Discovery potential with early LHC data for R-parity violating mSUGRA with stau-LSP

based on arXiv:1008.1580 [hep-ph]

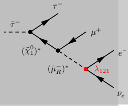
Klaus Desch[1] Herbi Dreiner[1,2] Sebastian Fleischmann[1]
Sebastian Grab[3] Peter Wienemann[1]

[1]Physics Institute, University of Bonn, Bonn, Germany

[2]Bethe Center for Theoretical Physics, University of Bonn, Bonn, Germany

[3]Santa Cruz Institute for Particle Physics, University of California, Santa Cruz

SUSY10
27th August 2010



Outline

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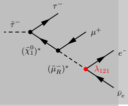


R-parity violating terms

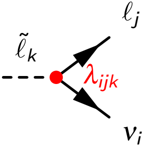
A short reminder and introduction

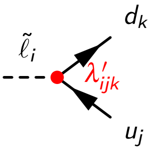
- Most general fully-renormalizable gauge invariant terms in the MSSM superpotential: Introduce baryon number (B) or lepton number (L) violating couplings

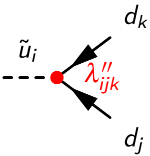
$$W_{R_p} = (\mathbf{Y}_E)_{ij} L_i H_1 \bar{E}_j + (\mathbf{Y}_D)_{ij} Q_i H_1 \bar{D}_j + (\mathbf{Y}_U)_{ij} Q_i H_2 \bar{U}_j + \mu H_1 H_2$$

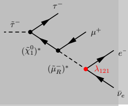
$$W_{\not{R}_p} = \frac{1}{2} \underbrace{\lambda_{ijk} L_i L_j \bar{E}_k}_{\text{violates } L} + \underbrace{\lambda'_{ijk} L_i Q_j \bar{D}_k}_{\text{violates } L} + \frac{1}{2} \underbrace{\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k}_{\text{violates } B} - \underbrace{\kappa^i L_i H_2}_{\text{violates } L}$$

where i,j,k are generation indices



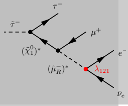






R-parity violating terms
Proton decay and other consequences

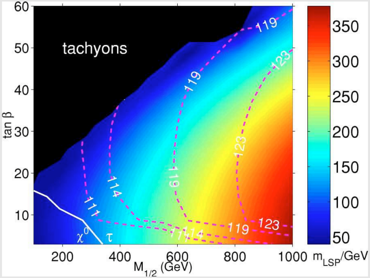
- Introduction of B and L violating couplings leads to rapid proton decay
- It is sufficient to suppress $\Delta L \neq 0$ or $\Delta B \neq 0$ terms to keep the proton stable
- Sparticles can be produced singly, possible on resonance
- Neutrino masses can be generated
- The lightest supersymmetric particle (LSP) is not stable anymore
  - The LSP is no dark matter (DM) candidate (but potential other DM candidates, e.g. Axino)
  - The LSP can be charged
- From existing precision measurements: Strong bounds on RPV couplings
  - Mass spectrum and production of SUSY particles not changed significantly by introduction of RPV couplings



Benchmark points in $\not{R}_p$ mSUGRA

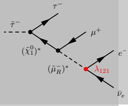
- $\tilde{\tau}$-LSP in broad range of mSUGRA parameter space
- Common feature, independent of RPV coupling: $\tilde{\chi}_1^0 \to \tilde{\tau}\tau$
- Additional leptons may come from RPV stau decays
- Generic signature: Multi-lepton/tau final states + jets

LSP in no-scale mSUGRA



Allanach, Dedes, Dreiner, Phys. Rev. D69 115002

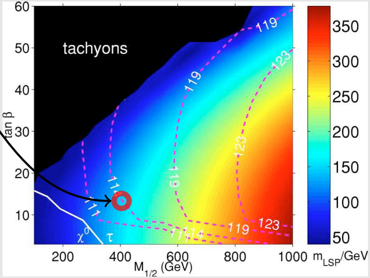
Mass and nature of the LSP in no-scale mSUGRA: $M_0 = A_0 = 0$. Dashed lines show contours of lightest Higgs mass



Benchmark points in $\not{R}_p$ mSUGRA

- Benchmark points with $\tilde{\tau}^{\pm}$ LSP proposed by Allanach et al.
  $A_0 = M_0 = 0$ @M_{GUT}
  $\text{sgn}(\mu) = +1$
  $\tan\beta = 13$,
  $M_{1/2} = 400\text{GeV}$
- $\tilde{\tau}$ is LSP, $\tilde{\chi}_1^0$ is NNNLSP
- λ or λ' coupling
- expected cross section @$\sqrt{s} = 7\text{TeV}$:
  $\sigma = 0.28\text{pb}$

