BNL Very Long Baseline Neutrino Oscillation Expt.

Next Generation of Nucleon Decay and Neutrino Detectors 8/04/2005

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Outline

- **The case for a very long baseline ν experiment**
- **Highlights from BNL's Conceptual Design Report**
- **BNL physics sensitivies for $L = 2540$ km and $L = 1290$ km**
- **Conclusions**

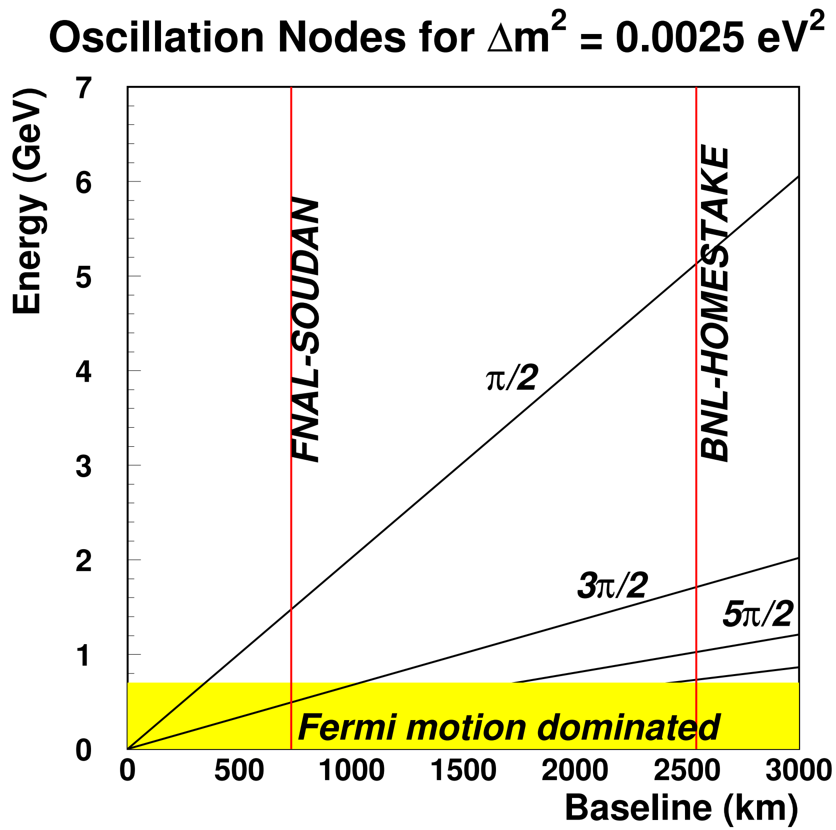
Why a Very Long Baseline?

Sensitivity to atmospheric (Δm^2_{32}) AND solar (Δm^2_{21}) oscillation scales

Verify oscillation behaviour by observing multiple nodes. Multiple nodes = higher precision.

Resolution of $E_{\nu_\mu} < 1$GeV/c^2 dominated by Fermi motion $\Rightarrow$ maximize $L = \mathcal{O}(1000)$ km

Higher energies = larger cross-sections



BNL 1MW, $L = 2540$ km, 500 kT $\sim 1\%$ resol on Δm^2_{32} and $\sin^2 2\theta_{23}$

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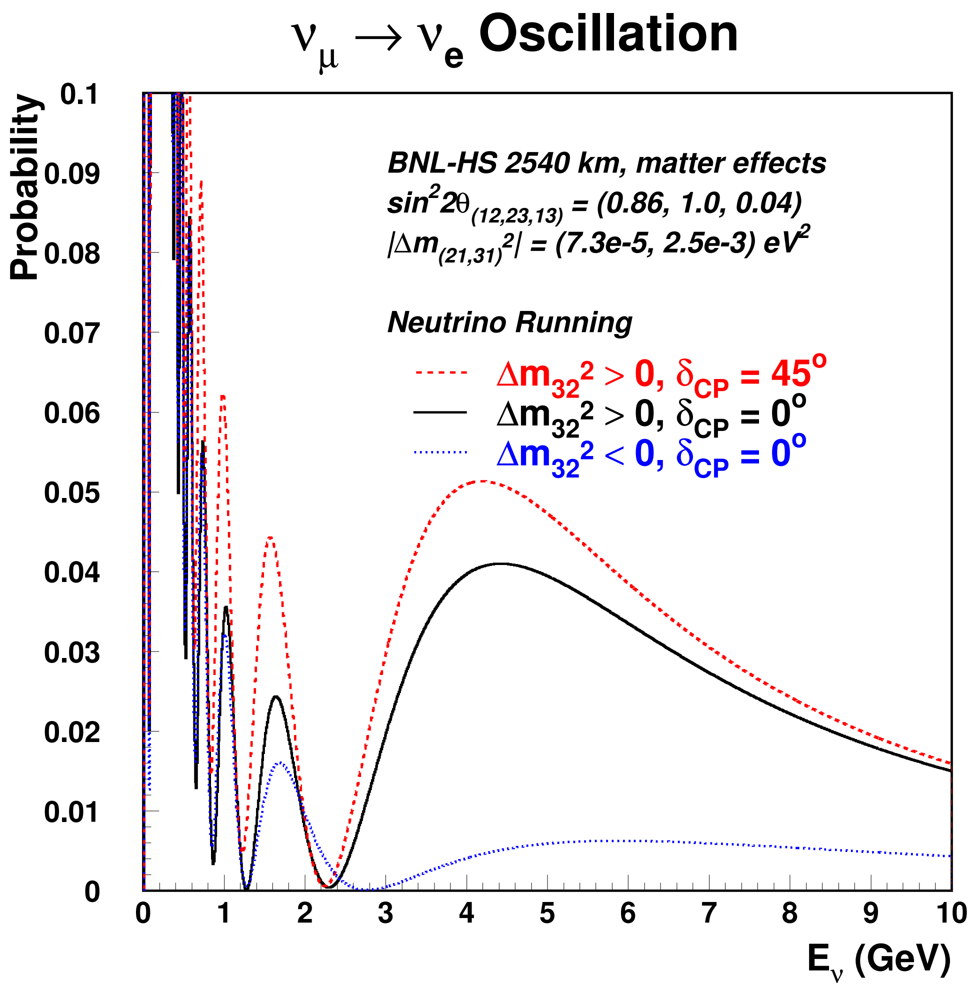
Sensitivity to δ_{cp} & $sign(\Delta m_{32})$

