Measurements of the top-quark mass from boosted jets at CMS

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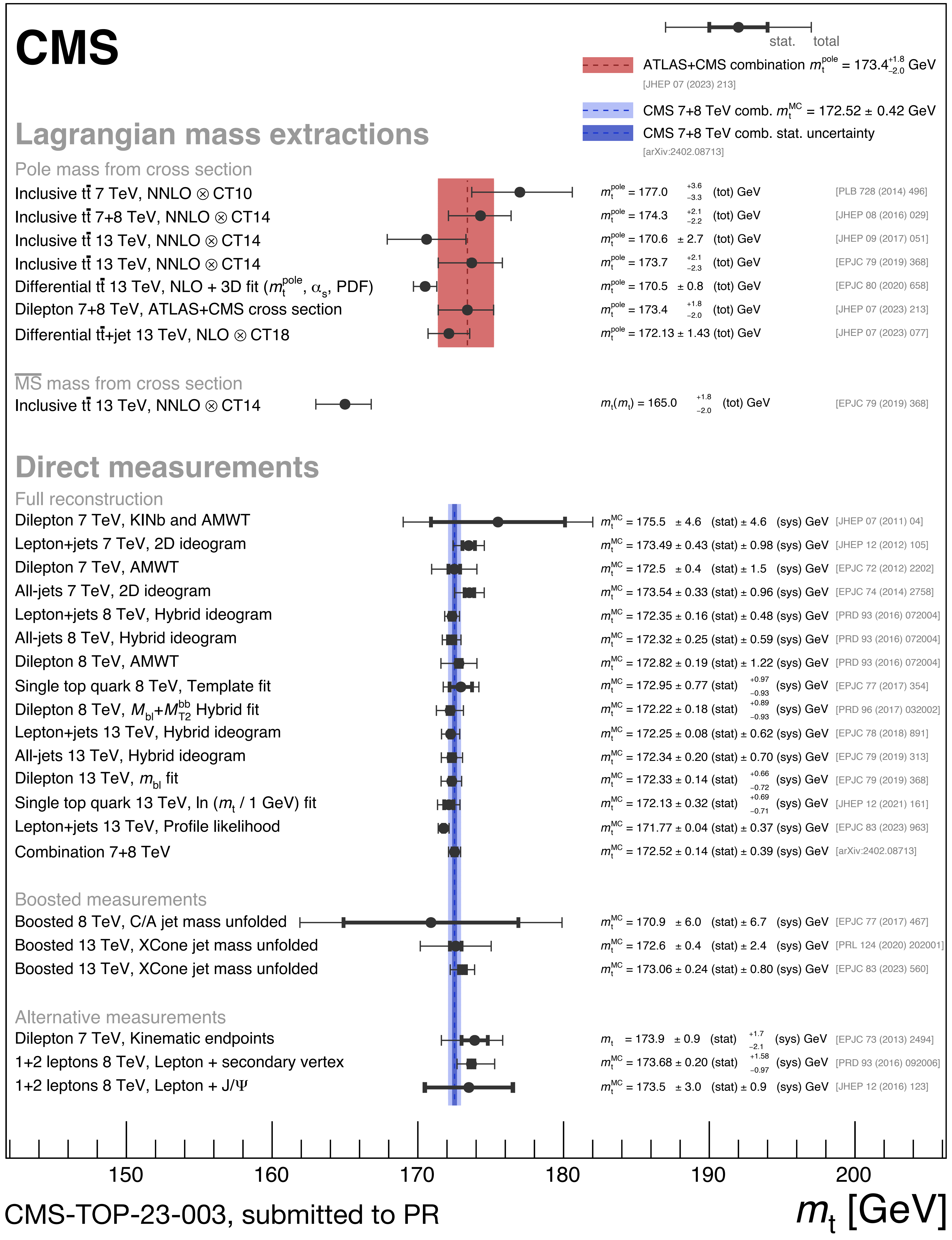
How to measure m_{top}?



CMS-TOP-23-003, submitted to PR

- Most precise single measurement of m_{top}

  CMS, EPJC 83, 963, 2023
  - Profile likelihood in ℓ+jets channel from $t\bar{t}$
  - $\Delta m_{\text{top}}^{\text{MC}} = 0.37$ GeV

- Explore boosted regime

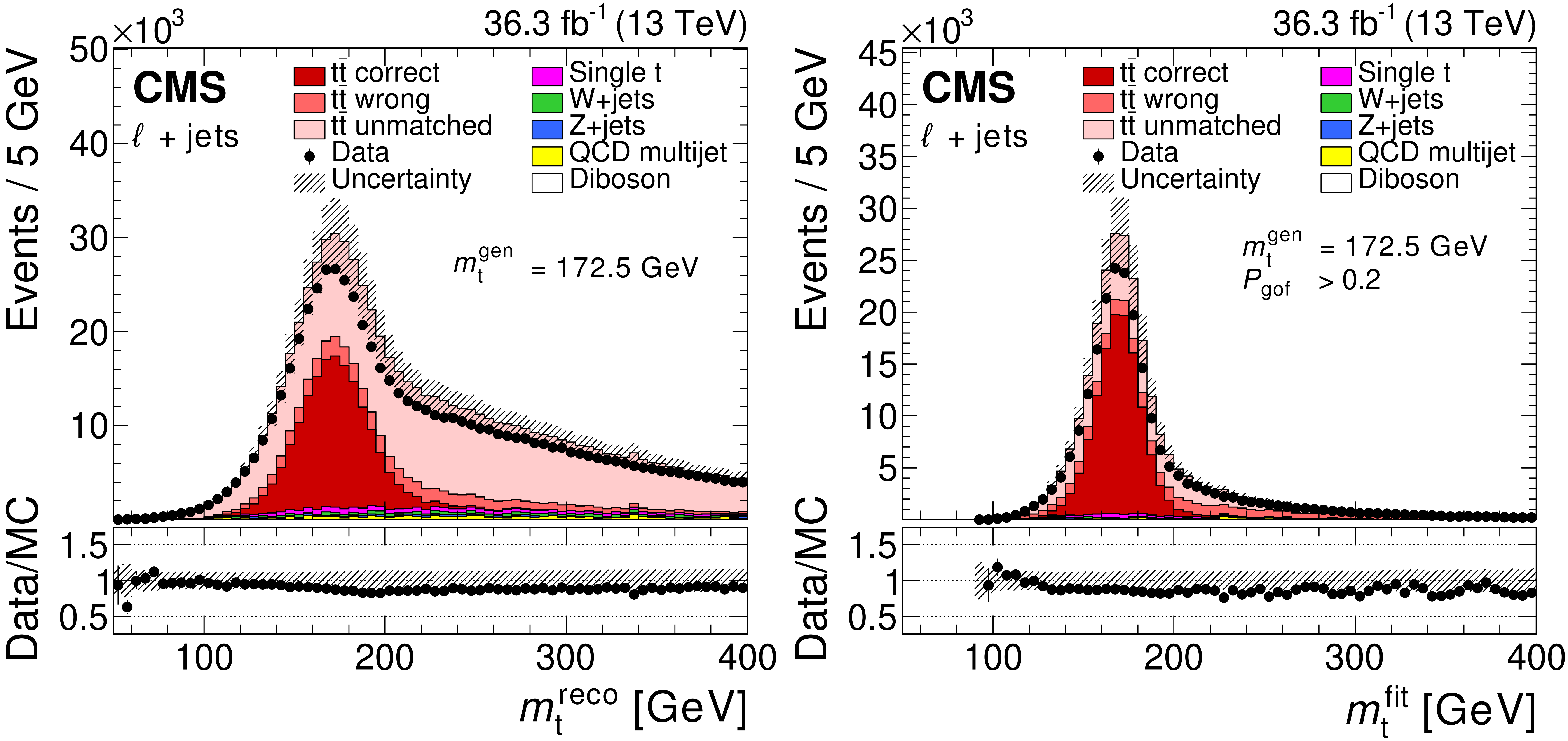
  CMS, EPJC 83, 560, 2023
  - Reconstruct top quark in single jet
  - Extract m_{top} from jet mass
  - $\Delta m_{\text{top}}^{\text{MC}} = 0.84$ GeV

Profile likelihood fit to measure m_t

CMS, EPJC 83, 963, 2023

- Most precise m_t measurement so far
- Performed in the ℓ+jets channel: $= 1$ electron or muon, ≥ 4 jets, ≥ 2 b-jets
- Construct m_t^{reco} from three jets
- Kinematic fit to $t\bar{t}$ hypothesis
  - Constrain m_W and mass system
  - Select events with

