LHC — More than just Discoveries

Tilman Plehn

MPI für Physik & University of Edinburgh

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Outline

Weak Boson Fusion and Supersymmetry

Supersymmetric parameter space

Markov chains

SUSY parameter maps

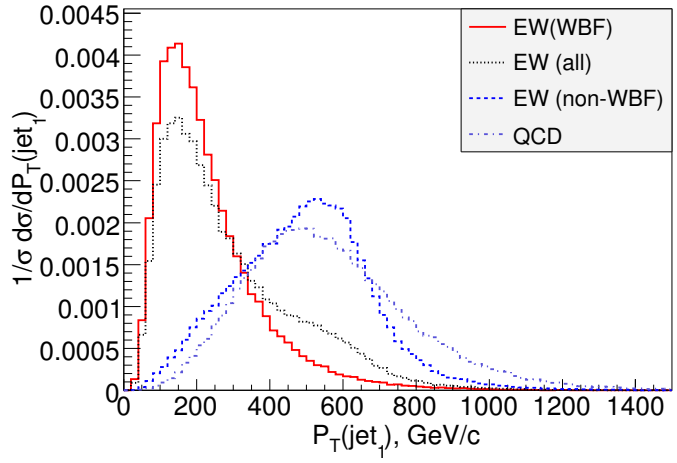
Weak Boson Fusion and Supersymmetry

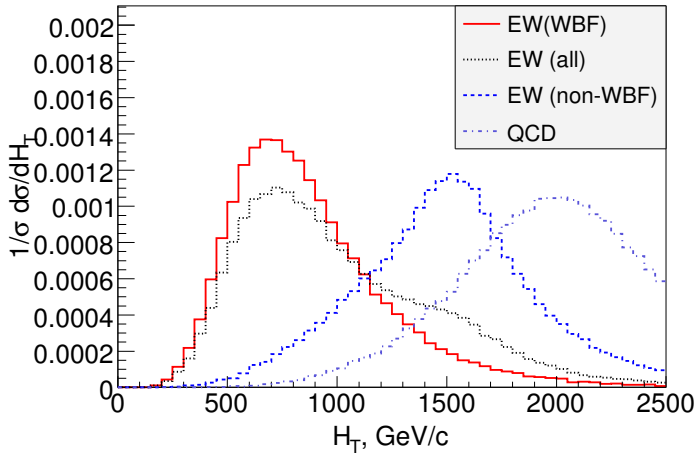
Supersymmetry — or else...

- Majorana gluino identifiable once seen
- Majorana neutralinos? Majorana LSP?
- signature: like–sign charginos [Alwall, TP, Rainwater]
- stable for simplicity — chargino kinematics not necessary [SM backgrounds]

$\Rightarrow$ (1) visible over backgrounds? [SUSY–QCD backgrounds only]
(2) distinct WBF signal? [LHC precision physics attempt]

$\Rightarrow$ long shot, but interesting and not swamped by SUSY-QCD





Alternative Hypotheses

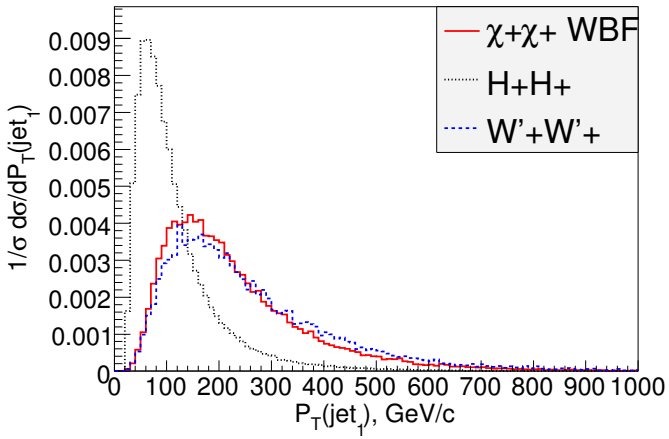
Like-sign scalars without Majorana neutralinos

