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Developing LAr Scintillation Light Collection Ideas in the Short Baseline Neutrino Detector

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ABSTRACT: Scintillation light is becoming the most rapidly developing feature of Liquid Argon Time Projection Chamber (LArTPC) neutrino detectors due to its capability to enhance and expand their physics reach traditionally based on charge readout. The SBND detector, set to be built on the Booster Neutrino Beam Line at Fermilab, is in a unique position to test novel liquid argon scintillation light readout systems in a detector with physics neutrino events. The different ideas under consideration by the collaboration are described, including an array of PMTs detecting direct light, SiPM coupled lightguide bars and a setup which uses PMTs/SiPMS and wavelength shifter covered reflector foils, as well as their respective strengths and physics foci and the benchmarks used to compare them.

KEYWORDS: Noble liquid detectors (scintillation, ionization, double-phase);Photon detectors for UV, visible and IR photons (vacuum) (photomultipliers, HPDs, others); Time projection chambers.

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Contents

1. The SBN Programme at Fermilab

Experimental neutrino physics is an extremely active field with new results continously defining and deepening our understanding of oscillations in the three neutrino model. In addition, in recent years several experiments have obtained results that may suggest oscillations into a fourth sterile neutrino state. This would be a clear sign of physics beyond the Standard Model of Particle Physics. The most recent of such measurements is the observation of a low energy (>200 MeV neutrino energy) excess of electron-neutrinos in both neutrino and anti-neutrino modes in the Booster Neutrino Beam (BNB) by the MiniBooNE detector [1].

There is a large experimental programme underway to confirm or refute these claims and resolve the question of the low-mass sterile neutrino. The largest set of experiments is the so-called Short Baseline Neutrino (SBN) programme at Fermilab [2]. It comprises three detectors, MicroBooNE at a baseline of 470m, which has just finished commissioning, together with a far detector, the ICARUS-T600, currently being refurbished at CERN and the near detector - SBND at a distance of 110 meters from the target hall. All three detectors are Liquid Argon Time Projection Chambers (LArTPCs). LArTPC technology provides superiour photon background rejection [3] compared to e.g. Cherenkov detectors. The presence of SBND will enable a near-far detector combination analysis to determine whether an observed excess would be due to oscillatory behaviour. Its placement near the target hall will result in $\sim$O(1M) events/year which will allow unprecedented measurements of neutrino properties in argon. Fig. 1 (left) shows the sensitivity of the SBN programme to sterile neutrino oscillations.

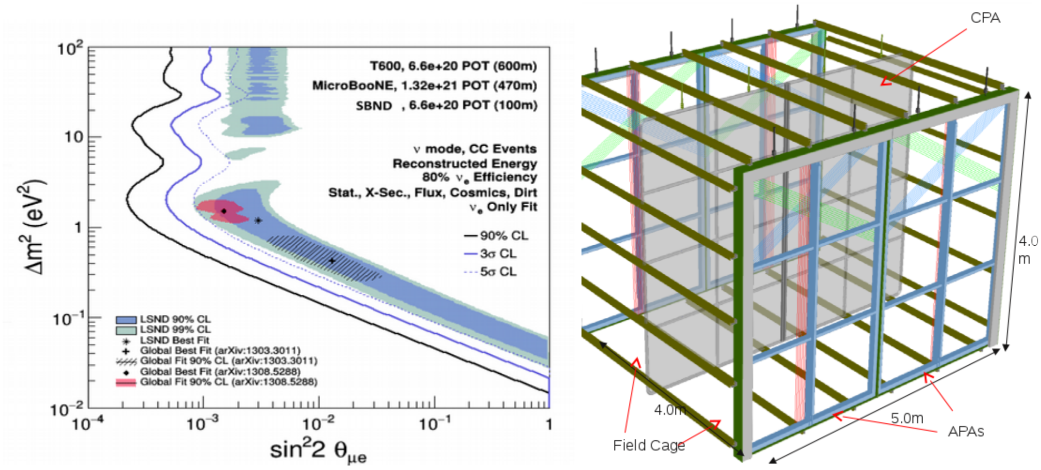

Figure 1. The sensitivity of the short baseline neutrino programme to sterile neutrino oscillations (left). The SBND detector design. The Cathode Plane Assembly is in the middle, and Anode Planes are on the outside (right).

