An aerogel Cherenkov threshold counter for the Water Cherenkov Test Experiment

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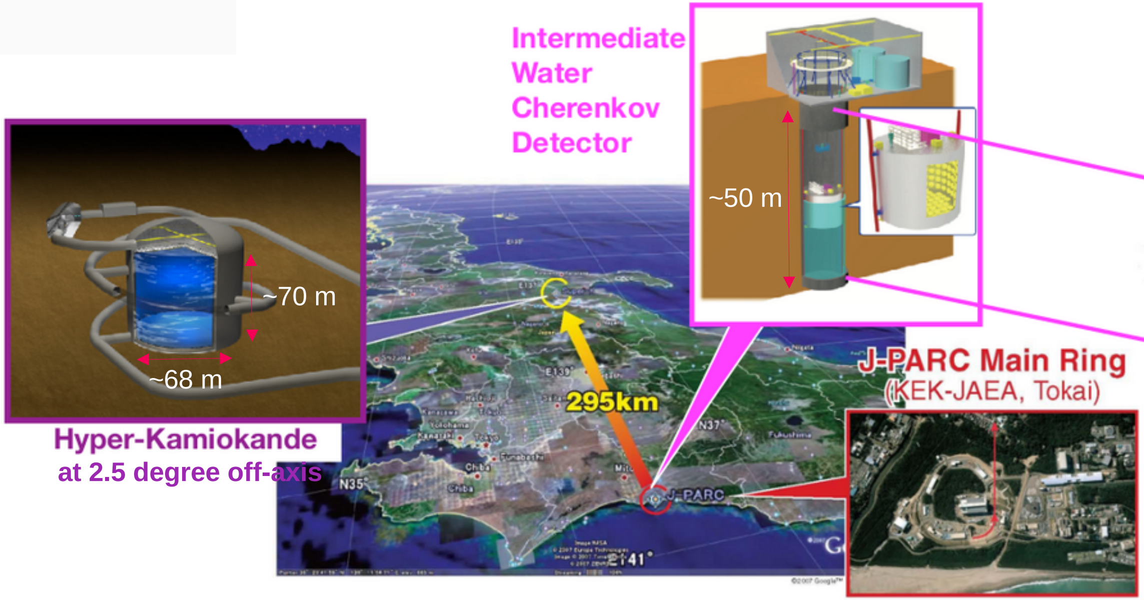
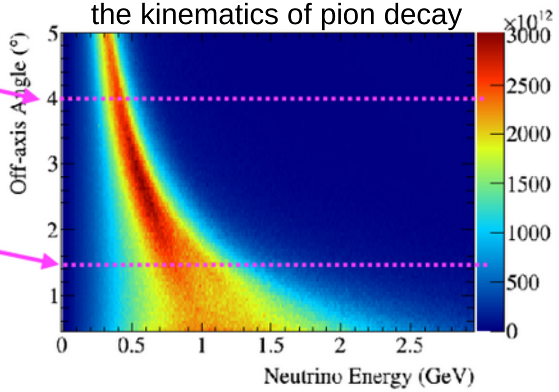
On behalf of WCTE collaboration

CAP Congress, London, ON
May 27, 2024

Hyper-K



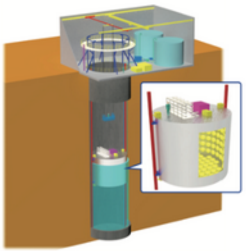


- A long-baseline neutrino experiment aiming to improve the sensitivity of studying neutrino oscillations, expected to collect first data in 2027.
- IWCD enables extracting nearly mono-energetic neutrino spectrum before oscillation, thus eliminating the need to reconstruct energy using theoretical models of neutrino interaction.
- The same type of intermediate/far detectors with the same angular and momentum acceptance allows comparison without relying on detector response simulations.
- Combination of independence on neutrino interaction model and detector response allows minimizing systematic uncertainties in oscillation analysis.

