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# Measurement of the jet mass distribution in hadronic decays of boosted top quarks [arXiv:1911.03800]

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on behalf of the CMS Collaboration

LHCtopWG

November 15, 2019

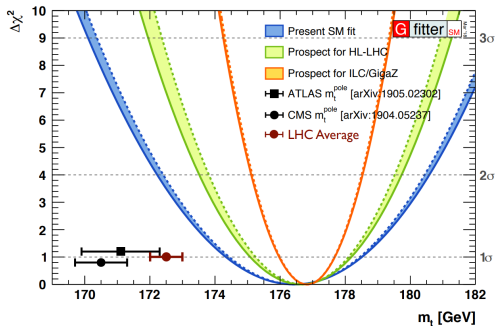
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# The top quark mass



Tensions between:

- fit  $\leftrightarrow$  measurements
- direct  $\leftrightarrow$  pole mass measurements

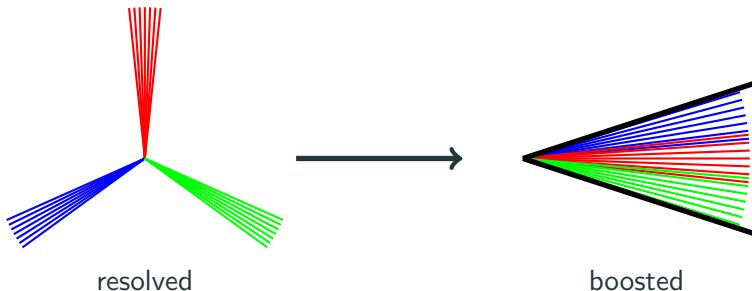
dominated by threshold production  $\rightarrow$  explore boosted regime

## Direct measurements

- Select  $t\bar{t}$  in resolved regime
  - Reconstruct top mass
  - Fit MC to data
- rely on MC

## This approach

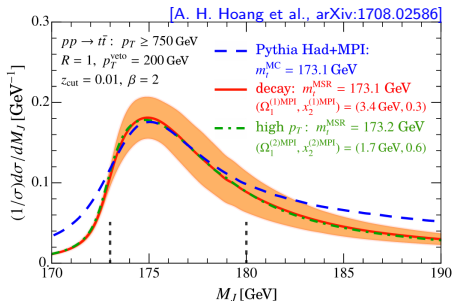
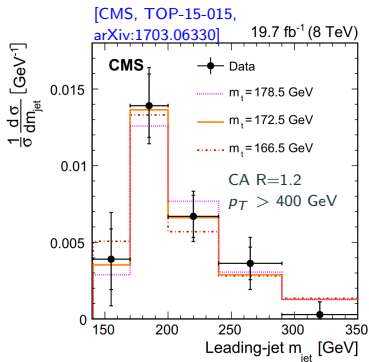
- Boosted regime
  - Jet mass  $m_{\text{jet}} = \sqrt{p_{\text{jet}}^2}$
  - Unfold to particle level
- analytical calculations

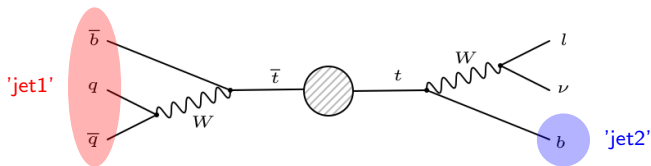


# Analysis goal



- Measure differential cross section as function of  $m_{\text{jet}}$
- Important substructure measurement
- Extract  $m_t$  from unfolded distribution
- Phase space of theory and experiment not compatible yet





- **Select lepton+jets** (tag  $t\bar{t}$  with lepton)

- $N_\ell = 1$

- $p_T > 60$  GeV

- **Boosted** top quark decays

- $p_{T,\text{jet1}} > 400$  GeV

- **Suppress unmerged events**

- $m_{\text{jet1}} > m_{\text{jet2}} + \text{lepton}$

→ Measure hadronic top decay (jet1) only

(Detector level: additional b tagging, lepton isolation, cut on  $p_T^{\text{miss}}$ )

