# A Fixed-Target Program for STAR: Extending the Low Energy Reach of the RHIC Beam Energy Scan Program

Brooke Haag, for the STAR Collaboration

University of California, Davis

## MOTIVATION

The RHIC Beam Energy Scan (BES) was proposed to search for the possible critical point and to study the nature of the phase transition between hadronic and partonic phases of matter. Data from the NA49 experiment at CERN had suggested the onset of deconfinement at a collision energy of 7.7 GeV [1]. Though RHIC has not demonstrated sufficient luminosity to access collisions below 7.7 GeV in collider mode, interactions between beam nuclei and a stationary gold target will allow STAR to study Au+Au events at center-of-mass energies between 3.0 and 4.5 GeV during the BES phase II. A proof-of-principle study, using interactions between nuclei in the beam halo and the aluminum beam pipe (RHIC data taking in years 2010 and 2011), has been investigated to demonstrate the feasibility of extracting physics from fixed-target interactions at center-of-mass energies below 7.7 GeV. Performance results from this proof-of-principle study will be presented. The gold target was installed for trigger tests during the 14.5 GeV Au+Au run in March of 2014. The first results of these gold target tests ($\sqrt{s_{NN}}$ = 3.9 GeV) are also presented.

[1] C. Alt *et al.* [NA49 Collaboration], Phys. Rev. C **77**, 024903 (2008).

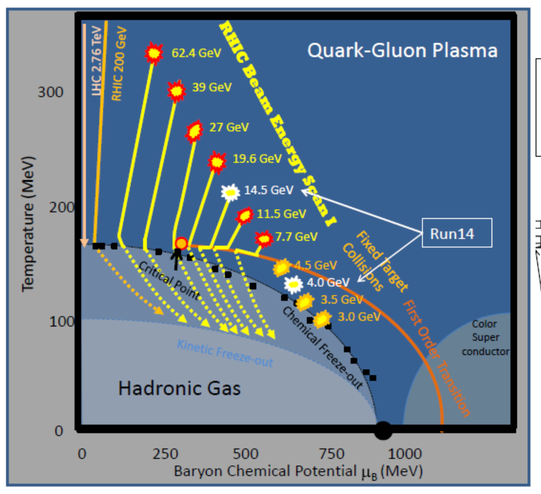


**Figure 1.** A cartoon of the phase diagram of QCD matter with indications of the regions that are explored by the Beam Energy Scan.

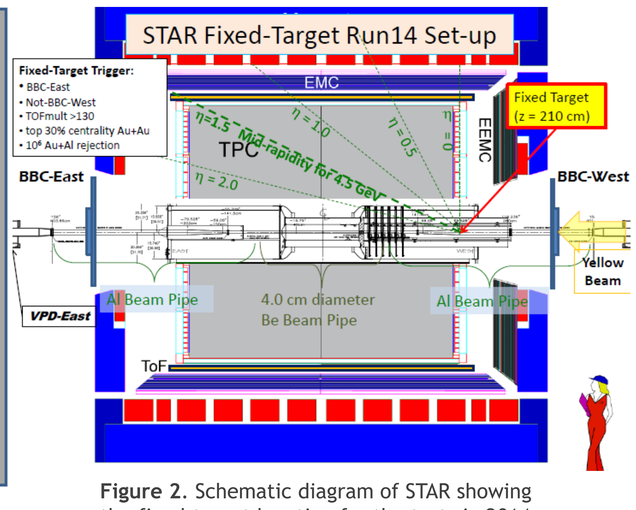


**Figure 2.** Schematic diagram of STAR showing the fixed-target location for the tests in 2014. The target is a gold foil; the projectiles are ions from the halo of the "yellow beam".

