Long Baseline Beam Studies

Homestake DUSEL meeting, 4/24/08

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Beam Design Requirements

The design specifications of conventional neutrino beams based at the Fermilab MI are driven by the physics of $\nu_\mu \longrightarrow \nu_e$ oscillations:

Requirements:

-Maximal possible neutrino fluxes to encompass the 1st (2.4 GeV at 1300 km) and 2nd (0.8 GeV at 1300km) oscillation nodes. $\Rightarrow$ beam has to be Wide-Band Low-Energy (WBLE).

-For broad-band beams: Minimize the neutral-current feed-down contamination at lower energy, therefore minimizing the flux of neutrinos with energies greater than 1st maxima where there is no sensitivity to the oscillation parameters is highly desirable.

-High purity ν_μ beam with negligible ν_e

FNAL Beam Specs: E & Power

Beam upgrade options at FNAL:

ANU: **Use the *existing* recycler to store protons from the 8 GeV 15 Hz Booster during the MI cycle then inject to MI $\Rightarrow$ 700kW at 120 GeV.**

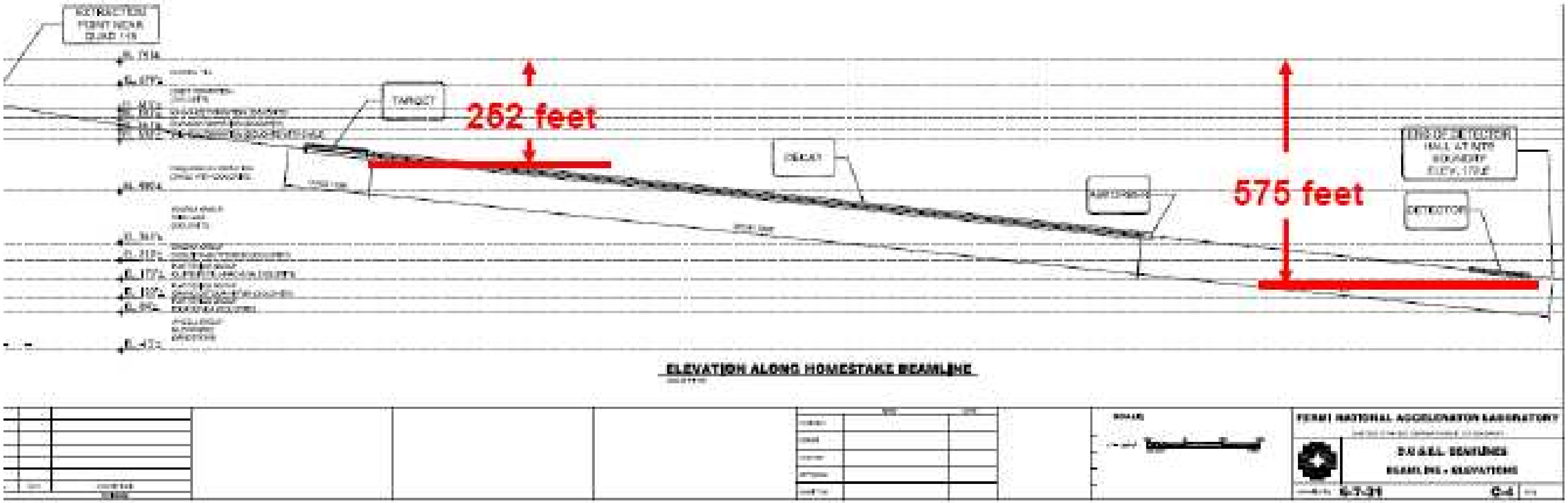
SNuMI: **In addition to recycler, also use the existing anti-proton accumulator to store additional protons during the MI cycle then inject to MI $\longrightarrow$ increases MI intensity up to 6×10^{13} protons (if losses can be controled) $\Rightarrow$ 1.2 MW at 120 GeV.**

Project X: **S.C. Linac replaces 8 GeV Booster, MI upgrades $\Rightarrow$ 2.3MW at 60-120GeV**

ANU/SNuMI max power at 120 GeV. Lower energies = lower power.

Project X $\Rightarrow$ possibility of using lower p energy beams with same beam power.

DUSEL Beamline Siting at FNAL



This elevation view of the Homestake Beamline (-5.84^{o}) is drawn to take the detector to the site boundary at Kirk Road. The maximum decay pipe length available in this configuration is about 627m (compare to NuMI at 675m). The detector hall (and shaft) is about 575 feet deep (compare to MINOS at about 336 feet). This is still in the Galena-Platteville but deep.

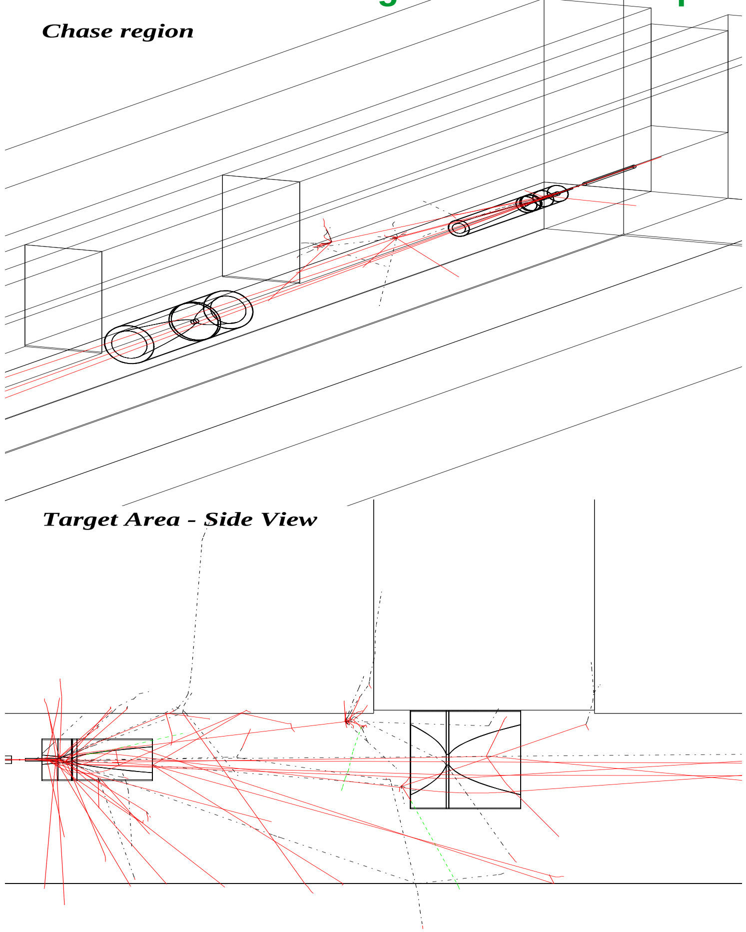
Jan. 25, 2007 Proj. X Phys. Wrkshp - M.I. Nu beams with Project X - J. Hylen 4

