The Fixed-Target Experiment at STAR

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Outline

I. Introduction to STAR’s Fixed Target (FXT) Program
II. FXT Test Run Results
III. Future FXT Measurements
IV. Conclusions
Why a Fixed-Target (FXT) Program?

- STAR Beam Energy Scan (BES-I) results suggest a softening of the equation of state (EOS) and hints at critical fluctuations.
- To help clarify these hints, STAR needs to access energies below 7.7 GeV where we expect no QGP formation.
- At these lower energies the luminosity of RHIC is too low, making it impractical to take data in collider mode.

The goals of BES-I:
1) Observe the disappearance of QGP signatures.
2) Find evidence of the possible first-order phase transition.
3) Find the possible Critical Point.

P. Shanmuganathan for the STAR Collaboration, Quark Matter 2015.


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RHIC Runs at or Below Nominal Injection Energy:

1. Au+Au 19.6 GeV 2001 (Test Run) 100 k events
2. Cu+Cu 22.4 GeV 2005 (Test Run) 250 k events
3. Au+Au 9.0 GeV 2007 (Test Run) 0 events
4. Au+Au 9.2 GeV 2008 (Test Run) 3 k events
5. Au+Au 7.7 GeV 2010 (Physics) 4 M events
6. Au+Au 11.5 GeV 2010 (Physics) 12 M events
7. Au+Au 5.5 GeV 2010 (Test Run) 0 events
9. Au+Au 5.0 GeV 2011 (Test Run) 1 event
10. Au+Au 14.5 GeV 2014 (Physics) 20 M events
Proof of Principle: Au + Al Beam Pipe Studies

Vertex Distribution of Au + Al Beam Pipe Events

Pion Spectra for the Au + Al Data at $\sqrt{s_{NN}} = 3.0, 3.5$ and $4.5$ GeV

<table>
<thead>
<tr>
<th>Energy</th>
<th>Particle</th>
<th>$T$ (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0 GeV</td>
<td>$\pi^+$</td>
<td>$103 \pm 3 \pm 5$</td>
</tr>
<tr>
<td></td>
<td>$\pi^-$</td>
<td>$99 \pm 3 \pm 3$</td>
</tr>
<tr>
<td>3.5 GeV</td>
<td>$\pi^+$</td>
<td>$115 \pm 3 \pm 9$</td>
</tr>
<tr>
<td></td>
<td>$\pi^-$</td>
<td>$111 \pm 3 \pm 8$</td>
</tr>
<tr>
<td>4.5 GeV</td>
<td>$\pi^+$</td>
<td>$102 \pm 8 \pm 10$</td>
</tr>
<tr>
<td></td>
<td>$\pi^-$</td>
<td>$110 \pm 4 \pm 6$</td>
</tr>
</tbody>
</table>

- Curves are Bose-Einstein Fits to Spectra
Coulomb Potential

Pion Spectra for the Au + Al Data at $\sqrt{S_{NN}} = 3.0$, 3.5 and 4.5 GeV

$$N_{\pi^\pm} / N_{\pi^0} \mid_{m_{\pi^\pm}-m_{\pi^0}}$$

$$\frac{\pi^+}{\pi^-}$$

Pion Ratio for the Au + Al Data at $\sqrt{S_{NN}} = 3.0$, 3.5 and 4.5 GeV

$$\frac{n^+(E_f-V_c)}{n^-(E_f+V_c)} = \frac{A^+(e^{(E_f+V_c)/T}\pi - 1)}{A^-(e^{(E_f-V_c)/T}\pi - 1)}$$

$$V_{\text{eff}} = V_c (1-e^{-E_{\text{max}}/T})$$

$$E_{\text{max}} = \sqrt{\left(\frac{m_p P_{\pi\pi}}{m_{\pi\pi}}\right)^2 + m_p^2 - m_p}$$

STAR PRELIMINARY

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Proof of Principle: Au + Al Beam Pipe Studies

- Coulomb Potential has been extracted and shown to be consistent with previous experiments

- STAR software framework can successfully reconstruct fixed target vertices and has good acceptance and PID capabilities up to mid-rapidity

arXiv:1408.1369
Gold Target Installed for Run 14

Run 14 details:
- Fixed Target 3.9 GeV data taken concurrently with 14.5 GeV Au + Au collider events
- The target foil is held 2 cm below of the beam axis.
- The foil is 1 mm thick (4%).

