

Misure Sperimentali nei B

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Bibliografia

Per queste trasparenze :

<http://lxmi.mi.infn.it/~palombo/didattica/CPViolation/Lezione4-Apparati-MisureSperimentali.pdf>

Le misure sperimentali possono essere trovate nel “Review of Particle Physics” : <http://pdg.lbl.gov>

Per i risultati piu' aggiornati e sulle medie mondiali relative ai mesoni B si veda: <http://www.slac.stanford.edu/xorg/hfag>

Per la descrizione del rivelatore BaBar si veda una qualunque tesi di BaBar

I Mesoni B

I mesoni B sono stati scoperti nell'esperimento CLEO a CESR (Cornell) :

$$e^+ e^- \rightarrow Y(4S) \rightarrow BB \quad 50\% B^0 \bar{B}^0 \text{ e } 50\% B^+ B^- \quad (\text{PRL } 50, 881 (1983))$$

In termine di struttura a quark:

$$B_d^0 = (bd) , B_s^0 = (bs) , B^+ = (bu) , B^- = (\bar{b}u)$$

In questi mesoni il beauty B e' il numero quantico che distingue in produzione B^0 e $\bar{B}^0$ ma che non e' definito nel decadimento debole degli stati fisici i quali quindi possono oscillare (oscillazione del B).

Questi mesoni sono pesanti a causa del quark b : $M_B = 5279.50 \pm 0.33 \text{ MeV}$ [PDG (<http://pdg.lbl.gov> cercare Bottom Mesons)] e per questo motivo possono decadere in moltissimi modi, grande spazio delle fasi quindi.

A differenza degli stati fisici del K^0 (K_S e K_L) , qui i due stati fisici del B neutro e' meglio caratterizzarli per la massa : B_H e B_L

Beauty molto meglio della Stranezza

❖ I mesoni B hanno diversi vantaggi sui mesoni K

- 1) le osservabili di violazione di CP hanno valori aspettati molto maggiori (~ 1 vs 10^{-3})
- 2) molti piu' modi di decadimento $\rightarrow$ misure di cross-check con diversi decadimenti in cerca di inconsistenze
- 3) inferiori incertezze teoriche $\rightarrow$ constraints piu' forti sul MS

❖ Permettono un confronto diretto del MS con l'esperimento e la possibilita' di distinguere tra diversi modelli della violazione di CP

❖ Problemi sperimentali:

- 1) Distinguere i vertici dei due B
- 2) Distinguere bene il tipo di particelle (PID)
- 2) Decadimenti rari (servono un numero enorme di mesoni B)

B-factories

B-Factory e^+e^- e Collider adronici

In un collider adronico la sezione d'urto di produzione di coppie BB e' di circa 100 μb in confronto a $\sim 1.0 \text{ nb}$ ad una macchina e^+e^-

Ci sono svantaggi e vantaggi.

Alle macchine adroniche: alla maggiore statistica si contrappongono efficienze molto piu' basse, trigger molto selettivi per abbattere il fondo adronico, canali che non si possono osservare, ecc

$e^+e^- \rightarrow$	Cross Section (nb)
$b\bar{b} (\sigma_{b\bar{b}})$	1.05
$c\bar{c} (\sigma_{c\bar{c}})$	1.30
$s\bar{s} (\sigma_{s\bar{s}})$	0.35
$u\bar{u} (\sigma_{u\bar{u}})$	1.39
$d\bar{d} (\sigma_{d\bar{d}})$	0.35
$\tau^+\tau^- (\sigma_\tau)$	0.94
$\mu^+\mu^- (\sigma_\mu)$	1.16
$e^+e^- (\sigma_e)$	~ 40

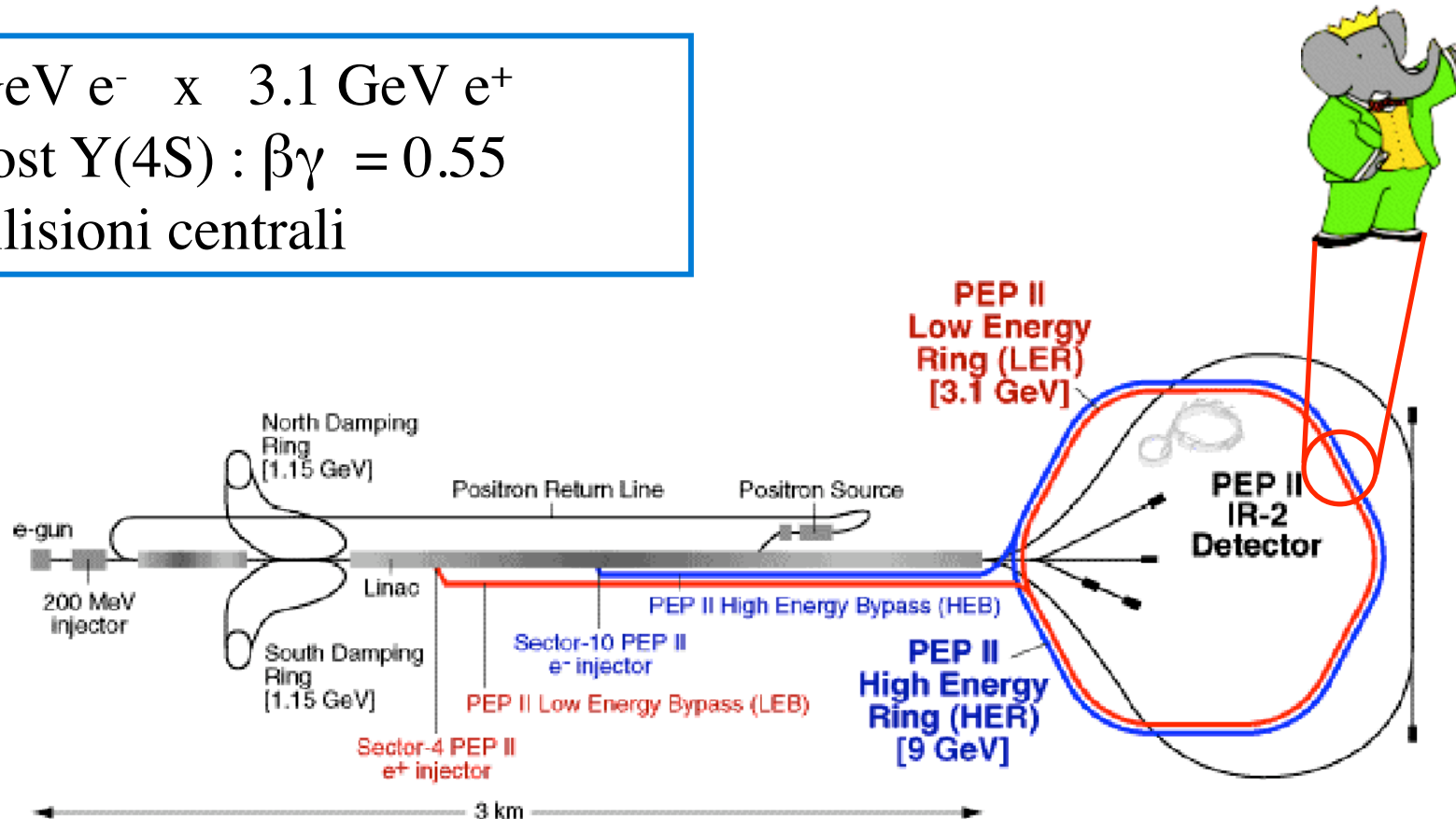
$$\text{nb} = 10^{-33} \text{ cm}^2$$

Alle macchine e^+e^- sezioni d'urto piu' basse ma fondi adronici trascurabili, segnali molto puliti, si producono solo coppie di BB, cc, etc.

Si noti che una b-factory e' anche una c-factory : molti risultati importantissimi sui charm ottenuti da BaBar (e Belle) (mixing dei D, molte nuove particelle, ecc) nonostante l'esiguo numero di analisi fatte.

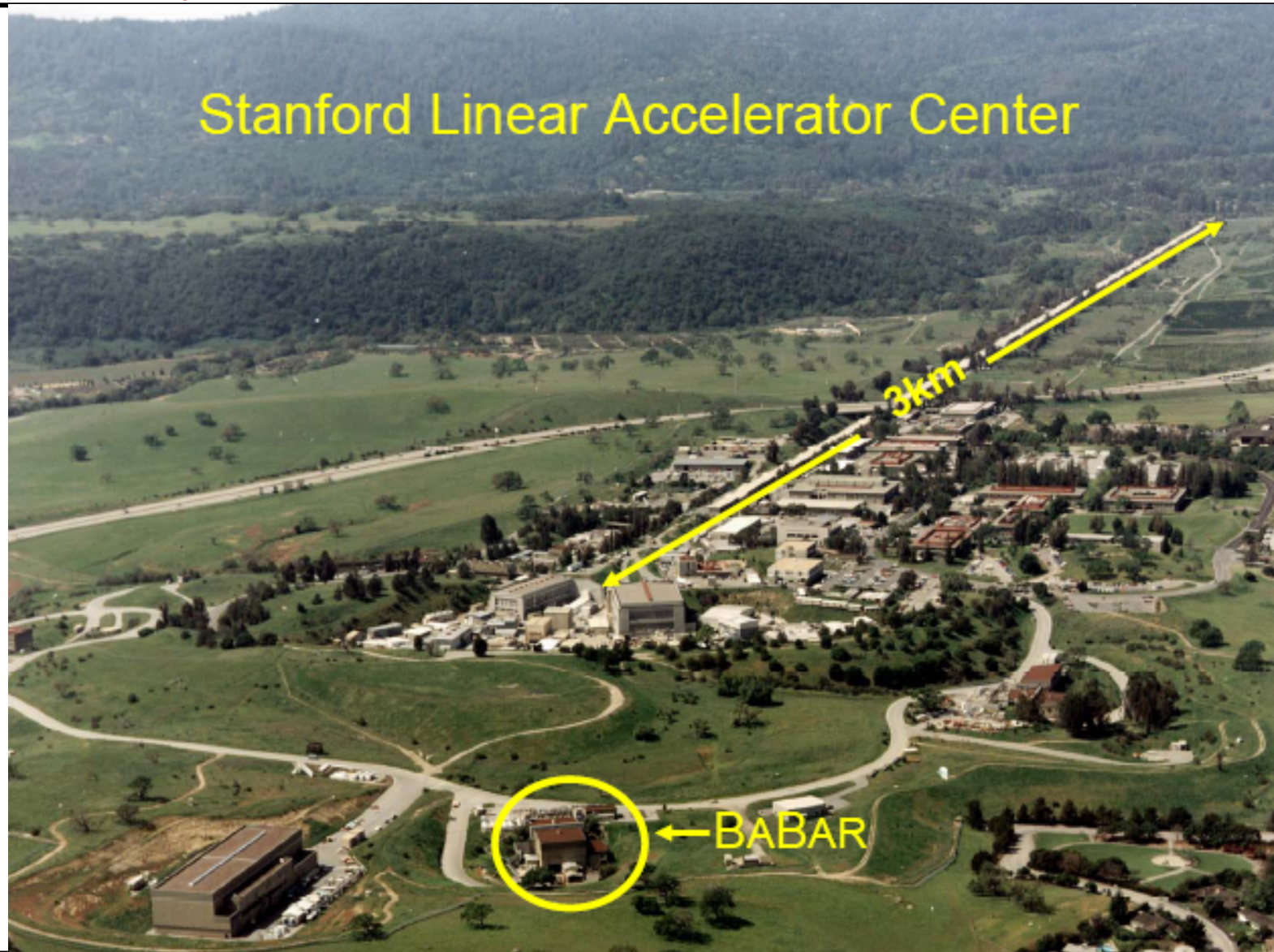
B-Factory Asimmetrica PEP-II at SLAC

$9 \text{ GeV } e^- \times 3.1 \text{ GeV } e^+$
Boost $Y(4S) : \beta\gamma = 0.55$
Collisioni centrali

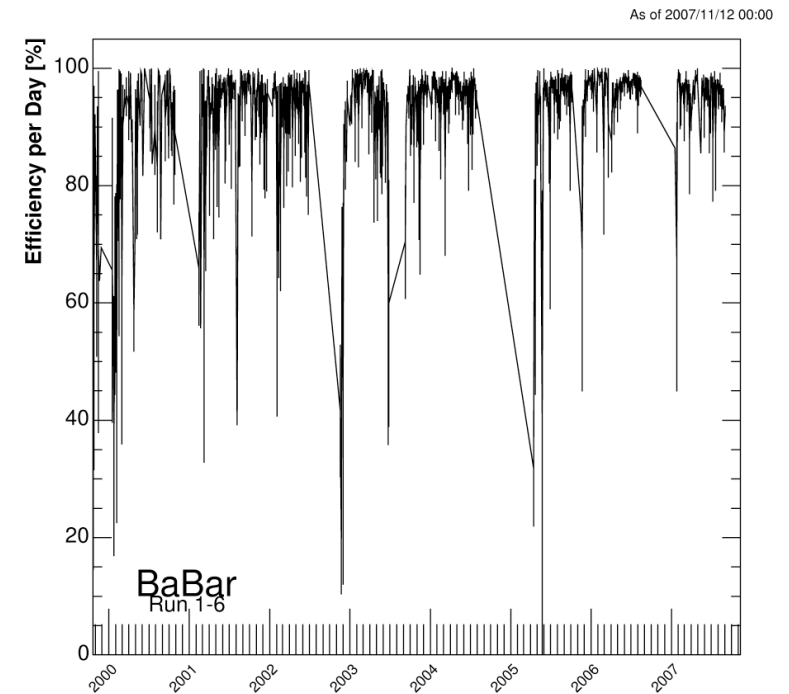
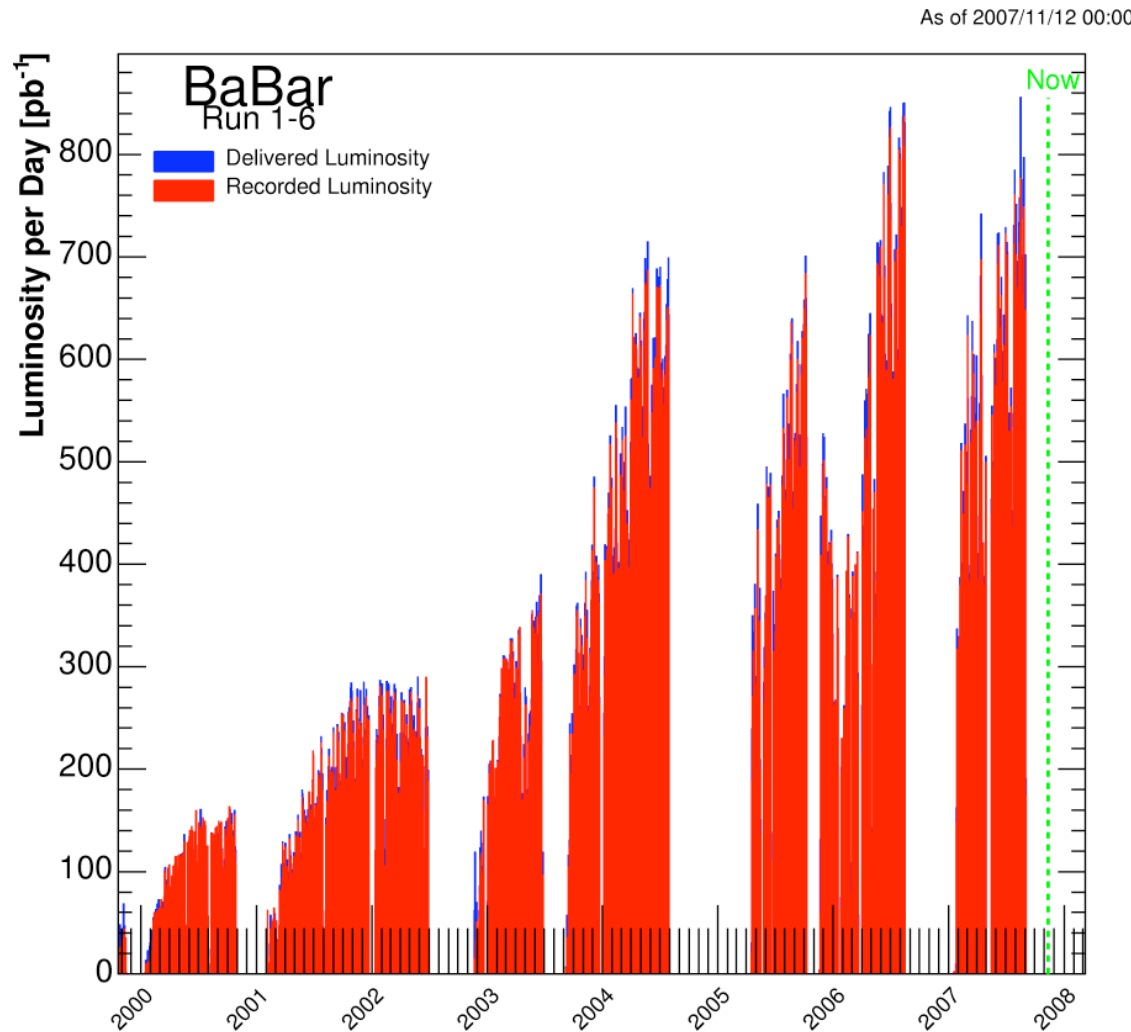


Stanford Linear Accelerator Center (SLAC)

