6-1-2016

The new JENSA gas-jet target for astrophysical radioactive beam experiments

D. W. Bardayan
University of Notre Dame

K. A. Chipps
ORNL Physics Division

S. Ahn
University of Tennessee

J. C. Blackmon
Louisiana State University

J. Browne
Michigan State University

See next page for additional authors

Recommended Citation

Bardayan, D., Chipps, K., Ahn, S., Blackmon, J., Browne, J., Greife, U., Jones, K., Kontos, A., Kozub, R., Linhardt, L., Manning, B., Matoš, M., O'Malley, P., Montes, F., Ota, S., Pain, S., Peters, W., Pittman, S., Sachs, A., Schatz, H., Schmitt, K., Smith, M., & Thompson, P. (2016). The new JENSA gas-jet target for astrophysical radioactive beam experiments. *Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms, 376*, 326-328. https://doi.org/10.1016/j.nimb.2015.11.042

Authors

D. W. Bardayan, K. A. Chipps, S. Ahn, J. C. Blackmon, J. Browne, U. Greife, K. L. Jones, A. Kontos, R. L. Kozub, L. Linhardt, B. Manning, M. Matoš, P. D. O'Malley, F. Montes, S. Ota, S. D. Pain, W. A. Peters, S. T. Pittman, A. Sachs, H. Schatz, K. T. Schmitt, M. S. Smith, and P. Thompson

The new JENSA gas-jet target for astrophysical radioactive beam experiments

D. W. Bardayan[a], K. A. Chipps[b,c,d], S. Ahn[c,e], J. C. Blackmon[f], J. Browne[e], U. Greife[d], K. L. Jones[c], A. Kontos[e], R. L. Kozub[g], L. Linhardt[f], B. Manning[h], M. Matoš[b,c], P. D. O'Malley[a], F. Montes[e], S. Ota[h], S. D. Pain[b], W. A. Peters[b,c], S. T. Pittman[b,c], A. Sachs[c], H. Schatz[e,i], K. T. Schmitt[b,c], M. S. Smith[b], P. Thompson[c]

[a]*Dept. of Physics, University of Notre Dame, Notre Dame, IN 46556, USA*
[b]*Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA*
[c]*Dept. of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA*
[d]*Physics Dept., Colorado School of Mines, Golden, CO 80401, USA*
[e]*National Superconducting Cyclotron Laboratory, East Lansing, MI 48824, USA*
[f]*Dept. of Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803, USA*
[g]*Physics Dept., Tennessee Technological University, Cookeville, TN 38505, USA*
[h]*Dept. of Physics and Astronomy, Rutgers University, Piscataway, NJ 08854, USA*
[i]*Dept. of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA*

Abstract

To take full advantage of advanced exotic beam facilities, target technology must also be advanced. Particularly important to the study of astrophysical reaction rates is the creation of localized and dense targets of hydrogen and helium. The Jet Experiments in Nuclear Structure and Astrophysics (JENSA) gas-jet target has been constructed for this purpose. JENSA was constructed at Oak Ridge National Laboratory (ORNL) where it was tested and characterized, and has now moved to the ReA3 reaccelerated beam hall at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University for use with radioactive beams.

The application of nuclear transfer reaction studies to exotic nuclei is a primary method by which reactions of astrophysical interest can be experimentally constrained. Such studies require that the outgoing reaction products be detected with good energy and angular resolution and that the

Preprint submitted to Nuclear Instruments and Methods B *November 25, 2015*

reactions of interest be clearly distinguished from background reactions. Application of transfer reactions techniques on exotic nuclei are greatly facilitated by the availability of a localized high-density target of gaseous elements. The target must be of sufficient density ($> 5\times10^{18}$ atoms/cm^2) to apply these techniques to exotic beams. For a given elemental thickness, the use of pure gases reduces the energy loss of the beam through the target (i.e., degradation of the energy resolution is minimized) and reduces the probability of contaminant reactions. Ideally, the gas volume should be well-matched to the beam spot size ($\sim$3 mm) such that reaction angles can be unambiguously determined. Finally, the beam-target interaction point should be surrounded with an efficient high-resolution charged particle array [e.g., the SuperORRUBA (Oak Ridge Rutgers University Barrel Array)[1] of silicon detectors]. The JENSA gas-jet target has been constructed with these design criteria in mind [2] allowing approximately 50% coverage over the detector angular range $20^\circ - 160^\circ$ in the laboratory.

