THE STUDY OF NEUTRINO-NUCLEUS INTERACTIONS USING A MONTE CARLO EVENT GENERATOR

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In cadrul unui experiment cu neutrini din fascicol se determina compozitia fascicolului de neutrini la o distanta cat mai mica de sursa acestuia si inainte de a avea loc fenomenul de oscilatie a neutrinilor pentru a putea controla fondul reprezentat de contaminarea fascicolului de neutrini. Analiza a fost realizata folosind un generator de evenimente, o unealta suplimentara, pentru a studia interactiile neutrinilor si pentru a simula raspunsul detectorului. In aceasta lucrare prezentam o metoda prin care poate fi determinat numarul de neutrini ce pot interactiona in volumul sensibil al unui detector situat la distanta mica de originea fascicolului de neutrini in cadrul unui experiment cu neutrini din fascicol. Acest studiu este necesar pentru a imbunatati potentialul de descoperire al detectorilor plasati in laboratoare subterane cu scopul de a determina proprietatile neutrinilor.

In a long baseline neutrino experiment we have to measure beam neutrinos before oscillations can occur, at the close proximity of the beam source, to control backgrounds, like beam contamination. The analysis was realized using a neutrino generator which is a supplementary tool used to study neutrino interactions and to simulate the detector response. In this paper, we present a method to determine and analyze the number of neutrinos that can interact in a fiducial volume of a near detector from a neutrino beam experiment. The present study is useful for improving underground detectors discovery potential for determining the neutrino properties.

Keywords: neutrino physics, neutrino event generator, GENIE, neutrino flux, detector geometry.

1. Introduction

The study of neutrino interactions with nuclei is an active field of investigation and crucial to any type of long baseline neutrino oscillation experiment. Study of neutrino–nucleus reactions in the few GeV energy region is complicated and requires many intermediate steps, such as a description of the nuclear model, understanding the neutrino–nucleon cross sections, modeling of hadronization, as well as the modeling of intranuclear hadron transport and other

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secondary interactions. All this steps would be solved if GEANT [1] had a validated neutrino interaction package. Because this tool kit can not describe the passage of neutrino through matter there are a number of Monte Carlo (MC) generators and numerical packages dedicated to description of neutrino interactions: GENIE [2], GiBUU [3], FLUKA [4], NEUT [5], NuWro [6] and Nuance [7].

Simulation in particle physics is a computer-aided method of modeling particle interactions with an aim to predict results of experiment. Simulations are used to evaluate the feasibility and physics reach of proposed experiments, optimize the detector design, analyze the collected data samples and evaluate systematic errors.

LAGUNA [8] is a collaborative project whose principal goal is to assess the feasibility of a new pan-European research infrastructure able to host the next generation, very large volume, deep underground neutrino observatory. LAGUNA is a long baseline experiment aimed at measuring neutrino oscillation phenomenon using artificial neutrino beam. This means that neutrinos are produced at a certain location and shot towards a detector that is sufficiently far from the neutrino source to observe oscillation effects at their maximum. However, to control backgrounds, like beam contamination, one also has to measure beam neutrinos before oscillations can occur, at the close proximity of the beam source. This is a role of a second detector. Those two detectors are called, correspondingly, far and near. In our geometrical setup, Glacier plays a role of a near detector. The Glacier detector is the foreseen extrapolation up to 100 kton of the liquid Argon Time Projection Chamber (TPC) technique. The liquid Argon TPC is a new and challenging technology and is the fruit of many years of R&D effort conducted by the ICARUS Collaboration [9]. One of the seven potential underground sites in Europe to install the LAGUNA detectors is "Unirea" salt mine, Slănic-Prahova (Romania), where there is located an underground laboratory with ultra low radiation background [10]. The proposed detector for this location is Glacier.

In this paper we studied neutrino interactions with ^{40}Ar nuclei using a simple detector geometry for Glacier and a neutrino flux that can be sent from CERN to Unirea salt mine.

2. Physics processes and their simulation

A precise estimate of all processes relevant for neutrino interactions with nuclei is needed. In our analysis of a few GeV energy range, neutrino interactions arise from a variety of sources. The main processes are: quasi-elastic (QE), resonant single-pion production processes (RES) and deep inelastic scattering

(DIS) interactions. The DIS processes are predominantly at these energies and fully dominate at higher neutrino energies.

All these interactions can be classified into two groups – charged current (CC) or neutral current (NC) depending, respectively, on whether a $W^{\pm}$ or Z^0 boson is exchanged. NC interactions are inherently harder to detect than CC interactions because there is no charged lepton that can be seen in the detector. Therefore understanding CC neutrino–nucleus interactions in the few GeV energy region is very important for many current and future neutrino experiments.

