

All that (s)fitting

Tilman Plehn

SUSY parameters

Markov chains

Errors

Cascade decays

Toy model

MSSM

Higgs sector

All that (s)fitting

Tilman Plehn

SFitter collaboration

Neckarzimmern, 2/2010

Outline

Motivation: Supersymmetric parameters

Markov chains

Errors

Masses from cascade decays

Toy model: mSUGRA

Real thing: MSSM

Higgs sector

Motivation: Supersymmetric parameters

New physics in the LHC era

- complex models, including dark matter, flavor physics, low-energy physics,...
- honest parameters: weak-scale Lagrangean
- measurements: masses or edges
branching fractions
cross sections
- errors: statistics & systematics & theory, fully correlated
- problem in grid: huge phase space, find local minima?
problem in fit: domain walls, find global minima?

First go at problem

- ask a friend how SUSY is broken $\Rightarrow$ mSUGRA
- fit $m_0, m_{1/2}, A_0, \tan \beta, y_t, \dots$ minimizing

$$\chi^2 = -2 \log \mathcal{L} = \vec{\chi}_d^T C^{-1} \vec{\chi}_d \quad \text{with} \quad \chi_{d,i} = \frac{|d_i - \bar{d}_i|}{\sigma_i^{(\text{exp})}}$$

- best-fitting point to LHC data

$\Rightarrow$ use edges, not masses [more later]

	SPS1a	Δ LHC masses	Δ LHC edges
m_0	100	3.9	1.2
$m_{1/2}$	250	1.7	1.0
$\tan \beta$	10	1.1	0.9
A_0	-100	33	20

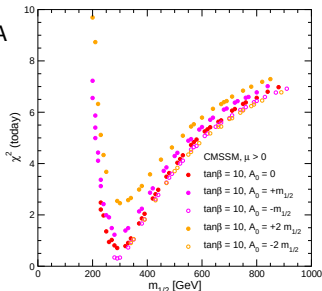
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- ask a friend how SUSY is broken $\Rightarrow$ mSUGRA
 - fit $m_0, m_{1/2}$, fix rest [why???]
 - no problem, include indirect constraints
 - determine ILC energy [Ellis, Weinemeyer, Olive, Heiglein]
- $\Rightarrow$ no theory bias, except it's mSUGRA



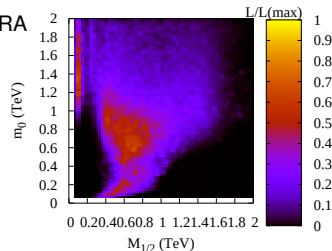
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- ask a friend how SUSY is broken $\Rightarrow$ mSUGRA
 - fit $m_0, m_{1/2}, A_0, \tan \beta, \text{sign}(\mu), y_t, \dots$
 - no problem, include dark matter
 - probability map [Allanach, Lester, Weber]
- $\Rightarrow$ beautiful example for frequentist/Bayesian



Markov chains

Probability maps

- need handle for agreement as function of parameters
 - likelihood: data given a model $p(d|m) \sim |\mathcal{M}|^2$
 - Bayes' theorem: $p(m|d) = p(d|m) p(m)/p(d)$ [$p(d)$ through normalization]
 - theorist's prejudice: model $p(m)$
- ⇒ given measurements: (1) compute map $p(d|m)$
 (2) rank local maxima
 (3) derive probabilities for parameters

Markov chains

- classical: representative set of spin states
compute average energy on this reduced sample
- BSM physics: map $p(d|m)$ of parameter points
evaluate same probability or additional function
- Metropolis-Hastings
starting probability $p(d|m)$ vs suggestion probability $p(d|m')$
 (1) accept new point if $p(d|m') > p(d|m)$
 (2) otherwise accept with $p(d|m')/p(d|m) < 1$
- free proposal probability $q(m \rightarrow m') \neq q(m' \rightarrow m)$
no memory $\leftrightarrow$ detailed balance
- 25% success rate to aim for

Improving Markov chains

Weighted Markov chains

- special situation
measure of ‘representative’: probability itself
- example with 2 bins, probability 10%:90%
10 entries needed for good Markov chain
2 entries needed if weight kept
- binning with weight would double count
bin with inverse averaging

$$P_{\text{bin}}(p \neq 0) = \frac{\text{bincount}}{\sum_{i=1}^{\text{bincount}} p^{-1}}$$

- good choice for $\mathcal{O}(6)$ dimensions

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Cooling Markov chains

- need to zoom in on peak structures
- modified condition [inspired by simulated annealing]
Markov chain in 100 partitions, numbered by j

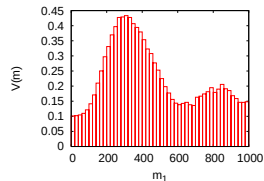
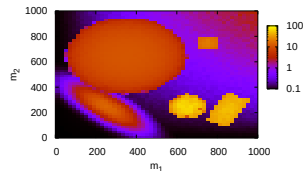
$$\frac{p(m')}{p(m)} > r^{\frac{100}{j^c}} \quad \text{with } c \sim 10, \quad r \in [0, 1] \quad \text{random number}$$

