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Leptogenic Supersymmetry

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Based on arXiv:0903.5305
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OUTLINE

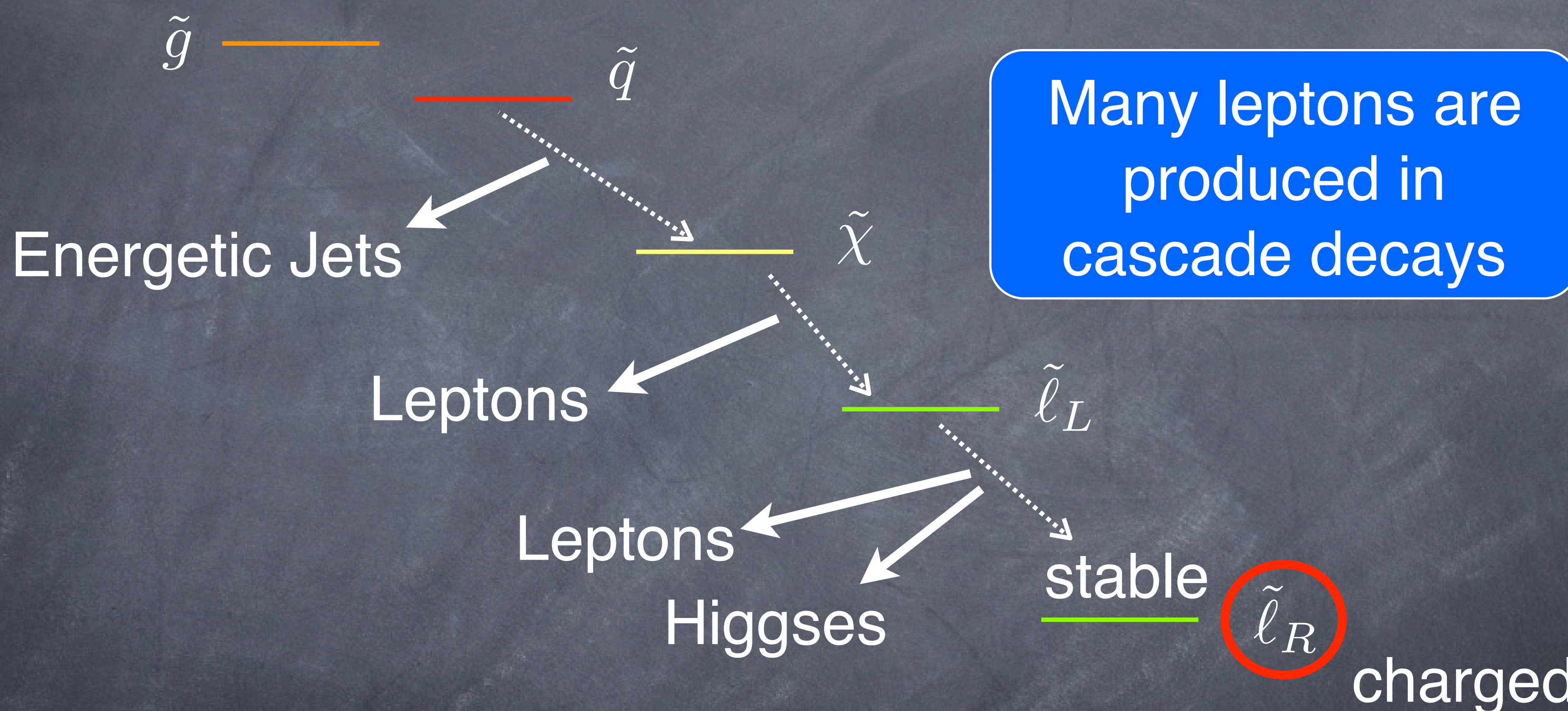
- What is Lepto-SUSY?
- Main Features
- Phenomenology. Channels with:
  - 4 leptons
  - Higgs

WHAT IS LEPTO-SUSY?

- Yet another SUSY model? No...
- A particular *ordering* of the SUSY spectrum.
- Not interested in how the hierarchy of masses gets generated at high energies.
- Look at what LHC can access.
  Striking and unusual collider signatures.

WHAT DOES “LEPTOGENIC” MEAN?

Leptogenic spectrum:



$$m_{\tilde{g}}, m_{\tilde{q}} > m_{\tilde{\chi}^0}, m_{\tilde{\chi}^\pm} > m_{\tilde{\ell}_L} > m_h, m_{\tilde{\ell}_R}$$

SOME FEATURES

- Gauginos heavier than scalars.

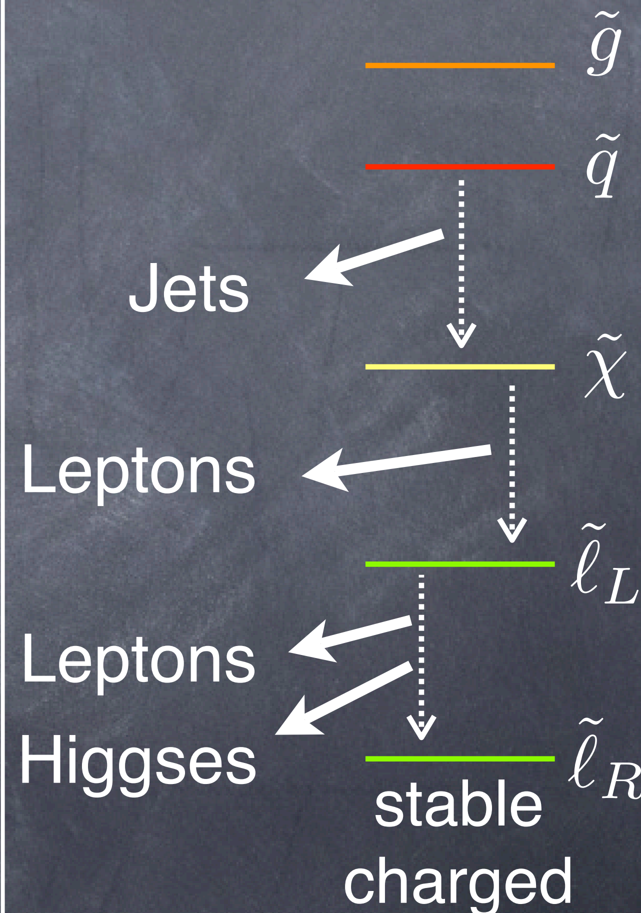
- All sleptons lie at the bottom.
The decay chains pass through $\tilde{\ell}_L$, $\tilde{\ell}_R$ and produce many leptons.

- $\tilde{\ell}_R$ NLSP : long-lived, collider stable.
No significant missing energy!

  (SUSY models with neutralino LSP, give large $\not{E}_T$).

- Gravitino LSP, no role at colliders.

Lepto-SUSY spectrum



SOME FEATURES

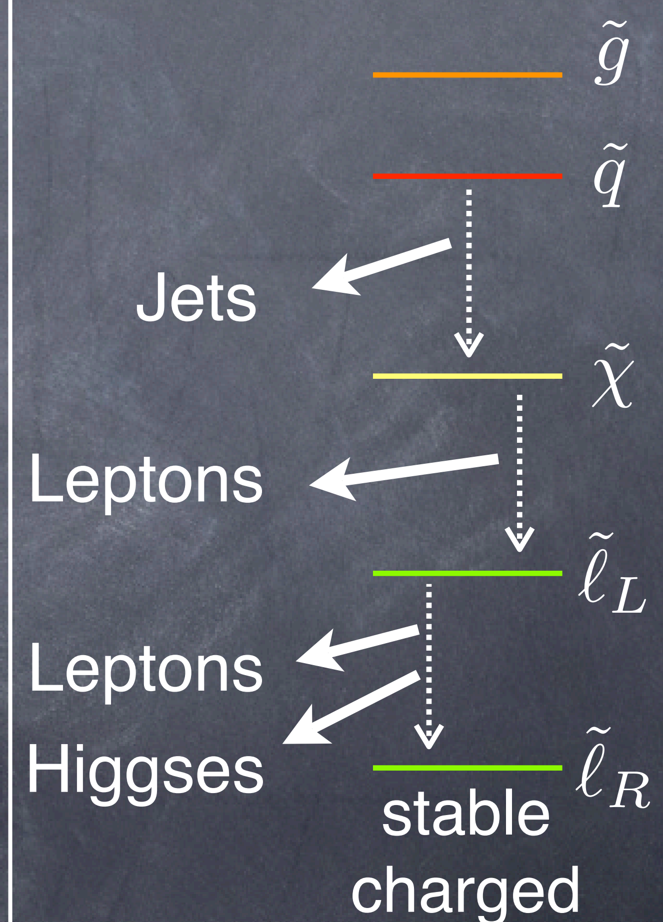
- Higgs is produced in slepton decays. $h \to b\bar{b}$: important channel.