In this paper we used GENIE that is an advanced and freely available neutrino MC generator designed by Dr. Costas Andreopoulos at the Rutherford Appleton Laboratory, for the purpose of the MINOS Collaboration [11], using object-oriented methodologies. It simulates neutrino interactions, for all neutrino flavors and all nuclear targets, over a large energy range from a few MeV to several hundred GeV. The technical details regarding physical models used in the program can be found in Ref. [2]. GENIE is a widely used tool, which has already been adopted by the majority of neutrino experiments, including those using the JPARC [12] and NuMI [11] neutrino beam lines. While existing neutrino MC generators simply simulate neutrino interactions and may include the ability to use some form of user-defined neutrino flux, GENIE can analyze detector geometries written in ROOT [13] or GEANT and can also interface with GEANT in order to feed the generated events into MC detector.

The GENIE 2.6.0 version was installed on a LINUX distribution that required more external packages to enable certain specialized features: ROOT, LHAPDF [14], PYTHIA6 [15] and other C++ libraries. The user is allowed to choose target nucleus that is important, because final state interactions (FSI) are strongly dependent on number of protons and neutrons in the nucleus. A primary state is defined as the topology of particles produced by the primary neutrino interaction and the final state is defined as the topology of the particles after any secondary interactions, such as intranuclear rescattering, that have taken place.

We generated 100,000 events simulating υ_e interactions on ^{40}Ar nuclei in the energy range (0-5 GeV). The considered neutrino flux can be sent from CERN to Unirea salt mine.

In the first phase we generated the neutrino flux specifying the weight, the pdg code, the 4-momentum and 4-position. The neutrino flux is a cylindrical one of arbitrary 3-D beam direction and radius described by a constant function. We set the beam direction along the x axis (1, 0, 0) and the radius of the flux generation surface at R_T =5 m. To fully specify the position of the flux generation surface we set the "beam spot" 3-vector at (100, 0, 0) which means that we will propagate the neutrino over the 100 m distance between the beam spot and the detector location (Fig.1).

The next step was to combine the flux with the detector geometry (Fig.2), written in ROOT, and generate events. The detector geometry is a simple model of a tube filled with liquid Argon, including all the parts of the detector densities and material composition in terms of chemical elements. GENIE will take the neutrino through the geometry and calculate the corresponding interaction probability for each target. GENIE can decide where and on which nucleus a given neutrino interacts. If it will interact, the event kinematics will be generated.

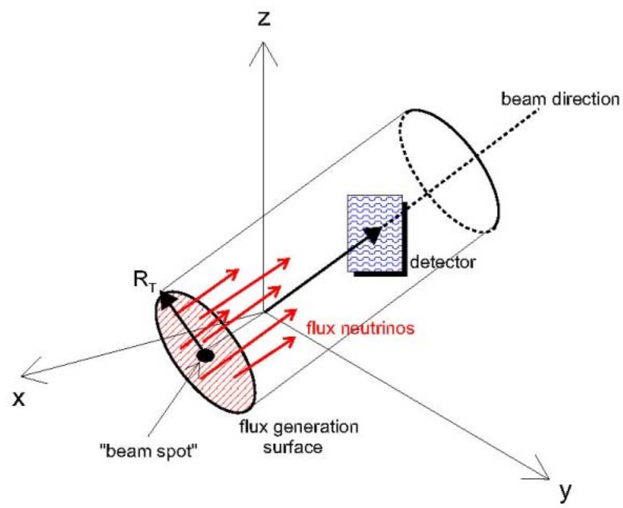
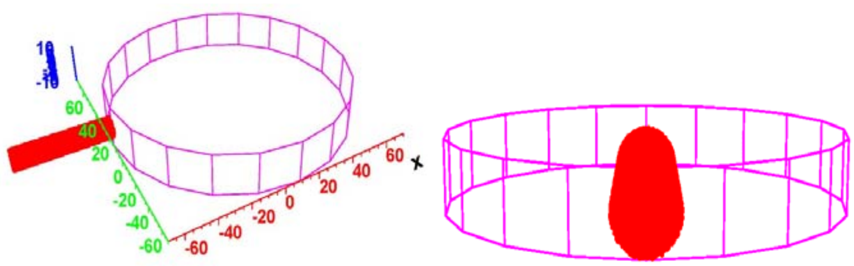


Fig. 1 Geometrical setup for the υN simulations [16]

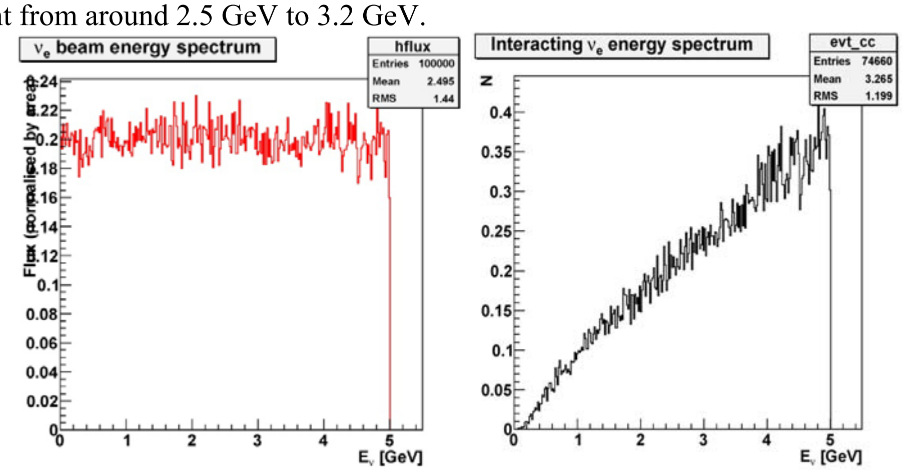


(a) (b)

Fig. 2 The neutrino flux and the detector geometry before (a) and after interaction (b).

