Exclusive μ+Np topologies with ArgoNeuT

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Abstract. The Argon Neutrino Test, ArgoNeuT, is a small scale Liquid Argon Time Projection Chamber (LAr TPC) that is one step towards the construction of large scale LAr TPCs for long-baseline neutrino physics. LArTPCs provide bubble-chamber-like quality images for excellent particle ID and background rejection. Due to its superb capabilities it is well suited for topological analysis by reporting what it sees in a final state. Preliminary analysis of ArgoNeuT's 0.1 to 10 GeV neutrino μ+Np topologies together with first ever study of proton multiplicities in neutrino-argon interactions was presented and compared with GENIE Monte Carlo generator.

Keywords: LArTPC, ArgoNeuT, topological analysis

ARGONEUT EXPERIMENT

ArgoNeuT is a small Liquid Argon Time Projection Chamber (LArTPC) at Fermilab that was taking data from September 2009 to February 2010. The chamber, with active volume of 170 L, was filled with purified liquid argon and imposed with an electric field of 500V/cm. The charged particles produced in neutrino interactions drift towards wire planes which are positioned at 60-degree angle with respect to each other. This alignment together with timing information allows for 3D event reconstruction and calorimetry. ArgoNeuT sat upstream of Minos Near Detector (MND) about 100m underground and collected 0.1E20 POT in neutrino mode and 1.25E20 POT in anti-neutrino mode both in low energy NuMI beam configuration. A more detailed description was presented at this conference and is provided in [1].

TOPOLOGICAL ANALYSIS

The Golden channel in oscillation searches is so called CCQE (Charged Current Quasi-Elastic) interaction which was historically defined as an emission of a lepton and a nucleon. Even though it seems very simple, nuclear effects play a crucial role and can alter what is emitted in the final state. Final State Interactions (FSI) and other nuclear re-scattering processes can lead to additional nucleons, pions and de-excitation photons. Modeling FSI in neutrino generators is one of the biggest challenges and thus one should try to avoid correcting for their effects based on Monte Carlo. Instead, one should aim for a measurement of the final state itself to reduce such model dependencies. Due to the imaging capabilities of LArTPCs one can reconstruct what is present in the final state after FSI, for example, muon and any number of protons (μ+Np), muon and any number of pions (μ+Nπ) and so forth and thus separate analyses based on a given final state. The first topological analysis, μ+Np, is currently being finalized which aims to measure proton multiplicities and kinematics with a proton threshold of 21MeV (kinetic energy).

EVENT RECONSTRUCTION AND CLASSIFICATION

For the μ+Np analysis, events are selected by using a combination of automated cuts and visual scanning. A typical topology is shown in Figure 1. The long track is identified as a muon and matched with the MND. In the μ+0p event, no vertex activity is present and the event only has a single muon track. The highly ionizing and short tracks around the vertex in the μ+1p and μ+2p example events were identified as protons. An example of proton track identification from the residual range versus dE/dx for μ+1p event is shown in Figure 2. The residual range is calculated starting from the end of a track and the high dE/dx corresponds to the end part of a stopping track. The black data points are hits along the track and they nicely lie on top of the MC prediction for the proton. The same automated reconstruction procedure and visual scanning is performed on both MC and data events.

