SUSY parameter measurement and b-physics

Giacomo Polesello

INFN, Sezione di Pavia

Introduction and outline

Address interaction between new physics and b-physics. Concentrate on SUSY

Approach from b-physics side:

- Identify SUSY space not excluded by measurements
- Address possibility of finding a SUSY signal in b-physics measurements

View from the side of LHC high p_T physics:

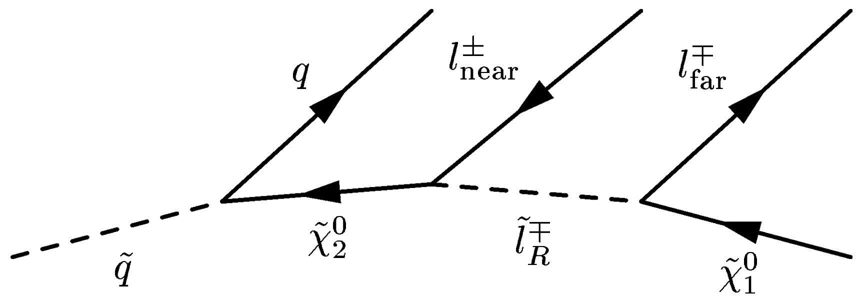
- On benchmark models assess achievable measurements of SUSY parameters
- Connect to b-physics, assess:
  - How precisely b-physics variables can be predicted using measured SUSY parameters?
  - Vice versa: can we use b-physics measurements to constrain badly measured SUSY parameters?
  - Are the precisions of the measurements on the two sides adequate to rule out minimal flavour violation and to constrain flavour violation in squark sector?

Work only recently started. Present some preliminary plots as input to discussion

Brief reminder: measurement of model parameters

Start from sparticle masses. Key result:

If a chain of at least three two-body decays can be isolated, can measure masses and momenta of involved particles in model-independent way.



Example: full reconstruction of squark decays in models with light $\tilde{\ell}_R$ ($m_{\tilde{\ell}_R} < m_{\tilde{\chi}^0_2}$):

Edges and thresholds in invariant mass distributions functions of sparticle masses

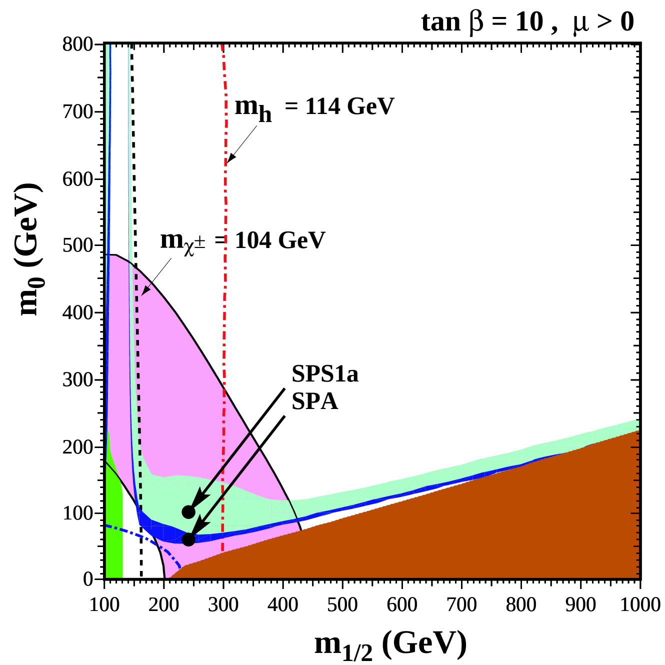
Example: SPA Point

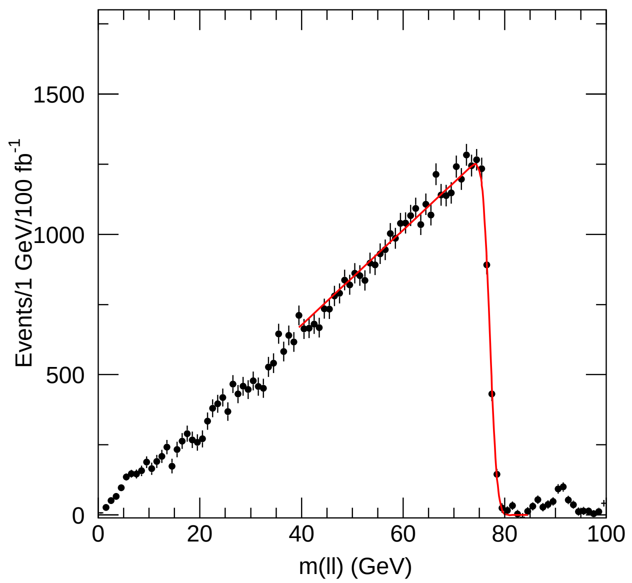
$m_0 = 70$ GeV, $m_{1/2} = 250$ GeV

$A = -300$ GeV, $\tan\beta = 10$, $\mu > 0$

Compatible with WMAP

Phenomenology similar to SPS1a for which complete study available





Lepton-lepton edge

Select events with high jet multiplicity and $\not{E}_T$

Require two opposite-sign same-flavour e, μ (OSSF)

SUSY background: uncorrelated $\tilde{\chi}_1^\pm$ decays

Subtract SUSY and SM background via flavour correlation: $e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp$

