Performance and optimization study of Intermediate Water Cherenkov Detector for J-PARC long baseline experiment

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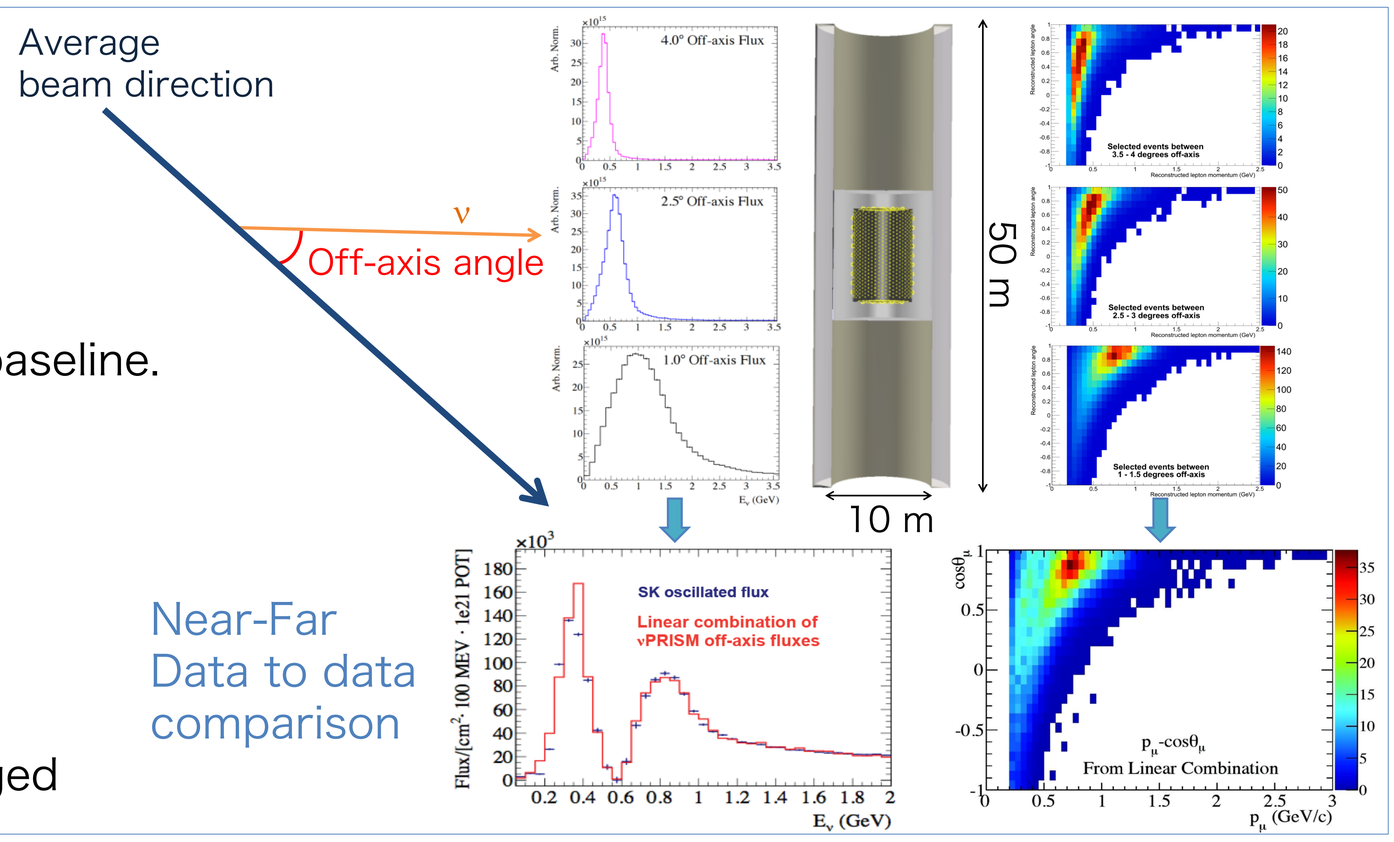
Motivation

Reduce neutrino interaction model uncertainty
- One of the main systematics in T2K and future T2HK experiment

