Once we have all that LHC data...

Tilman Plehn

Heidelberg

Mainz 2/2009

Outline

Effective Standard Model

Masses from cascades

Interlude: MRSSM and jets

Interlude: spins from jets

Underlying parameters

TeV-scale MSSM: SFitter

Effective Standard–Model

Data vs renormalizable Standard Model

– dark matter? [only solid evidence for new physics, weak–scale?]

– $(g-2)_\mu$? [loop effects around weak scale?]

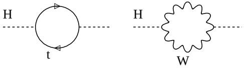
– flavor physics? [new operators above 10^4 GeV?]

– neutrino masses? [see-saw at 10^{11} GeV?]

– gauge–coupling unification? [something happening above 10^{16} GeV?]

– gravity? [mostly negligible below 10^{19} GeV]

⇒ obviously effective theory, cutoff negotiable



Problem with fundamental Higgs

– Higgs introduced for fundamental theory in UV

– mass driven to cutoff: $\delta m_H^2/m_H^2 \propto g^2(2m_W^2 + m_Z^2 + m_H^2 - 4m_t^2)\,\Lambda^2$

– tuned counter term: fundamental gauge theory betrayed

– or new physics at TeV scale: supersymmetry
extra dimensions
little Higgs, Higgsless, composite Higgs...

– typically cancellation by new states or discussing away high scale

– beautiful concepts, challenged at TeV scale

⇒ whatever is there - LHC's job to sort it out

Effective Standard Model in the LHC era

Expectations from the LHC [Uli Baur's rule: 'there is always new physics at higher scales']

– find light Higgs?

– find new physics stabilizing Higgs mass?

– see dark–matter candidate?

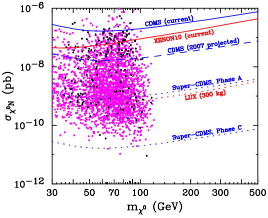
Particle theory and new physics

– model–independent analyses likely not helpful

– testing testable hypotheses [theory: e.g. Higgs sector and underlying theory?]
discrete hypotheses: spins,....
continuous hypotheses: masses,...

– link to other observations [DM+Tevatron: Hooper, TP, Valinotto]

– reconstruction of Lagrangian [theory+experiment]



Effective Standard Model in the LHC era

Expectations from the LHC [Uli Baur's rule: 'there is always new physics at higher scales']

– find light Higgs?

– find new physics stabilizing Higgs mass?

– see dark–matter candidate?

Particle theory and new physics

– model–independent analyses likely not helpful

– testing testable hypotheses [theory: e.g. Higgs sector and underlying theory?]
discrete hypotheses: spins,....
continuous hypotheses: masses,...

– link to other observations [DM+Tevatron: Hooper, TP, Valinotto]

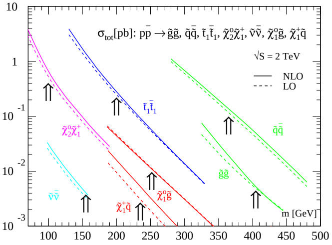
– reconstruction of Lagrangian [theory+experiment]

Special about LHC [except bigger than Tevatron]

– beyond inclusive searches [that was Tevatron]
lots of strongly interacting particles
cascade decays to DM candidate

– general theme: try to survive QCD

⇒ aim at underlying theory



Effective Standard Model in the LHC era

Expectations from the LHC [Uli Baur's rule: 'there is always new physics at higher scales']

- find light Higgs?
- find new physics stabilizing Higgs mass?
- see dark–matter candidate?

