What if the LHC does not find Supersymmetry (here: mSUGRA) by the end of 2011/2012?

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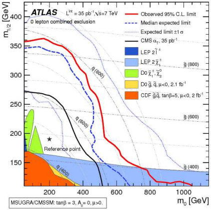
Rencontres de Moriond

1. Introduction and Methods

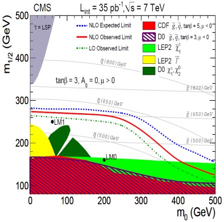
2. Fit Results

3. Model Independent Data from LHC, Model Dependent Fits

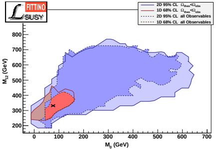
An Incomplete Overview of the Current Situation

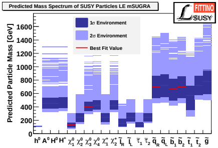


arXiv:1102.5290 [hep-ex]



arXiv:1101.1628 [hep-ex]





e.g. arXiv:0907.2589 [hep-ph]

- Does the non-observation of SUSY in the 2010 LHC searches agree with mSUGRA?
- If mSUGRA-like SUSY is realized, can we expect to discover SUSY in 2011/2012?
- If not, what are the implications for mSUGRA/SUSY and for Collider Physics?

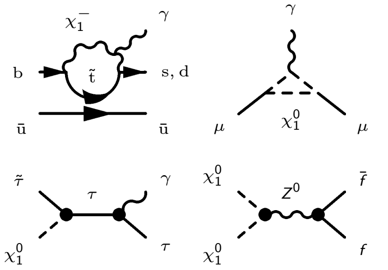
Confronting LHC Searches with Precision Data

- See PB et al. arXiv:1102.4693 [hep-ph]:
  Frequentist Markov Chain Global Fit of mSUGRA using NLO+NLL/Herwig++ predictions
- Fit with Fittino hep-ph/0412012, using also SPheno hep-ph/0301101, theory codes collected in Mastercode arXiv:0907.5568 [hep-ph], and HiggsBounds arXiv:0811.4169 [hep-ph]
- See e.g. also
  Buchmüller et al. arxiv:1102.3149 [hep-ph], Allanach arxiv:1102.4585 [hep-ph], Strumia arxiv:1101.2195 [hep-ph], Cassel et al. arXiv:1101.4664 [hep-ph] (list incomplete, just a snapshot)
- Many activities converging in LPCC meetings (e.g. http://indico.cern.ch/categoryDisplay.py?categId=2689)
  and many interesting discussions in the Terascale Alliance
  http://www.terascale.de/research_topics/rt1_physics_analysis/susy___bsm_fit_working_group/

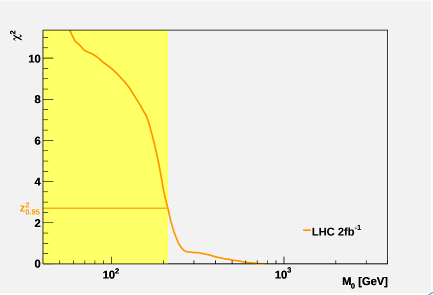
Confronting LHC Searches with Precision Data

- Multi-Messenger: Combine Information about SUSY from different sources
- For LHC: Do not only use the 95 % CL as a brick wall, but calculate $\Delta\chi^2$

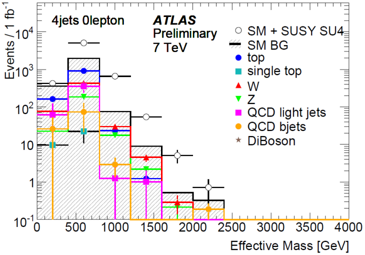
Processes sensitive to SUSY



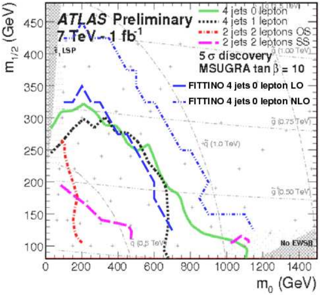
Combining χ^2 of LE and LHC



Implementation of an LHC Limit Projection

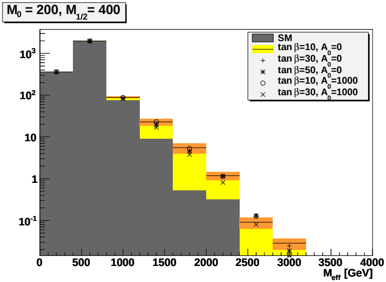


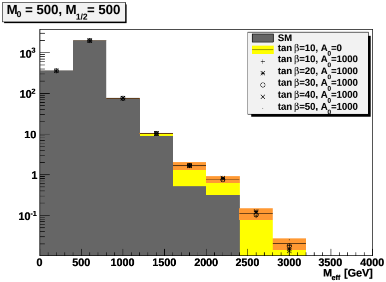
$$M_{eff} = \sum_i p_{T,i} + E_{Tmiss}$$



