PHYSICS AT THE TERA SCALE
Helmholtz Alliance

Global fits of SUSY parameters

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FITTINO SUSY SFitter MASTERCODE G fitter

3rd Annual Workshop of the Helmholtz Alliance
"Physics at the Terascale"
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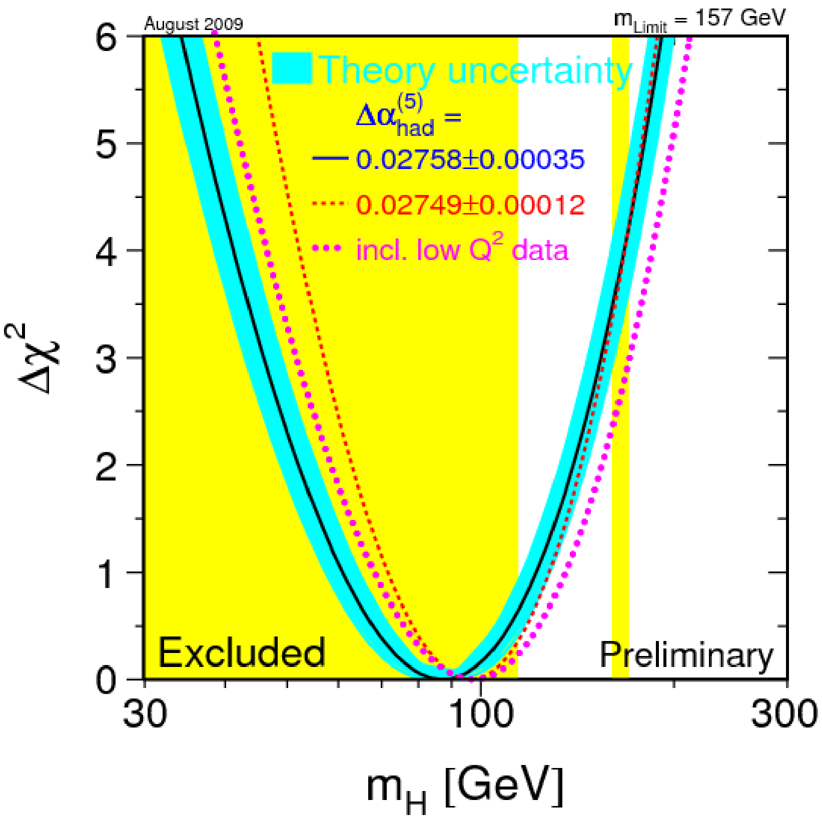
DESY

Parameter fits: A brief history

Much work went into SM fits:

- very precise measurements
- equally precise theoretical calculations (→ radiative corrections)

→ G_F, $\alpha_s(M_Z^2)$, $\Delta\alpha_{em}^{(5)}(M_Z^2)$, m_Z, m_t, m_H



Similarly, need to fit parameters of more complex extended theory if BSM physics is found

Supersymmetry

Despite of tremendous success, SM also exhibits shortcomings:

- Instability of the Higgs boson mass
- No dark matter candidate
- Unification of gauge couplings impossible
- …

Remedy could be provided by introduction of single additional symmetry:

Bosons ↔ Fermions ($\Delta s=1/2$)

Entails introduction of additional particles to SM. Since still undiscovered, SUSY must be broken.

To cure shortcomings of SM, SUSY particles must be light (~ O(1) TeV)

→ LHC and ILC will decide about fate of SUSY

Challenges for parameter fits

Stumbling block: observables ≠ parameters

Observables: masses, asymmetries, rates, …

Parameters: α_s, $\tan\beta$, M_1, A_τ, ...

Establish mapping

parameters → observables

is "easy".

But constructing mapping

observables → parameters

is cumbersome (→ lots of CO_2).

SUSY/BSM fit programs

- Fittino (P. Bechtle, K. Desch, P. Wienemann, *et al.*)
  `http://www-flc.desy.de/fittino`

- SFitter (R. Lafaye, T. Plehn, D. Zerwas, *et al.*)

- Mastercode (O. Buchmüller, R. Cavanaugh, A. De Roeck, S. Heinemeyer, G. Isidori, F. Ronga, G. Weiglein, *et al.*)

- (Gfitter) (H. Flächer, M. Goebel, J. Haller, A. Höcker, K. Mönig, J. Stelzer, *et al.*)
  `http://gfitter.desy.de`

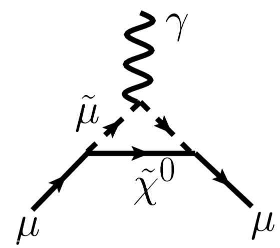
“Low energy” precision measurements

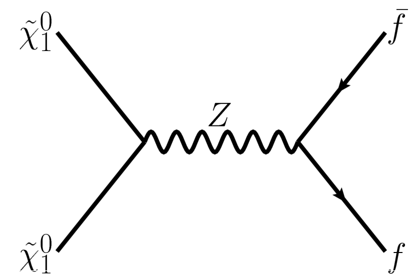
Can look for SUSY effects in already available data from LEP, Tevatron, SLC, B/K physics, $(g\text{-}2)_\mu$ and astrophysics.

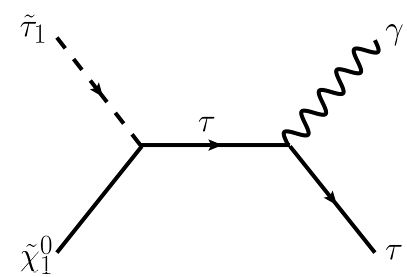
“Low energy” precision observables exhibit sensitivity to SUSY parameters, in particular

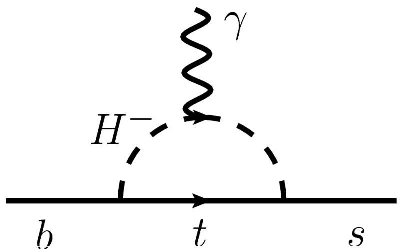
- $(g\text{-}2)_\mu$
- $\Omega_{CDM}\ h^2$
- $BR(b \rightarrow s\ \gamma)$

Diagram examples:





