PROCEEDINGS OF SCIENCE

Kaon production in charged-current neutrino interactions in the T2K near detector

Katarzyna Kowalik* **for the T2K Collaboration**

National Centre for Nuclear Research,
Pasteura 7, Warsaw, Poland

E-mail: Katarzyna.Kowalik@ncbj.gov.pl

Studies of kaon production in accelerator-based neutrino experiments provide an important constraint on a K^+ production by atmospheric neutrinos in proton decay searches. Current neutrino-nucleus event generators largely rely on theoretical models for the descriptions of backgrounds due to kaons and need to be verified by measurements.
At neutrino energies below 2 GeV, the event rate for processes with a K^+ production is low as compared to pion production channels because of Cabibbo suppression and the relatively large kaon mass. At higher neutrino energies, a different production mechanism dominates, where K^+ is always accompanied by another strange particle to conserve the strangeness.
T2K searches for charged-current neutrino interactions that produce a K^+ in the final state in the Fine Grained Detector, a scintillator-based tracking calorimeter, within the T2K near detector ND280. Events with a K^+ are identified in T2K by studying the energy deposition of tracks in the Time Projection Chamber. These proceedings discuss the K^+ sample selection together with the method used to estimate the backgrounds and evaluate a single-bin cross section.

41st International Conference on High Energy Physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

*Speaker

PoS(ICHEP2022)999

1. T2K Experiment

T2K (Tokai to Kamioka) is a long-baseline neutrino experiment [1] in Japan designed to measure neutrino oscillations parameters by studying the $\nu_\mu(\bar{\nu}_\mu)$ disappearance and the $\nu_e(\bar{\nu}_e)$ appearance in the $\nu_\mu(\bar{\nu}_\mu)$ initial beam at the far detector.

The near detectors, located about 280 meters from the beam production point at the J-PARC accelerator complex in Tokai, are designed to constrain the beam composition and the neutrino interaction models. At a distance of 295 km further away, the oscillated beam is measured by the far detector Super-Kamiokande, 22.5 kt fiducial volume water Cherenkov detector situated in Kamioka mine, known also for proton decay searches and studies of neutrinos from other sources [2].

At J-PARC, the ν_μ beam production begins with 30 GeV protons hitting the graphite target. The positively charged mesons (mainly π^+ but also K^+) coming out from such interactions are then focused by three magnetic horns before they decay in flight to produce neutrinos. By reversing the polarity of the horns, the negatively charged particles are selected resulting in predominately the $\bar{\nu}_\mu$ beam.

T2K is the first neutrino oscillation experiment to use the off-axis technique. The beam is directed 2.5° off-axis with respect to the Super-Kamiokande direction. This method results in a narrow-band neutrino beam with a flux peaking at an energy of ~0.6 GeV, maximizing the oscillation probability.

2. The T2K near detectors

The T2K near detector complex consists of several detectors that probe the neutrino spectra at different energies. The ND280 detector is situated at 2.5° off-axis angle, WAGASCI is also off-axis detector at 1.5° and the INGRID detector is located on-axis.

This analysis is based on the ND280 detector. Its central part is composed of the π^0 detector, two Fine Grained Detectors (FGD) sandwiched between three Time Projection Chambers (TPC). The detector is surrounded by an electromagnetic calorimeter and a 0.2T magnet. FGDs consist of layers of plastic scintillators and are used as tracking detectors as well as targets for neutrino interactions. FGD1 is purely made of hydrocarbon while FGD2 contains additional water layers. TPCs are high-resolution tracking detectors providing particle identification based on the energy loss dE/dx and are capable of measuring particle momentum and charge from a track curvature in the magnetic field.

3. K^+ Sample Selection in ND280

Events of interest have at least a negative muon, a positive kaon ($\nu_\mu CC1K^+$) and a vertex in FGD1. There are no restrictions placed on the presence of other particles.

The K^+ selection is based on the particle identification in TPC2 situated downstream from FGD1. The selection is valid for K^+ momentum below ~1.0 GeV/c since at higher momentum kaons are indistinguishable from other particles. TPC PID selections require a high K^+ likelihood and a low likelihood of other particles. Additional phase-space restrictions are applied to address the rapid change in acceptance at low K^+ momentum below ~0.4 GeV/c because K^+ needs to have enough energy to reach TPC2. The phase-space restrictions are also applied for the muon and kaon angle. The selection purity is ~50% while the efficiency ~15% based on GENIE [3] version 2.8.0. Fig. 1 shows selected sample as a function of the K^+ reconstructed momentum and angle split by true particle type.

