Measurement of the $t\bar{t}H$ production cross-section with $H \rightarrow b\bar{b}$ in the boosted topology with the ATLAS detector

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ATLAS EXPERIMENT

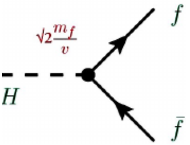
Cluster of Excellence PRISMA+

Precision Physics, Fundamental Interactions and Structure of Matter

GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

Higgs production and decay modes



- ***Top Yukawa coupling***:
  - largest Higgs coupling to fermions
  - sensitive to effects of physics Beyond SM

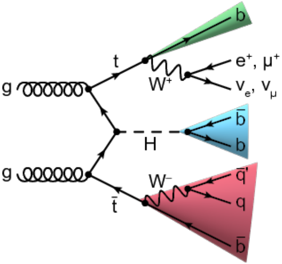
- For its **direct measurement**, most favourable:
  - Higgs production mode: $t\bar{t}H$
    - only contributes $\sim$ 1% of total Higgs production cross-section
    - but top quarks in Final State (FS) $\xrightarrow{access}$ many Higgs decay modes with high background
  - Higgs decay mode: $H \rightarrow b\bar{b}$
    - largest BR $\sim$ 58%
    - Higgs kinematics reconstruction possible

$t\bar{t}H(H \to b\bar{b})$ *channel*

- Challenge in measuring signal strength of this process due to:
  - highly complex FS
  - large SM backgrounds (especially $t\bar{t}$ + heavy-flavour jets)

  $\Rightarrow$ assignment of jets in FS (containing b-hadrons) to their original particles $\xrightarrow{becomes}$ combinatorial problem

- Mitigate this challenge:
  - **lepton+jets** (*semi-leptonic*) $t\bar{t}$ decay:
    exploit lepton for background
    + combinatorics reduction
    + high statistics
  - **Boosted topology**:
    Higgs and/or hadronically decaying top $\rightarrow$ boosted: high $p_T \sim$ rest mass $\Rightarrow$ decay products collimated in large-R jets ($R = 1.0$)

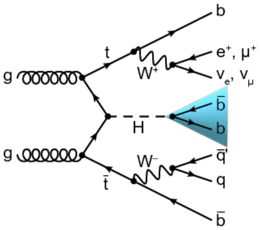


Event Selection & Reconstruction arXiv:2111.06712

# leptons	$== 1$ ($p_T > 27$ GeV)
# small-R[1] jets	≥ 4 ($p_T > 25$ GeV)
# b-tagged jets @85% w.p.	≥ 4

- First, searching for ***Higgs candidate*** requiring 1 Reclustered[2] jet with:

reco p_T [GeV]	300
mass [GeV]	[100-140]
subjets b-tagged @85% w.p.	==2
DNN P(true Higgs)[3]	≥ 0.6



- if $\exists > 1$ such RC jets $\xrightarrow{choose}$ that with mass closest to Higgs mass

[1] formed from topological clusters using anti-k_t algorithm with R=0.4

[2] (also *RC jets*) large-R jets (R=1.0), formed from small-R subjets

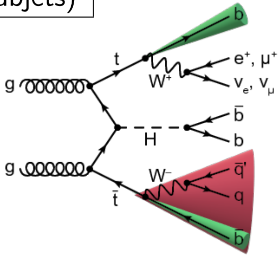
[3] DNN custom-made variable: DNN trained to quantify probability that an RC jet originated from Higgs

Event Selection & Reconstruction arXiv:2111.06712

- Additional selection requirement:

# b-tagged jets @77% w.p.	≥ 2 ($\neq$ Higgs subjets)

- Then, searching ***Hadronic Top candidate***:
  - if $\exists$ RC jet with $p_T \geq 300$ GeV $\rightarrow$ *boosted reconstruction*
  - otherwise, reconstruction using low p_T small-R jets

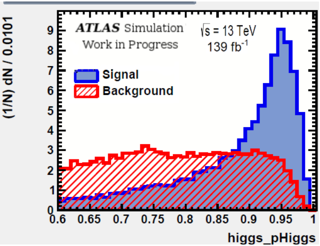


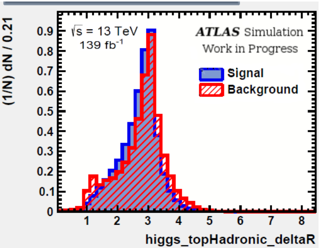
- Finally, searching ***Leptonic Top candidate***
  - using small-R jet + lepton + neutrino

- **Higgs**, **Hadronic Top** and **Leptonic Top** jets don't overlap
- Events containing large-R jets passing boosted selection $\rightarrow$ removed from resolved topology[4]
- This reconstruction used to define input BDT variables

