XII. INTERNATIONAL CONFERENCE ON HADRON SPECTROSCOPY

INFN Istituto Nazionale di Fisica Nucleare

HadronPhysics I3 Study of Strongly Interacting Matter

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Laboratori Nazionali di Frascati (Rome)

The Physics Case of the SuperB Facility

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SuperB

Conceptual Design Report: arXiv:0709.0451 (hep-ex)
http://www.pi.infn.it/SuperB/

Overview

- Introduction
  - Physics case – in a nutshell
  - Data sample
- New Physics Search Capability
  - New Physics in Loops ($\Delta F=1$ Transitions)
  - New Physics in $\Delta F=2$ Transitions
  - Minimal Flavour Violation
  - SUSY CKM
  - τ Decays
    - Lepton Flavour Violation; CP and CPT Violation; τ anomalous magnetic moment.
- Summary
- Conclusion

Physics Case

Physics Case – in a Nutshell

- We expect New Physics (NP) at the TeV scale:
  - Same motivation as the LHC!
- This physics will have some kind of flavour structure:
  - Rich structure: *we have to measure it*!
  - Trivial structure: *we have to confirm*!
- SuperB can make complementary measurements to the LHC programme:
  - Many rare decay final states are only accessible to SuperB.
  - Sensitive to off-diagonal terms in the squark mixing matrix.
  - Test Lepton Flavour Violation (LFV) in τ decay.
  - Can study CP and CPT violation in τ decay, τ anomalous magnetic moment.
  - Search for CP (and CPT) violation in D decays.

Data Sample

- Aim: integrate 50-100 ab^{-1} of data.

- Two orders of magnitude larger data set than the current B-factories:
  - i.e. 110 Billion $B\bar{B}$ pairs operating at the Y(4S).
  - Similar numbers of D mesons and τ leptons.
  - Can run at different $\sqrt{s}$, e.g. Y(5S) for B_s physics.

- Also see talks by:
  - Eugenio Paoloni on the detector (next).
  - Francesco Forti in the Plenary session (This afternoon).

Today's calibration channel is tomorrow's background

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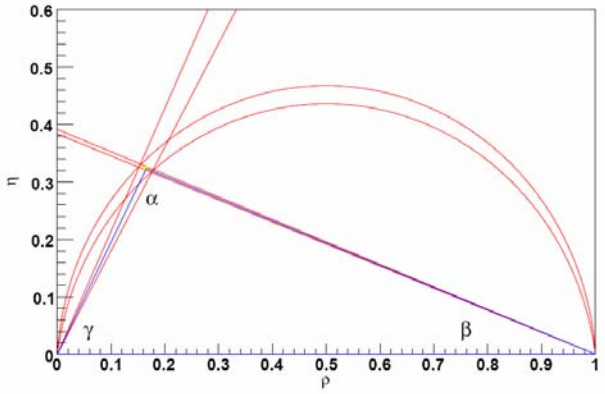
Today's golden channel is tomorrow's calibration mode

- Unitarity Triangle will be well measured at SuperB.
- The angles and sides are calibration measurements, required in order to search for NP.



Today's calibration channel is tomorrow's background

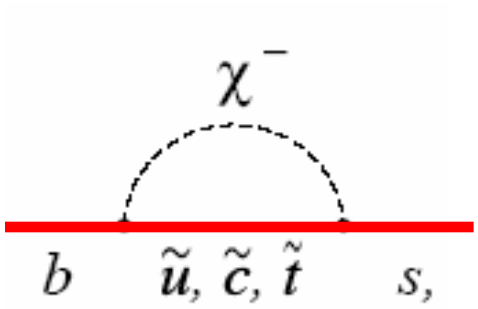
Today's golden channel is tomorrow's calibration mode

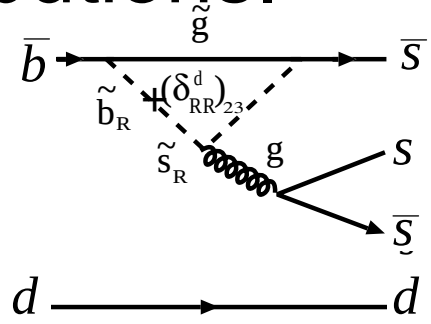
Tomorrow we look for new physics

New Physics Search Capability

New Physics in Loops (ΔF=1)

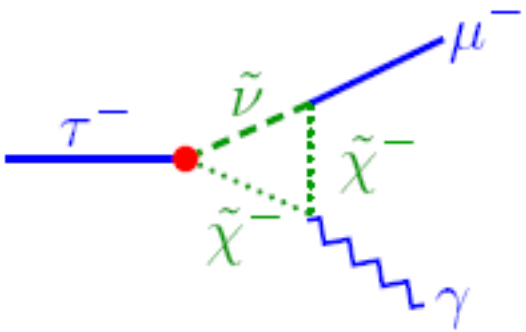
- Rare loop processes can have significant NP contributions.





