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 180 degree apart in RF of RFQ and accelerated to the full energies. These protons are bend in the opposite direction of the H^- 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.

1 INTRODUCTION

The Brookhaven National Laboratory (BNL) 200 MeV drift tube linac (DTL) provides H^- beam at 6.67 Hz, 200 MeV for the polarized proton program at Relativistic Heavy Ion Collider (RHIC) and 66-200 MeV for Brookhaven Linac Isotope Production (BLIP) [1-5]. The RHIC 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 linac consists of a 35 keV high intensity (magnetron) ion source, polarized source (optically pumped polarized H^- ion source, OPPIS), 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^- 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^- beam.

2. Low Energy Beam Transport (LEBT)

The LEBT connects the RFQ to two ion sources, namely high intensity magnetron ion source (source-1) [6] and OPPIS [7]. Figure 1 shows the layout the LEBT. A 45 degrees pulse magnet connects these two ion sources to the RFQ. The high intensity part of LEBT consists of two solenoids, two quadrupoles, and two set of steering magnet 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 just before the RFQ. The base pressure in the line is about $2x10^{-7}$ Torr with ion source gate valve closed and with ion source gate valve open, the pressures are about 1.0 10^{-6} Torr. The cryopump is located under the chopper box and equipped with two gate valves, one pneumatic and hand operated gate valve. There is a provision to inlet various gas via needle valve at two places, first in the ion source gate valve and second in the chopper box.

Last year (Run 2018), no polarized protons were needed for RHIC operations, a second magnetron source, a solenoid and two steering magnets were installed by replacing spin solenoid and diagnostic box in the OPPIS line before the 45-degree dipole magnet. Second source was installed for source development and as backup source for BLIP. Second source (source-2) is at 0 degrees with RFQ. Source-2 is bit different than source-1; it has smaller vacuum chamber and turbo pump. It operated a little higher pressure ($8 x10^{-6}$ Torr) than source-1; it has better gas injection pulse valve, ion source body temperature control, better electric connection etc.

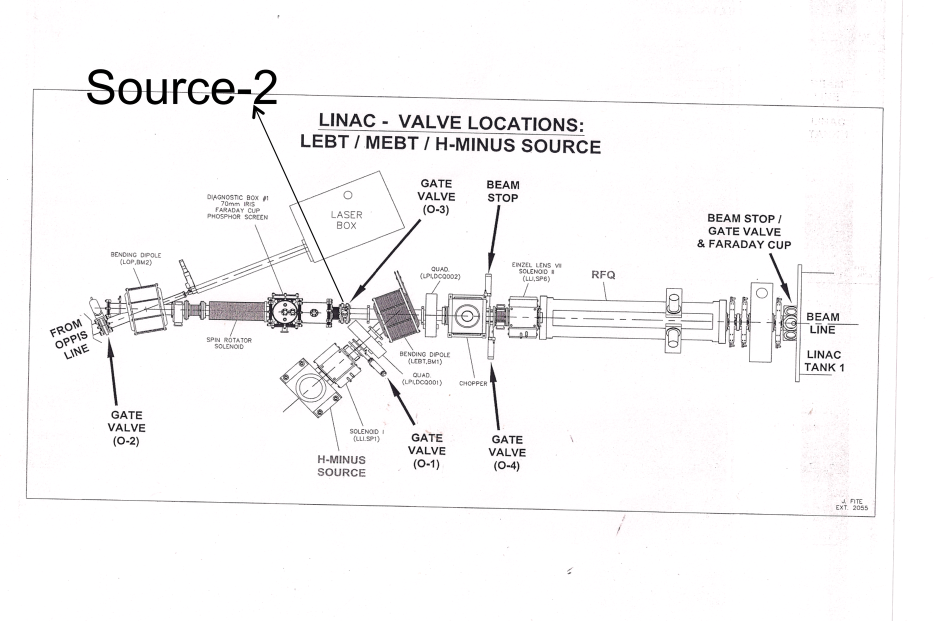

Figure 1: 2 m long, two solenoids, two set of steering magnet in each plane, two quadrupoles, one 45 degree dipole, two gate valve, one beam dump, one 2000 l/s cryo-pump , operating pressure $3.0x10^{-6}$ Torr.

