SUPERSYMMETRY AT THE LHC

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- News from the Higgs
- My personal 04-05 highlights: Susy at the LHC
- Split Susy at the LHC

n.b. Lots of figures in this talk stolen or preliminary!

SUSY–HIGGS AT THE LHC

NLO and parton shower in MC@NLO [Frixione, Webber, DelDuca, O'Leari]

- combine collinear jets, hard jets, virtual corrections in Herwig
- THE tool for analyses, currently in use in Atlas & CMS
- unfortunately only Standard Model [DY, W, Z, H, $t\bar{t}$, ...]

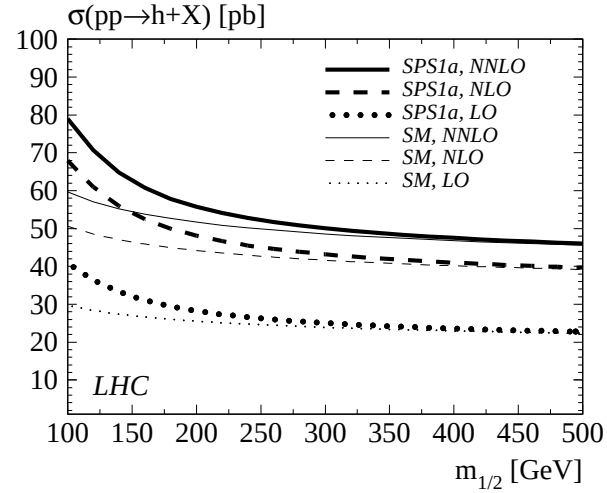
Higher-order SUSY-Higgs production [Harlander, Steinhauser, Hofmann]

- Standard Model $gg \to H$ known to NLO [Spira]

$\Rightarrow$ exact NLO squark contributions large [talk Mühlleitner, Spira]

- (SUSY) Wilson coefficient for heavy particles

$\Rightarrow$ approximate NNLO cross section in heavy-mass limit



Bottom parton issues resolved [charged Higgs reach reduced]

- conceptual problem with bottom partons clarified [Boos, TP, Maltoni, Willenbrock,...]
- NLO $gg \to b\bar{b}H$ and NNLO $b\bar{b} \to H$ agree [Dittmaier, Spira,... ; Dawson,... ; Harlander & Kilgore]
- distributions checked for $gb \to tH^-, b\bar{b} \to H^+H^-$ [Berger, Han, Jiang, TP; Alves & TP]

SUSY SIGNALS AT LHC (AND TEVATRON)

10 years of discovering:

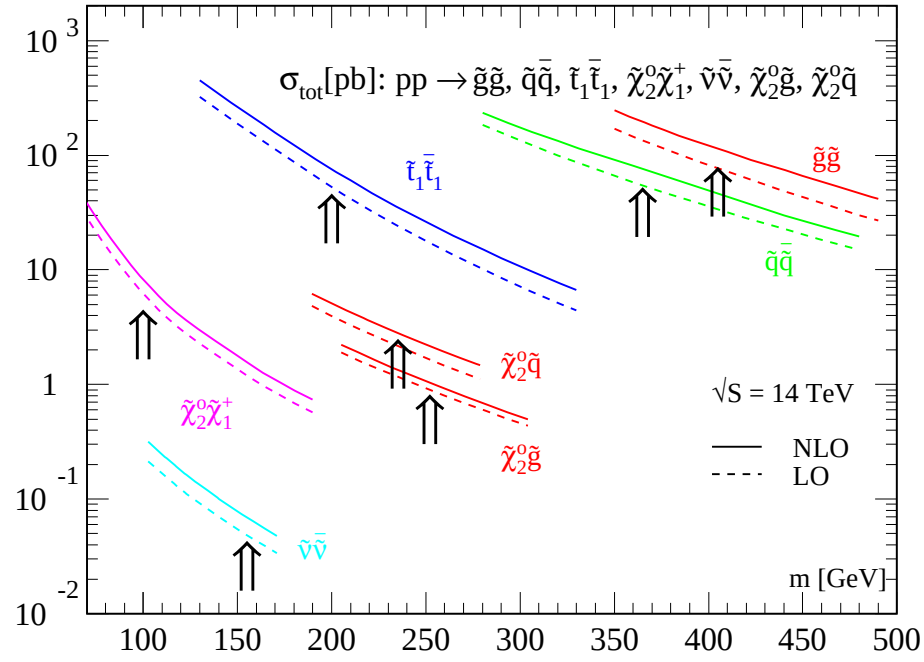
(1) possible discovery — signals for new physics, exclusion of parameter space

