ISBN: 978-3-95450-262-2 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2025-WEPCO04

H^- BUNCH SHAPE MEASUREMENTS AT LANSCE*

M. J. Kay†, C. E. Taylor, P. M. Anisimov
Los Alamos National Laboratory, Los Alamos, New Mexico, USA

Abstract

A Feschenko-style Bunch Shape Monitor (BSM) was used to measure the longitudinal profile of H^- bunches at the Los Alamos Neutron Science Center (LANSCE) accelerator. The measurements were taken in the 201.25 MHz drift tube linac (DTL), where the design beam energy is 72.72 MeV. The results of the measurements are presented, and several unexpected features of the measurements are discussed.

INTRODUCTION

Ion beams with three different beam structures are accelerated in the 201.25 MHz DTL at LANSCE. These include a 4 mA H^+ beam and two H^- beams, distinguished by different chopping patterns and peak currents of 10 mA and 25 mA [1]. To better understand the longitudinal dynamics of each beam type, a BSM system was acquired from the Institute for Nuclear Research (INR) at the Russian Academy of Sciences and installed between the 3rd and 4th accelerating modules in the DTL, where the design beam energy is 72.72 MeV. The BSM measures the longitudinal profile of individual bunches with comparatively high resolution and is independent of the charge of the incident beam particles. These devices were originally developed for the H^+ linac at INR in the 1980s [2, 3] and have since become common diagnostic tools in hadron accelerators around the world [4]. The authors report the results of a study done at the end of the 2024 run cycle to measure longitudinal bunch profiles of the H^- beam and discuss several unanticipated features of the measurements.

BSM WORKING PRINCIPLE

The operation at the core of the BSM is a coherent transformation of the longitudinal bunch distribution in the temporal domain into a spatial distribution of secondary electrons emitted from a wire target. All variations of the original design put forth by Feschenko perform this core operation [5,6]. The working principle of the BSM at LANSCE is illustrated in Fig. 1. Following from left to right, the bunched ion beam crosses a thin tungsten wire, which is 100 µm in diameter and biased at −10 kV. The interaction liberates low-energy secondary electrons from the surface of the wire at a rate correlated with the incident beam current. The electrons are accelerated away from the wire by the high negative potential, and a fraction pass through an input slit with narrow angular acceptance into the RF deflector. The field inside the RF deflector is a superposition of an electrostatic focusing field and a 402.5 MHz RF field, which imparts a time-dependent transverse kick along the electron beam. The deflecting field maps the phase coordinate of the electrons to a transverse position downstream, coherently transforming the longitudinal distribution into a transverse distribution. The transverse distribution is sampled by the output slit, which transmits electrons corresponding to a "slice" of the longitudinal distribution. The transmitted electrons are then collected in a secondary electron multiplier (SEM) to generate a measurable signal. The steering magnet between the RF deflector and output slit is used to correct static offsets, and the bending magnet and registration collimator provide energy discrimination before the SEM.

The intensity of the SEM signal is proportional to the charge density within a phase slice of the original bunch. The BSM has a phase resolution of 0.5°, which is equivalent to 3.45 ps. The entire longitudinal profile is measured by scanning the phase offset of the deflecting RF field over a sufficient range, which has the effect of translating the spatial distribution of secondary electrons across the output slit. Each phase slice is measured in a separate macropulse, under the assumption that all macropulses are identical. The phase sampling rate is limited to the repetition rate of the macropulses, while the SEM signal is digitized at 1 MHz, allowing observation of the bunch profile evolution within the macropulse. The BSM produces a 2-D measurement of SEM signal strength versus time and phase offset of the deflecting field, which is, in general, not equal to the phase of the linac RF. The BSM wire can also be translated over a 6 mm range to take measurements at different points along the horizontal profile of the beam.

BUNCH SHAPE MEASUREMENTS

The ion beam parameters used during the study differed from the normal production settings. The macropulse length and repetition rate were lowered from the operational duty factor of 625 µs at 120 Hz to 150 µs at 4 Hz, and the H^- beam current was reduced. This change of configuration was necessary to avoid destroying the BSM wire. A phase step size of 0.2° was used throughout the study, and bunches were sampled within the macropulse every 1 µs. A total of 13 measurements were taken at different horizontal positions separated by 0.5 mm. Figure 2 shows 5 scans, taken at the approximate center of the beam and ±1.0 mm and ±2.5 mm from the center. The top row shows the 2-D scan results. The colormaps are scaled to the maximum signal recorded at each location to maximize contrast with the background. The bottom row shows the longitudinal bunch profiles averaged over the region between 110 µs and 140 µs. The shaded area around the lines represents the $\pm 2\sigma$ uncertainty. The measurements in Fig. 2 exhibit three unexpected features: an intra-macropulse temporal instability; asymmetric bunch