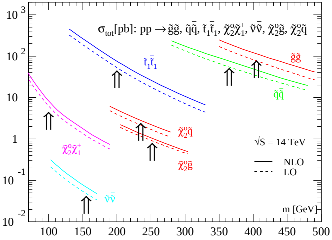
Particle theory and new physics

- model–independent analyses likely not helpful
- testing testable hypotheses [theory: e.g. Higgs sector and underlying theory?]
  discrete hypotheses: spins,....
  continuous hypotheses: masses,...
- link to other observations [DM+Tevatron: Hooper, TP, Valinotto]
- reconstruction of Lagrangian [theory+experiment]

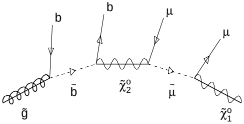
Special about LHC [except bigger than Tevatron]

- beyond inclusive searches [that was Tevatron]
  lots of strongly interacting particles
  cascade decays to DM candidate
- general theme: try to survive QCD

⇒ aim at underlying theory



Masses from cascades



Cascade decays [Atlas-TDR, Cambridge people]

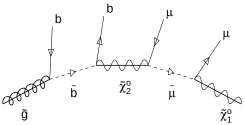
- if new particles strongly interacting and LSP weakly interacting
- like Tevatron: jets + missing energy
- tough: $(\sigma \mathrm{BR})_1/(\sigma \mathrm{BR})_2$ [model dependence, QCD uncertainty]
  easier: cascade kinematics [$10^7 \cdots 10^8$ events]
- long chain $\tilde{g} \to \tilde{b}\bar{b} \to \tilde{\chi}_2^0 b\bar{b} \to \mu^+\mu^- b\bar{b}\tilde{\chi}_1^0$
- 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 endpoints
- new–physics spins from shapes [Barr, Lester, Smillie, Webber; Alves, Eboli, TP;...]

Masses from cascades

Cascade decays [Atlas-TDR, Cambridge people]



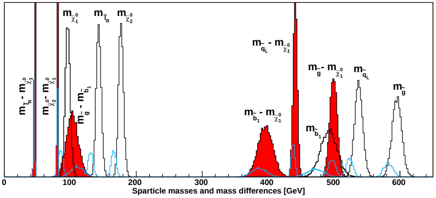
- if new particles strongly interacting and LSP weakly interacting
- like Tevatron: jets + missing energy
- tough: $(\sigma\mathrm{BR})_1/(\sigma\mathrm{BR})_2$ [model dependence, QCD uncertainty]
  easier: cascade kinematics [$10^7 \cdots 10^8$ events]
- long chain $\tilde{g} \to \tilde{b}\bar{b} \to \tilde{\chi}_2^0 b\bar{b} \to \mu^+\mu^- b\bar{b}\tilde{\chi}_1^0$
- thresholds & edges

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

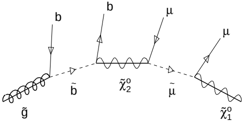
- new–physics mass spectrum from endpoints
- new–physics spins from shapes [Barr, Lester, Smillie, Webber; Alves, Eboli, TP;...]

Gluino decay [Gjelsten, Miller, Osland, Raklev...]

- only b jets [otherwise dead by QCD]
- no problem: off-shell [Catpiss]
- no problem: jet radiation? [later
- gluino mass to $\sim 1\%$



Masses from cascades



Cascade decays [Atlas-TDR, Cambridge people]

- if new particles strongly interacting and LSP weakly interacting
- like Tevatron: jets + missing energy
- tough: $(\sigma \mathrm{BR})_1/(\sigma \mathrm{BR})_2$ [model dependence, QCD uncertainty]
  easier: cascade kinematics [$10^7 \cdots 10^8$ events]
- long chain $\tilde{g} \to \tilde{b}\bar{b} \to \tilde{\chi}_2^0 b\bar{b} \to \mu^+\mu^- b\bar{b}\tilde{\chi}_1^0$
- thresholds & edges

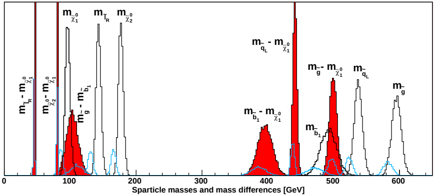
$$0 < m_{\mu\mu}^2 < \frac{m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\ell}}^2}{m_{\tilde{\ell}}} \; \frac{m_{\tilde{\ell}}^2 - m_{\tilde{\chi}_1^0}^2}{m_{\tilde{\ell}}}$$

- new–physics mass spectrum from endpoints
- new–physics spins from shapes [Barr, Lester, Smillie, Webber; Alves, Eboli, TP;...]

