Measurement and EFT interpretation of the $t\bar{t}$ differential cross-section in the boosted lepton+jets channel with the ATLAS detector at $\sqrt{s} = 13$ TeV

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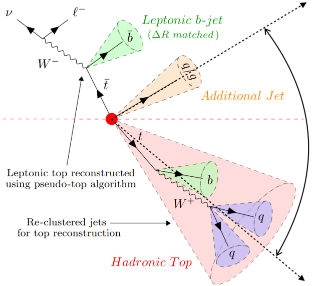
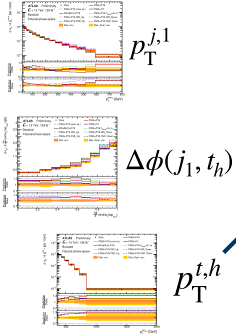
ATLAS EXPERIMENT

ErUM-FSP T02 ATLAS

Motivation: $t\bar{t}$ production in the boosted l+jets channel (ATLAS-CONF-2021-031)

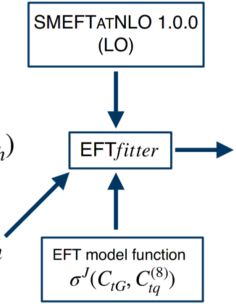
Precision measurement

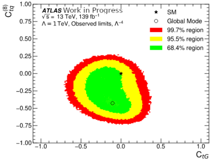


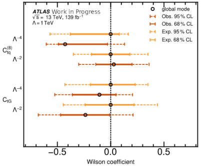


- Boosted: $p_T^{\text{top}} > 355\,\text{GeV}$
- Unf. 1D & 2D differential cross-sections
- Use improved precision (modelling, stat, **JSF method**) to test generators

New physics: EFT

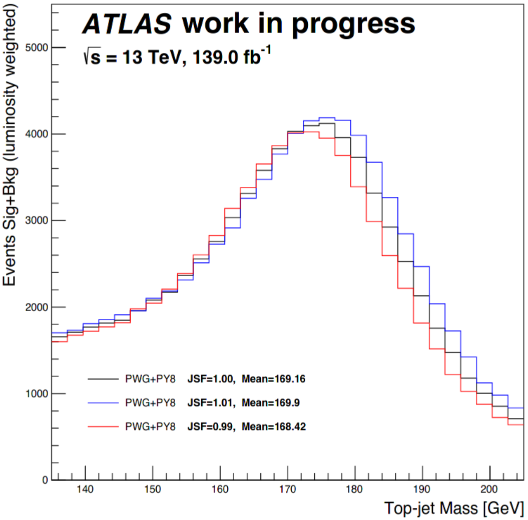


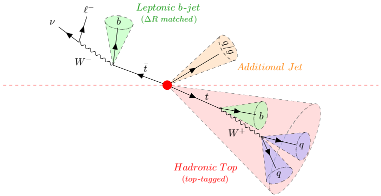




- Extract limits on BSM physics in **EFT**
- Boosted regime especially interesting
- Improved sensitivity in differential measurement

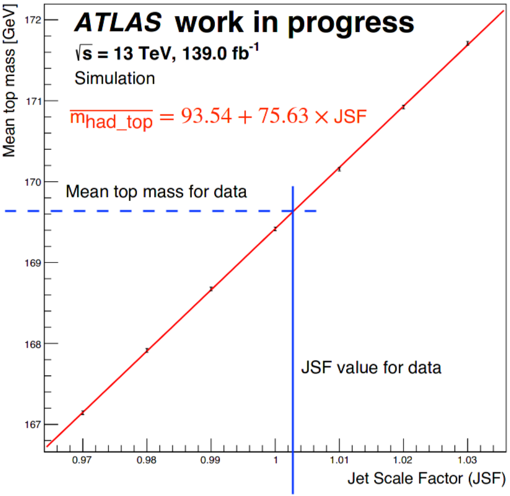
JSF Methodology





- Jet Energy Scale (JES) dominant detector uncertainty
- Mass of reclustered top-tagged jet depends on the energy-scale of its small-R sub-jets
- $\overline{m_{\text{top-jet}}}$ of MC can be matched to data
- Thus: use $m_{\text{top-jet}}$ and knowledge about top mass to reduce impact of JES uncertainties

