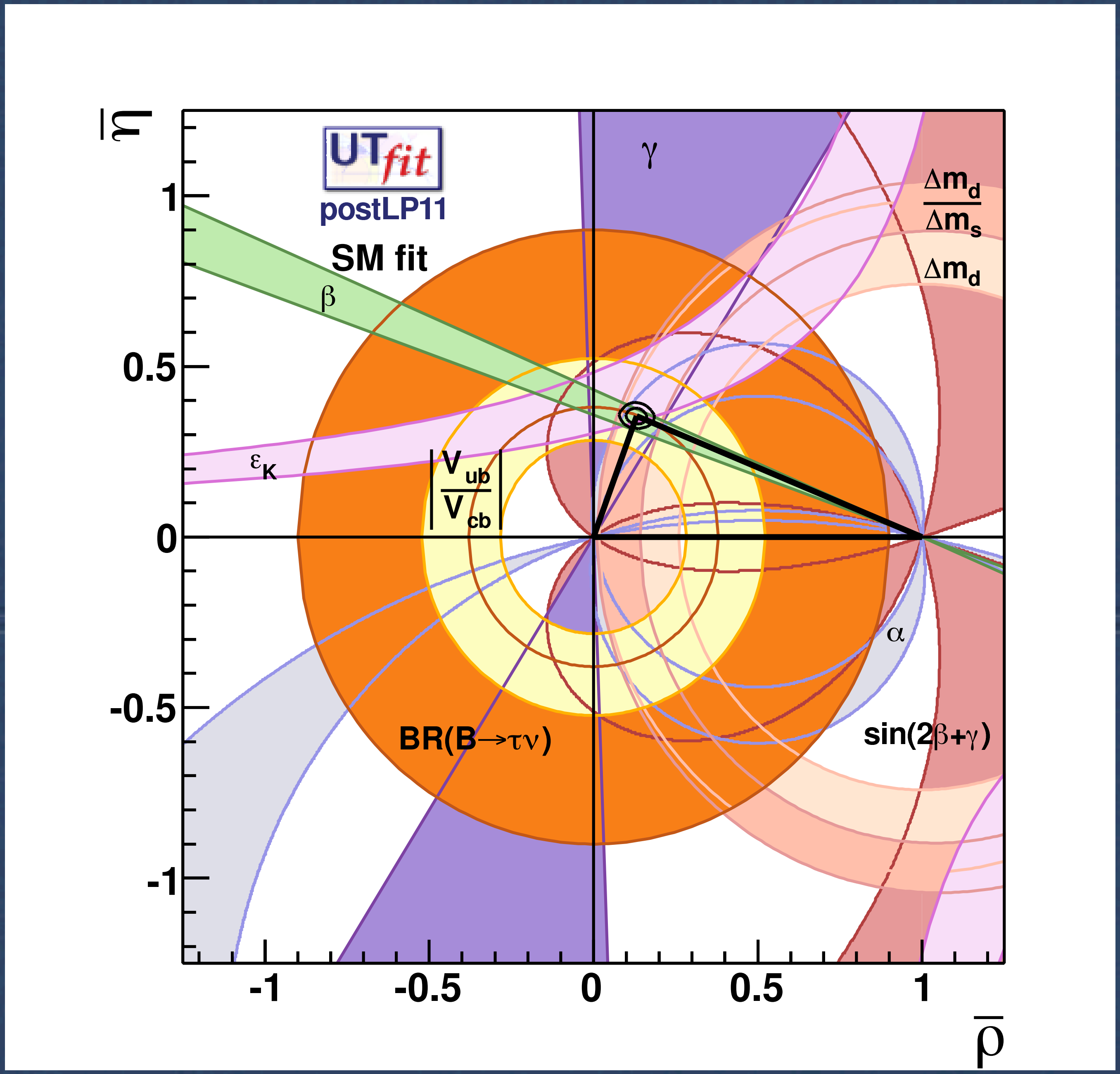
Misura di sin 2β