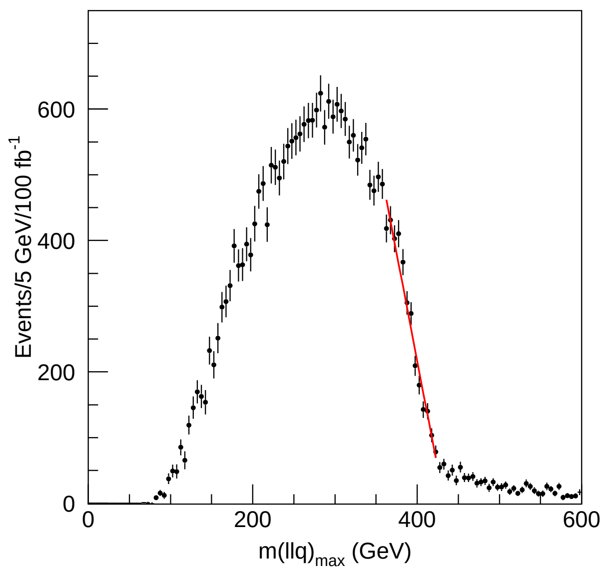
Lepton-lepton-jet edges

Distributions fall $\sim$linearly to end point.

Four additional edges/thresholds measured

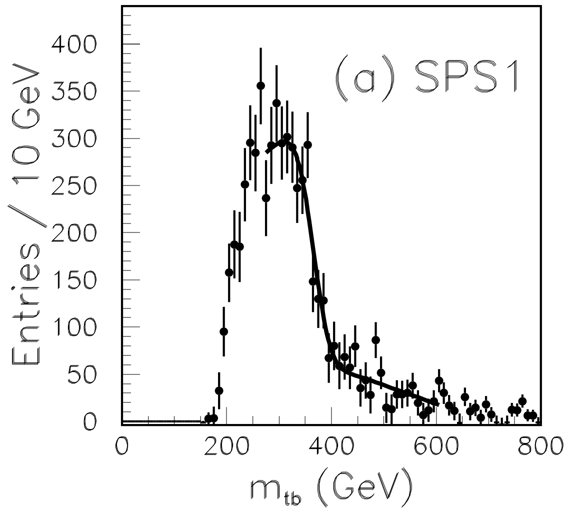
Enough constraints to solve for masses of $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\ell}_R$, $\tilde{q}_L$

Strong correlation among calculated sparticle masses: error on masses: $5-10\%$, error on differences: few hundred MeV.



Constraints on stop sector

Hisano Kawagoe Nojiri, Phys.Rev. D68 (2003) 035007



a Study tb invariant mass from decay:

$\tilde{g} \longrightarrow \tilde{t}_1 t \longrightarrow tb\tilde{\chi}_1^{\pm}$ (1)

Same final state for the decay:

$\tilde{g} \longrightarrow \tilde{b}_1 b \longrightarrow tb\tilde{\chi}_1^{\pm}$ (2)

$\Rightarrow$ Position of fitted tb edge reproduces average of the edges for the two decays weighted by relative BR

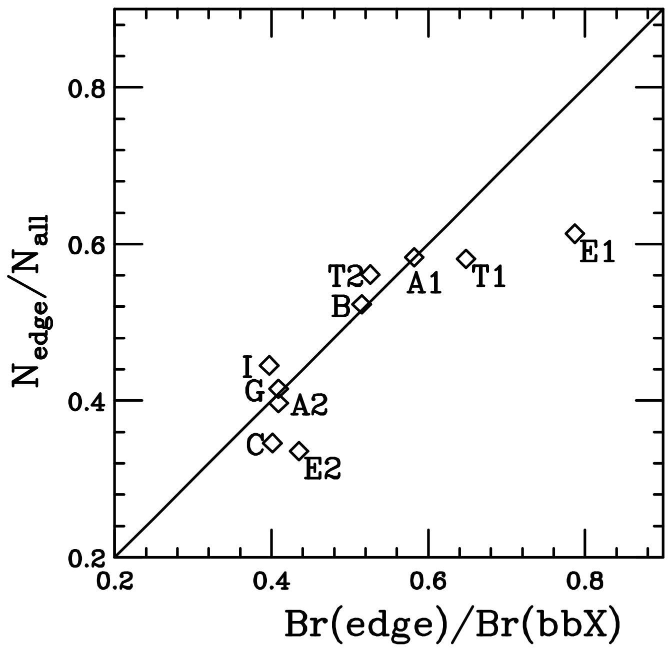
$M_{tb}^{fit} \quad = \quad f(m(\tilde{t}_1), m(\tilde{b}_1), m(\tilde{g}), m(\tilde{\chi}_1^{\pm}), \theta_t, \theta_b) \quad +$

gaugino parameters

Additional constraint: ratio of events in edge to all SUSY events with b pair in final state correlated to:

$$BR(edge)/BR(\tilde{g} \rightarrow bbX)$$

Where $BR(edge) = BR(1) + BR(2)$



Strategy to access soft parameters from measurements

Smear with a gaussian the available measurements and build a set of n Monte Carlo experiments

Start with explicit calculation of sparticle masses from edges for each MC experiment