- only reliable for many Markov chains

Frequentist vs Bayesian

Getting rid of model parameters

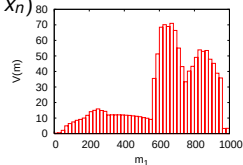
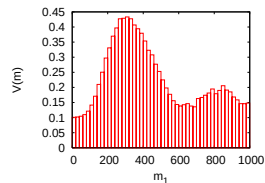
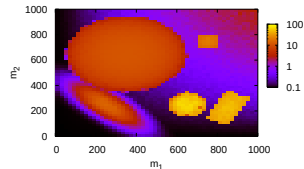
- poorly constrained directions
interested in special parameter
unphysical parameters [JES part of m_t extraction]
 - two ways to marginalize likelihood map
- (1) integrate over probabilities
normalization etc mathematically correct
integration measure unclear
noise accumulation from irrelevant regions
classical example: convolution of two Gaussians



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classical example: convolution of two Gaussians
 - (2) profile likelihood $\mathcal{L}(\dots, x_{j-1}, x_{j+1}, \dots) \equiv \max_{x_j} \mathcal{L}(x_1, \dots, x_n)$
not normalized, no comparison of structures
no integration needed
no noise accumulation
classical example: best-fit point
- childish civil war if applied to same question
frequentist: flavor, Higgs, ...
Bayesian: dark matter, new physics, ...
- simply: two questions, two answers



Error analysis

Sources of uncertainty

- statistical error: Gaussian
- systematic error: Gaussian, if measured
- theory error: not Gaussian
- simple argument
 - QCD rate $\pm 10\%$ off: no problem
 - QCD rate $\pm 30\%$ off: no problem
 - QCD rate $\pm 300\%$ off: Standard Model wrong
- theory likelihood flat centrally and zero far away
- profile likelihood construction: RFit [CKMFitter]

$$\chi^2 = \vec{\chi}_d^T \mathbf{C}^{-1} \vec{\chi}_d$$

$$\chi_{d,i} = \begin{cases} 0 & |d_i - \bar{d}_i| < \sigma_i^{(\text{theo})} \\ \frac{|d_i - \bar{d}_i| - \sigma_i^{(\text{theo})}}{\sigma_i^{(\text{exp})}} & |d_i - \bar{d}_i| > \sigma_i^{(\text{theo})} \end{cases},$$

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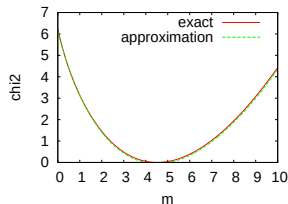
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(Inconsistent) combination of errors

- Gaussian $\otimes$ Gaussians: half width added in quadrature
- Gaussian $\otimes$ flat: RFit scheme
- Gaussian $\otimes$ Poisson
- approximate formula

$$\frac{1}{\log \mathcal{L}_{\text{comb}}} = \frac{1}{\log \mathcal{L}_{\text{Gauss}}} + \frac{1}{\log \mathcal{L}_{\text{Poisson}}}$$

- good to 5% for 5 events with 10% Gaussian



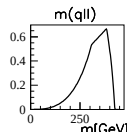
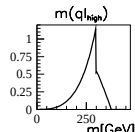
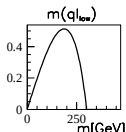
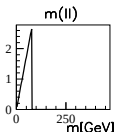
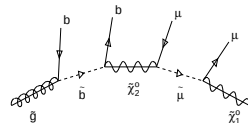
Masses from cascade decays

Cascade decays [Atlas-TDR, Cambridge, Review: Morrissey, TP, Tait]

- if new particles strongly interacting and LSP weakly interacting
- like Tevatron: jets + missing energy
- tough: $(\sigma\text{BR})_1/(\sigma\text{BR})_2$ [unavoidable: focus point]
- easier: cascade kinematics [$10^7 \dots 10^8$ events]
- thresholds & edges

$$0 < m_{\mu\mu}^2 < \frac{m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\ell}}^2}{m_{\tilde{\ell}}} \frac{m_{\tilde{\ell}}^2 - m_{\tilde{\chi}_1^0}^2}{m_{\tilde{\ell}}}$$

⇒ new-physics mass spectrum from cascade kinematics



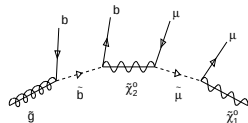
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Gluino decay [Gjelsten, Miller, Osland]

- all decay jets b quarks [otherwise dead by QCD]
- no problem: off-shell [Catpiss: Hagiwara et al.]

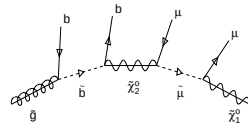
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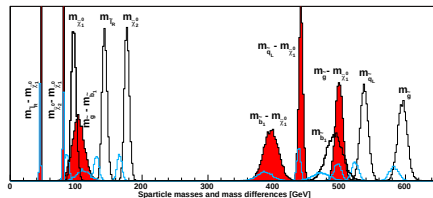
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- gluino mass to few percent (if interested in masses)



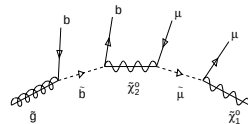
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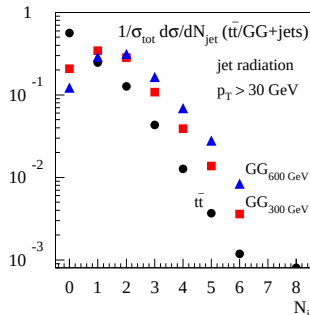
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Likely bad ideas