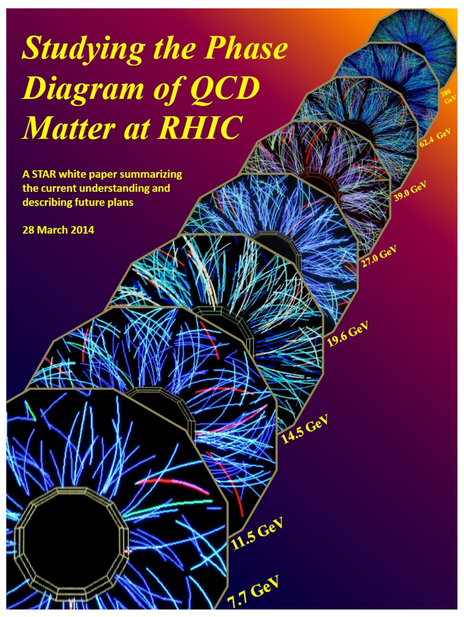


**Figure 3.** The STAR Beam Energy Scan Phase II White Paper details the motivation and the plans to return to energy scans at RHIC in years 2018 and 2019.

The Goals of the Beam Energy Scan Program:
1) Find the disappearance of QGP signatures
2) Find evidence of a first-order phase transition
3) Find the possible Critical Point

The Fixed-Target Program will extend the search range for all of these features of the QCD phase diagram up to $\mu_B$ = 720 MeV

| Collision Energy (GeV) | Fixed Target $\sqrt{s_{NN}}$ | Center of Mass Rapidity | Single Beam Kinetic | Chemical Potential Collider | Chemical Potential $\mu_B$ (MeV) |
|---|---|---|---|---|---|
| 19.6 | 4.471 | 1.522 | 8.87 | 206 | 589 |
| 17.2 | 4.214 | 1.456 | 7.67 | 230 | 608 |
| **14.5** | **3.904** | **1.370** | **6.32** | **264** | **633** |
| 13.0 | 3.721 | 1.315 | 5.57 | 288 | 649 |
| 11.5 | 3.528 | 1.253 | 4.82 | 316 | 666 |
| 9.1 | 3.196 | 1.134 | 3.62 | 375 | 699 |
| 7.7 | 2.985 | 1.049 | 2.92 | 422 | 721 |

**Table 1.** Energies under consideration for BES Phase II and the resulting $\sqrt{s_{NN}}$, $y_{CM}$, AGeV, and $\mu_B$. In year 2014, RHIC was tuned for Au+Au collider events with $\sqrt{s_{NN}}$ = 14.5 GeV. These produce fixed-target events with $\sqrt{s_{NN}}$ = 3.9 GeV. In years 2010 and 2011, the collider was tuned for 7.7, 11.5, and 19.6 GeV collisions. These produced $Au_{Halo}$+$Al_{Beampipe}$ fixed-target events with $\sqrt{s_{NN}}$ = 3.0, 3.5, and 4.5 GeV respectively.

## Proof-of-Principle $Au_{Halo}$+$Al_{Beampipe}$ Studies (2010 and 2011)

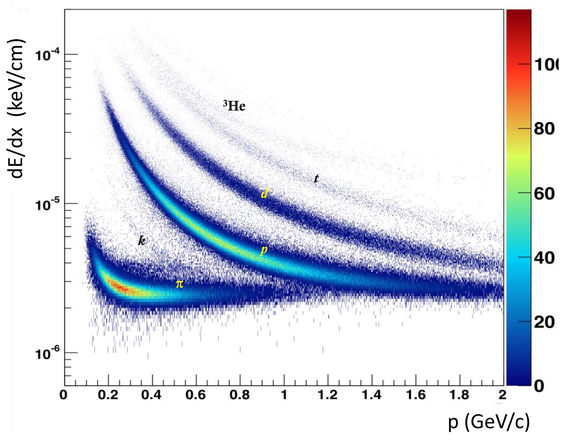


**Figure 4.** Particle identification is achieved using relative ionization in the TPC gas. A dE/dx versus momentum distribution is shown for 3.0 GeV Au+Al events with 1.5 m < $|V_z|$ < 2.0 m.

