

Searches for top-antitop quark resonances at $\sqrt{s} = 13$ TeV with the ATLAS detector

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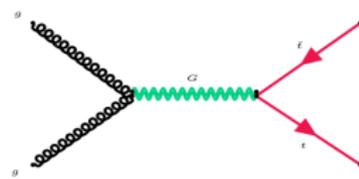
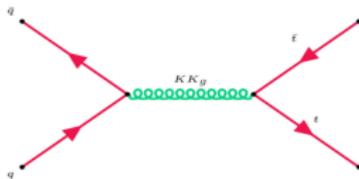
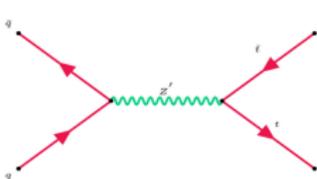
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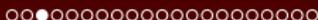
May 11, 2022



Introduction

- ✓ The top quark is the heaviest known elementary particle.
 - $m_t = 173.34 \pm 0.27(\text{stat}) \pm 0.71(\text{syst}) \text{ GeV}$
 - Plays an important role in searches for physics beyond the SM
- ✓ Many models (topcolor, extra dimensions, etc.) predict new heavy particles with enhanced coupling to the top quark
 - These particles may decay preferentially into $t\bar{t}$
- ✓ Focus only semi-leptonic final state, on which we are mainly involved.
- ✓ So far we considered the following benchmark scenarios:
 - Topcolour assisted technicolour leptophobic Z' : narrow resonance (width 1.2% of the mass, spin 1)
 - Randall–Sundrum (RS) Kaluza–Klein (KK) gravitons, G_{KK} ($\Gamma < 1\%$, spin 2)
 - Kaluza–Klein (KK) gluon g_{KK} ($\Gamma > 10\%$ of the mass, spin 1)





Object Definitions

Jets

Large-R jet

AntiKt-1.0 LCTopo Jets Pre-recommended trimmed jet
 ($f=5\%$, $R_{sub}=0.2$)
 $p_T > 300$ GeV
 $|\eta| < 2$
 Used for top-tagging

Small-R jet

AntiKt-0.4 EMPFlow Jets
 $p_T > 25$ GeV
 $|\eta| < 2.5$
 Standard JVT cut ($|JVT| > 0.64$)

Track jet (VR track jet)

AntiKtVR30Rmax4Rmin02 Track Jets
 Used for b-tagging (DL1r:FixedCutBEff_77, WP 77 %)
 $p_T > 10$ GeV
 $|\eta| < 2.5$

Leptons

Muon

MuonQuality Medium
 $p_T > 25$ GeV
 $|\eta| < 2.5$
 Isolation: TightTrackOnly_VarRad
 OR Procedure BoostedSlidingDRMu

Electron

ElectronID TightLH
 $p_T > 25$ GeV
 $|\eta| < 2.5$ excluding crack
 ($1.37 < |\eta| < 1.52$)
 Isolation: TightTrackOnly
 OR Procedure ElectronInJetSubtraction

Single-lepton Triggers

Muon

2015@mu20 iloose_L1MU15_OR_mu50
 2016@mu26_ivarmedium_OR_mu50
 2017@mu26_ivarmedium_OR_mu50
 2018@mu26_ivarmedium_OR_mu50

Electron

2015@e24_lhmedium_L1EM20VH_OR_e60_lhmedium_OR_e120_lhloose
 2016@e26_lhtight_nod0_ivarloose_OR_e60_lhmedium_nod0_OR_e140_lhloose_nod0
 2017@e26_lhtight_nod0_ivarloose_OR_e60_lhmedium_nod0_OR_e140_lhloose_nod0
 2018@e26_lhtight_nod0_ivarloose_OR_e60_lhmedium_nod0_OR_e140_lhloose_nod0

Event selection

Decay topologies in the lepton+jets channel:

common selection

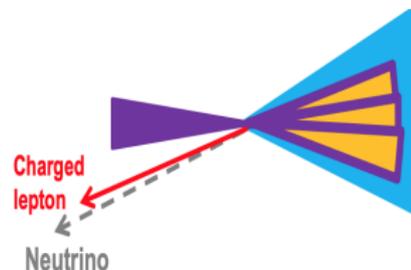
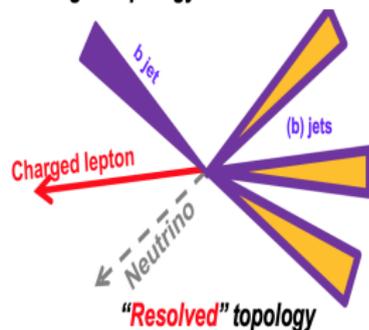
- GRL: Data events in the Good Run List (2015-2018)
- Single lepton trigger : Separate e and μ triggers
- Exactly one lepton : $== 1 e$ or μ with $p_T > 30$ GeV
- $E_T^{\text{miss}} > 20$ GeV
- $E_T^{\text{miss}} + m_{T,W} > 60$ GeV
- b -tagging : ≥ 1 b -tagged jet

Boosted Channel

- Large- R jet : ≥ 1 large- R jet, $p_T > 300$ GeV
- top-tagging : ≥ 1 with DNN top-tagger (80% WP)
- Close-to-lepton jet : ≥ 1 jet with ΔR (lepton, $R=0.4$ jet) $< 2.0 \rightarrow$ **selected jet**
- Back-to-back : ΔR ($R=1.0$ jet, lepton) > 1.0
- Back-to-back : ΔR ($R=1.0$ jet, selected $R=0.4$ jet) > 1.0

Resolved Channel

- At least four jets : ≥ 4 jets, $p_T > 30$ GeV
- $\log_{10}\chi^2 < 0.9$

Merged topology due to **boosted** tops

Systematics :

