Bilinear R parity violation at the ILC

Neutrino physics at colliders?

Benedikt Vormwald, Jenny List,
Gudrid Moortgat-Pick
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HELMHOLTZ ASSOCIATION

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DESY

Outline

- R parity violation – Phenomenology

- Potential of ILC

- Outlook

R parity

What is R parity?

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

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

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

$\longrightarrow$ SM particles: $P_R = +1$

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

⟶ SM particles: $P_R = +1$

⟶ SUSY partners: $P_R = -1$

BUT claim for conservation arbitrary from theoretical point of view

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

⟶ holds for **small RPV parameters** (for the two points above)

- LSP absolutely stable ⟶ **LSP decays!**

W. Porod et. al.
arXiv:hep-ph/0011248

Superpotential

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

MSSM superpotential

bRPV term
$i=1..3$

→ Higgs/Slepton-mixing

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

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

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: $L_m = -\frac{1}{2}(\psi^0)^T \mathbf{M_N}\psi^0 + h.c.$

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

4x4 MSSM neutralino mixing matrix → M_{χ^0}

4x3 RPV matrix → m

DESY

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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:

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

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

where $\Lambda_i = \varepsilon_i v_d + \mu v_i$ „alignment parameters“

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

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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

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

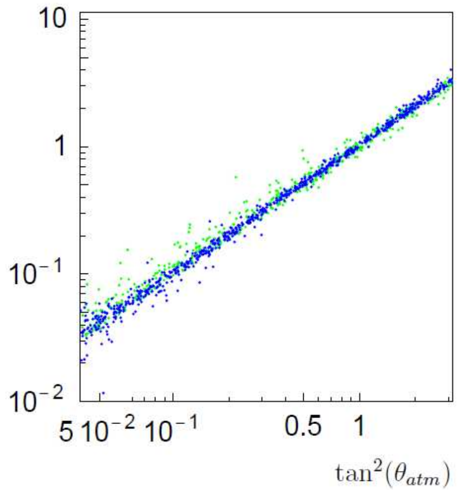
$$\tan\theta_{23} = \frac{\Lambda_\mu}{\Lambda_\tau}$$

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

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) Br($\mu q q'$)/Br($\tau q q'$)



