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The AGS High Power Upgrade Plan*

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Abstract. BNL could provide a Megawatt class neutrino beam from the AGS for very long baseline neutrino experiments. We have studied two possible approaches to upgrade the AGS to 1.0 MW beam power. The first is the linac option, comprising a new superconducting linac injector of 1.2 GeV, accelerating 9×10^{13} proton per pulse in the AGS to 28 GeV at 2.5 Hz. The second option is to extend the existing 200 MeV linac to 400 MeV, ramp the Booster to 2.5 GeV at 6 Hz, add a new 2.5 GeV accumulator ring in the AGS tunnel, and finally ramp the AGS to 28 GeV at 2.5 Hz. Due to the simplicity of the linac approach and minimum interference with the on going research program, the linac option is the preferred one.

INTRODUCTION

We have examined [1] possible upgrades to the AGS complex that would meet the requirements for the proton beam for a 1 MW neutrino super beam facility. Those requirements are summarized in Table 1 and a layout of the upgraded AGS is shown in Figure 1. Since the present number of protons per fill is already close to the required number, the upgrade will focus on increasing the repetition rate and on reducing beam losses to avoid excessive shielding requirements and to maintain the machine components serviceable by hand. It is also important to maintain all the present capabilities of the AGS, in particular its role as injector to RHIC.

We are proposing here 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. This will be discussed in the next section. The minimum ramp time to full energy is presently 0.5 s, which will have to be upgraded to reach the required repetition rate of 2.5 Hz. The required upgrade of the AGS power supply will be described in third section. Finally, the increase ramp rate requires a substantial upgrade to the AGS rf system.

TABLE 1. AGS Proton Driver Parameters.

Total beam power	1 MW
Beam energy	28 GeV
Average beam current	42 μA
Cycle time	400 ms
Number of protons per fill	9×10^{13}
Number of bunches per fill	6
Protons per bunch	1.6×10^{13}
Injection turns	360
Repetition rate	2.5 Hz
Pulse length	1.08 ms
Chopping rate	0.65
Linac average/peak current	20/30 mA

The front end consists of a high-intensity negative-ion source, followed by a 750 keV RFQ, and the first 5 tanks of the existing room temperature Drift-Tube Linac (DTL) to accelerate protons to 116 MeV. The SCL is made of three sections, each with its own energy range, and different cavity-cryostat arrangement.

The proposed new injector for the AGS is a 1.2 GeV superconducting linac upgrade with an average output beam power of about 50 kW. The injection energy is still low enough to control beam losses due to stripping of the negative ions that are used for multi-turn injection into the AGS. The duty cycle is about 0.5%. The injection into the AGS is modeled after the SNS [2]. However, the repetition rate and consequently the average beam power is much lower. The larger circumference of the AGS also reduces the number of foil traversals. Beam losses at the injection into AGS are estimated to be about 3% of controlled losses [1]. The AGS injection parameters are also summarized in Table 1.

SUPERCONDUCTING LINAC

The superconducting linacs accelerate the proton beam fro, 116 MeV to 1.2 GeV. The presented configuration follows a similar design described in detail [3]. All three linacs are built up from a sequence of identical periods.

The major parameters of the three sections of the SCL are given in Table 3. The low energy section operates at 805 MHz and accelerates from 116 to 400 MeV.

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The following two sections, accelerating to 800 MeV and 1.2 GeV respectively, operate at 1.61 GHz. A higher frequency is desirable for obtaining a larger accelerating gradient with a more compact structure and reduced cost.

