Neutron Selection using the T2K ND280 Electromagnetic Calorimeter

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IOP APP & HEPP CONFERENCE 2026

NEUTRINO SESSION

Overview

- The Tokai-to-Kamioka Experiment (T2K)
- Near Detector Samples
- Neutron Selection
- Applications within T2K

T2K Collaboration, November 2025

t2k.org

The Tokai-to-Kamioka Experiment

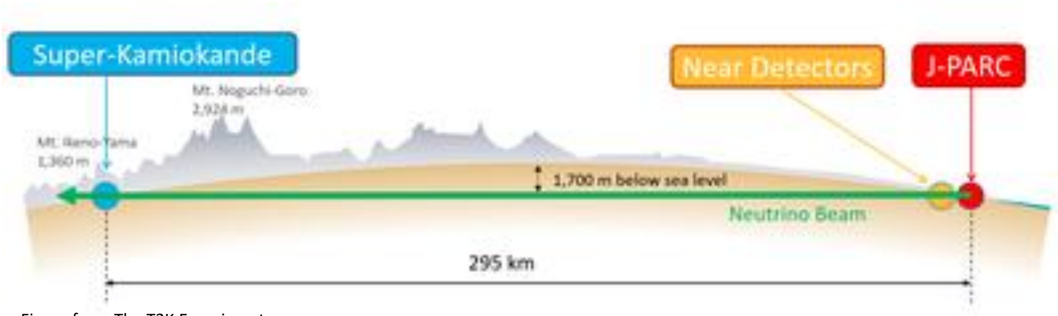

Figure from The T2K Experiment

(Anti)Neutrino beam production

- J-PARC

Near detectors at 280 m

- INGRID – on axis
- WAGASCI-BabyMIND – 1.5° off-axis
- ND280 – 2.5° off-axis

Far detector at 295 km

- Super-Kamiokande – 2.5° off-axis

The Tokai-to-Kamioka Experiment

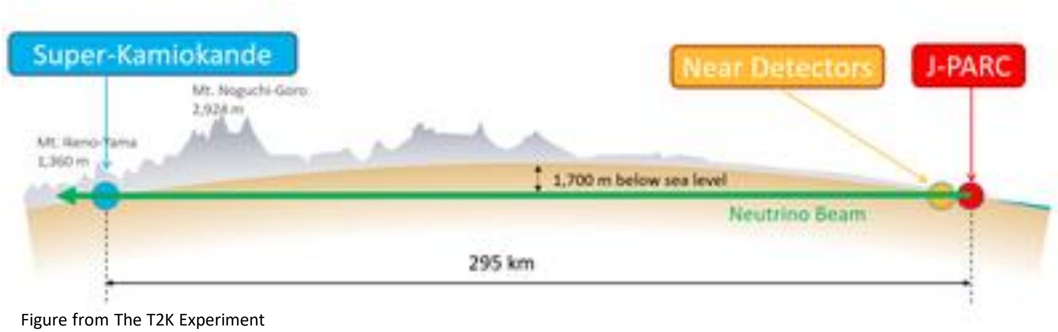

Figure from The T2K Experiment

ND280
Magnetised detector
Measure beam composition before oscillation
Constrains beam related model parameters
Neutrino interaction cross-section measurements

(Anti)Neutrino beam production

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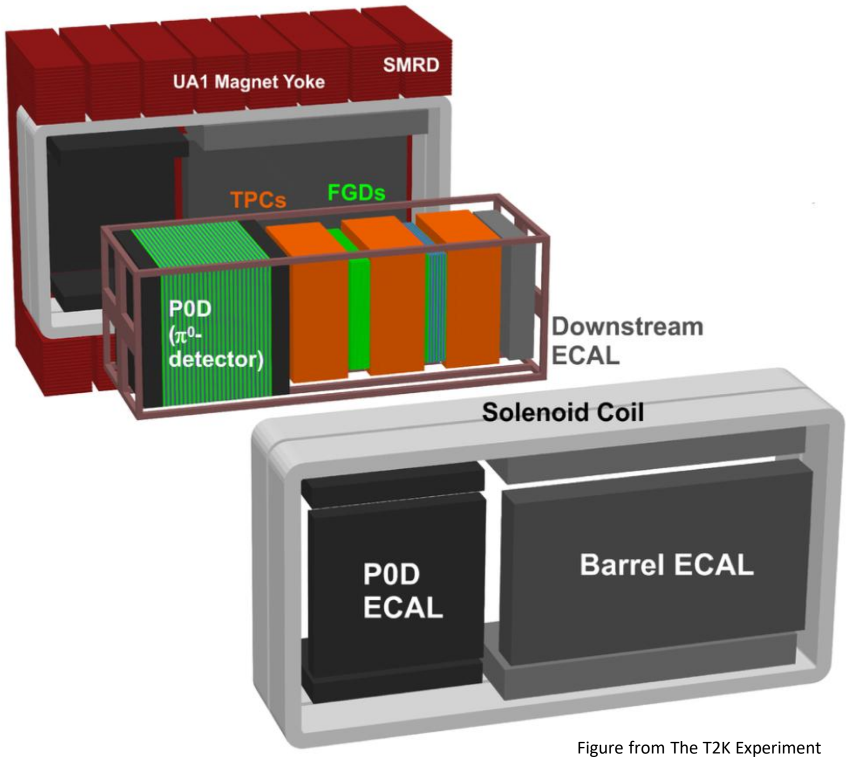

