Neutrino Oscillation Experiments for Precise Measurements of Oscillation Parameters and Search for $\nu_\mu to \nu_e$ Appearance and CP Violation.

M. Diwan, W. Marciano, Brett Viren, Dana Beavis

Department of Physics Brookhaven National Laboratory Box 5000, Upton, NY 11973-5000

T. Roser, W. Weng, S. Kahn, Z. Parsa, H. Kirk

Center for Accelerator Physics, Brookhaven National Laboratory Box 5000, Upton, NY 11973-5000

W. Frati, J.R. Klein, K. Lande, A.K. Mann

R. Van Berg and P. Wildenhain University of Pennsylvania Philadelphia, PA 19104-6396

R. Corey

South Dakota School of Mines and Technology Rapid City, S.D. 57701

D.B. Cline, K. Lee, B. Lisowski, P.F. Smith

Department of Physics and Astronomy, University of California, Los Angeles, CA 90095 USA

A. Badertscher, A. Bueno, L. Knecht, G. Natterer, S. Navas, A. Rubbia

Institut fr Teilchenphysik, ETHZ, CH-8093 Zürich, Switzerland

R.F. Burkart, W. Burgett, E.J. Feynves

Department of Physics, University of Texas at Dallas, Richardson, TX 75083 USA

J.G. Learned

Department of Physics and Astronomy, University of Hawaii, Honolulu, HI 96822 USA

V. Palladino

Universita di Napoli "Federico II", 80138 Napoli, Italy

I. Mocioiu, R. Shrock

C.N. Yang Institute for Theoretical Physics, State University of New York, Stony Brook, NY 11974 USA

C. Lu, K.T. McDonald

Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544 USA

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Abstract

The possibility of making a low cost very intense source of high energy protons using the Brookhaven AGS as well as the forthcoming national underground science laboratory (NUSL) in Homestake, South Dakota allows us to propose a program of experiments that will address fundamental aspects of neutrino oscillations and CP-invariance violation. This program of experiments is unique because of the extra-long terrestrial baseline of 2540 km from Brookhaven National Laboratory to Homestake, the high intensity of the proposed conventional neutrino beam, and the possibility of constructing a very large array of water Cerenkov detectors with total mass approaching 1 Megaton. As part of this program we will also consider experiments at moderately long baselines ($\sim$ 400 km) using other detector technologies that can yield valuable and complementary information on neutrino oscillations. This letter of intent focuses on the design and construction of the necessary AGS upgrades and the new neutrino beam which will initially use a proton beam of power $\sim$ 0.5 MW; the power will be eventually upgraded to 1 MW in a later phase.

1 Introduction

This is a letter of intent to build a new high intensity neutrino beam at BNL in two phases. The first phase will involve AGS upgrades consisting of an addition to the present linac to yield a total linac energy of 400 MeV, and an accumulator ring with permanent magnets mounted in the AGS tunnel. This will allow AGS injection at 2.5 GeV and the the resultant AGS cycle time will be 1 hz. The intensity should be 1.2×10^{14} protons per pulse and the power 0.47 MW The second phase will require new power supplies for the AGS and booster magnets for rapid cycling, an rf upgrade, and additional shielding; these will produce an AGS cycle time of 2.5 hz and 1.0 Mwatt power. The new intense proton beam will be used to produce a conventional horn focussed neutrino beam directed at far detectors. We propose to send the beam to two different distances: the very long distance of 2540 km to the Homestake laboratory, and a much shorter distance of 400 km in upstate New York where there are many possible locations for a new detector.

It is now well known that the strongest evidence for neutrino oscillations, so far, comes from astrophysical observations of atmospheric neutrinos with $\Delta m^2_{32} = 0.003^{+0.0016}_{-0.001} eV^2$ and solar neutrinos with $\Delta m^2_{12} \sim 10^{-5} - -10^{-4} eV^2$, both with large mixing. The observation by the LSND experiment will soon be re-tested at Fermilab by the mini-Boone experiment, therefore we will not discuss it in the following. There are several accelerator based experiments (K2K, MINOS, and CNGS) currently in data-taking or construction phase designed to confirm the astrophysical signatures for neutrino oscillations. There is a consensus now that there are four main goals in this field that can be addressed by accelerator neutrino beams:

1) Precise determination of Δm^2_{23} and definitive observation of oscillatory behaviour.

2) Detection of $\nu_\mu \to \nu_e$ in the appearance mode. If the Δm^2 for this measurement is near Δm^2_{23} then this appearance signal will show that the $\sin\theta_{13}$ from the neutrino mixing matrix in the standard parameterization is non-zero.

3) Detection of the matter enhancement effect in $\nu_\mu \to \nu_e$ in the appearance mode. This effect will also allow us to measure the sign of Δm^2_{32}; i.e. which neutrino is heavier.

4) Detection of CP violation in neutrino physics. The "Standard Model" CP-violation in neutrino physics comes from the phase multiplying $\sin\theta_{13}$ in the mixing matrix. This can be detected by observing an asymmetry in the oscillation rates $\nu_\mu \to \nu_e$ versus $\bar{\nu}_\mu \to \bar{\nu}_e$.

In the following we will briefly describe how all of these goals can be achieved under reasonable assumptions for the various parameters using the intense AGS based beam and the long and very long baselines.

In the first section of this letter of intent we describe the physics purpose of the new beam to 2540 km. The second section describes the physics case for the shorter distance of 400 km. The third section briefly discusses the design and construction of the AGS upgrades. And the last section describes the construction of the new neutrino beam.

2 Very Long Baseline Experiment

The calculated and measured energy distributions of a ν_μ beam produced by 28 GeV protons is shown in Fig. 1; roughly, the spectrum peaks at about 1 GeV with a total spread at half intensity of about 1 GeV [1]. Further work on the optimization of this spectrum for the very long baseline experiment is on going. We calculate the event rate without oscillations assuming a 0.5 MW proton beam power with 28 GeV protons, a 0.5 MT fiducial mass detector and 5 years are running. Because the AGS can run in a parasitic mode to RHIC we expect to get beam for as much as 1.8×10^7 sec per year. Using these parameters we calculate that the number of quaelastic muon neutrino events in a detector located at 2540 km will be $\sim$ 7500. The number of neutrino events of all types will be approximately twice this number. This large statistics combined with the long baseline makes many of the following measurements possible and exciting. The angular and energy distributions of the muons from the quasielastic process $\nu_\mu + n \to \mu^- + p$ produced by the 0 degree beam in Fig. 1 are shown in Fig. 4; the principal background, $\nu_\mu + n \to \mu^- + p + \pi$ is also shown. A variety of strategies are possible to reduce this background further in a Water Cerenkov detector; we will discuss them in later updates of this proposal. Knowing the direction of an incident ν_μ accurately, the energy of the ν_μ can be calculated from the measured energy and angle of the observed muon. This method has been used by the currently running K2K experiment [3]. The known resolution capability of large water Cherenkov detectors indicates that at low energies the resolution on ν_μ energy will be dominated by Fermi motion and nuclear effects at energies lower than 1 GeV. The contribution to the resolution from water Cerenkov track reconstruction depends on the photo-multiplier tube coverage. With adequate converage, greater than $\sim$ 10%, we expect that the reconstruction resolution should be adequate for our purposes. In the following we assume a 10% resolution on the ν_μ energy; below neutrino energy of 1 GeV we have parameterize the energy resolution to be greater than 10% to account for nuclear effects.

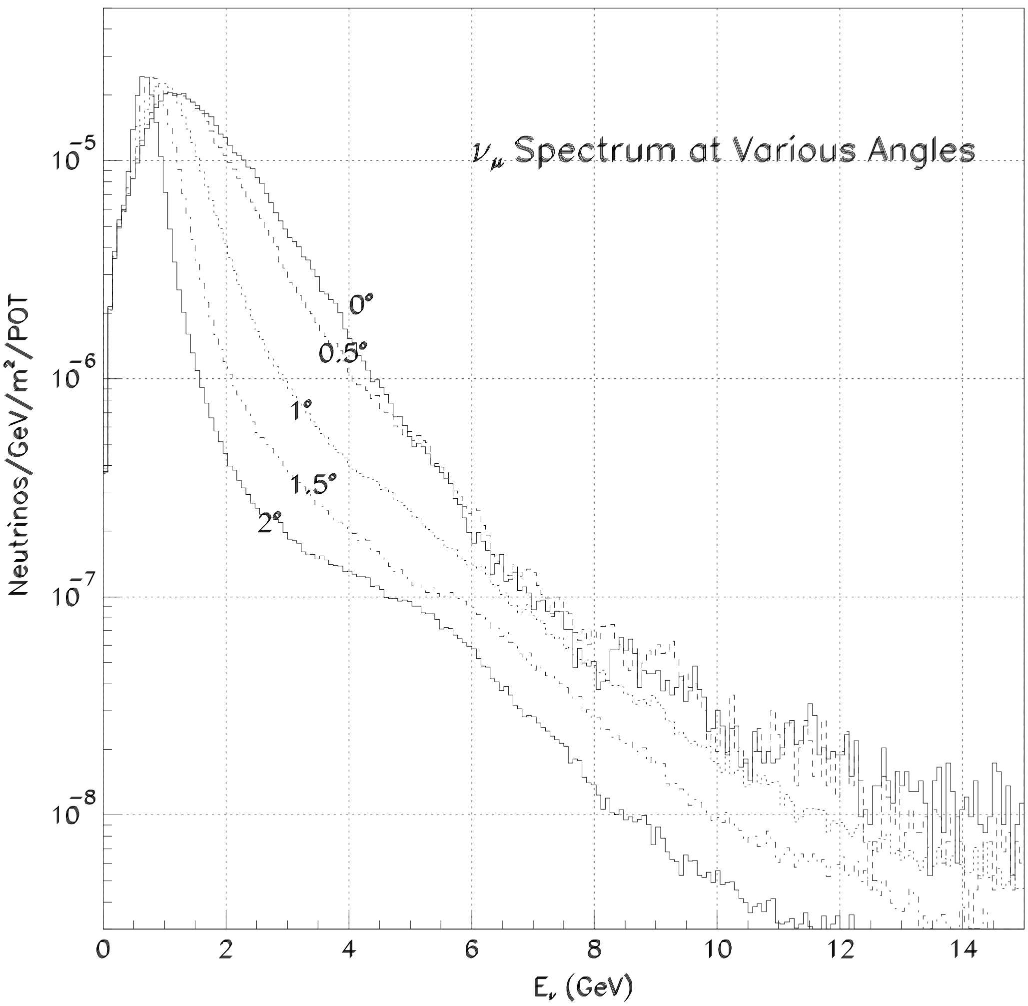


Figure 1: Wide band horn focussed neutrino spectrum for 28 GeV protons. Spectrum of neutrinos calculated at various angles with respect to the decay tunnel axis at the AGS.

