Supersymmetry with lots of leptons

aka "lepto-SUSY"

Witold Skiba

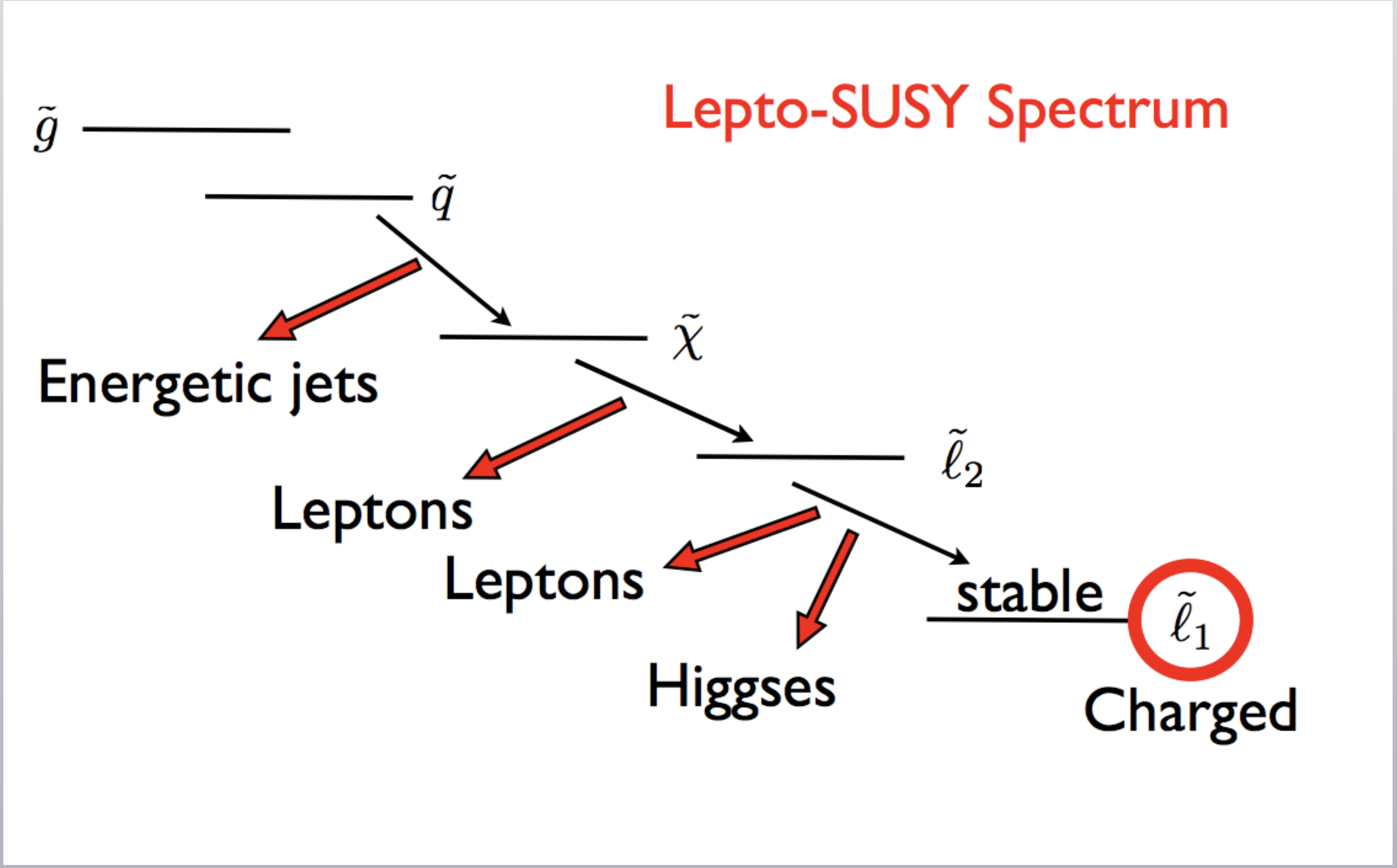
with A. De Simone, J. Fan, V. Santz, M. Schmaltz

arxiv: 0808.2052 [hep-ph]

arxiv: 0903.5305 [hep-ph]

Outline

- What is lepto-SUSY?
- Collider signatures
- How can lepto-SUSY arise?
- Low-scale gaugino mediation



LSP - the gravitino

NLSP - right-handed stau

but looks like the "co-NLSP" scenario

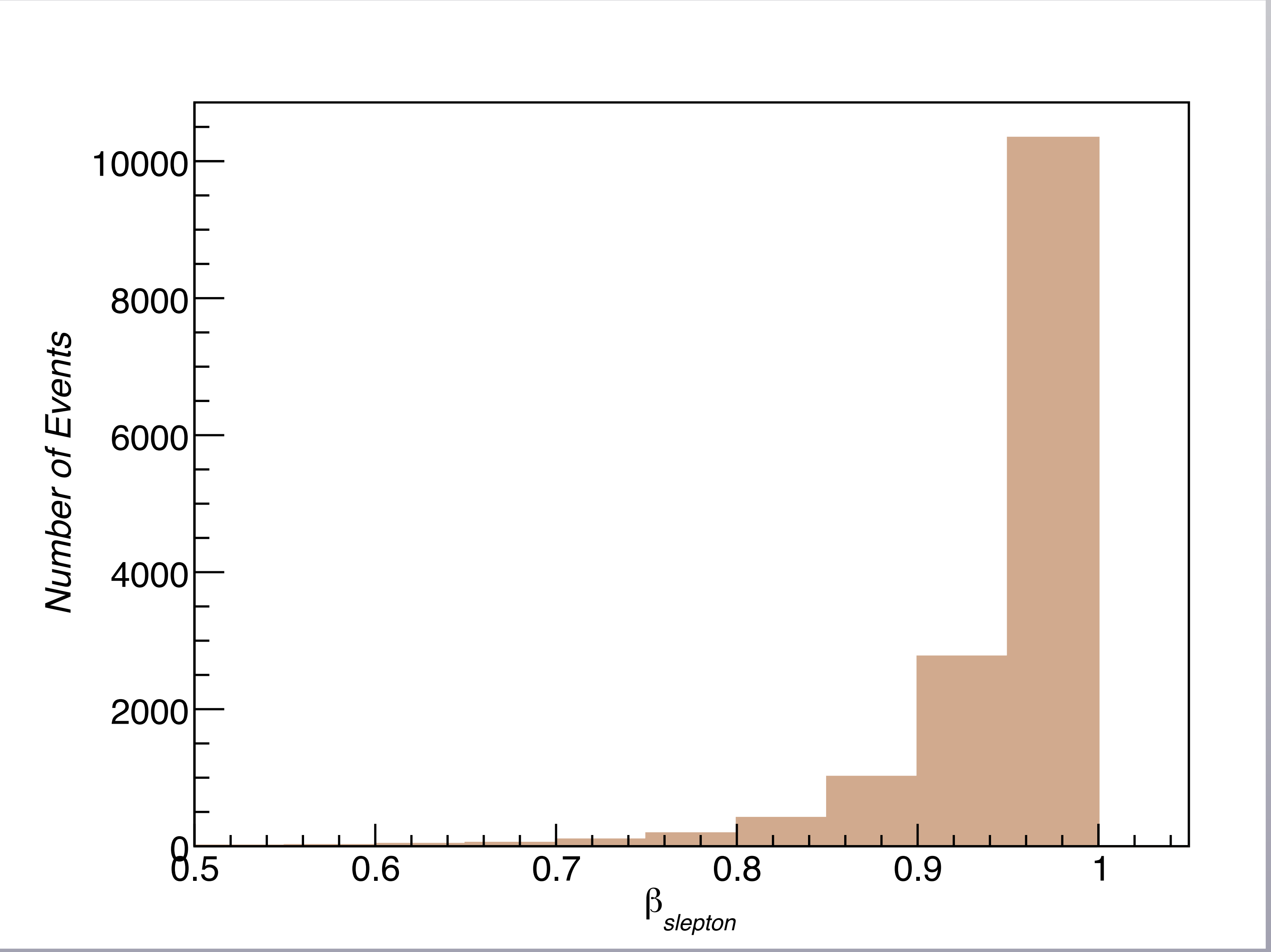
Examples of squark decays or why lots of leptons

$$\tilde{u}_L \xrightarrow{55\%} d_L\ \tilde{W}^+ \xrightarrow{20\%} d_L\ l_L^+\ \tilde{\nu} \xrightarrow{66\%} d_L\ l_L^+\ \nu\ l_R^\pm\ \tilde{l}_R^\mp$$

$$\tilde{u}_L \xrightarrow{28\%} u_L\ \tilde{W}^0 \xrightarrow{20\%} u_L\ l_L^\pm\ \tilde{l}_L^\mp \xrightarrow{55\%} u_L\ l_L^\pm\ l_L^\mp\ l_R^\pm\ \tilde{l}_R^\mp$$

Even more leptons

The sleptons are energetic if they originate from heavy squarks. It is difficult to distinguish collider-stable sleptons from muons if slepton velocity is larger than 0.8



