Sfitting

Tilman Plehn

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Motivation: Supersymmetric parameters

New physics in the LHC era [Review: Morrissey, TP, Tait]

- 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
- grid: find local minima?
  fit: find global minima?

First go at problem

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

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

- best-fitting point to LHC data

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

	SPS1a	ΔLHC masses	ΔLHC 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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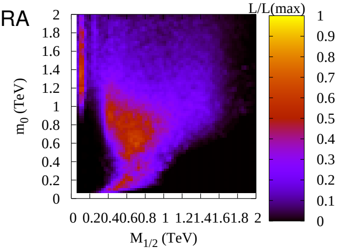
– fit $m_0, m_{1/2}, A_0, \tan\beta, \text{sign}(\mu), y_t, ...$

– no problem, include dark matter

– probability map [Allanach, Lester, Weber]

⇒ nothing you cannot predict...



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 $p(m)$

$\Rightarrow$ 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
- 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 $q(m \to m') \neq q(m' \to m)$
  no memory $\leftrightarrow$ detailed balance
- 25% success rate to aim for

Improving Markov chains

Weighted Markov chains

– special situation in BSM physics
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

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

– only reliable for many Markov chains

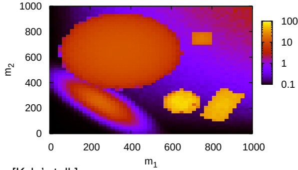
Frequentist vs Bayesian

Getting rid of model parameters

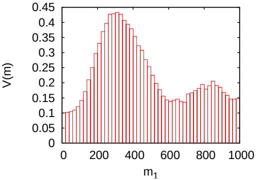
– poorly constrained directions
intersted in special parameter
unphysical parameters [JES part of m_t extraction]

– two ways to marginalize common likelihood map

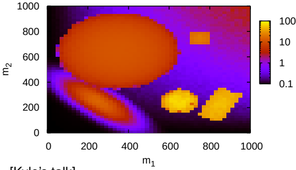
(1) integrate over probabilities
normalization etc mathematically correct
integration measure unclear
noise accumulation from irrelevant regions
classical example: convolution of two Gaussians



[Kyle's talk]



Frequentist vs Bayesian



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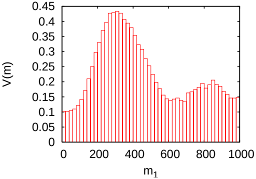

(1) integrate over probabilities
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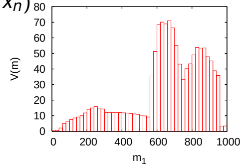
(2) profile likelihood $\mathcal{L}(.., x_{j-1}, x_{j+1} ....) \equiv \max_{x_j} \mathcal{L}(x_1, ..., x_n)$
not normalized, no comparison of structures
no integration needed
no noise accumulation
classical example: best-fit point



- frequentist: flavor, Higgs,...
  Bayesian: cosmology, dark matter, new physics,...
- simply: two questions — two answers, we may not get to pick

Error analysis

Sources of uncertainty

- statistical error: Gaussian
  systematic error: Gaussian, if measured
  theory error: not Gaussian
- simple argument [Ben's talk]
  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]

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

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

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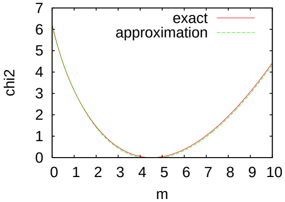
(Inconsistent) combination of errors

– Gaussian $\otimes$ Gaussians: half width added in quadrature
  Gaussian $\otimes$ flat: RFit scheme
  Gaussian $\otimes$ Poisson

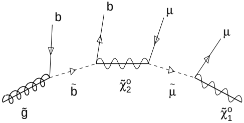
– approximate formula

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

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



Masses from cascade decays



Cascade decays [Atlas-TDR, Oxbridge]

– 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 [$10^7 \cdots 10^8$ events]

