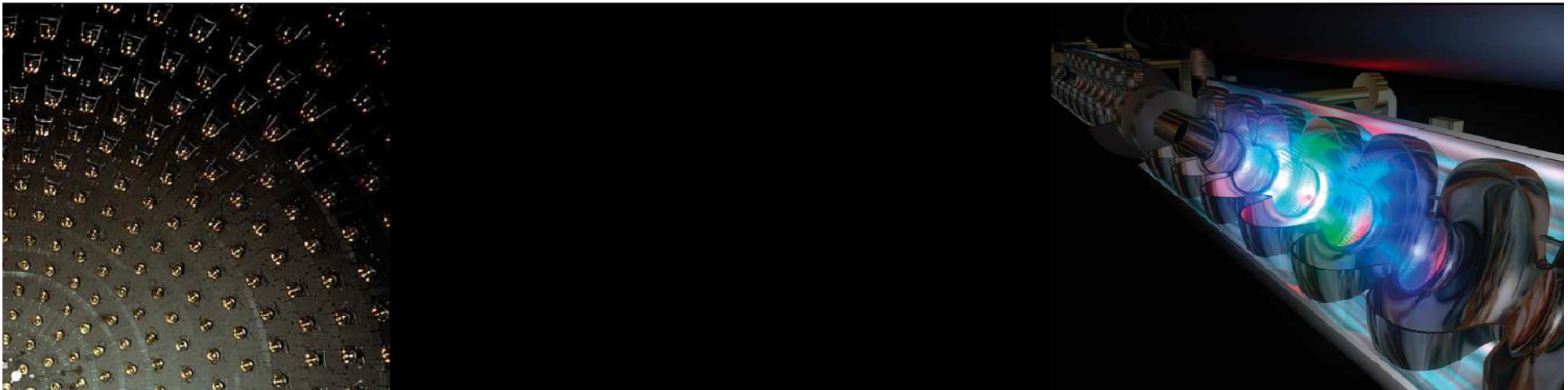


Bilinear R parity violation at the ILC

Neutrino physics at colliders?



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4th Annual Workshop of the Helmholtz Alliance
„Physics at the Terascale“
Dresden, 01.-03.12.2010

Outline

- > R parity violation – Phenomenology
- > Potential of ILC
- > Outlook



R parity

What is R parity?

- B and L violating terms allowed in superpotential (\Leftrightarrow SM)
- B and L violation never observed (proton decay)

→ Invent new symmetry which is a combination of B , L (and S)

$$P_R = (-1)^{3B+L+2S}$$

→ SM particles: $P_R = +1$

→ SUSY partners: $P_R = -1$

Consequences of conservation:

- proton decay prohibited
- sparticles can only be produced in pairs
- SUSY decay products contain odd number of LSPs
- LSP absolutely stable



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Consequences of conservation:

- proton decay prohibited → just break L or B
 - sparticles can only be produced in pairs
 - SUSY decay products contain odd number of LSPs
 - LSP absolutely stable → **LSP decays!**
- holds for **small RPV parameters**

BUT claim for conservation arbitrary from theoretical point of view



Superpotential

$$W = \underbrace{\varepsilon_{ab} \left(h_U^{ij} \hat{Q}_i^a \hat{U}_j \hat{H}_u^b + h_D^{ij} \hat{Q}_i^b \hat{D}_j \hat{H}_d^a + h_E^{ij} \hat{L}_i^b \hat{R}_j \hat{H}_u^a - \mu \hat{H}_d^a \hat{H}_u^b \right)}_{\text{MSSM superpotential}} + \underbrace{\varepsilon_i \hat{L}_i^a \hat{H}_u^b}_{\text{bRPV term}}$$

→ Higgs/Slepton-mixing

→ Sneutrinos acquire VEV $\langle \tilde{\nu}_i \rangle = v_i$

→ corresponding RPV soft SUSY breaking term $L_{soft}^{BRpV} = -B_i \varepsilon_{ab} \varepsilon_i \tilde{L}_i^a H_u^b$

$i=1..3$

masses and mixings of neutral fermions

Basis of neutral fermions: $\psi^{0T} = (-i\lambda', -i\lambda^3, \tilde{H}_d^1, \tilde{H}_u^2, \nu_e, \nu_\mu, \nu_\tau)$

Mass terms in the Lagrangian are given by: $L_m = -\frac{1}{2} (\psi^0)^T \mathbf{M}_N \psi^0 + h.c.$

4x4 MSSM neutralino mixing matrix

$$\mathbf{M}_N = \begin{pmatrix} M & & & & & & \\ & \chi^0 & & & & & \\ & & m^T & & & & \\ & & & 0 & & & \\ & m & & & & & \\ & & & & & & \end{pmatrix}$$

4x3 RPV matrix



Approximate diagonalization of \mathbf{M}_N

$$\mathbf{M}_N = \begin{pmatrix} M_{\chi^0} & m^T \\ m & 0 \end{pmatrix}$$

\mathbf{M}_N can be block-diagonalized for small RPV parameters via the Seesaw-like diagonalization:

$$\mathbf{M}_N = \text{diag}(M_{\chi^0}, m_{\text{eff}})$$

$$m_{\text{eff}} = -m M_{\chi^0} m^T = \frac{M_1 g^2 + M_2 g'^2}{4 \det M_{\chi^0}} \begin{pmatrix} \Lambda_e^2 & \Lambda_e \Lambda_\mu & \Lambda_e \Lambda_\tau \\ \Lambda_\mu \Lambda_e & \Lambda_\mu^2 & \Lambda_\mu \Lambda_\tau \\ \Lambda_\tau \Lambda_e & \Lambda_\tau \Lambda_\mu & \Lambda_\tau^2 \end{pmatrix}$$

where $\Lambda_i = \mathcal{E}_i v_d + \mu v_i$ „alignment parameters“

A final diagonalization of M_{χ^0} leads to the neutralino masses $m_{\chi_i^0}$ and a diagonalization of m_{eff} leads to one tree level neutrino mass.