- decay jets vs QCD radiation
- collinear initial state radiation [$p_{T,j} < M_{\text{hard}}$]
- proper description: CKKW/MLM [in MadEvent]
- $\langle N_{\text{jet}} \rangle$ dependent on hard scale
- study: scalar gluons [TP & Tait]

⇒ QCD basics always useful at LHC



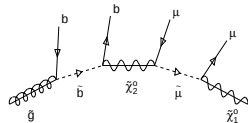
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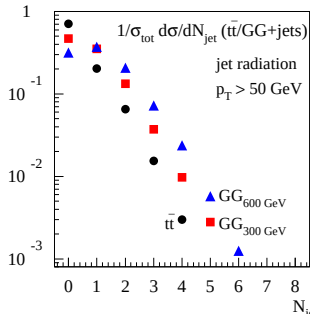
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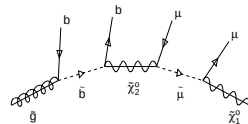
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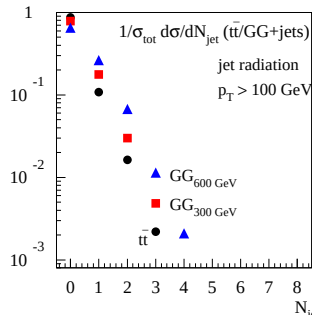
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SPSa1

Our favorite parameter point: SPS1a

- low masses to help ILC
- many decay chains to help LHC
- studied to death in LHC-ILC report
- SPS1a' with correct dark matter density
- mass spectrum

	m_{SPS1a}	LHC	ILC	LHC+ILC		m_{SPS1a}	LHC	ILC	LHC+ILC
h	108.99	0.25	0.05	0.05	H	393.69		1.5	1.5
A	393.26		1.5	1.5	$H_{\pm}$	401.88		1.5	1.5
χ_1^0	97.21	4.8	0.05	0.05	χ_2^0	180.50	4.7	1.2	0.08
χ_3^0	356.01		4.0	4.0	χ_4^0	375.59	5.1	4.0	2.3
$\chi_{1\pm}^\pm$	179.85		0.55	0.55	$\chi_{2\pm}^\pm$	375.72		3.0	3.0
$\tilde{g}$	607.81	8.0		6.5					
$\tilde{t}_1$	399.10		2.0	2.0	$\tilde{b}_2$	544.85	7.9		6.2
$\tilde{b}_1$	518.87	7.5		5.7	$\tilde{q}_R$	543.82	9.5		8.0
$\tilde{q}_L$	562.98	8.7		4.9	$\tilde{e}_R$	142.65	4.8	0.05	0.05
$\tilde{e}_L$	199.66	5.0	0.2	0.2	$\tilde{\mu}_R$	142.65	4.8	0.2	0.2
$\tilde{\mu}_L$	199.66	5.0	0.5	0.5	$\tilde{\tau}_2$	203.69		1.1	1.1
$\tilde{\tau}_1$	133.35	6.5	0.3	0.3					
$\tilde{\nu}_e$	183.79		1.2	1.2					

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- endpoint measurements

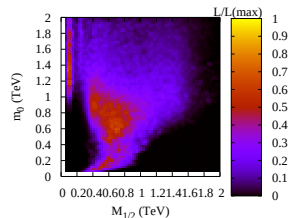
type of measurement		nominal value	stat.	LES error	JES	theo.
m_h		108.99	0.01	0.25		2.0
m_t		171.40	0.01		1.0	
$m_{\tilde{L}} - m_{\chi_1^0}$		102.45	2.3	0.1		2.2
$m_{\tilde{g}} - m_{\chi_1^0}$		511.57	2.3		6.0	18.3
$m_{\tilde{q}_R} - m_{\chi_1^0}$		446.62	10.0		4.3	16.3
$m_{\tilde{g}} - m_{\tilde{b}_1}$		88.94	1.5		1.0	24.0
$m_{\tilde{g}} - m_{\tilde{b}_2}$		62.96	2.5		0.7	24.5
$m_{ll}^{\max}$:	three-particle edge($\chi_2^0, \tilde{l}_R, \chi_1^0$)	80.94	0.042	0.08		2.4
$m_{llq}^{\max}$:	three-particle edge($\tilde{q}_L, \chi_2^0, \chi_1^0$)	449.32	1.4		4.3	15.2
m_{lq}^{low} :	three-particle edge($\tilde{q}_L, \chi_2^0, \tilde{l}_R$)	326.72	1.3		3.0	13.2
$m_{ll}^{\max}(\chi_4^0)$:	three-particle edge($\chi_4^0, \tilde{l}_R, \chi_1^0$)	254.29	3.3	0.3		4.1
$m_{\tau\tau}^{\max}$:	three-particle edge($\chi_2^0, \tilde{\tau}_1, \chi_1^0$)	83.27	5.0		0.8	2.1
m_{lq}^{high} :	four-particle edge($\tilde{q}_L, \chi_2^0, \tilde{l}_R, \chi_1^0$)	390.28	1.4		3.8	13.9
$m_{llq}^{\text{thres.}}$:	threshold($\tilde{q}_L, \chi_2^0, \tilde{l}_R, \chi_1^0$)	216.22	2.3		2.0	8.7
$m_{llb}^{\text{thres.}}$:	threshold($\tilde{b}_1, \chi_2^0, \tilde{l}_R, \chi_1^0$)	198.63	5.1		1.8	8.0

- challenge: find more LHC measurements
- add flavor, $(g-2)_\mu$, dark matter

Toy model: mSUGRA

mSUGRA as of today [Allanach, Cranmer, Lester, Weber]

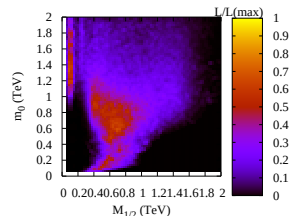
- remember frequentist vs Bayesian
- always remember:
different questions — different answers
- ‘Which is the most likely parameter point?’
‘How does dark matter annihilate/couple?’