Figure from The T2K Experiment

The Tokai-to-Kamioka Experiment

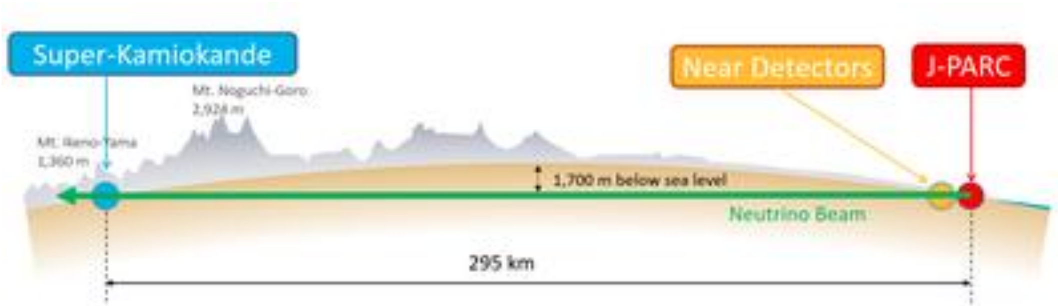

Figure from The T2K Experiment

Super-Kamiokande [1]
50 kt Gd-doped water Cherenkov detector [2]
Neutron capture capabilities
In the same beam as ND280
Measure beam composition at oscillation maximum

(Anti)Neutrino beam production

- J-PARC

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Far detector at 295 km

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Use inputs from near detector samples to constrain cross-section models, flux, and associated uncertainties

Differences in expected (assuming no oscillation) and observed composition allows measurements of oscillation parameters to be made

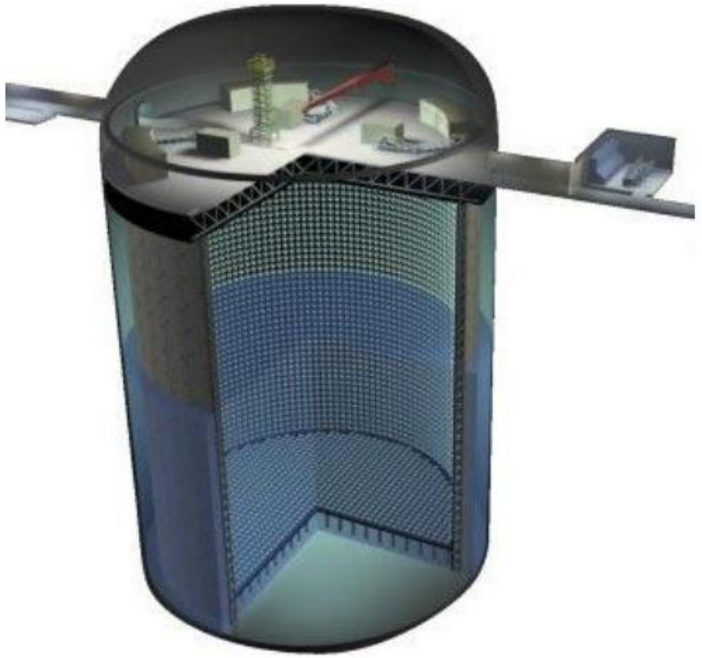

Figure from Recent Neutrino Oscillation Results from T2K 21ST RENCONTRES DU VIETNAM
https://ifirse.icise.vn/nugroup/nuview2025/docs/Latest%20oscillation%20results%20from%20T2K.pdf

[1] Nucl. Instrum. Meth. A501 (2003) 418-462
[2] Nucl. Inst. Meth. A 1065, 169480 (2024).

