Simulation of a Wide-Band Low-Energy Neutrino Beam for Long Baseline Experiments

using GNUMI

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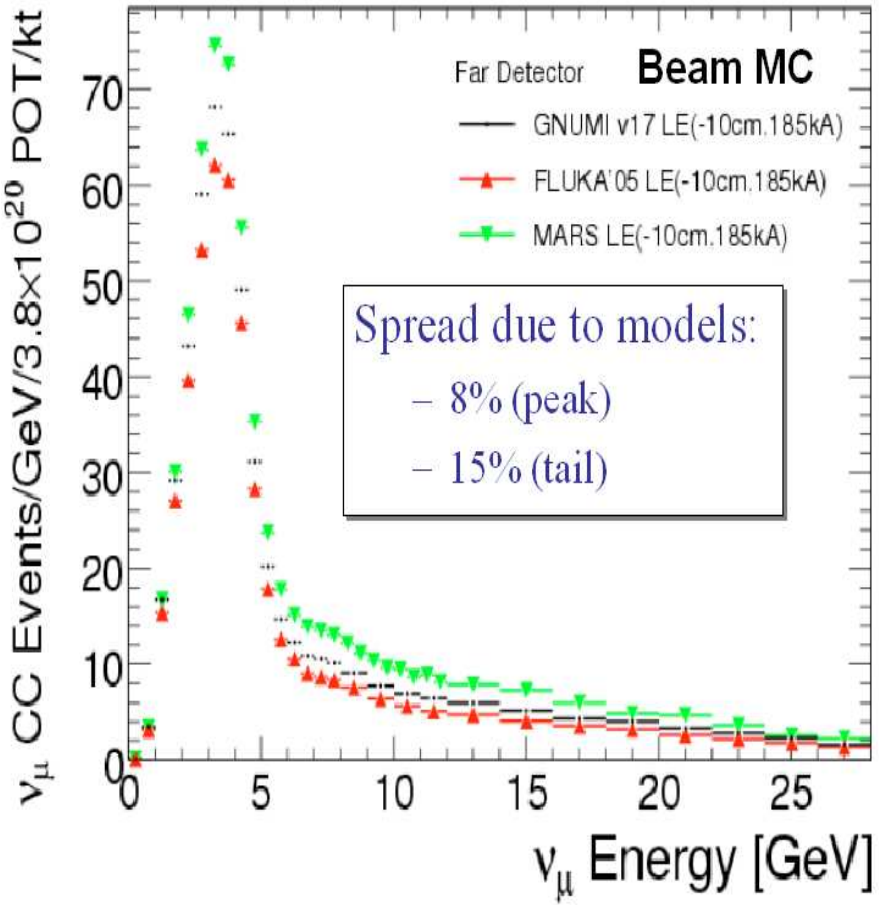
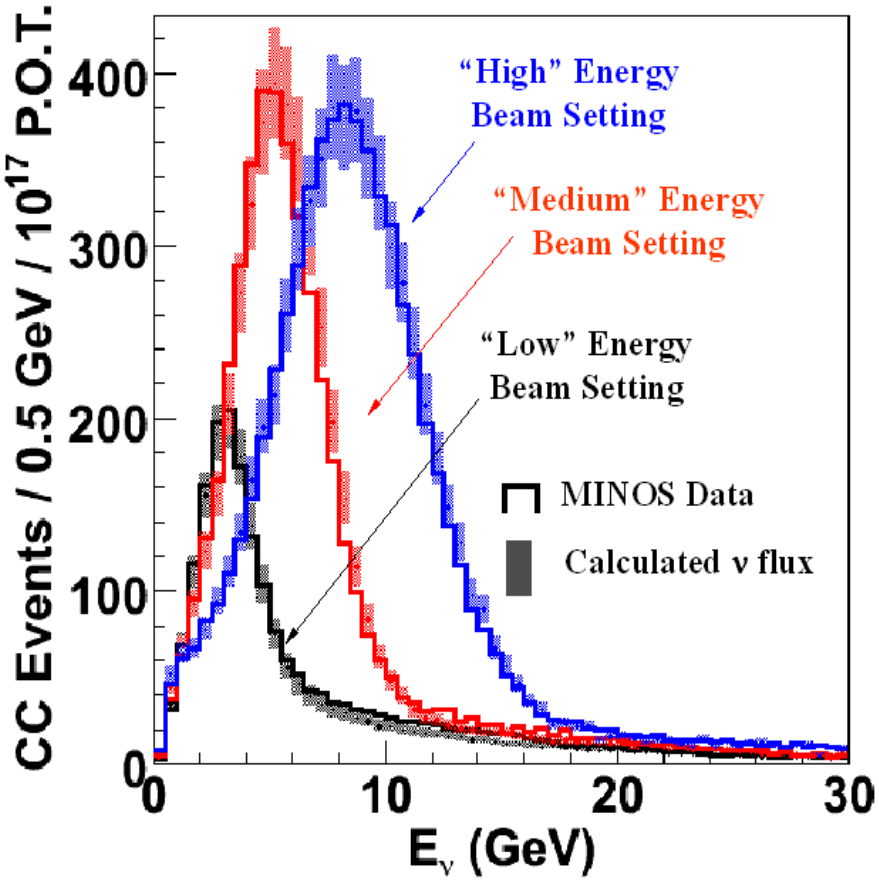
Whats GNUMI?

- Simulation of the NuMI beamline using GEANT v3.21
- The default uses built in GEANT-FLUKA with for hadroproduction from a given target
- Can use independent programs, like FLUKA 05 or MARS, to produce hadron spectra and then use GNUMI to swim hadrons through horns, decay tunnel...etc.



How well does it work?





