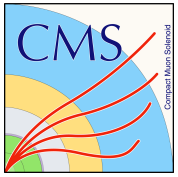


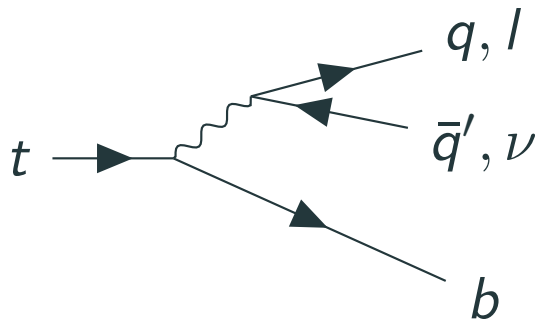
Studies of top quark properties in CMS

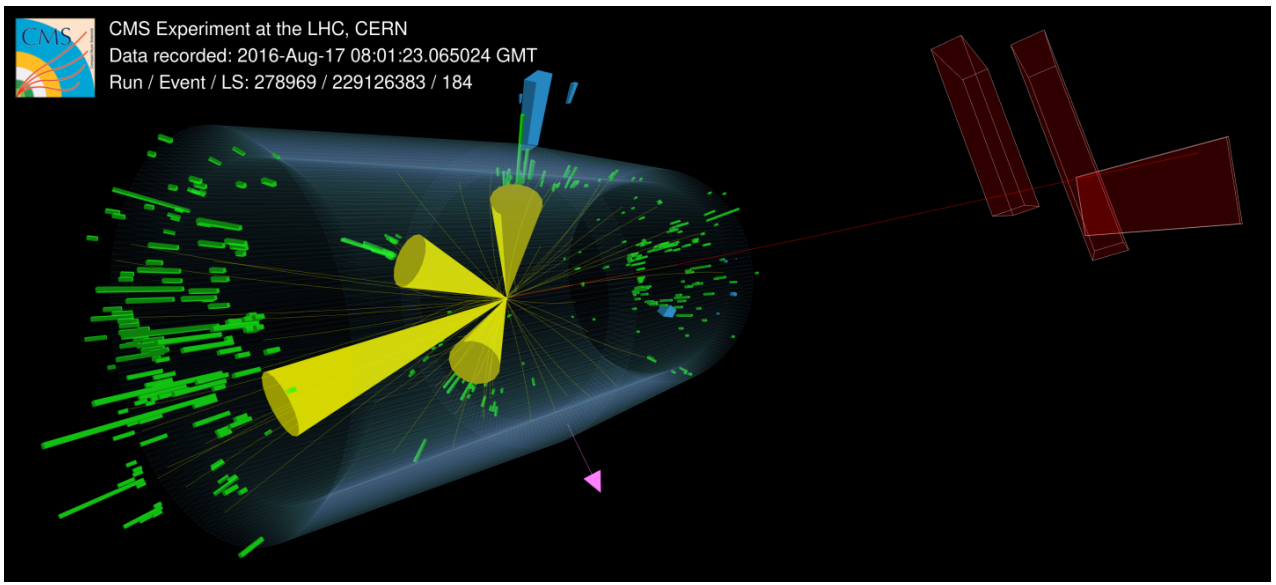
Dennis Schwarz
on behalf of the CMS Collaboration

TOP 2022

The top quark

- So far no signs for BSM physics in direct searches
- Precision measurements of its properties could reveal indirect effects
- Includes both QCD and EW

