LA-UR- 10-06024

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Intended for: XXV Linear Accelerator Conference
Tsukuba, Japan
September 12-17, 2010

Los Alamos
NATIONAL LABORATORY
EST. 1943

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Form 836 (7/06)

STRIPPING OF H^- BEAMS BY RESIDUAL GAS IN THE LINAC AT THE LOS ALAMOS NEUTRON SCIENCE CENTER

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Abstract

The linear accelerator at the Los Alamos Neutron Science Center (LANSCE) accelerates both protons and H^- ions using Cockroft-Walton-type injectors, a drift-tube linac and a coupled-cavity linac. The vacuum is maintained in the range of 10^{-6} to 10^{-7} Torr; the residual gas in the vacuum system results in some stripping of the electrons from the H^- ions resulting in beam spill and the potential for unwanted proton beams delivered to experiments. We have measured the amount of fully-stripped H^- beam (protons) that end up at approximately 800MeV in the beam switchyard at LANSCE using image plates as very sensitive detectors. We present here the motivation for the measurement, the measurement technique and results.

INTRODUCTION

The linac at the Los Alamos neutron Science Center (LANSCE) is able to simultaneously accelerate both protons and H^- ions. One particular experiment under consideration requires a beam of protons with a pulsed structure consisting of 200ns of beam on and 2000ns of beam off, repeated approximately 300 times during each machine macropulse. This experiment requires very low contaminations of the beam-off periods, with the charge delivered during the beam-off periods being less than 10^{-9} times that delivered during the beam-on periods.

One scenario for delivering beam to this experiment involves accelerating protons during machine cycles when H^- ions are also accelerated and separating the two beams with a DC bending magnet at the end of the linac. A potential source of contamination of the beam-off periods of the proton beam is H^- ions that are stripped of their electrons by residual gas in the beam vacuum system.

THE LANSCE LINAC

In order for stripped H^- ions to pose a background threat to proton-beam experiments, the resulting protons must end up with kinetic energies near the 800MeV kinetic energy of the proton beam. The potential sources of stripped H^- ions are limited by the topology of the injectors and linac, as illustrated in Figure 1. Two likely sources for contaminating H^- ions are those that are stripped in the low-energy beam transport (LEBT) and are then accelerated as protons, and those that are accelerated as H^- ions and then are stripped at an energy near 800MeV. Other sources require both stripping and migration from H^- accelerating buckets into the proton accelerating buckets, or are disallowed due to the presence of bending magnets.

A stopping-length beam-plug is present in the proton-only beam-line in the 100MeV beam-transport between the drift-tube linac (DTL) and coupled-cavity linac. This beam-plug can be inserted and retracted; this allowed us to determine the amount of contaminating protons that originated upstream of this point.

