Liquid argon scintillation light studies in LArIAT

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Abstract. The LArIAT experiment is using its Liquid Argon Time Projection Chamber (LArTPC) in the second run of data-taking at the Fermilab Test Beam Facility. The goal of the experiment is to study the response of LArTPCs to charged particles of energies relevant for planned neutrino experiments. In addition, it will help to develop and evaluate the performance of the simulation, analysis, and reconstruction software used in other LAr neutrino experiments. Particles from a tertiary beam detected by LArIAT (mainly protons, pions and muons) are identified using a set of beamline detectors, including Wire Chambers, Time of Flight counters and Cherenkov counters, as well as a simplified sampling detector used to detect muons. In its effort towards augmenting LArTPC technology for other neutrino experiments, LArIAT also takes advantage of the scintillating capabilities of LAr and is testing the possibility of using the light signal to help reconstruct calorimetric information and particle ID. In this report, we present results from these studies of the scintillation light signal to evaluate detector performance and calorimetry.

1. Introduction
The LArIAT experiment is a Liquid Argon Time Projection Chamber running at the Fermilab Test Beam Facility. It has finished its second run in August 2016 and is currently preparing for the third one, planned to start in early 2017. The goal of this experiment is to study the response of LArTPCs to charged particles of energies relevant for neutrino experiments. Collected data will be used to test and validate the LAr software framework – a LArSoft. Although the standard data analysis relies on charge signals registered by the TPC wires, it is the light collection which makes this detector stand out from other LArTPC detectors. This unique system, using solutions known in Dark Matter detectors, enables studies of possible applications of argon scintillation light in LArTPCs.

2. Light Readout System in LArIAT
Liquid argon scintillates in the VUV spectrum (around 128 nm wavelength); therefore it must be wavelength-shifted to be detected by photosensitive devices, e.g. PMTs. Unlike in other neutrino detectors, which deposit the wavelength shifter (WLS) compounds on the light detectors themselves, the LArIAT fieldcage is lined with WLS – covered reflector foils (scheme of setup in Fig. 1 left). This provides uniformity and high light yield, which is important for calorimetry and particle identification applications. The light is collected by cryogenic PMTs (3”Hamamatsu and 2” ETL), as well as SiPMs (standard in Run 1 and standard plus a VUV sensitive prototype for Run 2) (Fig. 1 right). A complex setup of this sort with a high light yield requires a more advanced simulation of the light.
3. Simulations of Light Yield
To simulate light detection in LArIAT, GEANT4 [1] [2] [3] software embedded in LArSoft [4] and solutions developed within the LArSoft framework [5] were used. A precise model of the detector geometry was implemented in gdml. The simulation was updated and expanded by adding many new elements, such as the detailed description of a light detection efficiency spectrum and the WLS properties of TPB (Tetraphenylobutadiene). The details of their implementation were optimized, by tuning of the list of used physical processes. The simulation takes into account optical properties of the TPC walls (G10 laminate), TPB – covered reflector and the copper cathode. The NEST [6] software package was used to model scintillation light as the most advanced software model available. Ray tracing simulation of each photon is extremely difficult due to computing constraints and to facilitate efficient simulation of such numerous photons, fast lookup libraries were built.

Preliminary analysis shows a reasonable agreement of the LY expected from simulation with the value obtained from data (preliminary MC results for the ETL PMT show a central value of around 2.3 phel/MeV).

4. Using Scintillation Light to Determine the Nitrogen Contamination
Scintillation light can be used to determine the nitrogen contamination of the argon, as nitrogen quenching will result in an effective shortening of the slow time component of argon scintillation light [7]. Measurements of nitrogen contamination by LArIAT’s gas analyzers (Fig. 2 top) were used to validate the results extracted from fits of the slow component of the scintillation light (Fig. 2 bottom). They were found to be in agreement confirming the usefulness of this method in neutrino detectors. With the nitrogen concentration dropping (Fig. 2 top), an increase of a lifetime of the slow component of the LAr scintillation light can be seen (Fig. 2 bottom) and the trend of this change agrees with the model.

5. Calorimetry with Combined Light and Charge
Recombination of ionization with argon ions leads to non-linear effects in charge vs energy comparison, as demonstrated e.g. by ArgoNeuT [8]. If only ionization charge is used to reconstruct the energy of the particle, corrections must be made to account for these effects. However, if scintillation light is also used in the energy reconstruction, linearity can be recovered since the ionization charge lost to recombination can instead be detected as the emitted scintillation light. LArIAT is studying whether using the combined charge and light can provide a useful improvement to energy reconstruction for single tracks. Fig. 3 shows a simulated proton
Figure 2. Top – nitrogen concentration measurement using the dedicated sensor and bottom – decay times for the slow component of a LAr scintillation light as a function of the changing nitrogen concentration level, obtained using LArIAT data. At higher nitrogen concentrations statistics were insufficient to perform the analysis.

sample in the LArIAT detector and compares proton energy, obtained from the NIST range table [9], with an energy estimate based on light and charge deposited in the TPC.

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Figure 3. Simulated proton sample energy, calculated based on NIST range tables [9] compared with an energy estimate from the light and charge.

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