Higgs production

Left-handed sleptons decay mostly through the off-shell Bino with a 3-body final state. However, often the 2 body decay

$$\tilde{l}_L \longrightarrow h\, \tilde{l}_R$$

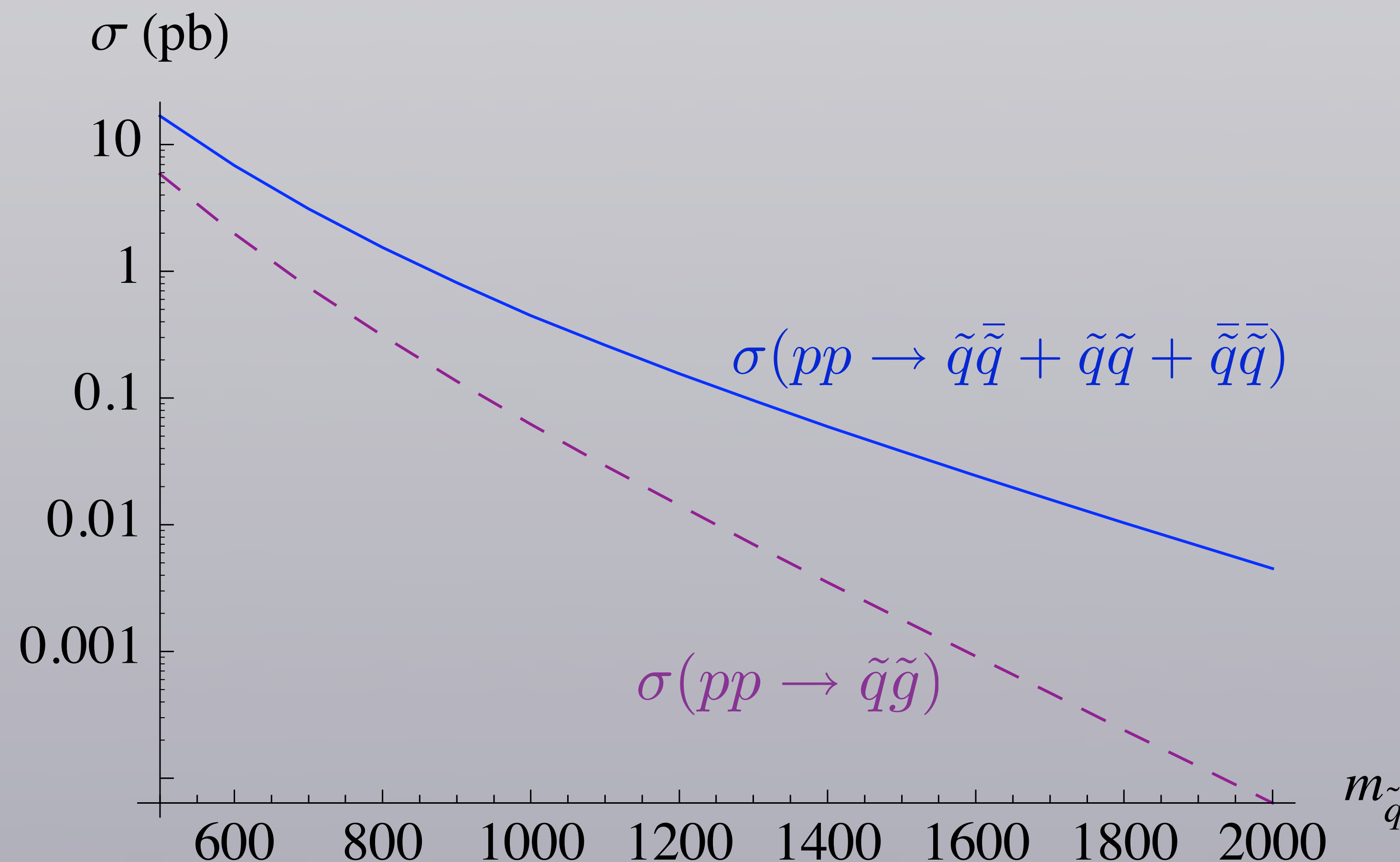
is kinematically allowed. This proceeds through the left-right mixing, so it is most important for the staus, but even for the smuons it can be significant.

$$\mathrm{BR}(\tilde{\tau}_2 \to h^0(Z) + \tilde{\tau}_1) = 53.3\%\,(46.6\%)$$

$$\mathrm{BR}(\tilde{\mu}_2 \to h^0(Z) + \tilde{\mu}_1) = 44.1\%\,(35.1\%)$$

Slepto-SUSY at LHC

$m_{\tilde{g}}$	1938	$m_{\tilde{u}_L}$	949
$m_{\tilde{\chi}_1^\pm}$	291	$m_{\tilde{u}_R}$	920
$m_{\tilde{\chi}_2^\pm}$	676	$m_{\tilde{d}_L}$	952
$m_{\tilde{\chi}_4^0}$	676	$m_{\tilde{d}_R}$	919
$m_{\tilde{\chi}_3^0}$	353	$m_{\tilde{t}_1}$	920
$m_{\tilde{\chi}_2^0}$	302	$m_{\tilde{t}_2}$	962
$m_{\tilde{\chi}_1^0}$	271	$m_{\tilde{\ell}_L}$	248
m_h	115	$m_{\tilde{\ell}_R}$	108
$m_{H^\pm}$	387	$m_{\tilde{\nu}}$	236
m_A	379	m_1	106
m_{H_0}	379	m_2	249



