Flavour physics as a probe of SUSY scenarios and interplay with the LHC results

Nazila Mahmoudi

CERN TH & LPC Clermont-Ferrand (France)

Planck 2011 - Lisbon, 31 May 2011

Introduction

- We know that going beyond the SM is a necessity.
- Good point: The LHC is running and we hope that we will find something new!
- BUT: Many theoretical models beyond the SM, within reach of the LHC, in the market.

$\Rightarrow$ Need for additional information and constraints.

The most used constraints:

- Electroweak precision tests
- The anomalous magnetic moment of the muon $(g-2)_\mu$
- Flavour Physics
- Cosmological constraints, in particular from the dark matter relic density

Introduction

- We know that going beyond the SM is a necessity.
- Good point: The LHC is running and we hope that we will find something new!
- BUT: Many theoretical models beyond the SM, within reach of the LHC, in the market.

$\Rightarrow$ Need for additional information and constraints.

The most used constraints:

- Electroweak precision tests
- The anomalous magnetic moment of the muon $(g-2)_\mu$
- Flavour Physics
- Cosmological constraints, in particular from the dark matter relic density

Introduction

- We know that going beyond the SM is a necessity.
- Good point: The LHC is running and we hope that we will find something new!
- BUT: Many theoretical models beyond the SM, within reach of the LHC, in the market.

$\Rightarrow$ Need for additional information and constraints.

The most used constraints:

- Electroweak precision tests
- The anomalous magnetic moment of the muon $(g-2)_\mu$
- Flavour Physics
- Cosmological constraints, in particular from the dark matter relic density

Motivations

Flavour Physics

- sensitive to new physics effects
- complementary to other searches
- probes sectors inaccessible to direct searches
- tests quantum structure of the SM at loop level
- constrains parameter spaces of new physics scenarios
- valuable data already available
- promising experimental situation
- consistency checks with direct observations

In R-parity conserving models, SUSY effects appear:

- in the sparticle loops
  $\rightarrow$ radiative and electroweak penguins

- in the charged Higgs mediated tree level decays
  $\rightarrow$ leptonic and semileptonic decays

Flavour Observables

I) Radiative penguin decays

- inclusive branching ratio of $B \to X_s \gamma$
- isospin asymmetry of $B \to K^* \gamma$

II) Electroweak penguin decays

- branching ratio of $B_s \to \mu^+ \mu^-$
- inclusive branching ratio of $B \to X_s \ell^+ \ell^-$
- branching ratio of $B \to K^* \mu^+ \mu^-$

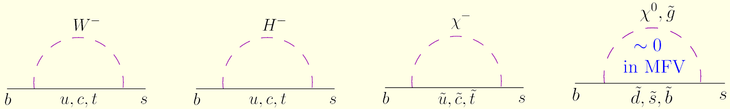
III) Neutrino modes

- branching ratio of $B \to \tau\nu$
- branching ratio of $B \to D\tau\nu$
- branching ratios of $D_s \to \tau\nu/\mu\nu$
- branching ratio of $K \to \mu\nu$
- double ratios of leptonic decays

I) Radiative penguin decays: Inclusive Branching ratio of $B \to X_s\gamma$

Effective Hamiltonian: $\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum C_i(\mu)\mathcal{O}_i(\mu)$

Important operators: $\mathcal{O}_7 = \frac{e}{(4\pi)^2} m_b (\bar{s}_L \sigma^{\mu\nu} b_R) F_{\mu\nu}$ $\quad \mathcal{O}_8 = \frac{g}{(4\pi)^2} m_b (\bar{s}_L \sigma^{\mu\nu} T^a b_R) G^a_{\mu\nu}$



$$\mathcal{B}[\bar{B} \to X_s\gamma]_{E_\gamma > E_0} = \mathcal{B}[\bar{B} \to X_c e\bar{\nu}]_{\rm exp} \left|\frac{V_{ts}^* V_{tb}}{V_{cb}}\right|^2 \frac{6\alpha_{\rm em}}{\pi C} [P(E_0) + N(E_0)]$$

$$\begin{aligned} P(E_0) &= P^{(0)}(\mu_b) + \alpha_s(\mu_b)\left[P_1^{(1)}(\mu_b) + P_2^{(1)}(E_0,\mu_b)\right] \\ &+ \alpha_s^2(\mu_b)\left[P_1^{(2)}(\mu_b) + P_2^{(2)}(E_0,\mu_b) + P_3^{(2)}(E_0,\mu_b)\right] + \mathcal{O}\left(\alpha_s^3(\mu_b)\right) \end{aligned}$$

