

Prospects for Measuring the Four-Top Production Cross Section Using 139 fb^{-1} of Data Collected by the ATLAS Experiment

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Search for 4-top Quark Production

- Production of 4-top quarks is a process predicted by the Standard Model
 - ▶ SM NLO predicted cross-section is $11.97^{+18\%}_{-21\%}$ fb [1]

Previous 4top Search Results at $\sqrt{s} = 13$ TeV

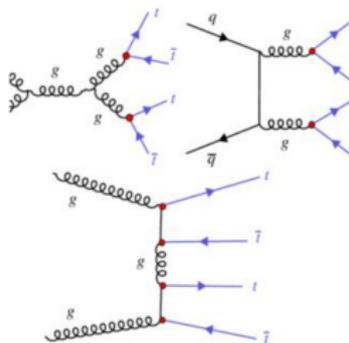
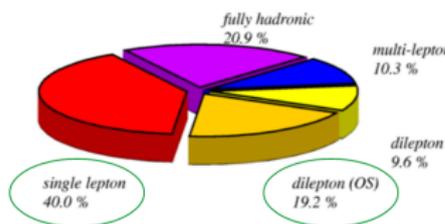
Search	Cross-Section Limit	Significance	Int. Luminosity	Channels	Source
ATLAS	49	2.8	36 fb^{-1}	1LOS + SSML	[2],[3]
CMS	48	1.96	36 fb^{-1}	1LOS	[4]

- Many theories Beyond the Standard Model (BSM) predict enhancement of the cross-section, due to high mass of top quark

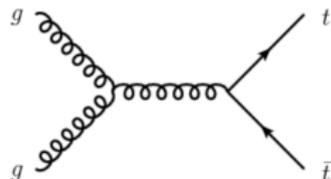
The 1LOS Channel

- Search over full Run2 dataset is divided into 2 channels based on final decay state
 - ▶ 1 lepton (1L) and 2 lepton opposite sign (OS) = 1LOS
 - ▶ 2 lepton same sign (SS) and multi-lepton (ML) = SSML
 - ▶ While SSML has greater sensitivity, the 1LOS channel is still necessary to achieve sufficient significance
- **1LOS is the focus of the remainder of this presentation**
- Major background of 1LOS analysis is $t\bar{t}$

Top Quark Decay Channels



Signal



Background^[5]

Signal Regions in 1LOS

- 4-top vs. $t\bar{t}$: 2x number of top quarks produced = 2x number of b-quarks, high-pt jets, and large-radius reclustered jets, etc.
- 4-top analysis uses a number of selection criteria on jet variables to isolate signal 4-tops from $t\bar{t}$ background
 - ▶ Signal regions: defined by number of reclustered jets N_J , number of b-jets N_b , number of jets N_j
 - ▶ Different jets are in turn defined by cuts on pt, mass
 - ▶ Jet activity, HT, is used to perform fits between MC samples and data

SR#	N_J	N_b	N_j
SR0	= 0	= 3	= 7
SR1	≥ 1		
SR2	= 0	≥ 4	
SR3	≥ 1	≥ 4	≥ 8
SR4	= 0	= 3	
SR5	≥ 1		
SR6	= 0	≥ 4	≥ 10
SR7	= 1	= 3	
SR8	≥ 2		
SR9	= 0	≥ 4	
SR10	= 1	≥ 4	
SR11	≥ 2		

Table 2: Signal regions definitions for 2l channel.

Table 1: Signal regions definitions for 1l channel.

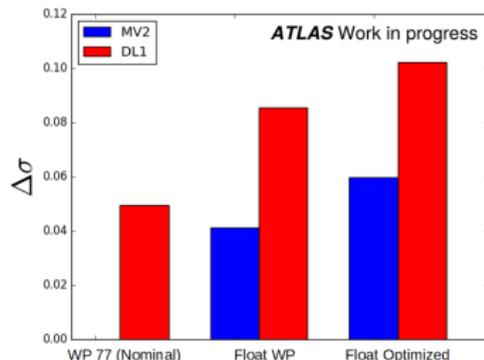
Optimization of Selection-Based Analysis

- **The objective: vary selection parameters in order to maximize the significance**
- Vary selection parameters individually
- For each value, calculate significance and determine if the new significance is above or below the nominal significance
- Significance calculation performed using profile likelihood ratio fitting
 - ▶ Distribution of jet activity, HT, is used to perform the ratio fitting
 - ▶ No systematics included in this study yet
 - ▶ Using Asimov data
 - ▶ Using Monte Carlo generated samples reweighted with data to correct mismodelling