[4] decay products from Higgs/Top candidates well separated $\rightarrow$ assigned to anti-k_t small-R jets

- Classification with **Boosted Decision Tree (BDT)**:
  - $\xrightarrow{enhance}$ discrimination between $t\bar{t}H$ signal and backgrounds
  - $\xrightarrow{built}$ combining kinematic variables based on:
    - resulting performance in terms of signal and bckg separation,
    - importance on training & correlations among them,
    - modelling & final fit results
- Input variables (arXiv:2111.06712):
  - invariant masses
  - transverse momenta
  - angular separations of pairs of reconstructed jets
  - b-tagging scores
  - DNN probability of true Higgs





- Measuring $t\bar{t}H(b\bar{b})$ signal strength (arXiv:2111.06712):
  - in inclusive phase space
  - templates divided in 5 true Higgs p_T bins (STXS formalism): $p_T^H \in$ [0,120), [120,200), [200,300), [300,450), [450,∞) GeV
    (binning discussed with CMS and theorists $\rightarrow$ optimised to facilitate future combinations)
- Splitting signal regions[5] (SR) into reconstructed Higgs p_T bins $\rightarrow$ 2 boosted SR: reco $p_T^H \in$ [300,450) GeV & [450,∞) GeV
- STXS framework (LHCHXSWG-2019-003): template fit to perform differential measurement
  - maximising sensitivity of measurement
  - benefiting from combination of measurements in all decay channels
- To get final $t\bar{t}H(b\bar{b})$ signal strength $\rightarrow$ combine *single-lepton boosted* with *single-lepton* & *dilepton resolved* regions

[5] analysis regions with higher signal-to-background ratio

Motivation

Event Selection and Reconstruction in single-lepton Boosted region

Analysis Strategy

Data/MC comparison & Truth studies in Boosted region

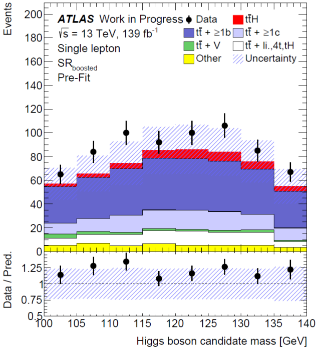
Fit process and results

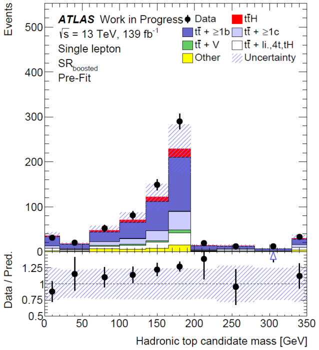
Summary and Outlook

Backup

Higgs and Hadronic Top mass distributions

- Data from pp collisions at $\sqrt{s} = 13$ TeV:
  - during 2015-2018 (full Run2)
  - *integrated luminosity*: $139\,fb^{-1}$



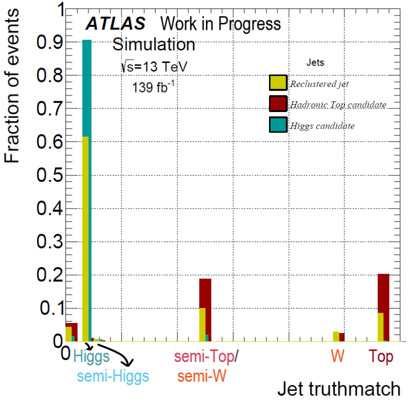


- 43.6 $t\bar{t}H$ signal & 543.4 background (expected) events
- $t\bar{t} + jets$ main background process $\rightarrow t\bar{t} + 1 \geq b$ dominant
- good Data/MC agreement already pre-fit

Truth Studies

▶ Checking which of true partons fall within large-R jets according to boosted topology

- **Higgs/Top**: complete and clean Higgs/hadronic-Top
- **semi-Higgs**: b leading (in p_T) from Higgs and b from leptonic Top
- **semi-Top/-W**: b from hadronic Top and q leading (in p_T) from W
- **W**: 2 q (sub-)leading in p_T from W
- **0**: none of these partons are in the reclustered jets



- without any selection:
  Higgs/hadronic-Top candidates not always correctly reconstructed
- with Boosted selection:
  significant increase in reconstruction efficiency of Higgs $\rightarrow 91\%$, but also of hadronic-Top candidate