    $P_{gof} = \exp(-\chi^2/2) > 0.2$

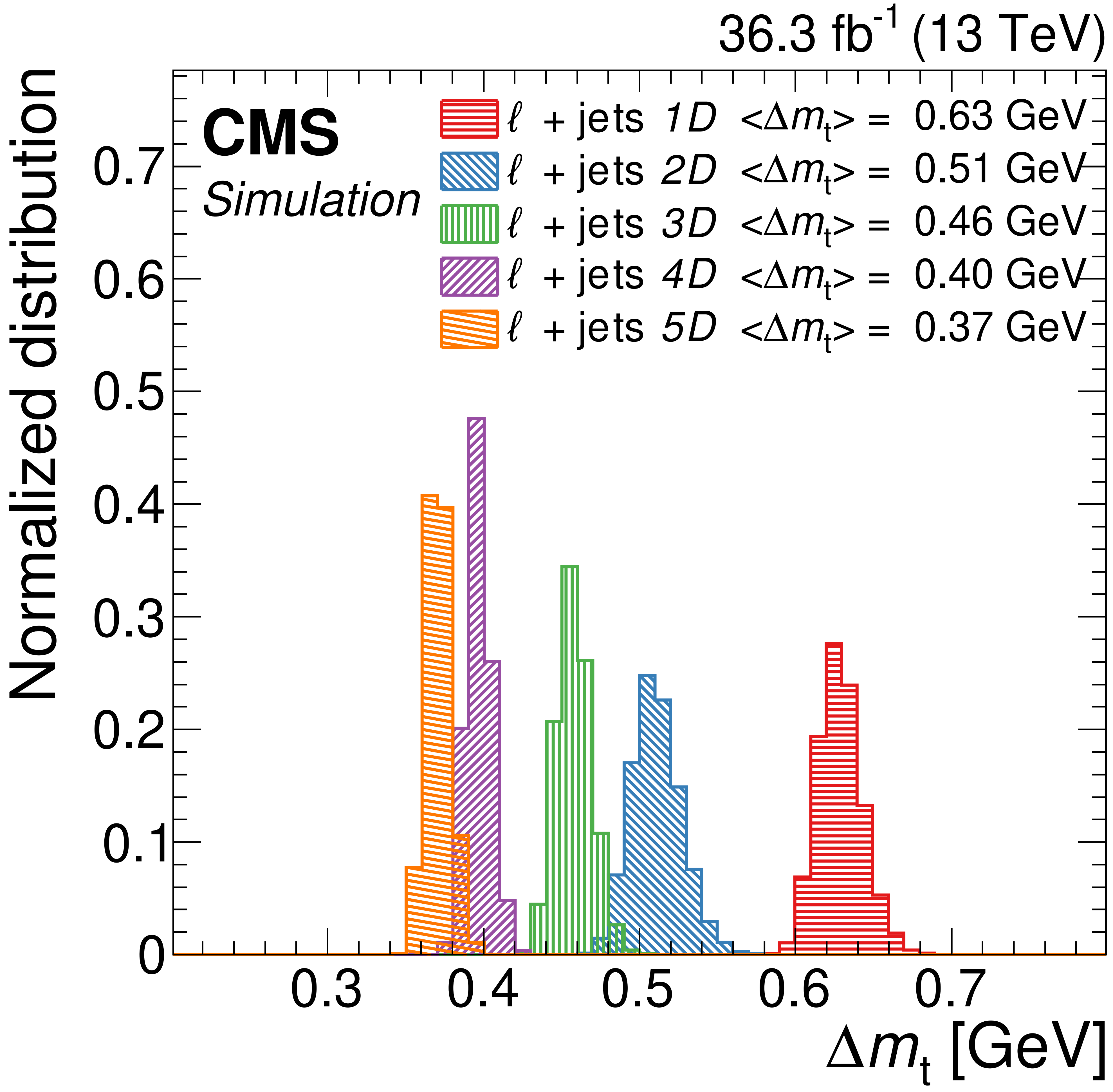


Profile likelihood approach to measure m_t

CMS, EPJC 83, 963, 2023

*$R^{\text{reco}}_{\text{bq}} = \frac{p_T^{b1} + p_T^{b2}}{p_T^{q1} + p_T^{q2}}$

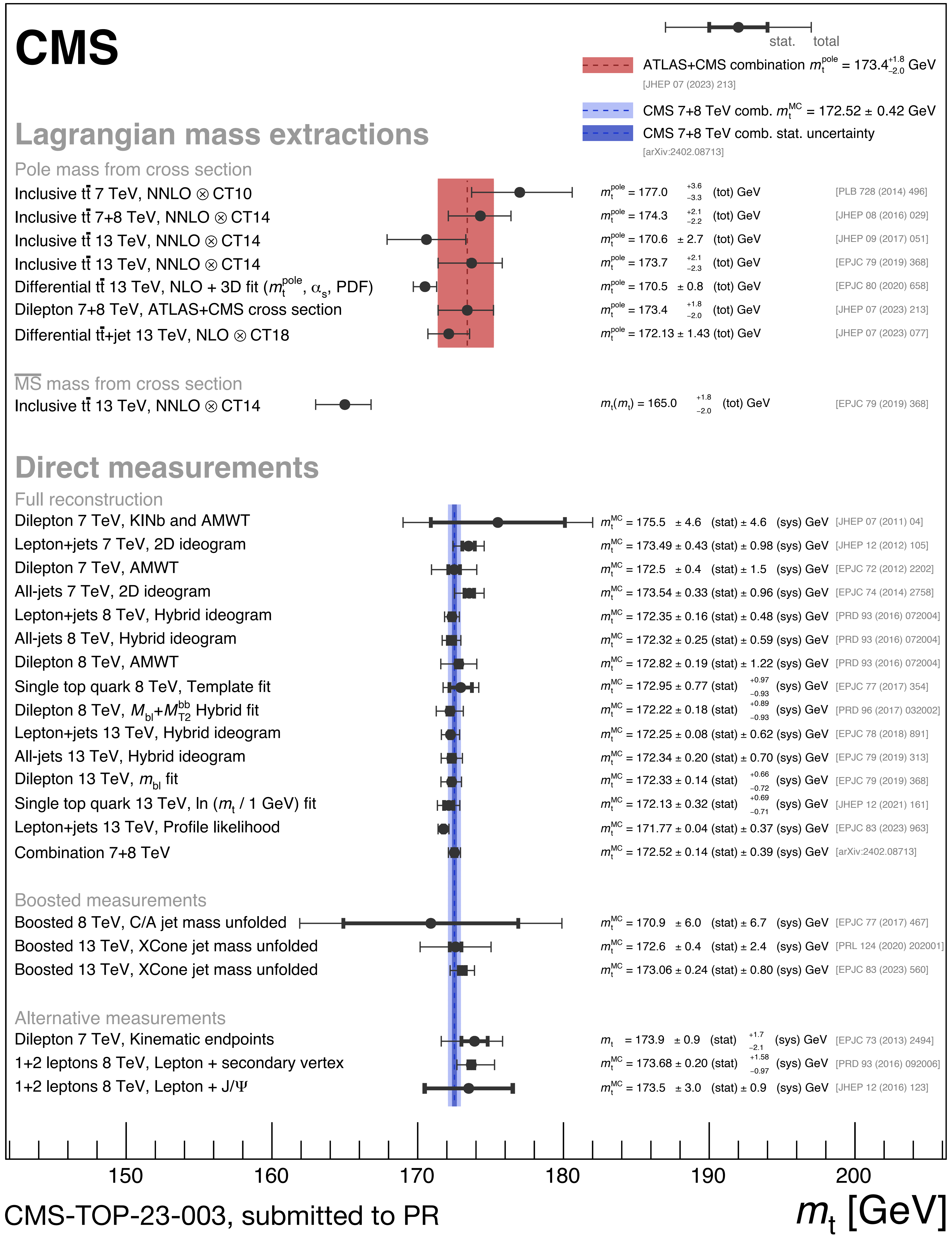
- $m^{\text{MC}}_{\text{top}}$ from minimizing a negative log-likelihood
- Systematic uncertainties included via nuisance parameters



- Include up to 5 observables
  - m_t^{fit} to measure m_t
  - m_W^{reco} to constrain JES
  - $m_{\ell b}^{\text{reco}}(P_{\text{gof}}<0.2)$ include full statistics
  - $R_{\text{bq}}^{\text{reco}}$* and $m_{\ell b}^{\text{reco}}/m_t^{\text{fit}}$ to constrain modeling and JES of b jets

$$m_{\text{top}}^{\text{MC}} = 171.77 \pm 0.37\ \text{GeV}$$

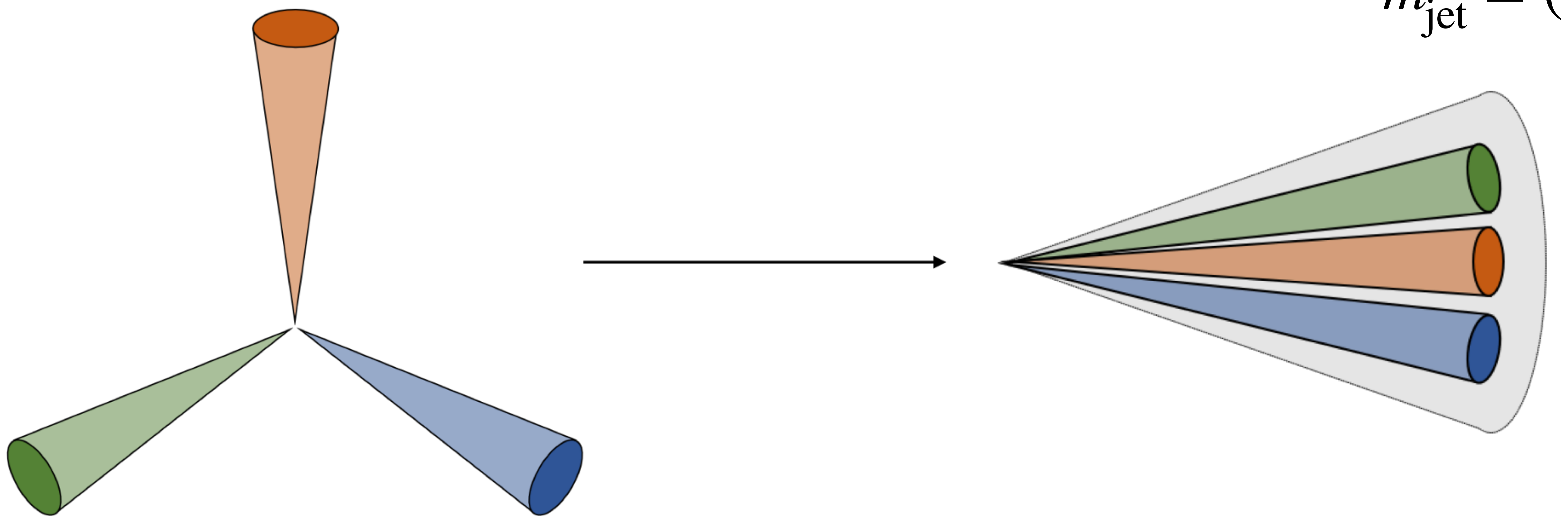
Why m_{top} from boosted top quarks?



CMS-TOP-23-003, submitted to PR

- m_{top} predominantly at threshold production
  - Reconstruct decay products separately
  - Commonly direct measurements: rely on $m_{\text{top}}^{\text{MC}}$
- Complementary approach: Boosted regime
  - m_{jet} sensitive to m_{top}
  - Extract well-defined m_{top}

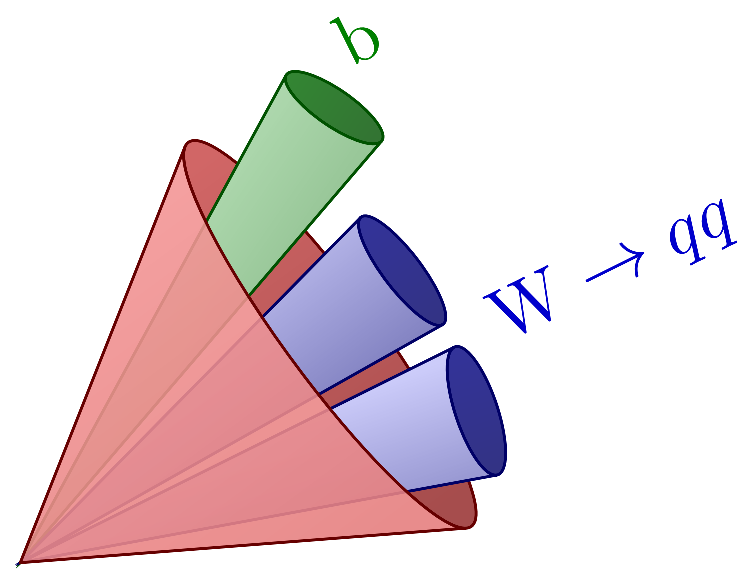
$$m_{\text{jet}}^2 = \left(\sum_{\text{i}} p_{\text{i}}\right)^2$$



Resolved　　Boosted

Well-defined m_{top} with large-radius jets

* low-scale short-distance mass scheme



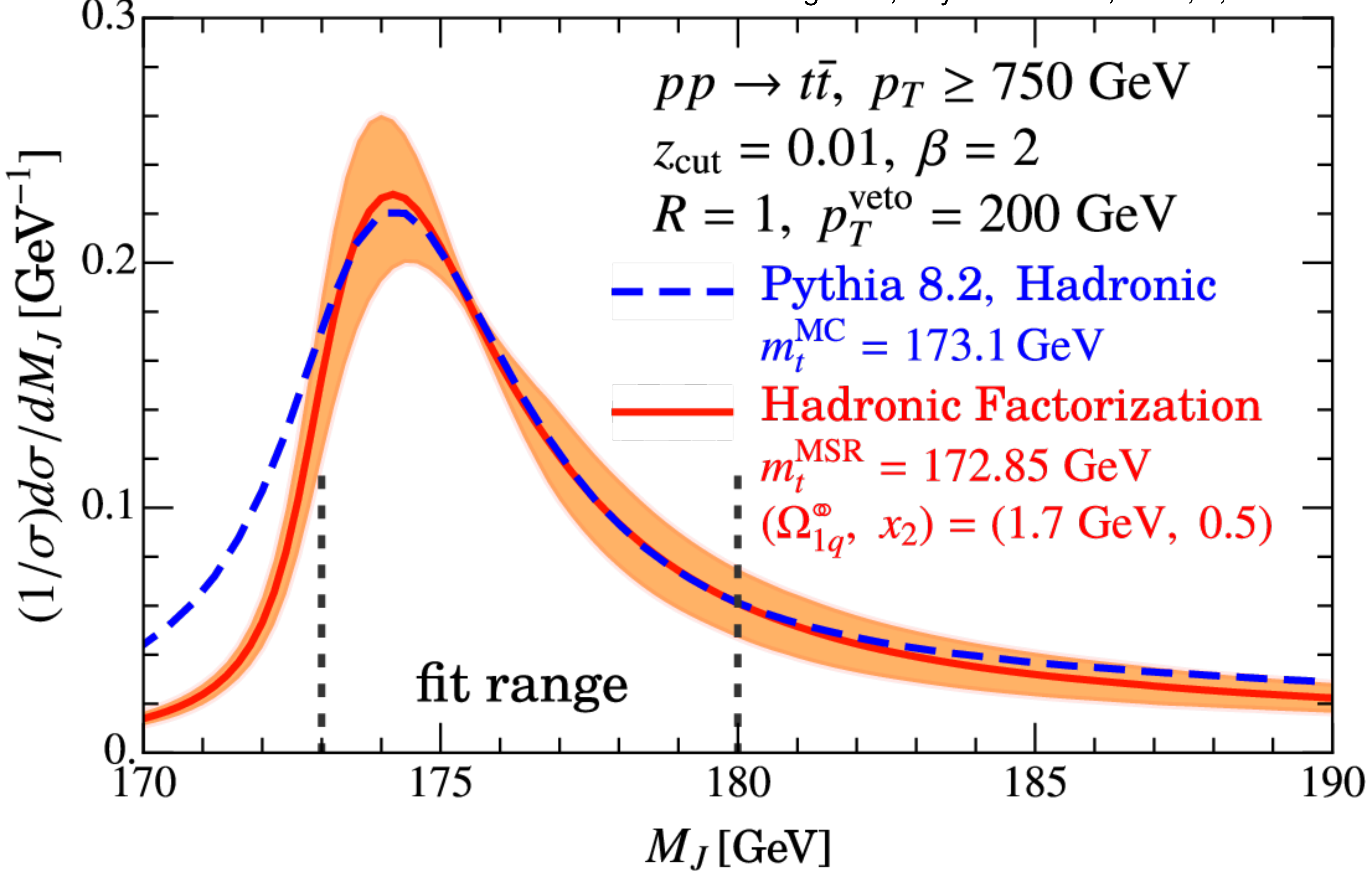
- Compare measurement to well-defined field theory parameter
- No additional uncertainty from $m_{\text{top}}^{\text{MC}} \rightarrow m_{\text{top}}^{\text{MSR*}}$
- Phase-space of theory and experiment different
  - **Calculations** only at $p_{\text{T}} \geq 750$ GeV
  - **Experimental** only at $p_{\text{T}} \geq 400$ GeV

