Cross-section measurements of neutral pion production in neutrino-nucleus scattering in T2K

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11th International Workshop on Neutrino-Nucleus Scattering in the Few-GeV Region
NuInt 2017

27 June 2017, Toronto

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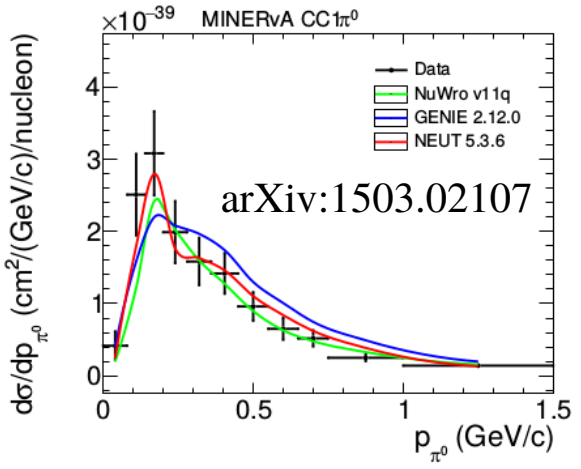
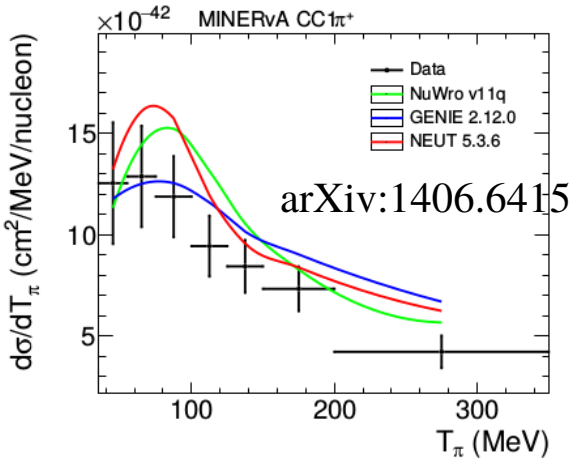
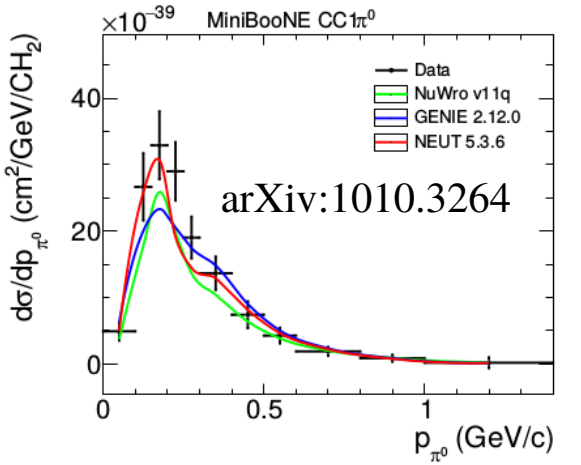
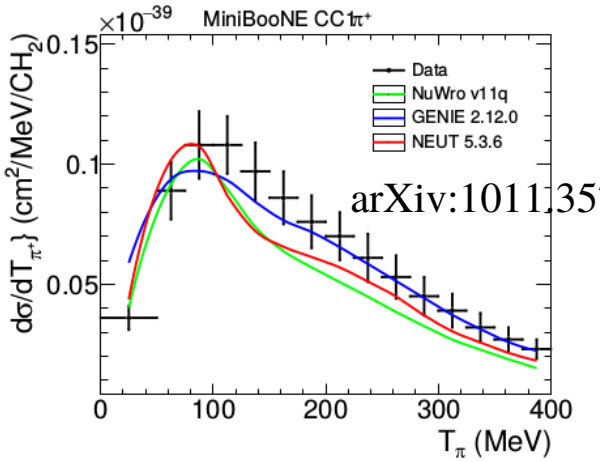
Motivation

- Different detectors have different acceptances
- Theoretical model should describe not only the overall number of interactions of a certain type, but also kinematic properties of produced particles
- Currently, it seems that there is no model, which would match both π^0 and π^+ measurements, but data statistics is too low to draw any firm conclusion