- assume stable charged Higgs (type-II two-Higgs doublet model)
- H^+H^- same as simple heavy H^0 [TP, Rainwater, Zeppenfeld; Hankele, Klamke, Figy]
- WBF signal: two key distributions $\Delta\phi_{jj}, p_{T,j}$
- scalars with flat $\Delta\phi_{jj}$, similar to fermions
- Goldstone modes in W coupling to final–state fermions:

$$P_T(x, p_T) \sim \frac{1+(1-x)^2}{2x} \frac{p_T^2}{(p_T^2+(1-x)\, m_W^2)^2} \longrightarrow \frac{1+(1-x)^2}{2x} \frac{1}{p_T^2}$$

$$P_L(x, p_T) \sim \frac{(1-x)^2}{x} \frac{m_W^2}{(p_T^2+(1-x)\, m_W^2)^2} \longrightarrow \frac{(1-x)^2}{x} \frac{m_W^2}{p_T^4}$$

$\Rightarrow$ scalars identified by softer $p_{T,j}$

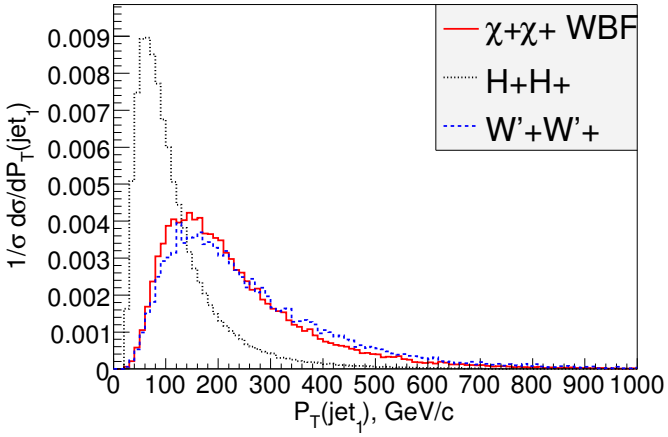


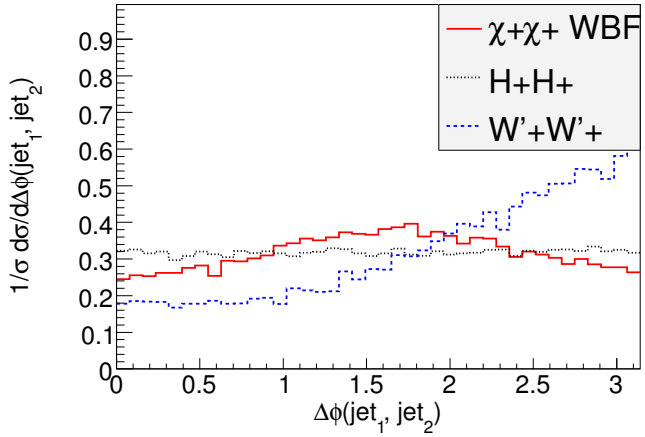
Alternative Hypotheses

Like-sign vectors without Majorana neutralinos

- problem: define consistent hypothesis to kill
- start with copy of SM, heavy W', Z', H', f'
- good news: H' necessary for unitarity, but irrelevant at LHC
- transverse–type $p_{T,j}$ distribution like charginos

