Neutrino interaction studies in the near detector of the T2K Experiment

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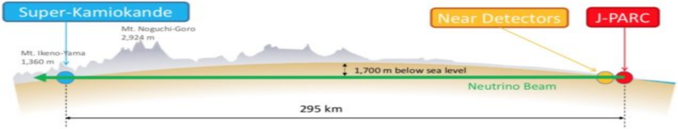
Outline

Brief history of neutrinos

1914: Chadwick's observation of continuous β decay spectrum.
1930: Pauli's proposal for a new particle to explain β decay spectrum.
1933: Fermi's neutrino and β decay theory.
1956: Reines and Cowan observed the first neutrino interaction.
1962: ν_μ discovery at BNL, USA.
1975: τ lepton discovered at SLAC... ν_τ proposed.
1986: Solar Neutrino Problem.
1989: LEPC's measurement of Z^0 properties... Exactly three light neutrinos.
1998: Atmospheric neutrino oscillations.
2000: DONUT discovered ν_τ.
2001: Solar neutrino deficit explained by SNO
2013: First observation of high-energy astrophysical neutrinos by IceCube

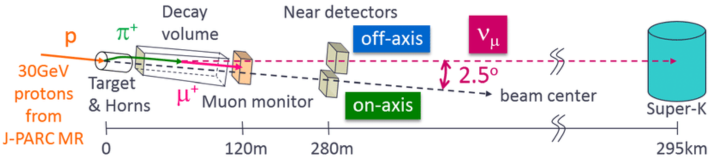
The T2K Experiment

- **Long baseline** neutrino oscillation experiment in Japan since 2010.
- The experiment sends a beam of muon neutrinos from Tokai to Kamioka at a distance of 295 km.



https://t2k-experiment.org/t2k/

- World's **first off-axis** neutrino experiment!



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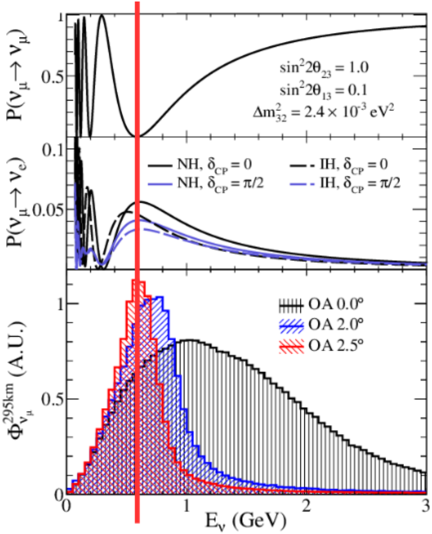
Why Off-Axis?

- The average energy of the neutrino decreases with the deviation from the beam axis.
- 2.5° chosen to maximize the probability of oscillation at the far detector.



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Near Detector and Components

- ND280 Detector
  - 3 vertical Time Projection Chambers
  - active material: plastic scintillator
  - passive materials: water, iron, lead
  - beam content before oscillations
  - neutrino interaction studies
- Fine Grain Detector-1
  - plastic scintillator bars
  - target for neutrino interactions
- Time Projection Chamber
  - Filled with Argon-based gas mixture
  - Used for momentum and $\frac{dE}{dX}$ measurements
- ECal
  - plastic and lead bars
  - surrounds the inner part of ND280

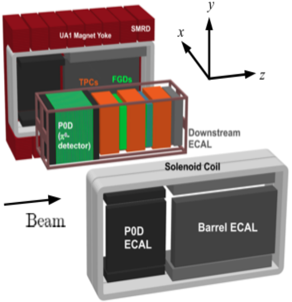


Figure: ND280

Charged Current Neutrino-Nuclei interactions

CC interactions

mediated by $W^{+/-}$ bosons

NC interactions

mediated by Z^0 boson

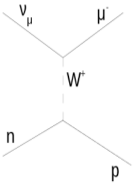


Figure: CCQE

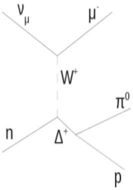


Figure: RES

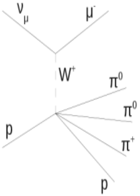


Figure: DIS

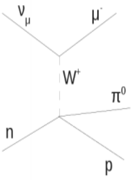
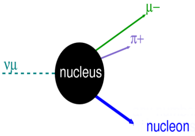