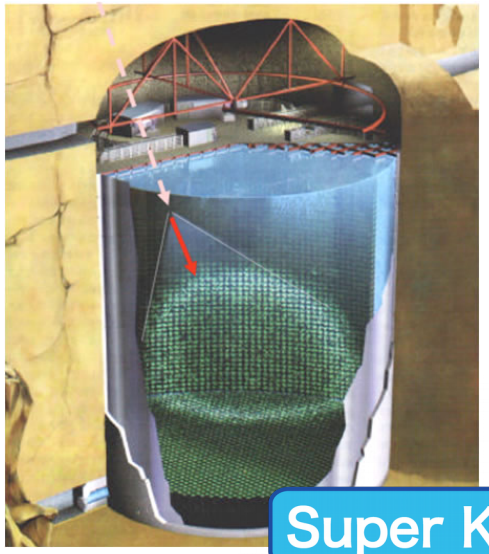


MINERvA data has been scaled up by +11% to account for changes in flux predictions.

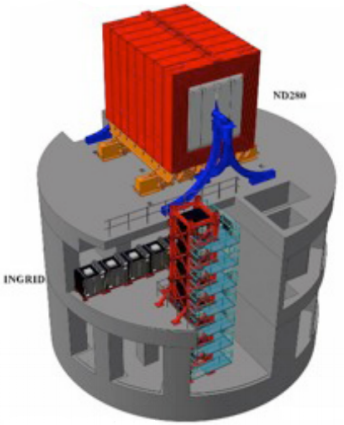
Plots prepared using Nuisance v1r0 Validation:
NUISANCE: a neutrino cross-section generator tuning and comparison framework.
P. Stowell, C. Wret, C. Wilkinson, L. Pickering, et. al., 2017 JINST 12 P01016, arXiv:1612.07393

