

# DOUBLY STRIPPED PROTON CAUSING VACUUM LEAK AT BROOKHAVEN 200 MeV LINAC COMPLEX\*

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## Abstract

Doubly stripped protons in the low energy transport are captured at 180 degree apart in RF of RFQ and accelerated to the full energies. These protons are bend in the opposite direction of the H<sup>-</sup> after 200 MeV drift tube linac and caused a vacuum leak. A new beam dump and a faraday cup for these stripped protons are planned.

## INTRODUCTION

The Brookhaven National Laboratory (BNL) 200 MeV drift tube linac (DTL) provides H<sup>-</sup> beam at 6.67 Hz, 200 MeV for the polarized proton program of Relativistic Heavy Ion Collider (RHIC) and 66-200 MeV for Brookhaven Linac Isotope Production (BLIP) [1-5]. The RHIC polarized proton program needs 2 pulses every super cycle (~4 sec), one for injection into booster and other for polarization measurement at 200 MeV-polarimeter located in the high-energy transport line (HEBT). The rest of the pulses go to BLIP. BNL 200 MeV H<sup>-</sup> linac consists of a 35 keV high intensity (magnetron) ion source [6], polarized source (optically pumped polarized H<sup>-</sup> ion source, OPPIS) [7], low energy beam transport (LEBT), a 750 keV radio frequency quadrupole accelerator (RFQ), medium energy beam transport (MEBT) and 200 MeV drift tube linac. Space charge effects are most severe at low energy i.e. in the LEBT where the H<sup>-</sup> energy is 35 keV and current excess of 100 mA. To overcome space charge effects in the LEBT, different gases are used to charge neutralize the H<sup>-</sup> beam.

## LOW ENERGY BEAM TRSPORT (LEBT)

LEBT connects RFQ to two ion sources, namely high intensity magnetron ion source (source-1) and OPPIS. Figure 1 shows layout of LEBT. A 45-degree pulse dipole magnet connects these two ion sources to RFQ. High intensity part of LEBT consists of two solenoids, two quadrupoles, and two set of steering magnets in each horizontal and vertical plane, a beam chopper, a beam stop, a cryopump, and two gate valves. First gate valve is located just after the first solenoid and second gate valve is located just before the RFQ. Base pressure in LEBT is about  $2 \times 10^{-7}$  Torr with ion source gate valve closed and with ion source gate valve open, pressure is about  $1 \times 10^{-6}$  Torr.

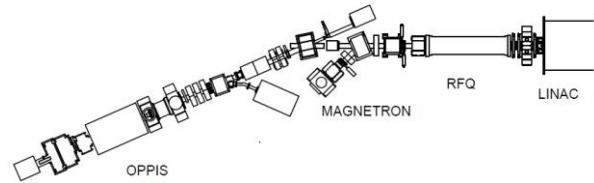


Figure 1: LEBT layout showing OPPIS and Magnetron source.

Cryopump is located under chopper box and equipped with two gate valves, one pneumatic and other hand operated gate valve. There is a provision to inlet various gas via needle valves at two places, first in ion source gate valve and second in chopper box.

Last year (Run 2018), no polarized protons were needed for RHIC program; a second magnetron source (source-2), a solenoid and two steering magnets were installed by replacing spin-solenoid and diagnostic box in OPPIS line before the 45-degree dipole magnet. Second source was installed for source development and as back-up source for BLIP. Source-2 is at 0 degrees with RFQ. Source-2 is bit different than source-1; it has smaller vacuum chamber and smaller turbo pump. It operates at little higher pressure ( $8 \times 10^{-6}$  Torr) than source-1; it has better gas injection pulse valve, ion source body temperature control, better electric connection etc.

## DOUBLY STRIPPED H<sup>-</sup>

H<sup>-</sup> can be converted to protons via two channels, (1) stripping two electrons H<sup>-</sup> => P and (2) two step process (a) H<sup>-</sup> => H<sup>0</sup> (b) H<sup>0</sup> => P. Cross-sections for these processes at 35 keV and Hydrogen & Nitrogen as background gases are given in Table 1 [8, 9].