Next step is solving the neutralino mixing matrix, depending on M_1, M_2, μ, $\tan\beta$

$$\mathcal{M} = \begin{pmatrix} M_1 & 0 & -m_Z c_\beta s_W & m_Z s_\beta s_W \\ 0 & M_2 & m_Z c_\beta c_W & -m_Z s_\beta c_W \\ -m_Z c_\beta s_W & m_Z c_\beta c_W & 0 & -\mu \\ m_Z s_\beta s_W & -m_Z s_\beta c_W & -\mu & 0 \end{pmatrix} \quad (1)$$

In SPA point measure mass of three neutralinos (1,2 and 4): constrain all parameters in matrix except $\tan\beta$. In order to get a grasp on $\tan\beta$:

- Higgs sector: observation of H/A either through SM or through MSSM decays or in SUSY cascades
- Third generation sector: need to use branching ratios besides masses. Sensitive to $\tan\beta$, but observables depend on combination of $\tan\beta$ and trilinear couplings A. No direct info on $\tan\beta$ if no unification assumed.

Start by studying extraction of MSSM parameters for fixed $\tan\beta$, and study a posteriori dependence on $\tan\beta$

Solving neutralino matrix

Use measured masses for $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_4^0$

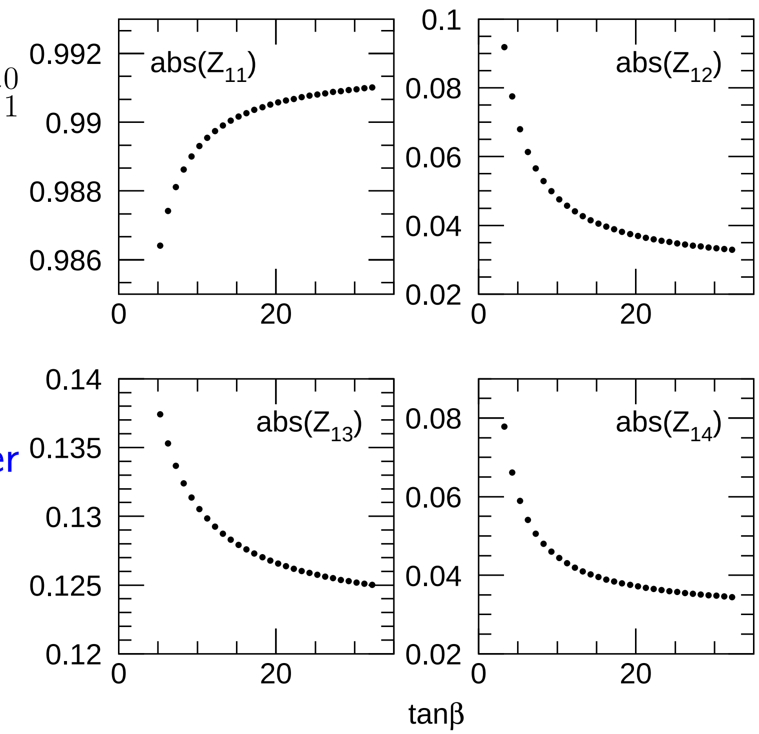
Input fixed value for $\tan\beta$, and get numerically the values of M_1, M_2, μ.

Uncertainty is ∼5-6 GeV, corresponding to uncertainty on neutralino masses. In the range $3 < \tan\beta < 30$, dependence on assumed $\tan\beta$ is < 5 GeV

Study the dependence of the values of the $\tilde{\chi}_1^0$ components from the assumed value of $\tan\beta$

$$\tilde{\chi}_1^0 = Z_{11}\tilde{B} + Z_{12}\tilde{W}^3 + Z_{13}\tilde{H}_1^0 + Z_{14}\tilde{H}_2^0$$

Little dependence for the bino component, larger variation for subdominant components



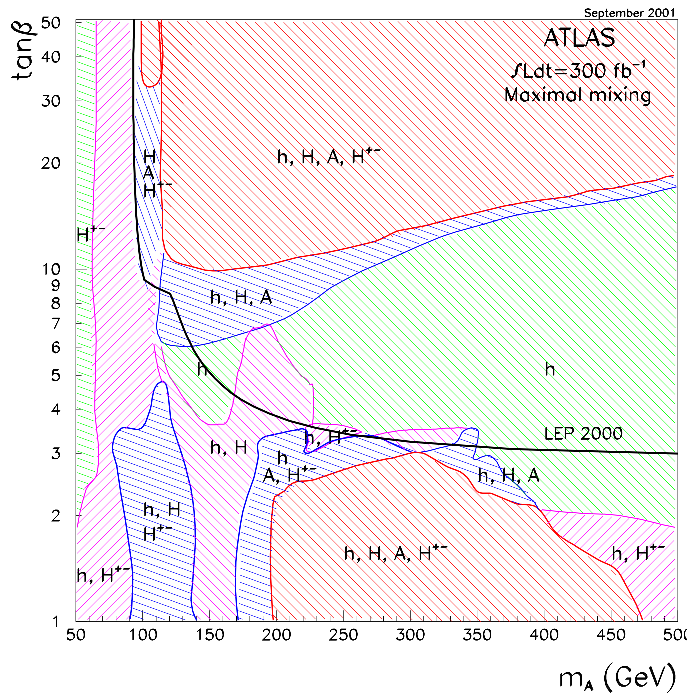
Constraints from higgs sector

h can be discovered over the whole parameter space

For high $\tan\beta$ little info on $\tan\beta$ from $m(h)$

Can assume approx $\tan\beta > 5$, need detailed study of stop sector

Heavy higgses can not be discovered at the LHC in their SM decay modes for the selected model: m(A)∼425 GeV, $\tan\beta = 10 \Rightarrow$ try with SUSY sector



