If the neutralino is not dark matter, can it be heavier than the chargino?

N.-E. Bomark [1]

[1] University of Bergen, Norway

Dec 18, 2012/ from Higgs to Drak Matter, Geilo

Outline

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Why Supersymmetry?

- Yes, why???
- Maybe it solves the hierarchy problem? Only if we find something soon.
- Maybe the SM vacuum is unstable?
- Maybe the Higgs is not SM? Unclear if SUSY can fix that.
- But we are running out of arguments.

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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
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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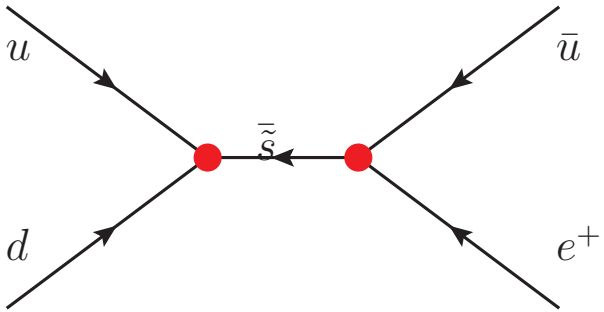
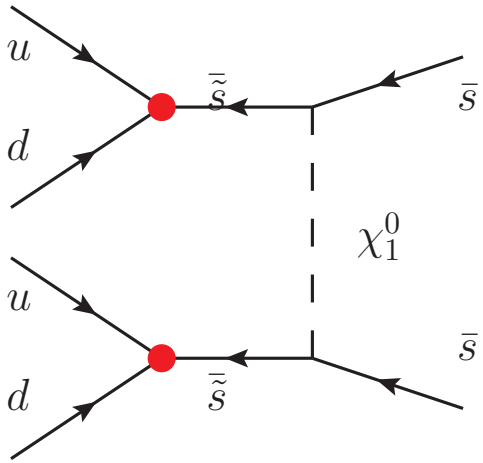
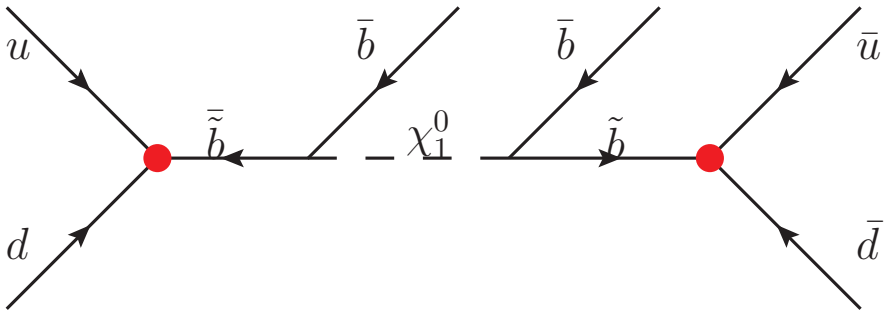
Trilinear Lepton number violating couplings

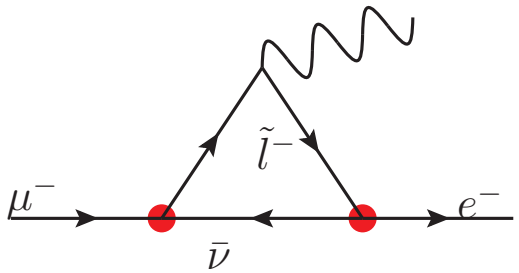
Trilinear Baryon number violating couplings

Constraints on B, L Violating Couplings









R-Parity

"Standard" solution: remove them all, i.e. R-Parity

$$R_p = (-1)^{B-L+2S}$$

- Discovered particles different from non-discovered ones?
- Discrete symmetries are often broken: C, P, CP, lepton flavour number, B(?), L(?)
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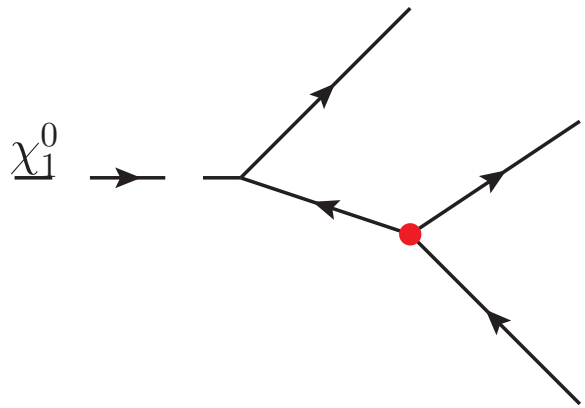
Dark Matter?