– thresholds & edges

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

$\Rightarrow$ new–physics mass spectrum from cascade kinematics

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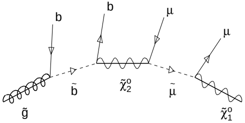

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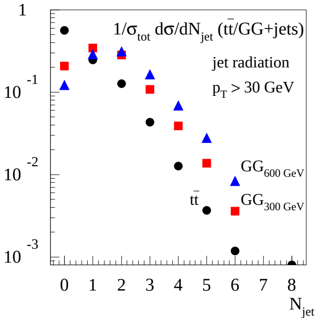
⇒ new–physics mass spectrum from cascade kinematics

Likely bad ideas

- decay jets vs QCD radiation
- collinear initial state radiation [$p_{T,j} < M_{\text{hard}}$]
- proper description: CKKW/MLM [e.g. 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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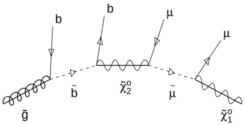

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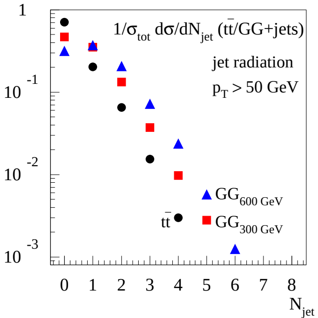

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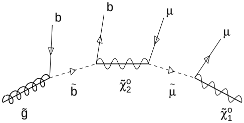

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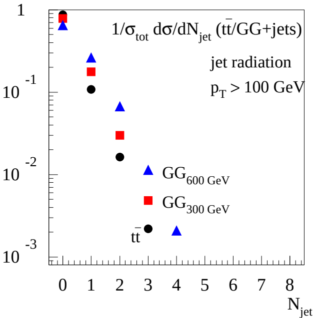
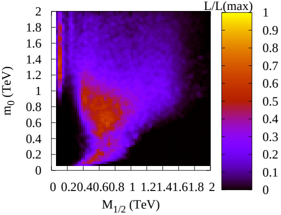


Toy model: mSUGRA



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

- ‘Which is the most likely parameter point?’
  ‘How does dark matter annihilate/couple?’
- trivial model, but still issues...

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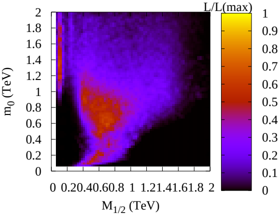

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Proper high-scale model [Lafaye, TP, Rauch, D. Zerwas]

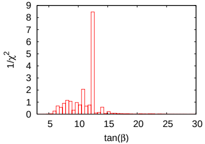
– $m_{1/2}, m_0, A_0$ at high scale
$\tan\beta$ at low scale
m_Z assuming e-w symmetry breaking

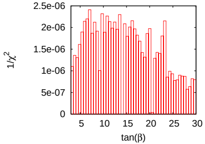
– replace $\tan\beta$ with high-scale B

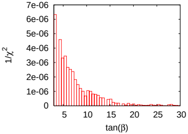
$$\mu^2 = \frac{m_{H,2}^2 \sin^2\beta - m_{H,1}^2 \cos^2\beta}{\cos 2\beta} - \frac{1}{2} m_Z^2$$

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

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







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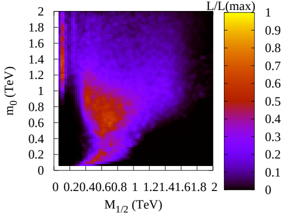

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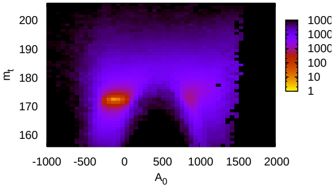
Correlations and secondary maxima

- 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
  maxima distinguishable by quality of fit



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
...						

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?]

