Search for four-top-quark production in the single-lepton and opposite-sign dilepton final states in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

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INTERPRETING THE LHC RUN 2 DATA ANA BEYOND

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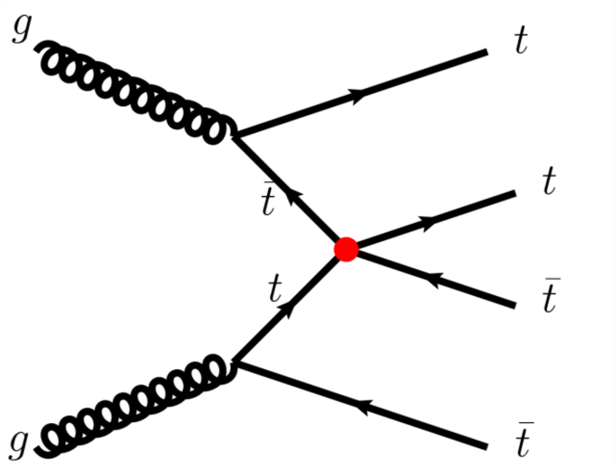
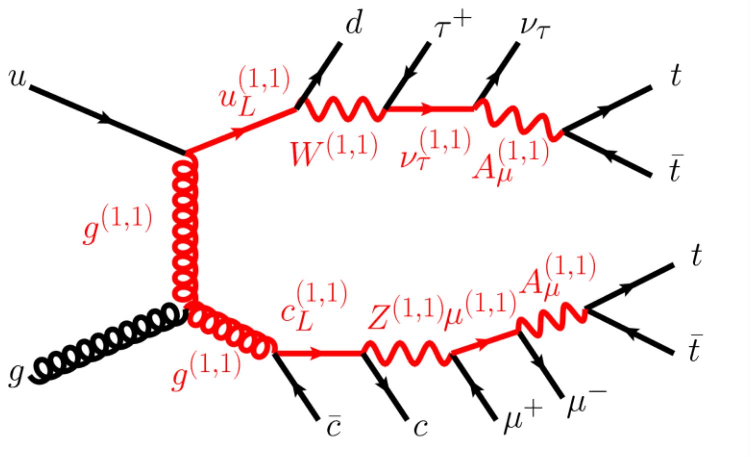
Outline

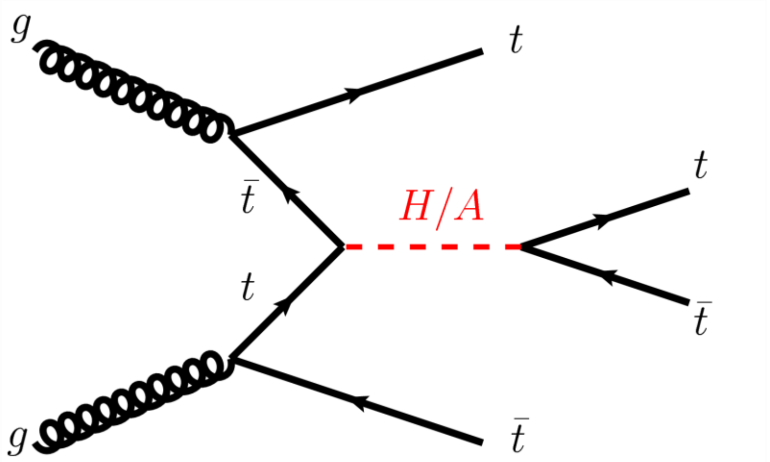
- Introduction.
- Object selections.
- Event selections and classifications.
- Backgrounds.
- Discriminating variables.
- Results.
- Summary.
- References.

Introduction

- Top quark is predicted to have large couplings to new particles in many models beyond the Standard Model (BSM).





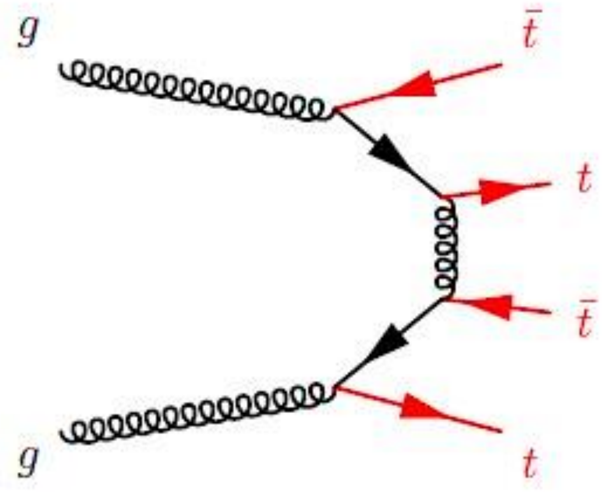


Introduction

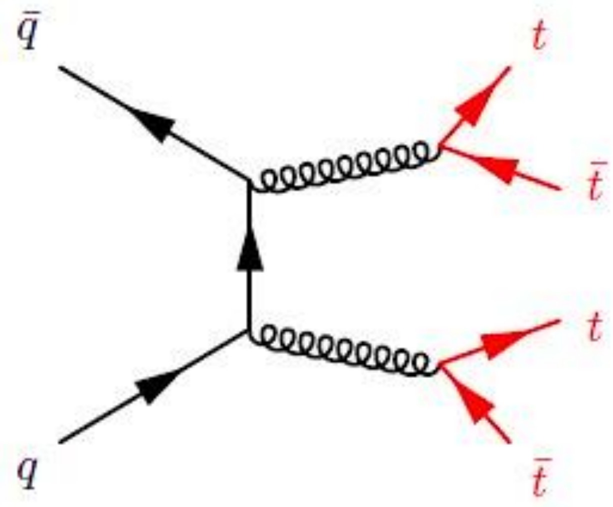
Rare process

The SM four-top-quark production $\sigma_{SM}^{t\bar{t}t\bar{t}}$ at NLO is predicted to be ~9.2 fb at $\sqrt{s} = 13$ TeV. Ref[1,2]

- The dominated process productions are:



Gluon-gluon fusion



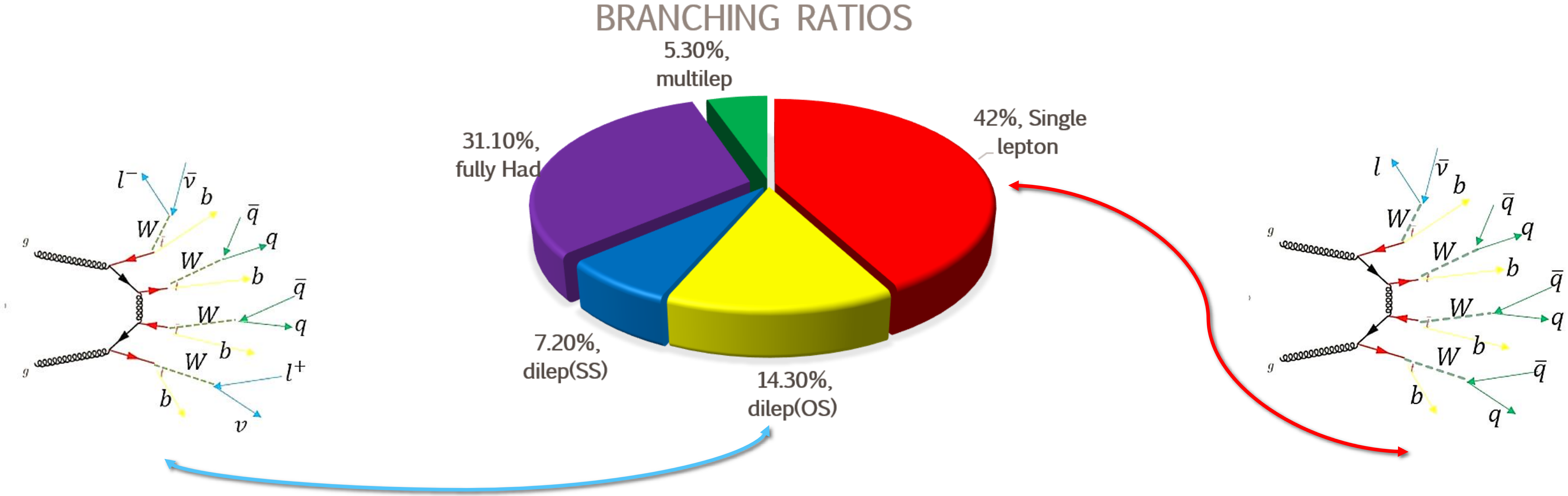
Quark-antiquark annihilation

Introduction

Final states

The SM $t\bar{t}t\bar{t}$ process is characterized by several final states depending on the W-boson decay.

Lepton: is either electron or muon, where the tau decay is included in the totals.