3 Doubly Stripped H^-

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

Table I: Summary of 35 keV H- cross section used in calculations

Gas	σ_{-10} (10^{-16} cm²)	σ_{-11} (10^{-16} cm²)	σ_{01} (10^{-16} cm²)
H_2	7.3	0.43	*2.4
N_2	13.2	1.7	*4.4

* scaled

For source-1, doubly stripped protons, generated between 45-degree dipole and the RFQ, are captured and accelerated by RFQ . For source-2, doubly stripped proton, generated between source-2 and RFQ, are captured and accelerated. At the first dipole magnet (BM1) after the linac, radiations were about five times higher for source-2 compare to source-1 for the same H^- average current. Nitrogen gas was injected at the chopper camber, which is located after the 45 degree dipole magnet, to optimize the average beam current at the BLIP target. For both sources , optimized pressure in the LEBT was 3 x 10^{-6} Torr. Transmissions and average currents were same for the both sources.

4 Estimates for Stripped Proton

In magnetron source hydrogen gas is injected through a pulsed valve at linac repetition rate, which cause relative higher pressure (~ 1.0. 10^{-3} Torr) at source exit (~ 5-10 cm) during the beam pulse. The source-1 has bigger volume than source-2, and it consume about half the gas than source-2. Source-1 also has high capacity vacuum pump. The estimated pressure at exit of source (5 cm) is about $1x10^{-4}$ and $3x10^{-4}$ Torr for source-1 and source-2 respectively. The estimated fractions of the H^- which stripped at source to protons via both stripping channels are $0.7x10^{-3}$ and $21x10^{-3}$ for source-1 and source-2 respectively. For source-1 the proton generated before 45-degree bending magnet will bend in the opposite direction of the H^- and proton generated between 45-degree bending magnet and RFQ will reach to the RFQ. In this part of the LEBT, background gas mainly is Nitrogen at $3x10^{-6}$ Torr. Estimated proton fraction is about 0.17 %. For source two, estimated proton fraction at the RFQ is about 0.81 %.

These protons will be capture in the RFQ at 180 degree apart from the H^- . and accelerated to final energy of the RFQ which is 750 keV. The proton and H^- enter MEBT in the same orientation of the transverse phase space but at 180 degree apart in the longitudinal phase. The transmission efficiencies through MEBT and linac for protons are only 1% (PAMILA simulation). The fractions of protons, which reach BM1, are $1.7x10^{-5}$ and $8.1x10^{-5}$ for source-1 and source-2 respectively.

It is counter intuitive that fraction of proton increases approximately as square of the background pressure.

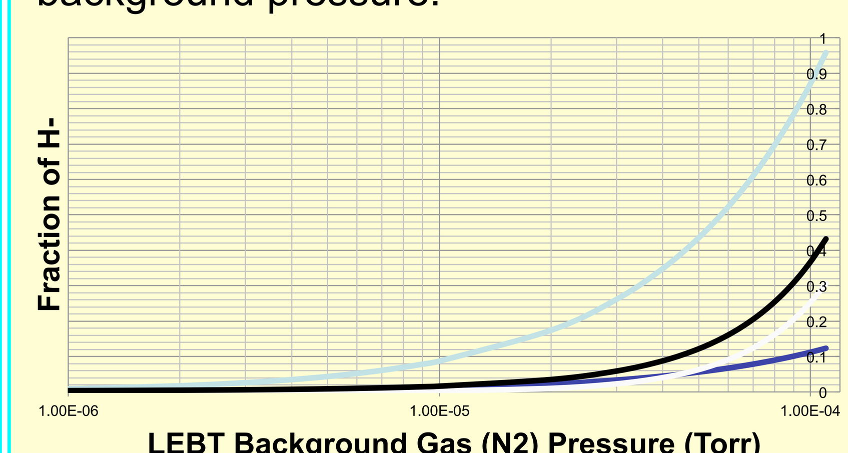

Figure 2: Fraction of H^- as a function of background gas (Nitrogen) pressure. Blue: Neutrals, (σ_{-10}), Dark Blue: Protons, channel-1 (σ_{-11}), White: Protons, channel 2 (σ_{-10} *σ_{01}), Black: Proton, sum of channel 1 and 2 (σ_{-11}+σ_{-10} *σ_{01})

At higher pressure ($5x10^{-5}$ Torr) protons produce by channel 2 is higher than channel 1. At pressure 1.1 $x10^{-4}$ Torr H^- beam is fully striped and about 30% of proton are generated.

