# Multi-jet production

## Measurement of multi-jet cross sections in proton-proton collisions at 7 TeV center-of-mass energy

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# Dataset and aims

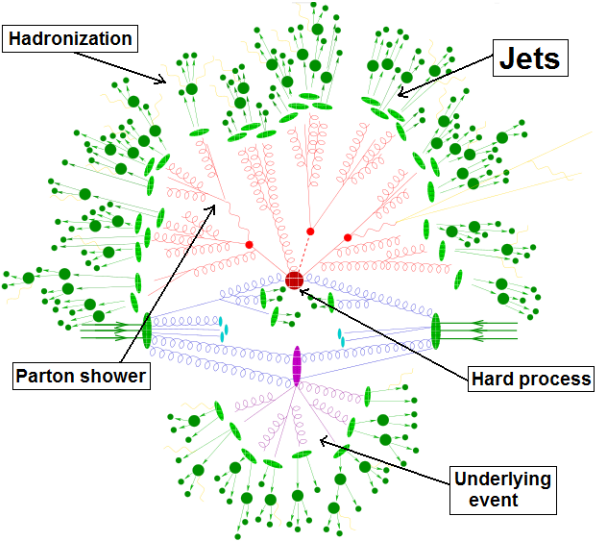
## Dataset

- pp collisions at the LHC collected with the ATLAS detector
- 7 *TeV* center-of-mass energy
- Total integrated luminosity of 2.4 $pb^{-1}$
- Multi-jet events (2-6) were preselected
- $0.5 \cdot 10^6$ events

## What are the aims?

- Evaluating how robust leading-order perturbative QCD (LO pQCD) calculations are in representing high jet-multiplicity events.
- Testing next-to-leading order perturbative QCD (NLO pQCD) calculations.

# Jets primer


Hadronization
Jets
Parton shower
Hard process
Underlying event

# Jet reconstruction and selection

## Reconstruction

- Input: Topological clusters of calorimeter energy deposits
- Apply anti-$k_T$ algorithm

Distance between protojets:

$$d_{ij} = min(E_t^{-2}, i, E_t^{-2}, j)(\Delta y_{ij}^2 + \Delta \phi_{ij}^2)/R^2$$

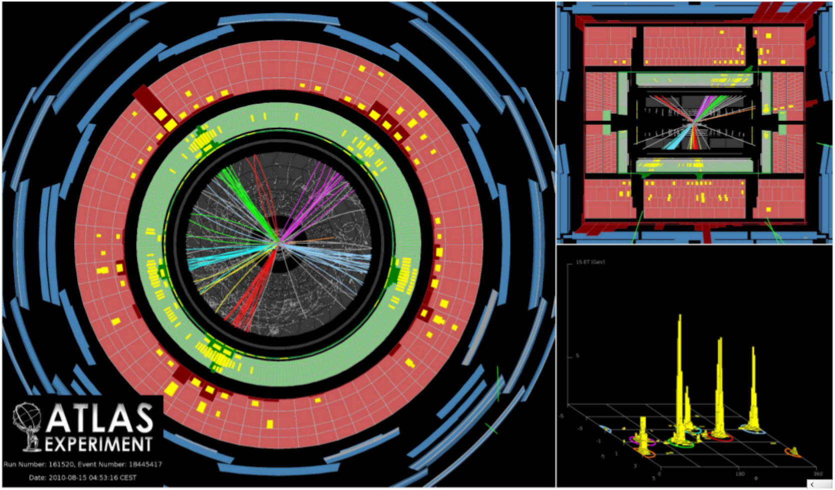
with cone parameter $R = 0.4$ (LO) or $R = 0.6$ (NLO).

## Selection criteria

- all jets in $|y| < 2.8$,
- all jets $p_T > 60 GeV$, at least one jet with $p_T^{lead} > 80 GeV$,
- cleaning cuts, pile-up reduction,

For conditions listed above we reach 100% efficiency in the trigger.

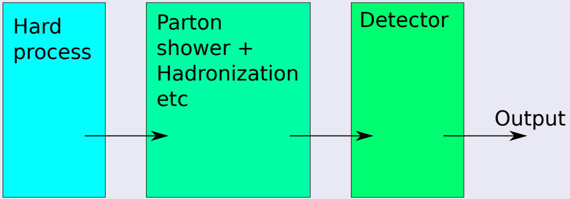
# Multi-jet event example



# Jet correction

## Correction

Various detector effects (trigger inefficiency, detector resolution etc.) give rise to distortions in jet identification and event counting.




For correction we use MC simulations (GEANT4). We study how the detector affects the outgoing particles and, therefore, the jets. By comparing jets of particles and jets of topoclusters we compute corrections and apply them to the data.

# Jet energy - calibration and uncertainties

## Calibration

We need to calibrate $p_T$ jet energy correctly. It is needed because of different response of the calorimeters to hadrons. Again, MC simulations are helpful.

## Uncertainty

The major sources of uncertainty in the jet $p_T$ are:

- estimation of the uncertainty for isolated jets (biggest)
- presence of nearby calorimeter deposits
- flavor composition (big for 5,6-jets and below $p_T = 200\ GeV$)

It is the dominant uncertainty component for most results given here!