JSF Methodology

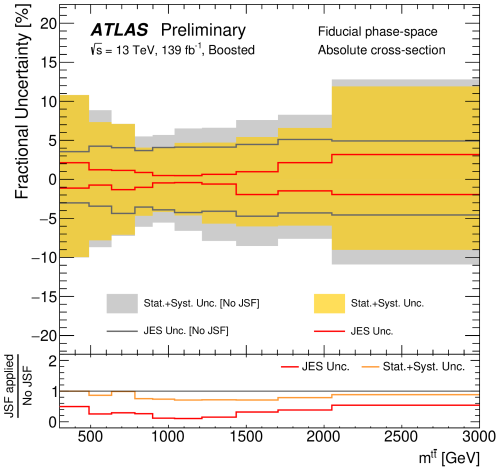


- Assume data and MC differ in small-R jet energy-scale by multiplicative factor: **Jet Scale Factor (JSF)**

$$E^{\text{corrected}}_{\text{jet,data}} = E^{\text{nominal}}_{\text{jet,data}} \times \frac{1}{\text{JSF}_{\text{data}}}$$

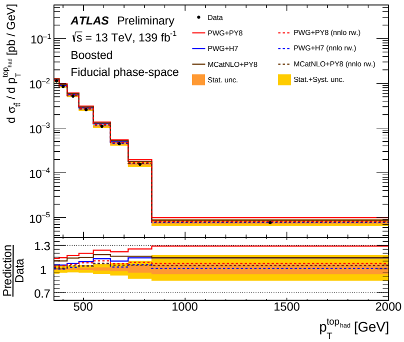
- Value derived from linear parametrisation between top-jet mass peak value and JSF
- Scale energy of **all small-R jets** in signal+background MC and systematic variations
- JSF can absorb any overall systematic difference between data and MC in jet energies

JSF impact and result (ATLAS-CONF-2021-031)



$$\sigma_{\text{tot}} = 1.267 \pm 0.005\,(\text{stat}) \pm 0.053\,(\text{syst})\,\text{pb}$$

- JES uncertainties are not gone, but reduced (from 4.2 % to 0.7 % for σ_{tot})
- Precision at 4.2 %
- NNLO rew. predictions in better agreement



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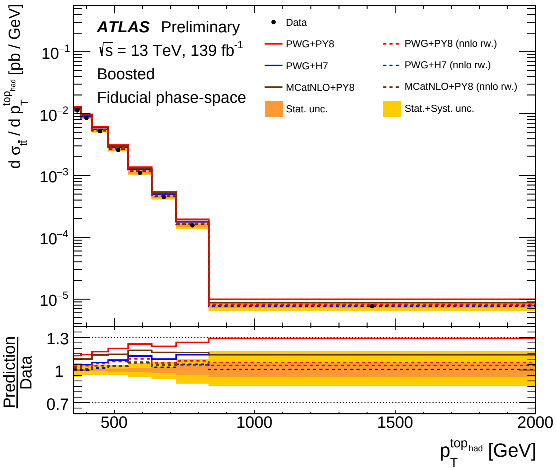

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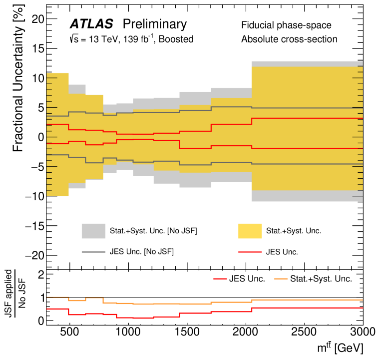


EFT recipe - describing new physics with effective field theories

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_1 + \mathcal{L}_2 + \ldots, \qquad \underbrace{\mathcal{L}_i = \sum_j \frac{1}{\Lambda^i} C_j O_j}_{\text{EFT terms of mass-dimension } 4+i}$$

- EFT terms: **gauge-invariant**, higher dimensional terms built from **SM fields** [1802.07237].
- BSM energy scale Λ (1 TeV hereafter)
- measure for strength of operator: Wilson coefficients C_j
- only even-dimensional operators O_j can conserve lepton and baryon number

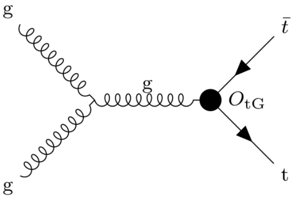
Dimension-6 operators in physics observables

$$\sigma = \overbrace{\underbrace{\sigma_{\text{SM}} + \frac{1}{\Lambda^2}\sigma_{\text{SM-EFT}}}_{\Lambda^{-2}} + \frac{1}{\Lambda^4}\sigma_{\text{EFT}}}^{\Lambda^{-4}}$$

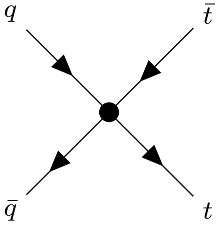
$\mathcal{O}(\frac{1}{\Lambda^2})$ SM-dim6-interference terms
$\mathcal{O}(\frac{1}{\Lambda^4})$ pure dim6 contributions

