On the Super-B Physics Potential: the "other" physics cases

Marco Ciuchini
INFN Roma III

1 The golden goal: Bd & Bs physics + τ LFV

2 The next-to-main goal: LFC τ physics

3 The last-but-not-least goal: charm physics
D-$\bar{D}$ mixing + D CPV decays

thanks to: I. Bigi, P. Paradisi, M. Pierini, V. Porretti, L. Silvestrini and G. Gonzalez

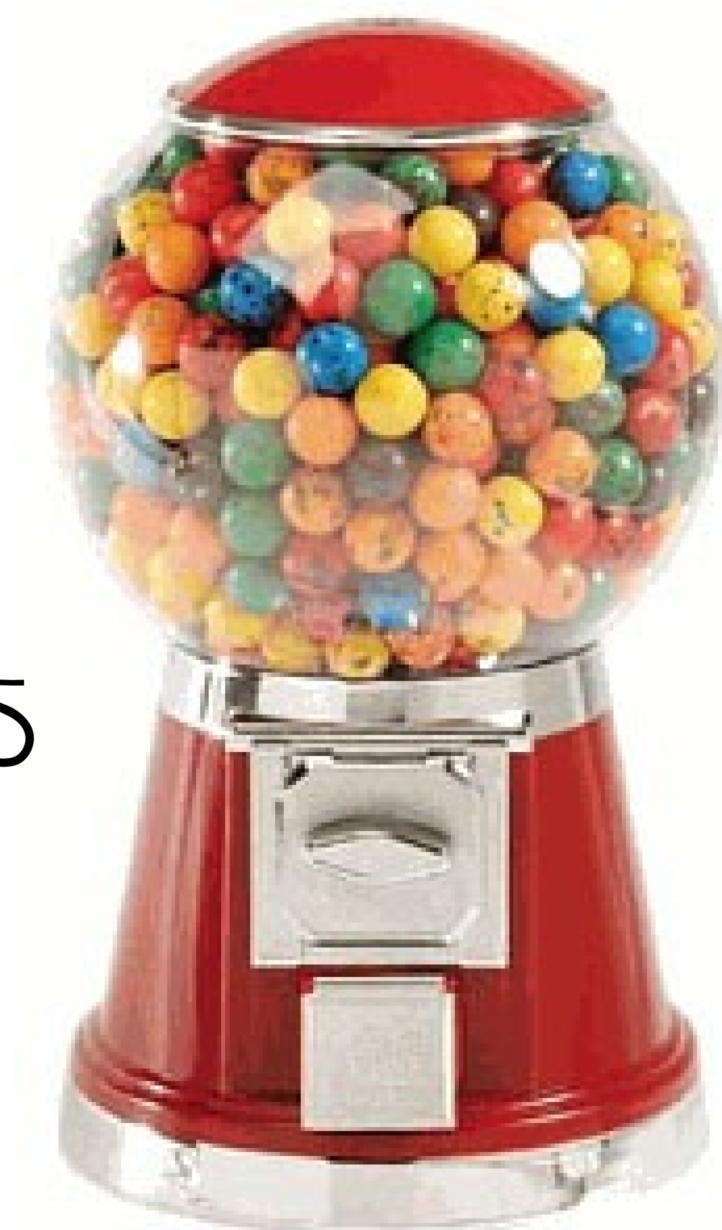
From Super-B to Super-Flavour Factory

$10^{10}\ \tau^+\tau^-$

$10^9\ D\bar{D}$

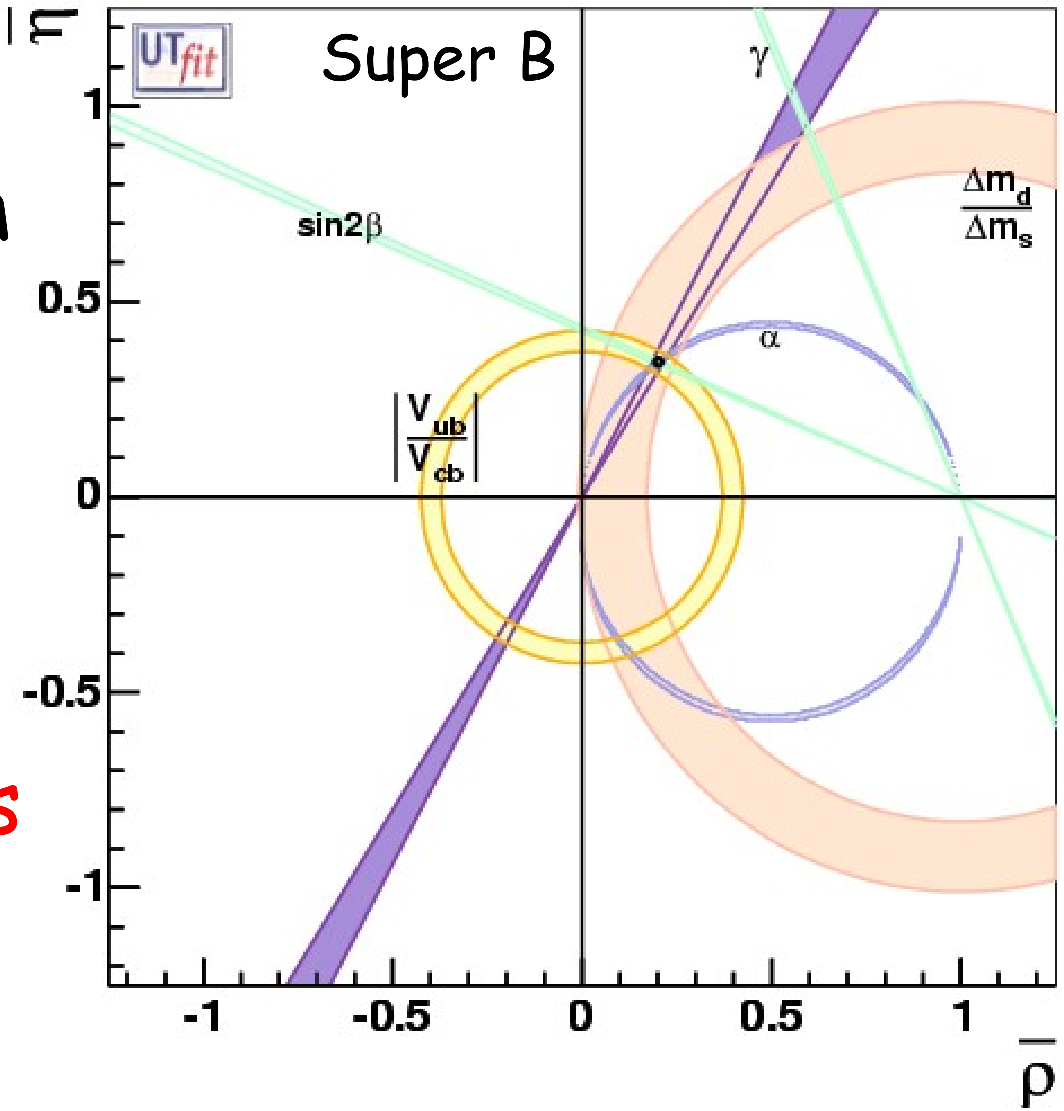
$10^{10}\ B\bar{B}$

$10^{10}\ B_s\bar{B}_s$



B_d and B_s physics program

Push the present B factory physics program to unprecedented accuracy



redundancy + precision is the key to new physics

A plethora of new opportunities with the B_s (+ rare modes - $B_s \to \mu\,\mu$)

CPV in Rare Decays		e^+e^- Precision		
Measurement	**Goal**	**3/ab**	**10/ab**	**50/ab**
$S(B^0 \to \phi K_S^0)$	$\approx 5\%$	16%	8.7%	3.9%
$S(B^0 \to \eta' K_S^0)$	$\approx 5\%$	5.7%	3%	1%
$S(B^0 \to K_S^0 \pi^0)$		8.2%	5%	4%
$S(B^0 \to K_S^0 \pi^0 \gamma)$	SM: $\approx 2\%$	11%	6%	4%
$A_{CP}(b \to s\gamma)$	SM: $\approx 0.5\%$	1.0%	0.5%	0.5%
$A_{CP}(B \to K^* \gamma)$	SM: $\approx 0.5\%$	0.6%	0.3%	0.3%

