

Incontri di Fisica delle Alte Energie

14-16 Aprile 2004, Torino

Adroni con beauty:


- **Rapporti di vite medie:** $\tau(B^+)/\tau(B_d), \tau(B_s)/\tau(B_d), \tau(\Lambda_b)/\tau(B_d)$
- **Differenze di larghezze:** $\Delta \Gamma_{B_{d,s}}$
- **Violazione di CP dovuta al mixing:** $|q/p|_{B_{d,s}}$

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Sistemi $B_q^0 - \bar{B}_q^0$ ($q=d,s$)

$$\hat{H} = \hat{M} - \frac{i}{2} \hat{\Gamma}$$



$$\hat{M} = \begin{pmatrix} M_{11} & M_{21}^* \\ M_{21} & M_{11} \end{pmatrix}$$

Oscillazione



$$\hat{\Gamma} = \begin{pmatrix} \Gamma_{11} & \Gamma_{21}^* \\ \Gamma_{21} & \Gamma_{11} \end{pmatrix}$$

Decadimento

Autostati:

$$|B_q^{L,H}\rangle = p_q |B_q^0\rangle \pm q_q |\bar{B}_q^0\rangle$$

$$\Gamma_{11}^q \quad (\Delta B = 0)$$

- Vite medie: $\Gamma_{B_q} = \Gamma_{11}^q$

$$\Gamma_{21}^q \quad (\Delta B = 2)$$

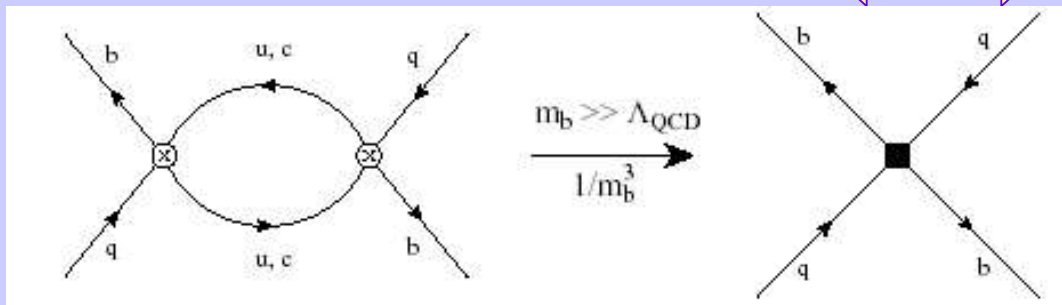
- Differenze di larghezze: $\Delta \Gamma_{B_q} = \Gamma_{B_L^q} - \Gamma_{B_H^q} \rightarrow \Gamma_{21}^q$
 - Violazione di CP dovuta al mixing: $|\mathbf{q}/\mathbf{p}|_{B_q} \rightarrow \Gamma_{21}^q$
- (V_{CKM} diversi)

$$\Gamma_{11}^q \propto \text{Disc} \langle B_q^0 | \mathcal{T} | B_q^0 \rangle \quad \Gamma_{21}^q \propto \text{Disc} \langle \bar{B}_q^0 | \mathcal{T} | B_q^0 \rangle$$

$$\mathcal{T} = i \int d^4x T (\mathcal{H}_{eff}^{\Delta B=1}(x) \mathcal{H}_{eff}^{\Delta B=1}(0))$$

HQE ($m_b \gg \Lambda_{\text{QCD}}$)

Grande rilascio di energia \longleftrightarrow interazione locale



(Effetti spettatore)

$$\Gamma_{21}^q = \sum_k \frac{\bar{c}_k^q(\mu)}{m_b^k} \langle \bar{B}_q^0 | O_k^{q \Delta B=2}(\mu) | B_q^0 \rangle$$

