Towards the cross-section measurement of the $\bar{\nu}_\mu$ CC single π^- production in the T2K near detector

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Introduction

- T2K [1] is a long-baseline neutrino oscillation experiment based in Japan.
- The experimental setup includes intense neutrino beam source and *off-axis* detectors: near detector ND280 and far detector Super-Kamiokande.

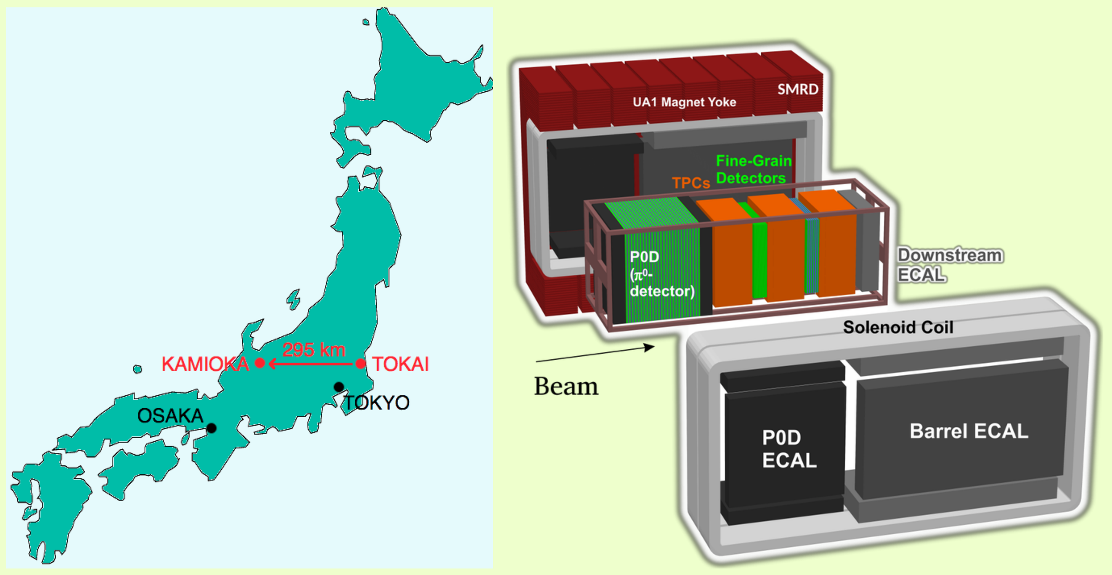

Figure 1: Left: Location of T2K experimental sites. Right: Cut-away drawing showing sub-detectors of ND280.

- **Goal of the presented analysis is cross section measurement of single π^- production $\bar{\nu}_\mu$ CC1π^-**, which occurs mostly via interactions with baryon resonance.
- Tracker part of ND280: scintillator detectors (FGD) interleaved with gaseous time projection chambers (TPC).
- Studies obtained using Monte Carlo corresponding to 8.9×10^{21} protons on target (POT) with the NEUT neutrino generator [2]. Data statistics correspond to 6.3×10^{20} POT.

Selection of $\bar{\nu}_\mu$ CC1π^- topology

- **Defined as a topology with one μ^+ and one π^- in the final state, with no other types of mesons:**

$$\bar{\nu}_\mu + \mathrm{N} \rightarrow \mu^+ + \pi^- + \mathrm{X}$$

- ND280 magnetic field enables charge identification and momentum reconstruction.
- TPC particle identification based on energy loss dE/dx allows for selection of π/μ-like tracks.
- **Selection: one track starting in FGD1 fiducial volume (FV) reconstructed as a μ^+ and the other track starting in FGD1 FV reconstructed as a π^-.** Possible signatures of selected events presented in Fig. 2.

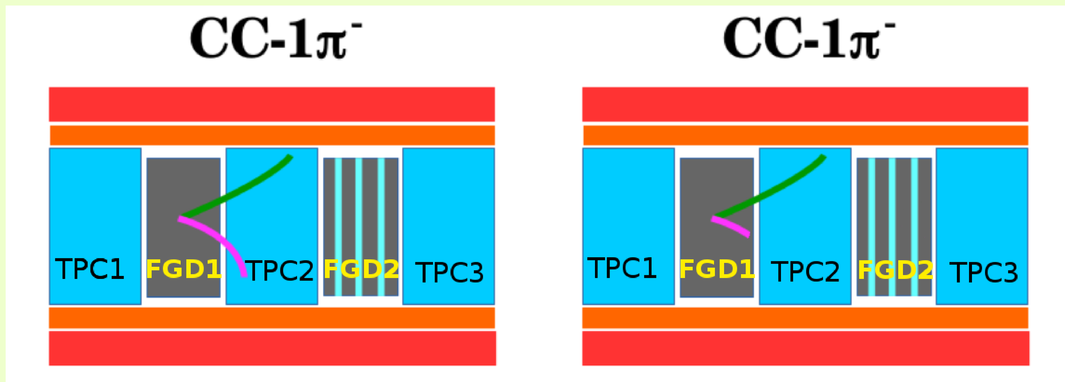

Figure 2: CC1π^- topology event in the ND280 tracker. Green track: μ^+ candidate - always with TPC segment. Purple track: π^- candidate. Left: π^- candidate containing a segment in TPC. Right: Event with an isolated track in FGD1 interpreted as π^-.