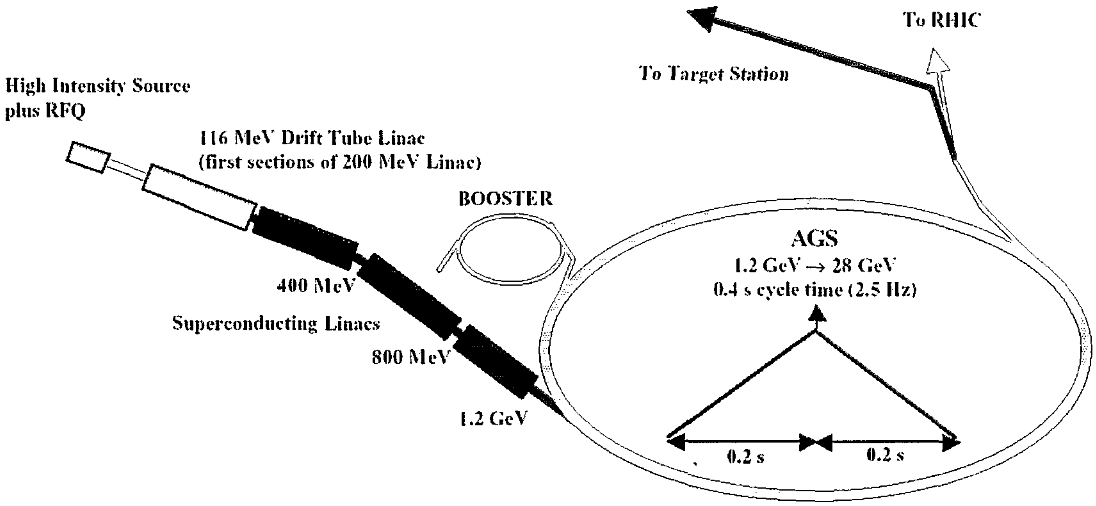

FIGURE 1. AGS Proton Driver Layout.

TABLE 2. Parameters of the Superconducting Linac.

	Low	Medium	High
Beam Power, kW	16	32	48
Kinetic Energy, MeV	116-400	400-800	800-1200
Velocity, $c\beta$	0.4560	0.7131	0.8418
	0.7131	0.8418	0.8986
Frequency, MHz	805	1610	1610
Protons/μBunch, 10^8	9.32	9.32	9.32
Temperature, °K	2.0	2.0	2.0
Cells/Cavity	4	8	8
Cavities/Cryo-Module	4	4	4
Cell Length, cm	9.68	6.98	8.05
Cell reference velocity, $c\beta_0$	0.520	0.750	0.865
Cavity internal diameter	10	5	5
Cavity Separation, cm	32	16	16
Cold-to-Warm transition	30	30	30
Accelerator Gradient, MeV/m	11.9	22.0	21.5
Cavities/Klystron	4	4	4
No. of Klystrons	18	10	9
Klystron Power, kW	720	1920	2160
Energy Gain/Period, MeV	16.0	42.7	48.0
Length of a period, m	4.2	4.4	4.7
Total length, m	75.4	43.9	42.6

AGS MAIN POWER SUPPLY UPGRADE

The AGS ring consists of 240 magnets hooked up in series with a total resistance R = 0.27 Ω and a total inductance L = 0.75 H. Two stations of power supplies are each capable of delivering up to 4500 V and 6000 A. The two stations are connected in series and the magnet coils are arranged to have a total resistance R/2 and a total inductance of L/2. The grounding of the power supply is done only in one place, in the middle of station 1 or 2 through a resistive network. With this grounding configuration, the maximum voltage to ground in the magnets will not exceed 2500 Volt. The magnets are hi-potted to 3000 Volt to ground, prior of each starting of the AGS MMPS after long maintenance periods.

To cycle the AGS ring to 24 GeV at 2.5 pulses per second and with ramp time of 250 ms, the magnet peak current is 4300 Amp and the peak voltage is 25 kV. The total average power dissipated in the AGS magnets has been estimated to be 3.7 MW. To limit the AGS coil voltage to ground to 2.5 kV the AGS magnets will need to be divided into six identical sections, each powered similarly to present half AGS power system, except that now the magnet loads is 1/6 of the total resistance and inductance.

The peak power required is approximately 110 MW exceeding the 50 MW rating of the existing motor generator. The new motor-generator should also operate with 6 or 12 phases to limit or even eliminate phase-shifting transformers so that every power supply system generates 24 pulses.

