The New, the Rare and the Beautiful

Role of Flavour Physics in the LHC Era

Tobias Hurth

University of Zurich
6th - 8th January, 2010

Ambiguity of new physics scale from flavour data

$$\mathcal{L} = \mathcal{L}_{Gauge} + \mathcal{L}_{Higgs} + \sum_i \frac{c_i^{New}}{\Lambda_{\rm NP}} \mathcal{O}_i^{(5)} + \ldots$$

- SM as effective theory valid up to cut-off scale $\Lambda_{\rm NP}$
- Typical example: $K^0 - \bar{K}^0$-mixing $\mathcal{O}^6 = (\bar{s}\, d)^2$:

$$c^{SM}/M_W^2 \times (\bar{s}\, d)^2 + c^{New}/\Lambda_{\rm NP}^2 \times (\bar{s}\, d)^2 \qquad \Rightarrow \quad \Lambda_{\rm NP} > 10^4\,\text{TeV}$$

(tree-level, generic new physics)

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- Natural stabilisation of Higgs boson mass (hierarchy problem)

  (i.e. supersymmetry, little Higgs, extra dimensions) $\Rightarrow \quad \Lambda_{\text{NP}} \leq 1\text{TeV}$

- EW precision data $\leftrightarrow$ little hierarchy problem $\Rightarrow \Lambda_{\text{NP}} \sim 3 - 10\text{TeV}$

Possible New Physics at the TeV scale has to have a very non-generic flavour structure

$$(\, C_{\text{SM}}^i / M_W + C_{\text{NP}}^i \,/ \Lambda_{\text{NP}} \,) \times \mathcal{O}_i$$

Parameter bounds from flavour physics are model-dependent

Status of the inclusive mode $\bar{B} \to X_s\gamma$

NLO matrix elements in $b \to s\gamma$

PHYSICAL REVIEW D VOLUME 54, NUMBER 5 1 SEPTEMBER 1996

Virtual $O(\alpha_s)$ corrections to the inclusive decay $b \to s\gamma$

Christoph Greub
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309

Tobias Hurth* and Daniel Wyler
Institute for Theoretical Physics, University of Zürich, Winterthurerstr. 190, CH-8057 Zürich, Switzerland

(Received 26 March 1996)

We present in detail the calculation of the $O(\alpha_s)$ virtual corrections to the matrix element for $b \to s\gamma$. In addition to the one-loop virtual corrections of the electromagnetic and color dipole operators O_7 and O_8, we include the important two-loop contribution of the four-Fermi operator O_2. By applying the Mellin-Barnes representation to certain internal propagators, the result of the two-loop diagrams is obtained analytically as an expansion in m_c/m_b. These results are then combined with existing $O(\alpha_s)$ bremsstrahlung corrections in order to obtain the inclusive rate for $B \to X_s\gamma$. The new contributions drastically reduce the large renormalization scale dependence of the leading logarithmic result. Thus, a very precise standard model prediction for this inclusive process will become possible once the corrections to the Wilson coefficients are also available.

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Status of the inclusive mode $\bar{B} \to X_s \gamma$

HFAG: $\mathcal{B}(B \to X_s \gamma) = (3.57 \pm 0.24) \times 10^{-4}$ (for $E_\gamma > 1.6$ GeV)

vs

SM: $\mathcal{B}(B \to X_s \gamma) = (3.15 \pm 0.23) \times 10^{-4}$ (for $E_\gamma > 1.6$ GeV) PRL98,022003(2007)

NNLO calculation by M.Misiak et al.

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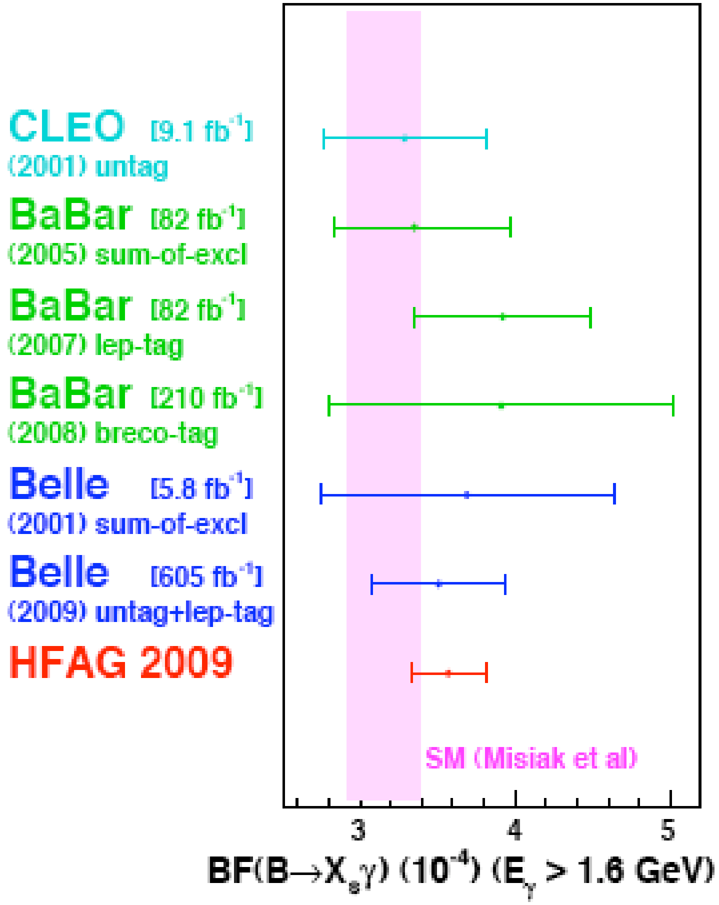

Courtesy of Mikihiko Nakao

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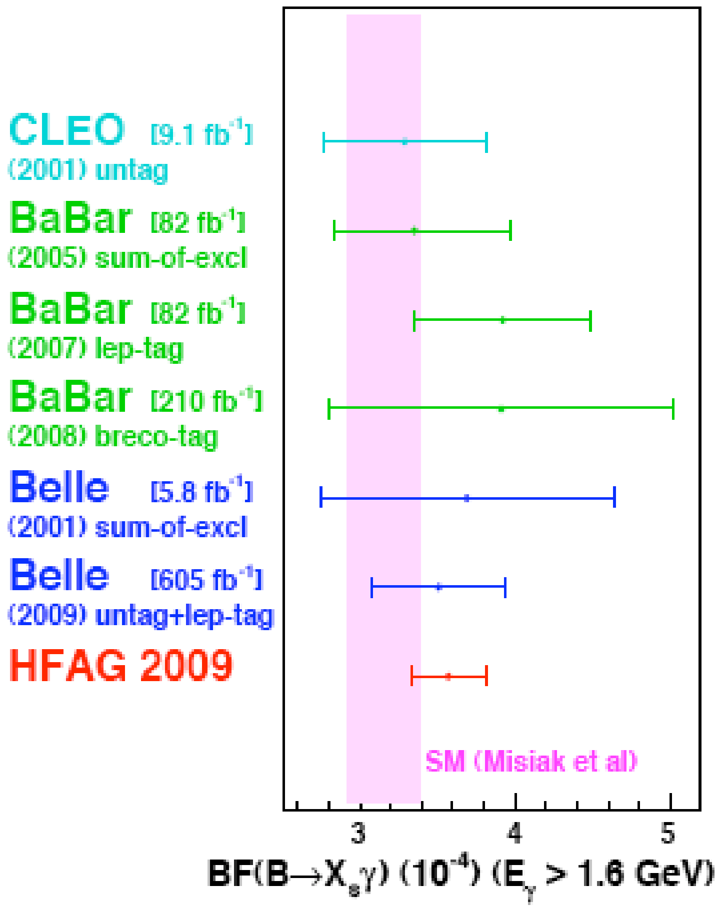
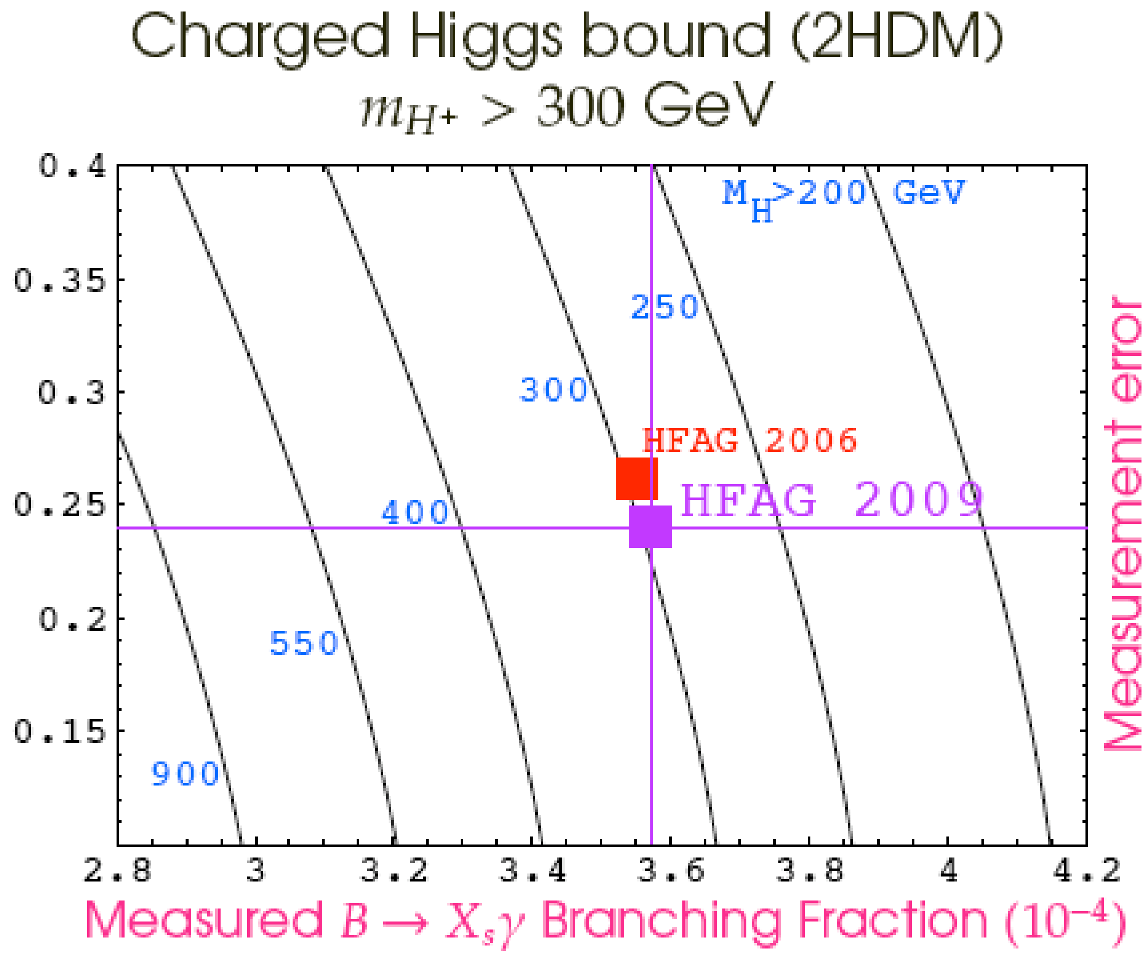




Courtesy of Mikihiko Nakao

Flavour@High-p_T Interplay

Can ATLAS/CMS exclude MFV ?