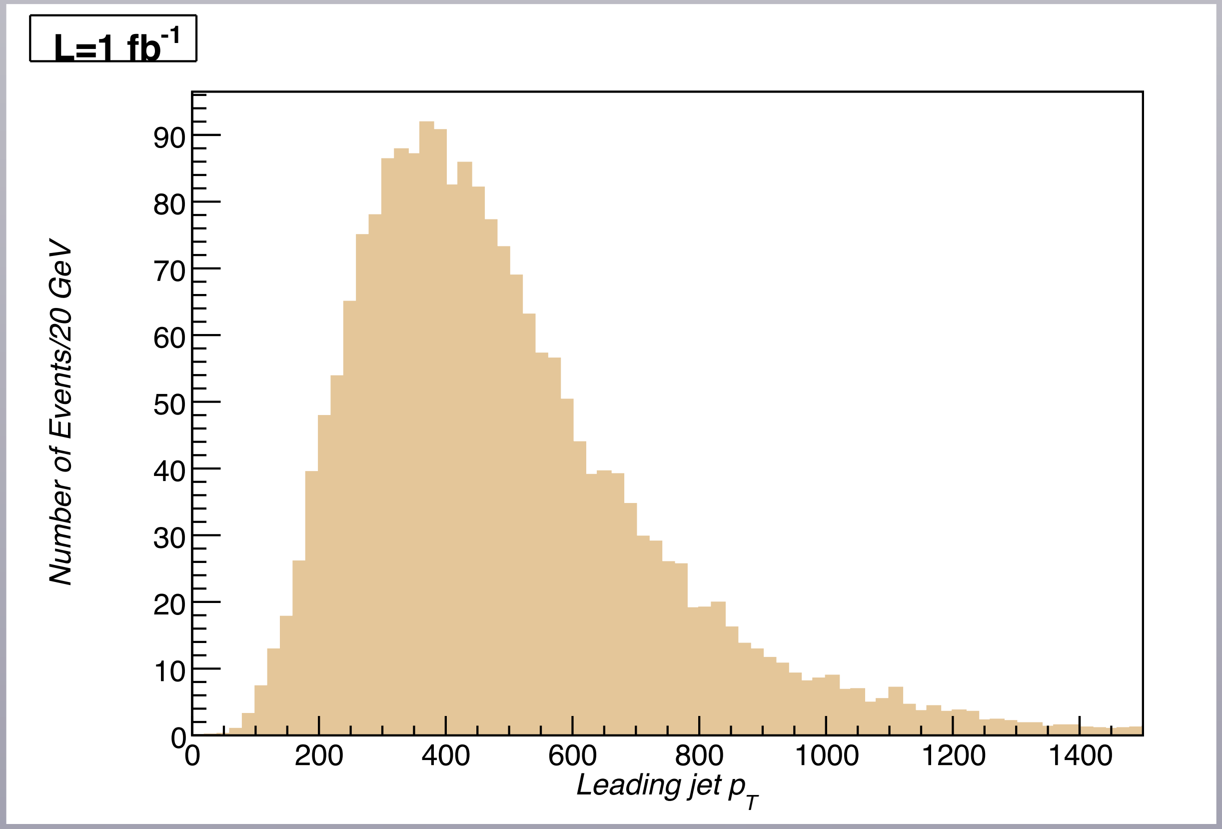
NLO, courtesy of Prospino, 14 TeV

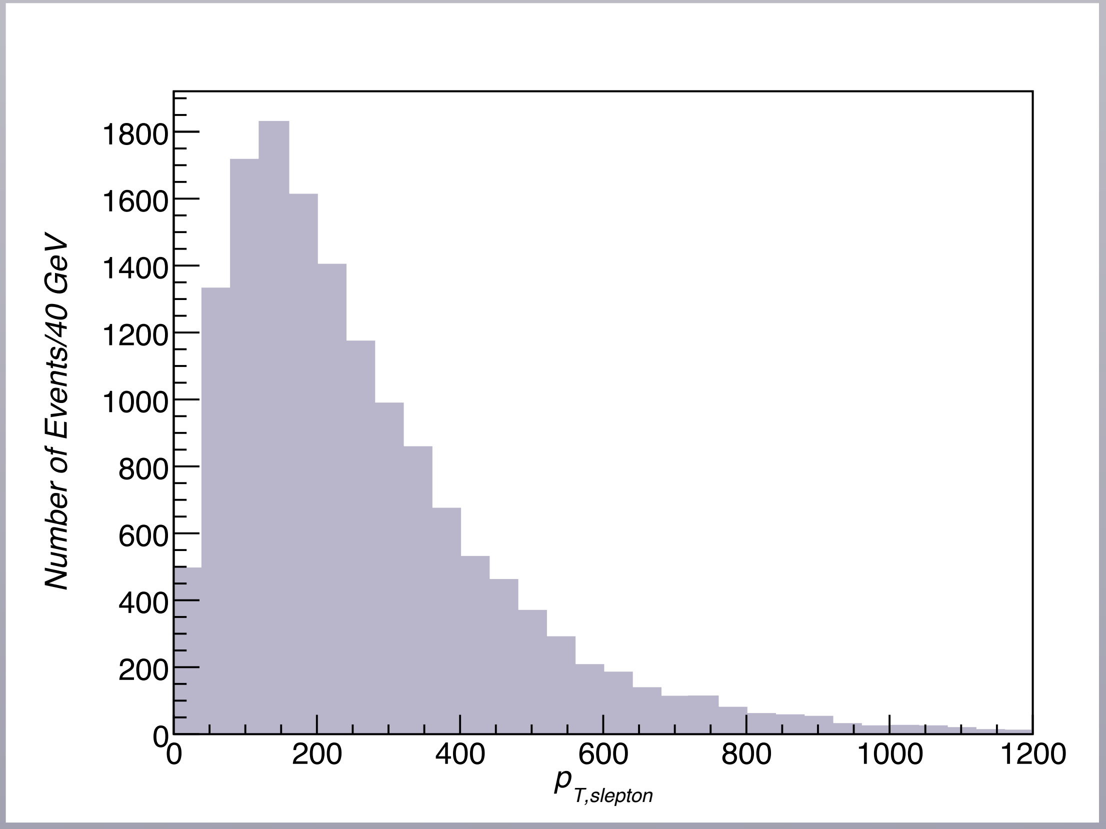
We studied 4-, 5-, and 6-lepton events (2 of which are misidentified sleptons)

Typical cuts:

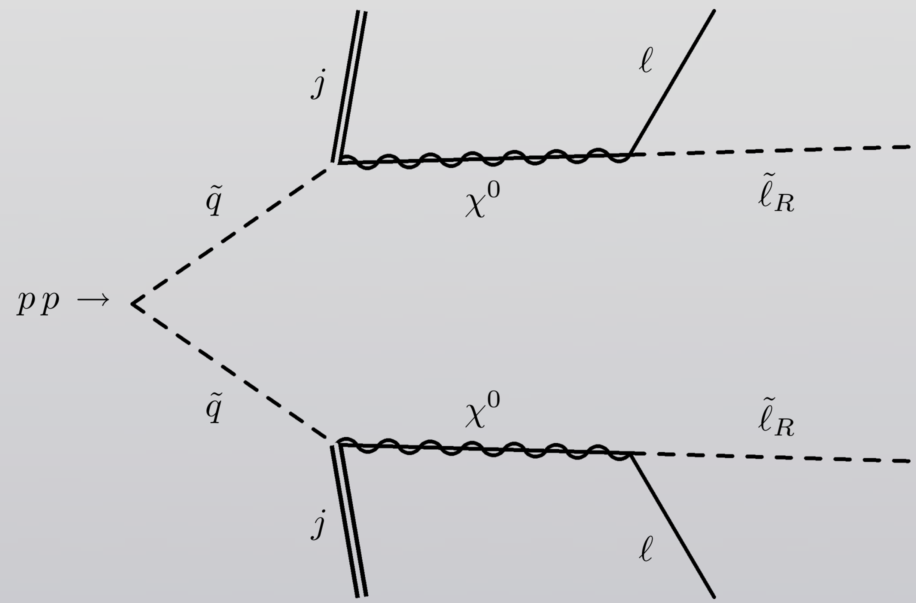
$\mathrm{n}_j \geqslant 2$ with $|\eta| < 2.5,\ p_T > 15$ GeV
and post-PYTHIA isolation cuts $\Delta R_{jj} > 0.4$

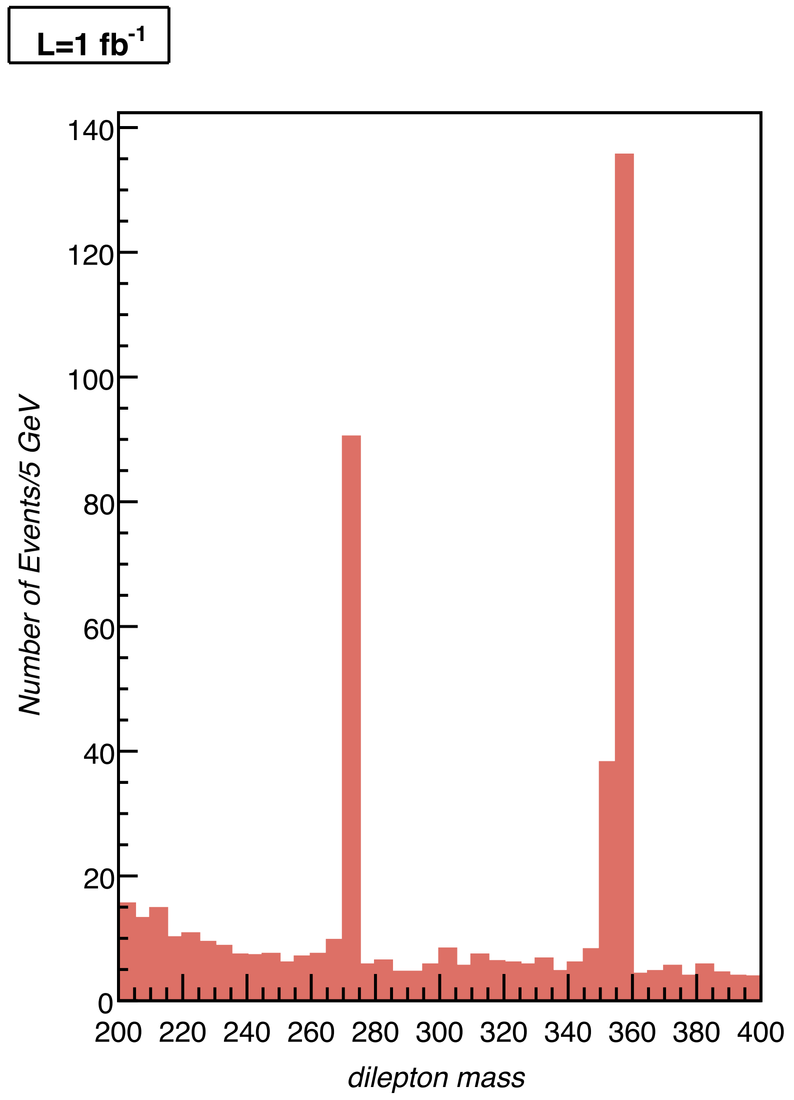
$\mathrm{n}_l = 4, 5, 6$ with $|\eta| < 2.5,\ p_T > 10$ GeV
and parton level isolation cuts $\Delta R_{\ell\ell} > 0.4,\ \Delta R_{\ell j} > 0.4$

