The SuperB physics program

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* flavour physics and new physics
* the SuperB physics program
* the impact of SuperB: illustrative scenarios
  i. supersymmetry @ LHC
  ii. lepton flavour violation and Little Higgs
  iii. new right-handed currents
* conclusions and outlook

SuperB Workshop
LAL, Orsay, February 15-18, 2009

Beyond the SM with flavour physics: why?

Indirect searches look for new physics through virtual effects of new particles in loop corrections

* SM FCNCs and CP-violating processes occur at the loop level

* SM quark FV and CPV are governed by the weak interactions and suppressed by mixing angles

* SM quark CPV comes from a single source (neglecting θ_{QCD})

New Physics does not necessarily share the SM pattern of FV and CPV: very large NP effects are possible

Past (SM) successes:

1970: charm from $K^0 \to \mu^+\mu^-$ (GIM)

1973: 3rd generation from ϵ_K (Kobayashi & Maskawa)

early 90s: heavy top from Δm_B

$$\mathcal{L}_{eff}^{NP} = \mathcal{L}_{SM} + \sum_k \left(\sum_i C_i^k Q_i^{(k+4)}\right)/\Lambda^k$$

NP flavour effects are governed by two players:

i) **the new physics scale Λ**

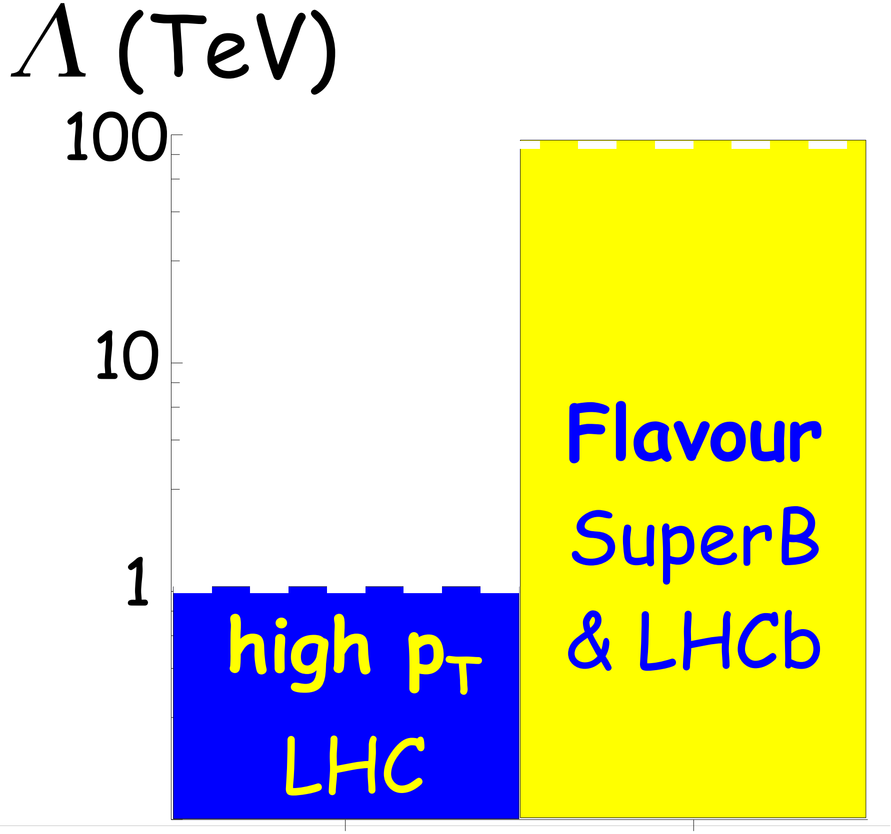
ii) **the effective flavour-violating couplings C's**

The "flavour problem":

if $\Lambda \approx 1$ TeV, C's $\ll 1$

The bright side:

flavour physics could probe NP scales beyond the reach of the LHC



SuperB physics goals

NP found at LHC

- determine the FV and CPV couplings of the NP Lagrangian
- look for heavier states beyond the LHC discovery reach

NP not found at LHC

- look for any deviation from the SM signalling NP in the energy region 5-100 TeV

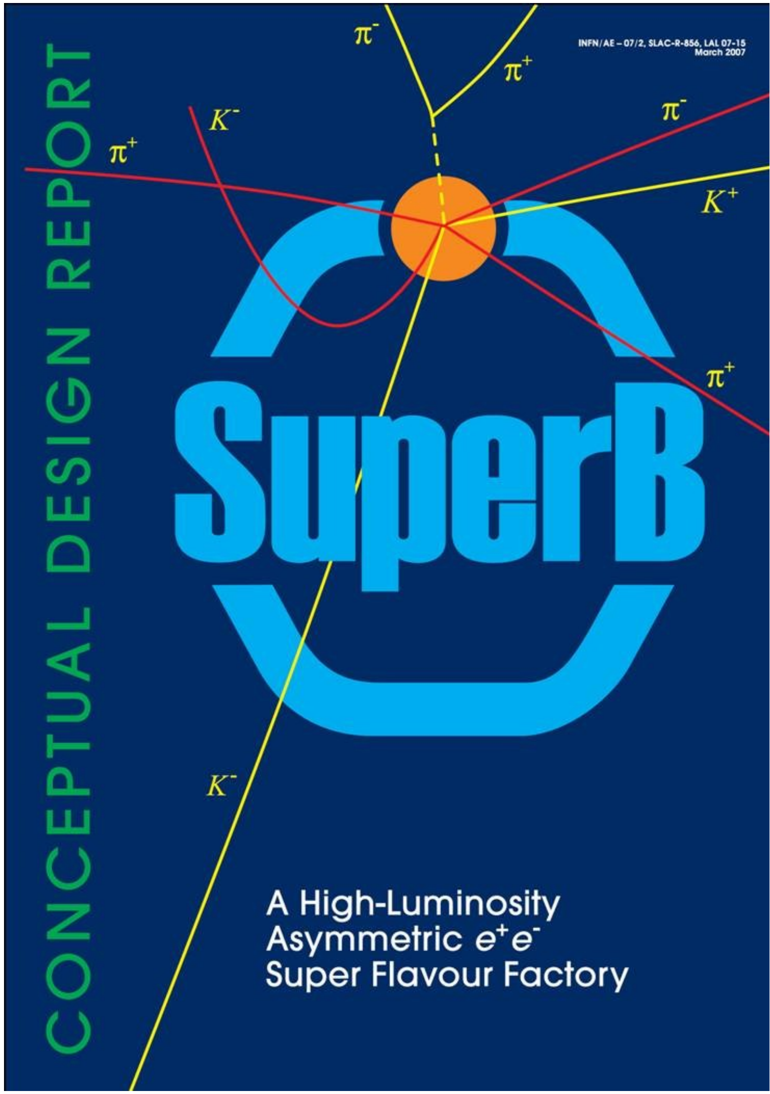
- exclude regions of the NP parameter space

What SuperB is for

- improve precision/sensitivity of B-factories x5-10
- test the CKM paradigm and determine V_{CKM} at 1% level
- increase sensitivity to LFV in τ decays by 1 order of magnitude
- explore CPV with charm
- many other studies...

feasible with 75 ab^{-1} collected at $\Upsilon(4S)$ (+ $D\bar{D}$ & $\tau\bar{\tau}$ thresholds)

T. Browder at al., arXiv:0710.3799
SuperB Workshop 6, arXiv:0810.1312



320 signers of ~80 institutions
476 pages (~130 about physics)
arXiv:0709.0451

SuperB physics in tables

arXiv:0709.0451
arXiv:0810.1312

B_d physics @$\Upsilon(4S)$

Observable	B factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ $(J/\psi\, K^0)$	0.018	0.005 (†)
$\cos(2\beta)$ $(J/\psi\, K^{*0})$	0.30	0.05
$\sin(2\beta)$ (Dh^0)	0.10	0.02
$\cos(2\beta)$ (Dh^0)	0.20	0.04
$S(J/\psi\,\pi^0)$	0.10	0.02
$S(D^+D^-)$	0.20	0.03
$S(\phi K^0)$	0.13	0.02 (*)
$S(\eta' K^0)$	0.05	0.01 (*)
$S(K^0_S K^0_S K^0_S)$	0.15	0.02 (*)
$S(K^0_S \pi^0)$	0.15	0.02 (*)
$S(\omega K^0_S)$	0.17	0.03 (*)
$S(f_0 K^0_S)$	0.12	0.02 (*)
γ $(B \to DK$, $D \to CP$ eigenstates)	$\sim 15^\circ$	2.5°
γ $(B \to DK$, $D \to$ suppressed states)	$\sim 12^\circ$	2.0°
γ $(B \to DK$, $D \to$ multibody states)	$\sim 9^\circ$	1.5°
γ $(B \to DK$, combined)	$\sim 6^\circ$	1–2°
α $(B \to \pi\pi)$	$\sim 16^\circ$	3°
α $(B \to \rho\rho)$	$\sim 7^\circ$	1–2° (*)
α $(B \to \rho\pi)$	$\sim 12^\circ$	2°
α (combined)	$\sim 6^\circ$	1–2° (*)
$2\beta+\gamma$ $(D^{(*)\pm}\pi^\mp,\ D^\pm K^0_S \pi^\mp)$	20°	5°
$\lvert V_{cb}\rvert$ (exclusive)	4% (*)	1.0% (*)
$\lvert V_{cb}\rvert$ (inclusive)	1% (*)	0.5% (*)
$\lvert V_{ub}\rvert$ (exclusive)	8% (*)	3.0% (*)
$\lvert V_{ub}\rvert$ (inclusive)	8% (*)	2.0% (*)
$BR(B \to \tau\nu)$	20%	4% (†)
$BR(B \to \mu\nu)$	visible	5%
$BR(B \to D\tau\nu)$	10%	2%
$BR(B \to \rho\gamma)$	15%	3% (†)
$BR(B \to \omega\gamma)$	30%	5%
$A_{CP}(B \to K^*\gamma)$	0.007 (†)	0.004 († *)
$A_{CP}(B \to \rho\gamma)$	~ 0.20	0.05
$A_{CP}(b \to s\gamma)$	0.012 (†)	0.004 (†)
$A_{CP}(b \to (s+d)\gamma)$	0.03	0.006 (†)
$S(K^0_S \pi^0 \gamma)$	0.15	0.02 (*)
$S(\rho^0\gamma)$	possible	0.10
$A_{CP}(B \to K^*\ell\ell)$	7%	1%
$A^{FB}(B \to K^*\ell\ell)s_0$	25%	9%
$A^{FB}(B \to X_s\ell\ell)s_0$	35%	5%
$BR(B \to K\nu\overline{\nu})$	visible	20%
$BR(B \to \pi\nu\bar{\nu})$	–	possible

charm physics

Mode	Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$D^0 \to K^+K^-$	y_{CP}	2–3×10^{-3}	5×10^{-4}
$D^0 \to K^+\pi^-$	y'_D	2–3×10^{-3}	7×10^{-4}
	x'^2_D	1–2×10^{-4}	3×10^{-5}
$D^0 \to K^0_S\pi^+\pi^-$	y_D	2–3×10^{-3}	5×10^{-4}
	x_D	2–3×10^{-3}	5×10^{-4}
Average	y_D	1–2×10^{-3}	3×10^{-4}
	x_D	2–3×10^{-3}	5×10^{-4}