Some results of this model

- **largest neutrino mass** at tree level
- **2 mixing angles** at tree level
- remaining masses/angles at 1-loop-level
- **correct scales** of mass differences Δm_{ij}^2

$$m_\nu = \frac{M_1 g^2 + M_2 g'^2}{4 \det M_{\chi^0}} |\vec{\Lambda}|^2$$

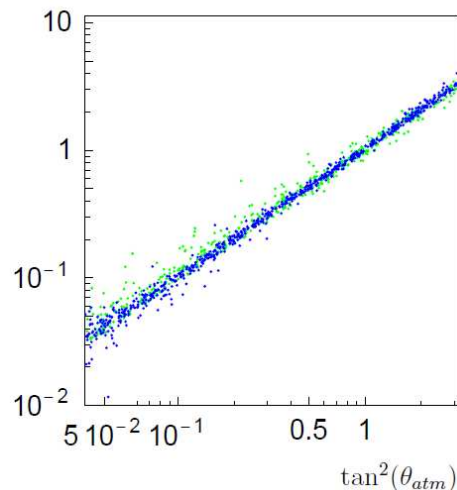
$$\tan \theta_{23} = \frac{\Lambda_\mu}{\Lambda_\tau}$$

$$\tan \theta_{13} = -\frac{\Lambda_e}{\sqrt{\Lambda_\mu^2 + \Lambda_\tau^2}}$$

How is that connected to colliders?

dominant part of $\tilde{\chi}_1^0 - W - l_i$ coupling: $O_i^L = \Lambda_i \cdot f(M_1, M_2, \mu, \tan \beta, v_d, v_u) \propto \Lambda_i$

a) $\text{Br}(\mu q q') / \text{Br}(\tau q q')$



$$\tan^2 \theta_{23} = \left| \frac{\Lambda_\mu}{\Lambda_\tau} \right|^2 \cong \frac{\text{BR}(\tilde{\chi}_1^0 \rightarrow \mu W)}{\text{BR}(\tilde{\chi}_1^0 \rightarrow \tau W)}$$

→ **Neutrino physics at collider experiments**



ILC potential

Benchmark scenario/ mass spectrum

MSSM – mSUGRA

SPS 1a'

$$m_0 = 70 \text{ GeV}$$

$$m_{1/2} = 250 \text{ GeV}$$

$$\tan \beta = 10$$

$$\text{sgn}(\mu) = 1$$

$$A_0 = -300 \text{ GeV}$$

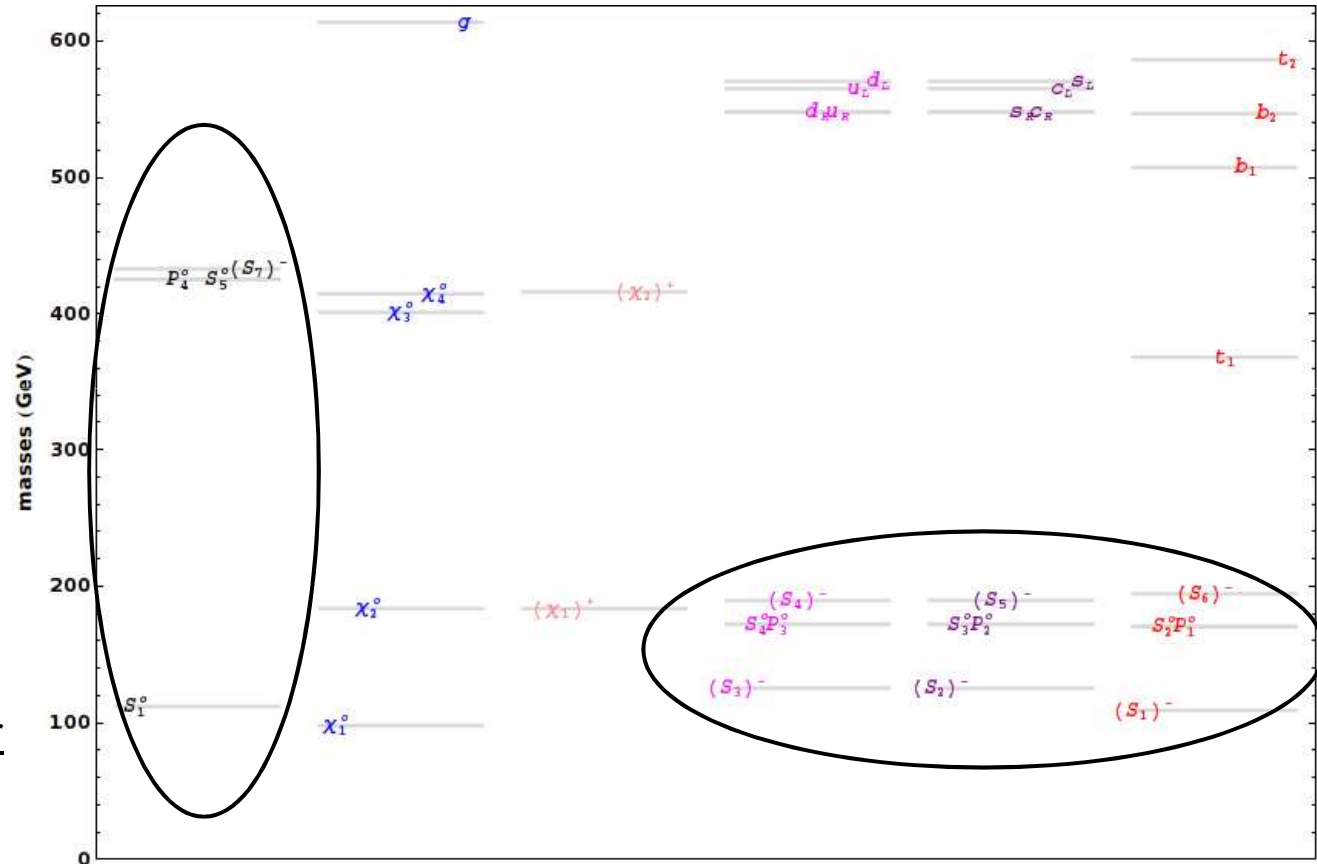
bRPV parameters

Fit to neutrino data

Spectrum generator

SPheno 3.0beta

(arXiv:hep-ph/0301101)