B-Factory Asimmetrica PEP-II at SLAC



B-Factory PEP-II a SLAC



**96% efficienza su tutto
il tempo di presa dati
di BABAR !**

PEP-II Arc Section





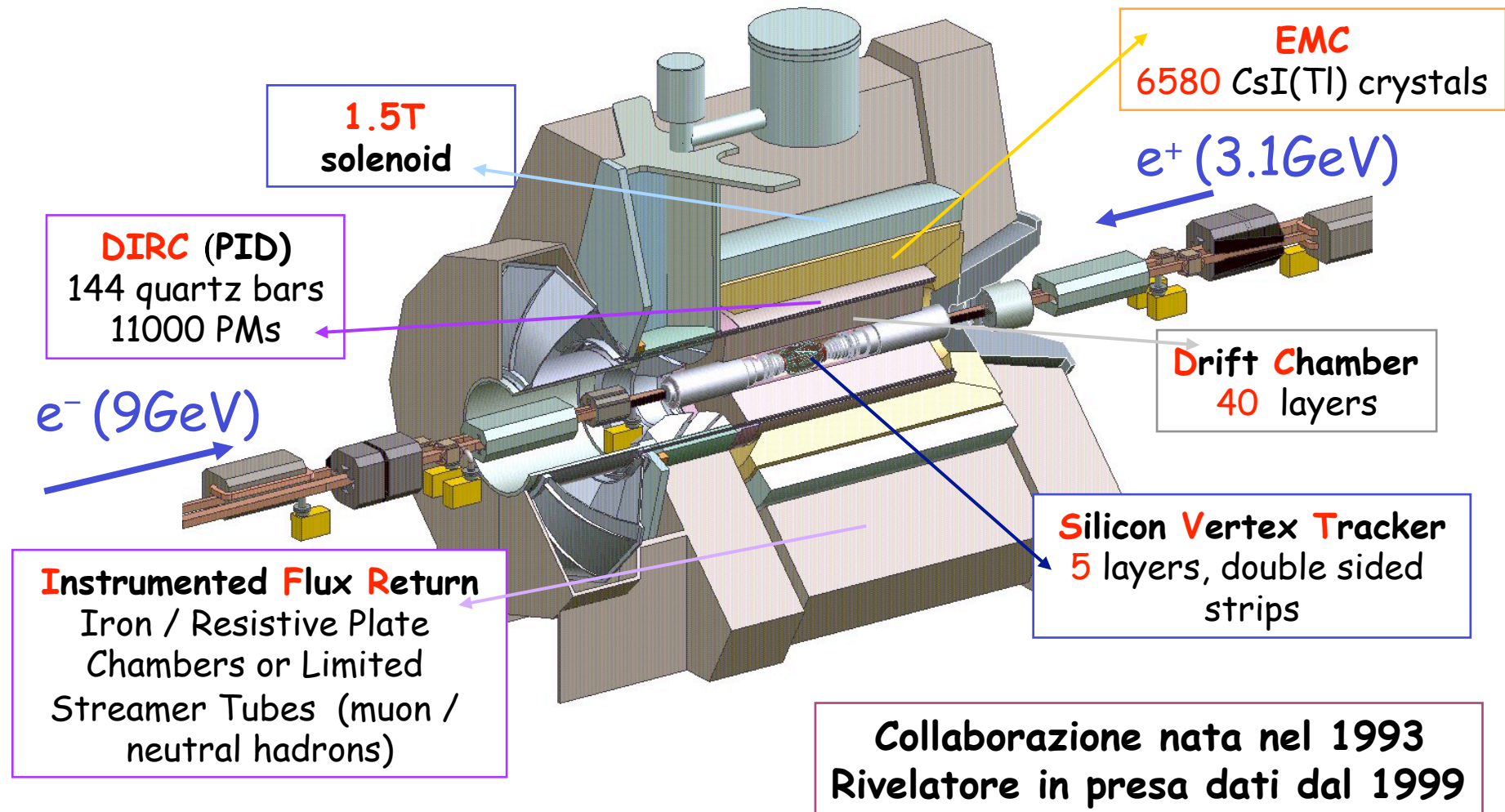
Collaborazione BaBar

11 Paesi

80 Istituzioni

623 Fisici (+ing)

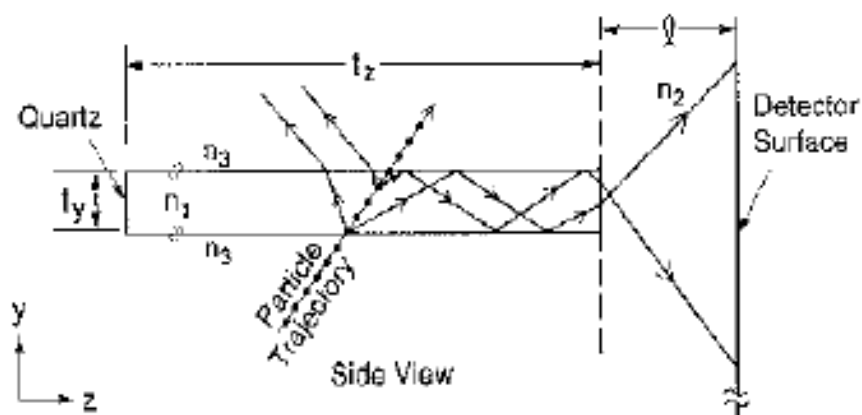
BABAR detector



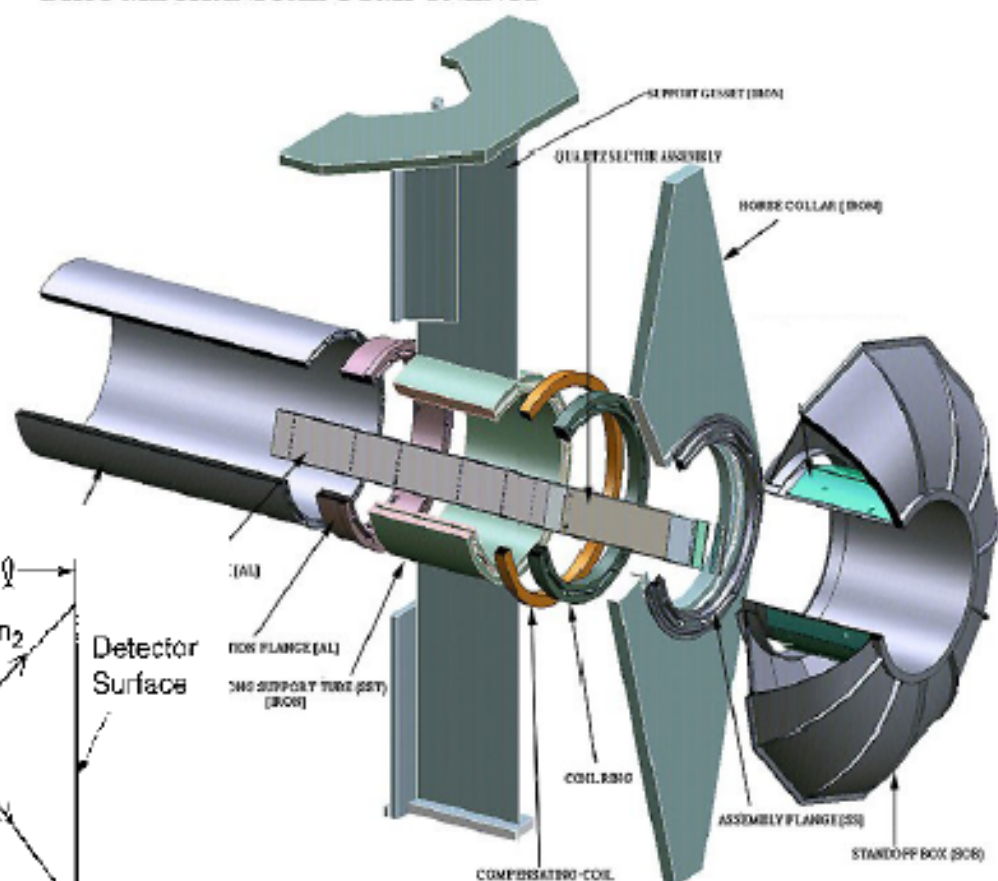
Particle identification: the DIRC

- Detector of Internally Reflected Cherenkov light

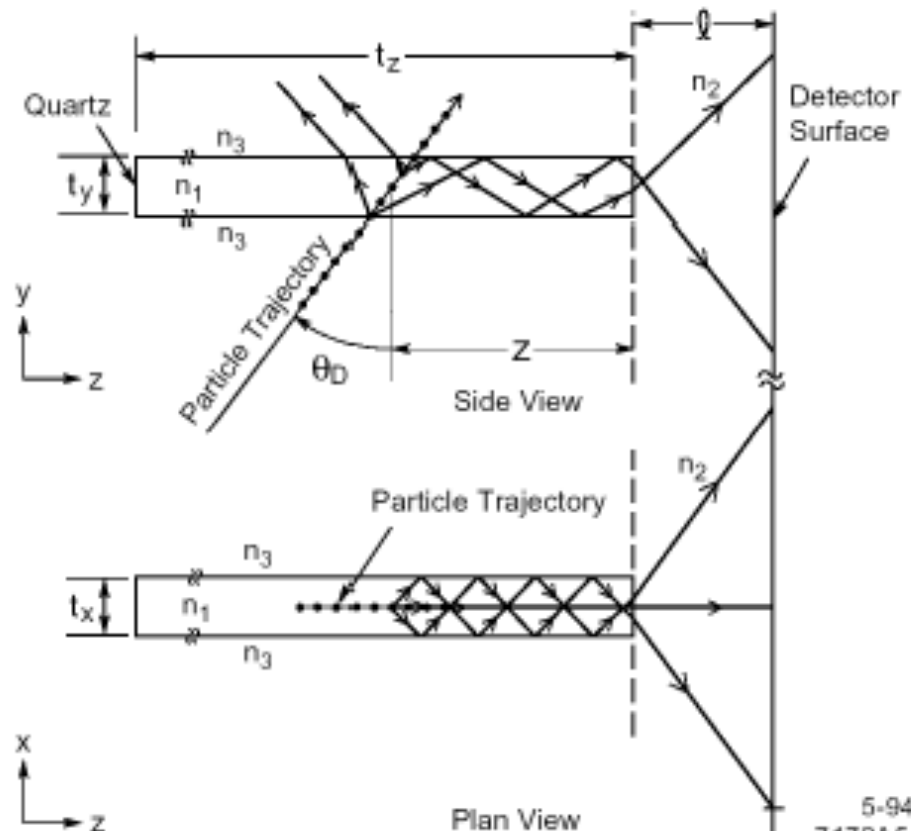
144 quartz bars (1.5 cm thick)
11000 PMTs, 25-50
p.e./particle,
9mrad single photon resolution



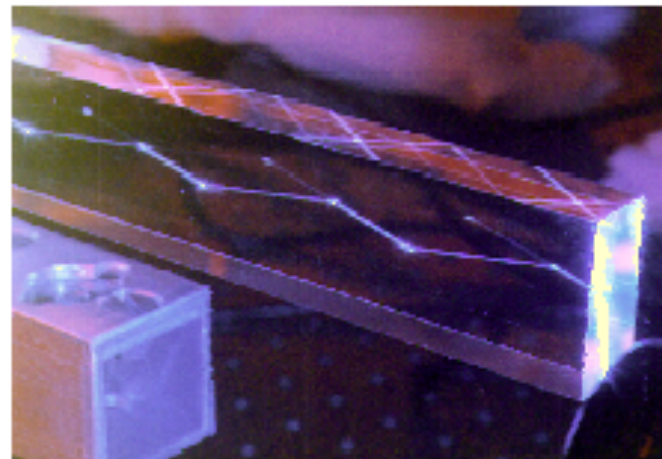
DIRC MECHANICAL COMPONENTS



Principle of the DIRC



- o UV Cherenkov light generated in quartz with characteristic $1/\beta$ opening angle
- o Light transmitted length of bar by internal reflection, preserving angle information due to precision surfaces
- o Rings projected in water-filled standoff box (best match to quartz index), where photons are detected with an array of 10K PMTs



K identification performance

Charged K identified by

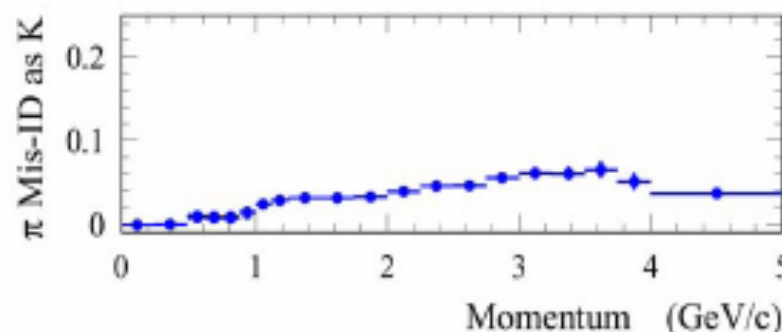
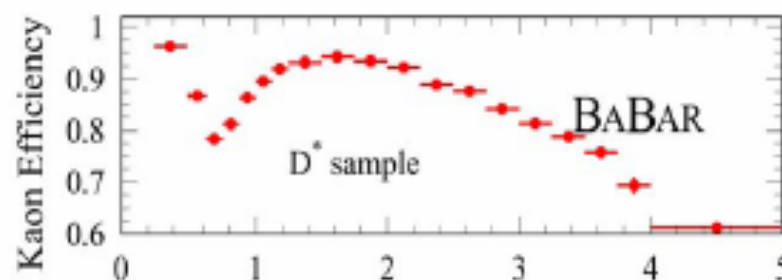
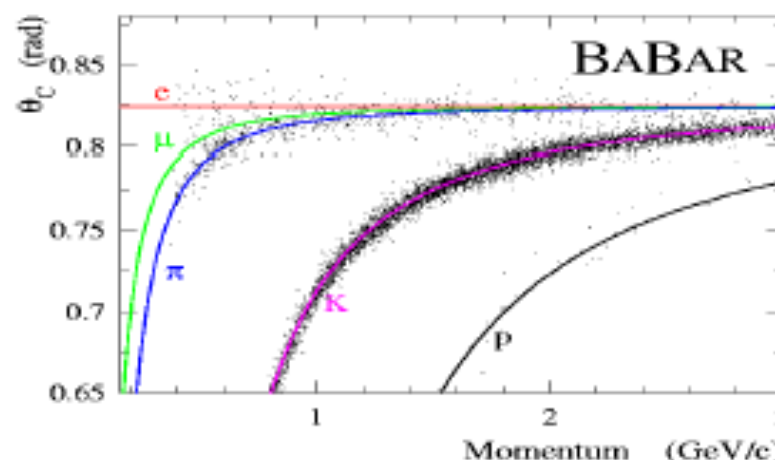
DIRC: Cerenkov angle

DCH: dE/dx ($p < 0.7$ GeV/c)

Efficiency and purity measured on
control samples (soft pion tag)

$D^{*+} \rightarrow D^0 \pi^+$, $D^0 \rightarrow K^- \pi^+$

$> 3.4\sigma$ π/K separation up to $\approx$
3.5 GeV/c



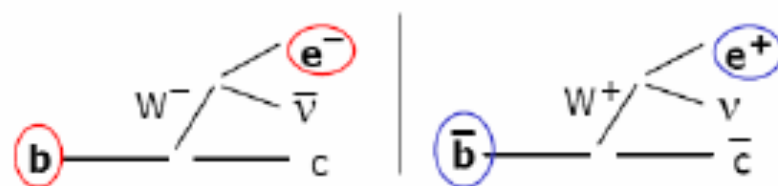
B Flavour Tagging

CP asymmetry is between $B^0 \rightarrow f$ and $\bar{B}^0 \rightarrow f$

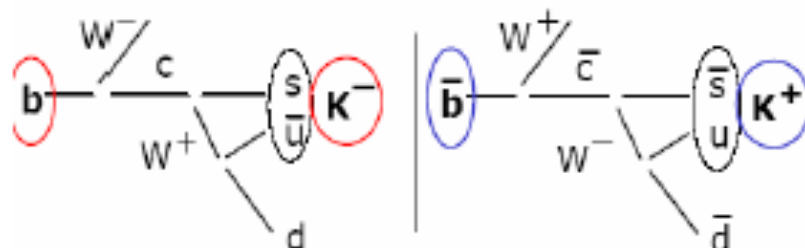
Must tag flavor at $\Delta t=0$ (when we know flavor of two Bs is opposite).

Use decay products of *other* (tag) B.

