Supersymmetry at Hadron Colliders

Tilman Plehn

MPI für Physik & University of Edinburgh

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Outline

Peter at work

Supersymmetric signatures at NLO

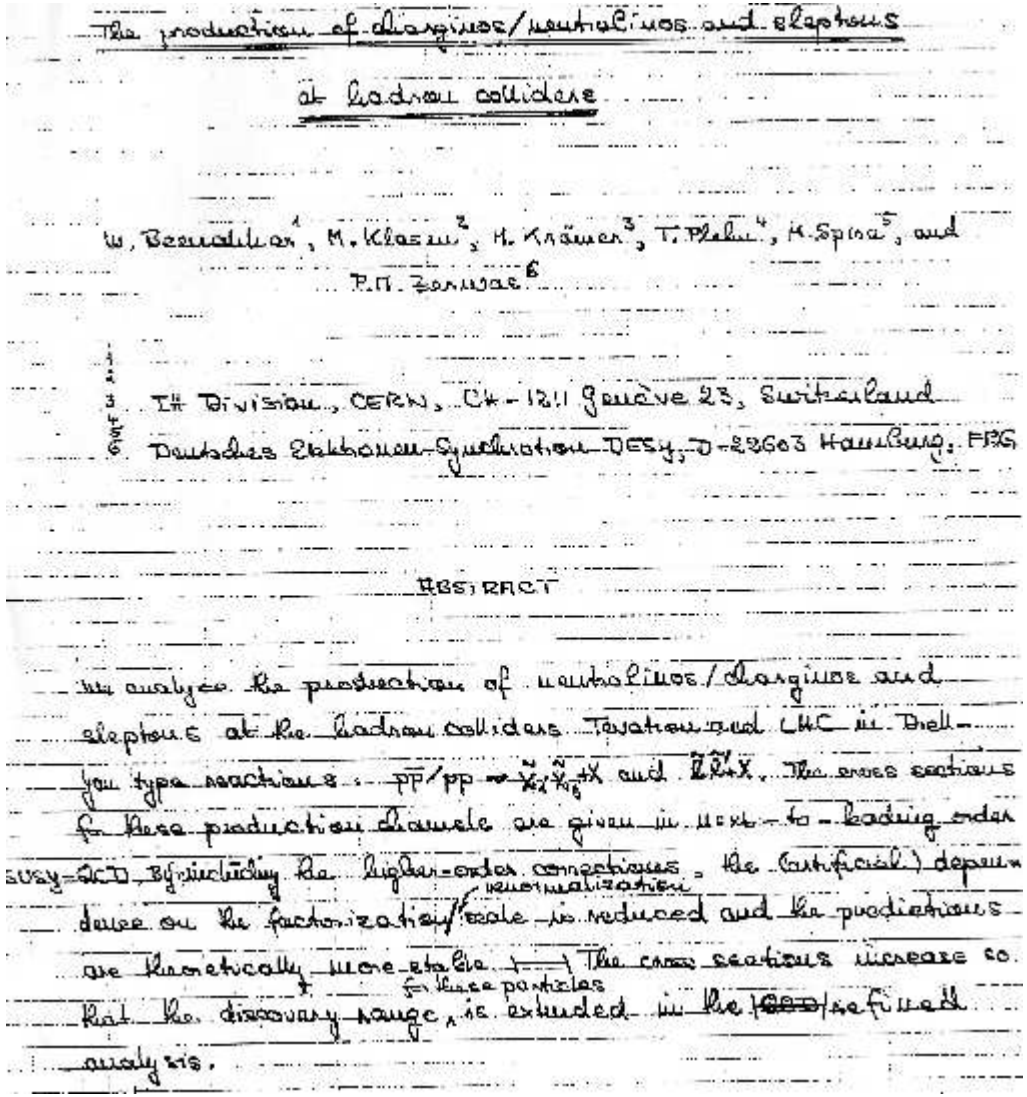
New physics measurements

Supersymmety breaking at LHC

Thank You!

Peter at work

Instead of just putting his name on the final draft...



