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

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Physics at the Terascale
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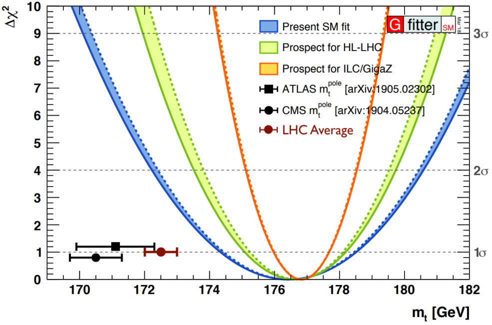
GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

The top quark mass



Tensions between:

- fit ↔ measurements
- direct ↔ pole mass measurements

dominated by threshold production → explore boosted regime

Motivation

Direct measurements

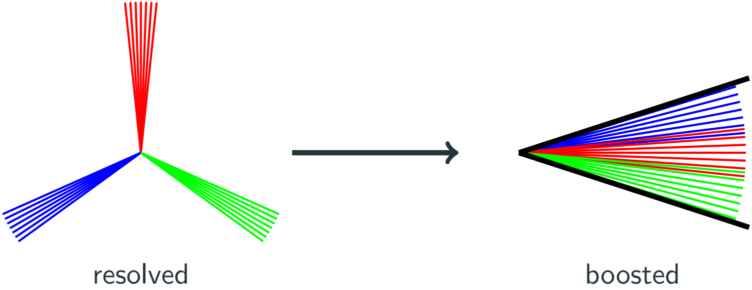
- Select $t\bar{t}$ in resolved regime
- Reconstruct top mass
- Fit MC to data

$\rightarrow$ rely on MC

This approach

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

$\rightarrow$ analytical calculations



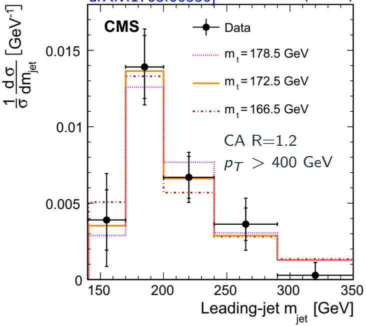
Analysis goal

- Measure differential cross section as function of m_{jet}

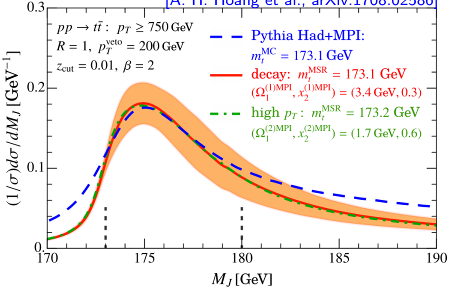
$\rightarrow$ Important substructure measurement

- Extract m_t from unfolded distribution
- Phase space of theory and experiment not compatible yet

[CMS, TOP-15-015, arXiv:1703.06330]

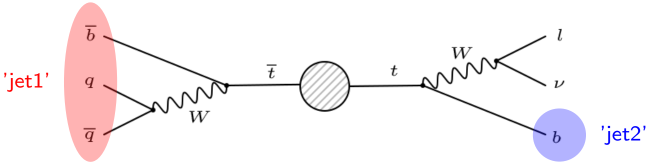


[A. H. Hoang et al., arXiv:1708.02586]



$\rightarrow$ new measurement on 13 TeV with substantial improvements

Particle level selection



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

$\rightarrow$ Measure hadronic top decay (jet1) only

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

XCone

Novel jet reconstruction!

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

- Exclusive jet algorithm → returns exactly N jets

→ Event signature (number of jets) defines clustering

- Jet axes found by minimizing N-jettiness

  (N-jettiness = measure how N-jet-like the event looks)

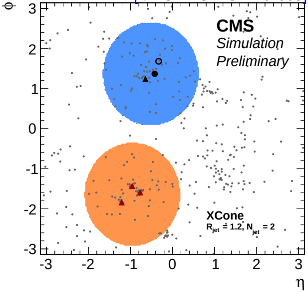
- Cluster particles inside R around axes
- Easier to include in theory calculations than other algorithms

2-step clustering using XCone
[CMS, TOP-19-005]

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

1. Find 2 jets with large radius

[CMS-PAS-TOP-19-005]