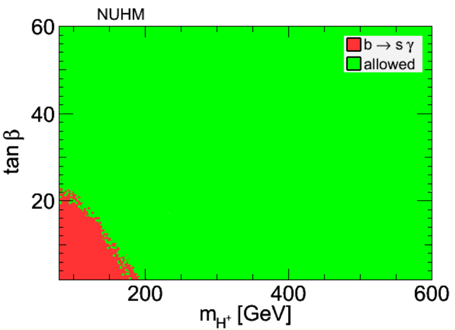
$$\left\{ \begin{aligned} P^{(0)}(\mu_b) &= \left(C_7^{(0)\rm eff}(\mu_b)\right)^2 \\ P_1^{(1)}(\mu_b) &= 2C_7^{(0)\rm eff}(\mu_b) C_7^{(1)\rm eff}(\mu_b) \\ P_1^{(2)}(\mu_b) &= \left(C_7^{(1)\rm eff}(\mu_b)\right)^2 + 2C_7^{(0)\rm eff}(\mu_b) C_7^{(2)\rm eff}(\mu_b) \end{aligned} \right.$$

M. Misiak et al., Phys. Rev. Lett. 98 (2007)

I) Radiative penguin decays: Inclusive Branching ratio of $B \to X_s\gamma$

- Theoretical values for the SM:
  NNLO (Misiak & Steihauser '07): $\mathcal{B}[\bar{B} \to X_s\gamma] = (3.15 \pm 0.23) \times 10^{-4}$
  or (Becher & Neubert '07): $\mathcal{B}[\bar{B} \to X_s\gamma] = (2.98 \pm 0.26) \times 10^{-4}$
  or (Gambino & Giordano '08): $\mathcal{B}[\bar{B} \to X_s\gamma] = (3.30 \pm 0.24) \times 10^{-4}$

- Experimental values:
  HFAG 2010: $\mathcal{B}[\bar{B} \to X_s\gamma] = (3.55 \pm 0.25) \times 10^{-4}$



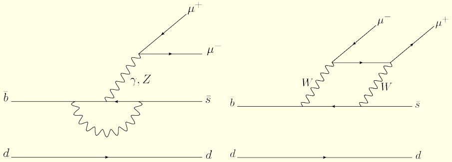
II) Electroweak penguin decays: $b \to s\ell\ell$ transitions

Effective Hamiltonian:

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left(\sum C_i(\mu) \mathcal{O}_i(\mu) + \sum C_{Q_i}(\mu) Q_i(\mu) \right)$$

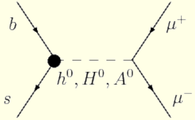
Important operators:

$$\mathcal{O}_9 = \frac{e^2}{(4\pi)^2} (\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu \ell)$$
$$\mathcal{O}_{10} = \frac{e^2}{(4\pi)^2} (\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu \gamma_5 \ell)$$
$$Q_1 = \frac{e^2}{16\pi^2} (\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\,\ell)$$
$$Q_2 = \frac{e^2}{16\pi^2} (\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\gamma_5 \ell)$$



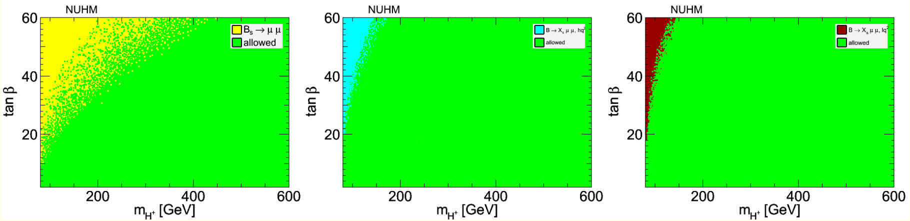
Very sensitive to new physics, especially for large tan β:

SUSY contributions in $\mathcal{B}(B_s \to \mu^+\mu^-)$ can lead to an O(100) enhancement over the SM!



$$\mathcal{B}(B_s \to \mu^+\mu^-)_{MSSM} \sim \frac{m_b^2 m_\mu^2 \tan^6 \beta}{M_A^4}$$

II) Electroweak penguin decays: $b \to s\ell\ell$ transitions



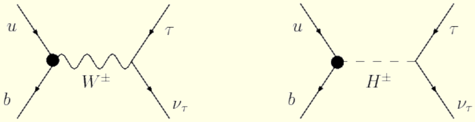
III) Neutrino modes

Tree level processes, mediated by W^+ and H^+, higher order corrections from sparticles

Advantage: very sensitive to the charged Higgs mass and its couplings to fermions

Drawback: uncertainties from hadronic decay constants and CKM matrix elements.

