

Measurement of π -nuclei interactions PIA ν O-Harpsichord

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Abstract. We introduce a new experiment to measure cross sections of interactions between charged pions and nuclei (^{12}C and ^{16}O). The current analysis status and future plans are also explained.

1. Introduction

The latest T2K result [1] shows an indication of $\nu_\mu \rightarrow \nu_e$ oscillation via non-zero θ_{13} . If θ_{13} is relatively large, it is possible to measure θ_{13} precisely and discover δ_{CP} in the near future. In this case, the precision on the θ_{13} measurement by T2K will be systematics dominated, where one of the major sources of systematic error is the uncertainty on pion-nucleus interaction cross sections [1]. Thus, we performed a new experiment to precisely measure these cross sections.

In interactions of low energy (sub-GeV) neutrinos, predominant in the T2K beam, the pion production probability through the delta resonance is relatively high. Thus, the understanding of interactions of these pions with matter is important to reduce the systematic error for the T2K measurement. The uncertainty is present at two levels: within the target nucleus of the primary neutrino interaction (FSI: final state interaction), and at the detector level with secondary interactions of pions that emerge from the target nucleus. However, data from past experiments that are used to constrain the π -nuclei transport model in the T2K simulation have 20-30% uncertainties in the absorption cross section around 100-400 MeV/c pion momentum. Therefore, our first goal is to measure the π -nuclei absorption and charge exchange cross sections using a newly developed scintillator tracker with an uncertainty less than 10%. The results of our measurement will improve the uncertainty on the neutrino interaction simulation significantly. For example, the error contribution from π FSI, to the expected number of T2K ν_e events is currently 10%. This uncertainty will be improved to 5% if our goals are achieved. In addition, better understanding of pion propagation in our detector materials will improve both the near and far detector systematic uncertainties for T2K.

2. Experimental setup

Our data was taken at the M11 beamline in TRIUMF, fed by a 500 MeV proton cyclotron. At M11, we can obtain secondary particles such as pions, muons and electrons from collisions between the proton beam and target (secondary protons are also present in higher beam momentum settings). Pions can be selected with purity of more than 99% in our analysis by using information of TOF(time-of-flight) and the Cherenkov detector (Fig. 1). The momentum

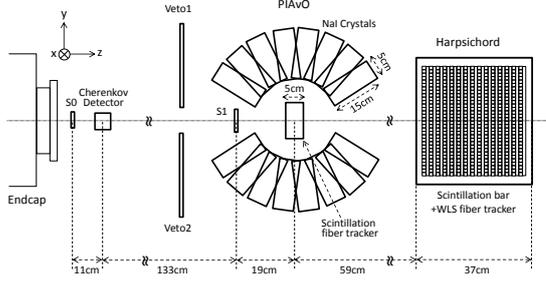


Figure 1. Experimental setup (configuration A)

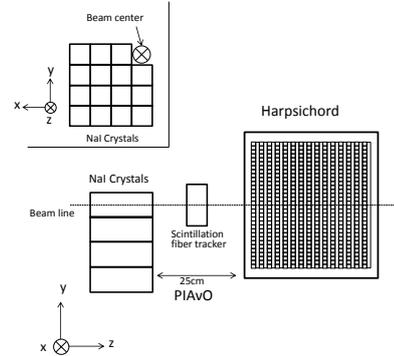


Figure 2. PIA ν O and HARPSICHORD in configuration B

of beam particles can be selected by changing the current of magnets in the beamline. In this measurement, we took mainly π^+ data from 150 MeV/c to 375 MeV/c in steps of about 25 MeV/c during a period from October to December, 2010.