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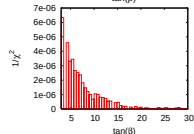
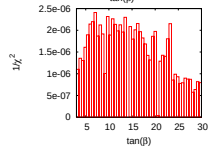
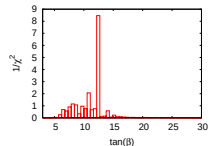
Proper high-scale model [SFitter: Lafaye, TP, Rauch, D. Zerwas]

- $m_{1/2}, m_0, A_0$ at high scale
 $\tan \beta$ at low scale
 m_Z assuming e-w symmetry breaking
- replace $\tan \beta$ with high-scale B

$$\mu^2 = \frac{m_{H,2}^2 \sin^2 \beta - m_{H,1}^2 \cos^2 \beta}{\cos 2\beta} - \frac{1}{2} m_Z^2$$

$$2B\mu = \tan 2\beta \left(m_{H,1}^2 - m_{H,2}^2 \right) + m_Z^2 \sin 2\beta$$

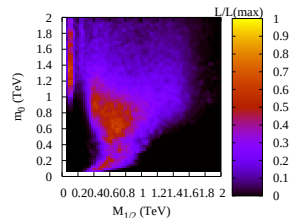
- phrase results in $\tan \beta$
no net change for profile likelihood
shift to small $\tan \beta$ for flat B prior



Toy model: mSUGRA

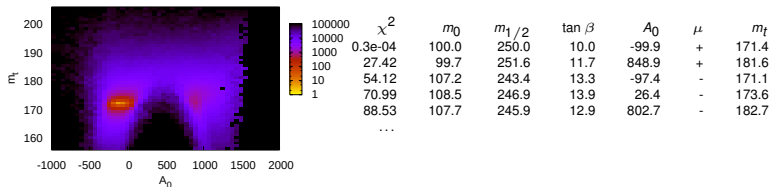
mSUGRA as of today [Allanach, Cranmer, Lester, Weber]

- remember frequentist vs Bayesian
- always remember:
different questions — different answers
- ‘Which is the most likely parameter point?’
‘How does dark matter annihilate/couple?’



Correlations and secondary maxima

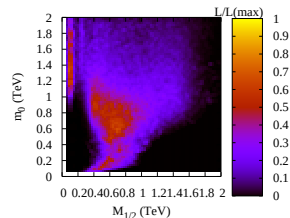
- SFitter output #1: fully exclusive likelihood map from Markov chain
SFitter output #2: ranked list of local maxima from hill climber
- strong correlation e.g. of A_0 and y_t [do not forget m_t]
maxima distinguishable by quality of fit



Toy model: mSUGRA

mSUGRA as of today [Allanach, Cranmer, Lester, Weber]

- remember frequentist vs Bayesian
- always remember:
different questions — different answers
- ‘Which is the most likely parameter point?’
‘How does dark matter annihilate/couple?’



Get errors right

- three sources of errors, correlated
- flat theory errors [Gaussian better than none]
- masses or endpoints?

	SPS1a	$\Delta_{\text{theo-exp zero}}$	$\Delta_{\text{expNoCorr zero}}$	$\Delta_{\text{theo-exp zero}}$	$\Delta_{\text{theo-exp gauss}}$	$\Delta_{\text{theo-exp flat}}$
		masses	endpoints			
m_0	100	4.11	1.08	0.50	2.97	2.17
$m_1/2$	250	1.81	0.98	0.73	2.99	2.64
$\tan \beta$	10	1.69	0.87	0.65	3.36	2.45
A_0	-100	36.2	23.3	21.2	51.5	49.6
m_t	171.4	0.94	0.79	0.26	0.89	0.97

⇒ use data close to actual measurement

Real thing: MSSM

19-dimensional MSSM [unless God tells you how she breaks SUSY]

- SFitter approach and outputs still the same [weighted Markov chain plus hill climber]
- but in several steps
 - (1) Markov chains over entire parameter space
 - (2) MC and hill climber over $M_1, m_2, M_3, \mu, \tan \beta$ [flat proposal function, 15 best points]
 - (3) MC and hill-climber over orthogonal coordinates [BW proposal function, 5 best points]
 - (4) error analysis with all parameters [pseudo-measurements]
- degeneracies: 22 measurements from 15 masses
 $m_A, m_{\tilde{\tau}_R}, A_t$ not covered, $\tan \beta$ bad
- assignment of particles to measurements assumed [which neutralino, slepton?]

Why theorists involved?