$\phi, \eta', (KK)_{CP}$

K^0_S

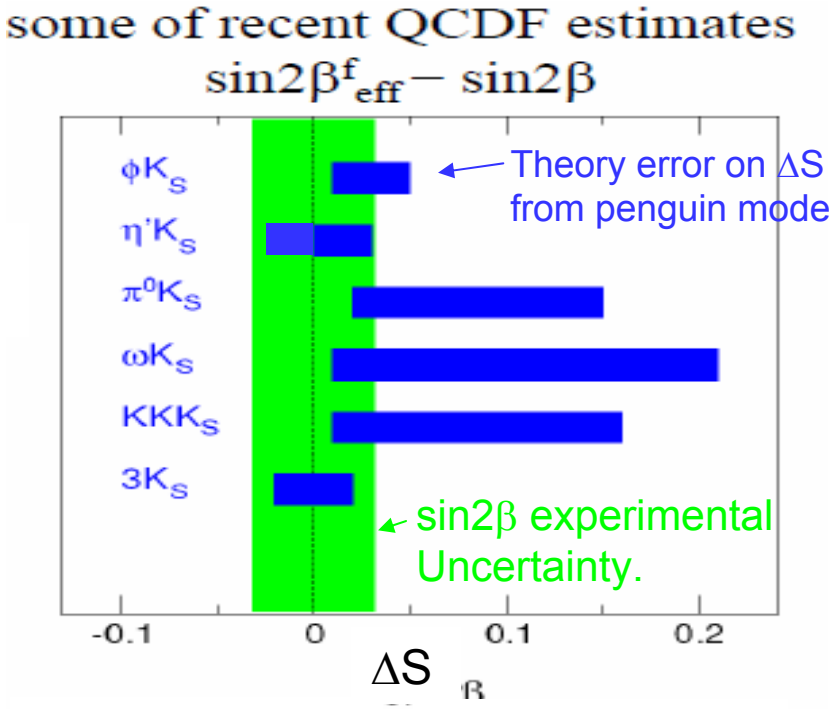


- NP can modify the expected Standard Model (SM) amplitudes and asymmetries.
- Want to look in as many different modes (and with as many different observables) as possible.

New Physics in Loops (ΔF=1)

- β_{eff} measured in b→s penguin decays can differ from β in b→cc̄s.

- Small uncertainties come from SM corrections to the decays.
  - O(0.01) on sin(2β_{eff}) in η'K^0 and 3K^0_s.



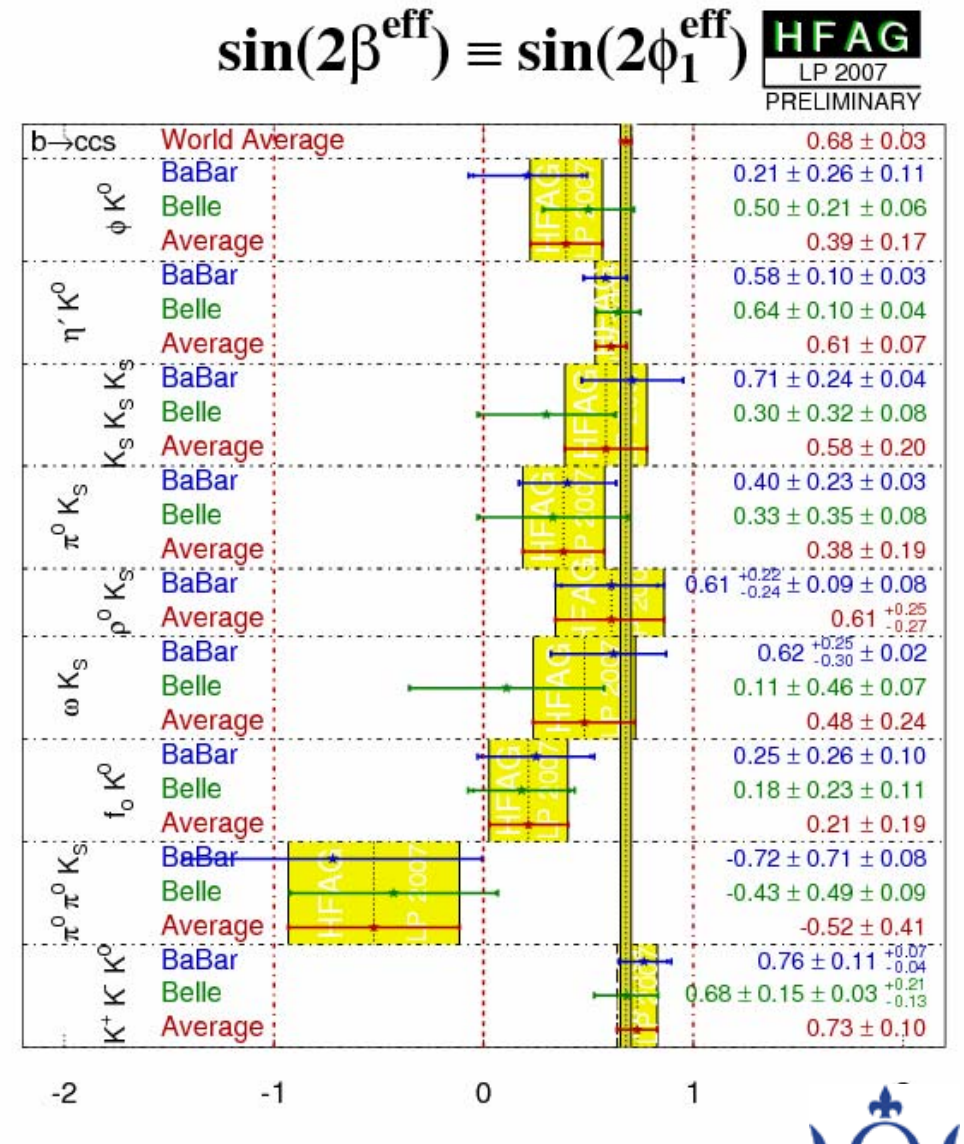
QCDF: (Beneke, PLB620 (2005), 143-150, Cheng et al., PRD72 (2005) 094003 etc.
SCET: (Williamson & Zupan, hep-ph/0601214)
Can estimate ΔS and mostly see a positive shift.

