Physics Importance of Neutrino Oscillations

Complete measurement of the ***neutrino oscillation parameters*** is a physics goal of fundamental importance:

- neutrinos are fundamental particles whose full description in terms of mass and mixing parameters is basic to the progress of particle physics
- the mass scales among the neutrinos may help us understand the evolution of all particle masses down from the Planck scale
- if CP-violation is observed in the neutrino system, it will be quite large and may drive the much smaller CP-violation in the quark sector
- the early universe implications of large CP-violation in the neutrino sector might help explain the mass asymmetry in the present universe

Physics Goals of the Very Long Baseline Neutrino Program

We introduce a plan to provide the following goals in a ***single facility***:

- precise determination of the oscillation parameters Δm_{32}^2 and $\sin^2 2\theta_{23}$
- detection of the oscillation of $\nu_\mu \rightarrow \nu_e$ and measurement of $\sin^2 2\theta_{13}$
- measurement of $\Delta m_{21}^2 \sin^2 2\theta_{12}$ in a $\nu_\mu \rightarrow \nu_e$ appearance mode, can be made if the value of θ_{13} is zero
- verification of matter enhancement and the sign of Δm_{32}^2
- determination of the CP-violation parameter δ_{CP} in the neutrino sector

The use of a *single neutrino super beam source* and *half-megaton neutrino detector* will optimize the efficiency and cost-effectiveness of a full program of neutrino measurements. If the value of $\sin^2 2\theta_{13}$ happens to be larger than ~0.01, then all the parameters, including CP-violation can be determined in the VLB program presented here.

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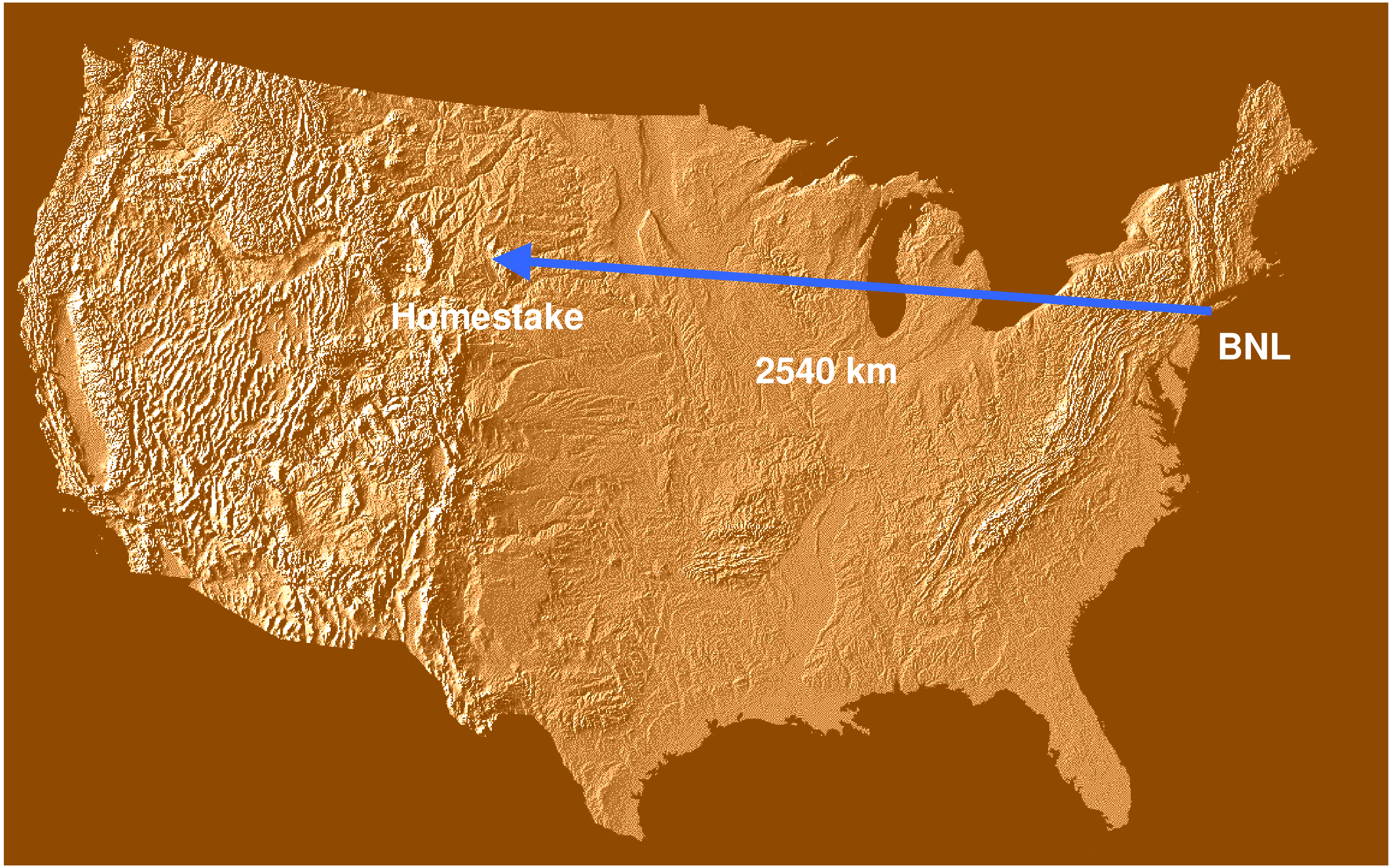
BNL → Homestake Super Neutrino Beam