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

→ Neutrino physics at collider experiments

ILC potential

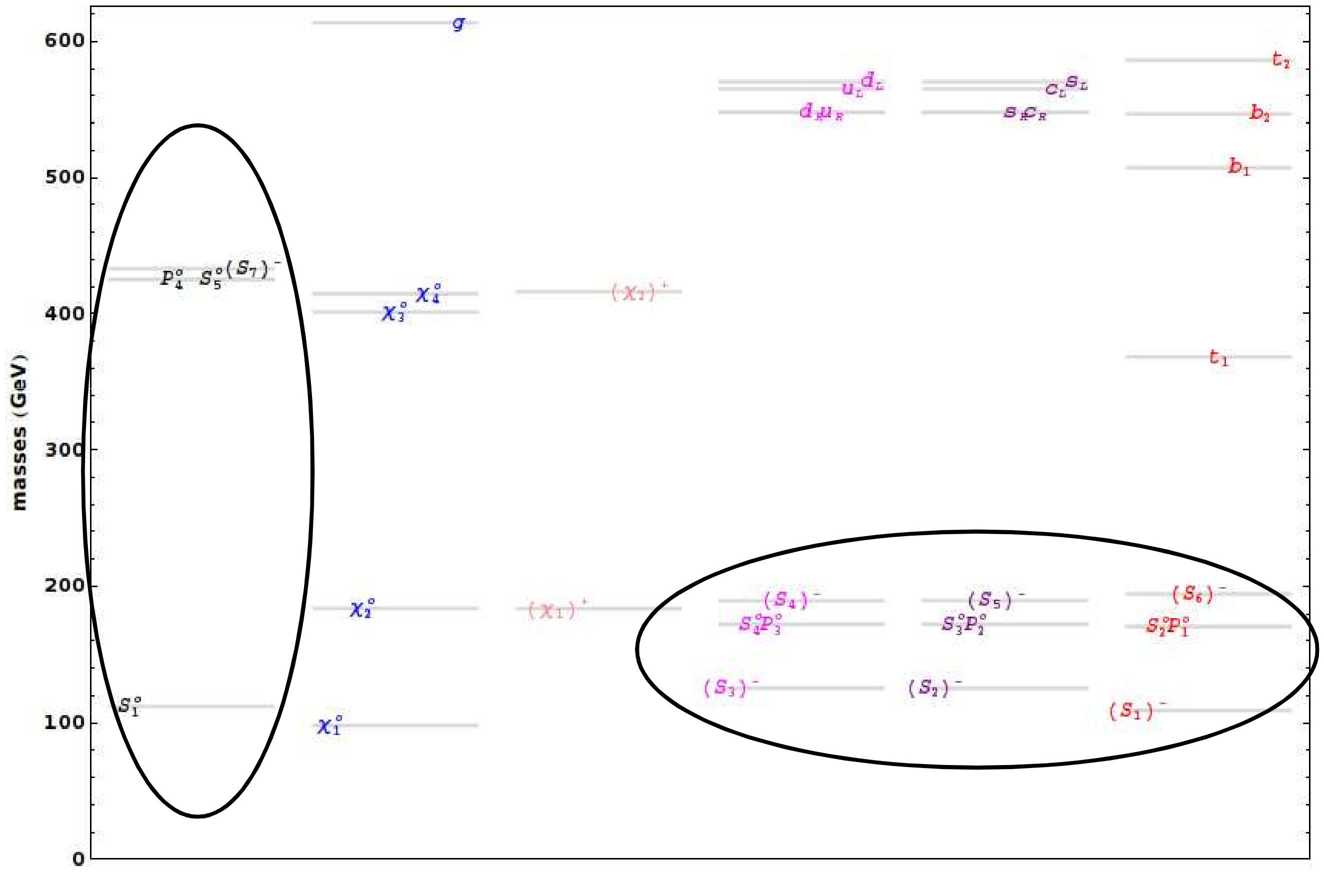
Benchmark scenario/ mass spectrum

MSSM – mSUGRA

SPS 1a‘
m_0 = 70 GeV
$m_{1/2}$ = 250 GeV
tan β = 10
sgn(μ) = 1
A_0 = -300 GeV

bRPV parameters
Fit to neutrino data

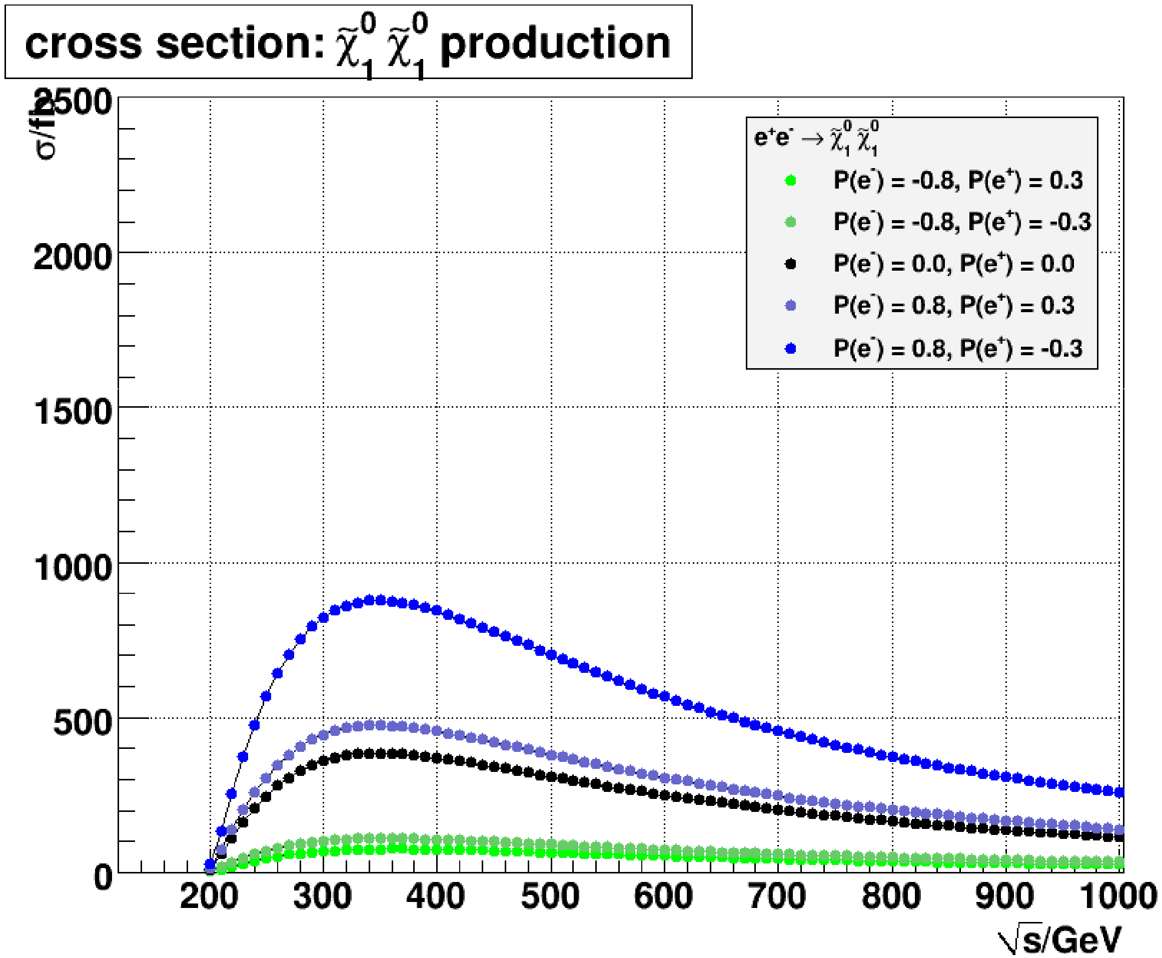
Spectrum generator
SPheno 3.0beta
(arXiv:hep-ph/0301101)



