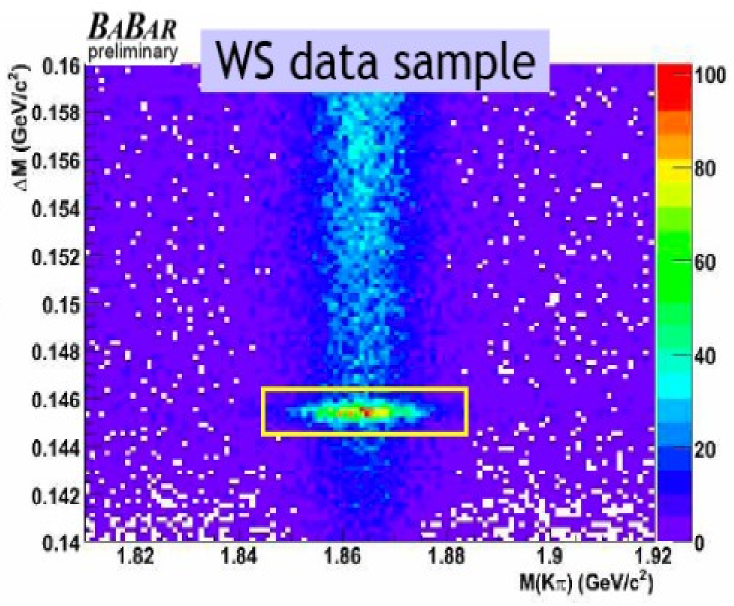
$$R_D=\frac{\Gamma(DCS)}{\Gamma(CF)}$$

$$x' = x\cos\delta + y\sin\delta$$
$$y' = -x\sin\delta + y\cos\delta$$

$$\longmapsto \quad x'^2+y'^2=x^2+y^2$$

La Misura di BABAR





D^0 selection:

- Identified K and π
- p*(D^0)> 2.5 GeV/c
- 1.81<m($K\pi$)<1.92 GeV/c²

Slow π selection:

- p*(π_s)< 0.45 GeV/c
- p_{lab}(π_s)> 0.1 GeV/c
- 0.14<Δm<0.16 GeV/c²

Δm=m($K\pi\pi_s$)-m($K\pi$)

Fondi caratterizzati nei dati:

Misreconstructed D^0:

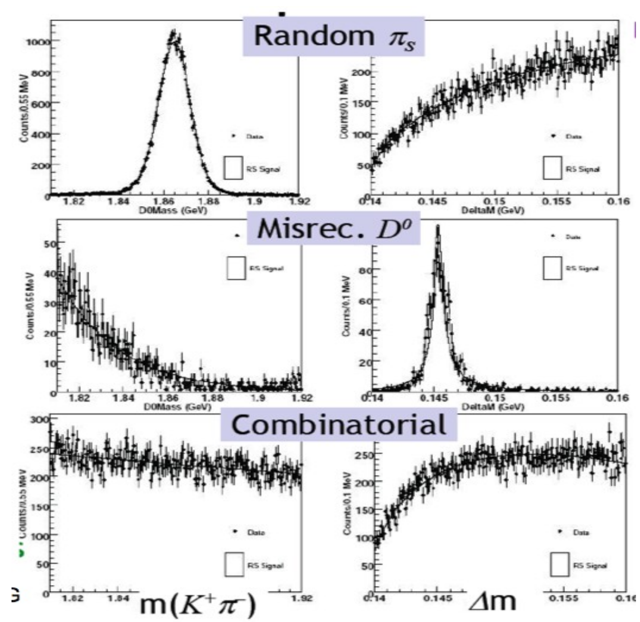
- Partially reco. D^0, $D^0 \to K^- \mu^+ \nu$
- Double misid $D^0 \to K^- \pi^+$ (WS events only)
- Peaks in Δm, not m($K\pi$)

Random π_s:

- Correct D^0, wrong π_s
- Peaks in m($K\pi$), not Δm

Combinatoric:

- Random tracks

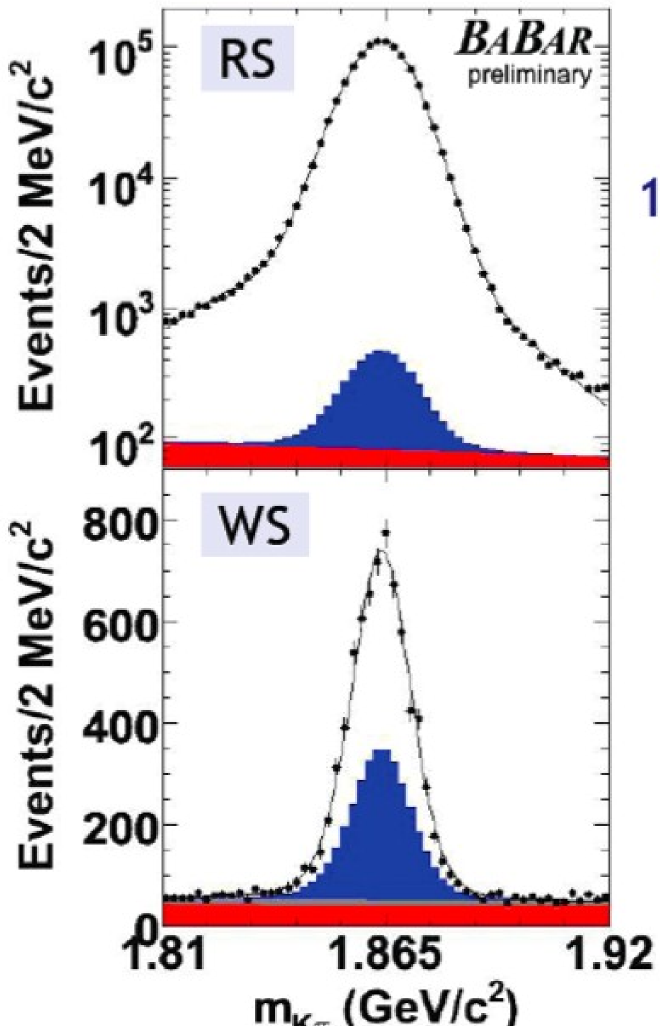


Estrazione del Segnale ...

- ... da fit simultaneo M(Kπ), ΔM (incluse correlazioni)

