Limitations of current Computer Tools

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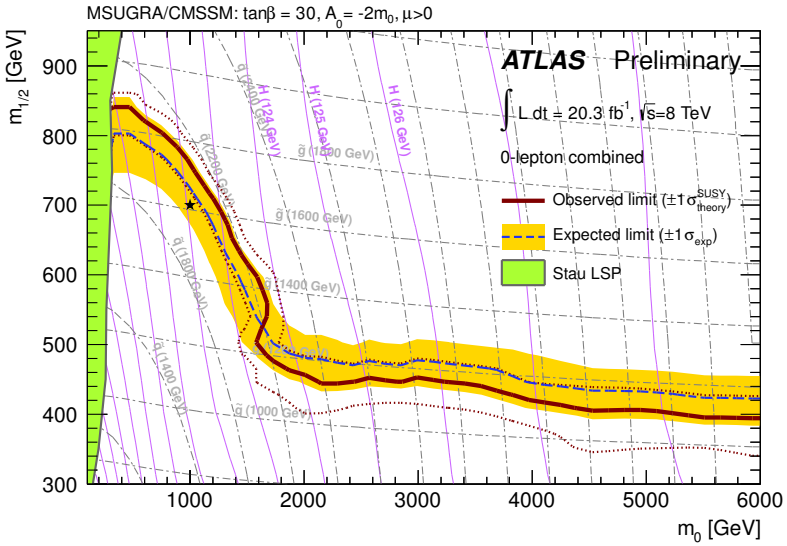
LHC, the first years

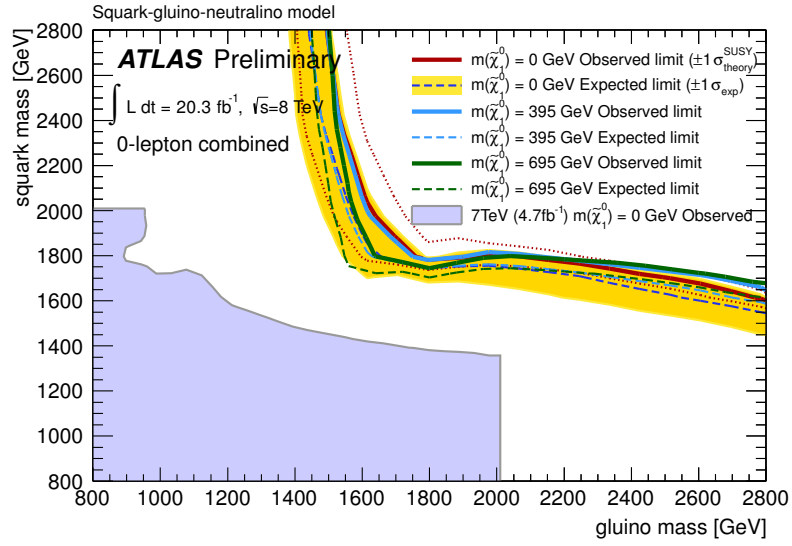
- discovery of a Higgs boson with $m_h \sim 125$ GeV, BRs SM-like
- no physics beyond SM (yet)

  e.g. jets + 0 l + miss. E_T (ATLAS-CONF-2013-047)

  mSUGRA/CMSSM



  simplified models



- however, ways out, e.g.
  - compressed spectra
  - strongly interacting particles (very) heavy but electroweakly interacting ones relativey light