* Work supported by the U.S. Department of Energy and the National Nuclear Security Agency under contract no. DE-AC52-06NA25396.
† mkay@lanl.gov

ISBN: 978-3-95450-262-2 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2025-WEPCO04

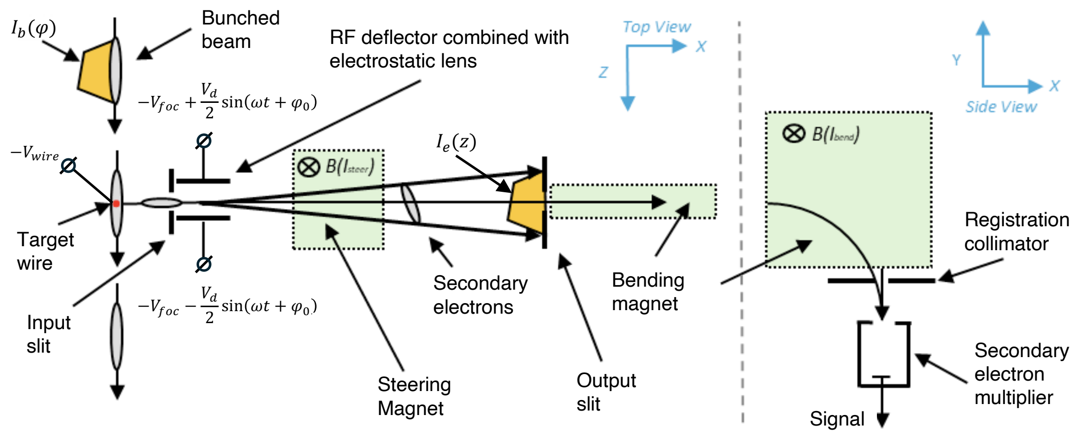

Figure 1: Working principle of the BSM in use at LANSCE.

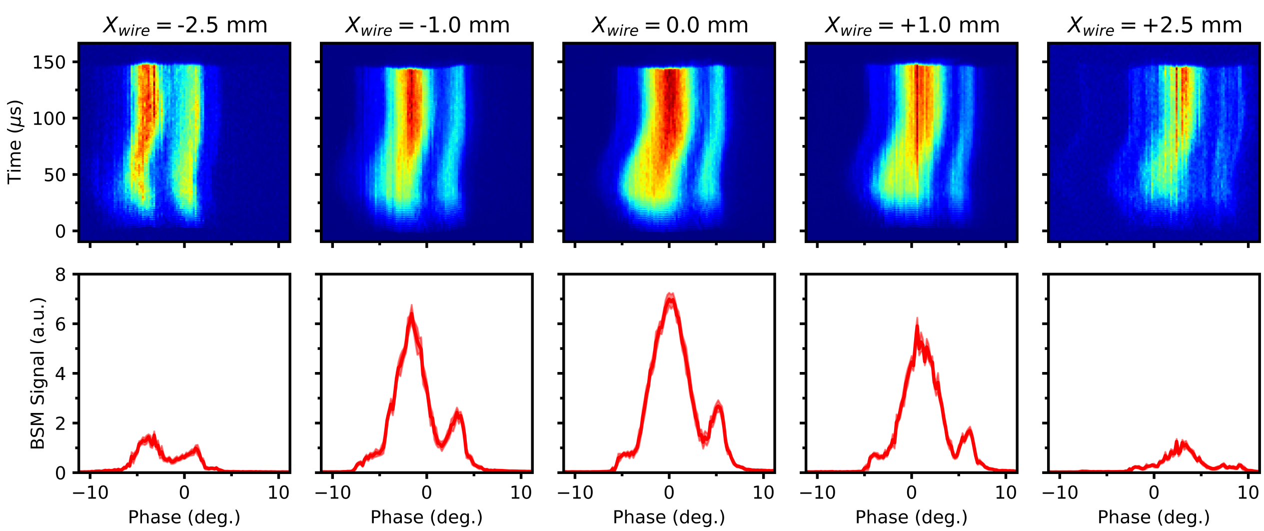

Figure 2: BSM scans at five different transverse positions.

shapes; and transverse dependence of both the shape and center phase of the longitudinal distributions. The remainder of this section is devoted to a discussion of each.

