Hunting stops with tau leptons using the ATLAS detector

XXIV Cracow EPIPHANY Conference

On behalf of the ATLAS Collaboration

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Conference Note for SUSY17:

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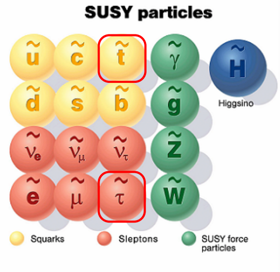
Brief Review of Supersymmetry

Motivation

- shortcomings of SM
  - no unification of coupl. const.
  - no dark matter candidate
  - loop corrections of Higgs mass
- can be solved by SUSY



Implementation

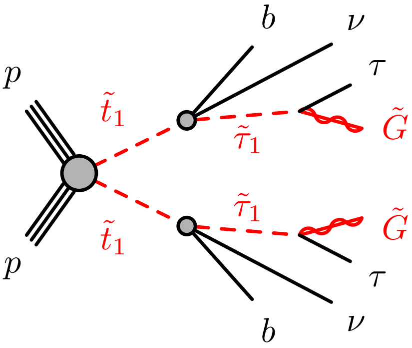
- extend symmetries of Poincaré group
- operator Q relating fermions and bosons:

  $Q\,|\text{Boson}\rangle = |\text{Fermion}\rangle$ and v.v.
- SUSY broken by unknown mechanism
- consider minimal supersymmetric extension of SM: MSSM

Signal Model

Production & Decay

- direct production of scalar-top pairs
- 3-body decay of stop to b-quark, neutrino and stau
- stau decays into tau and gravitino (massless LSP)
- simplified model (BRs = 1)

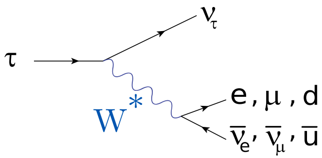


Final State

- 2 taus
- 2 b-quarks
- large $E_{\mathrm{T}}^{\mathrm{miss}}$

How do taus look in the detector?

tau decay



leptonic (35%):

electron/muon signature

hadronic (65%):

jet-like signature, 1 or 3 tracks

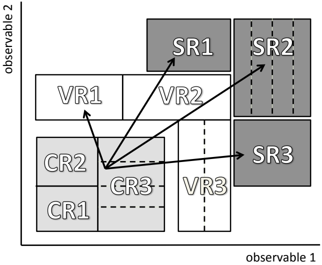
Analysis Strategy

General Layout

- di-tau final state → separation into lep-had and had-had channels
- combine both channels in statistical model to maximize sensitivity

Strategy for Background Estimation

- define signal-enriched region (SR)
- check and normalize background predictions in CR
- extrapolate from CR to SR
- verify extrapolation in VR



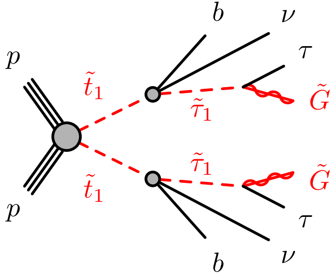
General Event Selection

Trigger

- lep-had: single-electron and single-muon trigger
- had-had: E_T^{miss} and di-tau trigger

Event selection for SRs

- opposite charge of leptons
- high-pt tau lepton(s)
- large E_T^{miss}
- $\geq$ 1 b-tagged jet



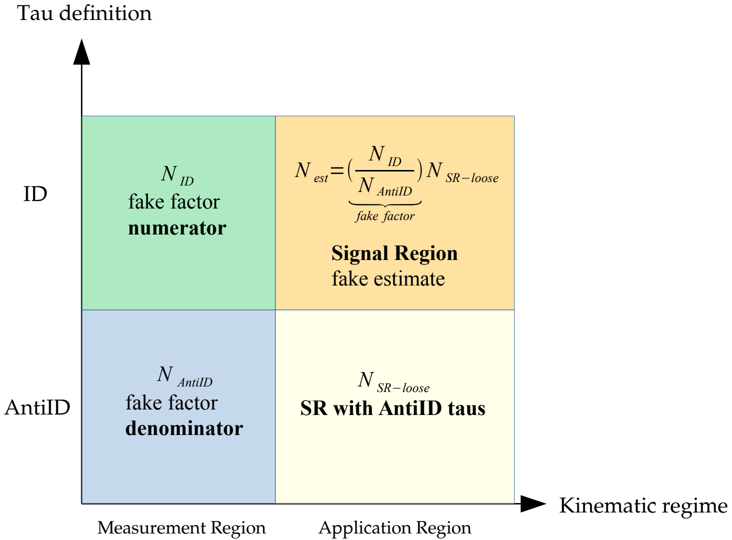
Important Backgrounds

- $t\bar{t}$, $t\bar{t}V$, diboson
  $\rightarrow$ dedicated CRs
- V+jets, single top
  $\rightarrow$ taken from simulation
- main challenge: events with mis-identified taus (fakes)

