Measurement of the boosted top jet mass distribution in CMS

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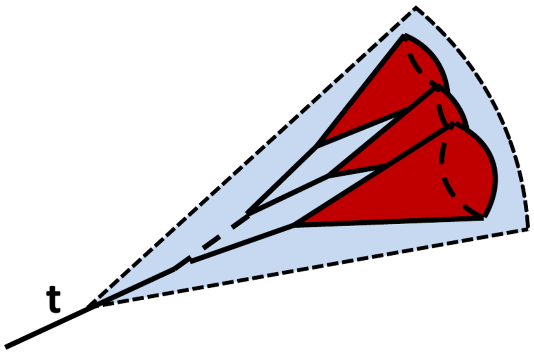
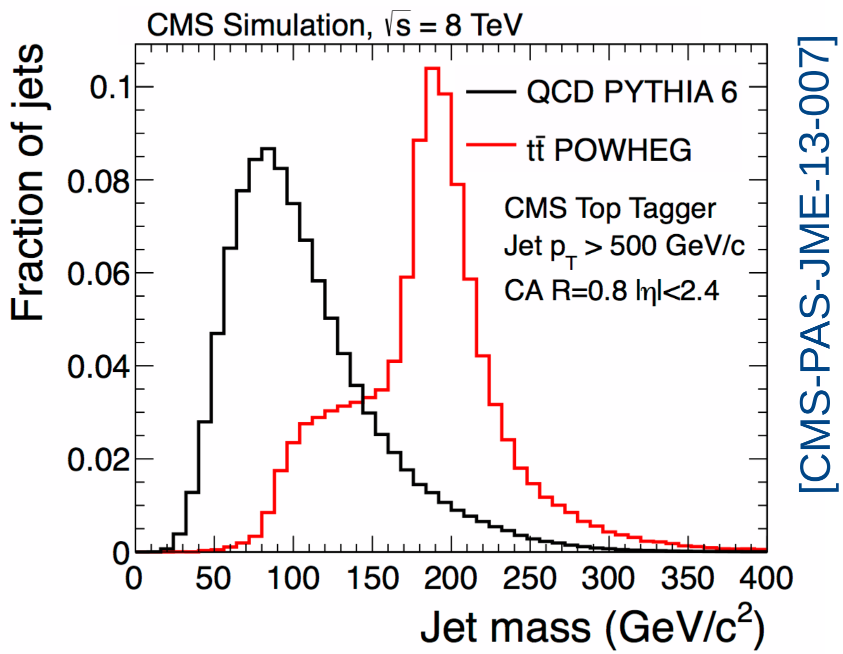
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Boosted top and jet mass

- Jet mass: invariant mass of all stable particles in a jet
- High momentum top quarks
  - Large Lorentz boost
  - Reconstruction in one large jet
  - → m_{jet} sensitive to m_t
- Important substructure variable
  - Used for top tagging
  - Searches for new physics
- Analysis aim:
  - Measurement of the differential $t\bar{t}$ cross section as a function of m_{jet}
  - Extraction of m_t from the m_{jet} distribution





Theoretical motivation

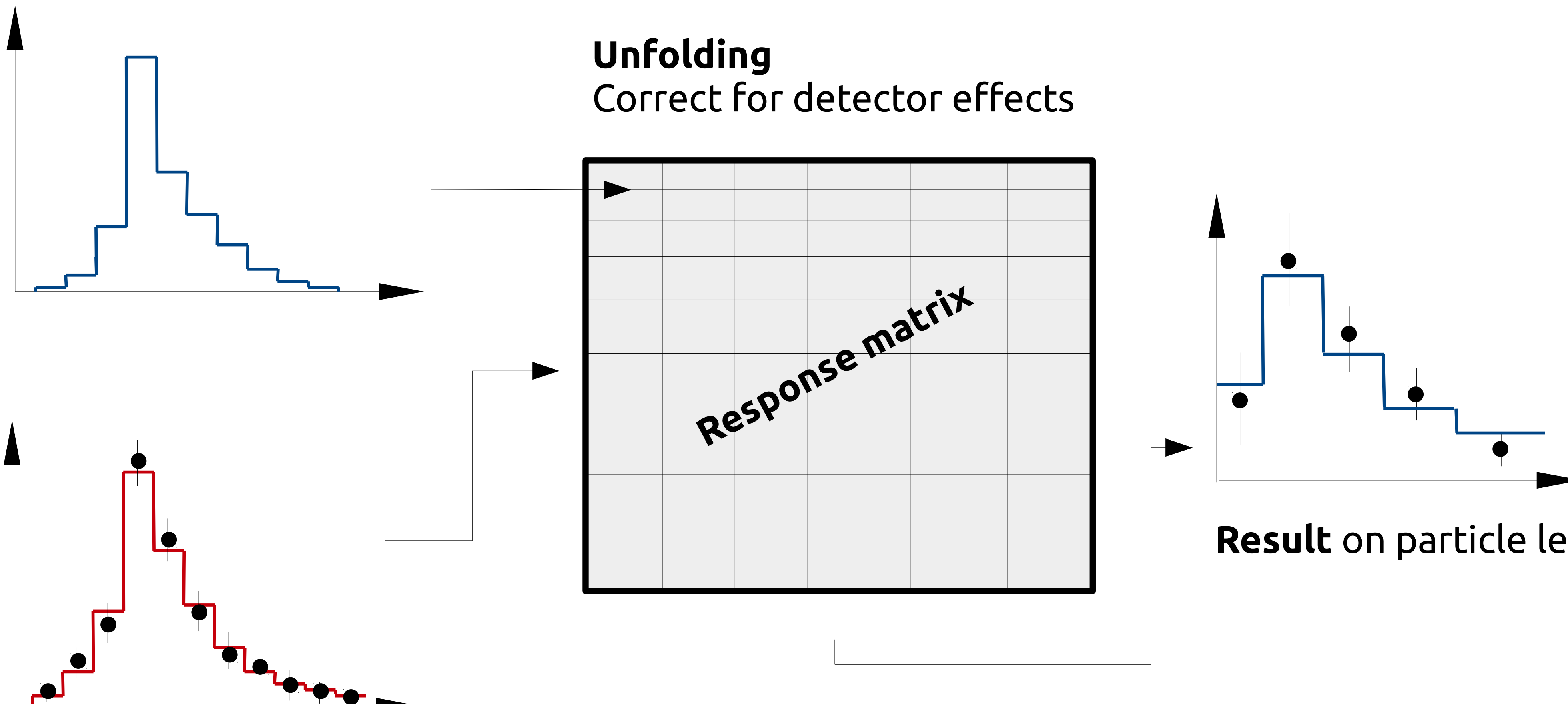
- Theoretical calculations of the boosted jet mass exist
  - Effective field theory
  - At the particle level
- Calculations first performed and discussed for e^+-e^- collisions:
  - S. Fleming, A. H. Hoang, S. Mantry, and I. W. Stewart, Phys. Rev. D77(2008) 074010

    ⋮
- First proton-proton calculations:
  - A. H. Hoang, S. Mantry, A. Pathak and I. W. Stewart, arXiv:1708.02586
- Comparison to data at the particle level could be possible
  - Extract m_t in a well defined renormalization scheme

Measurement strategy

Definition of the measurement phase space (**particle level**)