Current best guess for maximum decay pipe diameter that can be accomodated in FNAL rock with concrete shielding for a MW beam is 4m.

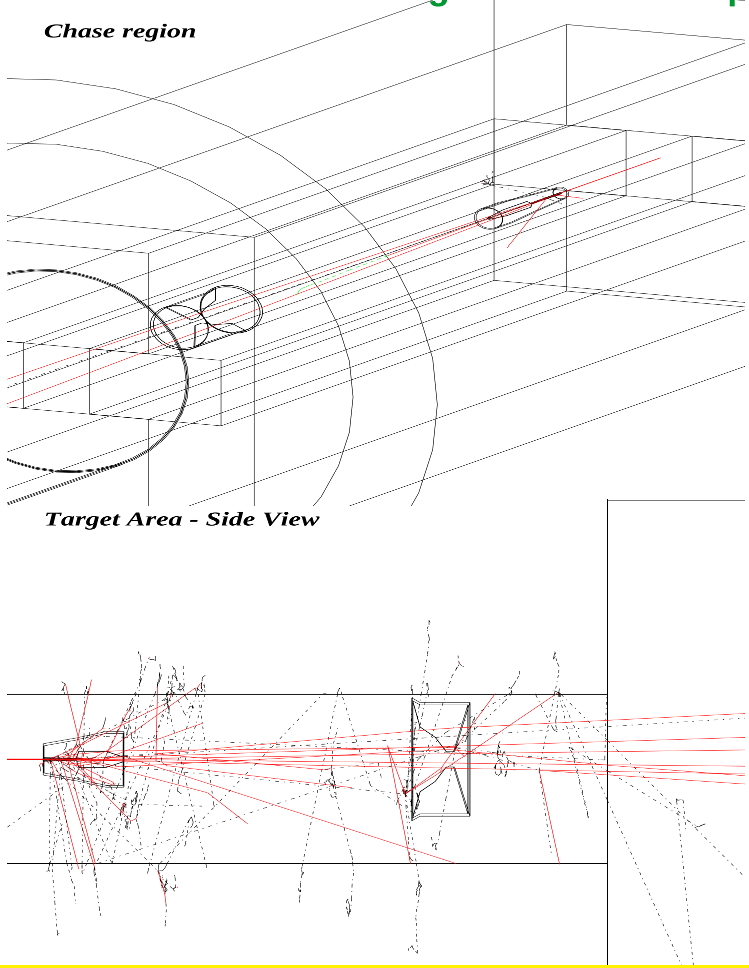
Current targeting system design

Beam to DUSEL: carbon-composite target with a density of 2.1g/cm^3 for a MW class beam + 2 wide-band horns based on BNL-AGS E734/E889:

NuMI horns/target with 120 GeV p+

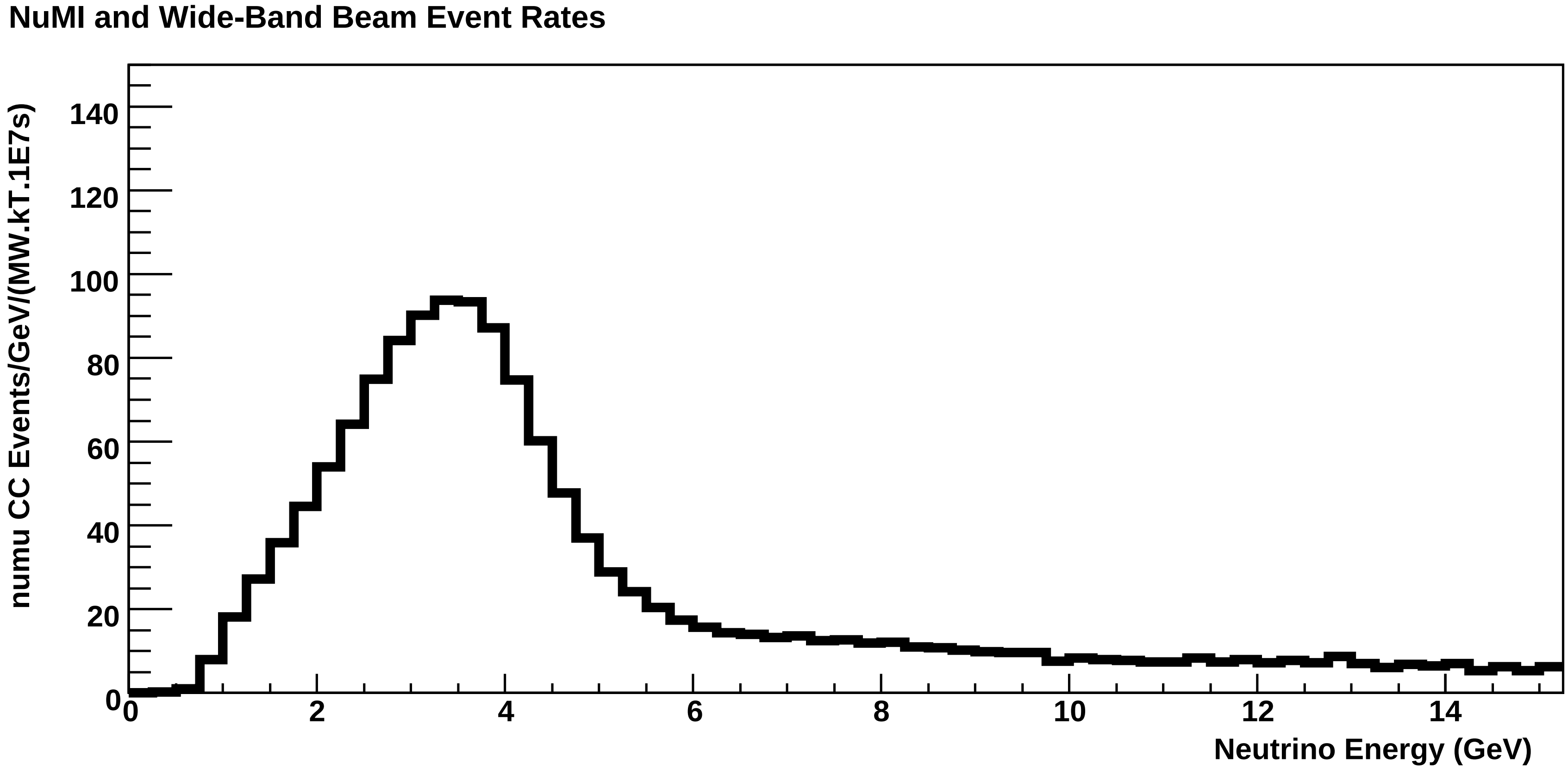


Wide-band horns/target with 120 GeV p+



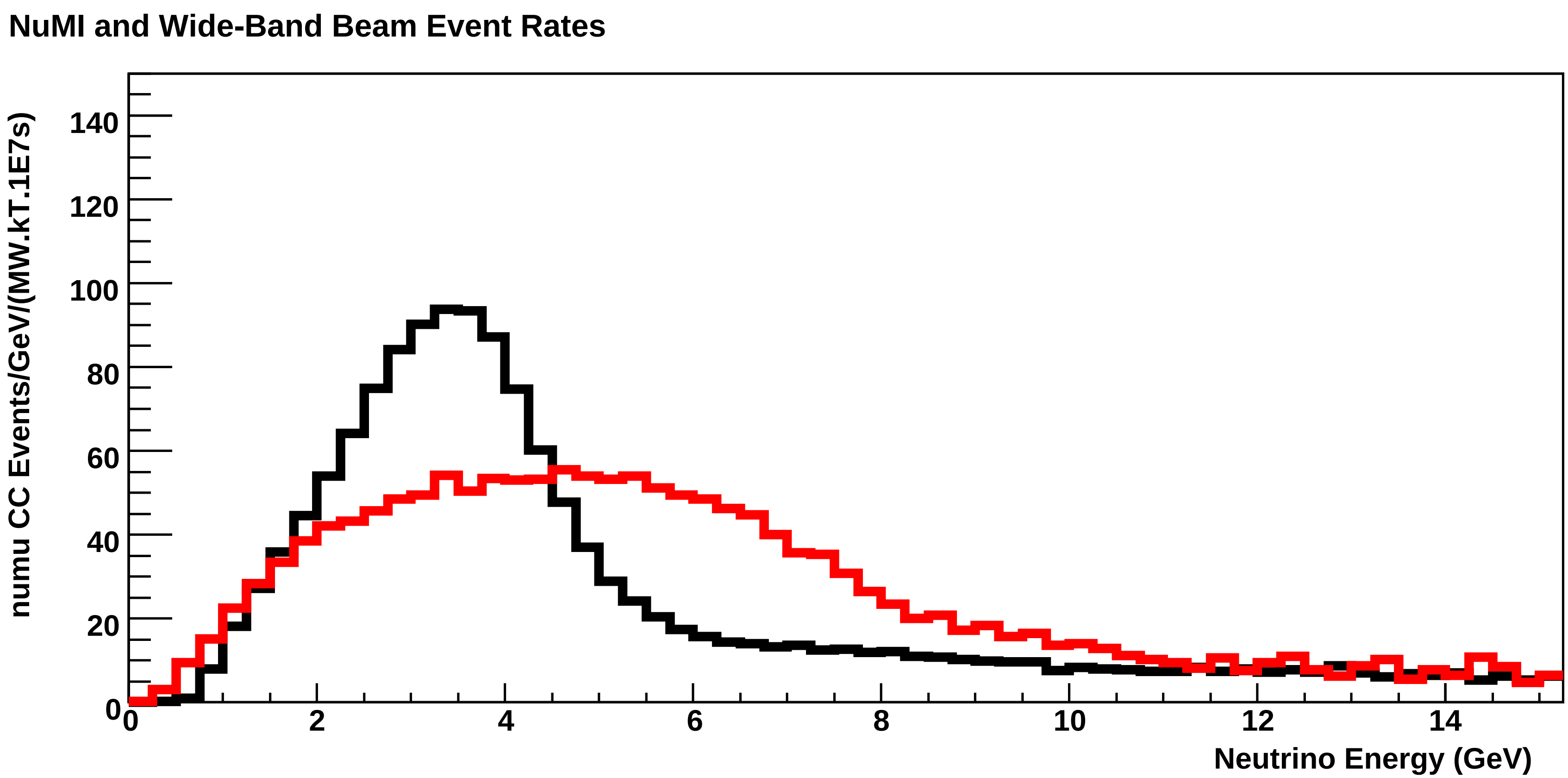
GEANT 3.21 simulation of wide-band horns+decay pipe, with FLUKA ’05 for target hadro-production.