J. Albert et al.

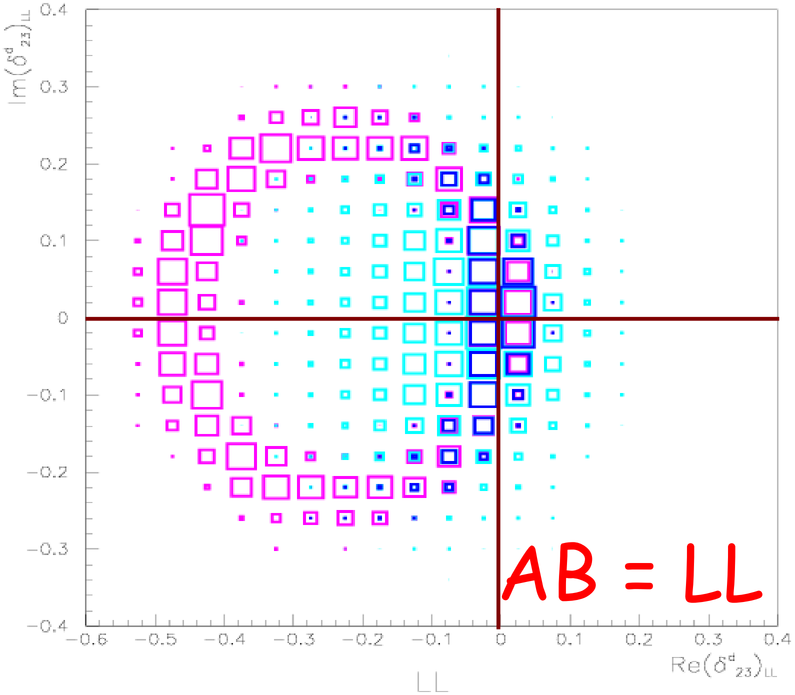
physics/0512235

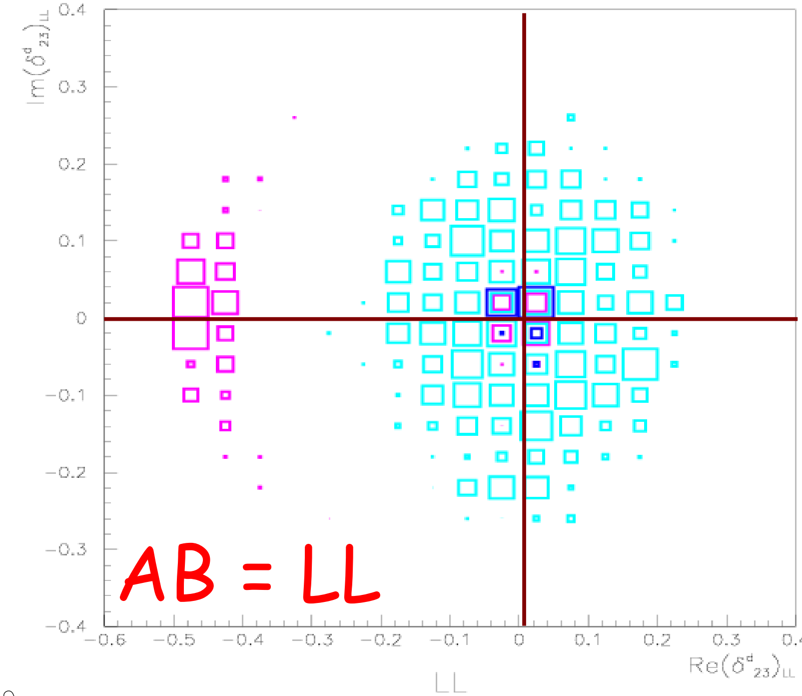
Rare Decays		e^+e^- Precision		
Measurement	**Goal**	**3/ab**	**10/ab**	**50/ab**
$\lvert V_{td}\rvert/\lvert V_{ts}\rvert \sim \sqrt{\frac{\mathcal{B}(b\to d\gamma)}{\mathcal{B}(b\to s\gamma)}}$		19%	12%	5%
$\mathcal{B}(B \to D^* \tau \nu)$	$\mathcal{B} = 8 \times 10^{-3}$	10%	5.6%	2.5%
$\mathcal{B}(B \to s\nu\bar{\nu})$ $(K^{-,0}, K^{*-,0})$	1 exclusive: $\sim 4 \times 10^{-6}$	$\sim 1\sigma$ (per mode)	$> 2\sigma$ (per mode)	$> 4\sigma$ (per mode)
$\mathcal{B}(B_d \to \text{invisible})$		$< 2 \times 10^{-6}$	$< 1 \times 10^{-6}$	$< 4 \times 10^{-7}$
$\mathcal{B}(B_d \to \mu\mu)$	$\sim 8 \times 10^{-11}$	$< 3 \times 10^{-8}$	$< 1.6 \times 10^{-8}$	$< 7 \times 10^{-9}$
$\mathcal{B}(B_d \to \tau\tau)$	$\sim 1 \times 10^{-8}$	$< 10^{-3}$	$O(10^{-4})$	?

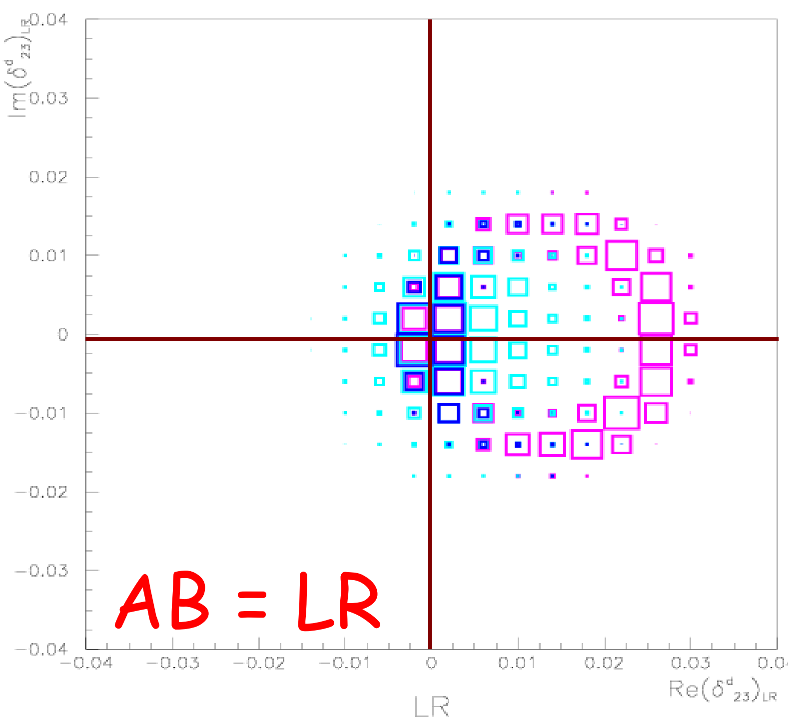
Re $(\delta^d_{23})_{AB}$ vs Im $(\delta^d_{23})_{AB}$

