Search for Supersymmetry in Multileptonic Final States with Collimated τ Pairs with the ATLAS Detector

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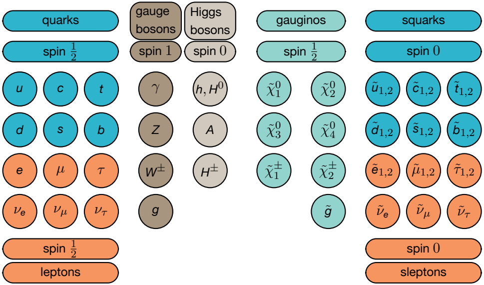
Supersymmetry

Supersymmetry (SUSY) predicts a boson for each SM fermion and vice versa (same quantum numbers except spin).



New conserved quantity in most SUSY models:

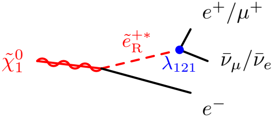
$$P_R = (-1)^{3(B-L)+2s} = \begin{cases} +1 & \text{for SM particles} \\ -1 & \text{for SUSY particles} \end{cases}$$

Consequence: lightest SUSY particle is stable

R-parity Violating Supersymmetry

In some SUSY models R-parity is not conserved

$$W_{\Delta L=1} = \frac{1}{2}\lambda^{ijk} L_i L_j \bar{E}_k$$



Two scenarios with λ^{12k} and λ^{i33} coupling:

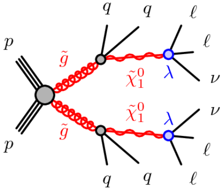
	$k/i = 1$	$k/i = 2$
λ^{12k}	$ee\nu_\mu$ / $e\mu\nu_e$	$e\mu\nu_\mu$ / $\mu\mu\nu_e$
λ^{i33}	$e\tau\nu_\tau$ / $\tau\tau\nu_e$	$\mu\tau\nu_\tau$ / $\tau\tau\nu_\mu$

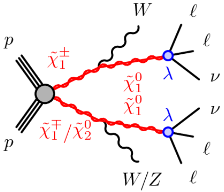
Final states with high lepton multiplicity

$\rightarrow$ Search for the four lepton final state

Advantages: low Standard Model background contribution

Considered processes:





Event Selection

	Electron	Muon	Tau	Jet
p_T	> 7 GeV	> 5 GeV	> 20 GeV	> 20 GeV
$\|\eta\|$	< 2.47	< 2.7	< 2.47	< 2.8

Leptons have to be isolated from hadronic activity

Reject events with: $|m_{\ell^+\ell^-} - m_Z| < 10$ GeV

Discriminating variable:

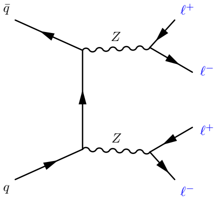
$$m_{\text{eff}} = \sum_{\ell=e,\mu,\tau} p_T(\ell) + \sum_{p_T(j)>40\text{ GeV}} p_T(j) + E_T^{\text{miss}}$$

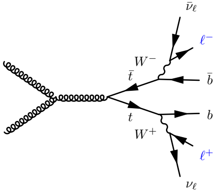
SR	N_ℓ	N_τ	m_{eff}
SR0A	≥ 4	$= 0$	> 600 GeV
SR0B	≥ 4	$= 0$	> 1100 GeV
SR1	$= 3$	≥ 1	> 700 GeV
SR2	$= 2$	≥ 2	> 650 GeV

Two types of background:

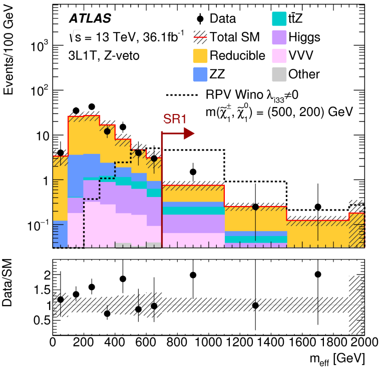
- Irreducible background:
  - Processes with four or more leptons in the final state
  - e.g. *ZZ*, $t\bar{t}Z$, *VVZ* ($V = Z, W$)
  - Estimated from Monte Carlo simulation