Leptons : Cleanest tag. Correct >95%



Kaons : Second best. Correct 80-90%



Soft and hard pion tagging

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

$$\hookrightarrow D^0 \pi^+$$

$\bar{B}^0$: fast π^- , soft π^+

B^0 : fast π^+ , soft π^-

Overall tagging performance

$$\sum_i \varepsilon_i (1 - 2\omega_i)^2 \approx 28\%$$

recently improved to 30.5%

BaBar

ε_i tag efficiency

ω_i wrong tag probability

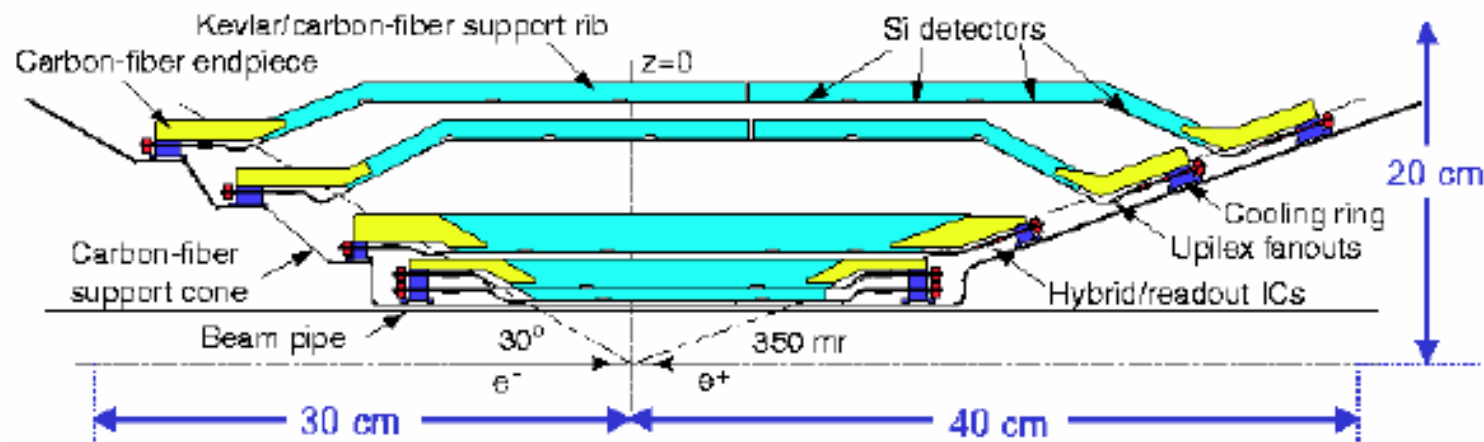
BaBar: the Silicon Vertex Tracker

double-sided Si microstrip
detectors

5 layers: 340 wafers, 150000
readout channels

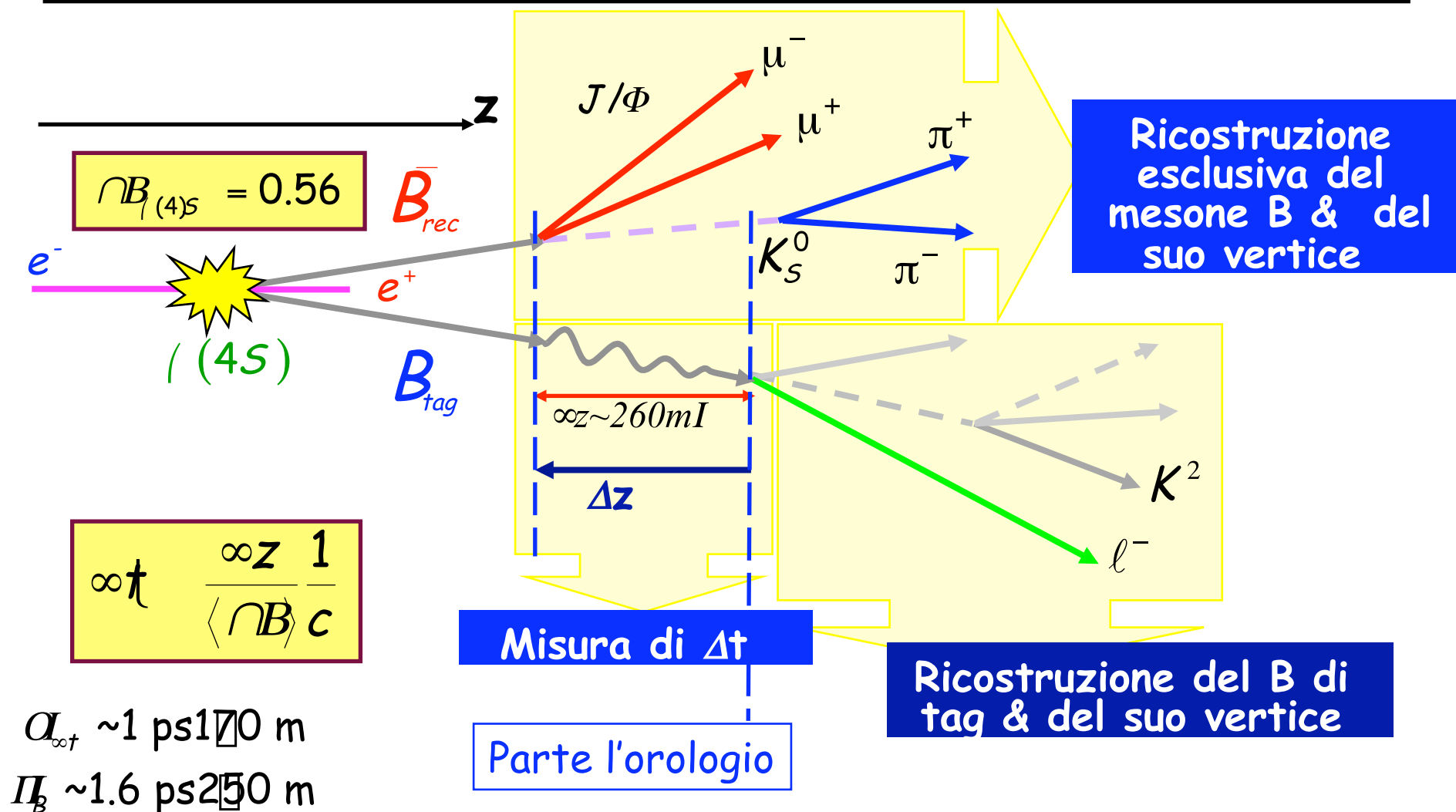
$20^\circ < \theta < 150^\circ$

$\sigma_{\text{point}} \approx 10\text{-}15\ \mu\text{m}$ for the inner
layers



High Density Interconnect (HDI) e Tails fatte a Milano (F. Palombo)
Chip di readout (parte analogica) da P.F. Manfredi (Pavia)

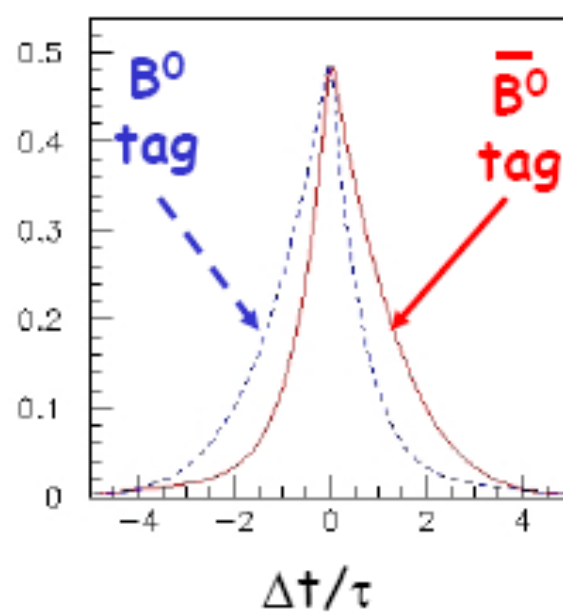
Collisioni con Energie Asimmetriche



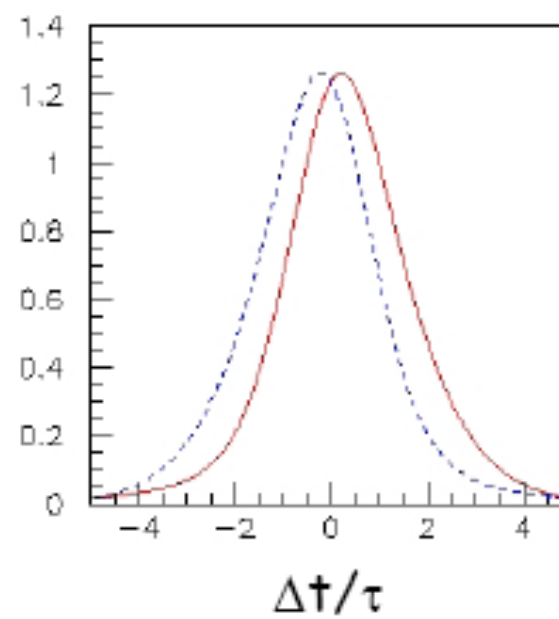
Δt resolution effect

CP time-dependent asymmetry ($C=0$, $S \neq 0$)

Tag from
"other B"



perfect resolution



smeared resolution

Time-integrated asymmetry = 0
 $\Rightarrow$ Need both Δt and tag !

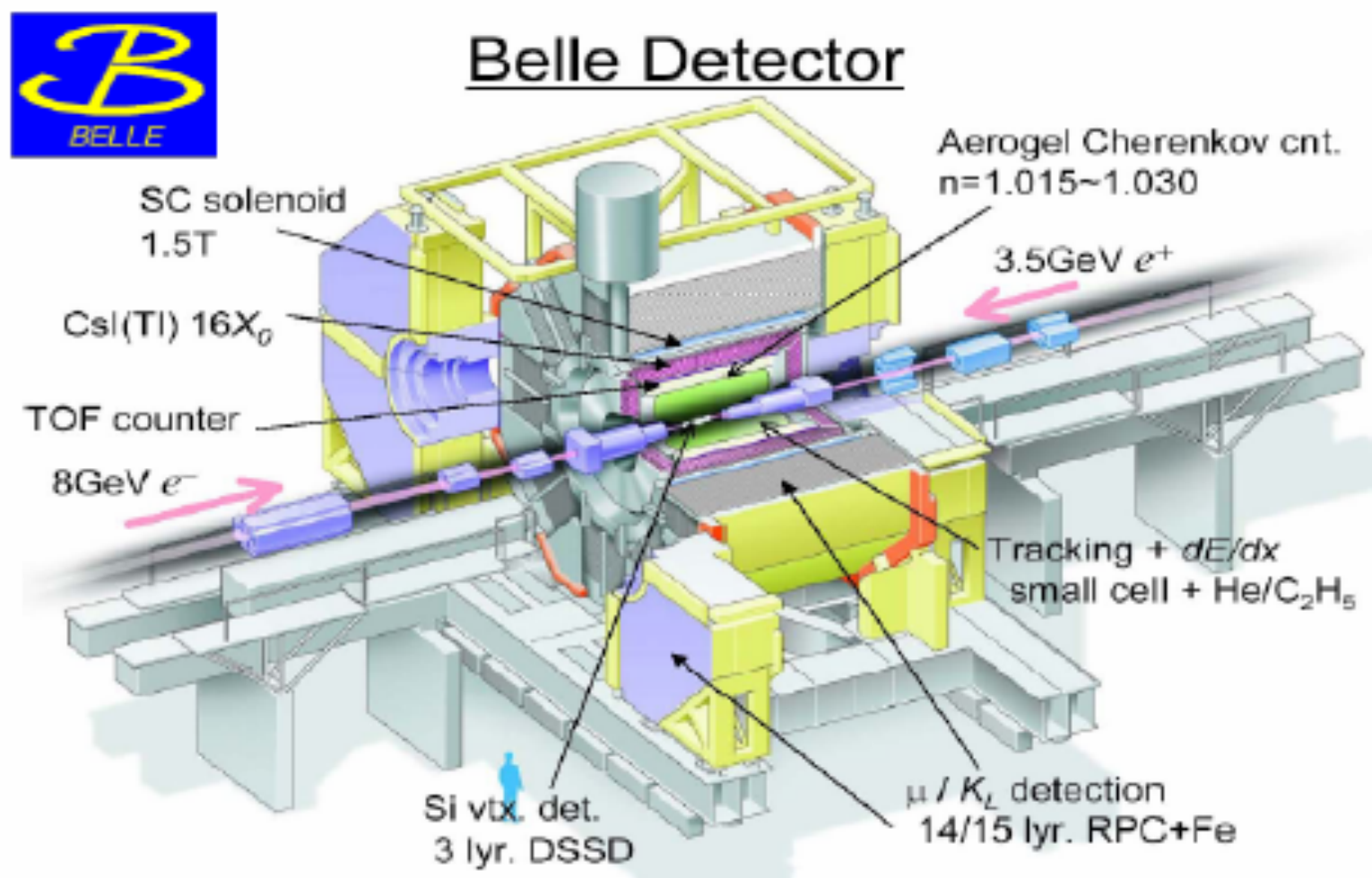
$$B^0(\bar{B}^0) \rightarrow f_{CP}$$

Δt resolution dominated
by tag side:

$$\sim 1 \text{ ps} \Leftrightarrow 170 \text{ } \mu\text{m}$$

$$\tau_B \sim 1.6 \text{ ps} \Leftrightarrow 250 \text{ } \mu\text{m}$$

Belle detector at KEK



Both BaBar and Belle: optimized for CP asymmetries

Metodi di Analisi (selezione del segnale)

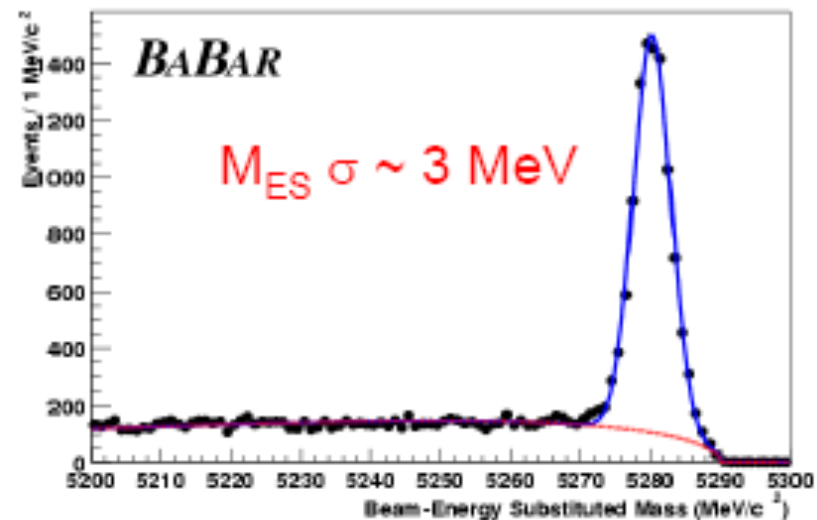
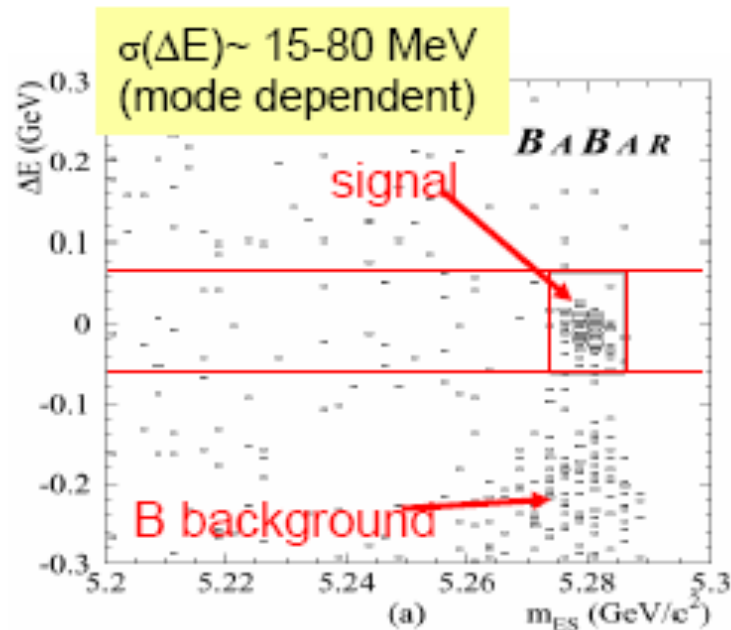
- Energia del fascio molto ben conosciuta in un collider e^+e^- come PEP-II :

$$e^+e^- \rightarrow Y(4S) \rightarrow B\bar{B}$$

- Differenza di energia e massa effettiva per selezionare eventi:

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

$$m_{ES} = \sqrt{(E_{beam}^*)^2 - P_B^2}$$



Metodi di Analisi (selezione del segnale)

- Forma dell'evento per distinguere tra eventi $Y(4S) \rightarrow BB$ ed eventi $e^+e^- \rightarrow qq$



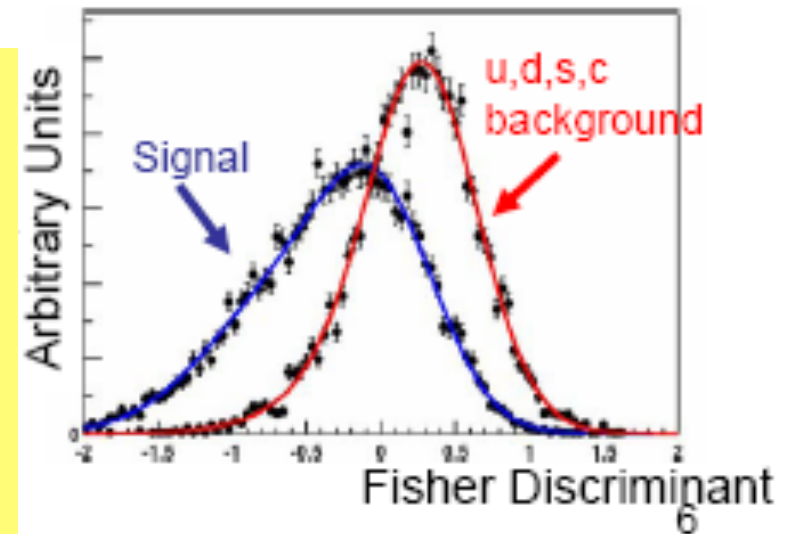
Eventi B a forma sferica



Continuo qq a forma di jet

Si combinano diverse variabili della forma dell'evento in una singola variabile discriminante : Fisher, reti neurali, rapporti di likelihood, decision trees, Boosted decision trees, ecc

Discriminazione tra segnale e eventi del continuo



Strumenti di Analisi Dati a Milano

- Gli eventi di tutte le analisi fatte a Milano ricostruiti col package **MiReco** a SLAC o Rutherford (tutte n-tuple in formato root trasferite a Milano per l'analisi dei dati).
- Selezione dei dati e analisi dei dati fatte col package **MiFit**. Questo e' una interfaccia a RooFit, il package di BaBar per l'analisi dei dati in ambiente ROOT (C++, linux)
- **MiFit** e' un package molto potente e molto "user-friendly". I laureandi sono messi in grado in breve tempo di fare analisi molto complesse. Gli studenti hanno un ruolo notevole !
- Nel 2006 Milano ha pubblicato 5 lavori (2 PRL e 3 PRD-RC) e un altro PRL su "Time-dependent Analysis in $B^0 \rightarrow a_1 \pi$ " agli inizi del 2007.