The range of $\Delta m^2 \sim 1.23 \frac{E_\nu/(GeV)}{L/(km)}$ covered by an AGS to NUSL experiment using the beam in Fig. 1 extends to the low value of about 5×10^{-4} eV^2. The lower end of this extensive range of values is considerably below the corresponding values for other proposed long baseline terrestrial experiments [3]. If the value of Δm^2_{23} turns out to be towards the lower end ($\sim 10^{-3}$) of its current range or if the value of Δm^2_{21} turns out to be towards its high end ($\sim 10^{-4} eV^2$) then there will be very large interference effects in the very long baseline experiment.

Moreover, extra-long neutrino flight paths open the possibility of observing multiple nodes (minimal intensity points) in neutrino oscillations. Observation of one such pattern will for the first time directly demonstrate the oscillatory nature of the flavor changing phenomenon. The nodes occur at distances $L_n = 1.23(2n-1)E_\nu/\Delta m^2$, $n = 1, 2, 3, \ldots$. In Fig. 2, as an example, we show the flight path L versus E_ν relationship of the nodes for $\Delta m^2 = 0.003$eV^2, a value close to the value measured in atmospheric neutrino experiments [6]. An advantage of having a very long baseline is that the multiple node pattern is detectable over a broad range of Δm^2.

numu to nue signal with matter effect

CP violation argument using higher nodes perhaps CP can be found with just neutrino running by comparing nodes

numu to nue signal with large $deltam_1 2$

The conversion of Homestake Gold Mine in Lead, South Dakota, into the National Underground Science Laboratory (NUSL), tentatively to take place in 2002, will provide a unique opportunity for a program of extra-long baseline neutrino oscillation experiments. As explained above these will be possible because of the length of the baseline, 2540 km from the Brookhaven National Laboratory (BNL) to Lead, South Dakota. It is proposed that the NUSL facility will accommodate an array of detectors with total mass approaching 1 Megaton. Most of these will be water cherenkov detectors that can observe neutrino interactions in the desired energy range with sufficient energy and time resolution [2].

An alternative to Homestake also exists at the Waste Isolation Pilot Plant (WIPP) located in an ancient salt bed at a depth of $\sim 700m$ in Carlsbad, New Mexico. The distance from BNL to WIPP is about 2880 km. The cosmic ray background will be higher at WIPP because the facility is not as deep as Homestake which has levels as deep as $\sim 2500m$. The increased background, although undesirable, may not be an insumountable problem. However, the mechanical design for a large cavity in a salt bed has to be very different because of the slow

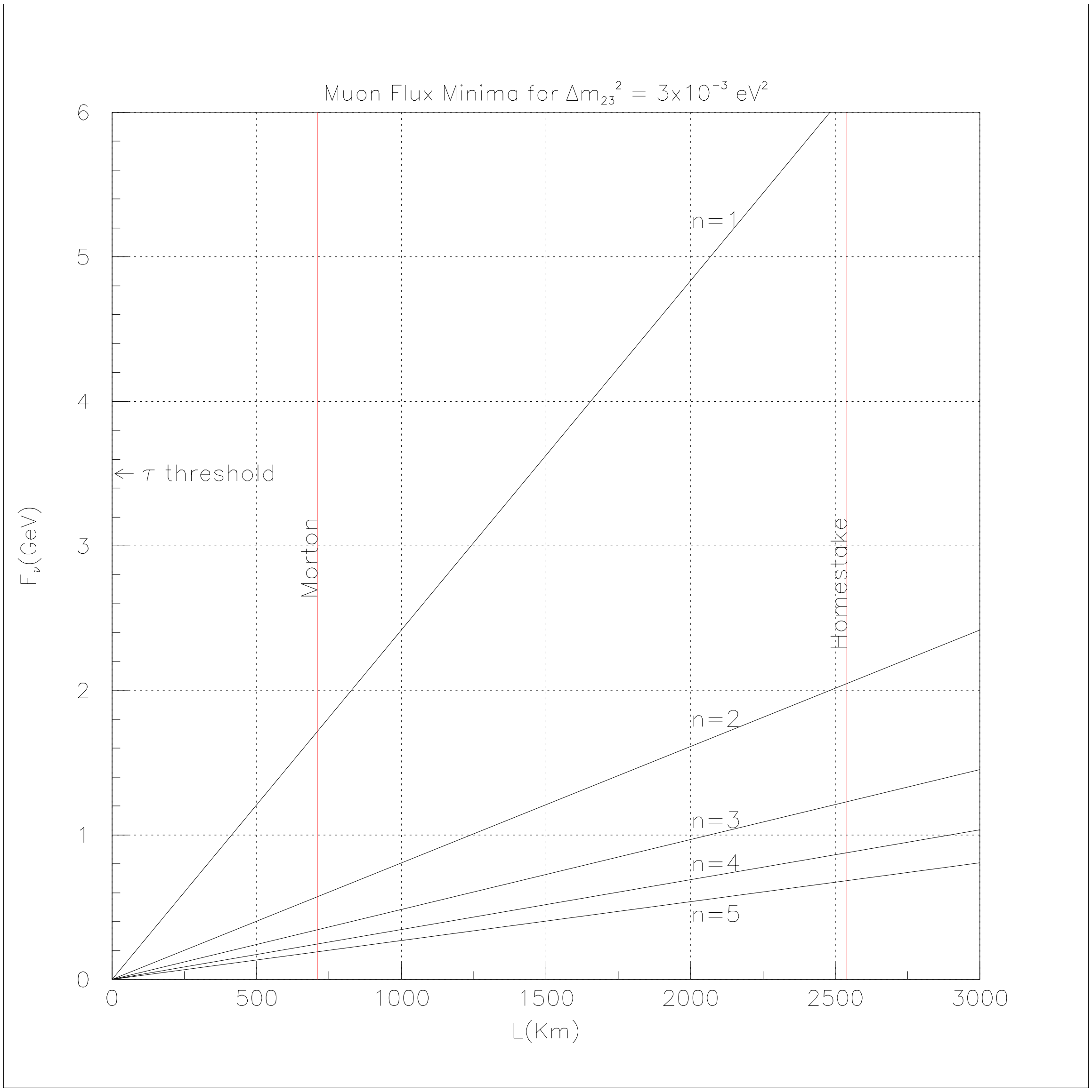
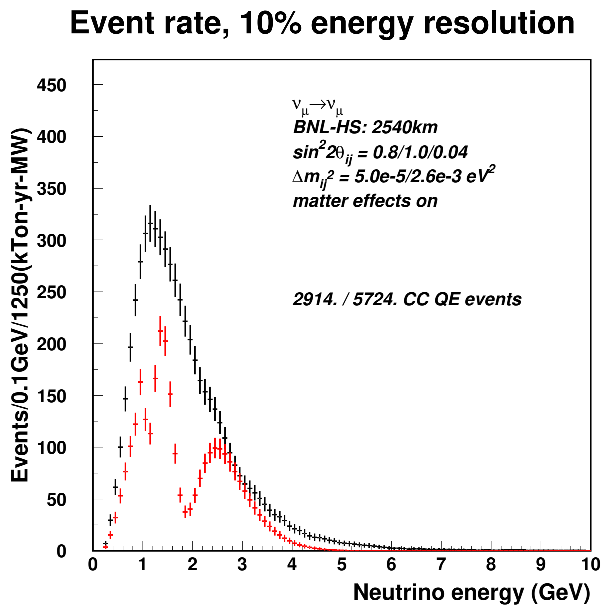


Figure 2: Nodes of neutrino oscillations as a function of oscillation length and energy for $\Delta m^2 = 0.003 eV^2$.



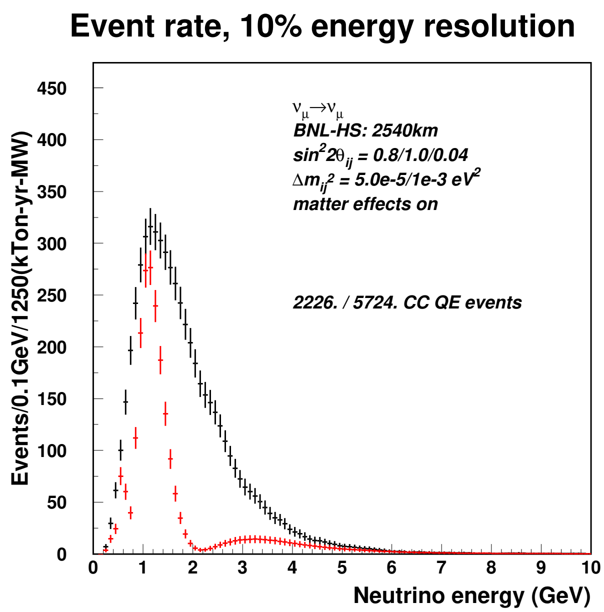


Figure 3: Spectrum of detected quasielastic events in a 0.5 MT detector at 2540 km from BNL. We have assumed 0.5 MW of beam power and 5 years of running. The top data points are without oscillations and bottom are with oscillations. The top plot is for $\Delta m^2_{23} = 0.0026 eV^2$ and the bottom id for $\Delta m^2_{23} = 0.001 eV^2$. The error bars correspond to the statistical error expected in the bin. A 10 % energy resolution is assumed; this corresponds to the expected resoltion due to both nuclear effects and the muon momentum reconstruction in the detector.

