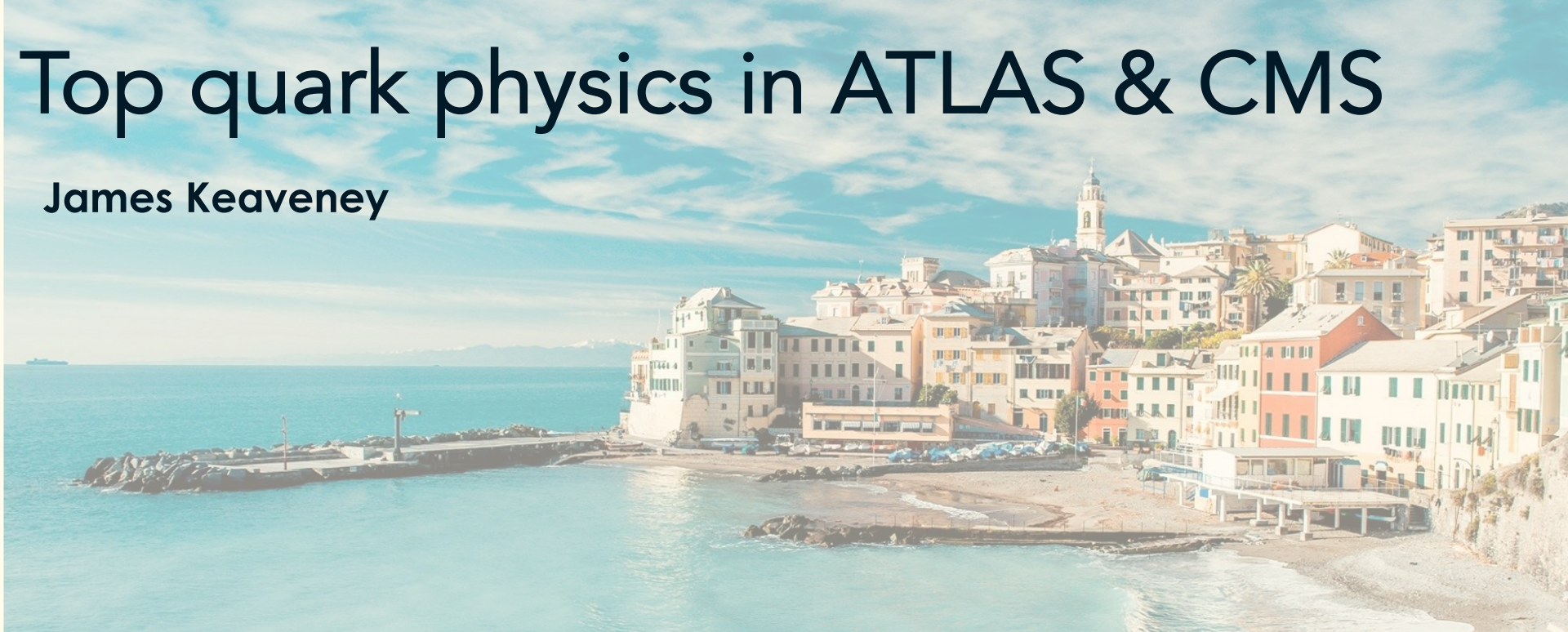
Top quark physics in ATLAS & CMS

James Keaveney



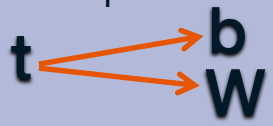
Corfu Workshop on the Standard Model and Beyond

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

m_t = 172 GeV

‘bare’ quark

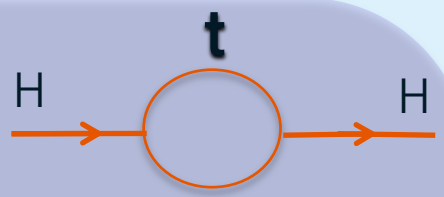
- decays before hadronisation
- *window* into quark properties
- spin info. preserved



SM parameters

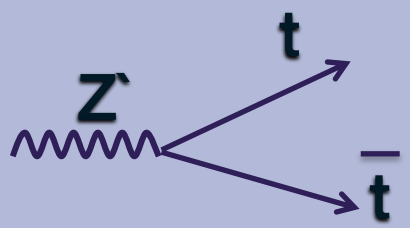
- Rates & kinematics sensitive to m_t,α_S and PDFs
- precision probes higher-order SM calculations, e.g. NNLO+a^3_{EW}

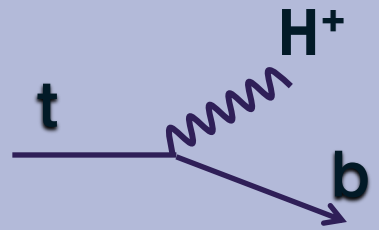
new physics



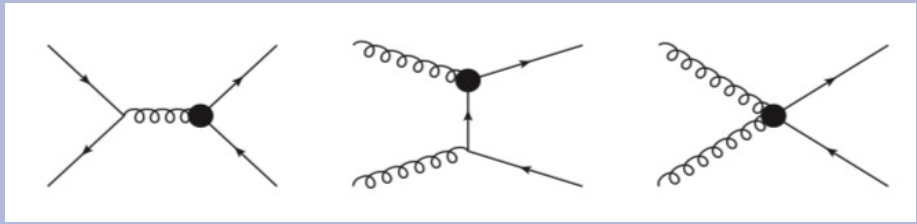
top likely plays a role in m_H stabilisation

new states in production, decay





new physics @ large scale Λ – described in **EFT**



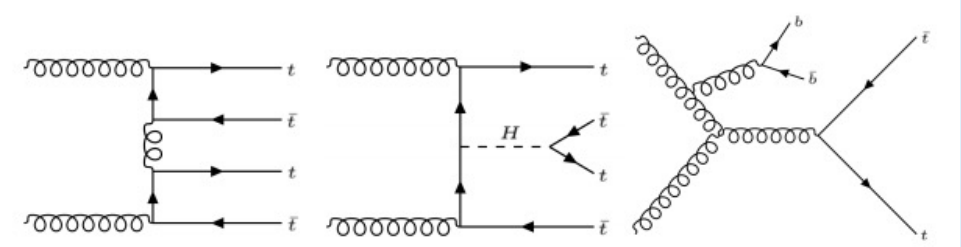
the top quark – experimental programme

- **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**
  - b-fragmentation
  - tuning of underlying event
  - parton shower, hadronisation
- **mass + properties**
  - mass, width, charge, W-helicity
  - Lepton universality
  - charge asymmetries
- **reinterpretations**
  - m_t (pole), m_t, PDF and α_S
  - EFT constraints

