Optimization Studies for Direct Stau Pair Production with the ATLAS Detector at $\sqrt{s} = 13\text{TeV}$

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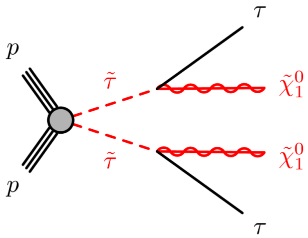
Introduction

Motivation and goal

Physical Motivation

- In many SUSY models the supersymmetric partner of the third lepton generation is the lightest one.
- Co-annihilation between dark matter and a light stau leads to a dark matter relic density consistent with cosmological observations.



RPC simplified model for direct stau pair production.

Goal

- Find the highest possible signal sensitivity by optimizing the event selection.

  (First time this study is perfomed)

Benchmark model

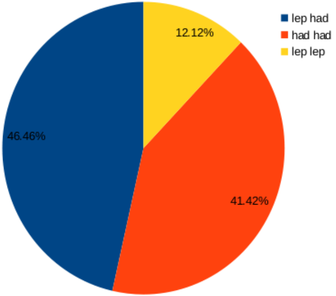
- $\mathrm{m}(\tilde{\tau}) = 200$ GeV
- $\mathrm{m}(\tilde{\chi}_1^0) = 1$ GeV

$\rightarrow$ Sensitivity study based on the full run 2 dataset of $140\,\mathrm{fb}^{-1}$.

Introduction

Lepton-Hadron Final State

τ-pair branching fractions:



Object Selection

- e: $p_\mathrm{T} > 15$ GeV, $|\eta| < 2.47$
- μ: $p_\mathrm{T} > 25$ GeV, $|\eta| < 2.5$
- τ: $p_\mathrm{T} > 20$ GeV, $|\eta| < 2.5$

  ↳ Number of tracks = 1,3 (in $\Delta R < 0.2$)

Preselection

- $N(\tau) = 1$ & $N(\ell) = 1$
- $OS(\tau, \ell)$
- b-Jet veto & loose lepton veto

  → 0 or 1 jet region with $p_T > 60$ GeV

  → low/high $E_\mathrm{T}^\mathrm{miss}$ region in 0HighJet region

Difficulties

- Low signal cross section (~ 200 events after preselection)
- Overwhelming background (~ 2.5 mio. events after preselection)

Introduction

Finding the best cut

For optimization two different measures are under consideration:

$$\text{efficiency separation 1} : (1 - \epsilon_b) \times \epsilon_s$$

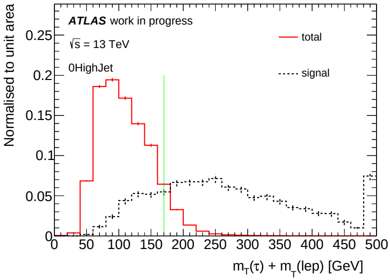
$$\text{efficiency separation 2} : \frac{\epsilon_s}{\sqrt{\epsilon_b}}$$

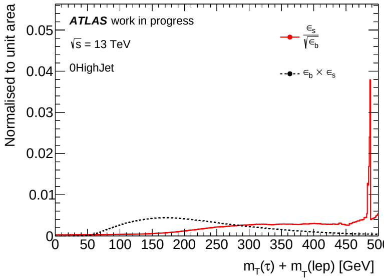
ϵ_b is the background efficiency in the signal region.
ϵ_s is the signal efficiency in the signal region.

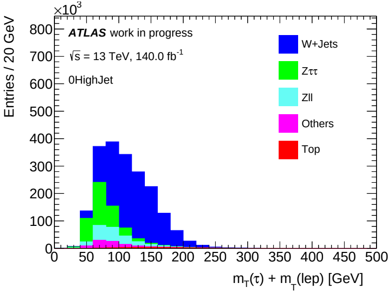
Criterion for a Cut:

- maximize efficiency separation 1 or 2.
- Relative statistical error for each background $< 50\,\%$.
- Take correlation between different variables into account.