- Using the open parametrized detector simulation tool DELPHES `arXiv:0903.2225 [hep-ph]`
- Careful tuning against public ATLAS full simulation
- Implement the 4jet+MET cuts from `atl-pub-phys-2010-010` and generate a grid in $(\Delta M_{1/2} = 25\,\mathrm{GeV}, \Delta M_0 = 50\,\mathrm{GeV})$
- Use a bilinear interpolation to obtain the resulting M_{eff} spectrum

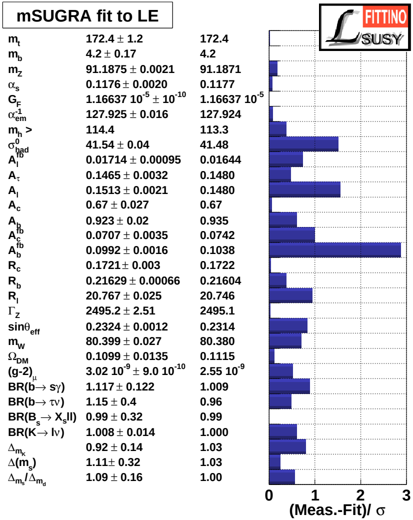
Systematic Check of the MSUGRA Parameter Grid



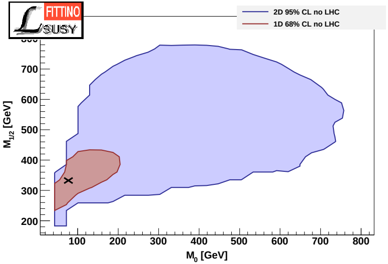


- Variations of the signal shape for different $\tan\beta$ and A_0 covered by systematic uncertainty
- This is specific for the 0ℓ search – more complicated grids would be necessary for other searches
- Based on the full M_{eff} distribution, calculate CL_{s+b} for the median background hypothesis
- Transfer CL_{s+b} into $\chi^2 = 2[\mathrm{erf}^{-1}(1 - 2\,CL_{s+b})]^2$

Pre-LHC knowledge about mSUGRA/CMSSM



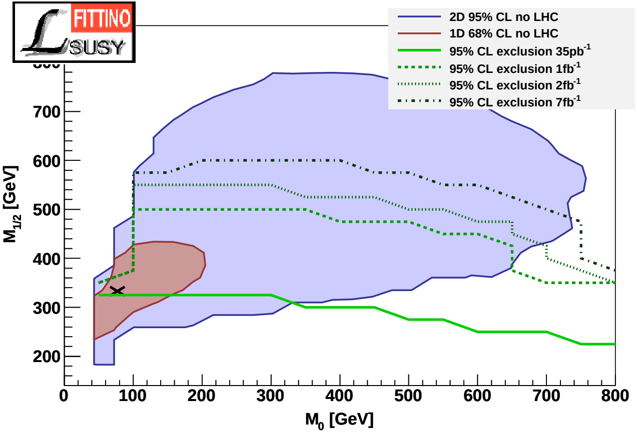
- mSUGRA Fit to measured observables



Parameter	Best fit value + Unc.
$\tan\beta$	12.8 ± 9.7
M_{12}	332.8 ± 88.6
M_0	$77.1^{+113.4}_{-30.6}$
A_0	426.2 ± 734.1
signμ	$+1$
χ^2/ndf	$20.4/21$

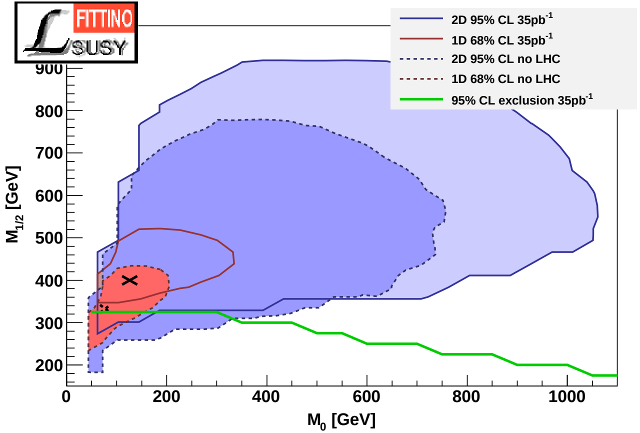
Projection: Low Energy Fit vs. Present and Future (?) LHC Exclusion

