Installed in the G-straight section, is the RF-solenoid. Besides being able to create depolarizing resonances for ring spin dynamics studies (CE-20), this solenoid can "flip" the spin of the beam in the ring on a relatively fast time scale. This sytem is nearly ready for other experiments to use as a way to minimize systematic errors in polarized beam experiments.

HIGH-LUMINOSITY HYDROGEN JET TARGET DEVELOPMENT

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Development work toward an improved high-luminosity hydrogen jet target has continued over the past year. A new method was developed that made it possible to study in detail the density profiles of hydrogen jets. The dependence on the nozzle temperature and geometry has been investigated exhaustively.

This work was motivated by the expectation that unpolarized internal hydrogen targets will continue to play an important role in experiments demanding high luminosity, such as in pion production near threshold, or as a meson production target in studies of rare decay modes. Typically, for the IUCF Cooler storage ring with proton beam energies of a few hundred MeV, the time averaged luminosity is maximum for a H_2 target thickness of $\sim 10^{16}$ atoms/cm^2 (Ref. 1). This is much higher than what has been achieved with H_2 cluster jet targets for which thicknesses of up to 3×10^{14} atoms/cm^2 have been reported[2] (for higher energy storage rings, such as LISS, this shortfall is even more severe). Our supersonic jet target,[3] which has been in operation for over six years, easily provides the optimum thickness because the nozzle is positioned close (3 - 7 mm) to the Cooler beam. However, there is background gas surrounding the jet, representing 20 - 40% of the target thickness. Obviously, the presence of such background gas can create severe difficulties, depending on the specifics of the experiment. The goal of the development reported here has been to improve the localization of our jet target without sacrificing the capability of reaching optimum thicknesses.

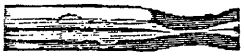
The main effort for reducing the background gas was directed toward optimizing the jet formation in the nozzle in order to minimize the gas flow rate needed to achieve the optimum jet thickness, i.e., $\sim 10^{16}$ atoms/cm^2. A year ago, we reported[4] results obtained with the "fractional flow" method. Unfortunately, this method is quite cumbersome and fraught with uncertainties that severely limited its usefulness. Therefore, we made an effort to develop another method which is based on scanning the gas jet with an ionizing electron beam. While this method had been used successfully at our laboratory to study jets of N_2, Ar,[5] and H_2O,[6] its application to H_2 proved more difficult mainly for two reasons. First, the ionization cross-section is much smaller and second, the signal-to-background ratio in the ionization current was worse because H_2 jets are relatively less dense than those of heavier gases and the background gas density is higher due to the lower compression ratio of turbo pumps. Furthermore, the high background gas pressure adversely affected the performance of the electron gun.

Our experimental setup was similar to that used in previous experiments.[4,5] The nozzle was mounted on the head of a closed-cycle helium expander refrigerator (Leybold RG1040), connected to a side port of the main vacuum chamber. The jet was directed horizontally towards the center of the chamber into a conical-shaped catcher tube which was separated from the nozzle by typically 20 mm and pumped through the side port opposite to the cold head and nozzle. In order to alleviate the above mentioned difficulties caused by the high background pressure encountered in the old setup, we have significantly improved the pumping capacity. The turbo pump on the main chamber (Balzers TPH 1500) was replaced with a faster one (TPH 2200), which has twice the H_2 pumping speed, and which was then backed by the TPH 1500. This reduced the background pressure by more than a factor of three. We also improved the pumping on the catcher with a second turbo (Balzers TPU 510) backing the first (TPU 510).

