

SIMULATION AND ANALYSIS OF HIGH-ENERGY BEAM TRANSPORT LINES AT LANSCE

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Abstract

The Los Alamos Neutron Science Center (LANSCE) target stations require reliable beam quality to carry out experiments under optimal conditions. Maintaining the bunch structure through the beam transport from the 800-MeV Linac to the target stations is crucial. Currently, beam transport tuning is the primary tool to control the beam from the source to end of the linac, but not as readily used for the beams' remaining travel to the target stations. Our legacy models for the high-energy beamlines (HEBT) are simulated with TRANSPORT simulation code. Now, we are exploring newer more accurate accelerator physics codes such as Elegant and MAD-X. These models are continuously improved by incorporating key known beam characteristics and updated lattice elements. They are benchmarked against experimental data where diagnostics are available. We are improving these tools to better understand beam optics and conduct studies aimed at optimizing beam performance. In this paper, we present the latest simulation results supporting more predictive beam transport downstream of the 800-MeV Linac.

INTRODUCTION

The Los Alamos Neutron Science Center provides high-intensity neutron beams over a broad energy range for material research. To meet the diverse experimental requirements, the facility produces two proton beams with distinct energies. The Isotope Production Facility (IPF) utilizes a 100 MeV H^+ beam, whereas four downstream user stations—Proton Radiography (pRad), Ultra-Cold Neutrons (UCN), Lujan Center, and Weapons Neutron Research (WNR)—are supplied with an 800 MeV H^- beam with distinct timing patterns. Both beams have an initial energy of 0.75 MeV and are accelerated to 100 MeV by the 201.25 MHz Drift Tube Linac. Subsequently, the H^- beam is further accelerated to 800 MeV by the 805 MHz Side Coupled-Cavity Linac (CCL) and distributed downstream to the user stations via the High-Energy Beam Transfer (HEBT) lines.

In recent years, efforts have been made to improve the models of the HEBT beamlines, downstream the CCL, delivering beam to several user stations [1], primarily using Elegant [2] and MAD-X [3]. Ultimately, this will improve our understanding of beam transport and enable better control of the beam parameters along the beamlines.

In this paper, we present current efforts to model the beamlines delivering beam to the Weapons Neutron Research. The first section provides an overview of the beamline configuration, followed by the presentation of simulation results.

HEBT BEAMLINES CONFIGURATION TO THE WNR TARGET

The Weapons Neutron Research (WNR) facility is a pulsed neutron source used for nuclear science, material studies and detector development. The high-energy neutrons (from 100 keV to 800 MeV) are produced via spallation: the high-energy proton beam, generated at the end of the 805-MHz CCL and transported downstream through 250 m beamline length, strikes a tungsten target. Then, neutrons travel along a flight path that depends on the type of experiment (goals, energy ranges, and resolutions). For more details on the neutron experiments at LANSCE, see Reference [4].

In this paper, we focus on the high-energy beam transport from the end of the 805-MHz CCL to the WNR target. The configuration of these beamlines is presented in Fig. 1.

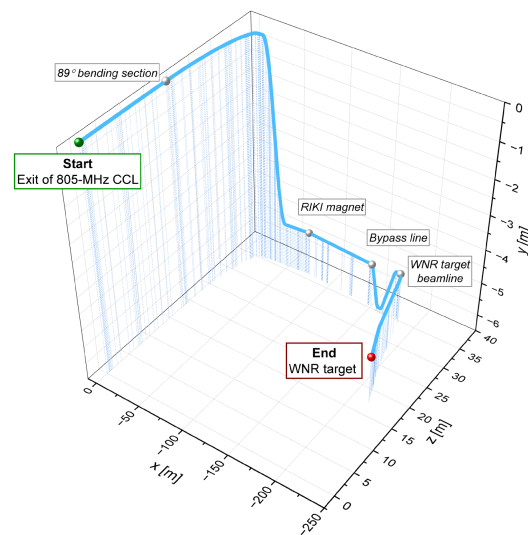


Figure 1: Beamline floor plan (Z–X–Y) from the 805 MHz CCL exit to the WNR target, where z, x and y respectively defined along the beam trajectory from the CCL, the horizontal north–south direction, and the vertical up–down direction. The intermediate markers in gray indicate the entrance of each beamline section.

