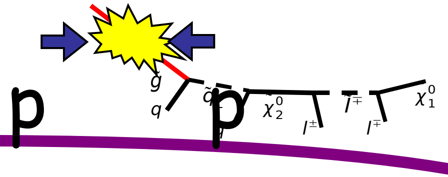
SuperB New Physics

Marco Ciuchini - INFN

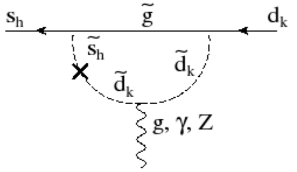
"The relativistic path"



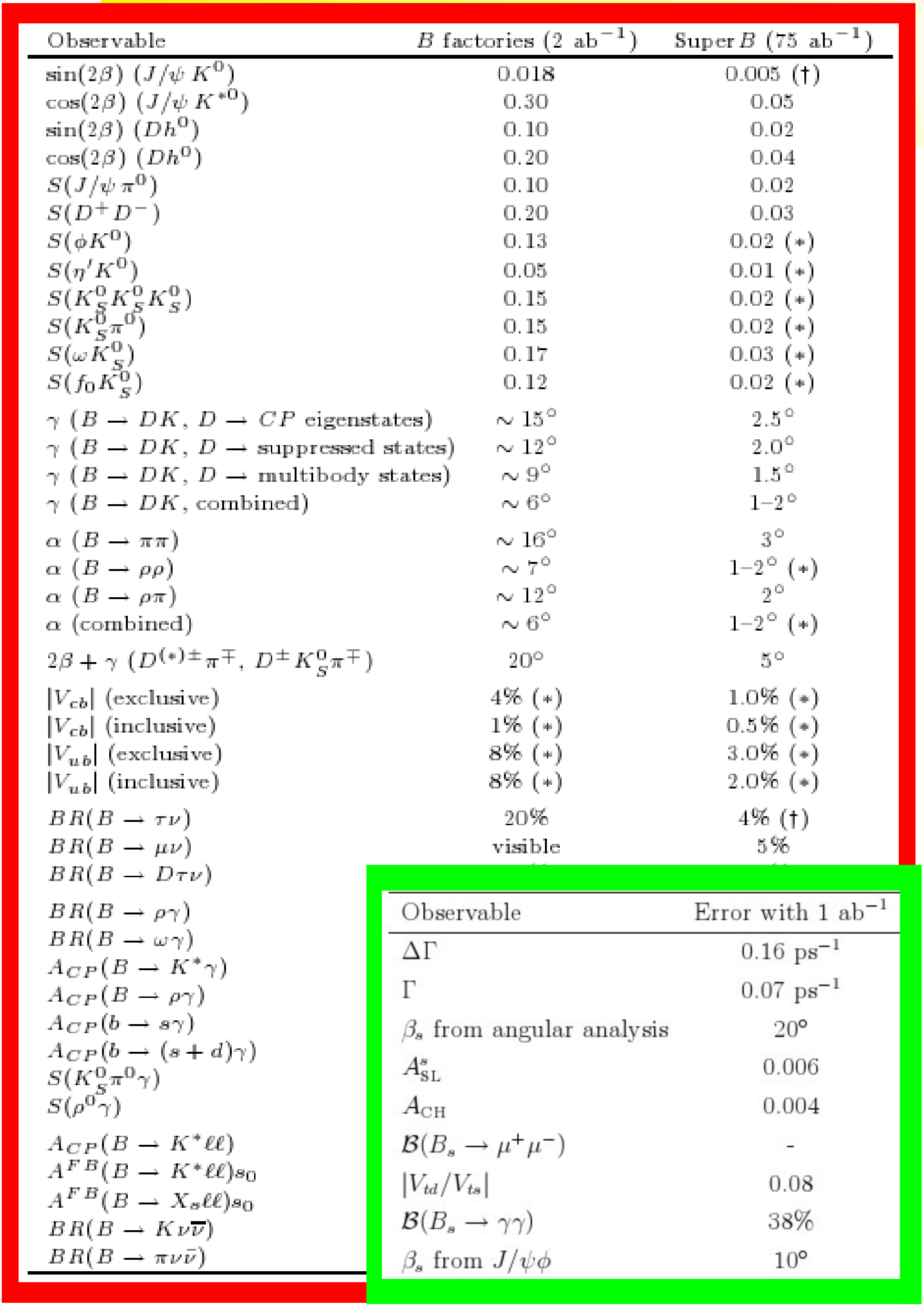
Standard Model

New Physics

"The quantum path"