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
$M_{\tilde{\tau}L}$	114.9	2704.3	128.3	4794.2	128.0	229.9	3269.3	118.6
$M_{\tilde{\tau}R}$	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
$M_{\tilde{q}3_L}$	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 mearuring more parameters

Error bars

Locally around SPS1a

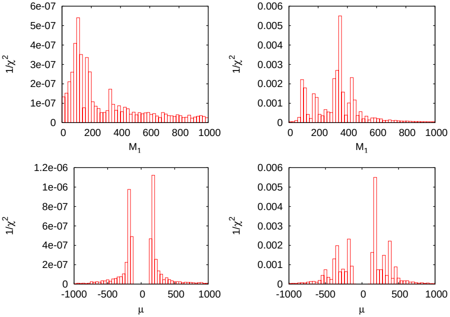
- three kinds of parameters
  well-measured, as expected
  poorly measured, unexpected
  poorly measured, as expected
- fixed parameters need check
- poor measurements need explain
- side remark:
  fat jets for stops

	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
$M_{\tilde{\tau}_L}$	196.2 $\pm\, \mathcal{O}(10^2)$	227.8 $\pm\, \mathcal{O}(10^3)$	193.6
$M_{\tilde{\tau}_R}$	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
$M_{\tilde{q}3_L}$	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
$A_{l1,2}$	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

Pretty colored plots

Parameters and correlations

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



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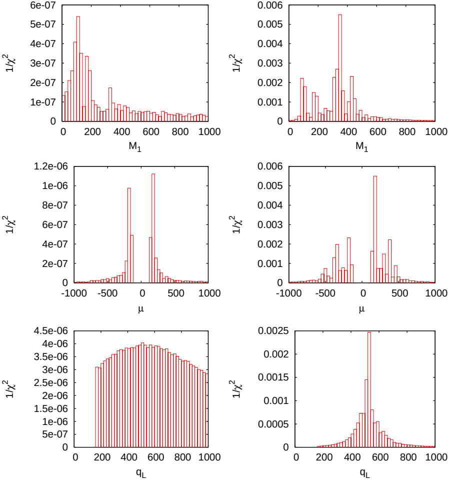
- sensitive to marginalization
- test profile likelihood vs marginalized probability
- visible best 1-dimensionally:
  clear (dis)advantages of two questions



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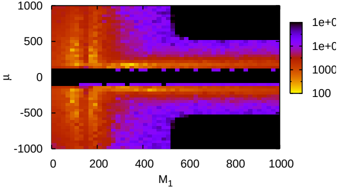
– 2-dimensional correlations in color [not crucial for MSSM]

– ino-scalar correlations hard to evaluate, luckily absent

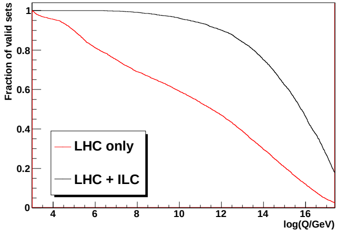


⇒ whatever...

Testing a SUSY GUT

Renormalization group analysis [Adams, Kneur, Lafaye, TP, Rauch, Zerwas; SFitter+SuSpect]

– are all mass parameters defined at high scales? [tachyonic solutions]
  do they unify?
  where is the GUT scale?
  what are the unified values?



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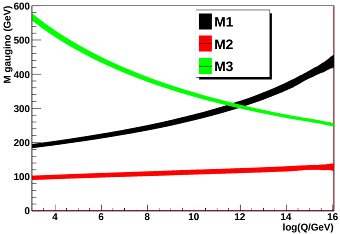
Interpretation of LHC results

– measuring $m_{1/2}$: 8-fold degeneracy solved [modulo sign of μ]



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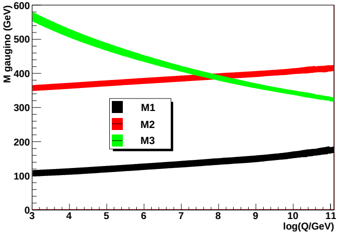