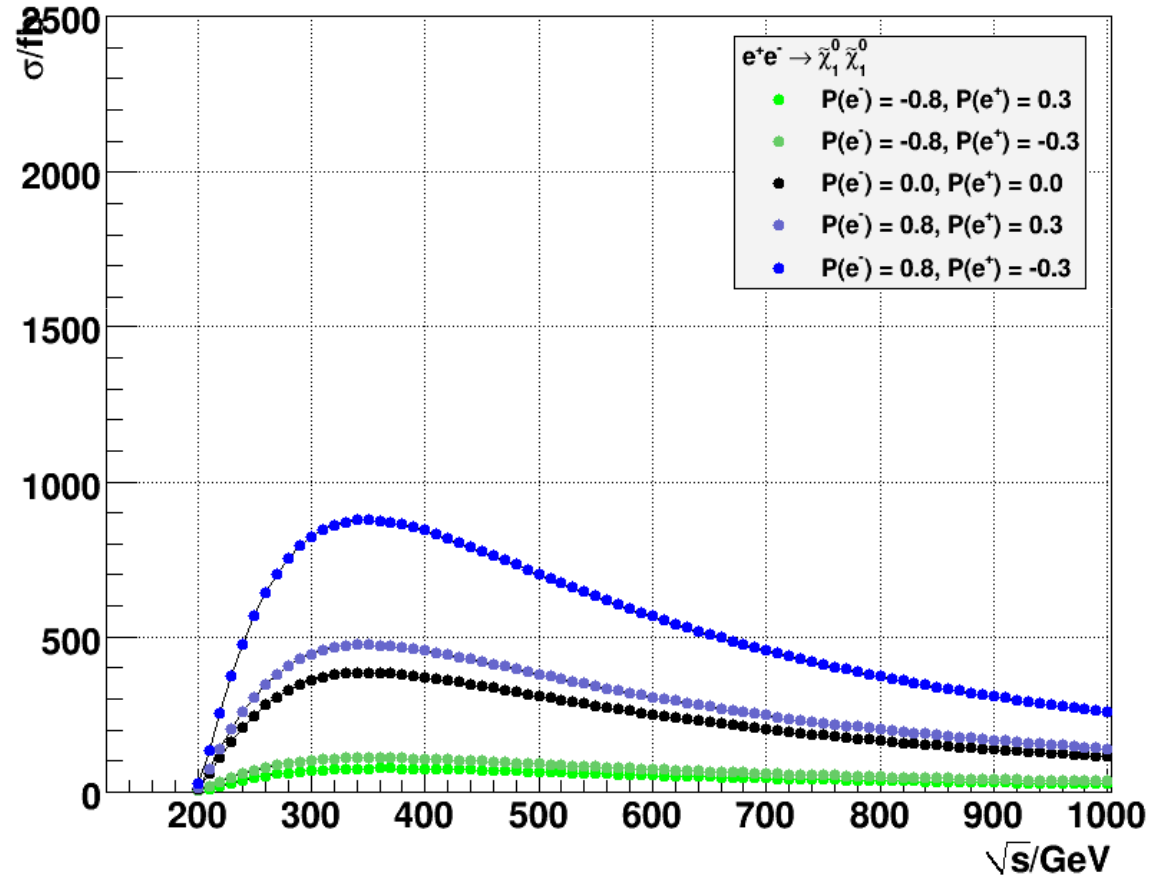
→ Higgs/Slepton mixing (new particle names S, P)



ILC potential

Production cross section

cross section: $\tilde{\chi}_1^0 \tilde{\chi}_1^0$ production



LSP mixing character:
 83,9% Bino
 4,0% u Higgsino
 4,0% d Higgsino
 8,1% Wino

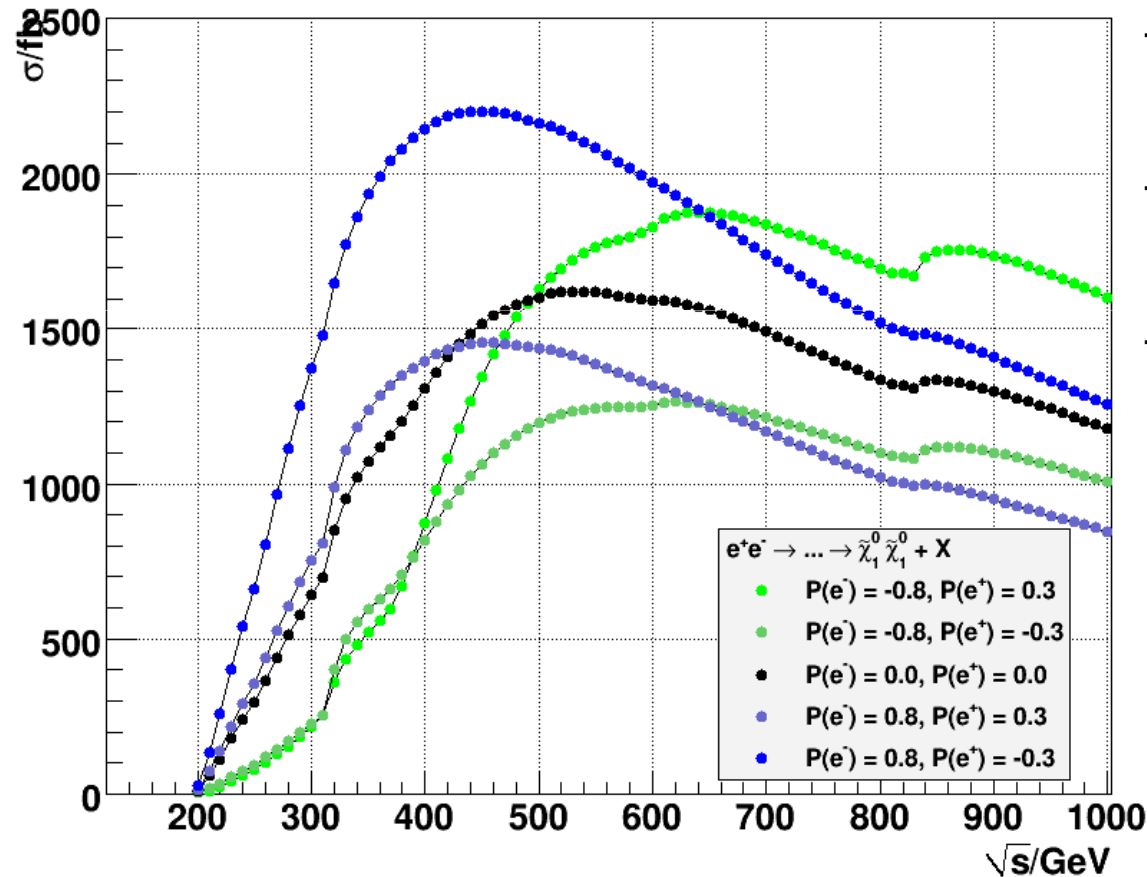
- main production processes:
t-, u-channel
- „selectron“ exchange
($S_3^- \approx \sim e^-_R, S_4^- \approx \sim e^-_L$)
- $m(S_3^-) < m(S_4^-) \rightarrow \sigma_{+-} > \sigma_{-+}$