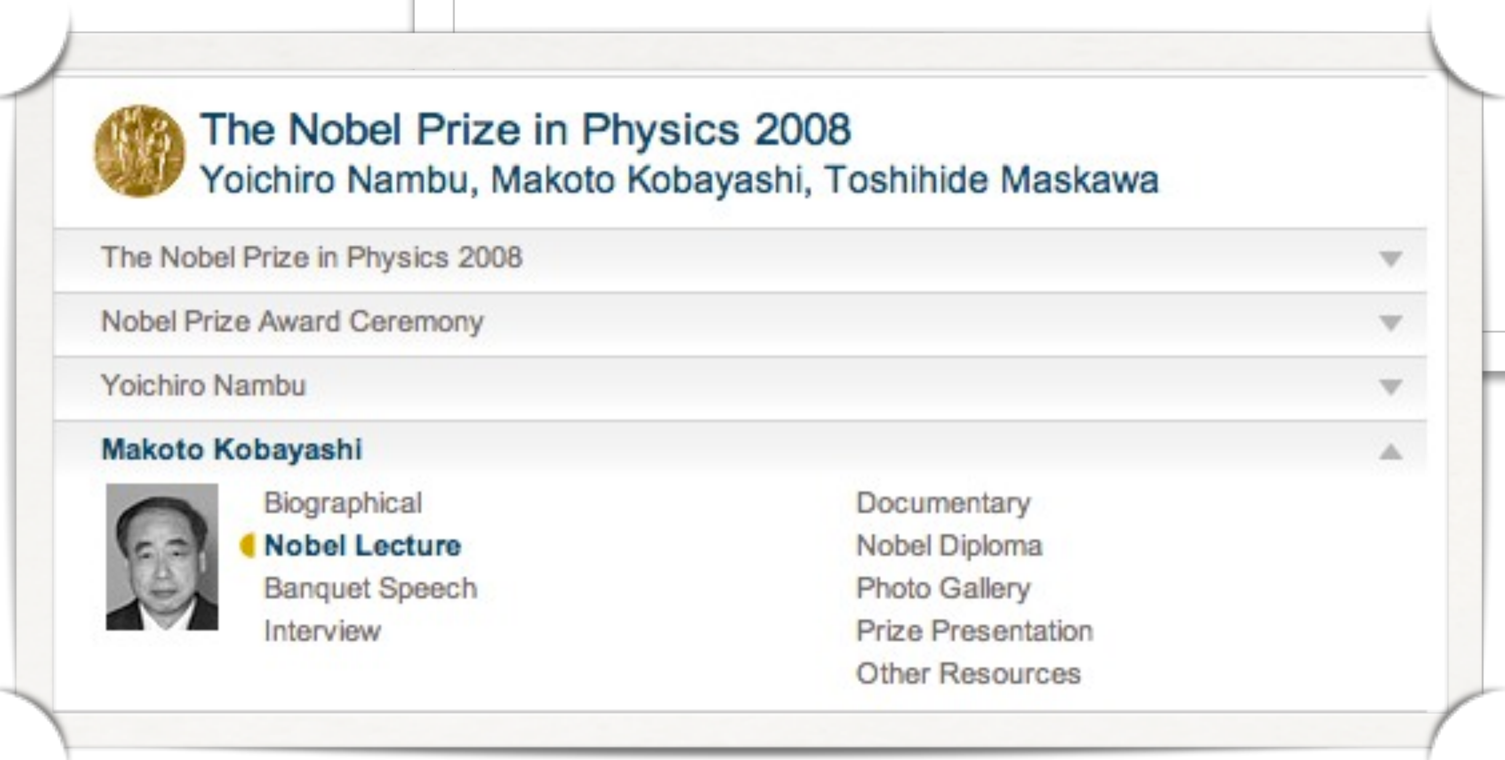


E.Paoloni (INFN & Università di Pisa)