focusing on **recent** results

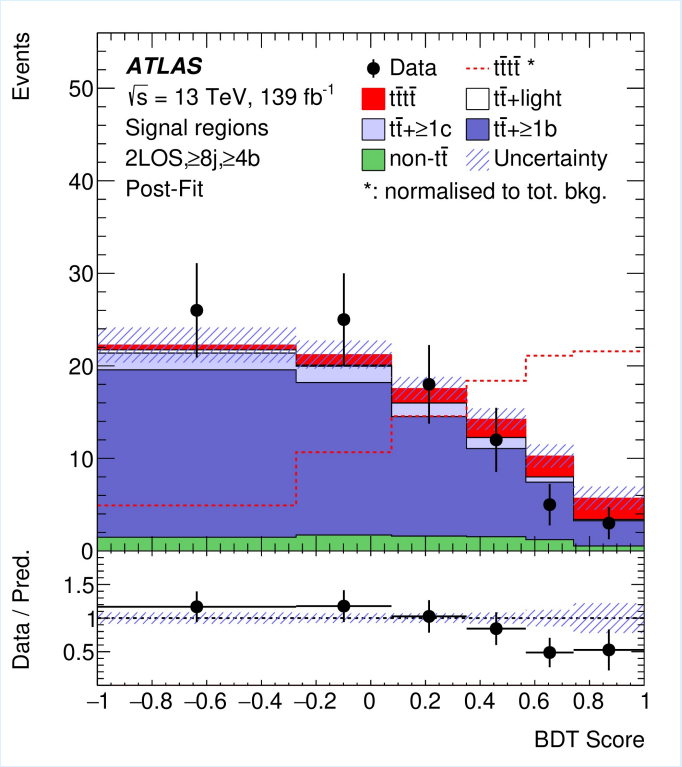
tttt production

evidence for tttt production



arXiv:2106.11683 submitted to JHEP

- tttt cross section ~12 fb in SM
  - enhanced in BSM scenarios
  - sensitive to top Yukawa coupling
- search using single lepton, opposite sign dilepton + jets and b-jets channels
- obs (exp) sig of **1.9** (**1.0**) sigma over the background-only hypothesis
- combination with previous more sensitive multilepton search yields excess of obs. (exp) significance of **4.7** (**2.6**) sigma



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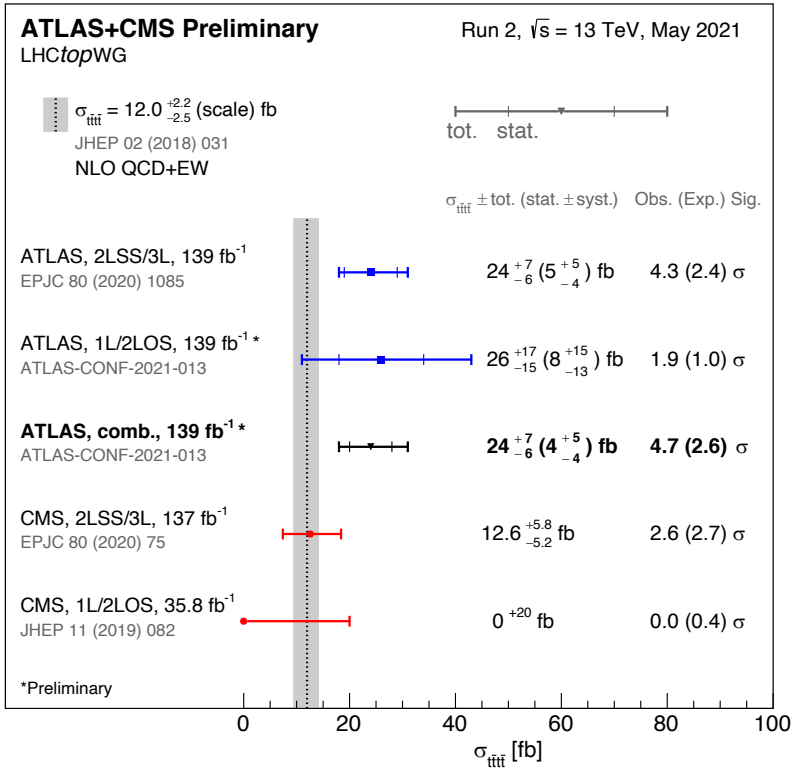


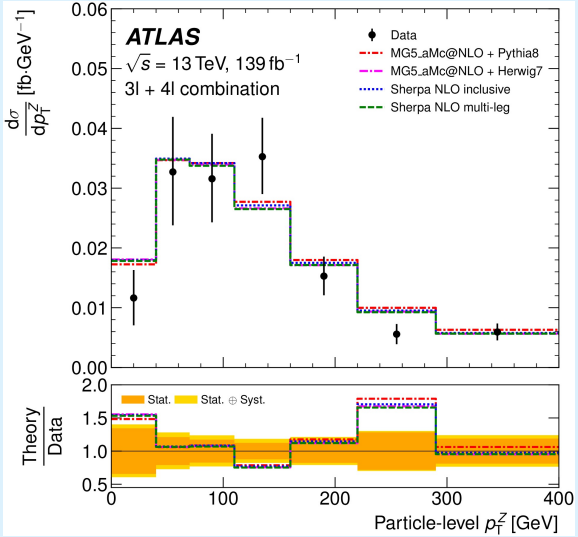
similar results also from CMS

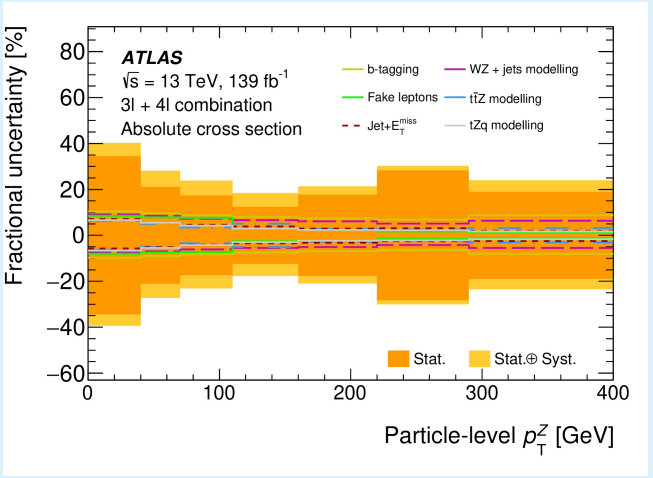
ttZ production

σ_{ttZ} (inclusive & differential)

Eur. Phys. J. C 81 (2021) 737 ***JHEP 03 (2020) 056***

- Combination of 3 and 4 lepton channels
- **Inclusive cross sections**
  - **ATLAS**: $\sigma_{ttz} = 0.99 \pm 0.05$ (stat) ± 0.08 (syst) pb
  - **CMS**: $\sigma_{ttz} = 0.95 \pm 0.05$ (stat) ± 0.06 (syst) pb
  - Both agree with SM
- **Differential cross sections**
  - Measured for a range of observables
  - Abs. and Norm. @ particle & parton levels
    - Agrees with SM
- **Strongly statistically limited**
  - Leading systematic from fake lepton bkg.