Separazione di scale

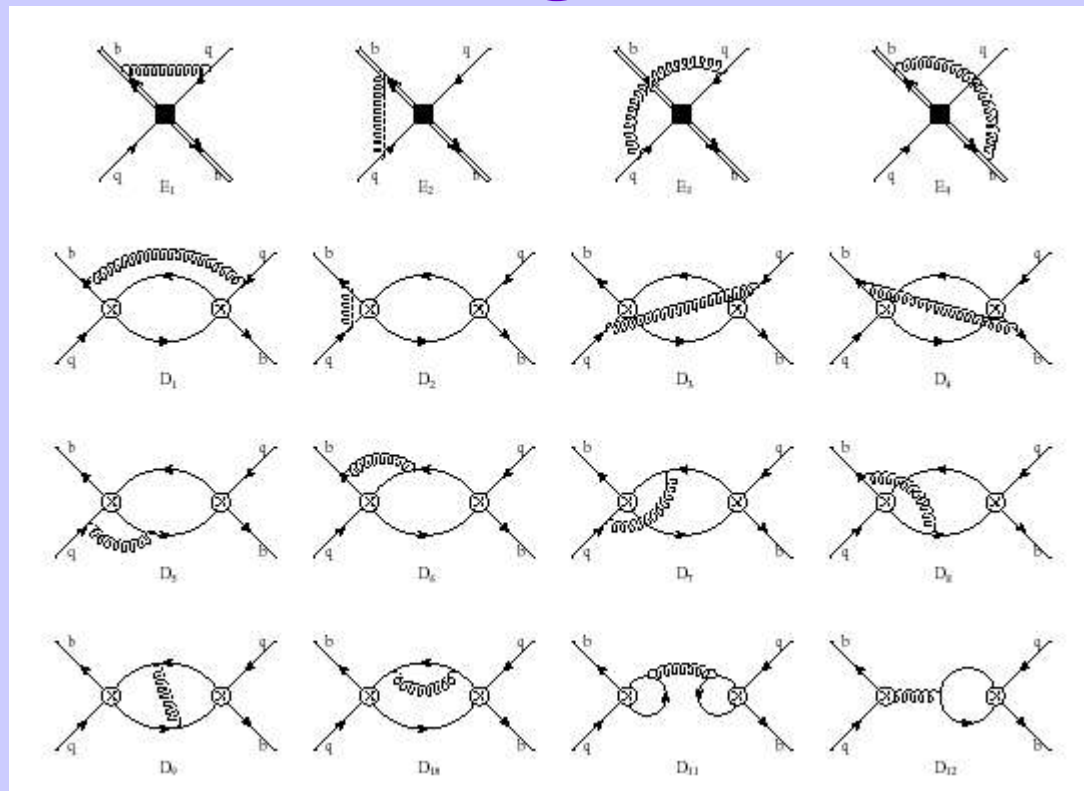
- $c_k^q(\mu)$: corta-distanza (perturbativi)
- $\langle \bar{B}_q^0 | O_k^{q \Delta B=2}(\mu) | B_q^0 \rangle$: lunga-distanza (non-perturbativi)

Coefficienti di Wilson

$$Disc \langle \mathcal{T} \rangle = \vec{c}(\mu) \cdot \langle \vec{O}(\mu) \rangle$$

Matching al NLO in QCD

$\Delta B = 2(\Delta B = 0)$ Diagrammi al NLO



- **Rapporti di vite medie (2002):**

- [E. Franco, V. Lubicz, F. Mescia e C.T.]
- [M. Beneke, G. Buchalla, C. Greub, A. Lenz e U. Nierste]

- **Differenze di larghezze,**
Violazione di CP dovuta al mixing (2003):

- [M. Ciuchini, E. Franco, V. Lubicz, F. Mescia e C.T.]
- [M. Beneke, G. Buchalla, A. Lenz e U. Nierste]

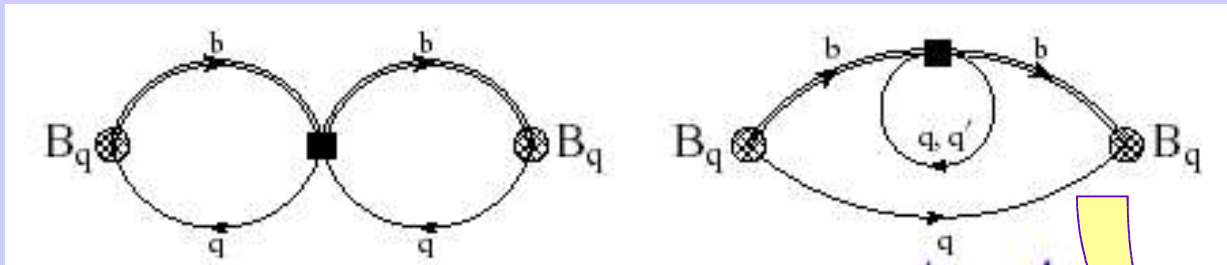
Elementi di matrice: Operatori con $\Delta B = 0$