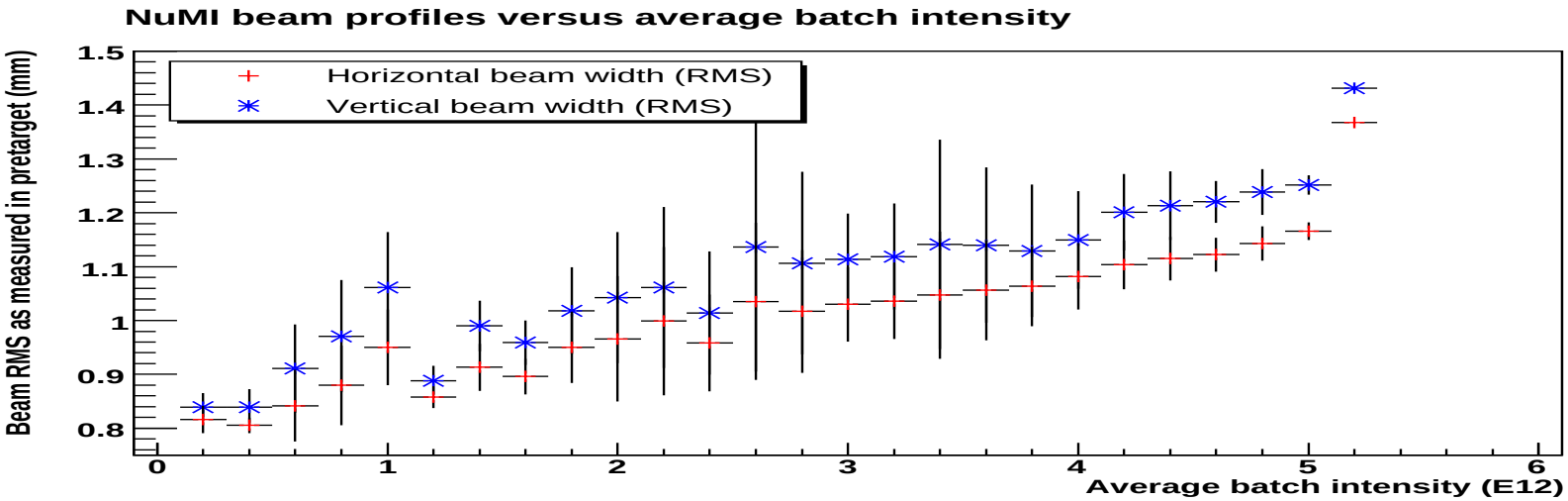
WFLUKA/FLUKA05/MARS

ND spectrum vs FLUKA05, POT normalized



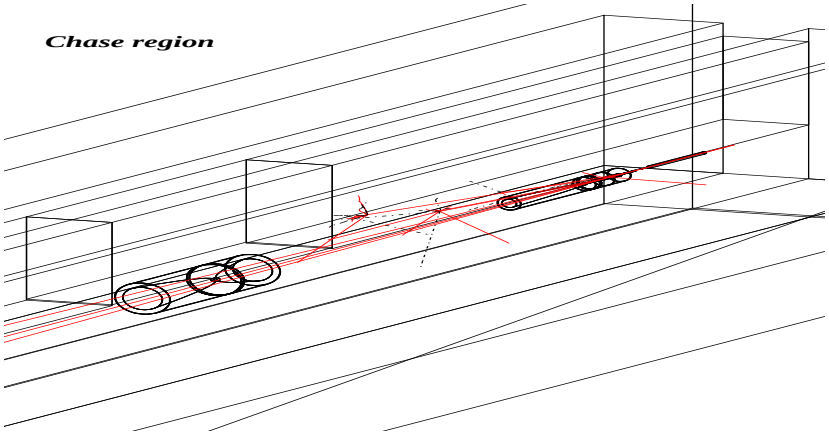
NuMI/WBLE differences

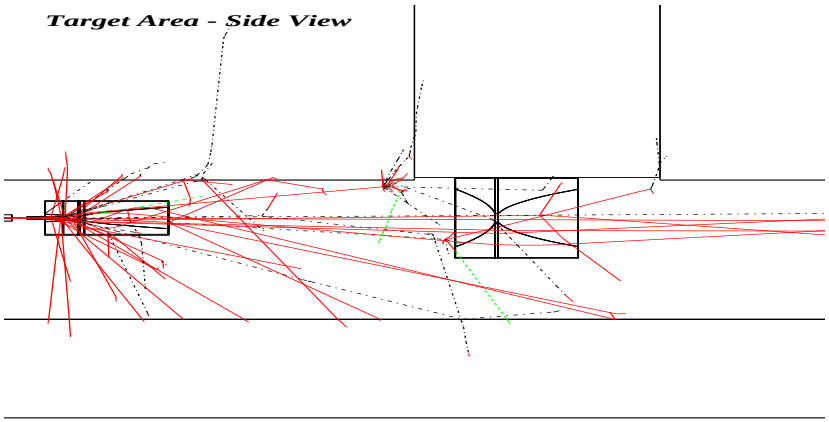
Component	NuMI	WBLE
Target:	rectangle, 6.4mmx20mmx1m	tube, r=6mm, l=0.6m
	graphite	graphite
Horns:	2	2
	2 paraboloids/horn	multi cylinders/horn
	Al	Al
Target shielding	upstream baffle, budal monitor	no baffle, no budal montor
	cement blocks	no blocks
Beam:	$\sigma_x = 1.1$mm, $\sigma_y = 1.25$mm	$\sigma_x = 1.5$mm, $\sigma_y = 1.5$mm