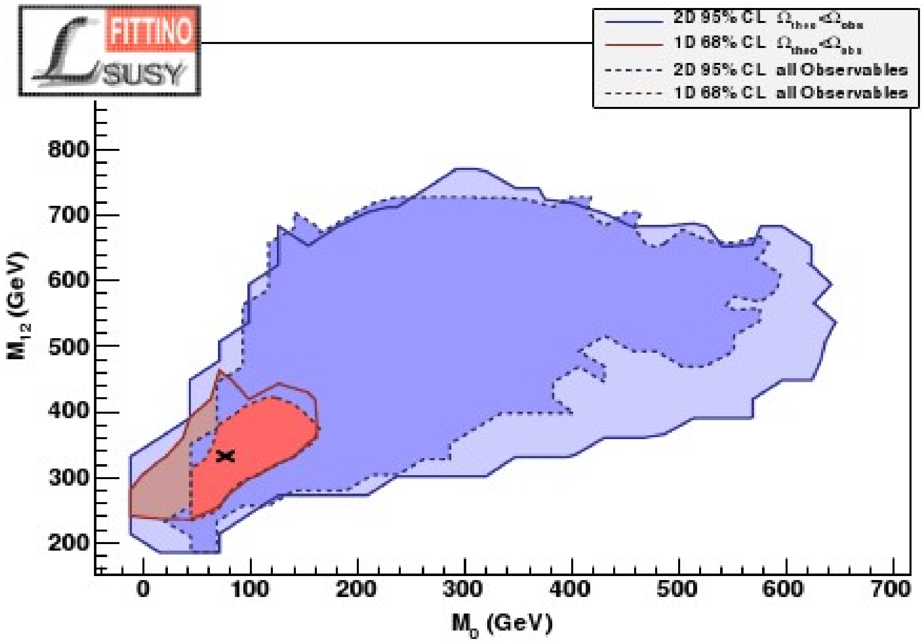


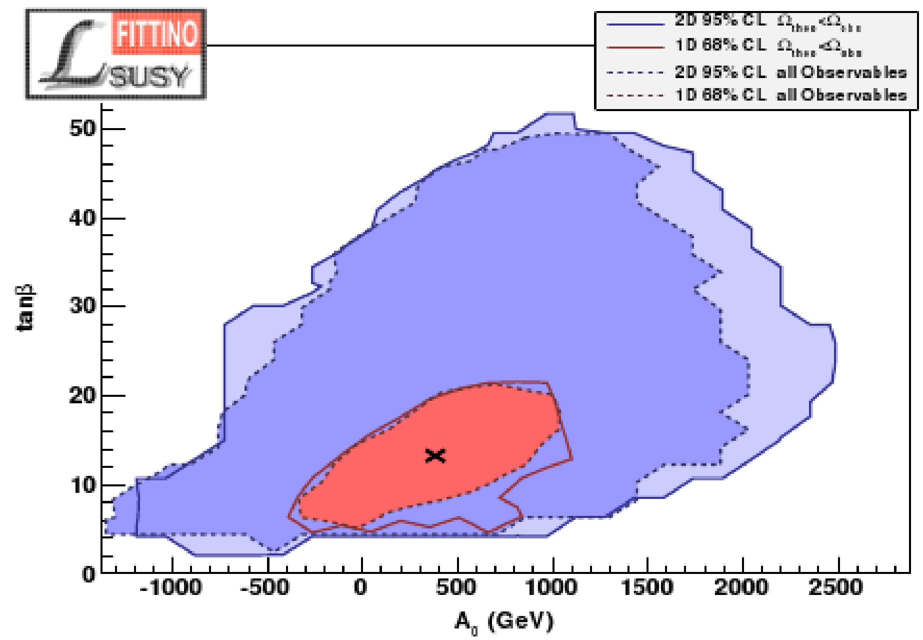


LE: mSUGRA parameters

Bechtle, Desch, Uhlenbrock, Wienemann

Fit of mSUGRA parameters to 35 LE measurements:



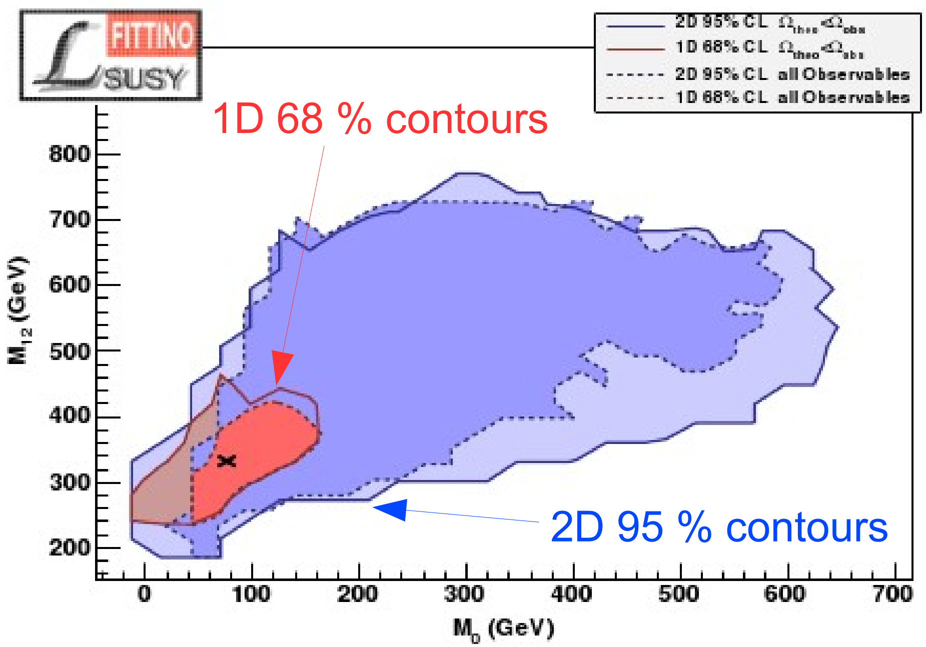


LE data favours light SUSY (consistent with findings by MASTERCODE group)

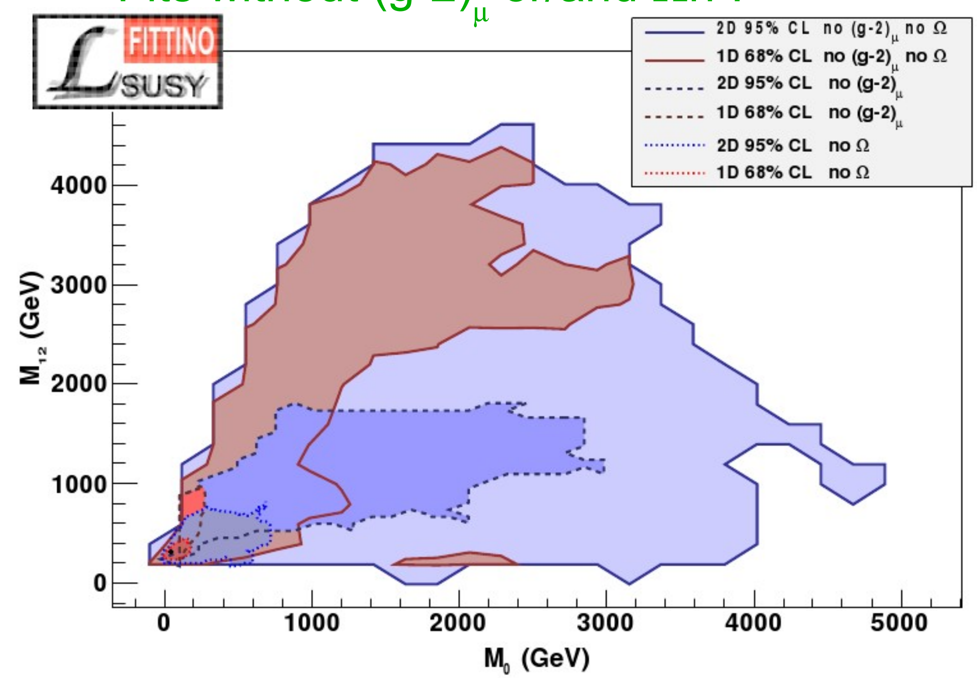
LE: Impact of individual observables

Bechtle, Desch, Uhlenbrock, Wienemann

Fits with all observables:



Fits without $(g-2)_\mu$ or/and Ωh^2:

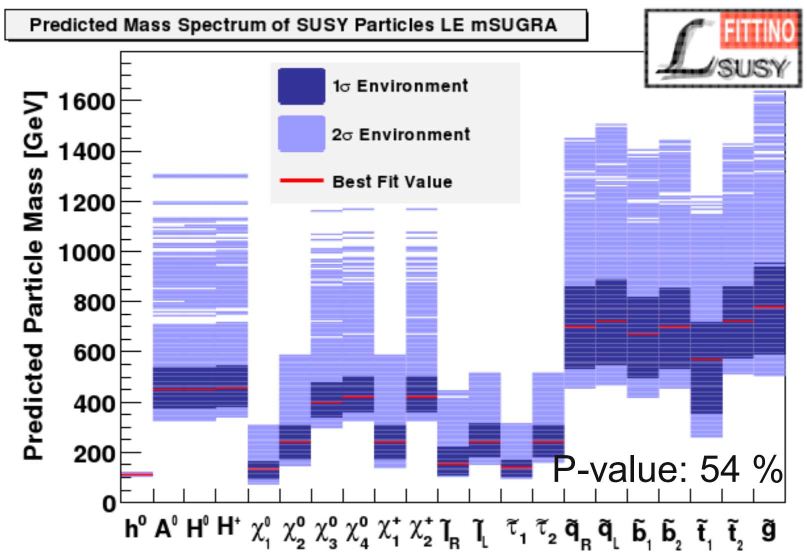


- Preferred region rather stable
- $(g-2)_\mu$ and to lesser extent Ωh^2 most constraining

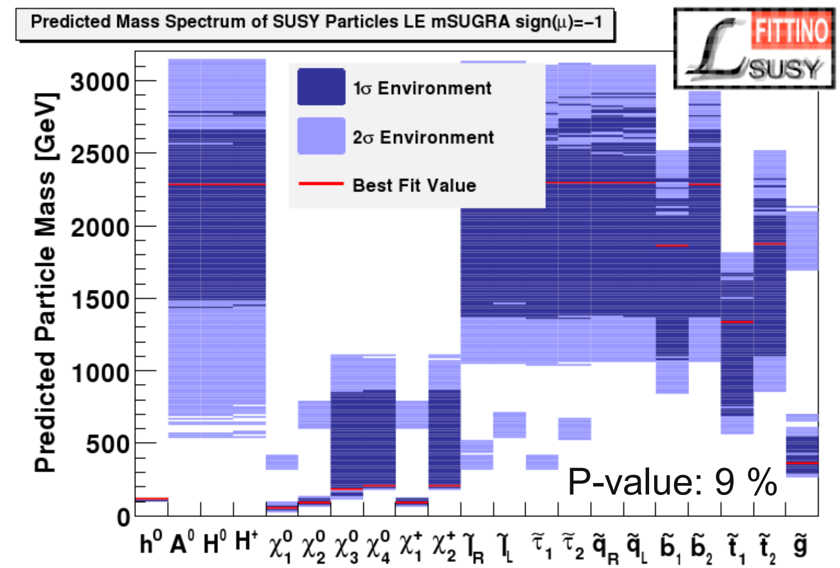
LE: Predicted mass spectra

Bechtle, Desch, Uhlenbrock, Wienemann

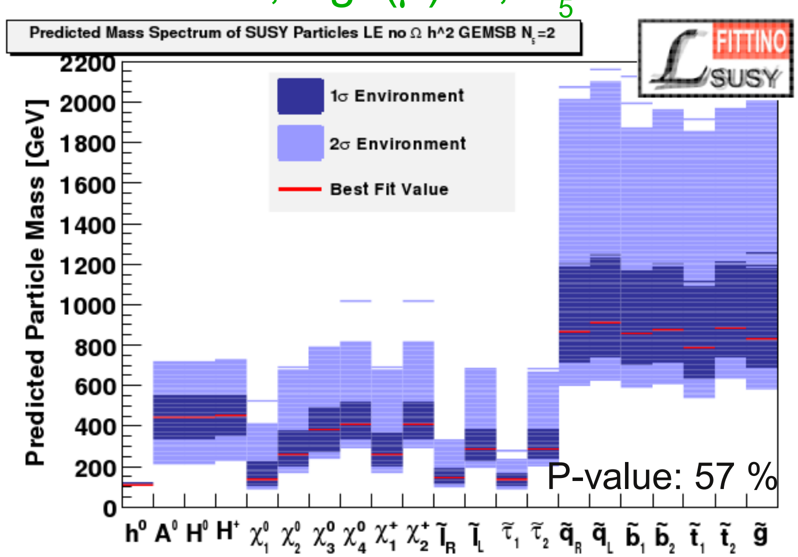
mSUGRA, sign(μ)>0:



mSUGRA, sign(μ)<0:



GMSB, sign(μ)>0, N_5 = 2:

