# R-parity violating mSUGRA with stau LSP

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- Introduction
- Phenomenology of the RPV mSUGRA model (benchmark points)
- Results and open questions
- Summary

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# Introduction

- R-parity usually taken as conserved to avoid rapid proton decay; results in stable LSP
- Stable LSP needs to be neutral and weakly interacting by cosmological constraints
- Other symmetries exists which stabilize the proton, but break R-parity: LSP not stable $\Rightarrow$ no constraints on LSP
  - Baryon triality
  - Lepton parity

# R-parity violating terms

- All possible fully-renormalizable gauge invariant terms:
  Introduce Baryon number (*B*) or Lepton number (*L*) violating couplings

$$\mathbf{W}_{\not{R}_P} = \epsilon_{ab} \left[ \frac{1}{2} \underbrace{\lambda_{ijk} L_i^a L_j^b \bar{E}_k}_{\text{violates } L} + \underbrace{\lambda'_{ijk} L_i^a Q_j^{bx} \bar{D}_{kx}}_{\text{violates } L} \right]$$

$$+ \frac{1}{2} \epsilon_{xyz} \underbrace{\lambda''_{ijk} \bar{U}_i^x \bar{D}_j^y \bar{D}_k^z}_{\text{violates } B} - \epsilon_{ab} \underbrace{\kappa^i L_i^a H_u^b}_{\text{violates } L}$$

- Only *B* **or** *L* violating couplings allowed to prevent proton decay

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# R-parity violating terms:
## Existing Bounds

- Strong bounds from precision measurements exist on those couplings
  - RPV and bounds studied by [Allanach, Dedes, Dreiner: Phys.Rev.D69:115002,2004]
  - Couplings too small to change SUSY mass spectrum significantly compared to the related RPC case, but nature of LSP may change

- Choosing one non-vanishing $\lambda$, $\lambda'$ or $\lambda''$ coupling at $M_{\mathrm{GUT}}$ generates several other RPV couplings at the weak scale by RGEs.
  - full RGEs given in the above paper (will be available in S0FTSUSY)
  - Choosing 2 non-vanishing couplings at GUT scale gives even stronger bounds, so usually only one coupling chosen at a time
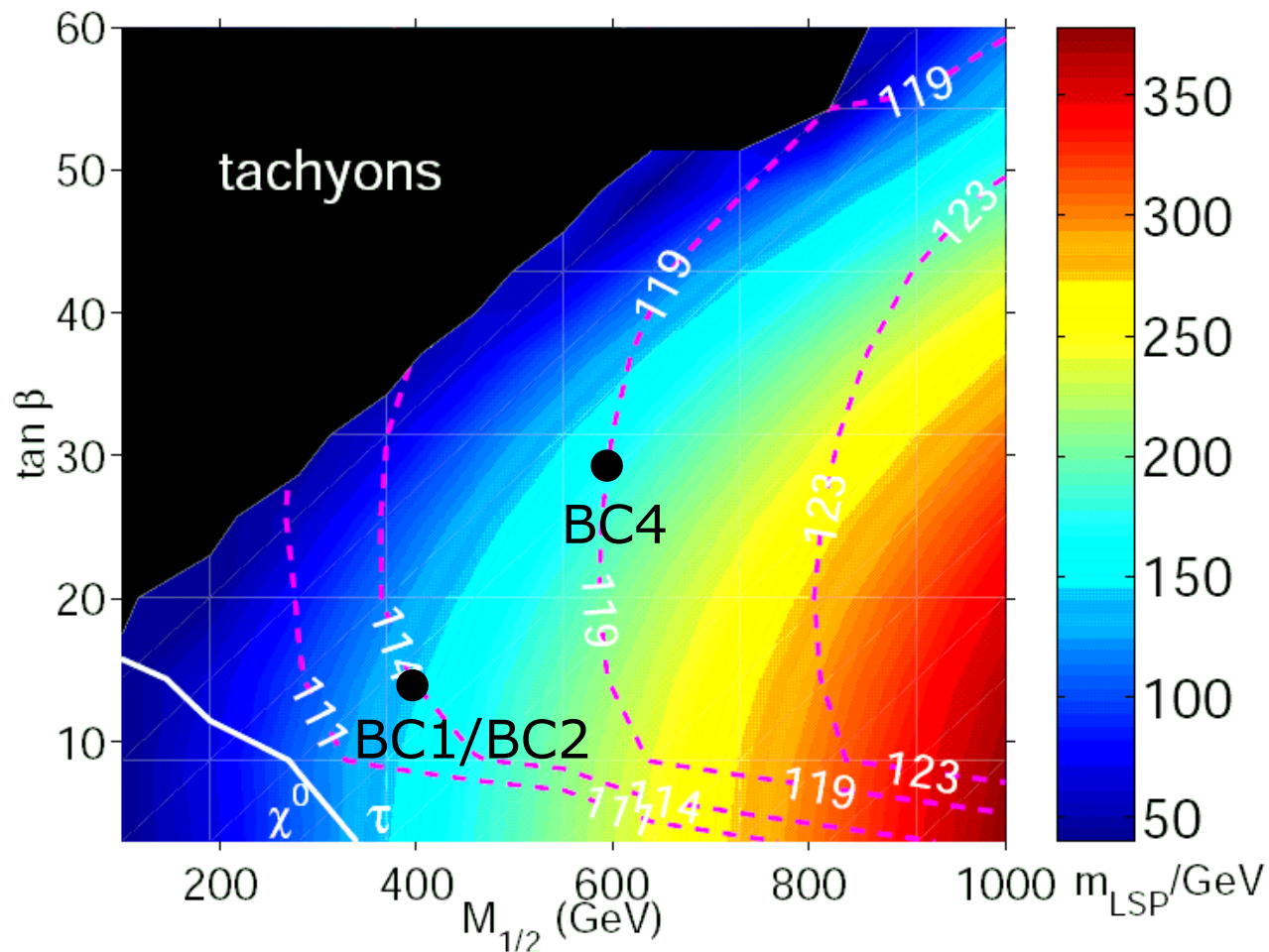
# no-scale mSUGRA:
## LSP mass and type

- dashed lines show contours of lightest Higgs mass
- LEP2 bound on SM Higgs mass: $m_h = 114.4 \text{ GeV}$