Matter effects enhance (suppress) $\nu_\mu \rightarrow \nu_e$ oscillation probability for $m_3 > m_2 > m_1$ ($m_2 > m_1 > m_3$). Effect largest for $E_\nu > 3$ GeV/c^2

For $1 < E_\nu < 3$ GeV/c^2 appearance spectrum is sensitive to δ_{cp}

Marciano (hep-ph/0108181): CP asymmetry in $\nu_\mu \rightarrow \nu_e$, A, grows with L, flux at far detector goes as $1/L^2$. $\Rightarrow$ FOM $= A^2 N_\nu/(1 - A^2)$ is $\sim$ constant.



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Separating Multiple $\nu_\mu \to \nu_e$ Effects

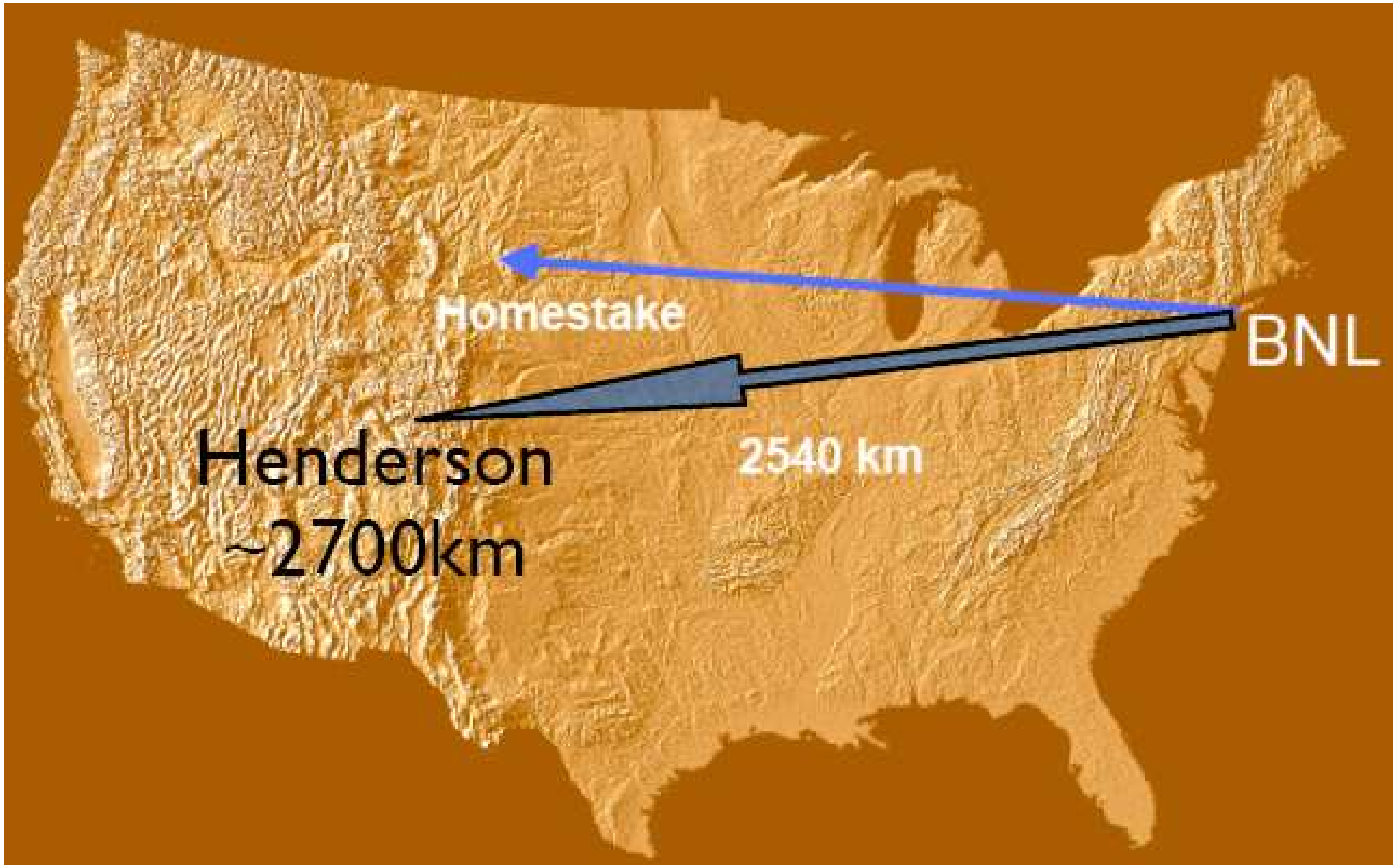
Need a broadband beam with $E_\nu = 1$ to 6 GeV to resolve degeneracies