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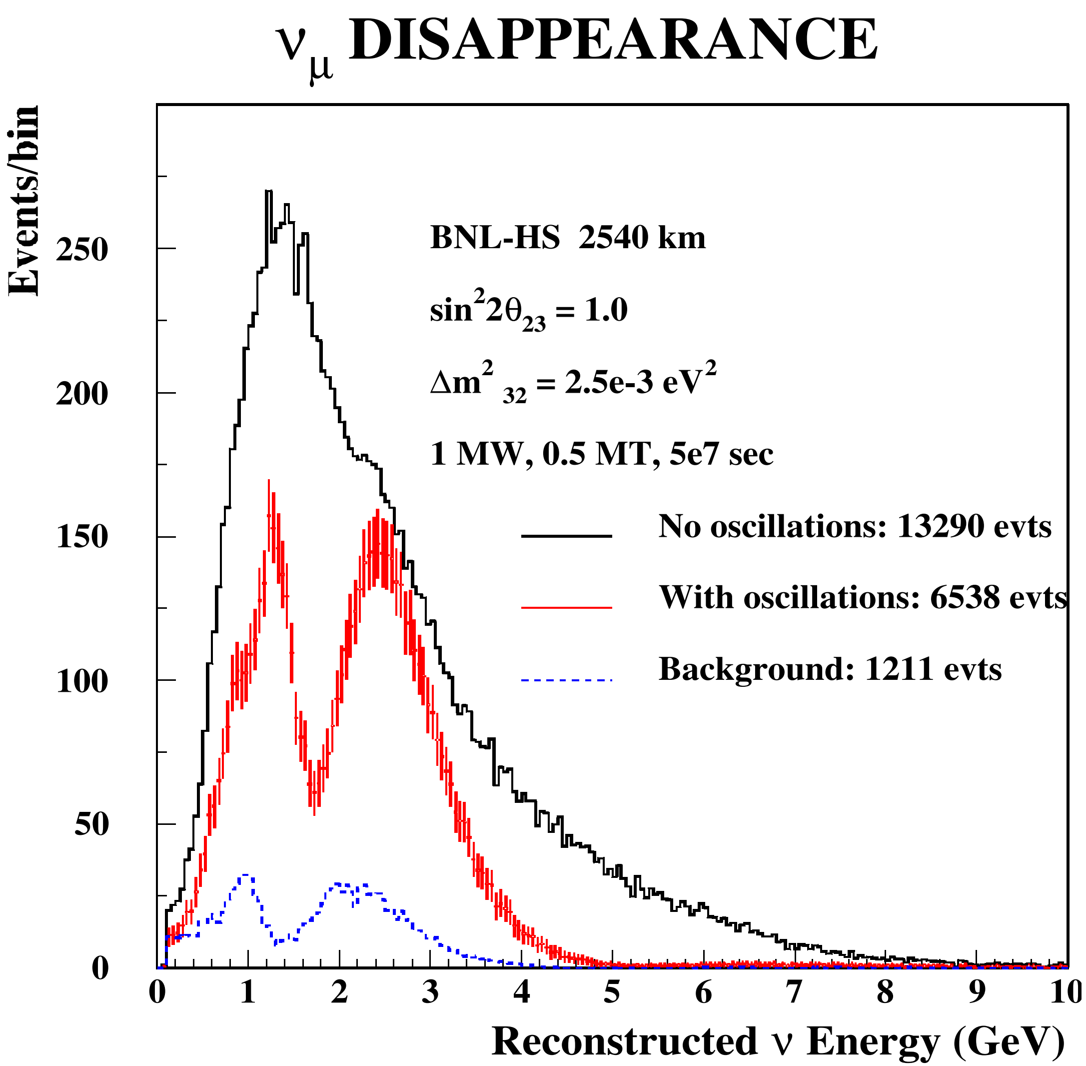
Advantages of a Very Long Baseline



- neutrino oscillations result from the factor $\sin^2(\Delta m_{32}^2\ L\ /\ 4E)$ modulating the ν flux for each flavor (here ν_μ disappearance)
- the oscillation period is directly proportional to distance and inversely proportional to energy
- with a *very long baseline* actual oscillations are seen in the data as a function of energy
- the multiple-node structure of the very long baseline allows the Δm_{32}^2 to be precisely measured by a *wavelength* rather than an amplitude (reducing systematic errors)

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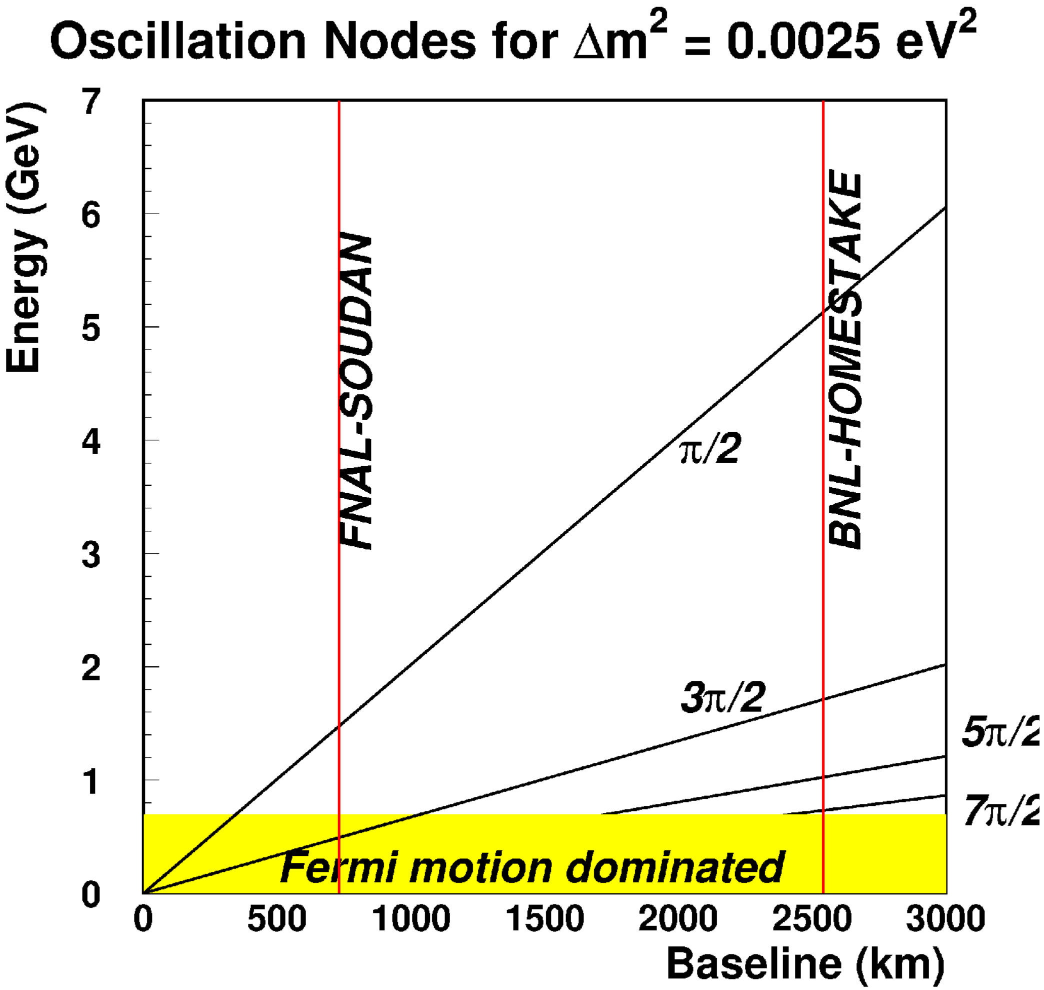
Baseline Length and Neutrino Energy