- $M_0 = A_0 = 0$
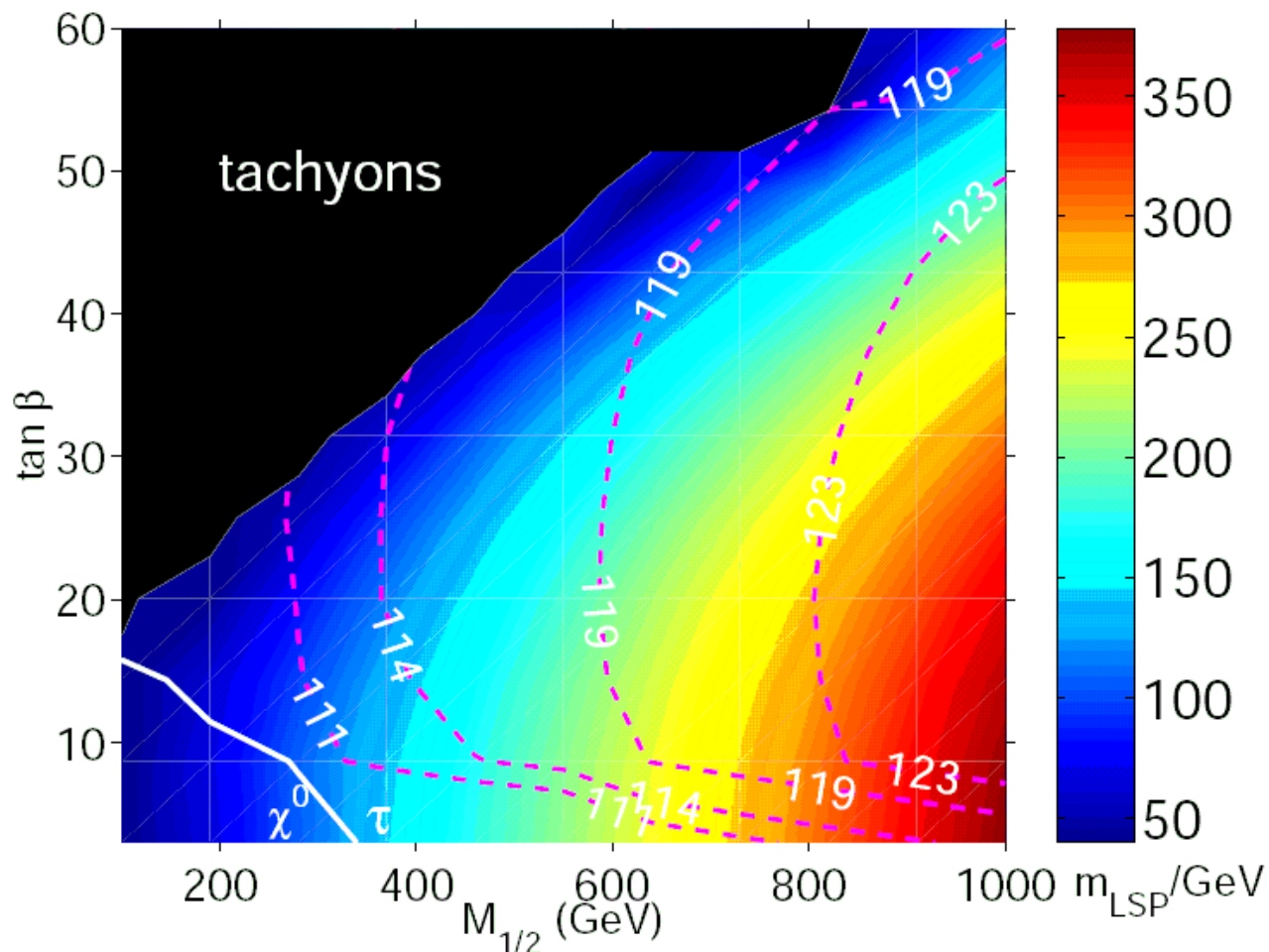
# no-scale mSUGRA:
# Stau LSP Benchmark Points

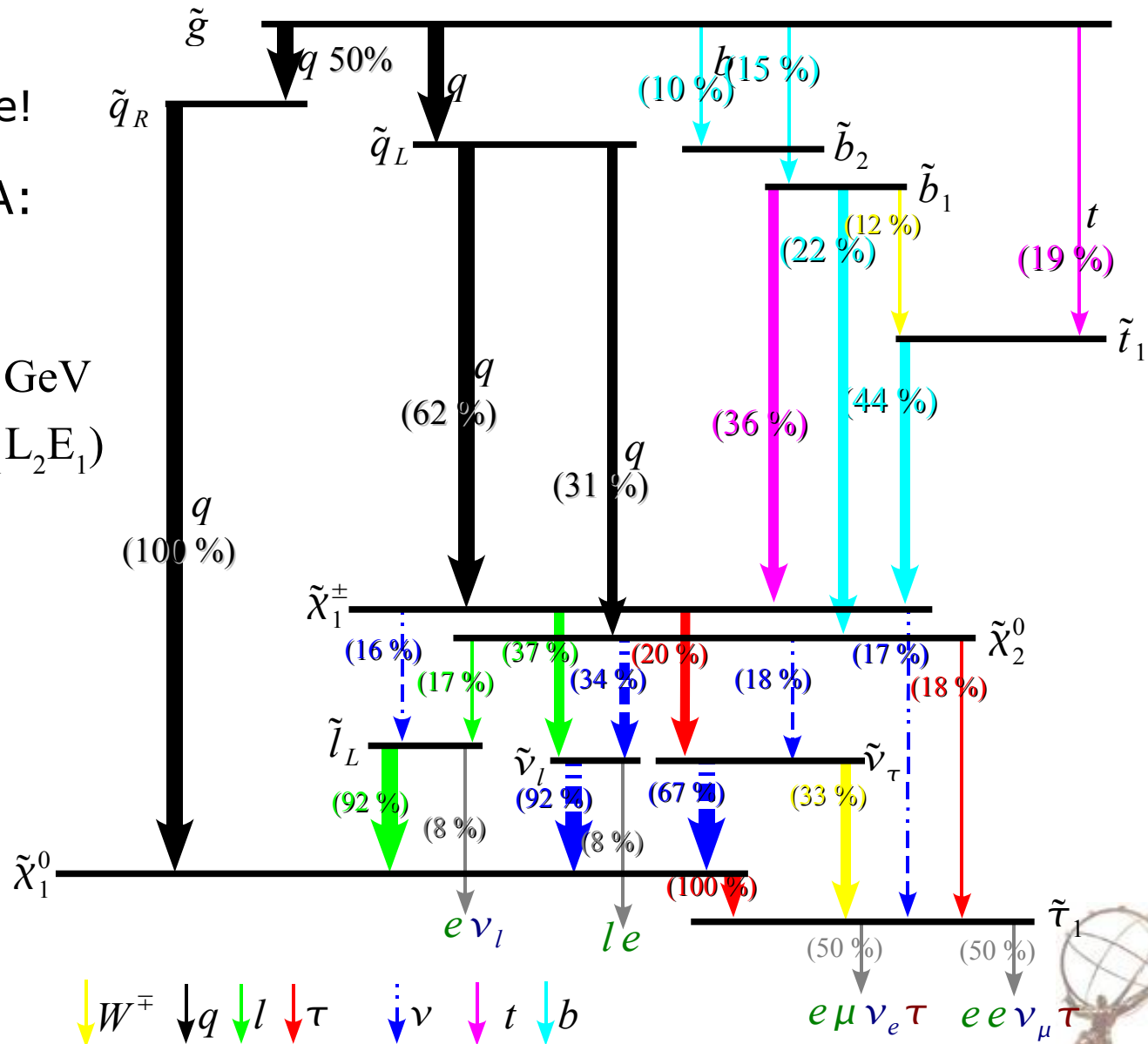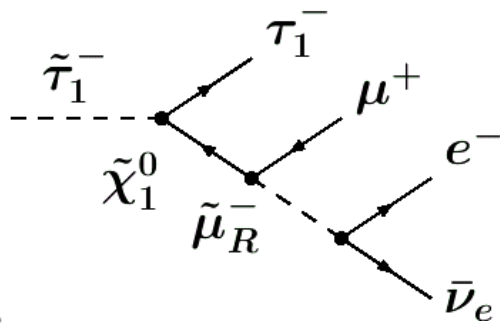- Benchmark points with stau LSP proposed in [Allanach et. al., Phys.Rev.D75:035002,2007]

# RPV mSUGRA Benchmark Points:
## BC1

Spectrum not to scale!