Can we ignore flavour when analysing possible new physics at the electroweak scale?

⇒ CERN workshop on the interplay of flavour and collider physics
Fleischer,Hurth,Mangano see http://mlm.home.cern.ch/mlm/FlavLHC.html

5 meetings between 11/2005 and 3/2007

arXiv:0801.1800 [hep-ph] “Collider aspects of flavour physics at high Q”

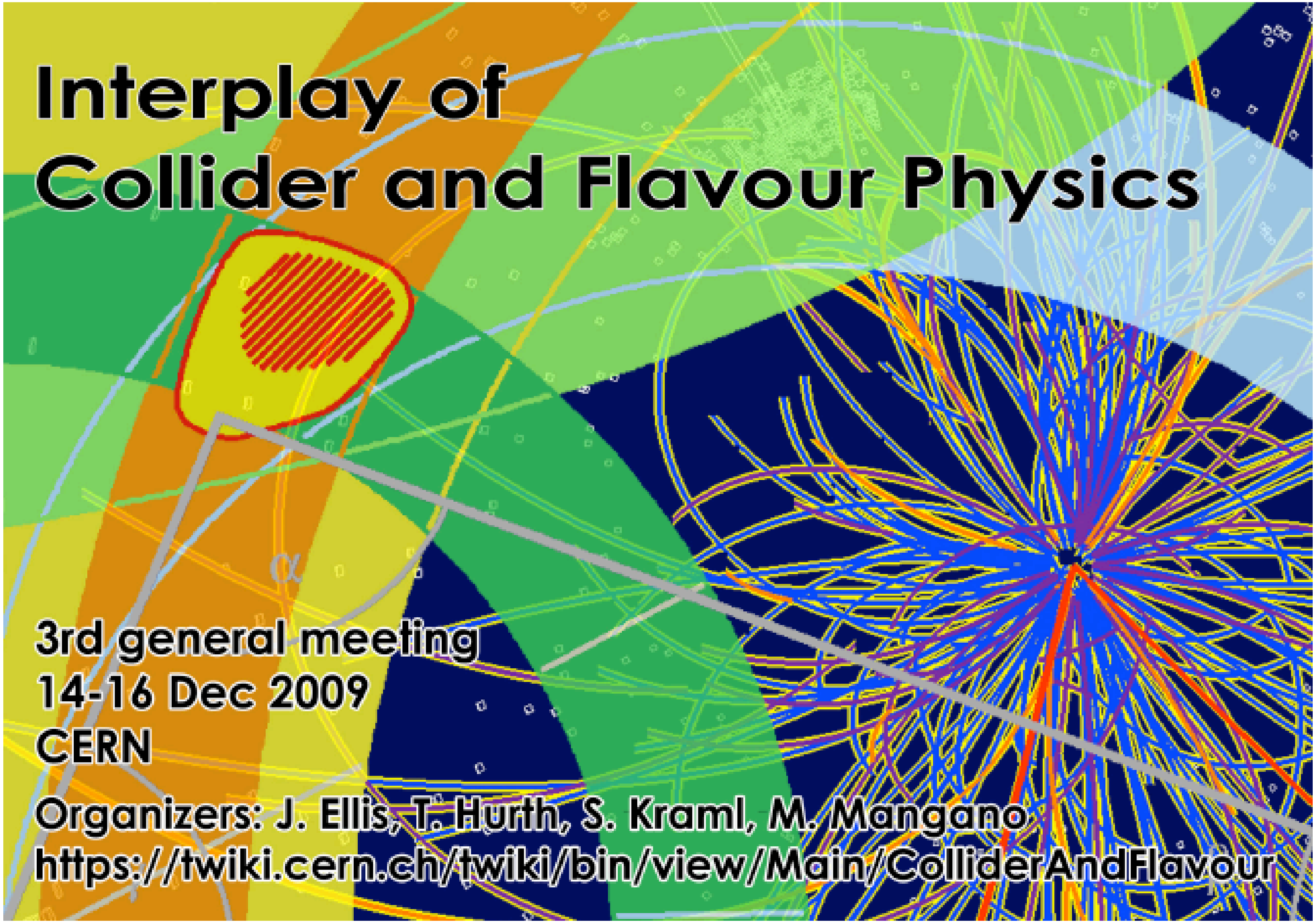
arXiv:0801.1833 [hep-ph] “B, D and K decays”

arXiv:0801.1826 [hep-ph] “Flavour physics of leptons and dipole moments”

published in EPJC 57 (2008) 1-492

and in Advances in the Physics of Particles and Nuclei, Vol 29, 480p, 2009

Follow-up workshop



Quark flavour at ATLAS/CMS

- **Probing Minimal Flavour Violation at the LHC**

Grossman,Nir,Thaler,Volansky,Zupan,arXiv:0706.1845

To an accuracy of $\mathcal{O}(0.05)$

$$V^{\mathrm{CKM}}_{\mathrm{LHC}} = \begin{pmatrix} 1 & 0.23 & 0 \\ -0.23 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}.$$

New particles (i.e. heavy vector-like quarks) that couple to the SM quarks decay to either 3rd generation quark, or to non-3rd generation quark, but not to both.

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If ATLAS/CMS measures $BR(q_3) \sim BR(q_{1,2})$ then this excludes MFV.

MFV prediction for events with B' pair production:

$$\frac{\Gamma(B'\overline{B'} \to X q_{1,2} q_3)}{\Gamma(B'\overline{B'} \to X q_{1,2} q_{1,2}) + \Gamma(B'\overline{B'} \to X q_3 q_3)} \lesssim 10^{-3}$$

Flavour tagging efficiencies are crucial.

Quark flavour at ATLAS/CMS II

- **Flavour-violating squark and gluino decays**

Hurth,Porod,hep-ph/0311075
arXiv:0904.4574 [hep-ph],
to appear in JHEP

- Squark decays:

$$\tilde{u}_i \to u_j \tilde{\chi}_k^0\,,\; d_j \tilde{\chi}_l^+ \qquad \tilde{d}_i \to d_j \tilde{\chi}_k^0\,,\; u_j \tilde{\chi}_l^-$$

  with $i = 1, .., 6$, $j = 1, 2, 3$, $k = 1, .., 4$ and $l = 1, 2$.

- These tree decays are governed by the same mixing matrices as the contributions to flavour violating low-energy observables

- In the unconstrained MSSM new contributions to flavour violation
  - CKM-induced contributions from H^+, χ^+ exchanges
  - flavour mixing in the sfermion mass matrix

- Possible disalignement of quarks and squarks

Strategy:

- Take susy benchmark points: SPS1a',γ, and I''
- Vary flavour nondiagonal parameters

  (off-diagonal squark mass entries)
- Use all experimental and theoretical bounds

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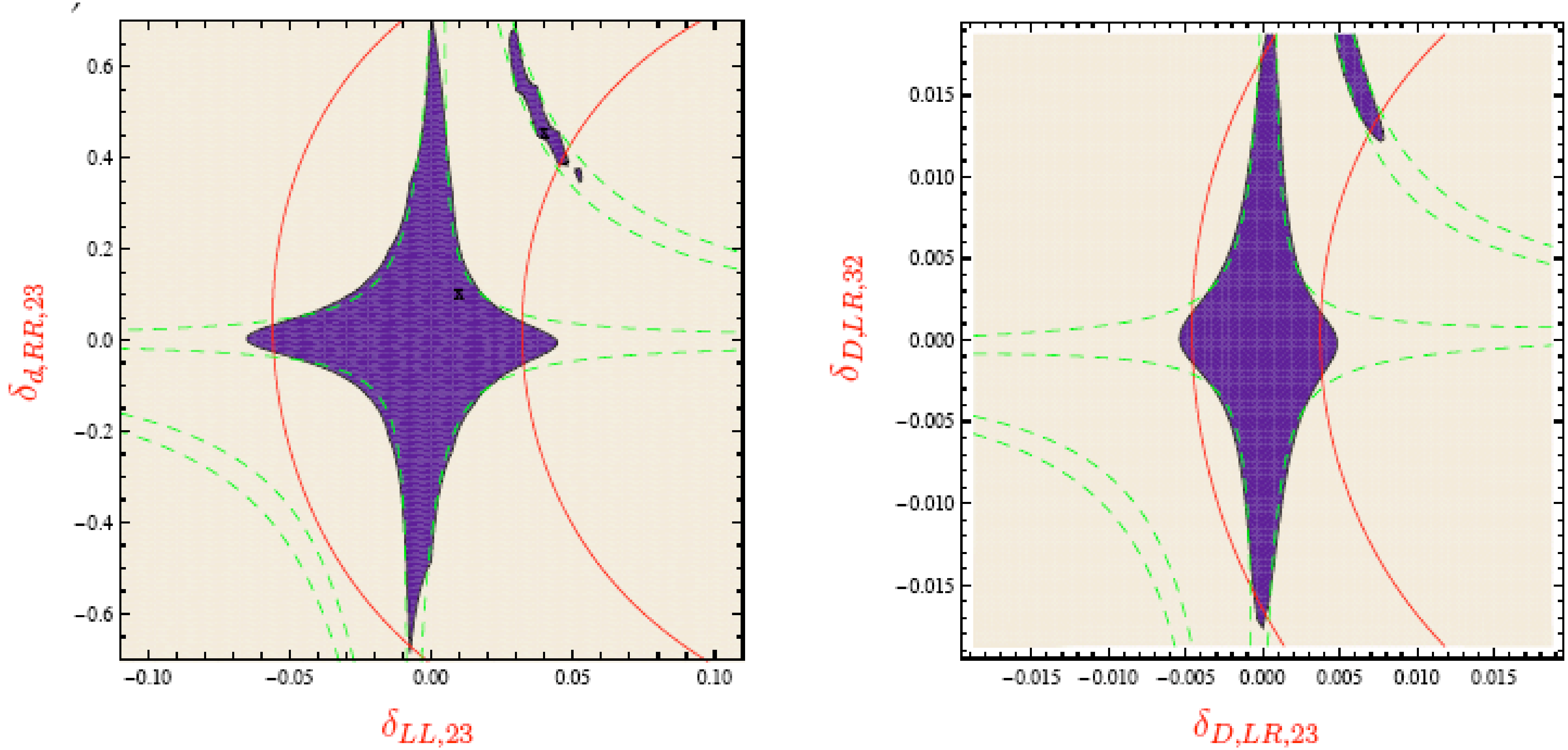
$\Rightarrow$ Bounds on δ parameters