ILC potential

Production cross section

cross section: $\tilde{\chi}_1^0 \tilde{\chi}_1^0 + X$ production



- small RPV parameters
→ LSP decays into SM
- typical SUSY cascades with LSP decay in the end
- almost all sparticle-production processes can be used to study LSP decays



ILC potential

Decay channels of LSP (BR>0.01)

LSP decay	Branching ratio
$W \mu$	0.034
$W \tau$	0.031
$\nu_2 b b$	0.035
$\nu_1 \tau e$	0.159
$\nu_1 \tau \mu$	0.279
$\nu_1 \tau \tau$	0.453

Study neutrino parameters

neutrino mixing, ...

Study LSP parameters

mass (endpoint), mixing character, ...

Decay width of LSP

$$\bar{\Gamma} = 3.77 \cdot 10^{-13} \text{ GeV} \quad \rightarrow \quad \bar{\Gamma} \approx 523 \text{ } \mu\text{m}$$

Displaced vertices expected!

Analysis strategy

- Looking for:
- LFV signal
 - two displaced vertices per event (+cascade products from IP)
 - high effective mass per event



ILC potential

Systematical uncertainties (one example)

$\int L dt = 500 \text{ fb}^{-1}$ (4 years of ILC running)
 $\sigma_{+}(500\text{GeV}) = 2200 \text{ fb}$
 Detection efficiency = 0.5

$\rightarrow N_{W\mu} = 37500 \cdot 0.5 = 18750 \quad \sigma_{\text{rel}}^{\text{stat}} = 0.74\%$
 $\rightarrow N_{W\tau} = 34100 \cdot 0.5 = 17050 \quad \sigma_{\text{rel}}^{\text{stat}} = 0.77\%$
 $\sigma_{\text{rel}}^{\text{stat}}(\text{Br}(\chi \rightarrow W\mu) / \text{Br}(\chi \rightarrow W\tau)) \approx 1\%$
 $\rightarrow \theta_{\text{atm}} = (46.36 \pm 0.15)^\circ$

Signal/background estimation

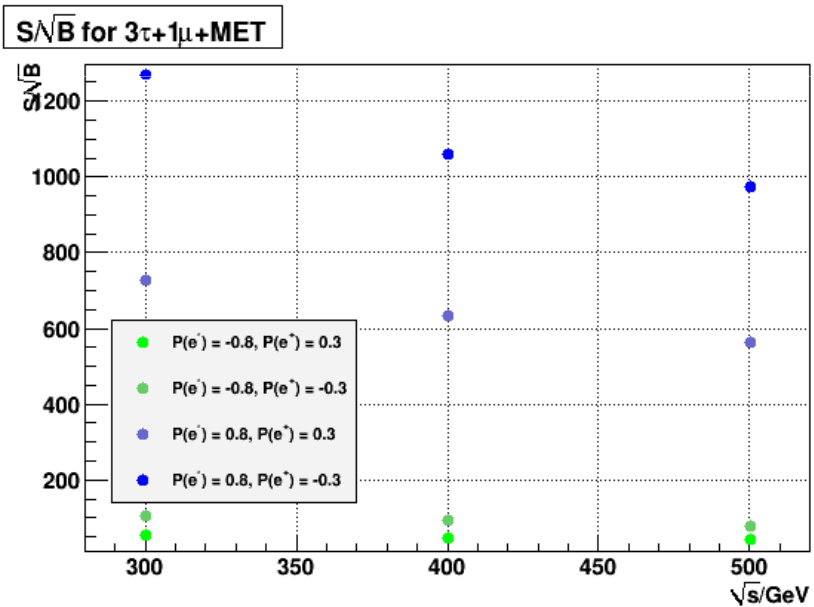
- tree level cross sections for SM BG (Whizard 2.0; arXiv:0708.4233)
- just looking for similar final states

for example:

$$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow (\nu\tau\tau)(\nu\tau\mu)$$

$$e^+e^- \rightarrow SM \rightarrow \tau\tau\nu\mu\nu$$

$= 3\tau + 1\mu + \text{MET}$



\rightarrow Comparable results for almost all decay channels (at least $S/\sqrt{B} > 10$)