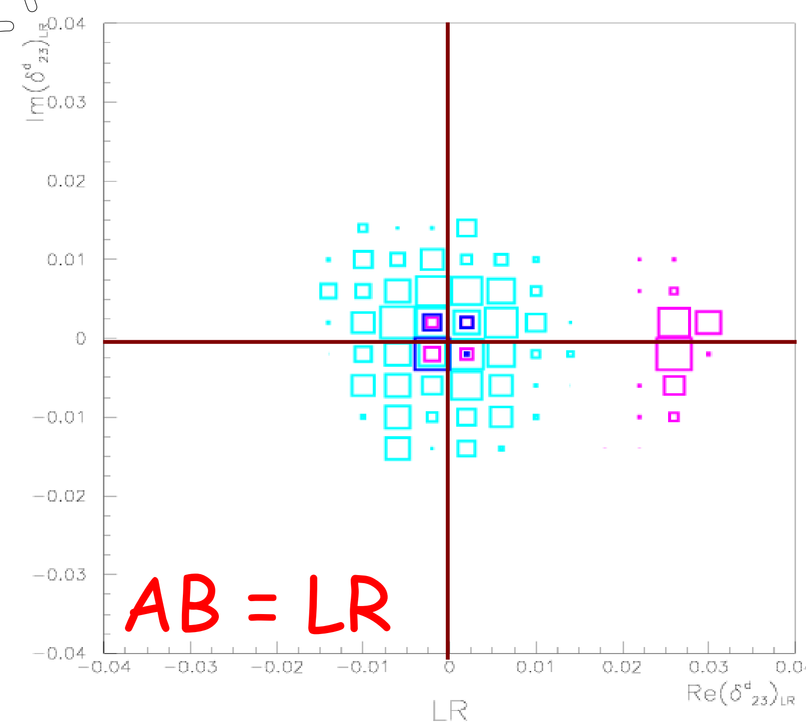
present | future

PRELIMINARY









$b \to s \gamma$ only

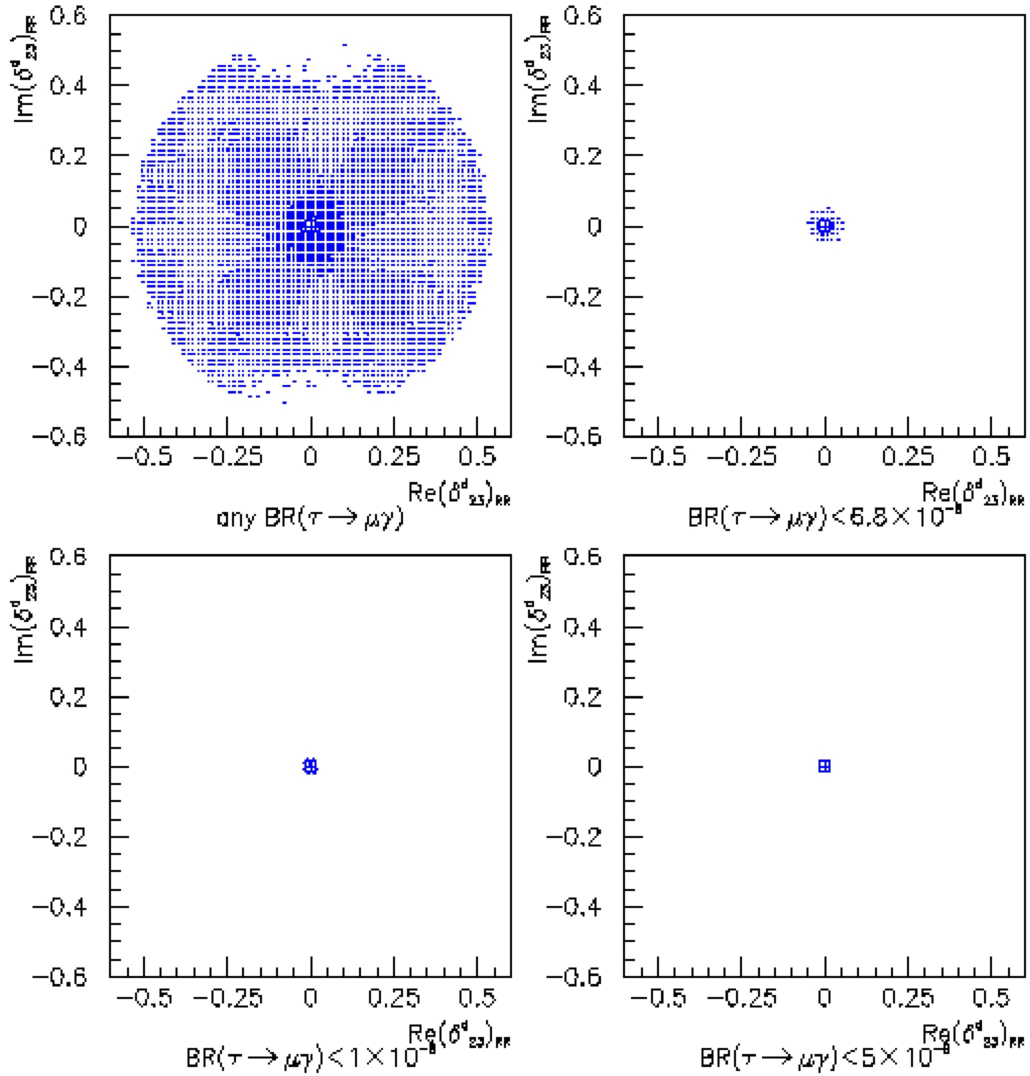
$b \to s\, ll$ only

All constraints

Lepton Flavour Violation: τ -> μ/e γ

Unmistakable signal of new physics

Negative results still powerful in constraining GUT scenarios



Interesting interplay between quark and lepton FV

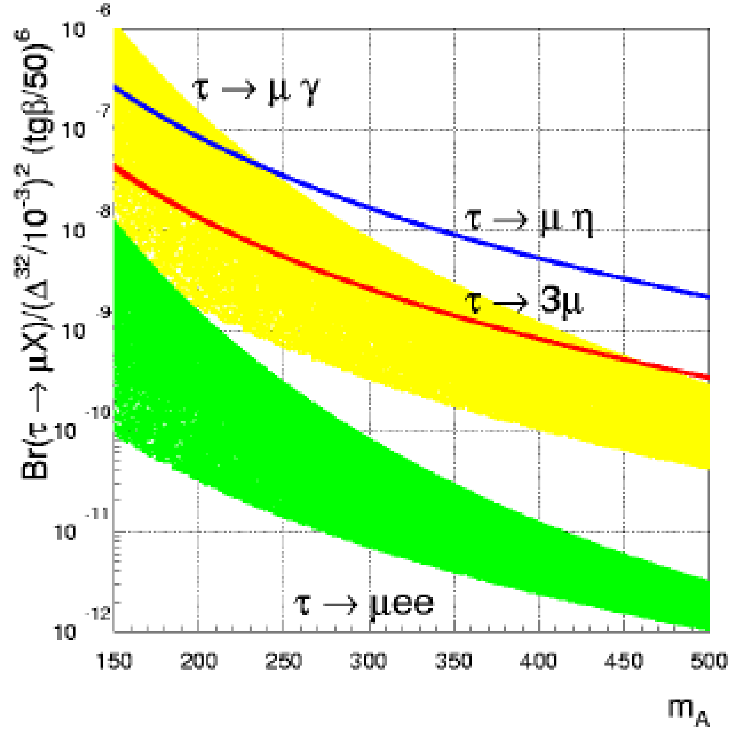