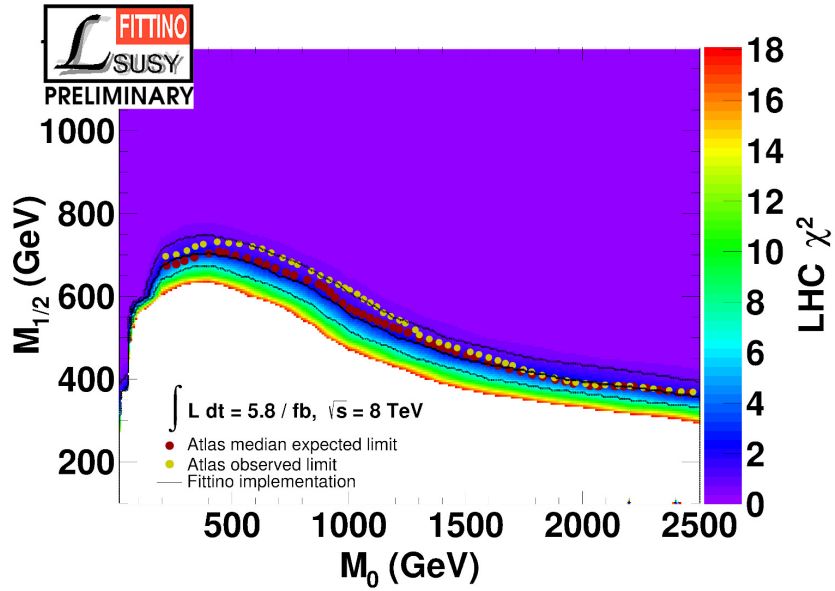
How are tools used?

first: calculation of spectrum, e.g. with SPheno

LHC

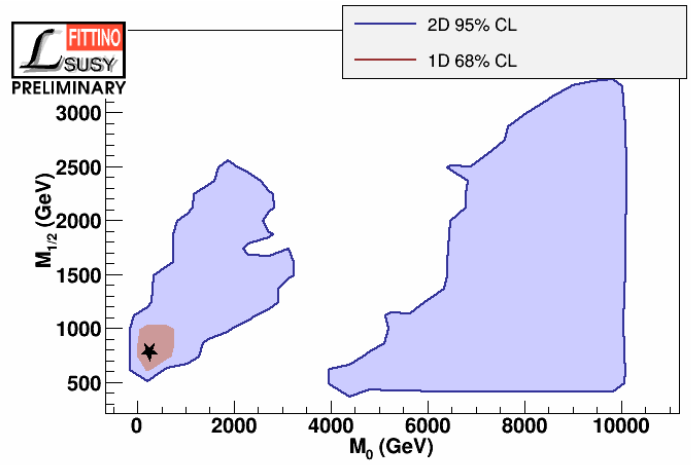
Grid in M_0 – $M_{1/2}$ produced using

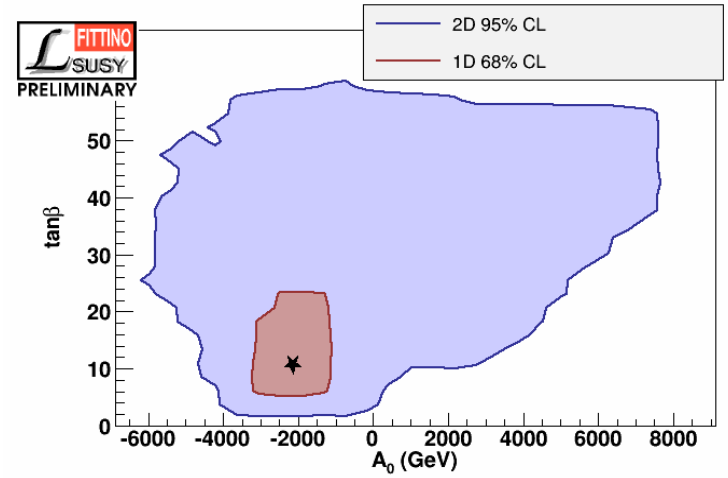
- ***Herwig++***
- ***Delphes***
- ***Prospino***



Simple Higgs implementation

Assuming again mh = (126 +- 2 +- 3) GeV





χ^2 / ndf
= 13.8 / 9

Higher masses / FP & Funnel-Region allowed due to floating of scale Q.

Better fit quality due to new measurement of b-> tau nu.

Limitations, the correct questions?