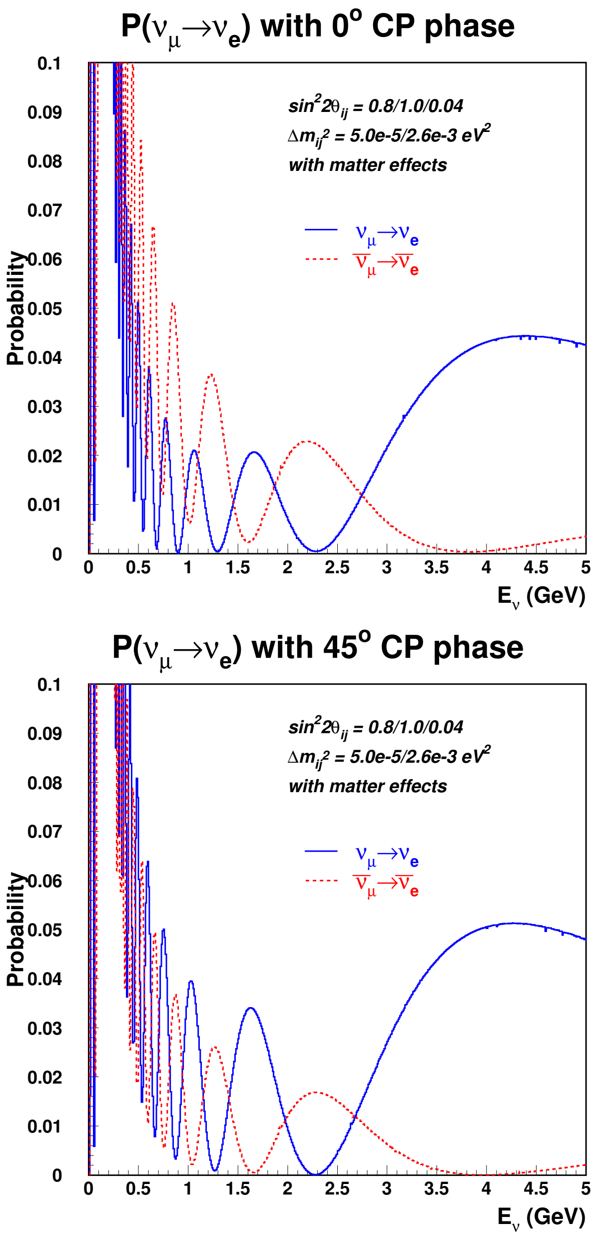


Figure 4: Probability of ν_μ oscillating into ν_e after 2540 km. The parameters assumed are listed in the figures. The top plot assumes that there is no CP violation in the neutrino matrix. The bottom plot is with a CP violation phase of 45^o.

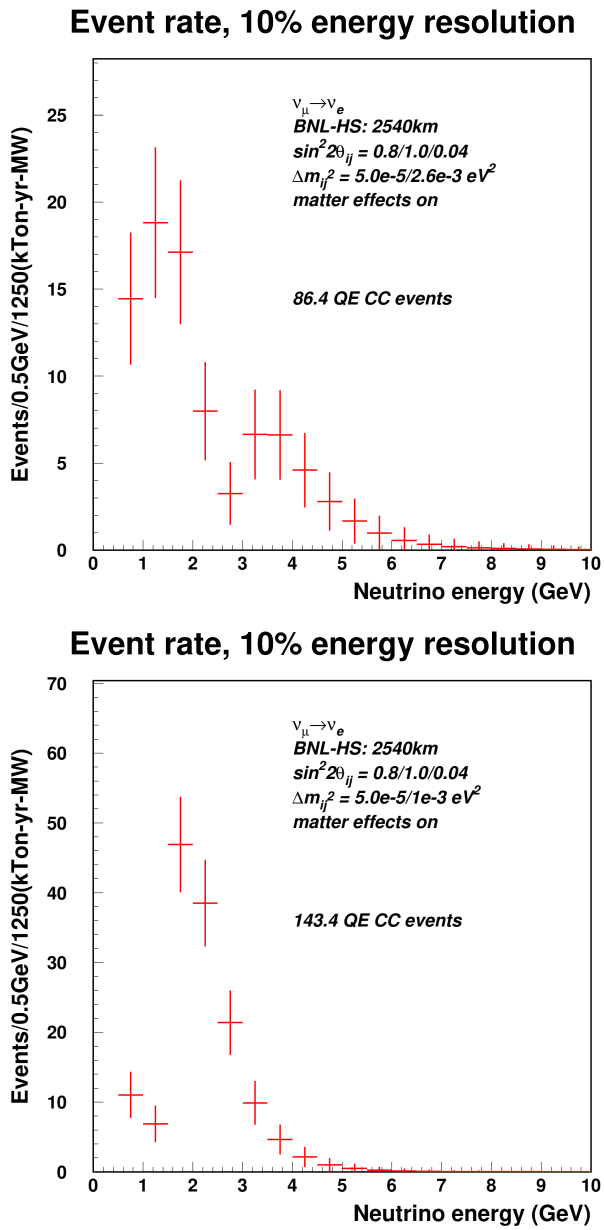


Figure 5: Spectrum of detected quasielastic electron neutrino events in a 0.5 MT detector at 2540 km from BNL. We have assumed 0.5 MW of beam power and 5 years of running. The top plot is for $\Delta m^2_{23} = 0.0026 eV^2$ and the bottom id for $\Delta m^2_{23} = 0.001 eV^2$. We have assumed $\sin^2 2\theta_{13} = 0.04$. The error bars correspond to the statistical error expected in the bin. A 10 % energy resolution is assumed; this corresponds to the expected resolution due to both nuclear effects and the muon momentum reconstruction in the detector.

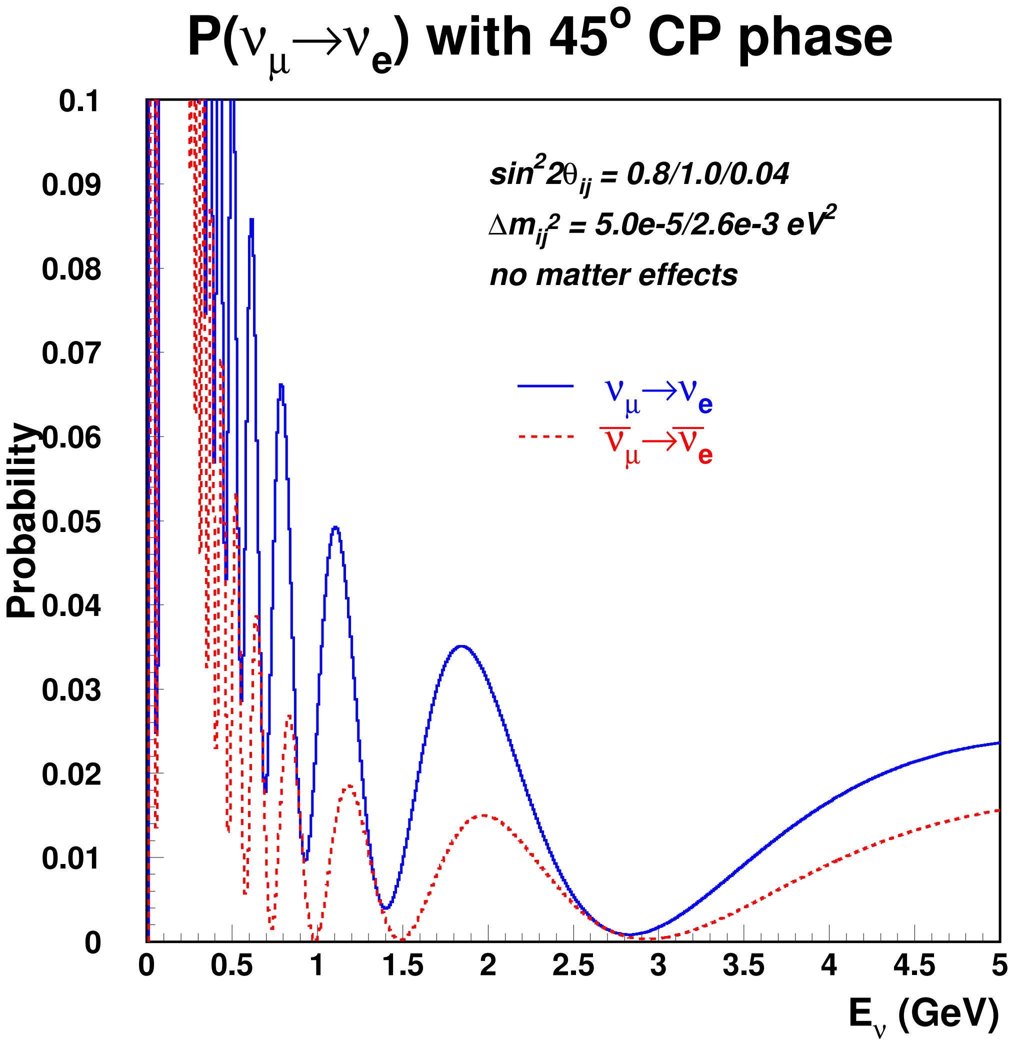


Figure 6: Probability of $\nu_\mu \to \nu_e$ and $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations at 2540 km assuming a 45^o Cp violation phase. It can be seen that the CP asymmetry between ν_μ and $\bar{\nu}_\mu$ increases for lower energies because the CP asymmetry is proportional to $\Delta m^2_{12} L/E$ which increases for lower energies.