Channel	Sensitivity
$D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$	1×10^{-8}
$D^0 \to \pi^0 e^+e^-$, $D^0 \to \pi^0\mu^+\mu^-$	2×10^{-8}
$D^0 \to \eta e^+e^-$, $D^0 \to \eta\mu^+\mu^-$	3×10^{-8}
$D^0 \to K^0_s e^+e^-$, $D^0 \to K^0_s\mu^+\mu^-$	3×10^{-8}
$D^+ \to \pi^+ e^+e^-$, $D^+ \to \pi^+\mu^+\mu^-$	1×10^{-8}
$D^0 \to e^\pm\mu^\mp$	1×10^{-8}
$D^+ \to \pi^+ e^\pm\mu^\mp$	1×10^{-8}
$D^0 \to \pi^0 e^\pm\mu^\mp$	2×10^{-8}
$D^0 \to \eta e^\pm\mu^\mp$	3×10^{-8}
$D^0 \to K^0_s e^\pm\mu^\mp$	3×10^{-8}
$D^+ \to \pi^- e^+e^+$, $D^+ \to K^- e^+e^+$	1×10^{-8}
$D^+ \to \pi^-\mu^+\mu^+$, $D^+ \to K^-\mu^+\mu^+$	1×10^{-8}
$D^+ \to \pi^- e^\pm\mu^\mp$, $D^+ \to K^- e^\pm\mu^\mp$	1×10^{-8}

Mode	Observable	$\Upsilon(4S)$ (75 ab^{-1})	$\psi(3770)$ (300 fb^{-1})	LHCb (10 fb^{-1})
$D^0 \to K^+\pi^-$	x'^2	3×10^{-5}		6×10^{-5}
	y'	7×10^{-4}		9×10^{-4}
$D^0 \to K^+K^-$	y_{CP}	5×10^{-4}		5×10^{-4}
$D^0 \to K^0_S\pi^+\pi^-$	x	4.9×10^{-4}		
	y	3.5×10^{-4}		
	$\lvert q/p\rvert$	3×10^{-2}		
	ϕ	2°		
$\psi(3770) \to D^0\overline{D}^0$	x^2		$(1-2) \times 10^{-5}$	
	y		$(1-2) \times 10^{-3}$	
	$\cos\delta$		$(0.01-0.02)$	

τ physics

Process	Sensitivity
$\mathcal{B}(\tau \to \mu\,\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to e\,\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to \mu\,\mu\,\mu)$	2×10^{-10}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \to e\eta)$	6×10^{-10}
$\mathcal{B}(\tau \to \ell K^0_s)$	2×10^{-10}

+ τ FC physics (CPV, ...)

+B_s physics @$\Upsilon(5S)$

SuperB a "treasure chest" of new physics-sensitive observables

Golden modes or not golden modes...

no single golden mode

many observables sensitive to New Physics

	H^+ high tanβ	Minimal FV	Non-Minimal FV (1-3)	Non-Minimal FV (2-3)	NP Z-penguins	Right-Handed currents
$\mathcal{B}(B \to X_s\gamma)$		X		O		O
$A_{CP}(B \to X_s\gamma)$				X		O
$\mathcal{B}(B \to \tau\nu)$	X-CKM					
$\mathcal{B}(B \to X_s l^+ l^-)$				O	O	O
$\mathcal{B}(B \to K\nu\overline{\nu})$				O	X	
$S(K_S\pi^0\gamma)$						X
β			X-CKM			O

Examples from the B sector

SuperB Workshop VI, arXiv:0810.1312

X The GOLDEN channel for the given scenario

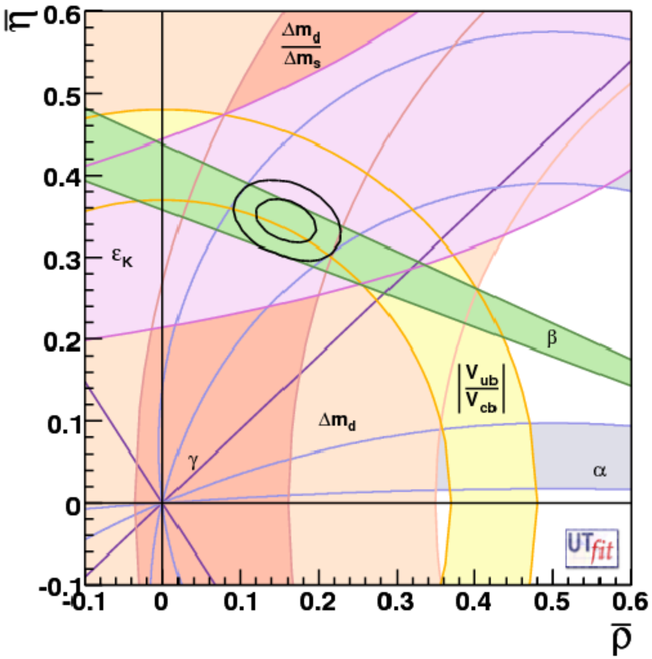
(-CKM) requires an improved CKM determination

O Not the GOLDEN channel for the given NP scenario

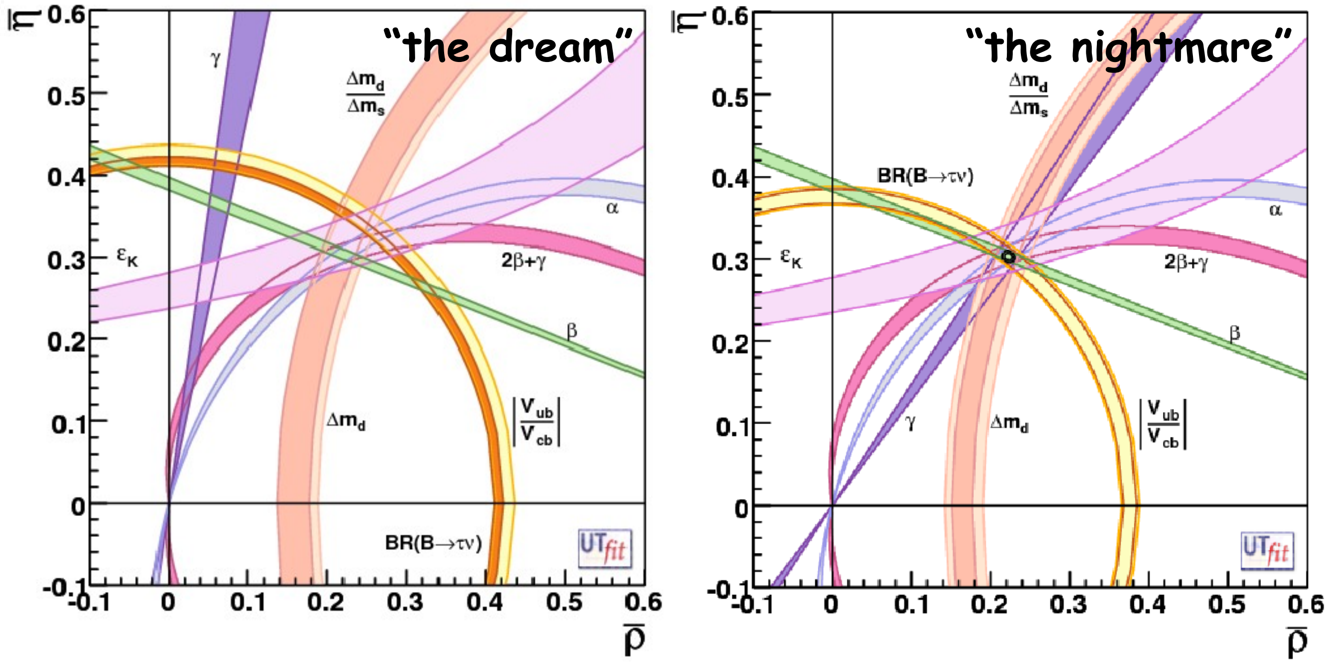
but can show measurable deviations from the SM

Overture: CKM matrix at 1%

Today



With a SuperB in 2015



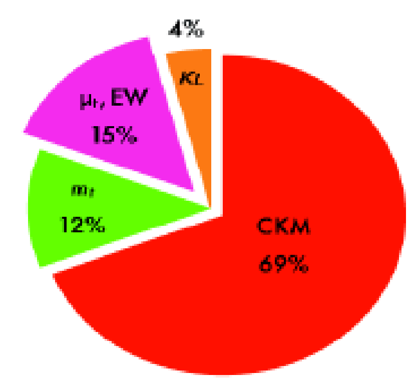
Generalized UT fits:
CKM at 1% in the presence of NP!

	today	SuperB
$\bar\rho$	0.187±0.056	±0.005
$\bar\eta$	0.370±0.036	±0.005

- crucial for many NP searches with flavour (not only in the B sector!)

error budget

$K_L \to \pi^0 \nu \bar\nu$



U. Haisch, Kaon '07

First scenario: SUSY!

Suppose in 201x we will have:

- several candidate sparticles (incl. squark(s)) with masses below 1 TeV compatible with a MSSM spectrum found at Atlas and CMS
- a value of the B_s-$\bar{B}_s$ mixing phase much larger than the SM expectation measured at LHCb
- inconclusive hints of deviation from the SM in BR($B_s \to \mu^+ \mu^-$) at LHCb, Atlas and CMS

Great success of the LHC!!! Evidence for a non-MFV MSSM, but which one?

MSSM: reconstructing the Lagrangian

Parameters	MSSM	SM
gauge+Higgs	14	6
masses	30 (+ν_R 36)	9 (+ν_R 12)
mixing angles	39 (+ν_R 54)	3 (+ν_R 6)
phases	41 (+ν_R 56)	1 (+ν_R 2)
Total	124 (+ν_R 160)	19 (+ν_R 26)

SM parameter match: FC vs FV&CPV 16-8

MSSM parameter match: FC vs FV&CPV 50-110

* fast increase of the # of FV&CPV parameters
* FV&CPV are related to basic properties of the NP Lagrangian (e.g. SUSY breaking in the MSSM)

Flavour violation in the squark sector

LHCb, SuperB

LHC, ILC - HE frontier

$$M^2_{\tilde d} \approx \begin{pmatrix} m^2_{\tilde d_L} & m_d(A_d - \mu \tan\beta) & (\Delta^d_{12})_{LL} & (\Delta^d_{12})_{LR} & (\Delta^d_{13})_{LL} & (\Delta^d_{13})_{LR} \\ & m^2_{\tilde d_R} & (\Delta^d_{12})_{RL} & (\Delta^d_{12})_{RR} & (\Delta^d_{13})_{RL} & (\Delta^d_{13})_{RR} \\ & & m^2_{\tilde s_L} & m_s(A_s - \mu \tan\beta) & (\Delta^d_{23})_{LL} & (\Delta^d_{23})_{LR} \\ & & & m^2_{\tilde s_R} & (\Delta^d_{23})_{RL} & (\Delta^d_{23})_{RR} \\ & & & & m^2_{\tilde b_L} & m_b(A_b - \mu \tan\beta) \\ & & & & & m^2_{\tilde b_R} \end{pmatrix}$$

and similarly for $M^2_{\tilde u}$

NP scale: $m_{\tilde q}$

FV & CPV couplings: $(\delta^d_{ij})_{AB} = (\Delta^d_{ij})_{AB}/m_{\tilde q}^2$

Back to our scenario...