SU(3): Grossman *et al*, PRD68 (2003) 015004; Gronau *et al*, PRD71 (2005) 074019; …).

SM corrections to b→s penguin decays tend to prefer $\beta_{eff} > \beta$.

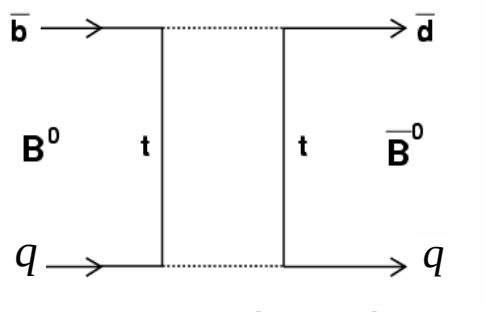
New Physics in Loops (ΔF=1)

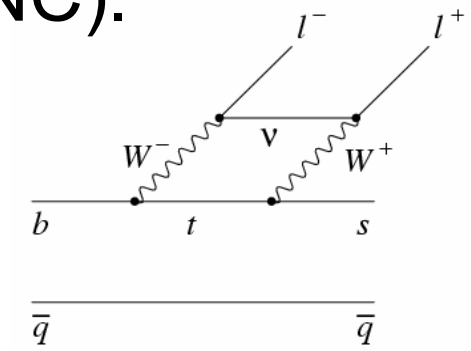
- β_{eff} measured in b→s penguin decays can differ from β in b→c$\bar{c}$s.
- Small uncertainties come from SM corrections to the decays.
  - O(0.01) on sin(2β_{eff}) in $\eta'K^0$ and $3K^0_s$.
- Large deviations from SM expectation would indicate NP.
  - Discrepancy decreases year by year!
- SuperB will be able to probe these asymmetries on a mode-by-mode basis to the level of current SM uncertainties.



New Physics in ΔF=2 Transitions

- ΔF=2 transitions in $B^0_{d,s}\overline{B}^0_{d,s}$ systems are box diagrams (mixing or FCNC).





$q = d, s$

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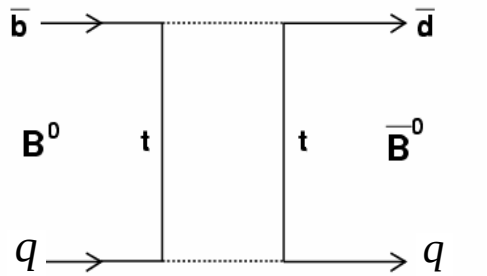
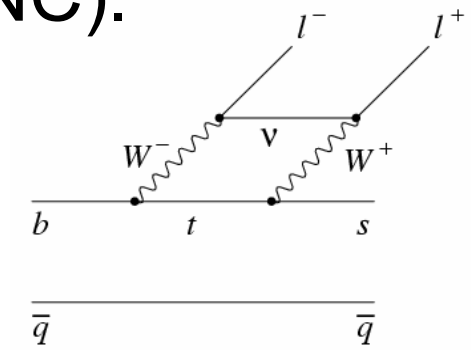