	energy (GeV)	$\sin^2 2\theta_{13} > 0$	Δm^2_{32} $(> 0, < 0)$	$\delta_{CP} =$ $(\frac{\pi}{4}, -\frac{\pi}{4})$	θ_{23} $(< \frac{\pi}{4}, > \frac{\pi}{4})$
ν	0–1.2	$\uparrow$	–, –	$\uparrow, \downarrow$	$\Uparrow, \Downarrow$
	1.2–2.2	$\uparrow$	–, –	$\Uparrow, \Downarrow$	$\downarrow, \uparrow$
	$>$ 2.2	$\uparrow$	$\Uparrow, \Downarrow$	$\uparrow, \downarrow$	$\downarrow, \uparrow$
$\bar{\nu}$	0–1.2	$\uparrow$	–, –	$\downarrow, \uparrow$	$\Uparrow, \Downarrow$
	1.2–2.2	$\uparrow$	–, –	$\Downarrow, \Uparrow$	$\downarrow, \uparrow$
	$>$ 2.2	$\uparrow$	$\Downarrow, \Uparrow$	$\downarrow, \uparrow$	$\downarrow, \uparrow$

For 3 generations we do not need $\bar{\nu}$!

BNL baselines

The US is $\approx$ 4500 km coast-to-coast. Brookhaven National Lab is located on the eastern coast $\Rightarrow$ ideal for $\mathcal{O}(2000)$ km baselines.



BNL-Homestake mine = 2540 km **BNL-Henderson mine = 2700 km**

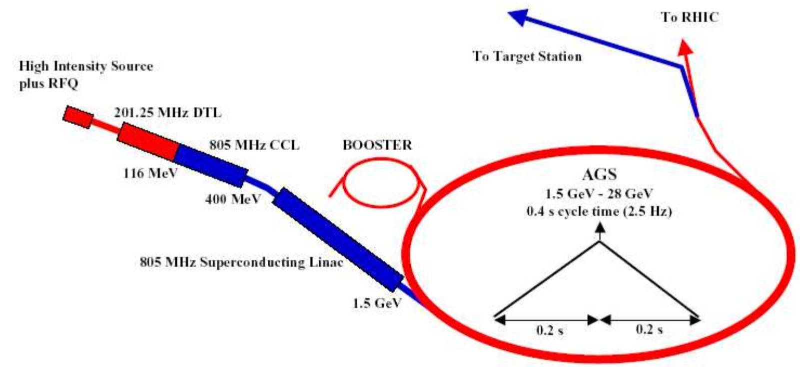
BNL Conceptual Design Report

BNL-73210-2004-IR available at http://raparia.sns.bnl.gov/nwg_ad/

AGS = highest intensity proton beam in the world. $E_p = 28$ GeV.

Upgrade AGS intensity from 7×10^{13} ppp to 9×10^{13} ppp.

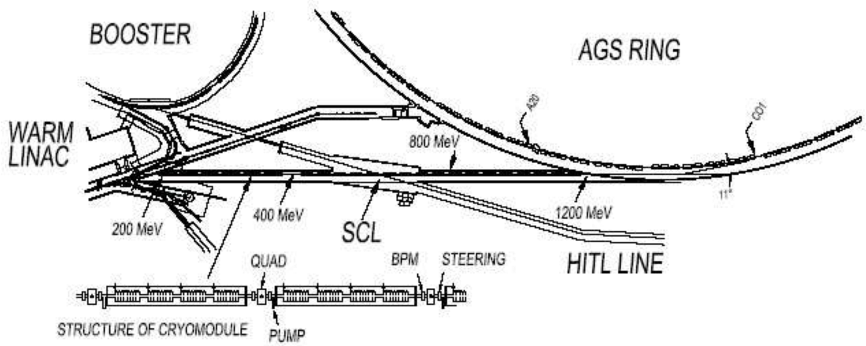
+ 0.5 Hz rep. rate to 2.5 Hz $\Rightarrow$ 1 MW