5. LEBT Higher Pressure Caused Leak

During Run 18, ion source-1 was shorted, 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 within seconds stripped proton 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 remain unaffected. Figure 4 depicts beam current at RFQ, at linac and after linac during LEBT tuning with injected gas. Figure 5 shows radiation at BM1 and average current at BLIP. Source-1 was shorted at 17:45 HRS and source-2 cane on line at 20:00 HRS. Radiation lable for source-2 is about 10 times. Figure 6 show the dipole chamber, bellow and the Y chamber. Figure 7 shows the leaked bellow.

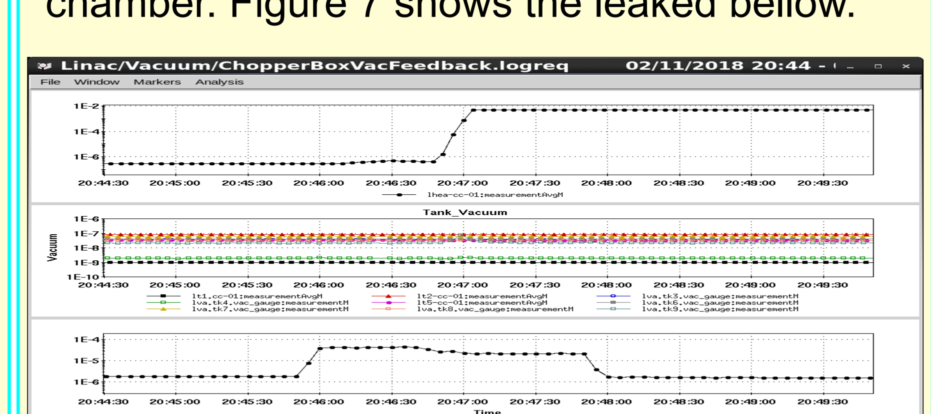

Figure 3: Vacuum at LEBT (top), Linac tanks (middle) and HEBT (bottom) in Torr.

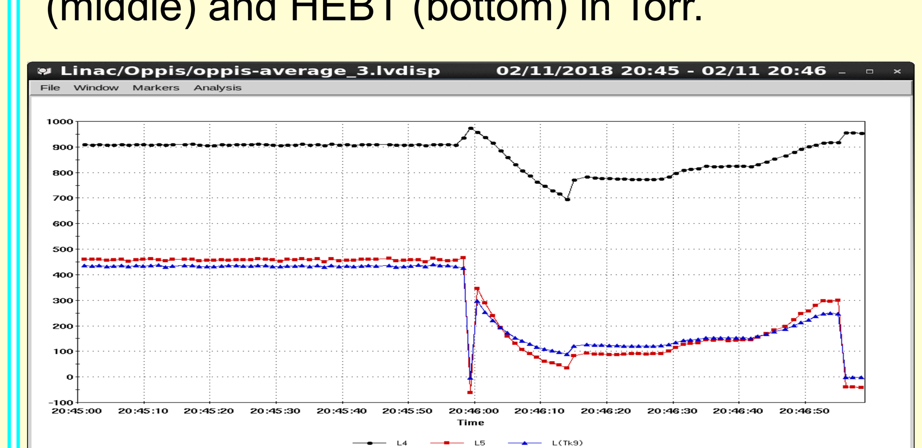

Figure 4: Beam current at RFQ (**Black**, L4), at linac (**Red** L5), and after linac (**Blue**, T9).