- Reducible background:
  - Processes with at least one fake lepton
  - Estimated with data-driven fake-factor method
  - e.g. $t\bar{t}$, $Z+$jets



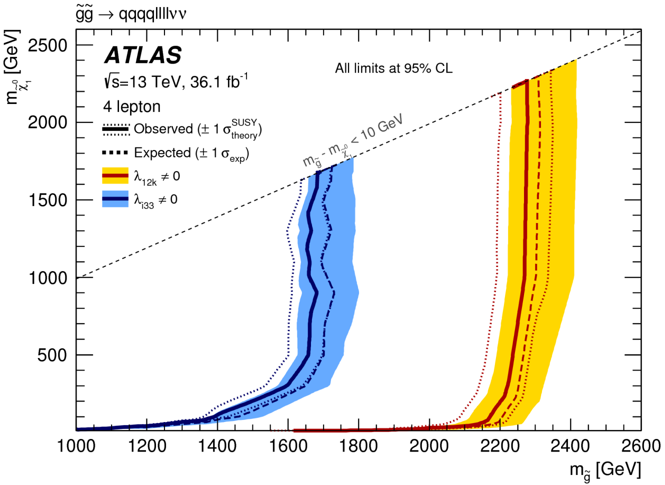


- m_{eff} distribution in the SR1 region
- Analysis based on data taken in 2015-2016 (36.1fb^{-1})
- No significant excess of data observed

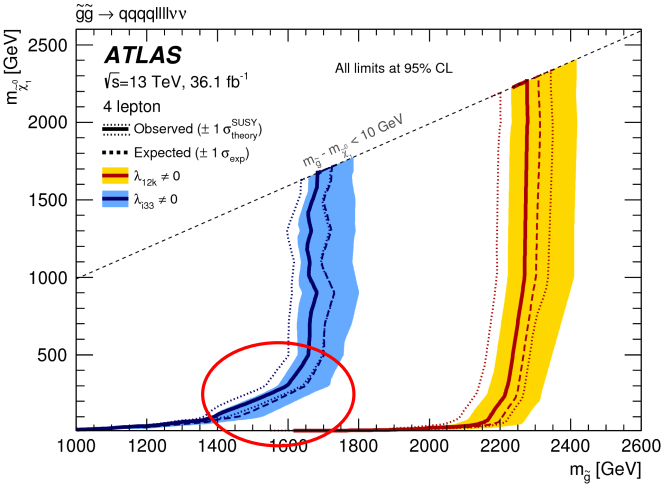


arXiv:1804.03602

Results



sensitivity drops for low LSP masses in case of LSP decays into τs



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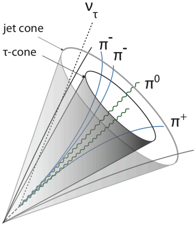
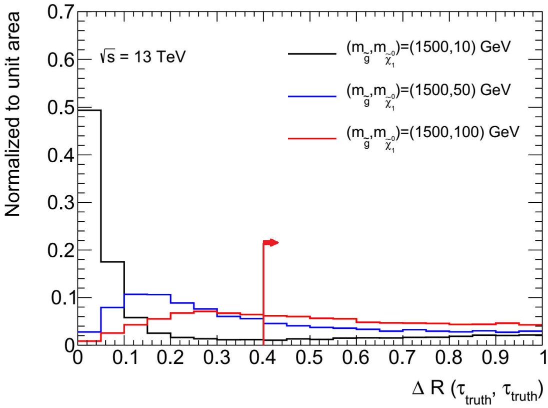
τ Reconstruction

τ reconstruction targets hadronically decaying τs

- Group calorimeter signals from hadrons into a cone (jet). Cone size: $R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$
- Taus are seeded using jets with $R = 0.4$.
- Two regions core- and isolation-cone
- Tracks within a cone of < 0.2 are associated to the tau candidate
- Multivariate-based rejection of fake τ (quark- and gluon-initiated jets, electrons)



ΔR Distribution



- events enriched with collimated τ pairs for low LSP masses
- efficiency of τ reconstruction decreases rapidly for $\Delta R(\tau, \tau) < 0.4$

