SUPERSYMMETRY AT THE LHC

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- TeV scale supersymmetry
- Signals at LHC
- Measurements at LHC (+ILC)
- Split Susy (only if too few questions)

TeV Scale Supersymmetry: 1

Starting from data...

– ...which seem to indicate a light Higgs

– problem of light Higgs: scalar masses perturbatively unstable
  quadratic divergences $\delta m_h^2 \propto g^2 \Lambda^2$
  all–orders Higgs mass driven to cutoff $m_h \to \Lambda$

$\Rightarrow$ solution: counter term for exact cancellation $\Rightarrow$ artificial, unmotivated, ugly

$\Rightarrow$ or new physics at TeV scale: supersymmetry
  extra dimensions
  little Higgs (pseudo–Goldstone Higgs)
  Higgsless/composite Higgs
  YourFavoriteNewPhysics...

$\Rightarrow$ all beautiful concepts and symmetries

$\Rightarrow$ in general problematic to realize at TeV scale [data seriously in the way]

Idea of supersymmetry: cancellation of divergences through statistics factor (-1)
[scalars vs. SM fermions; fermions vs. SM gauge bosons; fermions vs. SM scalars]

TeV Scale Supersymmetry: 2

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 [effective theory of everything]

Dark side

- unknown SUSY breaking
  $\longrightarrow$ masses, couplings, phases...
  $\longrightarrow$ e.g. hierarchical spectrum?
- flavor physics and SUSY breaking
  $\longrightarrow$ CKM and lepton flavor?
- 2 Higgs doublet model
  $\longrightarrow$ μ parameter and SUSY breaking?

$\Rightarrow$ as many as exclusive analyses as possible

		spin	d.o.f.	
fermion	f_L, f_R	1/2	1+1	
$\longrightarrow$ sfermion	$\tilde{f}_L$, $\tilde{f}_R$	0	1+1	
gluon	G_μ	1	n-2	
$\longrightarrow$ gluino	$\tilde{g}$	1/2	2	Majorana
gauge bosons	γ, Z	1	2+3	
Higgs bosons	h^o, H^o, A^o	0	3	
$\longrightarrow$ neutralinos	$\tilde{\chi}_i^o$	1/2	$4 \cdot 2$	Majorana
gauge bosons	$W^\pm$	1	$2 \cdot 3$	
Higgs bosons	$H^\pm$	0	2	
$\longrightarrow$ charginos	$\tilde{\chi}_i^\pm$	1/2	$2 \cdot 4$	Dirac

Structures in the SUSY spectrum [Drees, Martin]

– gauginos–higgsinos mixing: $m_{\tilde\chi_2^0} \sim m_{\tilde\chi_1^+}$ or $m_{\tilde\chi_1^0} \sim m_{\tilde\chi_1^+}$ in MSSM

$$\begin{pmatrix} m_{\tilde B} & 0 & -m_Z s_w c_\beta & m_Z s_w s_\beta \\ 0 & m_{\tilde W} & m_Z c_w c_\beta & -m_z c_w s_\beta \\ -m_Z s_w c_\beta & m_Z c_w c_\beta & 0 & -\mu \\ m_Z s_w s_\beta & -m_Z c_w s_\beta & -\mu & 0 \end{pmatrix} \quad \begin{pmatrix} m_{\tilde W} & \sqrt{2} m_W s_\beta \\ \sqrt{2} m_W c_\beta & -\mu \end{pmatrix}$$

– stop and sbottom mixing in MSSM

$$\begin{pmatrix} m_Q^2 + m_t^2 + \left(\frac{1}{2} - \frac{2}{3} s_w^2\right) m_Z^2 c_{2\beta} & -m_t \left(A_t + \mu \cot\beta\right) \\ -m_t \left(A_t + \mu \cot\beta\right) & m_U^2 + m_t^2 + \frac{2}{3} s_w^2 m_Z^2 c_{2\beta} \end{pmatrix}$$

– heavy gluinos and squarks through unification: $m_{\tilde B,\tilde W,\tilde g}/m_{1/2} \sim 0.4, 0.8, 2.6$

$m_{\tilde\ell,\tilde q}/m_{1/2} \sim 0.7, 2.5$ [$m_0 \ll m_{1/2}$]

[mass and coupling unification independent]

– experimentalists: ask your local SUSY breakers!

TeV Scale Supersymmetry: 4

Supersymmetric parameter conventions

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

⇒ fix SUSY conventions once for all

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

SUSY Les Houches Accord [Allanach, 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

⇒ fixed parameter convention and read-write format [list to be extended]

SUSY SIGNALS AT LHC: 1

Supersymmetry at the LHC

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

(2) measurements — masses, cross sections, decays

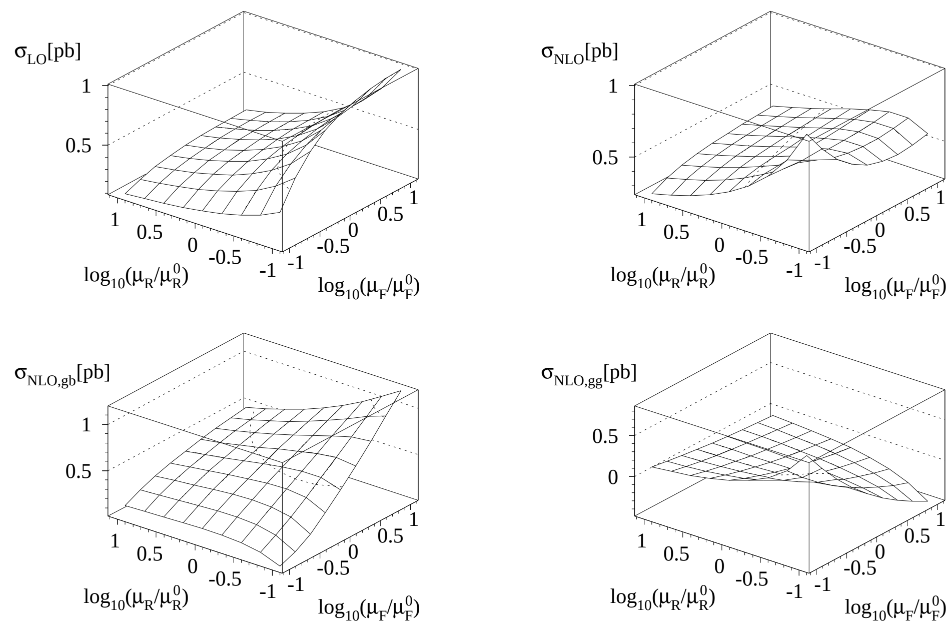
(3) parameter studies — MSSM Lagrangean, SUSY breaking

$\Rightarrow$ at least 10% precision to be matched at LHC [theorist's nightmare, yet unsolved]

Hadron collider observables with errors

- $\star$ masses from $\sigma_{\rm tot}$
- $\star$ branching fractions from $\sigma_{\rm tot}$
- – renormalization scale from $\alpha_s, y_{b,t}$
- – factorization scale from pdf's
- – perturbative series $N_c\alpha_s/\pi \sim 10\%$
- – finite terms [LO-NLO-NNLO: DY, Higgs]

