Global Variables in Heavy Ion Collisions at the LHC using the ATLAS Detector

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for the ATLAS Collaboration

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Jaipur, India
“Global Variables”

Charged-particle Multiplicity & Spectra

Transverse Energy

Elliptic Flow
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<th>Nuclear PDFs</th>
<th>Experimental Observable</th>
<th>Theoretical Tools</th>
<th>Physics</th>
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<td>Hard Processes</td>
<td>Particle multiplicities, monojets</td>
<td>Color Glass Condensate (Parton Saturation)</td>
<td>High-density pQCD</td>
</tr>
<tr>
<td>(non-) Ideal Hydrodynamics</td>
<td>Jets, Photons, Heavy Quarks &amp; Onia, Z&amp;W</td>
<td>pQCD</td>
<td>QCD in medium</td>
</tr>
<tr>
<td>Hadron Freezeout</td>
<td>$\frac{d^3N}{d\eta d\phi dp_T}$</td>
<td>3+1D Hydro Initial conditions</td>
<td>Equation of State (Degrees of Freedom)</td>
</tr>
<tr>
<td></td>
<td>Particle yields, correlations, fluctuations</td>
<td>Statistical models, Cluster models</td>
<td>Hadronization</td>
</tr>
</tbody>
</table>

Global variables provide access to full range of evolution history
“Day 1” @ the LHC

• **Global variables are really “day 1” physics in Pb+Pb**
  • up to 2M events/day @ 50Hz
  • Within a few days we will have data to test extrapolations of RHIC data

• **Of course, there is another “day 1” coming first**
  • p+p data will start becoming available in Summer 2008
  • Major preparation for data taking, trigger, and analysis underway

• **Expect Pb+Pb day 1 in 2009 or 2010, depending on performance**

The ATLAS Detector @ LHC
ATLAS Acceptance

Unprecedented acceptance for tracking, longitudinally-segmented calorimetry (6 layers + presampler)
Forward detectors in beamline extend far out in eta
Forward Physics Detectors

LUCID ($5 < |\eta| < 6$)
Stage 1: $5.6 < |\eta| < 6$

ZDC

Roman pots
ATLAS ZDC

π² → γγ

η → γγ

η' → γγ

M(γγ), MeV

ZDC installation
ATLAS TAN
Jan 2008

Fast simulation of ZDC & FCAL
Centrality Selection

Multiple variables correlate with event centrality

Total energy in FCAL, EM, Tile from HIJING

Multiple variables correlate with event centrality
Resolution on Centrality Parameters

High multiplicities enable precise centrality estimation -- triggered fraction of cross section will be dominant uncertainty
Energy Evolution of Multiplicities (p+p & A+A)

Log linear rise is suggested by existing A+A (not p+p!) data, CGC is preferred by theory, Landau may be relevant -- LHC is the test
ATLAS Acceptance for Global Variables

Rest frame of projectile clearly important for RHIC physics: ATLAS overlaps RHIC with forward detectors

![Graph showing dN/dη/⟨N_{part}/2⟩ for different conditions](image)
June 2007: Lowering the ATLAS pixel detector into the pit
Estimating Multiplicity with Silicon Hits

Pixel detector covers $|\eta|<2.5$

Particle density can be reconstructed event-by-event (with $\eta$-dependent corrections)
dN/d\eta from Pixel Tracklets

3-point tracks, including event vertex from high p_T tracks

“Tracklets” are another way to do event-by-event estimation of density: additional redundancy
ATLAS Calorimetry
Measuring Transverse Energy

Hermetic coverage allows reconstruction of total transverse energy out to $\eta=5$, both integrated and differentially, event-by-event.
The question of “minijets”

At RHIC, many expect particle production and energy from hard & semi-hard processes that scale with \( N_{\text{coll}} \).

Should be extreme at LHC (cf. HIJING)

If so, the centrality dependence of \( N_{\text{ch}} \) and \( E_T \) will definitively test “two-component model” (hard + soft)

→ hard physics should dominate at LHC
Centrality Evolution of Multiplicity and $E_T$

A great "day 1" topic at the LHC!
Charged particle tracking in Inner Detector

- 11 space points in silicon: 3 pixel, 8 SCT
- TRT useful for p+p, ~90% occupied for Pb+Pb
- Low $p_T$ tracks do not curl up in tracker

![Graph showing efficiency vs $p_T$](image)
Particle tracking works out to high $p_T$ (ATLAS is designed for TeV physics)

Fake rate at very high $p_T$ can be controlled by requiring correlation with calorimeters
Energy evolution of elliptic flow ($v_2$)

$w_2 \propto \log(s)$?

