LONGITUDINAL BUNCH SHORTENING FOR THE LASER STRIPPING PROJECT*

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Abstract

The realization of high efficiency laser stripping at the SNS accelerator requires good longitudinal overlap between H^- bunch and laser pulse. The default H^- bunch length at the interaction point is 5 times larger than needed in order to achieve 90% stripping efficiency. This paper presents theoretical and experimental studies of longitudinal H^- bunch shortening.

INTRODUCTION

The laser assisted method of H^- stripping has been studied for a long time at the SNS, and the most detailed description can be found in [1-6]. At present the laser stripping project is under intense development, and details about its current status can be found in [7].

Successful realization of laser stripping requires appropriate H^- bunch tailoring that involves tuning of about 10 bunch parameters simultaneously. We have successfully demonstrated tuning of all transverse parameters through the work in [6]. This paper provides a theoretical and experimental study of longitudinal bunch tuning in order to get 90% efficiency laser stripping.

The laser pulse that makes excitation of the H^0 beam at the interaction point has a temporal Gaussian profile with FWHM = 55ps (see Fig. 1).

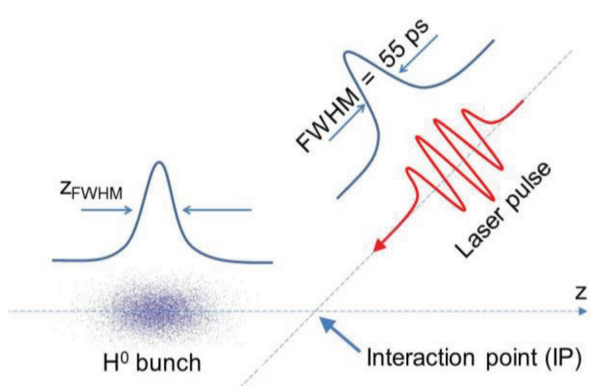

Figure 1: Scheme of interaction between laser pulse and H^0 bunch.

The overlap between the laser and the H^0 bunch must be good enough for high efficiency interaction between two beams and, hence, the longitudinal FWHM of the H^0 beam should be smaller than 55ps. Figure 2 shows simulation of H^0 efficiency excitation as a function of H^0 longitudinal size for the given length of the laser pulse FWHM = 55ps.

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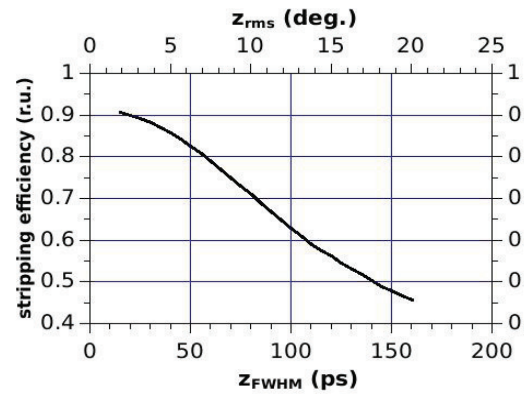

Figure 2: Stripping or excitation efficiency as a function of the longitudinal H^0 size for a given size of laser pulse FWHM = 55ps. The lower axis represents FWHM, and the upper axis represents the rms parameter in degrees corresponding to the 805 MHz frequency.

The upper axis represents the longitudinal (temporal) size of the H^0 bunch in degrees related to the frequency of the Bunch Shape Monitor (BSM) equal to 805 MHz. This figure shows that the H^0 FWHM needs to be 25-30 ps (3-5 degrees rms) to achieve 90% excitation or stripping efficiency.

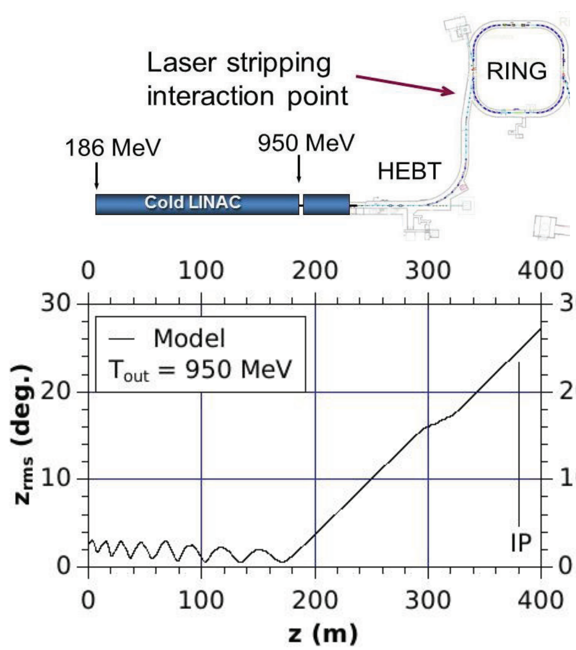

Figure 3: Longitudinal bunch size during SNS production with output energy of 950 MeV.