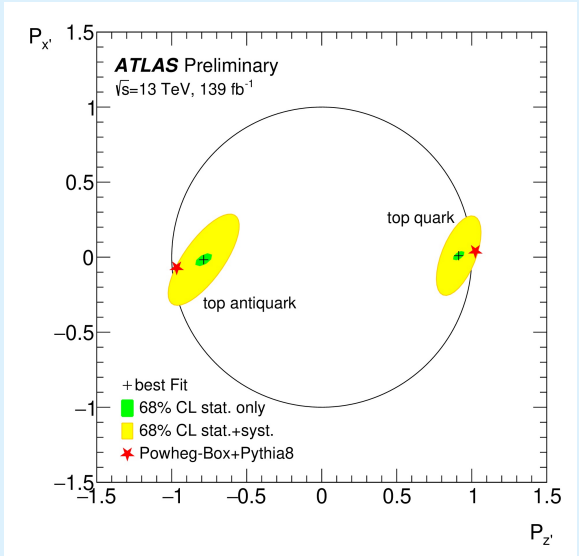
For details on recent CMS ttZ/tZ result, see SM+EW Talk from K.Kordas this (Tue.) morning

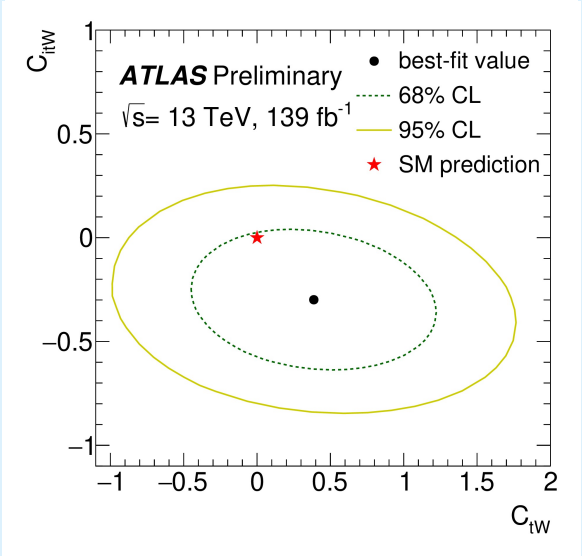
single top production

top quark polarisation in single top production

ATLAS-CONF-2021-027

- First measurement of the full polarisation vectors of the top quark and antiquark polarisation in t-channel single-top-quark production
- 1 lepton, 2 jets (1 b-tagged), large missing ET
- Polarisation extracted from distributions of cosines of the charged lepton momentum in the top-quark rest frame
- Results interpreted as EFT constraints
  - c_{tW} sensitive to CP violating effects



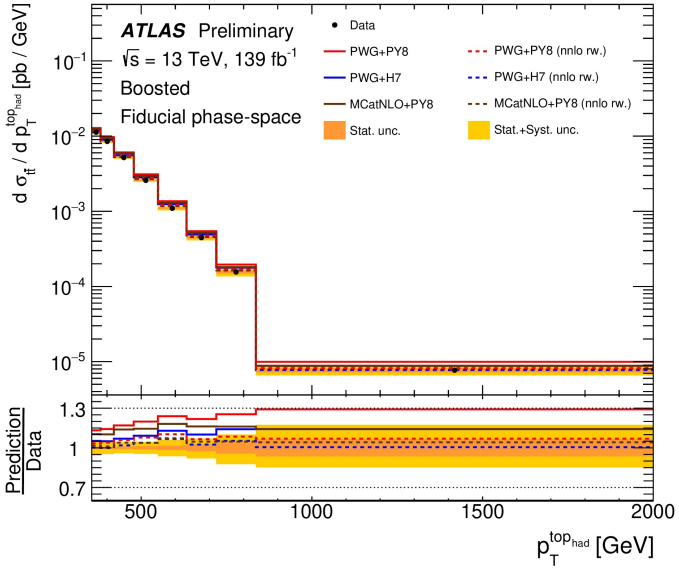


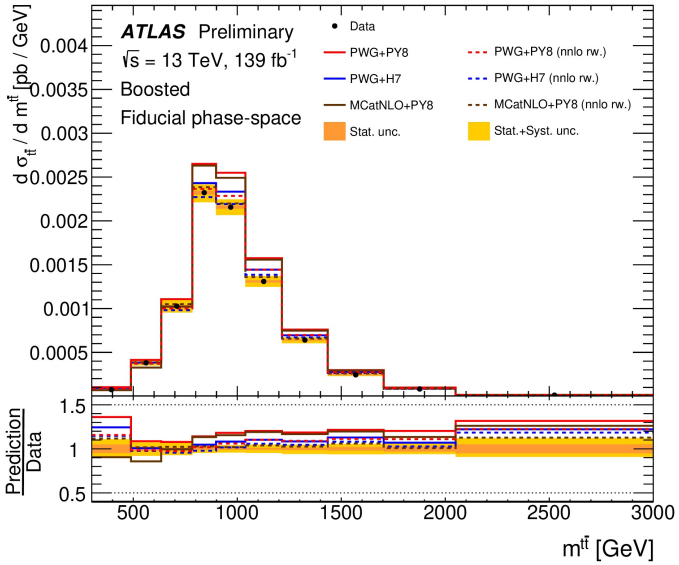
tt production

σ_{tt} (boosted, differential)

ATLAS-CONF-2021-031

- **Lepton + jets channel**
  - p_T (had. Top) > 355 GeV
  - JES unc. reduced with in-situ correction
- **Fiducial cross section**
  - σ = 1.267 ± 0.005 (stat.) ± 0.053 (syst.) pb
  - Agrees with SM
- **Differential cross sections**
  - Measured for a range of observables in fiducial region including separate N_{jet} bins @ particle level
  - Agreement with SM
    - NLO MC reweighted to NNLO
- **Strongly systematically limited**
  - Leading systematic from tt modelling





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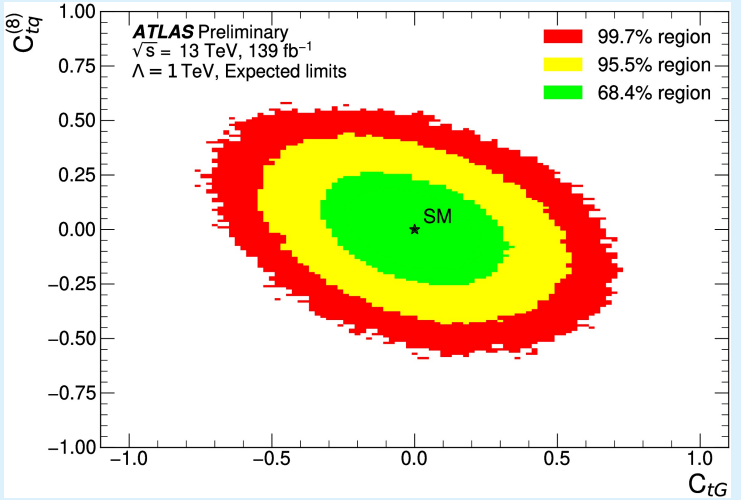
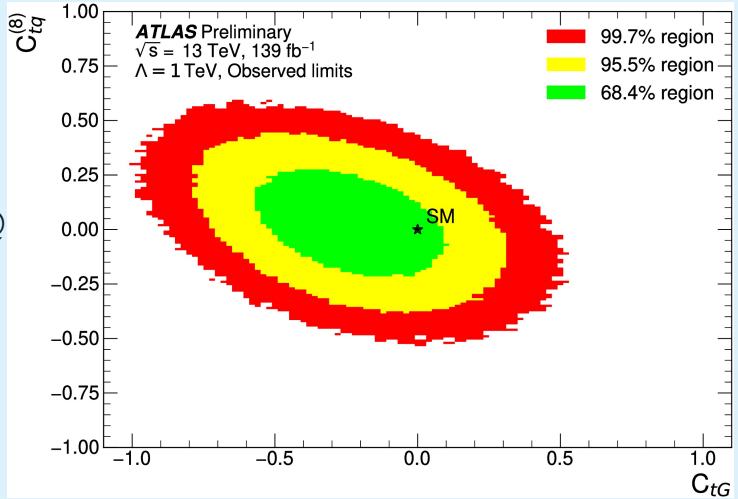
  - Agreement with SM
    - NLO MC reweighted to NNLO
- **Differential cross sections**
  - Measured for a range of observables in fiducial region including sperate N_{jet} bins @ particle level
- **2-coefficient fit demonstrates sensitivity to EFT**