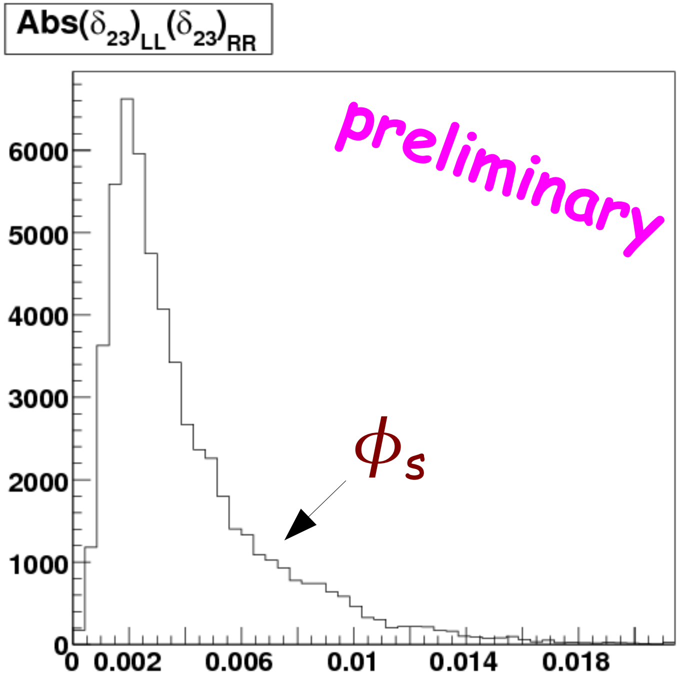
Assume that the LHC measured:

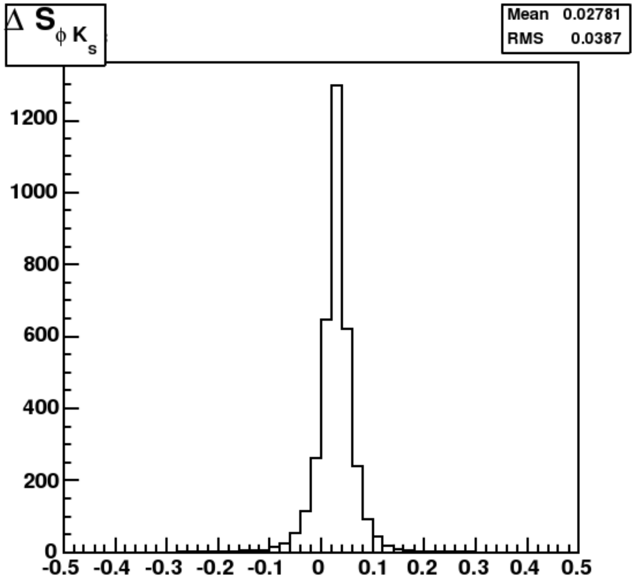
$m_{\tilde{q}} \sim 500$ GeV

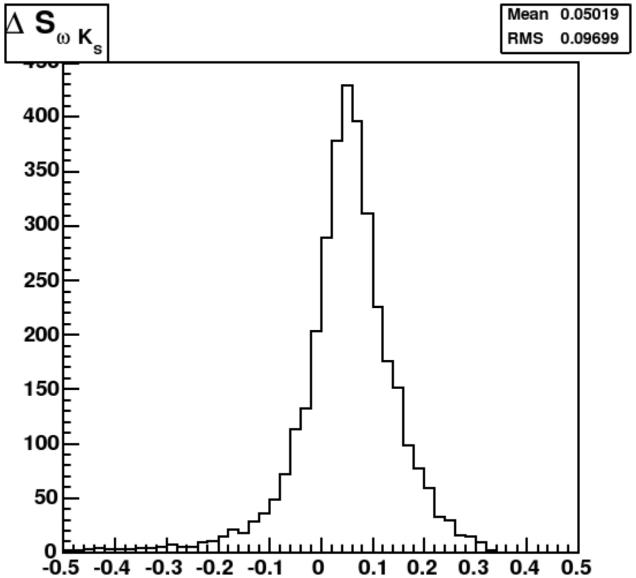
$\Phi_s \sim 10\ \Phi_s^{SM} \sim -20°$

This would already imply:

$|(\delta^d_{23})_{LL}(\delta^d_{23})_{RR}| \sim 0.003$

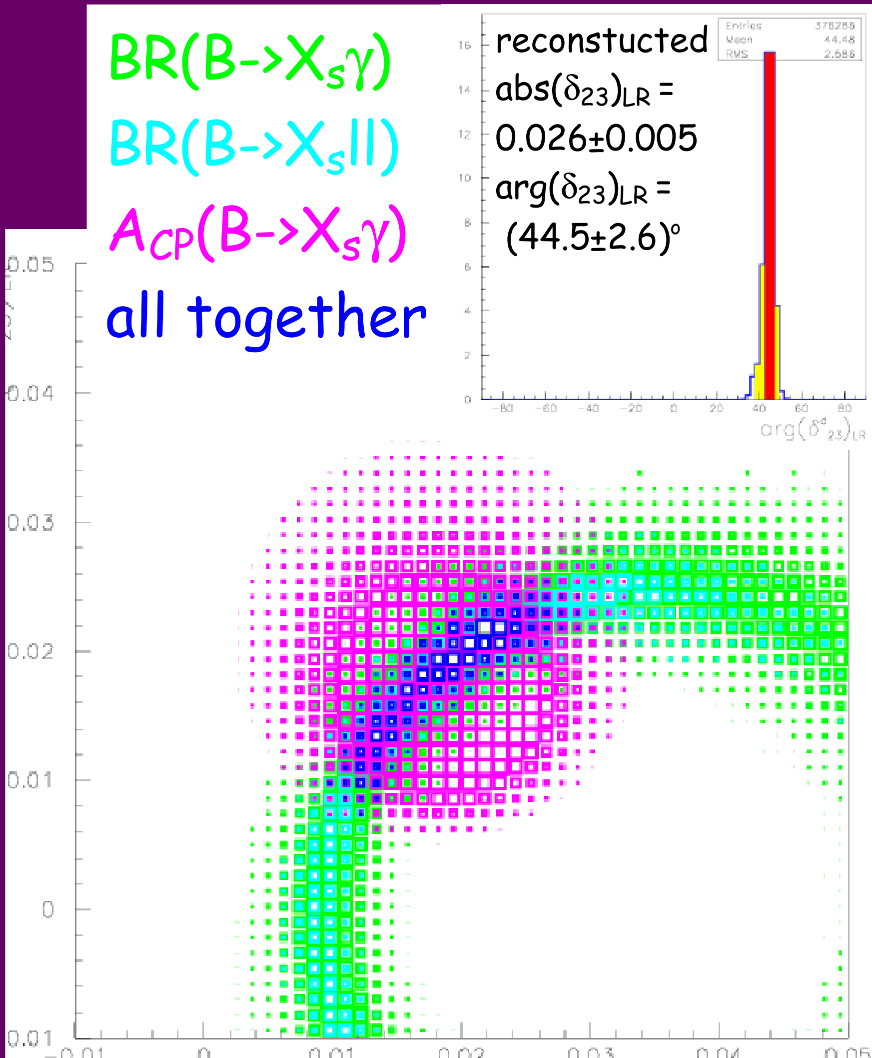






|ΔS| up to 0.1 in $b \to s$ penguin-dominated CP asymmetries

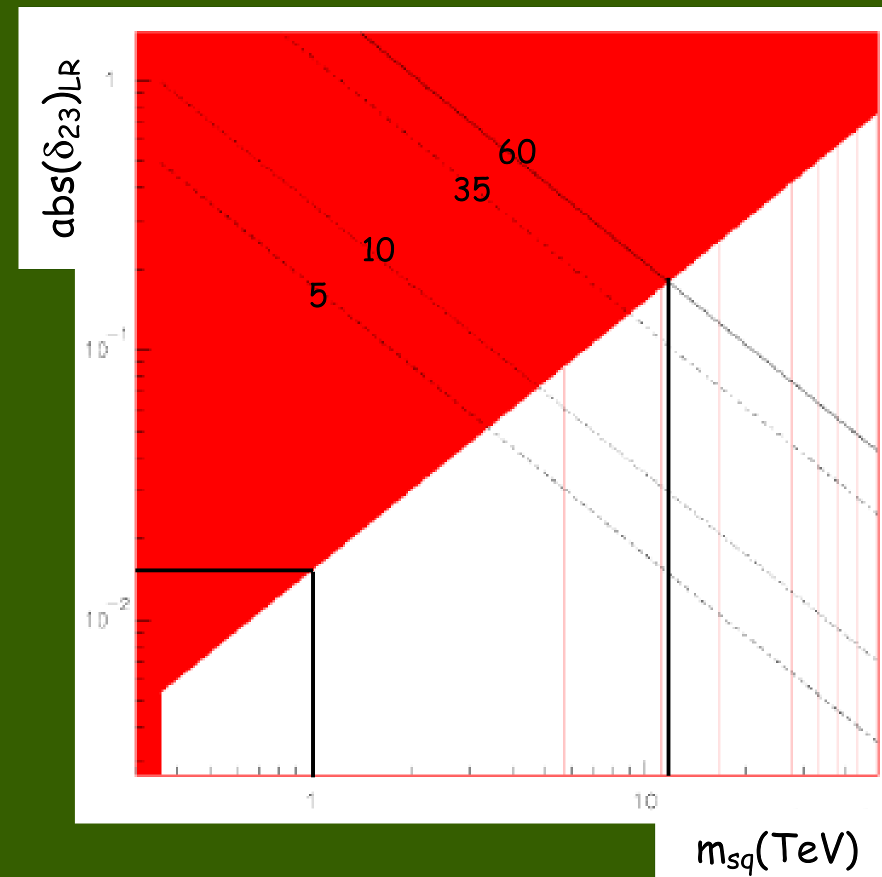
Determination of $(\delta^d_{23})_{LR}$ using SuperB data