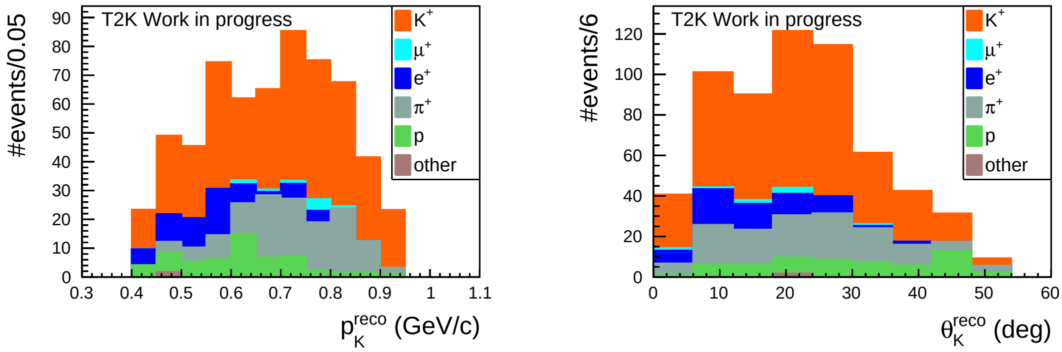

Figure 1: The reconstructed K^+ momentum (on the left) and angle (on the right) broken by the particle type are shown for GENIE. The sample used is about 10 times bigger than the T2K neutrino data sample.

Together with the signal sample, control samples are defined to constrain the main backgrounds to the selected signal. Fig. 1 shows these backgrounds are mostly due to pions and positrons being misidentified as kaons. There is also smaller contribution coming from protons. Two control samples are defined by inverting the lower and upper limits on the kaon pull thus selecting events with pions and positrons or protons just outside the signal region. The other two considered regions can be used to test the background extraction method, and are based on inverting either the cut on momentum or the cut on dE/dx. The former selects low momentum pions while the latter protons at high dE/dx.

4. Analysis strategy

The $\nu_\mu CC1K^+$ cross section is extracted in a single-bin due to the limited statistics. The phase-space for muon and kaon is restricted to minimize the model dependence. Backgrounds in the signal region are constrained by the fit between data and Monte Carlo for the control samples. The parameters describing various background contributions are then used to re-scale the corresponding true Monte Carlo backgrounds in the signal region.

The number of the K^+ signal events is calculated as a difference between a total selected events in data and estimated backgrounds. To get the single-bin cross section σ, the number of selected kaons N_K is then divided by efficiency correction ϵ, the number of targets T in FGD1 and the integrated T2K flux Φ:

$$\sigma = \frac{N_K}{\epsilon T \Phi}$$

The systematic uncertainties are obtained by repeating the cross section calculations for sets of Monte Carlo parameters describing variations in the detector and the cross section model as well as the T2K flux. The total systematic uncertainty, with the leading contribution coming from detector systematic, is smaller than the expected statistical error calculated for the T2K data sample collected with ν_μ beam so far.

A number of fake data studies have been performed to test the fitting method and the model sensitivity with different Monte Carlo generators. The modelling uncertainties are being finalized with a cross section result with the real data expected in the near future.

5. Outlook

The measurement of the K^+ production in the charged current ν_μ interactions is challenging at the T2K energies. Due to limited statistics, a single-bin cross section measurement is planned and the comparisons of kinematic distributions to existing models that differ by up to 30% in the number of predicted K^+ events.

There are a few existing K^+ production measurements. The first measurements, performed with bubble chambers [4–7], have even lower statistics. Recent measurement with large statistics for the K^+ production was reported by the Minerva [8] experiment at higher neutrino energies.

As a part of the ongoing ND280 detector upgrade, the π^0 detector will be replaced with a higher resolution FGD, surrounded by high angle TPCs and time of flight detectors [9]. The upgraded detector with a larger TPCs acceptance coverage and enhanced identification capabilities will help in the future to improve a K^+ kinematic coverage increasing the statistics of selected sample.

References

[1] K. Abe *et al.* [T2K], Nucl. Instrum. Meth. A **659** (2011), 106-135

[2] Y. Fukuda *et al.* [Super-Kamiokande], Nucl. Instrum. Meth. A **501** (2003), 418-462

[3] C. Andreopoulos, A. Bell, D. Bhattacharya, F. Cavanna, J. Dobson, S. Dytman, H. Gallagher, P. Guzowski, R. Hatcher and P. Kehayias, *et al.* Nucl. Instrum. Meth. A **614** (2010), 87-104

[4] S. J. Barish, M. Derrick, L. G. Hyman, P. Schreiner, R. Singer, R. P. Smith, H. Yuta, V. E. Barnes, D. D. Carmony and A. F. Garfinkel, *et al.* Phys. Rev. Lett. **33** (1974), 1446

[5] H. Deden, F. J. Hasert, W. Krenz, J. Von Krogh, D. Lanske, J. Morfin, M. Pohl, K. Schultze, H. Weerts and G. H. Bertrand-Coremans, *et al.* Phys. Lett. B **58** (1975), 361-366

[6] N. J. Baker, P. L. Connolly, S. A. Kahn, H. G. Kirk, M. J. Murtagh, R. B. Palmer, N. P. Samios and M. Tanaka, Phys. Rev. D **24** (1981), 2779-2786

[7] W. A. Mann, T. Kafka, M. Derrick, B. Musgrave, R. Ammar, D. Day and J. Gress, Phys. Rev. D **34** (1986), 2545-2553

[8] C. M. Marshall *et al.* [MINERvA], Phys. Rev. D **94** (2016) no.1, 012002

[9] K. Abe *et al.* [T2K], [arXiv:1901.03750 [physics.ins-det]]

PoS(ICHEP2022)999