Links between direct NP signal at ATLAS/CMS and indirect signals in the flavour sector

Introduction to the discussion

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Introduction

Address interaction between new physics and b-physics from the side of LHC high p_T physics. Concentrate on SUSY as new physics template

Basic approach:

- Once SUSY discovered, perform detailed analysis of exclusive signatures and assess achievable measurements of SUSY parameters. As long as data not available, exercise on benchmark models
- 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 combined measurements adequate to provide information on the flavour structure of SUSY?

As an introduction, I will show what we hope we can contribute from the SUSY discovery side

In the discussion adress what do we need to do on the side of both of b-physics and SUSY searches to make this program viable

Many issues in common with tool discussion tomorrow

Minimal Supersymmetric Standard Model (MSSM)

For our purpose: new physics model with rich spectrum of new particles with quantum numbers related to the ones of SM particles, and 5 Higgs bosons

Resulting physical spectrum:

quarks	$\longrightarrow$	squarks	$\tilde{q}_L$, $\tilde{q}_R$	
leptons	$\longrightarrow$	sleptons	$\tilde{\ell}_L$ $\tilde{\ell}_R$	
$W^\pm$	$\longrightarrow$	winos	$\tilde{\chi}^\pm_{1,2}$	charginos
$H^\pm$	$\longrightarrow$	charged higgsinos	$\tilde{\chi}^\pm_{1,2}$	charginos
γ	$\longrightarrow$	photino	$\tilde{\chi}^0_{1,2,3,4}$	neutralinos
Z	$\longrightarrow$	zino	$\tilde{\chi}^0_{1,2,3,4}$	neutralinos
g	$\longrightarrow$	gluino	$\tilde{g}$	

Masses and coupings of new particles defined in terms of $\sim$100 parameters

Most of the parameters are complex mixing matrices among generations

Impose phenomenological constraints, typically from flavour physics to reduce SUSY breaking parameters.

Standard approach: MFV, assume all flavour matrices in SUSY sector aligned with SM ones, end up with 15-20 parameters:

- Three gaugino masses (M_1, M_2, M_3)
- higgsino mass (μ)
- $\tan\beta \equiv v_1/v_2$ ratio of vev of two Higgs doublets
- sfermion masses
- trilinear couplings A

Masses of EW gauginos determined in terms of matrices depending on 4 parameters: (M_1, M_2, μ, $\tan\beta$)

Typical ingredients of LHC SUSY analysis:

- Measure gaugino masses and BR from cascade decays, constrain parameters of mixing matrix
- Further measure some of the sfermion masses and BR (stops, sbottoms rather difficult)
- Measurements on the higgs sector (masses and BR's of one or more higgs bosons)
- Based on these measurements reconstruct as many of the weak-scale parameters as possible
- From the pattern of observed weak-scale parameters constrain SUSY breaking

Flavour structure of the model assumed as input of the study, this kind of analysis alone not sensitive to it, unless explicit flavour violation signals (e.g. $\tilde{\chi}^0_2 \to \tau\mu$) seen

Dependence of B observables from measured SUSY parameters

Connect to b-physics as a window to flavour structure

Concentrate here as an example on specific model point for which complete analysis performed, and incorporate projected measurement uncertainties in the studies.

Use measurement uncertainties for SPA point: mSUGRA model with:

$m_0 = 70$ GeV, $m_{1/2} = 250$ GeV $A = -300$ GeV, $\tan\beta = 10$, $\mu > 0$

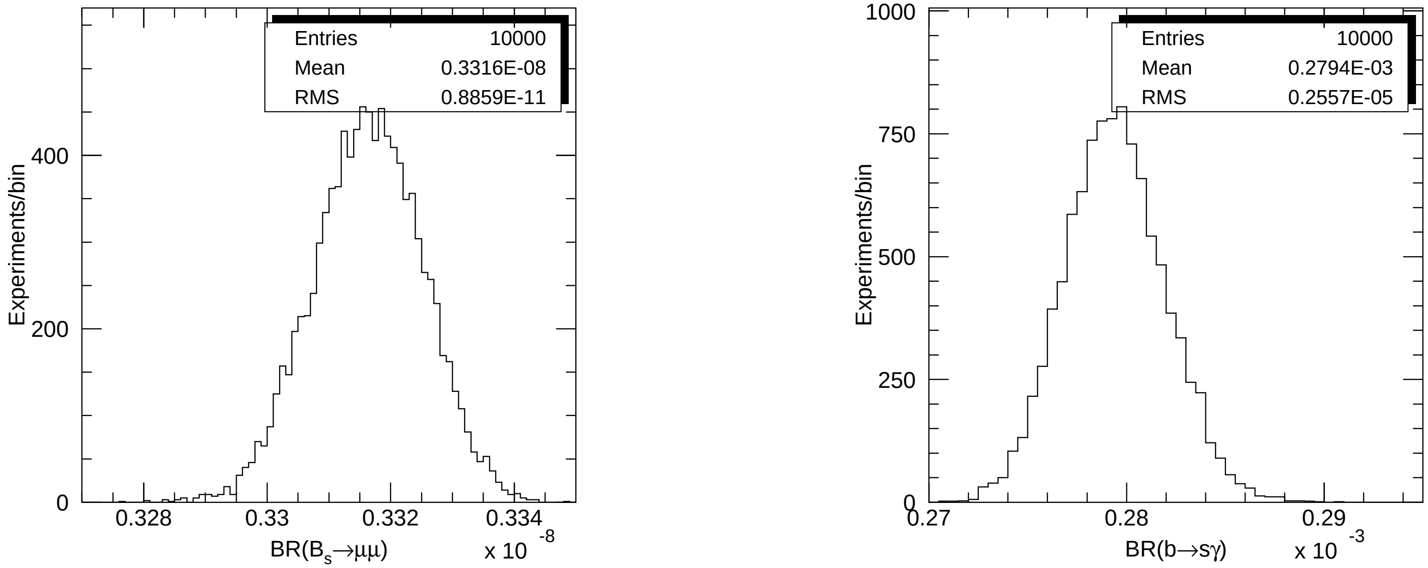
Use mSUGRA to compute weak-scale paramters, but do not use mSUGRA assumption in analysis

Study:

- Uncertainties on $B_s \to \mu\mu$ and $B \to X_s\gamma$ from expected uncertainty on mixing matrix at fixed $\tan\beta$
- For SPA parameters, variation of $B_s \to \mu\mu$ and $B \to X_s\gamma$ on $(m(A), \tan\beta)$ plane
- Variation of $B_s \to \mu\mu$ and $B \to X_s\gamma$ as a function of paramters of stop sector

$B_s \to \mu\mu$ and $B \to X_s\gamma$ computations in MFV publicly available in ISAJET and Micromegas, calculated with Micromegas

Uncertainties from errors on gaugino matrix

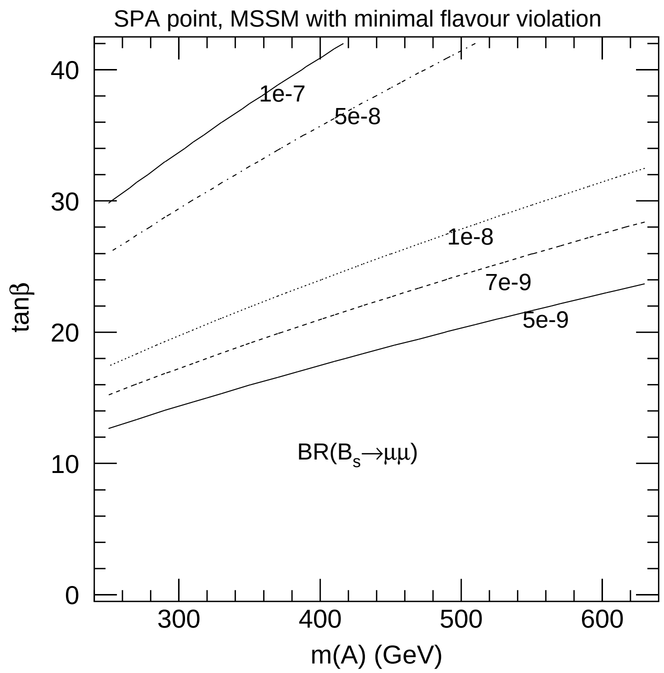


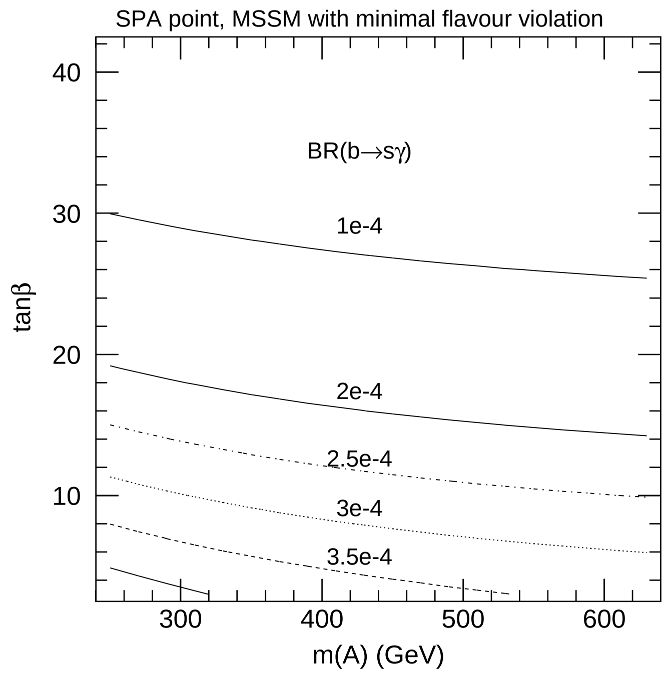
Values of M_1 (100 GeV), M_2(193 GeV), μ (393 GeV) measured with 5-6 GeV uncertainty

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

Theoretical uncertainties neglected

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





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

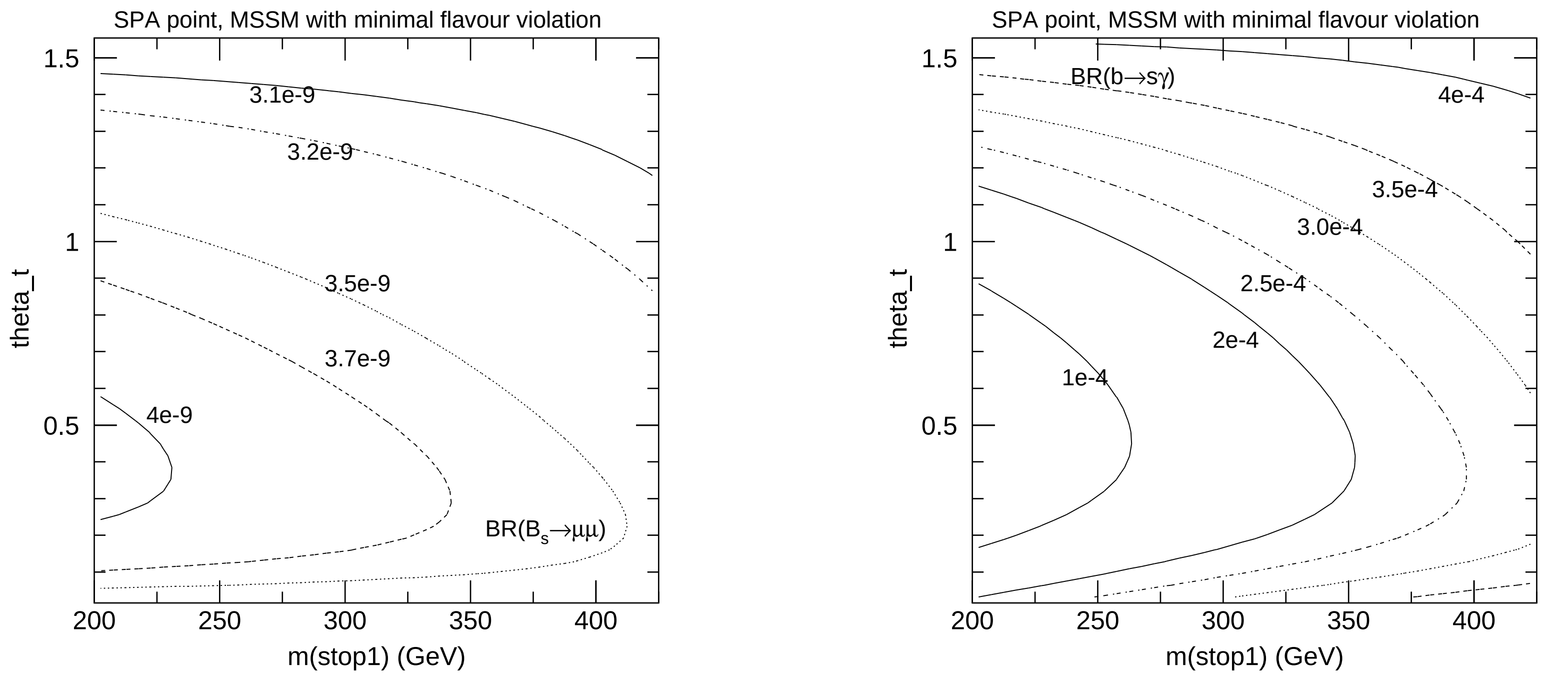
Strong constraining power on $\tan\beta$ if $\tan\beta \gtrsim 15$ For lower $\tan\beta \sim$ indistinguishable from SM

