Search for $t\bar{t}H/A \to t\bar{t}t\bar{t}$ production in the multilepton final state in proton-proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

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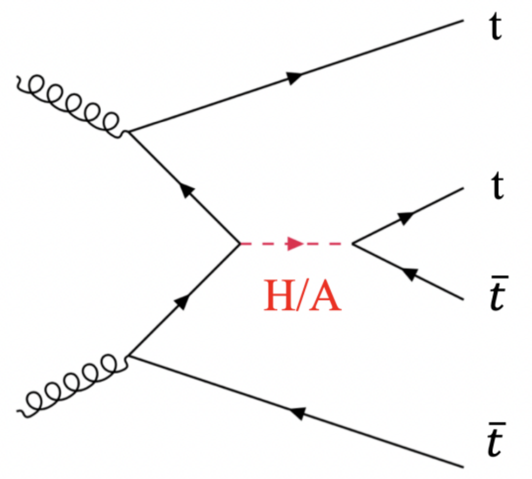
Introduction

$t\bar{t}t\bar{t}$ is a very rare process in the Standard Model (SM) and heavy final state with a minimum mass of almost 700 GeV

- Sensitive to Top Yukawa coupling, Higgs CP properties and models beyond SM (BSM)
- Observed $\mu_{t\bar{t}t\bar{t}} = 2.0^{+0.8}_{-0.6}$ wrt to SM prediction $\sigma_{t\bar{t}t\bar{t}} = 12$ fb at NLO QCD+EW in ATLAS full Run2 paper (Eur. Phys. J. C 80 (2020) 1085)

In this analysis, we targets 2HDM type-I/II $t\bar{t}H/A \to t\bar{t}t\bar{t}$ signal and interpretation on low $\tan\beta$ region (where $A/H \to t\bar{t}$ dominates) in the alignment limit $\sin(\beta-\alpha) \to 1$ for which the lighter Higgs boson is SM like

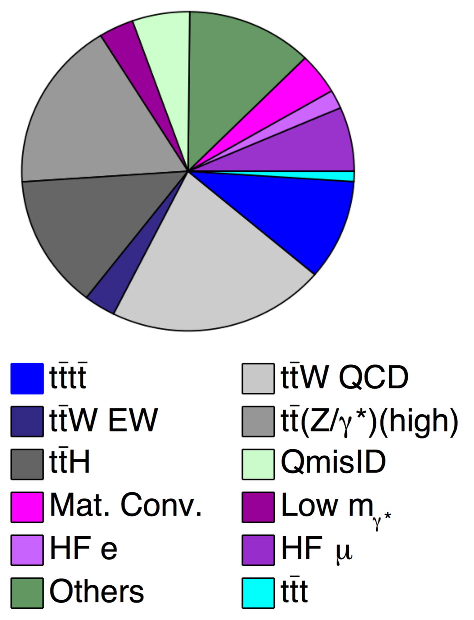


Overview of the analysis:

- Analysis using full Run2 dataset (139 fb^{-1})
- Search for heavy Higgs boson in a mass range of 400 GeV to 1 TeV
- Same-sign dilepton and multilepton (SSML) final states is explored

Analysis strategy based on the SM $t\bar{t}t\bar{t}$ analysis:

- Dedicated control regions (CR) to constrain the dominant backgrounds with template fit
- $t\bar{t}t\bar{t}$-enriched region is defined with Baseline signal region (SR): SSML with ≥ 6 jets, ≥ 2 b-jets and $H_T = \sum p_T^{\ell} + \sum p_T^{j} \geq$ 500 GeV
- Two Boosted Decision Tree (BDT) models using XGBoost for signal versus background discrimination in the Baseline SR
- SM $t\bar{t}t\bar{t}$ fixed to SM prediction in the statistical interpretation