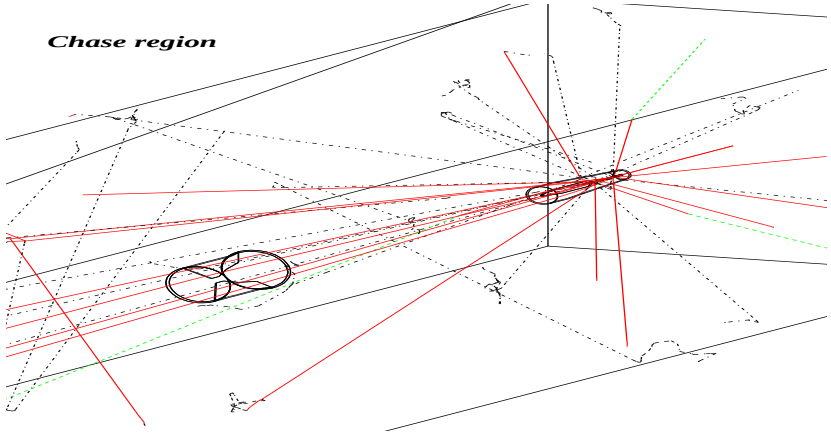
Target region simulation

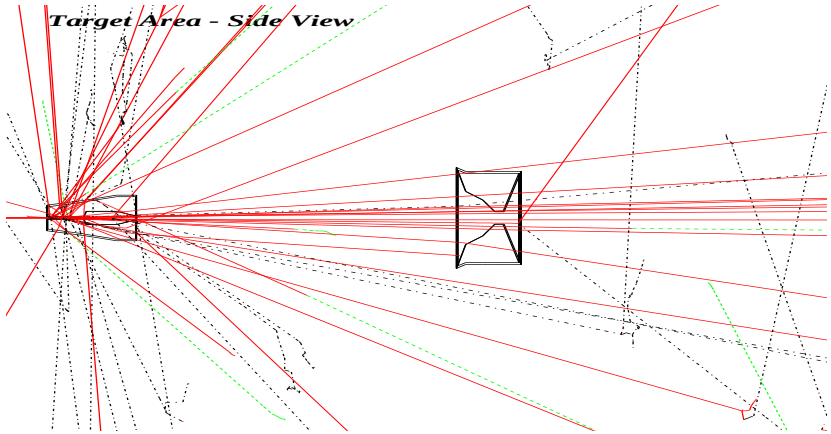
NuMI horns/target with 120 GeV p+





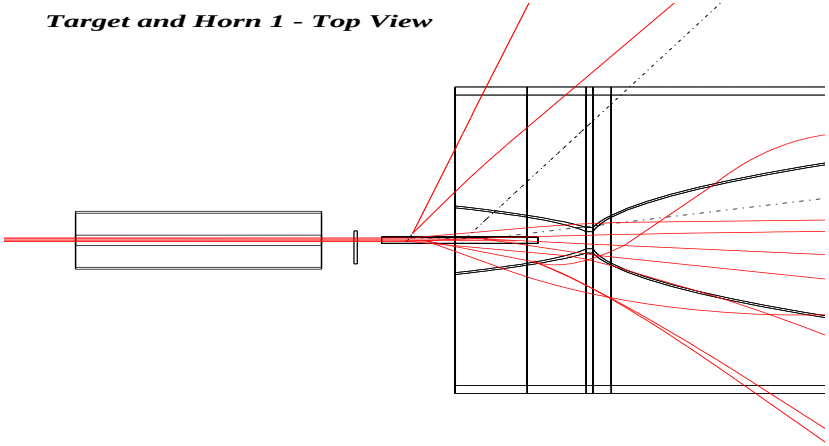
WBLE horns/target with 120 GeV p+

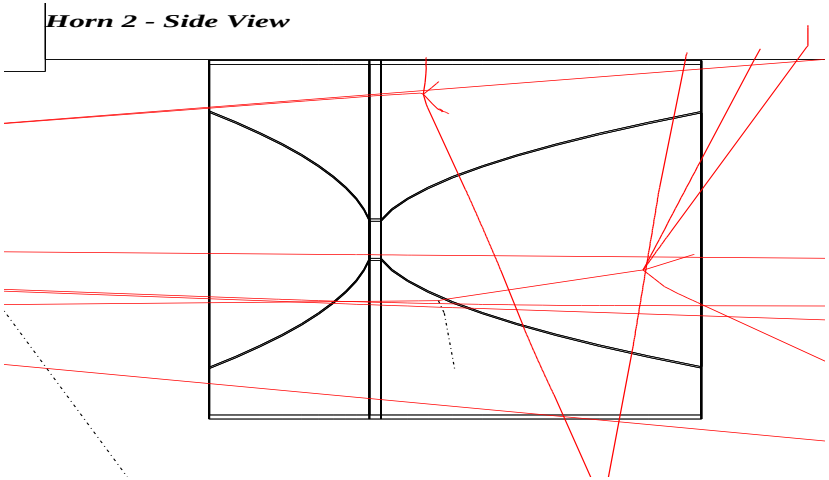




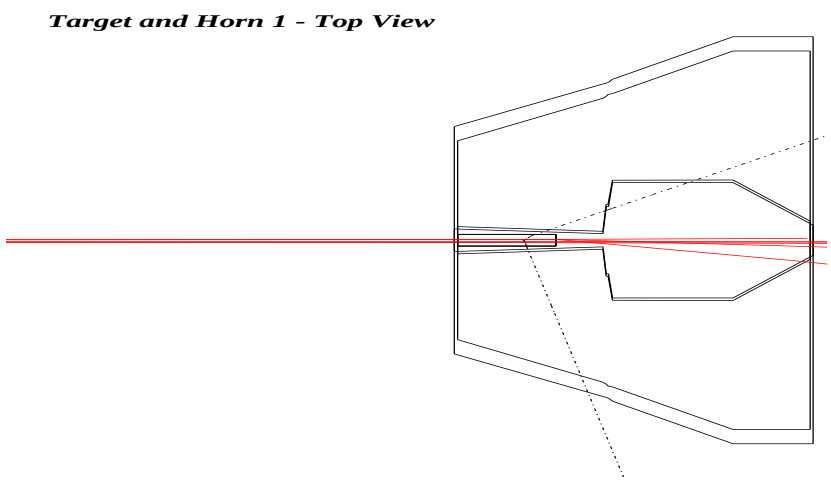
Target/Horn details

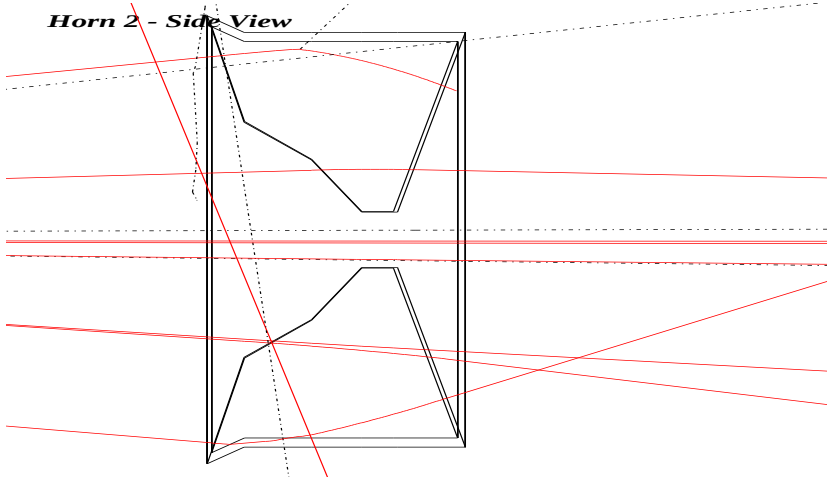
NuMI horns/target with 120 GeV p+





WBLE horns/target with 120 GeV p+

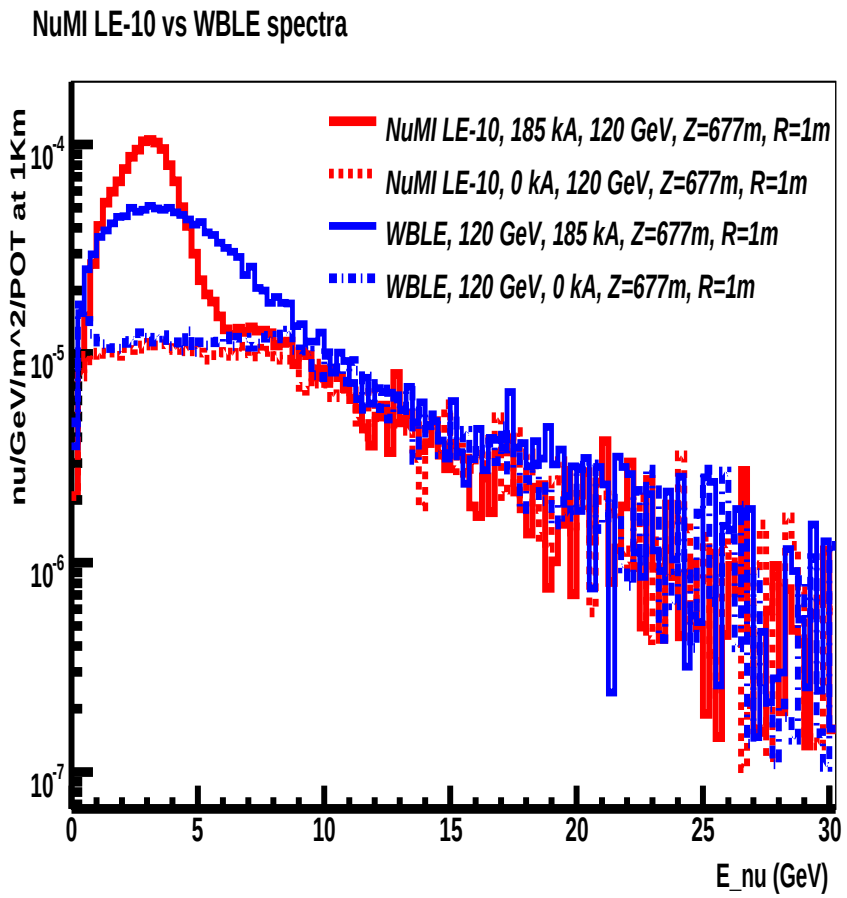




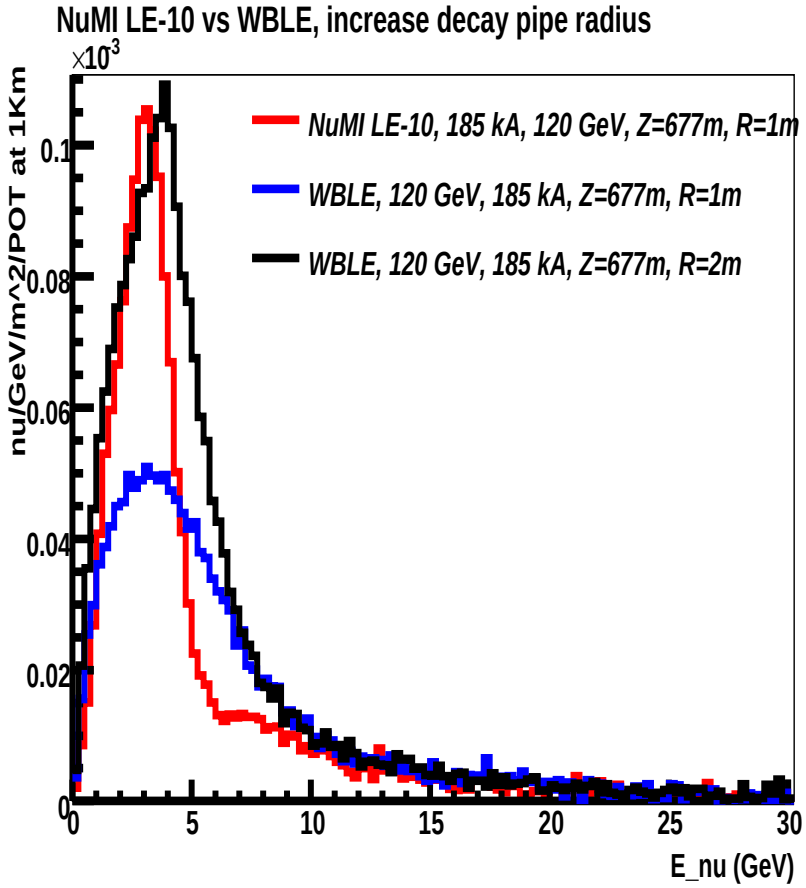