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 $H/A \to \tau\tau$

Measurement of BR($B \to X_s\gamma$): selects narrow band in $m(A) - \tan\beta$ plane

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

$B_s \to \mu\mu$ 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 $B \to X_s\gamma$

Difficult, but at least one example in which it looks doable

Possible test scenarios

• In all cases assume measurement of M_1, M_2, μ for fixed $\tan\beta$, and of mass scale of squarks and gluinos

• In all cases the mass of the light higgs h is measured

Various possible scenarios:

- No heavy higgs boson observed, no measurement of stop sector available
- Only either stop sector or higgs sector fixed by high energy measurements.
- Both stop sector and higgs sector fixed by high energy measurements

Each of these scenarios offers a different model of interplay between SUSY direct measurements and low energy data

Tools for performing this kind of studies require running in consistent way different types of code (see "Master Code" project) $\longrightarrow$ discussion tomorrow

Need to develop collaboration and discussion and collaboration between collider and b-physics experts:

In each of these scenarios how to make the best of the available information for unravelling the flavour structure of the theory?

Assorted questions

- In which of the considered scenarios one can get to a level of redundancy of information that allows us to observe a deviation/ confirm MFV hypothesis?
- If no complete set of information available, what kind of constraints can one put on the underlying model and which future experimental program would improve the situation?
- Are the present/expected precisions in measurements/calculations from the two sides adequate for this program?
- Can one directly observe flavour violation is SUSY signatures (some work done on this at the CERN workshop)?
- Can one play a similar game in a more generic NP model than MSSM?

A forum for discussing these issues (from T. Hurth)

Follow-up workshop:

Working Group on the Interplay Between Collider and Flavour Physics

The working group addresses the complementarity and synergy between the LHC and the flavour factories within the new physics search. New collaborations on this topic were triggered by the two recent CERN workshop series Flavour in the Era of the LHC and CP Studies and Non–Standard Higgs Physics at the border line of collider and flavour physics and experiment and theory. This follow–up working group wants to provide a continuous framework for such collaborations and trigger new research work in this direction. Regular meetings at CERN (well–connected by VRVS) are planned in the near future.

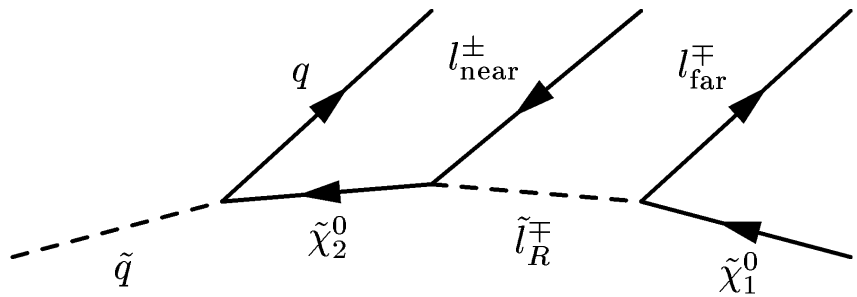
https://twiki.cern.ch/twiki/bin/view/Main/ColliderAndFlavour

BACKUP MATERIAL

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

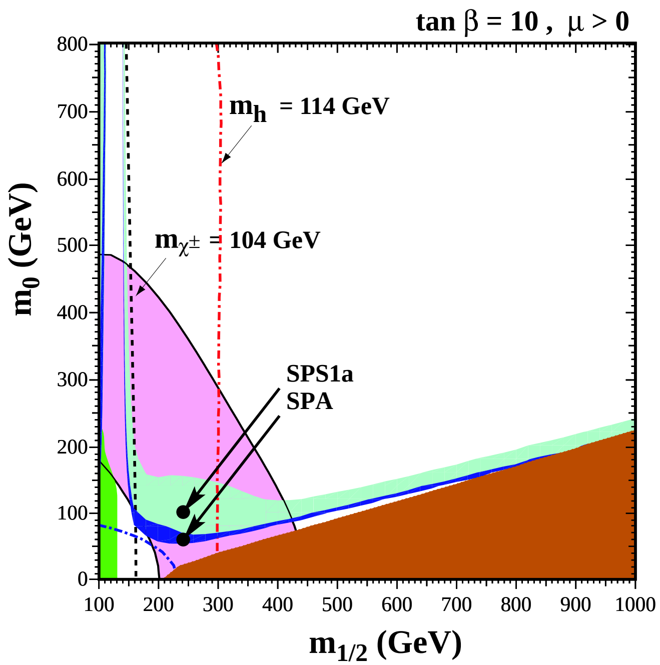
Example: SPA Point

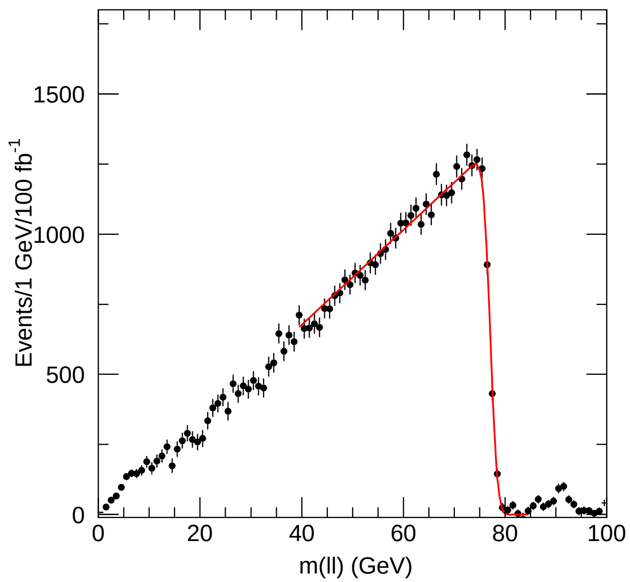
$m_0 = 70$ GeV, $m_{1/2} = 250$ GeV

$A = -300$ 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: $e^+e^- + \mu^+\mu^- - e^{\pm}\mu^{\mp}$