The Switchyard receives the 800 MeV H^- beam and transports it in a straight section. The beam is focused by two quadrupole doublets, while the final bending magnets deflect the beam by approximately 6° to the right into Line D.

The beam then enters an 89° horizontal bending section composed of four bending magnet triplets that steer the beam south. Achromatic conditions are achieved using quadrupole triplets, ensuring minimization of dispersion. In the vertical bend, the beam is directed downward, producing an elevation

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drop of approximately 5 m. A downstream matching section is used to adjust the beam optics. At this point, the beam encounters the RIKI kicker magnet, which selectively deflects the beam toward the Ring Injection Line for the Proton Storage Ring (PSR), while the un-kicked beam continues along Line D toward the WNR target. Four quadrupole doublets in this straight section provide beam focusing and transport control.

Further downstream, the beam is directed into a bypass line, since the main Line D is locally occupied by the beam returning from the PSR toward the Lujan Center. The bypass is implemented using four bending magnets to steer the beam around this section. Then, the beam is matched using a quadrupole doublet located in the final section of Line D and subsequently bended 30° into the WNR target beamline via a bending magnet.

In the WNR target beamline, an additional quadrupole doublet provides transverse matching, followed by an 8° bend toward the target. A final doublet upstream of the target is used to optimize the optical conditions at the WNR target.

SIMULATIONS RESULTS

Elegant code, developed at the Advanced Photon Source, performs 6D beam dynamics simulations using a combination of matrix-based and element-by-element tracking. It supports linear and nonlinear optics and includes models for collective effects such as longitudinal space charge. In contrast, MAD-X, developed at CERN, is primarily a beam optics code based on first and second-order transport matrices.

The beam transport simulation starts at the exit of the 805-MHz CCL, after the beam has been accelerated to reach 800 MeV. The Twiss parameters α and β and rms geometric emittances are measured at the exit of the CCL every run cycle. The beam parameters used in this simulation correspond to typical operating conditions and are summarized in Tables 1 and 2.

Table 1: Twiss Parameters at the Exit of the 805-MHz CCL

Plane	Alpha	Beta [cm/mrad]
x	-0.546	1.326
y	-0.913	1.697

Table 2: Geometric RMS Emittance at the Exit of the 805-MHz CCL

Plane	Emittance [$\pi \cdot \text{cm} \cdot \text{mrad}$]
x	0.043
y	0.041

MAD-X is used to compute the lattice optics using the TWISS module with the measured initial Twiss param-

eters, which provides the Twiss functions based on the Courant–Snyder formalism.

Elegant requires a complete six-dimensional (6D) phase-space description; thus, the measured beam parameters are complemented by two additional parameters. The typical longitudinal beam extent in LANSCE's HEBT is about 0.48 cm and momentum spread $\Delta p/p$ is $0.0813\% = 8.13 \cdot 10^{-4}$. Then, elegant generates an ideal Gaussian bunch representation for particle tracking simulations.

Figure 2 presents the simulated transverse beam width in x and y using Elegant and MAD-X. These simulations are compared with experimental beam data from multiple run cycles obtained from wire scanner measurements along the beamlines where available. Simulations agree well with experimental data up to 100 m (RIKI kicker magnet location) for both horizontal and vertical beam width, while larger deviations are observed beyond this point with limited diagnostics data. These discrepancies may result from a combination of different effects. A mismatch between the simulated input beam and magnetic field settings and the experimental conditions is a likely contributor, as the simulations use typical magnet readout values in the absence of run-specific information. In addition, experimental uncertainties may also contribute. New measurements are expected to be performed later this year.