Temporal Instability

The bunch is unstable throughout roughly the first two thirds of the macropulse, and the temporal instability is characteristically similar at each transverse position along the ion beam. The longitudinal distribution shifts along the phase axis and grows in peak intensity until it stabilizes after around 110 µs. The temporal instability is more closely examined in Fig. 3. Figure 3(a) shows the peak and integrated signals for each time slice in the center data set (X_{wire} = 0.0 mm). Both curves rise steeply for the first 40 µs. Then, the integrated signal flattens, while the peak signal grows more gradually until it levels off after 110 µs. Together, these curves suggest there are three distinct regions within the macropulse, which are distinguished by the slope of the curves. In the first region, the overall bunch intensity grows at a constant rate until it reaches a constant value. In the second region, the bunches are fully populated but become more compressed longitudinally later in the macropulse. In the final region, the bunch shape is stable for the remaining duration of the macropulse. Figure 3(b) shows the longitudinal bunch profile within each of these three regions. This kind of intra-macropulse instability was observed during the commissioning of LINAC4 at CERN, and it was concluded to be caused by beam loading [4]. It is not known what exactly caused the temporal instability observed in Fig. 2 or if it is unique to the beam configuration used during this study.

Bunch Shape Asymmetry

A second peak is observed in all but the X_{wire} = +2.5 mm data set, and it is especially prominent in the measurements near the transverse center of the beam. There are two likely explanations for this. The first is that electrons detached from H^- colliding with the wire target are being picked up by the detector. Ref. [5] includes a discussion about the effect of stripped electrons being detected by the BSM.

ISBN: 978-3-95450-262-2 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2025-WEPCO04

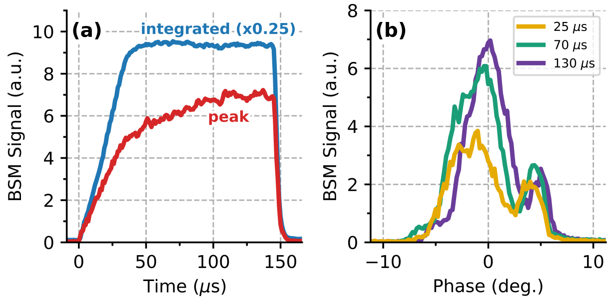

Figure 3: Temporal instability within the macropulse. (a) Evolution of the peak and integrated signal along the macropulse; (b) Bunch profiles at the beginning, middle, and end of the macropulse.

This problem was identified early on in H^- accelerators and was the motivation for adding the bending magnet before the SEM. Simulation studies show that most stripped electrons scatter off the wire with little energy loss [7]. The vast majority of these stripped electrons would have much greater energy than the secondary electrons emitted from the wire and would be filtered out by the bending magnet. The second explanation is that there is a second core in the real beam. This is most likely the case, as a second peak was also observed in the LANSCE H^+ beam in an earlier study [8]. Further studies are required to determine whether the second peak is real or an artifact of the measurement.

Transverse Dependence

Aside from the expected decrease in signal intensity with distance from the beam center, there are two noticeable transverse effects displayed in Fig. 2. The first is that the longitudinal distribution is not symmetric about the center of the beam, and the difference is more pronounced near the tails. This is most likely caused by a combination of magnet errors and misalignment of beamline components or the beam itself. The second transverse effect is the shifting of the longitudinal distribution along the phase axis, which implies that the bunch is tilted in the $x - \phi$ plane. Figure 4 shows the spatial distribution of the bunch reconstructed

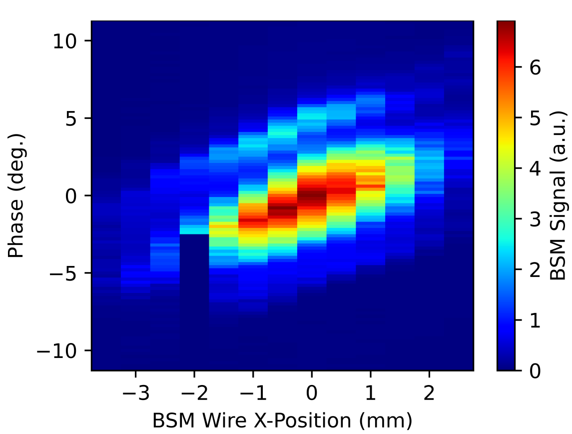

Figure 4: Spatial distribution of the bunch in the $x - \phi$ plane.

