Our Nuclear Astrophysics Playground:

...there is interest on the proton rich side....

Courtesy of Frank Timmes
Reverse/Inverse Kinematics Experiments

Radioactive ion beam on a Hydrogen/Helium Target

- Hydrogen or Helium reaction partners
- Not very intense beams (reversed kinematics)
- Low energy reaction products

- Need high efficiency setups (small yields)
- If possible recoil detection (fight backgrounds)
- If possible gamma detection (fight backgrounds)
- Direct approach needs $>10^7$ 1/s beams
Few beams of sufficient strength for direct approaches have been developed......have to look at indirect methods:

- astrophysics
  - cross sections
  - resonances
  - reaction rates
- structure
  - halo nuclei
  - level schemes
  - spin/parity

(\(^3\text{He},d\)) (\(^3\text{He},t\)) (\(^3\text{He},p\))
Transfer Reactions need angular distribution for $J^\pi$

Neutron transfer (d,p) with $^{18}$F ion beam (plastics target; background due to Carbon)

$^{18}$F (108 MeV) $\rightarrow$ SIDAR $\rightarrow$ DRS $\rightarrow$ 0.2 mg/cm$^2$ CD$_2$ $\rightarrow$ $^{19}$F $\rightarrow$ $^{15}$N $\rightarrow$ (3He,d) reaction products have quite low energies
What are we talking about:

**RHINOCEROS**
Gas jet at Stuttgart

We want a factor 10-20 higher target density and match to RIB diameter
Making a few more assumptions (a 4mm jet diameter and desired target density of $10^{19}$ atoms/cm$^2$)

<table>
<thead>
<tr>
<th>Gas</th>
<th>Flow (G) in m$^3$/hour</th>
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<tbody>
<tr>
<td>$H_2$</td>
<td>54.6</td>
</tr>
<tr>
<td>$D_2$</td>
<td>38.6</td>
</tr>
<tr>
<td>$^3$He</td>
<td>76.4</td>
</tr>
<tr>
<td>$^4$He</td>
<td>66.3</td>
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geometry and measurements of actual nozzle and collection port must allow for placement of silicon detector arrays covering a large angular range (in the backward angle for inverse kinematics)
• high gas flow will require industrial compressors and cleaning stages

• levels of gas contamination will have to be determined
On Dec. 11, 2008, the U.S. Department of Energy (DOE) announced that Michigan State University (MSU) in East Lansing, MI has been selected to design and establish the Facility for Rare Isotope Beams (FRIB), a cutting-edge research facility to advance understanding of rare nuclear isotopes and the evolution of the cosmos. The new facility—expected to take about a decade to design and build and to cost an estimated $550 million—will provide research opportunities for an international community of approximately 1000 university and laboratory scientists, postdoctoral associates, and graduate students.

MSU has proposed an FRIB that affords users opportunities with fast, stopped, and reaccelerated beams of rare isotopes and is proposed to adjoin the current NSCL facility as shown in Figure 1.
Reaccelerated beam rates at a future 100 kW driver based facility

Expected Reaccelerated Beam-on-Target Rates for SCF
100 kW at 200 MeV/u

Rate per Second

- $> 10^{10}$
- $10^{8}$
- $10^{6}$
- $10^{4}$
- $10^{2}$
- $10^{0}$
- $10^{-2}$
Reaccelerated beam rates at a future 100 kW driver based facility
(for rp-process applications)

Rates in pps
- $10^{>10}$
- $10^{9-10}$
- $10^{8-9}$
- $10^{7-8}$
- $10^{6-7}$
- $10^{5-6}$
- $10^{4-5}$
- $10^{2-4}$
ReA3 – concept and overview

Stopped beam area
- Relocated LEBIT
- Laser spectroscopy

N4 – beam stopping vault

LINAC

EBIT charge breeder

3 MeV/u experimental area

Layout plan
Reaccelerated beam rates with current NSCL driver

Expected Reaccelerated Beam-on-Target Rates for CCF2008

Rate per Second
- $>10^8$
- $10^7$
- $10^6$
- $10^5$
- $10^4$
- $10^3$
- $10^2$
- $10^1$
- $10^0$
- $10^{-2}$
Reaccelerated beam rates with current NSCL driver
(for rp-process application)

Rates in pps

- $>10^8$
- $10^7$-$8$
- $10^6$-$7$
- $10^5$-$6$
- $10^4$-$5$
- $10^2$-$4$
Alternative Uses