LSP in no-scale mSUGRA



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Mass and nature of the LSP in no-scale mSUGRA: $M_0 = A_0 = 0$. Dashed lines show contours of lightest Higgs mass

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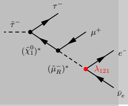
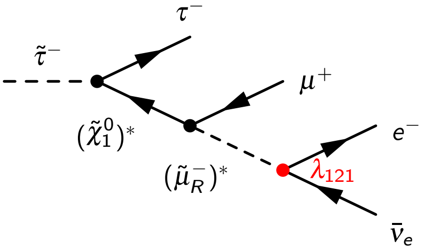
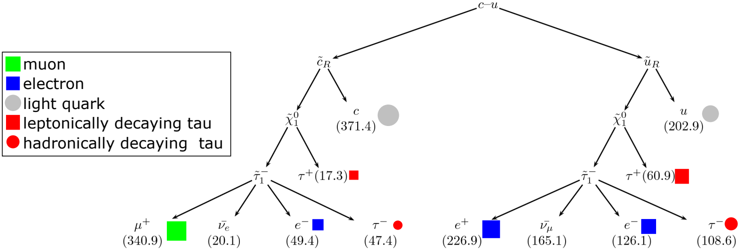


RPV mSUGRA benchmark scenario BC 1

- $\lambda_{121}(M_{GUT}) = 0.032$ $(L_1 L_2 \bar{E}_1$ coupling)
- Leads to 4-body decay of the $\tilde{\tau}$-LSP: $\tilde{\tau}_1^{\pm} \to \tau^{\pm} \ell^{\mp} \ell'^{\pm} \nu$



- Example event:



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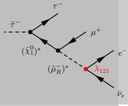
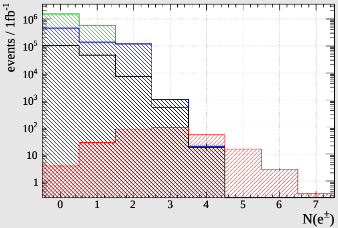


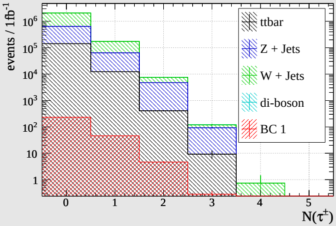
BC 1: Number of objects per event

after ATLAS standard object selection and overlap removal; Delphes detector simulation, $\sqrt{s} = 7\text{TeV}$

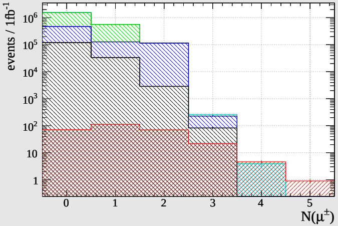
Electrons



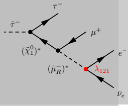
Taus



Muons



- Difference in $e^\pm$, $\mu^\pm$ due to λ_{121}



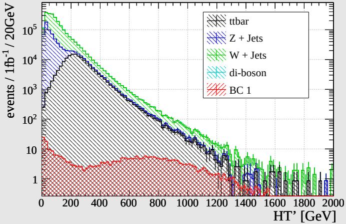
BC 1: Jet and lepton momenta

scaled to $\int L dt = 1 \text{fb}^{-1}$, $\sqrt{s} = 7$ TeV
Delphes simulation

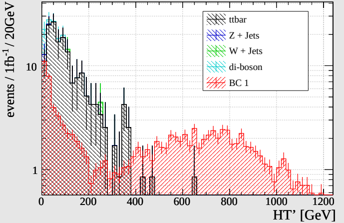
Scalar sum of jet momenta

$HT' = \sum_{\text{jet}1-4} p_T$

before cuts:

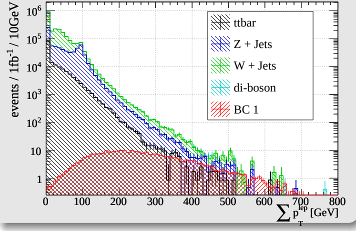


after event selection cuts on leptons:

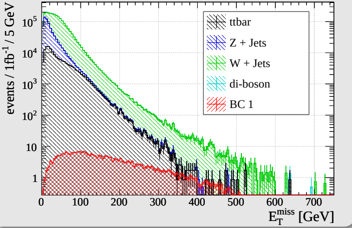


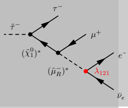
Scalar sum of lepton momenta

$\sum p_T^{\ell} = \sum p_T^{\mu^\pm} + \sum p_T^{e^\pm}$



Missing transverse energy $\not{E}_T$



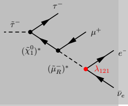


BC 1: Cut Flow

scaled to $\int Ldt = 1\text{fb}^{-1}$, $\sqrt{s} = 7$ TeV
Delphes simulation

cut	all SM	BC 1	$S/\sqrt{B}$
before cuts	2 260 000	283	0.2
$p_T(1\text{st }\mu^\pm) > 40$ GeV	320 000	142	0.3
$p_T(1\text{st }e^\pm) > 32$ GeV	1 800	126	2.9
$p_T(2\text{nd }e^\pm) > 7$ GeV	185	114	8.4
$\sum p_T^\ell > 230$ GeV	15.1	86	22.0
$HT' > 200$ GeV	6.1	60	24.3
$HT' > 300$ GeV	3.4	57	30.7
$HT' > 400$ GeV	$\lesssim 1$	53	

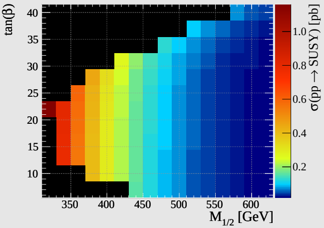
- At $\sqrt{s} = 7$ TeV possible to select (nearly) background free samples at high signal efficiency
- QCD contribution assumed to be negligible
- Most important background: $t\bar{t}$



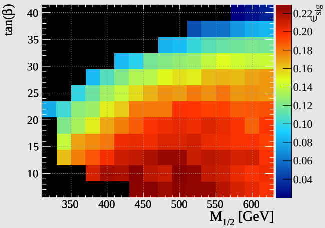
Parameter scan around BC 1

Delphes simulation, $\sqrt{s} = 7\text{TeV}$, $\int L dt = 1\text{fb}^{-1}$

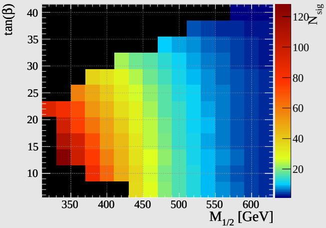
Signal cross section



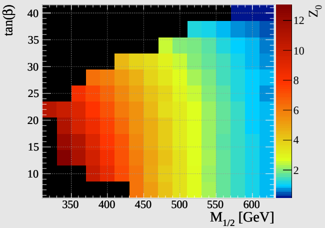
Selection efficiency

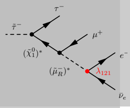


Number of selected signal events



Significance Z_0, 50% bkg uncertainty



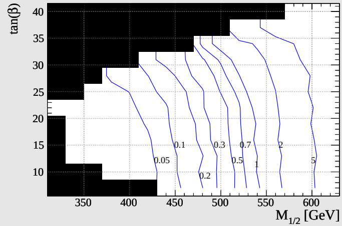


Parameter scan around BC 1

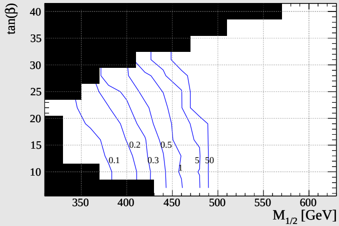
Required luminosity for 5σ discovery
Delphes simulation, $\sqrt{s} = 7$TeV

- Estimated required luminosity for discovery depends strongly on uncertainty of the background estimate

$S/\sqrt{B}$



Binomial Z_0, 50% bkg uncertainty



- Systematic uncertainties need detailed study using full detector simulation and data driven methods
- Compared various significance definitions w/ and w/o systematic uncertainty

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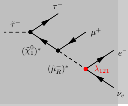
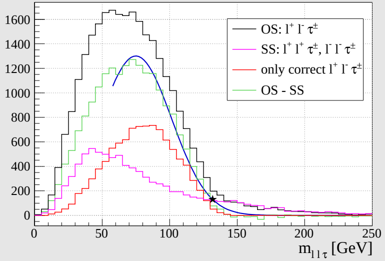
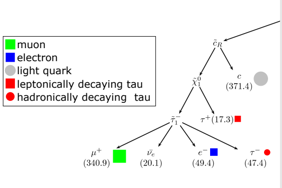


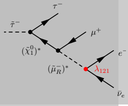
Stau Invariant Mass at Generator Level in BC 1