Operators of Interest: O_{tG} and $O_{tq}^{(8)}$

$$O_{tG} = ig_s(\bar{Q}\sigma^{\mu\nu}T^A t)\tilde{\Phi}G^A_{\mu\nu}$$



$$O_{tq}^{(8)} = (\bar{q}_i\gamma^\mu T^A q_i)(\bar{t}\gamma_\mu T^A t)$$

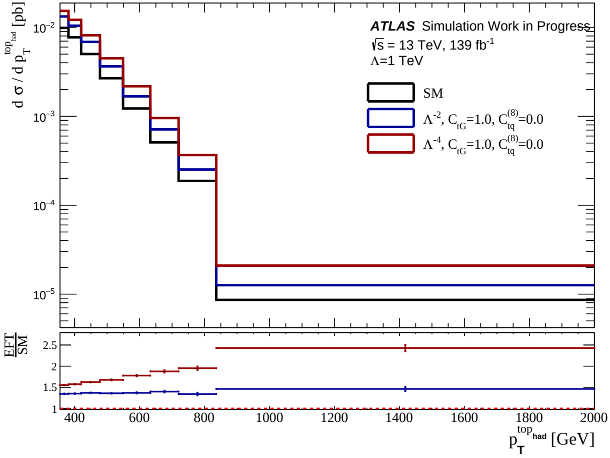


- largest impact on $t\bar{t}$
- Among strongest of the 4-fermion operators in $t\bar{t}$

Goal:

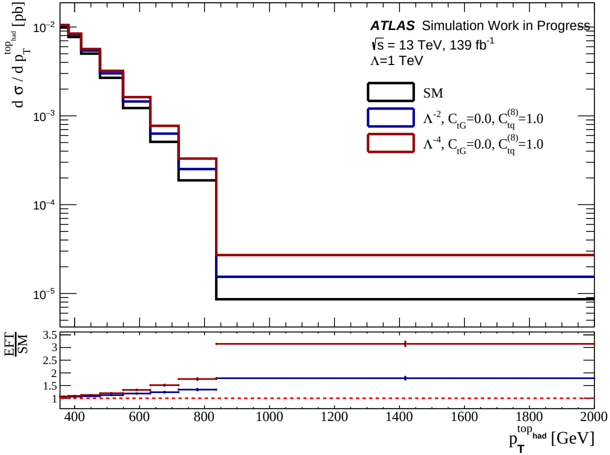
Disentangle and constrain these two quite different operators at the same time in a differential measurement.

EFT observables: impact of the operator O_{tG}



- EFT MC simulation produced at LO using `MadGraph5` and the `SMEFTatNLO` UFO model
- Replace SM prediction by NNLO reweighted `Powheg`
- Observable of choice: $p_T^{\mathrm{top_{had}}}$
  - Agreement to nominal MC
  - Strength of expected limits
- Effects of O_{tG} at Λ^{-2} flat, energy dependence at Λ^{-4}

EFT observables: impact of the operator $O_{tq}^{(8)}$



- Effects of $O_{tq}^{(8)}$ smaller than O_{tG}, but show stronger energy dependence at both orders
- At large momenta effects larger than O_{tG}

EFT analysis overview using EFT*fitter*.jl[1]

Parameters:
- C_{tG} and $C_{tq}^{(8)}$
- flat priors

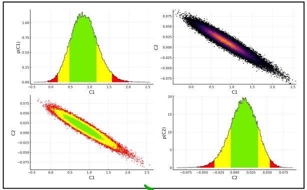
Observables:
- differential rates

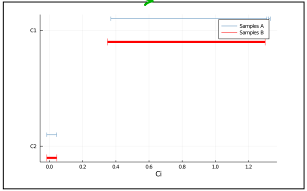
(EFT MC + Powheg SM)