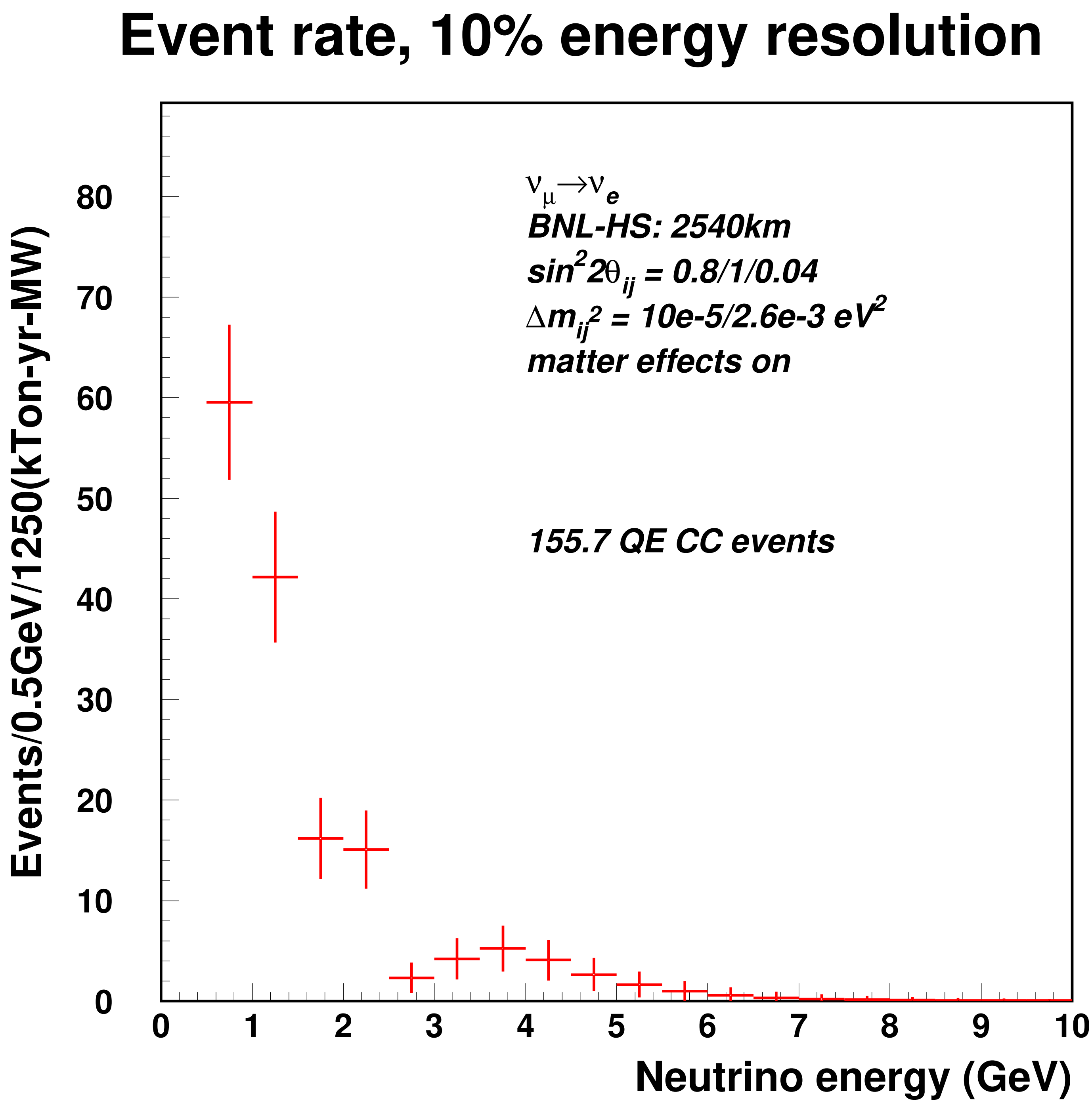

Event rate, 10% energy resolution
Events/0.5GeV/1250(kTon-yr-MW)
Neutrino energy (GeV)
νμ→νe
BNL-HS: 2540km
sin²2θij = 0.8/1/0.04
Δmij² = 10e-5/2.6e-3 eV²
matter effects on
155.7 QE CC events
0
10
20
30
40
50
60
70
80
0
1
2
3
4
5
6
7
8
9
10

Figure 7:

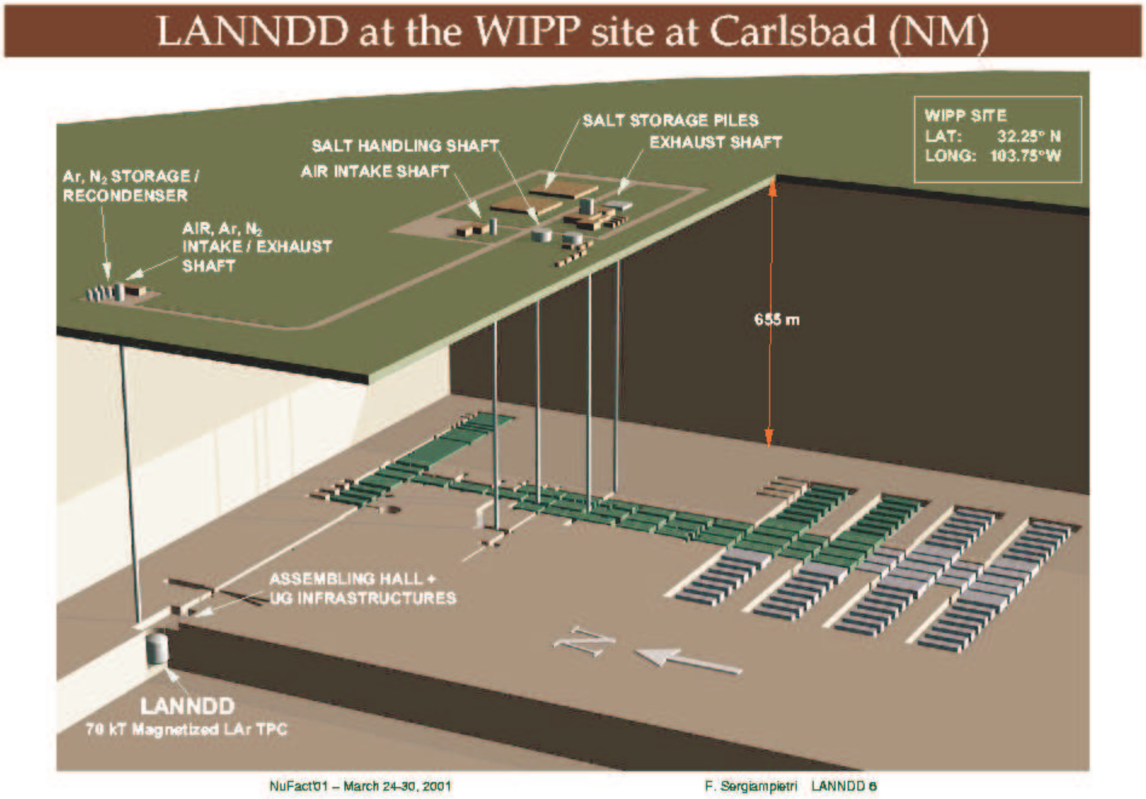


Figure 8: Schematic of the WIPP underground site and a location for the LANNDD detector. A Water Cerekov detector could also be accomodated at the WIPP site.

creep of the salt that causes a cavity to slowly collapse in a salt mine. In this LOI we will not address the detailed issues of detectordesign and cost.

Currently, a study is in progress to site the LANNDD, 70 KT liquid Argon detector there. The key issue at this stage is one of safety and a proposal to the DOE to study this is in preparation. In Figure 8, we show the LANNDD detector in a possible underground location at WIPP. One advantage of the WIPP Site is that, it is owned by the DOE and now has a program of underground science. We note that the recent Neutrino Factory Study at BNL identified the WIPP Site as one possible location for a far detector (about 3000 KM), and the current BNL neutrino beam could use the same concept. The LANNDD detector concept includes a detector for neutrino physics, in addition to the search for proton decay and other Astroparticle Physics goals . Currently, the ICARUS detector at the Gran Sasso is being constructed with a 3KT detector as a goal. The operation of this detector will provide key information for the eventual construction of LANNDD and for the Neutrino Physics identified in the LOI.

3 Long Baseline Experiment

A dedicated experiment to detect $\nu_\mu \rightarrow \nu_e$ appearance signature needs to have low background from the intrinsic ν_e contamination as well as neutral current events that produce π^0s. This can be achieved by placing a fine grained detector 1.5 degrees off-axis from the BNL neutrino beam. As originally pointed out by the E889 collaboration [1] at angles larger than the divergence of the pion beam the neutrino spectrum is almost independent of the pion energy and has a narrow spectrum peaking at 1 GeV (See figure 1). If the value of $\Delta m^2_{23} = 0.003eV^2$ is known with good precision then the detector could be placed at 412 km which is at the point of the first maximum for oscillations. This is shown in figure 9. At this distance and energy the effect of matter enhancement is small and a very sensitive experiment for $\nu_\mu to \nu_e$ appearance could be performed with a high resolution fine grained detector such as a 10 kT liquid argon calorimeter [?], with maximum performance achieved if the detector is immersed in a large magnetic field [?]. We calculate the number of events in a 1.5 degree off-axis beam in a 10 kT liquid Argon detector assuming 0.5 MW of beam power and 5 years of running. In the absence of oscillations there will be about 3000 quasielastic muon neutrino events. The total number of events including neutral current events will be about 1.5 times this number. If $\Delta m^2_{23} = 0.003eV^2$ the number of muon quasielastic events will drop to only ∼300. If $\sin^2\theta_13 = 0.01$ then the number of electron neutrino quasielastic events will be about 60. The background from the electron neutrino contamination in the beam and the neutral current π^0 will be spread widely in the energy, but the signal of 60 events will be in the peak of the neutrino spectrum. It has been shown in previous studies that the high energy resolution of the liquid Argon detector as well as the granularity should make it possible to reduce the neutral current background to negligible level. The intrinsic electron neutrino background from the BNL is known to be at 0.5 % level [1]. A complete study of the sensitivity of this approach will be presented in an update to this proposal.

The viability of a large liquid argon detector is presently being demonstrated by the ICARUS collaboration [?] in cosmic-ray tests of a 300-ton module located on the Earth's surface. Fig. 10 shows an example of the detailed tracking information obtainable with this technology.

A magnetized liquid argon detector would give the maximal discrimination against backgrounds in a neutrino beam, would enhance the ability to perform CP violation experiments, and would permit use of a beam that contains both neutrino and antineutrinos. An R&D experiment is proposed to use a prototype liquid argon detector in a magnetic field to determine the sign of electrons via analysis of their electromagnetic showers up to several GeV.