- Projection of how the LHC exclusion potential would evolve during the 7 TeV run compared to the LE data preferred region:



Combined Fit of real LE Data and Estimated Present ATLAS Exclusion

- Not surprisingly: Combined Fit allows a small area below LHC exclusion



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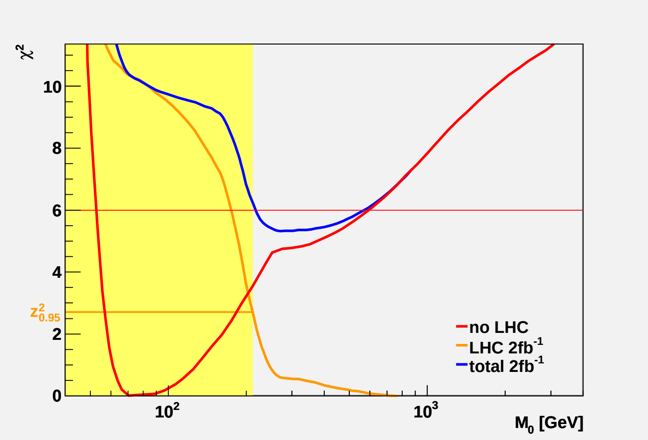
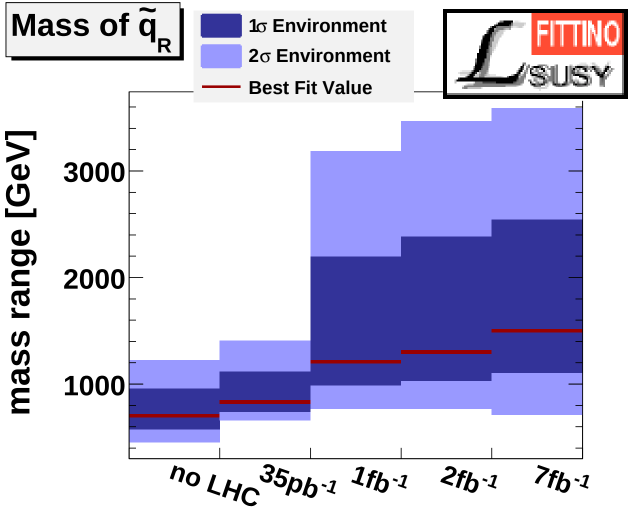


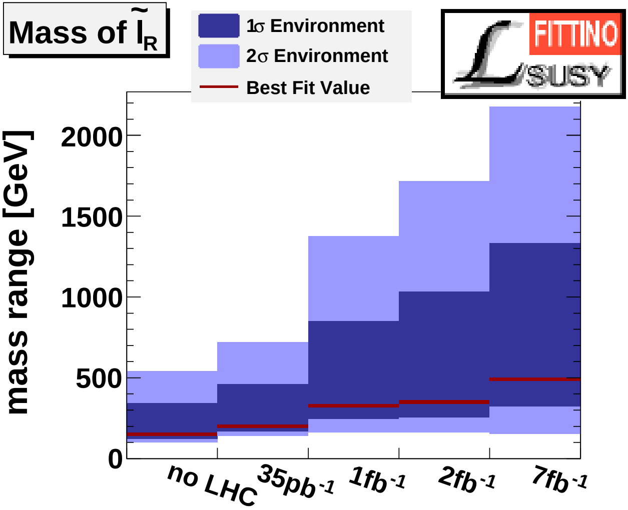
Outlook for the Coloured Sector

- Not so strongly model dependent



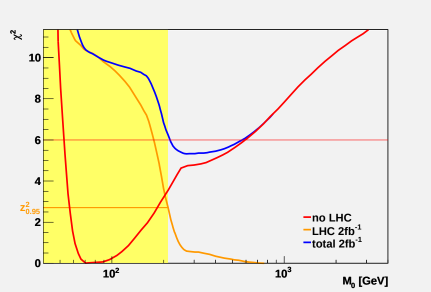
Outlook for the Non-Coloured Sector

- Strongly model dependent



Is there a Tension Building Up?