Metodi di Analisi (estrarre l'informazione)

Decadimenti rari : $BF \sim 10^{-5} - 10^{-7}$

- Fondo largamente dominato da eventi $e^+ e^- \rightarrow qq$ ma anche con contributi da altri decadimenti del B .
- Informazione discriminante generalmente disponibile in piu' dimensioni.
- Si fanno fit di massima verosimiglianza estesa, non istogrammata per estrarre e studiare gli eventi di segnale

$$L = \text{Poisson term} \times \prod_{\text{events}} \left(N_{\text{signal}} P_{\text{signal}} + \sum_{\text{backgrounds}} N_{\text{background}} P_{\text{background}} \right)$$

Analisi Blind

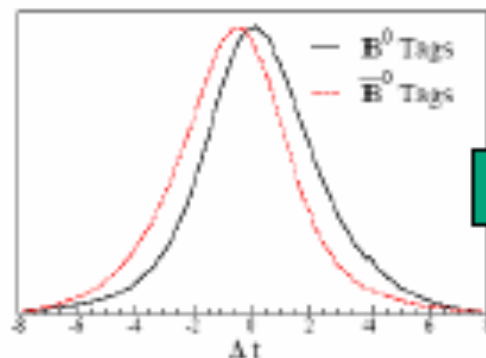
CP Analysis: a Blind Analysis

Blind Analysis in Particle Physics → Exciting "unblinding parties"...

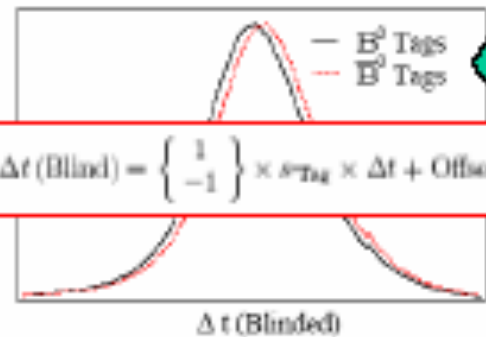
Aaron Roodman

Stanford Linear Accelerator Center, Stanford, CA 94025, USA

PHYS112003, SLAC, Stanford, California, September 8-11, 2003



Blinded...



$$\Delta t(\text{Blind}) = \begin{Bmatrix} 1 \\ -1 \end{Bmatrix} \times s_{\text{Tag}} \times \Delta t + \text{Offset}$$

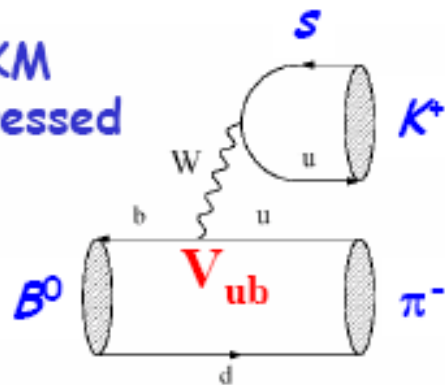


Violazione di CP Diretta nei B

$B^0 \rightarrow h^+ h^-$: direct CPV ?

Tree-level $b \rightarrow u = T$

CKM suppressed



$$BF(B^0 \rightarrow K^+ \pi^-) = (18.5 \pm 1.0) \times 10^{-6}$$

Penguin dominated:

$$A_{K\pi} = \lambda^2 e^{i\gamma} T + P$$

Expect direct *CPV* asymmetry and constraints on γ (theoretically difficult!)

$$A = \frac{\Gamma(B \rightarrow f) - \Gamma(\bar{B} \rightarrow \bar{f})}{\Gamma(B \rightarrow f) + \Gamma(\bar{B} \rightarrow \bar{f})} = \frac{2|T||P| \sin \delta \sin \gamma}{|T|^2 + |P|^2 + 2|T||P| \cos \delta \cos \gamma}$$

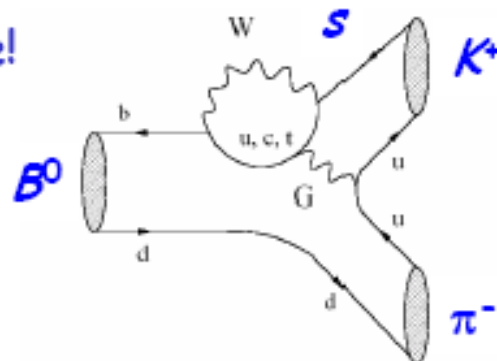
(where δ = CP-conserving strong phase complicated by long-distance & re-scattering)



Look for direct CPV!

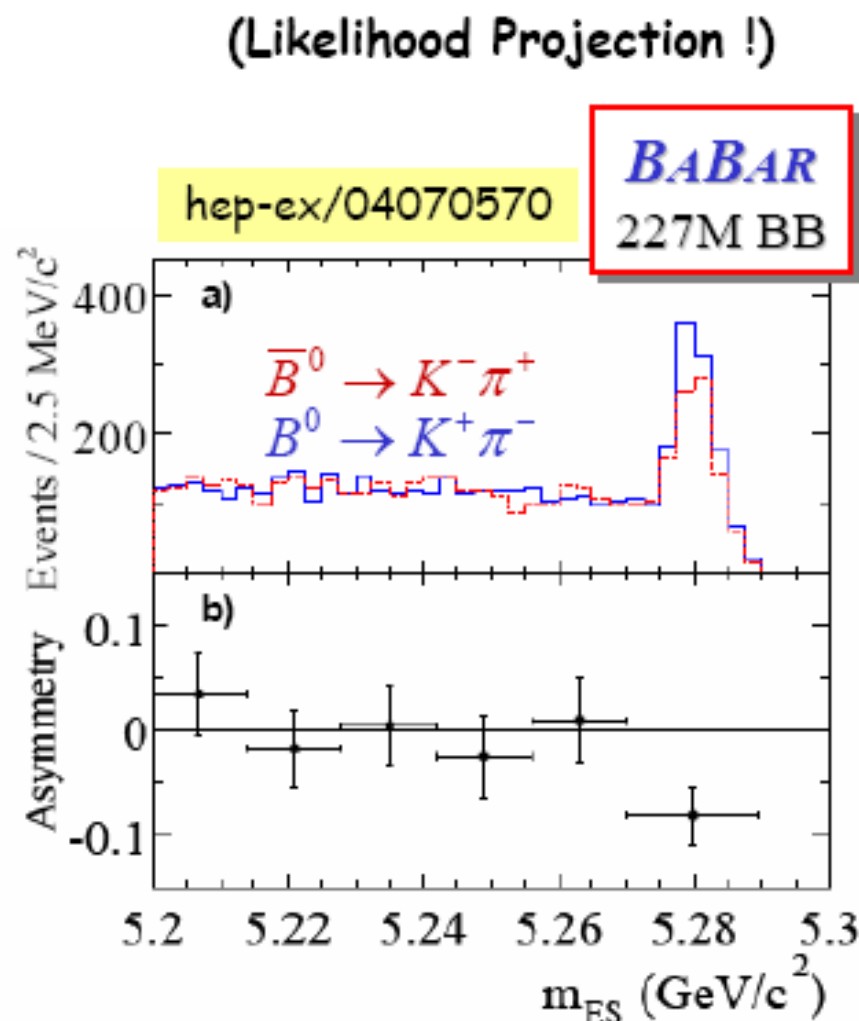
Internal Penguin = P

Large!



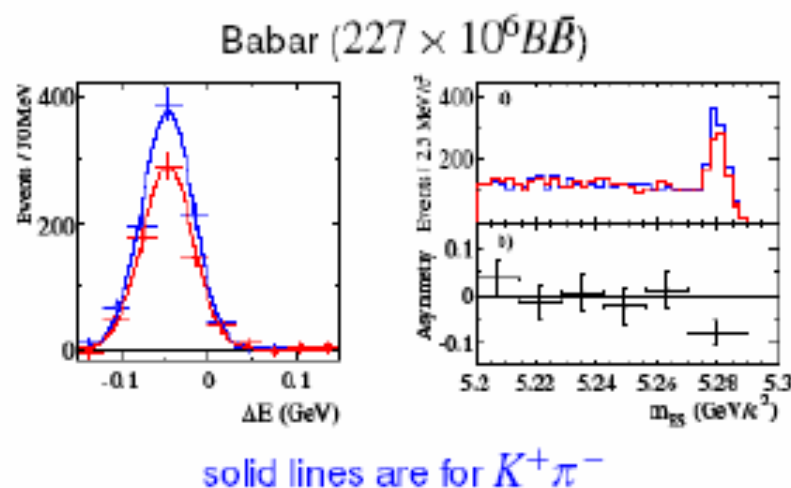
Direct CP asymmetry in $B^0 \rightarrow K^+ \pi^-$!

- **BaBar analysis (2004)**
 - 227 M $B\bar{B}$ events
 - 68030 selected events
- **Extended ML fit:**
 - discriminating variables:
 $\vec{x}_j = \{m_{ES}, \Delta E, \mathcal{F}, \theta_c^+, \theta_c^-\}$
 - Fisher, Cherenkov angles
- **Fitted parameters**
 - Yields for $K\pi$, $\pi\pi$, KK
 $n_{K\pi} = 1606 \pm 51$
 $n_{\pi\pi} = 467 \pm 33$
 $n_{KK} = 3 \pm 12$
 - asymmetries for signal and background $A_{K\pi}$, $A_{K\pi}^b$



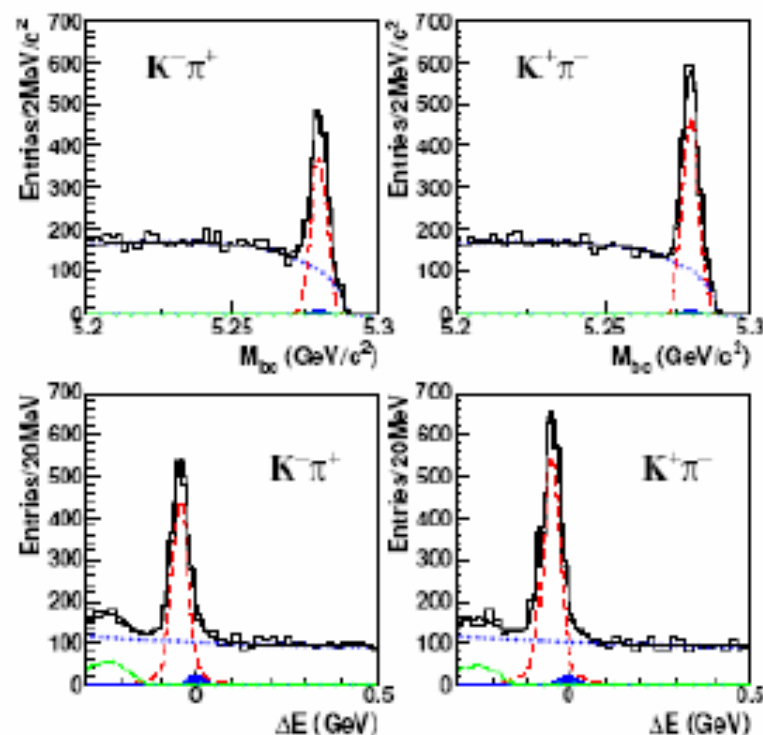
Update at LP 2005

$\bar{B}^0 \rightarrow K^- \pi^+$ is Different from $B^0 \rightarrow K^+ \pi^-$



$$A_{CP}(K^+ \pi^-) = -0.133 \pm 0.030 \pm 0.009$$

Belle ($386 \times 10^6 B\bar{B}$)



$$A_{CP}(K^+ \pi^-) = -0.113 \pm 0.022 \pm 0.008$$

Definitively rules out Superweak models

Violazione di CP nel Mixing nei B

B_d lifetime : status

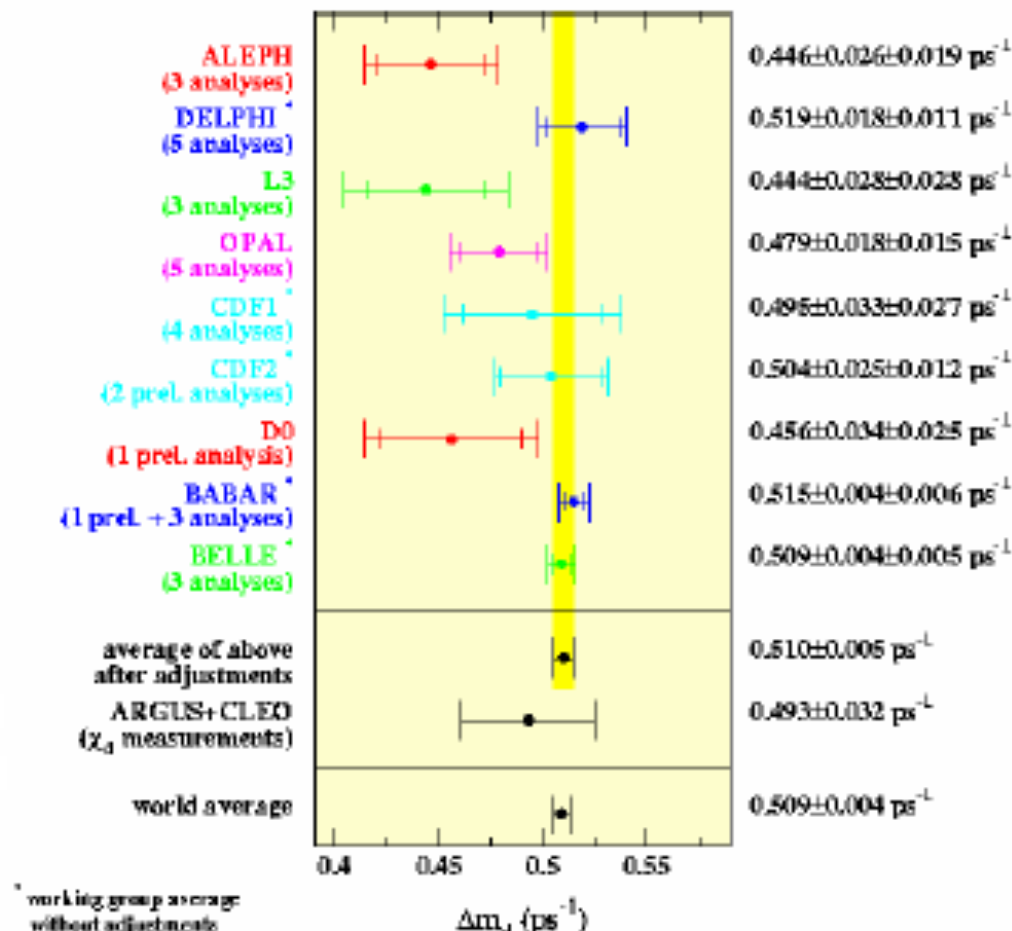
HFAG, Winter 2005

(from all ALEPH, DELPHI, L3,
OPAL, CDF, D0, BABAR,
BELLE, ARGUS and CLEO
measurements)

assuming

$$\tau_{B_d} = 1.528 \pm 0.009 \text{ ps}$$

$$\Delta m_d = 0.509 \pm 0.004 \text{ ps}^{-1}$$



A_{SL} , $|q/p|$, ε_B are related

A_{SL} observable and CP parameters:

$$A_{SL} \equiv \frac{P(\bar{B}^0 \rightarrow B^0) - P(B^0 \rightarrow \bar{B}^0)}{P(\bar{B}^0 \rightarrow B^0) + P(B^0 \rightarrow \bar{B}^0)}$$

$$A_{SL} = \frac{\Gamma_{Y(4S) \rightarrow l^+ l^+} - \Gamma_{Y(4S) \rightarrow l^- l^-}}{\Gamma_{Y(4S) \rightarrow l^+ l^+} + \Gamma_{Y(4S) \rightarrow l^- l^-}} =$$

← at the B-factories

$$= \frac{|p/q|^2 - |q/p|^2}{|p/q|^2 + |q/p|^2} = \frac{1 - |q/p|^4}{1 + |q/p|^4} \equiv \frac{4 \operatorname{Re} \varepsilon_B}{1 + |\varepsilon_B|^2}$$

← equivalent to ε_K
in the K system

$$\varepsilon_B = \frac{p - q}{p + q} \Rightarrow \frac{q}{p} = \frac{1 - \varepsilon_B}{1 + \varepsilon_B}$$

$$\left| \frac{q}{p} \right| = \sqrt[4]{\frac{1 - A_{SL}}{1 + A_{SL}}}$$

CPV in B_d mixing: A_{SL}

Experimental status:

from measurements at LEP, CLEO, BaBar and Belle:

$$\begin{aligned} |q/p| &= 1.0013 \pm 0.0067 \\ A_{SL} &= -0.0026 \pm 0.0034 \\ \frac{\text{Re } \epsilon_B}{1 + |\epsilon_B|} &= -0.0007 \pm 0.0017 \end{aligned}$$

HFAG, Winter'05 average

Not easy to improve: systematics!

For example, the most recent paper: *BELLE*, [hep-ex/0505017](#):

$$\begin{aligned} A_{sl} &= (-1.1 \pm 7.9(\text{stat}) \pm 7.0(\text{sys})) \times 10^{-3}, \\ |q/p| &= 1.0005 \pm 0.0040(\text{stat}) \pm 0.0035(\text{sys}). \\ \frac{\text{Re}(\epsilon_B)}{1 + |\epsilon_B|^2} &= (-0.3 \pm 2.0(\text{stat}) \pm 1.7(\text{sys})) \times 10^{-3} \end{aligned}$$

BELLE 2005
(78 + 9) fb⁻¹

< 1/5 of the
available data !