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

ILC potential

Production cross section



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

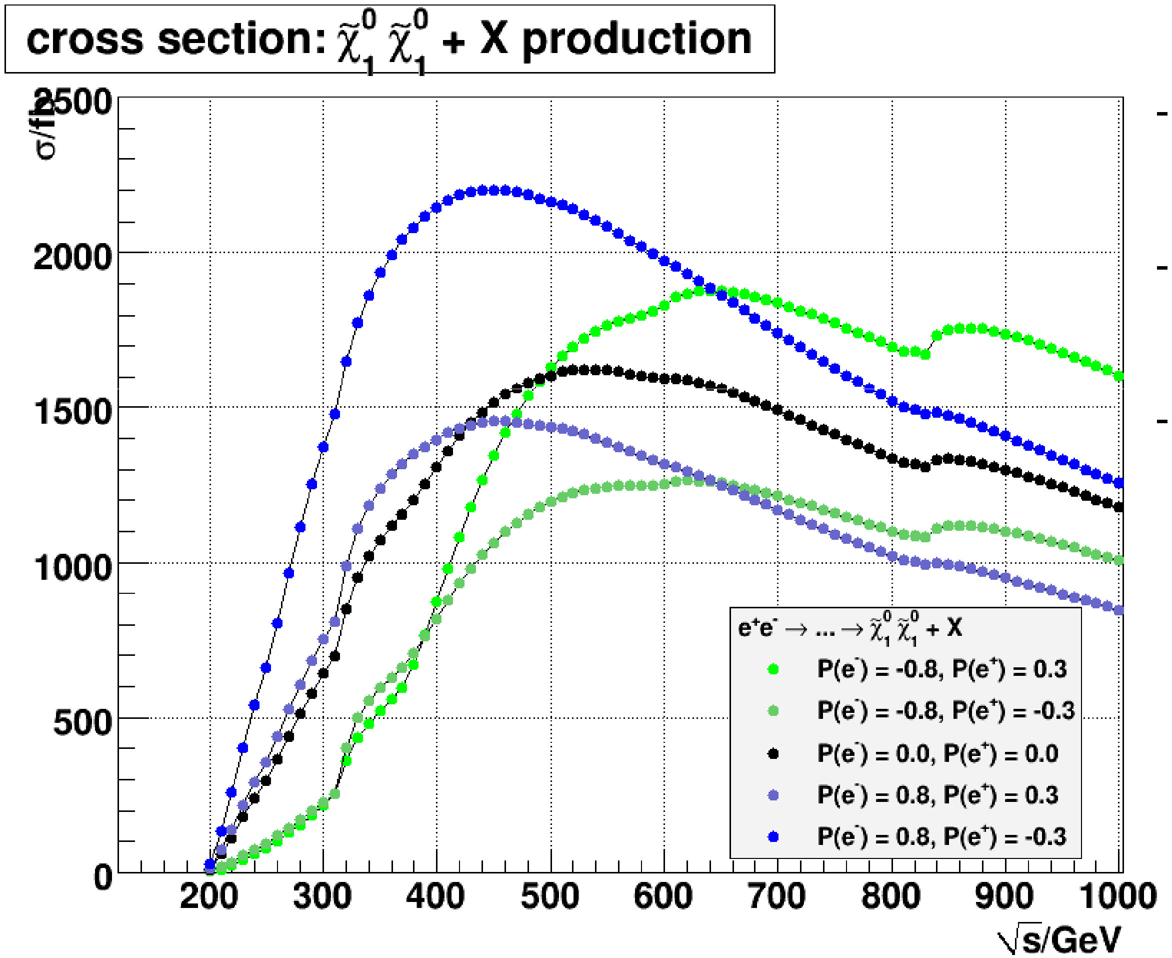
- main production processes:
  t-, u-channel