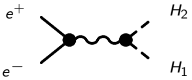
- LE prefers low mass scales (for non-coloured sector),
  LHC prefers high mass scales (for coloured sector)



$\mathcal{L}^{int}/\mathrm{fb}^{-1}$	χ^2/ndf	$\mathcal{P}-Value$
0	18.9/20	53.1 %
0.035	20.4/21	49.8 %
1	23.7/21	30.9 %
2	24.2/21	28.3 %
7	25.0/21	24.6 %

- Using the present systematic uncertainties on the background estimation (and ignoring fine-tuning), even mSUGRA will survive the 2011/2012 run.
  You may not find the model too attractive anymore, but that's an entirely different question

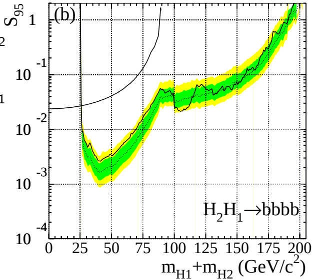
Why SUSY is different than e.g. the Higgs-Sector

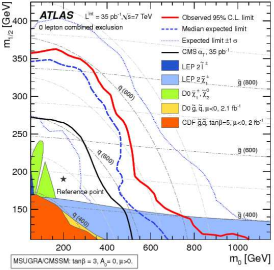


$S_{95} \equiv$

$\max(\cos^2(\beta-\alpha)$

$\times\mathcal{B}(H_i \to b\bar{b}))$





- Higgs Searches (at least at LEP) could be presented in terms of S_{95} for each signature separately, because the signatures can be nicely isolated experimentally: $hZ \to b\bar{b}\ell\ell$, $hA \to b\bar{b}\,b\bar{b}\ldots$
- Higgs: Only very few parameters: $m_h, m_A, \cos^2(\beta-\alpha)$, model-independent comparison with all possible models e.g. in

  PB et al. arXiv:0811.4169 [hep-ph]
- SUSY: incredibly complicated signatures possible, many masses and relations of couplings

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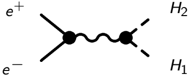

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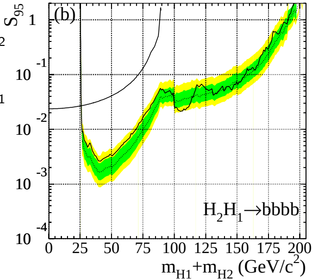

	Signal region A
QCD	$7\ ^{+8}_{-7}$[u+j]
W+jets	50 ± 11[u] $^{+14}_{-10}$[j] $\pm$ 5[$\mathcal{L}$]
Z+jets	52 ± 21[u] $^{+15}_{-11}$[j] $\pm$ 6[$\mathcal{L}$]
$t\bar{t}$ and t	$10 \pm$ 0[u] $^{+3}_{-2}$[j] $\pm$ 1[$\mathcal{L}$]
Total SM	118 ± 25[u] $^{+32}_{-23}$[j] $\pm$ 12[$\mathcal{L}$]
Data	87

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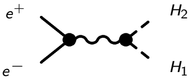

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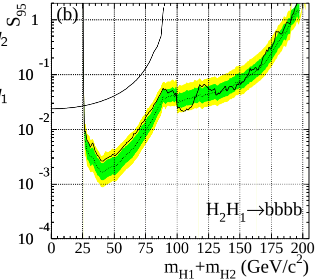

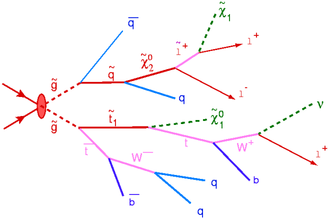

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Other Approaches to Parametrizations of Searches

- Obvious: For model independent results, everything has to be presented in terms of (pseudo)observables (e.g. M_{eff}, masses, couplings, . . .)

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- Obvious: For model independent results, everything has to be presented in terms of (pseudo)observables (e.g. M_{eff}, masses, couplings, ...)
- 95 % CL Limit on $\sigma \times \prod_i \mathcal{B}_i$ for a given signature
  - 95 % CL not very useful for global fits $\rightarrow$ need full CL_{s+b} space
  - Very high dimensional binning would be needed (many masses)
  - Can any given signature be isolated experimentally? If yes (e.g. $\ell\ell$ egde), much less sensitive for discovery or exclusion
- 95 % CL Limit on the number of events for a given selection
  - Simulation needed to determine number of events for any model prediction
- Distributions of b, d in discriminating variables corrected for detector effects, acceptances
  - Sounds nice, but probably impossible: Correction depends on many factors (many masses, couplings)
- 95 % CL Limit on "Simplified Model": see CL above, + not (yet?) proven that for each model point in a global fit there is a matching simplified model