  $\rightarrow$ had-had: CR

  $\rightarrow$ lep-had: fake factor method

Fake Factor Method: Idea & Application

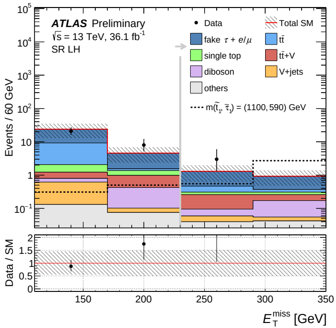


Results

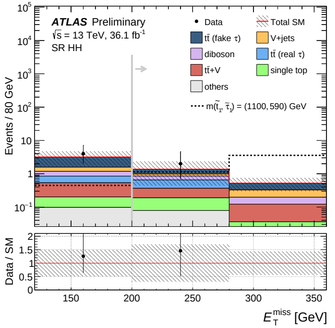
- using complete 36.1 fb^{-1} of 2015 and 2016 data taking
- no significant excess beyond SM expectation observed

  $\rightarrow$ set exclusion limits for this model

	SR LH	SR HH
Observed events	3	2
Total background	2.2 ± 0.6	1.9 ± 1.0
fake $\tau + e/\mu$	1.4 ± 0.5	—
$t\bar{t}$ (fake τ)	—	$0.6 \pm^{0.7}_{0.6}$
$t\bar{t}$ (real τ)	0.22 ± 0.12	$0.28 \pm^{0.30}_{0.28}$
$t\bar{t} + V$	0.25 ± 0.14	0.26 ± 0.12
diboson	0.15 ± 0.11	0.28 ± 0.13
single-top	$0.10 \pm^{0.24}_{0.10}$	0.13 ± 0.11
$V +$jets	0.033 ± 0.011	0.26 ± 0.06
others	0.082 ± 0.020	0.09 ± 0.04
signal	3.3 ± 0.7	4.7 ± 1.2
$(m(\tilde{t}_1) = 1100\,\mathrm{GeV},\ m(\tilde{\tau}_1) = 590\,\mathrm{GeV})$		

