Empowering the next generation of neutrino experiments through measurements at the Water Cherenkov Test Experiment

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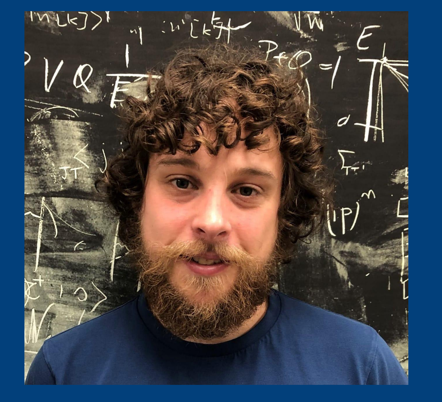
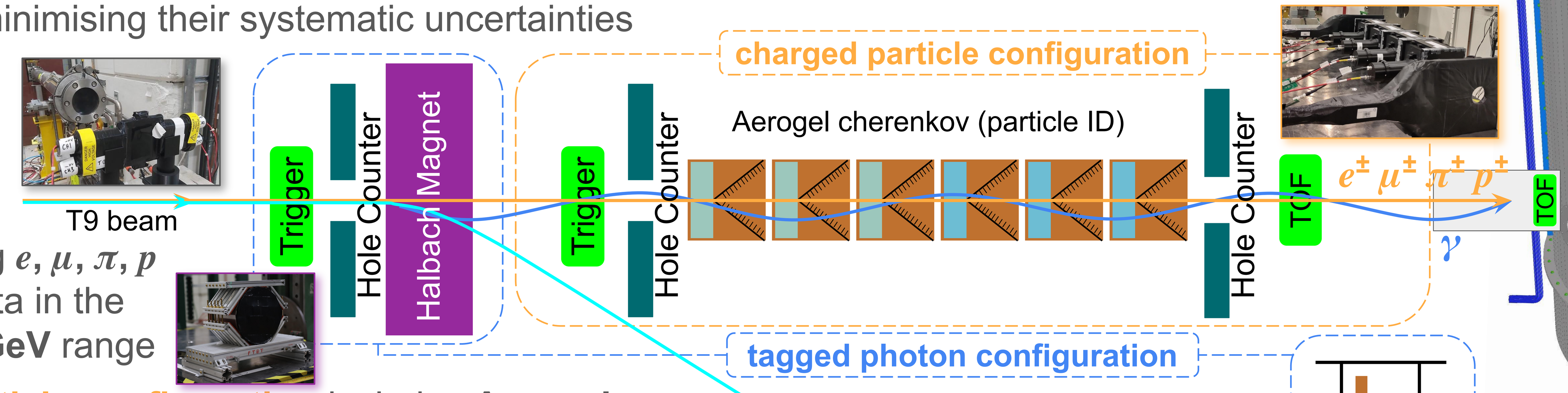
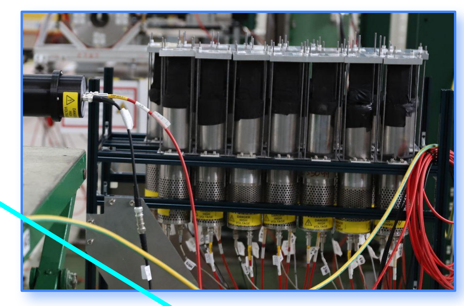
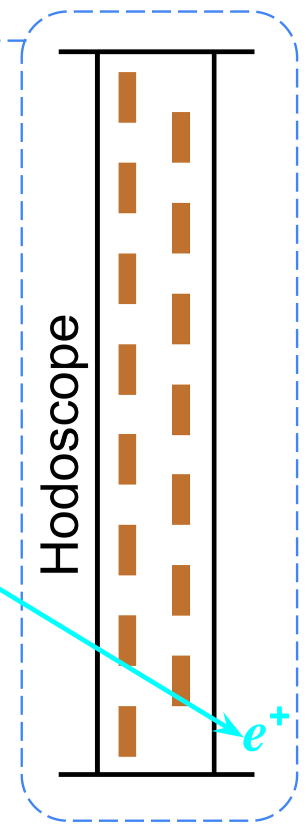


