Flavour physics as a probe of SUSY scenarios

Farvah (Nazila) Mahmoudi

CERN TH & LPC Clermont-Ferrand (France)

IPP 2011 - Tehran, 7 September 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

Two Higgs Doublet Model (THDM)

Charged Higgs boson couplings to fermions:

$$H^+ D\bar{U}: \qquad \frac{ig}{2\sqrt{2}m_W} V_{UD} \left[\lambda^U m_U \left(1-\gamma^5\right) - \lambda^D m_D \left(1+\gamma^5\right)\right]$$

$$H^+ \ell^- \bar{\nu}_\ell: \qquad -\frac{ig}{2\sqrt{2}m_W} \lambda^\ell m_\ell \left(1+\gamma^5\right)$$

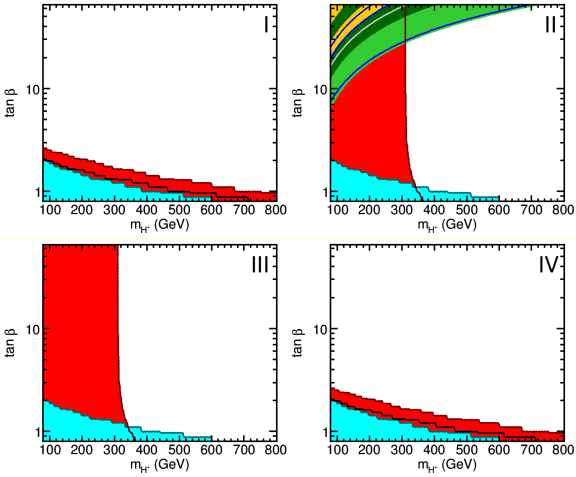
THDM types I–IV

- Type I: one Higgs doublet provides masses to all quarks (up and down type quarks) ($\sim$ SM)
- Type II: one Higgs doublet provides masses for up type quarks and the other for down-type quarks ($\sim$ MSSM)
- Type III,IV: different doublets provide masses for down type quarks and charged leptons

Type	λ_U	λ_D	λ_L
I	$\cot\beta$	$\cot\beta$	$\cot\beta$
II	$\cot\beta$	$-\tan\beta$	$-\tan\beta$
III	$\cot\beta$	$-\tan\beta$	$\cot\beta$
IV	$\cot\beta$	$\cot\beta$	$-\tan\beta$

THDM

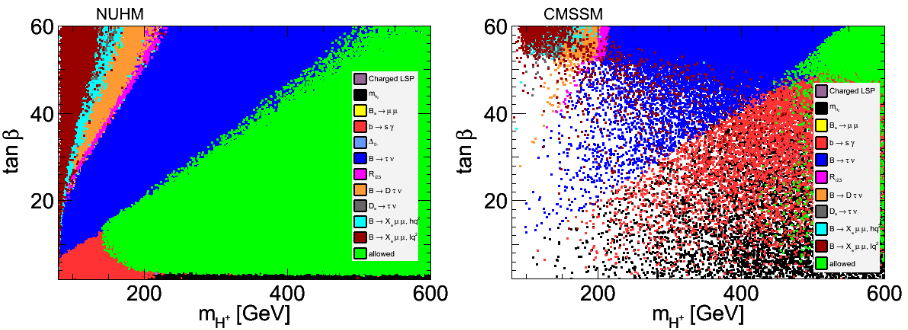
THDM (Types I–IV)



Red: $b \to s\gamma$
Cyan: ΔM_{B_d}
Blue: $B_u \to \tau\nu_\tau$
Yellow: $B \to D\ell\nu_\ell$
Gray: $K \to \mu\nu_\mu$
Green: $D_s \to \tau\nu_\tau$
Dark green: $D_s \to \mu\nu_\mu$