Purposes of computer tools (incomplete)

- to calculate spectra of BSM models (mainly SUSY):
  ISAJET, Softsusy, SPheno, SUSEflav, SUSPECT, ...
- code to generate spectrum generator code for specific models: SARAH
- to calculate cross sections, branching ratios of SM and SUSY particles:
  CALCHEP, COMPHEP, HERWIG, ISAJET, MadGraph, PHYTIA, SHERPA, WHIZARD
  Prospino, Resummino
  SPheno, SUSYHIT, SFOLD
  FeynArts, FormCalc
- specific for Higgs: FeynHiggs, CPsuperH, NMSSMtools, HFOLD, HDECAY
- dark matter: DarkSUSY, IsaTools, Micromegas
- low energy observables: SUSY_Flavor, SusyBSG, IsaTools, SPheno, SUSEflav, Micromegas
- communication: SLHA

ultimately: used to either confirm SM or find signals beyond SM + parameter determination

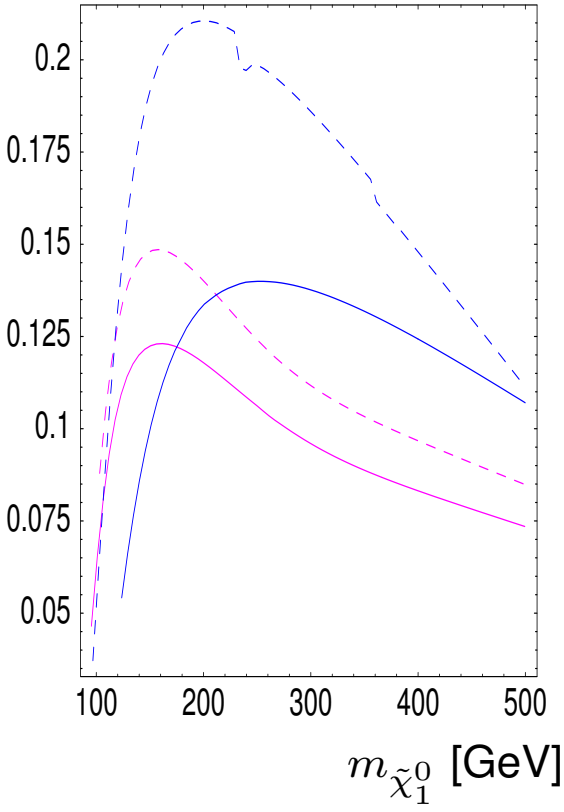
Limitations, cross sections

- Prospino: NLO but only total cross sections, overall K-factor but these are process dependent, e.g. $pp \to \tilde{q}\tilde{q}$ versus $pp \to \tilde{q}\tilde{q}^*$ and also flavour dependent
  work is going on in Aachen, Karlsruhe, Munich, ...
- most MC are tree-level, exceptions are: ALPGEN, MC@NLO + several for specific SM processes
- usually cascades are built up using narrow width approximation
  however CALCHEP, MadGraph, SHERPA, WHIZARD allow for up to $2 \to 8$ processes

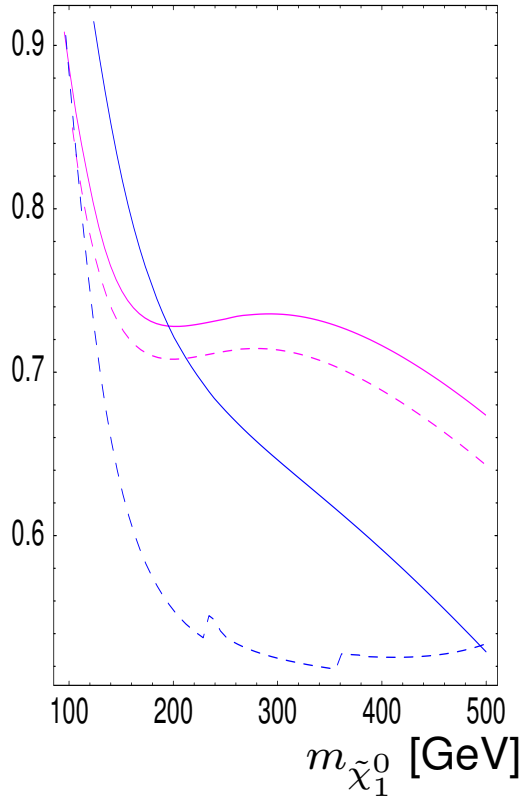
  fine for processes like $pp \to \tilde{t}_1\tilde{t}_1^* \to b\tilde{\chi}_1^+ t\tilde{\chi}_1^0 \to \ldots$ (agree within 3-5 per-cent) but becomes worse for gluinos