Unfolding
Correct for detector effects



Result on particle level

Event reconstruction (**detector level**)

systematic **uncertainties**

Phase space definition

goal: phase space calculable theoretically and measurable experimentally

Theory constraints:

all decay products in the jet

→ large p_T

→ veto on additional jets

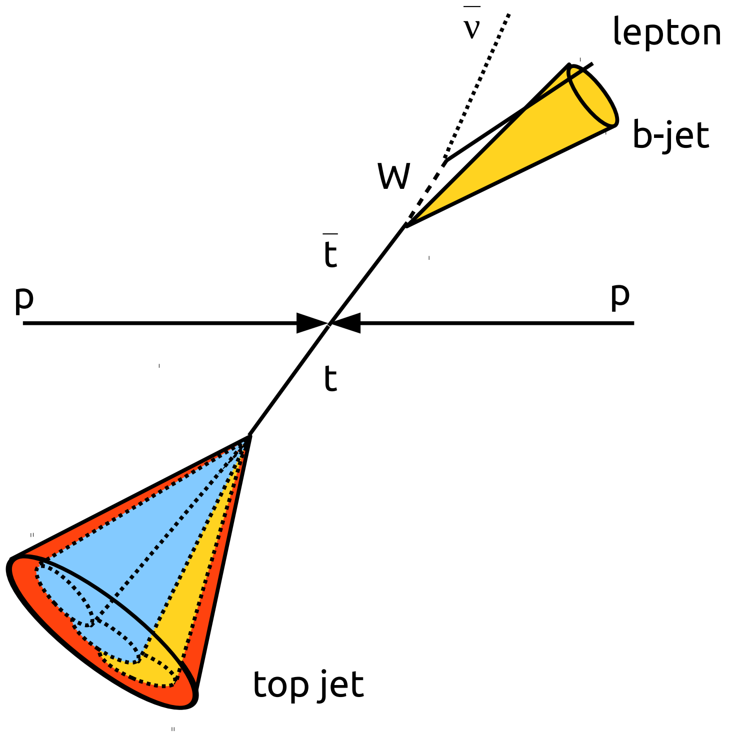
Experimental constraints:

enough statistics

→ p_T not too large

→ large jets

small background



=> Measurement in **lepton + jets** channel

Cambridge/Aachen (CA) jets with **R = 1.2** and $\mathbf{p_T}$ **> 400 GeV**

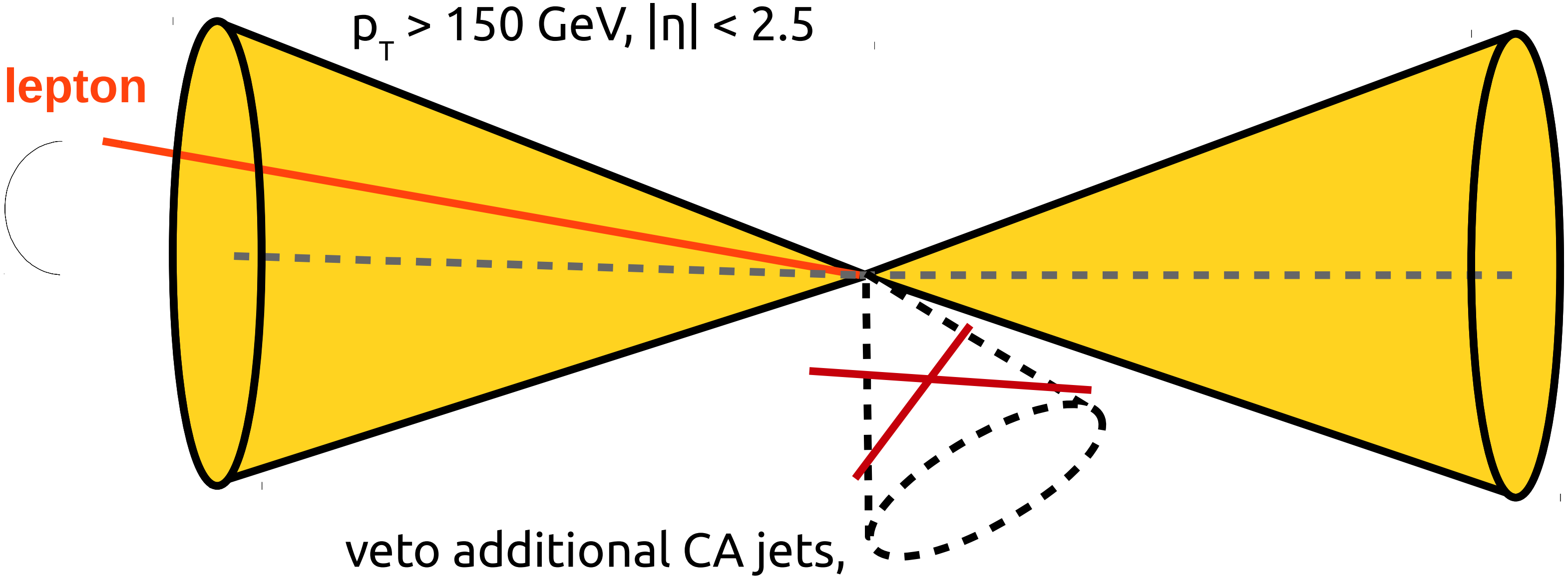
Particle level phase space definition

high p_T lepton (e, mu)
p_T > 45 GeV, $|\eta|$ < 2.1

leading (CA) jet
p_T > 400 GeV, $|\eta|$ < 2.5

2^{nd} CA jet,
p_T > 150 GeV, $|\eta|$ < 2.5

$\Delta R < 1.2$



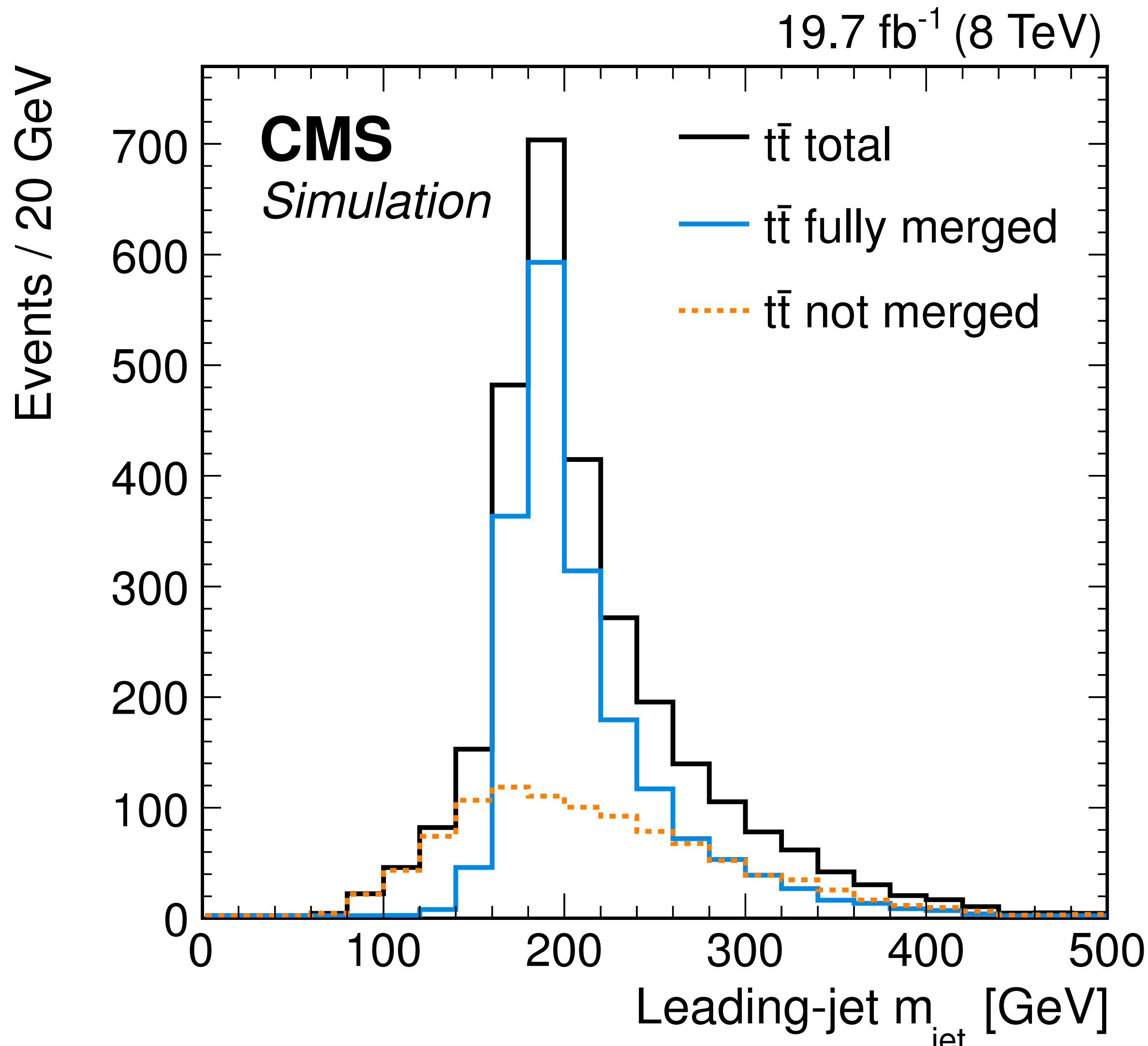
veto additional CA jets,
p_T > 150, $|\eta|$ < 2.5

No cuts on leading jet substructure!