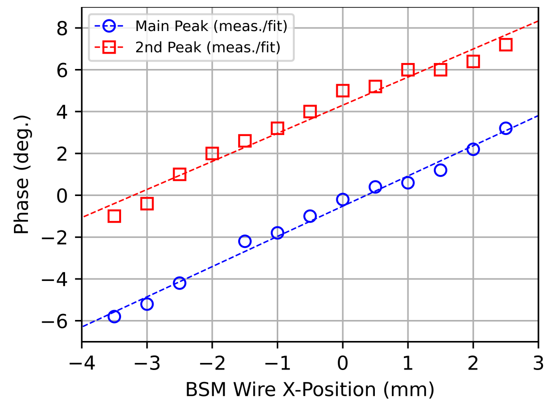

Figure 5: Phase shift as a function of wire position.

from BSM measurements. The data set at $X_{wire} = -2.0$ mm was corrupted halfway through the scan. The apparent tilting is explained by the time-of-flight difference that results from changing the path length between the wire target and the detector. Figure 5 shows the phases of the main peak and second peak in the longitudinal profile as a function of wire position. The best-fit line for the main peak is given by $y = 1.44x - 0.53$, and for the second peak it is given by $y = 1.34x + 4.30$. The fact that both lines have close to the same slope is evidence that the second peak is indeed real and not due to higher energy stripped electrons. Considering the secondary electron density decreases as $1/(2\pi r)$, where r is the radial distance from the wire, increasing the path length also leads to fewer electrons being accepted through the input slit. This results in lower overall signal intensity and could partially explain the large difference in the longitudinal profiles in the transverse tails of the distribution. Both the time-of-flight shift and signal intensity must be corrected when using the BSM to reconstruct the $x - \phi$ distribution.

CONCLUSION

A BSM was used to measure the longitudinal profile of H^- bunches at 72.72 MeV in the LANSCE DTL. The BSM produces a 2-D measurement of signal intensity versus phase and time within a macropulse, and measurements can be taken at different horizontal positions. Several unanticipated features of the measurements were also discussed.

ACKNOWLEDGMENTS

The authors thank the members of AOT-OPS who assisted with the experiment and members of the LANSCE Physics Team, whose insights helped guide the analysis and shape future experiments.

REFERENCES

[1] Y.K. Batygin, “Multi-beam operation of LANSCE accelerator facility,” *J. Instrum.*, vol. 19, p. T06007, 2024. doi:10.1088/1748-0221/19/06/T06007

[2] A. V. Feschenko and P. N. Ostroumov, “Bunch Shape Measuring Technique and its Application for an Ion Linac Tuning”,

ISBN: 978-3-95450-262-2 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2025-WEPCO04

in *Proc. LINAC'86*, Stanford, CA, USA, Sep. 1986, paper WE3–30, pp. 323–327.

[3] A.V. Feschenko and P.N. Ostroumov, “Bunch shape measurements at the INR linac”, in *Proc. ABI'91*, Tsukuba, Japan, Apr. 1991, pp. 236-245.

[4] S.A. Gavrilov, A.V. Feschenko and V.A. Gaidash, “Development and implementation of bunch shape instrumentation for ion linacs”, in *Proc. RuPAC'21*, Alushta, Russia, Sep.–Oct. 2021, paper MOX02, pp. 1-6. doi:10.18429/JACoW-RuPAC2021-MOX02

[5] A. V. Feschenko, “Methods and Instrumentation for Bunch Shape Measurements”, in *Proc. PAC'01*, Chicago, IL, USA, Jun. 2001, paper ROAB002, pp. 517–521.

[6] S. Gavrilov, A. Feschenko and D. Chermoshentsev, “Bunch shape monitors for modern ion linacs”, *J. Instrum.* vol. 12, p. P12014, 2017. doi:10.1088/1748-0221/12/12/P12014

[7] A. Denisov, A. Feschenko, and A. Aleksandrov, “PECULIARITIES OF BUNCH SHAPE MEASUREMENTS OF H-MINUS BEAMS IN LINEAR ACCELERATORS”, in *Proc. RuPAC'08*, Zvenigorod, Russia, Sep.-Oct. 2008, paper WEEAU02, pp. 298–300.

[8] I. N. D. Draganic *et al.*, “Bunch Shape Monitor Measurements at the LANSCE Linac”, in *Proc. NAPAC'16*, Chicago, IL, USA, Oct. 2016, pp. 25–27. doi:10.18429/JACoW-NAPAC2016-MOA3CO03