BaBar Collaboration

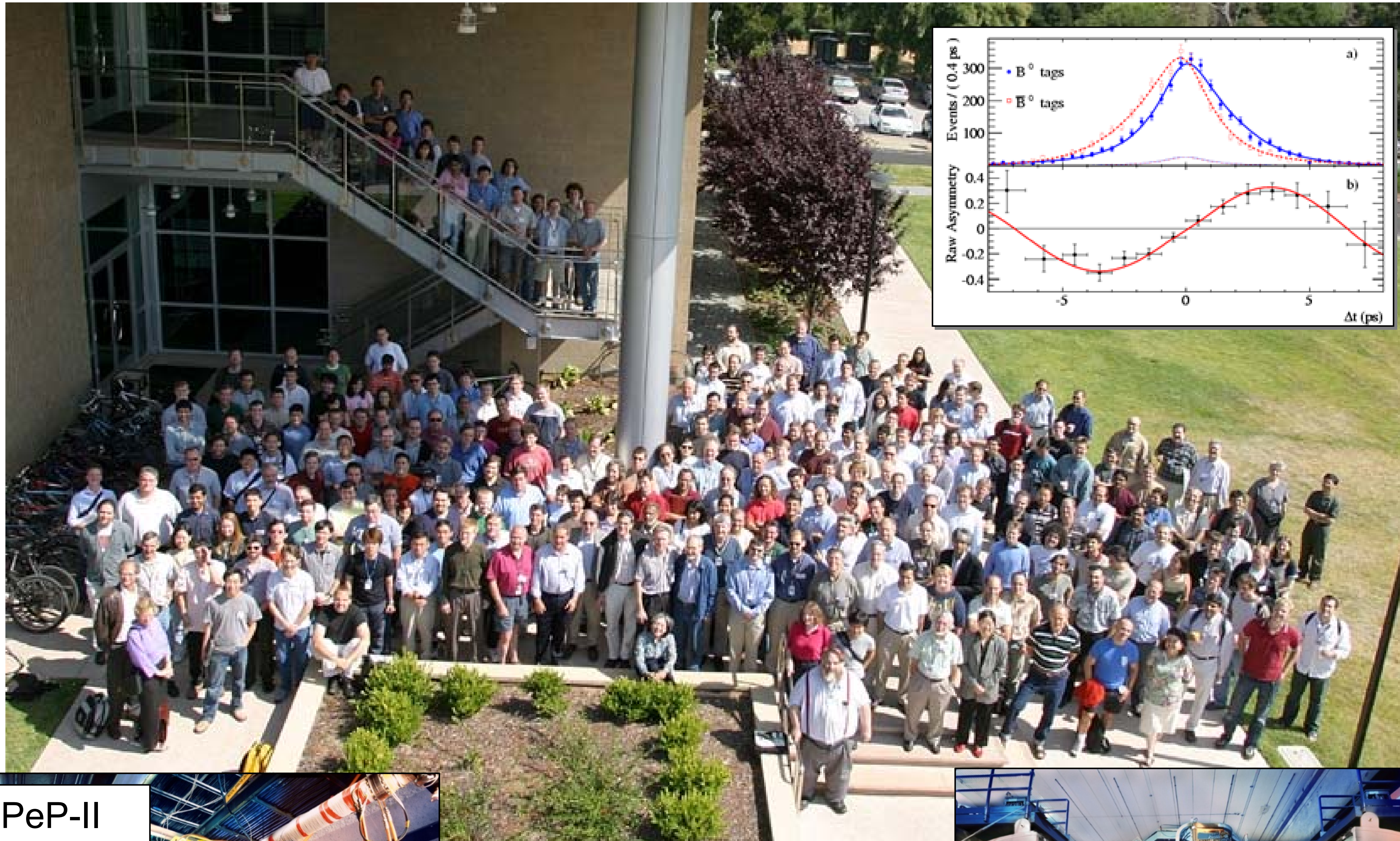
CP Violation and Flavor Mixing

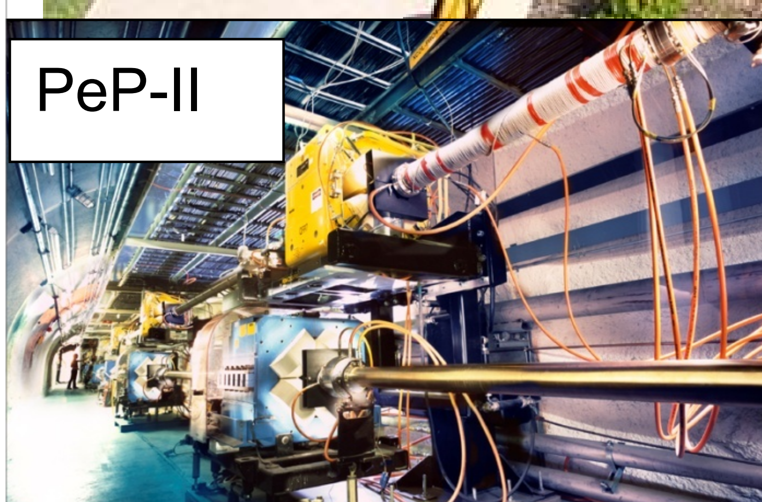
Makoto Kobayashi
KEK and JSPS

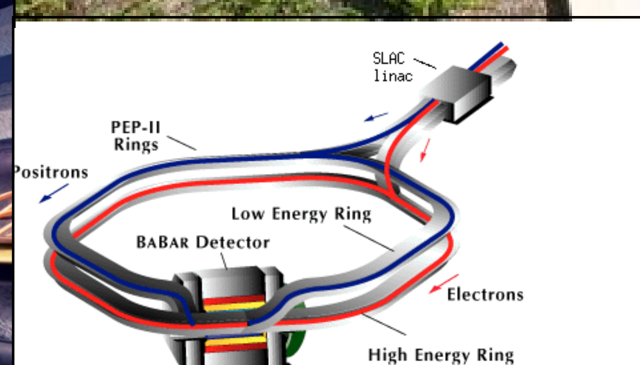


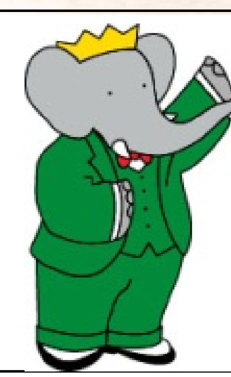
Stoccolma dicembre 2008, Cerimonia

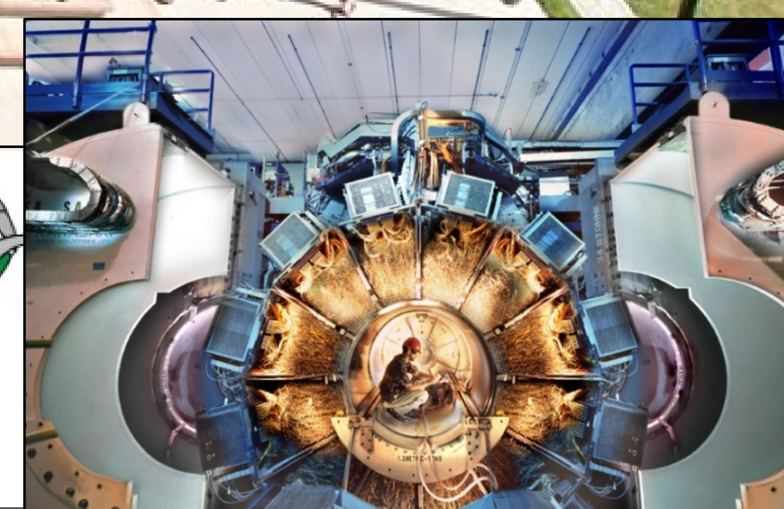
di conferimento dei premi Nobel









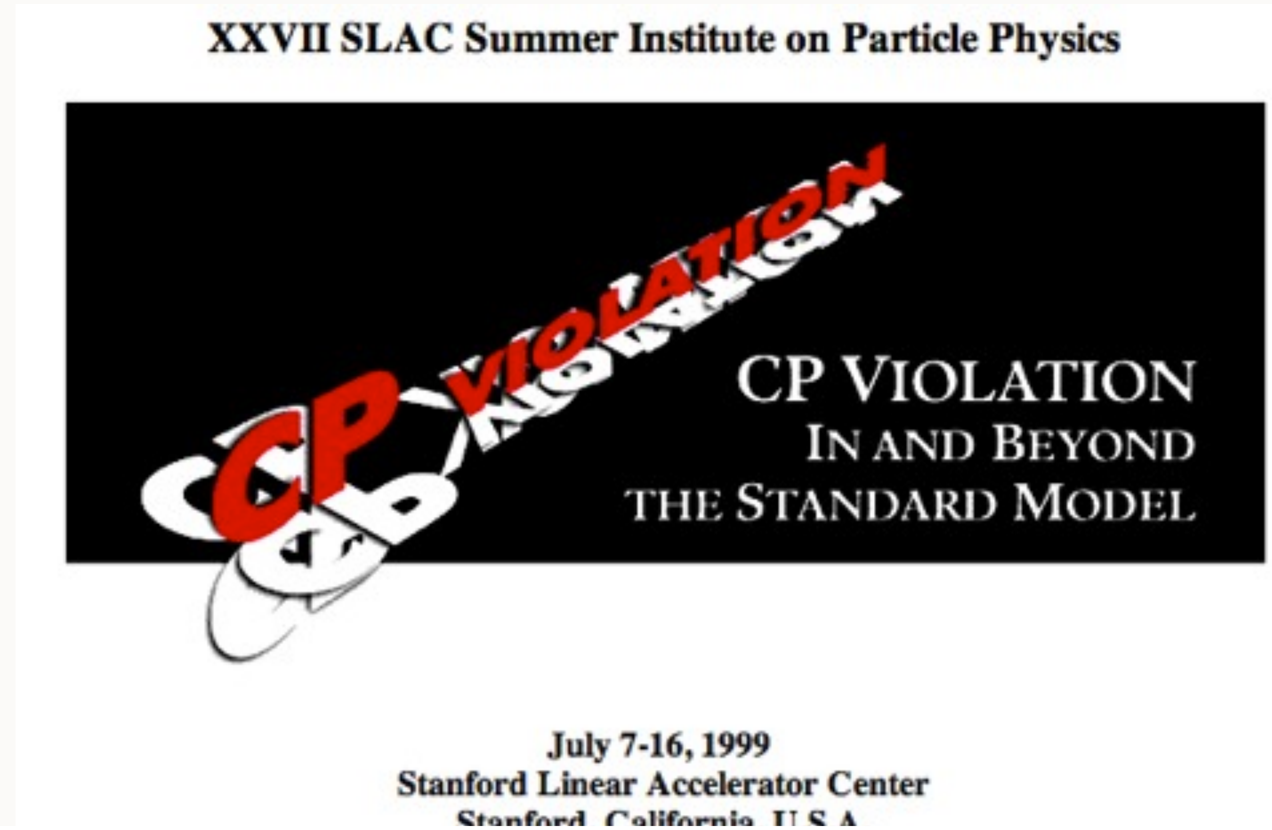


Stoccolma 2008, Cerimonia di conferimento dei premi Nobel

VIOLAZIONE DI CP

http://www.slac.stanford.edu/gen/meeting/ssi/1999/

Yosef Nir lectures


XXVII SLAC Summer Institute on Particle Physics

July 7-16, 1999
Stanford Linear Accelerator Center

There are three different types of CP violation in meson decays:

(i) CP violation in mixing, which occurs when the two neutral mass eigenstate admixtures cannot be chosen to be CP-eigenstates;

(ii) CP violation in decay, which occurs in both charged and neutral decays, when the amplitude for a decay and its CP-conjugate process have different magnitudes;

(iii) CP violation in the interference of decays with and without mixing, which occurs in decays into final states that are common to B^0 and $\bar{B}^0$.