Object selection

Jet

- ❑ Anti-k_t algorithm with radius parameter 0.4.
- ❑ $p_T > 25$ GeV and $|\eta| < 2.5$
- ❑ Overlap-removal procedure is applied.

b-tag jet

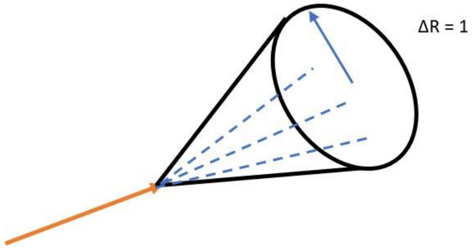
- ❑ MVA b-tagging Algorithm applied (Working point 77%).

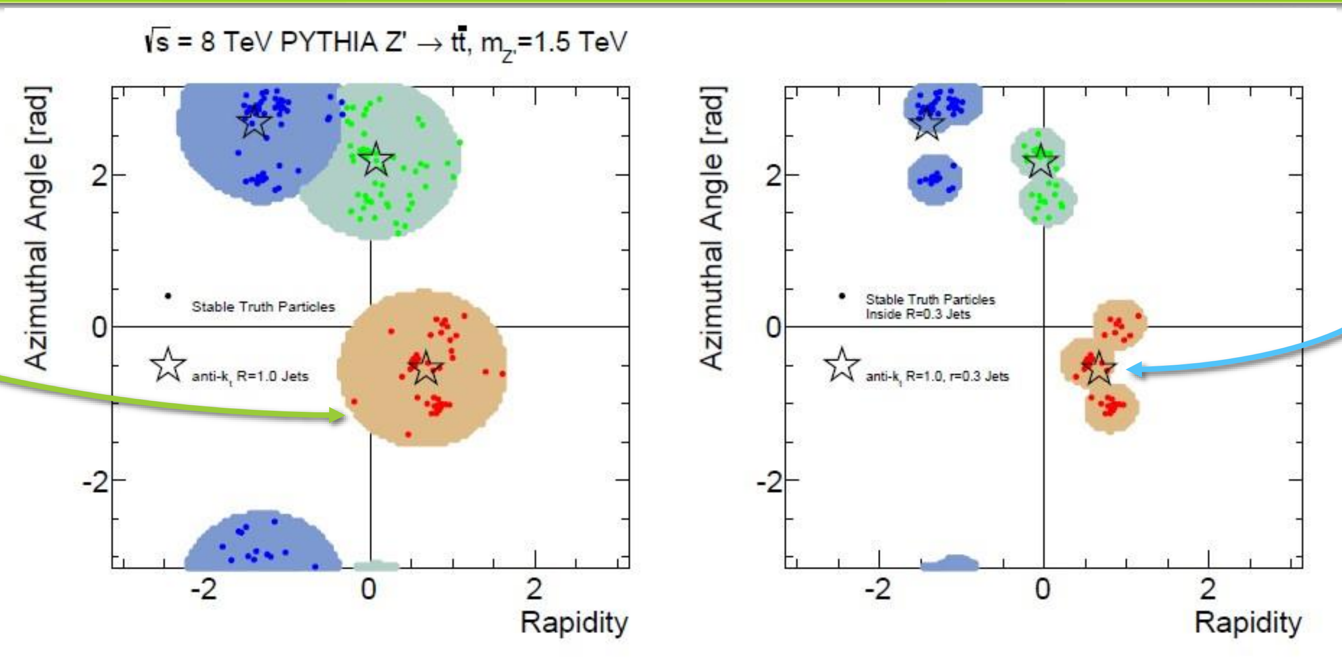
Lepton

- ❑ Triggers with isolation requirements.
- ❑ $p_T > 30$ GeV and $|\eta| < 2.5$
- ❑ Overlap-removal procedure is applied.

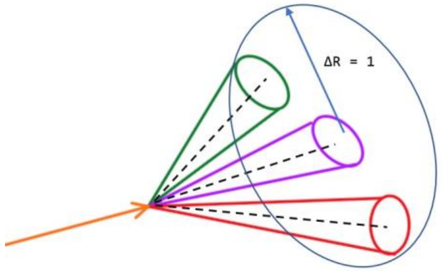
Jets re-clustering

Events clustered using Anti-k with R=1





Events re-clustered with R=1 using Anti-k for re-clustered jets R=0.3



Jets re-clustering method

- Select small-R jets with $p_T > 25$ GeV and passing JVT and overlap removal as input for jet re-clustering.
- Remove the small-R jets coming from pileup.

Advantages

- Jets with a large radius $R \geq 1$ using Anti-k algorithm is widely used to capture the products of the heavy particles decaying hadronically (W/Z bosons, Top quark).
- The large-R re-clustered jets are automatically including the calibrations, corrections and the uncertainties from small-R jets. Ref[3]

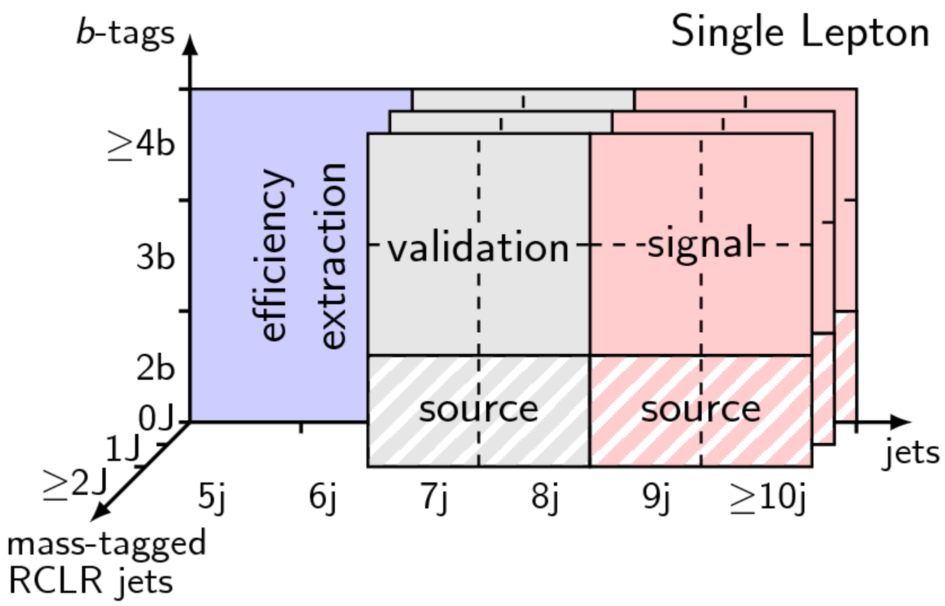
Event selections and classifications

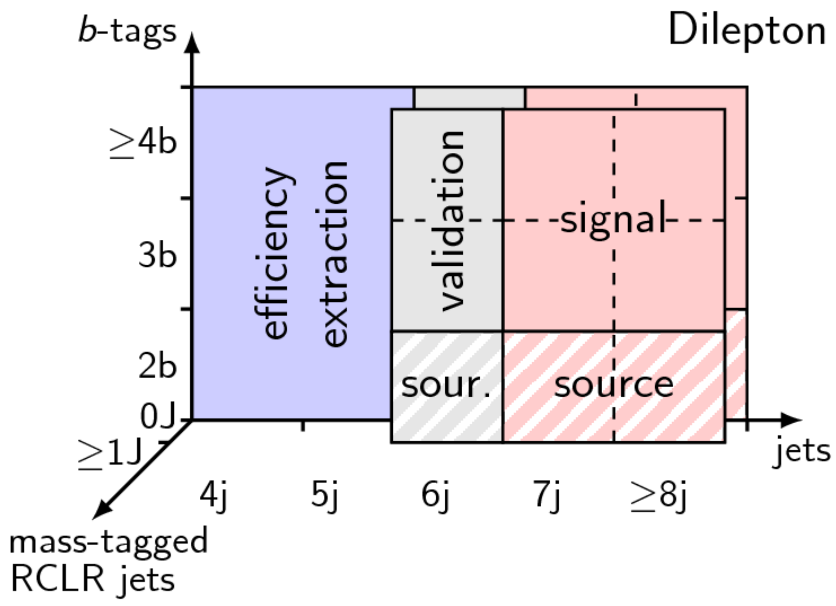
Mass-tagged reclustered large-R (RCLR) jets

- Jets $p_T > 25$GeV, JVT and overlap-removal.
- Re-clustered jet using Anti-k_t algorithm R = 1.
- RCLR $p_T > 200$ GeV.
- RCLR Mass > 100 GeV.
- $|\eta| < 2$.

Preselection requirements		
Requirement	Single-lepton	Dilepton
Trigger	Single-lepton triggers	
Leptons	1 isolated	2 isolated, opposite-sign
Jets	$\geq$5 jets	$\geq$4 jets
b-tagged jets	$\geq$2 b-tagged jets	
Other	$E_T^{miss} > 20$ GeV	$m_{\ell\ell} > 50$ GeV
	$E_T^{miss} + m_T^W > 60$ GeV	$\|m_{\ell\ell} - 91 \text{ GeV}\| > 8$ GeV

Event selections and classifications





For both decay modes the preselected events are classified according to the jet and b-tagged jet multiplicities and to the number of RCLR jets.