R-Parity Violation
$\Rightarrow$ all sparticles decay,



Gravitino! All interactions suppressed by M_{planck}^{-1}

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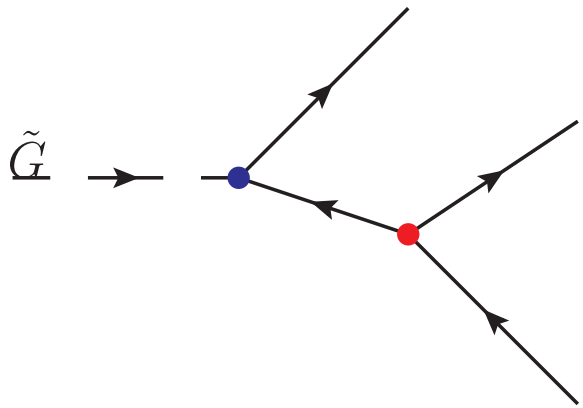

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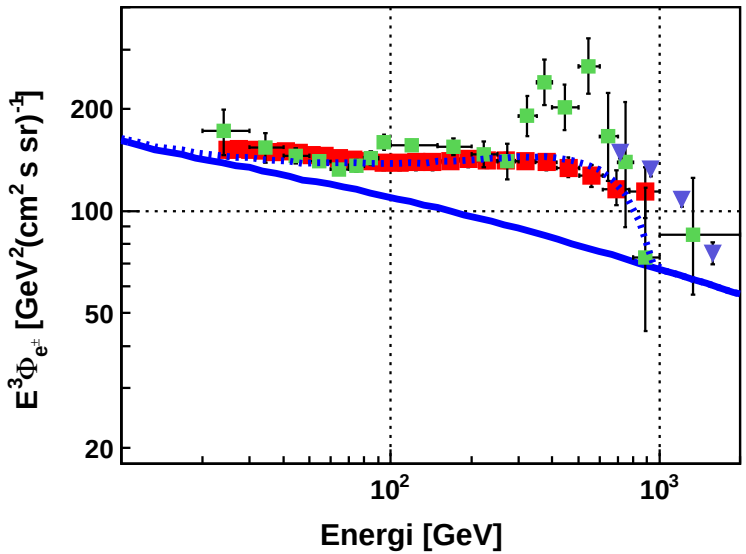
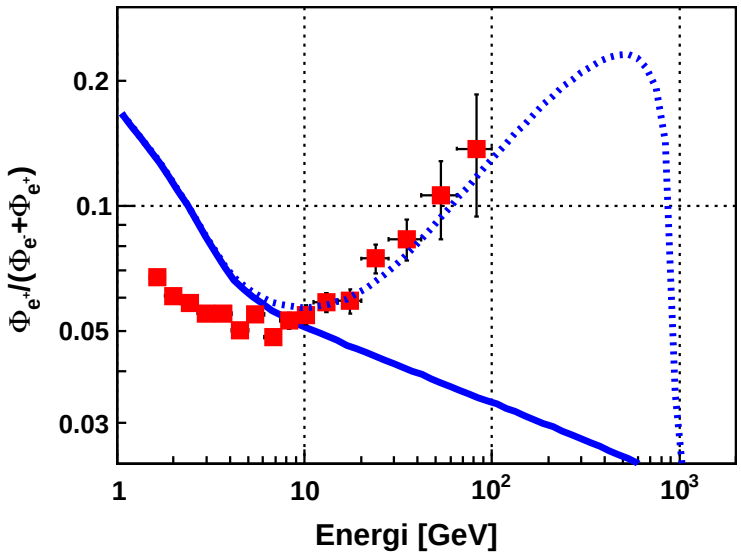
Electrons and positrons, LLE-133, M_{SUSY} = 6 TeV, M_G = 1.8 TeV





Outline

Decaying charginos

- Possibility for R-parity violating chargino decay at the LHC.
- Similar features as neutralino decay.
- Pair production of squarks and gluinos
- Cascade decay down to chargino
- Three-body decay of chargino

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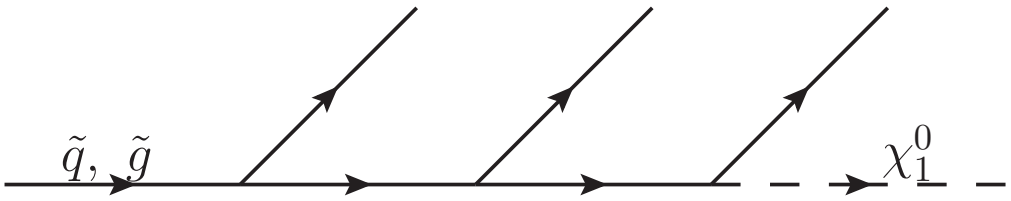