$q = d, s$

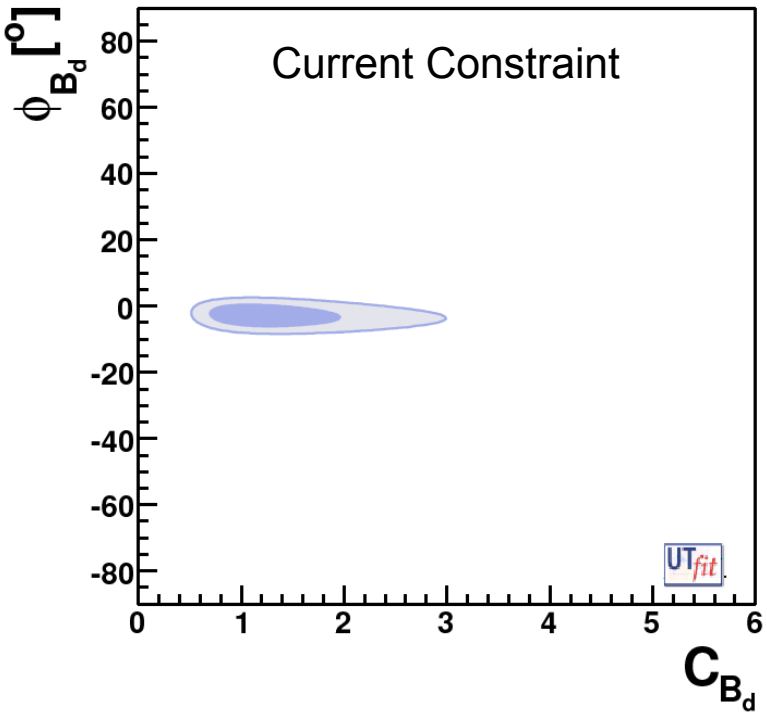
- NP can contribute to these processes.
  - Parameterise with an amplitude ratio C_q and phase ϕ_q.

$$C_q e^{i\phi_q} = \frac{\left\langle B^0_q \mid H_{SM+NP} \mid \bar{B}^0_q \right\rangle}{\left\langle B^0_q \mid H_{SM} \mid \bar{B}^0_q \right\rangle}$$

- C_q=1, and ϕ_q=0 for the SM.