Near Detector Samples

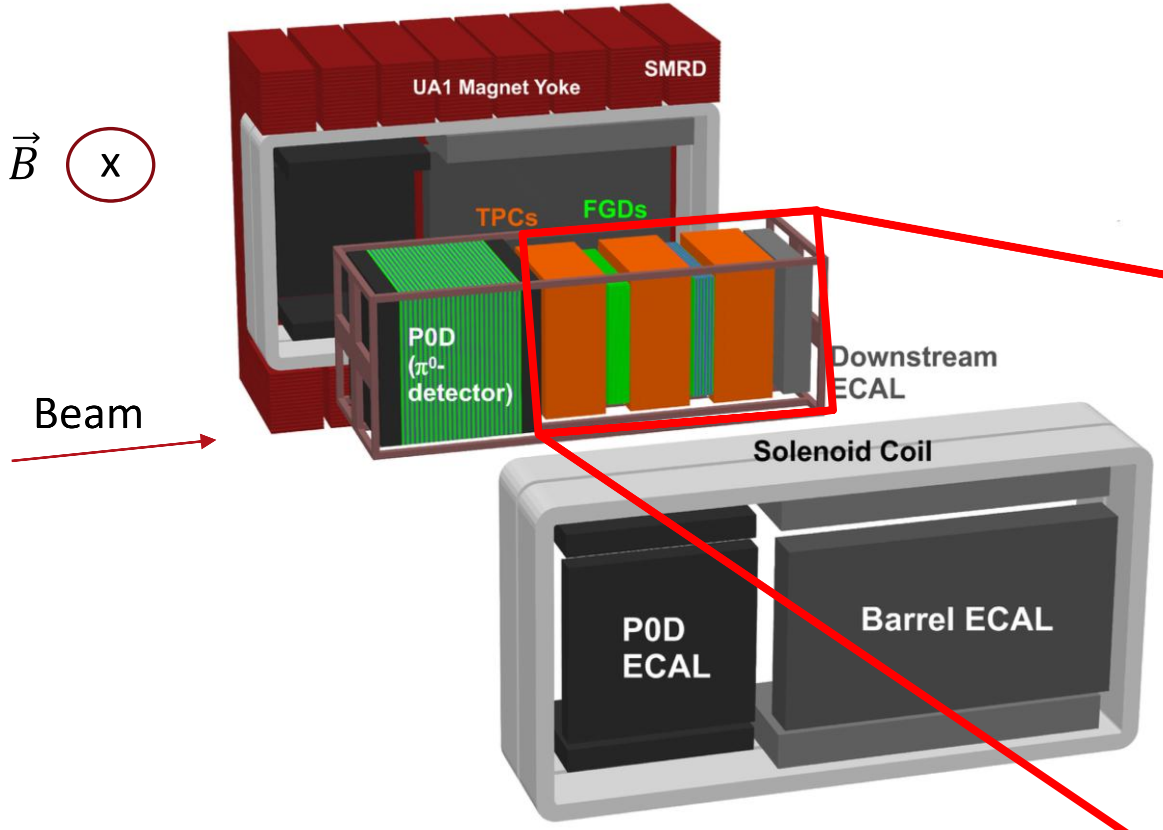

Figure from The T2K Experiment

Tracking system

C-H Interaction target: 2x Fine Grained Detector (FGDs)

Momentum measurements via track curvature: 3x Time Projection Chamber (TPCs)

Near Detector Samples

$\vec{B}$ x

Beam

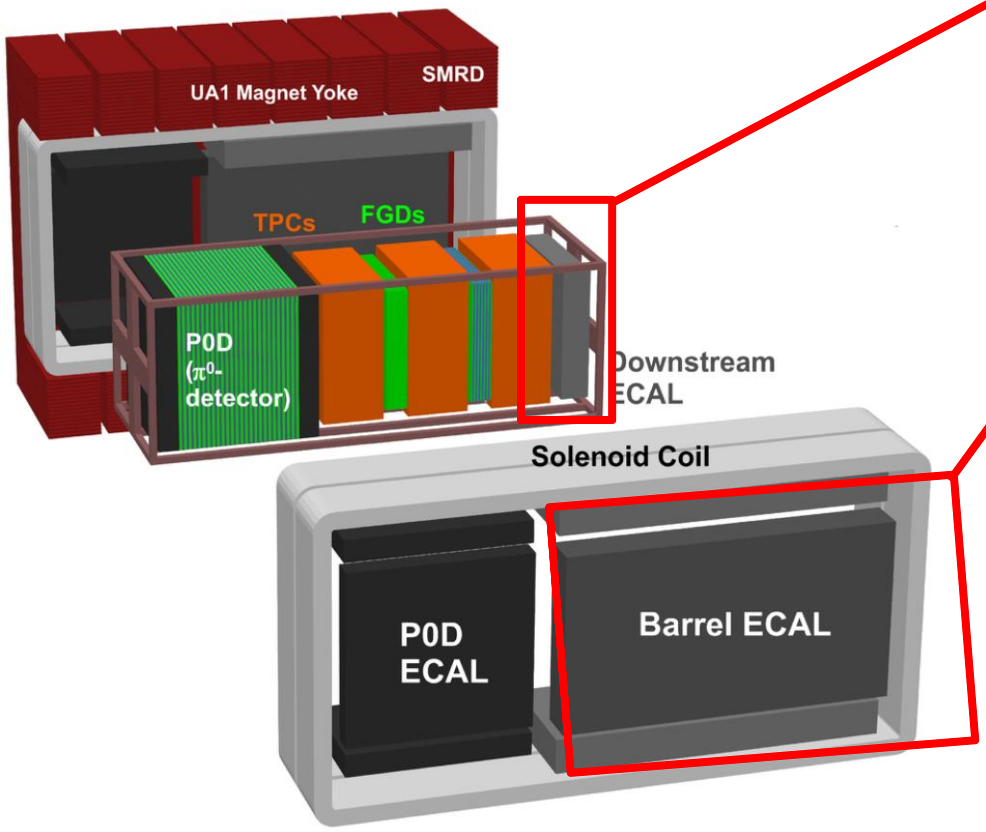

Figure from The T2K Experiment

Calorimetry

Particle ID: Barrel + Downstream Electromagnetic Calorimeter (ECal)
Primarily electron/photon discrimination

Tracking system

C-H Interaction target: 2x Fine Grained Detector (FGDs)

Momentum measurements via track curvature: 3x Time Projection Chamber (TPCs)