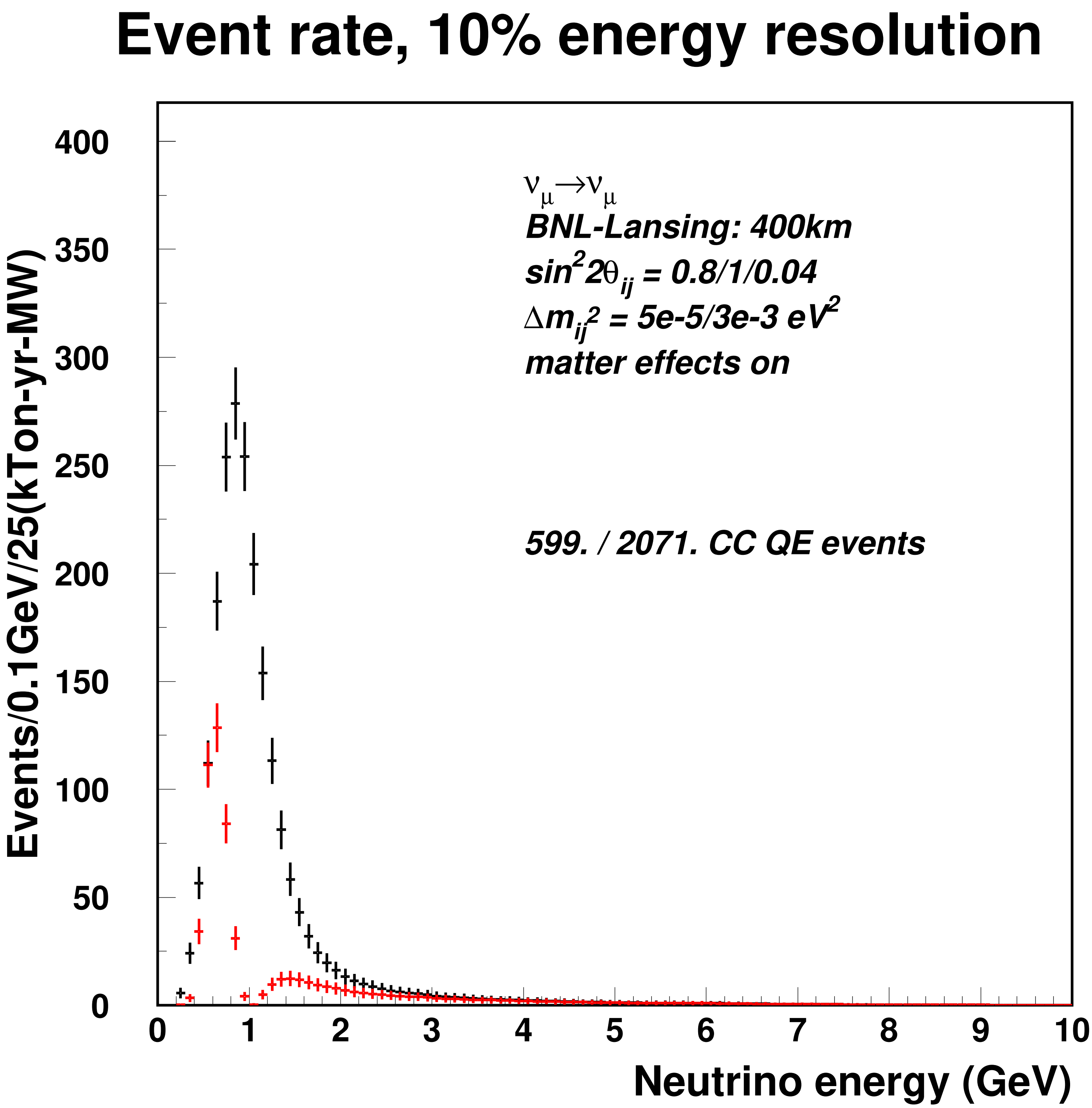


Figure 9: Spectrum of neutrinos at 1.5 degrees with and without oscillations with $\Delta m^2 = 0.003 eV^2$ and full mixing.

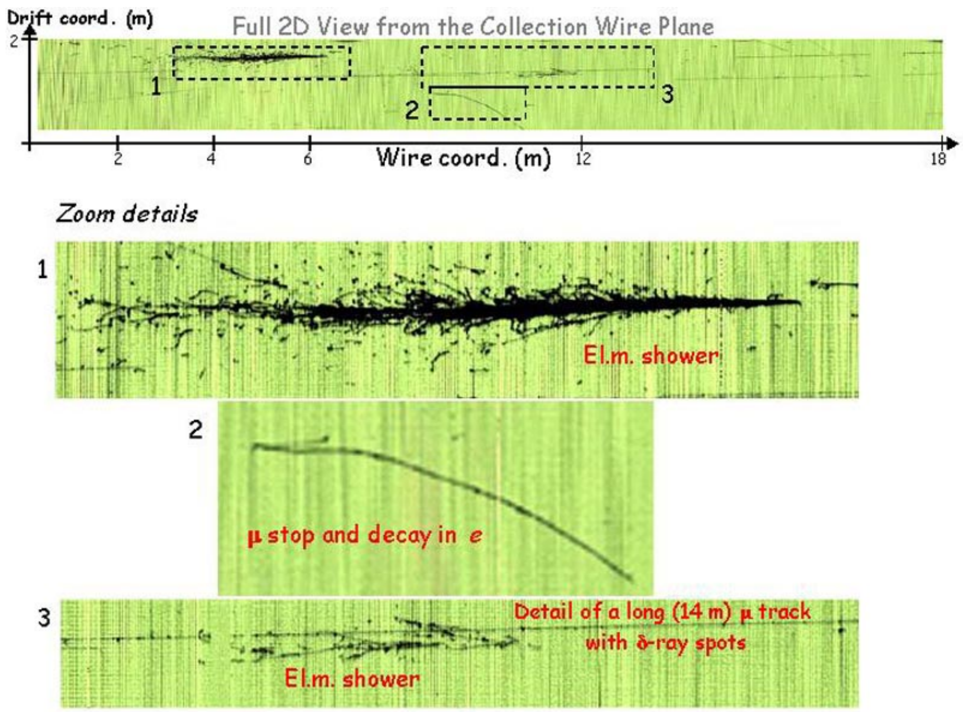


Figure 10: An event from the recent cosmic-ray test run of ICARUS [?], showing excellent track resolution over long drift distances in zero magnetic field.

4 AGS Upgrade

The preliminary design of the AGS upgrades and the new neutrino beam have been produced by the AGS department to reach an AGS power of 0.47 Mwatt in its first phase. In this 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 between the booster (located in the same ring as the AGS) and the AGS main ring 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 0.47 Mwatt. Figures 11 to 13 show the proposed additions. Figure 14 shows the present and proposed AGS injection modes. The AGS intensity upgrades and parameters are shown in Table **??**. The location of the accumulator ring in the AGS tunnel is shown in Figures 12 and 13 and the accumulator parameters given in Figure 15. The fixed field magnets of the accumulator ring will be essentially copies of the magnets produced for a similar purpose at Fermilab. We have consulted Bill Foster at Fermilab to design and calculate the cost of the accumulator ring proposed here.

The tentative cost estimates for the various upgrades and improvements are shown in Table 2, separated into two relatively independent phases of roughly equal cost. It is possible to rearrange the order in which the improvements are made. A detailed study of space charge, intensity, injection energies, rep rate, power and cost needs to be made to make a much more specific proposal for this upgrade. This would come about with approval of the present letter of intent.

5 Neutrino Beam Design

The geographic location of BNL on one side of the continent allows us to send beams to a variety of distances including very long baselines of 2000 km or more. This is shown in Fig. 16. The distances from BNL to Lansing, Soudan, Lead (Homestake), and WIPP are 350, 1770, 2540, and 2880 km, respectively. The dip angles are 1.7 degrees to Lansing, 7.9 degrees to Soudan, 11.5 degrees to Homestake, and 13.0 degrees to WIPP. The difficulty of building the beam and the cost increases with the dip angle.

For the purposes of this LOI we use the design for a conventional horn focussed neutrino beam. We use the tried and tested design used in previous experiments at BNL including

	Now	400 MeV Linac	2.5 GeV Accumulator	
				400 MeV Linac
Linac Energy (MeV)	200	400	200	400
Booster Intensity (ppp)	1.5×10^{13}	2.0×10^{13}	1.5×10^{13}	2.0×10^{13}
Booster energy (GeV)	1.8	1.8	2.5	2.5
Booster Cycles	4	4	6	6
AGS energy (GeV)	24	28	28	28
AGS Intensity (Tp/sec)	36	48	90	120
AGS Rep Rate (Hz)	0.6	0.6	1.0	1.0
AGS Current (μ A)	5.6	7.7	14	19
AGS Intensity (ppp)	6×10^{13}	8×10^{13}	9×10^{13}	12×10^{13}
AGS power (kW)	140	215	350	540

Table 1: AGS Intensity Upgrade Plan. See text for details

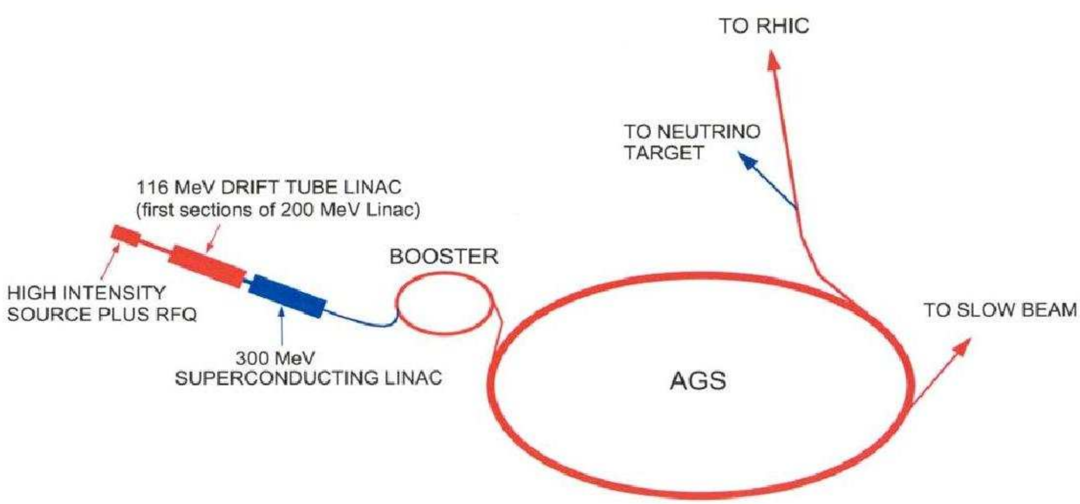


Figure 11: Layout of the AGS facility with the addition of the super conducting linac.