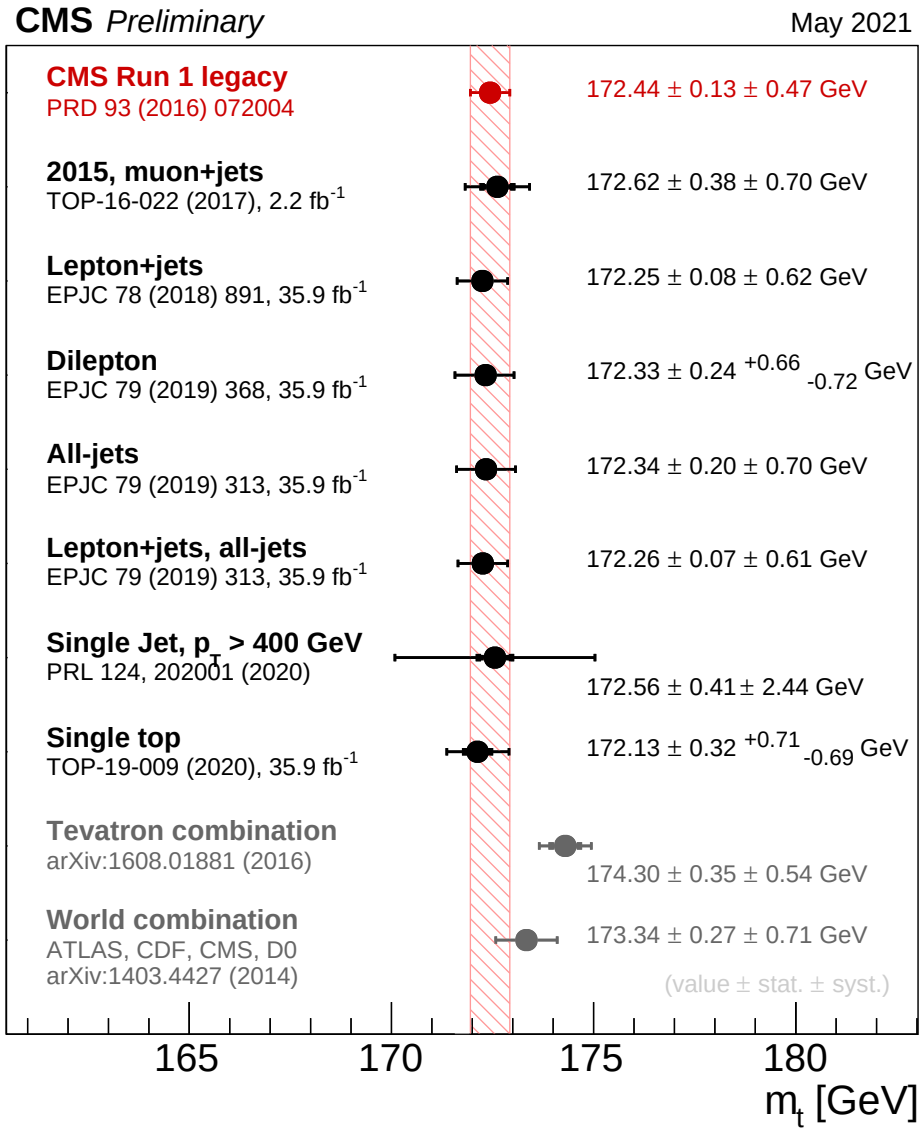




The top quark mass

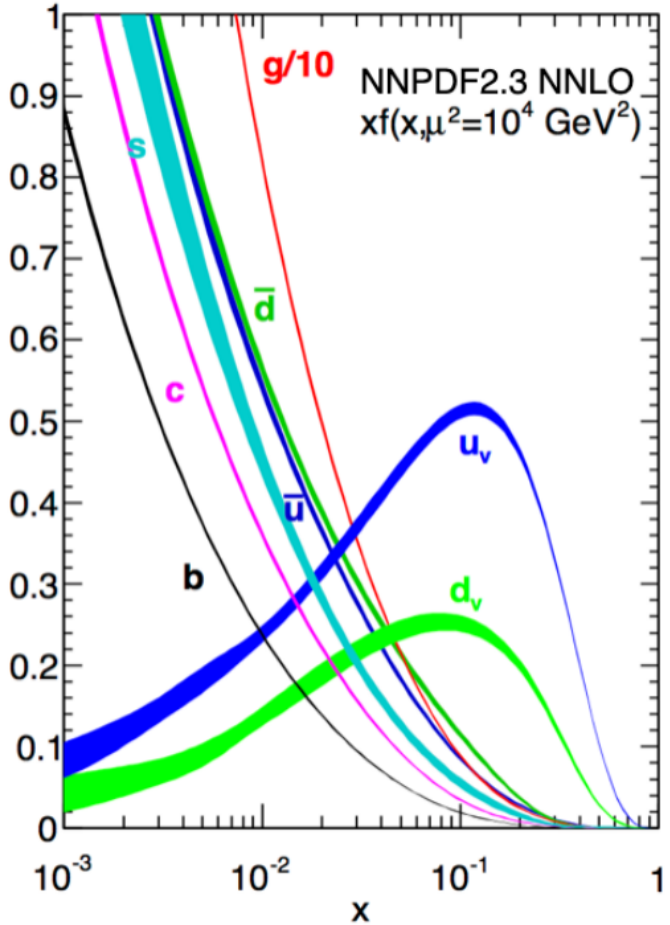
- Extensive effort in CMS to measure m_t
- Covered in [Marco's talk] and [Matteo's talk]

Many more already published $\longrightarrow$



Charge asymmetry in $t\bar{t}$ NEW!

[TOP-21-014, submitted to Phys. Lett. B]



- Study of central-forward asymmetry in $t\bar{t}$
- $A_C = \frac{N(\Delta|y|>0) - N(\Delta|y|<0)}{N(\Delta|y|>0) + N(\Delta|y|<0)}$
  $(\Delta|y| = |y_t| - |y_{\bar{t}}|)$
- At LO, no asymmetry
- Higher order effects in $q\bar{q} \rightarrow t\bar{t}$
- Boosted regime enriches $q\bar{q}$ production
- SM prediction $\sim 1\%$
- Could be influenced by BSM

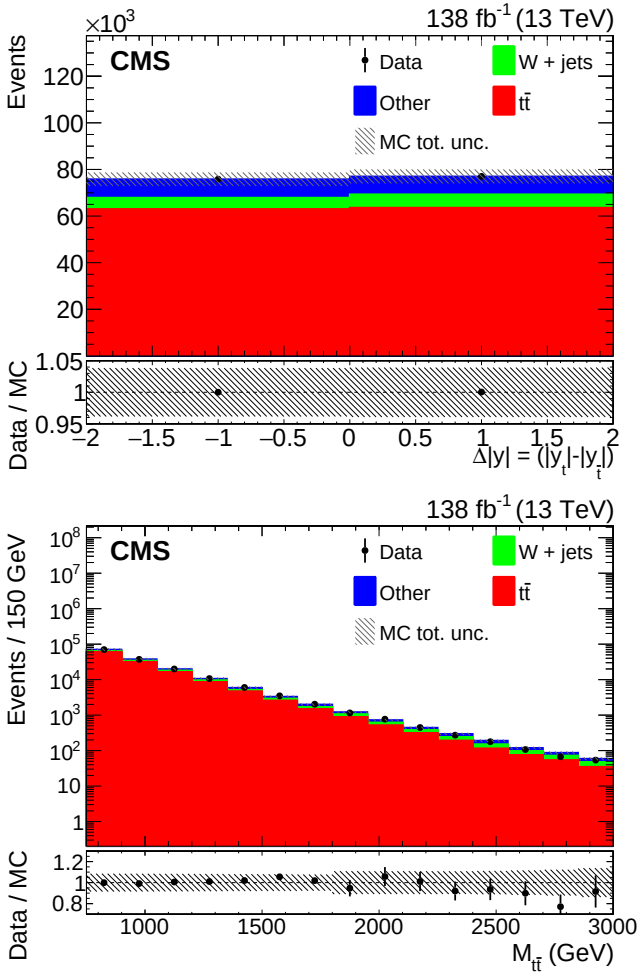
Charge asymmetry in $t\bar{t}$ NEW!

[TOP-21-014, submitted to Phys. Lett. B]

- Measurement in ℓ+jets
- AK8 jets with $p_T > 400$ GeV
- Top and W tagging
- Boosted, semi-resolved and resolved reconstruction strategies
- Choose best $t\bar{t}$ reconstruction with

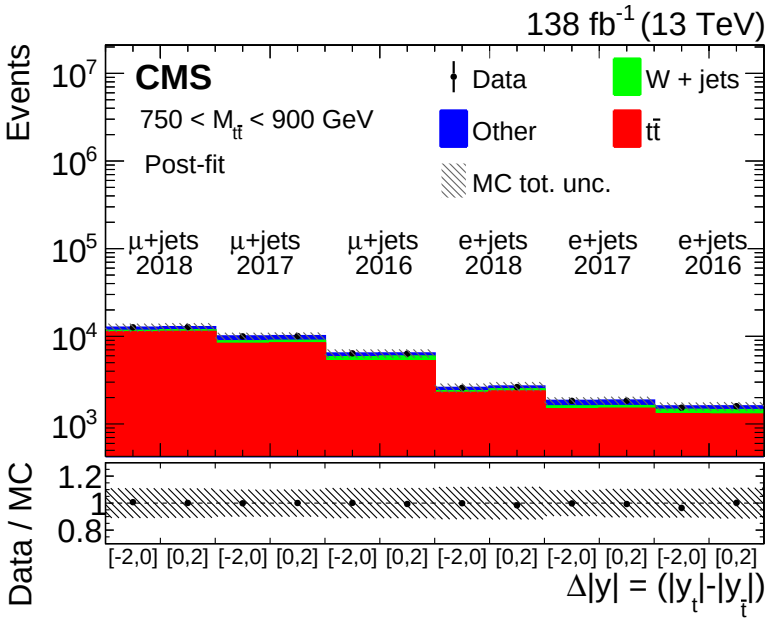
$$\chi^2 = \left(\frac{M_{\text{lep}} - \overline{M}_{\text{lep}}}{\sigma_{\text{lep}}}\right)^2 + \left(\frac{M_{\text{had}} - \overline{M}_{\text{had}}}{\sigma_{\text{had}}}\right)^2$$