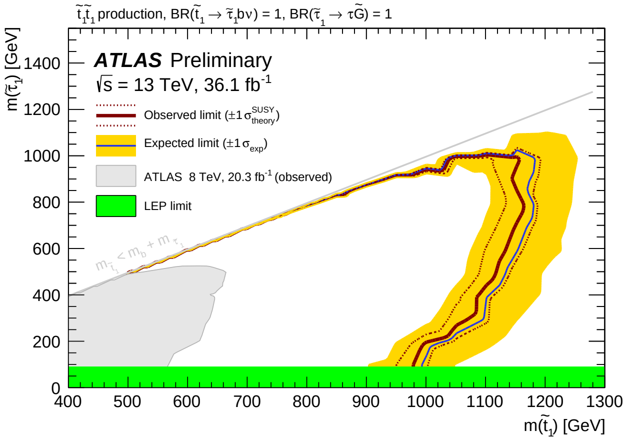


lep-had SR



had-had SR

Exclusion Limits for Benchmark Model



Model-Dependent Limits

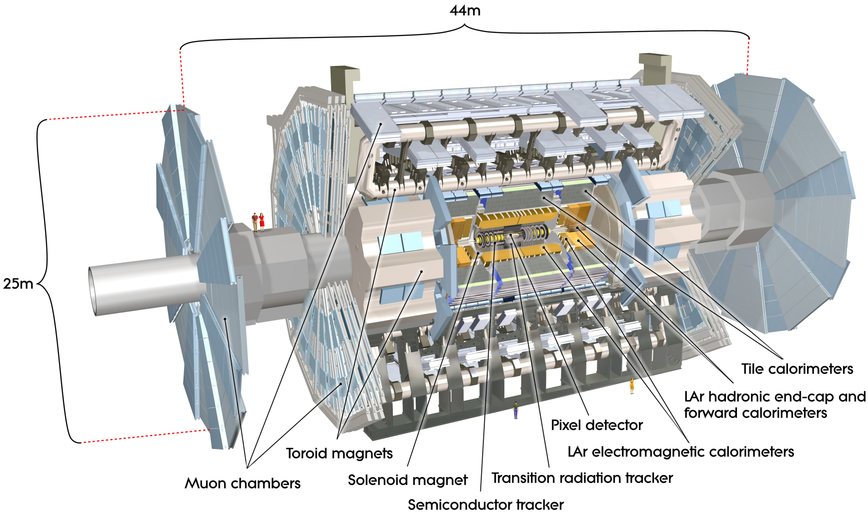
- contour in $m(\tilde{t}_1)$-$m(\tilde{\tau}_1)$ plane
- exclusion of $m(\tilde{t}_1)$ up to 1160 GeV and $m(\tilde{\tau}_1)$ up to 1000 GeV

Summary

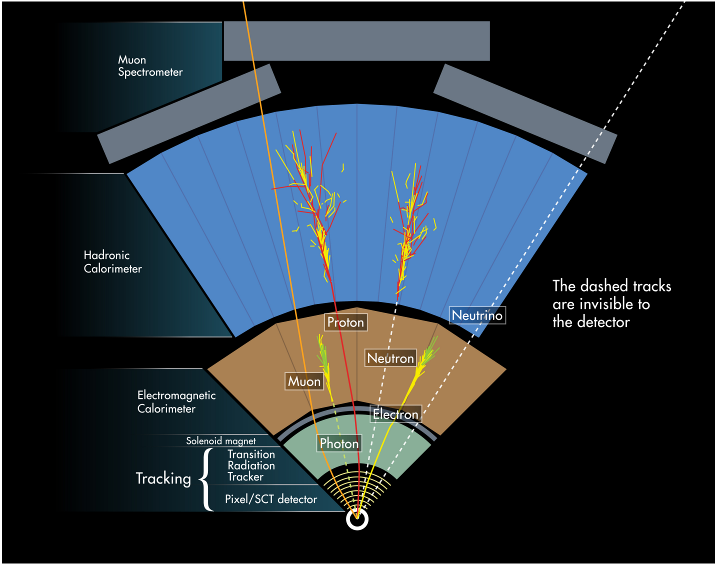
- presented search for top squarks using final states with tau leptons
- outlined idea of fake factor method to estimate contribution of tau fakes
- no hint for physics beyond the SM
- strong limits set on $m(\tilde{t}_1)$ and $m(\tilde{\tau}_1)$, reaching out to the TeV regime

BACKUP

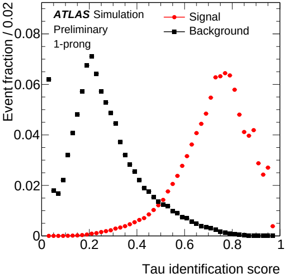
ATLAS Detector

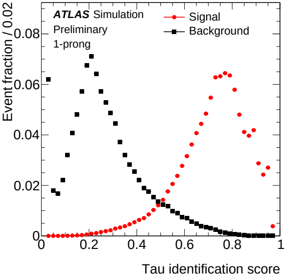


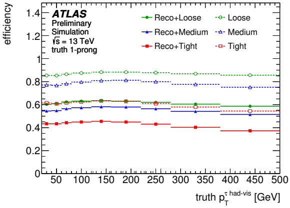
Particle Detection at ATLAS

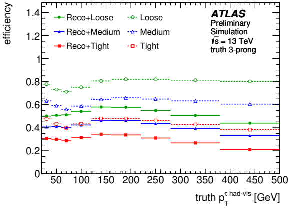


Tau Reconstruction





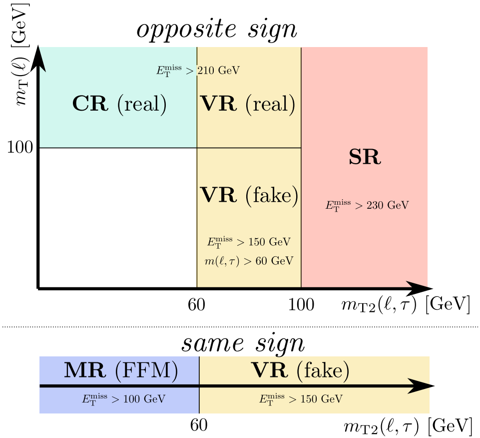




Event Selection – Lep-Had

Preselection

- trigger requirements
- 1 signal electron/μ
- 1 Medium τ
- no add. leptons
- $p_{\mathrm{T}}(\mathrm{jet}_2) > 26$ GeV
- $p_{\mathrm{T}}(\tau) > 70$ GeV
- $n_{b\text{-jet}} \geq 1$