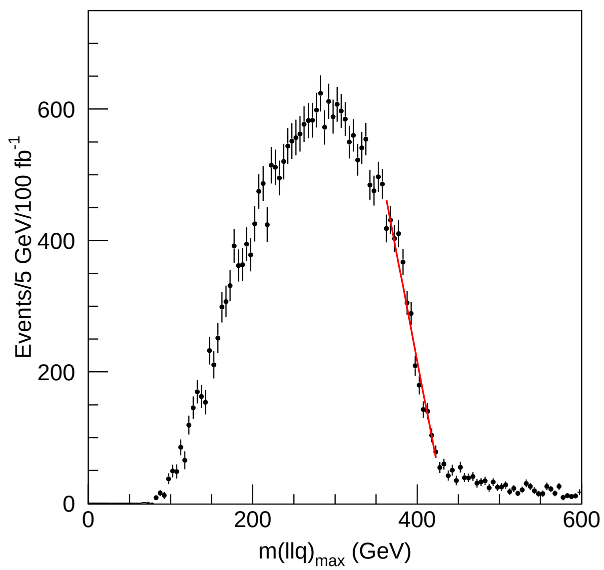
Lepton-lepton-jet edges

Distributions fall ∼linearly to end point.

Four additional edges/thresholds measured

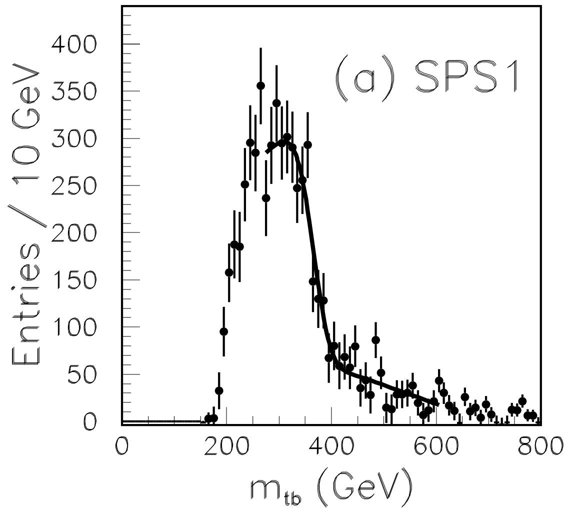
Enough constraints to solve for masses of $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\ell}_R$, $\tilde{q}_L$

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)

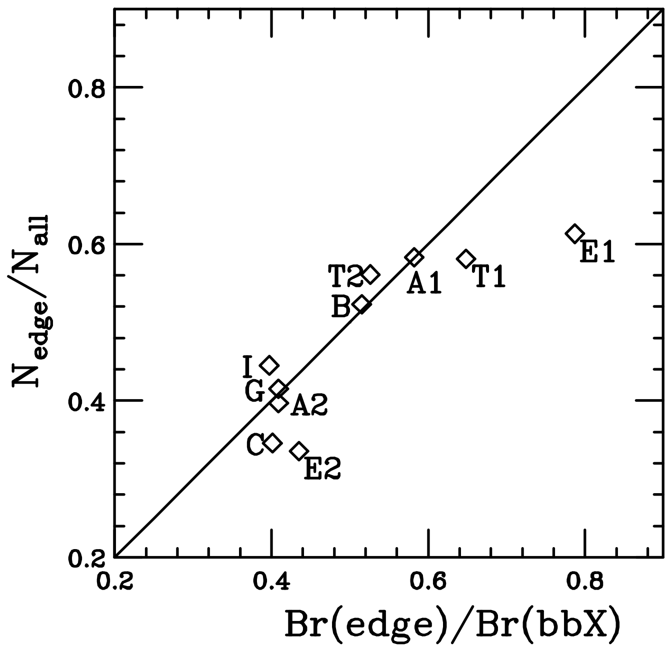
$\Rightarrow$ Position of fitted tb edge reproduces average of the edges for the two decays weighted by relative BR