$\Rightarrow$ vectors identified by Dirac structure's $\Delta\phi_{jj}$





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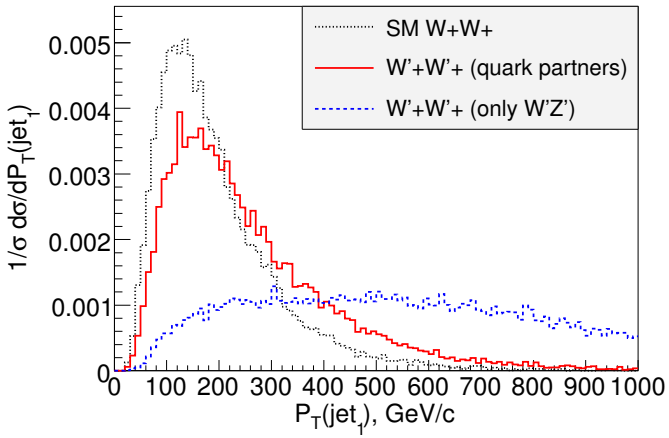
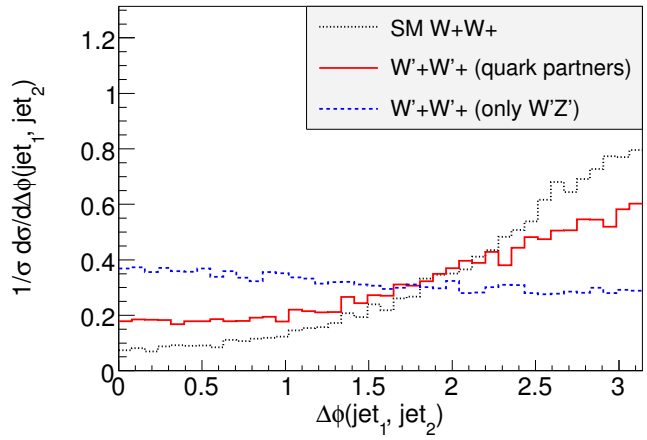
Role of heavy fermions

- not part of the naive set of WBF diagrams
- gauge connected for Standard Model WW production
- huge effect on transverse momentum and other scaling distributions





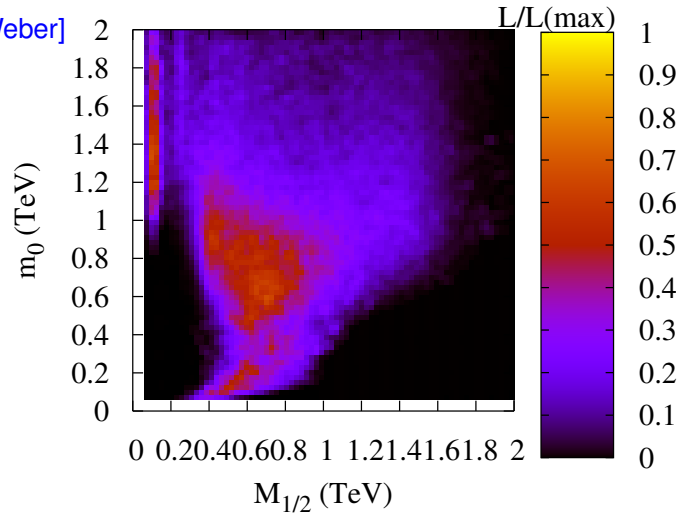
Supersymmetric parameter space

Skipping masses and edges for today...

- parameters: weak-scale Lagrangean
- measurements: masses or edges,
  branching fractions, rates,... [SM and BSM backgrounds, QCD environment]
- errors: general correlation, statistics & systematics & theory
- problem in grid: huge phase space, no local minimum?
  problem in fit: domain walls, no global minimum?
  problem in interpretation: marginalization, secondary minima?

Ben's and Chris' weather forecasts [Allanach, Lester, Weber]

- assume it's SUGRA
- extract $m_0, m_{1/2}, A_0, \tan\beta, \text{sign}(\mu), y_t, \ldots$
- include all indirect constraints
- Bayesian probability map as of today



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Sfitter: TeV-scale MSSM

- originally purely best-fit search
- technically painful
  (1) grid for closed subset
  (2) fit of other parameters
  (3) complete fit

$\Rightarrow$ measurements conclusive!

$\Rightarrow$ secondary minima?