Observations:
- differential rates
- uncertainties
- correlations

Model:
per bin model function
$\sigma_i^j(C_{tG}, C_{tq}^{(8)})$

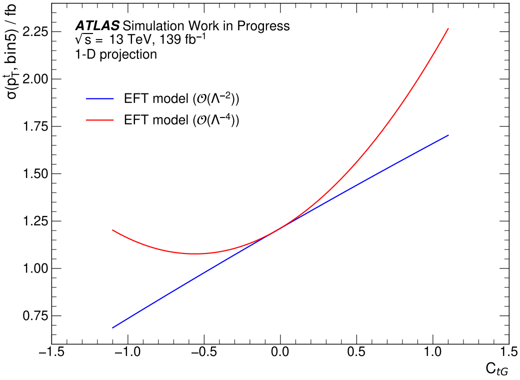
EFT*fitter*:
Bayesian Analysis

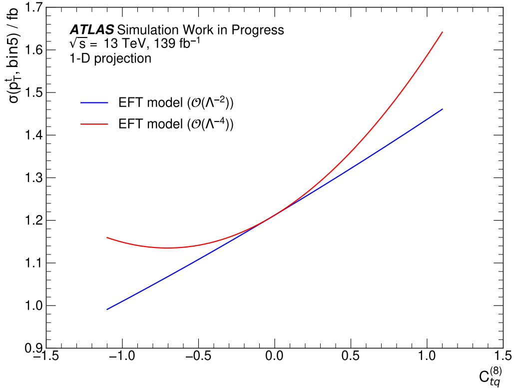




[1] https://tudo-physik-e4.github.io/EFTfitter.jl/stable/

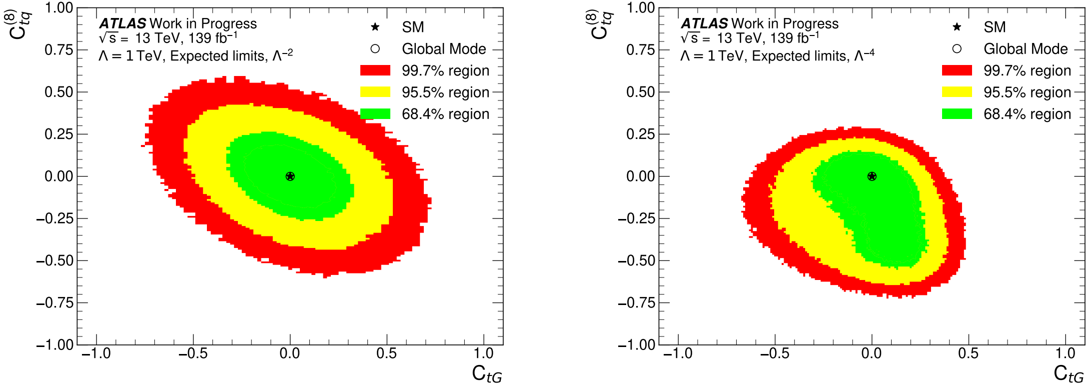
EFT model function





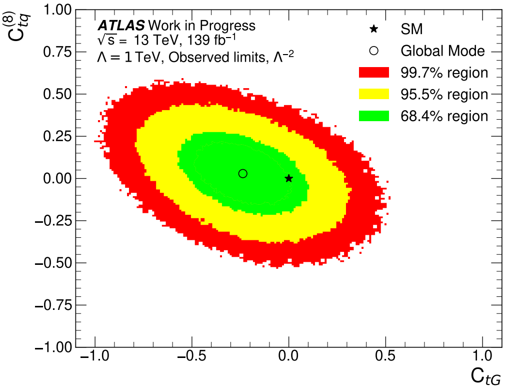
- Quadratic model introduces degeneracy
- Limits will be skewed towards negative values or have a second island in Λ^{-4} model

Expected EFT limits



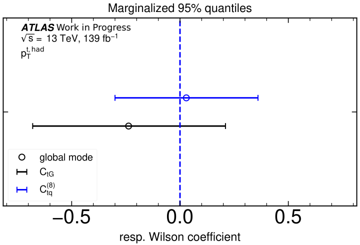
- The expected asymmetry due to the degeneracy of the quadratic model is seen in the posterior

Observed EFT limits



- Posteriors in data shifted toward the negative due to data undershooting the prediction
- Operator effects are nicely disentangled (high-p_T bins)

Observed EFT limits



- Observed limits shifted toward the negative due to data undershooting the prediction
- Effect in Λ^{-2} model only on O_{tG}
- In both models results in agreement with the SM
- Limits in $O_{tq}^{(8)}$ competitive with global analysis $\rightarrow$**great input to combinations**

	Wilson coefficient	Expected limit [TeV^{-2}]	Observed limit [TeV^{-2}]	Global fit[2] [TeV^{-2}]
$\mathcal{O}(\Lambda^{-2})$	C_{tG}	[-0.41, 0.42]	[-0.63, 0.20]	[0.007, 0.111]
	$C_{tq}^{(8)}$	[-0.35, 0.36]	**[-0.34, 0.27]**	**[-0.40, 0.61]**
$\mathcal{O}(\Lambda^{-4})$	C_{tG}	[-0.44, 0.28]	[-, -]	[0.006, 0.107]
	$C_{tq}^{(8)}$	**[-0.57, 0.18]**	[-, -]	**[-0.48, 0.39]**

[2] J. J. Ethier et al., Combined SMEFT interpretation of Higgs, diboson, and top quark data from the LHC, (2021), arXiv: 2105.00006 [hep-ph]

Summary

- New full Run-2 differential cross-sections for boosted $t\bar{t}$ in lepton+jets channel
- Much improved uncertainties also due to method reducing impact of JES
- Interpretation in context of EFT shows potential of differential measurements
- Successful disentanglement of two operators and competitive limits on $O_{tq}^{(8)}$ with a single measurement
- Paper out soon and results already published as ATLAS-CONF-2021-031