2. Applications of Scintillation Light in LArTPCs

LArTPC detectors are designed to collect ionization charge drifted in an electric field. This charge, collected on anode sense wires, can be combined into a two-dimensional image of the neutrino interaction with the third dimension given by the time it took for the charge to drift. Liquid argon is a prolific scintillator, emitting 40k phel/MeV at zero electric field, giving an additional observable that can be used to extract information about the interactions. Up to now, scintillation light in liquid argon has been most often used as trigger and to determine the drift start time - "t_0", given that it is much quicker to arrive at the detectors than drifting charge. The full potential of using scintillation light in LArTPCs has not yet been realized and there is vigorous activity to develop advanced methods to detect and fully exploit it in neutrino detectors.

The physics requirements of LAr neutrino detectors may result in optimizing different aspects of the scintillation light readout system. For example, detectors situated on the surface would tailor the light collection system to reject cosmic ray interactions as opposed to detectors residing underground. However, there is significant interplay between the different quantities observable by an advanced scintillation light system, and exploring this interplay should lead to best results in terms of physics gains.

2.1 Trigger and Cosmic Removal

A scintillation light burst coincident with the beam gate gives an indication that a beam event like a neutrino interaction has happened. It is also currently the only way to trigger on non-beam events in a LArTPC detector.

If the timing of the light flash can be associated to a charge event in the TPC, which requires timing and position reconstruction, and the timing is determined to be outside of the beam window, then the event can be tagged as a background cosmic ray track. This is a feature which is extremely important for surface LArTPC detectors, such as MicroBooNE, SBND and ICARUS. All of these experiments are considering using an overburden as a method of passive reduction of the rate of cosmic ray generated backgrounds. Alternatively, the cosmic ray rejection can be significantly improved by using an external veto system CRT (Cosmic Ray Tracker).

2.2 Timing

Scintillation light is much faster than charge and potentially offers improved timing resolution which could open new features accessible to a LArTPC detector. The level of these features depends on how much this resolution could be improved. Obtaining a resolution of a few hundred ns is needed to tag events in the beam spill. Such resolution also enables tagging Michel electron decays using scintillation light [4],[5], which would also benefit from a uniform response of the detector and a high efficiency of collection.

A timing resolution of the order of five ns would allow tagging muon tracks as entering or exiting based on light arrival times. This would require positional resolution obtainable either from the scintillation light itself or from an external CRT system.

A resolution of the order of one to two nanoseconds could lead to resolving the neutrino beam bucket structure. This would allow an even better rejection of non-beam backgrounds by tightening the allowed time window for signal events. In addition it could be used to detect heavier than neutrino beam-exotics, which would arrive slightly later than neutrinos.

It should be noted that the performance in terms of timing may be limited by the nature of scintillation light and in turn detector parameters which could affect the photon emission times, e.g. argon purity [6].

2.3 Energy Resolution

Scintillation light can be instrumental in energy reconstruction in LArTPCs. The most basic use is to determine the t_0 for non beam events. This allows correct determination of the drift distance and correcting for loss of charge due to impurities.

Scintillation light carries information complementary to that of charge, and has been used to reconstruct energy by itself in Dark Matter experiments [7], although at energies significantly lower as compared to neutrino energies. Combining scintillation light and charge in a system with high collection efficiency and uniformity will significantly improve the energy resolution in the detector.

3. Light Detection in SBND

3.1 The SBND Detector

The SBND detector will be placed near the SciBooNE hall at 110 meters from the target hall of the Booster Neutrino Beam. It will consist of two TPCs, each with dimensions of 5m (beam) x 2m (width) x 4m (height), resulting in an active volume of $\sim$112 tonnes. The two TPCs will be joined by a cathode in the middle and their respective wire planes on the outside sides of the TPCS. The detector scheme is shown in Fig. 1

SBND is an excellent venue to test and refine elements of liquid argon technology for neutrinos, as it offers a unique opportunity to test new solutions in a working neutrino beam. A primary example is the scintillation light collection system, which in SBND will be installed outside the TPCs, behind the wire planes - see Fig. 2 (right).