Out of time pile-up of electron-capture Au halo nuclei
3.9 GeV Au + Au Test Run

Excellent PID with Time Projection Chamber (TPC) and Time of Flight (TOF) detectors for fixed target events

Energy Loss in TPC

3.8 cm radius Al Beam Pipe

BBC-East

Al Beam Pipe

TPC

η = 1.5

η = 1.37 mid rapidity

η = 1.0

η = 0.5

η = 0

BBC-West

EMC

Al Beam Pipe

2.0 cm radius Be Beam Pipe

2.0 cm radius Al Beam Pipe

Fixed target at z = 2.1 m

TOF 1/β

1/β

3He

K+

π

π+

p

e−
e−
e−
e−
e−
e−

t

d

K−
Our result for Coulomb potential is consistent with previous experiments.

Projectile is consistent with gold ion.
Au + Au $\sqrt{s_{NN}} = 4.5$ GeV 2015 Test Run Performance

- May 20th, 2015 4 hour test run
- Dedicated FXT test run (not concurrent running)
- 6 bunches, ~1.3 million triggers
- Beam lowered to graze the top edge of the target
Can take ~1 million events in half an hour, as opposed to ~5000 events in 3 weeks

Dedicated fixed-target runs are a better conduct of operations than concurrent runs

Official production completed, awaiting embedding

Coming soon: HBT, fluctuation, spectra, flow comparison paper with AGS
- Top 10% centrality
- Fit CF with Gaussian to extract 5 parameters:
  \[ R_{out}^2, R_{side}^2, R_{long}^2, \lambda, \text{ and a normalization} \]
FXT HBT Comparison with AGS

Top 10% Centrality, 0.1 GeV < $p_T$ < 0.3 GeV, only using $\pi^-$

Efficiency corrections still needed for official physics result

Peaks have similar width, expect physics result with similar statistical significance as AGS result
Al + Au $\sqrt{S_{NN}} = 4.9$ GeV

June 16, 2015
• 2 hour test run
• $\sim 3$ million triggers
• $\sqrt{S_{NN}} = 4.9$ GeV, $y_{\text{mid}} = -1.62$

➢ Can obtain second half of phase space to complement beam pipe studies
Future: BES-II

- FXT Program will collect huge statistics up to ~50 million events per day
- 1-2 days of dedicated fixed target running at each energy would collect sufficient statistics to extend BES-II to lower energies
- Detector upgrades would extend our midrapidity acceptance for additional fixed target energies
- Physics goals include looking for a 1\textsuperscript{st} order phase transition (eg. dv$_1$/dy...) and clarifying possible evidence for a critical point (eg. kurtosis...)

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Increased acceptance for tracking and PID allows the FXT program to extend its energy range to 7.7 GeV allowing comparisons with collider analyses.
Kurtosis in FXT

• Probing lower energies can clarify this signature

Need to go to lower energies to confirm a return to baseline values


STAR Preliminary
Expect to be able to measure turn-on of lamdhas and cascades

Might be able to measure omegas and anti-lamelas

Hypernuclei in FXT

Simulated Yield of Hypertritons
1 day of FXT running
\( \sqrt{S_{NN}} = 4.5 \text{ GeV} \)


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Conclusions

- Successful FXT test runs demonstrated that dedicated FXT runs are a preferable conduct of operations to concurrent FXT runs.

- Coulomb potentials and preliminary HBT radii were also measured and are consistent with previous experiments.

- The detector upgrades will allow the FXT program to run at $\sqrt{s_{NN}} = 7.7$ GeV which will allow for comparison with collider mode analyses at the same energy.

- The FXT program will allow us to extend BES-II down to $\sqrt{s_{NN}} = 3.0$ GeV.