Neutrons as probes of nuclear effects in muon neutrino CC0pi at T2K's upgraded near detector

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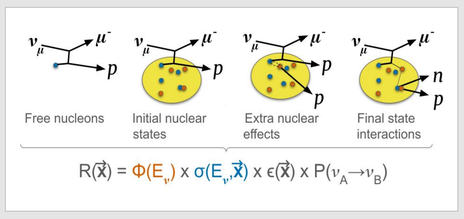
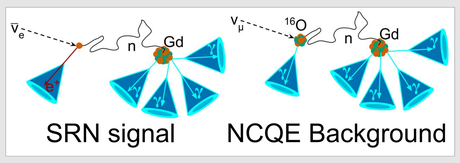
Neutron tagging in the ND280 can give insight into what is happening inside the nucleus in neutrino-nucleus interactions to **reduce cross section uncertainties** and **improve (anti)neutrino energy** reconstruction.

In the next-generation Hyper-K oscillation experiment, neutrino interaction uncertainties will be one of the limiting factors.[1]



Precise knowledge of **interaction cross sections** and **beam energy** in ND280 and possible ND280++ at Hyper-K will be vital for oscillation analyses.

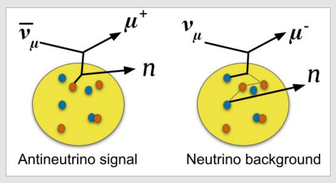
Atmospheric ν_μ ^{16}O NCQE (neutral-current quasielastic) background must be constrained to improve detection of supernova relic neutrinos.



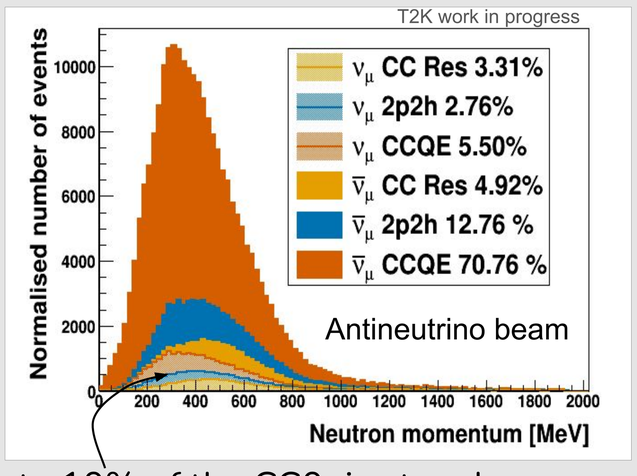
Super-Kamiokande Gadolinium

Neutrons from these interactions can now be tagged with high efficiency in Super-K. T2K can measure and constrain ν_μ ^{16}O NCQE-n to reduce uncertainties.

Neutrons can come from both muon neutrino and antineutrino interactions. The $\bar{\nu}_\mu$ CC0π-n 'topology' (charge-current, no pion, one or more neutrons) is the dominant signal in antineutrino mode.

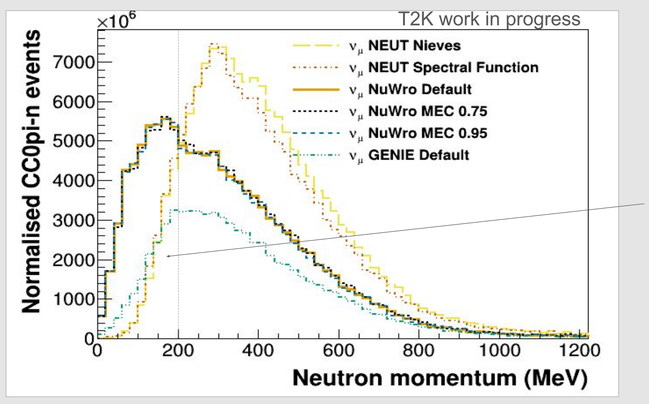


Muon neutrinos produce neutrons through final-state interactions (FSI) in the nucleus. They are an important background in the antineutrino beam.