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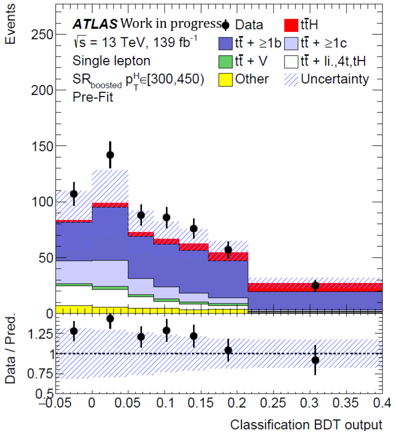
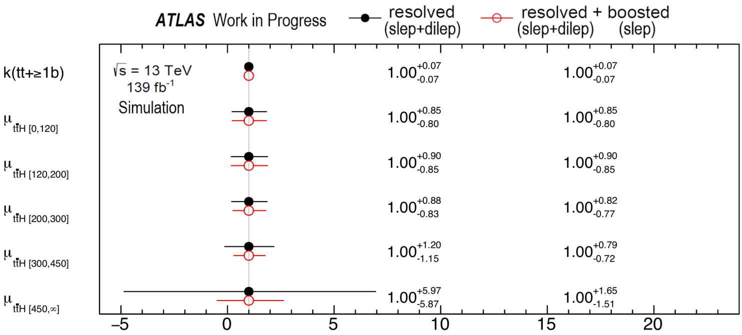
Fit process

- Profile Likelihood fit performed combining *single-lepton* (boosted + resolved) & *dilepton* regions, simultaneously



- Input: classification BDT distribution in SR → final discriminant for fit
- All systematic uncertainties included in fit function as Gaussian nuisance parameters (NPs)
- Free parameters:
  - signal strength μ
  - normalisation factor for $t\bar{t} + \geq 1b$ background: $k(t\bar{t} + \geq 1b)$
- Total uncertainty:
  - effects of all systematic sources + MC statistical uncertainty → constrained after fit

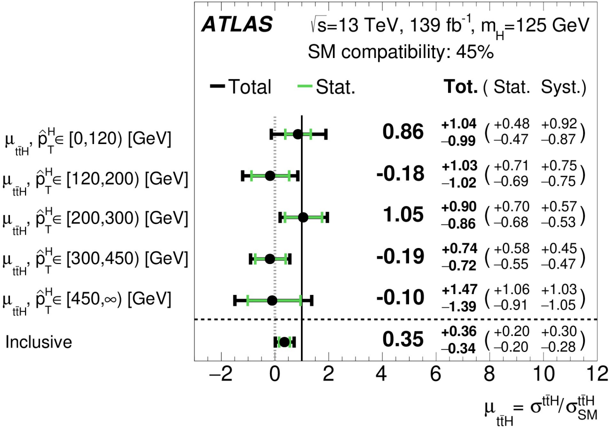
STXS measurement: *asimov S+B all-uncertainties fit*



- Comparing resolved-only (single-lepton + dilepton) fit with full combination *resolved + boosted*:
  - small differences in sensitivity in 3 lower p_T^H bins
  - p_T^H ∈[200,300]GeV: $\sim$ 7% improved uncertainties on μ
  - p_T^H ∈[300,450]GeV: $\sim$ 36% improved uncertainties on μ
  - p_T^H ∈[450,∞]GeV: $\sim$ 73% improved uncertainties on μ
  - same $k(tt+ \geq 1b)$ uncertainties

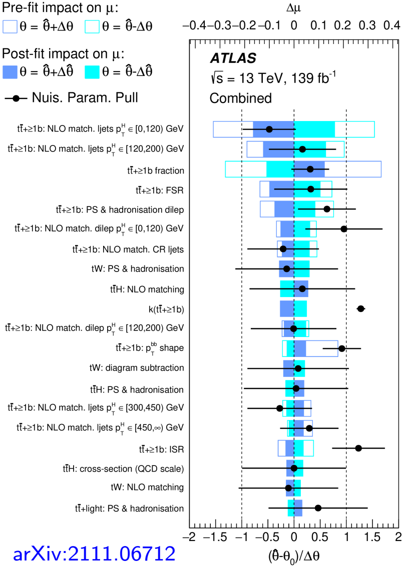
Inclusive & STXS Data S+B fit

- Signal strength μ best fit-value arXiv:2111.06712 :



- Measured normalisation factor for $t\bar{t}+\geq 1b$ background: $k(t\bar{t}+\geq 1b) = 1.27 \pm 0.08$ (inclusive), $\quad 1.28 \pm 0.08$ (STXS)
- Observed (expected) significance of 1.0 (2.7) standard deviations
- Compatibility with SM expectation ($\mu_{SM} = 1.0$): 8.5%

