Supersymmetric theory

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Outline

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Supersymmetry

Supersymmetry transforms fermions into bosons and vice versa.

SM particle	spin	Supersymmetric partner	spin
quark	$\frac{1}{2}$	squark	0
lepton	$\frac{1}{2}$	slepton	0
neutrino	$\frac{1}{2}$	sneutrino	0
$W_0, W^{\pm}, B_0$	1	Wino, Bino	$\frac{1}{2}$
Higgs	0	Higgsino	$\frac{1}{2}$
gluon	1	gluino	$\frac{1}{2}$
graviton	2	gravitino	$\frac{3}{2}$

Bino, Wino and Higgsinos mix in Neutralinos $\chi^0_{1,2,3,4}$

Charged Higgsinos and Winos mix in Charginos $\chi^{\pm}_{1,2}$

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Supersymmetry at Colliders

Pair-Production of squarks and gluions.

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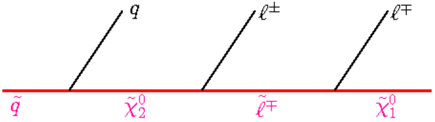

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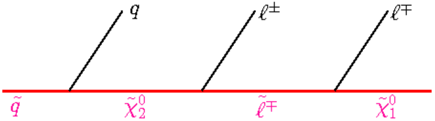

Detect particles from chain and Missing E_T

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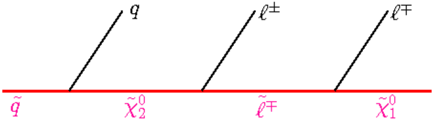

Detect particles from chain and Missing E_T

How to measure SUSY masses?

Invariant Mass Distributions

Theory of relativity $\Rightarrow m = \sqrt{E^2 - |\vec{p}|^2}$ is lorentz invariant.

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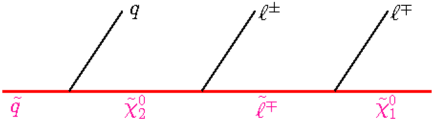
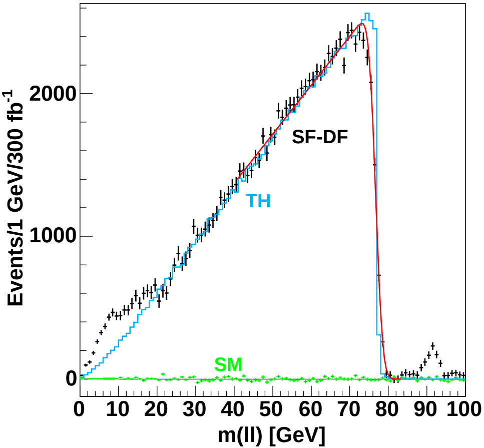


Endpoints; e.g. $M_{ll}^2 = \frac{\left(M^2_{\tilde{\chi}_2^0} - M^2_{\tilde{l}}\right)\left(M^2_{\tilde{l}} - M^2_{\tilde{\chi}_1^0}\right)}{M^2_{\tilde{l}}}$.

Invariant Mass Distributions



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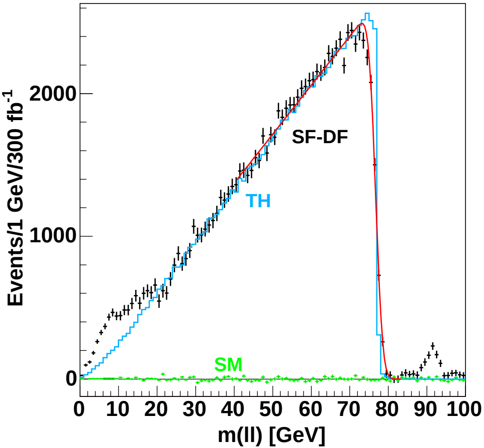
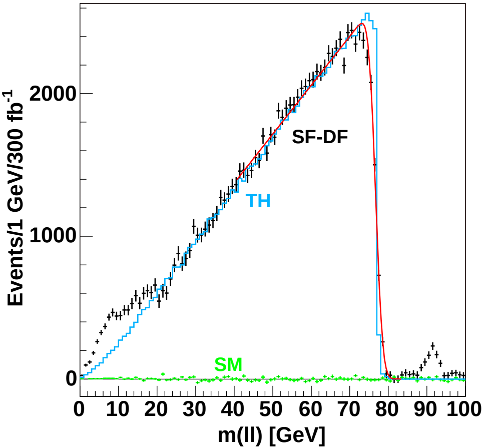


$e^{\pm}$ $l^{\mp}$
$e^{\mp}$

- $e^{\pm} l^{\mp} \Rightarrow$ combinatorial background.
- l equally often e as μ.

