Optimization of the Detector Design of NuPRISM, a New Water Cherenkov Neutrino Near Detector

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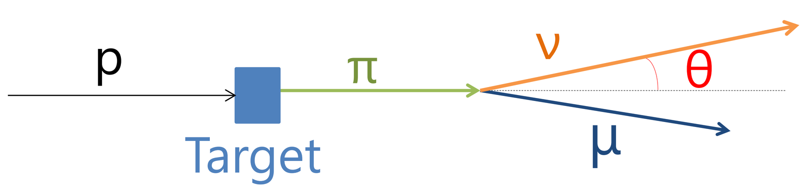
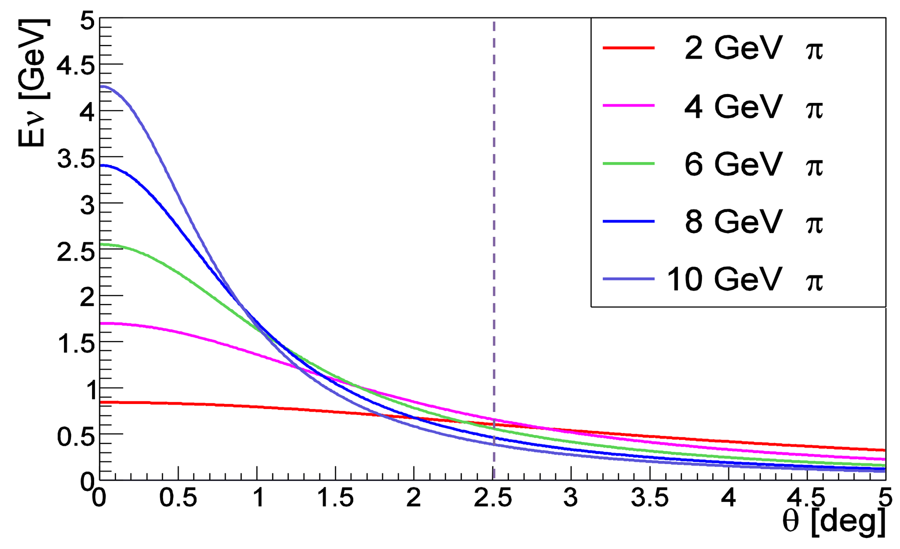
J-PARC neutrino off-axis beam

- The J-PARC neutrino beam is directed 2.5° away from the far detector. (Off-Axis beam)