- Several classes of models give rise to a Lepto-SUSY spectrum

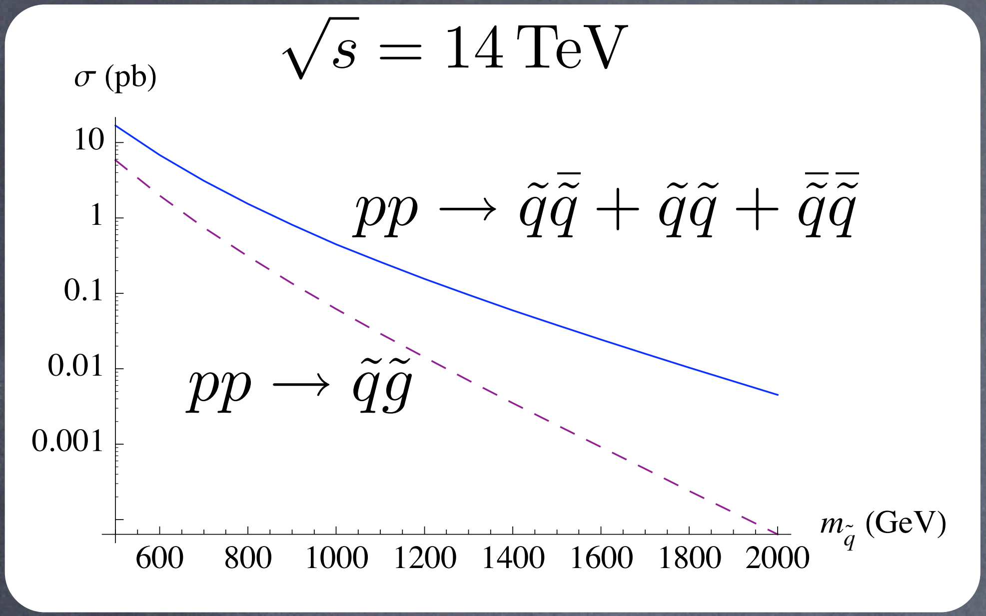
  (GMSB with large Nmess, Gaugino mediation at low-scale, AMSB ...)

- ...or just the MSSM in a region of its parameter space

Lepto-SUSY spectrum

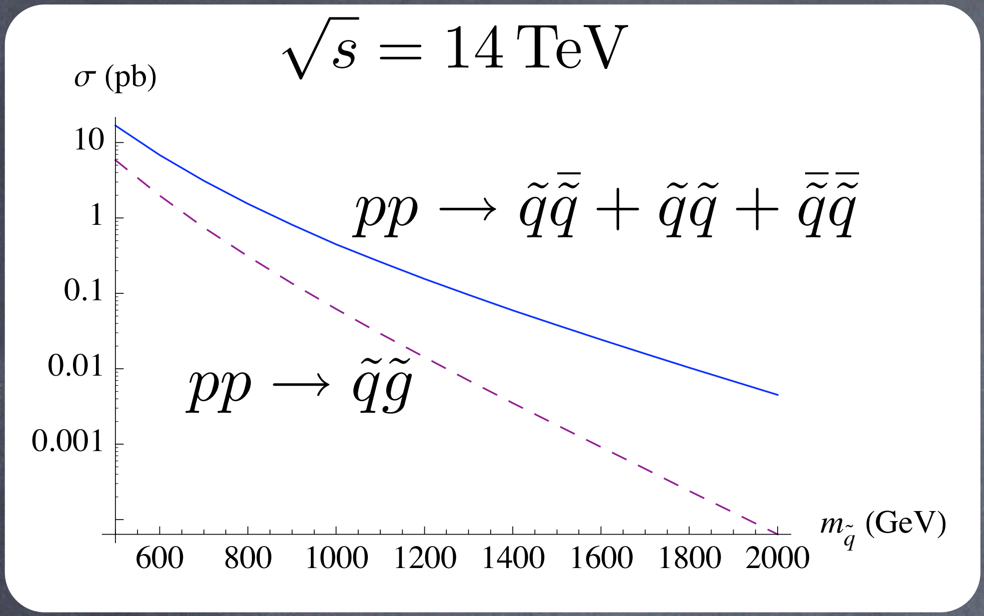


PRODUCTION AND DECAY

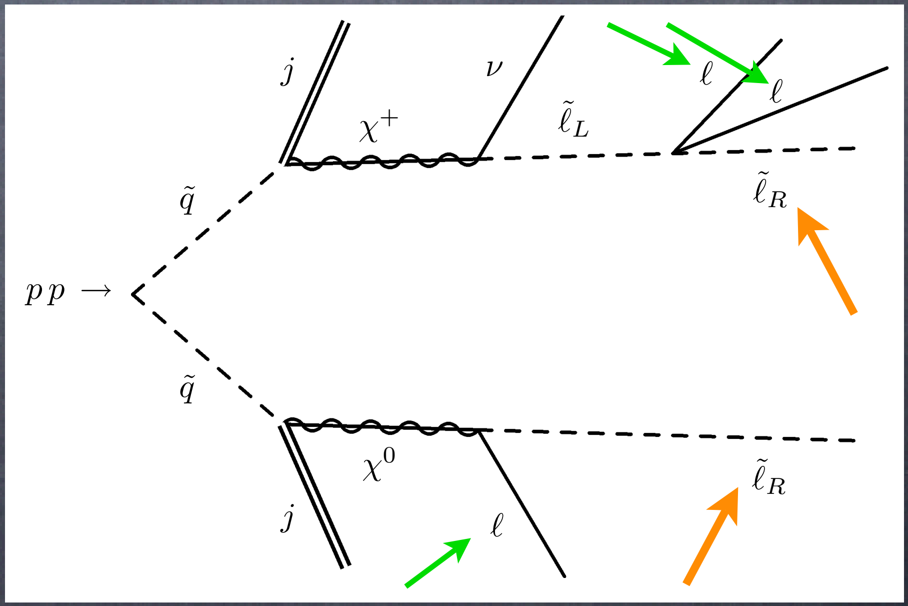


- Strong production cross-section.
- Squark-pair production is the dominant process.

PRODUCTION AND DECAY



- Strong production cross-section.
- Squark-pair production is the dominant process.
- Typical final state of squark cascade decays:
  2 jets + (2,3,4) leptons +
  2 stable charged tracks
- No significant missing energy.



BENCHMARK POINTS

Lepto-SUSY is not in ATLAS/CMS benchmark points!