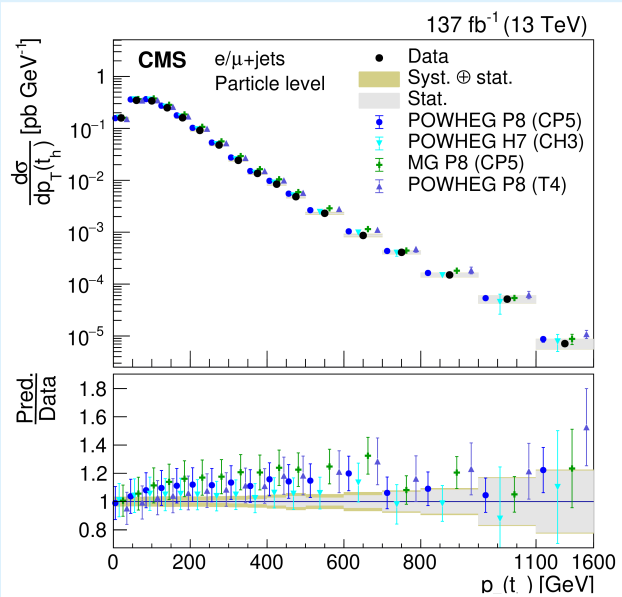




σ_{tt} (boosted & resolved, differential)

TOP-20-001 Submitted to Phys. Rev. D

- **Lepton + jets channel**
  - combines low p_T (resolved) and high p_T (boosted) regimes
  - measured @ parton & particle levels
- **Inclusive cross section**
  - σ_{tt} = 791 ± 25 pb
- **Differential cross sections**
  - Agreement with SM
    - NLO MC reweighted to NNLO
- **Strongly systematically limited**
  - Leading systematic from b-tagging



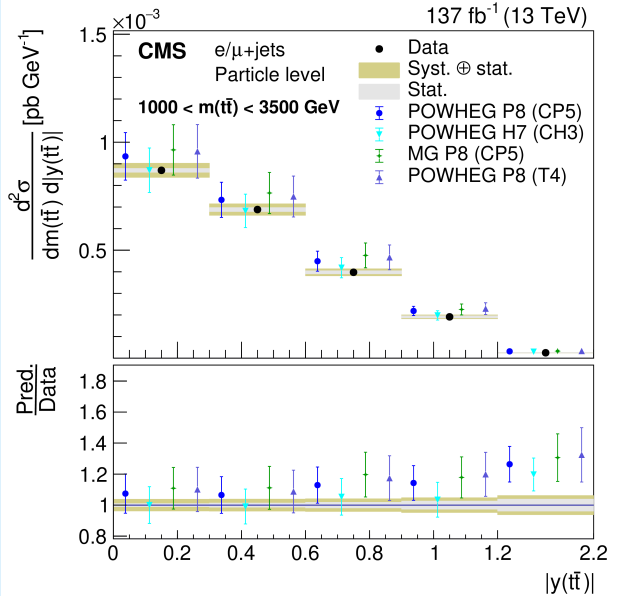
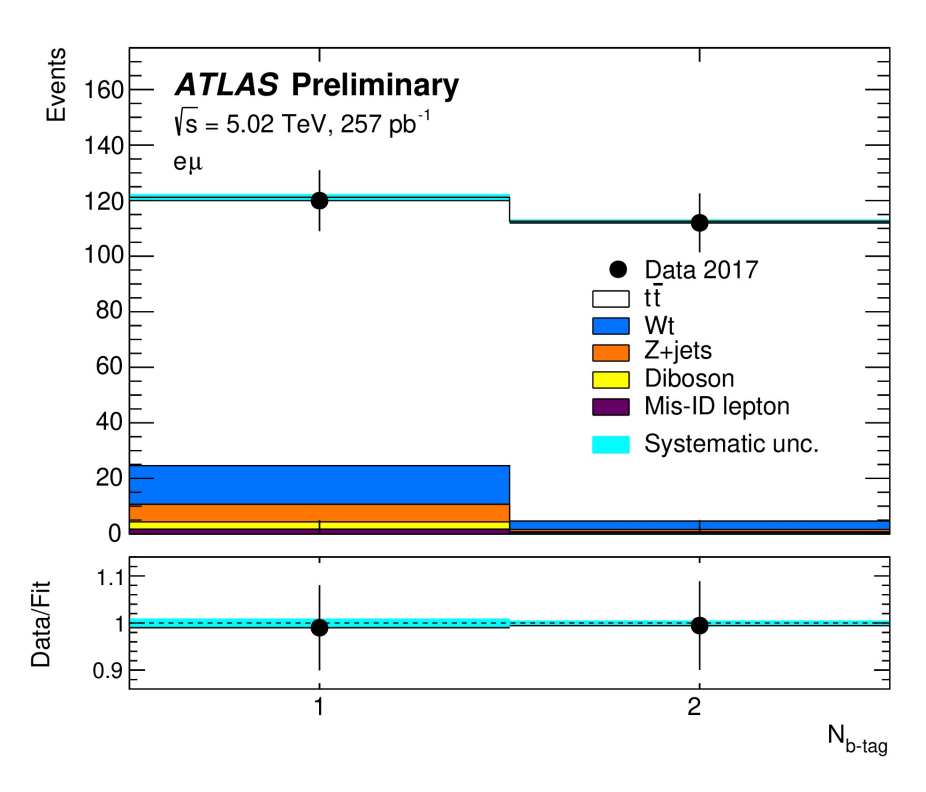


Table of z-values for large number of observables in backup

Inclusive σ_{tt} @ 5 TeV

ATLAS-CONF-2021-003

- Uses 257 pb^{-1} of 5 TeV data collected in 2017
- Events selected with opposite-charge pair of leptons and b-tagged jets
- Cross section extracted by maximising likelihood based on yields in N_{btag} regions
- Sensitivity to high-x gluon pdf due to low centre of mass energy



- **Inclusive cross section**
  - **σ_{tt} = 66.0 ± 4.5 (stat.) ± 1.6 (syst.) ± 1.2 (lumi.) ± 0.2 (beam energy) pb**
  - Agrees with SM
  - Strongly statistically limited

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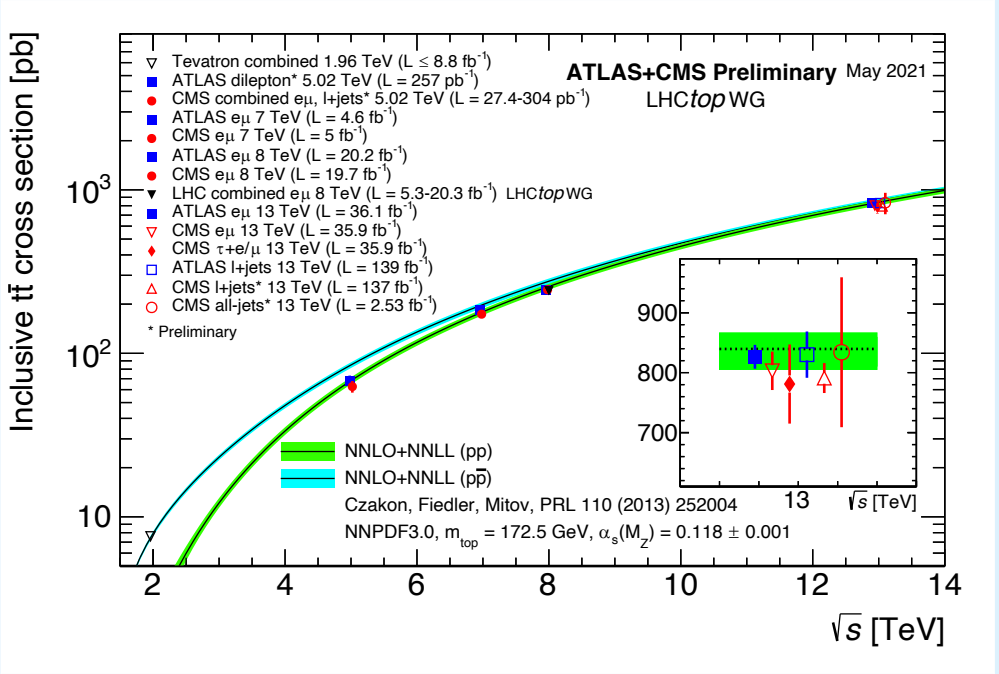