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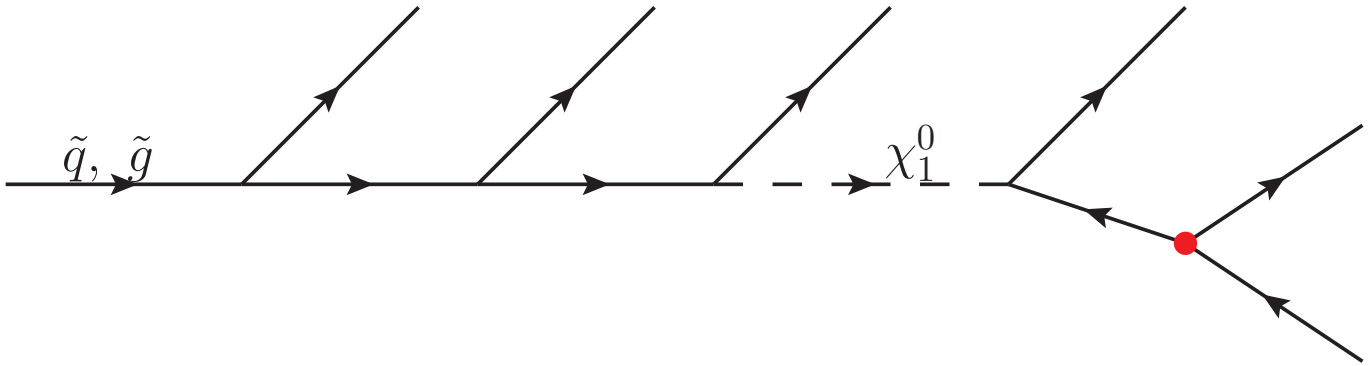

LHC signatures

- $\chi_1^{\pm} \to \ell_1^{\pm}\ \ell_2^{\mp}\ \ell_3^{\pm}$ or $\chi_1^{\pm} \to \ell_1^{\pm}\ \nu_{\ell_2^{\mp}}\ \bar{\nu}_{\ell_3^{\pm}}$
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- But taus will destroy the peak.
- Difficult combinatoric background.
- Interesting di-lepton signals too!

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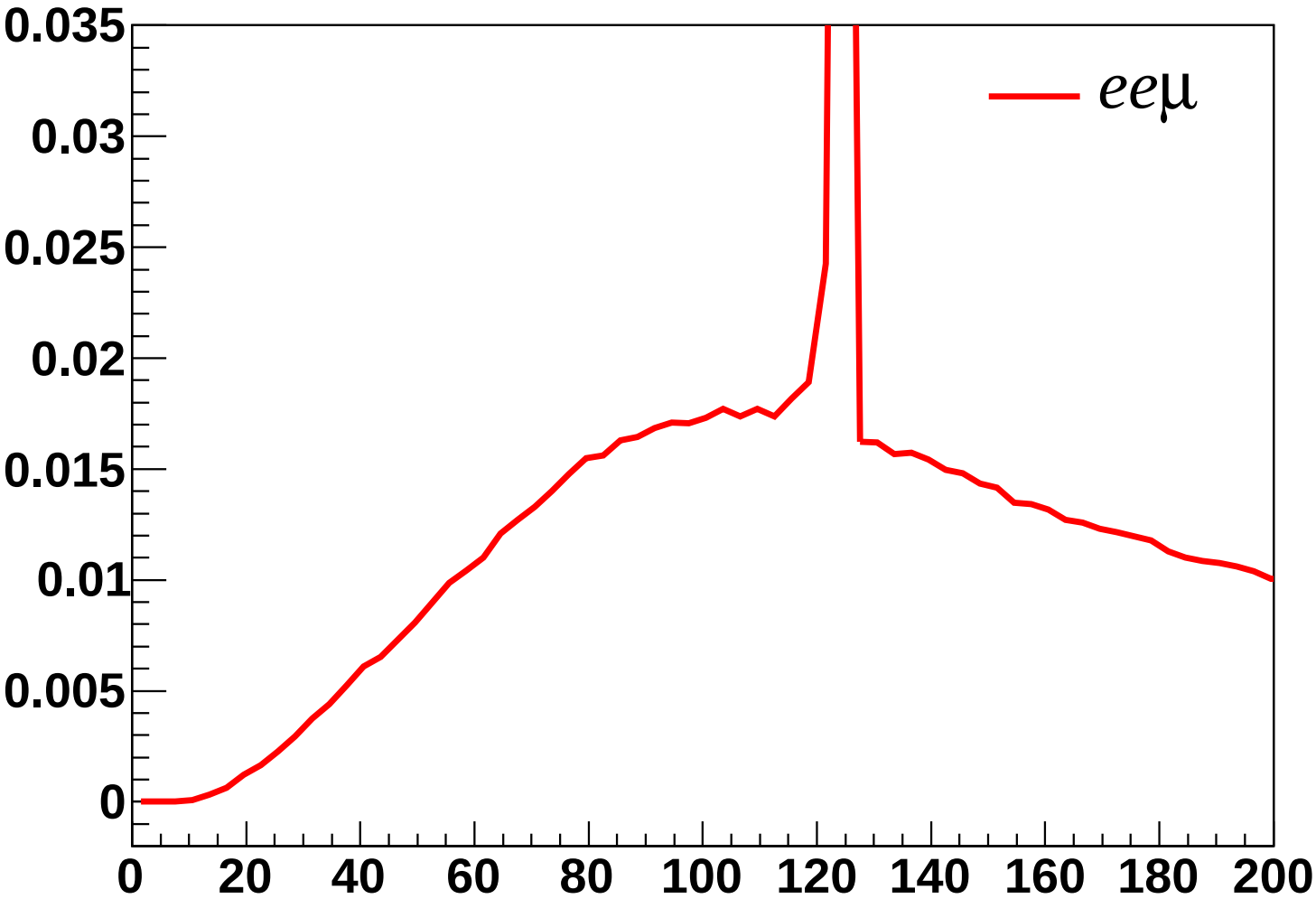
Invariant Mass Distributions – $L_1 L_2 \bar{E}_1$