All the experimental systematic uncertainties are added:

- Standard recommendations are followed for JES, JER, JMS and JMR systematics
- B-tagging is done on the PFlow jets and b-tagging SF uncertainties are considered
- Top-tagging (Inclusive DNN top-tagger, 80%) SF uncertainties
- MET, Electron, Muon

Theory and modeling uncertainties are considered for the $t\bar{t}$ background:

- Top modeling uncertainties using top-systematics samples and MC weights variations
- PDF variations
- NNLO Reweighting uncertainties

- QCD modelling uncertainty: flat 50%

- $t\bar{t}$ PDF and $W+jets$ PDF uncertainties are not included. (added soon)

b-tagging Categories

- Both boosted and resolved regions are split into several b-tagging categories
- **Cat 0:** b-tagged jet matching the hadronic nor leptonic top candidates.
- **Cat 1:** only the leptonic top candidate has a matching b-tagged jet
- **Cat 2:** only the hadronic top candidate has a matching b-tagged jet
- **Cat 3:** the hadronic top candidate and the leptonic top candidate both have a matching b-tagged jet.

Background composition:

The pie chart shows the relative contributions per process in the different SRs.

ATLAS

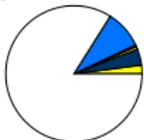
Simulation Work in Progress

$\sqrt{s} = 13$ TeV

$t\bar{t}$ 1-lepton Search



be1



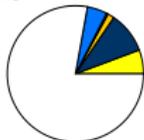
bmu1



re1



rmu1



be2



bmu2



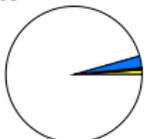
re2



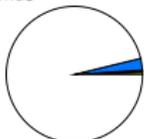
rmu2



be3



bmu3



re3



rmu3

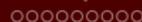


Strategy for $W+$ jets normalization correction

- **Strategy:** use data in the signal regions to calculate the corrections
- Different corrections for boosted and resolved SRs

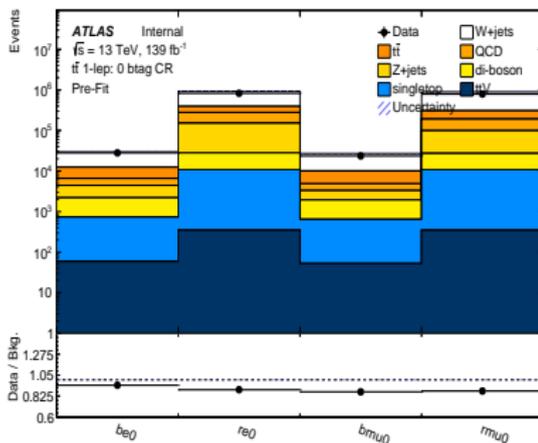
$$\text{CA norm} = \frac{N_{data}^{W+jets}}{N_{MC}^{W+jets}} \approx \frac{A_{data}^W}{A_{MC}^W} = \frac{N_{data}^{W^+} - N_{data}^{W^-}}{N_{MC}^{W^+} - N_{MC}^{W^-}}$$

- The charge asymmetry is calculated for data ($N_{data}^{W^\pm}$) by subtracting the MC contributions from all the charge-asymmetric processes like **singletop**, **diboson**, **tt+V**.
- Define normalization factors (unconstrained parameters) in the fit: boosted and resolved (0,1,2,3 btag category)
- Use the $W+$ jets correction factors at the nominal value of the norm factors

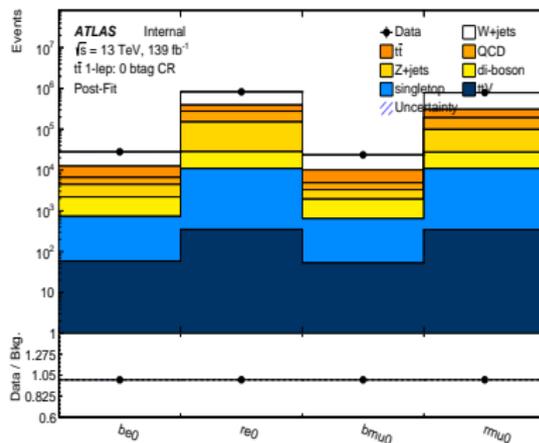


Pre(Post)-fit Data/MC in the 0bCRs

Data/MC comparison is better with the new Sherpa 2.2.11 sample and differences are expected to be within the systematics uncertainties



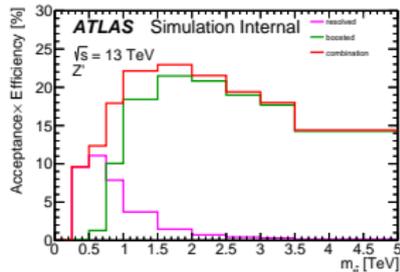
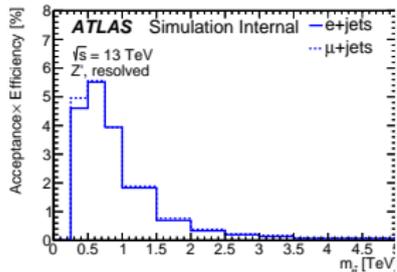
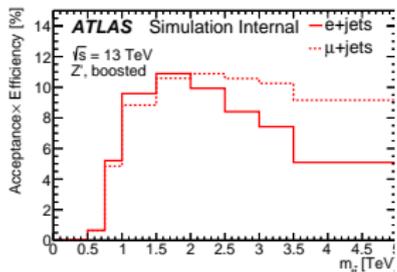
Pre-Fit



