Karlsruhe Institute of Technology

Fitting New Physics

Michael Rauch | November 4, 2010

Institute for Theoretical Physics

Outline

- Fitting techniques
- "LHC SUSY Weather Forecast"
- Low luminosity prospects
- High luminosity and ILC data
- Higgs couplings

Determining SUSY parameters

Parameters in the Lagrangian

m_0, μ, $\tan(\beta)$, $M_{\{1,2,3\}}$, ...

Feynman diagrams, RG evolution, ...

Observables:

- Masses
- Kinematic endpoints
- Cross sections
- Branching ratios
- ...

Observables

m_{h^0}, $\Delta m_{\tilde{g}\chi_1^0}$, three-particle edge($\chi_4^0$,$\tilde{e}_L$,$\chi_1^0$), BR, ...

?

Lagrangian parameters

M_1	□ ± □ GeV
M_2	□ ± □ GeV
M_3	□ ± □ GeV
μ	□ ± □ GeV
$\tan\beta$	□ ± □
...	...

$\Rightarrow$ Tools to reconstruct SUSY parameters

Fitting Groups

- SFitter:
  Lafaye, Plehn, MR, Zerwas
- Fittino:
  Bechtle, Desch, Wienemann
- MasterCode:
  Buchmüller, Cavanaugh, De Roeck, Ellis, Flächer, Hahn, Heinemeyer, Isidori, Olive, Rogerson, Ronga, Weiglein
- Roszkowski, Ruiz de Austra, Trotta
- Allanach, Cranmer, Lester, Weber
- AbdusSalam, Allanach, Dolan, Quevedo, Feroz, Hobson
- Brummer, Fichet, Kraml, Singh
- Dreiner, Krämer, Lindert, O'Leary
- . . .

Fitting Techniques

- MSSM parameter space is high-dimensional:
  - SM: 3+ parameters (m_t, α_s, α, ...)
  - mSUGRA: 5 parameters (m_0,$m_{1/2}$, A_0, $\tan(\beta)$, $\mathrm{sgn}(\mu)$)
  - General MSSM: 105 parameters
- On loop-level observables depend on every parameter
  Simple inversion of the relations not possible
  $\Rightarrow$ Parameter scans
- Error estimates on parameters in the minimum

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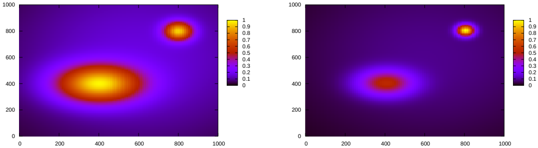
Find best points (best χ^2) using different fitting techniques:

- Gradient search (Minuit) $\left(\begin{array}{c} + \text{ Reasonably fast} \\ - \text{ Limited convergence, only best fit} \end{array} \right)$



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- fixed Grid scan (+ scans complete parameter space / − many points needed ($\mathcal{O}(e^N)$))

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- fixed Grid scan (+ scans complete parameter space / − many points needed ($\mathcal{O}(e^N)$))
- Markov Chains
- Simulated Annealing

Markov Chains

Markov Chain (MC):

- Sequence of points, chosen by an algorithm (Metropolis-Hastings), only depending on its direct predecessor
- Picks a set of "average" points according to a potential V (e.g. inverse log-likelihood, $1/\chi^2$)
- Point density resembles the value of V (i.e. more points in region with high V)
- Scans high dimensional parameter spaces efficiently [Baltz, Gondolo 2004]

$+$ Fast scans of high-dimensional spaces $\mathcal{O}(N)$
$+$ Does not rely on shape of χ^2 (no derivatives used)
$+$ Can find secondary distinct solutions
$-$ Exact minimum difficult to find $\Rightarrow$ Additional gradient fit
$-$ Bad choice of proposal function for next point leads to bad coverage of the space

Simulated Annealing:

- Acceptance propability dependent on "temperature"
- Temperature gradually decreased during MC run
- Gradual changeover between parameter-space scanning and finding optimum

Bayesian vs. Frequentist

- Bayesian *"How likely is a given parameter value given the data?"*
  - based on Bayes theorem: $p(m|d) = p(d|m)\frac{p(m)}{p(d)}$

    $p(m|d)$: probability of the model, given the data

    $p(d|m)$: probability of the data, given the model ("χ^2")