- „selectron“ exchange
  ($S^-_3 \approx \sim e^-_R$, $S^-_4 \approx \sim e^-_L$)

- $m(S^-_4) > m(S^-_3) \rightarrow \sigma_{-+} > \sigma_{+-}$

ILC potential

Production cross section



- 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 μ	0.034
W τ	0.031
ν_2 b b	0.035
ν_1 τ e	0.159
ν_1 τ μ	0.279
ν_1 τ τ	0.453

Study neutrino parameters

neutrino mixing, …

Study LSP parameters

mass (endpoint), mixing character, …

Decay width of LSP

$\overline{\Gamma} = 3.77 \cdot 10^{-13}$ GeV → $\overline{l} \approx 523$ μm

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)

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

→ $N_{W\mu} = 37500 \cdot 0.5 = 18750$ $\sigma_{rel}^{stat}=0.73\%$
→ $N_{W\tau} = 34100 \cdot 0.5 = 17050$ $\sigma_{rel}^{stat}=0.77\%$

$\sigma_{rel}^{stat}(Br(\chi \to W\mu) / Br(\chi \to W\tau)) \approx 1\%$

Signal/background estimation

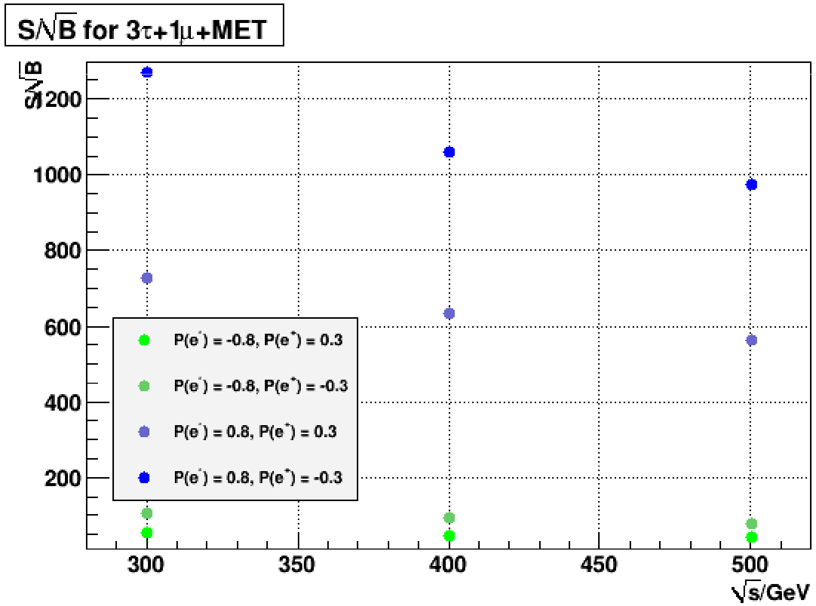
- tree level cross sections for SM BG (Whizard 2.0; arXiv:0708.4233)
- just looking for similar final states

for example:

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

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

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

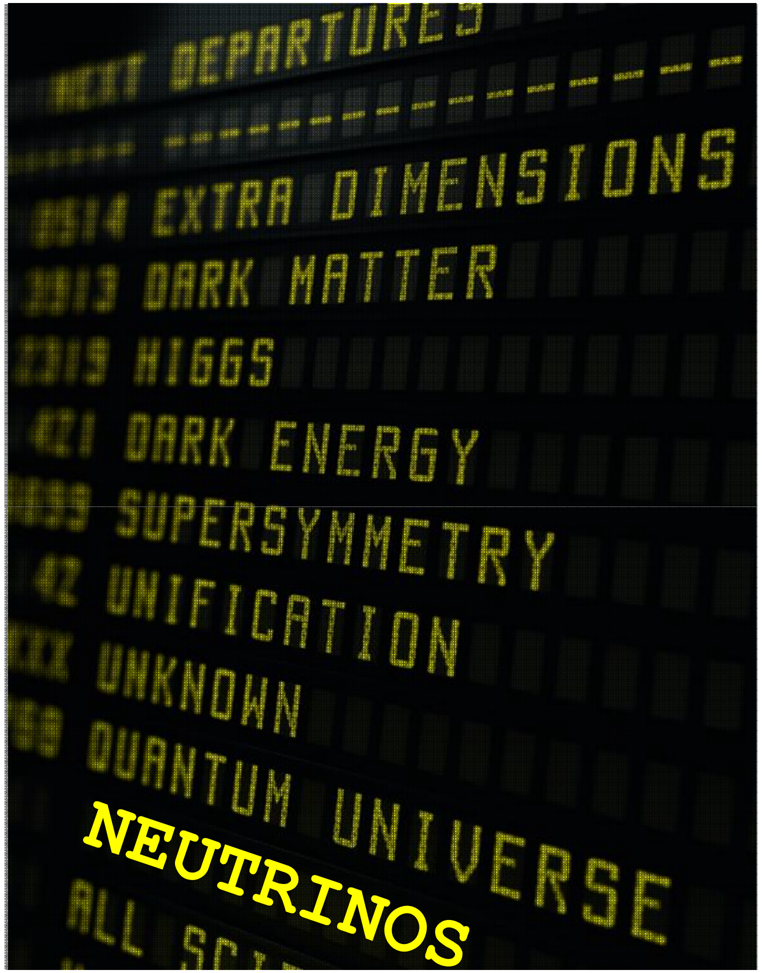


→ **Comparable results for almost all decay channels** (at least S/sqrt(B) > 10)

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



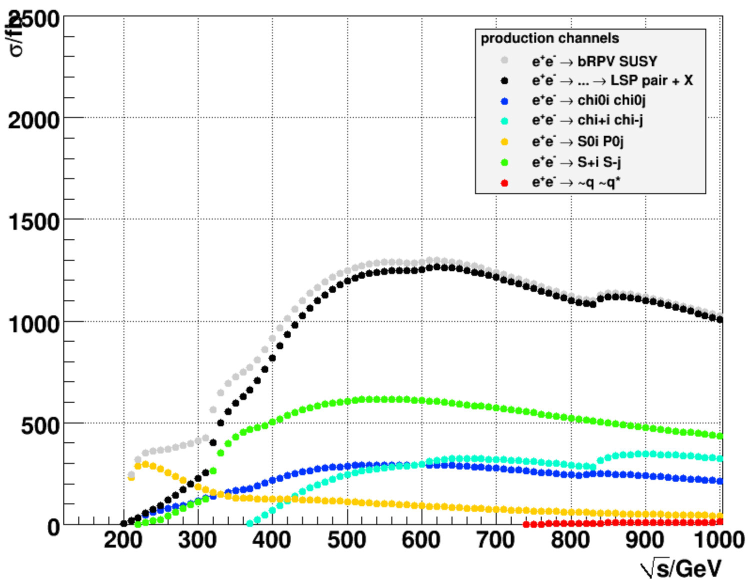
Outlook

- Implementation of bRPV in Whizard using FeynRules on the way (Benjamin Fuks)
- Detailed study in progress

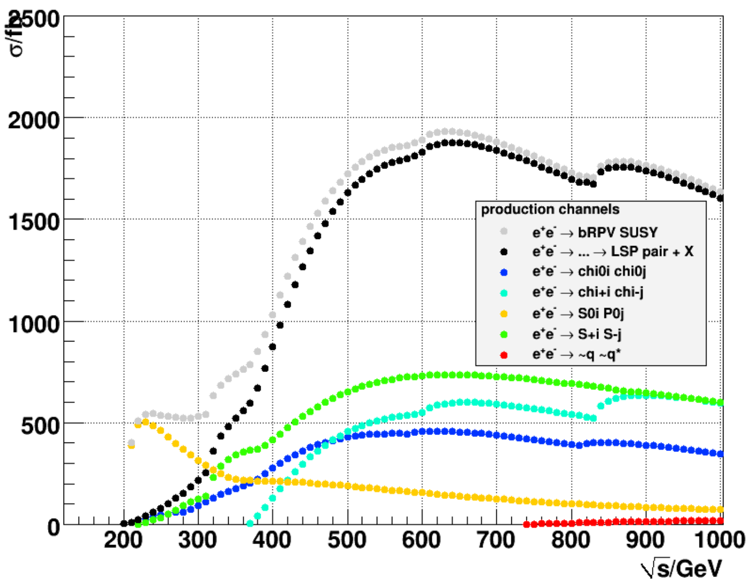
Thank you for your attention.

