Prospects for $\not{R}_p$-mSUGRA with $\tilde{\tau}$-LSP with Early LHC Data

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based on **arXiv:1008.1580** by
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PHYSICS AT THE TERA SCALE
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Introduction

- Supersymmetry (SUSY): Fundamental symmetry between bosons and fermions
- mSUGRA: SUSY breaking model with 4.5 parameters only
  M_0, $M_{1/2}$, A_0, $\tan\beta$, $\mathrm{sgn}(\mu)$
- R-parity (R_p) usually considered conserved to prevent rapid proton decay
  $\Rightarrow$ SUSY particles produced in pairs
  $\Rightarrow$ lightest supersymmetric particle (LSP) stable
  $\Rightarrow$ stable LSP neutral and only weakly interacting for cosmological reasons
- Alternative symmetries exist that stabilize proton but violate R-parity ($\not{R}_p$):
  Baryon Triality, Lepton Parity

  $\Rightarrow$ LSP not stable and not cosmologically constrained

R–Parity Violating Terms in the Superpotential

- Most general renormalizable gauge invariant potential can contain terms that violate baryon (B) or lepton (L) number:

$$W_{\not R_p} = \epsilon_{ab}\Big(\frac{1}{2}\underbrace{\lambda_{ijk} L_i^a L_j^b \bar{E}_k}_{\text{violates } L} + \underbrace{\lambda'_{ijk} L_i^a Q_j^{bx} \bar{D}_{kx}}_{\text{violates } L}\Big) + \frac{1}{2}\epsilon_{xyz}\underbrace{\lambda''_{ijk} \bar{U}_i^x \bar{D}_j^y \bar{D}_k^z}_{\text{violates } B} - \epsilon_{ab}\underbrace{\kappa^i L_i^a H_u^b}_{\text{violates } L}$$

i, j, k generation-,

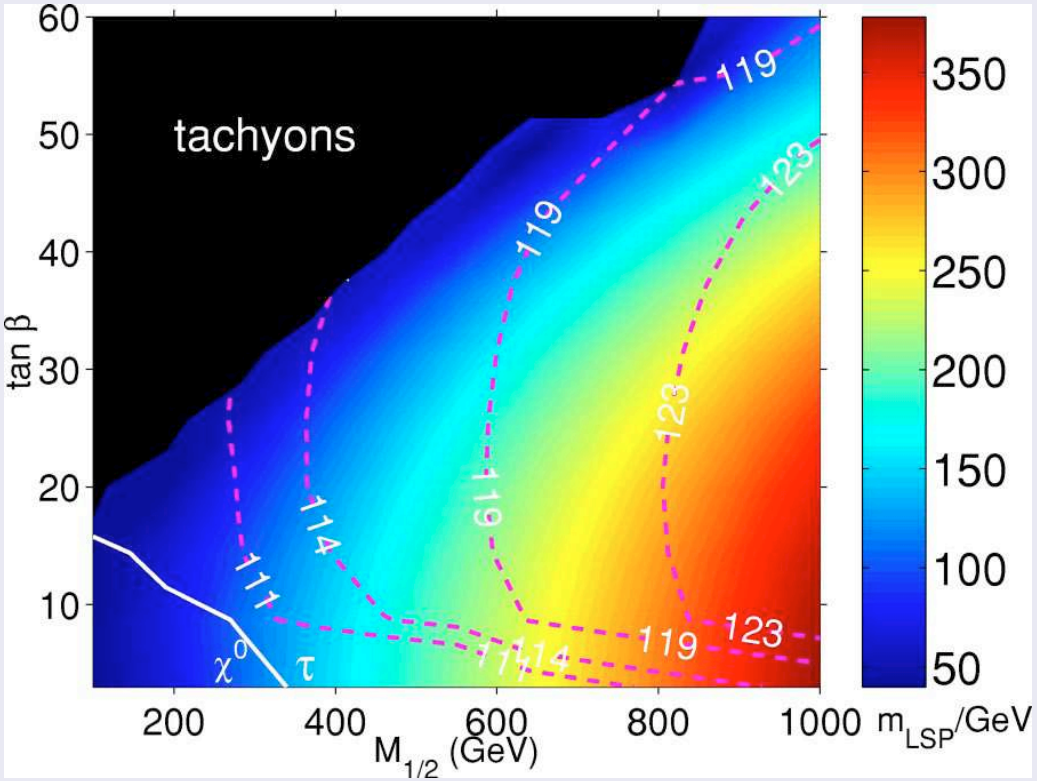
x, y, z SU(3) gauge- (color-),

a, b SU(2) gauge- indices

- To prevent rapid proton decay **either** B **or** L violating terms allowed only
- Strong bounds on $\not R_p$ couplings (λ,λ',λ'',κ) from existing precision measurements
  - $\Rightarrow$ Mass spectrum and production of SUSY particles mostly unchanged

Mass and Type of LSP in no-scale mSUGRA

- No-scale mSUGRA: $M_0 = A_0 = 0$
- Dashed contours show mass of lightest higgs
- In R_p-conserving case excluded by LEP SM higgs mass bound

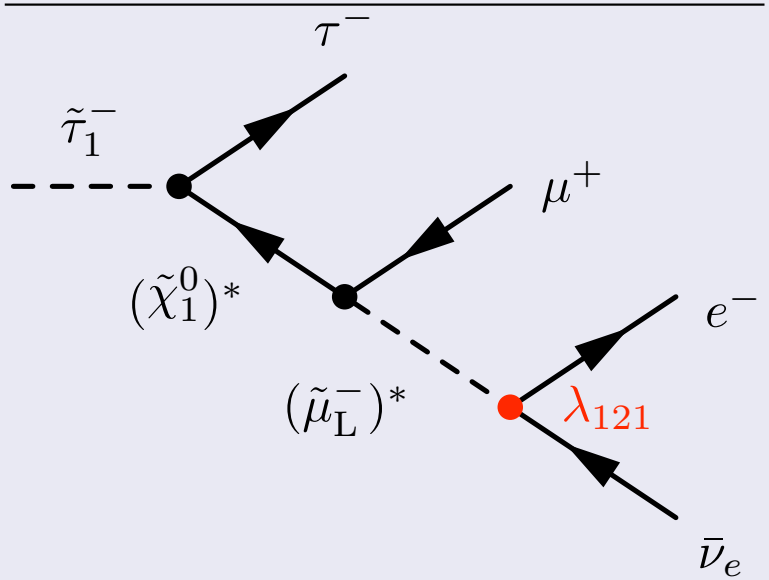


$\tilde{\tau}$ is LSP in significant part of mSUGRA parameter space

$\not{R}_p$ mSUGRA benchmark scenario BC 1

- mSUGRA parameters:
  $M_0 = A_0 = 0$ @M_{GUT},
  $\operatorname{sgn}\mu = +1$,
  $\tan\beta = 13$,
  $M_{1/2} = 400$ GeV
- $\tilde{\tau}^{\pm}$ is LSP,
  $\tilde{\chi}_1^0$ is NNNLSP
- Typical production:
  $\tilde{\chi}_1^0 \to \tilde{\tau}\tau$
- LSP decays promptly
- Expected cross section at
  7 TeV: $\sigma = 0.28\,\text{pb}$