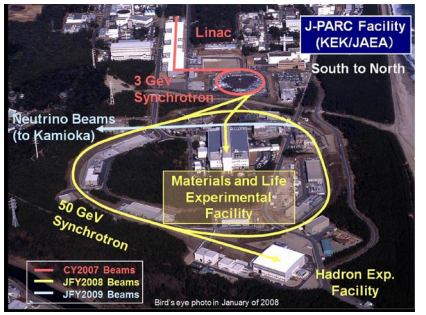
T2K experiment

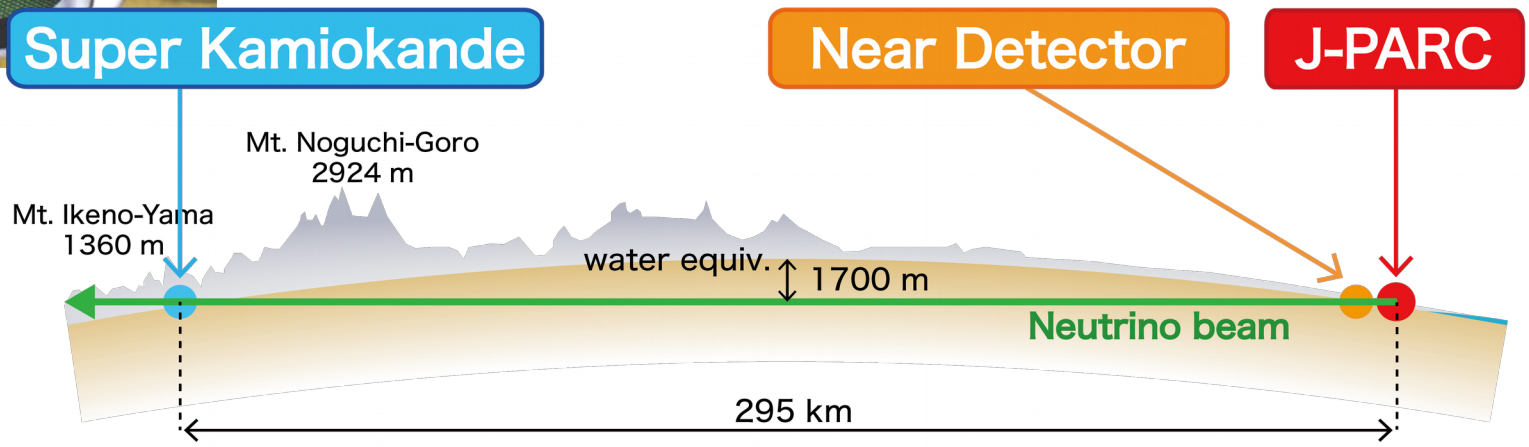
Far detector
in Kamioka



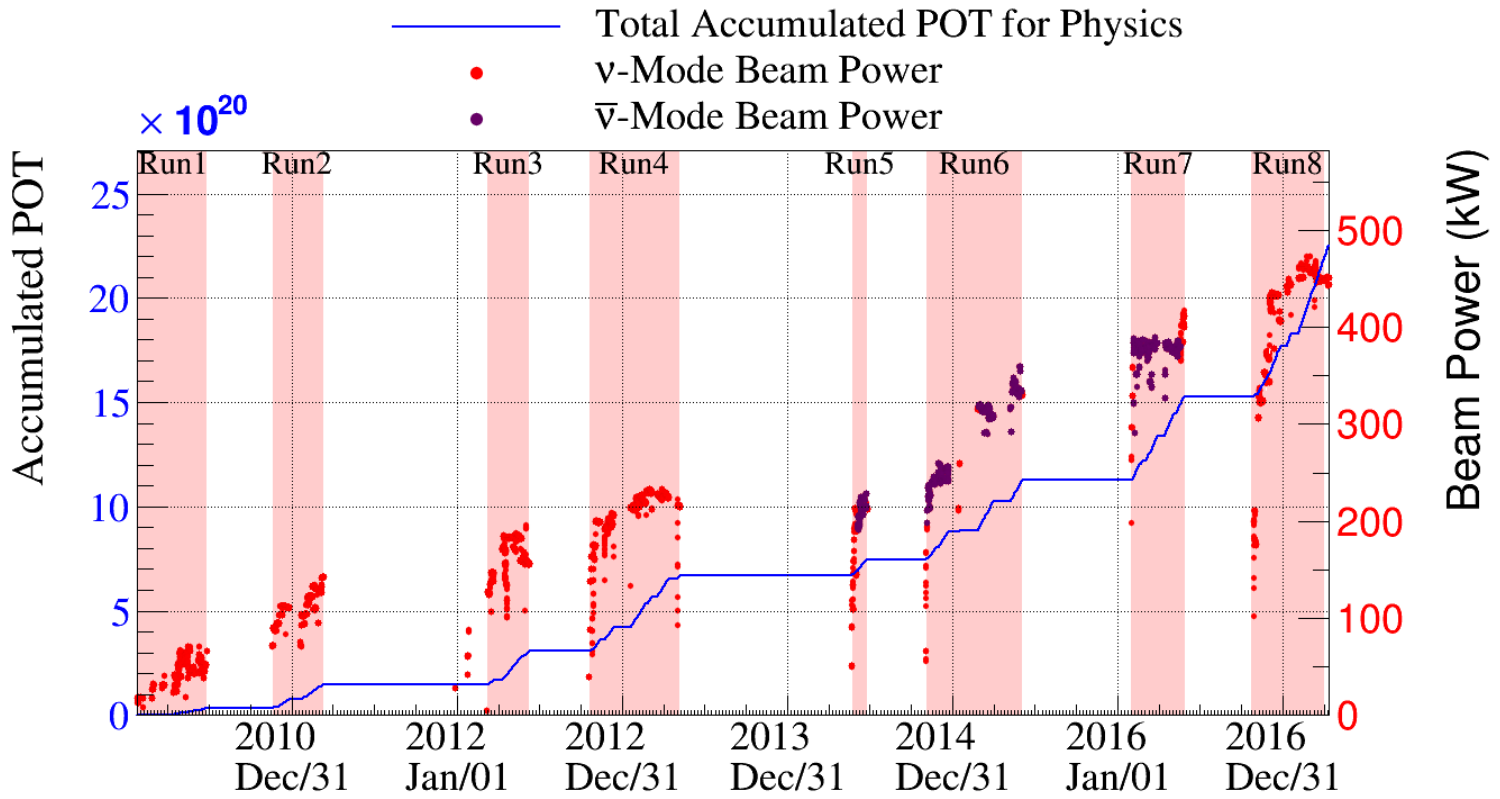
Accelerator complex and
near detectors in Tokai