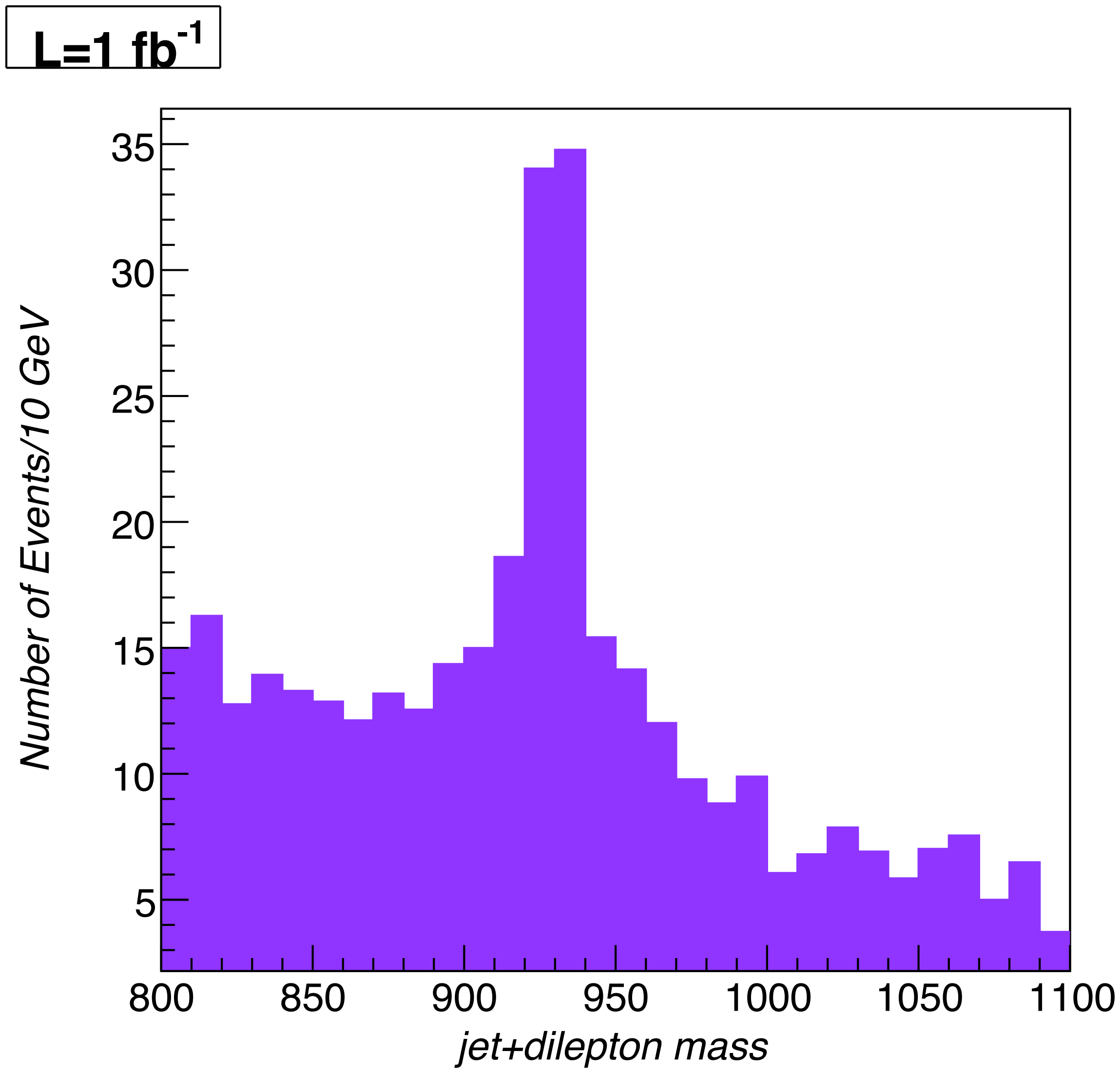




4-lepton channel

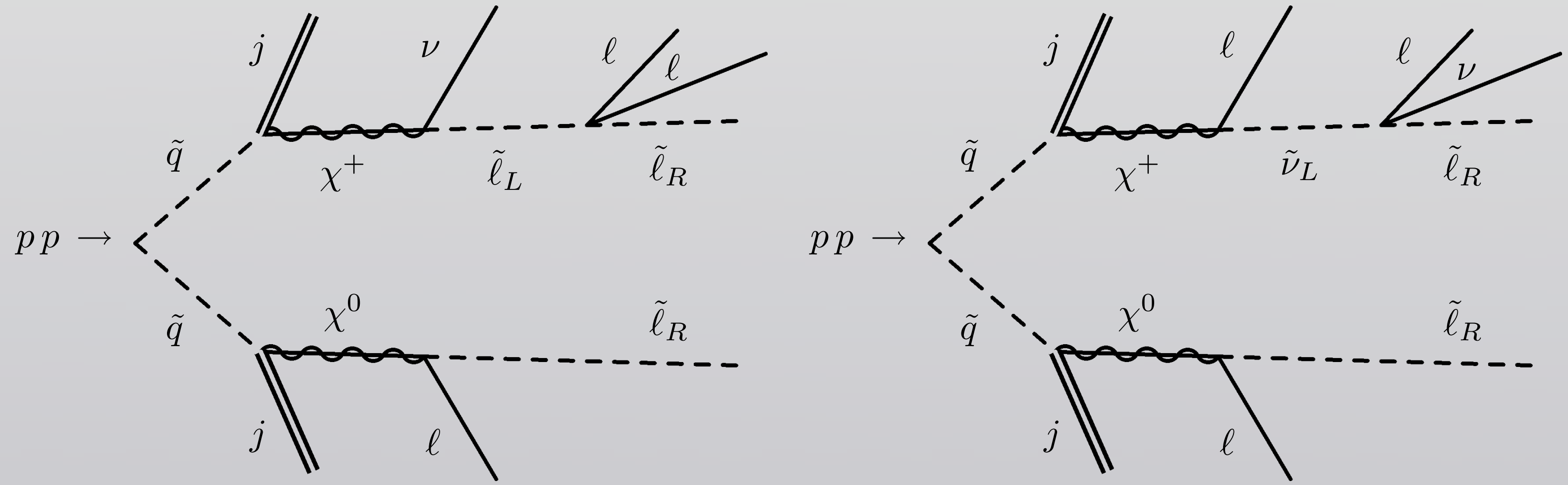


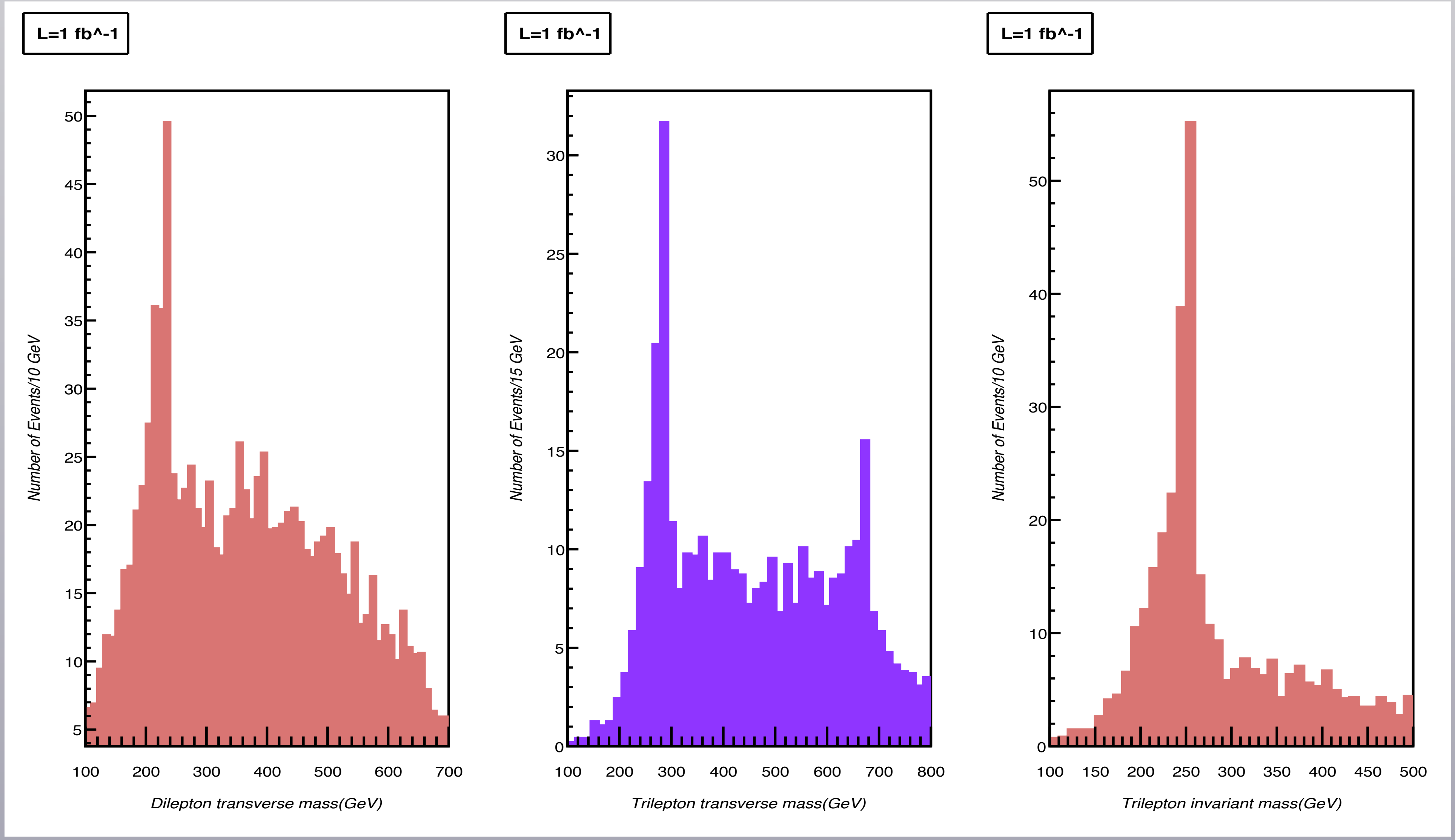




neutralinos and squark masses (14 TeV)