- $\lambda_{121} = \begin{cases} 0.032 \text{ @}M_{\text{GUT}} \\ 0.048 \text{ @}M_{\text{EM}} \end{cases}$
  ($L_1 L_2 \bar{E}_1$ coupling)
- 4 body decay of LSP:
  $\tilde{\tau}_1^{\pm} \to \tau^{\pm}\ell^{\mp}\ell'^{\pm}\nu$



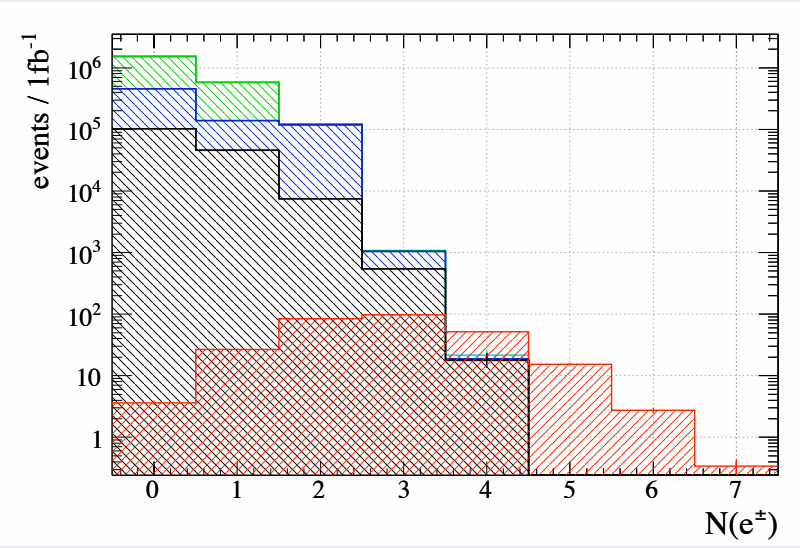
BC 1–4 defined in: Allanach, Dedes, Dreiner, `Phys. Rev. D69 115002`

- Recent paper (arXiv:1008.1580, accepted by Phys. Rev. D) studying prospects for BC1 with early LHC data
- Includes parameter scan around benchmark point
- Includes study of feasibility of $\tilde{\tau}$-LSP mass reconstruction
- Sample cutflow for $1\,\mathrm{fb}^{-1}$ @ $7\ \mathrm{TeV}$ (Delphes):

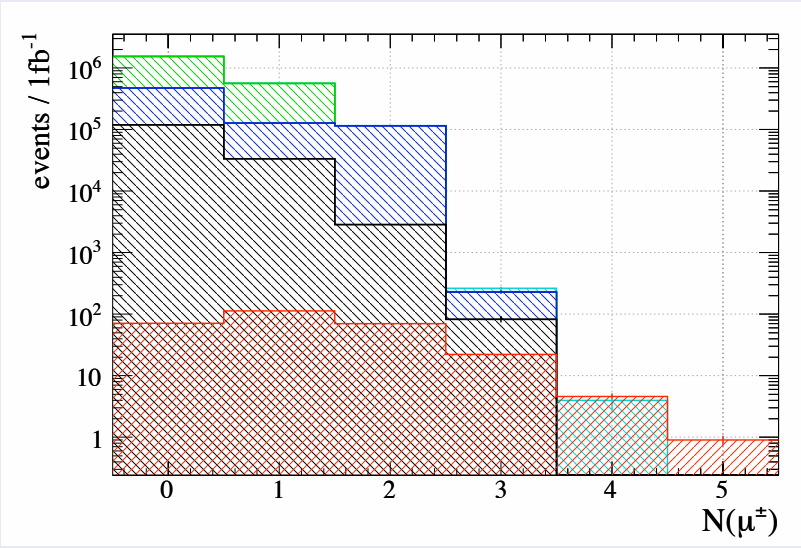
cuts [GeV]	$t\bar{t}$	all SM	BC1
before cuts	155500 ± 416	2258230 ± 1392	282.8 ± 2.8
$p_T^{\mu 1} > 40$	16745 ± 135	319975 ± 510	141.6 ± 2.0
$p_T^{e1} > 32$	1492 ± 40	1837 ± 43	125.9 ± 1.9
$p_T^{e2} > 7$	165.6 ± 14.4	184.9 ± 14.8	113.7 ± 1.8
$\sum p_T^{\ell} > 230$	13.6 ± 4.2	15.1 ± 4.3	85.7 ± 1.6
$\sum_1^4 p_T^{\mathrm{jet}} > 200$	5.1 ± 2.1	6.1 ± 2.3	60.3 ± 1.3
$\sum_1^4 p_T^{\mathrm{jet}} > 300$	3.4 ± 1.7	3.4 ± 1.7	56.6 ± 1.3
$\sum_1^4 p_T^{\mathrm{jet}} > 400$	$\lesssim 1.0$	$\lesssim 1.0$	52.5 ± 1.2

Numbers of Selected Leptons and Cut Variables (Delphes)