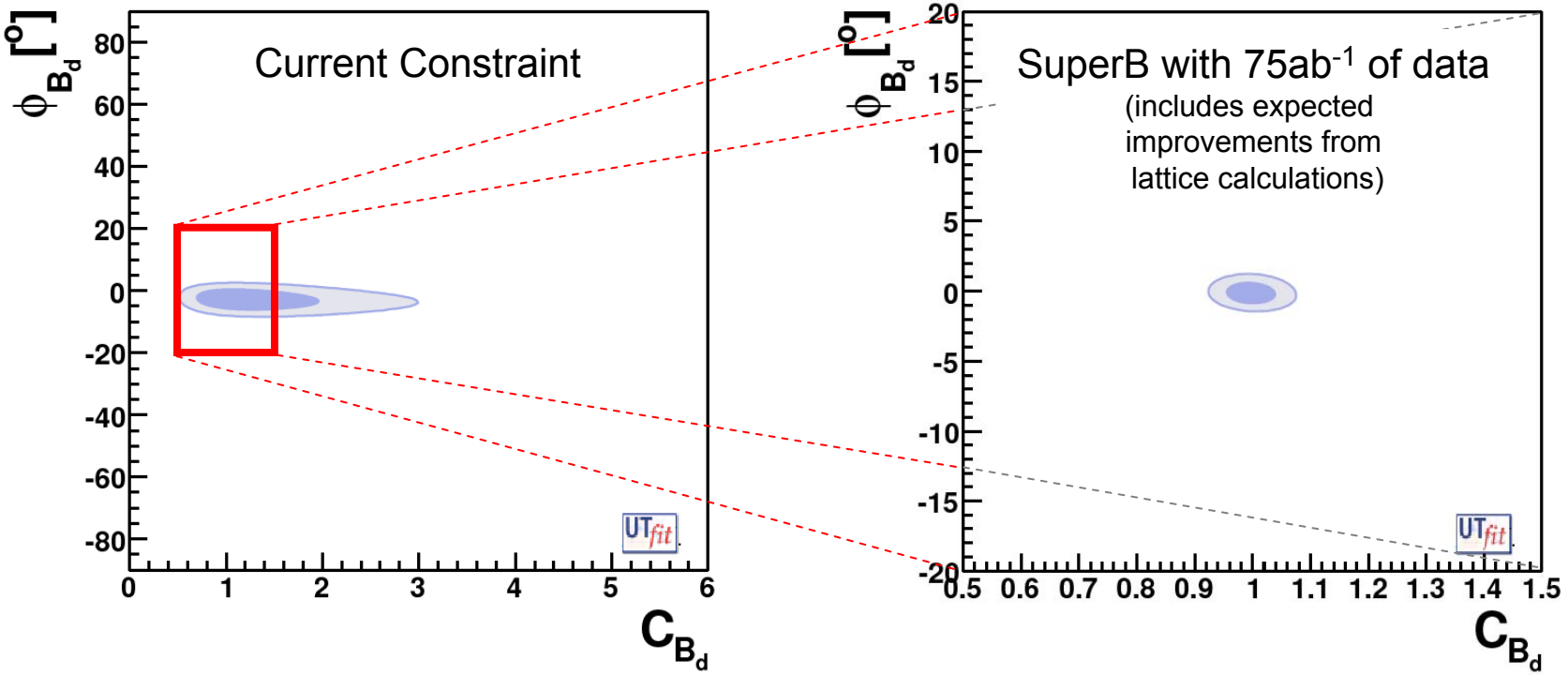
New Physics in ΔF=2 Transitions

- Existing measurements already constrain NP in B_d mixing.



New Physics in ΔF=2 Transitions

- Existing measurements already constrain NP in B_d mixing.
- SuperB will significantly improve this constraint.



Note that the two plots have very different scales!

Minimal Flavour Violation

- Suppose that there are no new physics flavour couplings (MFV).
  - CP violation comes from the known SM Yukawa couplings.
  - The top quark contribution dominates the SM.
  - NP contribution in $\Delta B=2$ transitions is:

SM Scale ~2.4 TeV

$$\Lambda_0 = Y_t \sin^2 \theta_W M_W / \alpha$$

$$\delta S_0 = 4a \left(\frac{\Lambda_0}{\Lambda} \right)^2$$

Real Wilson coefficient $O(1)$

New Physics Scale

  - MFV Includes many NP scenarios i.e. 1HDM/2HDM, MSSM, ADD, RS.
- What is the energy scale that we are sensitive to?

e.g. see hep-ph/0509116 (NMFV), hep-ph/0509219(MFV) and references therein.

Minimal Flavour Violation

- Sensitive to new physics contributions with Λ up to 14 TeV (= $6\Lambda_0$).
- For loop mediated NP contributions the constraint can be weakened so that Λ ~ 700GeV.

- Don't require that the EWSB scale match Λ.
- e.g. 2HDM with small tanβ allows a sub-TeV search for NP in $B^+ \to \tau^+ \nu$. If we allow for larger tanβ, the NP search is 3 $\times$ more sensitive.

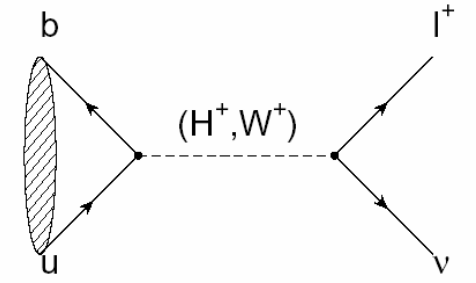
e.g. see hep-ph/0509116 (NMFV), hep-ph/0509219(MFV) and references therein.

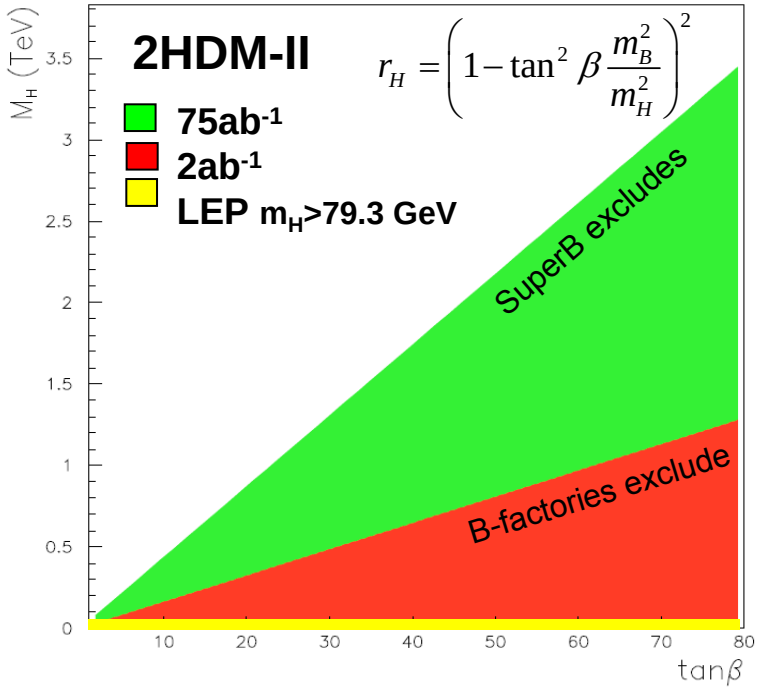
Charm equivalent: $D_s^+ \to \mu^+\nu,\ \tau^+\nu$

