STOPPING ENERGETIC BEAMS IN GAS

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1 INTRODUCTION

The investigation of nuclei far off stability and with very short half-lives is for the most part limited to experiments that use in-flight techniques. The efficient production and in-flight separation of these exotic nuclei involves high beam energies of at least 50–100 MeV/nucleon. This makes it difficult or even impossible to study very exotic or short-lived nuclei at low energies or in ion traps. A solution would be to produce and separate the exotic nuclei at high energies and to slow them down far enough to be able to stop them in a catcher gas cell. From the gas cell, the ions can then subsequently be extracted in a very short time, as is done in the IGISOL (ion guide isotope separator) technique [1], and reaccelerated or loaded into an ion trap.

The atomic slowing down in matter provides the fastest method to reduce an energetic beam to energies of a few MeV/nucleon, which are suited to catch the ions in a gas cell. The efficiency of the gas stopping technique will depend on how range straggling in the degrader and stopping gas effects the range distribution of the ions. To investigate this question, we undertook a simple experiment where we measured the range straggling of ^{36}Ar ions in a He filled gas cell after they passed through an aluminum energy degrader. A Monte Carlo simulation was employed to reproduce these measurements.

2 THE MEASUREMENT

Primary beams of ^{36}Ar at 75 and 100 MeV/nucleon passed through a plastic scintillator and a variable aluminum energy degrader before entering a gas cell that was filled with He gas. The transmission of the primary beam particles between the plastic scintillator and a set of two 500 µm silicon detectors inside the gas volume was measured at pressures of 0–1000 Torr. The thickness of the aluminum degrader was adjusted so that the complete range distribution could be scanned within the range of available gas pressures. Reaction products were discriminated by a ΔE-E measurement in the silicon detectors.

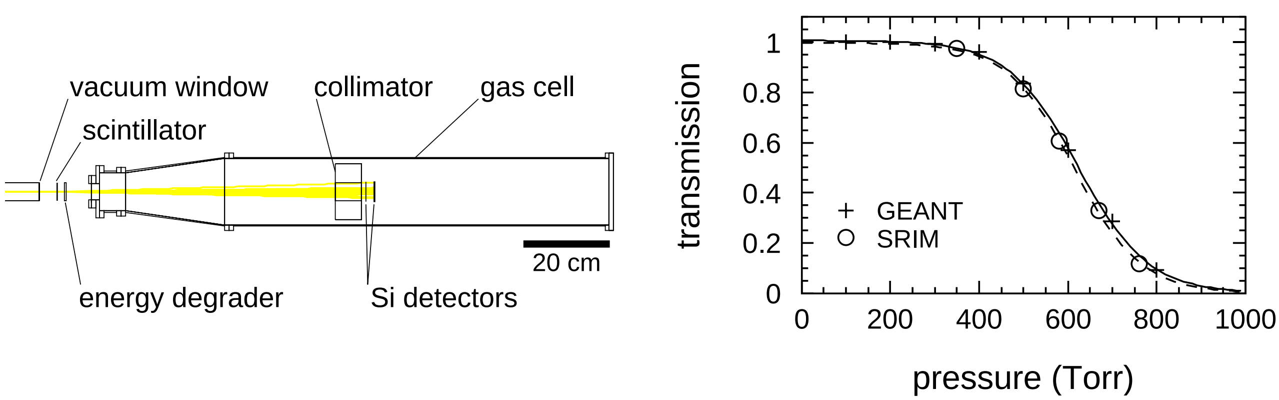

Figure 1: Basic layout of the experimental setup (left panel). The right panel shows a comparison of transmission curves calculated by SRIM and GEANT for 100 MeV/u ^{36}Ar in 50 cm He gas. A 4.135 mm Al energy degrader was used for the simulations. The width parameter of a Woods-Saxon fit to the SRIM distribution (circles) is 76 Torr, while GEANT (cross-hairs) yields 78 Torr.

The range straggling was inferred from the transmission of particles as a function of gas pressure. In order to be identified, the particles had to be detected in both silicon detectors. Particles that stopped in the first silicon detector therefore were not counted. The range distribution that would be obtained if all particles stopped in the gas can then be determined using a simulation that reproduces the transmission measurements.

3 THE SIMULATION

In a gas catcher cell, the geometry of the cell has a major impact on the rate of ions that can be stopped in the gas volume and extracted. Especially in consideration of the complex dynamics of the gas flow for extracting the ions, it is crucial to know where the ions stop if precise predictions about the efficiency and lifetime limitations have to be made. Considering this, we chose the Monte Carlo code GEANT [2] in combination with the hadronic interaction package FLUKA [3] for our simulation. Since GEANT was not specifically designed for this task, careful checks and adjustments of parameters were undertaken.