$\Rightarrow$ NLO errors: 15...40 % for SUSY particles



SUSY SIGNALS AT LHC: 2A

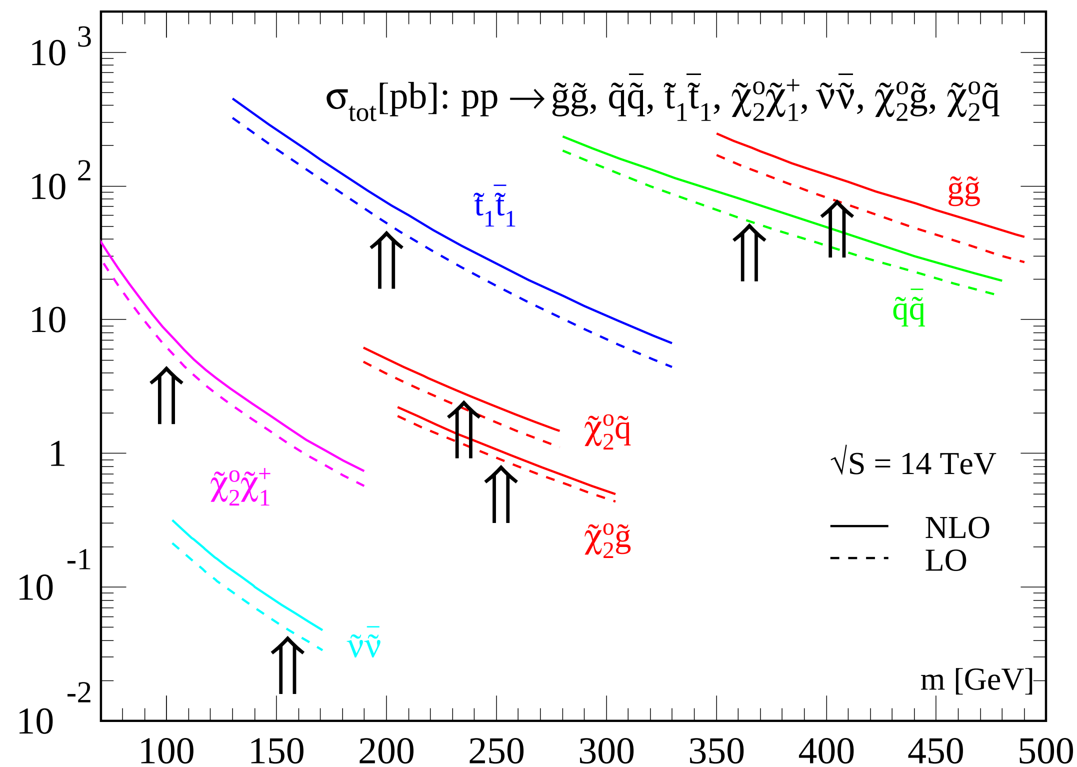
Prospino2: NLO cross sections for LHC

– 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 $\not{E}_T$: $pp \to \tilde{q}\tilde{q}^*, \tilde{g}\tilde{g}, \tilde{q}\tilde{g}$

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

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

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

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

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

– bottoms and $\not{E}_T$: $pp \to \tilde{b}_1\tilde{b}_1^*$

SUSY SIGNALS AT LHC: 2B

Prospino2: NLO cross sections for Tevatron

- all two-particle SUSY production channels included
- download from Prospino2 page: http://pheno.physics.wisc.edu/~plehn
- extended version beyond Prospino2: $pp \to SS^*, tH^- \ldots$

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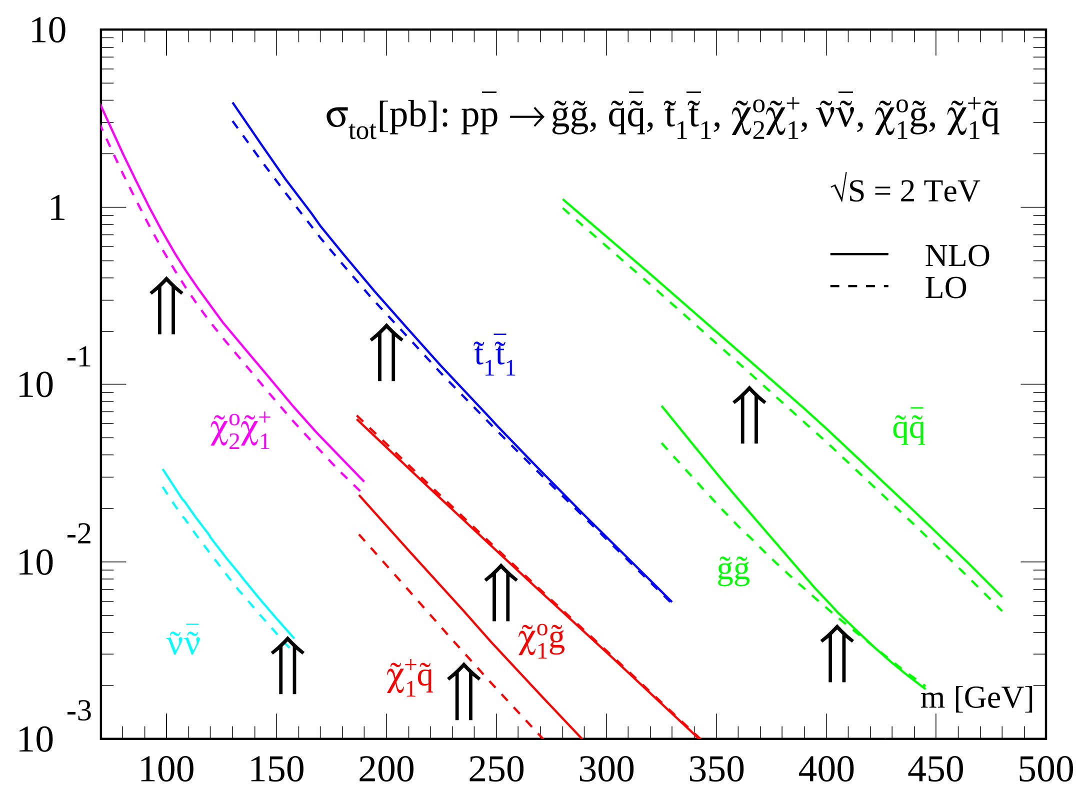


SUSY MEASUREMENTS AT LHC: 1

SUSY spectra from cascade decays

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

– cross sections some 100 pb [more than 10^7 events]

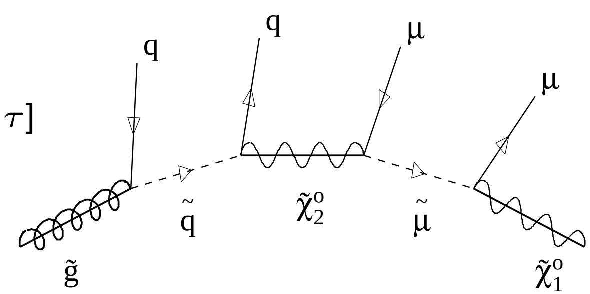
– thresholds & edges [Hinchliffe, Paige...; Cambridge ex-th]