- want to learn statistics [usually get that badly wrong]
- theory errors not negligible [rates for focus–point scenarios]
- LHC link with other TeV–scale observations model dependent

Alternative solutions

Degenerate best-fit points, not yet discussing errors

- observe 16 parameter points with perfect χ^2 :
 sign of μ
 sign of A_t [now with same m_t]
 lightest neutralino governing M_1 , M_2 or μ [for latter again $M_{1,2}$]

	$\mu < 0$				$\mu > 0$			
					SPS1a			
M_1	96.6	175.1	103.5	365.8	98.3	176.4	105.9	365.3
M_2	181.2	98.4	350.0	130.9	187.5	103.9	348.4	137.8
μ	-354.1	-357.6	-177.7	-159.9	347.8	352.6	178.0	161.5
$\tan \beta$	14.6	14.5	29.1	32.1	15.0	14.8	29.2	32.1
M_3	583.2	583.3	583.3	583.5	583.1	583.1	583.3	583.4
$M_{\tilde{t}_L}$	114.9	2704.3	128.3	4794.2	128.0	229.9	3269.3	118.6
$M_{\tilde{t}_R}$	348.8	129.9	1292.7	130.1	2266.5	138.5	129.9	255.1
$M_{\tilde{\mu}_L}$	192.7	192.7	192.7	192.9	192.6	192.6	192.7	192.8
$M_{\tilde{\mu}_R}$	131.1	131.1	131.1	131.3	131.0	131.0	131.1	131.2
$M_{\tilde{e}_L}$	186.3	186.4	186.4	186.5	186.2	186.2	186.4	186.4
$M_{\tilde{e}_R}$	131.5	131.5	131.6	131.7	131.4	131.4	131.5	131.6
$M_{\tilde{q}_L}$	497.1	497.2	494.1	494.0	495.6	495.6	495.8	495.0
$M_{\tilde{t}_R}$	1073.9	920.3	547.9	950.8	547.9	460.5	978.2	520.0
$M_{\tilde{b}_R}$	497.3	497.3	500.4	500.9	498.5	498.5	498.7	499.6
$M_{\tilde{q}_L}$	525.1	525.2	525.3	525.5	525.0	525.0	525.2	525.3
$M_{\tilde{q}_R}$	511.3	511.3	511.4	511.5	511.2	511.2	511.4	511.5
$A_t (-)$	-252.3	-348.4	-477.1	-259.0	-470.0	-484.3	-243.4	-465.7
$A_t (+)$	384.9	481.8	641.5	432.5	739.2	774.7	440.5	656.9
m_A	350.3	725.8	263.1	1020.0	171.6	156.5	897.6	256.1
m_t	171.4	171.4	171.4	171.4	171.4	171.4	171.4	171.4

- improve by observing more particles or measuring more parameters

⇒ central values useless without errors

Error bars

Locally around SPS1a

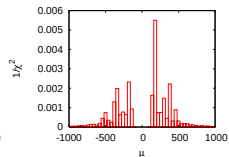
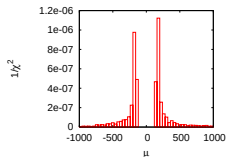
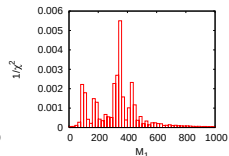
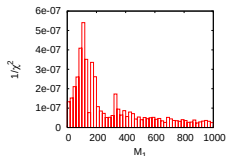
- three kinds of parameters
well-measured, as expected
poorly measured, unexpected
poorly measured, as expected
- fixed parameters need check
- poor measurements need explain
- LHC needs help...

	no theory error		flat theory error		SPS1a
$\tan \beta$	$9.8 \pm$	2.3	$10.0 \pm$	4.5	10.0
M_1	$101.5 \pm$	4.6	$102.1 \pm$	7.8	103.1
M_2	$191.7 \pm$	4.8	$193.3 \pm$	7.8	192.9
M_3	$575.7 \pm$	7.7	$577.2 \pm$	14.5	577.9
$M_{\tilde{t}_L}$	$196.2 \pm$	$\mathcal{O}(10^2)$	$227.8 \pm$	$\mathcal{O}(10^3)$	193.6
$M_{\tilde{t}_R}$	$136.2 \pm$	36.5	$164.1 \pm$	$\mathcal{O}(10^3)$	133.4
$M_{\tilde{\mu}_L}$	$192.6 \pm$	5.3	$193.2 \pm$	8.8	194.4
$M_{\tilde{\mu}_R}$	$134.0 \pm$	4.8	$135.0 \pm$	8.3	135.8
$M_{\tilde{e}_L}$	$192.7 \pm$	5.3	$193.3 \pm$	8.8	194.4
$M_{\tilde{e}_R}$	$134.0 \pm$	4.8	$135.0 \pm$	8.3	135.8
$M_{\tilde{g}_L}$	$478.2 \pm$	9.4	$481.4 \pm$	22.0	480.8
$M_{\tilde{t}_R}$	$429.5 \pm$	$\mathcal{O}(10^2)$	$415.8 \pm$	$\mathcal{O}(10^2)$	408.3
$M_{\tilde{b}_R}$	$501.2 \pm$	10.0	$501.7 \pm$	17.9	502.9
$M_{\tilde{q}_L}$	$523.6 \pm$	8.4	$524.6 \pm$	14.5	526.6
$M_{\tilde{q}_R}$	$506.2 \pm$	11.7	$507.3 \pm$	17.5	508.1
A_τ	fixed 0		fixed 0		-249.4
A_t	$-500.6 \pm$	58.4	$-509.1 \pm$	86.7	-490.9
A_b	fixed 0		fixed 0		-763.4
$A_{u1,2}$	fixed 0		fixed 0		-251.1
$A_{u1,2}$	fixed 0		fixed 0		-657.2
$A_{d1,2}$	fixed 0		fixed 0		-821.8
m_A	$446.1 \pm$	$\mathcal{O}(10^3)$	$406.3 \pm$	$\mathcal{O}(10^3)$	394.9
μ	$350.9 \pm$	7.3	$350.5 \pm$	14.5	353.7
m_t	$171.4 \pm$	1.0	$171.4 \pm$	1.0	171.4