($b \to s\gamma$ red lines, ΔM_{B_s} magenta)

Strategy:

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  (off-diagonal squark mass entries)
- Use all experimental and theoretical bounds

$\Rightarrow$ Information on flavour-violating tree decays

- Flavour-violating squark and gluino decays can be typically of order of 10%,

  - consistent with the present flavour data.

  - common feature for a couple of SUSY benchmark points like SPS1a',γ, and I''

  - even 40% possible for large new physics contributions

Typical results for squark and gluino decays

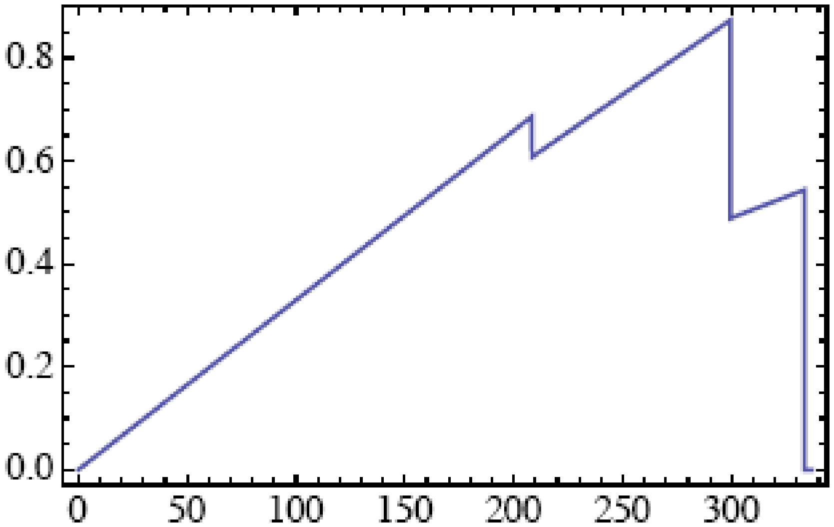
decaying particle	final states and corresponding branching ratios in % for.					
	I. $\delta_{LL,23} = 0.01, \delta_{D,RR23} = 0.1$			II. $\delta_{LL,23} = 0.04, \delta_{D,RR23} = 0.45$		
$\tilde{d}_1 \to$	$\tilde{\chi}^0_1 b\,,\ 4.4$	$\tilde{\chi}^0_2 b\,,\ 29.8$	$\tilde{\chi}^-_1 t\,,\ 37.0$	$\tilde{\chi}^0_1 s\,,\ 36.8$	$\tilde{\chi}^0_1 b\,,\ 42.2$	$\tilde{\chi}^0_2 b\,,\ 10.9$
I: $\tilde{b}_L(\tilde{b}_R)$	$\tilde{u}_1 W^-\,,\ 27.7$			$\tilde{\chi}^-_1 t\,,\ 9.6$		
$\tilde{d}_2 \to$	$\tilde{\chi}^0_1 s\,,\ 8.0$	$\tilde{\chi}^0_1 b\,,\ 6.4$	$\tilde{\chi}^0_2 b\,,\ 19.0$	$\tilde{\chi}^0_1 b\,,\ 2.1$	$\tilde{\chi}^0_2 b\,,\ 27.3$	$\tilde{\chi}^-_1 t\,,\ 34.6$
I: $\tilde{b}_R(\tilde{b}_L, \tilde{s}_R)$	$\tilde{\chi}^0_3 b\,,\ 1.1$	$\tilde{\chi}^0_4 b\,,\ 1.8$	$\tilde{\chi}^-_1 t\,,\ 24.6$	$\tilde{u}_1 W^-\,,\ 33.2$		
	$\tilde{u}_1 W^-\,,\ 38.9$					
$\tilde{d}_4 \to$	$\tilde{\chi}^0_1 s\,,\ 9.1$	$\tilde{\chi}^0_1 b\,,\ 6.3$	$\tilde{\chi}^0_2 s\,,\ 25.3$	$\tilde{\chi}^0_1 d\,,\ 2.3$	$\tilde{\chi}^0_2 d\,,\ 31.7$	$\tilde{\chi}^-_1 u\,,\ 59.7$
I: $\tilde{s}_R(\tilde{s}_L, \tilde{b}_R)$	$\tilde{\chi}^-_1 u\,,\ 2.1$	$\tilde{\chi}^-_1 c\,,\ 47.3$	$\tilde{u}_1 W^-\,,\ 4.8$	$\tilde{\chi}^-_1 c\,,\ 3.0$	$\tilde{\chi}^-_2 u\,,\ 2.3$	
$\tilde{d}_5 \to$	$\tilde{\chi}^0_1 d\,,\ 2.3$	$\tilde{\chi}^0_2 d\,,\ 31.7$	$\tilde{\chi}^-_1 u\,,\ 59.9$	$\tilde{\chi}^0_1 s\,,\ 2.2$	$\tilde{\chi}^0_2 s\,,\ 30.7$	$\tilde{\chi}^-_1 u\,,\ 2.9$
I: $\tilde{d}_L$	$\tilde{\chi}^-_1 c\,,\ 2.8$	$\tilde{\chi}^-_2 u\,,\ 2.3$		$\tilde{\chi}^-_1 c\,,\ 58.5$	$\tilde{\chi}^-_2 c\,,\ 2.3$	
$\tilde{d}_6 \to$	$\tilde{\chi}^0_1 s\,,\ 3.1$	$\tilde{\chi}^0_2 s\,,\ 30.6$	$\tilde{\chi}^-_1 u\,,\ 2.7$	$\tilde{\chi}^0_1 s\,,\ 19.7$	$\tilde{\chi}^0_1 b\,,\ 18.8$	$\tilde{\chi}^0_3 b\,,\ 2.9$
I: $\tilde{s}_L(\tilde{s}_R)$	$\tilde{\chi}^-_1 c\,,\ 58.1$	$\tilde{\chi}^-_2 c\,,\ 2.4$		$\tilde{\chi}^0_4 b\,,\ 2.9$	$\tilde{\chi}^-_2 t\,,\ 5.8$	$\tilde{g} s\,,\ 2.2$
				$\tilde{g} b\,,\ 39.8$	$\tilde{u}_1 W^-\,,\ 5.5$	
$\tilde{g} \to$	$\tilde{u}_1 t\,,\ 19.2$	$\tilde{u}_2 c\,,\ 8.2$	$\tilde{u}_3 u\,,\ 8.3$	$\tilde{u}_1 t\,,\ 13.5$	$\tilde{u}_2 c\,,\ 5.8$	$\tilde{u}_3 u\,,\ 5.8$
	$\tilde{u}_4 u\,,\ 4.2$	$\tilde{u}_5 c\,,\ 4.2$		$\tilde{u}_4 c\,,\ 2.6$	$\tilde{u}_5 u\,,\ 2.6$	
	$\tilde{d}_1 s\,,\ 1.4$	$\tilde{d}_1 b\,,\ 20.6$		$\tilde{d}_1 s\,,\ 21.1$	$\tilde{d}_1 b\,,\ 22.7$	
	$\tilde{d}_2 s\,,\ 6.3$	$\tilde{d}_2 b\,,\ 9.0$	$\tilde{d}_3 d\,,\ 8.3$	$\tilde{d}_2 b\,,\ 14.0$		$\tilde{d}_3 d\,,\ 5.9$
	$\tilde{d}_4 s\,,\ 2.3$	$\tilde{d}_4 b\,,\ 1.3$	$\tilde{d}_6 s\,,\ 2.8$	$\tilde{d}_4 d\,,\ 2.3$	$\tilde{d}_5 d\,,\ 3.3$	

II: $\tilde{d}_1 \simeq \tilde{b}_R, \tilde{s}_R(\tilde{b}_L)$, $\tilde{d}_6 \simeq \tilde{s}_R, \tilde{b}_R(\tilde{b}_L)$, $\tilde{d}_2 \simeq \tilde{b}_L$, $\tilde{d}_3 \simeq \tilde{d}_R$, $\tilde{d}_4 \simeq \tilde{d}_L$ and $\tilde{d}_5 \simeq \tilde{s}_L$