B physics observables for New Physics discovery



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%
$BR(B \to D\tau\nu)$		
$BR(B \to \rho\gamma)$		
$BR(B \to \omega\gamma)$		
$A_{CP}(B \to K^*\gamma)$		
$A_{CP}(B \to \rho\gamma)$		
$A_{CP}(b \to s\gamma)$		
$A_{CP}(b \to (s+d)\gamma)$		
$S(K^0_S \pi^0 \gamma)$		
$S(\rho^0\gamma)$		
$A_{CP}(B \to K^*\ell\ell)$		
$A^{FB}(B \to K^*\ell\ell)s_0$		
$A^{FB}(B \to X_s\ell\ell)s_0$		
$BR(B \to K\nu\overline{\nu})$		
$BR(B \to \pi\nu\bar{\nu})$		

Observable	Error with 1 ab^{-1}
$\Delta\Gamma$	0.16 ps^{-1}
Γ	0.07 ps^{-1}
β_s from angular analysis	$20°$
$A^s_{\rm SL}$	0.006
$A_{\rm CH}$	0.004
$\mathcal{B}(B_s \to \mu^+\mu^-)$	-
$\lvert V_{td}/V_{ts}\rvert$	0.08
$\mathcal{B}(B_s \to \gamma\gamma)$	38%
β_s from $J/\psi\phi$	$10°$

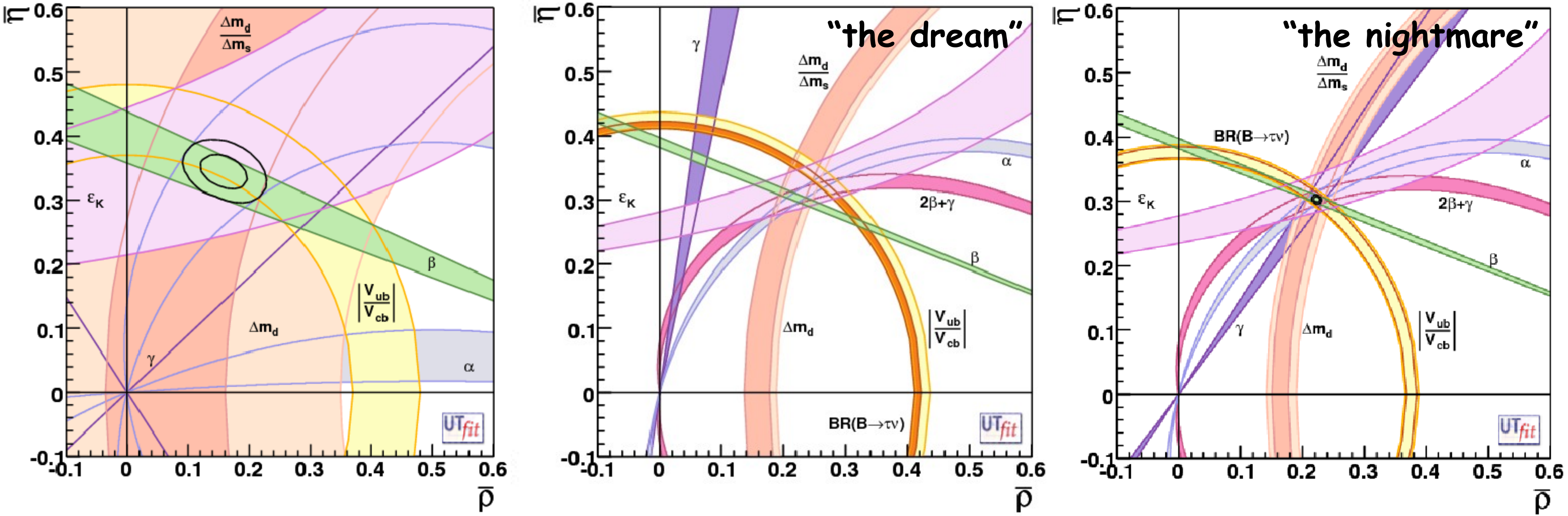
all these are good enough, even those NP independent

any of them can be the best one if the appropriate NP scenario is realized

other considerations (SuperB only, no lattice, ...) are required to select few flagship measurements

