

# Search for $t\bar{t}H(H \rightarrow b\bar{b})$ fully hadronic with ATLAS detector

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## 2 Fully hadronic $t\bar{t}H(H \rightarrow b\bar{b})$ analysis strategy

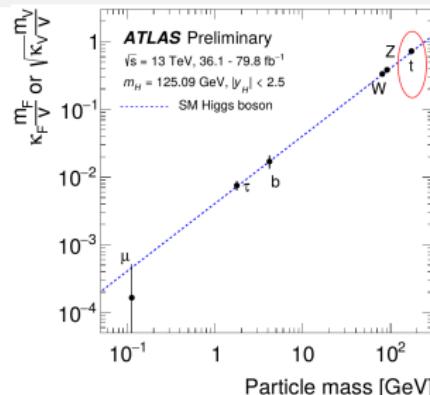
- Analysis strategy
- Multijet background estimation using  $TRF_{MJ}$  method
- Validation of  $TRF_{MJ}$  in Pythia8 dijet events
- Prediction event across jet multiplicities

## 3 Search for RpV SUSY in fully hadronic final state

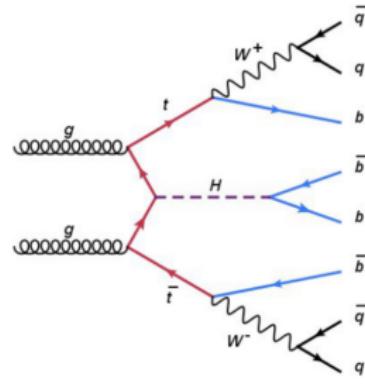
## 4 Conclusions and outlook

# OVERVIEW - TOP QUARK - INDIRECT PROBE OF NEW PHYSICS

- Since the discovery of Higgs boson in 2012, the measures of its properties give a compatible picture with **Standard Model**
- $t\bar{t}H$  production provides direct access to top Yukawa coupling
  - top quark has the largest Yukawa coupling ( $y_t \sim 1$ )
  - Deviation in  $y_t$  could be a hint of **new physics**
- Motivation to study  $t\bar{t}H(H \rightarrow b\bar{b})$  in fully hadronic channel
  - Direct production of  $t\bar{t}H(H \rightarrow b\bar{b})$  into all jets final state is challenging final state
    - largest BR and smallest S/B
  - Contribute  $\sim 10\%$  of sensitivity to  $t\bar{t}H$  production in Run 1 [[1604.03812](#)]
  - Run 2 analysis by ATLAS is in progress

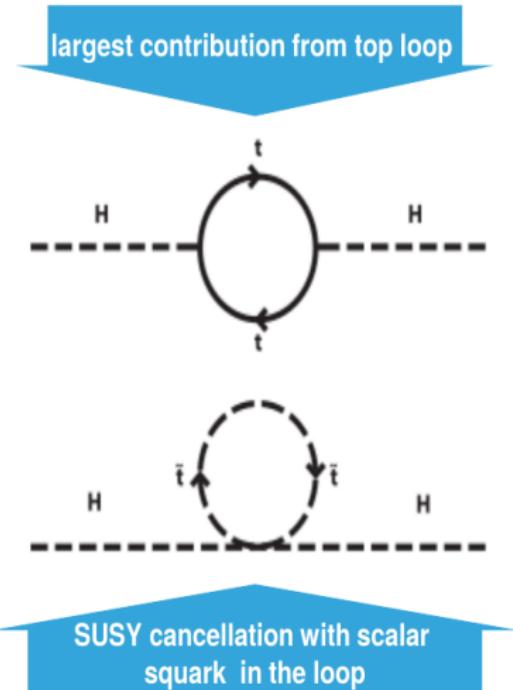


Higgs couplings [[ATLAS-CONF-2018-031](#)]

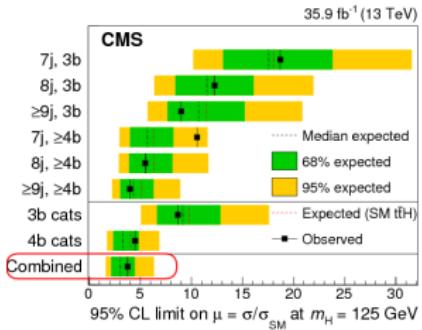
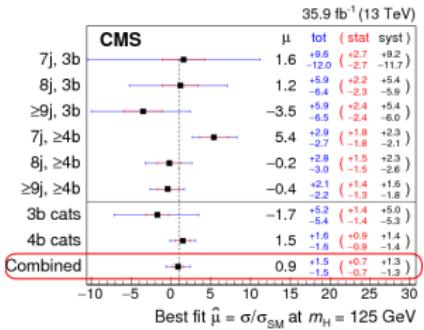
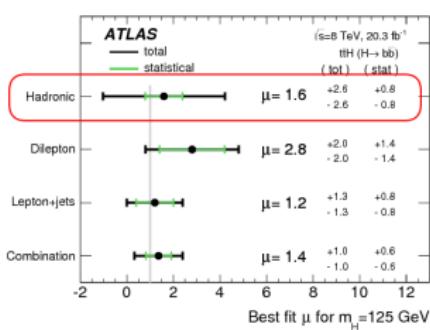
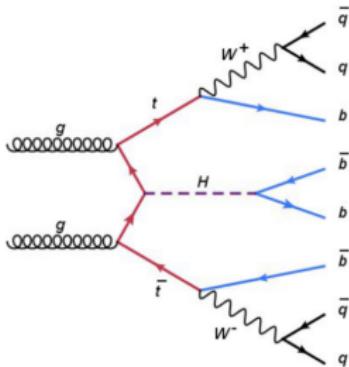


# OVERVIEW - TOP QUARK - INDIRECT PROBE OF NEW PHYSICS

- Standard Model presents some shortcomings
  - Gravitational evidence for dark matter, problem with SM naturality ,...
- Top quark has an important role in any BSM theory
- **Higgs mass hierarchy:** radiative correction to Higgs mass from  $t$ -quark leads to divergence
  - Can be fixed by any BSM which has top-partner
  - To avoid unnatural cancellation top-partner mass must be  $O(\text{TeV})$



# CURRENT RESULTS ON FULLY HADRONIC $t\bar{t}H(H \rightarrow b\bar{b})$



[arxiv:1604.03812]

[arxiv:1803.06986]

[arxiv:1803.06986]

## ANALYSIS STRATEGY: PRE-SELECTION

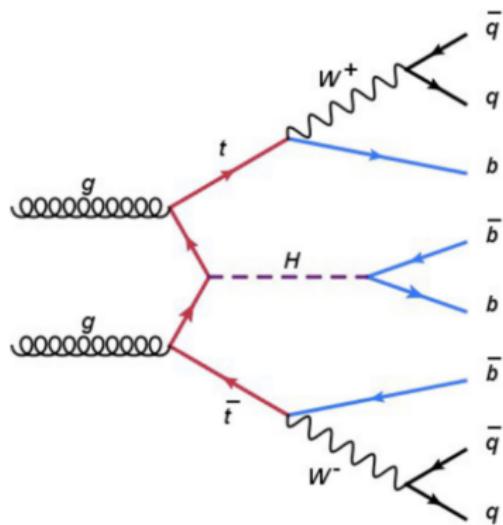
- Triggers

- HLT\_4j100 (2015+2016),  $36.1 \text{ fb}^{-1}$
- HLT\_4j120 (2017),  $44.2 \text{ fb}^{-1}$

- Preselection:

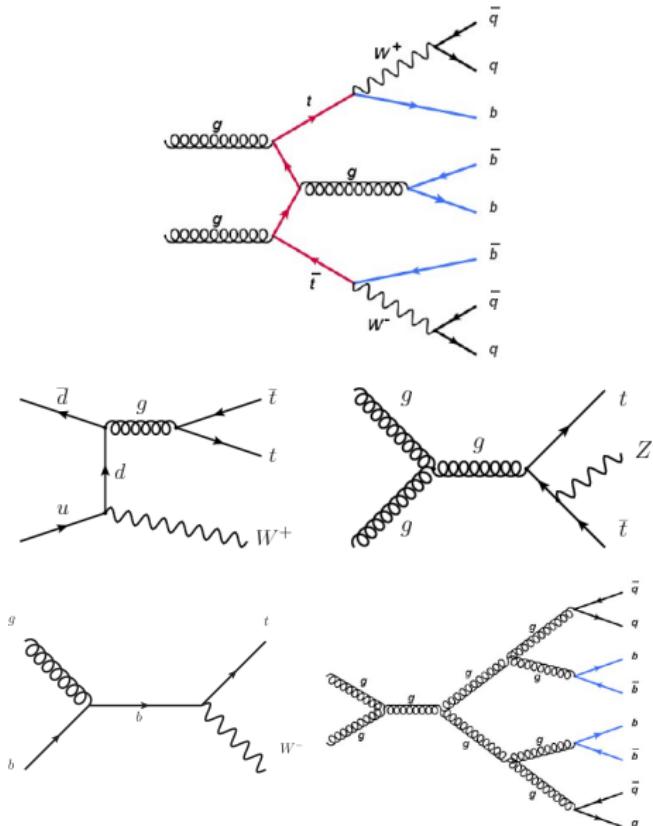
- $\geq 4$  jets  $p_T > 100 \text{ GeV}$  (2015+2016)  
or  $\geq 4$  jets  $p_T > 120 \text{ GeV}$  (2017),  
 $|\eta| < 2.5$
- any additional jets must have  
 $p_T > 25 \text{ GeV}$ ,  $|\eta| < 2.5$
- Veto on a presence of an isolated  
lepton to ensure orthogonality with  
other channels
- b-tagging used Mv2c10 at 60% OP
- Weights applied: pile up, jvt,  
b-tagging SF

- STRATEGY: Search for signal in event  
with high jet and b-jet multiplicity  
( $\geq 8j, \geq 4b$ )



# BACKGROUND ESTIMATION

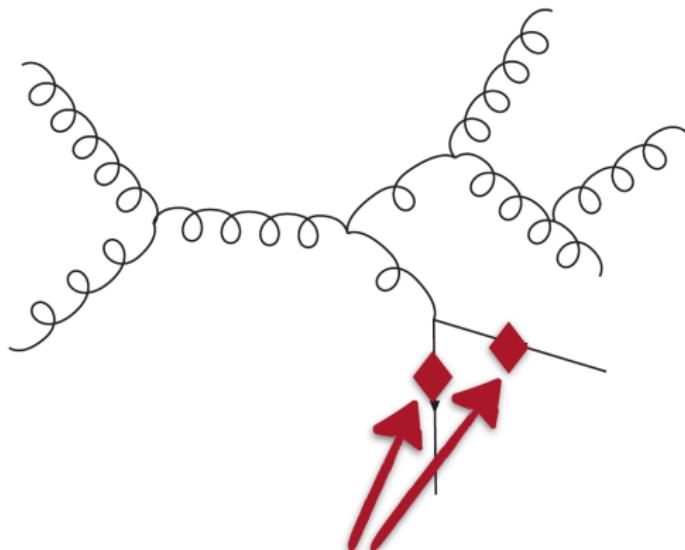
- Signal
  - $t\bar{t}H$ : Powheg+Pythia8
- Top background from MC
  - $t\bar{t} + \text{jets}$ : Powheg+Pythia8
  - $t\bar{t} + V$ : aMC@NLO+Pythia8
  - Single top (Wt-channel): Powheg+Pythia8
- Multijet (QCD) extracted from data
  - Tag-Rate-Function Multi-Jet (TRF<sub>MJ</sub>) method
  - TRF<sub>MJ</sub> is used to estimate the number of events with  $\geq(m+n)$  b-tagged jets from a sample with  $\geq n$  b-tagged jets
  - TRF<sub>MJ</sub> is based on the probability of tagging a QCD jet ( $\epsilon_{MJ}$ )