Impact on LHC

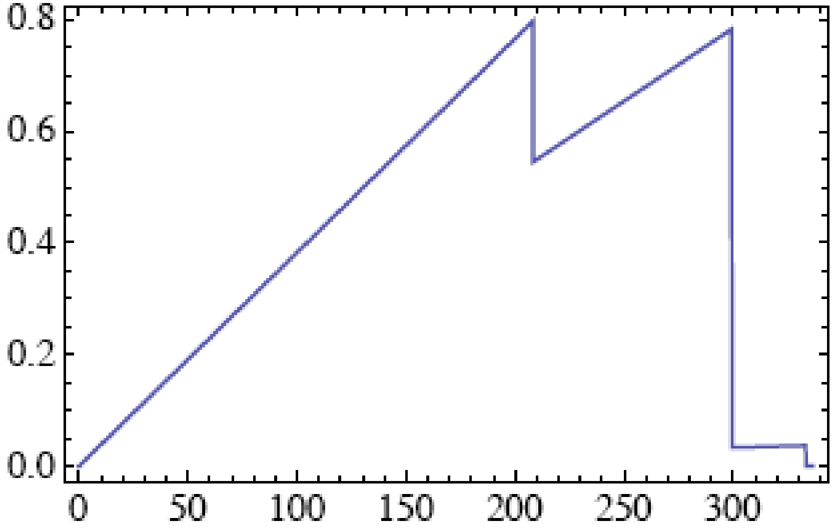
This can complicate determination of sparticle masses: $\tilde{g} \longrightarrow b\tilde{b}_j \longrightarrow b\bar{b}\tilde{\chi}_k^0$

$10^4\ d(\mathrm{BR}(\tilde{g} \to b\bar{b}\tilde{\chi}_1^0)/dm_{bb}$



$m_{bb} = \sqrt{(p_b + p_{\bar{b}})^2}$

$10^4\ d(\mathrm{BR}(\tilde{g} \to bs\tilde{\chi}_1^0)/dm_{bs}$



m_{bs}

Again: flavour-tagging at LHC important, but difficult

Additional information from ILC or from Superflavour factory needed !

Further observables work in progress

Future Opportunities

- LHCb (5 years) $10 fb^{-1}$: allows for wide range of analyses,

  highlights: B_s mixing phase, angle γ, $B \to K^* \mu\mu$, $B_s \to \mu\mu$,$B_s \to \phi\phi$

  then possibility for upgrade to $100 fb^{-1}$

- Dedicated kaon experiments J-PARC E14 and CERN P-326/NA62:

  rare kaon decays $K_L^0 \to \pi^0 \nu\bar{\nu}$ and $K^+ \to \pi^+ \nu\bar{\nu}$

- Two proposals for a Super-B factory:

  BELLE II at KEK and SuperB in Frascati ($75 ab^{-1}$)

  Super-B is a Super Flavour factory: besides precise B measurements, CP violation in charm, lepton flavour violating modes $\tau \to \mu\gamma$,...

Opportunity for LHCb (restriction to exclusive modes): $B \to K^* \ell^+ \ell^-$

in collaboration with Egede, Reece (LHCb,Imperial) and Matias, Ramon (Barcelona)

JHEP 0811:032,2008, arXiv:0807.2589 [hep-ph] and arXiv:0912.1339, arXiv:0912.1349

Factorization formulae based on soft-collinear effective theory (SCET):

for $B \to K^*$ formfactors $\quad F_i = H_i \xi^P(E) + \phi_B \otimes T_i \otimes \phi^P_{K^*} + O(\Lambda/m_b)$

for the decay amplitudes $\quad \mathcal{T}^{(i)}_a = C^{(i)}_a \xi_a + \phi_B \otimes T^{(i)}_a \otimes \phi_{a,K^*} + O(\Lambda/m_b)$

– Separation of perturbative hard kernels from process-independent nonperturbative functions like form factors

– Relations between formfactors in large-energy limit

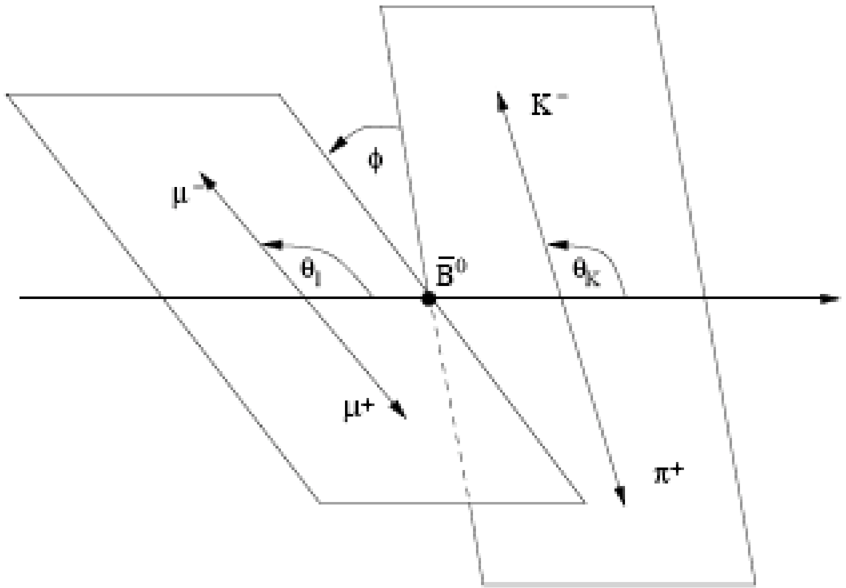
– Limitation: insufficient information on power-suppressed Λ/m_b terms (breakdown of factorization: 'endpoint divergences')

Phenomenologically highly relevant issue

general strategy of LHCb to look at ratios of exclusive modes

Angular analysis of $B \to K^* \ell^+ \ell^-$

Assuming the $\bar{K}^*$ to be on the mass shell, the decay $\bar{B}^0 \to \bar{K}^{*0}(\to K^- \pi^+)\ell^+\ell^-$ described by the lepton-pair invariant mass, s, and the three angles θ_l, θ_{K^*}, ϕ.



After summing over the spins of the final particles:

$$\frac{d^4\Gamma_{\overline{B}_d}}{dq^2\, d\theta_l\, d\theta_K\, d\phi} = \frac{9}{32\pi} I(q^2, \theta_l, \theta_K, \phi) \sin\theta_l \sin\theta_K$$

$$I = I_1 + I_2 \cos 2\theta_l + I_3 \sin^2\theta_l \cos 2\phi + I_4 \sin 2\theta_l \cos\phi + I_5 \sin\theta_l \cos\phi + I_6 \cos\theta_l$$
$$+ I_7 \sin\theta_l \sin\phi + I_8 \sin 2\theta_l \sin\phi + I_9 \sin^2\theta_l \sin 2\phi.$$

LHCb statistics ($10\, fb^{-1}$, $\succ 2\, fb^{-1}$) allows for a full angular fit!

K^* spin amplitudes in the heavy quark and large energy limit

$$A_{\perp,\parallel} = (H_{+1} \mp H_{-1})/\sqrt{2}, \quad A_0 = H_0$$

$$A_{\perp L,R} = N\sqrt{2}\lambda^{1/2}\left[(C_9^{\rm eff} \mp C_{10})\frac{V(s)}{m_B + m_{K^*}} + \frac{2m_b}{s}(C_7^{\rm eff} + C_7^{\rm eff\prime})T_1(s)\right]$$

$$A_{\parallel L,R} = -N\sqrt{2}(m_B^2 - m_{K^*}^2)\left[(C_9^{\rm eff} \mp C_{10})\frac{A_1(s)}{m_B - m_{K^*}} + \frac{2m_b}{s}(C_7^{\rm eff} - C_7^{\rm eff\prime})T_2(s)\right]$$

$$A_{0L,R} = -\frac{N}{2m_{K^*}\sqrt{s}}\left[(C_9^{\rm eff} \mp C_{10})\left\{(m_B^2 - m_{K^*}^2 - s)(m_B + m_{K^*})A_1(s) - \lambda\frac{A_2(s)}{m_B + m_{K^*}}\right\}\right.$$
$$\left. + 2m_b(C_7^{\rm eff} - C_7^{\rm eff\prime})\left\{(m_B^2 + 3m_{K^*}^2 - s)T_2(s) - \frac{\lambda}{m_B^2 - m_{K^*}^2}T_3(s)\right\}\right]$$

$$A_{\perp L,R} = +\sqrt{2}Nm_B(1-\hat{s})\left[(C_9^{\rm eff} \mp C_{10}) + \frac{2\hat{m}_b}{\hat{s}}(C_7^{\rm eff} + C_7^{\rm eff\prime})\right]\xi_\perp(E_{K^*})$$

$$A_{\parallel L,R} = -\sqrt{2}Nm_B(1-\hat{s})\left[(C_9^{\rm eff} \mp C_{10}) + \frac{2\hat{m}_b}{\hat{s}}(C_7^{\rm eff} - C_7^{\rm eff\prime})\right]\xi_\perp(E_{K^*})$$

$$A_{0L,R} = -\frac{Nm_B}{2\hat{m}_{K^*}\sqrt{\hat{s}}}(1-\hat{s})^2\left[(C_9^{\rm eff} \mp C_{10}) + 2\hat{m}_b(C_7^{\rm eff} - C_7^{\rm eff\prime})\right]\xi_\parallel(E_{K^*})$$

Careful design of observables

- Good sensitivity to NP contribitions, i.e. to $C_7^{eff'}$
- Small theoretical uncertainties
  - Dependence of soft form factors, $\xi_\perp$ and $\xi_\|$, to be minimized !
    form factors should cancel out exactly at LO, best for all s
  - unknown Λ/m_b power corrections
    $A_{\perp,\|,0} = A^0_{\perp,\|,0}\left(1 + c_{\perp,\|,0}\right)$ vary c_i in a range of ±10% and also of ±5%
  - Scale dependence of NLO result
  - Input parameters
- Good experimental resolution

New observables

$$A_T^{(2)} = \frac{|A_\perp|^2 - |A_\||^2}{|A_\perp|^2 + |A_\||^2} \qquad A_T^{(3)} = \frac{|A_{0L}A^*_{\|L} + A^*_{0R}A_{\|R}|}{\sqrt{|A_0|^2|A_\perp|^2}}$$

$$A_T^{(4)} = \frac{|A_{0L}A^*_{\perp L} - A^*_{0R}A_{\perp R}|}{|A^*_{0L}A_{\|L} + A_{0R}A^*_{\|R}|}$$

Next step: design of observables sensitive to other new physics operators

(see also Buras et al. 2008)

Phenomenological analysis

Analysis of SM and models with additional right handed currents ($C_7^{eff'}$)

Specific model:

MSSM with non-minimal flavour violation in the down squark sector

4 benchmark points

Diagonal: $\mu = M_1 = M_2 = M_{H^+} = m_{\tilde{u}_R} = 1$ TeV $\tan\beta = 5$

- Scenario A: $m_{\tilde{g}} = 1$ TeV and $m_{\tilde{d}} \in [200, 1000]$ GeV

  $-0.1 \leq (\delta^d_{LR})_{32} \leq 0.1$

  a) $m_{\tilde{g}}/m_{\tilde{d}} = 2.5$, $(\delta^d_{LR})_{32} = 0.016$

  b) $m_{\tilde{g}}/m_{\tilde{d}} = 4$, $(\delta^d_{LR})_{32} = 0.036$.