Figure 1 shows the overall setup. There are two main components. One is PIA ν O (PIon detector for Analysis of neutrino Oscillation), and the other one is HARPSICHORD (HADron Reconstruction Performance Studies In CH On Reduced Detector). A trigger is generated by the coincidence of a beam particle passing through the S0 and S1 scintillators. The particle then enters the PIA ν O scintillation fiber tracker. This tracker is a fully active target. While most π^+ s penetrate the tracker, about 10% of π^+ interact via elastic and inelastic scattering, absorption or charge exchange. The final state for each interaction is as follows: there is only a π^+ after elastic scattering, π^+ and nucleons after inelastic scattering, no π^+ and zero or more nucleons after absorption, and a π^0 and zero or more nucleons after charge exchange. Therefore, the tracker is required to observe all particle tracks and identify the particle types to categorize the interaction types. Since π^0 cannot be observed in the tracker, we installed NaI detectors surrounding the tracker to detect γ from the decay of π^0 for separation of absorption and charge exchange events. HARPSICHORD is downstream of PIA ν O and consists of removable lead plates sandwiched between scintillator tracking planes. When the lead plates are installed, HARPSICHORD acts as another π^0 detector together with the NaI detectors.

2.1. Configurations of PIA ν O and HARPSICHORD

There are two configurations as shown in Fig. 1. In configuration A, 16 NaI detectors are installed around the scintillator fiber tracker, and lead plates are not installed in HARPSICHORD. From this configuration, the angular distribution of γ of π^0 from charge exchange interactions can be measured. The measured angular distribution can be cross-checked with configuration B as shown in Fig. 2. Since it is expected that γ are mostly emitted in the forward and backward direction, configuration B can give more statistics for charge exchange events due to the larger solid angle of HARPSICHORD with lead plates.

2.2. PIA ν O

In order to make a super fine grained tracker to observe all tracks, the PIA ν O tracker is composed of 1024 of 1.5 mm square scintillation fibers. The tracker has 16 tracking planes (x and y layers in

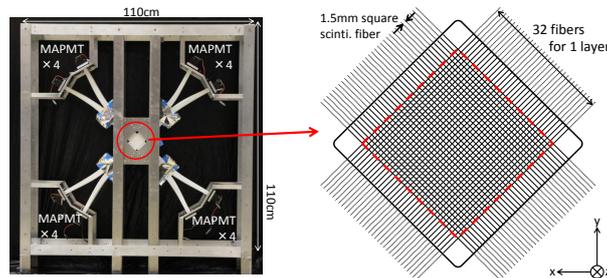


Figure 3. Photo of the PIA ν O tracker and drawing of the detector volume (red dashed line).

one plane). One layer consists of 32 fibers as shown in Fig 3. Each fiber is coated by about $25 \mu\text{m}$ thickness reflective paint (EJ-510). One end-face of a fiber is coated by evaporated aluminum, and the other end-face is connected to one channel of a 64 channel multi-anode PMT (MAPMT: Hamamatsu H8804). We use 16 MAPMTs in total. Signals are recorded by DAQ electronics recycled from the SciBar detector [2]. The detector volume of the tracker is $5 \text{ cm} \times 5 \text{ cm} \times 5 \text{ cm}$. Each NaI detector is a $5 \text{ cm} \times 5 \text{ cm} \times 15 \text{ cm}$ NaI crystal connected to a 38mm (1.5 inch) PMT (Hamamatsu:R580).

2.3. HARPSICHORD

HARPSICHORD is composed of 960 $1 \text{ cm} \times 1 \text{ cm} \times 30 \text{ cm}$ scintillator bars. A wave length shifting fiber, inserted in each bar, is coupled to a Multi Pixel Photon Counter (MPPC). The same DAQ system as that of Fine Grained Detector (FGD), which is one of near detectors for T2K, is used [3]. HARPSICHORD has 15 tracking planes and one layer consists 32 bars. Removable lead plates ($\sim 1.4 \text{ mm}$ thickness) are installed between each tracking plane in configuration B to increase the conversion rate of γ .