    $p(d)$: probability of the data, typically $p(d) = 1$

    $p(m)$: probability of the model = prior
  - prior $p(m)$: subjective quantity of initial knowledge/ignorance about parameters introduces measure in parameter space
  - typical choices:

    linear: $p(m) \propto const.$, flat in m

    logarithmic: $p(m) \propto \frac{1}{m}$, flat in $\log(m)$

    Gaussian: $p(m) \propto \exp^{-(m-\bar{m})^2/2\sigma^2}$
  - Nuisance Parameters:
    parameters which are "uninteresting" (*e.g.* SM parameters)
    $\longrightarrow$ Marginalization (integrating over them)

- Frequentist *"How probable is the data, given certain parameters?"*

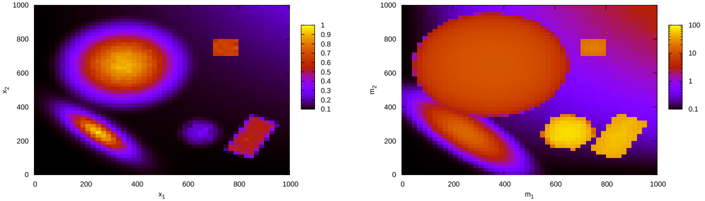
Bayesian vs. Frequentist

- Bayesian *"How likely is a given parameter value given the data?"*
- Frequentist *"How probable is the data, given certain parameters?"*
  - Frequency interpretation of probability
    Infinite repetition of the same experiment, statistically independent results
    Outcome distributed around true value
    (Gaussian, Poisson for counting experiments, . . .)
  - $x\%$ Confidence level: in $x\%$ of the cases outcome at least as extreme
  - Defined only for single points in parameter space
  - Profile likelihood:
    Maximum likelihood over unseen parameters

Bayesian vs. Frequentist

Toy example (5-dim):

- Bayesian (left) *"How likely is a given parameter value given the data?"*



- Frequentist (right) *"How probable is the data, given certain parameters?"*
  Objects:
  - Small Hypersphere $r = 100$, $V_{\text{max}} = 75$ @ (650, 250, 350, 350, 350)
  - Cuboid $d = (173, 120, 200, 200, 200)$, $V_{\text{max}} = 60$ @ (850, 225, 650, 650, 650)
  - Cube $d = (100, 100, 300, 300, 300)$, $V_{\text{max}} = 25$ @ (750, 750, 450, 450, 450)
  - Gaussian $\sigma = (50, 150, 150, 150, 150)$, $V_{\text{max}} = 16$ @ (250, 250, 550, 550, 550)
  - Big Hypersphere $r = 300$, $V_{\text{max}} = 12$ @ (350, 650, 650, 650, 650)
  - Background $V = 0.1 + 4 \cdot 10^{-30} \cdot x_1^2 x_2^2 x_3^2 x_4^2 x_5^2$

Current Fits

If TeV-scale supersymmetry is out there, what can we tell today? (without LHC data)
$\longrightarrow$ Fits of current data to supersymmetry (mSUGRA)

[Allanach, Cranmer, Lester, Weber]
[Roszkowski, Ruiz de Austra, Trotta]
[MasterCode, Fittino]

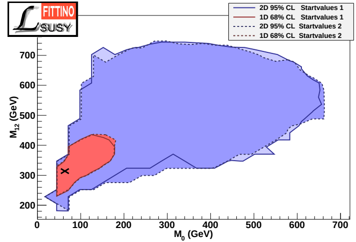
(pMSSM) [AbdusSalam, Allanach, Quevedo, Feroz, Hobson]

Observables:

- Dark Matter $\Omega_{\mathrm{DM}} h^2$
- $)(g-2)_\mu$
- M_W
- $\sin^2\theta_W$
- $\mathrm{BR}(b \to s\gamma)$
- $\mathrm{BR}(B_s \to \mu^+\mu^-)$
- ...

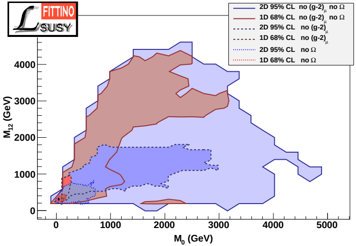
$\Rightarrow$ Predictions for SUSY mass spectrum

Fit Results (mSUGRA)



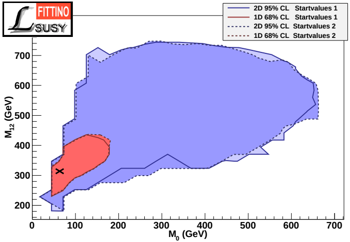
Prediction for m_0 vs. $m_{1/2}$
including all measurements

red: 68% CL
blue: 95% CL



dashed: $(g-2)_\mu$ constraint removed
dotted: Ωh^2 constraint removed
solid: both $(g-2)_\mu$ and Ωh^2 constraint removed