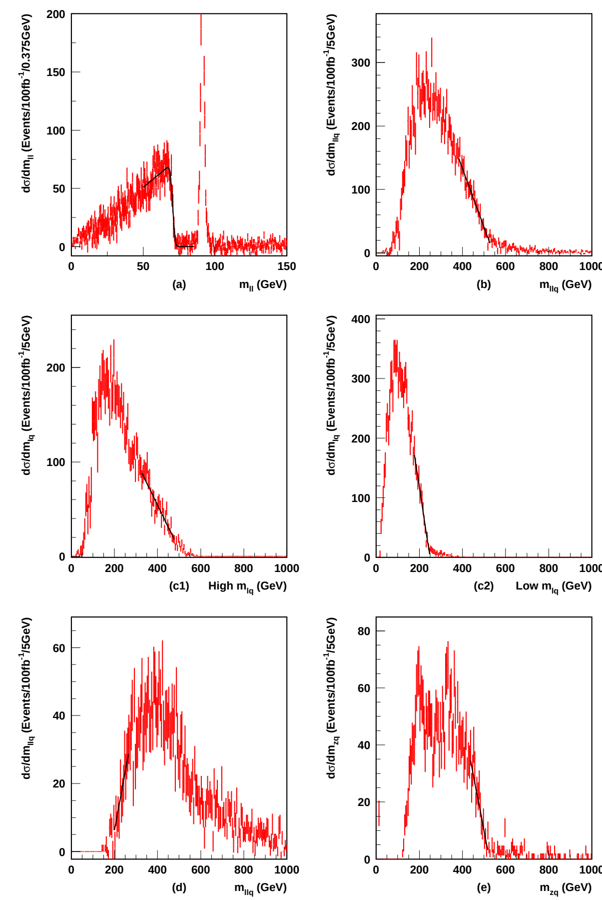
classical $m^2_{\ell\ell} < (m^2_{\tilde{\chi}_2^0} - m^2_{\tilde{\ell}})(m^2_{\tilde{\ell}} - m^2_{\tilde{\chi}_1^0})/m^2_{\tilde{\ell}}$

– cross sections as additional input?

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

[Polesello, Gjelsten, Miller, Osland]





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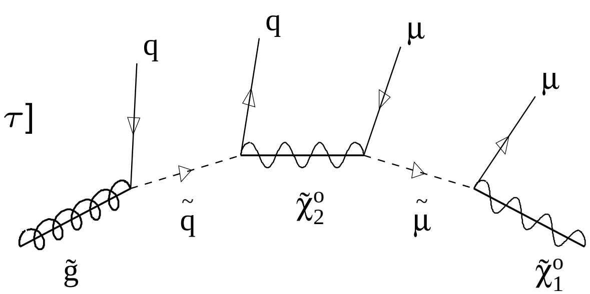

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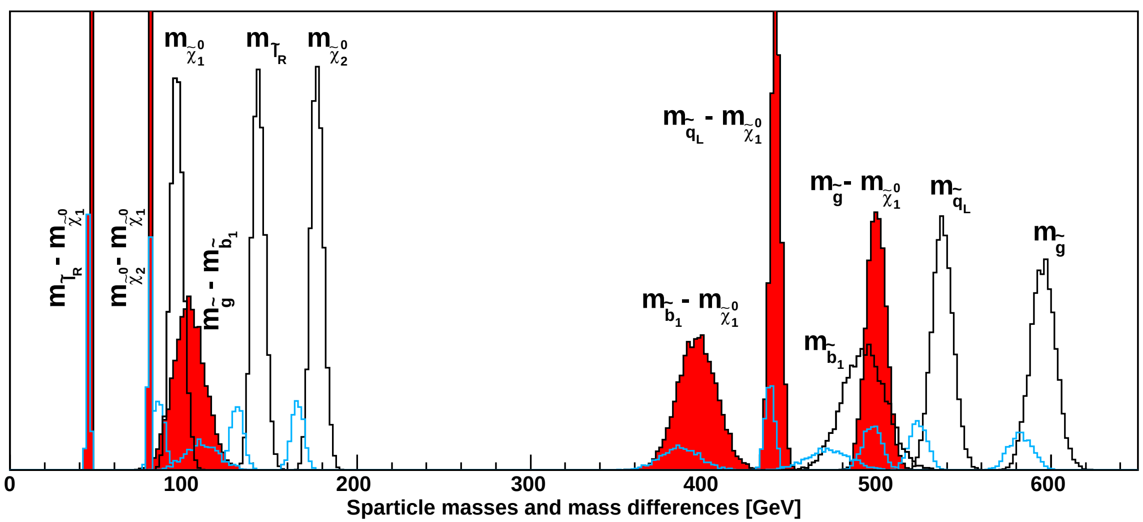
[Polesello, Gjelsten, Miller, Osland]

Mass determination



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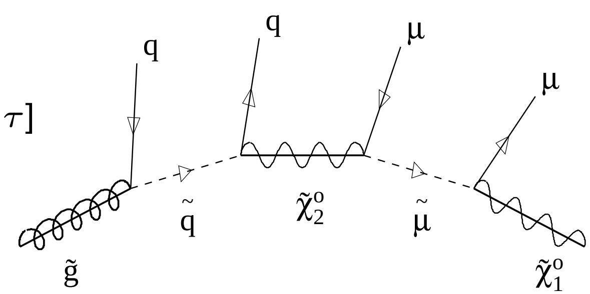

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- cross sections as additional input?

$\Rightarrow$ detector resolution, calibration, systematic errors? [Polesello, Gjelsten, Miller, Osland]

Mass determination

	m_{SPS1a}	LHC	ILC	LHC+ILC		m_{SPS1a}	LHC	ILC	LHC+ILC
χ_1^0	97.03	4.8	0.05	0.05	χ_2^0	182.9	4.7	1.2	0.08
					χ_4^0	370.3	5.1		2.3
$\chi_1^\pm$	182.3		0.55	0.55	$\chi_2^\pm$	370.6		3.0	3.0
$\tilde{g}$	615.7	8.0		6.4					
$\tilde{t}_1$	411.8		2.0	2.0					
$\tilde{b}_1$	520.8	7.5		5.7	$\tilde{b}_2$	550.4	7.9		6.2
$\tilde{u}_1$	551.0	23.6		23.6	$\tilde{u}_2$	570.8	17.4		9.8
$\tilde{d}_1$	549.9	23.6		23.6	$\tilde{d}_2$	576.4	17.4		9.8
$\tilde{s}_1$	549.9	23.6		23.6	$\tilde{s}_2$	576.4	17.4		9.8
$\tilde{c}_1$	551.0	23.6		23.6	$\tilde{c}_2$	570.8	17.4		9.8
$\tilde{e}_1$	144.9	4.8	0.05	0.05	$\tilde{e}_2$	204.2	5.0	0.2	0.2
$\tilde{\mu}_1$	144.9	4.8	0.2	0.2	$\tilde{\mu}_2$	204.2	5.0	0.5	0.5
$\tilde{\tau}_1$	135.5	8.6	0.3	0.3	$\tilde{\tau}_2$	207.9		1.1	1.1
$\tilde{\nu}_e$	188.2		0.7	0.7					

SUSY MEASUREMENTS AT LHC: 2

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

– pseudo-cascade jets from higher order radiation?

– Smadgraph/Smadevent the proper tool [Hagiwara, Kanzaki, TP, Rainwater, Stelzer]

– compute $\tilde{g}\tilde{g}$+2j,...

