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 ...
STAR detector array

blue tracks = non-central beampipe event
## 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>

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

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

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

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

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

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

\[ y_{beam} = 3.0 \]

\[ y_{cm} = 1.5 \]
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

- Centrality definition underway
Particle identification via dE/dx

- dE/dx from beampipe events as per selection criteria in slide 8
- particle bands are well separated
$\pi^-$ spectra comparisons

- uncorrected STAR data points
- slopes of $\pi^-$ 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 \( V_c \)

- Coloumb 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

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**Coulomb Potential \( (V_c \) in MV):**
- E895: 17.60 +/- 0.56
- E866: 16.32 +/- 1.92
- Au+Al: 16.45 +/- 1.74

**Ratios:**
- E895: 0.717 +/- 0.004
- E866: 0.771 +/- 0.011
- Au+Al: 0.858 +/- 0.008
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 zVertex

• 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 $\sqrt{s_{NN}}$ 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 \(V_c\)
π⁺/π⁻ yield ratios fit parameters

**Coulomb Potential:**
- E895: 17.60 +/- 0.56
- E866: 16.32 +/- 1.92
- Au+Al: 17.60 +/- 0.86

**Ratios:**
- E895: 0.72 +/- 0.00
- E866: 0.77 +/- 0.01
- Au+Al: 0.81 +/- 0.00

**STAR Au+Al 8 AGeV**

**E895 Au+Au 8 AGeV**

**E866 Au+Au 10 AGeV**

Chi^2 1.20046

Chi^2 1.17822

Chi^2 0.184964
The Basics

nucleus = protons + neutrons

nucleons are hadrons (made of quarks)

mesons = 2 quarks
baryons = 3 quarks

matter in the universe is
made of atoms