R-parity violating SUSY with $\tilde{\tau}$-LSP in ATLAS

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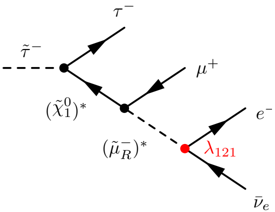
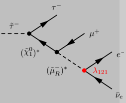
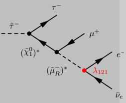
BSM session





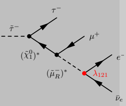
Outline



Introduction

Just a short reminder...

- Supersymmetry (SUSY): Fundamental symmetry between bosons and fermions
- *R*-parity (R_p) usually taken as conserved to avoid rapid proton decay; results in stable lightest supersymmetric particle (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



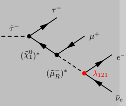
R-parity violating terms

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

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

where i, j, k are generation indices, x, y, z SU(3) gauge (color) indices and a, b SU(2) gauge indices

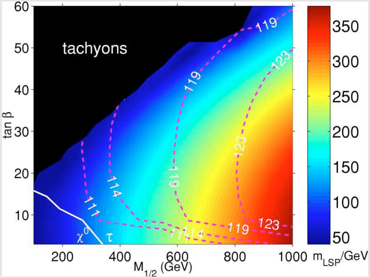
- Only B **or** L violating couplings are allowed to prevent rapid proton decay
- From existing precision measurements: Strong bounds on RPV couplings
  - Mass spectrum and production of SUSY particles not changed significantly by introduction of RPV couplings



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

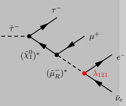
- $\tilde{\tau}$-LSP in broad range of mSUGRA parameter space
- Common feature, independent of RPV coupling: $\tilde{\chi}_1^0 \rightarrow \tilde{\tau}\tau$
- Additional leptons may come from RPV stau decays
- Generic signature: Multi-lepton/tau final states + jets

LSP in no-scale mSUGRA



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

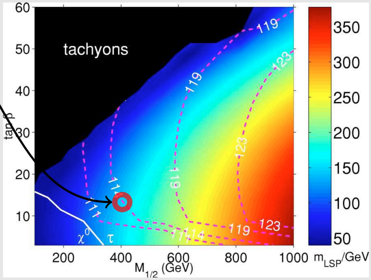
Mass and nature of the LSP in no-scale mSUGRA: $M_0 = A_0 = 0$. Dashed lines show contours of lightest Higgs mass



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}
  $\mathrm{sgn}(\mu) = +1$
  $\tan\beta = 13$,
  $M_{1/2} = 400\mathrm{GeV}$
- $\tilde{\tau}$ is LSP, $\tilde{\chi}_1^0$ is NNNLSP
- λ or λ' coupling
- expected cross section @10TeV: $\sigma = 1.16\mathrm{pb}$

LSP in no-scale mSUGRA



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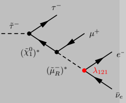
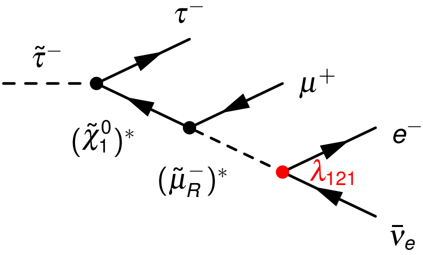
Mass and nature of the LSP in no-scale mSUGRA: $M_0 = A_0 = 0$. Dashed lines show contours of lightest Higgs mass

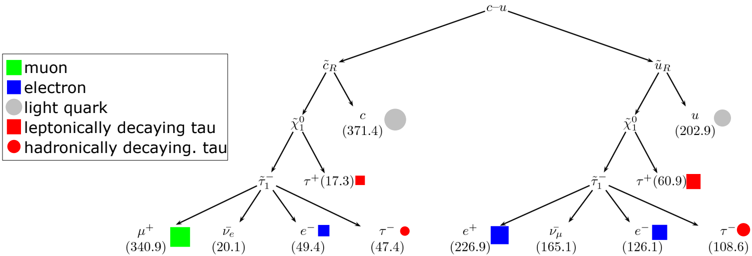


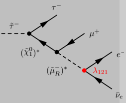
RPV mSUGRA benchmark scenario BC 1

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



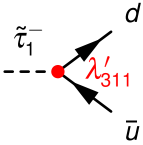
- Example event:



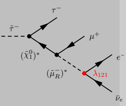


RPV mSUGRA benchmark scenario BC 2

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



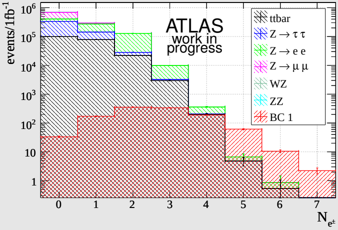
- Less taus as in BC 1, no leptons from the RPV decay, but $\tilde{\tau}$-mass (in principle) fully reconstructable
- BC 1 and BC 2 are two extreme cases of the RPV couplings in terms of the phenomenology of the resulting final states



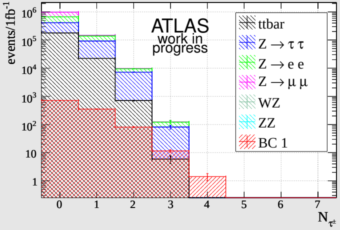
BC 1: Number of objects per event

after ATLAS standard object selection and overlap removal; full detector simulation

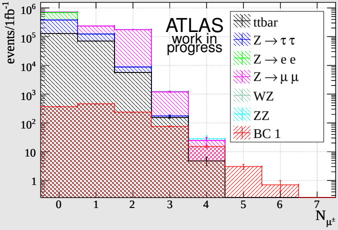
Electrons



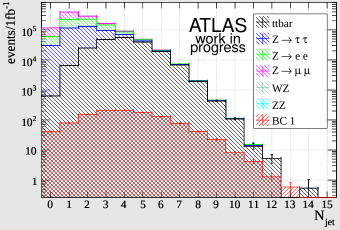
Taus



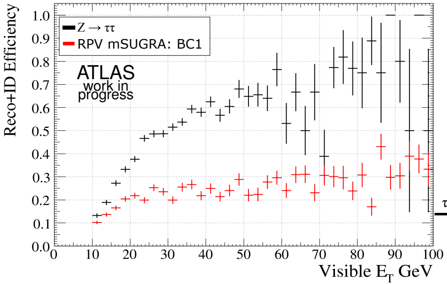
Muons

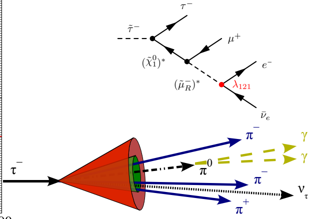


Jets

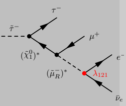


Efficiencies of the tau identification in BC 1





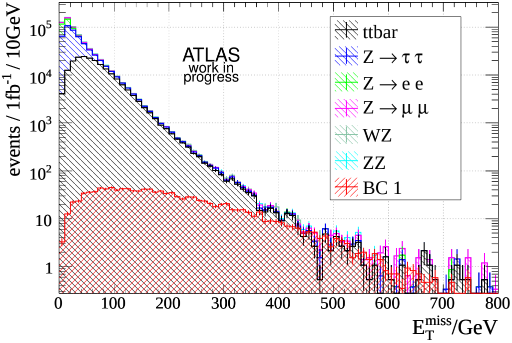
- Pure reconstruction and ID efficiency of τ leptons (hadronic decays only), no overlap removal included here
- Significant degradation of the tau ID efficiency in busy RPV events compared to the standard samples used for tau ID validation (mainly $Z \to \tau\tau$ and $W \to \tau\nu$)
- Needs special treatment in the estimation of ID efficiencies from data



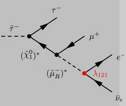
BC 1: Missing transverse energy

(scaled to $\int L dt = 1 \text{fb}^{-1}$, $E_{cm} = 10$ TeV)

- $\not{E}_T$ can be significant in BC 1 events due to ν (from $\tilde{\tau}$ and τ decays)



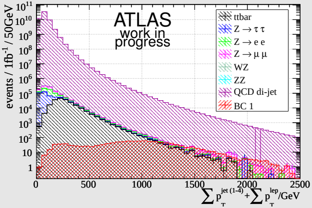
- However, we like to avoid $\not{E}_T$ in the event selection, because large systematic uncertainties are expected in the first data