T2K data-taking summary

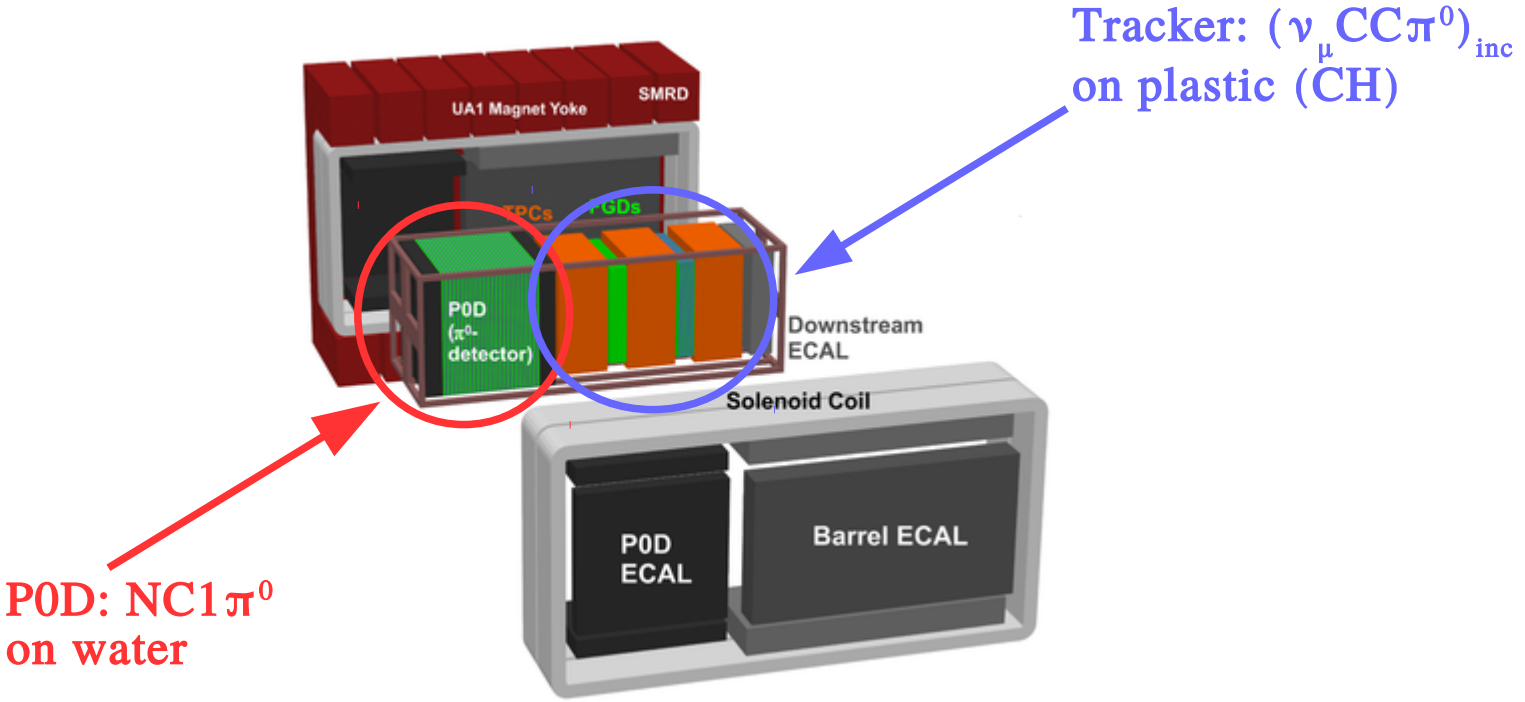


Total number of Protons On Target (POT) from 23 January 2010 to 12 April 2017

- neutrino mode: $14.93 \cdot 10^{20}$ POT
- antineutrino mode: $7.62 \cdot 10^{20}$ POT