	LHC	ILC	LHC+ILC	SPS1a
$\tan\beta$	10.22±9.1	10.26±0.3	10.06±0.2	10
M_1	102.45±5.3	102.32±0.1	102.23±0.1	102.2
M_3	578.67±15	fix 500	588.05±11	589.4
$M_{\tilde{\tau}_L}$	fix 500	197.68±1.2	199.25±1.1	197.8
$M_{\tilde{\tau}_R}$	129.03±6.9	135.66±0.3	133.35±0.6	135.5
$M_{\tilde{\mu}_L}$	198.7±5.1	198.7±0.5	198.7±0.5	198.7
$M_{\tilde{q}^3{}_L}$	498.3±110	497.6±4.4	521.9±39	501.3
$M_{\tilde{t}_R}$	fix 500	420±2.1	411.73±12	420.2
$M_{\tilde{b}_R}$	522.26±113	fix 500	504.35±61	525.6
A_τ	fix 0	-202.4±89.5	352.1±171	-253.5
A_t	-507.8±91	-501.95±2.7	-505.24±3.3	-504.9
A_b	-784.7±35603	fix 0	-977±12467	-799.4

Markov chains

New physics parameter spaces [Sfitter: Lafaye, TP, Rauch, Zerwas]

- always start at exclusive likelihood map $p(d|m)$ over m
- problem: blind directions in m [flavor physics is different]

(1) Bayes' theorem: $p(m|d) = p(d|m)\ p(m)/p(d)$ [measure theorist's prejudice $p(m)$]

(2) profile likelihood: best-fit point in blind direction [no integration, no pdf]

$\Rightarrow$ Sfitter: (1) compute map $p(m|d)$ of parameter space
(2) rank local maxima
(3) do your favorite Bayesian/frequentist dance...

Weighted Markov chains

- map (chain) based on probability of a state
  expensive energy function on sample
- BSM physics: map $p(m|d)$ of parameter points
  evaluate same probability from (binned) density

$\Rightarrow$ weighted Markov chains [inspired by weighted Monte Carlo]

- already for mSUGRA: MCMC resolution not sufficient

$\Rightarrow$ additional likelihood hill–climber to rank maxima

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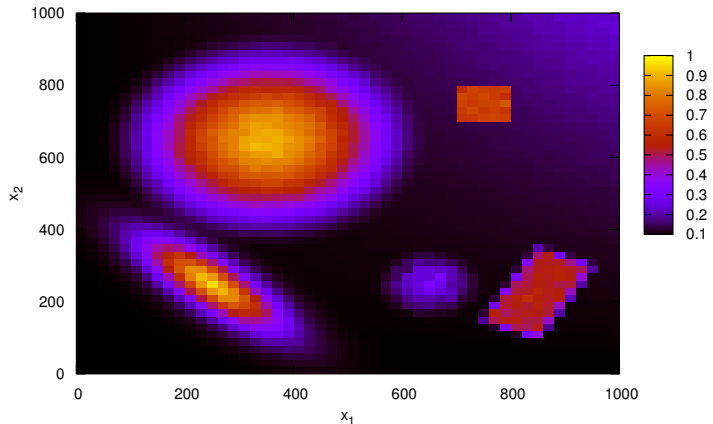
Sfitter toy model

– test function $V(\vec{x})$ in 5 dimensions [general high–dimensional extraction tool]

– Sfitter output #1: fully exclusive likelihood map [hard to plot]
Sfitter output #2: ranked list of local maxima

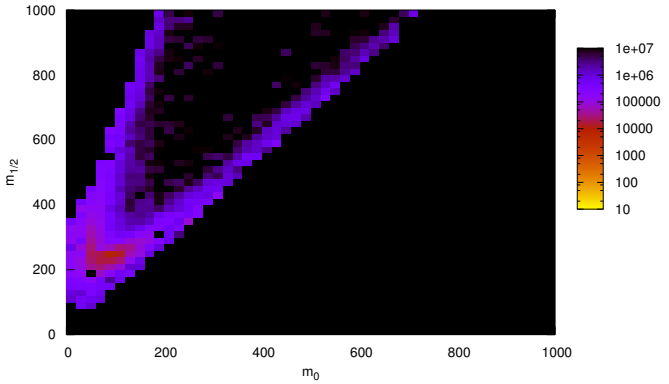


V=74.9	(655	253	347	348	349)
V=59.9	(850	224	650	649	654)
V=58.2	(849	225	587	650	650)
V=25.1	(750	749	450	450	450)
V=16.0	(245	253	552	542	544)
V=12.1	(350	650	650	650	650)
...					