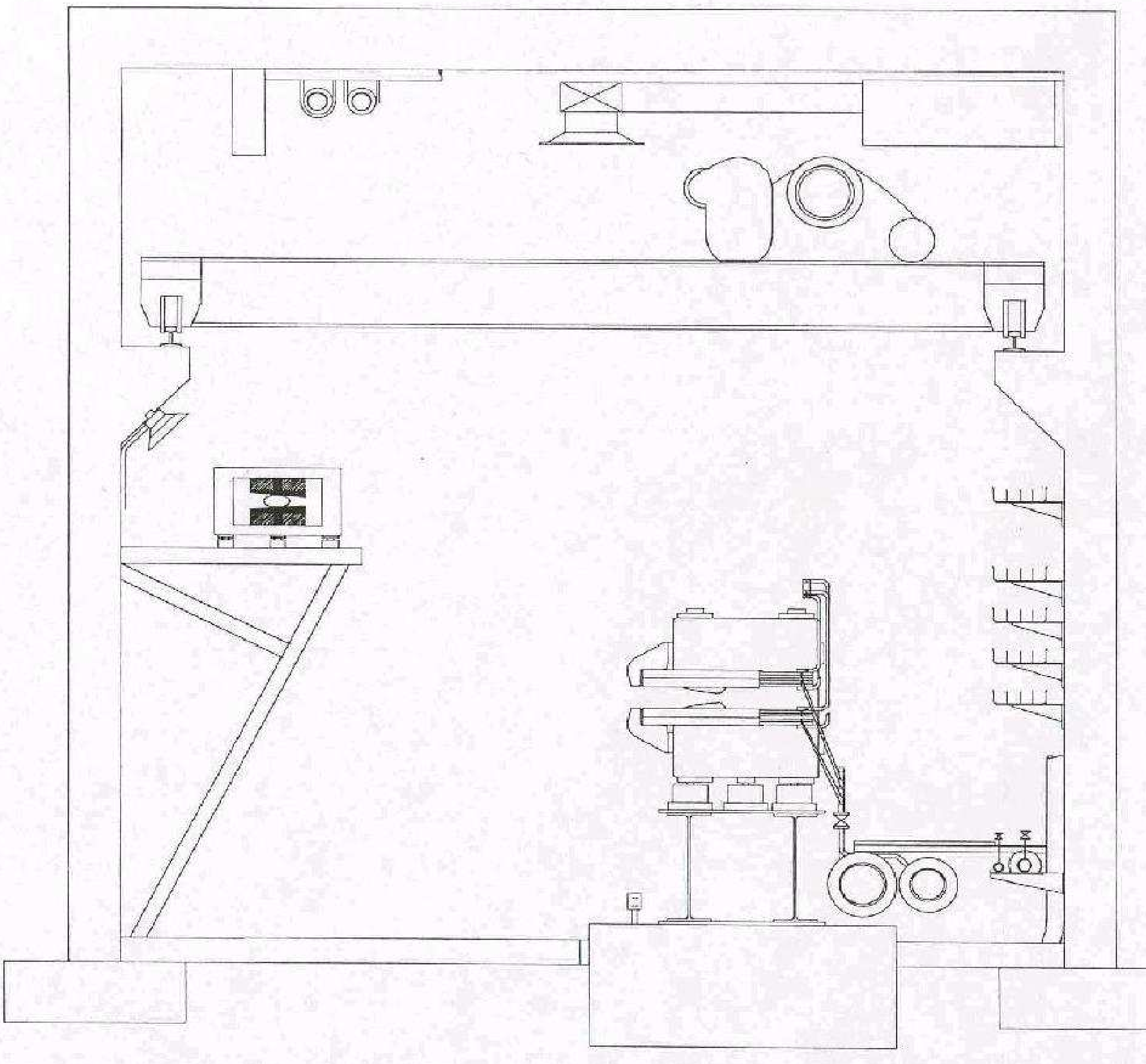


Figure 12: Placement of the permanent magnet accumulator ring inside the AGS tunnel.

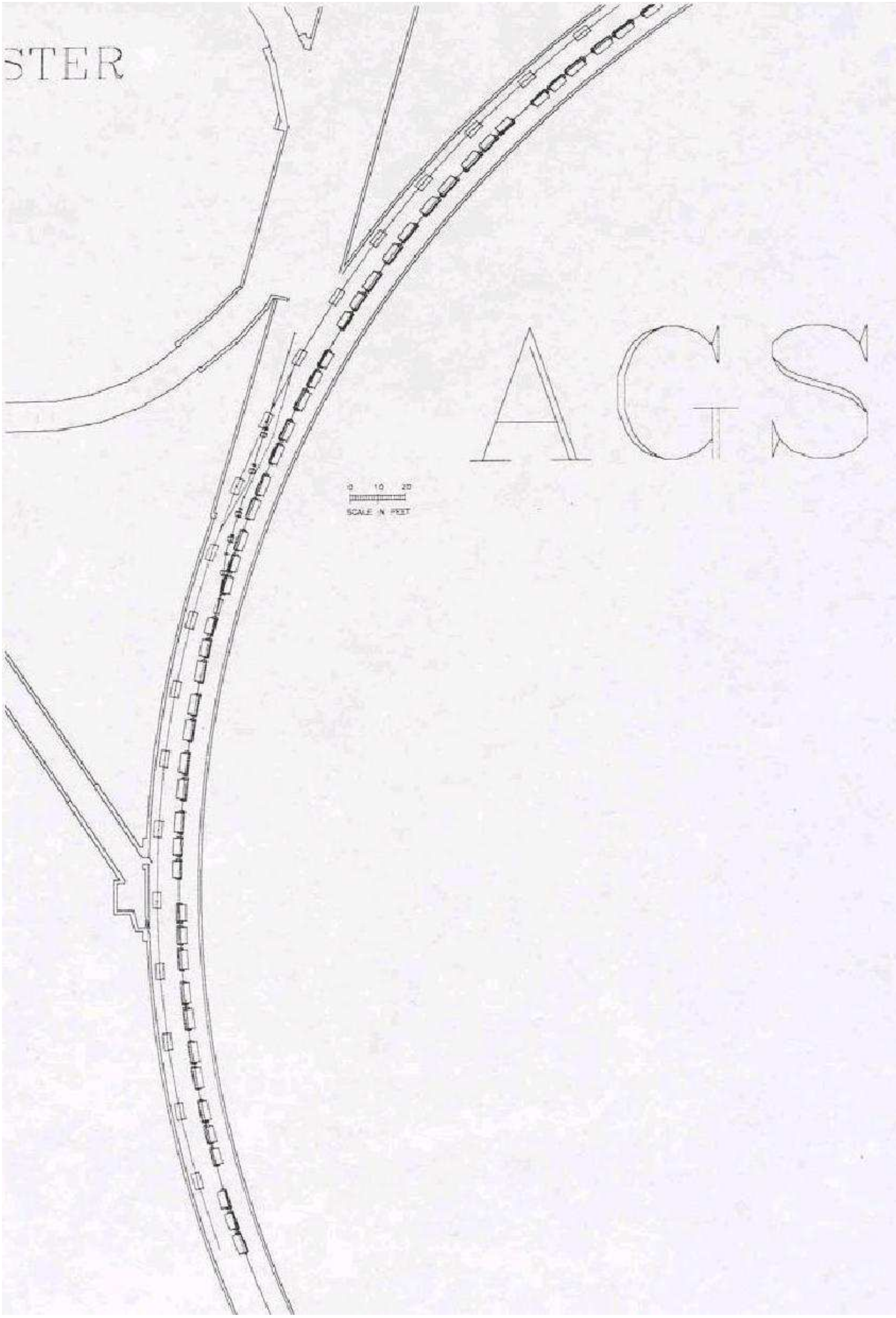


Figure 13: Placement of the permanent magnet accumulator ring inside the AGS tunnel. Satellite view.

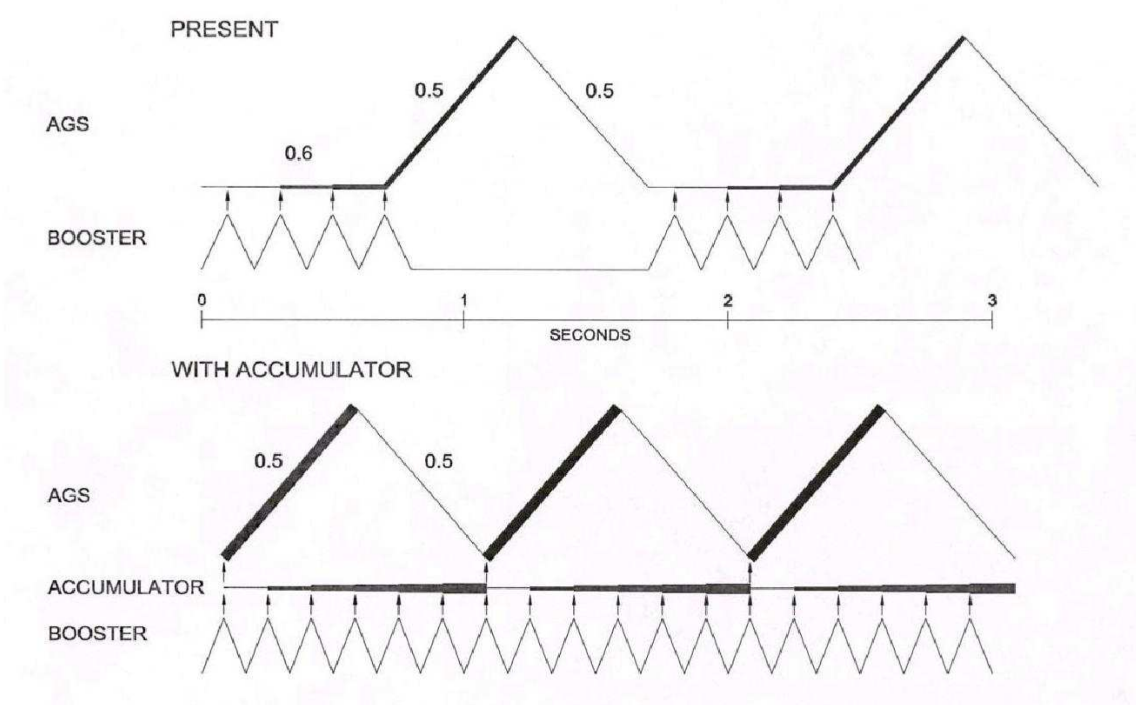


Figure 14: Time sequence of injecting pulses into the AGS. Top picture shows that at the moment 4 booster pulses are injected into the AGS during the period when the AGS magnets are at low field. In the new proposed configuration in the bottom picture the booster will inject 6 pulses into the accumulator which will store the beam until the AGS is at low field and then transfer the beam into the AGS.