$m_{jet1} > m_{jet\ 2\ +\ lepton}$

Particle level phase space definition

- POWHEG + PYTHIA 6
- At the particle level
- fully merged:
  - $\Delta R(q_i, \text{jet}) < 1.2, \quad i \in \{1,2,3\}$
  - q_i: quarks from top decay
  - Shown for illustration



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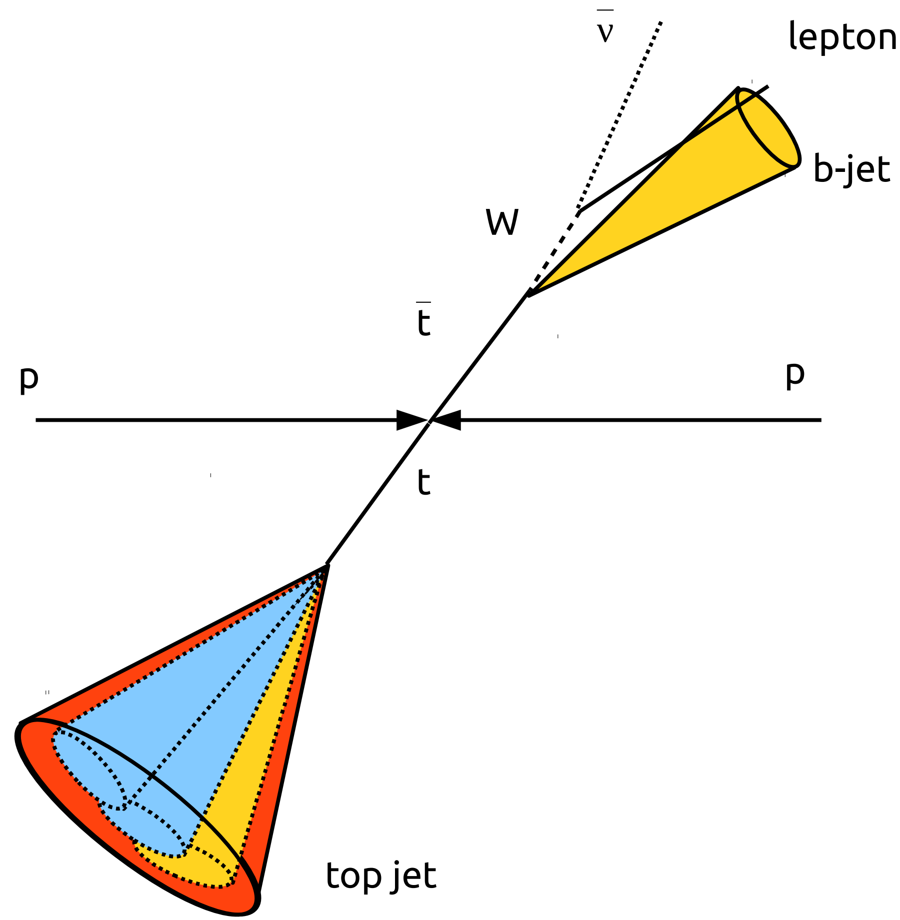
Detector level event selection

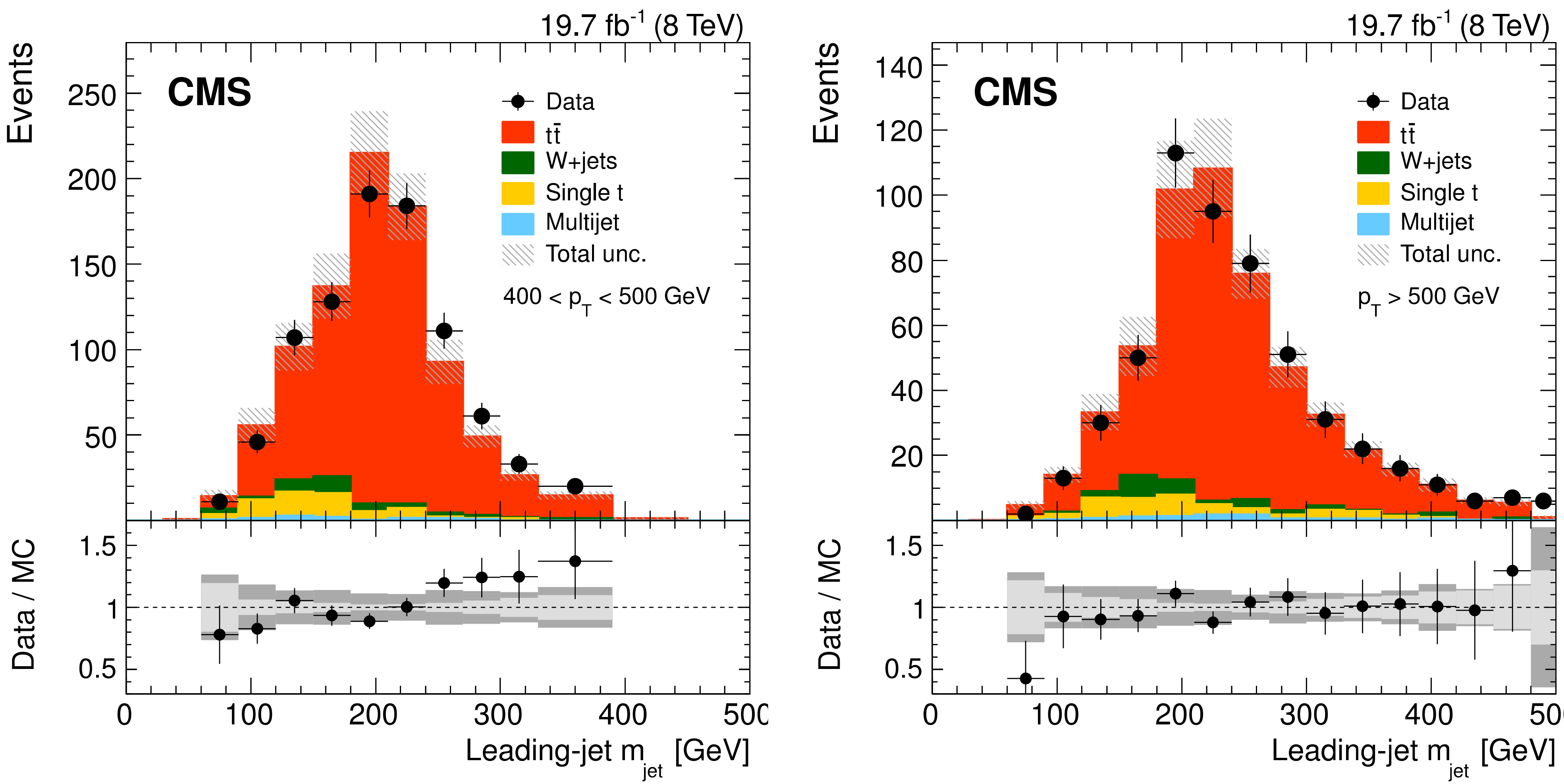
- Lepton plus jet $t\bar{t}$ event selection
  - b-tagging
  - Missing transverse momentum
  - ...