SUSY parameter maps

mSUGRA-SPS1a map with LHC edges

- kinematic edges with free y_b, y_t, flat theory errors included
- Sfitter output #1: fully inclusive likelihood map
  Sfitter output #2: ranked list of local maxima



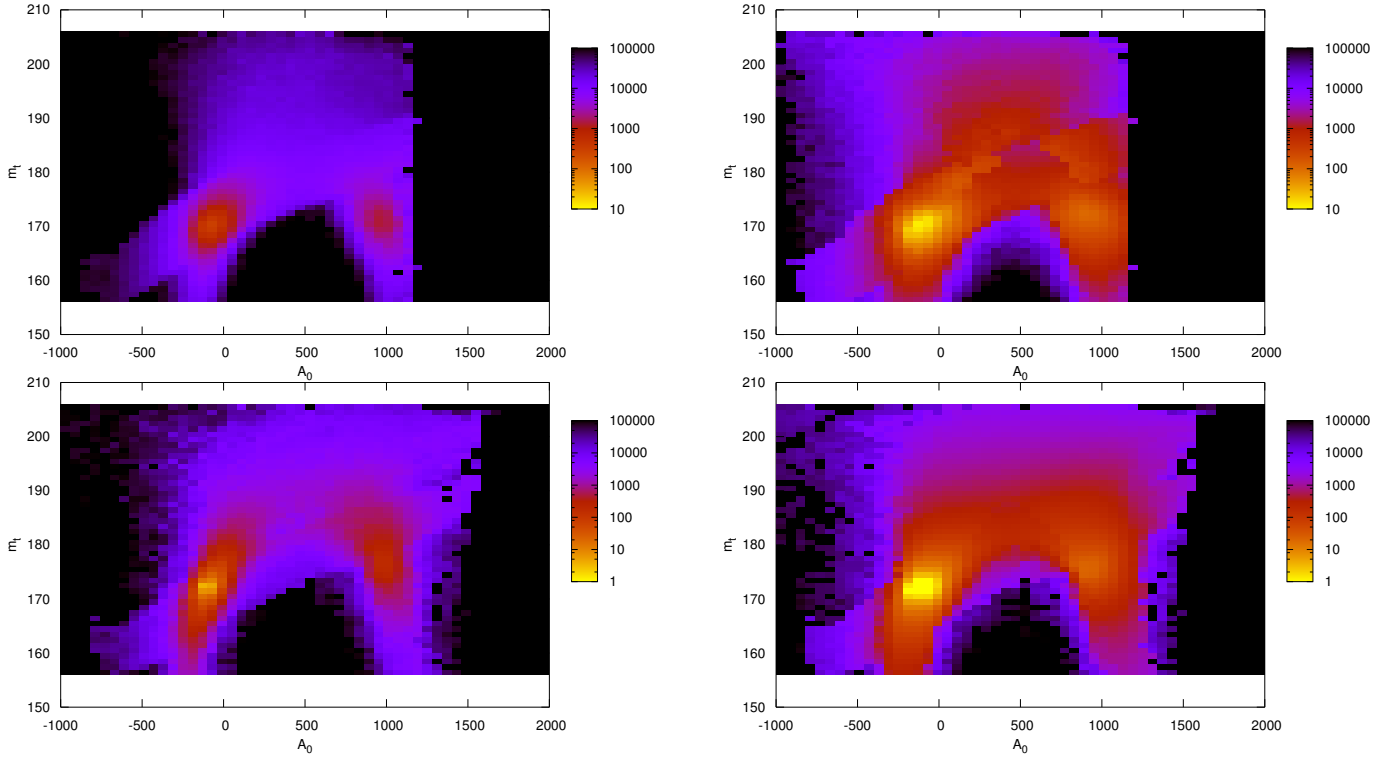
χ^2	m_0	$m_{1/2}$	$\tan\beta$	A_0	μ	m_t
0.3e-04	100.0	250.0	10.0	-99.9	+	171.4
27.42	99.7	251.6	11.7	848.9	+	181.6
54.12	107.2	243.4	13.3	-97.4	-	171.1
70.99	108.5	246.9	13.9	26.4	-	173.6
88.53	107.7	245.9	12.9	802.7	-	182.7
...						