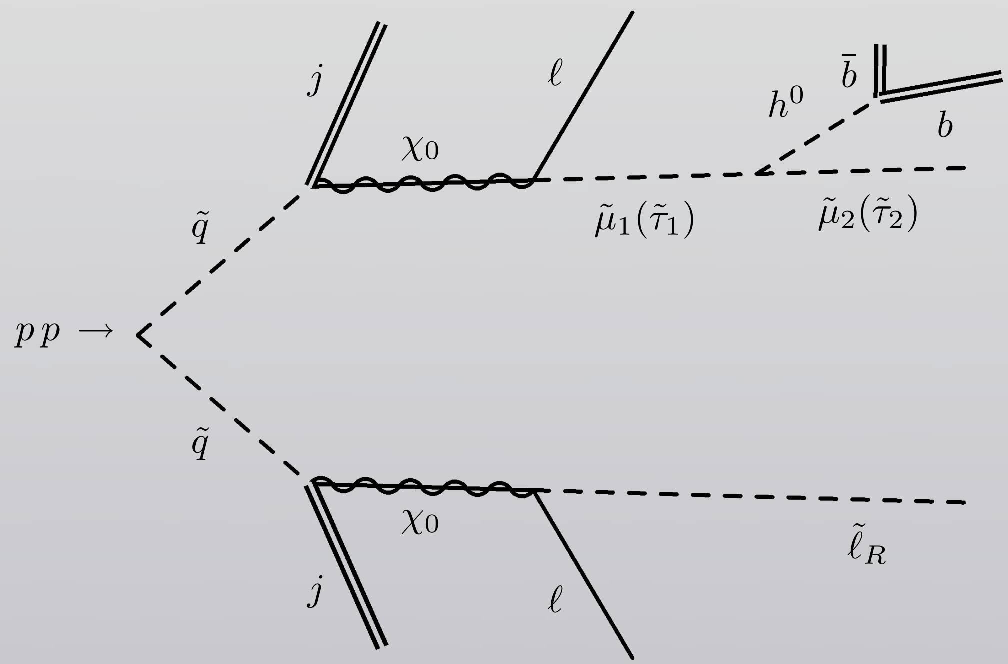
5-lepton channel



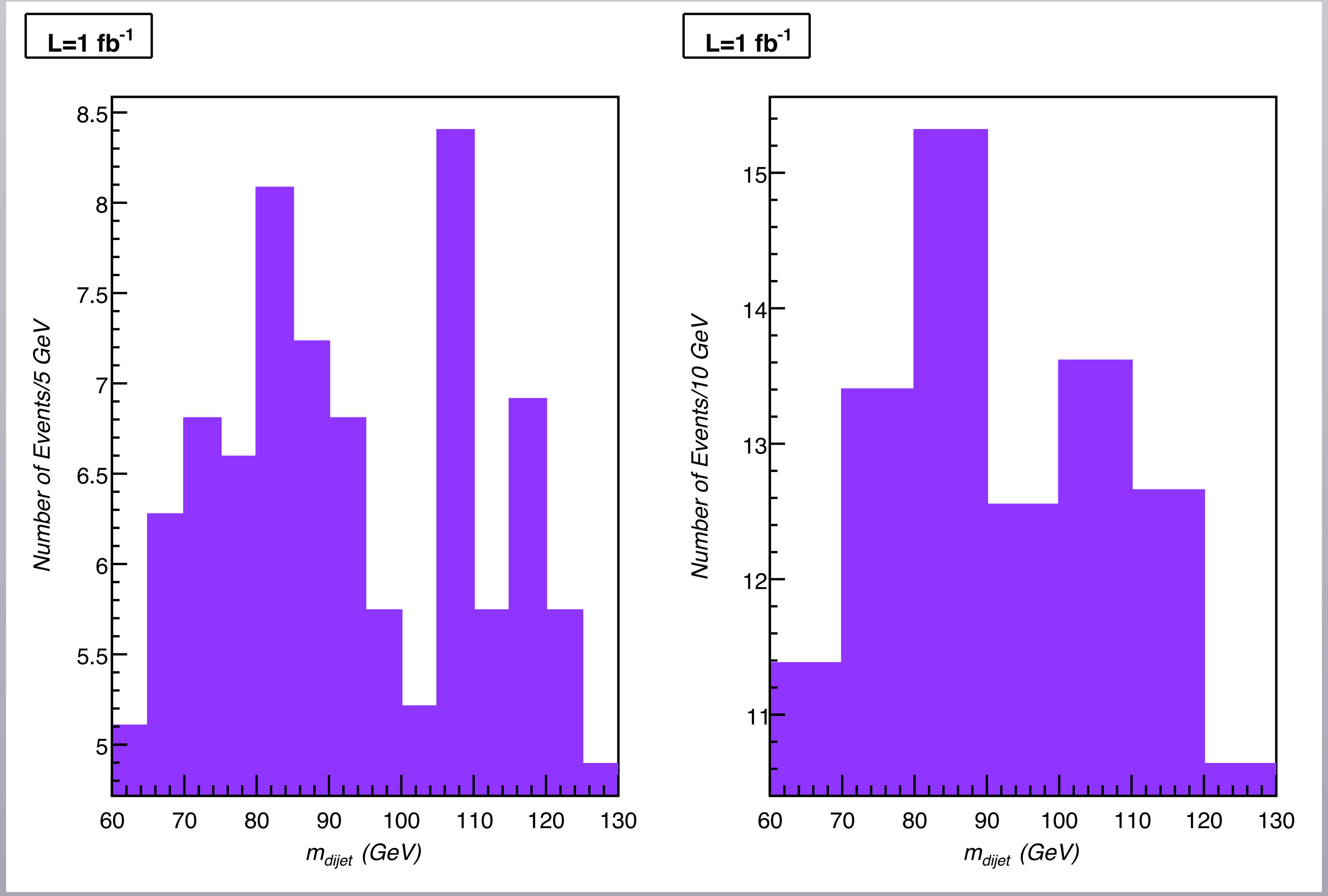


left-handed slepton, sneutrino, and chargino mass determination (14 TeV)

Higgs:



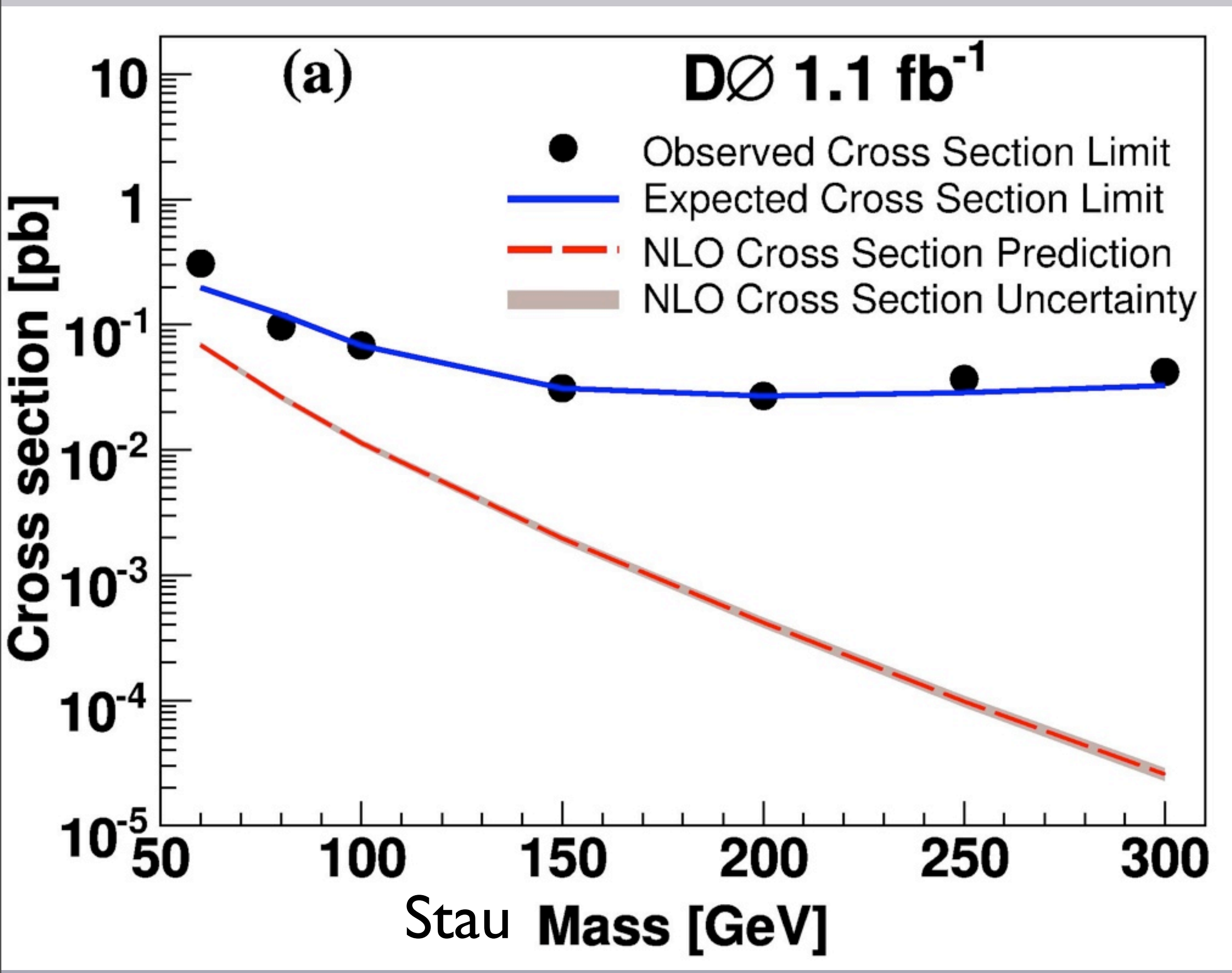
No b-tagging is used. 3rd and 4th most energetic jets are paired.