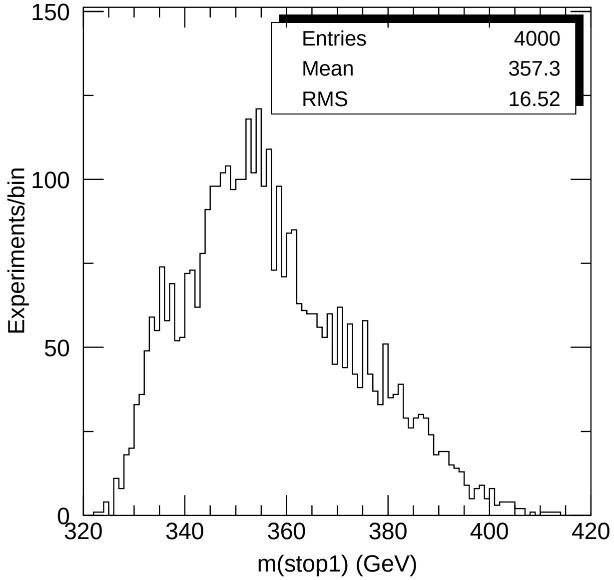
- Detection of A/H →bb in chargino/neutralino decays

Kinematically closed: can probably put a limit $m(A/H) < m(\tilde{\chi}^0_4) - m(\tilde{\chi}^0_1) \sim 300$ GeV from non-observation of $H/A \to bb$ peak in cascade decays. Detailed analysis needed

- Detection of $A/H \to \tilde{\chi}^0_2\tilde{\chi}^0_2 \to 4\ell\ell$

Very small rate: ~ 40 events/experiment for 300 fb^{-1}. Need detailed background study to verify observability.

Extraction of parameters of stop-sbottom sector PRELIMINARY!



Defined by 5 soft SUSY breaking parameters:

$m(Q_3)$, $m(t_R)$, $m(b_R)_3$, A_t, A_b

5 measurements available:

$m(\tilde{b}_1)$, $m(\tilde{b}_2)$, $BR(\tilde{g} \to b\tilde{b}_2 \to bb\tilde{\chi}_2^0)/BR(\tilde{g} \to b\tilde{b}_1 \to bb\tilde{\chi}_2^0)$,

M_{tb}^{fit}, $BR(edge)/BR(\tilde{g} \to bbX)$ $\Rightarrow$ solve for $m(\tilde{t}_1)$, θ_b, θ_t

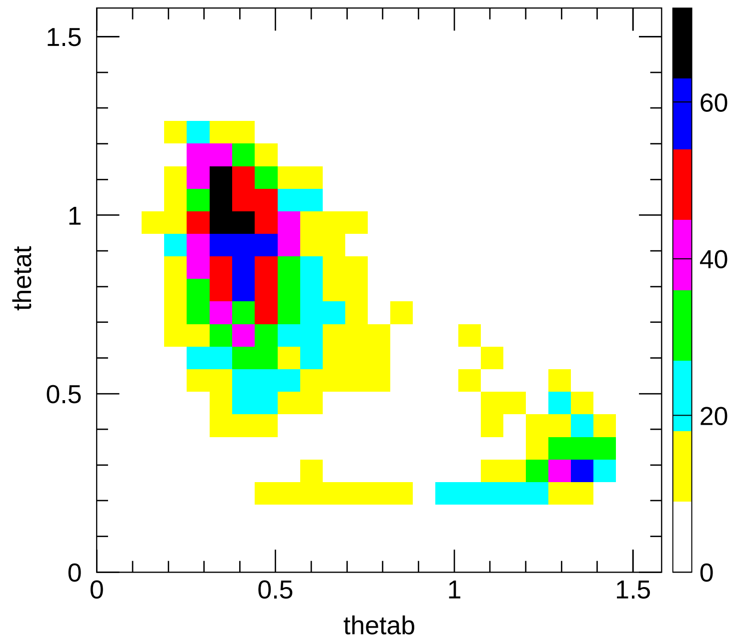
Difficulties:

When building MC experiment by smearing M_{tb}^{fit}, value can be above maximum allowed by masses

When minimizing χ^2 on θ_t and θ_b, sometimes find minimum at low θ_t and high θ_b.

(input values: $\theta_t = 0.933$, $\theta_b = 0.42$)

work in progress!



Conclusions on MSSM study of SPA point

Assume no FCNC effects from sfermion mixing matrices

- Neutralino/chargino mixing matrices fixed with good precision if the value of $\tan\beta$ is known.
- Slepton sector well constrained, including stau mixing angle
- Masses of first two generations squarks (L & R) and of gluino measured at ∼5-10% level
- Enough constraints to fix the 5 parameters of the stop/sbottom sector (in progress)
- Very weak constraints on $\tan\beta$ and $m(A)$

⇒ use measured MSSM parameters to predict effects in b-physics

Connecting MSSM parameter measurements to b-physics

Need publicly available programs which, using as input the MSSM parameters calculate variables in b sector.