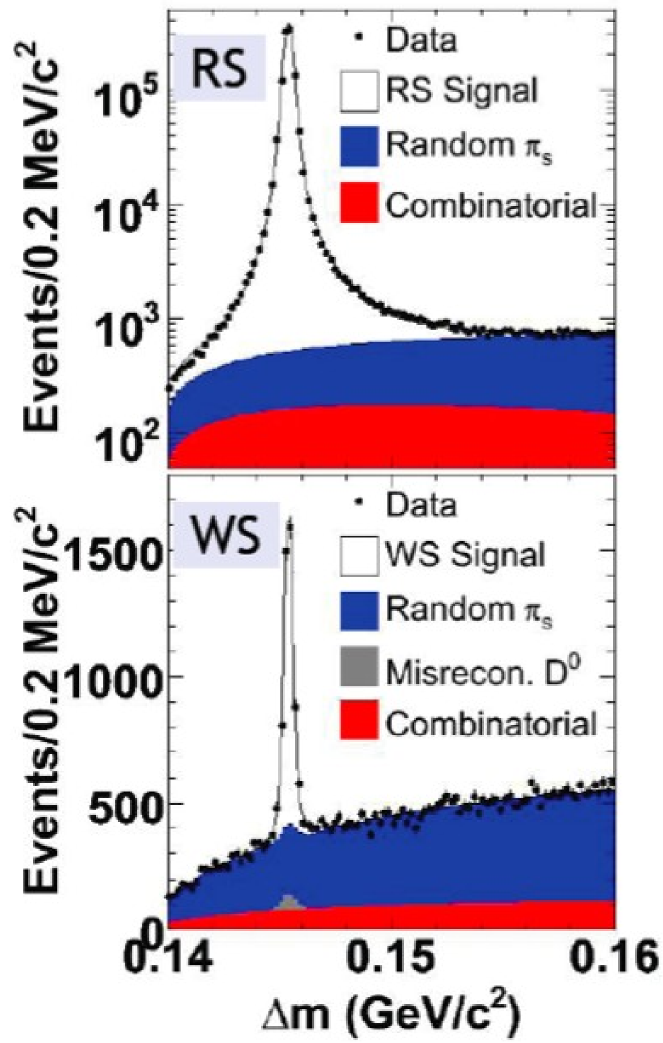
$0.1445 < \Delta M < 0.1485 \;\; GeV$

$1.843 < M(K\pi) < 1.883 \;\; GeV$



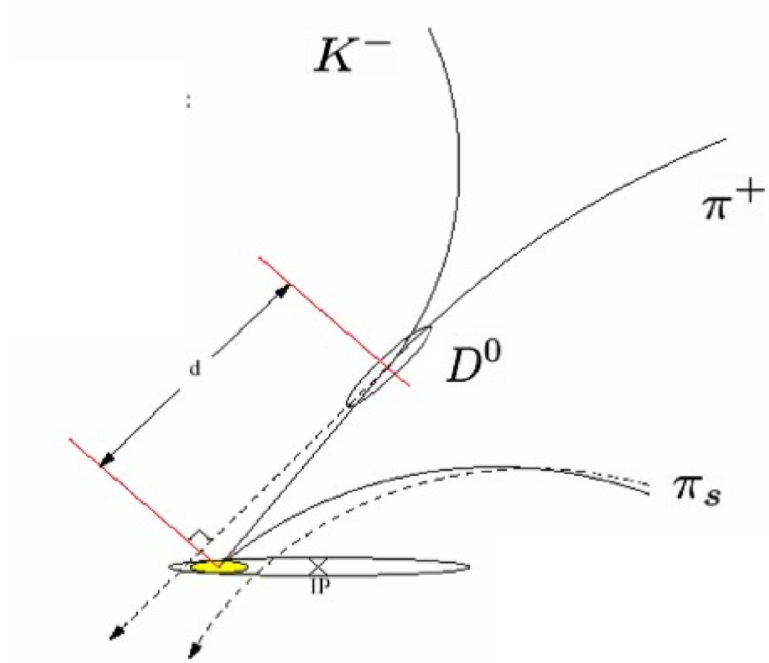
RS signal:
1,141,500±1200
combinations

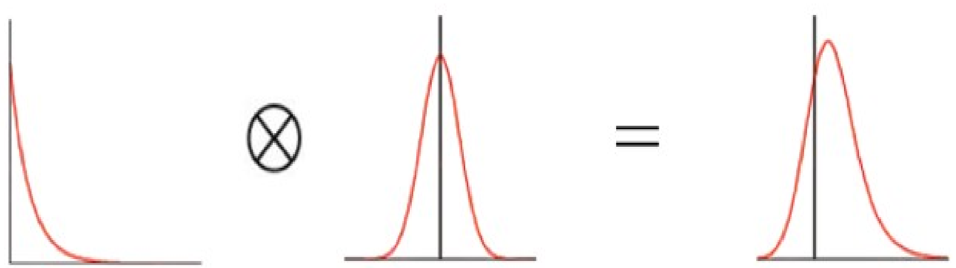
WS signal:
4,030±90
combinations



Misura di t

- D^0,π_s costretti al beam-spot
- Π(fit) >0.1 %
- -2<t< 4 ps
- σ(t)< 0.5 ps





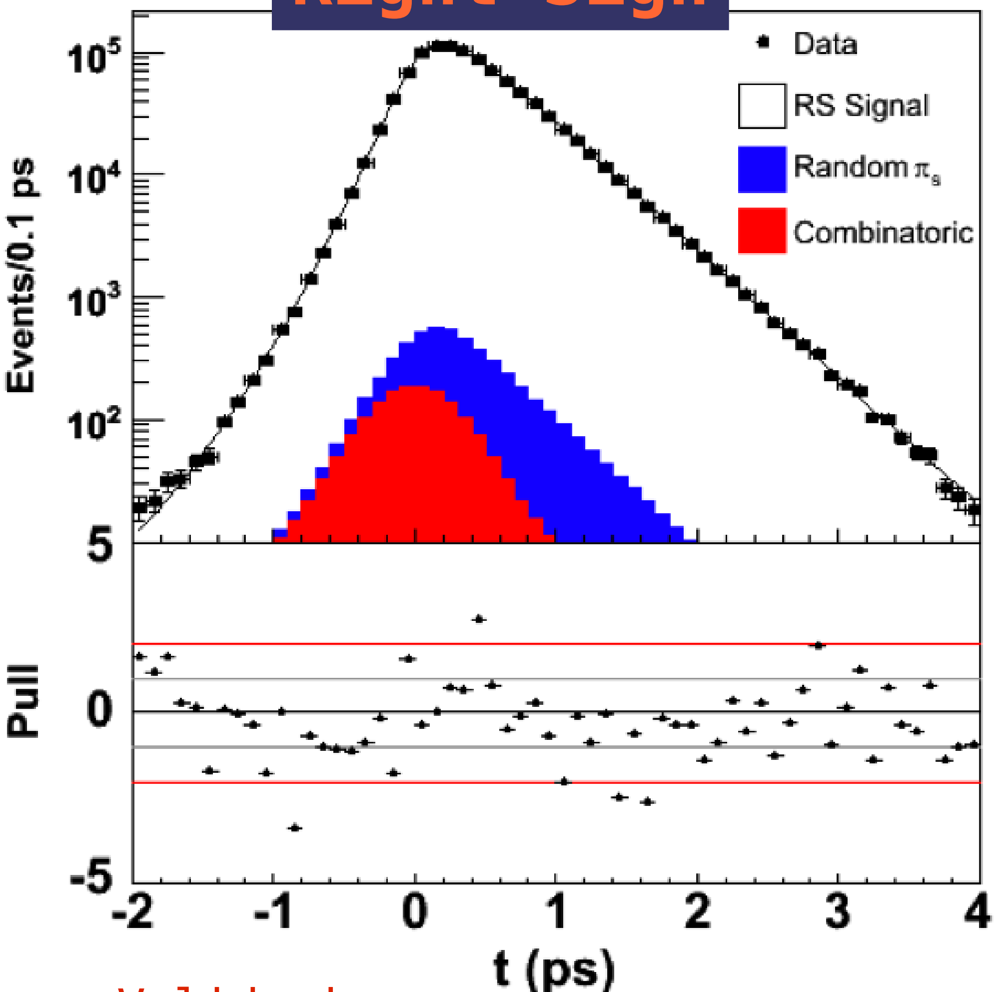
$e^{-t/\tau}$ $\otimes$ $\frac{1}{\sqrt{2\pi}\sigma} e^{-t^2/2\sigma^2}$ = $\frac{1}{\sqrt{2\pi}\sigma}\int_0^\infty e^{-t'/\tau} e^{-(t-t')^2/2\sigma^2}\, dt'$

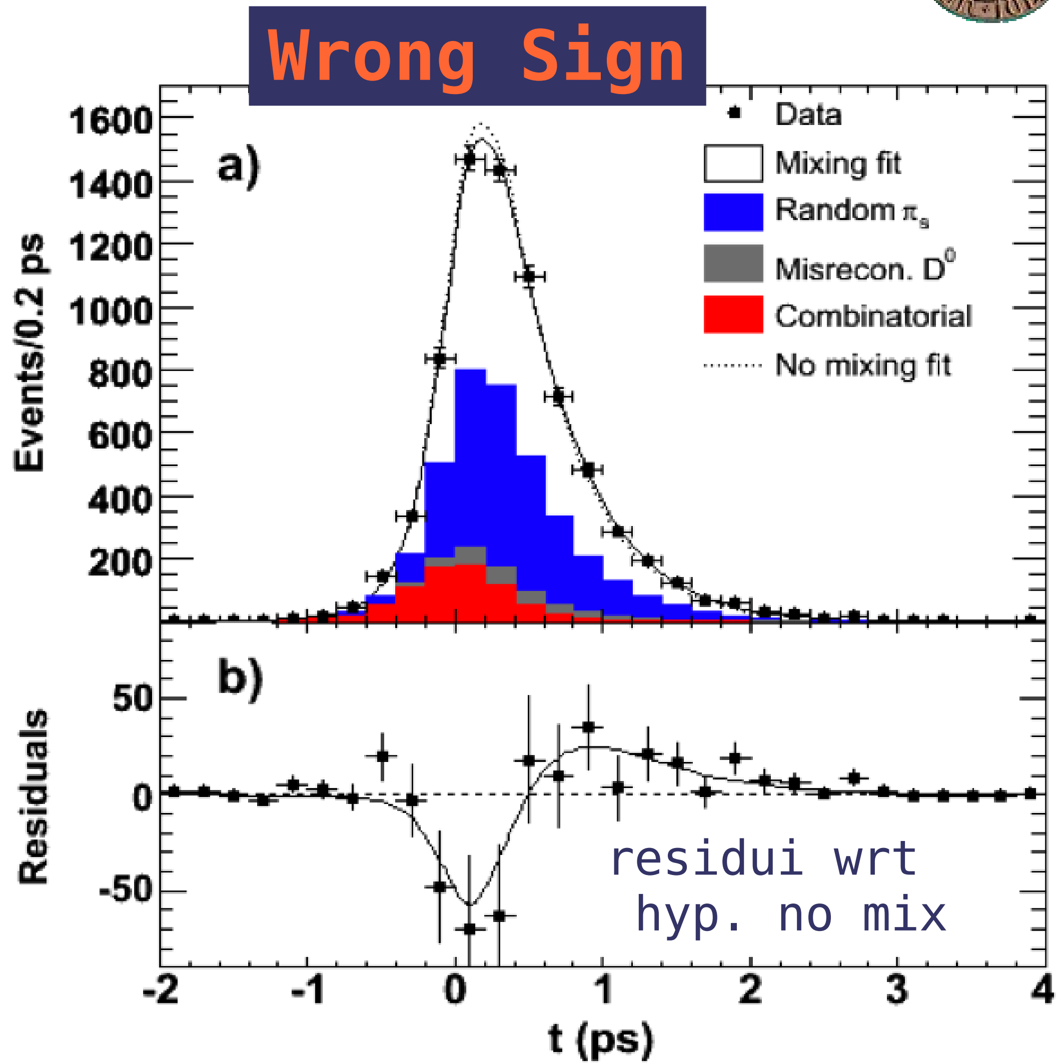
R.S.:
  Risoluzione, τ

W.S.:
  R_D,x',y'

hyp:
  R.S.,W.S. hanno la stessa funzione di risoluzione

Risultati





Validazione:

$\tau(D^0) = 410.3 \pm 0.6_{(stat)}$ fs

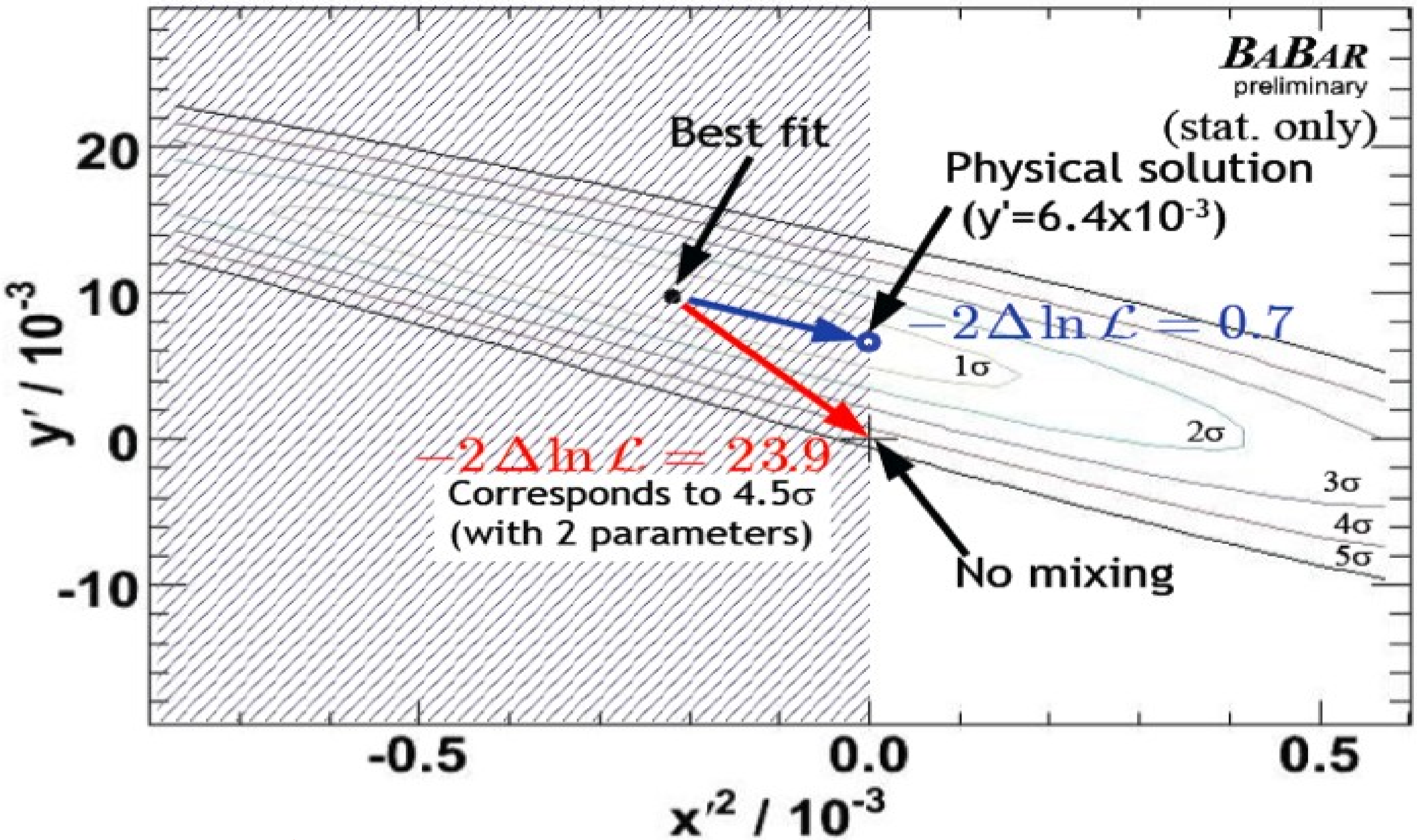
$\tau(D^0) = 410.1 \pm 1.1$ fs (PDG)

$R_D = (\ 3.03 \pm 0.16 \pm 0.10)\ 10^{-3}$

$x'^2 = (-0.22 \pm 0.30 \pm 0.21)\ 10^{-3}$

$y' = (\ 9.7 \pm 4.4 \pm 3.1\ )\ 10^{-3}$

Evidenza dell' Oscillazione



- Soluzione favorita non-fisica
- Includendo le sistematiche l'evidenza e' di 3.9 σ

Errori Sistematici

Fit e modello:

- Funzione di risoluzione
- PDF e frazioni di segnale e fondi

Selezione

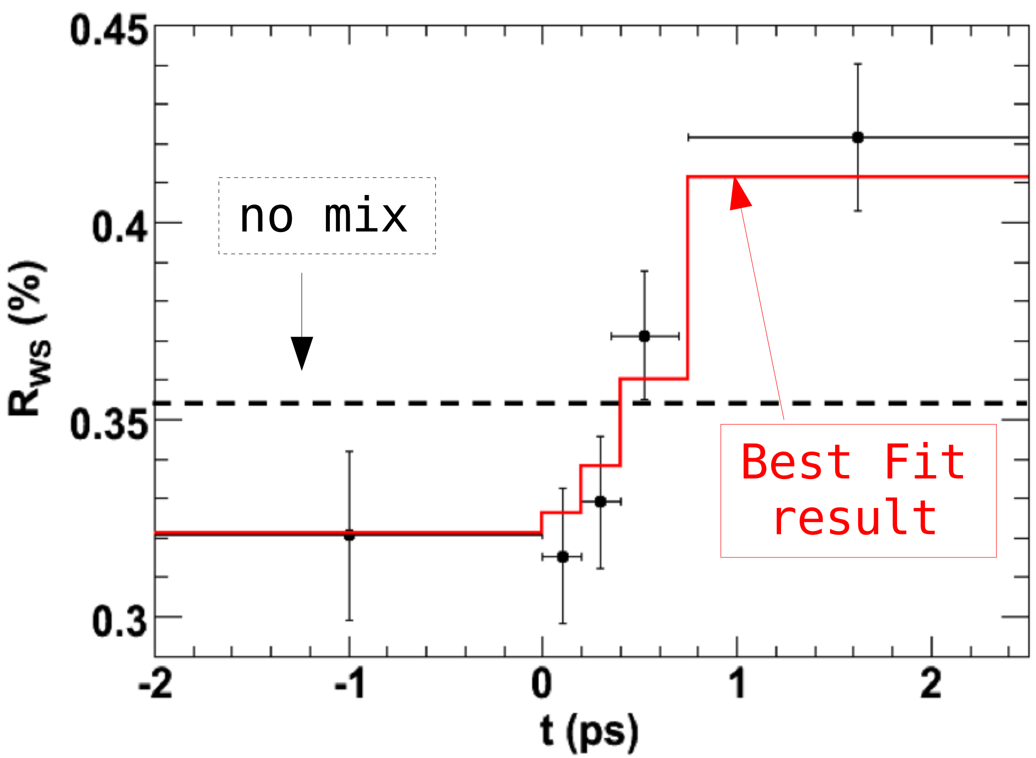
- Sensibilita' ai tagli

Par	Fit	Tagli	Totale
R_D	0.59	0.24	0.63
x'^2	0.40	0.57	0.70
y'	0.45	0.55	0.71

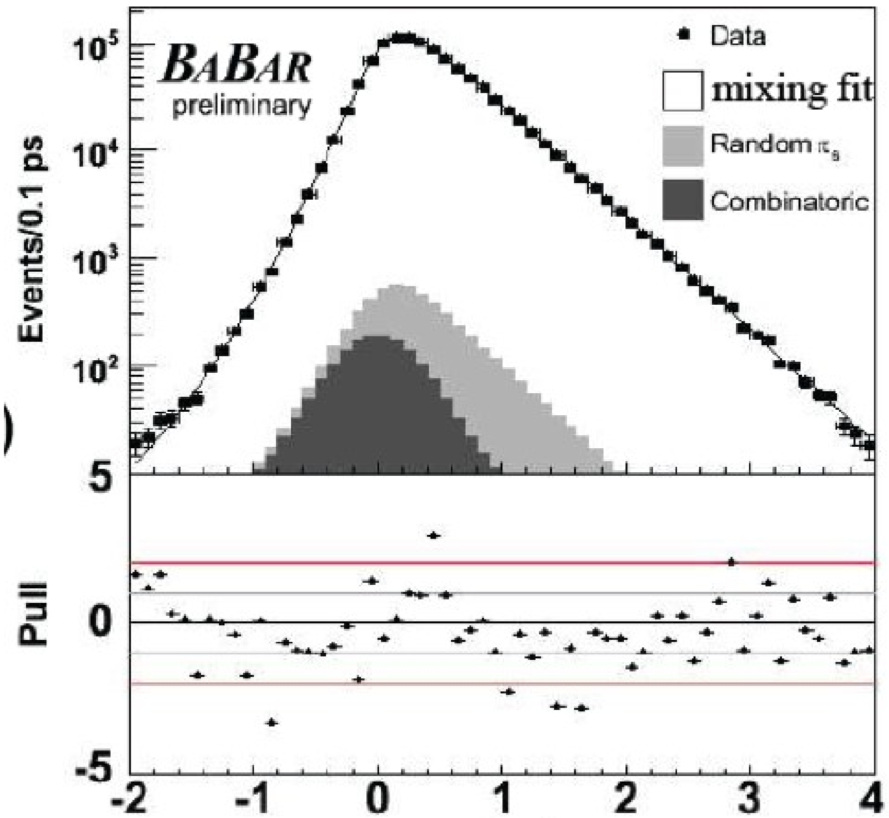
Errore sistematico espresso come frazione dell'errore statistico

Validazioni ...