- no-scale mSUGRA:
  $A_0 = M_0 = 0 \; @ \; M_{GUT}$,
  $\mathrm{sgn}(\mu) = +1$,
  $\tan \beta = 13$, $M_{1/2} = 400$ GeV
- $\lambda_{121}(M_{GUT}) = 0.032$ (L$_1$L$_2$E$_1$)



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# RPV mSUGRA Benchmark Points:
## BC1 – signal rates

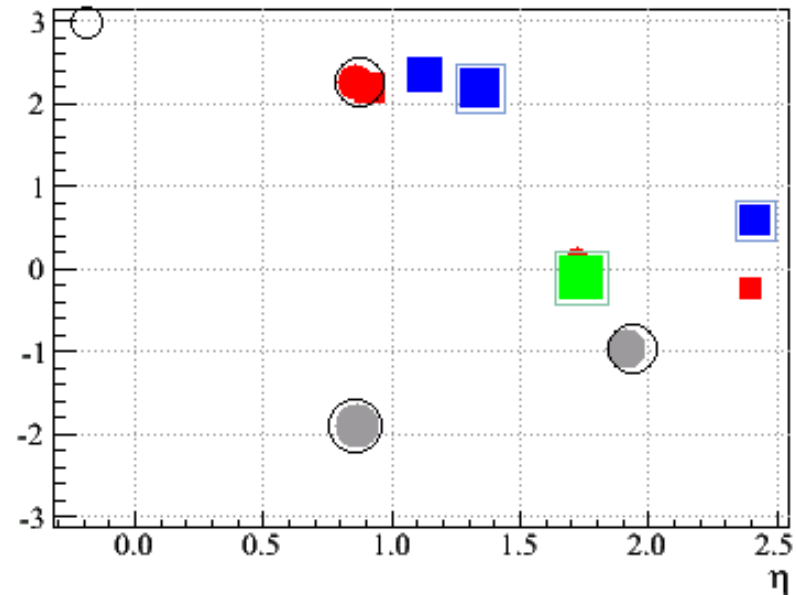| $e^+/\mu^+$ | $e^-/\mu^-$ | $\tau^+$ | $\tau^-$ | events  fraction |
|---|---|---|---|---|
| 2 | 2 | 2 | 2 | 33.9% ± 0.3% |
| 3 | 2 | 2 | 2 | 12.2% ± 0.2% |
| 2 | 3 | 2 | 2 | 8.0% ± 0.1% |
| 3 | 3 | 2 | 2 | 7.6% ± 0.1% |
| 2 | 2 | 2 | 1 | 4.5% ± 0.1% |
| 2 | 2 | 3 | 2 | 4.4% ± 0.1% |
| 2 | 2 | 2 | 3 | 2.9% ± 0.1% |
| 2 | 2 | 1 | 2 | 2.9% ± 0.1% |
| 2 | 2 | 1 | 1 | 2.4% ± 0.1% |
| 3 | 2 | 2 | 3 | 1.7% ± 0.1% |

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# RPV mSUGRA Benchmark Points:
## BC1 – sample event
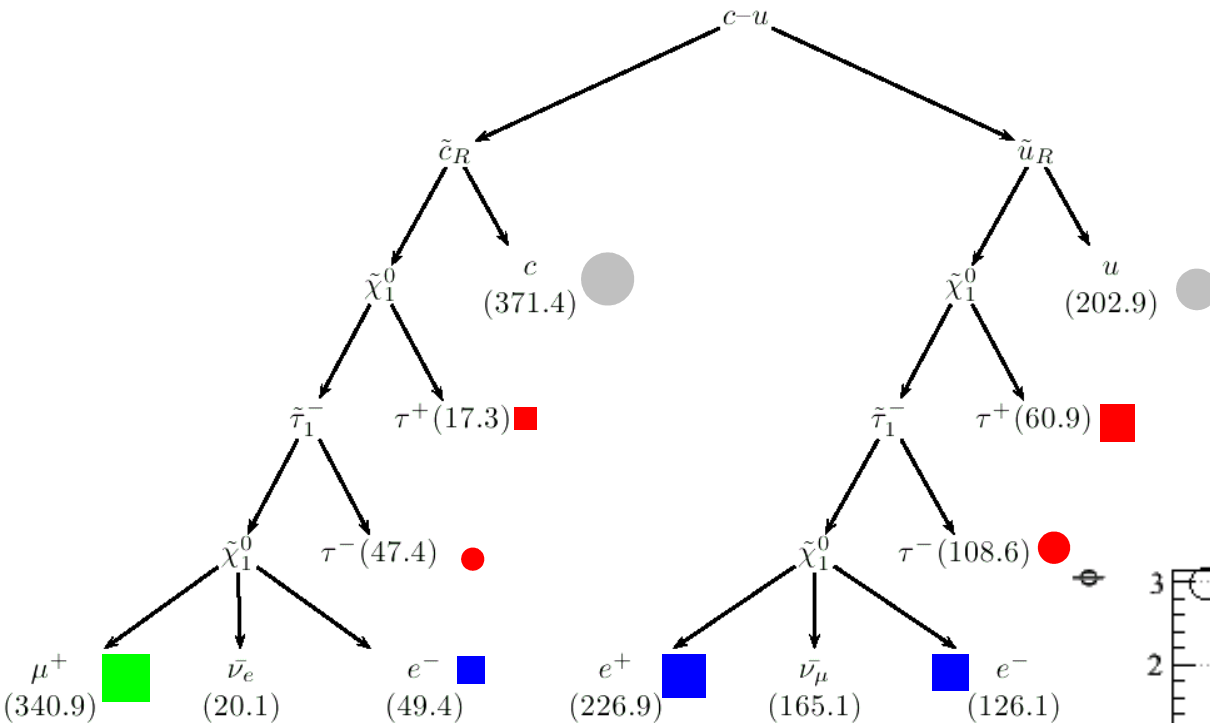
■ muon
■ electron
⬤ light quark

■ leptonically decayed tau
⬤ hadronically decayed tau

$c\text{-}u$

$\tilde{c}_R$

$\tilde{u}_R$

$\tilde{\chi}_1^0$
$c$ (371.4) ⬤

$\tilde{\chi}_1^0$
$u$ (202.9) ⬤

$\tilde{\tau}_1^-$
$\tau^+(17.3)$ ■

$\tilde{\tau}_1^-$
$\tau^+(60.9)$ ■

$\tilde{\chi}_1^0$
$\tau^-(47.4)$ ⬤

$\tilde{\chi}_1^0$
$\tau^-(108.6)$ ⬤

$\mu^+$ (340.9) ■
$\bar{\nu}_e$ (20.1)
$e^-$ (49.4) ■

$e^+$ (226.9) ■
$\bar{\nu}_\mu$ (165.1)
$e^-$ (126.1) ■

marker size prop. to log($p_T$)

open symbols represent ATLfast "reconstructed" objects

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# RPV mSUGRA Benchmark Points:

## BC1 – sample event 2
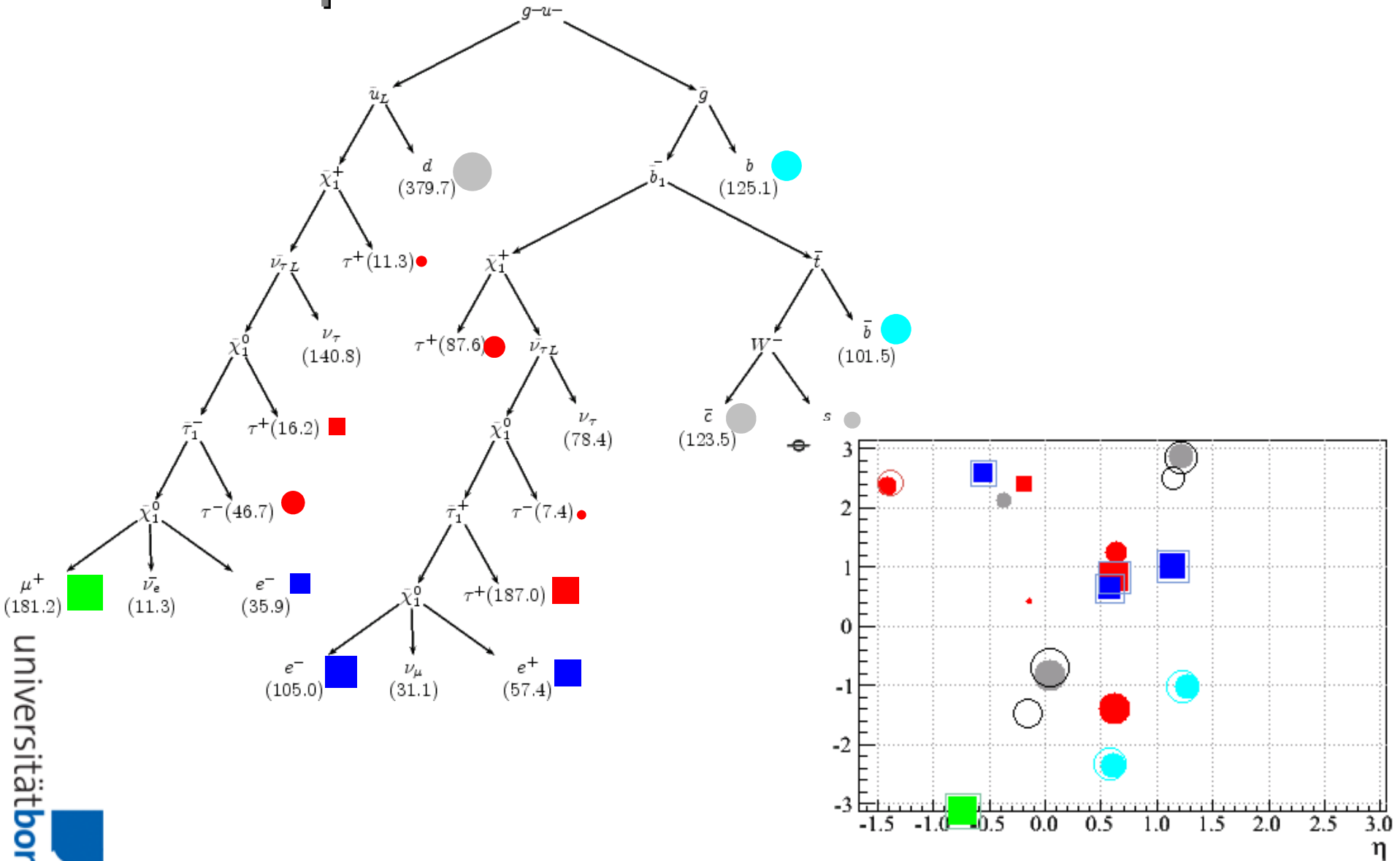
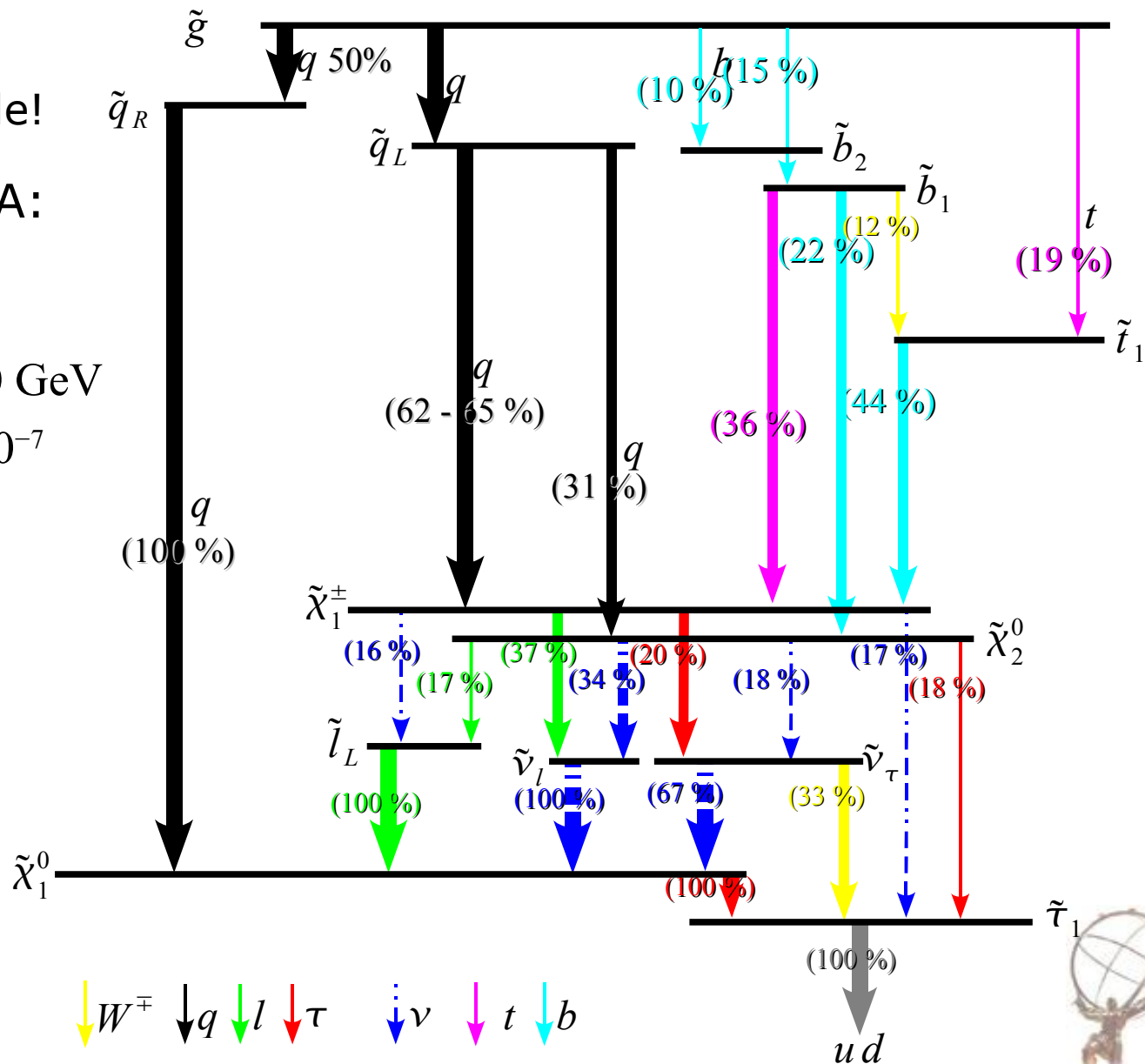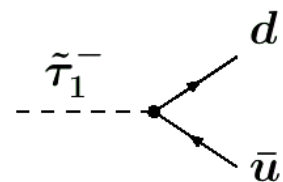# RPV mSUGRA Benchmark Points:
## BC2

Spectrum not to scale!