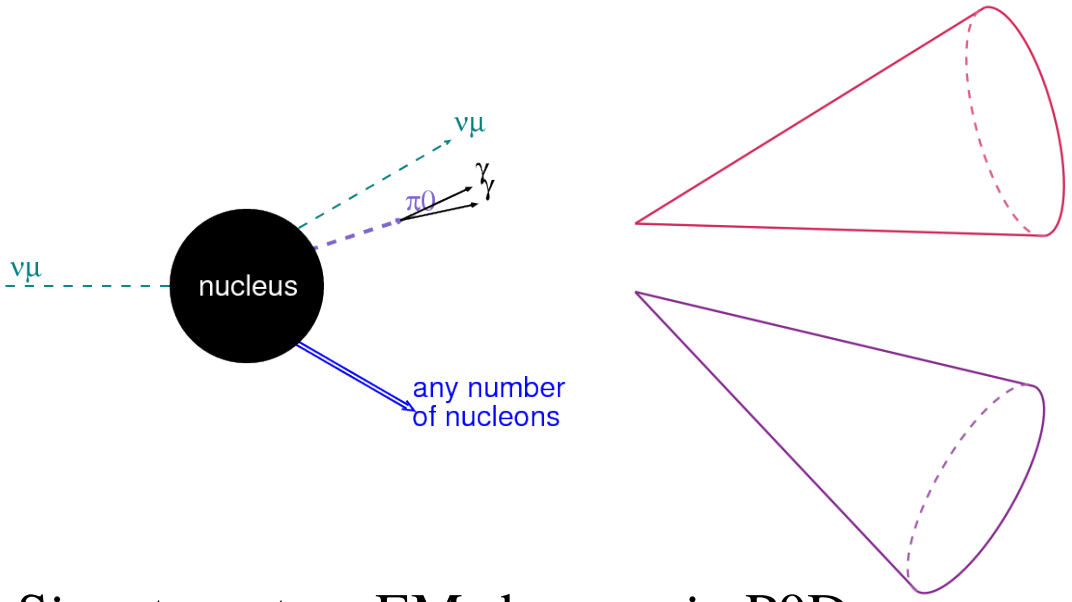
ND280 detector

- π^0 detector (P0D): layers of plastic scintillator (CH) sandwiched with lead and (drainable/removable) water layers
- Tracker: 3 Time Projection Chambers (TPC) + 2 Fine-Grained Detectors (FGD). TPC: 95% Argon; FGD1: plastic scintillator; FGD2: plastic scintillator sandwiched with water layers
- Electromagnetic Calorimeter (ECal): plastic scintillator sandwiched with lead
- Side Muon Range Detector (SMRD): plastic scintillator in slots of (iron) magnet yoke



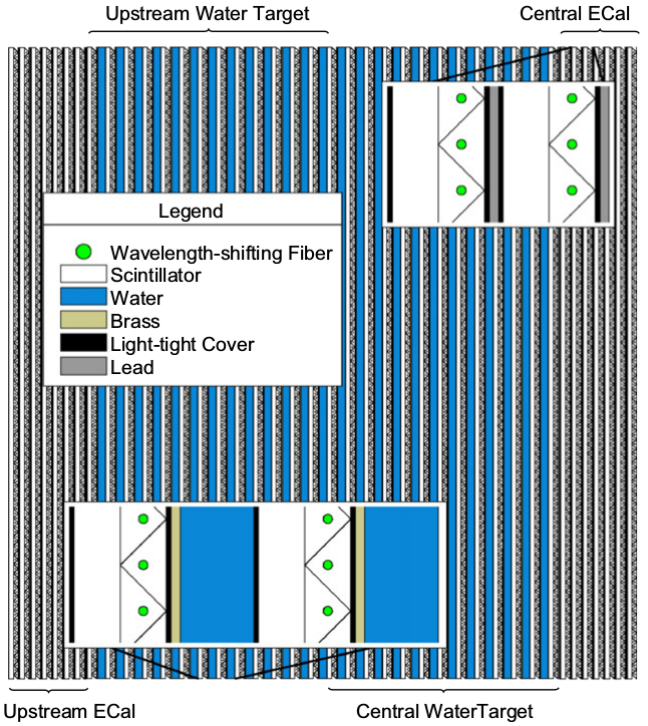
NC1π^0 event rate on water

- Main sources of NC1π^0:
  - Coherent NC1π^0
  - Resonance NC1π^0



Signature: two EM showers in P0D.

Measurement done by comparison of water-in and water-out event rates.

