Searches for electroweak production of supersymmetric gauginos and sleptons with the ATLAS detector

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ATLAS EXPERIMENT

Introduction

Supersymmetry (SUSY): One of the most popular Standard Model (SM) extensions

Why SUSY?

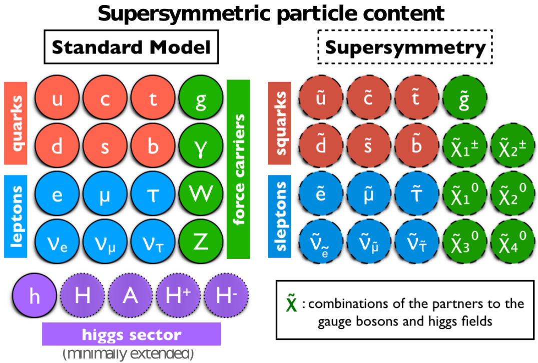
- Alleviates hierarchy problem.
- Provide a dark matter candidate (R-parity conservation)
- Unify the fundamental forces at high energies

How?

- Adding a new symmetry between fermions and bosons.
- Introduce sfermions and gauginos

But ...

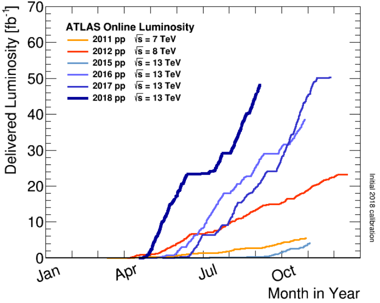
- More than 100 free parameters: wide range of possible experimental signatures

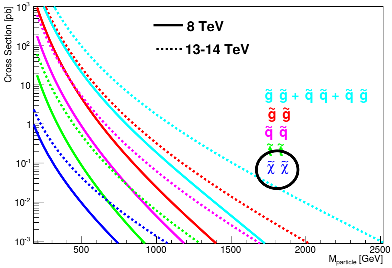


Minimal Supersymmetric Standard Model (MSSM)

Electroweak (EWK) SUSY

- Low cross sections.
  - More data needed to be explored.
- Heavy gluino and squark mass $\rightarrow$EWK production dominant.
- Latest ATLAS: squark and gluino production beyond the TeV scale (simplified model).
  - EWK production of sparticles is a promising and important probe to search for SUSY.

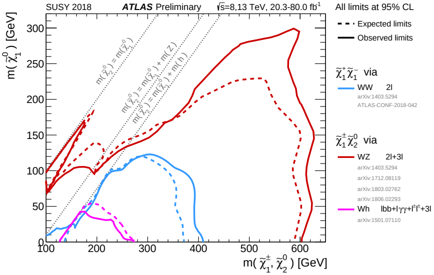


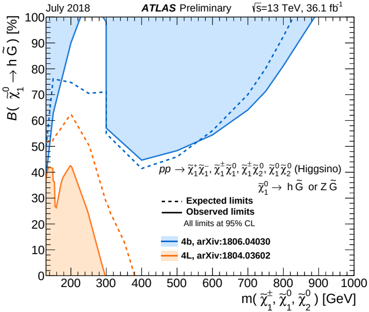


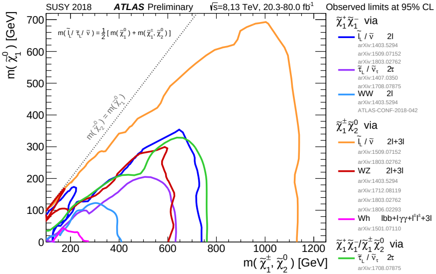
Halkiadakis, Eva et al. Ann. Rev. Nucl. Part. Sci. 64 (2014)

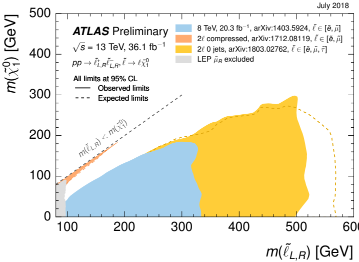
ATLAS EWK summary plots

LSP (Lightest SUSY particle)
NLSP (Next to LSP)







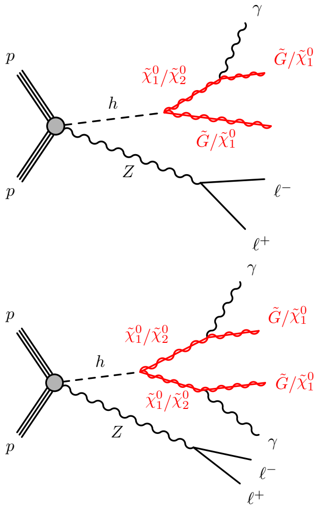


On this talk, an overview of the latest results on search for gaugino production (~ 80 fb^{-1}) and the latest results on search for the direct sleptons production (~ 36.1 fb^{-1}).