- Scenario B: $m_{\tilde{d}} = 1$ TeV and $m_{\tilde{g}} \in [200, 800]$ GeV

  mass insertion as in Scenario A.

  c) $m_{\tilde{g}}/m_{\tilde{d}} = 0.7$, $(\delta^d_{LR})_{32} = -0.004$

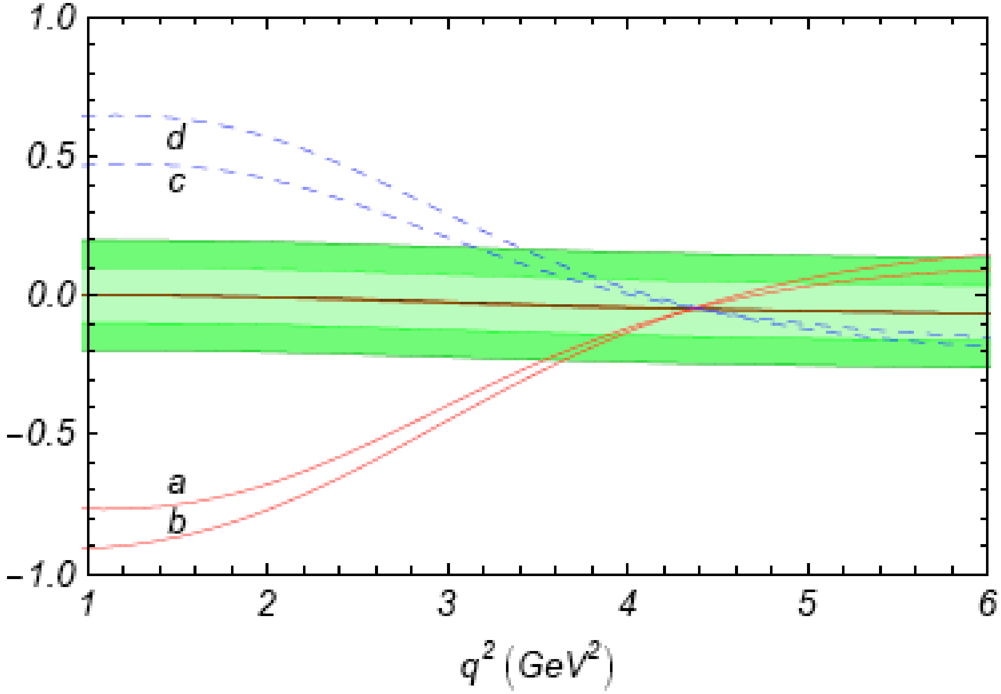
  d) $m_{\tilde{g}}/m_{\tilde{d}} = 0.6$, $(\delta^d_{LR})_{32} = -0.006$.

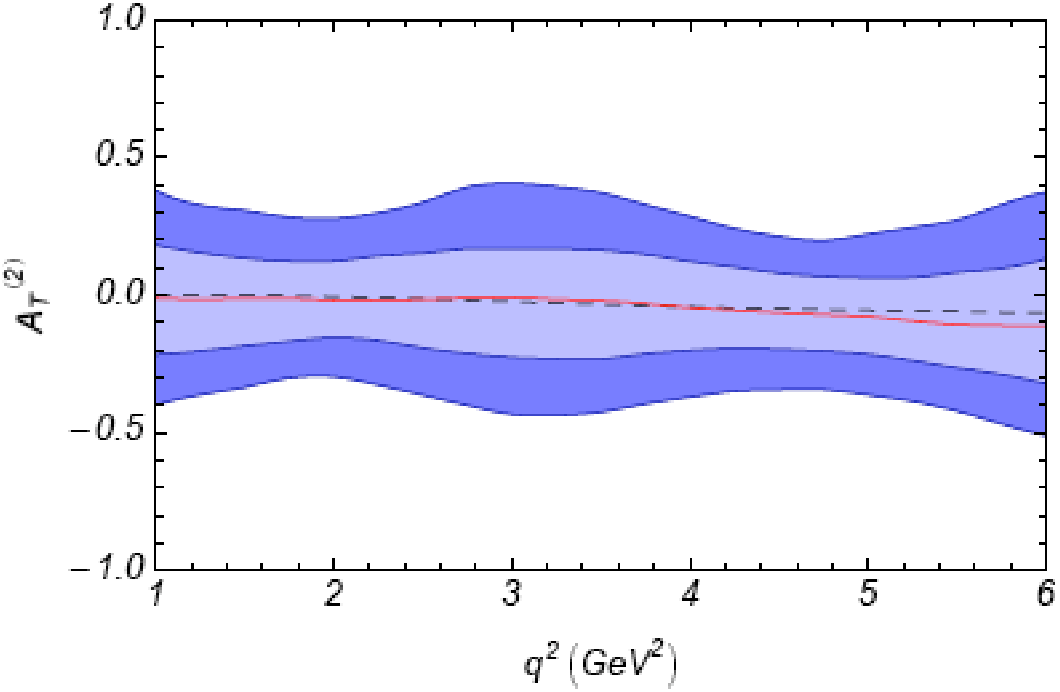
Check of compatibility with other constraints (B physics,ρ parameter,