- for a fixed phase angle, e.g. $\pi/2$, the ratio of distance to energy is fixed (see sloped lines in Figure)
- the useful neutrino energy range in a beam derived from a proton production source is restricted:
  - below ~1 GeV by *Fermi mom.* in the target nucleus
  - above ~8 GeV by *inelastic* ν *interactions* background
- these conditions prescribe a needed baseline of greater than *2000 km* from source to detector
- by serendipity, the distance from BNL to the Homestake Mine in Lead, SD is 2540 km

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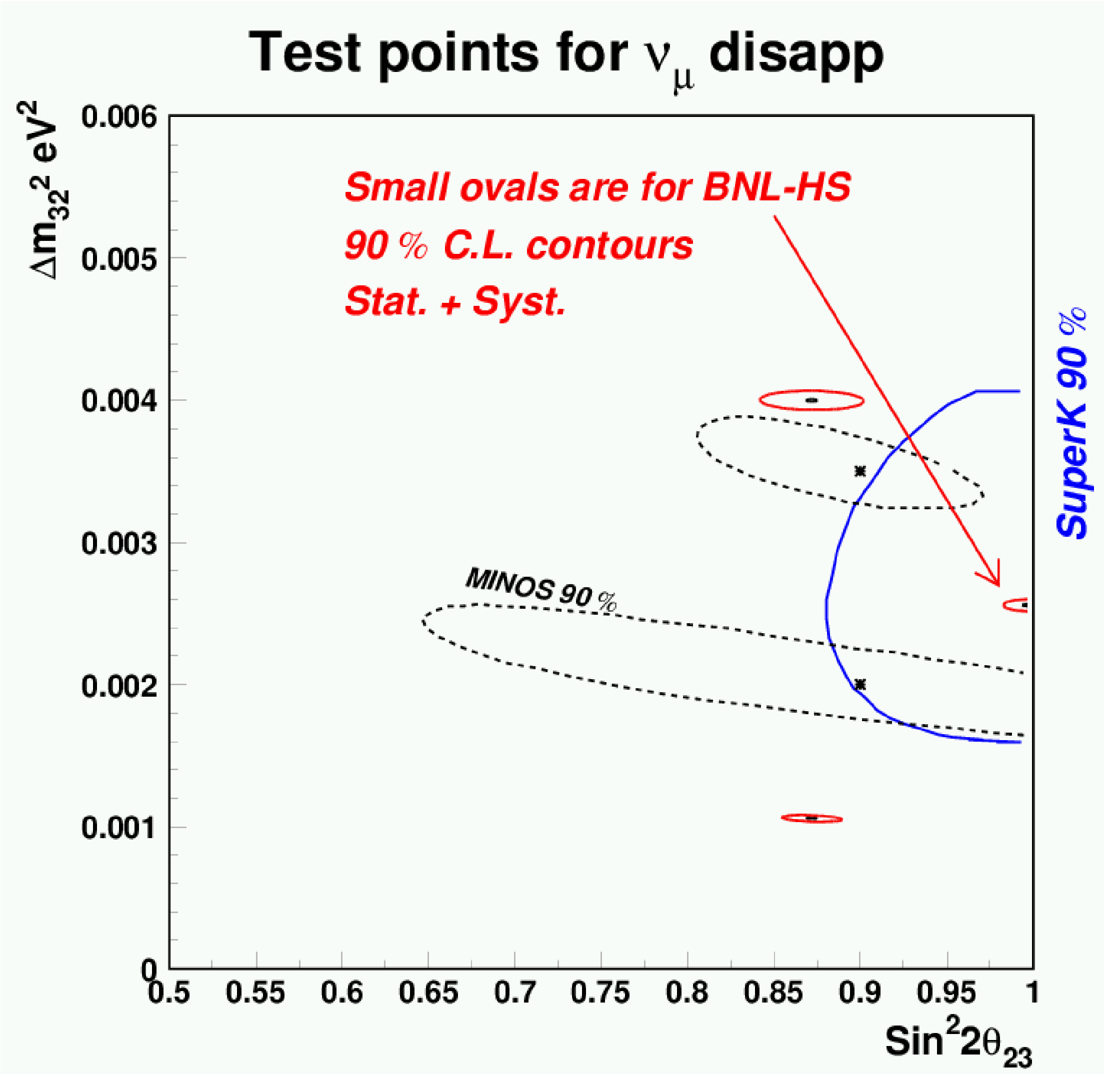
VLB Application to Measurement of Δm_{32}^2



