Results on top quark physics from ATLAS, CMS and LHCb

Discovery physics at the LHC, Kruger, 2018

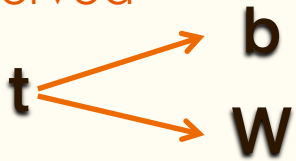
James Keaveney

the top quark - king of the particle jungle

heaviest fundamental particle

'bare' quark

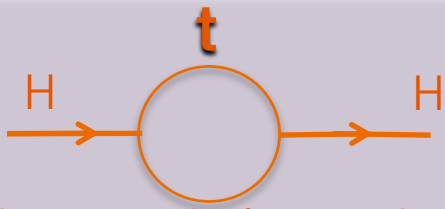
- decays before hadronisation
- window into quark properties
- spin info. preserved



SM parameters

- rates and kinematics sensitive to m_t, α_S and PDF
- precision probes higher-order SM calculations, eg. NNLO+ α^3_{EW}

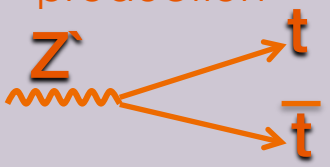
new physics



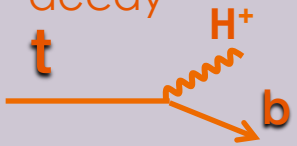
top likely plays a role in m_H stabilisation

BSM effects with tops -

new states in production

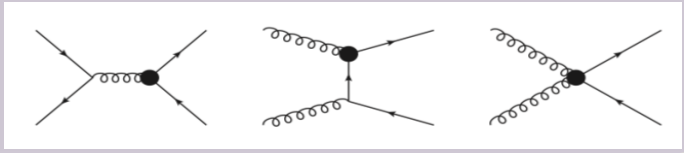


new states in decay



new physics at a large scale Λ

new interactions described in EFT



the top quark
– experimental programme

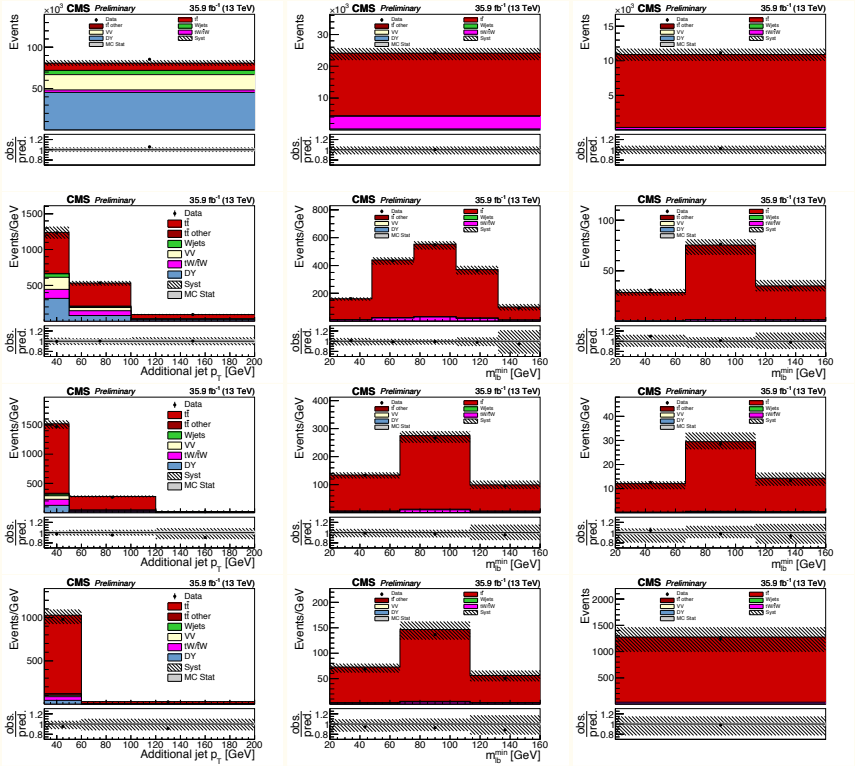
- **cross sections**
  - inclusive and (multi)-differential
  - tt, single top
  - boosted regime
- **rare production & decay modes**
  - tt+Z,W, γ
  - tZq production
  - FCNC decays
  - tttt
- **modelling**
  - tuning of underlying event
  - parton shower, hadronisation
- **mass + properties**
  - mass, width, charge
  - charge asymmetries
- **reinterpretations**
  - m_t (pole), m_t ($\overline{ms}$), PDF and α_S
  - EFT constraints

focusing on recent 13 TeV results

σ_{tt} incl. with m_t and α_S extraction

CMS-PAS-TOP-17-001

- simultaneous fit in 9 ($N_{additional\ jet}$ $N_{b\text{-}jet}$) categories



- **fit of σ_{tt}**

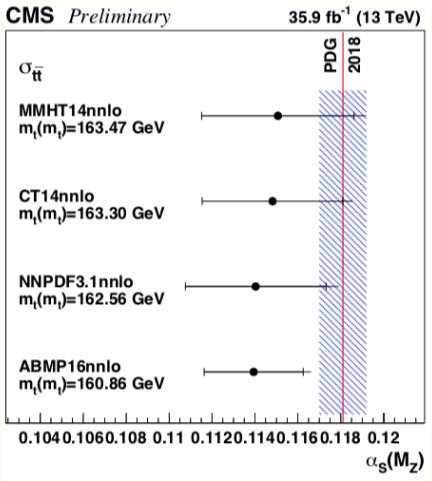
σ_{tt} = 803 ± 2(stat.) ± 25(syst.) ± 20(lumi.) pb

- fit of σ_{tt} and m_t^{MC}

σ_{tt} = 815 ± 2(stat.) ± 29(syst.) ± 20(lumi.)

m_t^{MC} = 172.33 ± 0.14(stat.) $^{+0.66}_{-0.72}$(syst.) GeV

- **m_t (pole), $m_t(\overline{ms})$ and α_S**



- m_t, α_S and PDF fitted simultaneously
- α_S extracted for various PDFs
- all results slightly below world average

- syst. uncertainties reduced via fitting of nuisance parameters

σ_{tt} inclusive (dilepton)