CP Violation

Our phase convention for the CP transformation law of the neutral B mesons is defined by

$$\mathrm{CP}|B^0\rangle = \omega_B|\bar{B}^0\rangle, \quad \mathrm{CP}|\bar{B}^0\rangle = \omega_B^*|B^0\rangle, \quad (|\omega_B| = 1). \tag{3.1}$$

The time evolution of the ket:

$$a|B^0\rangle + b|\bar{B}^0\rangle,$$

is governed by a time-dependent Schrödinger equation,

$$i\frac{d}{dt}\begin{pmatrix} a \\ b \end{pmatrix} = H\begin{pmatrix} a \\ b \end{pmatrix} \equiv \left(M - \frac{i}{2}\Gamma\right)\begin{pmatrix} a \\ b \end{pmatrix}, \tag{3.3}$$

for which M and Γ are 2×2 Hermitian matrices.

The off-diagonal terms in these matrices, M_{12} and Γ_{12}, are particularly important in the discussion of mixing and CP violation. M_{12} is the dispersive part of the transition amplitude from B^0 to $\bar{B}^0$, while Γ_{12} is the absorptive part of that amplitude.

The light B_L and heavy B_H mass eigenstates are given by

$$|B_{L,H}\rangle = p|B^0\rangle \pm q|\bar{B}^0\rangle. \tag{3.4}$$

CP VIOLATION

(iii) CP violation in the interference between decays with and without mixing:

$$|\lambda_{f_{CP}}| = 1, \quad \mathcal{I}m\ \lambda_{f_{CP}} \neq 0. \tag{3.29}$$

Any $\lambda_{f_{CP}} \neq \pm 1$ is a manifestation of CP violation. The special case (3.29) isolates the effects of interest since both CP violation in decay, eq. (3.25), and in mixing, eq. (3.21), lead to $|\lambda_{f_{CP}}| \neq 1$. For the neutral B system, this effect can be observed by comparing decays into final CP eigenstates of a time-evolving neutral B state that begins at time zero as B^0 to those of the state that begins as $\bar{B}^0$:

$$a_{f_{CP}} = \frac{\Gamma(\bar{B}^0_{\rm phys}(t) \to f_{CP}) - \Gamma(B^0_{\rm phys}(t) \to f_{CP})}{\Gamma(\bar{B}^0_{\rm phys}(t) \to f_{CP}) + \Gamma(B^0_{\rm phys}(t) \to f_{CP})}. \tag{3.30}$$

This time dependent asymmetry is given (for $|\lambda_{f_{CP}}| = 1$) by

$$a_{f_{CP}} = -\mathcal{I}m\lambda_{f_{CP}} \sin(\Delta m_B t). \tag{3.31}$$

Facile Esercizio Lasciato al Lettore

- Creare un quantitativo "sufficiente" di mesoni B
- Cercare fra questi i mesoni B che decadono in un autostato di CP
  (E.g. J/ψ Ks -> pi+ pi-)
- Determinare il flavor del mesone B ad un qualche istante precedente il suo decadimento (tagging)
- Misurare la differenza di tempi fra l'istante di decadimento e quello di tag
- Produrre il plot dell'asimmetria dipendente dal tempo:

$$a_{f_{CP}} = \frac{\Gamma(\bar{B}^0_{\text{phys}}(t) \to f_{CP}) - \Gamma(B^0_{\text{phys}}(t) \to f_{CP})}{\Gamma(\bar{B}^0_{\text{phys}}(t) \to f_{CP}) + \Gamma(B^0_{\text{phys}}(t) \to f_{CP})}.$$

QUANTI B CI OCCORRONO?

B^0 $\qquad I(J^P) = \frac{1}{2}(0^-)$

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

- Mass $m_{B^0} = 5279.50 \pm 0.30$ MeV
- $m_{B^0} - m_{B^\pm} = 0.33 \pm 0.06$ MeV
- Mean life $\tau_{B^0} = (1.519 \pm 0.007) \times 10^{-12}$ s
  - $c\tau = 455.4\ \mu$m
- $\tau_{B^+}/\tau_{B^0} = 1.079 \pm 0.007$ (direct measurements)

B^0-$\overline{B}^0$ mixing parameters

- $\chi_d = 0.1863 \pm 0.0023$
- $\Delta m_{B^0} = m_{B^0_H} - m_{B^0_L} = (0.507 \pm 0.004) \times 10^{12}\ \hbar\ s^{-1}$
  - $= (3.337 \pm 0.033) \times 10^{-10}$ MeV
- $x_d = \Delta m_{B^0}/\Gamma_{B^0} = 0.771 \pm 0.008$
- $\mathrm{Re}(\lambda_{CP} / |\lambda_{CP}|)\ \mathrm{Re}(z) = 0.01 \pm 0.05$
- $\Delta\Gamma\ \mathrm{Re}(z) = -0.007 \pm 0.004$
- $\mathrm{Re}(z) = 0.00 \pm 0.12$
- $\mathrm{Im}(z) = -0.015 \pm 0.008$

Esercizio: quante vite medie?