- LS1: squark masses ~ 1 TeV
- LS2: squark masses ~ 520-700 GeV

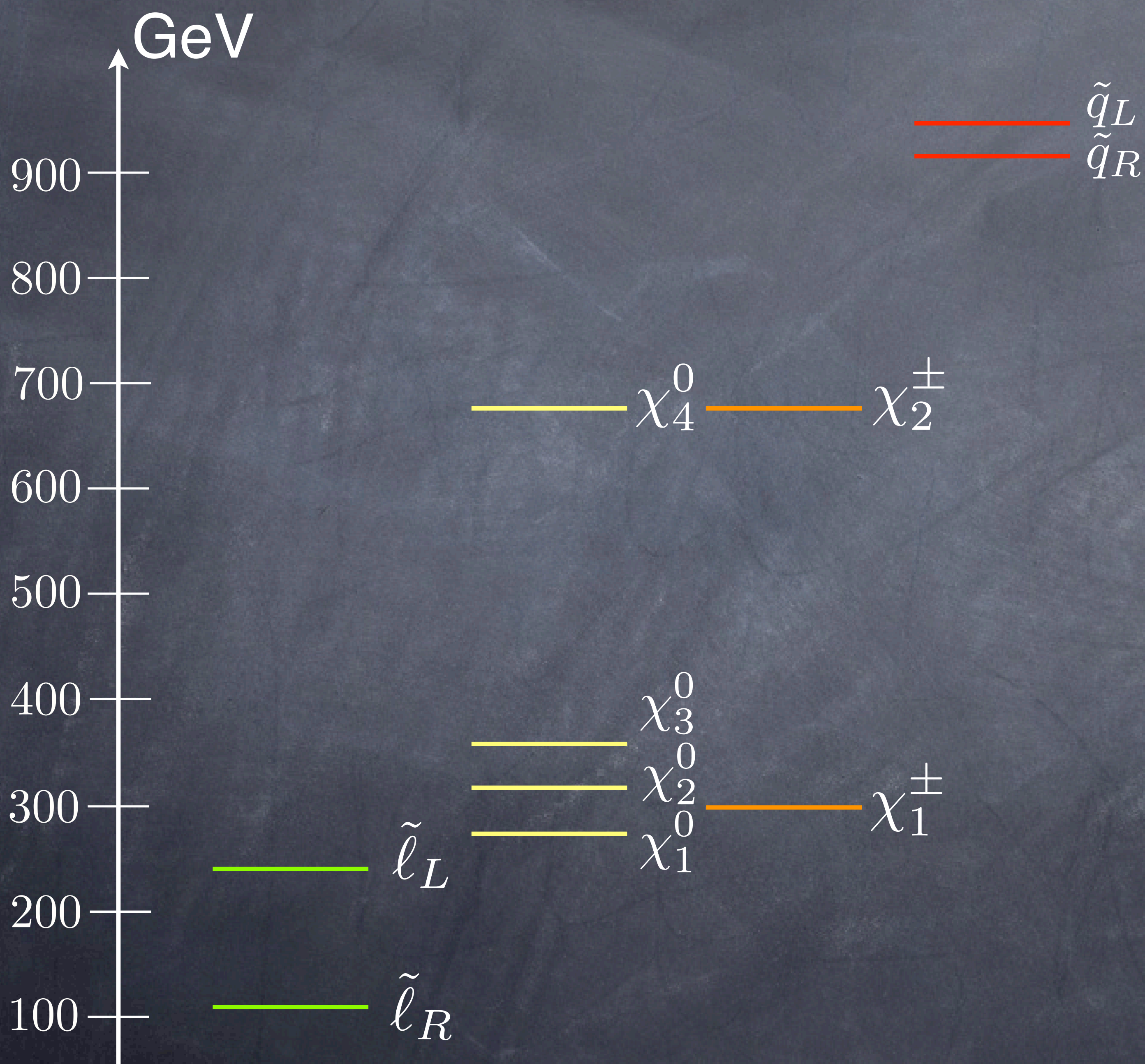
sleptons ~ 110 GeV

Higgs ~ 115 GeV

Production cross-section (fb)

	10 TeV	14 TeV
LS1	680	2170
LS2	5040	13700

BENCHMARK POINT "LS1"

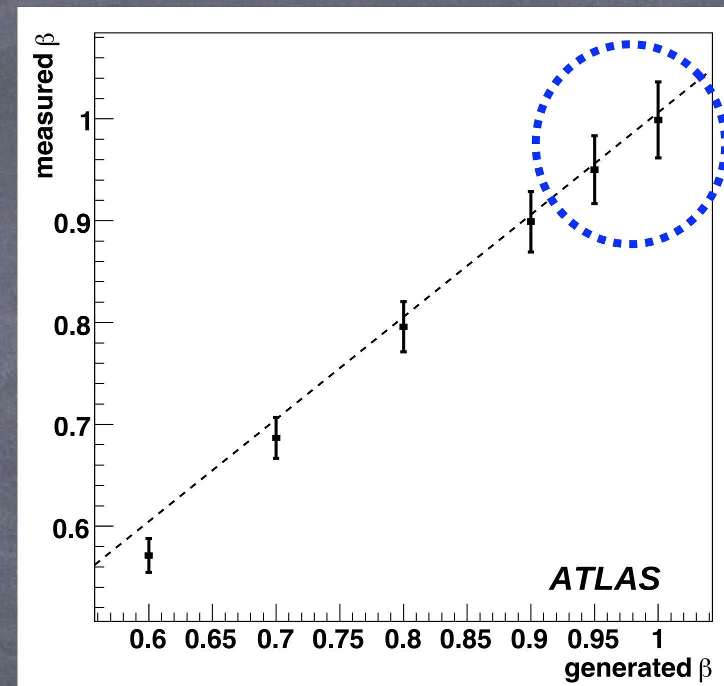


		mass (GeV)
gluino:	$m_{\tilde{g}}$	1938
neutralinos:	$m_{\chi_1^0}$	271
	$m_{\chi_2^0}$	302
	$m_{\chi_3^0}$	353
	$m_{\chi_4^0}$	676
charginos:	$m_{\chi_1^\pm}$	291
	$m_{\chi_2^\pm}$	676
Higgs:	m_{h^0}	115
	m_{H^0}	379
	m_A	379
	$m_{H^\pm}$	387
	μ	294
	$\sqrt{B_\mu}$	119
sleptons:	$m_{\tilde{\ell}_R}$	108
	$m_{\tilde{\ell}_L}$	248
	$m_{\tilde{\nu}}$	236
	$m_{\tilde{\tau}_1}$	106
	$m_{\tilde{\tau}_2}$	249
squarks:	$m_{\tilde{u}_L}$	949
	$m_{\tilde{u}_R}$	920
	$m_{\tilde{d}_L}$	952
	$m_{\tilde{d}_R}$	919
	$m_{\tilde{t}_1}$	920
	$m_{\tilde{t}_2}$	962

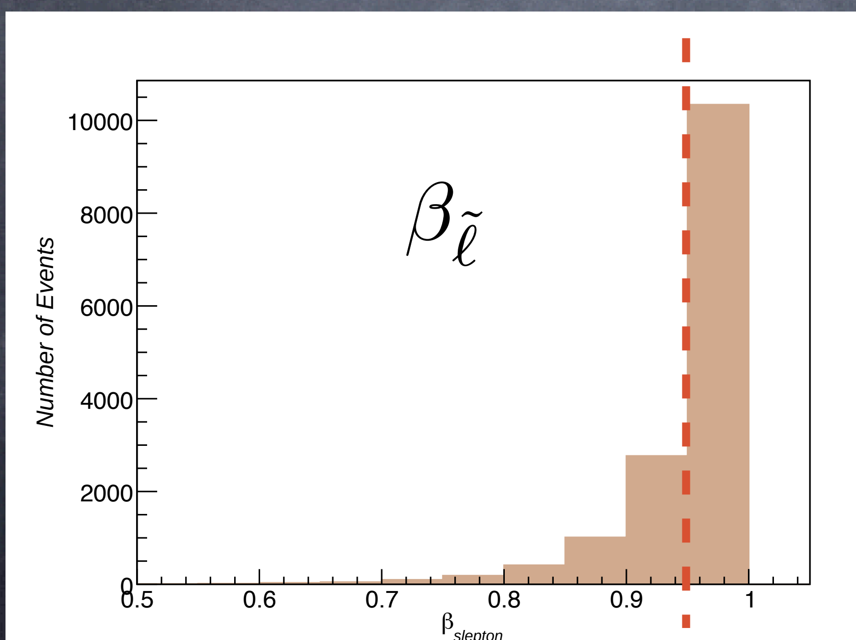
SLEPTONS OR MUONS?

Long-lived sleptons hits like muons with lower β

Fast sleptons ($\beta > 0.9$) misidentified as muons



[ATLAS TDR 2008]



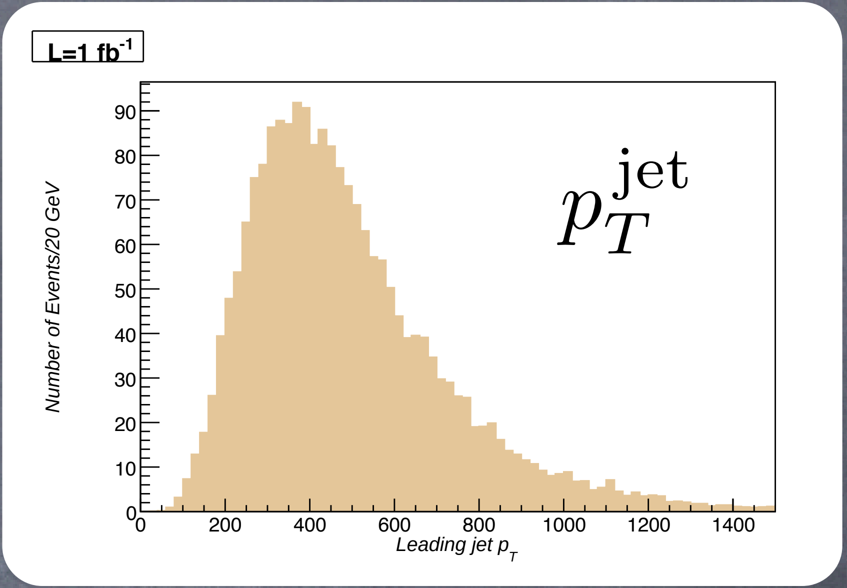
Many sleptons are very fast in the signal

CHANNELS

Focus on channels with:

– 2 hard jets

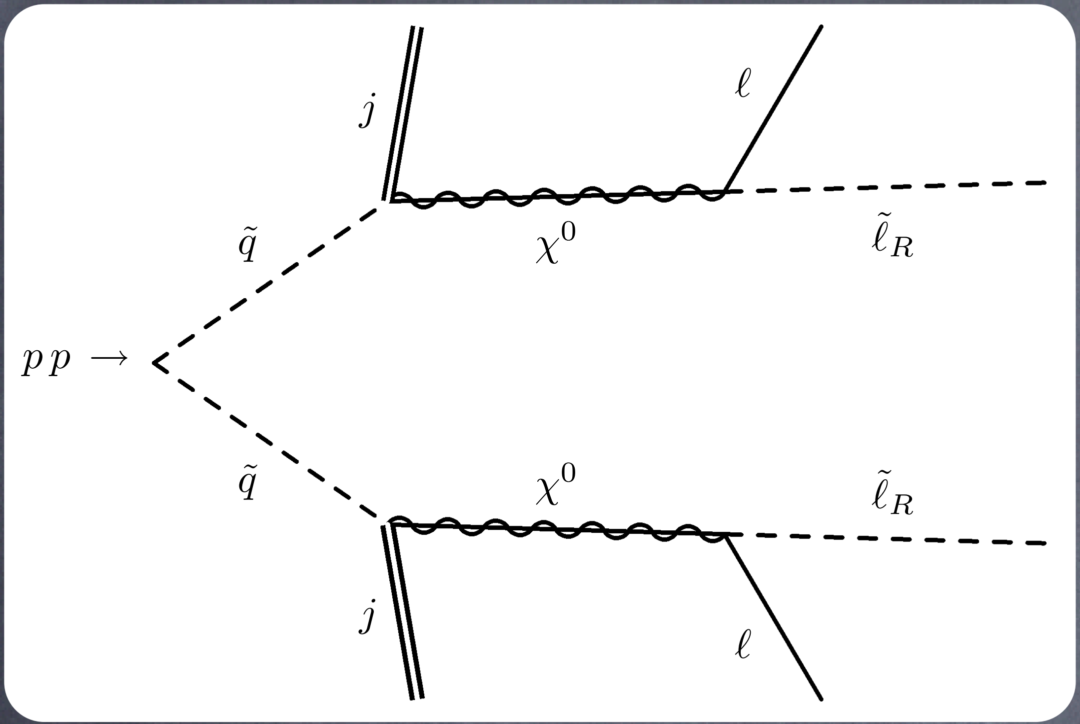
– $\geq$ 4 lepton-like particles (leptons or stable sleptons)



New channels for SUSY searches!

- Almost background-free.
- Statistically significant excesses of events already at low luminosity ($\leq$ 1 fb^{-1}).
- Mass reconstruction of several sparticle states.
- Higgs can be discovered in the $h \to b\bar{b}$ mode.

4-LEPTONS CHANNEL



seen as muons

Event selection:

$n_\ell = 4$ (including sleptons)

$n_{\rm jet} \geq 2$

with standard cuts

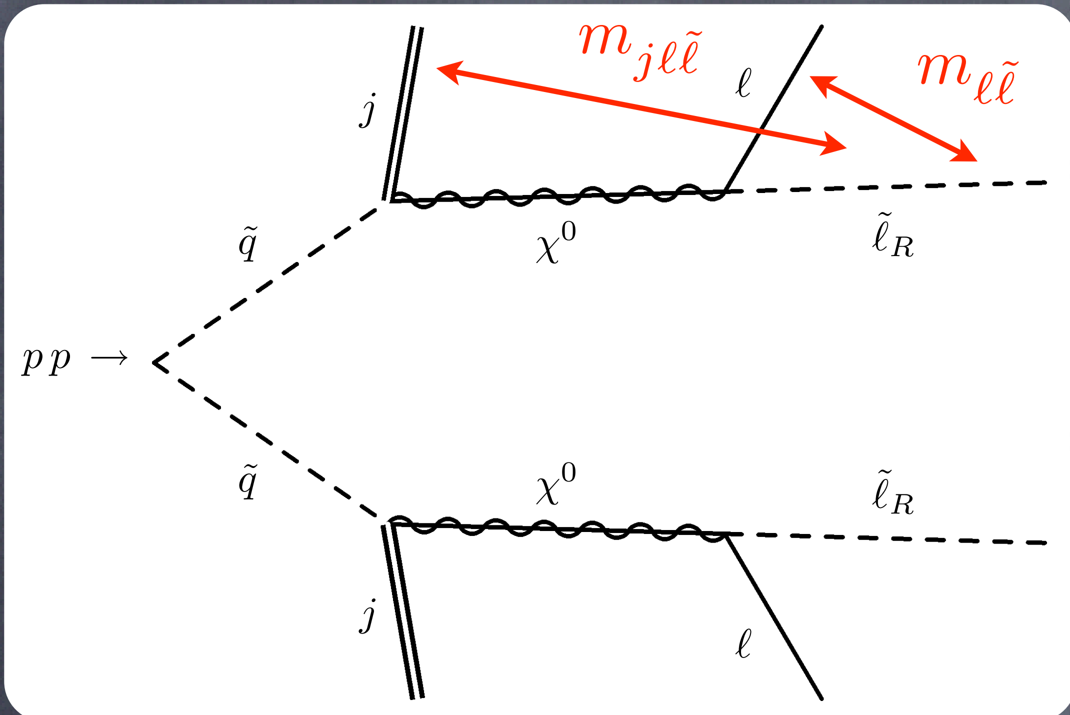
$$|\eta_{\rm jet}| < 2.5\,, \qquad |\eta_\ell| < 2.5$$

$$p_T^{\rm jet} > 15\,{\rm GeV}\,, \quad p_T^\ell > 10\,{\rm GeV}$$

$$\Delta R_{{\rm jj},\ell\ell,\ell{\rm j}} > 0.4$$

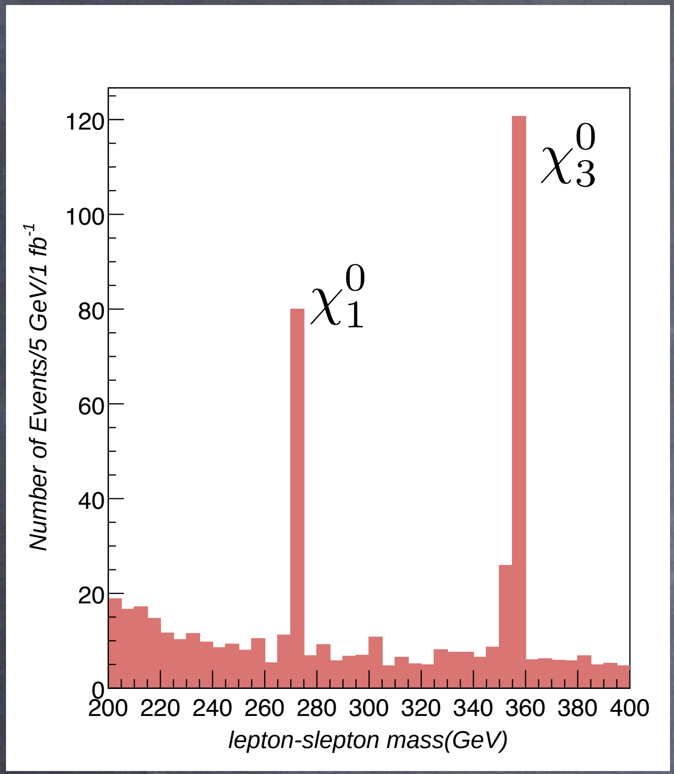
	10 TeV	14 TeV
σ (fb)	220	690
Events at 0.2 fb^{-1}	45	140

4-LEPTONS CHANNEL

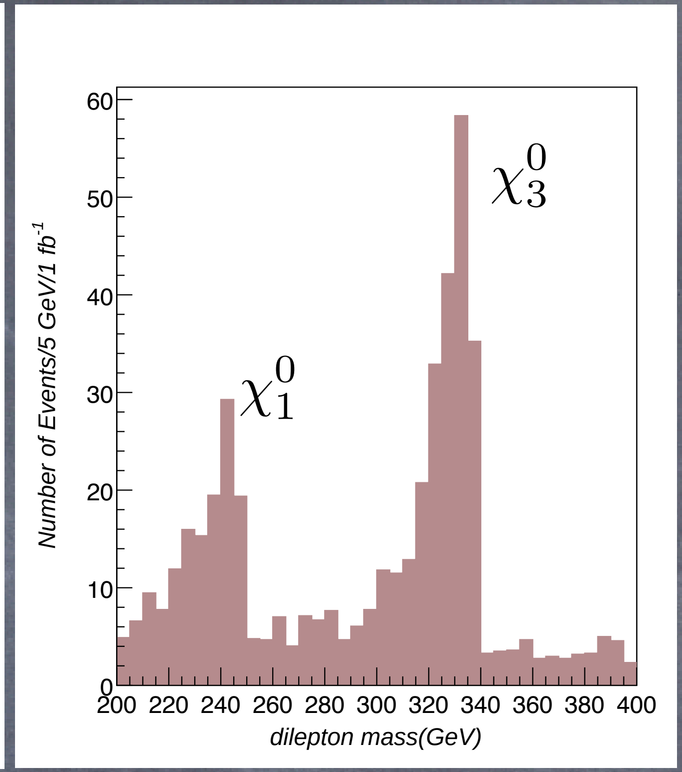


- It allows $\chi_1^0, \chi_3^0, \tilde{q}$ mass reconstruction.
- Channel with no MET. No MET cut imposed.
- Hard cuts on the p_T of the leading jet can be applied and suppress the BG efficiently.
- All SM BGs are below 1 fb.