Calculations of two variables made available in the framework of neutralino Dark Matter programs:

- $B_s \to \mu\mu$: available both in MicrOMEGAs and in ISAJET 7.72. Calculations in MicrOMEGAs based on the formulas of Bobeth et al. PRD64 (2001) 074014
- $B \to X_s\gamma$ Also available both in MicrOMEGAs and ISAJET 7.72. NLO calculation collecting various contributions. SUSY contribution based on the formulas of Degrassi, Gambino Giudice. Minimal flavour violation MSSM

In the following use the calculation available in MicrOMEGAs.

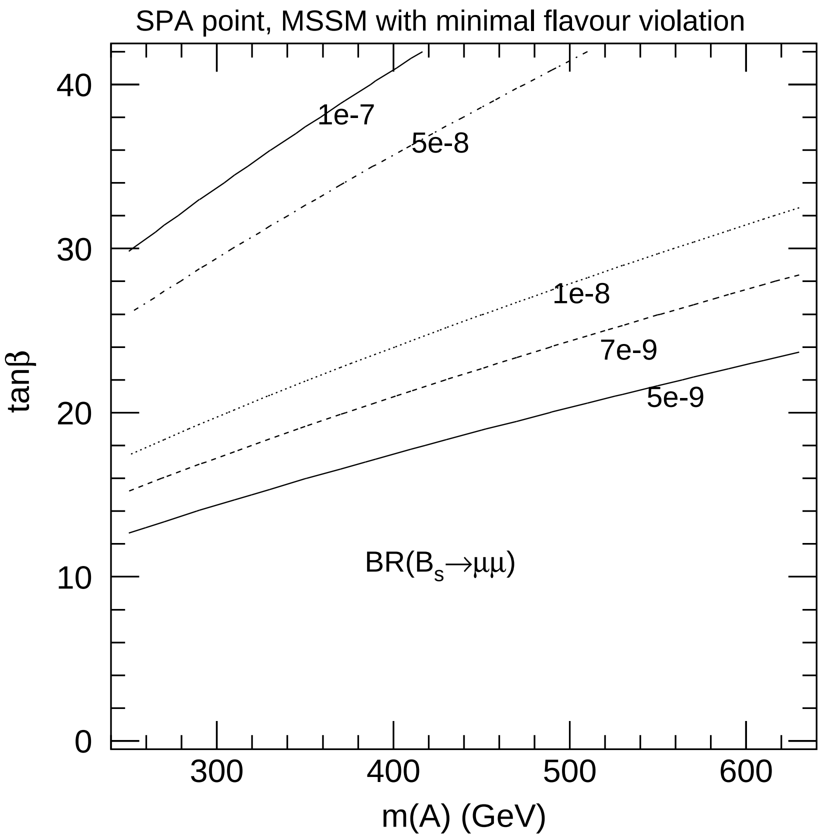
Method of the study

- Parameter scan: Study variation of predicted b-physics quantities as a function of the most relevant parameters:
  - Scan in badly constrained $m(A) - \tan\beta$ plane
  - Scan in $m(\tilde{t}_1) - \theta_t$ plane
- Measurement uncertainties: Effect of the expected measurement precision for the MSSM parameters on the predictivity for $B_s \to \mu\mu$ and $B \to X_s\gamma$.

  Keep $m(A)$ and $\tan\beta$ fixed, and for each of the Monte Carlo experiments calculate the expected value of BR($B_s \to \mu\mu$) and BR($B \to X_s\gamma$). The distribution of the calculated values gives the uncertainty of the prediction

  Perform it twice:
  - Once by varying gaugino sector, $\tilde{\ell}$ sector, first two squark generations, $m(\tilde{b}_1)$, $m(\tilde{b}_2)$, to verify assumed small dependence
  - Once by varying also the parameters $m(t\tilde{o}p_1)$, θ_t, θ_b VERY PRELIMINARY!