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

reconstruction of
$(\delta^d_{23})_{LR}=0.028\ e^{i\pi/4}$ for
$\Lambda = m_{\tilde{g}} = m_{\tilde{q}} =$ 1 TeV

"3σ" sensitivity plot



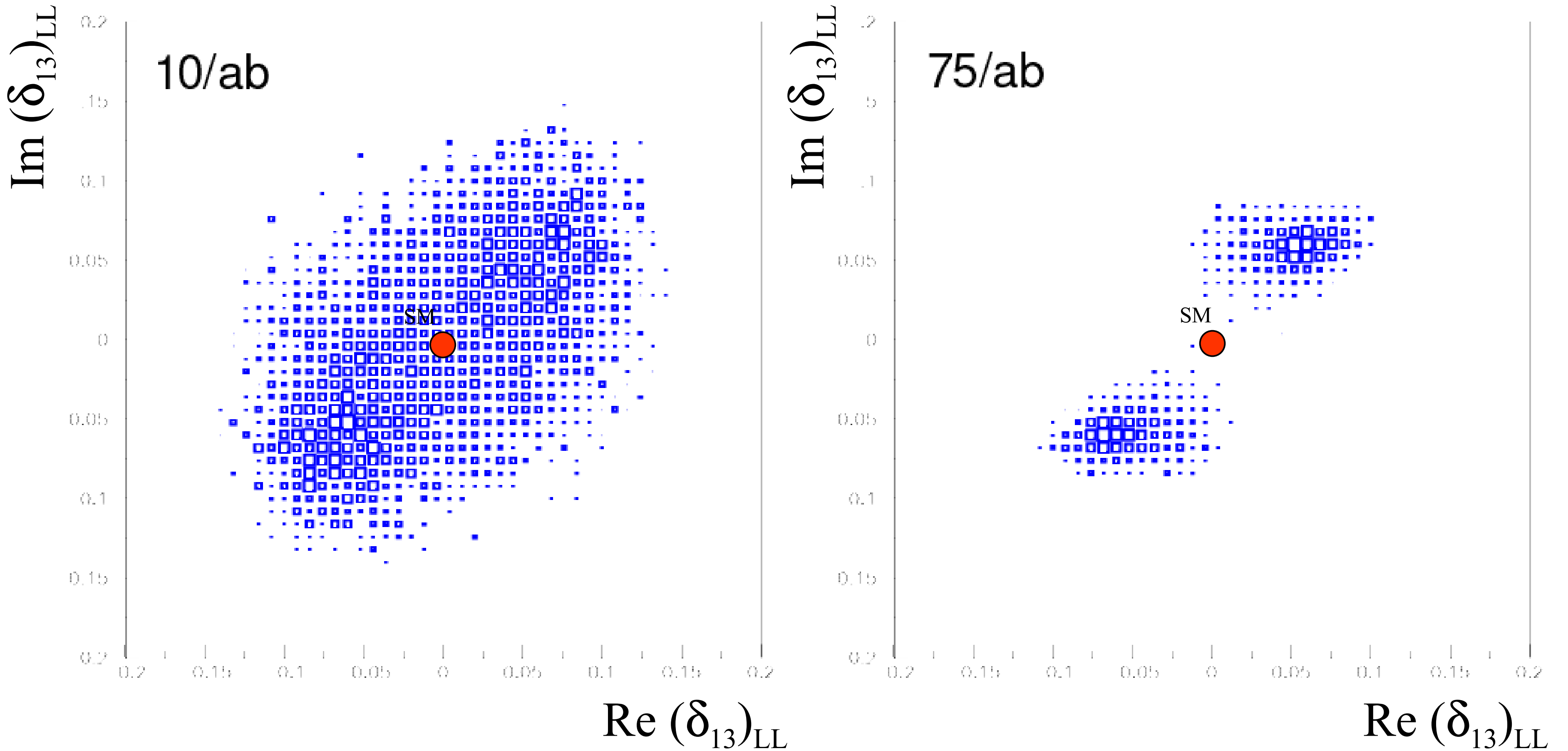
i) sensitive to $m_{\tilde{q}}$ < 20 TeV
ii) sensitive to $|(\delta^d_{23})_{LR}|$ > 10^{-2}
for $m_{\tilde{q}}$ < 1 TeV

Determination of $(\delta^d_{13})_{LL}$ using SuperB data

reconstruction of $(\delta^d_{13})_{LL}$=0.085 $e^{i\pi/4}$

for $m_{\tilde{g}}=m_{\tilde{q}}$=1 TeV

constraints: β, A_{SL}, Δm_d



An example: hierarchical soft terms

Nardecchia, Giudice, Romanino, arXiv:0812.3610
Cohen, Kaplan, Nelson, hep-ph/9607394
Dine, Kagan, Samuel, PLB243 (1990)

Sparticles at the EW scale

but for 1st and 2nd generation squarks and sleptons

- no "unnatural" correction to the Higgs mass
- alleviate the flavour problem
- indicate "natural" values for the δ's:

$\hat{\delta}^{LL}_{db} \approx V^*_{td} \sim \mathbf{0.01}$ $\qquad$ $\hat{\delta}^{LL}_{sb} \approx V^*_{ts} \sim \mathbf{0.05}$

$$\hat{\delta}^{LR}_{i3} \equiv \frac{\mathcal{M}^2_{L3,R3}}{\tilde{m}^2} \hat{\delta}^{LL}_{i3} \qquad i,j = 1,2$$

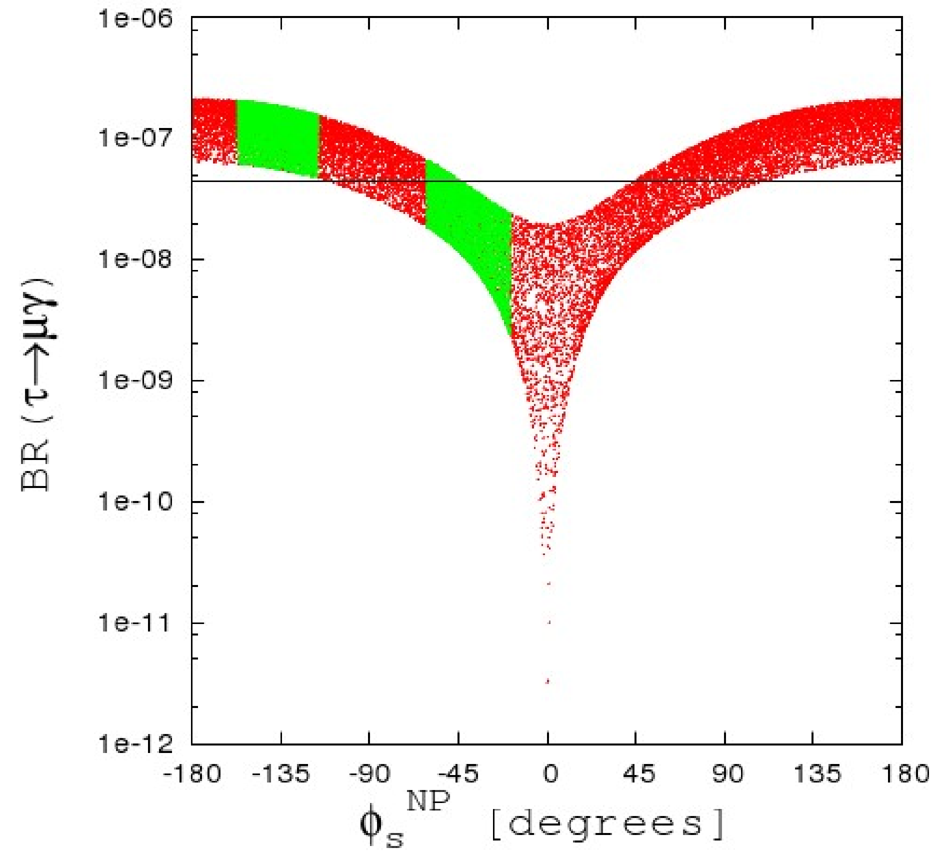
$$\hat{\delta}^{LL}_{ij} \equiv \hat{\delta}^{LL}_{i3} \hat{\delta}^{LL*}_{j3} \qquad \hat{\delta}^{LR}_{ij} \equiv \frac{\mathcal{M}^2_{L3,R3}}{\tilde{m}^2} \hat{\delta}^{LL}_{i3} \hat{\delta}^{RR*}_{j3}$$

these figures are in the ballpark of SuperB sensitivities

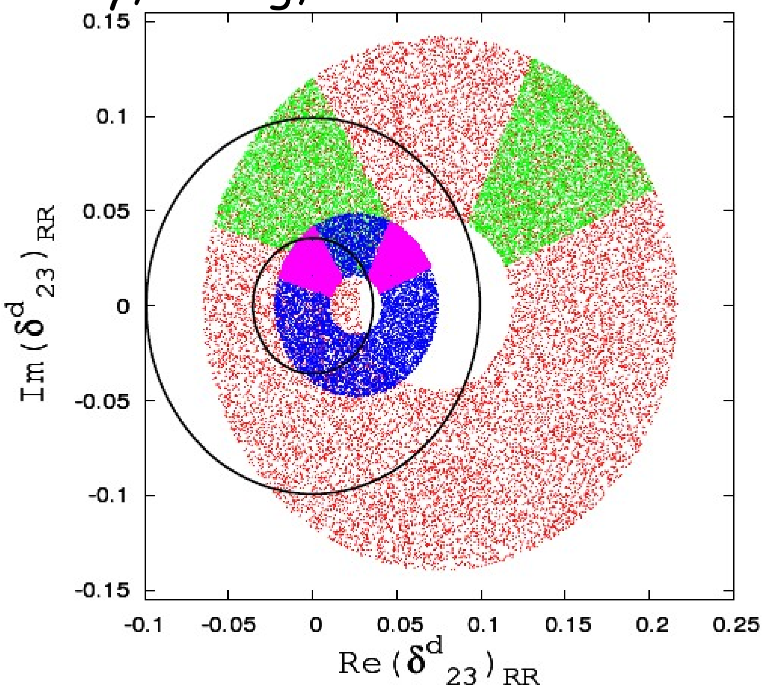
Are there SUSY-GUT's?

