# Report from the BSM group

On behalf of the BSM group

Conveners: M. Nojiri, T. Plehn, G. Polesello

# Introduction

Two main issues for SUSY studies with the impending arrival of the LHC data:

- Make sure that we will discover it, if it exists
- Once a deviation from the Standard Model is observed, develop a strategy for understanding the origin of the observed deviation

The first issue is dominantly an issue of being able to predict correctly the Standard Model backgrounds in the kinematic region where we expect SUSY to show up

These issues were mostly tackled in the SM group

During the workshop we had a stimulating meeting between ATLAS and CMS physicists with exchange of views of techniques for measuring Standard Model background from data

Work on simulation of top backgrounds together with top group (M. Tytgat, F. Moortgat)

PDF uncertainty on top background estimates studied by D. Tovey and C. Gwenlan

Work in BSM group mostly concentrated on what is sometimes referred to as the "inverse problem"

# Strategies for model reconstruction

Three main lines of investigation:

- Development of measurement techniques on simulated data: work on two classes of models giving Dark Matter through either light slepton exchange/coannihilation or higgsino mixing in LSP candidate

  1. Generic novel techniques, typically on our well worn favourite toy: SPS1a
  2. A closer look to mSUGRA focus point/ comparison with split-SUSY models
  3. Measurement for CMSSM models with Non Universal Higgs Masses (NUHM)

- Based on the expected measurements, development of techniques for matching the measurements with a generic MSSM-like model

  1. "by hand", progressively reducing the parameter space
  2. Global $\chi^2$ incorporating all of the measurements
  3. Bayesian/Markov chain methods

These two groups of topics are intertwined: once you have a set of measurements available for a given model you can try to analyse them with the different methods.

An exercise spanning the two subjects is the blind SUSY analysis proposed by S. Muanza

- Development/comparisons of model tools for SUSY/Dark Matter

  1. Off-shell effects
  2. Uncertainties in spectrum computations
  3. Dark matter with CPV (S. Kraml)
  4. Dark Matter in NMSSM
  5. Incorporation of direct detection cross-sections into Micromegas (A. Pukhov)
  6. GMSB scans
  7. Dirac gauginos (K. Benakli): Well studied model, but no phenomenology yet available
  8. Development of a consistent interface for EW precision calculations, low energy observables, SUSY codes (Buchmuller, Cavanaugh)
  9. Discussion sessins on SLHA2 Accord

# Studies based on full reconstruction of decay chain

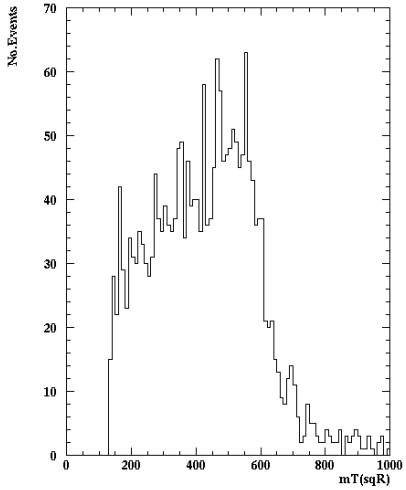
Dan Tovey
Study production $pp \to \tilde{q}_R \tilde{q}_L$.

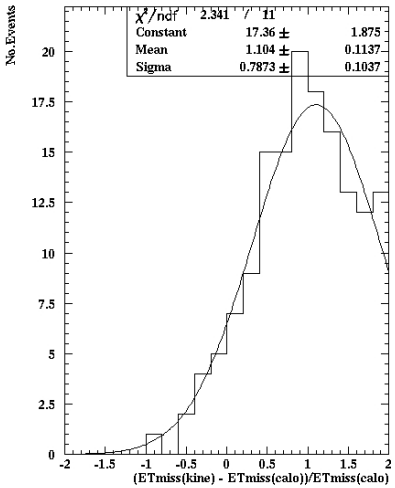
From the chain:

$$\tilde{q}_L \to q\tilde{\chi}_2^0 \to \ell\tilde{\ell}_R \to \tilde{\ell}\tilde{\chi}_1^0$$

reconstruct the momentum of the $\tilde{\chi}_1^0$ and subtract neutralino $p_T$ from $\not{E}_T$. Build the transverse mass of the jet from the $\tilde{q}_R$ side with the obtained quantity

Observe Jacobian shape from $\tilde{q}_R \to \tilde{\chi}_1^0$ decay




Take 4-lepton events, and reconstruct on both sides the $\tilde{q}_L$ decay chain

Compute the "kinematic" $\not{E}_T$, and compare it to "calorimetric" $\not{E}_T$. If different, neutralinos have decayed in the detector

Example: fractional difference of two $\not{E}_T$ definitions whem adding 50% of energy of 1 neutralino in each event to calorimetric $\not{E}_T$

# Z-bosons in mSUGRA

- In SPS1a mass of $\chi^0_{3,4}$ is hard to measure.
- We saw that transverse mass of $(Z \to \ell\ell, \not{E}_T)$ and $P_T(Z \to \ell\ell)$ coming from $\chi^0_{3,4}$, $\chi^\pm_2$ or $\tilde{t}_2$ are sensitive to their masses.
- Channels are
  - $\tilde{q}\tilde{g}$ with $\tilde{q} \to \chi^0_{3,4} + jet \to Z + \chi^0_1 + jet$
  - $\tilde{q}\tilde{g}$ with $\tilde{q} \to \chi^\pm_2 + jet \to Z + \chi^\pm_1 + jet$
  - $\tilde{t}_2 \to Z + \tilde{t}_1$
  - $\tilde{g}$ pairs?
- Backgrounds after cuts are SUSY, $ZZ$-jets production, other...
- Also look at Focus Point...