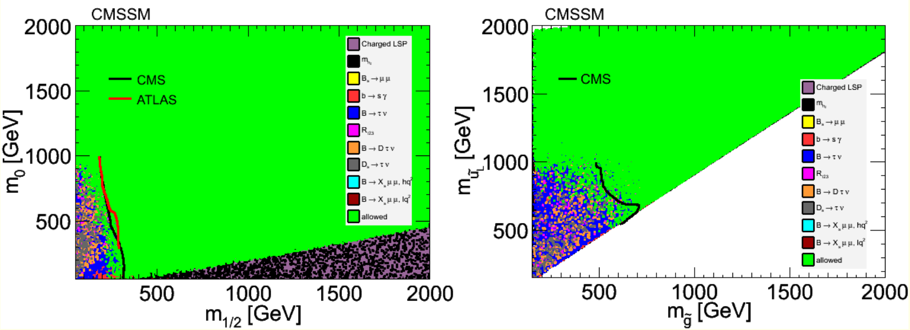
F. Mahmoudi & O. Stål, Phys. Rev. D81, 035016 (2010)

MSSM



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

LHC and flavour observables



Double ratios of leptonic decays

So far:

- Very interesting constraints from leptonic decays
- But large uncertainties due to decay constants
- Not very robust constraints on new physics

A way out is to define double ratios of purely 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:

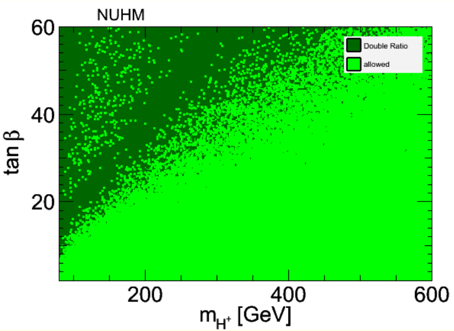
$$R \propto \frac{|V_{ts} V_{tb}|^2}{|V_{ub}|^2} \frac{(f_{B_s}/f_B)^2}{(f_{D_s}/f_D)^2} \qquad \text{with:} \qquad \frac{(f_{B_s}/f_B)}{(f_{D_s}/f_D)} \approx 1$$

B. Grinstein, Phys. Rev. Lett. 71 (1993)

A.G. Akeroyd, FM, JHEP 1010 (2010)

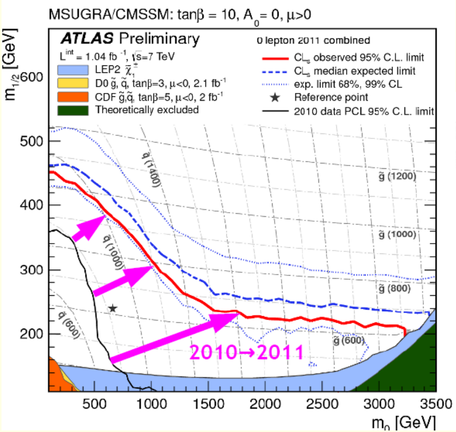
Double ratios of leptonic decays

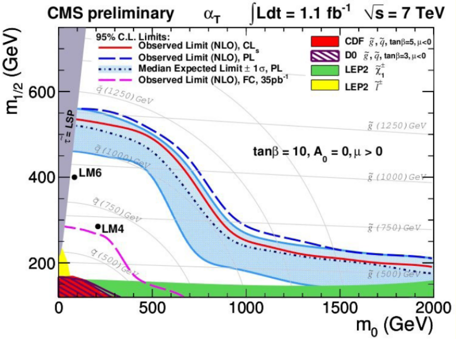
- No dependence on lattice quantities
- Interesting for V_{ub} determination
- Interesting for probing new physics
- Promising experimental situation



A.G. Akeroyd, FM, JHEP 1010 (2010)

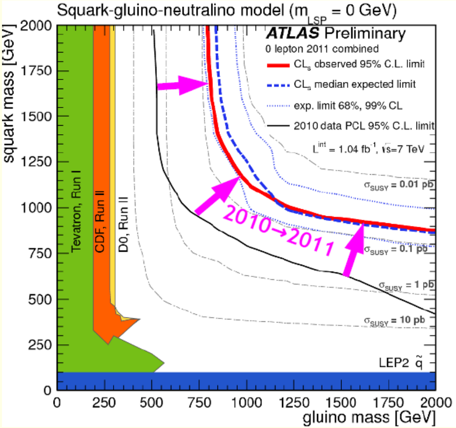
Latest ATLAS and CMS results on SUSY





Lepton Photon 2011

Latest ATLAS and CMS results on SUSY



Lepton Photon 2011

LHCb results on $B_s \to \mu^+\mu^-$

At present, the best upper limit for $\mathrm{BR}(B_s \to \mu^+\mu^-)$ measured in a single experiment comes from LHCb:

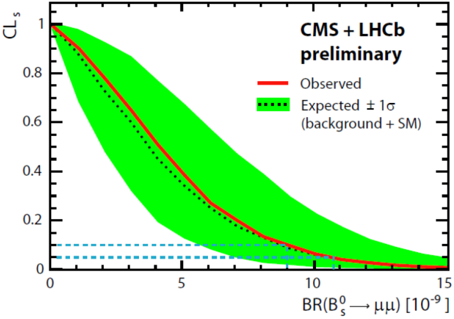
$$\mathrm{BR}(B_s \to \mu^+\mu^-) < 1.6 \times 10^{-8}$$

This is followed closely by the result from CMS:

$$\mathrm{BR}(B_s \to \mu^+\mu^-) < 1.9 \times 10^{-8}$$

These two results were officially combined for EPS 2011 conference:

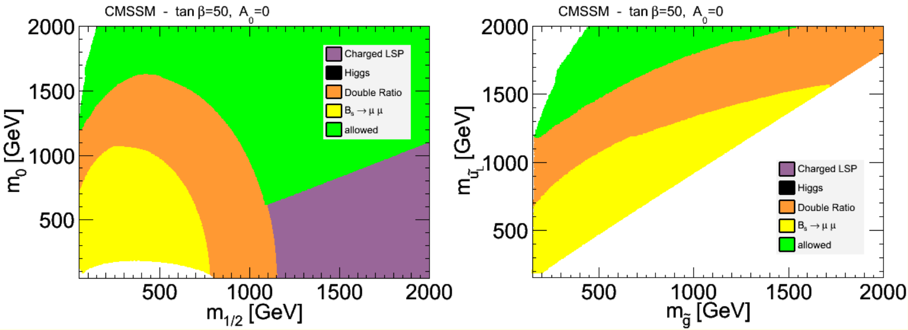
$$\mathrm{BR}(B_s \to \mu^+\mu^-) < 1.1 \times 10^{-8}$$



EPS 2011

New constraints from $B_s \to \mu^+\mu^-$

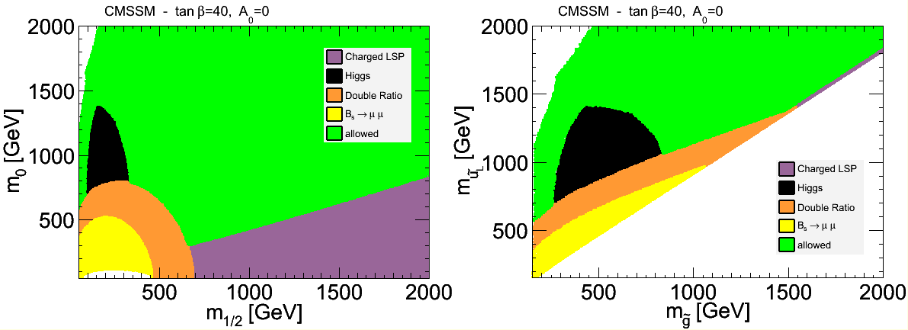
Impressive effect on the SUSY parameters!



A.G. Akeroyd, FM, D. Martinez Santos, arXiv:1108.3018

New constraints from $B_s \to \mu^+\mu^-$

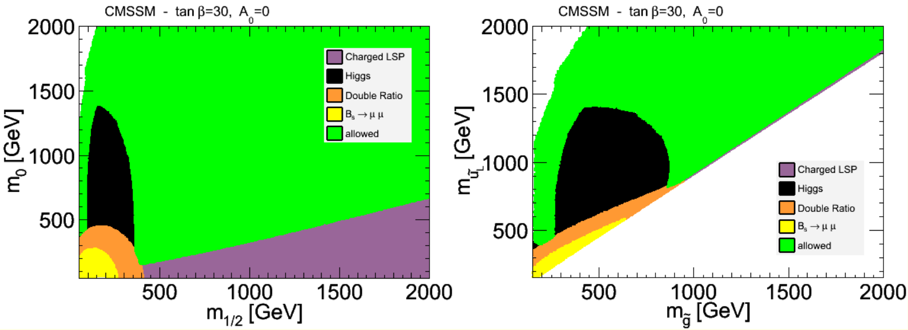
Impressive effect on the SUSY parameters!