Cut 1: $M_T(\ell, E_T^{miss}) + M_T(\tau, E_T^{miss})$

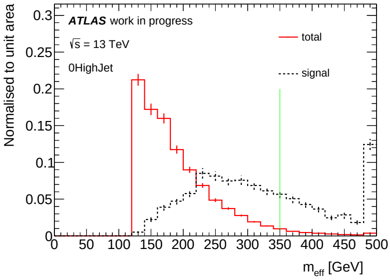


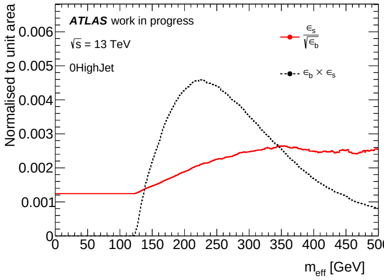


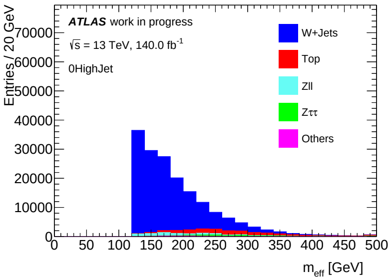


Cut at:	$\sum M_T > 170$ GeV
Expected signal:	120.73±3.26
Expected background:	177927.23 ± 3469.58
Expected W+jets:	152185.41 ± 2800.21 (∼ 85 %)
Signal reduction:	1.27
Background reduction:	11.79

Cut 2: Effective Mass

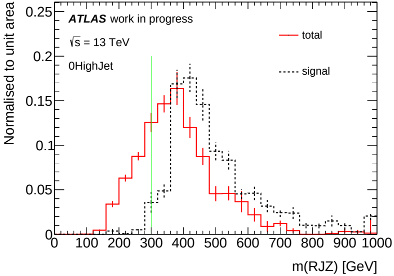


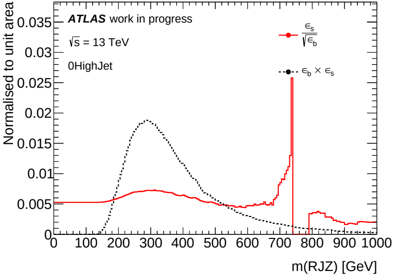


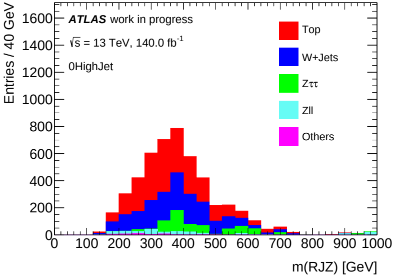


Cut at:	$m_{\mathrm{eff}} > 350$ GeV
Expected signal:	42.2 ± 1.68
Expected background:	4811.12 ± 206.87
Expected W+jets:	1663.4 ± 126.98 ($\sim$ 34 %)
Signal reduction:	2.86
Background reduction:	369.55

Cut 3: Z mass

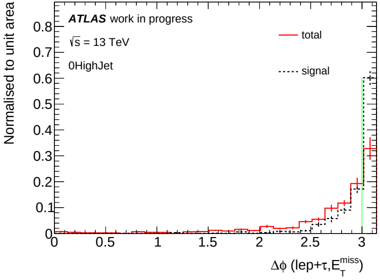


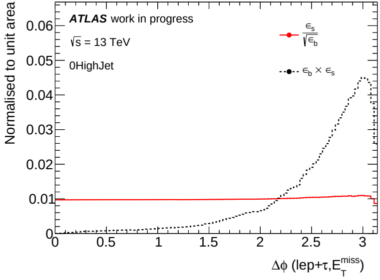


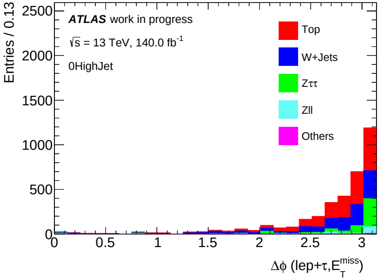


Cut at:	$m(RJZ) > 300$ GeV
Expected signal:	41.4 ± 1.64
Expected background:	3630.36 ± 199.67
Expected W+jets:	1218.09 ± 158.35 ($\sim 33\,\%$)
Signal reduction:	1.02
Background reduction:	1.33

Cut 4: $\Delta\phi(\ell + \tau, E_T^{miss})$







Cut at:	$\Delta\phi(\ell + \tau, E_T^{miss}) > 3$
Expected signal:	26.07 ± 1.21
Expected background:	1344.33 ± 165.98
Expected W+jets:	385.68 ± 132.46 ($\sim 26\,\%$)
Signal reduction:	1.59
Background reduction:	2.7

