Nuclear Data for Space Exploration
Opportunities at RHIC

Daniel Cebra (UC Davis)
Opportunity for 2023-25

Light Fragment Yields from He, C, Si, and Fe on C, Al, and Fe Targets with beam energies from 3 to 50 GeV

Note: This “opportunity” was included in the STAR 2022-2025 Beam Use Request

Note: 2022 is not possible as there is no opportunity to change targets
High Energy double differential measurements are needed
(See John Norbury’s Monday presentations)

- There are no data for beams from 3-50 GeV/n
- Identified as a key need for space radiation protection
- RHIC can supply the beam species and energies of interest
- STAR can make the double differential measurements

These are figures for protons, but all light nuclei are needed
Overview of the Accelerator Facility

Ion Sources:
- LINAC
- EBIS
- Tandems

Synchrotrons:
- Booster
- AGS
- RHIC

Experimental Areas
- NSRL
- RHIC IP6 (STAR)
- RHIC IP8 (PHENIX)

STAR has completed a fixed target energy scan using Au beams from 3-100 AGeV on Au targets.

→ Could install other targets, and run other beams
• STAR has acceptance from 90 to 12 degrees.

• No acceptance for projectile fragmentation

→ Must have A+B and B+A

Using a collider detector as a fixed-target experiment

Converting $\eta$ to $\theta$:
Online Event Display – FXT Event

√s_{NN} = 3.9 \text{ GeV Au+Au}
STAR light fragment particle identification

PID through $dE/dx$ in the TPC gas

PID through Time-of-Flight
Spectra ➔ Differential Cross Sections
protons and deuterons

3 GeV Au+Au
Spectra – tritons, $^3$He, and $^4$He

3 GeV Au+Au

Note, the low $p_T$ thresholds could be a problem.
Summary

• Light fragment cross section data are needed for projectiles in the energy range 3-50 GeV.

• RHIC/STAR have capabilities that could contribution to filling that need.
  ➔ As long as the detector acceptances are not prohibitive

• We could run this program during the 2023-2025 running periods.
  ➔ Scheduling beam time at RHIC is challenging, and a well considered proposal is necessary.
BACKUPS
About me

• Michigan State University Ph.D. (1990)
• LBNL Post-Doc (1990-1992)
  • Part of the original Letter of Intent for STAR
  • Contributed to Revised Letter of Intent
  • Contributed to Conceptual Design Report
  • First visited BNL in 1991
• University of California – Davis, Faculty (1992-Present)
  • Principal Author: Beam Energy Scan Proposal (2009)
  • Principal Author: BES-II Proposal (2015)
  • Principal Author: Fixed-Target Program (2017)
  • Deputy Project Manager: iTPC upgrade (2017-2019)

And... a frequent visitor at Brookhaven Lab
• Sabbatical Leave (1999)
• Sabbatical Leave (AY 2018/2019)
• Many summers
• Shifts at RHIC every year

Why I am here:
The RHIC/STAR Fixed-Target program may be able to meet some of the Nuclear Data needs.
Justification: (Quick overview)

- Cosmic rays are a serious concern to astronauts, electronics, and spacecraft.

- The cosmic ray flux is composed of nuclei (90% protons, 9% He, and 1% nuclei up to Fe).

- The damage is proportional to $Z^2$, therefore the component due to ions is very important.

- Damage from secondary production of $p$, $d$, $t$, $^3$He, and $^4$He is also significant.

- Extensive double differential measurements for light fragments production have been made for projectile energies below 3 GeV/n.

- No data exist for projectile energies from 3-50 GeV/n.

- The Space Radiation Protection community has identified this high energy regime as an area of need. [https://doi.org/10.3389/fphy.2020.565954](https://doi.org/10.3389/fphy.2020.565954)

- The STAR detector at RHIC has excellent light fragment capabilities.

- RHIC can deliver the ion beam species (He, C, Si, Fe) and energies (3-50 GeV/n) of need to the Space Radiation Community. STAR can install the targets of interest (C, Al, Fe).
The STAR Detector

**inner TPC upgrade**

**Endcap TOF**

**Event Plane Detector**

Detects Particles in the $0 < \eta < 2$ range

- $\pi, K, p, d, t, h, \alpha$ through $dE/dx$ and TOF
- $K^0_s, \Lambda, \Xi, \Omega, \phi, ^3\Lambda H, ^4\Lambda H$ through invariant mass
Gold Target:
• 250 μm foil
• 2 cm below the nominal beam axis
• 2 m from the center of STAR
• Beam is steered to graze the edge of target
• Typically, 12 hours to develop a new beam

➡️ Can install Be, C, Al, Fe foils; no gas targets
From 2018-2021, RHIC/STAR has beam running a fixed-target program performing an energy scan of gold beams on a gold target.

**Note on energies:** There are a few different units to use to describe the collision energy.

Note that acceptance is dependent on the collision energy.

<table>
<thead>
<tr>
<th>FXT Energy $\sqrt{s_{NN}}$</th>
<th>Single Beam $E_T$ (GeV)</th>
<th>Single beam $E_k$ (AGeV)</th>
<th>Center-of-mass Rapidity</th>
<th>Chemical Potential $\mu_B$ (MeV)</th>
<th>Year of Data Taking</th>
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<td>99.1</td>
<td>2.69</td>
<td>276</td>
<td>2021</td>
</tr>
</tbody>
</table>
Performance with Beam Energy

Fewer tracks, more helium nuclei

More tracks, fewer helium nuclei
STAR light fragment acceptance

- Acceptance in 2018, now better
- Low $p_T$ cut-in may be a challenge
- Target rapidity acceptance can be fixed
Yields of light nuclei

Au+Au Collisions
FXT $\sqrt{s_{NN}} = 3$ GeV

- $0-10\%$
- $20-40\%$
- $10-20\%$
- $40-80\%$
- reflection

STAR Preliminary

Daniel Cebra
3/01/2022
WANDA 2022
Experimental Panel
Average $p_T$ for light nuclei

Au+Au Collisions
FXT $\sqrt{s_{NN}} = 3$ GeV

- 0-10%
- 20-40%
- 10-20%
- 40-80%
- reflection

STAR Preliminary