- Misura r =WS/RS in cinque bin di t, da fit a ΔM,M(Kπ)
- Nessuna ipotesi sulla dipendenza temporale di segnale e fondi



- Fit mixing nel campione Right Sign



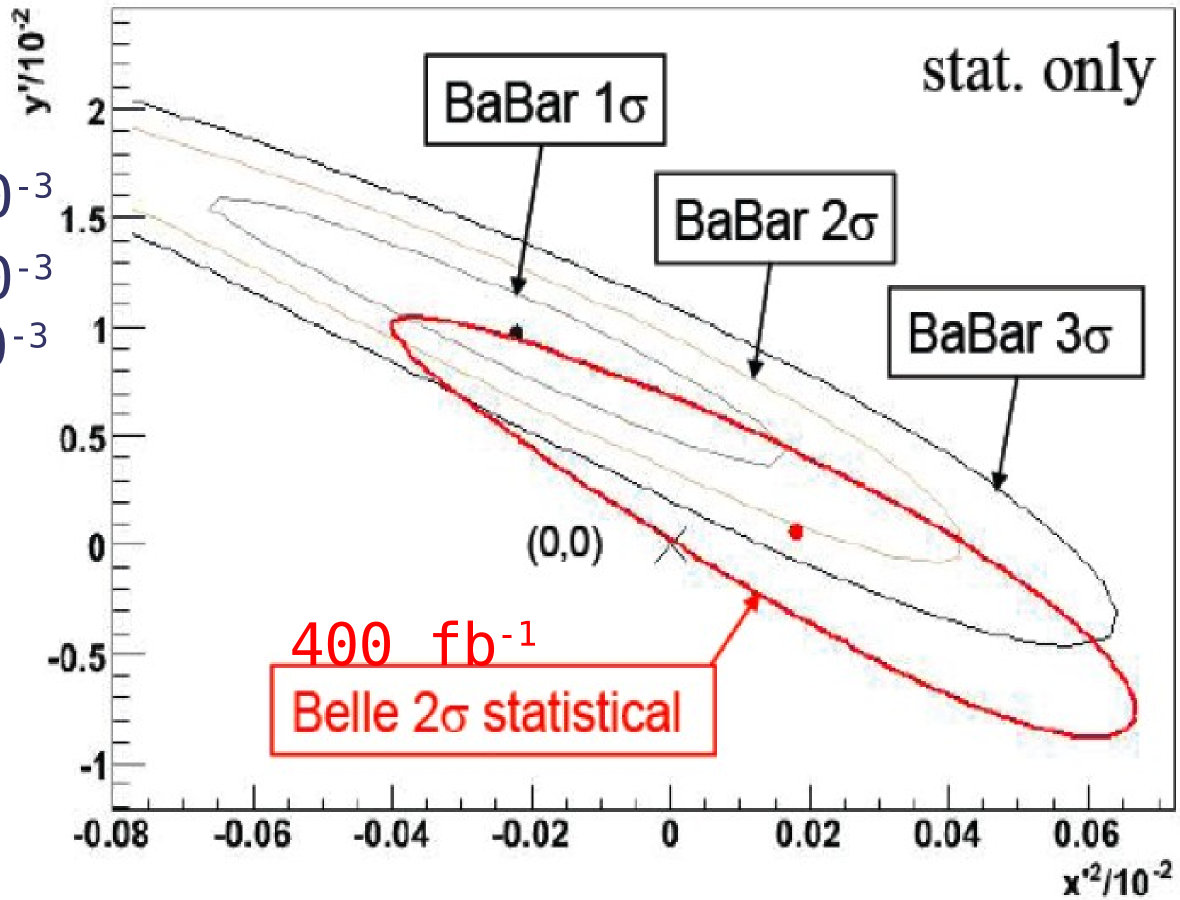
x'^2: $(-0.01\pm0.01)\times10^{-3}$

y': $(0.26\pm0.24)\times10^{-3}$

$-2\Delta\ln\mathcal{L} = 1.4$ (w.r.t. no mixing)

Conclusioni (parziali)

R_D = (3.03±0.16±0.10) 10^{-3}
x'^2= (-0.22±0.30±0.21) 10^{-3}
y' = (9.7 ±4.4 ±3.1) 10^{-3}



- (0,0) escluso a 3.9 σ
- risultato compatibile con precedente misura di Belle

☺ Prima osservazione dell'oscillazione D^0 anti-D^0

☹ x',y' fortemente correlati

☹ x',y' parametri efficaci (fase δ incognita)

y_{CP} da Autostati di Massa

- $\Gamma = \frac{1}{2}\,(\Gamma_1+\Gamma_2) = (410\ \text{fs})^{-1}$ e' un parametro efficace
- Se CP conservata, $|D_{1,2}\rangle \equiv |D_{CP+,-}\rangle$
- Evoluzione temporale autostati CP +, CP- regolata da Γ_1 e Γ_2
- Si misura

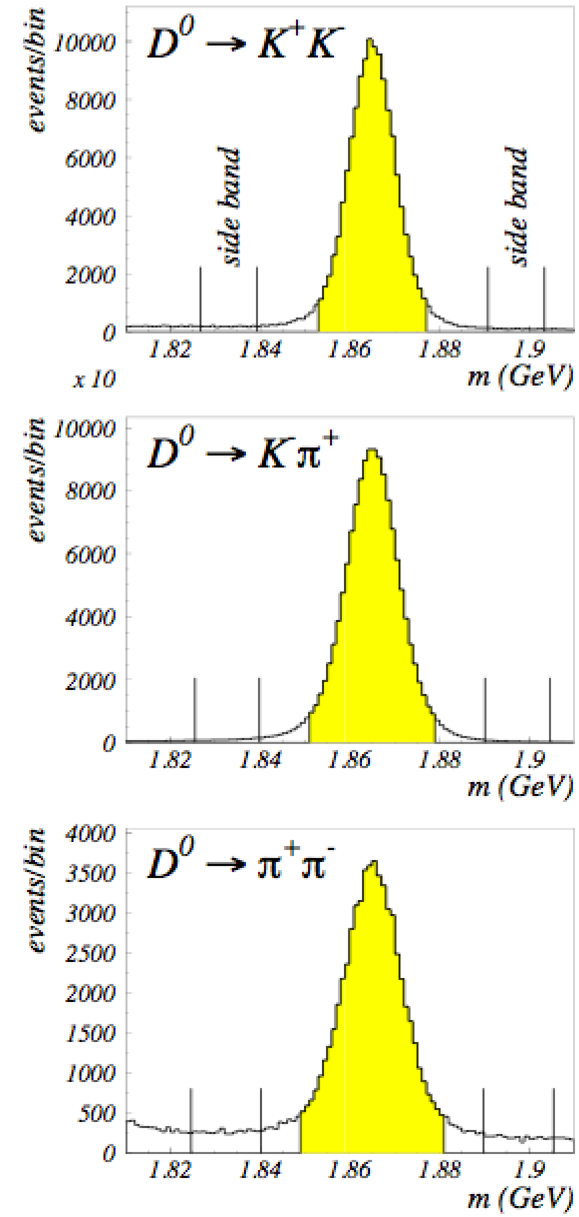
$$y_{CP} = \frac{\Gamma(K^+ K^-)}{\Gamma(K^- \pi^+)} - 1 = \frac{\Gamma(\pi^+ \pi^-)}{\Gamma(K^- \pi^+)} - 1 = \frac{\Delta\Gamma}{\Gamma}$$

y_{CP} Belle, Moriond

- Selezione eventi, controllo dei fondi, misura tempo proprio simili a misura precedente