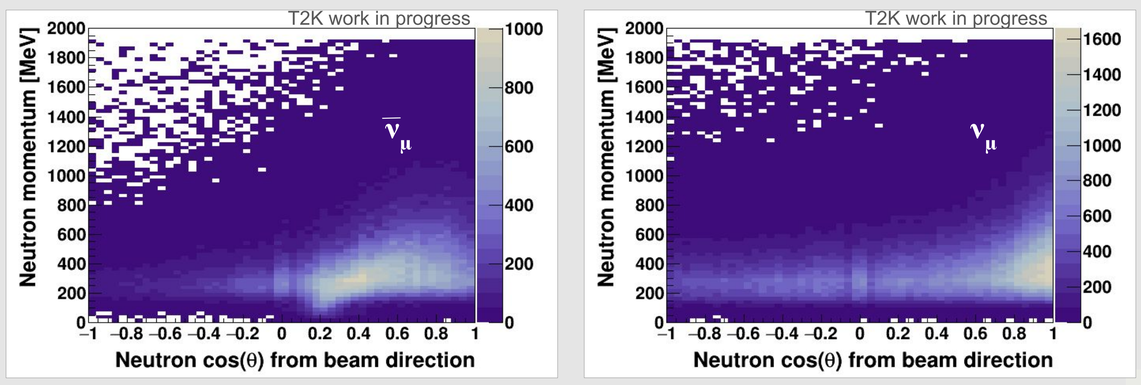
Up to 10% of the CC0pi-n topology in the antineutrino beam comes from muon neutrinos.

Neutrons can be used for model discrimination. Generators take neutrino flux and cross section models and output neutrino-nucleus interactions. Neutron kinematics are sensitive to FSI and can provide discrimination between cross section models and generators.



Neutron momentum <200 MeV shows excellent discrimination between NEUT[3], NuWro[4] and GENIE[5] generators for the ν_μCC0pi-n topology (left).

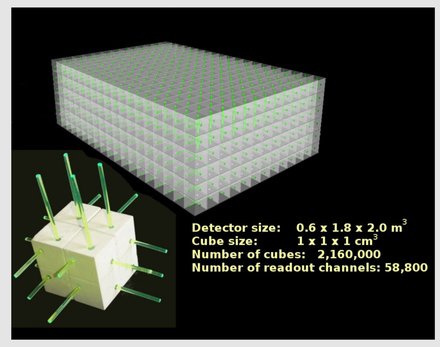
Neutrons can discriminate between neutrinos and antineutrinos to better understand the beam flux and reject backgrounds.



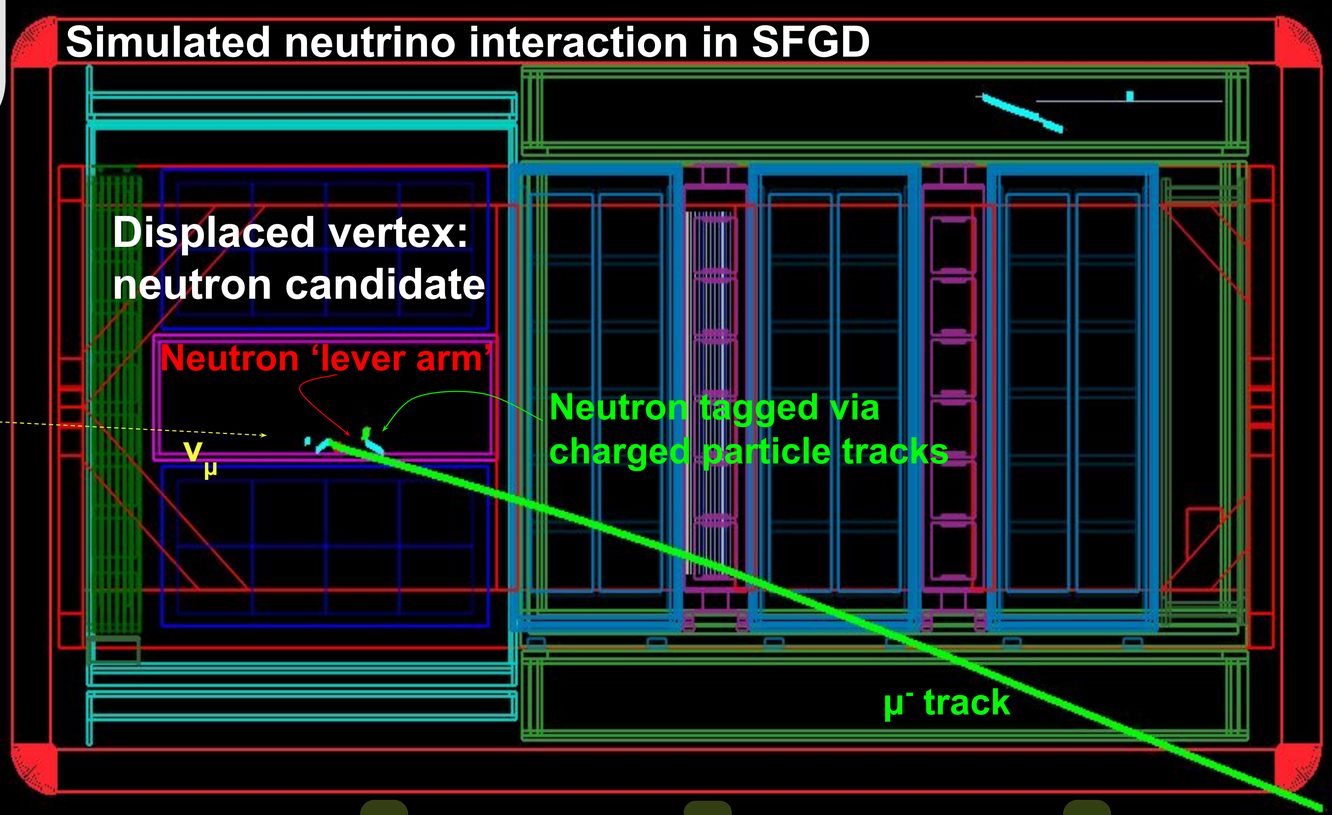
Neutron momentum vs angle from beam direction for $\bar{\nu}_\mu$(left) and ν_μ (right) in the CC0pi-n topology (smearing applied).