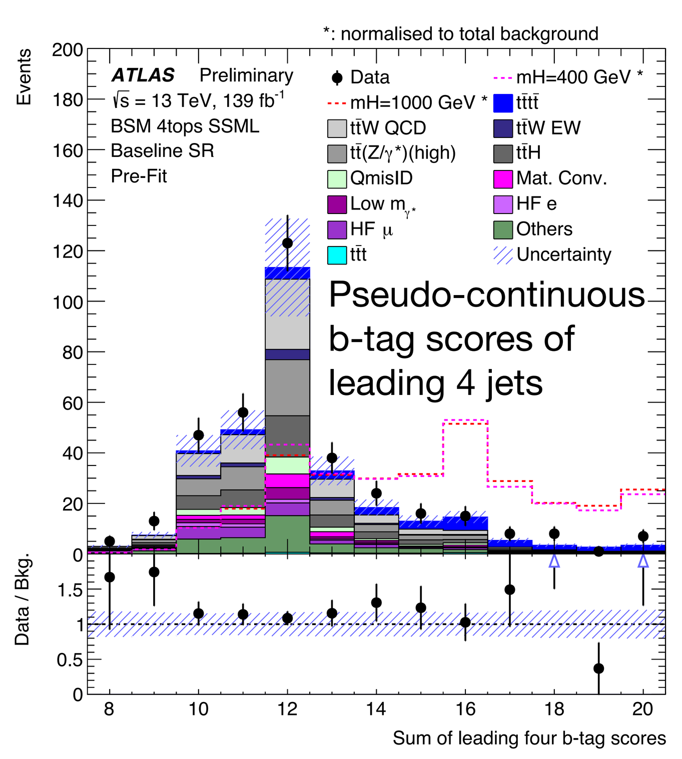


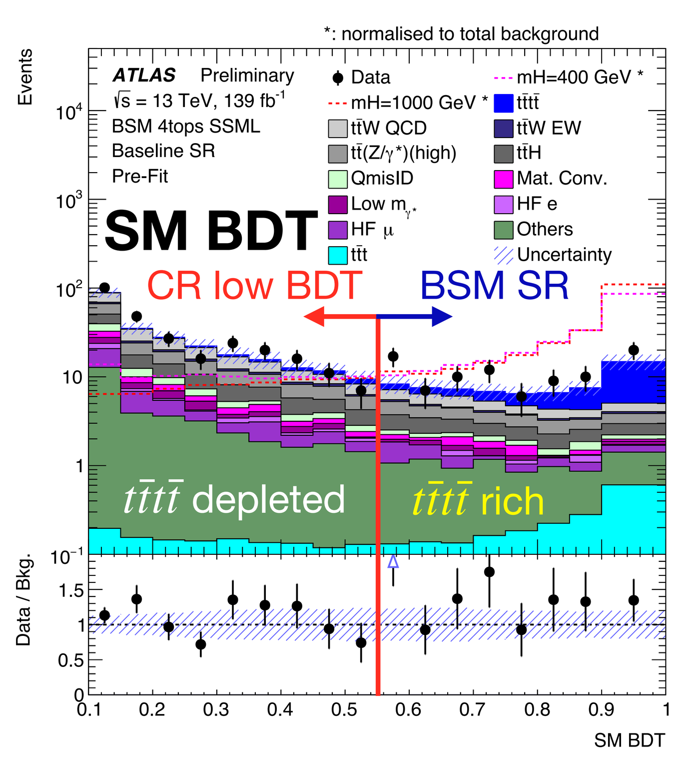
Background contribution in Baseline SR:

- **Physics processes: (~75%)**
  - SM $t\bar{t}t\bar{t}$, $t\bar{t}W$ QCD/EW, $t\bar{t}\gamma^*$, $t\bar{t}Z$, $t\bar{t}H$ and minor processes
- **Instrumental and fake backgrounds: (~25%)**
  - Charge mis-identification
  - Non-prompt leptons from heavy-flavor decays and photon conversion
  - Minor fake backgrounds