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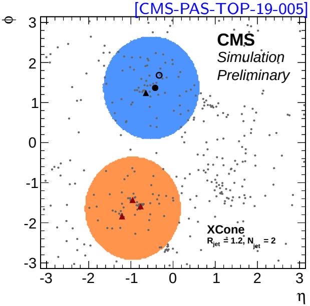
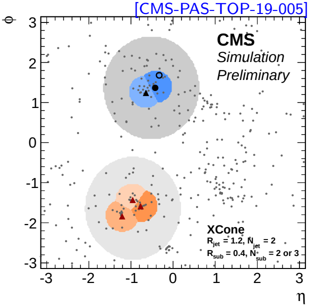
set-up for $\ell +$ jets $t\bar{t}$ idea from: [J. Thaler and T. F. Wilkason, JHEP 1512 (2015) 051]

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



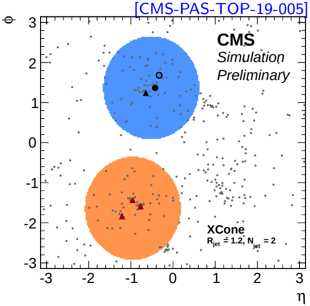


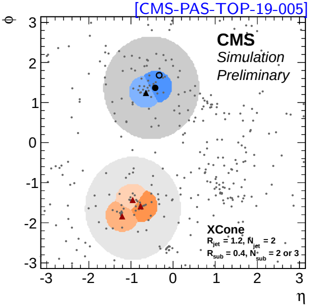
2-step clustering using XCone
[CMS, TOP-19-005]

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

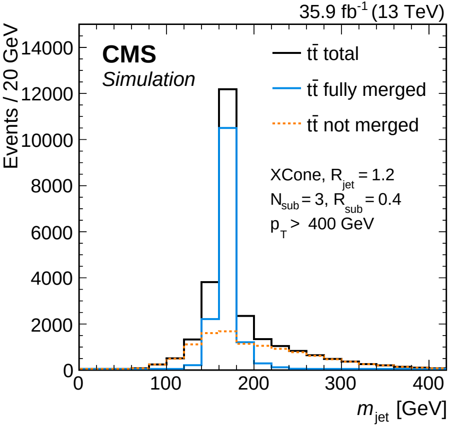
1. Find 2 jets with large radius
2. Find subjets: 3 in hadronic jet, 2 in jet with lepton
3. Combine subjets to final jet

→ Smooth transition from resolved to boosted regime





Particle level distribution
[CMS, TOP-19-005]

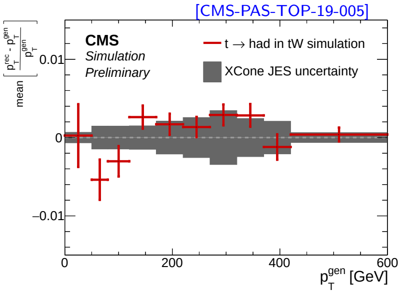


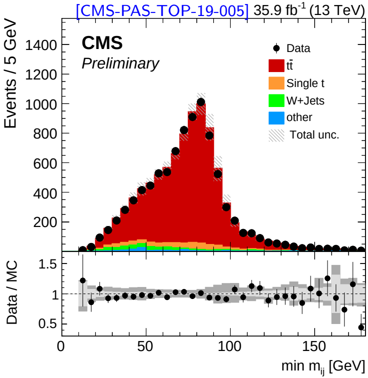
- Width factor 2 smaller than 8 TeV
- Veto on 3rd jet not necessary
- 75% merged top decays in peak

- Identical to AK4 in isolated case

$\rightarrow$ Standard AK4 JES

Calibrating XCone jets
[CMS, TOP-19-005]

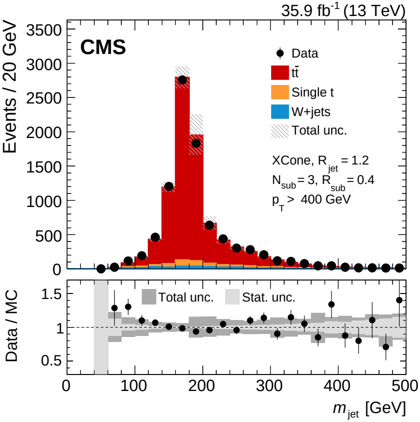




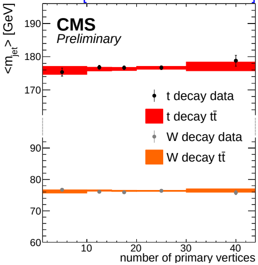
- Small residual correction $[p_T, \eta]$ due to non-isolated topology
- Closure in tW after correction
- Cross check in W reconstruction