- Investigate feasibility of invariant mass estimation
- Use only "best combination" per event:
  1. Search for (p_T-)hardest tau (independent of tau charge).
  2. Search for nearest positive and nearest (here ΔR) negative lepton.
- Reject combination, if $\Delta R(\tau, \ell^+)$ or $\Delta R(\tau, \ell^-) > 1.5$
- **For (unphysical) same sign combinations use the best matching and second best matching lepton of each charge.**





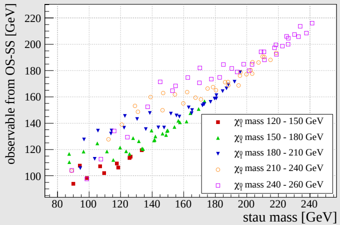
No peak expected, but endpoint at simulated $\tilde{\tau}_1$ mass (148 GeV), due to νs



Stau Invariant Mass at Generator Level in BC 1

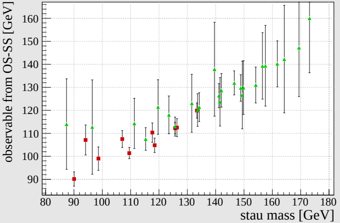
Results in parameter scan

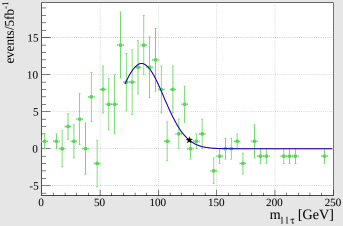
Calibration curve (full stat.)



- Take points from parameter scan
- Calibration curve to get stau mass estimate from observable (10% value of truncated Gaussian fit)

Expectation at 5 fb^{-1}, including event selection cuts





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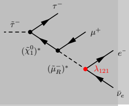
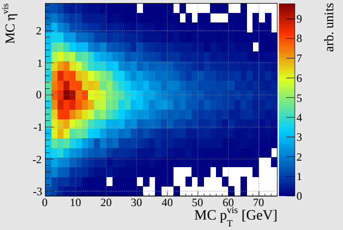


Tau reconstruction in BC 1

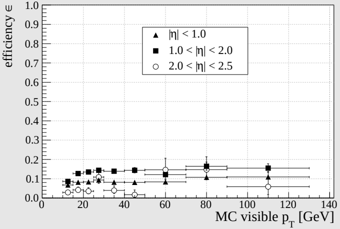
η-p_T distribution of taus (MC visible momentum)



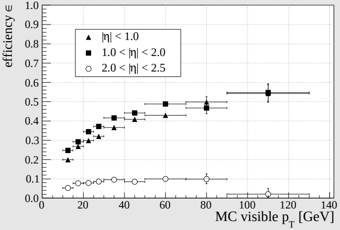
- very low p_T taus
- large overlaps between taus and other objects from SUSY decay chain
- Tau ID efficiency strongly reduced compared to "simple" event topologies

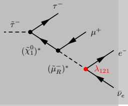
Tau ID efficiency (Delphes)

BC1:



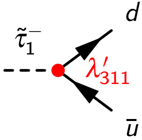
$Z \rightarrow \tau\tau$:





RPV mSUGRA benchmark scenario BC 2

- $\lambda'_{311}(M_{GUT}) = 3.5 \cdot 10^{-7}$ ($L_3 Q_1 \bar{D}_1$ coupling)
- Leads to 2-body decay of the $\tilde{\tau}$-LSP: $\tilde{\tau}_1 \rightarrow \bar{u}d$



- Less taus as in BC 1, no leptons from the RPV decay, but $\tilde{\tau}$-mass (in principle) fully reconstructable
  - Leptonic tau decays can be used for selection
  - Study done at $\sqrt{s} = 10$ TeV, currently repeated at 7 TeV
- BC 1 and BC 2 are two extreme cases of the RPV couplings in terms of the phenomenology of the resulting final states

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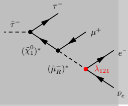
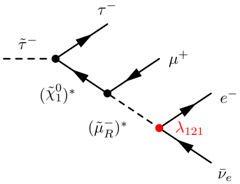
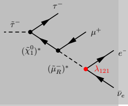


Summary

- R-parity violation opens mSUGRA parameter space to other LSPs as $\tilde{\chi}_1^0$
- Different $\not{R}_p$ couplings lead to various collider signatures
- BC 1 ($\tilde{\tau}_1^\pm \to \tau^\pm \ell^\mp \ell'^\pm \nu$) and BC 2 ($\tilde{\tau}_1^\pm \to qq$) scenarios are phenomenological "extreme cases" of RPV models with $\tilde{\tau}$-LSP
- BC 1 scenario easy to discover; clean signal sample
  - Parameter scan (in $M_{1/2}$ and $\tan\beta$) around the benchmark point shows sufficient cut efficiency
  - Reconstruction of $\tilde{\tau}_1$ mass difficult in BC 1, but mass estimate possible with few years data
  - Tau ID experimentally challenging (low-p_T taus and overlaps between tau jets and other particles)

