BEAM-ENERGY AND LASER BEAM-PROFILE MONITOR AT THE BNL LINAC*

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Abstract

We are developing a non-interceptive beam profile and energy monitor for H^- beams in the high energy beam transport (HEBT) line at the Brookhaven National Lab linac. Electrons that are removed from the beam ions either by laser photodetachment or stripping by background gas are deflected into a Faraday cup. The beam profile is measured by stepping a narrow laser beam across the ion beam and measuring the electron charge vs. transverse laser position. There is a grid in front of the collector that can be biased up to 125 kV. The beam energy spectrum is determined by measuring the electron charge vs. grid voltage. Beam electrons have the same velocity as the beam and so have an energy of 1/1836 of the beam protons. A 200 MeV H^- beam yields 109keV electrons. Energy measurements can be made with either laser-stripped or gas-stripped electrons.

INTRODUCTION

In 2002 we reported on a project at BNL to develop a beam profile monitor for H^- beams using photoneutralization by a laser beam directed perpendicular to the ion beam [1]. That effort was in support of the Spallation Neutron Source being built at Oak Ridge National Lab [2]. In 2008 we reported on a prototype profile and energy monitor developed at BNL for Fermi National Lab [3] to use on the High Intensity Neutrino Source project [4]. Based on the success of the Fermi device we received funding from the BNL Linac Isotope Producer (BLIP) facility [5] to build a detector to measure beam energy and transverse profiles in the linac HEBT.

An H^- ion has a first ionization potential of 0.75 eV and can be neutralized by the 1eV photons from a Nd:YAG laser (λ=1064nm). To measure beam profiles, a narrow laser beam is stepped across the ion beam, removing electrons from the portion of the H^- beam intercepted by the laser. These electrons are deflected into a Faraday cup by a magnetic field. To measure the energy distribution of the electrons, the laser position is fixed and the voltage on a screen in front of the Faraday cup is raised in small steps.

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At the time of this writing, the laser platform is not yet installed. However we found that accurate energy measurements can be made on high-current beams (>5mA) by measuring the electrons stripped from the beam by background gas. Electrons are stripped by the residual gas in the beamline at a rate of ~$1.5x10^{-8}$/cm at $1x10^{-7}$ torr. In this detector a 30 mA beam produces about 40 nA of electron current.

In this paper we describe the detector and show results from the gas-stripped energy measurements.

DETECTOR

Figure 1 is a cutaway diagram of the detector from the side showing the signal-electron path. The neutralization chamber is a six-way cross with the laser beam passing through viewports either horizontally or vertically. An optics plate with the laser head and scanning optics is mounted on this chamber. The 100mJ/pulse, Q-switched Nd:YAG laser neutralizes 70% of the beam it intercepts during the 10ns pulse. The laser beam is scanned across the ion beam by reflecting it from a 45° mirror mounted on a linear translation stage.

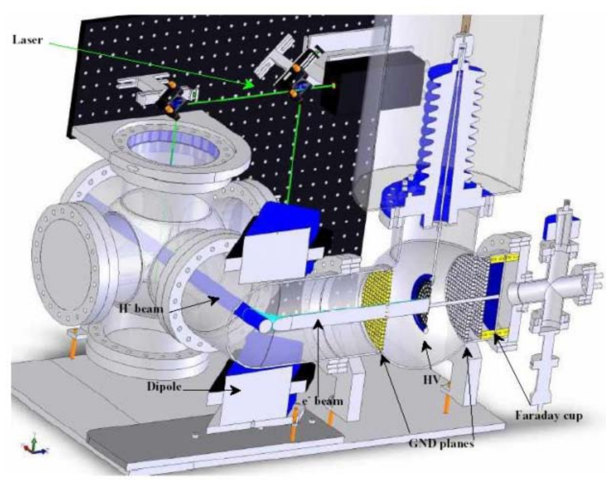

Figure 1: Cutaway schematic. Electrons from the H^- beam are deflected by a magnet through a HV grid into the Faraday collector.