Conclusion Based on Our Experience

- As obviously already done here and in many other approaches, and in the first papers by ATLAS and CMS: Publish distributions of b, d in any discriminating variable/regions not corrected for any detector effects or acceptances
- Determine s from a simulation for every model in an appropriate way
- Use very fast rate calculations (e.g. `Dreiner et al. arXiv:1003.2648`) to check parameter space for the necessary grid dimensions and spacing

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  - Very personal addition:
    The Power of Open Source
    ATLAS and CMS could release officially endorsed, public, fast simulation tools

Conclusion and Outlook

- It is possible to reconcile the LE measurements (dominated by $(g-2)_\mu$ and Ω_{DM}) with a possible non-discovery of mSUGRA at the LHC in 2011/2012
- As expected, LHC generally moves the lower bounds on sparticles to higher values (directly true only for coloured ones)
- As expected, but less obvious:
  As long as global fit χ^2/ndf remain acceptable: LHC moves up the upper bound on sparticles very significantly
- For other SUSY than mSUGRA, the coloured and non-coloured sector can be more decoupled, no definite statements on non-coloured sector yet
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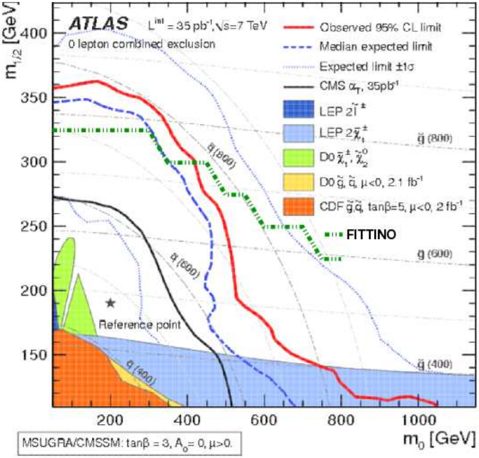
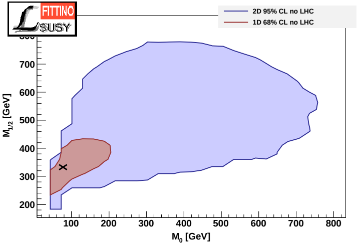
  - Find and Identify New Physics

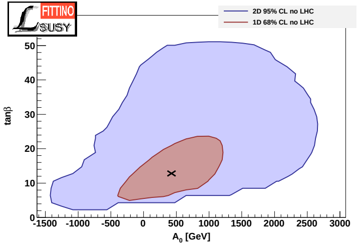
Backup Slides

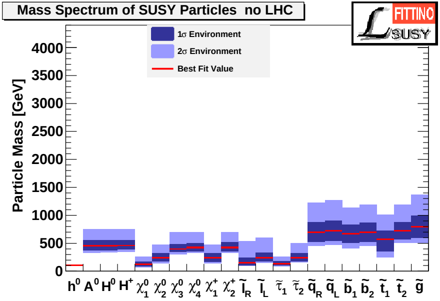
Agreement of our Implementation with the Actual ATLAS Analysis with Data



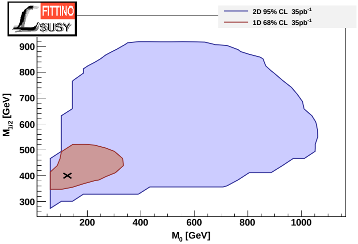
Full Results for no LHC

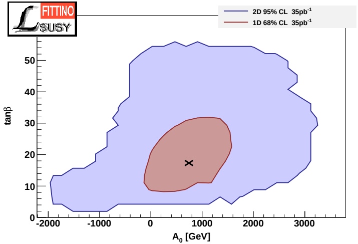


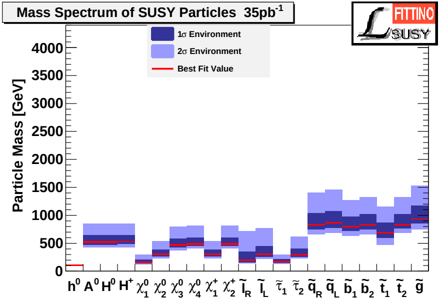




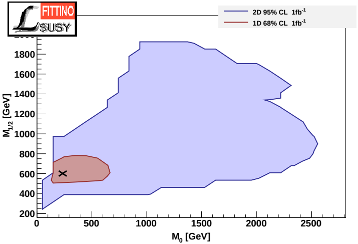
Full Results for $35\,\mathrm{pb}^{-1}$ ATLAS Search