Invariant Mass Distributions



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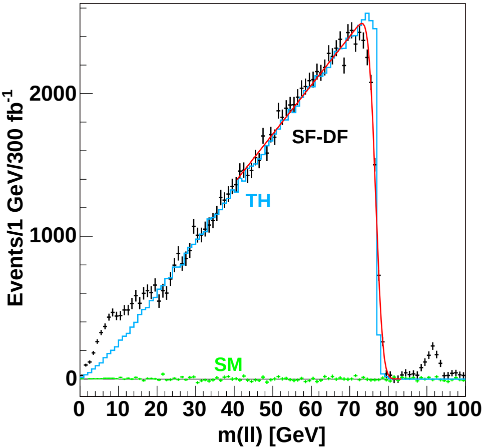

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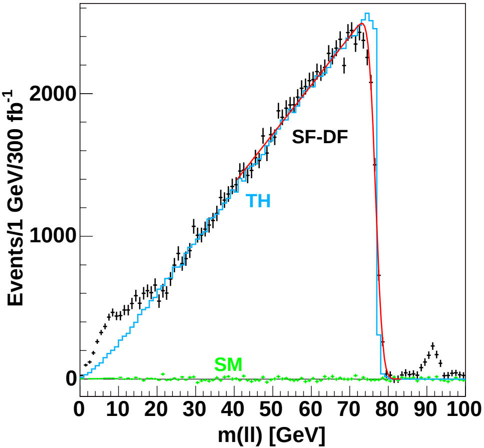

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$\Rightarrow$ $ee + \mu\mu - e\mu$ "free" of background.

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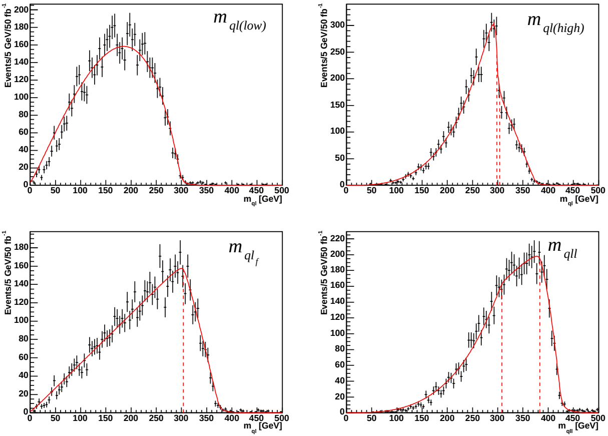

Outline

B and L Violating Couplings.

$$\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k + \mu_i H L_i$$

L_i, Q_i, H – lepton, quark, Higgs doublets
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Bilinear Lepton number violating couplings; induces neutrino–neutralino mixing. Not our primary focus

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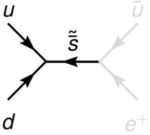
Trilinear Lepton number violating couplings

Trilinear Baryon number violating couplings

Proton Decay

$$\lambda''_{112}\bar{U}_1\bar{D}_1\bar{D}_2 + \lambda'_{112}L_1Q_1\bar{D}_2 \Rightarrow$$



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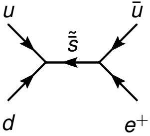

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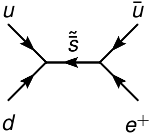
$\lambda''_{112}\bar{U}_1\bar{D}_1\bar{D}_2 + \lambda'_{112}L_1Q_1\bar{D}_2 \Rightarrow$ 

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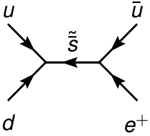

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Supersymmetric partners: R-parity -1

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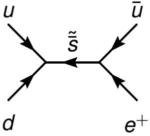