Correlations (pretty colored plots)

Correlations

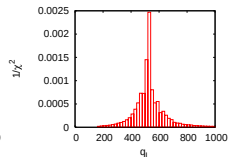
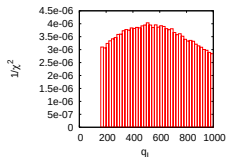
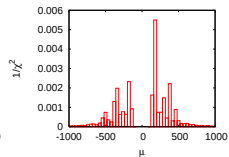
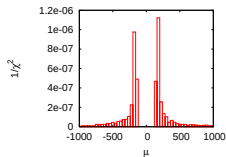
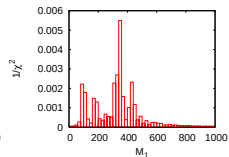
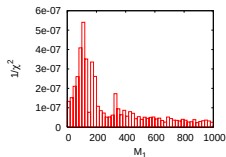
- sensitive to marginalization
- test profile likelihood vs marginalized probability
- visible best 1-dimensionally:
clear (dis)advantages of two questions



Correlations (pretty colored plots)

Correlations

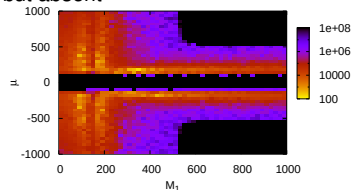
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Correlations (pretty colored plots)

Correlations

- sensitive to marginalization
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- visible best 1-dimensionally:
clear (dis)advantages of two questions
- 2-dimensional correlations in color [not crucial for MSSM]
- ino-scalar correlations hard to evaluate, but absent



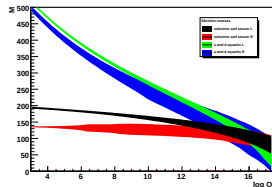
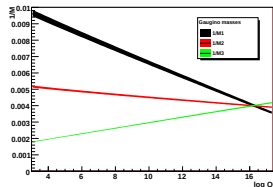
Correlations (pretty colored plots)

Correlations

- sensitive to marginalization
- test profile likelihood vs marginalized probability
- visible best 1-dimensionally:
clear (dis)advantages of two questions

On to the high scale

- SUSY breaking, unification, GUT? [ask Uli]
scale-invariant sum rules? [Cohen, Schmalz]
- the real reason for measuring TeV-scale parameters
- renormalization group running bottom-up [Kneur]
- all errors included



⇒ we might be able to do it

Higgs sector

SUSY parameters

Markov chains

Errors

Cascade decays

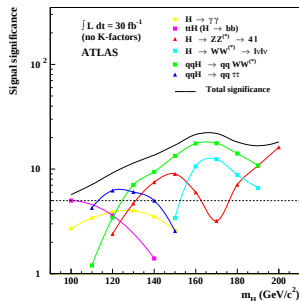
Toy model

MSSM

Higgs sector

Higgs-sector analysis at the LHC [Zeppenfeld, Kinnunen, Nikitenko, Richter-Was; Dührssen et al.]

- optimistic LHC scenario: everything working and good data
- Higgs vs. scalars? SM vs MSSM? doublet vs. general Higgs?
- light Higgs around 120 GeV: 10 main channels ($\sigma \times BR$) [*bb* channel new]
- measurements: $GF : H \rightarrow ZZ, WW, \gamma\gamma$
 $WBF : H \rightarrow ZZ, WW, \gamma\gamma, \tau\tau$
 $VH : H \rightarrow b\bar{b}$ [Butterworth, Davison, Rubin, Salam]
 $t\bar{t}H : H \rightarrow \gamma\gamma, WW, (b\bar{b})...$
- parameters: couplings $W, Z, t, b, \tau, g, \gamma$ [plus Higgs mass]
- hope: cancel uncertainties
 $(WBF : H \rightarrow WW)/(WBF : H \rightarrow \tau\tau)$
 $(WBF : H \rightarrow WW)/(GF : H \rightarrow WW)...$



Higgs sector

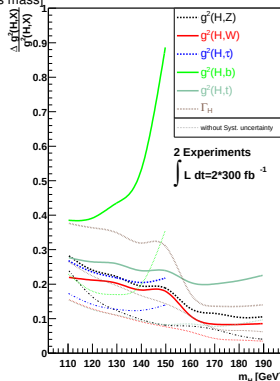
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- hope: cancel uncertainties
 $(WBF : H \rightarrow WW)/(WBF : H \rightarrow \tau\tau)$
 $(WBF : H \rightarrow WW)/(GF : H \rightarrow WW)...$