Wide-Band Low-Energy



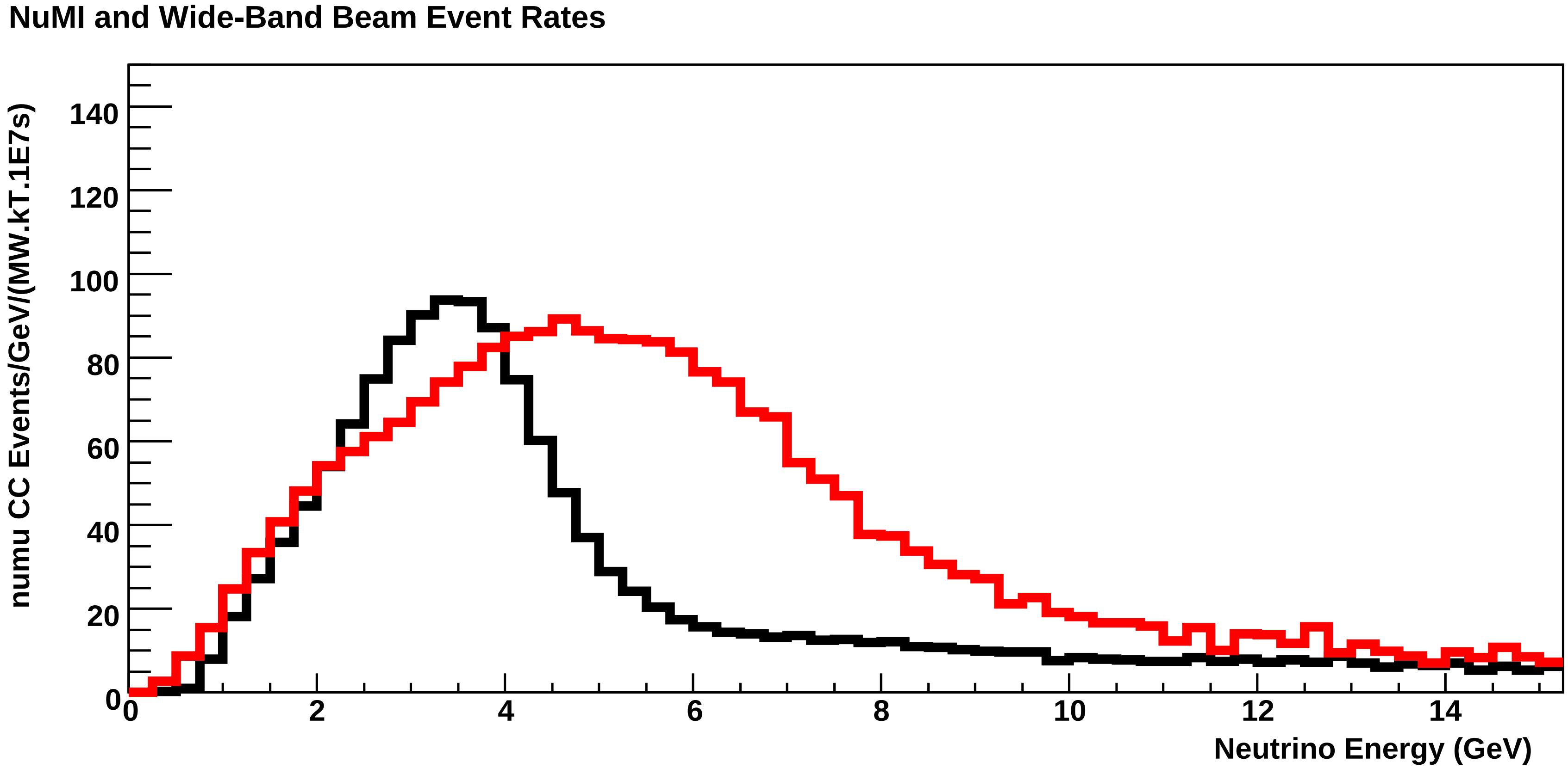
The NuMI LE beam at 735 km, 120 GeV, with 185kA horn current

Wide-Band Low-Energy



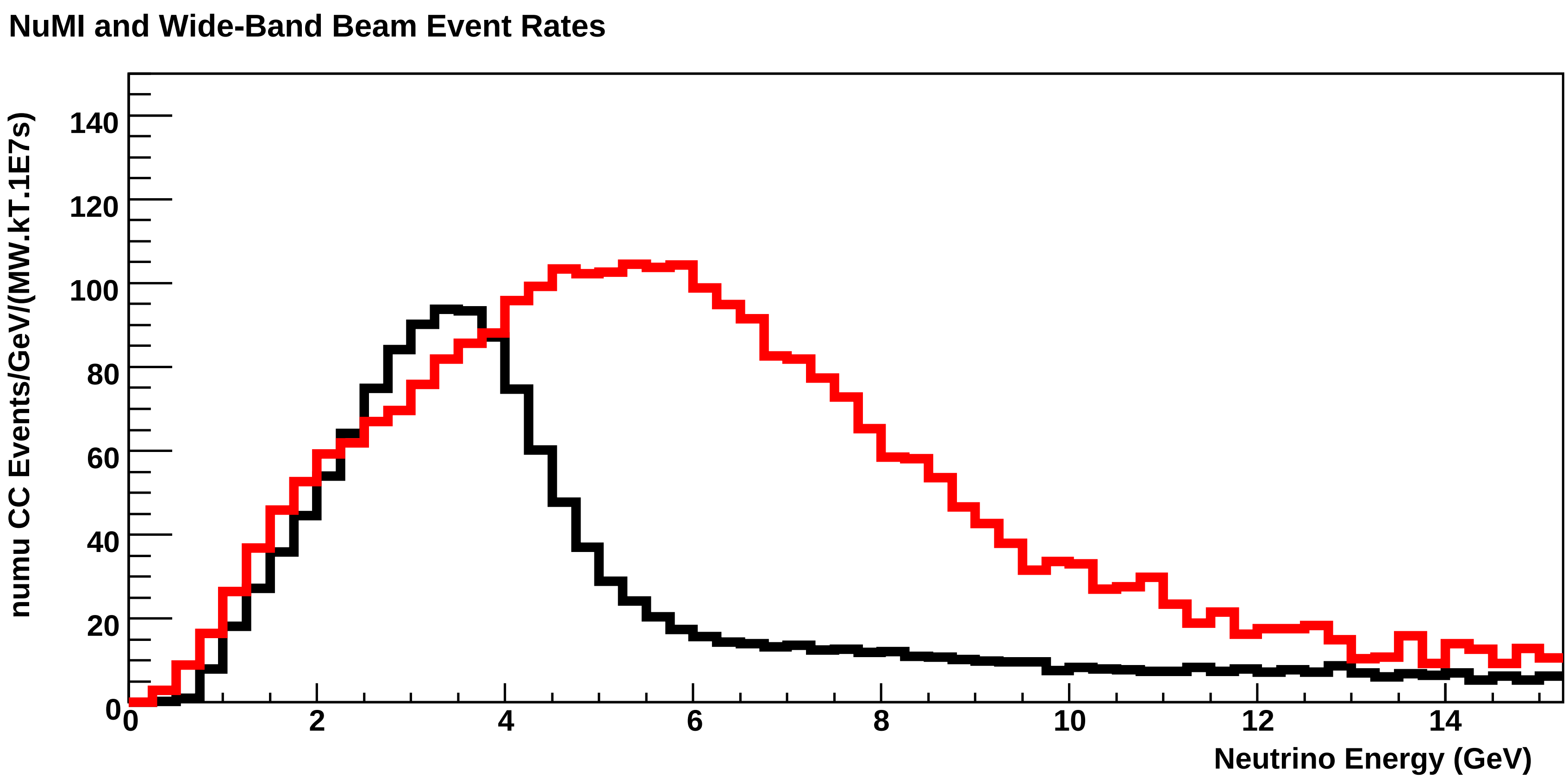
Replace with BNL wide-band target/horns at 120 GeV, 185kA horn current