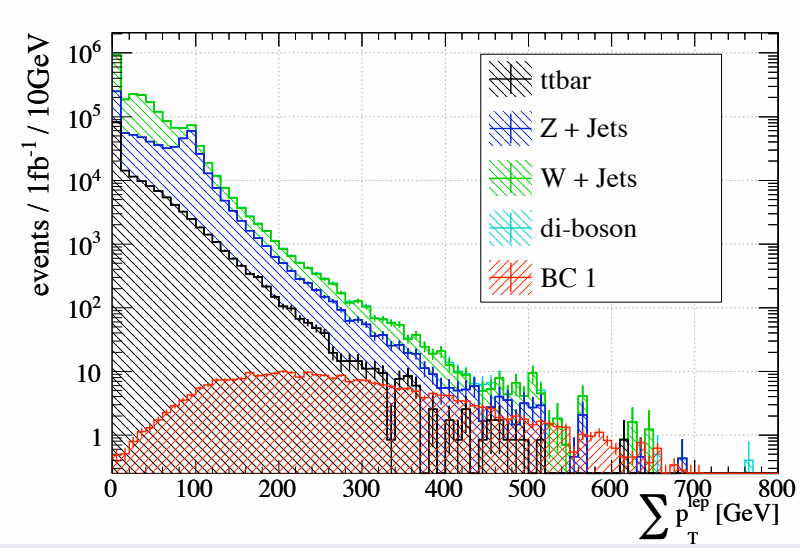
Electrons



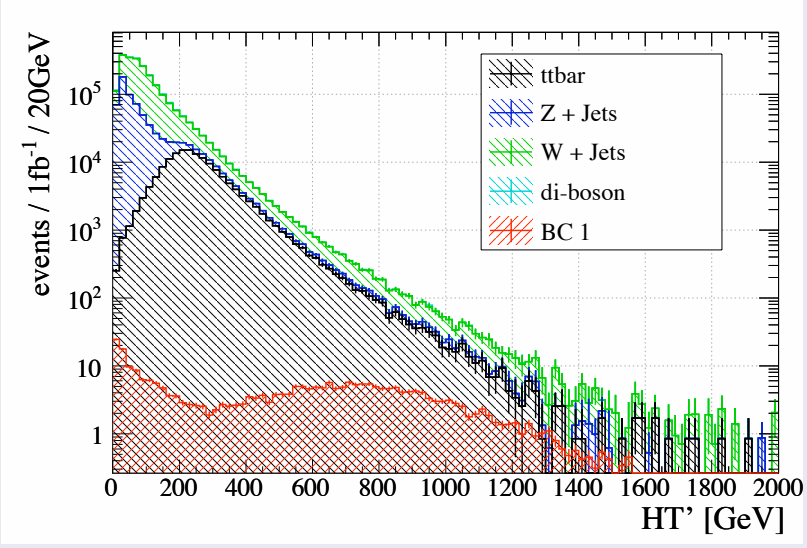
Muons



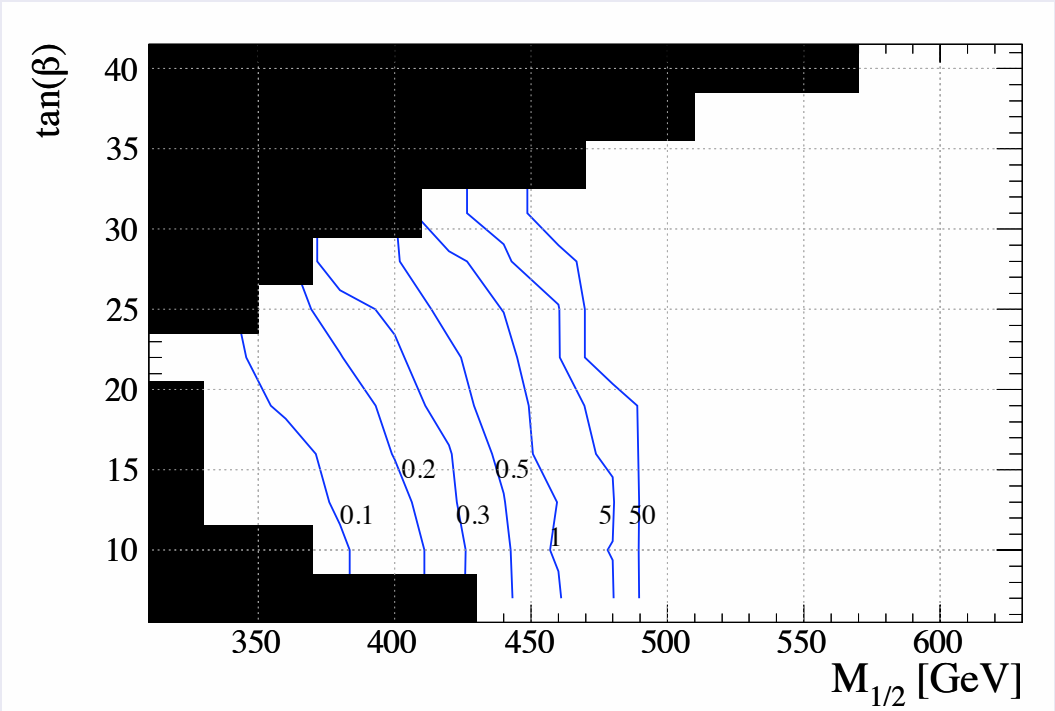
$\sum p_t^{lep}$



HT' $= \sum p_t^{jet\ 1\text{-}4}$



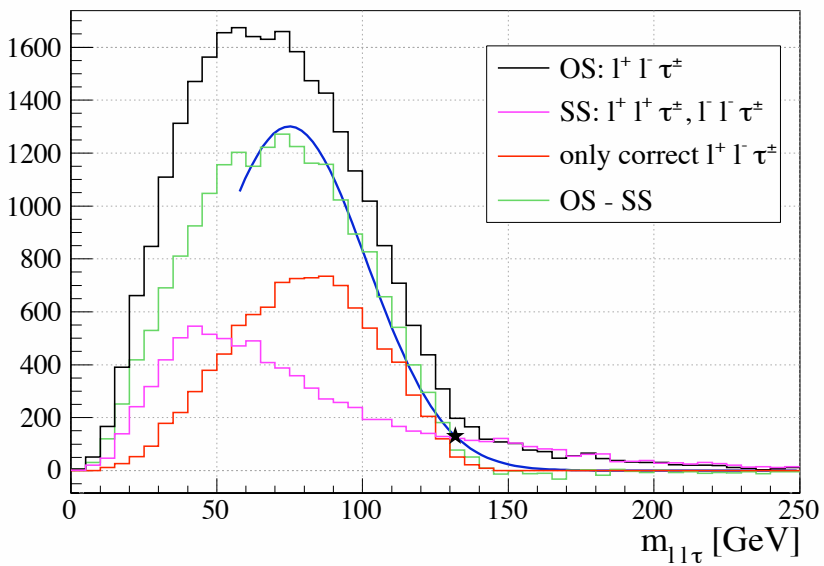
Discovery Reach at $\sqrt{s} = 7$ TeV

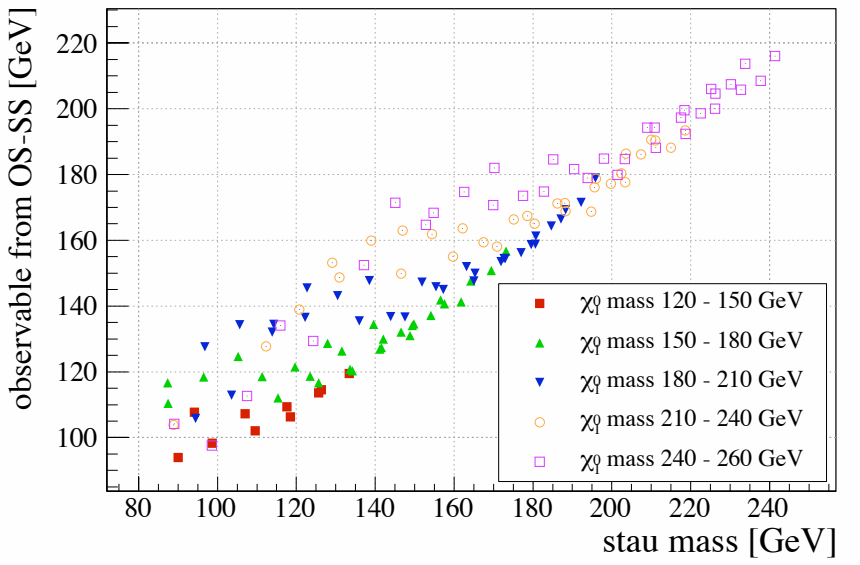


Contours show int. luminosity (in fb^{-1}) necessary to reach a significance $Z_0 > 5$ (incl. 50% bkg. uncertainty)

- Reach for 1fb^{-1}: $M_{1/2} \lesssim 460$ GeV
- Corresponds to squark/gluino masses of ~ 950 GeV/1.1 TeV
- $\lesssim 200\text{pb}^{-1}$ needed for benchmark point BC1

LSP Mass Reconstruction (Generator-Level)





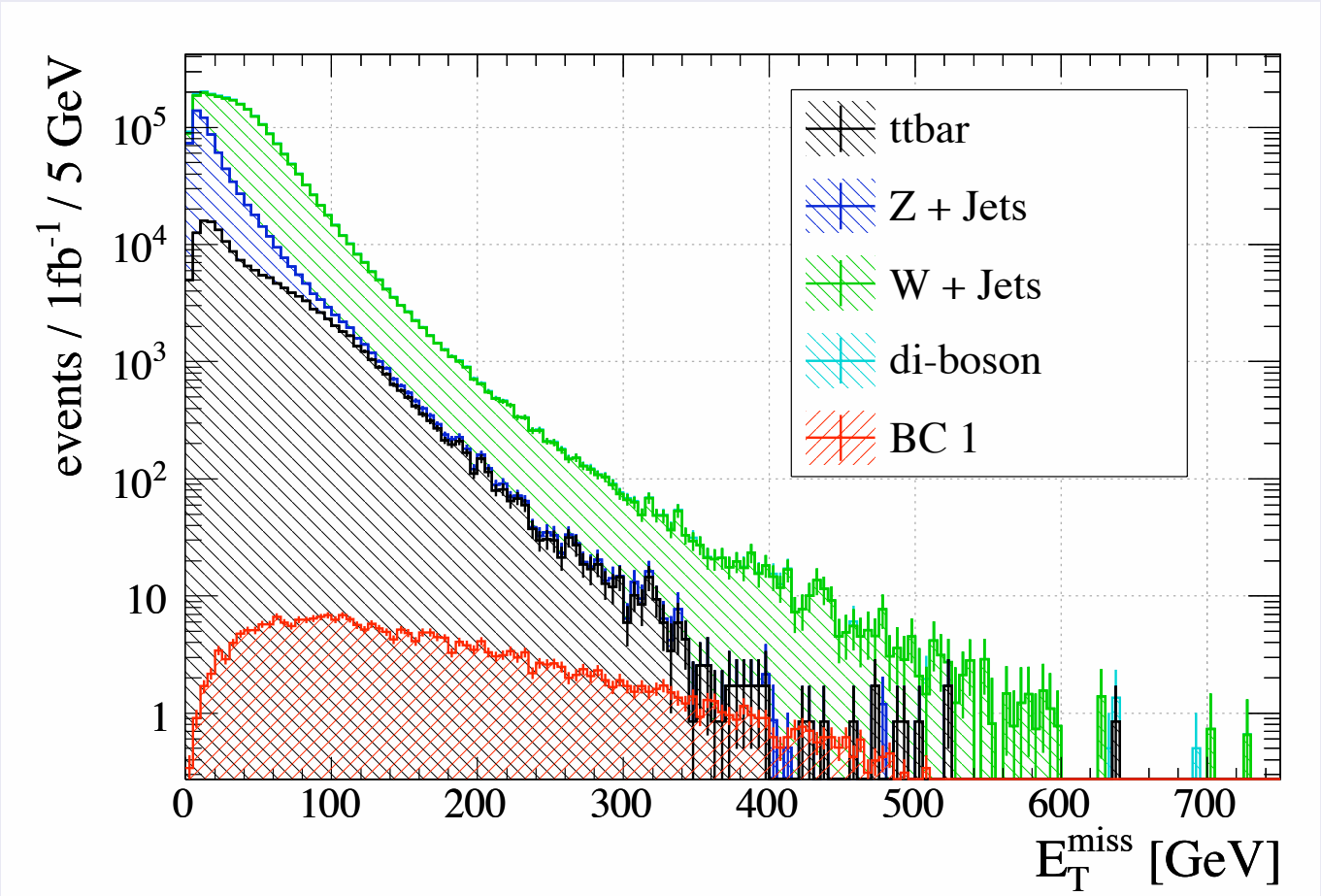
- Compute inv. mass of τ and two closest leptons
- Expect no mass peak (νs), but an endpoint at $\tilde{\tau}_1$ mass (148 GeV)
- But: combinatorical bkg. e.g. from second decay chain $\Rightarrow$ Use OS-SS substraction method
- Can use obs. correlation of $\tilde{\tau}_1$-mass with 10%-value of gaussian fit to OS-SS curve
- Create calibration curve from parameter scan around BC1

Summary

- SUSY models that do not conserve R-parity allow lightest supersymetric particle other than the "usual" $\tilde{\chi}_1^0$
- First comprehensive signal over background analysis of $\tilde{\tau}$-LSP scenarios with early LHC data performed using fast simulation
- BC1 with its multi-lepton signature nearly background free
- Parameter space up to BC1 can be probed already with $\lesssim 200\text{pb}^{-1}$
- Mass reconstruction of $\tilde{\tau}_1$ not so easy, but mass estimate possible within the first few years of LHC data taking
- ATLAS analysis in progress