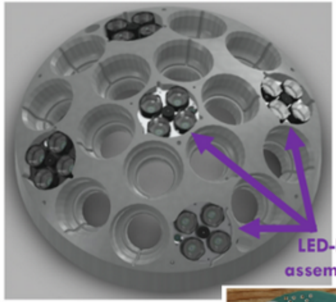
Photosensors

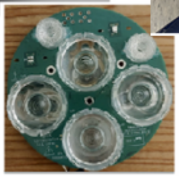
mPMT

IWCD

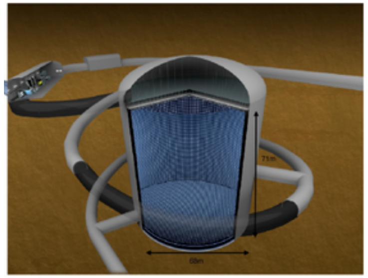


7 m ø x 8 m tall (ID)
370 mPMTs
Operation from 2027

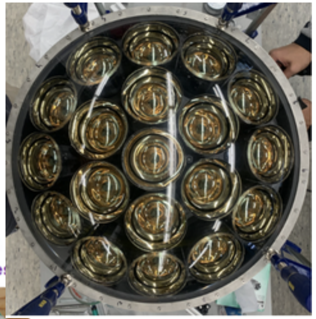




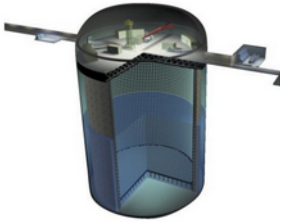
Hyper-K



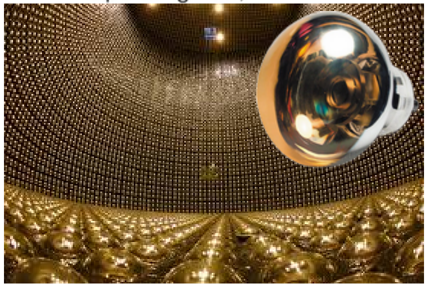
68 m ø x 71 m tall
20,000 20-inch PMTs
800 mPMTs (200 LED-mPMT)
Operation from 2027



Super-K



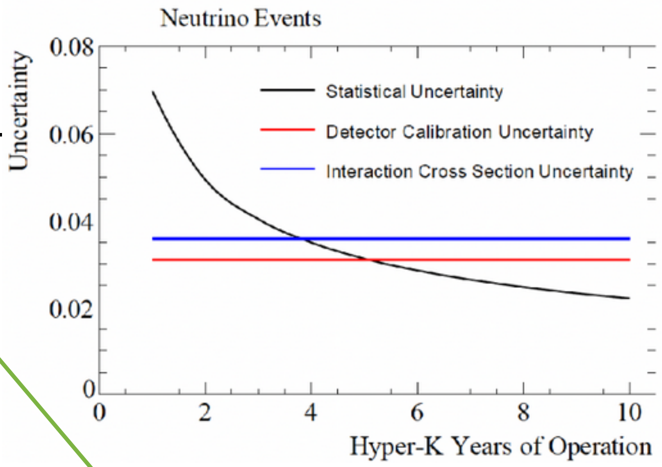
39 m ø x 41 m tall
11,000 20-inch PMTs
Operating now,



- Multi-PMTs are a major part of Canada’s contribution to Hyper-K.

Photosensor calibration

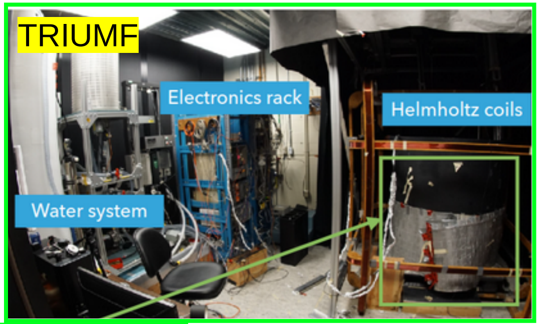
- Current Super-K detector systematic uncertainty is ≥ 2%.
- Hyper-K target: < 1% overall detector systematic uncertainties and < 0.5% energy scale error.
- Simply increasing statistics will not reduce detector systematic uncertainties to the levels needed.

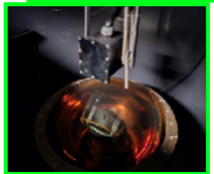


mPMTs themselves will not be able to measure the angular response of the 20” PMTs, but will help breaking the degeneracy between their angular response and water parameters.