Exotic decays of the Higgs boson to at least one photon and missing transverse momentum

Motivation

- Branching fraction of the Higgs boson to new process beyond SM (BSM) are constrained to be less than 34% at the 95% confidence level.
- A wide variety of theories predict decays of Higgs to BSM particles:
  - Gauge Mediated Supersymmetry Breaking (GMSB)
  - Next to MSSM (nMSSM).
- Decays allowed:
  - if $m_h/2 < m_{\tilde{\chi}_1^0}(m_{\tilde{\chi}_2^0}) < m_h : h \to \tilde{\chi}_1^0 \tilde{G}(\tilde{\chi}_2^0 \tilde{\chi}_1^0)$
  - if $m_{\tilde{\chi}_1^0}(m_{\tilde{\chi}_2^0}) < m_h/2 : h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0(\tilde{\chi}_2^0 \tilde{\chi}_2^0)$
- hZ production are considered with $Z \to ee$ or $Z \to \mu\mu$ to reduced backgrounds.



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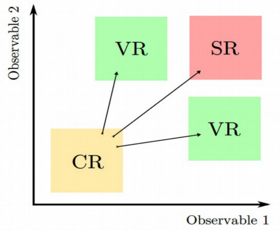
Search strategy

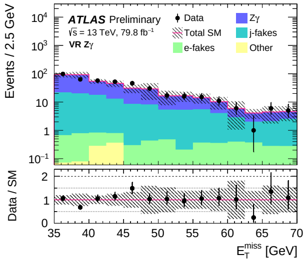
- $E_{\mathrm{T}}^{miss} > 95$GeV
- Events containing jets with $p_{\mathrm{T}} > 30$ GeV rejected.
- $Z \to \ell\ell$ pair balancing the $h \to \gamma E_{\mathrm{T}}^{miss}$ system in transverse plane.
  - $\gamma E_{\mathrm{T}}^{miss}$ system: vector sum of the two (or one) highest p_{T} photons with E_{T}^{miss}
  - Z system: two opposite-sign electrons or muons, with $\Delta\phi_{\ell\ell} < 1.4$
  - Two new variables defined:
    - $\Delta\phi_{\ell\ell,\gamma E_{\mathrm{T}}^{miss}}$: Absolute separation between the two systems.
    - $\mathrm{Bal}_{p_{\mathrm{T}}}$: the asymmetry between systems. $\frac{|p_{\mathrm{T}}^{\ell\ell} - p_{\mathrm{T}}^{\gamma E_{\mathrm{T}}^{miss}}|}{p_{\mathrm{T}}^{\gamma E_{\mathrm{T}}^{miss}}}$

Background Modeling

Four sources with similar signatures on the detector

- $e \to \gamma$: primarily coming from $WZ \to e\nu\ell\ell$.
  - Obtained using data-driven method based on $Z \to ee/e\gamma$ decays.
- $j \to \gamma$: primarily coming from $Z + \text{jets}$.
  - Obtained using fake factors estimated using data-driven method.
- Events with non-resonant leptons in Z mass that contain a real photon: $t\bar{t}\gamma$
  - Estimated using MC simulation to be negligible.
- Events with resonant Z bosons that contain a real photon: $Z\gamma$.
  - CR-Zγ: defined to normalize MC background simulation to data.

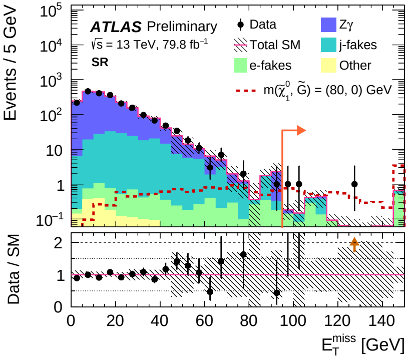




Good agreement on different kinematic variables.