- no-scale mSUGRA:
  $A_0 = M_0 = 0$ @ $M_{GUT}$,
  sgn($\mu$) = +1,
  tan $\beta$ = 13, $M_{1/2}$ = 400 GeV
- $\lambda'_{311}(M_{GUT}) = 3.5 \times 10^{-7}$
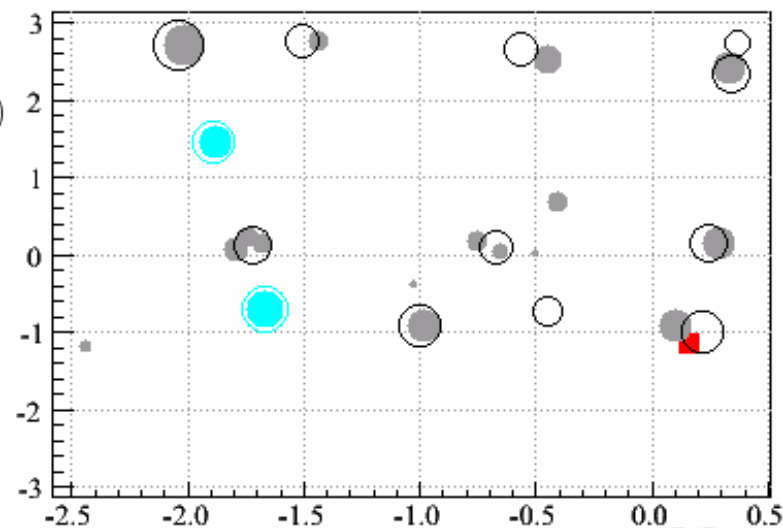  $(L_3 Q_1 D_1)$

# RPV mSUGRA Benchmark Points:
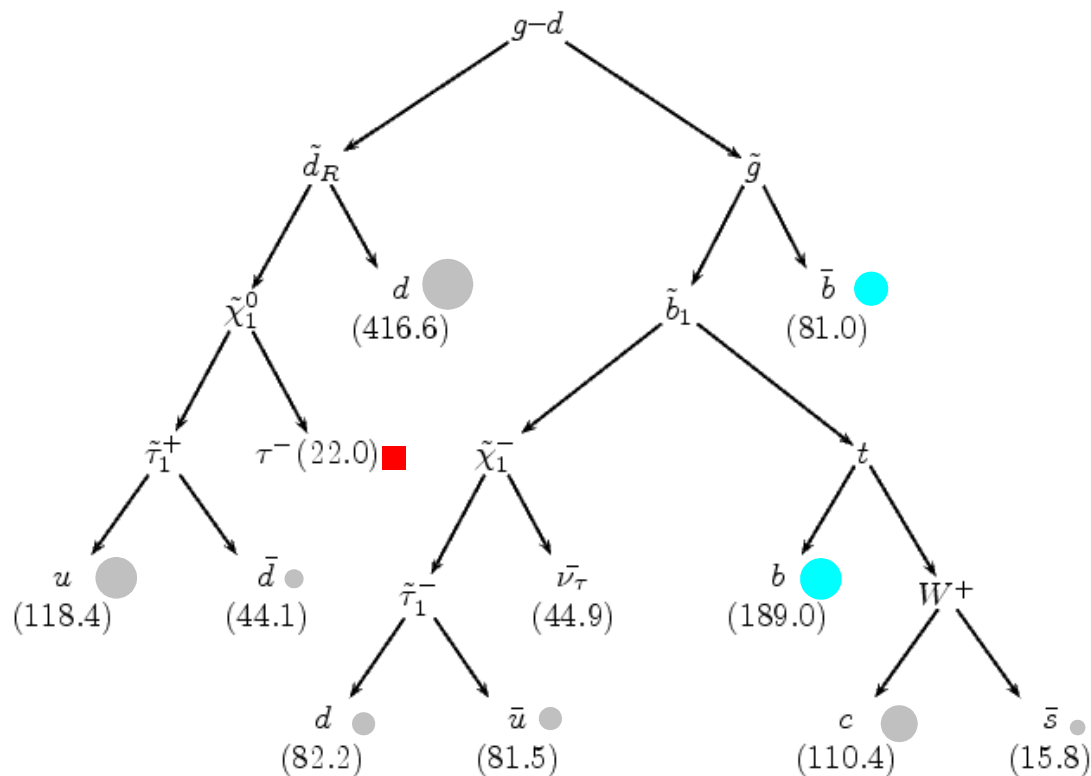## BC2 – signal rates

| $e^+/\mu^+$ | $e^-/\mu^-$ | $\tau^+$ | $\tau^-$ | events fraction |
|---|---|---|---|---|
| 0 | 0 | 1 | 1 | 17.6% ± 0.2% |
| 0 | 0 | 2 | 0 | 9.0% ± 0.1% |
| 0 | 0 | 0 | 2 | 8.8% ± 0.1% |
| 1 | 0 | 1 | 1 | 6.6% ± 0.1% |
| 1 | 1 | 1 | 1 | 4.6% ± 0.1% |
| 0 | 1 | 1 | 1 | 4.4% ± 0.1% |
| 0 | 0 | 0 | 1 | 3.7% ± 0.1% |
| 0 | 0 | 1 | 0 | 3.6% ± 0.1% |
| 1 | 0 | 2 | 0 | 3.4% ± 0.1% |
| 1 | 0 | 0 | 2 | 3.4% ± 0.1% |