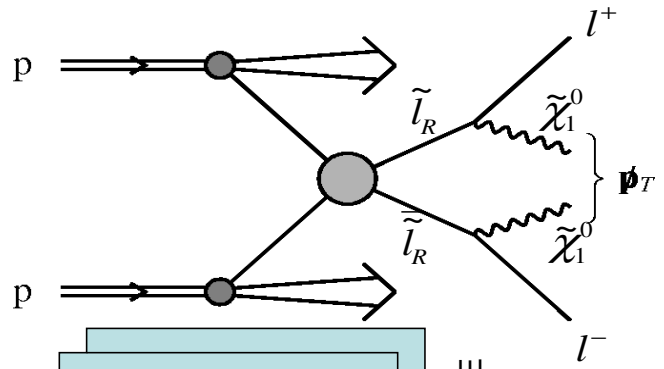
Rikkert Frederix / Emmanuel Turlay

# Matrix element study for sleptons

## DI-SLEPTONS

Only one approach (analytic M.E. with numerical integration) is shown on this slide. Two other approaches are also being pursued: (1) brute force Herwig binned likelihood – much better for BG and EXPTL cuts, and (2) "optimal observables".

**Contact persons: Alan Barr, Christopher Lester, Steffen Schumann**




Sherpa Event Generation

Do this once only

Di-slepton events at fixed M1, M2, Spin

ALREADY DONE

DRIVES

**To begin with:**
Grid scan over **M1, M2, Spin hypotheses**

**Later:**
MCMC scan over **M1, M2, Spin, BG parameters**

TO BE DONE

**Joint event likelihood** calculator, using:

Sherpa
Phase Space Generator used as Numerical Integrator over x1 and x2 DOF

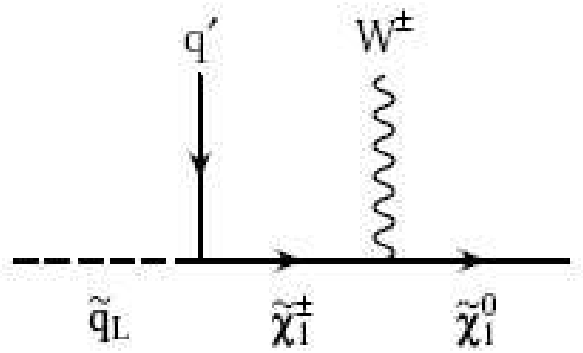
Sherpa Matrix Element

Custom calculation of phase space into ***OBSERVED*** components of event (integration over unobserved components)

ALREADY DONE

# Hadronic decays of massive bosons (MB) in SUSY

- The long neglected kid-brother of the di-lepton edge




Large backgrounds to reconstructing MB in SUSY events

Decay products in one jet:
Need to identify W and reject background

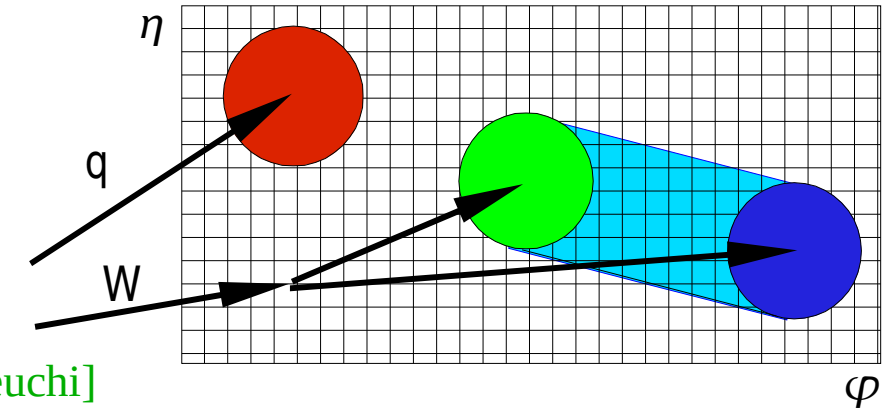
Structure of jets: mass, separation scale
Jet-algorithms: kT, Cambridge

[Butterworth, Raklev, Salam]

Decay products in two jets:
Need help in reducing SUSY combinatorics

Color connected jets:
Look at energy in region between jets

[Butterworth, Nojiri, Raklev, Takeuchi]



# Focus Point

M. Consonni, R. Lafaye, T. Lari, T. Plehn, G. Polesello, M. Rauch, E. Turlay, D. Zerwas

mSUGRA FocusPoint region: heavy scalars (~3 TeV) , 800 GeV gluino,
light neutralinos and charginos. Gluino decays mostly into $\chi^0$ tt, $\chi^0$ bb, $\chi^\pm$ tb

**Project: How well can we constrain the gaugino sector parameters?**
**Can we distinguish from other scenarii with heavy scalars (split SUSY) ?**

Possible LHC measurements (300 $fb^{-1}$):

1) $m(\chi^0_3)$ - $m(\chi^0_1)$
2) $m(\chi^0_2)$ - $m(\chi^0_1)$
3) $\sigma$ x BR ($\chi^0_2$ $\chi^\pm_1$ -> 3 leptons)
4) A3/A2
5) AZ/(A2+A3)

where

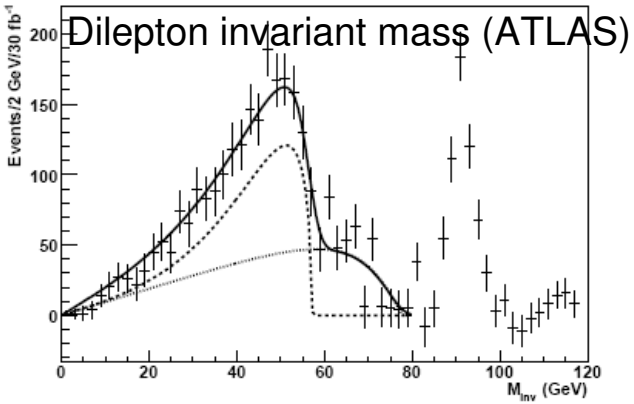
A2 = BR(g → $\chi^0_2$ → $\chi^0_1$ ll)