## Novel jet reconstruction!

### XCone [I. W. Stewart et al., JHEP 1511 (2015) 072]

- Exclusive jet algorithm  $\rightarrow$  returns exactly  $N$  jets
- $\rightarrow$  Event signature (number of jets) defines clustering
- Jet axes found by minimizing N-jettiness  
(N-jettiness = measure how N-jet-like the event looks)
- Cluster particles inside  $R$  around axes
- Easier to include in theory calculations than other algorithms

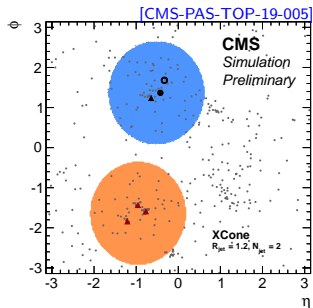
# 2-step clustering using XCone

[CMS, TOP-19-005]



**set-up for  $\ell + \text{jets } t\bar{t}$**  idea from: [J. Thaler and T. F. Wilkason, JHEP 1512 (2015) 051]

1. Find 2 jets with large radius



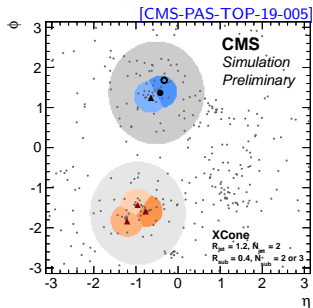
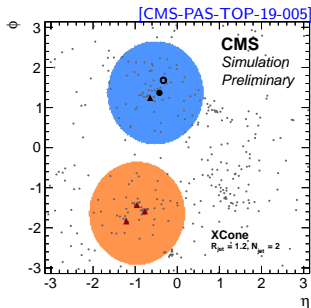
# 2-step clustering using XCone

[CMS, TOP-19-005]



**set-up for  $\ell + \text{jets } t\bar{t}$**  idea from: [J. Thaler and T. F. Wilkason, JHEP 1512 (2015) 051]

1. Find 2 jets with large radius
2. Find subjets: 3 in hadronic jet, 2 in jet with lepton





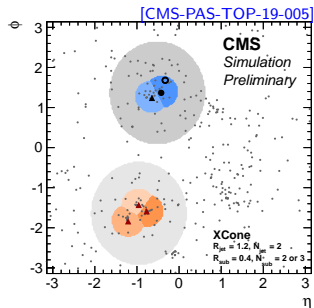
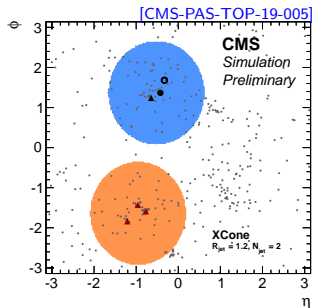
# 2-step clustering using XCone

[CMS, TOP-19-005]



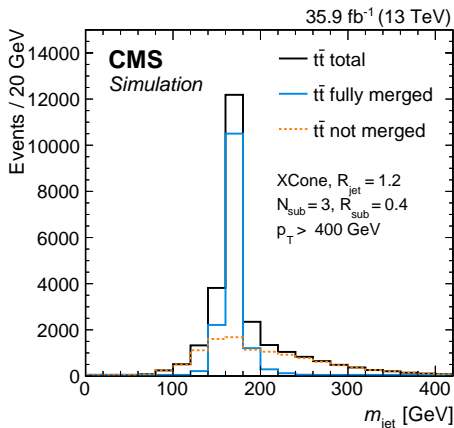
**set-up for  $\ell + \text{jets } t\bar{t}$**  idea from: [J. Thaler and T. F. Wilkason, JHEP 1512 (2015) 051]

1. Find 2 jets with large radius
  2. Find subjects: 3 in hadronic jet, 2 in jet with lepton
  3. Combine subjects to final jet
- Smooth transition from resolved to boosted regime