Backup Slides

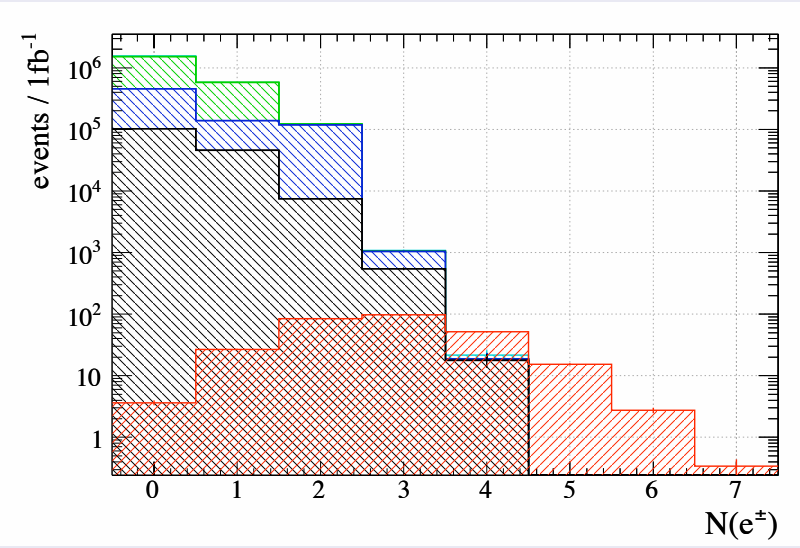
Missing Transverse Energy (Delphes)



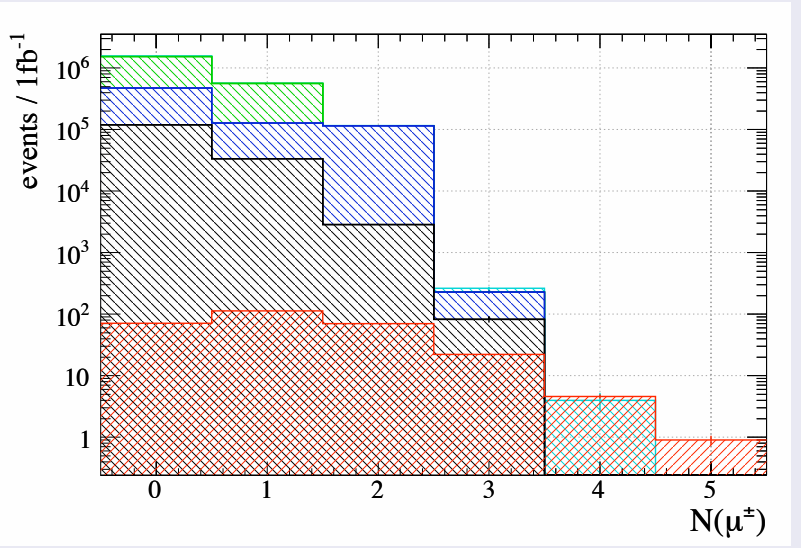
E_T^{miss} can be significant in $\not{R}_p$ models, even though LSP does not escape detection "per se" (here: νs from $\not{R}_p$ LSP decays and τs)

Number of Selected Objects per Event (Delphes)

