WG2 experimental summary
multi-jet final states and energy flows

Eduardo Rodrigues
University of Glasgow

4th HERA-LHC Workshop, CERN, 26-30 May 2008

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Last but not least

Thanks!

to all the speakers for their valuable contributions
Disclaimer(s)

- This was the last workshop before LHC start-up
- Talk will mention the achievements since after the 2005 workshop proceedings
- Not all contributions individually summarised
Workshop sessions since 2005 proceedings

29 Oct. – 2 Nov. 2007, DESY:

- Working group week
- WG2 + MC Tools joint session: mostly theoretical contributions

12-16 March 2007, DESY:

- 3rd workshop
- Good mix of WG2 talks from HERA and LHC communities
- First presentations of new developments on jet algorithms (e.g. SISCone and jet areas)
- WG2 + MC Tools joint session: focus on multiple interactions

6-9 June 2006:

- 2nd workshop
- WG2 + MC Tools joint session: focus on underlying event
- Good mix of WG2 talks from HERA and LHC communities
# This week’s WG2 sessions with an experimental flavour

## Multi-jet final states and energy flows (joint session with MCTools)

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Location</th>
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<tbody>
<tr>
<td>09:00</td>
<td>New Results from CDF on the Underlying Event and Extrapolations to the LHC</td>
<td>40-S2-D01</td>
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<tr>
<td>09:25</td>
<td>Underlying event studies with Castor calorimeter in CMS experiment</td>
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<td>09:45</td>
<td>Modeling the underlying event: MC tunes for the LHC</td>
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<td>10:05</td>
<td>COFFEE (25')</td>
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<td>10:30</td>
<td>The underlying event in Herwig++</td>
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<td>10:55</td>
<td>Double parton scattering studies with Pythia 8 and Herwig++</td>
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<td>11:20</td>
<td>A new framework for estimating multi-jet final states</td>
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<td>11:45</td>
<td>Multiple Interactions in photoproduction at H1</td>
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<tr>
<td>12:10</td>
<td>Prerequisites for the Validation of Experiment and Theory</td>
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**Summarised in MC Tools report**

## Multi-jet final states and energy flows: Jets and jet algorithms

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<thead>
<tr>
<th>Time</th>
<th>Topic</th>
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<tbody>
<tr>
<td>14:00</td>
<td>Jet finding strategies in ATLAS</td>
<td>40-S-AD1</td>
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<tr>
<td>14:20</td>
<td>Performance of Jet Reconstruction at CMS</td>
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<tr>
<td>14:40</td>
<td>b-jets at LHCb</td>
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<td>15:00</td>
<td>Forward jets with the calorimeter CASTOR in the CMS experiment</td>
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<tr>
<td>15:20</td>
<td>COFFEE (20')</td>
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<tr>
<td>15:40</td>
<td>Update on the SISCon and Anti-kT algorithms</td>
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<td>16:00</td>
<td>Jet areas and subtraction</td>
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<tr>
<td>16:20</td>
<td>Performance of jet algorithms at the LHC</td>
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<tr>
<td>16:40</td>
<td>Non-perturbative effects for QCD jets at hadron colliders</td>
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<td>17:00</td>
<td>Azimuthal de-correlations in QCD jets</td>
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<tr>
<td>17:20</td>
<td>Discussion - ALL</td>
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Eduardo Rodrigues  
4th HERA-LHC Workshop, WG2 experimental summary, CERN, 26-30 May 2008  
4/18
Jet physics
Challenges at the LHC

- **Environment related:**
  - pile-up – ~23 interactions / bunch crossing

- **Physics related:**
  - the underlying event
  - and multi-parton interactions

- **Detector related:**
  - calorimeters resolutions,
  - noise, and “slow” response

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**LHC prediction:** x2.5 the activity measured at Tevatron!


Analysis of jets – connection to theory

Many developments in the past 2 years!

Jet algorithms:
- New algorithms on the market:
  - Infrared-safe cone algorithm: SISCon
  - Recombination algorithms: anti-\(k_T\)
- Fast implementations available in the fast-\(k_T\) package

Jet reconstruction performance:
- New variables exist for a quantitative assessment of the jet quality

Dealing with pile-up and underlying event:
- Exploitation of the concept of jet area

M. Cacciari, J. Rojo, G. Salam, G. Soyez
Jet reconstruction strategies

LHC preparations:

- Jet reconstruction crucial to ATLAS and CMS physics programs
- Analysis demand excellent jet resolution and small energy scale uncertainties

General ATLAS and CMS strategies – “the power of flexibility”:

- Use/exploit/study different jet algorithms and tools
- Develop several jet energy scale correction strategies, both MC-based and data-driven
- Develop several calibration methods
  data will “dictate” best strategy to adopt in the future
Jet studies in ATLAS (1/2)

Jet algorithms considered:
- ATLAS allows choice among several:
  - Cone-based algorithms: seeded cone, MidPoint cone, SISCone
  - Clustering algorithms: \( k_T \) with fast-kt implementation

Studies:
- Comparison of algorithms
- Methods of jet calibration
- Methods of jet energy scale determination (di-jets balance, Z+jets, etc.)
Jet studies in ATLAS (2/2)

Calibration efforts:
- Challenge: ATLAS possesses a non-compensation calorimeter (e/h ~1.3-1.6)
  ⇒ electromagnetic component of jets is important and shape of corrections non-trivial vs. jet \( \eta, E, E_T \)

Jet energy scale efforts:
- Challenge: aim at ~1% JES uncertainty!