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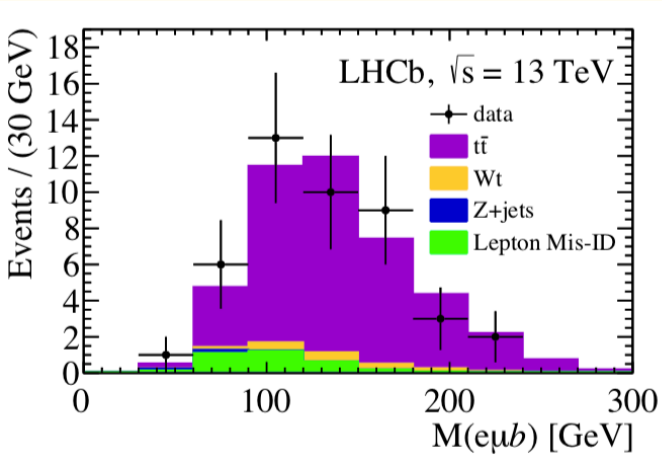
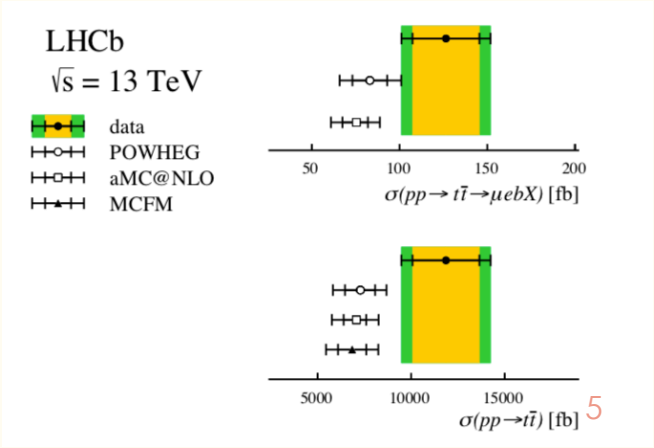
- fiducial cross section in the **forward region**
  - 1.93 fb^{-1} (2015+2016)
  - exploits e μ b final state
  - pure sample of tt events
  - limited by stat. and b-tagging uncertainties
- results agree with NLO MC
  - unique test of SM and modelling
  - more data will yield interesting possibilities
    - very high-X gluon PDF
    - measure charge asymmetry in forward region





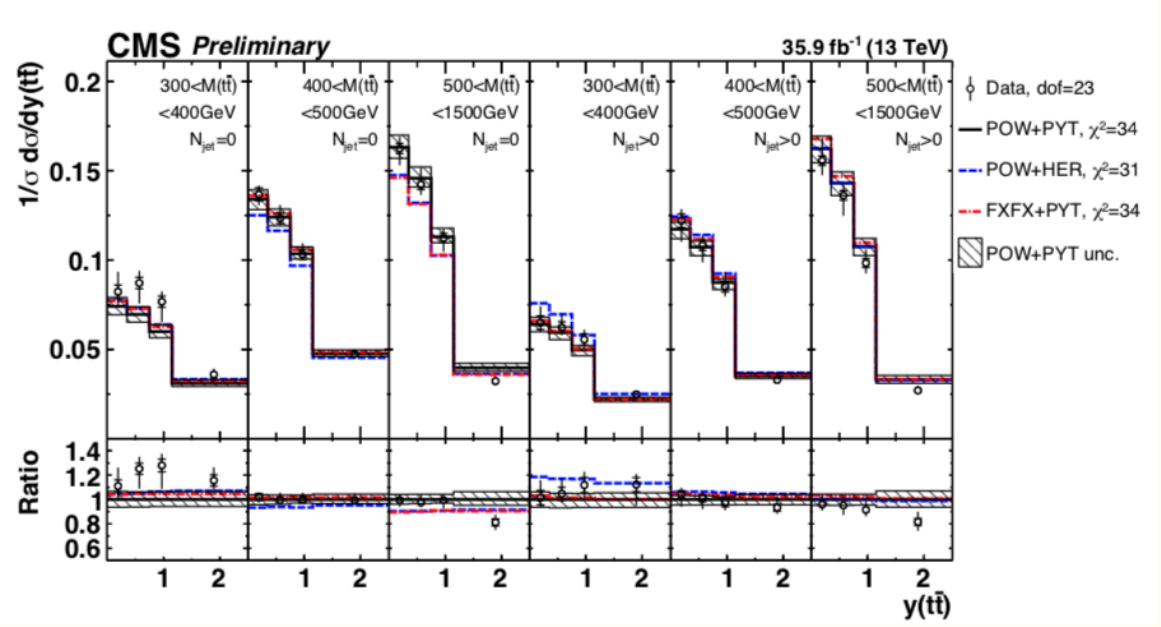
σ_{tt} double/triple diff. (dilepton)

CMS-PAS-TOP-18-004

- $d\sigma_{tt}$ measured as 2 and 3 dim. functions of kinematic variables
- deep probe of NLO SM predictions
- allows simultaneous, independent extraction of m_t , α_S and PDF

double diff. for variable pairs:

- y (top) & p_T (top)
- m (tt) & y (top)
- m (tt) & y (tt)
- m (tt) & $\Delta\eta$ (tt)
- m (tt) & $\Delta\Phi$ (tt)
- m (tt) & p_T (tt)
- m(tt) & p_T (top)



triple diff. for:

- m (tt) & y (tt) & N_{jet} ($N_{jet} = 0$, $N_{jet} > 0$)
- m (tt) & y (tt) & N_{jet} ($N_{jet} = 0$, $N_{jet} = 1$, $N_{jet} > 1$)

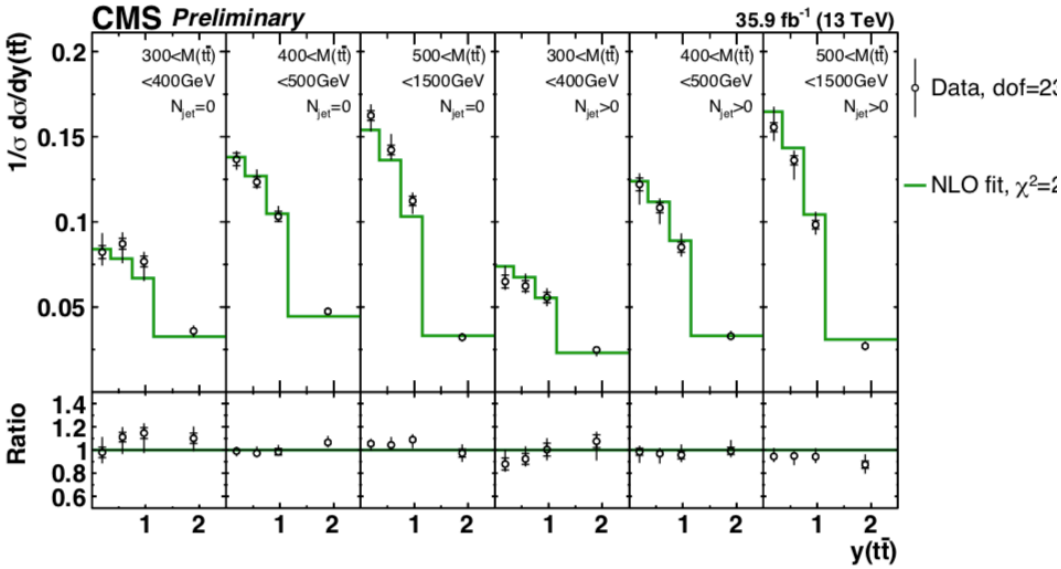
no prediction successfully describes all distributions