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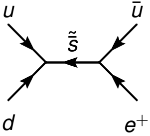

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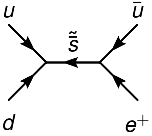

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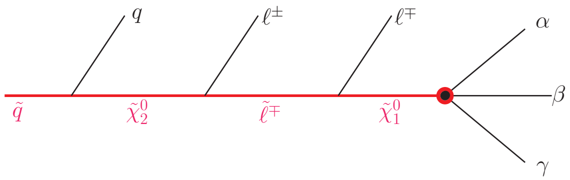
Supersymmetric particles produced in pairs
Lightest Supersymmetric Partner (usually Neutralino) stable;
Dark Matter

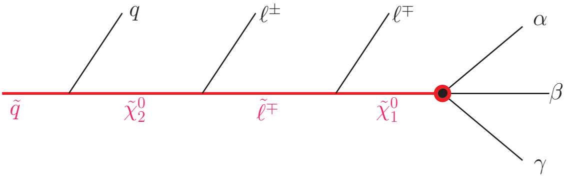
R-parity violation



Not much Missing E_T, lots of leptons and/or JETs.

How to measure $M_{\chi^0_1}$?
How to determine flavour of RPV coupling?

R-parity violation



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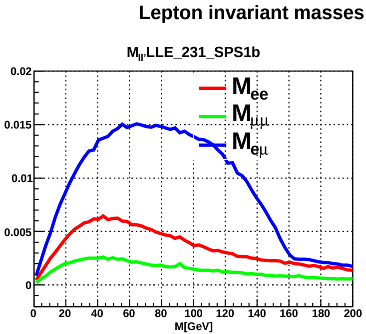
Lepton Invariant Mass Distributions for $LL\bar{E}$ Operators



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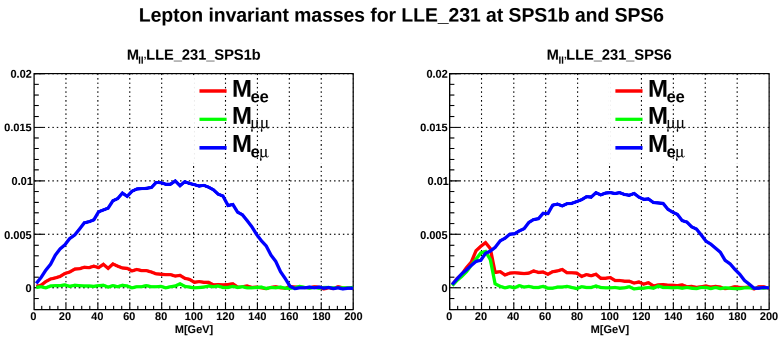

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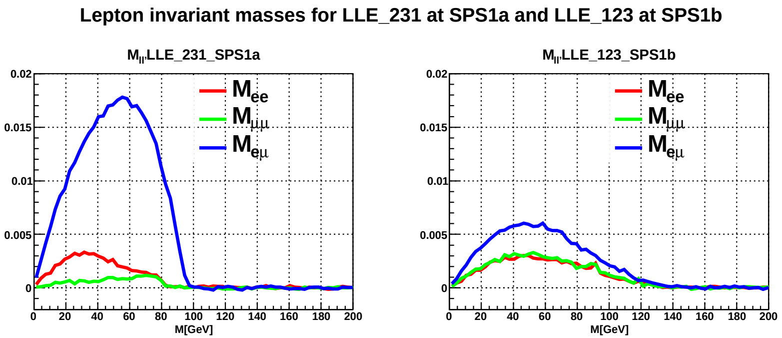

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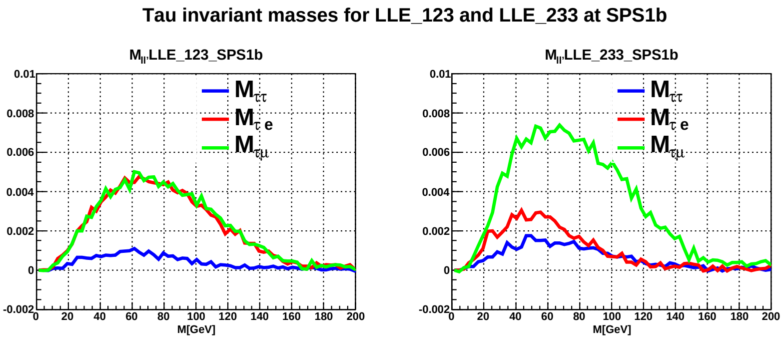