- the multiple node method of the VLB measurement is illustrated by comparing the BNL 5-year measurement precision with the present Kamiokande results and the projected MINOS 3-year measurement precision; all projected data include both statistical and systematic errors
- there is no other plan, worldwide, to employ the VLB method (a combination of target power and geographical circumstances limit other potential competitors)
- other planned experiments are can't achieve the VLB precision

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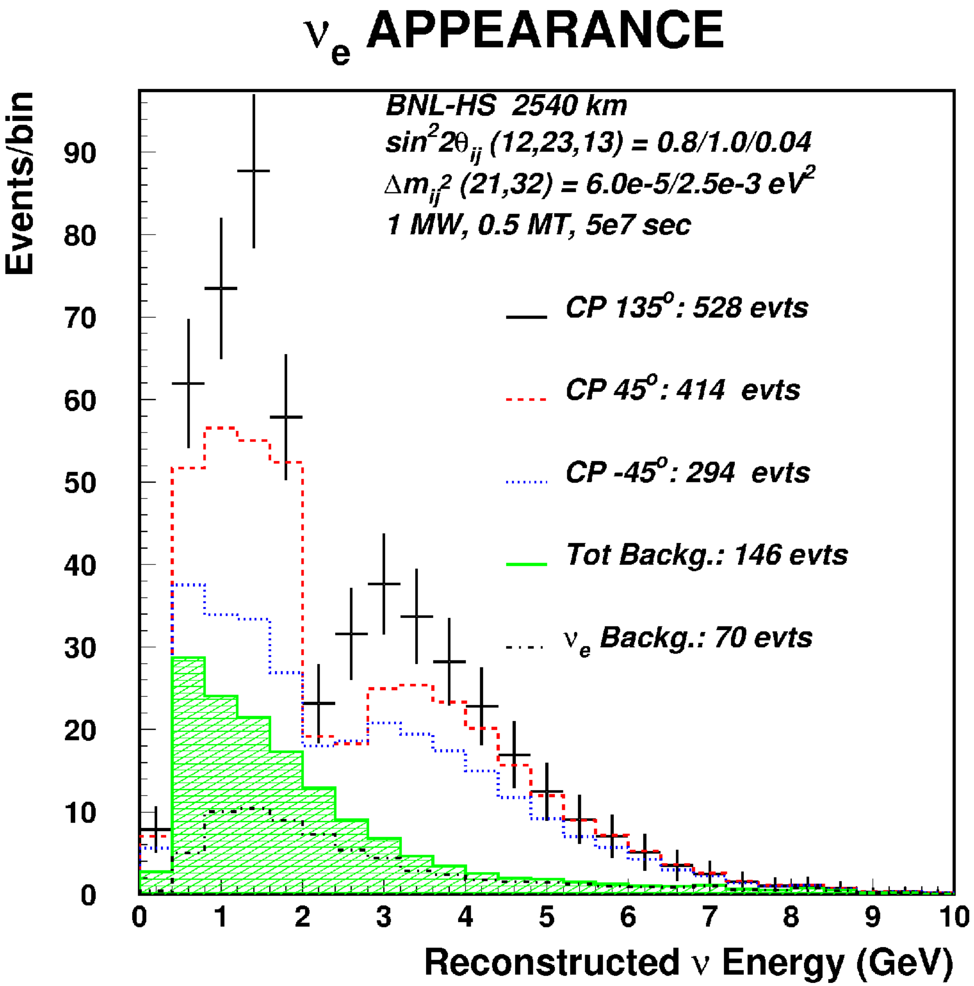
ν_e Appearance Measurements



- a direct measurement of the appearance of $\nu_\mu \rightarrow \nu_e$ is important; the VLB method competes well with any proposed super beam concept
- for values > 0.01, a measurement of $\sin^2 2\theta_{13}$ can be made (the current experimental limit is 0.12)
- for most of the possible range of $\sin^2 2\theta_{13}$, a good measurement of θ_{13} and the CP-violation parameter δ_{CP} can be made by the VLB experimental method