$$E_\nu = \frac{m_\pi^2 - m_\mu^2}{2E_\pi}\frac{1}{1-\beta_\pi\cos\theta}$$

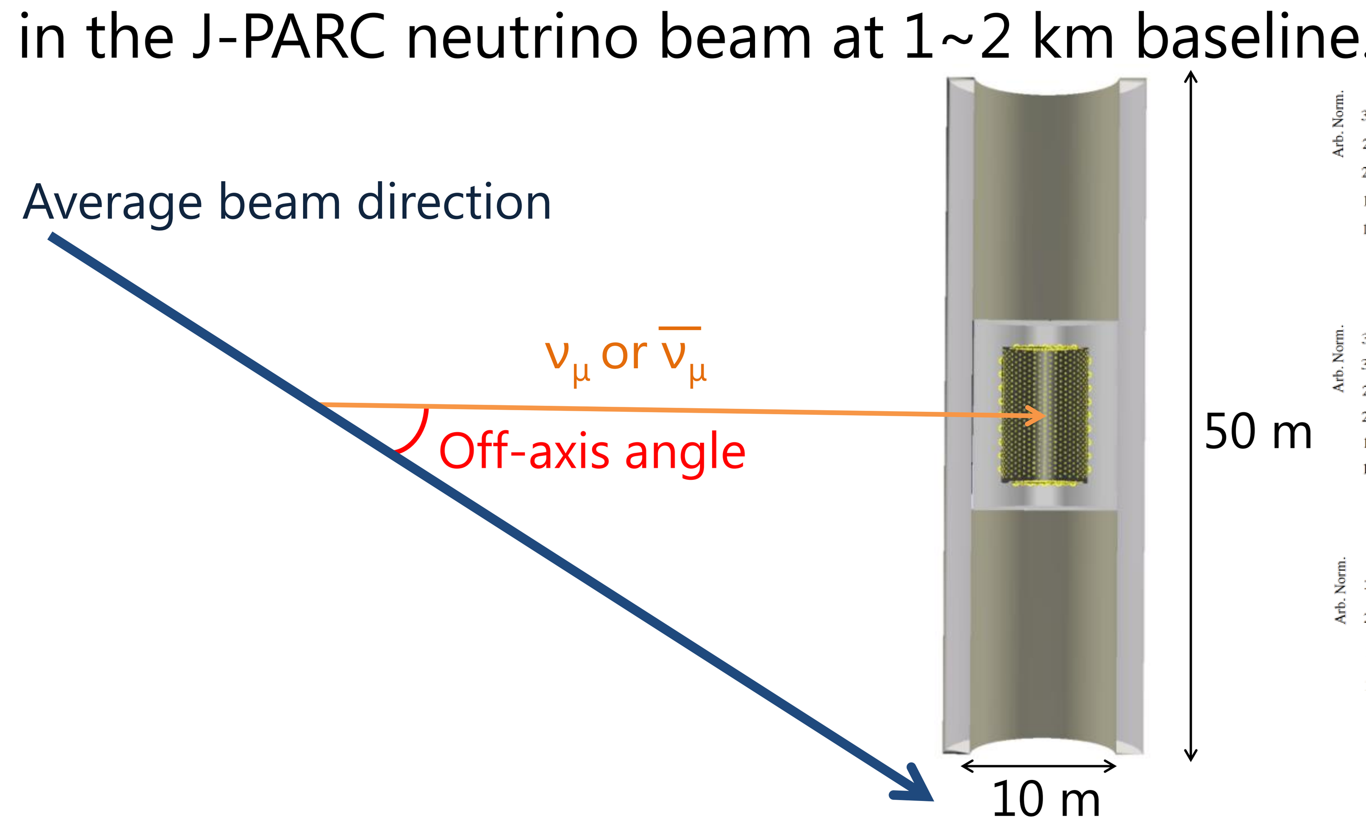


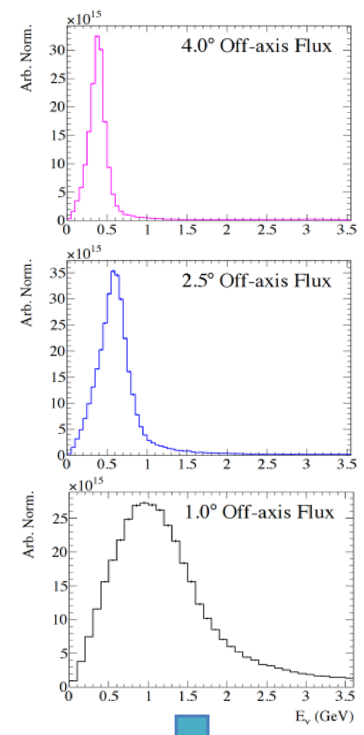
Motivation for NuPRISM

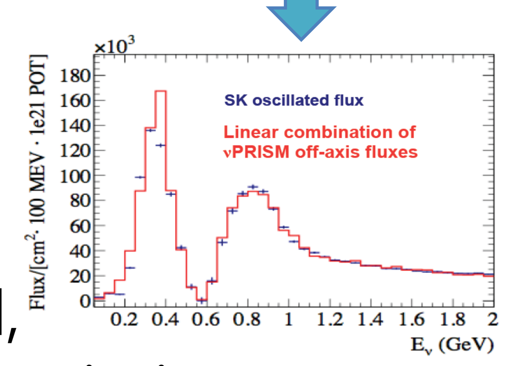
- Neutrino-nucleus cross sections are not well measured, which causes systematic uncertainties in long-baseline experiments.
- In the J-PARC neutrino beamline, near detectors measure flux and cross sections before oscillation.
- However, the uncertainties remain since neutrino spectra differ between far and near detectors.

NuPRISM Detector

- A proposed water Cherenkov detector in the J-PARC neutrino beam at 1~2 km baseline.







- NuPRISM measures neutrino interactions over off-axis angle 1 ~ 4°.
- Taking linear combination of them, oscillated neutrino spectra are regenerated, resulting in cancellation of systematic uncertainties.