Jet finding efforts:
- Choice of algorithm can impact significantly on analysis
- Need to “tune” algorithm (e.g. R size parameter)
- “Tracks jets” also available:
  - used to correct energy scale
  - track jet vertex helps rejecting pile-up jets

Atlas MC preliminary

Top quark mass distribution for different values of the D parameter of \( k_T \) algorithm
Jet studies in CMS (1/2)

Jet algorithms considered:
- Cone-based algorithms: iterative cone, MidPoint cone, SISCone
- Clustering algorithms: $k_T$ with fast-kt implementation

Studies:
- Comparison of algorithms
  - similar computing time for all algorithms
  - SISCone and $k_T$ tend to have better performance
- Calorimeter jet calibration:
  - both MC-truth-based and data-driven methods
- Performance on t-tbar events

 disadvantaged

(smaller cone size parameter $\rightarrow$ better matching eff.)
Jet studies in CMS (2/2)

CMS preliminary

\[
\text{Response} = \frac{\text{Calorimeter jet } p_T}{\text{Particle jet } p_T}
\]

Good agreement for data-driven dijet-balance and MC-truth

\[
|\eta| < 1.3
\]

Good agreement between data-driven and MC-truth methods

**di-jets balance**

 CMS Preliminary

IConc, R=0.5  \(|\eta| < 1.4\)

- Asymmetry method
- MC truth resolution

**t-tbar events**

 CMS Preliminary  Fast k_T, D=0.4

GEN
Mean: 80.6
RMS : 8.04

CALO
Mean: 53.4
RMS : 10.2

L5(CORR+FLV)
Mean: 85.4
RMS : 12.1

CORR
Mean: 92
RMS : 12.6

GEN
Mean: 175.9
RMS : 14.1

CALO
Mean: 110.9
RMS : 18.7

L5(CORR+FLV)
Mean: 177.7
RMS : 21.6

CORR
Mean: 187.2
RMS : 22.2

Eduardo Rodrigues  4\textsuperscript{th} HERA-LI
Forward jet studies with CASTOR & CMS

Detector:
- CMS “add-on” Cherenkov radiation calorimeter
- Very forward: $5.2 < \eta < 6.6$

Purpose:
- At HERA DGLAP describes well inclusive measurements but fails for more exclusive final states, ex. forward jet production
- Study of QCD dynamics, try to distinguish between different parton evolution models (DGLAP vs. BFKL)
Jet studies in LHCb (1/2)

**Forward spectrometer**

**Acceptance:** $1.8 < \eta < 4.9$

**Luminosity:** $2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

**Nr of B’s / year:** $10^{12}$

**Detector:** excellent tracking

**Detector:** excellent PID

**Reconstruction:**
- muons: easy
- hadronic tracks: fine
- electrons: OK
- $\pi^0$’s: tricky
- neutrinos: no

**Mission statement**

- Search for new physics probing the flavour structure of the SM
- Study CP violation and rare decays in the B-meson sector

**Tracking:**

*Expected tracking resolution*  
$\delta p/p = 0.35\%$ to $0.55\%$

**Calorimeter resolution:**

*Design ECAL resolution*  
$\sigma/E = 10\% \sqrt{E} + 1\%$ ($E$ in GeV)

*HCAL resolution from test-beam data*  
$\sigma/E = (69 \pm 5)\% \sqrt{E} + (9 \pm 2)\%$ ($E$ in GeV)
Jet studies in LHCb (2/2)

Jet reconstruction issues:
- Rather restricted detector angular coverage
- Calorimeter optimised for B-physics, not jet physics

Jet reconstruction strategy:
- $k_T$ algorithm
- Use calorimeter information
- Use tracks information for charged particles
- Energy corrections
- B-jet tagging

Dijet mass resolution is affected

LHCb allow reconstruction of b-jets in the range $2 < \eta < 4$

SM Higgs decaying to $\bar{b}b$ with $m_H=120\text{GeV}$ in association with $e$ or $\mu$ from W or Z

Pseudorapidity of b-quarks coming from $H(120\text{GeV})$ (high pt lepton in the acceptance)
Multi-parton interactions and underlying event

- typically presented in joint sessions with MC Tools WG
- Present status in Paolo Bartalini’s summary
- Focus here on experimental aspects and tools rather than MC tunings

P. Bartalini, L. Fano, R. Field, A. Moraes et al., D. Treleani, etc.
Multi-parton interactions & underlying event (1/2)

Multi-parton interactions:
- Great deal understood with HERA data (see e.g. Magro’s talk)
- HERA and TeVatron data used to tune MCs

UE before the LHC:
- Many studies of the UE at TeVatron
- New models implemented in new MCs (e.g. Herwig++)
- Testing of new models on (TeVatron) data

Double-parton scattering: Florian Bechtel
- Identified in final states with $\gamma + 3$ jets
- Direct evidence for multi-parton interactions
- MPI models agree with TeVatron data
- Studies ongoing for similar analyses at the LHC, where MI expected to contribute significantly

Status report given at joint session with MC tools WG. See Paolo Bartalini’s summary
Multi-parton interactions & underlying event (2/2)

Underlying event at the LHC:
- To be measured from jet events & Drell-Yan $\mu$-pair production
- CASTOR can also extend the TeVatron results to the very forward region (jet profiles help determining UE component)

How to deal with the UE and pile-up?
- Concept of jet area used to determine and subtract these contributions on an event-by-event basis
- Key observation: jet $E_T / \text{jet area} \sim \text{constant except for hard jets}$
- LHC experiments urged to explore the idea ...
  ... it fits well now that both ATLAS and CMS need to study jet reconstruction in the presence of pile-up ...

Matteo Cacciari et al.
Zuzana Rurikova
Outlook

- Workshop has seen the birth of many new ideas

- There has been a constant flow of ideas/tools/etc. from HERA to LHC community

- Looking forward to seeing all these developments “in action” using LHC data …!