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Figure 3 represents the longitudinal H^- bunch size in a superconducting linac (SCL) during normal operation of the SNS. The cavities located in the SCL transform the bunch size, keeping it small up to 180 m, where the last cavity is located. The beam then begins longitudinal drifting inflation reaching a large size at the interaction point at 380 m. The Bunch Shape Monitor (BSM) measures the bunch size to be 14-20 degree rms (see Figure 4), which is capable of providing just 50% stripping efficiency.

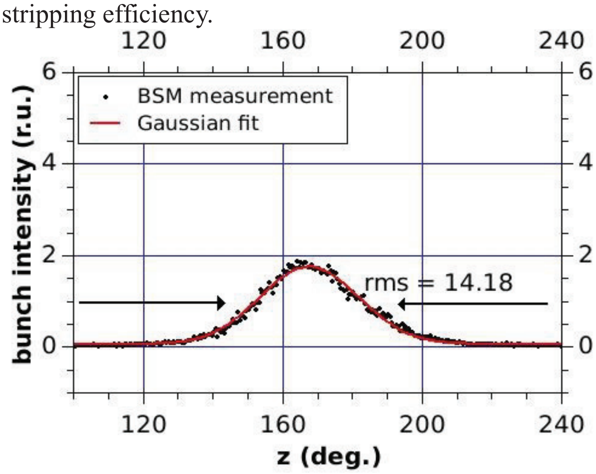

Figure 4: Example of longitudinal bunch shape measured by BSM located close to the interaction point.

SIMULATION OF BUNCH SHORTENING

For simplicity, this paper will skip most of the experimental and simulation details. The bunch length can be manipulated with the help of cavities, along with its acceleration function. The acceleration phase and amplitude can be set up individually for each cavity. The default acceleration phases have about -20 degrees defined as a phase shift for each cavity from the maximum accelerating phase. The negative phase shift corresponds to the longitudinal focusing of the bunch. The principal goal of this work was to find the configuration of cavity phases that would provide the largest longitudinal focusing of the bunch at the interaction point (see Fig. 5).

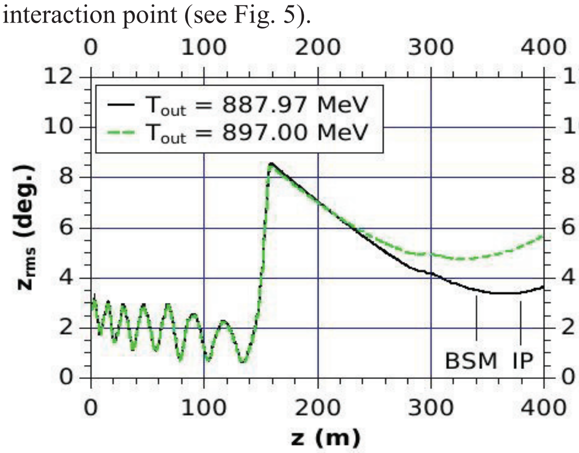

Figure 5: Two example special focusing configurations of the SCL cavities.

After extensive theoretical, empirical studies and experimental optimizations we decided to set the last 10 cavities to the following phase shifts: {45,45,45,45,45,45,off,off,-90,-90}, where 6 cavities make medium acceleration along with longitudinal defocusing-inflation and the last two cavities make no acceleration and a strong focusing kick to the interaction point. This special "focusing" configuration of the linac has an output energy about 50-70 MeV less than the default accelerating phases shown in Fig. 3. For the laser stripping experiment we expect to achieve maximum beam energy of 1070 MeV that will drop to the design energy of 1000 MeV after the longitudinal tuning.

PYORBIT VS. XAL

For the calculations in this paper we used the PyOrbit accelerator code, which was developed at SNS. This code tracks particles through the SNS linac lattice and shows the nonlinear behavior of the bunch compared to a linear envelope tracking codes. Figure 6 compares tracking of the same input bunch with the same conditions through PyOrbit and XAL. Both programs agree at the beginning of the linac for a small bunch size that stays linear, but then disagree when it becomes large in comparison to the RF period of oscillation.

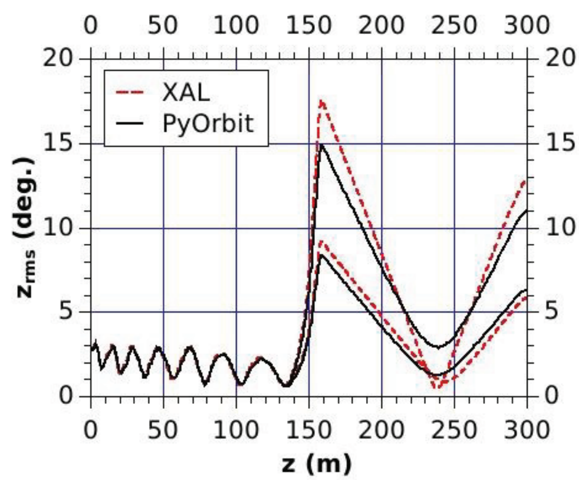

Figure 6: Benchmark of PyOrbit vs. XAL shows nonlinear effects by PyOrbit for the laser stripping "focusing" configuration of linac.