Contributo degli effetti spettatore ($O(1/m_b^3)$)

$$\begin{aligned} \mathcal{O}_1^q &= (\bar{b}q)_{V-A} (\bar{q}b)_{V-A} \leftrightarrow B_1^q, & \mathcal{O}_2^q &= (\bar{b}q)_{S-P} (\bar{q}b)_{S+P} \leftrightarrow B_2^q, \\ \mathcal{O}_3^q &= (\bar{b}T^a q)_{V-A} (\bar{q}T^a b)_{V-A} \leftrightarrow \epsilon_1^q, & \mathcal{O}_4^q &= (\bar{b}T^a q)_{S-P} (\bar{q}T^a b)_{S+P} \leftrightarrow \epsilon_2^q, \end{aligned}$$

$$O_P = (\bar{b}T^a b)_V \sum_{q=u,d,s,c} (\bar{q}T^a q)_V \quad \leftarrow \text{(non calcolato)}$$

$$[(\bar{q}q)_{V-A} = \bar{q}\gamma_L^\mu q, (\bar{q}q)_{S\pm P} = \bar{q}(1 \pm \gamma_5)q, (\bar{q}q)_V = \bar{q}\gamma^\mu q]$$



(non calcolato)

B-parametri:

- Λ_b : calcolati sul reticolo in HQET, evoluti al LO

[M. Di Pierro, C. T. Sachrajda and C. Michael(UKQCD collaboration), 1999]

B-parametri dei mesoni

$$B_d - B_s - B^+$$

- Sul *reticolo*, in **HQET** ($m_b \rightarrow \infty$)

$$B_1^d = 1.06 \pm 0.08, \quad B_2^d = 1.01 \pm 0.07, \\ \epsilon_1^d = -0.01 \pm 0.03, \quad \epsilon_2^d = -0.03 \pm 0.02.$$

[M. Di Pierro e C. T. Sachrajda, 1998]

- Sul *reticolo*, in **QCD** ($m_c \lesssim m_Q < m_b, m_Q \rightarrow m_b$)

$$B_1^d = 1.2 \pm 0.2, \quad B_2^d = 0.9 \pm 0.1, \\ \epsilon_1^d = 0.04 \pm 0.01, \quad \epsilon_2^d = 0.04 \pm 0.01.$$

[APE (D. Becirevic et al.), 2001]

- Con le **regole di somma**, in **HQET**

$$B_1^d = 1.01 \pm 0.01, \quad B_2^d = 0.99 \pm 0.01, \\ \epsilon_1^d = -0.08 \pm 0.02, \quad \epsilon_2^d = -0.01 \pm 0.03.$$

[M. S. Baek et al., 1998]

Contributo subleading degli effetti spettatore ($O(1/m_b^4)$)

6 operatori indipendenti, dalla *VSA* (B-mesoni) o dal *modello quark-diquark* (barione)

Elementi di matrice: Operatori con $\Delta B = 2$

Contributo leading ($O(1/m_b^3)$)

$$\mathcal{O}_1^q = (\bar{b}q)_{V-A} (\bar{b}q)_{V-A} \leftrightarrow B_1^q, \quad \mathcal{O}_2^q = (\bar{b}q)_{S-P} (\bar{b}q)_{S-P} \leftrightarrow B_2^q.$$

B_q^1, B_q^2  Calcolati sul *reticolo* con metodi diversi

Contributo subleading ($O(1/m_b^4)$)

4 operatori ($R_1^q, R_2^q, R_3^q, R_4^q$):

- R_1^q, R_4^q : esprimibili in termini di operatori calcolati sul *reticolo*, tramite Fierz ed eq. del moto
- R_2^q, R_3^q : dalla *VSA*