The Water Cherenkov Test Experiment (WCTE) at CERN T9 Beamline

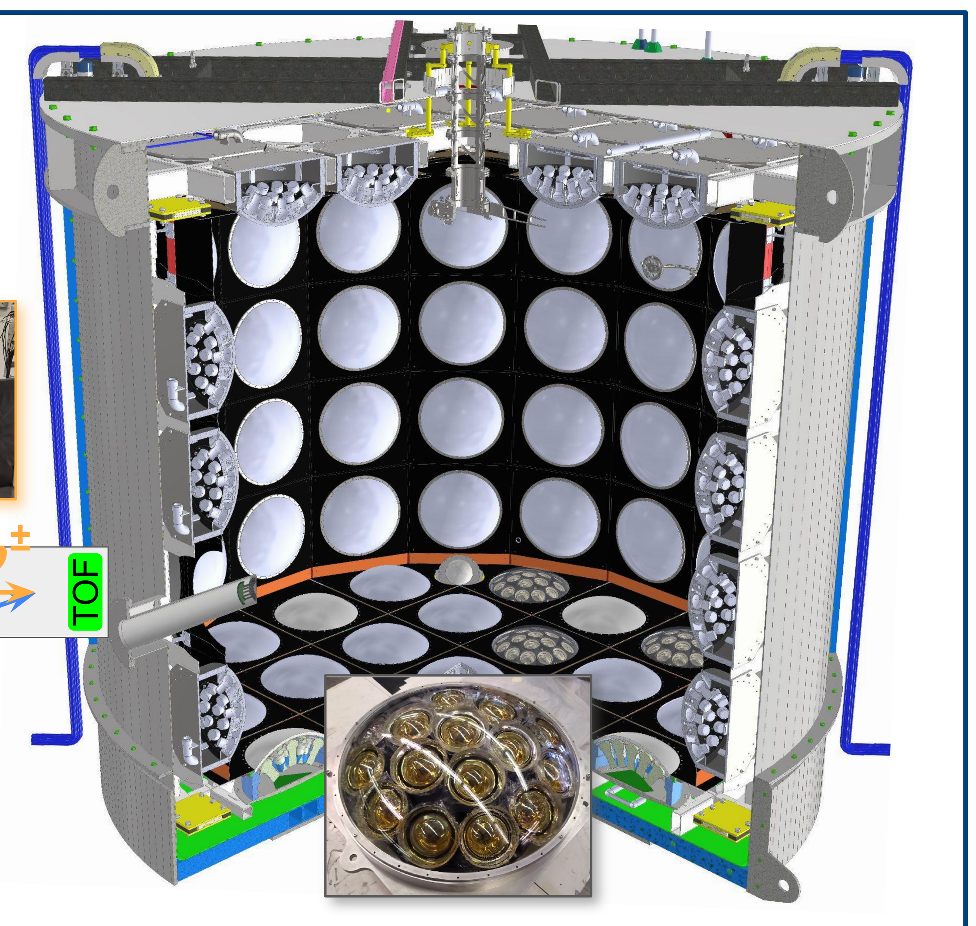
- **WCTE** is a unique opportunity to study water-Cherenkov detector response, novel technologies for optical detection, calibration and event reconstruction, and physics measurements to empower future neutrino experiments by minimising their systematic uncertainties
- The CERN **T9 beamline** provides WCTE with charged particles including e, μ, π, p at known momenta in the **100 MeV to 1.1 GeV** range







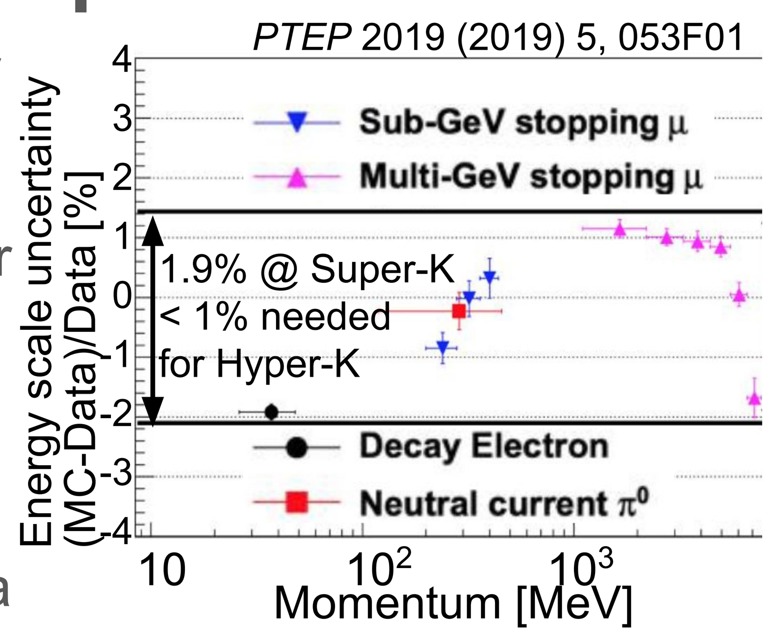
- The **charged particle configuration** includes **Aerogel Cherenkov counters** with different refractive indices chosen for each beam momentum, for tagging of electrons and muons through their Cherenkov threshold; **Time of Flight** (TOF) detectors with 100 ps timing resolution provide identification of the heavier hadrons (p, π, K, etc.)
- The **tagged photon configuration** includes a **1 Tesla permanent magnet** to deflect positrons while bremsstrahlung photons continue towards the water-Cherenkov detector; A **hodoscope** measures the deflected positron's energy to determine the photon's energy
- July 2023 beam test successfully demonstrated capability of both beam monitor configurations
- Data taking is scheduled for 6 weeks Oct-Nov 2024 with additional beamtime expected in 2025



