MEASURING THE MSSM LAGRANGEAN

Tilman Plehn

– Supersymmetry at the LHC

– Higher order cross sections: Prospino2

– SUSY plus jets: SmadGraph

– Parameter extraction: Sfitter

TeV Scale Supersymmetry

Bright side

- ⋆ 3 running gauge couplings meet — GUT gauge group

- ⋆ 2 Higgs doublets — radiative symmetry breaking

- ⋆ R parity — stable proton yields dark matter

- ⋆ local supersymmetry – including gravity?

- ⋆ rich LHC phenomenology — no nasty surprises

Dark side

- ⋆ unknown SUSY breaking
  - → masses, scalar couplings, phases...
  - → e.g. hierarchical spectrum?   [Split SUSY]

- ⋆ flavor physics and SUSY breaking
  - → CKM and lepton flavor?

- ⋆ 2 Higgs doublet model
  - → μ parameter and SUSY breaking?

- ⇒ as many as exclusive analyses as possible

		spin	d.o.f.	
quark	q_L , q_R	1/2	1+1	
→ squark	$\tilde{q}_L$, $\tilde{q}_R$	0	1+1	6 flavors
gluon	G_μ	1	n-2	
→ gluino	$\tilde{g}$	1/2	2	Majorana
gauge bosons	γ , Z	1	2+3	
Higgs bosons	h^o , H^o , A^o	0	3	
→ neutralinos	$\tilde{\chi}^o_i$	1/2	4 · 2	Majorana
gauge bosons	$W^\pm$	1	2 · 3	
Higgs bosons	$H^\pm$	0	2	
→ charginos	$\tilde{\chi}^\pm_i$	1/2	2 · 4	Dirac

SUSY LES HOUCHES ACCORD

Problem: Supersymmetric parameter conventions

- comparison of specialized codes [remember: e.g. Comphep–Pythia–Isajet]

$\Rightarrow$ fix SUSY conventions once for all

soft breaking parameters [e.g. $\pm A_t$]
scale dependence of couplings, masses [e.g. $m(q = \mathrm{TeV}, v, m_t)$?]
definitions of mass matrixes, mixing angles [e.g. $\tilde{t}_{L,R}$ up or down?]

SUSY Les Houches Accord [P. Skands et al.]

- spectrum generators: SoftSusy, SPheno, FeynHiggs,...

- multi-purpose Monte Carlos: Pythia, Herwig, Sherpa

- matrix element generators: Whizard, SmadGraph

- NLO cross sections: Prospino2

- NLO decay rates: Sdecay

- SUSY parameter extraction: Fittino, Sfitter

- dark matter: Micromegas

$\Rightarrow$ fixed parameter convention and read-write format

Supersymmetry at the LHC

(1)   possible discovery — signals for new physics, exclusion of parameter space

(2)   measurements — masses, cross sections, decays

(3)   parameter studies — MSSM Lagrangean, SUSY breaking

$\Rightarrow$ at least 10% precision to be matched at LHC (theorist's nightmare)

Hadron collider observables with errors

– renormalization scale from $\alpha_s, y_{b,t}$

– factorization scale from parton densities

– perturbative series $N_c \alpha_s / \pi \sim 10\%$

– finite terms

   [LO-NLO-NNLO: Drell-Yan, Higgs]

$\Rightarrow$ NLO errors: 15...40 % for SUSY particles
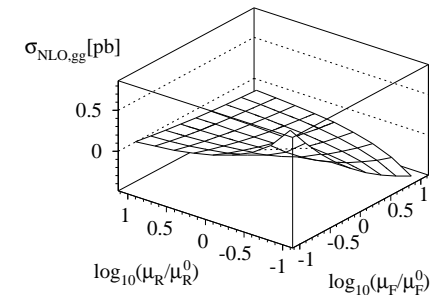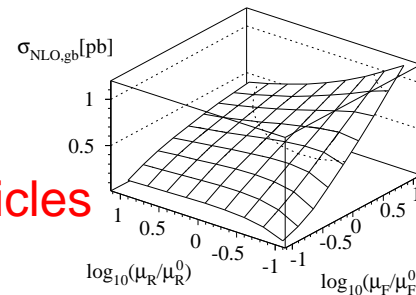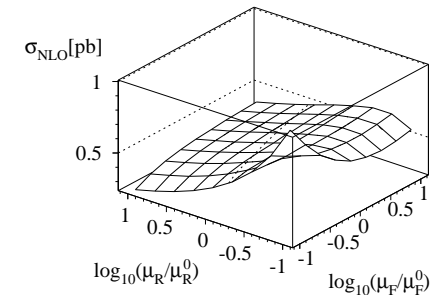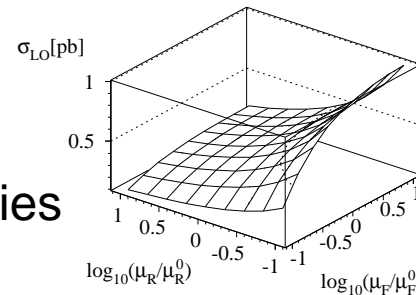
Prospino2: NLO cross sections for Tevatron and LHC