Backup slides

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



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



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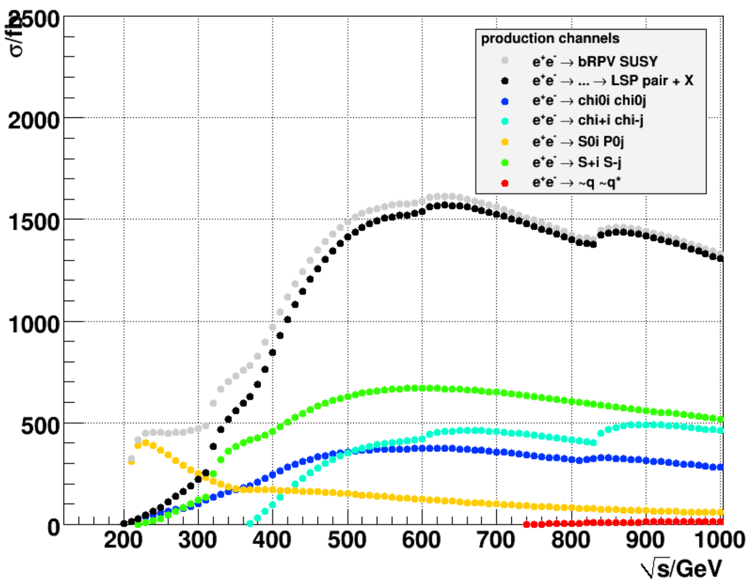
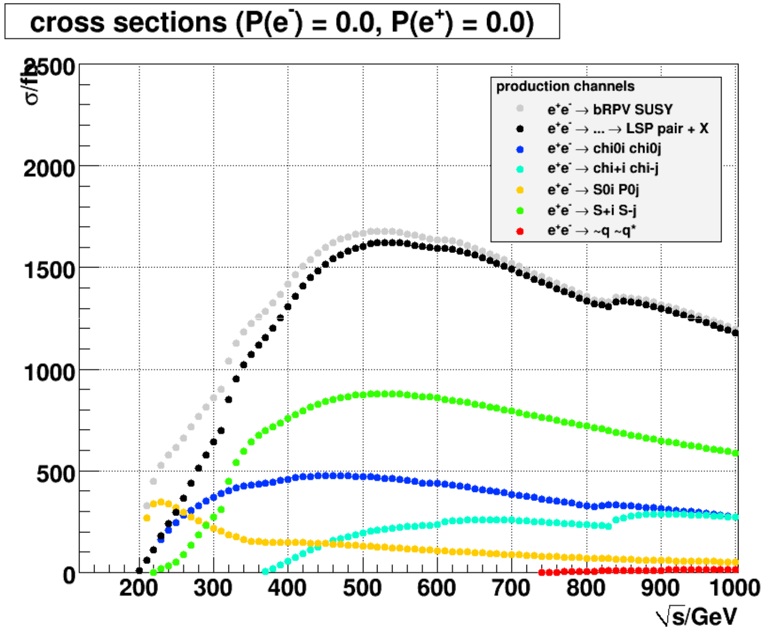
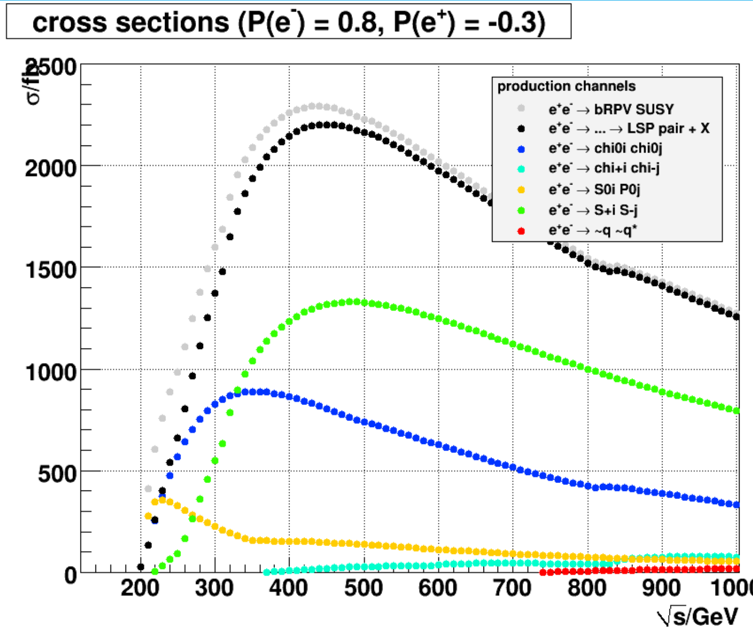