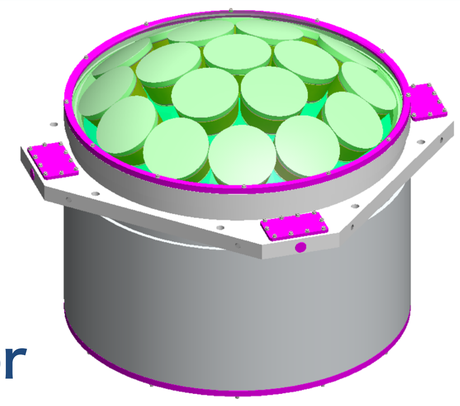
Detector concepts

- Proposed in the J-PARC neutrino beam at ~1km baseline.
- Use the same target material as far detector.
- Measure neutrino interactions at multiple energies over off-axis angles 1– 4°
- By taking linear combination of measurements of multiple off-axis angles, oscillated neutrino spectra are regenerated
- Two collaborations, NuPRISM and TITUS are merged



Near-Far Data to data comparison

Detector R&D ongoing



- Multi-PMT module holding 3inch PMTs
- Electronics
- Support structure

Phase-0 prototype detector

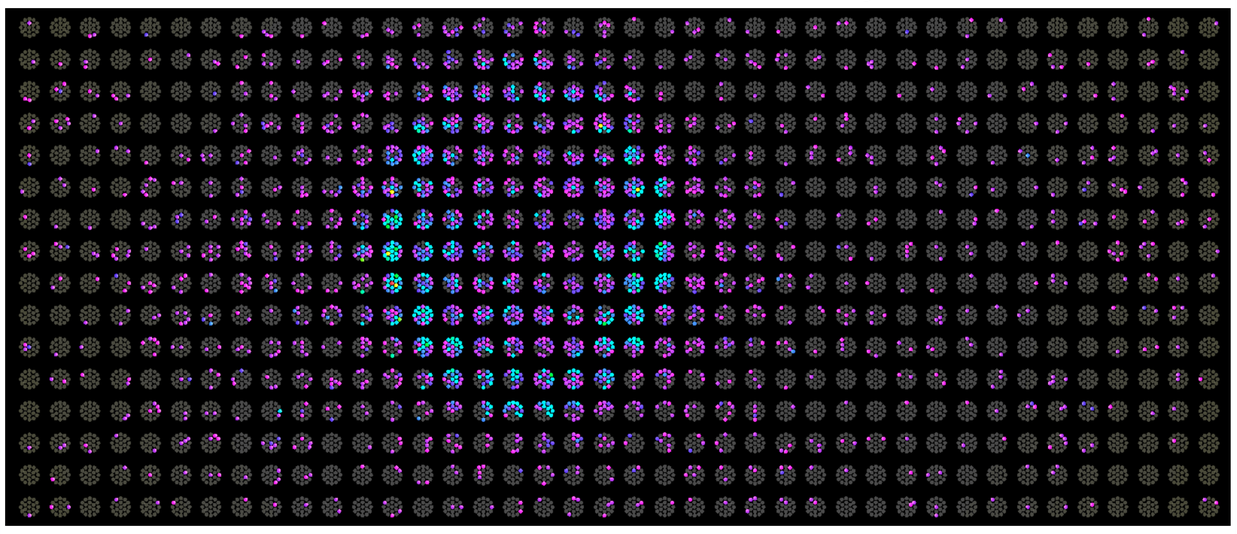
- Shorter detector on surface
- Confirm detector performance
- Measure neutrino interaction at large off-axis angle with more ν_e contamination
- Measure $\sigma(\nu_e)/\sigma(\nu_\mu)$ at the precision of 3% for $E_\nu < 1$GeV

Phase-0 background studies ongoing

- Beam-induced backgrounds
- Cosmic muon and spallation neutron

Full detector simulation and reconstruction

- WCSim - Geant4 based detector simulation multi-PMT simulation is ready



Event display

- FiTQun - Event reconstruction algorithm using maximum-likelihood method Tuning for multi-PMT is ongoing

$$L(\boldsymbol{x}) = \prod_{j}^{unhit} P_j(\mathrm{unhit}|\boldsymbol{x}) \prod_{i}^{hit} \{1 - P_i(\mathrm{unhit}|\boldsymbol{x})\} f_q(q_i|\boldsymbol{x}) f_t(t_i|\boldsymbol{x})$$