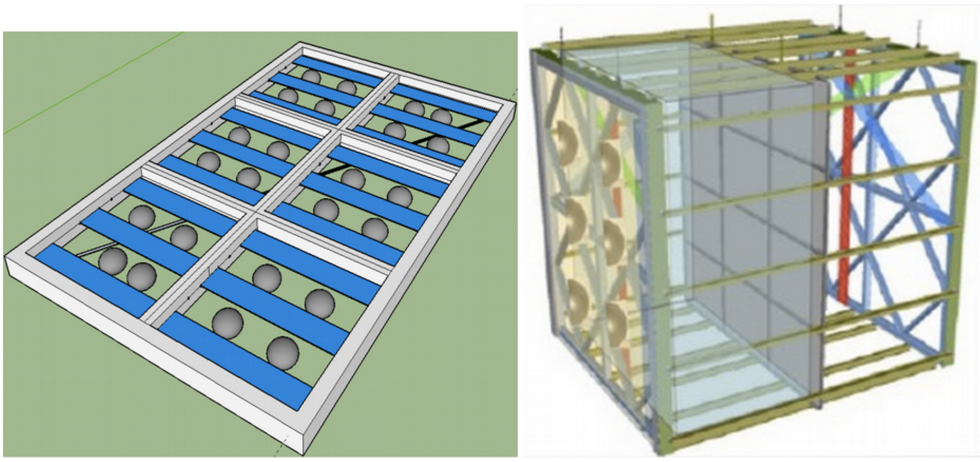

Figure 2. The primary and secondary light collection system layout (left) and the generic R&D foil setup placing (right).

3.2 The SBND Light Readout System

Apart from the neutrino oscillation physics goals, an important part of the mission of SBND is R&D on liquid argon technology. In order to fulfill this mission, SBND will implement a multi-technology setup to maximize the diverse yet interconnected physics goals and objectives. Due to the VUV nature of scintillation light in liquid argon all setups described below need to wavelength shift it to visible light in order to detect it. The light collection system will be enhanced by a Cosmic Ray Tagger system on the outside of the cryostat, which will provide additional information and help benchmark the capabilities of the scintillation light system.

3.2.1 PMTs

The primary SBND light collection system will be an enhanced MicroBooNE-like [8] design. It will consist of ∼100 8” 14 dynode Hamamatsu PMTs in the full two-TPC detector - the final number of PMTs to be installed will be driven by science requirements. Such photocathodic coverage should provide on the order of 27 PE/MeV at an electric field of 500 V/cm and at a distance of 2 meters from the wires. The advantage of this system is that it is a proven detector technology in liquid argon and it provides excellent timing resolution.

3.2.2 Scintillating Light Guide Bars

A part of the SBND R&D mission will be fulfilled by installing SiPM read-out light guide bars such as those considered by the DUNE experiment [9]. Operating these prototype detectors side-by-side with the PMT system gives valuable cross-calibration opportunities. Installing the light guide bars should provide an additional 20-30% of light, which should enhance the physics case of the detector and be sufficient for tests as a standalone system.

The light guide bar system is anticipated to improve position resolution in the detector and will be a unique opportunity to operate a full-scale system in a running neutrino experiment. This would provide invaluable insight into improving the design of the system foreseen in the first single phase DUNE module.

3.2.3 Reflective Foils

SBND is also pursuing generic R&D to develop possible solutions for future large scale detectors. One current option is to install wavelength shifter covered reflector foils on the inner surface of the TPC. This solution would increase the light detection efficiency roughly by a factor of three for a given photocathodic coverage without increasing the number of channels. This setup, based on Dark Matter experiments also ensures uniformity of light collection. A similar design has been tested in the LArIAT detector [10].

The advantages of this setup, i.e. the enhanced light collection efficiency and uniformity should improve the understanding of low energy interactions: nuclear effects, supernova signals, etc. On the other hand, the question whether the track matching efficiency would be degraded in a surface detector due to the reflected light washing out the direct light, is currently subject of intense study and detailed MC simulations.

4. Conclusions

The SBND collaboration is currently finalizing the design of the light readout system. The result will ensure the performance of the SBN physics goals and maximize the R&D potential of the detector. The system as described can be built, the final details are still being optimized.

SBND will be a major step in developing liquid argon neutrino detectors and the light detection system will take a major step in R&D in neutrino detectors.

Acknowledgement

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