B_q^1, B_q^2 dal reticolo

- HQET ($m_b \rightarrow \infty$)

$$B_1^s = 0.83(5)(6), \quad B_2^s = 0.81(2)(10)$$

[V. Giménez e J. Reyes, 2000]

- NRQCD $\mathcal{O}(1/m_b)$

$$B_1^s = 0.85(3)(11), \quad B_2^s = 0.82(2)(11)$$

[Hi-KEK (S. Hashimoto et al.), 2000]

- unquenched NRQCD $n_f = 2$

$$B_1^s = 0.85(2)(6), \quad B_2^s = 0.84(6)(8)$$

[JLQCD (S. Aoki et al.), 2001-2003]

- QCD ($m_c \lesssim m_Q < m_b, m_Q \rightarrow m_b$)

$$B_1^s = 0.91(3)_{-6}^{+0}, \quad B_2^s = 0.86(2)_{-3}^{+2}$$

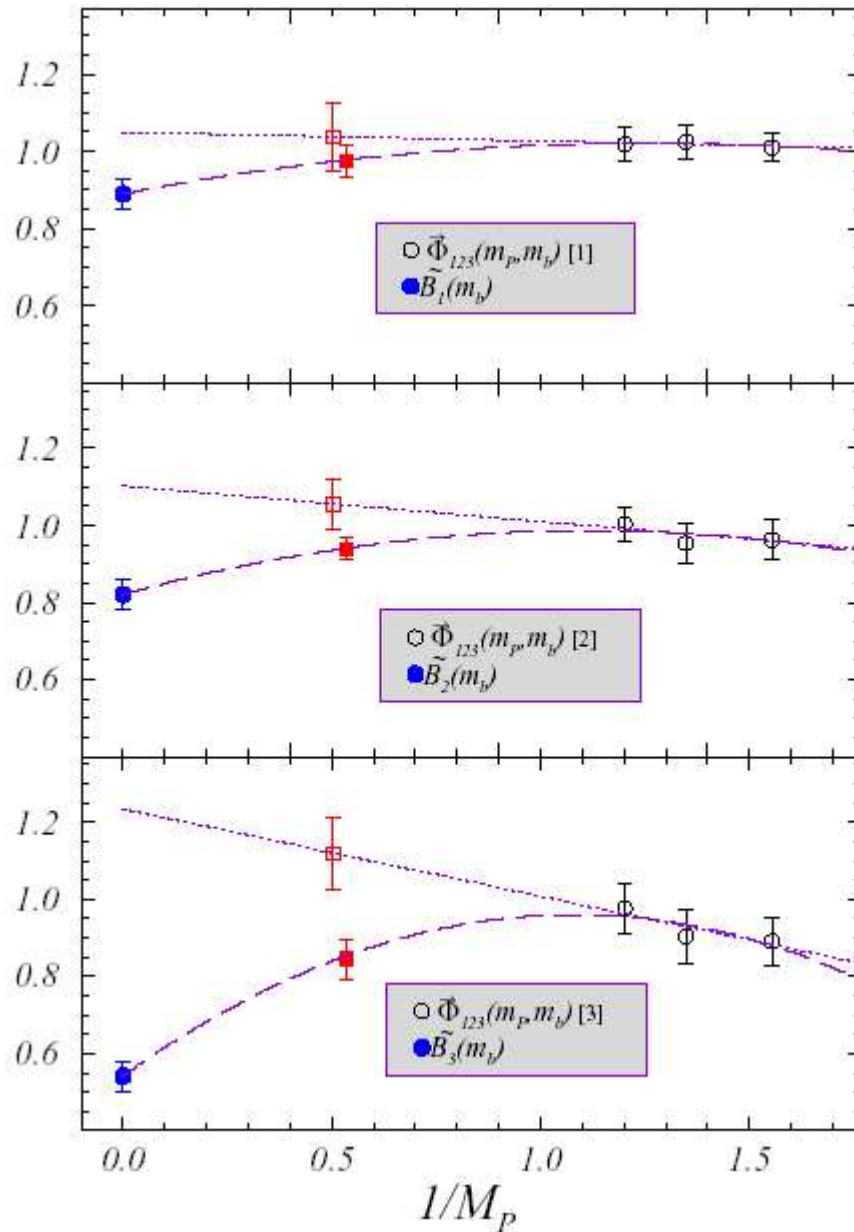
[APE (D. Becirevic et al.), 2000]