Wide-Band Low-Energy



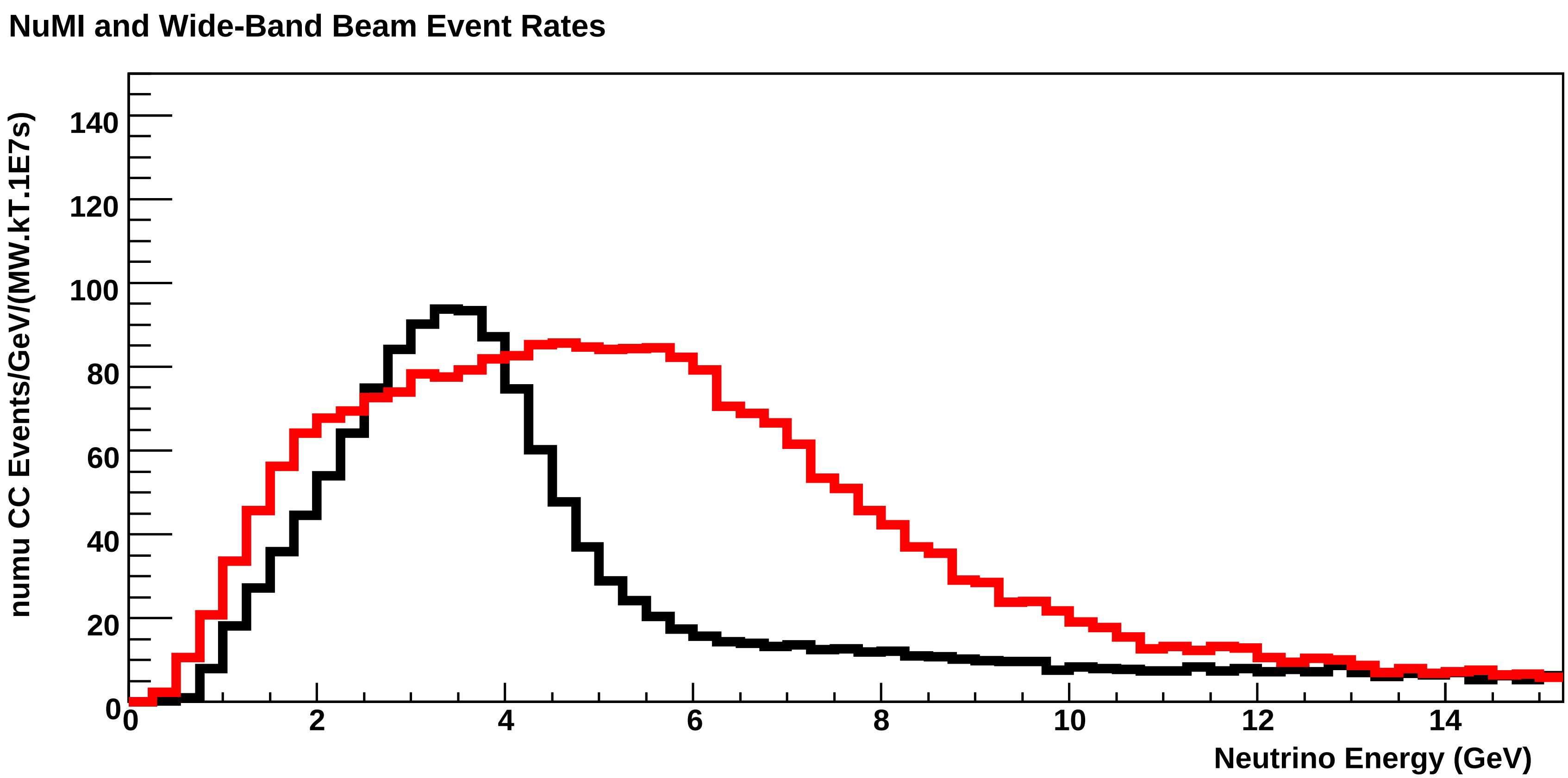
Increase tunnel diameter from 2 to 4m

Wide-Band Low-Energy



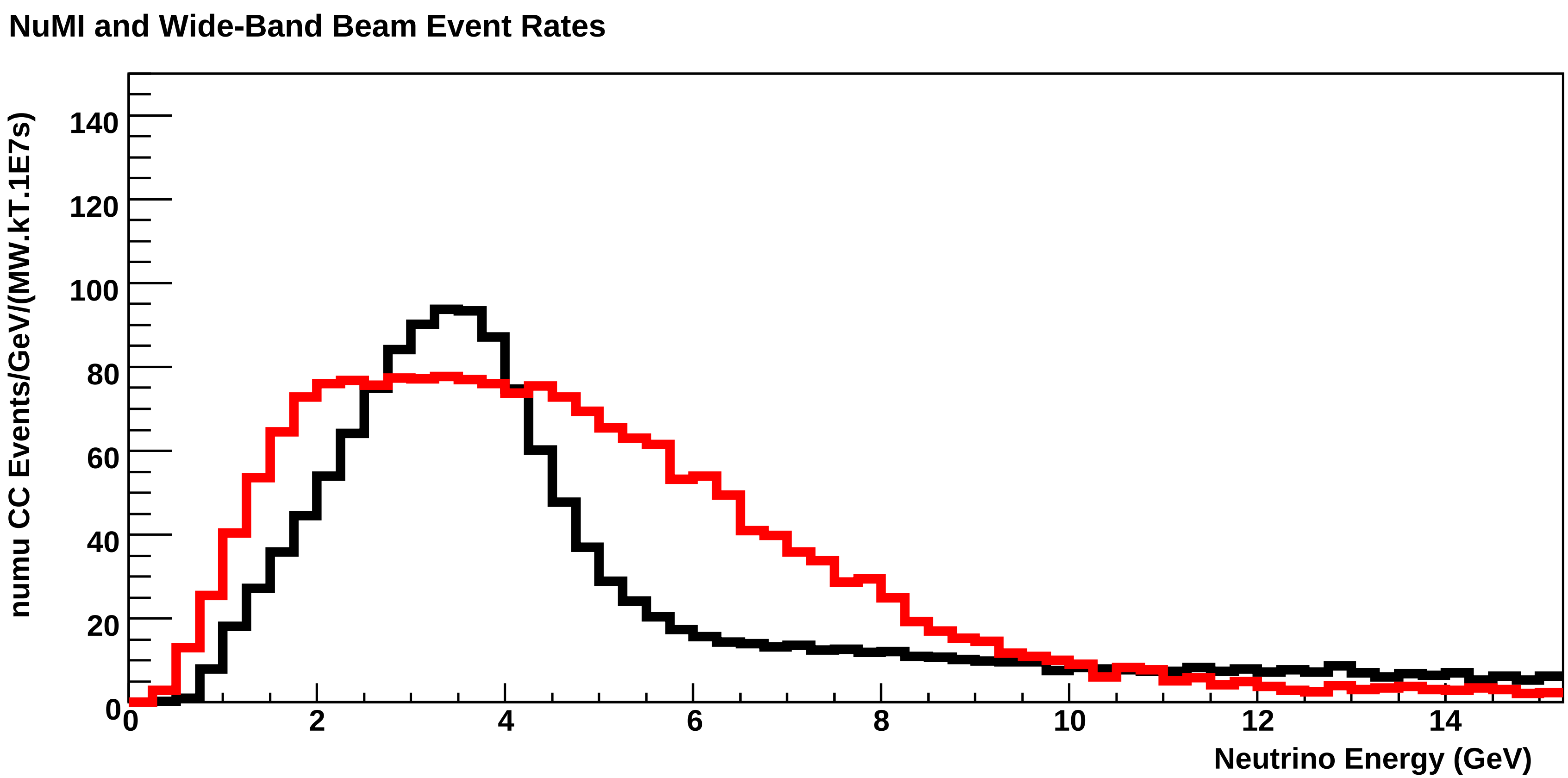
Increase wide-band horn current to 250kA

Wide-Band Low-Energy