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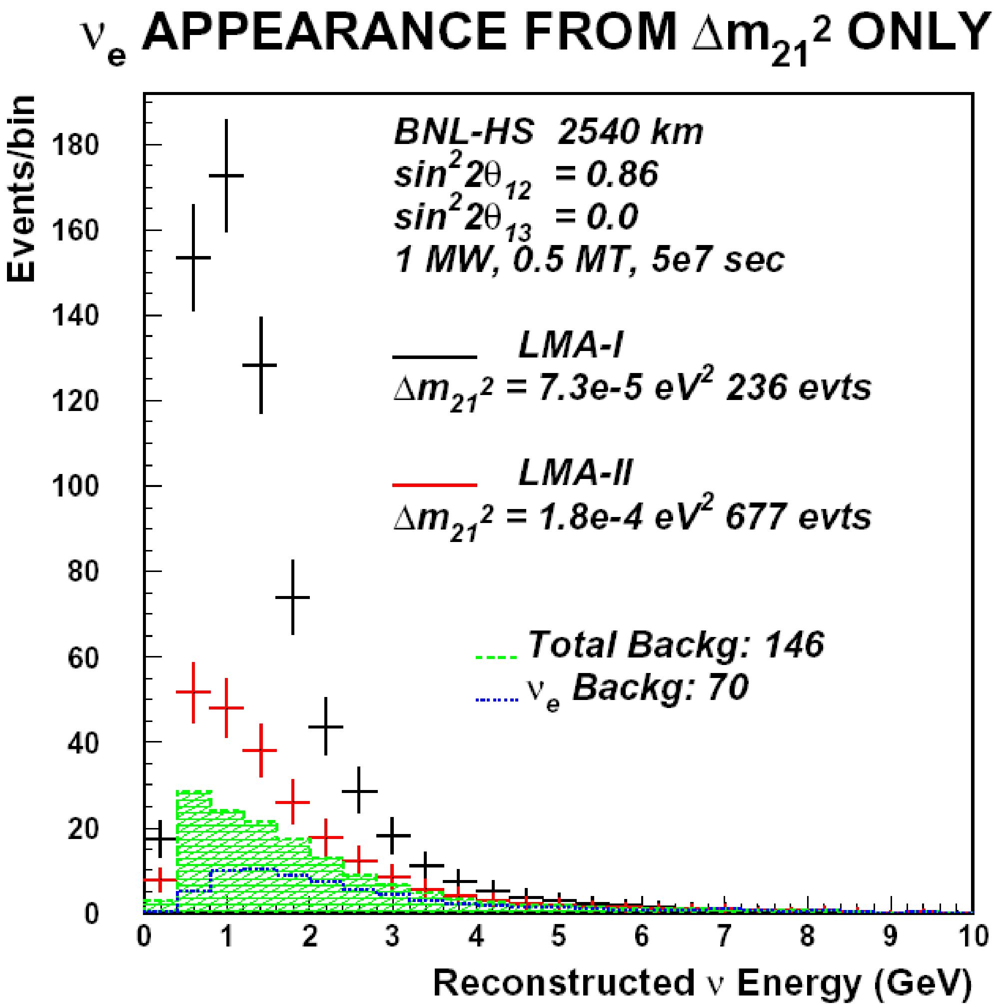
ν_e Appearance Measurements (Cont.)



- even if $\sin^2 2\theta_{13} = 0$, the current best-fit value of $\Delta m_{21}^2 = 7.3\times10^{-5}$ induces a ν_e appearance signal
- the size of the ν_e appearance signal above background depends on the value of Δm_{21}^2; the figure left indicates the range of possible measured values for the ν_e yields above background for various assumptions of the final value of Δm_{21}^2

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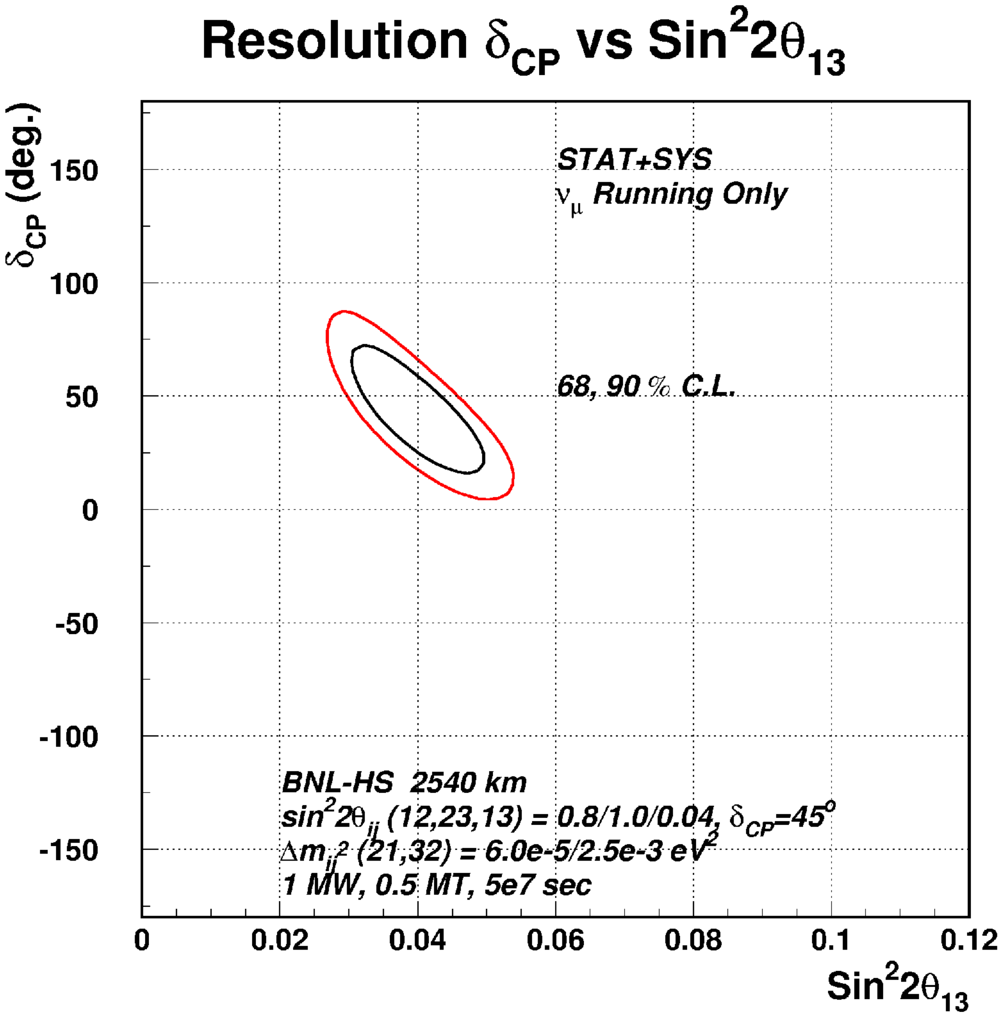
Mass -ordering and CP-violation Parameter δ_{CP}



- the CP-violation parameter δ_{CP} can be measured in the VLB exp. And is relatively insensitive to the value of $\sin^2 2\theta_{13}$
- the mass-ordering of the neutrinos is determined in the VLB exp;
  $\nu_1 < \nu_2 < \nu_3$ is the natural order
  but $\nu_1 < \nu_3 < \nu_2$ is still possible experimentally; VLB determines this, using the effects of matter on the higher-energy neutrinos

