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+Au</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>

$\sqrt{(s_{NN})}$ = center of mass energy

- $\sqrt{(s_{NN})} = \sqrt{(2m^2 + 2Em)} $
- $m = 0.9315$ GeV/c$^2$; $E = 9.8$ GeV 
- $\sqrt{(s_{NN})} = 4.47$ GeV

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

rapidity ($y$)

- $y_{beam} = 0.5*\ln(E + p_z)/(E - p_z)$
- $y_{beam} = 3.0$
- $y_{cm} = 1.5$
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

- $|z_{\text{Vertex}}| > 100$ cm
- pion multiplicity > 10
- $5 \text{ cm} > r_{\text{Vertex}} > 2 \text{ cm}$

- 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
\[ \pi^- \text{ spectra comparisons} \]

- 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 → 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

<table>
<thead>
<tr>
<th>Experiment</th>
<th>(V_c) (MV)</th>
<th>(R)</th>
<th>(\Delta R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E895 Au+Al</td>
<td>17.60 +/- 0.56</td>
<td>0.717</td>
<td>0.004</td>
</tr>
<tr>
<td>E866 Au+Au</td>
<td>16.32 +/- 1.92</td>
<td>0.771</td>
<td>0.011</td>
</tr>
<tr>
<td>Au+Al</td>
<td>16.45 +/- 1.74</td>
<td>0.858</td>
<td>0.008</td>
</tr>
</tbody>
</table>

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

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

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

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

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 \(V_c\)
\( \pi^+/\pi^- \) 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
The Basics

matter in the universe is made of atoms

nucleus = protons + neutrons

nucleons are hadrons (made of quarks)

mesons = 2 quarks
baryons = 3 quarks

nucleons are hadrons (made of quarks)
$\pi^+$ spectra