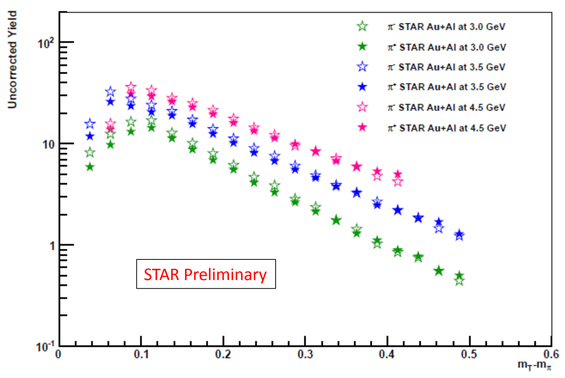


**Figure 5.** Invariant pion yields for Au+Al collisions, top 10% centrality, for $\sqrt{s_{NN}}$ = 3.0, 3.5, 4.5 GeV. Efficiency corrections have not yet been applied to these preliminary spectra.

## GOLD TARGET INSTALLATION (2014)


**Figure 6.** A technician holds the target mount prior to installation. The insets show an isolation of the target mount and a detail drawing. These illustrate how the gold foil is supported. The mount holds the gold foil 210 cm from the center of the detector.

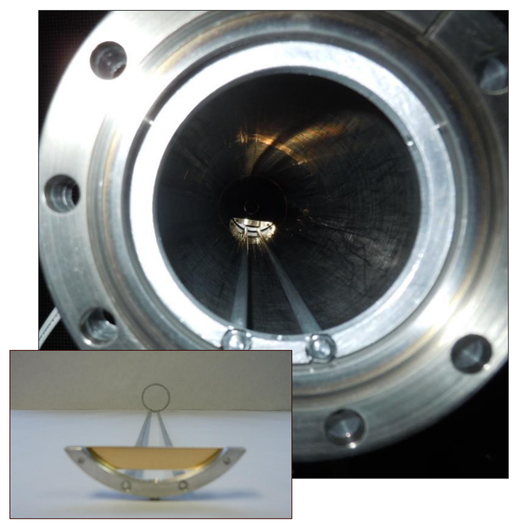

**Figure 7.** A view down the beam pipe shows the internal target mounting bracket installed in the west end of the STAR detector facility. The inset shows how the 1 mm thick gold foil (4% target) is supported 2 cm below the beam axis.

## FIXED TARGET TRIGGER TESTS (2014)

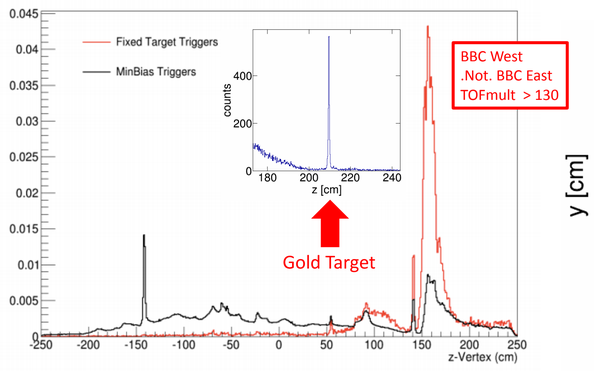


**Figure 8.** The distribution of the *z* location of event vertices for the collider minimum bias trigger are show in black. Vertices from the fixed-target trigger are shown in red. The inset shows *z* vertex location with tight *x*-*y* cuts around the location of the gold target.

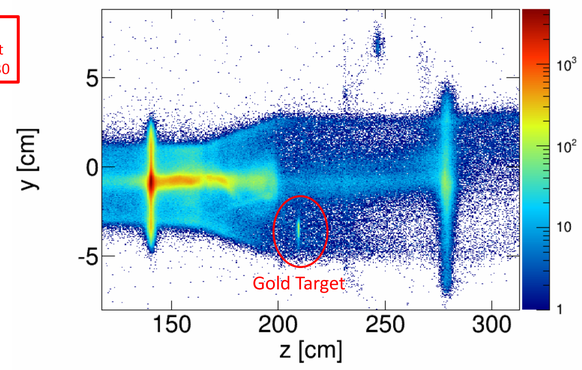


**Figure 9.** A *y*-*z* distribution of minimum bias event vertices from the 14.5 GeV run shows evidence of gold target events at *z* = 210 cm.