(2) measurements — masses, cross sections, decays

(3) parameter studies — MSSM Lagrangean, SUSY breaking

SUSY signals [also Tevatron]

- jets and $\not{E}_T$: $pp \to \tilde{q}\tilde{q}^*, \tilde{g}\tilde{g}, \tilde{q}\tilde{g}$
- funny tops: $pp \to \tilde{t}_1\tilde{t}_1^*$
- like sign dileptons: $pp \to \tilde{g}\tilde{g}$
- tri-leptons: $pp \to \tilde{\chi}_2^0\tilde{\chi}_1^-$ ....



Theory tools for high precision

- NLO ($2 \to 2$) cross sections: Prospino2
- NLO SUSY branching ratios: Sdecay [Mühlleitner]
- LO ($2 \to n$) matrix elements: Smadgraph, Sherpa, Whizard
- all SUSY input through Les Houches Accord [Allanach, Skands,...]

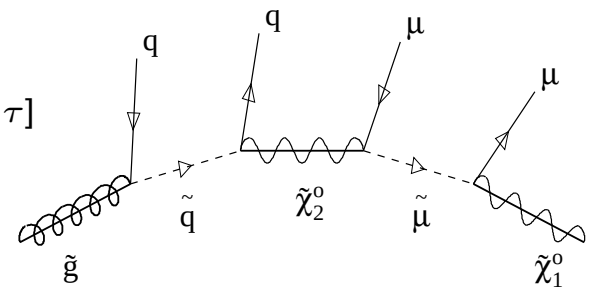
SUSY CASCADE ANALYSES

Spectra from cascade decays

- decay $\tilde{g} \to \bar{q}q\bar{q} \to \tilde{\chi}_2^0 q\bar{q} \to \mu^+\mu^- q\bar{q}\tilde{\chi}_1^0$ [better not via Z or to τ]
- cross sections some 100 pb [more than 3×10^5 events]
- thresholds & edges [Hinchliffe, Paige...; Cambridge ex-ph]

  classical $m^2_{\ell\ell} < (m^2_{\tilde{\chi}_2^0} - m^2_{\tilde{\ell}})(m^2_{\tilde{\ell}} - m^2_{\tilde{\chi}_1^0})/m^2_{\tilde{\ell}}$
- detector resolution, calibration, systematic errors, shape analysis? [talk Miller]
- cross sections as additional input? [Lester...]

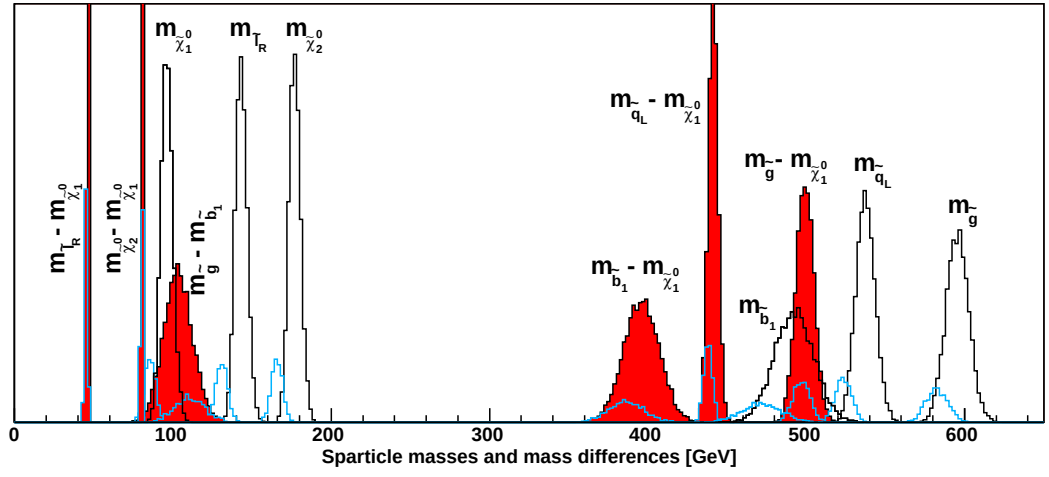
$\Rightarrow$ $\tilde{q}_L$ cascade reconstruction great for SPS1a [mass differences better; talk Hinchliffe]