# RPV mSUGRA Benchmark Points:
## BC2 – sample event

# RPV mSUGRA Benchmark Points:

## BC4

Spectrum not to scale!
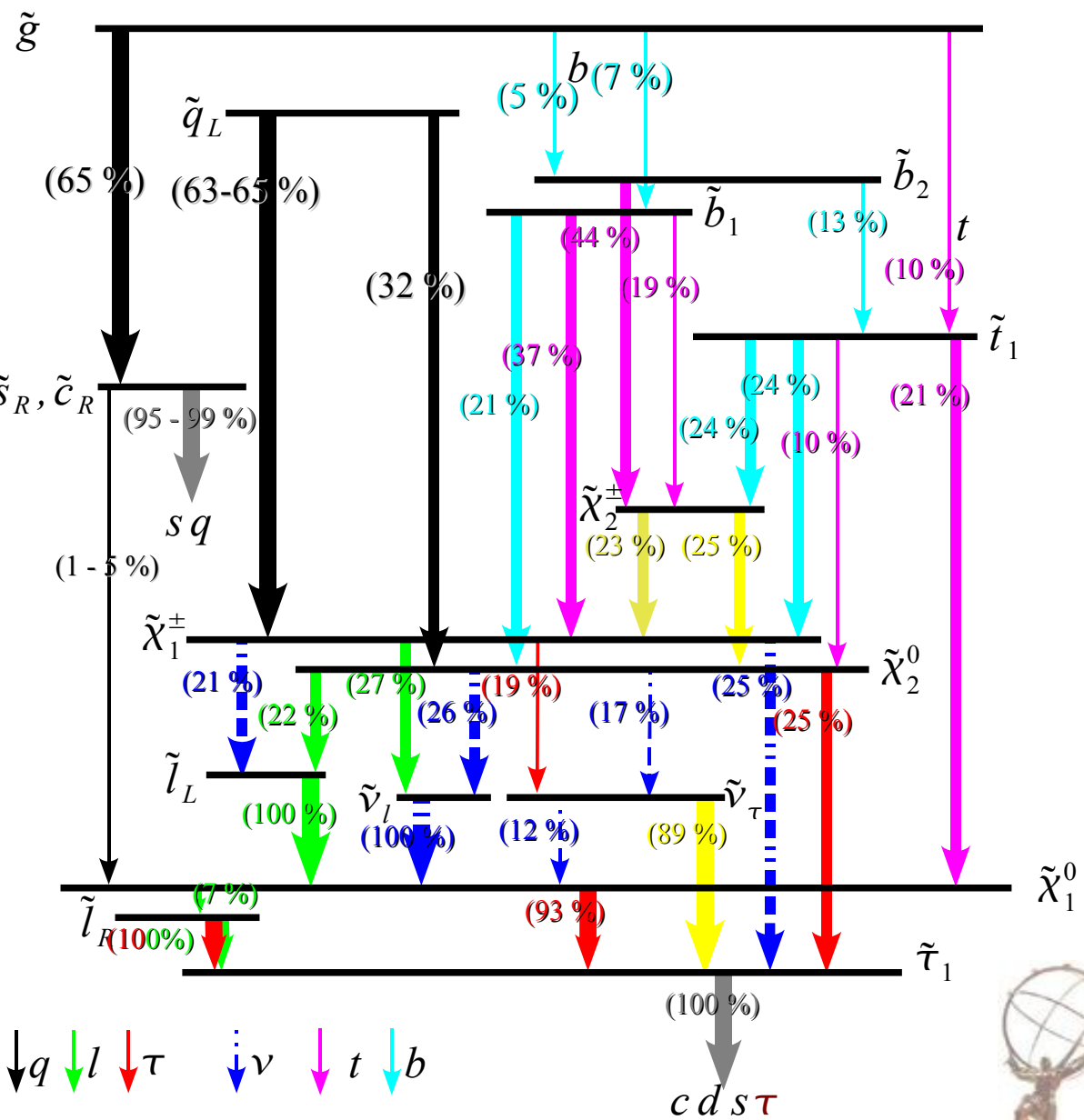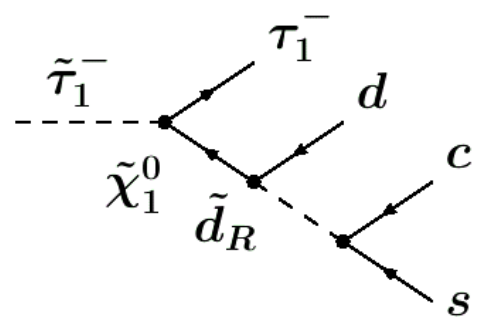
- no-scale mSUGRA:
  $A_0 = M_0 = 0 \ @ \ M_{GUT}$,
  $\text{sgn}(\mu) = +1$,
  $\tan \beta = 30$, $M_{1/2} = 600$ GeV
- $\lambda''_{212}(M_{GUT}) = 0.5$ $(U_2 D_1 D_2)$

# RPV mSUGRA Benchmark Points:
## BC4 – signal rates
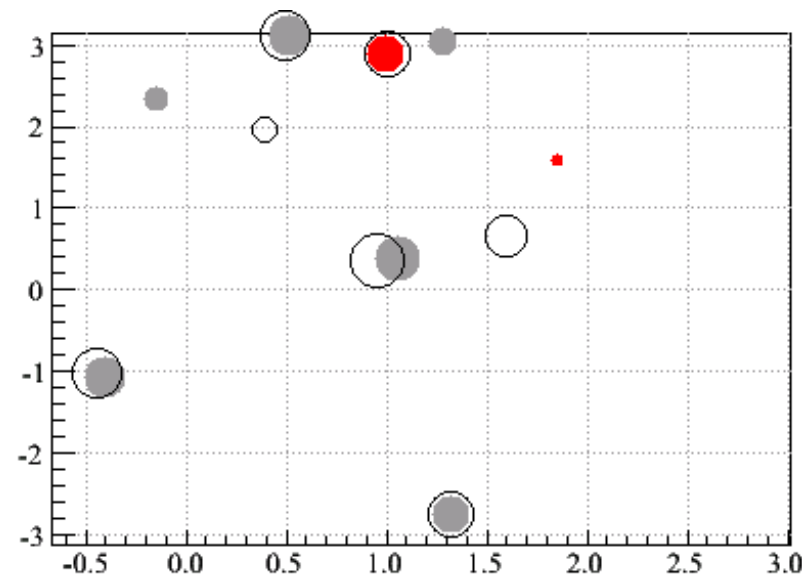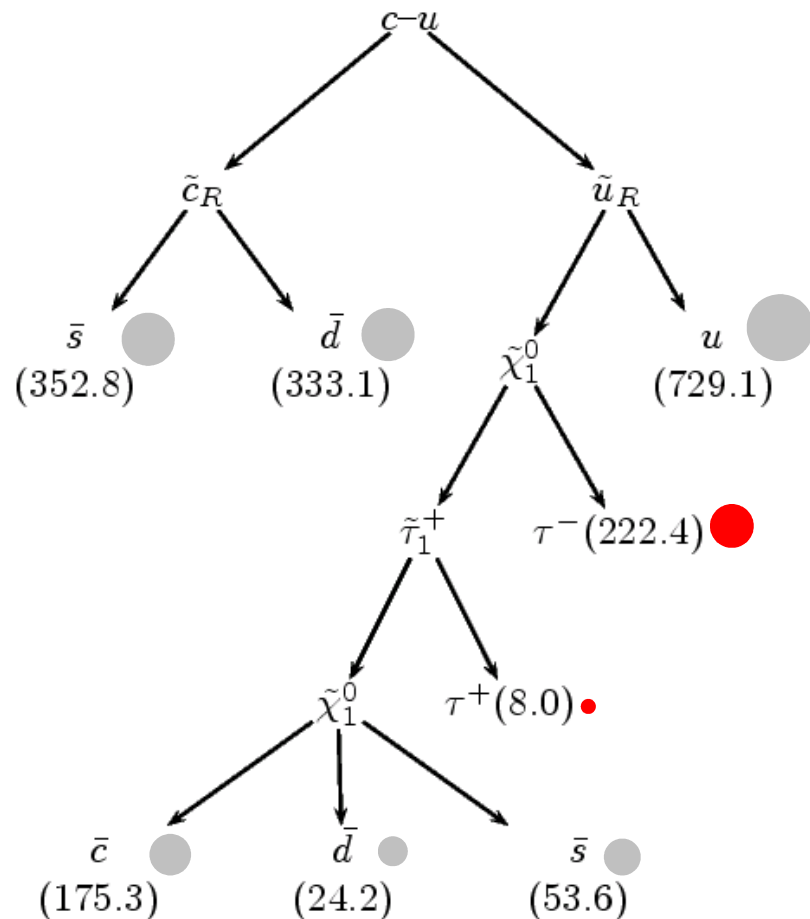
| $e^+/\mu^+$ | $e^-/\mu^-$ | $\tau^+$ | $\tau^-$ | events fraction |
|---|---|---|---|---|
| 0 | 0 | 1 | 1 | 22.6% ± 0.2% |
| 0 | 0 | 0 | 0 | 15.8% ± 0.2% |
| 0 | 0 | 2 | 2 | 7.4% ± 0.1% |
| 0 | 0 | 1 | 0 | 4.7% ± 0.1% |
| 1 | 0 | 1 | 1 | 4.3% ± 0.1% |
| 1 | 0 | 2 | 2 | 4.2% ± 0.1% |
| 0 | 0 | 2 | 1 | 4.1% ± 0.1% |
| 1 | 1 | 2 | 2 | 3.6% ± 0.1% |
| 0 | 0 | 0 | 1 | 3.6% ± 0.1% |
| 0 | 0 | 1 | 2 | 3.0% ± 0.1% |