Total width

- degeneracy: $\sigma BR \propto (g_p^2/\sqrt{\Gamma_H}) (g_d^2/\sqrt{\Gamma_H})$
- additional constraint: $\sum \Gamma_i(g^2) < \Gamma_H \rightarrow \Gamma_H|_{\min}$
- $WW \rightarrow WW$ unitarity: $g_{WWH} \lesssim g_{WWH}^{\text{SM}} \rightarrow \Gamma_H|_{\max}$
- width extraction hard

⇒ **this analysis:** $\Gamma_H = \sum_{\text{obs}} \Gamma_j$



Higgs couplings

SFitter analysis [Dührssen, Lafaye, TP, Rauch, Zerwas]

- all couplings varied around SM values $g_{HXX} = g_{HXX}^{\text{SM}} (1 + \delta_{HXX})$
 $\delta_{HXX} \sim -2$ means sign flip [$g_{HWW} > 0$ fixed]
- need assumption about loop-induced couplings $g_{ggH}, g_{\gamma\gamma H}$
- likelihood map and local errors as before
- experimental/theory errors on signal and backgrounds [do not ask theorists!]

luminosity measurement	5 %
detector efficiency	2 %
lepton reconstruction efficiency	2 %
photon reconstruction efficiency	2 %
WBF tag-jets / jet-veto efficiency	5 %
b -tagging efficiency	3 %
τ -tagging efficiency (hadronic decay)	3 %
lepton isolation efficiency ($H \rightarrow 4\ell$)	3 %

σ (gluon fusion)	13 %
σ (weak boson fusion)	7 %
σ (VH -associated)	7 %
σ ($t\bar{t}$ -associated)	13 %

Higgs couplings

SFitter analysis [Dührssen, Lafaye, TP, Rauch, Zerwas]

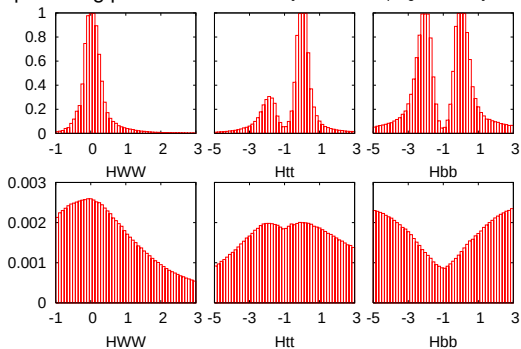
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- need assumption about loop-induced couplings $g_{ggH}, g_{\gamma\gamma H}$
- likelihood map and local errors as before
- experimental/theory errors on signal and backgrounds [do not ask theorists!]
- error bars for Standard Model hypothesis [smeared data point, 30fb^{-1}]

coupling	without eff. couplings			including eff. couplings		
	σ_{symm}	σ_{neg}	σ_{pos}	σ_{symm}	σ_{neg}	σ_{pos}
δ_{WWH}	± 0.23	-0.21	$+0.26$	± 0.24	-0.21	$+0.27$
δ_{ZZH}	± 0.50	-0.74	$+0.30$	± 0.44	-0.65	$+0.24$
$\delta_{t\bar{t}H}$	± 0.41	-0.37	$+0.45$	± 0.53	-0.65	$+0.43$
$\delta_{b\bar{b}H}$	± 0.45	-0.33	$+0.56$	± 0.44	-0.30	$+0.59$
$\delta_{\tau\bar{\tau}H}$	± 0.33	-0.21	$+0.46$	± 0.31	-0.19	$+0.46$
$\delta_{\gamma\gamma H}$	—	—	—	± 0.31	-0.30	$+0.33$
δ_{ggH}	—	—	—	± 0.61	-0.59	$+0.62$
m_H	± 0.26	-0.26	$+0.26$	± 0.25	-0.26	$+0.25$
m_b	± 0.071	-0.071	$+0.071$	± 0.071	-0.071	$+0.072$
m_t	± 1.00	-1.03	$+0.98$	± 0.99	-1.00	$+0.98$

Higgs couplings

One-dimensional distributions to check....

(1) noisy environment preferring profile likelihoods [no effective couplings, 30 fb^{-1}]

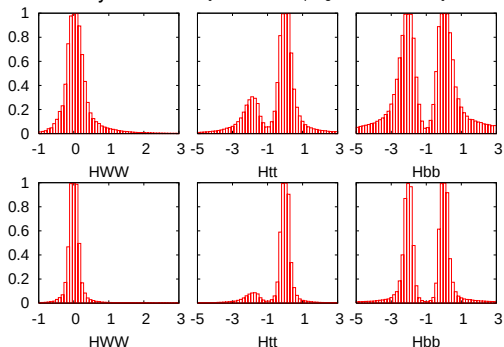


Higgs couplings

One-dimensional distributions to check....

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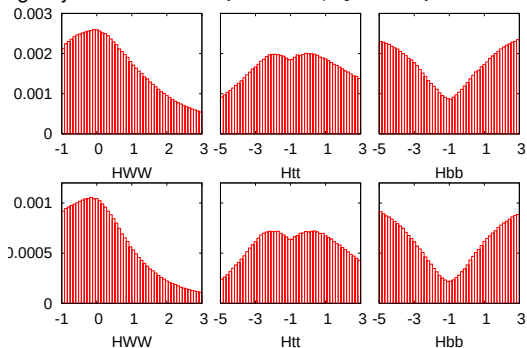
(2) higher luminosity quantitatively different [no effective couplings, $30 \text{ vs } 300 \text{ fb}^{-1}$]



Higgs couplings

One-dimensional distributions to check....