mass insertion analysis in a SU(5) SUSY-GUT scheme

- * RG-induced $(\delta_{23})_{LL}$
- * explicit $(\delta_{23})_{RR}$



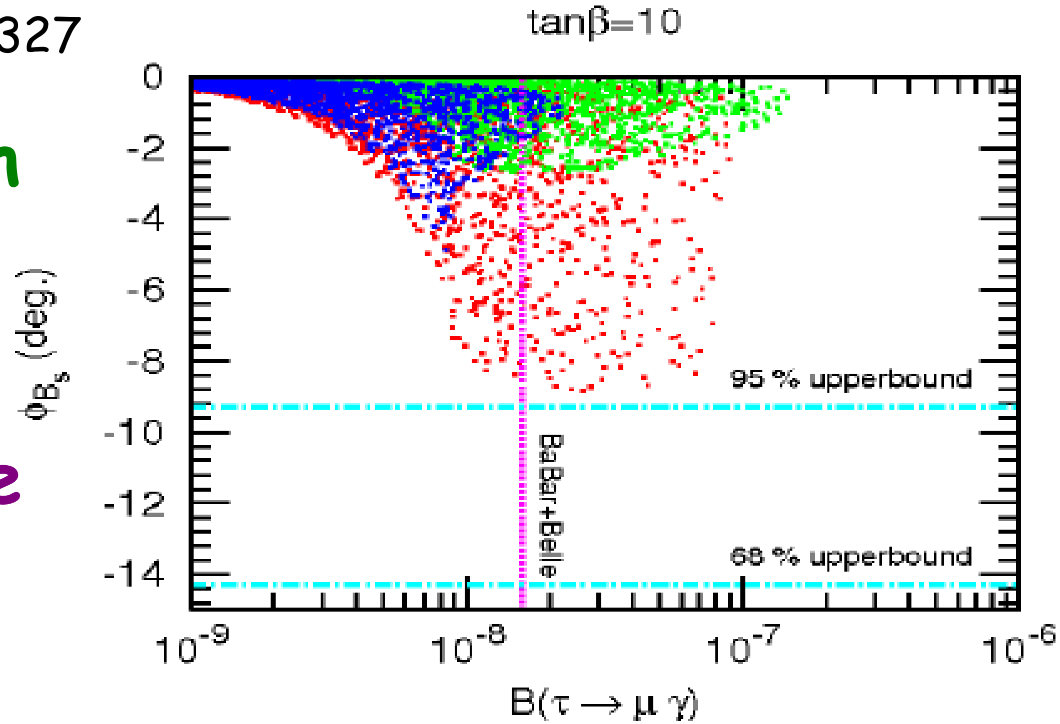
Parry, Zhang, arXiv:0710.5443v2



In the UTfit range for the B_s mixing phase:

$$BR(\tau \rightarrow \mu\gamma) > 3 \times 10^{-9}$$!!

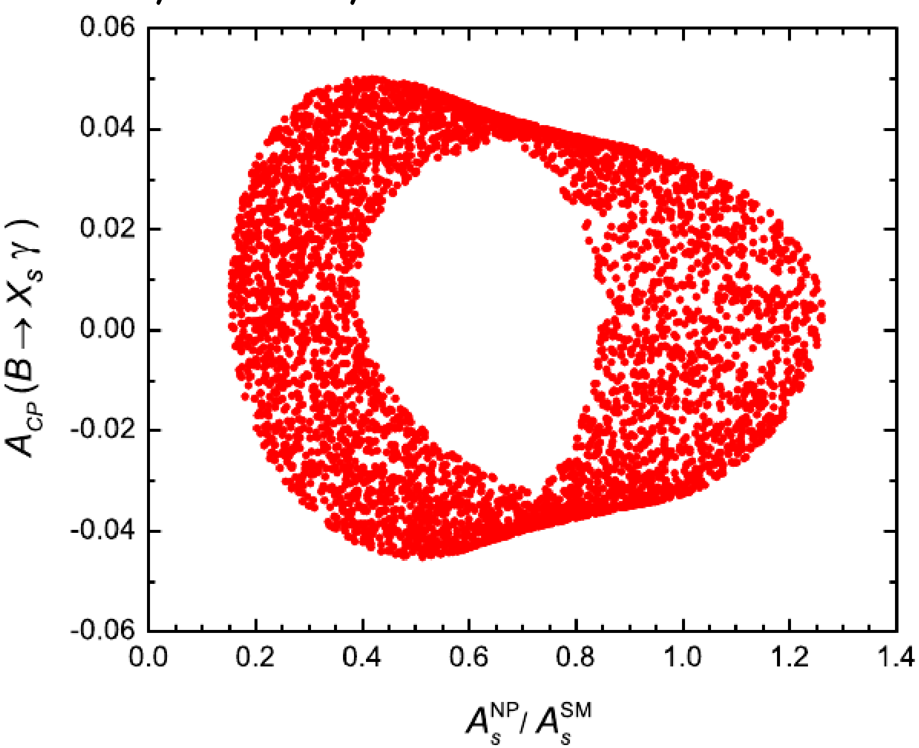
Hisano, Shimizu, arXiv:0805.3327



In a SU(5) SUSY-GUT with ν_R and supergravity-like boundary conditions:

large φ_s requires too large BR($\tau \to \mu\gamma$): marginal !!!

Dutta, Mimura, arXiv:0805.2988

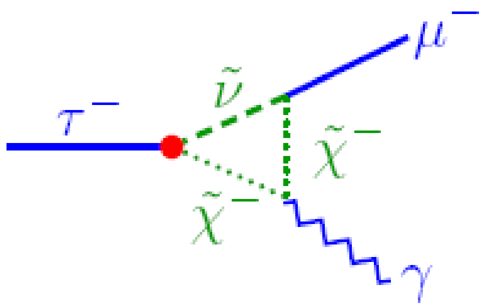


In SO(10), due to the richer Higgs structure, the correlation φ_s-BR($\tau \to \mu\gamma$) can be relaxed

large φ_s correspond to large CP asymmetries in $B \to X_s\, \gamma$

τ flavour violation

Process	Sensitivity
$\mathcal{B}(\tau \to \mu\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to e\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$	2×10^{-10}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \to e\eta)$	6×10^{-10}
$\mathcal{B}(\tau \to \ell K_s^0)$	2×10^{-10}



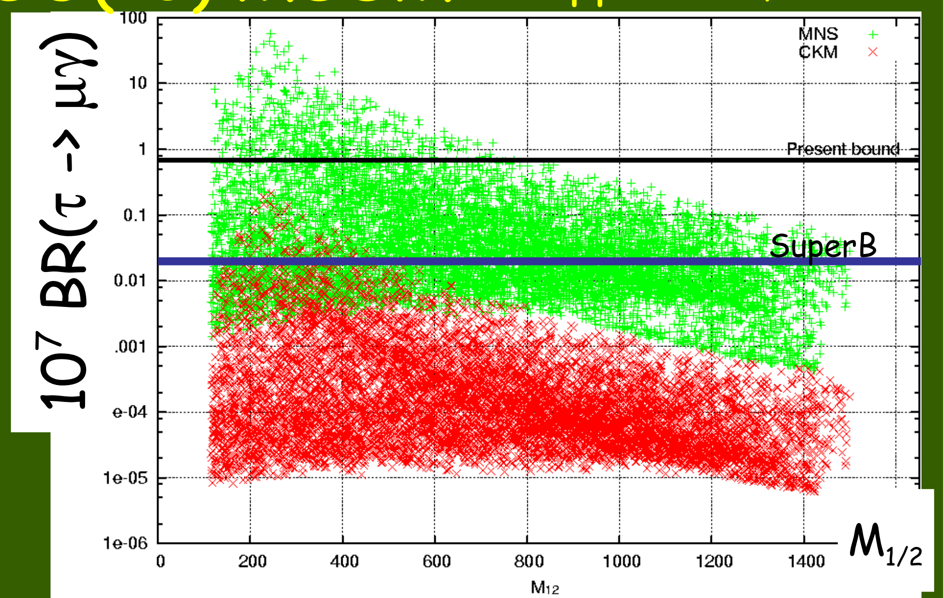
not just yet-another order of magnitude: start probing the interesting region

- help disentangle SUSY and LHT models
- in Grand-Unified models:

* can identify the origin of LFV (CKM or PMNS);

* is complementary to the MEG sensitivity to BR(μ->eγ) ~10^{-13}

SO(10) MSSM Calippi et al., PRD74



Lepton MFV GUT models

Isidori, 4th SuperB workshop

$B(\tau \to \mu\gamma) : B(\tau \to e\gamma) : B(\mu \to e\gamma) \sim \lambda^{-6} : \lambda^{-4} : 1 \sim 10^4 : 500 : 1$ ← LFV from CKM

$B(\tau \to \mu\gamma) : B(\tau \to e\gamma) : B(\mu \to e\gamma) \sim [500{-}10] : 1 : 1$ ← LFV from PMNS

OVERALL SUSY ASSESSMENT

Combining high-p_t and flavour data we can constrain $\mathscr{L}_{SUSY}$ and thus learn about:

- * the SUSY-breaking mediation mechanism
- * the flavour breaking mechanism
- * the underlying presence of a GUT structure
- * the origin of lepton flavour violation

Okada et al., arXiv:0711.2935

Model	$A_{CP}(s\gamma)$	$S_{CP}(K^*\gamma)$	$A_{CP}(d\gamma)$	$S_{CP}(\rho\gamma)$	$\Delta S_{CP}(\phi K_S)$	$S_{CP}(B_s \to J/\psi\phi)$	$\Delta m_{B_s}/\Delta m_{B_d}$ vs. ϕ_3	$\mu \to e\gamma$	$\tau \to \mu\gamma$	$\tau \to e\gamma$
mSUGRA										
MSSM+RN										
Degenerate ν_R, NH								√		
Degenerate ν_R, IH								√	√	
Degenerate ν_R, D								√	√	
Non-degen. ν_R (I), NH									√	
Non-degen. ν_R (II), NH										√
SU(5)+RN										
Degenerate ν_R, NH		•		•	•	•		√		
Degenerate ν_R, IH		√		•	√	√	•	√	√	
Degenerate ν_R, D		•		•	•	•		√	√	
Non-degen. ν_R (I), NH		√			√	√	•	√	√	
Non-degen. ν_R (II), NH				√			•	√		√
U(2)FS	√	√		√	√	√	•	–	–	–

√ large deviation expected

• detectable deviation possible

Second scenario: SUSY or little Higgs?

Let's change scenario:

- MEG observed LFV in $\mu \to e\gamma$
- evidence of new particles but no clear NP picture emerges at LHC
- LFV possibly observed at LHCb in $\tau \to \mu\mu\mu$ if BR is very large

Could it still be SUSY?
Or is it Little Higgs model?
Or something else? How can we tell?