- all two-particle SUSY production channels included

- download from Prospino2 page: http://pheno.physics.wisc.edu/~plehn

- extended version beyond Prospino2: $pp \to SS^*, tH^- ...$

  [thanks to: W. Beenakker, R.Höpker, M. Krämer, M. Spira, P. Zerwas]
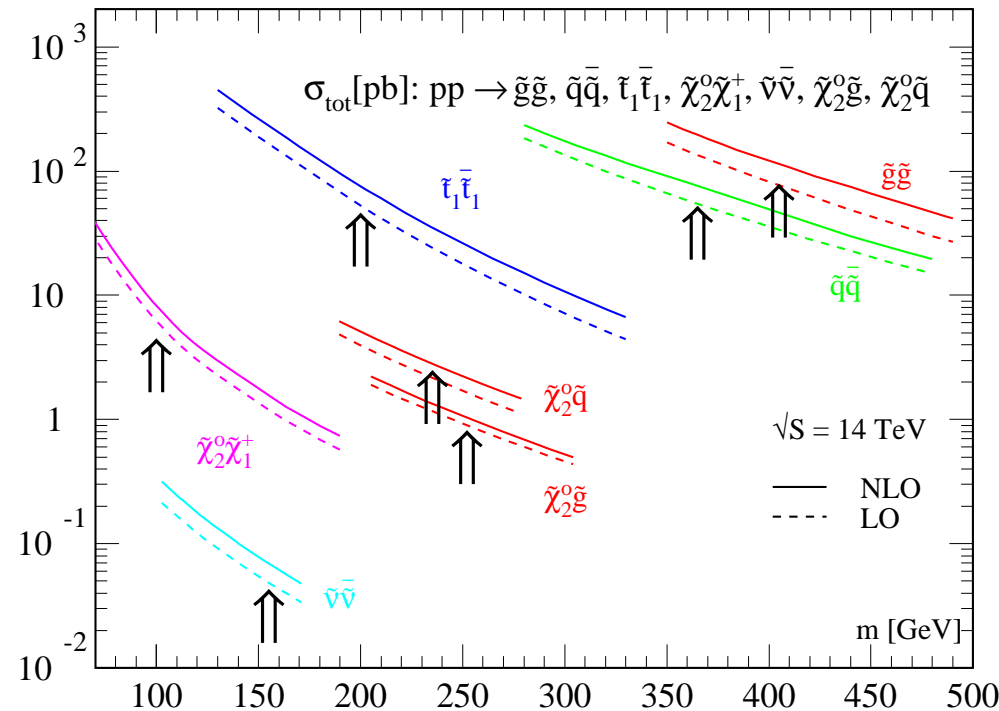
SUSY signals included

- jets and $E\!\!\!/_T$: $pp \to \tilde{q}\tilde{q}^*, \tilde{g}\tilde{g}, \tilde{q}\tilde{g}$

- bottoms and $E\!\!\!/_T$: $pp \to \tilde{b}_1\tilde{b}_1^*$

- like sign dileptons: $pp \to \tilde{g}\tilde{g}$

  $[\tilde{g} \to \tilde{u}\bar{u} \to \tilde{\chi}_1^+ d\bar{u} \text{ or c.c.}]$

- tri-leptons: $pp \to \tilde{\chi}_2^0 \tilde{\chi}_1^-$

  $[\tilde{\chi}_2^0 \to \tilde{\ell}\bar{\ell} \to \tilde{\chi}_1^0 \ell\bar{\ell}; \tilde{\chi}_1^- \to \tilde{\chi}_1^0 \ell\bar{\nu}]$

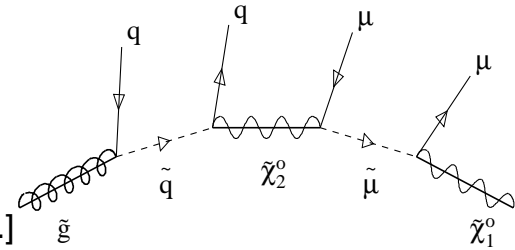- funny tops: $pp \to \tilde{t}_1\tilde{t}_1^*$

SUSY spectra from cascade decays

- decay $\tilde{g} \to \tilde{q}\bar{q} \to \tilde{\chi}_2^0 q\bar{q} \to \mu^+\mu^- q\bar{q}\tilde{\chi}_1^0$ [hopefully not via Z]

- cross sections some 100 pb [more than 3×10^5 events]

- thresholds & edges in spectra [Hinchliffe, Paige...;Allanach, Parker,...]
  critical: enough thresholds and edges available?

  classical $m_{\ell\ell}^2 < (m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\ell}}^2)(m_{\tilde{\ell}}^2 - m_{\tilde{\chi}_1^0}^2)/m_{\tilde{\ell}}^2$

$\Rightarrow$ detector resolution, calibration, systematic errors?