Theoretical Calculation

Assume isotropic χ_1^0 decay: $f_E(E) = \frac{8E}{M^2}, \quad \text{for } E \in \left[0, \frac{M}{2}\right].$

A little algebra gives: $f_{M_{ll}}(M_{ll}) = \frac{4M_{ll}}{M^4}(M^2 - M_{ll}^2).$

What if one lepton comes from tau decay?

Assume isotropic decay of tau, lorentz boost and take limit of massless tau.
Find a way to simulate cuts.

What about tau-JETs?

Assume three-body decay, JET gets $E_\tau - E_\nu$.

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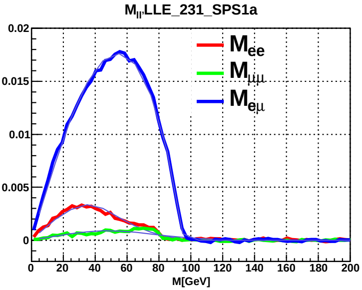

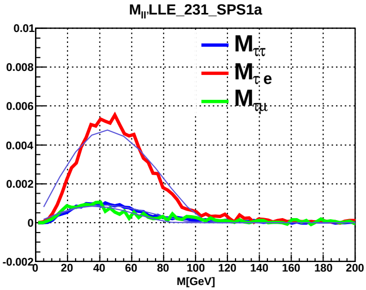

$M_{\chi_1^0}$	116	—	95.7		112	—	—

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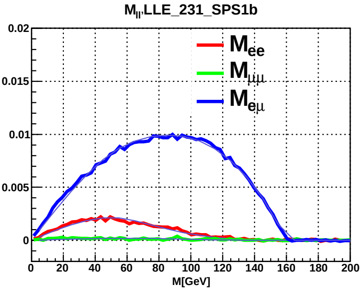

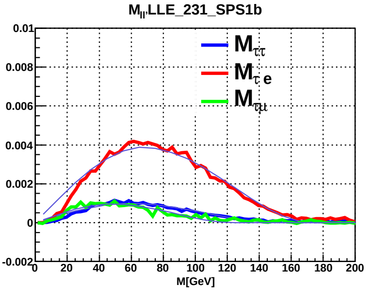

$M_{\chi_1^0}$	162	—	160		173	—	—

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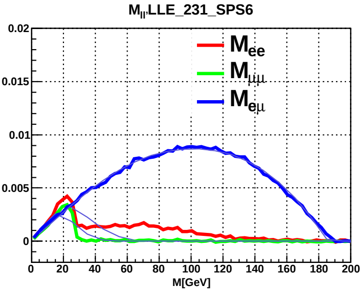

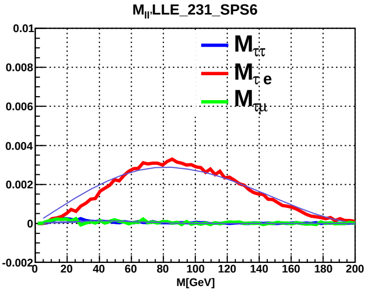

$M_{\chi_1^0}$	77.6	—	186		207	—	—

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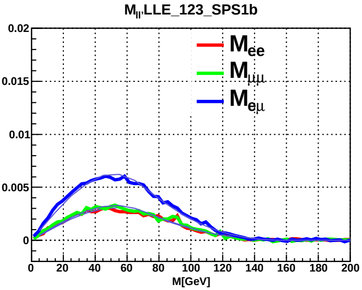