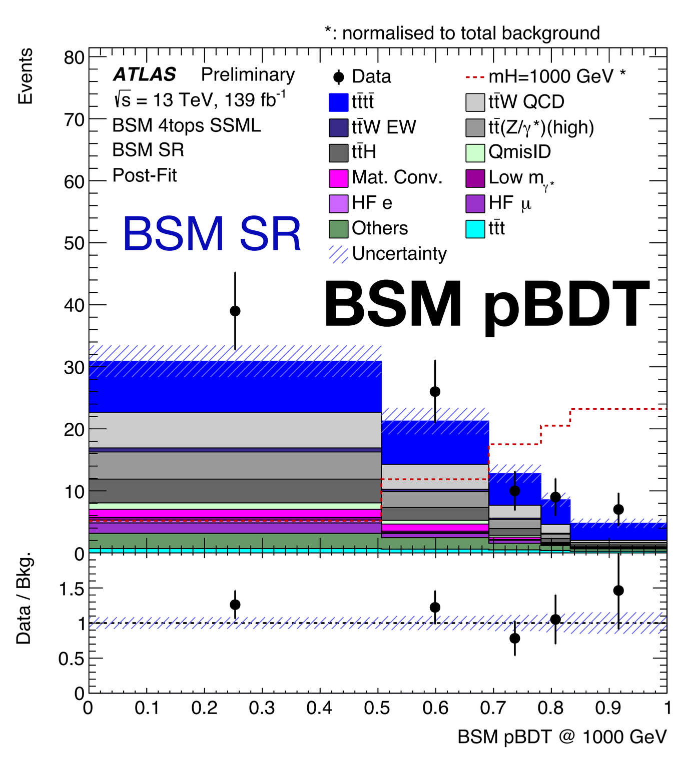
Signal Discrimination

SM BDT used to extract $t\bar{t}t\bar{t}$-like events and to define BSM signal region





BSM mass-parameterized BDT (BSM pBDT): discriminate BSM $t\bar{t}t\bar{t}$ from the SM backgrounds (important input: H_T and SM BDT)



BSM pBDT trained in the baseline SR but reweighing on the background fractions to mimic BSM SR yields in the training

Baseline SR split into two fitted regions with two BDTs sequentially

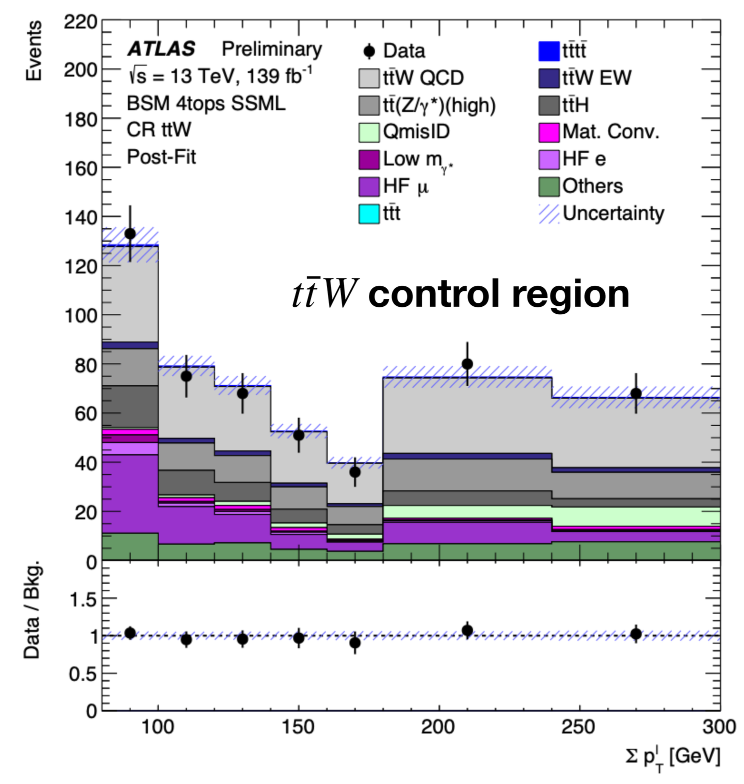
- **BSM SR**: Additional BSM pBDT as discrimination
- **CR low BDT**: Use SM BDT to control the background modeling