Near Detector Samples

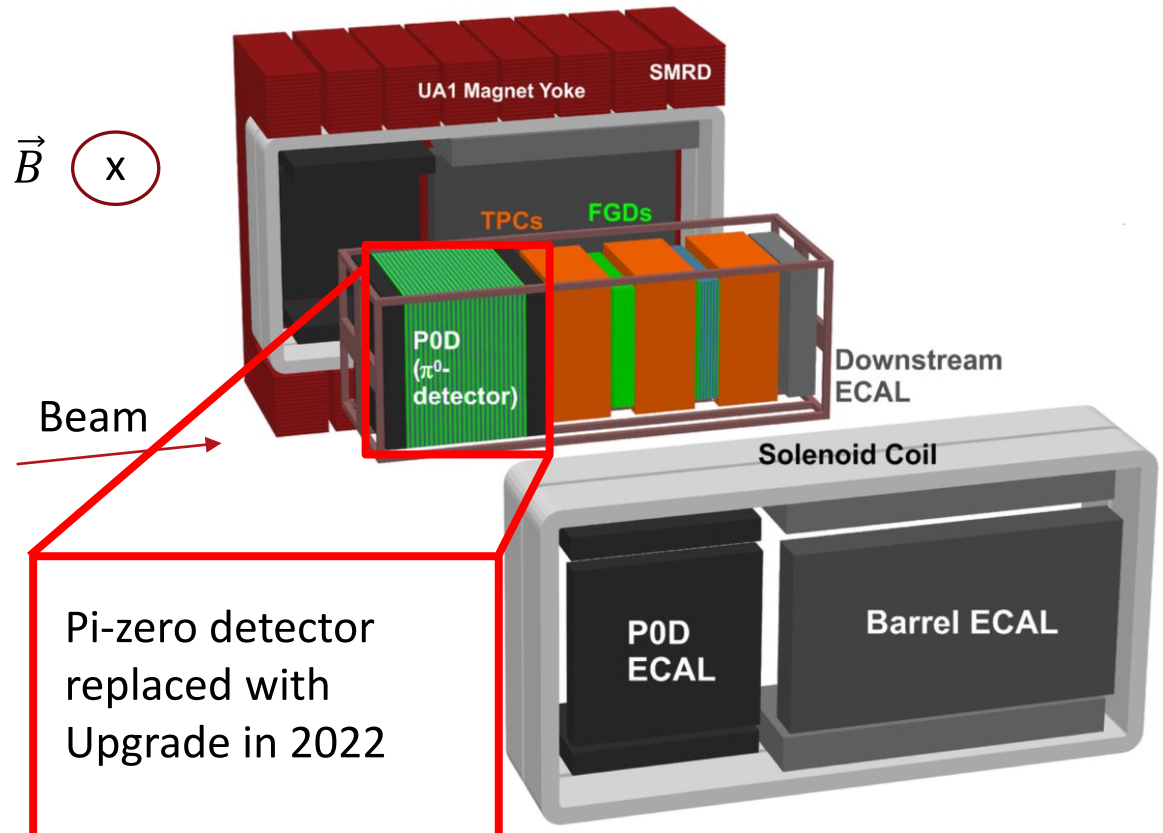

Figure from The T2K Experiment

Pi-zero detector replaced with Upgrade in 2022

Upgrade data is not used in the work presented in this talk

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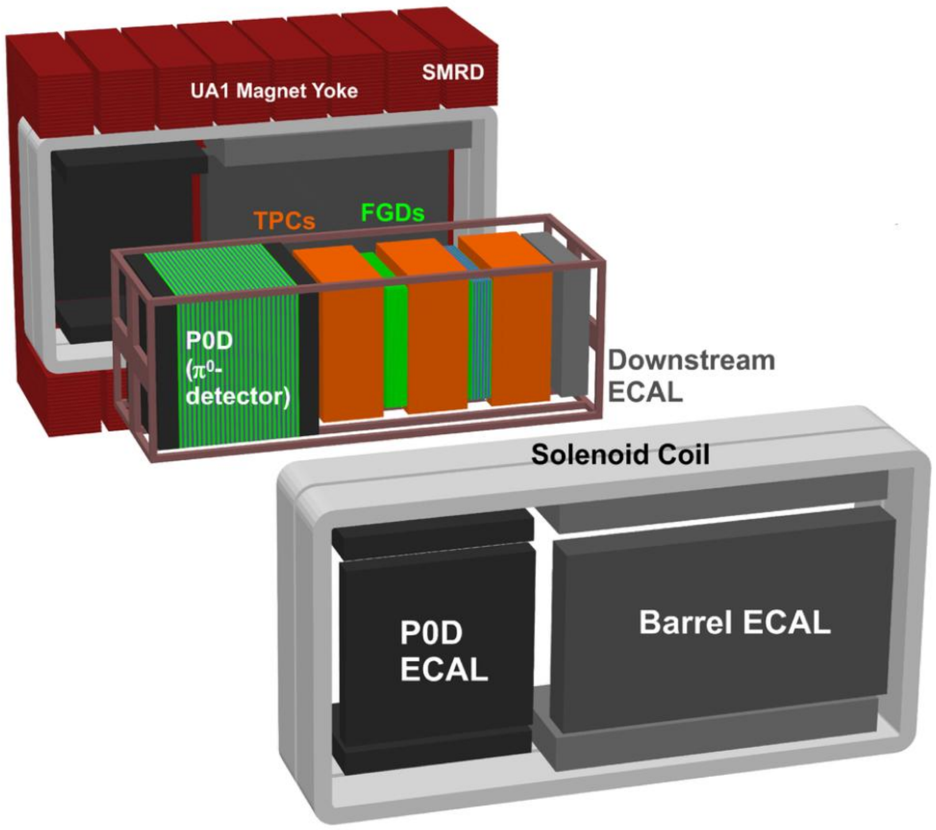


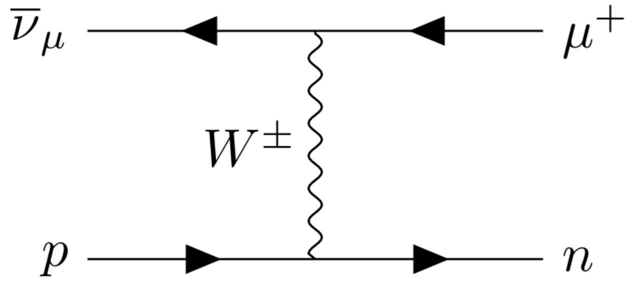
Figure from The T2K Experiment

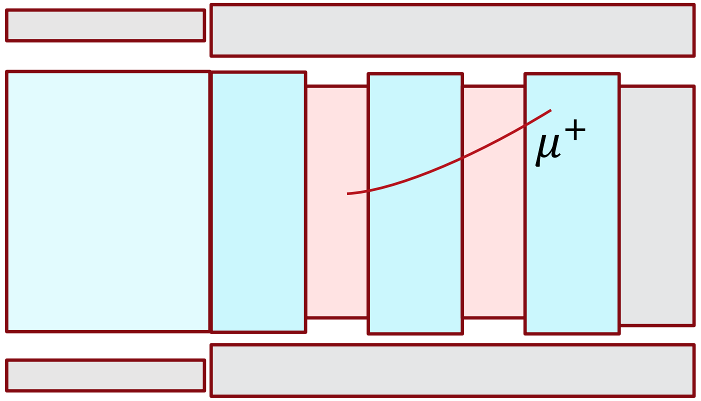
How do we make near detector samples?