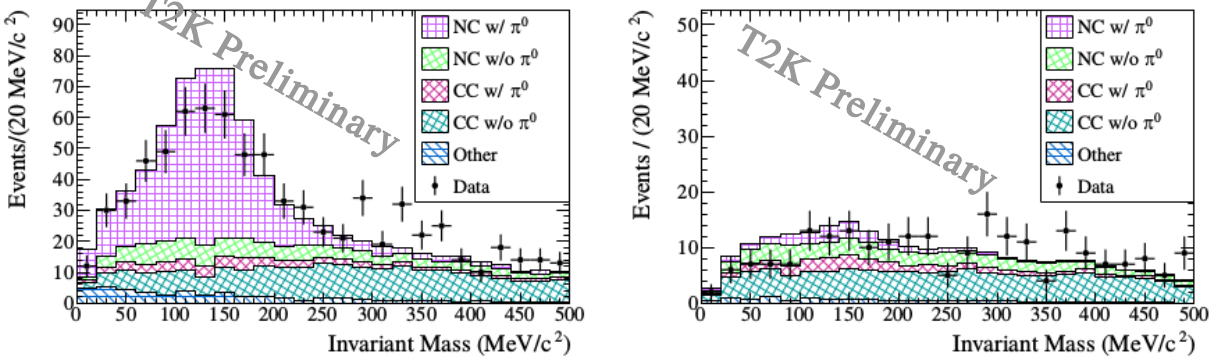


The P0D detector

NC1π^0 event rate on water

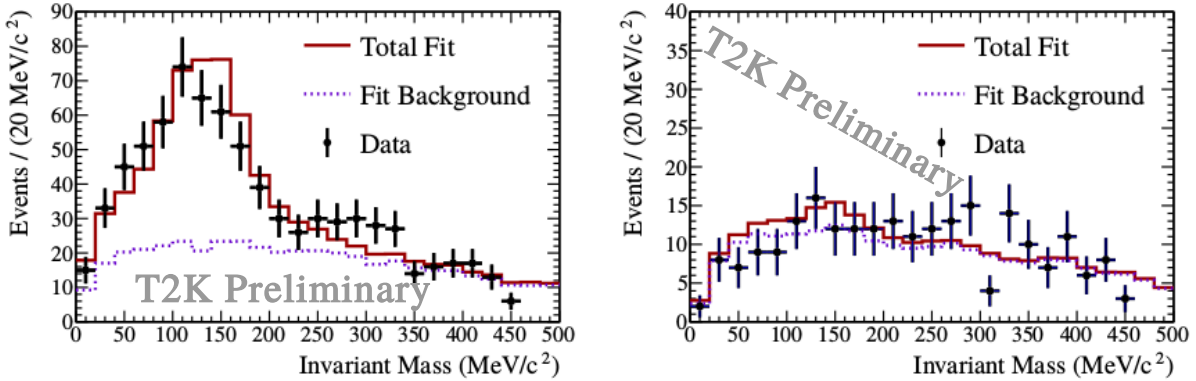
- Event selection
  - event quality
  - 3D vertex in P0D fiducial volume
  - whole event contained in P0D
  - no muon decay cluster
  - two EM showers containing most of total charge
  - reconstructed π^0 direction < 60 degrees
  - π^0 candidate invariant mass < 500 MeV/c^2
- Sideband selection:
  - muon decay cut reversed

Reconstructed invariant mass in signal-enriched and background-enriched sample



(a)Water-In configuration

Comparison of the data to the best fit invariant mass distribution, with the best fit energy scale applied to the data



(a)Water-In configuration

arXiv:1704.074672

NC1π^0 event rate on water

- Number of signal events on water (WI – water in, WO – water out):

$$N_{On-Water} = N_{WI} - \frac{\epsilon_{WI} POT_{WI}}{\epsilon_{WO} POT_{WO}} N_{WO}$$

- For $3.49 \cdot 10^{20}$ POT ($+2.64 \cdot 10^{20}$ POT for WO, run 1 – 4), the measured number is[1]:

$$N_{On-Water} = 106 \pm 41(stat) \pm 69(syst)$$

- Measured to expected (by neutrino interaction generator NEUT[2,3]) ratio:

$$data/MC\ ratio = 0.68 \pm 0.26(stat) \pm 0.44(syst) \pm 0.12(flux)$$

- Expected number of NC1π^0 background is not underestimated in oscillation analyses