540 fb^{-1} :

channel	KK	$K\pi$	$\pi\pi$
signal	110K	1.2M	50K
purity	98%	99%	92%



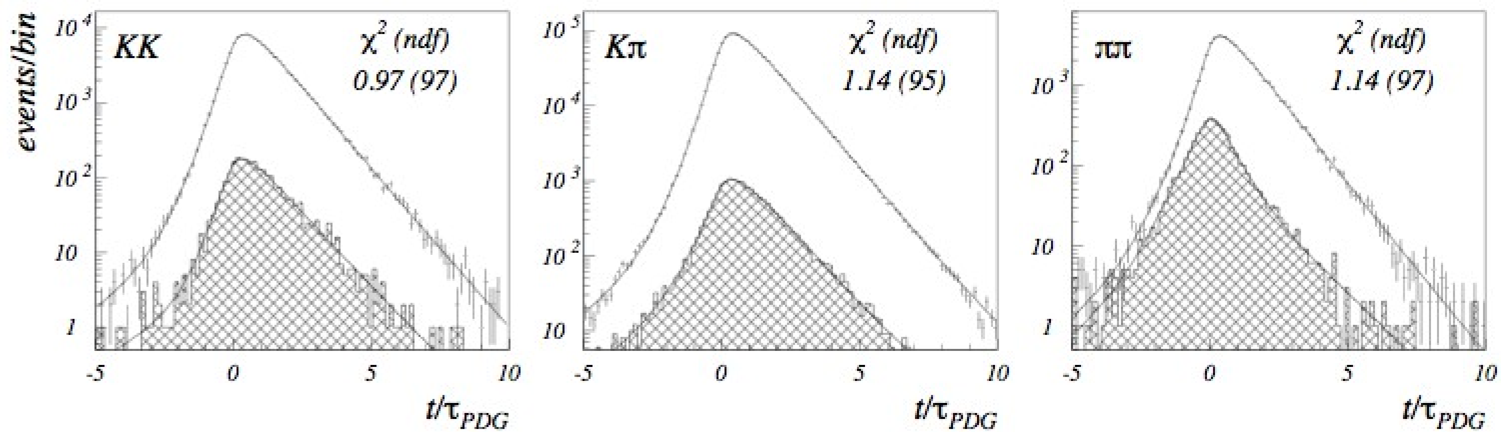
y_{CP} Belle, Moriond

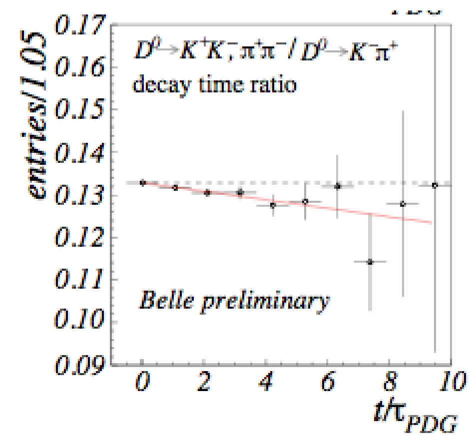
	y_{CP} (%)
KK	1.25±0.39±0.28
$\pi\pi$	1.44±0.57±0.42
$KK+\pi\pi$	1.31±0.32±0.25

Simultaneous $KK/\pi\pi/K\pi$ binned likelihood fit

quality of fit: $\chi^2 = 1.084$ (289)

$$\tau(K\pi) = 408.7 \pm 0.6 \ fs$$





source	y_{CP}	A_Γ
acceptance	0.12%	0.07%
equal t_0 assumption	0.14%	0.08%
mass window position	0.04%	0.003%
difference btw. background and side bands	0.09%	0.06%
difference btw. final states in opening angle	0.02%	
background parameterization	0.07%	0.07%
resolution function	0.01%	0.01%
analysis cuts	0.11%	0.05%
binning	0.01%	0.01%
total	0.25%	0.15%

y_{CP} = (1.31±0.32±0.25) %

4.1 σ stat

>3 σ stat+syst.

Separare x , y : Analisi di Dalitz $D^0/\overline{D^0} \to K_s\pi^0\pi^0$

Dalitz Plot :

- Cabibbo Favoriti : $D^0 \to K^{*-}\ \pi^+\ , \ldots$
- Cabibbo Sopressi : $D^0 \to K^{*+}\ \pi^-\ , \ldots$
- Autostati di CP (Massa) $D^0 \to K_S\ \rho^0$

Analisi evoluzione temporale sul Dalitz Plot misura simultaneamente

- Ampiezze CF, CS
- Fasi forti
- Parametri di Mixing

Il Metodo

Ampiezza time-dependent sul Dalitz Plot (CP conservata):

$$M(m_-^2, m_+^2, t) = A(m_-^2, m_+^2)\frac{e_1(t)+e_2(t)}{2} + A(m_+^2, m_-^2)\frac{e_1(t)-e_2(t)}{2}$$

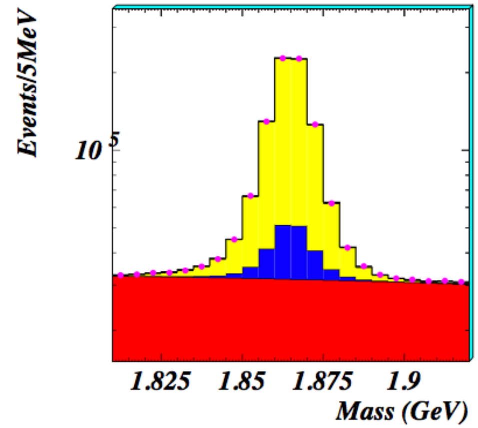
$m_{+,-}$ e' definita col tag di D* :

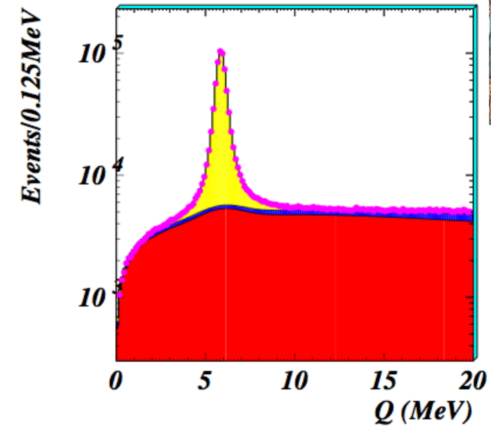
$$m_\pm = \begin{cases} m(K_s, \pi^\pm) & D^{*+} \to D^0\pi^+ \\ m(K_s, \pi^\mp) & D^{*-} \to \bar{D}^0\pi^- \end{cases}$$

$e_{1,2}(t)$ contengono la dipendenza da x,y :

$$e_{1,2}(t) = e^{-i(m_{1,2} - i\Gamma_{1,2}/2)t}$$

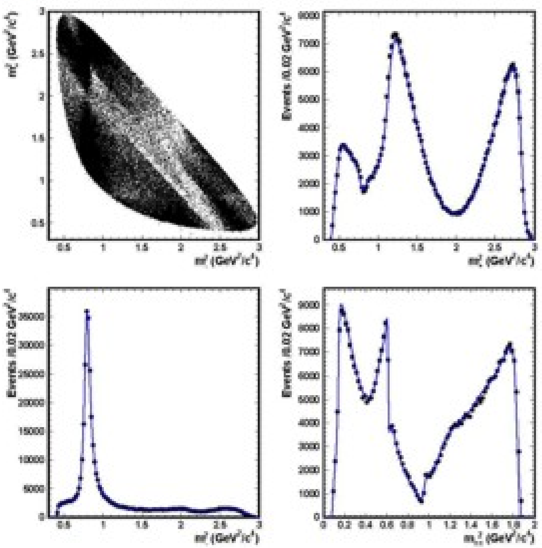
Belle Moriond 2007



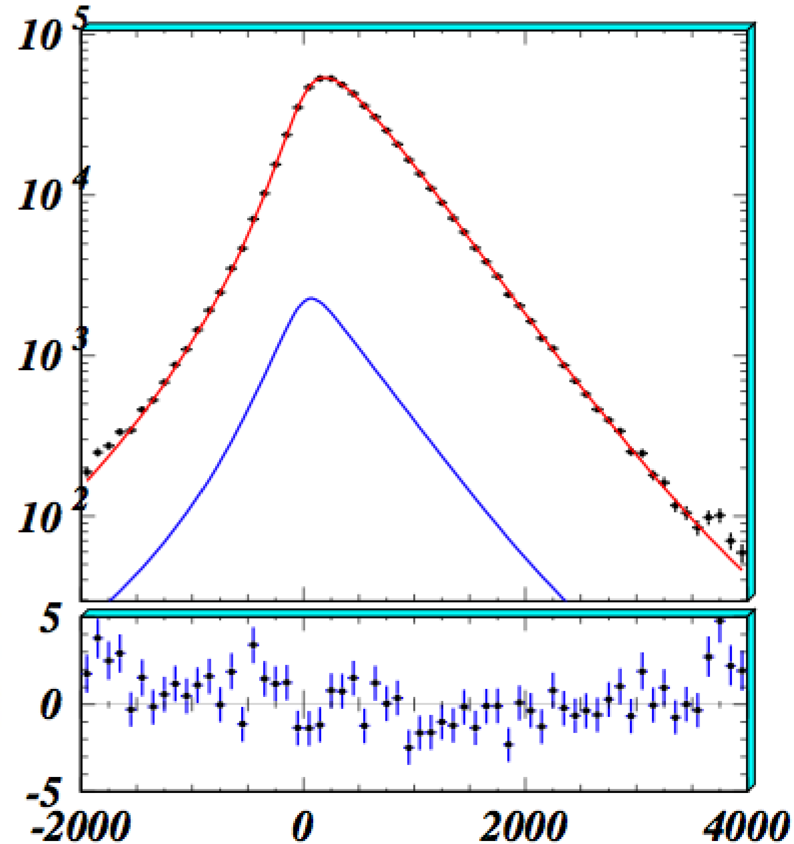


- 534000 eventi
- Purezza ~ 95 %

Dalitz fit



Resonance	Amplitude	Phase (deg)	Fit fraction
$K^*(892)^-$	1.629 ± 0.005	134.3 ± 0.3	0.6227
$K_0^*(1430)^-$	2.12 ± 0.02	-0.9 ± 0.5	0.0724
$K_2^*(1430)^-$	0.87 ± 0.01	-47.3 ± 0.7	0.0133
$K^*(1410)^-$	0.65 ± 0.02	111 ± 2	0.0048
$K^*(1680)^-$	0.60 ± 0.05	147 ± 5	0.0002
$K^*(892)^+$	0.152 ± 0.003	-37.5 ± 1.1	0.0054
$K_0^*(1430)^+$	0.541 ± 0.013	91.8 ± 1.5	0.0047
$K_2^*(1430)^+$	0.276 ± 0.010	-106 ± 3	0.0013
$K^*(1410)^+$	0.333 ± 0.016	-102 ± 2	0.0013
$K^*(1680)^+$	0.73 ± 0.10	103 ± 6	0.0004
$\rho(770)$	1 (fixed)	0 (fixed)	0.2111
$\omega(782)$	0.0380 ± 0.0006	115.1 ± 0.9	0.0063
$f_0(980)$	0.380 ± 0.002	-147.1 ± 0.9	0.0452
$f_0(1370)$	1.46 ± 0.04	98.6 ± 1.4	0.0162
$f_2(1270)$	1.43 ± 0.02	-13.6 ± 1.1	0.0180
$\rho(1450)$	0.72 ± 0.02	40.9 ± 1.9	0.0024
σ_1	1.387 ± 0.018	-147 ± 1	0.0914
σ_2	0.267 ± 0.009	-157 ± 3	0.0088
NR	2.36 ± 0.05	155 ± 2	0.0615