Gluino mass [Gjelsten, Miller, Osland]

- now four jets instead of two
- jet identification crucial
- $\tilde{b}_L$ instead, all jets b-tagged

$\Rightarrow$ gluino mass to $\sim 1\%$
statistical error dominant



SUSY MATRIX ELEMENTS FOR THE LHC

Complex final states: SUSY-Madgraph [Hagiwara, Kanzaki, TP, Rainwater, Stelzer]

- Majoranas and fermion number violation in Madgraph [Denner, Eck, Hahn, Küblbeck]
- complete set of Feynman rules [400+ processes compared with Whizard and Sherpa]
- first physics projects started [talk Rainwater]

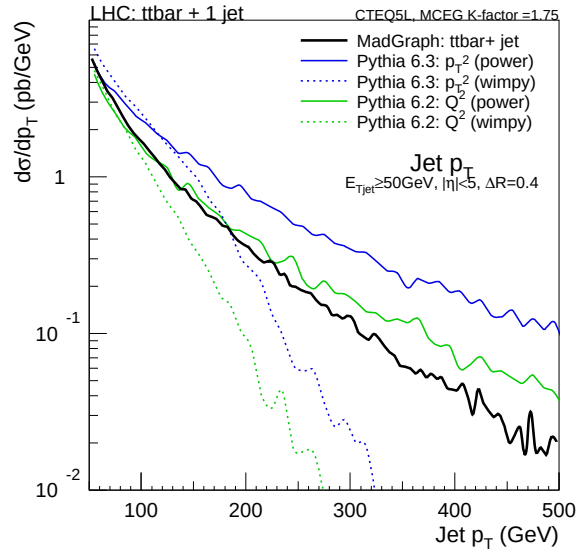
Squarks and gluinos plus jets [TP, Rainwater, Skands]

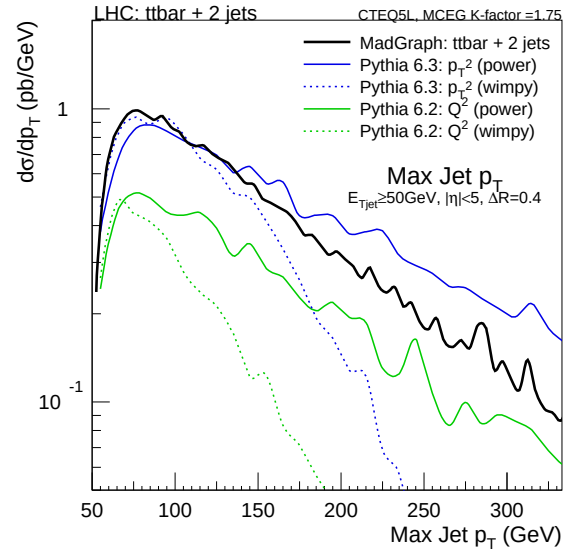
- cascade studies sensitive to jets?
- Smadevent: $\tilde{g}\tilde{g}$+2j and $\tilde{u}_L\tilde{g}$+2j $[p_{T,j} > 100\text{GeV}]$

σ[pb]	$t\bar{t}_{600}$	$\tilde{g}\tilde{g}$	$\tilde{u}_L\tilde{g}$
σ_{0j}	1.30	4.83	5.65
σ_{1j}	0.73	2.89	2.74
σ_{2j}	0.26	1.09	0.85

$\Rightarrow$ Pythia shower?