# Particle level distribution

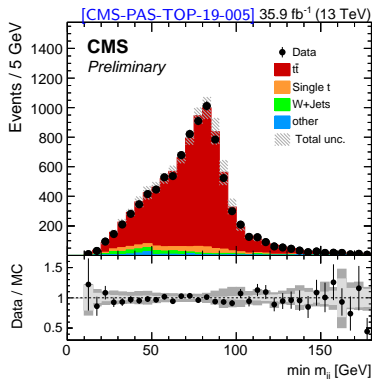
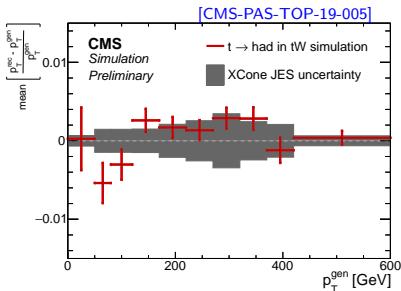
[CMS, TOP-19-005]



- Width factor 2 smaller than 8 TeV
  - Veto on 3rd jet not necessary
  - 75% merged top decays in peak
  - Identical to AK4 in isolated case
- Standard AK4 JES

# Calibrating X Cone jets

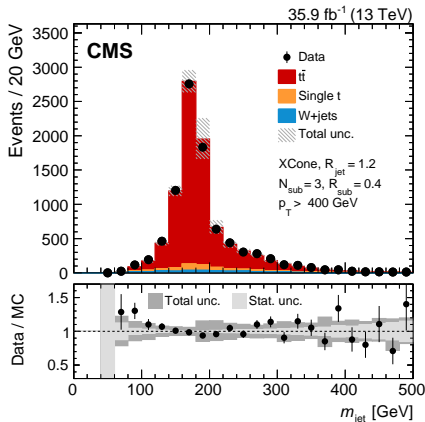
[CMS, TOP-19-005]



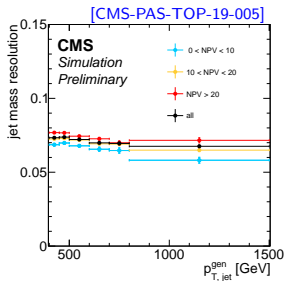
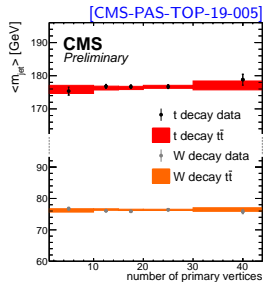
- Small residual correction  $[p_T, \eta]$  due to non-isolated topology
- Closure in  $tW$  after correction
- Cross check in  $W$  reconstruction

# Detector level distribution

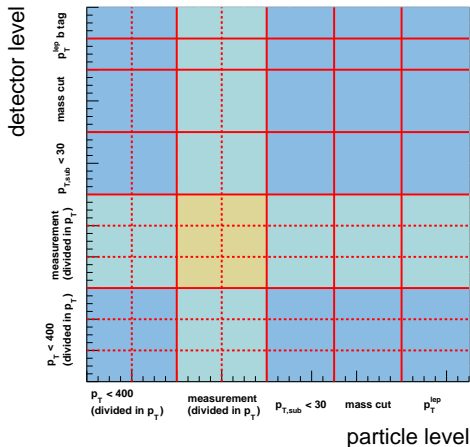
[CMS, TOP-19-005]



- Width better by a factor of 2
- $m_{jet}$  stable against pileup
- $m_{jet}$  resolution improved 14%  $\rightarrow$  6%