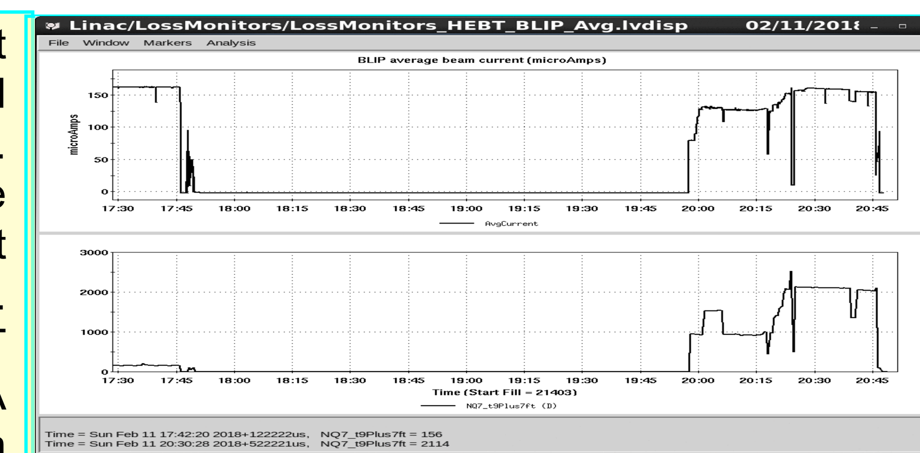

Figure 5: Average beam current and count on beam loss monitor as a function of time in HRS.

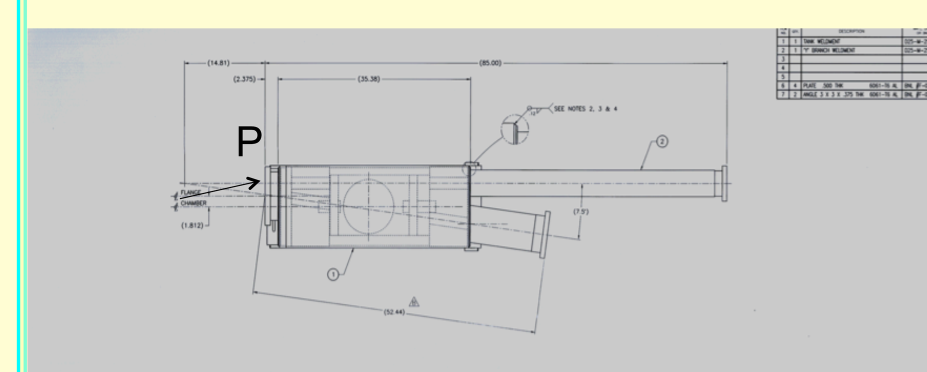

Figure 6: Bellow and Y chamber after the first dipole BM1 after the linac

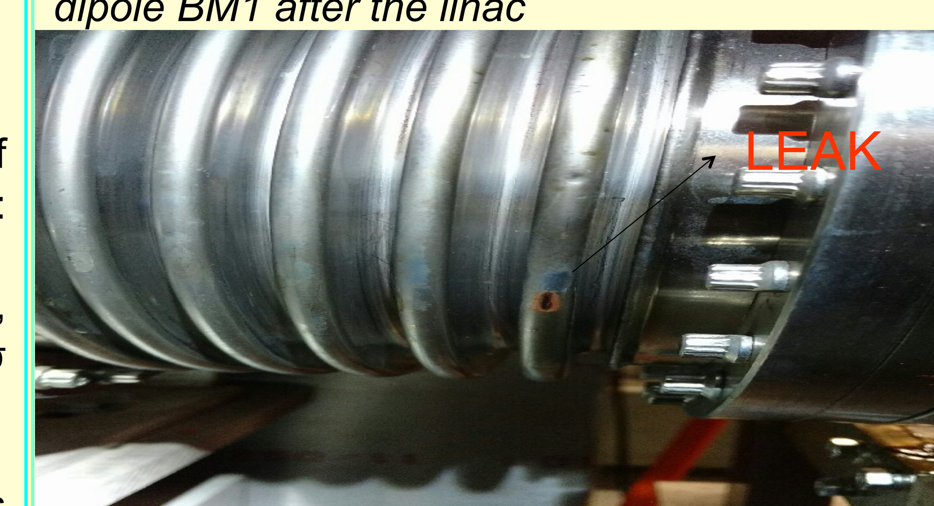

Figure 7: Hole in the bellow after the magnet chamber consistent with proton trajectory

Beam size at the bellow is approximately 0.1 X 1 cm ². 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.

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 to move source-2 at -45 degree by installing a new dipole magnet; BM1 vacuum chamber to accommodate proton beam dump and faraday cup to measure proton beam current.

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