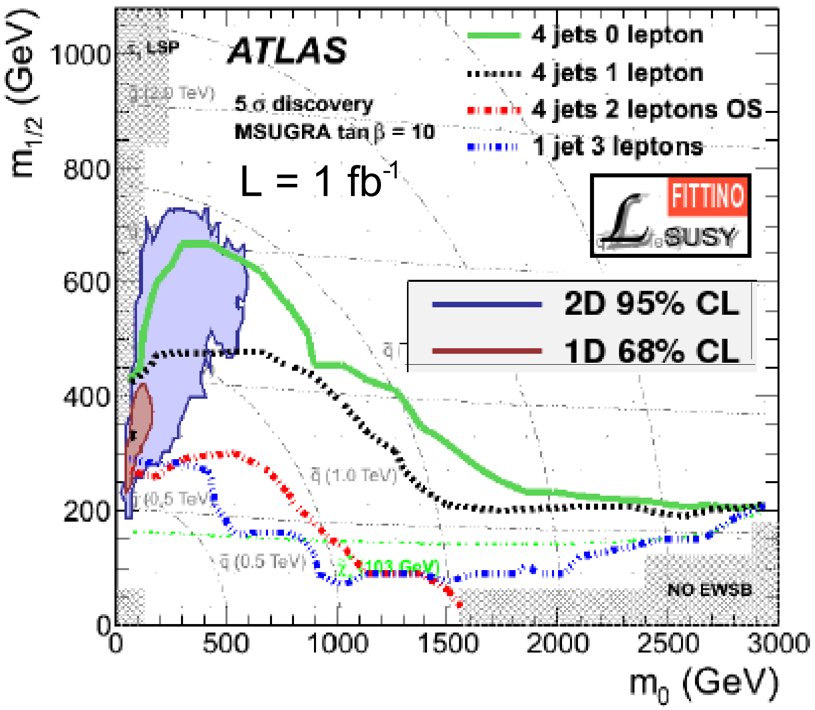


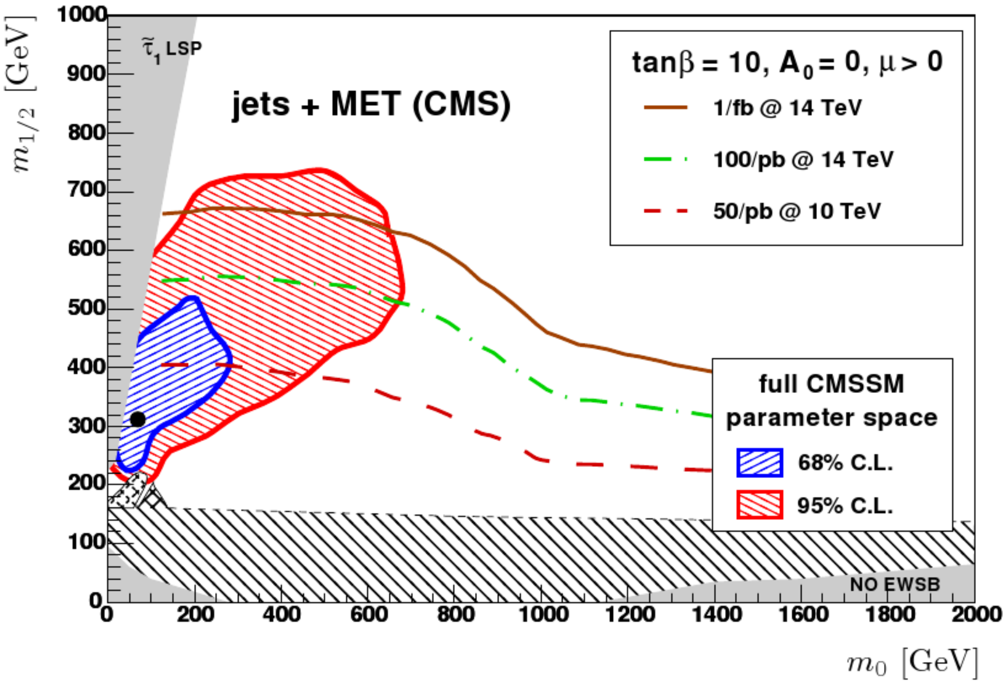
Light SUSY particles favoured

LE: Comparison with LHC potential

Bechtle, Desch, Uhlenbrock, Wienemann

Buchmüller, et al.

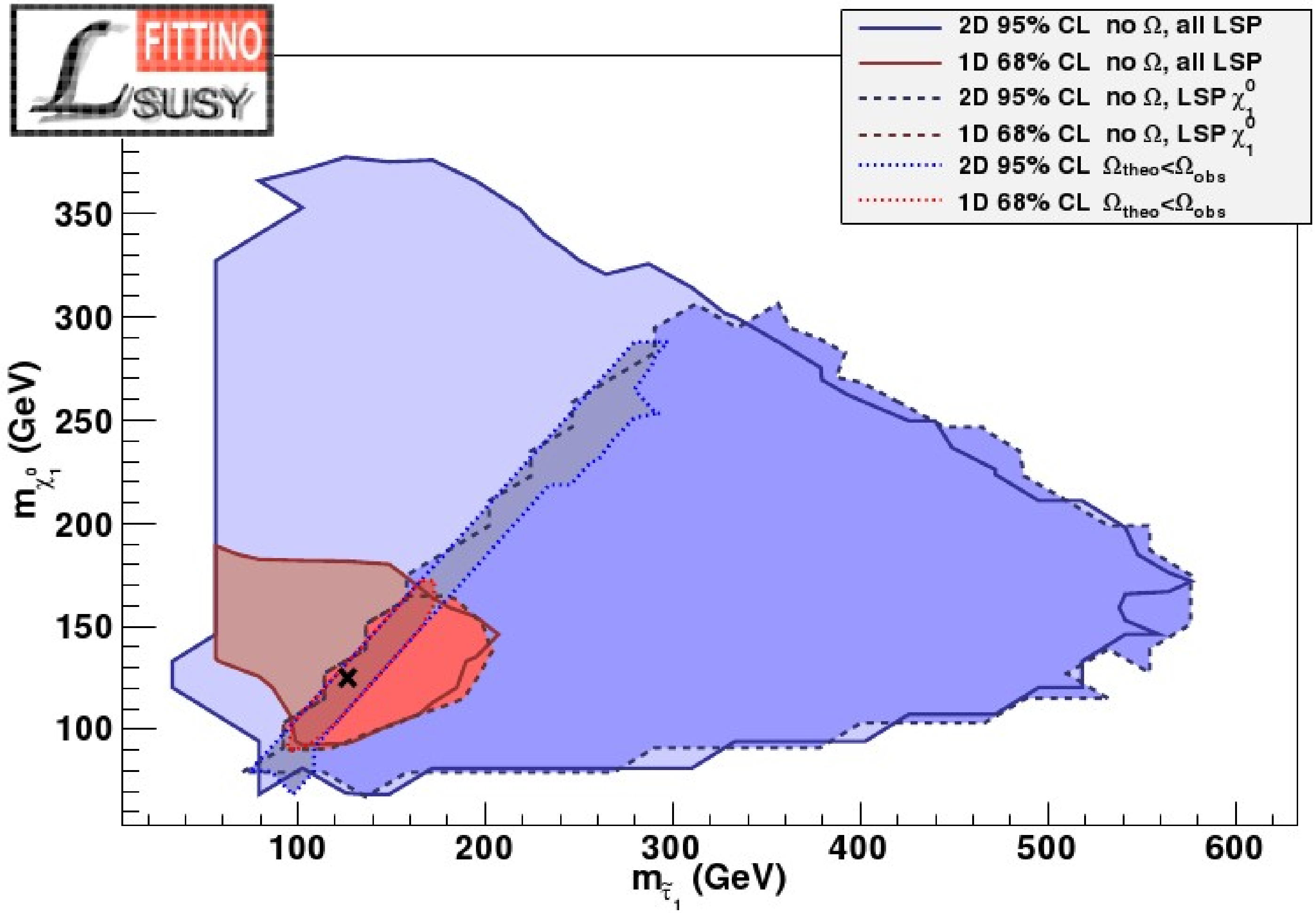




Good prospects for early BSM hints at LHC

LE: Predicted LSP and NLSP masses

Bechtle, Desch, Uhlenbrock, Wienemann



- DM relic density prefers co-annihilation region
- Seeing excess might be easy, measuring certain processes might be more difficult (soft taus!)

Projection to LHC

Fit result of mSUGRA fit to LE data accidentally close to experimentally well studied SUSY benchmark point:

				SPS1a values
$\tan\beta$	13.2	$\pm$	7.2	10
$M_{1/2}$ (GeV)	331.5	$\pm$	86.6	250
M_0 (GeV)	76.2		$^{+79.2}_{-29.1}$	100
A_0 (GeV)	383.8	$\pm$	647	-100