$v_2 \propto dN/d\eta$ and $E_T$?

"hydrodynamic limit"?

Scaling with eccentricity and particle density?

Multiplicity $\times 2-3$ @ LHC!
Event plane estimation & resolution

Event plane estimated with silicon hits, calorimeter towers, or full tracks

\[ \Psi_n = \frac{1}{n} \tan^{-1} \left( \frac{\sum w_i \sin(n\varphi_i)}{\sum w_i \cos(n\varphi_i)} \right) \]

Resolution from subevents: \( R \equiv \left\langle \cos[n(\Psi_n^N - \Phi_{RP})] \right\rangle = \left\langle \cos[n(\Psi_n^P - \Phi_{RP})] \right\rangle = \sqrt{\left\langle \cos[n(\Psi_n^N - \Psi_n^P)] \right\rangle} \)

<table>
<thead>
<tr>
<th>Sub-system</th>
<th>( \eta ) coverage for sub-events</th>
<th>Resolution correction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( b = 10 - 12 \text{ fm} )</td>
</tr>
<tr>
<td>EM-Barell1</td>
<td>0.2 &lt; (</td>
<td>\eta</td>
</tr>
<tr>
<td>EM-EndCaps</td>
<td>1.5 &lt; (</td>
<td>\eta</td>
</tr>
<tr>
<td>HAD-EndCaps</td>
<td>1.6 &lt; (</td>
<td>\eta</td>
</tr>
<tr>
<td>FCAL0</td>
<td>3.1 &lt; (</td>
<td>\eta</td>
</tr>
<tr>
<td>Pixel, 1st layer</td>
<td>0.2 &lt; (</td>
<td>\eta</td>
</tr>
<tr>
<td>SCT, 1st layer</td>
<td>0.2 &lt; (</td>
<td>\eta</td>
</tr>
<tr>
<td>Reconstructed tracks</td>
<td>0.2 &lt; (</td>
<td>\eta</td>
</tr>
</tbody>
</table>
Estimation of $v_2$

**Table 5.1: Resolution corrections calculated for di-**

<table>
<thead>
<tr>
<th>Method</th>
<th>$v_2^{\text{rec}}$</th>
<th>$v_2^{\text{rec}} / v_2^{\text{true}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>pixel clusters ($\varphi$)</td>
<td>0.018 ± 0.003</td>
<td>0.60 ± 0.10</td>
</tr>
<tr>
<td>FCAL0 ($\Psi_2$)</td>
<td>0.034 ± 0.002</td>
<td>0.68 ± 0.04</td>
</tr>
<tr>
<td>tracks ($\varphi$)</td>
<td>0.070 ± 0.002</td>
<td>0.70 ± 0.02</td>
</tr>
<tr>
<td>FCAL0 ($\Psi_2$)</td>
<td>0.60 ± 0.10</td>
<td>0.68 ± 0.04</td>
</tr>
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</table>

**Table 5.2: Resolution corrected reconstructed flow signal from this analysis,**

<table>
<thead>
<tr>
<th>Method</th>
<th>$v_2^{\text{rec}}$</th>
<th>$v_2^{\text{rec}} / v_2^{\text{true}}$</th>
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</tr>
</tbody>
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30-40% suppression of $v_2$ reduced with tracks
Elliptic Flow vs. $p_T$

\[ v_2 \text{ vs. } p_T \]

- $b=2.3 \text{ fm}$
- $b=7 \text{ fm}$
- $b=10.7 \text{ fm}$

In addition to reaction plane method, 2P correlations with measured tracks

$\Delta \phi [\text{rad}]$

$C(\Delta \phi)$

$\Delta \phi$ [rad]
Experimental Outlook: day-1 p+p & Pb+Pb

• **Day 1 physics with Pb+Pb in ATLAS**
  • Charged multiplicity & spectra, transverse energy, elliptic flow
  • Testing simple extrapolations of RHIC data
  • *Anything we measures will contribute to understanding of A+A*