NuMI LE vs WBLE with GNUMI

For these studies, I used the latest version of GNUMI to model the target.

R and Z refer to the geometry of the decay volume which is cylindrical.



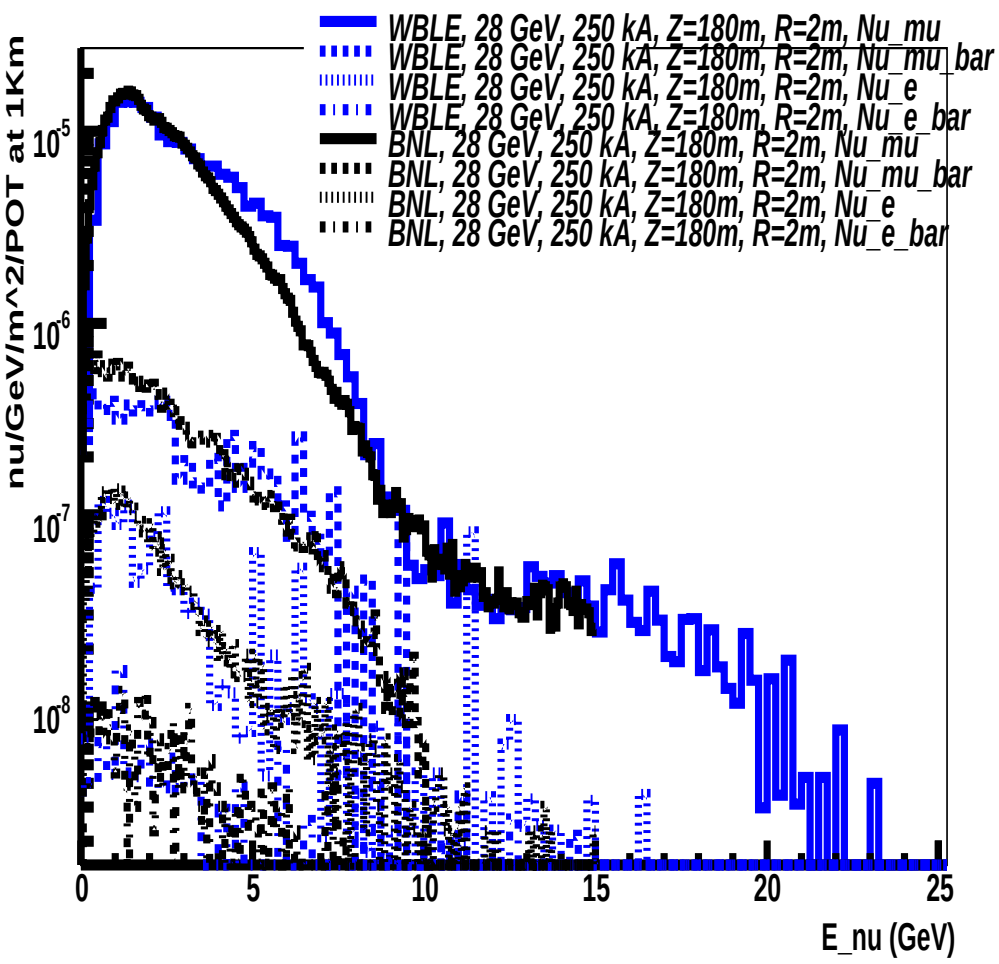
1m radius decay pipe

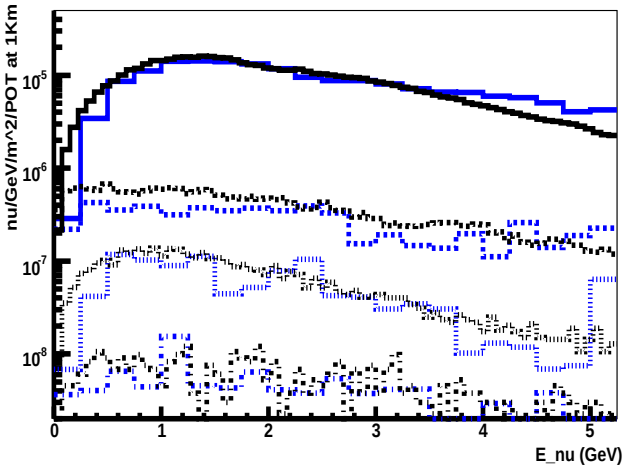


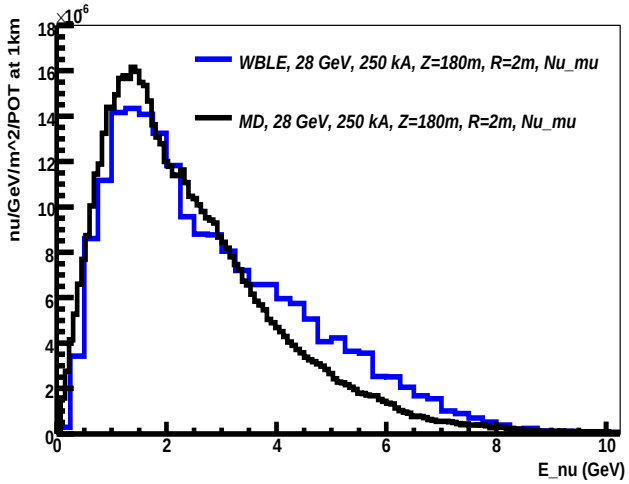
increase to 2m radius

WBLE/BNL-Beam comparison

The current estimates of the physics sensitivities of a wide band on-axis long baseline experiment used a simulation of 28 GeV beam with the same horn design as described previously.