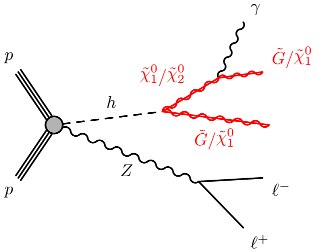
Results

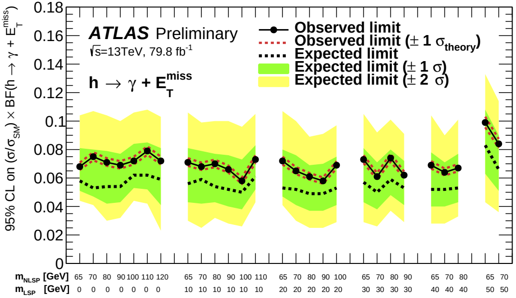
Observed events	3
Expected background events	2.1 ± 0.5
Expected signal events m_{NLSP}, m_{LSP} = 80, 0 GeV	8.1
$e \to \gamma$ fakes	1.5 ± 0.3
j $\to \gamma$ fakes	0.6 ± 0.3
SM $Z\gamma$	$0.03^{+0.15}_{-0.03}$
Other	$0.00^{+0.01}_{-0.00}$

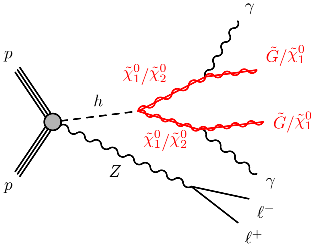


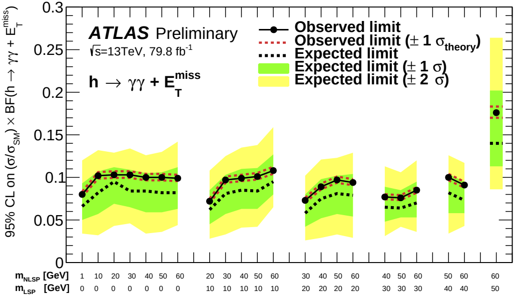
$p_0 = 0.32(< 1\sigma)$, no significant excess above Standard Model expectation is observed.

Interpretation





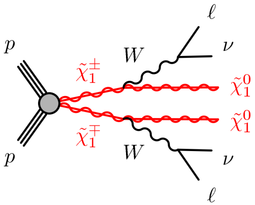




Direct chargino pair production with W-boson mediated decays in events with two leptons and missing transverse momentum

Motivation

- Targeting direct production of $\tilde{\chi}_1^+ \tilde{\chi}_1^-$
- LSP $\tilde{\chi}_1^0$
- Only leptonic decays mode of W-boson considered.
- Challenging channel due to low signal expected cross section and significant background from SM WW.



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Search strategy

- Two opposite sign leptons.
- b-jets veto
- High $m_{T2}(\ell, \ell, E_T^{miss})$: $t\bar{t}$ and WW decays have a kinematic endpoint at the mass of W-boson.
- Events are separated by:
  - “same flavour" (SF), i.e. e^+e^- and $\mu^+\mu^-$, and "different flavour" (DF), i.e. $e^{\pm}mu^{\mp}$.
  - multiplicity of non b-tagged jets ($n_{non-b-tagged\ jets}$).

Signal region (SR)	SR-DF-0J	SR-DF-1J	SR-SF-0J	SR-SR-1J
$n_{\text{non-}b\text{-tagged jets}}$	$= 0$	$= 1$	$= 0$	$= 1$
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	–		>30	
E_T^{miss} [GeV]	>110			
E_T^{miss} significance	>10			
Binned SRs				
m_{T2} [GeV]	$\in$ [100,105]			
	$\in$ [105,110]			
	$\in$[110,120]			
	$\in$[120,140]			
	$\in$[140,160]			
	$\in$[160,180]			
	$\in$[180,220]			
	$\in$ [220, ∞]			
Inclusive SRs				
m_{T2} [GeV]	$\in$ [100, ∞]			
	$\in$ [160, ∞]			
	$\in$ [100, 120]			
	$\in$ [120, 160]			

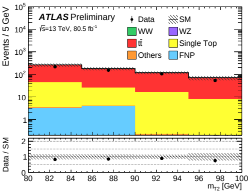
Background Modeling

- Main irreducible backgrounds: dibosons (WW, WZ, ZZ) and top.
  - using MC simulation but normalized to data using dedicated CRs:

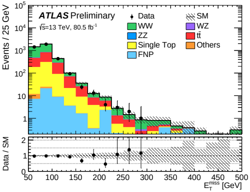
Region	CR-VZ	CR-WW	CR-top
Lepton flavour	SF	DF	DF
$n_{b\text{-tagged jets}}$	$= 0$	$= 0$	$= 1$
$n_{\text{non-}b\text{-tagged jets}}$	$= 0$	$= 0$	$= 0$
m_{T2} [GeV]	> 120	$\in$ [60,65]	> 100
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 110	> 60	> 110
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	> 10	> 5	> 5
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	< 30	–	–

- Subdominant irreducible background contributions are estimated directly from MC.
- Backgrounds from fake/non-prompt lepton (FNP).
  - Estimated using Matrix Method.

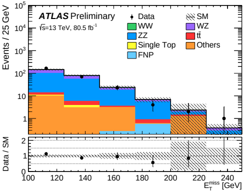
VR-top-low:



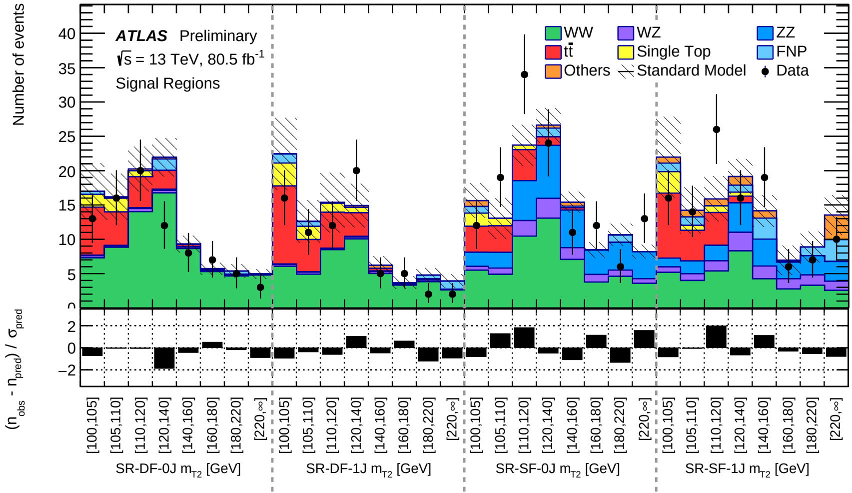
VR-WW-0J:



VR-VZ:

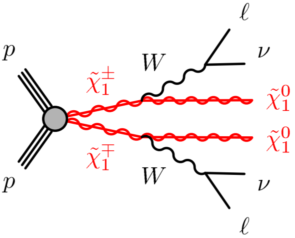


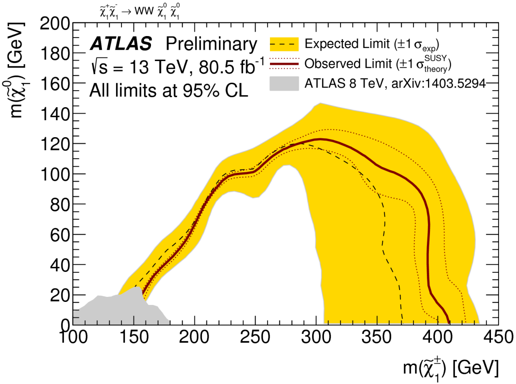
Results



- No significant deviations from SM predictions.

Interpretation



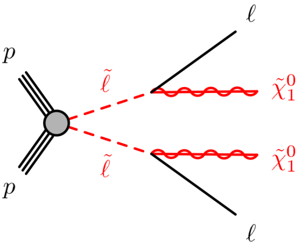


- Limits greatly extended beyond those from Run 1
- Due to statistical limitations $\rightarrow$ improvement in sensitivity and limits with the full Run 2 dataset

Summary of the latest results in searches for direct sleptons production (R-parity conserved)

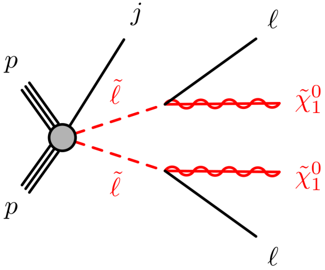
Sleptons scenarios

Bulk Scenario
($\Delta m(\tilde{l}, \tilde{\chi}_1^0) > 50$GeV):