Backgrounds

In 1L/OS dilepton decay channels, there are several backgrounds with different contributions in the signal regions

- $t\bar{t} + jets$: estimated using data-driven method and MC simulations.
- Single tops .
- W/Z + jets.
- Dibosons (WW, ZZ, WZ).
- $t\bar{t}$ +H/V ($t\bar{t}$H, $t\bar{t}$W, $t\bar{t}$Z).

(Single tops, W/Z + jets, Dibosons, $t\bar{t}$ +H/V:) Estimated using MC simulations.

- Fake Leptons from 1L and OS dilepton: Estimated using Data (1L) and MC simulation (OS).

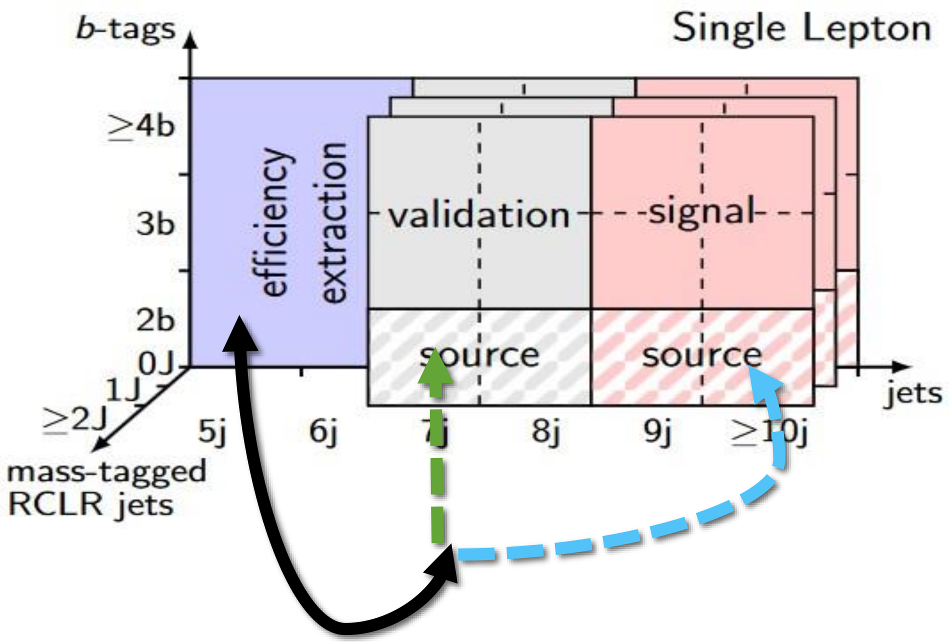
$TRF_{t\bar{t}}$ method

$t\bar{t} + jets$ estimation

- $t\bar{t}$ prediction based on the MC simulation at NLO accuracy in QCD is expected to have large uncertainties in high jet multiplicity.
- $TRF_{t\bar{t}}$ method “tag rate function” is used to extrapolate the $t\bar{t}$ events using data sample at low jet multiplicity “efficiency region” to the signal region.
- From efficiency region we measure the probability (ϵ_b) to tag another jet (c-jet or b-jet).

$TRF_{t\bar{t}}$ procedure

- b-tagged jets with highest value for b-tagging in the event are excluded.
- ϵ_b measured as function of jet P_t *and* $\Delta R_{min}^{jet,jet} \times N^{jet}$
- Build pseudo-data samples in Validation and Signal regions.
- Apply this method on MC simulation to extract systematics and correction factors. Ref[4,5]



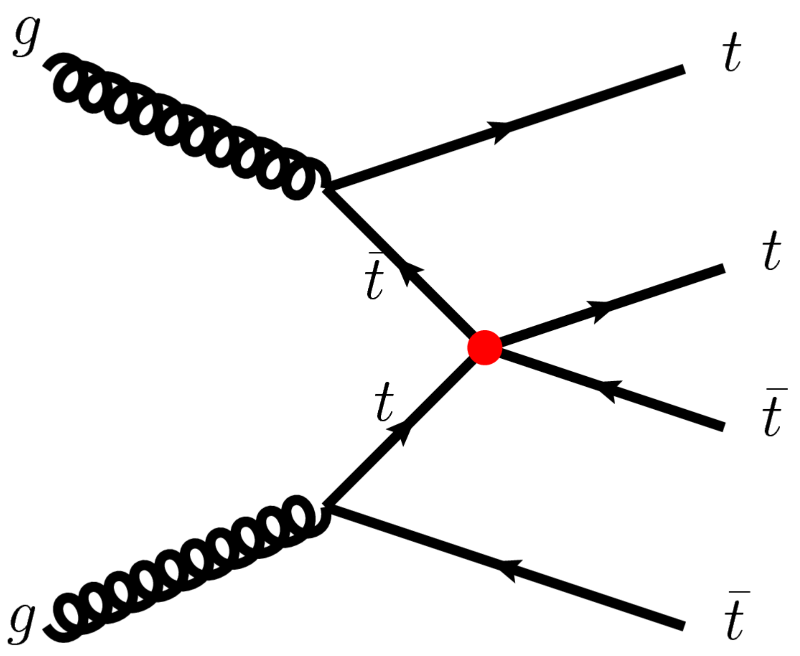
Contact interaction CI

Contact interaction Lagrangian

$$\mathcal{L}_{4t} = \frac{C_{4t}}{\Lambda^2}(\bar{t}_R\gamma^\mu t_R)(\bar{t}_R\gamma_\mu t_R)$$

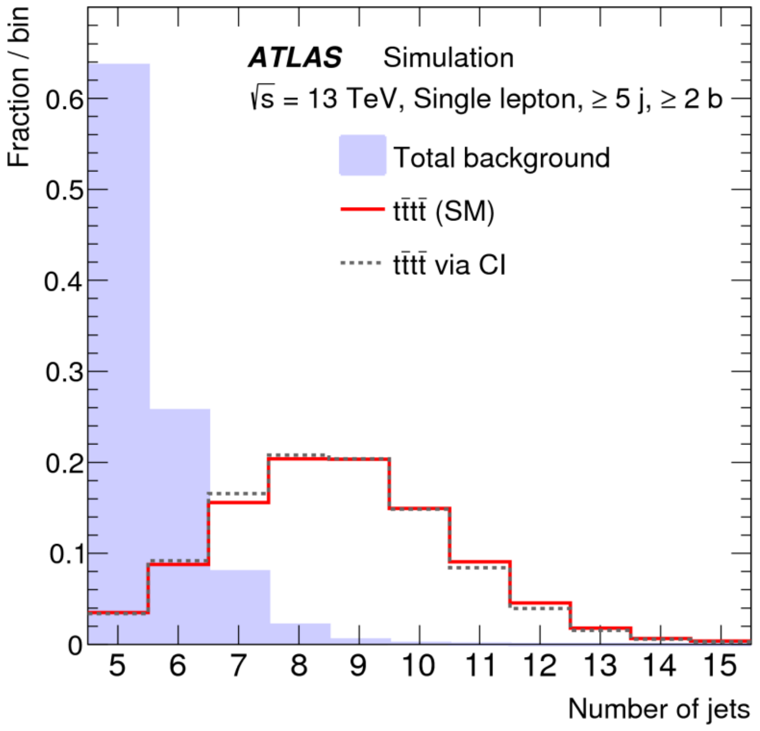
t_R: right handed top spinor.
γ_μ: Dirac matrices.
Λ: new-physics energy scale.
C_{4t}: dimensionless constant.