Limitations, full matrix element versus narrow width

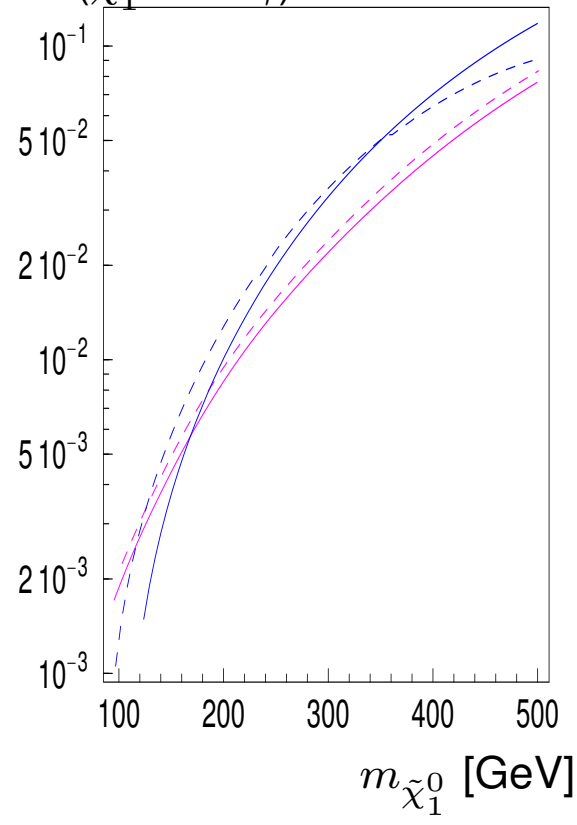
BR($\tilde{\chi}_1^0 \to \sum_i W l_i$)



BR($\tilde{\chi}_1^0 \to \sum_{ij} \nu_i \tau l_j$)



BR($\tilde{\chi}_1^0 \to \tilde{G}\gamma$)