All the LFV τ decay modes are interesting and can be exploited to identify the source of NP contribution

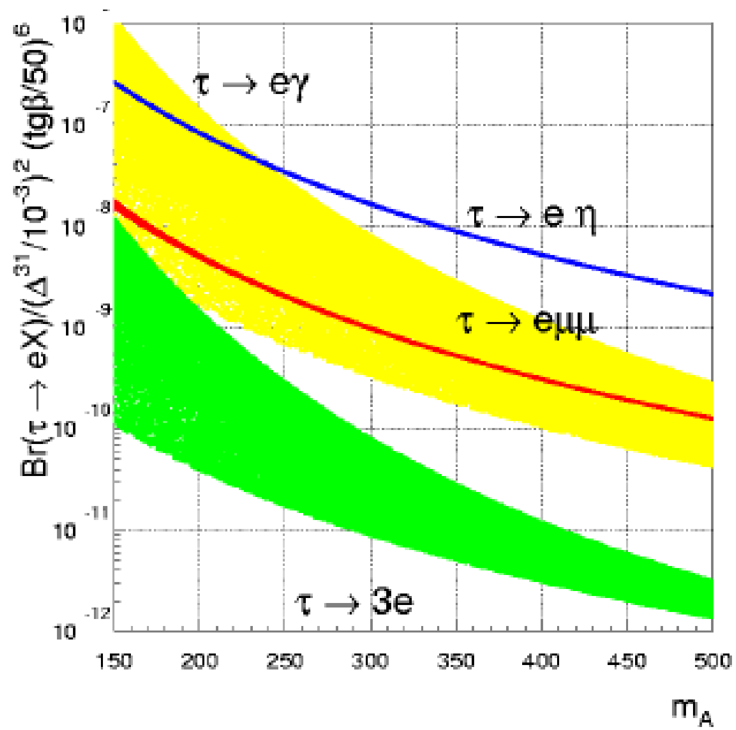
For instance, in supersymmetry gaugino-mediated LFV predicts

$$BR(\tau \to l_j l_k l_k)/BR(\tau \to l_j \gamma) \sim \alpha_e/3\pi\,(\log(m_\tau^2/m_k^2) - 3)$$

Higgs-mediated LFV does not exhibit this correlation

P. Paradisi, hep-ph/0508054





Other topics in τ physics

τ properties: mass, lifetime (CPT ~ 10^{-4}-10^{-5})