Detector level distribution

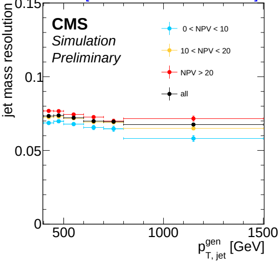
[CMS, TOP-19-005]



[CMS-PAS-TOP-19-005]



[CMS-PAS-TOP-19-005]



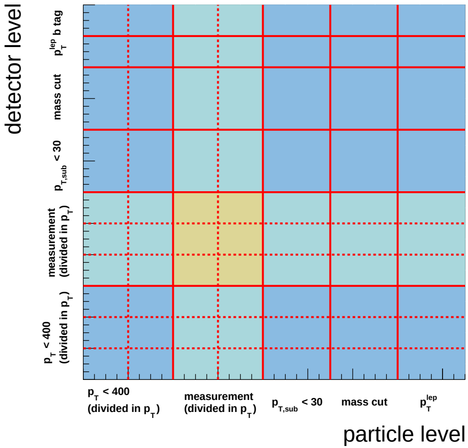
- Width better by a factor of 2
- m_{jet} stable against pileup
- m_{jet} resolution improved 14% $\rightarrow$ 6%

Unfolding setup

- Regularized unfolding in TUnfold
- Higher granularity in migration matrix

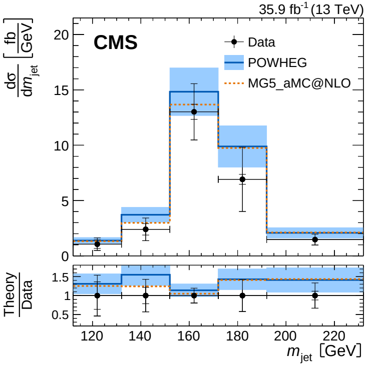
→ $N_{\mathrm{rec}} = 200$, $N_{\mathrm{gen}} = 72$

→ Various sideband regions



Unfolded distribution

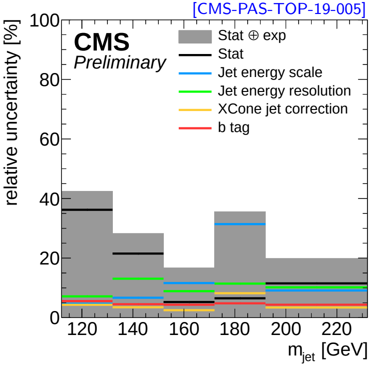
[CMS, TOP-19-005]

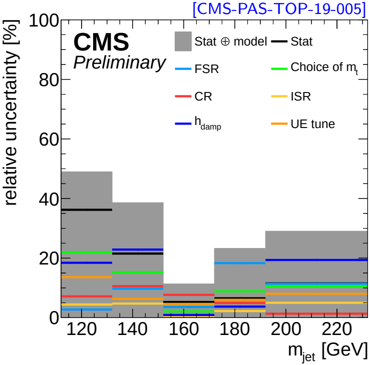


- Smaller cross section in data than MC
- Theo uncertainties: parton shower, UE, scales

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

Uncertainties
[CMS, TOP-19-005]

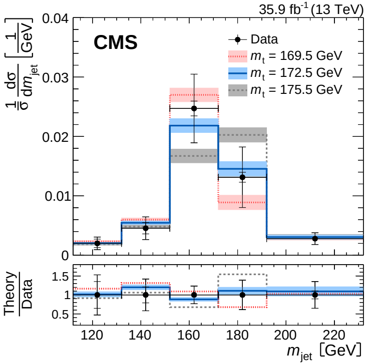




- Dominant experimental uncertainties: JES, JER
- Dominant model uncertainty from parton shower (e.g. FSR)

Extraction of m_t

[CMS, TOP-19-005]



- 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]

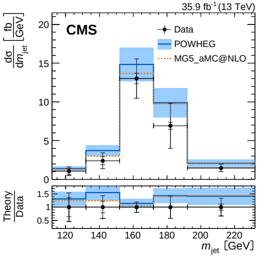
$$m_t = 172.6 \pm 0.4\,(\text{stat}) \pm 1.6\,(\text{exp}) \pm 1.5\,(\text{model}) \pm 1.0\,(\text{theo})\ \text{GeV}$$