Probability that the j-th photo-sensor does not detect photon

Charge probability distribution

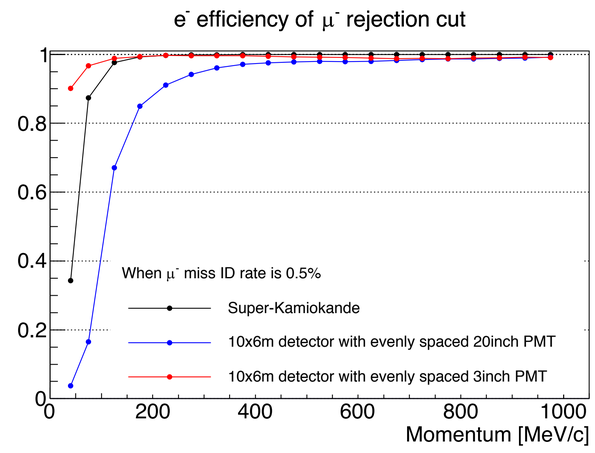
Time probability distribution

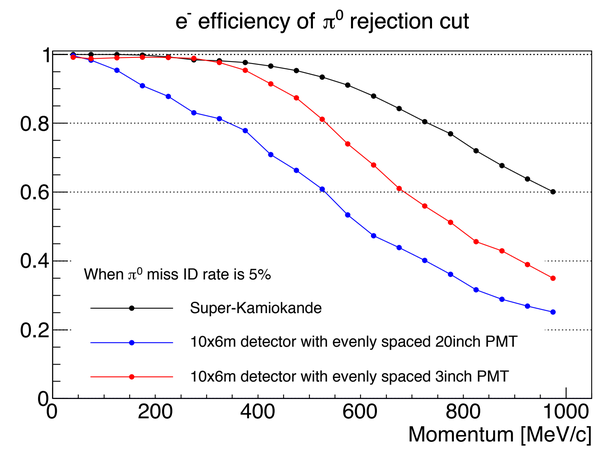
Detector PID performance study

- Need pure ν_e sample for $\sigma(\nu_e)$ measurement
- ν_μ flux is about 10^2 times larger than ν_e flux
  → PID (e/μ and e/π^0) are important
  Studied using particle gun simulation

PID performance vs PMT granularity

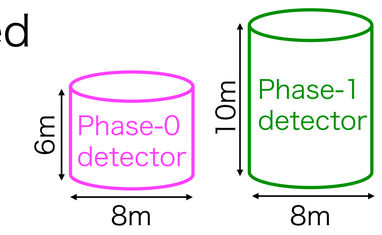
- e/μ : PMT hit pattern (diffused or clear ring)
- e/π^0 : PMT hit pattern(1ring like or 2ring like) and reconstructed $m_{\pi 0}$
- PMT granularity improves PID

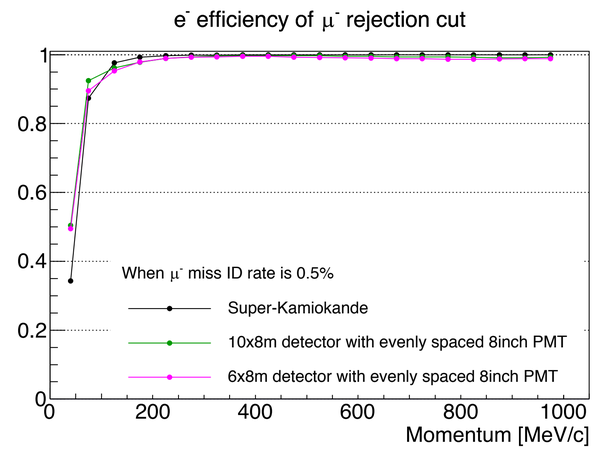


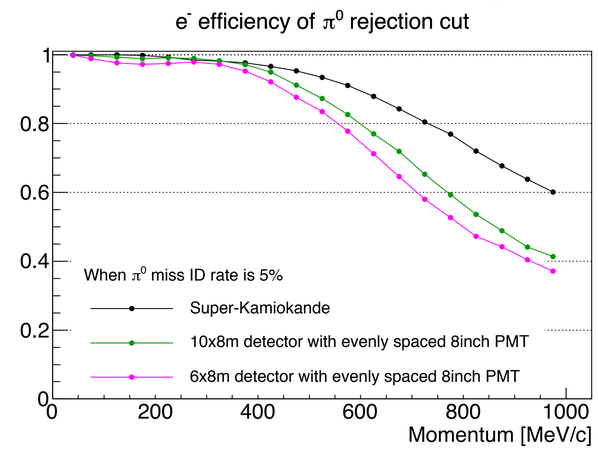


PID performance vs detector size

- Shorter Phase-0 detector considered
- e^- efficiency differences are ~1% for μ rejection cut ~5% for π^0 rejection cut







Summary

- A new water Cherenkov detector is proposed in the J-PARC neutrino beamline to reduce systematic uncertainties of T2K and future T2HK experiments.
- Sensitivity studies and detector R&D are ongoing.
- The detector performance to be confirmed with prototype detector, called phase0.