Phase-Space Tracking with Elegant

While tuning, beam losses are reduced or at least controlled to limit activation of accelerator components. Transverse halo and longitudinal phase-space tails can lead to beam loss and activation of surrounding material. To better capture the phase-space evolution along the beam transport from the exit of the 805-MHz to the WNR target, a realistic bunch distribution is used in Elegant to better represent the true phase-space properties of the beam and improve the accuracy of the simulation. Figure 3 shows the 6D phase space distribution at the exit of the 805-MHz CCL and at the WNR target. The input distribution has been generated using the simulation model HPSim [5]. A significant increase is observed in the transverse (x - x_p , y - y_p) and longitudinal (t -KE) phase spaces. Note that a double-Gaussian structure, corresponding to the core and halo, appears in the transported beam distribution. This initial phase-space tracking with elegant illustrates that further investigation is required to characterize the bunch structure in the HEBT transport.

CONCLUSION

The high-energy transport lines from the exit of the 805-MHz CCL to the WNR target are simulated using elegant and MAD-X and benchmarked where possible against measurements, showing a reasonable agreement. A first realistic phase-space tracking is performed, indicating a phase-space growth along the HEBT transport. These results demonstrate that further improvements to the models and more detailed analysis are required to achieve predictive beam transport.

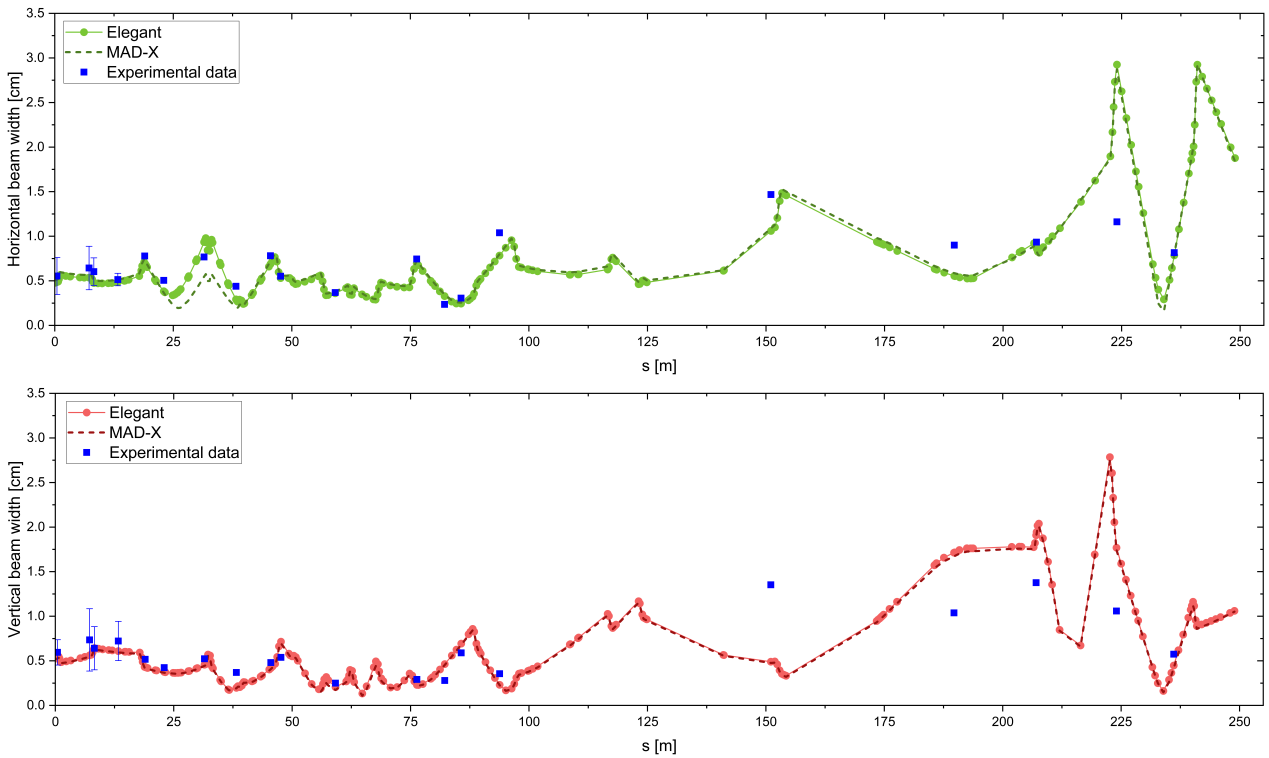


Figure 2: Horizontal (top) and vertical (bottom) beam widths simulated with Elegant and MAD-X and compared with wire scanner measurements where available (blue dots).

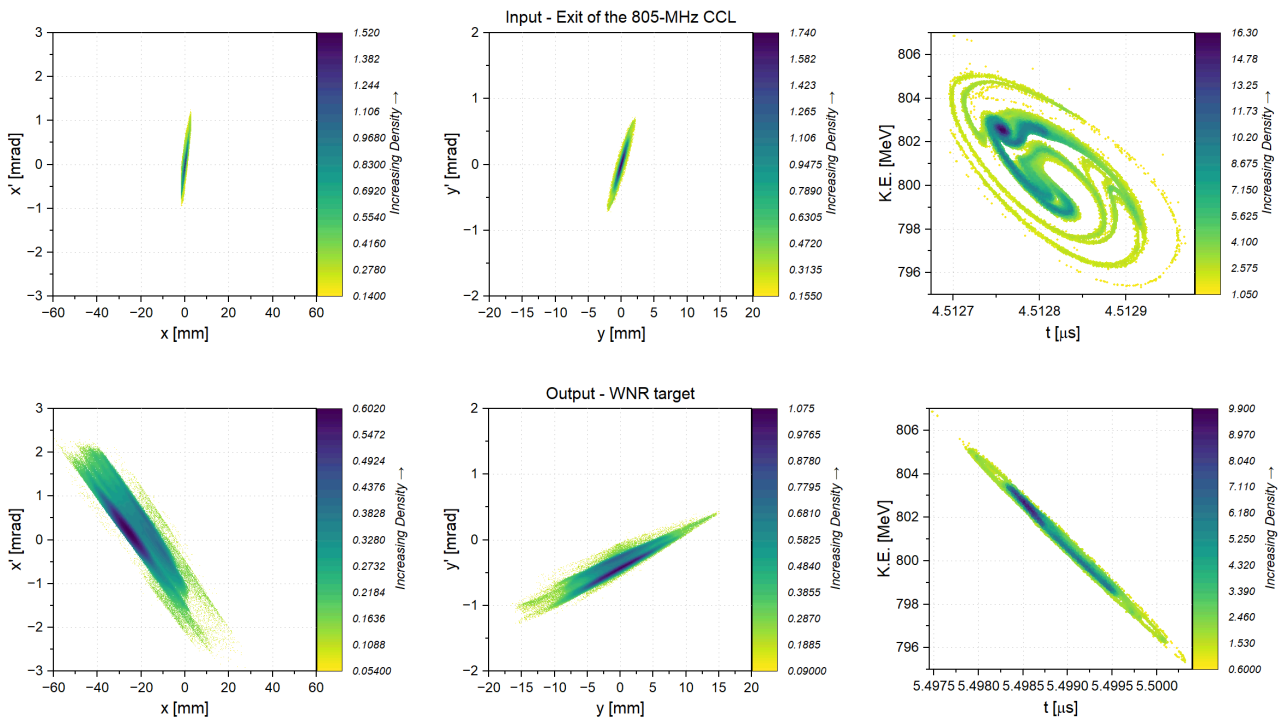


Figure 3: Phase-space distributions of the 800 MeV H⁻ beam in the transverse planes (x - x' , y - y') and longitudinal plane (t -KE) at the exit of the 805-MHz CCL (top) and at the WNR target (bottom).

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