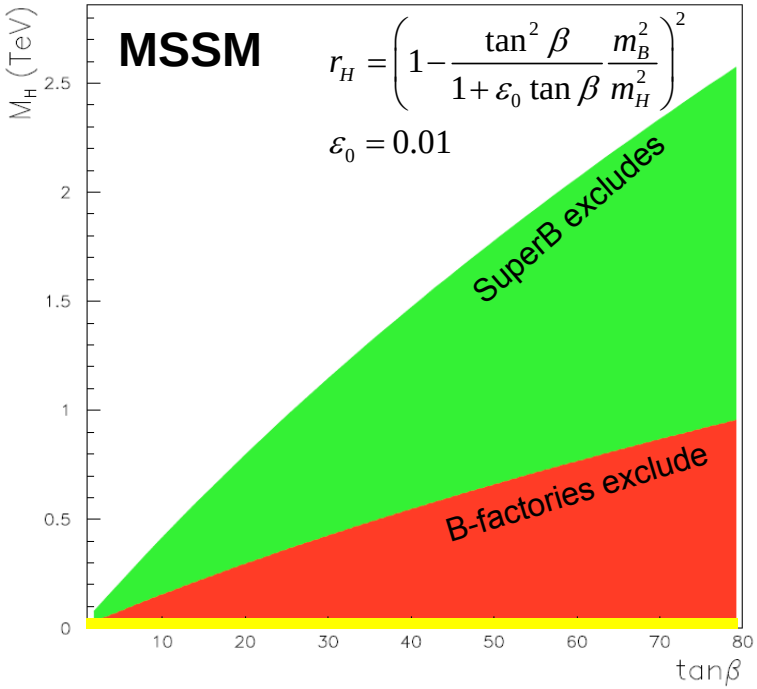
$B \to \tau\ \nu$

- Higgs mediated MFV:

$$r_H = \frac{\mathcal{B}_{SM+NP}}{\mathcal{B}_{SM}}$$







- Multi TeV search capability for large tanβ.

SUSY CKM

- The SM encodes quark mixing in the CKM matrix.
- SUSY encodes squark mixing in a Super CKM equivalent of the CKM matrix: V_{SCKM}.
  - Have couplings for LL, LR, RL, RR interactions.
- LHC probes the High Energy Frontier.
  - Measures the diagonal elements of V_{SCKM}.
- SuperB probes the Luminosity Frontier.
  - Measures the off-diagonal elements V_{SCKM}.

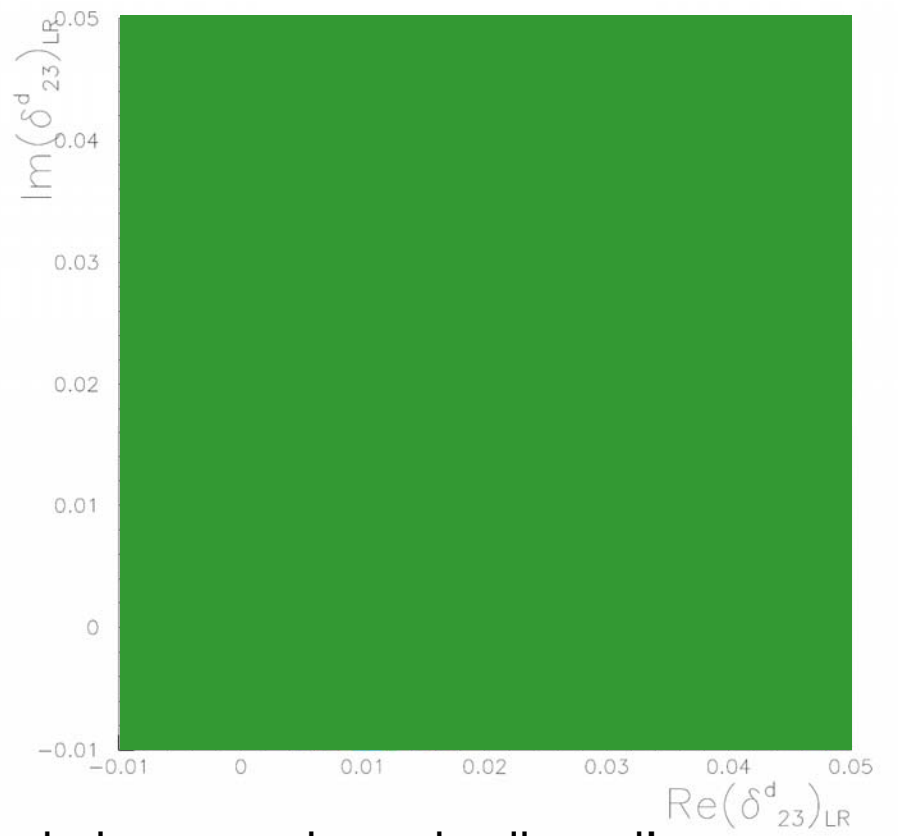
SUSY CKM

- Couplings are $\left(\delta_{ij}^{q}\right)_{AB}$

  where *A*,*B*=*L*,*R*, and *i*,*j* are squark generations.