Decrease tunnel length from 677 to 380m (smaller target chase)

Wide-Band Low-Energy

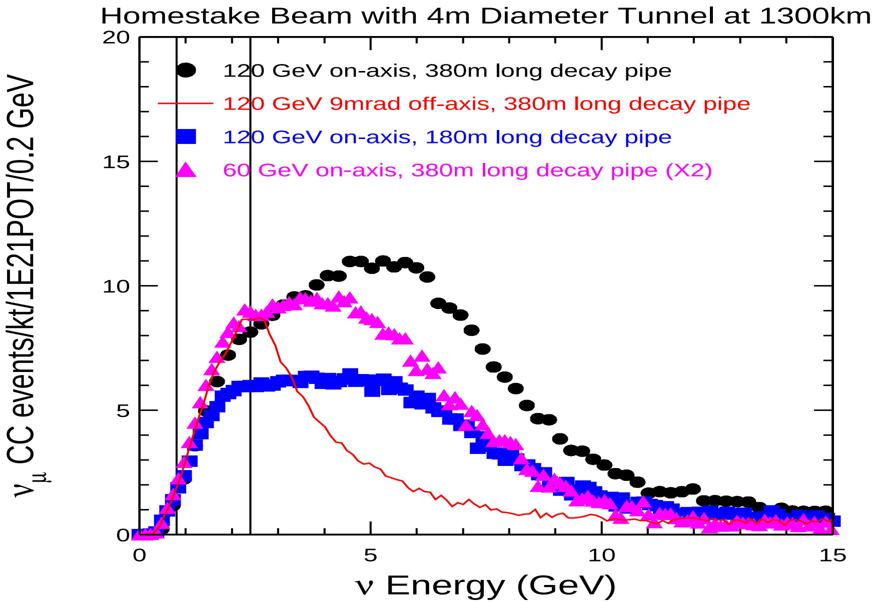


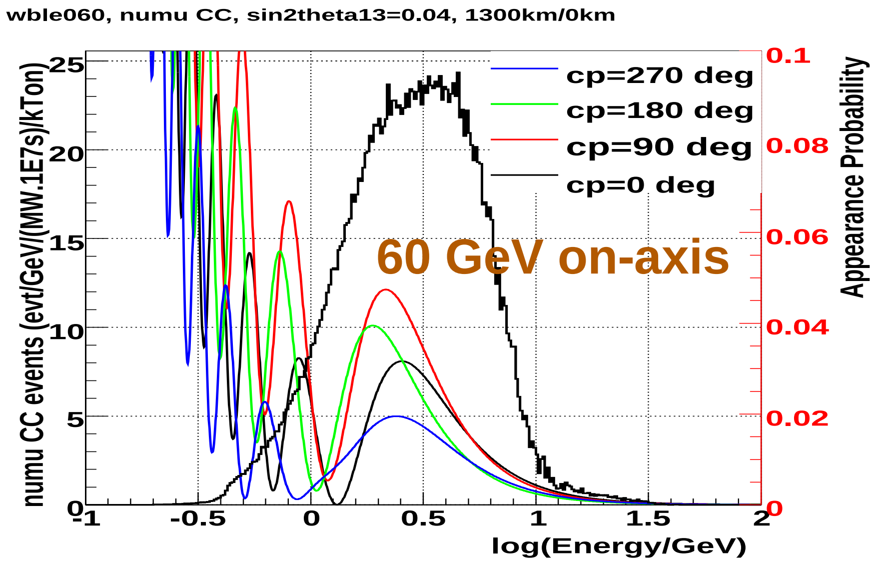
Decrease proton beam energy from 180 to 60 GeV

