Measurement of neutrino interactions in gaseous argon with T2K

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Measurement of neutrino interactions in gaseous argon with T2K

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Abstract. The T2K near-detector, ND280, employs three large argon gas TPCs (Time Projection Chambers) for particle tracking and identification. The gas inside the TPCs can be used as an active target to study the neutrino interactions in great detail. The low density of the gas leads to very low track energy thresholds, allowing the reconstruction of very low momentum tracks, e.g. protons with kinetic energies down to $\mathcal{O}(1\,\mathrm{MeV})$. Since different nuclear interaction models vary considerably in their predictions of those low momentum track multiplicities, this makes neutrino interactions on gases a powerful probe to test those models. The TPCs operate with an argon-based gas mixture (95% by volume) and have been exposed to the T2K neutrino beam since the beginning of the experiment in 2010. Due to the low total mass of the gas, neutrino argon interactions happen only rarely, compared to the surrounding scintillator-based detectors. We expect about 600 such events in the recorded data so far (about 200 in the fiducial volume). We are able to separate those events from the background and thus demonstrate the viability of using gaseous argon as a target for a neutrino beam. This enables us to do a cross-section measurement on gaseous argon, the first measurement of this kind. All previous neutrino cross-section measurements on argon were performed in liquid argon TPCs.

1. T2K and the ND280 near detector

The long-baseline neutrino experiment T2K uses the near detector ND280 – 280 m downstream from the accelerator's graphite target – to measure the intensity and composition of its neutrino beam at the source. It consists of scintillation detectors, e.g. P0D, FGDs and ECALs, and three TPCs inside a magnet yoke. The scintillators provide the target material for the neutrinos, while the TPCs are instrumental in identifying the different particles (see table 1) [1].

Table 1. TPC technical data

Gas mixture (by volume)	Ar (95%), CF (3%), iC4H10(2%)
Gas density	~ 1.74 g/l (varies with T,p)
Fiducial volume	$\sim 3 \times 1\,\mathrm{m}^3$
Expected number of neutrino interactions (in FV) in current data ($\sim 7 \times 10^{20}$ protons on target each)	~ 600 (~ 200) in neutrino mode, ~ 120 (~ 40) in anti-neutrino mode

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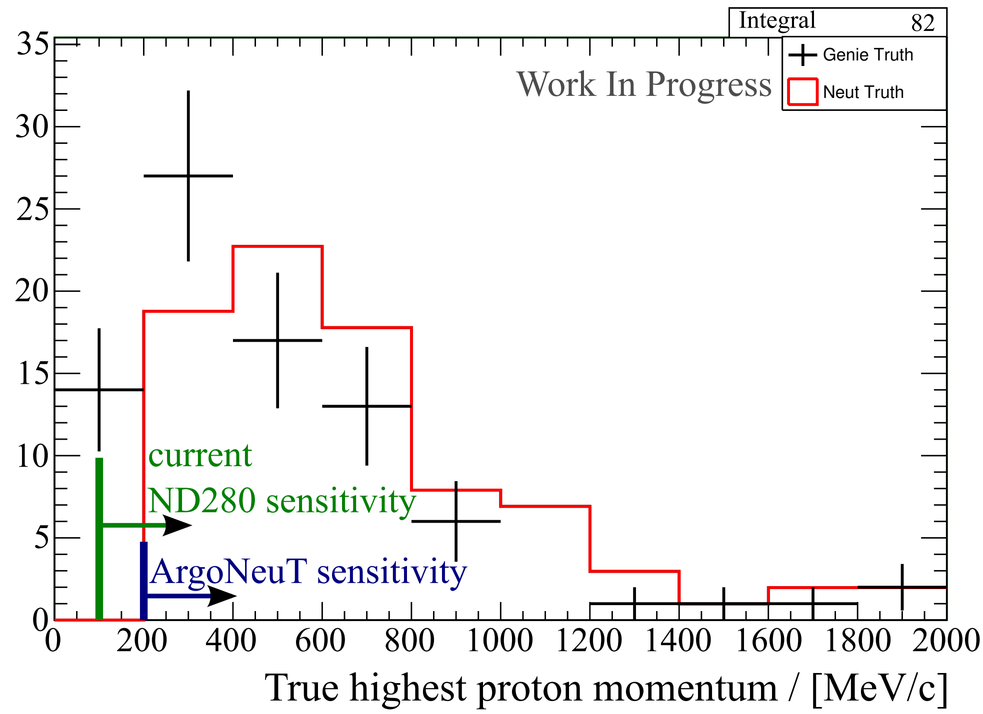

Figure 1. Comparison of predicted proton momenta between event generators. The neutrino event generators Neut[3] and Genie[4] differ in their predictions of proton multiplicities, especially in the low-momentum region. The Neut data is area normalized to the Genie data. Previous cross-section measurements performed by the ArgoNeuT collaboration had a proton momentum threshold of 200 MeV/c [2]. The current threshold in the gaseous TPCs of ND280 lies at 100 MeV/c and is expected to reduce with improvements of the reconstruction software.

