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

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Abstract

In 2009 a beam-energy monitor was installed in the high energy beam transport (HEBT)line at the Brookhaven National Lab linac. This device measures the energies of electrons stripped from the 40mA H^- beam by background gas. Electrons are stripped by the 2.0×10^{-7}torr residual gas at a rate of $\sim1.5\times10^{-8}$/cm. Since beam electrons have the same velocities as beam protons, the beam proton energy is deduced by multiplying the electron energy by $m_p/m_e=1836$. A 183.6MeV H^- beam produces 100keV electrons. In 2010 we installed an optics plates containing a laser and scanning optics to add beam-profile measurement capability via photodetachment. Our 100mJ/pulse, Q-switched laser neutralizes 70% of the beam during its 10ns pulse. This paper describes the upgrades to the detector and gives profile and energy measurements.

INTRODUCTION

In 2010 we presented the first results from a new diagnostic installed in the HEBT of the BNL linac [1]. The goal of the project is to provide measurements of beam energy, energy spread and transverse profiles. During the 2009 shutdown we installed the dipole magnet which deflects signal electrons into the detection chamber, but we did not install the optics plate with the laser and the second magnet which corrects the bend the detector magnet imparts to the H^- beam. During the 2010 shutdown we finished the tunnel installation and bought a new signal amplifier.

An H^- ion has a first ionization potential of 0.75eV so one electron can be removed by the 1eV photons from a Nd:YAG laser (λ=1064nm). Beam profiles can be measured by stepping a narrow laser beam across the ion beam to remove electrons from the portion of the H^- beam intercepted by the laser. The electrons are deflected into a Faraday cup by a magnetic field.

Electrons stripped from the H^- beam have the same velocity as the beam so the electron energy/proton energy ratio is the electron mass/proton mass ratio of 1836 [$E_k=(\gamma-1)mc^2$]. We measure the energy distribution of the electrons by passing the electrons through a chamber with a biased grid between two parallel grounded grids. For all energy measurements reported here we have used the electrons produced by background gas stripping. Gas stripping produces usable signals for beams above 5mA. Laser stripping will be required for energy measurements of the 200µA polarized beams.

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.

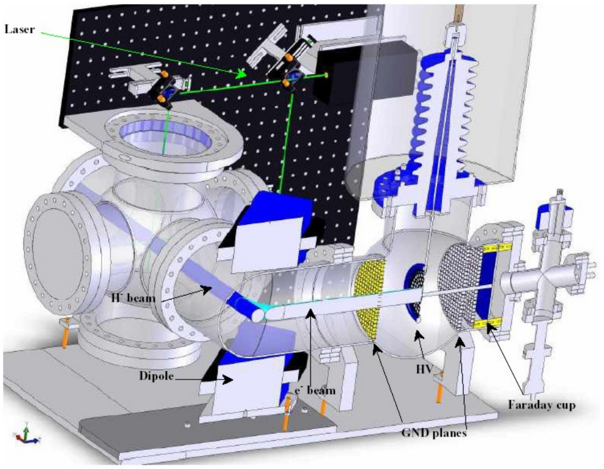

Figure 1: Cutaway schematic. Electrons from the H^- beam are deflected by a magnet through a HV grid into the Faraday collector.

Downstream a dipole magnet deflects the signal electrons 90° through the retarding grid and into the 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, amplified by a Stanford Research Systems SR570 amplifier, and digitized by a LeCroy LT584L

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oscilloscope. Figure 2 shows the detector installed in the HEBT beamline.

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 20Hz so only one data point can be obtained per linac cycle (6.6Hz). A profile 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.

For energy measurements on gas-stripped electrons a linac timing signal triggers the scope. An integration gate is set on the scope. In both cases the scope delivers the integral of the signal over either the 10ns duration of the laser pulse or some fraction of the 400μs duration of the

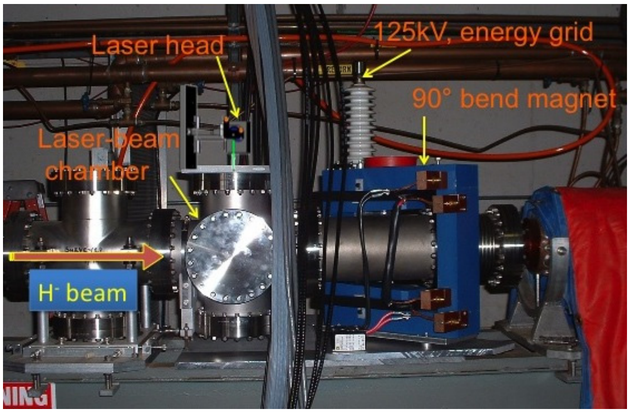
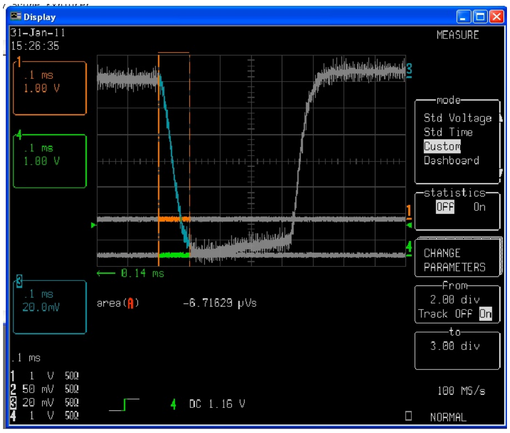