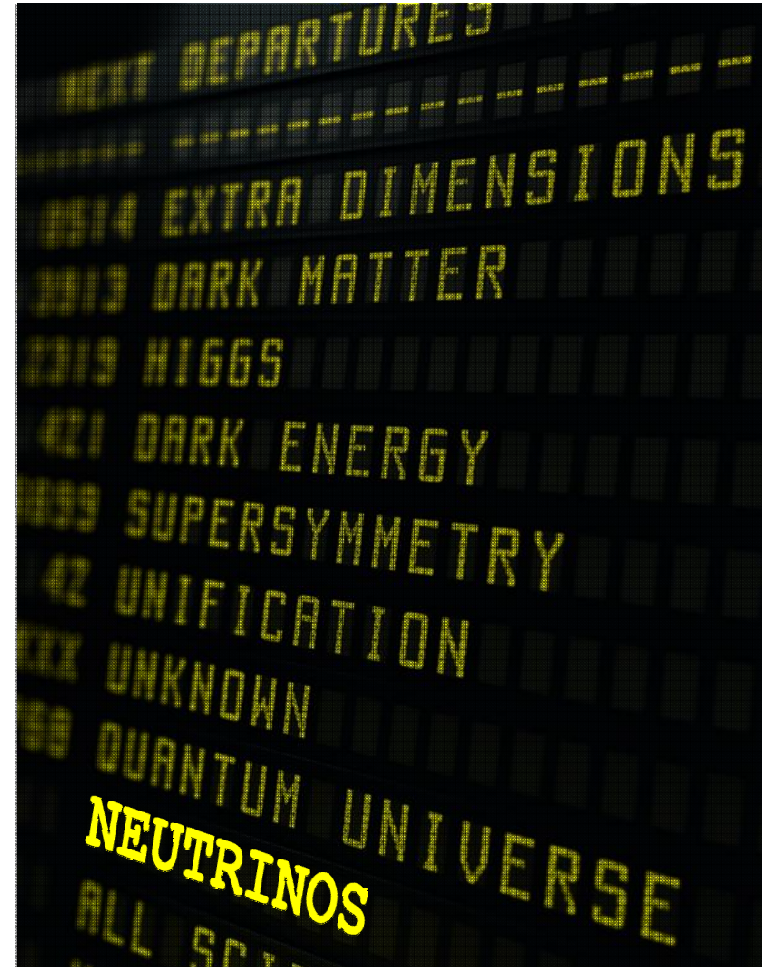
Conclusion, Outlook

Conclusion

- > bRPV enables access to neutrino parameters at colliders
- > Predicted cross sections are quite promising
- > SM background small
- > Need for very good vertex detection
- > Polarisation is a very useful tool to increase signal over background
- > ILC is highly capable to look at that kind of models

Outlook

- > Implementation of bRPV in Whizard using FeynRules on the way
- > Detailed study in progress



Friday, 03.12., 14:00-17:00: LFV/neutrino masses working group meeting
Bilinear RPV at ATLAS (LSP mass reconstruction)



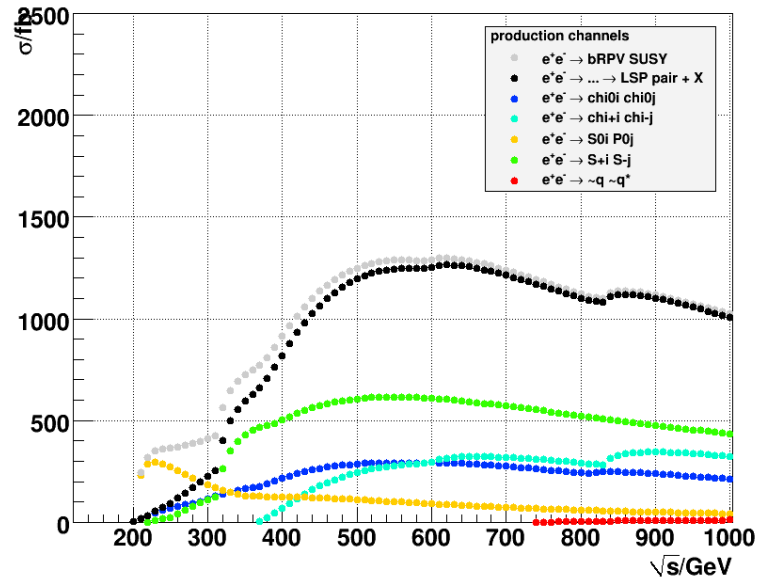
Thank you for your attention.



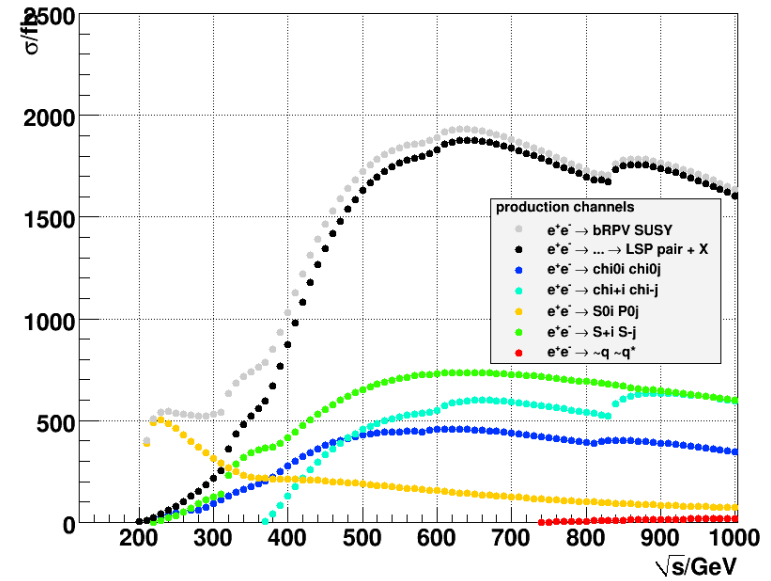
Backup slides



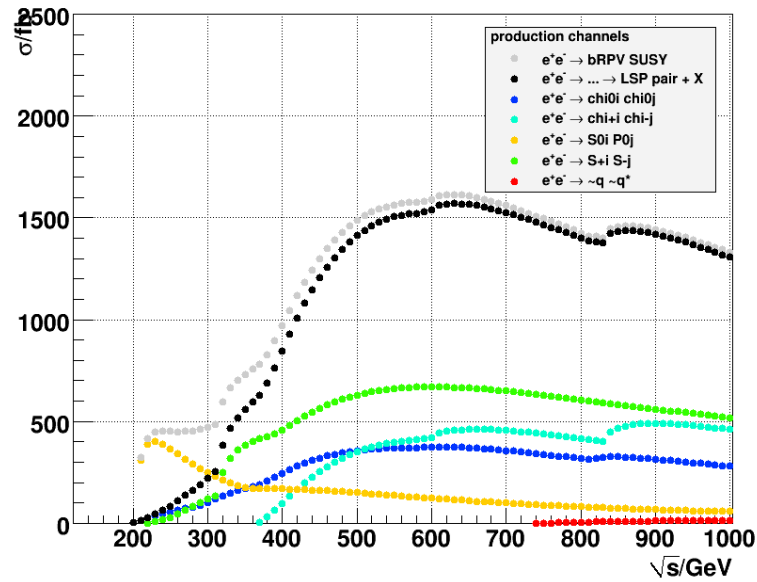
cross sections ($P(e^-) = -0.8, P(e^+) = -0.3$)