*still extract $m_{\text{top}}^{\text{MC}}$

- **Longer-term Target:**

  Define common phase space

A. H. Hoang et al., Phys.Rev.D 100, 2019, 7, 074021

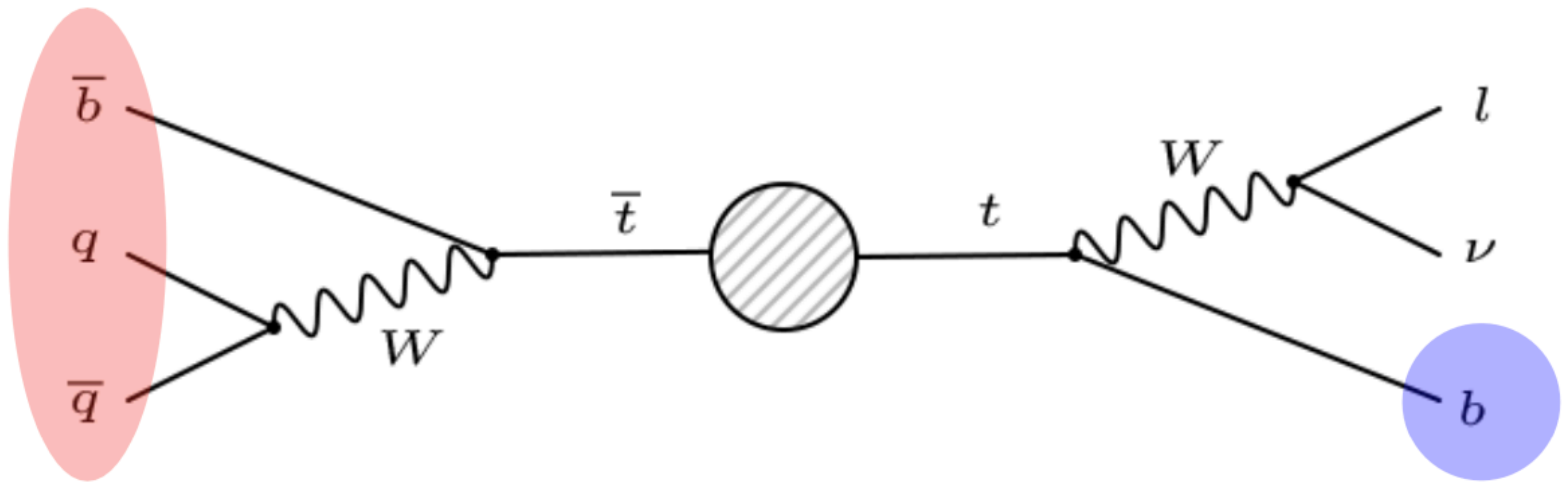


Measure the differential cross section

CMS, EPJC 83, 560, 2023

Aiming for $\ell + \text{jets}$ channel of $\mathrm{t\bar{t}}$ events

- Use leptonic decay as a tag for $\mathrm{t\bar{t}}$ events
- Exactly one lepton (μ or e)



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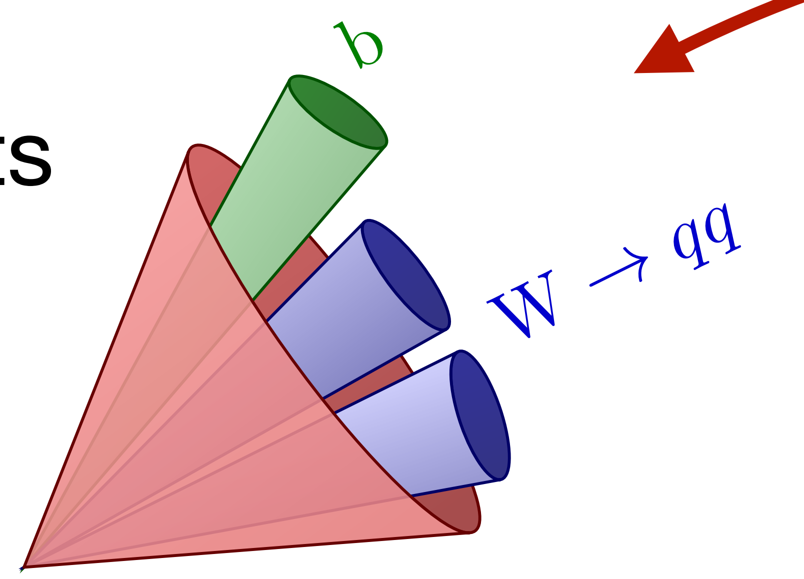

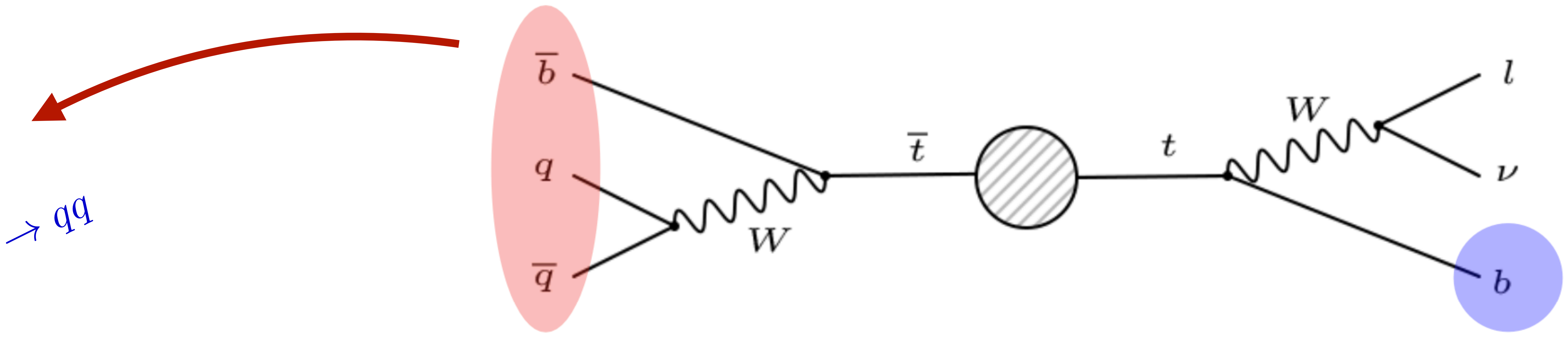

Select boosted top quarks

- $p_{\mathrm{T,\ hadjet}} > 400\ \mathrm{GeV}$

Suppress unmerged top quark decays

- $m_{\mathrm{hadjet}} > m_{\mathrm{lepjet}+\ell}$

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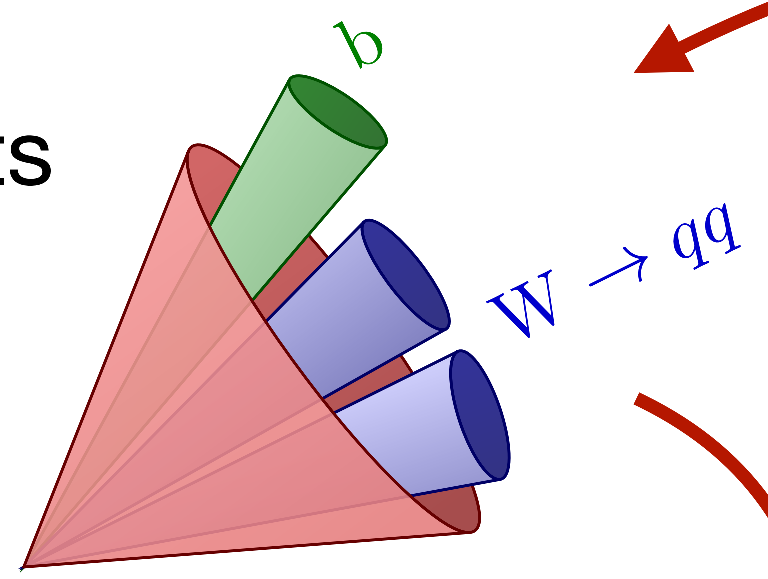