- Selection of similar phase space as on particle level



Jet mass on detector level

- Jet mass depends on p_T
  - Measurement phase space divided into two p_T bins



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Unfolding

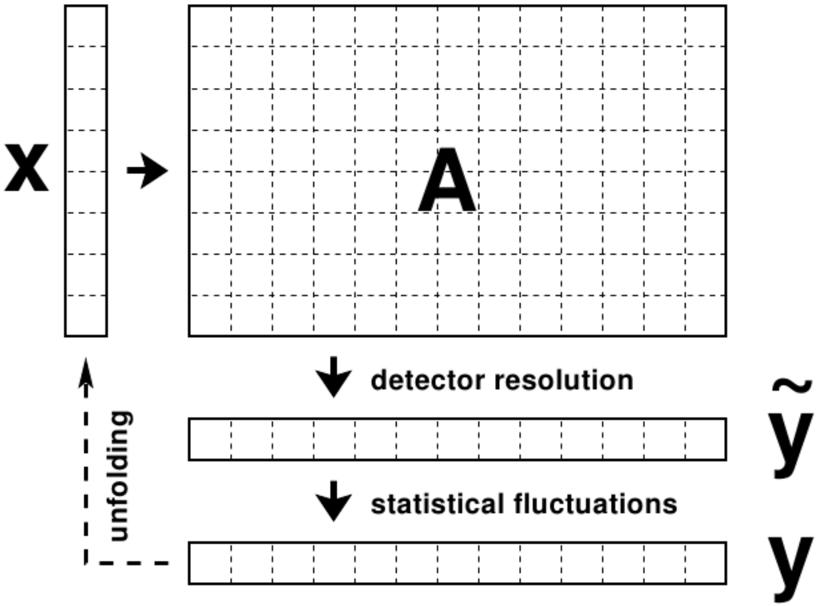
TUnfold framework

[S.Schmitt, JINST 7 (2012) T10003]

$$\tilde{y}_i = \sum_{j=1}^{m} A_{ij}\tilde{x}_j \quad , \quad 1 \leq i \leq n,$$

→ Obtain true distribution **x** from reconstructed distribution **y** by maximum likelihood fit

$$\chi^2 = (\mathbf{y} - \mathbf{A}\mathbf{x})^{\mathrm{T}}\mathbf{V}_{\mathbf{yy}}{}^{-1}(\mathbf{y} - \mathbf{A}\mathbf{x})$$



[S.Schmitt, JINST 7 (2012) T10003]

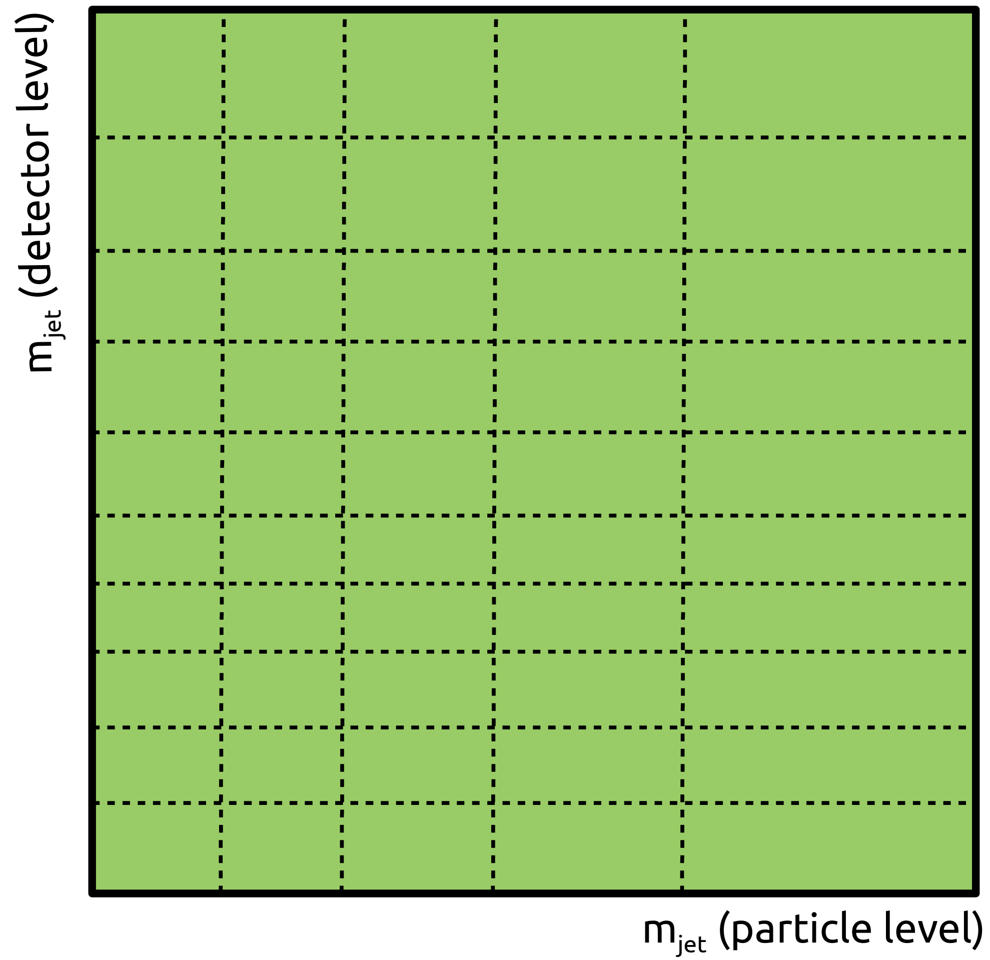
→ Amplification of statistical fluctuations

→ Suppress with regularization term

$$\chi^2 = (\mathbf{y} - \mathbf{A}\mathbf{x})^{\mathrm{T}}\mathbf{V}_{\mathbf{yy}}{}^{-1}(\mathbf{y} - \mathbf{A}\mathbf{x}) + \tau^2(\mathbf{x} - f_b\mathbf{x_0})^{\mathrm{T}}(\mathbf{L}^{\mathrm{T}}\mathbf{L})(\mathbf{x} - f_b\mathbf{x_0})$$

