ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEOBA03

STATUS OF PREPARATIONS FOR A 10 MICROSECOND LASER-ASSISTED H$^-$ BEAM STRIPPING EXPERIMENT

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Abstract

The concept of laser-assisted H$^-$ stripping, originated over three decades ago, was successfully demonstrated for a 6 ns, 900 MeV H$^-$ beam in 2006. Plans are underway to build on this foundation by performing laser-assisted H$^-$ stripping of a 10 μs, 1 GeV H$^-$ beam at the Spallation Neutron Source facility; this constitutes a three orders of magnitude improvement over the initial proof of principle demonstration. The central theme of the experiment is the reduction of the required laser power through ion beam manipulations and laser-ion beam temporal matching. This paper discusses the configuration of the experiment, the results of recent parameter realization experiments, and the schedule.

INTRODUCTION

It is unclear whether injection foils will survive in beam powers greater than 1.5 MW. At the SNS accelerator, which routinely operates with beam powers above 1 MW, several cases of foil damage have been observed [1]. For the development of future multi-megawatt proton drivers, it is important to investigate alternative technologies for H$^-$ stripping injection.

In 2006 a proof of principle experiment successfully demonstrated laser-assisted H$^-$ stripping of a 6 ns, 900 MeV H- beam with ~90% efficiency [2]. A straightforward scaling of this experiment to longer pulse widths on the order of microseconds requires unrealistically high average laser powers. Therefore, to extend the pulse width of the stripped beam, it is necessary to reduce the average laser power requirement through beam manipulations and laser-beam temporal matching [3].

At the Spallation Neutron Source accelerator, preparations are underway to demonstrate 90% stripping efficiency for a 5 – 10 μs, 1 GeV H$^-$ beam. The design, fabrication, and execution of the experiment are planned over a three year time span, with a 2016 completion goal. The experiment will incorporate the ion and laser beam manipulations necessary to reduce the average laser power to an obtainable level. In the first year of preparations, efforts have focused on finalizing the experimental configuration, demonstrating the laser and ion beam parameters, and designing the stripping magnets and experimental chamber. These efforts and their results are described in the following sections. The schedule for the work is presented in the last section.

EXPERIMENTAL CONFIGURATION AND HARDWARE

The design of the experimental configuration has been guided by four objectives:

1) Protect the laser from radiation damage.
2) Prevent disruptions to normal beam operations.
3) Provide schedule flexibility for the experiment.
4) Provide high efficiency laser stripping.

In the first year of the project, the locations of the experimental chamber and the laser have been chosen, and the stripping magnets and experimental chamber designs have been finalized.

Interaction Point Location

The final location of the interaction point (IP) was chosen to be near the end of the High Energy Beam Transport (HEBT) line, downstream of the ninety-degree arc and mid-way through an empty drift between two quadrupoles. This location meets the beam optics requirements with a high degree of flexibility due to the upstream arc and several independently powered quadrupoles. Additionally, it is a safe distance away from any radiation hot spots, and allows for a reasonable waste beam disposal scenario.

Laser Remote Placement

Probably the single highest risk factor for the experiment is the possibility of radiation damage to the laser, particularly the electronics. Loss of the high power UV laser represents a single-point failure for the experiment, and as such, the decision was made to locate the laser assembly outside of the HEBT tunnel. The laser will be placed in the Ring Service Building and will be transported through a chase in the ring injection area down to the experimental station. The UV laser transport system will be composed of a ~70 m long in-air pipe with approximately nine mirrors and two windows.

Obviously, the remote placement of the laser brings a number of challenges, such as minimizing laser power

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loss during transport and laser pointing stability. Assessing the impacts of these effects has been the focus of much of the work by the laser team in the last year, and is discussed later in this paper. To summarize, the results suggest that the remote laser placement is feasible.

In addition to protecting the laser, the remote placement also simplifies the scheduling of the experiment. In the alternate scenario where the laser is placed locally in the tunnel, the system would have to be installed and removed in the days neighbouring the stripping demonstration in order to protect the laser from 1 MW production levels of radiation. This would tie the experiment to the accelerator start up periods following the twice-annual maintenance outages of the accelerator. It's unlikely that this would allow for a sufficient time window for troubleshooting the experiment. In addition, these start up periods are frequently burdened by unanticipated hardware problems that limit the availability of time for accelerator physics studies.