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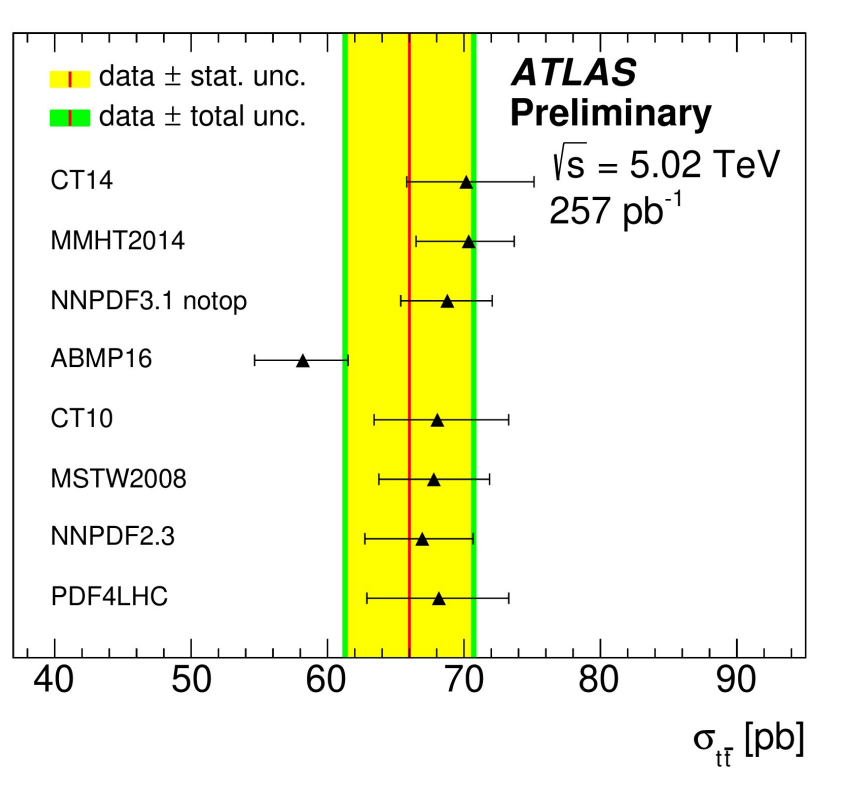

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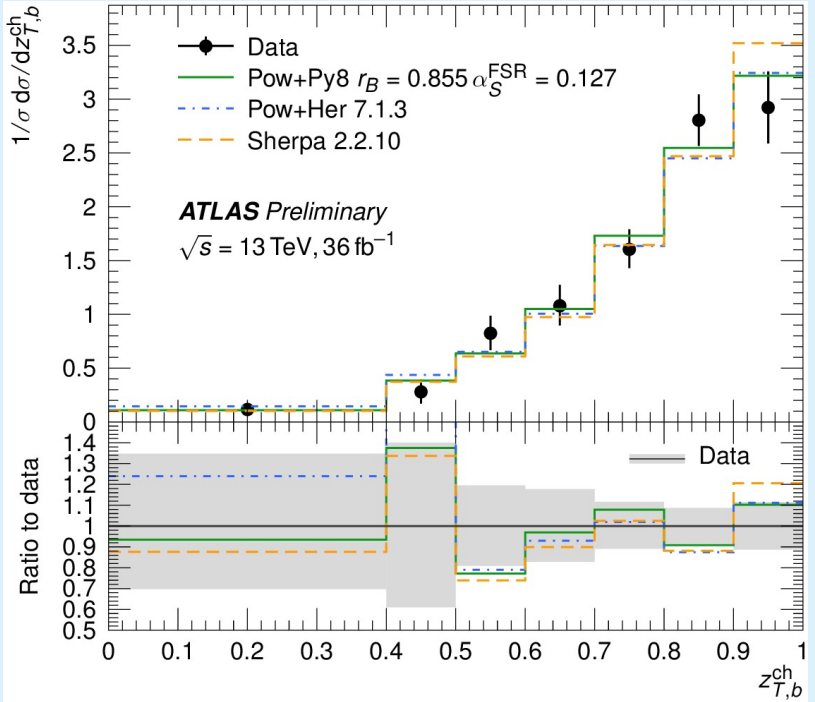
  - Agrees with SM
  - Strongly statistically limited

b-fragmentation in tt production

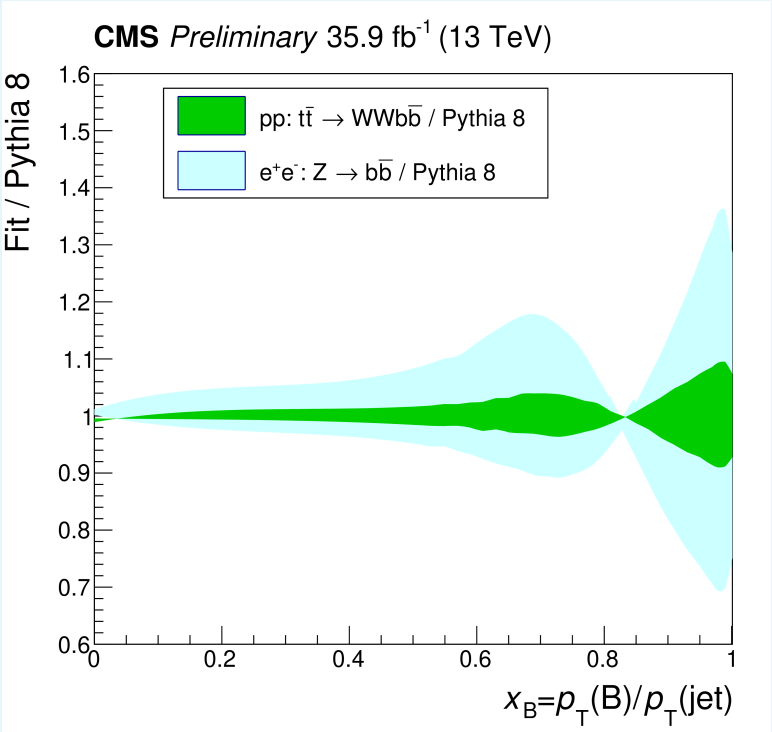
ATLAS-CONF-2020-050

- B-fragmentation large source of uncertainty in top modelling, e.g, top mass measurements
- observables sensitive to b- fragmentation measured with 36 fb^{-1} @ 13 TeV
- Events selected with opposite-charge pair of leptons and b-tagged jets
- Selection of tracks associated with b-hadron allows:
  - high-res. observables related to b-hadron momentum
- Distributions unfolding to particle level using max. like. unfolding
- Largely in agreement with generator predictions