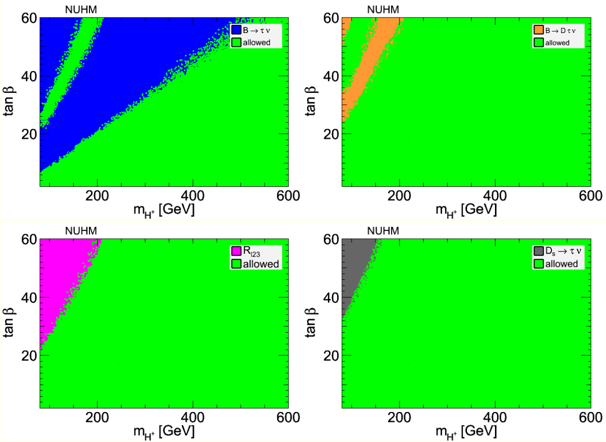
Typical example: branching ratio of $B \to \tau\nu$



$$\mathcal{B}(B \to \tau\nu) = \frac{G_F^2 |V_{ub}|^2}{8\pi} m_\tau^2 f_B^2 m_B \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 \left|1 - \left(\frac{m_B^2}{m_{H^+}^2}\right) \frac{\tan^2\beta}{1 + \epsilon_0 \tan\beta}\right|^2$$

$$\text{with: } \epsilon_0 = -\frac{2\alpha_s}{3\pi} \frac{\mu}{m_{\tilde{g}}} H_2\left(\frac{m_{\tilde{Q}}^2}{m_{\tilde{g}}{}^2}, \frac{m_{\tilde{D}}^2}{m_{\tilde{g}}{}^2}\right)$$

III) Neutrino modes



D. Eriksson, FM, O. Stål, JHEP 0811 (2008)

III) Neutrino modes: Double ratios of leptonic decays

For example:

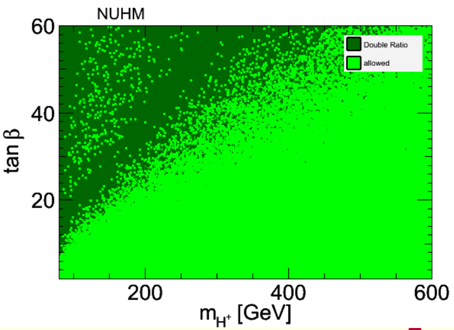
$$R = \left(\frac{\mathrm{BR}(B_s \to \mu^+ \mu^-)}{\mathrm{BR}(B_u \to \tau\nu)} \right) \Big/ \left(\frac{\mathrm{BR}(D_s \to \tau\nu)}{\mathrm{BR}(D \to \mu\nu)} \right)$$

From the form factor and CKM matrix point of view:

$$R \propto \frac{|V_{ts}V_{tb}|^2}{|V_{ub}|^2} \frac{(f_{B_s}/f_B)^2}{(f_{D_s}/f_D)^2} \qquad \text{with:} \qquad \frac{(f_{B_s}/f_B)}{(f_{D_s}/f_D)} \approx 1$$

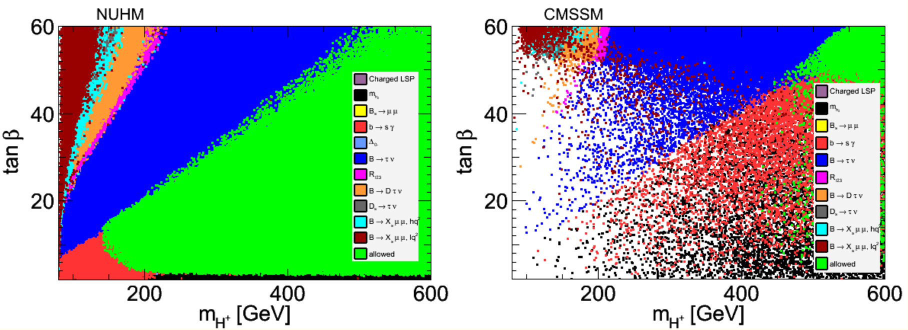
R has no dependence on the decay constants, contrary to each decay taken individually!