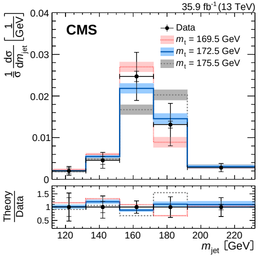
$$m_t = 172.6 \pm 2.5\,(\text{total})\ \text{GeV}$$

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

Summary and Outlook
[CMS, TOP-19-005]

- Huge improvement (factor 3)
  - XCone 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

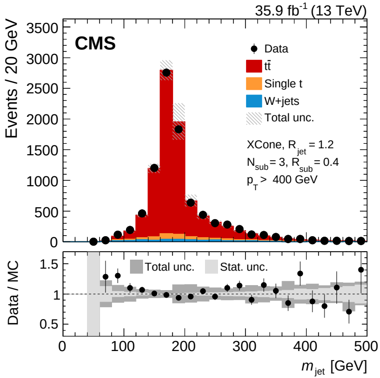


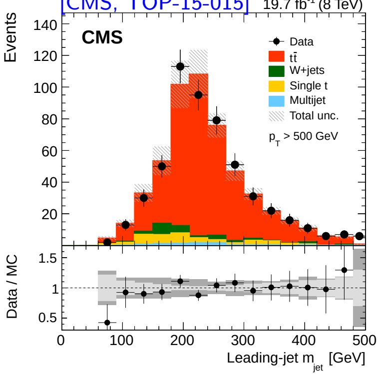


additional material

13 TeV vs 8 TeV

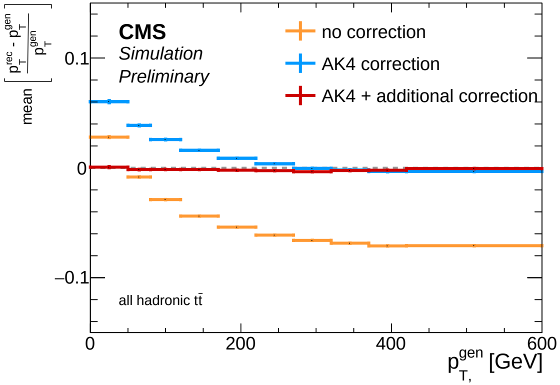
[CMS, TOP-19-005]





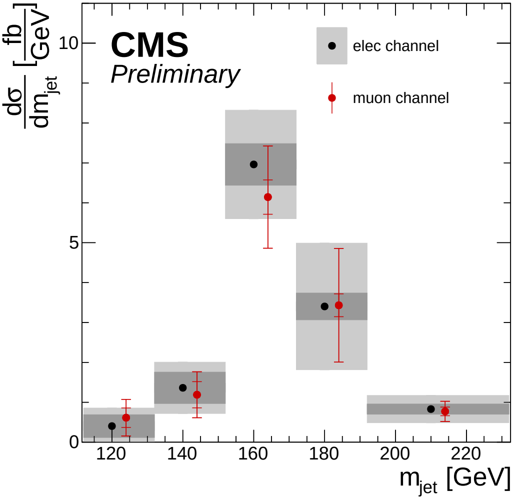
Calibrating XCone jets
[CMS, TOP-19-005]

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

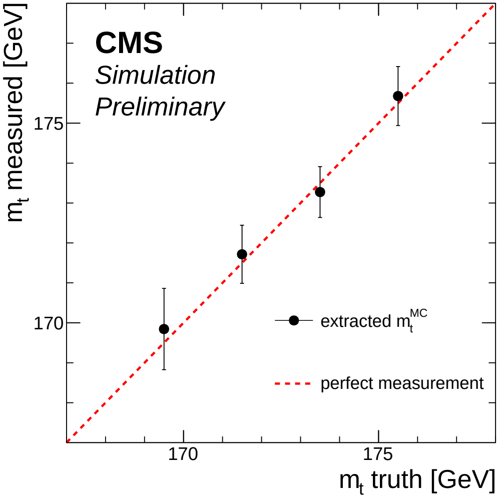


Channel Comparision

[CMS, TOP-19-005]



Mass Calibration
[CMS, TOP-19-005]



Subjet kinematics
[CMS, TOP-19-005]