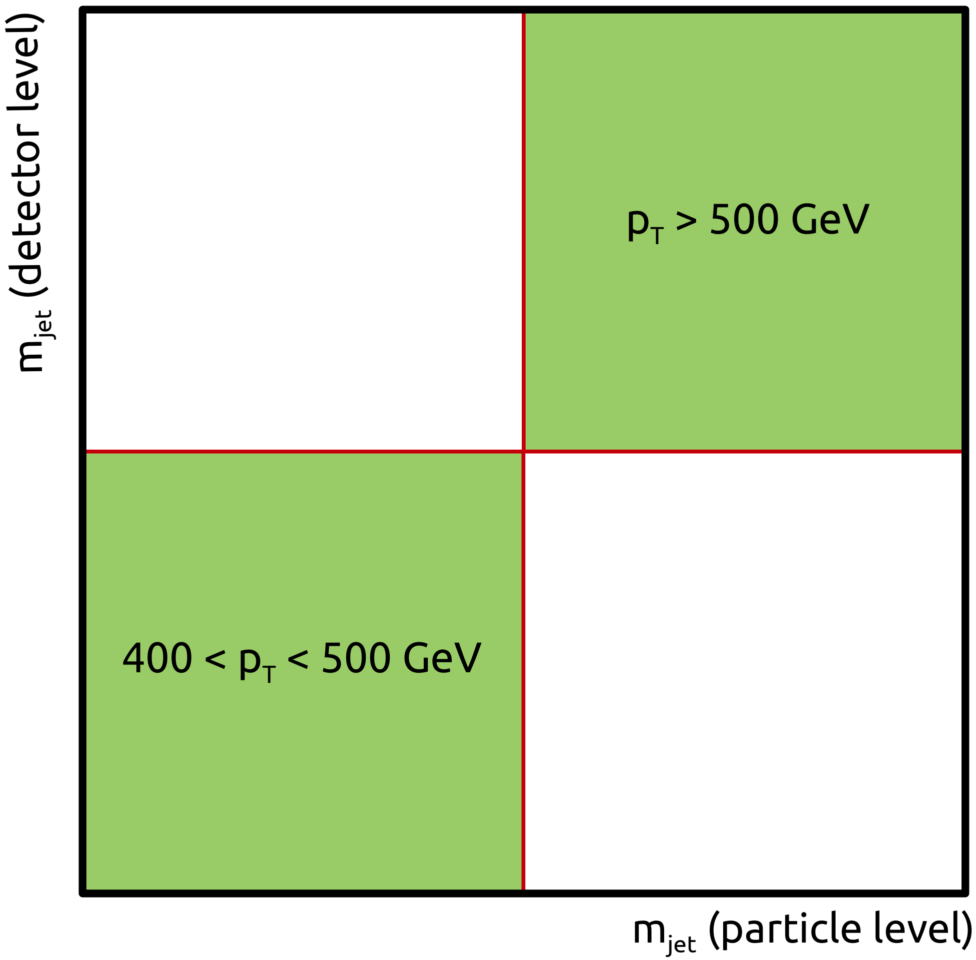
Response matrix

- Obtained from simulation



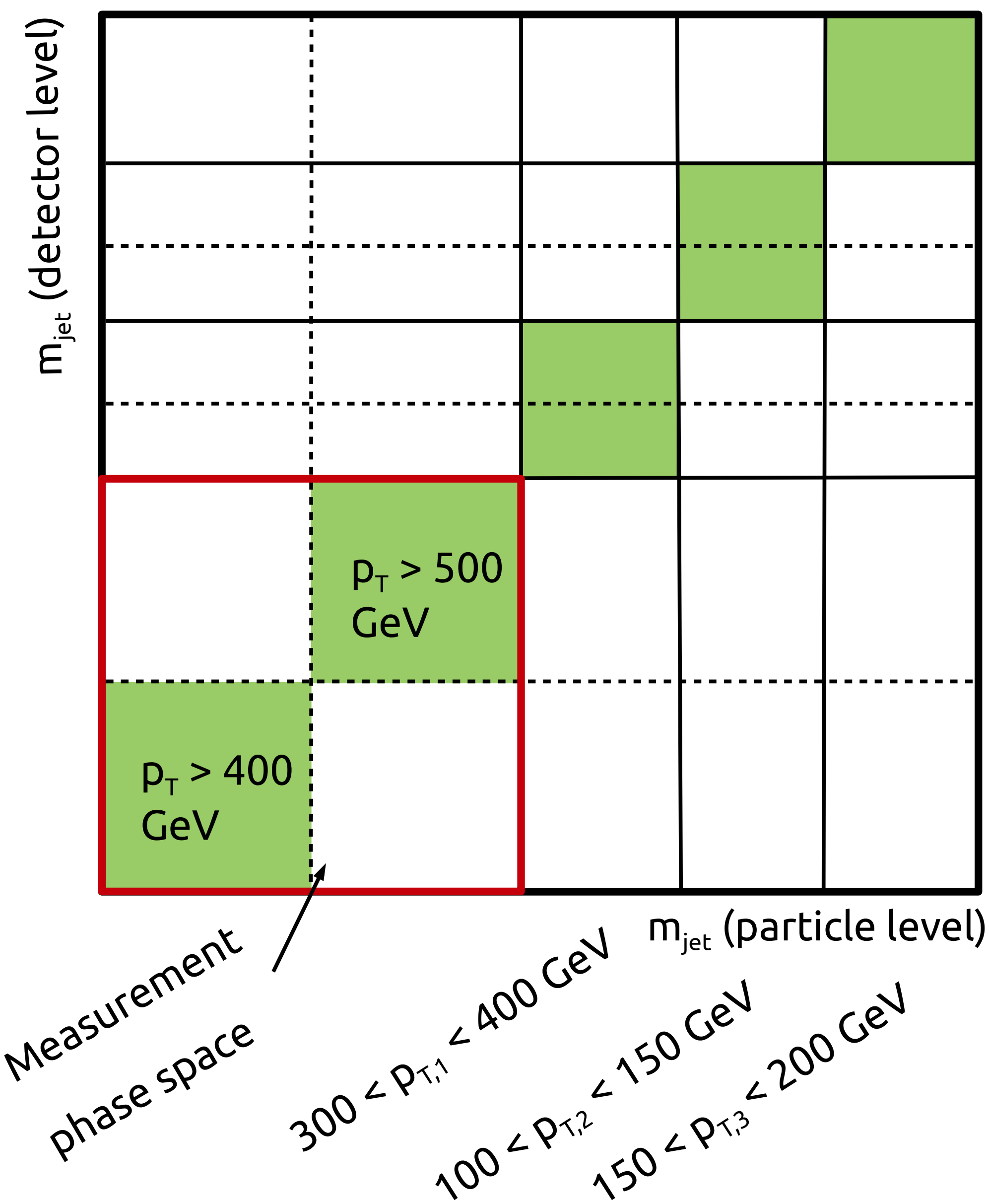
Response matrix

- Obtained from simulation
- Measurement phase space
  - Divided into two p_T bins
  - Less p_T dependence
  - Recombined after the unfolding



Response matrix

- Obtained from simulation
- Measurement phase space
  - Divided into two p_T bins
  - Less p_T dependence
  - Recombined after the unfolding
- Additional sideband regions
  - Unfolded simultaneously
  - More information from data
  - Cut efficiencies constrained by data



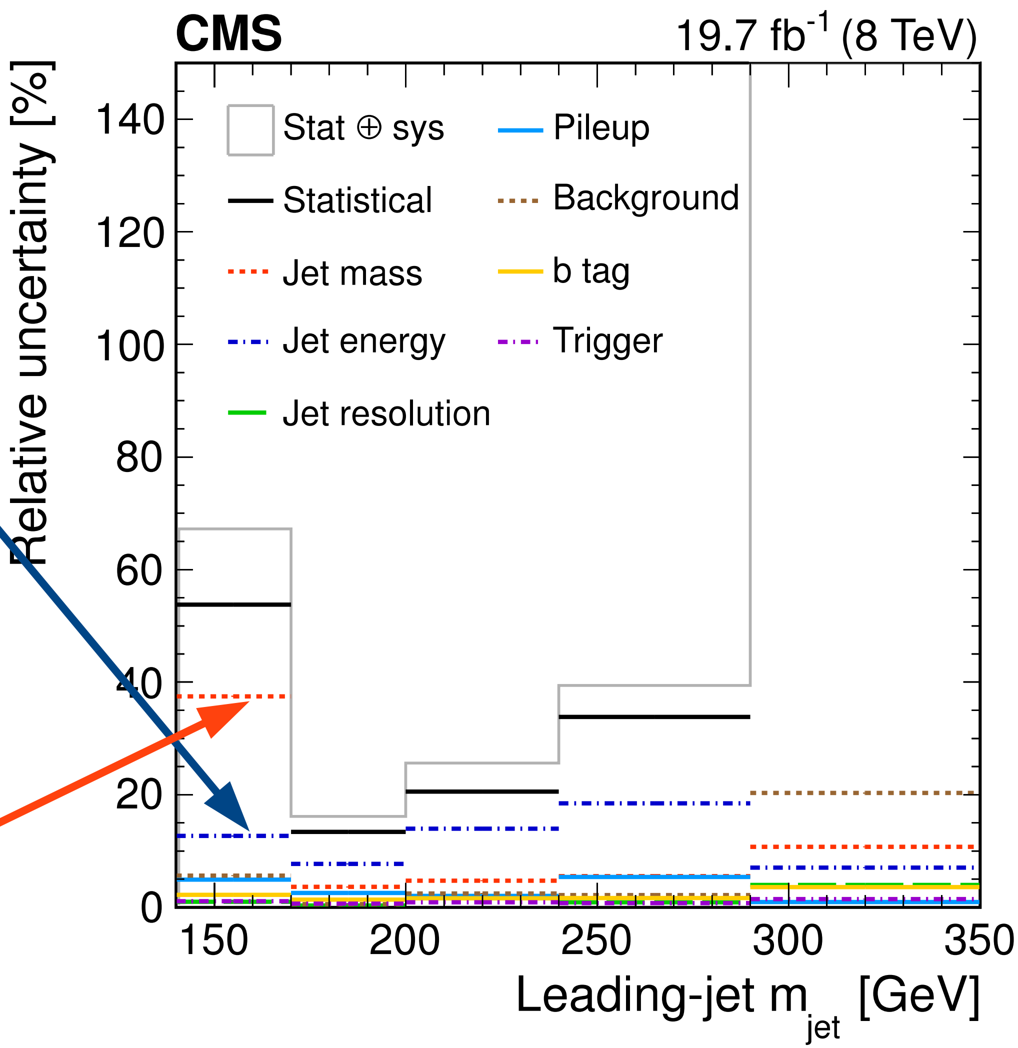
Experimental uncertainties

- Response matrix from simulation

- Affected by experimental uncertainties on detector level

- **Jet Energy scale:**
  - Expect improvement at 13 TeV
  - Higher statistics and smaller jets

- **Jet mass scale:**
  - Possible improvements by:
  - smaller jets
  - grooming