Fit Results (mSUGRA)



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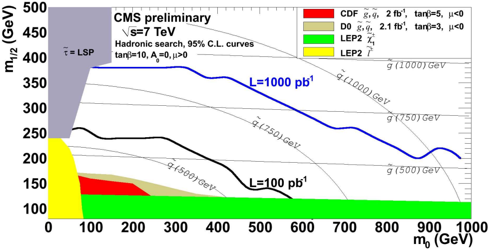
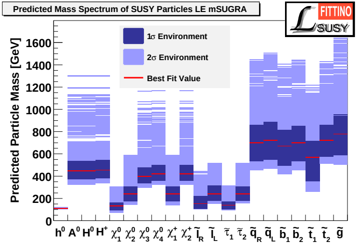
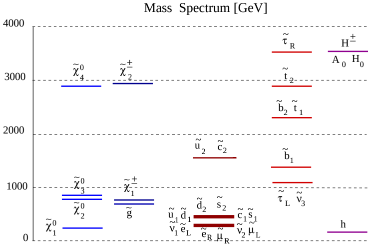


CMS physics reach for the LHC ($\sqrt{S} = 7$ TeV)

Mass Spectrum



mSUGRA fit



pMSSM fit [Allanach et al.]

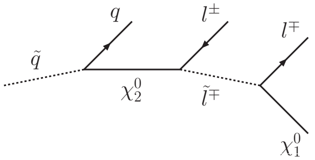
(20 MSSM parameters +
5 SM parameters)

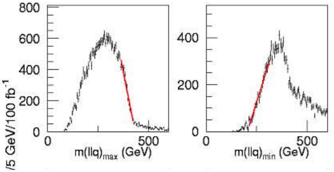
$\longrightarrow$ much heavier mass spectrum

mSUGRA constraints $\leftrightarrow$ Bayesian preference for decoupling limit (?)

Experimental Input (Edges)

mSUGRA SPS1a as a benchmark point:
$m_0 = 100\ \mathrm{GeV}$, $m_{1/2} = 250\ \mathrm{GeV}$, $A_0 = -100\ \mathrm{GeV}$, $\tan\beta = 10$, $\mathrm{sgn}\,\mu = +1$,
$m_t = 171.4\ \mathrm{GeV}$
LHC "experimental" data from cascade decays (best precision obtainable)



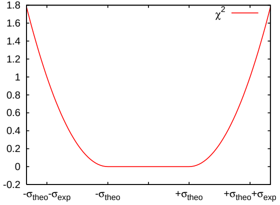


Measurement	Value (GeV)	Errors (GeV) (stat)	(LES)	(JES)	(theo)
(m_{llq}^{max}):Edge($\tilde{q}_L$,χ_2^0,χ_1^0)	449.08	1.4		4.3	5.1
(m_{llq}^{min}) :Thres($\tilde{q}_L$,χ_2^0,$\tilde{\mu}_R$,χ_1^0)	216.00	2.3		2.0	3.3
(m_{ll}^{max}):Edge(χ_2^0,$\tilde{l}_R$,χ_1^0)	80.852	0.042	0.08		1.2
m_h	108.7	0.01	0.25		2.0
...	...	...			

Error Determination

Treatment of errors:

- All experimental errors are Gaussian
  $$\sigma^2_{\text{exp}} = \sigma^2_{\text{stat}} + \sigma^2_{\text{syst}(j)} + \sigma^2_{\text{syst}(l)}$$
- Systematic errors from jet ($\sigma_{\text{syst}(j)}$) and lepton energy scale ($\sigma_{\text{syst}(l)}$) correlated



- Theory errors (missing higher-order corrections):
  - Gaussian
  - Box-shaped (RFit scheme [Hoecker, Lacker, Laplace, Lediberder])

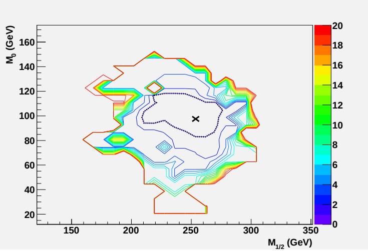
$$\Rightarrow -2\log L \equiv \chi^2 = \sum_{\text{measurements}} \begin{cases} 0 & \text{for } |x_{\text{data}} - x_{\text{pred}}| < \sigma_{\text{theo}} \\ \left(\frac{|x_{\text{data}} - x_{\text{pred}}| - \sigma_{\text{theo}}}{\sigma_{\text{exp}}}\right)^2 & \text{for } |x_{\text{data}} - x_{\text{pred}}| \geq \sigma_{\text{theo}} \end{cases}$$