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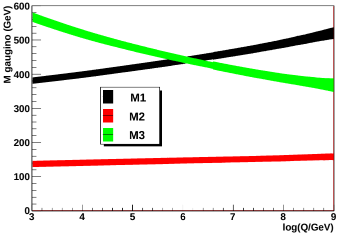

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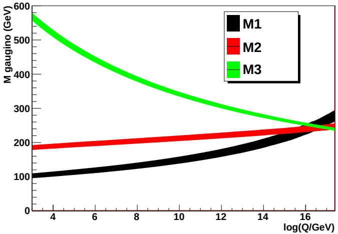

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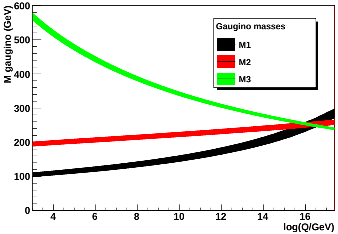

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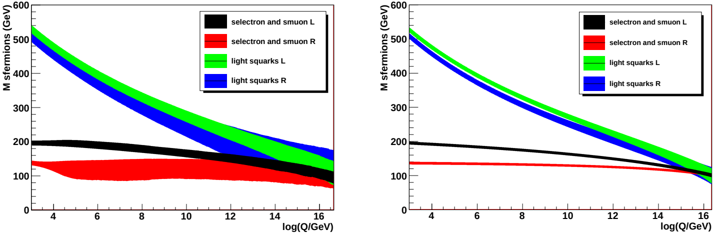

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– measured high-scale masses

	$\Delta m/m_{\text{top-down}}$	m_{unified}	$\log M_{\text{GUT}}/\text{GeV}$	$m(1.7 \cdot 10^{16}\ \text{GeV})$
$m_{1/2}$	1%	251.9 ± 5.9	16.23 ± 0.29	252.3 ± 3.2
m_0	2%	98.5 ± 10.5	16.5 ± 0.6	100.8 ± 4.9

$\Rightarrow$ one more aspects to better do right

Higgs sector

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

– optimistic LHC scenario: everything working and good data

– light Higgs around 120 GeV: 10 main channels ($\sigma \times BR$) [bb channel new]

– measurements: $GF : H \to ZZ, WW, \gamma\gamma$

$WBF : H \to ZZ, WW, \gamma\gamma, \tau\tau$

$VH : H \to b\bar{b}$ [Butterworth, Davison, Rubin, Salam]

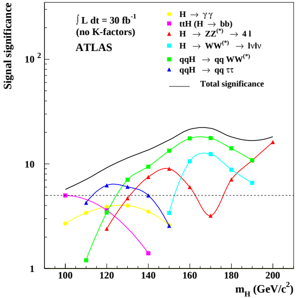
$t\bar{t}H : H \to \gamma\gamma, WW, (b\bar{b})$...

– parameters: couplings $W, Z, t, b, \tau, g, \gamma$ [plus Higgs mass]

– hope: cancel uncertainties

$(WBF :\ H \to WW)/(WBF :\ H \to \tau\tau)$

$(WBF :\ H \to WW)/(GF :\ H \to WW)$...



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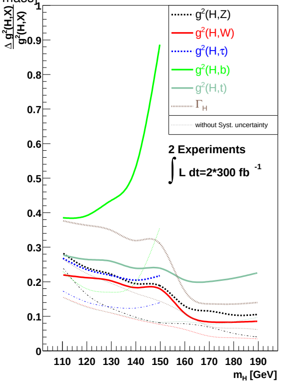