- Separate neutrino interactions based on:
  - Neutrino flavour $(\nu_\mu, \bar{\nu}_\mu, \nu_e, \bar{\nu}_e)$
  - Number and PID of outgoing particles

The interaction: Charged Current Quasi Elastic (CCQE)

No pions in final state (CC0π)





- 1 long upward-curved track
- Muon-like in TPC
- No other signals

How can we use this to detect neutrons?

Neutron Production and Detection in ND280

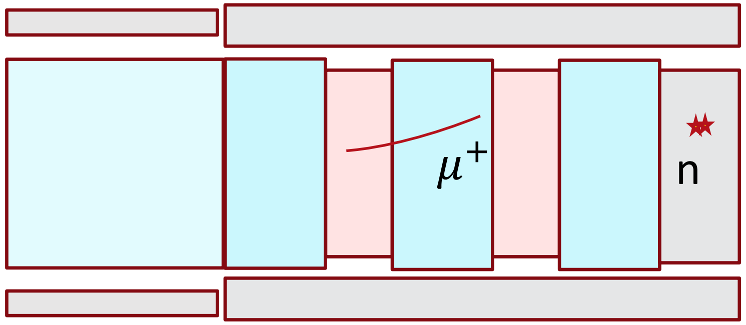
Neutrons are difficult to detect in detectors like ND280
No hadronic calorimeter

BUT…

Like photons, they may interact in the electromagnetic calorimeter to leave small charge deposits

We call these isolated electromagnetic calorimeter objects

From this we use the knowledge that neutrons will behave differently to photons to build a selection

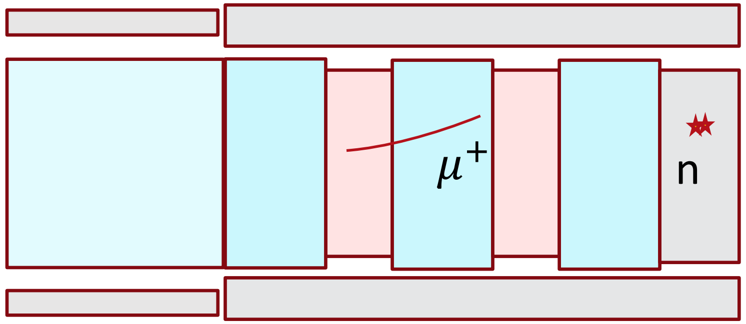


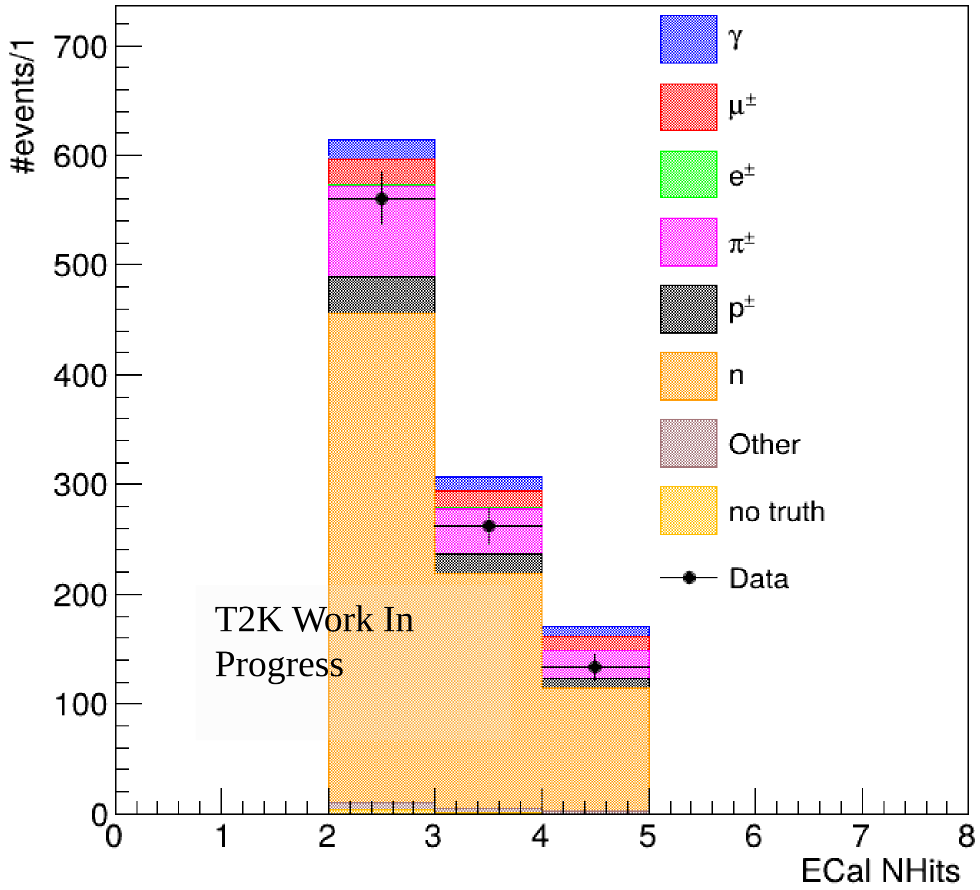
Neutron Production and Detection in ND280

Neutrons are more massive than photons

So neutrons will:

1. Deposit less energy in the ECal
   Leave fewer hits in the calorimeter





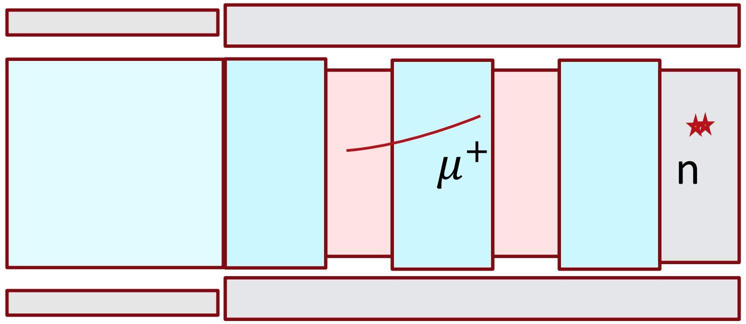
Number of hits in the ECal for selected neutron candidates

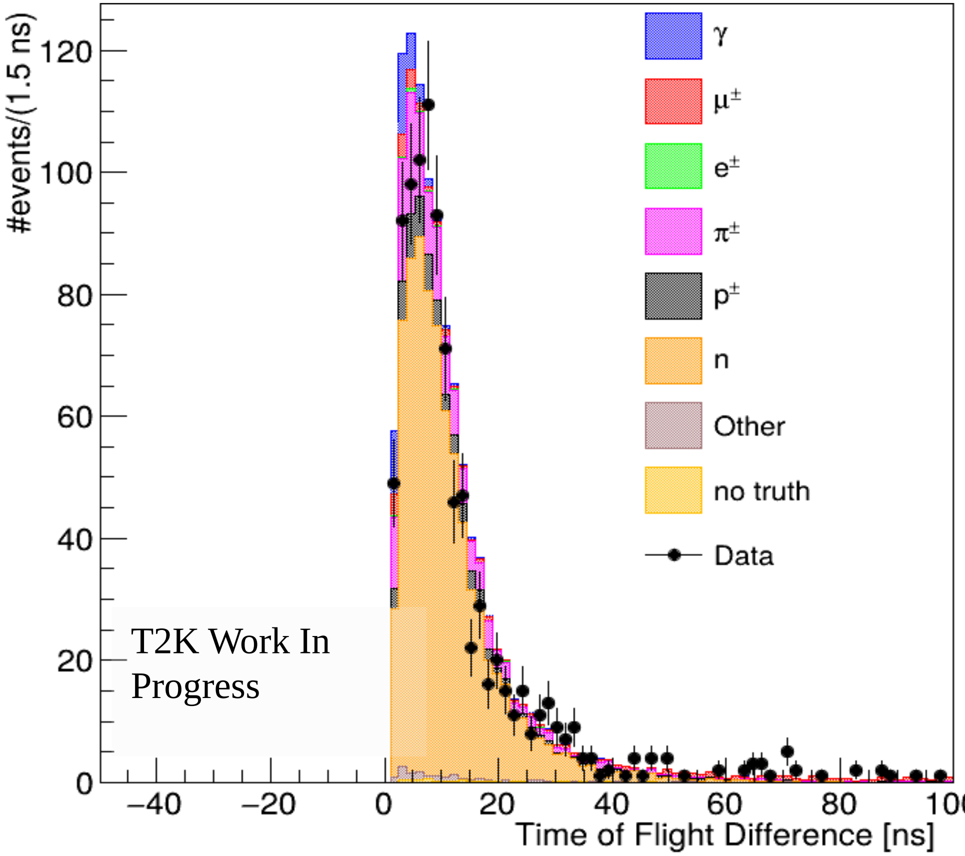
Neutron Production and Detection in ND280

Neutrons are more massive than photons

So neutrons will:

1. Deposit less energy in the ECal
   Leave fewer hits in the calorimeter
2. Travel more slowly through the detector
   Have a larger difference in inter-detector time stamps





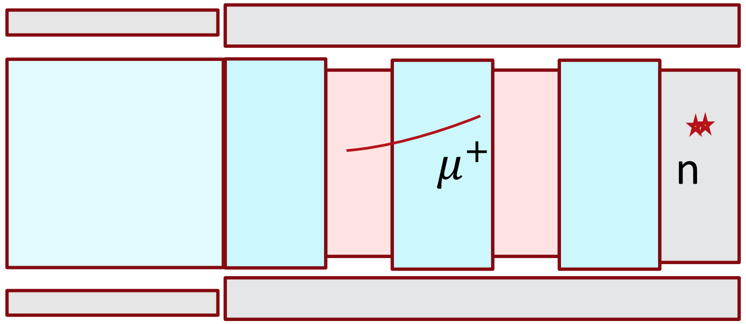
Time of flight difference for selected neutron candidates