Universality of lepton (charged) currents

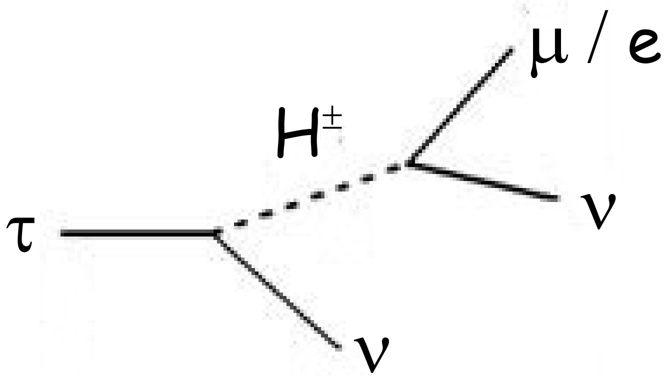
$$\tau_\tau = \tau_\mu \left(\frac{g_\mu}{g_\tau}\right)^2 \left(\frac{m_\mu}{m_\tau}\right)^5 \mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau) \frac{f(m_e^2/m_\mu^2) r_{RC}^\mu}{f(m_e^2/m_\tau^2) r_{RC}^\tau}$$

$$\tau_\tau = \tau_\mu \left(\frac{g_e}{g_\tau}\right)^2 \left(\frac{m_\mu}{m_\tau}\right)^5 \mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau) \frac{f(m_e^2/m_\mu^2) r_{RC}^\mu}{f(m_\mu^2/m_\tau^2) r_{RC}^\tau}$$

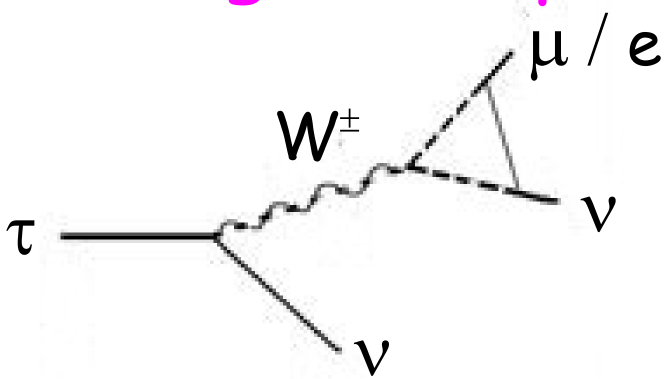
$\frac{g_\mu}{g_\tau}, \frac{g_e}{g_\tau}, \frac{g_\mu}{g_e}$ with an error ~ 10^{-4}

Universality violation in SUSY are induced by

- tree-level charged Higgs exchange



- neutralino/chargino-slepton loop



High precision measurements might constrain SUSY parameters: quantitative study under way

P. Paradisi

CPV in τ decays: T-odd moments

(1) $\tau^- \to \nu K^-\pi^0 / K^0\pi^-$: $\langle s_\tau . (p_K \times p_\pi)\rangle$

Bigi, Sanda

(2) $$e^+(\vec{p})e^-(-\vec{p}) \to \tau^+(\vec{k},\vec{S}_+)\tau^-(-\vec{k},\vec{S}_-) \to \overline{B}(\vec{q}_{\overline{B}})\overline{\nu}_\tau + A(\vec{q}_A)\nu_\tau$$

$$O_1 = \frac{1}{2}\left[\hat{p}\bullet\left(\overrightarrow{q_{\overline{B}}}\times\overrightarrow{q_A}\right)+\hat{p}\bullet\left(\overrightarrow{q_{\overline{A}}}\times\overrightarrow{q_B}\right)\right]$$

Ananthanarayan, Rindani

$$\mathrm{Re}(d_\tau) = \frac{1}{c^1_{AB}}\frac{e}{\sqrt{s}}\left(\langle O_1(P)\rangle - \langle O_1(-P)\rangle\right)$$

Error on τ EDM $\sim 5 \times 10^{-21}$ e cm

($d_e < 1.6 \times 10^{-27}$ e cm)

Sensitivity to new physics to be assessed

Charm Physics

Unique opportunity: D's are the only mesons available to study oscillations in the up-quark sector

Charm is not light nor heavy wrt the QCD scale

- large long-distance effects
- large strong phases
- very large theoretical uncertainty