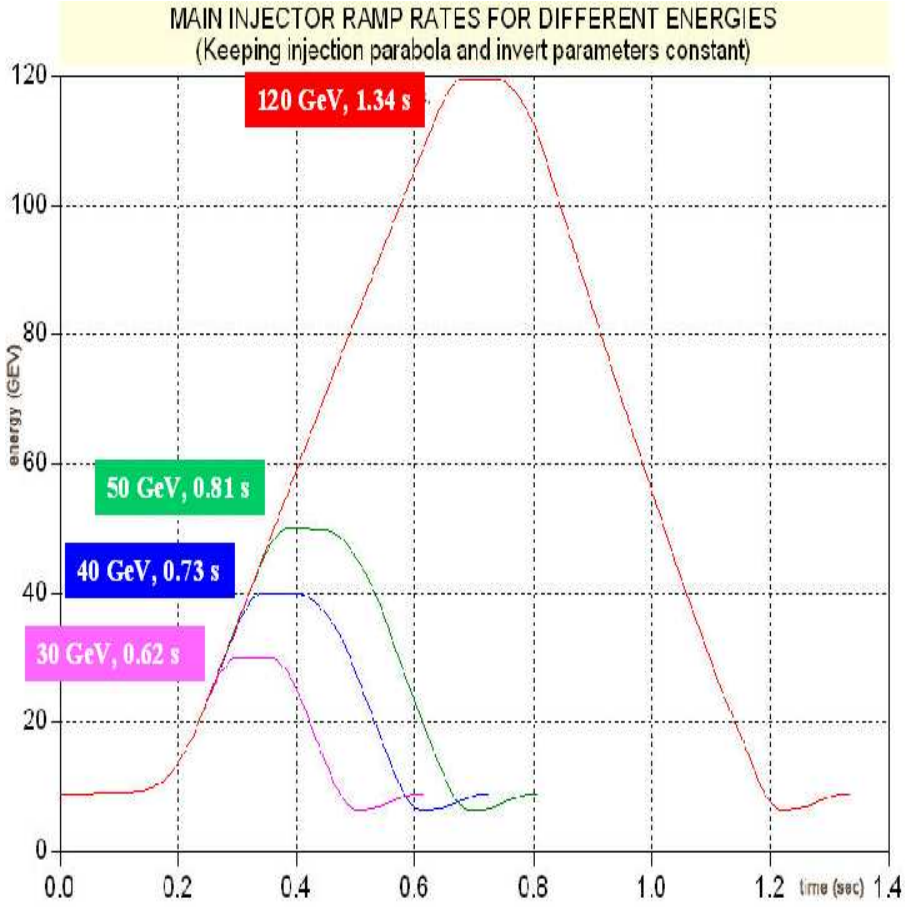


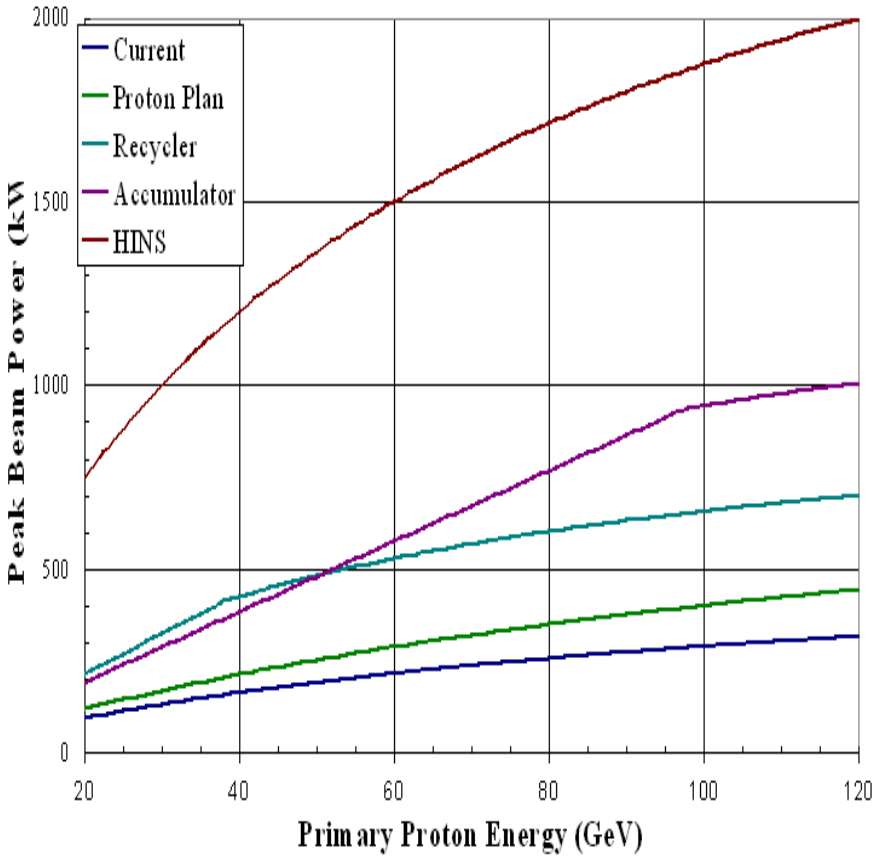




Optimization params: E & Power

Bob Zwaska (FNAL)





Optimization params: Decay Pipe

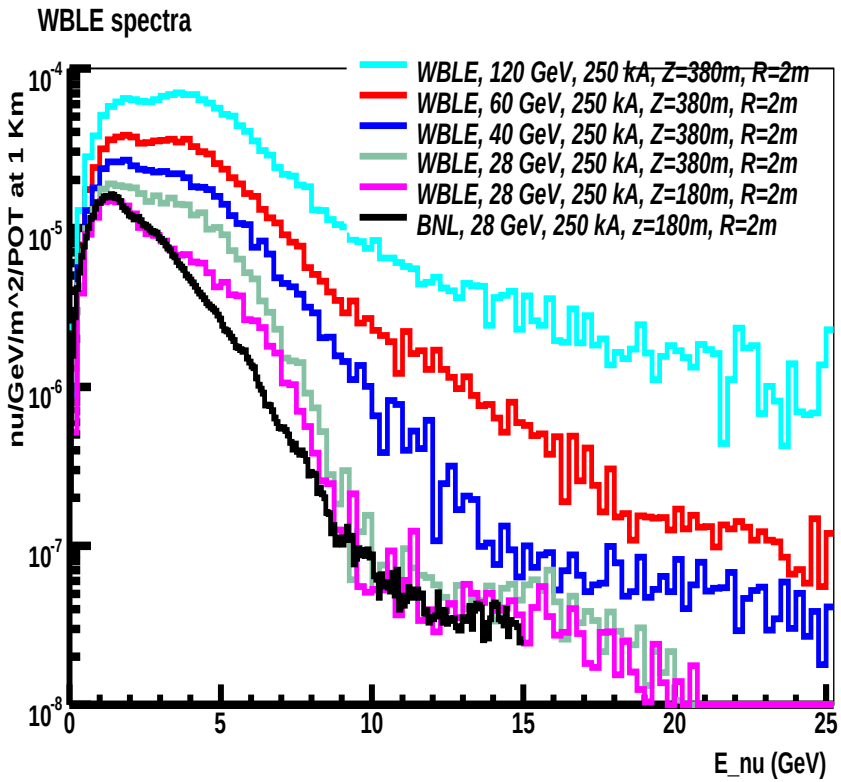
Greg Bock (FNAL)