# TAG-RATE-FUNCTION MULTI-JET: $\text{TRF}_{\text{MJ}}$

$\text{TRF}_{\text{MJ}}$  derived in events with 5 jets

$\text{TRF}_{\text{MJ}}$  derived in events with  $\geq 2$  b-tags



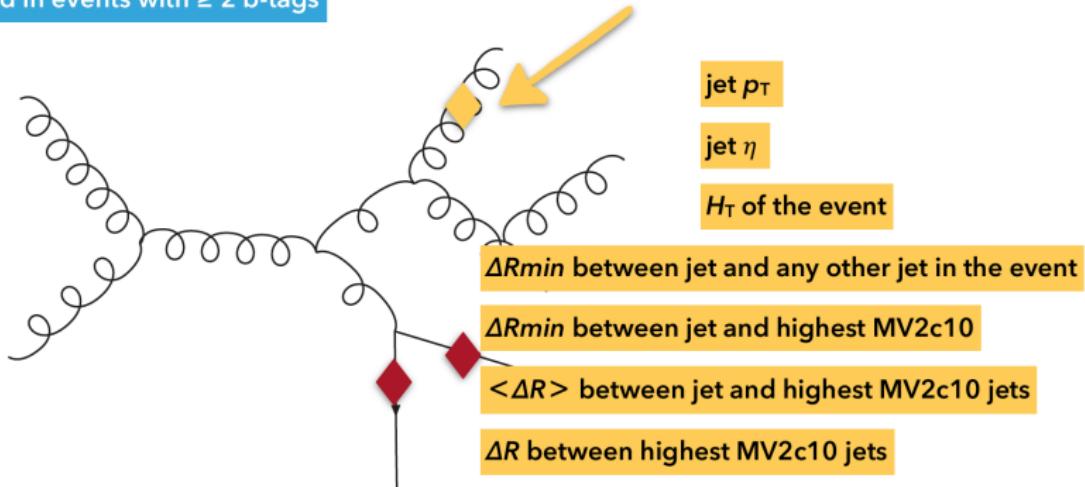
2 jets with highest  $\text{MV2c10}$  removed from  $\epsilon_{\text{MJ}}$  computation

## TAG-RATE-FUNCTION MULTI-JET: TRF<sub>MJ</sub>

TRFMJ derived in events with 5 jets

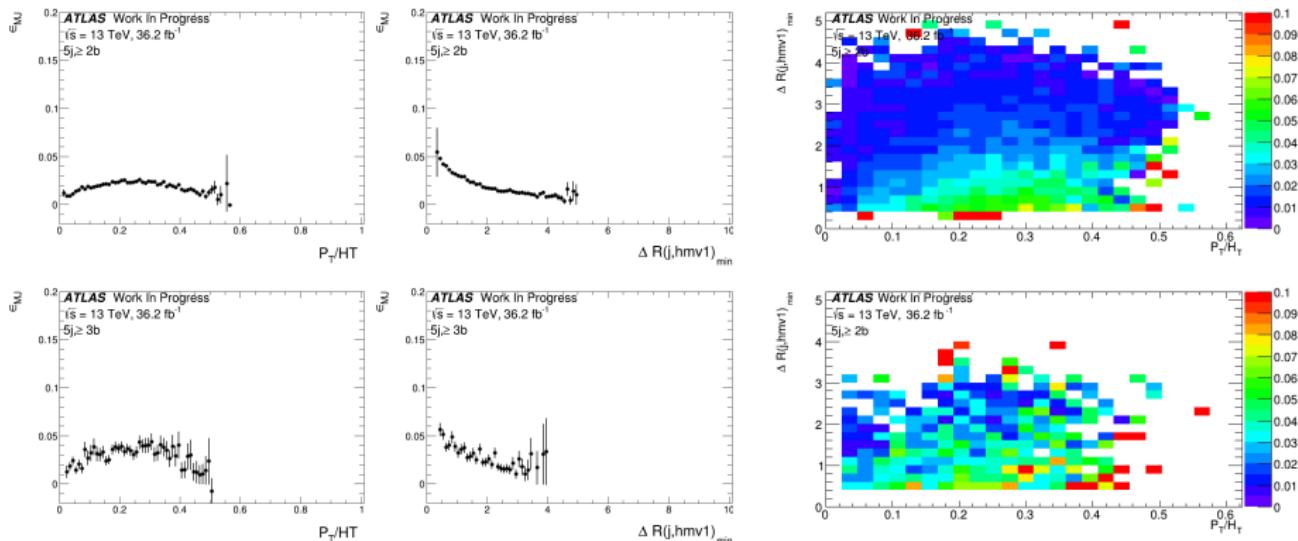
TRFMJ derived in events with  $\geq 2$  b-tags

$\epsilon_{MJ}$  is derived from all other jets in the event  
function of variables sensitive to flavor and  
whom the efficiency depends upon:



2 jets with highest MV2c10 removed from  $\epsilon_{MJ}$  computation

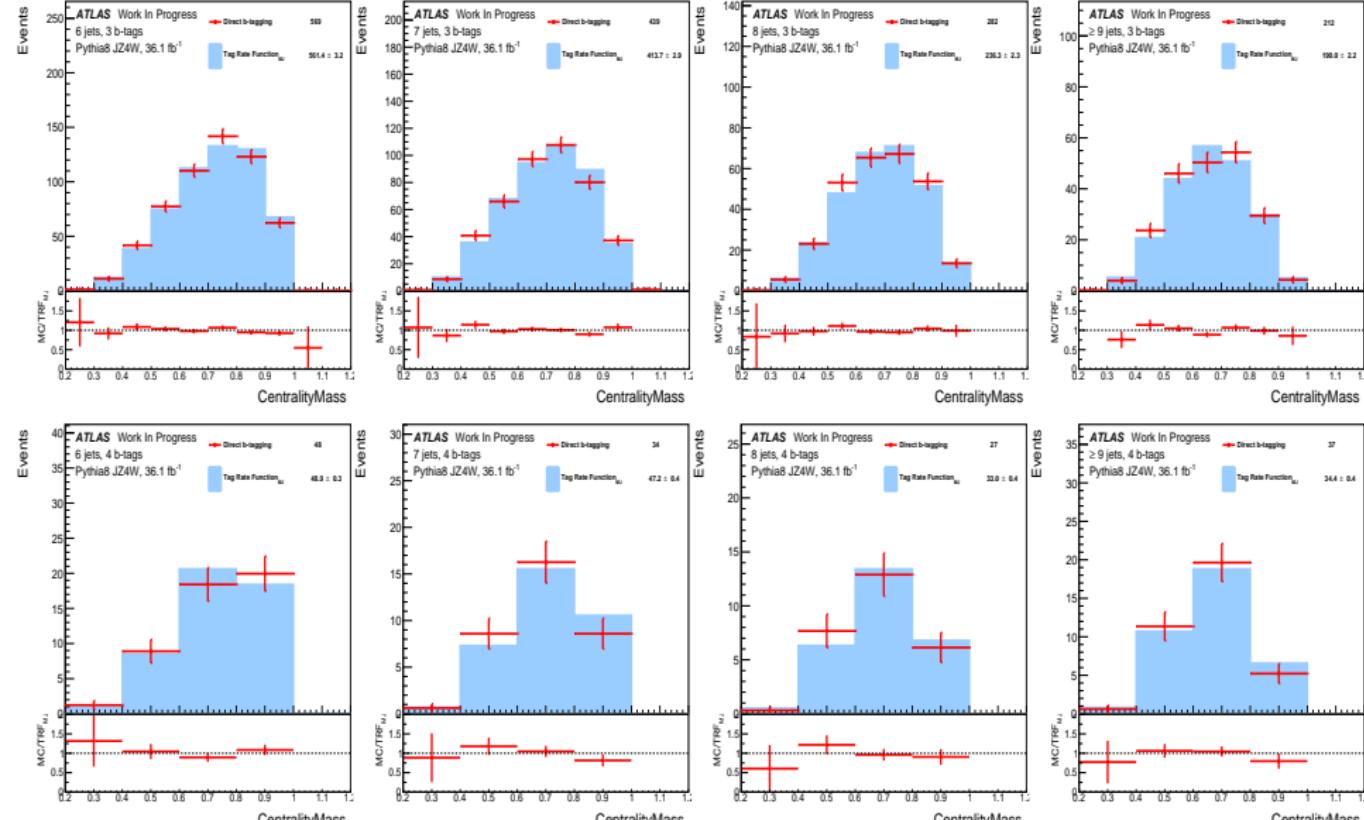
# QCD BACKGROUND ESTIMATION TRF<sub>MJ</sub>



- $\epsilon_{MJ}$  is parametrized as function of
  - $p_T/H_T$
  - $\Delta R_{min}(j, hmv1)$ : minimum  $\Delta R$  between jet and highest Mv2c10 jets
- $\epsilon_{MJ}$  is then applied to all jet multiplicities
- TRF<sub>MJ</sub> method will be validated in dijet Pythia8 MC events

# TRF<sub>MJ</sub> VALIDATION IN DIJET PYTHIA8

(JZ4W corresponds to leading jet's  $p_T$  in the range of [400,800] GeV)



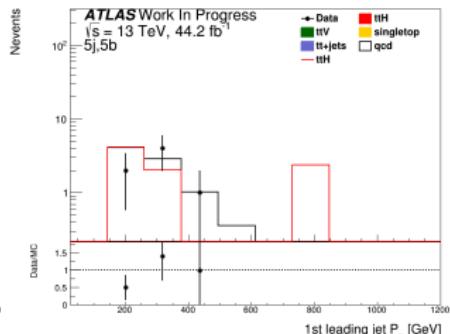
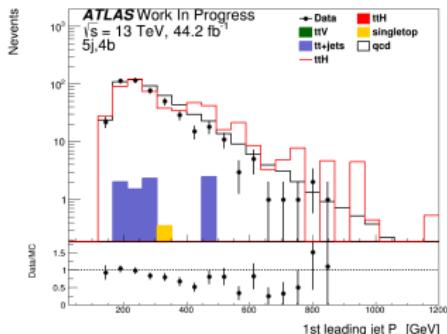
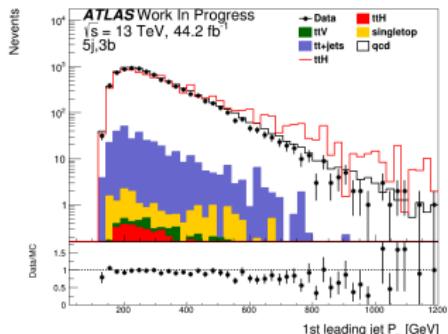
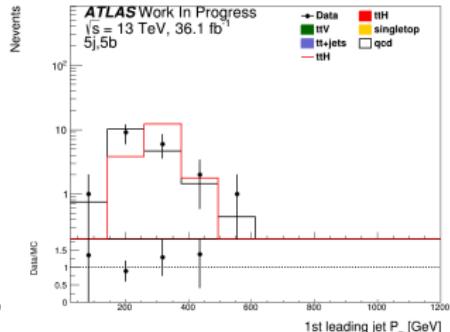
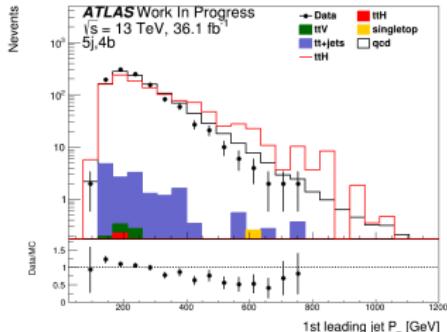
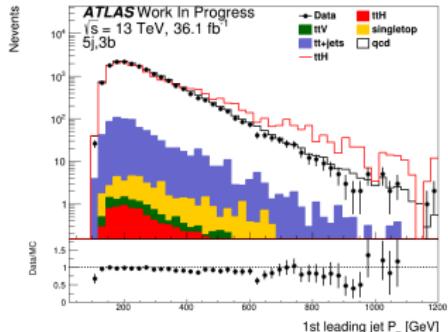
# CLOSURE TEST IN EVENTS WITH EXACTLY 5 JETS

	5j,2b	5j,3b	5j,4b	5j,5b
ttH	$33.2 \pm 0.3$	$11.9 \pm 0.2$	$1.57 \pm 0.06$	$0.018 \pm 0.007$
ttb	$1055 \pm 26$	$283 \pm 12$	$14 \pm 3$	—
ttc	$2559 \pm 42$	$147 \pm 11$	$1.8 \pm 1.0$	—
ttl	$20218 \pm 118$	$627 \pm 22$	$7 \pm 3$	—
ttV	$65 \pm 1$	$6.8 \pm 0.5$	$0.7 \pm 0.1$	$0.00 \pm 0.02$
singletop	$1213 \pm 19$	$44 \pm 4$	$0.5 \pm 0.3$	—
QCD	$432384 \pm 665$	$26317 \pm 45$	$1643 \pm 3$	$26.14 \pm 0.08$
Total Background	$457527 \pm 677$	$27435 \pm 53$	$1668 \pm 5$	$26.2 \pm 0.1$
data	458908	26064	1580	26