Overture: CKM matrix at 1%

Today | **With a SuperB in 2015**



Generalized UT fits:

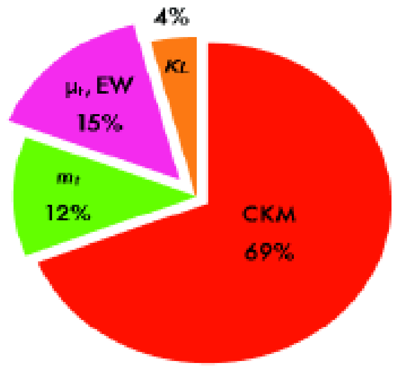
CKM at 1% in the presence of NP!

	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 for B decays!)

error budget

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



U. Haisch, Kaon '07

evaluating NP discovery potential

using EFT's

- **fully NP model free**
  encompass any NP
- **refined dim. analysis**
  up to "O(1)" factors
- **not fully specified**
  may miss correlations
- **virtual NP contrib. only**
  new particle content unspecified

using explicit models

- **theoretically biased**
  may miss the point
  partially cured using several models
- **fully specified**
  can exploit correlations
- **real processes calculable**
  known particle content
  interplay with direct searches possible

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

$$\mathcal{L} = \mathcal{L}_{SM} + \Sigma_k (\Sigma_i C_i^k Q_i^{(k+4)}) / \Lambda^k$$

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 (SM: M_W)

C ~ loop coupling × flavour coupling

(SM/MFV: α_W × CKM)

B physics: why?

SM FCNC and CPV processes occur at the loop level and thus could receive O(1) NP corrections but effects >20% are excluded

common misconception: this result points to MFV (or even establishes MFV)

if NP < 1 TeV

- * suppression of flavour-violating couplings required in all sectors *possibly* pointing to MFV
- * SUSY can stabilize the Fermi scale with "mild" fine-tuning

if 1< NP < 10-100 TeV

- * suppression of flavour-violating couplings needed in sector 1-2 only. No indication of MFV
- * SUSY can still stabilize the Fermi scale with "moderate" fine-tuning

SuperB physics goals

NP found at LHC

* determine the flavour- and CP-violating couplings the NP Lagrangian

* look for the effects of heavier states beyond the LHC discovery reach

NP not found at LHC

* look for indirect NP signals coming from the 1-100 TeV energy range

* exclude regions of the NP parameter space

Reconstructing the MSSM Lagrangian

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

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

* flavour and high-p_T physics are complementary

* the region of “small” masses **AND** large FV&CPV couplings is largely ruled out already

from “LHC ready” to “full LHC”

Full LHC
1 TeV

Are the FV couplings of new particles below the TeV scale measurable at a SuperB even in the worst case (MFV)?

Likely, but not guaranteed (yet)!

The EFT analysis of $\Delta F=2$ processes finds SuperB sensitivity of ~0.6 TeV for strict MFV couplings in the low tanB regime

The ΔF=2 effective Hamiltonian

$$H_{eff}^{\Delta B=2}=\sum_{i=1}^{5} C_i(\mu)Q_i(\mu)+\sum_{i=1}^{3}\tilde{C}_i(\mu)\tilde{Q}_i(\mu)$$

$$Q_1=\bar{q}_L^{\alpha}\gamma_{\mu}b_L^{\alpha}\,\bar{q}_L^{\beta}\gamma^{\mu}b_L^{\beta}\qquad \text{(SM/MFV)}$$

$$Q_2=\bar{q}_R^{\alpha}b_L^{\alpha}\,\bar{q}_R^{\beta}b_L^{\beta}\qquad Q_3=\bar{q}_R^{\alpha}b_L^{\beta}\,\bar{q}_R^{\beta}b_L^{\alpha}$$

$$Q_4=\bar{q}_R^{\alpha}b_L^{\alpha}\,\bar{q}_L^{\beta}b_R^{\beta}\qquad Q_5=\bar{q}_R^{\alpha}b_L^{\beta}\,\bar{q}_L^{\beta}b_R^{\alpha}$$

$$\tilde{Q}_1=\bar{q}_R^{\alpha}\gamma_{\mu}b_R^{\alpha}\,\bar{q}_R^{\beta}\gamma^{\mu}b_R^{\beta}$$

$$\tilde{Q}_2=\bar{q}_L^{\alpha}b_R^{\alpha}\,\bar{q}_L^{\beta}b_R^{\beta}\qquad \tilde{Q}_3=\bar{q}_L^{\alpha}b_R^{\beta}\,\bar{q}_L^{\beta}b_R^{\alpha}$$