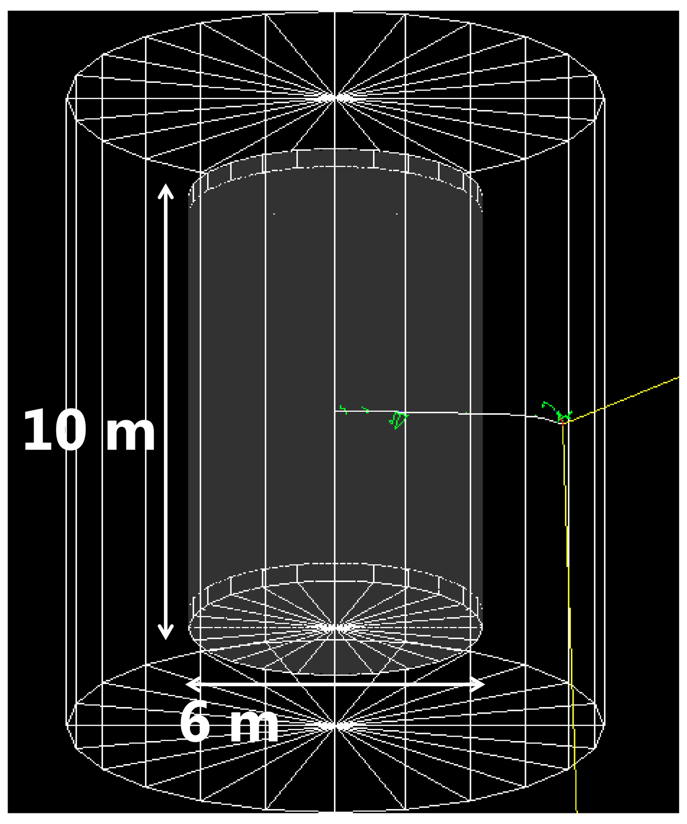
Optimization of NuPRISM detector

- For short baseline oscillation search and ν_e cross section measurement, we need to find a photo-sensor configuration that allows us to select pure ν_e samples.
- As a first step, event reconstruction performances between some configurations with different photo coverages are compared using detector simulation.

Simulation Configuration

- Based on Geant4 (WCSim)
- PMTs with 8 inch diameter
- Position of particles : uniform
  Direction : isotropic

Particle	Momentum [MeV/c]
e^-	30, 100, 500, 1000
μ^-	200, 500, 800, 1000



- Only events whose track is fully contained in the detector are used for analyses.

Event reconstruction algorithm, fiTQun

- Developed for T2K experiment
- Tuning for NuPRISM is ongoing.
- Reconstructs particles from charge and time information by all photo sensors with the maximum likelihood method.

$$L(\boldsymbol{x}) = \prod_j^{unhit} P_j(\text{unhit}|\boldsymbol{x}) \prod_i^{hit}\{1 - P_i(\text{unhit}|\boldsymbol{x})\} f_q(q_i|\boldsymbol{x}) f_t(t_i|\boldsymbol{x})$$

Probability that the j-th photo sensor does not detect photon — Charge probability distribution — Time probability distribution