The operating principle of the JENSA target is as follows. Target gas is compressed by an industrial compressor [PDC Machines PDC-4-100-500(150)] to high pressure (200-400 psi) before injection through a Laval nozzle into the target chamber. After traveling $\sim$ 14 mm through vacuum, the gas is collected in a pair of concentric conical receivers which are pumped in parallel by high throughput roots pumps (Leybold WSU2001 and WSU1001). Multistage rootsblowers (Ebara A10S) compress the gas further before injection back into the PDC compressor for recirculation. Differential pumping through flow-restricting apertures has been employed to maintain low beamline pressures outside of the target. The aperture sizes range from 3-5 mm and 15-28 mm on the upstream and downstream sides of the target chamber, respectively. Each pumping region, separated by an aperture, is independently pumped by turbomolecular pumps resulting in pressures ranging from $\sim 10^{-6} - 10^{-7}$ Torr at 50 cm from the target jet. The beam is tuned through these apertures for bombardment of the target gas.

The spatial distribution and density of the gas jet have been determined with measurements of α energy loss from radioactive sources [2]. One detector of the SuperORRUBA array was used to detect the α particles after they traveled through the gas jet. The transmission of the α particles through the jet produces energy loss observable from the energy vs. position detector spectra. The energy loss measured in the shadow of the jet could be extrapolated back to the jet position to determine the target width and areal density. For a jet of ^{4}He gas injected through a Laval nozzle 1.1-mm wide

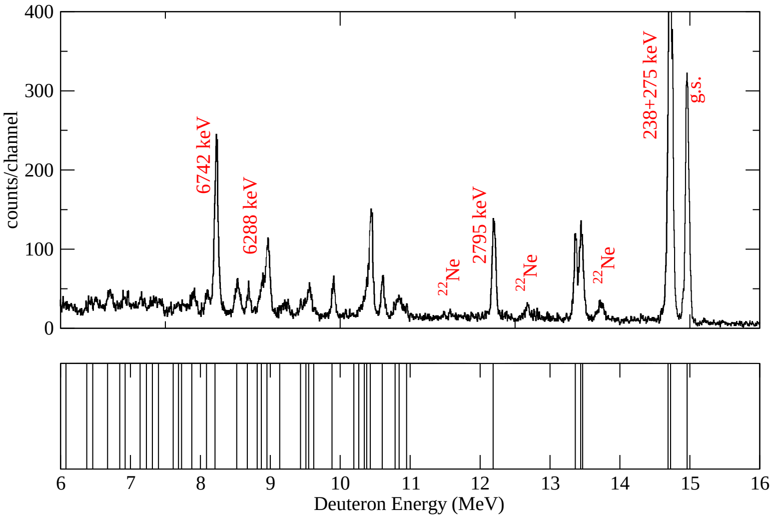

Figure 1: (top)The deuteron spectrum from the $^{20}\mathrm{Ne}(p,d)^{19}\mathrm{Ne}$ reaction are shown. All observed peaks are from reactions on $^{20}\mathrm{Ne}$ except for those labeled $^{22}\mathrm{Ne}$. (bottom) The expected energies of deuterons populating known levels in $^{19}\mathrm{Ne}$.

at an inlet pressure of 400 psi, target densities greater than 10^{19} atoms/cm^2 were obtained with a spatial width of 5 mm FWHM.

First experiments with JENSA have been performed at the ORNL Holifield Radioactive Ion Beam Facility (HRIBF). Targets were made of natural abundance He, N_2, and Ne gases. These were used to study the $^{4}\mathrm{He}(^{15}\mathrm{N},\alpha)^{15}\mathrm{N}$, $^{14}\mathrm{N}(p,t)^{12}\mathrm{N}$, $^{20}\mathrm{Ne}(p,d)^{19}\mathrm{Ne}$, and $^{20}\mathrm{Ne}(p,t)^{18}\mathrm{Ne}$ reactions to address open questions in nuclear astrophysics and nuclear structure. The observed deuteron energy spectrum from the $^{20}\mathrm{Ne}(p,d)^{19}\mathrm{Ne}$ study is plotted in Fig. 1. Excellent correspondence was obtained between the observed spectrum and known energy levels in $^{19}\mathrm{Ne}$ indicating the chemically-pure nature of the target. This is in sharp contrast to the previous attempt to study this reaction with an implanted target, which suffered from severe contamination of the spectrum due to the large number of the target constituents [3, 4].