σ_{tt} double/triple diff. (dilepton)

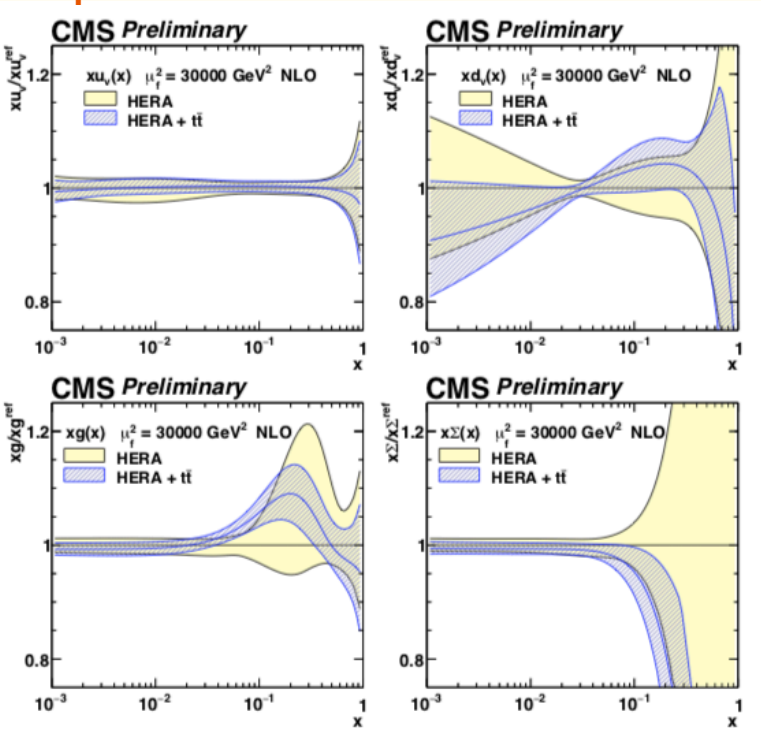
CMS-PAS-TOP-18-004

- **simultaneous fit of m_t, α_S and PDF**
  - triple diff σ_{tt} (m (tt), y (tt), N_{jet}) + HERA data input to **xFitter**

data vs. NLO with fitted m_t, α_S and PDF



impact on PDFs



fitted m_t, α_S values

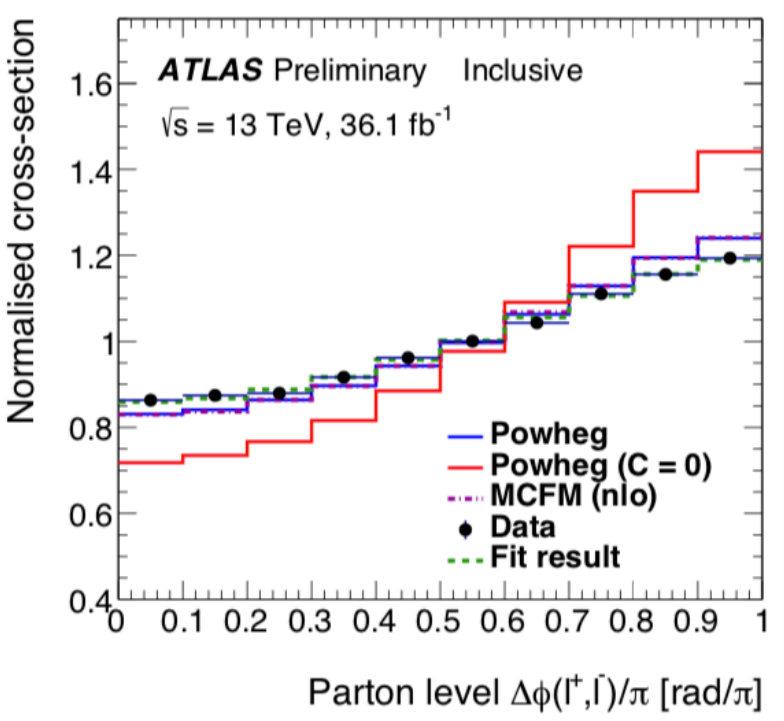
$$\alpha_s(M_Z) = 0.1135 \pm 0.0016(\text{fit})^{+0.0002}_{-0.0004}(\text{mod})^{+0.0008}_{-0.0001}(\text{par})^{+0.0011}_{-0.0005}(\text{scale}) = 0.1135^{+0.0021}_{-0.0017}(\text{total}),$$

$$m_t^{\text{pole}} = 170.5 \pm 0.7(\text{fit})^{+0.1}_{-0.1}(\text{mod})^{+0.0}_{-0.1}(\text{par})^{+0.3}_{-0.3}(\text{scale})\ \text{GeV} = 170.5 \pm 0.8(\text{total})\ \text{GeV}.$$

spin correlations in tt (dilepton)

ATLAS-CONF-2018-027

- new physics in tt production can disrupt tt spin correlations
- Δ Φ between leptons in dilepton tt events is sensitive to SC
- Δ Φ measured inclusively at parton and particle levels and in m_{tt} bins
  - high purity and only leptons required -> precision measurement!