SuperB can help telling SUSY and LHT apart

Blanke et al., hep-ph/0702136
SuperB CDR, arXiv:0709.0451

ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{\mathcal{B}(\tau^- \to e^- e^+ e^-)}{\mathcal{B}(\tau \to e\gamma)}$	$0.4 \ldots 2.3$	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$
$\frac{\mathcal{B}(\tau^- \to \mu^- \mu^+ \mu^-)}{\mathcal{B}(\tau \to \mu\gamma)}$	$0.4 \ldots 2.3$	$\sim 2 \cdot 10^{-3}$	$0.06 \ldots 0.1$
$\frac{\mathcal{B}(\tau^- \to e^- \mu^+ \mu^-)}{\mathcal{B}(\tau \to e\gamma)}$	$0.3 \ldots 1.6$	$\sim 2 \cdot 10^{-3}$	$0.02 \ldots 0.04$
$\frac{\mathcal{B}(\tau^- \to \mu^- e^+ e^-)}{\mathcal{B}(\tau \to \mu\gamma)}$	$0.3 \ldots 1.6$	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$
$\frac{\mathcal{B}(\tau^- \to e^- e^+ e^-)}{\mathcal{B}(\tau^- \to e^- \mu^+ \mu^-)}$	$1.3 \ldots 1.7$	~ 5	$0.3 \ldots 0.5$
$\frac{\mathcal{B}(\tau^- \to \mu^- \mu^+ \mu^-)}{\mathcal{B}(\tau^- \to \mu^- e^+ e^-)}$	$1.2 \ldots 1.6$	~ 0.2	$5 \ldots 10$

The ratio $BR(\tau\to\ell\ell\ell)/BR(\tau\to\ell\gamma)$ is not suppressed by α_e in LHT. It could allow distinguishing between LHT and e.g. MSSM

FC right-handed quark currents

New FC right-handed currents may:

- change the effective γ/g vertex, particularly the magnetic dipole term

  constraints: b -> sγ, b -> s$\ell\ell$

- change the effective Z vertex (+box)
- introduce a new effective Z' vertex

  constraints: b -> s$\ell\ell$, b -> s$\nu\nu$

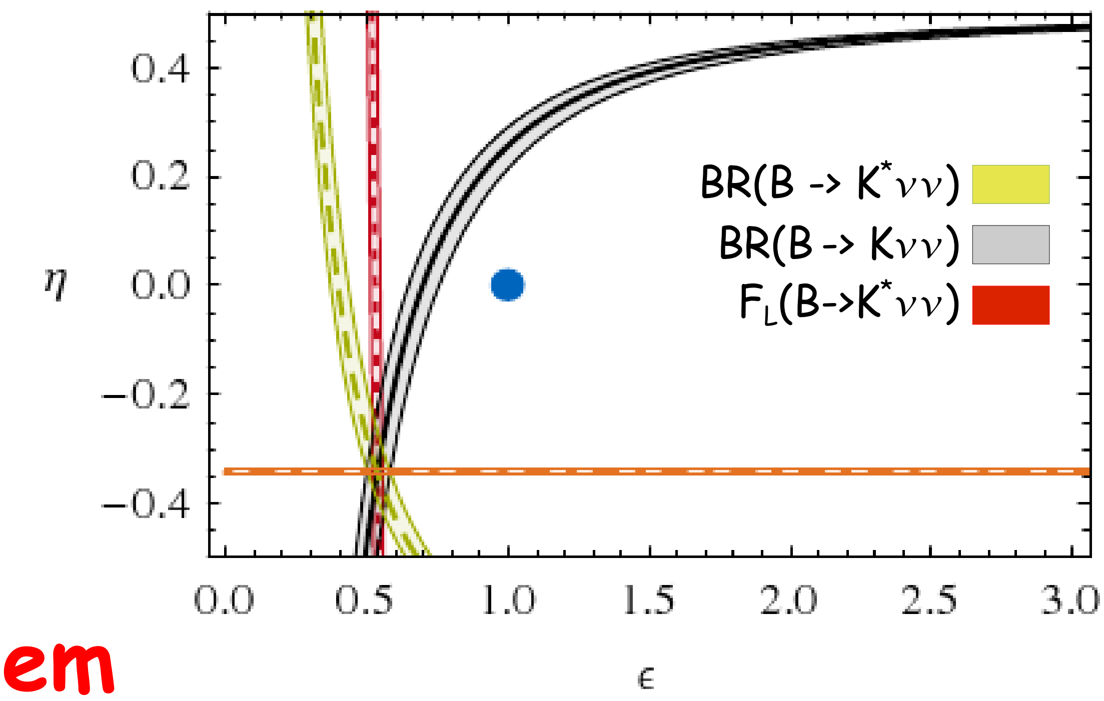
Disentangling the different contributions helps identifying the NP model

extreme example: leptofobic Z'

Altmannshofer et al, arXiv:0902.0160

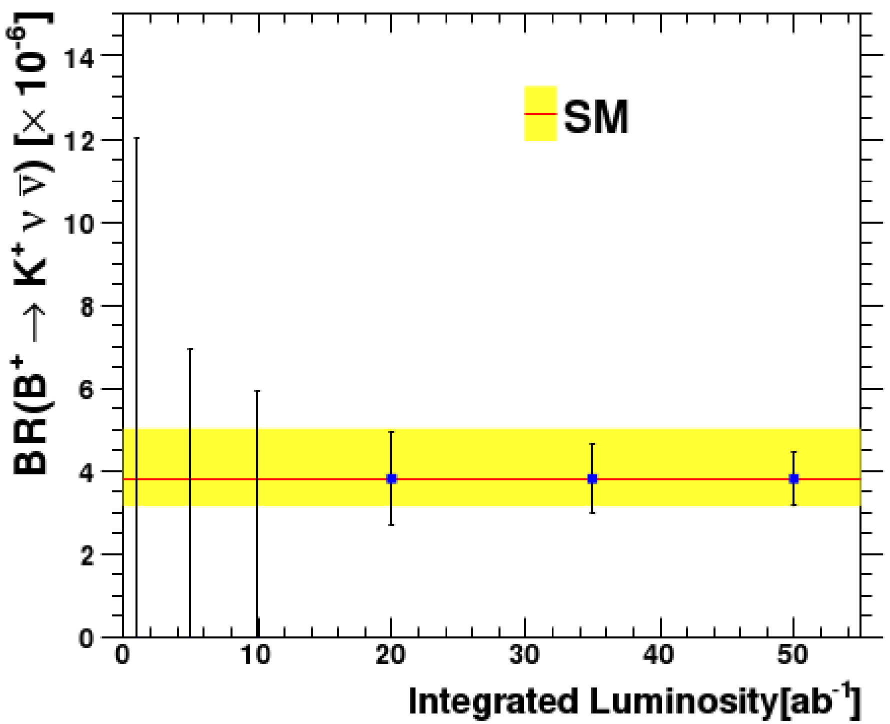
$$\epsilon = \frac{\sqrt{|C_L^\nu|^2 + |C_R^\nu|^2}}{|(C_L^\nu)^{\rm SM}|}$$

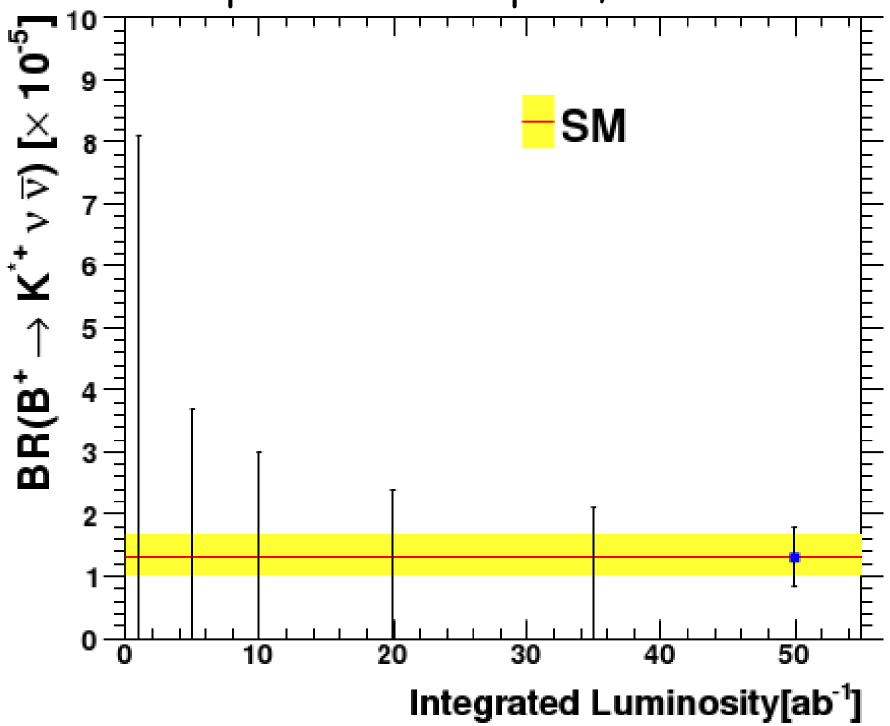
$$\eta = \frac{-{\rm Re}\,(C_L^\nu C_R^{\nu *})}{|C_L^\nu|^2 + |C_R^\nu|^2}$$



A SuperB-only problem

SuperB Workshop VI, arXiv:0810.1312





Conclusions and outlook

Presented scenarios reflect the taste of the speaker but the messages are plain:

i) if new physics is found, we want to know its flavour structure as we can learn a lot from it

ii) if not, precision flavour physics is a good handle to access the multiTeV region

In the table of SuperB measurements, several are not limited by systematics or theory

The name of the game is statistics: SuperB can be a winner

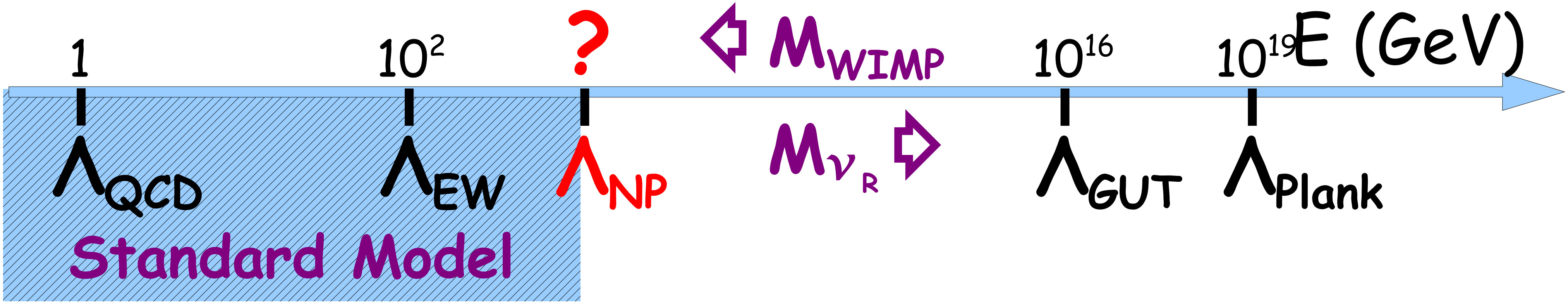
from S. Tomassini,
SuperB Workshop VII

Spare Slides

Flavour physics confronts NP searches

The problem of today particle physics:

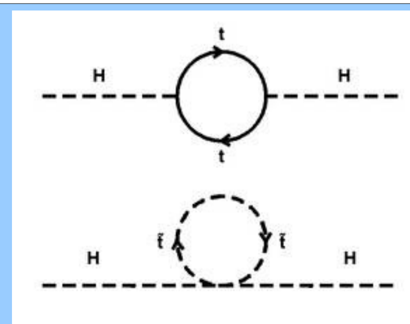
where is the NP scale Λ_{NP}? 0.5, 1, 10, 10^{13}, 10^{16} TeV?