Charmonium modes

$\eta_c K^0$	$(8.9 \pm 1.6) \times 10^{-4}$		1753
$\eta_c K^*(892)^0$	$(6.1 \pm 1.0) \times 10^{-4}$		1648
$\eta_c(2S) K^{*0}$	$< 3.9 \times 10^{-4}$	CL=90%	1159
$h_c(1P) K^{*0}$	$< 4 \times 10^{-4}$	CL=90%	1253
$J/\psi(1S) K^0$	$(8.71 \pm 0.32) \times 10^{-4}$		1683
$J/\psi(1S) K^+ \pi^-$	$(1.2 \pm 0.6) \times 10^{-3}$		1652
$J/\psi(1S) K^*(892)^0$	$(1.33 \pm 0.06) \times 10^{-3}$		1571

QUANTI B CI OCCORRONO?

$J/\psi(1S)$ $\qquad I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 3096.916 \pm 0.011$ MeV
Full width $\Gamma = 92.9 \pm 2.8$ keV (S = 1.1)
$\Gamma_{ee} = 5.55 \pm 0.14 \pm 0.02$ keV

$J/\psi(1S)$ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
hadrons		(87.7 ± 0.5) %		–
virtual $\gamma \to$ hadrons		(13.50 ± 0.30) %		–
ggg		(64.1 ± 1.0) %		–
γgg		(8.8 ± 0.5) %		–
e^+e^-		(5.94 ± 0.06) %		1548
$e^+e^-\gamma$	[a]	$(8.8 \pm 1.4) \times 10^{-3}$		1548
$\mu^+\mu^-$		(5.93 ± 0.06) %		1545
Decays involving hadronic resonances				
$\rho\pi$		(1.69 ± 0.15) %	S=2.4	1448
$\rho^0\pi^0$		$(5.6 \pm 0.7) \times 10^{-3}$		1448
$a_2(1320)\rho$		(1.09 ± 0.22) %		1123

} ~12%

Quanti B ci Occorrono?

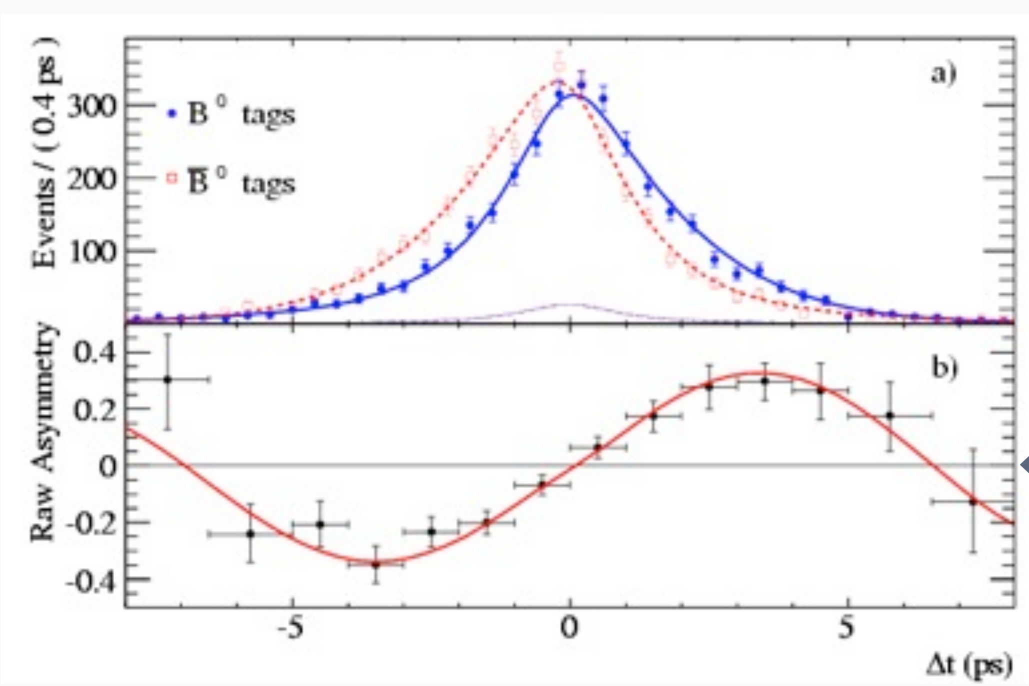
K_S^0 DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes			
$\pi^0\pi^0$	(30.69 ± 0.05) %		209
$\pi^+\pi^-$	(69.20 ± 0.05) %		206
$\pi^+\pi^-\pi^0$	$(3.5\ ^{+1.1}_{-0.9})\times10^{-7}$		133