Ranking sources of systematic uncertainty



arXiv:2111.06712

- NPs with largest impact on signal strength μ, related to:
  - $t\bar{t}+\geq 1b$ and tW bckg modelling
  - $t\bar{t}H$ signal modelling
- NPs corresponding to MC statistical uncertainties not included
- NPs with largest pulls:
  - $tt+\geq 1b$ ISR $\sim 1.2\sigma \rightarrow$ mostly driven by renormalisation scale
  - p_T^{bb} shape (in $tt+\geq 1b$ bckg) $\rightarrow$ expected from pre-fit modelling
- <u>However</u>: boosted region $\rightarrow$ mostly dominated by statistics

- Impact of NP ($\Delta\mu$): comparing nominal best fit-value of μ with fit result when fixing NP to its best-fit value $\hat{\theta}$ shifted by its pre-(post-)fit uncertainties $\pm\Delta\theta(\pm\Delta\hat{\theta})$
- Black points: pulls of NPs relative to their nominal value θ_0 (lower scale)

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- $t\bar{t}H(b\bar{b})$ measurement with full Run-2 data submitted to JHEP $\rightarrow$ already available on arXiv:2111.06712
  - Measurement also performed in p_T^H bins in STXS framework $\rightarrow$ **first differential measurement of $t\bar{t}H$ signal strength**
  - Measured signal strength corresponds to observed (expected) significance of 1.0σ (2.7σ)
  - Background events dominated by $t\bar{t}$+jets processes
  - Measurement dominated by systematics - $t\bar{t}+\geq 1b$ modelling
  - Observed results: agreement with SM within large uncertainties

- Boosted selection targeting Higgs boson with high p_T $\rightarrow$ part of $t\bar{t}H(b\bar{b})$ analysis:
  - dominant contribution in $p_T^H > 300$ GeV
  - small gain in sensitivity in inclusive-μ fit
  - quite large gain in sensitivity in STXS fit, especially in 2 highest p_T^H bins

Outlook

- Use ParticleFlow jets instead of calorimeter-only jets (current study)
- Further optimise kinematic object reconstruction of hadronic and leptonic Top candidates
- Include selection for ultra boosted Higgs (targeting $t\bar{t}H$ events with very high Higgs p_T - decay products within a small-R jet)
- Investigate other MVA or DNN discriminating methods for background separation

Re-clustered jet mass definition

- **Re-clustered jet mass** (m_{RC})[6] : for large-R jet J with constituents i with energy E_i, momentum $\vec{p}_i$ ($|\vec{p}_i| = E_i$)

$$m_{RC} = \sqrt{\left(\sum_{i \in J} E_i\right)^2 - \left(\sum_{i \in J} \vec{p}_i\right)^2} \tag{1}$$

- Large-R jets, formed from anti-k_T R = 0.4 jets, with anti-k_T R = 1.0, then trimmed requiring $\frac{p_{T_i}}{p_{T_{large-jet}}} \geq 0.1$

[6]based on arXiv:1407.2922 [hep-ph]

Boosted reconstruction: searching Hadronic & Leptonic Top candidates arXiv:2111.06712

- ***Hadronic Top*** cand. reconstruction:
  searching for additional reclustered jet ($\neq$ Higgs cand. jet), with $p_T \geq 300$ GeV and P(true Top) $\geq$ 0.3
  - if $\exists > 1 \xrightarrow{choose}$ that w/ inv. mass closest to Top mass
- If **Hadronic Top** found $\rightarrow$ ***Leptonic Top*** reconstruction:
  searching for additional small-R jet
  \+ neutrino + lepton,
  w/ inv. mass $\in$ [130,200] GeV
  - Excluding small jets overlapping with ***Higgs*** or **Hadronic Top**
  - *Neutrino* reconstruction: using MET and W boson mass constraint
- if $\exists > 1$ such small-R jets $\xrightarrow{choose}$ w/ inv. mass closest to Top mass
- if $\nexists$ additional small-R jet $\rightarrow$ ***Leptonic top*** defined as sum of lepton and neutrino

Boosted reconstruction: searching Hadronic & Leptonic Top candidates arXiv:2111.06712

- If **Hadronic Top not found** $\rightarrow$ ***Leptonic Top*** reconstruction: small-R jets non-overlaping w/ **Higgs** cand. into account $\xrightarrow{considering}$ all possible combinations for **Hadronic** and **Leptonic Top** simultaneously:
  - small-R jets w/ inv. mass $\in$ [70,195] GeV $\rightarrow$ **Hadronic Top**
  - small-R jet + neutrino + lepton, w/ inv. mass $\in$ [130,200] GeV $\rightarrow$ **Leptonic Top**
- if $\exists > 1$ combinations for both $\xrightarrow{choose}$ that w/ minimum: $|m^{reco}_{HadTop} - 172.5| + |m^{reco}_{LepTop} - 172.5|$
- If $\nexists$ non-overlaping combinations $\xrightarrow{choose}$
  - **Hadronic Top** reconstructed from3 highest p_T small-R jets (non-overlap **Higgs** candidate)
  - **Leptonic Top** reconstructed as sum of lepton and neutrino

