Elucidating Jet Energy Loss Using Jets: Prospects from ATLAS

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Outline:

- With full electromagnetic and hadronic calorimetry ATLAS will directly measure jets event-by-event.
- Jets offer new handles to reduce energy-loss bias.
- New variables using full jet measurements have sensitivity to unexplored aspects of energy loss.
The ATLAS Detector

Full azimuthal acceptance

Muons

0.2x0.2

0.1x0.1

0.1x0.1

0.2x0.2

0.2x0.2

0.1x0.1

0.05x0.025

0.025x0.025

0.003x0.1

M. Rosati 4A #1

η

Tracking in 2T solenoid

Muon ID

Nathan Grau
The ATLAS Detector

Full azimuthal acceptance

Muon Spectrometer

Tracking in 2T solenoid

Muon ID

M. Rosati 4A #1

M. Baker 3C #5

Photons

\( \eta \)
The ATLAS Detector

Full azimuthal acceptance

Muon Spectrometer

Inner Detector

FCAL LAr Hadronic Tile LAr HAD FCAL
0.2x0.2 0.1x0.1 0.1x0.1 0.2x0.2

LAr EM
0.2x0.2

0.05x0.025

0.25x0.025

0.003x0.1

0.1x0.1

ZDC EM ZDC HAD ZDC EM ZDC HAD

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Photons

\( \eta \)

Tracking in 2T solenoid

Muon ID

Jets

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The ATLAS Detector

100 GeV jet depositing energy

Muon Spectrometer

Full azimuthal acceptance

Tracking in 2T solenoid

Muon ID

M. Rosati 4A #1

M. Baker 3C #5

Photons

Jets
Cone Jet Reconstruction: Overview

General features of a cone algorithm

1. Choose a position
2. Sum 4-momentum of particles/towers in a fixed cone in $\eta-\phi$
3. Repeat step 2 with the 4-momentum sum as new position. **Iterate** until convergence.
4. Split or merge jets based on fraction of cone overlap

68 GeV jet

**Iterate**
Cone Jet Reconstruction: Overview

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### Parameters
- Seed $p_T$ - initial positions
- $R$ - cone radius
- Convergence/Overlap

### Potential Bias
- Leading particle bias a la RHIC
- Out of cone radiation
- Non-cone structures, hard radiation
Cone Jet Reconstruction: HI Events

- Calorimeter energy in 0.1x0.1 towers

- Embed full PYTHIA di-jet events into HIJING events at 5.5 TeV

- Subtract underlying event pedestal
  - event-by-event
  - layer-by-layer
  - $\eta$ dependent

NG QM ‘08 Plenary
Differential Studies of Jet $R_{AA}$

Vitev, Wicks, and Zhang JHEP 11 (2008) 093

$R_{AA}^{jet} = \frac{Pb + Pb \text{ Jet Yield}}{\langle N_{coll} \rangle p + p \text{ Jet Yield}}$

- All energy lost is recovered: $R_{AA}^{jet} = 1$
- Out of cone radiation will reduce $R_{AA}^{jet}$
- Measurable by measuring jets with different $R$

$R_{max} = R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$

$R_{max} = 2.0$, $R_{max} = 1.0$, $R_{max} = 0.7$, $R_{max} = 0.4$, $R_{max} = 0.2$

$E_T (GeV)$

$R_{AA}$ vs $E_T$ (GeV)

$R_{jet} = \frac{Pb + Pb \text{ Jet Yield}}{\langle N_{coll} \rangle p + p \text{ Jet Yield}}$
ATLAS Sensitivity for Jet $R_{AA}$

- Ratio $\sim 20\%$
- Will be sensitive to this level of effects from perturbative energy loss on $R_{AA}^{jet}$

Reconstructed spectrum uncorrected for efficiency and energy resolution
Jet Shapes

\[ \Psi(r, R) = \frac{\int_{0}^{R} dE_T}{\int_{0}^{R} d\rho} \]

Integral

\[ \psi(r, R) = \frac{d\Psi}{dr} \]

Differential

Comparison to PYTHIA
Red dotted - gluon
Blue dashed - quark

CDF Collaboration PRD 71 (2005) 112002
Jet Shapes in ATLAS

Integral

Differential

ATLAS Preliminary

Not Embedded

E_{T}>70 \text{ GeV}

Integral and Differential jet shapes in PYTHIA and PYQUEN

Energy loss modifies these distributions

- Energy transferred from center to periphery of the jet
Fragmentation Functions: $D(z)$

- High momentum fragments lose energy and are measured at low $z$.