- Individual PMT response
  - Relative gain
  - Absolute SPE gain, relative QE, SPE distribution
  - Charge nonlinearity
  - PMT relative timing
  - TQ map
  - **Angular response**
- **Reflectance** from PMT and black sheet
- Water parameters (Rayleigh scattering, Mie scattering, attenuation, **Raman scattering**)
- Energy scale
- **Geometry (PMTs and calibration sources)**
- **Cherenkov physics**

LEDs
mPMT
NiCf source
Laser diffuser
Light injectors
Control samples
eLINAC
Ex-situ PMT measurement
Photogrammetry
Test beam (WCTE)



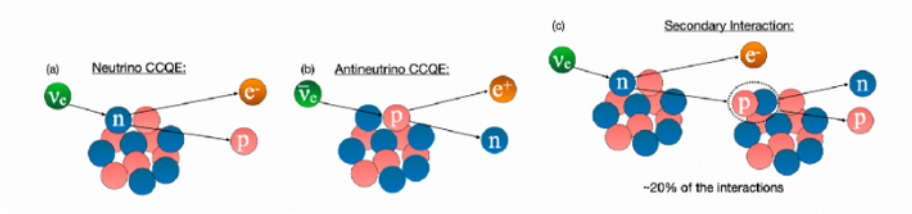


WCTE will be a major milestone towards delivery of mPMTs for IWCD!

WCTE physics

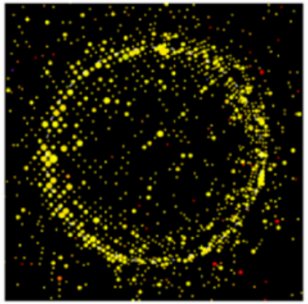
- Antineutrino interactions tend to produce neutrons, while neutrinos tend to produce protons
- Capability to tag antineutrinos vs. neutrinos with neutron detection is limited by secondary production of neutrons (right)
- WCTE will measure secondary neutron production
- Important for using neutrons to ID antineutrino events in Super-K

Neutron production in neutrino interactions



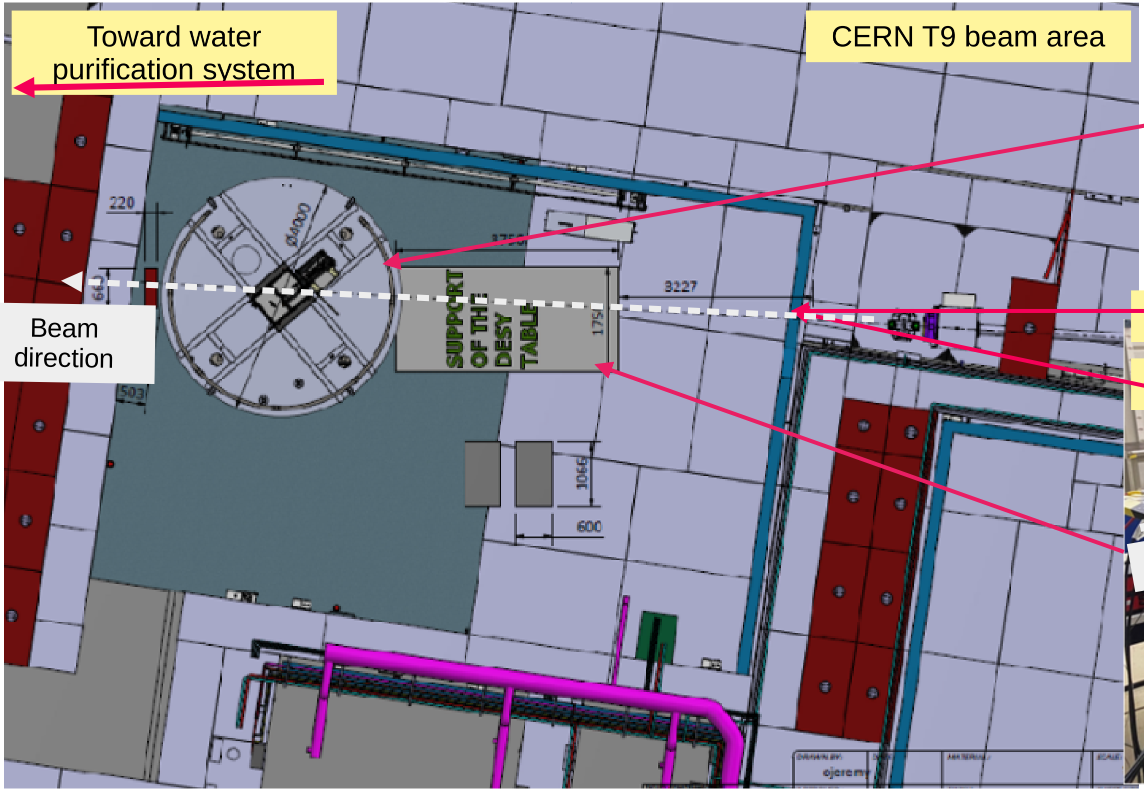
- Electrons are identified as “fuzzy” rings in WC detectors due to EM shower
- High energy gammas can fake electron
- WCTE will study capability to tag gammas by additional light produced by e+e- pair at beginning of shower
- Gammas can also be used to study pion photoproduction, which is important for understanding gamma production through pion production in neutrino interactions
- Requires tagged photon beam