An electron gun (Cliftronics type 406) was installed in a little chamber, separated from the main chamber by a differential pumping aperture, and pumped by a 4 inch diffusion pump (Cooke model DPD4-1250). The 1 keV electron beam scanned the jet at a right angle. Its current, typically about 0.7 μA, was measured with a 2.5 cm by 2.5 cm tantalum beam stopper, positioned a few cm after the jet and biased at +40 V. In order to tune the electron gun and to scan its beam profile, the beam was swept across a 0.3 mm hole at the center of the tantalum plate, horizontally and vertically, while measuring the current on a stopping electrode behind it. The beam profile FWHM was slightly less than 1 mm in both dimensions. The gas jet thickness profile was scanned by sweeping the electron beam vertically across the jet and measuring the positive ion current with a collector electrode at the entrance of the catcher tube. The collector consisted of two concentric rings (11 and 25-mm diam.) in a plane perpendicular to the jet axis, held together by three radial wires designed to minimize interference with the jet. We determined experimentally that the collector had to be biased at −50 V to ensure complete collection of ions from the jet. Jet scanning was automated by a PC and a programmable electrometer (Keithley model 617) which, for a preset range and step size, put out the voltage to the vertical e-beam deflector and read in the ion current on the collector. Background scans were done by leaking gas elsewhere into the chamber, adjusted to maintain the same background pressure. The jet thickness $t = i_i/(i_e \sigma)$, where i_e and i_i are the electron beam and background subtracted ion current, and $\sigma = 2.3 \times 10^{-17}$ cm^2 is the total ionization cross section for 1 keV electrons on H_2.[7] As a check on this method, we compared our results with a measurement based on small angle elastic scattering of 25 keV electrons[8] using the same nozzle at room temperature. The thickness profiles agree within the estimated 20% uncertainty of each method.

We have scanned jets from 23 different nozzles. All but one were made from glass capillaries of 1 - 2 mm i.d. (the only exception being the copper nozzle of the existing jet target[3]). The capillaries were heated locally with a torch, under slow rotation about their axis to achieve an even temperature distribution, until the inner diameter narrowed to form a converging-diverging passage. While it is difficult to control the resulting geometry of

Figure 1. Full size photograph of a nozzle made from a 2 mm i.d. glass capillary. The throat diameter is 108 μm, widening to 1.4 mm at the exit.



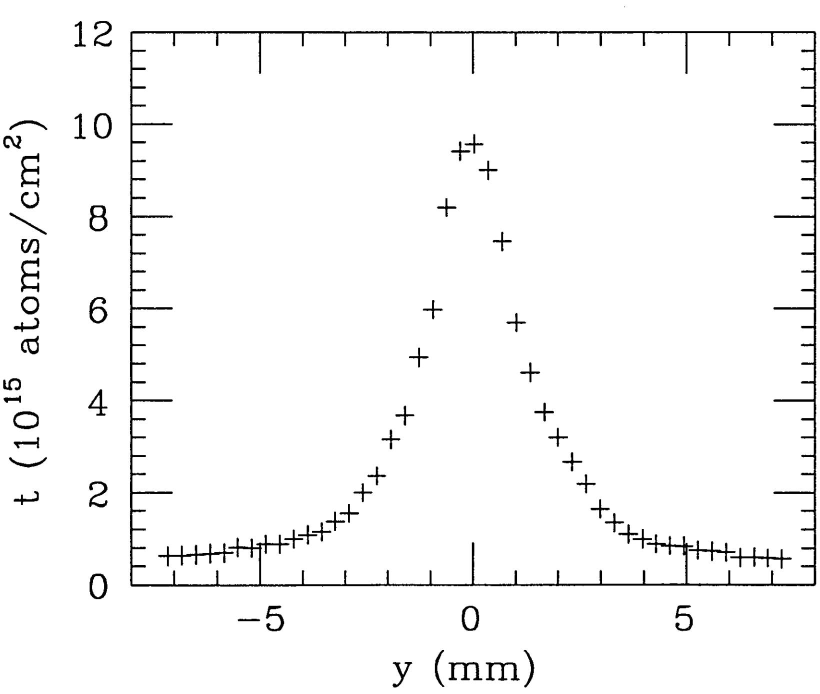


Figure 2. Thickness profile of an H_2 jet from the nozzle of Fig. 1, measured with a 1 keV electron beam scanning the jet transversely (y-axis) 5 mm from the nozzle tip. The flow rate was 1.04 $\times 10^{20}$ molecules/s and the nozzle temperature was 38 K.

any individual nozzle, we have ended up with a selection covering a large range of shapes. An example is shown in Fig. 1. In order to cool these glass nozzles efficiently over their full length, they were mounted on the cold head inside a massive conical copper piece. The temperature was measured with a sensor sunk into the copper mount.