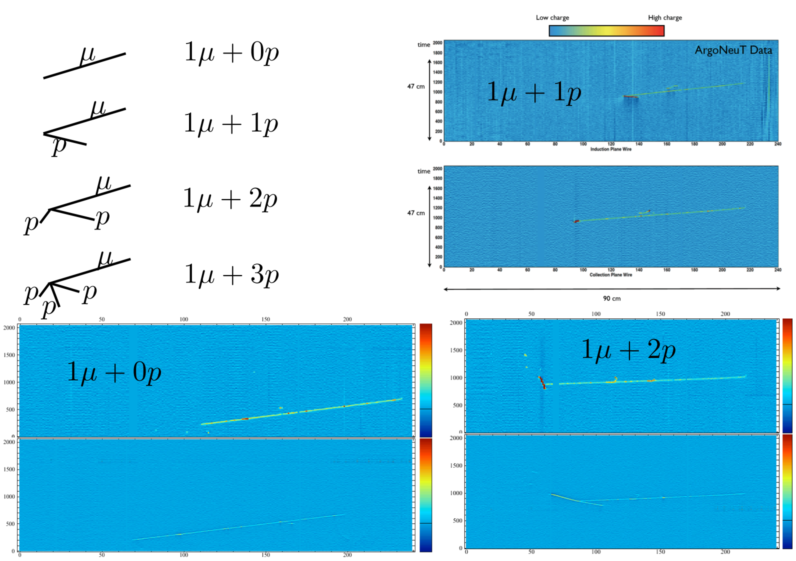

FIGURE 1. Topology appearance of μ+Np events in ArgoNeuT

Due to ArgoNeuT's small size, most muons are not contained and enter the magnetized MND and thus matching of those tracks is required. MINOS provides the muon sign and momentum and the sample can be split into neutrinos and anti-neutrinos. The muon energy lost in LAr is accounted for by using calorimetric reconstruction of the deposited energy. A more detailed description of the whole procedure is described in [2]. The muon momentum reconstruction for matched muons in the μ+Np sample is shown in Figure 3. It can be seen that besides the absolute normalization, the shape nicely agrees with the MC prediction.

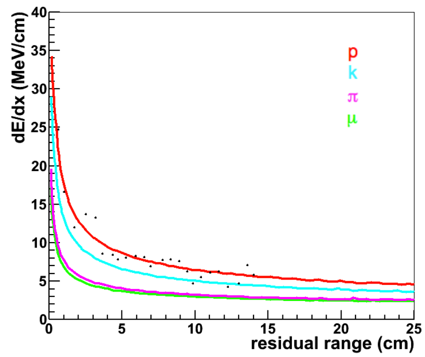

FIGURE 2. dE/dx versus residual range plot for a proton from a μ+1p event. Data points correspond to reconstructed hits along a track.

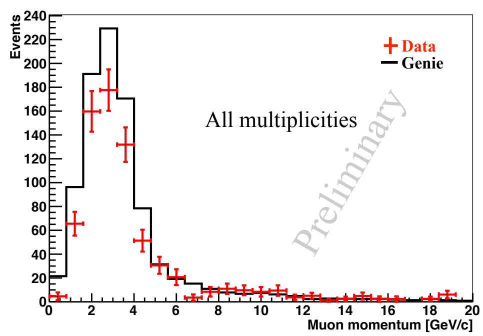

FIGURE 3. Muon momentum comparison between data and MC for antineutrino μ+Np events in anti-nu mode

RESULTS

A comparison of data and MC in terms of proton multiplicity is shown in Table 1 for neutrino mode. The comparison is provided up to a proton multiplicity of 4, higher multiplicities are included in the total sum. The MC generator used for this comparison is GENIE version 3470. Besides the absolute values for each multiplicity N for μ+Np events, the percentage of the total is shown for each N. This analysis has focused on lower multiplicity events. An optimization for higher N is in progress as well as further antineutrino mode flux studies. It can be seen that GENIE predicts more events for N=0 and N=1 proton multiplicities, however percentages of total number of events agree quite well with MC predictions. A similar comparison is done in anti-neutrino mode that has much better statistics. Comparison of MC and data for both neutrinos and antineutrinos are shown in Tables 2 and 3. For anti-neutrinos in anti-neutrino mode, GENIE predicts more events for N=0,2,3 but less for N=1. Percentage of total number of events is quite close for N=0 between data and MC. However, MC predicts a much smaller fraction of events with N=1 than found in the data. For neutrinos in anti-neutrino mode, GENIE predicts less events for N=0 than found in the data. For N=1, data and MC agree within the error but the percentage of total number of events is quite different. Plots of multiplicity and comparisons with MC are shown in Figure 4 for neutrinos and anti-neutrinos in anti-nu mode. As can be seen, besides absolute normalization, the shape with respect to MC is better reproduced for neutrinos. Overall it can be seen that in both neutrino and anti- neutrino mode there is less data than predicted by GENIE by 38% for neutrinos in neutrino mode, 21% lower for anti-neutrinos in anti-neutrino mode and 23% lower for neutrinos in anti-neutrino mode. For discussion and commentary of nuclear effects in ArgoNeuT see [3] .