4-LEPTONS CHANNEL



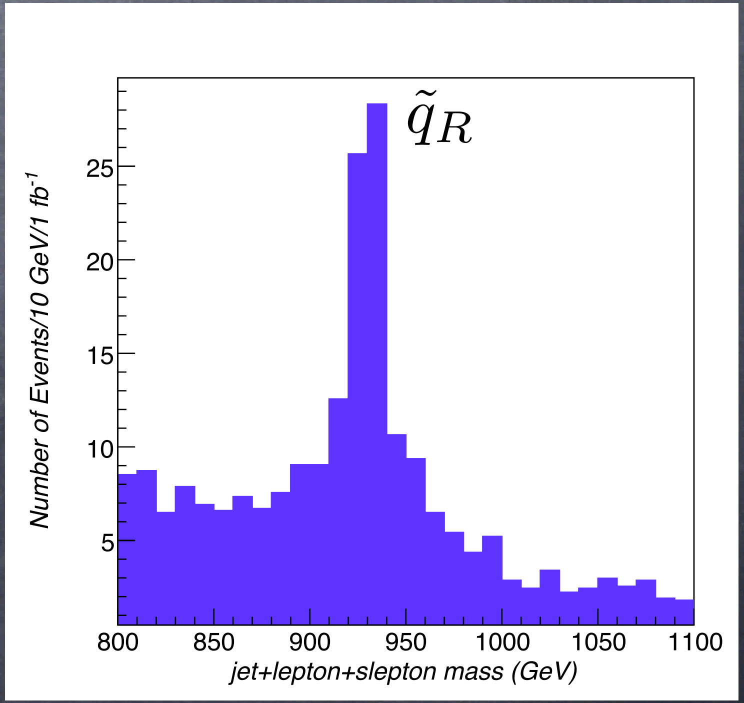
sleptons identified



sleptons misidentified

OSL pairs selected according to minimal ΔR separation.

Further pairing with the nearest jet →



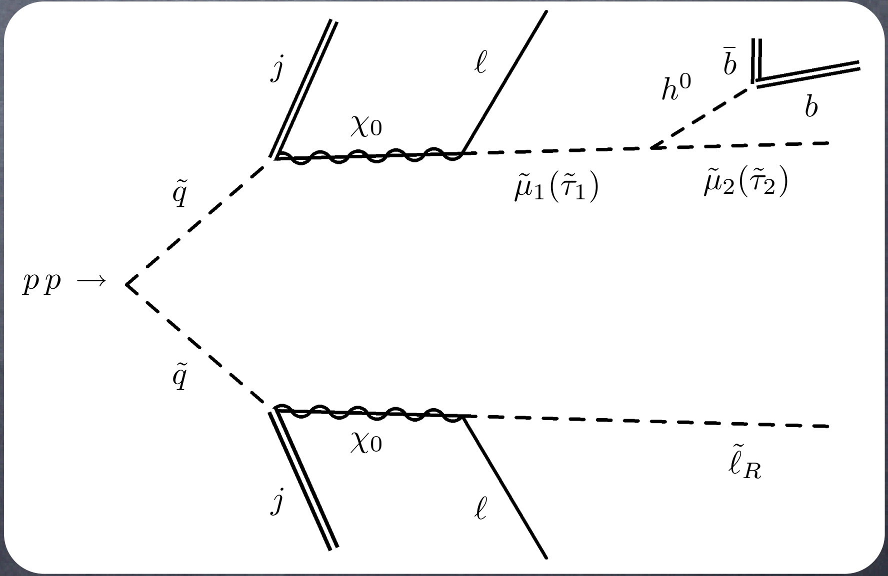
HIGGS CHANNEL

Standard lore:

- No Higgs searches in b-bbar, due to large BG.

In Lepto-SUSY:

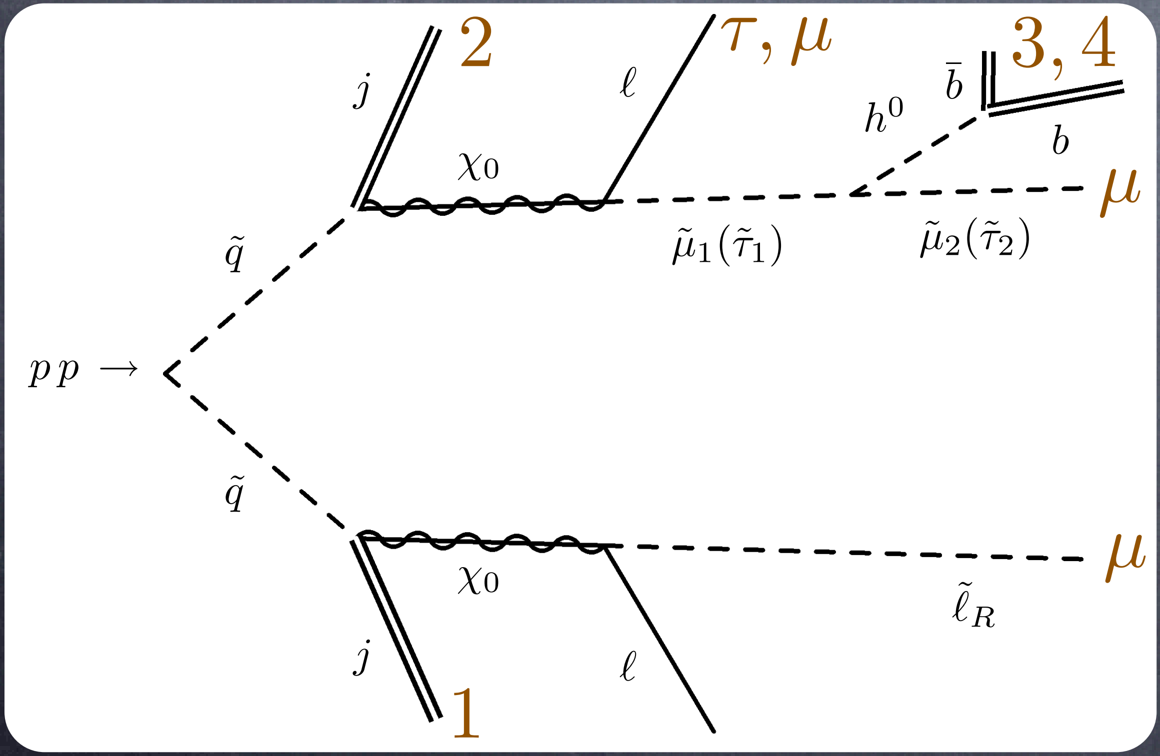
- Higgs is copiously produced in slepton decays $\tilde{\ell}_L \to h\,\tilde{\ell}_R$, and then decays to b-bbar.
- BG efficiently suppressed by lepton multiplicity.
- $h \to b\bar{b}$ is a discovery channel.