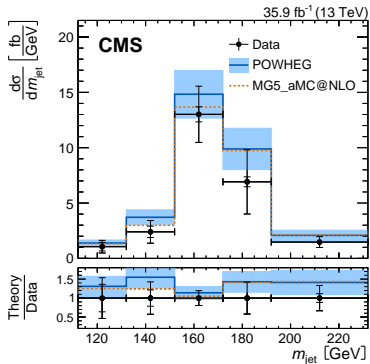


- Regularized unfolding in TUnfold
  - Higher granularity in migration matrix
- $N_{\text{rec}} = 200, N_{\text{gen}} = 72$
- Various sideband regions



# Unfolded distribution

[CMS, TOP-19-005]

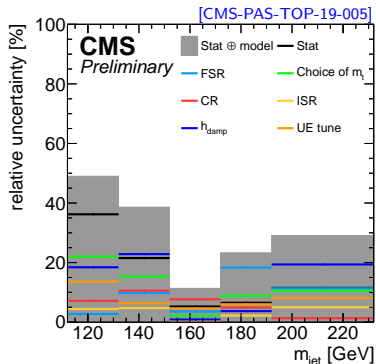
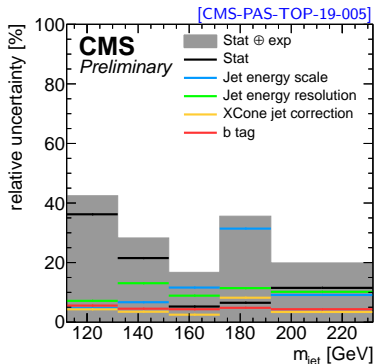


- Smaller cross section in data than MC
- Theo uncertainties: parton shower, UE, scales

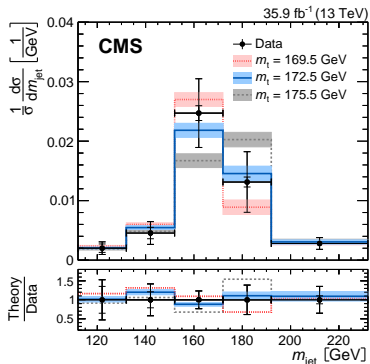
$$\begin{aligned}\sigma &= 527 \pm 15 \text{ (stat)} \pm 39 \text{ (exp)} \pm 29 \text{ (model)} \text{ fb} \\ &= 527 \pm 51 \text{ (total)} \text{ fb} \\ \sigma^{\text{MC}} &= 680 \pm 109 \text{ fb}\end{aligned}$$

# Uncertainties

[CMS, TOP-19-005]



- Dominant experimental uncertainties: JES, JER
- Dominant model uncertainty from parton shower (e.g. FSR)



- Normalized distribution sensitive to  $m_t$
- Offers an orthogonal measurement of  $m_t$

8 TeV result:  $\Delta m_t = \pm 9$  GeV

[Eur. Phys. J. C 77 (2017) 467]

$$m_t = 172.6 \pm 0.4 (\text{stat}) \pm 1.6 (\text{exp}) \pm 1.5 (\text{model}) \pm 1.0 (\text{theo}) \text{ GeV}$$

$$m_t = 172.6 \pm 2.5 (\text{total}) \text{ GeV}$$

→ Will enable comparison with analytical calculations ( $m_t^{\text{pole}}$ )

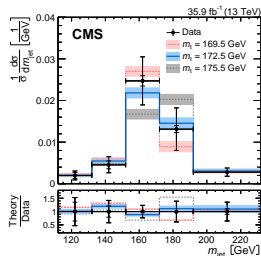
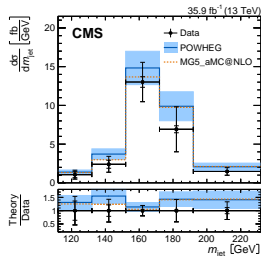


# Summary and Outlook

[CMS, TOP-19-005]



