Jet Quenching Measurements with ATLAS at LHC

Will Brooks for the ATLAS Collaboration

VIII Latin American Symposium on Nuclear Physics and Applications Santiago de Chile, December 2009
• Jet quenching: context
• Introduction to ATLAS
• Survey of ATLAS heavy-ion program
• Jet suppression physics
• Conclusion
The Relativistic Heavy Ion Collider (RHIC/BNL) has discovered a *new state of matter* in heavy ion collisions.

Experimental evidence indicates it is a hot, dense, strongly interacting system that behaves as a liquid with ultra-low viscosity.

The most compelling evidence that a super-dense medium is formed is *jet quenching* - the disappearance of one of the jets in high-$p_T$ two-jet events.

The phenomenon is qualitatively understood, but a number of puzzles remain.

The study of jet quenching in heavy ion collisions at LHC offers many new possibilities:

- Much wider kinematic range and larger cross sections
- Well-defined jets
- Heavy quark jets
Introduction to the ATLAS Experiment
The Large Hadron Collider is a 27 km long collider ring housed in a tunnel about 100 m underground near Geneva.
The ATLAS Experiment

The ATLAS Collaboration and G Aad et al 2008 JINST 3 S08003

2700 collaborators (700 students)
7000 tons, 22 m diameter, 46 m long
Superconducting solenoid and toroid magnets
88 million detector channels
550 M CF
ATLAS Physics Programme

- B Physics
- Exotics
- Heavy Ions
- Higgs
- Standard Model
- SUSY
- Top Quark Physics

ATLAS Collaboration,
Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics,
Reminder:
$$\eta = 3 \iff \theta \sim 0.1^\circ$$
$$\eta = 5 \iff \theta \sim 0.001^\circ$$
ATLAS Detector Status

<table>
<thead>
<tr>
<th>Subdetector</th>
<th>Number of Channels</th>
<th>Approximate Operational Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixels</td>
<td>80 M</td>
<td>98.0%</td>
</tr>
<tr>
<td>SCT Silicon Strips</td>
<td>6.3 M</td>
<td>99.3%</td>
</tr>
<tr>
<td>TRT Transition Radiation Tracker</td>
<td>350 k</td>
<td>98.2%</td>
</tr>
<tr>
<td>LAr EM Calorimeter</td>
<td>170 k</td>
<td>98.8%</td>
</tr>
<tr>
<td>Tile calorimeter</td>
<td>9800</td>
<td>99.5%</td>
</tr>
<tr>
<td>Hadronic endcap LAr calorimeter</td>
<td>5600</td>
<td>99.9%</td>
</tr>
<tr>
<td>Forward LAr calorimeter</td>
<td>3500</td>
<td>100%</td>
</tr>
<tr>
<td>MDT Muon Drift Tubes</td>
<td>350 k</td>
<td>99.7%</td>
</tr>
<tr>
<td>CSC Cathode Strip Chambers</td>
<td>31 k</td>
<td>98.4%</td>
</tr>
<tr>
<td>RPC Barrel Muon Trigger</td>
<td>370 k</td>
<td>&gt;97%</td>
</tr>
<tr>
<td>TGC Endcap Muon Trigger</td>
<td>320 k</td>
<td>99.8%</td>
</tr>
<tr>
<td>LVL1 Calo trigger</td>
<td>7160</td>
<td>99.8%</td>
</tr>
</tbody>
</table>

Operational fraction as of 28 September 2009

ATLAS:
CHANNEL COUNT, READINESS
A jet event in ATLAS from this week!

Friday, December 18, 2009
The ATLAS Heavy-ion Program
First Year’s Pb-Pb Collision Data

• Baseline measurements for 2010 HI run:
  • RHIC data at $E_{CM} = 200$ GeV
  • ATLAS p-p data ($E_{CM} = 7$ TeV $\rightarrow 14$ TeV)
• For HI, $E_{CM} = 2.75$ TeV $\rightarrow 5.5$ TeV (per nucleon)
• Factor of up to 30 increase in energy means basic features are unknown; focus on:
  • Global properties of collisions
  • Quarkonia
  • Hard probes