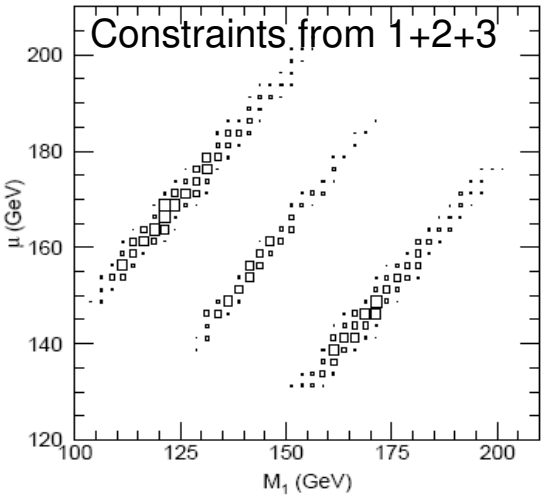
A3 = BR(g → $\chi^0_3$ → $\chi^0_1$ ll)

AZ = BR(g → $\chi^0_4$ → $\chi^0_3$ Z) + BR(g -> $\chi^\pm_2$ -> $\chi^\pm_1$ Z)

6) Nb/Nq = BR(g -> b X)/BR(g -> qX) [including quarks from gaugino and top, W, Z decays]
7) m(h)

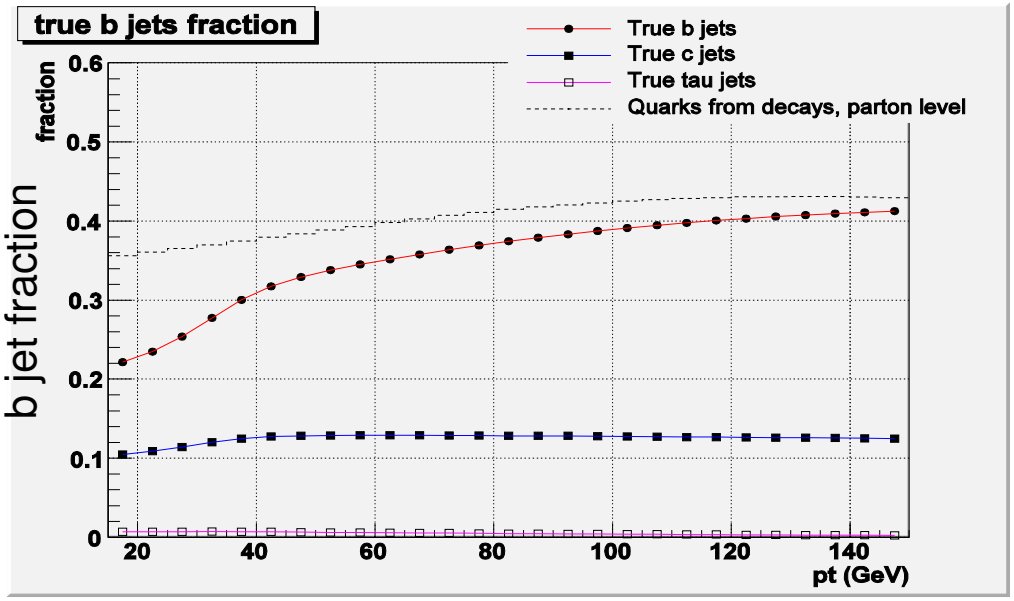
1+2+3+4: Already documented
5+6: investigated during this workshop



Measure the fraction of b jets in SUSY events:

- Reject/correct SM contamination: EtMiss+jets+2lepton cuts, with lepton flavour subtraction
- Correct flavour tagging efficiency (should be known to a few %)
- Reject jets from ISR (reject low Pt and high η jets, correct residual contamination from MC)
- Dependence of true fraction of b quarks in SUSY decays on pt cut (slope of dashed line) – somewhat dependent on SUSY point…





During the workshop, most of the new measurements including ratios of BR's and cross-sections have been Implemented in SFitter

# NUHM studies

M. Consonni, N. Kanaya, T Lari, G Polesello, S Sekmen, M Tytgat, A Raklev, M. Nojiri

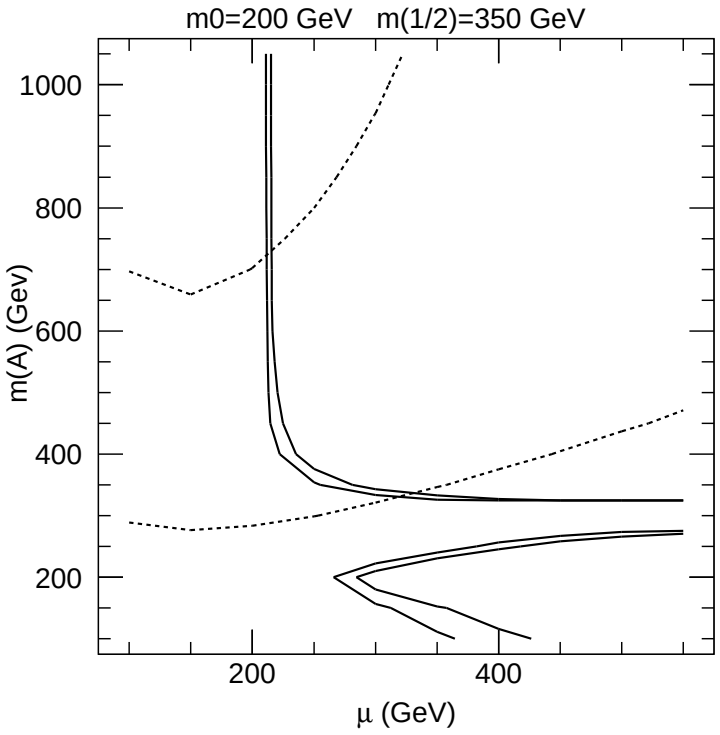
In mSUGRA masses of sfermions and of higgs boson determined by same parameter $m_0$

In NUHM models two new paramtrs: masses of two Higgs at high scale

Can ne traded for $m(A)$, $\mu$ at soft scale

By varying the values of $\mu$ and $m(A)$, for each $(m_0, m_{1/2})$ point can find set of parameters obeying dark matter and $B \to s\gamma$ constraints

Typically two solutions: $m(A)$ resonant with neutralinos, or $\mu$ giving adequate higgsino admixture in LSP for annihilation