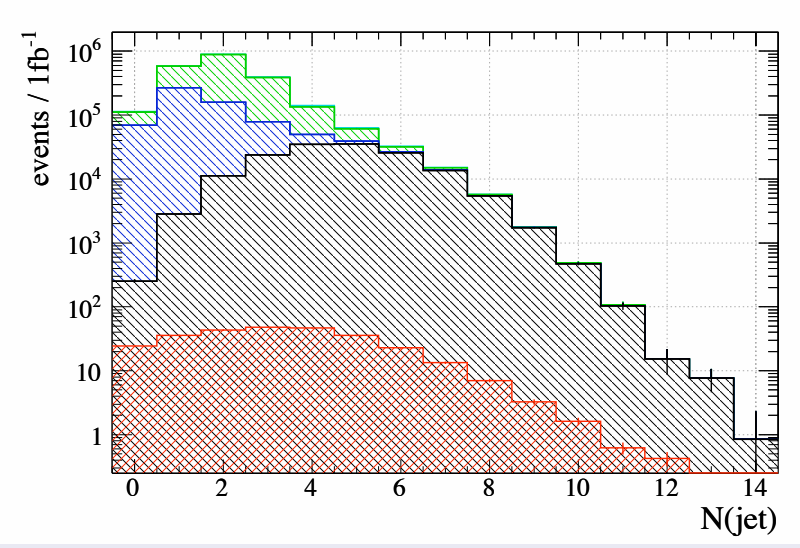
Electrons



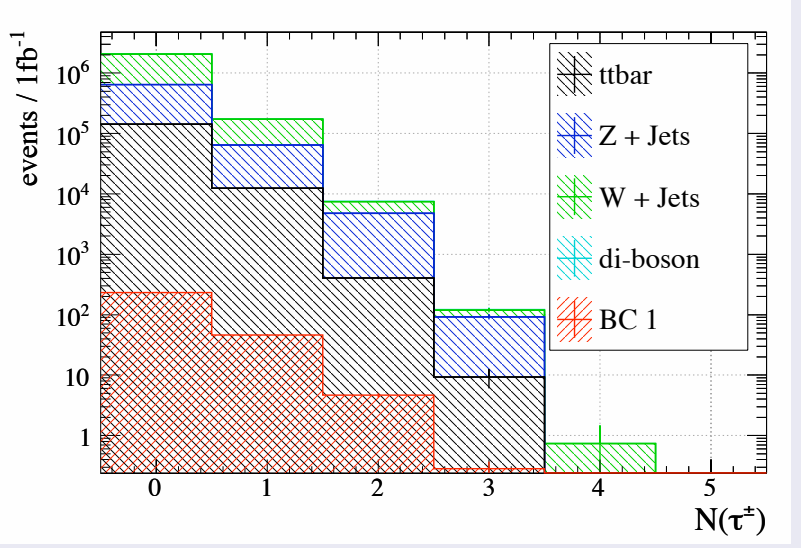
Muons



Jets

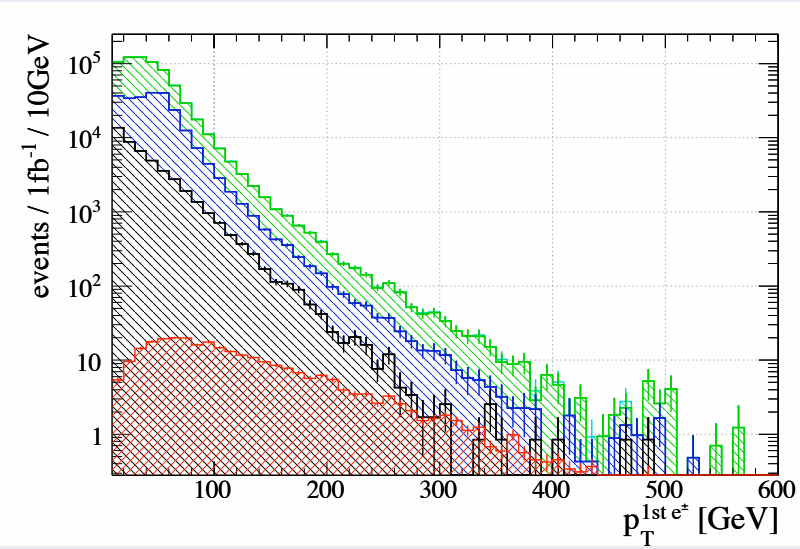


Taus

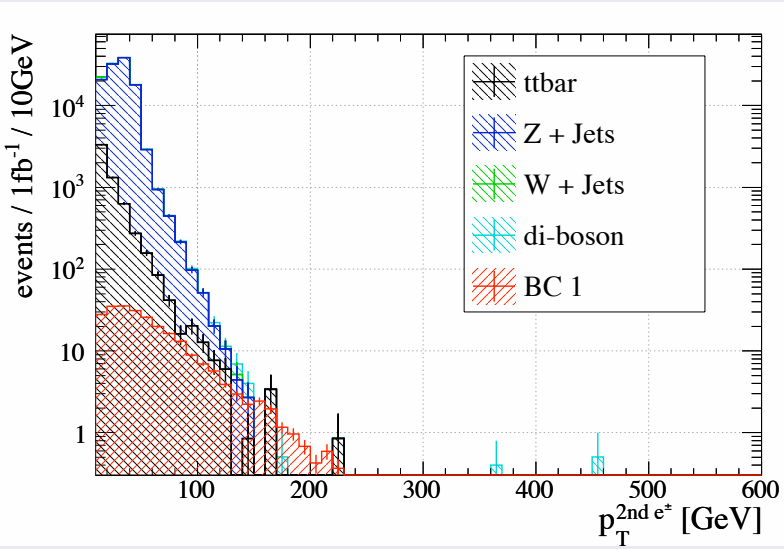


p_t of Leading Leptons (Delphes)

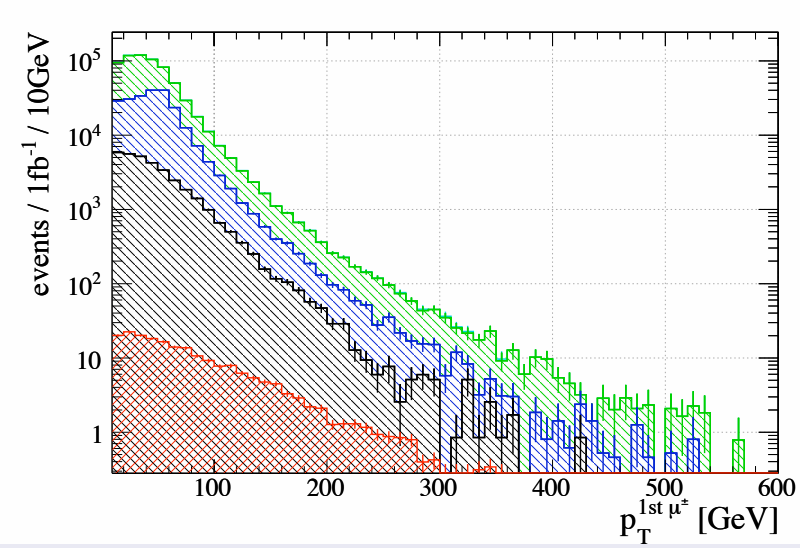
Electron 1



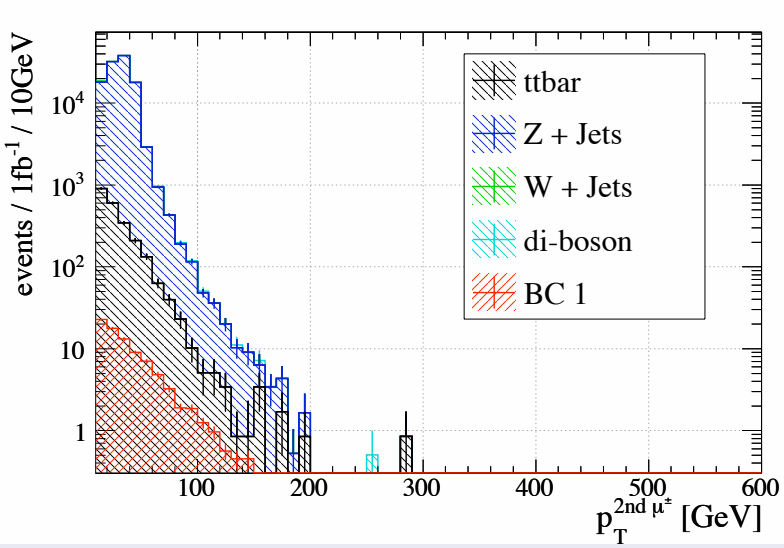
Electron 2



Muon 1

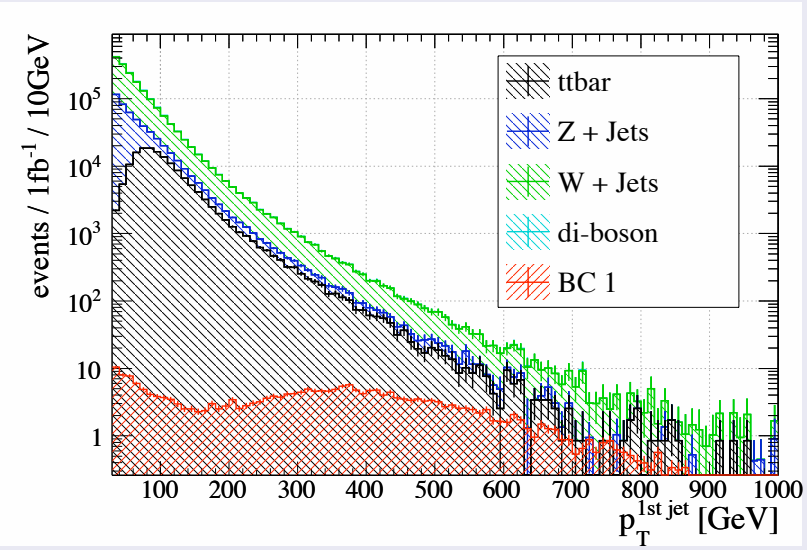


Muon 2

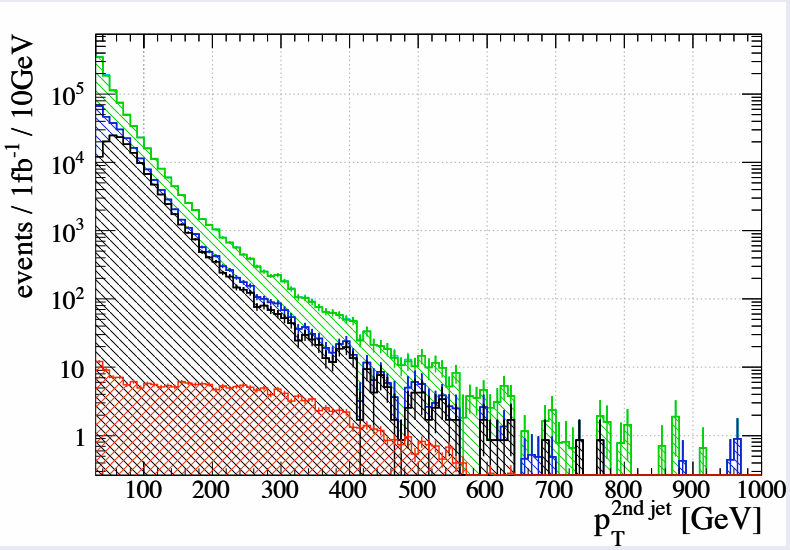


p_t of Leading Jets (Delphes)