As a result, the XAL predicts unphysically small beam sizes at the interaction point, while the PyOrbit gives limited minimum and optimal configuration for the minimum.

SHORTENING OPTIMIZATION AND CONTROL

The optimal phase configuration {45,45,45,45,45,45,off,off,-90,-90}, was found empirically. The fine-tuning of the shortest bunch at the interaction point has been realized by scanning the amplitude of the last cavity. In this way we can experimentally change the focusing strength of the cavity and achieve the smallest longitudinal bunch size at the interaction point. Figure 7 shows PyOrbit simulations and BSM measurements as a function of the last cavity amplitude. This shows that PyOrbit predicts optimum cavity amplitude with precision of 0.1 or 10%.

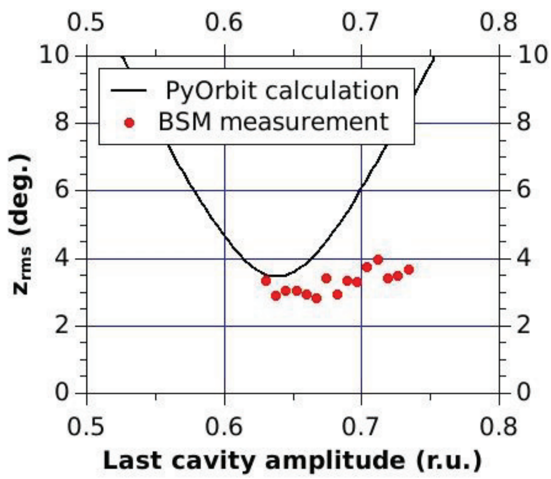

Figure 7: Longitudinal beam size at the interaction point as a function of last cavity amplitude.

Figure 8 shows one of the best cases for a short bunch measured by the BSM. The rms bunch width is about 3 degrees.

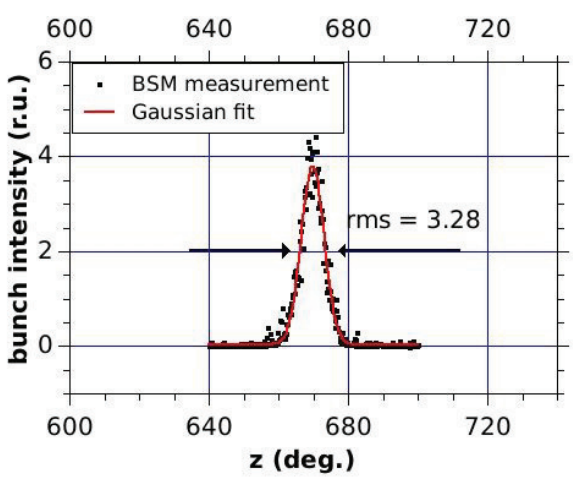

Figure 8: Example measurement of the shortened bunch for laser stripping.

In this way we achieved the longitudinal bunch length of about 3-degree rms or 25 ps FWHM that corresponds to 90% laser stripping efficiency using Figure 2.

SPACE CHARGE EFFECT

The default operation peak beam current of SNS is 30-40 mA. The space charge of the H^- bunch for this current limits its focusing capabilities compared to the results of Figure 5 with no space charge. We could successfully achieve a short bunch only after reducing the beam current to 1 mA, using a beam aperture. Figure 9 shows the longitudinal bunch size as a function of its current at the interaction point.

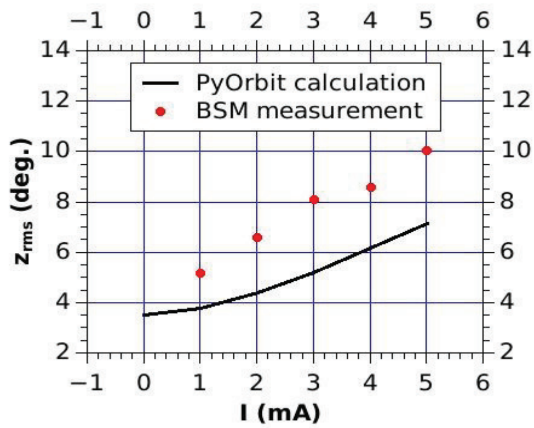

Figure 9: Bunch size at the interaction point as a function of beam current.

Unfortunately, the experimental points have been measured for different amplitudes of the last cavity. However, the slope of the curve is in good agreement with the model prediction.

The total procedure for longitudinal bunch tuning consists of phase setting for the last 10 cavities, with the help of the automatic linac tuning application that takes about 20 minutes. It then requires some minor beam tuning for lower energy and bunch size optimization with the last cavity amplitude, which takes 20-30 minutes.

The next step for the experiments is to realize simultaneous longitudinal and transverse tuning of the beam for laser stripping experiment.

CONCLUSIONS

A method for H^- bunch shortening has been developed, and the longitudinal bunch size at the laser striping interaction point for 90% stripping efficiency has been achieved. The focusing configuration set-up is repeatable.

ACKNOWLEDGMENT

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