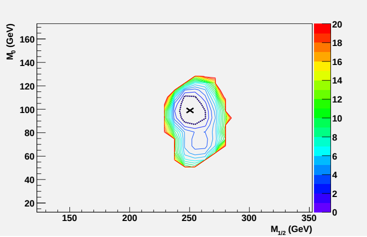
- All values within 1 unit equally likely
- No preference for vanishing corrections
- No huge corrections possible
  ($> \mathcal{O}(1)$ break-down of perturbation theory)

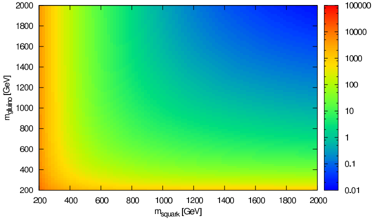
Cross sections

At early running cross sections yield additional information

[Dreiner, Krämer, Lindert, O'Leary]







Top left: only early-running kinematic edges (7 TeV, 1 fb^{-1})

Top right: including rate information

Left: integrated cross section for squark/gluino production

$\longrightarrow$ significant improvement

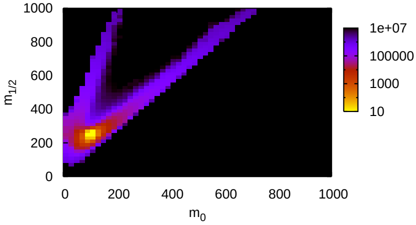
mSUGRA as a Toy Model

mSUGRA with LHC measurements (SPS1a kinematic edges):
pick one set of "measurements", randomly smeared from the true values

[SFitter]

Free parameters:
m_0, $m_{1/2}$, $\tan(\beta)$, A_0, $\mathrm{sgn}(\mu)$, m_t

SFitter output 1:
Fully-dimensional exclusive likelihood map
(colour:
minimum χ^2 over all unseen parameters)



SFitter output 2:
Ranked list of minima:

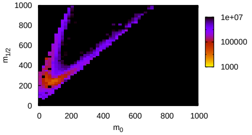
	χ^2	m_0	$m_{1/2}$	$\tan(\beta)$	A_0	μ	m_t
SPS1a		100.0	250.0	10.0	-100.0	$+$	171.4
1)	0.09	102.0	254.0	11.5	-95.2	$+$	172.4
2)	1.50	104.8	242.1	12.9	-174.4	$-$	172.3
3)	73.2	108.1	266.4	14.6	742.4	$+$	173.7
4)	139.5	112.1	261.0	18.0	632.6	$-$	173.0

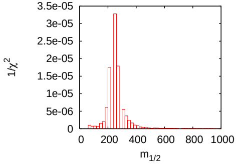
Bayesian or Frequentist?

Fully-dimensional log-likelihood map

$\longrightarrow$ "project" onto plotable 1- or 2-dimensional spaces

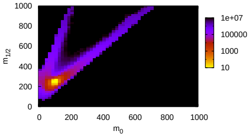
Bayesian:

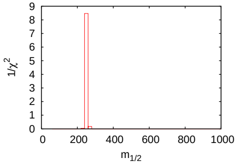




Marginalisation of χ^2 in all other directions

Frequentist:





Profile likelihood: Value of bin is value of smallest χ^2 occuring in this bin

Purely high-scale model

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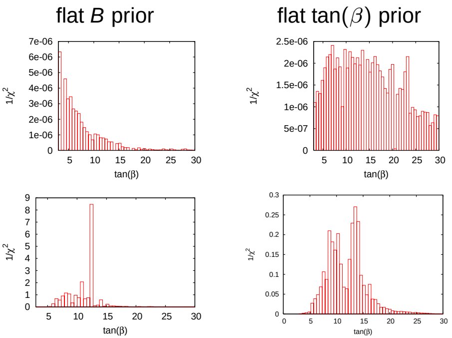
$m_0, m_{1/2}, A_0$ defined at the GUT-scale $\Leftrightarrow$ $\tan(\beta)$ defined at the weak scale
$\Rightarrow$ Replace $\tan(\beta)$ with high-scale quantity B
$\Rightarrow$ Flat prior in B yields prior $\propto \frac{1}{\tan(\beta)^2}$

SPS1a with LHC kinematic edges ($\tan(\beta)$ vs. $1/\chi^2$):



Bayesian:
Large influence of choice of prior
Choosing flat B prior strongly favours low values of $\tan(\beta)$.