The production of charginos/neutralinos and sleptons
at hadron colliders

W. Beenakker[1], M. Klasen[2], M. Krämer[3], T. Plehn[4], M. Spira[5], and P.M. Zerwas[6]

TH Division, CERN, CH-1211 Geneve 23, Switzerland
Deutsches Elektronen-Synchrotron DESY, D-22603 Hamburg, FRG

ABSTRACT

We analyze the production of neutralinos/charginos and sleptons at the hadron colliders Tevatron and LHC in Drell-Yan type reactions $pp/p\bar{p} \to \tilde{\chi}_i^\pm \tilde{\chi}_j^0 + X$ and $\tilde{l}\tilde{l}^* X$. The cross sections for these production channels are given in next-to-leading order SUSY-QCD. In particular the higher-order corrections, the (artificial) dependence on the factorization/renormalization scale is reduced and the predictions are theoretically more stable. The cross sections increase so that the discovery range for these particles is extended in the search analysis.

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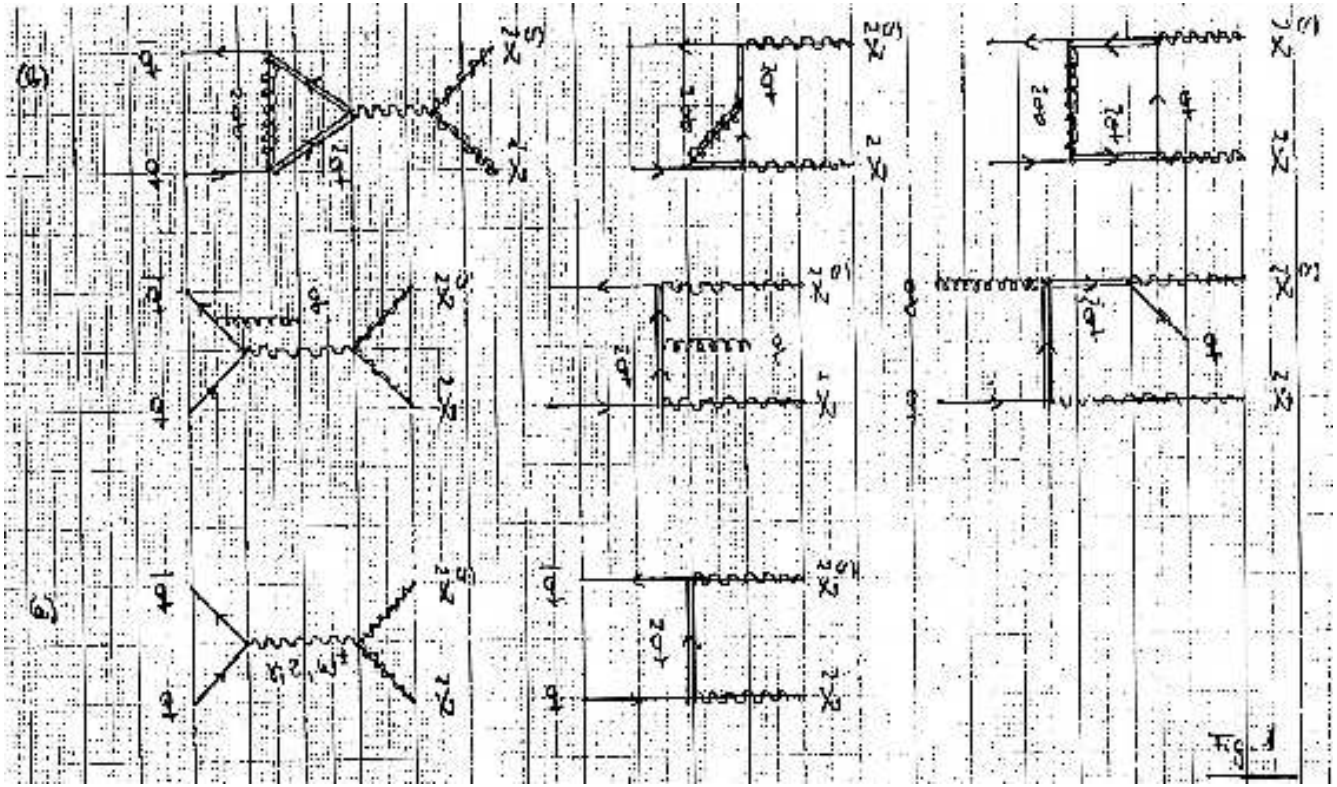

Peter at work

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The Production of Charginos/Neutralinos and Sleptons at Hadron Colliders