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

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

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 $\tan\beta$

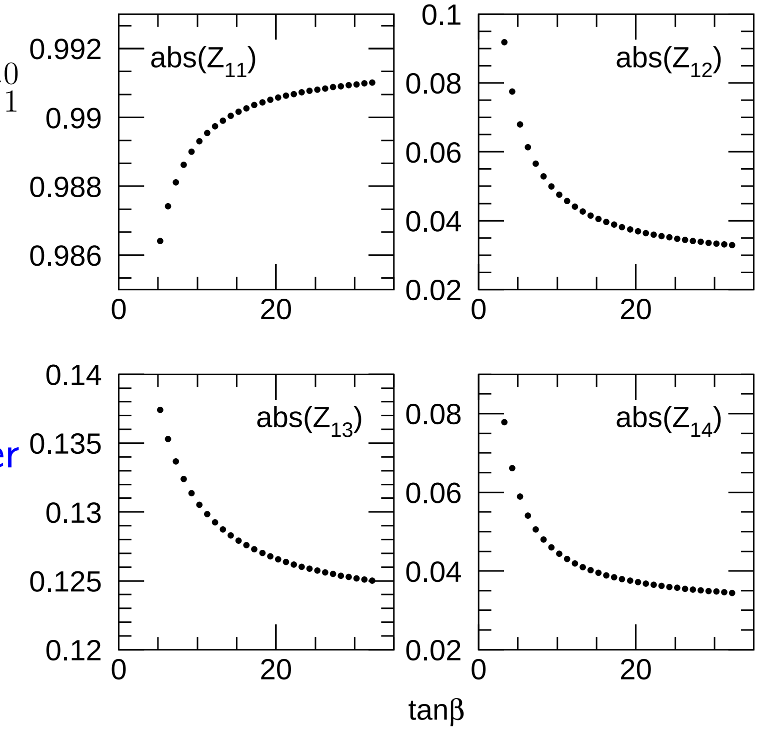
Solving neutralino matrix

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

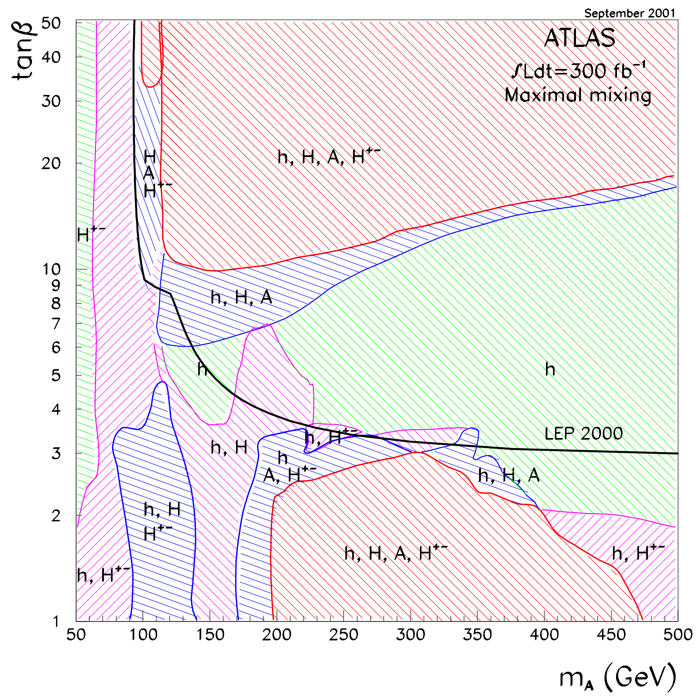
Constraints from higgs sector

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



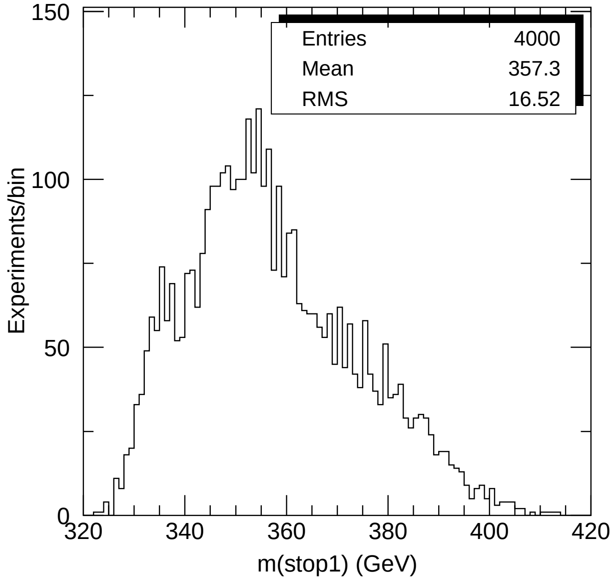
- Detection of A/H →bb in chargino/neutralino decays

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

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

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

Extraction of parameters of stop-sbottom sector



Defined by 5 soft SUSY breaking parameters:

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

5 measurements available:

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

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

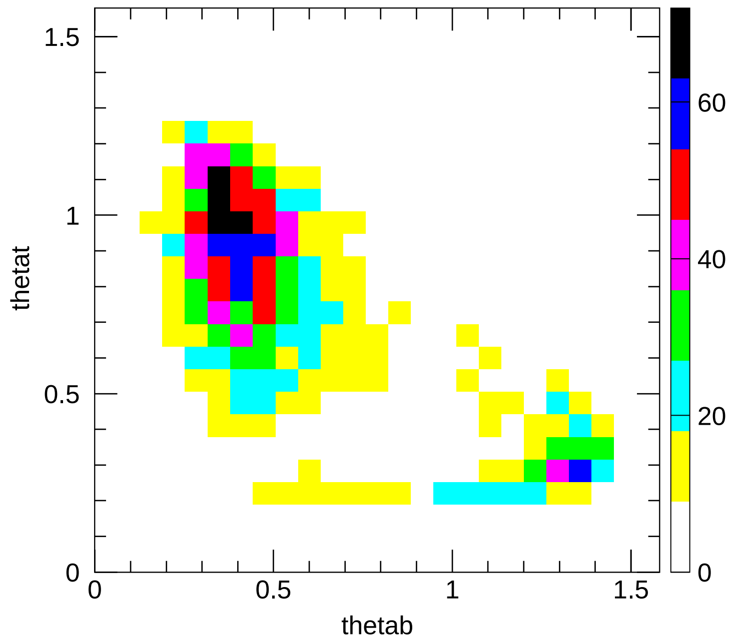
Difficulties:

When building MC experiment by smearing M^{fit}_{tb}, 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.

