Fun with New Physics

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HCP Elba, May 2007

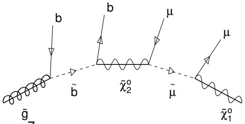
Outline

New physics measurements

Supersymmetric parameter studies

Chiral 4th Generation

New physics mass measurements

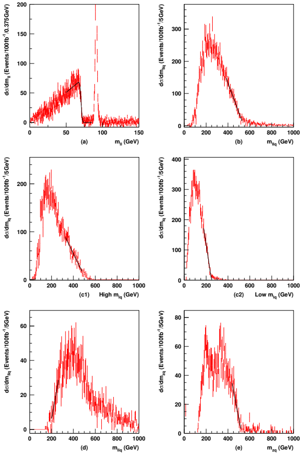


Spectra from cascade decays

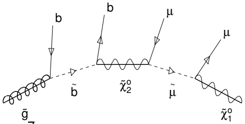
- strongly interacting new physics not far away [more than 3×10^7 events]
- decay $\tilde{g} \to \tilde{b}\bar{b} \to \tilde{\chi}_2^0 b\bar{b} \to \mu^+\mu^- b\bar{b}\tilde{\chi}_1^0$ [better not via Z or to τ]
- thresholds & edges $[m_{\ell\ell}^2 < (m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\ell}}^2)(m_{\tilde{\ell}}^2 - m_{\tilde{\chi}_1^0}^2)/m_{\tilde{\ell}}^2]$
- detector resolution, calibration, systematic errors, shape analysis, cross sections as input?

$\Rightarrow$ spectrum information from decay kinematics

[Hinchliffe,...;Allanach,...; not only SUSY: Meade & Reece]



New physics mass measurements



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- detector resolution, calibration,
  systematic errors, shape analysis,
  cross sections as input?

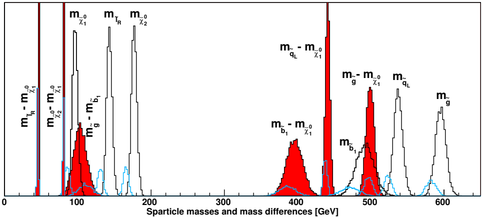
$\Rightarrow$ spectrum information from decay kinematics [mass differences with smaller errors]

Gluino mass from kinematic endpoints

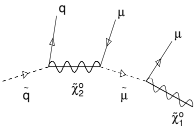
- all decay jets b-tagged [Gjelsten, Miller, Osland]
- most of time: cascade assumption correct

$\Rightarrow$ gluino mass to $\sim$ 1%

[theoretically defined?]



New physics spin measurements



New physics is hypothesis testing [nothing ‘model independent at LHC’]

– assume squark cascade observed

⇒ strongly interacting scalar?

⇒ straw-man model where squark is a fermion: universal extra dimensions

[Appelquist, Cheng, Dobrescu; Cheng, Matchev, Schmaltz; spectra degenerate — ignore; cross section larger — ignore]

Squark–slepton cascade [Barr; Smillie, Webber, Athanasiou, Lester]

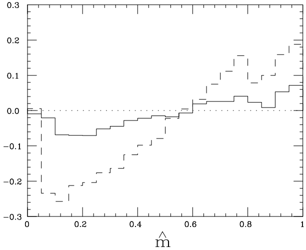
– decay chain $\tilde{q} \to \tilde{\chi}_2^0 \to \tilde{\ell} \to \tilde{\chi}_1^0$

– trick 1: compare with KK q, Z, ℓ, γ

– trick 2: ‘invariant angles’
⇒ $\widehat{m} = m_{j\ell}/m_{j\ell}^{\max}$ most promising

– typically largest $pp \to \tilde{q}\tilde{g}$

– trick 3: production asymmetry $\tilde{q} : \tilde{q}^* \sim 2:1$
⇒ $\mathcal{A} = [\sigma(j\ell^+) - \sigma(j\ell^-)]/[\sigma(j\ell^+) + \sigma(j\ell^-)]$



Masses or spin or both? [Arkani-Hamed,...]

– masses from kinematic endpoints [use $m_{\ell j}, m_{\ell\ell}, m_{j\ell\ell}\cdots$]

– spins from distributions between endpoints [endpoints identical in SUSY and UED]

New physics spin measurements

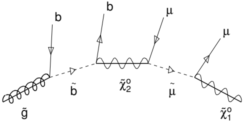
Back to sign of SUSY–QCD

– like–sign dileptons indicate Majorana fermion?