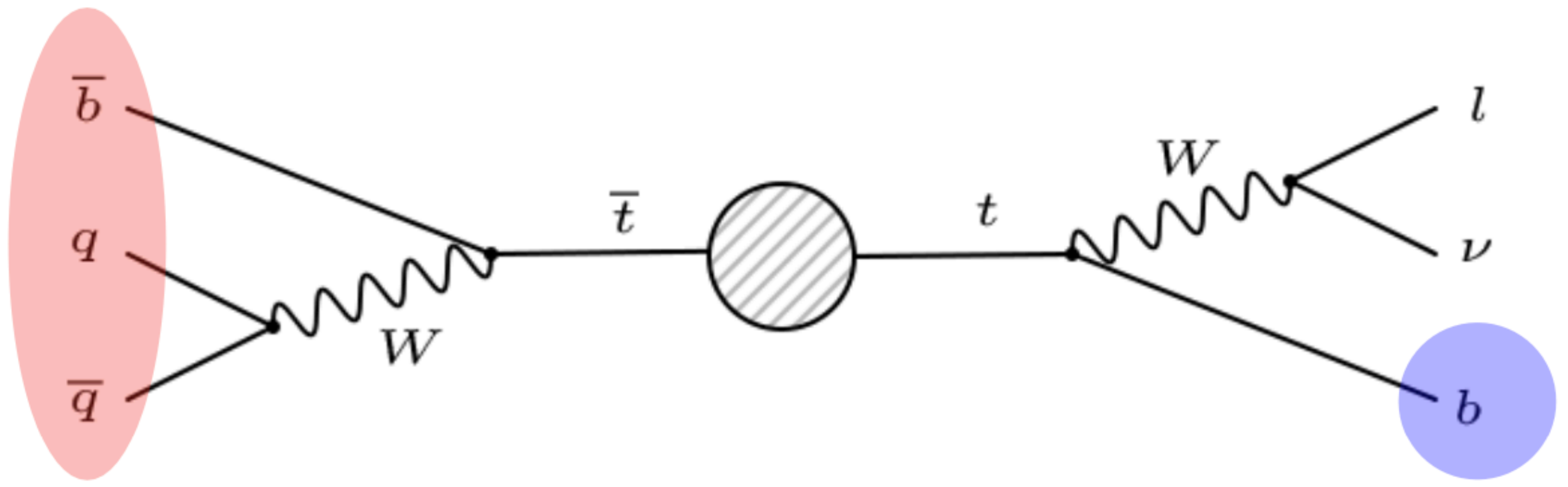

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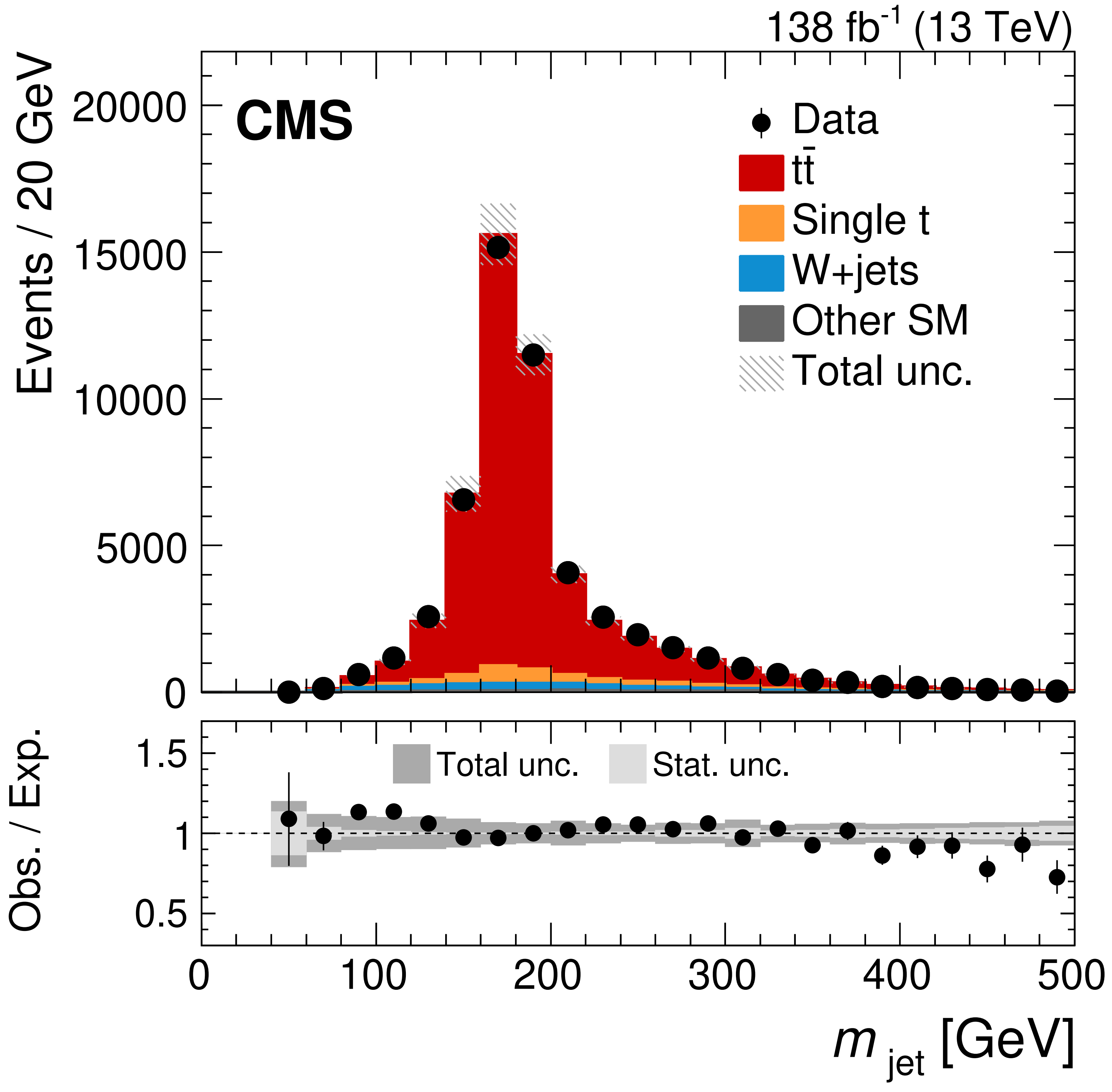

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CMS, EPJC 83, 560, 2023

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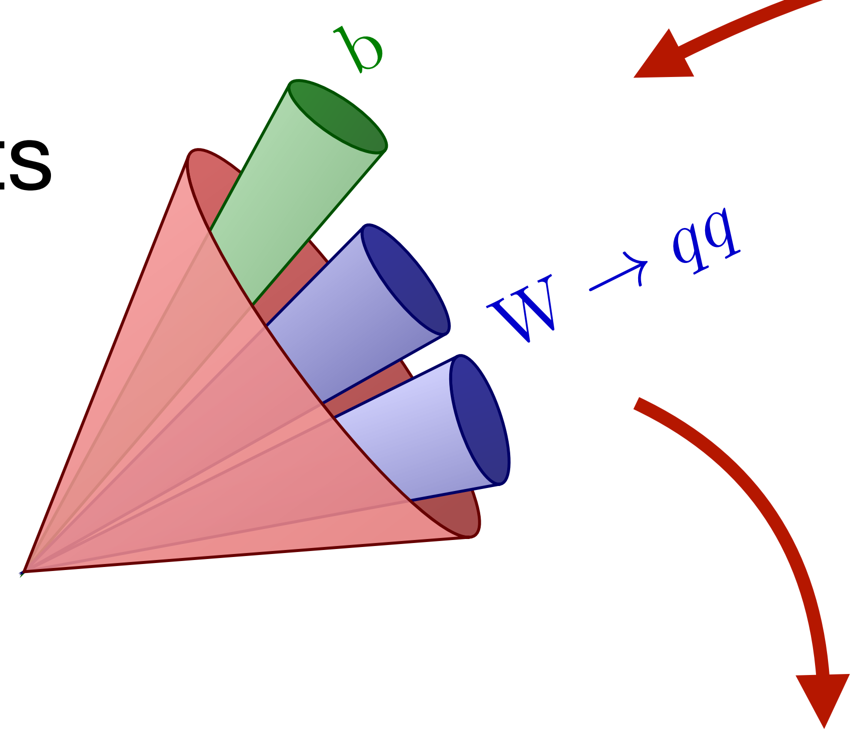
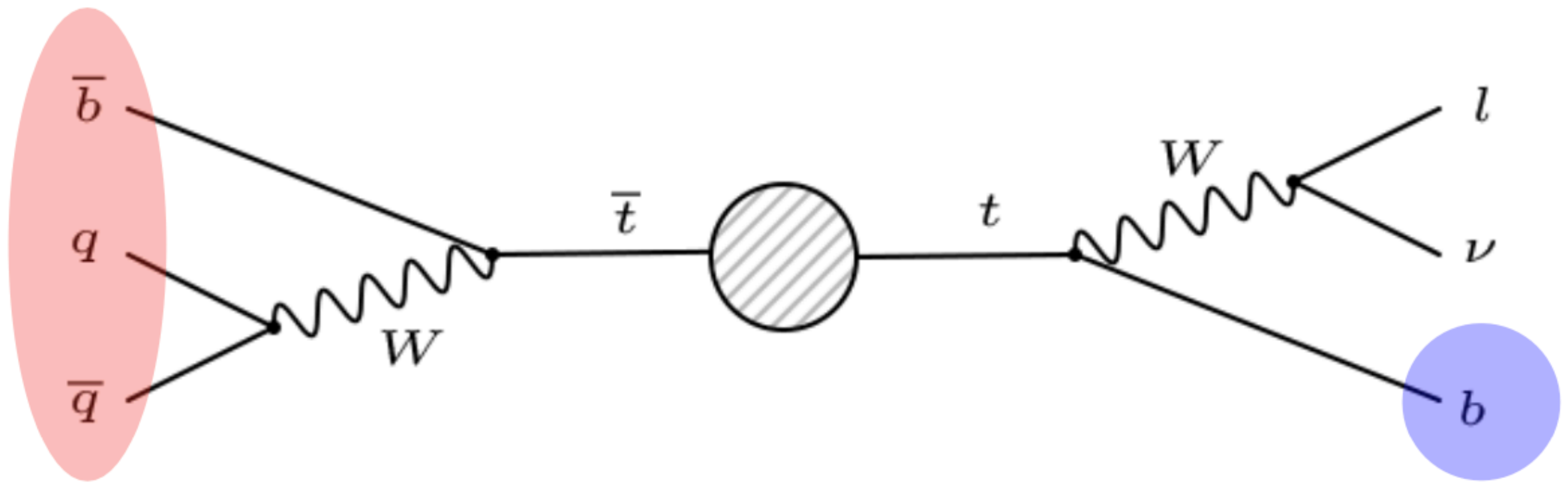
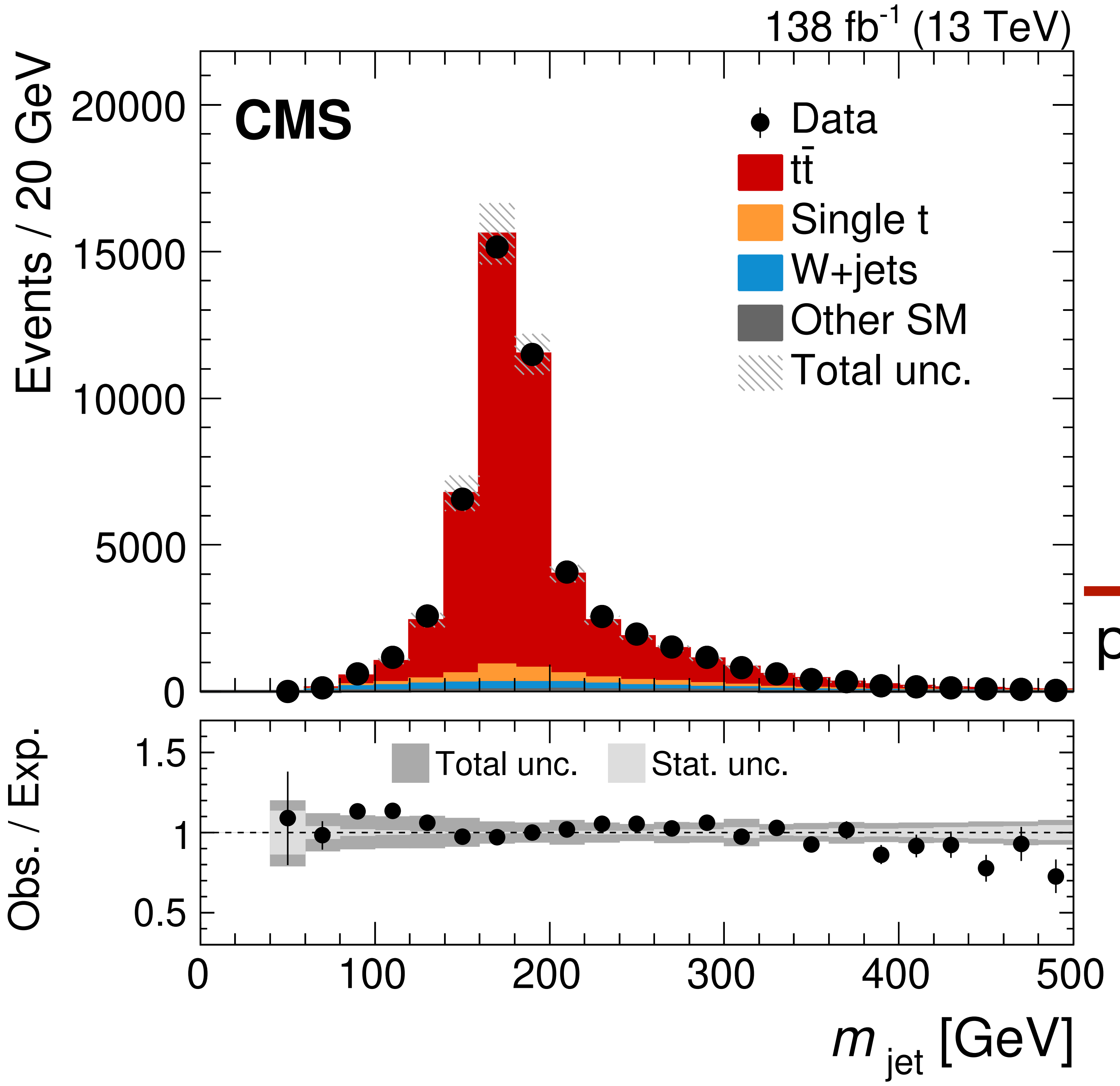
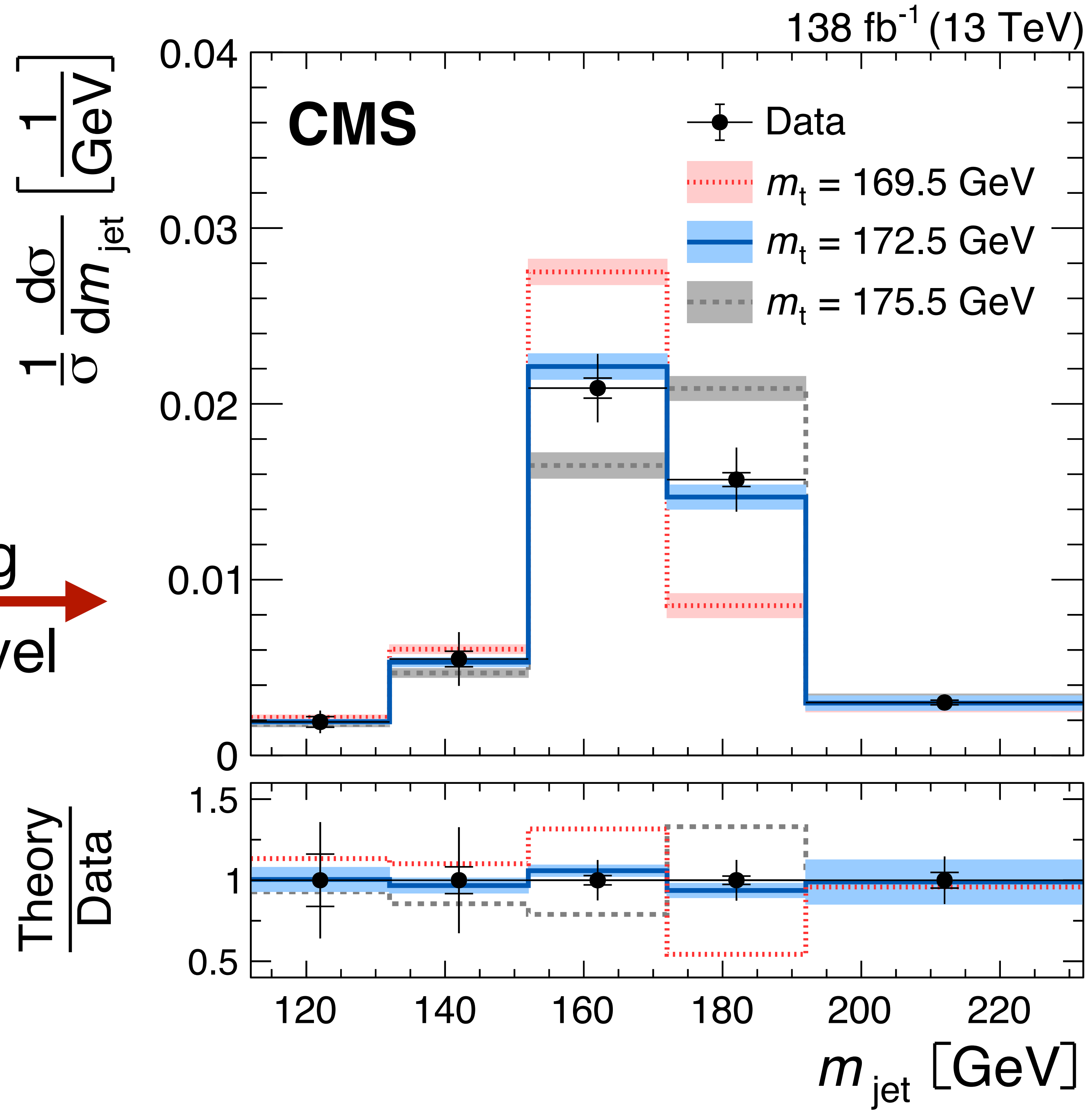