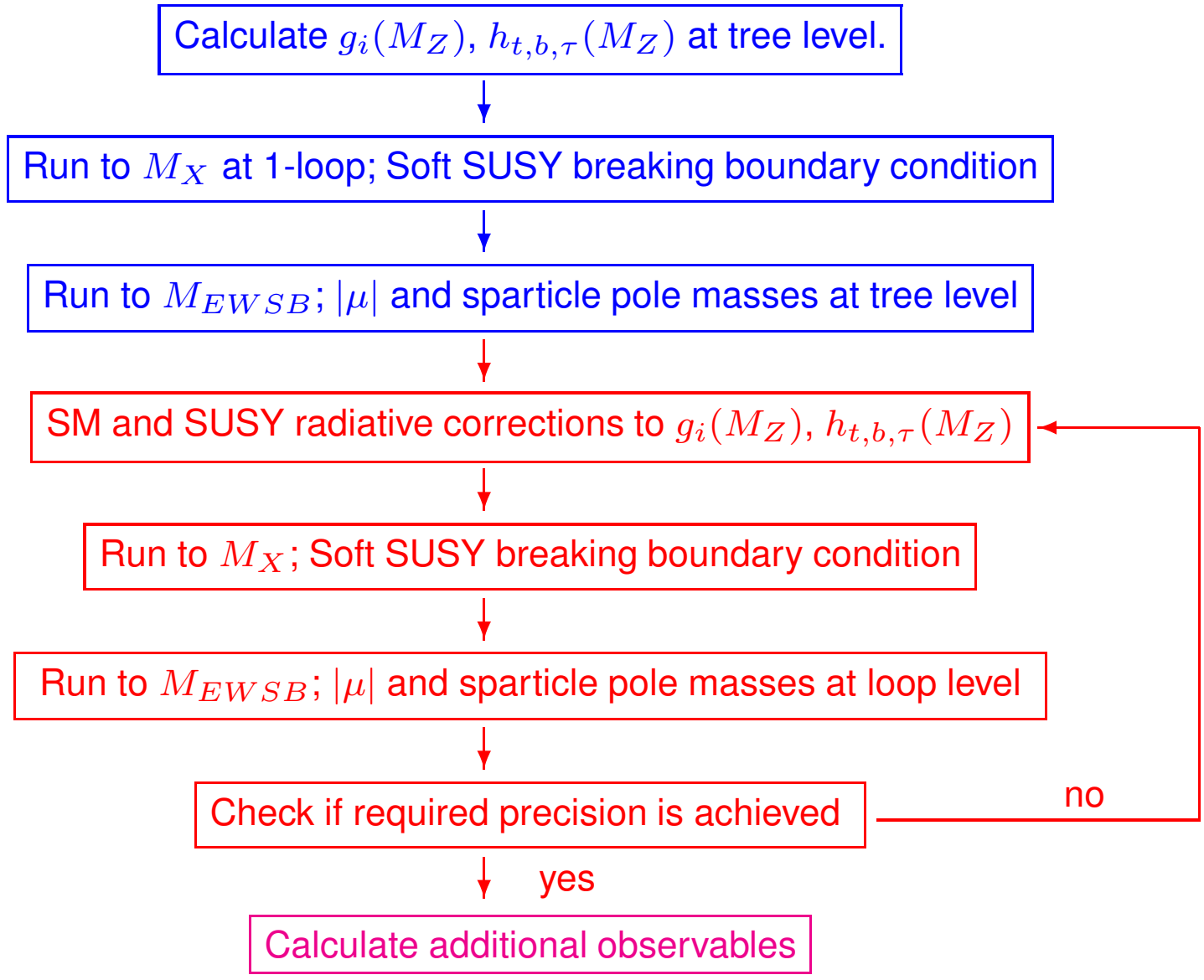


— $\tan\beta = 10$, $\mu > 0$, - - $\tan\beta = 10$, $\mu < 0$, — $\tan\beta = 35$, $\mu > 0$, - - $\tan\beta = 35$, $\mu < 0$

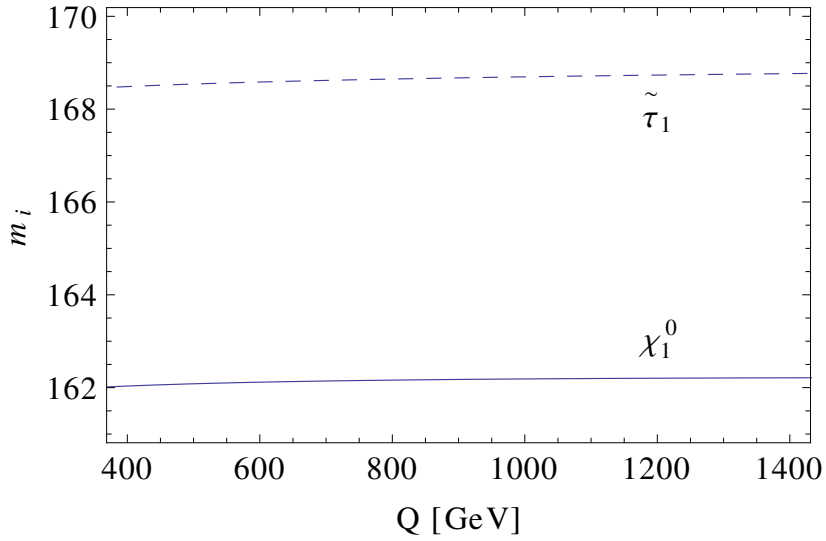
$m_{3/2} = 100$ eV, $n_5 = 1$ [M. Hirsch, W. P. und D. Restrepo, JHEP **0503**, 062 (2005)]