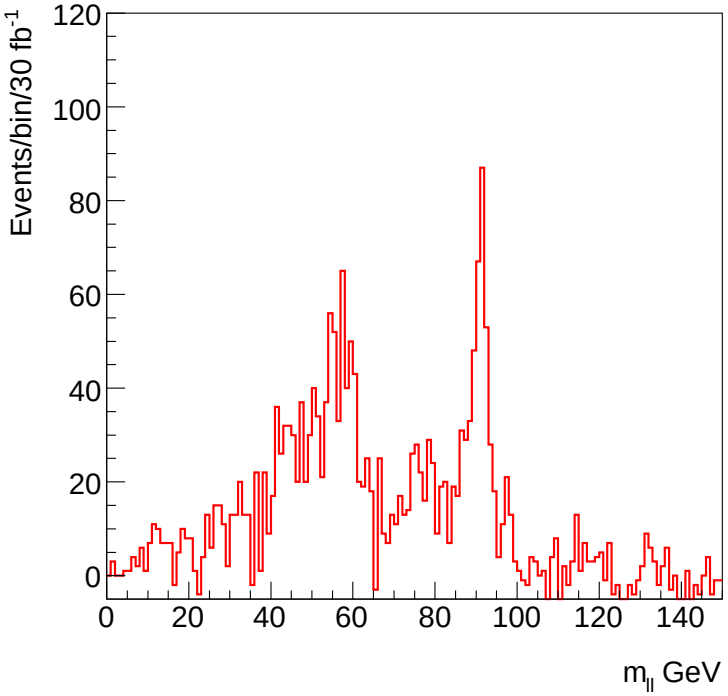



Situation with highly mixed gauginos in SUGRA only present for very high $m_0$

Selected 4 NUHM points with squark/gluino masses smaller than 1000 GeV for detailed study

Develop a measurement program not based on the pre-knowledge of decay chains

Statistics of 200k events per point (10-30 $fb^{-1}$) produced in Les Houches




Starting point is invariant mass of two leptons opposite-sign same-flavour

Observe rich structure due to mixed nature of neutralinos

From info derived from this distribution start constraining the possible range of models

Rich analysis program in development

# Other topics

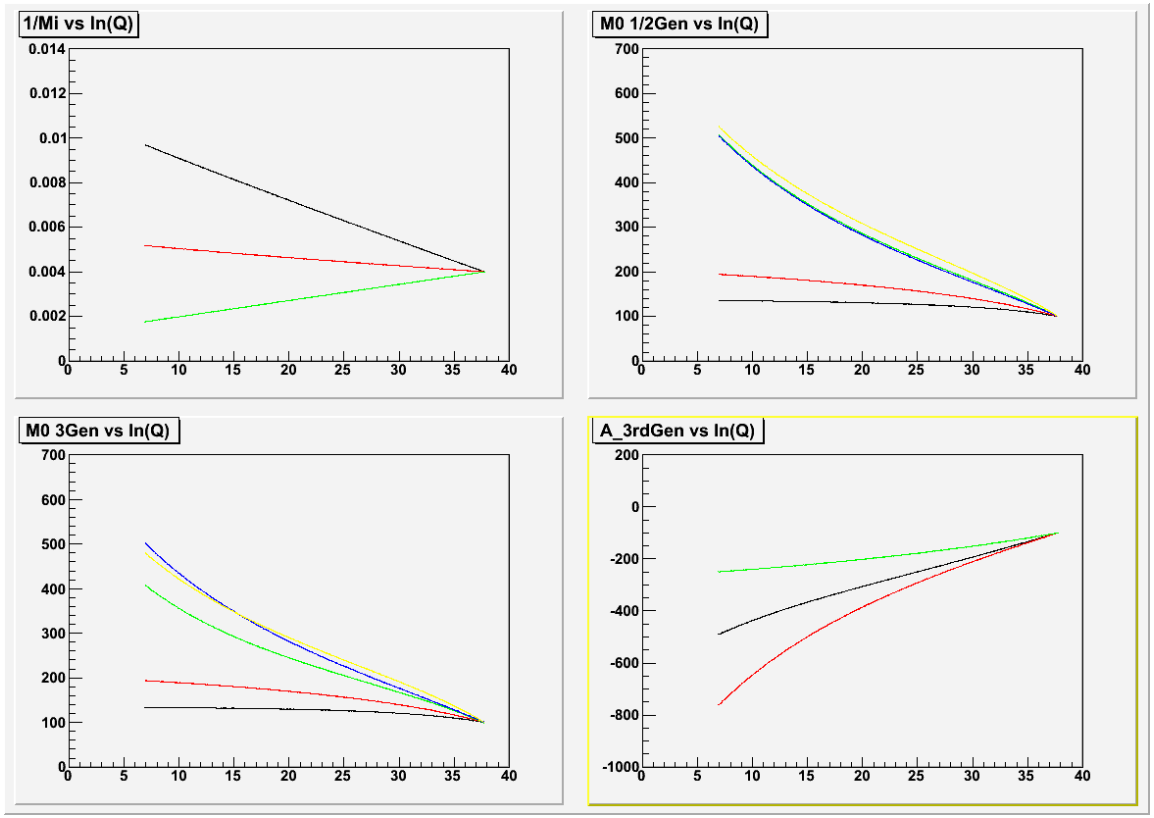
Other ideas for measurements discussed here

- Incorporation of stop/sbottom measurements for SPS1a into Sfitter, and constraints on low energy sector ( Nojiri, Plehn, Polesello)
- SPS1a-like decays in nMSSM, where $\tilde{\chi}_1^0$ decays into singlino and soft leptons (Kraml, Raklev)
- Study of direct production of light stop with stop deacaying 4-body (Kraml, Polesello, Raklev, Skands)

# SFitter: From the LowScale MSSM to the GUT Scale

**SFitter + Jean-Loic Kneur**

- **SPS1a: measurements**
- **determine MSSM parameters at 1TeV (EWSB)**
- **run up to the GUT scale**
- **see unification (or not)**