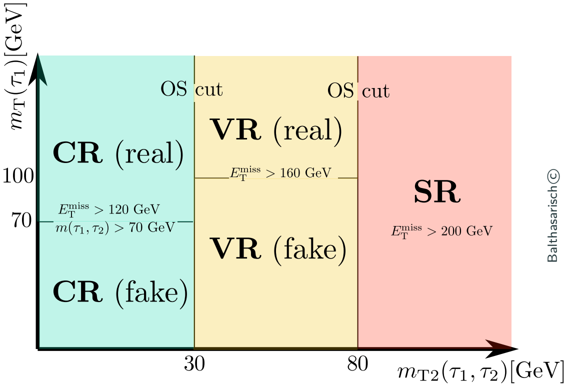


Variable	CR LH $t\bar{t}$-real	VR LH $t\bar{t}$-real	VR LH $t\bar{t}$-fake (OS)	VR LH $t\bar{t}$-fake (SS)	SR LH
charge(ℓ,τ)	opposite	opposite	opposite	same	opposite
$m_{\mathrm{T2}}(\ell,\tau)$	< 60 GeV	[60, 100] GeV	[60, 100] GeV	> 60 GeV	> 100 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 210 GeV	> 210 GeV	> 150 GeV	> 150 GeV	> 230 GeV
$m_{\mathrm{T}}(\ell)$	> 100 GeV	> 100 GeV	< 100 GeV	—	—
$m(\ell,\tau)$	—	—	> 60 GeV	—	—

Event Selection – Had-Had

Preselection

- trigger requirements
- 2 Medium τ's
- no add. leptons
- $p_T(\mathrm{jet}_2) > 20$ GeV
- $p_T(\tau_1) > 70$ GeV
- $n_{b\text{-jet}} \geq 1$

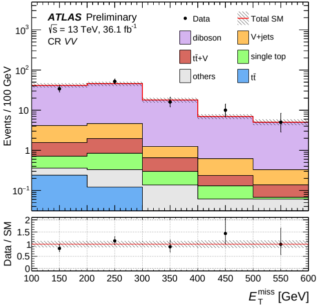


	CR HH $t\bar{t}$-fake	CR HH $t\bar{t}$-real	VR HH $t\bar{t}$-fake	VR HH $t\bar{t}$-real	SR HH
charge(τ_1,τ_2)	—	opposite	—	opposite	opposite
$m_{T2}(\tau_1,\tau_2)$	< 30 GeV	< 30 GeV	[30, 80] GeV	[30, 80] GeV	> 80 GeV
E_T^{miss}	> 120 GeV	> 120 GeV	> 160 GeV	> 160 GeV	> 200 GeV
$m_T(\tau_1)$	< 70 GeV	> 70 GeV	< 100 GeV	> 100 GeV	—
$m(\tau_1,\tau_2)$	> 70 GeV	> 70 GeV	—	—	—

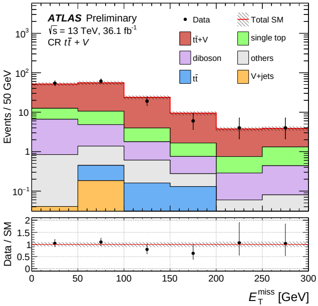
Common Control Regions

- sizable contribution of $t\bar{t}+V$ and VV in SRs
- single electron/muon triggers
- based on 2 lepton selection
- select events containing Z boson using m_Z^{closest}
- veto or require b-jets to enrich in VV and $t\bar{t}+V$

	CR $t\bar{t}+V$	CR VV
$p_{\mathrm{T}}(\mathrm{jet}_2)$	$> 26\,\mathrm{GeV}$	$> 26\,\mathrm{GeV}$
m_Z^{closest}	$[80,\ 100]\,\mathrm{GeV}$	$[80,\ 100]\,\mathrm{GeV}$
$n_{b\text{-jets}}$	≥ 2	0
n_{lepton}	≥ 3	≥ 2
$n_{\mathrm{lepton}} + n_{\mathrm{jet}}$	≥ 6	—
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$	—	$> 15\sqrt{\mathrm{GeV}}$
$m_{\mathrm{T2}}(\ell,\ell)$	—	$> 120\,\mathrm{GeV}$