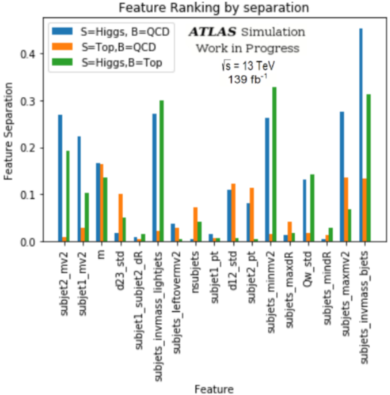
Strategy (more info and plots here) (Glasgow group studies)

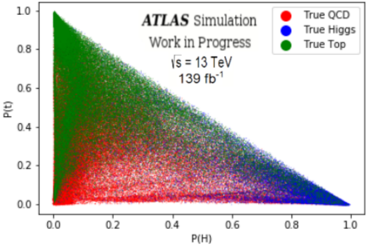
- **Aim**: simultaneous identification of Higgs and Top with DNN using RC jets[7]
- **Setup**:
  - 3 layers of 100 nodes sequential DNN
  - Training:
    - Jet by jet
    - Single lepton $t\bar{t}H$ sample
    - all RC jets: $p_T \geq 200$ GeV + ≥ 2 subjets
    - 3 types of jets used for training:
      - **Higgs**: RC jet $\rightarrow$ subjets ΔR matched to 2 true b-quarks
      - **Top**: RC jet $\rightarrow$ subjets ΔR matched to true b-quark + ≥ 1 W decay product
      - **QCD**: all other RC jets

[7] Reclustered (RC) jets = large-R jets (R=1.0), formed from small-R (R=0.4) subjets

Strategy (Glasgow group studies)

- DNN input variables:
  - invariant masses
  - transverse momentum of subjets
  - jet substructure variables
  - ΔR separations btw subjets
  - pseudo continuous b-tagging (PCB) scores





- DNN output values: probabilities P(H), P(t), P(Q) for each type of jets

BDT input variables in Boosted selection arXiv:2111.06712

Variable	Definition
m_{bb}^{Higgs}	Higgs candidate mass
p_{T}^{H}	Higgs candidate transverse momentum
$\eta_{\text{lep}}^{\text{Higgs}}$	η of the Higgs candidate relative to the lepton
$P(H)_{\text{Higgs}}$	DNN Higgs probability for the Higgs candidate
$m_{\text{had top}}$	Hadronic top candidate mass
$p_{\text{T}}^{\text{had top}}$	Hadronic top candidate transverse momentum
$\eta_{\text{had top}}^{\text{lep}}$	η of the hadronic top candidate relative to the lepton
$B_{\text{had top}}^{i}$	i^{th} largest jet b-tagging discriminant associated to the hadronic top candidate
$m_{\text{lep top}}$	Leptonic top candidate mass
$p_{\text{T}}^{\text{lep top}}$	Leptonic top candidate transverse momentum
$B_{\text{lep top}}$	b-tagging discriminant of the jet associated to the leptonic top candidate
n_{jets}	Small-R jets multiplicity
$\Delta R_{H,\text{had top}}$	ΔR between the Higgs and the hadronic top candidates
$\Delta R_{H,\text{lep top}}$	ΔR between the Higgs and the leptonic top candidates
$\Delta R_{\text{had top,lep top}}$	ΔR between the hadronic top and the leptonic top candidates
$p_{\text{T}}^{t\bar{t}H}$	$t\bar{t}H$ system transverse momentum
$p_{\text{T}}^{t\bar{t}}$	$t\bar{t}$ system transverse momentum
$w_{b\text{-tag}}^{\text{sum}}$	Sum of b-tagging discriminants of jets from Higgs, hadronic and leptonic top candidates
$w_{b\text{-tag}}^{\text{add jet}}$	Fraction of the sum of b-tagging discriminants of all jets not associated to Higgs or hadronic top candidates