$\Rightarrow$ All will be tuned





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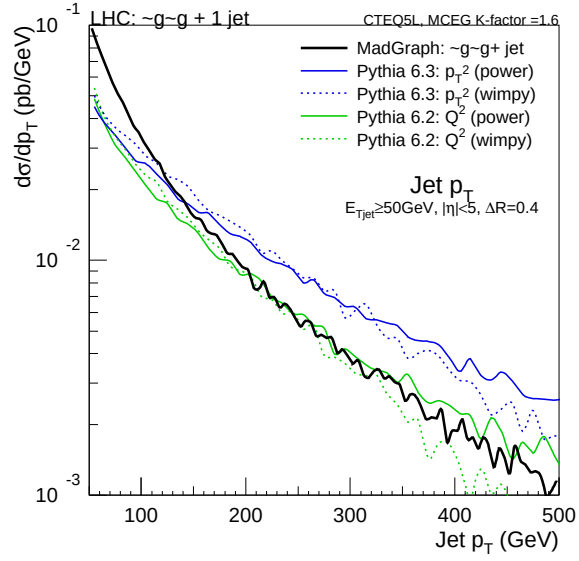

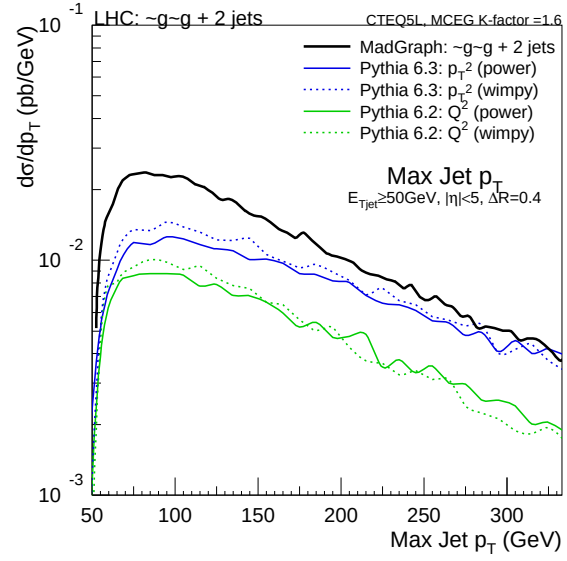

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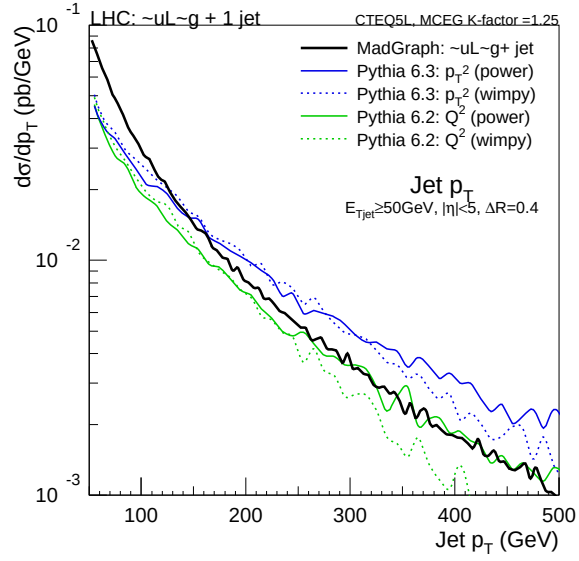
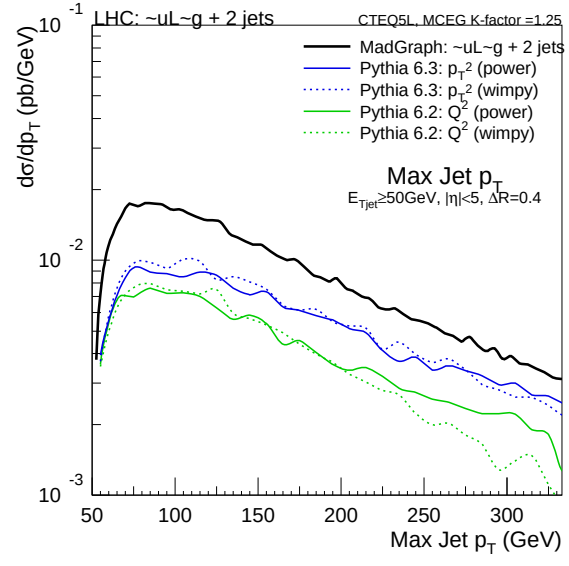




SUSY PARAMETERS FROM LHC DATA

SUSY parameters from observables

- parameters: weak-scale MSSM Lagrangean
- measurements: masses or edges
  branching fractions [MSMlib, Sdecay]
  cross sections [Prospino2, MSMlib],...
- errors: general correlation, statistics & systematics & theory
- problem in grid: huge phase space, local minimum?
  problem in fit: domain walls, starting values, global minimum?