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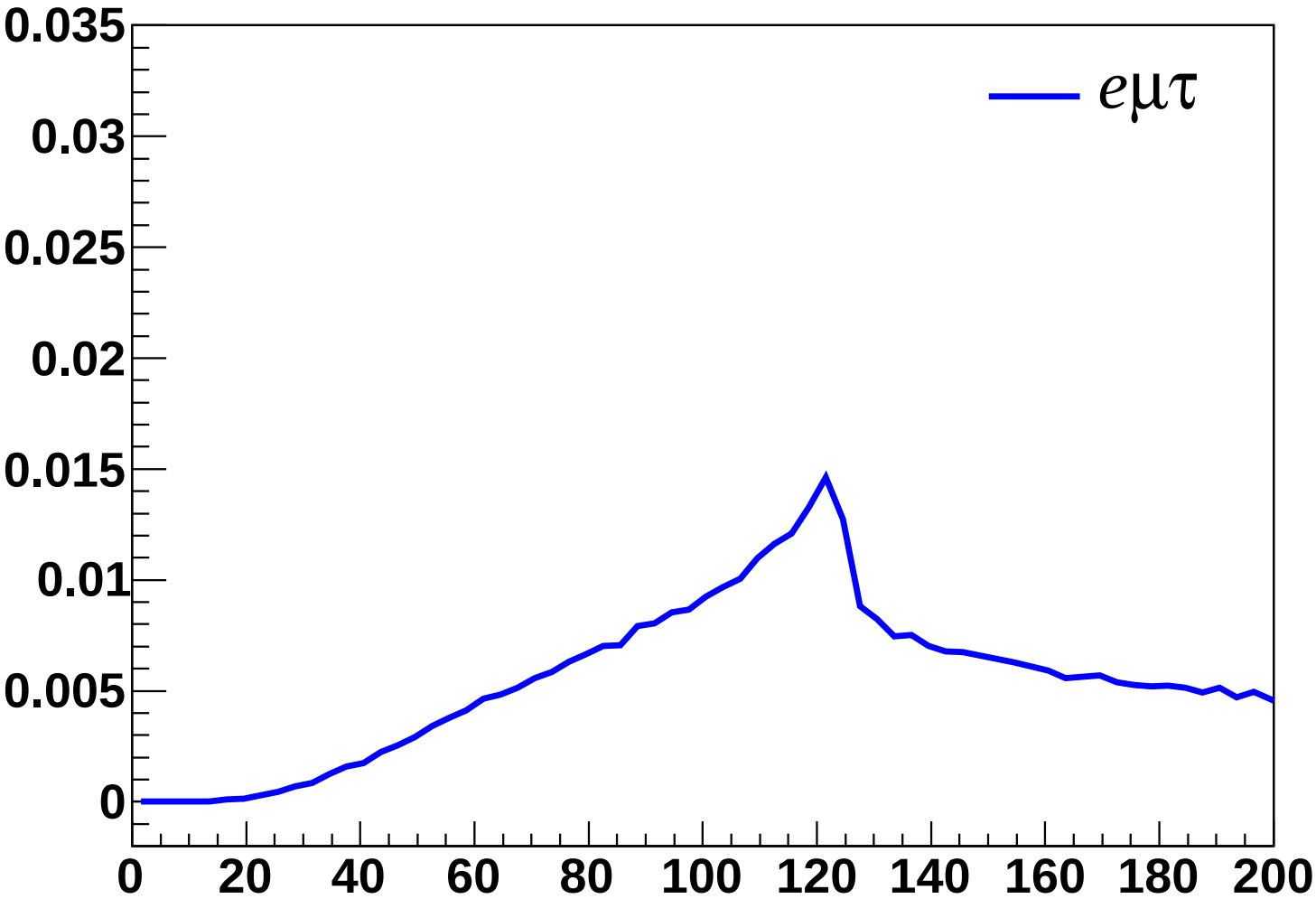