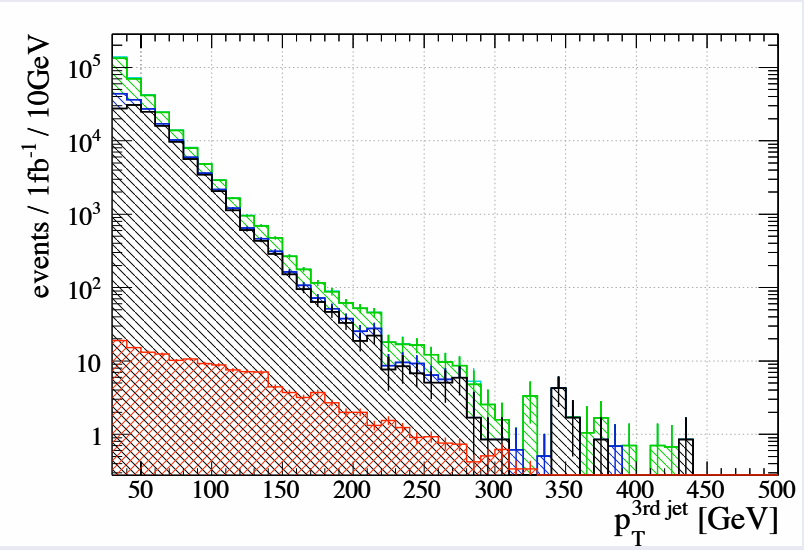
Jet 1



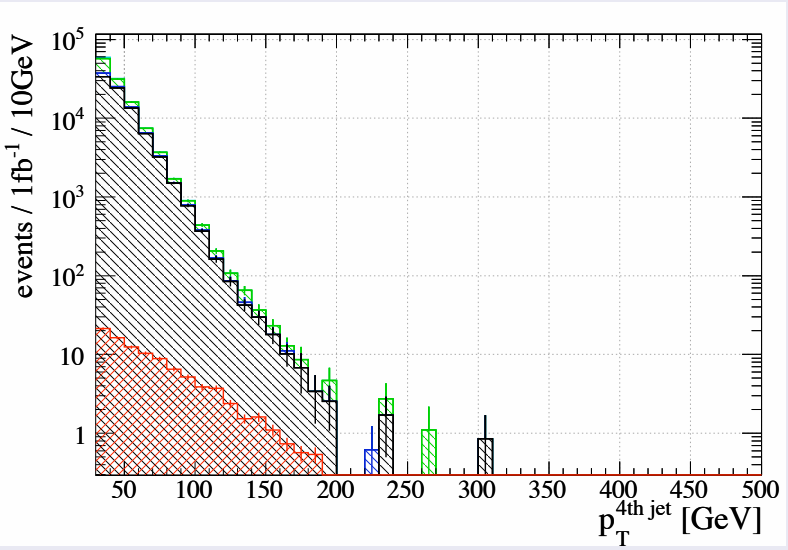
Jet 2



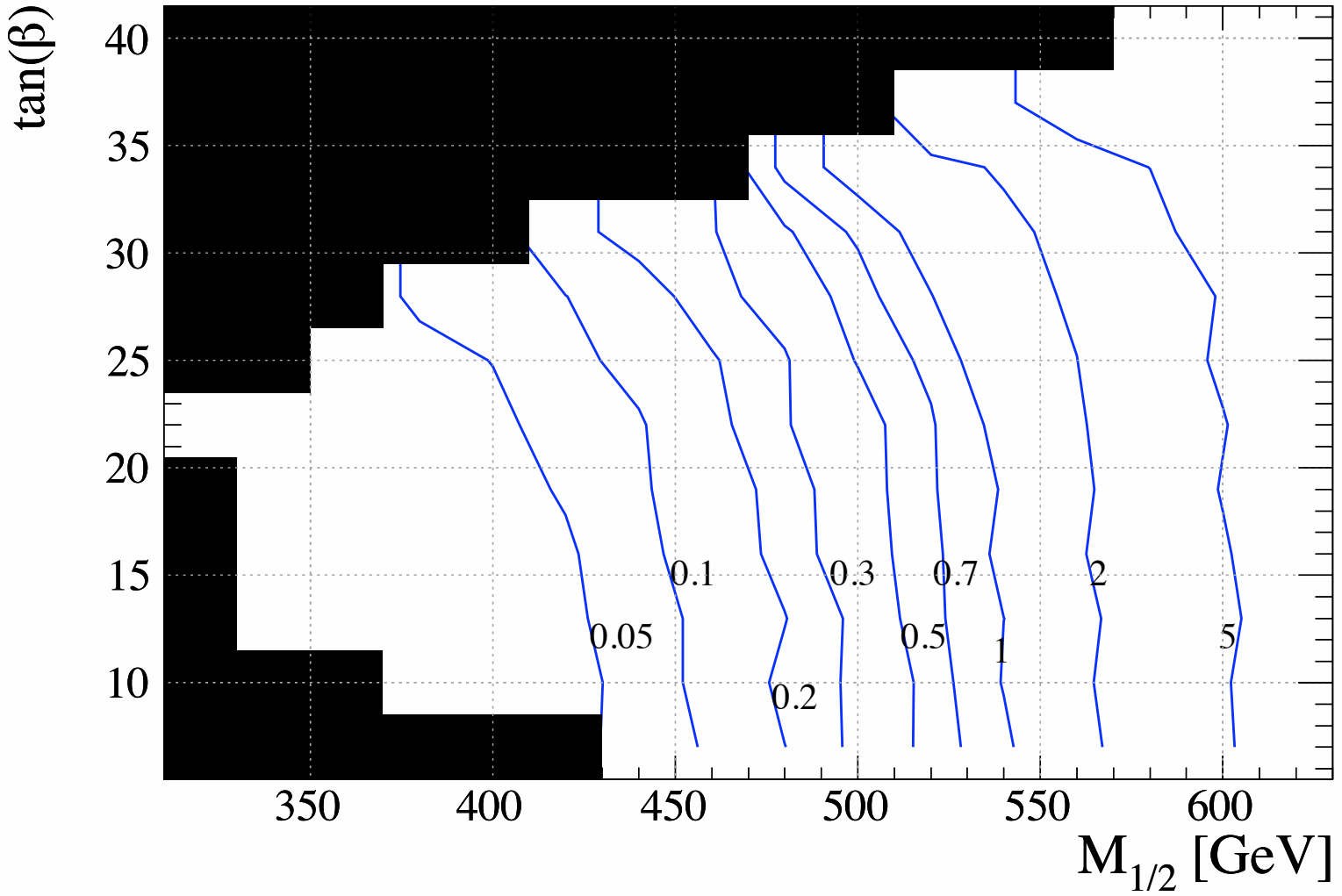
Jet 3



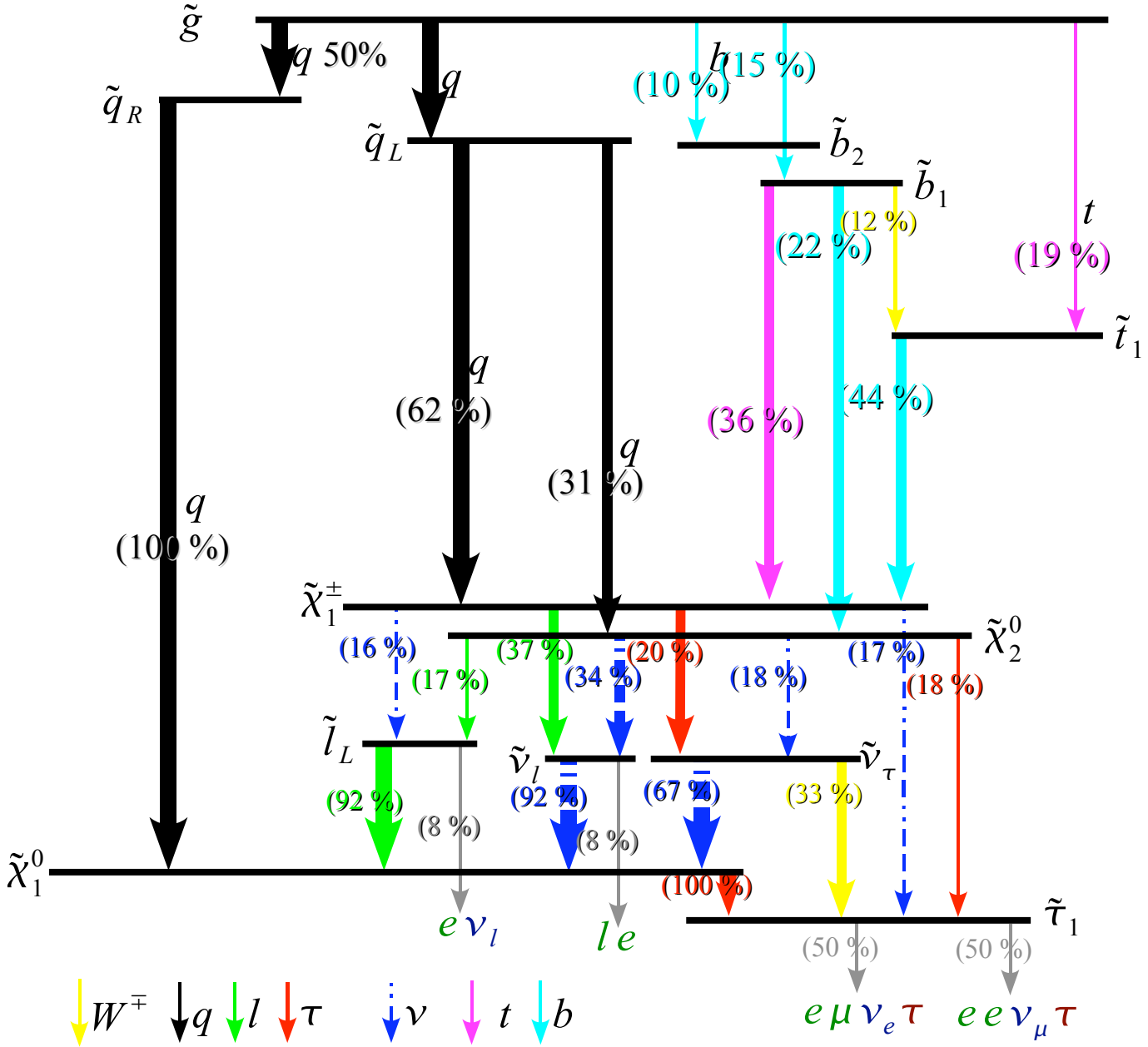
Jet 4



Discovery Reach at $\sqrt{s} = 7$ TeV — $S/\sqrt{B}$



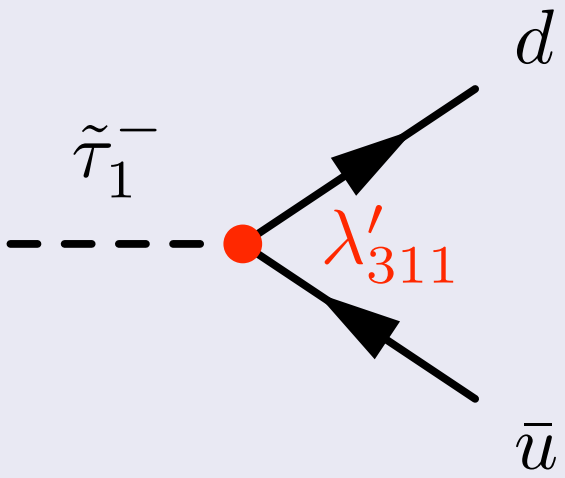
BC1 Mass Spectrum



$\not{R}_p$ mSUGRA benchmark scenario BC 2

- $\lambda'_{311} = \begin{cases} 3.5 \cdot 10^{-7} \ @M_{\text{GUT}} \\ 1.1 \cdot 10^{-6} \ @M_{\text{EM}} \end{cases}$
  ($L_3 Q_1 \bar{D}_1$ coupling)

$\Rightarrow$ 2 body decay $\tilde{\tau}$ LSP:
$\tilde{\tau}_1 \to \bar{u} d$



- Less taus then in BC 1, no leptons from $\not{R}_p$ decays, but $\tilde{\tau}$ mass (in principle) fully reconstructable!