Higgs mass, particle searches, vacuum stability constraints

Results

$$A_T^{(2)} = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}$$





Theoretical sensitivity

light green $\pm 5\% \Lambda/m_b$

dark green $\pm 10\% \Lambda/m_b$

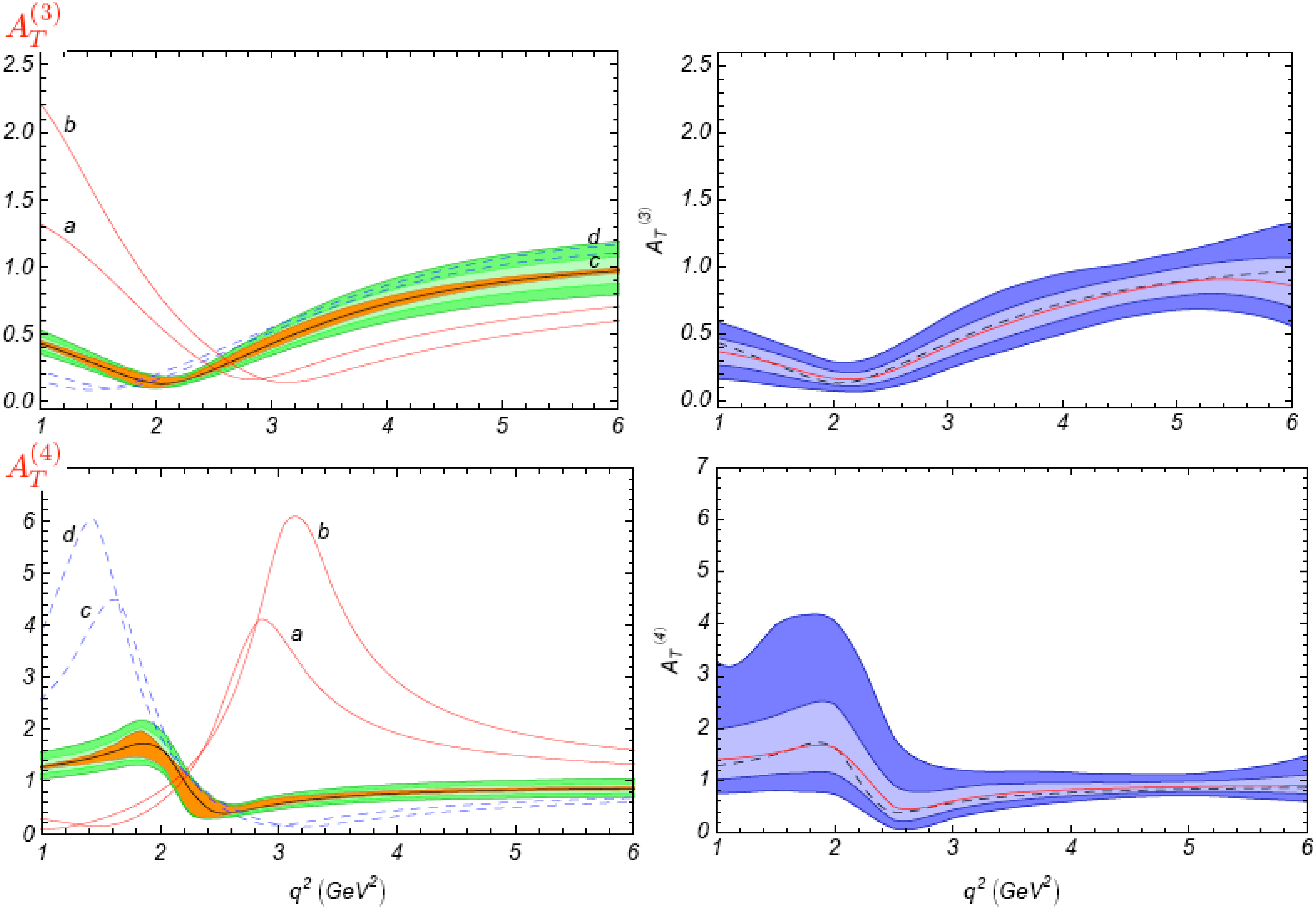
Experimental sensitivity $(10 fb^{-1})$

light green 1 σ

dark green 2 σ

Remark: SuperLHCB/SuperB can offer more precision

Crucial: theoretical status of Λ/m_b corrections has to be improved



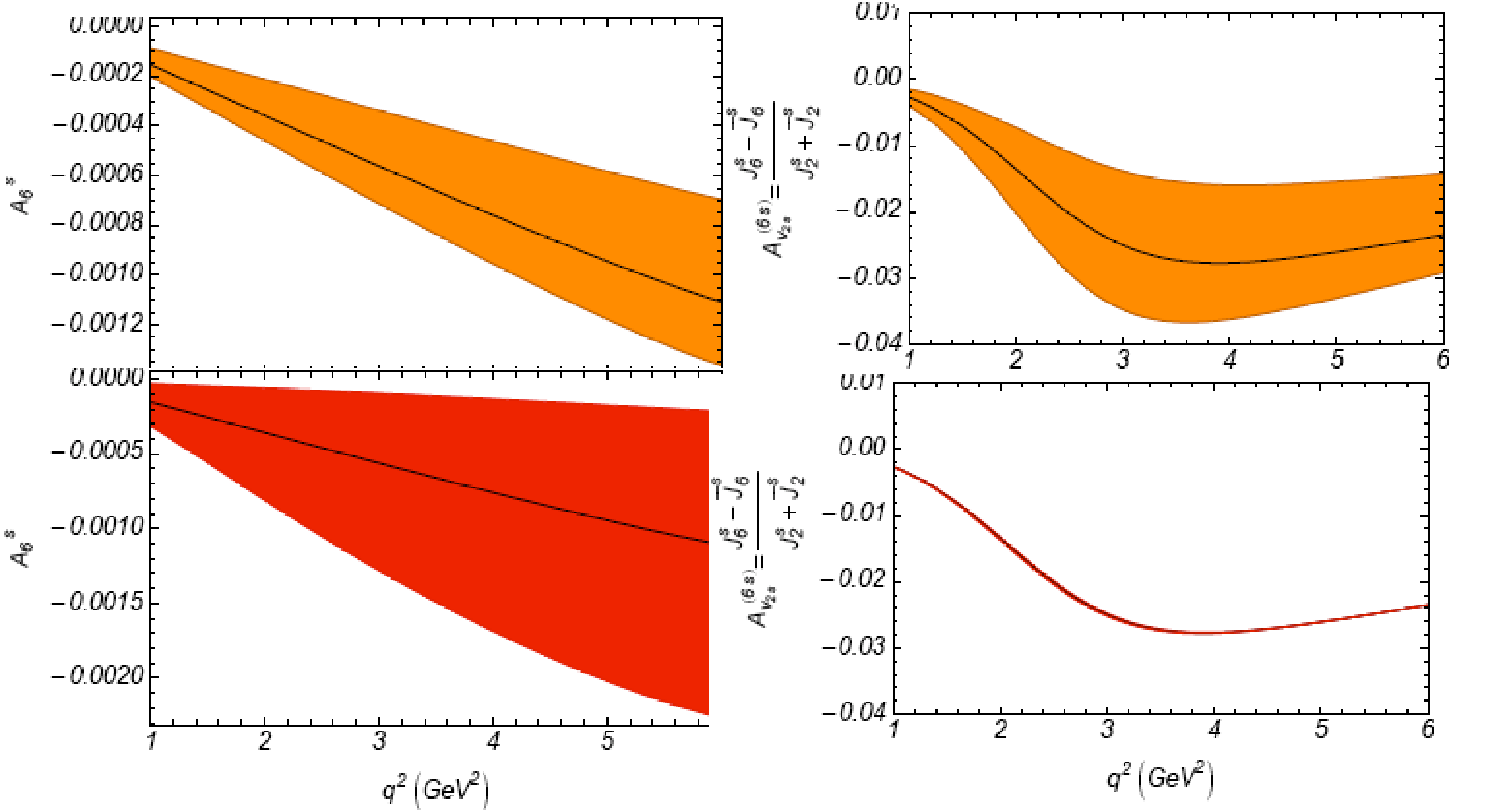
$A_T^{(3)}$
b
a
d
c
$A_T^{(3)}$
$A_T^{(4)}$
d
c
b
a
$A_T^{(4)}$
q^2 (GeV^2)
q^2 (GeV^2)

CP violating observables

- Angular distributions allow for the measurement of 7 CP asymmetries
  (Krüger,Seghal,Sinha^2 2000,2005)
- NLO (α_s) corrections included: scale uncertainties reduced
  (however, some CP asymmetries start at NLO only)
  (Bobeth,Hiller,Piranishvili 2008)
- New CP-violating phases in C_{10},$C_{10}^{'}$, C_9, and $C_9^{'}$ are by now NOT very much constrained and enhance the CP-violating observables drastically
  (Bobeth,Hiller,Piranishvili 2008; Buras et al. 2008)
- New physics reach of CP-violating observables of the angular distributions depends on the theoretical and experimental uncertainties:
  - soft/QCD formfactors
  - other input parameters
  - scale dependences
  - Λ/m_b corrections
  - experimental sensitivity in the full angular fit

Appropriate normalization eliminates uncertainties due to formfactors

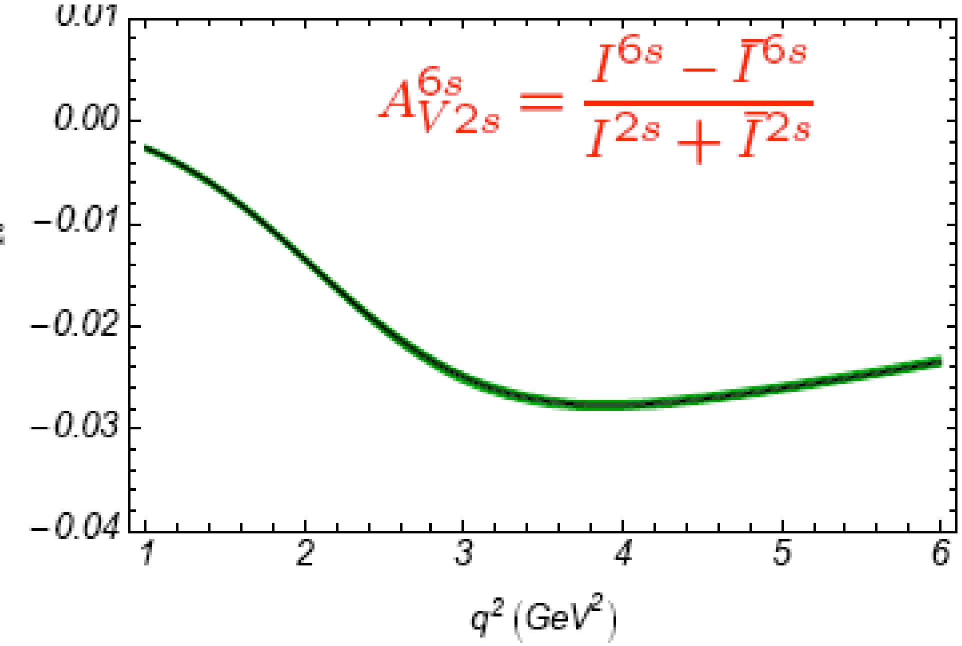
$$A^{6s} = \frac{I^{6s} - \bar{I}^{6s}}{d(\Gamma + \bar{\Gamma})/dq^2} \qquad A^{6s}_{V2s} = \frac{I^{6s} - \bar{I}^{6s}}{I^{2s} + \bar{I}^{2s}}$$