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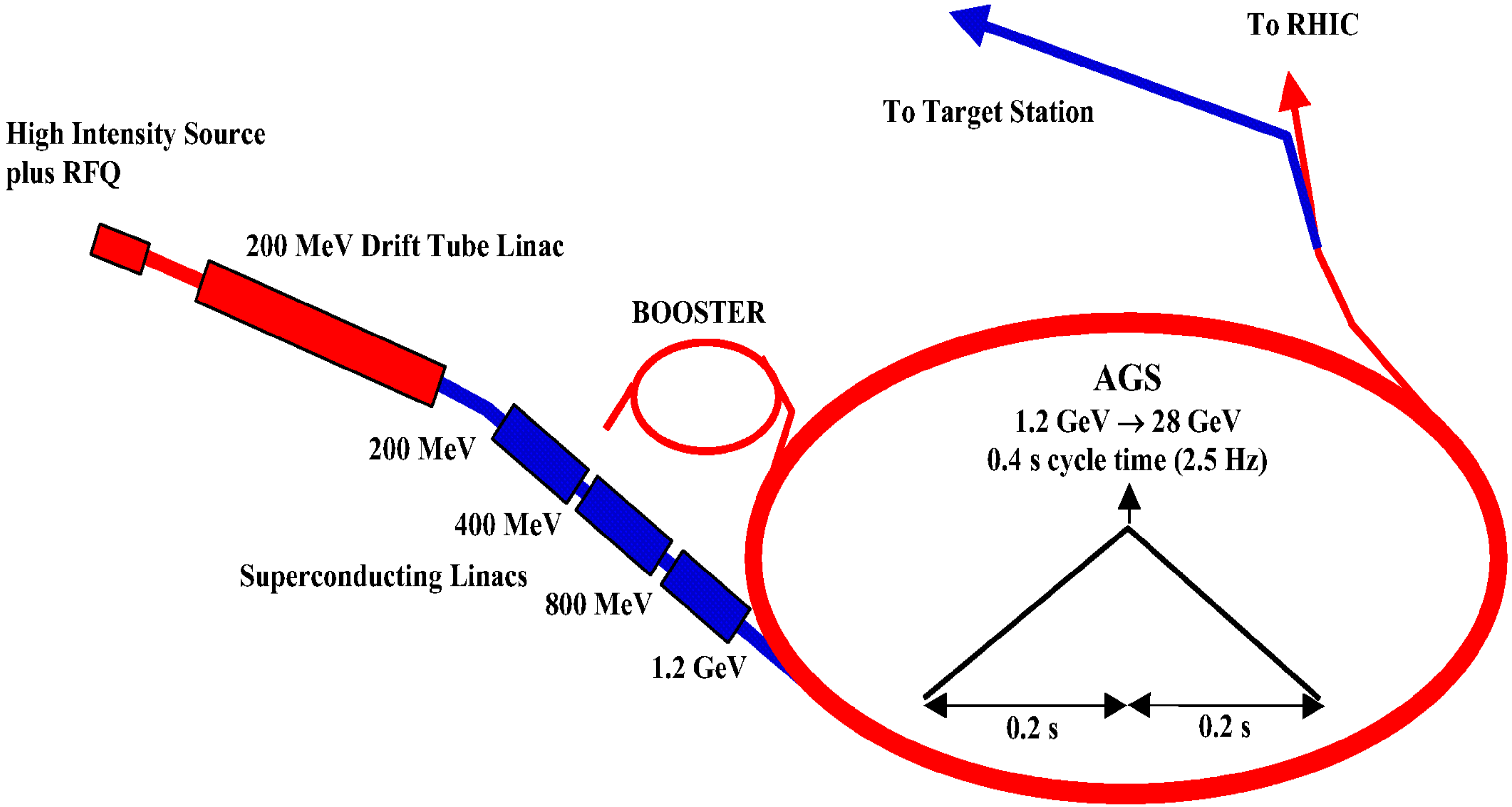
AGS Target Power Upgrade to 1 MW



- the *AGS Upgrade* to provide a source for the 1.0 MW Super Neutrino Beam will cost $265M FY03 (TEC) dollars

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AGS 1 MW Upgrade and SC Linac Parameters

Proton Driver Parameters

Item	Value
Total beam power	1 MW
Protons per bunch	0.4×10^{13}
Beam energy	28 GeV
Injection turns	230
Average beam current	38 mA
Repetition rate	2.5 Hz
Cycle time	400 ms
Pulse length	0.72 ms
Number of protons per fill	9.6×10^{13}
Chopping rate	0.75
Number of bunches per fill	24
Linac average/peak current	20/30 mA

Superconducting Linac Parameters

Linac Section	LE	ME	HE
Av Beam Pwr, kW	7.14	14.0	14.0
Av Beam Curr, mA	35.7	35.7	35.7
K.E. Gain, MeV	200	400	400
Frequency, MHz	805	1610	1610
Total Length, m	37.82	41.40	38.32
Accel Grad, MeV/m	10.8	23.5	23.4
norm rms ε, π mm-mr	2.0	2.0	2.0