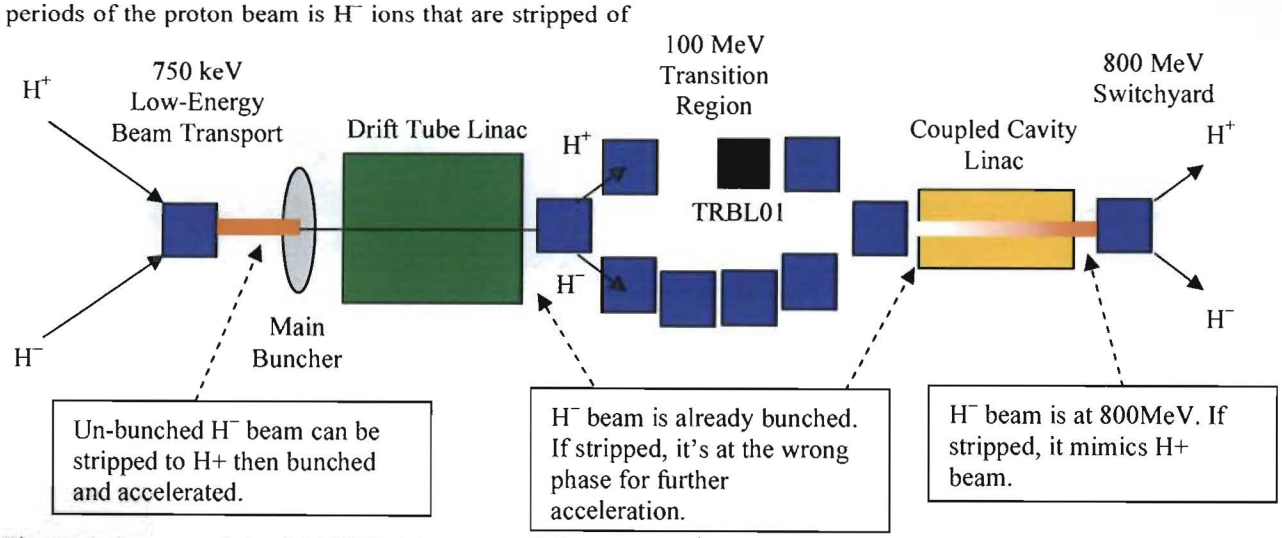

Figure 1: Layout of the LANSCE injectors and linac. The H^+ (proton) and H^- ions are accelerated to 750keV in Crockroft-Walton-type injectors. Bending magnets are shown as blue squares.

DETECTING STRIPPED BEAM

Immediately downstream of the 800MeV linac the proton and H^- beams are separated by a DC bending magnet. To measure the amount of proton beam produced by stripped H^- beam we placed image-plates in an air-gap in a proton-only beam-line and accelerated 115μA of H^- beam for specific amounts of time. This is illustrated in Figure 2.

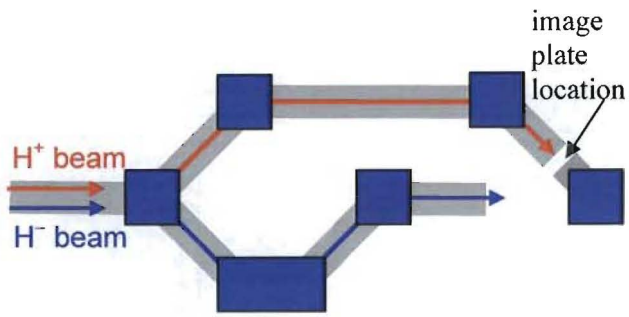

Figure 2: Layout of the beam switchyard showing the location of the image-plate used in detecting the protons that result from stripping of H^- ions. Downstream of this section H^- beam is bent out of the plane of the drawing for delivery to experiment areas.

To demonstrate that 800MeV protons would be transported to the image-plates' location we inserted into the H^- beam a 100μm-thick SiC wire at the end of the linac; the resulting protons were observed on a phosphor screen viewed by a television camera and an image plate showed a clear signal.

Image-plates are attractive for this type of measurement because of their high sensitivity and wide dynamic range. Ionizing radiation passing through the active medium in the image plate produces localized excitations to a particular metastable state, producing a record of the passage of the particle. When the image plate is illuminated by a laser beam in the readout system this metastable state emits light that is detected by a photomultiplier tube (PMT) [1]. Two major parameters to choose in the readout system are the scanning density of the laser beam and the voltage on the PMT. We chose a scanning density of 200 pixels per inch and a PMT voltage of 200V, yielding signal strengths near the middle of the system's range.

The image-plate response was calibrated by sending a known amount of protons to image-plates and processing them as those used in the contamination measurement.

The image produced by the beam is shown in Figure 3 and the analysis is summarized in Table 1. The number of protons in the calibration pulse was taken to be the same as in similar pulses delivered to beam users during the production operations period immediately preceding this experiment.

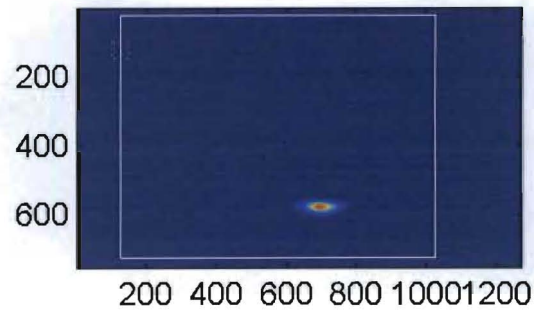

Figure 3: Image plate exposed to the calibration beam pulse. The numbers on the axes are pixel numbers; the image was scanned with a pixel density of 200/inch (200/25.4mm.) The solid and dashed rectangles indicate the signal and background regions used in the analysis.

Table 1: Analysis of the calibration beam pulse.