Post-Fit

Acceptance \times Efficiency

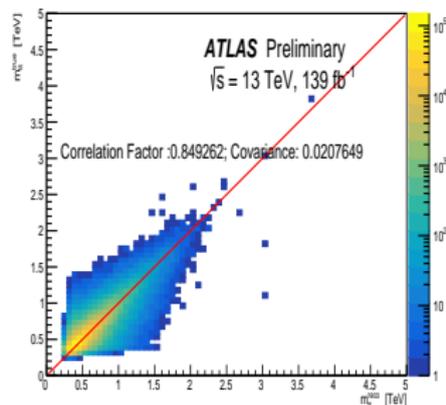
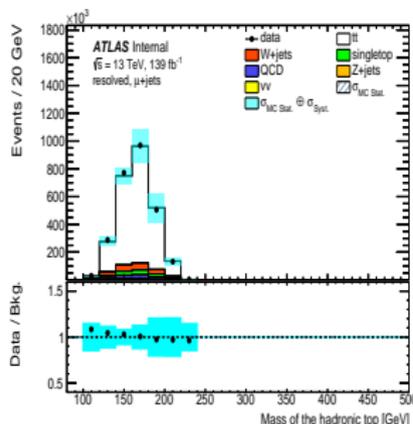
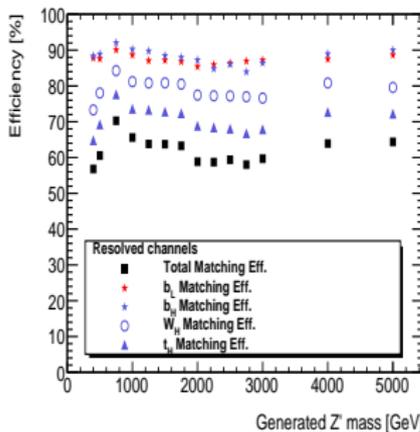
- The efficiency times acceptance is dominated by the resolved-topology selection in the range $m_{t\bar{t}}^{\text{truth}} < 0.75$ TeV
- The probability for an event to pass the boosted-topology selection increases steadily for $m_{t\bar{t}}^{\text{truth}} > 0.75$ TeV because higher values of $m_{t\bar{t}}^{\text{truth}}$ correspond to more energetic top quarks collimated in Large jet
- Clear differences between the e- and the μ +jets channels are observed for $m_{t\bar{t}}^{\text{truth}} > 2.5$ TeV,



Reconstruction in resolved Topology

- The χ^2 minimization method aims to select the right combination of jets
- The χ^2 is defined as follows :

$$\chi^2 = \left(\frac{m_{jj} - m_W}{\sigma_W} \right)^2 + \left(\frac{m_{jjb} - m_{jj} - m_{th-W}}{\sigma_{th-W}} \right)^2 + \left(\frac{(pT_{jjb} - pT_{j\nu}) - (pT_{th} - pT_{t\bar{t}})}{\sigma_{diff-pT}} \right)^2 + \left(\frac{m_{j\nu} - m_{t\bar{t}}}{\sigma_{t\bar{t}}} \right)^2$$

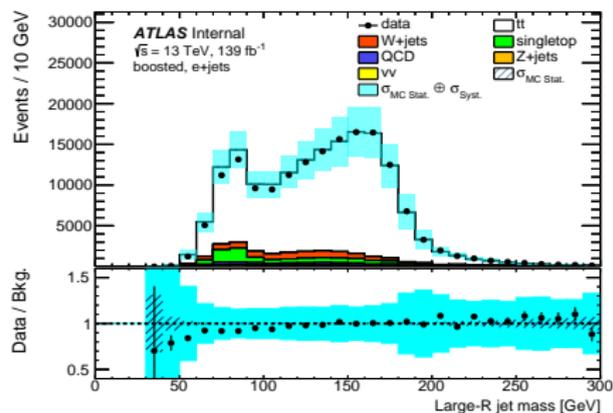
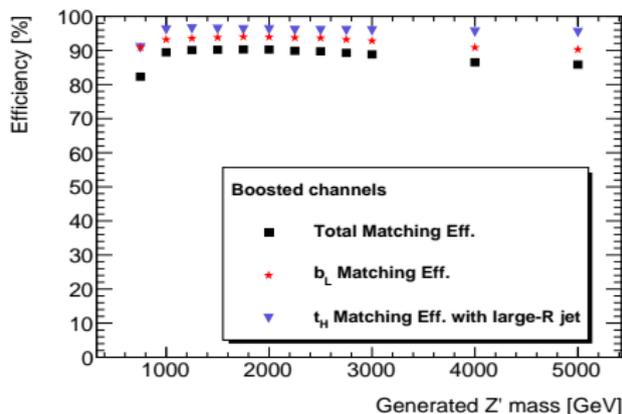


The performance of the reconstruction varies from 60 to 70% determined on parton-matched for Z'_{TC2} signal.

High correlation between truth and reconstructed $m_{t\bar{t}}$

Reconstruction in boosted Topology

- $m_{t\bar{t}}^{reco}$ is reconstructed from the **leptonic** top candidate and **hadronic** top candidate:
 - **Hadronic top:** 4-vector of the « large-R » jet.
 - **Leptonic top:** highest- p_T « small-R » jet (close to the lepton) combined to the lepton and the neutrino 4-momenta (the latter derived from E_T^{miss} and lepton kinematics with a constraint on the W mass).