A.G. Akeroyd, FM, D. Martinez Santos, arXiv:1108.3018

New constraints from $B_s \to \mu^+\mu^-$

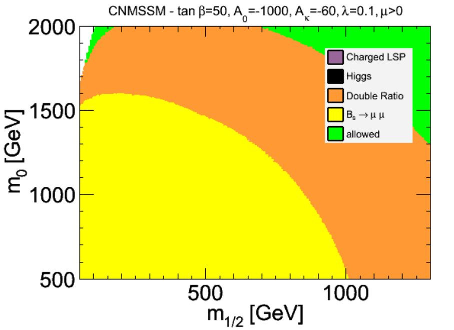
Impressive effect on the SUSY parameters!



A.G. Akeroyd, FM, D. Martinez Santos, arXiv:1108.3018

New LHCb results on $B_s \to \mu^+\mu^-$

Interesting constraints also for other SUSY scenarios.
For example, in the NMSSM:



Propaganda plot!

A.G. Akeroyd, FM, D. Martinez Santos, arXiv:1108.3018

Phenomenological MSSM (pMSSM)

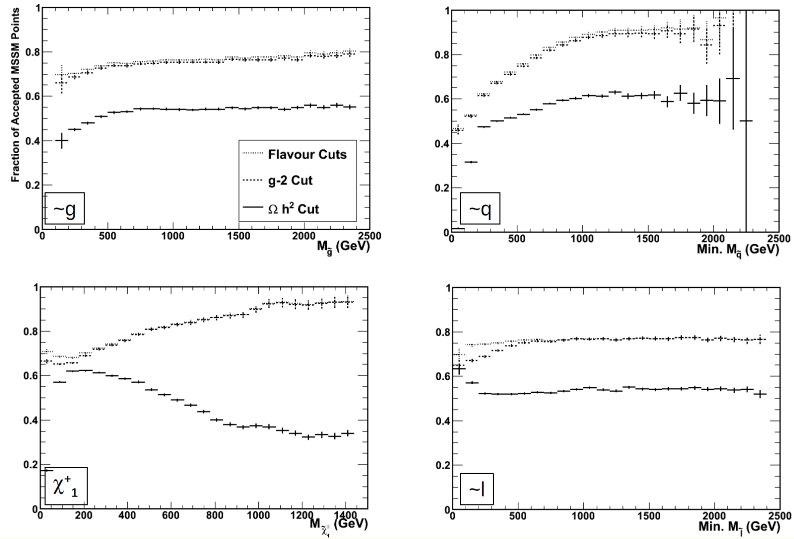
Many studies have been performed within several constrained SUSY models (CMSSM, NUHM, ...). How do their conclusions change when moving to the MSSM?

pMSSM: general MSSM with MFV and assuming that first and second sfermion generations are universal.

$\longrightarrow$ 19 free parameters

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, ...