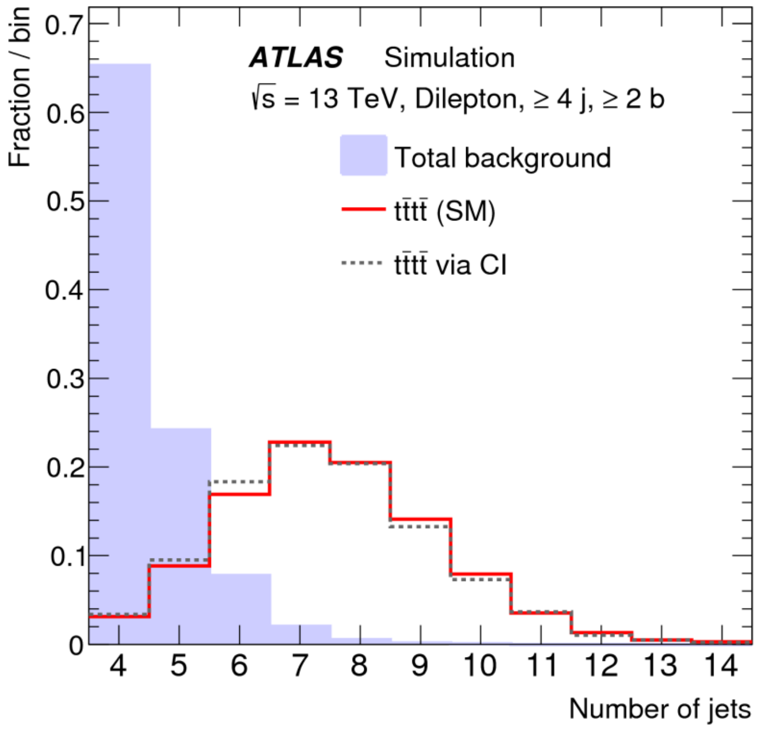
- Left-handed top operators are constrained by the electroweak precision data. Ref[6,7]



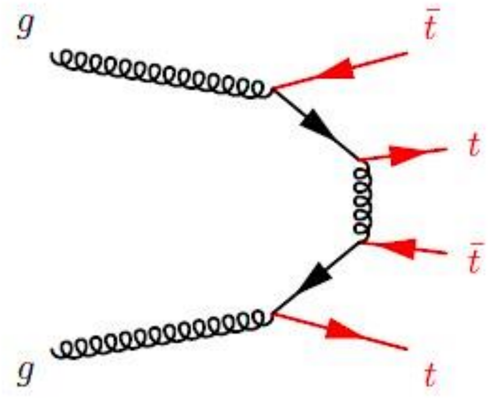
Discriminating variables

After applying the preselection in 1L/OS dilepton channels, the expected shapes for different discriminating variables are:

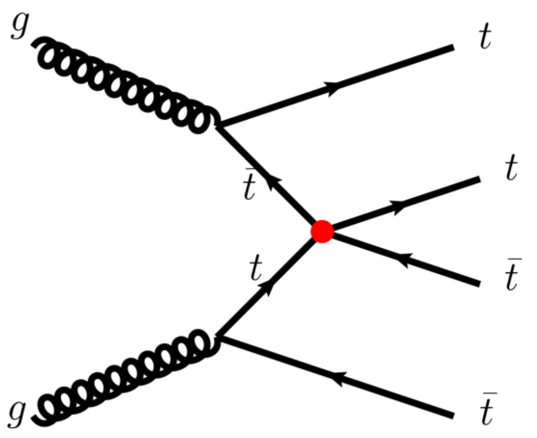




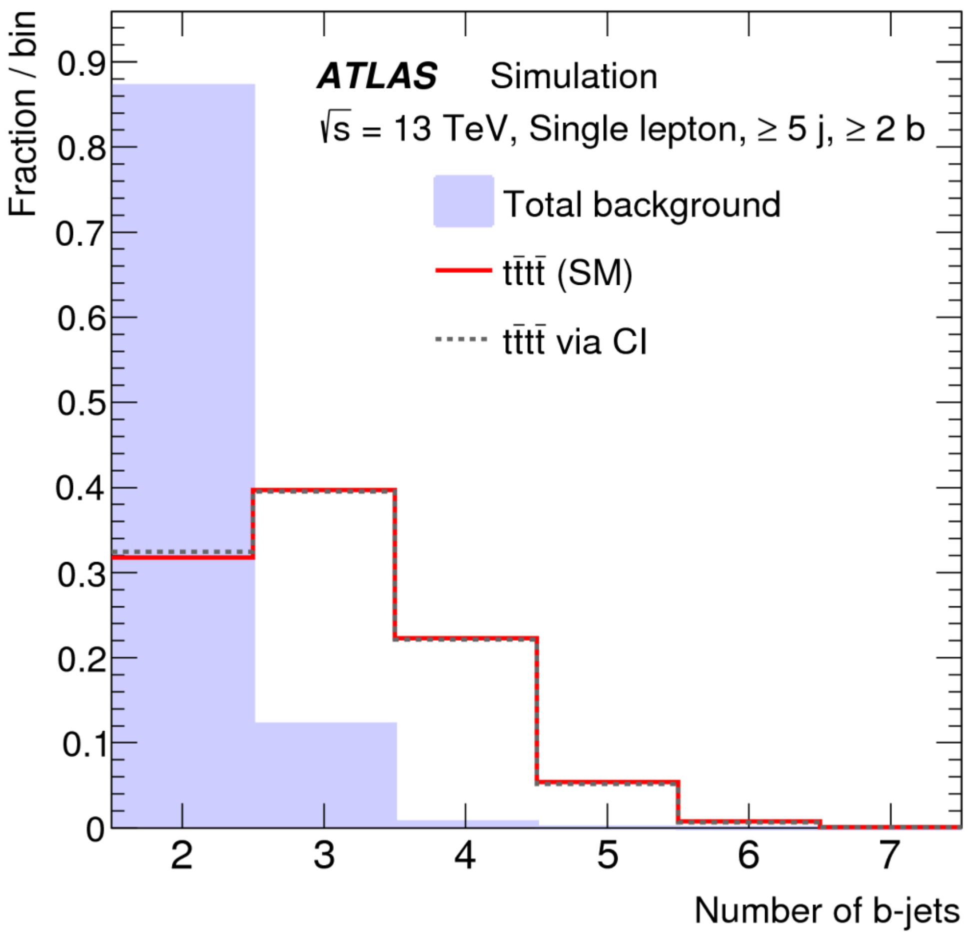
$t\bar{t}t\bar{t}(SM)$

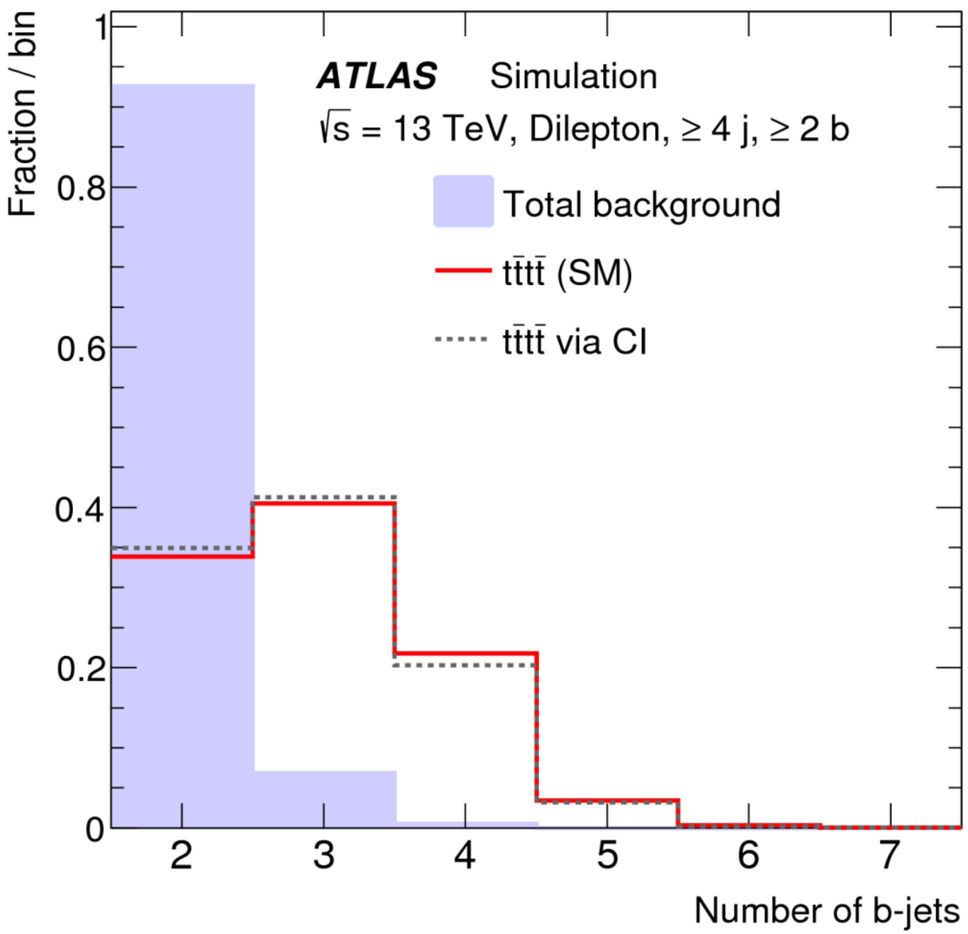


$t\bar{t}t\bar{t}(CI)$

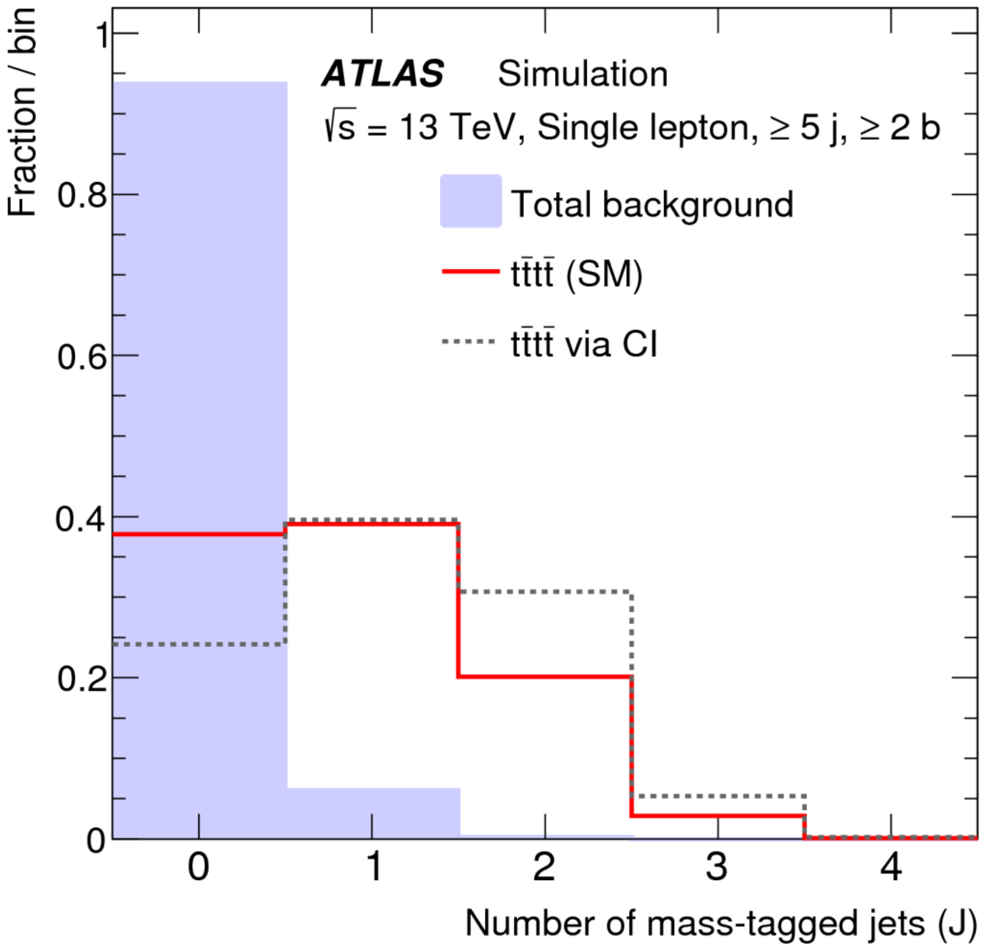


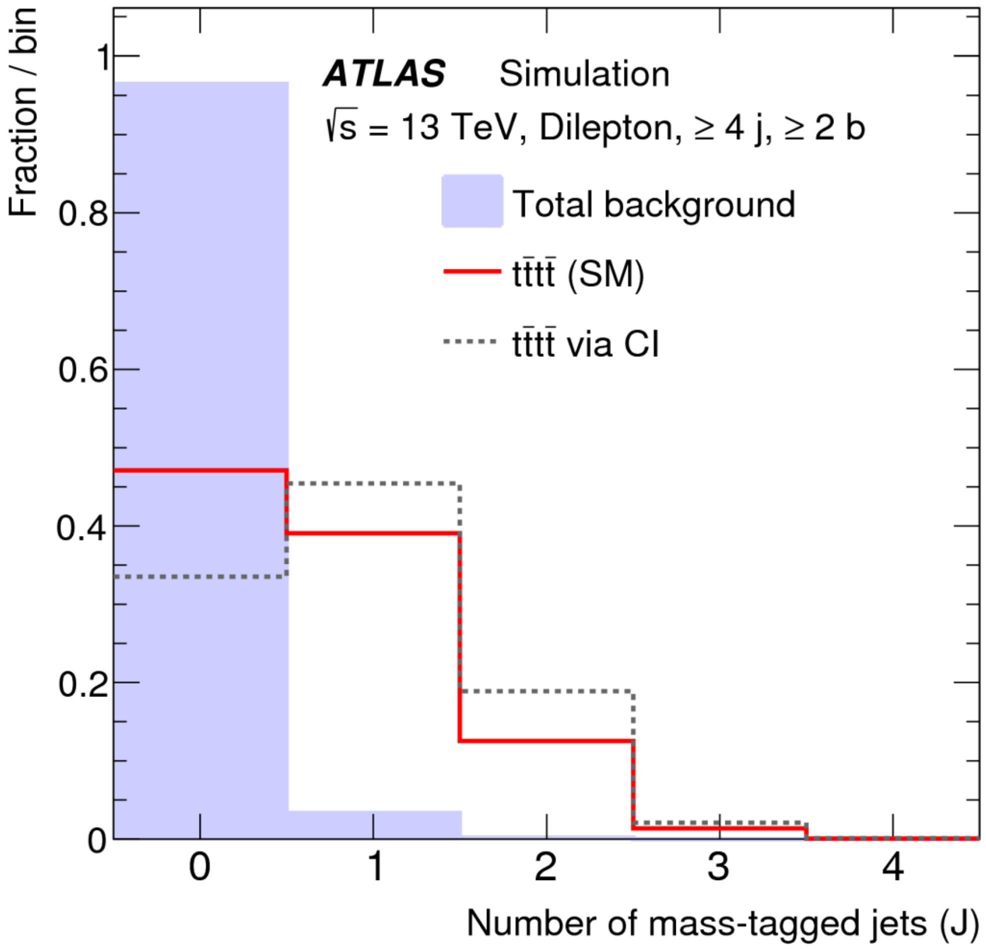
Discriminating variables



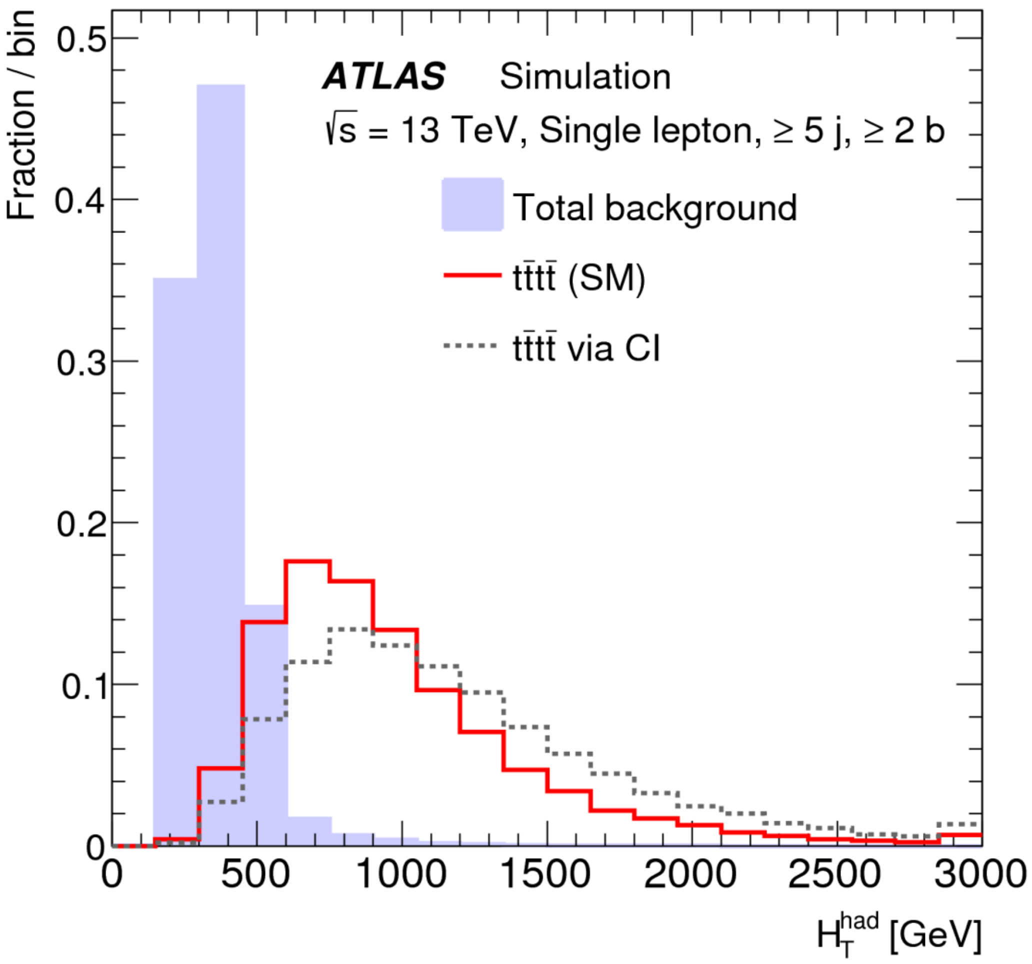


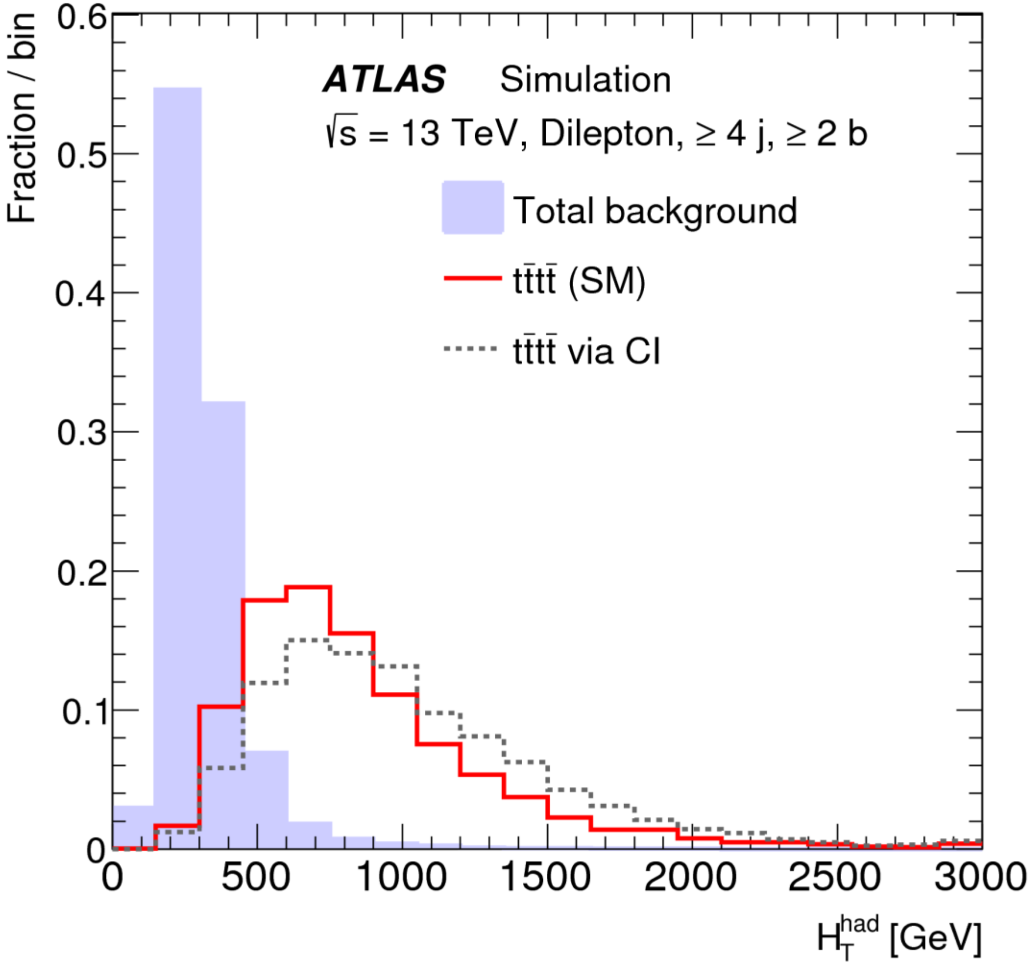
Discriminating variables





Discriminating variables

