1 Event rates

The proposed prototype will collect a large number of neutrino interactions if a neutrino beam will be built in the North Area.

These interactions will be used to measure neutrino cross section on Argon in the GeV region. The lack of a precise knowledge of the neutrino-nucleus interactions at this energy region is one of the main sources of systematic uncertainties in long baseline neutrino oscillation experiments. The measurements of ν_μ cross section still have large uncertainties while no measurements exist of ν_e cross section at this energy.

Future experiments, looking for CP violation in the leptonic sector, aim for systematic uncertainties of the order of (1-2)% and this will only be possible if precise measurements of ν_e and ν_μ cross section will be available.

In this appendix we have computed the expected event rates in the LBNO prototype for two different beams: a conventional neutrino beam (CENF) [?] in which mainly ν_μ are produced by the decay of pions and kaons with a small intrinsic component of ν_e and the NuSTORM beam [?] in which $\bar{\nu}_e$ and ν_μ (ν_e and $\bar{\nu}_\mu$) are produced from the decay of μ^- (μ^+). The event rates are obtained with the GENIE neutrino simulation program [?] in which we simulated the proposed prototype and the two different beam configurations.

1.1 CENF

For the conventional neutrino beam we used the CENF fluxes that are produced by the SPS accelerating protons to 100 GeV/c. To avoid large pile-up the beam is produced off-axis with respect to the detector. The center of the prototype is at a radial distance from the axis of the beam of ~ 9 m.

The detector is rotated by 45 degrees with respect to the beam direction to maximize the sharing on the two readout views of the ionization produced by particles coming from neutrino interactions.

The CENF neutrino fluxes are available for ν_μ and ν_e for different radial bins R_T with R_T going from 0 to 25 meters. An example of the fluxes is shown in Fig. 1.

The neutrino fluxes are used to obtain the event rates with the GENIE neutrino event generator. The geometry of the prototype is simulated and the neutrino cross section for the different materials that compose the detector are computed according to the predefined models included in GENIE.

We computed the event rate for an exposure of 10^{19} POT. We only counted neutrino interactions occurring inside the active area of the prototype corresponding to 300 tons of Liquid Argon.

The number of neutrino interactions inside the active area is shown in Tab. 1 for ν_μ and ν_e. The energy spectrum of the interacting neutrinos is shown in Fig. 2.

This large data sample will allow to perform precise measurements of ν_μ cross sections on Argon in different exclusive channels. As far as the ν_e cross section are concerned, the expected fraction of ν_e interactions inside the active

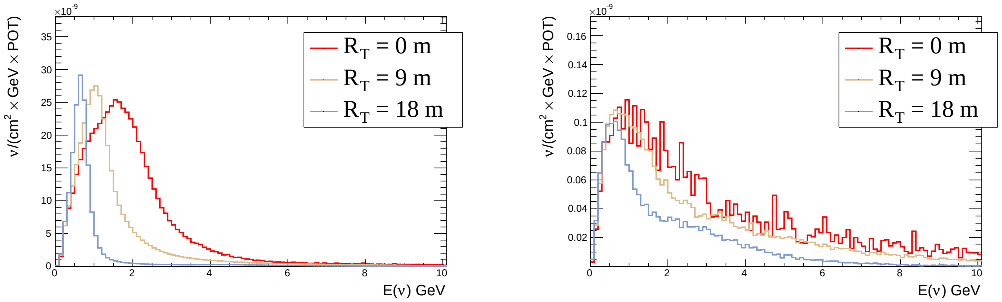

Figure 1: Expected CENF fluxes for ν_μ (left) and ν_e (right) for different off-axis distances.

Int. Type	N_{exp} ν_μ	Fraction (%)	Mean $E(\nu_\mu)$ (GeV)	N_{exp} ν_e	Fraction (%)	Mean $E(\nu_e)$ GeV
Inclusive	559168	100	2.44	9734	100	3.8554
CC	411004	73.5	2.47	7312	75.1	3.87
CCQE	235786	42.2	1.37	2448	25.1	2.44

Table 1: Expected ν_μ and ν_e event rates and mean neutrino energy for different neutrino interaction types, in the Liquid Argon active volume, for an exposure of 10^{19} POT and for $E(\nu) < 10$ GeV.

volume is 1.7% but the large mass of the prototype will allow to select a sizable data sample to measure also ν_e cross section.