7 new operators beyond MFV involving quarks with different chiralities

H_{eff} can be recast in terms of the high-scale $C_i(\Lambda)$

- $C_i(\Lambda)$ can be extracted from the data (one by one)
- the associated NP scale Λ can be defined as

$$\Lambda = \sqrt{\frac{L F_i}{C_i(\Lambda)}}$$

tree/strong interact. NP: $L \sim 1$

perturbative NP: $L \sim \alpha_s^2, \alpha_W^2$

Flavour structures:

MFV	next-to-MFV	generic
- $F_1 = F_{SM} \sim (V_{tq}V_{tb}^*)^2$ - $F_{i\neq 1} = 0$	- $\vert F_i \vert \sim F_{SM}$ - arbitrary phases	- $\vert F_i \vert \sim 1$ - arbitrary phases

present lower bound on the NP scale (TeV)

B + K

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

UTfit collaboration, arXiv:0707.0636

B only

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

SuperB: typically 3x present bounds

$\Lambda_{MFV} > 0.6$, $\Lambda_{NMFV} > 1.2$, $\Lambda_{GFV} > 220$ TeV

$\Delta F=2$ processes alone do not allow the detection at SuperB of particles with $M > 0.6$ TeV in the MFV scenario

$\Delta B=1$ processes, in particular radiative decays, have not been fully exploited yet

Present bounds D'Ambrosio et al., hep-ph/0207036

$b \to s \gamma$: $\Lambda_{MFV} > 9$ TeV

$b \to s\, ll$: $\Lambda_{MFV} > 3$ TeV

Dedicated experimental & theoretical studies needed to assess the SuperB potential for these processes

(starting here and now
with Hurth, Renga, Walsh, ...)

Explicit model: MSSM

$$M^2_{\tilde{d}} = \begin{pmatrix} m^2_{\tilde{d}_L} & m_d(A_d-\mu\tan\beta) & (\Delta^d_{12})_{LL} & (\Delta^d_{12})_{LR} & (\Delta^d_{13})_{LL} & (\Delta^d_{13})_{LR} \\ & m^2_{\tilde{d}_R} & (\Delta^d_{12})_{RL} & (\Delta^d_{12})_{RR} & (\Delta^d_{13})_{RL} & (\Delta^d_{13})_{RR} \\ & & m^2_{\tilde{s}_L} & m_s(A_s-\mu\tan\beta) & (\Delta^d_{23})_{LL} & (\Delta^d_{23})_{LR} \\ & & & m^2_{\tilde{s}_R} & (\Delta^d_{23})_{RL} & (\Delta^d_{23})_{RR} \\ & & & & m^2_{\tilde{b}_L} & m_b(A_b-\mu\tan\beta) \\ & & & & & m^2_{\tilde{b}_R} \end{pmatrix}$$