→ new method: di-τ reconstruction

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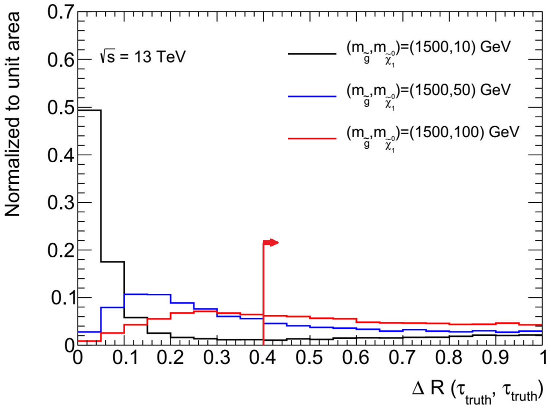

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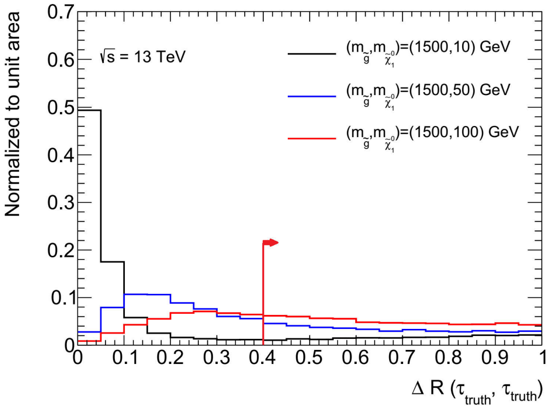

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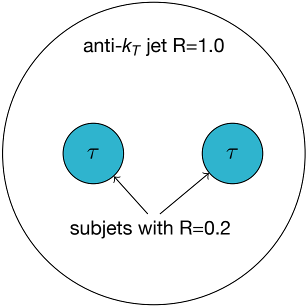
$\rightarrow$ new method: di-τ reconstruction

Di-τ Reconstruction

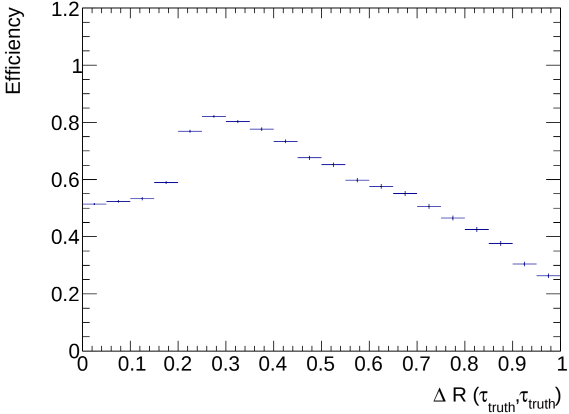
Di-τ reconstruction: reconstruct two hadronically decaying τ into a single object

Originally developed and optimized using boosted Higgs decays

- Seeds from a jet with $R = 1.0$ (0.4 for standard τ reconstruction)
- $p_{\mathrm{T}} > 50$ GeV (reduced from $p_{\mathrm{T}} > 300$ GeV)
- $|\eta| < 2.5$
- At least 2 subjets ($R = 0.2$) with at least one associated track



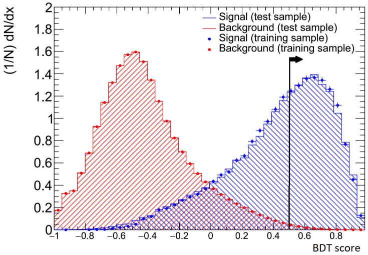
Reconstruction Efficiency

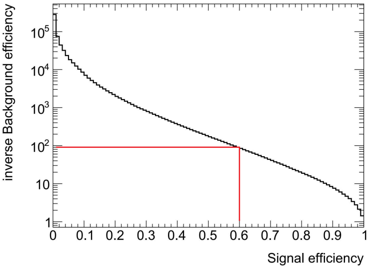


50-80% efficiency for $0.2 < \Delta R < 0.4$

BDT-based fake di-τ rejection

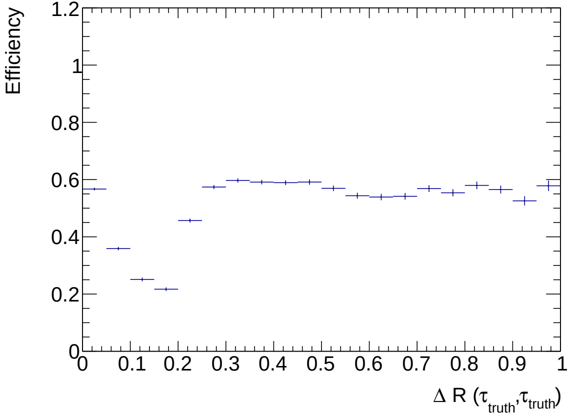
- Signal: truth-matched di-τ from SUSY gluino process
- Background: di-τ candidates from data (dominated by QCD jet production), $t\bar{t}$, $Z \rightarrow e^{+}e^{-}$