HIGGS CHANNEL

Analysis (simple-minded and conservative):

- ask for $n_\ell = 3, 4$ and $n_{\mathrm{jet}} \geq 4$
- order jets in pT and ask 4th pT>25 GeV
- assume 1st and 2nd jets are from squarks
- form invariant mass of 3rd and 4th jets



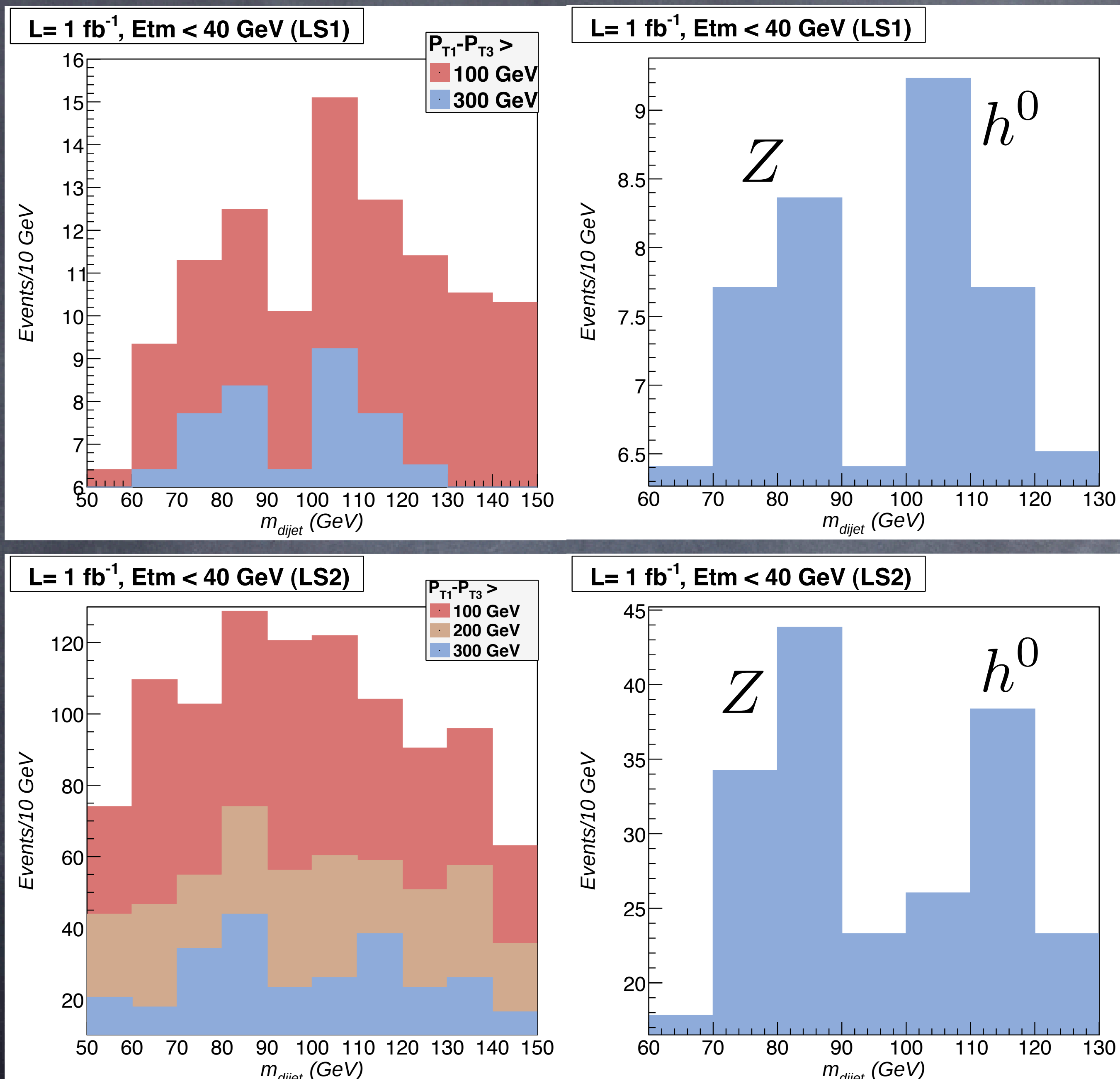
NB: No b-tagging.
Not precisely known at early stages.

	10 TeV	14 TeV
σ (fb)	100	320
Events at 0.2 fb^{-1}	20	64

HIGGS CHANNEL

LS 1

LS 2



14 TeV to 10 TeV is a factor of ~1/3

Combinatorial BG: more detailed analysis needed.

Under study by ATLAS coll.

DISCOVERY PROSPECTS

- The ease of multi-leptonic channels (~absence of BG) implies a tremendous discovery potential of LHC.

- The discovery of the stable slepton is possible with the very first data.

- Most of the sparticle spectrum can be reconstructed (at least 10 clean events) with

  $\boxed{0.2 - 0.4 \text{ fb}^{-1} \text{ at } 10 \text{ TeV}}$ (for TeV-squarks)

- Prospects of Higgs discovery in the $h \to b\bar{b}$ channel may be good with ≤ 1 fb^{-1} at 14 TeV.
  Significance of this channel requires full simulation.

CONCLUSIONS

- Leptogenic SUSY spectra are characterized by many leptons in the final state of *pp* collisions.
- They arise in several well-motivated models.
- Extremely clean (almost BG-free) channels.
  One of the most "LHC-friendly" SUSY scenarios.
- Different from standard SUSY searches.
- Relevant for very early stage of LHC.
  It can be discovered/ruled out with ~ 0.2 fb^{-1} at 10 TeV.

CONCLUSIONS

- Leptogenic SUSY spectra are characterized by many leptons in the final state of *pp* collisions.

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- Different from standard SUSY searches.

- Relevant for very early stage of LHC.
  It can be discovered/ruled out with ~ 0.2 fb^{-1} at 10 TeV.

If you see many leptons... remember LEPTO-SUSY !!!

THANK YOU

BACK-UP SLIDES

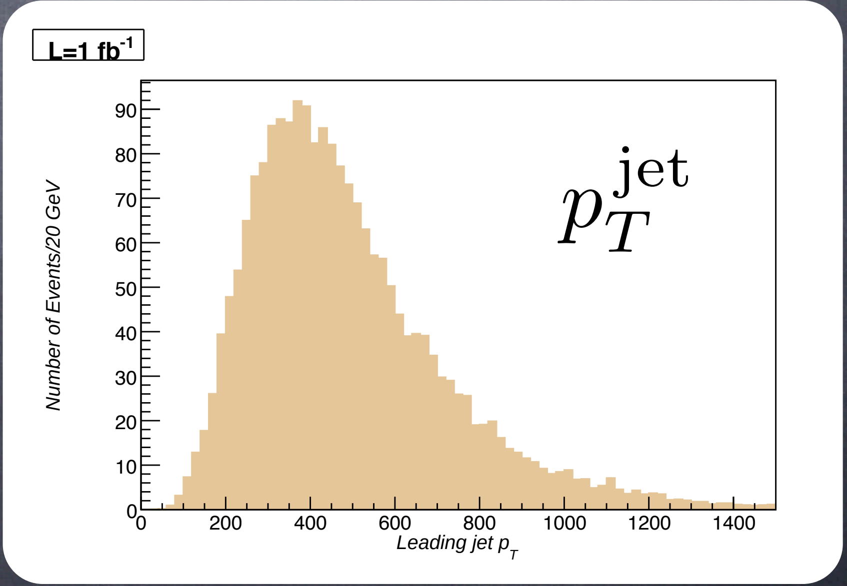
BACKGROUND (1)

- SM background in (3,4) leptons + 4 jets:
  $t\bar{t}$ +jets, W/Z+jets, WZ+jets, ZZ+jets, QCD jets.

- Rate for jets faking leptons ~ 10^{-4} (ATLAS TDR)
  b-decay producing isolated leptons ~ 5 10^{-3}
  Significant cross-section suppression:
  e.g. for QCD jets faking 4 leps: 10^{8} pb x $(10^{-4})^{4}$ = 10^{-5} fb

- Possibility to apply hard cuts on p_T of the leading jet and lepton, without losing signal.

  Efficient BG suppression.