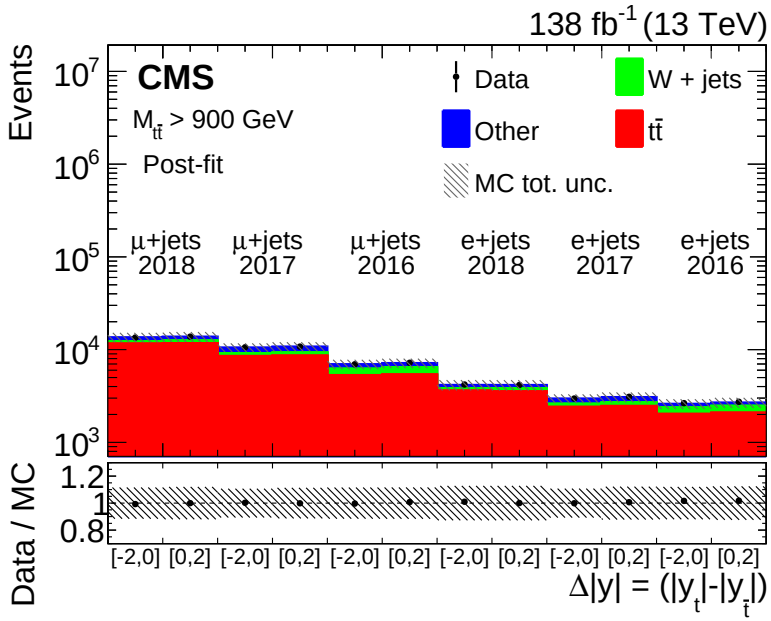
$\rightarrow$ Measure $\Delta|y|$ in bins of $M_{t\bar{t}}$ ($M_{t\bar{t}} > 750$ GeV)



Charge asymmetry in $t\bar{t}$ NEW!

[TOP-21-014, submitted to Phys. Lett. B]



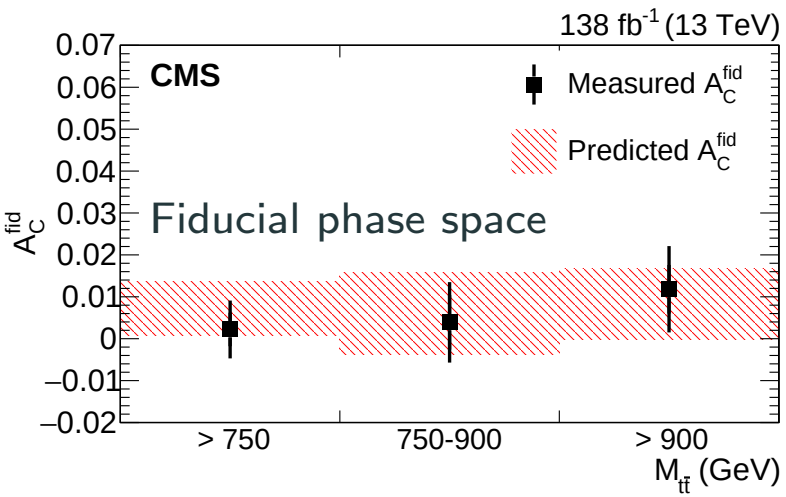


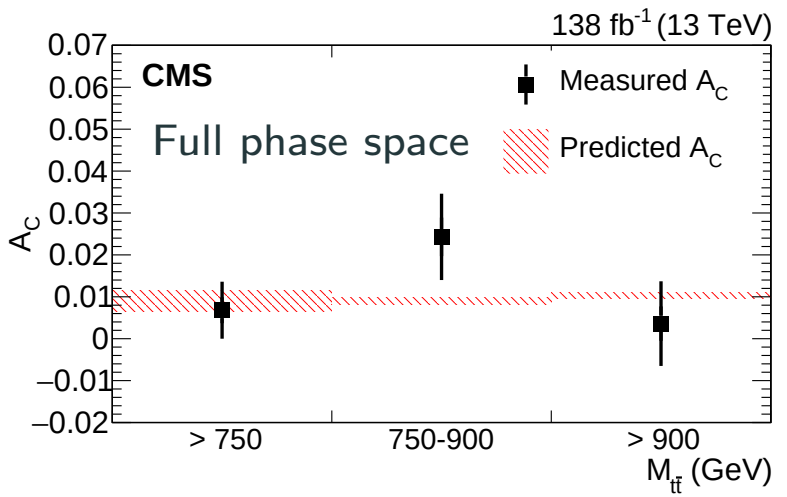
- Maximum likelihood fit and likelihood-based unfolding
- Two $M_{t\bar{t}}$ bins: $[750, 900], [900, \infty]$
- Differential in lepton flavor (electron, muon)
- Three years

Charge asymmetry in $t\bar{t}$ NEW!

[TOP-21-014, submitted to Phys. Lett. B]

- A_C also obtained in **fiducial** and **full** phase space with acceptance from generator level
- Good agreement with SM
- Largest uncertainties:
  QCD scales, FSR, Top p_T modelling, JEC





CP violation in $t\bar{t}$ (ℓ+jets)

[TOP-20-005, submitted to JHEP]

- Search for CP violation in $t\bar{t}$
- Can be caused by BSM physics, see chromoelectric dipole moment (CEDM) interpretation in [Jiwon's talk]
- Construction of 4 CP observables based on final state 4-momenta $\rightarrow$ full reconstruction

$$O_3 = Q_\ell \epsilon(p_\mathrm{b}, p_{\bar{\mathrm{b}}}, p_\ell, p_{j_1}) \propto Q_\ell \vec{p}^{\,*}_\mathrm{b} \cdot (\vec{p}^{\,*}_\ell \times \vec{p}^{\,*}_{j_1}),$$

$$O_6 = Q_\ell \epsilon(P, p_\mathrm{b} - p_{\bar{\mathrm{b}}}, p_\ell, p_{j_1}) \propto Q_\ell (\vec{p}_\mathrm{b} - \vec{p}_{\bar{\mathrm{b}}}) \cdot (\vec{p}_\ell \times \vec{p}_{j_1}),$$

$$O_{12} = q \cdot (p_\mathrm{b} - p_{\bar{\mathrm{b}}}) \epsilon(P, q, p_\mathrm{b}, p_{\bar{\mathrm{b}}}) \propto (\vec{p}_\mathrm{b} - \vec{p}_{\bar{\mathrm{b}}})_z \cdot (\vec{p}_\mathrm{b} \times \vec{p}_{\bar{\mathrm{b}}})_z,$$

$$O_{14} = \epsilon(P, p_\mathrm{b} + p_{\bar{\mathrm{b}}}, p_\ell, p_{j_1}) \propto (\vec{p}_\mathrm{b} + \vec{p}_{\bar{\mathrm{b}}}) \cdot (\vec{p}_\ell \times \vec{p}_{j_1}).$$

CP violation in $t\bar{t}$ (ℓ+jets)