3. Analysis status

Event reconstruction is applied to find an incident track, an interaction point (vertex), and secondary tracks. Then, particle identification of each track is determined by dE/dx of the track. The algorithm of the reconstruction is as follows. The first step is to search for an incident track. Assuming a horizontal incidence, a straight-line trajectory which includes the maximum number of hits is chosen as an incident track. The angle of the incident track is fitted by a least squares method using the selected hits. A secondary track is found by searching for a track which starts from near the end point of the incident track and has the most number of hits along it. The cross point of the incident track and the secondary track is assigned as the event vertex.

After reconstruction, absorption or charge exchange events can be selected as follows. 1) Events which have a good incident track are selected. The criteria of a good incident track is that the incident position is within the tracker's fiducial volume and the incident angle is within $\pm 4^\circ$ for both the x and y directions (Fig. 4). 2) Events which have a vertex within the fiducial volume are selected. 3) Events which have no π^+ secondary track are selected. At this stage, both absorption and charge exchange like events are selected. 4) To isolate charge exchange events, events with large NaI hits or shower like tracks in HARPSICHORD are selected.

The left plot in Fig. 5 shows the vertex z distribution in the 250 MeV/c beam momentum run after the fiducial volume cut. The fiducial volume is indicated by the arrows in the figure. The right plot in Fig. 5 shows the fraction of events after the fiducial volume cut to the total number of events which have a good incident track as a function of the beam momentum. A

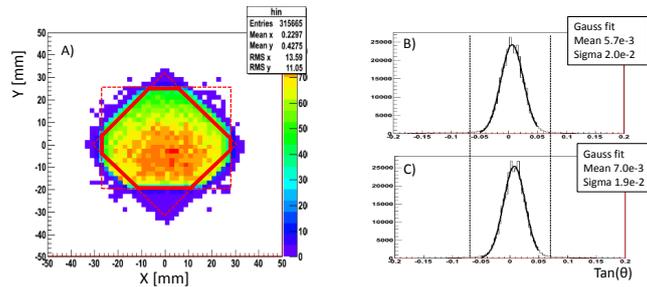


Figure 4. The distributions of incident position (A), x direction (B), and y direction (C) (250 MeV/c, data). The red solid area in (A) shows the fiducial volume in x-y plane

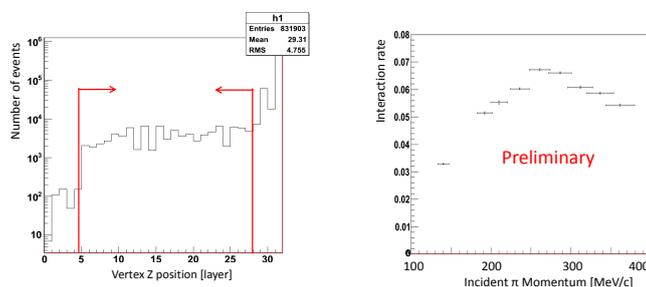


Figure 5. *Left:* The distribution of z position in 250 MeV/c (data). *Right:* The interaction rate as a function of beam momentum (data).

clear Δ resonance peak can be seen.

4. Future plan

We plan to complete this data analysis and measure the cross sections by the end of 2011. Following that, we will evaluate how much our result can constrain T2K's neutrino interaction model, and update the systematic error contribution from the uncertainty in pion interaction cross sections. We hope that the updated model and systematic error will be ready for T2K analysis in 2012. In addition to the data taken in the last year, we took data with a water target in August of this year. The analysis of the water target will be released as soon as possible.

5. Conclusion

Precise measurements of the interaction of charged pions in a nuclear medium are very important for reducing systematic uncertainties in neutrino experiments. Therefore, we started a new experiment using the pion beam at TRIUMF. Our goal is to measure the absorption and charge exchange cross sections separately within 10% uncertainty. In order to achieve this goal, we developed two new detectors: PIA ν O and HARPSICHORD. The results from both the scintillator target and the water target will be completed soon to improve the T2K analysis in 2012.

References

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