- QCD +HQET

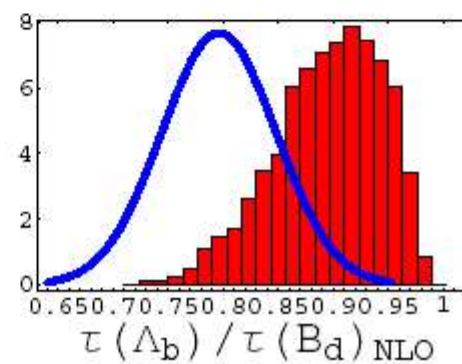
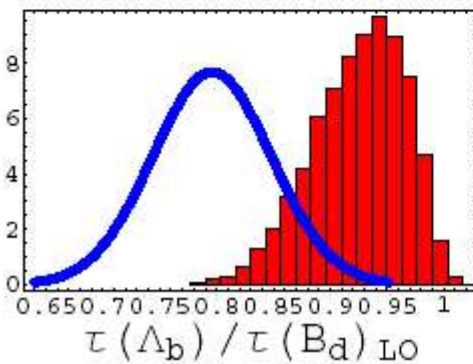
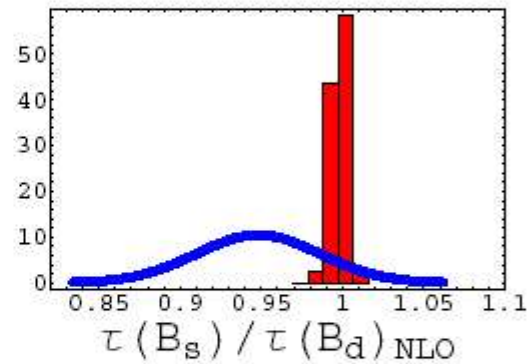
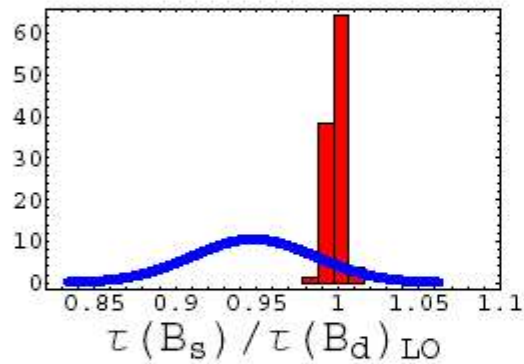
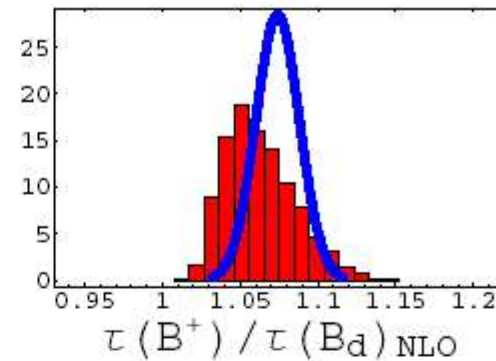
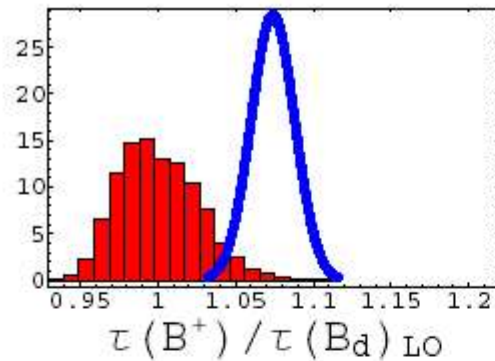
$$B_1^s = 0.87(2)(5), \quad B_2^s = 0.84(2)(4)$$

[APE (D. Becirevic et al.), 2001]