- **Using nominal values: works**

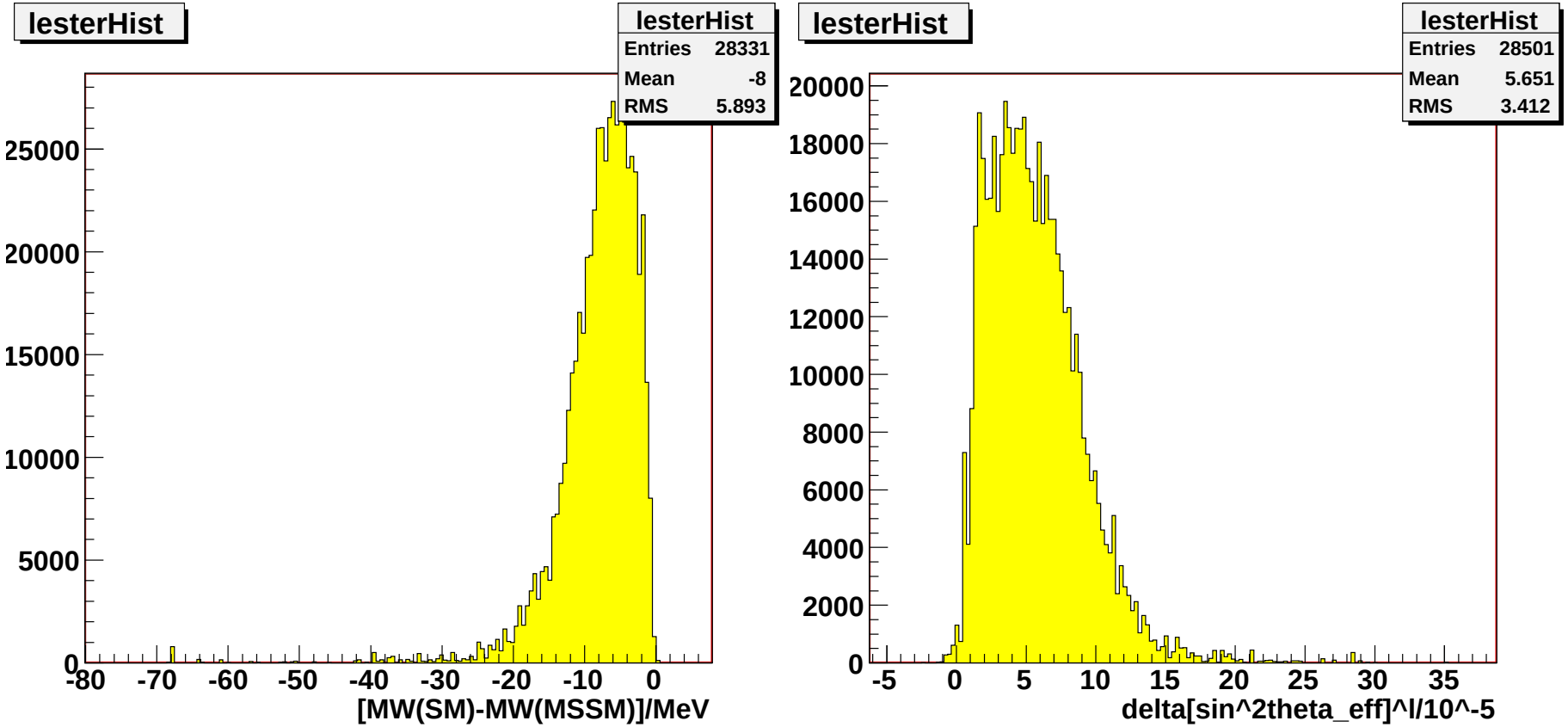
**To be done:**

- **sensitivity to exp and theoretical errors**
- **influence of undetermined parameters**
- **influence of systematic shifts of MSSM parameters at EWSB**
- **and more……**

# mSUGRA Bayesian study

B. Allanach, C. Lester

Estimate of the mSUGRA contribution to $M_W$ and $\sin^2\theta_W$ from a Bayesian scan of mSUGRA parmeter space (flat priors)