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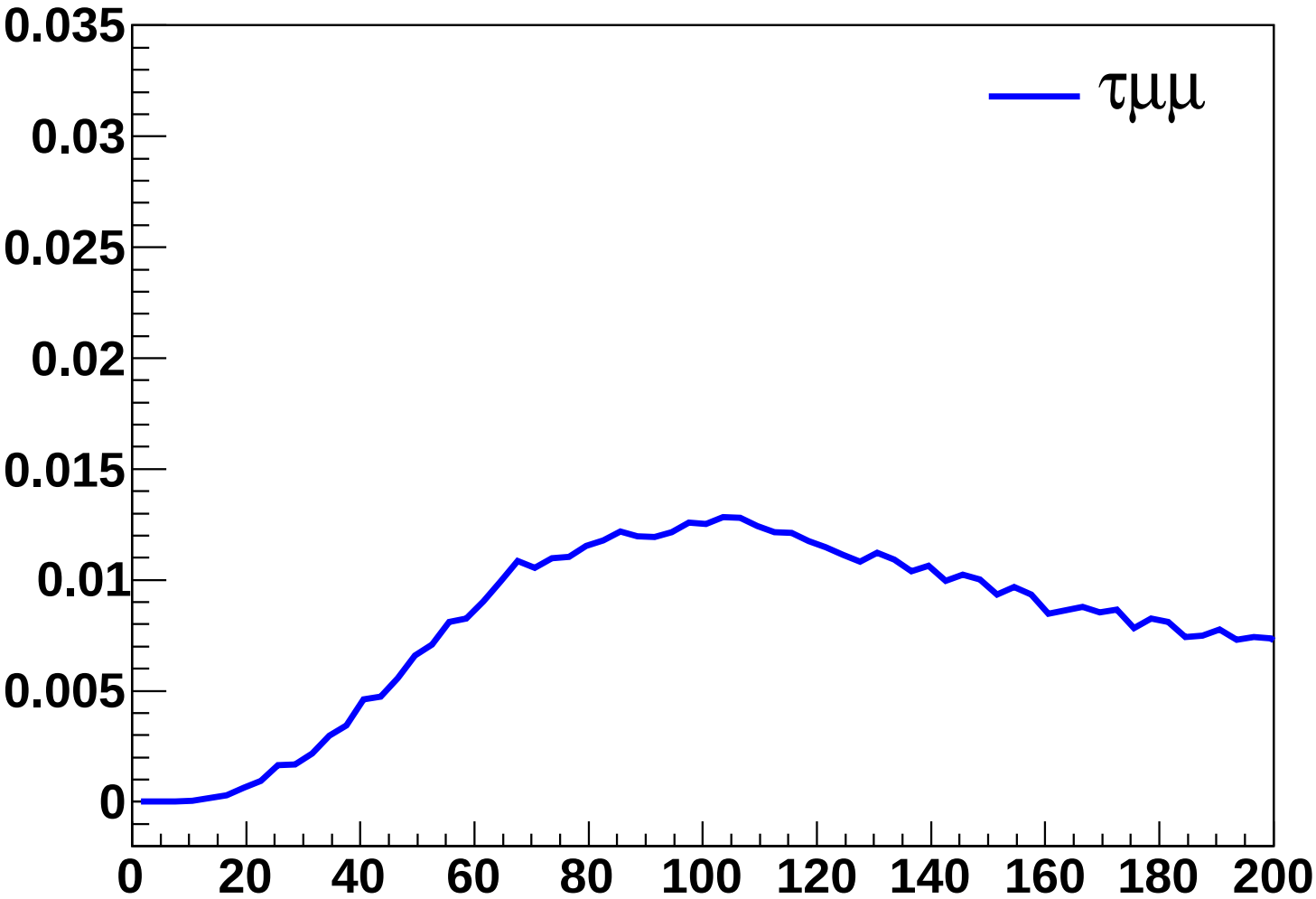