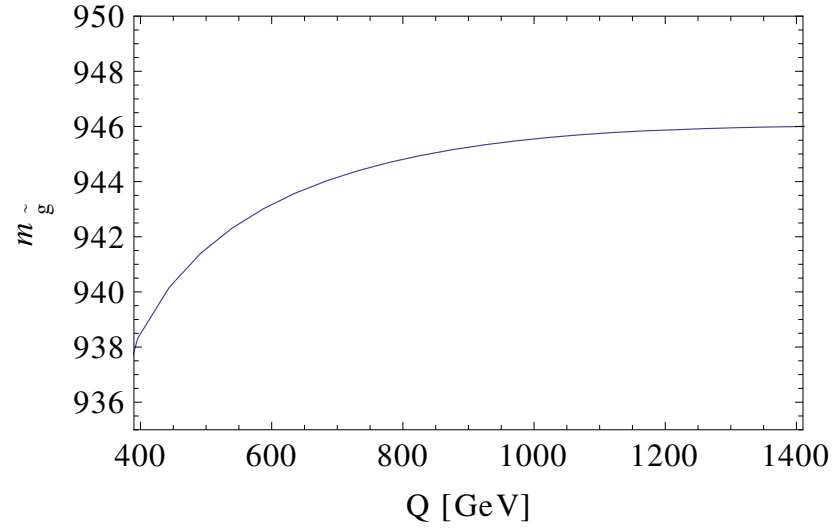
interferences?? e.g. $\tilde{\chi}_1^0 \to \mu^{\pm}\tau^{\mp}\nu_i$, see also N. Kauer hep-ph/0703077,arXiv:0708.1161

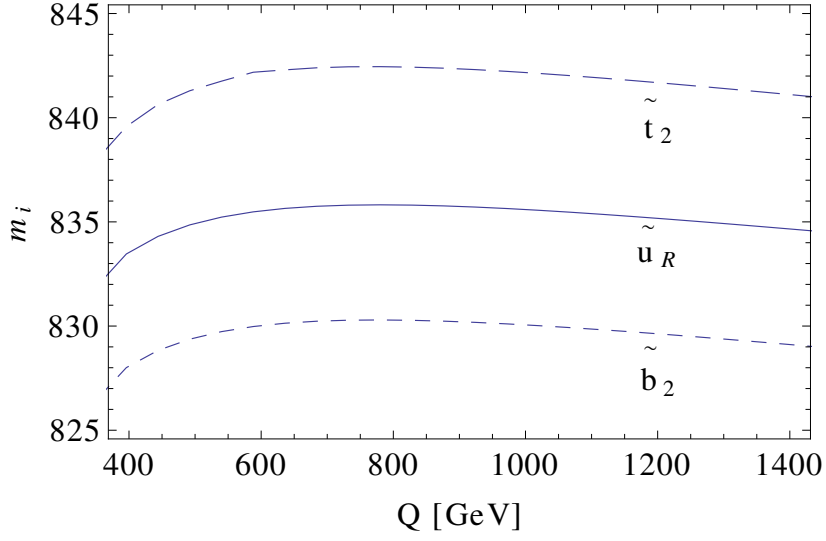
spectra, RGE codes schematic



Spectra, scale dependence as measure of uncertainties?







$M_{1/2} = 400$ GeV, $m_0 = 90$ GeV, A_0=0,
$\tan\beta = 10$, $\mu > 0$

But: taking gluinopole by S. Martin: $\delta m_{\tilde{g}} \simeq 15$ GeV at 2-loop

Limitations, spectra and non-collider observables

- which precision is needed for which purpose:
  - 2- and even 3-loop corrections are important in Higgs sector
  - 1-loop corrections are important for all SUSY particles
    - QCD corrections can be up to 30 per-cent
    - DM requires special mass constellations, often mass differences are very important

    what about 2-loop effects?
- larger masses require decoupling of particles at higher scales
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- low energy observables: usually Wilson coefficients calculated at m_Z or m_t
  decays like $b \to s\gamma$ are known to NNLO within SM but in SUSY only partially at NLO or even 'only' leading order
  proper treatment: calculate Wilson coefficients at scale(s) of SUSY particles + RGE evolution
  To which extent is flavour mixing included in the RGE running of the SUSY parameters

Preliminary summary

- LHC: either BSM rather heavy (at least QCD part) and/or compressed spectra
- SUSY spectrum calculations: within the (N)MSSM in principle in good shape but
  - proper treatment of multi-scale decoupling
  - 2-loop corrections might be important (for sure in fitting area)
  - no measures for theoretical uncertainties given

  but other extensions currently only/mainly SARAH
- proper calculation of $2 \to n$ processes ($n \leq 6$) including higher order(s),
- NLO corrections are process dependent and can affect distributions
- DM tools: higher order corrections only partially implemented
- low energy: mismatch between SM and BSM accuracies