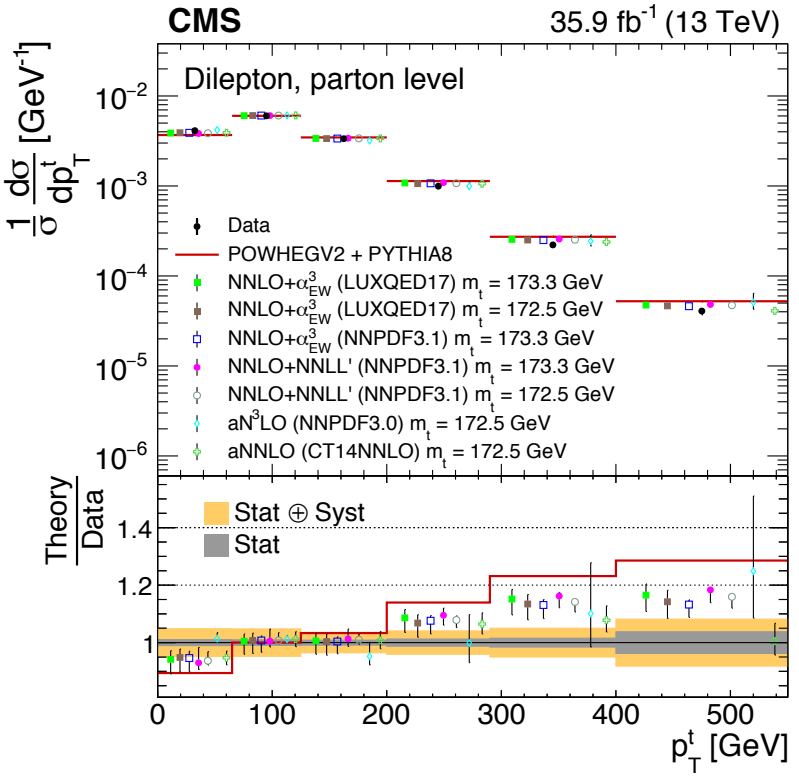


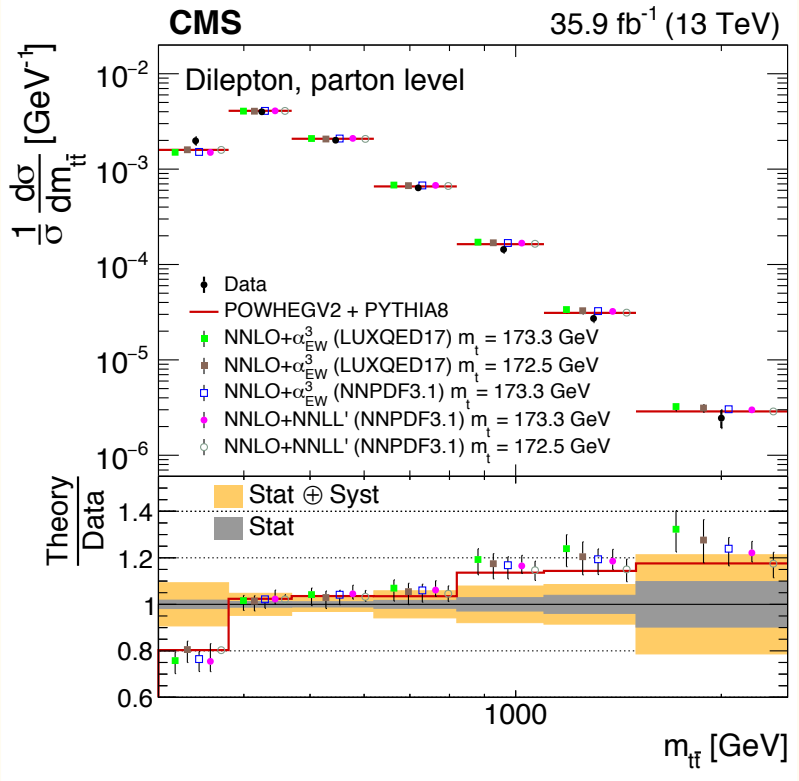
- parton level results show 3.2 **σ** deviation with respect to NLO SM predictions
- data favours stronger SC
- deviations < 1.4 **σ** in individual m_{tt} bins

σ_{tt} differential (dilepton)

CMS-PAS-TOP-17-014

- comprehensive set of **1D** differential cross sections
  - (parton/particle-level) X (absolute, normalised) = 94 distributions