Frequentist:
Two plots should be identical (no prior in χ^2 calculation)
Indirect influence via Markov Chain proposal function

Weak-scale MSSM

- No need to assume specific SUSY-breaking scenario
  $\Rightarrow$ SUSY-breaking mechanism should be induced from data
- Use of Markov Chains makes scanning the 19-dimensional parameter space feasible
- Lack of sensitivity on one parameter does not slow down the scan
  (no need to fix parameters)

Full scan of 19D parameter space challenging
Four-step procedure yields better and faster results:

- Markov-Chain run with flat pdf over full parameter space
  5 best points additionally minimised
  (full scan, no bias on starting point)
- Markov Chain with flat pdf on Gaugino-Higgsino subspace:
  M_1, M_2, M_3, μ, $\tan\beta$, m_t
  Additional Minuit run with 15 best solutions

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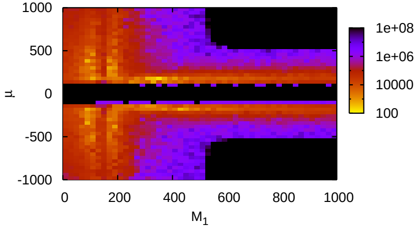
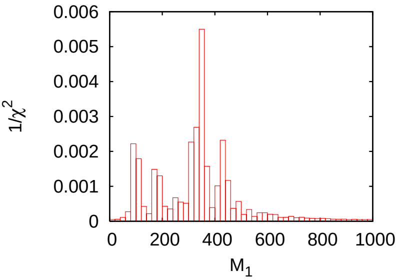
  Additional Minuit run with 15 best solutions

Search Strategy (2) - results

- Only three neutralinos ($\chi_1^0, \chi_2^0, \chi_4^0$) with masses ($97.2\,\mathrm{GeV}$, $180.5\,\mathrm{GeV}$, $375.6\,\mathrm{GeV}$) and no charginos observable at the LHC in SPS1a
- $\Rightarrow$ Mapping $(M_1, M_2, \mu) \longrightarrow (\chi_1^0, \chi_2^0, \chi_4^0)$ not unique
- sgn μ basically undetermined by collider data
- $\Rightarrow$ 8-fold solution





Search Strategy (2) - results

- Only three neutralinos (χ_1^0, χ_2^0, χ_4^0) with masses (97.2 GeV , 180.5 GeV , 375.6 GeV) and no charginos observable at the LHC in SPS1a
- $\Rightarrow$ Mapping (M_1, M_2, μ) $\rightarrow$ (χ_1^0, χ_2^0, χ_4^0) not unique
- sgn μ basically undetermined by collider data
- $\Rightarrow$ 8-fold solution

	DS1	DS2	DS3	DS4	DS7 (SPS1a-like)	DS8	DS9	DS10
$\tan\beta$	12.3±5.6	12.4±5.0	14.9±9.8	8.9±5.9	13.8±7.5	12.6±7.9	19.2±14.3	23.0±15.6
M_1	102.7±7.1	189.5±6.2	107.2±9.2	383.2±9.1	105.0±6.9	191.7±6.6	116.3±7.5	380.9±9.3
M_2	185.5±7.0	96.±6.4	356.9±8.7	114.2±10.7	194.7±7.3	105.5±7.3	354.0±8.2	137.2±9.1
μ	-362.7±7.8	-364.7±6.8	-186.0±8.5	-167.0±9.6	353.0±7.7	357.1±8.3	188.9±7.1	172.8±8.7
$\Delta\chi^2_{\mathrm{ILC}}$	73	22000	1700	25000	0.4	22000	2000	24000
ILC	$\tilde{\tau}_1$	$\chi_1^\pm$	χ_3^0	$\chi_1^\pm$	$\tilde{\tau}_1$	$\chi_1^\pm$	χ_3^0	$\chi_1^\pm$

Search Strategy (3+4)

Full scan of 19D parameter space challenging
Four-step procedure yields better and faster results:

- Markov-Chain run with flat pdf over full parameter space
  5 best points additionally minimised
  (full scan, no bias on starting point)
- Markov Chain with flat pdf on Gaugino-Higgsino subspace:
  M_1, M_2, M_3, μ, $\tan\beta$, m_t
  Additional Minuit run with 15 best solutions
- Markov Chain with Breit-Wigner-shaped pdf on remaining parameters for all solutions of previous step
  Minimisation for best 5 points
- Minuit run for best points of last step keeping all parameters variable

Degenerate Solutions

- In total 19 parameters constrained by 22 measurements
- Measurements constructed from only 15 underlying masses
- $\Rightarrow$ Complete determination of parameter set not possible
- Five parameters not well constrained
  - m_A
    $\leftarrow$ no heavy Higgses measurable
  - $M_{\tilde{t}_R}$
  - A_t
    $\leftarrow$ stop sector parameters do not enter edge measurements
  - $M_{\tilde{\tau}_L}$ or $M_{\tilde{\tau}_R}$
    $\leftarrow$ only the lighter stau measured
  - $\tan\beta$
    $\leftarrow$ change can always be accomodated by rotating $M_1, M_2, M_{\tilde{q}_3}, \ldots$
- Single common link: m_{h^0}
- $\Rightarrow$ 4-dimensional hyperplane in parameter space undetermined
- Can still assign errors to some of the badly determined parameters

General Higgs Sector

How well can we determine the SM Higgs couplings?
Can we distinguish a non-Standard-Model-like Higgs sector?

- Theory: Standard Model plus general Higgs sector
- For Higgs couplings present in the Standard Model $j = W, Z, t, b, \tau$ replace general couplings by

$$g_{jjH} \longrightarrow g_{jjH}^{\mathrm{SM}} \; (1 + \Delta_{jjH}) \qquad (\to \Delta = -2 \text{ means sign flip})$$

- For loop-induced Higgs couplings $j = \gamma, g$ replace by

$$g_{jjH} \longrightarrow g_{jjH}^{\mathrm{SM}} \; \left(1 + \Delta_{jjH}^{\mathrm{SM}} + \Delta_{jjH}\right)$$

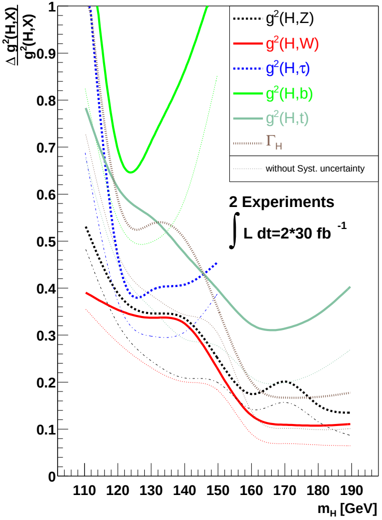
where g_{jjH}^{SM}: (loop-induced) coupling in the Standard Model
$\Delta_{jjH}^{\mathrm{SM}}$: contribution from modified tree-level couplings to Standard-Model particles
Δ_{jjH}: additional (dimension-five) contribution

- Additional free parameters:
  - Higgs boson mass m_H
  - Top-quark mass m_t
  - Bottom-quark mass m_b

Higgs at the LHC

[Zeppenfeld, Kinnunen, Nikitenko, Richter-Was; Dührssen et al.]

production	decay
$gg \to H$	ZZ
qqH	ZZ
$gg \to H$	WW
qqH	WW
$t\bar{t}H$	$WW(3\ell)$
$t\bar{t}H$	$WW(2\ell)$
inclusive	$\gamma\gamma$
qqH	$\gamma\gamma$
$t\bar{t}H$	$\gamma\gamma$
WH	$\gamma\gamma$
ZH	$\gamma\gamma$
qqH	$\tau\tau(2\ell)$
qqH	$\tau\tau(1\ell)$
$t\bar{t}H$	$b\bar{b}$
WH/ZH	$b\bar{b}$ (subjet)



Total width

- degeneracy $\sigma \cdot BR \propto g_p^2 \frac{g_d^2}{\Gamma_H}$ $\quad (\Gamma_H \propto g^2)$
- additional contribution to total width can compensate increase in coupling constant
- Here: $\Gamma_H = \Sigma_{SM} \Gamma_i$