For this off-axis configuration the event pile-up is expected to be small: by assuming that in each spill there will be 10^{13} protons, we expect ~ 0.6 neutrino interactions per spill in the active area.

1.2 NuSTORM

We have also computed the expected event rates using neutrinos produced by the decays of stored muons (NuSTORM proposal). In this case we have assumed muon decays in a straight line of 226 m with the end point of the straight line at a distance of 55 m from the center of the detector. The neutrino fluxes have been simulated using a software developed by the NuSTORM collaboration.

We have simulated 10^{16} muon decays that, assuming a 1/1000 ratio between the number of useful muons and the number of protons would roughly correspond to an exposure of 10^{19} POT (the same exposure used for the event rates with the CENF). The spectrum of ν_μ and ν_e produced by muons decays in NuSTORM and arriving to a disk with a 3 m radius at a distance of 50 m from the end of the straight line is shown in Fig. 3.

The expected number of events in the active area of the prototype for the neutrino fluxes of Fig. 3 are shown in Tabs. 2 and 3 for the μ^- and μ^+ decays

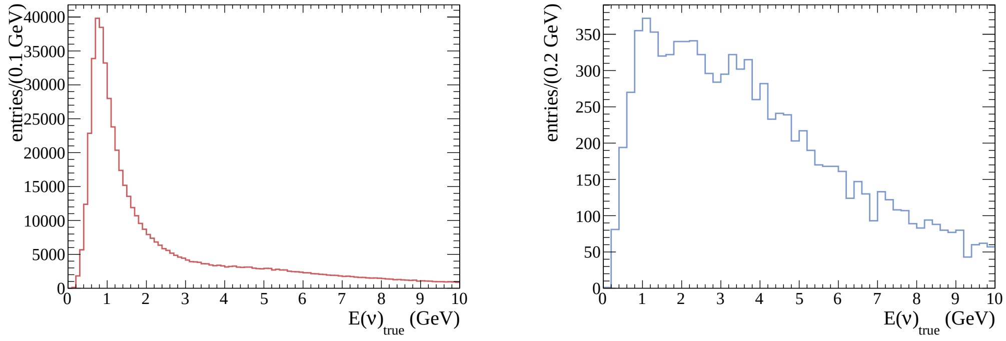

Figure 2: True neutrino energy for the inclusive sample of neutrino interactions occurring inside the prototype active area for 10^{19} POT for ν_μ (left) and ν_e (right) interactions.

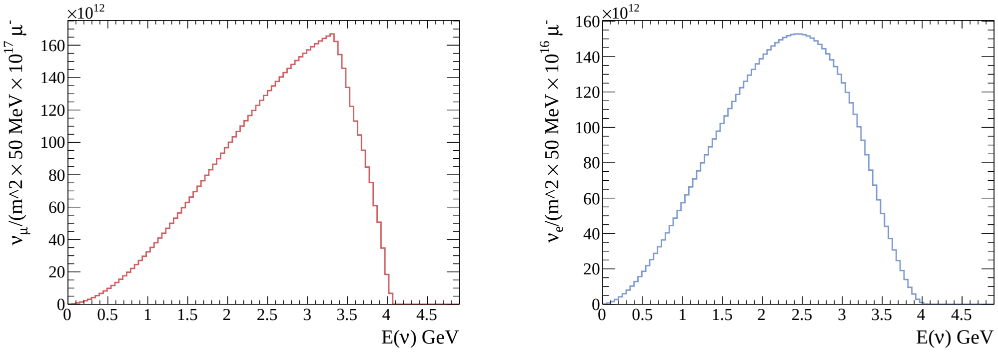

Figure 3: Expected NuSTORM fluxes for ν_μ (left) and $\bar{\nu}_e$ (right) ($\bar{\nu}_\mu$ and ν_e) produced in μ^- (μ^+) decays.

respectively. The energy spectra of the interacting neutrinos for the inclusive samples are shown in Fig. 5 and 4.

The main advantage of the NuSTORM beam with respect to the CENF one will be to produce a large statistical sample of ν_e and $\bar{\nu}_e$ interactions, while in the CENF beam, ν_e are expected to be only 1.7% of the total flux. This will allow to perform precise measurements of ν_e cross section that are currently completed unknown.