Figure 2: HEBT installation. The ion beam travels left to right. The laser chamber is left of the cable bundle and the deflector magnet is right.



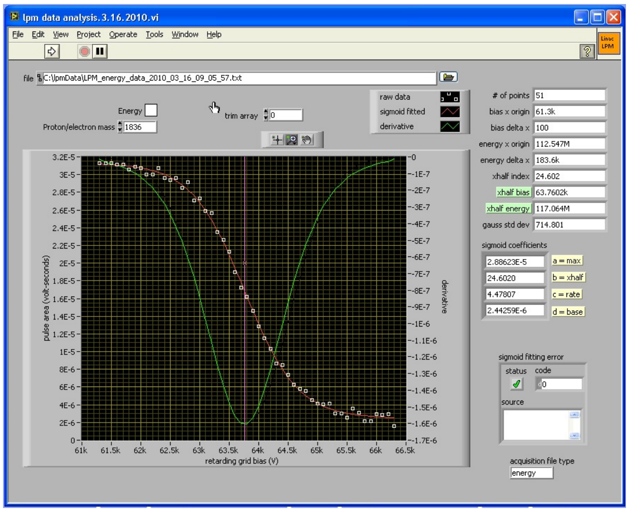
area(A) -6.71629 μVs

Figure 3: The gas-stripped electron signal from the full linac pulse. The pulse is 500 μs long and the integration gate is set to measure the first 100μs of the beam.

ENERGY MEASUREMENTS

To estimate the signal we find a gas-stripping cross section of σ≈4x10^{-18} cm^2/atom for oxygen and nitrogen from [2]. At the HEBT pressure of 2.0x10^{-7} torr and using this cross section, the half-meter drift from the upstream corrector magnet to our detector magnet would produce about 50nA of electron current from a 35mA beam. About half of this current is lost to the four grids that the signal electrons pass through so our estimate signal is about 25nA. The 130mV pulse shown in fig 3 was made with an amplifier gain of 100nA/V so we actually collected 13nA.

Figure 4 shows an energy scan that resulted in a measured beam energy of 117.06MeV. This data set was produced by sampling 51 grid voltages over a range of 62.0kV to 63.8kV. 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=63.760keV.



file C:\lpmData\LPM_energy_data_2010_03_16_09_05_57.txt
Energy ☐
Proton/electron mass 1836
trim array 0
# of points 51
bias x origin 61.3k
bias delta x 100
energy x origin 112.547M
energy delta x 183.6k
xhalf index 24.602
xhalf bias 63.7602k
xhalf energy 117.064M
gauss std dev 714.801
sigmoid coefficients
2.88623E-5 a = max
24.6020 b = xhalf
4.47807 c = rate
2.44259E-6 d = base
sigmoid fitting error
status ✓ code 0
source
acquisition file type energy

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

The bell curve is the derivative of the sigmoid. We fit a Gaussian to the derivative and define the energy spread of the electrons to be the rms width (σ) of this fit. The electron energy spread is from the beam-energy spread and the spread in electron energies arising from the space-charge potential variations within the beam bunch.

We made a series of measurements on a 117MeV H$^-$ beam in which we varied the beam current from 10mA to 35mA in 5mA steps. In Fig. 5 we plot the rms widths of the energy spectra vs. beam current. By extrapolating to zero beam current we deduce the electron energy spread due to the beam-energy spread to be 0.494kV, corresponding to 0.907MeV (0.78%) beam-energy spread.

Figure 3 shows that the full linac pulse is about 500μs long with full-current duration of 350μs. The scope is configured to integrate the first 100μs. By scanning a short integration window over the pulse we can measure the energy vs. time in the pulse. Figure 6 plots the data from a 20-point scan with a 25μs window. We see a 0.6% drop in beam energy during the pulse which we attribute to beam loading of the rf cavities.