Unfolding

particle level

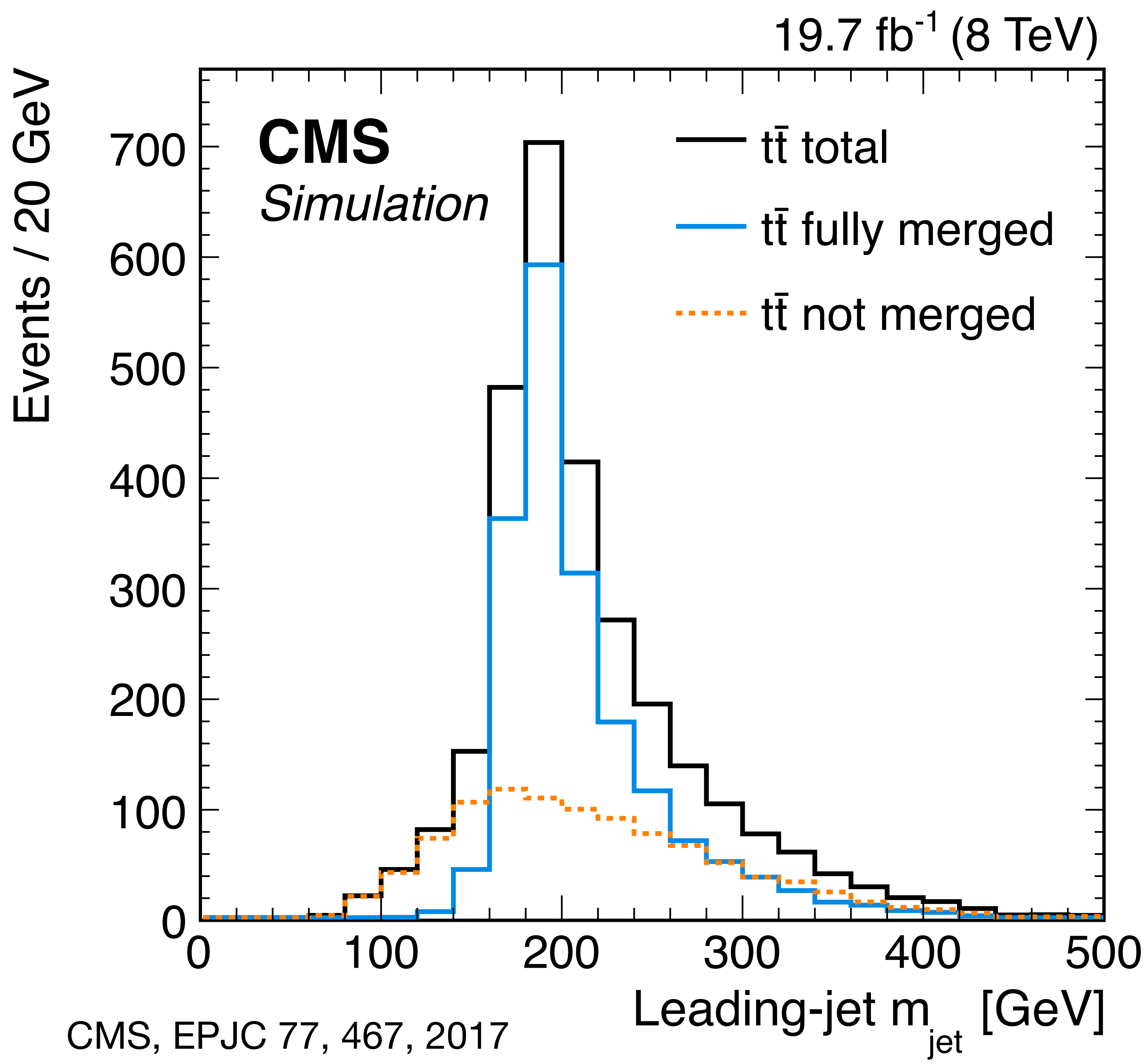


Previous measurements with CMS

First Measurement

in Run 1

- $m_{\text{top}} = 170.8 \pm 9.0\ \text{GeV}$



CMS, EPJC 77, 467, 2017

Previous measurements with CMS

First Measurement

in Run 1

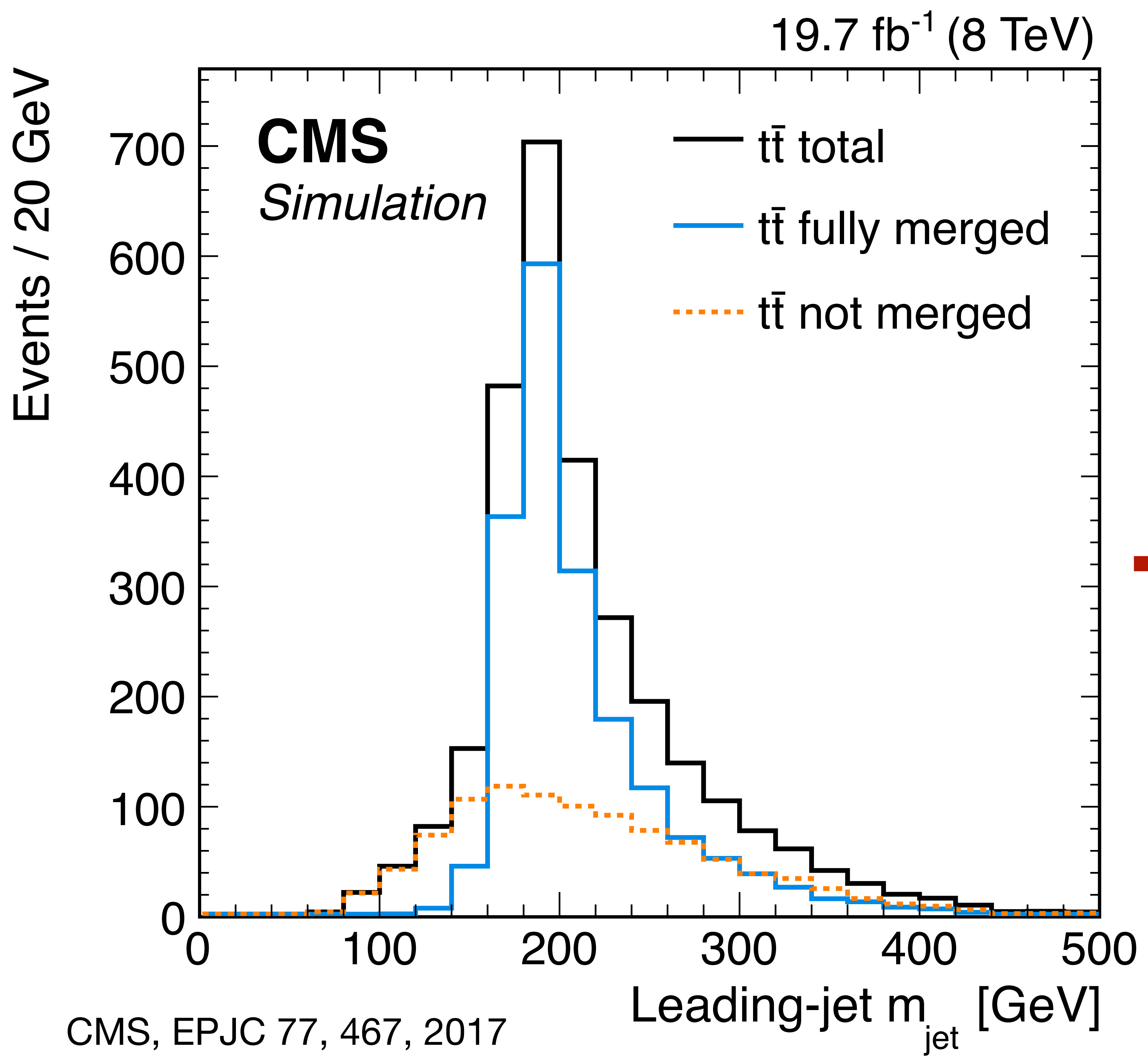
- $m_{\text{top}} = 170.8 \pm 9.0$ GeV

→

Improved reconstruction

in Run 2

- $m_{\text{top}} = 172.6 \pm 2.5$ GeV



CMS, EPJC 77, 467, 2017

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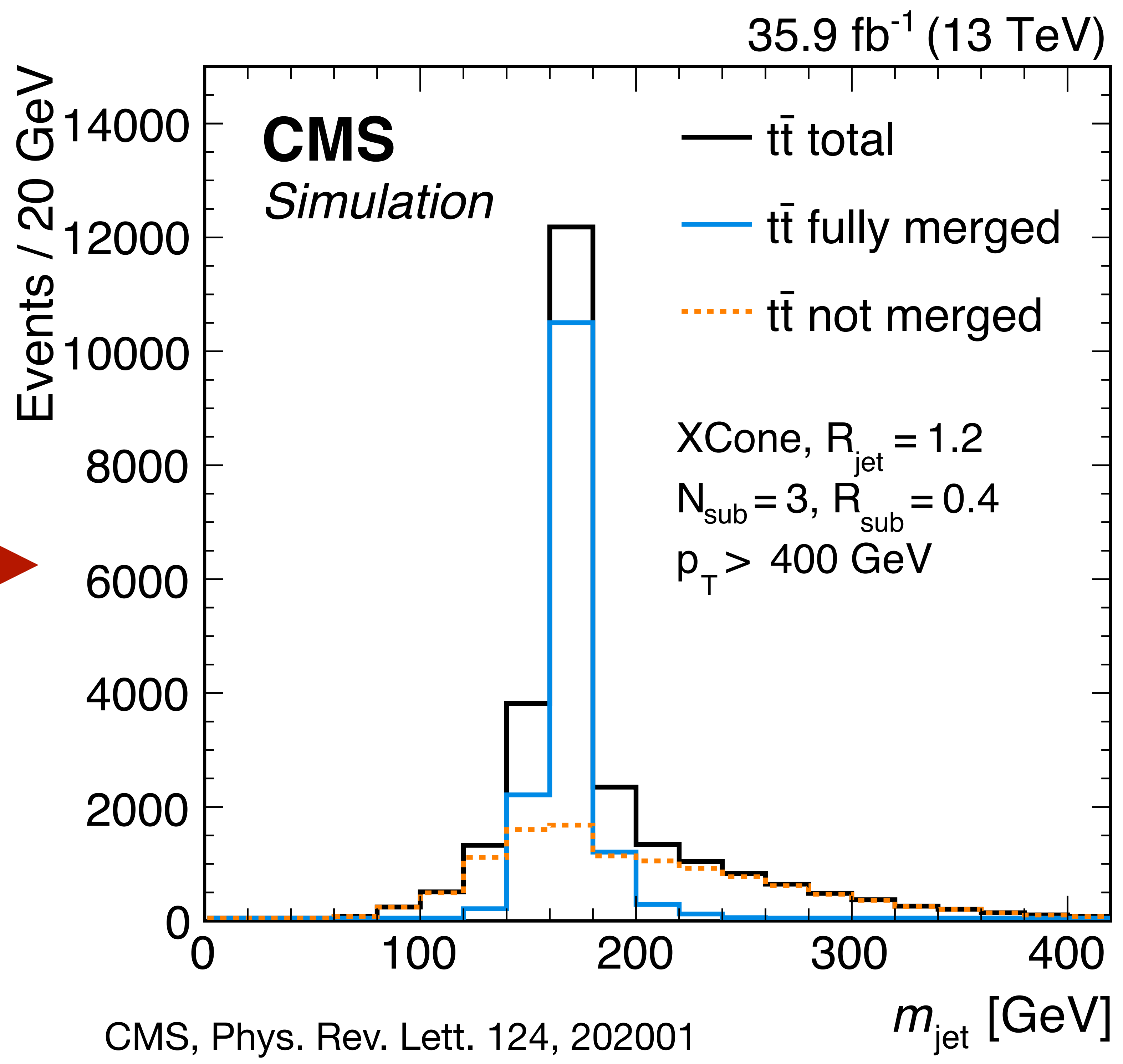