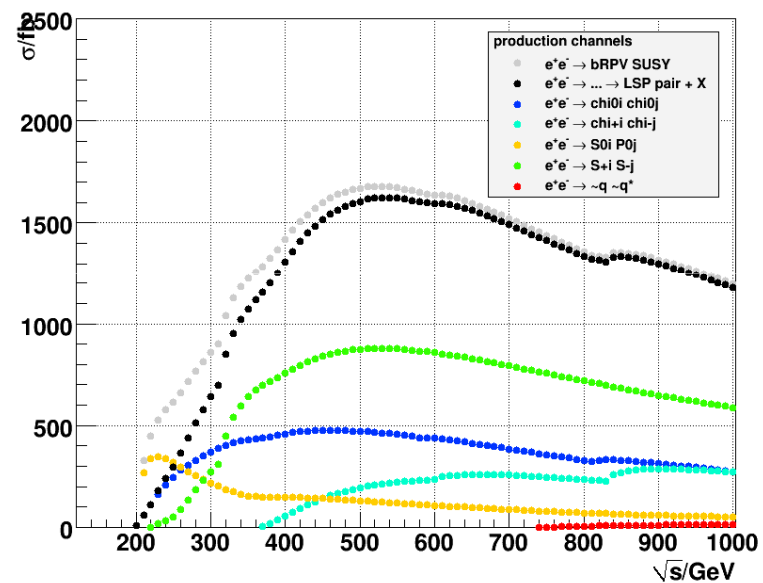
cross sections ($P(e^-) = -0.8, P(e^+) = +0.3$)



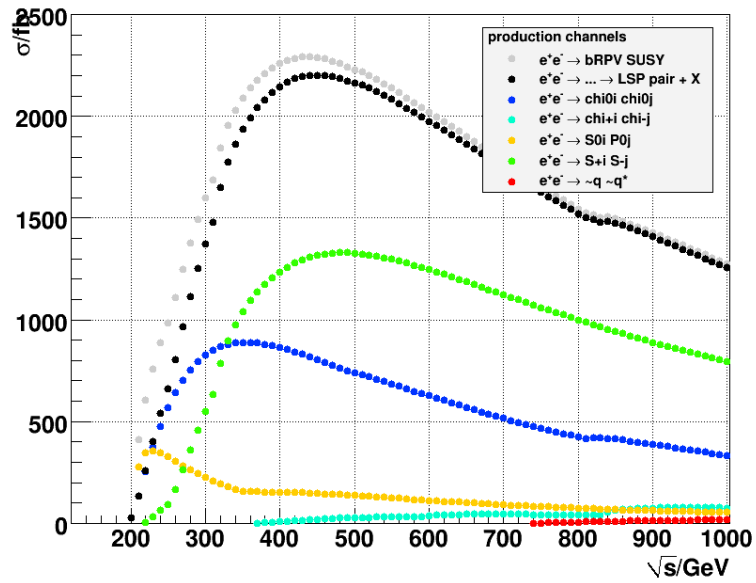
cross sections ($P(e^-) = -0.8, P(e^+) = 0.0$)



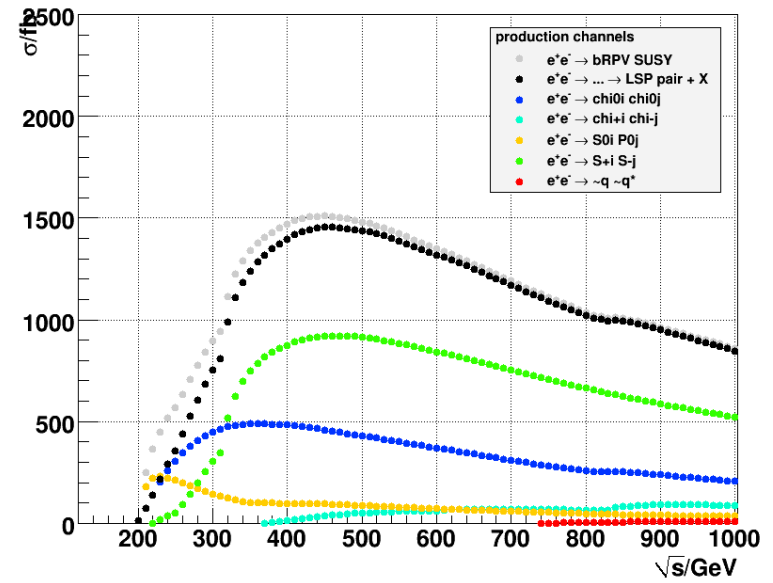
cross sections ($P(e^-) = 0.0, P(e^+) = 0.0$)