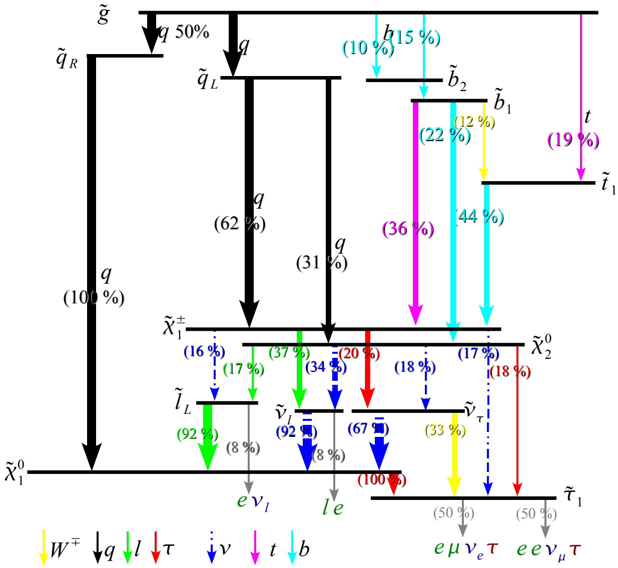
Backup





Decay spectrum of BC 1

Mass spectrum not to scale!



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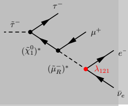


Mass spectrum of BC 1

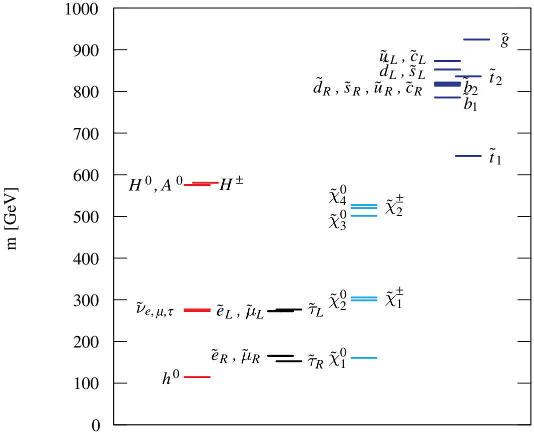
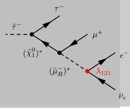


FIG. 9 (color online). Sparticle spectrum for no-scale mSUGRA parameter set: $M_{1/2} = 400$ GeV, $\tan\beta = 13$, $\text{sgn}(\mu) = +1$, and $\Lambda = 0$.



