Motivation - Search for the QCD Critical Point

Search for the QCD critical point requires beam energy scan in gold-gold collisions at center-of-mass energies between 5 GeV/nucleon and 30 GeV/nucleon.
The Relativistic Heavy Ion Collider

Circumference: $C = 3833.845$ m
Nominal Au beam energy range: $E = 10\text{ GeV/n} - 100\text{ GeV/n}$
Energy range for critical point search extends well below design energies
Challenges at Low Collision Energies

- Space charge limits bunch intensity
- Beam-beam in space charge dominated beams requires near-integer tunes
- Apertures limit achievable $\beta^*$
- Power supply resolution Limits machine tuneability
- ...
History of Low Energy Running at RHIC

<table>
<thead>
<tr>
<th>beam energy [GeV/n]</th>
<th>$\sqrt{s_{NN}}$ [GeV/n]</th>
<th>run duration [days]</th>
<th>no. of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.8</td>
<td>19.6</td>
<td>10</td>
<td>36 M</td>
</tr>
<tr>
<td>7.3</td>
<td>14.6</td>
<td>24</td>
<td>20 M</td>
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<tr>
<td>5.75</td>
<td>11.5</td>
<td>10</td>
<td>12 M</td>
</tr>
<tr>
<td>3.85</td>
<td>7.7</td>
<td>32</td>
<td>4 M</td>
</tr>
<tr>
<td>2.5</td>
<td>5.0</td>
<td>0.2</td>
<td>1</td>
</tr>
</tbody>
</table>

Event rates at low energies are very low, making collider mode operation inefficient.

Collider operation below 3.85 GeV/n practically impossible.
Reconstructed Vertices with 3.85 GeV Colliding Au Beams

Large number of background collision events on detector beampipe
⇒ Idea: Install a dedicated Au target in the detector beampipe
Proof-of-Principle Experiment Using Collimator

- Demonstrate controllability of (target) loss rate, bunch-by-bunch uniformity, and lack of short-term variations

- At injection, insert vertical collimator until it becomes limiting aperture

- Vary horizontal and vertical tunes, observe collimator loss rate

Collimator tests were performed with proton beam, which has very low IBS growth rates
Collimator Loss Rates as Function of Tune

Loss rates during the tune scan with fixed collimator position at 11.5 mm
A vertical tune near 2/3 stabilizes the rate
Bunch-by-bunch Loss Rates

All bunches contribute equally
Collimator Loss Monitor Signal at 720 Hz

No fast rate fluctuations due to orbit jitter or target vibration
Successful proof-of-principle experiment warrants design and installation of a dedicated internal gold target in STAR detector
Internal Target at STAR

Target is installed 2.05 m from the IP in the Yellow ring
16 mm target aperture would not interfere with high energy operations, but would allow for dedicated target mode
During Run-14 target was installed with 20 mm aperture (same as detector beam pipe) to study background situation
With this aperture the target cannot be hit by circulating beam particles
Imaging the Target with Background Events

Reconstructed vertices match target geometry
With 20 mm target aperture, these are all background events (likely fragments of Au ions having hit the upstream triplet)
At $\beta^* = 8\,\text{m}$, a 10 mm vertical orbit bump allows the target to become the limiting aperture at 16 mm from the beam pipe center. Existing target was moved to this new position for Run-15 to allow dedicated running.
30 min Physics store at 9.8 GeV/n RHIC injection energy

6 Au bunches in the YELLOW ring
STAR recorded 1 million events in 30 minutes at $\sqrt{s_{NN}} = 4.5$ GeV/n
Conclusion

• Collected 1 million events in 30 minutes at $\sqrt{s_{NN}} = 4.5\text{ GeV}/n$, compared to a single event in several hours in collider mode at $\sqrt{s_{NN}} = 5.0\text{ GeV}/n$

• Physics data are still being analyzed by STAR collaboration

• Internal target mode extends energy reach down to $\sqrt{s_{NN}} = 3.0\text{ GeV}/n$, at a beam energy of 3.85 GeV/n

• Internal target provides a very efficient method to study low energy Au-Au collisions at RHIC