QCD + HQET



Rapporti di vite medie



Previsioni teoriche al LO:

$$\frac{\tau(B^+)}{\tau(B_d)} = 1.01 \pm 0.03, \quad \frac{\tau(B_s)}{\tau(B_d)} = 1.00 \pm 0.01, \quad \frac{\tau(\Lambda_b)}{\tau(B_d)} = 0.93 \pm 0.04$$

[M. Neubert e C. T. Sachrajda, 1997]

Previsioni teoriche al NLO:

+ contributo di $O(1/m_b^4)$ [F. Gabbiani, A. I. Onishchenko and A. A. Petrov, 2003]

$$\frac{\tau(B^+)}{\tau(B_d)} = 1.08 \pm 0.02, \quad \frac{\tau(B_s)}{\tau(B_d)} = 1.00 \pm 0.01, \quad \frac{\tau(\Lambda_b)}{\tau(B_d)} = 0.88 \pm 0.05$$

[E. Franco, V. Lubicz, F. Mescia and C. T., 2002-2003]

Misure sperimentali:

$$\frac{\tau(B^+)}{\tau(B_d)} = 1.085 \pm 0.017, \quad \frac{\tau(B_s)}{\tau(B_d)} = 0.951 \pm 0.038, \quad \frac{\tau(\Lambda_b)}{\tau(B_d)} = 0.786 \pm 0.034$$

[LEP+CDF+B-factories average, Heavy Flavor Averaging Group (HFAG), 2003]

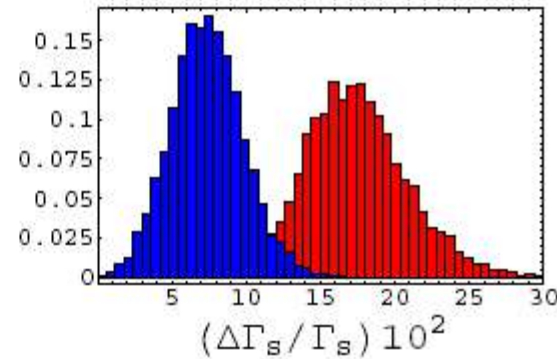
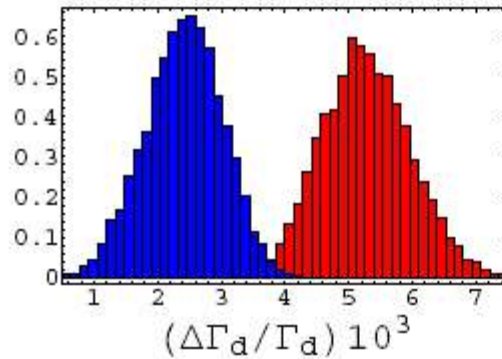
- **Buon accordo al NLO** ($\tau(\Lambda_b)/\tau(B_d)$ a 1.5σ)
- **Possibili miglioramenti teorici in** $\tau(B_s)/\tau(B_d), \tau(\Lambda_b)/\tau(B_d)$
- **Importanza di una misura piu' accurata di** $\tau(B_s)/\tau(B_d)$

Differenze di larghezze

$$\frac{\Delta\Gamma_q}{\Gamma_q} = -\frac{\Delta m_q}{\Gamma_q} \mathcal{R}e\left(\frac{\Gamma_{21}^q}{M_{21}^q}\right)$$

$$(\Gamma_{21}^q/M_{21}^q = \mathcal{O}(m_b^2/m_t^2), \Delta\Gamma_d/\Delta\Gamma_s = \mathcal{O}(\lambda^2))$$

NLO distr. vs LO distr.