ATLAS Work in Progress

- TRF<sub>MJ</sub> works well in predicting the yields of QCD background in 5 jets events
  - Largest deviation is 5.6% in (5j,4b)
- Only statistical uncertainties shown

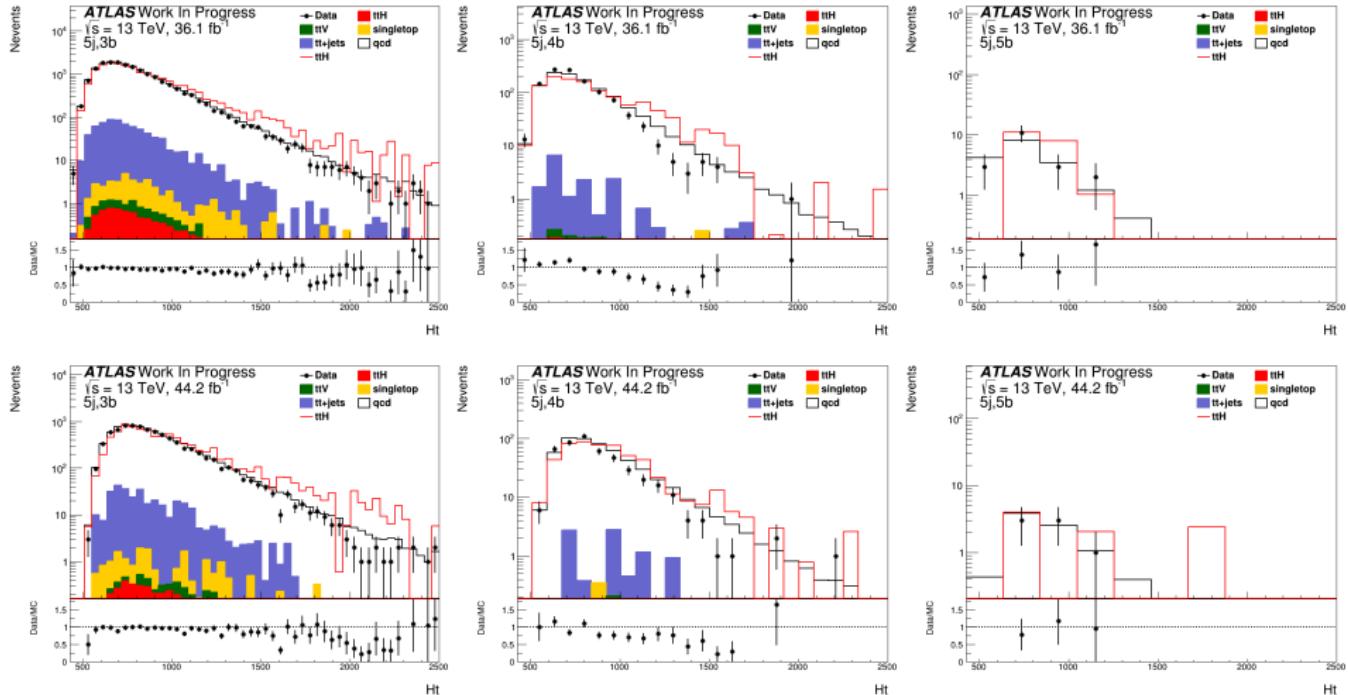
# $1^{st}$ LEADING JET $p_T$



Red solid histogram:  $t\bar{t}H$  normalized to lumi, stacked.

Red empty histogram:  $t\bar{t}H$  normalized to total background.

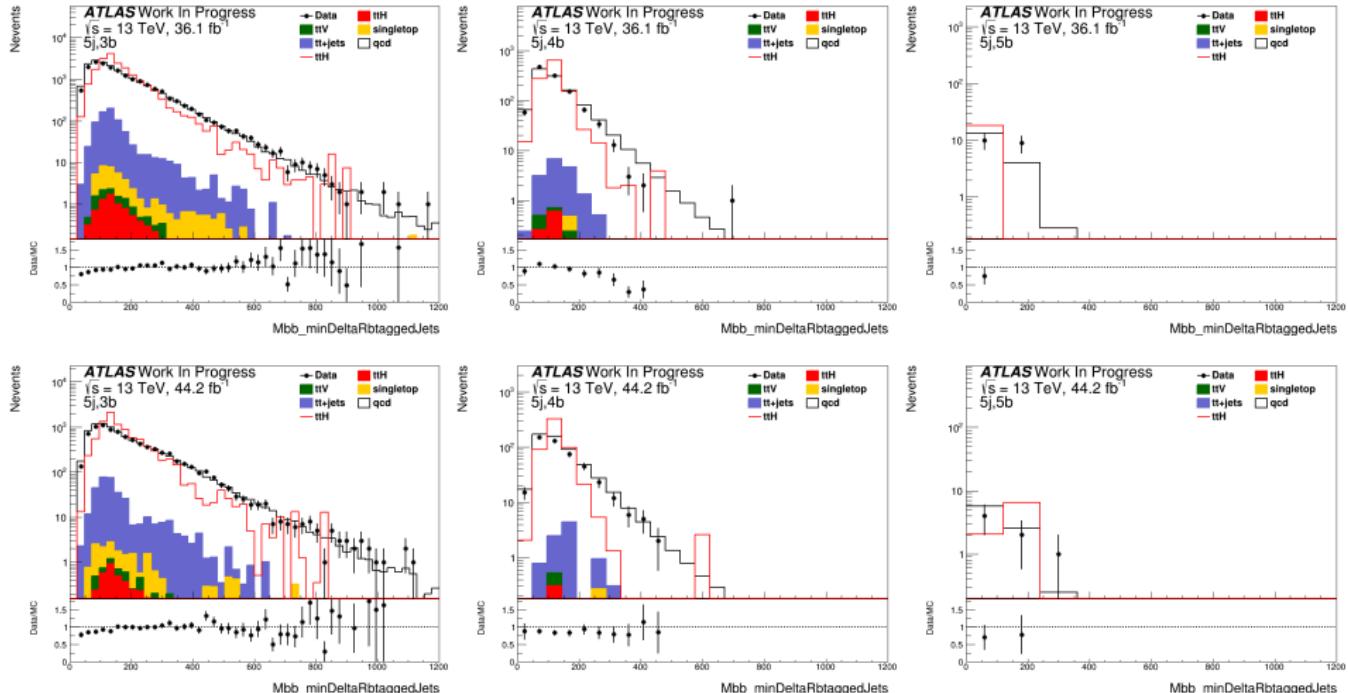
# $H_T$ : SCALAR SUM OF JET'S $p_T$



Red solid histogram:  $t\bar{t}H$  normalized to lumi, stacked.

Red empty histogram:  $t\bar{t}H$  normalized to total background.

# $M_{bb}^{min\Delta R}$ : INVARIANT MASS OF TWO B-JETS WITH MINIMUM $\Delta R$

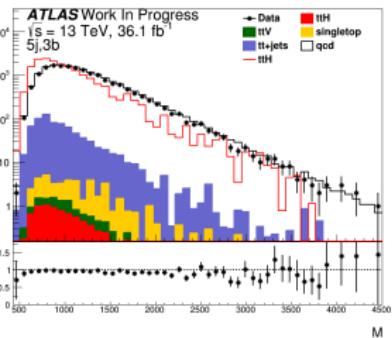


Red solid histogram:  $t\bar{t}H$  normalized to lumi, stacked.

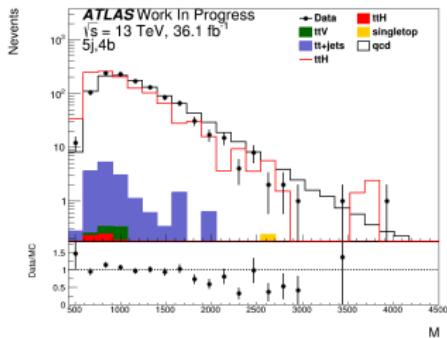
Red empty histogram:  $t\bar{t}H$  normalized to total background.

# M: INVARIANT MASS OF JETS

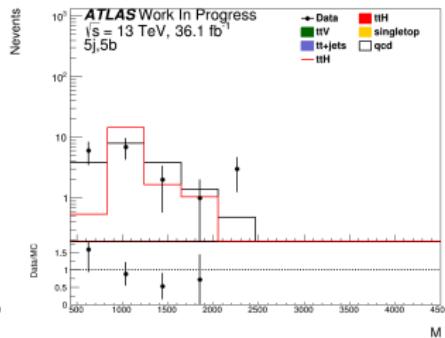
Nevents



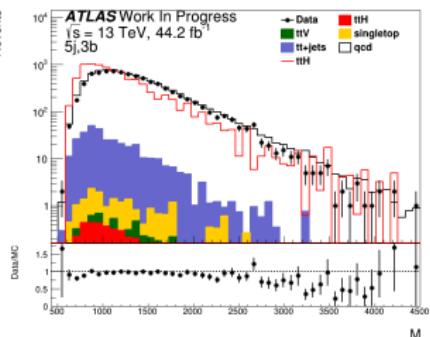
Nevents



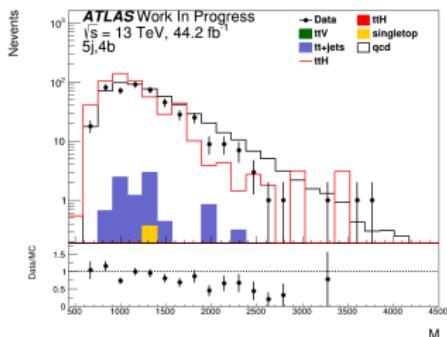
Nevents



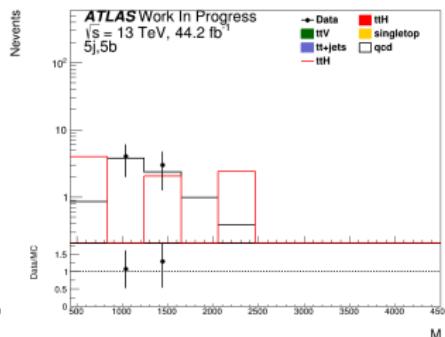
Nevents



Nevents



Nevents



Red solid histogram:  $t\bar{t}H$  normalized to lumi, stacked.

Red empty histogram:  $t\bar{t}H$  normalized to total background.