Table 1: Summary of 35 keV H<sup>-</sup> Cross Sections Used in Calculations.

Gas	$\sigma_{-10}$ ( $10^{-16}$ cm <sup>2</sup> )	$\sigma_{-11}$ ( $10^{-16}$ cm <sup>2</sup> )	$\sigma_{01}$ ( $10^{-16}$ cm <sup>2</sup> )
Hydrogen	7.3	0.43	*2.4
Nitrogen	13.2	1.7	*4.4

\* Scaled

For source-1, doubly stripped protons generated between 45-degree dipole and RFQ are captured and accelerated by RFQ. For source-2, doubly stripped protons generated between source-2 and RFQ are captured and accelerated by RFQ. Nitrogen gas was injected at the chopper chamber, which is located after the 45-degree dipole magnet in LEBT, to optimize the average beam current at the BLIP target. For both sources, optimized pressure in LEBT was about  $3 \times 10^{-6}$  Torr. Transmissions

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and average currents at BLIP were same for the both sources. At the first dipole magnet (BM1) after linac, radiations were about five times higher for source-2 compared to source-1 for the same H<sup>+</sup> average current.

### Estimates for Stripped Protons

In magnetron source hydrogen gas is injected through a pulsed valve at linac repetition rate, which causes relatively higher pressure (~1.0x10<sup>-4</sup> Torr) at source exit (5-10 cm) during the beam pulse. Source-1 housing has bigger volume than source-2, and it consumes about half hydrogen gas than source-2. Source-1 also has high capacity vacuum pump. Estimated pressures at exit of source (5 cm) are about 1x10<sup>-4</sup> and 3x10<sup>-4</sup> Torr for source-1 and source-2 respectively. Estimated fractions of the H<sup>+</sup>, which stripped at source exit to protons via both stripping channels are 0.7x10<sup>-3</sup> and 21x10<sup>-3</sup> for source-1 and source-2 respectively.

For source-1, proton generated before 45-degree dipole magnet will bend in the opposite direction of the H<sup>+</sup> and protons generated between 45-degree dipole magnet and RFQ will reach to the RFQ. In this part of the LEBT, background gas mainly is Nitrogen at 3x10<sup>-6</sup> Torr. Estimated protons fraction at RFQ is about 0.17%. For source-2, estimated protons fraction at RFQ is about 0.81%.

These protons will be capture in the RFQ at 180 degree apart from H<sup>+</sup> and accelerated to the final energy of RFQ, which is 750 keV. Protons and H<sup>+</sup> enter MEFT in the same orientation of the transverse phase space but at 180 degree apart in the longitudinal phase. Transmission efficiencies through MEFT and linac for protons are only about 1% (PAMILA simulation). Fractions of H<sup>+</sup> as protons, which reach at BM1, are 1.7x10<sup>-5</sup> and 8.1x10<sup>-5</sup> for source-1 and source-2 respectively.

It is counter intuitive that fraction of proton increases approximately as x<sup>2</sup>, where x is pressure. Figure 2 depicts protons and neutrals as fraction of H<sup>+</sup> generated by different stripping channels.