- only a few high correlations among input variables

TRExFitter

- **Profile likelihood** method:
  - Useful when fitting simultaneously:
    - parameter(s) of interest μ
    - nuisance parameter(s) θ encoding effects of systematic uncertainties
  - Allows for reduction of systematic uncertainties, by effectively performing in-situ calibrations
  - Profile likelihood ratio $\rightarrow$ significance

$$\lambda(\mu) = \frac{\mathcal{L}(\mu = \mu_0, \hat{\hat{\theta}}_\mu)}{\mathcal{L}(\hat{\mu}, \hat{\theta})} \qquad (2)$$

conditional likelihood: $\hat{\hat{\theta}}_\mu$ best-fit value for given $\mu = \mu_0$ maximises $\mathcal{L}$

unconditional likelihood: $\hat{\theta}$ overall best-fit value maximises $\mathcal{L}$

Signal and Background modelling

- Nominal model:
  - $t\bar{t}H$: PowHeg+Pythia8
    (used in training of classification BDT in all channels)
  - $t\bar{t}+\geq 1b$: PowHeg+Pythia8 $t\bar{t}b\bar{b}$ (4FS)
    (used in training of classification BDT in all channels)
  - $t\bar{t}+\geq 1c$ and $t\bar{t}+$ *light*: PowHeg+Pythia8 $t\bar{t}$ (5FS)
    (used in training of classif. BDT in single lepton channels)
  - also other backgrounds
    (used in training of classification BDT in single lepton boosted channels)

Generators used for MC samples arXiv:2111.06712

Process	ME generator	ME PDF	PS	Normalisation
Higgs boson				
$t\bar{t}H$	PowhegBox v2	NNPDF3.0NLO	Pythia8.230	NLO+NLO (EW) [19]
	PowhegBox v2	NNPDF3.0NLO	Herwig7.04	NLO+NLO (EW) [19]
	MadGraph5_aMC@NLO v2.6.0	NNPDF3.0NLO	Pythia8.230	NLO+NLO (EW) [19]
$tHjb$	MadGraph5_aMC@NLO v2.6.2	NNPDF3.0NLOnf4	Pythia8.230	–
tWH	MadGraph5_aMC@NLO v2.6.2 [DR]	NNPDF3.0NLO	Pythia8.235	–
$t\bar{t}$ and single-top				
$t\bar{t}$	PowhegBox v2	NNPDF3.0NLO	Pythia8.230	NNLO+NNLL [45,46,47,48,49,50,51]
	PowhegBox v2	NNPDF3.0NLO	Herwig7.04	NNLO+NNLL [45,46,47,48,49,50,51]
	MadGraph5_aMC@NLO v2.6.0	NNPDF3.0NLO	Pythia8.230	NNLO+NNLL [45,46,47,48,49,50,51]
$t\bar{t}+b\bar{b}$	PowhegBoxRes	NNPDF3.0NLOnf4	Pythia8.230	–
	Sherpa v2.2.1	NNPDF3.0NNLOnf4	Sherpa	–
tW	PowhegBox v2 [DR]	NNPDF3.0NLO	Pythia8.230	NLO+NNLL [52,53]
	PowhegBox v2 [DS]	NNPDF3.0NLO	Pythia8.230	NLO+NNLL [52,53]
	PowhegBox v2 [DR]	NNPDF3.0NLO	Herwig7.04	NLO+NNLL [52,53]
	MadGraph5_aMC@NLO v2.6.2 [DR]	CT10NLO	Pythia8.230	NLO+NNLL [52,53]
t-channel	PowhegBox v2	NNPDF3.0NLOnf4	Pythia8.230	NLO [54,55]
	PowhegBox v2	NNPDF3.0NLOnf4	Herwig7.04	NLO [54,55]
	MadGraph5_aMC@NLO v2.6.2	NNPDF3.0NLOnf4	Pythia8.230	NLO [54,55]
s-channel	PowhegBox v2	NNPDF3.0NLO	Pythia8.230	NLO [54,55]
	PowhegBox v2	NNPDF3.0NLO	Herwig7.04	NLO [54,55]
	MadGraph5_aMC@NLO v2.6.2	NNPDF3.0NLO	Pythia8.230	NLO [54,55]
Other				
$W+$jets	Sherpa v2.2.1 (NLO [2j], LO [4j])	NNPDF3.0NNLO	Sherpa	NNLO [56]
$Z+$jets	Sherpa v2.2.1 (NLO [2j], LO [4j])	NNPDF3.0NNLO	Sherpa	NNLO [56]
VV (had.)	Sherpa v2.2.1	NNPDF3.0NNLO	Sherpa	–
VV (lep.)	Sherpa v2.2.2	NNPDF3.0NNLO	Sherpa	–
VV (lep.) + jj	Sherpa v2.2.2 (LO [EW])	NNPDF3.0NNLO	Sherpa	–
$t\bar{t}W$	MadGraph5_aMC@NLO v2.3.3	NNPDF3.0NLO	Pythia8.210	NLO+NLO (EW) [19]
	Sherpa v2.0.0 (LO [2j])	NNPDF3.0NNLO	Sherpa	NLO+NLO (EW) [19]
$t\bar{t}\ell\ell$	MadGraph5_aMC@NLO v2.3.3	NNPDF3.0NLO	Pythia8.210	NLO+NLO (EW) [19]
	Sherpa v2.0.0 (LO [1j])	NNPDF3.0NNLO	Sherpa	NLO+NLO (EW) [19]
$t\bar{t}Z$ $(qq,\nu\nu)$	MadGraph5_aMC@NLO v2.3.3	NNPDF3.0NLO	Pythia8.210	NLO+NLO (EW) [19]
	Sherpa v2.0.0 (LO [2j])	NNPDF3.0NNLO	Sherpa	NLO+NLO (EW) [19]
$t\bar{t}t\bar{t}$	MadGraph5_aMC@NLO v2.3.3	NNPDF3.1NLO	Pythia8.230	NLO+NLO (EW) [57]
tZq	MadGraph5_aMC@NLO v2.3.3 (LO)	CTEQ6L1	Pythia8.212	–
tWZ	MadGraph5_aMC@NLO v2.3.3 [DR]	NNPDF3.0NLO	Pythia8.230	–