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# RPV mSUGRA Benchmark Points:
## BC4 – sample event



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# RPV mSUGRA in ATLAS

- HERWIG was modified for new four-body decays of R-parity violating mSUGRA by P. Richardson, et al.

- We have integrated the modified HERWIG in ATHENA

- Events have been classified on generator level and using ATLfast (as in release 12.0.6)

- Work is done in collaboration with Bernhardt, Dreiner, Grab and Richardson

- Analysis strategy for the stau-LSP benchmark points will be developed

# Open questions
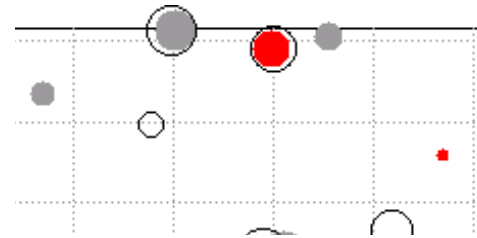


- Truth labeling of taus in ATLfast:
  - Why are "reconstructed" jets often not truth labeled (tau efficiency mostly affected by labeling, not by tagging)?

- Is Triggering possible for BC2?
  - less leptons (stau → u d)
  - no taus from LSP decay
  - jets may not be hard enough

- Event selection for BC4?
  - many jets (stau → c d s $\tau$)
  - less taus, sometimes hidden behind other jets

# Summary & Conclusions

- R-parity violating couplings strongly constrained
- non-stable LSP allows for different phenomenology compared to R-parity conserving models
- mSUGRA model with stau-LSP is investigated
- Benchmark point BC 1 seems to be "nice"
- BC 2 and BC 4 may be hard to trigger / select
- Full simulation needed to understand tau simulation in ATLfast and for trigger studies
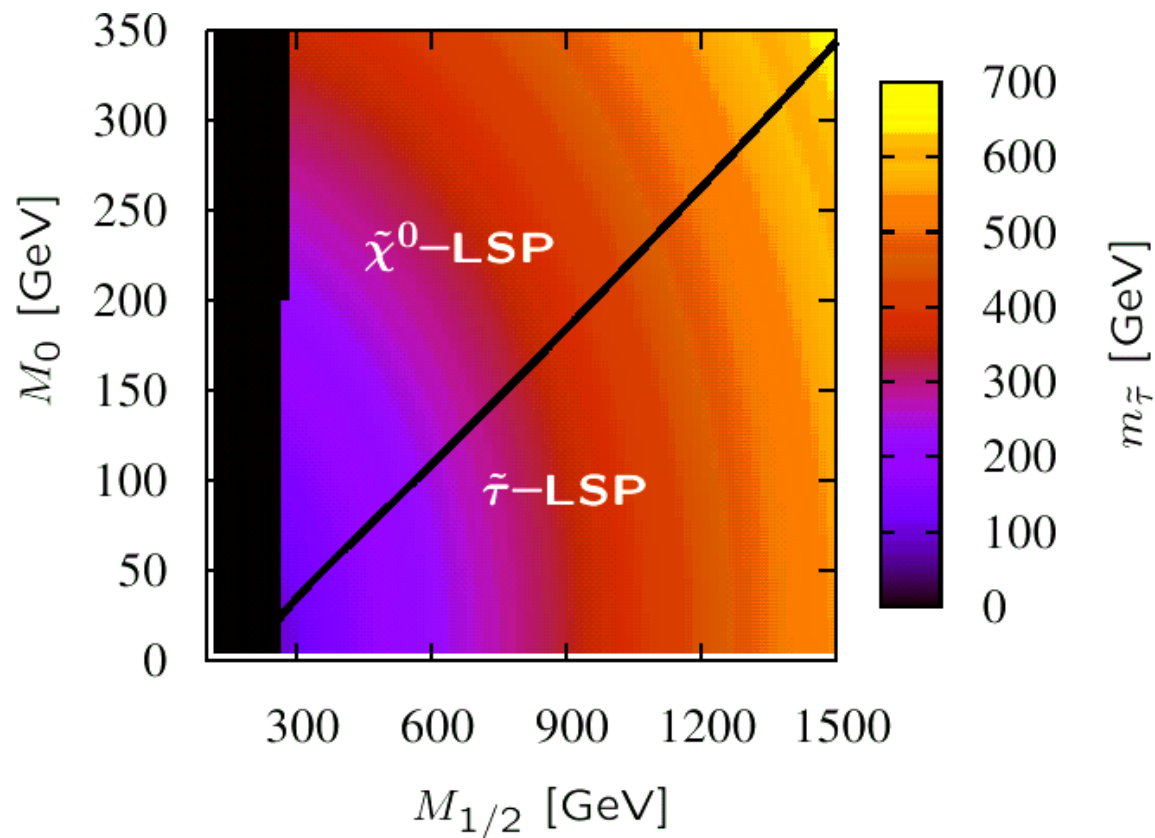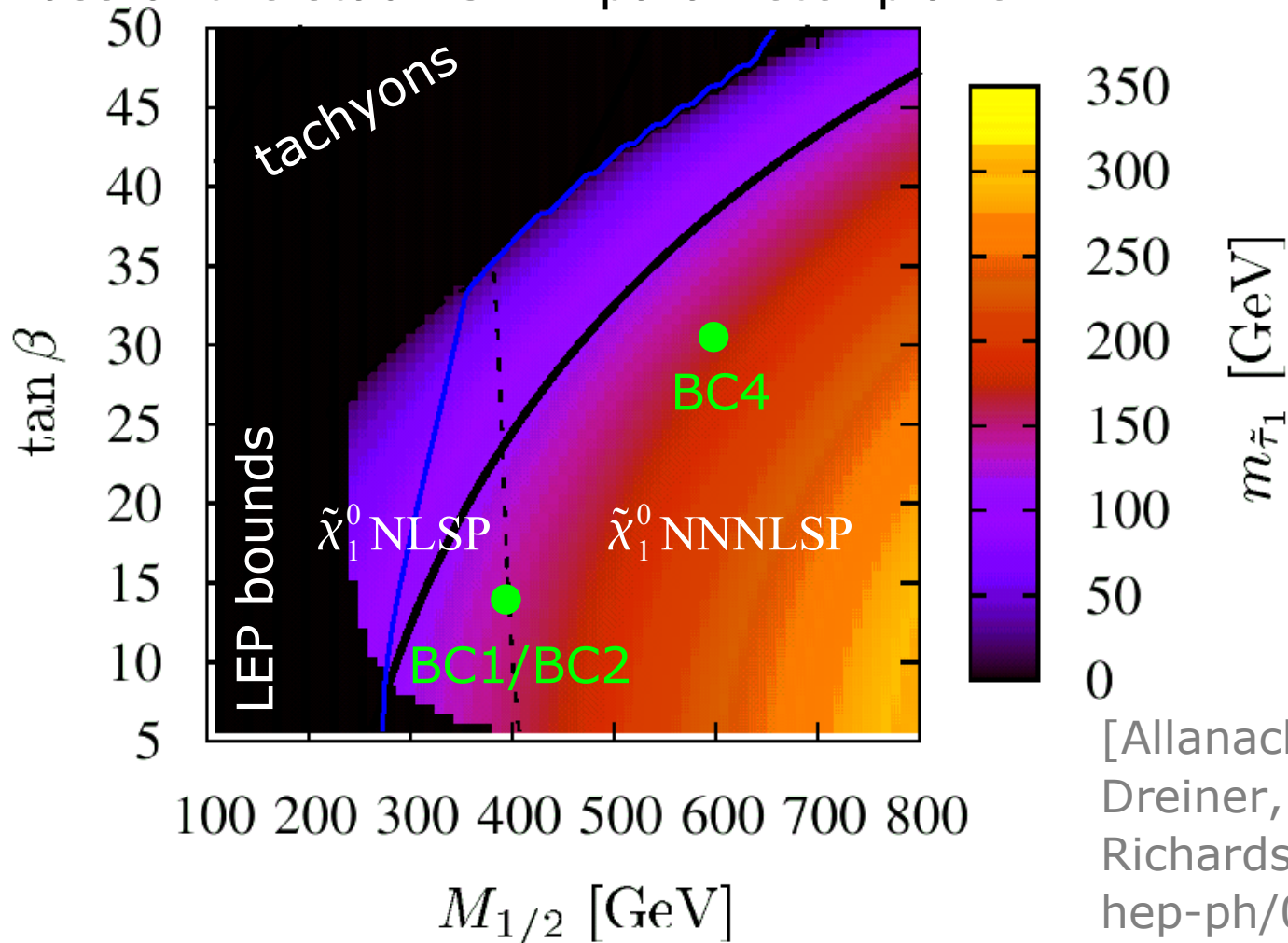
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# Backup