W. Beenakker[1], M. Klasen[2], M. Krämer[3], T. Plehn[4], M. Spira[5], and P.M. Zerwas[6]

[1] Durham, UK

[2] Argonne National Laboratory, Argonne, IL 60439

[3] CERN

[4] Department of Physics, Univ. of Wisconsin, Madison, WI 53706

[5] Universität Hamburg, Kniehl–Institut, D–22603 Hamburg

[6] Deutsches Elektronen–Synchrotron DESY, D–22603 Hamburg

Abstract

We analyze the production of neutralinos/charginos and sleptons at the hadron colliders Tevatron and LHC in Drell–Yan type reactions, $pp \to \tilde{\chi}_i \tilde{\chi}_j + X$ and $\tilde{\ell}\tilde{\ell}' + X$. The cross sections for these production channels are given in next-to-leading order SUSY QCD. By including the higher-order corrections, the artificial dependence on the factorization and renormalization scale is reduced and the predictions are theoretically more reliable. The cross sections increase so that the discovery range for these particles is extended in the refined analysis.

1 INTRODUCTION

Non-colored supersymmetric particles, charginos/neutralinos and sleptons, can be searched for at hadron colliders in cascade decays of squarks/gluinos and sleptons in Drell–Yan type processes [1]:

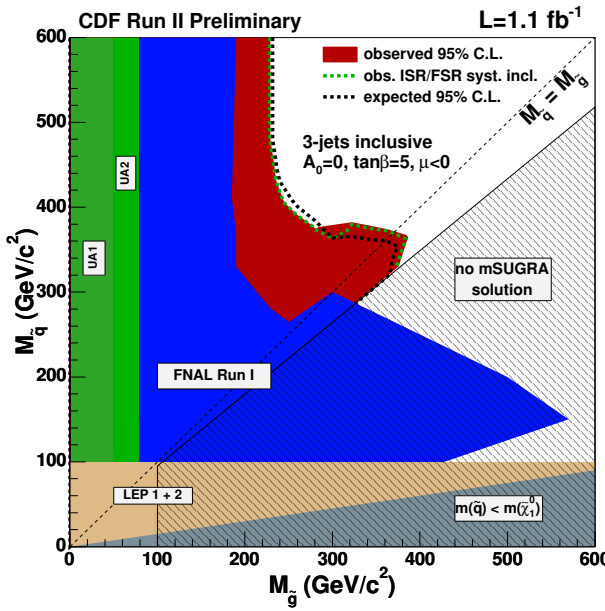
$$p\bar{p} \to \tilde{\chi}_i \tilde{\chi}_j + X$$
$$p\bar{p} \to \tilde{\ell}\tilde{\ell}' + X \qquad (1)$$

Supersymmetric signatures at NLO

Inclusive: squarks and gluinos at Tevatron

- squarks, gluinos strongly interacting
  $p\bar{p} \to \tilde{q}\tilde{q}^*, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}$ [best if $m(\tilde{q}) \sim m(\tilde{g})$]
- large rates at hadron colliders
- decays to jets and LSP
  $\tilde{g} \to \tilde{q}\bar{q}$, $\tilde{q}_L \to q\tilde{\chi}_2^0$, $\tilde{q}_R \to q\tilde{\chi}_1^0$
  [additional jets and leptons possible]
- gaugino mass unification assumed for details

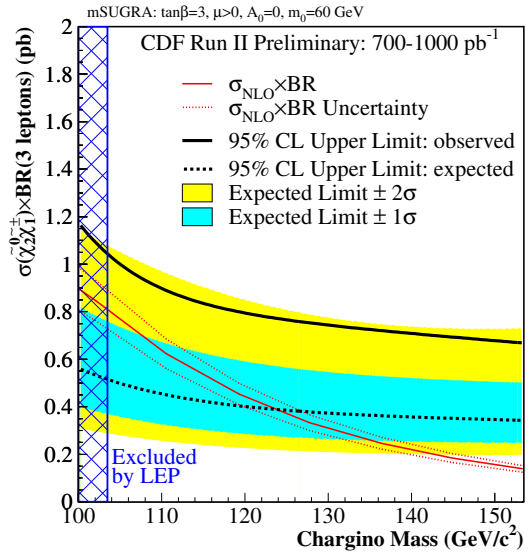
$\Rightarrow$ we know jets plus LSP [using Prospino, et.al & Zerwas]



More specialized: trileptons at Tevatron

- generally assumed: charginos/neutralinos light
- largest cross section $p\bar{p} \to \tilde{\chi}_1^+ \tilde{\chi}_2^0$
  decays $\tilde{\chi}_1^+ \to \ell^+ \nu \tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \to \ell^+ \ell^- \tilde{\chi}_1^0$
- gaugino rate determined by t–channel squark
- plagued by W, Z background

