Calorimetry for Global Event Characterization in PHENIX

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\[ \frac{dE_t}{d\eta} (\eta = 0) \]

- PHENIX \[ \frac{dE_t}{d\eta} (\eta = 0) \] vs. participant#
- EMCal Design and Performance
- Forward Detectors and Collision Geometry
- Results

*See also: G. David, A. Milov, A. Denisov and A. Bazilevsky, H. Torii (poster)
Energy Flow in a Heavy Ion Collision

Forward, spectator Energy charged, neutral

Zero Degree Calorimeter

EMCal

Beam-Beam Counters
Definitions:

\[ E_t^i = \sin(\theta^i) \ast (E_{\text{kin}}^i + m^i) \quad \pi, \ K... \]
\[ (E_{\text{kin}}^i) \quad \text{baryons} \]

\[ N_{\text{participant}}: \]

"direct"

1) \[ N_{\text{part}} + E_{\text{spectator}} / (m_n * \gamma_{\text{beam}}) = A_{\text{beam}} \]

Glauber Model

2) \[ \pi b'^2 = \int_{E_f}^{E_f'} \frac{d\sigma}{dE_f} dE_f' \text{, calculate } N_{\text{participant}} \text{ from } b' \]

Physical Limitations:

- Finite Coverage \((\frac{\pi}{4}, |h| \leq 0.38)\) -> \(E_t\) fluctuations from acceptance
- Backgrounds, Hadron Response -> net correction of 17%
- Detectable "Spectator" Neutron Fraction \(~\{1/2:0\}\)
$E_t$ produced is related to energy density $\sim \frac{dE_t}{d\eta} / \text{Volume}$

How does it increase from SPS to RHIC?

Naïve extrapolation;

$$\frac{dE_t}{d\eta} = \frac{dN_{ch}}{d\eta} \bigg|_{pp} \times 1.5 < E_{trk}^t > \times (N_{part} / 2)$$

$$0.01 + 0.22 \times \ln(s) \qquad (A - N_{spectator})$$

$$\cong 0.5 \text{GeV} \quad \text{(assume constant)}$$

Is it proportional to $N_{\text{participant}}$?
Phenix EM Calorimeter Parameters

- **Pb-scintillator sampling calorimeter (PbSc)**
  - WLS fiber readout
  - 66 layers of Pb 1.5mm + Sc 4mm
  - laser monitoring system
  - 1 super-module = 12 x 12 towers
  - 1 module = 2x2 towers

- **Lead glass calorimeter (PbGl) from WA98**
  - LED monitoring system
  - 1 super-module = 4 x 6 towers

<table>
<thead>
<tr>
<th></th>
<th>PbSc</th>
<th>PbGl</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size (cm x cm)</strong></td>
<td>5.535 x 5.535</td>
<td>4.0 x 4.0</td>
</tr>
<tr>
<td><strong>Depth (cm)</strong></td>
<td>37.5</td>
<td>40</td>
</tr>
<tr>
<td><strong>Number of towers</strong></td>
<td>15552</td>
<td>9216</td>
</tr>
<tr>
<td><strong>Sampling fraction</strong></td>
<td>~ 20%</td>
<td>100%</td>
</tr>
<tr>
<td>η cov.</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>φ cov.</td>
<td>90+45deg</td>
<td>45deg</td>
</tr>
<tr>
<td>η/ mod</td>
<td>0.011</td>
<td>0.008</td>
</tr>
<tr>
<td>φ/ mod</td>
<td>0.011</td>
<td>0.008</td>
</tr>
<tr>
<td>X₀</td>
<td>18</td>
<td>14.4</td>
</tr>
<tr>
<td>Molière Radius</td>
<td>~ 3cm</td>
<td>3.68cm</td>
</tr>
</tbody>
</table>

Pb/Sc “module”

Pb/Gl “supermodule”
Production control and precalibration (to 5%)

Energy Scale from beam tests

$1\text{GeV} \ e^- : \mu_{\text{Trans}} : \mu_{\text{long}}$

= $1\text{GeV}$: 38 MeV: 280 MeV
Internal timing/light yield uniformity of Calorimeter

- EM Shower distributed within several modules
- Uniformity of response affects ultimate t and Energy resolution
- Signal (in fiber) and shower velocity partially cancel
- Signal attenuation partially compensates shower depth

**Transverse Uniformity**
Pb/Sc Linearity, resolution

Stochastic, constant term:

\[
\frac{\sigma}{E} \approx \frac{8.2\%}{\sqrt{E(GeV)}} \oplus 1.9\%
\]

\((E_{\text{EMCal}} - E_{\text{beam}}) / E_{\text{beam}}\)

Testbeams at BNL,Cern

Linearity = \( \frac{E_{\text{emc}} - E_{\text{beam}}}{E_{\text{beam}}} \) %
• Et measurement is corrected for hadron response of the EMCal.
• On average this is a factor of 0.8.
• Calorimeter timing in principle a tool for particle id.

Intrinsic Resolution (testbeam)
Response to identified hadrons, RHIC data

Identified **protons**: EMC energy vs. momentum

antiprotons
EMCal global energy calibration

**E/p matching**
for electron enriched sample (with RICH):
$p>0.5$ GeV/c

**MIP peak position**
for 1 GeV/c charged tracks (mostly pions):
Within 1% from Test Beam results

**π0’s**
$p_T>2$ GeV, asym<0.8
$m=136.7$ MeV/c$^2$
Particles contributing to Et

Simulation: geant particle id vs. energy deposit

Simulation & Data: Cluster Energy distribution from fast($\pi^0, \pi^{+/-}$) and slow(baryons) particles
Beam Beam Counter

BBC event Display, $t_0$, $Z_{vtx}$ ($\sim \delta t$)

$\delta_{vertex}(\text{cms})$, $\sigma \sim 2 \text{ cm}$

BBC vs. ZDC
**ZDC Calorimeter construction:**
- Tungsten absorber/ fiber (C)sampling
- 2 Lint/module, 3 modules total
- C sampling filters shower secondaries
- Uniform response vs. impact point
Zero Degree Calorimetry: Effective Shower Size Scintillator vs. ZCA1

\[ Containment \equiv \frac{Signal(r < R)}{Total} \]
Testbeam Measurements (100 GeV p)

Response uniformity

Directional response
ZDC Energy/Multiplicity Scale: Determination of Participant #

Fit to distribution of 1, 2, 3, 65 GeV neutron peaks

\( \sigma / E \sim 25\% \)

ZDC/BBC multiplicities vs. Centrality determined from cross sections
\[ \frac{dE_t}{d\eta} \] and participant dependence

\[ \frac{\langle dE_t,\eta \rangle / N_{\text{part}}}{\langle GeV \rangle} \]

PHENIX (preliminary)  
WA98

\[ dE_t \bigg|_{\eta=0} \sim N_{\text{part}}^\alpha \quad , \alpha = 1.13 +/- 0.05 \]
2 ZDC’s measure same multiplicity to $\Delta/<> \sim 10\%$
Conclusions

• EMCal energy scale determined to 2%
• Et/event scale to +/- 4%
• BBC, ZDC measure global properties of events (z_{vert}, t_0, Centrality)
• dE_t/d\eta increases by ~50% from SPS to RHIC
• clear departure from linear N_{participant} dependence seen