B-tagging Optimization

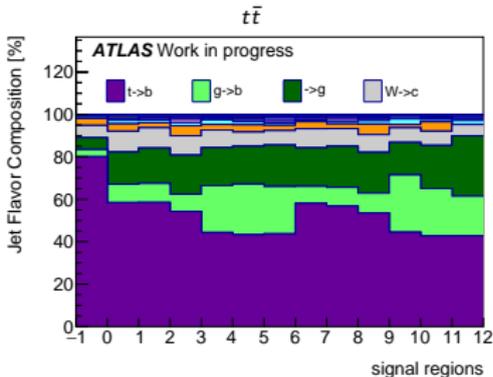
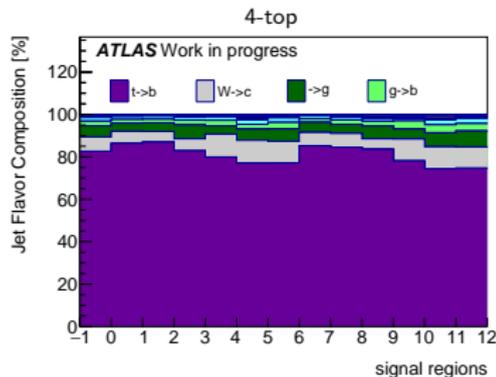
- Two algorithm options for tagging bjets
 - ▶ MV2c10: BDT-based algorithm using variable inputs from more basic jet algorithms
 - ▶ DL1: Same inputs as MV2c10, but NN-based
 - ▶ Output of both algorithms is a score: the higher the score, the more likely the jet is a b-jet
 - ▶ Can select working point (WP), efficiency for b-jet selection
 - ▶ Test new "floating" WP, which changes efficiency criteria for different numbers of b-jets

WP Cuts	$N_b = 1$	$N_b = 2$	$N_b = 3$	$N_b \geq 4$
Nominal	77	77	77	77
Floating WP	60	60	77	85
Float Optimized	60	77	77	85



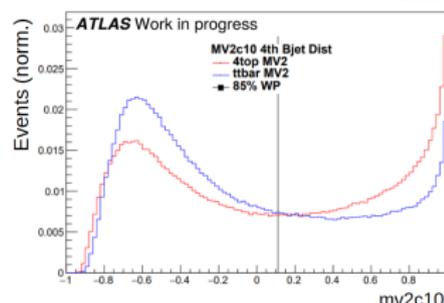
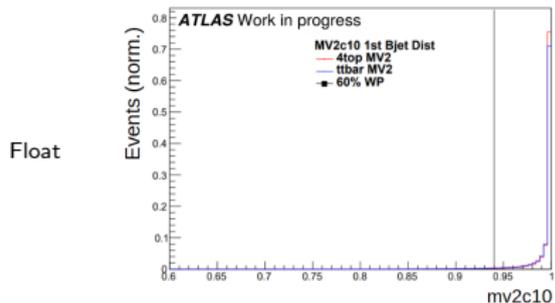
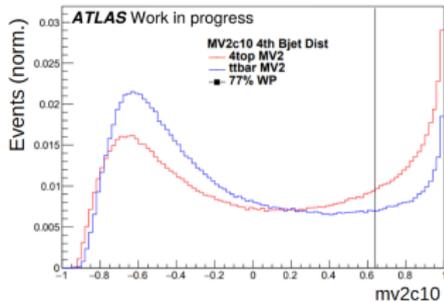
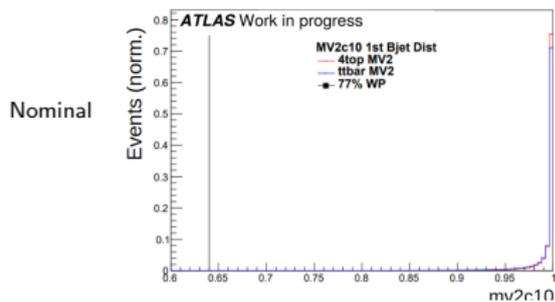
- In general, lower efficiency selection for low n-bjets and higher efficiency for high n-bjets improve significance

B-Jet Composition Studies



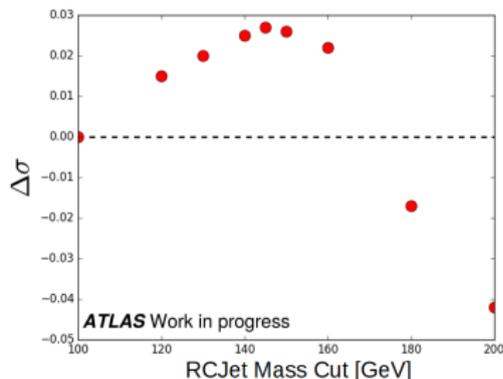
- Fewer top decays in $t\bar{t}$ means more false b-tags coming from gluon decay and c-quarks
- Knowing the source of false tags can inform improvements for the tagging/other cut choices
- False b-tags will yield lower scores from DL1 and MV2c10
- Adjusting efficiency will accept or reject more false b-tags accordingly