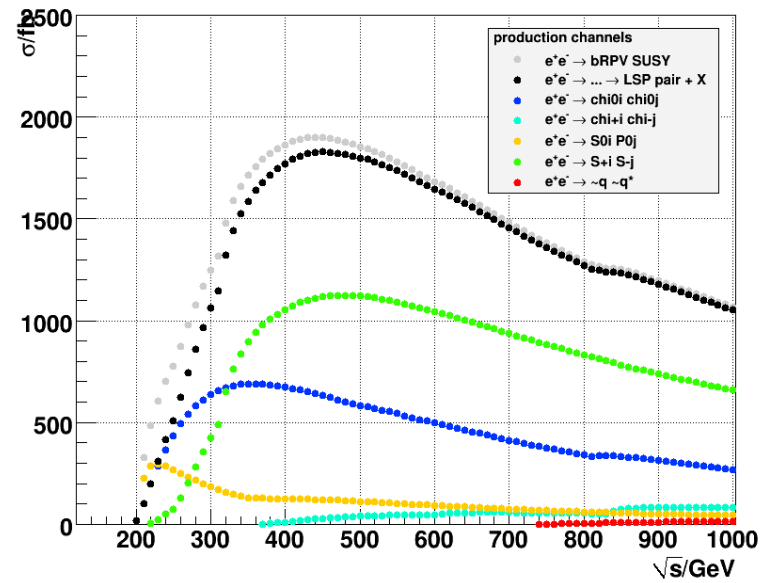
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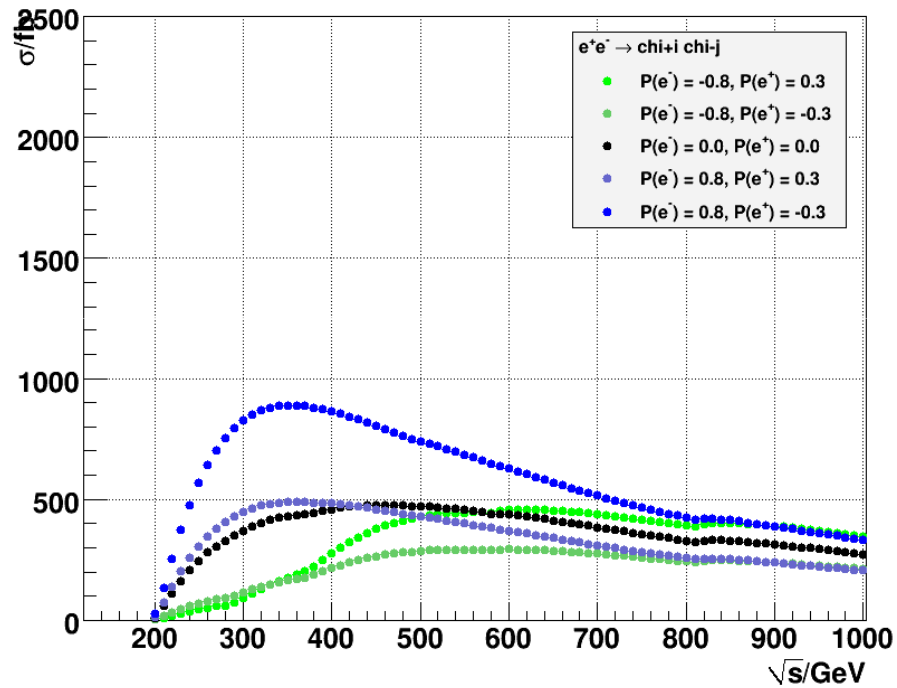
cross sections ($P(e^-) = 0.8, P(e^+) = 0.3$)



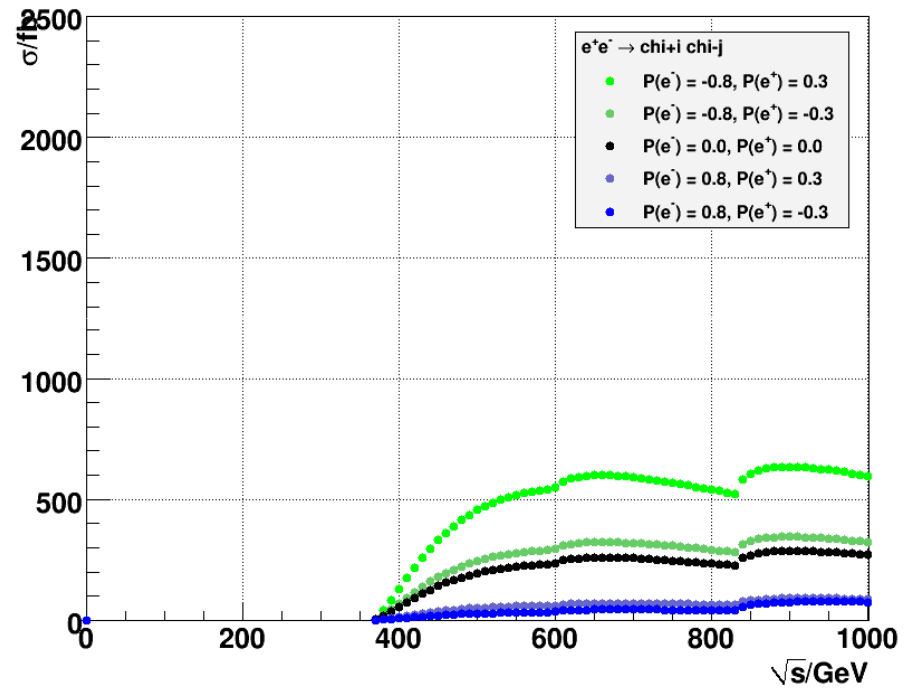
cross sections ($P(e^-) = 0.8, P(e^+) = 0.0$)