Violazione di CP nell'Interferenza sen 2β

$K^0, D^0, B^0_d, B^0_s: \Delta m$ and $\Delta \Gamma$

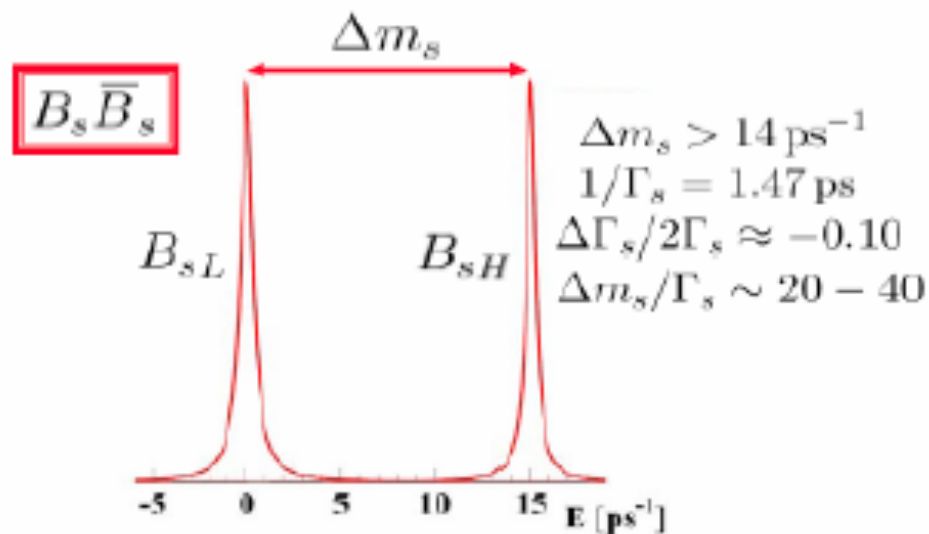
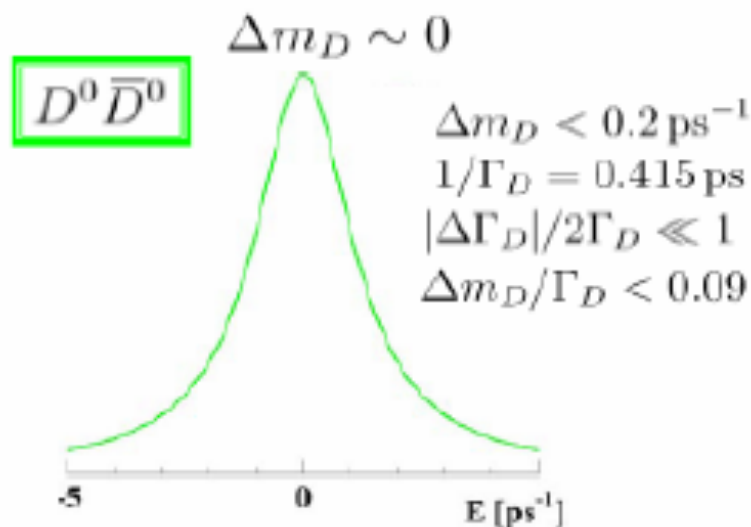
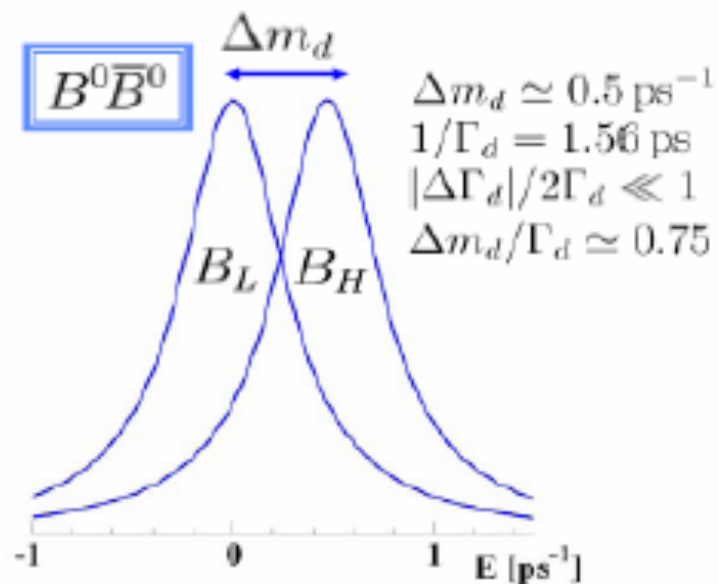
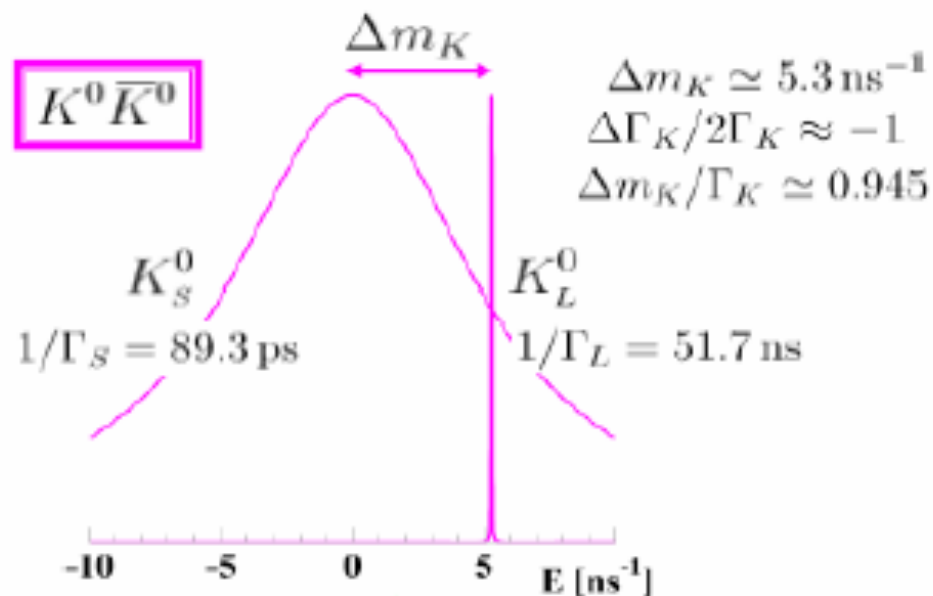
Consider meson $|P^0\rangle$ where $P^0 = K^0, D^0, B^0$, or B_s

pairs of charge-conjugate mesons, which can be transformed to each other via flavor changing weak interaction transitions

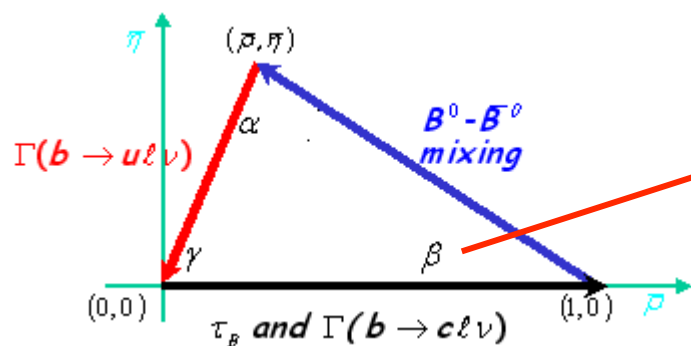
$$|K^0\rangle = |\bar{s}d\rangle \quad |D^0\rangle = |c\bar{u}\rangle \quad |B^0\rangle = |\bar{b}d\rangle \quad |B_s\rangle = |\bar{b}s\rangle$$

	$K^0/\bar{K}^0$	$D^0/\bar{D}^0$	$B^0/\bar{B}^0$	$B_s/\bar{B}_s$
$\tau(\text{ps})$	$89.3 \pm 0.1; 51700 \pm 400$	0.415 ± 0.004	1.564 ± 0.04	1.47 ± 0.06
$\Gamma(\text{ps}^{-1})$	5.61×10^{-3}	$\simeq 2.4$	0.641 ± 0.016	0.62 ± 0.04
$y = \Delta\Gamma/2\Gamma$	-0.9966	$ y < 0.08$	$ y < 0.01$	$\simeq -0.10$
$\Delta m(\text{ps}^{-1})$	$(5.301 \pm 0.014) \times 10^{-3}$	< 0.2	0.490 ± 0.019	> 14
$x = \Delta m/\Gamma$	0.945 ± 0.002	< 0.09	0.72 ± 0.03	$\sim 20 - 40$
δ	$(3.27 \pm 0.12) \times 10^{-3}$	~ 0	$\sim -10^{-3}$	$ \delta < 10^{-3}$

Time units (ps) for all quantities...!



Violazione di CP nel Charmonio

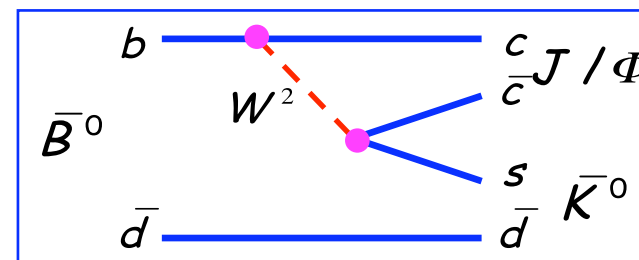
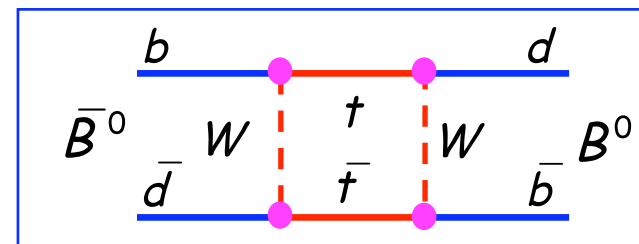


CPV in B_{JK}^{00} / Φ_s

Interferenza

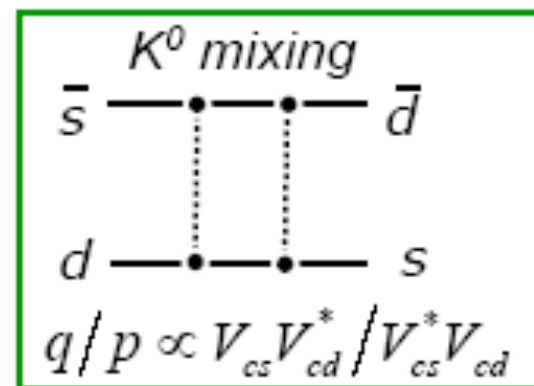
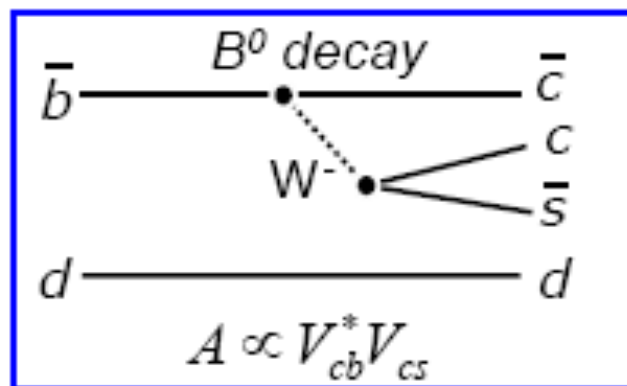
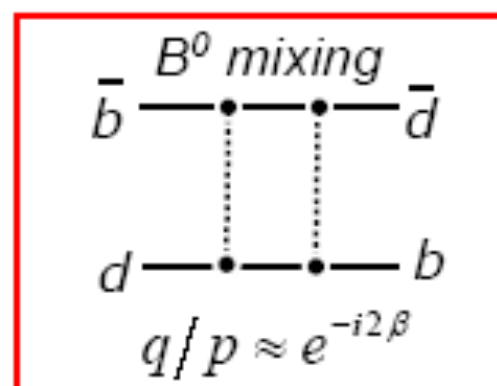
Canali di decadimento $b \rightarrow cc s$:

- senza fondo teorico
- senza fondo sperimentale
- frazione di decadimento relativamente alto



$$a(\Delta t) = \underbrace{\frac{2\text{Im}\lambda}{1+|\lambda|^2}}_{S_f} \sin(\Delta m_d \Delta t) - \underbrace{\frac{1-|\lambda|^2}{1+|\lambda|^2}}_{C_f} \cos(\Delta m_d \Delta t)$$

sin2β from mixing & b→c $\bar{c}$ s “tree” amplitudes



Clean!

$$\lambda_f = \eta_f \left(\frac{q}{p} \right)_B \frac{\bar{A}_f}{A_f} \left(\frac{q}{p} \right)_K = \eta_f e^{-i2\beta}$$

THEORY:

- all decay amplitudes have the same weak phase $\Rightarrow$ clean prediction

$$\text{Im}(\lambda_{\psi K_S}) = -\text{Im}(\lambda_{\psi K_L}) = \sin(2\beta) = S$$

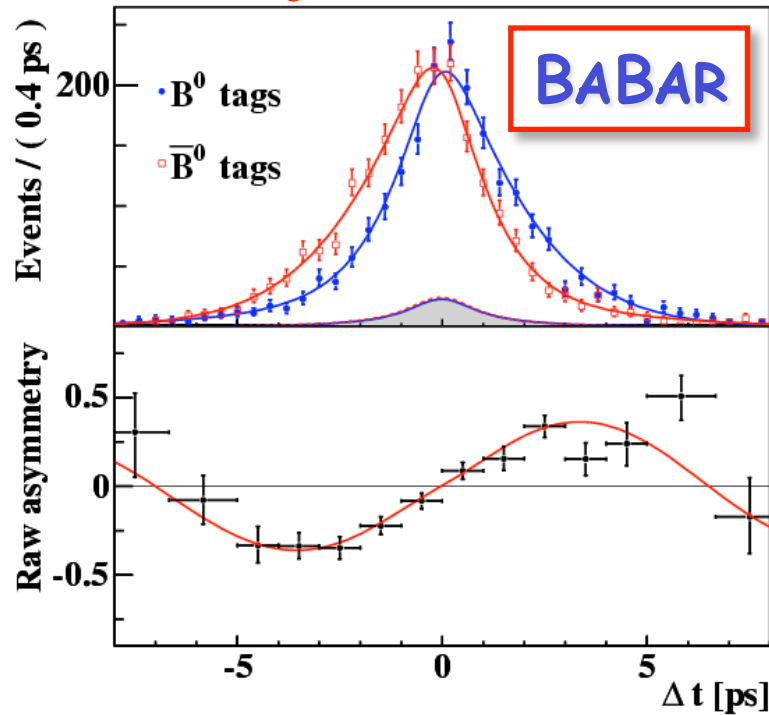
$$C = 0 \quad \left| \lambda_{\psi K_S} \right| = 1$$

EXPERIMENT:

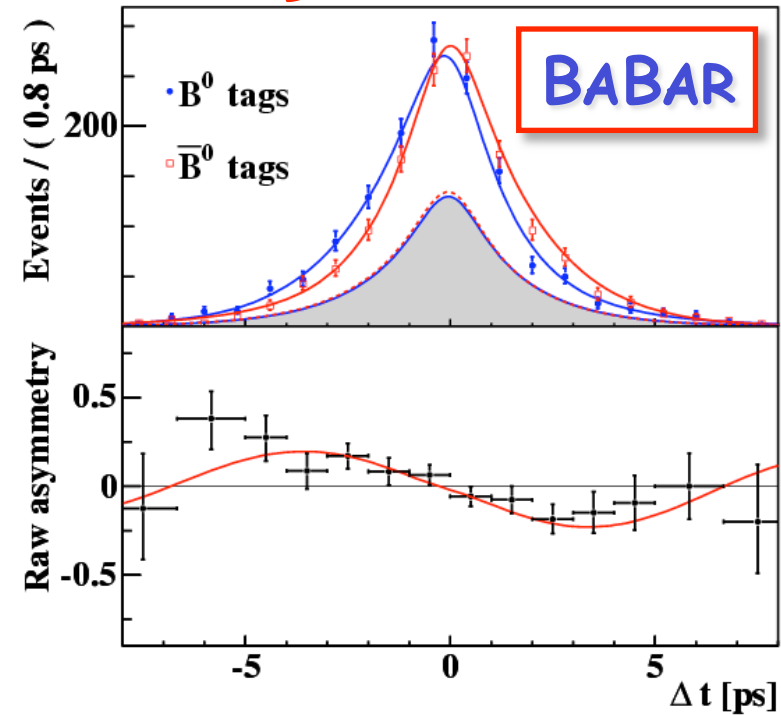
- “Large” branching fractions, i.e.: $\text{BF}(\psi(l^+l^-)K_S(\pi^+\pi^-)) = 3.5 \times 10^{-4}$
- High purity: **up to** 97% for $J/\psi K_S$, somewhat less for other charmonium modes

Risultati di BaBar per $\sin 2\beta$

$(\bar{c}\bar{c}K_S^0)$ modes



$(\bar{c}\bar{c}K_L^0)$ modes



$$\sin 2\beta = 0.400 \pm 0.023$$

$$|\theta| = 410.9500 \pm 0.0310 \pm 0.013$$

$(\bar{c}\bar{c}K_S^0)$
 $(\bar{c}\bar{c}K_L^0)$

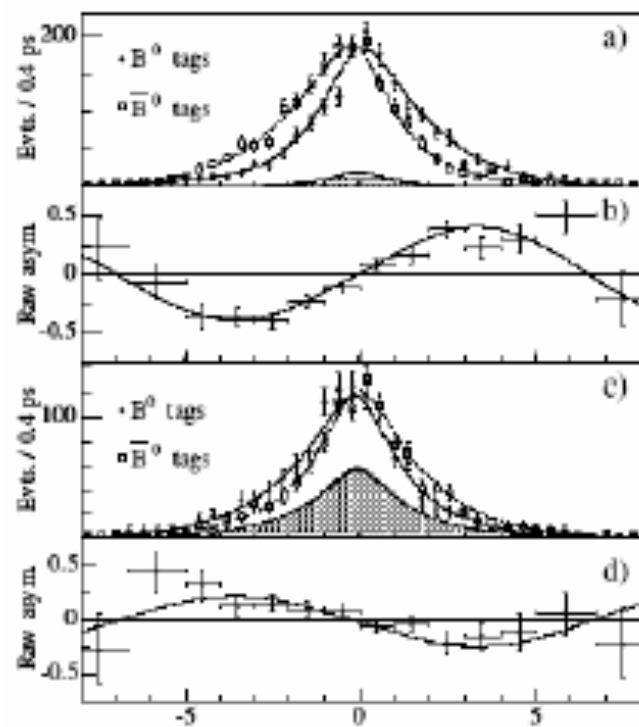
Dopo 37 anni !