CMS, Phys. Rev. Lett. 124, 202001

Previous measurements with CMS

First Measurement in Run 1

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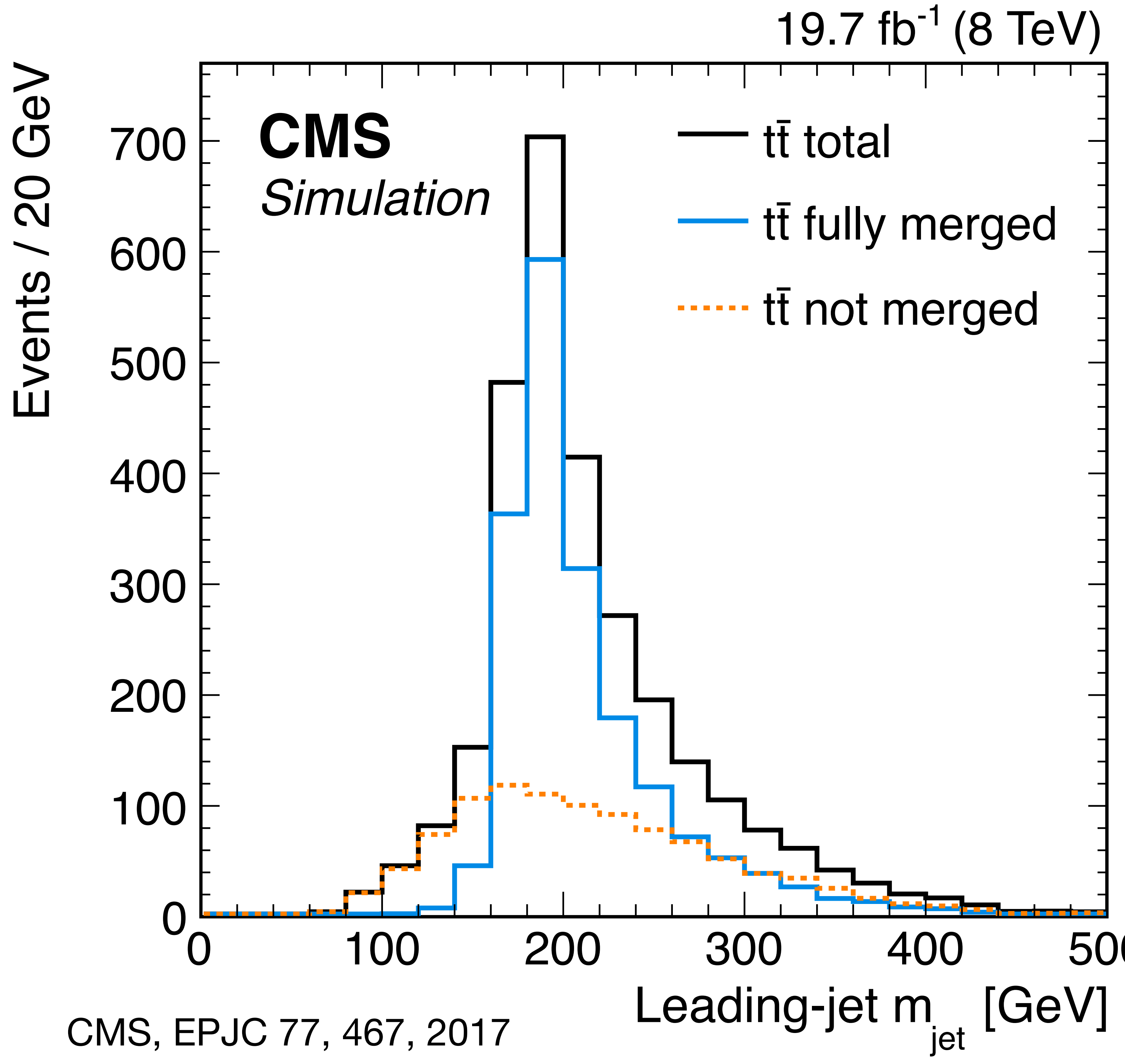
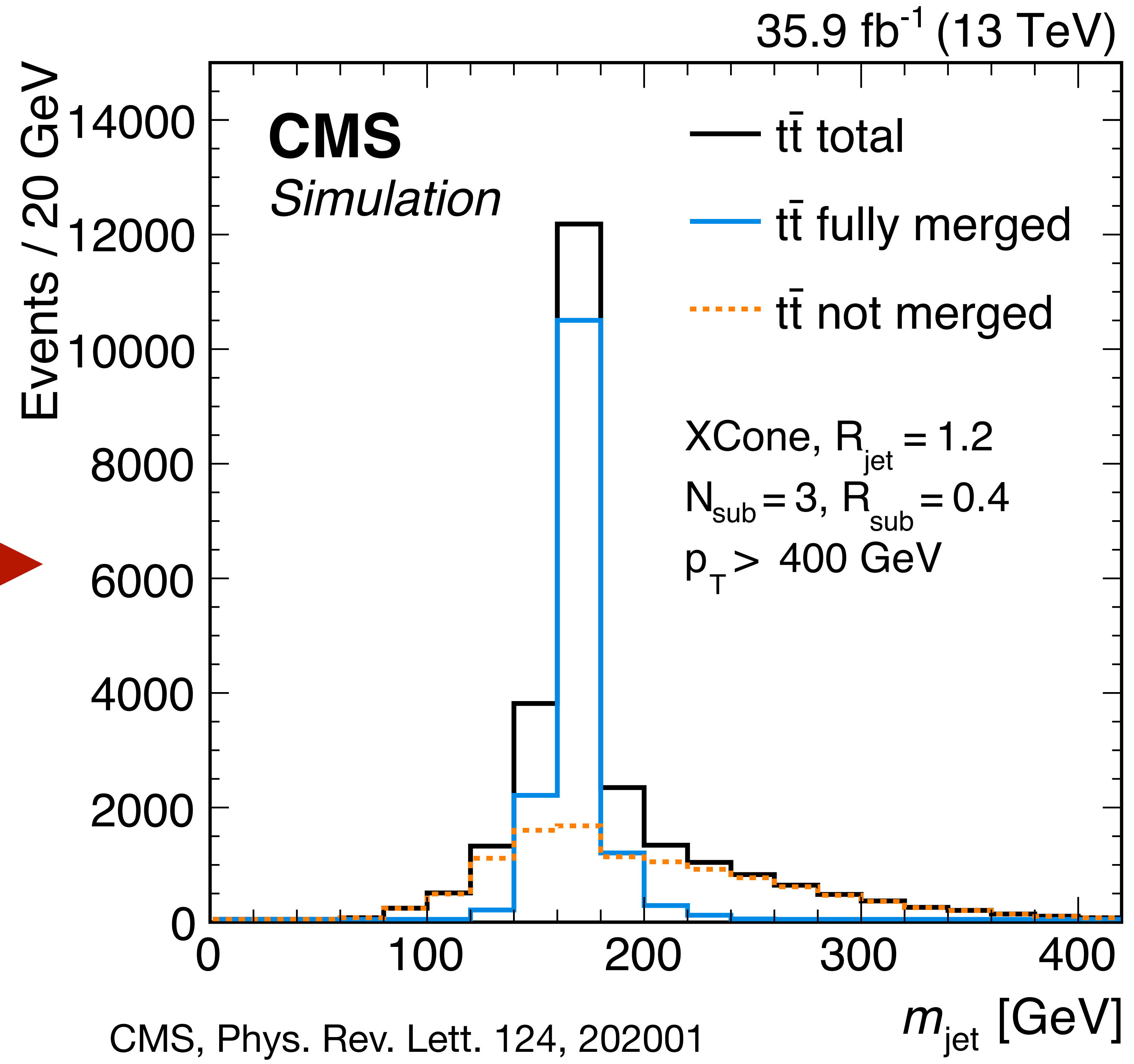


