Off-Axis and Beam Studies for the NOvA

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Introduction

The event yield for the NuMI (Neutrinos at Main Injector) Off-Axis ν_e Appearance (NOvA) experiment is written as:

$$N \propto (\text{beam power})(t)(\nu \text{ per proton}) \times (M)(\epsilon) \quad (1)$$

where, the number of protons on target is beam power multiplied by the running time (t) of the experiment, M is the mass of the neutrino detector and ϵ is the detector efficiency for finding the events of interest. ν per proton is the efficiency of the NuMI target and horn system to produce useful neutrinos in the NOvA detector. We look systematically at ways which might increase the ν per proton yield of the NuMI target and horn system in 1-3 GeV energy range.

NuMI Target and Horn System

The NOvA uses NuMI beam-line to get an almost pure, narrow-band beam of ν_μ peaked at 2 GeV in energy. The NOvA target has 50 graphite segments with a total length of 120 cm. Downstream of the target, there is a focusing system of magnetic horns with horn1 placed at the origin and horn2 at 19 cm w.r.t the horn1. The positive (negative) horn current of 200 kA focus π^+ (π^-), K^+ (K^-) which will decay to produce a beam of ν_μ ($\bar{\nu_\mu}$) (See fig. 1) and is termed as Forward (Reverse) Horn Current (FHC and RHC) beam configuration [1].

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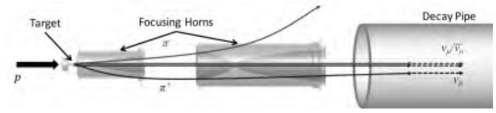

FIG. 1: Figure showing an interaction of protons with the NOvA target in FHC beam configuration.

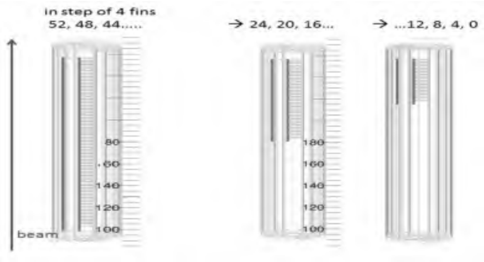

FIG. 2: Geometry showing the standard and shorter NOvA targets.

Monte-Carlo Study

Simulations are performed using G4NuMI [1] to optimize the NuMI target and horn system. It is found that shorter targets than the standard NOvA target (See fig. 2) gives the maximum ν ($\bar{\nu}$) yield in FHC (RHC) beam configuration. The event yields (1-3 GeV energy range) for the various target configurations are shown in fig. 3 which shows that 40 fins target gives the maximum ν yield for the NOvA. Similar gains are seen with RHC configuration [1]

Further, the kinematic distributions of parent pions, that give 1-3 GeV $\nu' s$, which exit the target if placed closer and far from the horn1 (See fig. 4) are studied. Fig. 5 shows that the target part closer to the horn1 is 50% more efficient in producing neutrinos as compare to the target which is far from

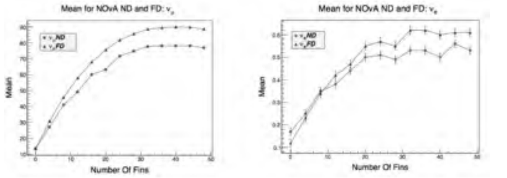

FIG. 3: G4NuMI neutrino flux variation (ν_μ flux (left) and ν_e flux (right) on changing the target fin configuration for NOvA ND (circle) and FD (triangle). The FD numbers are multiplied by 10^6.

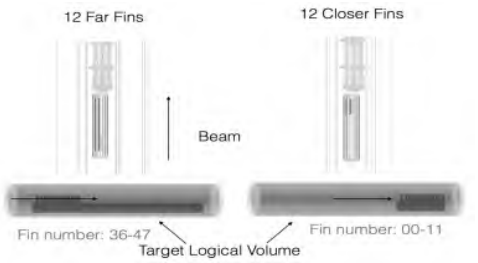

FIG. 4: Geometry for NOvA target with different configurations, closer and far from the horn1.

the horn1.

These studies motivate for a new target for the NOvA (Minimal NOvA target) which is designed using GEANT4 and is simulated using FLUGG [1] that increase the ν event yield by 11%. Minimal NOvA target has 50 graphite segments and is a composite target design (See fig. 6) where first half is the standard NOvA target and another half is the new design which is designed in such a way that it

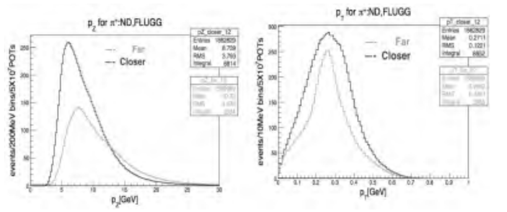

FIG. 5: p_Z (Left) and p_T (Right) distributions of the parent pions for target with two different target configurations.

can go inside the horn1 [1]. Fig. 7 shows the event yield spectra comparison between the standard and Minimal NOvA target designs (graphite and Be fins target in left and right respectively).

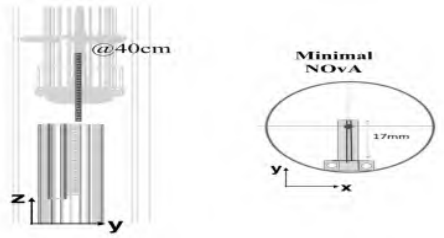

FIG. 6: A new target design (Minimal NOvA target) shown in YZ and XZ view.

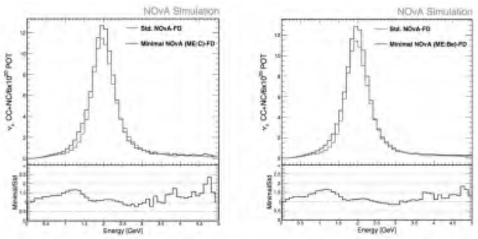

FIG. 7: FLUGG event yield comparison for the standard and Minimal NOvA target design with different target materials.

TABLE I: The event numbers in 1-3 GeV range for the standard and Minimal NOvA targets.

NOvA Target	FD ν_μ	FD (Bkg)	FD ($\bar{\nu}_\mu$)	FD (Bkg)
Std.	91.4	2.2	34.70	4.1
Minimal [C]	101.8	2.6	38.8	4.7
Minimal [Be]	103.3	2.5	40.4	4.4

Acknowledgments

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References

[1] D. Kalra et al., NOvA Off-Axis Beam Studies, NOVA-doc-16233 (2018).