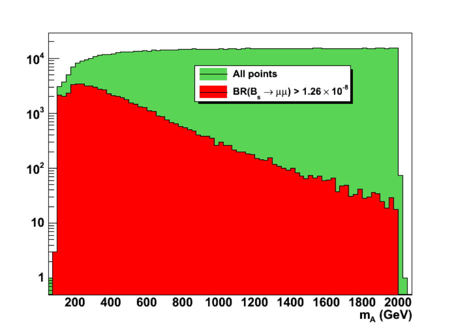
pMSSM



A. Arbey, M. Battaglia, FM, in preparation.

pMSSM

Constraints from $\mathrm{BR}(B_s \to \mu^+\mu^-)$



A. Arbey, M. Battaglia, FM, in preparation.

Model independent constraints

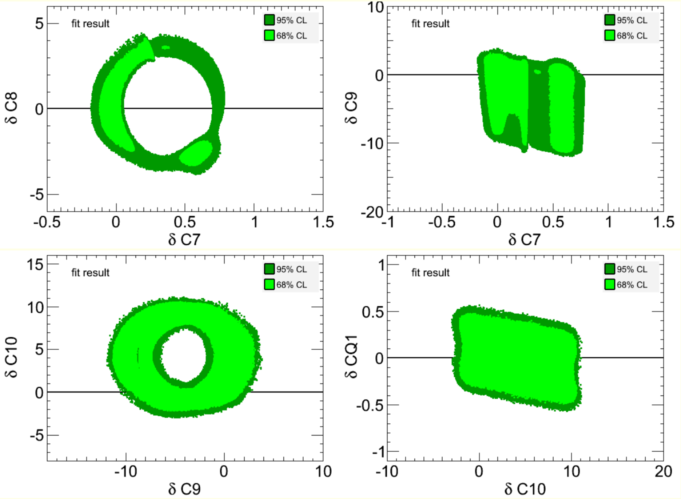
Putting constraints on the Wilson coefficients instead of model parameters.

Used observables:

- $b \to s\gamma$
- $B \to K^*\gamma$
- $B_s \to \mu^+\mu^-$
- $b \to s\mu^+\mu^-$

Fitting all the results by χ^2 minimization.

Model independent constraints



T. Hurth and FM, in preparation.

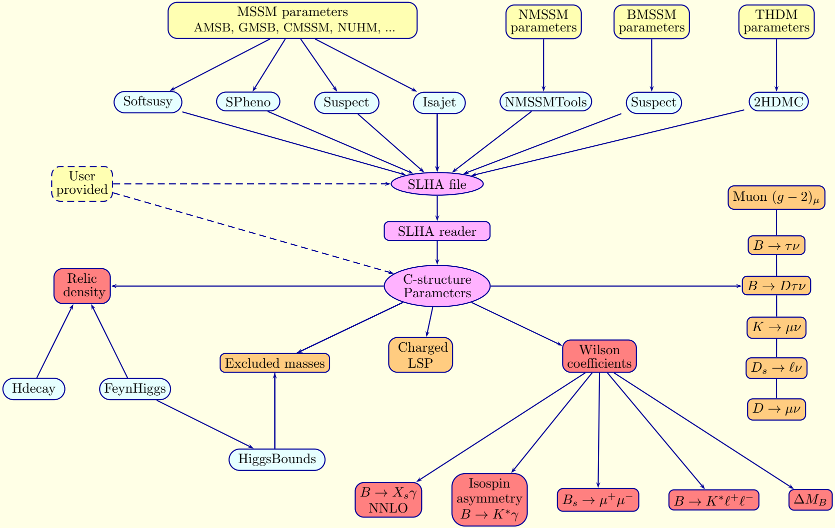
SuperIso

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
Muon $(g-2)_\mu$
$B \to \tau\nu$
$B \to D\tau\nu$
$K \to \mu\nu$
$D_s \to \ell\nu$
$D \to \mu\nu$
$B \to X_s\gamma$ NNLO
Isospin asymmetry $B \to K^*\gamma$
$B_s \to \mu^+\mu^-$
$B \to K^*\ell^+\ell^-$
ΔM_B