b-fragmentation in tt production CMS-PAS-TOP-18-012

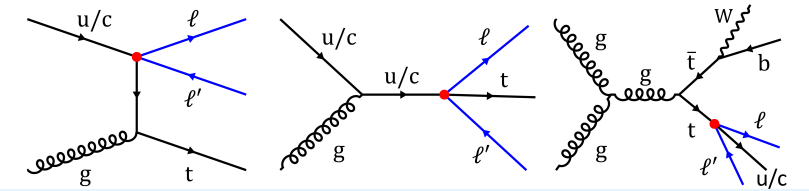
- B-fragmentation large source of uncertainty in top modelling, e.g, top mass measurements
- observables sensitive to b- fragmentation measured with 36 fb^{-1} @ 13 TeV
- Events selected with opposite-charge pair of leptons and b-tagged jets
- D0 and J/ψ mesons are reconstructed from the decays $D0 \rightarrow K^{\pm}\pi^{\mp}$ and $J/\psi \rightarrow \mu^{+}\mu^{-}$ using charged particle track information.
- fragmentation function shape parameter, rb extracted from fit



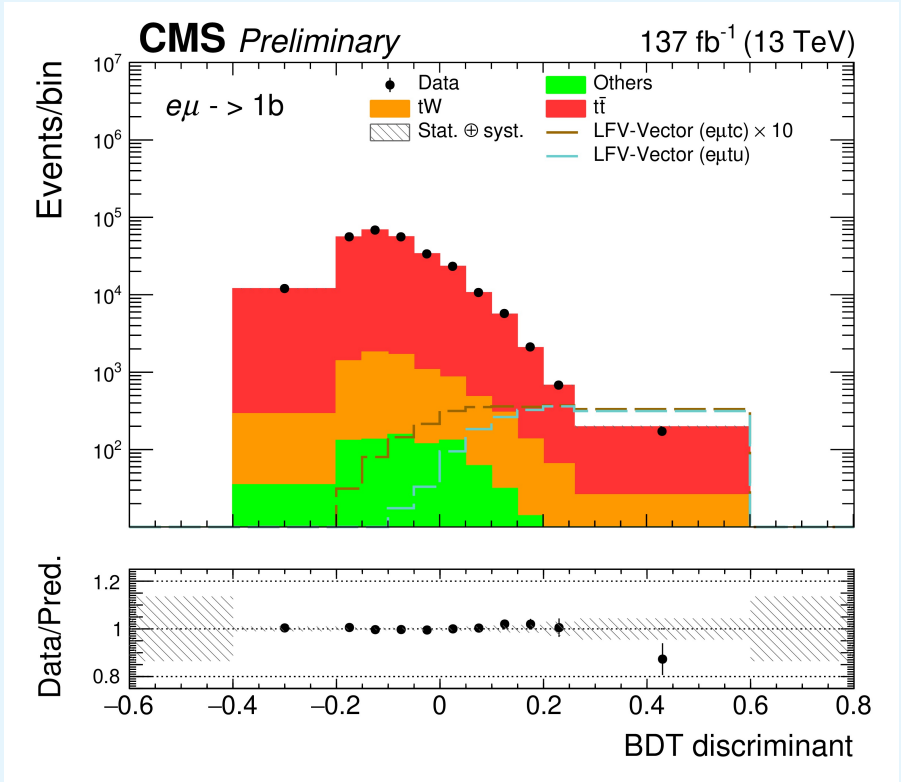
top interactions

search for CLFV in top production & decay

CMS-PAS-TOP-19-006

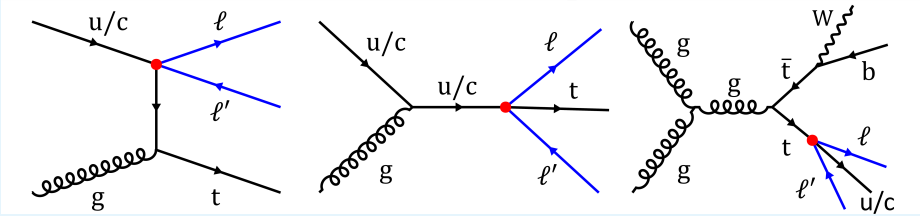


- charged lepton flavour violation = evidence for BSM physics
- CLFV signal modelled in EFT
  - qg -> t + (ll') **production**
  - t-> q (ll') **decay**
  - q = {u,c}, l = {e, μ, τ} and l ≠ l'
- OS lepton pair & b-jet events
- no sign of cLFV signal
- limits set on BR and EFT coefficients



search for CLFV in top production & decay

CMS-PAS-TOP-19-006



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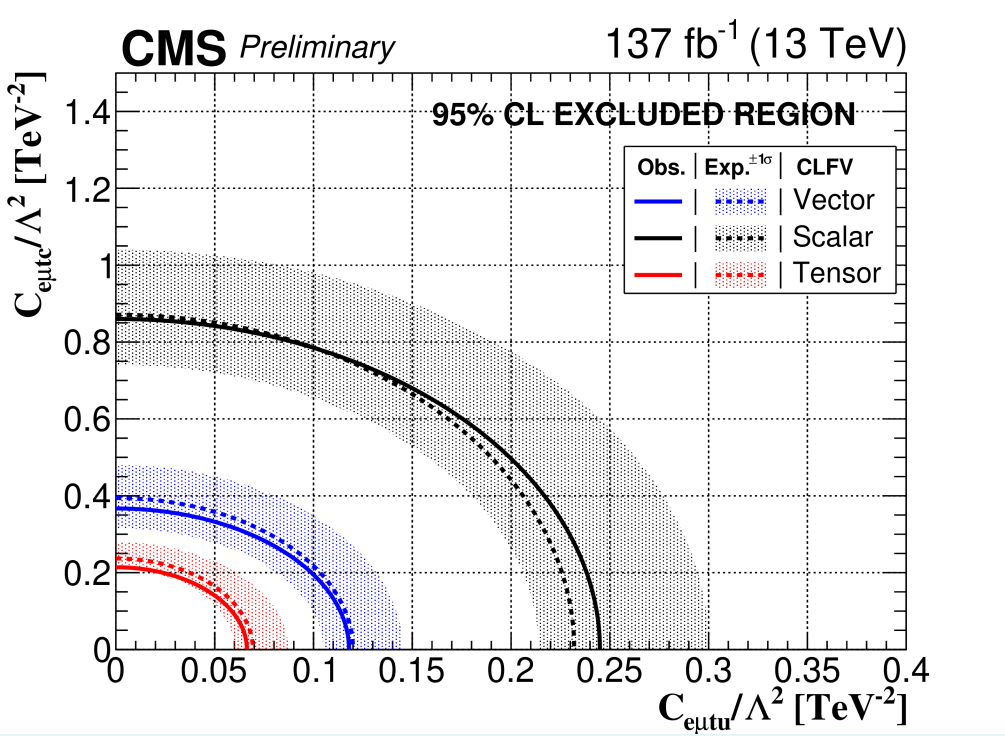
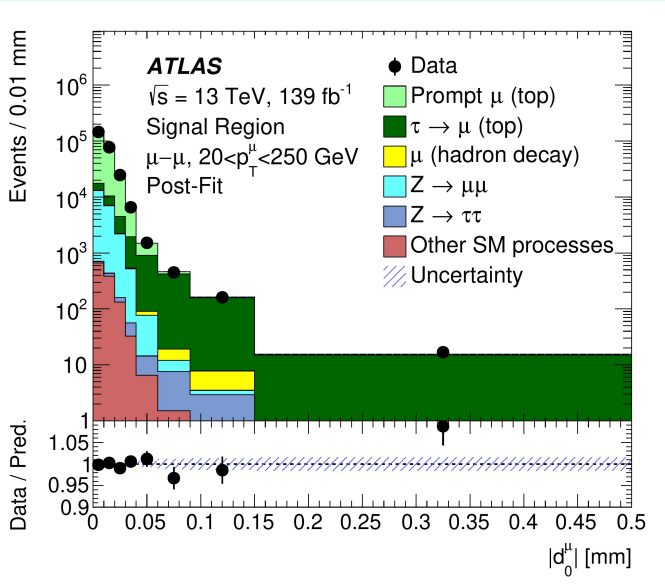
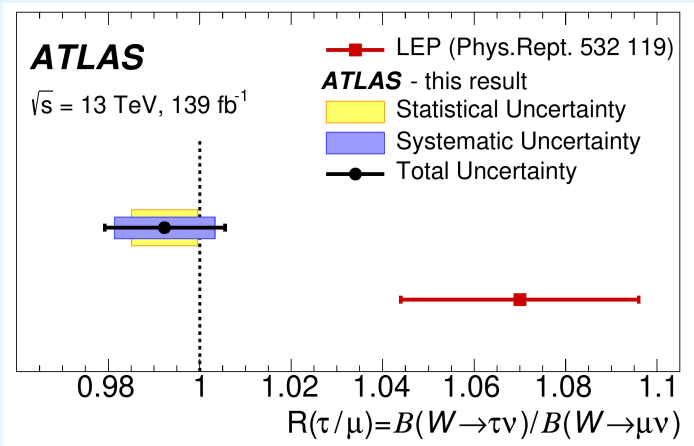