In general, good agreement between data and prediction in closure test

# PREDICTION IN HIGH JET MULTIPLICITIES

	8j,2b	8j,3b	8j,4b	8j, $\geq 5$ b
ttH	$157.5 \pm 0.6$	$80.4 \pm 0.4$	$20.4 \pm 0.2$	$1.10 \pm 0.05$
ttb	$3609 \pm 51$	$1583 \pm 33$	$209 \pm 12$	$12 \pm 3$
ttc	$6509 \pm 68$	$525 \pm 20$	$16 \pm 4$	$0.3 \pm 0.3$
ttl	$22100 \pm 126$	$861 \pm 26$	$20 \pm 5$	—
ttV	$287 \pm 3$	$51 \pm 1$	$8.4 \pm 0.6$	$0.5 \pm 0.2$
singletop	$1164 \pm 19$	$110 \pm 6$	$8 \pm 1$	—
QCD	$149965 \pm 429$	$14688 \pm 46$	$1867 \pm 6$	$98.0 \pm 0.4$
Total Background	$183792 \pm 455$	$17899 \pm 66$	$2149 \pm 15$	$112.3 \pm 2.8$
$S/\sqrt{B}$	0.37	0.60	0.44	0.10

ATLAS Work in Progress

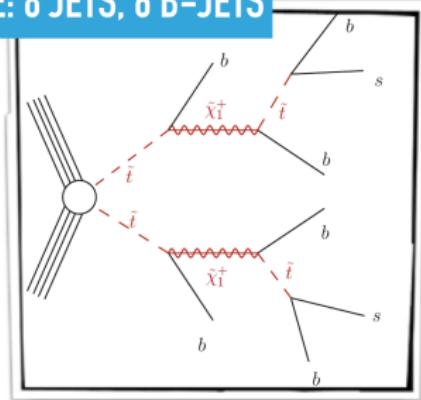
	$\geq 9j,2b$	$\geq 9j,3b$	$\geq 9j,4b$	$\geq 9j,\geq 5b$
ttH	$232.4 \pm 0.7$	$127.9 \pm 0.5$	$37.3 \pm 0.3$	$3.49 \pm 0.09$
ttb	$4801 \pm 59$	$2460 \pm 42$	$432 \pm 17$	$27 \pm 4$
ttc	$7926 \pm 77$	$739 \pm 24$	$26 \pm 4$	$1 \pm 1$
ttl	$18765 \pm 117$	$795 \pm 26$	$9 \pm 3$	—
ttV	$381 \pm 4$	$78 \pm 2$	$15 \pm 1$	$1.0 \pm 0.3$
singletop	$833 \pm 16$	$103 \pm 6$	$10 \pm 2$	$1.0 \pm 0.5$
QCD	$110976 \pm 383$	$12514 \pm 46$	$1923 \pm 8$	$131.9 \pm 0.6$
Total Background	$143914 \pm 412$	$16817 \pm 72$	$2452 \pm 20$	$165.2 \pm 4.5$
$S/\sqrt{B}$	0.61	0.99	0.75	0.27

ATLAS Work in Progress

- Need to perform a Multivariate technique to discriminate signal from background

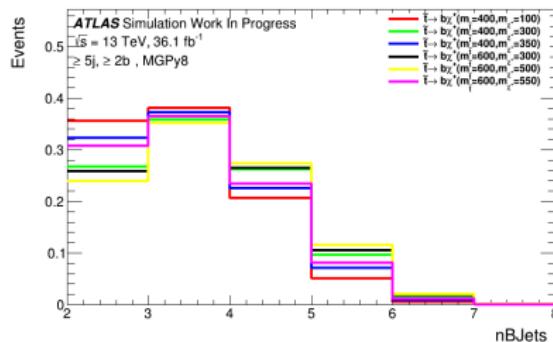
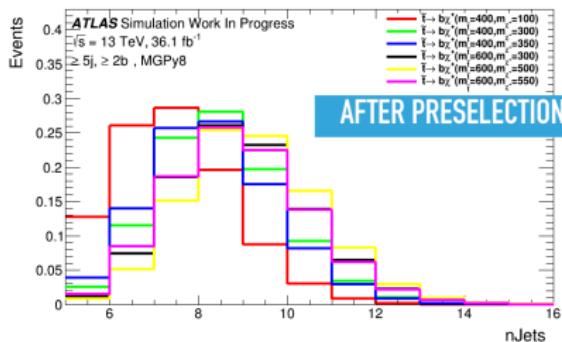
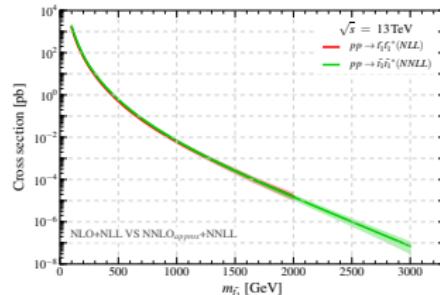
# STOP PAIR PRODUCTION - ANOTHER APPROACH TO MULTI-JETS FINAL STATE

@ME: 8 JETS, 6 B-JETS



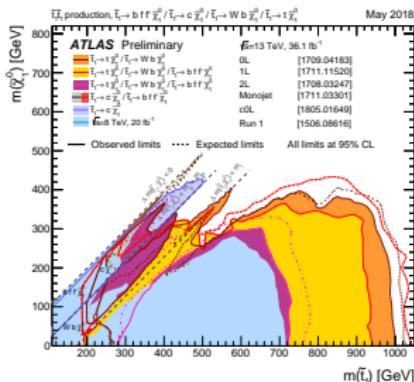
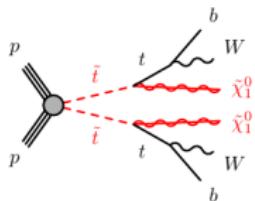
- Stop ( $\tilde{t}$ ) - scalar partner of top quark in Supersymmetry Model

- Lightest squark
- stop pair production has large cross-section



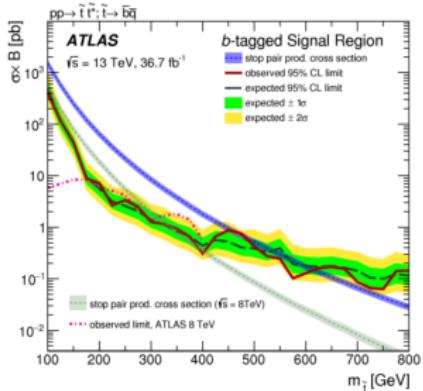
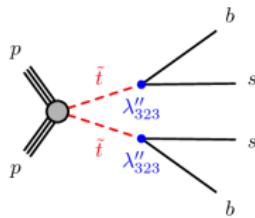
# CURRENT RESULTS ON STOP PAIR PRODUCTION

- R-parity:  $R = (-1)^{3(B-L)+2S}$ 
    - R-parity conservation (RpC)
    - R-parity violation (RpV)

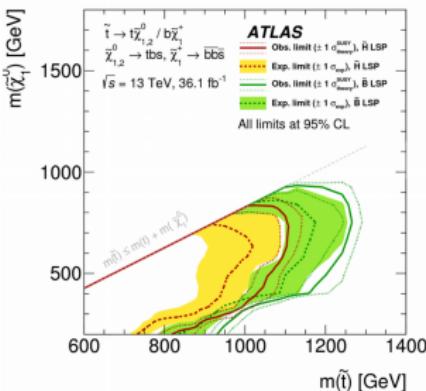
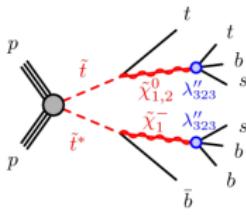


RpC [ATLAS\_SUSY\_Stop\_tLSP]

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RpV [arxiv:1710.07171]

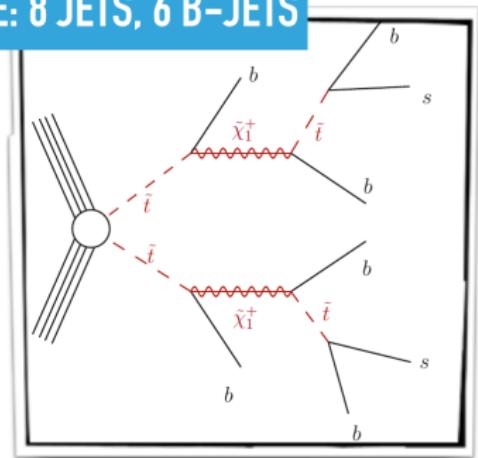


RpV [arxiv:1704.08493]

## ANALYSIS STRATEGY

- Signal: pair of  $\tilde{t} \rightarrow b\chi^+ (\chi^+ \rightarrow bbs)$
- Generated 6 mass points ( $m_{\tilde{t}}, m_{\chi^0, \chi^\pm}$ )  
 $= (600, 550), (600, 500), (600, 300),$   
 $(400, 350), (400, 300), (400, 100)$  GeV
- Put in place a simplified analysis, cut and count in different jet and b-jet multiplicity
  - Will provide model independent limits using most sensitive region

@ME: 8 JETS, 6 B-JETS



# PREDICTION IN HIGH JET MULTIPLICITY 8 JETS

	8j,2b	8j,3b	8j,4b	8j, $\geq 5b$
ttH	$157.5 \pm 0.6$	$80.4 \pm 0.4$	$20.4 \pm 0.2$	$1.10 \pm 0.05$
ttb	$3609 \pm 51$	$1583 \pm 33$	$209 \pm 12$	$12 \pm 3$
ttc	$6509 \pm 68$	$525 \pm 20$	$16 \pm 4$	$0.3 \pm 0.3$
ttl	$22100 \pm 126$	$861 \pm 26$	$20 \pm 5$	—
ttV	$287 \pm 3$	$51 \pm 1$	$8.4 \pm 0.6$	$0.5 \pm 0.2$
singletop	$1164 \pm 19$	$110 \pm 6$	$8 \pm 1$	—
QCD	$149965 \pm 429$	$14688 \pm 46$	$1867 \pm 6$	$98.0 \pm 0.4$
<b>Total Background</b>	<b><math>183792 \pm 455</math></b>	<b><math>17899 \pm 66</math></b>	<b><math>2149 \pm 15</math></b>	<b><math>112.3 \pm 2.8</math></b>
$\tilde{t} \rightarrow b\chi^+(400,100)$	$1461 \pm 26$	$1755 \pm 28$	$1081 \pm 21$	$362 \pm 12$
$\tilde{t} \rightarrow b\chi^+(400,300)$	$2054 \pm 33$	$2915 \pm 38$	$2254 \pm 33$	$967 \pm 21$
$\tilde{t} \rightarrow b\chi^+(400,350)$	$2011 \pm 32$	$2636 \pm 35$	$1626 \pm 27$	$580 \pm 16$
$\tilde{t} \rightarrow b\chi^+(600,300)$	$554 \pm 16$	$749 \pm 18$	$566 \pm 16$	$245 \pm 10$
$\tilde{t} \rightarrow b\chi^+(600,500)$	$485 \pm 15$	$725 \pm 18$	$540 \pm 15$	$249 \pm 10$
$\tilde{t} \rightarrow b\chi^+(600,550)$	$606 \pm 17$	$714 \pm 17$	$438 \pm 13$	$158 \pm 8$
$S/\sqrt{B}(400,100)$	3.4	13.1	23.3	34.1
$S/\sqrt{B}(400,300)$	4.8	21.8	48.6	91.3
$S/\sqrt{B}(400,350)$	4.7	19.7	35.1	54.7
$S/\sqrt{B}(600,300)$	1.3	5.6	12.2	23.1
$S/\sqrt{B}(600,500)$	1.1	5.4	11.6	23.5
$S/\sqrt{B}(600,550)$	1.4	5.3	9.4	14.9

ATLAS Work in Progress

# PREDICTION IN HIGH JET MULTIPLICITY $\geq 9$ JETS

	$\geq 9j, 2b$	$\geq 9j, 3b$	$\geq 9j, 4b$	$\geq 9j, \geq 5b$
ttH	$232.4 \pm 0.7$	$127.9 \pm 0.5$	$37.3 \pm 0.3$	$3.49 \pm 0.09$
ttb	$4801 \pm 59$	$2460 \pm 42$	$432 \pm 17$	$27 \pm 4$
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<b>Total Background</b>	<b><math>143914 \pm 412</math></b>	<b><math>16817 \pm 72</math></b>	<b><math>2452 \pm 20</math></b>	<b><math>165.2 \pm 4.5</math></b>
$\tilde{t} \rightarrow b\chi^+(400,100)$	$895 \pm 20$	$1170 \pm 23$	$766 \pm 17$	$290 \pm 11$
$\tilde{t} \rightarrow b\chi^+(400,300)$	$2055 \pm 33$	$3378 \pm 42$	$2908 \pm 37$	$1636 \pm 28$
$\tilde{t} \rightarrow b\chi^+(400,350)$	$1953 \pm 31$	$2682 \pm 35$	$2118 \pm 31$	$993 \pm 20$
$\tilde{t} \rightarrow b\chi^+(600,300)$	$791 \pm 19$	$1309 \pm 24$	$1091 \pm 21$	$604 \pm 15$
$\tilde{t} \rightarrow b\chi^+(600,500)$	$838 \pm 19$	$1373 \pm 24$	$1284 \pm 24$	$720 \pm 17$
$\tilde{t} \rightarrow b\chi^+(600,550)$	$881 \pm 21$	$1177 \pm 23$	$919 \pm 20$	$441 \pm 13$
$S/\sqrt{B}(400,100)$	2.4	9.0	15.5	22.6
$S/\sqrt{B}(400,300)$	5.4	26.1	58.7	127.3
$S/\sqrt{B}(400,350)$	5.1	20.7	42.8	77.2
$S/\sqrt{B}(600,300)$	2.1	10.1	22.0	47.0
$S/\sqrt{B}(600,500)$	2.2	10.6	25.9	56.0
$S/\sqrt{B}(600,550)$	2.3	9.1	18.5	34.3