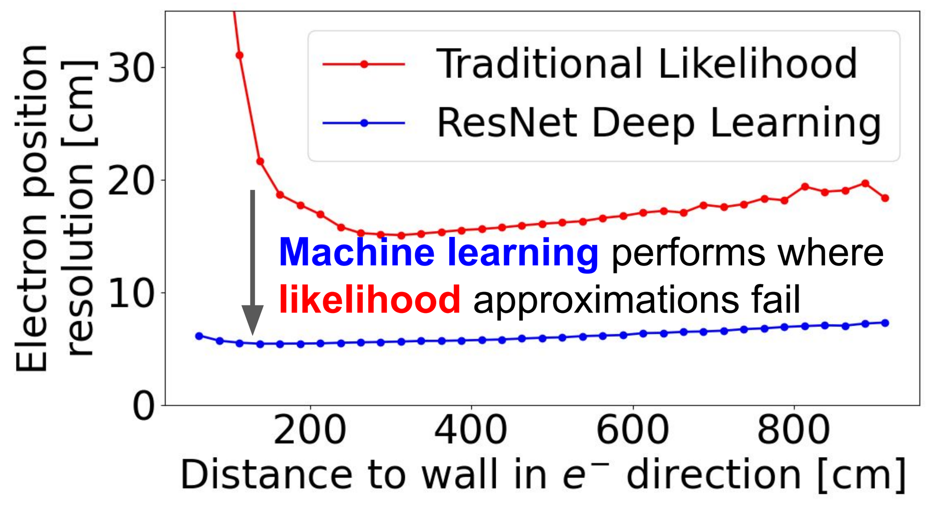
- 50 ton **water-Cherenkov detector** currently under construction
- 3.4 m height x 3.8 m diameter tank
- **100 multi-PMT modules** each containing 19 individual 8cm PMTs
- **Pure water** phase and **Gd-doped water** phase for neutron detection
- Novel optical calibration systems and calibration source deployment
- **Installation to T9 in October 2024**

Detector Response

- **WCTE directly measures response** to reduce detector uncertainties
- e.g. **measure** e / μ **charge ratio** at fixed beam momenta
- **Reduction to < 1% uncertainty** is necessary for ν measurements at Hyper-Kamiokande