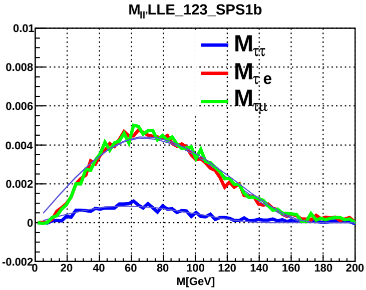

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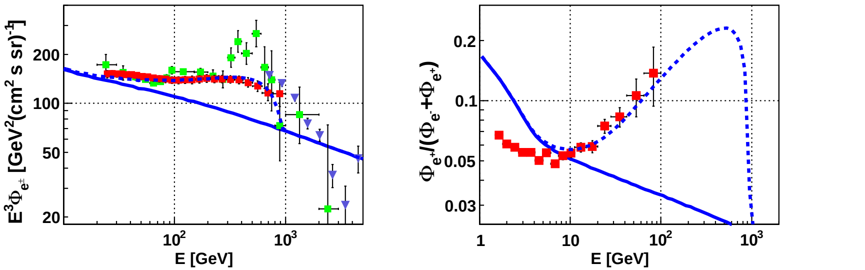
The PAMELA and Fermi LAT Anomalies

$$\lambda_{133} L_1 L_3 \bar{E}_3$$



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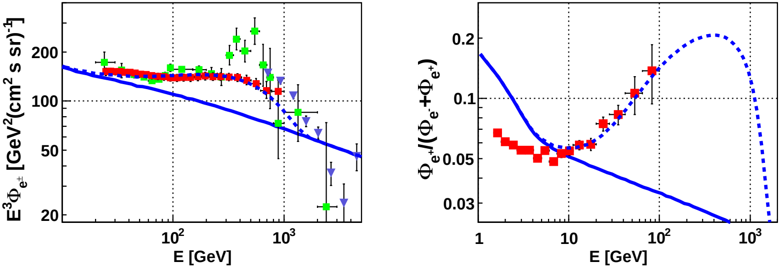
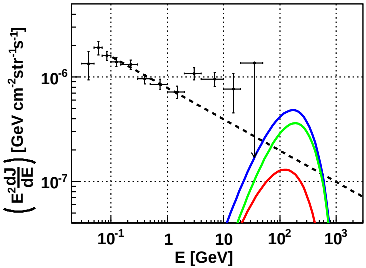
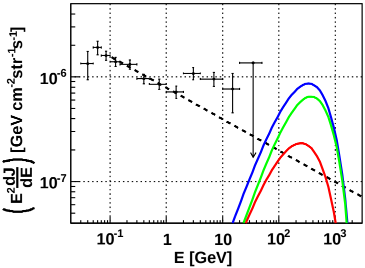
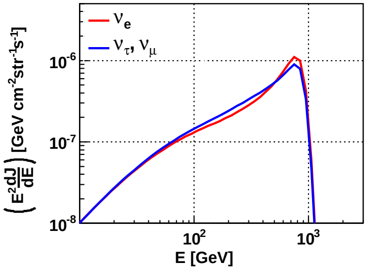


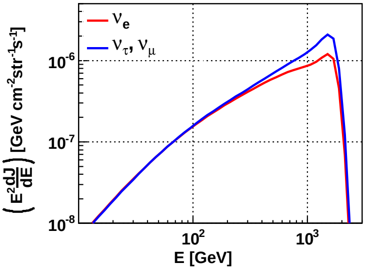
Gamma Ray Signals for Fermi LAT





Neutrino Signals from Gravitino Decay





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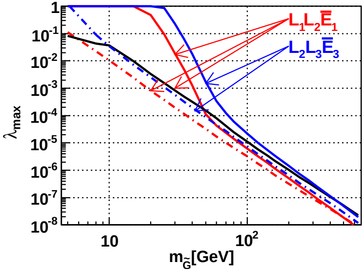
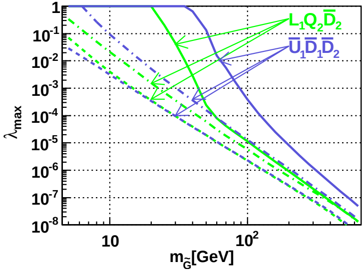
Constraints on λ from Cosmic Ray Measurements





Final Comments

- R-Parity Violating Supersymmetry may give interesting signals at LHC and may be easier to discover and measure than R-Parity Conserving Supersymmetry.
- Gravitino Dark Matter in R-Parity Violating Supersymmetric models can well explain the recent anomalies in cosmic ray electrons and positrons, seen by PAMELA, Fermi/LAT and ATIC.
- The above two scenarios are completely incompatible with each other.

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Final Comments

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