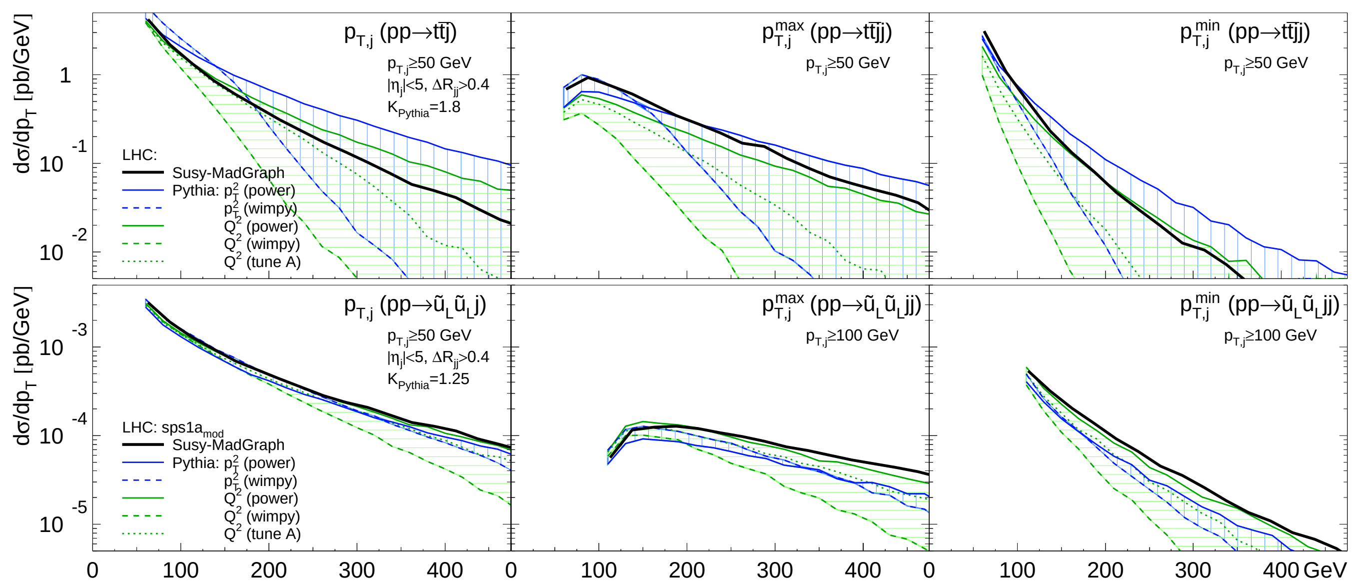
[$p_{T,j} > 50, 100$GeV]

– no suppression α_s/π

	σ_{tot} [pb]	$\tilde{g}\tilde{g}$	$\tilde{u}_L\tilde{g}$	$\tilde{u}_L\tilde{u}_L^*$	$\tilde{u}_L\tilde{u}_L$	$T\bar{T}$
$p_{T,j} > 100$ GeV	σ_{0j}	4.83	5.65	0.286	0.502	1.30
	σ_{1j}	2.89	2.74	0.136	0.145	0.73
	σ_{2j}	1.09	0.85	0.049	0.039	0.26
$p_{T,j} > 50$ GeV	σ_{0j}	4.83	5.65	0.286	0.502	1.30
	σ_{1j}	5.90	5.37	0.283	0.285	1.50
	σ_{2j}	4.17	3.18	0.179	0.117	1.21

⇒ Pythia shapes work!

[NLO rates: Prospino2]



SUSY Measurements at LHC: 2

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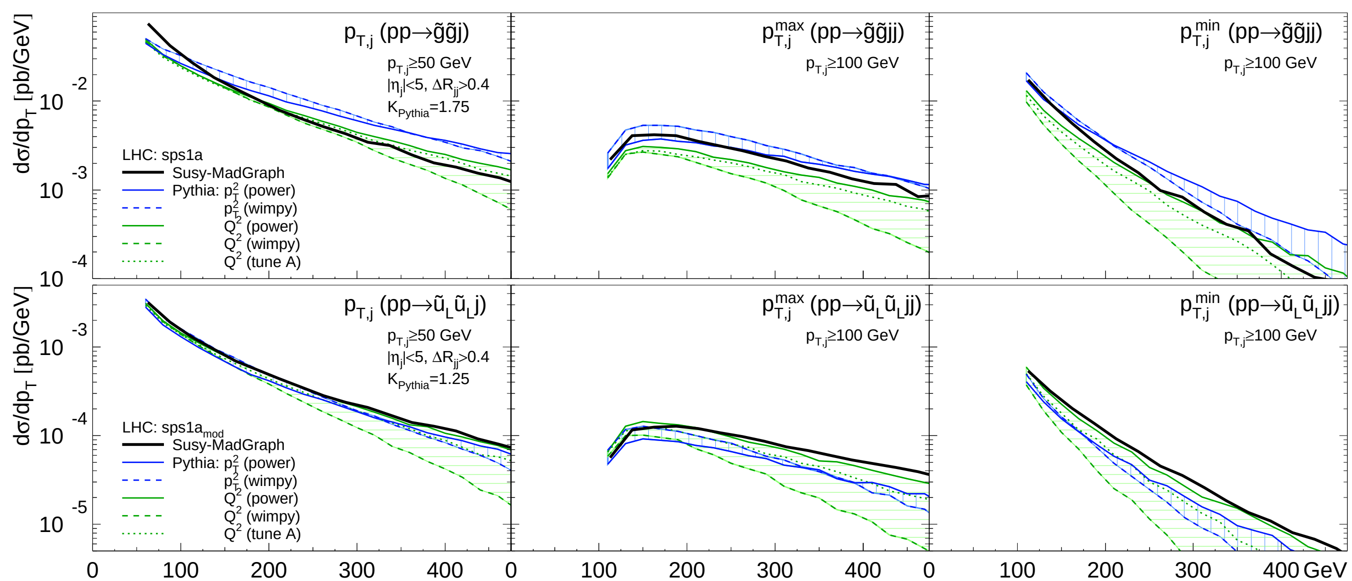


SUSY Measurements at LHC: 3

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: Sugra top–down fit with errors [unsmeared measurements]

– fit including all errors

[Allanach et al; Jack & Jones]

– spectrum from Suspect

[Djouadi, Kneur]

abs. errors		Δ at LHC		Δ at ILC		Δ at LHC+ILC	
	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

$\Rightarrow$ masses alone

$\Rightarrow$ LHC edges alone

$\Rightarrow$ wrong $\mu < 0$

$\Rightarrow$ SoftSusy fit [Allanach]

LHC	Masses	Δ	Edges	Δ	$\mu < 0$	Δ	Softsusy	Δ
m_0	100	3.9	100	1.2	101.4	1.8	97.9	4.6
$m_{1/2}$	250	1.7	250	1.0	249.8	0.01	252.5	2.9
$\tan\beta$	10	1.1	10	0.9	13.8	0.002	11.6	3.6
A_0	-100	33	-100	20	-150.2	1.7	14.7	58.9
LHC+ILC	Masses	Δ					Softsusy	Δ
m_0	100	0.6					95.2	1.1
$m_{1/2}$	250	0.5					249.8	0.5
$\tan\beta$	10	0.5					9.8	0.5
A_0	-100	13					-97	10

$\Rightarrow$ But all wrong... [mass unification assumed!]