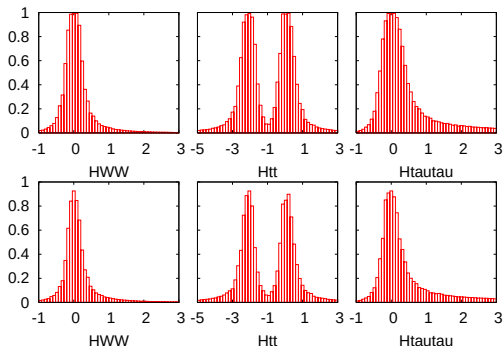
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- (3) 300 fb^{-1} not saving Bayesian statistics [no effective couplings, 300 fb^{-1}]



Higgs couplings

One-dimensional distributions to check....

- (1) noisy environment preferring profile likelihoods [no effective couplings, 30 fb^{-1}]
- (2) higher luminosity quantitatively different [no effective couplings, $30 \text{ vs } 300 \text{ fb}^{-1}$]
- (3) 300 fb^{-1} not saving Bayesian statistics [no effective couplings, 300 fb^{-1}]
- (4) theory errors not dominant for 30 fb^{-1} [with effective couplings, 30 fb^{-1}]

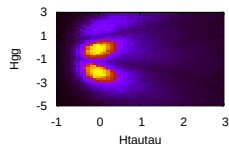
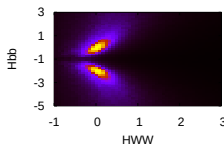
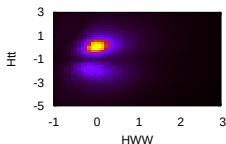


⇒ profile likelihood analysis for 30 fb^{-1} good for local structures

More colorful pictures

Two-dimensional correlations and effective couplings

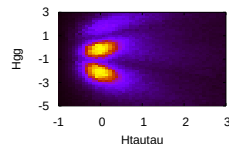
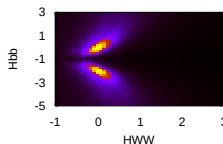
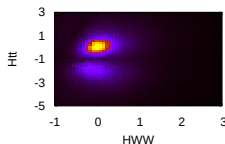
- (1) including effective g_{Hgg}
sign of g_{Htt} fixed by $g_{HWW} > 0$
correlation of g_{Hbb} and g_{HWW} [loops and width]
 g_{Hgg} accessible



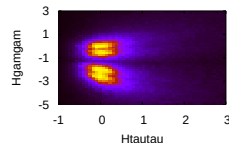
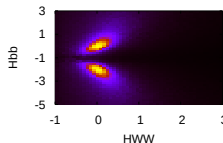
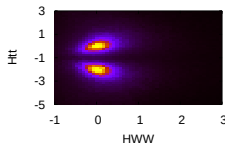
More colorful pictures

Two-dimensional correlations and effective couplings

- (1) including effective g_{Hgg}
 sign of g_{Htt} fixed by $g_{HWW} > 0$
 correlation of g_{Hbb} and g_{HWW} [loops and width]
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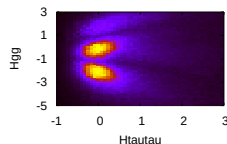
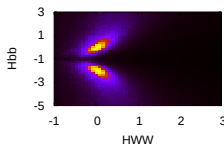
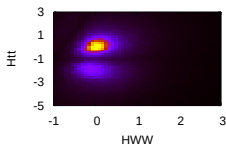
- (2) only effective $g_{H\gamma\gamma}$
 correlated g_{Htt} and g_{HWW} on both branches
 $g_{H\gamma\gamma}$ structure more complex



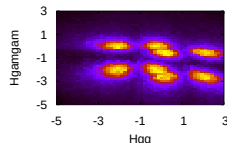
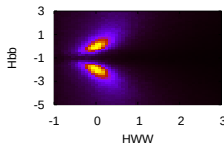
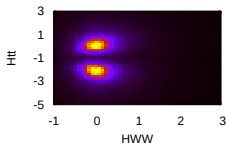
More colourful pictures

Two-dimensional correlations and effective couplings

- (1) including effective g_{Hgg}
 sign of g_{Htt} fixed by $g_{HWW} > 0$
 correlation of g_{Hbb} and g_{HWW} [loops and width]
 g_{Hgg} accessible



- (2) only effective $g_{H\gamma\gamma}$
 correlated g_{Htt} and g_{HWW} on both branches
 $g_{H\gamma\gamma}$ structure more complex
- (3) both effective couplings
 discrete structures getting out of hand



What's left....

Unobserved or invisible?

- invisible Higgs decay actually observable
 $pp \rightarrow qqH$: tagging jets plus nothing [Eboli & Zeppenfeld]
 $pp \rightarrow ZH$: recoil against nothing [Atlas CSC notes]
- unobserved Higgs decay into backgrounds
 photons/leptons not possible
 $H \rightarrow$ jets promising, increase g_{Hcc} not to affect production rate
 funny features if not included in Higgs width
 test by only fitting total width correction...

⇒ hard to hide the Higgs at LHC

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Finally...

SFitter-type analyses rock

let's go for a beer

All that (s)fitting

Tilman Plehn

SUSY parameters

Markov chains

Errors

Cascade decays

Toy model

MSSM

Higgs sector