$B_s \to \mu\mu$ on $m(A) - \tan\beta$ plane



BR($B_s \to \mu\mu$)$\propto \tan\beta^6/m(A)^4$

Strong constraining power on $\tan\beta$ if $\tan\beta \gtrsim 15$

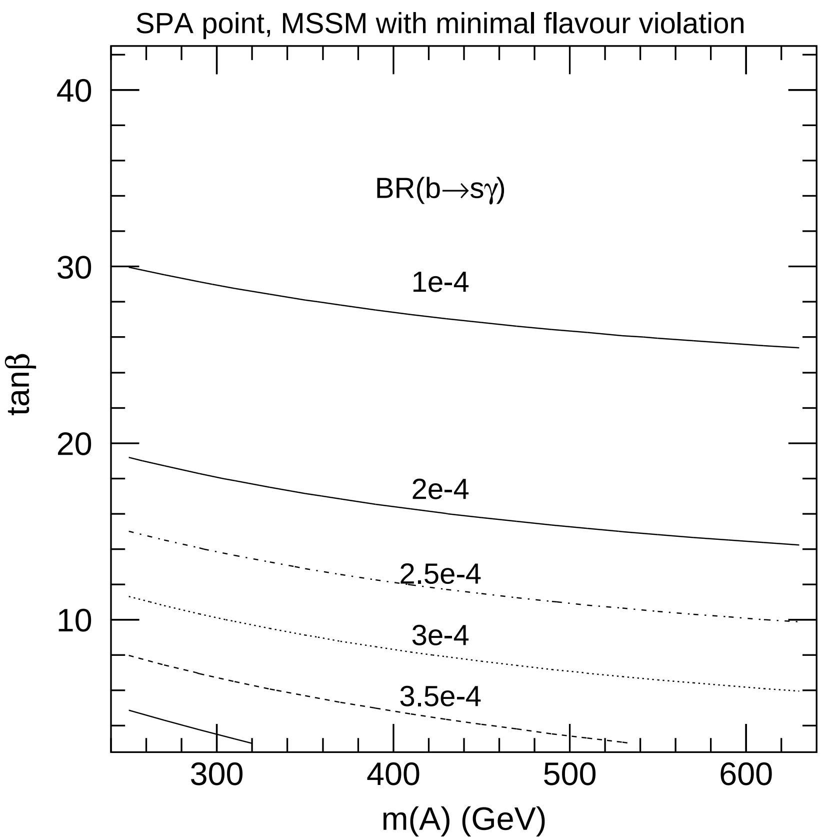
For lower $\tan\beta \sim$ indistinguishable from SM

Present limits only eliminate small upper left corner

Expected 90% bound from ATLAS: 6.6×10^{-9} for 30 fb^{-1}. Exclude region in $m(A) - \tan\beta$ similar to the one excluded by non-discovery of $H/A \to \tau\tau$

For higher $\tan\beta$ nice cross-check with $\tan\beta$ measured from H/A production

$B \to X_s\gamma$ on $m(A) - \tan\beta$ plane



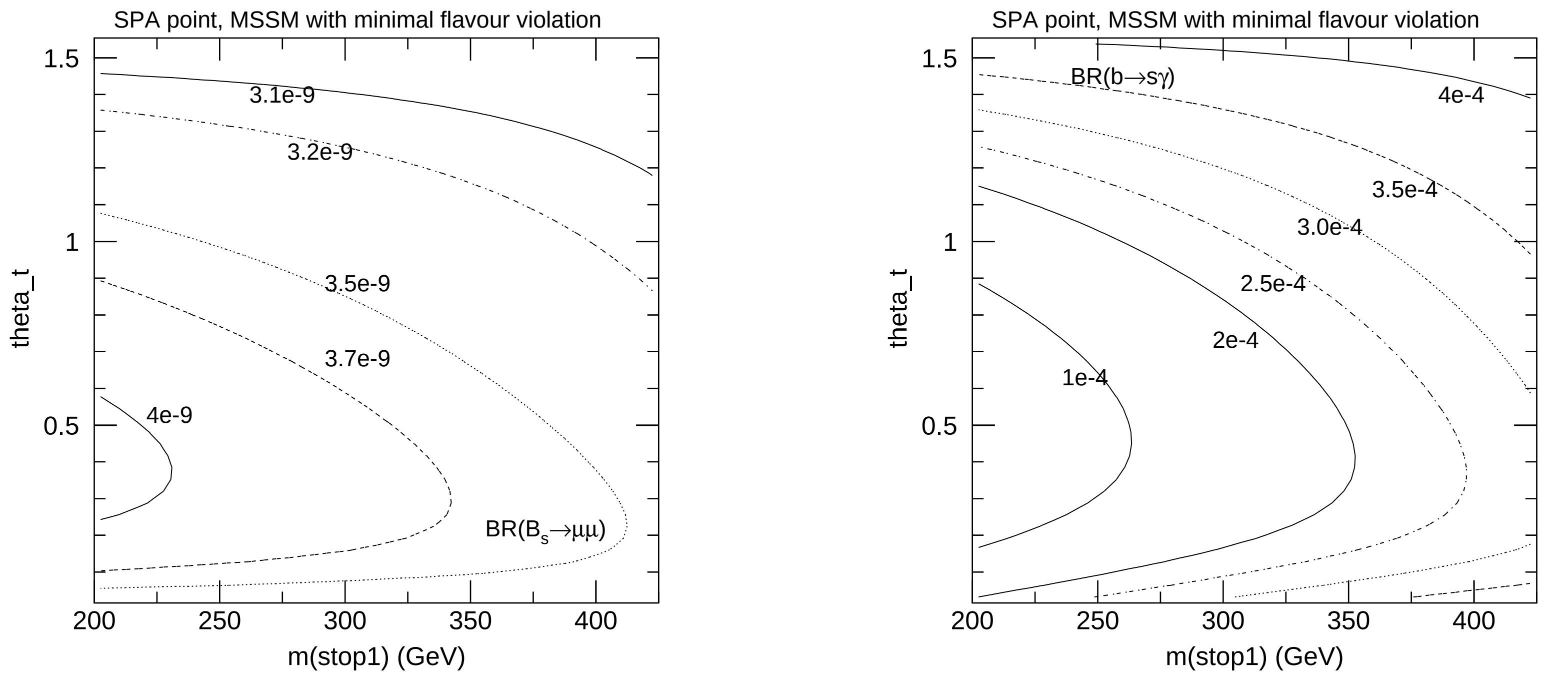
Measurement of BR($B \to X_s\gamma$):

$$\sim (3.3 \pm 0.4) \times 10^{-4}$$

Select narrow band in $m(A) - \tan\beta$ plane

Bounds with similar shape expected using measurement of h mass if good control of stop parameters possible.