$\Rightarrow$ passing LEP2 limits [using Prospino, et.al & Zerwas]



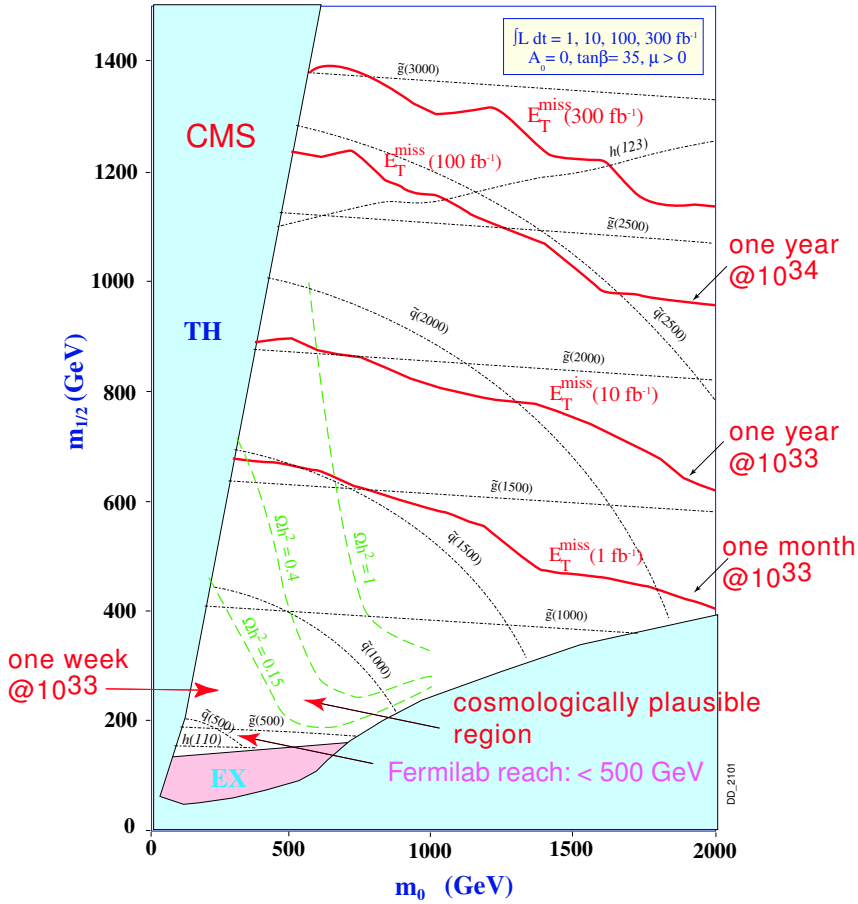
Supersymmetric signatures at NLO

New physics at the LHC - not only Peter's view

(1) possible discovery — general signals for new physics

(2) measurements

(3) parameter studies



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New physics at the LHC - not only Peter's view

(1) possible discovery — general signals for new physics

(2) measurements — masses, cross sections, decays

(3) parameter studies — SUSY breaking

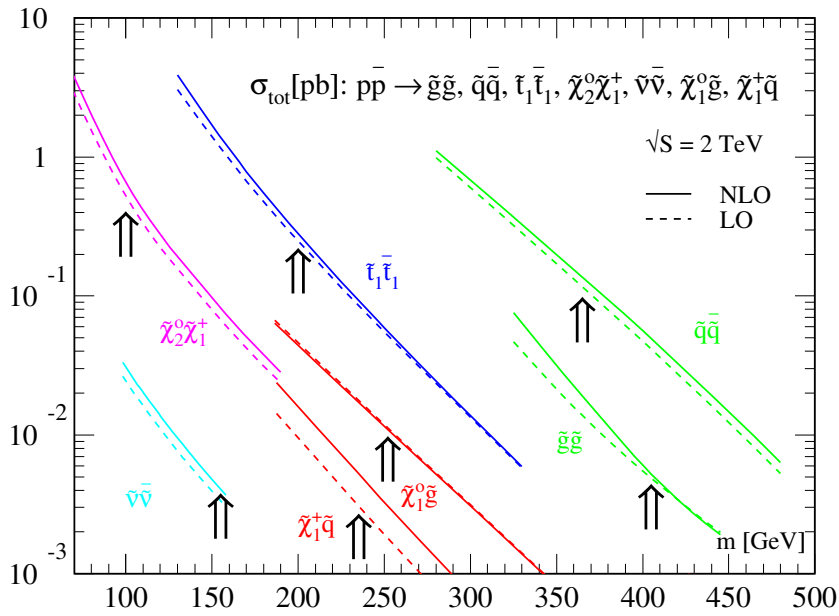
$\Rightarrow$ approach independent of new physics model [except for Little Higgs — Peter says it's wrong!]