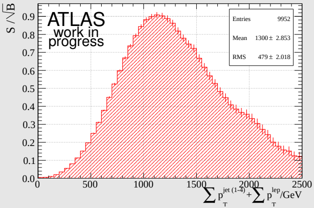


BC 1: Effective Mass without $\not{E}_T$

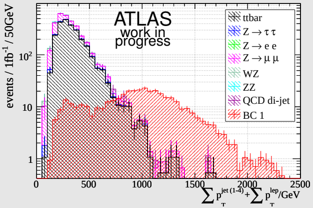
including standard overlap removal, scaled to $\int Ldt = 1\text{fb}^{-1}$, $E_{cm} = 10$ TeV

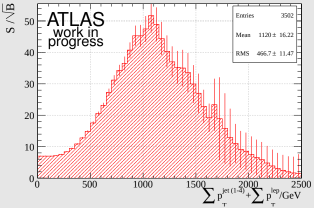
Without further cuts

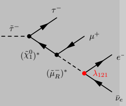




$N_{\mu^\pm} \geq 1$ and $N_{e^\pm} \geq 1$ with $p_T > 40$ GeV each



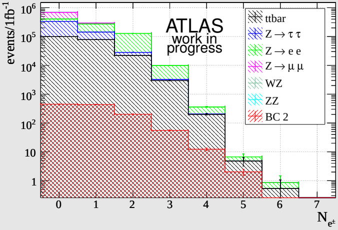




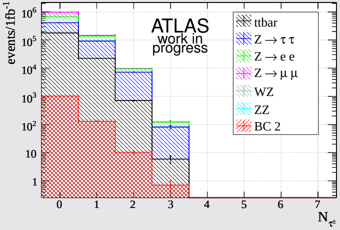
BC 2: Number of objects per event

after ATLAS standard object selection and overlap removal

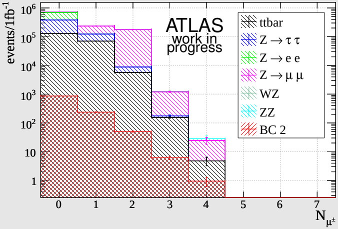
Electrons



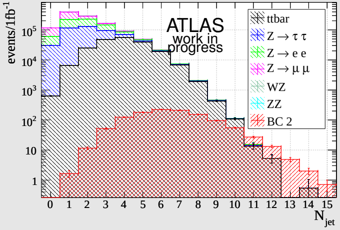
Taus

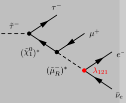


Muons



Jets



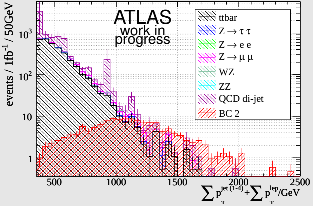


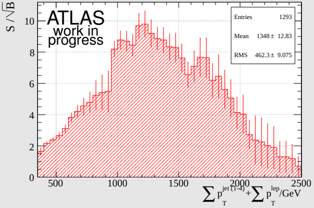
BC 2: Effective Mass without $\not{E}_T$

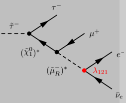
including standard overlap removal, scaled to $\int Ldt = 1\text{fb}^{-1}$, $E_{cm} = 10$ TeV

- Expect jets and 2 low-p_T taus for BC 2 events
- QCD is most difficult background
- Hadronic τ leptons not useful against QCD background even at high jet rejections of the τ ID
- Use $\mu^{\pm}$ from leptonic τ decays

$N_{\mu^{\pm}} \geq 1$ with $p_T > 20$ GeV and $N_{jet} \geq 4$ with $p_T > 50$ GeV