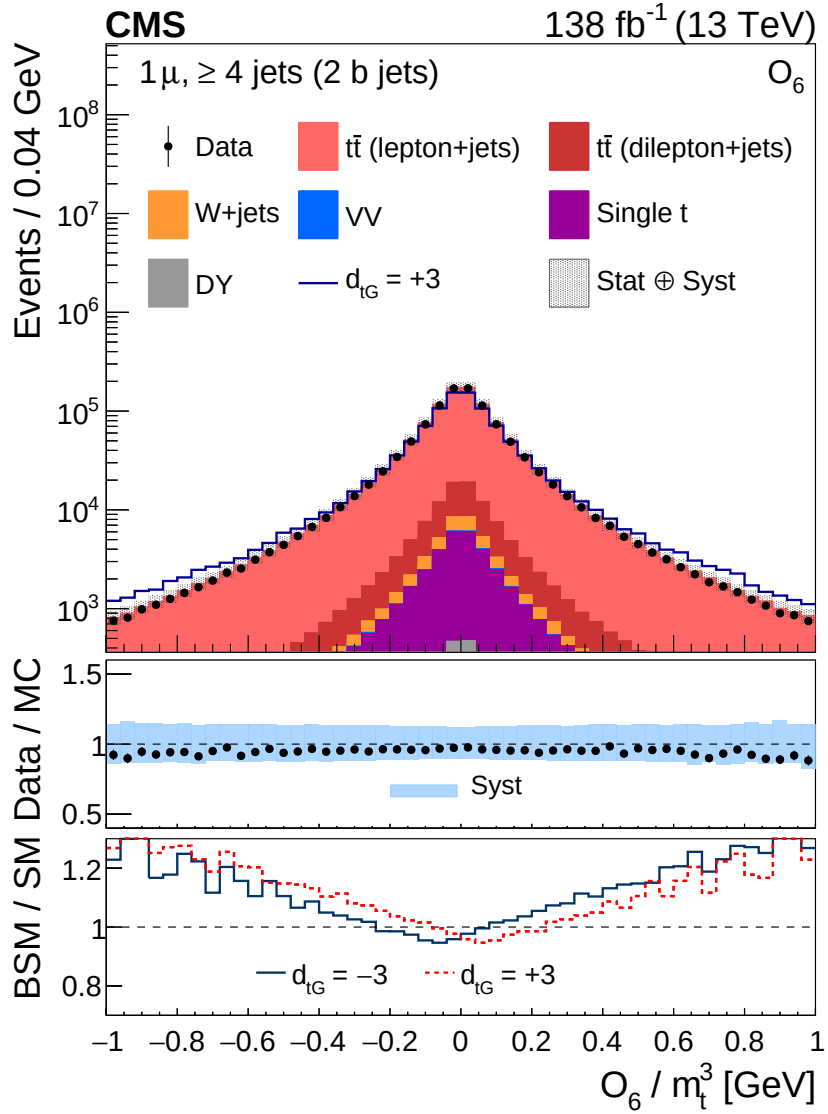
[TOP-20-005, submitted to JHEP]

- ℓ+jets channel, ≥ 4 jets, 2 b-tagged
- $t\bar{t}$ reconstruction with χ^2
- Measure CP observables and define asymmetry:

$$A_{CP} = \frac{N(O_i>0) - N(O_i<0)}{N(O_i>0) + N(O_i<0)},$$

$i = 3, 6, 12, 14$

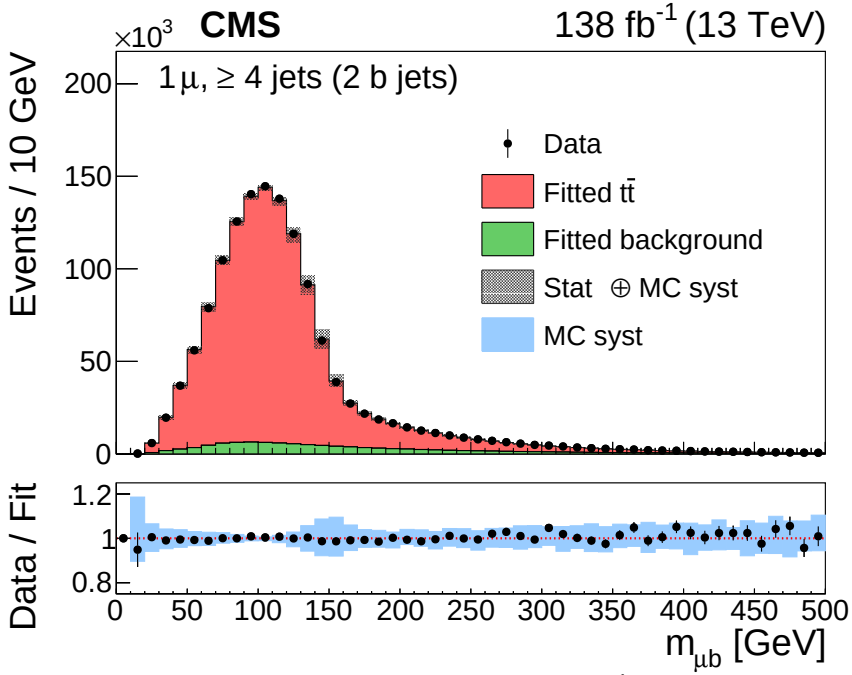
- Expected to be zero in SM

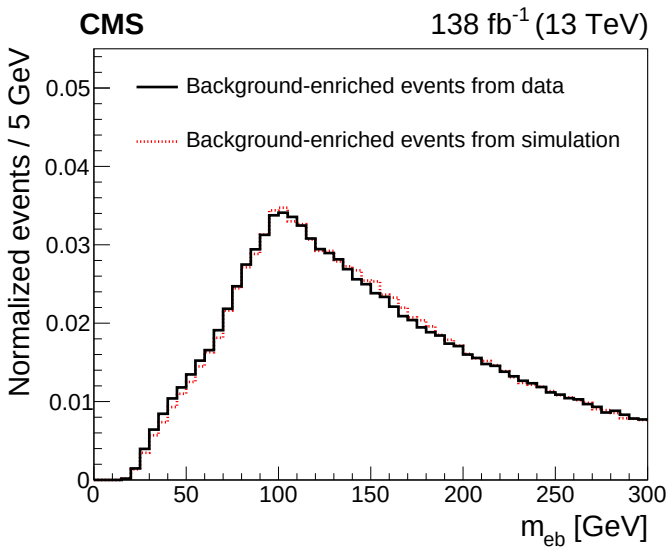


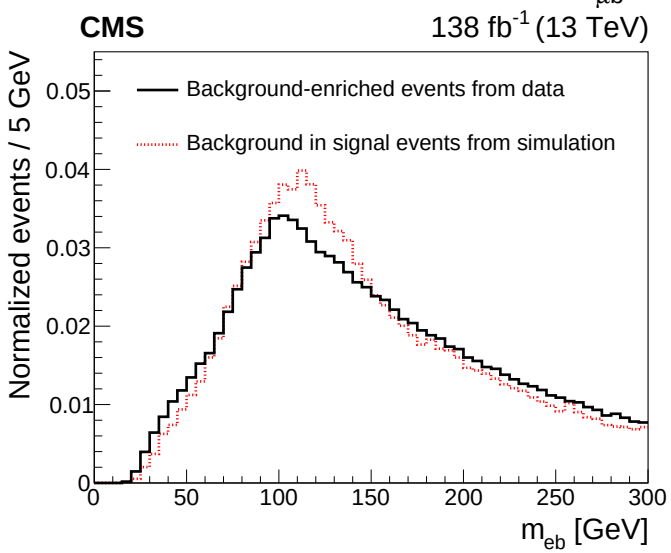
CP violation in $t\bar{t}$ (ℓ+jets)