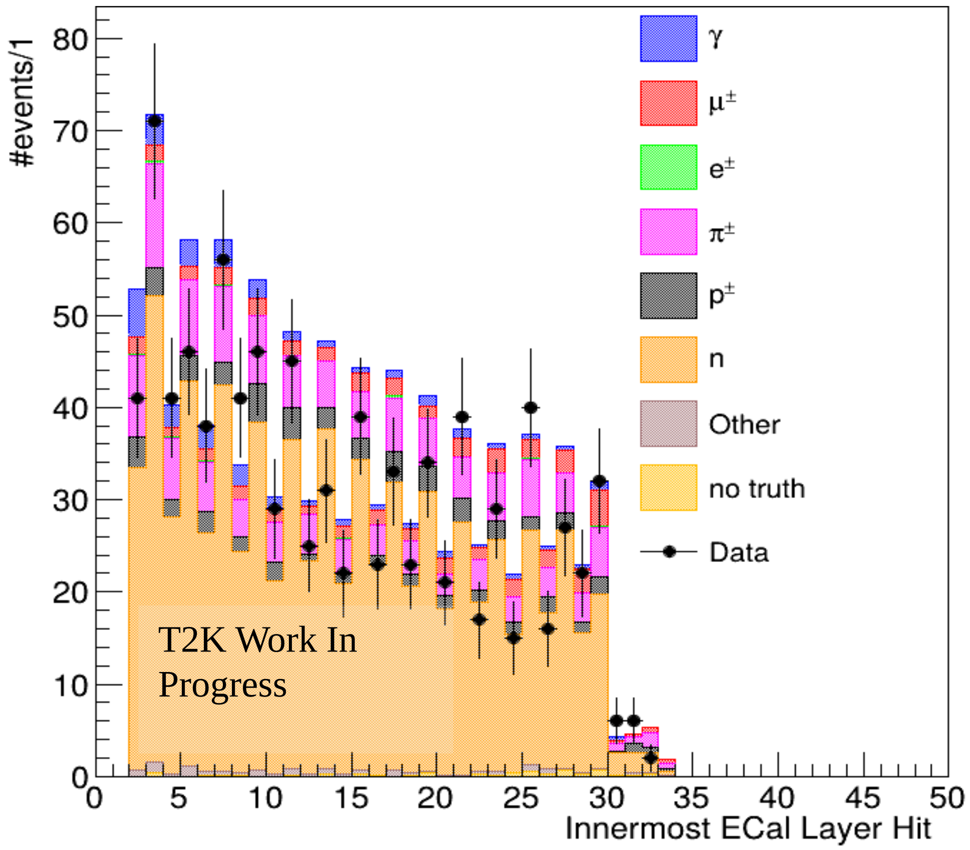
Neutron Production and Detection in ND280

Neutrons are more massive than photons

So neutrons will:

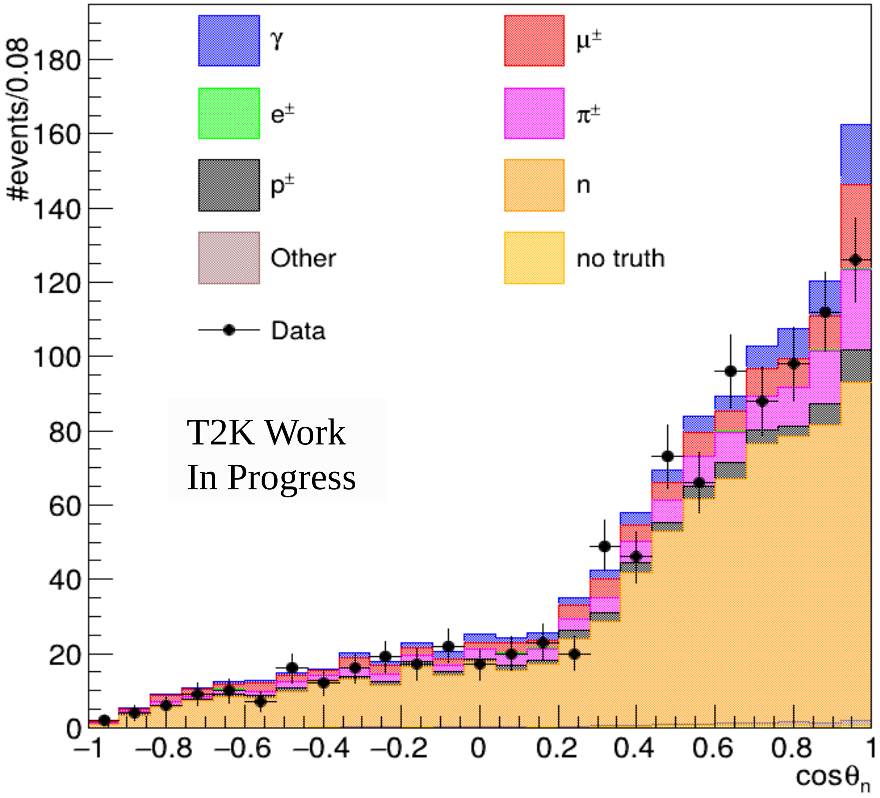
1. Deposit less energy in the ECal
   Leave fewer hits in the calorimeter
2. Travel more slowly through the detector
   Have a larger difference in inter-detector time stamps
3. Interact later in the electromagnetic calorimeter
   First hit will be deeper in the calorimeter