Gluino decay [Gjelsten, Miller, Osland, Raklev...]

- only b jets [otherwise dead by QCD]
- no problem: off-shell [Catpiss]
- no problem: jet radiation? [later]
- gluino mass to $\sim 1\%$

$\Rightarrow$ but why physical masses?



Interlude: MRSSM and jets

Bored without a collider: solving old MSSM problems

– problematic general ansatz: 6×6 squark mass matrix
– flavor violation: K-$\overline{K}$ mixing, etc
– CP violation in flavor sector
– flavor-violating decays: $b \to s\gamma$
– electric dipole moments...

$\Rightarrow$ well-known problem for squark sector [include 500 citations here]

Solution via symmetries [Kribs, Poppitz, Weiner]

– continuous global symmetry $R[\theta] = +1$ [Hall & Randall]
– chiral superfield $\Phi^{(+1)} = \phi^{(+1)} + \theta \cdot \chi^{(0)} + \theta\theta\ F^{(-1)}$
vector superfield $V^{(0)} = \theta\sigma^\mu\bar{\theta}A_\mu^{(+1)} - i\bar{\theta}\bar{\theta}\theta\lambda^{(+1)} + \theta\theta\bar{\theta}\bar{\theta}\ D^{(0)}/2$
superpotential $R[\int d^2\theta W^{(+2)}] = 0$
– forbidden soft-breaking terms $\phi^3, \phi^*\phi^2, \tilde{\lambda}\tilde{\lambda}$
allowed soft-breaking terms $\phi^2, \phi^*\phi, \tilde{\lambda}\psi$
– no Majorana masses, no A terms, no μ term... [Majorana neutrino okay]
– gluino mass via additional state [chiral superfield, sgluon lowest state, weak sector ugly]

$\Rightarrow$ at least proof of power of symmetries

Interlude: MRSSM and jets

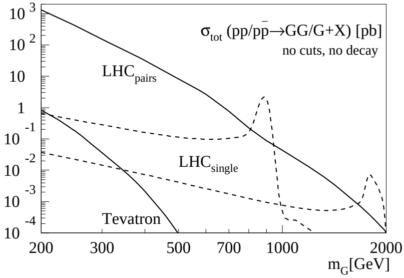
Testable at the LHC

- $\mathcal{L} \sim -m_{\tilde{g}} \tilde{g} \tilde{G} - m_{\tilde{g}}^2 G^2 - \sqrt{2} g m_{\tilde{g}} G \, \tilde{q}^* T \tilde{q}$
- sgluon G integrated out for supersoft SUSY breaking [Fox, Nelson, Weiner]
- G-G-g coupling tree level
  G-g-g coupling loop-induced $\propto m_{\tilde{g}}/m_G^2$
  G-q-q coupling loop-induced $\propto m_{\tilde{g}} m_q/m_G^2$

$\Rightarrow$ pair production, decay to top quark [TP, Tait]

Like-sign top quarks [preliminary numbers]

- production determined by QCD [always same at LHC]
- incoming partons: steep drop for large masses
- decay through $G \to t\bar{q}, \bar{t}q$
- leptonic decays: no background
- also LHC physicists being bored...



Interlude: MRSSM and jets

Testable at the LHC

– $\mathcal{L} \sim -m_{\tilde{g}} \tilde{g} \tilde{G} - m_{\tilde{g}}^2 G^2 - \sqrt{2} g m_{\tilde{g}} G \, \tilde{q}^* T \tilde{q}$

– sgluon G integrated out for supersoft SUSY breaking [Fox, Nelson, Weiner]

– G-G-g coupling tree level
G-g-g coupling loop-induced $\propto m_{\tilde{g}}/m_G^2$
G-q-q coupling loop-induced $\propto m_{\tilde{g}} m_q/m_G^2$

$\Rightarrow$ pair production, decay to top quark [TP, Tait]

Likely bad ideas [Tait & TP; Alwall, Maltoni, de Visscher; TP, Rainwater, Skands]

– sgluon identification?
hadronic W reconstruction?
top 4-momentum measurement?