Figure: non-RES

Aim of the project and Event Selection

0. The following analysis was done using sample of events containing pre-selected μ^- candidate starting in FGD1 Fiducial Volume.
1. To select tracks having **at least** 18 hits and starting inside the **FGD1 Fiducial Volume**.
2. To identify particles based on $\frac{dE}{dx}$ and other information.
3. To select $CC\text{-}1\pi^+$ interactions by choosing events with $1\pi^+$ and 1 or 0 proton candidates based on pull variables.
4. To calculate **kinematical properties** related to selected neutrino interactions.
5. To calculate **purity** and **efficiency** of the selection.



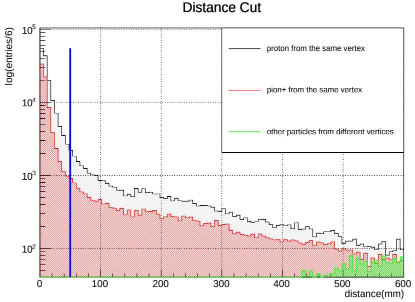
Products of $CC\text{-}1\pi^+$ signal interaction

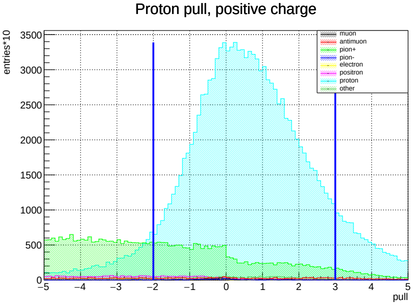
μ^-, π^+, and 0 or 1 proton

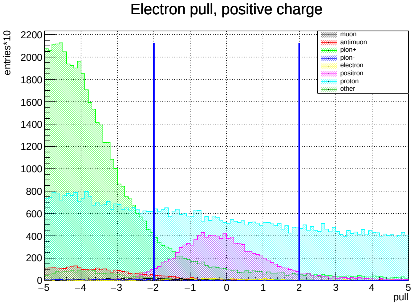
Pull Variable

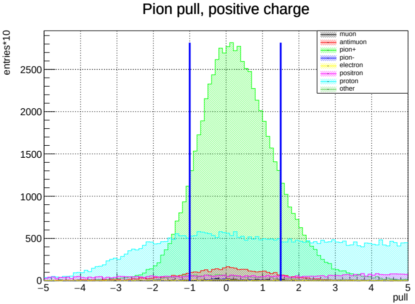
$$P_a = \frac{\left(\frac{dE}{dx}\right)_{teor_a} - \left(\frac{dE}{dx}\right)_{exp}}{\sigma_{exp}}$$