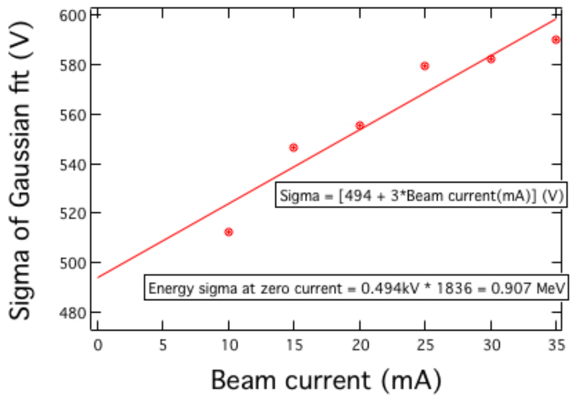


Figure 5: Energy spread of electrons vs. beam current.

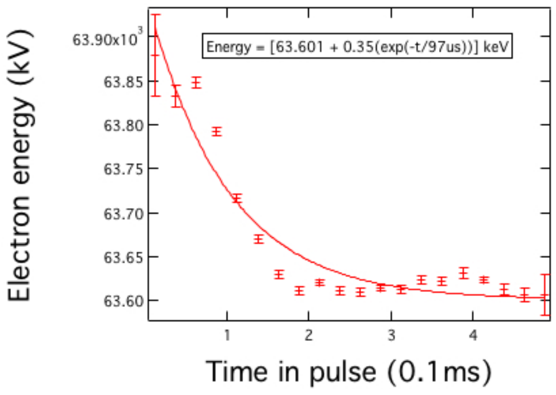


Figure 6: Measured electron energy vs. time in beam pulse showing energy droop from rf cavity beam loading.

PROFILE MEASUREMENTS

We measure transverse profiles by passing the laser beam through the H^- beam and measuring the electron signal integrated over the laser pulse vs. the transverse position of the laser beam. Figures 7 and 8 show horizontal and vertical beam profiles with Gaussian fits to the data.

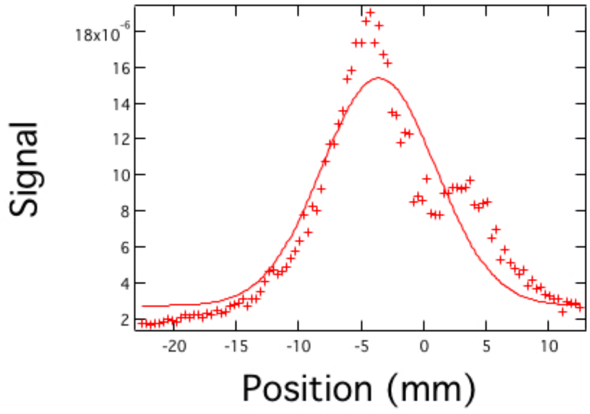


Figure 7: Horizontal profile. The notch in the profile on the right is probably from an obstruction in the beampipe.

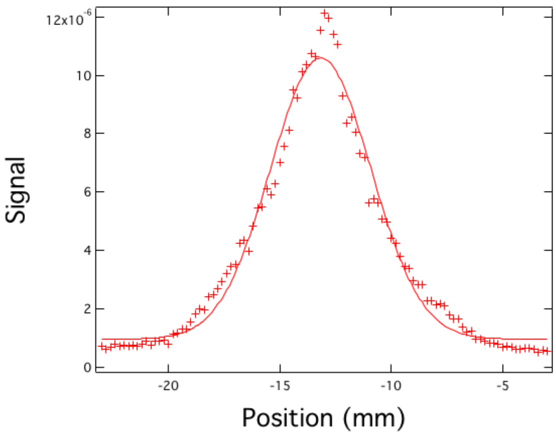


Figure 8: Vertical profile.

DISCUSSION

This detector is producing accurate energy measurements for the 35mA beam used by the isotope production facility [3]. The highest beam energy we have measured is 117MeV. Voltage conditioning issues have prevented the measurement of higher energy beams.

For linac tuning we are interested in beam profiles and beam energy spread. The energy spread of the 200µA RHIC polarized beam is important for matching into the booster accelerator. Both of these measurements depend on laser neutralization. We have demonstrated energy spread measurements with the gas-stripped electrons. Also we have demonstrated laser beam profile measurements but the laser head that is mounted next to the beamline stopped working after a month of beam, before we could demonstrate laser energy measurements on the polarized beam. Radiation damage is suspected despite 10 cm of lead shielding around the laser head.

ACKNOWLEDGMENTS

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REFERENCES

[1] R. Connolly et al., "Beam-Energy and Laser Beam-Profile Monitor at the BNL Linac," Proc. 2010 Beam Instrumentation Workshop, Sante Fe.
[2] George H. Gillespie, Phys. Rev. A., 16 (3), 1977.
[3] http://www.bnl.gov/medical/Isotope_Distribution/Isodistoff.htm