Jet reconstruction in ALICE using the EMCal

Christine Nattrass (University of Tennessee at Knoxville) for ALICE
Motivation: Full jet reconstruction

- **p+p**
  - Tests of pQCD calculations
  - Measurements of momentum distributions of jet fragments
  - Baseline for A+A
- **A+A**
  - Measurement of partonic energy loss
  - Look for modification of fragmentation
  - Enables studies of energy loss at a partonic level
Challenges

- Background subtraction
  - p+p: pile-up, underlying event
  - A+A: background
    - Simulations are not a good description of background
    - Subject to event-by-event fluctuations

- Multiple algorithms
  - Must compare theoretical and experimental results using the same algorithm
  - Trade-offs between CPU requirements and infrared safety

- Experimental biases
  - Triggering
  - Tracking inefficiency
  - Energy resolution
  - $p_T$ cuts in tracking and calorimetry
  - Edge effects
  - Unobserved particles (i.e., neutrons, $K^0_L$)
The Large Hadron Collider
Size: 16 x 26 meters
Weight: 10,000 tons
Detectors: 18
EMCal

Current coverage:
$\Delta \eta = 1.4, \Delta \phi = 39^\circ$ (R$\approx$0.3 max)
Full calorimeter installation during the next long shut down
• Planned for 2012
• May be possible in 2011

- Lead-scintillator sampling calorimeter
- 13 k towers
- Each tower $\Delta \eta \times \Delta \phi = 0.014 \times 0.014$
- Shashlik geometry
- Avalanche photodiodes
- Full coverage: $\Delta \eta = 1.4, \Delta \phi = 107^\circ$
- $\sigma(E)/E = 0.12/\sqrt{E} + 0.02$
- High level triggering $\rightarrow$ jet patch trigger
Jet reconstruction algorithms

Sequential recombination:
Cluster pairs of objects close in relative $p_T$

4. $K_T$ (starting point: low $p_T$ particles)
5. Anti-$K_T$ (starting point: high $p_T$ particles)

$R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2}$

Cone Algorithm:
1. Mid Point Cone: Merging & Splitting
2. SIS CONE
   - Insensitive to "soft" radiation
   - Splitting doesn't change jets
3. Leading Order High Seed Cone (LOHSC)


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ALICE hard physics capabilities:

- Electron/hadron discrimination (TRD, EMCal)
- $\mu$ measurements (forward muon arm)
- Good $\gamma/\pi^0$ discrimination (EMCal, PHOS)
- Fast trigger on jets (EMCal)

Hard Probes statistics in ALICE:

$10^4$/year minbias Pb+Pb at nominal luminosity*

- Inclusive jets: $E_T \sim 200$ GeV
- Dijets: $E_T \sim 170$ GeV
- $\pi^0$: $p_T \sim 75$ GeV/c
- Inclusive $\gamma$: $p_T \sim 45$ GeV/c
- Inclusive e: $p_T \sim 30$ GeV/c

*One year of running = one month of Pb+Pb collisions
ALICE EMCal Jet Trigger

Gain for jets with $p_T > 100$ GeV/c

<table>
<thead>
<tr>
<th>System</th>
<th>$\sqrt{s}$ (TeV)</th>
<th>$L_{\text{mean}}$ ($cm^{-2}s^{-1}$)</th>
<th>Time (s)</th>
<th>DAQ rate (Hz)</th>
<th>Gain at L1</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-p</td>
<td>5.5</td>
<td>$5 \times 10^{30}$</td>
<td>$10^5$</td>
<td>500</td>
<td>110</td>
</tr>
<tr>
<td>p-p</td>
<td>14</td>
<td>$5 \times 10^{30}$</td>
<td>$10^7$</td>
<td>500</td>
<td>500</td>
</tr>
</tbody>
</table>