2. Nuclear interactions

Nuclear effects, e.g. nucleon correlations and final state interactions (FSI), are one of the dominant sources of systematic uncertainties for oscillation analyses. They can produce low-momentum particles that are invisible to the detectors and thus lead to a misreconstruction of the neutrinos' energy. Since these low-momentum particles currently cannot be measured, the influence of the nuclear effects has to be modeled and simulated.

3. Neutrino gas interactions inside the TPCs

The gas inside the TPCs can be used as an active target to study the neutrino interactions in great detail. The low density of the gas leads to very low track energy thresholds, allowing the reconstruction of very low momentum tracks, e.g. protons with kinetic energies down to $\mathcal{O}(1\,\mathrm{MeV})$. To achieve this, a new 3D reconstruction algorithm was implemented.

4. Generator models

Different nuclear interaction models have substantial differences in their predictions of low momentum track kinematics (see figure 1). This makes neutrino interactions on gases a powerful probe to test and constrain them. ND280 is currently able to identify protons down to a momentum of 100 MeV/c. This limit is expected to reduce to about 60 MeV/c with improved reconstruction and particle identification methods.

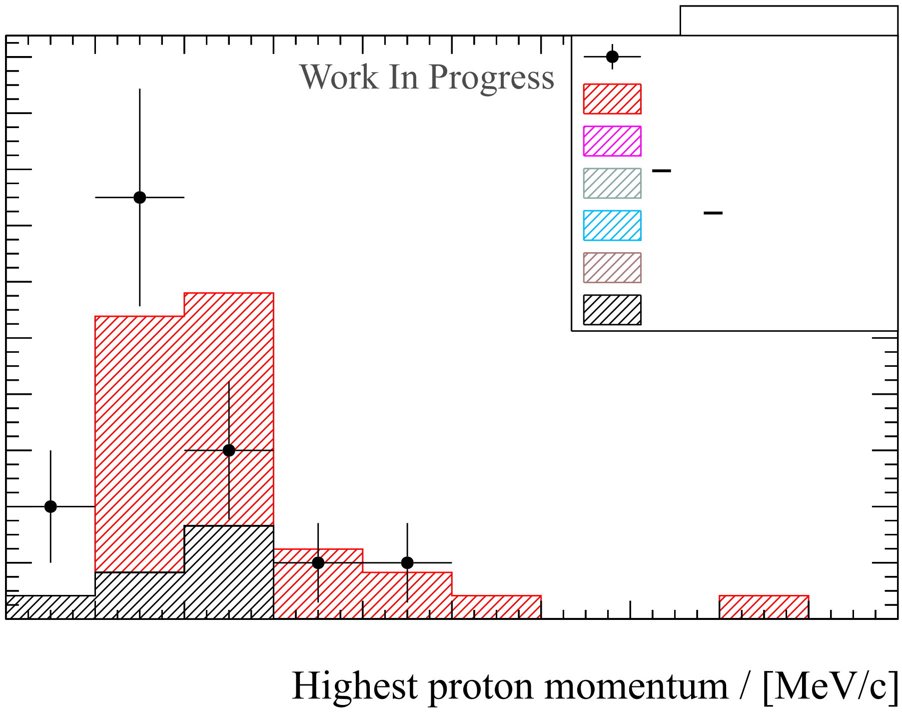

Figure 2. Fake data distribution of proton momenta. The fake data was generated with the event generator Genie. The Monte Carlo was generated with the event generator Neut. The error bars show statistical errors only. The Neut data is area normalized to the Genie data.

5. Selection performance

We perform a charged-current inclusive selection of neutrino interactions in the TPCs:

$$\nu_\mu + N \rightarrow \mu^- + X.$$

The achieved total purity is about 55% and the efficiency about 45%. The numbers are identical for both the Neut and Genie generators, within the statistic uncertainties of the Monte Carlo samples that have been looked at so far. The selection looks for events with a muon starting in the TPC FV. The main background consists of muons entering the TPCs from the outside and the reconstruction misidentifying a vertex along its track.

A Monte Carlo study of the selection can be seen in figure 2. It compares the reconstruction and selection results between Genie 2.8.0 and Neut 5.3.2 Monte Carlo data. The amount of data in each sample corresponds to $\sim 40\%$ of the amount of real data available for the final analysis.

6. Conclusion

The ND280 TPCs offer a unique opportunity to study nuclear effects in neutrino interactions with a very low detection threshold for the product particles. We are able to separate the gas interaction events from the background and perform a charged-current inclusive selection. This will enable us to test the kinematic predictions of different nuclear models.

References

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