Systematic uncertainties modelling

- Sources of systematic uncertainty affecting $t\bar{t}$ + jets bckg modelling arXiv:2111.06712:

Uncertainty source	Description		Components
$t\bar{t}$ cross-section	$\pm 6\%$		$t\bar{t}$ + light
$t\bar{t} + \geq 1b$ normalisation	Free-floating		$t\bar{t} + \geq 1b$
$t\bar{t} + \geq 1c$ normalisation	$\pm 100\%$		$t\bar{t} + \geq 1c$
NLO matching	MadGraph5_aMC@NLO+Pythia8 vs. PowhegBox+Pythia8		All
PS & hadronisation	PowhegBox+Herwig7 vs. PowhegBox+Pythia8		All
ISR	Varying α_S^{ISR} (PS), μ_{R}&μ_{F} (ME)	in PowhegBoxRes+Pythia8	$t\bar{t} + \geq 1b$
		in PowhegBox+Pythia8	$t\bar{t} + \geq 1c$, $t\bar{t}$ + light
FSR	Varying α_S^{FSR} (PS)	in PowhegBoxRes+Pythia8	$t\bar{t} + \geq 1b$
		in PowhegBox+Pythia8	$t\bar{t} + \geq 1c$, $t\bar{t}$ + light
$t\bar{t} + \geq 1b$ fractions	PowhegBox+Herwig7 vs. PowhegBox+Pythia8		$t\bar{t} + 1b/1B$, $t\bar{t} + \geq 2b$
p_{T}^{bb} shape	Shape mismodelling measured from data		$t\bar{t} + \geq 1b$

- Dedicated p_T^{bb} modelling systematic, derived
  - to cover Higgs p_T mis-modelling, assigned to $t\bar{t} + \geq 1b$ bckg
  - derived in inclusive dilepton/single-lepton SRs
  - normalisation effects removed
  - weight computed in each p_T^H bin: ratio between data and MC
  - weights for single-lepton also applied in boosted channel

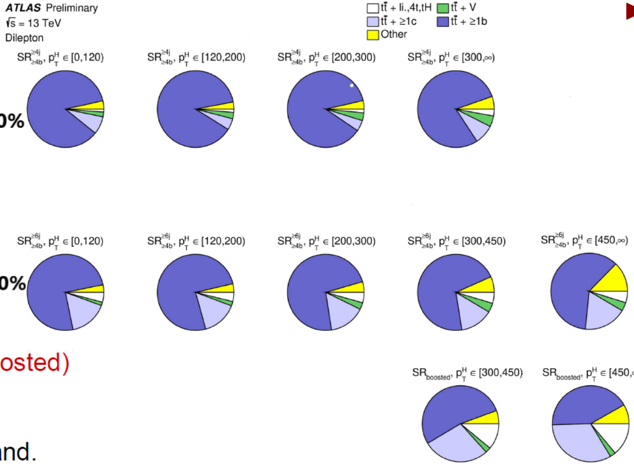
Analysis regions: Signal regions (SR)

reco p_T^H 0-120 GeV 120-200 GeV 200-300 GeV 300-450 GeV 450- GeV

2-lepton
≥4 b-jets@**70%**
≥4 jets

1-lepton
(resolved)
≥4 b-jets@**70%**
≥6 jets

1-lepton (boosted)
≥4 b-jets
≥4 jets
≥boosted cand.