SUSY Measurements at LHC: 4

SUSY parameters from observables

- parameters: weak-scale MSSM Lagrangean
- measurements: masses [Suspect, Softsusy, FeynHiggs...]
  branching fractions [MSMlib, Sdecay]
  cross sections [Prospino, MSMlib, Spheno],...
- 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]

- (0) start: smeared measurements
  (1) grid for closed subset
  (2) fit of remaining parameters
  (3) complete fit

$\Rightarrow$ LHC+ILC with no assumptions

	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

SPLIT SUSY AT COLLIDERS: 1

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 all scalars heavy [hope but wrong: $\widetilde{m} \to m_{GUT}$?]

$\Rightarrow$ protect all gaugino and higgsino masses [$m_{\tilde{\chi}_i}, m_{\tilde{g}} \lesssim$ TeV]

What's new for phenomenology?

– no squarks, sleptons for colliders, astro-particle physics [Giudice, Romanino; Pierce]

– no cascade decays

– stable (hadronizing) gluinos [$\tau \sim \widetilde{m}^{-4} \sim 6.5$s for $\widetilde{m} = 10^9$GeV]

– heavy hadrons $R_g, R_{q\bar{q}}, R_{qqq}$ [Farrar, Fayet; Baer, Cheung, Gunion; UKQCD; Kraan]

– renormalization group running without scalars [e.g. different ino Yukawa couplings by $\lesssim 20\%$]

Collider tests

(1) Is it supersymmetry?

(2) Is it split?

Split SUSY at Colliders: 2

Manuel's argument [Drees: hep-ph/0501106]

– remember Higgs potential and B parameter [$V \sim -\mu B\, H_u H_d$]

$\longrightarrow$ Higgsino mass $\mu \sim m_{weak}$ by symmetry, but where is B?

$$\sin 2\beta = 2\,\frac{\tan\beta}{1+\tan^2\beta} = 2\,\frac{B\,\mu}{m^2_{H,u}+m^2_{H,d}} = 2\,\frac{B\,m_{weak}}{\widetilde{m}^2} = 2\,x\,\frac{m_{weak}}{\widetilde{m}} \qquad \text{for} \quad B = x\,\widetilde{m}$$

$\longrightarrow$ two easy solutions in limits:

$$\tan\beta \ll 1: \qquad \tan\beta = \frac{x\,m_{weak}}{\widetilde{m}} \qquad\qquad \tan\beta \gg 1: \qquad \tan\beta = \frac{\widetilde{m}}{x\,m_{weak}}$$

$\longrightarrow$ perturbative Yukawa couplings: $\tan\beta = 1...100$:

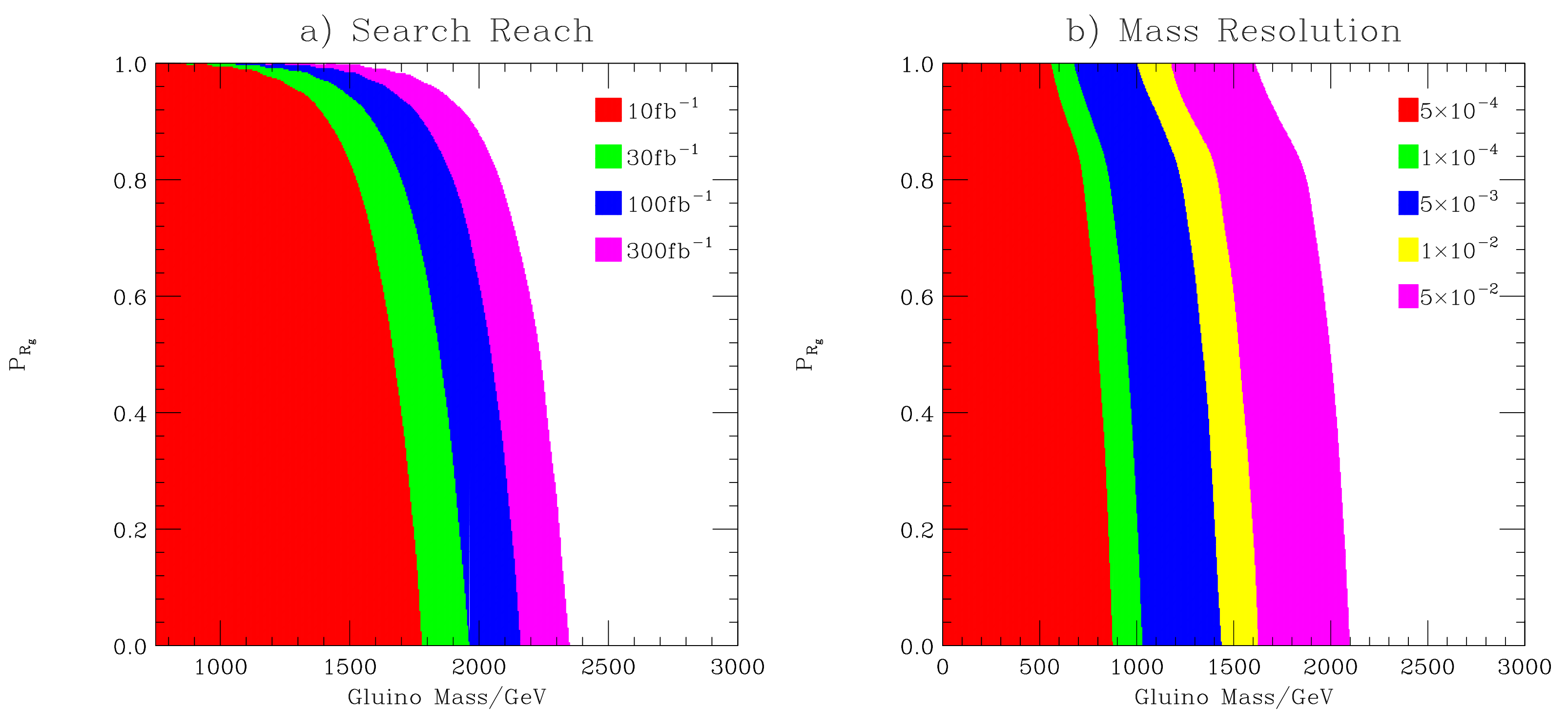
$$\tan\beta < 100 \quad \Rightarrow \quad x > \frac{\widetilde{m}}{100\,m_{weak}} \quad \Rightarrow \quad B > \frac{\widetilde{m}^2}{100\,m_{weak}}$$

$\longrightarrow$ second mass scale not protected by anything [pointing above Planck scale?]