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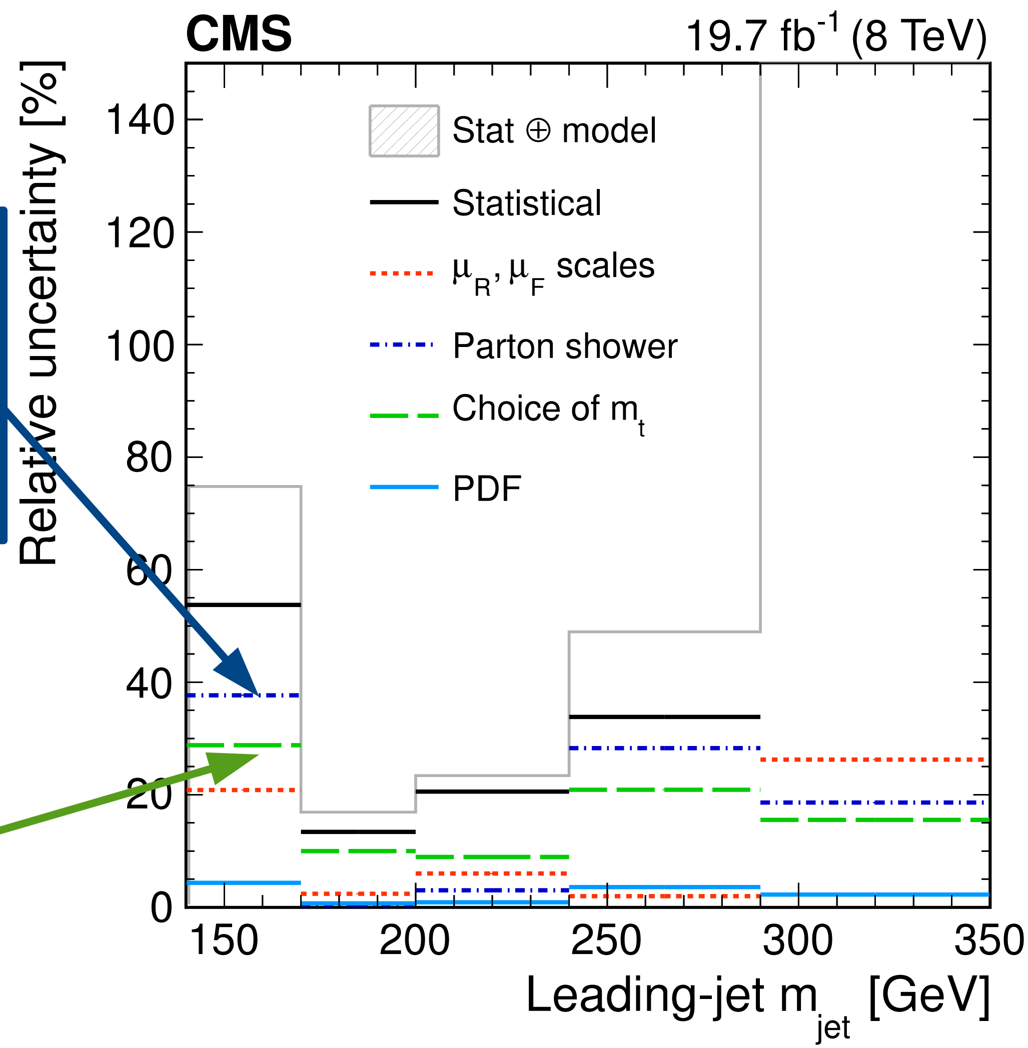
Model uncertainties

- Response matrix depends on simulation model

- **Parton shower:**
  - Expect smaller uncertainty at 13 TeV
  - Smaller jets and groomed mass

- **Choice of m_t:**
  - Expect improvement
  - More p_T bins in the unfolding
  - More sideband regions



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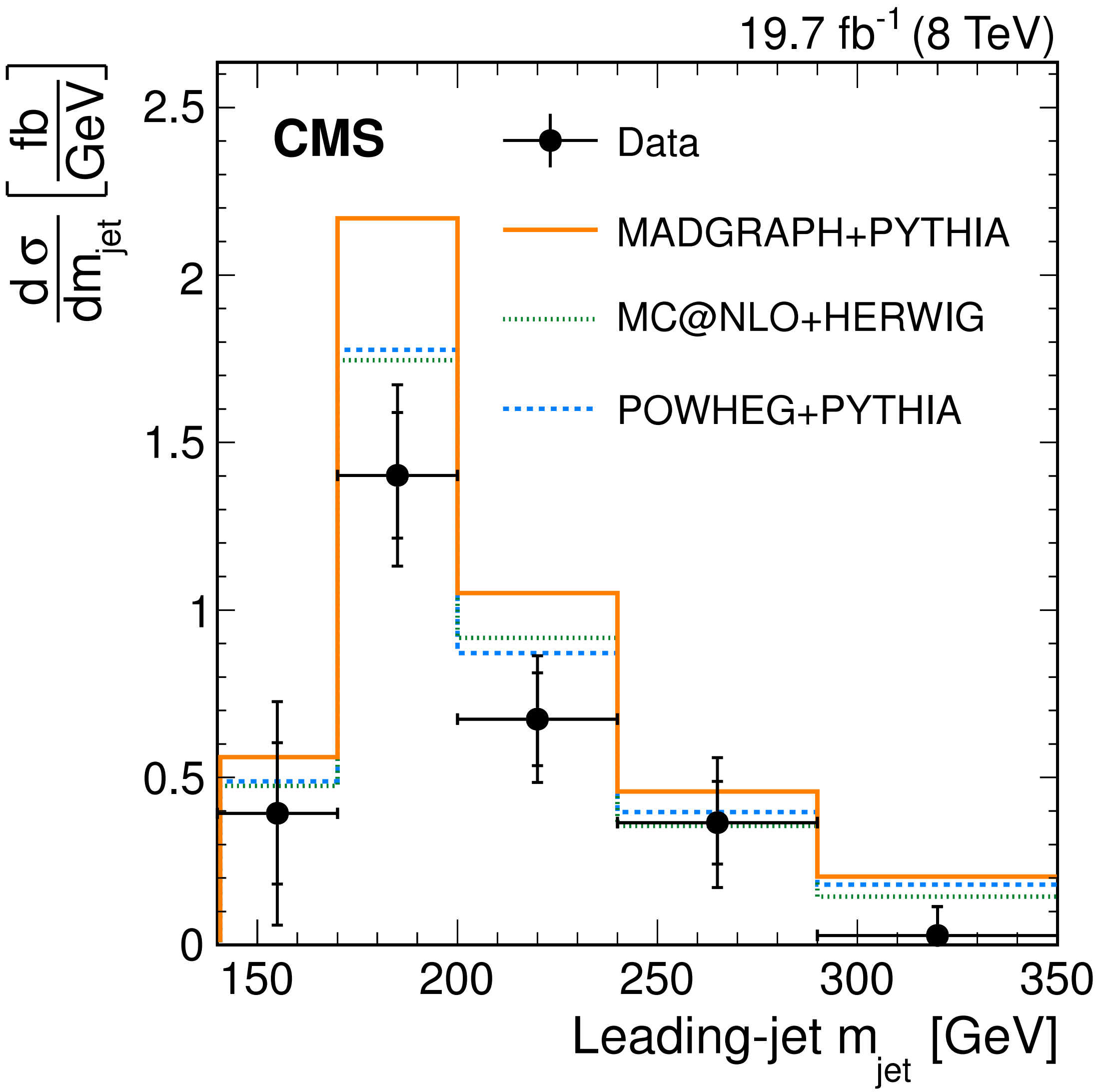
Differential cross section

- particle level
- boosted $t\bar{t}$ events
- Cross section smaller in data
  - Top p_T spectrum softer in data
  - Known problem at LHC