TABLE 1. Data comparison with GENIE for proton multiplicity of μ+Np events for neutrinos in neutrino mode with statistical and preliminary systematic uncertainties.

Multiplicity	Genie Expectation	Genie % of Total	DATA	DATA % of Total
0p+μ	28±4	16%	15±3	14%
1p+μ	80±7	47%	51±10	48%
2p+μ	23±4	13.4%	28±6	26%
3p+μ	14±3	8.3%	13±3	12%
4p+μ	8±2	4.5%	0	0%
Total(including>4p)	172±10	-%	107±12	-%

TABLE 2. Same as Table 1 for antineutrinos in anti-neutrino mode.

Multiplicity	Genie Expectation	Genie % of Total	DATA	DATA % of Total
0p+μ	553±11	60%	422±42	58%
1p+μ	160±6	17%	266±53	37%
2p+μ	68±4	7%	30±6	4%
3p+μ	50±3	5%	3±1	0.4%
4p+μ	32±3	4%	3±1	0.4%
Total(including>4p)	925±15	-%	727±68	-%

TABLE 3. Same as Table 1 for neutrinos in anti-neutrino mode.

Multiplicity	Genie Expectation	Genie % of Total	DATA	DATA % of Total
0p+μ	46±3	14%	60±12	23%
1p+μ	163±6	48%	154±31	59%
2p+μ	46±3	13.6%	33±7	13%
3p+μ	23±2	7%	9±2	3.5%
4p+μ	16±2	5%	4±1	1.5%
Total(including>4p)	337±9	-%	260±34	-%

A data, MC comparison of reconstructed neutrino energy is shown in Figure 5. The energy is reconstructed using only muon kinematics and the shape looks different from GENIE's prediction. However, neutrino energy can also be reconstructed using both muon and proton kinematics. This work is currently in progress and aims at showing a comparison between the two approaches.

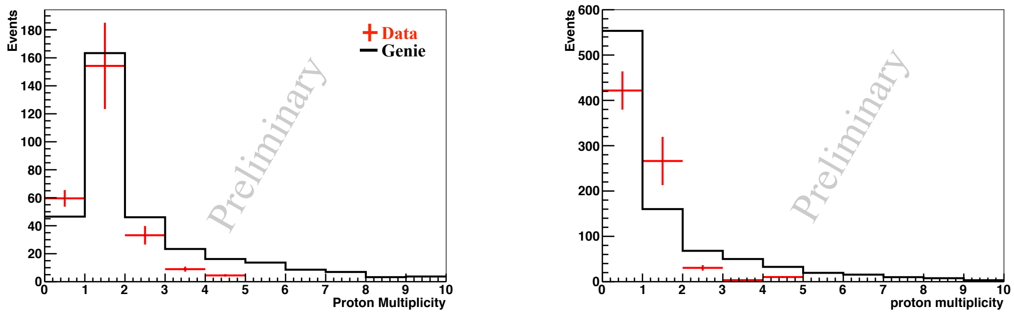

FIGURE 4. Proton multiplicities comparison between data and MC for neutrinos in anti-nu mode (left) and antineutrinos in anti-nu mode (right) (absolute normalization).

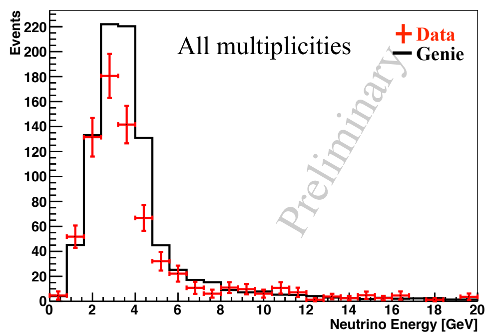

FIGURE 5. Neutrino energy comparison between data and MC for antineutrinos in anti-nu mode (absolute normalization).

CONCLUSION

ArgoNeuT, alongside other LArTPCs, has been developing important tools for particle identification and reconstruction. The idea of topological measurement and its advantages were explained. Preliminary results for 1μ+Np topological analysis with a LArTPC with proton multiplicities and energy reconstruction were shown.

ACKNOWLEDGMENTS

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REFERENCES

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