The performance of the reconstruction is about 90%

Multijet background estimation via Matrix Method

Matrix Method is used to estimate the QCD multi-jet background production:

- ✗ Quark or gluon jet mis-identified as a lepton

The event yields N_{loose} and N_{tight} for the data samples can then be written as:

$$\begin{pmatrix} N_{loose} \\ N_{tight} \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ \epsilon_{fake} & \epsilon_{real} \end{pmatrix} \begin{pmatrix} N_{QCD} \\ N_{prompt} \end{pmatrix}$$

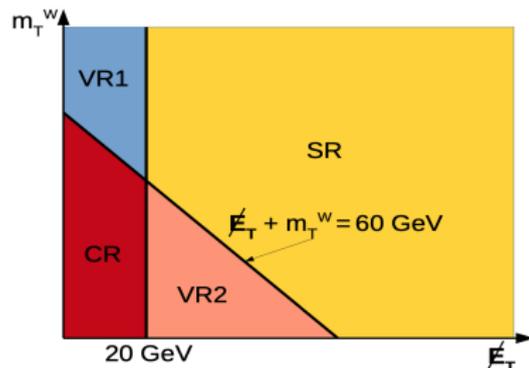
- real eff (ϵ_{real}) computed from MC:

$$\epsilon_{real} = \frac{(T\bar{T})_{tight}}{(T\bar{T})_{loose}}$$

- fake eff (ϵ_{fake}) measured in QCD enriched control region (CR) with $\geq 1bjet$ ($=0$ bjet):

$$\epsilon_{fake} = \frac{(DATA_MC)_{tight}}{(DATA_MC)_{loose}}$$

- rates for full run2 dataset are combined to increase statistics in fuction of topetcone20 and lepton p_T (see back-up)



VR1 and VR2 used to validate the QCD estimation

Estimation of Multijet background via:

$$\epsilon_{fake} \times N_{QCD} = \frac{(\epsilon_{real} - 1)\epsilon_{fake}}{(\epsilon_{real} - \epsilon_{fake})} N_{tight} + \frac{\epsilon_{real}\epsilon_{fake}}{(\epsilon_{real} - \epsilon_{fake})} N_{anti\ tight}$$

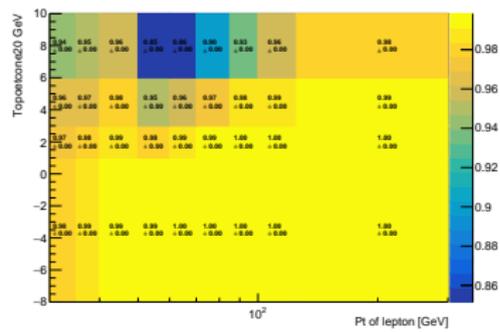
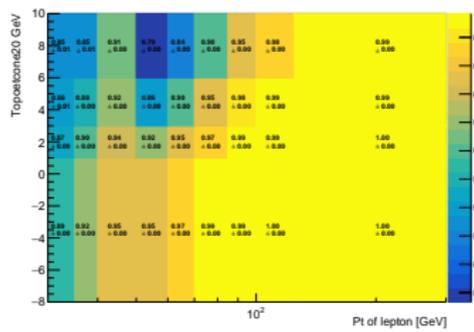


Multijet background estimation: rates (Muon Channel)

Real:

$$\Delta R(\mu, jet) < 0.4$$

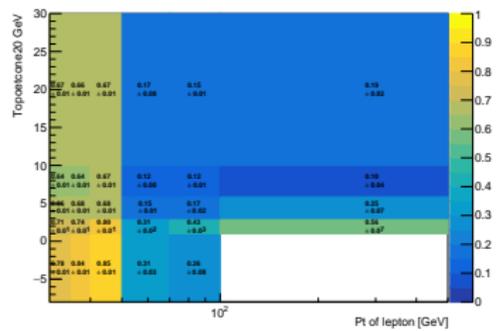
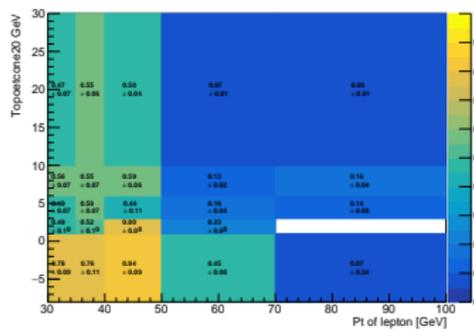
$$\Delta R(\mu, jet) \geq 0.4$$



Fake:

$$\Delta R(\mu, jet) < 0.4$$

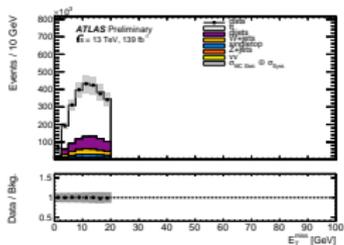
$$\Delta R(\mu, jet) \geq 0.4$$



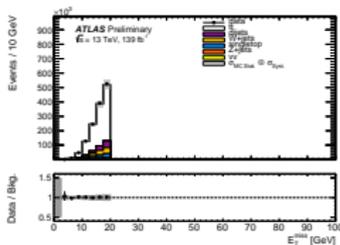
Multijet background estimation: Closure test

$\geq 1b_{tag}$

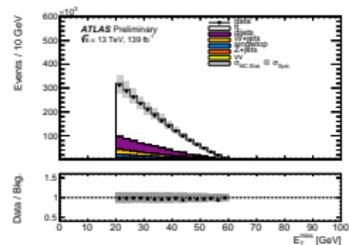
CR



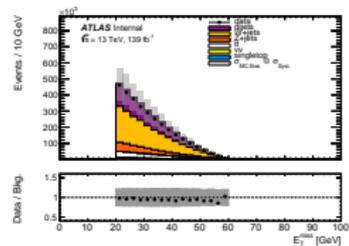
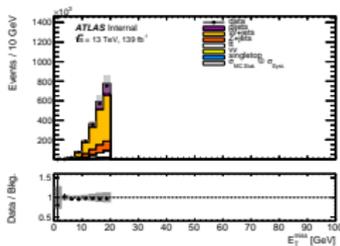
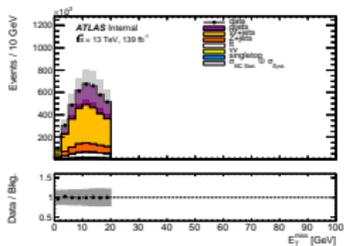
VR1



