The High Energy Jets Framework

Jennifer M. Smillie
Edinburgh

DIS Bonn 27 March, 2012
A New Framework for a New Era

High Energy Jets = flexible description of wide-angle QCD radiation

- Usual starting point = fixed-order calculation

- Standard to sum large effects from small $s_{ij}$ between partons
  Parton showers describe soft and/or collinear well

- At LHC, effects from large $s_{ij}$ are important
  These arise in wide-angle radiation (soft and hard)
  These are treated in High Energy Jets (HEJ)
A New Framework for a New Era

High Energy Jets = flexible description of wide-angle QCD radiation

- Usual starting point = fixed-order calculation

- Standard to sum large effects from small $s_{ij}$ between partons
  Parton showers describe soft and/or collinear well

- At LHC, effects from large $s_{ij}$ are important
  These arise in wide-angle radiation (soft and hard)
  These are treated in High Energy Jets (HEJ)

Additional tool for LHC, final aim = best bits of ALL
Why?

Higher energy at LHC \(\Rightarrow\) increased impact of hard emissions

**ATLAS W+jets, arXiv:1201.1276**

High \(H_T\): Inclusive 2j and 3j rate comparable to inclusive 1j

Relative cross sections also high:

Impact will be increased further at 8 TeV, then 14 TeV!!
How?

Amplitudes factorise in the High Energy (HE) limit:

For all partons \((i, j)\):

\[ s_{ij} = (p_i + p_j)^2 \rightarrow \infty, \]

with \(|p_\perp|\) fixed

In practice = well-separated partons
How?

Amplitudes factorise in the High Energy (HE) limit:

For all partons \((i, j)\):

\[ s_{ij} = (p_i + p_j)^2 \to \infty, \]

with \(|p_\perp|\) fixed

In practice = well-separated partons

- Includes dominant pieces of all higher loops
  \[ \alpha_s^n \log^n \left( \frac{s_{ij}}{t} \right) \]
  - Scales simply with number of partons
A HEJ Amplitude
Andersen & JMS, arXiv:0908.2786, 0910.5113

Built from:

- Two currents \( j^\mu = \bar{u} \gamma^\mu u \) (or generalisation for \( W/Z \))

- Modified Lipatov vertex: \( V^\rho(q_1, q_2) \)

- Lipatov ansatz for virtual corrections:
  \[
  = \frac{1}{t_i} \exp \left[ \hat{\alpha}(q_i)(y_{i-1} - y_i) \right], \quad \hat{\alpha} = -g_s^2 C_A \frac{\Gamma(1-\epsilon)}{(4\pi)^{2+\epsilon}} \frac{2}{\epsilon} \left( \frac{q^2}{\mu^2} \right)^\epsilon
  \]
The HEJ Event Generator
Andersen & JMS, arXiv:1101.5394

Pieces implemented in public Monte Carlo Event Generator

*Completely exclusive in final state momenta of partons*

*Flexible* enough to merge with

- LO matrix elements from MadGraph

- Parton shower (after careful treatment of overlap)
  - First implementation with Ariadne \cite{Andersen:2011ga}
  - Work in progress with authors of Sherpa, Pythia, Herwig++

HEJ & HEJ+Ariadne available for jets: [www.cern.ch/hej](http://www.cern.ch/hej)
CMS Analysis: One Central + One Forward Jet

**arXiv:1202.0704**

**Described pretty well**

**Forward jet $p_T$**

J.M.Smillie, Edinburgh High Energy Jets

**DIS 2012**
CMS Analysis: One Central + One Forward Jet

\textit{arXiv:1202.0704}

Central jet $p_T$

Small rapidity separation not described well

HEJ still good agreement
ATLAS Analysis: Gap Fraction/Jet Veto Analysis

\[ \text{Gap Fraction} = \frac{\text{no jets in gap}}{2j \text{ inclusive}} \]

\[ \bar{p}_T = \text{average } p_T \text{ of tagging jets} \]

Here, tagging jets are most forward and most backward.

Good agreement with \text{POWHEG+PYTHIA} and HEJ
ATLAS Analysis: Gap Fraction/Jet Veto Analysis
arXiv:1107.1641

Here tagging jets are leading $p_T$

Two visible drivers of radiation:

1. Hierarchy in $p_T$ (up to factor 10!)

systematic $p_T$ evolution not included (yet!) in HEJ:
description poor, but understood

2. Evolution in rapidity

HEJ description good,
POWHEG undershoots
Dijet Comparison of HEJ and POWHEG
Alioli, Andersen, Oleari, Re, JMS, arXiv:1202.1475

Have seen POWHEG and HEJ can give similar predictions. Can the descriptions be distinguished?

\[ p_{T,j} > 35 \text{ GeV}, \ p_{T,j_1} > 45 \text{ GeV}, \ |y_j| < 4.7 \]

- Cuts here do not induce \( p_T \) hierarchy
- Average number of jets more sensitive to 4j, 5j,...
Dijet Comparison of HEJ and POWHEG
Alioli, Andersen, Oleari, Re, JMS, arXiv:1202.1475

Other variables show little difference, e.g. \( \cos \phi_{fb} \),
\( \phi_{fb} = \) azimuthal angle between most forward and most backward jet

Azimuthal decorrelation gives measure of additional radiation
(deviation from back-to-back)
Summary

- Jets important across LHC physics programme
  Are our theoretical descriptions adequate at LHC?

- High Energy Jets resums contributions from wide-angle radiation, publicly available as fully-flexible Monte Carlo

- These contributions have \textit{already} been seen in early data!

- New parton shower releases coming soon!

- Also relevant for $W$, $Z$, $H+\text{jets}$ and beyond. See
  - Les Houches proceedings
  - Work in progress with Andersen, Maître, Winter