$$\mathcal{B}.\mathcal{R}.(B\to J/\psi\ K_s)\times$$
$$\mathcal{B}.\mathcal{R}.(J/\psi\to\ell^+\ \ell^-)\times$$
$$\mathcal{B}.\mathcal{R}.(K_s\to\pi^+\ \pi^-)$$

$$\sim 7.3\cdot10^{-5}$$

Tenendo conto che gli errori scalano in prima approssimazione con la radice della dimensione del campione, che nel plot di a_{fCP} uno vorrebbe almeno una decina di bin in tempo con 100 eventi per bin e delle efficienze di ricostruzione, uno desiderebbe un campione di ~ 30 milioni di B

All'epoca CLEO aveva raccolto i dati relativi a ~ 5 Milioni di B neutri



BaBar final: 467 10^6 neutr. B mesons

PRODUZIONE DEI B

- Macchine adroniche
  - Tevatron:
    $p\ \bar{p} \to b\bar{b} + X$
  - LHC:
    $p\ \ p \to b\bar{b} + X$

  Pro: enorme sezione d'urto di produzione. Contro: difficolotà di determinare il flavor del mesone B

- Collisori e^+e^-
  - CLEO, BaBar, KEK-B e loro discendenti
    $e^+e^- \to \Upsilon(4S) \to B^0\bar{B}^0$

  Pro: facile determinare il flavor del mesone B. Contro: sezione d'urto di produzione della $\Upsilon(4S) \sim 1$nb

LUMINOSITÀ DI UN ACCELERATORE

$$\mathcal{R} = \mathcal{L}\,\sigma$$

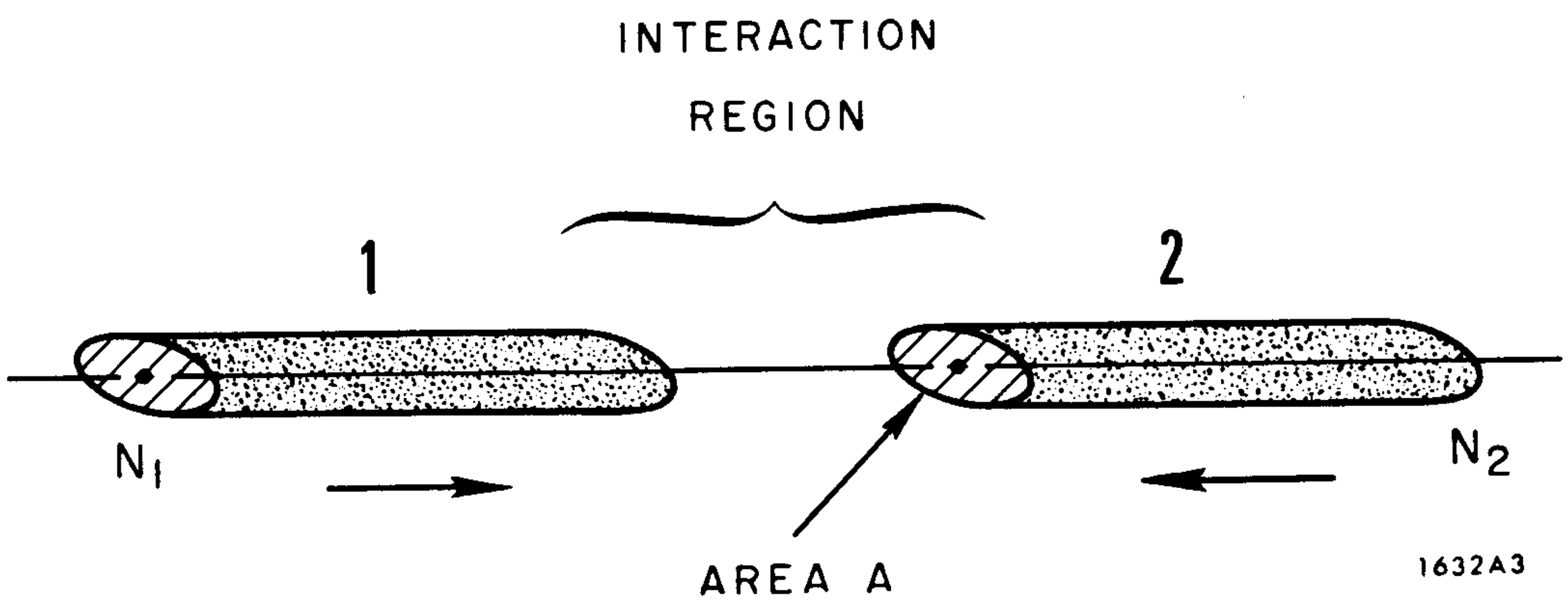


FIG. 3--Head-on collision of two bunches.