cross sections (P(e-) = 0.0, P(e+) = 0.0)
σ/fb
2500
2000
1500
1000
500
0
200
300
400
500
600
700
800
900
1000
√s/GeV
production channels
e+e- → bRPV SUSY
e+e- → ... → LSP pair + X
e+e- → chi0i chi0j
e+e- → chi+i chi-j
e+e- → S0i P0j
e+e- → S+i S-j
e+e- → ~q ~q*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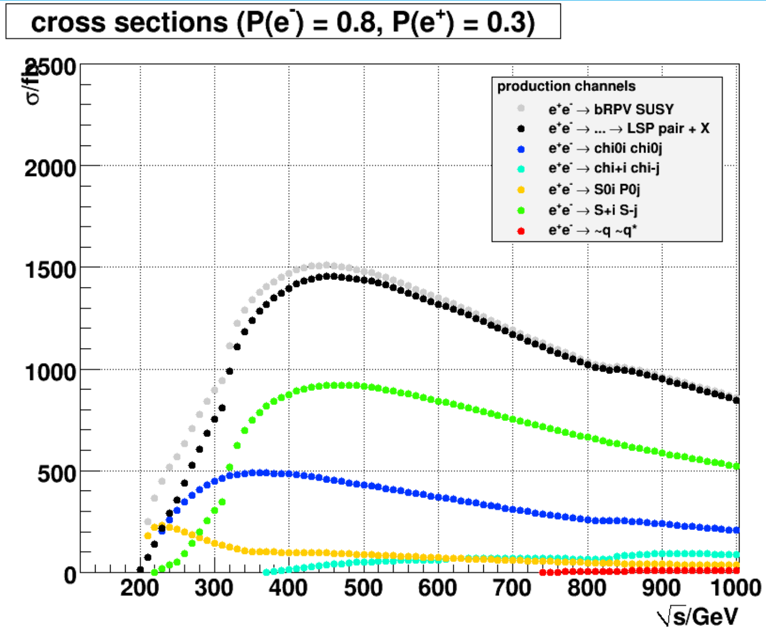
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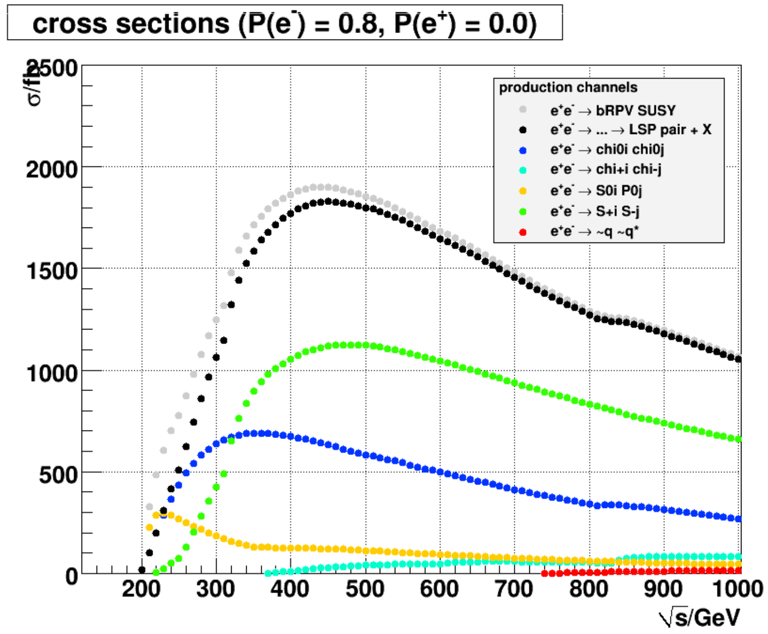
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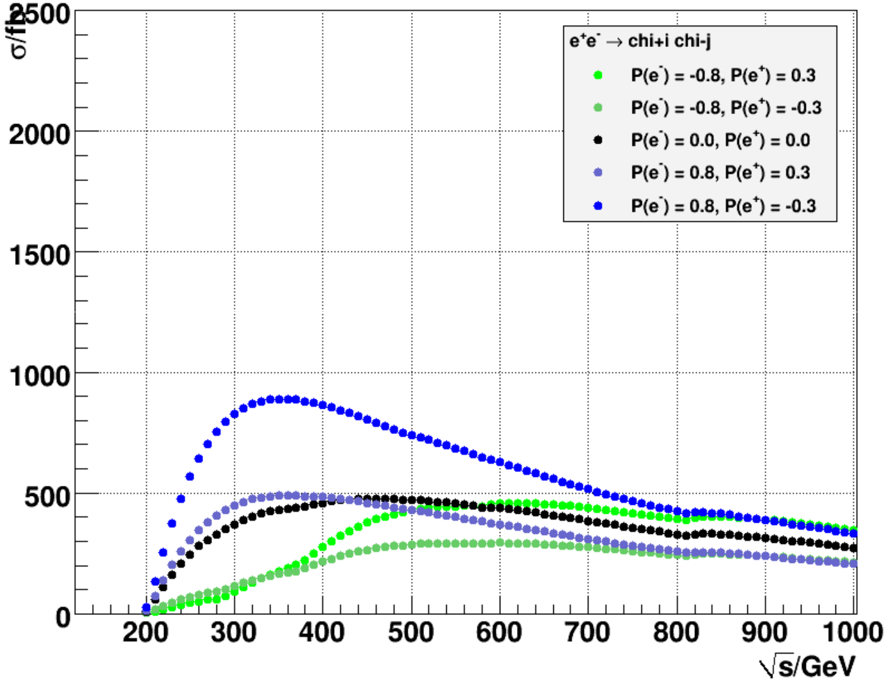
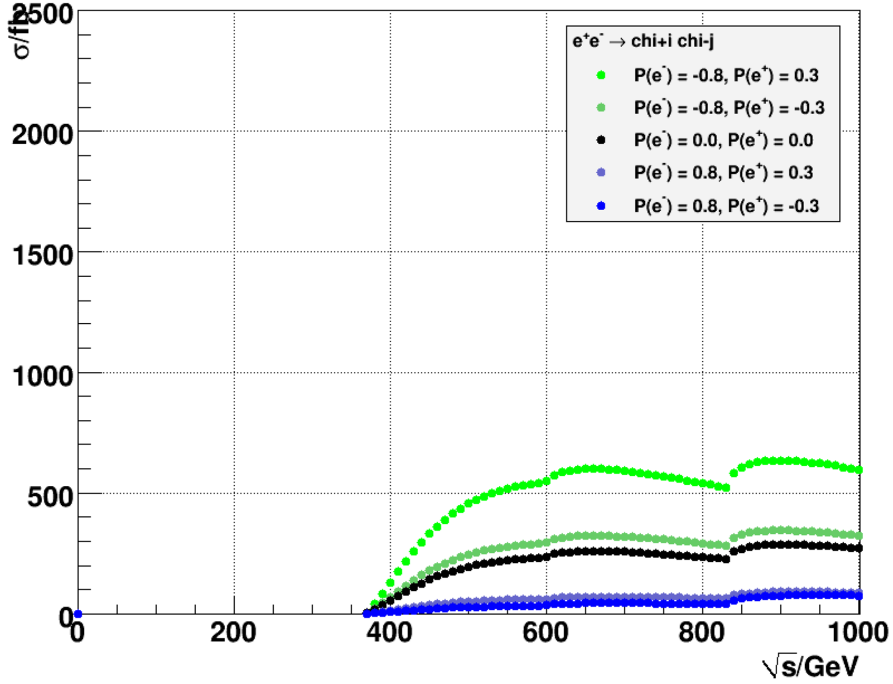
√s/GeV