SUSY parameter maps

mSUGRA-SPS1a map with LHC edges

- kinematic edges with free y_b, y_t, flat theory errors included
- strong correlation e.g. of A_0 and y_t after properly including all (theory) errors
- points around maximum in m_0-$m_{1/2}$ plane

[left: Bayesian pdf; right: p-likelihood; top: $\mu < 0$; bottom: $\mu > 0$]

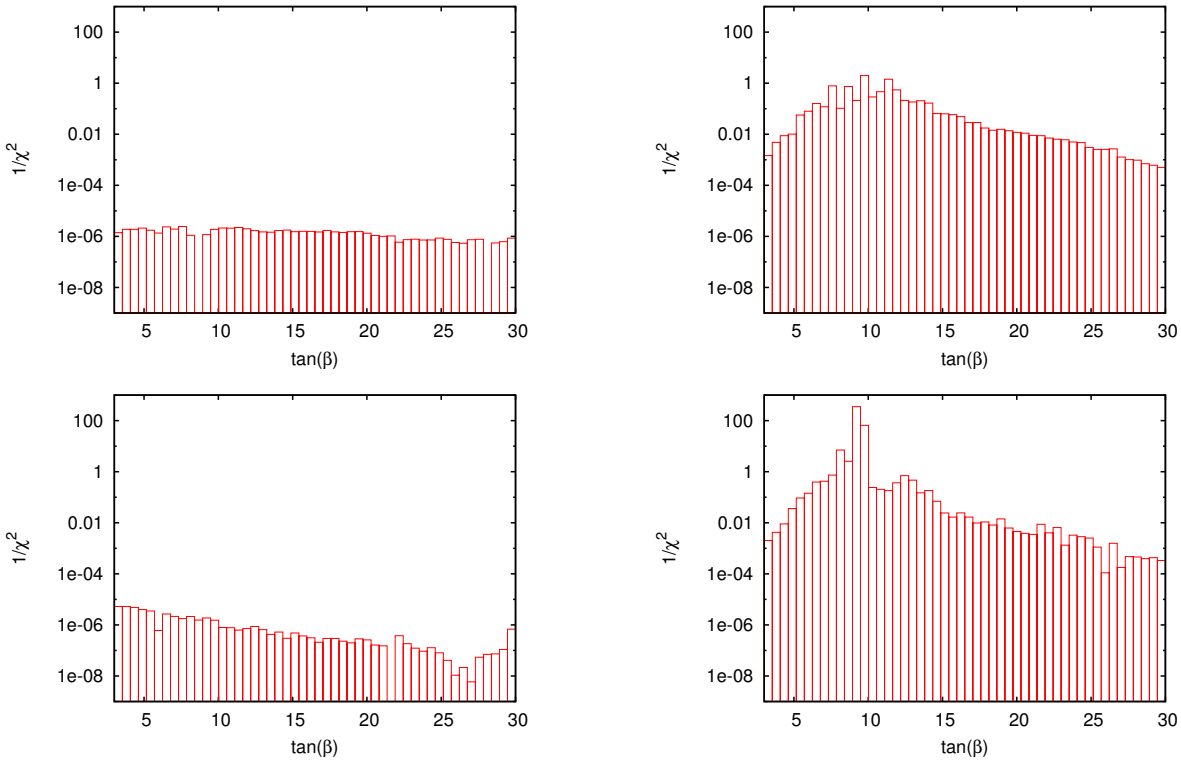


SUSY parameter maps

mSUGRA-SPS1a map with LHC edges

- kinematic edges with free y_b, y_t, flat theory errors included
- statistics does not make a difference to you, look at tan β