• **LHC is preparing for a Summer 2008 startup for p+p**
  • ATLAS commissioning of full detector is full swing!
  • Detector will be calibrated by Day 1 Pb+Pb
  • First measurements with p+p to tune models & expectations

• **Pb+Pb effort strong and growing within ATLAS**
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\textsuperscript{11}Yale University, USA
Trigger & Event Selection

- Heavy ion triggering schemes being developed in tandem with minimum-bias p+p effort

- Day-1 triggering strategies
  - Random + space-point cut + track trigger - minimal bias, while rejecting empty events (less useful beyond day-1 A+A)
  - Minimum Bias Trigger Scintillators - installed at 2.12<|\eta|<3.85 (very useful - limited scintillator lifetime)

- Calorimeter event trigger limited by readout noise
  - With thresholding, can reliably trigger on 85% of total inelastic cross section
## p+p conditions

<table>
<thead>
<tr>
<th>( k_b )</th>
<th>N</th>
<th>( \beta^* )</th>
<th>Luminosity</th>
<th>Events/BC</th>
<th>P(0)</th>
<th>P(1)</th>
<th>P(&gt; 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( 10^{10} )</td>
<td>18</td>
<td>( 10^{27} )</td>
<td>&lt; 1</td>
<td>0.99</td>
<td>0.01</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>43</td>
<td>( 10^{10} )</td>
<td>18</td>
<td>( 4 \cdot 10^{28} )</td>
<td>&lt; 1</td>
<td>0.99</td>
<td>0.01</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>43</td>
<td>( 4 \cdot 10^{10} )</td>
<td>18</td>
<td>( 2 \cdot 10^{29} )</td>
<td>&lt; 1</td>
<td>0.99</td>
<td>0.01</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>43</td>
<td>( 4 \cdot 10^{10} )</td>
<td>2</td>
<td>( 6 \cdot 10^{30} )</td>
<td>0.76</td>
<td>0.47</td>
<td>0.36</td>
<td>0.18</td>
</tr>
<tr>
<td>156</td>
<td>( 4 \cdot 10^{10} )</td>
<td>2</td>
<td>( 2 \cdot 10^{31} )</td>
<td>0.76</td>
<td>0.47</td>
<td>0.36</td>
<td>0.18</td>
</tr>
<tr>
<td>156</td>
<td>( 9 \cdot 10^{10} )</td>
<td>2</td>
<td>( 10^{32} )</td>
<td>3.9</td>
<td>0.03</td>
<td>0.10</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Table 3: Beam Parameters for the Stage 1 Physics Run in 2008.

<table>
<thead>
<tr>
<th>Cut on SCT spacepoints</th>
<th>Trigger Efficiency in %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Empty events</td>
<td>23.0</td>
</tr>
<tr>
<td>Minimum bias (non-diff.)</td>
<td>99.5</td>
</tr>
<tr>
<td>Single-diffractive</td>
<td>53</td>
</tr>
<tr>
<td>Double-diffractive</td>
<td>57.3</td>
</tr>
<tr>
<td>Beam-gas</td>
<td>77.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>MBTS_1</th>
<th>MBTS_2</th>
<th>2-track</th>
<th>5-track</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-diffractive</td>
<td>99%</td>
<td>100%</td>
<td>99%</td>
<td>93%</td>
</tr>
<tr>
<td>Double-diffractive</td>
<td>54%</td>
<td>82%</td>
<td>44%</td>
<td>2%</td>
</tr>
<tr>
<td>Single-diffractive</td>
<td>45%</td>
<td>68%</td>
<td>47%</td>
<td>5%</td>
</tr>
</tbody>
</table>

Random triggers w/ SCT spacepoint cut

MBTS hits, e.g. 1 hit on each side, with cut on number of tracks
Tracking in p+p

Multiple algorithms now support tracking below $p_T=300$ MeV.

Pattern recognition difficult in Pb+Pb (esp. memory usage) but not a limitation of detector or tracking algorithms (just the current software!)
Estimating reaction plane @ ATLAS

Correlation with true reaction plane

ATLAS provides a large distinct set of measurables to estimate reaction plane

\[ \Psi_n = \frac{1}{n} \tan^{-1} \left( \frac{\sum w_i \sin(n \varphi_i)}{\sum w_i \cos(n \varphi_i)} \right) \].