Branching rations in BC 1

RPV mSUGRA with $\tilde{\tau}$ LSP

Sebastian Fleischmann

Outline

RPV SUSY

RPV scenarios

Event Selection

Parameter Scans and discovery potential

Estimation of Stau Invariant Mass

Tau reconstruction

Summary and Outlook

Backup

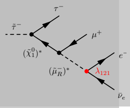
20

50

	mass [GeV]	channel	BR	channel	BR
$\tilde{\tau}_1^-$	148	$\mu^+e^-\tau^-\bar{\nu}_e$	**32.2%**	$e^+e^-\tau^-\bar{\nu}_\mu$	**32.1%**
		$\mu^-e^+\tau^-\nu_e$	**17.9 %**	$e^-e^+\tau^-\nu_e$	**17.8%**
$\tilde{e}_R^-$	161	$e^-\nu_e$	**50%**	$\mu^-\nu_e$	**50 %**
$\tilde{\mu}_R^-$	161	$\tilde{\tau}_1^+\mu^-\tau^-$	51.2%	$\tilde{\tau}_1^-\mu^-\tau^+$	48.7%
$\tilde{\chi}_1^0$	162	$\tilde{\tau}_1^+\tau^-$	49.8%	$\tilde{\tau}_1^-\tau^+$	49.8%
$\tilde{\nu}_\tau$	261	$\tilde{\chi}_1^0\nu_\tau$	67.2%	$W^+\tilde{\tau}_1^-$	32.8%
$\tilde{\nu}_e\,(\tilde{\nu}_\mu)$	262	$\tilde{\chi}_1^0\nu_e(\nu_\mu)$	92.4%	$e^-\mu^+(e^+)$	**7.5%**
$\tilde{e}_L^-\,(\tilde{\mu}_L^-)$	274	$\tilde{\chi}_1^0e^-(\mu^-)$	91.9%	$e^-\bar{\nu}_e(\bar{\nu}_\mu)$	**8.1%**
$\tilde{\tau}_2^-$	278	$\tilde{\chi}_1^0\tau^-$	63.0%	$\tilde{\tau}_1^-Z$	17.6%
		$h^0\tilde{\tau}_1^-$	19.4%		
$\tilde{\chi}_2^0$	303	$\tilde{\nu}_\tau\bar{\nu}_\tau$	9.1%	$\tilde{\nu}_\tau^*\nu_\tau$	9.1%
		$\tilde{\tau}_1^-\tau^+$	9.1%	$\tilde{\tau}_1^+\tau^-$	9.1%
		$\tilde{\nu}_e\bar{\nu}_e$	8.5%	$\tilde{\nu}_e^*\nu_e$	8.5%
		$\tilde{\nu}_\mu\bar{\nu}_\mu$	8.5%	$\tilde{\nu}_\mu^*\nu_\mu$	8.5%
		$\tilde{e}_L^-e^+$	4.5%	$\tilde{e}_L^+e^-$	4.5%
		$\tilde{\mu}_L^-\mu^+$	4.5%	$\tilde{\mu}_L^+\mu^-$	4.5%
		$\tilde{\tau}_2^-\tau^+$	3.1%	$\tilde{\tau}_2^+\tau^-$	3.1%
		$\tilde{\chi}_1^0h$	3.5%		
$\tilde{\chi}_1^-$	303	$\tilde{\nu}_\tau\tau^-$	20.2%	$\tilde{\nu}_\mu\mu^-$	18.6%
		$\tilde{\nu}_ee^-$	18.6%	$\tilde{\tau}_1^-\bar{\nu}_\tau$	16.7 %
		$\tilde{e}_L^-\bar{\nu}_e$	8.1%	$\tilde{\mu}_L^-\bar{\nu}_\mu$	8.1%
		$\tilde{\tau}_2\bar{\nu}_\tau$	5.5%	$\tilde{\chi}_1^0W^-$	4.0%
$\tilde{\chi}_3^0$	514	$\tilde{\chi}_1^-W^+$	28.9%	$\tilde{\chi}_1^+W^-$	28.9%
		$\tilde{\chi}_2^0Z$	24.1%	$\tilde{\chi}_1^0Z$	10.2%
		$\tilde{\chi}_1^0h$	1.8%	$\tilde{\tau}_1^-\tau^+$	1.0%
		$\tilde{\tau}_1^+\tau^-$	1.0%		
$\tilde{\chi}_4^0$	529	$\tilde{\chi}_1^-W^+$	26.5%	$\tilde{\chi}_1^+W^-$	26.5%
		$\tilde{\chi}_2^0h$	17.5%	$\tilde{\chi}_1^0h$	7.1%
		$\tilde{\nu}_\tau\bar{\nu}_\tau$	1.8%	$\tilde{\nu}_\tau^*\nu_\tau$	1.8%
		$\tilde{\nu}_e\bar{\nu}_e$	1.8%	$\tilde{\nu}_e^*\nu_e$	1.8%
		$\tilde{\nu}_\mu\bar{\nu}_\mu$	1.8%	$\tilde{\nu}_\mu^*\nu_\mu$	1.8%
		$\tilde{\tau}_2^-\tau^+$	1.7%	$\tilde{\tau}_2^+\tau^-$	1.7%

