Snowmass 2021 Letter of Interest: Instrumentation Frontier
Magnetizing the Liquid Argon TPC

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Abstract: After the successful operation of the Icarus T600 detector, the Liquid Argon Time Projection Chamber (LAr TPC) has become the reference technology for high energy neutrino physics. There have already been futher successful implementations in large scale detectors, such as MicroBooNE and ProtoDUNE, which will be followed in the near future by SBND and, ultimately, by DUNE. Future neutrino experiments, especially those searching for CP violation or aiming to confirm or exclude the anomalies in the anti-neutrino sector that have appeared in reactor and beam based experiments, would greatly benefit from the presence of an adequate magnetic field that would allow to unambiguously discriminate the charge. It is the purpose of the program synthetically described in this letter to implement such a feature in detectors of increasing size, with the ultimate goal to magnetize the fourth module of the DUNE far detector.

Introduction: The present letter is a proposal to equip one of the four modules of DUNE with a magnetic field. Such a field should be realized with large superconducting solenoids surrounding the whole detector. The detector should be designed as a direct evolution of the wires chambers developed for the other DUNE modules and of other detector components such as scintillation light detection devices, argon purification systems, etc..
With a magnetic field analyzer and aiming to low detection thresholds, this module will allow a unique scientific program with various natural and artificial sources, that includes but it is not limited to neutrino oscillations, detection and measurement of atmospheric, solar and supernovae neutrinos, nucleon decay searches. A magnetic field in the range of 0.5 to 1 Tesla, together with an improved spatial resolution would allow, in the energy region of all of these phenomena, for an effective measurement of momentum, charge discrimination, better energy resolution for hadron showers, improved particle identification and identification of the starting point of low energy electrons. Cross-comparison with the other DUNE modules will also improve understanding of and add significance to the physics output of the overall observatory.
With the intention to collect experience across several countries for its design and realization, this detector should represent, to some limited but representative extent, the spirit to develop competitive excellence through competence and dedication.

R&D and construction program

The development of a magnetized LAr TPC of the size of one of the DUNE modules is a major undertaking that can only be achieved through a robust R&D program.

A few years ago, an important study was carried out about the possibility to implement a magnetic field in one of the existing Icarus modules and in a smaller detector by adding two Helmholtz coils at the two ends of the detectors [1]. In that study it was shown that a reasonably uniform field can be reached (0.7 Tesla to 1 Tesla) with coils of 6 x 6 m^2 cross-section. The reference choice for the superconductor was MgB_2, operated at 15-20 K.
An alternative solution would be hot superconductors for the magnetizing coil. This would offer several advantages both in terms of the simplification of the cryogenic plant and for the potential development of industrial applications. There are several materials that are of interest for an industrial development. The most known is YBCO ($YBa_2Cu_3O_7$ – also coded as Y-123) that is already available in several forms (wire, tape, foam) from some producers. The critical temperature of YBCO is 92K, comfortably above the boiling temperature of Nitrogen at atmospheric pressure (77 K). It was recently proven that, at liquid Nitrogen temperature (77K), YBCO can be operated at a magnetic field of about 0.6 T and, in the same test, a field of 15 T was reached at 20K [2]. The downside of YBCO is the large cost of the superconducting cable, partially offset by the simplified cryogenic system.
A particularly interesting solution would be to insert the coils directly inside the liquid argon volume, possibly with a dedicated cooling circuit to bring the superconductor temperature to 77 K. This requires some additional R&D effort to develop a layout of the superconductor capable of providing a 1 Tesla field at the boiling temperature of liquid Nitrogen. Working at liquid Nitrogen temperature is obviously highly desirable in the case of a LAr TPC as the same cooling circuit, with some adjustments, can be used to serve both the magnet and the LAr vessel. This development is also of interest for the particle accelerator community as it could provide large superconducting magnets working at temperatures significantly higher than the ones presently used. Furthermore, the possibility to increase the current at 77K, especially if coupled with methods to reduce the cost of the superconductor, has obvious interests in the energy transport market. This part of the R&D should be carried on in cooperation with an industrial partner with the capability to produce the cable in the quantities, cost and time required by the experiment.
The R&D should also cover the following subjects:

1) Definition, through Monte Carlo studies, of the minimal characteristics of the magnetic field (intensity and uniformity) required to achieve the scientific goals;
2) Design studies of possible magnet implementations (engineering studies) including the integration of the magnet with the liquid argon TPC and the scintillation light readout;
3) Small scale prototyping that will be useful for first detailed studies of the quality of reconstruction of liquid argon TPC events in presence of a magnetic field and first integration studies.
4) Intermediate scale prototyping to test the engineering solution selected for the final module.

It is important to note that both the SBND and the ICARUS detectors, as parts of the SBN program [3], would greatly benefit from the presence of an adequate magnetic field as this would allow a highly effective run in the anti-neutrino mode with the Booster Neutrino beam. These detectors are the natural candidates for the intermediate scale prototyping.
Overall, the R&D program will take about 6 years with the ultimate goal of developing and qualifying the technical design of the magnet for the DUNE module.

References

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