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

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

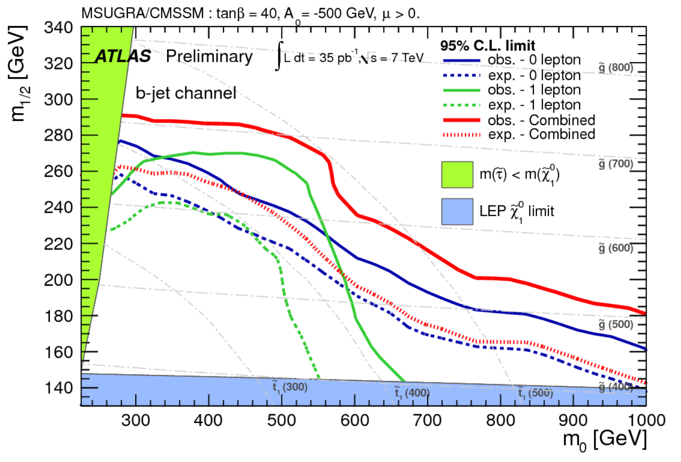
Involved people

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

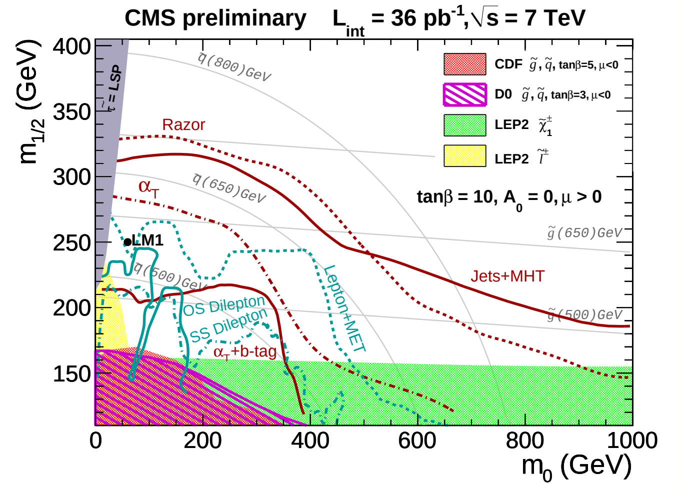
For more information

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

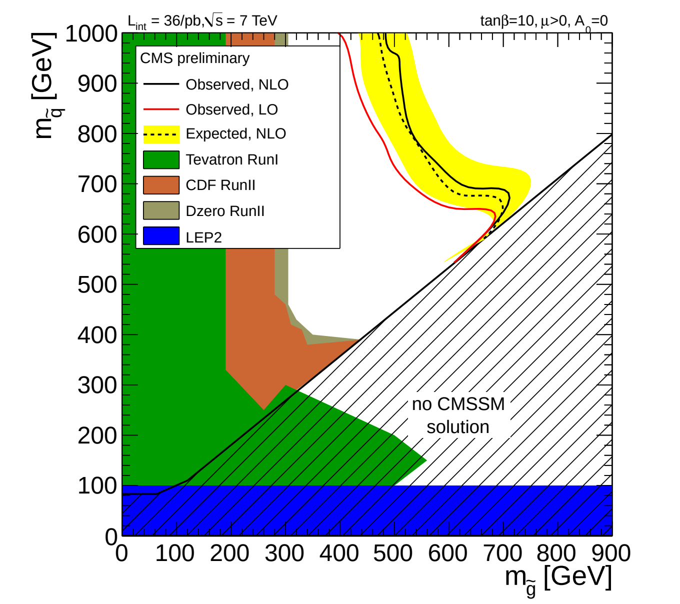
ATLAS contours



CMS contours



CMS contours



pMSSM

pMSSM Scans

Parameter	Range
$\tan\beta$	[1, 60]
M_A	[50, 2000]
M_1	[-2500, 2500]
M_2	[-2500, 2500]
M_3	[50, 2500]
$A_d = A_s = A_b$	[-2000, 2000]
$A_u = A_c = A_t$	[-2000, 2000]
$A_e = A_\mu = A_\tau$	[-2000, 2000]
μ	[-1000, 2000]
$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$	[50, 2500]
$M_{\tilde{e}_R} = M_{\tilde{\mu}_R}$	[50, 2500]
$M_{\tilde{\tau}_L}$	[50, 2500]
$M_{\tilde{\tau}_R}$	[50, 2500]
$M_{\tilde{q}_{1L}} = M_{\tilde{q}_{2L}}$	[50, 2500]
$M_{\tilde{q}_{3L}}$	[50, 2500]
$M_{\tilde{u}_R} = M_{\tilde{c}_R}$	[50, 2500]
$M_{\tilde{t}_R}$	[50, 2500]
$M_{\tilde{d}_R} = M_{\tilde{s}_R}$	[50, 2500]
$M_{\tilde{b}_R}$	[50, 2500]

Flat scan of 19 pMSSM parameters:

presently have 10M pMSSM points generated

→ 903k valid MSSM spectra after mass limit cuts
→ 688k accepted after flavour cuts
→ 677k accepted after g-2 cut
→ 275k accepted after Ωh^2 cut
→ 273k simulated & analysed

In the process to increase statistics x 5

Parameter	Value
$\alpha_s(M_Z)$	0.1184
$\bar{m}_b(\bar{m}_b)$	4.19 GeV
m_t^{pole}	172.9 GeV