	mass [GeV]	channel	BR	channel	BR
$\tilde{\chi}_2^-$	532	$\tilde{\chi}_2^0W^-$	28.3%	$\tilde{\chi}_1^-Z$	25.3%
		$\tilde{\chi}_1^-h$	19.8%	$\tilde{\chi}_1^0W^-$	8.1%
		$\tilde{\tau}_2\bar{\nu}_\tau$	4.4%	$\tilde{e}_L\bar{\nu}_e$	3.7%
		$\tilde{\mu}_L\bar{\nu}_\mu$	3.7%	$\tilde{\nu}_\tau^*\tau^-$	2.8%
		$\tilde{\nu}_e^*e^-$	1.6%	$\tilde{\nu}_\mu^*\mu^-$	1.6%
$\tilde{t}_1$	647	$\tilde{\chi}_1^+b$	44.0%	$\tilde{\chi}_1^0t$	23.7%
		$\tilde{\chi}_2^+b$	17.0%	$\tilde{\chi}_2^0t$	15.4%
$\tilde{b}_1$	780	$\tilde{\chi}_1^-t$	36.0%	$\tilde{\chi}_2^-t$	25.2%
		$\tilde{\chi}_2^0b$	22.0%	$W^-\tilde{t}_1$	12.0%
		$\tilde{\chi}_1^0b$	2.4%	$\tilde{\chi}_3^0b$	1.2%
$\tilde{b}_2$	816	$\tilde{\chi}_2^-t$	40.8%	$\tilde{t}_1W^-$	15.2 %
		$\tilde{\chi}_1^0b$	12.7%	$\tilde{\chi}_1^-t$	10.0%
		$\tilde{\chi}_4^0b$	8.6%	$\tilde{\chi}_3^0b$	6.7%
		$\tilde{\chi}_2^0b$	6.0%		
$\tilde{t}_2$	835	$\tilde{\chi}_4^0t$	23.5%	$\tilde{\chi}_1^+b$	23.0%
		$\tilde{\chi}_2^+b$	15.0 %	$\tilde{t}_1Z$	12.3%
		$\tilde{\chi}_3^0t$	9.6 %	$\tilde{\chi}_2^0t$	9.6 %
		ht	5.7%	$\tilde{\chi}_1^0t$	2.3 %
$\tilde{d}_R\ (\tilde{s}_R)$	855	$\tilde{\chi}_1^0$	99.4%		
$\tilde{u}_R\ (\tilde{c}_R)$	822	$\tilde{\chi}_1^0u(c)$	99.4%		
$\tilde{u}_L\ (\tilde{c}_L)$	852	$\tilde{\chi}_1^+d(s)$	64.6%	$\tilde{\chi}_2^0u(c)$	31.8%
		$\tilde{\chi}_2^+d(s)$	1.5%	$\tilde{\chi}_4^0u(c)$	1.1%
		$\tilde{\chi}_1^0u(c)$	1.0%		
$\tilde{d}_L\ (\tilde{s}_L)$	855	$\tilde{\chi}_1^-u(c)$	61.6%	$\tilde{\chi}_2^0d(s)$	31.8%
		$\tilde{\chi}_2^-u(c)$	3.8%	$\tilde{\chi}_1^0d(s)$	1.8%
		$\tilde{\chi}_4^0d(s)$	1.4%		
$\tilde{g}$	932	$\tilde{q}\bar{q}$	25.0%	$\tilde{q}^*q$	25.0%
		$\tilde{t}_1\bar{t}$	9.5%	$\tilde{t}_1^*t$	9.5%
		$\tilde{b}_1\bar{b}$	7.7%	$\tilde{b}_1^*b$	7.7%
		$\tilde{b}_2\bar{b}$	5.2%	$\tilde{b}_2^*b$	5.2%

TABLE VII: SUSY mass spectrum and branching ratios (BRs) of the benchmark scenario BC1 [18]. Only only decays with a BR of at least 1% are shown. R-parity violating decays are bold face.



Event selection cuts and significances

cut	all SM	BC 1	$S/\sqrt{B}$	Z_0
before cuts	2 258 230 $\pm$1 393	282.8$\pm$2.8	0.2	—
p_T(1st $\mu^\pm$) > 40 GeV	319 975 $\pm$ 510	141.6$\pm$2.0	0.3	—
p_T(1st $e^\pm$) > 32 GeV	1 838 $\pm$ 44	125.9$\pm$1.9	2.9	—
p_T(2nd $e^\pm$) > 7 GeV	184.9$\pm$ 14.8	113.7$\pm$1.8	8.4	0.7
$\sum p_T^\ell > 230$ GeV	15.1$\pm$ 4.3	85.7$\pm$1.6	22.0	4.9
$HT' > 200$ GeV	6.1$\pm$ 2.3	60.3$\pm$1.3	24.3	6.4
$HT' > 300$ GeV	3.4$\pm$ 1.7	56.6$\pm$1.3	30.7	8.1
$HT' > 400$ GeV	$\lesssim 1$	52.6$\pm$1.2		

- Z_0 with 50% background uncertainty

cut	$S/\sqrt{B}$	Z_0	Z_{PLH}	Z_P	Z_W	Z_{Bi}
before cuts	0.2	–	0.1	0.2	0.2	0.1
p_T(1st $\mu^\pm$) > 40 GeV	0.3	–	0.2	0.2	0.3	0.2
p_T(1st $e^\pm$) > 32 GeV	2.9	–	2.1	2.9	2.9	2.1
p_T(2nd $e^\pm$) > 7 GeV	8.4	0.7	5.5	7.6	7.7	5.5
$\sum p_T^\ell > 230$ GeV	22.0	4.9	8.8	14.5	14.5	8.8
$HT' > 200$ GeV	24.3	6.4	7.8	13.9	14.0	7.8
$HT' > 300$ GeV	30.7	8.1	7.9	15.2	15.2	8.1