Choosing Candidates

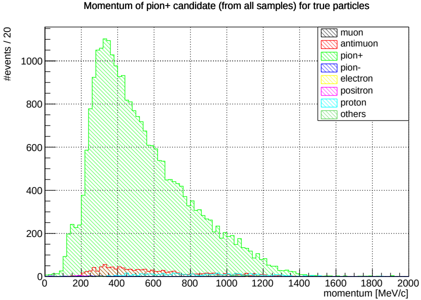


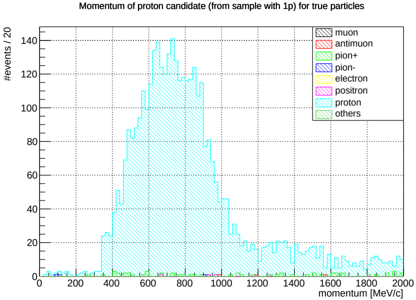


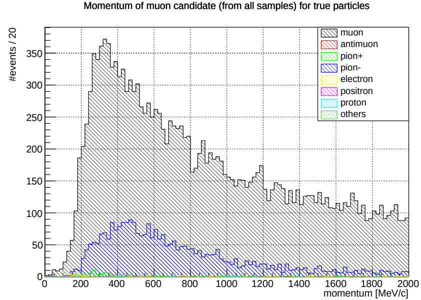


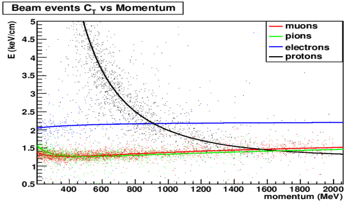


The Chosen Candidates



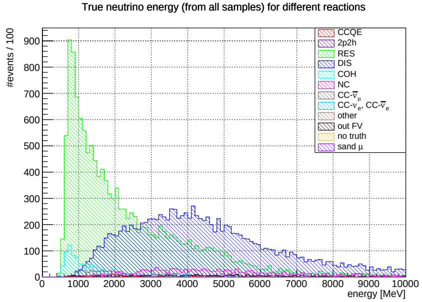


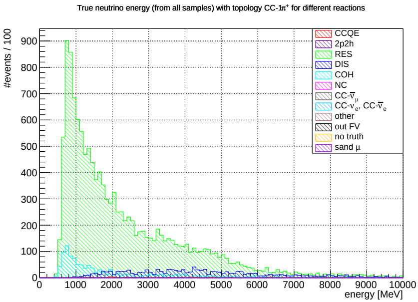


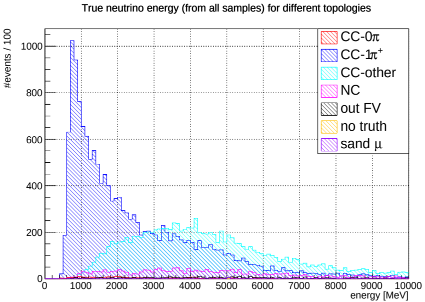


(T2K)-Not always possible to distinguish particles based on $\frac{dE}{dx}$

Reactions and Topologies







- **Reaction**: Primary neutrino nucleon interaction type
- **Topology**: Reaction type based on the particles leaving the nucleus

Purity and Efficiency

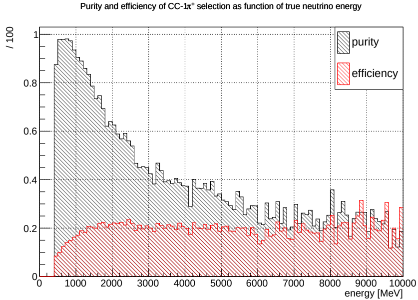
The estimation of the quality of event selection is done by observing the following quantities.

Purity

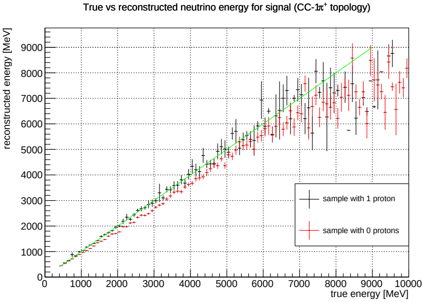
$$\frac{\text{Number of selected signal events}}{\text{Number of all selected events}}$$

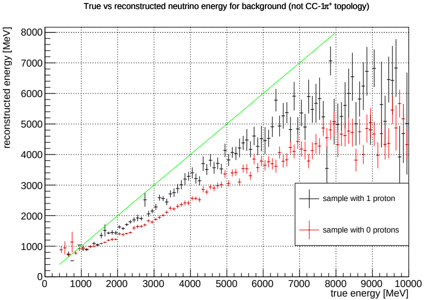
Efficiency

$$\frac{\text{Number of selected signal events}}{\text{Number of all signal events}}$$