- e.g. Constrain parameters in V_{SCKM} using:

  - $\mathcal{B}(B \to X_s \gamma)$ [green]
  - $\mathcal{B}(B \to X_s l^+ l^-)$ [cyan]
  - $A_{CP}(B \to X_s \gamma)$ [magenta]
  - Combined [blue]



With current data, the whole range shown is allowed!

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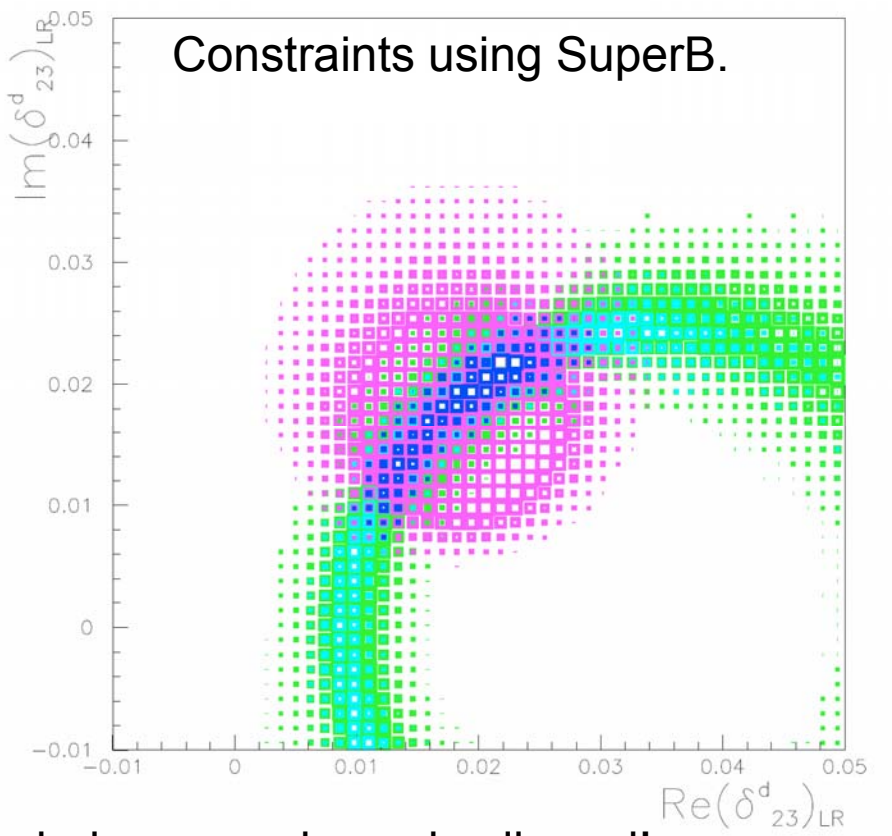