List of Cuts

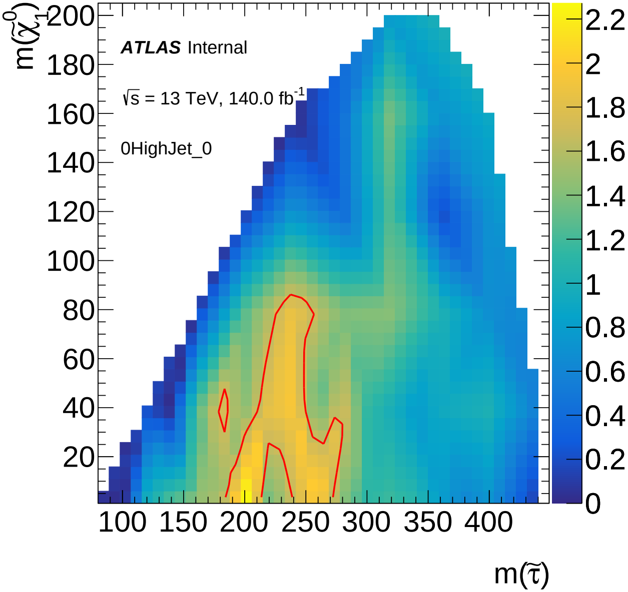
0HighJet (high E_T^{miss})		0HighJet (low E_T^{miss})		1HighJet	
Variable	Cut	Variable	Cut	Variable	Cut
$MT(\tau, E_T^{miss}) + MT(\ell, E_T^{miss})$	$>$ 170 GeV	E_T^{miss}	$<$ 120 GeV	$MT(\tau, E_T^{miss}) + MT(\ell, E_T^{miss})$	$>$ 180 GeV
m_{eff}	$>$ 350 GeV	$p_T(\tau)$	$>$ 50 GeV	E_T^{miss} significance	$>$ 7
$m(RJZ)$	$>$ 300 GeV	$MT(\tau, E_T^{miss}) + MT(\ell, E_T^{miss})$	$>$ 250 GeV	m_{eff}	$>$ 350 GeV
$\Delta\phi(\ell + \tau, E_T^{miss})$	$>$ 3	$m_{invariant}$	$>$ 80 GeV	$\Delta\eta(\ell, \tau)$	$<$ 1.4
$\Delta\eta(\ell, \tau)$	$<$ 1.3	$\Delta\phi(\tau, \ell)$	$>$ 1.5	$m(RJZ)$	$>$ 320 GeV
$\Delta R(\ell, \tau)$	$<$ 3	$MT_2(min)$	$>$ 90 GeV	$p_T(\tau)$	$>$ 30 GeV
$p_T(\tau)$	$>$ 50 GeV	$m(RJW)$	$>$ 150 GeV	$MT_2(min)$	$>$ 80 GeV
$MT_2(min)$	$>$ 80 GeV	Thrust	$>$ 0.7	$\Delta\phi(\ell, \tau)$	$>$ 1.4
$m_{invariant}$	$>$ 90 GeV	$p_T(RJW)$	$>$ 100 GeV	$m(RJW)$	$>$ 100 GeV
E_T^{miss}	$>$ 120 GeV	un. Fox-Wofram Moment 7	$>$ 0.35	$\Delta R(\ell, jet)$	$>$ 1
$p_T(RJW)$	$>$ 70 GeV	VecSumPt(ℓ, τ, E_T^{miss})	$<$ 90 GeV	E_T^{miss}	$>$ 120 GeV
VecSumPt(ℓ, τ, E_T^{miss})	$<$ 50 GeV			$\Delta\eta(\tau, jet)$	$<$ 2.2
$m(RJW)$	$>$ 100 GeV				
un. Fox-Wofram Moment 6	$>$ 0.4				
un. Fox-Wofram Moment 4	$>$ 0.35				
$\Delta\phi(\tau, \ell)$	$>$ 1.2				
E_T^{miss} significance	$>$ 9				
un. Fox-Wofram Moment 9	$>$ 0.35				

Summary for m($\tilde{\tau}$) = 200 GeV, m($\tilde{\chi}_1^0$) = 1 GeV

	0HighJet(high E_T^{miss})	0HighJet(low E_T^{miss})	1HighJet	combined
exp. s	4 ± 0.52	1.93 ± 0.44	2.04 ± 0.43	7.97
exp. b	1.37 ± 1	1.03 ± 1.42	2.24 ± 1.74	4.64
$\frac{s}{\sqrt{b}}$	3.42	1.9	1.36	4.14
σ **(stat⊕30 %)**	**1.66**	**0.78**	**0.71**	**1.97**

	HighJet(high E_T^{miss})	0HighJet(low E_T^{miss})	1HighJet
W+Jets	0.57	-0.76	0.95
$Z\ell\ell$	0	0.03	0
$Z\tau\tau$	0	0	0.02
Top	0.6	1.98	1.04
Others	0.2	0.05	0.23

Expected Median Significance



Outlook

First attempt to study direct $\tilde{\tau}$-pair production in lep-had final state with ATLAS.