GIM suppression of FCNC extremely efficient

Huge NP contributions still possible

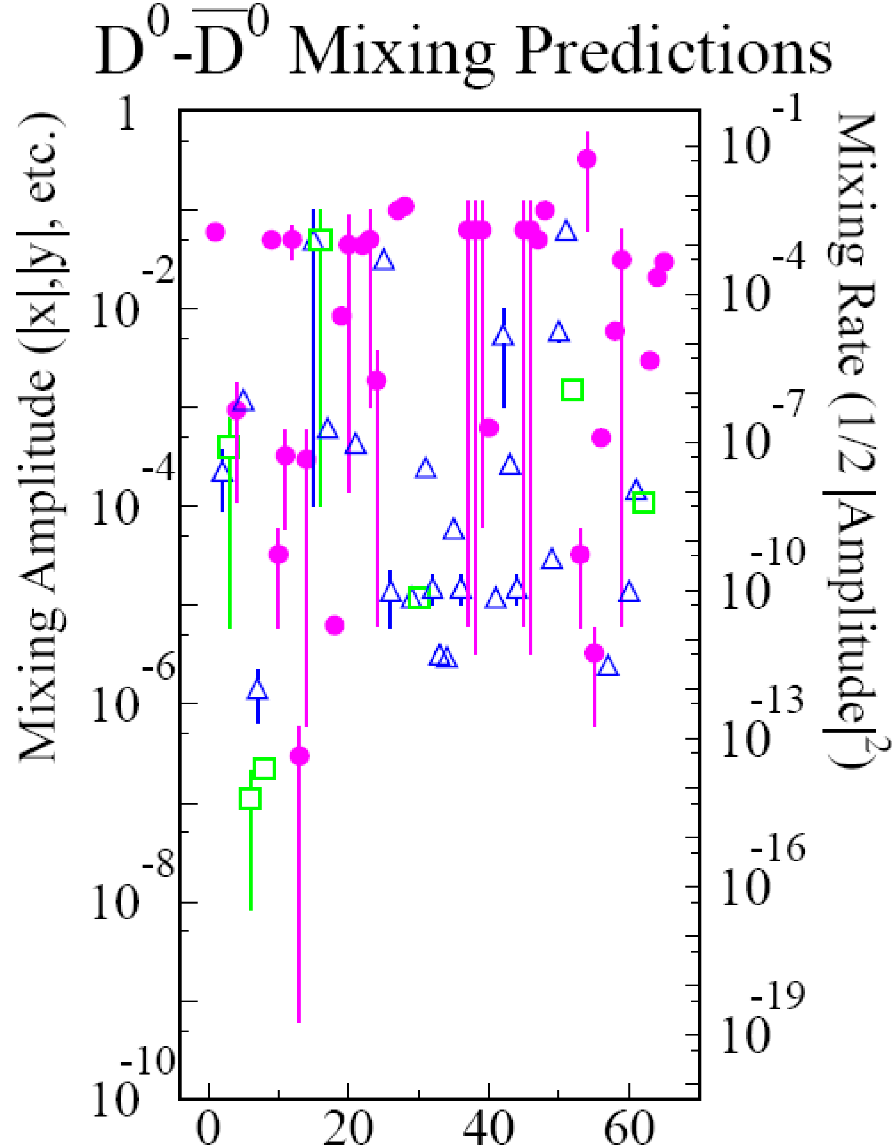
D-$\bar{D}$ mixing

H. Nelson

The predictions of the relevant mixing parameters $x_d=\Delta M/\Gamma$ and $y_d=\Delta\Gamma/2\Gamma$ span 2 orders of magnitude

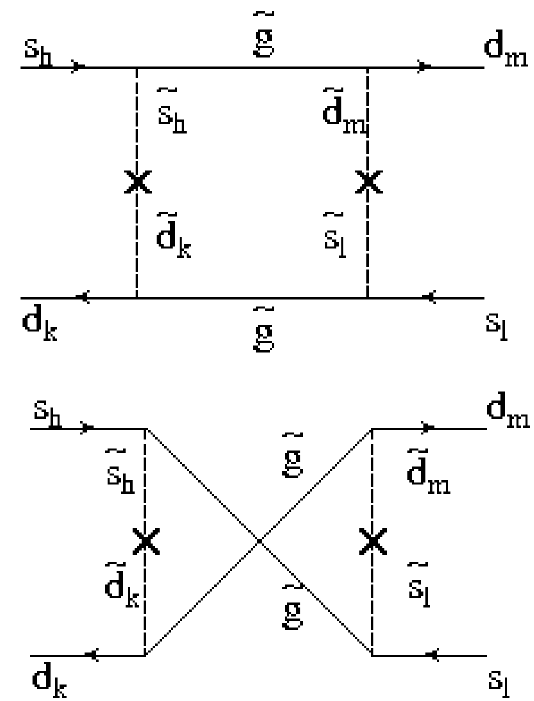
Long-distance dominated $x_d^{SD} \sim 10^{-5}$

Case for NP based on x_d uncertain!! (I. Bigi)



D-$\overline{\text{D}}$ mixing in SUSY

Yet NP contributions can be so large that non-trivial bounds can be obtained anyway



For example: MSSM with non-diagonal squark mass matrices

x	$\sqrt{\left\|\mathrm{Re}\,(\delta^u_{12})^2_{LL}\right\|}$	$\sqrt{\left\|\mathrm{Re}\,(\delta^u_{12})^2_{LR}\right\|}$	$\sqrt{\left\|\mathrm{Re}\,(\delta^u_{12})_{LL}\,(\delta^u_{12})_{RR}\right\|}$
0.3	4.7×10^{-2}	6.3×10^{-2}	1.6×10^{-2}
1.0	1.0×10^{-1}	3.1×10^{-2}	1.7×10^{-2}
4.0	2.4×10^{-1}	3.5×10^{-2}	2.5×10^{-2}