[top: tan β; bottom: B; left: Bayesian pdf; right: p-likelihood]



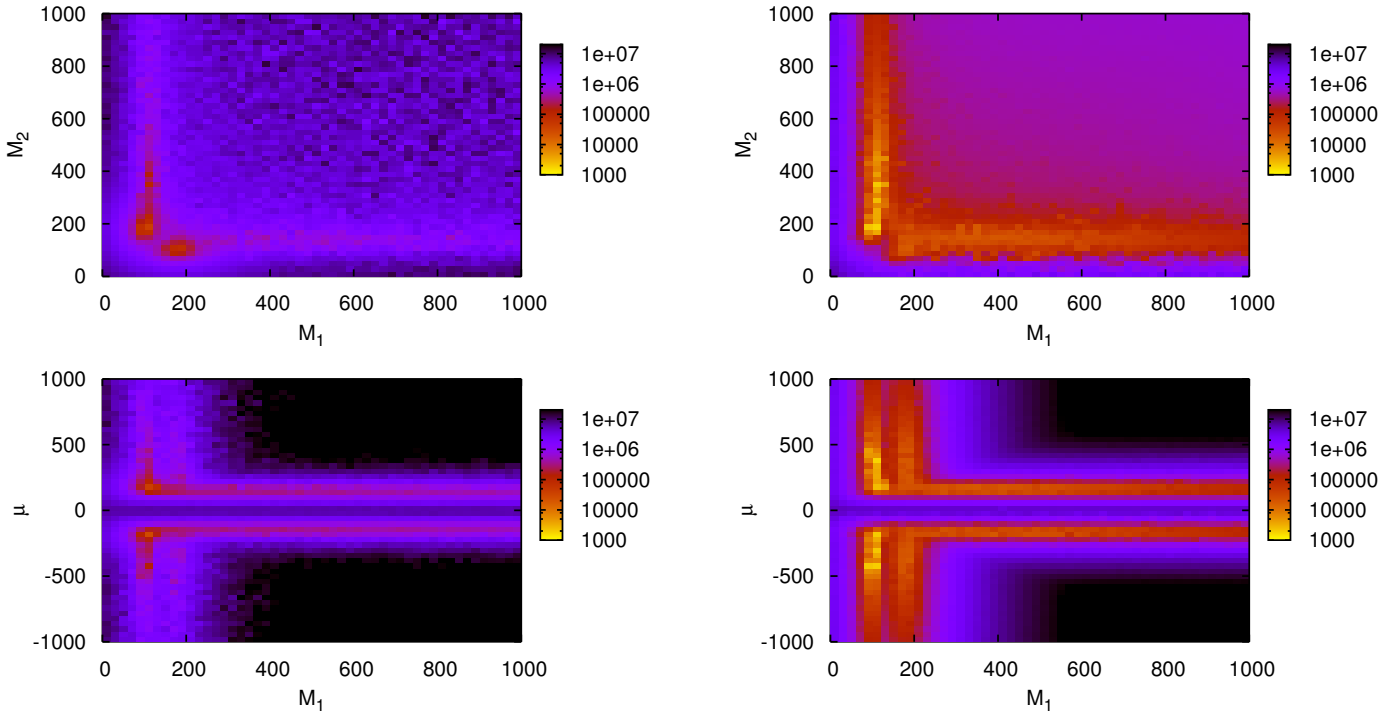
$\Rightarrow$ we can do mSUGRA properly, more observables via brand-new SLHA2

SUSY parameter maps

MSSM: the real thing

- nothing but going from 6D to 15D space
  practically: killing grids, Minuit, laptop analyses, ‘Master Code’,...
- Sfitter outputs #1 and #2 still the same [weighted Markov chain plus hill climber]
- p-likelihood or Bayesian probability maps for correlated space

[left: Bayesian pdf; right: p-likelihood]