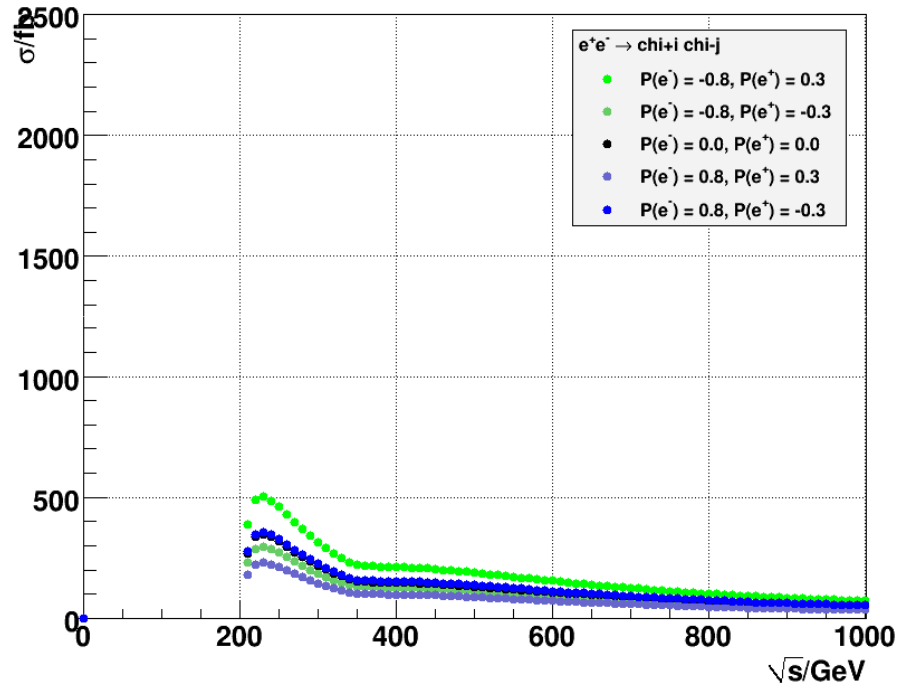
cross section: neutralino production



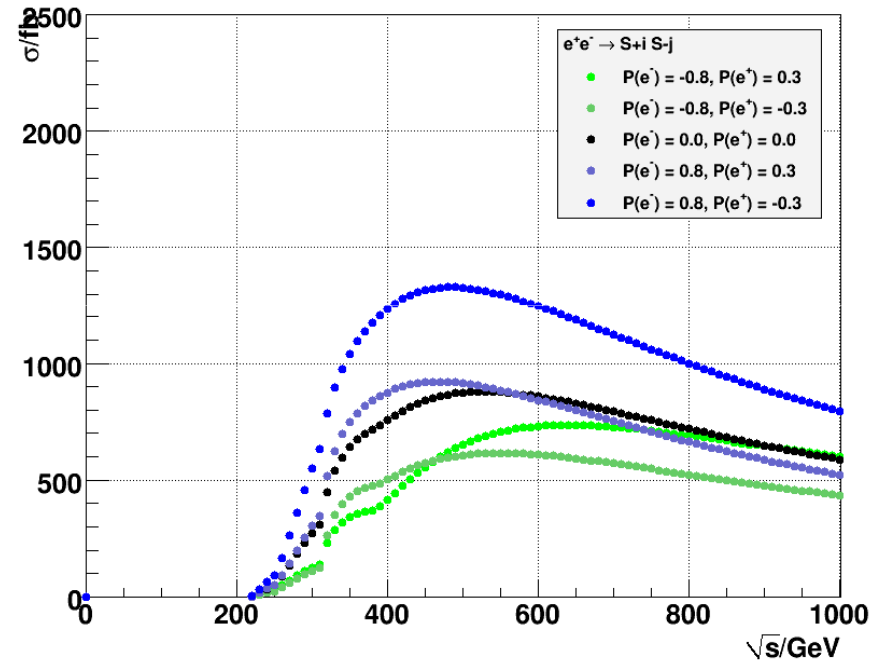
cross section: chargino production



cross section neutral scalar production



cross section charged scalar production



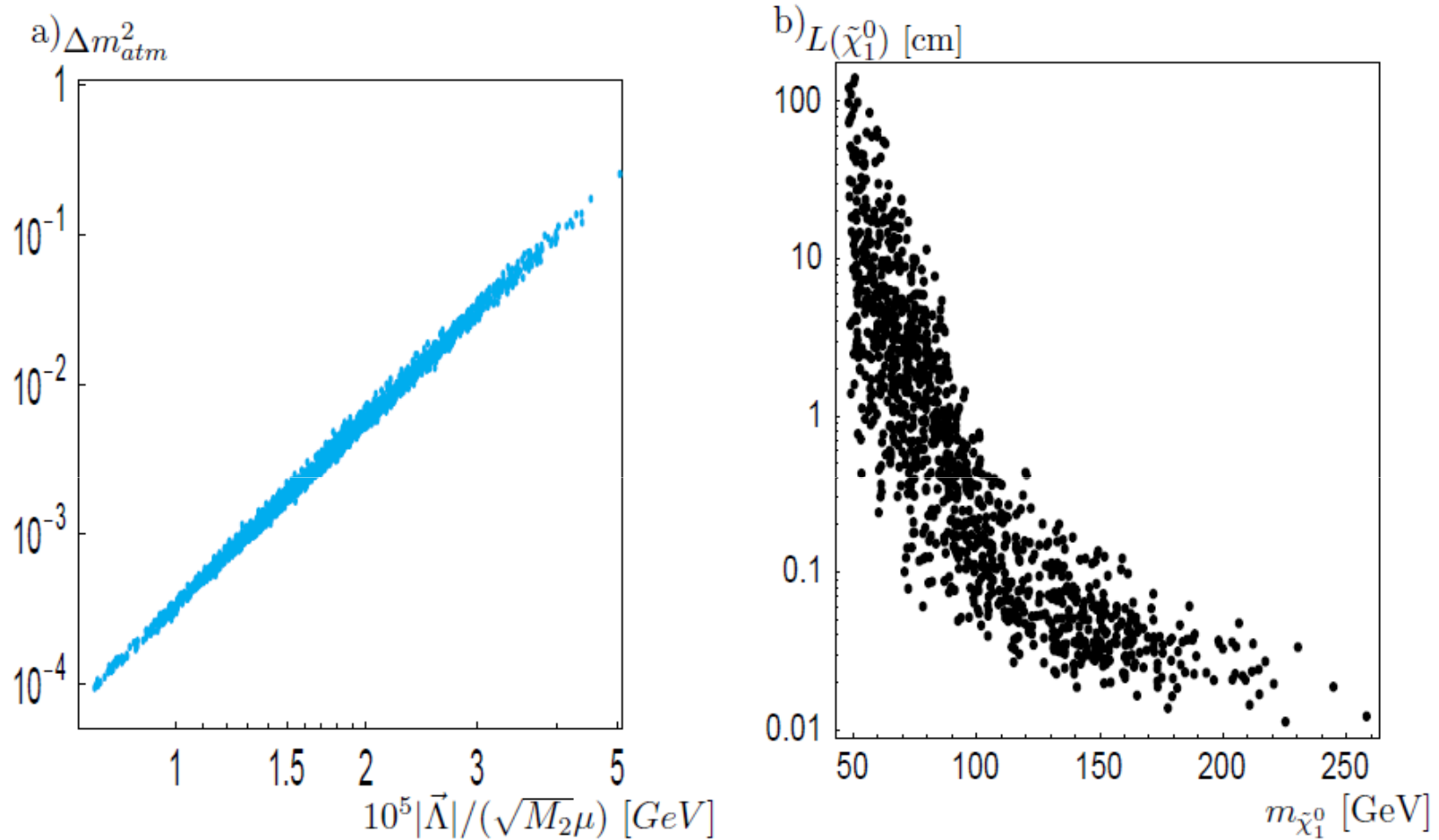


Figure 4: a) Δm_{atm}^2 and b) neutralino decay length.