The quantum stabilization of the weak scale suggests ≤ 1 TeV (naturalness argument)

$$m_H^2 \to m_H^2 + \delta m_H^2$$

$$\delta m_H^2 = \frac{3 G_F}{\sqrt{2}\pi^2} m_t^2 \Lambda_{NP}^2 \sim \left(0.3\, \Lambda_{NP}\right)^2$$



* LHC explores this energy range...

EFT approach to New Flavour Physics
a game of scale and couplings

$$\mathcal{L}_{eff}=\mathcal{L}_{SM}+\sum_{k=1}\left(\sum_i C_i^k\, Q_i^{(k+4)}\right)/\Lambda^k$$

NP flavour effects are governed by two players:

i) **the value of the new physics scale Λ**

ii) **the effective flavour-violating couplings C's**

In explict models:

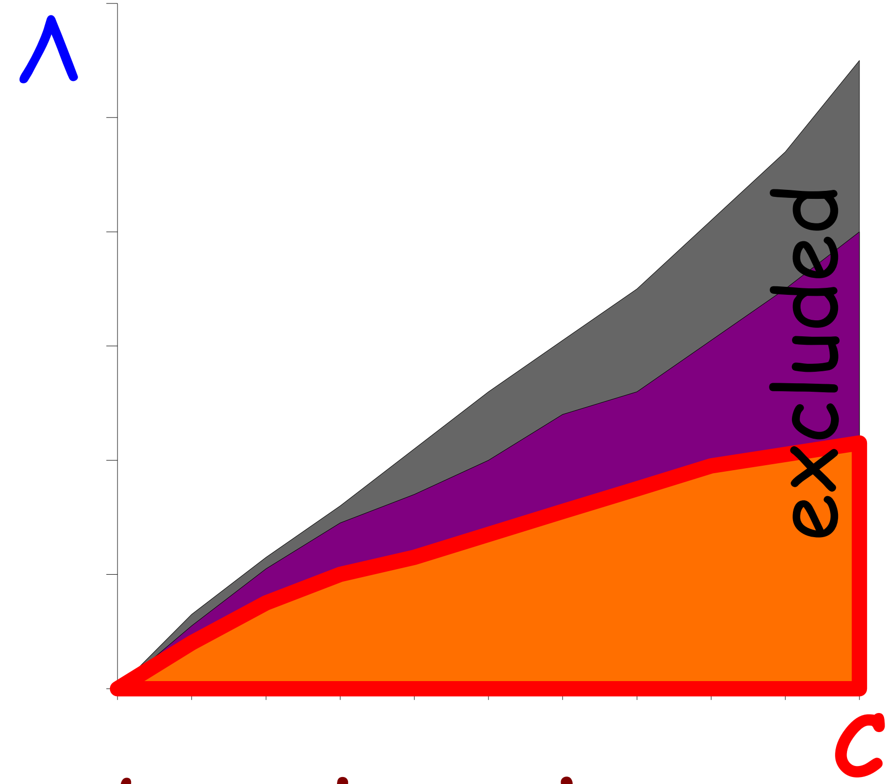
Λ ~ mass of virtual particles (Fermi th.: M_W)

C ~ loop coupling × flavour coupling

(SM/MFV: α_w × CKM)

Pictorially :

- exp. constraints give a bound on Λ for any given *c* and vice-versa
- curves correspond to different model classes



For example: present lower bound on the NP scale from ΔF=2 transitions (TeV @95%)

B + K — UTfit, arXiv:0707.0636

Scenario	strong/tree	α_s loop	α_W loop
MFV	5.5	0.5	0.2
NMFV	62	6.2	2
General	24000	2400	800

B only (w/o new Φ_s)

strong/tree	α_s loop	α_W loop
–	–	–
14	1.4	0.4
2200	220	66

What about theoretical errors?

* how much does the SuperB physics program count on improvements of the theory?
* what are the theoretical tools needed for doing precision flavour physics? Are they available?
* could theoretical uncertainties hinder NP contributions irrespective of the achieved experimental precision?

clean or dirty?

Theory keeps up...

- lattice QCD can reach the O(1%) precision goal in time
- some progress for inclusive techniques for SL B decays
- non-leptonic B decays are more problematic

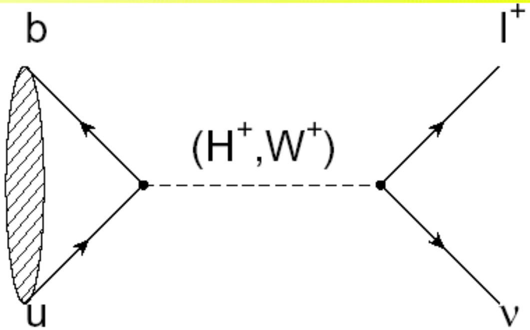
Measurement	Hadronic Parameter	Present Error	6 TFlops	60 TFlops	1-10 PFlops (Year 2015)
$K \to \pi l \nu$	$f_+^{K\pi}(0)$	0.9 %	0.7 %	0.4 %	< 0.1 %
ε_K	$\hat{B}_K$	11 %	5 %	3 %	1 %
$B \to l \nu$	f_B	14 %	3.5-4.5 %	2.5-4.0 %	1.0-1.5 %
Δm_d	$f_{Bs}\sqrt{B_{B_s}}$	13 %	4-5 %	3-4 %	1-1.5 %
$\Delta m_d/\Delta m_s$	ξ	5 %	3 %	1.5-2 %	0.5-0.8 %
$B \to D/D^* l \nu$	$\mathcal{F}_{B\to D/D^*}$	4 %	2 %	1.2 %	0.5 %
$B \to \pi/\rho l \nu$	$f_+^{B\pi}, \ldots$	11 %	5.5-6.5 %	4-5 %	2-3 %
$B \to K^*/\rho\,(\gamma, l^+l^-)$	$T_1^{B\to K^*/\rho}$	13 %	——	——	3-4 %

V. Lubicz, 4th SuperB Workshop and SuperB CDR

no theory improvements needed	$\beta(J/\psi\ K)$, $\gamma(DK)$, $\alpha(\pi\pi)$*, lepton FV and UV, $S(\rho^0\gamma)$ CPV in $B\to X\gamma$, D and τ decays zero of FB asymmetry $B\to X_s l^+ l^-$	NP insensitive or null tests of the SM or SM already known with the required accuracy
improved lattice QCD	meson mixing, $B\to D(*)l\nu$, $B\to\pi(\rho)l\nu$ $B\to K^*\gamma$, $B\to\rho\gamma$, $B\to l\nu$, $B_s\to\mu\mu$	target error: ~1-2% Feasible (see below)
improved OPE+HQE	$B\to X_{u,c}l\nu$, $B\to X\gamma$	target error: ~1-2% Possibly feasible with SuperB data getting rid of the shape function. Detailed studies required
improved QCDF/SCET or flavour symmetries	S's from TD A_{CP} in b -> s transitions	target error: ~2-3% large and hard to improve uncertainties on small corrections. FS+data can bound the th. error

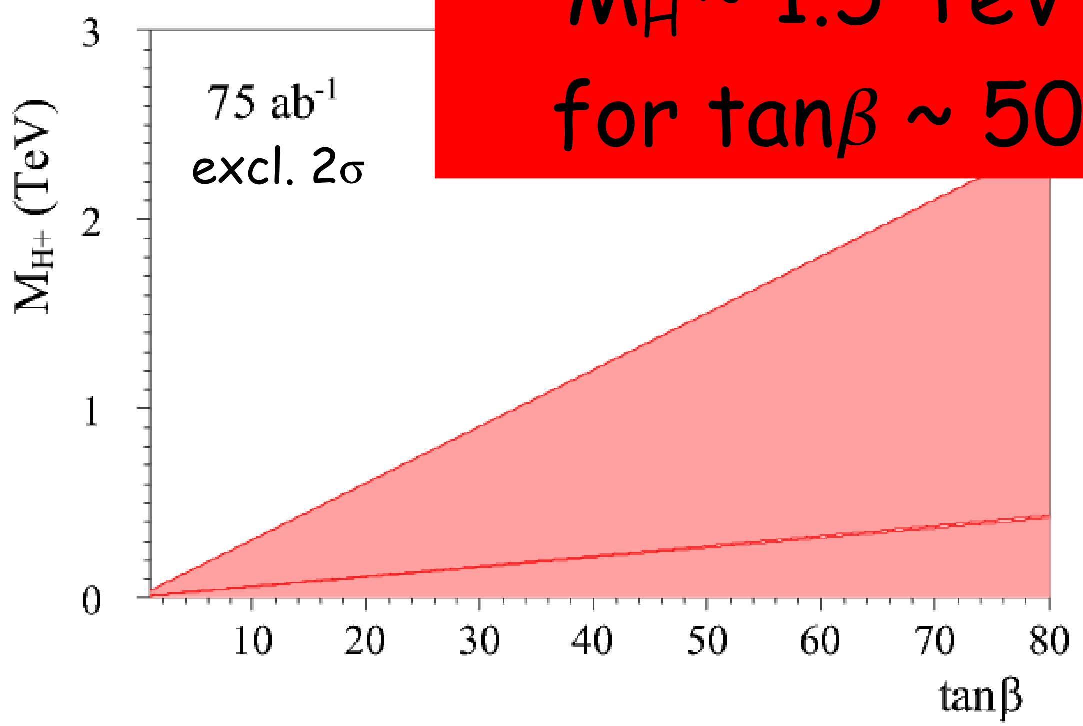
Higgs-mediated NP in MFV at large tanβ

$$BR(B^+ \to l^+ \nu) = BR_{SM}(B^+ \to l^+ \nu)\left(1 - \frac{m_B^2}{M_H^2}\tan^2\beta\right)^2$$



formula and plots for 2HDM

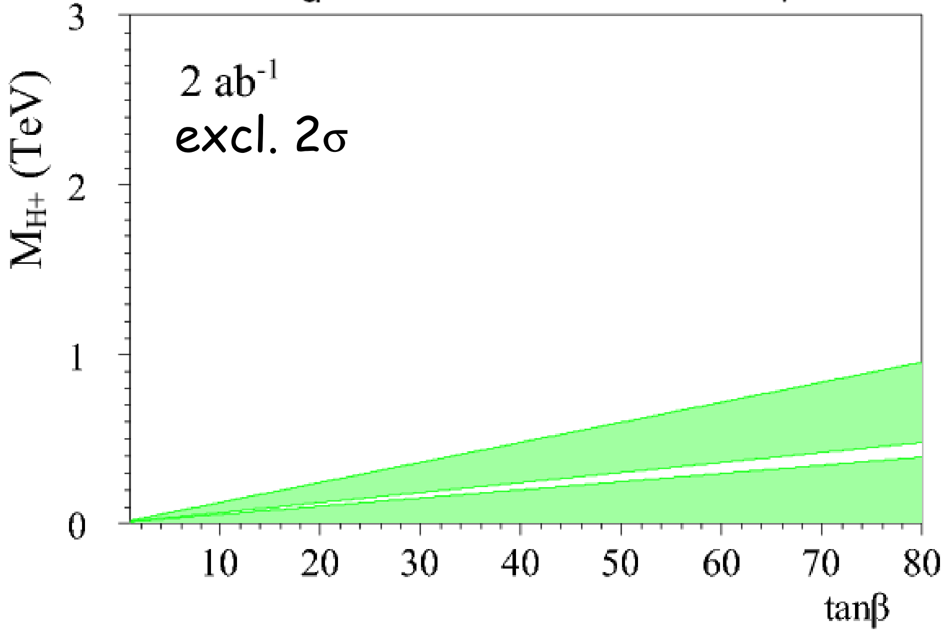
similar results for MSSM



SuperB (75/ab)