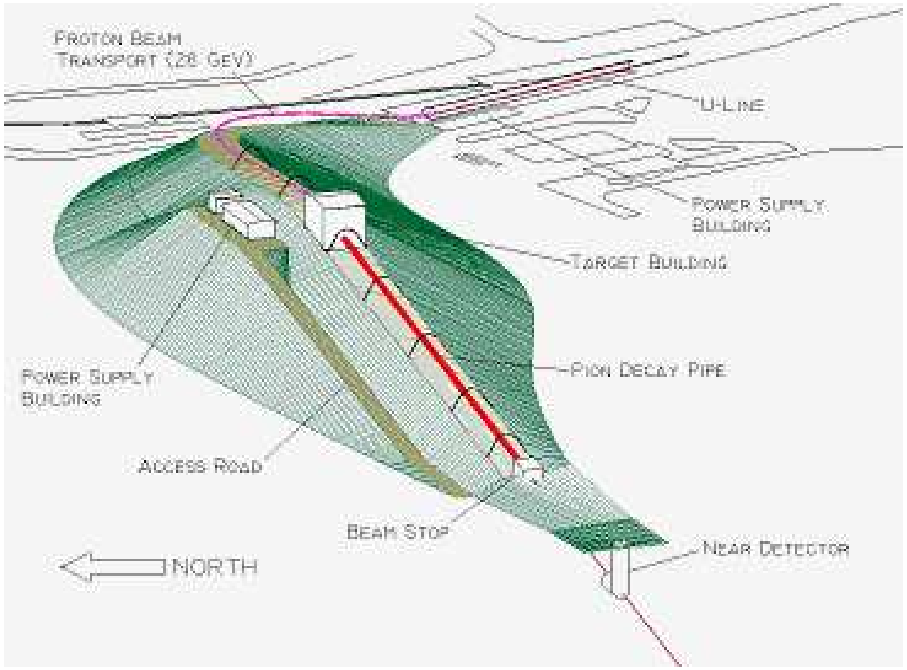
To achieve 2.5 Hz rep rate:

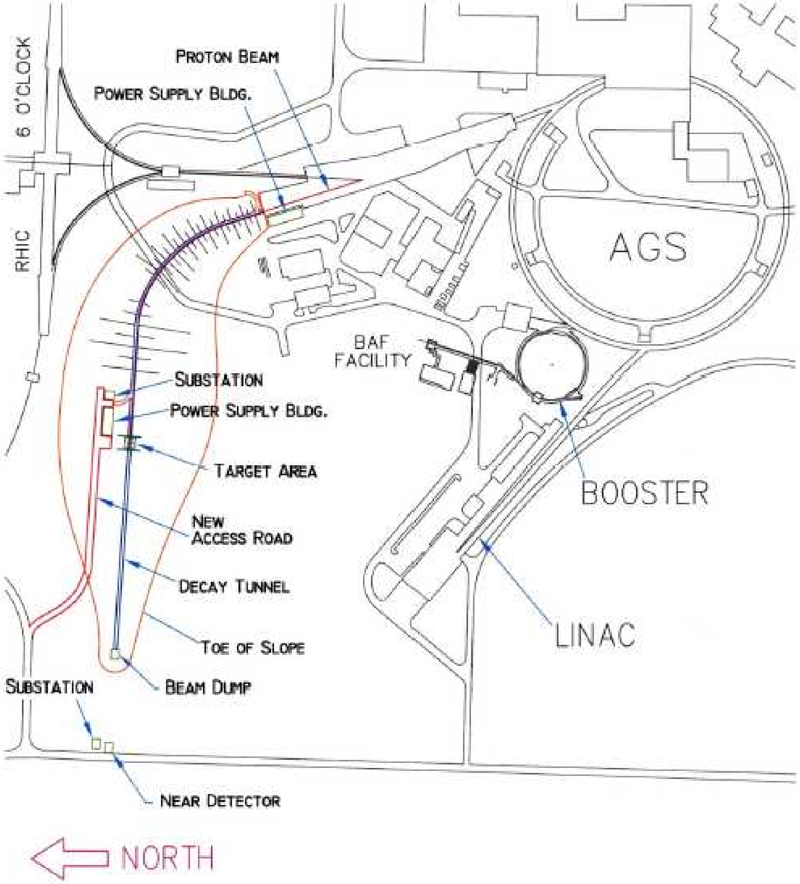
Upgrade 200 MeV Linac to 400 MeV a la Fermilab c. 1993

Replace booster with 1 GeV superconducting linac (SCL) using SNS 805 MHz technology.