→ dare projection to LHC era based on SPS1a studies

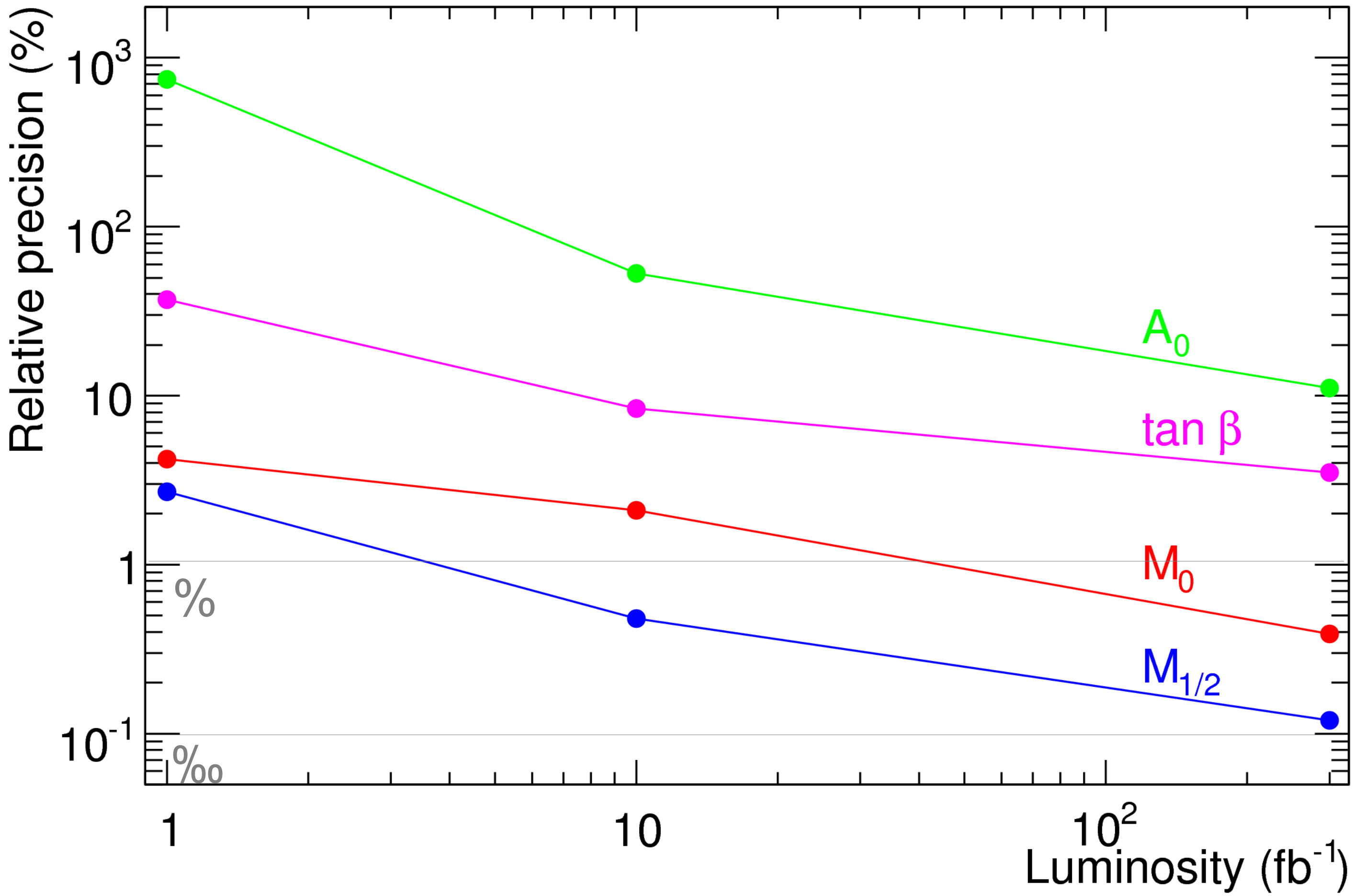
Caveat emptor:

- No decay chain ambiguities considered
- Uncertainties on theoretical calculations (mostly) not considered
- Mostly no information on LHC production rates

LHC: mSUGRA parameters vs. luminosity

Bechtle, Desch, Uhlenbrock, Wienemann

Precision on mSUGRA parameters for 1, 10 and 300 fb^{-1}:

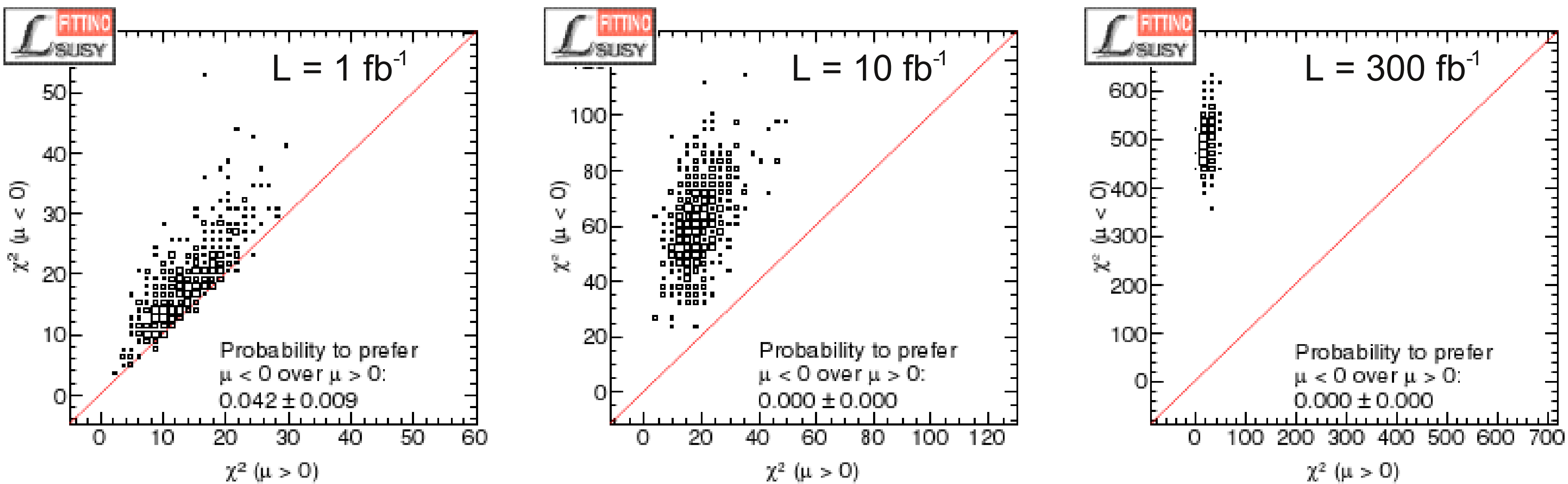


LHC: sign(μ)

Bechtle, Desch, Uhlenbrock, Wienemann

Perform fits to toy datasets generated by smearing observables within uncertainties

χ^2 correlations for fits with sign(μ)>0 and sign(μ)<0 to same toy dataset:



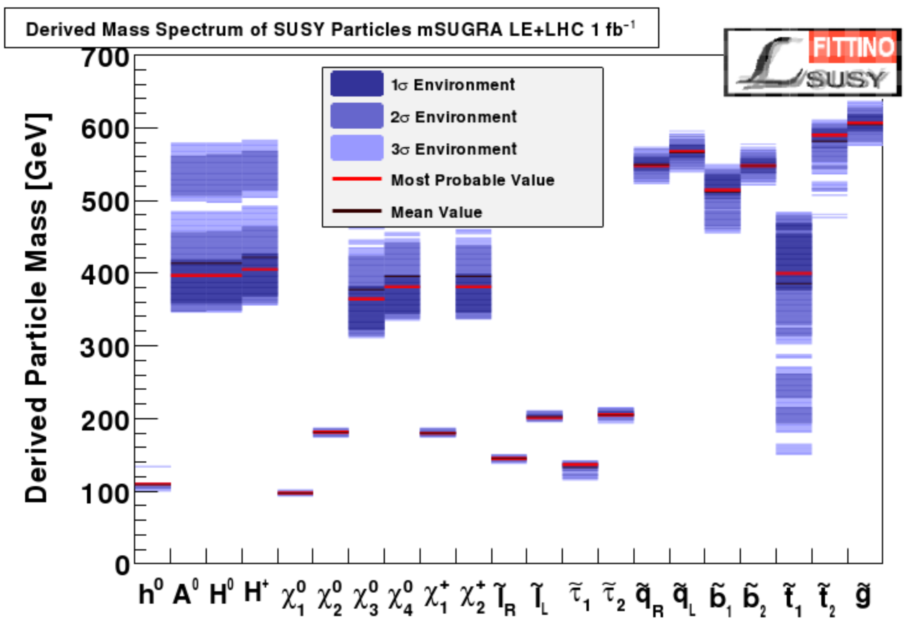
Any discrete “degree of freedom” (parameter, ambiguity, …) can be treated this way