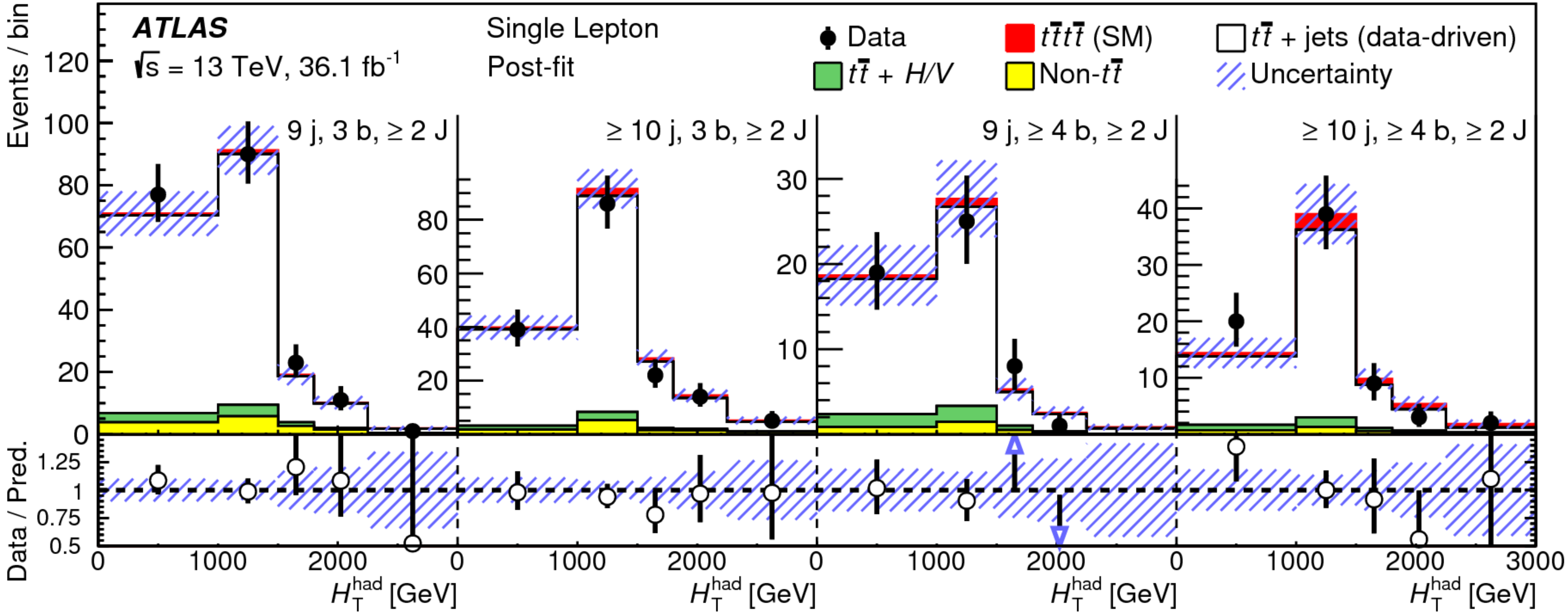




Results

Comparison between data and the predicted H_T^{Had} distributions in 1Lchannel in the signal regions.

H_T^{Had}: the scalar sum of the jet transverse momenta. ($\sum_{i=0}^{n} jet_i^{pT}$)

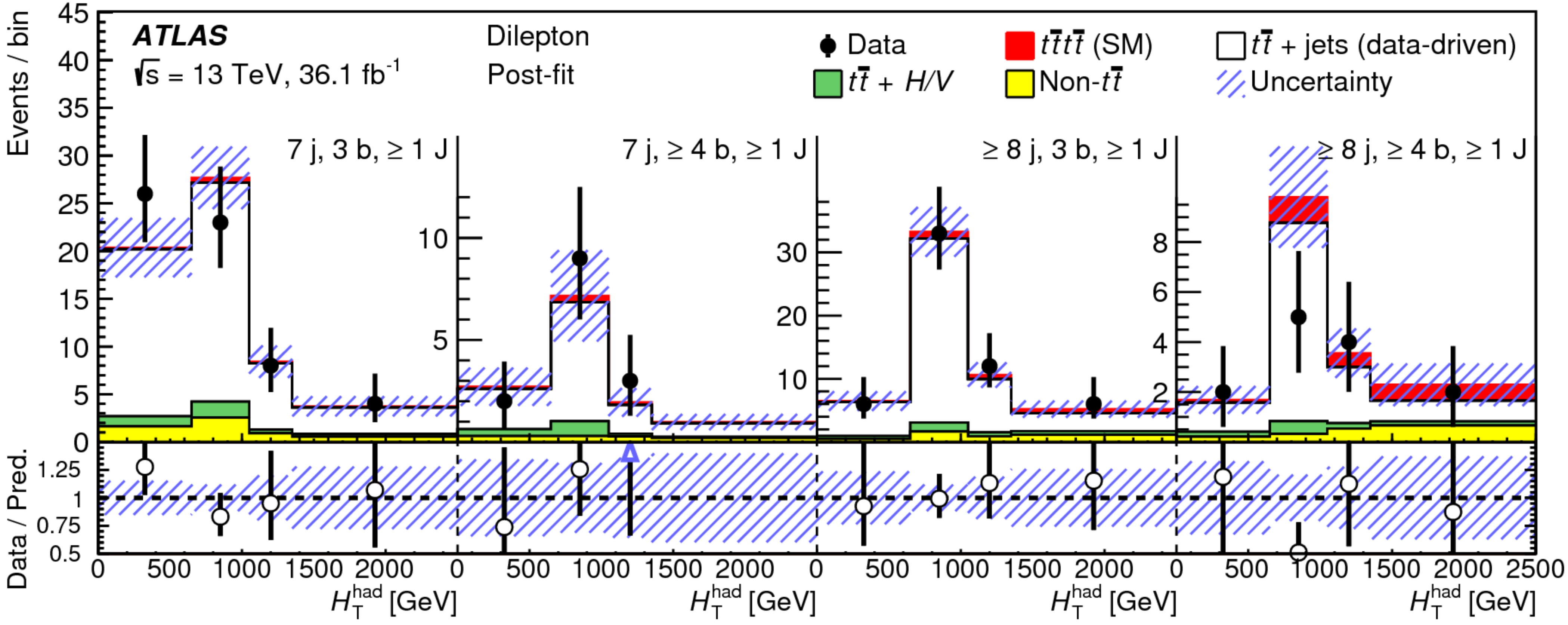


tt̄ + jets estimated using data-driven method. tt̄ + H/V are tt̄H + tt̄W + tt̄Z.
Non- tt̄ are single top + W/Z+jets + diboson.