With this data sample it will be possible to precisely investigate cross section differences between ν_e and ν_μ and this will be of fundamental importance for future experiments looking for CP violation and the mass hierarchy in the leptonic sector. All these experiments aim to measure CP and the mass hierarchy by observing ν_e ($\bar{\nu}_e$) appearance in ν_μ ($\bar{\nu}_\mu$) beams. In such experiments, systematic uncertainties are constrained mainly by observing the unoscillated

Int. Type	N_{exp} ν_μ	Fraction (%)	Mean $E(\nu_\mu)$ (GeV)	N_{exp} $\bar{\nu}_e$	Fraction (%)	Mean $E(\bar{\nu}_e)$ GeV
Inclusive	97251	100	2.82	34794	100	2.51
CC	72213	74.2	2.82	23645	67.9	2.52
CCQE	23284	24.0	2.60	11123	32.0	2.36

Table 2: Expected ν_μ and $\bar{\nu}_e$ event rates and mean neutrino energy for different neutrino interaction types and for 10^{16} μ^- decays.

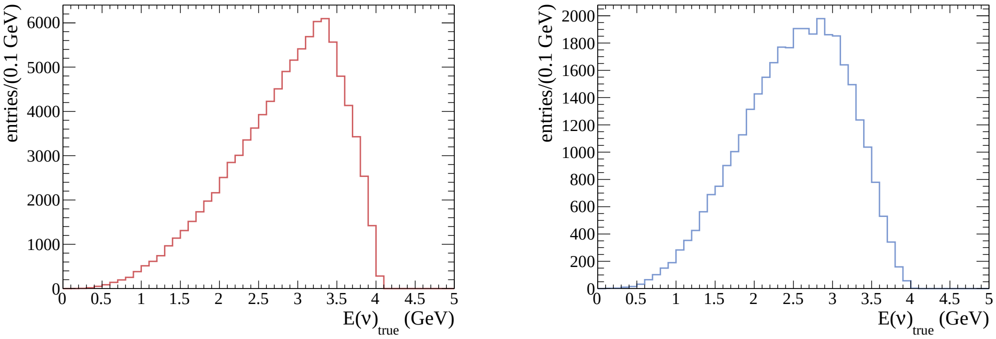

Figure 4: True neutrino energy for the inclusive sample of neutrino interactions occurring inside the prototype active area for 10^{16} μ^- decays for ν_μ (left) and $\bar{\nu}_e$ (right) interactions.

ν_μ flux at the Near Detector, while after the oscillation ν_e interactions are observed at the Far Detector. As a consequence, if ν_e/ν_μ cross section differences will not be precisely measured, they will have a large impact on the systematic uncertainties and on the discovery potential of the experiments.

Int. Type	N_{exp} $\bar{\nu}_\mu$	Fraction (%)	Mean $E(\bar{\nu}_\mu)$ (GeV)	N_{exp} ν_e	Fraction (%)	Mean $E(\nu_e)$ GeV
Inclusive	40328	100	2.86	86074	100	2.46
CC	27538	68.3	2.87	64071	74.4	2.46
CCQE	11991	29.7	2.73	23288	27.1	2.25

Table 3: Expected $\bar{\nu}_\mu$ and ν_e event rates and mean neutrino energy for different neutrino interaction types and for 10^{16} μ^+ decays.

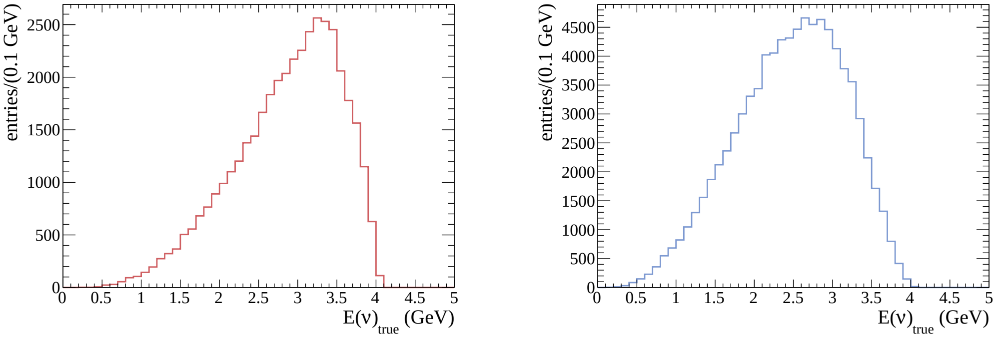

Figure 5: True neutrino energy for the inclusive sample of neutrino interactions occurring inside the prototype active area for 10^{16} μ^+ decays for $\bar{\nu}_\mu$ (left) and ν_e (right) interactions.