Prospino Propaganda Plot at Tevatron

- Roland Höpker sends greetings from Pacific Ocean
- all rates at NLO [technical details: 'correct']
- jets and $\not{E}_T$: $pp \to \tilde{q}\tilde{q}^*, \tilde{g}\tilde{g}, \tilde{q}\tilde{g}$
- like–sign dileptons: $pp \to \tilde{g}\tilde{g}$
- funny tops: $pp \to \tilde{t}_1\tilde{t}_1^*$
- trileptons: $pp \to \tilde{\chi}_2^0\tilde{\chi}_1^-$

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

$\Rightarrow$ inclusive: Tevatron



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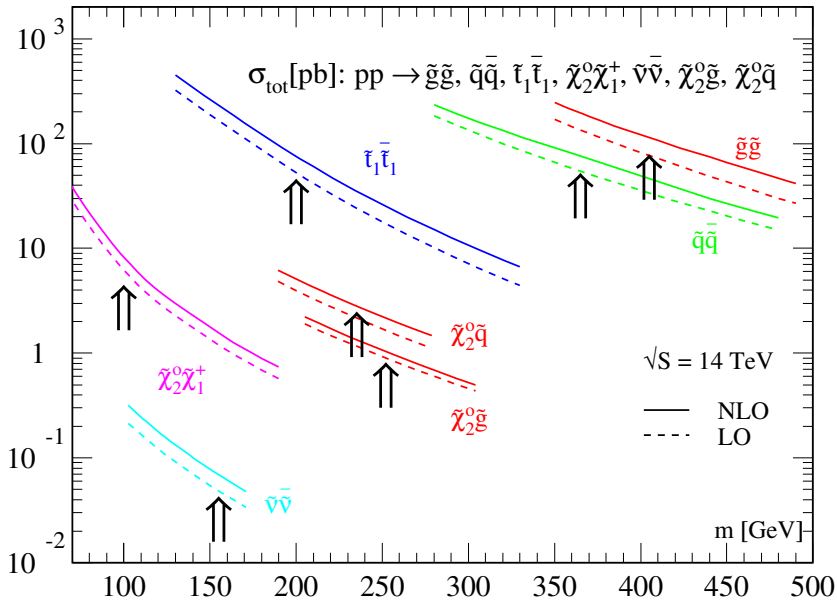
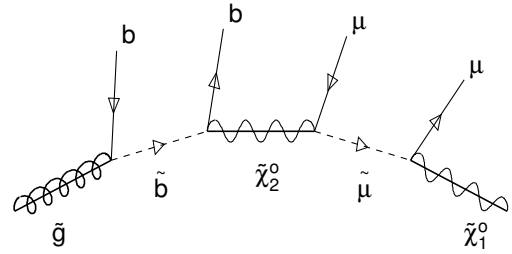
$\Rightarrow$ detailed studies: LHC



New physics masses



Spectra from cascade decays

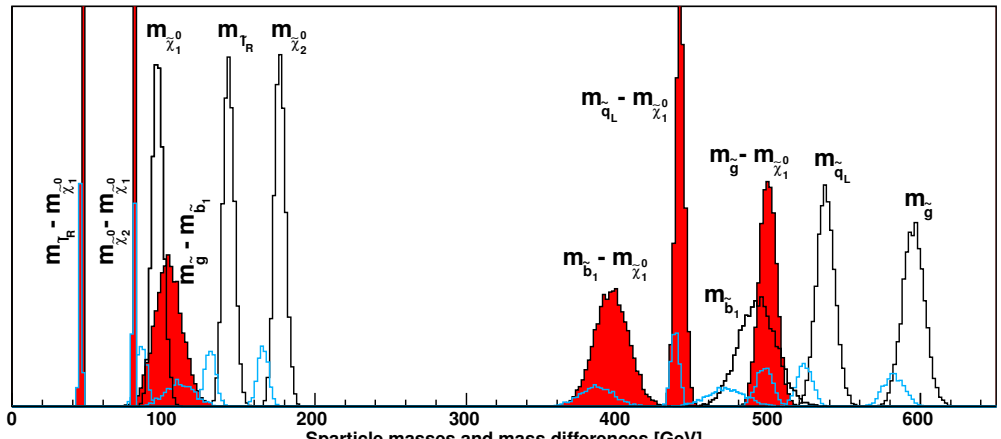
- strongly interacting new physics plenty [more than 3×10^7 events]
- decay $\tilde{g} \to \tilde{b}\bar{b} \to \tilde{\chi}_2^0 b\bar{b} \to \mu^+\mu^- b\bar{b}\tilde{\chi}_1^0$ [better not via Z or to τ]
- thresholds & edges $[m^2_{\ell\ell} < (m^2_{\tilde{\chi}_2^0} - m^2_{\tilde{\ell}})(m^2_{\tilde{\ell}}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