SuperB

LHC, ILC - HE frontier

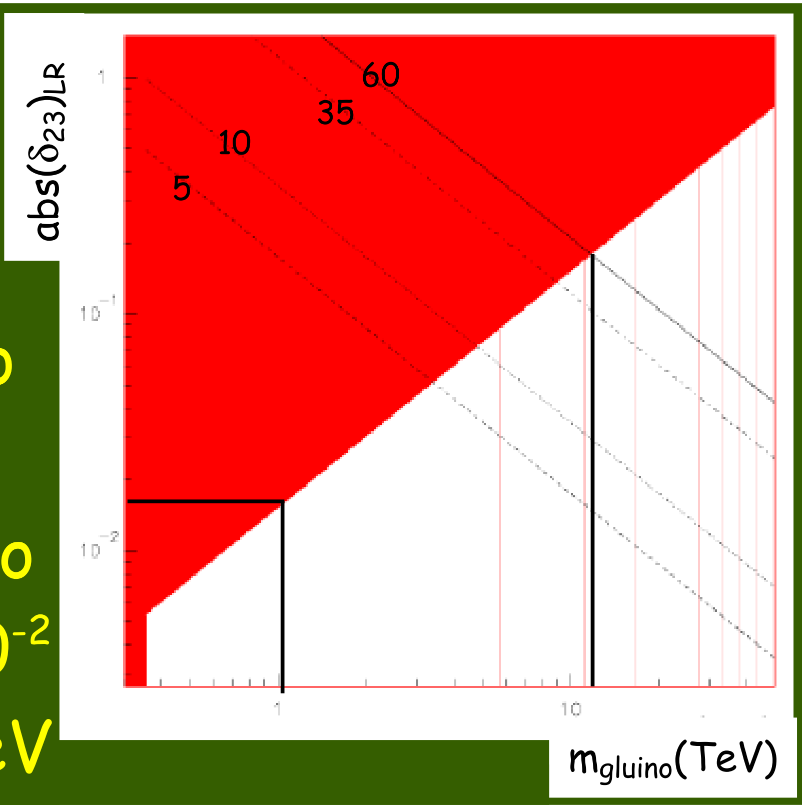
Mass Insertions

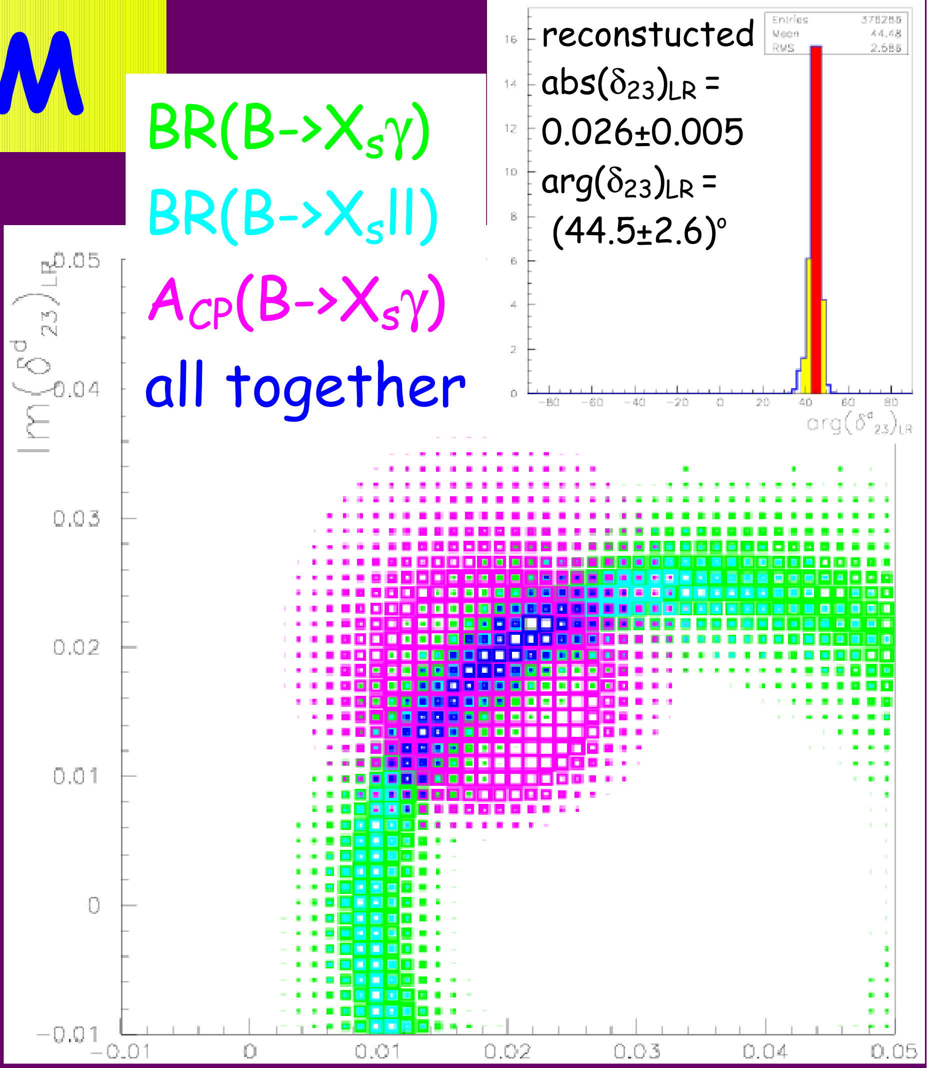
$(\delta^d_{ij})_{AB} = (\Delta^d_{ij})_{AB}/m^2_{\tilde{q}}$