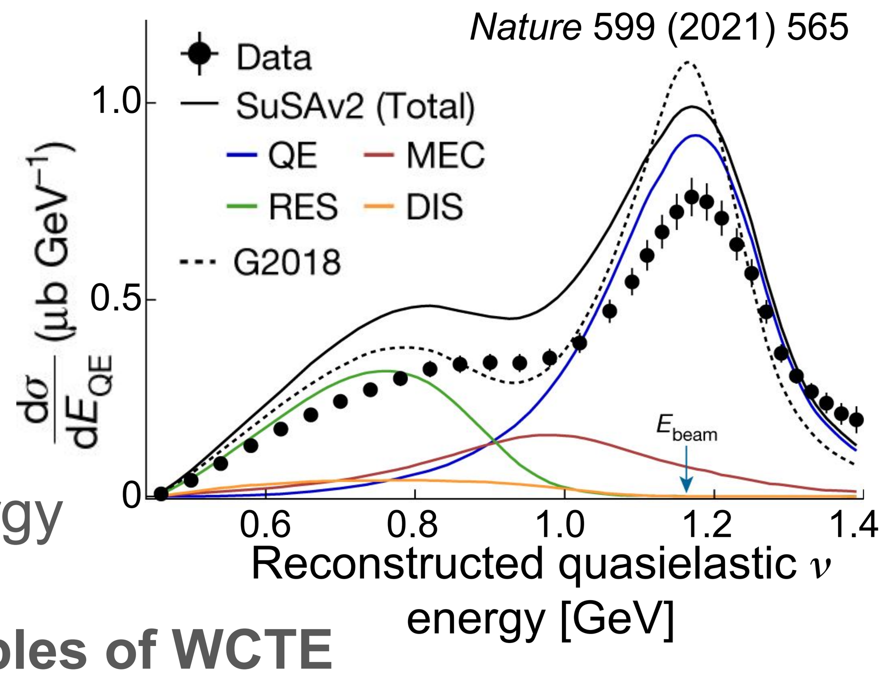
Event Reconstruction



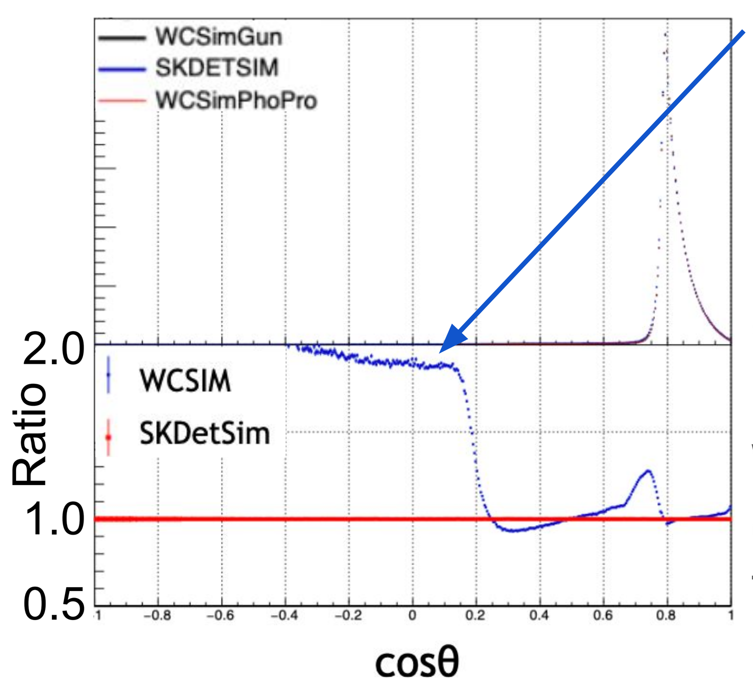
- **WCTE leading development of new calibration & reconstruction**
- Essential data-driven validation of **machine-learning based methods**

Interactions on Water

- **Controlling ν cross-section** uncertainties essential for future ν measurements
- Nuclear interaction of ν products also complicates ν energy reconstruction
- **Pure control samples of WCTE** feed improvement and validation of interaction models