$B_s \to \mu\mu$ and $B \to X_s\gamma$ on $m(\tilde{t}_1) - \theta_t$ plane



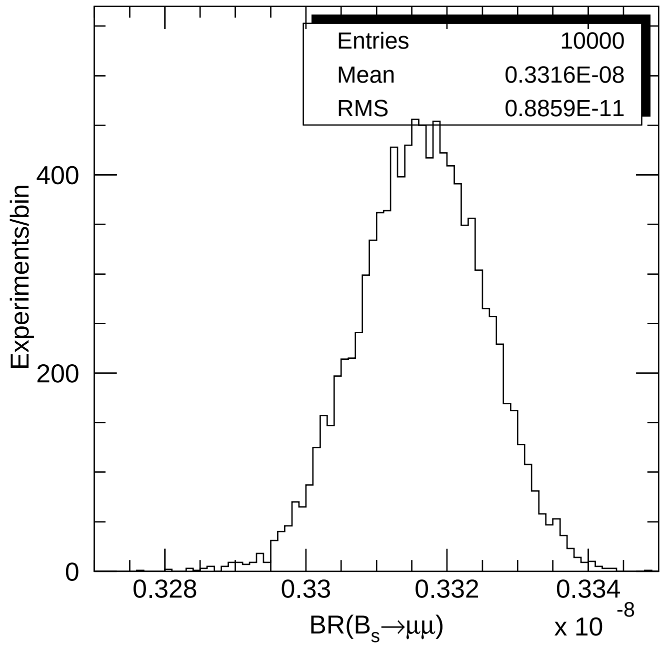
Moderate variation of $B_s \to \mu\mu$ in considered space

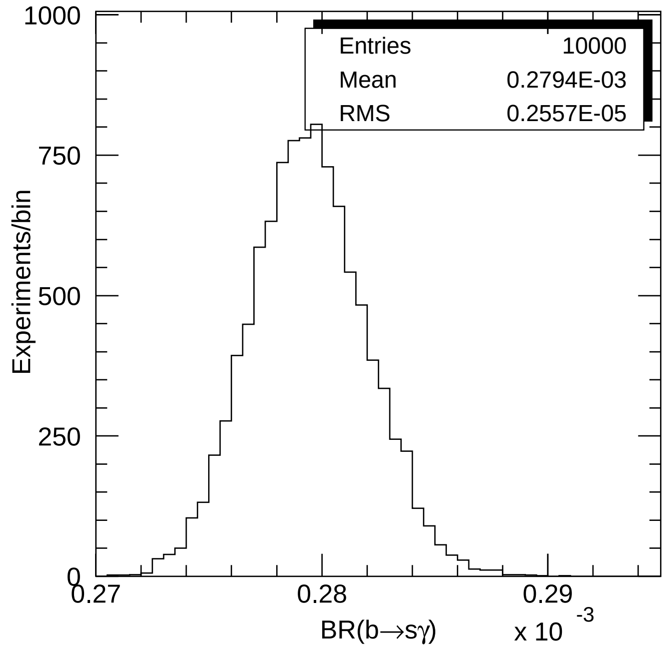
Present measurement of $B \to X_s\gamma$ defines a very small slice on $m(\tilde{t}_1) - \theta_t$ plane

For fixed θ_t moderate dependence on $m(\tilde{t}_1)$

Need to constrain well θ_t for good prediction of $B \to X_s\gamma$

Measurement uncertainty for fixed stop sector, $m(A)$, $\tan\beta$





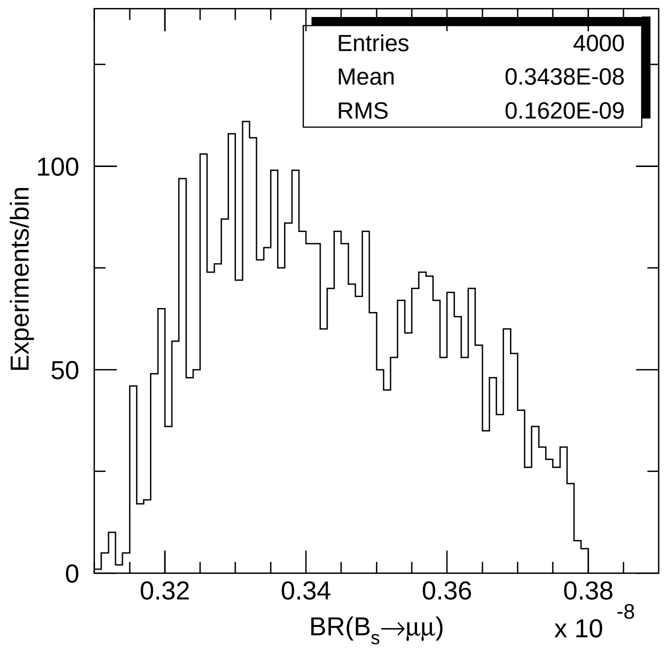
Effect of measurement uncertainty small, 0.3% on prediction for BR($B_s \to \mu\mu$) and 1% for prediction on BR($B \to X_s\gamma$)