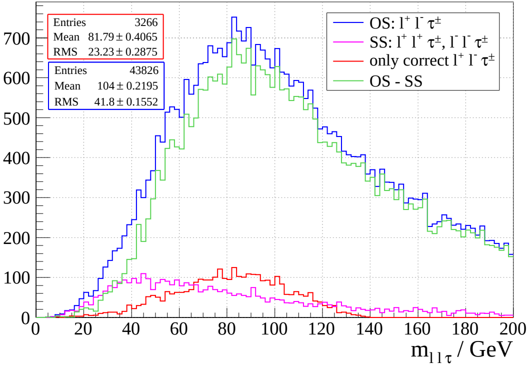


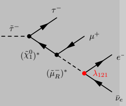




Reconstruction of Invariant Masses

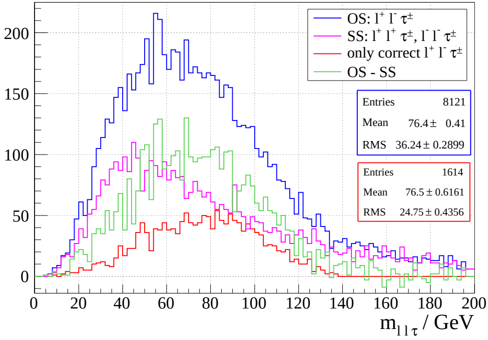
- Pre-study at MC generator level to investigate the feasibility of invariant mass reconstruction in BC 1
- No peak expected, but endpoint at simulated $\tilde{\tau}_1$ mass (148 GeV), due to ν $(\tilde{\tau}_1^{\pm} \rightarrow \tau^{\pm}\ell^{\mp}\ell'^{\pm}\nu)$
- All combinations of $\ell^+\ell'^-\tau^{\pm}$ and visible 4-momentum of taus (5000 BC 1 events), only particles with $p_T^{\mathrm{vis}} > 10\mathrm{GeV}$ and $|\eta| < 2.5$:

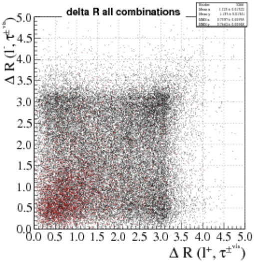


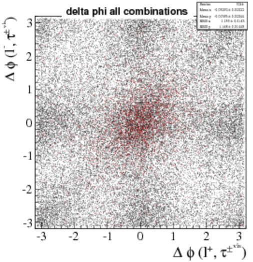


Reconstruction of Invariant Masses

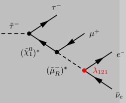
- Try to select good combinations by cut on $\Delta\phi = \phi_{\ell^\pm} - \phi_{\tau^\pm} < 1$





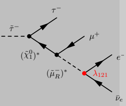


- Cut on $\Delta R(\ell^\pm, \tau^\pm)$ gives similar results

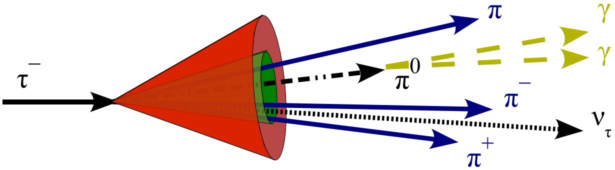


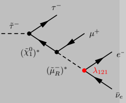
Conclusions and Outlook

- BC 1 and BC 2 scenarios are considered as "extreme cases" of the phenomenology of RPV models with $\tilde{\tau}$-LSP
- BC 1 scenario would be easy to discover in ATLAS, very clean signal sample can be selected
  - However, ATLAS standard overlap removal seems to be non-optimal for BC 1.
  - Reconstruction of $\tilde{\tau}_1$ mass seems to be difficult in BC 1 due to combinatorial background
  - Usual tricks (OS–SS subtraction) do not remove all wrong combinations
- BC 2 harder to discover due to QCD background
- Generator study of RPV scenarios with $\tilde{\tau}$-LSP in collaboration with the theory group of H. Dreiner ongoing
- Next step: Parameter scan (in $M_{1/2}$ and $\tan\beta$) around the benchmark points to avoid over-tuning of event selections


$\tilde{\tau}^-$
τ^-
μ^+
$(\tilde{\chi}_1^0)^*$
$(\tilde{\mu}_R^-)^*$
λ_{121}
e^-
$\bar{\nu}_e$