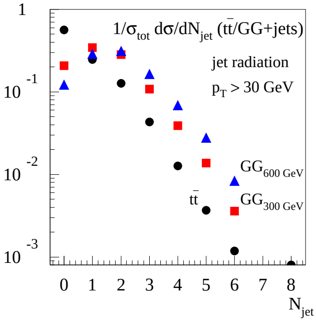
– decay jet or QCD radiation?

– collinear initial state radiation [$p_{T,j} < M_{\rm hard}$]

– proper description: CKKW/MLM [in MadEvent]

– $\langle N_{\rm jet} \rangle$ dependent on hard scale
$\langle N_{\rm jet} \rangle$ dependent on $p_{T,j}$

$\Rightarrow$ QCD under control



Interlude: MRSSM and jets

Testable at the LHC

– $\mathcal{L} \sim -m_{\tilde{g}} \tilde{g} \tilde{G} - m_{\tilde{g}}^2 G^2 - \sqrt{2} g m_{\tilde{g}} G \, \tilde{q}^* T \tilde{q}$

– sgluon G integrated out for supersoft SUSY breaking [Fox, Nelson, Weiner]

– G-G-g coupling tree level
G-g-g coupling loop-induced $\propto m_{\tilde{g}}/m_G^2$
G-q-q coupling loop-induced $\propto m_{\tilde{g}} m_q / m_G^2$

$\Rightarrow$ pair production, decay to top quark [TP, Tait]

Likely bad ideas [Tait & TP; Alwall, Maltoni, de Visscher; TP, Rainwater, Skands]

– sgluon identification?
hadronic W reconstruction?
top 4-momentum measurement?

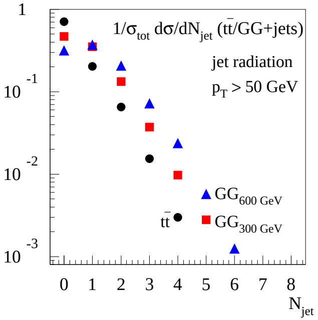
– decay jet or QCD radiation?

– collinear initial state radiation [$p_{T,j} < M_{\rm hard}$]

– proper description: CKKW/MLM [in MadEvent]

– $\langle N_{\rm jet} \rangle$ dependent on hard scale
$\langle N_{\rm jet} \rangle$ dependent on $p_{T,j}$

$\Rightarrow$ QCD under control



Interlude: MRSSM and jets

Testable at the LHC

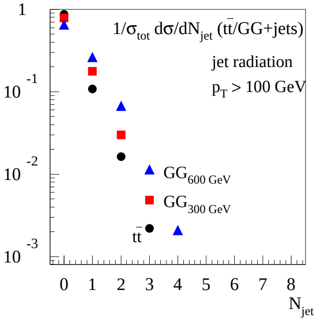
- $\mathcal{L} \sim -m_{\tilde{g}} \tilde{g} \tilde{G} - m_{\tilde{g}}^2 G^2 - \sqrt{2} g m_{\tilde{g}} G \, \tilde{q}^* T \tilde{q}$
- sgluon G integrated out for supersoft SUSY breaking [Fox, Nelson, Weiner]
- G-G-g coupling tree level
  G-g-g coupling loop-induced $\propto m_{\tilde{g}} / m_G^2$
  G-q-q coupling loop-induced $\propto m_{\tilde{g}} m_q / m_G^2$

$\Rightarrow$ pair production, decay to top quark [TP, Tait]

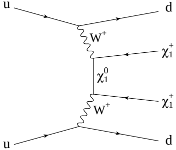
Likely bad ideas [Tait & TP; Alwall, Maltoni, de Visscher; TP, Rainwater, Skands]

- sgluon identification?
  hadronic W reconstruction?
  top 4-momentum measurement?
- decay jet or 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
  $\langle N_\text{jet} \rangle$ dependent on $p_{T,j}$

$\Rightarrow$ QCD under control



Interlude: spins from jets



Illustrating useful jets: spin of LSP [Alwall, TP, Rainwater]

– Majorana LSP with like-sign charginos?