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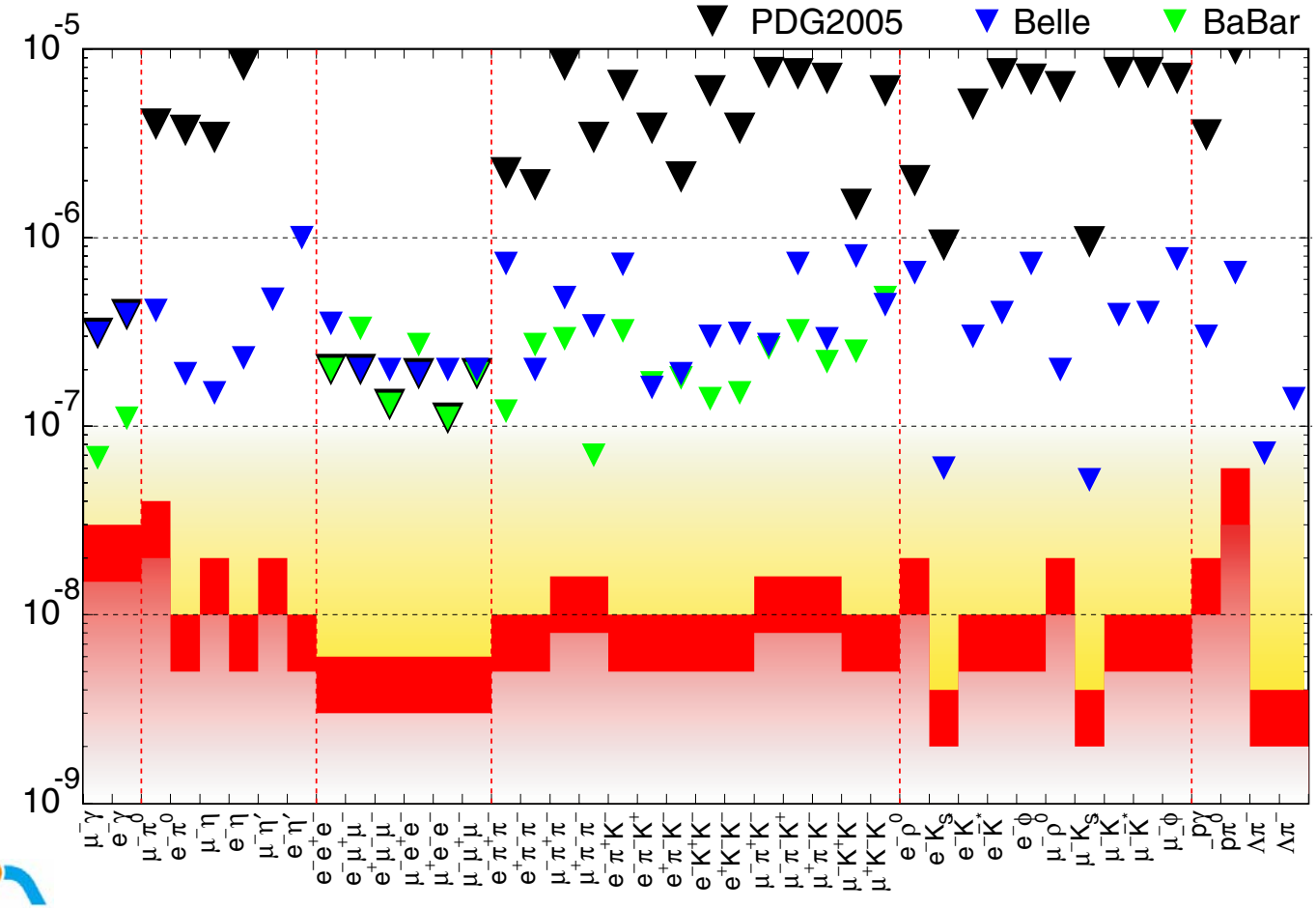
τ Decays

Lepton Flavour Violation

- SUSY breaking at low energies should result in FCNC [e.g. $\tau \to \mu\gamma$, $\mu \to e\gamma$].



$\tau \to \mu\gamma$ is the golden channel for LFV searches at SuperB.

Current Best Limit

New Physics ?

SuperB sensitivity @ 10ab^{-1}

CP and CPT Violation

- CP Violation.
  - SM decays of the τ have only a single amplitude – so any CP violation signal is an unambiguous sign of NP.
  - e.g. Can have NP contributions from a $H^{\pm}$ in $\tau \to N\pi\nu$, N=3,4.

e.g. see Datta et al., hep-ph/0610162

- CPT Violation.
  - Expect to be able to measure $\frac{\tau_{\tau-} - \tau_{\tau+}}{\tau_{\tau-} + \tau_{\tau+}}$ at the level of 10^{-4} (statistical).
  - Current bound is $(0.12 \pm 0.32)\%$.

Nucl. Phys. Proc. Suppl. **144** 105 (2005)

- Polarisation of e^+e^- beams benefits the search for CP and CPT violation in τ decay and the τ anomalous magnetic moment.

e.g. PRD **51** 3172 (1995);
arXive:0707.2496 [hep-ph]

Summary

Conclusion

- The SuperB programme has a rich physics case.
  - Much more than I've had time to cover here!
  - See the 'Physics' section of the SuperB CDR for details.
- Rare decay searches in the worlds largest samples of B, D, τ particles.
- Probe:
  - flavour structure of new physics found at the LHC.
  - $\geq O(\text{TeV})$ indirect NP search capability using rare decays.
- Many important measurements unique to SuperB.
- Complementarity with the LHC high energy frontier and flavour programmes.
  - Need a SuperB to start understanding the flavour coupling of NP in the LHC era.


CONCEPTUAL DESIGN REPORT
INFN/AE – 07/2, SLAC-R-856, LAL 07-15
March 2007
SuperB
A High-Luminosity
Asymmetric e^+e^-
Super Flavour Factory
All we need to do is build it!
http://www.pi.infn.it/SuperB/
VA4b
P19a
P19b
Sg3
0
50
100m