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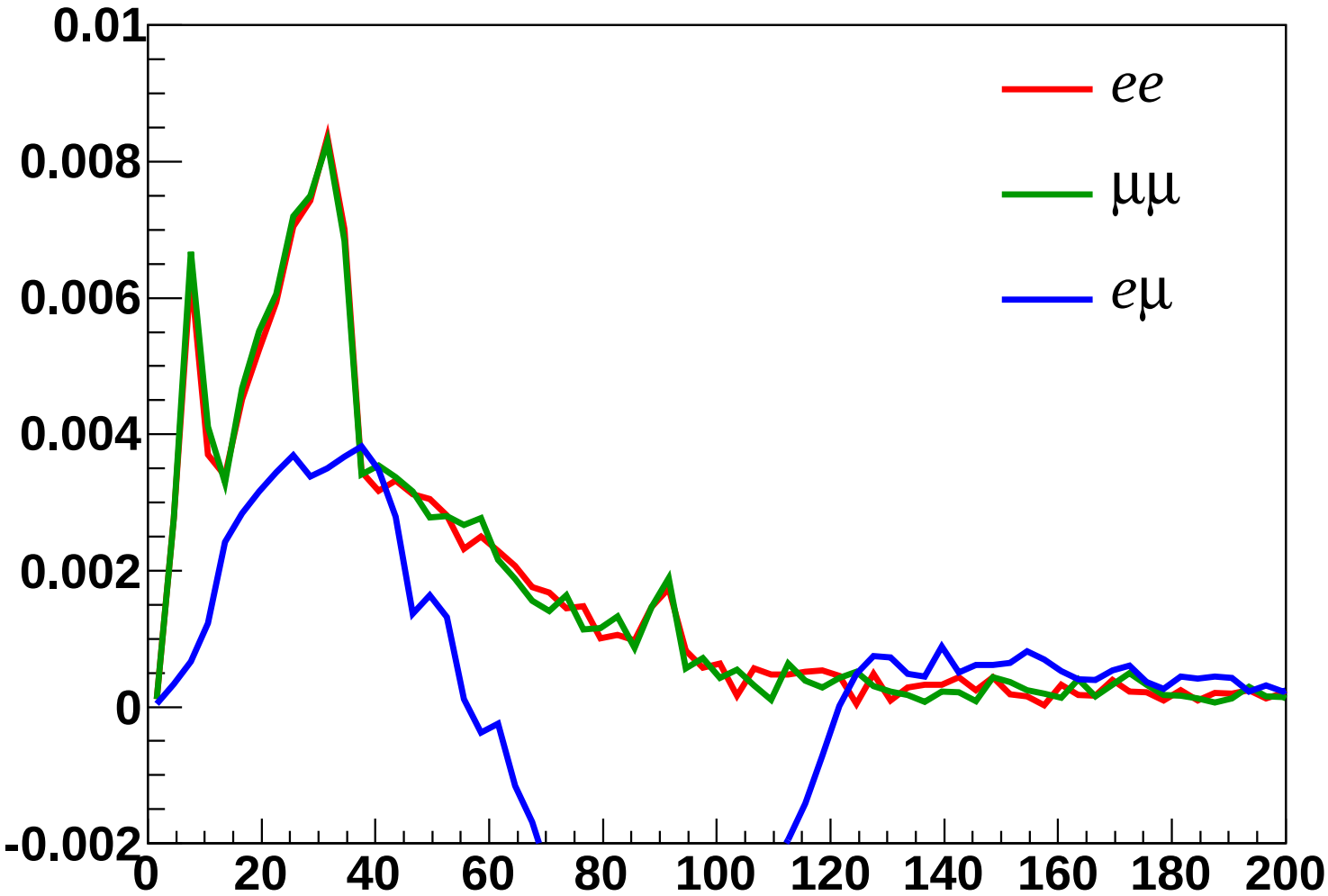

$LQ\bar{D}$

$$Q_3 \Rightarrow \chi_1^0 \rightarrow \nu q \bar{q}$$

but: $\chi_1^{\pm} \rightarrow \ell^{\pm} q \bar{q}$!

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$\bar{U}\bar{D}\bar{D}$

Neutralinos: $\bar{U}_3 \Rightarrow \begin{cases} M_{\chi_1^0} < M_{top} & \Rightarrow \quad \chi_1^0 \ escapes \\ M_{\chi_1^0} > M_{top} & \Rightarrow \quad \chi_1^0 \rightarrow t(\bar{t}) + 2 \ (soft) \ jets \end{cases}$

For charginos the above does not happen!

Outline

Neutralinos and charginos

Neutralino are mixtures of winos, binos and higgsinos.

Charginos are mixtures of winos and higgsinos.

I.e. only if the lightest neutralino is wino or higgsino dominated, can the chargino be equally light.

$$\Delta m \equiv m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}$$

Wino limit

$$M_2 < M_1, \mu$$

$$\begin{aligned}\Delta m &= \frac{M_W^2}{\mu^2}\frac{M_W^2}{M_1 - M_2}\tan^2\theta_W \sin^2 2\beta + 2\frac{M_W^4 M_2 \sin 2\beta}{(M_1 - M_2)\mu^3}\tan^2\theta_W \\ &+ \frac{M_W^6 \sin^3 2\beta}{(M_1 - M_2)^2\mu^3}\tan^2\theta_W(\tan^2\theta_W - 1) + \mathcal{O}\left(\frac{1}{\mu^4}\right).\end{aligned}$$

(AMSB)

Loops

$$\Delta m_{1-\text{loop}} = \frac{\alpha_2 M_2}{4\pi}[f(M_W/M_2) - \cos^2\theta_W f(M_Z/M_2) - \sin^2\theta_W f(0)],$$

where

$$f(a) = 2\int_0^1 (1+x)\ln\left(x^2 + (1-x)a^2\right) dx.$$

Loops

$$\Delta m_{1-\text{loop}} \approx 150 \text{ MeV}$$

Higgsino limit

$$M_1, M_2 > \mu, M_W$$

$$\Delta m = \left[\frac{M_2}{M_1}\tan^2\theta_W + 1 + \operatorname{sgn}\mu\left(\frac{M_2}{M_1}\tan^2\theta_W - 1\right)\sin 2\beta\right]\frac{M_W^2}{2M_2} + \mathcal{O}\left(\frac{1}{M_2^2}\right).$$

How to scan multidimensional parameter spaces.