LE+LHC: Mass spectrum

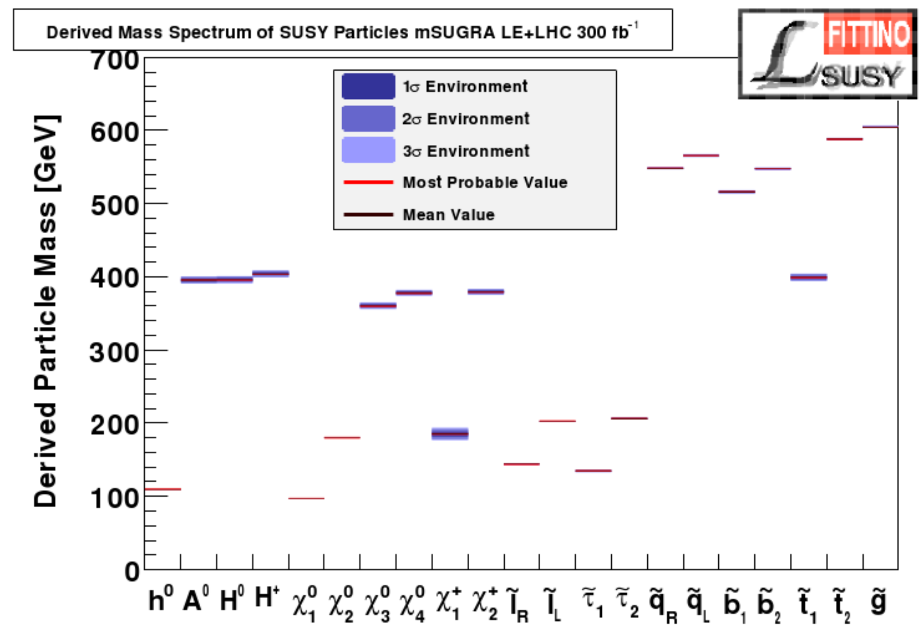
Bechtle, Desch, Uhlenbrock, Wienemann

SUSY mass spectra derived from LE and LHC (1 fb^{-1} and 300 fb^{-1}) observables assuming mSUGRA model:

mSUGRA, LE+LHC1:



mSUGRA, LE+LHC300:

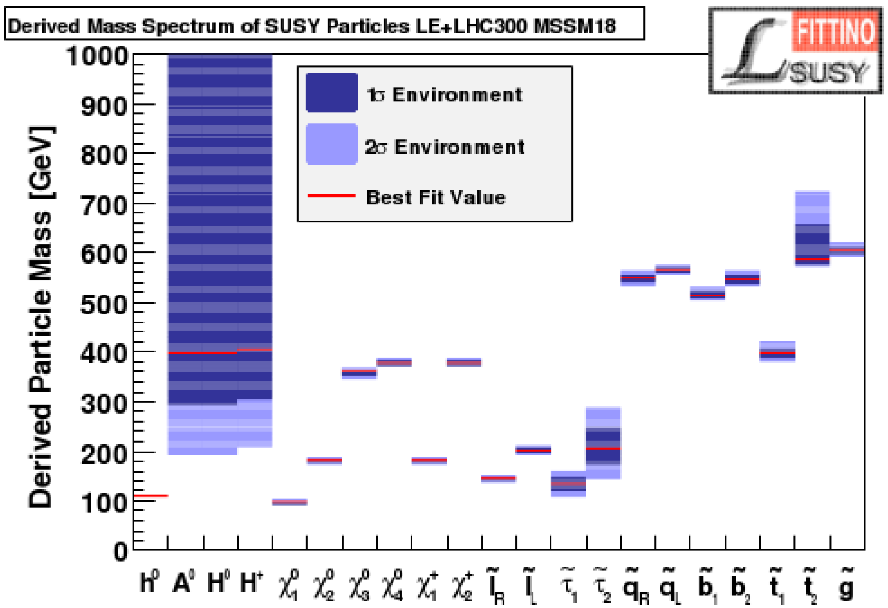


LE+LHC+ILC: Mass spectrum

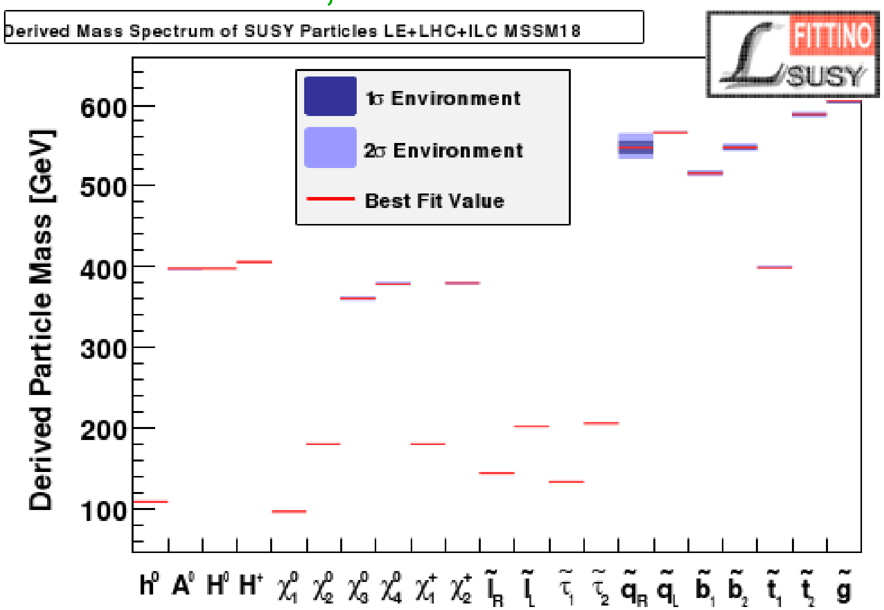
Bechtle, Desch, Uhlenbrock, Wienemann

SUSY mass spectra derived from LE and LHC (300 fb^{-1}) and optionally ILC observables assuming MSSM18 model:

MSSM18, LE+LHC300:



MSSM18, LE+LHC300+ILC:

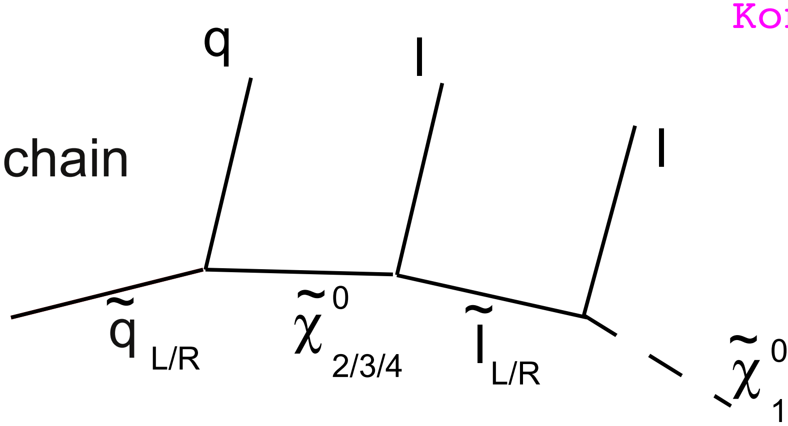


Next steps: Decay chain ambiguities at LHC

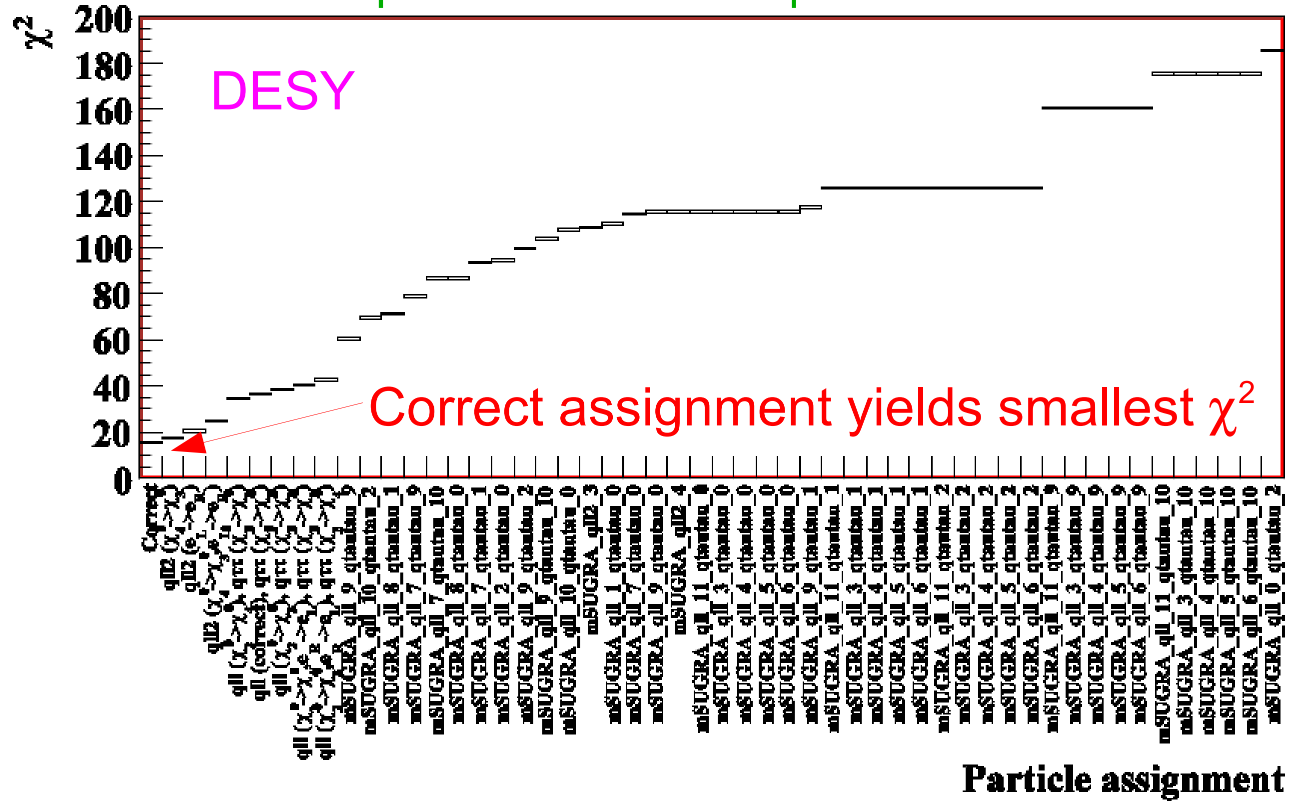
Kono

Certain final state at LHC cannot be unambiguously assigned to single decay chain

First steps started to include all these ambiguities in parameter analysis:



Perform separate fit for each option



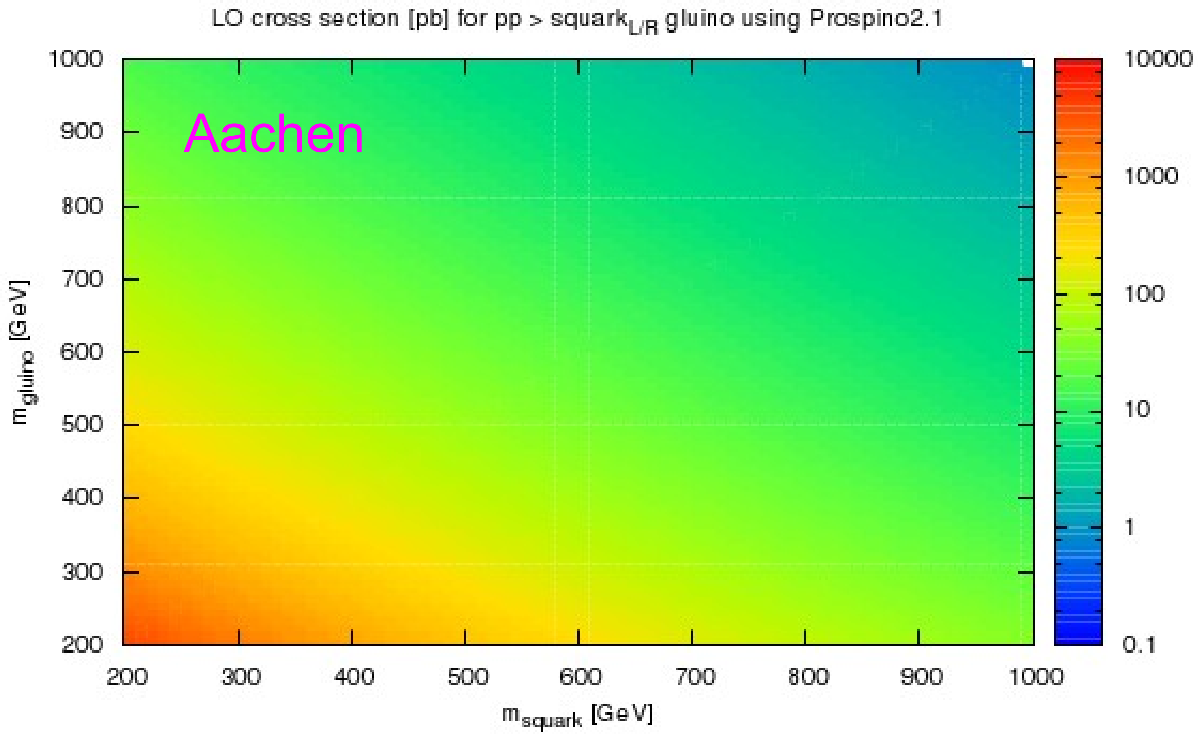
Next steps: LHC production rates

Krämer, Lindert, O'Leary

Conventional calculation of production rates at LHC too slow.

Investigated way out:

- Prospino look-up table (only 2 parameters: squark and gluino mass)
- Calculation of BRs by SPheno/SDecay
- Parametrised detector response



Fittino workshop

Held on October 29-30, 2009 at DESY with 17+2 participants

Discussion of present and future work:

- Fitting algorithm speed-ups (Dresden, DESY)
- Inclusion of SUSY exclusion limits from Tevatron (Mainz, ...)
- Inclusion of indirect dark matter search results (Hamburg)
- Systematic comparison of different RGE codes (Göttingen)
- Inclusion of uncertainties/correlations of theory predictions (Würzburg, DESY, Heidelberg, …)
- Inclusion of `HiggsBounds` (Freiburg)
- Discrimination of NMSSM and MSSM (DESY)
- Fitting studies within ATLAS and CMS (DESY/Hamburg)
- SPheno developments (Würzburg)
- Discrimination of MSSM and cE6MSSM (Dresden)
- and as seen: fitting rates and shapes at LHC (Aachen) and decay chain ambiguities (DESY)

very successful, plan to apply for Helmholtz Alliance working group

Summary

- Constraining SUSY parameter space will be essential task in upcoming years (both if ∃ SUSY and if ∄ SUSY)
- Several powerful SUSY fitting frameworks developed during recent years
- Obtained fascinating results with them:
  - Light SUSY preferred by LE precision data
  - Demonstration of possible LHC and ILC potential
- Present parameter analyses do not yet fully exploit possible LHC measurements (rates, ...). Also, full consideration of decay chain ambiguities and theory uncertainties still owing.
- But Alliance-wide joint effort by experimentalists and theorists has started to address open issues
- Many interesting new results can be expected soon ...