CR VV



CR $t\bar{t}+V$

Systematic Uncertainties

Experimental

- using systematic variations as released by CP groups, e,g. uncertainties on reconstruction and identification efficiencies, energy scales of physics objects, pile-up, ...
- derived dedicated set of uncertainties for fake estimate by variation of parameters in Fake Factor derivation:
  - choice of AntiID WP
  - definition of Measurement region
  - extrapolation in m_{T2}
  - subtraction of real contribution

Theoretical

- comparison of nominal MC with alternative samples recommended by PMG for important backgrounds
- $t\bar{t}$ and singletop: uncertainties on hard-scatter modeling, fragmentation, radiation and interference in Wt channel
- $t\bar{t} + V$ and diboson: uncertainties on hard-scatter modeling and factorization and hadronization scales

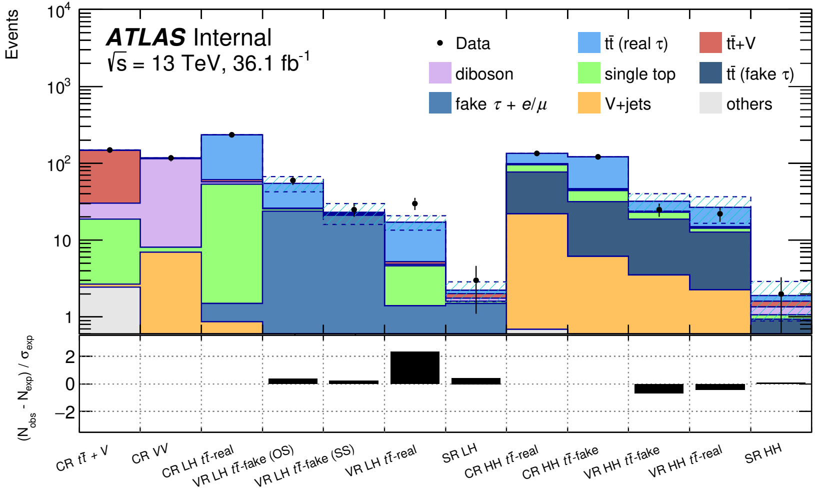
Systematic Uncertainties

Dominating Uncertainties

- lep-had: Fake Factor Method
- had-had: tau energy scale, jet pile-up subtraction
- both channels: jet and tau energy calibration, pile-up reweighting, E_T^{miss} measurement

	SR LH	SR HH
Total systematic uncertainty	± 29 %	± 53 %
Fake-factor method	± 23 %	—
Jet-related	± 9.3 %	± 36 %
Tau-related	± 7.2 %	± 32 %
Other experimental	± 6.1 %	± 12 %
Theory modelling	± 8.3 %	± 20 %
MC statistics	± 7.5 %	± 17 %
Normalization factors	± 4.8 %	± 14 %
Luminosity	± 0.3 %	± 0.8 %

Results – Overview

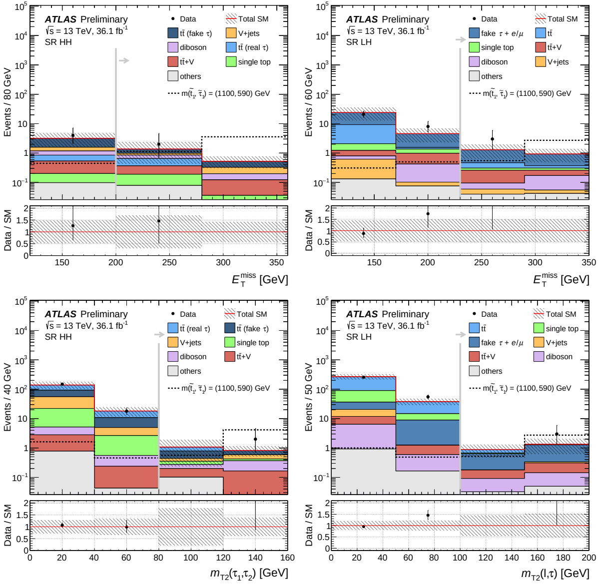


- small pulls in all VRs except in VR LH $t\bar{t}$-real
- ca 2.3 σ excess in VR LH $t\bar{t}$-real interpreted as statistical fluctuation