In the Fall of 2013, the JENSA target was moved to the reaccelerated beam hall, ReA3 [5], at the NSCL for use with exotic beams. At ReA3 primary beam fragments are thermalized in a gas cell, extracted, and then reaccelerated to energies of 3-6 MeV/u. The JENSA target will be used to study reactions in inverse kinematics such as $(^{3}\mathrm{He},d)$, (d,p), and (α,p) on beams primarily of astrophysical interest. Commissioning of JENSA at ReA3 is in progress but stable beams have already been successfully tuned through

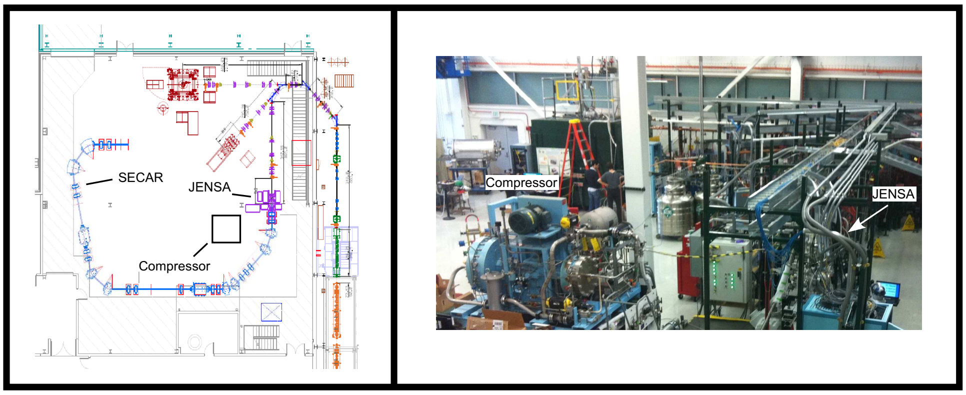

Figure 2: (right) A picture showing the placement of JENSA in the ReA3 hall. The industrial compressor is visible at the bottom left. (left) A schematic of the ReA3 experimental hall. A preliminary design of the coupling to SECAR is shown.

the target. Use of the target for the study of $(^3\mathrm{He}, d)$ reactions is of high priority, and approximately one-half of the required 200 liters of ^{3}He has been procured with the remainder expected to be purchased in 2016. A picture of JENSA in place at ReA3 is shown in Fig. 2. As the NSCL transitions to the Facility for Rare Isotope Beams, it is envisioned that JENSA will become the target for a new recoil separator SECAR [6].

In conclusion, advances in nuclear astrophysics are often driven by technical advances in studying the nuclear reaction rates. The construction of the JENSA gas-jet target represents such an advance and enables a new program of studies with exotic beams. First tests and experiments with JENSA at HRIBF have demonstrated its remarkable performance. JENSA has now been installed at ReA3 at the NSCL and commissioning is in progress. The first measurement with a radioactive beam will be a study of the $^4\mathrm{He}(^{34}\mathrm{Ar},p)^{37}\mathrm{K}$ reaction of importance to X-ray burst nucleosynthesis [7]. This work was supported by U.S. DOE Office of Nuclear Physics and by the NSF under grant nos. NSF PHY 08-22648 (JINA) and NSF PHY-1430152 (JINA CEE).

[1] D. W. Bardayan *et al.*, Nucl. Instrum. Meth. A **711**, 160 (2013).
[2] K. A. Chipps *et al.*, Nucl. Instrum. Meth. A **763**, 553 (2014).
[3] P. D. O'Malley, Ph. D. thesis, Rutgers University (2012).
[4] S. D. Pain, AIP Advances **4**, 041015 (2014).
[5] D. Leitner, Nucl. Instrum. Meth. B **317**, 235 (2013).
[6] G. Berg *et al.*, AIP Conf. Proc. **1269**, 445 (2010).
[7] K. A. Chipps *et al.*, NSCL experiment No. 15232.