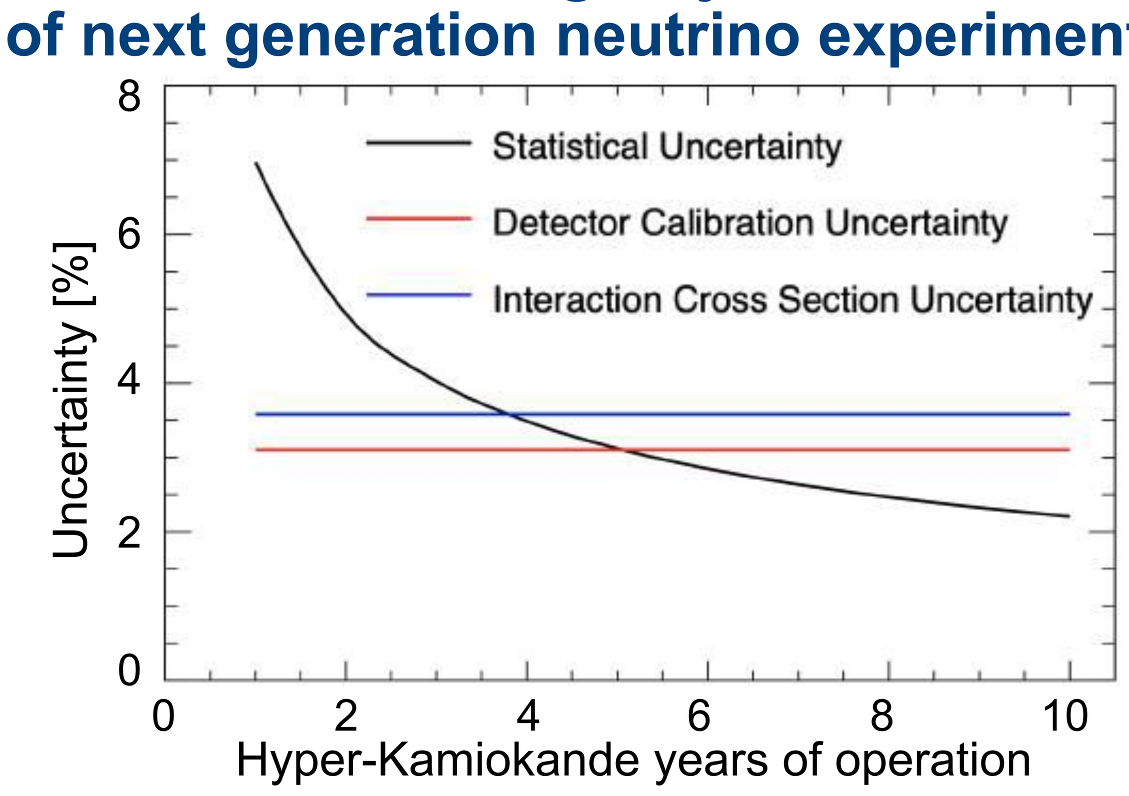
Cherenkov Emission Profile



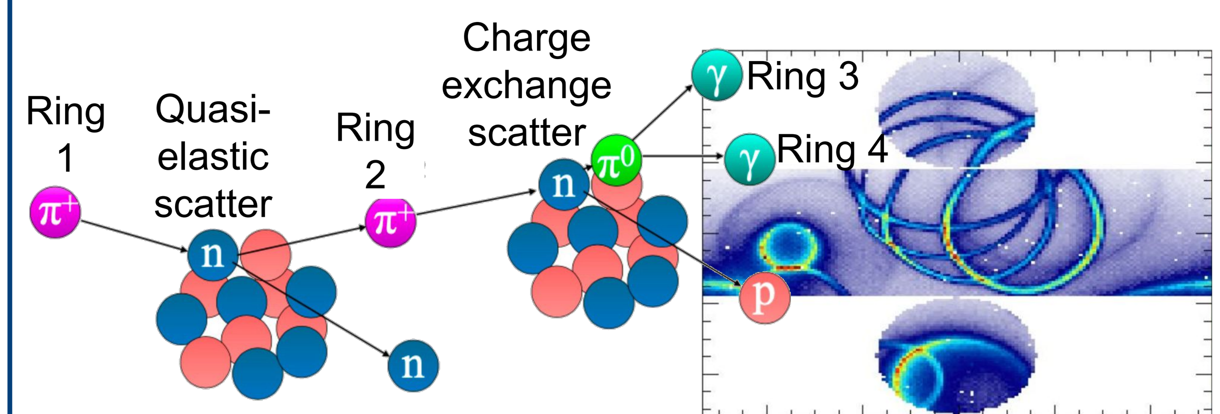
Discrepancies between models limit ability to use backward-going Cherenkov light to enhance event reconstruction

WCTE measures emission profile from e and μ of known momenta

Broad physics programme of WCTE with focus on controlling major uncertainties of next generation neutrino experiments