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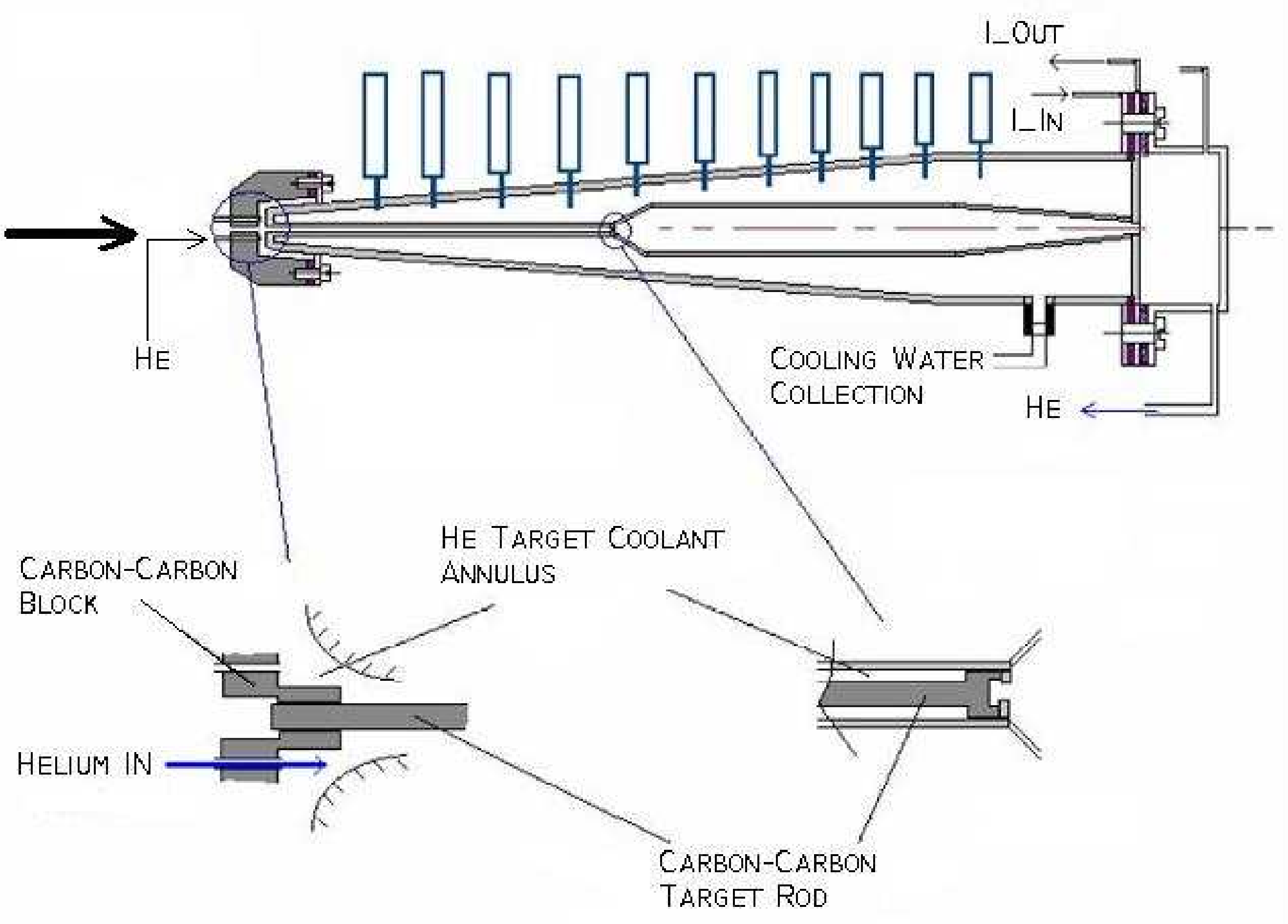
1 MW Target for AGS Super Neutrino Beam



- 1.0 MW He gas-cooled, Carbon-Carbon target for the Super Neutrino Beam

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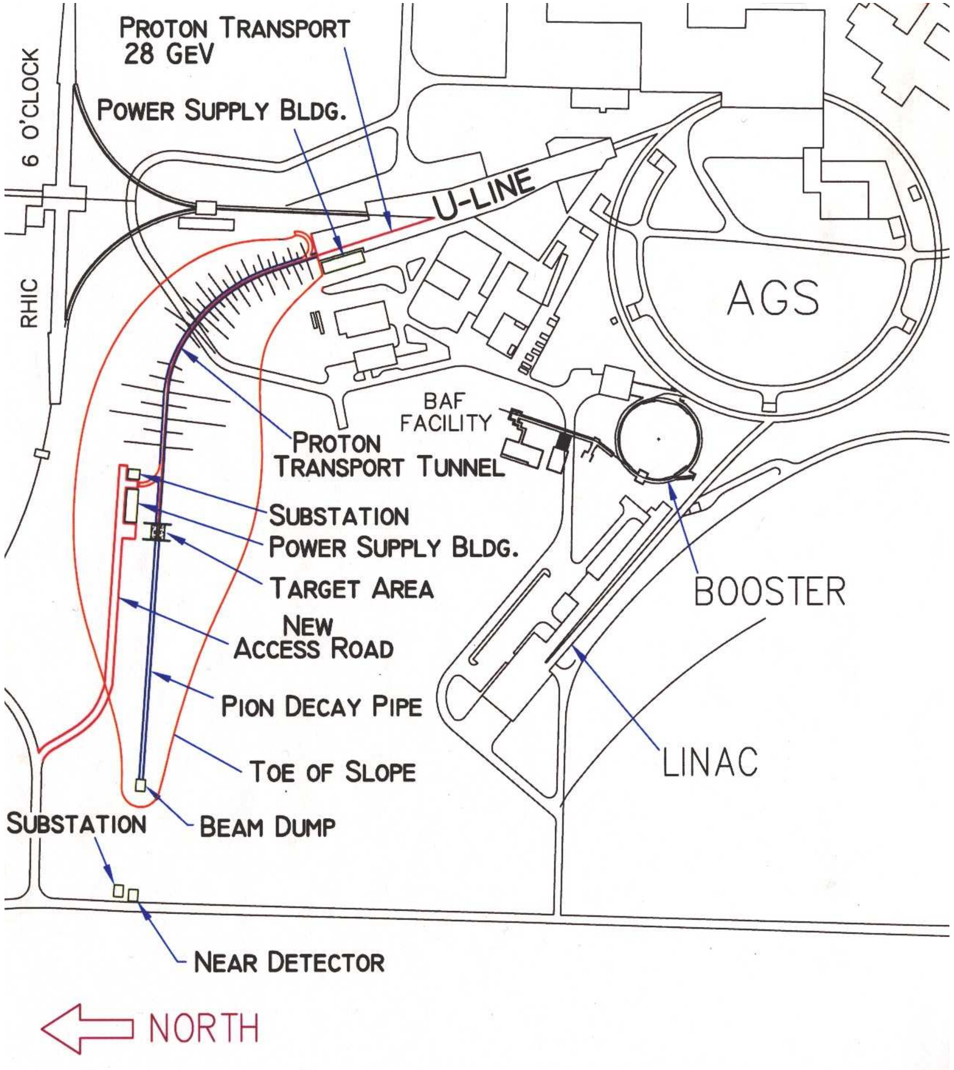
Super Neutrino Beam Geographical Layout