- Dalitz model: 13 different (BW) resonances and a non-resonant contribution
- Results with this refined model consistent with the analysis performed for the Belle ϕ_3 measurement, PRD73, 112009 (2006)
- To test the scalar $\pi\pi$ contributions, K-matrix formalism is also used

Risultati

$$x = 0.80 \pm 0.29 \pm 0.17\ \%$$

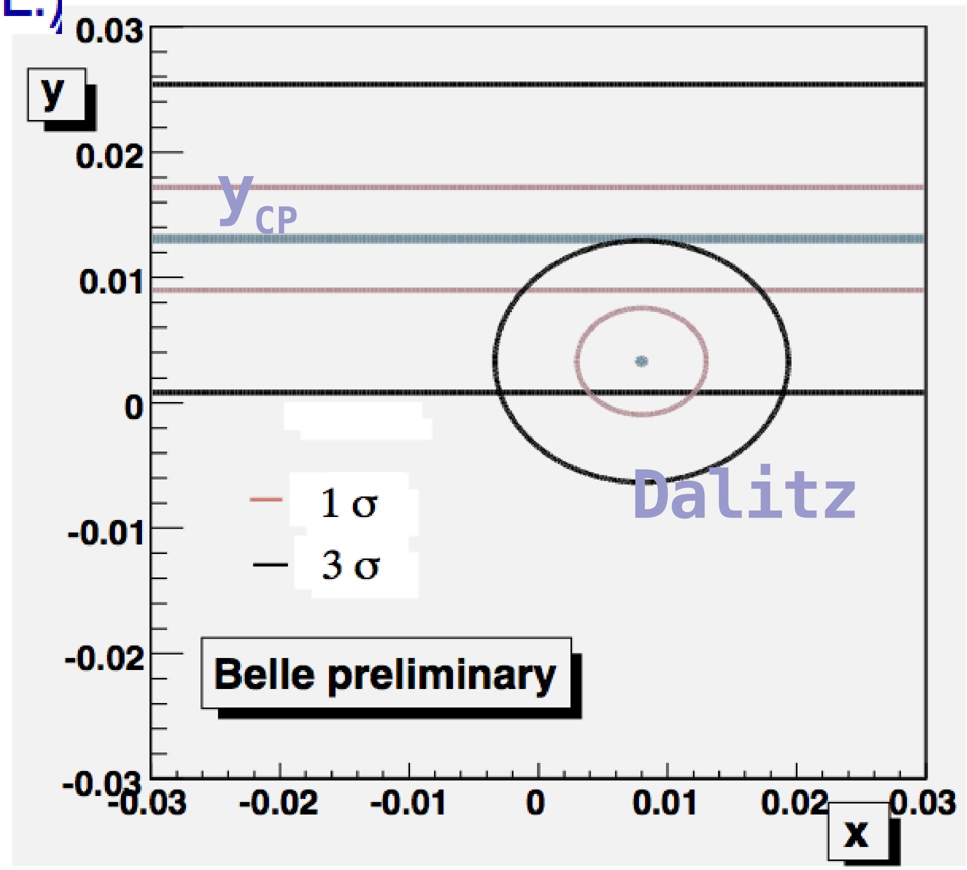
$$y = 0.33 \pm 0.24 \pm 0.15\ \%$$

σ syst :
Modello Dalitz (x),
Modello e PDF(t) (y)

(x=0,y=0) point:

$$-2\Delta \ln L = 7.3\ (2.6\%\ \text{C.L.})$$

- x, y non correlati
- x > y
- y consistente ~2 σ con y_{CP}



CP conservata ?

$$|M^0(t)\rangle = e^{-\bar{\gamma}t/2}\left(\cosh(\Delta\gamma t/2)|M^0\rangle - \frac{q}{p}\sinh(\Delta\gamma t/2)|\overline{M}^0\rangle\right)$$

CP violata :

- funzione d'onda $\Delta = \frac{|q^2|-|p^2|}{|q^2|+|p^2|} \neq 0$
- nel decadimento $A_f = A(D^0 \to f) \neq A(\overline{D}^0 \to \overline{f}) = \overline{A}_{\overline{f}}$

Conseguenze

- diversi parametri per eventi con tag D^{*+}, D^{*-}
- autostati massa ≠ autostati CP :

$$y_{CP} = y \cos\phi + x \,\Delta\, \sin\phi \neq y$$

$$\phi = Arg\left(\frac{q\,\overline{A}_{f_{CP}}}{p\,A_{f_{CP}}}\right) \quad \left(\simeq 2A^2 \sin^4\theta_C \eta < 10^{-3} \;\; nel \;\; M.S.\right)$$

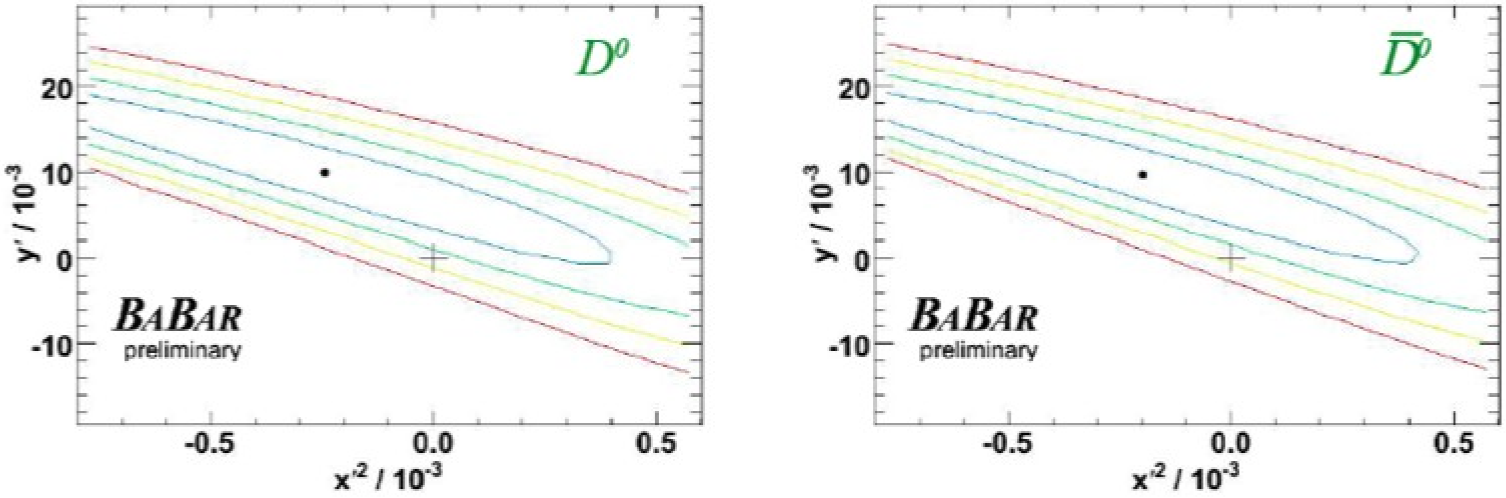
Verifiche

- Misure separate per D*+ / D*- :

x'^{+2}: $(-0.24\pm0.43\pm0.30)\times10^{-3}$ x'^{-2}: $(-0.20\pm0.41\pm0.29)\times10^{-3}$

y'^{+}: $(9.8\pm6.4\pm4.5)\times10^{-3}$ y'^{-}: $(9.6\pm6.1\pm4.3)\times10^{-3}$

$$A_{CP} = \frac{\Gamma(D^0 \to KK/\pi\pi) - \Gamma(\overline{D^0} \to KK/\pi\pi)}{\Gamma(D^0 \to KK/\pi\pi) + \Gamma(\overline{D^0} \to KK/\pi\pi)} = (.01\pm.30\pm.15)\ \%$$