Figure 1, right panel, shows a comparison between two transmission curves calculated with SRIM [4] and GEANT/FLUKA, based on an ideal setup consisting of an Al degrader and a He gas volume only. The GEANT simulation gives us the possibility to track each ion through various materials and the gas, taking the detailed geometrical setup into account, and to graphically display these tracks. The measured transmission curves for ^{36}Ar at 100 and 75 MeV/nucleon are presented in Fig. 2. Three parameters in the simulation were adjusted in order to reproduce the measured curves: the thickness of the aluminum degrader, the divergence of the beam, and the energy spread of the incoming beam particles. With the degrader thickness the position of the curve on the pressure scale was adjusted. The thickness that was needed in the simulation deviates by about 2% due to uncertainties in the degrader setting and uncertainties the thickness of other materials in the beam path. Since there were no position sensitive detectors used in this simple setup, the transmissions at zero gas pressure was used to adjust the angular divergence of the incoming beam. Finally, inhomogeneities in the degrader thickness and the energy spread of the incoming beam particles broaden the range distribution in the gas cell. In the simulation, only the energy

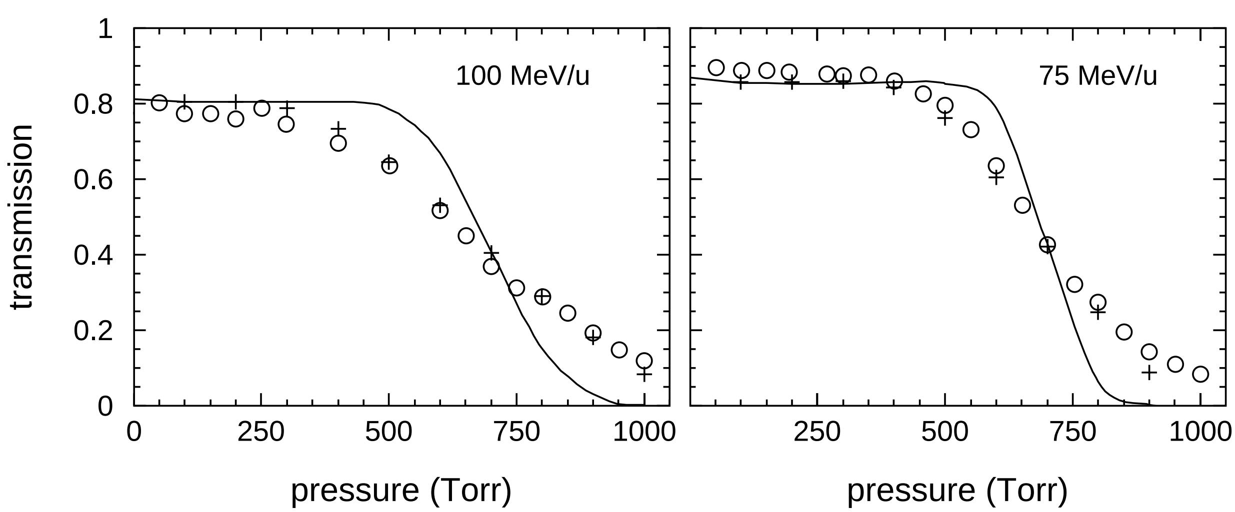

Figure 2: Transmission curves obtained with beams of ^{36}Ar at 100 MeV/nucleon (left panel) and 75 MeV/nucleon (right panel). The experimental data (circles) are shown together with the results of the GEANT calculation (cross-hairs). The solid curves correspond to calculations with no energy spread in the primary beam.

spread of the incoming beam was adjusted to account for this. The measured transmission curves could be reproduced with an energy spread of 3.5‰. Since the primary beam has an energy spread of approximately 1‰, there is a large contribution from inhomogeneities in the degrader. Transmission curves that were obtained by removing any energy spread, reflecting the actual range straggling in the gas, are plotted as solid lines in Fig. 2. The simulation yields a range straggling for a 100 MeV/nucleon ^{36}Ar beam on 4.135 mm Al and He gas at 760 Torr of $\sigma_R = 8.5$ cm with ideal conditions, i.e. with homogeneous energy degrader and no energy spread of the incoming beam particles. Without the energy degrader, the range straggling would be 7.4 cm (at a range of about 50 m). ATIMA [5–7] yields a comparable value of $\sigma_R = 9.3$ cm.

4 CONCLUSION

The comparison of measurement and simulation shows that the homogeneity of the energy degrader and the energy spread of the beam are crucial parameters in obtaining a narrow range distribution. Although the range distribution in the gas is not considerably broadened by the energy degrader, it appears that the width of the range distribution will put a limit on the minimum achievable size of the gas cell. The energy spread of the incoming beam particles directly influences the range distribution. For secondary beams with typically large energy spreads special measures have to be taken in order to overcome this problem. If the main slowing down is done in a homogeneous degrader that is followed by a dispersive spectrometer stage, a wedge-shaped monoenergetic degrader at the dispersive plane can exactly compensate the energy spread of the secondary beam and the energy straggling that arises in the homogeneous degrader [8]. This results in a range straggling that is smaller than that of an ideal monoenergetic beam slowed down without the method of range bunching.

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