First go at problem

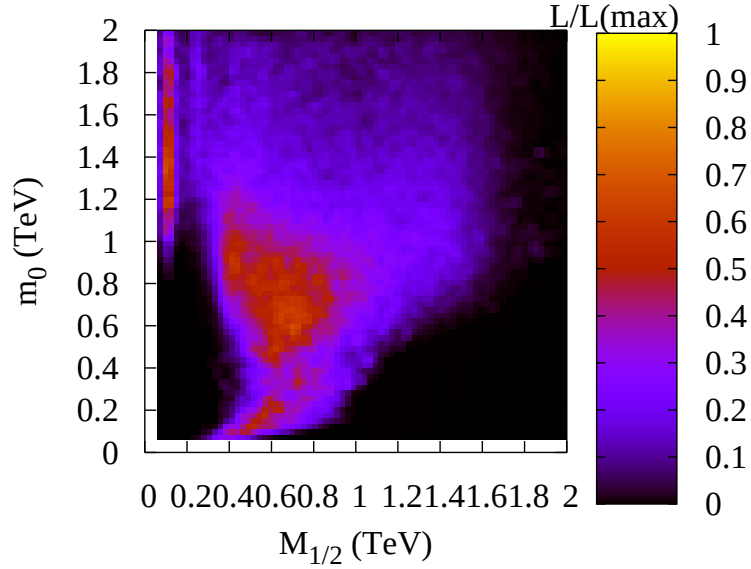
- ask a friend who knows how SUSY is broken

$\Rightarrow$ mSUGRA [talk Falkowski, Weiglein]

- fit $m_0, m_{1/2}, A_0, \tan\beta, \mathrm{sign}(\mu)$
- no problem, include indirect constraints [Allanach]

$\Rightarrow$ who would bet a month's salary on mSUGRA?

- admittedly: mSUGRA a very useful testing ground for methods



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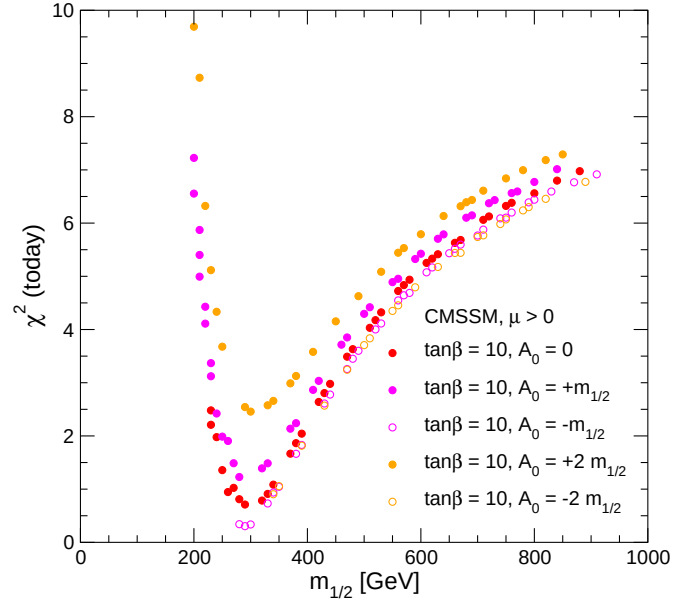

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Sfitter/Fittino [Lafaye, TP, Zerwas; Bechtle, Desch, Wienemann]

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

- LHC better than expected
- LHC+ILC without assumptions
- SUSY breaking bottom–up

[talk Wienemann]

	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	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

DIMENSIONAL REDUCTION

Problem in renormalization group: consistent dimensional reduction [talk Stöckinger]

- $(4-2\epsilon)$-dim. space-time, 4-dim. gauge fields and γ_μ [2 d.o.f. for gluons and gluinos]
- no general all-orders proof yet that Dred preserves SUSY
- mathematical inconsistency