# Theoretical frameworks

## Leading order (LO) MC simulations

- ALPGEN+HERWIG AUET1
  - PS: HERWIG
  - PDF: CTEQ6L1
  - ME: up to $2 \rightarrow 6$
- PYTHIA AMBT1
  - PS: built-in
  - PDF: MRST2007
  - ME: $2 \rightarrow 2$
- ALPGEN+PYTHIA MC09'
  - PS: PYTHIA
  - PDF: CTEQ6L1
  - ME: up to $2 \rightarrow 6$
- SHERPA
  - PS: built-in
  - PDF: built-in
  - ME: up to $2 \rightarrow 6$

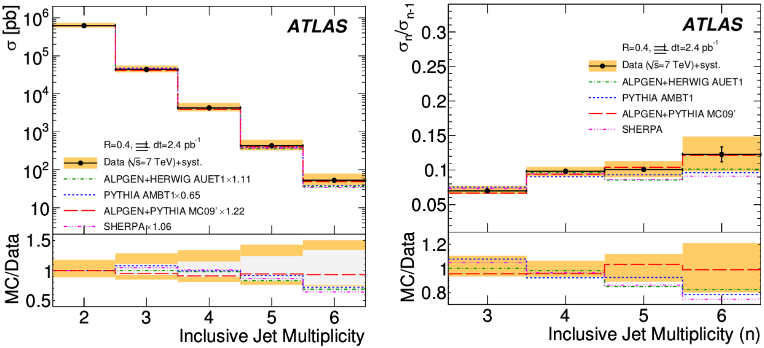
## Next-to-leading order (NLO)

- NLOJet++
  - PS: none
  - PDF: MSTW 2008 NLO
  - ME: $2 \rightarrow n$
  - comparison feasible by multiplicative term

$$C = \frac{\sigma_{UE}^{particle}}{\sigma_{no\ UE}^{parton}},$$

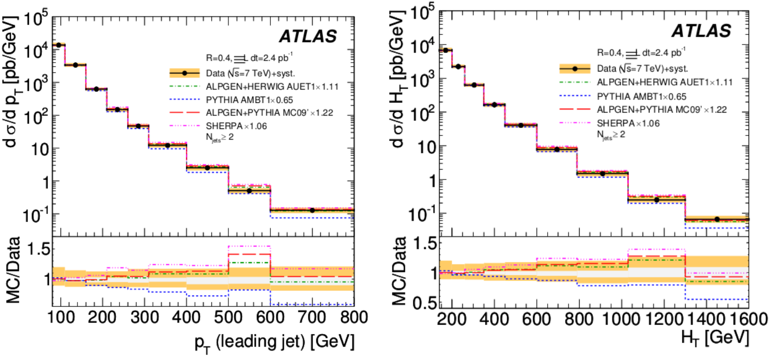
calculated with the LO MC simulations.

# Total cross section vs. jet multiplicity (LO)




- Why ratio?
- Grey and orange error bands
- Good agreement

# Differential cross section vs. $p_T$ and $H_T$ (LO)

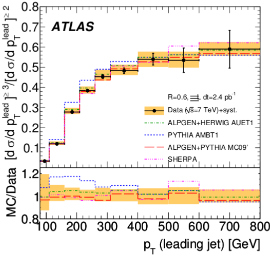


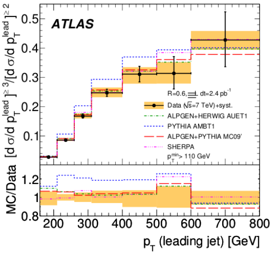

- $H_T = \sum_i p_{T,i}$ (used in top-quark physics)
- PYTHIA has problems (steeper slope)

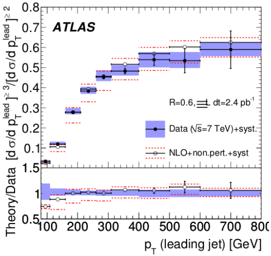
# Differential cross section ratio vs. $p_T$ (LO & NLO)

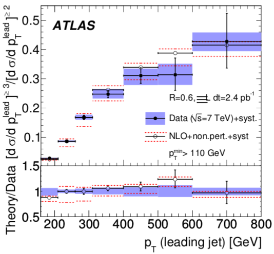
Standard selection of multi-jet events

$p_T^{lead} > 160\ GeV$ and $p_T > 110\ GeV$




- Ratio of the inclusive three-jet to two-jet differential cross section
- Reduced experimental and theoretical uncertainties in the ratio
- PYTHIA does not describe the data
- ALPGEN and SHERPA in agreement with data
- NLO QCD describes the data well except in first bin

# Summary

- First study of multi-jet events in pp collisions at 7 *TeV* using the ATLAS detector
- Study of jet multiplicities and differential cross sections up to 6-jet events
- Measurements up to 0.8 *TeV* in $p_T$ and up to 1.6 *TeV* in $H_T$
- All models reproduce the main features of the multi-jet data
- MC models based on $2 \rightarrow 2$ calculations show some deviations from the data
- MC models based on $2 \rightarrow$ n calculations do a better job in describing the data
- Ratio of the inclusive three-jet to two-jet differential cross section:
  - ALPGEN and SHERPA describe well the measurements
  - NLO QCD calculations give a good description except in lowest $p_T$ bin

# End

**These two are the lecturers, think about it before asking questions!**