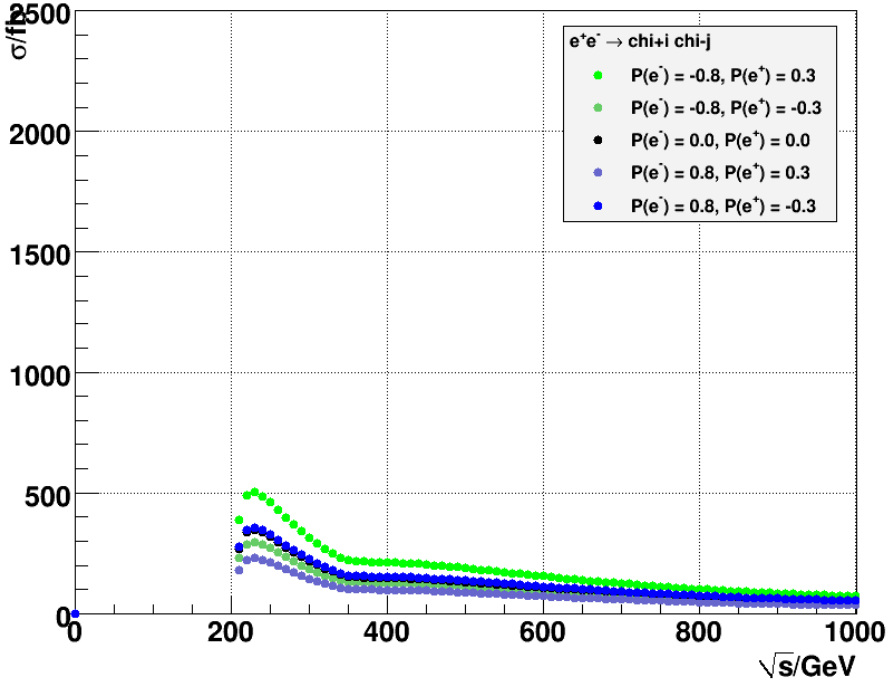
cross section: neutralino production



cross section: chargino production



cross section neutral scalar production



cross section charged scalar production