Pb–Pb Centrality

<table>
<thead>
<tr>
<th>Centrality</th>
<th>$\sqrt{s}$ (TeV)</th>
<th>$L_{\text{mean}}$ ($cm^{-2}s^{-1}$)</th>
<th>Time (s)</th>
<th>DAQ rate (Hz)</th>
<th>Gain at L1</th>
</tr>
</thead>
<tbody>
<tr>
<td>min. bias</td>
<td>5.5</td>
<td>$5 \times 10^{26}$</td>
<td>$10^6$</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>min. bias</td>
<td>5.5</td>
<td>$5 \times 10^{26}$</td>
<td>$10^6$</td>
<td>50</td>
<td>9</td>
</tr>
<tr>
<td>min. bias</td>
<td>5.5</td>
<td>$5 \times 10^{26}$</td>
<td>$10^6$</td>
<td>100</td>
<td>4</td>
</tr>
<tr>
<td>0–10%</td>
<td>5.5</td>
<td>$5 \times 10^{26}$</td>
<td>$10^6$</td>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>0–10%</td>
<td>5.5</td>
<td>$5 \times 10^{26}$</td>
<td>$10^6$</td>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>60–80%</td>
<td>5.5</td>
<td>$5 \times 10^{26}$</td>
<td>$10^6$</td>
<td>50</td>
<td>12</td>
</tr>
<tr>
<td>60–80%</td>
<td>5.5</td>
<td>$5 \times 10^{26}$</td>
<td>$10^6$</td>
<td>100</td>
<td>6</td>
</tr>
</tbody>
</table>

• Based on the simulation results presented in this chapter we find that in order to correct for the trigger bias and recover the full inclusive jet cross sections from the triggered samples with a 5% systematic uncertainty, ALICE will need to record statistics of 25 M minimum bias p–p events and 2 M minimum bias Pb–Pb events. This can be easily accommodated within the ALICE DAQ bandwidth by downscaled minimum bias triggers.
Inclusive spectra

$p+p \sqrt{s}=5.5$ TeV
Anti-$k_T$ $R=0.4$
3 pb$^{-1}$

$Pb+Pb \sqrt{s}_{NN}=5.5$ TeV
10% Central
0.5 nb$^{-1}$

Anti-$k_T$ $R=0.4$
$\hat{q}=17$ GeV$^2$/fm

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R_{AA} : From RHIC to the LHC

- Much greater kinematic reach at the LHC
- Smaller systematic errors
- Comparison between RHIC and LHC: studies of partonic energy loss at different regions on the phase diagram
Jet broadening

- QPYTHIA not optimized (yet) – do not draw conclusions from shape differences
- Jet energy profile (Au+Au data) BROADENED indicating JET QUENCHING
- Small experimental systematic uncertainties in measurements (ratios from same data set) → a precision measurement in ALICE
Conclusions

- With the EMCal fully installed ALICE will be able to measure
  - Jet spectra to \( \sim 200 \) GeV
  - \( R_{AA} \) for jets
  - Modified fragmentation/jet broadening
- Measurements are enhanced by EMCal triggering capabilities

Thank you!

See Yaxian Mao's talk Wednesday for more on jet physics in ALICE
EMCal Assembly

- 3072 identical modules, 2x2 towers
- $1.5^\circ$ taper in $\eta$
- Tower granularity $\delta \eta = \delta \phi = 0.014$
- $20.1 \ X_0$
- 77 layers Pb:Sc = 1.44 : 1.76 mm
### Table: Systematic Uncertainties

<table>
<thead>
<tr>
<th>Systematic effect</th>
<th>Incl. cross section sys. uncert.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Common in p+p and A+A</strong></td>
<td></td>
</tr>
<tr>
<td>Tracking distortions (space charge etc.)</td>
<td>unknown</td>
</tr>
<tr>
<td>Tracking efficiency</td>
<td>1%</td>
</tr>
<tr>
<td>Hadronic and electron energy double counting</td>
<td>3-4%</td>
</tr>
<tr>
<td>EMCal energy scale</td>
<td>8-10%</td>
</tr>
<tr>
<td>Unobserved neutral energy</td>
<td>13-15%</td>
</tr>
<tr>
<td><strong>Underlying event (central Pb–Pb)</strong></td>
<td></td>
</tr>
<tr>
<td>Fluctuations</td>
<td>20% (75 GeV/c), 3% (150 GeV/c)</td>
</tr>
<tr>
<td>False Jets</td>
<td>small (&gt;50 GeV/c)</td>
</tr>
</tbody>
</table>