# DESIGN OF THE BNL SUPER NEUTRINO BEAM FACILITY*

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*Abstract*

A very long base line super neutrino beam facility is needed to determine the neutrino mixing amplitudes accurately, as well as measure the CP violation phase angle. This is possible due to the long distance and wideband nature of the neutrino beam for the observation of several oscillations from one species of the neutrino to the other.

BNL plans to upgrade the AGS proton beam from the current 0.14 MW to higher than 1.0 MW and beyond for such a neutrino facility which consists of three major subsystems. First is a 1.2 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, and finally is the target and horn system for the neutrino production. The major contribution for the higher power is from the increase of the repetition rate of the AGS from 0.3 Hz to 2.5 Hz, with moderate increase in the intensity.

The design consideration to achieve high intensity and low losses for the linac and the AGS will be reviewed. The target-horn design for high power operation and easy maintenance will also be presented.

## 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. We are proposing to build a superconducting upgrade to the existing 200 MeV linac to an energy of 1.2 GeV for direct $H^-$ injection into the AGS.

The requirements of the proton beam for the super neutrino beam are summarized in Table 1 and a layout of upgraded AGS is shown in Figure 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 maintain activation of the machine components at workable level). It is also important to preserve all the present capabilities of theAGS, in particular its role as injector to RHIC.

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 | $0.9 \times 10^{14}$ |
| Number of bunches per fill | 24 |
| Protons per bunch | $0.4 \times 10^{13}$ |
| Injection turns | 230 |
| Repetition rate | 2.5 Hz |
| Pulse length | 0.72 msec |
| Chopping rate | 0.75 |
| Linac average/peak current | 20 / 30 mA |

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. To reduce the injection time to about 1 msec, the booster will be replaced by a 1.2GeV linac. The injection linac consists of the existing warm linac of 200 MeV and a new superconducting linac to 1.2 GeV. The multi-turn injection from a source of 28 mA and 720 μsec pulse width is sufficient to accumulate $0.9\times10^{14}$ 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.

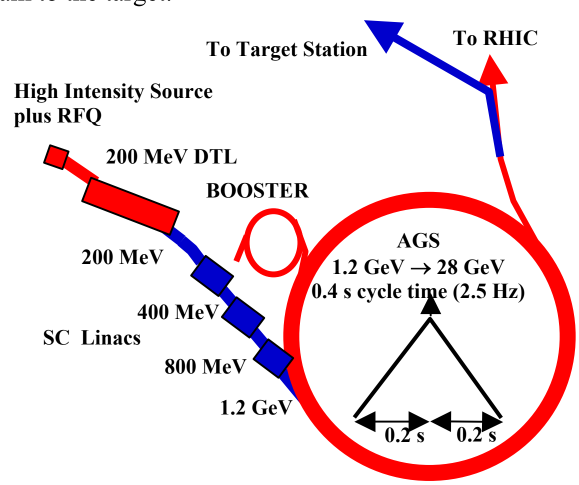


Figure 1: Schematic diagram of the accelerators for the "neutrino production".

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## SUPERCONDUCTING LINAC (SCL)

The superconducting linacs accelerate the proton beam from 200 MeV to 1.2 GeV. The presented configuration follows a design described in detail in the study group report. The major parameters of the three sections of the SCL are given in Table 2. The low energy section operates at 805 MHz and accelerates proton from 200 to 400 MeV. The two sections, accelerating to 800 MeV and 1.2 GeV, operate at 1.61 GHz. A higher frequency is desirable for obtaining a larger accelerating gradient in a more compact structure and reduced cost. The SCL will be operated at 2 $^{o}$K for reaching the desired gradients.

Table 2: General parameters of the SCL.

| Linac section | LE | ME | HE |
|---|---|---|---|
| Average beam power, kW | 7.14 | 14 | 14 |
| Average beam current, μA | 35.7 | 35.7 | 35.7 |
| Initial kinetic energy, MeV | 200 | 400 | 800 |
| Final kinetic energy, MeV | 400 | 800 | 120 |
| Cell reference □$_0$ | 0.615 | 0.755 | 0.887 |
| Frequency, MHz | 805 | 1610 | 1610 |
| Cells/cavity | 8 | 8 | 8 |
| Cavities/cryo-module | 4 | 4 | 4 |
| Cavity internal diameter, cm | 10 | 5 | 5 |
| Total length, m | 37.82 | 41.4 | 38.32 |
| Accelerating gradient, MeV/m | 10.8 | 23.5 | 23.4 |
| Cavities/Klystron | 1 | 1 | 1 |
| Norm. rms emittance, □mm mrad | 2 | 2 | 2 |
| rms bunch area,□° MeV (805 MHz) | 0.5 | 0.5 | 0.5 |

## 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. In this paper, we present the estimate of emittance growth and uncontrolled beam losses as function of linac emittance by computer simulations.

All of the physical quantities used in the simulations (Table 1 and 3) 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. A significant effort has been made to optimize injection painting. The optimized injection bump collapses as an exponential function of time with a time-constant of 0.1 msec. The initial foil-hit by each incident $H^-$ is counted as thrice to include the effects of two stripped electrons. The average 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 beam as a function of normalized RMS emittance of linac beam. Here, the Halo/tail generation is defined as the ratio of number of particles with emittance larger than the designed acceptance of 49□ mm-mrad to the total number of particles in the circulating beam. The existing ion source and RFQ has to be relocated next to DTL tank 1 to meet emittance requirement for the AGS injection with low loss.