Downstream a dipole magnet deflects the signal electrons 90° into the retarding grid and Faraday cup assembly. A corrector magnet upstream keeps the ion beam straight. A voltage grid in front of the collector provides secondary-electron suppression. The electron signal is transported from the tunnel over 1/4" heliax cable and digitized by a LeCroy LT584L oscilloscope. Figure 2 shows the detector installed in the HEBT beamline.

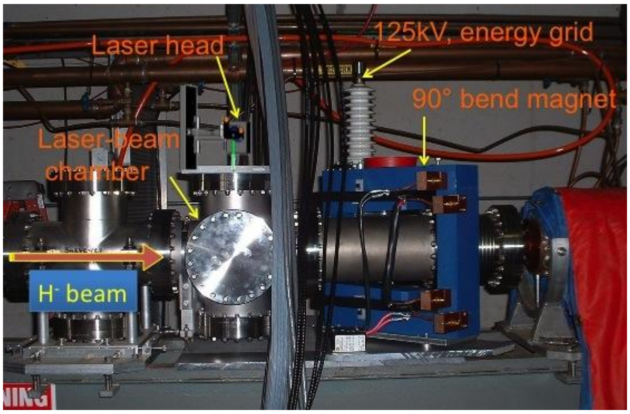

Figure 2: HEBT installation. The ion beam travels left to right. The laser chamber is left of the cable bundle and the deflector magnet is right. Electrons are deflected back through the grid and into the electron collector.

The control system is a Labview program running on a dedicated PC with digital and analog I/O through a National Instruments USB-6229 BNC. The maximum firing rate of the laser is 20 Hz so only one data point can be obtained per linac cycle (6.6 Hz). A measurement cycle is initiated by a timing pulse from the linac, which triggers the laser. The laser outputs a Q-switch synchronous pulse, which triggers the scope. The signal pulse from the Faraday cup is passed through a 10 MHz low-pass filter into the scope, which does a baseline subtraction and integrates the pulse. Upon completion of this process, the scope signals the computer, which reads the pulse.

ENERGY MEASUREMENTS

When the 2009-10 beam run started, the optics plate and enclosure were not finished. The high radiation level in the HEBT during the run prevents us from completing installation until the 2010 summer shutdown. However the BLIP program is primarily interested in beam-energy measurements, which we provide without the laser by using the gas-stripped-electron signal.

We estimate from ref. 6 a gas-stripping cross section of $\sigma \approx 4 \times 10^{-18}$ cm^2/atom. At the HEBT pressure of $\sim 1 \times 10^{-7}$ torr, the one meter drift from the upstream quad to our chamber produces about 40nA of electron current from a 30mA beam. About half of this current is lost to the four grids the signal electrons pass through. The signal current is amplified by 10^7V/A resulting in a full-beam signal of ~200 mV into the oscilloscope.

An energy measurement starts with a scan of the deflector magnet current to center the electron beam on the collector. The electron signal is integrated over each linac pulse of 400 µs, which gives data in units of volt*second. Figure 3 is the Labview screen showing the results of a magnet scan done with a 117 MeV beam.

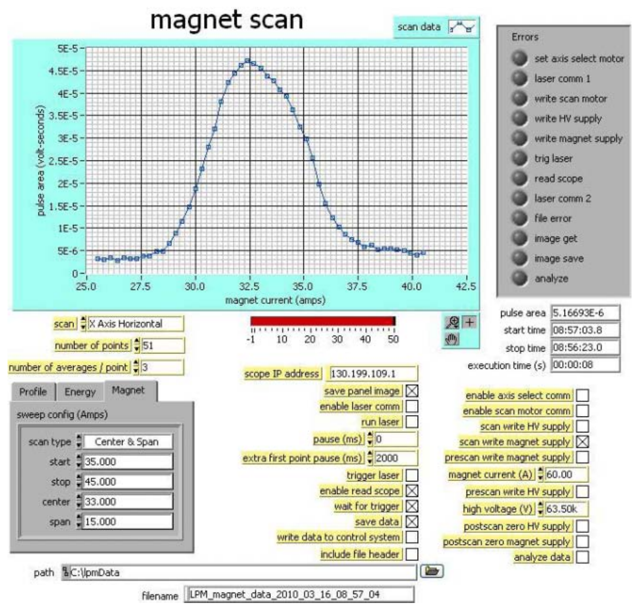

Figure 3: A magnet scan showing electron signal vs. deflector magnet current.