- **$\bar{\nu}_\mu$ beam contaminated with ν_μ**
- One of the main background topologies: ν_μ CC1π^+:

$$\nu_\mu + \mathrm{N} \rightarrow \mu^- + \pi^+ + \mathrm{X}.$$

- **$\mu^+\pi^-$ (signal) and $\mu^-\pi^+$ (background) events are difficult to distinguish due to the same μ/π-like energy loss.**
- **Additional cut based on range of the μ^+ and π^- candidates**: reconstructed μ^+ must reach further downstream parts of the tracker than π^-.
- 49.5% of selected events are true $\bar{\nu}_\mu$ CC1π^- signal. The selection efficiency is 20.6%.
- Total detector systematic uncertainty introduces a 4.1% relative error on the number of selected events.

Background control samples

- Background in the signal sample consists mostly of **events with multiple pions that were misidentified or not reconstructed or CC ν_μ interactions.**
- **Two background control samples** are chosen: CC1π^- sample with reversed range cut and a sample with π^+ candidate, multiple pion tracks or π^0 signature (CC-other sample).

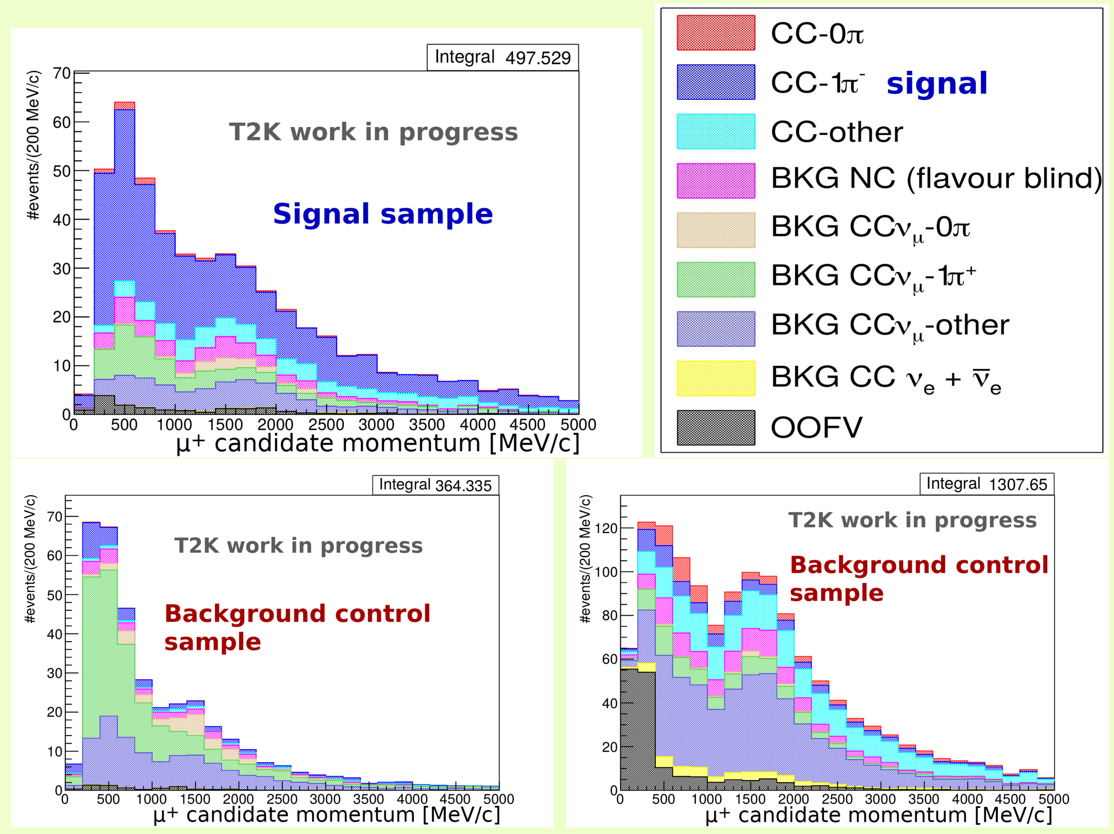

Figure 3: Distribution of reconstructed momentum of μ^+ candidate in the signal and background control samples. Colors indicate the true final state topology. Top: Signal CC1π^- sample. Bottom left: CC1π^- sample with reversed range cut. Bottom right: CC-other sample. Plots normalized to data POT.

Likelihood Fitter

- The cross-section will be reported as double-differential in μ^+ momentum and $\cos\theta$.
- **Restricted phase-space** presented in Fig. 4.