$\Rightarrow$ spectrum information from decay kinematics [Peter off on ILC mission...]

Gluino mass from kinematic endpoints [Gjelsten, Miller, Osland]

- mass differences better than masses
- masses nevertheless possible

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

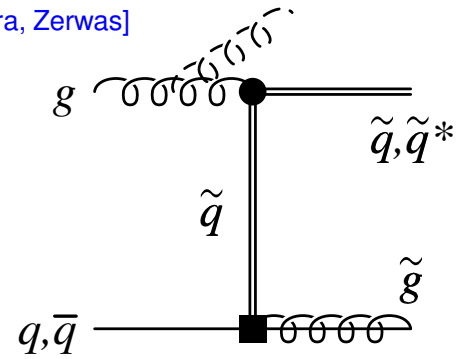


New physics couplings

ILC–inspired LHC physics: rate measurements [Freitas, Skands, Spira, Zerwas]

- dashed gluon lines in $N = 1$ supersymmetry !?
- rate measurement for squark/gluino pairs
- test SUSY–protected couplings $g_{qqg} = g_{\tilde{q}\tilde{q}g} = g_{q\tilde{q}\tilde{g}}$

$\Rightarrow$ Ayres' talk



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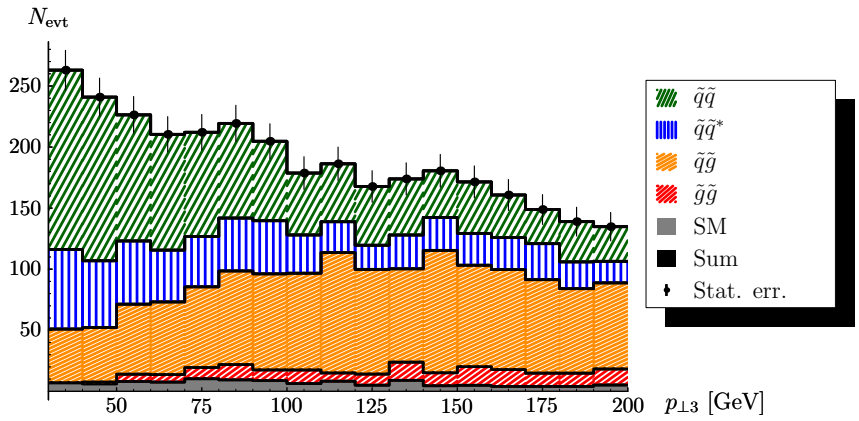
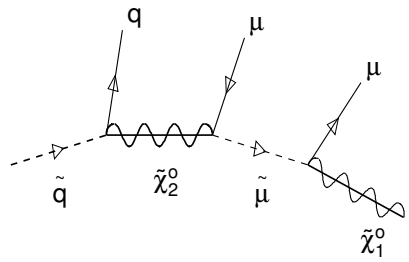


New physics spins



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

- assume squark cascade observed

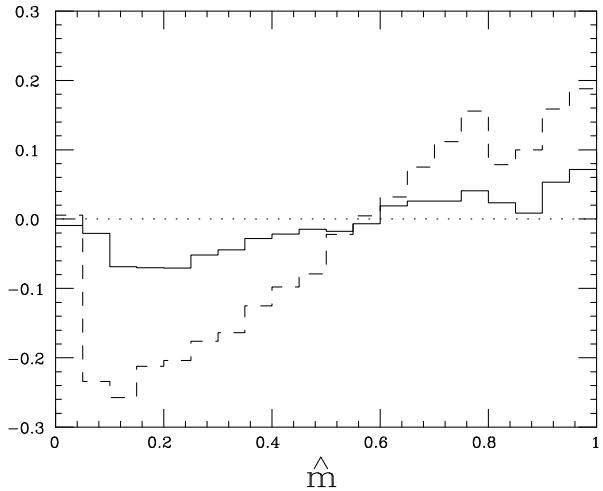
$\Rightarrow$ squark a strongly interacting scalar?