ATLAS Work in Progress

## EXPECTED LIMIT ON CROSS-SECTION OF RPV SIGNALS

- Used only 2015+2016 luminosity for the Fit
- Fitting number of events in 6j, 7j, 8j and  $\geq 9j$  with 3b, 4b and  $\geq 5b$
- Set of systematics:
  - Instrumental: Luminosity, pileup modelling, JVT, JES, flavour tagging
  - Cross section of all MC background
  - ttbar and ttc are treated as normalization factor
  - TRF<sub>MJ</sub> enclosure systematics
    - Uncorrelated across jet and b-jet multiplicity

Mass points	XSection (pb)	expected limit on XS (pb)
$\tilde{t} \rightarrow b\chi^+(400,100)$	1.835	0.159
$\tilde{t} \rightarrow b\chi^+(400,300)$	1.835	0.075
$\tilde{t} \rightarrow b\chi^+(400,350)$	1.835	0.141
$\tilde{t} \rightarrow b\chi^+(600,300)$	0.175	0.024
$\tilde{t} \rightarrow b\chi^+(600,500)$	0.175	0.022
$\tilde{t} \rightarrow b\chi^+(600,550)$	0.175	0.028

ATLAS Work in Progress

- ⇒ Possible to exclude current mass points

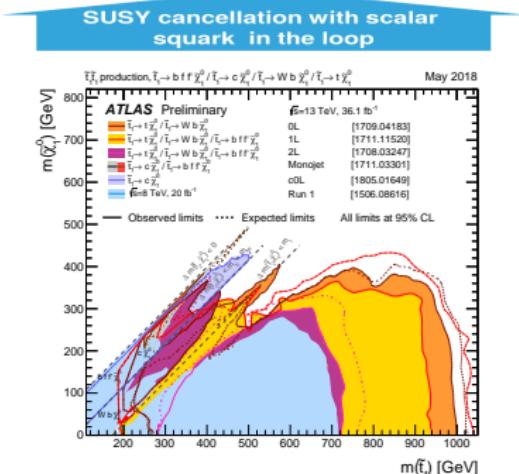
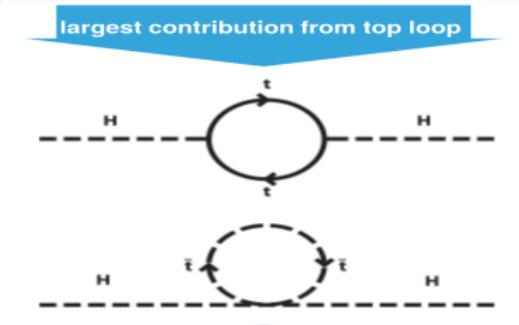
## Conclusions and outlook

- $t\bar{t}H(H \rightarrow b\bar{b})$  full hadronic analysis: Analyzed  $80.3 \text{ fb}^{-1}$  of 2015+2016+2017 data
  - Multijet background is estimated by TRF<sub>MJ</sub> method
  - Validation of the TRF<sub>MJ</sub> using Pythia 8 dijet events and data
- Looking at large jet and b-jet multiplicity allow to look for new physics in a regime never looked at
  - Model dependent search on  $\tilde{t} \rightarrow b\chi^+(\chi^+ \rightarrow bbs)$
  - Performed ASIMOV Fit on 2015+2016 data, which resulted on expected exclusion of the whole mass grid
  - Will put model independent limits using different scenario

BACK UP

# NATURAL SUPERSYMMETRY

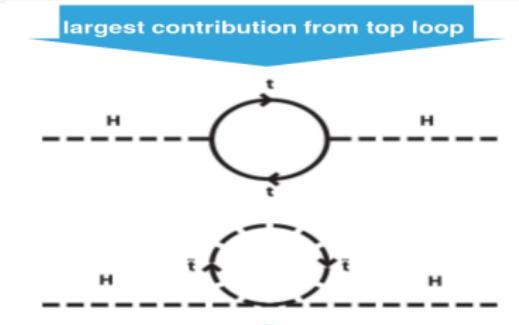
- Standard Model has some limits
  - Dark matter, dark energy, hierarchy issue,...
- Supersymmetry is a natural extension of SM
- Scalar partner of top quark (stop) could compensate SM contribution to Higgs mass
  - To avoid unnatural cancellation stop mass must be  $O(\text{TeV})$
- R-parity:  $R = (-1)^{3(B-L)+2S}$
- If R-parity is conserved
  - Neutral stable Lightest MSSM particle escaping detection
  - large amount of missing energy → striking signatures → strong constraint on stop quark



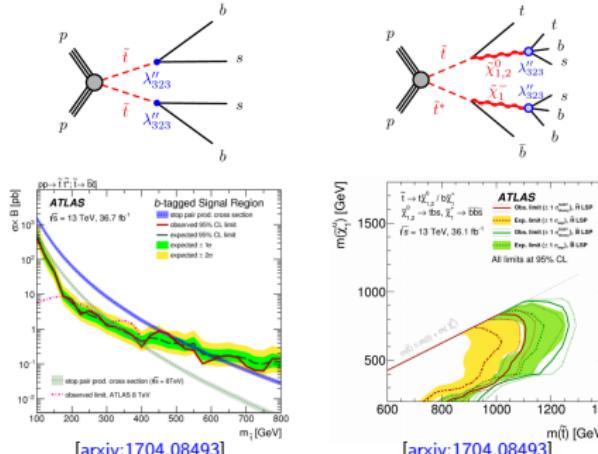
[ATLAS\_SUSY\_Stop\_tLSP]

NATURAL SUPERSYMMETRY

- Standard Model has some limits
    - Dark matter, dark energy, hierarchy issue,...
  - Supersymmetry is a natural extension of SM
  - Scalar partner of top quark (stop) could compensate SM contribution to Higgs mass
    - To avoid unnatural cancellation stop mass must be  $O(\text{TeV})$
  - R-parity:  $R = (-1)^{3(B-L)+2S}$
  - If R-parity is **not** conserved
    - Lightest MSSM Particle not necessary neutral and/or stable  $\rightarrow$  original signatures + no MET
    - RpV couplings: the minimal flavor violation hypothesis favors a large  $\lambda_{323}''$  coupling



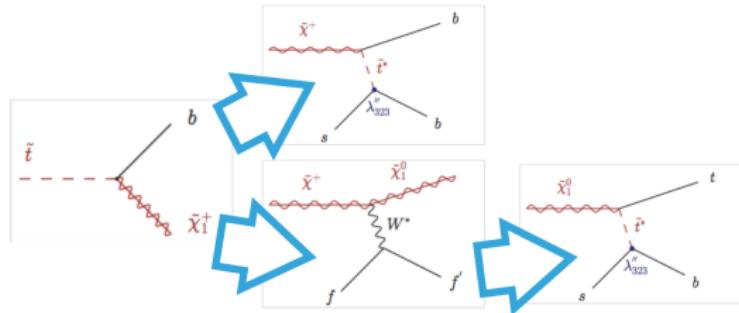
## SUSY cancellation with scalar squark in the loop



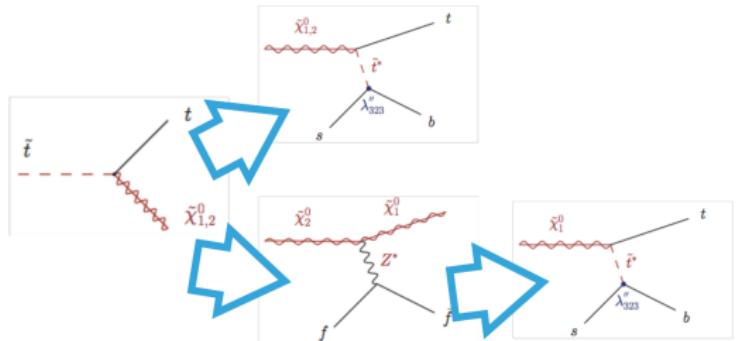
# STOP RPV PHENOMENOLOGY

- Higgsino is Lightest-Supersymmetric-Particle (LSP)

- $m_t > m_{\tilde{t}} - m_{\chi^0, \chi^\pm}$

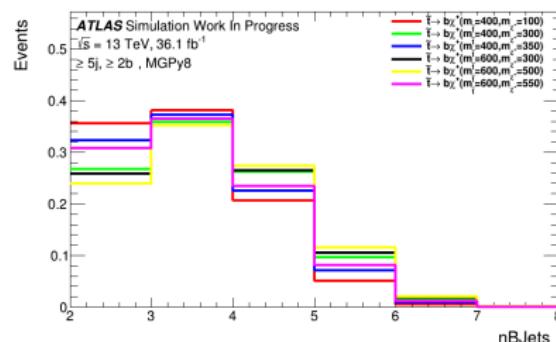
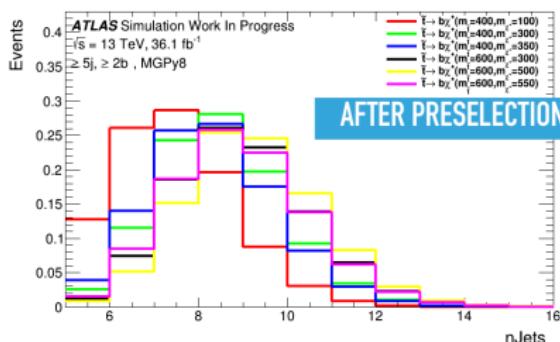
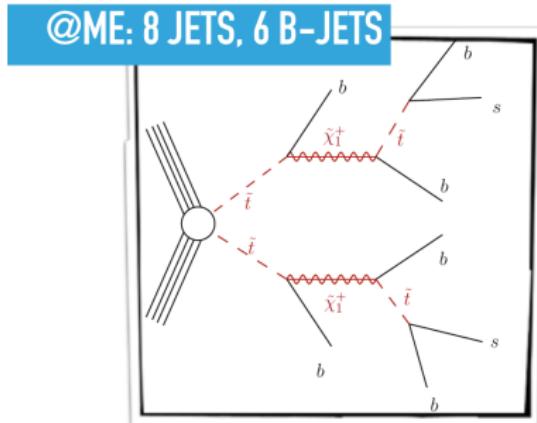


- $m_t < m_{\tilde{t}} - m_{\chi^0, \chi^\pm}$



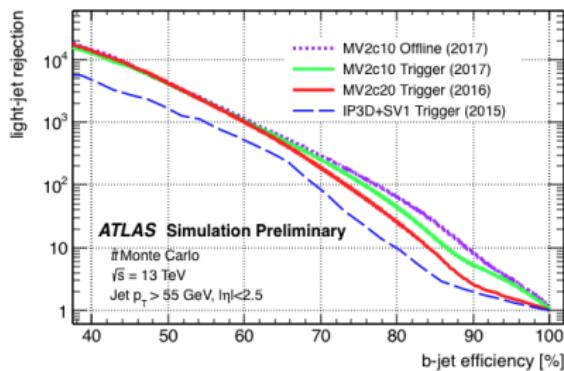
# SEARCH FOR $\tilde{t}$ PAIR PRODUCTION $\tilde{t} \rightarrow b\chi^+(\chi^+ \rightarrow b\bar{b}s)$ AT $\sqrt{S} = 13$ TEV

- Apply the same strategy from  $t\bar{t}H(H \rightarrow b\bar{b})$  fully hadronic analysis
- Signal:  $\tilde{t} \rightarrow b\chi^+(\chi^+ \rightarrow b\bar{b}s)$ 
  - hasn't been looked at before
- Generated 6 mass points ( $m_{\tilde{t}}, m_{\chi^0, \chi^\pm}$ )  
 $= (600, 550), (600, 500), (600, 300),$   
 $(400, 350), (400, 300), (400, 100)$  GeV
- $t\bar{t}H$  is now one of MC backgrounds