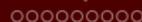
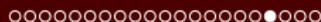
VR2



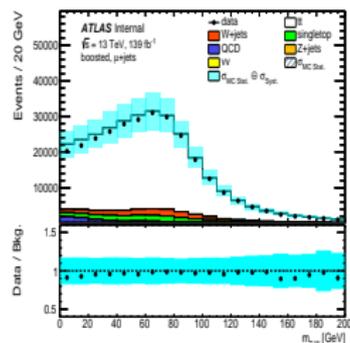
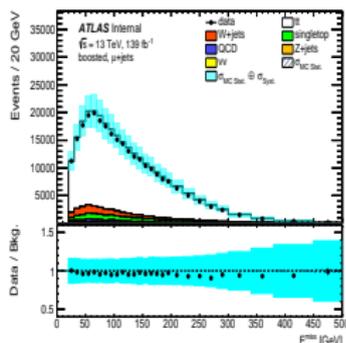
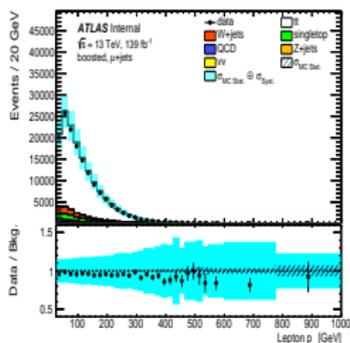
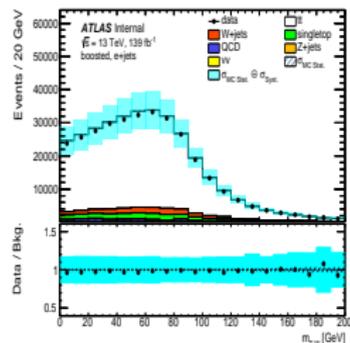
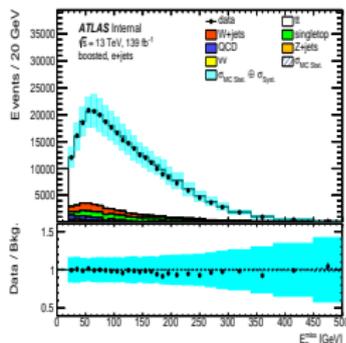
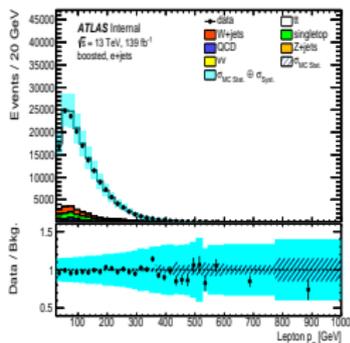
$= 0b_{tag}$



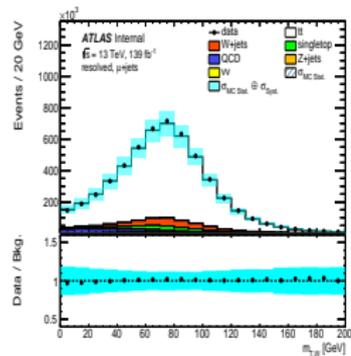
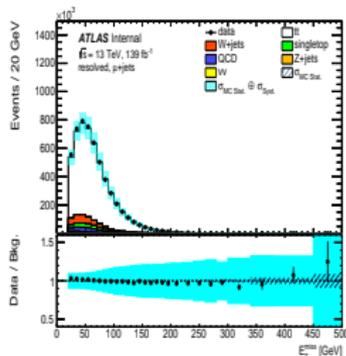
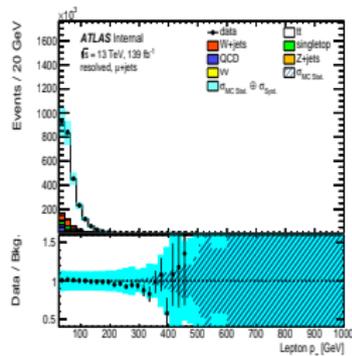
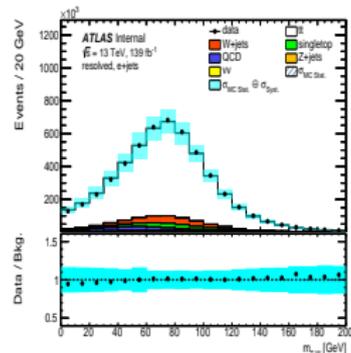
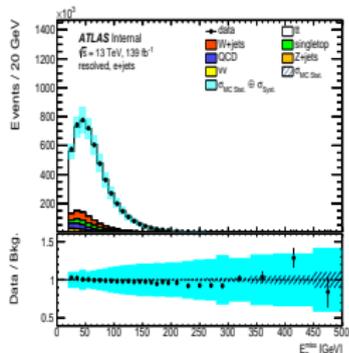
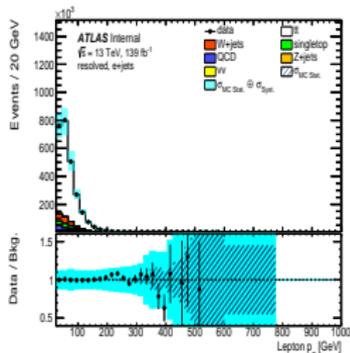
Good agreement between MC prediction and the data for CR and VR's.



Control Plots: Boosted Topology SR



Control Plots: Resolved Topology SR



Summary

- Full Run-2 data/MC agreement is reasonably good and discrepancies are covered by the systematic band.
- Backgrounds estimated and checked with control plots.
- Major systematic uncertainties included.
- The limits calculation is ongoing.