NESSUNA EVIDENZA DI ~~CP~~

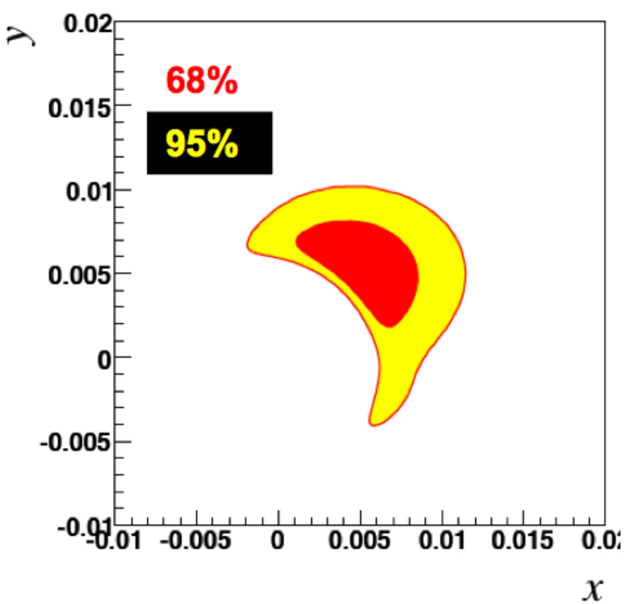
Interpretazioni

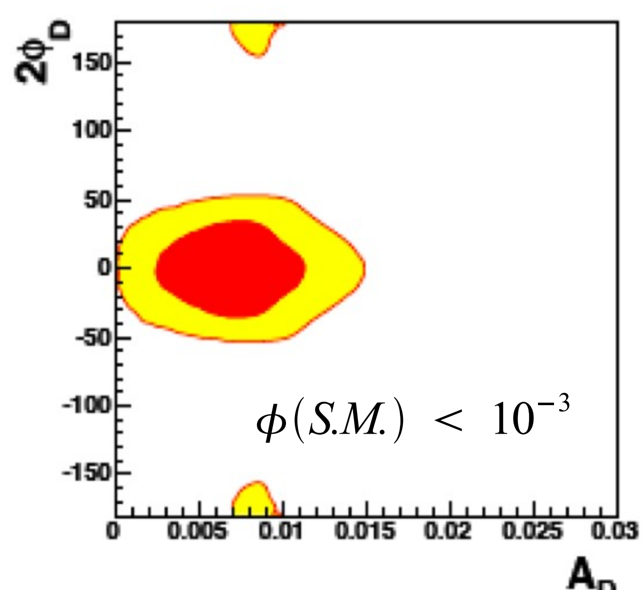
Analisi (Bayesiana) che include tutte le misure

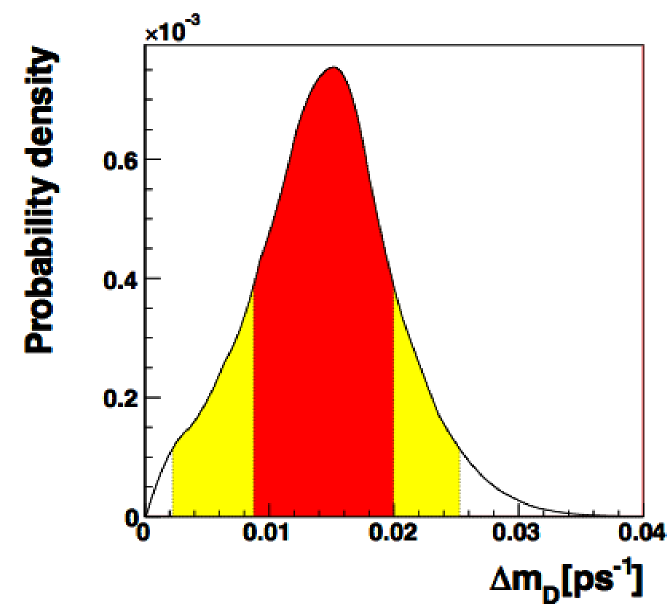
$$
\begin{aligned}
y'_{\pm} &= (1 \pm A_m)(y' \cos 2\phi_D \mp x' \sin 2\phi_D)\,, \\
x'^2_{\pm} &= (1 \pm 2A_m)(x' \cos 2\phi_D \pm y' \sin 2\phi_D)^2\,, \\
y_{\mathrm{CP}} &= y \cos 2\phi_D - A_m x \sin 2\phi_D\,, \\
A_\Gamma &= A_m y \cos 2\phi_D - x \sin 2\phi_D\,,
\end{aligned}
$$

$$A_m = 1 - |q/p|$$

Parameter	68% prob.	95% prob.
x	$(5.5 \pm 2.2) \cdot 10^{-3}$	$[0.0005, 0.0102]$
y	$(5.4 \pm 2.0) \cdot 10^{-3}$	$[0.0010, 0.0091]$
$2\phi_D$	$(0 \pm 22)^\circ$	$[-50^\circ, 50^\circ]$
δ	$(-38 \pm 46)^\circ$	$[-130^\circ, 36^\circ]$
A_m	-0.02 ± 0.15	$[-0.33, 0.29]$
Δm_D [ps^{-1}]	$(14.5 \pm 5.6) \cdot 10^{-3}$	$[0.0027, 0.0256]$







$$\Delta m_D = (14.5 \pm 5.6) \times 10^{-3}\, ps^{-1}$$

Ciuchini et al.
hep-ph/0703294

Vincoli su Nuova Fisica ?

- S.M. poco predittivo
- Tuttavia si possono estrarre delle conclusioni (generali) su N.F.
- V.Porretti (Meeting BABAR Italia) :

In molti scenari sono attesi notevoli segnali di D-Mixing

FCNC for D > FCNC for K

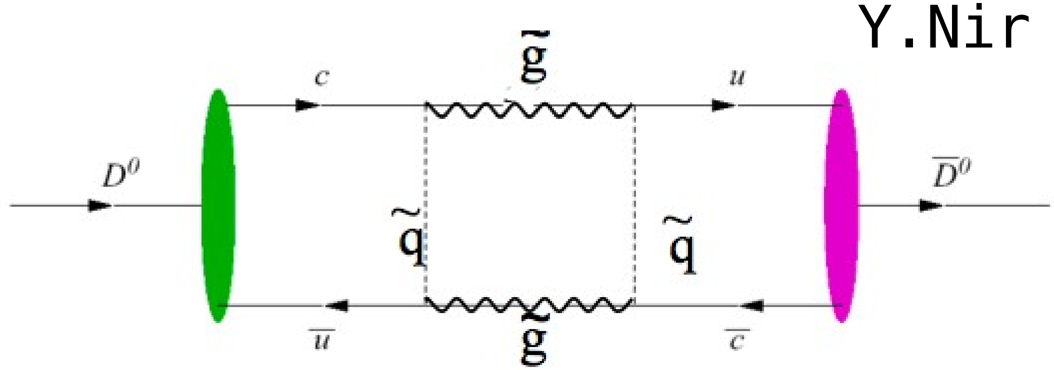
In words: in order to satisfy the bounds on the down sector, FCNC induced by the CKM must be shifted in the up sector.

This is a general reasoning that applies also to other models that predict large signals in D mixing (variants of technicolor and 2HDM models, some scenarios in extraD, littlest higgs models…)

- Un esempio ....

D-Mixing & SUSY

Y.Nir hep-ph/0703325



- *Questi diagrammi introducono sensibilita' a squarks e gluini*

The measurements constrain squark and gluino masses > 2 TeV

(MSSM con allineamento quark-squark)

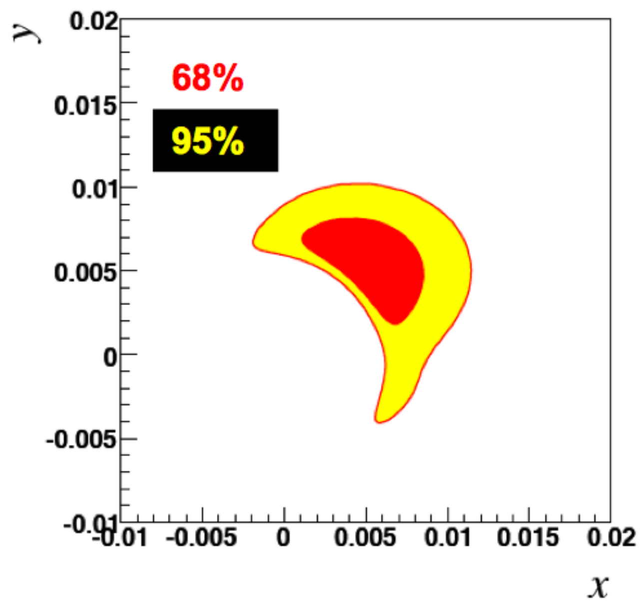
- *... brutte nuove per LHC*

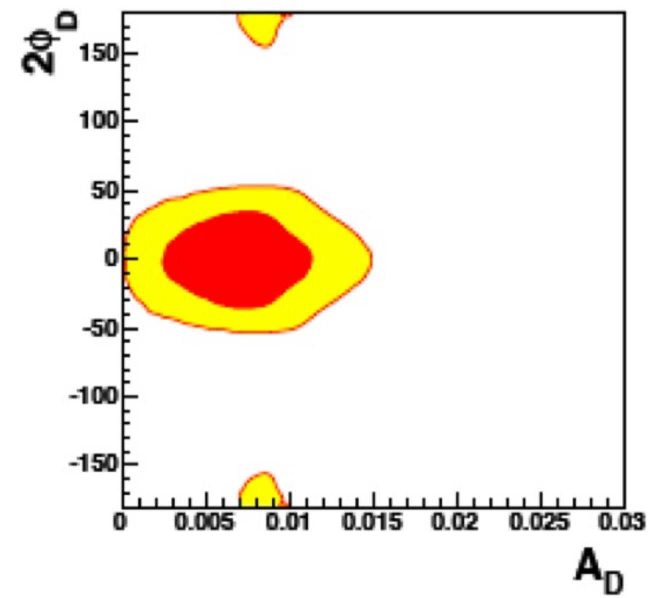
Ciuchini et al.
hep-ph/0703294

Conclusioni

Prime evidenze da BABAR e Belle di mixing del charm

- $x^2 + y^2 > 0$
- $x > y$?
- no CP ?