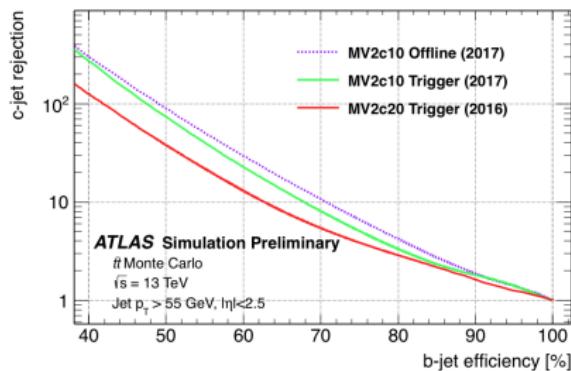
# B-TAGGING PERFORMANCE IN ATLAS

- The ATLAS  $b$ -tagging uses MV2 algorithm to separate  $b$ -jet from light and  $c$ -jet which depends on
  - Impact parameters.
  - Invariant mass of tracks, jet energy fraction associated to Secondary Vertex.
  - Topological structure of weak  $b$ - and  $c$ - hadron decays inside jet.
- Expected performance of the ATLAS  $b$ -tagging algorithm
- For fully hadronic analysis, tight  $b$ -tagging at 60% efficiency is used



Expected performance of  $b$ -tagging algorithms in terms  
of light-jet rejection on  $t\bar{t}$  simulation

[ATL-COM-DAQ-2017-062]

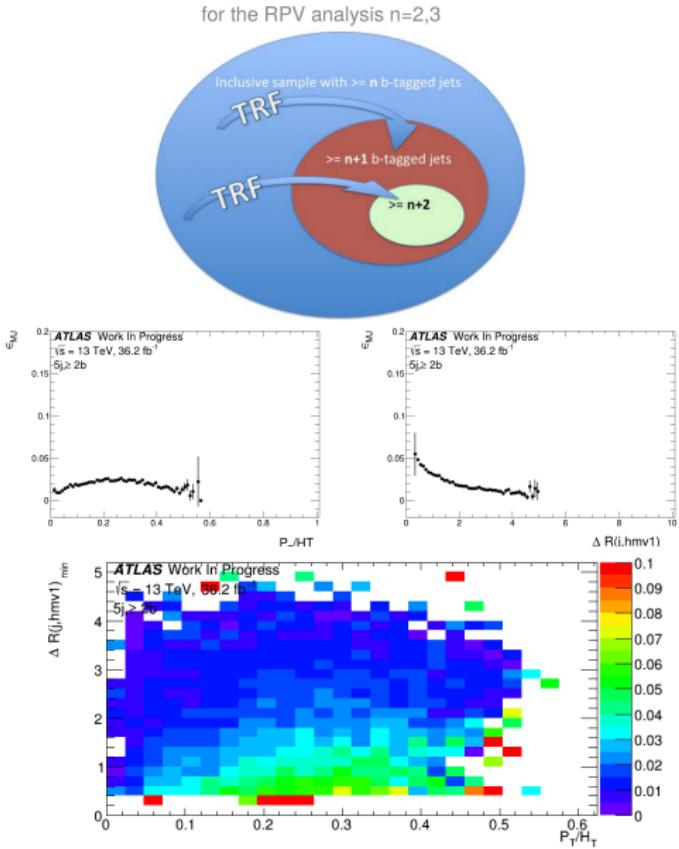


Expected performance of  $b$ -tagging algorithms in terms  
of  $c$ -jet rejection on  $t\bar{t}$  simulation

[ATL-COM-DAQ-2017-062]

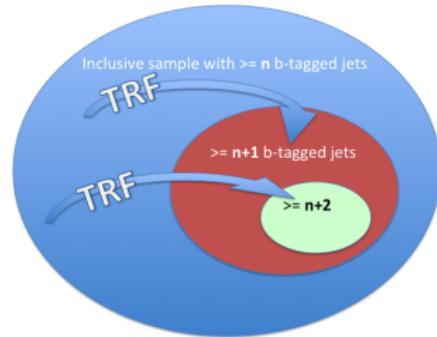
# QCD BACKGROUND ESTIMATION: TRF<sub>MJ</sub>

- TRF<sub>MJ</sub> method is used to estimate the number of events with ( $\geq$ )m b-tagged jets from a sample with  $\geq n$  ( $n \geq m$ ) b-tagged jets
- TRF<sub>MJ</sub> is based the probability of tagging a QCD jet ( $\epsilon_{MJ}$ )
  - $\epsilon_{MJ}$  derived away from signal region
    - 5 jets events, not used in the analysis
  - parametrized vs kinematical and angular variables
    - $P_T/H_T$
    - $\Delta R_{min}(j, hmv1)$ : minimum  $\Delta R$  between the jet and the jets with highest b-tagging weight:
- $\epsilon_{MJ}$  is then applied to all jet multiplicities



## QCD BACKGROUND ESTIMATION: TRF<sub>MJ</sub>

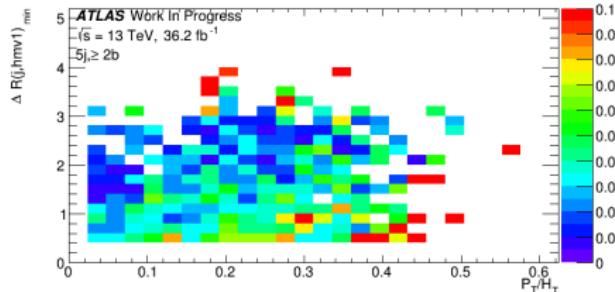
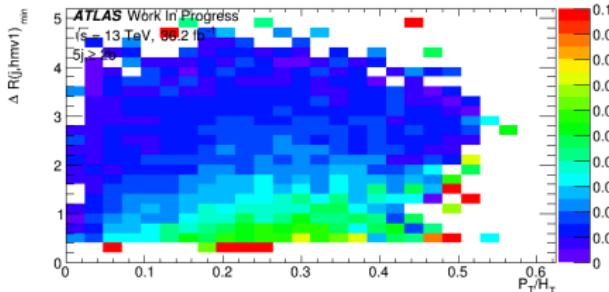
- Tag-rate-function Multi-jet (TRF<sub>MJ</sub>) method is used to estimate the number of events with  $\geq(m+n)$  b-tagged jets from a sample with  $\geq n$  b-tagged jets
- TRF<sub>MJ</sub> is based the probability of tagging a QCD jet ( $\epsilon_{MJ}$ )
  - $\epsilon_{MJ}$  derived away from signal region
  - parametrized vs kinematical and angular variables
    - $p_T/H_T$
    - $\Delta R_{\min}(j, hmv1)$ : minimum  $\Delta R$  between the jet and the jets with highest b-tagging weight:
- $\epsilon_{MJ}$  is then applied to all jet multiplicities



Probabilities of having  $n+m$  b-tag jets ( $m=0,1,2$ )

$$\begin{aligned}
 P_{m=0} &= \prod_{i=1}^{N_{jet}-n} (1 - \epsilon_i), \\
 P_{m=1} &= \sum_{j=1}^{N_{jet}-n} \left( \epsilon_j \prod_{i \neq j} (1 - \epsilon_i) \right), \\
 &\dots
 \end{aligned}$$

# TRF<sub>MJ</sub> combination method



- Pros and cons of different TRF<sub>MJ</sub> strategy
  - TRF<sub>MJ</sub>(n=2) → start from a lower  $b$ -tag multiplicity
    - further from the signal region
    - it does not predict well higher  $b$ -tag region.
  - TRF<sub>MJ</sub>(n=3) → start from a high  $b$ -tag multiplicity
    - it predicts well at higher  $b$ -tag multiplicity
    - it is close to the signal region.
- ⇒ TRF are then combined in two steps
  - TRF<sub>MJ</sub>(n=2) is used to predict 2b and  $\geq 3b$ , then promote an untagged jet to a  $b$ -jet for  $\geq 3b$
  - Use TRF<sub>MJ</sub>(n=3) to predict 3b, 4b and  $\geq 5b$

# b-jet promotion method

- The aim of b-jet promotion method is to promote an untagged jet into a b-jet.
  - Estimate variables that depend directly to b-jet. For example:  $H_T^b = \Sigma_{\text{b-jet}} P_T$

Probability of a b-tagging configuration (1 is btag, 0 is not btag) in 6j region as example

configuration	$j_1$	$j_2$	$j_3$	$j_4$
$\alpha_1$	1	1	0	0
$\alpha_2$	1	0	1	0
$\alpha_3$	1	0	0	1
$\alpha_4$	0	1	1	0
$\alpha_5$	0	1	0	1
$\alpha_6$	0	0	1	1

with  $\left\{ \begin{array}{l} \alpha_1 = \epsilon_1 \epsilon_2 (1 - \epsilon_3)(1 - \epsilon_4) \\ \alpha_2 = \epsilon_1 \epsilon_3 (1 - \epsilon_2)(1 - \epsilon_4) \\ \alpha_3 = \epsilon_1 \epsilon_4 (1 - \epsilon_2)(1 - \epsilon_3) \\ \alpha_4 = \epsilon_2 \epsilon_3 (1 - \epsilon_1)(1 - \epsilon_4) \\ \alpha_5 = \epsilon_2 \epsilon_4 (1 - \epsilon_1)(1 - \epsilon_3) \\ \alpha_6 = \epsilon_3 \epsilon_4 (1 - \epsilon_1)(1 - \epsilon_2) \end{array} \right.$

- Emulate the b-tag algorithm by taking a random number  $r=[0, A]$  with  $A = \sum_{i=1}^6 \alpha_i$

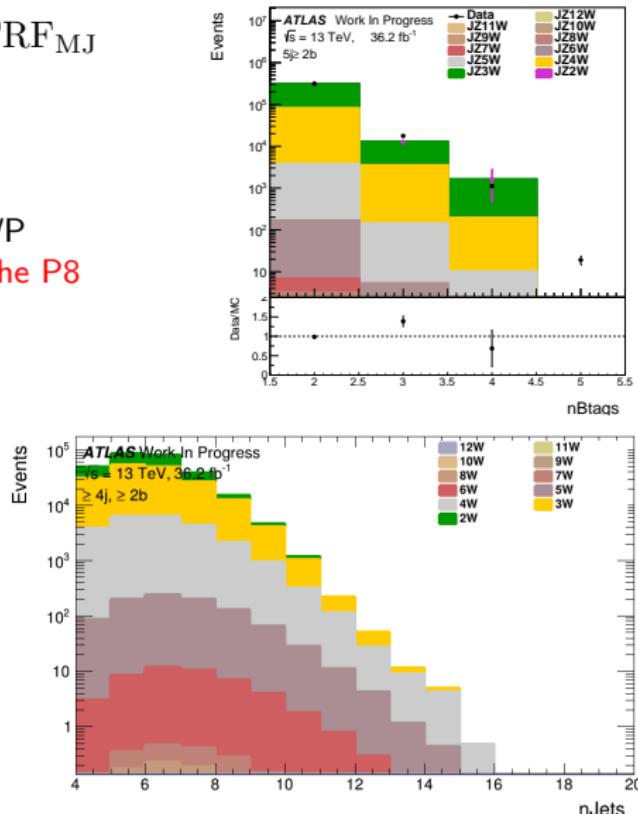
if  $\left\{ \begin{array}{ll} 0 \leq r \leq \alpha_1 & \text{choose } \alpha_1 \\ \alpha_1 < r \leq \alpha_1 + \alpha_2 & \text{choose } \alpha_2 \\ \alpha_1 + \alpha_2 < r \leq \alpha_1 + \alpha_2 + \alpha_3 & \text{choose } \alpha_3 \\ \alpha_1 + \alpha_2 + \alpha_3 < r \leq \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 & \text{choose } \alpha_4 \\ \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 < r \leq \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 & \text{choose } \alpha_5 \\ \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 < r \leq A & \text{choose } \alpha_6 \end{array} \right.$

- Jets in the chosen configuration are promoted to b-jet.