Outlook:

- Use tau-lepton triggers in combination with single lepton triggers.
- Split signal region into low E_T^{miss} and high E_T^{miss} region.
- QCD estimation using ABCD method and fake factor method.

End

With special thanks to:

Johannes Josef Junggeburth
&
Zinonas Zinonos

Backup

Input variables of the optimization

Kinematic	
$M_T(\tau, E_T^{miss})$	$M_T(\ell, E_T^{miss})$
$M_T(\ell, E_T^{miss}) + M_T(\tau, E_T^{miss})$	E_T^{miss}
E_T^{miss} centrality	E_T^{miss} significance
m_{vis}	m_{eff}
VecSumPt(ℓ, τ)	VecSumPt(ℓ, τ, E_T^{miss})
$MT2_{max}$	$MT2_{min}$
Angular	
$\sum \Delta\phi(i, E_T^{miss})$ $(i = \tau, \ell)$	$\lvert \sum \Delta\phi(i, E_T^{miss}) \rvert$ $(i = \tau, \ell)$
$\Delta\phi(\ell, \tau)$	$\lvert \Delta\eta(\ell, \tau) \rvert$
$\Delta R(\ell, \tau)$	$\cos\alpha(\ell, \tau)$
$\Delta\phi(\ell + \tau, jet)$	$\Delta R(\ell + \tau, jet)$
$\cos\alpha(\ell + \tau, jet)$	$\Delta\phi(\ell + \tau, E_T^{miss})$
$\Delta\phi(\ell + \tau + E_T^{miss}, jet)$	
Eventshape variables	
Thrust	Planarity
Aplanarity	Sphericity
Unnorm. Fox-Wolfram moment 0-10	
Jicksaw Candidates for $V = W-$ &$Z-$boson $(i = \ell, \tau)$	
$m(RJV)$	$p_T(RJV)$
$\cos\theta^\star(RJV)$	dPhiDecayPlane(RJV)
$\Delta\phi(RJV, i)$	$\lvert \Delta\eta(RJV, i) \rvert$
$\cos\alpha(RJV, i)$	$\Delta R(RJV, i)$
$\Delta\phi(RJV + i, jet)$	$\Delta R(RJV + i, jet)$
$\cos\alpha(RJV + i, jet)$	$\Delta\phi(RJV + i + E_T^{miss}, jet)$
$\Delta\phi(RJV + i, E_T^{miss})$	

Backup

Significance computation (Asimov)

$$\sigma = \left[2 \left((s+b) \left[\frac{(s+b)(b+\sigma_b^2)}{b^2 + (s+b)\sigma_b^2} \right] - \frac{b^2}{\sigma_b^2} \ln \left[1 + \frac{\sigma_b^2 s}{b(b+\sigma_b^2)} \right] \right) \right]^{1/2}$$

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Centrality

Computation of centrality for leptons:

$$\text{centrality}(\ell) = \frac{A + B}{\sqrt{A^2 + B^2}}$$

with

$$A = \frac{\sin \Delta\phi(\mathrm{E}_T^{miss}, \ell)}{sin\Delta\phi(\ell, \tau)}$$

$$B = \frac{\sin \Delta\phi(\mathrm{E}_T^{miss}, \tau)}{sin\Delta\phi(\ell, \tau)}$$

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Thrust

The quantity thrust T is defined by

$$T = \max_{|\mathbf{n}|=1} \frac{\sum_i |\mathbf{n} \cdot \mathbf{p}_i|}{\sum_i |\mathbf{p}_i|}$$

and the thrust axis $\mathbf{v}_1$ is given by the $\mathbf{n}$ vector for which maximum is attained. The allowed range is $1/2 \leq T \leq 1$, with a 2-jet event corresponding to $T \approx 1$ and an isotropic event to $T \approx 1/2$.

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Fox-wolfram moments

The Fox-Wolfram moments H_l, $l = 0, 1, 2, \ldots$, are defined by

$$H_l = \sum_{i,j} \frac{|\mathbf{p}_i||\mathbf{p}_j|}{E_{vis}^2} P_l(\cos\theta_{ij})$$

where θ_{ij} is the opening angle between hadrons i and j and E_{vis} the total visible energy of the event. Note that also autocorrelations, $i = j$, are included. The $P_l(x)$ are the Legendre polynomials. If

momentum is balanced then $H_1 \equiv 0$. 2-jet events tend to give $H_l \approx 1$ for l even and ≈ 0 for l.