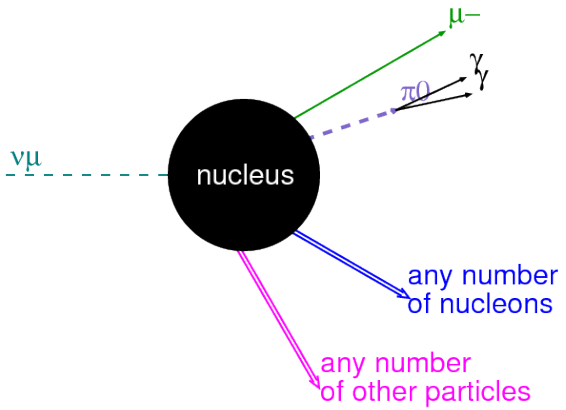
[1] Measurement of the single π^0 production rate in neutral current neutrino interactions on water - T2K Collaboration, arXiv:1704.07467

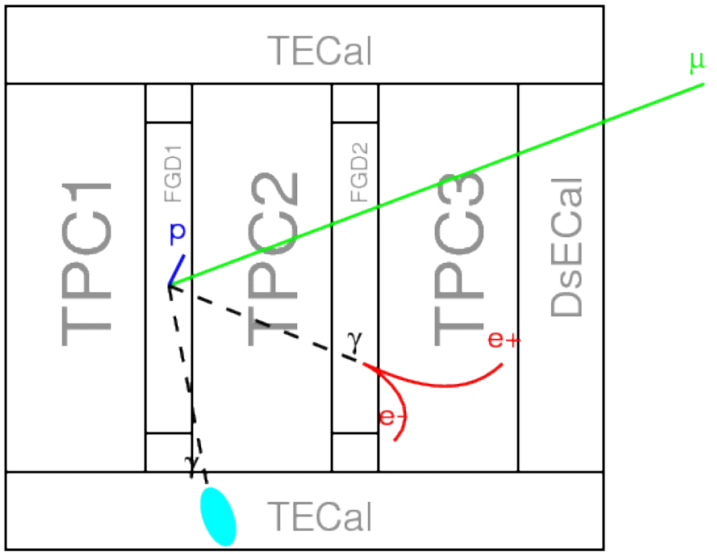
[2] A neutrino interaction simulation program library NEUT – Y.Hayato, Acta Phys.Polon. B40 (2009) 2477-2489

[3] Neut - Y.Hayato, Nucl.Phys.Proc.Suppl. 112 (2002) 171-176

Inclusive $\nu_\mu CC\pi^0$ cross section on CH

- Main sources of $(\nu_\mu CC\pi^0)_{inc}$:
  - Resonance $CC1\pi^0$
  - CC DIS





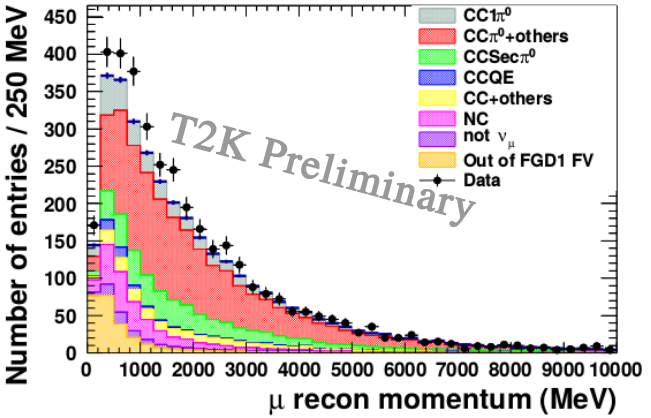
Tracker part + Tracker ECal

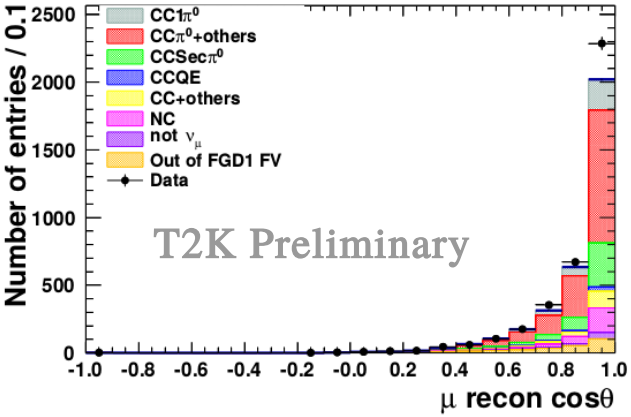
Signature: muon-like track starting in FGD1 fiducial volume + at least two π^0 decay products (shower in ECal and/or e-like track in TPC).