# R-parity violating mSUGRA

- SPS1a region: $A_0 = -100$ GeV, $\tan \beta = 10$, $\mathrm{sgn}(\mu) = +1$

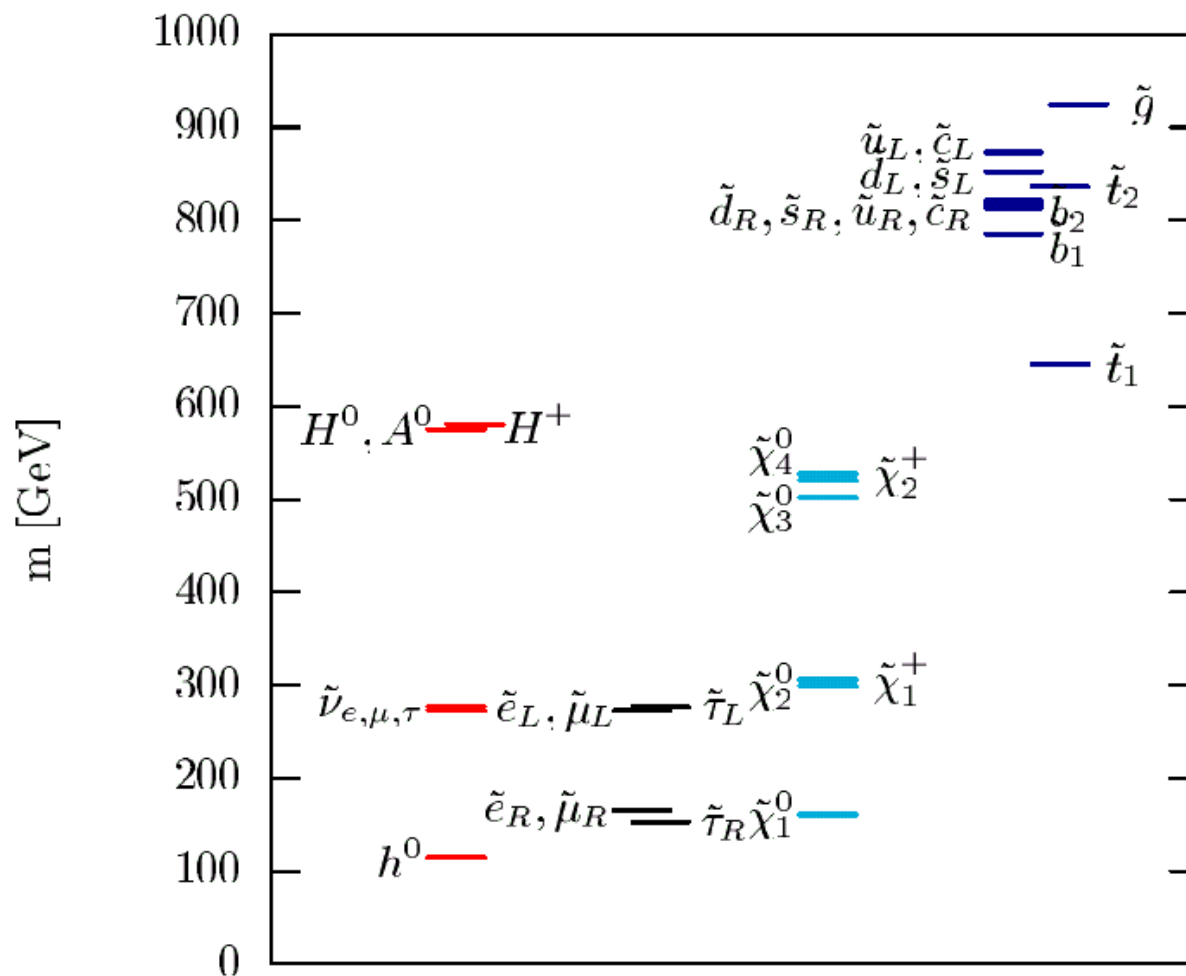universität**bonn**

# R-parity violating mSUGRA

- no-scale mSUGRA: $A_0 = M_0 = 0\ @\ M_X$, $\text{sgn}(\mu) = +1$

- mass of the stau LSP in parameter plane



[Allanach, Bernhardt, Dreiner, Korn, Richardson: hep-ph/0609263]

# BC1 / BC2 mass spectrum

# BC4 mass spectrum