Previsioni teoriche al NLO:

$$\frac{\Delta\Gamma_d}{\Gamma_d} = (2.42 \pm 0.59)10^{-3} \quad \frac{\Delta\Gamma_s}{\Gamma_s} = (7.4 \pm 2.4)10^{-2}$$

[M. Ciuchini, E. Franco, V. Lubicz, F. Mescia and C. T., 2003]

Misure sperimentali:

$$\left| \frac{\Delta\Gamma_d}{\Gamma_d} \right| = 0.008 \pm 0.037 \pm 0.018 \text{ (BaBar collaboration, 2003 (preliminary))}$$

$$\frac{\Delta\Gamma_s}{\Gamma_s} = 0.07_{-0.07}^{+0.09} \text{ (HFAG, 2003)}$$

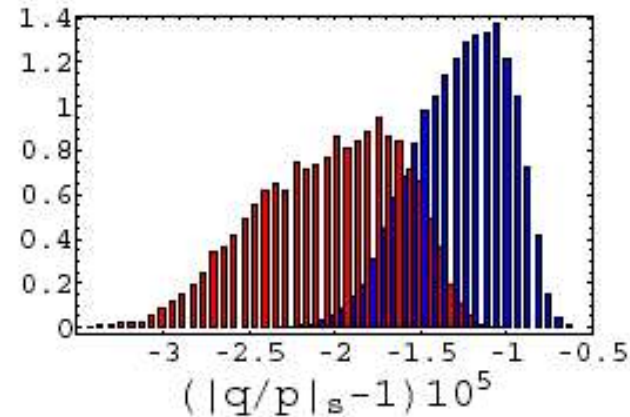
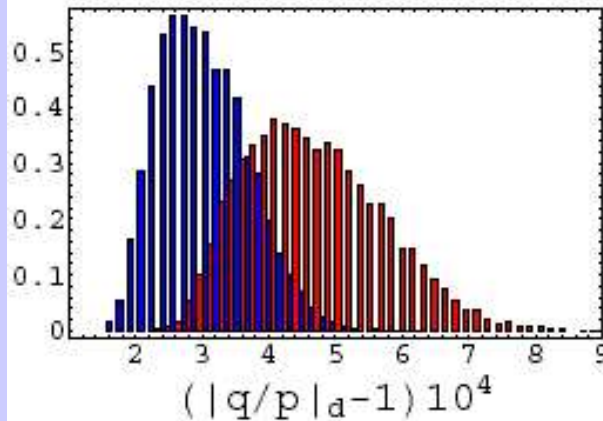
- **Importanza di maggiore accuratezza sperimentale (B-factories, Tevatron)**

Violazione di CP

$$\left| \left(\frac{q}{p} \right)_q \right| - 1 = \frac{1}{2} \mathcal{I}m \left(\frac{\Gamma_{21}^q}{M_{21}^q} \right)$$

$$\left(\left| \left(\frac{q}{p} \right)_q \right| - 1 \right) / \Delta\Gamma_q = \mathcal{O}(m_c^2/m_b^2), \quad \left(\left| \left(\frac{q}{p} \right)_s \right| - 1 \right) / \left(\left| \left(\frac{q}{p} \right)_d \right| - 1 \right) = \mathcal{O}(\lambda^2)$$

NLO distr. vs LO distr.



Previsioni teoriche al NLO:

$$\left| \left(\frac{q}{p} \right)_d \right| - 1 = (2.96 \pm 0.67) 10^{-4}, \quad \left| \left(\frac{q}{p} \right)_s \right| - 1 = -(1.28 \pm 0.27) 10^{-5}$$

[M. Ciuchini, E. Franco, V. Lubicz, F. Mescia and C. T., 2003]

Misura sperimentale *preliminare*:

$$\left| \left(\frac{q}{p} \right)_d \right| - 1 = 0.029 \pm 0.013 \pm 0.011$$

[BABAR Collaboration, 2003]

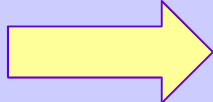
- **Importanza di maggiore accuratezza sperimentale (B-factories, Tevatron)**

Conclusioni

- **Importanza delle correzioni NLO in QCD**
- **Buon accordo** tra previsioni teoriche e misure sperimentali

Rapporti di vite medie

$$\tau(\Lambda_b)/\tau(B_d) \text{ a } 1.5\sigma$$

$\tau(B_s)/\tau(B_d), \tau(\Lambda_b)/\tau(B_d)$  **possibili miglioramenti teorici**

$\tau(B_s)/\tau(B_d)$  **importanza di maggiore accuratezza sperimentale**

Differenze di larghezze e Violazione di CP

- **Importanza di maggiore accuratezza sperimentale (B-factories, Tevatron)**