# PYTHIA8 DIJET JZxW MC

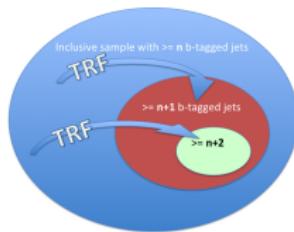
- Dijet P8 events are used to validate TRF<sub>MJ</sub>
- Pre-selection used for P8 validation:
  - No lepton with  $p_T > 10$  GeV
  - $\geq 4$  jets with  $p_T > 25$  GeV,
  - $\geq 2$  b-tagged jets at mv2c10 60% WP
  - No trigger requirement applied for the P8 validation**

P8 dijets	$p_T$ range [GeV]	Cross section (pb)
JZ1W	20-60	52600215.0
JZ2W	60-160	811423.536
JZ3W	160-400	8453.64024
JZ4W	400-800	134.9920945
JZ5W	800-1300	4.19814486
JZ6W	1300-1800	0.241941709
JZ7W	1800-2500	0.006358874
JZ8W	2500-3200	0.006354782
JZ9W	3200-3900	0.000236819
JZ10W	3900-4600	7.054e-06
JZ11W	4600-5300	1.13e-07
JZ12W	5300-7000	4.405975e-10



## TRF<sub>MJ</sub> VALIDATION IN DIJET PYTHIA8 SAMPLES IN 5 JETS

- Each sample is treated individually, TRF<sub>MJ</sub> is derived and applied in each sample separately
- JZ2/3/4/5/6W samples contribute the most



MC P8 dijets	5j,2b	5j,3b	5j,4b	5j,5b
JZ2W direct tagging	6274	261	14	—
JZ2W TRF <sub>MJ</sub>	$6297 \pm 78$	$238 \pm 3$	$14.6 \pm 0.3$	$0.22 \pm 0.01$
JZ3W direct tagging	34081	1588	93	1
JZ3W TRF <sub>MJ</sub>	$34149 \pm 181$	$1516 \pm 8$	$96.3 \pm 0.9$	$1.54 \pm 0.03$
JZ4W direct tagging	40456	1704	106	2
JZ4W TRF <sub>MJ</sub>	$40331 \pm 196$	$1826 \pm 9$	$109.8 \pm 0.7$	$1.67 \pm 0.02$
JZ5W direct tagging	29260	1035	29	—
JZ5W TRF <sub>MJ</sub>	$29213 \pm 168$	$1079 \pm 7$	$31.0 \pm 0.4$	$0.235 \pm 0.007$
JZ6W direct tagging	24581	606	10	—
JZ6W TRF <sub>MJ</sub>	$24517 \pm 154$	$656 \pm 4$	$24.0 \pm 0.3$	$0.179 \pm 0.009$

ATLAS Work in Progress

- Numbers not normalized to cross-section, direct *b*-tagging compared to TRF<sub>MJ</sub> prediction

## TRF<sub>MJ</sub> validation in dijet Pythia samples in 6j and 7j regions

MC P8 dijets	6j,2b	6j,3b	6j,4b	6j, $\geq$ 5b
JZ2W direct tagging	1695	108	7	—
JZ2W TRF <sub>MJ</sub>	$1722 \pm 40$	$81 \pm 2$	$7.3 \pm 0.3$	$0.22 \pm 0.01$
JZ3W direct tagging	18260	1149	90	6
JZ3W TRF <sub>MJ</sub>	$18393 \pm 132$	$1011 \pm 7$	$98.1 \pm 0.9$	$3.30 \pm 0.05$
JZ4W direct tagging	31806	1855	158	4
JZ4W TRF <sub>MJ</sub>	$31829 \pm 173$	$1829 \pm 10$	$159 \pm 1$	$4.78 \pm 0.04$
JZ5W direct tagging	28209	1385	85	1
JZ5W TRF <sub>MJ</sub>	$28161 \pm 163$	$1456 \pm 9$	$61.8 \pm 0.5$	$0.92 \pm 0.02$
JZ6W direct tagging	26203	1141	57	—
JZ6W TRF <sub>MJ</sub>	$26304 \pm 159$	$1021 \pm 6$	$74.4 \pm 0.7$	$1.51 \pm 0.04$

ATLAS Work in Progress

MC P8 dijets	7j,2b	7j,3b	7j,4b	7j, $\geq$ 5b
JZ2W direct tagging	443	32	1	—
JZ2W TRF <sub>MJ</sub>	$449 \pm 21$	$24 \pm 1$	$3.0 \pm 0.2$	$0.14 \pm 0.01$
JZ3W direct tagging	7665	545	52	2
JZ3W TRF <sub>MJ</sub>	$7701 \pm 85$	$495 \pm 6$	$64.7 \pm 0.8$	$3.39 \pm 0.07$
JZ4W direct tagging	19730	1431	111	3
JZ4W TRF <sub>MJ</sub>	$19766 \pm 136$	$1348 \pm 10$	$154 \pm 1$	$6.81 \pm 0.07$
JZ5W direct tagging	20599	1340	90	6
JZ5W TRF <sub>MJ</sub>	$20606 \pm 139$	$1353 \pm 9$	$73.9 \pm 0.6$	$1.59 \pm 0.02$
JZ6W direct tagging	20142	1211	69	3
JZ6W TRF <sub>MJ</sub>	$20293 \pm 139$	$1008 \pm 7$	$119 \pm 1$	$4.77 \pm 0.08$

ATLAS Work in Progress

- We have an agreement between direct tagging and TRF<sub>MJ</sub> prediction except

## TRF<sub>MJ</sub> validation in dijet Pythia samples in 8j and $\geq 9j$ regions

MC P8 dijets	8j,2b	8j,3b	8j,4b	8j, $\geq 5b$
JZ2W direct tagging	86	3	1	—
JZ2W TRF <sub>MJ</sub>	$84 \pm 9$	$5.0 \pm 0.5$	$0.75 \pm 0.09$	$0.043 \pm 0.008$
JZ3W direct tagging	2779	272	35	2
JZ3W TRF <sub>MJ</sub>	$2842 \pm 51$	$209 \pm 4$	$34.6 \pm 0.7$	$2.43 \pm 0.06$
JZ4W direct tagging	9674	918	88	2
JZ4W TRF <sub>MJ</sub>	$9798 \pm 95$	$770 \pm 8$	$107 \pm 1$	$6.29 \pm 0.08$
JZ5W direct tagging	12513	1081	81	2
JZ5W TRF <sub>MJ</sub>	$12614 \pm 108$	$994 \pm 9$	$67.8 \pm 0.7$	$1.96 \pm 0.03$
JZ6W direct tagging	12583	964	84	3
JZ6W TRF <sub>MJ</sub>	$12740 \pm 109$	$760 \pm 7$	$126 \pm 1$	$8.0 \pm 0.1$

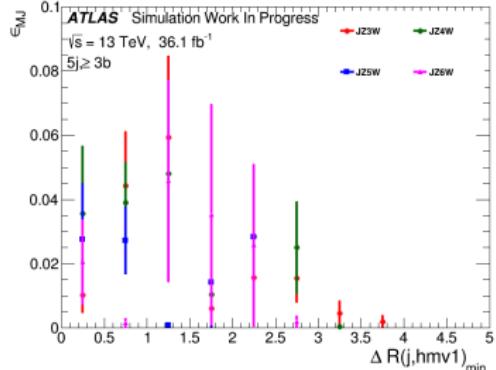
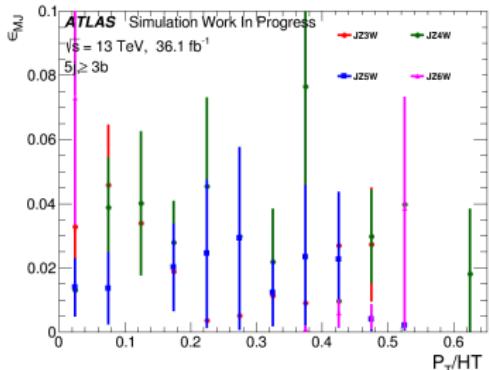
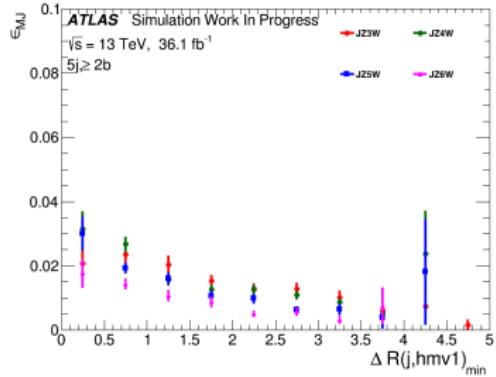
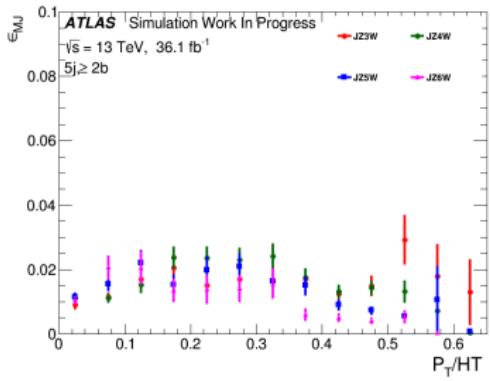
ATLAS Work in Progress

MC P8 dijets	$\geq 9j,2b$	$\geq 9j,3b$	$\geq 9j,4b$	$\geq 9j,\geq 5b$
JZ2W direct tagging	7	1	—	—
JZ2W TRF <sub>MJ</sub>	$7 \pm 3$	$0.6 \pm 0.2$	$0.08 \pm 0.04$	$0.006 \pm 0.003$
JZ3W direct tagging	1179	108	19	—
JZ3W TRF <sub>MJ</sub>	$1182 \pm 33$	$99 \pm 3$	$21.8 \pm 0.7$	$2.21 \pm 0.08$
JZ4W direct tagging	6643	692	120	4
JZ4W TRF <sub>MJ</sub>	$6718 \pm 78$	$619 \pm 7$	$112 \pm 1$	$9.4 \pm 0.1$
JZ5W direct tagging	10472	1062	127	9
JZ5W TRF <sub>MJ</sub>	$10524 \pm 97$	$1049 \pm 10$	$93 \pm 1$	$3.82 \pm 0.06$
JZ6W direct tagging	11836	1128	135	6
JZ6W TRF <sub>MJ</sub>	$11976 \pm 105$	$868 \pm 8$	$232 \pm 2$	$28.9 \pm 0.5$

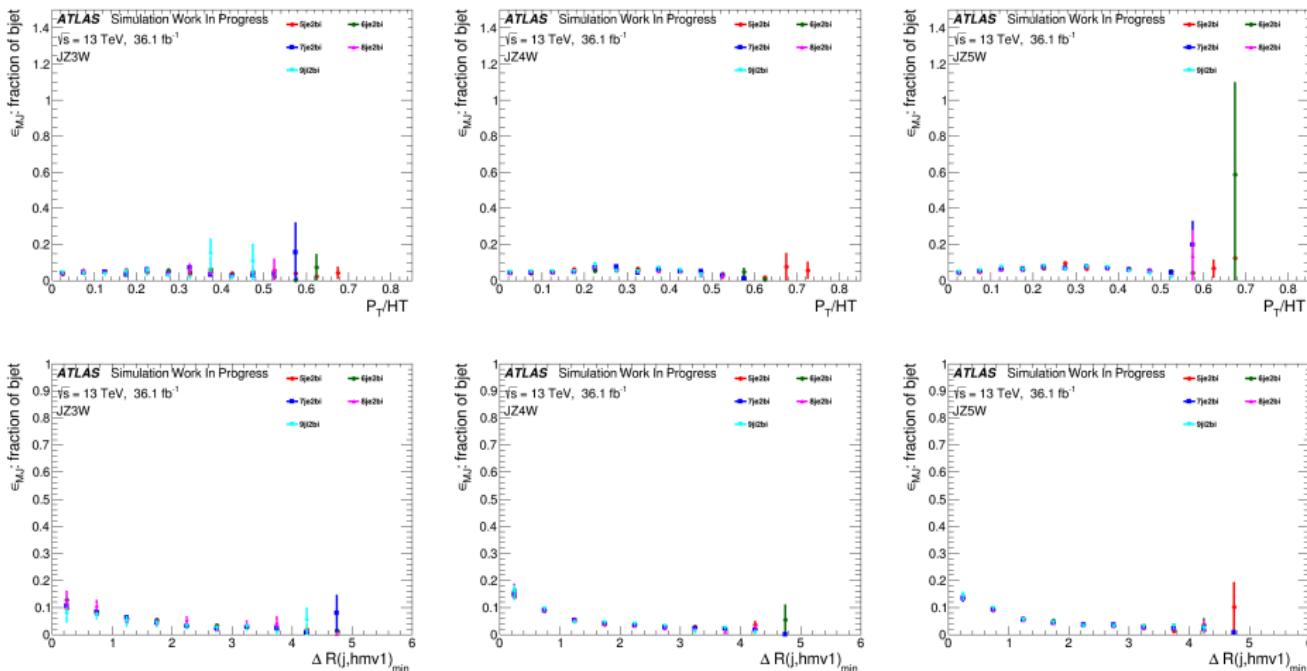
ATLAS Work in Progress

- We have an agreement between direct tagging and TRF<sub>MJ</sub> prediction except