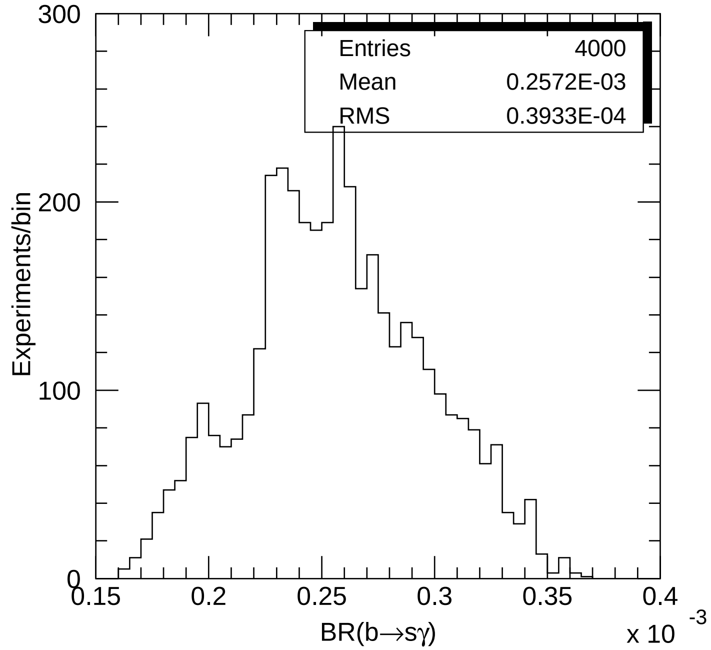
Need to take into account also theoretical uncertainties

Now incorporate in calculation effect of uncertainty in stop sector

Full measurement uncertainty - PRELIMINARY

For these plots, vary all of the MSSM parameters, according to the expected measurement precision at the LHC for the SPA point, except $M(A)$ nd $\tan\beta$, which are kept fixed.





$\sim$5% error on prediction for BR($B_s \to \mu\mu$), and $\sim$15% error on prediction for BR($B \to X_s\gamma$)

Uncertainty dominated by loose constraint on θ_t

Beyond MFV models

In favourable cases good enough measurement of MSSM parameters that sensible predictions for BR($B \to X_s \gamma$), BR($B_s \to \mu\mu$) are possible

Once the LHC data are available, one can imagine different scenarios, e.g.

- $A/H \to \tau\tau$ can be observed and $\tan\beta$ and $m(A)$ measured, and a) either the prediction for BR($B \to X_s \gamma$) or BR($B_s \to \mu\mu$) or both are incompatible with the measured values b) all the measurements are consistent with MFV

- $\tan\beta$ is not constrained by high p_T searches, but a) $m(h)$, BR($B \to X_s \gamma$), and BR($B_s \to \mu\mu$) point to incompatible ranges of $\tan\beta$ or b) all the measurements are consistent with MFV

Question is, what are the precisions required on the MSSM and on the b-physics measurements and on the theoretical calculations to be able to claim a signal for flavour-changing terms in the squark mass matrices?

In case the measurements are consistent with MFV, what additional constraints on the flavour violation sector can be extracted by combining MSSM studies and b-physics measurements?

Beyond MFV (continued)

Various analyses in literature, based on assessing present allowed regions of non-diagonal elements in Super-CKM matrix, parametrised in terms of $(\delta^d_{23})AB$, where AB can be RR, LL, RL, LR

See e.g Ciuchini et al. Phys.Rev. D67 (2003) 075016, Foster et al. JHEP 0508 (2005) 094, hep-ph/0510422

Bounds on δ normally expressed for some token parametrisation of soft SUSY breaking, e.g $m(\tilde{q}) = m(\tilde{g}) = \mu = -A_u$ for different choices of $m(\tilde{q})$

Additional variables considered such as ΔM_B, BR($B \to X_s \ell^+ \ell^-$), $A_{CP}(B \to X_s \gamma)$

It would be useful to be able to have programs for all the relevant variables and General Flavour Violation, and generate boundary plots for δ for expected MSSM LHC performance in different benchmark points

Can we assume that squark flavour violation only marginally affects benchmark studies performed already in ATLAS and CMS, and we can reuse what learned from those studies in this context?

Detailed studies might help LHC focus on MSSM measurements which are crucial to discover flavour violation

Conclusions

The LHC experiment will discover SUSY through studies of inclusive channels if the scale of squarks and gluino is below 2-3 TeV

Once SUSY discovered, excellent potential for measurement of SUSY parameters exploiting the large variety of signal available

Studies of benchmark models motivated by specific SUSY breaking scenarios have all shown at least some parameter measurement possibilities

In favourable scenarios most of the parameters of MFV MSSM can be measured, and predictions for b-physics related variables given

Potentially the combination of MSSM and b-physics measurements could give clear indication for SUSY flavour violation in the squark sector

Dedicated studies and appropriate tools needed to assess to what extent this program can be carried out, and what are the limitations from the experimental and theoretical points of view