3σ from 0 sensitivity plot

i) sensit. to $\Lambda<20$ TeV

ii) sensit. to $|(\delta^d_{23})_{LR}|>10^{-2}$ for $\Lambda<1$ TeV





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

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

- assessing the SuperB potential on flavour-nasty SUSY models (such as mSUGRA) would be highly desirable. Furthermore the IRC asked to evaluate SuperB performances on LHC benchmarks (starting here with help from Shindou and from our high-p_T friends Heinemeyer and Ronga)

- consider other models besides SUSY (some LHT already in the CDR, here extra dimensions with Kou)

An issue to debate: 10^{36} vs 10^{35}

we plan to complete the exercise for B physics during this week. Yet O(1) differences on accessible scales and couplings can be anticipated

although any such difference could be crucial, they are likely not very impressive to present and difficult to defend, given the intrinsic uncertainty of the EFT approach which was heavily used

we should look for qualitative differences in the physics that can be done with 75/ab vs the physics possible with say 10-15/ab

This means that we have to look at qualifying points which are difficult to achieve even at 10^{36}!

A couple comes to my mind:

i) the "full LHC" label, i.e. the possibility to to measure flavour effects in the whole LHC discovery energy range, fully playing the complementarity game with high-pT searches

ii) the possibility of measuring theoretically interesting values of LFV BRs and of being complementary with the MEG measurement

These goals are not attainable with 10^{35} but we have to clearly show that they are at SuperB

Working Group on B physics

* totally informal working group setup

* program subject to last-minute changes

* few presentations (some of them, notably mine, rather working plans). For theory, we have:

- Paolo Gambino (by phone) on V_{ub}
- Emi Kou on B -> $\tau\nu\gamma$ and extra dimensions
- Tetsuo Shindou on SUSY breaking scenarios
- Tobias Hurth on b -> s γ and b -> s ll
- Florian Domingo on Next-to-MSSM

* a lot of spare time for discussions, work, new ideas, coffee, local attractions, ...

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Let's make it a SuperB workshop!!!

Spare
Slides

Conclusions

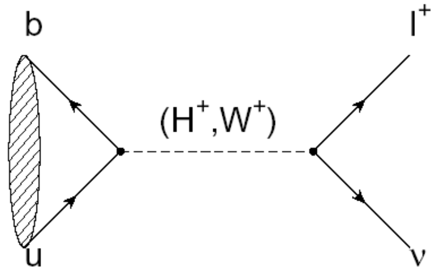
The SFF physics program complements and extends the NP searches with high p_T at LHC

(i) NP is behind the corner:
once the LHC finds it, (only) a SFF can measure systematically the new FV & CPV couplings, i.e. the flavour structure of NP

(ii) NP is a few corners ahead:
NP at scales beyond the LHC reach could give measurable effects at a SFF: unique opportunity to unveil the 1-100 TeV range

Higgs-mediated NP in MFV at large tanβ

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



formula and plot for 2HDM

similar results for MSSM

sensitivity:

B factories (2/ab)