# TRF<sub>MJ</sub> derived for MC Pythia8 dijet

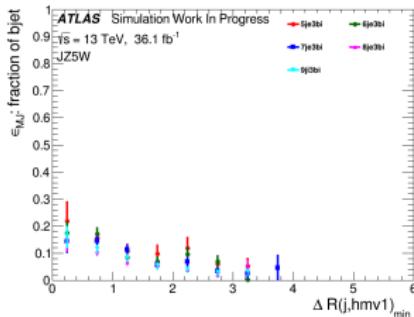
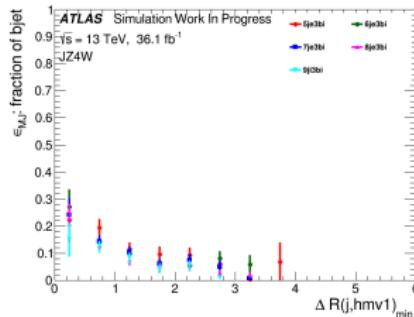
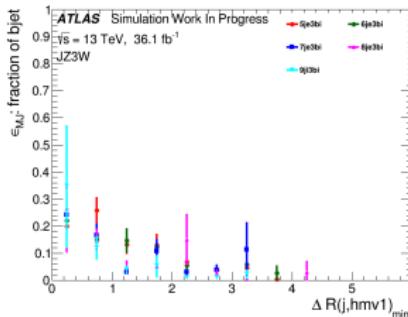
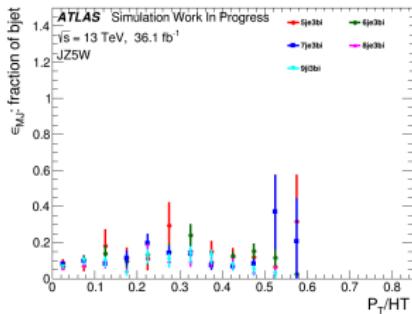
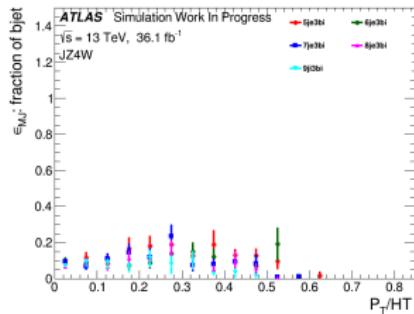
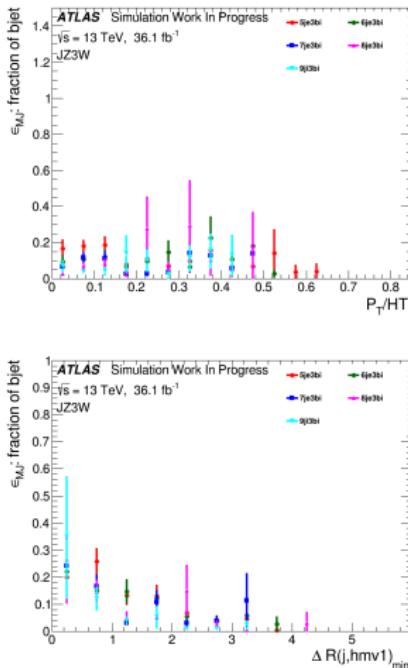


# TRF<sub>MJ</sub>: Flavor vs. Jet Multiplicities



- $\epsilon_{M,J}(2\text{bi})$ : heavy flavor fraction approx constant through jet multiplicities and  $P_T$  range
  - 5–10% of b-jet content across jet multiplicities

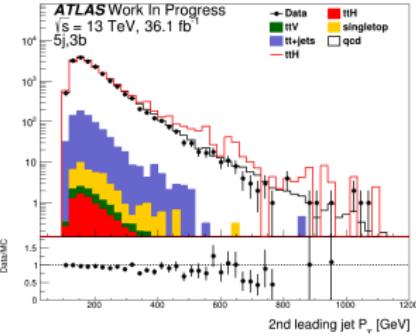
# TRF<sub>MJ</sub>: Flavor vs. Jet Multiplicities



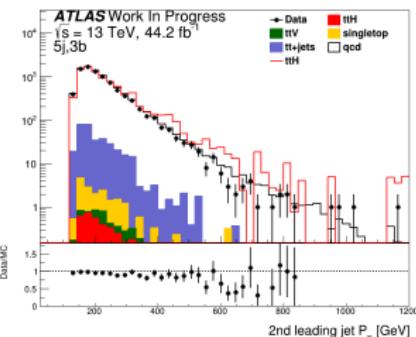
- $\epsilon_{M_J}(3\text{bi})$ : quite fluctuates due to lack of statistics

## 2<sup>nd</sup> leading jet $P_T$

Nevents



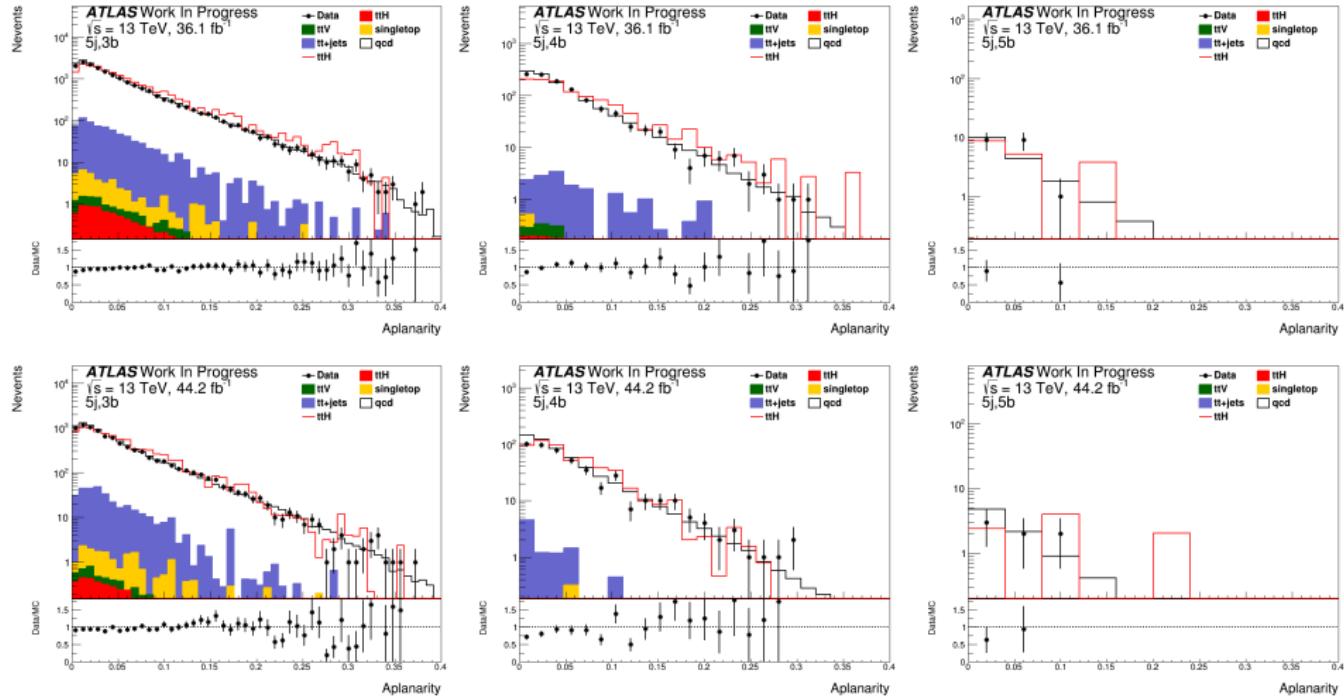
Nevents



Red solid histogram:  $t\bar{t}H$  normalized to lumi, stacked.

Red empty histogram:  $t\bar{t}H$  normalized to total background.

# APLANARITY



Red solid histogram:  $t\bar{t}H$  normalized to lumi, stacked.

Red empty histogram:  $t\bar{t}H$  normalized to total background.

## PREDICTION IN 6 JETS AND 7 JETS EVENTS

	6j,2b	6j,3b	6j,4b	6j, $\geq 5$ b
ttH	$95.0 \pm 0.5$	$40.6 \pm 0.3$	$7.4 \pm 0.1$	$0.25 \pm 0.03$
ttb	$2589 \pm 42$	$883 \pm 24$	$73 \pm 7$	$1.7 \pm 1.0$
ttc	$5771 \pm 64$	$367 \pm 16$	$8 \pm 2$	—
ttl	$33513 \pm 155$	$1217 \pm 31$	$11 \pm 3$	—
ttV	$179 \pm 2$	$24.2 \pm 0.9$	$3.4 \pm 0.3$	$0.16 \pm 0.06$
singletop	$2047 \pm 25$	$111 \pm 6$	$3.1 \pm 0.9$	—
QCD	$413518 \pm 668$	$31069 \pm 56$	$2688 \pm 6$	$79.2 \pm 0.2$
Total Background	$457712 \pm 690$	$33710 \pm 70$	$2793 \pm 10$	$81.4 \pm 1.0$

### ATLAS Work in Progress

	7j,2b	7j,3b	7j,4b	7j, $\geq 5$ b
ttH	$151.5 \pm 0.6$	$72.8 \pm 0.4$	$16.5 \pm 0.2$	$0.64 \pm 0.04$
ttb	$3734 \pm 51$	$1439 \pm 30$	$160 \pm 10$	$5 \pm 2$
ttc	$7355 \pm 72$	$550 \pm 21$	$16 \pm 3$	—
ttl	$32317 \pm 152$	$1214 \pm 31$	$12 \pm 4$	—
ttV	$289 \pm 3$	$44 \pm 1$	$7.3 \pm 0.5$	$0.4 \pm 0.1$
singletop	$1831 \pm 24$	$133 \pm 6$	$8 \pm 1$	—
QCD	$278430 \pm 565$	$24330 \pm 54$	$2624 \pm 7$	$108.9 \pm 0.3$
Total Background	$324108 \pm 592$	$27783 \pm 73$	$2844 \pm 13$	$114.6 \pm 1.8$

### ATLAS Work in Progress

- $80.3 \text{ fb}^{-1}$  of luminosity
- Numbers are still preliminary

## FIT SETUPS

- Fit 12 regions
  - 6, 7, 8 and  $\geq 9$  jets
  - 3, 4,  $\geq 5$  b-tagged jets
  - Variable: CentralityMass ( $H_T/M$ )
- Used only 2015+2016 luminosity for the Fit
- Fit tool: TRexFitter 4.2
  - **BONLY** Asimov Fit
- Set of systematics:
  - Instrumental: Luminosity, pileup modelling, JVT, JES, flavour tagging
  - Cross section of all MC background
  - ttbar and t-channel are treated as normalization factor
  - TRF<sub>MJ</sub> enclosure systematics
    - Uncorrelated across jet and b-jet multiplicity
- Not yet included systematics: Radiation, FSR, PS+had, gen, etc

## Conclusions and outlook

- $t\bar{t}H(H \rightarrow b\bar{b})$  full hadronic analysis framework is in place
  - Analyzed  $80.3 \text{ fb}^{-1}$  of 2015+2016+2017 luminosity
  - Multijet background is estimated by TRF<sub>MJ</sub> method
    - Good agreement compared to data in 5 jets events
  - Validation of the TRF<sub>MJ</sub> using Pythia 8 dijet events
- RpV analysis framework is also in place
  - Benefit from  $t\bar{t}H$  full hadronic analysis framework
  - Performed ASIMOV Fit on 2015+2016 luminosity, which results in putting limits on the cross-section
- Add more statistics to TRF<sub>MJ</sub> validation study using dijet
  - Dedicated  $b\bar{b}$  samples have been requested
- RpV samples at different period (2017, 2018) are being processed, requesting new signal samples at higher mass points (800 GeV, 1.2 TeV)
- Possibility to unblind the analysis and process full Run 2 data