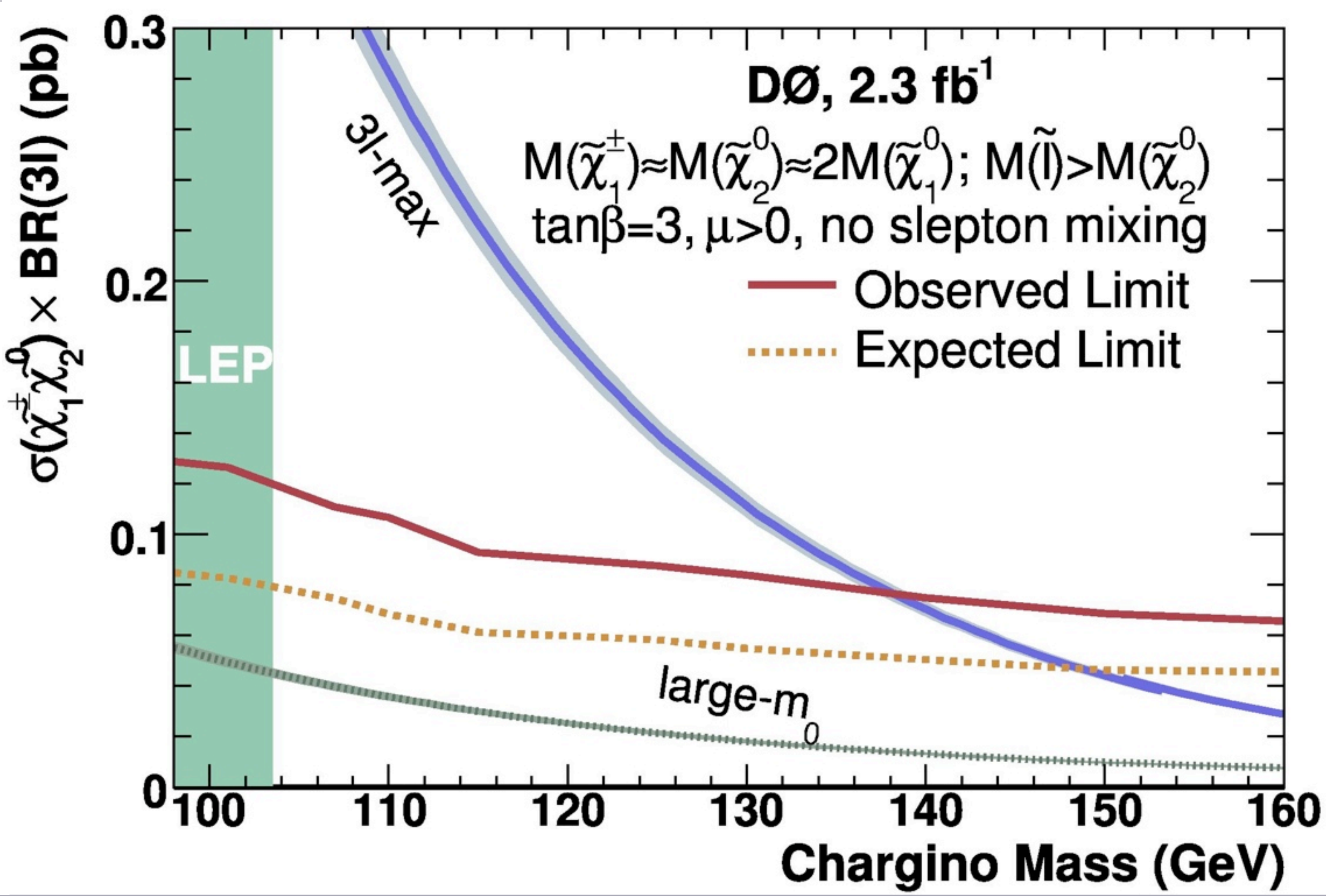
(14 TeV)

What about the Tevatron?

Direct production of right-handed sleptons:



Direct production of charginos:



Scenarios with slepto-SUSY spectra

In most SUSY breaking scenarios,
the squarks are as heavy or heavier than the gluinos and the sleptons as heavy or heavier than the charginos/neutralinos.

In gauge mediation, $\mathrm{m}_{\tilde{g}_i} \propto \frac{\alpha_i}{4\pi}\frac{F}{M}$ $\mathrm{m}^2_{\tilde{f}_i} \propto \left(\frac{\alpha_i}{4\pi}\frac{F}{M}\right)^2$

In any high-scale mediation the same thing happens due to the RG running

$$\frac{d}{d(log\mu)} m^2_{\tilde{f}_i} \propto -\frac{\alpha_i}{4\pi} m^2_{\tilde{g}_i}$$

Gauge mediation with many messengers:

$$m_{\tilde{g}} \propto \frac{\alpha}{4\pi}\frac{F}{M}N_m \qquad m^2_{\tilde{f}} \propto \left(\frac{\alpha}{4\pi}\frac{F}{M}\right)^2 N_m$$

$$m^2_{\tilde{f}} \propto \frac{1}{N_m} m^2_{\tilde{g}}$$

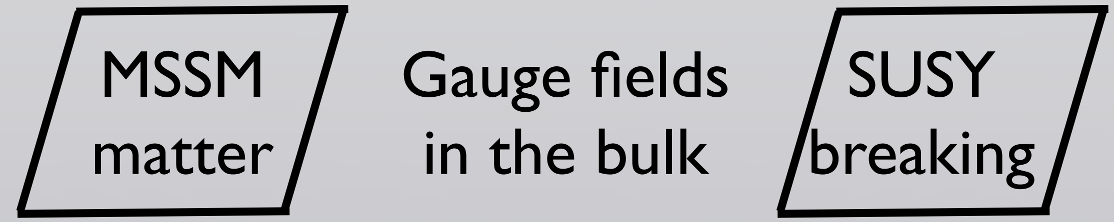
Supersoft breaking:

$$m_{\tilde{g}} \propto \frac{D}{M} \qquad m^2_{\tilde{f}} \propto \frac{D^4}{M^6}$$

Fox, Nelson, Weiner, JHEP 0208 (2002) 035

Gaugino mediation

At a 'high' scale f, matter fields and Higgs have no soft masses



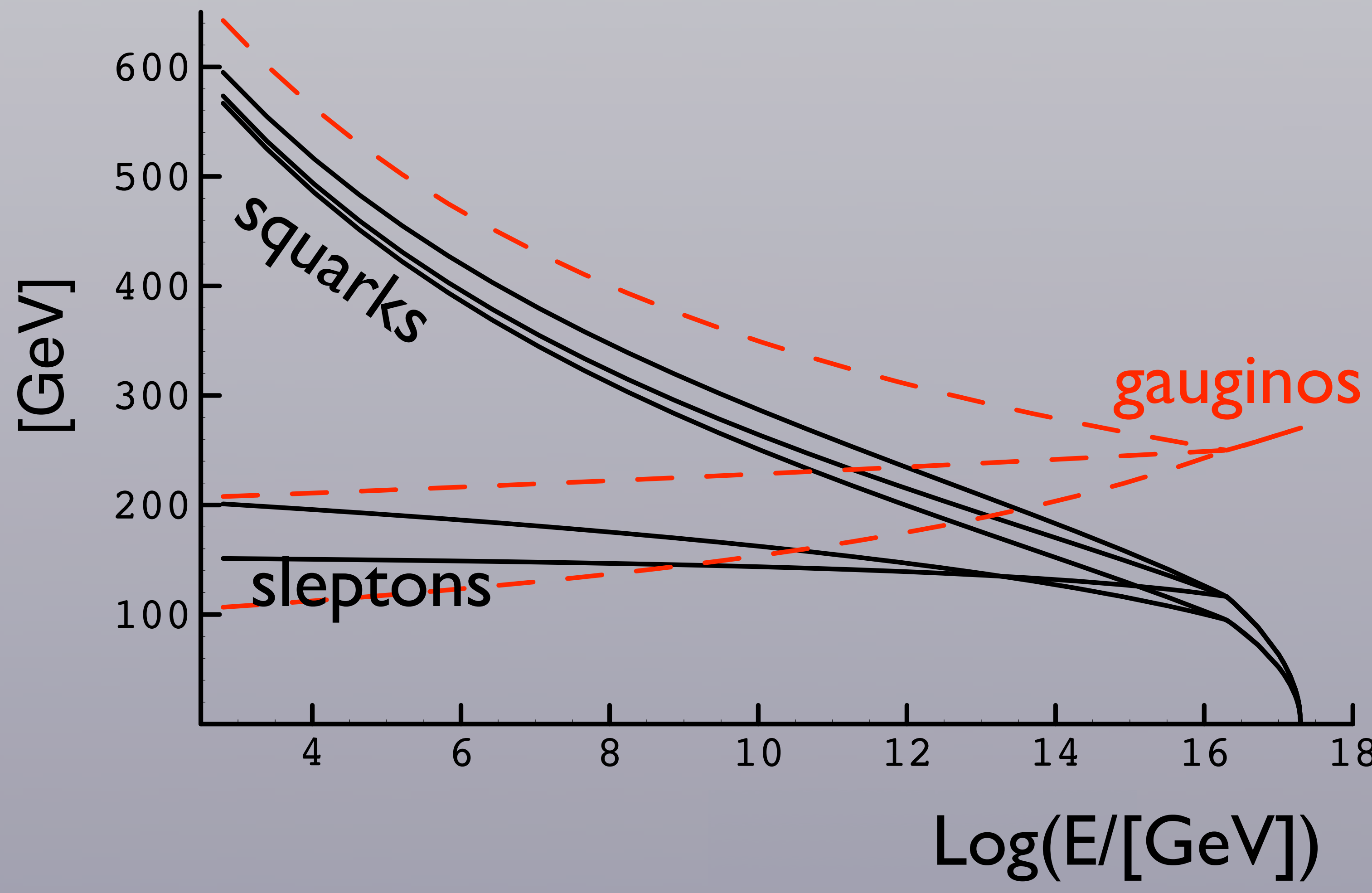
Scalar masses are generated radiatively:

- Threshold contributions at the high scale f
- Running from f to EW scale
- Threshold contributions at the EW scale

Kaplan, Kribs, Schmaltz, PRD62 (2000) 035010; Chacko, Luty, Nelson, Ponton, JHEP0001 (2000) 003

In gaugino mediation the high scale was chosen at, or above, the GUT scale to avoid charged LSP (stau)

Consequently, threshold corrections were neglected as the log running dominates



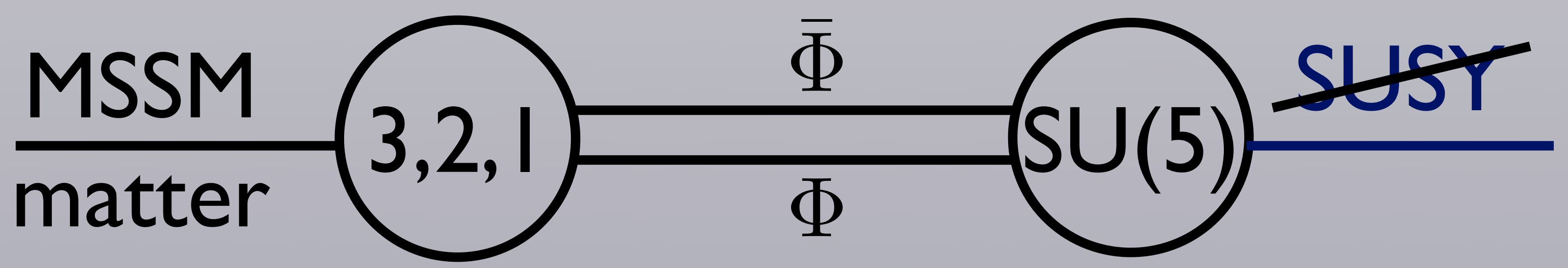
When the gravitino is light the charged LSP disappears.
Log(f/EW) can be small as long as scalar masses are positive.

- Threshold contributions at the high scale f (model dependent)
- Running from f to EW scale (model independent)
- Threshold contributions at the EW scale (model independent)

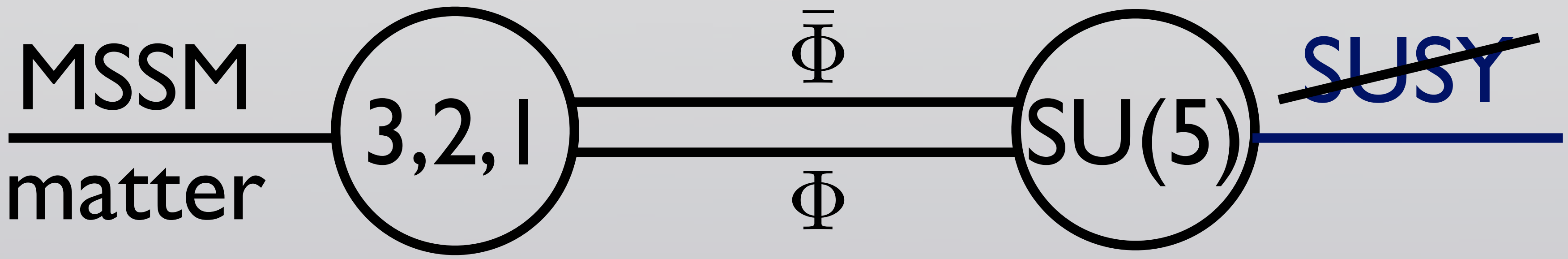
$$m^2_{\tilde{f}_i} \propto \frac{\alpha_i}{4\pi} m^2_{\tilde{g}_i}$$

Our model

- product gauge group [SU(3)xSU(2)xU(1)]xSU(5)
- SUSY breaking communicates only to the SU(5) sector
- MSSM matter transforms under SU(3)xSU(2)xU(1)
- at a few TEV gauge group broken to SU(3)xSU(2)xU(1)

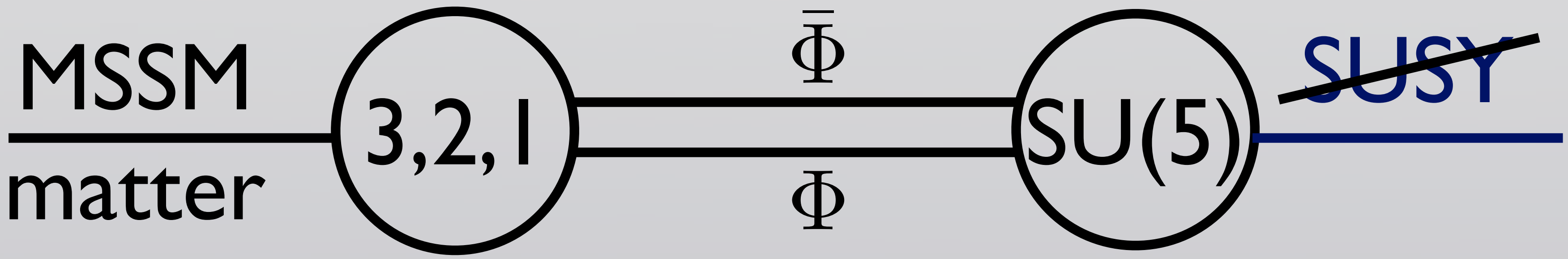


"Deconstructed gaugino mediation," Cheng, Kaplan, Schmaltz, Skiba, PLB 515 (2001) 395
Csaki, Erlich, Grojean, Kribs, PRD 65 (2002) 015003

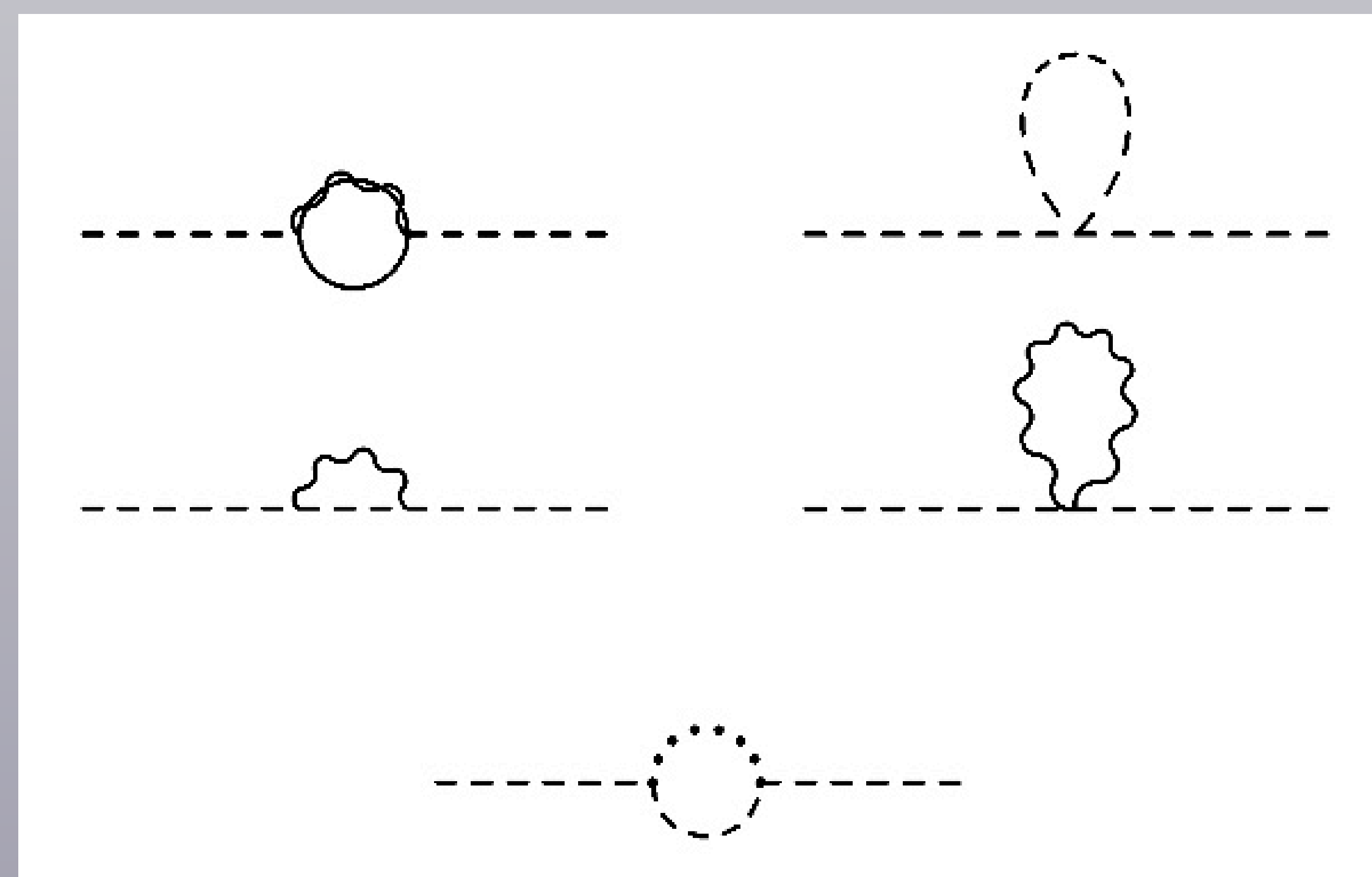


SU(5) gauginos obtain mass from direct coupling to SUSY breaking, for example gauge mediation with the messengers charged under SU(5) only

After the product gauge groups is broken to the SM, $\langle \Phi \rangle = \langle \bar{\Phi} \rangle = f$, the MSSM gauginos acquire soft masses.