Thank You For Your Attention

BACKUP



QCD Control and Validation Regions

Lepton definition	Electron	Muon
Loose	MediumLH and No isolation	Loose Quality and No isolation
Tight	TightLH and TightTrackOnly	Medium Quality and TightTrackOnly_VarRad

Control Region Definition

- muon channel:

- exactly one loose muon
- no tight electron
- $E_T^{\text{miss}} < 20 \text{ GeV}$, $E_T^{\text{miss}} + M_T < 60 \text{ GeV}$
- at least 4 jets
- at least 1 b-tagged jet

- electron channel:

- exactly one loose electron
- no tight muon
- $E_T^{\text{miss}} < 20 \text{ GeV}$, $E_T^{\text{miss}} + M_T < 60 \text{ GeV}$
- at least 4 jets
- at least 1 b-tagged jet

- $\text{VR1}_{\text{QCD}}^{4j,1b}$: $E_T^{\text{miss}} < 20\text{GeV}$ and $E_T^{\text{miss}} + m_T^W > 60 \text{ GeV}$

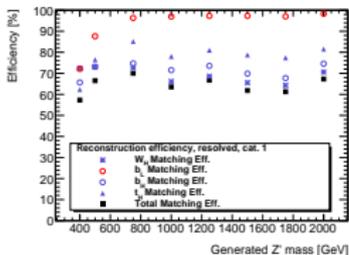
- $\text{VR2}_{\text{QCD}}^{4j,1b}$: $E_T^{\text{miss}} > 20\text{GeV}$ and $E_T^{\text{miss}} + m_T^W < 60 \text{ GeV}$



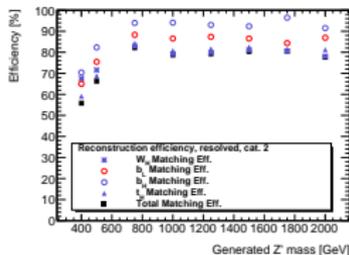
Performance of the reconstruction

Resolved

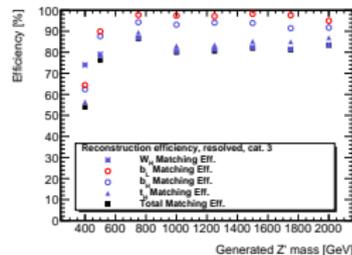
b-Cat 1



b-Cat2

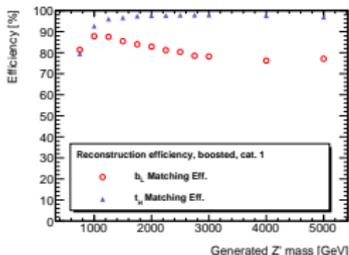


b-Cat3

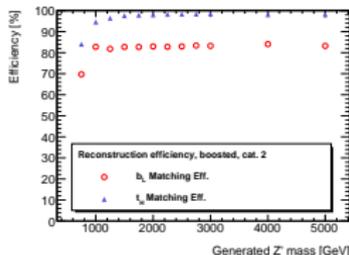


Boosted

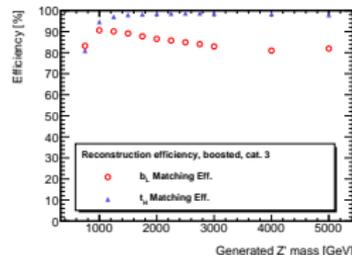
b-Cat 1

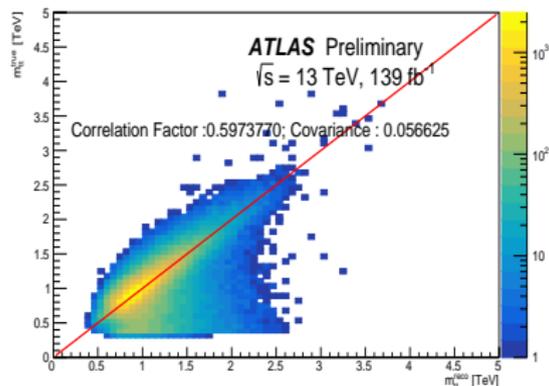
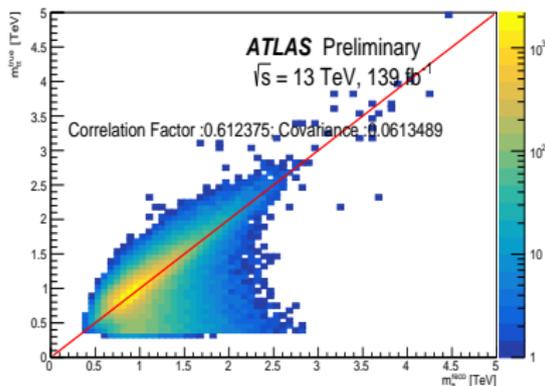
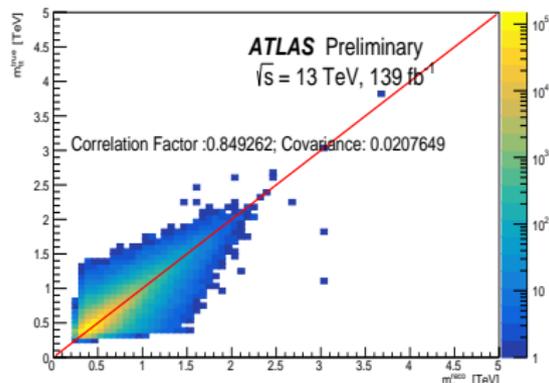
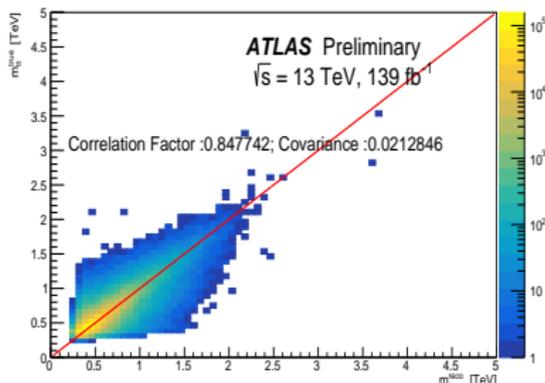