$M_H \sim 1.5$ TeV

for $\tan\beta \sim 50$



B factories (2/ab)

$M_H \sim 0.4$ TeV

for $\tan\beta \sim 50$

B physics on LHC benchmarks: SNOWMASS points

Typical points in the mSUGRA parameter space

SPS	$M_{1/2}$ (GeV)	M_0 (GeV)	A_0 (GeV)	$\tan\beta$	μ
1 a	250	100	-100	10	> 0
1 b	400	200	0	30	> 0
2	300	1450	0	10	> 0
3	400	90	0	10	> 0
4	300	400	0	50	> 0
5	300	150	-1000	5	> 0

	SPS1a	SPS4	SPS5
$\mathcal{R}(B \to s\gamma)$	0.919 ± 0.038	0.248	0.848 ± 0.081
$\mathcal{R}(B \to \tau\nu)$	0.968 ± 0.007	0.436	0.997 ± 0.003
$\mathcal{R}(B \to X_s l^+ l^-)$	0.916 ± 0.004	0.917	0.995 ± 0.002
$\mathcal{R}(B \to K\nu\overline{\nu})$	0.967 ± 0.001	0.972	0.994 ± 0.001
$\mathcal{B}(B_d \to \mu^+\mu^-)/10^{-10}$	1.631 ± 0.038	16.9	1.979 ± 0.012
$\mathcal{R}(\Delta m_s)$	1.050 ± 0.001	1.029	1.029 ± 0.001
$\mathcal{B}(B_s \to \mu^+\mu^-)/10^{-9}$	2.824 ± 0.063	29.3	3.427 ± 0.018
$\mathcal{R}(K \to \pi^0\nu\overline{\nu})$	0.973 ± 0.001	0.977	0.994 ± 0.001

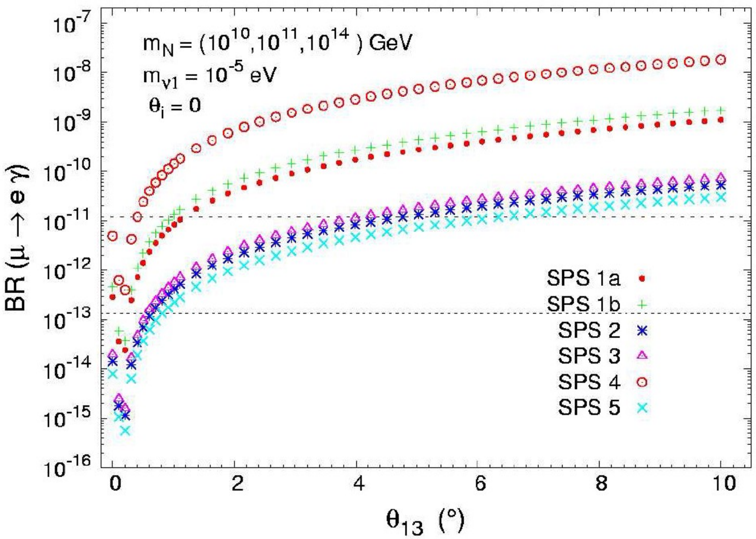
SPS4 ruled out by the present value of BR($b \to s\gamma$)

SPS1a is the least favorable point for flavour, yet SuperB can observe 2σ deviations in several observables

LFV on LHC benchmarks: SNOWMASS points

LFV	Snowmass points predictions						SuperB	
	1 a	1 b	2	3	4	5	90% UL	5σ disc
$BF(\tau \to \mu\gamma) \times 10^{-9}$	4.2	7.9	0.18	0.26	97	0.019	2	5
$BF(\tau \to 3\mu) \times 10^{-12}$	9.4	18	0.41	0.59	220	0.043	200	880

* SuperB could find >2σ LFV effect even in the unfavourable mSUGRA case
* $\tau \to \mu\gamma$ could be the only observable LFV in minimal scenarios with vanishing neutrino mixing angle θ_{13}

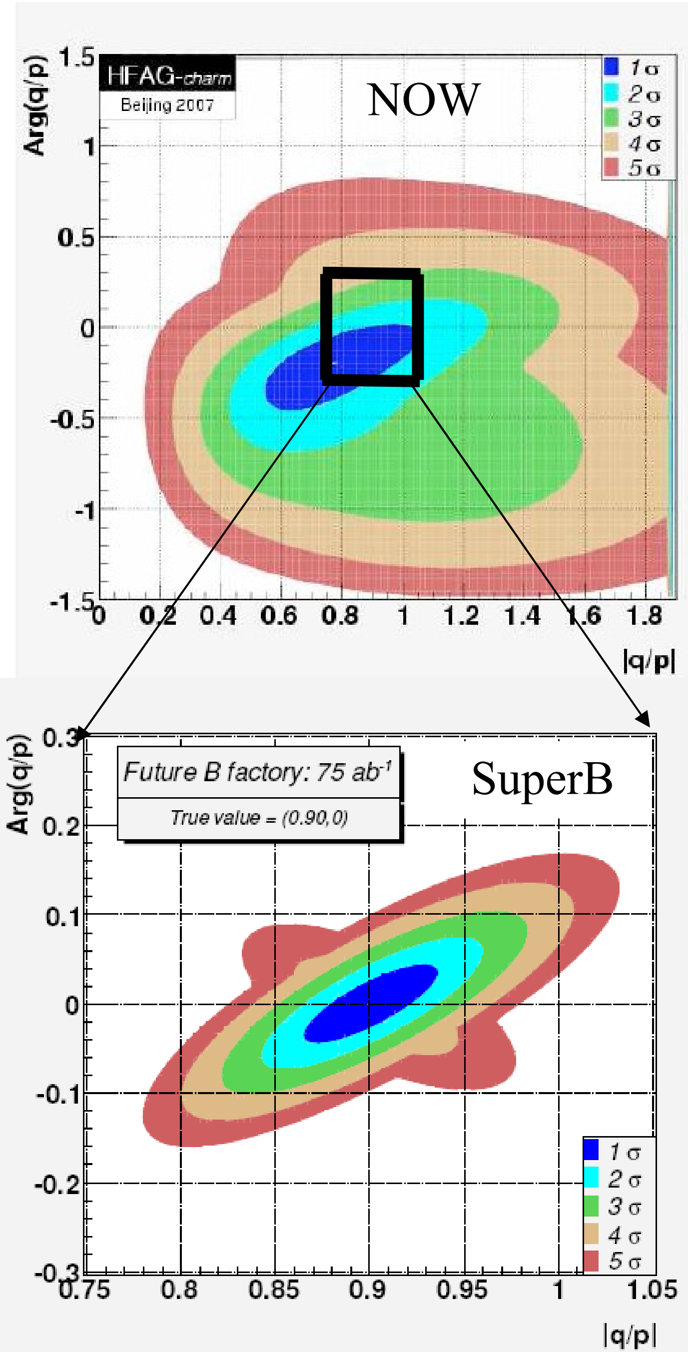


BR($\mu \to e\gamma$) vanishes as $\theta_{13} \to 0$ for at all SPS points

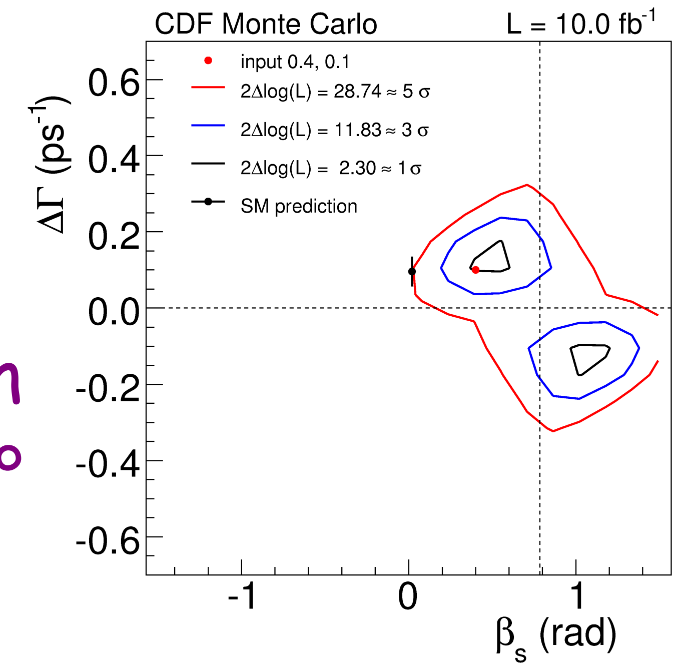
BR($\tau \to \mu\gamma$) is independent of θ_{13}

CP Violation in charm

Mode	Observable	$\Upsilon(4S)$ $(75\ \mathrm{ab}^{-1})$	$\psi(3770)$ $(300\ \mathrm{fb}^{-1})$
$D^0 \to K^+\pi^-$	x'^2	3×10^{-5}	
	y'	7×10^{-4}	
$D^0 \to K^+K^-$	y_{CP}	5×10^{-4}	
$D^0 \to K^0_S\pi^+\pi^-$	x	4.9×10^{-4}	
	y	3.5×10^{-4}	
	$\vert q/p \vert$	3×10^{-2}	
	ϕ	2°	
$\psi(3770) \to D^0\overline{D}^0$	x^2		$(1-2) \times 10^{-5}$
	y		$(1-2) \times 10^{-3}$
	$\cos\delta$		$(0.01-0.02)$



Flavour Physics Roadmap



now-2009: TeVatron

observation of $\phi_s \sim -20°$

2009-2015: LHC

+MEG
+JPARC
+CERN

- ϕ_s down to the SM value
- BR($B_s \to \mu\mu$) down to SM value
- UT angle γ with $\sigma(\gamma)$~2-3°

2015-2020: TOV?

EVERYTHING ELSE!!! (but K's)

τFV, $A_{CP}(b \to s)$, $b \to s$ penguins, CKM at 1% (with LQCD help), $B \to l\nu$, $S(K^*\gamma)$, $B \to K\nu\nu$, D CPV, ...