Getting the beam to Homestake





Beam needs to point downwards at 11.3° to reach detector at 2540 km

Build a hill instead of a tunnel! = hadrons above water

Civil engineering costs (including linac gallery) = FY 04 $ 69 M

BNL 1MW ν beam cost estimate

Cost Estimate of the AGS Super Neutrino Beam Facility

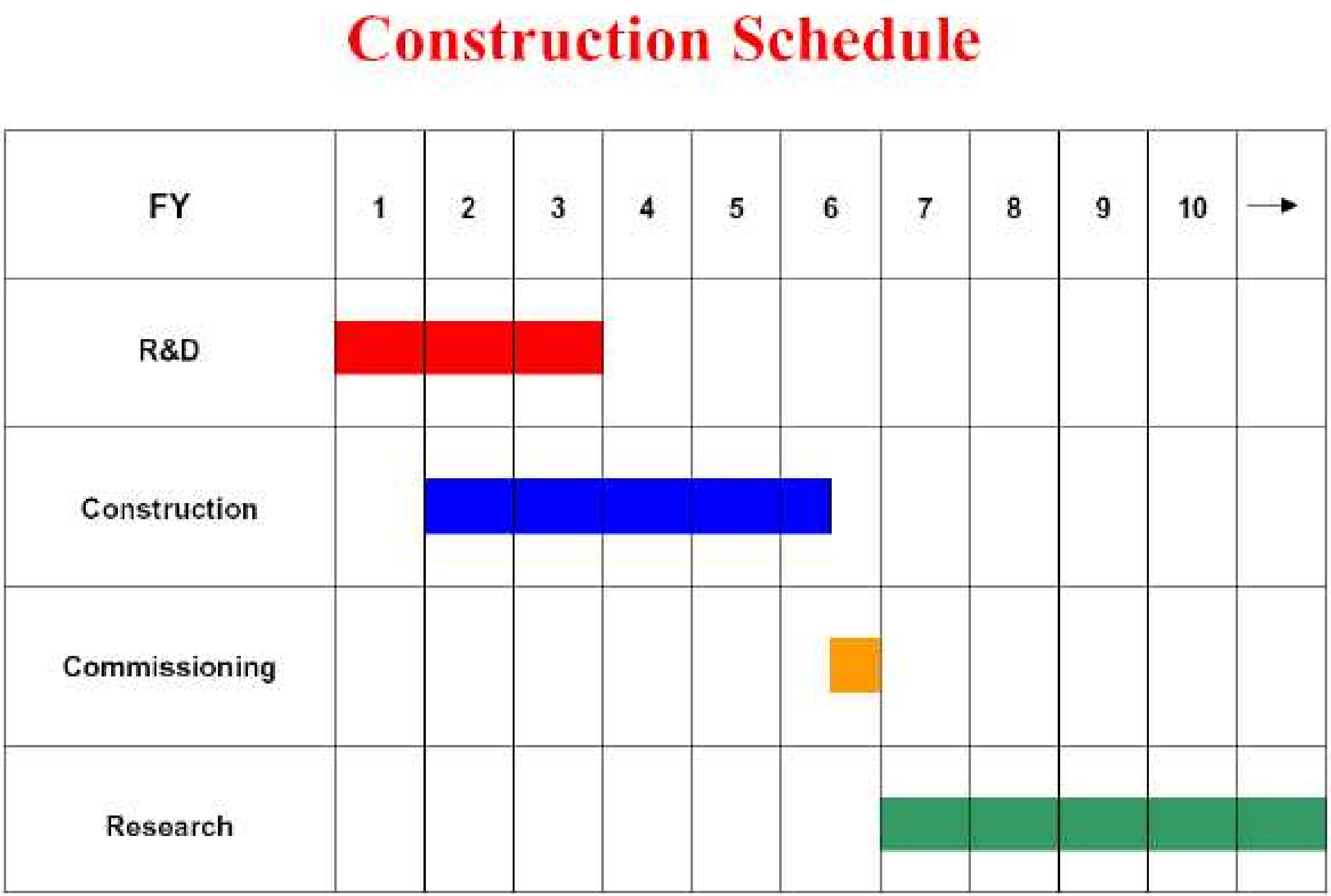
Construction Phase - Direct FY04 Dollars