$\Rightarrow$ straw-man model where squark is a fermion: universal extra dimensions

[spectra degenerate — ignore; cross section larger — ignore]

Squark–slepton cascade [Cambridge]

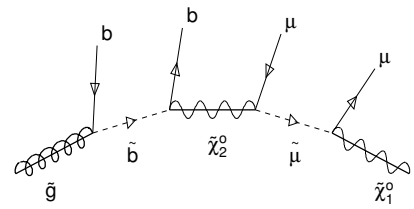
- decay chain $\tilde{q} \to \tilde{\chi}_2^0 \to \tilde{\ell} \to \tilde{\chi}_1^0$
- trick 1: compare with KK q, Z, ℓ, γ
- trick 2: 'invariant angles'
  $\Rightarrow \hat{m} = m_{j\ell}/m_{j\ell}^{\max}$ most promising
- typically largest $pp \to \tilde{q}\tilde{g}$
- trick 3: production asymmetry $\tilde{q} : \tilde{q}^* \sim 2:1$
  $\Rightarrow \mathcal{A} = [\sigma(j\ell^+) - \sigma(j\ell^-)]/[\sigma(j\ell^+) + \sigma(j\ell^-)]$



Peter back at LHC — welcome!

- masses or spins or both?
- masses from kinematic endpoints [use $m_{\ell j}$, $m_{\ell\ell}$, $m_{j\ell\ell}$ ...]
- spins from distributions between endpoints [endpoints identical in SUSY and UED]

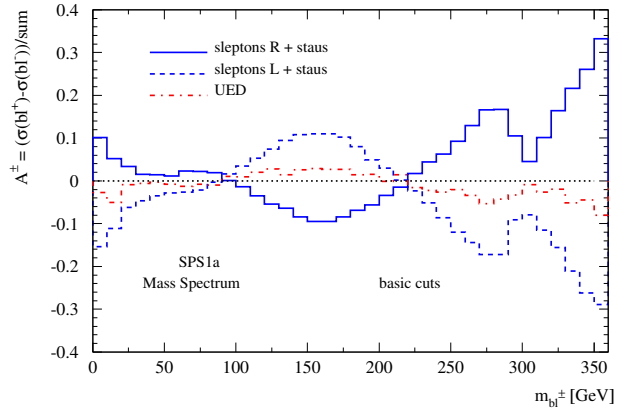
New physics spins



Gluino–bottom cascade

- exchange $\tilde{\ell}_{LR}$ in cascade
- impact of lepton couplings to bino/wino

$\Rightarrow$ chickening out: purely hadronic ϕ_{bb}



Peter's solution [Choi, Hagiwara, Kim, Mawatari, Zerwas]

- bulldoze problem instead of being scared
- momentum fraction in hadronic tau decays

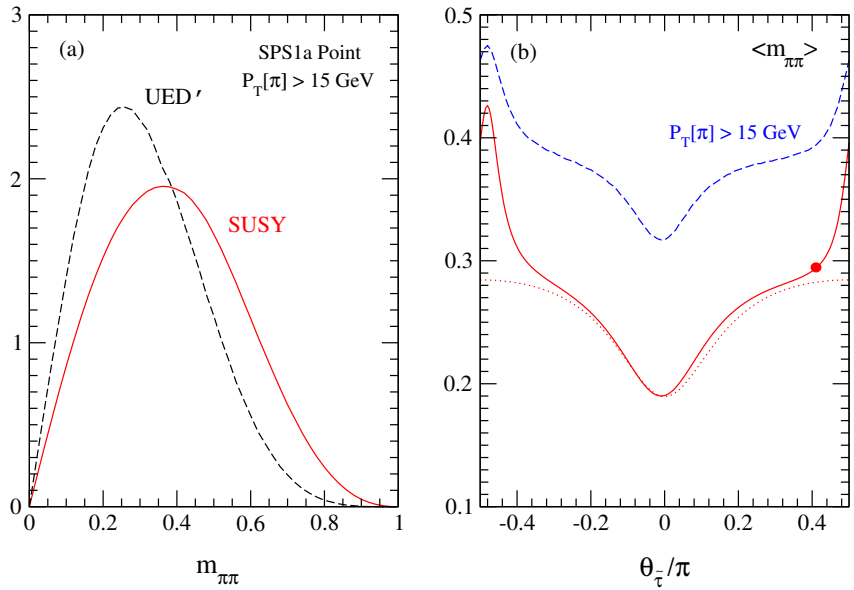
$$\tau_R \to \nu\pi : F_R(z) = 2z$$

- pions from radiated taus

$$\left\langle m^2_{\pi\pi} \right\rangle = \{4, 2, 1\}/18 \text{ for } \tau\tau_{RR,RL,LL}$$