Making a grid with 12 parameters, 10 points per dimension.
$\Rightarrow 10^{12}$ points.

If we calculate 100 points per second
$\Rightarrow 10^{10}$ s $\approx$ 300 years....

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Scanning constraints

Constraint	mean value	error (theor, exp)	limit type
$(g-2)_\mu$	29.5×10^{-10}	$(1.0, 8.8) \times 10^{-10}$	gaussian
$\sin^2\theta_W$	0.23153	$(1.50, 1.60) \times 10^{-4}$	gaussian
$\Delta M_{B_s^0}$	$17.7 \times 10^{12}\hbar/\mathrm{s}$	$(2.4, 0.12) \times 10^{12}\hbar/\mathrm{s}$	gaussian
$b \to s\gamma$	3.55×10^{-4}	$(0.21, 0.26) \times 10^{-4}$	gaussian
$B_u \to \tau\nu$	1.32×10^{-4}	$(0.38, 0.49) \times 10^{-4}$	gaussian
$B_s \to \mu\mu$	0.77×10^{-8}	$(0.14, 0) \times 10^{-7}$	upper limit
M_h	125.5 GeV	(1.5, 0.5) GeV	gaussian
$M_{\tilde{g}} - M_{\chi_1^\pm}$	5 GeV	(0.1, 0) GeV	lower limit
$M_{\chi_1^\pm} - M_{\chi_1^0}$	1 GeV	(0.1, 0) GeV	upper limit

Scan parameters

Start with CMSSM; M_0, $M_{1/2}$, A_0, $\tan\beta$ ($sgn(\mu) = +1$)

Split $M_{1/2} \rightarrow M_1, M_2, M_3$

Use NUHM, i.e. scan over M_{H_u}, M_{H_d} or M_A and μ

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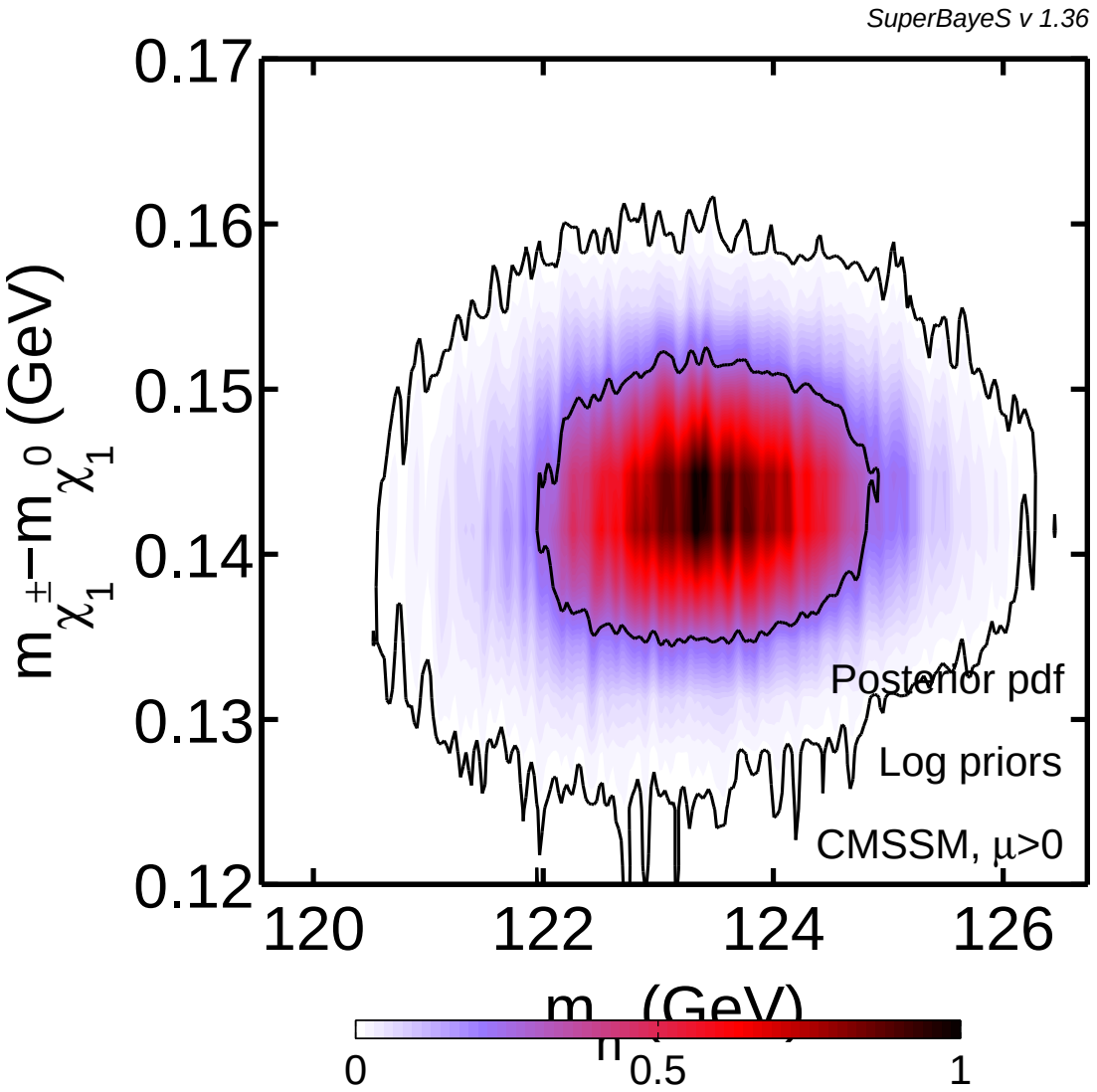
Scan results