Experimental Station

The experimental station, shown in Figure 1 below, will contain two stripping magnets, two corrector magnets, two wirescanners, a BCM, four optical ports, a general diagnostics cross, and a laser defocusing lens.

To produce high efficiency stripping while also minimizing emittance growth in the ion beam, the stripping magnets must have ~1.2 T field in the stripping region and 40 T/m field gradient. The final magnet is a permanent magnet Halbach cylindrical array with inner radius 14.5 mm and outer radius 60 mm. The two stripping magnets will be arranged with opposite polarity in the experimental vessel to minimize the field at the IP. Taking into account the charge state change between magnets, one consequence of this arrangement is that the vertical kicks to the beam will add up, producing a net ~17 mrad vertical kick. Too compensate, corrector magnets are located just upstream and downstream of the first and second stripping magnets, respectively. The two stripper-corrector pairs are individually mounted on actuators to allow remote insertion and retraction of the magnets from the vacuum pipe. The design of the magnets is outlined in more detail in reference [4], in these proceedings.

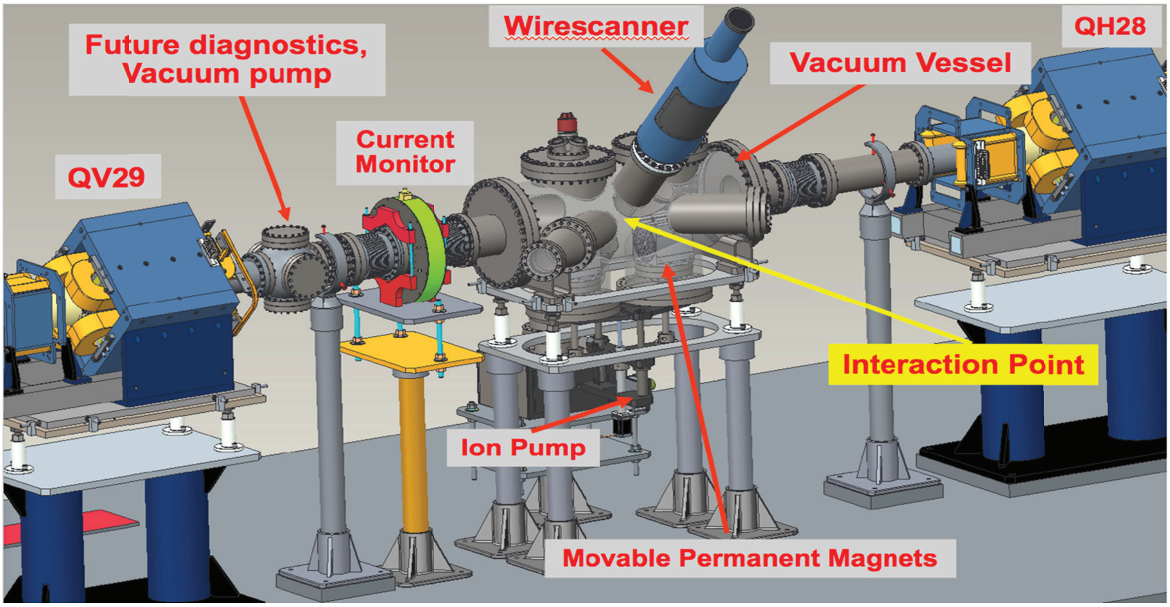

Figure 1: Drawing of the experimental station or the 10 μs laser-assisted stripping experiment.

The experimental station contains four optical ports – two for the laser to enter and exit the experimental station, and two for viewing. In order to reduce the laser power density on the exit window and to prevent window breakage, a defocusing lens is positioned between the IP and the exit window. The main laser station will be located remotely in the Ring Service Building, but a small final focusing table will be positioned adjacent to the experimental station.

The BCM of the IP will be used to measure the stripping efficiency. To assist in the ion beam configuration, one dual-plane wirescanner is located at the IP, and another downstream of the QV29 quadrupole magnet (not shown in the figure). An upstream bunch shape monitor (BSM) capable of measuring picosecond-level pulse widths is located ~40 meters upstream and will be used to confirm the longitudinal bunch length for the experiment.