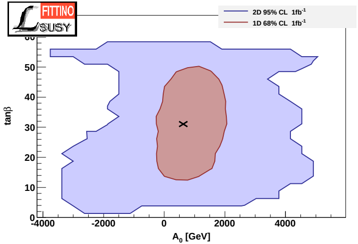


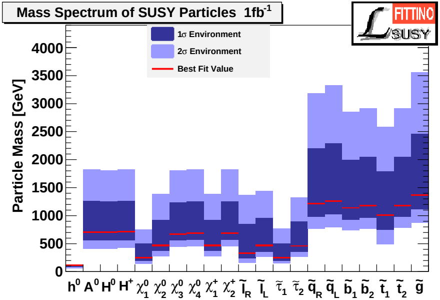




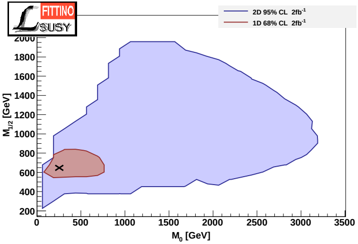
Full Extrapolated Results for $1\,\mathrm{fb}^{-1}$ ATLAS Search

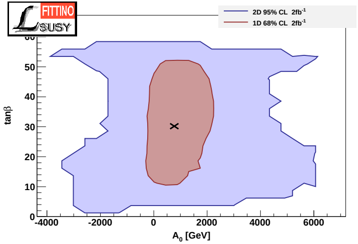


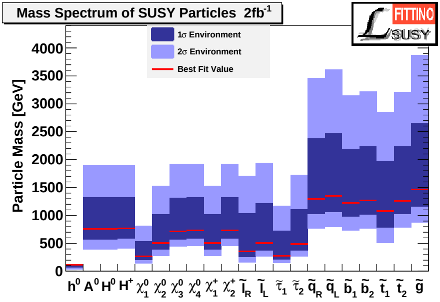




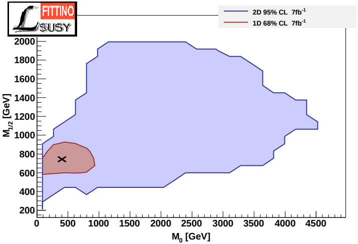
Full Extrapolated Results for $2\,\mathrm{fb}^{-1}$ ATLAS Search

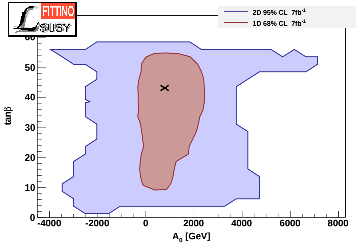


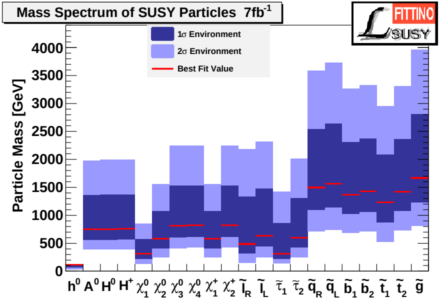




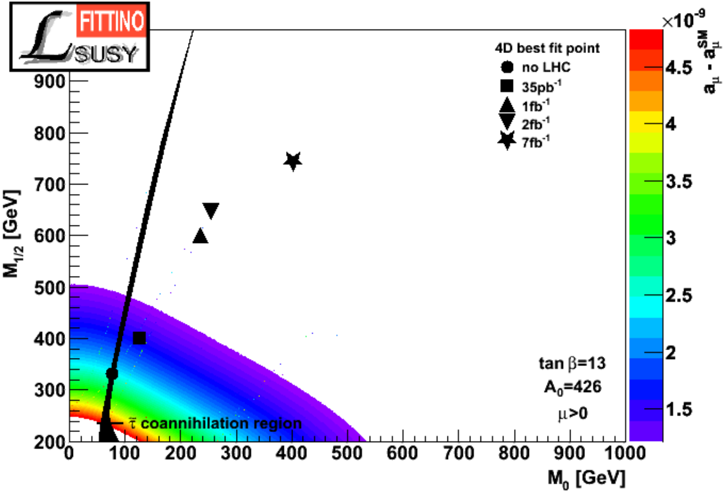
Full Extrapolated Results for $7\,\mathrm{fb}^{-1}$ ATLAS Search







Why does $\tan\beta$ move to higher values for growing LHC exclusions?