[TOP-20-005, submitted to JHEP]

- Background estimation with fit to m_{lb}
- Additional uncertainty from different shapes in signal region



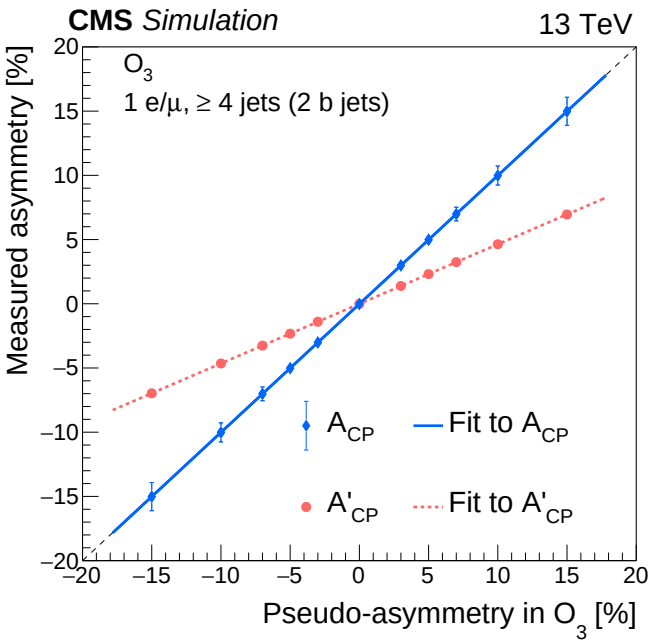


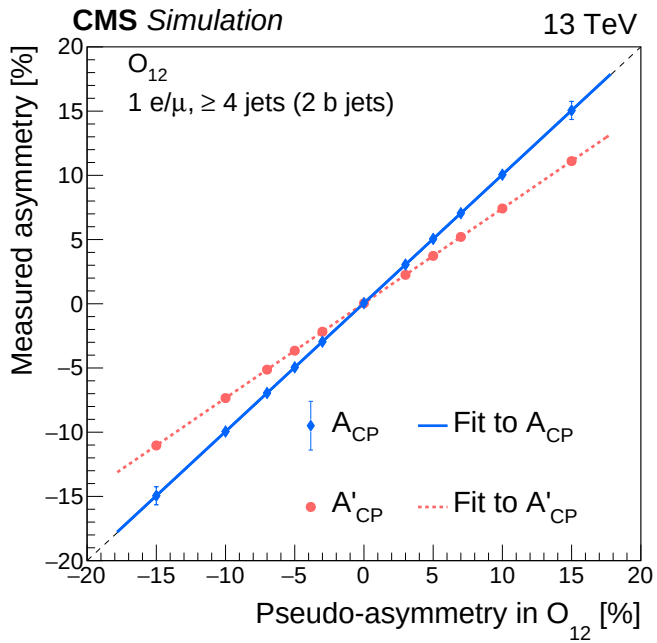


CP violation in $t\bar{t}$ (ℓ+jets)

[TOP-20-005, submitted to JHEP]

- True A_{CP} is diluted by detector and reconstruction effects
- Measurement of $A'_{CP} = D \cdot A_{CP}$
- Estimate dilution factor $D = \epsilon_c - \epsilon_w$ (fractions of correct and wrong sign of O_i compared to generator level)
- Smaller D for O_3 and O_6 because they are sensitive to charge of b quarks

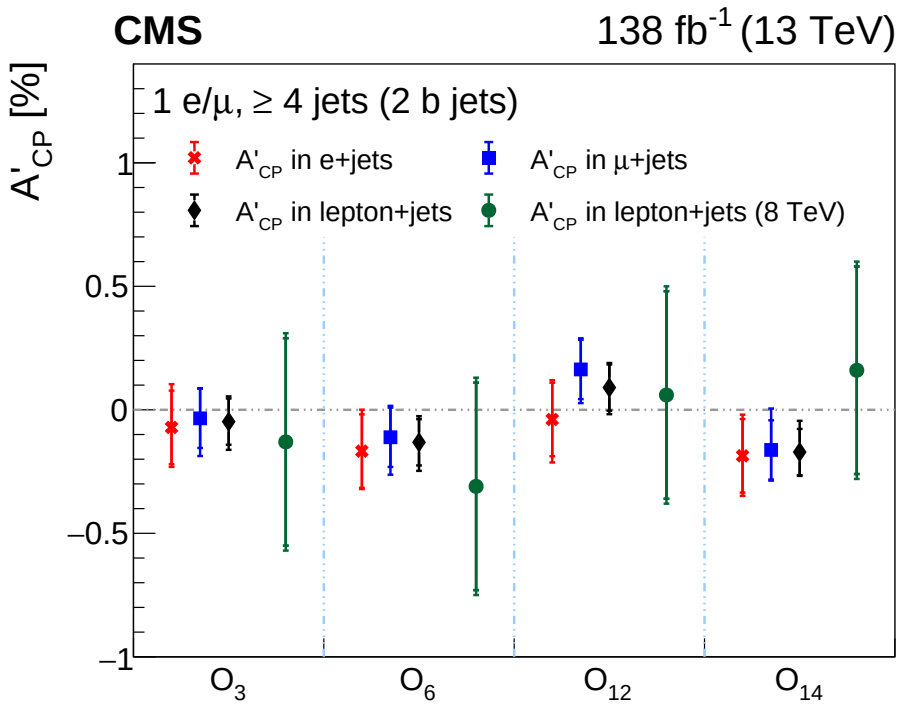




CP observable	Dilution factor D
O_3	$0.46\,^{+0.01}_{-0.02}$
O_6	$0.44\,^{+0.01}_{-0.02}$
O_{12}	$0.74\,^{+0.01}_{-0.02}$
O_{14}	$0.60\,^{+0.01}_{-0.01}$

CP violation in $t\bar{t}$ (ℓ+jets)

[TOP-20-005, submitted to JHEP]