Measurement of impact parameter

Estimate impact parameter, number of collision participants, number of collisions via total energy in calorimeters
Extrapolations of energy dependence of multiplicity

P. Steinberg, Nuclear Physics A 827 (2009) 128c–136c
Global Event Properties

ATLAS Preliminary

$\frac{dN}{d\eta}$

Pixel hits in **first**, **second**, and **third** layers independently determine $dN_{\text{charged}}/d\eta$

$b=2.3 \text{ fm}$

Pb-Pb collisions

5.5 TeV/nucleon

Multiplicity reconstruction from pixel cluster for a single HIJING event

A. Truzpek, ATL-PHYS-PROC-2009-090

Friday, December 18, 2009
Global Event Properties

Sum over EM and hadronic calorimeter cells

Good event-by-event measure of $E_T$

Single event reconstruction of Transverse energy vs pseudorapidity

ATLAS Preliminary

- $b=2.3$ fm
- Pb-Pb collisions
- 5.5 TeV/nucleon
- Red points are reconstructed
Elliptic Flow

Asymmetry of particle emission relative to the event plane
Elliptic Flow

Asymmetry of particle emission relative to the event plane

\[ \cos(2(\phi - \Psi)) \]
Elliptic Flow

Asymmetry of particle emission relative to the event plane

\[ \frac{dN}{d(\phi - \Psi)} = N_0 (1 + 2v_1 \cos (\phi - \Psi) + 2v_2 \cos (2(\phi - \Psi)) + \ldots) \]
Elliptic Flow

Asymmetry of particle emission relative to the event plane

Three separate reconstruction methods give similar results

\[
dN/d(\phi - \Psi) = N_0 \left( 1 + 2v_1 \cos(\phi - \Psi) + 2v_2 \cos(2(\phi - \Psi)) + \ldots \right)
\]
Test predictions that different quarkonium states disassociate at different plasma temperatures.

Good rate, good mass resolution - can study color screening through Upsilon and J/Ψ suppression.

J. Dolejší, Nucl. Phys, A 830 (2009) 89c
Inclusive Jet Reconstruction

Method requires subtraction of background from underlying heavy ion event

Calorimeter energy in 0.1x0.1 towers

Feasible to extract accurate fragmentation functions

Can extract jet quenching if it is of the size given by Pyquen

N. Grau, ATL-PHYS-PROC-2009-046.pdf
Simulated gamma jet correlations

- Well-correlated $\gamma\gamma\gamma$'s and jets for $\gamma$-$\gamma$ physics
- Can vary jet quality cuts and use $\gamma$-$\gamma$-jet correlation to confirm our understanding of jet reconstruction.

Tight jet quality cuts
Loose jet quality cuts

Tight jet quality cuts
Loose jet quality cuts

See also: Nathan Grau et al. in session 6A on Friday

Direct photons, Gamma-Jet Correlations

The excellent ATLAS calorimetry permits good neutral hadron rejection

Clean $\gamma$-jet signal ideal for jet suppression studies

**Heavy Quark Jet Suppression**

\[
R_{AA} = \frac{1}{N_{\text{coll}}} \frac{dN}{dp_T}|_{AA} \frac{dN}{dp_T}|_{pp}
\]

- Naive radiative energy loss picture predicts minimal suppression of heavy quarks
- Radiation and collisional losses in 2 and 3-body interactions provide only partial explanation
- This puzzle can be probed at LHC with much higher \( p_T \), better statistics, and potentially with directly identified heavy mesons


Ko and Liu, Nuclear Physics A 783 (2007) 233c–240c
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Ko and Liu, Nuclear Physics A 783 (2007) 233c–240c
Heavy Quark Jets via 
Muon-Tagging in ATLAS

- Semi-leptonic decay of heavy quarks can be tagged by muons
- Clean environment in standalone muon system, trigger by single/double tracks
- High purity for muon $E_T$ above ~50 GeV

Purity vs $E_T^{\text{truth}}$ (GeV) for b jets and b+c jets.
Conclusions

• Exciting physics program for heavy ions with ATLAS
• ATLAS instrumentation is ideal for measuring jet quenching
• Methods of global event characterization are understood; ready for first data
• Heavy-quark jet quenching may yield new insights