Problem in decay studies

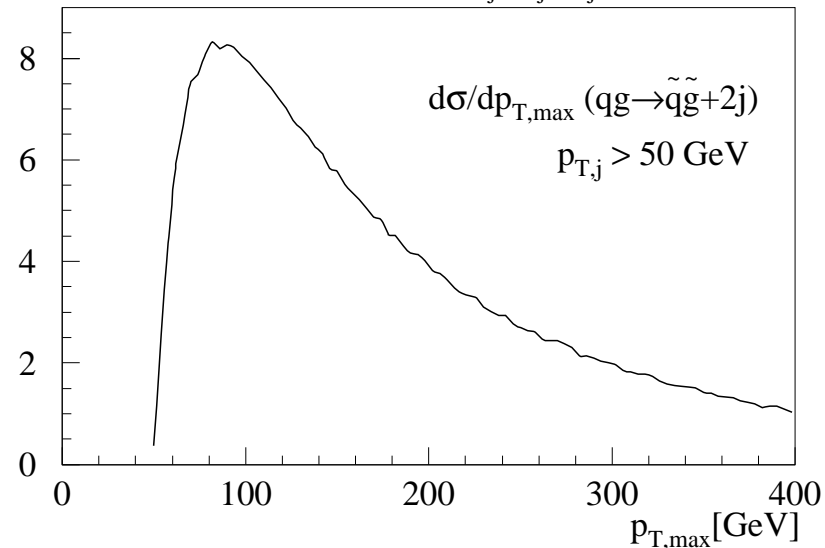- typical cuts: $p_{T,j} > 150, 100, 50, 50$ GeV

- (a) cuts on $p_{T,j}$ hierarchy?
  (b) combinatorics through jet radiation?

$\Rightarrow$ matrix elements for SUSY + hard jets

$\Rightarrow$ Smadgraph [Hagiwara, Kanzaki, TP, Rainwater, Stelzer]

total rates $\sigma_{0j}:\sigma_{1j}:\sigma_{2j} = 1 : 0.7 : 0.4$

$d\sigma/dp_{T,max}$ ($qg \to \tilde{q}\tilde{g}+2j$)

$p_{T,j} > 50$ GeV

$p_{T,max}$[GeV]

Theorist's point of view

– measured masses, cross sections, decays secondary

– parameters in SUSY Lagrangean from measurements

$\Rightarrow$ SUSY breaking parameters at TeV (or higher) scale

Warmup exercise: Sugra top–down fit

– fit including all errors

[Allanach et al; Jack & Jones]

abs. errors		$\triangle$ at LHC		$\triangle$ at LC		$\triangle$ at LHC+LC	
	SPS1a	stat	stat+theo	stat	stat+theo	stat	stat+theo
m_0	100	4.0	4.7	0.09	0.6	0.08	0.6
$m_{1/2}$	250	1.8	2.6	0.13	0.6	0.11	0.5
$\tan\beta$	10	1.3	3.5	0.14	0.3	0.14	0.4
A_0	-100	31.8	32.4	4.43	8.5	4.23	12.6

– spectrum from Suspect   [Djouadi, Kneur]
fit Suspect and Softsusy   [Allanach]

LHC	Suspect	$\triangle$	Softsusy	$\triangle$
m_0	100.00	4.7	97.9	4.6
$m_{1/2}$	250.00	2.7	252.5	2.9
$\tan\beta$	10.00	3.5	11.6	3.6
A_0	-99.96	32.4	14.7	58.9

LHC+LC				
m_0	100.0	0.59	98.4	0.7
$m_{1/2}$	249.99	0.49	254.3	0.8
$\tan\beta$	9.99	0.44	7.3	0.3
A_0	-100.1	12.6	902.0	18

$\Rightarrow$ best way to estimate theory errors?

SUSY parameters from observables

- – parameters: weak-scale MSSM Lagrangean

- – measurements: masses   [Suspect, Softsusy, FeynHiggs...]
  branching fractions   [MSMlib, Sdecay]
  cross sections   [Prospino, MSMlib]**,...**

- – errors: general correlation, statistics & systematics & theory

- – problem in grid: huge phase space, local minimum?
  problem in fit: domain walls, starting values, global minimum?

SFitter   [Lafaye, TP, D. Zerwas, also Fittino]

- – (1) grid for closed subset
  (2) fit of remaining parameters
  (3) complete fit

⇒   LHC+LC without assumptions

	LHC	LC	LHC+LC	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	fi x 500	588.05±11	589.4
$M_{\tilde{\tau}_L}$	fi x 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
$M_{\tilde{t}_R}$	fi x 500	420±2.1	411.73±12	420.2
$M_{\tilde{b}_R}$	522.26±113	fi x 500	504.35±61	525.6
A_τ	fi x 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	fi x 0	-977±12467	-799.4

OUTLOOK

Theory tools for supersymmetry at LHC

    –   spectrum generators $\to$ LHC cross sections all available with SLHA

    –   major progress on errors for SUSY at LHC

    –   many tools in testing phase or beyond, for example...

        Prospino2 — NLO cross sections at Tevatron/LHC

        SmadGraph — MSSM matrix elements

        Sfitter — MSSM parameter extraction