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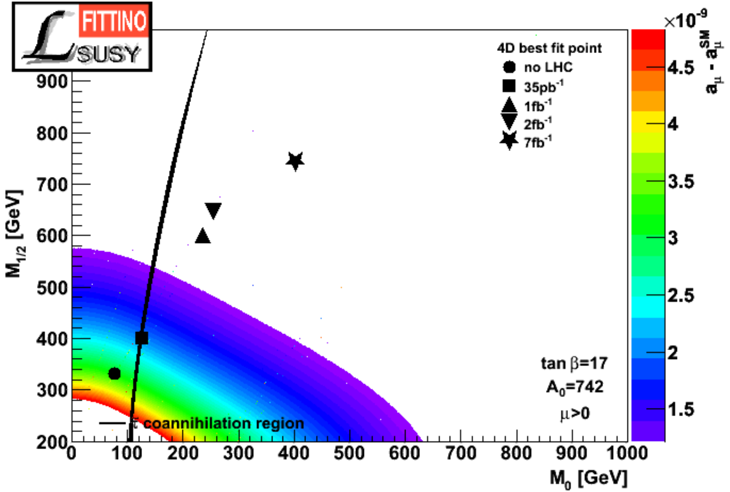

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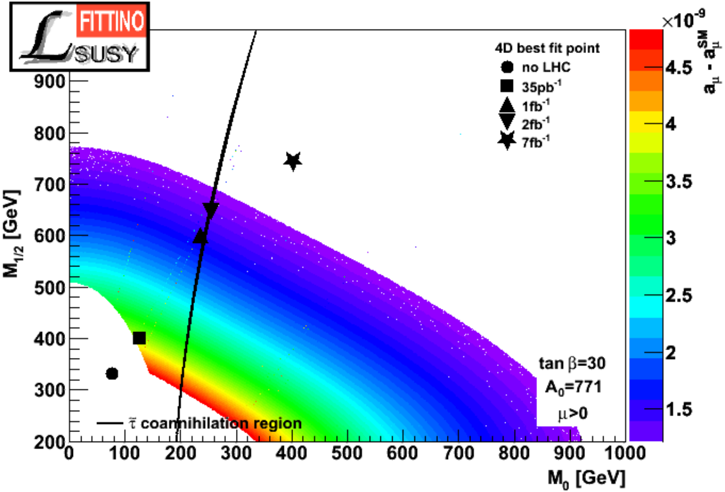

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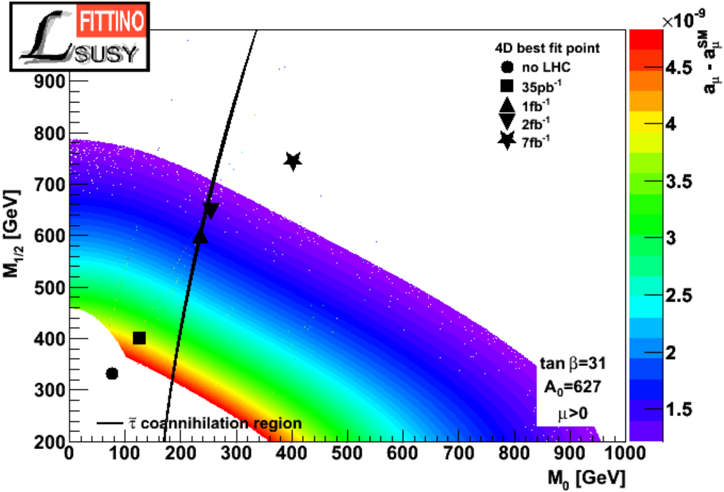

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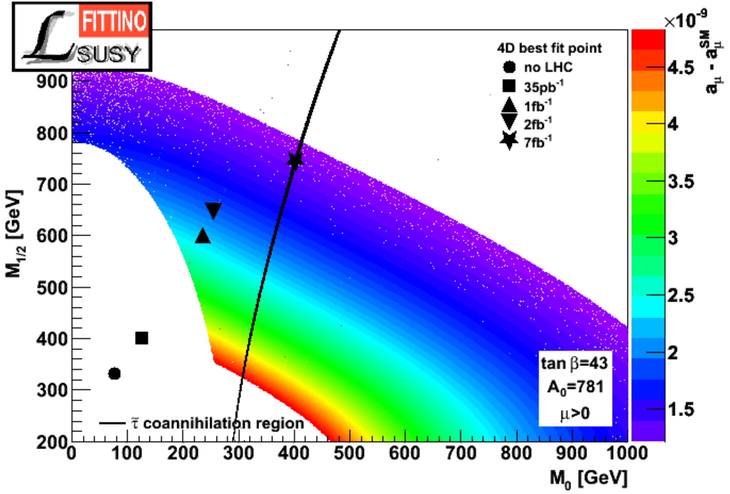
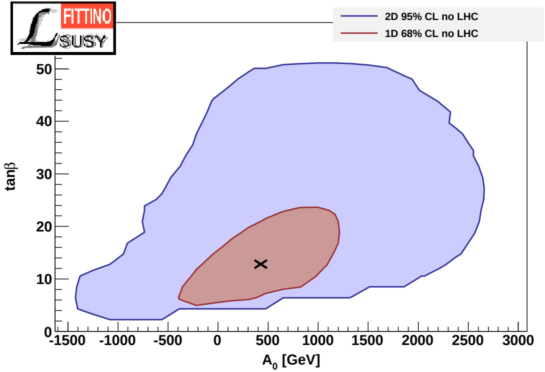


Why are global fits of SUSY so CPU-consuming?