1.0 AGS Super Neutrino Beam Facility	EDIA	M&S	Labor	Total
1.1 The Linac System	**6,879,116**	**98,556,970**	**16,783,762**	**122,219,848**
1.1.1 Front End and RT Linac Upgrade	313,000	2,383,000	856,000	**3,552,000**
1.1.2 SCL Accelerating Cavity System	954,240	22,254,200	11,040,000	**34,248,440**
1.1.3 SCL RF Source	3,620,988	51,668,800	402,332	**55,692,120**
1.1.4 SCL Cryogenic System	370,000	13,700,000	2,200,000	**16,270,000**
1.1.5 SCL Vacuum System	641,598	3,474,570	1,148,378	**5,264,546**
1.1.6 SCL Instrumentation	460,957	1,390,400	409,061	**2,260,418**
1.1.7 SCL Magnet and Power Supply	518,332	3,686,000	727,991	**4,932,324**
1.2 The AGS Upgrade	**10,496,245**	**53,619,159**	**6,472,590**	**70,587,994**
1.2.1 AGS Main Magnet Power Supply	503,959	28,200,000	1,342,337	**30,046,296**
1.2.2 AGS RF System Upgrade	6,082,625	9,850,000	675,847	**16,608,472**
1.2.3 AGS Injection/Extraction	644,000	6,437,066	1,668,330	**8,749,396**
1.2.4 Beam Transport to Target	1,636,771	7,852,241	2,637,290	**12,126,302**
1.2.5 Control System	1,628,890	1,279,852	148,786	**3,057,528**
1.3 The Target and Horn System	**664,742**	**3,417,152**	**1,208,338**	**5,290,232**
1.3.1 The Target System	127,008	229,284	50,130	**406,422**
1.3.2 The Horn System	454,524	2,358,568	656,224	**3,469,316**
1.3.3 Shielding and Remote Handling	83,210	809,300	125,300	**1,017,810**
1.3.4 Target & Horn Physics Support	0	20,000	376,684	**396,684**
1.4 The Conventional Facility	**7,550,300**	**60,090,300**	**1,210,700**	**68,851,300**
1.4.1 Linac Tunnel/Klystron Gallery	2,253,000	11,529,000	230,000	**14,012,000**
1.4.2 AGS Power Supply Building	2,024,000	13,347,000	432,000	**15,803,000**
1.4.3 Beam Transport and Target Area	1,674,300	25,091,000	172,500	**26,937,800**
1.4.4 The Decay Tunnel and Beam Stop	184,000	1,225,300	115,200	**1,524,500**
1.4.5 Site Utilities & Roads	1,088,000	6,820,000	140,000	**8,048,000**
1.4.6 Modifications for AGS RF System	327,000	2,078,000	121,000	**2,526,000**
1.5 ES&H	**104,652**	**275,211**	**437,355**	**817,218**
1.5.1 ES&H	20,000	105,000	270,000	**395,000**
1.5.2 Access Controls	84,652	170,211	167,355	**422,218**
1.6 Project Support	**1,148,681**	**384,109**	**4,096,963**	**5,629,753**
1.6.1 Project Management	0	100,000	1,178,000	**1,278,000**
1.6.2 Technical Support	1,148,681	214,109	2,146,963	**3,509,753**
1.6.3 Project Controls	0	70,000	772,000	**842,000**
AGS Super Neutrino Beam Facility Project Total	**26,843,736**	**216,342,901**	**30,209,709**	**273,396,345**

Total direct cost is FY 04 $ 273.4 M.

Total *estimated* cost is FY 04 $ 406.9 M (including 30% contingency)