Most jets were scanned transversely at 5 mm from the nozzle exit (typically the distance at which the Cooler beam interacts with the jet) as a function of nozzle temperature below 100 K. In a few cases, we also measured jet profiles as a function of distance from the nozzle, of nozzle flow rate, or of temperature up to 300 K. As an example, Fig. 2 shows a thickness profile of a jet from the nozzle of Fig. 1. Each of the measured profiles was fitted with a bell-shaped function in order to determine the peak thickness and the width.

The results can be summarized as follows. First, our original expectation that narrower nozzles (than the 110 μm throat diameter nozzle of the existing jet target[3]) would produce more forward peaked jet flows and greater thickness was not born out by our experiments. We used nozzles with throat diameters, d_t, ranging from 24 to 220 μm. The optimum d_t appears to be in the range of 90 - 120 μm. There, we observed the narrowest jets with the highest peak thickness (for an example see Fig. 2). As far as other parameters of the nozzle geometry, such as the length and opening angle of the divergent part, we have not observed any pronounced effect on the jet profile. The measured temperature dependence of peak thickness, t_{peak}, and width of a jet from the nozzle of Fig. 1 is shown in Fig. 3. The thickness increases with decreasing temperature until it reaches a plateau at about 40 K, while the jet width narrows until it is minimum at 40 K, then widens again. Obviously, the optimum temperature for this nozzle is 40 K. Generally, the optimum temperature was found to depend somewhat on the nozzle diameter, decreasing with increasing d_t. For our widest nozzles, the onset of the t_{peak} plateau and the minimum width were apparently below the lowest temperature we could reach ($\sim$ 25 K). On the other hand, the thickness of jets from our narrowest nozzles leveled off ($\sim$ 30% below the highest values, obtained with the nozzle of Fig. 1 and shown in Fig. 2) at higher temperatures. Their width did not have the pronounced minimum shown in Fig. 3. Possibly, viscous effects are more important for narrower nozzles. For comparison with the glass nozzles, we also scanned the jet from our previously used 110 μm copper nozzle.[3] Surprisingly (considering the ragged wall surface of this nozzle), the results are quite similar to those shown in Figs. 2 and 3, with the maximum t_{peak} being just 7% lower.

Finally, we briefly measured another factor affecting the background gas pressure, namely the catcher efficiency, i.e., the fraction of the jet flow removed through the catcher. Measurements done with two catcher tubes (opening diameter: 26 and 29 mm) over a nozzle temperature range of 30 to 90 K indicated little dependence on these two parameters, with a value of 60% for the 26 mm catcher at 40 K.

The jet target, with the nozzle shown in Fig. 1, was installed in April, 1994 in the Cooler T-section for CE38 ($p\vec{p} \rightarrow pn\pi^+$) and CE49 [pionium production in $pd \rightarrow {}^3He(\pi^+\pi^-)$]. Improvements in the pumping speed on the first stage were implemented, as described above for the test setup. The deuterium jet target performed without problems during the first pionium run, and jet profiles from the luminosity monitor, based on pd elastic scattering, will soon be available.

In conclusion, our studies did not demonstrate any dramatic jet formation effect from different nozzle geometries. More important seems to be the dependence on the nozzle temperature. For the time being, we have concluded this development project. Should the need arise in the future, any further significant improvement in H_2 jet localization would probably have to come from a more radical redesign of the jet target. Background gas could be reduced with one or two jet skimmers between nozzle and the target chamber, and with differential pumping along the jet, similar to the design used for cluster jet targets.[2]