PARAMETER REALIZATION EFFORTS

The ion beam manipulations necessary to reduce the required average laser power result in an off-nominal set of transverse and longitudinal beam optics. Additionally,

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the laser beam must be temporally matched to the ion beam microstructure. In the past year efforts have been focused on experimentally demonstrating these parameters for both the ion and laser beam. The final stripping efficiency, anticipated to be about 90%, will be determined once all of the parameters have been experimentally verified.

Ion Beam Optics

Typically, the longitudinal rms micropulse bunch length in the HEBT is ~150 ps. For full overlap with the laser, the stripping experiment requires an rms bunch length of ~25 ps. To achieve this, the last 10 cavities in the SCL were manipulated to minimize the bunch length at the IP. Details of this work are discussed in reference [5], in these proceedings. Generally, a few tens of MeV of energy are sacrificed in the cavity reconfiguration. However, enough energy margin should be available in the stripping experiment to accommodate the loss and still yield a 1 GeV H^- beam.

A complicating factor of the bunch length squeezing is the impact of space charge in the ~150 meter drift between the last SCL cavity and the IP. This correlates the minimum achievable bunch length with the beam current. Specifically, the minimum rms bunch length goes up ~3.45 ps per mA of beam current. The space charge limitation would not be present in an operational H^- stripping experiment where dedicated focusing cavities would be placed just upstream of the IP.

The shortest experimentally measured bunch length is 26.6 ps FWHM (11.3 ps rms) for a ~1 mA H^- beam, shown in Figure 2.

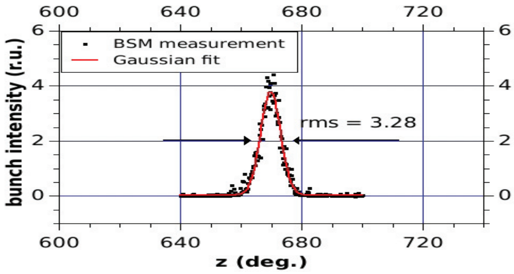

Figure 2: BSM measurement of 3.28 deg (11.3 ps) rms.

The transverse beam optics manipulations are aimed at minimizing the excitation frequency spread and maximizing the cross section for interaction with the laser. Elimination of the excitation frequency spread is primarily accomplished by tailoring the dispersion function to give D=0 and D’= -2.6 m at the IP [2]. This has been repeatedly demonstrated experimentally.

Beyond the dispersion tailoring, it is also necessary to minimize the remaining frequency spread by setting α_x=0 and β_x large. To maximize the laser power density at the IP, the laser spot size, and in turn the ion beam size in the plane of interaction (β_y), should be minimized. Experimental verification of these parameters has been demonstrated for a previous IP candidate location, and is in progress to for the final IP location.

Laser Parameters

Much work has been done to finalize the laser beam parameters and to confirm the feasibility of remote laser placement.

Two major concerns of the remote laser placement are the laser power loss in transport and the pointing stability. To estimate the total power loss, the power loss on the mirrors and windows were independently measured, and the total path length in air was simulated by cycling the laser through six iterations of a 8 m, four-mirror loop. The results are promising: The power loss per mirror was less than 1%, and the power loss in air, extrapolated to 70 m, was less than one third. The major source of the power loss in air is believed to be due to Fresnel diffraction at the apertures and loss of higher order modes in transport. The remaining laser power is sufficient to support 90% stripping efficiency at the IP.

An optical correlator was constructed to measure the picosecond-level UV laser pulses [6]. The laser has been demonstrated to operate with 10 µs macropulses at a repetition rate of up to 10 Hz. The total laser power was measured to be in the range of 1.35 – 2 MW for micropulse lengths of 30 – 55 ps (FWHM. This will allow flexibility for trading stripping efficiency for bunch length during the experiments.

SCHEDULE

All design work for the equipment will be completed in 2014. The first installations will occur during the January 2015 maintenance outage, and will continue during the August 2015 and possibly the January 2016 outages. The stripping experiments will commence in the spring of 2016.

ACKNOWLEDGMENT

This work has been partially supported by U.S. DOE grant DE-FG02-13ER41967. Oak Ridge National Laboratory is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.

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