Results

Comparison between data and the predicted H_T^{Had} distributions in OS dilepton channel in the signal regions.

H_T^{Had}: the scalar sum of the jet transverse momenta. $(\sum_{i=0}^{n} jet_i^{pT})$



tt̄ + jets estimated using data-driven method. tt̄ + H/V are tt̄H + tt̄W + tt̄Z.
Non- tt̄ are single top + W/Z+jets + diboson.

Results

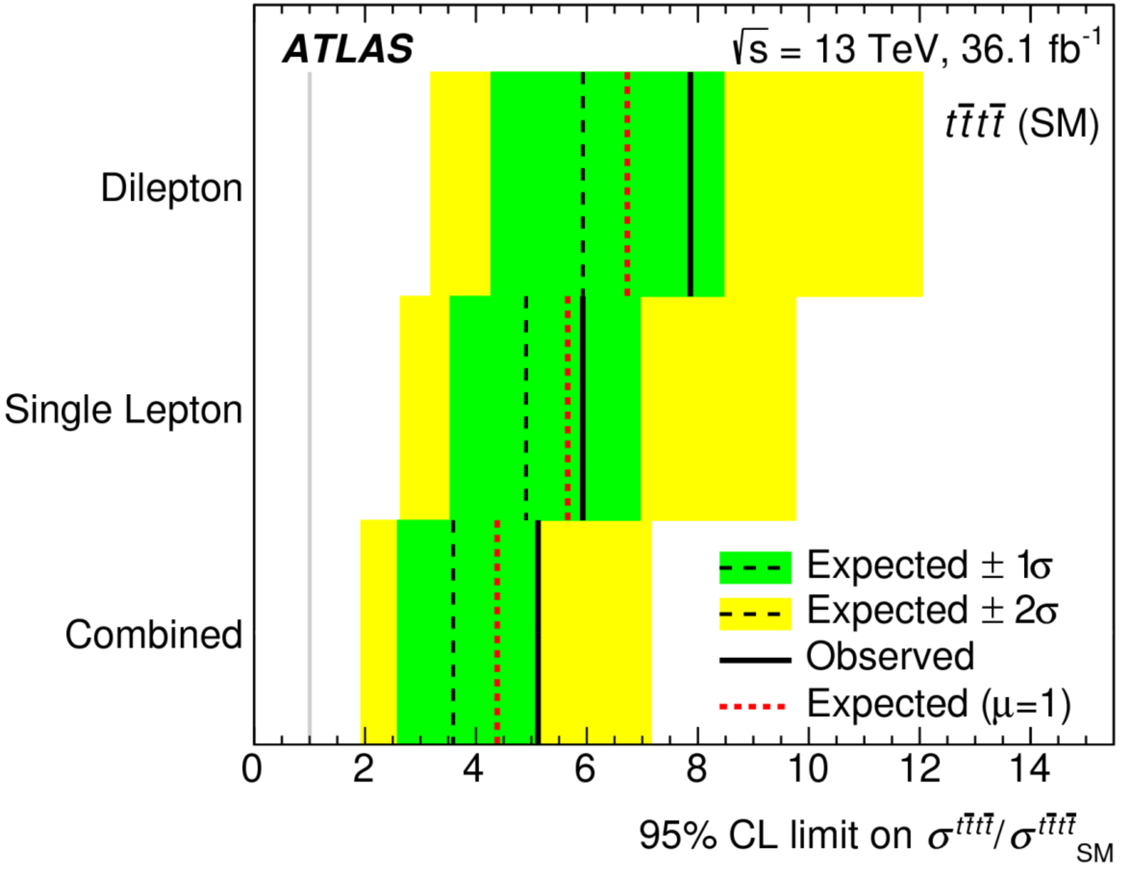
Uncertainty source	$\pm\Delta\mu$	
$t\bar{t}$+jets modeling	+1.2	−0.96
Background-model statistical uncertainty	+0.91	−0.85
Jet energy scale and resolution, jet mass	+0.38	−0.16
Other background modeling	+0.26	−0.20
b-tagging efficiency and mis-tag rates	+0.33	−0.10
JVT, pileup modeling	+0.18	−0.073
$t\bar{t}+H/V$ modeling	+0.053	−0.055
Luminosity	+0.050	−0.026
Total systematic uncertainty	+1.6	−1.4
Total statistical uncertainty	+1.1	−1.0
Total uncertainty	+1.9	−1.7

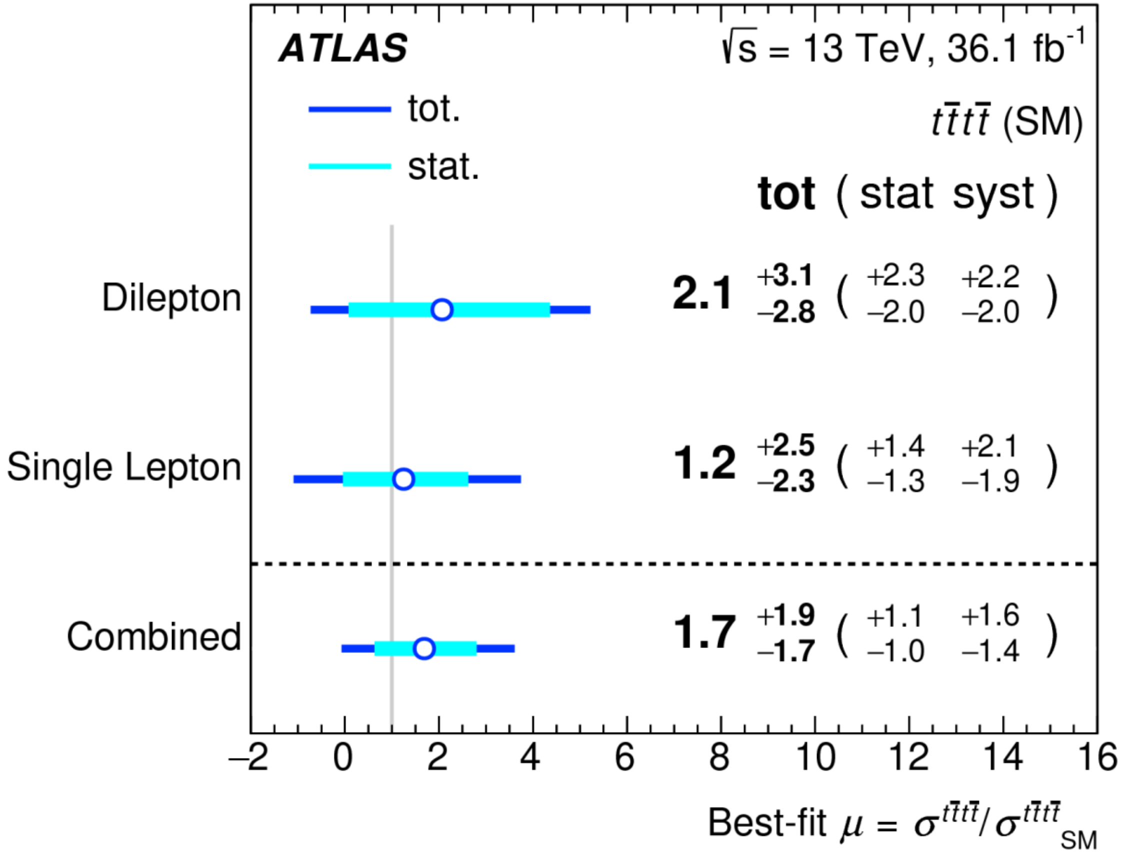
The impact of different uncertainties on the signal strength μ in the 1L/OS dilepton channels.

$$\mu = \frac{cross\text{−}section\ (measured)}{cross\text{−}section\ (theory)}$$

The search on four-top-quark signals are performed using the binned profile likelihood method to fit H_T^{Had} distribution simultaneously between data and the prediction in signal regions for single-lepton (12 regions) and dilepton (8 regions).