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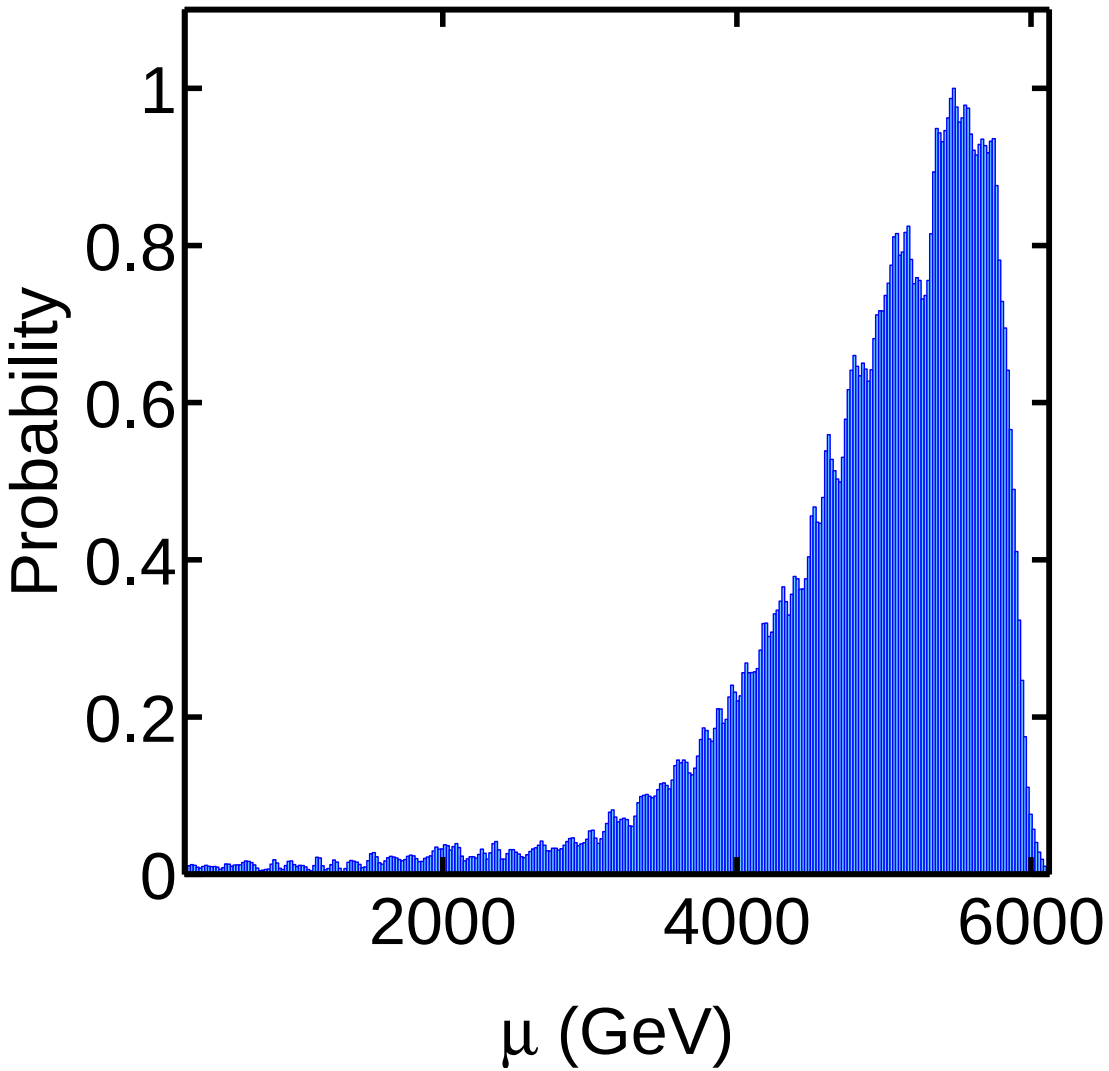

Summary

- R-parity violating decays of charginos could lead to spectacular LHC signatures.
- The chargino-neutralino mass difference is not likely to be much below the pion mass.
- But a mass difference very close to the pion mass is plausible and would give RPV chargino decay.