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 $p_T > 60\text{GeV}$, at least one jet with $p_T^{\text{lead}} > 80\text{GeV}$,
- cleaning cuts, pile-up reduction,

For conditions listed above we reach 100% efficiency in the trigger.
Multi-jet event example
Jet 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!
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
    \[
    C = \frac{\sigma_{\text{particle}}^{\text{UE}}}{\sigma_{\text{parton}}^{\text{no UE}}},
    \]

  calculated with the LO MC simulations.
Total cross section vs. jet multiplicity (LO)

- Why ratio?
- Grey and orange error bands
- Good agreement
$H_T = \sum_i p_{T,i}$ (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
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
These two are the lecturers, think about it before asking questions!