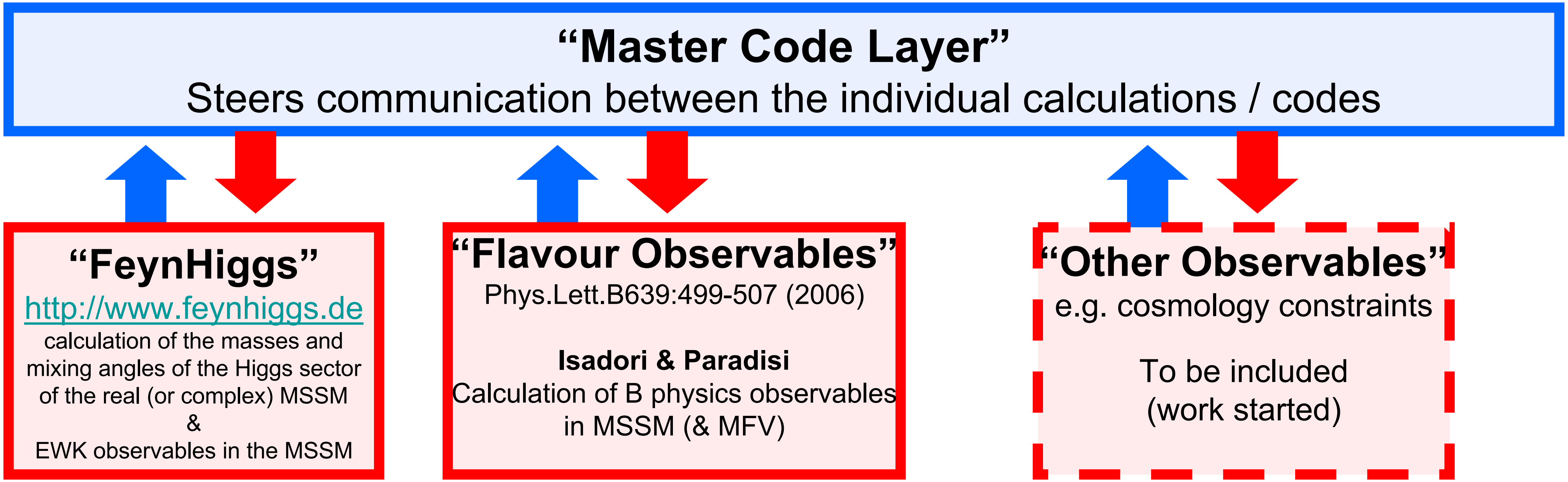
(input values: $\theta_t = 0.933$, $\theta_b = 0.42$)

work in progress!



"Master Code": Low Energy (LE) and Electroweak (EWK) Constraints on SUSY

- **Collaboration between**
  - **Theorists:** S.Heinemeyer, G.Isadori, P.Paradisi, A.Weber, G.Weiglein
  - **Experimentalists:** O.Buchmuller, R.Cavanaugh, F.Ronga
- **Work started at the LHC Flavour Workshop in Oct. 2006**
  - **Combine LE and EWK calculations in one common "master code"**
    - **Great care taken to ensure that both sets (LE & EWK) of calculations are steered with a consistent set of input parameters.**
  - **New physics parameter space: MSSM**
    - **Very general tool: not restricted to reduced MSSM parameter space**



Constraining Model Parameters using Observed Data

Example: MSSM Parameter fit

$$\chi^2 = \sum_i^{N_{const.}} \frac{(Const._i - Pred._i(\mathrm{MSSM}))^2}{\Delta Const.^2 + \Delta Pred.^2}$$

Const. = Experimental Constraint Value

***Pred.*(MSSM)** = Predicted Value for a given MSSM parameter set

"2009" Reference (pessimistic) Scenario

Observable	Constraint	theo. error
$R_{\mathrm{BR}_{b\to s\gamma}}$	1.127 ± 0.1	0.1
$R_{\Delta M_s}$	0.8 ± 0.2	0.1
$\mathrm{BR}_{b\to\mu\mu}$	$(3.5 \pm 0.35) \times 10^{-8}$	2×10^{-9}
$R_{\mathrm{BR}_{b\to\tau\nu}}$	0.8 ± 0.2	0.1
Δa_μ	$(27.6 \pm 8.4) \times 10^{-10}$	2.0×10^{-10}
M_W^{SUSY}	80.392 ± 0.020 GeV	0.020 GeV
$\sin^2\theta_W^{\mathrm{SUSY}}$	0.23153 ± 0.00016	0.00016
$M_h^{\mathrm{light}}(\mathrm{SUSY})$	> 114.4 GeV	3.0 GeV

MSSM Parameters varied in the fit

tan β - ratio of VEVs
M_A - mass of CP odd Higgs boson
A - trilinear Higgs stop coupling; all trilinear couplings set equal
μ - Higgs mixing parameter
M_{squark} - squark soft SUSY-breaking parameter; $M_{squark} = 2\ M_{slepton}$

Assumptions (varied to estimate systematic effect):

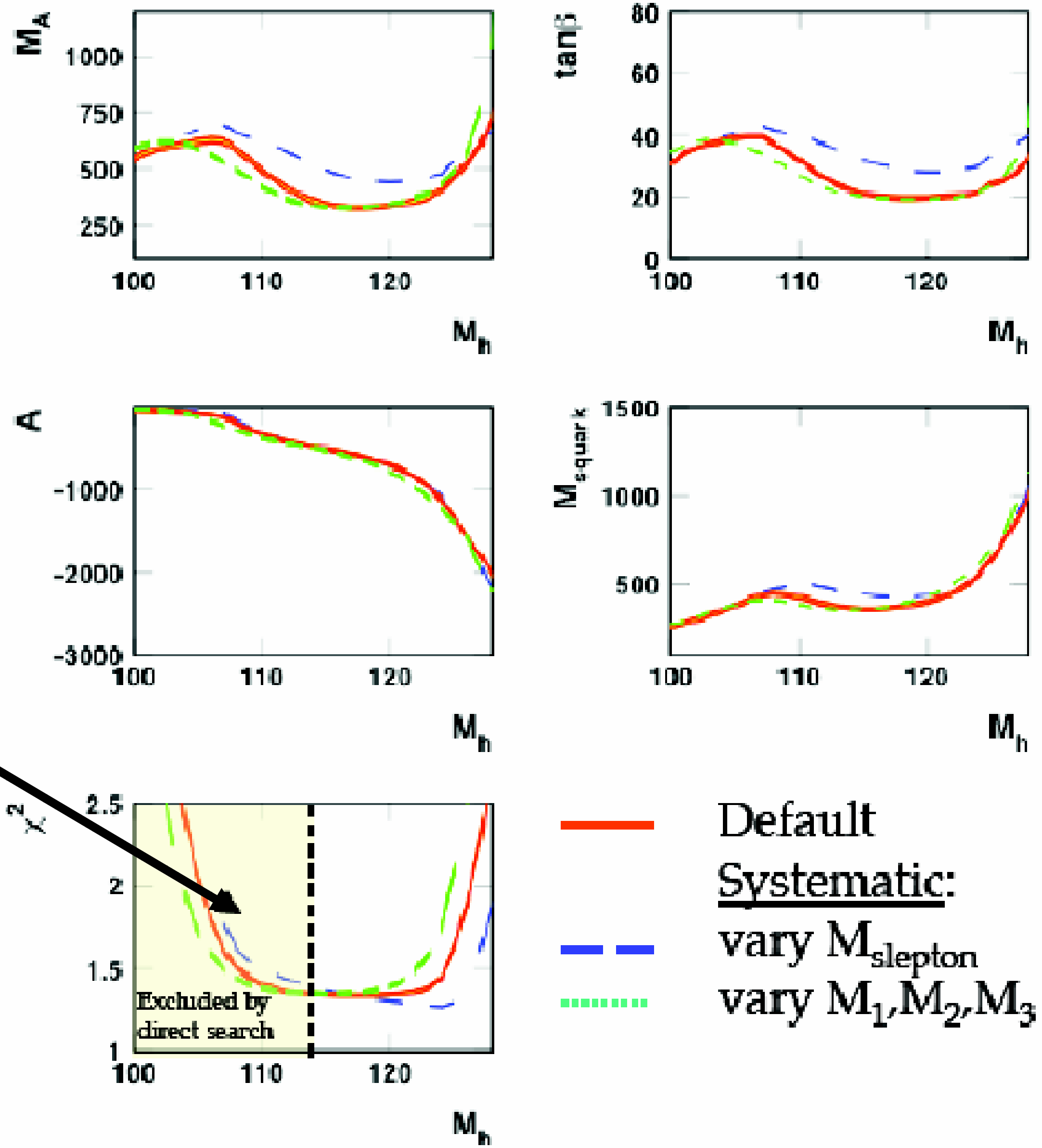
$M_1 = ½\ M_2$, M_2 = 200 GeV, M_3 = 300 GeV ; $M_{gluino} = M_{squark}$