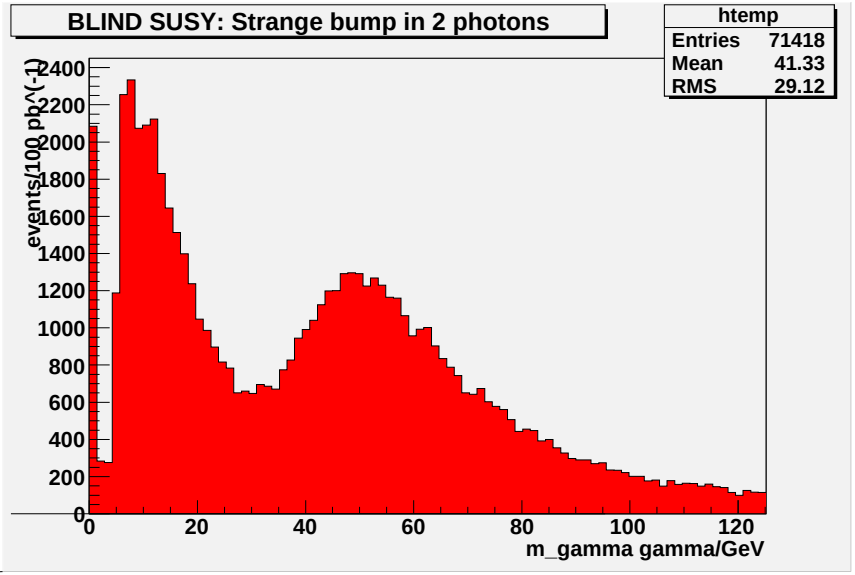
# Blind SUSY search

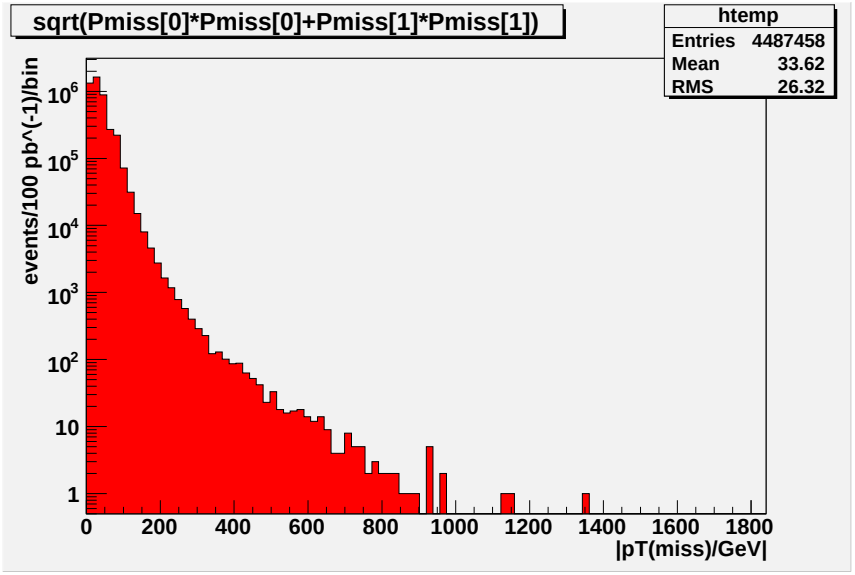
Analysis proposed by S. Muanza, who generated in fast simulation a full background set for 100 $pb^{-1}$ with a mystery SUSY model mixed in

Some preliminary plots produced during the workshop (B. Allanach):

Left: photon-photon invariant mass. Structure from generation cuts?

Right: ptmiss distribution. Seems larger than expected from SM



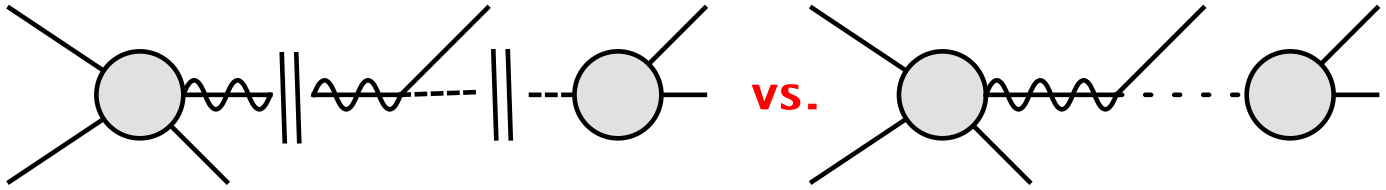



Models/tools

# Off-shell effects

M. Gigg, N. Kauer (contact), T. Plehn, P. Richardson, C. Uhlemann

**▶ on- vs. off-shell intermediate states in SUSY cascades**




- study of processes with cascade decays in (modified) SPS scenarios
- off-shell vs. nonresonant and interference effects
- guidelines when off-shell effects can be important
- prescriptions for off-shell-improved predictions

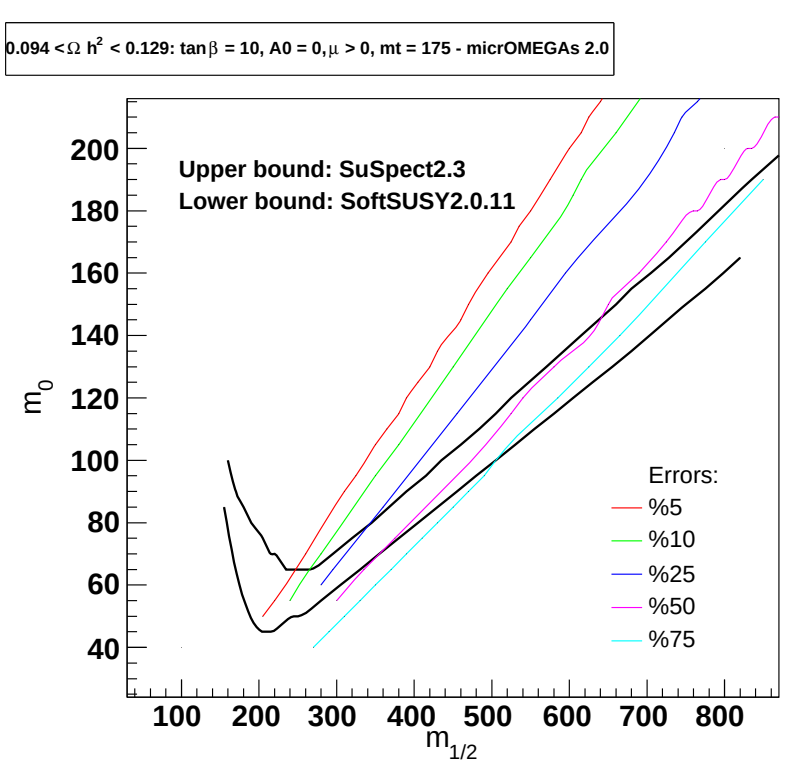
# Comparison of different SUSY codes

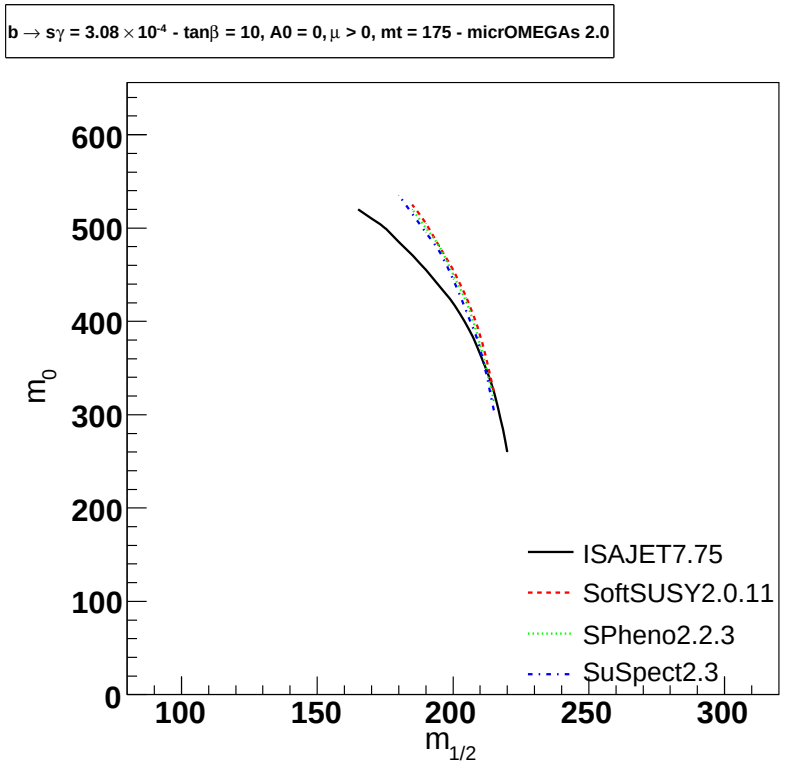
S. Kraml, S. Sekmen, B. Allanach, C. Lester, P. Zalewski

Compare for different RGE codes predictions for neutralino relic density.