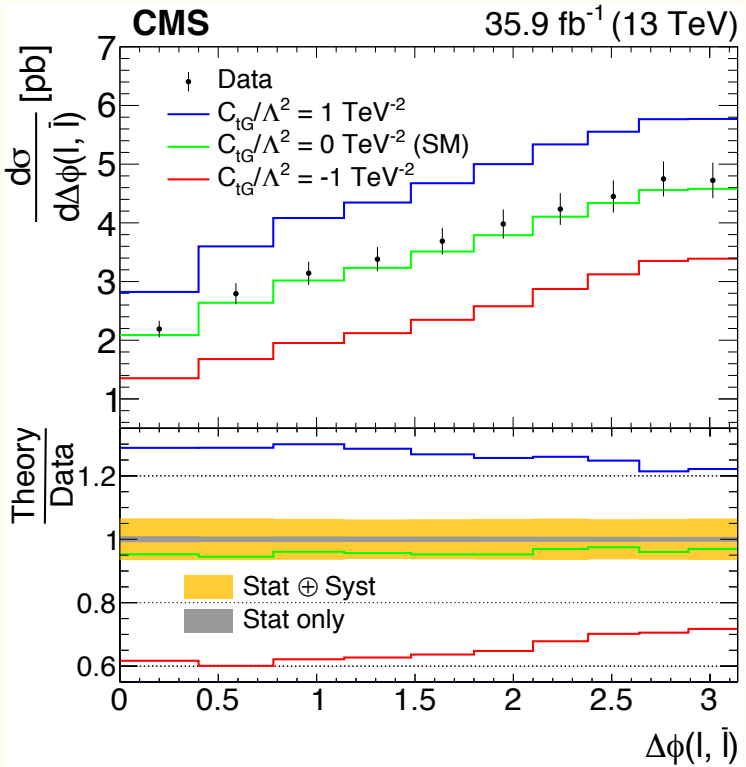


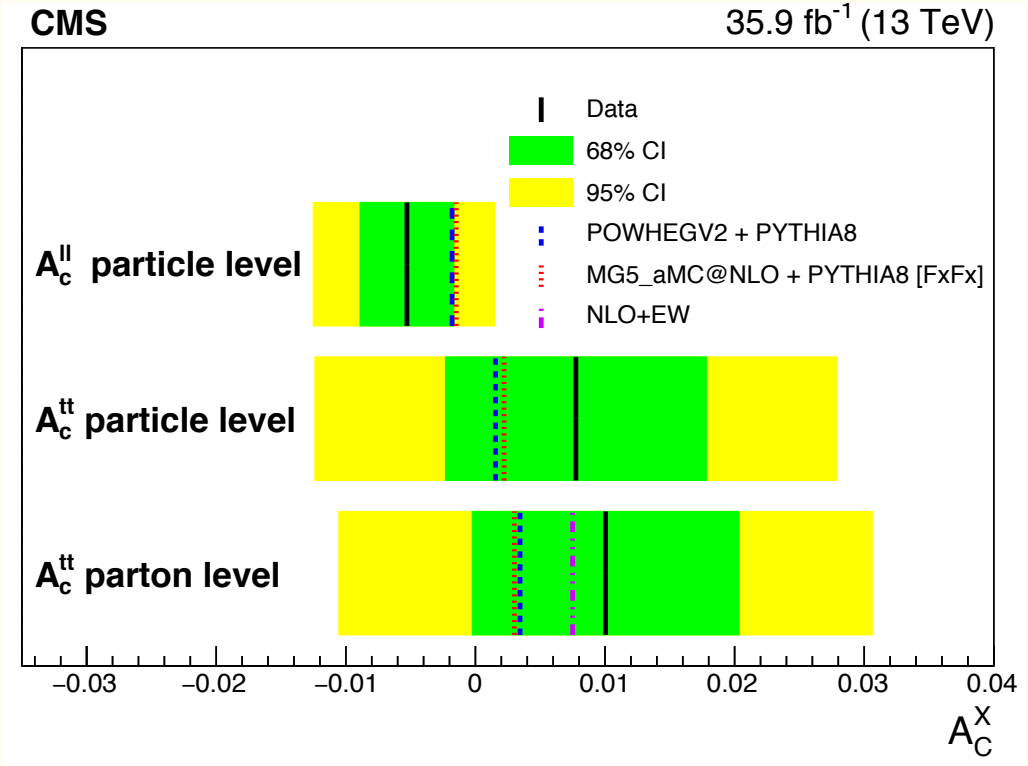


- data compared with state of the art predictions, e.g, NNLO+ α^3_{EW}, NNLO+NNLL'
- disagreement with all predictions for pt (top), m_{tt} and others

σ_{tt} differential (dilepton) arXiv:1811.06625

- comprehensive set of **1D** differential cross sections
  - (parton/particle-level) X (absolute, normalised) = 94 distributions



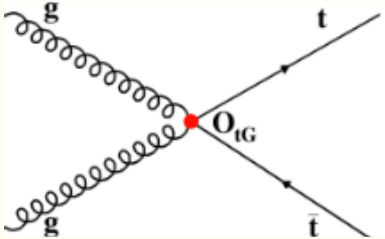


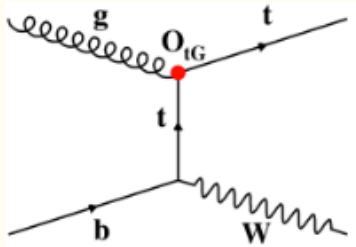
- particle level $\Delta\Phi(l,l)$ distribution used to constrain EFT coefficients
- top quark and leptonic charge asymmetries extracted (first time @ 13 TeV)

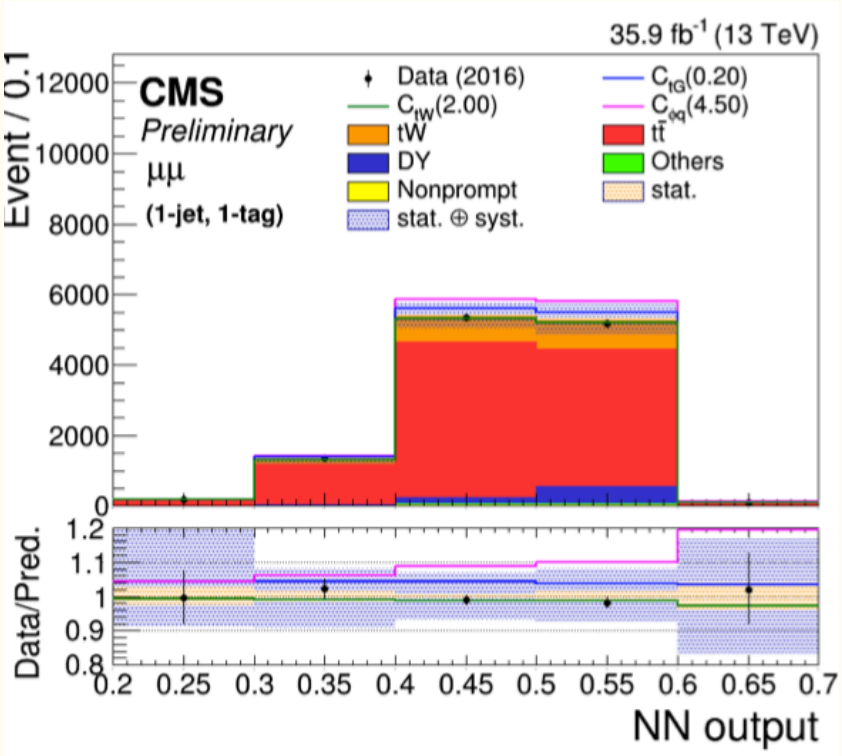
search for new physics in tt & tW

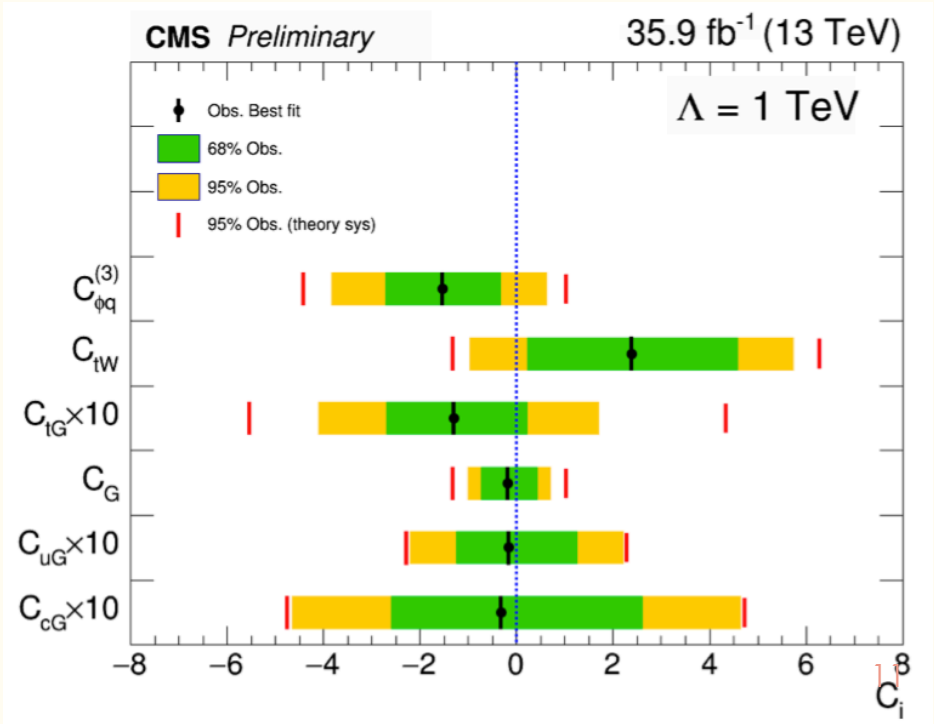
CMS-PAS-TOP-17-020

- constrain EFT with fiducial tt, tW rates
- same EFT operators can affect tt & tW
- neural net discriminant in categories
- separate fits for 6 operators



