Neutrino-nucleus Cross-Sections: development of tools for Exclusive Topologies reconstruction in LAr-TPC experiments

White Paper

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The analysis and interpretation of the present and future neutrino oscillation experiments strongly rely on the quantitative understanding of neutrino and antineutrino interactions with nuclei in the GeV energy range. In this energy range the most important interaction channel is the CC quasi elastic (QE) scattering, historically referring to the emission of a charged lepton and a single nucleon. For this reason, a lot of effort has been devoted to measurements of neutrino- and antineutrino-nucleus *"QE like"* cross-sections in a broad kinematical domain.
Nuclear effects, however, play a key role in neutrino-nucleus interactions in nuclear targets. Due to intra-nuclear re-scattering (FSI) and possible effects of correlation between target nucleons, a genuine QE interaction can hence often be accompanied by the ejection of additional nucleons, emission of many de-excitation γ's and sometimes by soft pions in the Final State (after hadronization). These products are usually neglected because not detectable, unless a high quality, low energy threshold imaging detector is in use. Neutrino interaction channel definitions are largely ill defined given the effects of FSI and all the measurements of specific channels largely rely on MC simulation.

LAr-TPC detectors, providing bubble-chamber-like quality images and excellent particle ID and background rejection, allow for MC independent measurements, FSI exploration and Exclusive Topology recognition with extraordinary sensitivity.
Instead of MC based classification of the events in the interaction channels (QE, RES, DIS etc), neutrino events in LAr can be classified in terms of Final State Topology based on Particle Multiplicity: 0 pion (μ+Np, where N=0,1,2...), 1 pion (μ +Np+1π) events, etc..
In imaging LAr-TPC detectors these exclusive topologies can be fully reconstructed, measurements of proton multiplicity at the neutrino interaction vertex and reconstruction of proton kinematics in events with different proton multiplicity can be performed with very low proton energy threshold, ultimately allowing for most precise reconstruction of the incoming neutrino energy from lepton AND proton kinematics. Ratios among rates of different exclusive topologies provide indications of the size of nuclear effects. A first Topological analysis, for the "0 pion" muon neutrino events in the few GeV energy region, is currently developed and exploited by the ArgoNeuT experiment with a proton threshold of 21 MeV Kinetic energy. Results have been recently presented at the NUINT 2012 workshop [1], [2]. Multi-p accompanying the leading muon and the presence of vertex activity are clearly visible (and measured) in the ArgoNeuT events (see Fig.1).

Accurate and extremely detailed MonteCarlo neutrino generators are needed for comparison with LAr data. FSI in MC codes represent the most difficult present challenge in MC development and present neutrino generators predict vastly varying amounts of proton emission. Data from LAr are extremely helpful for FSI understanding and can provide important hints (for example from the reconstruction also of the neutrons ejected in the final state) to tune MC generators and discriminate among models.

Progressing with development of more and more accurate reconstruction tools for data analysis within the LArSoft sw-package [3] in combination with larger mass LAr-TPC detectors (MicroBooNE and future LAr detectors like LBNE) is an important step - here proposed - for accurate topological analysis of neutrino events, on the line pioneered by ArgoNeuT.

[1] K. Partyka (for the ArgoNeuT Coll.), "Exclusive 0 pion topologies in ArgoNeuT".
[2] O. Palamara (for the ArgoNeuT Coll.), "Hints for nuclear effects from ArgoNeuT data".

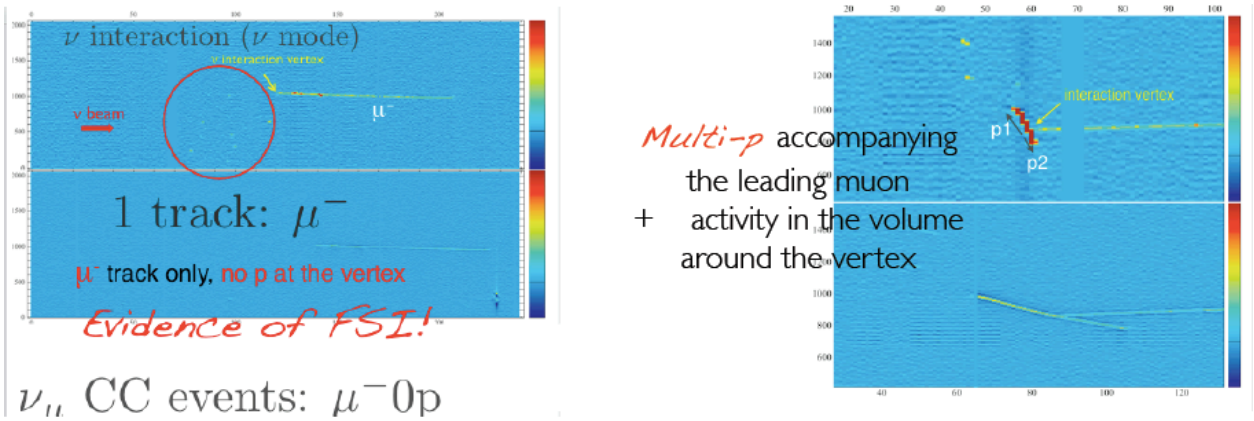

Figure 1: ArgoNeuT events. Single μ^- event (Left), Multi-proton event (Rigth)