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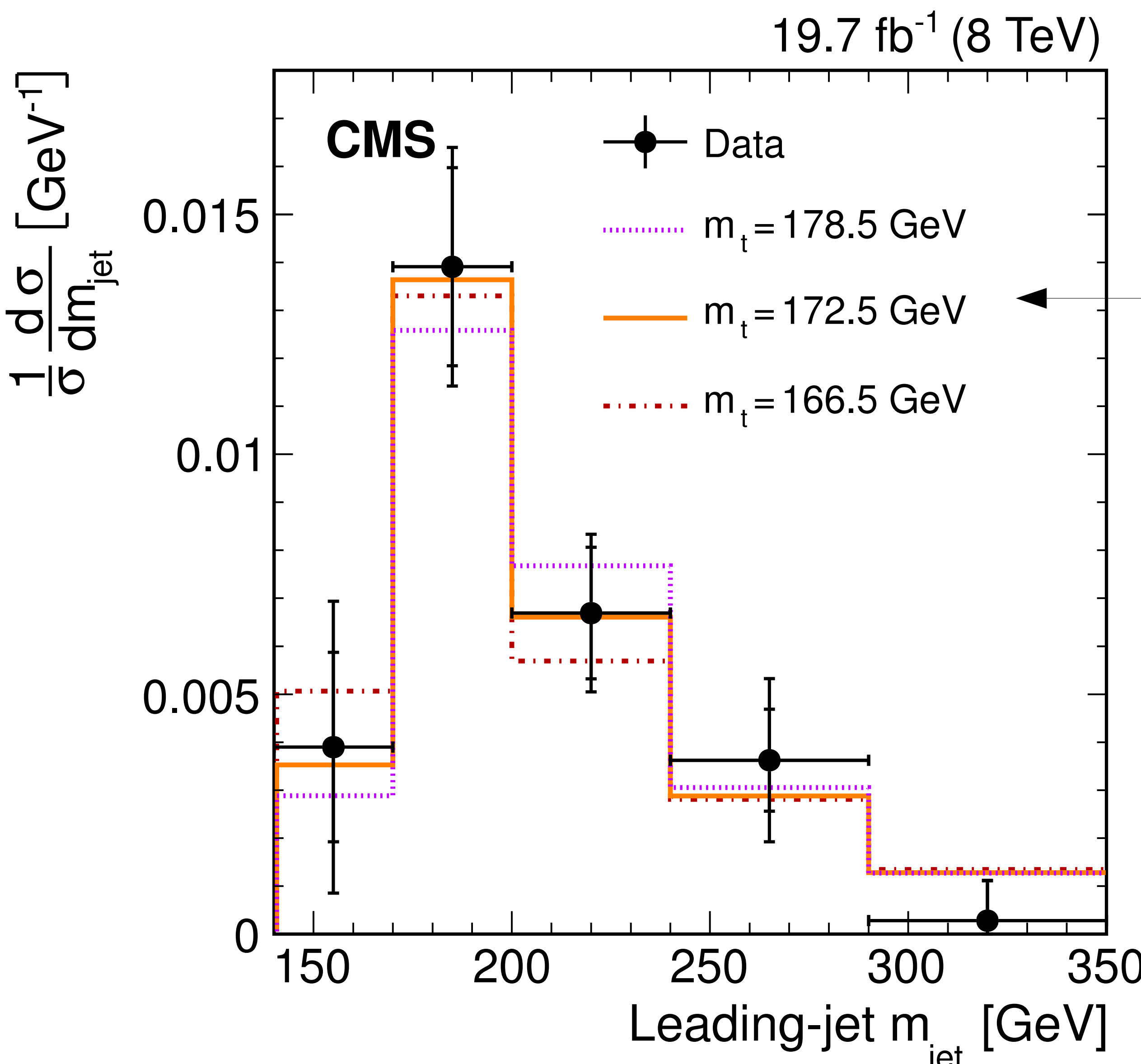
Normalized differential cross section



MADGRAPH+PYTHIA 6

→ Sensitivity to m_t clearly visible

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Sensitivity on the top quark mass

- Extract m_t from simulated templates
- Normalized cross section
- Calculate χ^2 for every template:

$$\chi^2 = (\vec{m}_{\text{data}} - \vec{m}_{\text{MC}})^{\text{T}} \mathbf{C}^{-1} (\vec{m}_{\text{data}} - \vec{m}_{\text{MC}})$$

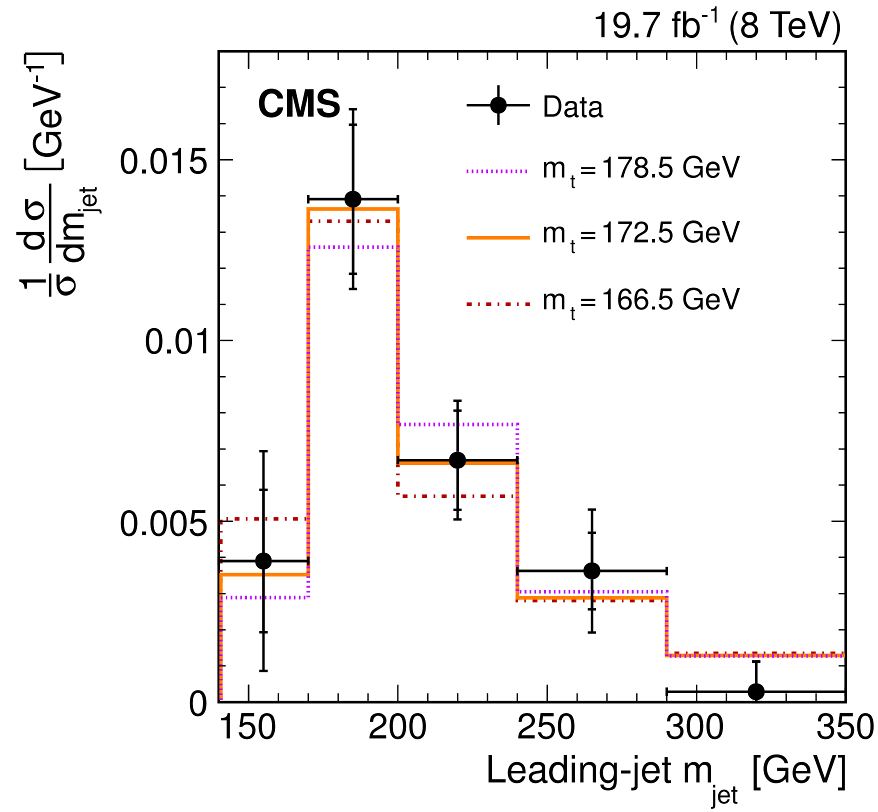
data bins — simulation bins — covariance matrix

- Perform fit to χ^2 (m_t)

Minimum at:

m_t = 170.8 ± 9.0 GeV

= 170.8 ± 6.0 (stat) ± 2.8 (syst) ± 4.6 (model) ± 4.0 (theo) GeV



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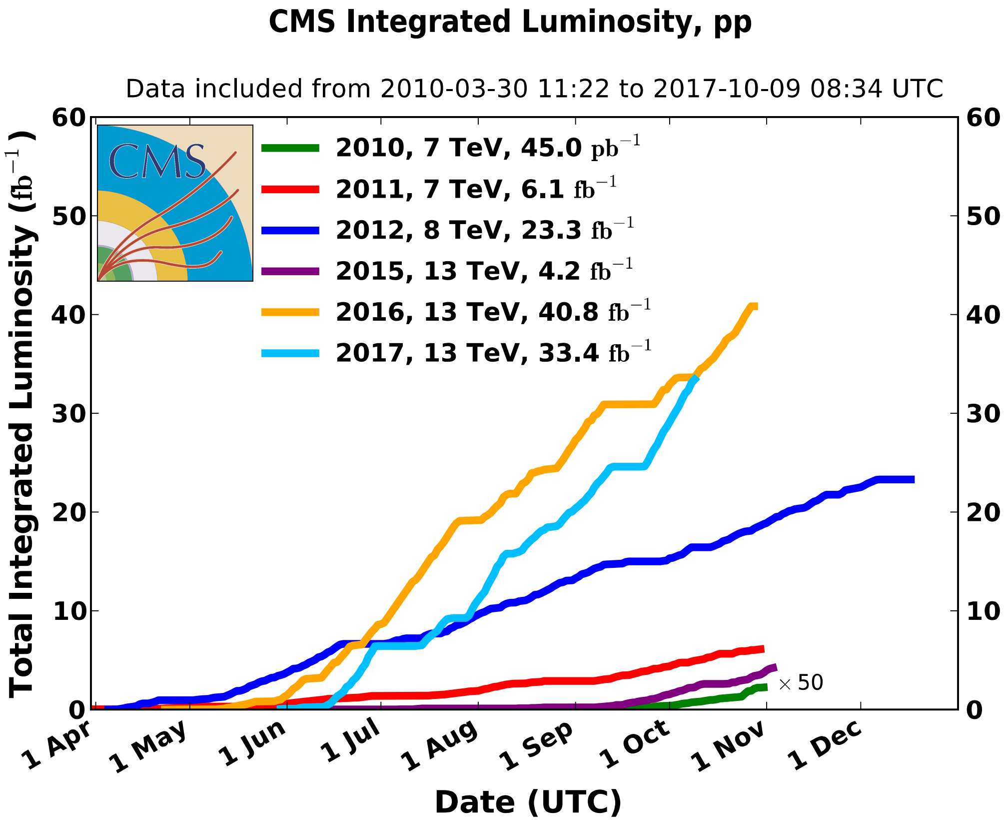
- Sensitivity test!
- Goal is extraction from EFT calculations (not available yet)