– always like–sign dileptons from bosonic gluon

$\Rightarrow$ show gluino fermionic

$\Rightarrow$ compare with usual straw man [UED–Madgraph: Alves]



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Gluino–bottom cascade [Alves, Eboli, TP]

– decay chain like for gluino mass

– compare with first KK g, q, Z, ℓ, γ

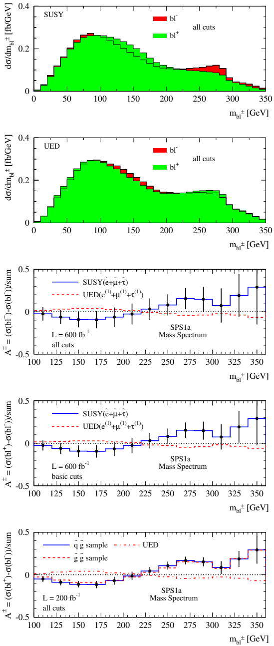
– replace initial–state asymmetry by b vs. $\bar{b}$

– independent of production channels

– asymmetry to write down:
$\mathcal{A} = [\sigma(b\ell^+) - \sigma(b\ell^-)]/[\sigma(b\ell^+) + \sigma(b\ell^-)]$

[still visible after cuts and smearing]

– my question: can we tell b from $\bar{b}$?



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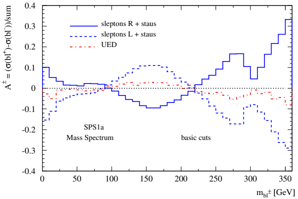
Beyond gluino–bottom

– exchange $\tilde{\ell}_{LR}$ in cascade

– test of lepton-ino couplings

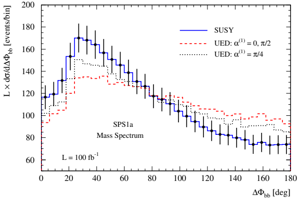
– stau mixing [Choi, Hagiwara, Kim, Mawatari, Zerwas]



– purely hadronic ϕ_{bb} [TP, Plümacher, Reinartz]

– independent of weak decays

– sensitive to gluino/KK-gluon boost



– compare two SUSY hypotheses

– neutralino–sneutrino LSP [TP, Pradler, Steffen]

⇒ masses and spins accessible in decays at LHC

Supersymmetric parameters

Theory output from LHC: SUSY parameters

- complex models, including dark matter, flavor physics, low-energy physics,...
- parameters: weak-scale Lagrangean [Sfitter: Lafaye, TP, Rauch, D Zerwas; Fittino; Harvard]
- measurements: masses or edges
  branching fractions
  cross sections
- errors: general correlation, statistics & systematics & theory
- problem in grid: huge phase space, local minimum?
  problem in fit: domain walls, global minimum?

First go at problem

- ask a friend how SUSY is broken $\Rightarrow$ mSUGRA
- fit $m_0, m_{1/2}, A_0, \tan\beta, \text{sign}(\mu), y_t, ...$
- no problem, include indirect constraints

$\Rightarrow$ probability map as of today [Allanach, Lester, Weber]

$\Rightarrow$ best fit to LHC/ILC

$\Rightarrow$ ILC factor 10 more precise, but late...

	SPS1a	ΔLHC masses	ΔLHC edges	ΔILC	ΔLHC+ILC
m_0	100	3.9	1.2	0.09	0.08
$m_{1/2}$	250	1.7	1.0	0.13	0.11
$\tan\beta$	10	1.1	0.9	0.12	0.12
A_0	-100	33	20	4.8	4.3

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MSSM instead of mSUGRA [TP, Lafaye, D Zerwas]

– technically painful:
(1) grid for closed subset
(2) fit of other parameters
(3) complete fit

– LHC+ILC perfect [Weiglein etal]

$\Rightarrow$ too few measurements?
secondary minima? ...