Figure 4 shows an energy scan that resulted in a measured beam energy of 117.06 MeV. This data set was produced by sampling 51 grid voltages over a range of 62.0 to 63.8 kV. Each point is averaged over 3 machine pulses. A sigmoid function is fitted to the data and the half-value point is taken as the electron center energy. Here the center electron energy is E_e=63.760 keV.

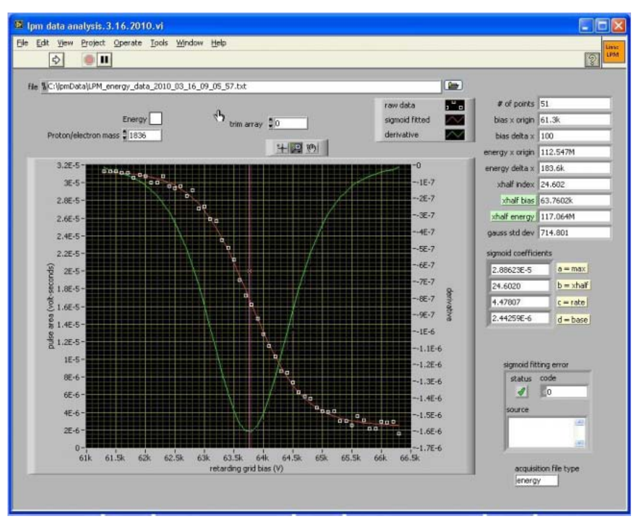

Figure 4: The analyzed data from an energy scan with a 117.06 MeV beam.

The Gaussian-like curve is the derivative of the sigmoid. From this we get the energy spread of the electrons. Most of this energy spread is from the space-charge potential spread in the bunched beam (Figure 5).

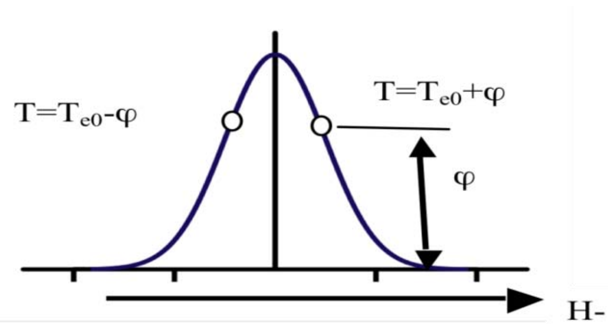

Figure 5: Illustration showing space-charge energy spread. Electrons in back of bunch lose the space-charge potential, φ, and those in front gain φ.

We did a series of energy measurements over one hour at five different beam currents (Table 1). Several measurements made at each current are averaged showing an rms measurement repeatability of about 0.03%.

Table 1. Results of energy measurements over one hour at five different beam currents.

BEAM CURRENT	FILE	MEASURED ENERGY (MeV)
40mA	09-03-43	116.99
	09-05-57	117.06
	09-07-11	117.06
	09-08-29	117.1
	09-10-20	117.01
	Average	117.04±0.04
35mA	9-16-05	117.12
	9-17-31	117.11
	9-18-59	117.11
	9-20-19	117.07
	Average	117.10±0.02
25mA	09-24-27	117.14
	09-25-38	117.14
	09-26-51	117.13
	09-28-01	117.07
	Average	117.12±0.03
15mA	09-42-01	117.17
	09-43-46	117.11
	09-45-21	117.21
	Average	117.16±0.05
5mA	09-52-54	117.01
	09-54-34	117.3
	09-56-07	117.04
	Average	117.12±0.16

DISCUSSION

When completed this detector will provide both energy and transverse-profile measurements of H^- beams with energies up to 200MeV and beam currents of 0.2-40 mA. During this beam run we are getting accurate energy measurements from the beam electrons produced by background-gas stripping. The gas-stripped-electron measurement has been demonstrated with beam currents as low as 5mA. Measurements on the 200µA polarized proton beam will probably require the laser, but we are testing new amplifier schemes.

ACKNOWLEDGEMENTS

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