Misure attuali vincolano alcuni modelli di NF

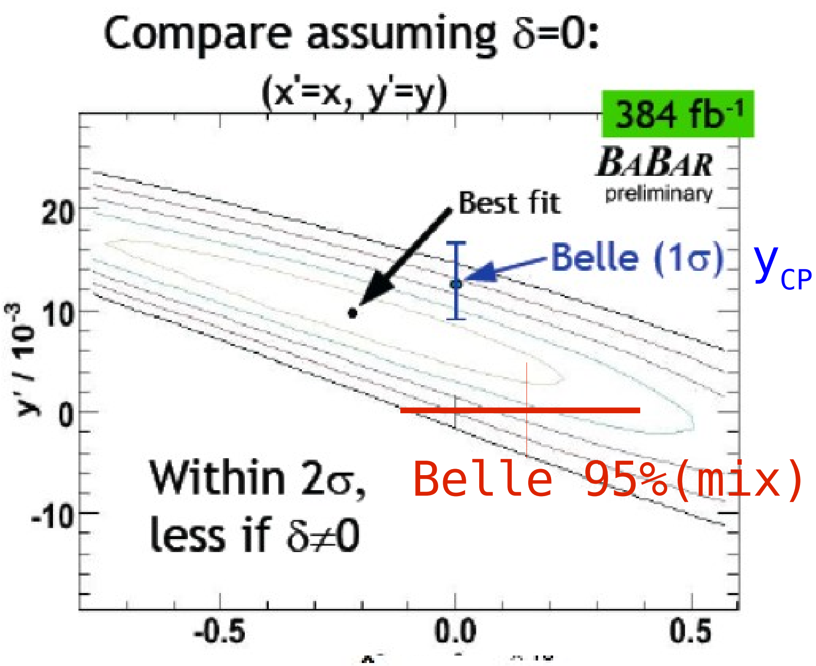
- no squark-gluini @LHC (R-conserved SUSY with alignment)

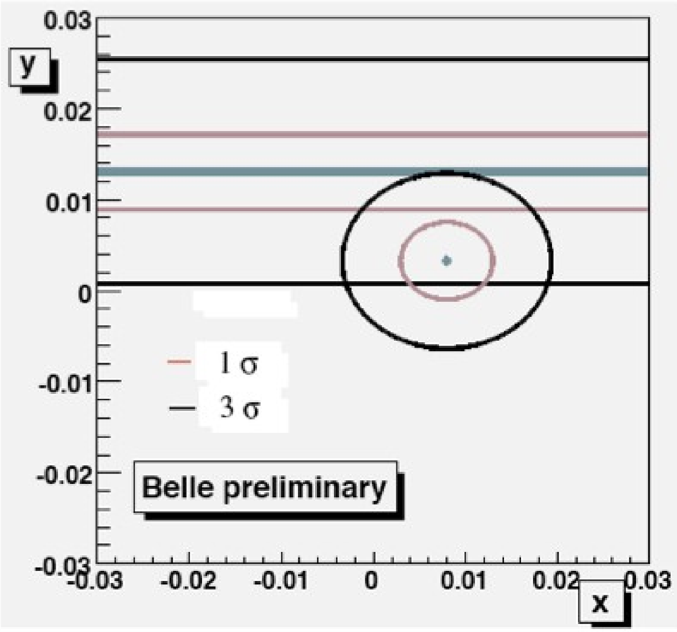
Estate: nuovi risultati da B-factories

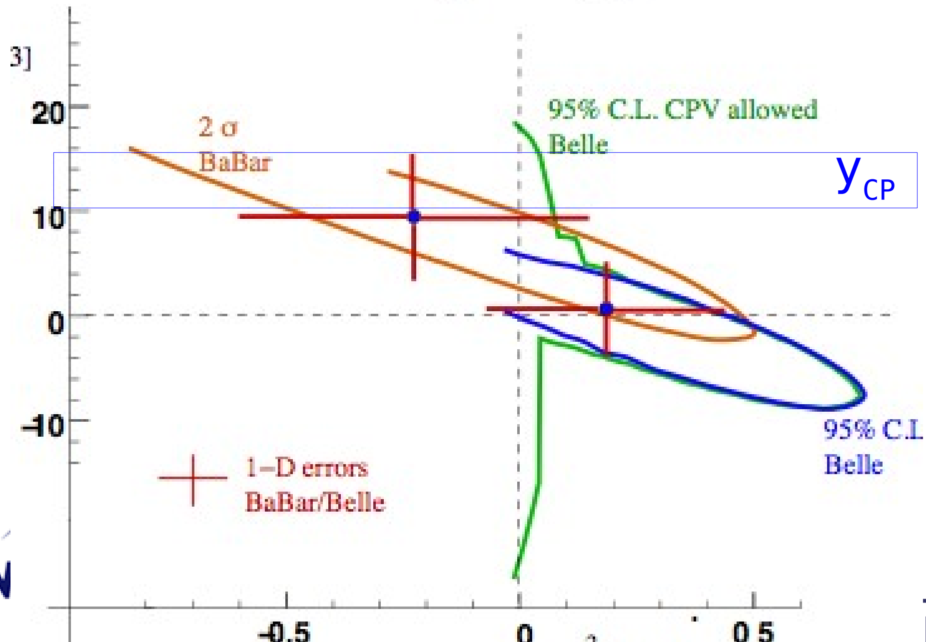
- Dalitz ($K3\pi$, $K_s\pi\pi$, $K^-\pi^+\pi^0$), y_{CP} (BABAR)

Miscellanea

Problemi di Consistenza ?







Il canale semileptonico

- Manca un neutrino ! (fondi abbondano nel wrong-charge)

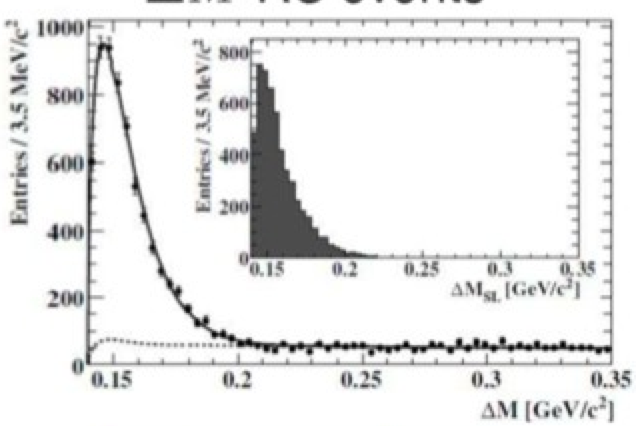
D-mixing with Semileptonic decay

$D^0 \to K^- l^+ \nu_l$

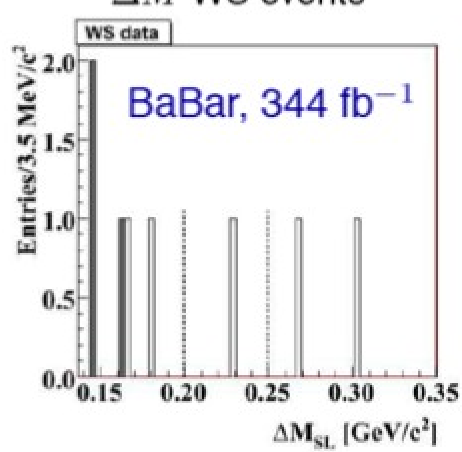
No DCS sl. ! $A_f = \bar{A}_{\bar{f}} = 0 \quad r(t) = \frac{e^{-t}}{4}(x^2+y^2)\,t^2\left|\frac{q}{p}\right|^2$

Double tag
$D^{*+} \to D^0\pi^+$, semil. and hadronic (fully rec.)
Several hadronic tagging modes

ΔM RS events



ΔM WS events



$$-1.3 \times 10^{-3} < R_M < 1.2 \times 10^{-3} \quad @\ 90\%\ C.L.$$

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Nuova Fisica ?

- Da Ciuchini et al ., citato :

$m_{\tilde{q}}$	$m_{\tilde{g}}$	$\left\|(\delta^u_{12})_{LL,RR}\right\|$	$\left\|(\delta^u_{12})_{LR,RL}\right\|$	$\left\|(\delta^u_{12})_{LL=RR}\right\|$
350	350	0.032	0.0056	0.0027
500	500	0.048	0.0080	0.0040
1000	1000	0.11	0.019	0.0080
500	1000	0.13	0.014	0.0060
500	350	0.028	0.0080	0.0036

TABLE III: Upper bounds at 95% probability for $\left|(\delta^u_{12})_{AB}\right|$ for various values of squark and gluino masses (in GeV).

It is very interesting that SUSY models with quark-squark alignment generically predict $(\delta^u_{12})_{LL} \sim 0.2$ [6]. We conclude that, to be phenomenologically viable, they need squark and gluino masses to be above ~ 2 TeV. Therefore, they probably lie beyond the reach of the LHC.