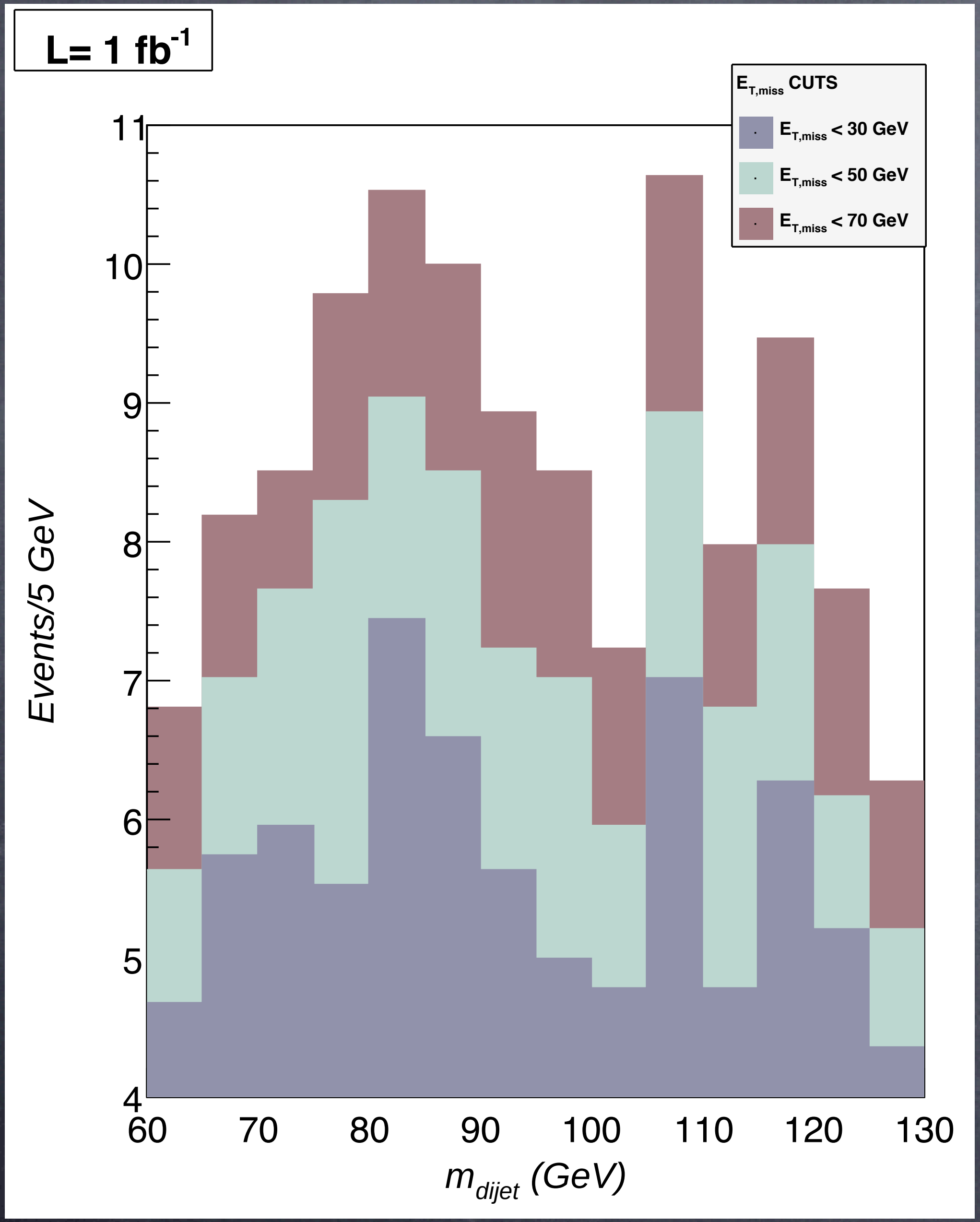
BACKGROUND (2)

SM BGs generated with ALPGEN and MG.

All < 1 fb after the cuts:

$$
\begin{aligned}
n_\ell &\geq 3 \\
n_j &\geq 4 \\
p_T^{j_1} &> 200\,\mathrm{GeV} \\
p_T^{j_4} &> 25\,\mathrm{GeV} \\
n_\mu &\geq 2 \\
p_T^{(\ell)} &> 50\,\mathrm{GeV} \\
\Delta R_{\ell\,\ell,\ell\,j,j\,j} &> 0.4
\end{aligned}
$$

HIGGS DECAYS

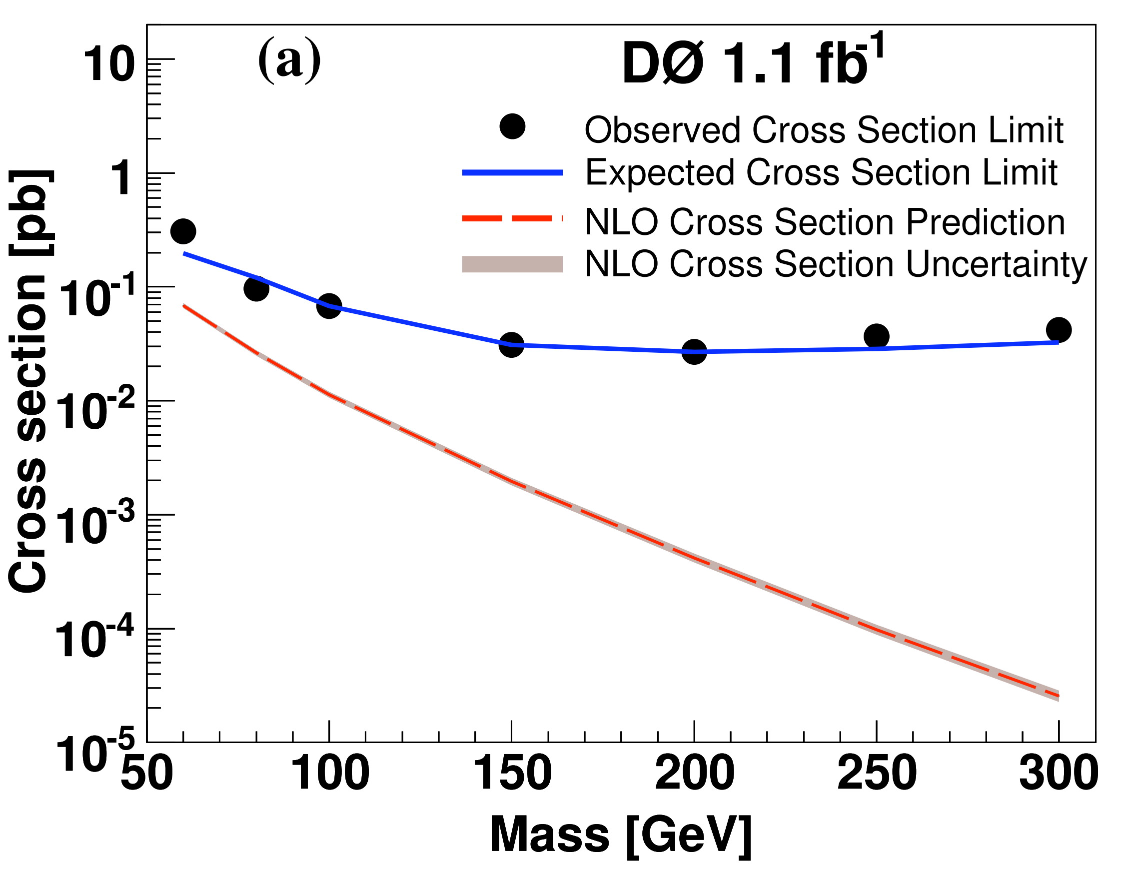


Varying missing ET cuts

combinatorial BG

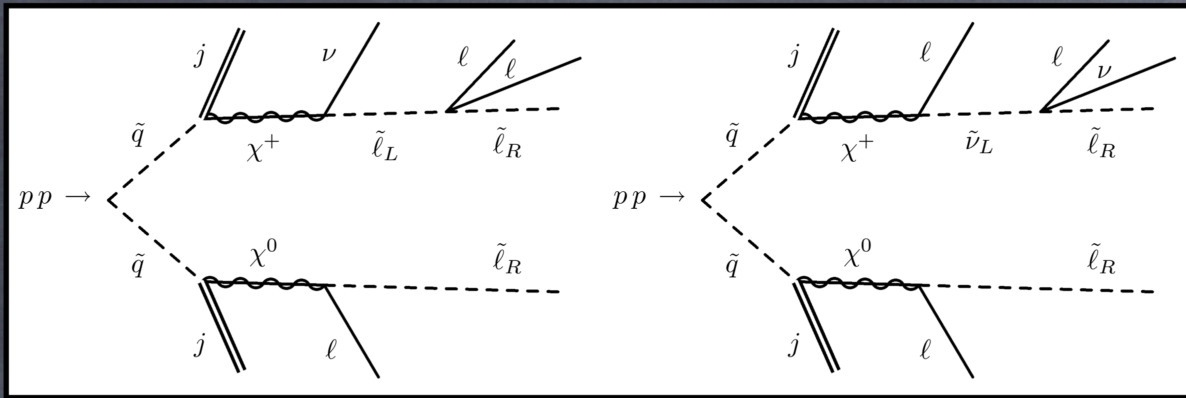
TEVATRON LIMITS

Only apply to slepton pair production (8 fb in our case).
Not constrained by TeVatron