MV2c10 Distributions vs. Working Points



- Highest-value MV2c10 jet: 60% WP eliminates more $t\bar{t}$
- Fourth-highest MV2c10 jet: 77% WP removes more 4-top signal than 85% WP
- **Floating WP improves background rejection and increases signal statistics**

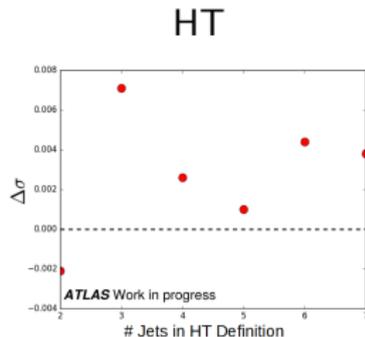
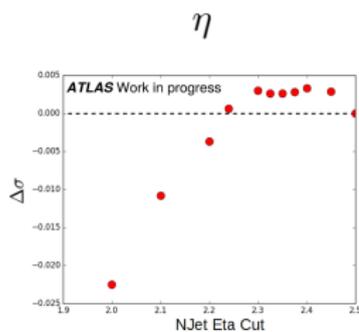
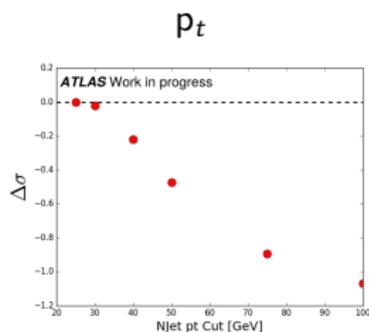
Reclustered Jet Mass Optimization



- Top quark hadronic decay produces high- p_t jets which may overlap each other
- Large-radius reclustering allows for reconstruction of overlapping jets, and can recover top mass
- RC-jet mass can be used to distinguish between hadronic jets from top decay and jets from other sources
- Selection of RC-jets with higher mass yields a noticeable increase in significance

Other Selection Tests

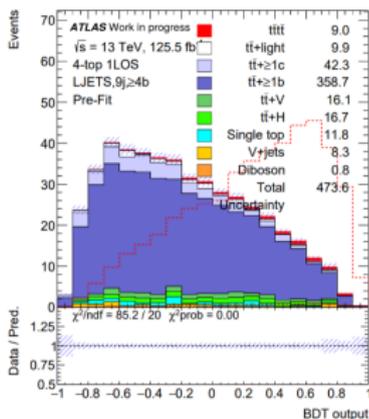
- Cuts on jet p_t and η
 - ▶ Jets from top quarks are harder than other jets, so higher cuts on p_t were tested for re-defining jets, bjets, and HT
 - ▶ These cuts reduced statistics, lowering significance
 - ▶ Reducing the η values from which jets were accepted did not substantially improve significance
- Re-definition of jet activity, HT
 - ▶ Nominal HT definition is the sum of p_t for all jets
 - ▶ Tested altering definition to include the highest X p_t jets
 - ▶ Only very small changes were observed



Results and Comparison with BDT

Cut-Based Optimization

Variable(s)	Selection	σ	difference
nominal	nominal	1.77	0.00
WP	Floating	1.87	0.10
RCJet m	145 GeV	1.79	0.03
RCJet m and WP	145 GeV and Floating	1.90	0.13



- Combining re-optimized parameters yields a 5-10% increase in significance
- Ultimately, signal regions will be optimized using boosted decision tree (BDT) analysis
 - Instead of simple selections made on single variables, BDT defines complex multivariate regions
- Preliminary results for stat-only BDT analysis yield higher improvements in significance, around 50%

Conclusions and Outlook

- The impact of number of b-jets and tagging effectiveness is substantial
 - ▶ Greater number of "false" b-jets in $t\bar{t}$
 - ▶ Harsher cuts on low numbers of b-jets eliminate some of this background
 - ▶ Looser cuts on high numbers of b-jets help improve statistics in 4-tops
- Harder reclustered jets cut may also increase significance
- Cuts on jet p_t generally reduce statistics too much to improve the significance
- Future work involves adding systematics to the significance calculation to see if cut optimization remains optimized in a more complete framework
- This study can be used to guide BDT analysis and provide a selection-based comparison
- Ultimately, this analysis helps to improve our understanding of 4-top isolation from $t\bar{t}$, a vital aspect of the 1LOS channel search.

References

[1] [\[arXiv:1711.02116\]](#)

[2] [\[arXiv:1811.02305\]](#)

[3] [\[arXiv:1807.11883\]](#)

[4] C. Collaboration, *Search for standard model production of four top quarks with the single-lepton and opposite-sign dilepton final states in proton-proton collisions at $\sqrt{s} = 13\text{TeV}$* , (2019)

[5] http://inspirehep.net/record/1103034/files/figures_Theory_LOProd.png

Backup

Significance Formula

- s = # significance events
- b = # background events
- σ_b = uncertainty on background events

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