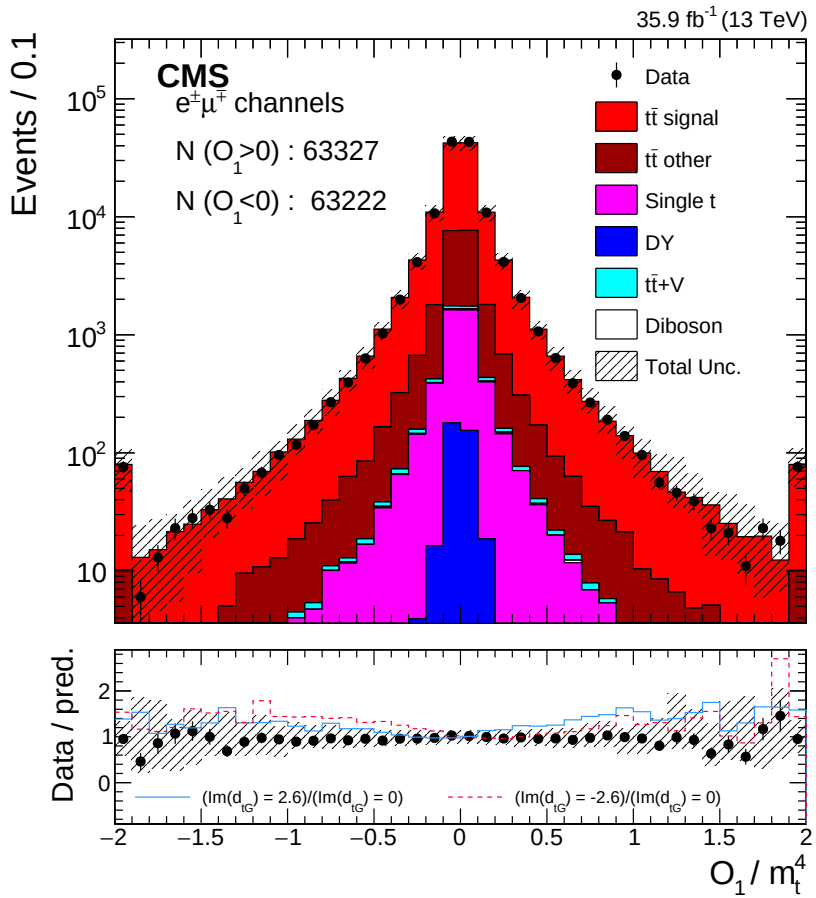
- A'_{CP} compatible with SM
- JEC, JER and background estimation largest exp. uncertainties
- ME-PS matching and UE largest model uncertainties
- Precision improved by a factor of 3
- BSM interpretation in [Jiwon's talk]

CP violation in $t\bar{t}$ (dilepton)

[TOP-18-007, submitted to JHEP]

- Similar analysis in dilepton
- 2 opposite sign leptons, ≥ 2 jets, ≥ 1 b-tagged
- $m_{\ell\ell} > 20$ GeV and outside Z mass for ee and $\mu\mu$
- Full $t\bar{t}$ reconstruction with m_t and m_W constraints
- Discard events where no solution for neutrinos is found
- Two CP observables:

$$O_1 = \epsilon(p_t, p_{\bar{t}}, p_{\ell^+}, p_{\ell^-}),\ O_3 = \epsilon(p_b, p_{\bar{b}}, p_{\ell^+}, p_{\ell^-})$$



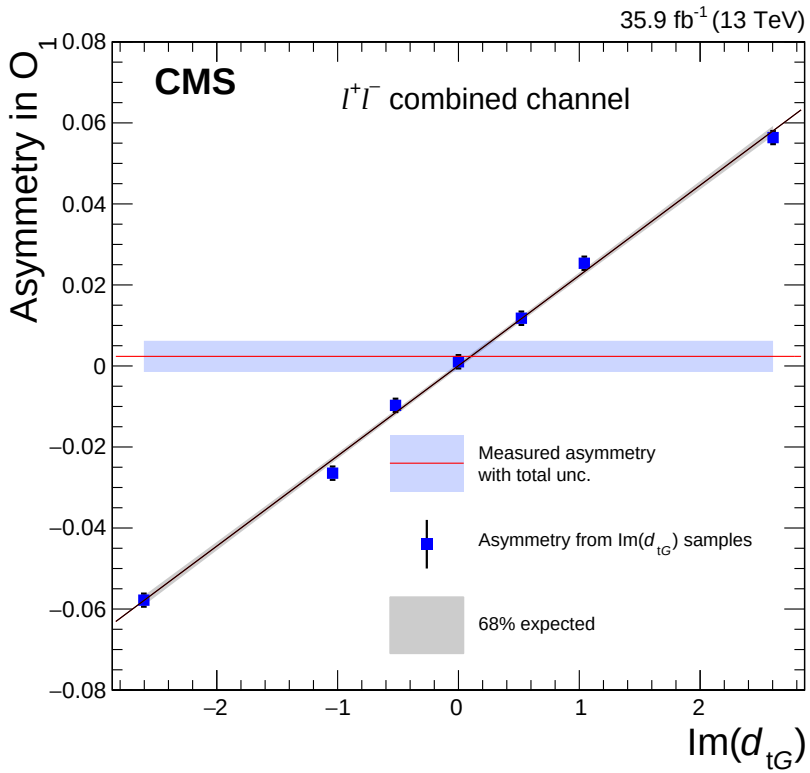
CP violation in $t\bar{t}$ (dilepton)

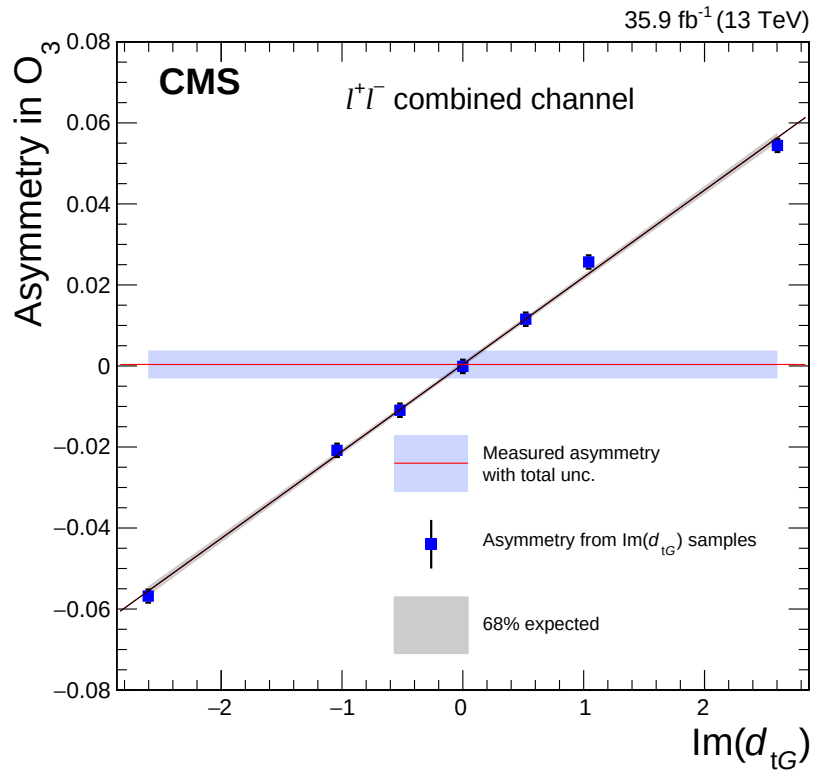
[TOP-18-007, submitted to JHEP]