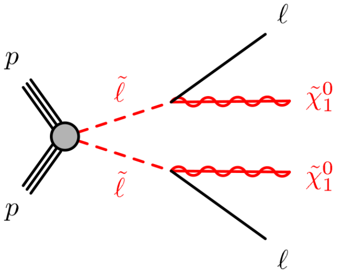
arxiv:1803.02762

Compressed Scenario
($\Delta m(\tilde{l}, \tilde{\chi}_1^0) \sim O$(GeV)):

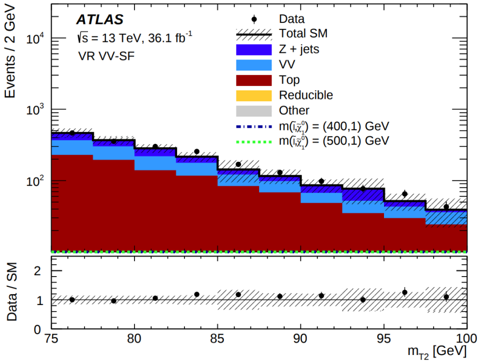


arxiv:1712.08119

Bulk scenario

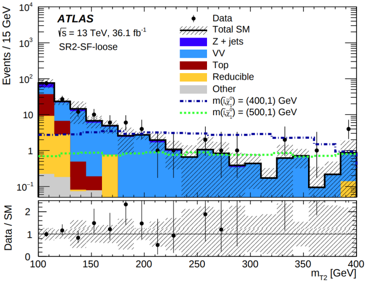


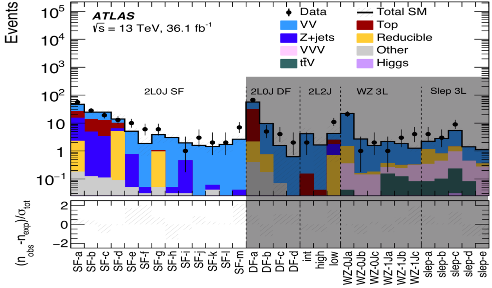
- On this model: $\tilde{e}_R$, $\tilde{\mu}_R$, $\tilde{\tau}_R$, $\tilde{e}_L$, $\tilde{\mu}_L$ and $\tilde{\tau}_L$ are assumed mass-degenerate.
- Requires exactly 2 same-flavor,oppositely-charged leptons.
- Large E_T^{miss} due to two LSPs in final state

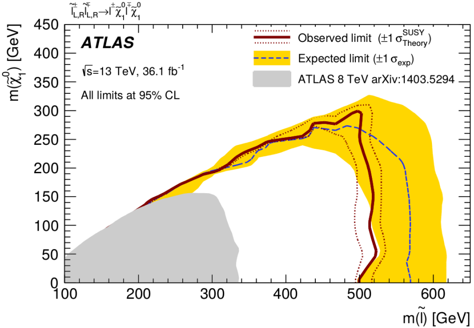


- Dominant SM backgrounds are dileptonic $t\bar{t}$ and diboson (WW) production
  - Rely on bins of m_{T2} and $m_{\ell\ell}$
  - Full jet veto to suppress backgrounds (mainly $t\bar{t}$)

Bulk scenario: results

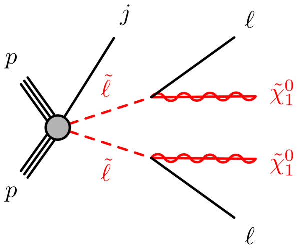






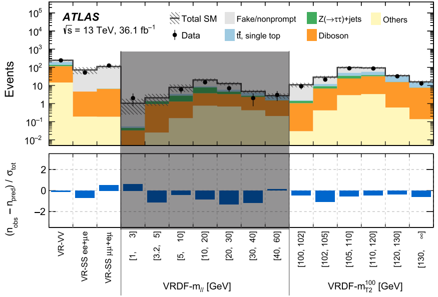
- No significant excesses seen w.r.t. the SM in any SRs
- Set limits on slepton model
  - Assuming mass-degenerate left- and right-handed sleptons, exclude $m_{\tilde{l}} < 500$ GeV

