PROPOSAL FOR REDUCTION OF TRANSVERSE EMITTANCE OF BNL 200 MEV LINAC*

D. Raparia, J. Alessi, J. Beebe Wang, W. T. Weng, Collider-Accelerator Department, Brookhaven National Laboratory, Upton, New York 11973, USA

Abstract

BNL has a plan to upgrade the AGS proton beam from the current 0.14 MW to higher than 1.0 MW and beyond for a neutrino facility which consists of two major subsystems. First is a 1.45 GeV superconducting linac (SCL) to replace the Booster as injector for the AGS. Second is the performance upgrade for the AGS itself for the higher intensity and repetition rate. For high intensity proton accelerators, such as the upgraded AGS, there are very stringent limitations on uncontrolled beam losses. A direct effect of increased linac beam emittance is the halo/tail generation in the circulating beam. Studies show the estimated halo/tail generation in the beam for the present normalized RMS emittance of the linac beam is unacceptable. To reduce the transverse emittance of the 200 MeV linac, the existing radio frequency quadrupole linac (RFQ) has to be relocated closer to drift tube linac (DTL) tank 1 to meet the emittance requirement for AGS injection with low loss. This paper will present the various options of matching between RFQ and DTL, and chopping options in the low energy beam transport (LEBT).

INTRODUCTION

We have examined possible upgrades to the AGS complex that would meet the requirements of the proton beam for a 1.0 MW neutrino superbeam facility [1]. We are proposing to upgrade the existing 200 MeV linac to 400 MeV using the Fermilab style CCL, followed by a superconducting linac to an energy of 1.45 GeV for direct H^- injection into the AGS [1].

The requirements of the proton beam for the super neutrino beam are summarized in Table 1. Since the present number of protons per fill is already close to the required number, the upgrade focuses on increasing the repetition rate and reducing beam losses (to avoid excessive shielding requirements and to keep activation of the machine components to a workable level). It is also important to preserve all the present capabilities of the AGS, in particular its role as injector to RHIC. Present injection into the AGS requires the accumulation of four Booster loads in the AGS, which takes about 0.6 sec, and is therefore not suited for high average beam power operation.

Table 1: AGS Proton Driver Parameters

Total beam power	1 MW
Beam energy	28 GeV
Average beam current	42 μA
Cycle time	400 msec
Number of protons per fill	0.9×10^{14}
Number of bunches per fill	24
Protons per bunch	0.4×10^{13}
Injection turns	230
Repetition rate	2.5 Hz
Pulse length	0.72 msec
Chopping rate	0.75
Linac average/peak current	20 / 30 mA

To reduce the injection time to about 1 msec, the Booster will be replaced by a 1.45 GeV linac. The injection linac consists of the existing warm linac of 200 MeV upgraded to 400 MeV and a new superconducting linac to 1.45 GeV. The multi-turn injection from a source of 28 mA and 720 μsec pulse width is sufficient to accumulate 0.9×10^{14} particle per pulse in the AGS. The minimum ramp time of the AGS to full energy is presently 0.5 sec. This must be reduced to 0.2 sec to reach the required repetition rate of 2.5 Hz to deliver the required 1 MW beam to the target.

HALO/TAIL GENERATION VS. LINAC EMITTANCE

For high intensity proton accelerators, such as the upgraded AGS, there are very stringent limitations on uncontrolled beam losses. We have examined the emittance growth and uncontrolled beam losses as a function of linac emittance by computer simulations.

All of the physical quantities used in the simulations (Table 1 and 2) are chosen according to the design specifications. Correlated painting is chosen for injection into AGS, considering the available aperture at injection and beam halo/tail control. The average stripping foil thickness is assumed to be 300 μg/cm^2. In order to separate the effects of linac emittance from the other issues, the effects of space charge and magnet errors are not included in this study.

A direct effect of linac beam emittance is the halo/tail generation in the circulating beam. Figure 2 shows the estimated halo/tail generation in the AGS beam as a function of normalized RMS emittance of linac beam.
Here, the halo/tail generation is defined as the ratio of the number of particles with emittance larger than the designed acceptance of 49π mm-mrad to the total number of particles in the circulating beam.