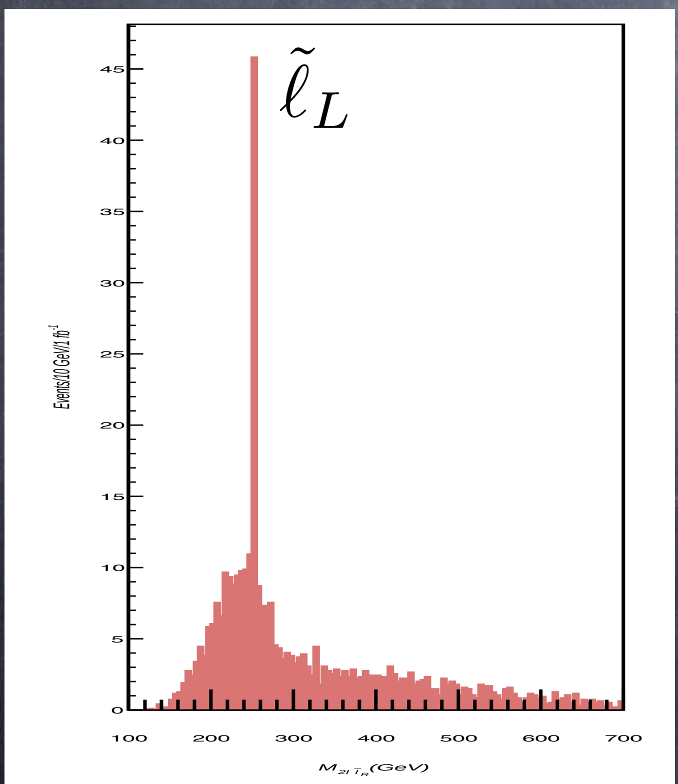


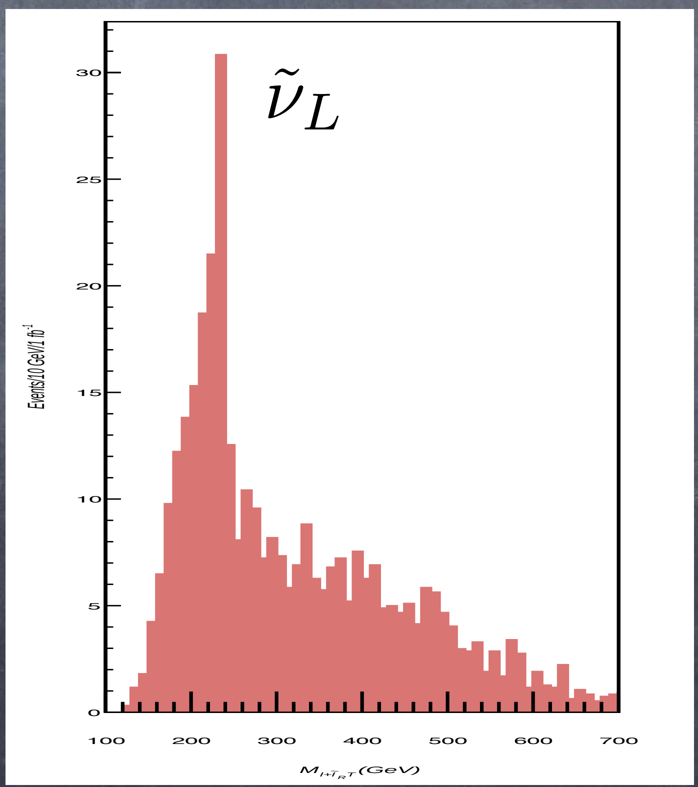
[Search for charged massive stable particles with D0 detector (2008)]

5-LEPTONS CHANNEL



	10 TeV	14 TeV
σ (fb)	137	426
Events at 0.2 fb^{-1}	27	85

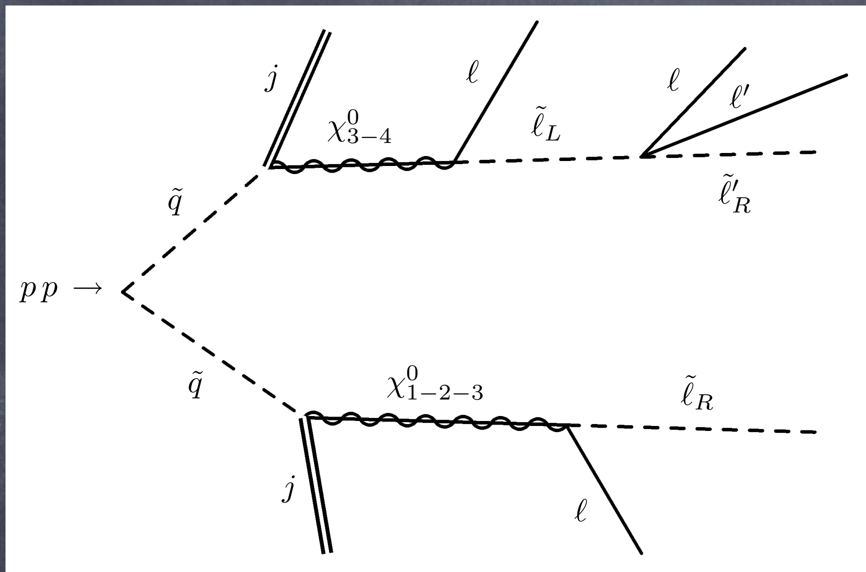


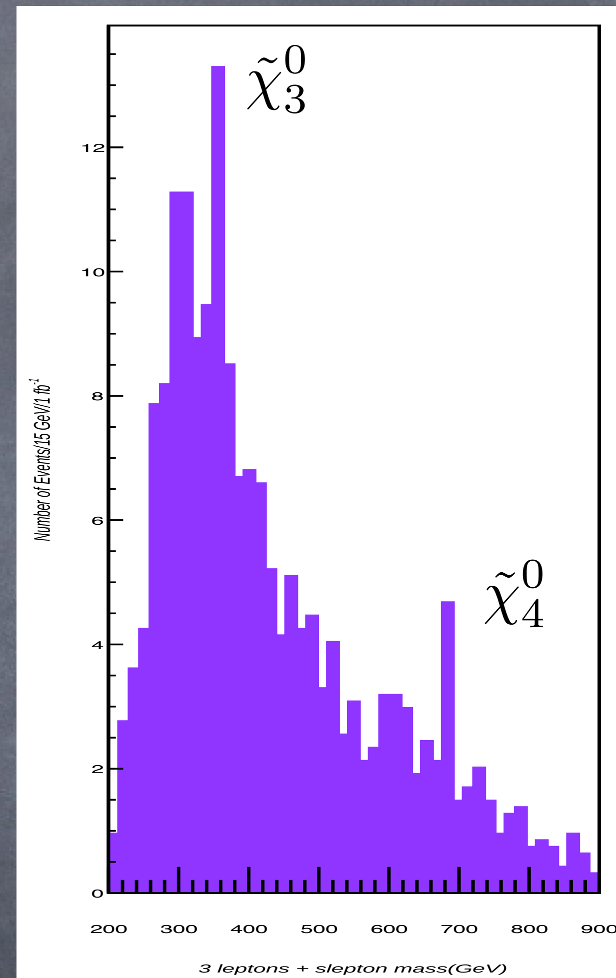


$\not{E}_T$ due to neutrino

$\tilde{\chi}^{\pm}$ mass reconstr. also possible with transverse mass.

6-LEPTONS CHANNEL





	10 TeV	14 TeV
σ (fb)	70	225
Events at 0.2 fb^{-1}	14	45

$\tilde{\ell}_L$, other neutralinos and squarks can also be reconstructed but with lower statistics than in $4\,\ell$.

PARAMETER SPACE

- Model-independent parametrization of soft masses:

$$\tilde{m}^2(R) = \sum_{i=1}^{3} C_2(R_i) K_i \qquad K_i = \frac{\alpha_i}{\pi} m_i^2 n_i^2$$

n_i : dimensionless numbers.

- In the Higgs sector: $\delta \equiv -m_{H_d}^2 + m_{H_u}^2 = -\frac{\alpha_3 \lambda_t^2}{4\pi^3} m_3^2 n_4^2$

Assuming gaugino mass unification, and A=0,
7 parameters: $m_3,\ n_i\ (i = 1, 2, 3, 4),\ \tan\beta,\ \mathrm{sign}\,\mu$

Parameter space of lepto-SUSY:

Parameter	Range
n_1	$[2,\ 5]$
n_2	$[0.5,\ 6]$
n_3	> 1.8
n_4	> 1.75

Our benchmark point:

m_3	2000 GeV
n_1	4.8
n_2	3.9
n_3	2.2
n_4	6.7
$\tan\beta$	10
sign μ	+

MODELS WITH LEPTO-SUSY

Lepto-SUSY spectra are realized for $n_i = \mathcal{O}(1-10)$.
Examples:

- Gaugino mediation at low-scale:
  no large log contribution from RGE.

- Gauge mediation with large N_m: $n_i \propto \frac{1}{\sqrt{N_m}}\sqrt{\frac{\pi}{\alpha_i}}$

- Supersoft SUSY breaking:
  D-term SUSY breaking is communicated to the visible sector through higher dim operators. Scalar masses naturally suppressed wrt gaugino masses.