b-Cat2



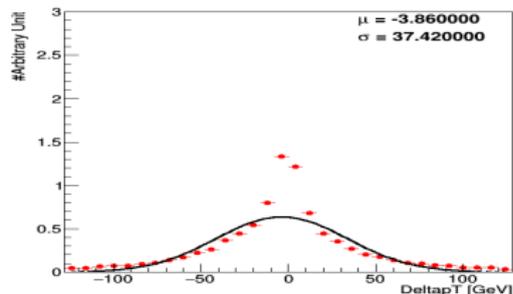
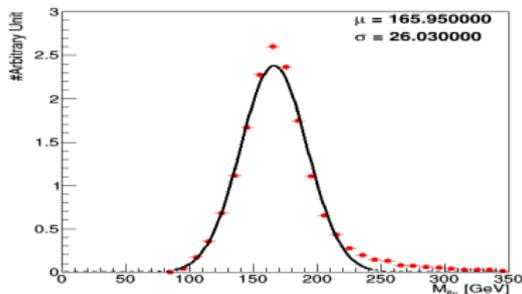
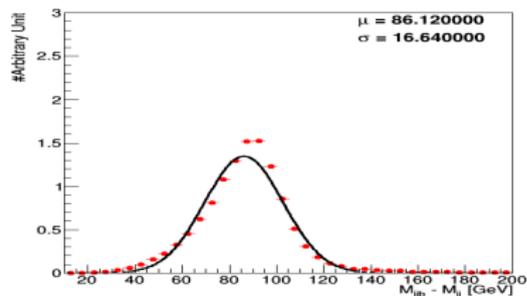
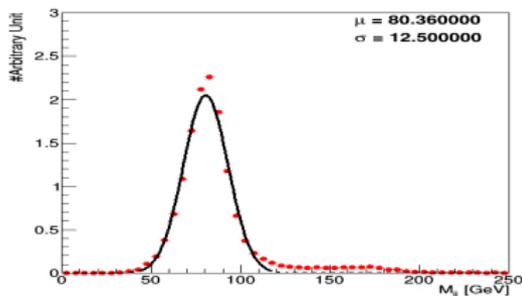
b-Cat3

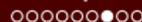
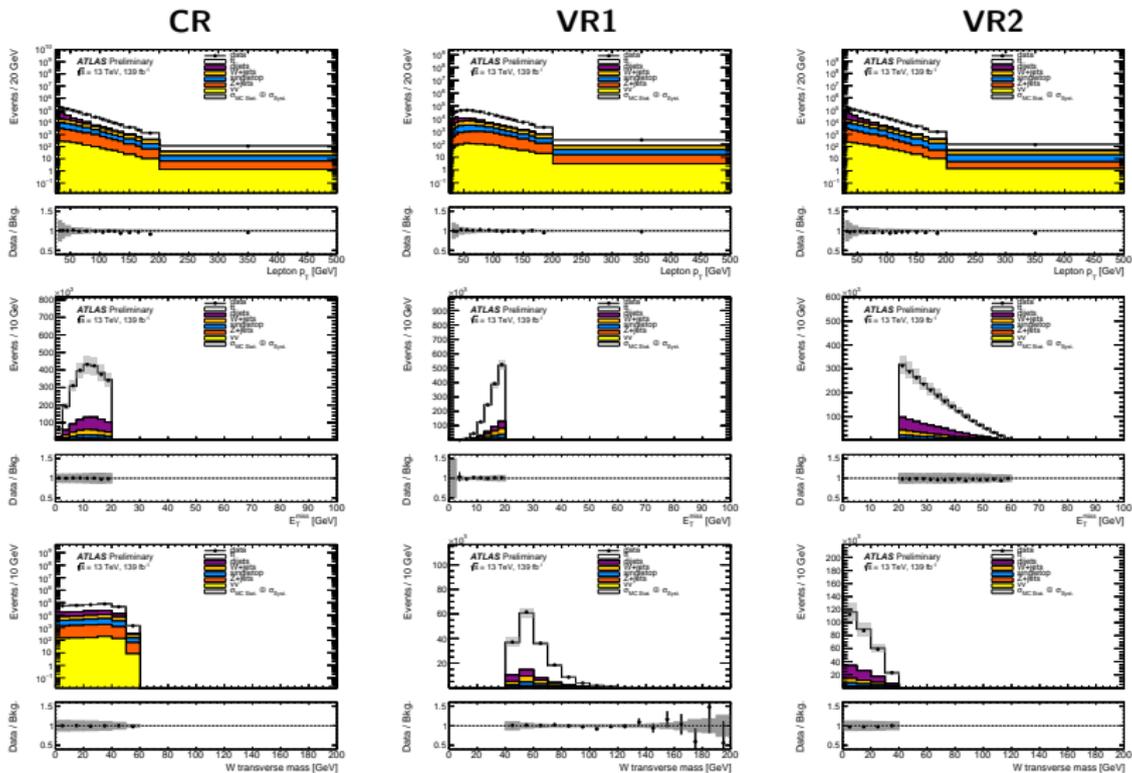


$t\bar{t}$ System mass Correlation

χ^2 Parameters

Measured on a mix of Z'_{TC2} samples (0.5 to 2 TeV)