Black lines are the extreme $1\sigma$ limits, coloured lines, percentage sped among programmes

Similar study for BR($b \to s\gamma$) (right)



# SLHAio, SFitter, Precision Constraints

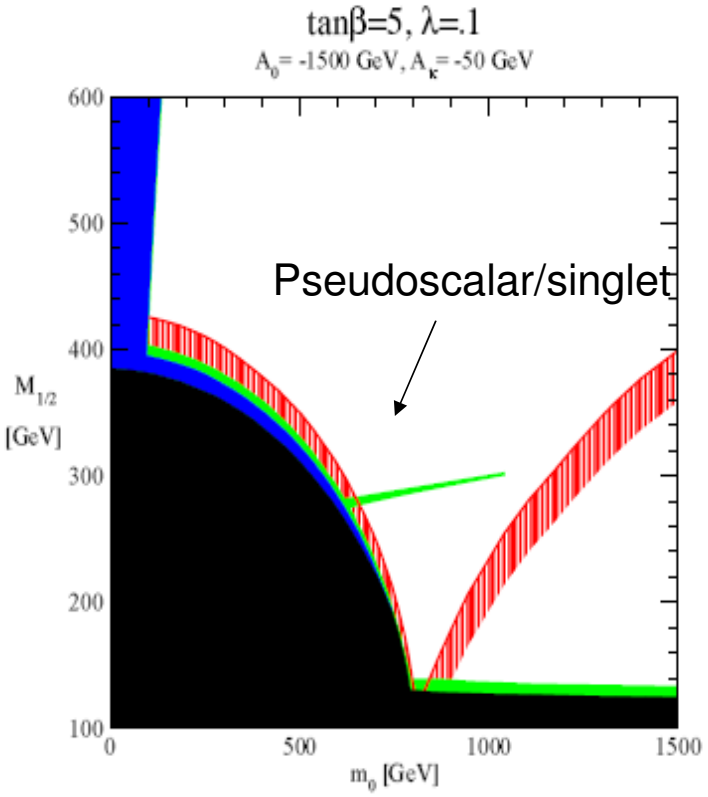
(S. Kreiss, R. Lafaye, T. Plehn, M. Rauch, D. Zerwas)

- SLHAio:
  New library which provides
  - Easy-to-use implementation of reading/writing SLHA files (v1 and v2)
  - Direct mapping onto program-internal variables
  - Fast connection between linked programs
  - Bindings: C/C++, Fortran
- Precision Constraints for SFitter:
  - The usual set:
    Electro-weak Constraints: $g_\mu - 2$, $M_W$, $\sin^2\theta_W$, $\delta\varrho$, ...
    Flavour Constraints: $b \to s\gamma$, $B_s \to \mu\mu$, ...
    Dark Matter: $\Omega h^2$
  - Fuzzy limits for observables with exclusion limits
  - Assess effect on constraining MSSM parameter space,
    when future LHC data is also taken into account

# CNMSSM and Dark matter

- CNMSSM : 7 par. model: MSSM+2
- NMSSMTools ---RGE + SUSY spectrum
- micrOMEGAs – relic density.
- Many features of MSSM +
  - Annihilation near pseudoscalar/singlet
  - Singlino LSP

- Higgs singlet can be light (~200GeV) but couplings are suppressed
  - Decays into b and tau
- SUSY spectrum rather light and MSSM-like – LHC good discovery potential
- If cannot see the singlet and assume MSSM will conclude that relic density is much too high – need to search for pseudoscalar
  - At small tanβ – difficult
  - At large tanβ – harder than in MSSM but estimate that LHC could reach




G. Belanger, C. Hugonie, A. Pukhov

# GMSB scan: SoftSUSY & $\mu\Omega$s

$4d \rightarrow (2d)^2$ "super scatter" plot

SoftSUSY: RGE

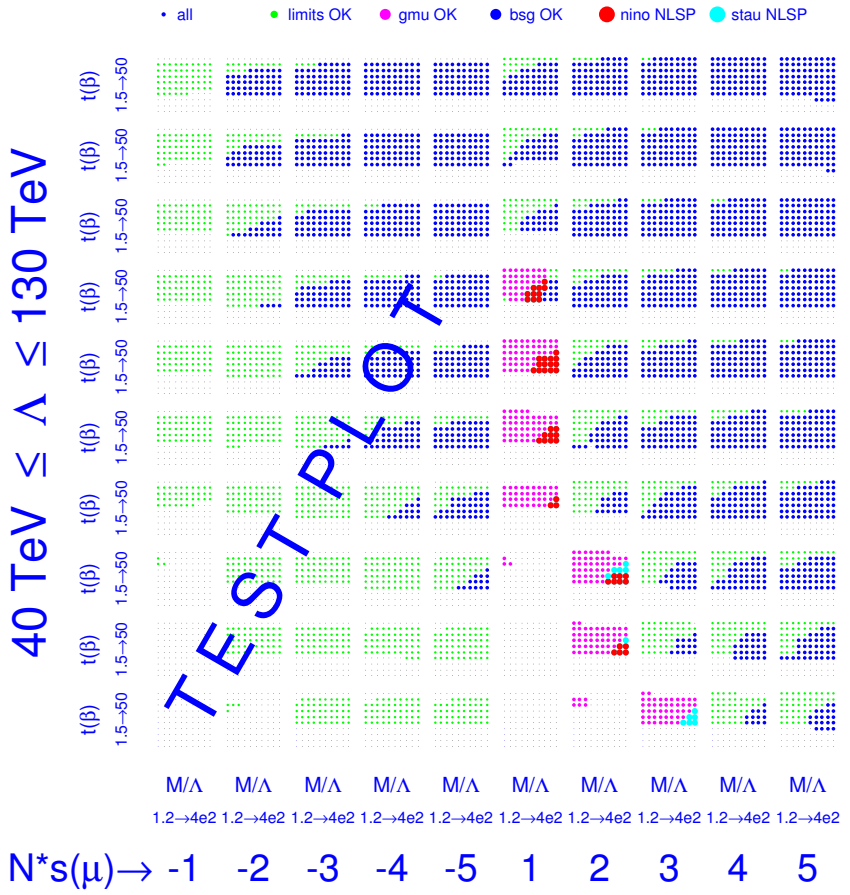
micromegas: $b \rightarrow s\gamma$, $(g-2)\mu$