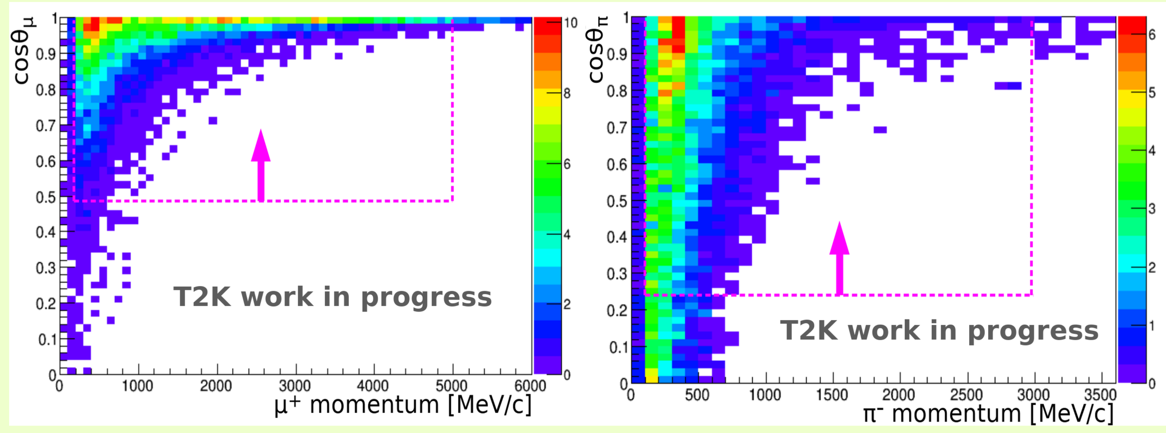

Figure 4: Distribution of signal events in $\cos\theta$ vs p. Dashed lines indicate phase-space restrictions. Left: True μ^+ kinematics. Right: True π^- kinematics.

- Extraction of the cross-section will be done by **template likelihood fit method**.
- Fit based on reweighting of MC events in each bin of the true phase-space.
- *Unfolding* provides mapping between the reconstructed phase-space and the true phase-space.
- Events distribution in the reconstructed phase-space fitted to data by minimazing a dedicated likelihood.

Status

- **Preliminary steps related to cross section measurement are essentialy finalized.**
- **Template likelihood fit method works properly in preliminary studies.**
- **Data not yet used.**

Preliminary fit results

- **Statistical fluctuations are applied to nominal Monte Carlo** (MC) in each bin of *reconstructed* phase-space.
- **Nominal MC sample is fitted to fluctuated MC sample.**
- Fit result expressed as the cross-section in true μ^+ momentum is presented in the Fig. 5.

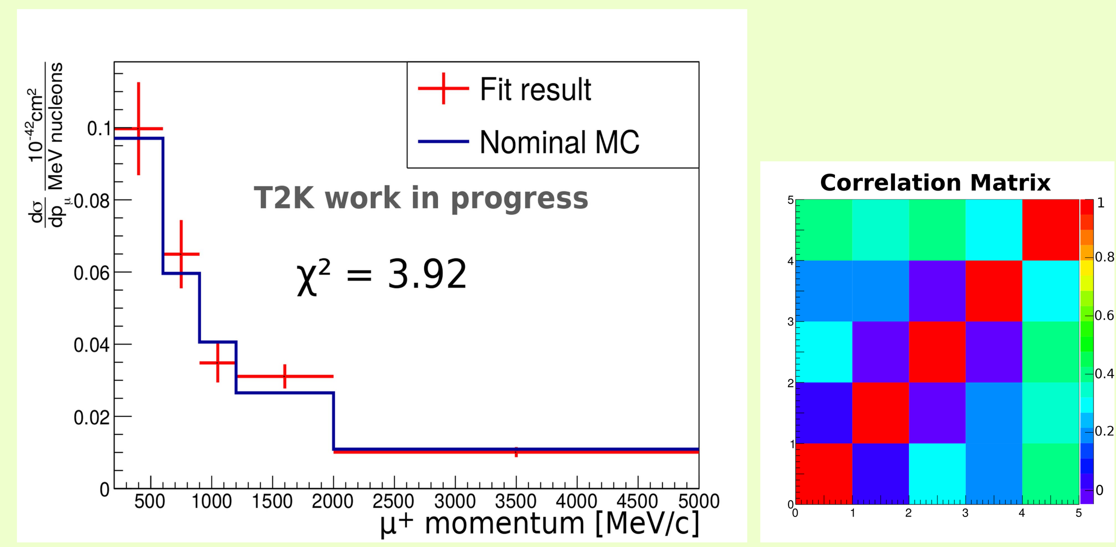

Figure 5: Left: Nominal cross-section proportional to distribution of signal events in true μ^+ momentum (dark blue line), fit result (red points). Right: Correlation matrix of reported cross-section in momentum bins.

Plans

- Before unblinding data **additional MC tests are necessary, including comparison of different MC generators.**
- Binning optimization will also be included.

References

[1] K. Abe *et al.* [T2K Collaboration], Nucl. Instrum. Meth. A **659** (2011) 106 doi:10.1016/j.nima.2011.06.067
[2] Y. Hayato, Acta Phys. Polon. B **40** (2009) 2477. Used version: NEUT 5.4.0