Split SUSY at Colliders: 3

Split SUSY at the LHC [Kilian, TP, Richardson, Schmidt]

- neutralinos, charginos like in MSSM, poor precision
- many gluinos pair-produced [$\sigma \gtrsim$ 1 pb, Prospino2]
- gluinonium $\tilde{g}\tilde{g} \to jj$ [Kühn, Ono; Goldman, Haber; CMS; reach $\sim$ TeV?]
- neutral R hadrons missing $\to$ missing energy signal
- charged R hadrons in tracker, calorimeter, muon chambers [Cambridge ex-th]
- mass measurement through time of flight tracker–muon chamber



SPLIT SUSY AT COLLIDERS: 4

Split Supersymmetry at the ILC [Kilian, TP, Richardson, Schmidt]

– gluinos not produced because of decoupled squarks

– neutralino–chargino sector analysis as usual [robust towards decay channels]

– anomalous Yukawas $\equiv$ off-diagonal mass matrix entries $[gs_\beta, gc_\beta, g' s_\beta, g' c_\beta]$

$\Rightarrow$ (1) direct measurements of $\chi\chi h$ [Whizard, Smadgraph $\to$ distinctly unpromising]

(2) indirect determination of mass matrices

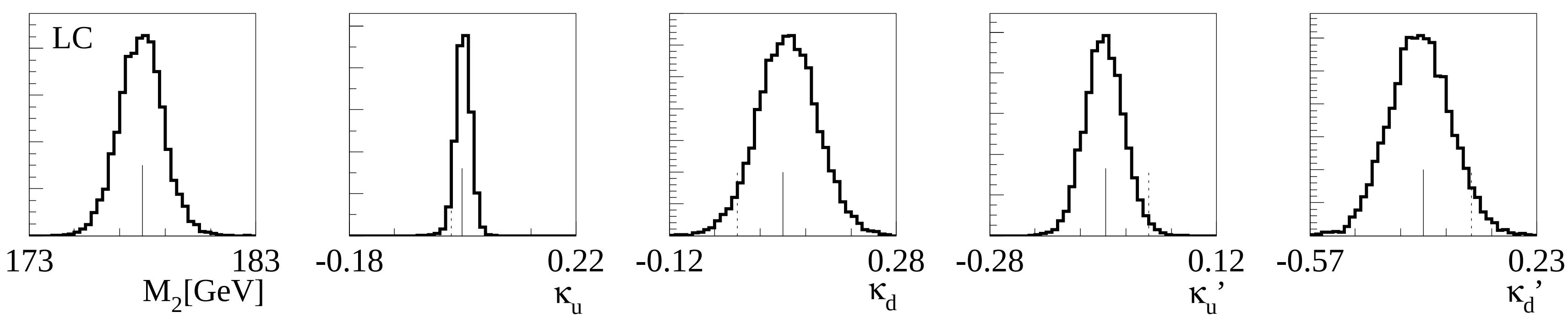
Indirect determination

– errors crucial [0.5 % error on masses at ILC]

– 10^4 smeared pseudo-measurements to extract parameters from

$\Rightarrow$ analytic inversion impossible, fit instead

$\Rightarrow$ $\mathcal{O}$(few%) errors on anomalous Yukawas



OUTLOOK

Pheno effort for SUSY@LHC picking up speed

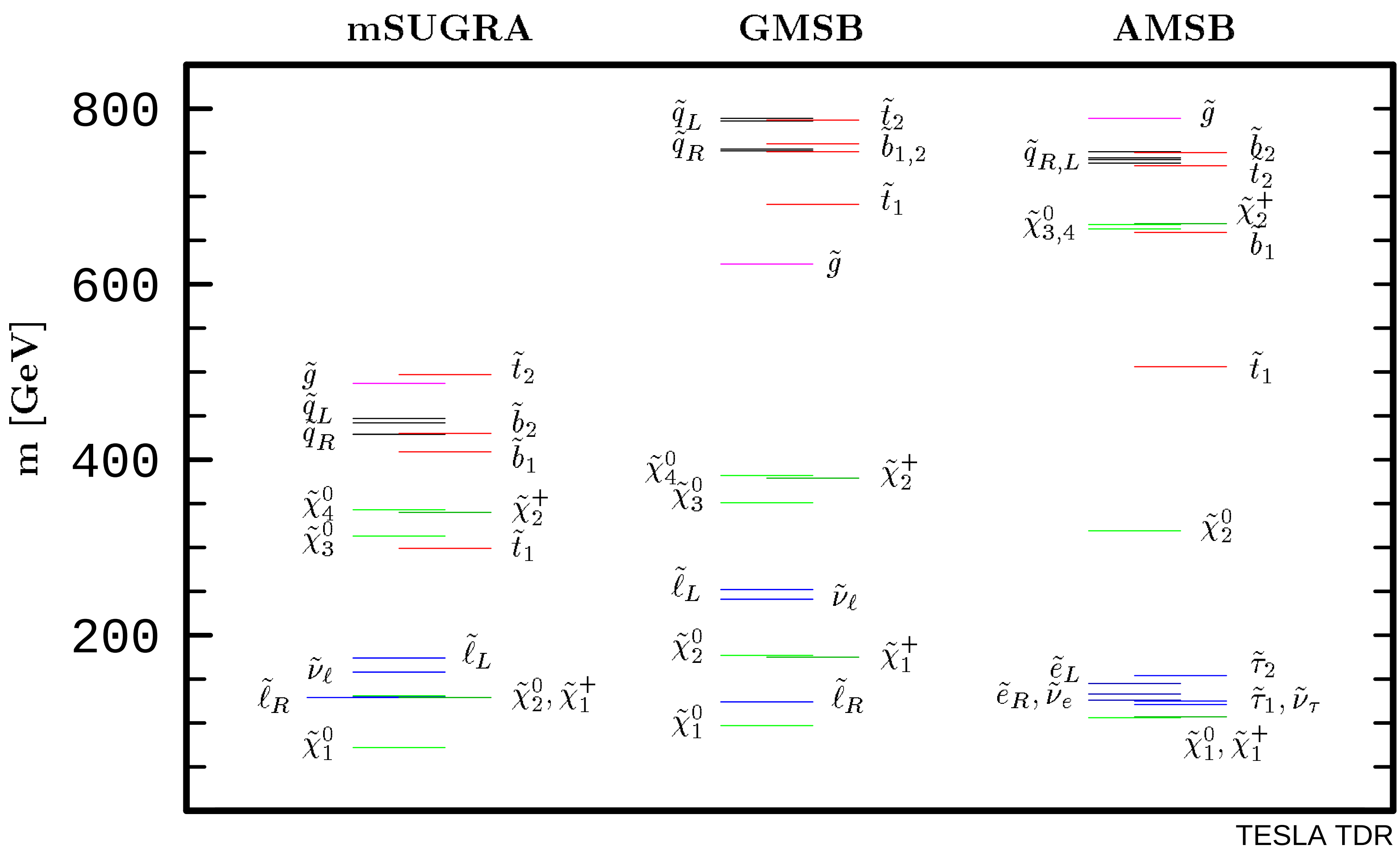
– inclusive searches plus cascade reconstruction with great promise
– relevant theoretical QCD problems yet to be solved [higher orders vs. shower]
– total cross sections available to NLO [Propino2]
– automatic matrix element generators tested [Smadgraph, Whizard, Sherpa]
– parameter extraction tools in use for LHC–ILC studies [Sfi tter, Fittino]