Model-Independent Limits

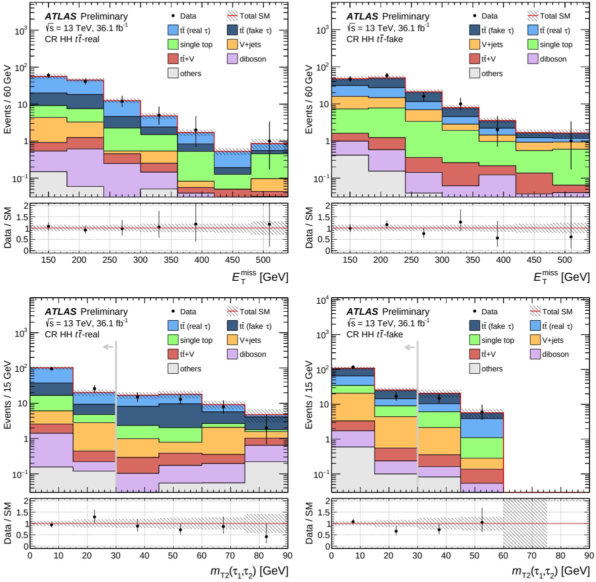
Signal channel	$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$[fb]	$S^{95}_{\rm obs}$	$S^{95}_{\rm exp}$	CL_b	$p(s=0)$ (Z)
SR LH	0.15	5.4	$4.5^{+2.6}_{-1.5}$	0.65	0.32 (0.47)
SR HH	0.13	4.7	$4.6^{+2.5}_{-1.5}$	0.52	0.48 (0.05)

Plots in SRs

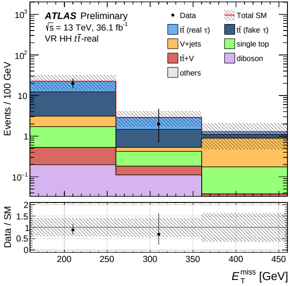


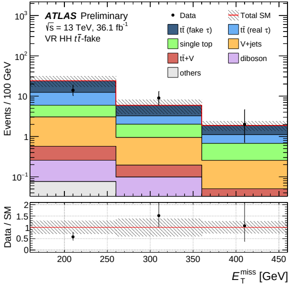
ATLAS Preliminary
√s = 13 TeV, 36.1 fb-1
SR HH
SR LH
Data
Total SM
tt̄ (fake τ)
tt̄ (real τ)
V+jets
diboson
tt̄+V
single top
others
fake τ + e/μ
tt̄
m(t̃1, τ̃1) = (1100, 590) GeV
Events / 80 GeV
Events / 60 GeV
Events / 40 GeV
Events / 50 GeV
Data / SM
E_T^miss [GeV]
m_T2(τ1,τ2) [GeV]
m_T2(l,τ) [GeV]

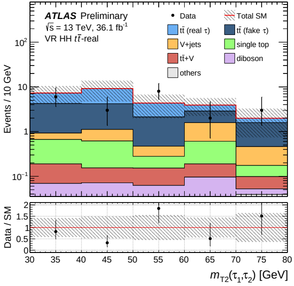
Plots in Had-Had CRs

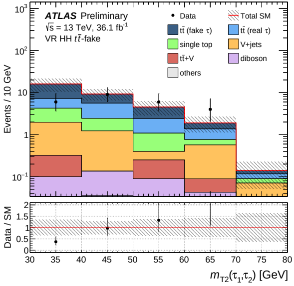


Plots in Had-Had VRs

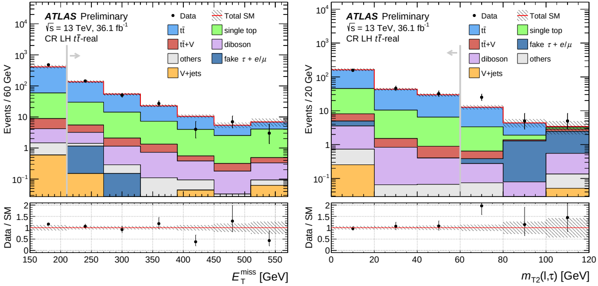








Plots in Lep-Had CRs



Plots in Lep-Had VRs