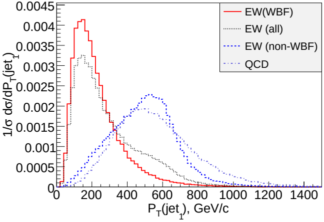
– hypotheses: like–sign charginos (SUSY)
like–sign scalars (scalar dark matter)
like–sign vector bosons (little–Higgs inspired)

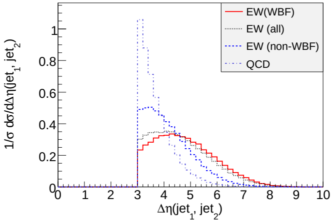
– chargino decay/kinematics not used

$\Rightarrow$ WBF : two key distributions $\Delta\phi_{jj}, p_{T,j}$ [like $H \to ZZ \to 4\mu$ or WBF-Higgs]

– distinct WBF signal? [$p_{T,j} \sim m_W$, forward jets]
visible over backgrounds? [SUSY–QCD backgrounds dominant]

– toy model, but not swamped by SUSY-QCD





Interlude: spins from jets

Like-sign scalars or fermions?

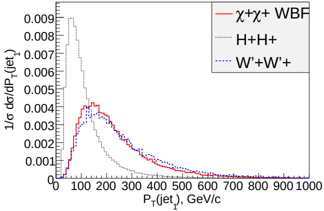
– charged Higgs in 2HDM

– $H^+ H^-$ same as simple H^0 [TP, Rainwater, Zeppenfeld; Hankele, Klamke, Figy]

– W radiated off quarks [Goldstone coupling to Higgs]

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

$\Rightarrow$ scalars with softer $p_{T,j}$



Interlude: spins from jets

Like-sign scalars or fermions?

– charged Higgs in 2HDM
– H^+H^- same as simple H^0 [TP, Rainwater, Zeppenfeld; Hankele, Klamke, Figy]
– W radiated off quarks [Goldstone coupling to Higgs]

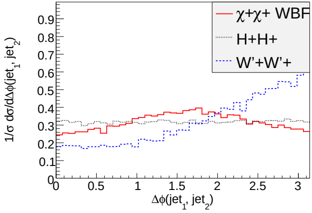
$$P_T(x, p_T) \sim \frac{1+(1-x)^2}{2x} \frac{1}{p_T^2} \qquad P_L(x, p_T) \sim \frac{(1-x)^2}{x} \frac{m_W^2}{p_T^4}$$

$\Rightarrow$ scalars with softer $p_{T,j}$

Like-sign vectors or fermions?

– little–Higgs inspired
– start with copy of SM, heavy W', Z', H', f' [H' necessary for unitarity, but irrelevant at LHC]
– Lorentz structure reflected in angle between jets

$\Rightarrow$ vectors with peaked $\Delta\phi_{jj}$



Interlude: spins from jets

Like-sign scalars or fermions?

– charged Higgs in 2HDM
– H^+H^- same as simple H^0 [TP, Rainwater, Zeppenfeld; Hankele, Klamke, Figy]
– W radiated off quarks [Goldstone coupling to Higgs]

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

$\Rightarrow$ scalars with softer $p_{T,j}$

Like-sign vectors or fermions?

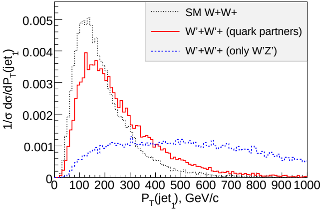
– little–Higgs inspired
– start with copy of SM, heavy W', Z', H', f' [H' necessary for unitarity, but irrelevant at LHC]
– Lorentz structure reflected in angle between jets

$\Rightarrow$ vectors with peaked $\Delta\phi_{jj}$

Heavy fermions in little–Higgs models

– part of unitary UV completion [Englert, Zeppenfeld]
– huge effects on distributions [at low scales]

$\Rightarrow$ more like strongly interacting Ws



Underlying parameters

From kinematics to weak–scale parameters [Fittino; SFitter: Lafaye, TP, Rauch, Zerwas]

– parameters: weak-scale Lagrangian

– measurements: better edges than masses,
branching fractions, rates,... [NLO, of course]
flavor, dark matter, electroweak constraints,...