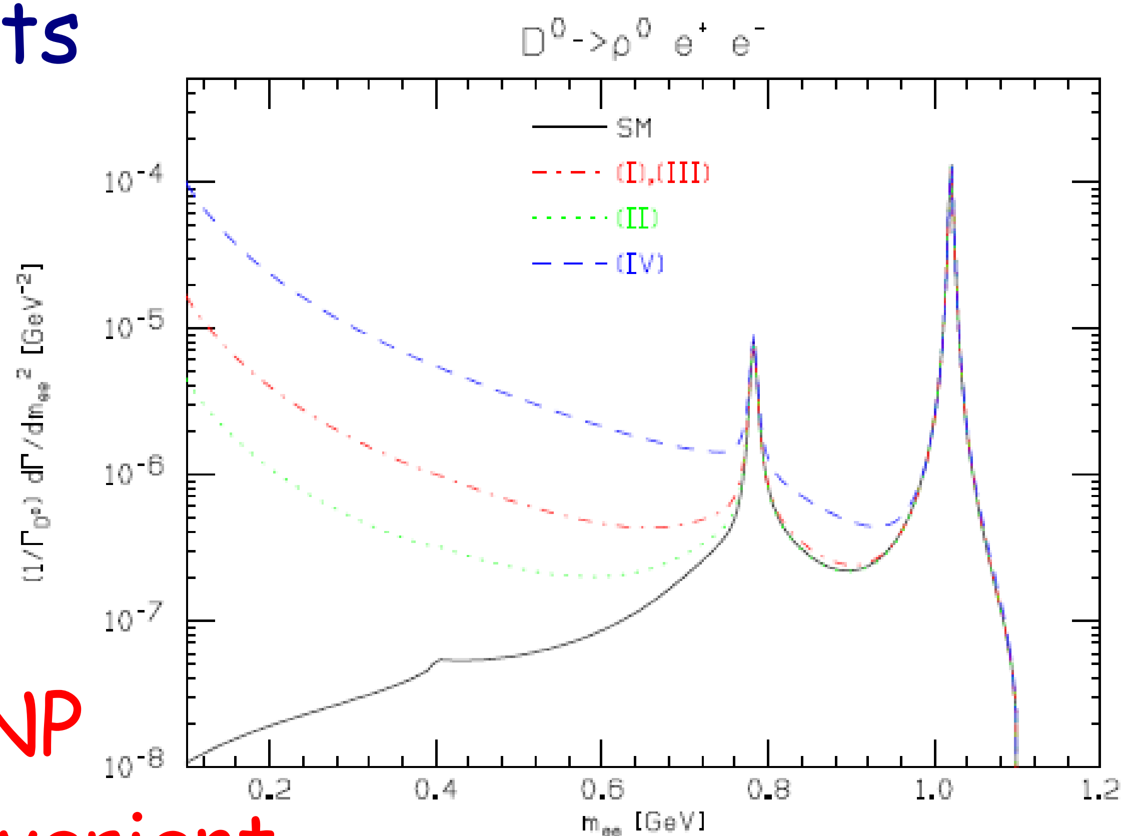
Gabbiani et al.

$\Delta m_d < 1.32 \times 10^{-10}$ MeV

Rare D decays

Again one has to fight against long distance to disentangle NP effects

- $c \to u\,\gamma$ transitions driven by LD contributions
- $D \to V\, l^+ l^-$ gets large NP effects in the low invariant mass region of the leptons



Burdman et al.

CPV in D decays

Direct CPV

© I. Bigi

☺ Cabibbo favour. (CF) modes: need New Physics (except *)

😐 1x Cabibbo supp. modes (SCS)

possible with KM -- benchmark: $O(\lambda^4) \sim O(10^{-3})$

New Physics models: $O(\%)$ conceivable

if observe direct ~~CP~~ ~ 1% in SCS decays -- is it New Physics?

must analyze host of channels

☺ 2x Cabibbo supp. modes (DCS):need New Physics (except *)

CPV in t-dependent CPA ~ $\sin(\Delta m_D t)\, \mathrm{Im}(q/p)\, \rho_f$

$D^0 \to K_S\, \phi/\pi^0$ vs. $\bar{D}^0 \to K_S\, \phi/\pi^0$

$D^0 \to K^+K^-/\pi^+\pi^-$ vs. $\bar{D}^0 \to K^+K^-/\pi^+\pi^-$

$D^0 \to K^+\pi^-$ vs. $\bar{D}^0 \to K^-\pi^+$

SM:
CPA ~ 10^{-6}

Conclusions (i)

B physics + τ LFV

τ physics (lepton cc univ. + CPV)

charm physics (mixing + rare + CPV)

Conclusions (ii)

Design considerations:

© I. Bigi

- hermeticity of detector & low backgrounds most helpful or even essential for beauty, τ & charm decays to control systematics; e.g., $B \to \tau\tau, \tau\nu, \tau\nu D, \tau\nu X$ / $\tau \to \nu l \nu, \nu K\pi$

- the resolution of the microvertex detector should be driven by the presumably much more demanding requirements of charm physics, in particular concerning D^0 - $\overline{D}^0$ oscillations and CP̸ there. This should benefit also
  - searches for CP̸ in τ decays
  - searches for CP̸ in B_s decays on Υ(5S) driven by $\Delta\Gamma$

- a polarized e- beam most helpful for CP̸ studies in τ & Λ_c decays -- also to address systematics

Conclusions (iii)

No problem to establish the physics case

Program complementary to the LHC

helps understanding NP models

Measurable NP virtual effects

probes scales beyond the LHC reach

O(10) interesting measurements

Phenomenological analyses not always match the foreseen accuracy: dedicated work is required