- No dependence on lattice quantities
- Interesting for V_{ub} determination
- Interesting for probing new physics
- Promising experimental situation



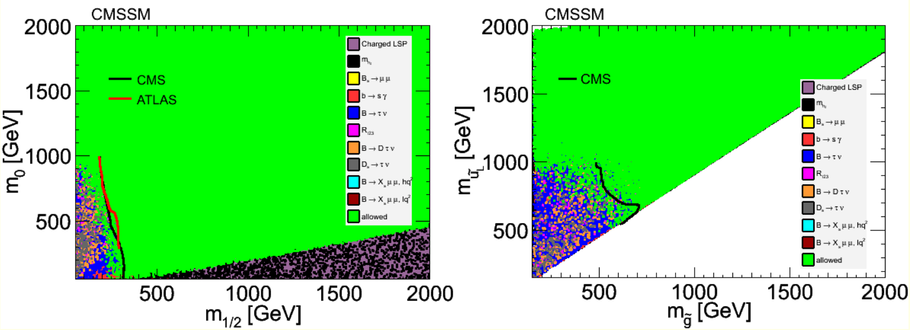
B. Grinstein, Phys. Rev. Lett. 71 (1993)
A.G. Akeroyd, FM, JHEP 1010 (2010)

Combined constraints



D. Eriksson, FM, O. Stål, JHEP 0811 (2008)

LHC and flavour observables

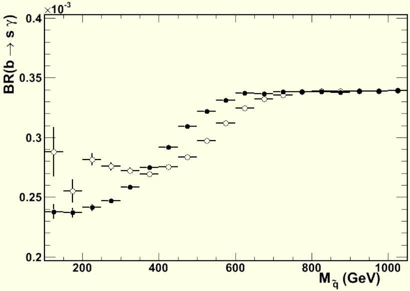


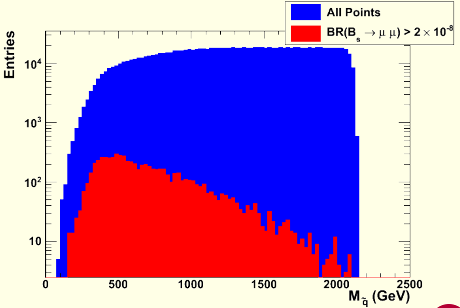
Phenomenological MSSM

Many studies have been performed within several constrained SUSY models (CMSSM, mSUGRA, NUHM, ...). How do their conclusions change when moving to the MSSM?

Extended MSSM scan: 14 parameters scan (assuming unified squark masses)

Two-phase program:
1) perform MSSM scans, study effects of different codes, define and apply constraints, ...
2) interface to experimental analyses, determine observability of selected points, ...





Work in progress, with Marco Battaglia and Alexandre Arbey.

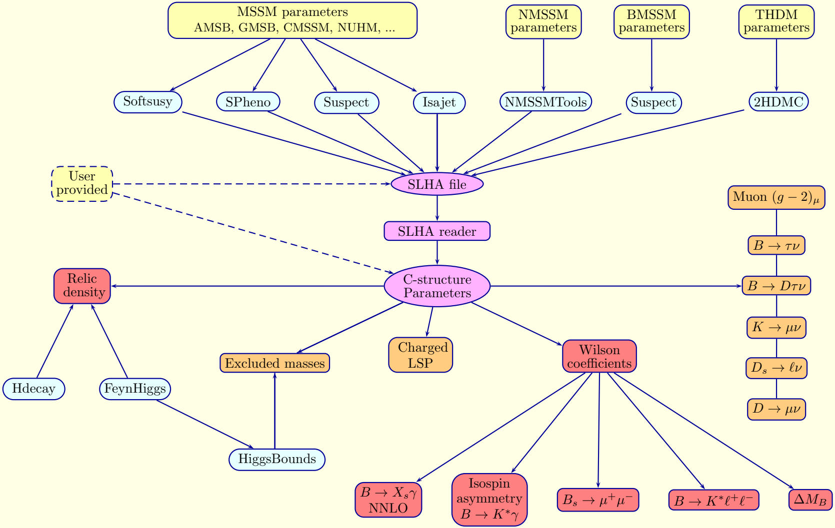
SuperIso

SuperIso

- public C program
- dedicated to the flavour physics observable calculations
- various models implemented
- interfaced to several spectrum calculators
- modular program with a well-defined structure
- SuperIso Relic (with Alex Arbey): extension to the relic density calculation, featuring alternative cosmological scenarios
- complete reference manuals available