T2K is a neutrino oscillation experiment. The **Super Fine-Grained detector (SFGD)** is part of the recent upgrade at the **ND280 near detector** close to the **muon (anti)neutrino beam**.

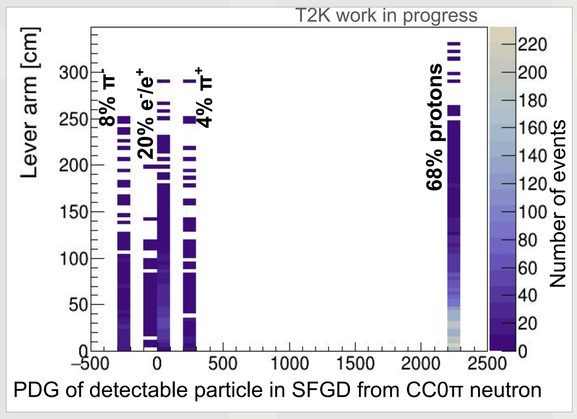
Over 2 million scintillator cubes:
3D tracking
Excellent time resolution (< 1 ns[2])
High light yield
4π acceptance



- **Particle identification and neutron tagging from muon neutrino and muon antineutrino interactions.**
- **More precise neutrino energy reconstruction by detecting neutrons and lower-energy protons and pions.**

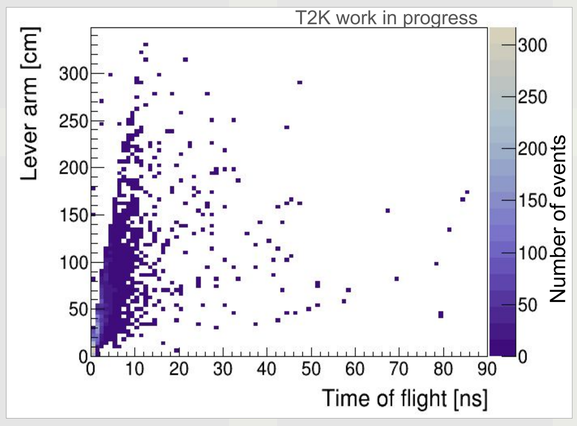


A neutron analysis is underway to probe the low-energy region for model discrimination.



Neutrons can be 'tagged' in the SFGD when they interact and produce charged particles, which leave tracks in the SFGD.

Almost 70% of the observable particles produced when CC0pi-n neutrons interact in the SFGD are protons.



Calculating neutron energy enables more accurate reconstruction of the initial muon neutrino energy.

Neutron energy is calculated from its 'lever arm' (the distance it travels before interacting) and time of flight.

High resolution 3D tracking and excellent time resolution in the SFGD will enable better knowledge of neutron kinematics.

Neutron tagging and reconstruction to exploit the SFGD technology in the ND280 upgrade and beyond will push sensitivity to lower energies for enhanced physics capabilities.

References:
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[4] Golan, Sobczyk, Żmuda 2012. Nucl.Phys.B Proc.Suppl. 229-232 499-499 doi.org/10.1016/j.nuclphysbps.2012.09.136
[5] Andreopoulos et al, 2010. Nucl.Instrum.Meth.A614:87-104 doi.org/10.1016/j.nima.2009.12.009