227 Milioni di coppie BB , 7730 eventi CP
 (segnale taggato)

Fit to tagged Δt distributions

LP 2005

BaBar ($227 \times 10^6 B\bar{B}$)



$\eta_f = -1$ (above)

$J/\psi K_S^0$

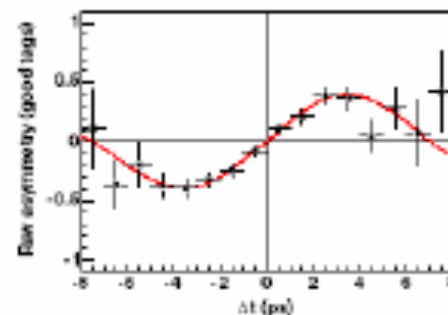
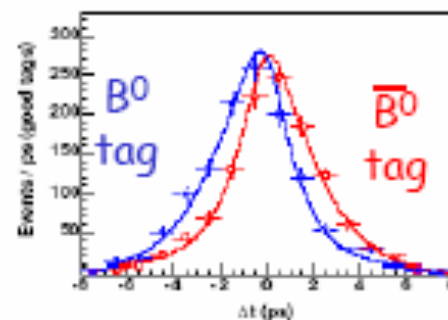
etc.

$\eta_f = +1$ (below)

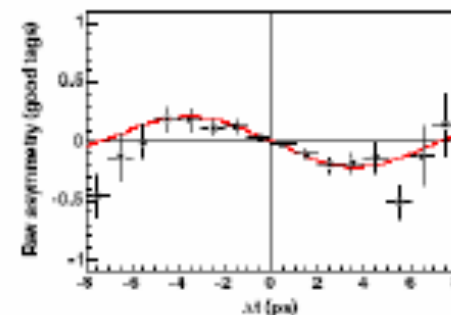
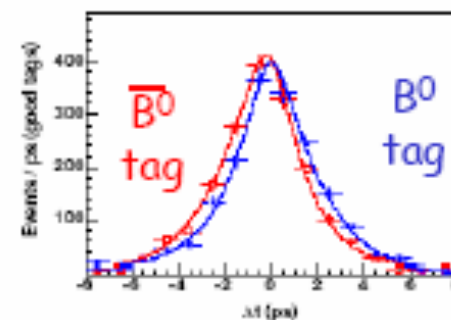
$J/\psi K_L^0$

Belle ($386 \times 10^6 B\bar{B}$)

$J/\psi K_S^0$



$J/\psi K_L^0$



$$a(\Delta t) = \underbrace{\frac{2\text{Im}\lambda}{1+|\lambda|^2}}_{S_f} \sin(\Delta m_d \Delta t) - \underbrace{\frac{1-|\lambda|^2}{1+|\lambda|^2}}_{C_f} \cos(\Delta m_d \Delta t)$$

sin2 β fit results

K.Abe
LP 2005

Winter 2005 Heavy Flavor Averaging Group (HFAG)

$$\sin 2\phi_1 = 0.725 \pm 0.037 \left\{ \begin{array}{l} 0.722 \pm 0.040 \pm 0.023 \text{ (BaBar } 227 \times 10^6 B\bar{B}) \\ 0.728 \pm 0.056 \pm 0.023 \text{ (Belle } 152 \times 10^6 B\bar{B}) \end{array} \right\}$$
$$C = 0.031 \pm 0.029 \left\{ \begin{array}{l} +0.051 \pm 0.033 \pm 0.014 \text{ (BaBar)} \\ -0.007 \pm 0.041 \pm 0.033 \text{ (Belle)} \end{array} \right\}$$

Excellent agreement between BaBar and Belle in spite of very different approaches for flavor-tagging and Δt fit. Techniques for time-dependent *CPV* analyses are well understood and constantly being refined.

LP05 update (Belle $386 \times 10^6 B\bar{B}$, $J/\psi K^0$ only)

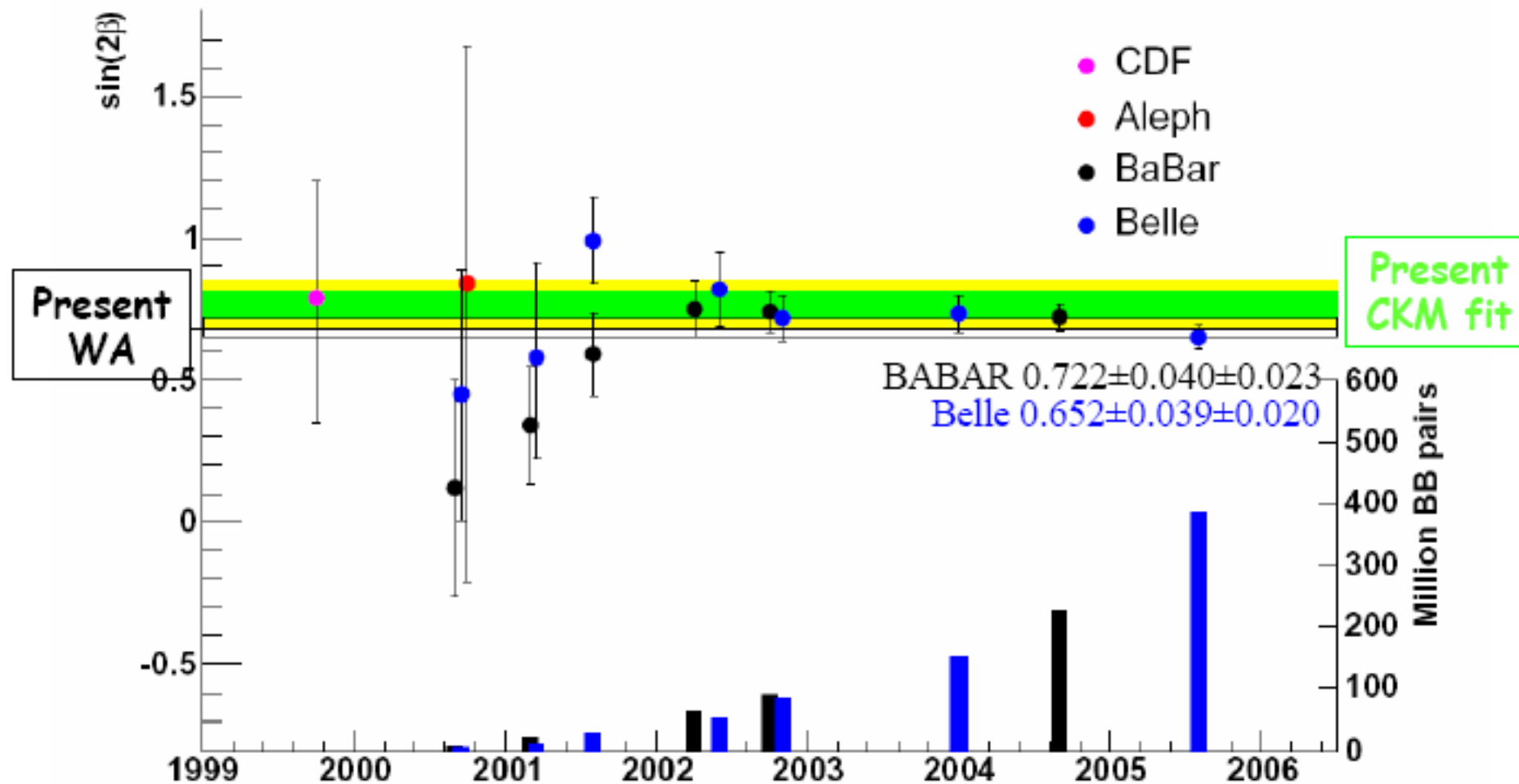
$$\sin 2\phi_1 = 0.652 \pm 0.039 \pm 0.020 \quad C = -0.010 \pm 0.026 \pm 0.036$$

New BaBar/Belle Averages

$$\sin 2\phi_1 = 0.685 \pm 0.032 \quad C = 0.016 \pm 0.046$$

Sono attutamente misure di precisione

Evolution of $\sin 2\beta$ measurements



Nuove Sorgenti di Violazione di CP ?

- La fase di Kobayashi-Maskawa nel Modello Standard predice un valore di $\sin 2\beta$ *in completo accordo col valore sperimentale !*
- La violazione di CP dovuta solo a questa fase e' troppo piccola per spiegare l'asimmetria materia-antimateria osservata nell'Universo !
- E' questa fase la **SOLA** sorgente di violazione di CP ?
- Noi dobbiamo studiare altri processi dove cercare eventuali nuove sorgenti di violazione di CP dovute a **Nuova Fisica** oltre il Modello Standard

Violazione di CP in Modi Dominati da Pinguini

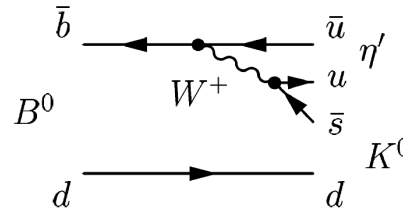
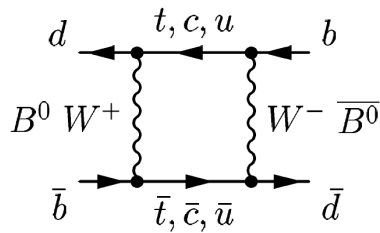


Diagramma ad albero:
Cabibbo soppresso

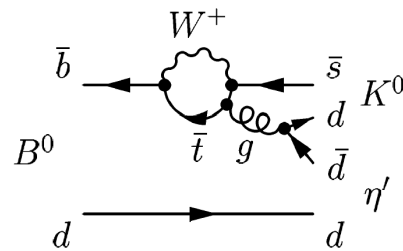
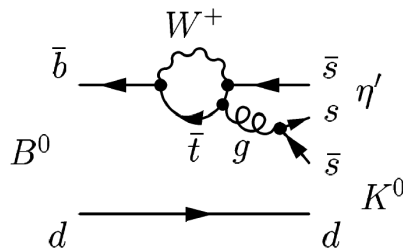
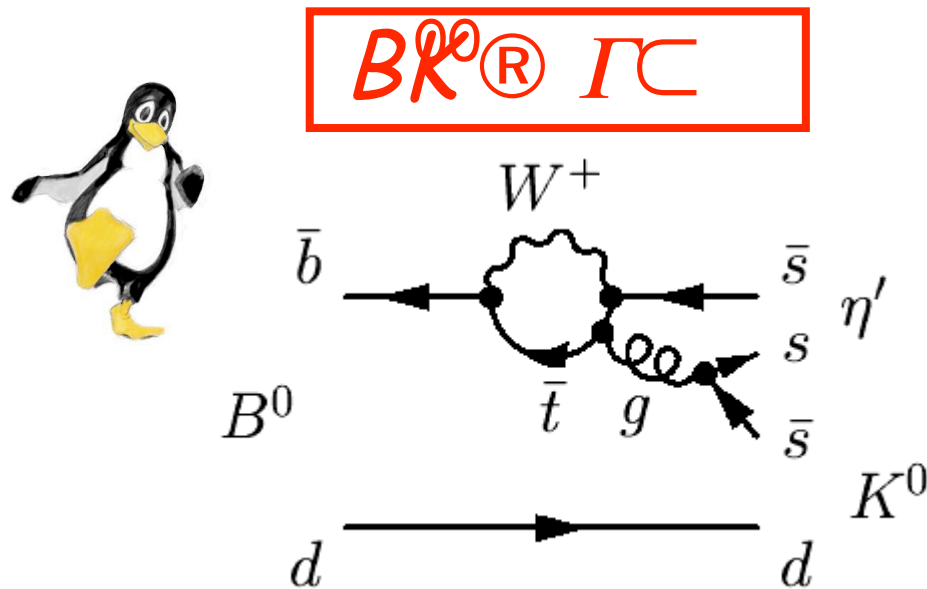


Diagramma a loop
(pinguino) : dominante

- Molti decadimenti dominati da pinguini (ϕK^0 , $\eta' K^0$, $\pi^0 K^0$, $\rho^0 K^0$, ωK^0 , etc)
- Contributo del diagramma ad albero con diversa fase debole puo' causare $\Delta S = S - \sin 2\beta$
- Molti approcci teorici : QCDF (Beneke, Neubert), SCET (Zupan), SU(3) (Gronau, Chiang). In SM ΔS aspettato **piccolo e dipendente** dal modo di decadimento (0.01 – 0.2)

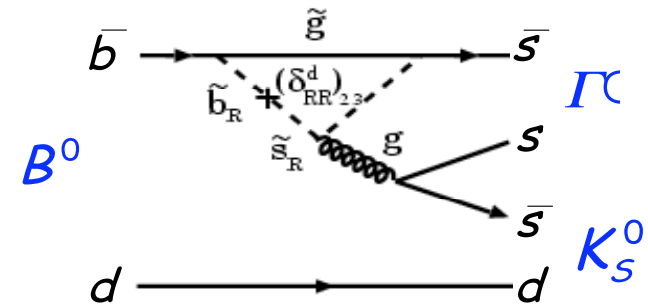
Contributi Potenziali da Nuova Fisica



$BK^0 \Gamma$

Nuova fisica nei loop?

Contributo SUSY con nuove fasi



Nuove particelle massive nel loop possono alterare S and C nella analisi dipendente dal tempo : deviazioni significative dal SM sono possibili (Buchalla et al., JHEP 0509,074(2005) (hep/ph 0503151).

Queste ricerche di NF sono attualmente al centro dello studio di violazione di CP alle B-factory

Modi con Pinguini e Ricerca di Nuova Fisica

Modo	autovalore di CP	Frazione di decadimento (10^{-6})
------	------------------	---------------------------------------

$B \rightarrow \phi K_S$	$(\eta_{CP} = -1)$	} 8.3 ± 1.2
$B \rightarrow \phi K_L$	$(\eta_{CP} = +1)$	
$B \rightarrow K^+ K^- K_S$	$(\eta_{CP} = +1 \text{ dominante})$	} 24.7 ± 2.3
$B \rightarrow K^+ K^- K_L$	$(\eta_{CP} = -1 \text{ dominante})$	
$B \rightarrow K_S K_S K_S$	$(\eta_{CP} = +1)$	6.2 ± 0.9
$B \rightarrow \eta' K_S$	$(\eta_{CP} = -1)$	} 64.9 ± 3.5
$B \rightarrow \eta' K_L$	$(\eta_{CP} = +1)$	
$B \rightarrow f^0 K_S$	$(\eta_{CP} = -1)$	$0.5 (5.9 \pm 0.8)$
$B \rightarrow \pi^0 K_S$	$(\eta_{CP} = -1)$	$0.5 (10.0 \pm 0.6)$
$B \rightarrow \omega K_S$	$(\eta_{CP} = -1)$	$0.5 (4.8 \pm 0.6)$



$B^0 \rightarrow \eta' K^0$ Analisi "Time-Dependent"

Inclusi sei sotto-decadimenti:

- $\eta' \rightarrow \rho \gamma$, $\eta' \rightarrow \eta_{(\pi^+\pi^-\pi^0)} \pi^+\pi^-$, $\eta' \rightarrow \eta_{(\gamma\gamma)} \pi^+\pi^-$
- $K_S^0 \rightarrow \pi^+\pi^-$, $K_S^0 \rightarrow \pi^0\pi^0$
- K_L^0 ($\eta_{CP} = +1$) e $\eta' \rightarrow \eta_{(\gamma\gamma)} \pi^+\pi^-$
- (altri sotto-decadimenti ricostruiti ma non usati nei fit finali !)