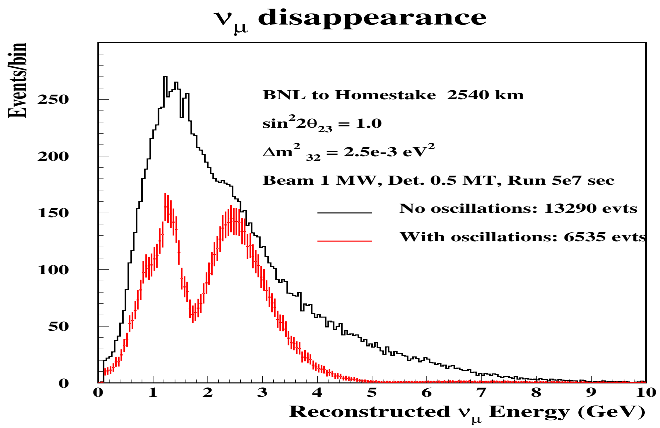
Construction Schedule

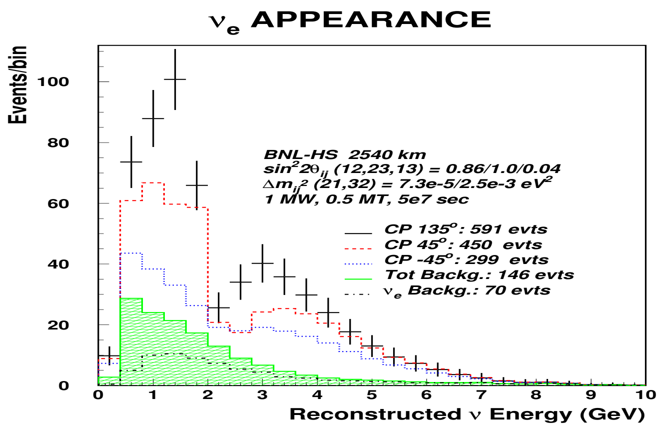


Physics potential of VLB

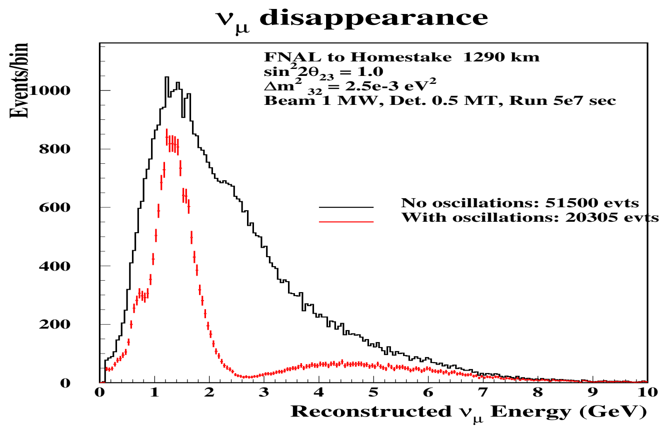
MC simulation with fermi motion, detector resolution and physics backgrounds for $L = 2540$ and 1290 km. M. Diwan, hep-ex/0407047:

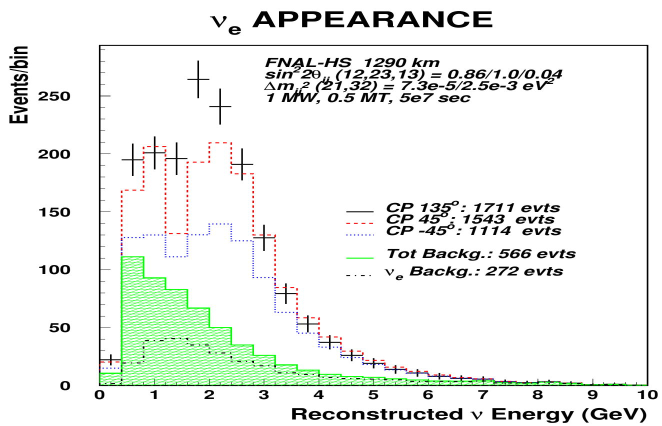
BNL beam $L = 2540$ km





BNL beam $L = 1290$ km





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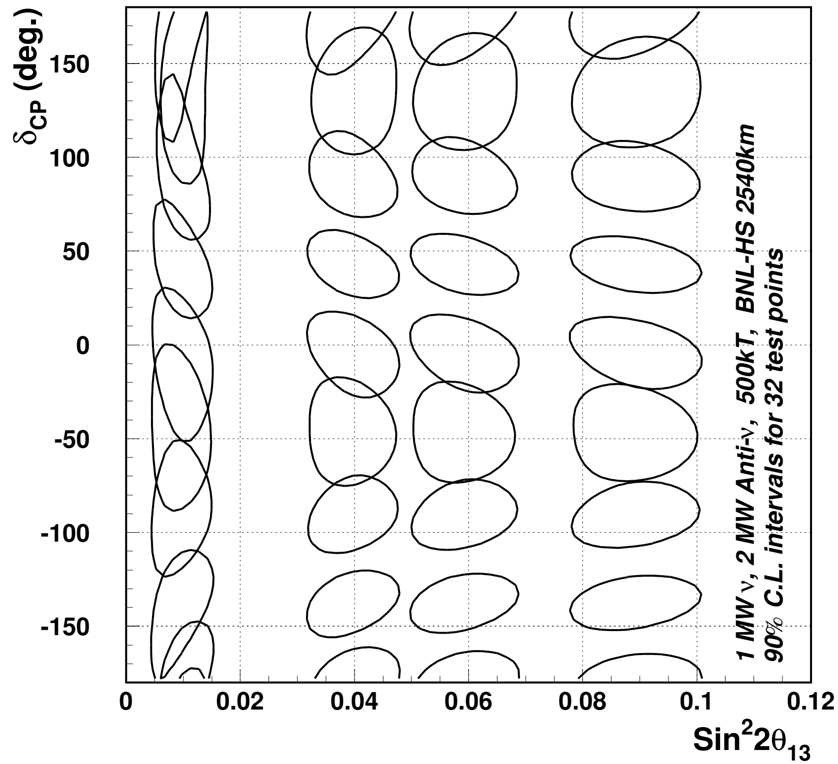
Limits after $\bar{\nu}$ running