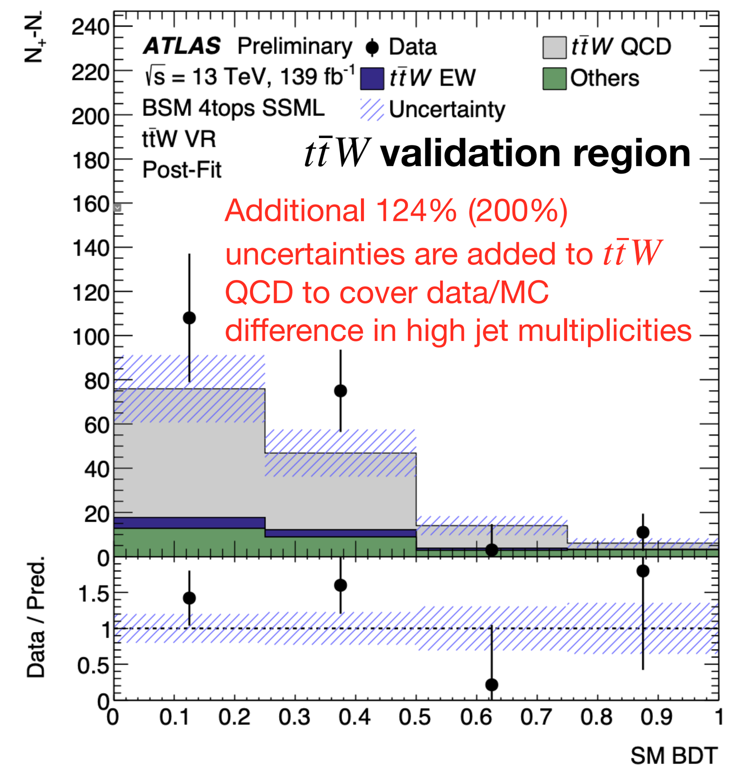
Background Estimation

Template fit method to estimate fake backgrounds and $t\bar{t}W$ QCD with normalization factors from the fit to real data in 5 dedicated control regions using shape from MC

- $t\bar{t}W$ **validation region** to check $t\bar{t}W$ modeling: $N_+ - N_-$ to remove charge symmetric processes with ≥ 4 jet and ≥ 2 b-jet

Region	Channel	N_j	N_b	Other selection cuts	Fitted variable
CR Conv	$e^\pm e^\pm$ || $e^\pm\mu^\pm$	$4 \leq N_j < 6$	≥ 1	$m_{ee}^{CV} \in [0, 0.1]$ GeV, $200 < H_T < 500$ GeV	m_{ee}^{PV}
CR HF e	eee || $ee\mu$		= 1	$100 < H_T < 250$ GeV	Yield
CR HF μ	$e\mu\mu$ || $\mu\mu\mu$		= 1	$100 < H_T < 250$ GeV	Yield
CR $t\bar{t}W$	$e^\pm\mu^\pm$ || $\mu^\pm\mu^\pm$	≥ 4	≥ 2	$m_{ee}^{CV} \notin [0, 0.1]$ GeV, $\lvert\eta(e)\rvert < 1.5$ for $N_b = 2$, $H_T < 500$ GeV or $N_j < 6$; for $N_b \geq 3$, $H_T < 500$ GeV	$\sum p_T^{\ell}$
CR lowBDT	SS+3L	≥ 6	≥ 2	$H_T > 500$ GeV, SM BDT < 0.55	SM BDT
BSM SR	SS+3L	≥ 6	≥ 2	$H_T > 500$ GeV, SM BDT ≥ 0.55	BSM pBDT





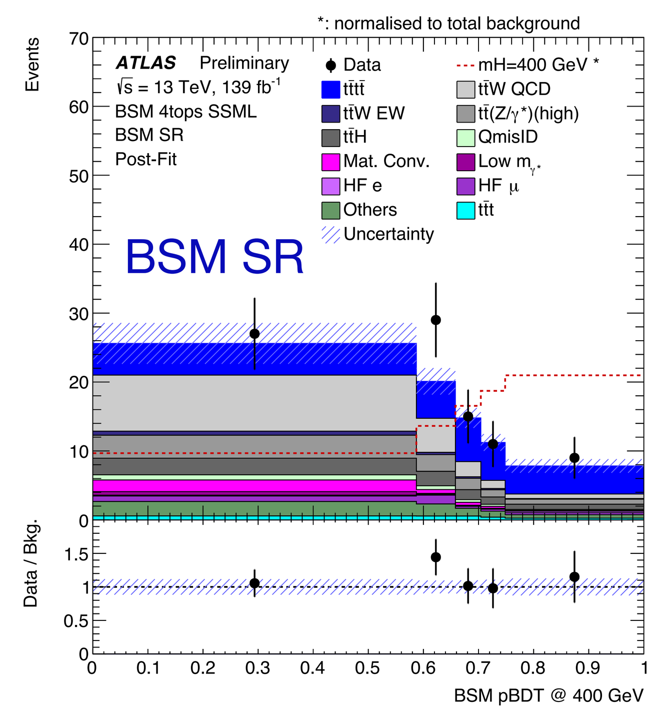
Normalization factors from background-only (B-Only) fit