Compressed scenario

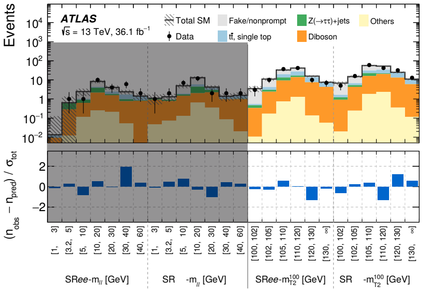


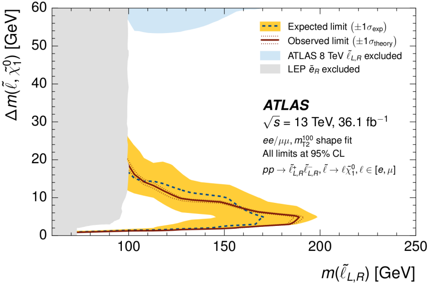
- 2 SFOS lepton requirement.
- Extremely compressed means soft leptons in final state. Lowest lepton p_{T} threshold of any ATLAS analysis: 4.5 (4) GeV for electrons (muons).
- $E_{\mathrm{T}}^{miss} > 200$ GeV (efficiency of trigger excess 95%).
- Two $\tilde{\chi}_1^0$ momenta must by aling recoiling against ISR jets ($p_{\mathrm{T}} > 100$ GeV & $\Delta\phi(j^{\mathrm{ISR}}, p_{\mathrm{T}}^{\mathrm{miss}}) > 2$).
- $m_{\ell\ell} \in [1, 60]$ GeV & b-jet veto

- Fake and non-prompt sources are the dominant background in the signal regions
  - Estimated using data-driven background
- Main irreducible backgrounds:
  - $t\bar{t}$, tW: CR-top.
  - $Z^{(*)}/\gamma^{(*)} \to \tau\tau$+jets: CR-tau.
  - WW/WZ: Estimated from MC simulation.



Compressed scenario: results





- No excesses seen in any of the exclusive SRs binned in m_{T2}^{100}.
- Limits set on mass-degenerate left- and right-handed sleptons.
- Sensitivity beyond LEP limits even in these compressed scenarios!

Final comments

- Numerous efforts in ATLAS searching for SUSY in the electroweak sector.
- No evidence for any SUSY physics within simplified models
- More data to be collected and explored (~ 150 fb^{-1} at $\sqrt{s} = 13$ TeV).
    - Not only accumulate luminosity but improve the performances and develop new analysis strategies and techniques

BACKUP

Selection

Standard object selection:

- Electrons: Medium selection criteria and isolated.
- Photons: Tight Selection and isolated.
- Muons: Medium selection criteria and isolated.
- Jets: anti-k_t; b-jets with a selection that provides 85 % efficiency for tagging.
- Overlap removal procedure is applied in order to avoid the double counting.
- MET: Calculation includes baseline objects $(e/\mu/j/\gamma)$ and track soft term.

$E_{\mathrm{T}}^{miss} = |\mathbf{p}_{\mathrm{T}}^{miss}| \rightarrow$ expected from ν and LSP in final states.

E_{T}^{miss} significance $\rightarrow$ A high value of is an indication that the event cannot be explained from momentum resolution effects

$m_{\mathrm{T}} = \sqrt{2p_T^{\ell}E_{\mathrm{T}}^{miss}\{1 - \cos(\Delta\phi(p_{\mathrm{T}}^{\ell}, E_{\mathrm{T}}^{miss})]\}} \rightarrow$ Reduce $t\bar{t}$, WW/WZ and $W + j$ backgrounds with a leptonic W decay.

$m_{\mathrm{T2}}\,(p_{\mathrm{T},1}, p_{\mathrm{T},2}, q_{\mathrm{T}}) = \min_{q_{\mathrm{T}}=q_{\mathrm{T},1}+q_{\mathrm{T},2}} \{\max[m_{\mathrm{T}}(p_{\mathrm{T},1}, q_{\mathrm{T},1}), m_{\mathrm{T}}(p_{\mathrm{T},2}, q_{\mathrm{T},2})]\} \rightarrow$ $t\bar{t}$ and WW with two leptonic decays, has end-point at W mass.

Data and Trigger

Search was performed using 78.9 fb^{-1} of proton-proton (pp) collision collected at $\sqrt{s} = 13$ TeV (2015, 2016 and 2017 data).

	Single lepton threshold [GeV]	Two lepton thresholds [GeV]
Electron trigger year		
2015	24	12, 12
2016	26	17, 17
2017	26	17, 17 and 24, 24
Muon trigger year		
2015	20	18, 8
2016	26	22, 8
2017	26	22, 8