Backup

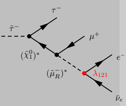

τ^-
π
γ
γ
π^0
π^-
ν_τ
π^+



R-parity violating terms

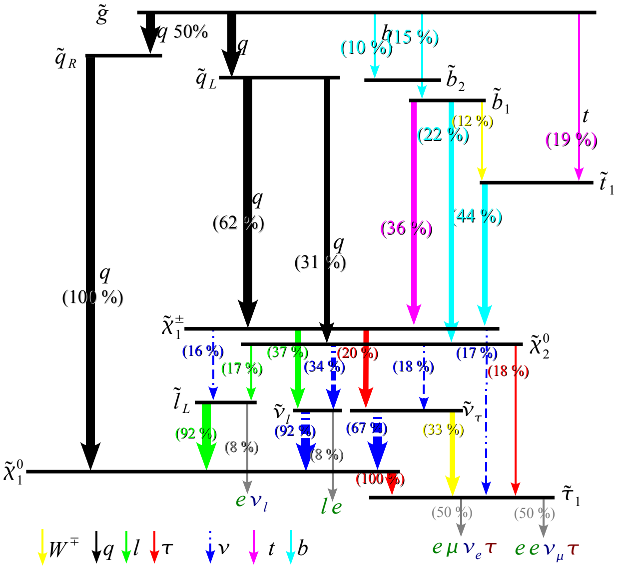
Existing bounds

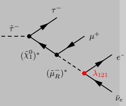
- Strong bounds from precision measurements exist on those couplings
  - RPV couplings and bounds studied by Allanach, Dedes, Dreiner (Phys. Rev. D69, 2004)
  - Couplings too small to change SUSY mass spectrum significantly compared to related RPC case, but nature of LSP may change
  - Phenomenology can change significantly, if LSP is non-stable
- Choosing one non-vanishing λ, λ' or λ'' coupling at M_{GUT} generates several other $\not{R}_p$ couplings at the weak scale by RGEs
  - Choosing two non-vanishing RPV couplings at GUT scale gives even stronger bounds, so usually only one coupling chosen at a time



Decay spectrum of BC 1

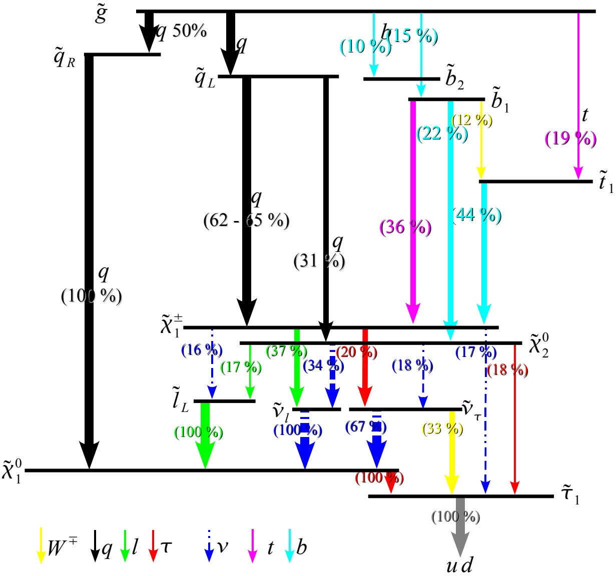
Mass spectrum not to scale!

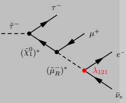




Decay spectrum of BC 2

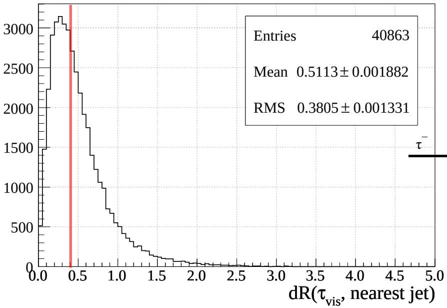
Mass spectrum not to scale!

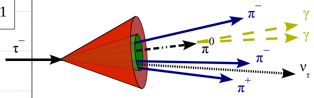




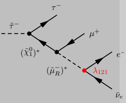
Tau leptons in benchmark scenario BC 2

- Generator-level: Directions of quarks and gluons before hadronisation to direction of the visible component of hadronic tau decays ($\Delta R = \sqrt{(\phi_\tau - \phi_{\text{parton}})^2 + (\eta_\tau - \eta_{\text{parton}})^2}$)





- Cone size used for τ jets: $\Delta R < 0.4$: Large fraction of τ leptons has overlapping jet within this cone



Object selection

Electrons

- IsEM flag: `ElectronMedium`
- $|\eta| < 2.5$ and $|\eta| \notin [1.37, 1.52]$
- $p_T > 7\text{GeV}$

Muons

- $|\eta| < 2.7$
- $p_T > 6\text{GeV}$
- Isolation: $E_T < 15\text{GeV}$ in isolation cone with $\Delta R < 0.1$

Taus

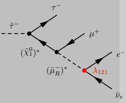
- $|\eta| < 2.5$
- $p_T > 10\text{GeV}$
- Tau likelihood > 4 for candidates with calo seed (`hasAuthor(tauRec)`)
- `TauJet::numTrack()` is 1 or 3
- charge is ± 1