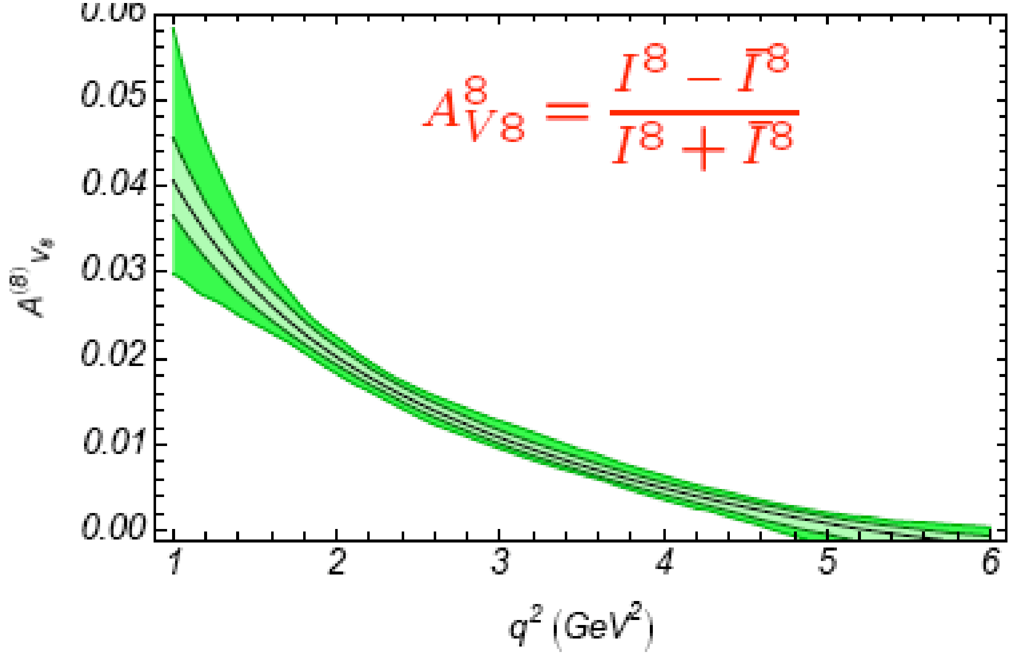


Orange bands: scale/input uncertainty including formfactors

Red bands: conservative estimate of uncertainty due to formfactors only

Λ/m_b corrections very small due to small weak SM phase





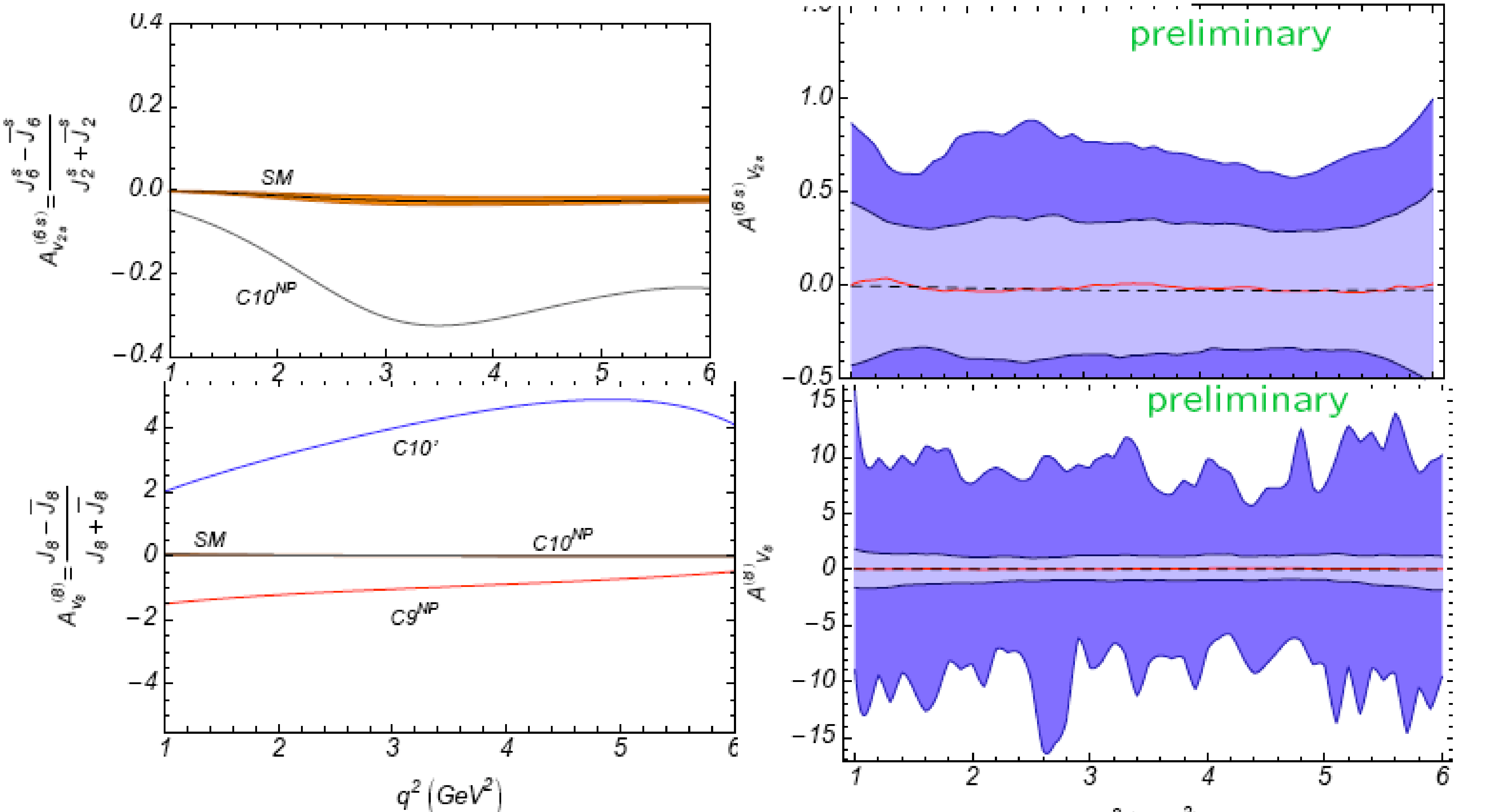
Uncertainty due Λ/m_b corrections significantly smaller than error due to input parameters

Ansatz with random strong phases $\Phi_{1/2}$ and $C_{1/2}$ with 5% and 10%

$$A = A_1(1 + C_1 e^{i\phi_1}) + e^{i\theta} A_2(1 + C_2 e^{i\phi_2})$$

Will be significantly larger in scenarios with large new physics phases

Possible new physics effects versus experimental uncertainties



$|C_{9,NP}| = 2, \Phi_9 = \pi/8; |C_{10}, NP| = 1.5, \Phi_{10} = \pi/8; |C'_{10}| = 2, \Phi_{10'} = \pi/8$

New physics not outside the experimental 2σ range.

However, all phases ($0 \to 2\pi$) are compatible with the present data

In contrast to observables like A_T^i, CP observables call for Super-LHCb

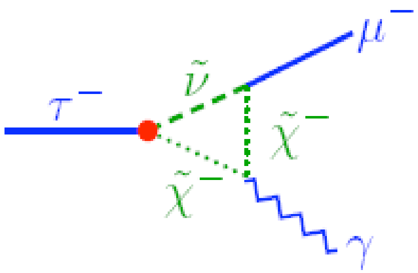
Opportunities at a Super Flavour Factory

see JHEP 0802 (2008) 110, arXiv:0710.379

Measurement of lepton flavour violation

$\tau \rightarrow \mu\gamma$ and $\rightarrow 3\mu$

$\mathrm{BR}(l_j^- \rightarrow l_i^- \gamma)|_{\mathrm{SM}_R} \approx (m_\nu/M_W)^2 \sim \mathcal{O}(10^{-54})$



Process	Expected 90%CL upper limited	4σ Discovery Reach
$\mathcal{B}(\tau \rightarrow \mu\gamma)$	2×10^{-9}	5×10^{-9}
$\mathcal{B}(\tau \rightarrow \mu\mu\mu)$	2×10^{-10}	8.8×10^{-10}

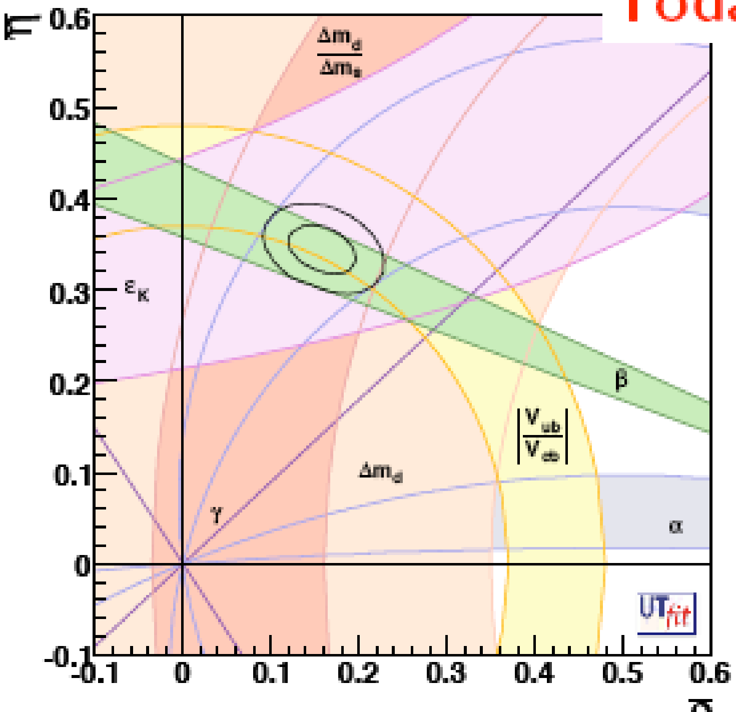
Use modes to distinguish SUSY vs LHT

Blanke et al.

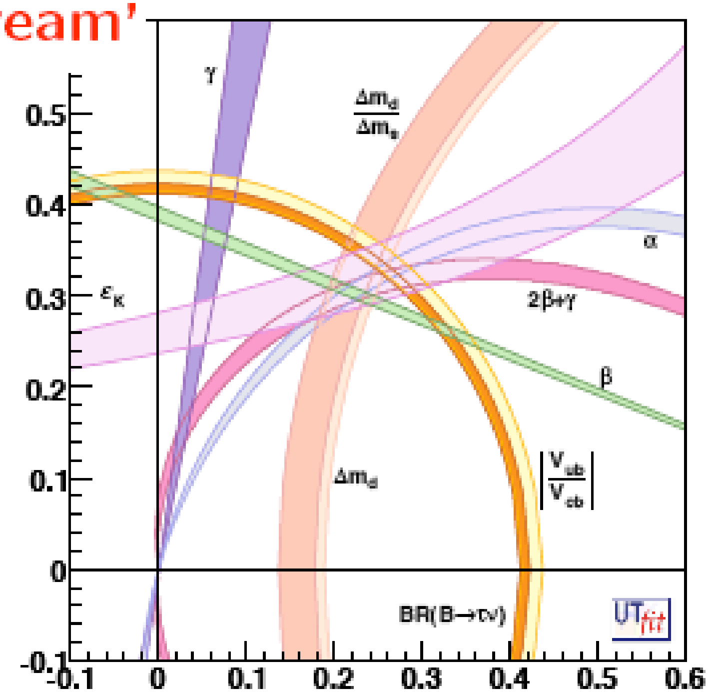
ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{\mathcal{B}(\tau^- \rightarrow e^- e^+ e^-)}{\mathcal{B}(\tau \rightarrow e\gamma)}$	$0.4 \ldots 2.3$	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$
$\frac{\mathcal{B}(\tau^- \rightarrow \mu^- \mu^+ \mu^-)}{\mathcal{B}(\tau \rightarrow \mu\gamma)}$	$0.4 \ldots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

Superflavour factory: CKM theory gets tested at 1%

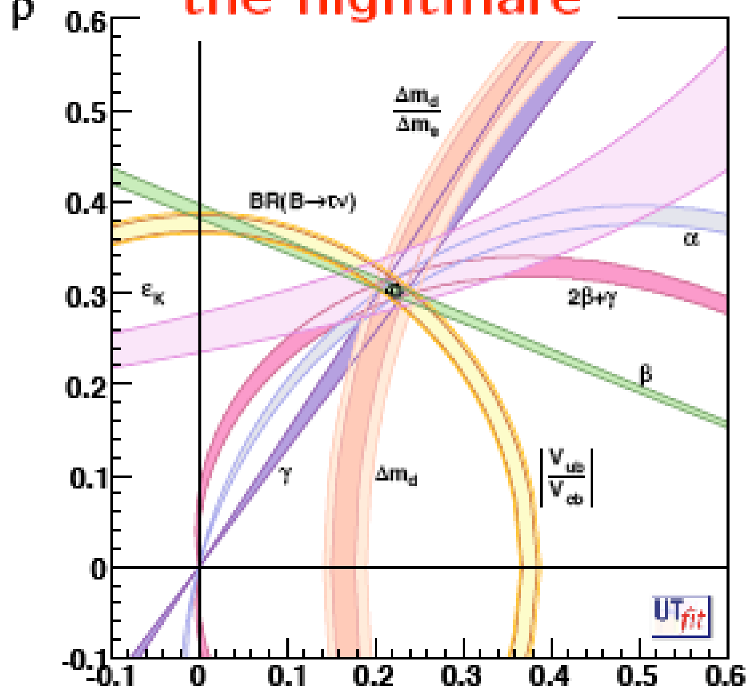
Today



'the dream'