$\Rightarrow$ new & consistent reformulation [c.f. Breitenlohner, Maison for $\overline{\text{MS}}$]

$\Rightarrow$ SUSY of Dred proven in several two-loop cases

Hadron colliders: dimensional reduction and factorization [Signer, Stöckinger]

- massive collinear factorization broken in Dred [Beenakker, Kuijf, v. Neerven, Smith]

$$\sigma_{\text{coll}} \neq f_{\text{parton}} \otimes \sigma_{\text{Born}}$$

- 'non-factorizing terms' rewritten with complete set of splittings $\sum_{g,\epsilon} f_i \otimes \sigma_i$
- from massless theory $f_\epsilon = f_g|_{m=0}$
- now ϵ-scalars in collinear limit [justifying usual pole subtraction]

$\Rightarrow$ factorization valid in consistently defined Dred

SUSY SPINS AT THE LHC

How to make sure it is SUSY

- assume neutralino is found in cascades

$\Rightarrow$ if fermion, then weakly interacting Majorana [that's what we call a neutralino]

$\Rightarrow$ compare with a model where gluino is a boson: universal extra dimensions

[Cheng, Dobrescu,...; mass spectra degenerate —ignore this information; cross section factor 10 larger —ignore this as well]

Slepton cascade [Smillie, Webber]

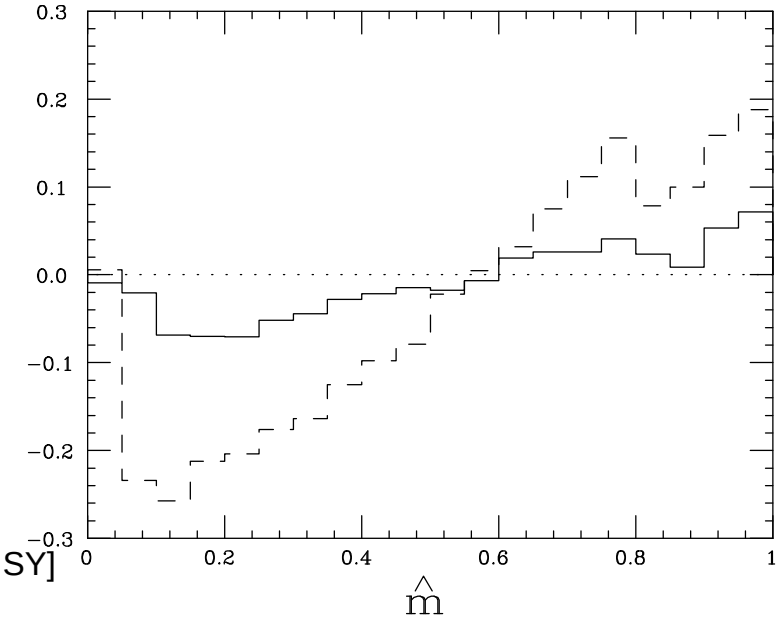
- decay chain $\tilde{\chi}_2^0 \to \ell\tilde{\ell}^* \to \ell\bar{\ell}\tilde{\chi}_1^0$
- compare with first KK Z and ℓ
- typically largest pp $\to \tilde{q}\tilde{g}$ [$\tilde{q}/\bar{\tilde{q}} \sim 2$]
- trick: mass variables, 'normalized angles' [Barr]

$\Rightarrow$ $\hat{m} = m_{j\ell}/m_{j\ell}^{max}$ most promising

$\mathcal{A} = [\sigma(j\ell^+) - \sigma(j\ell^-)]/[\sigma(j\ell^+) - \sigma(j\ell^-)]$

- assume hierarchical SPS1a spectrum [dashed SUSY]