Jets

- $|\eta| < 5$
- $p_T > 20\text{GeV}$

Overlap removal

- Remove muons within $\Delta R < 0.4$ to a jet
- Remove electrons within $0.2 < \Delta R < 0.4$ to a jet
- Remove tau jets within $\Delta R < 0.4$ to an electron
- Remove jets within $\Delta R < 0.4$ to remaining electrons and tau jets



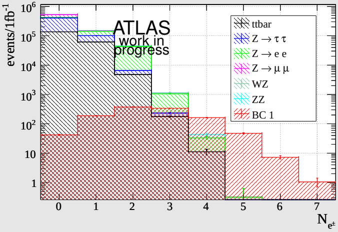
Number of selected objects per event

$\not{R}_p$ mSUGRA with $\tilde{\tau}$-LSP in ATLAS

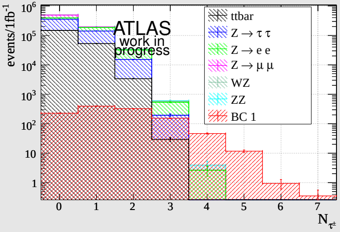
S. Fleischmann

- Outline
- Introduction
- RPV mSUGRA benchmark scenarios
- Object/Event Selection
- Reconstruction of Invariant Masses
- Summary
- **Backup**

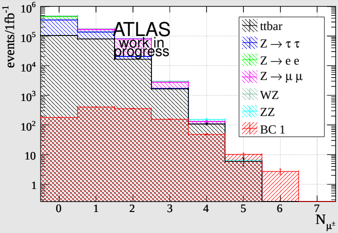
Electrons



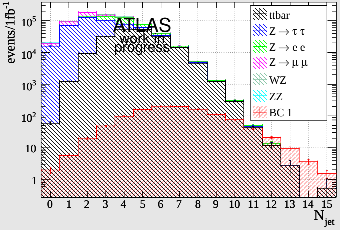
Taus

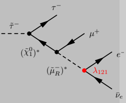


Muons



Jets

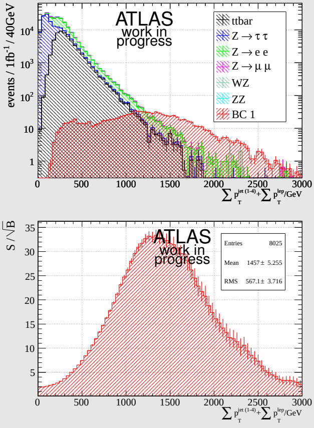




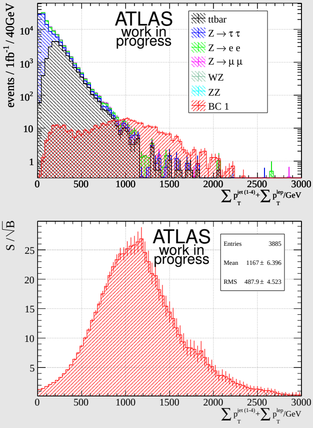
Effective Mass, requiring at least one tau lepton

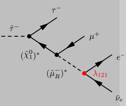
(scaled to $\int Ldt = 1\text{fb}^{-1}$)

M_{eff} no overlap removal



M_{eff} with overlap removal



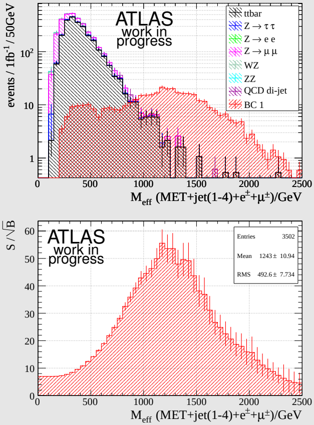


BC 1: Effective Mass for events with at least one muon and one electron with $p_T > 40$GeV each

including standard overlap removal, scaled to $\int Ldt = 1\text{fb}^{-1}$

M_{eff} with $E\!\!\!/_T$

$(\sum p_T^{jet(1-4)} + \sum p_T^{e^\pm,\mu^\pm} + E\!\!\!/_T)$



M_{eff} without $E\!\!\!/_T$

$(\sum p_T^{jet(1-4)} + \sum p_T^{e^\pm,\mu^\pm})$