BACKUP

LE observables

Observable	Experimental Value	Uncertainty stat	Uncertainty syst	Exp. Reference
$\mathcal{B}(B \to s\gamma)/\mathcal{B}(B \to s\gamma)_{\mathrm{SM}}$	1.117	0.076	0.096	[47]
$\mathcal{B}(B_s \to \mu\mu)$	$< 4.7 \times 10^{-8}$			[47]
$\mathcal{B}(B_d \to \ell\ell)$	$< 2.3 \times 10^{-8}$			[47]
$\mathcal{B}(B \to \tau\nu)/\mathcal{B}(B \to \tau\nu)_{\mathrm{SM}}$	1.15	0.40		[48]
$\mathcal{B}(B_s \to X_s\ell\ell)/\mathcal{B}(B_s \to X_s\ell\ell)_{\mathrm{SM}}$	0.99	0.32		[47]
$\Delta m_{B_s}/\Delta m_{B_s}^{\mathrm{SM}}$	1.11	0.01	0.32	[49]
$\frac{\Delta m_{B_s}/\Delta m_{B_s}^{\mathrm{SM}}}{\Delta m_{B_d}/\Delta m_{B_d}^{\mathrm{SM}}}$	1.09	0.01	0.16	[47,49]
$\Delta\epsilon_K/\Delta\epsilon_K^{\mathrm{SM}}$	0.92	0.14		[49]
$\mathcal{B}(K \to \mu\nu)/\mathcal{B}(K \to \mu\nu)_{\mathrm{SM}}$	1.008	0.014		[50]
$\mathcal{B}(K \to \pi\nu\bar{\nu})/\mathcal{B}(K \to \pi\nu\bar{\nu})_{\mathrm{SM}}$	< 4.5			[51]
$a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}}$	30.2×10^{-10}	8.8×10^{-10}	2.0×10^{-10}	[52,53]
$\sin^2\theta_{\mathrm{eff}}$	0.2324	0.0012		[46]
Γ_Z	2.4952 GeV	0.0023 GeV	0.001 GeV	[46]
R_l	20.767	0.025		[46]
R_b	0.21629	0.00066		[46]
R_c	0.1721	0.003		[46]
$A_{\mathrm{fb}}(b)$	0.0992	0.0016		[46]
$A_{\mathrm{fb}}(c)$	0.0707	0.0035		[46]
A_b	0.923	0.020		[46]
A_c	0.670	0.027		[46]
A_l	0.1513	0.0021		[46]
A_τ	0.1465	0.0032		[46]
$A_{\mathrm{fb}}(l)$	0.01714	0.00095		[46]
σ_{had}	41.540 nb	0.037 nb		[46]
m_h	> 114.4 GeV		3.0 GeV	[54,55,56]
$\Omega_{\mathrm{CDM}}h^2$	0.1099	0.0062	0.012	[57]
$1/\alpha_{em}$	127.925	0.016		[58]
G_F	$1.16637 \times 10^{-5}\,\mathrm{GeV}^{-2}$	$0.00001 \times 10^{-5}\,\mathrm{GeV}^{-2}$		[58]
α_s	0.1176	0.0020		[58]
m_Z	91.1875 GeV	0.0021 GeV		[46]
m_W	80.399 GeV	0.025 GeV	0.010 GeV	[58]
m_b	4.20 GeV	0.17 GeV		[58]
m_t	172.4 GeV	1.2 GeV		[59]
m_τ	1.77684 GeV	0.00017 GeV		[58]
m_c	1.27 GeV	0.11 GeV		[46]

LHC observables

Observable	Nominal Value	Uncertainty							
		1 fb^{-1}	10 fb^{-1}	300 fb^{-1}	LES_1	$\text{LES}_{10,300}$	JES_1	$\text{JES}_{10,300}$	syst.
m_h	109.6		1.4	0.1		0.1			
m_t	172.4	1.1	0.05	0.01			1.5	1.0	
$m_{\tilde{\chi}_1^\pm}$	180.2			11.4				1.8	
$\sqrt{m_{\tilde{\ell}_L}^2 - 2m_{\tilde{\chi}_1^0}^2}$	148.8			1.7		0.1			6.0
$m_{\tilde{g}} - m_{\tilde{\chi}_1^0}$	507.7		13.7	2.5				5.1	10.0
$\sqrt{m_{\tilde{q}_R}^2 - 2m_{\tilde{\chi}_1^0}^2}$	531.0	19.6	6.2	1.1			22.7	4.5	10.0
$m_{\tilde{g}} - m_{\tilde{b}_1}$	88.7			1.5				0.9	
$m_{\tilde{g}} - m_{\tilde{b}_2}$	56.8			2.5				0.6	
$m_{\ell\ell}^{\max}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\ell}_R})$	80.4	1.7	0.5	0.03	0.16	0.08			
$m_{\ell\ell}^{\max}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_4^0}, m_{\tilde{\ell}_L})$	280.6		12.6	2.3		0.28			
$m_{\tau\tau}^{\max}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\tau}_1})$	83.4	12.6	4.0	0.73			4.2	0.8	5.7
$m_{\ell\ell q}^{\max}(m_{\tilde{\chi}_1^0}, m_{\tilde{q}_L}, m_{\tilde{\chi}_2^0})$	452.1	13.9	4.2	1.4			22.7	4.5	
$m_{\ell q}^{\text{low}}(m_{\tilde{\ell}_R}, m_{\tilde{q}_L}, m_{\tilde{\chi}_2^0})$	318.6	7.6	3.5	0.9			16.2	3.2	
$m_{\ell q}^{\text{high}}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\ell}_R}, m_{\tilde{q}_L})$	396.0	5.2	4.5	1.0			19.9	4.0	
$m_{\ell\ell q}^{\text{thres}}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\ell}_R}, m_{\tilde{q}_L})$	215.6	26.5	4.8	1.6			10.8	2.2	
$m_{\ell\ell b}^{\text{thres}}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\ell}_R}, m_{\tilde{b}_1})$	195.9		19.7	3.6				2.0	
$m_{tb}^{\text{w}}(m_t, m_{\tilde{t}_1}, m_{\tilde{\chi}_1^\pm}, m_{\tilde{g}}, m_{\tilde{b}_1})$	359.5	43.0	13.6	2.5			18.0	3.6	
$\frac{\mathcal{B}(\tilde{\chi}_2^0 \to \tilde{\ell}_R \ell) \times \mathcal{B}(\tilde{\ell}_R \to \tilde{\chi}_1^0 \ell)}{\mathcal{B}(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau) \times \mathcal{B}(\tilde{\tau}_1 \to \tilde{\chi}_1^0 \tau)}$	0.076	0.009	0.003	0.001					0.008
$\frac{\mathcal{B}(\tilde{g} \to \tilde{b}_2 b) \times \mathcal{B}(\tilde{b}_2 \to \tilde{\chi}_2^0 b)}{\mathcal{B}(\tilde{g} \to \tilde{b}_1 b) \times \mathcal{B}(\tilde{b}_1 \to \tilde{\chi}_2^0 b)}$	0.168			0.078					