Parameter	$\lambda_{t\bar{t}W\,QCD}$	$\lambda_{\text{Mat. Conv.}}$	$\lambda_{\text{Low}\,m_{\gamma^*}}$	$\lambda_{\text{HF}\,e}$	$\lambda_{\text{HF}\,\mu}$
Value	1.3 ± 0.3	1.5 ± 0.5	0.6 ± 0.5	0.9 ± 0.4	1.0 ± 0.2

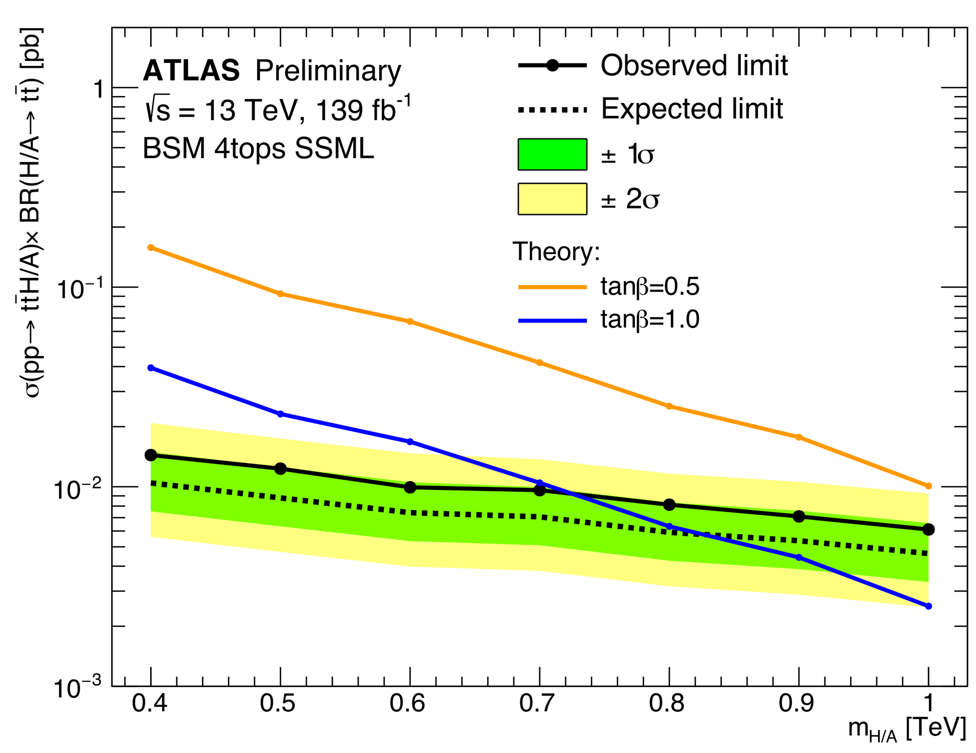
Results and Interpretation

Pre-fit and post-fit yields in BSM SR with B-Only fit

Process	Pre-fit	Post-fit
Total background	65.6 ± 13.2	79.5 ± 6.8
$t\bar{t}H(\to t\bar{t})$, $m_H = 400$ GeV	38.6 ± 2.4	–
$t\bar{t}H(\to t\bar{t})$, $m_H = 1000$ GeV	4.4 ± 0.2	–
Data	91	



No excess of events above the SM expectation is observed



Four times stronger expected upper limits at 95% CL on cross-section times branching ratio than previous ATLAS 36 fb^{-1} search (JHEP12(2018)039) with improved multivariate technique and larger dataset

$\tan\beta$ exclusion limits assuming that only one particle (both particles) exists