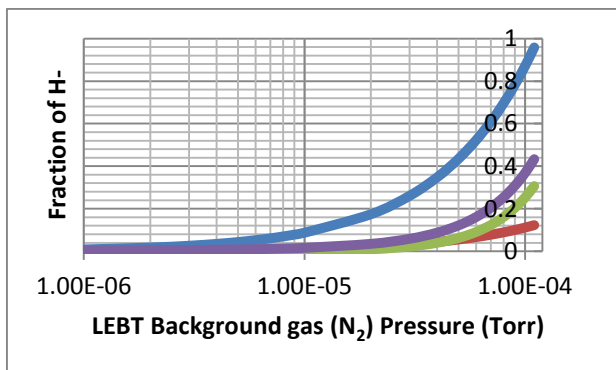


Figure 2: Fractions of H<sup>+</sup> as a function of background gas (Nitrogen) pressure. Blue: Neutrals ( $\sigma_{-10}$ ), Red: Protons, channel-1 ( $\sigma_{-11}$ ), Green: Protons, channel-2 ( $\sigma_{-10} * \sigma_{01}$ ), Violet: Proton, sum of channel 1 and 2 ( $\sigma_{-11} + \sigma_{-10} * \sigma_{01}$ ).

At higher pressure (5x10<sup>-5</sup> Torr) number of protons produce by channel 2 are higher than channel 1. At pres-

sure 1.1x10<sup>-4</sup> Torr, H<sup>+</sup> beam is fully stripped and about 30% of protons are generated.

## HIGHER PRESURE IN LEBT CAUSED VACUUM LEAK

During Run 18, ion source-1 was shorted and source-2 was brought on line to provide beam to BLIP. In the process of optimising beam current, a higher amount of gas (Nitrogen) was injected (human error) into LEBT through a pulse valve and within seconds stripped protons caused the leak in the bellow after the first dipole BM1. Figure 3 shows the pressure at LEBT, linac tanks and high-energy beam transport (HEBT) as a function of time. Pressure rise in LEBT causing pressure increase in HEBT but linac vacuum remains unaffected. Figure 4 depicts beam current at RFQ, at linac and after linac during the LEBT tuning with gas. Figure 5 shows radiation at BM1 and average current at BLIP. Source-1 was shorted at 17:45 HRS and source-2 came on line at 20:00 HRS. Radiation label for source-2 is about 10 times. Figure 6 shows bellow and the Y chamber after BM1. Figure 7 shows leaked bellow.

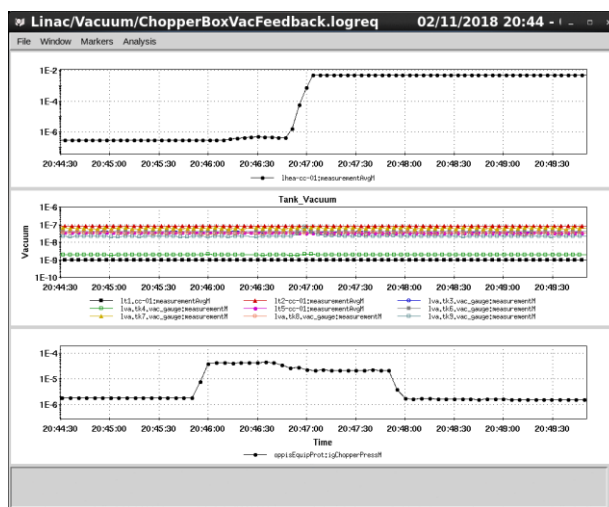


Figure 3: Vacuum at LEBT, Linac Tanks and HEBT in Torr as function of time in HRS.

Beam size at bellow is approximately 0.1x1 cm<sup>2</sup>. Stain steel bellow is 0.020 cm thick. For normal running protons deposit about 1.4 mW and 6 mW for source-1 and source-2 respectively. Calculations show that displacement per atom (DPA) is only 0.1 for integrated intensity for last 20 years. For last about 20 years, protons are going through at same spot.