Armesto, et al. JHEP 02 (2008b) 48
Fragmentation Functions: $D(z)$

- Extrapolate reconstructed tracks to match jets in the calorimeter.
- Cut on $p_T > 2$ GeV.
- Lower $p_T$ cut sensitive to recovered energy but has more background.
- Background from tracks in underlying HIJING event not associated with the jet.

Reliable reconstruction of $D(z)$ before any corrections to the reconstructed spectrum.

ATLAS Preliminary

NG QM '08 Plenary
ATLAS Sensitivity to D(z) Modification

- Compare reconstructed PYTHIA and PYQUEN jets
- Modification from PYQUEN is apparent
- Well within ATLAS ability to measure before corrections.

Recall: Embedding doesn’t modify fragmentation function appreciably

M. Spousta High $p_T$ @ LHC ‘09
Summary

- Jets offer more handles and variables to study energy loss than single and di-hadron measurements
- Differential studies of jet $R_{AA}$, jet shapes, $D(z)$ (and many others) will be sensitive to different aspects of energy loss
- Energy loss models will be rigorously tested when required to reproduce these various results.
Backup
Cone Jet Reconstruction: Embedding

-0.5<φ<-1.5

Calorimeter energy in 0.1x0.1 towers

- Pythia di-jets embedded in unquenched HIJING
  - Lots of correlations: Mini-jets, c-cbar, b-bbar, longitudinal strings, etc.

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Cone Jet Reconstruction: Subtraction

-0.5<φ<-1.5

Remove <E_T> layer-by-layer and vs. η

Calorimeter energy in 0.1x0.1 towers
Cone Jet Reconstruction: Jets

- Use Seed $E_T = 5$ GeV, $R=0.4$ split/merge fraction = 50%
- Reliably reconstruct the input jets

Calorimeter energy in 0.1x0.1 towers

[Diagram showing 3D distribution of $E_T$ vs $\phi$ and $\eta$]
Cone Jet Reconstruction Performance

ATLAS Preliminary

ATLAS Preliminary

ATLAS Preliminary

ATLAS Preliminary

ATLAS Preliminary

ATLAS Preliminary

ATLAS Preliminary

ATLAS Preliminary
Heavy Flavor Tagging with Muons

- Correlate a high-\(p_T\) (5 GeV) muon with a reconstructed jet
- \(\Delta \phi = 0\) tagged same jet
- \(\Delta \phi \sim \pi\) tagged recoil jet
Heavy Flavor Tagging with Muons

- Efficiency of tagging a bottom jet based on the $\Delta \phi$ between the jet and muon: 80%
- Purity of heavy flavors with a muon tag: 70%
ATLAS Level 1 Calorimeter Triggers

- HI rate doesn’t require rejection at Level1
- ATLAS requires trigger at Level1 to define a Region of Interest (RoI) to be processed at Level2
ATLAS Level 1 Calorimeter Triggers

- **eγ**
  - 0.1x0.2($\Delta \eta \times \Delta \phi$) EM > threshold
  - 0.2x0.2 hadronic core < threshold

- **tau/hadron**
  - 0.1x0.2 EM+hadronic > threshold

- **Jet trigger**
  - EM+hadronic 0.4x0.4 > threshold
  - 4 available thresholds
  - (No subtraction at Level1 is possible)
ATLAS HI Jet Trigger

- Set jet threshold based on total $E_T$ at Level 1.
- Combine $e\gamma+\tau+\text{jet}$
- Jet identification efficiency $\sim 95\%$ down to 40 GeV independent of centrality
- First attempt: improvement after further study is expected

M. Rybar High $p_T$ @ LHC ‘09