* Work performed under the auspices of the US Department of Energy
** E-mail raparia@bnl.gov

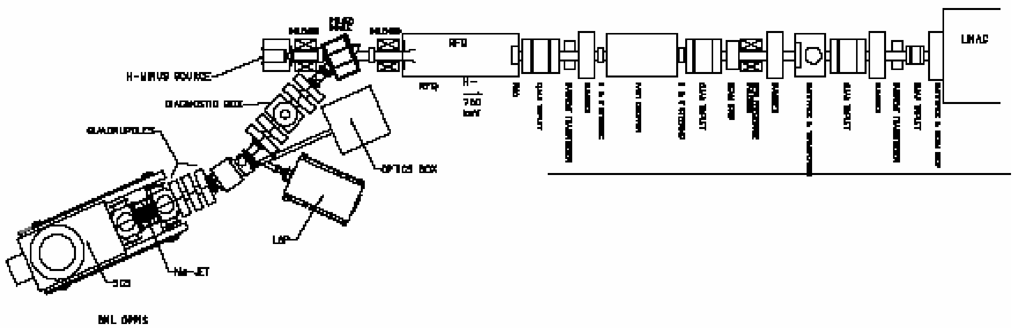

Figure 3: Layout of the MEBT

Table 2: Simulation parameters

Horizontal beta at the injection	28.0 m
Vertical beta at the injection	8.0 m
Horizontal emittance of injected beam	2π mm-mrad
Vertical emittance of injected beam	2π mm-mrad
Horizontal beam size at injection, σ_x	5.2293 mm
Vertical beam size at injection, σ_y	2.7952 mm
Horizontal Foil size (2.5 σ_x)	13.0731 mm
Vertical foil size (2.5 σ_y)	6.9878 mm

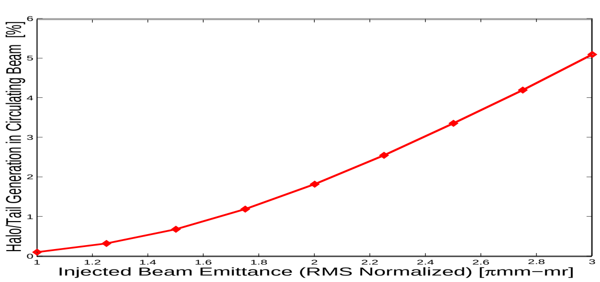

Figure 2: The estimated halo/tail generation in the circulating beam as functions of normalized RMS emittance of injected beam.

PRESENT MEBT

The source of the emittance growth in our linac lies in the medium energy beam transport (MEBT). The 7 meters long MEBT includes 10 quadrupoles and 3 bunchers for beam matching into the linac and a fast beam chopper which allow beam chopping with ~10 ns rise and fall time. Figure 3 shows the layout of the line.

The present configuration of the MEBT is the result of having to meet several requirements imposed on the line, like providing an approximate 1 m long drift space for a fast chopper, a 1 meter long drift for a dipole for beam injection from the old polarized ion source, a movable beam dump, diagnostics box etc. This configuration results in a lattice mismatch in both transverse as well as longitudinal direction. The RFQ ($\beta\lambda$~ 6cm) and DTL ($\beta\lambda$ = 6 cm) both have a FODO lattice (period length 6-12 cm) but in between, the MEBT has a triplet configuration to provide long drift spaces for fast and slow choppers and dipoles. Similarly in the longitudinal direction the focusing period in the RFQ and DTL is much smaller than the unevenly spaced bunchers in the MEBT, and the resulting beam is debunched by the time it enter the DTL. Figure 4 shows the longitudinal phase space at end of RFQ, 1st, 2nd, 3rd buncher, entrance of the DTL and after cell 20 in DTL Tank 1.

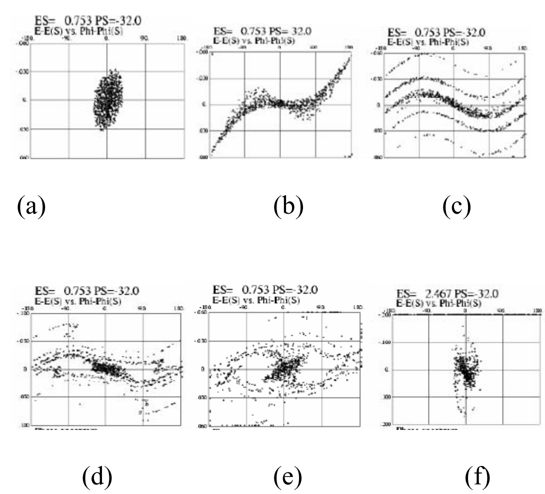

Figure 4: Longitudinal phase space plots (a) at end of RFQ, (b) after buncher 1, (c) after buncher 2, (d) after buncher 3, (e) at entrance of DTL and (f) at DTL cell 20.

It is clear from figure 4, beam is debunched at the entrance of the DTL, which results in beam loss (~ 40 %) and transverse emittance growth of 450-500% .

OPTIONS FOR MEBT

We have studied following MEBT configurations to reduce the transverse emittance: (1) adding a 4th

buncher after the fast chopper, (2) bring the RFQ close to the DTL, only providing space for a gate valve, and (3) a short (0.5m) MEBT with 3 quadrupoles and two bunchers.