Total width

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

$\Rightarrow$ this analysis: $\Gamma_H = \sum_{\rm obs} \Gamma_j$

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 from SFitter

– 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 ($H \to 4\ell$)	3 %

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

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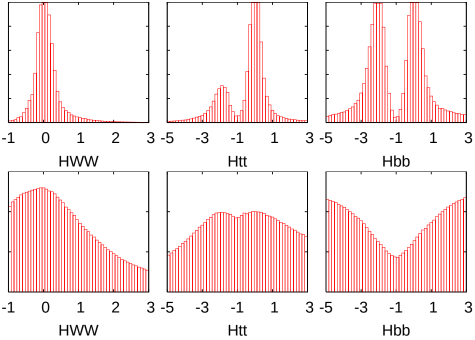
- likelihood map and local errors from SFitter
- experimental/theory errors on signal and backgrounds [do not ask theorists!]
- error bars for Standard Model hypothesis [smeared data point, 30fb^{-1}]

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

Higgs couplings

One-dimensional distributions to check....

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



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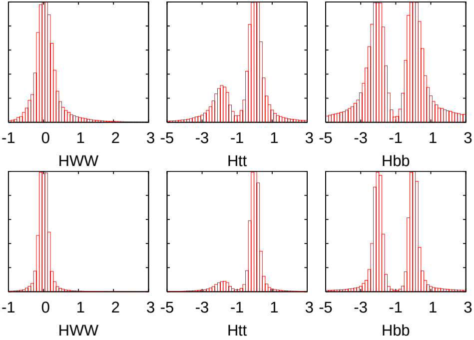

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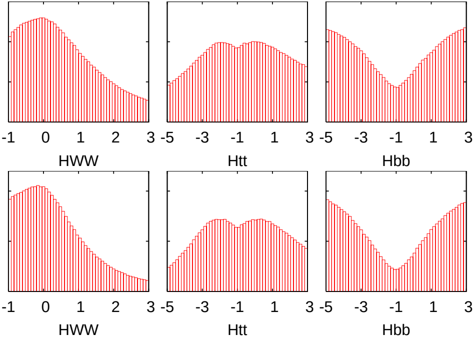

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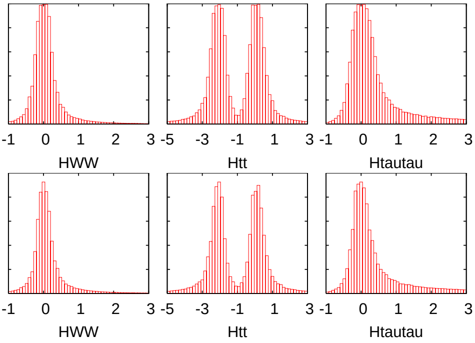
3– but not saving Bayesian statistics [no effective couplings, 300 fb^{-1}]

4– theory errors not dominant for 30 fb^{-1} [with effective couplings, 30 fb^{-1}]



⇒ profile likelihood promising for 30 fb^{-1}, errors a mess

Refining Higgs hypotheses

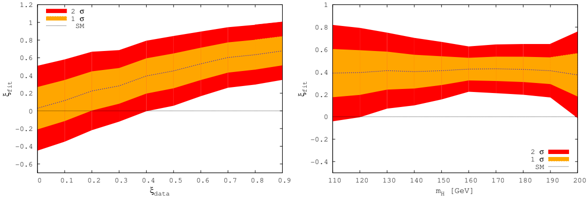
Strongly interacting Higgs at LHC [Espinosa, Grojean, Mühlleitner; SFitter + Block, Zerwas]

– looking like fundamental Higgs

1– all couplings scaled $g \to g\sqrt{1-\xi}$

– one-parameter fit in SFitter [SFitter + Bock, P Zerwas]

– 30 fb^{-1} and 120 GeV Higgs: $\Delta g/g \sim 10\%$
best around $m_H \sim 160$ GeV: $\Delta g/g \sim 5\%$



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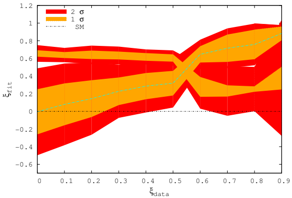
Yukawas $g \to g(1-2\xi)/\sqrt{1-\xi}$