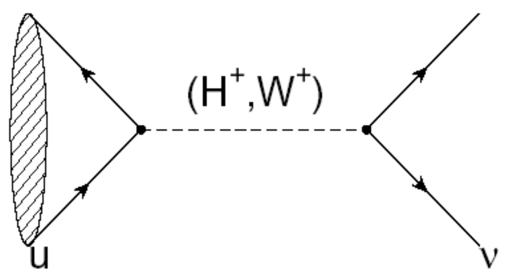
'the nightmare'



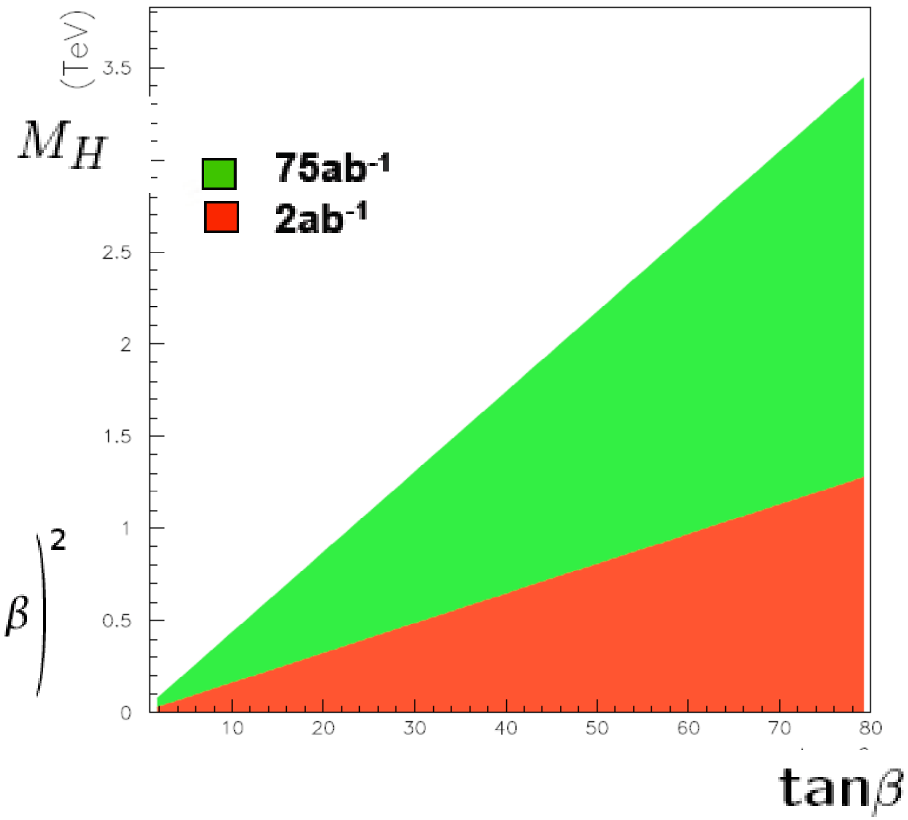
Superflavour factory: measurement of clean modes

$B \to \tau\nu$: B factories 20% Super B factories 4%

2HDM-II



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



(Assuming SM branching fraction is measured)

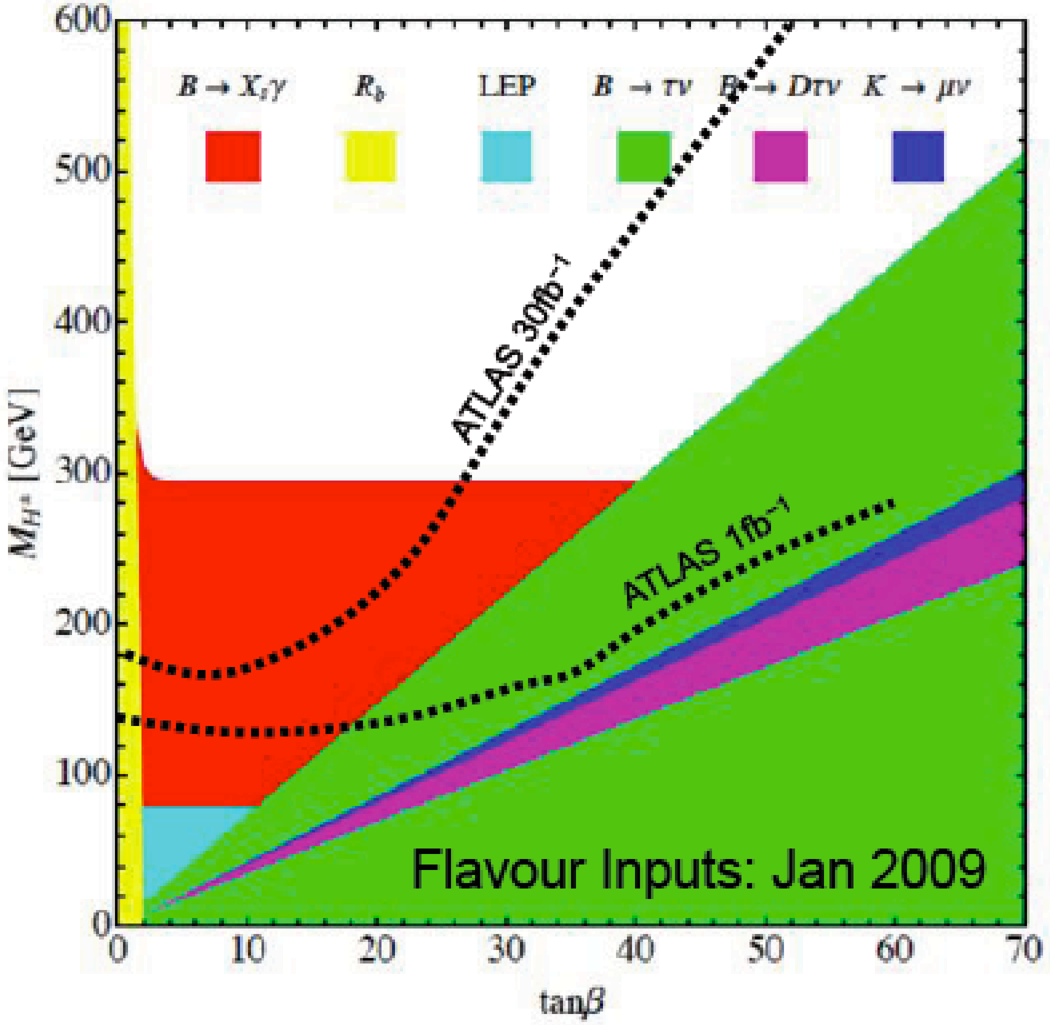
Two final remarks:

- **Experimental evidence beyond SM:**
  - Dark matter (visible matter accounts for only 4% of the Universe)
  - Neutrino masses (Dirac or Majorana masses ?)
  - Baryon asymmetry of the Universe (new sources of CP violation needed)

At least two of them have to do with flavour !

- LHC versus Flavour constraints

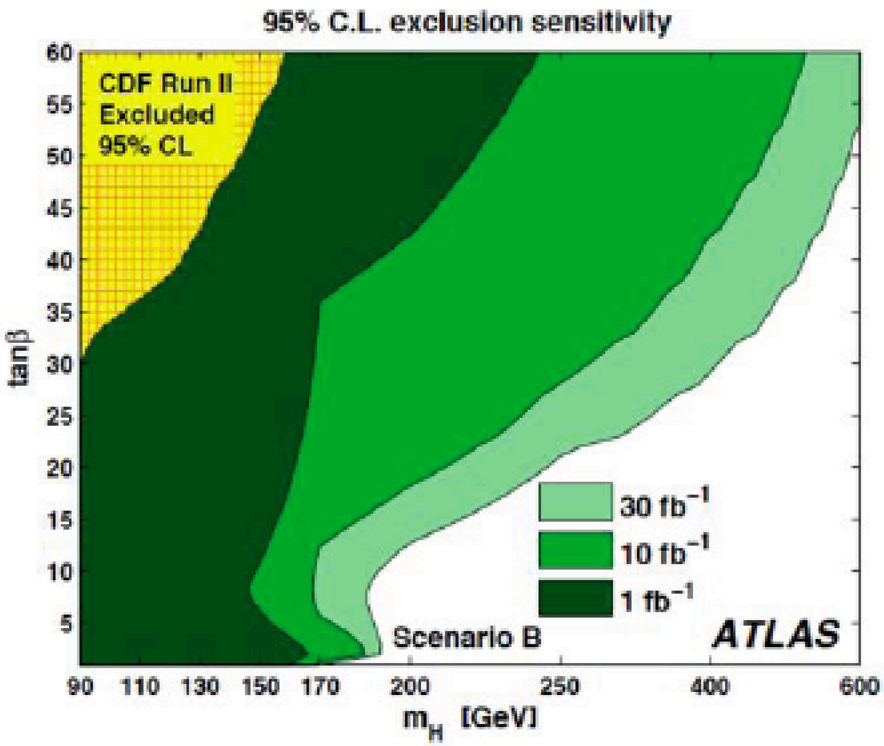
Combined Higgs search constraint from ATLAS: arXiv:0901.1502



U. Haisch 0805.2141

2HDM at FPCP 2008)

Converted constraints expected from ATLAS onto the plot by hand.



Courtesy of Adrian Bevan