Adding a 4th buncher after the chopper improve the transmission to ~ 75% and reduces emittance growth to 60-70%. Bringing the RFQ right against the DTL increases the transmission to 100% and reduces the emittance growth to 40-65%, since the beam is still bunched but mismatched to the DTL. The short MEBT provides enough degrees of freedom to match into the DTL in all three planes. The resulting emittance growth is only 0-20% in the transverse plane but ~75% in the longitudinal plane. The emittance growth in the longitudinal plane is due to the inherent mismatch between DTL Tanks. This mismatch is due to the fact that there is 0.6 – 1meter drift space between the tanks which causes discontinuities in the longitudinal focusing pattern. In the modern linacs, these discontinuities are compensated by shifting the synchronous phase of the first and last few cells in each tank [2]. Table III shows the result of PARMILA simulations for these options.

Table 3: MEBT upgrade options, emittance at source 0.4 π mm mrad (rms,nor)

Configuration	Transmission	RMS emit growth (x, y, z) %
(A)Present	~60%	450, 500, 350
(A) +4th B	79%	56, 70, 170
RFQ +DTL	100%	64, 40, 64
Short MEBT	100%	16, 0, 74

Our choice is the short MEBT, which provides enough degrees of freedom to match in all three planes. The choice of this MEBT forces the chopping to be done before the RFQ in the low energy beam transport (LEBT).

LOW ENERGY BEAM TRANSPORT

Previous experience at BNL has shown that due to space charge, the chopper in the magnetic LEBT would not work [3]. We are now considering an all electrostatic LEBT with einzel lenses and a 90 degree electrostatic spherical deflector to merge the H^- polarized beam into the RFQ. An electrostatic field can be used to deflect/reflect the H^- ions. The SNS LEBT uses an electrostatic chopper in deflection mode in the LEBT with a rise time of 50 ns [4]. We need to decrease the rise and fall times to 10 ns or better. At 35 keV, H^- ions travel about 2.5 cm in 10 ns. This implies the deflecting/reflecting field should be confined to 2.5 cm. Figure 5 shows the conceptual design of the chopping with einzel lenses in decelerating mode with (a) reflecting field on and (b) reflecting off. The required voltage for the reflecting mode is about 37 kV and for transmission mode is about 32 kV.

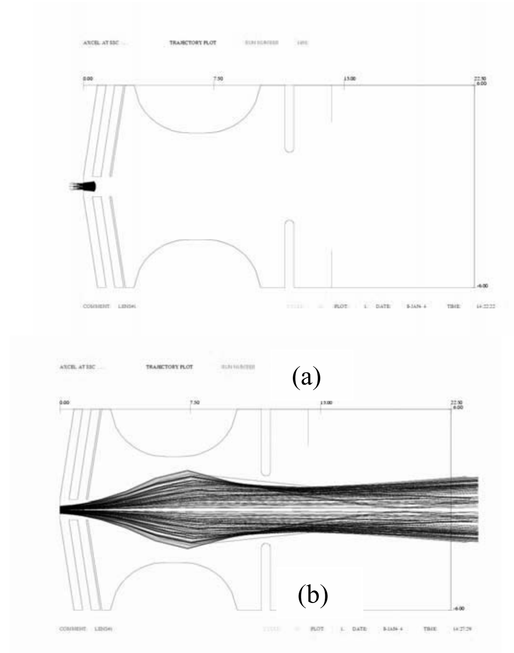

Figure 5: Conceptual design of chopper with einzel lens in decelerating mode with (a) reflecting field on and (b) reflecting field off.

H^- polarized beam will merge into the LEBT using a 90 degree spherical deflector and will able to maintain the desired polarization direction. Initial simulation has shown that rms emittance growth for polarized beam is less than 20% and for the high intensity H^- beam is about 30%. Some R&D effort is needed to realize the 10 ns rise time for this chopping and spherical deflector scheme.

CONCLUSIONS

Simulation studies have shown that the transverse emittance of the 200 MeV BNL linac could be reduced to achieve acceptable losses for 1MW AGS operation. R&D efforts are needed to realize chopping with a rise time of 10 ns in all electrostatic LEBT.

REFERENCES

[1] W.T. Weng and D. Raparia (editor), "The AGS-Based Super Neutrino Beam Facility, Conceptual Design Report", to be published.

[2] K. R. Crandall and D. Raparia, "Reducing the field perturbation produced by shifted gaps in a drift-tube linac", 1992 Linear Accelerator Conference, Ottawa, Canada, AECL-10728, pp504, August 1992.

[3] J. Alessi, et al., 'The BNL 200 MeV H^- Linac Performance and Upgrade", 1990 Linear Accelerator Conference, Albuquerque, NM, pp 774, September 1990

[4] J. W. Staples et al., "The SNS Four-Phase LEBT Chopper", 1999 Particle Accelerator Conference, New York, pp 1963, 1999.