$M_{1,2,3}$ = soft SUSY-breaking parameters in gaugino sector

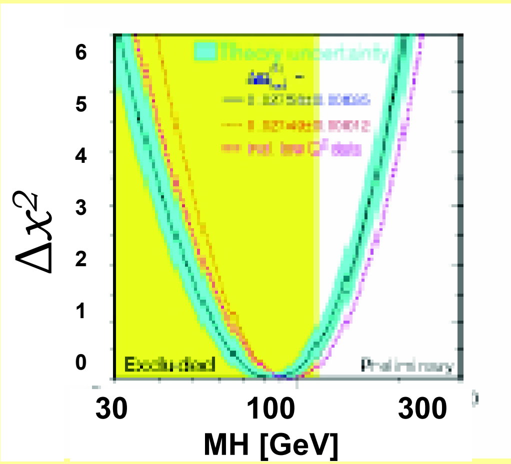
x^2 Scan in the Lightest Higgs Mass M_h

- **Determine the MSSM parameter set which minimizes x^2 , *for a given M_h***
- **Minimum x^2 of the scan is between:**

  110 GeV < M_h < 125 GeV



Comparison to SM



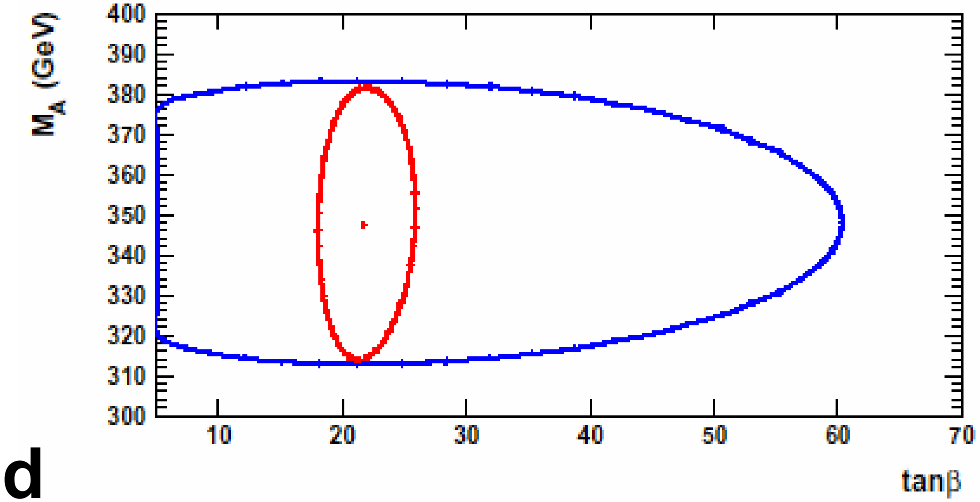
Nicely illustrates potential of external constraints to restrict allowed parameter space

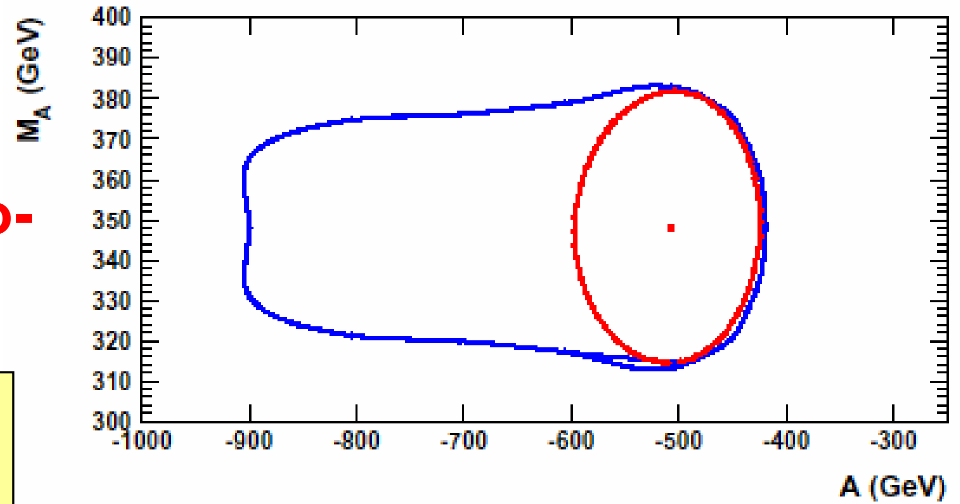
Early Work...just for illustration!