CMS, EPJC 77, 467, 2017

Improved reconstruction in Run 2

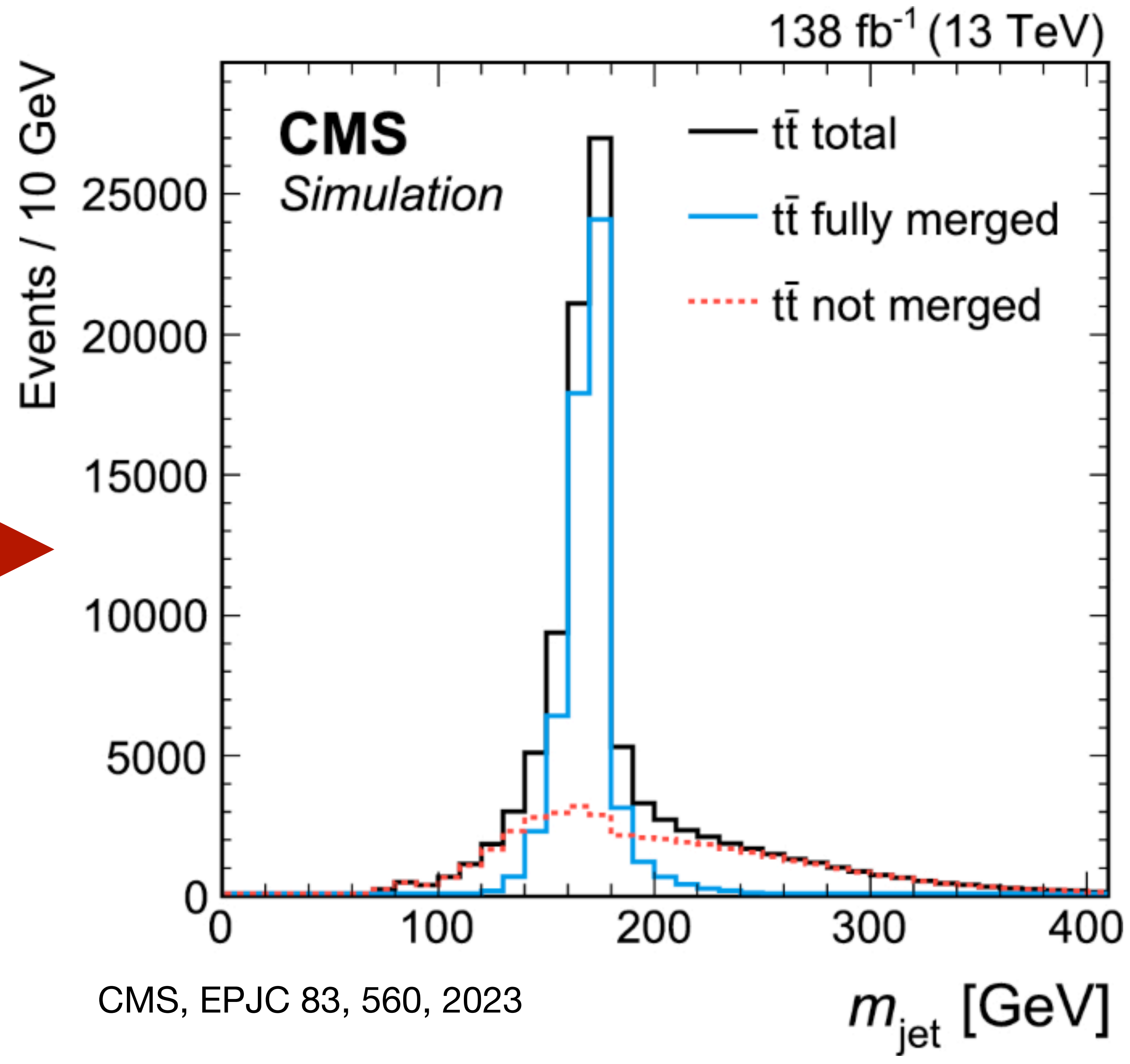
- $m_{top} = 172.6 \pm 2.5$ GeV



CMS, Phys. Rev. Lett. 124, 202001

Reduce dominant uncertainties

- $m_{top} = 173.06 \pm 0.84$ GeV

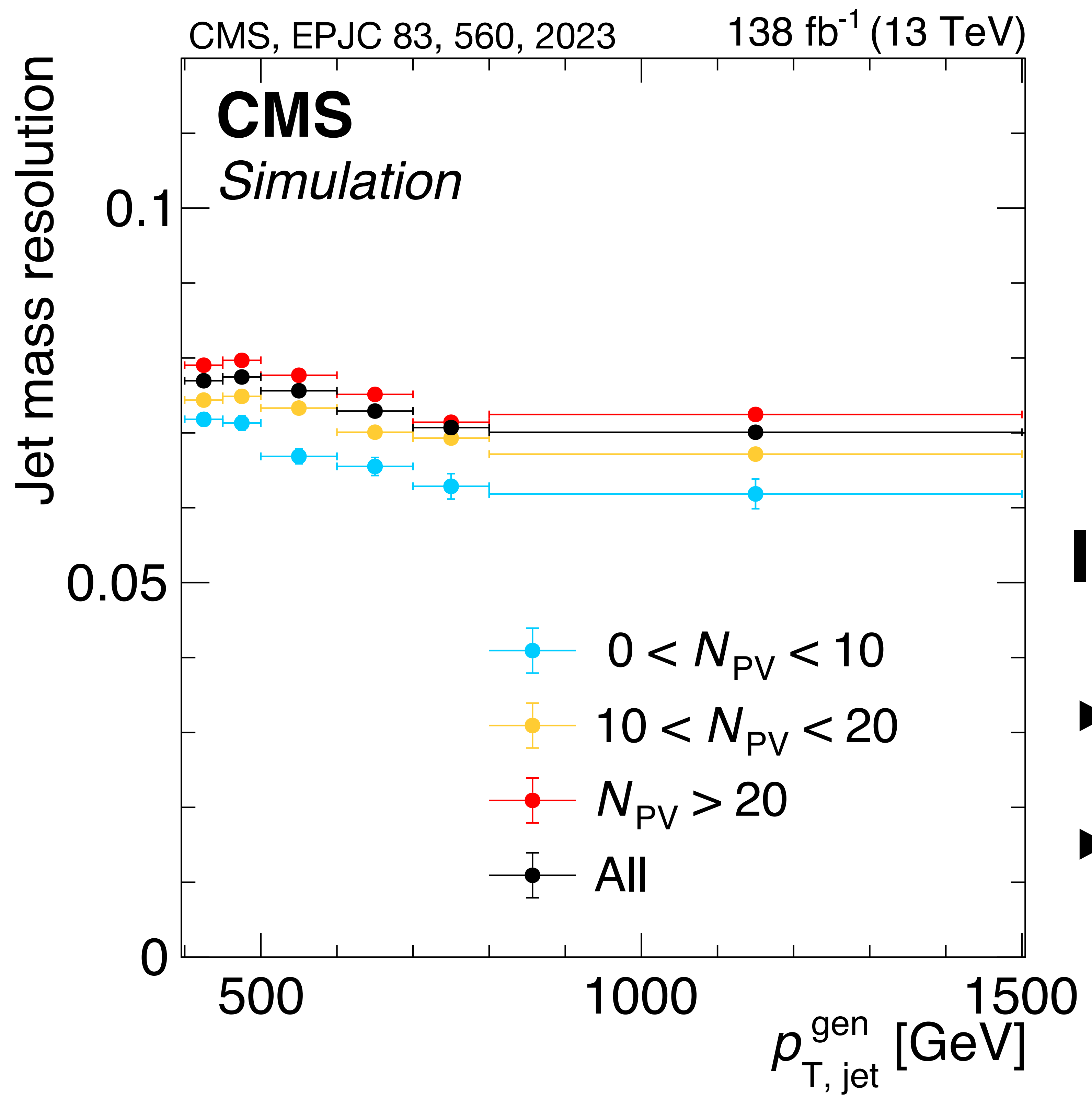


CMS, EPJC 83, 560, 2023

Improved reconstruction

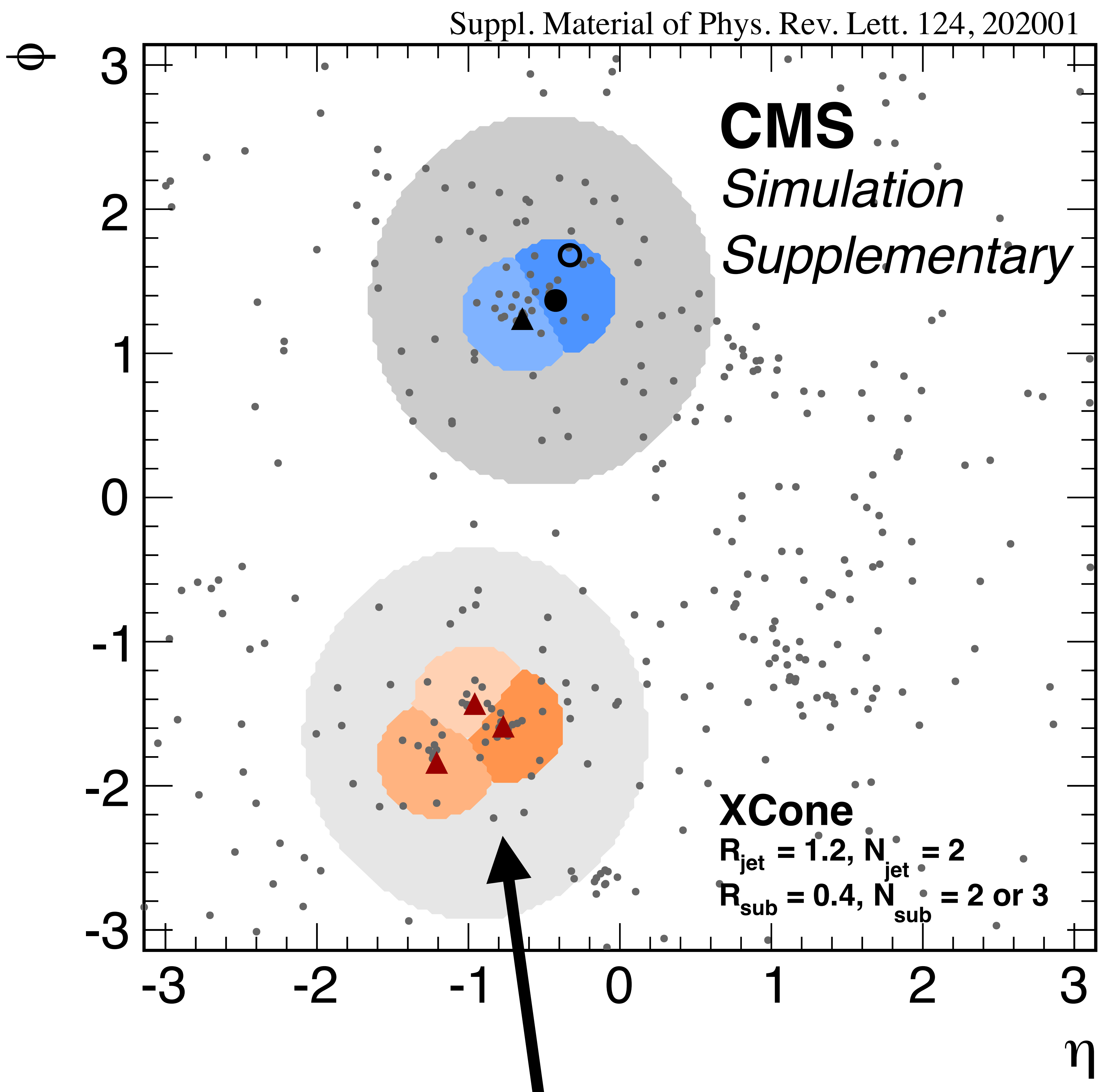
2-step clustering using XCone jet algorithm I. W. Stewart, et al. JHEP 2015, 72

- Significant improvement for Run 1 → Run 2
- Cluster two jets with large radius $R = 1.2$ (grey area)
- Rerun clustering with $N = 3$ to find subjets (colored area)