3. Results

All the following results were obtained using events generated with the neutrino flux and the detector geometry described in the previous section. In Fig. 3 we show the effect of convolving the neutrino energy spectrum with the interaction cross-section, obtaining the number of neutrinos that interact in the liquid Argon detector volume. On the left side of the figure is the energy spectrum of all neutrinos in the beam, and on the right side is the energy spectrum of neutrinos that interact in the detector. As a consequence of the cross-section being smaller for low energy neutrinos the mean of the two histograms has shifted by an amount from around 2.5 GeV to 3.2 GeV.



(a) (b)

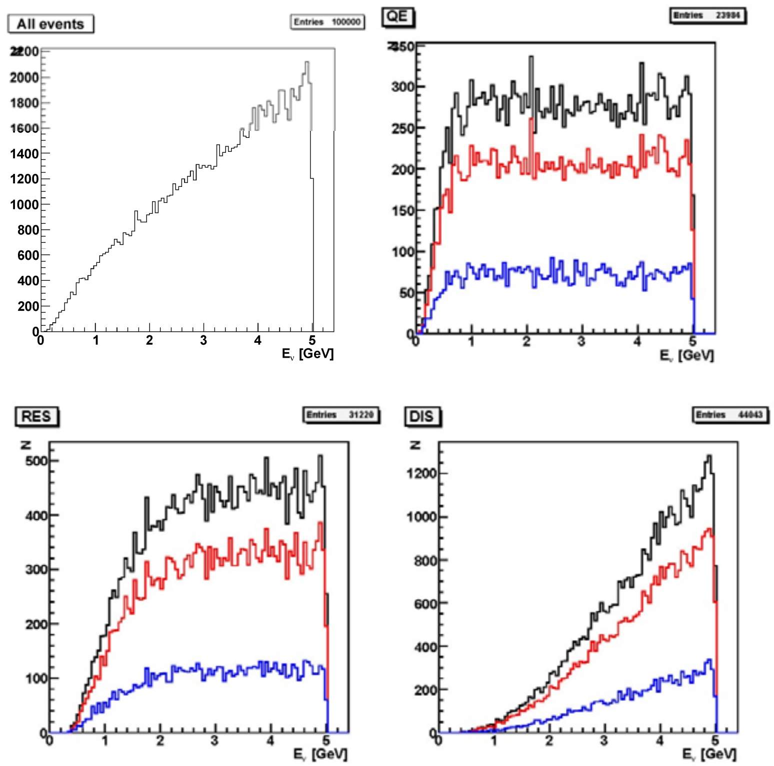
Fig. 3 (a) The energy spectrum of all neutrinos from the beam; (b) the energy spectrum of neutrinos that interact in the detector (CC interactions).

Fig. 4 (a) shows the energy of neutrinos that interact in the detector for all physics processes. Fig. 4 (b-d) show the energy of neutrinos that interact in the detector for three most significant production channels QE, RES and DIS. For each of the channels described above, neutrino interacts with a nucleon bound in the nucleus if interactions on nuclei (like argon) have to be taken into account. An important role is also played by interactions between hadronic products of a primary reaction of neutrino with a nucleon and other nucleons in the nucleus.

From these figures, we observe that DIS interactions are dominant. In the considered energy range this type of neutrino interactions are more probably at higher energy. For this three significant production channels CC neutrino interactions represent almost 75% of all neutrino interactions and this is very important, since they usually have only one observable product (lepton) and allow reconstruction of incoming neutrino energy.

Table 1 contains the interaction probabilities in different channel simulated for our analysis. For these calculations we used the cross section spline files for all modeled processes for υ_e scattered of nuclear target ^{40}Ar. CCDIS are the most probable processes in the considered energy range.

(a) (b)



(c) (d)

Fig. 4 Number of interactions in the detector geometry using a constant neutrino flux as a function of neutrino energy: (a) – all physics processes; (b) – QE, (c) – RES and (d) – DIS: red – CC interactions, blue – NC interactions, black – CC+NC interactions.

Table 1

Relative interaction probabilities of the neutrinos in the detector geometry

	CC [%]	NC [%]	All [%]
QE	18	6	24
RES	23	8	31
DIS	33	11	44
Other	1	0	1
All	75	25	100

4. Conclusions

In order to study neutrino-nucleus interactions in the few GeV energy region we considered a constant neutrino flux that was passed through a near detector geometry. We used GENIE Monte Carlo event generator both to study neutrino interactions and to feed the generated events into the Monte Carlo simulated detector. In the studied energy range deep inelastic scattering interactions are predominantly and fully dominate at higher neutrino energies. The present study is useful for improving underground detectors discovery potential for determining the neutrino properties.

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