- measure stau mixing

$\Rightarrow$ masses, spins, mixing accessible



Supersymmetry breaking at LHC

Theory and LHC data

- inclusive missing–energy signatures etc...
- parameters: weak-scale Lagrangean
- measurements: masses or edges
  branching fractions
  cross sections
- theory: gaugino mass unification etc.

MSSM instead of mSUGRA [Sfitter w/ Zerwas jr]

- technically painful:
  (1) grid for closed subset
  (2) fit of other parameters
  (3) complete fit
- LHC+ILC perfect [as always]

$\Rightarrow$ 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

Supersymmetry breaking

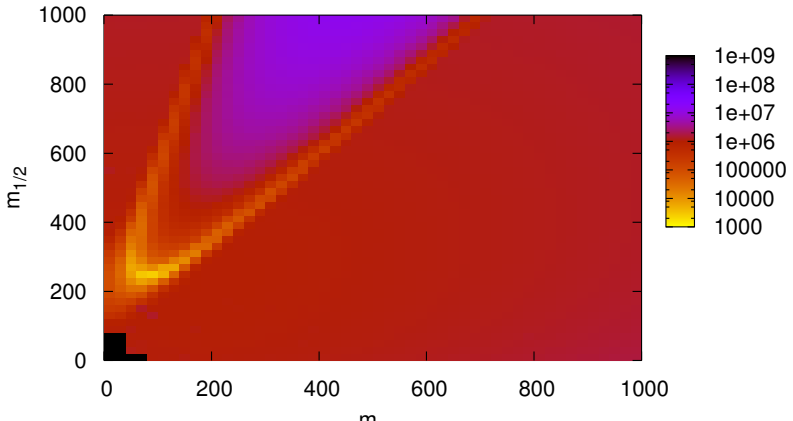
Probability maps of new physics

- Bayes' theorem: $p(m|d) = p(d|m)\ p(m)/p(d)$ [$p(d)$ through normalization]
- likelihood: data given a model $p(d|m)$ from simulations
- Peter's good taste in models: $p(m)$
  I dare you to tell Peter we found SUSY and no unification

$\Rightarrow$ given measurements: (1) probability map $p(m|d)$ of parameter space
(2) rank local maxima [to the unifying solution]
(3) integrate over poor dimensions and wait for ILC

mSUGRA with LHC measurements

- 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
...						

Supersymmetry breaking

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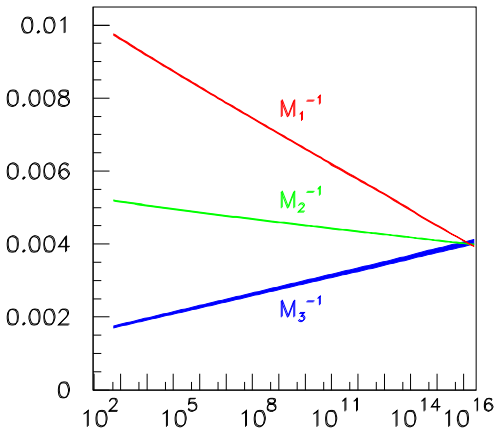
And off the GUT scale... [Blair, Porod, Zerwas]

- gauge couplings (kind of) unifying
- SUSY breaking at high scale?
- SUSY parameters also unifying [Cohen, Roy, Schmaltz]

$\Rightarrow$ run to GUT scale and compute $p(m)$ [Werner's talk]



Thank You!

- Everybody sees Peter as a leading ILC phenomenologist in the world
- Too few know him as a leading LHC phenomenologist

- Just look at this youthful emeritus and see how exciting LHC physics can be
- Everyone looking forward to a great many enlightening LHC papers coming out the center of the civilized world in the LHC years

- My personal thanks to Peter for
  1. rescuing me from many-particle physics and
  2. showing me that even QCD and LHC physics is more fun than pain