Improvement in m_{jet} resolution

- Combined subjets: 6-8%
- CA jet with $R = 1.2$: 14%



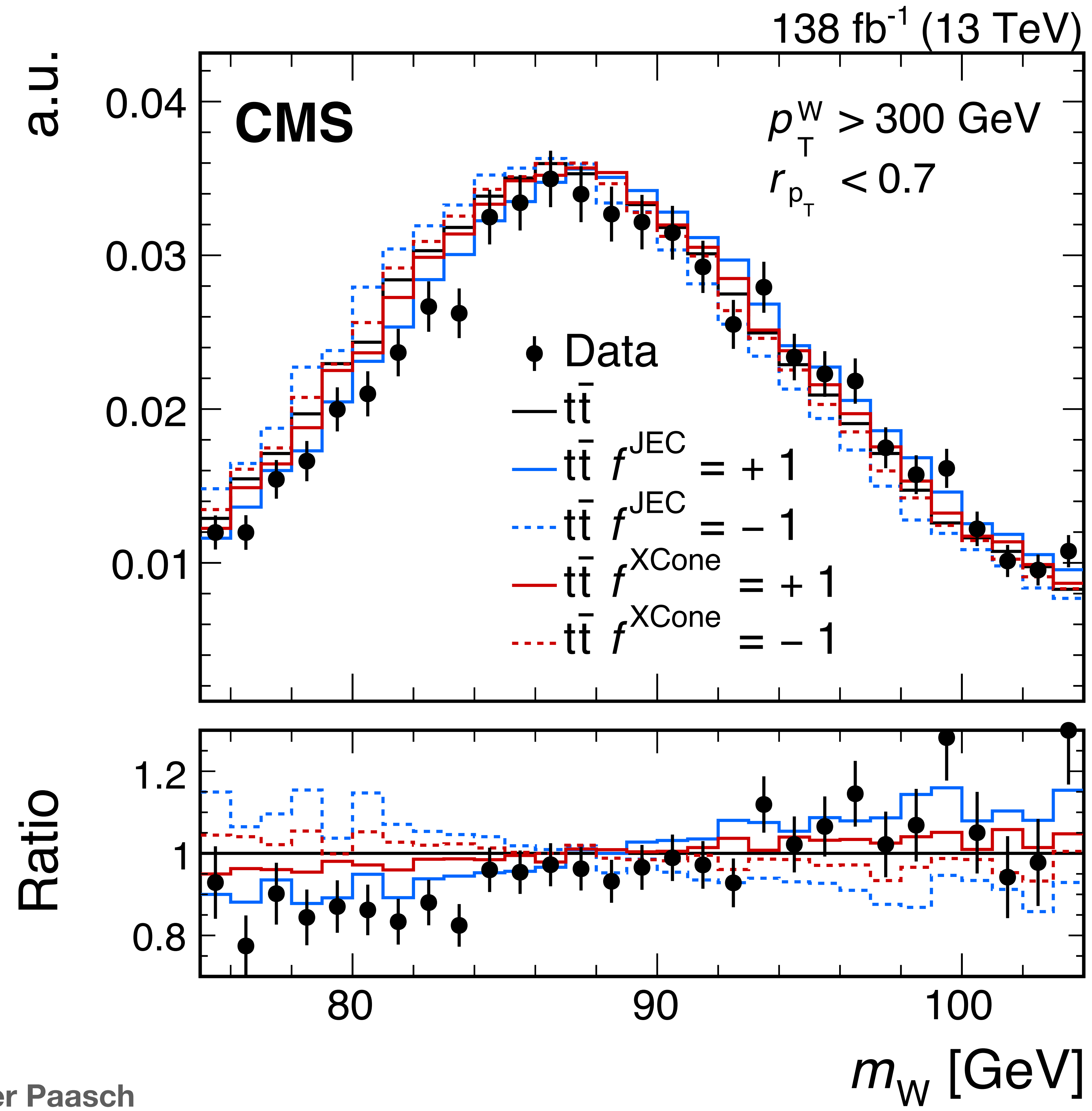
Measurement on orange area

Reduce dominant uncertainties

CMS, EPJC 83, 560, 2023

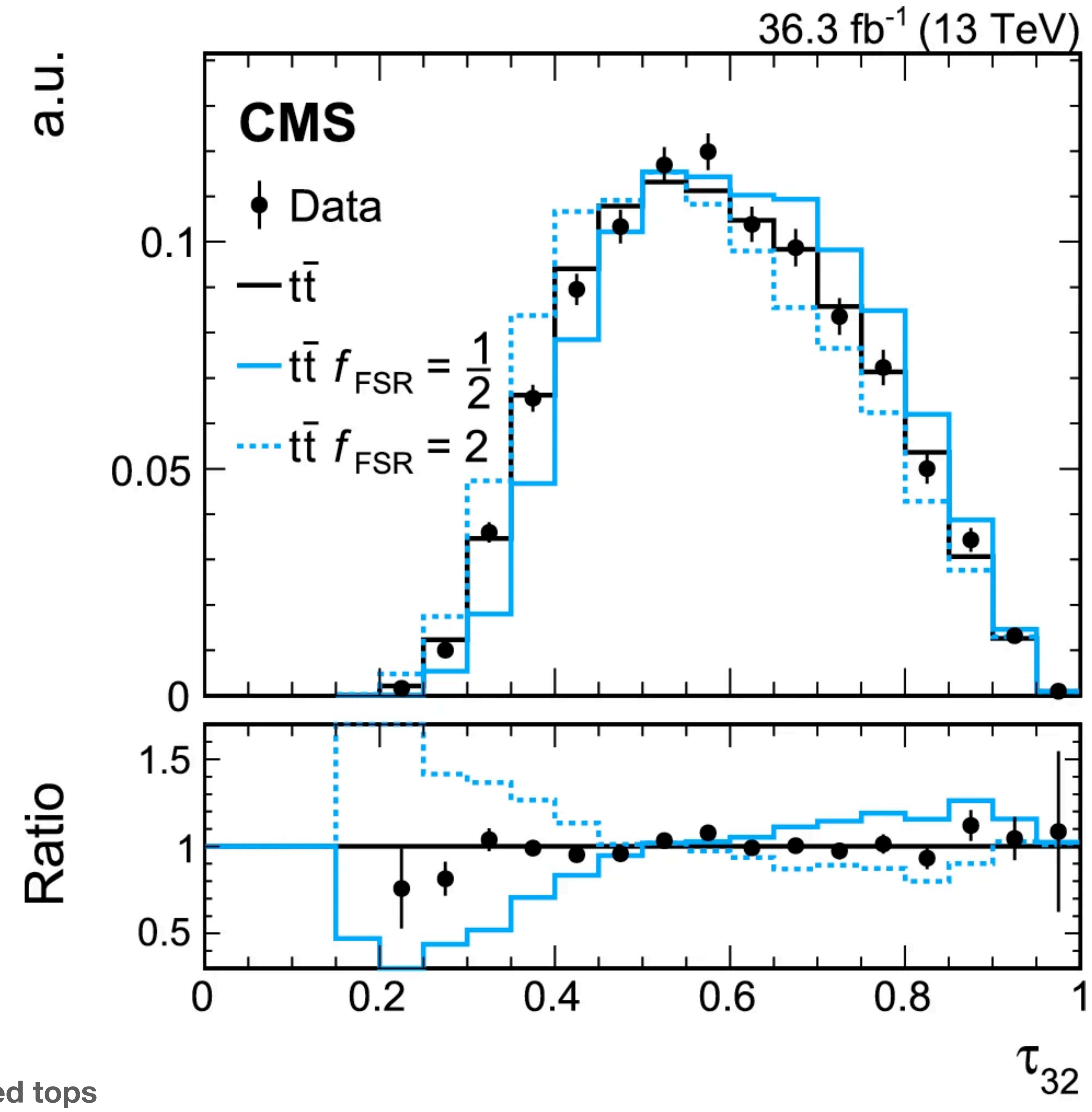
Calibration of the Jet Mass Scale (JMS)

- **Before:** JMS estimated with JES
- **Now:** Measure JMS independently with m_W
  - m_{jet}^{W} not sensitive to m_{top}



Modeling of the Final State Radiation (FSR)

- **Before:** Used centrally provided factors for $\alpha_S(f_{FSR} \cdot \mu_0)$
- **Now:** Dedicated measurement with τ_{32}



Unfolding and extraction of m_t

CMS, EPJC 83, 560, 2023

- Extract m_{top} from unfolded normalized distribution

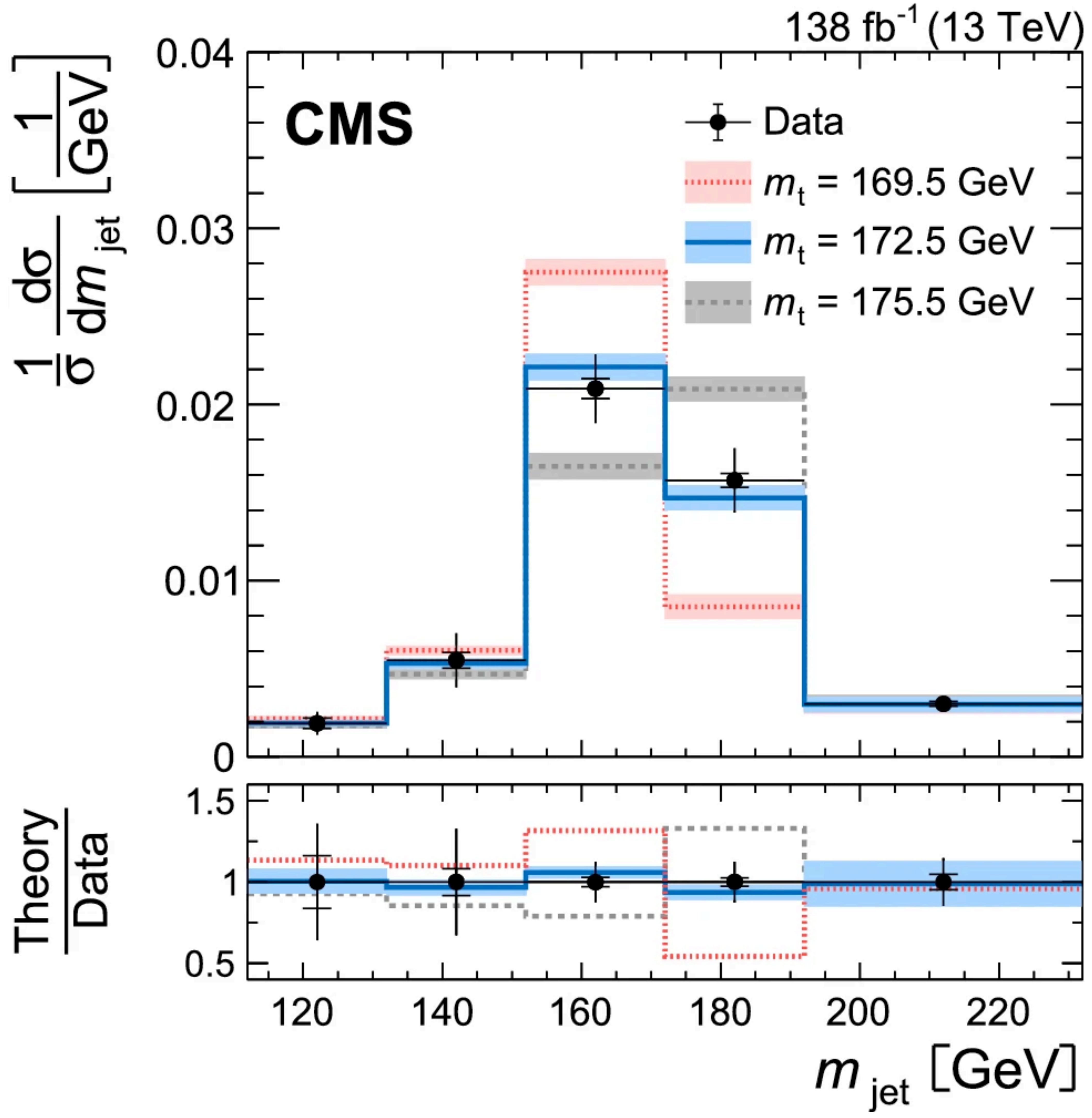
$$m_{top}^{MC} = \boxed{173.06 \pm 0.84\ \text{GeV}}$$

- Significantly reduced main uncertainties

Source	Uncertainty [GeV]
Statistical uncertainty	0.22
Experimental uncertainty	0.57
JER	0.40
JMS	0.27
JMS flavour	0.27
JES	0.10
Model uncertainty	0.48
Choice of m_{top}	0.37
CR	0.19
h_{damp}	0.19
FSR	0.02

Before **1.5 GeV**

Before **1.2 GeV**

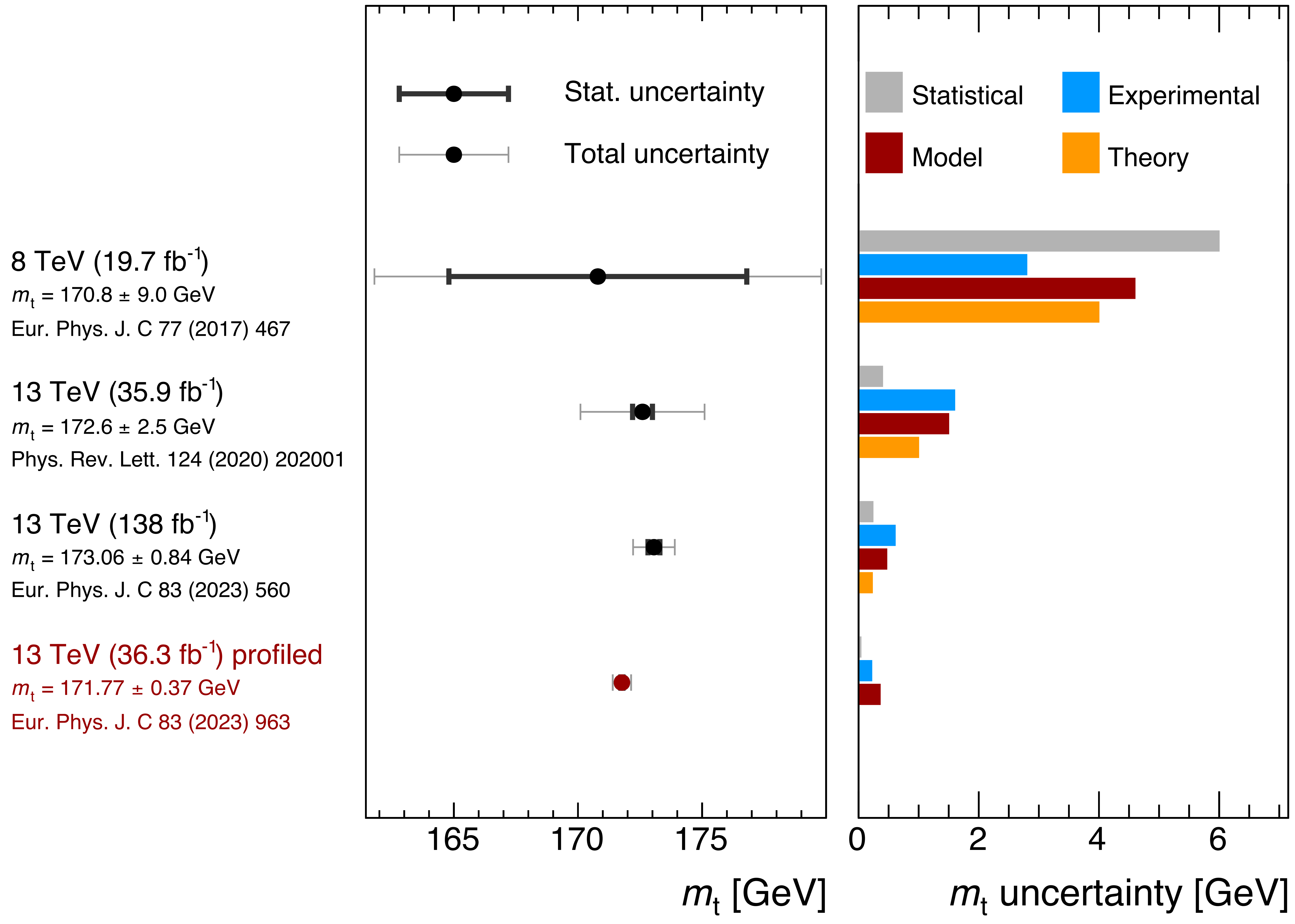


Summary & Outlook

CMS-TOP-23-003, submitted to PR

In boosted regime $\Delta m_{top} = 9.0 \rightarrow 0.84$ GeV

Adopted from CMS-TOP-23-003



- Further improvements ongoing
  - Reduce unfolding dependency to m_{top}
  - Optimize high-p_T reconstruction
  - Wait for more data