Supersymmetric theory

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Outline

Introduction Supersymmetry

Supersymmetry at Colliders "Ordinary" Supersymmetry R-parity

Gravitino Dark Matter

Electrons and Positrons Constraints on λ

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Supersymmetry

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	1 2
gluon	1	gluino	$\frac{1}{2}$
graviton	2	gravitino	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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Supersymmetry at Colliders

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Supersymmetry at Colliders

Pair-Production of squarks and gluions.



Detect particles from chain and Missing E_T

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Supersymmetry at Colliders

Pair-Production of squarks and gluions.



Detect particles from chain and Missing E_T

How to measure SUSY masses?

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"Ordinary" Supersymmetry R-parity

Invariant Mass Distributions

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

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"Ordinary" Supersymmetry R-parity

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

"Ordinary" Supersymmetry R-parity

Invariant Mass Distributions



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"Ordinary" Supersymmetry R-parity

Invariant Mass Distributions





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

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"Ordinary" Supersymmetry R-parity

Invariant Mass Distributions



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"Ordinary" Supersymmetry R-parity

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

"Ordinary" Supersymmetry R-parity

Invariant Mass Distributions



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"Ordinary" Supersymmetry R-parity

B and L Violating Couplings.

$$\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k + \mu_iHL_i$$

 L_i , Q_i , H – lepton, quark, Higgs doublets E_i , D_i , U_i – lepton, down, up quark singlets

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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

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Trilinear Lepton number violating couplings

Trilinear Baryon number violating couplings

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"Ordinary" Supersymmetry R-parity

Proton Decay



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"Ordinary" Supersymmetry R-parity

Proton Decay



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Proton Decay



 \Rightarrow Proton decay, but $\tau_{Proton} > 10^{30}$ years

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Proton Decay



 \Rightarrow Proton decay, but $au_{\it Proton}$ > 10³⁰ years

Standard model particles: R-parity 1 Supersymmetric partners: R-parity -1

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Proton Decay



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$$\lambda_{ijk}L_iL_jE_k + \lambda_{ijk}L_i = \sum_{j=1}^{n} \overline{D}_k + \lambda_{ijk}^{\mu} \overline{D}_i \overline{D}_i D_k + \mu_i HL_i$$

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$$\lambda_{ijk}L_iL_jE_k + \lambda_{ijk}L_iO_j\overline{D}_k + \lambda_{ijk}\overline{U}_i\overline{D}_iD_k + \mu_iHL_i$$

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

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R-parity violation



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

How to measure $M_{\chi_1^0}$? How to determine flavour of RPV coupling?

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Lepton Invariant Mass Distributions for *LLE* Operators



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"Ordinary" Supersymmetry R-parity

Lepton Invariant Mass Distributions for *LLE* Operators



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Lepton Invariant Mass Distributions for *LLE* Operators



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"Ordinary" Supersymmetry R-parity

Lepton Invariant Mass Distributions for *LLE* Operators

Tau invariant masses for LLE_123 and LLE_233 at SPS1b M.,LLE 123 SPS1b M.,LLE 233 SPS1b 0.01 0.0 Μ_{ττ} MTT Μ_{τe} 0.008 0.008 $M_{\tau e}$ Μ_{τu} M., 0.006 0.006 0.004 0.004 0.002 0.002 -0.002 -0.002 40 140 160 180 120 140 160 180 20 60 100 120 20 40 60 100 200 M[GeV] M[GeV]

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Theoretical Calculation

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

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

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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Compare to Monte Carlo



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Compare to Monte Carlo



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Compare to Monte Carlo



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Compare to Monte Carlo



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Electrons and Positrons Constraints on λ

The PAMELA and Fermi LAT Anomalies

$\lambda_{133}L_1L_3\bar{E}_3$



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Electrons and Positrons Constraints on λ

The PAMELA and Fermi LAT Anomalies

$\lambda_{233}L_2L_3\bar{E}_3$



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Electrons and Positrons Constraints on λ

Gamma Ray Signals for Fermi LAT



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Electrons and Positrons Constraints on λ

Neutrino Signals from Gravitino Decay



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Electrons and Positrons Constraints on λ

Constraints on λ from Cosmic Ray Measurements





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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.
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