- **For fit**:

classification BDT

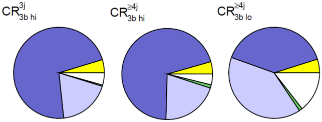
class.BDT, yield (last reco p_T^H bin)

classification BDT

- $t\bar{t}+ \geq 1b$ dominant background in all regions

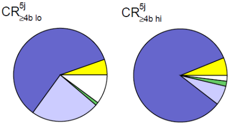
Analysis regions: Control regions (CR)[7]

- Dilepton



- event yield used in fit to correct amount of $t\bar{t}+\geq 1c$ background

- Single-lepton resolved



- shape and normalisation of ΔR^{avg}_{bb} distribution to better constrain the bckg contributions and correct their shape

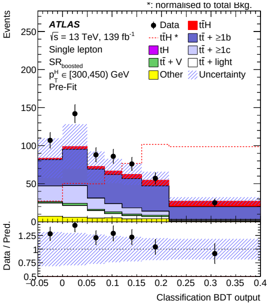
- $t\bar{t}+\geq 1b$ dominant background in all regions
- Classif. BDT in SR & event yield (ΔR^{avg}_{bb}) distributions in dilepton (single-lepton) CR $\rightarrow$ combined in profile likelihood fit

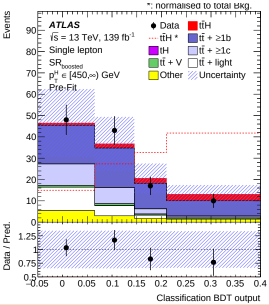
[7] analysis regions depleted in signal, with b-tagging w.p.:

- *lo*: ($\geq$)n b@70, <n b@60
- *hi*: ($\geq$)n b@60

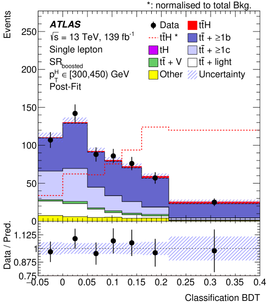
BDT distribution in Boosted regions

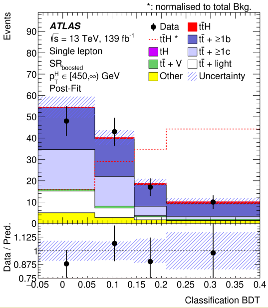
- Pre-fit





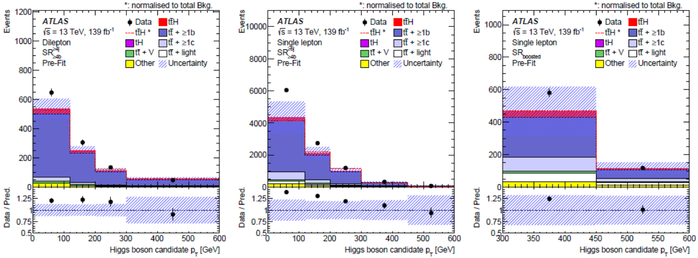
- Post-fit arXiv:2111.06712



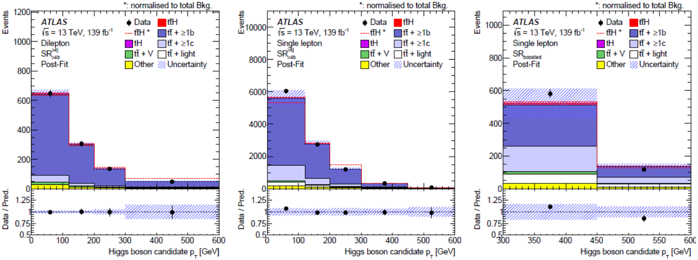


Reconstructed Higgs boson candidate p_T

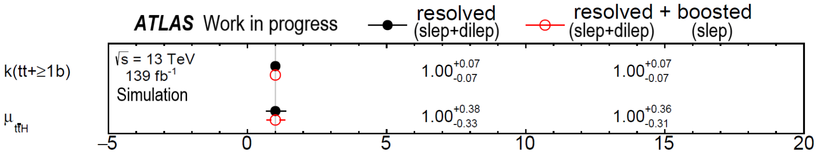
▶ Pre-fit arXiv:2111.06712



▶ Post-fit arXiv:2111.06712



Inclusive measurement: asimov S+B all-uncertainties fit



- Comparing resolved-only (single-lepton + dilepton) fit with full combination *resolved + boosted*:
  - $\sim$ 6% improved uncertainties on μ
  - same $k(tt+\geq 1b)$ uncertainties