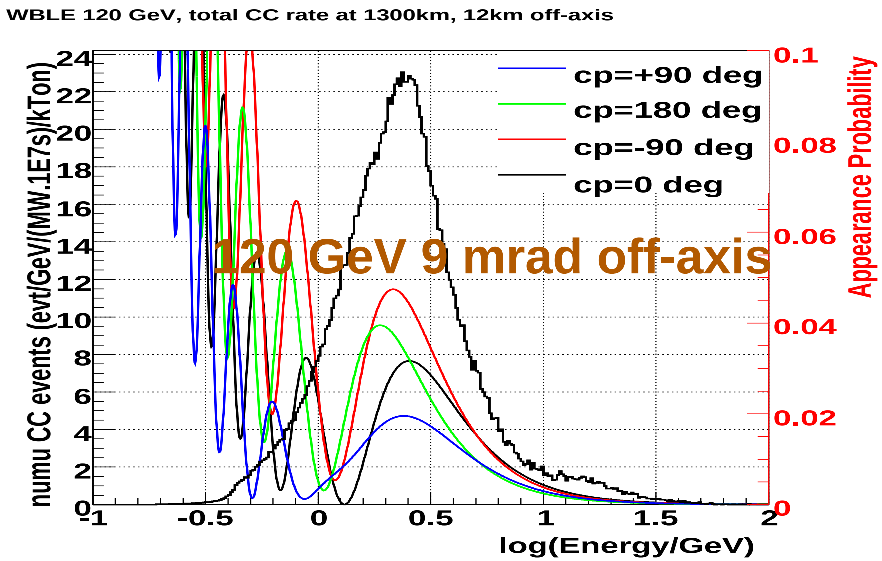
NuMI-Homestake beam options

For 120 GeV p energy of ANU/SNUMI, small off-axis angle can reduce long tails of the 120 GeV beam: $\Rightarrow$

For Project X we can run on-axis with p energy as low as 60 GeV.







A 120 GeV wide-band beam slightly off-axis is a good match to FNAL-Homestake baseline.

NuMI-Homestake Event Rates

$\Delta m^2_{21,31} = 8.6 \times 10^{-5}, 2.5 \times 10^{-3}$ eV^2, $\sin^2 2\theta_{12,23} = 0.86, 1.0$

Unoscillated ν_μ rates at 1300km:

120 GeV on-axis: 20,000 CC/MW.100kT.10^7, 9mrad off-axis: 9,000 CC/MW.100 kT.10^7s

60 GeV on-axis: 15,000 CC/MW.100kT.10^7s

Oscillated rates at 1300km:

		$\nu_\mu \longrightarrow \nu_e$ rate				$\bar{\nu}_\mu \longrightarrow \bar{\nu}_e$ rates			
(sign of Δm^2_{31})	$\sin^2 2\theta_{13}$	δ_{CP} deg.							
		0°	-90°	180°	$+90^\circ$	0°	-90°	180°	$+90^\circ$
WBLE beams at 1300km, per 100kT. MW. 10^7s									
120 GeV, 9 mRad off-axis		Beam ν_e = 47**				Beam $\bar{\nu}_e$ = 17**			
(+/-)	0.0	14	N/A	N/A	N/A	5.0	N/A	N/A	N/A
(+)	0.02	87	134	95	48	20	7.2	15	27
(-)	0.02	39	72	51	19	38	19	33	52
60 GeV, on-axis		Beam ν_e = 61**				Beam $\bar{\nu}_e$ = 22**			
(+)	0.02	138	189	125	74	30	12	19	37
(-)	0.02	57	108	86	34	46	27	48	67

* = 0-3 GeV ** = 0-5 GeV, 1 MW. 10^7s = 5.2×10^{20} POT at 120 GeV, 1yr $= 2 \times 10^7 s$

Water Cerenkov Sensitivities

For $\sin^2 2\theta_{13}$ and the mass hierarchy the sensitivity is given as the minimum value of $\sin^2 2\theta_{13}$ at which the experiment achieves 3σ reach for all δ_{cp}. For CPV the sensitivity is given as the minimum value of $\sin^2 2\theta_{13}$ at which the experiment achieves 3σ reach for 50% δ_{cp}.

Beam	Det size (FIDUCIAL)	Exposure $\nu + \bar{\nu}$	syst. uncert on bkgd	$\sin^2 2\theta_{13}$	sign(Δm^2_{31})	CPV
NuMI/HStake	100kT	700kW 2.6+2.6yrs	5%	0.018	0.044	$>$ 0.1
120 GeV	100kT	1MW 3+3yrs	5%	0.014	0.031	$>$ 0.1
9mrad off-axis	300kT	1MW 3+3yrs	5%	0.008	0.017	0.025
	300kT	1MW 3+3yrs	10%	0.009	0.018	0.036
	300kT	2MW 3+3yrs	5%	0.005	0.012	0.012
	300kT	2MW 3+3yrs	10%	0.006	0.013	0.015
NuMI/HStake	100kT	1MW 3+3yrs	5%	0.012	0.037	$>$0.1
60GeV on-axis	300kT	1MW 3+3yrs	10%	0.008	0.021	0.037
	300kT	2MW 3+3yrs	5%	0.005	0.013	0.015

For WCe 120 GeV off-axis is better than 60 GeV.