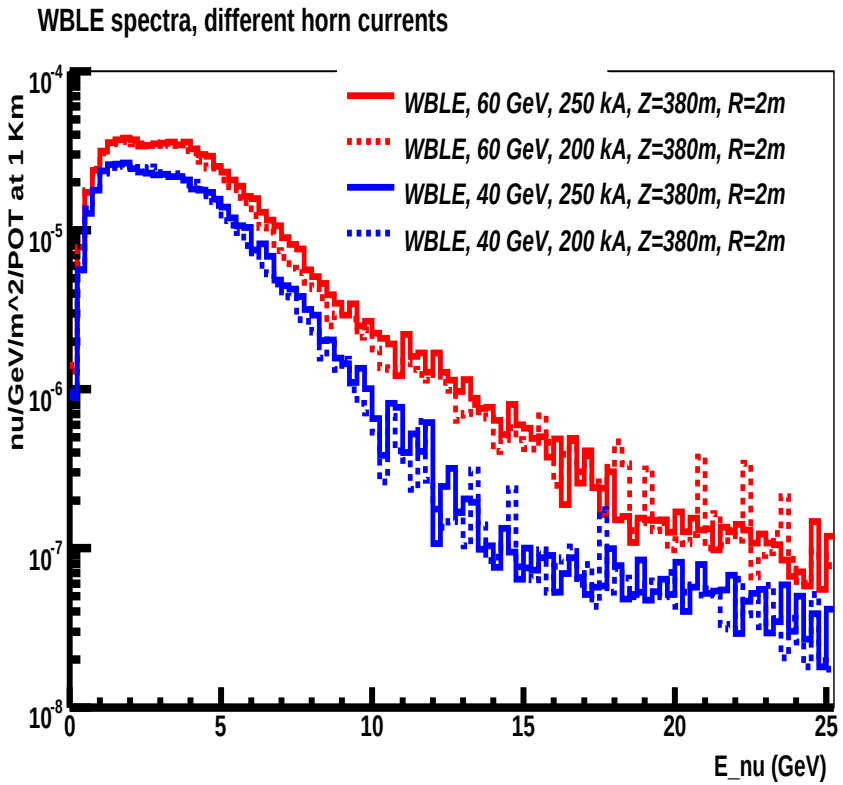


WBLE Optimization 1

Decay pipe radius chosen to be 2m.

Siting restrictions $\Rightarrow$ decay pipe is $\leq$ 400 m in length





Optimization variables

WBLE with 200kA horn current for 40 and 60 GeV, 250kA for 28 GeV.

Beam Scenario	Peak E (Flux at 1km) ν/(GeV.m^2.pot)	E, 50% max flux GeV	E, 10 % max flux GeV	Flux $\frac{<5}{>5}$	Purity peak	Purity Total	ν_μ CC events /(10^{20} pot.kT) (distance)
NuMI LE-10	3.1 GeV	4.3	8	2.7		86% ν_μ	116
Z=677, R=1m	(1×10^{-4})					0.9% ν_e	(735 km)
WBLE 60 GeV	1.9	5.5	8.3	3.2		92% ν_μ	17
Z=380, R=2m	(3.6×10^{-5})					1% ν_e	(1297 km)
WBLE 40 GeV	1.6	5.0	7.8	4.2		94% ν_μ	10
Z=380, R=2m	(2.6×10^{-5})					0.9% ν_e	(1297 km)
WBLE 28 GeV	1.4	5.0	7.0	5.5		95% ν_μ	6
Z=380, R=2m	(1.9×10^{-5})					0.9% ν_e	(1297 km)
WBLE 28 GeV	1.4	3.3	6.8	6.1		96% ν_μ	4
Z=180, R=2m	(1.5×10^{-5})					0.7% ν_e	(1297 km)
BNL 28 GeV	1.4	3.1	5.8	11		95% ν_μ	??
Z=180, R=2m	(1.6×10^{-5})					0.7% ν_e	(1297 km)

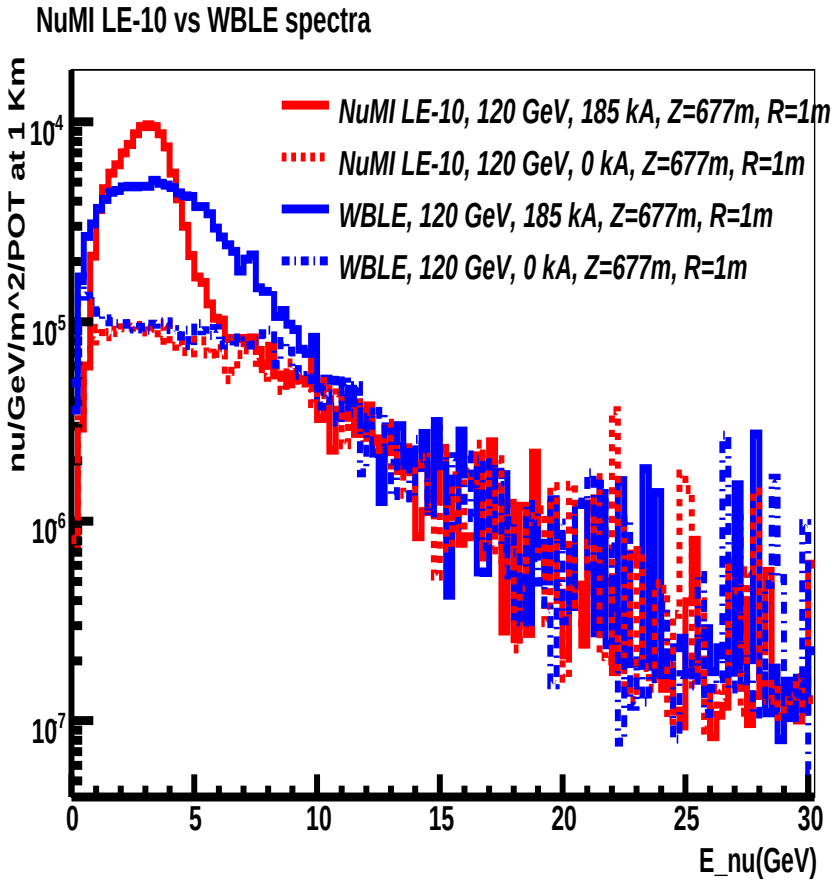
Note 1: 1kT = 1kT Fe = ?? kT H_2O, Note 2: Total POT (10^{20}) = $\frac{\text{beam power (kW)}}{1.6 E_{p+}(\text{GeV})} \times \text{time}(10^7 \text{seconds})$

WBLE studies using FLUKA05 for hadro-production off target + GNUMI for particle transport through the horns and beamline.

