Analysis of fixed target collisions with the STAR detector

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Creating mini-big bangs in the laboratory

**Goal:** Use relativistic collisions of nuclei to create hot dense matter which reproduces the earliest stages of the universe.
• We have created a new state of matter consistent with the QGP!

• In 2010 (and continuing through 2011) an extensive beam energy scan was undertaken at RHIC with a major goal to find the critical point.

• Fixed target collisions could extend the physics analysis to even lower $\sqrt{s}$. 
STAR has fixed target events

- gold beam ions collide with aluminum beam pipe atoms
- the events are asymmetrical
- acceptance is not optimal ...
## Kinematic Calculations

<table>
<thead>
<tr>
<th>Collision Energy (GeV)</th>
<th>Single Beam Energy</th>
<th>Single Beam $p_z$ (GeV/c)</th>
<th>Fixed Target $\sqrt{s}$</th>
<th>Single Beam Rapidity</th>
<th>Center of Mass Rapidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au+Au</td>
<td>9.8</td>
<td>9.76</td>
<td>4.47 Au+Al</td>
<td>3.04</td>
<td>1.52</td>
</tr>
<tr>
<td>Au+Al</td>
<td>5.75</td>
<td>5.67</td>
<td>3.53 Au+Al</td>
<td>2.51</td>
<td>1.25</td>
</tr>
<tr>
<td>Au+Au</td>
<td>3.85</td>
<td>3.74</td>
<td>2.99 Au+Al</td>
<td>2.10</td>
<td>1.05</td>
</tr>
</tbody>
</table>

\[
\sqrt{(s_{NN})} = \text{center of mass energy}
\]

\[
\sqrt{(s_{NN})} = \sqrt{(2m^2 + 2Em)}
\]

\[m = 0.9315 \text{ GeV/c}^2; \ E = 9.8 \text{ GeV}\]

\[
\sqrt{(s_{NN})} = 4.47 \text{ GeV}
\]

\[
p_z = \sqrt{(E^2 - m^2)} = 9.76 \text{ GeV/c}
\]

\[
y_{\text{beam}} = 0.5*[\ln(E + p_z)/(E - p_z)]
\]

\[
y_{\text{beam}} = 3.0
\]

\[
y_{\text{cm}} = 1.5
\]
Event Selection

- Run 11 – 19.6 AuAu collider data
- Au+Al $\sqrt{s_{NN}} = 4.5$ GeV
- 137k events pass selection cuts from 146 M total events

|zVertex| > 100 cm

- centrality definition underway

pion multiplicity > 10

5 cm > rVertex > 2 cm
Particle identification via dE/dx

- dE/dx from beampipe events as per selection criteria in slide 8
- particle bands are well separated
π⁻ spectra comparisons

• uncorrected STAR data points

• slopes of π⁻ spectra STAR data, AGS data, and UrQMD compare reasonably

• AGS yields are predictably above STAR for Au+Au (AGS) vs. Au+Al (STAR)
\( \pi^+/\pi^- \) yield ratios

- Net positive charge in the collision zone
  - expanding spherical source \( \rightarrow \) effective potential

- Extracted parameters include initial ratio \( R \) and the full coloumb potential \( V_c \)

- Coulomb potential (\( V_c \)) of the source modifies momentum distribution
  - greater effect for low-momentum \( \pi \)

- \( R \)-primordial ratio from initial yields, unmodified by the coloumb source

**Source Coulomb Potential, \( V_c \) (MVolts)**
- Y1: 8.54 +/- 0.78
- Y11: 8.07 +/- 0.61
- WA98: 9.83 +/- 0.63
- E866: 16.32 +/- 1.92

**Overall Pion Ratio, \( R \)**
- Y1: 0.960 +/- 0.005
- Y11: 0.953 +/- 0.002
- WA98: 0.935 +/- 0.004
- E866: 0.771 +/- 0.011

**STAR Au+Al 4.5 GeV measurement pending**
Conclusions and Outlook

- We can do physics with STAR as a fixed target experiment!
- We have been able to extract pion spectra for fixed target collisions at lab rapidity
- working to understand detector efficiency at high rapidities via simulated events
- checking pion contamination, stability of multiplicity as a function of $z_{\text{Vertex}}$
- Yields and slopes compare favorably with published data in this energy range
- We can extend the search for the critical point to lower energies
- We have more fixed target data at $\sqrt{s_{\text{NN}}}$ of 3.0 and 3.5 GeV
Backup Slides
Source Coulomb Potential

\[ \frac{\pi^+}{\pi^-} (m_T - m_\pi) = R \frac{\exp \left[ \frac{(E + V_{\text{eff}})}{T_\pi} \right] - 1}{\exp \left[ \frac{(E - V_{\text{eff}})}{T_\pi} \right] - 1} \cdot J \]

Ratio as a function of transverse kinetic energy with transformed B-E distribution

\[ J = \frac{E - V_{\text{eff}}}{E + V_{\text{eff}}} \frac{\sqrt{(E - V_{\text{eff}})^2 - m_\pi^2}}{\sqrt{(E + V_{\text{eff}})^2 - m_\pi^2}} \]

Jacobian of the transformation

\[ V_{\text{eff}} (\gamma_\pi \beta_\pi) = V_C \left( 1 - e^{-E_{\text{max}} (\gamma_\pi \beta_\pi)/T_p} \right) \]

Effective Coulomb potential accounting for the reduced charge seen by low momentum \( \pi \)

\[ E_{\text{max}} (\gamma_\pi \beta_\pi) = \sqrt{(m_p \gamma_\pi \beta_\pi)^2 + m_p^2} - m_p \]

Maximum kinetic energy of the corresponding \( \pi \) velocity

- Net positive charge in the collision zone
  - Expanding spherical source \( \rightarrow \) effective potential
- Coulomb potential \((V_c)\) of the source modifies momentum distribution
  - Greater effect for low-momentum \( \pi \)
- \( R \) – primordial ratio from initial yields, unmodified by the coulomb source
- Extracted parameters include initial ratio \( R \) and the full coulomb potential \( V_c \)
The Basics

mater in the universe is made of atoms

nucleus = protons + neutrons

nucleons are hadrons (made of quarks)

mesons = 2 quarks
baryons = 3 quarks

proton

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π spectra

\[ \frac{d^2N}{dm.dm.dy} \]

\[ m_T - m_0 \text{ (GeV)} \]

\[ \pi^+ \]

\[ \pi^- \]