- Dati (on-resonance) : $384 \cdot 10^6$ coppie BB
(off-resonance) : $30 \cdot 10^6$ coppie qq
- Eventi Monte Carlo simulati:
 $B^0 B^{00} 472 \cdot 10^6$, $B^+B^- 470 \cdot 10^6$
- Eventi Monte Carlo di segnale

$\eta'_{\eta_{\gamma\gamma}\pi\pi} K_S^0 (\pi^+\pi^-)$ 675K	$\eta'_{\rho\gamma} K_S^0 (\pi^+\pi^-)$ 675K	$\eta'_{\eta_{3\pi\pi\pi}} K_S^0 (\pi^+\pi^-)$ 117K	$\eta'_{\eta_{\gamma\gamma}\pi\pi} K_S^0 (\pi^0\pi^0)$ 134K	$\eta'_{\rho\gamma} K_S^0 (\pi^0\pi^0)$ 103K
$\eta'_{\eta_{\gamma\gamma}\pi\pi} K^+$ 675K	$\eta'_{\rho\gamma} K^+$ 675K	$\eta'_{\eta_{3\pi\pi\pi}} K^+$ 134K	$\eta'_{\eta_{\gamma\gamma}\pi\pi} K_L^0$ 143K	

BB Background ($\eta'_{\rho\gamma} K^0_S$)

Cross Feed Channel	Mode #	MC ϵ (%)	Est. $\mathcal{B}$ (10^{-6})	$\prod \mathcal{B}_i$	# evts in ML
$B^0 \rightarrow \pi^+ \pi^- K^0_{S(\pi^+ \pi^-)}$	6816	1.017	$44.8^{+2.6}_{-2.5}$	0.343	60
$B^0 \rightarrow a_1^0(\rho^+ \pi^-) K^0_{S(\pi^+ \pi^-)}$	4955	1.518	$15^\dagger$	0.172	30
$B^+ \rightarrow a_1^+ K^0_S$	4709	0.715	$15^\dagger$	0.500	21
$B^0 \rightarrow \phi_3 \pi K^0_{S(\pi^+ \pi^-)}$	2714	4.704	$8.3^{+1.2}_{-1.0}$	0.053	8
$B^+ \rightarrow \rho^+ K^0_S$	1933	0.595	$5.6^\dagger$	0.500	6
$B^+ \rightarrow \rho K^*(1430)$	6102	0.033	$40^\dagger$	1.000	5
$B^+ \rightarrow \rho^0 K^{*+}_{K^0_{S(\pi^+ \pi^-)}} \pi^+ \text{ (Long.)}$	2357	1.288	$3.6^{+1.9}_{-1.8}$	0.229	4
$B^0 \rightarrow \rho K^*(1430)$	6104	0.039	$20^\dagger$	1.000	4
$B^+ \rightarrow \eta'_{\rho\gamma} K^{*+}_{K^0_{S(\pi^+ \pi^-)}} \pi^+$	2770	2.275	$4.9^{+2.1}_{-1.9}$	0.067	3
$B^0 \rightarrow K^+ K^- K^0_{S(\pi^+ \pi^-)}$	6814	0.081	$24.7^{+2.3}_{-2.3}$	0.343	3
$B^0 \rightarrow K^{*+}_{K^0_S} \pi^+ \pi^-$	1589	0.222	$9.8^{+1.1}_{-1.1}$	0.333	3
$B^0 \rightarrow \omega K^0_{S(\pi^+ \pi^-)}$	1536	0.426	$4.8^{+0.6}_{-0.6}$	0.306	2
$B^0 \rightarrow \eta'_{\eta\pi\pi} K^0_{S(\pi^+ \pi^-)}$	1510	0.128	$64.9^{+3.5}_{-3.5}$	0.060	2
$B^+ \rightarrow \pi^+ K^0_{S(\pi^+ \pi^-)}$	991	0.048	$24^{+1.3}_{-1.3}$	0.343	1
$B^0 \rightarrow K^0_S K^{*0}_{K^+ \pi^-}$	1956	0.652	$0.95^{+0.95}_{-0.95}$	0.230	1
$B^0 \rightarrow \rho^- K^{*+}_{K^0_{S(\pi^+ \pi^-)}} \pi^+ \text{ (Long.)}$	2501	0.260	$2^\dagger$	0.229	0
$B^+ \rightarrow \phi_3 \pi K^{*+}_{K^0_{S(\pi^+ \pi^-)}} \pi^+$	3994	0.150	$9.7^{+1.5}_{-1.5}$	0.035	0
$B^+ \rightarrow K^0_S K^{*+}_{K^0_S} \pi^+$	1944	0.245	$0.95^\dagger$	0.167	0
Total					153

Risultato del Fit

Mode	# events	Signal yield	S	C
$\eta'_{\eta(\gamma\gamma)\pi\pi} K_{\pi^+\pi^-}^0$	664	224 ± 16	0.61 ± 0.23	-0.26 ± 0.14
$\eta'_{\rho\gamma} K_{\pi^+\pi^-}^0$	11943	566 ± 30	0.56 ± 0.14	-0.24 ± 0.10
$\eta'_{\eta(3\pi)\pi\pi} K_{\pi^+\pi^-}^0$	177	73 ± 9	0.89 ± 0.35	0.14 ± 0.25
$\eta'_{\eta(\gamma\gamma)\pi\pi} K_{\pi^0\pi^0}^0$	490	52 ± 9	0.84 ± 0.42	-0.26 ± 0.36
$\eta'_{\rho\gamma} K_{\pi^0\pi^0}^0$	13915	133 ± 24	0.56 ± 0.41	0.15 ± 0.27
$\eta' K_S^0$			0.62 ± 0.11	-0.18 ± 0.07
$\eta'_{\eta(\gamma\gamma)\pi\pi} K_L^0$	4199	204 ± 24	0.32 ± 0.28	0.08 ± 0.23
$\eta' K^0$			0.58 ± 0.10	-0.16 ± 0.07

Fit singolo combinato su tutti i modi con 93 parametri liberi.
Solo errori statistici

Incertezze Sistematiche

Source of error	$\sigma(S)$	$\sigma(C)$
PDF Shapes	0.017	0.011
$B\bar{B}$ Background	0.018	0.013
CP content in $B\bar{B}$ Background	0.001	0.004
Breco signal shape	0.004	0.012
SVT alignment	0.001	0.001
Beam position/size	0.001	0.001
Tag-side interference	0.002	0.014
Total	0.025	0.025

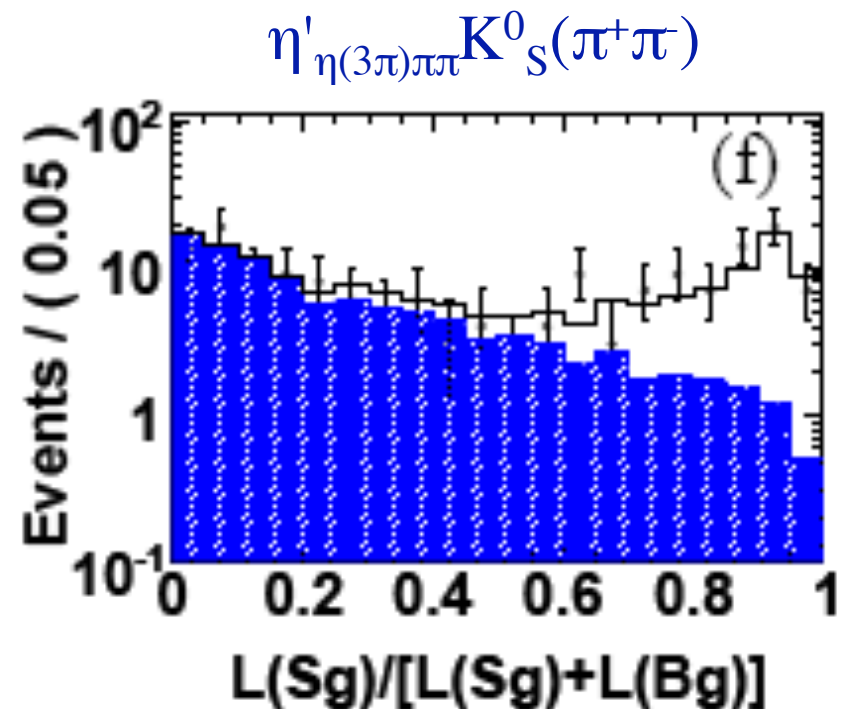
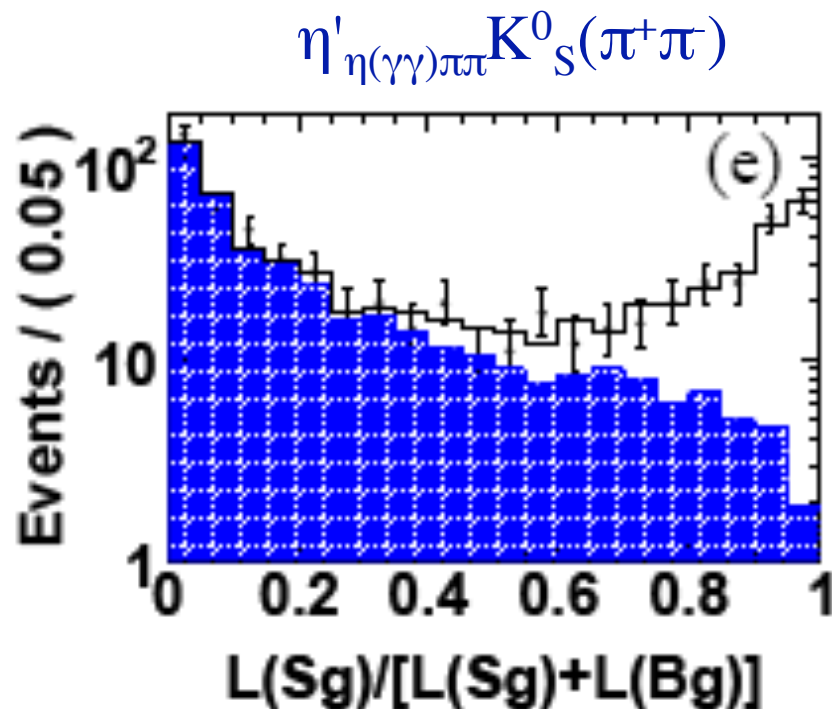
Validazione del Fit

- La procedura di fit e' verificata e calibrata tramite pseudo-esperimenti generati con Monte Carlo : qq generato da PDFs nel quale vengono inseriti eventi di segnale MC e fondo BB come trovato nel fit sui dati
- Fit con $B^+ \rightarrow \eta'_{\eta(\gamma\gamma)\pi\pi} K^+$, $\eta'_{(\rho\gamma)} K^+$ and $\eta'_{\eta(3\pi)\pi\pi} K^+$
Risultati per S and C compatibili con zero (come aspettato)
- Fit togliendo una variabile discriminante per volta
- Fit rimuovendo la componente BB e con componenti multiple di BB
- Fit sui singoli sotto-decadimenti

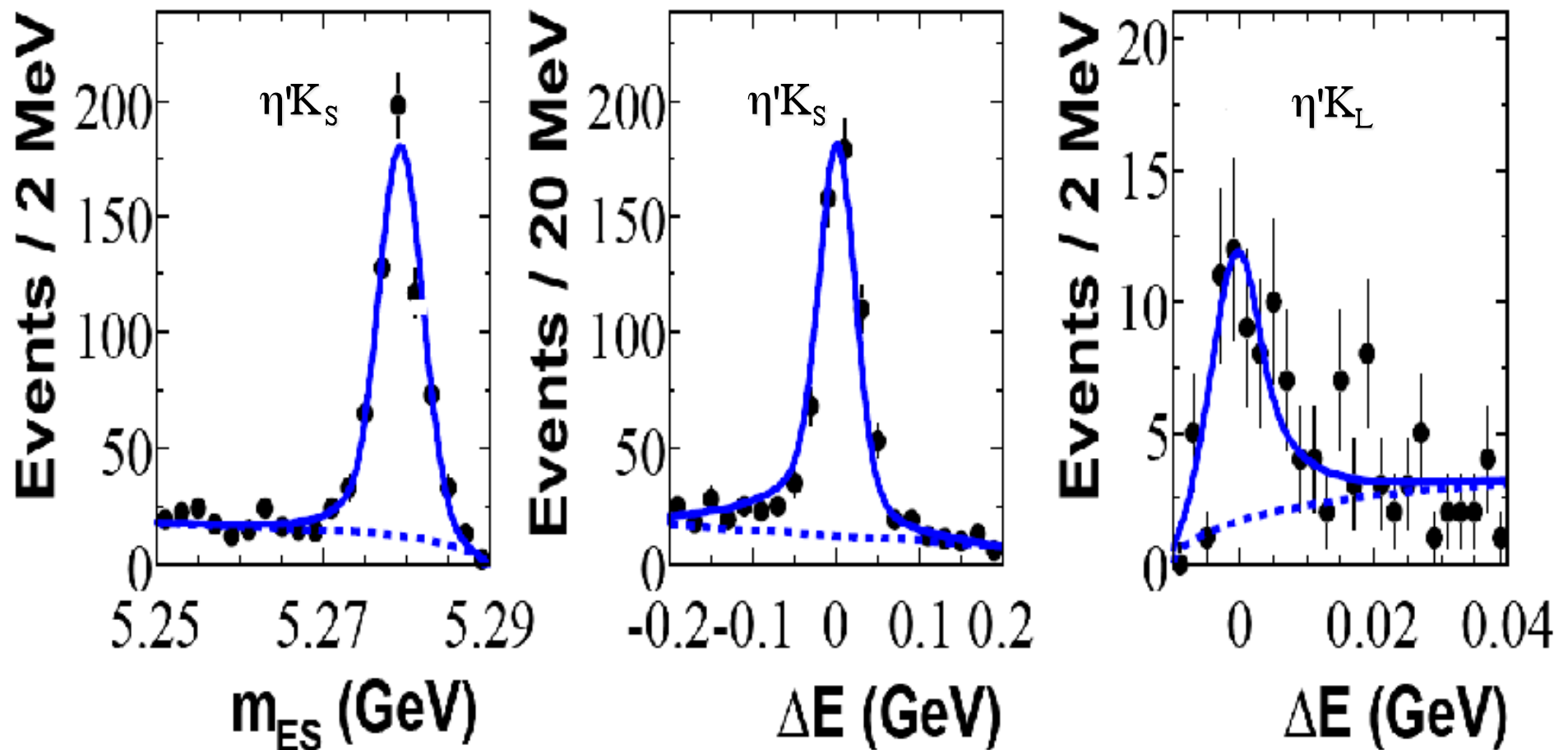
I risultati dei test sono tutti in accordo con quanto aspettato

Test di Verifica col Rapporto di Likelihood

Esempi di rapporto di likelihood in due sottodecadimenti: punti con barre di errore sono i dati, somma di tutti i fondi e' la zona colorata, istogramma e' la somma del segnale e di tutti i fondi .
Eventi MC generati da PDFs.



Proiezioni M_{ES} e ΔE

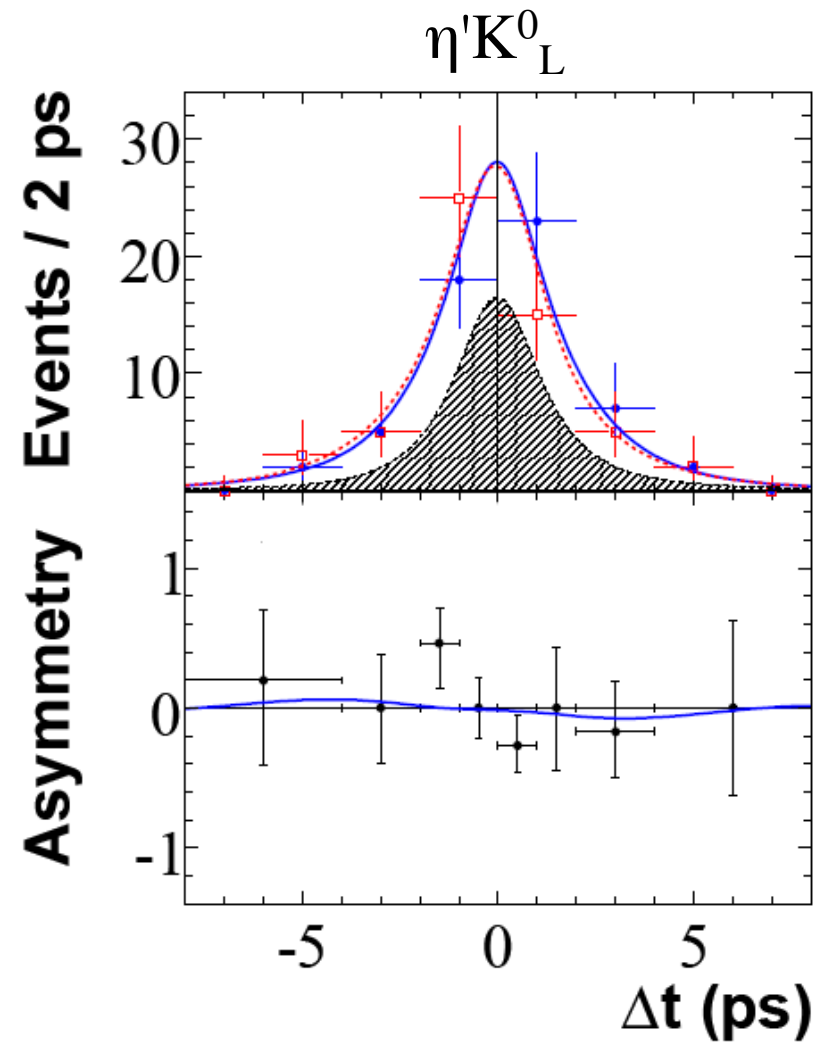
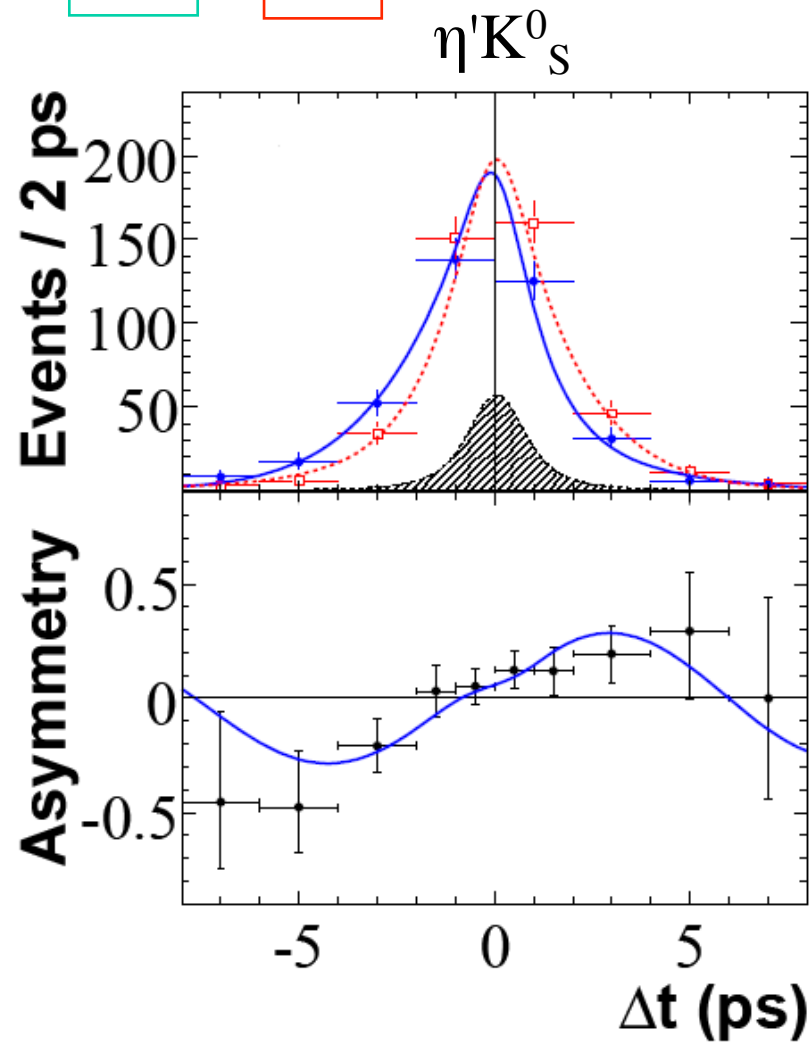


Proiezioni con taglio sul rapporto di likelihood
per esaltare il segnale

Proiezioni Δt

B^0

B^0



Risultati Finali

Con un campione di 1252 ± 50 eventi taggati $\eta' K^0$ noi abbiamo misurato i parametri di violazione di CP S and C :

$$S = 0.58 \pm 0.10 \pm 0.03 \quad C = -0.16 \pm 0.07 \pm 0.03$$

Inconsistenza con la conservazione di CP (S=0) ha una significanza di 5.5 deviazioni standard (inclusi sistematici)

Questa e' la prima osservazione di violazione di CP indotta da interferenza decadimento-mescolamento in un decadimento del B^0 dominato da pinguini. Un valore di C diverso da zero indicherebbe violazione CP diretta. La nostra misura e' a 2.1 deviazioni standard da zero !