– errors: general correlation, statistics & systematics & theory [flat theory errors!]

– problem in grid: huge phase space, no local maximum?
problem in fit: domain walls, no global maximum?
problem in interpretation: bad observables, secondary maxima?

Probability maps of new physics [Baltz,...; Roszkowski,...; Allanach,...; SFitter]

– want to evaluate probability of model being true $p(m|d)$

– can compute fully exclusive likelihood map $p(d|m)$ over m [tough]

– additional LHC challenge: remove poor directions [e.g. endpoints vs rates]

– Bayesian: $p(m|d) \sim p(d|m)\, p(m)$ with theorists' bias $p(m)$ [cosmology, BSM]
frequentist: best–fitting point $\max_m p(d|m)$ [flavor]

– LHC era: (1) compute high-dimensional map $p(d|m)$
(2) find and rank local best-fitting points
(3) predict additional observables

Markov chains

Define set of representative points in new–physics space

- measure of ‘representative’: likely to agree with data [Markov chain]
- evaluate any function over chain

(1) probability to agree with data
weighted Markov chains [Rauch & TP; Ferrenberg & Swendsen]

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

(2) Higgs mass from LEP and DM relic density
LHC rates from LEP and DM relic density
dark matter detection from LEP and/or LHC...

$\Rightarrow$ anything possible and well defined [but better not screw up technically]

Markov chains

Define set of representative points in new–physics space

– measure of ‘representative’: likely to agree with data [Markov chain]

– evaluate any function over chain

(1) probability to agree with data
weighted Markov chains [Rauch & TP; Ferrenberg & Swendsen]

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

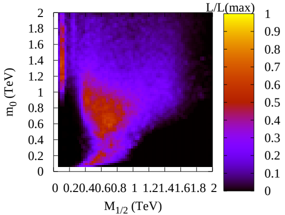
(2) Higgs mass from LEP and DM relic density
LHC rates from LEP and DM relic density
dark matter detection from LEP and/or LHC...

⇒ anything possible and well defined [but better not screw up technically]

Bayesian probabilities vs profile likelihood [Allanach, Cranmer, Lester, Weber; Roszkowski,...]

– ‘Which is the most likely parameter point?’

– ‘How does dark matter annihilate/couple?’

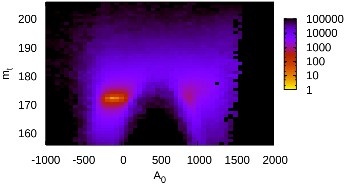


Correlations and errors

Toy model: MSUGRA map from LHC [LHC endpoints with free y_t]

- model unrealistic but useful testing ground [will do anything for citations]
- weighted Markov chains: several times faster
- SFitter output #1: fully exclusive likelihood map
  SFitter output #2: ranked list of local maxima
- strong correlation e.g. of A_0 and y_t [including all errors]

$\Rightarrow$ correlations and secondary maxima significant [0709.3985]



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
...						

Correlations and errors

Toy model: MSUGRA map from LHC [LHC endpoints with free y_t]

– model unrealistic but useful testing ground [will do anything for citations]

– weighted Markov chains: several times faster

– SFitter output #1: fully exclusive likelihood map
SFitter output #2: ranked list of local maxima

– strong correlation e.g. of A_0 and y_t [including all errors]

$\Rightarrow$ correlations and secondary maxima significant [0709.3985]

A word on errors

– central values secondary locally

– statistical errors Gaussian
systematic errors Gaussian, correlated
theory errors flat

– RFit scheme

[CKMFitter, profile likelihood inspired]

$$\chi^2 = -2 \log \mathcal{L} = \vec{\chi}_d^T \; C^{-1} \; \vec{\chi}_d$$

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

$$C_{i,i} = 1 \qquad C_{i,j} = C_{j,i} = \frac{0.99\; \sigma_i^{(\ell)}\; \sigma_j^{(\ell)} + 0.99\; \sigma_i^{\text{(j)}}\; \sigma_j^{\text{(j)}}}{\sigma_i^{\text{(exp)}}\; \sigma_j^{\text{(exp)}}}$$