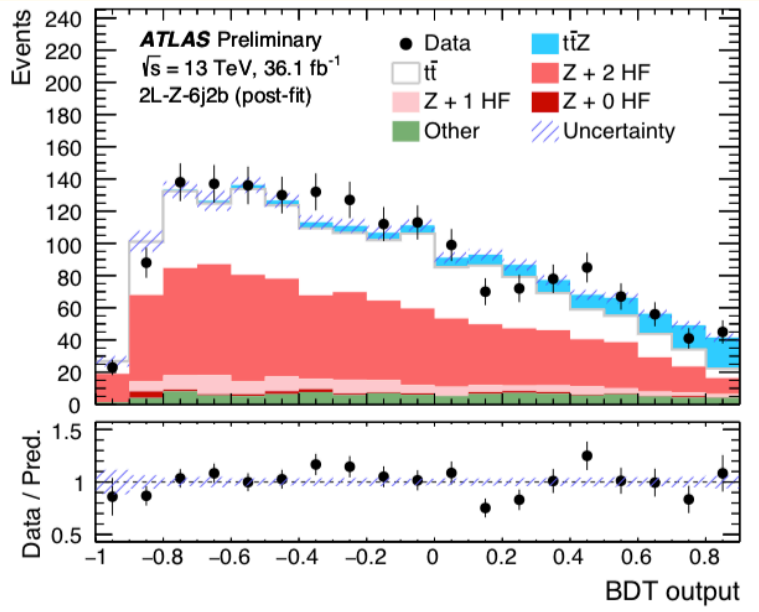


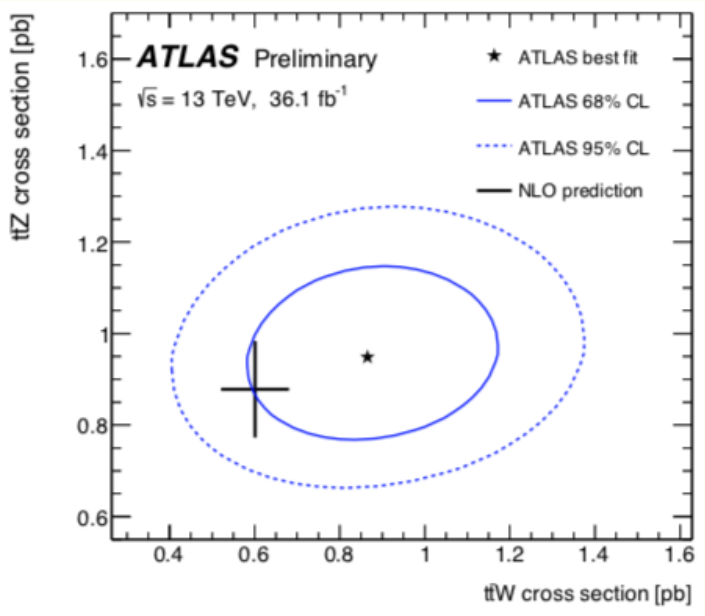




σ_{ttZ} , σ_{ttW} (multileptons) ATLAS-CONF-2018-047

- σ_{ttZ} , σ_{ttW} measured simultaneously using multi-lepton events
- BDT used to suppress backgrounds
- systematics suppressed with fit





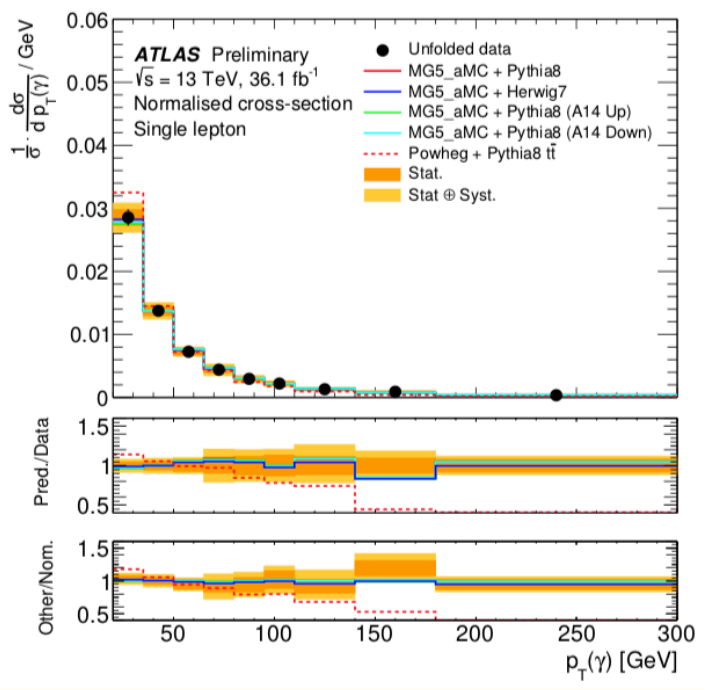
Coefficient	Expected limits at 68% and 95 % CL	Observed limits at 68% and 95 % CL	Previous constraints at 95 % CL
$(C^{(3)}_{\phi Q} - C^{(1)}_{\phi Q})/\Lambda^2$	[-2.1, 1.9], [-4.6, 3.7]	[-1.0, 2.7], [-3.4, 4.3]	[-3.4, 7.5]
$C_{\phi t}/\Lambda^2$	[-3.8, 2.8], [-23, 5.0]	[-2.0, 3.6], [-27, 5.7]	[-2.0, 5.7]
C_{tB}/Λ^2	[-8.3, 8.6], [-12, 13]	[-11, 10], [-15, 15]	[-16, 43]
C_{tW}/Λ^2	[-2.8, 2.8], [-4.0, 4.1]	[-2.2, 2.5], [-3.6, 3.8]	[-0.15, 1.9]