- BNL can provide a *1 MW capable Super Neutrino Beam* for $104M FY03 (TEC) dollars
- the neutrino beam can aim at any site in the western U.S.; the Homestake Mine is shown here
- there will be no environmental issues if the beam is produced atop the hill illustrated here and the beam dumped well above the local water table
- construction of the Super Neutrino Beam is essentially de-coupled from AGS and RHIC operations

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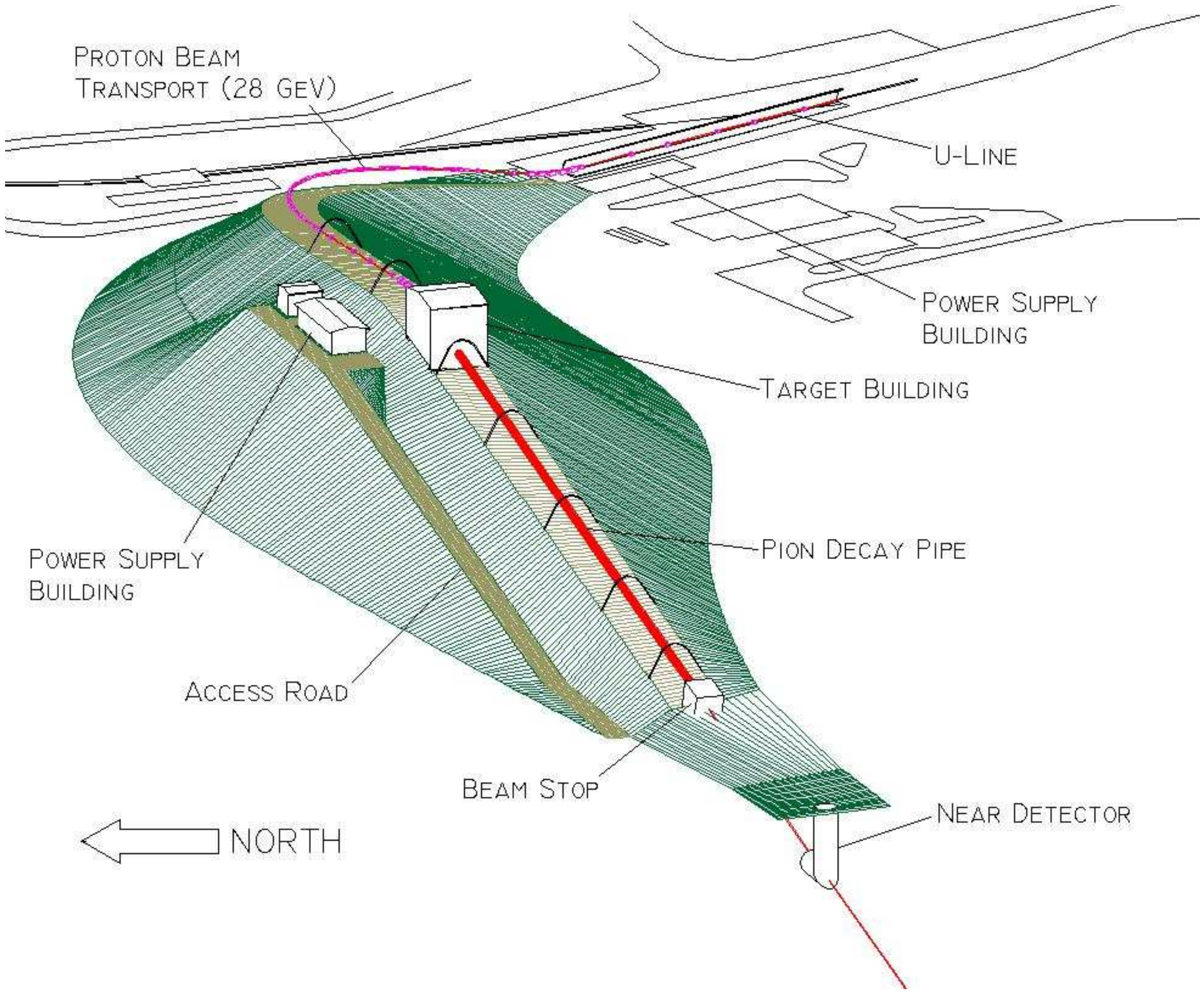
3-D Neutrino Super Beam Perspective



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Conclusions

- measurement of the *complete set of neutrino mass and mixing parameters* is very compelling for the advance of particle physics
- the *Very Long Baseline* method, utilizing a *1 MW Super Neutrino Beam* from BNL's AGS, coupled with a *half-megaton water Cerenkov detector* in the Homestake Mine in Lead, SD, offers a uniquely effective plan
- the half-megaton detector was not detailed in this presentation but we note that the UNO detector has all the properties needed for the VLB neutrino program and offers important and compelling physics beyond the neutrino oscillations work.

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