Goal of ArgonCube in the ND for Oscillation Measurements

The primary purpose of the liquid argon TPC near detector is to sample the unoscillated neutrino beam using the same target material as the far detector, which is essential in order to constrain uncertainties on neutrino cross sections. The relatively large mass of the ArgonCube near detector makes it possible to produce high-statistics measurements of many exclusive neutrino-Ar interaction processes simultaneously. The energy and angular resolution of ArgonCube is sufficient to extract a high-statistics, high-purity sample of neutrino-electron elastic scattering events, which have a known cross section and can be used to constrain the flux to better than 2%.

The rate of interactions is much higher in the near detector than in the far detector. Therefore the detector technology has to be adapted to minimize pileup. This is done by employing a pixelated charge readout for unambiguous track reconstruction, and containing scintillation light to make use of its prompt component for more accurate event timing.

It is not feasible to build a LArTPC sufficiently large to contain muons, and determining muon momentum is vital for reconstructing neutrino energy. Therefore, it is assumed that ArgonCube ~~is~~ will be coupled to a downstream muon spectrometer for measuring the charge and energy of forward, exiting muons.

Module Dimensions

The module dimensions are set to balance a number of factors maintaining a high drift field of 1 kV/cm with minimal bias voltage at the cathode, the detection of prompt scintillation light, and mitigating the effects of diffusion on drifting electrons.

The prompt scintillation light (τ =6.2 ns) can be efficiently measured with a dielectric light readout with O(1) ns timing resolution. To reduce attenuation and smearing due to Rayleigh scattering, the optical path must be kept below the ~$6.6\text{x}10^{-1}$ m scattering length. Additionally, the slow scintillation component can be further suppressed by operating at higher electric fields, which effectively reduces the ionisation density required to produce excited states.

A module is 3 m tall, with a 1 m x 1 m footprint split into two optically-segmented TPCs with drift lengths of 50 cm, requiring only a 50 kV bias at the cathode. Such voltages are easily achievable with commercial feedthroughs and power supplies. With the light readout mounted on either side of each 1 m-wide TPC, the maximum optical path is only 50 cm. Recording prompt scintillation enables association of detached energy deposits, for example from neutrons, to the correct neutrino vertex.

For a non-zero drift field, diffusion needs to be split into longitudinal and transverse components. Gushchin report a transverse diffusion of 13 cm^2/s at 1kV/cm. This results in a transverse spread 0.8 mm for the drift time of 250 μs; well below the the proposed pixel pitch of 3 mm. The longitudinal component is smaller than the transverse, and is therefore negligible.

The optimized beam corresponds to a neutrino event rate of 0.1 per tonne of argon per spill. Each TPC contains 2.1 t of active LAr, therefore 0.21 events are expected within each TPC. Keeping the event rate per TPC low mitigates pileup. While energy deposits from a single event will extend across several modules, reconstructing crossing tracks is relatively simple given the fully-3D readout. In addition, timing from associated prompt scintillation can be used to disentangle nearby deposits from different events.

Increasing module dimensions will require higher bias voltages at the cathode of each module, more complex and expensive HV feedthroughs and power supplies, and larger clearance volumes (volumes of dead argon to prevent HV breakdown). The higher voltages will also lead to more stored energy (parallel plate capacitor approximation) and potential risk to readout electronics in case of HV breakdown. A longer drift length will increase the readout window and therefore the diffusion. The longer optical path will reduce the light collection efficiency and complicate the association of detached energy deposits to the correct interaction. Furthermore, if the modules are made too large, it becomes more likely for multiple events to pile up in the same TPC; combined with worsened reconstruction of prompt scintillation light, these events can be difficult to separate.

Detector Dimensions

It is critical that hadronic showers are measured directly to avoid reliance on models to correct for unobserved energy. It is therefore important that high hadronic containment is achieved across a wide range of neutrino interaction kinematics. It is not necessary that every event be contained; neutrino interactions near the edge of the detector will often be poorly reconstructed, depending on the orientation of the event. However, it is essential that the acceptance is non-zero for every point in neutrino interaction phase space, taking the translational and rotational symmetries of the neutrino interaction into account. The detector size is determined to this end, and the optimal size is 4 m wide, 3 m tall, and 5 m in the beam direction. The width and height dimensions are interchangeable, and chosen as such due to engineering constraints on the hall design. A fiducial volume can be defined to exclude 50 cm around the sides of the detector and 150 cm from the downstream end, in which the acceptance does not change rapidly as a function of hadronic energy, or of the position of the interaction vertex.

An important consideration is the muons that pass from ArgonCube into the spectrometer. Muons can be measured when they stop in ArgonCube or when they pass into the spectrometer. Muons that stop in passive elements between the two regions cannot be reconstructed accurately. ArgonCube must be long enough so that there is no hole in the acceptance as a function of muon momentum.

The effect on the fiducial volume is important to consider when deducing detector dimensions. A 2 m buffer volume is required around the fiducial volume to achieve good containment, therefore a 5 m long detector has a 3 m fiducial volume. Reducing the length to 4 m would reduce the fiducial volume to 2 m, i.e. a 20% reduction in length reduces the fiducial volume by 33%. This has particularly concerning implications for measurements of nu-e scattering, where the statistics would be cut by 33%.

The current detector width is 7 m across the beam. This was set to mitigate the need for a side muon spectrometer. The width could be reduced to 4 m, but this will entail the inclusion of a side muon spectrometer, and all additional costs.