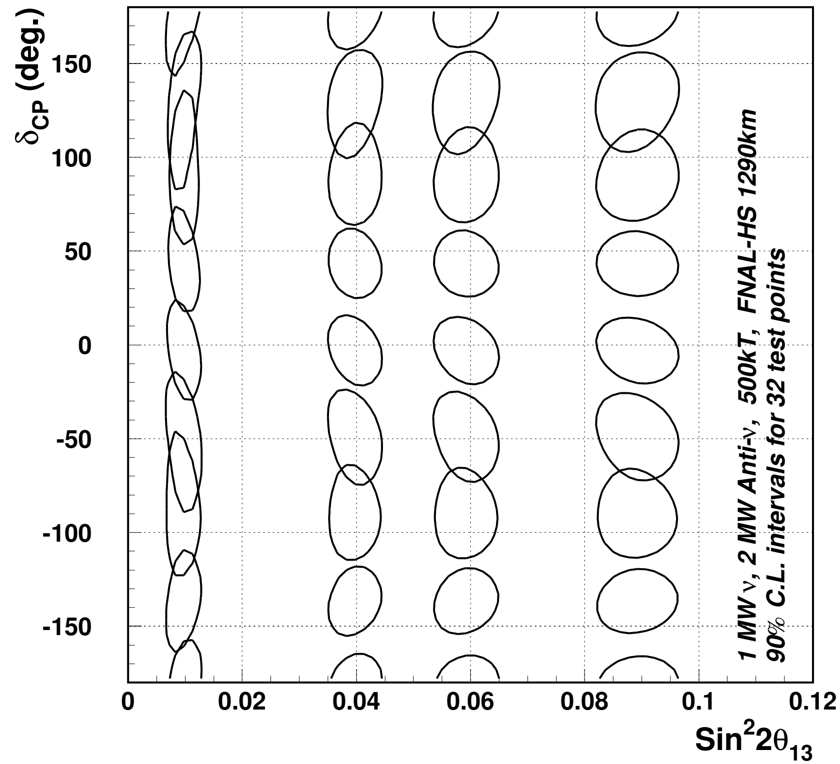
90% confidence level error contours. Statistical + 10% systematic errors:

BNL beam $L = 2540$ km | **BNL beam $L = 1290$ km**

Regular hierarchy ν and Antiν running



Regular hierarchy ν and Antiν running



If no $\nu_e \Rightarrow$ observed $\Rightarrow$ limit $\sin^2 2\theta_{13} \sim 0.003$ independant of δ_{cp}

Appearance of ν_e when $\theta_{13} = 0$

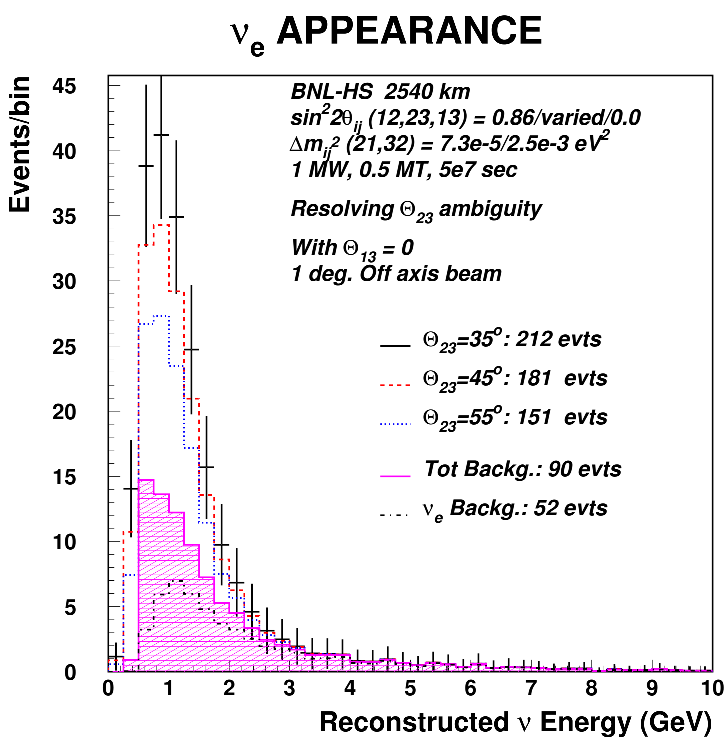
$$P(\nu_\mu \rightarrow \nu_e) \approx \left(\frac{\Delta m^2_{21} L}{4E}\right)^2 \cos^2\theta_{23} \sin^2 2\theta_{12}$$

BNL beam $L = 2540$ km

If $\sin^2 2\theta_{13}$ is small $\Rightarrow$ δ_{cp} measurement not possible

BUT observation of ν_e appearance is still possible from the current value of the solar parameters

Better S:B off axis capability is built into baseline BNL proposal



Only feasible with the longer baseline (2540 km) because of better S:B

Summary of BNL studies:

- **A very long baseline experiment can address both the solar and atmospheric oscillation scales.**
- **Very precise measurements of Δm^2_{32} and $\sin^2\theta_{23}$ can be acheived at either 1290 or 2540 km baseline.**
- **Very good bounds on θ_{13} from either baseline**
- **Longer baseline = more sensitivity to ν_e appearance if θ_{13} too small.**
- **If $\sin^2 2\theta_{13}$ not too small then δ_{cp} can be determined from ν running only.**
- **With the longer baseline = larger mass effects = better resolution of mass heirarchy and easier extraction of δ_{cp}.**
- **Sensitivity to new physics and further improvements in δ_{cp} measurement can then be achieved with $\bar{\nu}$ running.**