$$\mathscr{L} = \frac{N_1 N_2 f}{A}$$

Volendo produrre $30 \cdot 10^6$ mesoni B in un anno di operazioni (10^7 s), occorre costruire una macchina con una luminosità di 3 nb/s = $3 \cdot 10^{33}$Hz/cm^2

Cinematica del decadimento della Y(4S)

VOLUME 45, NUMBER 4 PHYSICAL REVIEW LETTERS 28 JULY 1980

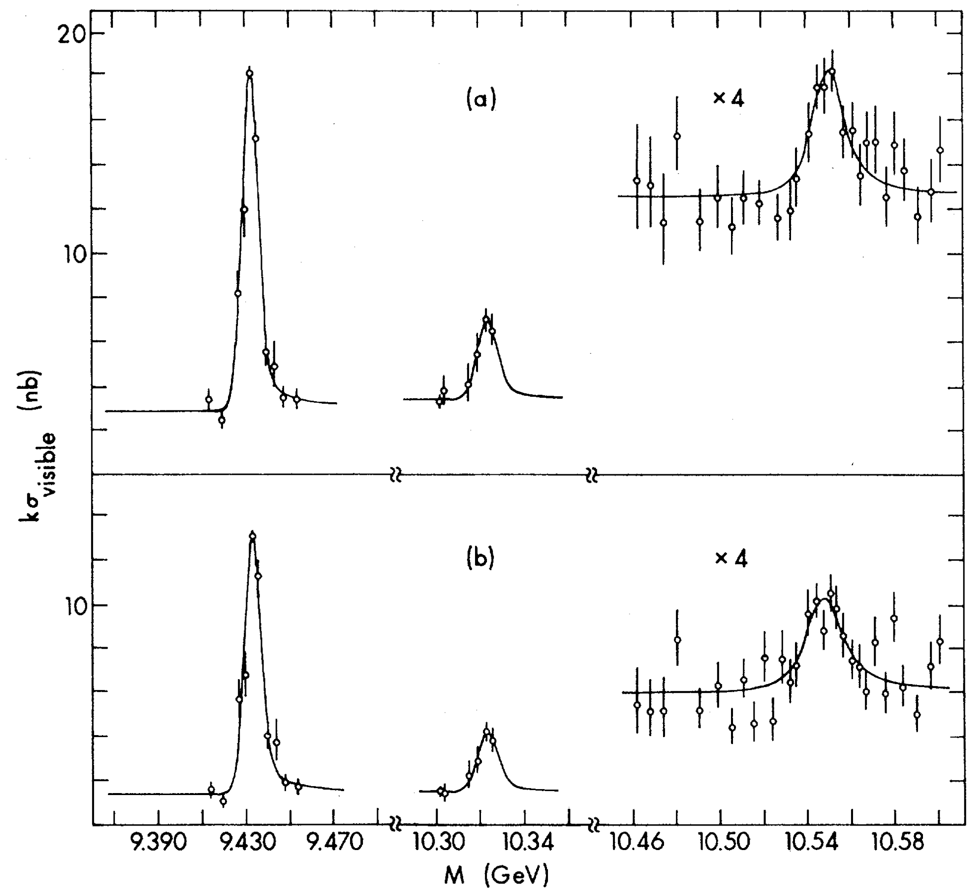


FIG. 2. (a) The observed cross section for $e^+e^- \to$ hadrons multiplied by $k = (M/M_\Upsilon)^2$. M is the e^+e^- invariant mass. (b) The same cross section after removing events with $T \geq 0.85$. The lines are fitted to the data including machine energy spread and radiative corrections. See text for explanation.

- Il picco della sezione d'urto di produzione dell Y(4S) è a 10.58 GeV
- Due mesoni B hanno una massa di 10.56 GeV
- L'energia cinetica dei mesoni è ~10 MeV
- A che velocità si muovono i B ? ~ 6% c
- Il che vuol dire percorrere in media ~ 30 µm prima di decadere.
- È possibile costruire un'apparato di tracciatura con risoluzione migliore di 10 µm per tracce di energia ~ 500 MeV?

$$\vartheta_0 \sim \frac{13.6\text{MeV}}{\beta c p}\sqrt{\frac{x}{X_0}}$$

$$\sigma z \sim \vartheta_0 \times \ell$$

UOVO DI COLOMBO

- Produrre la Υ(4S) in moto nel sistema di riferimento del laboratorio (Idea originale attribuita a Pierre Oddone, attuale direttore del Fermilab)
- E.g. producendo la Υ(4S) con un boost di 0.55 i mesoni B percorrono 260 μm prima di decadere

DESIGNING AND BUILDING PEP - II

PEP-II Overview

* Early machine concepts (1989-1992)
* Start of PEP-II construction (1993-1994)
* Project technical designs (1993-1998)
* Construction finished! (1997-1998)
* First collisions (1998)