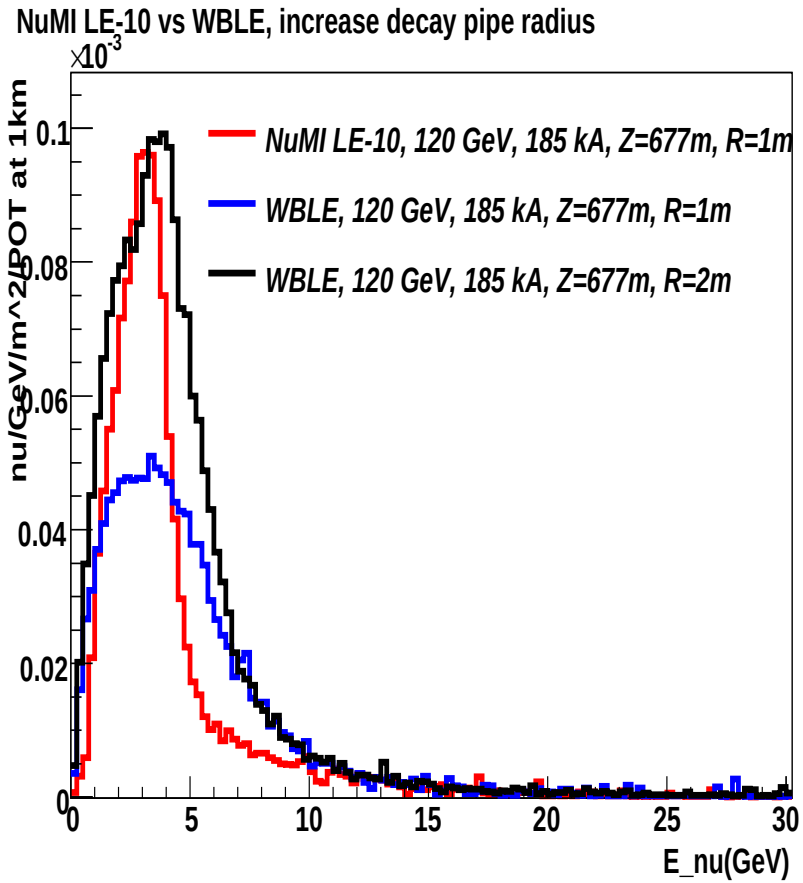


NuMI LE vs WBLE with FLUKA05

R and Z refer to the geometry of the decay volume which is cylindrical.



1m radius decay pipe



increase to 2m radius

WBLE vs BNL-Beam with FLUKA05

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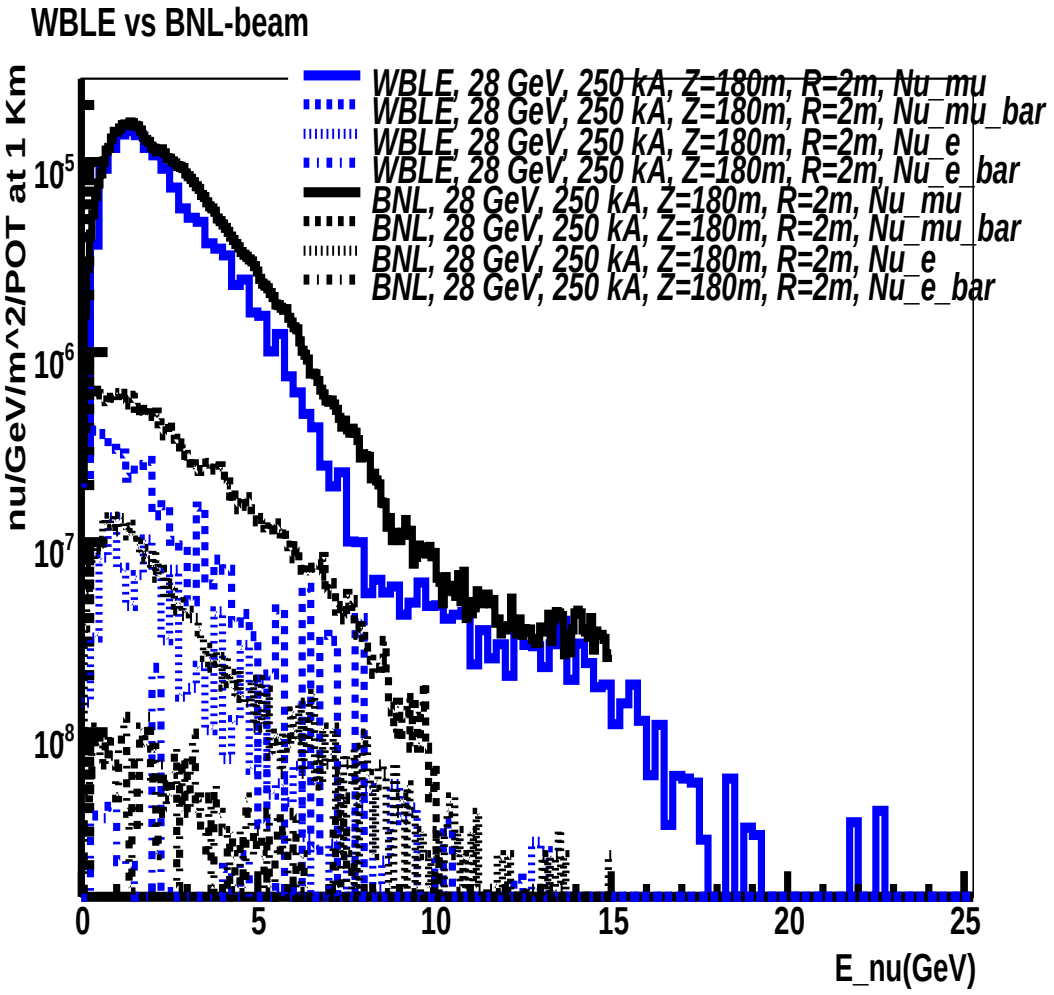
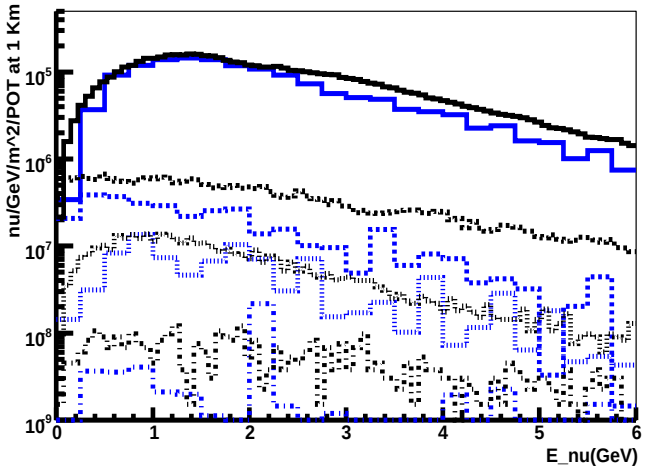
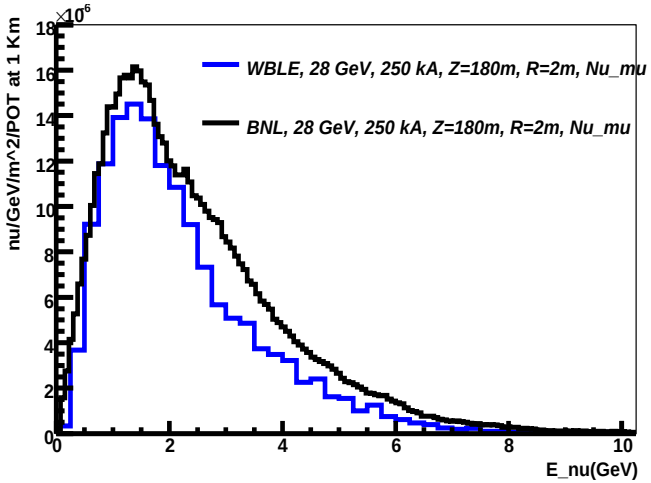