universality of τ and μ couplings in W decays in $t\bar{t}$

Nat. Phys. (2021)

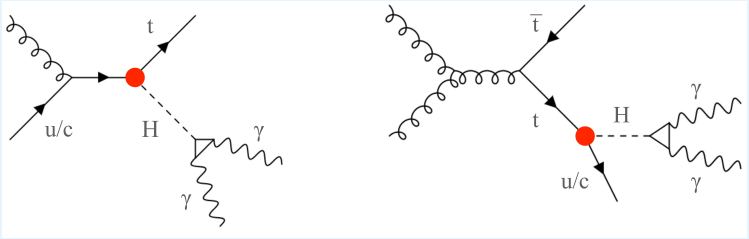
- $R(\tau/\mu) = B(W \rightarrow \tau\nu_\tau)/B(W \rightarrow \mu\nu_\mu)$
  - Test of Lepton Flavour Universality
- LEP data showed discrepancy from SM
- eμ and μμ selections
- Vertex and pt info used to distinguish
  - $W \rightarrow \tau\nu_\tau \rightarrow \mu\nu_\mu\nu_\tau\nu_\tau$
  - $W \rightarrow \mu\nu_\mu$
- **$R(\tau/\mu) = 0.992 \pm 0.013$ [±0.007 (stat) ± 0.011 (syst)]**
  - **In agreement with SM**



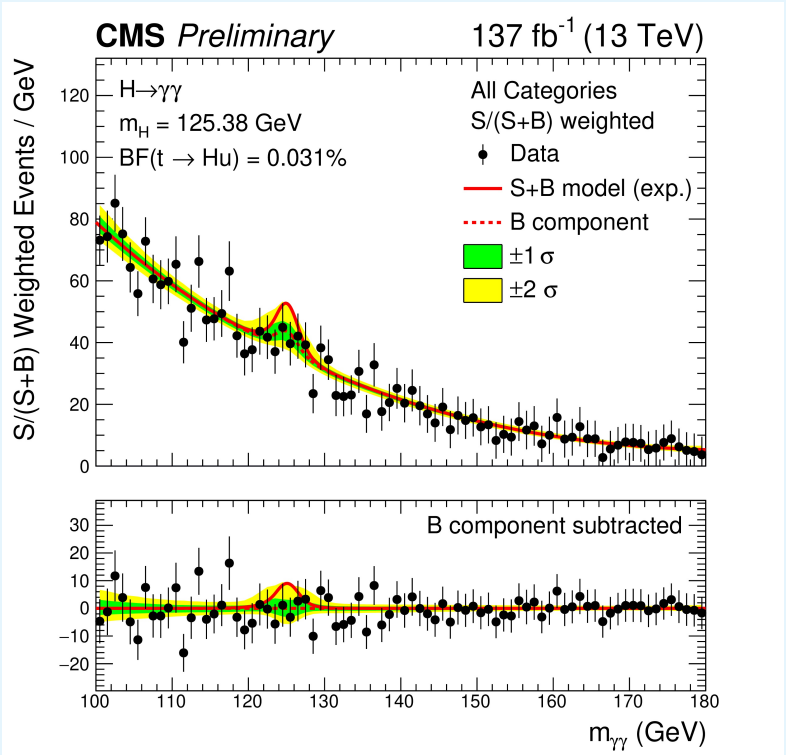


search for FCNC in top-Higgs (H->$\gamma\gamma$) interactions

CMS-PAS-TOP-20-007

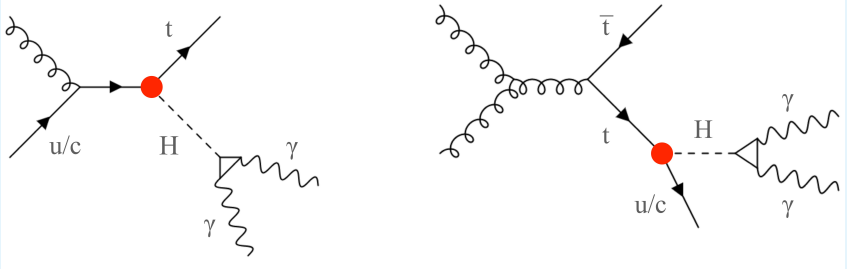


- t → Hq FCNC decays suppressed in SM
  - clear sign of new physics
- diphoton selection
  - Lept. & had. selections for top decay
- t → Hq branching fractions extracted via fit to $m_{\gamma\gamma}$ distribution
- no sign of FCFC signal