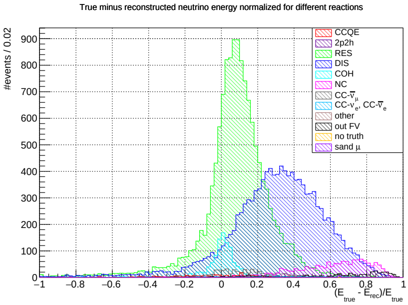


True v/s Reconstructed Energies

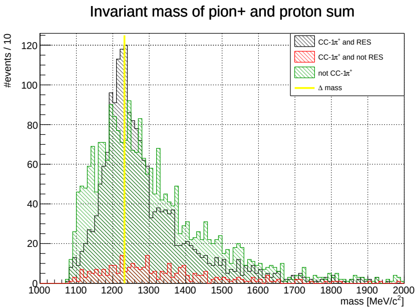


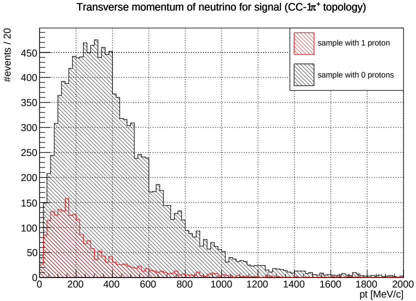


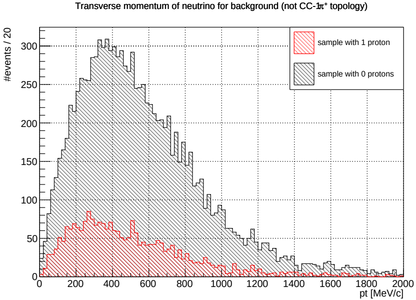
The green line shows ideal reconstruction.



Kinematical Properties from Reconstruction







- Fermi Momentum of a nucleon is $\approx 250\text{MeV}/c$

Summary

- We studied nucleon-neutrino interactions in the T2K near detector.
- We analysed the characteristics of $CC1\pi^+$ interaction with 0 and 1 proton samples.
- We also reconstructed kinematical properties for the $CC1\pi^+$ interaction.
- A similar analysis for $CC0\pi$ interactions (mainly $CCQE$ reactions) was made for comparison, but not added in this presentation.

Acknowledgements and Thanks

We would like to thank the PPSS 2021 organising committee for providing us with this opportunity.
Special thanks to our supervisor Dr Marcela Batkiewicz-Kwaśniak for her timely help and professional guidance.

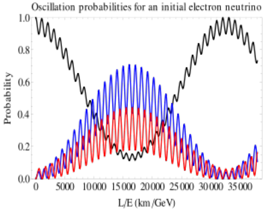
Thank You!

Backup Slides

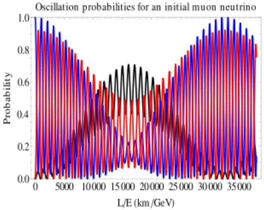
Pontecorvo–Maki–Nakagawa–Sakata matrix

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

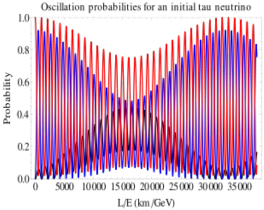
where $c_{ij} = \cos\theta_{ij}, s_{ij} = \sin\theta_{ij}, \delta = \delta_{CP}$



black : ν_e



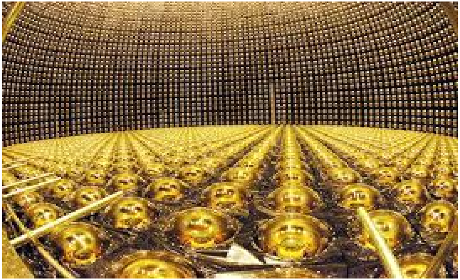
blue: ν_μ



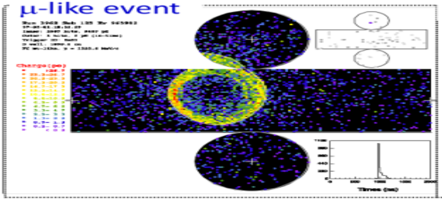
red: ν_τ

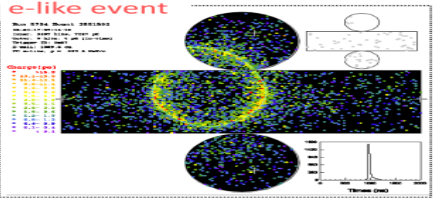
Super-Kamiokande Detector

- Located 1000m underground.
- Contains 50,220 tonnes of ultrapure water.
- A water-Cherenkov detector.
- No magnetic field to distinguish particles from anti-particles.
- particle identification based of light ring shape



Nature





Events' display in ND280 detector