($\Delta\rho$?, the rest does not constrains)

$\Lambda = 40, 50, \ldots, 130\text{TeV}$
$N \cdot \text{sign}\mu = -1, -2, -3, -4, -5, 1, 2, 3, 4, 5$
$\tan\beta = 1.5, 2, 3, 5, 10, 15, 20, 30, 40, 50$
$M/\Lambda = 1.2, 1.5, 2, 5, 10, 20, 50, 100, 200, 400$

limits OK: LEP limits & $mh > 110\text{GeV}$
gmu OK: $(10.5, 44.5) \cdot 10^{-10}$
bsg OK: $(3.05, 4.05) \cdot 10^{-4}$
nino NLSP: (gmu & bsg) OK & nino NLSP
stau NLSP: (gmu & bsg) OK & stau NLSP

Only positive $\mu$ light GMSB (gmu)
with large $M/\Lambda$ (bsg)
and moderate $\tan\beta$ (bsg)
is allowed.



# GMSB scan: bsg corrected

$4d \rightarrow (2d)^2$ "super scatter" plot

SoftSUSY: RGE

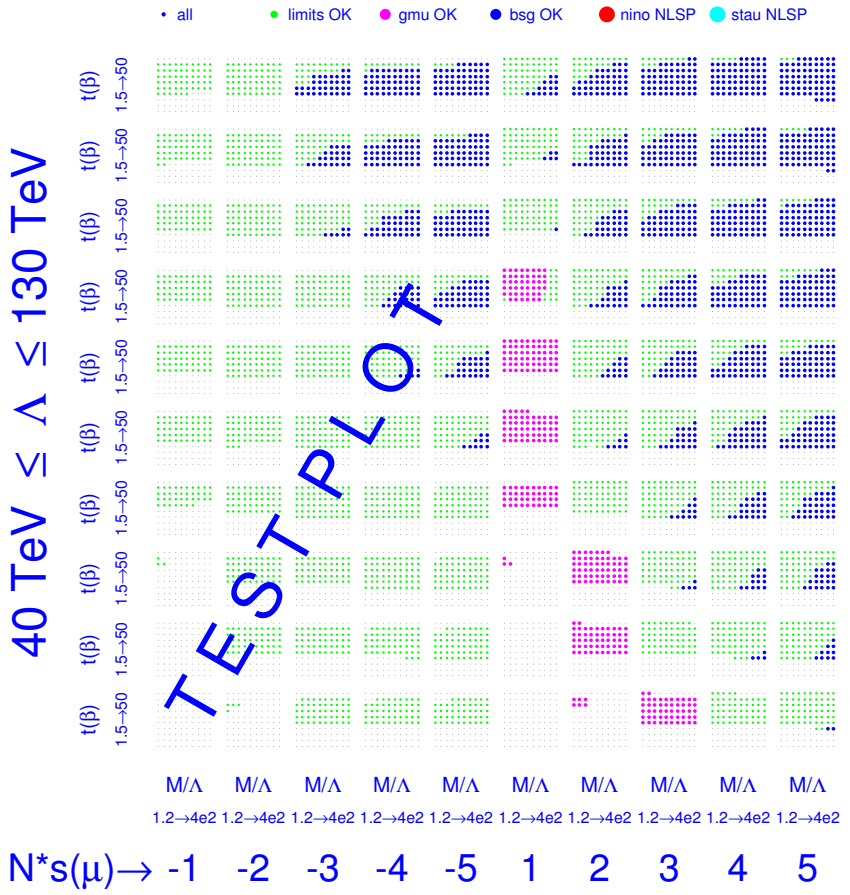
micromegas: $b \rightarrow s\gamma$, $(g-2)\mu$

($\Delta\rho$?, the rest does not constrains)

$\Lambda = 40, 50, \ldots, 130\mathrm{TeV}$
$N \cdot \mathrm{sign}\mu = -1, -2, -3, -4, -5, 1, 2, 3, 4, 5$
$\tan\beta = 1.5, 2, 3, 5, 10, 15, 20, 30, 40, 50$
$M/\Lambda = 1.2, 1.5, 2, 5, 10, 20, 50, 100, 200, 400$

limits OK: LEP limits & $mh > 110\mathrm{GeV}$
gmu OK: $(10.5, 44.5) \cdot 10^{-10}$
bsg OK: $(3.05, 4.05) \cdot 10^{-4}$
nino NLSP: (gmu & bsg) OK & nino NLSP
stau NLSP: (gmu & bsg) OK & stau NLSP

After correction of the (bsg) prediction by $(-0.35 \pm 0.23) \cdot 10^{-4}$ there is no allowed point left!



# Conclusions

Tilman had 4 transparencies for the introductory talk, and it took hin 15 minutes

I have 23 transparencies, essentially with plots/material produced during the workshop, and probably I have forgotten something (apologies...)

We hoped for a productive working meeting, from the numbers above it seems that at least something was done

Let's hope for correspondingly rich proceedings