$(\nu_\mu CC\pi^0)_{inc}$ on CH

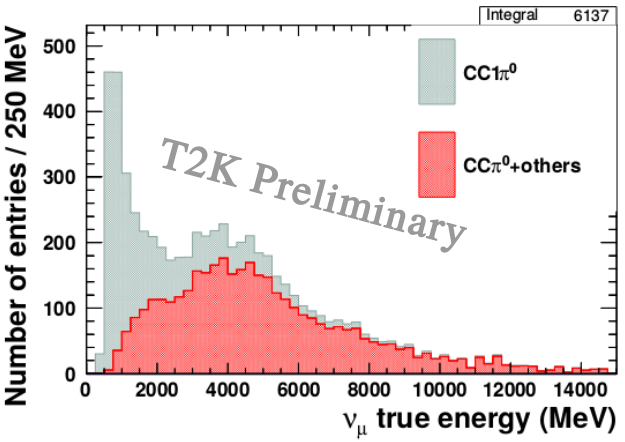
- Event selection
  - event quality
  - highest momentum negative (HMN) track starting in FGD1 FV
  - HMN must be muon-like
  - out-of-fiducial-volume veto
  - at least two π^0 decay products (2 showers/ 1 shower + 1 e-like track/2 e-like tracks)

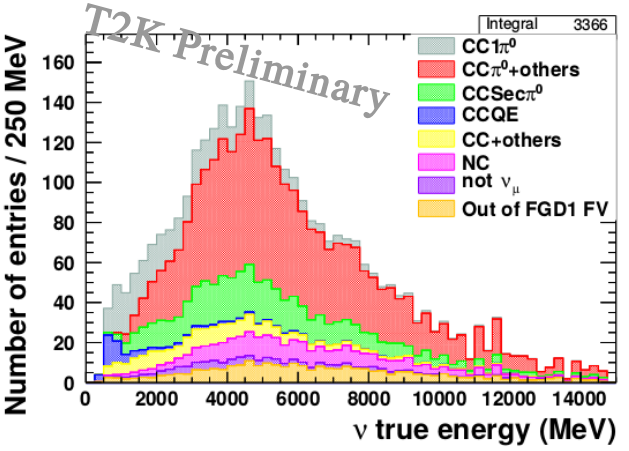
Momentum and cosθ of a muon candidate after all cuts





Neutrino energy for signal events before cuts and for events selected after all cuts





Inclusive $\nu_\mu CC\pi^0$ cross section on CH

- Total (single bin) flux-averaged cross section:

$$\sigma = \frac{N_{sel-data} - N_{expected\ bkgd}}{\epsilon \cdot \Phi \cdot T}$$

- For $5.49 \cdot 10^{20}$ POT (run $2-4$) measured cross section is

$$\sigma^{data} = \left(1.239 \pm 0.034(stat)\, {}^{+0.157}_{-0.158}(syst)\, {}^{+0.175}_{-0.149}(flux)\right) \cdot 10^{-39}\, cm^2/nucleon$$

- Cross section expected by the NEUT generator is

$$\sigma^{NEUT} = \left(1.0522 \pm 0.0028(stat)\right) \cdot 10^{-39}\, cm^2/nucleon$$

- Results agree within errors. Main source of discrepancy probably from secondary interactions

Summary

- NC1π^0 event rate measurement on water
  - the observed event rate is consistent within errors with expectation from the NEUT generator
  - the event rate is also not underestimated, and thus the NC1π^0 background to ν_e appearance is also not underestimated
  - results published in arXiv:1704.07467 and submitted to PRD
  - current work on migration to newer software and incorporation of more data samples
- Inclusive ν_μCCπ^0 cross section measurement on CH
  - the measured total flux-averaged cross section is consistent within errors with expectation from the NEUT generator
  - current work on migration to newer software and final validation of systematic errors
  - after that results will be published

T2K pion production results published since last NuInt

- Measurement of Coherent π^+ Production in Low Energy Neutrino-Carbon Scattering - DOI: 10.1103/PhysRevLett.117.192501
- First Measurement of the Muon Neutrino Charged Current Single Pion Production Cross Section on Water with the T2K Near Detector - DOI: 10.1103/PhysRevD.95.012010
- Measurement of the single π^0 production rate in neutral current neutrino interactions on water – published in arXiv:1704.07467 and submitted to PRD