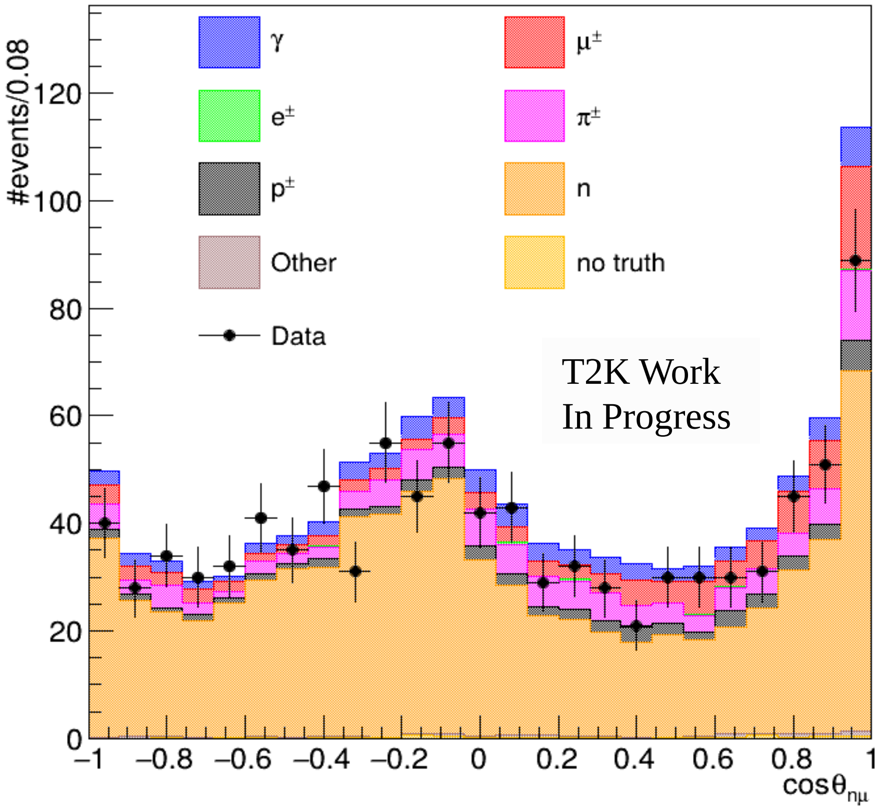


First layer of ECal hit for selected neutron candidates

Neutron Selection in ND280



Angle of the neutron with respect to beam direction



Opening angle between the neutron and antimuon

Select neutrons in the ECal with:

$71\pm1\%$ (stat) purity
$59\pm1\%$ (stat) efficiency

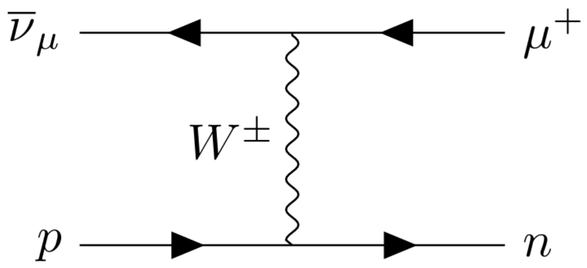
Selected neutrons are boosted in beam direction

At large opening angles to the muon

Applications Within T2K

- Tests of (anti)neutrino interaction and neutron production simulation models
  - Improve interaction model dependent uncertainties
  - See T. Peacock's talk
- Near detector inputs for the oscillation analysis samples
  - Improve constraints on event rates for oscillation measurements
  - See D. Langridge's talk
- Constrain neutrino interaction cross-sections with neutron multiplicity
  - Only published by one other experiment: MINERvA 2023: PhysRevD.108.112010

Applications Within T2K



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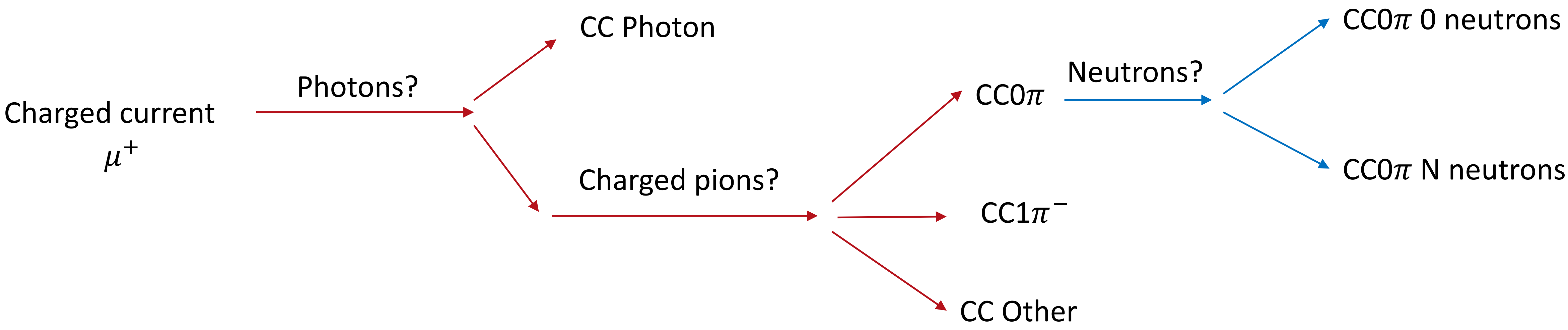
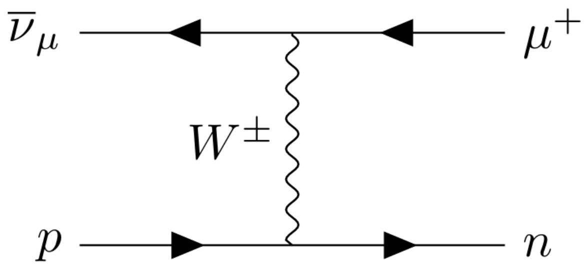


Neutron Samples in ND280



- Near detector inputs for the oscillation analysis samples
  - Improve constraints on event rates for oscillation measurements
- Test inclusion of neutron tagging in near detector oscillation samples
  - Do uncertainties on event rates reduce?
  - Is the parameter space better constrained?
- Use oscillation fitters to test model variations from the nominal
  - Neutron tagged sample to improve modelling

Summary

- T2K uses near detector samples to predict observations of neutrino interactions in the far detector under a no-oscillation hypothesis
- Neutron detection in the far detector gives need for a near detector neutron sample
- Using the ND280 Electromagnetic calorimeter a 70% pure neutron sample can be obtained
- Many possible uses for an ND280 neutron sample
  - Complement future Super-K and ND280 Upgrade analyses
  - Near detector oscillation samples
  - Neutron production cross section measurements on (hydro)carbon
  - Tests of neutron production and interaction models