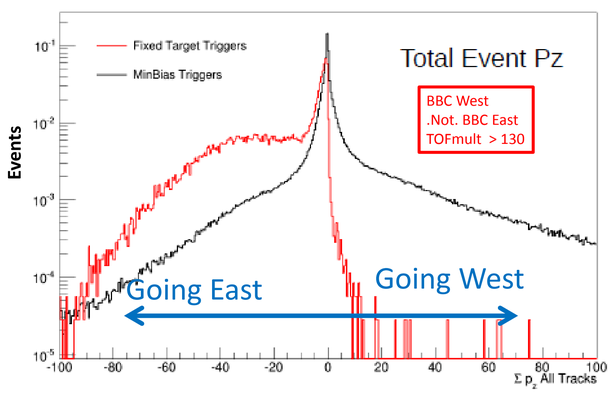


**Figure 10.** Au+Au collider events will have zero momentum in the *z* direction, whereas collisions with a fixed-target (beampipe or gold target) will not. Collider MinBias triggers (black) see background from both beams (East and West). The fixed-target trigger (red) selects events headed East (negative $\Sigma p_z$).

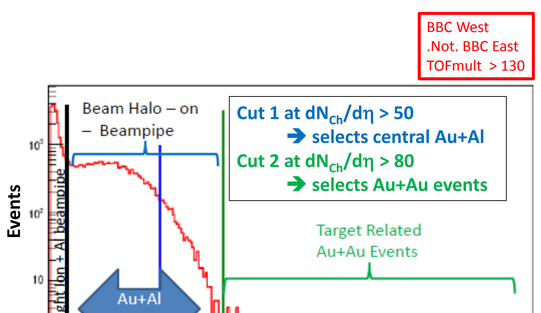


**Figure 11.** $dN_{Ch}/d\eta$ of fixed-target trigger events. Three classes of events can be recognized: 1) Light ion induced reactions on the beam-pipe, 2) Au ions incident on the beam-pipe, and 3) Au ions incident on the gold target.

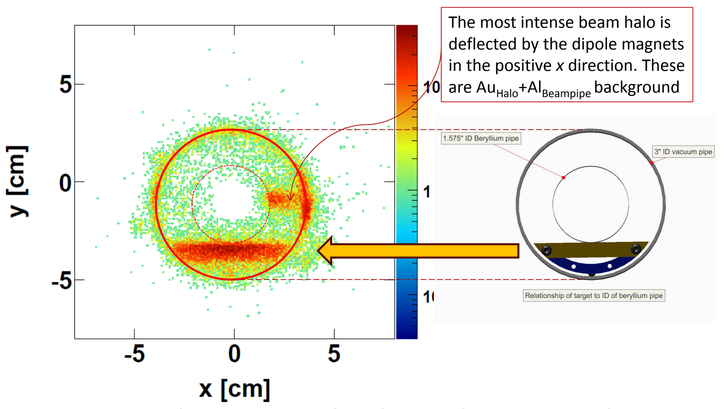


**Figure 12. Left)** *x*-*y* vertex distribution for events with 208.5 < $V_Z$ < 210.2 cm. **Right)** Schematic of the target mount.

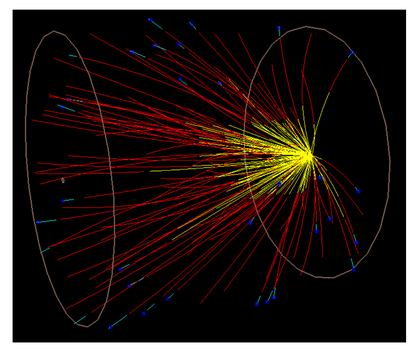

**Figure 13.** The reconstructed tracks from an event associated with the gold target.

## OUTLOOK

We have successfully installed a gold target in the STAR detector. Preliminary data show that the fixed-target trigger is selecting fixed-target events and rejecting beam-beam collisions. With more events, we expect fruitful physics analyses can be done as per prior proof-of-principle studies conducted on fixed-target $Au_{Halo}$+$Al_{Beampipe}$ events. This fixed-target program will enable STAR to make key measurements related to the phase diagram of QCD matter below the reported onset of deconfinement at $\sqrt{s_{NN}}$ = 7.7 GeV.

## ACKNOWLEDGEMENTS

This material is based upon work supported by the **National Science Foundation under Grant No. 1068833**. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily represent the views of the National Science Foundation.