Table 3: Simulation parameters.

| | |
|---|---|
| Horizontal beta at the injection | 28.0 m |
| Vertical beta at the injection | 8.0 m |
| Horizontal emittance of injected beam | 2□mm-mrad |
| Vertical emittance of injected beam | 2□mm-mrad |
| Horizontal beam size at injection, □$_x$ | 5.2293 mm |
| Vertical beam size at injection, □$_y$ | 2.7952 mm |
| Horizontal Foil size (2.5 □$_x$) | 13.0731 mm |
| Vertical foil size (2.5 □$_y$) | 6.9878 mm |

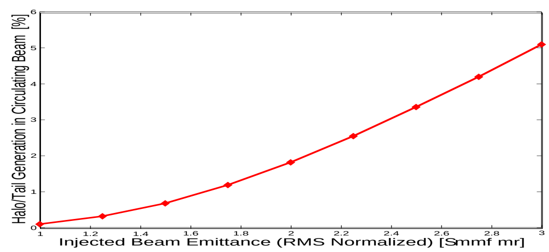


Figure 2: The estimated halo/tail generation in the circulating beam as functions of normalized RMS emittance of injected beam.

## TARGET STATION AND NEUTRINO BEAM

To achieve the 1 MW upgrade option of the proton driver at BNL, serious consideration must be given to the target selection. In evaluating the various choices of target materials and of target/horn configurations, the following concerns are being addressed:

- Optimization of neutrino flux,
- Heat removal from the target and horn,
- Survivability of the target intercepting energetic, high intensity proton bunches,
- Irradiation and integration issues.

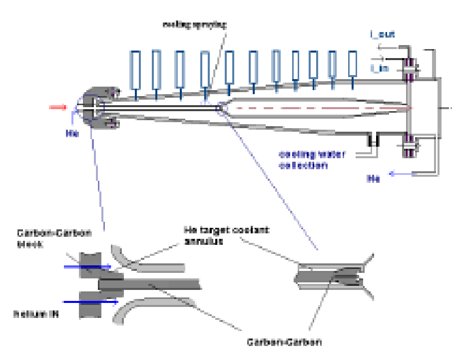


Figure 3: Proposed graphite target and horn configuration

The design of the target/horn configuration is shown in Fig. 3.The material selected for the superbeam target is a Carbon-Carbon composite. It is 3-D weaved material and exhibits extremely low thermal expansion for the temperatures up to 1000 °C while for the higher temperatures it responds like graphite. This property is significant since the thermoelastic stresses induced by intercepting the beam will be quite small thus extending the life of the target.

In the current option the target is an 80-cm long cylindrical rod with 12 mm diameter sizes. The 12 mm diameter target is chosen to intercept 100 TP, 2 mm rms proton beam. With this beam size, the total energy deposited as heat in the target is 7.3 kJ with peak temperature rise of about 280°C. Heat will be removed from the target through forced convection of helium through the outside surface

Using detailed finite element analysis incorporating the entire heat transfer scheme and the transient nature of the two inputs (protons and current) the "steady-state" temperatures in the target and horn were calculated and shown in Figures 4 and 5.

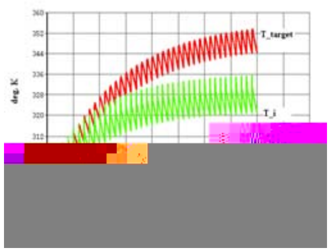

Figure 4: Transient temperatures in the horn conductor

Figure 5: Transient temperatures in the C-C target

The extracted beam will come into the existing U-line at the AGS, but it has to climb to a high hill for the target and decay channel. The hill arrangement is to keep the target and hadronic decay well above the water table in Long Island. The 11.3 degrees incline is suitable for aiming at Homestake site in South Dakota. A sketch of the hill is shown in Fig. 6.

The resultant $\nu_\mu$ spectrum is shown in Fig. 7. Which is used to study various neutrino processes and event rates at the distant detector.

Figure 6: Elevation view of the neutrino beam line to Homestake, South Dakota.

Figure7: Wide band horn focused muon neutrino spectrum for 28 GeV protons on a Carbon target. Spectrum of neutrinos are calculated at various angles with respect to the 200 m decay tunnel axis at the AGS and at a distance of 1 km from the target.

## CONCLUSIONS

We have produced a design for 1 MW AGS-based neutrino superbeam facility which can be further upgraded to 4 MW by 1) increase the linac energy to 1.5 GeV; 2) increase the AGS intensity to 1.8 X $10^{14}$ ppp, and 3) increase the AGS rep rate to 5.0 Hz. The associated problem in beam dynamics, power supply, rf system, beam losses and radiation protection are under study and shown to be feasible if such a capability is required by the physics experiments

Several R & D programs in the design of the superconducting cavity and the irradiation testing of target materials are actively pursued to improve on the design.

The design report and related technical notes can be found at http://www.agssnbf.bnl.gov The authors would like to acknowledge contributions from members of neutrino working group at BNL