- Both $A_{CP}(O_{1,3}) = \frac{N(O_{1,3}>0)-N(O_{1,3}<0)}{N(O_{1,3}>0)+N(O_{1,3}<0)}$ consistent with zero
- Largest source of uncertainties from limited background sample size

$A_{CP}(O_1) = 0.0024 \pm 0.0028$

$A_{CP}(O_3) = 0.0004 \pm 0.0028$





BSM interpretation in [Jiwon's talk]

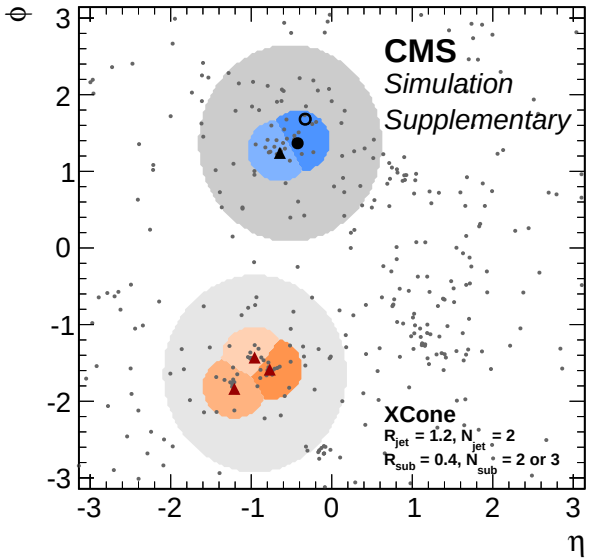
Measuring m_{jet} in boosted $t\bar{t}$ NEW!

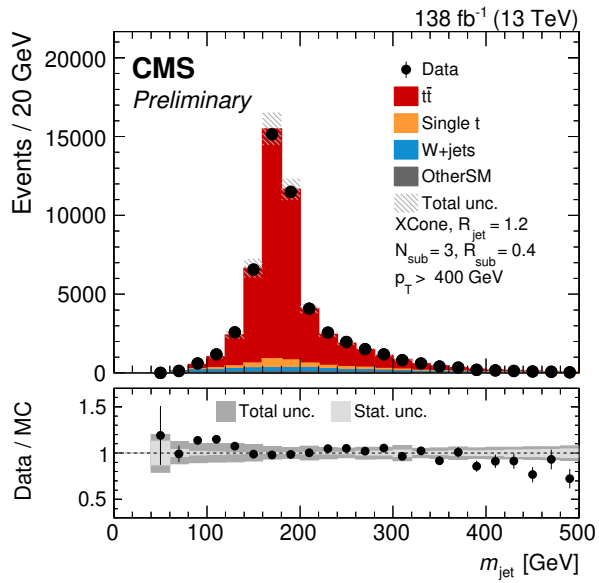
[TOP-21-012], [Stewart et al, JHEP 11 (2015) 072], [Thaler & Wilkason, JHEP 12 (2015) 051]

- Differential $t\bar{t}$ cross section as a function of m_{jet}
- m_{jet} important jet substructure observable (QCD, taggers, ...)
- m_t extraction covered in [Matteo's talk]

- ℓ+jets channel in boosted regime
- Two-step jet clustering with XCone

$\rightarrow$ Increase precision by calibrating jet mass scale and FSR modeling



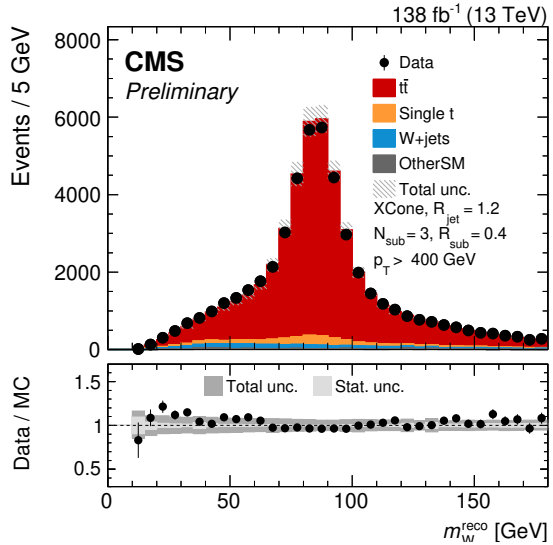


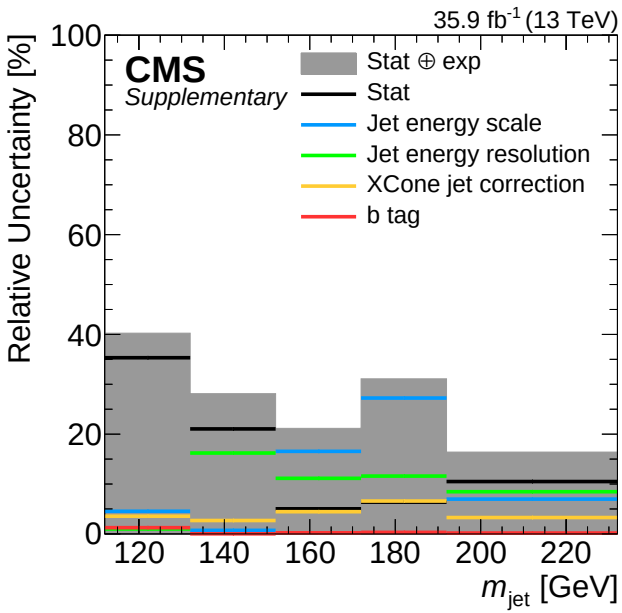
Measuring m_{jet} in boosted $t\bar{t}$

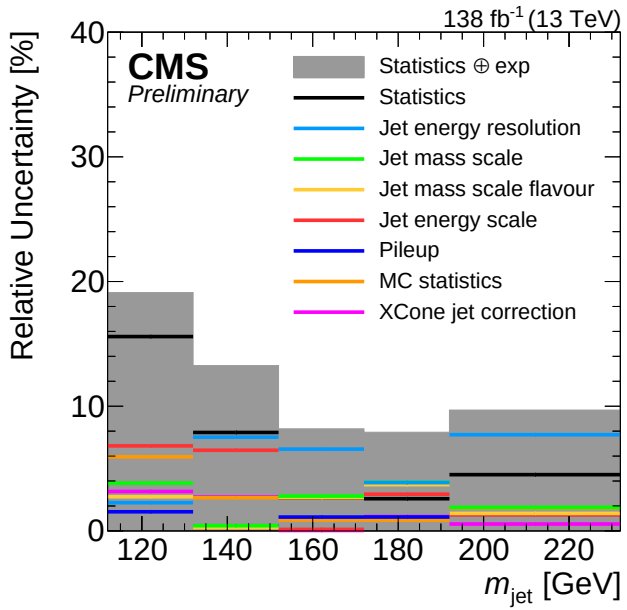
NEW!