SUSY parameter maps

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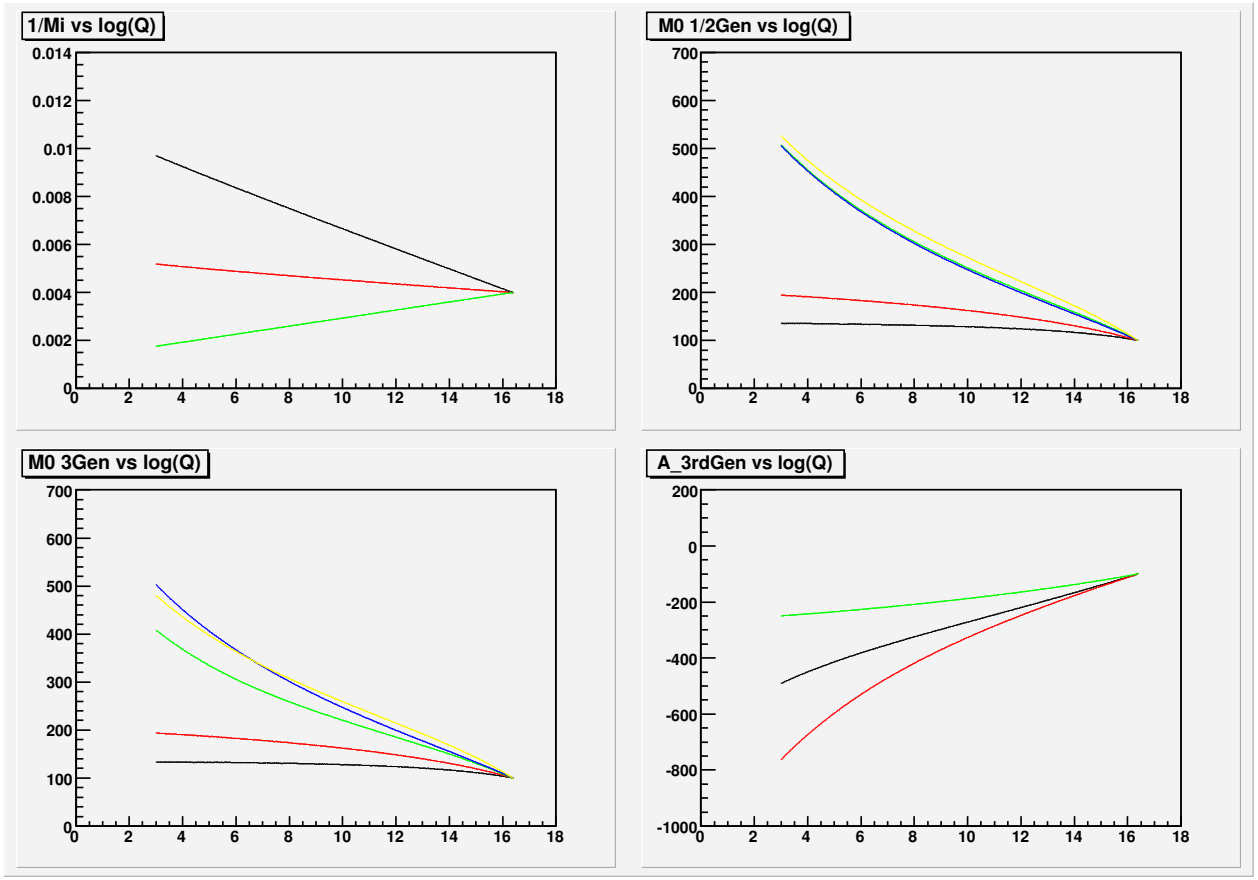
- bottom–up running of RGE [Sfitter + Kneur]



$\Rightarrow$ testing models instead of believing in them

LHC will do a great job...

- ...but you have to get things right
- LHC will find signals for TeV–scale new physics
- LHC will study exclusive signals
- LHC will provide us with mass and many other measurements

- we have to get the QCD part right
- we have to get the errors part right
- we have to get the statistics part right
- we have to talk to (the right) experimentalists