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

Supersymmetric parameters

New physics: as large as incomplete set of measurements

– Bayes' theorem: $p(m|d) = p(d|m)\ p(m)/p(d)$ [$p(d)$ through normalization]

– likelihood: data given a model $p(d|m) \sim |\mathcal{M}|^2$

– theorist's prejudice: model $p(m)$ [Allanach, Roszkowski]

$\Rightarrow$ given measurements: (1) compute probability map $p(m|d)$ of parameter space
(2) rank local maxima

Weighted Markov chains [scanning algorithm for many dimensions: Rauch & TP]

– classical: produce representative set of states
compute e.g. energy density of sample

$\Rightarrow$ map (chain) based on probability of states
expensive energy function on sample

– BSM physics: produce map $p(m|d)$ of parameter points
evaluate same probability from (binned) density [Allanach,...; Baltz,...; Roszkowski,...]

$\Rightarrow$ weighted Markov chain [like MC with phase–space weights]

– MCMC resolution not sufficient

$\Rightarrow$ additional hill climber to rank maxima

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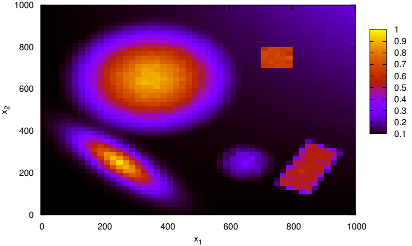
Toy model [Rauch & TP]

- test function $V(\vec{x})$ in 5 dimensions [general high–dimensional extraction tool]
- Sfitter output #1: probability map
  Sfitter output #2: list of local maxima [best fit]



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

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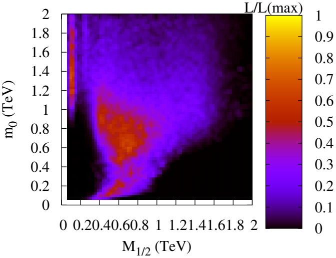
mSUGRA with today's measurements [Allanach, Lester, Weber]

– electroweak precision data, dark matter, $(g-2)_\mu$,... [Sfitter + Kreiss]



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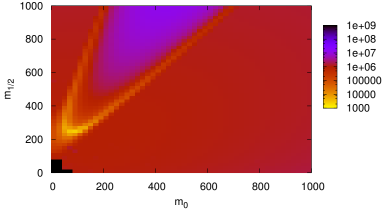
mSUGRA with LHC measurements [Lafaye, TP, Rauch, D.Zerwas]

– SPS1a kinematic edges with free m_b, m_t

– Sfitter output #1: probability map
Sfitter output #2: list of local maxima [best 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
...						

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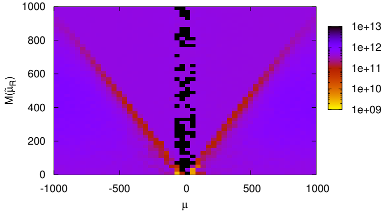
MSSM with LHC measurements

- complete weak–scale MSSM
- Sfitter output #1: probability map
  Sfitter output #2: list of local maxima soon

$\Rightarrow$ last week: up and running in $D = 20$! [interpretation determined by quality of data]



Chiral 4th Generation

Different kind of question [Kribs, TP, Spannowsky, Tait]

– SUSY etc: solutions hierarchy problem [not equally good...]

– more phenomenological: why three generations? [review: Framton, Hung, Sher]

– anomaly cancellation?
light neutrinos in LEP?
Majorana neutrinos in neutrinoless double beta decay?
electroweak precision data?

$\Rightarrow$ none of the constraints convincing [Feyerabend]

– benefits: electroweak baryogenesis? dark matter? 'top' condensation? [Holdom]

$\Rightarrow$ as all new physics: deserving solid Tevatron/LHC analyses

Our model [old story]

– complete additional generation [$Q_4, U_4, D_4, L_4, e_4, \nu_4$]

– masses from Yukawas

– representations as Standard Model: no FCNC

– charge currents: (4×4) fermion–mixing matrices [single-top (D0) $V_{bt} \gtrsim 0.68$]

– neutrino mass: $\mathcal{L} \sim y_4 \, \tilde{H} \bar{L}_4 \nu_{4R} + M \, \bar{\nu}^c_{4R} \nu_{4R}/2$

4th Generation Constraints

Vacuum stabiliy and triviality [review: Sher]