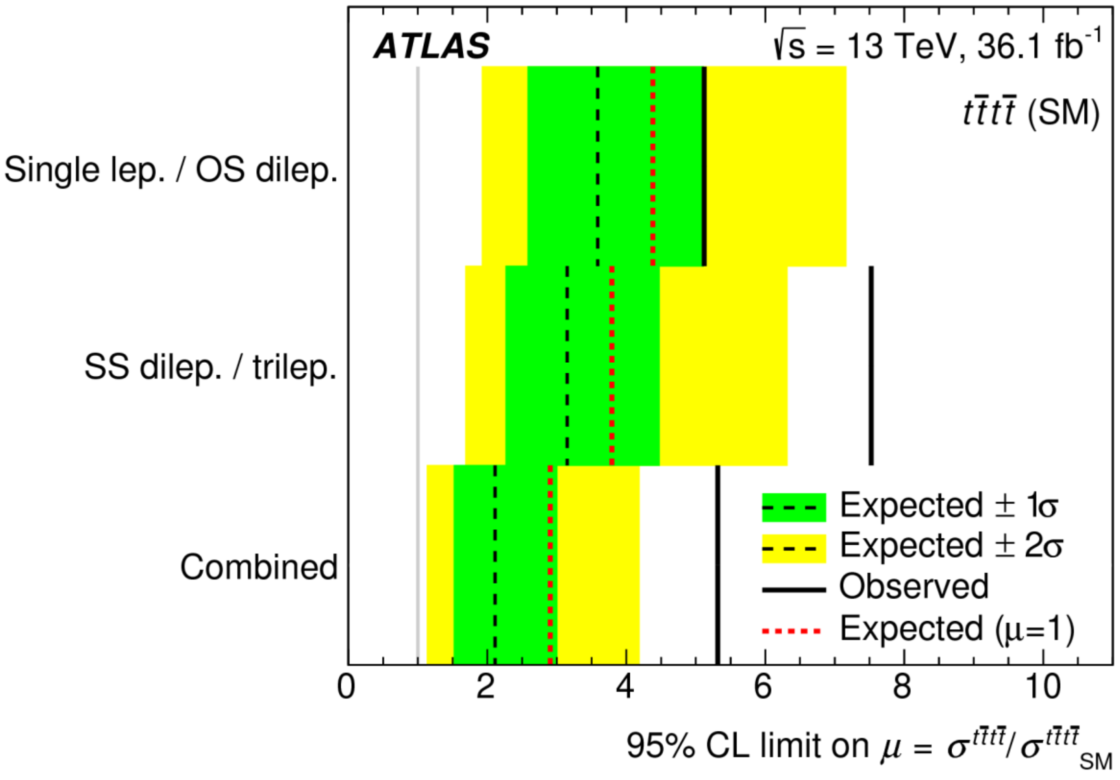
Results

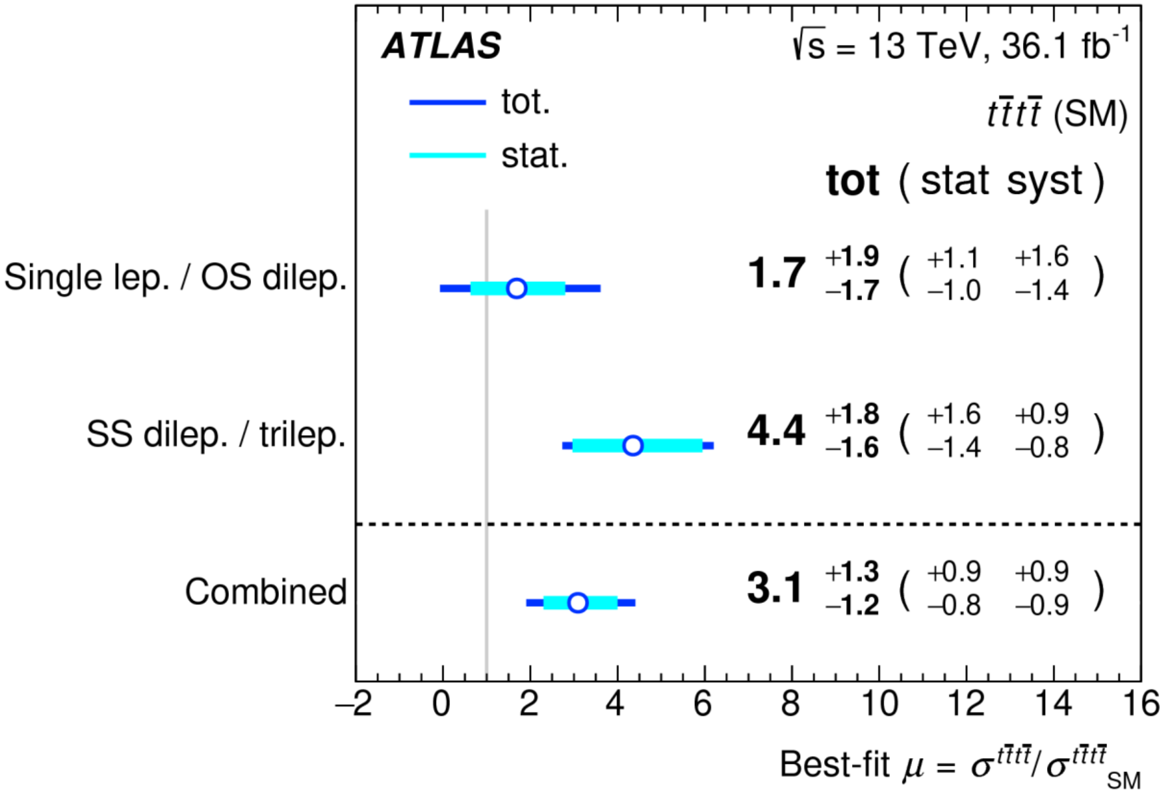




No significant excess of events above the SM expectation is observed. With CL 95% the observed (expected) upper limit on the production cross-section is obtained to be 5.1 (3.6) times $\sigma_{SM}^{t\bar{t}t\bar{t}}$.

Results

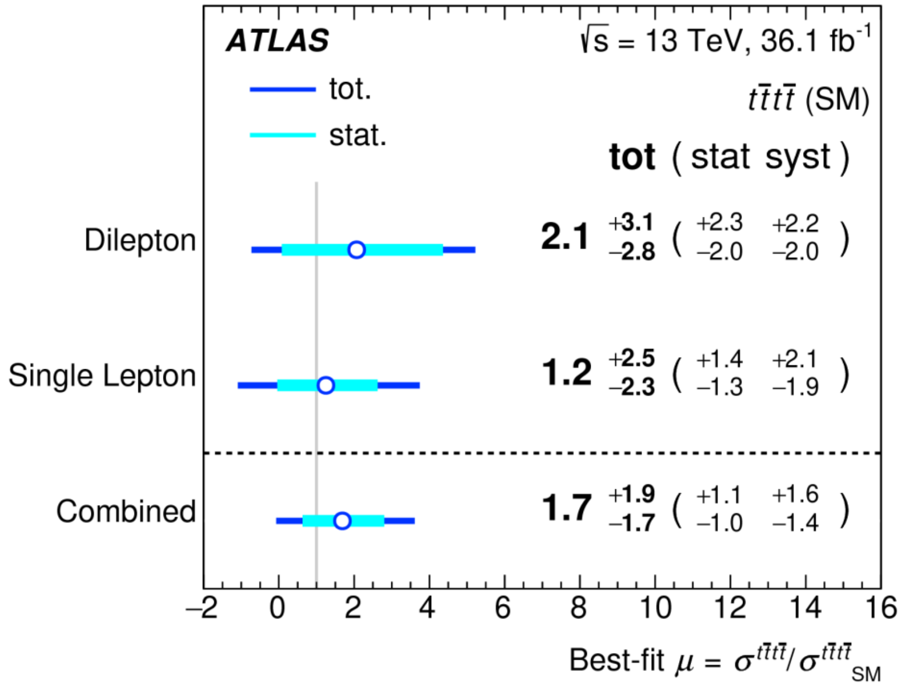




- The expected sensitivity from the combination of the two analysis channels gives an observed (expected) significance over the background expectation, equal to 2.8 (1.0)σ
- Uncertainty in μ SS 2L/3L is mainly statistical, while the systematic uncertainties dominate the 1L/OS dilepton search.

Summary

- No significant excess of events over background expectations was found.
- In 1L/OS dilepton channels the main background is $t\bar{t}$ + jets.
- New method "TRF method" used to estimate $t\bar{t}$ + jets in signal regions.
- The systematic uncertainties dominate in 1L/OS dilepton channels, while the statistical dominate in SS/Tri leptons channels.



References

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