Phys. Rev. Lett. 98,031801 (2007)

SLAC Press Release

<http://home.slac.stanford.edu/pressreleases/2006/20060928.htm>

Time Dependent CP violation in B^0 Meson Decays to $\eta' K_S^0$ and $\eta' K_L^0$ Summer 2006 “Vivace” Update

Alfio Lazzaro and Fernando Palombo
Dipartimento di Fisica dell'Università and INFN, Milano

Abstract

We update CP asymmetry measurements in the $\eta' K_S^0$ and $\eta' K_L^0$ final states for the “Vivace” dataset, using a sample of 383.6 ± 3.8 million $B\bar{B}$ pairs. We find

$$\begin{aligned} S_{\eta' K^0} &= 0.58 \pm 0.10 \text{ (stat)} \pm 0.03 \text{ (syst)} & S_{\eta' K^+} &= -0.08 \pm 0.06 \text{ (stat)} \\ C_{\eta' K^0} &= -0.16 \pm 0.07 \text{ (stat)} \pm 0.03 \text{ (syst)} & C_{\eta' K^+} &= 0.03 \pm 0.04 \text{ (stat)} \end{aligned}$$

where S and C are the coefficients of the sine and cosine oscillation terms in the $B\bar{B}$ decay rate distributions.

Inconsistency of our result for S with CP conservation ($S=0$) has a significance of 5.5 standard deviations. This represents the observation of mixing-induced CP in the rare decay mode $B^0 \rightarrow \eta' K^0$.

Our result for the direct- CP violation parameter C is 2.1 standard deviations from zero.

Ha anche il Bollino di qualita'!!

PRL **98**, 031801 (2007)

PHYSICAL REVIEW LETTERS

week ending
19 JANUARY 2007



Observation of CP Violation in $B \rightarrow \eta/K^0$ Decays

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R. G. Jacobsen,⁶ J. A. Kadyk,⁶ L. T. Kerth,⁶ Yu. G. Kolomensky,⁶ G. Kukartsev,⁶ D. Lopes Pegna,⁶ G. Lynch,⁶ L. M. Mir,⁶
T. J. Orimoto,⁶ M. Pripstein,⁶ N. A. Roe,⁶ M. T. Ronan,⁶ W. A. Wenzel,⁶ P. del Amo Sanchez,⁷ M. Barrett,⁷ K. E. Ford,⁷
T. J. Harrison,⁷ A. J. Hart,⁷ C. M. Hawkes,⁷ A. T. Watson,⁷ T. Held,⁸ H. Koch,⁸ B. Lewandowski,⁸ M. Pelizaeus,⁸ K. Peters,⁸
T. Schroeder,⁸ M. Steinke,⁸ J. T. Boyd,⁹ J. P. Burke,⁹ W. N. Cottingham,⁹ D. Walker,⁹ D. J. Asgeirsson,¹⁰
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M. Bondioli,¹³ M. Bruinsma,¹³ M. Chao,¹³ S. Curry,¹³ I. Eschrich,¹³ D. Kirkby,¹³ A. J. Lankford,¹³ P. Lund,¹³

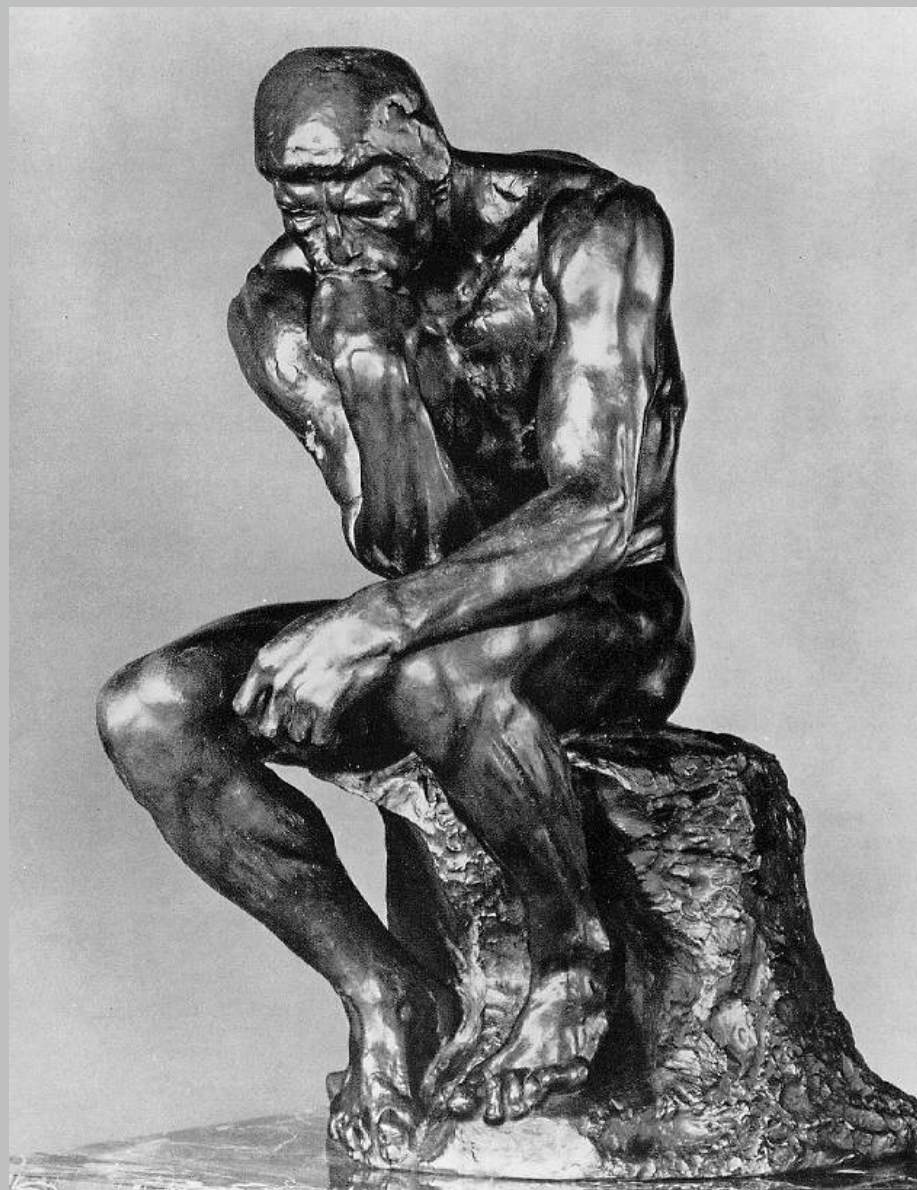
Conclusioni

Il valore di S trovato nella analisi time-dependent del decadimento $B^0 \rightarrow \eta' K^0$ e' in accordo col Modello Standard.

Per la prima volta e' stata osservata la violazione di CP in un decadimento $b \rightarrow s$ (dominato da pinguini) .

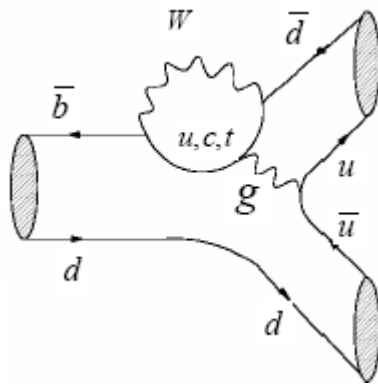
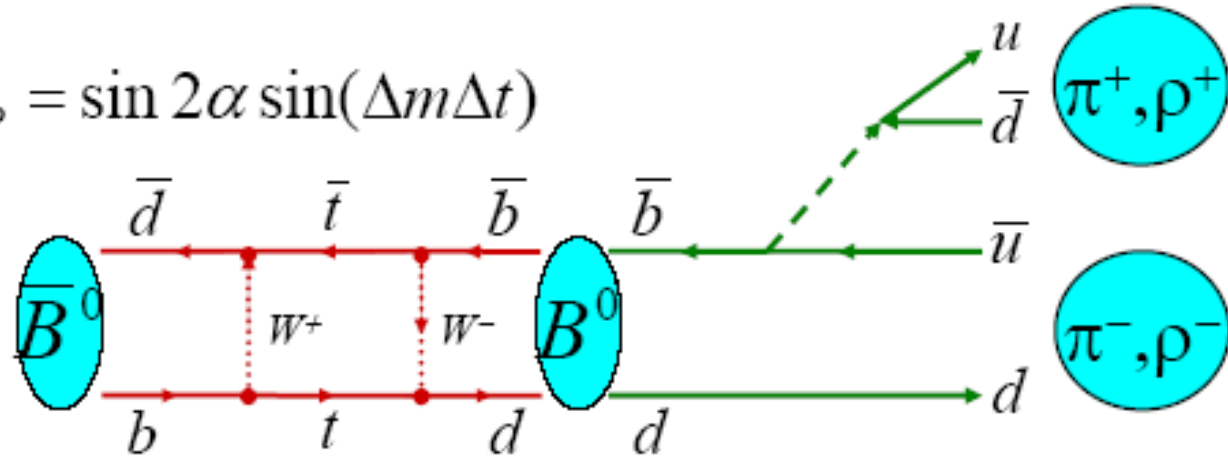
E' necessario diminuire gli errori sperimentali per avere sensibilita' ad eventuali contributi di CP da Nuova Fisica (soprattutto per gli altri modi di decadimento!)

La asimmetria cosmologica materia-antimateria resta comunque un problema fondamentale !



L'angolo α

$$A_{CP} = \sin 2\alpha \sin(\Delta m \Delta t)$$



Decadimenti piuttosto rari, contribuiti da diagrammi ad albero e a pinguino, necessita' di analisi complesse (in isospin per estrarre l'angolo α , dalitz, ecc) , risultati ancora dominati dagli errori statistici

From combined
 $\pi\pi, \rho\pi, \rho\rho$ results

$$\alpha = [103^{+10}_{-11}]^\circ$$

2005

L'angolo α da B^0 in $a_1^\pm \pi^\mp$

BABAR Analysis Document #1400

Version 21

September 12, 2007

Time-Dependent CP -violating Asymmetries in B^0 meson decays to $a_1^\pm(1260)\pi^\mp$ and branching fraction measurements in B^0 meson decays to $a_1^\pm(1260)K^\mp$ and $B^\pm$ to $a_1^\pm(1260)K^0$.

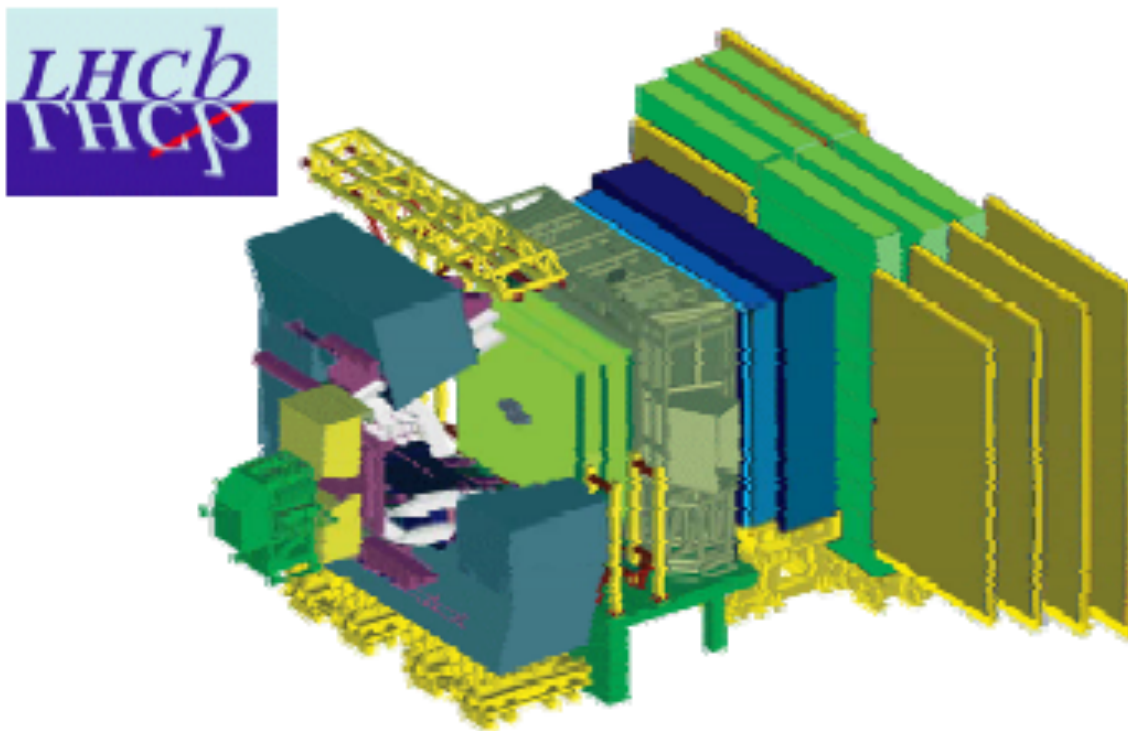
Vincenzo Lombardo^a and Fernando Palombo^b

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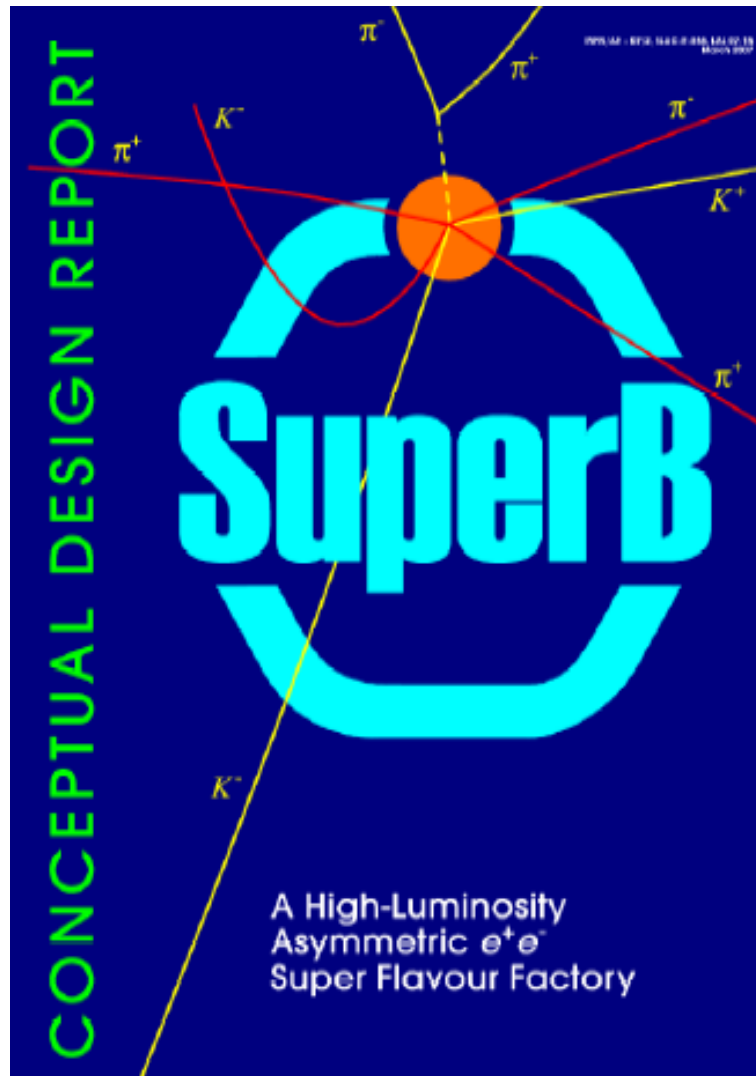
In stampa su Phys. Rev. Lett

Futuro: LHCb



Rivelatore dedicato alla fisica del B a LHC
Su alcune analisi (inizialmente) sono molto
competitivi Atlas e CMS

Futuro: SuperB (?)



Macchina $e^+ e^-$ complementare a quella adronica LHCb

Elevata luminosita' : $\sim 10^{36} \text{ cm}^{-2} \text{ s}^{-1}$

Test di precisione nel settore flavor del Modello Standard

Un comitato internazionale sta studiando la fattibilita' (ed opportunita' di) realizzare questo progetto.

Un sito proposto e' Tor Vergata , accanto ai Laboratori Nazionale dell'INFN di Frascati.

Collaborazione BaBar



Usa, Canada,
Cina, Francia,
Germania, Gran
Bretagna, Italia,
Olanda,
Norvegia, Russia,
Spagna, Stati Uniti

12 Sezioni INFN
Italia (~16%)
(2^a dopo gli USA)