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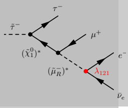
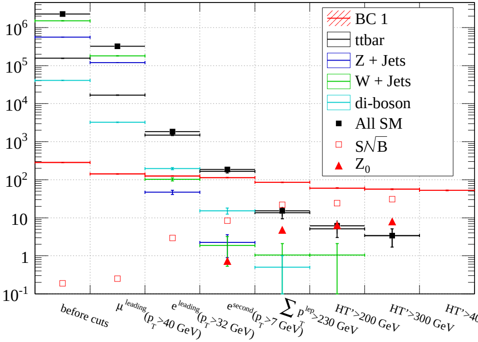


BC 1: Cut Flow

scaled to $\int Ldt = 1\text{fb}^{-1}$, $\sqrt{s} = 7$ TeV
Delphes simulation

cut	$t\bar{t}$	all SM	BC 1	$S/\sqrt{B}$	Z_0
before cuts	155 500	2 260 000	283	0.2	—
$p_T(\text{1st } \mu^\pm) > 40$ GeV	16 700	320 000	142	0.3	—
$p_T(\text{1st } e^\pm) > 32$ GeV	1 500	1 800	126	2.9	—
$p_T(\text{2nd } e^\pm) > 7$ GeV	166	185	114	8.4	0.7
$\sum p_T^\ell > 230$ GeV	13.6	15.1	86	22.0	4.9
$HT' > 200$ GeV	5.1	6.1	60	24.3	6.4
$HT' > 300$ GeV	3.4	3.4	57	30.7	8.1
$HT' > 400$ GeV	$\lesssim 1$	$\lesssim 1$	53		

- Even at $\sqrt{s} = 7$ TeV it is possible to select (nearly) background free samples at high signal efficiency
- QCD contribution assumed to be negligible



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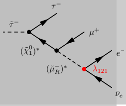
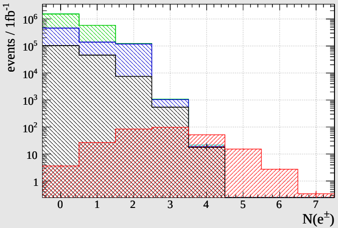


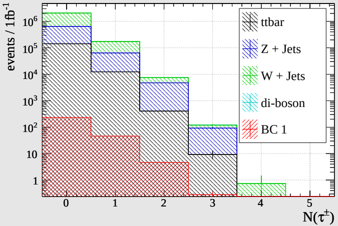
BC 1: Number of objects per event

after ATLAS standard object selection and overlap removal;
Delphes detector simulation, $\sqrt{s} = 7\text{TeV}$

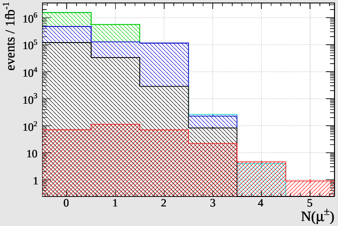
Electrons



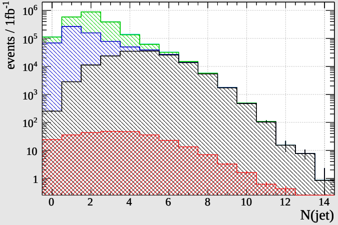
Taus



Muons



Jets



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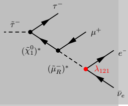
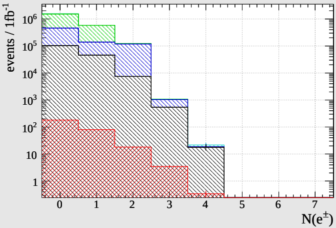


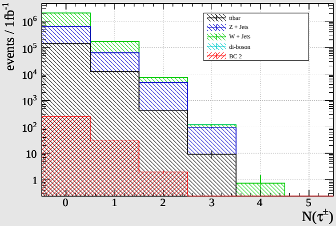
BC 2: Number of objects per event

after ATLAS standard object selection and overlap removal;
Delphes detector simulation, $\sqrt{s} = 7$TeV

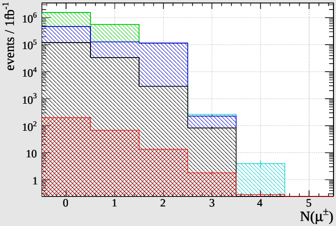
Electrons



Taus



Muons



Jets