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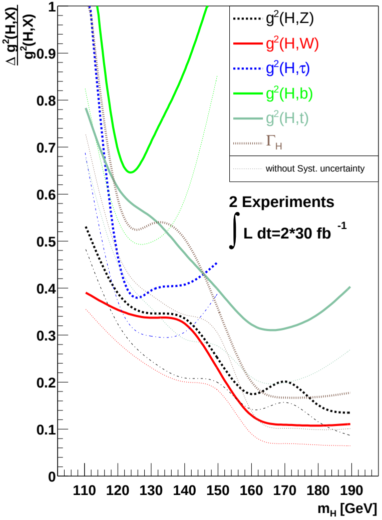

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Invisible vs. Unobserved

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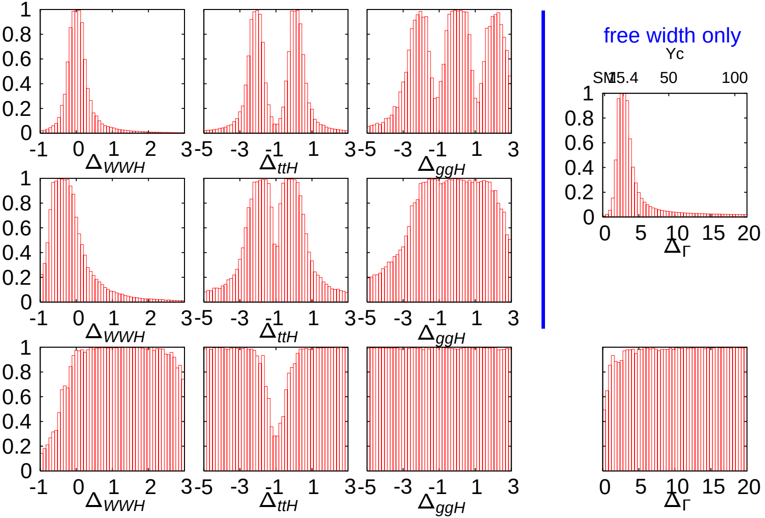
- Invisible Higgs decays actually observable
  - Vector-Boson Fusion: tagging jets plus $\not{E}_T$ [Eboli, Zeppenfeld]
  - WH/ZH: recoil against nothing [Choudhury, Roy; Godbole, Guchait, Mazumdar, Moretti, Roy]

- Unobservable decays into particles with large backgrounds (like $H \longrightarrow$ jets)
  e.g. increased ccH coupling (corresponding to 15.4 GeV Yukawa coupling)

Invisible vs. Unobserved

- Unobservable decays into particles with large backgrounds (like $H \to$ jets)
  e.g. increased *ccH* coupling (corresponding to 15.4 GeV Yukawa coupling)
  $\mathcal{L} = 30\ \mathrm{fb}^{-1}$, SM data / increased *ccH* / increased *ccH* plus free width



Conclusions

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- Fitting parameters of new-physics models requires dedicated tools
- Techniques: Markov Chain Monte Carlo plus Minuit
  Bayesian vs Frequentist
  Theory errors: Gaussian vs box-shaped (RFit)
- Fits of current data predict low-scale SUSY, accessible to 7-TeV LHC
  $\leftrightarrow$ parts of 95% CL region out of reach for next year's LHC run
  $\leftrightarrow$ mSUGRA vs. pMSSM results
- Kinematic edges as main input, cross sections helpful for early running
- Fitting a (18-parameter) pMSSM:
  - Reconstruction of Lagrangian parameters works fine
  - Discrete degenerate solutions for M_1, M_2, $|\mu|$
  - Undetermined parameters due to unseen sectors
- New-physics effects also in other sectors, e.g. Higgs sector
  $\longrightarrow$ SM with general Higgs couplings

see also:

- S. Fichet, On SUSY GUTs with a degenerate Higgs mass matrix
- J.-L. Kneur, Measuring unification
- R. Lafaye, Measuring Hidden Higgs and Strongly-Interacting Higgs Scenarios