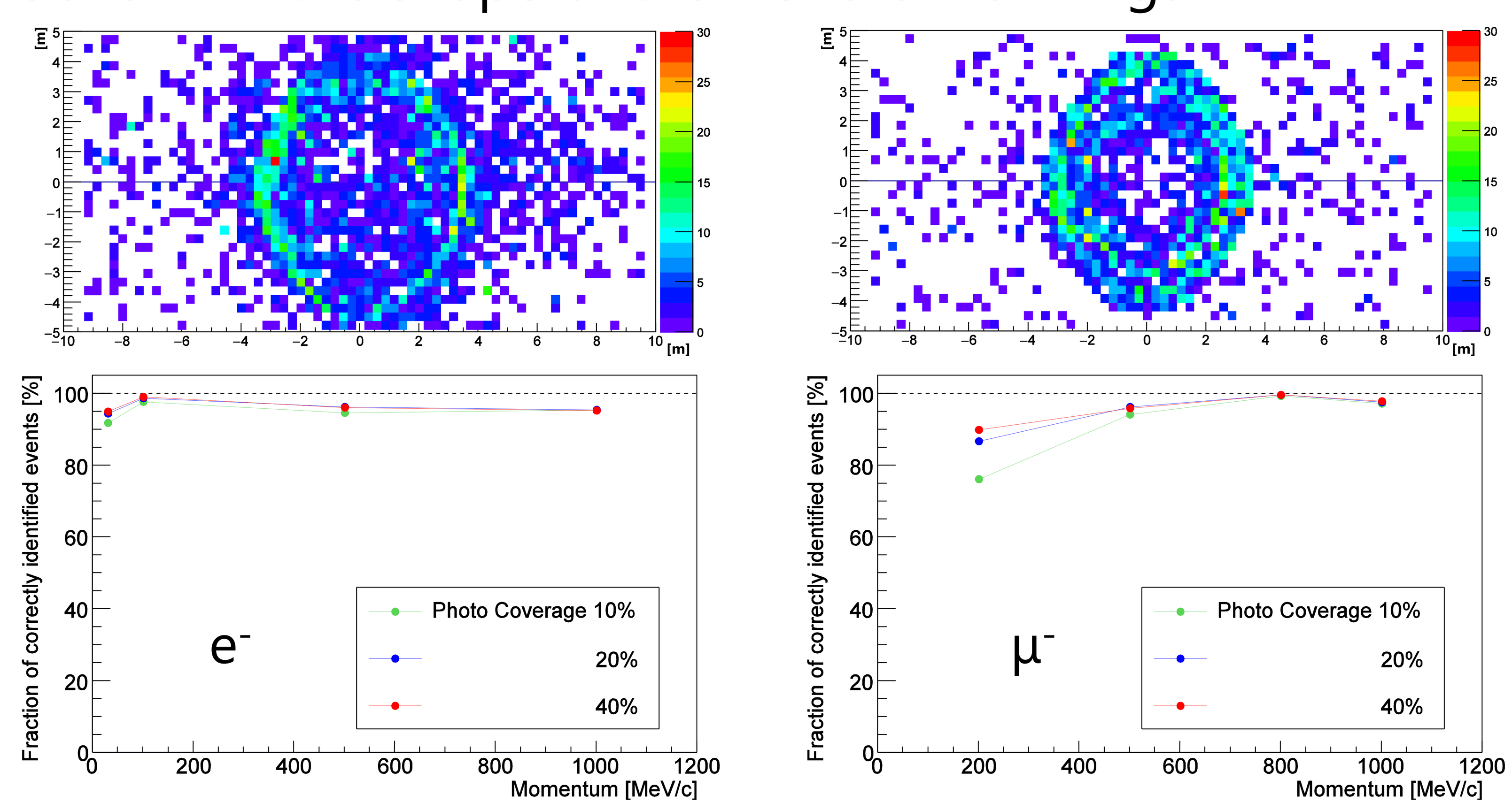
Summary

- A new water Cherenkov detector, NuPRISM, is proposed in the J-PARC neutrino beamline. NuPRISM is expected to reduce systematic uncertainty of T2K and future T2HK experiments.
- In the near future, sensitivities to physics measurements will be evaluated, and the detector design will be determined.

Results

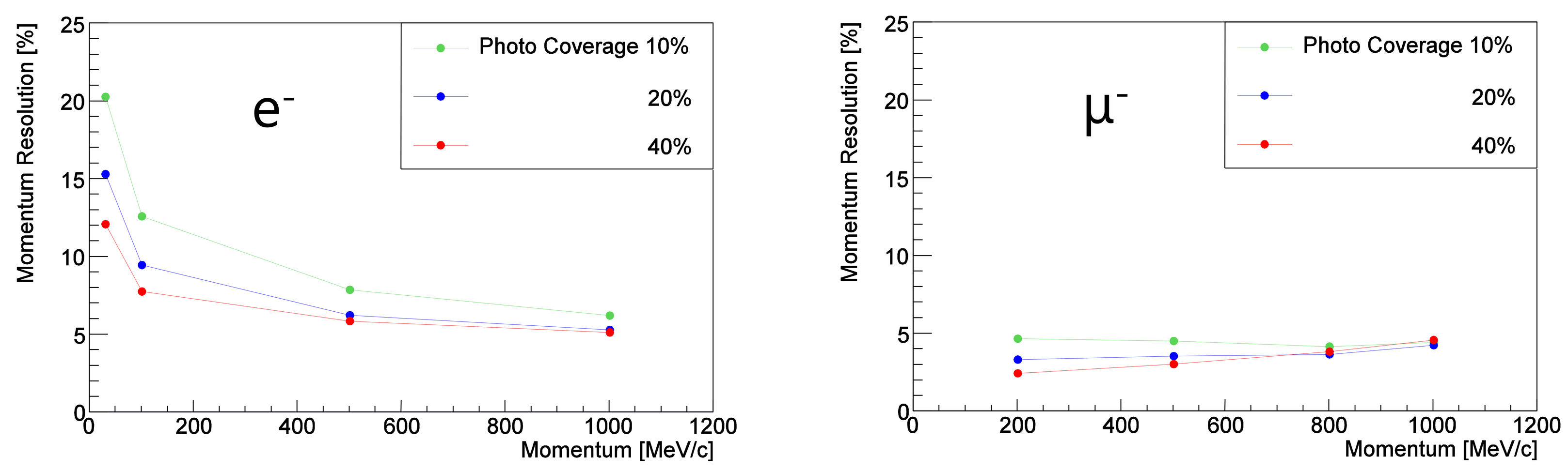
1. Particle identification

   Water Cherenkov detectors distinguish electrons and muons with the shape of their Cherenkov rings.



2. Momentum resolution

   With Gaussian fit of reconstructed momentum distribution



3. Position and direction resolution

   Based on the distributions of position/direction difference between true and reconstructed particles. The resolutions are defined as 68.3% coverage value.