[TOP-21-012], [Phys. Rev. Lett. 124 (2020) 202001]

- Jet mass scale measured with reconstructed W
- Add flavour uncertainty to account for differences of b jets and light jets





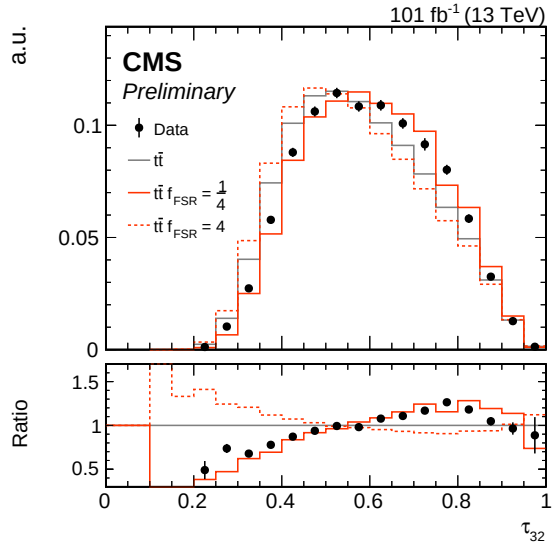


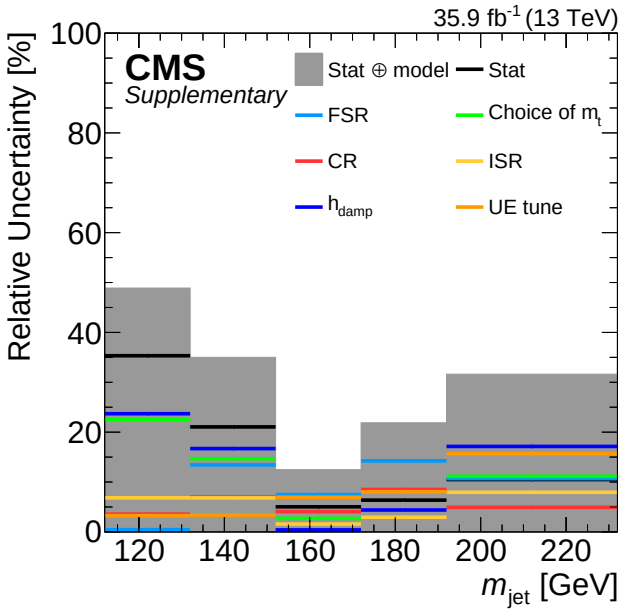
Measuring m_{jet} in boosted $t\bar{t}$

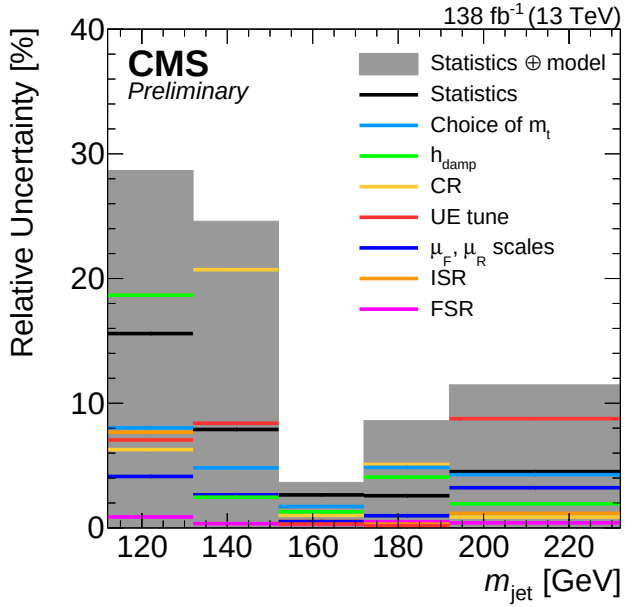
NEW!

[TOP-21-012], [Phys. Rev. Lett. 124 (2020) 202001]

- FSR modeling calibrated with jet substructure τ_{32}
- Tune MC to describe jet substructure in boosted regime





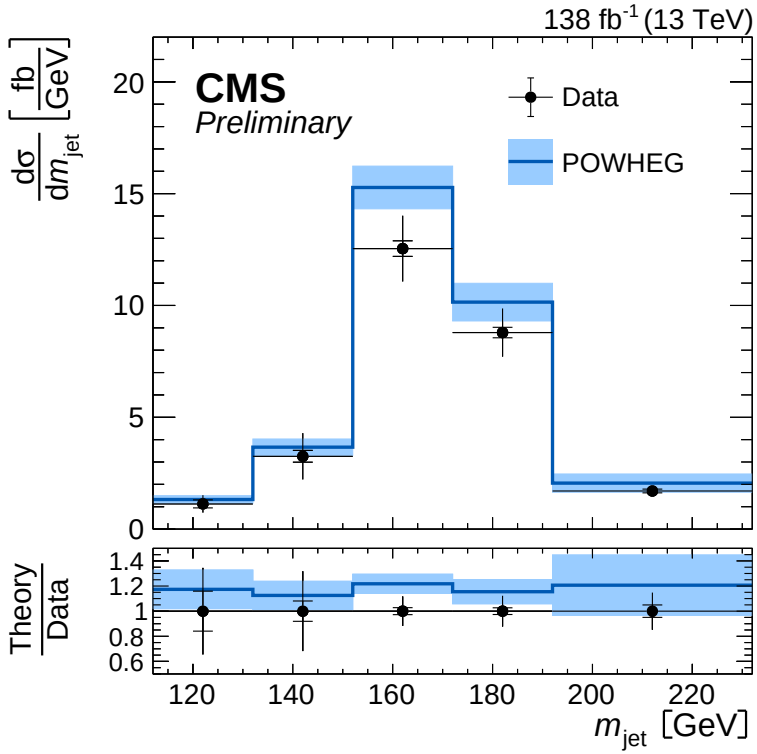


Measuring m_{jet} in boosted $t\bar{t}$ NEW!

[TOP-21-012]

- Regularized unfolding with TUnfold
- Important jet substructure measurement
- Dominant exp. uncertainties related to JMS
- Largest model uncertainties ME-PS matching, color reconnection, m_t
- Largely reduced uncertainties

(m_t extraction in [Matteo's talk])



Summary

- We are within precision era of top physics at LHC
- Many properties of the top quark are measured with high detail
- So far no significant deviation from the SM is found
- Experimental uncertainties well under control