AGS RF SYSTEM UPGRADE

At 2.5 Hz the peak acceleration rate is three times the present value for the AGS. With 10 accelerating stations each station will need to supply 270 kW peak power to the beam. The present power amplifier

TABLE 3. AGS Beam Power With Accumulator

	Now	AGS at 1 Hz	AGS at 2.5 Hz
Linac Energy (MeV)	200	400	400
Booster Intensity (ppp)	1.5×10^{13}	2.0×10^{13}	2.0×10^{13}
Booster energy (GeV)	1.8	2.5	2.5
Booster Cycles	4	6	6
AGS energy (GeV)	24	28	28
AGS Intensity	36	120	300
AGS Rep Rate (Hz)	0.6	1.0	2.5
AGS Current (μA)	5.75	19.2	48
AGS Intensity (ppp)	6×10^{13}	12×10^{13}	12×10^{13}
AGS power (kw)	138	538	1344

design, employing a 300 kW power tetrode will be suitable to drive the cavities and supply power to the beam. The number of power amplifiers will be double so that two amplifiers of the present design drive each station. This follows from the necessity to supply 2.5 times the rf voltage. An AGS rf station comprises four acceleration gaps surrounded by 0.35 m of ferrite stacks. The maximum voltage capability of a gap is limited by the ability of the ferrite to supply the magnetic induction. When the AGS operates at 0.5 Hz the gap voltage is 10 kV. At 2.5 Hz we will need up to 25 kV per gap.

The next concern is the power dissipation in ferrite and the thermal stress that is created by differential heating due to rf losses in the bulk of the material. We know from experience that below 300 mW/cm^3 ferrites can be adequately cooled.

ACCUMULATOR RING OPTION

There is another possible approach to provide 1 MW beam power by the AGS, this is to add an accumulator ring in the AGS [4]. In the first phase the linac will be improved to inject protons to the booster at 400 MeV (at present it is 200 MeV), and the booster energy increased to 2.5 GeV from 1.8 GeV. The addition of a fixed field accumulator storage ring in the AGS main tunnel will increase the AGS input beam from the present 4 booster pulses per AGS acceleration to 6 booster pulses per AGS acceleration and, at the same time, increase the AGS frequency from 0.6 Hz to 1.0 Hz. The AGS power increase would be from 0.14 to 0.53 MW. The new accumulator will be in the same tunnel as the AGS. Figure 2 shows the present and proposed AGS injection modes. The AGS intensity upgrades and parameters are shown in Table 3. The fixed field magnets of the accumulator ring will be essentially copies of the permanent magnets produced for a similar purpose at Fermilab [5]. In a second phase of the upgrades the AGS repetition rate will be increased to 2.5 Hz to reach a total beam power of 1.3 MW.

In this way, the injection time of 0.6 sec from the booster to the AGS is reduced to almost zero by pre-storing 6 batches of booster beam in the accumulator ring as shown in Figure 2.

The linac option is chosen as the baseline for its simplicity, only involves the linac and the AGS, and the clear upgrade path to 4.0 MW in the future. The accumulator option requires addition/modification of four accelerators, the linac, the booster, the accumulator ring and the AGS. In addition, the installation of the accumulator ring in the AGS tunnel will, inevitably, interference with existing RHIC program.

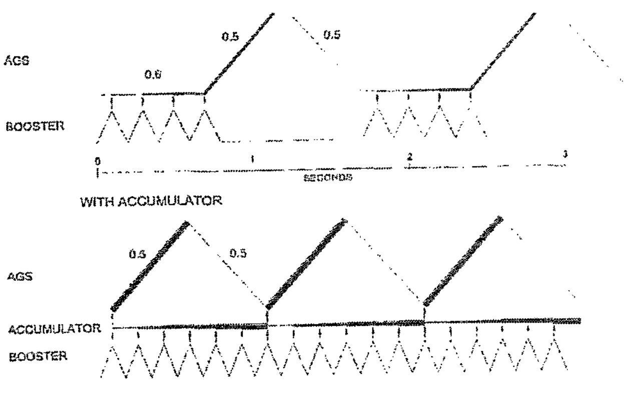

FIGURE 2. Time sequence of injecting pulses into the AGS. Top picture shows that at the moment 4 booster pulses are injected into the AGS during the period when the AGS magnets are at low field. In the new proposed configuration in the bottom picture the booster will inject 6 pulses into the accumulator which will store the beam until the AGS is at low field and then transfer the beam into the AGS.

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