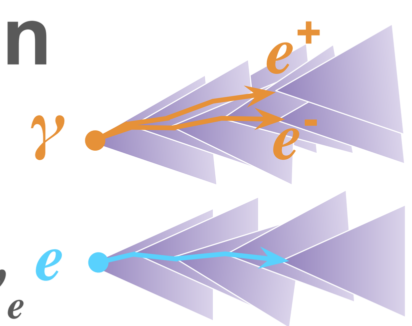


Hadronic Interactions

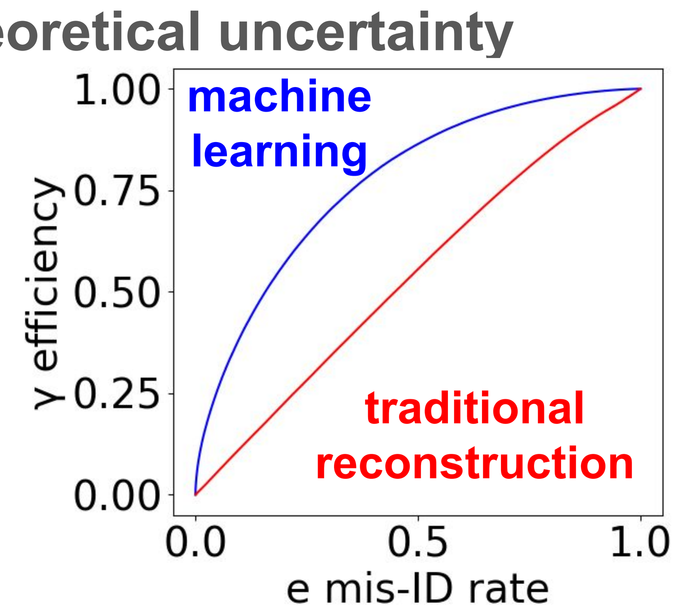


- **Pion production in ν interactions** introduces several challenges for ν measurements
- Complex hadronic interactions of pions **cannot be simulated from first principles** resulting in significant model uncertainties
- **Multi-ring event topologies are difficult to reconstruct** requiring development of new reconstruction methods to handle pion events
- **WCTE directly measures pions, including all their interactions and detector response**
- Potential to also measure **pion photo-production** in tagged gamma configuration

Gamma Identification



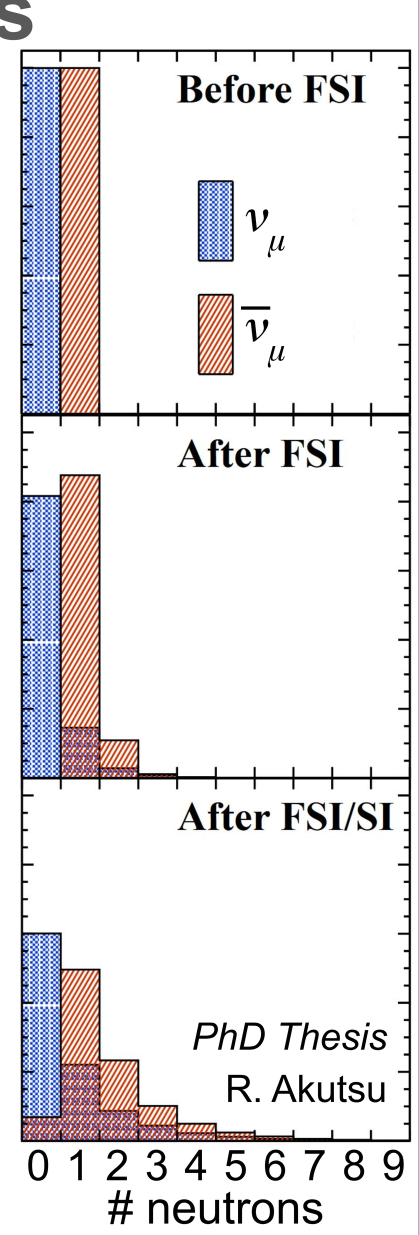
- Neutral current ν interactions producing single γ contribute **significant background to ν_e**
- This cross-section has not been measured and has **large theoretical uncertainty**
- **γ conversion to $e^+ + e^-$** produces overlapping electron rings
- **Single e** events look identical to **existing event reconstruction**



- Promising **70% separation accuracy** from novel **machine learning reconstruction**
- **WCTE measurements of electrons and tagged photons enable development and validation on pure samples of e & γ data**

Neutron Multiplicities

- Charged current quasielastic **neutrino interactions produce one proton**, while **antineutrino interactions produce one neutron**
- **Tagging neutrons** allows statistical ν / $\bar{\nu}$ separation
- **Large model uncertainties** in final state interactions (FSI) and secondary interactions (SI) that modify observed neutron distribution
- **Gadolinium doped water enables neutron detection** via gammas after n-capture
- **WCTE measures secondary neutron production from protons in water**



Leptonic Scattering

- **ν interaction cross-sections contribute significant uncertainty** to neutrino measurements
- Lepton-nuclear interactions **provide information on neutrino-nuclear interaction models** through corresponding electroweak cross-sections
- **WCTE can measure lepton scattering in water** by searching for two-ring events