Accumulator Parameters

Max. Kinetic Beam Energy	2.5 GeV
Rigidity	13 Tm
Circumference	819.07 m
Number of Superperiods	25
Number of FODO Cells	50
Number of (Combined-Function) Dipoles	100
Dipoles Length / Field	3.25 m / 0.25 T
Length of FODO Cell	16.45 m
Length of straight sections	8.22 m
Phase Advance per FODO Cell	72 degrees
Vacuum Chamber x / y	150 mm / 75 mm
Acceptance Geometric x / y	234 / 58 π mm mrad
Acceptance Normalized @ 2.5 GeV x / y	744 / 184 π mm mrad
Space Charge limit:	
(100 π mm mrad, $\Delta\nu = 0.3$, 2.5 GeV, debunched)	3.5×10^{14} ppp
Betatron Tunes x / y	10.3 / 10.5
Chromaticities x / y	-11.7 / -12.7
Beta Max. x / y	24.7 m / 24.3 m
Beta Min. x / y	7.8 m / 7.5 m
Dispersion Max.	1.8 m
Transition Gamma	9.6

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8

Figure 15: Parameters of the accumulator ring.

Summary of Preliminary Cost Estimate

Phase-I (AGS at 1 Hz)		
300 MeV SRF (116 -> 400)	$	35 M
2.5 GeV AGS Accumulator Ring	$	25 M
AGS Injection at 2.5 GeV	$	5 M
Initial 65 M$ (for 0.47 MW)		
Phase-II (AGS at 2.5 Hz)		
AGS power supply	$	32.0 M
AGS rf upgrade	$	8.6 M
Booster Power Supply	$	5.5 M
AGS Collimation and Shielding	$	8.0 M
Additional 54.1 M$ (for 1 MW)		

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11

Table 2:

E734 (Fig. 17). The design shown uses a water cooled copper target. For much higher intensities this target will have to be redesigned. It is very likely that we can adapt the graphite target design for NUMI at FNAL for our purposes. We also need to modify the horn focussing to make a wider band beam to increase the neutrino flux in the 4 GeV region. There are a number of ways to optimize the horn design; we will not discuss them here.

Our preliminary design for a beam to Homestake is shown in figures 18 and 19. This can clearly be adapted to any far location in the western direction. Our design addresses a number of issues. At BNL we are constrained to keep the beamline above the water table which is at a shallow depth ($\sim$ 20 m) on Long Island. Therefore the beam has to be constructed on a hill that is built with the appropriate 11.5 degree slope. Fortunately, it is relatively easy, and inexpensive to build such hills on Long Island because of the flat, sandy geology. It is important to keep the height of the hill low so that the costs are not dominated by the construction of the hill. The proton beam must be elevated to the top of the hill to a target station. The cost of the hill can be lowered by bending the proton beam upwards as quickly as possible. We have, however, used the design and bend angle used for the RHIC injection lines for our design beause the RHIC injection lines have well known costs.

The new fast extracted proton beam line in the U-line tunnel will be a spur off the line feeding RHIC which turns almost due west, a few hundred meters before the horn-target building. In addition to its 90 degree bend, the extracted proton beam will be bent upward through 13.76 degrees to strike the proton target. The downward 11.30 degree angle of the 667.8 ft. meson decay region will then be aimed at the 7000 ft. level of the Homestake Laboratory. This will require construction of a 39 meter hill to support the target-horn building, but will avoid any penetration of the water table. At its midpoint (about Lake Michigan) the center of the neutrino beam will be roughly 120 km. below the Earth's surface.

For a shorter baseline in approximately the same direction as Homestake, for example Lansing NY, we do not have to build the hill, therefore the cost will be lowered by a considerable amount. We are considering a number of strategies for combining the proton transport and the target station for two different baselines.

A preliminary estimate of the cost without any of the customery burdens is shown in table 3. The costs are based on the the RHIC injector work, as well as the E889 proposal and the neutrino factory study. The table shows that costs can be lowered by reducing the length of the decay tunnel. The conventional construction costs are dominated by the size of the hill which is approximately proportional to the third power of the decay tunnel length. In our cost estimate we assume that we will bury the beam dump underground to reduce the

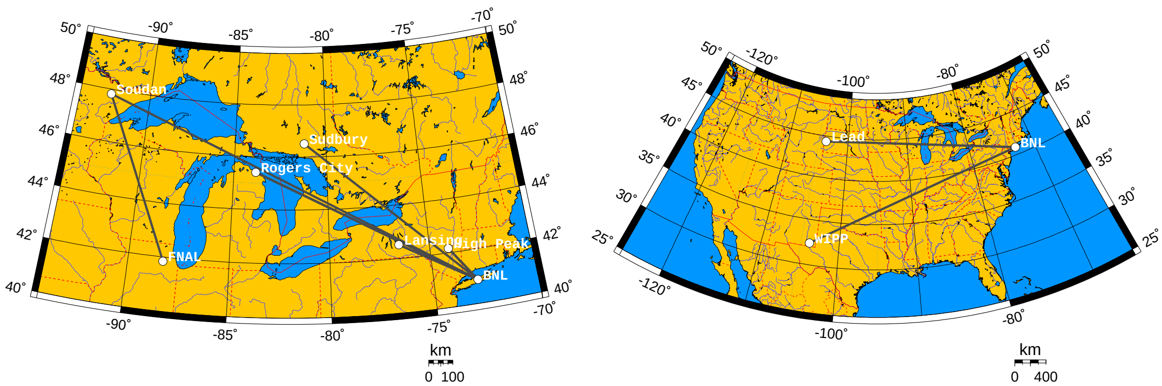

Figure 16: Possibilities for baselines from BNL. The distances from BNL to Lansing, Soudan, Lead (Homestake), and WIPP are 350, 1770, 2540, and 2880 km, respectively.

Item	basis	200 m	150 m
Proton transport	RHIC injector	\$8.3 M	\$8.3 M
Target/horn	E889	\$3.0 M	\$3.0
Installation/Beam Dump	New	\$2.67 M	\$2.67 M
Decay Tunnel	E889	\$0.45 M	\$0.45 M
Conventional const. (hill)	New	\$8.0 M	\$5.0 M
Conventional const. (other)	E889	\$6.77 M	\$6.77 M
Total		\$29.19	\$26.19

Table 3: Preliminary cost of building the neutrino beam. The third column is for a beam with 200 meter tunnel. The fourth column is for building the beam with a 150 meter tunnel.

height of the hill. We have also estimated the cost assuming 200 m and 150 m long decay tunnels. The spectra shown in Fig. 1 are based on a 200 m long tunnel. A shorter tunnel could reduce the intensity at higher energies because of the longer flight paths of parent pions. We will study this optimization further in future updates of this proposal.

6 Conclusion

We have outlined the neutrino physics program for an intense new neutrino beam from the Brookhaven AGS. The four goals of accelerator neutrino physics: precise determination of Δm^2_{23}, detection of $\nu_\mu to \nu_e$ appearance, measurement of the matter effect, and detection of CP asymmetries in the neutrino section are all possible for the proposed complex for reasonable

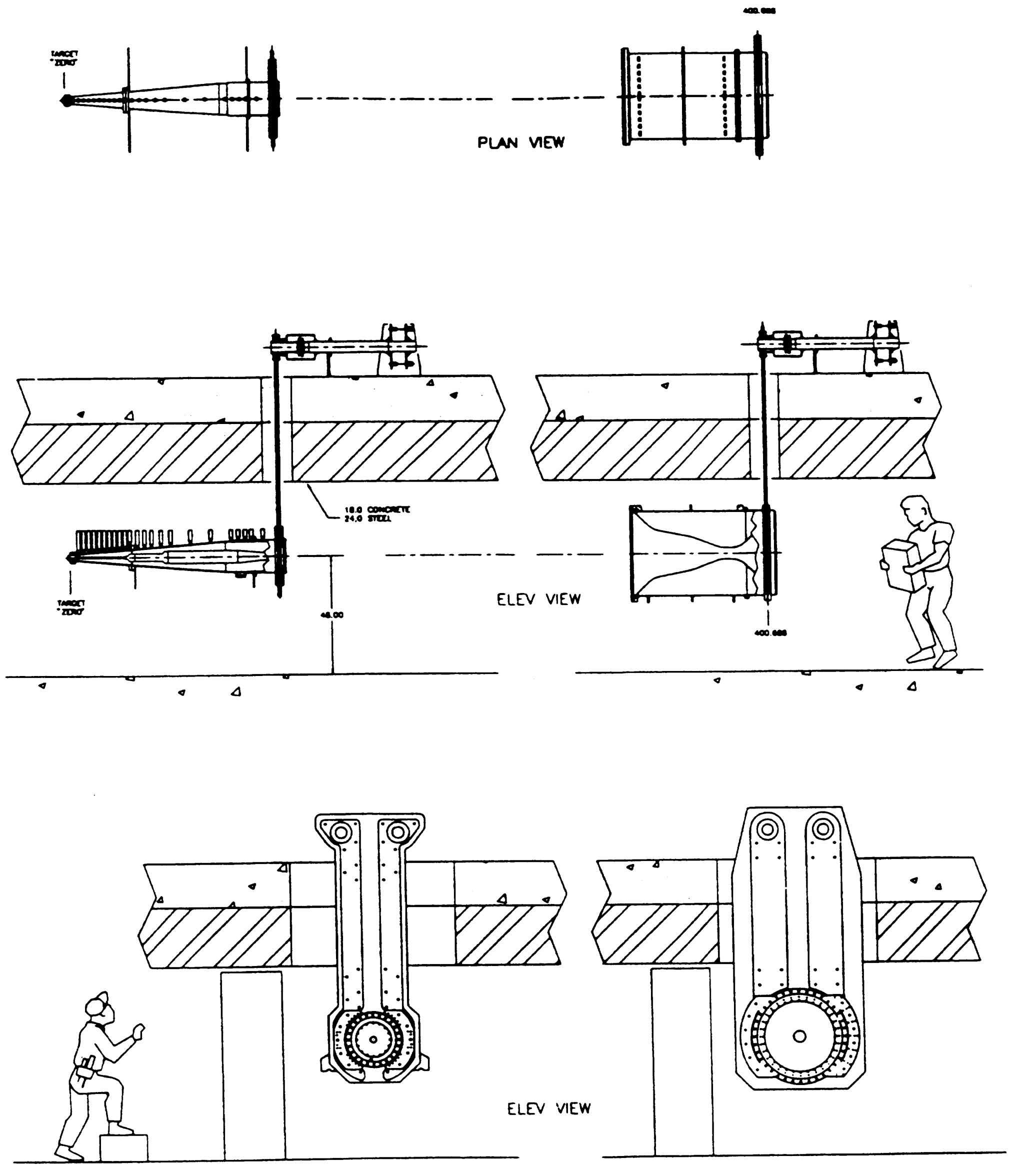

Figure 17: The design of the horn focussing system used for the E734 experiment adapted from the E889 proposl.