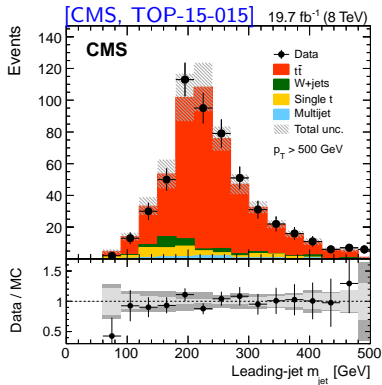
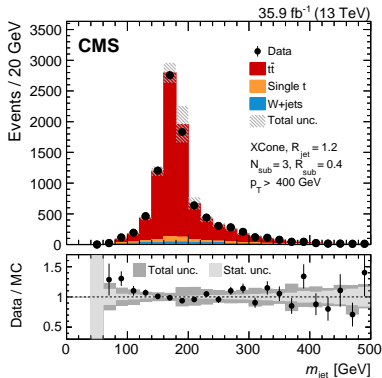
- Huge improvement (factor 3)
  - X Cone as novel jet algorithm
  - More precise unfolding
- Sensitivity approaching precision measurements of  $m_t$
- Importance of boosted regime in measurements of SM parameters
- Full Run2 analysis ongoing, work on improving systematic uncertainties



additional material

# 13 TeV vs 8 TeV

[CMS, TOP-19-005]

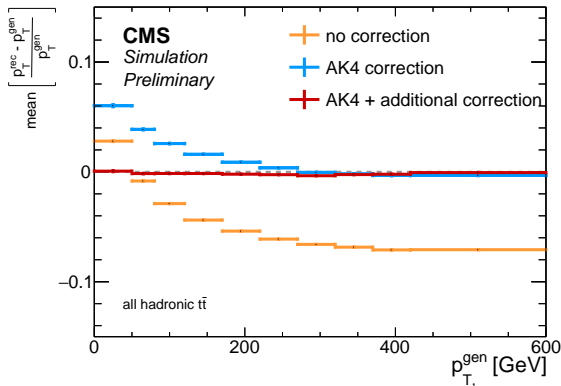


# Calibrating X Cone jets

[CMS, TOP-19-005]

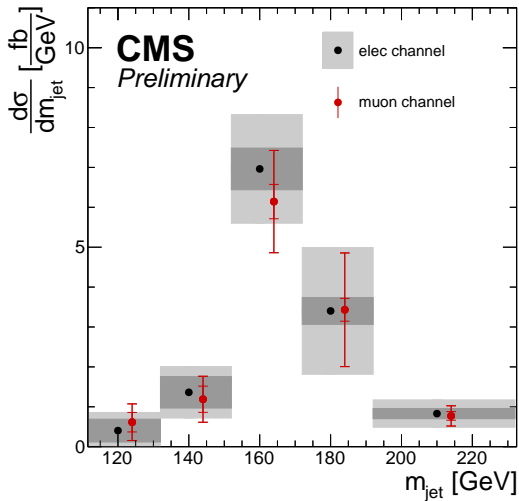


- No jet calibration for X Cone so far
- Idea: AK4 calibration + additional correction
- Correction derived in all hadronic  $t\bar{t}$
- Correction applied dependent on  $p_T$  and  $\eta$  of subjets



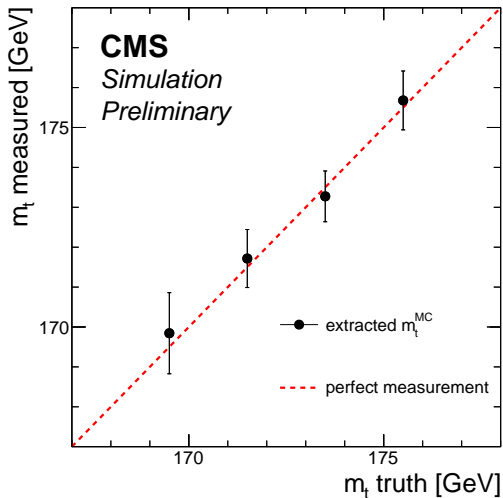
# Channel Comparison

[CMS, TOP-19-005]



# Mass Calibration

[CMS, TOP-19-005]



# Subjet kinematics

[CMS, TOP-19-005]