$\Rightarrow$ more than proof of feasibility



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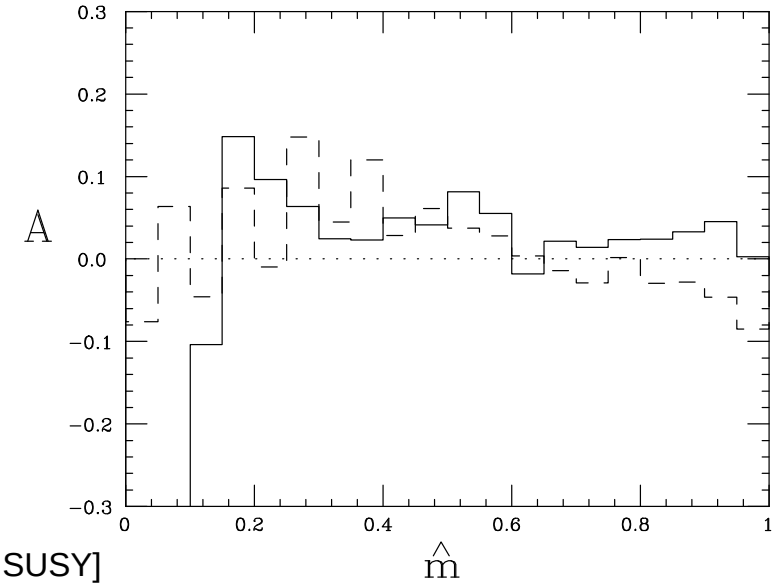
- assume non-hierarchical UED spectrum [dashed SUSY]

$\Rightarrow$ more than proof of feasibility



STABLE MASSIVE PARTICLES

Split Supersymmetry [Dimopoulos, Arkani-Hamed; Giudice, Romanino; Wells; Drees]

- forget about fine tuning [Higgs will never be as bad as cosmological constant]
- remember all the good things SUSY did for you [dark matter, unification]

$\Rightarrow$ make scalars heavy

$\Rightarrow$ protect gaugino and higgsino masses

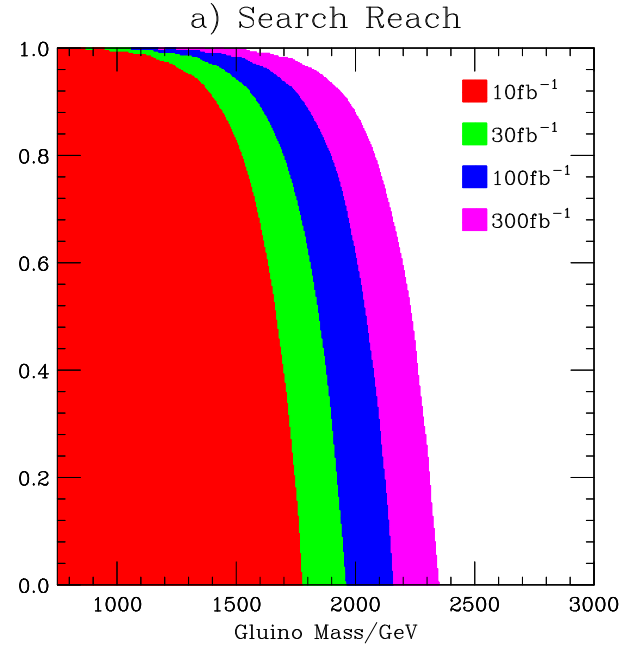
News for phenomenology [Kilian, TP, Richardson, Schmidt; Hewett, Lillie, Mazip, Rizzo]

- no cascade decays

$\Rightarrow$ hadronizing gluinos [$\tau \sim \tilde{m}^{-4} \sim 6.5$s for $\tilde{m} = 10^9$GeV]
heavy R hadrons [Farrar, Fayet; Baer, Cheung, Gunion; UKQCD; Kraan]
gluinonium, late decays,... [many unnamed talks]

- renormalization group running without scalars

$\Rightarrow$ corrections to protected couplings [ino Yukawas 20%]



Collider prospects [with proper errors, talk Richardson]

- LHC stable gluino to $\sim$ 2TeV [charge the key]
- ILC error on anomalous Yukawas $\lesssim$ 10% [indirect fit]

OUTLOOK

LHC phenomenology

- pheno-experimental efforts going very strong
- lots of new tools on the market, waiting to be tested

$\Rightarrow$ we will be able to do amazing things at the LHC

$\Rightarrow$ we still need the ILC for precision studies

Remember

- errors are tough, but the key to new physics
- we need more serious LHC man power

  [you can sign up in the back of this room after the talk]

Thanks to all the people whose work I presented, all those whose great work I did not manage to include, and to T. Falk