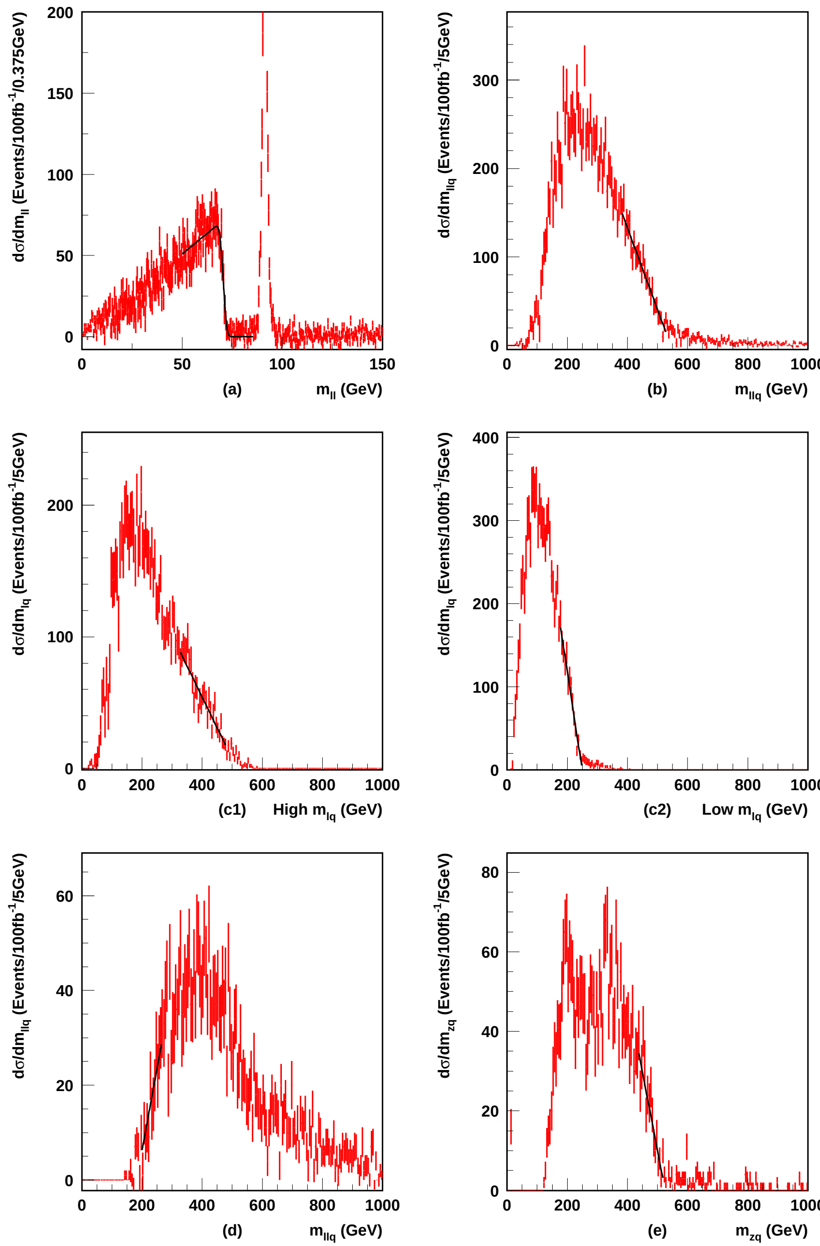
⇒ errors the key at LHC [tools mean no excuses for poor jobs]
⇒ whatever we learn for SUSY we will use for BSM

For entertainment: Split Supersymmetry

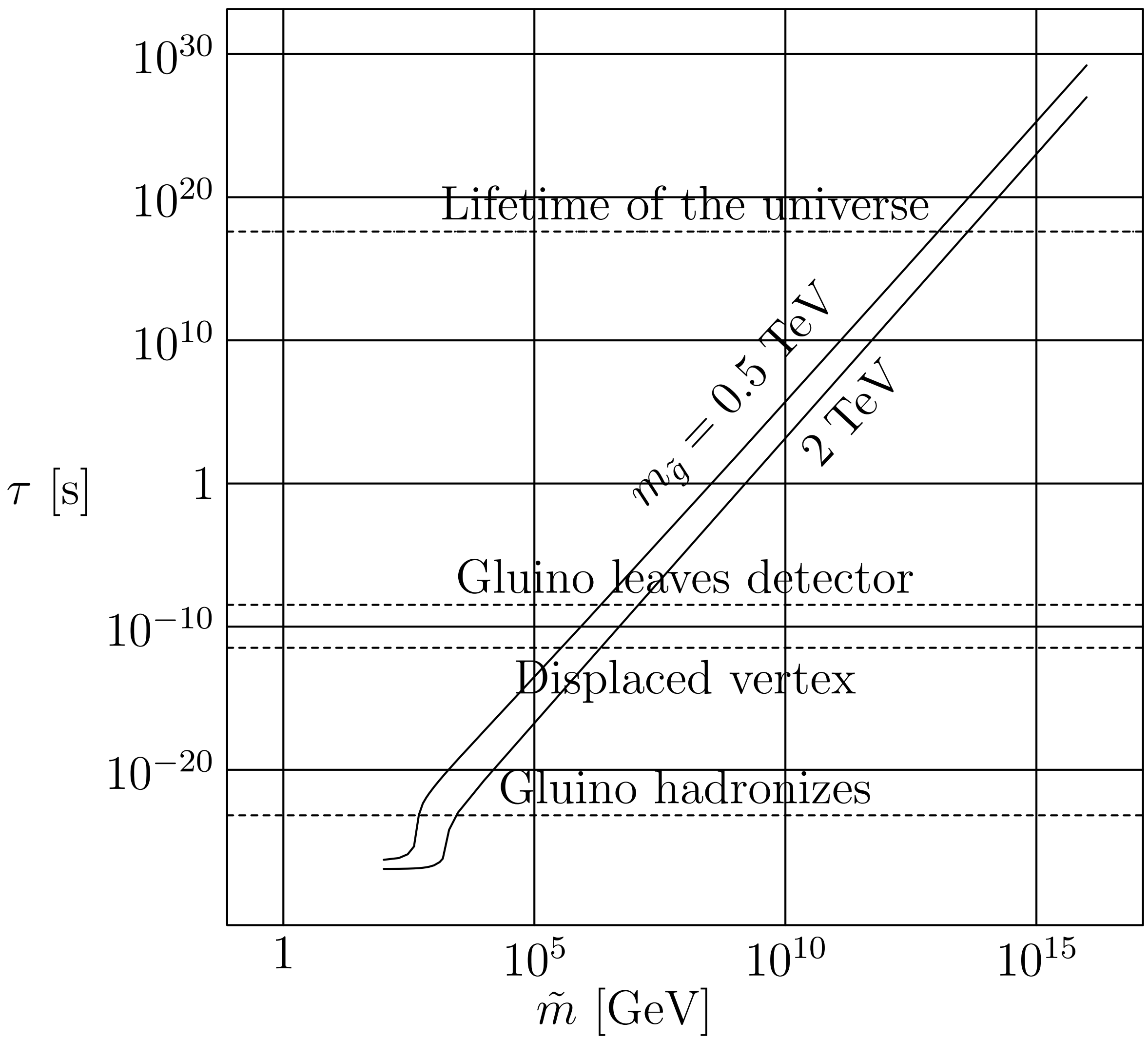
– interesting phenomenology [for dead model]
– LHC: R hadrons observable with mass measurement
– ILC: anomalous weak-ino Yukawas accessible