– sign change of Yukawas, $g_{\gamma\gamma H}$ correlated



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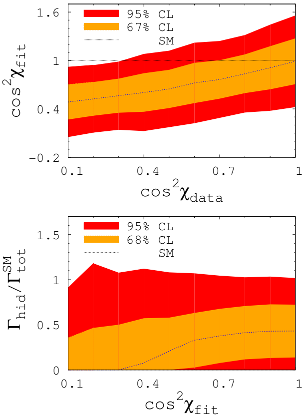
Higgs portal

– universal scaling $\sqrt{1-\xi} \equiv \cos\chi$

– invisible Higgs decay measurable [Eboli & Zeppenfeld]
two-parameter fit, project out Γ_{hid} or $\cos\chi$

⇒ hypotheses testable with 30 fb^{-1}



Outlook

High-dimensional parameter/measurement space everywhere

- MSSM [weak-scale new physics Lagrangian]
- running up to text unification
- Higgs operator analysis
- biased Higgs operator analysis

SFitter technicalities

- profile likelihood and Bayesian probability for SUSY
- unification test from likelihood map in GUT
- profile likelihood for Higgs sector
- Roberto's conclusions: there will never be 'enough statistics'

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	$H+$	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
$\chi_1^\pm$	179.85		0.55	0.55	$\chi_2^\pm$	375.72		3.0	3.0
$\tilde{g}$	607.81	8.0		6.5					
$\tilde{t}_1$	399.10		2.0	2.0					
$\tilde{b}_1$	518.87	7.5		5.7	$\tilde{b}_2$	544.85	7.9		6.2
$\tilde{q}_L$	562.98	8.7		4.9	$\tilde{q}_R$	543.82	9.5		8.0
$\tilde{e}_L$	199.66	5.0	0.2	0.2	$\tilde{e}_R$	142.65	4.8	0.05	0.05
$\tilde{\mu}_L$	199.66	5.0	0.5	0.5	$\tilde{\mu}_R$	142.65	4.8	0.2	0.2
$\tilde{\tau}_1$	133.35	6.5	0.3	0.3	$\tilde{\tau}_2$	203.69		1.1	1.1
$\tilde{\nu}_e$	183.79		1.2	1.2					

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– endpoint measurements

type of measurement		nominal value	stat. error	LES error	JES error	theo. error
m_h		108.99	0.01	0.25		2.0
m_t		171.40	0.01		1.0	
$m_{\tilde{l}_L} - m_{\chi_1^0}$		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
$m_{ll}^{\rm max}$:	three-particle edge($\chi_2^0,\tilde{l}_R,\chi_1^0$)	80.94	0.042	0.08		2.4
$m_{llq}^{\rm max}$:	three-particle edge($\tilde{q}_L,\chi_2^0,\chi_1^0$)	449.32	1.4		4.3	15.2
$m_{lq}^{\rm low}$:	three-particle edge($\tilde{q}_L,\chi_2^0,\tilde{l}_R$)	326.72	1.3		3.0	13.2
$m_{ll}^{\rm max}(\chi_4^0)$:	three-particle edge($\chi_4^0,\tilde{l}_R,\chi_1^0$)	254.29	3.3	0.3		4.1
$m_{\tau\tau}^{\rm max}$:	three-particle edge($\chi_2^0,\tilde{\tau}_1,\chi_1^0$)	83.27	5.0		0.8	2.1
$m_{lq}^{\rm high}$:	four-particle edge($\tilde{q}_L,\chi_2^0,\tilde{l}_R,\chi_1^0$)	390.28	1.4		3.8	13.9
$m_{llq}^{\rm thres}$:	threshold($\tilde{q}_L,\chi_2^0,\tilde{l}_R,\chi_1^0$)	216.22	2.3		2.0	8.7
$m_{llb}^{\rm thres}$:	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