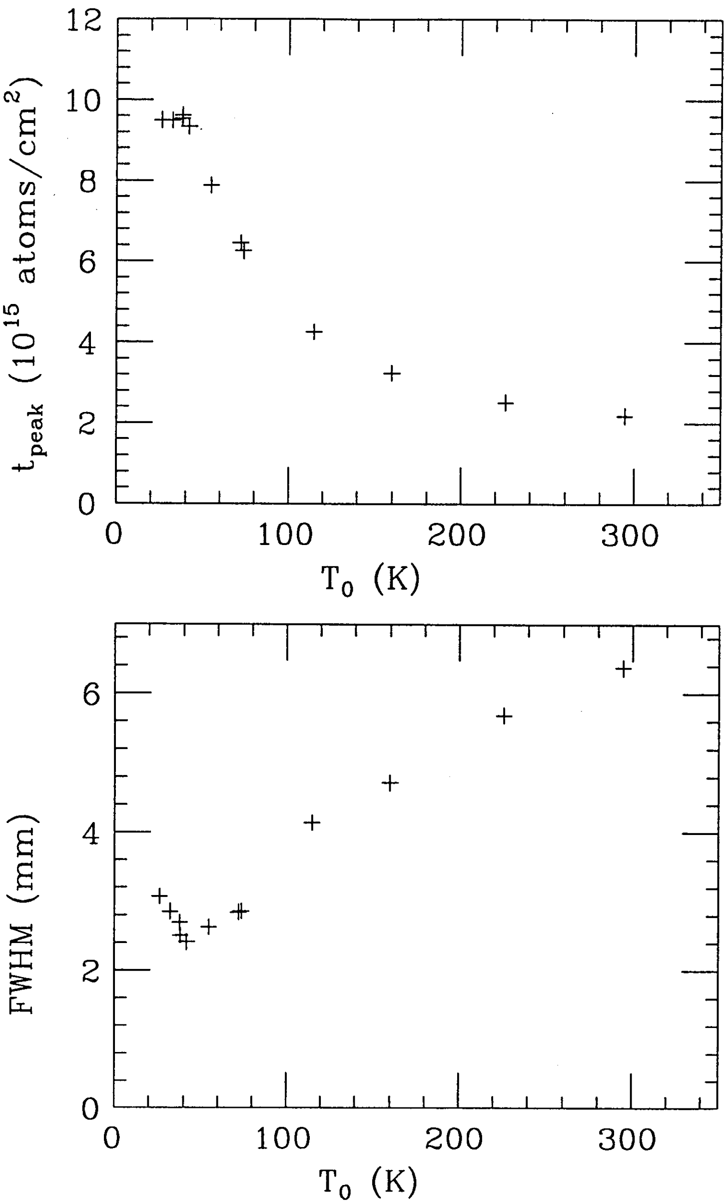


Figure 3. Temperature dependence of the peak thickness and the width of the H_2 jet profile obtained with the nozzle of Fig. 1. The distance from the nozzle was 5 mm and the flow rate was 1.04 $\times 10^{20}$ molecules/s.

However, this would increase the distance from nozzle to target point considerably, and thus would imply correspondingly higher nozzle flow rates in order to maintain optimum target thickness.

We would like to thank Richard Ghrist for his help with the development of the experimental method, Tom Rinckel for implementing the PC based scanning controls, and Bill Lozowski for his assistance with the preparation of the glass nozzles.

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POLARIZED HYDROGEN GAS TARGET IN THE COOLER

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In the previous Annual Report we described the installation of the Wisconsin polarized hydrogen gas target in the Cooler. The installation was nearly completed at that time, but no tests with beam through the target had yet been made. In the meantime, considerable experience has been gained in the use of this target. Preliminary results on pp spin correlation measurements are described in another contribution to this report.[1]

Briefly, the target consists of a 25-cm long cell into which polarized hydrogen atoms from an atomic-beam source are injected. The open aperture of the cell, through which the proton beam of the Cooler passes, is an 8 mm × 8 mm square. The purpose of the cell is to increase the target thickness by a factor of several hundred compared to using the atomic beam as a jet target. Protons scattered into forward angles ($\theta_{lab} = 3°$ to $18°$) by hydrogen nuclei in the cell are detected by a set of wire chambers and scintillators.[1] Recoil protons are detected in coincidence by eight silicon-strip detectors which surround the target cell. The detectors are 4 cm × 6 cm each and are placed 5 cm from the beam axis. The cell walls are made of Teflon film of 5 μm thickness. Separate tests carried out earlier at Wisconsin had shown that hydrogen atoms can tolerate at least 400 wall collisions with Teflon walls without significant loss in polarization.

In the following, we summarize the most important findings that were obtained since the commissioning of the polarized target setup at IUCF began a year ago. More details,