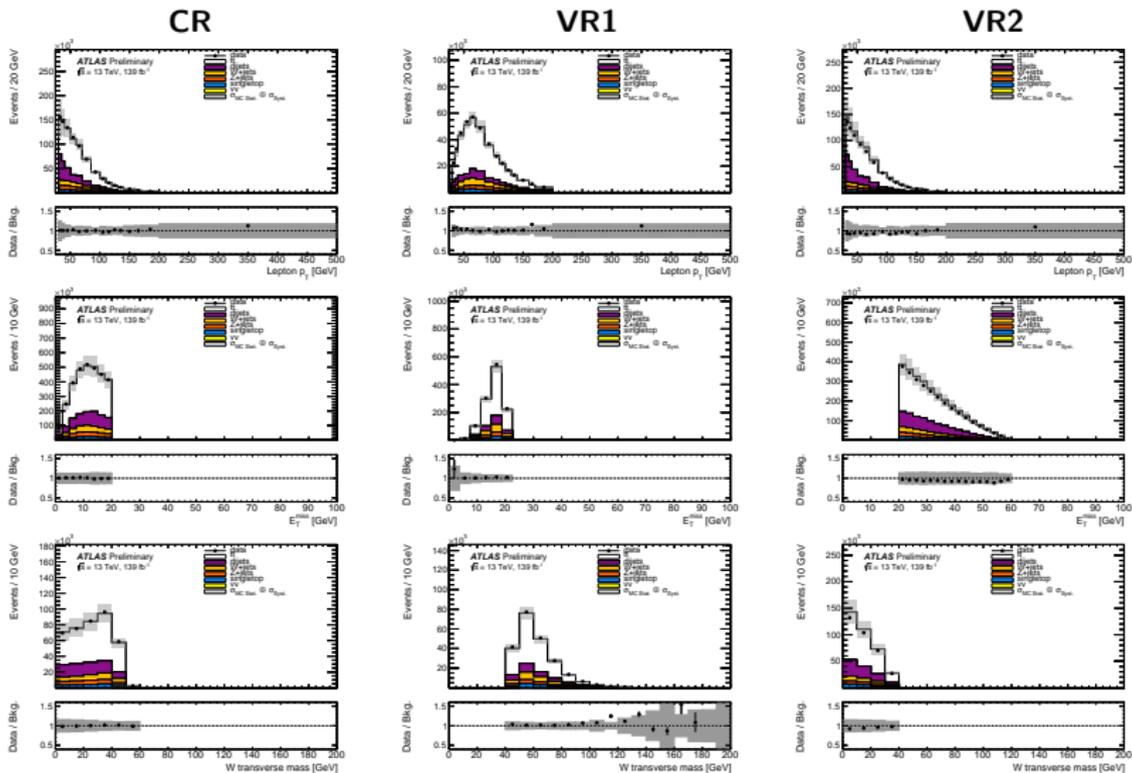


Closure test: μ channel

Good agreement between MC prediction and the data for CR and VR's.

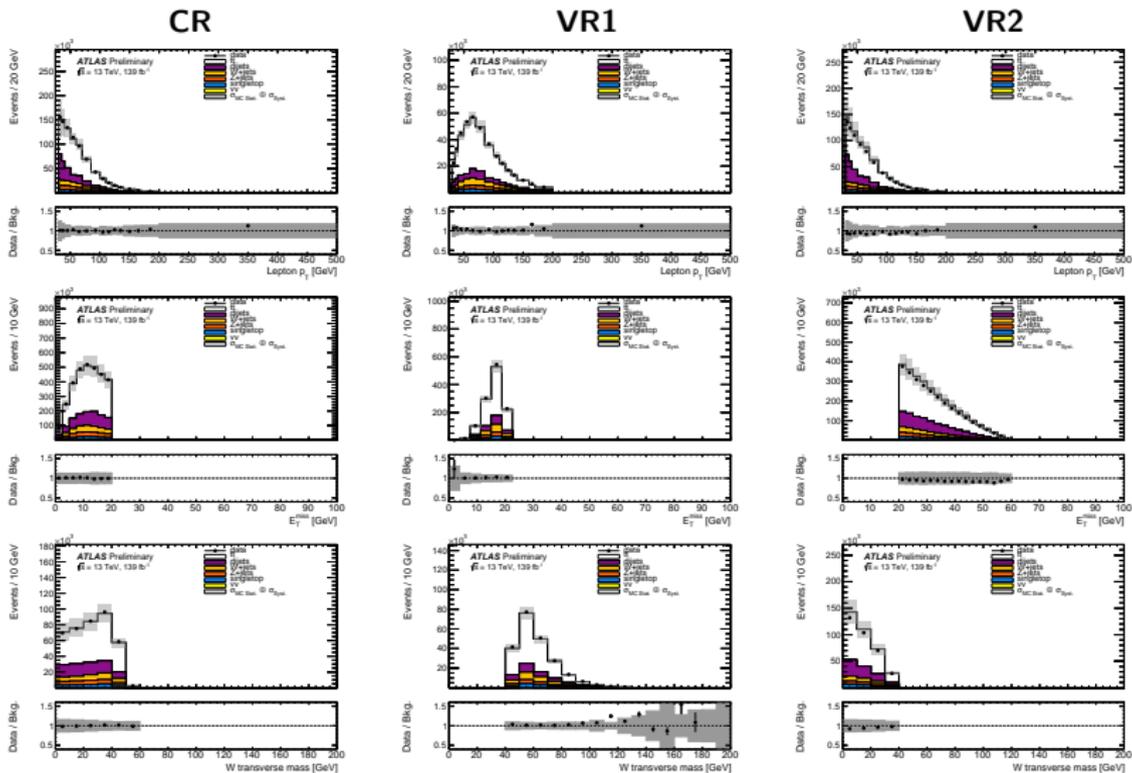


Closure test: e channel



Good agreement between MC prediction and the data for CR and VR's.

Closure test: e channel



Good agreement between MC prediction and the data for CR and VR's.