- **Scenario: Assume LHC discovers**
  - **the stop,**
  - **heavy higgs H/A,**
  - **light higgs h**

- **Model Parameters constrained from**
  - **experimental direct observation alone**
  - **including low-energy and electro-weak constraints**

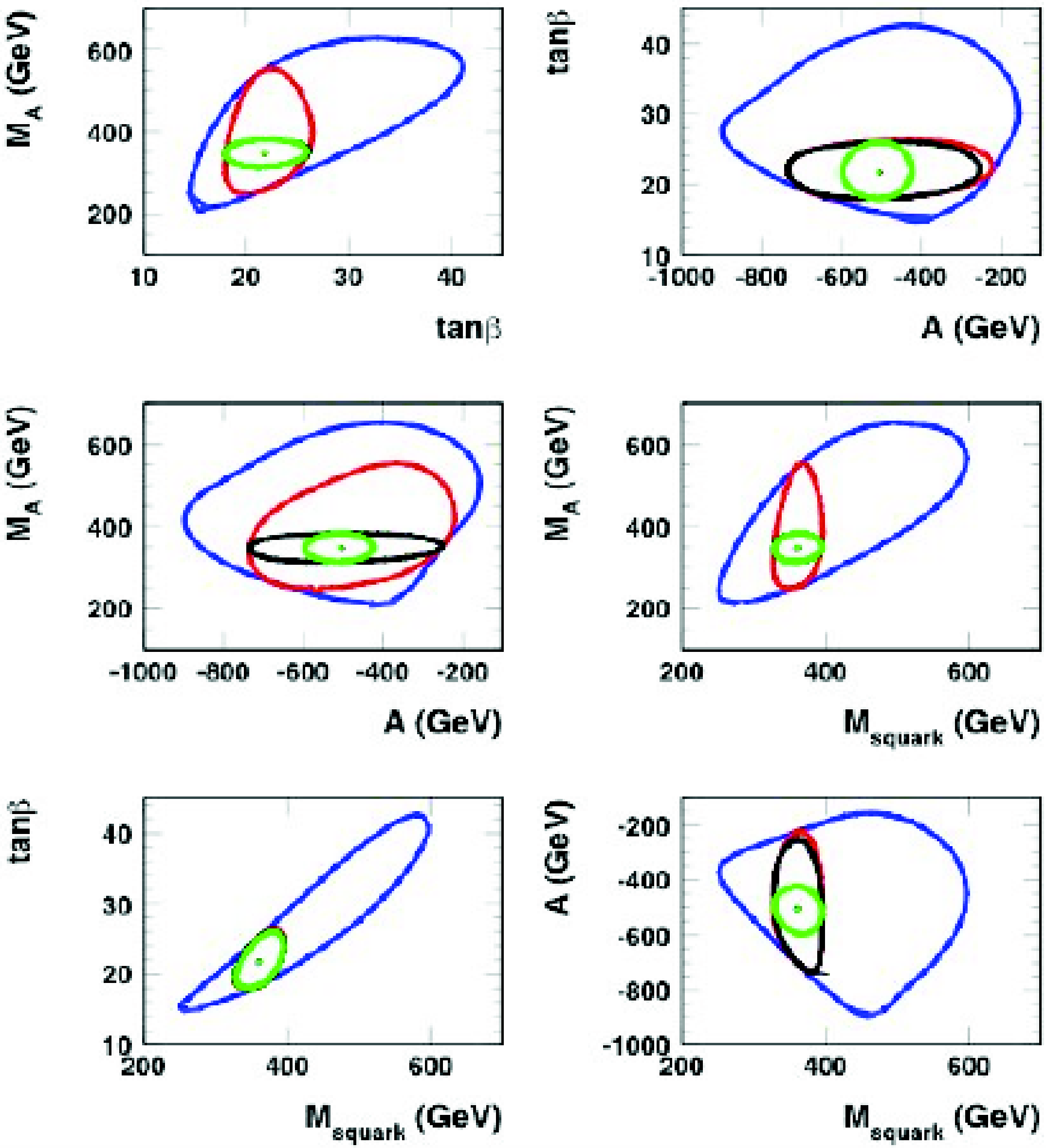
Including LE and EWK constraints facilitates the determination of fundamental MSSM parameters





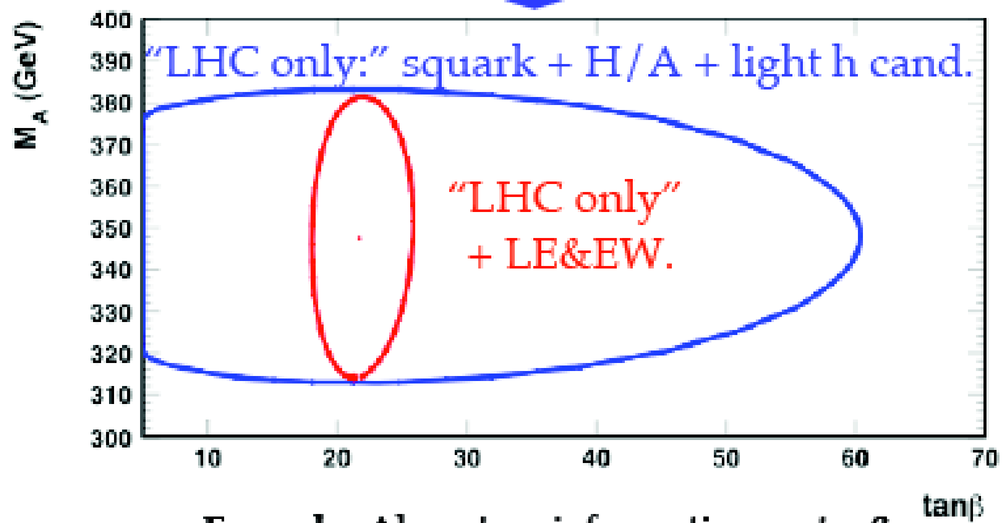
Tan β and A much less determined without applying SM constraints!

Interpretation & Consistency



- LE&EW: low-energy (LE) and EW constraints
- LE&EW + squark candidate
- LE&EW + squark cand. + H/A cand.
- LE&EW + squark + H/A + light h cand.

Including LW&EW constraints facilitates the determination of fundamental MSSM parameters



Example: Almost no information on tanβ without external constraints. Note that a direct measurement of tanβ is very difficult at the LHC

Illustrative Example