- . . . and impossible with naively employing Minuit?

Looking at any correlations for all other allowed parameters:



Looks OK

Why are global fits of SUSY so CPU-consuming?

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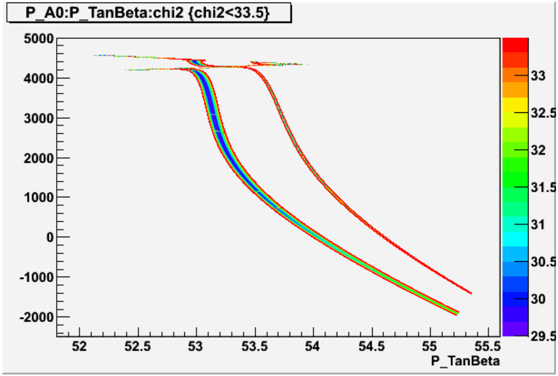
Looking at any correlations for fixed other parameters:

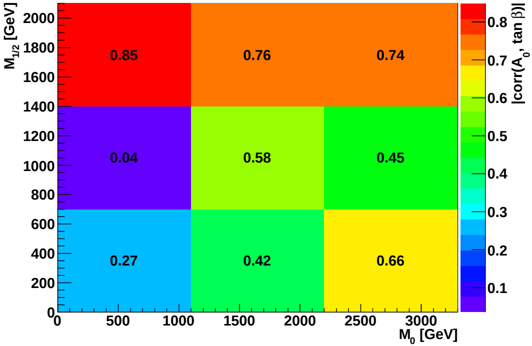


Looks Terrible

Why are global fits of SUSY so CPU-consuming?

- . . . and impossible with naively employing Minuit?

Looking at any correlations for regions of other parameters:



Correlations growing for higher mass parameters

Search Cuts

Number of jets	≥ 2 jets	≥ 3 jets	≥ 4 jets
Leading jet P_T (GeV)	> 180	> 100	> 100
Other jets P_T (GeV)	> 50 (Jet 2)	> 40 (Jet 2-3)	> 40 (Jet 2-4)
$\Delta\phi(jet_i, E_T^{miss})$	$[> 0.2, > 0.2]$	$[> 0.2, > 0.2, > 0.2]$	$[> 0.2, > 0.2, > 0.2, > 0.0]$
$E_T^{miss} > f \times M_{\text{eff}}$	$f = 0.3$	$f = 0.25$	$f = 0.2$

Table 1: Cuts on the P_T of the leading jet, the P_T of the other jets, the azimuthal angle between the leading jets and the missing transverse energy vector and the cut on the missing transverse energy expressed as a fraction of the effective mass. The cuts are shown for each of the studied jet multiplicities.

In the following we describe the event selection criteria for the 0, 1 and 2 lepton channels.

Zero-lepton channels In addition to the electron crack veto, the pre-selection cuts are:

1. Reject events with at least one lepton having $P_T > 20$ GeV.
2. Cut on the number of jets and jet transverse momenta as defined in Table 1.
3. Missing transverse energy $E_T^{miss} > 80$ GeV.
4. Cut on ratio f between E_T^{miss} and M_{eff} as defined in Table 1.
5. Cut on $\Delta\phi(jet_i, E_T^{miss})$ as defined in Table 1.
6. Transverse sphericity, $S_T > 0.2$.

Calculating the χ^2 from LHC

$$Q = \prod_{i=1}^{N_{\mathrm{bins}}} \frac{\mathcal{L}(\mu_i = s_i + b_i; n_i)}{\mathcal{L}(\mu_i = b_i; n_i)}. \tag{1}$$

$$\mathrm{CL}_{s+b} = \int_{t_{\mathrm{obs}}}^{\infty} P_{s+b}(t)\, dt < 0.05\,. \tag{2}$$

$$\chi^2 = 2[\,\mathrm{erf}^{-1}(1 - 2\,\mathrm{CL}_{s+b})]^2\,. \tag{3}$$