⇒ some aspects always benefits future analyses

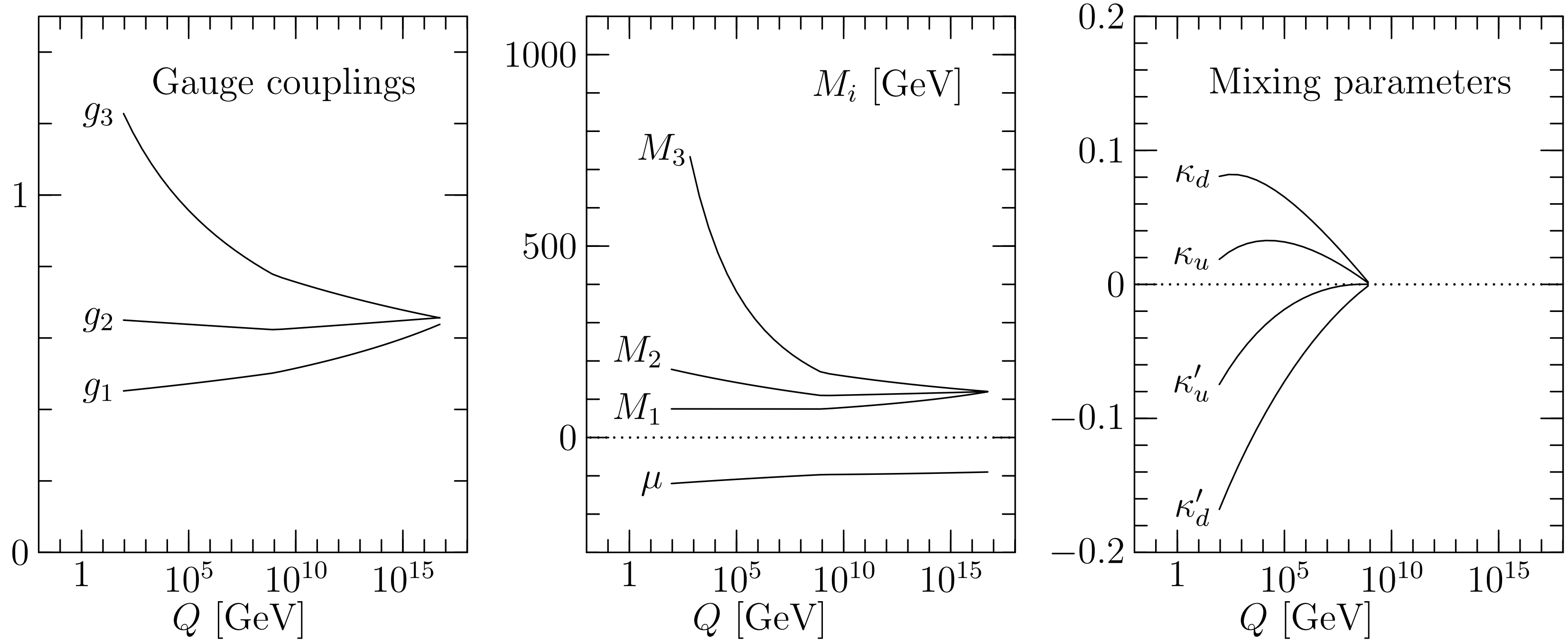

mSUGRA
GMSB
AMSB
m [GeV]
800
600
400
200
TESLA TDR



dσ/dm_ll (Events/100fb^-1/0.375GeV)
(a)
m_ll (GeV)
dσ/dm_llq (Events/100fb^-1/5GeV)
(b)
m_llq (GeV)
dσ/dm_lq (Events/100fb^-1/5GeV)
(c1)
High m_lq (GeV)
(c2)
Low m_lq (GeV)
dσ/dm_llq (Events/100fb^-1/5GeV)
(d)
m_llq (GeV)
dσ/dm_zq (Events/100fb^-1/5GeV)
(e)
m_zq (GeV)



10^{30}
10^{20}
10^{10}
1
10^{-10}
10^{-20}
τ [s]
Lifetime of the universe
$m_{\tilde{g}} = 0.5$ TeV
2 TeV
Gluino leaves detector
Displaced vertex
Gluino hadronizes
1
10^{5}
10^{10}
10^{15}
$\tilde{m}$ [GeV]



Gauge couplings
g_3
g_2
g_1
1
0
1
10^5
10^{10}
10^{15}
Q [GeV]
M_i [GeV]
1000
500
0
M_3
M_2
M_1
μ
Mixing parameters
0.2
0.1
0
−0.1
−0.2
κ_d
κ_u
κ'_u
κ'_d

APPENDIX

Regularization of supersymmetric theory: $\overline{\text{MS}}$ scheme

+ SUSY-QCD next-to-leading order is mostly QCD [i.e. α_s, y_b, pdf,...]
– $\overline{\text{MS}}$ breaks SUSY, but does not violate Ward identities [d.o.f. of gluinos; Jack, Jones]
→ correct vertices using additional ‘renormalization’ [Martin, Vaughn]

example: qqh, $\tilde{q}\tilde{q}h$, $q\tilde{q}\tilde{h}$ vertices in naive $\overline{\text{MS}}$

$$(mg)_{qqh} \equiv m\, g_{\overline{\text{MS}}} \qquad (mg)_{\tilde{q}\tilde{q}h} = (mg)_{qqh}\left(1 + \frac{\alpha_s C_F}{4\pi}\right) \qquad (mg)_{q\tilde{q}\tilde{h}} = (mg)_{qqh}\left(1 + \frac{3\alpha_s C_F}{8\pi}\right)$$

→ complete set of corrections purely technical complication [Stöckinger]

$\overline{\text{DR}}$ scheme

+ assume gauge invariance not an issue [Siegel]
+ $\overline{\text{DR}}$ scheme explicitely supersymmetric [only shift in space-time dimension]
– inconvenient, missing QCD infrastructure
– additional contribution to collinear factorization with massive final states
  [Beenakker...; van Neerven, Smith]

Error on anomalous Yukawa couplings

	Fit $\tan\beta$	m_i	σ_{ij}	$\Delta\kappa_u$	$\Delta\kappa_d$	$\Delta\kappa'_u$	$\Delta\kappa'_d$
ILC		•	•	0.9×10^{-2}	3×10^{-2}	1.3×10^{-2}	4×10^{-2}
ILC	•	•	•	1.2×10^{-2}	5×10^{-2}	2×10^{-2}	5×10^{-2}
ILC		•		1.1×10^{-2}	5×10^{-2}	3×10^{-2}	8×10^{-2}
ILC	•	•		1.2×10^{-2}	11×10^{-2}	4×10^{-2}	8×10^{-2}
LHC		•		2.2×10^{-1}	6×10^{-1}	2.7×10^{-1}	8×10^{-1}
ILC		•	•	1.4×10^{-2}	5×10^{-2}	3×10^{-2}	10×10^{-2}
ILC*	•	•	•	1.7×10^{-2}	9×10^{-2}	4×10^{-2}	13×10^{-2}
ILC	fix $\tan\beta = 3$	•	•	1.6×10^{-2}	4×10^{-2}	4×10^{-2}	9×10^{-2}

Verdict

– LHC: stable R hadrons, charginos and neutralinos

– ILC: anomalous Yukawa couplings

– IceCube: one event per year for low-mass R hadrons [Hewett, Lillie, Mazip, Rizzo]

– Pierre Auger: few events for $\widetilde{m} < 10^{11}$ GeV [Anchordoqui, Goldberg, Nunez]

$\Rightarrow$ split supersymmetry identifiable at combination of colliders

$\Rightarrow$ what stays: exotic heavy hadrons visible at LHC
why did we ever assume MSSM-type ino Yukawas?