Correlations and errors

Toy model: MSUGRA map from LHC [LHC endpoints with free y_t]

- model unrealistic but useful testing ground [will do anything for citations]
- weighted Markov chains: several times faster
- SFitter output #1: fully exclusive likelihood map
  SFitter output #2: ranked list of local maxima
- strong correlation e.g. of A_0 and y_t [including all errors]

$\Rightarrow$ correlations and secondary maxima significant [0709.3985]

A word on errors

- central values secondary locally
- statistical errors Gaussian
  systematic errors Gaussian, correlated
  theory errors flat
- theory error sizeable

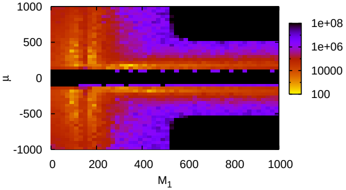
	SPS1a	$\Delta^{\text{theo}-\text{exp}}_{\text{zero}}$	$\Delta^{\text{expNoCorr}}_{\text{zero}}$	$\Delta^{\text{theo}-\text{exp}}_{\text{zero}}$	$\Delta^{\text{theo}-\text{exp}}_{\text{gauss}}$	$\Delta^{\text{theo}-\text{exp}}_{\text{flat}}$
		masses	endpoints			
m_0	100	4.11	1.08	0.50	2.97	2.17
$m_{1/2}$	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

$\Rightarrow$ errors mean: endpoints instead of masses

TeV-scale MSSM: SFitter

MSSM map from LHC

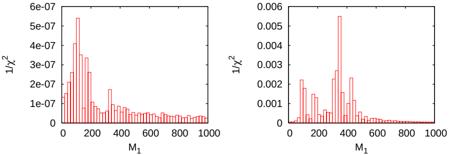
- shifting from 6D to 19D parameter space [killing grids, Minuit, laptop–style fits...]
- Markov chain globally + hill climber locally
- SFitter outputs #1 and #2 still the same [weighted Markov chain plus hill climber]
- three neutralinos observed [left: Bayesian — right: likelihood]



TeV-scale MSSM: SFitter

MSSM map from LHC

- shifting from 6D to 19D parameter space [killing grids, Minuit, laptop–style fits...]
- Markov chain globally + hill climber locally
- SFitter outputs #1 and #2 still the same [weighted Markov chain plus hill climber]
- three neutralinos observed [left: Bayesian — right: likelihood]



- quality of fit not always useful: all the same...

	$\mu < 0$				$\mu > 0$			
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
$M_{\tilde{\mu}_L}$	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
$A_t\ (-)$	-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

$\Rightarrow$ means probably much more work to do...

Beyond the LHC

Why theorists involved?

– want to learn statistics [usually get that badly wrong]

– theory errors not negligible [rates for focus–point scenarios]

– link with other observations model dependent

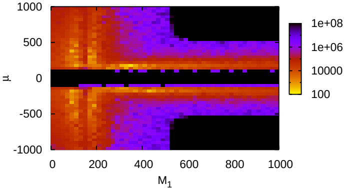
Beyond the LHC

Why theorists involved?

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

MSSM parameters beyond LHC

- remember: unknown sign(μ), believe–based $\tan\beta$ from m_h
- LHC rates: $\tan\beta$ from heavy Higgs tough [Kinnunen, Lehti, Moortgat, Nikitenko, Spira]



Beyond the LHC

Why theorists involved?

– want to learn statistics [usually get that badly wrong]

– theory errors not negligible [rates for focus–point scenarios]

– link with other observations model dependent

MSSM parameters beyond LHC

– remember: unknown sign(μ), believe–based $\tan\beta$ from m_h

– LHC rates: $\tan\beta$ from heavy Higgs tough [Kinnunen, Lehti, Moortgat, Nikitenko, Spira]

(1) use current precision on $(g-2)_\mu \sim \tan\beta$ [SFitter + Alexander, Kreiss]