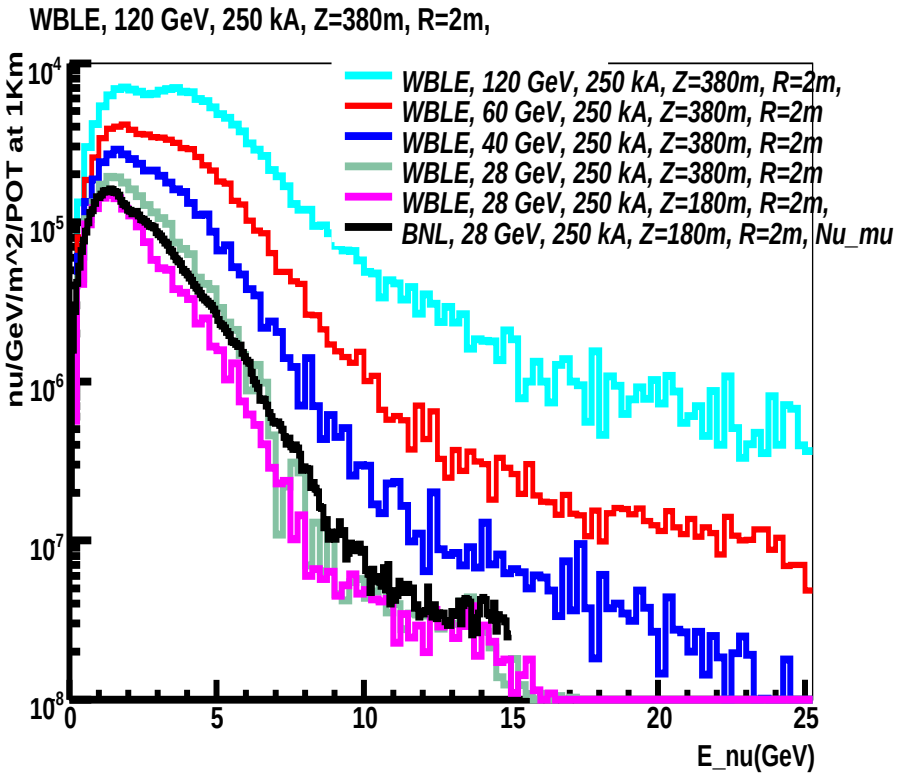


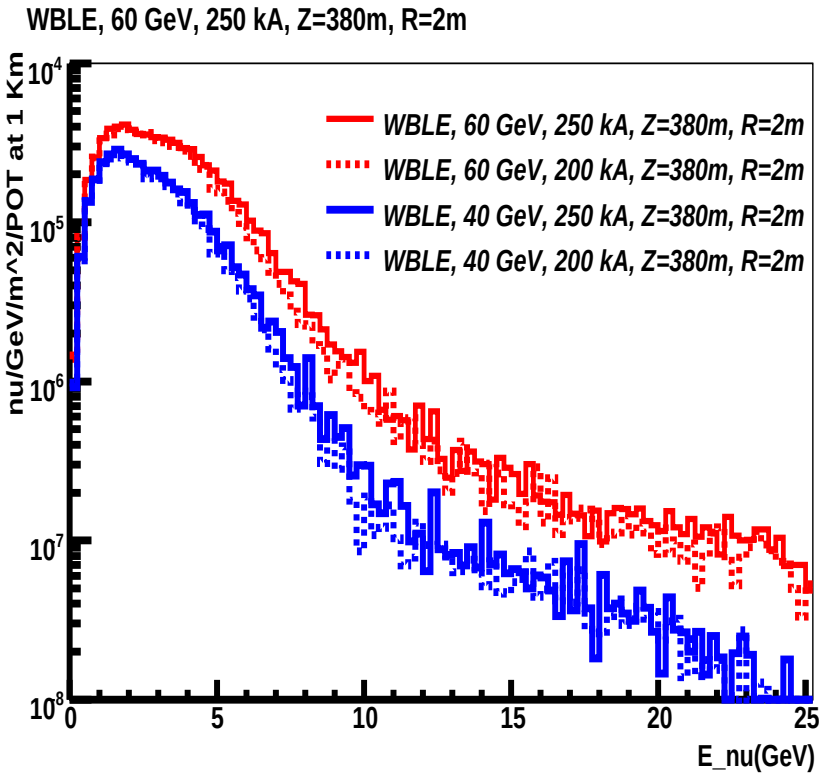


WBLE Optimization - FLUKA05

Decay pipe radius chosen to be 2m.

Siting restrictions $\Rightarrow$ decay pipe is $\leq$ 400 m in length





Optimization variables-FLUKA05

WBLE with 200kA horn current for 40 and 60 GeV, 250kA for 28 GeV.

Beam Scenario	Peak E (Flux at 1km) ν/(GeV.m^2.pot)	E, 50% max flux GeV	E, 10 % max flux GeV	Flux $\frac{\leq 5}{>5}$	Purity peak	Purity Total	ν_μ CC event /(10^{20} pot.k (distance)
NuMI LE-10	3.1 $\pm$ 0.13 GeV	4.1 $\pm$ 0.13	6.1 $\pm$ 0.13	4.1		89% ν_μ	82
Z=677, R=1m	(9.7×10^{-5})					1% ν_e	(735 km)
WBLE 60 GeV	1.6	4.4	7.1	5.0		94% ν_μ	13
Z=380, R=2m	(3.9×10^{-5})					0.9% ν_e	(1297 km)
WBLE 40 GeV	1.6	3.9	6.4	8.3		95% ν_μ	6
Z=380, R=2m	(2.6×10^{-5})					0.9% ν_e	(1297 km)
WBLE 28 GeV*	1.4	3.4	5.6	15		96% ν_μ	3.4
Z=380, R=2m	(1.9×10^{-5})					0.8% ν_e	(1297 km)
WBLE 28 GeV*	1.4	2.6	5.1	17		97% ν_μ	2.4
Z=180, R=2m	(1.5×10^{-5})					0.6% ν_e	(1297 km)
BNL 28 GeV*	1.39 $\pm$ 0.04	3.11	5.81	11		95% ν_μ	~ 4
Z=180, R=2m	(1.6×10^{-5})					0.7% ν_e	(1297 km)

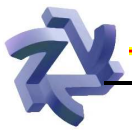


ν_μ CC Rates with FLUKA05

For NuMI (735 km): 1st osc max is at 1.5 GeV, 2nd osc max is at 0.5 GeV

For FNAL-Homestake (1297 km): 1st osc max is at 2.6 GeV, 2nd osc max is at 0.8 GeV

Beam Scenario	Peak E (CC rate) /(GeV.10^{20} pot.kT)	CC rate 1st osc max /(GeV.10^{20} pot.kT)	CC rate 2nd osc max /(GeV.10^{20} pot.kT)	Total CC rate /(10^{20} pot.kT) (distance)
NuMI LE-10 Z=677, R=1m	3.6 GeV (18)	6.1	0.13	82 (735 km)
WBLE 60 GeV Z=380, R=2m	3.9 (2.3)	2.1	0.55	13 (1297 km)
WBLE 40 GeV Z=380, R=2m	2.4 (1.2)	1.2	0.40	6 (1297 km)
WBLE 28 GeV Z=380, R=2m	1.9 (0.85)	0.78	0.30	3.4 (1297 km)
WBLE 28 GeV Z=180, R=2m	2.1 (0.67)	0.56	0.30	2.4 (1297 km)
BNL 28 GeV Z=180, R=2m	()			~ 4 (1297 km)



To Do:

- Optimization of WBLE target/horn design for higher energy beams
- Obtain a better estimate of decay tunnel allowable geometries based on siting and cost. Can we make it wider?.
- Improve optimization critirea for different fluxes
- Use NuMI/MINOS experience to estimate flux uncertainties due to hadroproduction
- Compute oscillation sensitivities for different beams using GloBES with best guess on hadroproduction and beam uncertainties