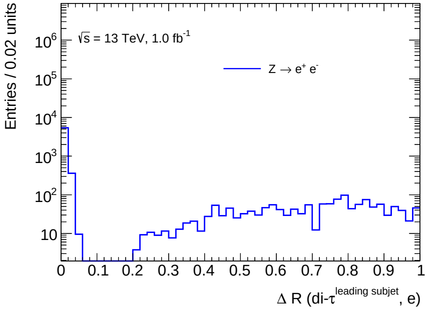
Identification Efficiency

Signal di-τ: candidate with BDT score>0.5



60% efficiency for $\Delta R > 0.2$

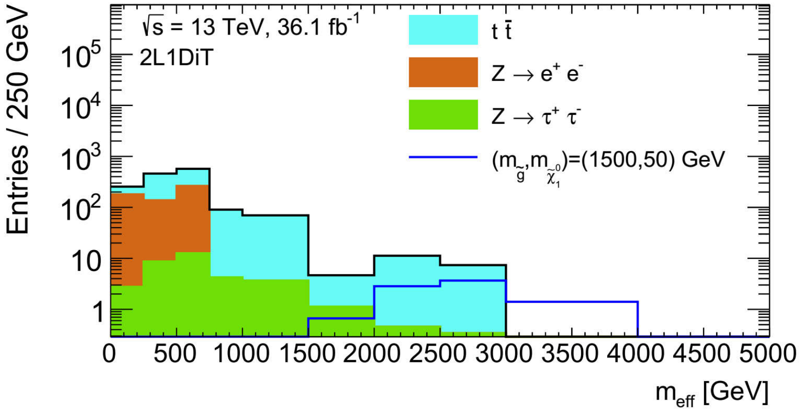
Improvement of Fake di-τ Rejection



- electrons can fake a subjet
- BDT fails to reject them
- reject di-τ if the two leading subjets are matched to an electron ($\Delta R < 0.2$)
- signal reduced by 40%
- background reduced by two orders of magnitude

Application to the Four-lepton Search

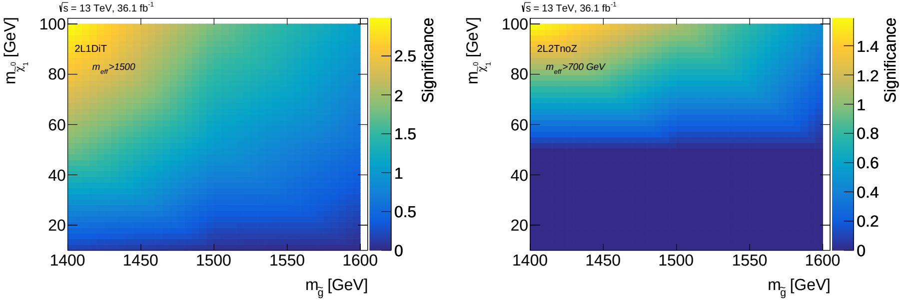
New region (2L1DiT) with $N_\ell = 2$, $N_\tau \leq 1$ and $N_{\text{Di-}\tau} \geq 1$



Expected Significances

Comparison of the expected significances between di-τ region and standard τ region

new region $m_{\text{eff}} > 1500$ GeV   old region (2L2T) $m_{\text{eff}} > 700$ GeV



higher significance in the di-τ region

Summary

- Final states with four lepton provides high sensitivity to RPV SUSY due to low SM background
- Low sensitivity for low LSP masses due to collimated τ pairs
- New di-τ reconstruction method
- Optimization for RPV SUSY processes
- Increased sensitivity to low LSP masses with di-τ reconstruction

$\rightarrow$ Use of the new di-τ for a four-lepton search with the data set of 2015-2018