– strongly correlated and promising

	LHC		LHC $\otimes(g-2)$		SPS1a
$\tan\beta$	**10.0±**	**4.5**	**10.3±**	**2.0**	**10.0**
M_1	102.1±	7.8	102.7±	5.9	103.1
M_2	193.3±	7.8	193.2±	5.8	192.9
M_3	577.2±	14.5	578.2±	12.1	577.9
$M_{\tilde{\mu}_L}$	193.2±	8.8	194.0±	6.8	194.4
$M_{\tilde{\mu}_R}$	135.0±	8.3	135.6±	6.3	135.8
$M_{\tilde{q}3_L}$	481.4±	22.0	485.6±	22.4	480.8
$M_{\tilde{b}_R}$	501.7±	17.9	499.2±	19.3	502.9
$M_{\tilde{q}_L}$	524.6±	14.5	525.5±	10.6	526.6
$M_{\tilde{q}_R}$	507.3±	17.5	507.6±	15.8	508.1
m_A	406.3±	$\mathcal{O}(10^3)$	411.1±	$\mathcal{O}(10^2)$	394.9
μ	350.5±	14.5	352.5±	10.8	353.7

Beyond the LHC

Why theorists involved?

– want to learn statistics [usually get that badly wrong]

– theory errors not negligible [rates for focus–point scenarios]

– link with other observations model dependent

MSSM parameters beyond LHC

– remember: unknown sign(μ), believe–based $\tan\beta$ from m_h

– LHC rates: $\tan\beta$ from heavy Higgs tough [Kinnunen, Lehti, Moortgat, Nikitenko, Spira]

(1) use current precision on $(g-2)_\mu \sim \tan\beta$ [SFitter + Alexander, Kreiss]

– strongly correlated and promising

(2) use BR($B_s \to \mu\mu$) with stop–chargino sector [Hisano, Kawagoe, Nojiri]

– 7% error on f_{B_s} by 2015 crucial [Della Morte, Del Debbio; SFitter + Jäger, Spannowsky]

– perturbative effects secondary

	no theory error			$\Delta\text{BR}/\text{BR} = 15\%$	
	true	best	error	best	error
$\tan\beta$	**30**	**29.5**	**3.4**	**29.5**	**6.5**
M_A	344.3	344.4	33.8	344.3	31.2
M_1	101.7	100.9	16.3	100.9	16.4
M_2	192.0	200.3	18.9	200.3	18.8
M_3	586.4	575.8	28.8	575.8	28.7
μ	345.8	325.6	20.6	325.6	20.6
$M_{\tilde{t},R}$	430.0	400.4	79.5	399.8	79.5

Beyond the LHC

Why theorists involved?

– want to learn statistics [usually get that badly wrong]

– theory errors not negligible [rates for focus–point scenarios]

– link with other observations model dependent

MSSM parameters beyond LHC

– remember: unknown sign(μ), believe–based $\tan\beta$ from m_h

– LHC rates: $\tan\beta$ from heavy Higgs tough [Kinnunen, Lehti, Moortgat, Nikitenko, Spira]

(1) use current precision on $(g-2)_\mu \sim \tan\beta$ [SFitter + Alexander, Kreiss]

– strongly correlated and promising

(2) use BR($B_s \to \mu\mu$) with stop–chargino sector [Hisano, Kawagoe, Nojiri]

– 7% error on f_{B_s} by 2015 crucial [Della Morte, Del Debbio; SFitter + Jäger, Spannowsky]

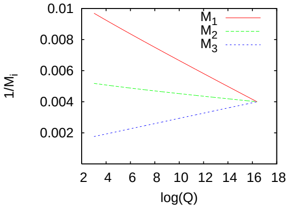
– perturbative effects secondary

Renormalization group bottom–up [SFitter + Kneur]

– SUSY breaking, unification, GUT?

– scale-invariant sum rules? [Cohen, Schmalz]

$\Rightarrow$ solidly inference from weak scale



Outlook

Understanding the TeV scale

(1) look for solid new–physics signals

(2) measure weak–scale Lagrangian

(3) determine fundamental physics

– construct new–physics hypotheses

– compute reliable predictions

– avoid getting killed by QCD

⇒ LHC more than a discovery machine!