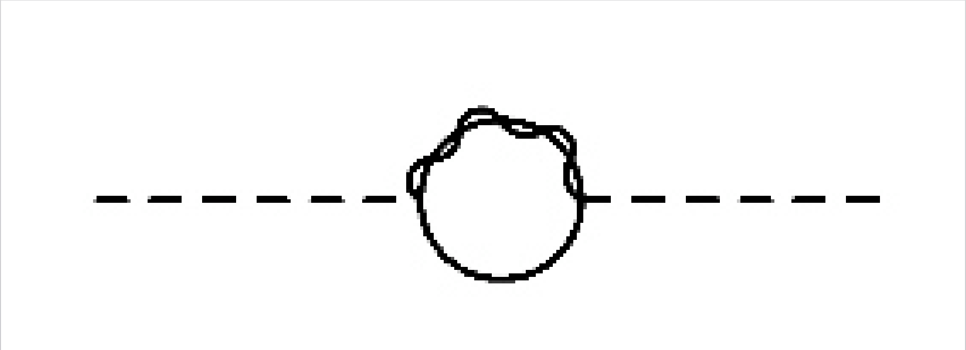


SUSY-breaking terms for
- the gauginos and
- the link fields



MSSM matter fields obtain soft masses at one loop

In practice, this calculation is a lot more complicated than what meets the eye

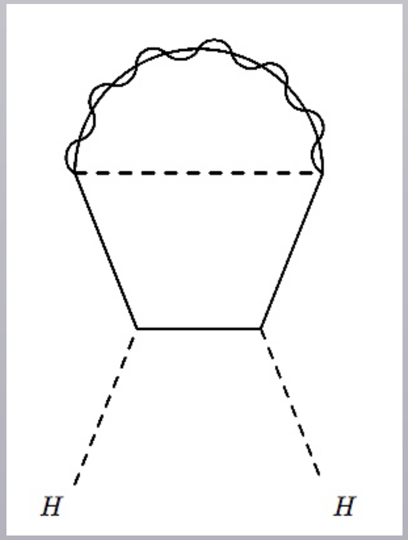


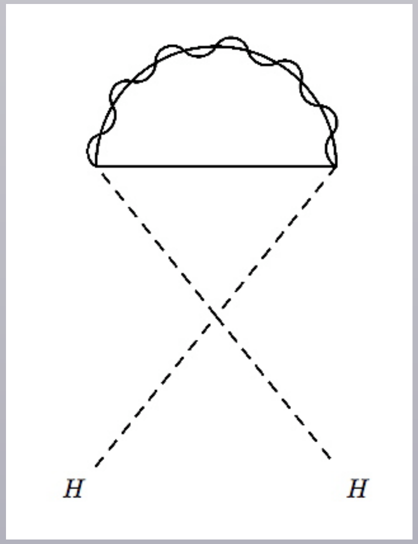
There are three adjoint fermions that run in the loop: two gauginos from the two gauge group and one fermion from the link field that has a Dirac mass with one of the gauginos.

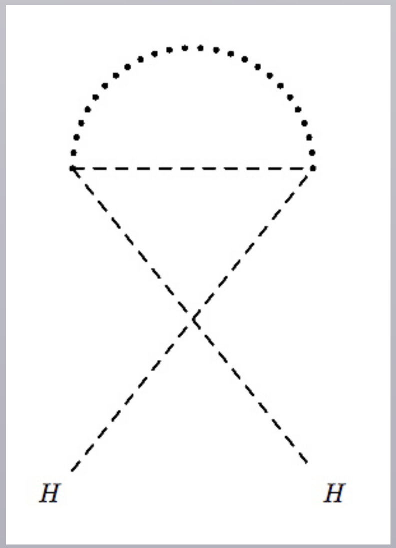
$$\Omega = \begin{pmatrix} 0 & 0 & g_A\sqrt{2}f \\ 0 & m_B & -g_B\sqrt{2}f \\ g_A\sqrt{2}f & -g_B\sqrt{2}f & 0 \end{pmatrix}$$

Breaking of SU(2)xU(1)?

- Higgs doublets get positive mass from the one loop diagrams, just like the matter fields do
- In high scale models, up-type Higgs gets a negative mass from the top-Yukawa contribution to the RG equations
- Radiative breaking happens in our model as well:







Why would 2 loops dominate over one loop?

- large Yukawa, color factors, SU(3) coupling

Addition contribution to the Higgs mass

There are two gauge groups, each with its own D terms.
In the absence of SUSY breaking the D-term for the diagonal (unbroken) group is governed by its coupling constant.

This is not the case with when SUSY is broken:

$$V_D = \frac{g_2^2(1+\Delta_2)}{8}\left|H_u^\dagger\sigma^a H_u + H_d^\dagger\sigma^a H_d\right|^2 + \frac{\frac{3}{5}g_1^2(1+\Delta_1)}{8}\left|H_u^\dagger H_u - H_d^\dagger H_d\right|^2$$

where $$\Delta_i = \frac{s_i^2}{c_i^2}\frac{2m_\Phi^2}{M_i^2+2m_\Phi^2}$$

Free parameters:

f - vev of the link fields

g_B - SU(5) gauge coupling

m_B - soft mass for the SU(5) gaugino

m_Φ - soft mass of the link field

μ, B_μ- traded for Higgs vev and $\tan\beta$

		mass
inputs:	f	5000
	m_B	5000
	$m_{\tilde{\Phi}}$	5000
	$\tan\beta$	8
	g_{A_3}/g_B	0.8
heavy gauge bosons:	M_3	15400
	M_2	12970
	M_1	12500
gluino:	m_3	1904
neutralinos:	$m_{\chi_1^0}$	232
	$m_{\chi_2^0}$	253
	$m_{\chi_3^0}$	383
	$m_{\chi_4^0}$	706
charginos:	$m_{\chi_1^\pm}$	243
	$m_{\chi_2^\pm}$	706
Higgs:	m_{h^0}	116
	m_{H^0}	324
	m_A	324
	$m_{H^\pm}$	334
	μ	249
	$\sqrt{B_\mu}$	114
sleptons:	$m_{\tilde{e}_R}$	102
	$m_{\tilde{e}_L}$	218
	$m_{\tilde{\nu}_L}$	203
squarks:	$m_{\tilde{u}_L}$	934
	$m_{\tilde{u}_R}$	914
	$m_{\tilde{d}_L}$	938
	$m_{\tilde{d}_R}$	913

Constraints: precision electroweak, cosmology

Precision electroweak observables are affected by heavy gauge bosons and an SU(2) triplet from the link fields.
All of these are much too heavy to be seriously constrained.

One needs to avoid overclosing of the universe by the LSP, and spoiling the successful predictions of the BBN by NLSP decays.
BBN: $\tau_{\mathrm{NLSP}} \lesssim 5 \times 10^3$ that translates to $m_{3/2} \lesssim 1\ \mathrm{GeV}$
Relic density: $m_{3/2} \lesssim 1\ \mathrm{keV}$, but larger values possible if gravitino abundance is diluted by late entropy production.

Open questions

- Solution to the μ/B_μ problem?
- A dynamical mechanism for generating the link field vevs perhaps tied to SUSY breaking
- Gauge coupling unification?
- More detailed phenomenology. Comparison with other models such as gauge mediation with a large number of messengers, scenarios with Dirac gaugino masses.

Open questions

- What happens for different lepto-SUSY spectra?
- Better kinematic variables for channels with missing energy
- Can one measure the bottom Yukawa coupling?
- Better use of the lepton (misidentified slepton) flavor information

Conclusions

- There are still well-motivated yet unexplored regions of the MSSM parameter space with distinct and interesting signatures.
- Statistically significant excesses in every lepton channel with 200 pb^-1 at 10 TeV (with 1 TeV squarks)
- Reconstruction of a significant portion of the MSSM spectrum possible with 1 fb^-1 at 14 TeV

the end