search for FCNC in top-Higgs (H->$\gamma\gamma$) interactions

CMS-PAS-TOP-20-007



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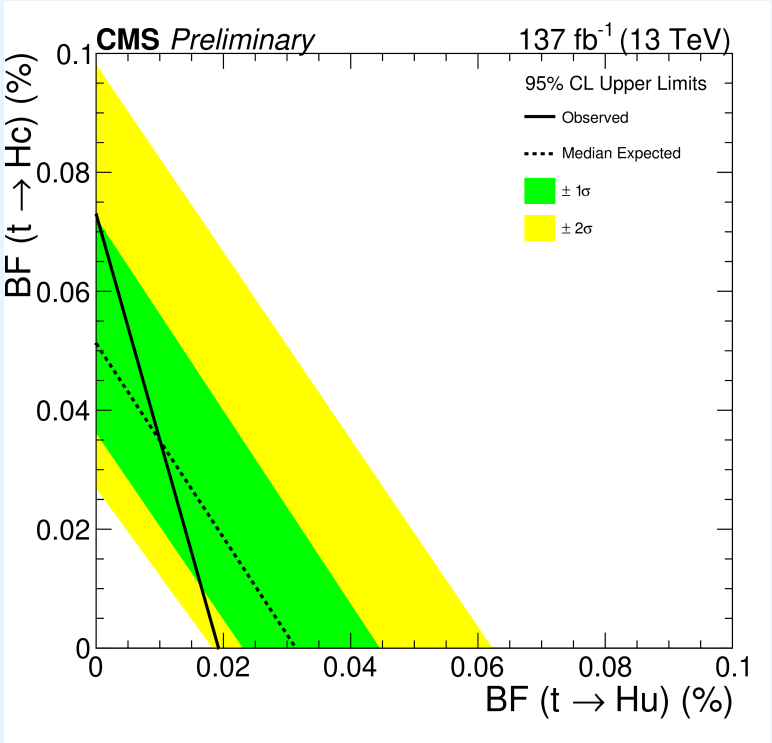
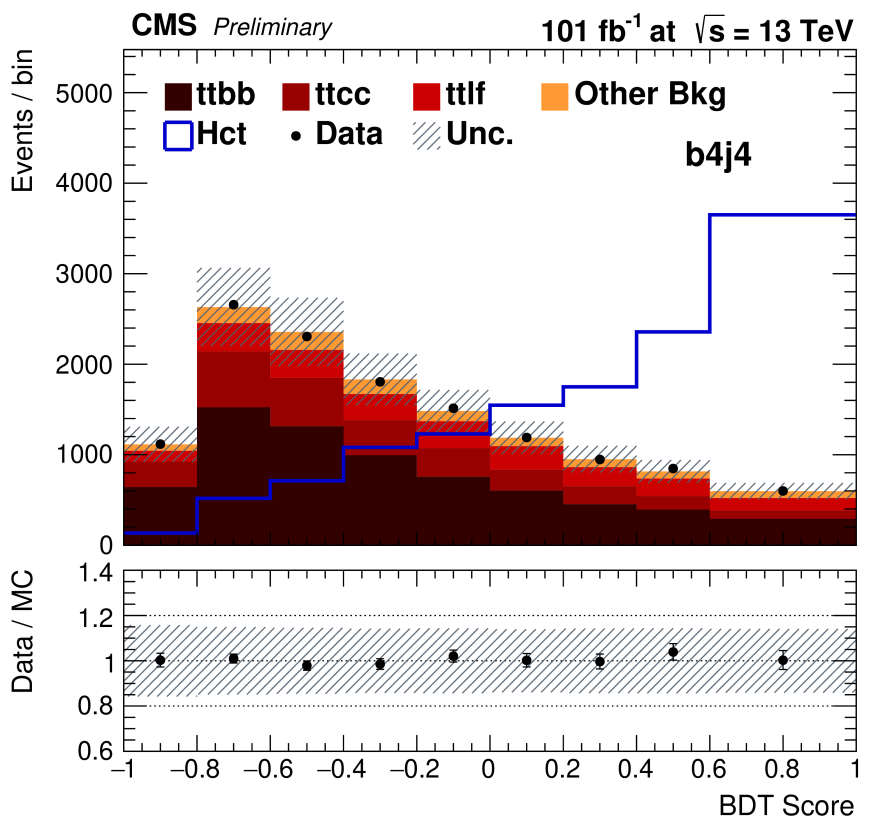
  - clear sign of new physics
- diphoton selection
  - Lept. & had. selections for top decay
- t → Hq branching fractions extracted via fit to $m_{\gamma\gamma}$ distribution
- no sign of FCFC signal
- limits set on BR



search for FCNC in top-Higgs (H->bb) interactions

CMS-PAS-TOP-19-002

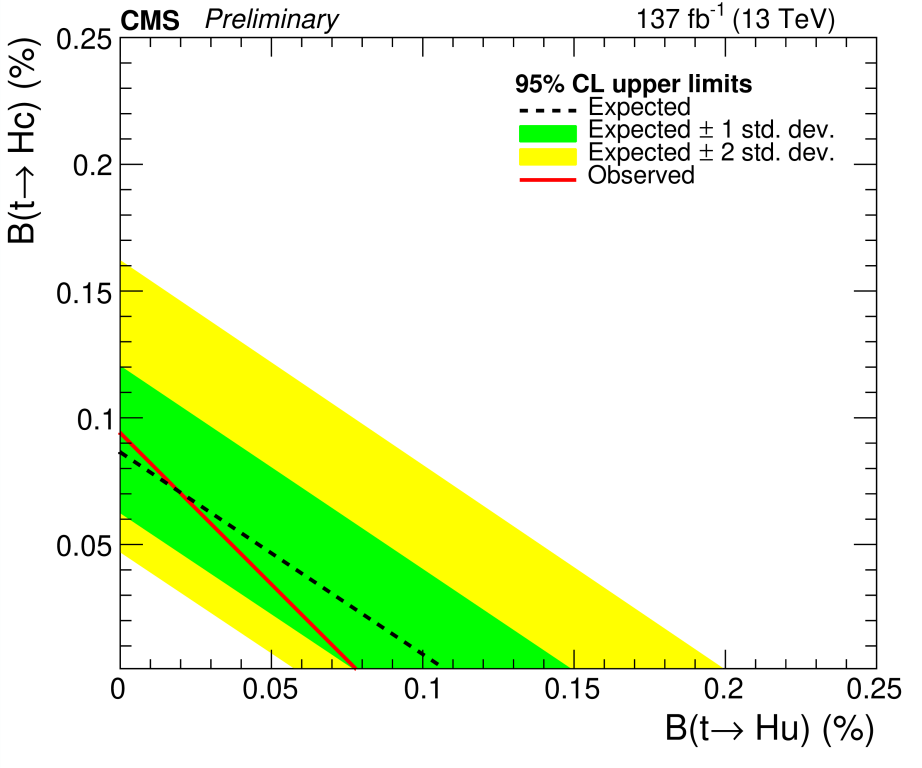
- t → Hq FCNC decays suppressed in SM
  - clear sign of new physics
- Lepton + bjets selection
  - DNN to assign jets to partons
  - BDT for Sig vs Bkg
- t → Hq branching fractions extracted via fit to BDT distributions
- no sign of FCFC signal
- limits set on BR



search for FCNC in top-Higgs (H->bb) interactions

CMS-PAS-TOP-19-002

- t → Hq FCNC decays suppressed in SM
  - clear sign of new physics
- Lepton + bjets selection
  - DNN to assign jets to partons
  - BDT for Sig vs Bkg
- t → Hq branching fractions extracted via fit to BDT distributions
- no sign of FCFC signal
- limits set on BR



Summary & conclusions

- The top quark is involved in numerous BSM theories
- Top quark measurements also sensitive to SM parameters, eg, m_t, α_S
- Top data can also constrain EFT parameters and PDFs
- Unique observables to aid MC modelling, e.g, b-fragmentation

- **With the full Run-II data, ATLAS & CMS are studying top quarks in all corners of the phase space and has numerous exciting recent results.**
  - High energy boosted regimes
  - Polarisation in single top production
  - Multi-dimensional differential distributions
  - Rare production processes: tttt, ttZ (differential), tqH, CLFV

Many more results on the way!

backup

σ_{tt} (boosted & resolved, differential)

TOP-20-001 Submitted to Phys. Rev. D

Chi-squared table details agreement for a large number of observables.