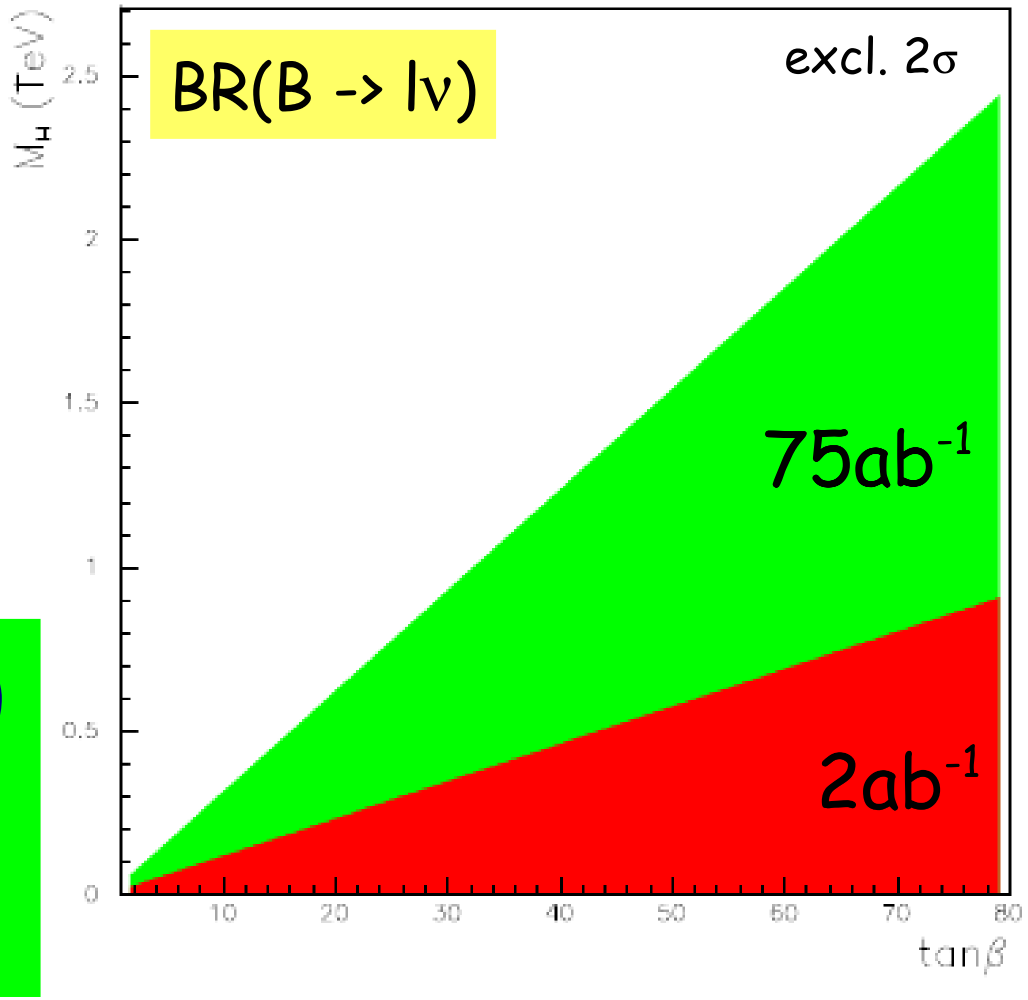
$M_H \sim 0.4$ TeV

for tanβ ~ 50

SuperB (75/ab)

$M_H \sim 1.5$ TeV

for tanβ ~ 50



Minimal Flavour Violation

Gabrielli, Giudice, NPB433
Buras et al., NPB500
D'Ambrosio et al., NPB645

No new sources of flavour and CP violation beyond the SM

- NP contributions governed by SM Yukawa couplings
  ex.: Constrained MSSM (MSUGRA), Universal Extra Dim.
- NP only modifies SM top contribution to FCNC & CPV
  unless other Yukawa couplings are enhanced; for example
  large tanβ enhances bottom contributions

1HDM/2HDM at small tanβ	2HDM at large tanβ
same operators as in H_{eff}^{SM}	new operators wrt H_{eff}^{SM}
NP in K and B correlated	NP in K and B uncorrelated

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 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

Crucial questions for NP searches with flavour

1. can NP be flavour blind? “no”,
NP couples to SM which violates flavour

2. can a “worst case” be defined? “yes”,
through the class of models with

Minimal Flavour Violation

NP follows the SM pattern of flavour
and CP symmetry breaking

Gabrielli, Giudice, NPB433
Buras et al, NPB500
D'Ambrosio et al., NPB645

Conclusions (ii)

Only part of the SuperB physics program relies on theory upgrades. For this part, theoretical errors of O(1-2%) are needed: feasible for LQCD; challenging but possibly reachable in inclusive measurements; factorization needs checking on channel basis

SuperB and S-LHCb physics programs are largely complementary. As for the part in common, they are competitive but SuperB can measure more and th. cleaner channels