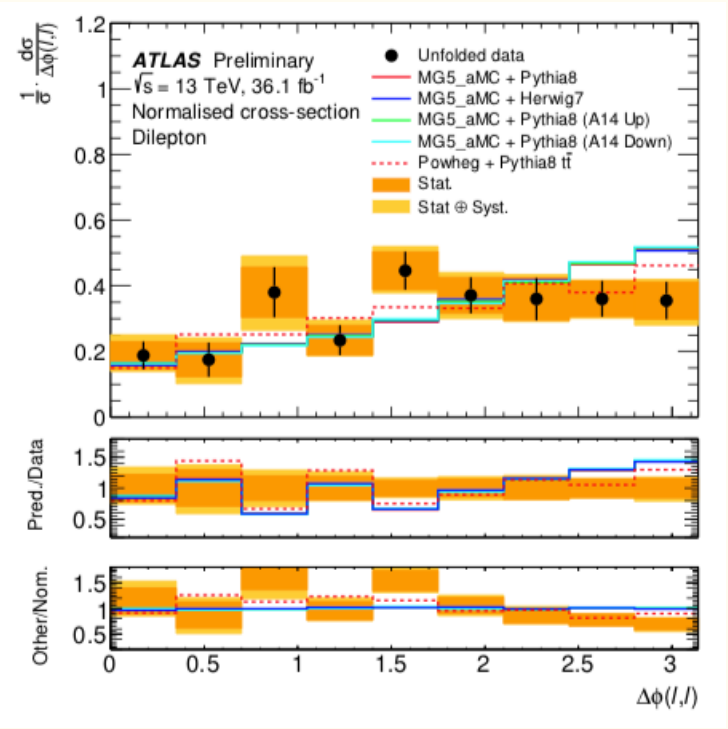
- results consistent with SM, used to constrain EFT coefficients

$\sigma_{tt\gamma}$ differential (l+jets, dilepton)

ATLAS-CONF-2018-048

- probes top electroweak coupling
  - sensitive to top charge & chromomagnetic/electric dipole moments
  - ttγ helps understanding of tension between LHC and Tevatron charge asymmetry results

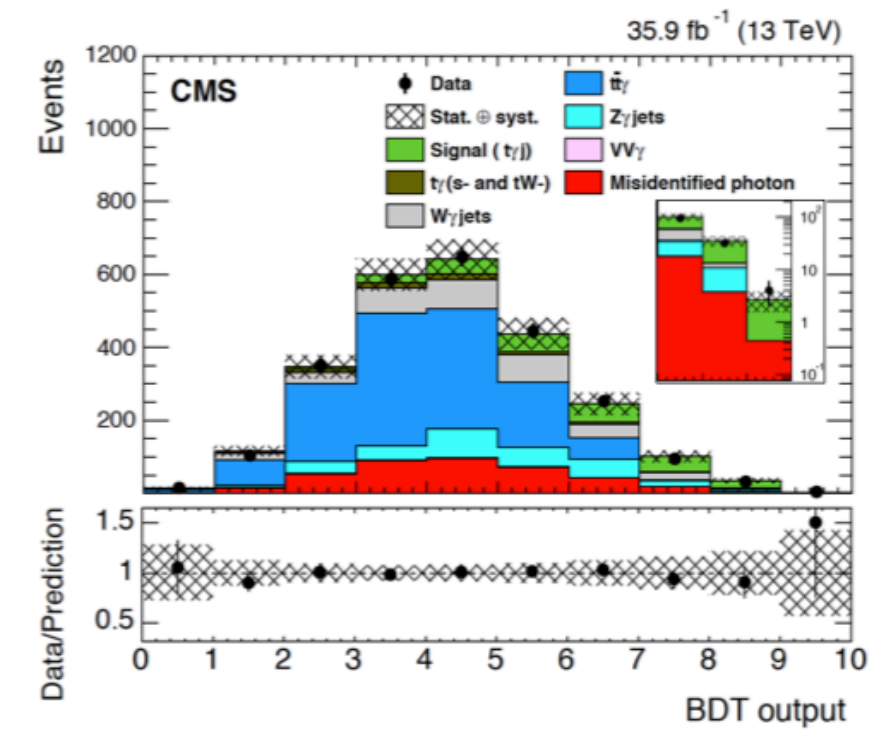




- data unfolded to fiducial phase
- multiple distributions measured
- data agree well with NLO predictions
- statistical uncertainties dominate

tγ arXiv:1808.02913

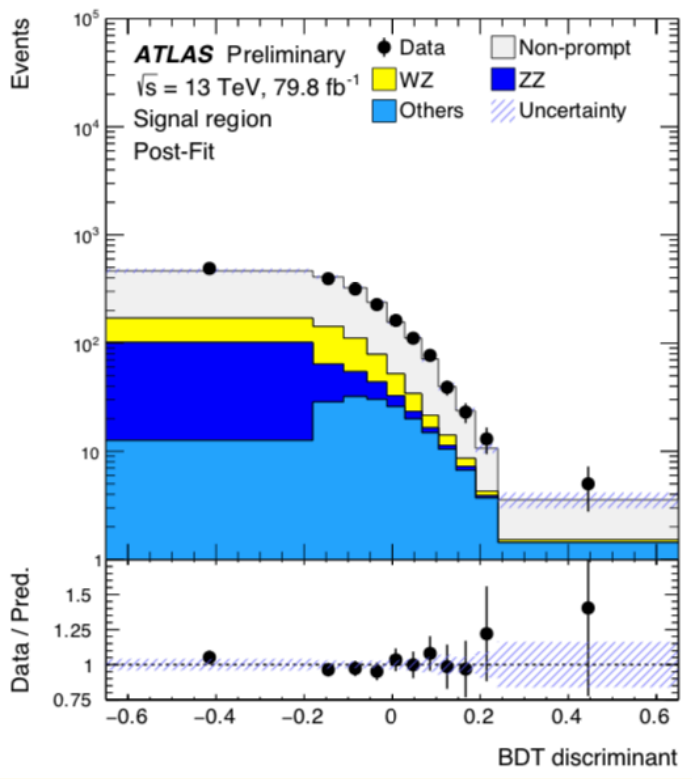
- first evidence for **tγ** production
  - sensitive to top charge and chromomagnetic/electric dipole moments
- muon + γ + MET + jets
- BDT used to to suppress backgrounds
- ML fit with nuisances to suppress systematics
- 4.4 σ (obs.) 3.0σ (exp)