Proton charge in calibration pulse	0.50pC
Summed signal on image plate	411
# pixels in signal region	630000
Background per pixel	1.06×10^{-4}
Background in signal region	67
Signal minus background	344
Beam charge per unit signal	1.4 fC

MEASURING THE STRIPPING FRACTION

To measure the fraction of the H^- beam that is stripped and results in ~800MeV protons we accelerated 115μA of H^- beam and exposed an image plate to the resulting protons as shown in Figure 2. With beam-plug TRBL01 inserted we found the fraction of H^- beam that is stripped is 4×10^{-7}; this is the CCL-only contribution. With the beam-plug retracted, 9×10^{-6} of the beam is stripped. The images are shown in Figures 4 and 5, and the analysis is summarized in Table 2.

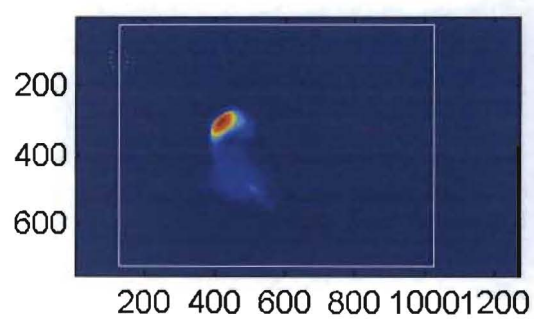

Figure 4: Image plate exposed to the contaminating proton beam with beam plug TRBL01 retracted, i.e. including protons that originate in the LEBT and DTL. The numbers on the axes are pixel numbers. The solid and dashed rectangles indicate the signal and background regions used in the analysis. The color axis has been scaled to show maximum detail in the image.

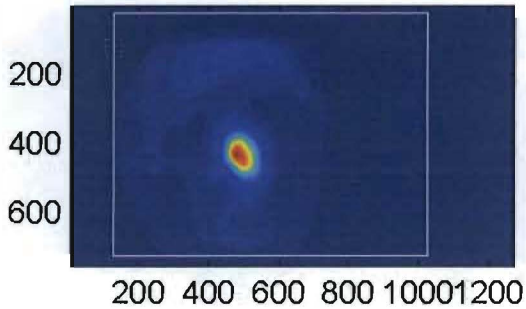

Figure 5: Image plate exposed to the CCL-only portion of the contaminating proton beam. The numbers on the axes are pixel numbers. The solid and dashed rectangles indicate the signal and background regions used in the analysis. The color axis has been scaled to show maximum detail in the image.

Table 2: Analysis of the images exposed to the protons resulting from stripping of the H^- beam ions.

	CCL-only	All
Summed signal on image plate	4678	3740
# pixels in signal region	630000	630000
Background per pixels	2.042×10^{-4}	0.944×10^{-4}
Background in signal region	129	59
Signal minus background	4550	3680
Beam charge in signal	6.6 nC	5.3 nC
H^- beam charge accelerated	16.5 mC	0.6 mC
Fraction of H^- beam stripped & contaminating	0.38×10^{-6}	9.2×10^{-6}

Stripping-induced contamination at this magnitude indicates very clearly that additional measures are necessary to remove the contamination if the experiment were to use protons accelerated simultaneously with H^- ions. As such, little effort has been expended in analyzing the precision of this measurement; initial estimates indicate that the uncertainty on the measurement is less than 10%, with the dominant sources being uncertainty in the charge in the calibration pulse, deviation from linearity in the response of the image-plates, and variations in the responses of the image-plates employed.

DISCUSSION

During this experiment a small leak resulted in vacuum pressure that was about 10 times higher than normal in the section of the LEBT just upstream of the DTL (10^{-6} Torr vs. 10^{-7} Torr.) Simulations [2] indicate that this 10-fold increase in pressure results in a 100-fold increase in stripping rate. This is due to the two-step nature of the stripping process, where H^- is first stripped to H^0+e^-, then H^0 is tripped to $H^+ + e^-$ [3]. With vacuum in this section at its normal level of 10^{-7} Torr we would expect the CCL-only contribution to be the dominant source of proton contamination; that source alone is enough to be very problematic for the proposed experiment. To mitigate this we are considering various ideas for pulsed deflectors operating on the 800MeV beam.

ACKNOWLEDGEMENT

This work was supported by the United States Department of Energy under contract DE-AC52-06NA25396.

We thank Terry Taddeucci for lending the image-plate readout system. We thank the LANSCE operators, vacuum and mechanical teams and radiological control technicians for prompt assistance while preparing and running this experiment.

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