Outlook on 13 TeV

- No public results
- Much higher statistics in data
  - Increased p_T threshold
  - Smaller jets
- Grooming
- better mass resolution
  - → finer binning



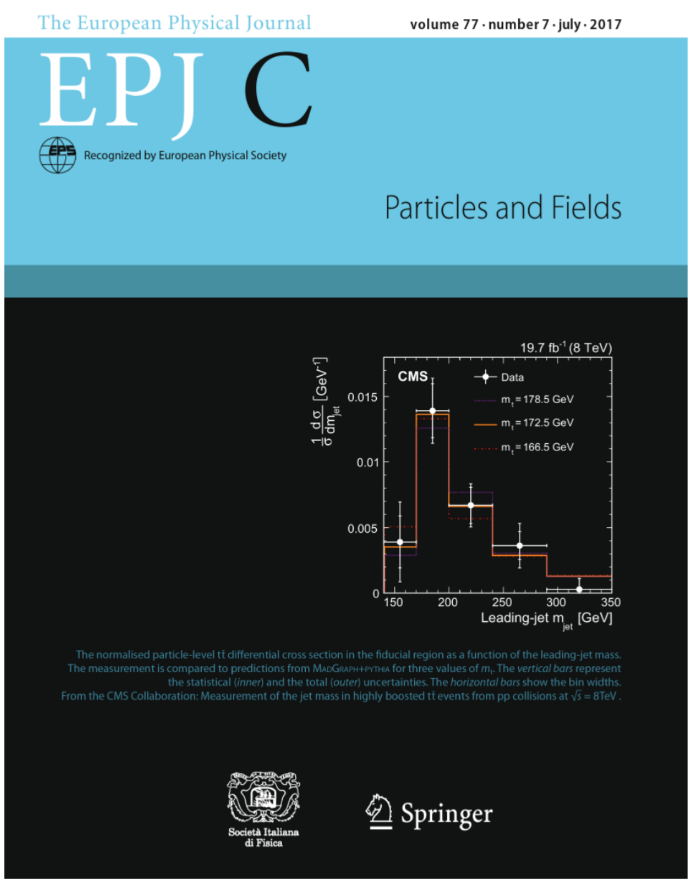
Summary

- First measurement of the boosted top jet mass distribution

- 8 TeV
  - Published: Eur.Phys.J. C77 (2017) no.7, 467
  - Statistical uncertainties dominant

- 13 TeV
  - More statistics and better mass resolution

    → large improvements expected



Back up

Kinematic distributions

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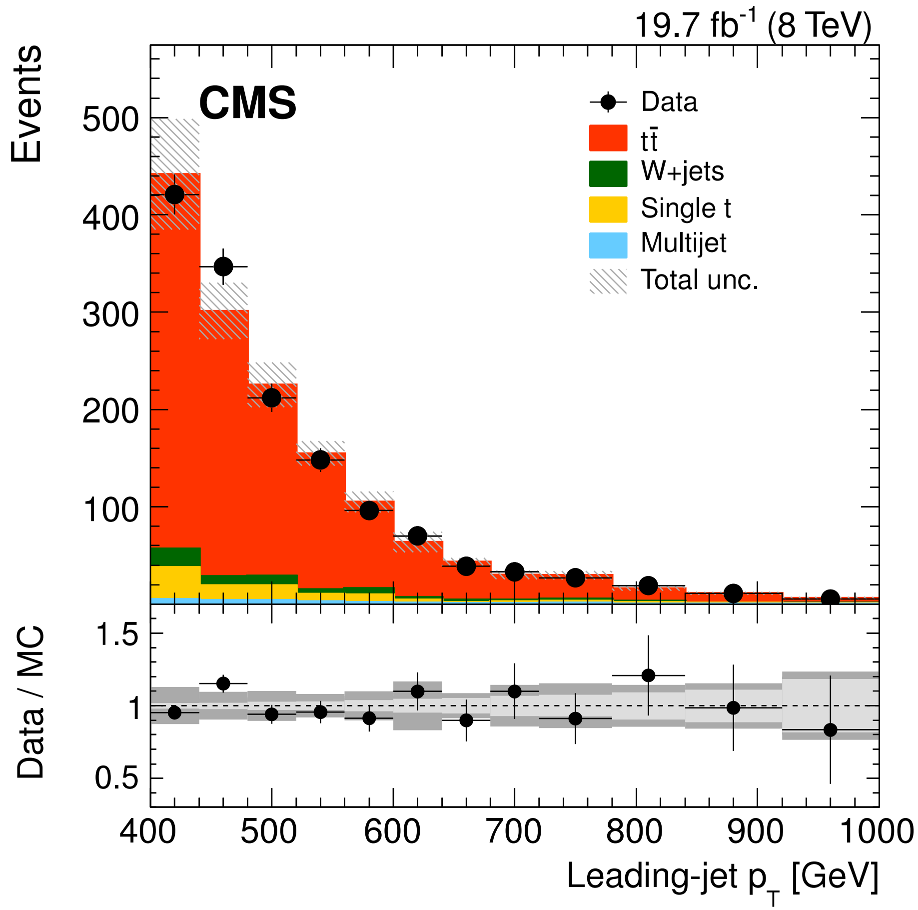

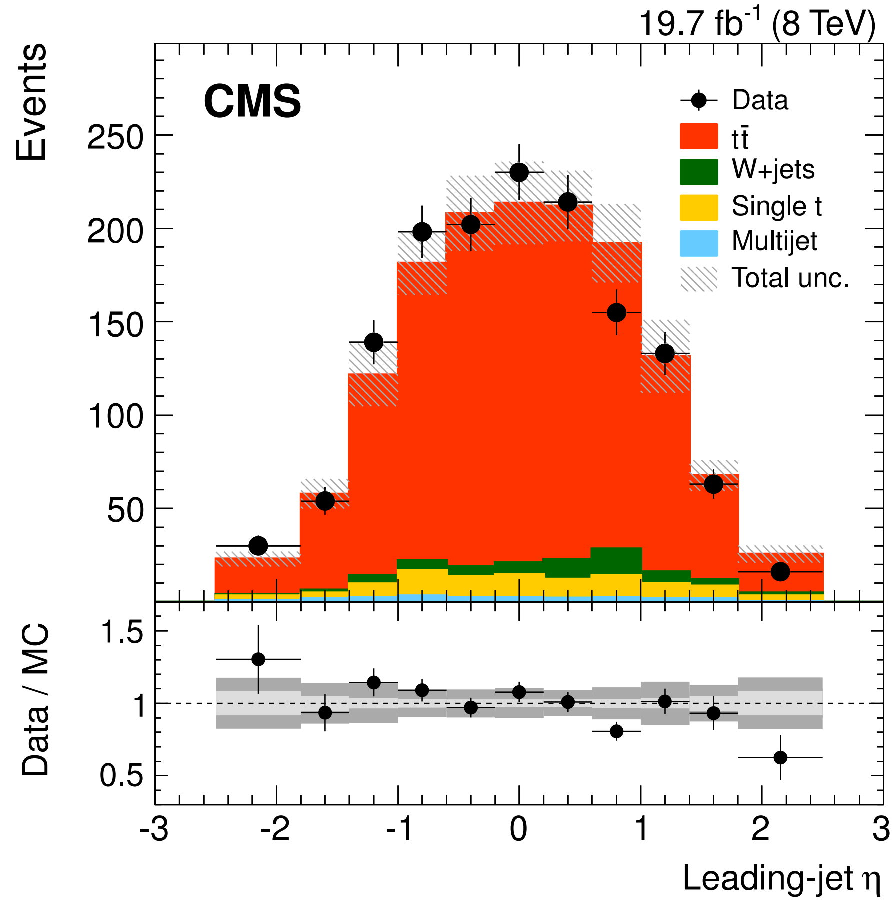

- Jet kinematics well described