Webpage: http://superiso.in2p3.fr

SuperIso


MSSM parameters
AMSB, GMSB, CMSSM, NUHM, ...
NMSSM parameters
BMSSM parameters
THDM parameters
Softsusy
SPheno
Suspect
Isajet
NMSSMTools
Suspect
2HDMC
User provided
SLHA file
SLHA reader
C-structure Parameters
Relic density
Hdecay
FeynHiggs
HiggsBounds
Excluded masses
Charged LSP
Wilson coefficients
$B \to X_s\gamma$ NNLO
Isospin asymmetry $B \to K^*\gamma$
$B_s \to \mu^+\mu^-$
$B \to K^*\ell^+\ell^-$
ΔM_B
Muon $(g-2)_\mu$
$B \to \tau\nu$
$B \to D\tau\nu$
$K \to \mu\nu$
$D_s \to \ell\nu$
$D \to \mu\nu$

Flavour Les Houches Accord

The Flavour Les Houches Accord format

Standard format for flavour related quantities, providing:

- A model independent parametrization
- A standalone flavour output in the FLHA format
- Based on the existing SLHA structure
- A clear and well-defined structure for interfacing computational tools of "New Physics" models with low energy flavour calculations
- Allows different programs to talk and be interfaced, and users to have clear and well defined results that can eventually be used for different purposes

Involved people

F. Mahmoudi, S. Heinemeyer, A. Arbey, A. Bharucha, T. Goto, T. Hahn, U. Haisch, S. Kraml, M. Muhlleitner, J. Reuter, P. Skands, P. Slavich

For more information

- Les Houches write-up: arXiv:1003.1643 [hep-ph]
- Official write-up: arXiv:1008.0762 [hep-ph]

Conclusion

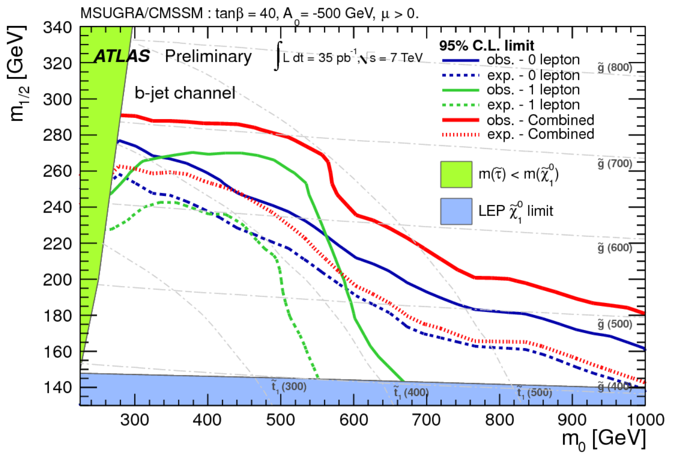
- Indirect constraints and in particular flavour physics are essential to restrict new physics parameters
- Important for consistency checks with collider data
- This kind of analysis can be generalized to more new physics scenarios, in particular beyond SUSY constrained scenarios

- We have learned a lot from flavour physics so far
- **But what is still to be discovered is more!**

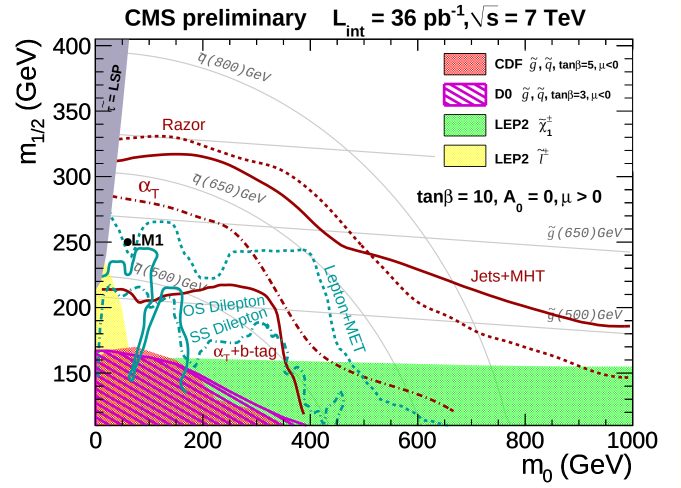
Backup

Backup

ATLAS contours



CMS contours



CMS contours