search for LFV in top decay

ATLAS-CONF-2018-044

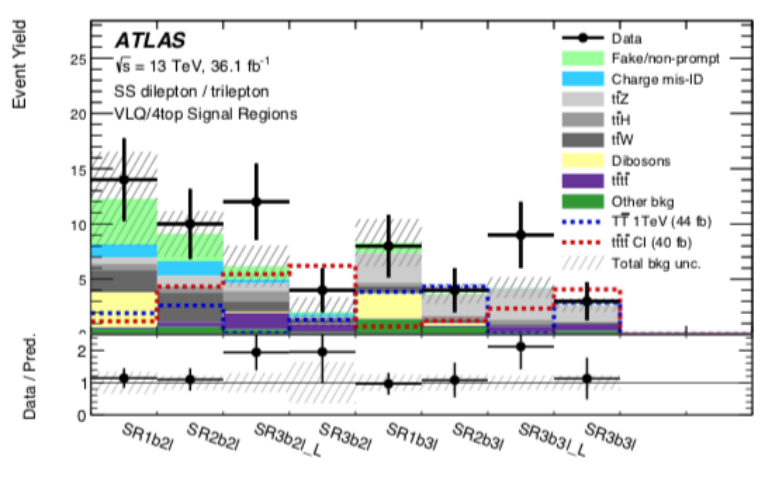
- charged lepton flavour violation = evidence for BSM physics
- focus on t-> q(ll') decays
  - q = {c,c}, l = {e, μ, τ} and l ≠ l'
- trilepton events {e, μ} with charge sum = ± 1
- no sign of cLFV signal
- limits set on Br -
  Br < (t->qll') < 1.86 * 10^{-5}



search for tttt production

arXiv:1807.11883

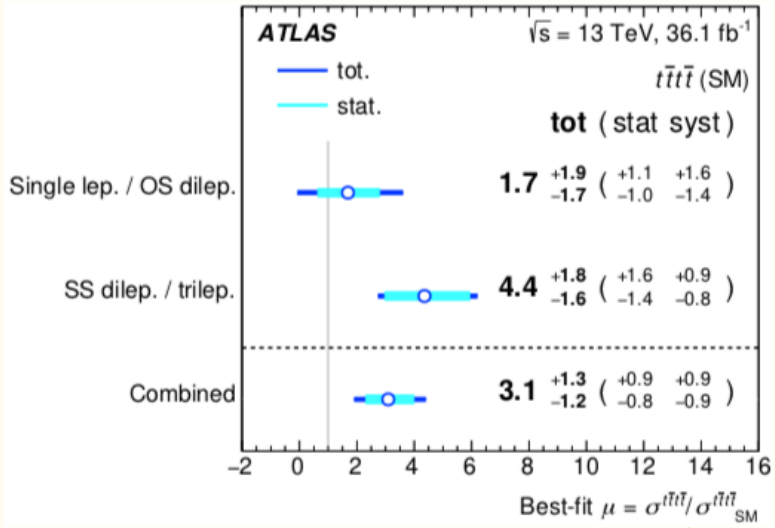
- tttt cross cross section ~9.2 fb in SM
- enhanced in numerous BSM scenarios
- **same-sign dilepton and trilepton (+ bjet)** channels most sensitive
- 3.0 **σ** excess observed when SM tttt not included in backgrounds (0.9**σ** expected)



arXiv:1811.02305

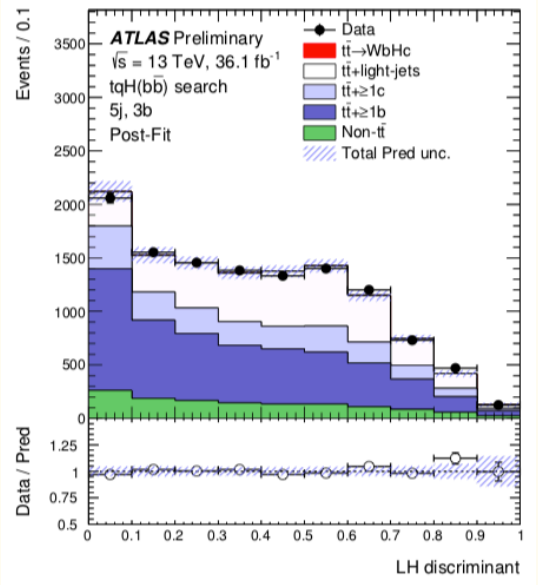
- search using single lepton, opposite sign dielpton + jets and b-jets channels

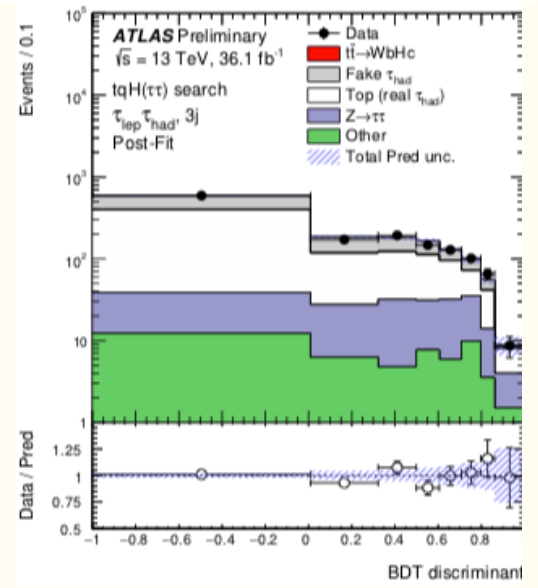
- combination with multilepton channels yields excess of 1.8 **σ** (1.0**σ** expected)



search for t→Hq ATLAS-CONF-2018-049

- search for FCNC top decays **t→Hq (q = u, c)**
- **H→bb**
  - l+jets selection - 9 categories based on N_{jets}, $N_{b\text{-}jets}$
  - likelihood discriminant to suppress backgrounds
- **H→ττ**
  - 4 categories based on τ decays, N_{jets}
  - kin. reco. of H→ττ system
  - BDT to suppress backgrounds





summary

- ATLAS and CMS have vibrant top physics programmes
- LHCb add interesting possibilities in the forward region
- With full large Run-II datasets, we are firmly in **the precision regime**
  - testing SM at the few percent level
  - robust extraction of SM parameters and PDFs
  - probe new physics with precision measurements or rare processes
    - EFT fits to simultaneously exploit disparate observables
- Run-II ~ O(100M) tt events
  - many exiting results on the horizon!