LHC measurements

	type of measurement	nominal value	stat.	LES	JES	theo.
				error		
m_h		108.7	0.01	0.25		2.0
m_t		171.20	0.01		1.0	
$m_{\tilde{l}_L} - m_{\chi_1^0}$		102.38	2.3	0.1		1.1
$m_{\tilde{g}} - m_{\chi_1^0}$		511.38	2.3		6.0	6.1
$m_{\tilde{q}_R} - m_{\chi_1^0}$		446.39	10.0		4.3	5.5
$m_{\tilde{g}} - m_{\tilde{b}_1}$		89.01	1.5		1.0	8.0
$m_{\tilde{g}} - m_{\tilde{b}_2}$		62.93	2.5		0.7	8.2
$m_{ll}^{\max}$:	three-particle edge(χ_2^0,$\tilde{l}_R$,χ_1^0)	80.852	0.042	0.08		1.2
$m_{llq}^{\max}$:	three-particle edge($\tilde{q}_L$,χ_2^0,χ_1^0)	449.08	1.4		4.3	5.1
m_{lq}^{low}:	three-particle edge($\tilde{q}_L$,χ_2^0,$\tilde{l}_R$)	326.32	1.3		3.0	5.2
$m_{ll}^{\max}(\chi_4^0)$:	three-particle edge(χ_4^0,$\tilde{l}_L$,χ_1^0)	277.36	3.3	0.3		2.0
$m_{\tau\tau}^{\max}$:	three-particle edge(χ_2^0,$\tilde{\tau}_1$,χ_1^0)	83.21	5.0		0.8	1.0
m_{lq}^{high}:	four-particle edge($\tilde{q}_L$,χ_2^0,$\tilde{l}_R$,χ_1^0)	390.18	1.4		3.8	5.0
m_{llq}^{thres}:	threshold($\tilde{q}_L$,χ_2^0,$\tilde{l}_R$,χ_1^0)	216.00	2.3		2.0	3.3
m_{llb}^{thres}:	threshold($\tilde{b}_1$,χ_2^0,$\tilde{l}_R$,χ_1^0)	198.41	5.1		1.8	3.1

ILC measurements

particle	m_{SPS1a} value	±stat.err.	±theo.err.
h	108.7	± 0.05	± 2.0
H	395.34	± 1.5	± 2.0
A	394.9	± 1.5	± 2.0
$H+$	403.5	± 1.5	± 2.0
χ_1^0	97.22	± 0.05	± 0.5
χ_2^0	180.44	± 1.2	± 0.9
χ_3^0	355.45	± 4.0	± 1.8
χ_4^0	375.09	± 4.0	± 1.9
$\chi_1^\pm$	179.79	± 0.55	± 0.9
$\chi_2^\pm$	375.22	± 3.0	± 1.9
$\tilde{t}_1$	398.93	± 2.0	± 4.0
$\tilde{e}_L$	199.59	± 0.2	± 1.0
$\tilde{e}_R$	142.68	± 0.05	± 0.7
$\tilde{\mu}_L$	199.59	± 0.5	± 1.0
$\tilde{\mu}_R$	142.68	± 0.2	± 0.7
$\tilde{\tau}_1$	133.36	± 0.3	± 0.7
$\tilde{\tau}_2$	203.62	± 1.1	± 1.0
$\tilde{\nu}_e$	183.72	± 1.2	± 0.9

MSSM errors

	LHC	LHC+ILC	SPS1a
$\tan\beta$	13.8 ± 7.4	10.7 ± 3.1	10.0
M_1	105.0 ± 6.9	103.1 ± 0.7	103.1
M_2	194.7 ± 7.3	193.0 ± 1.6	192.9
M_3	568.3 ± 11.6	568.5 ± 7.8	567.7
$M_{\tilde{\tau}_L}$	321.4 ± 248	192.4 ± 4.7	193.5
$M_{\tilde{\tau}_R}$	164.3 ± 120	134.9 ± 5.7	133.4
$M_{\tilde{\mu}_L}$	196.3 ± 7.6	194.4 ± 1.2	194.3
$M_{\tilde{\mu}_R}$	138.0 ± 7.0	135.8 ± 0.6	135.8
$M_{\tilde{e}_L}$	196.4 ± 7.5	194.3 ± 0.8	194.3
$M_{\tilde{e}_R}$	137.9 ± 7.1	135.8 ± 0.6	135.8
$M_{\tilde{q}3_L}$	491.4 ± 16.2	486.2 ± 11.1	481.1
$M_{\tilde{t}_R}$	483.4 ± 232	409.6 ± 17.1	409.4
$M_{\tilde{b}_R}$	502.6 ± 15.3	499.1 ± 13.1	502.7
$M_{\tilde{q}_L}$	529.6 ± 12.1	526.4 ± 5.3	526.4
$M_{\tilde{q}_R}$	508.9 ± 16.4	507.8 ± 14.4	506.8
A_τ	fixed 0	-102.9 ± 681	-249.3
A_t	-394.4 ± 353	-497.3 ± 74	-496.8
A_b	fixed 0	-274.2 ± 1830	-764.0
m_A	558.2 ± 271.2	394.9 ± 1.5	394.9
μ	353.1 ± 7.7	350.8 ± 2.5	351.0