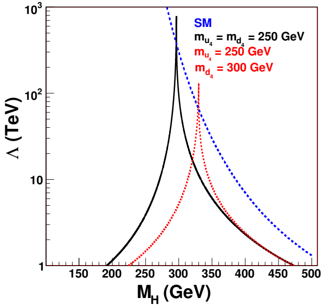
– Higgs mass and potential:

$$m_H^2 = \lambda v^2 \qquad\qquad 16\pi^2 \frac{d\lambda}{d\log\mu} \sim 12\lambda^2 + 4\sum_f N_c^2 \left(\lambda y_f^2 - y_f^4\right) + \cdots$$

– (meta–) stable vaccuum requiring essentially $\lambda(\mu) > 0$ [Altarelli, Isidori]

– triviality bound: $\lambda(\mu) \lesssim \mathcal{O}(1)$

$\Rightarrow$ 4th generation valid to as high scales as Little Higgs



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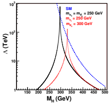


Electroweak precision data [LEPEWWG]

– for our purpose: only S and T [$\Delta U \sim 0$ as in SM]

– neutrino with Dirac mass [$\Delta S < 0$ for Majorana neutrinos: Kniehl, Kohrs]

– mixing fermions: $\Delta S = N_f/(6\pi)(1 - 2Y \log m_u^2/m_d^2)$ [$Y_\ell = -1/2$; $Y_q = 1/6$]

– small m_H: $\Delta S \sim 0.2$ implies $\Delta T \sim \Delta S$ allowed
large m_H: $\Delta S \sim 0.1$ implies $\Delta T \sim \Delta S + 0.2$ allowed

m_{u_4}	m_{d_4}	m_h	ΔS_{tot}	ΔT_{tot}
310	260	115	0.15	0.19
310	260	200	0.19	0.20
330	260	300	0.21	0.22
400	350	115	0.15	0.19
400	340	200	0.19	0.20
400	325	300	0.21	0.25

4th Generation at Colliders

Direct searches

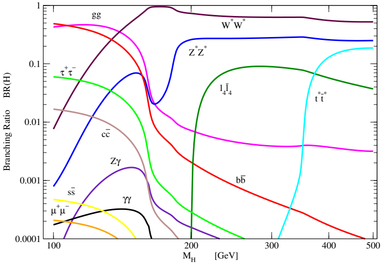
- heavy leptons constrained by LEP
- hard to avoid via CKM: $u_4 \to bW, qW$ [CDF $m_u > 260$ GeV]
- decays to gauge bosons: $d_4 \to tW$ or loop–induced $d_4 \to bZ$ [CDF $m_u \gtrsim 270$ GeV]

$\Rightarrow$ bread–and–butter searches for Tevatron

Funky Higgs physics at Tevatron and LHC

- enhancement by factor 9 for $gg \to H$ [Tevatron limit for $m_H \sim 160$ GeV]
- all light–Higgs decays suppressed by $H \to$ jets
- decay to photons gone?

$\Rightarrow$ what a great straw man!



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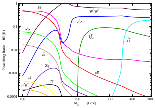
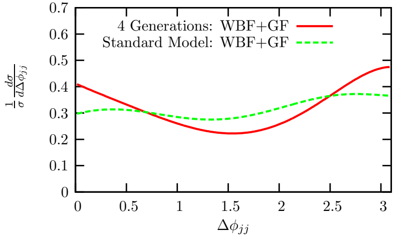
– angular correlations in WBF plus gluon fusion at LHC [TP, Rainwater, Zeppenfeld,...]

$\Rightarrow$ misleading Higgs coupling structure





New Physics at Hadron Colliders

Hadron collider physics is hard!

– QCD tries to kill us [usually my favorite topic]
– all (interesting) analyses are and will be hypothesis testing
– likelihood methods next on pheno agenda
$\Rightarrow$ phenomenologists and experimentalists have to work together

Hadron collider physics is fun!

– mass and spin measurements possible
– parameter extraction/probability maps in full swing
– amusing aspect: 4th generation not ruled out and great fun
$\Rightarrow$ phenomenologists and experimentalists should have a good time together

Electroweak Precision Data

LEP-EWWG: precision constraints

– slice $U = 0$

– origin defined by $m_t = 175$ GeV, $m_H = 150$ GeV

– small m_H: $\Delta S \sim 0.2$ implies $\Delta T \sim \Delta S$ allowed
large m_H: $\Delta S \sim 0.1$ implies $\Delta T \sim \Delta S + 0.2$ allowed