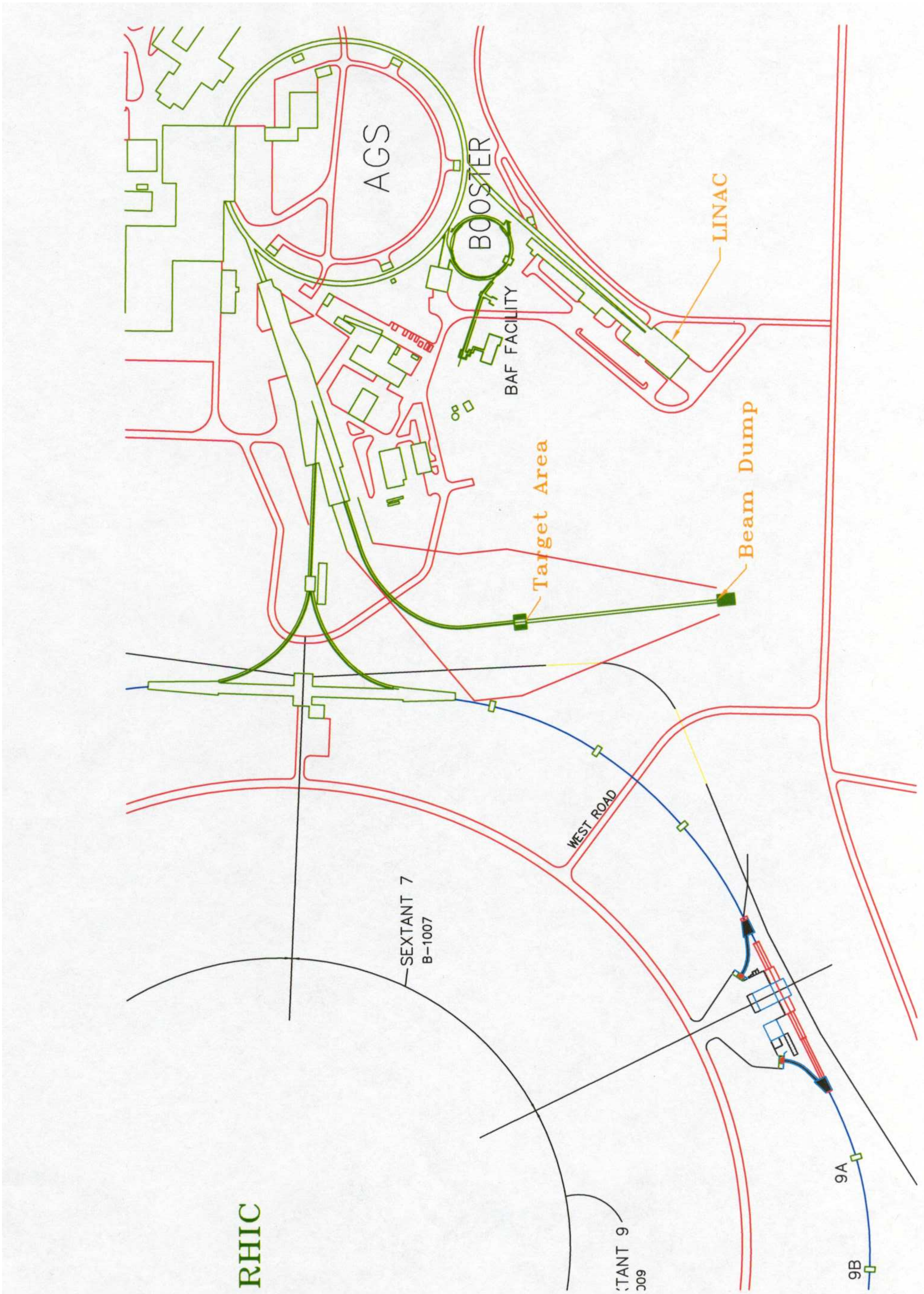

Figure 18: The beamline for sending a neutrino beam to Homestake mine, South Dakota. This same beamline can be adapted for any far location in the Western direction.

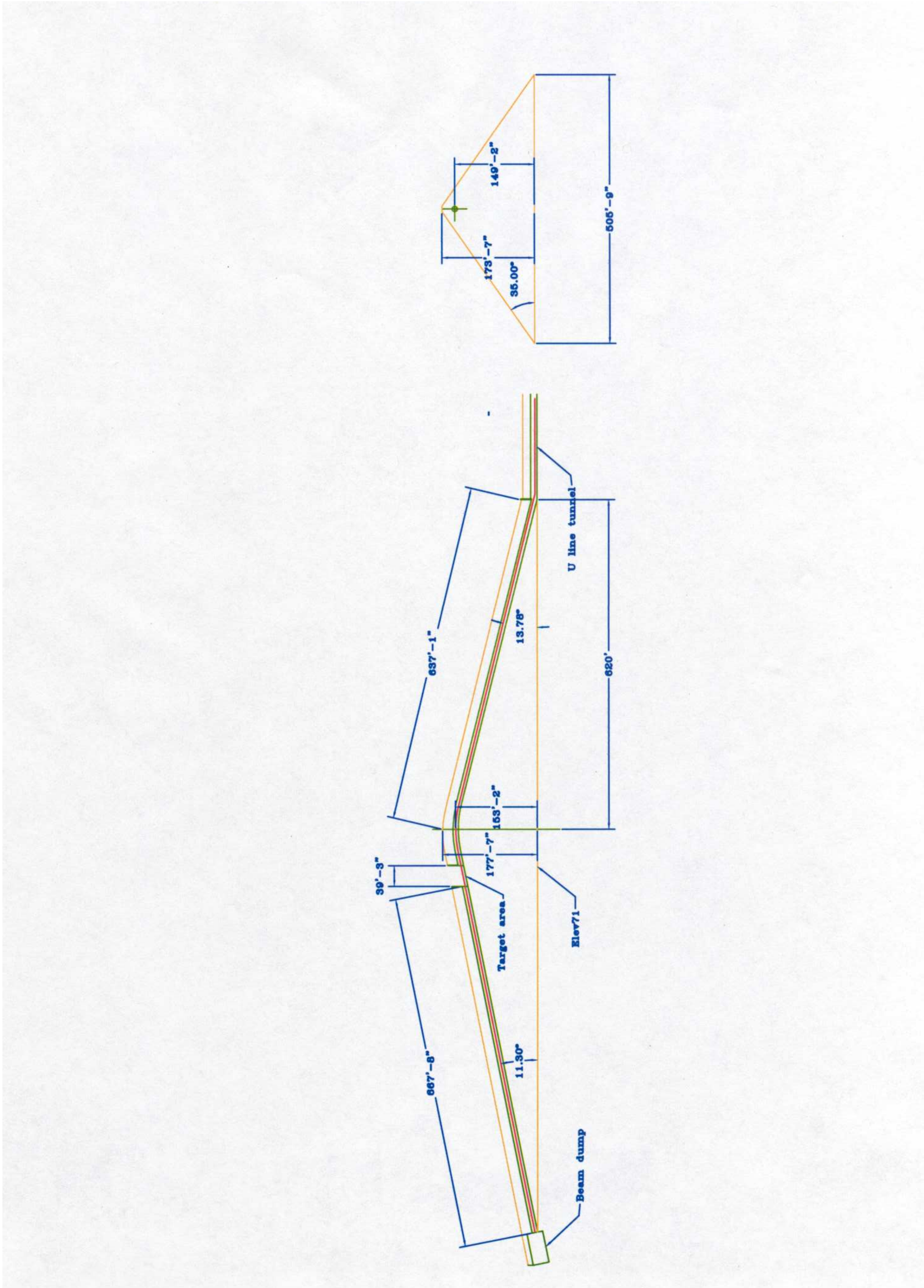

Figure 19: Elevation view of the neutrino beamline to Homestake, South Dakota. For a nearer location a much smaller hill can be constructed. In this beam we assume a decay tunnel length of 200 m. For a shorter tunnel the cost of the hill will reduce as shown in table 3.

values of the oscillation and mixing parameters, some of which are not yet known. Further surprises in neutrino physics should not be discounted, therefore any new facility must have sufficient flexibility to address new challenges. Our proposal allows such flexibility because of the possibility to mount both very long (over 2500 km) and intermediate (400 km) baseline experiments with beam intensity that can be increased in stages.

The AGS complex, although quite old, is unique because it can be upgraded simply by decreasing the cycle time of the machine. This ability allow us the flexibility to continuously upgrade the facility to as much as 4 MW. In this proposal we have examined upgrades upto 1 MW. The estimated cost of the first phase of the AGS upgrades to reach 0.47 MW, plus the new neutrino beam directed to Homestake is approximately \$95M. With a 30 percent contingency, the total cost is \$122M. It is probable that the first three modules of the detector array will be produced in about five years, so that construction of the AGS upgrades and neutrino beam would be planned for that period and involve an average expenditure of approximately \$30M/yr. For a detector at intermediate baseline the costs will be less. The total yearly cost to the AGS department to provide protons for and maintain the neutrino beam would be about \$9M, approximately equal to the operations expense at present for HEP experiments. Neither the duration of the construction period nor the anticipated cost of the improvements to the BNL AGS complex is large in relation to plans and expenditures now usual for major apparatus in high energy and elementary particle physics. Witness the effort and expense that have rightly gone into the search for CP-invariance violation in the b-quark family alone in the past few years. Moreover, the improvements to the AGS and the new beam will be available for carefully chosen other physics; an aging facility will be given a new life on an exciting new frontier of elementary particle physics.

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[3] k2k PRL

[4] hep-ex/?????

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