To Do

- <u>Targeting system R&D:</u> **Further studies have shown carbon-composite is not rad hard. Lots of work needed to identify appropriate target materials and designs for MW class beams.**
- <u>Focusing system:</u> **Optimization of the BNL horn focusing system design for higher energy beams.**
- <u>Beam plug:</u> **Investigate the use of a movable beam plug to decrease high energy tails.**
- <u>Decay pipe and tunnel design:</u> **Optimization of decay tunnel design (shielding, vacuum/He). Can we increase tunnel diameter to greater than 4m?**
- <u>Alternative focusing systems?</u> **More studies are needed on Palmer solenoid (improve focusing by x2 but focuses all charge hadrons) and plasma focusing systems (too ambitious??).**

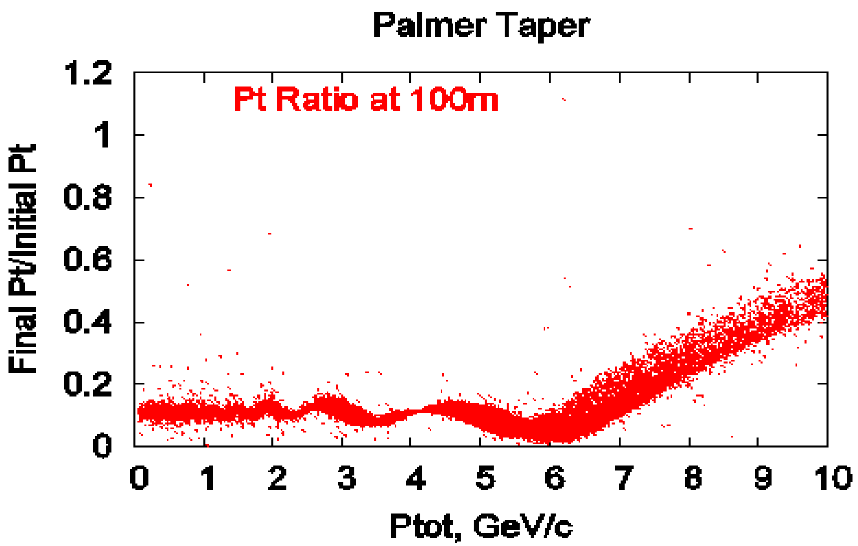
The Beam Plug

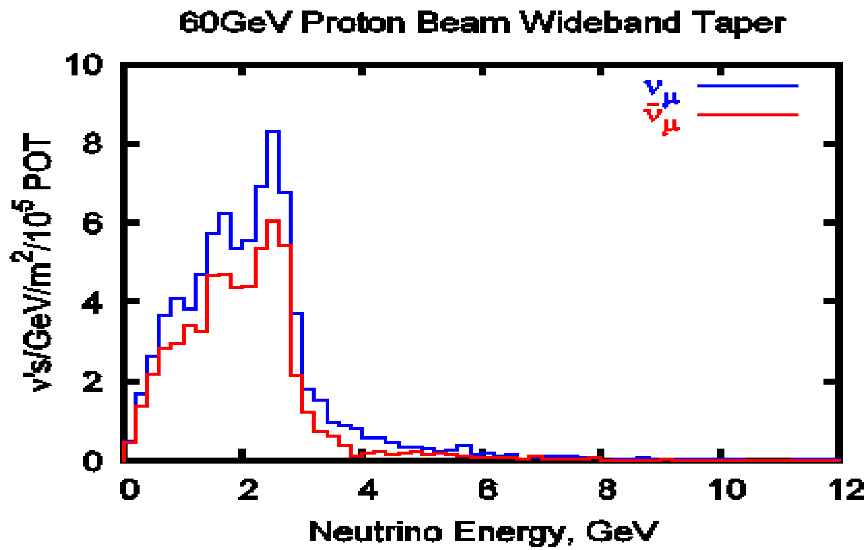
Percent change in number of ν_μ interactions in the far detector with different size plugs placed between NuMI/MINOS horn 1 and horn 2 in the LE tune.

Plug configuration			Energy range (GeV)			
Material	Length	Location	0-3	3-6	6-10	10-50
Graphite	1.5m	4m	-7.6%	-2.5%	-26%	-70%
Graphite	2.5m	3.5m	-10%	-3.4%	-41%	-82%
Copper	1.5m	4.0m	-11%	-4.8%	-38%	-85%

Effect on $\bar{\nu}$ rates??

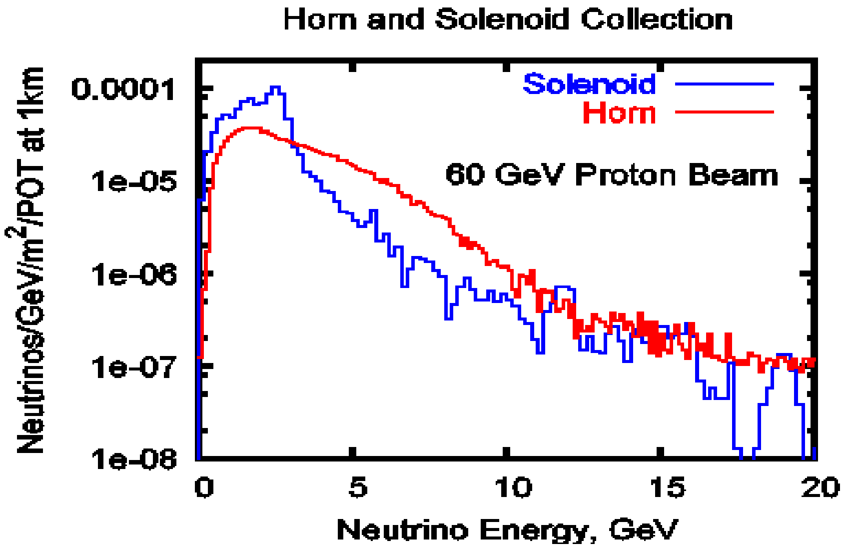
Solenoid vs Horn fluxes





PROs: **Higher flux at lower neutrino energies. Smaller high energy tails $\Rightarrow$ can use higher p-beam energies. DC operation = longer lifetime.**

CONs: **Beam is equal part ν and $\bar{\nu}$ = need magnetized detectors. Expensive.**



BACKUP