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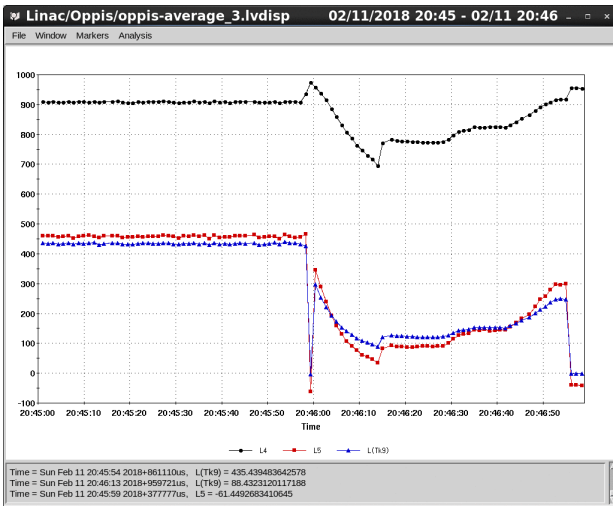


Figure 4: Beam current in unit of 0.1 mA at RFQ entrance (Black, L4), at linac entrance (Red L5), and after linac (Blue, T9) as function of time in HRS.

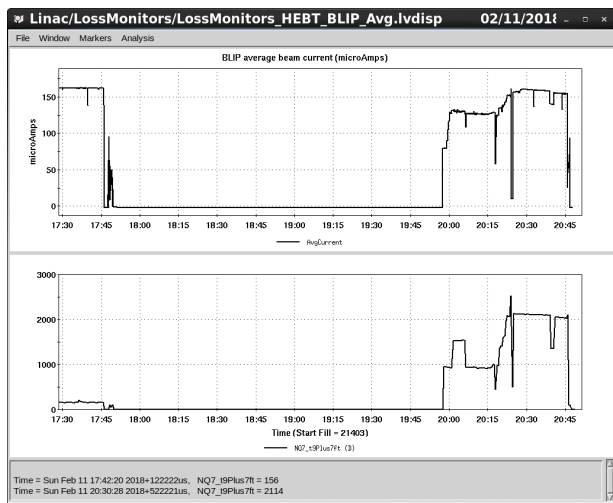


Figure 5: Average beam current and count on beam loss monitor as a function of time in HRS. Source-1 shorted at 17:45 and source-2 came on line at 20:00. Radiation for source-2 is about 10 times than source-1 for the similar average current.

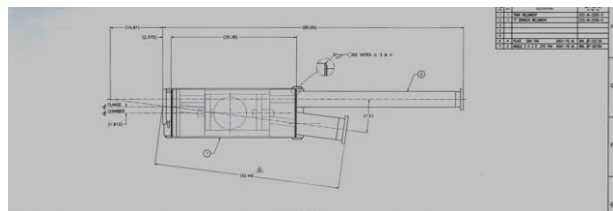


Figure 6: Bellow and Y chamber after the first dipole (BM1) after the linac.

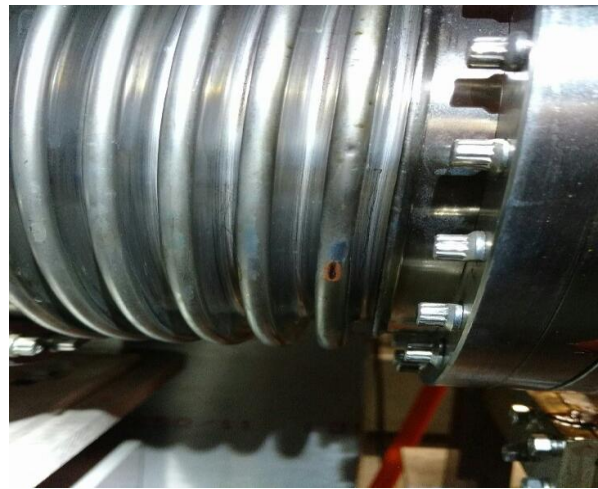


Figure 7: Hole in the bellow after BM1 chamber consistent with proton trajectory.

## OUTLOOK

After Run 18, polarity of dipole in the LEBT was reverse to measure protons by Faraday cup in front of Linac for source-1 and source-2. The measured values were 0.09% and 0.27 % for source- 1 and 2 respectively. It is planed (a) to move source-2 at -45 degree by installing a new dipole magnet; (b) modify BM1 vacuum chamber to accommodate proton beam dump and (c) faraday cup to measure proton current.

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