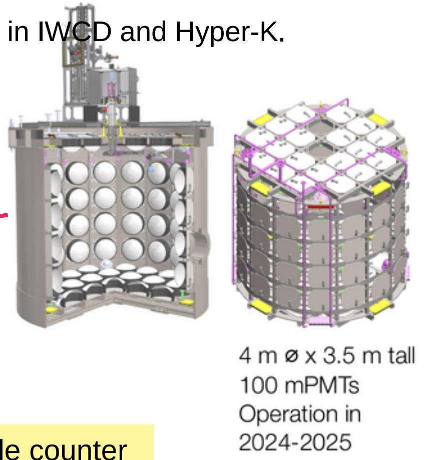
Example electron ring in Super-K

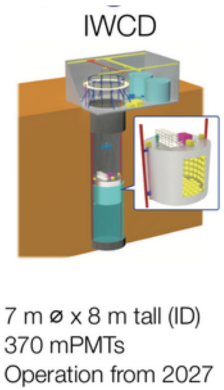


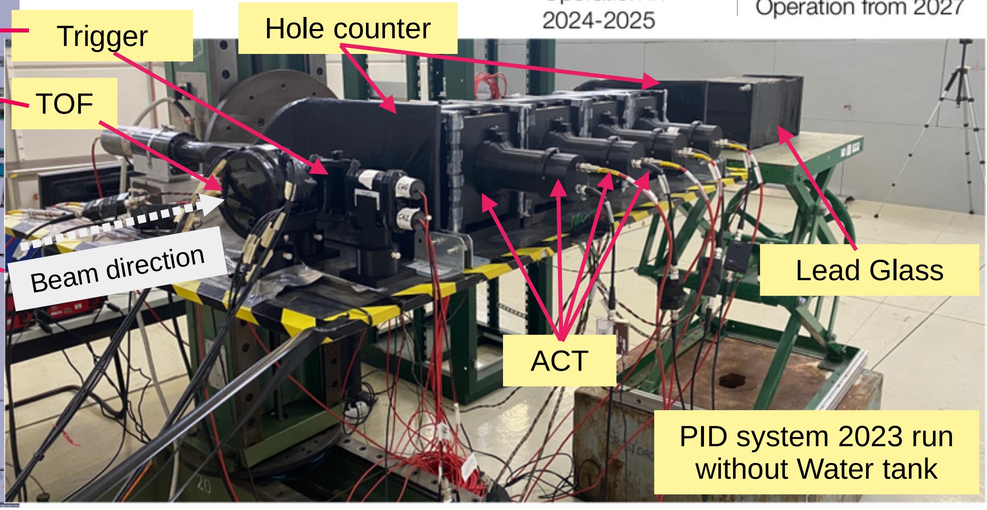
WCTE

- Operation in WCTE will be a major milestone towards delivery of mPMTs for IWCD!
- WCTE can be seen as testbeds for detector systems, calibration techniques and event reconstruction to be used in IWCD and Hyper-K.
- WCTE measurements can be inputs to Super-K measurements in the near term.



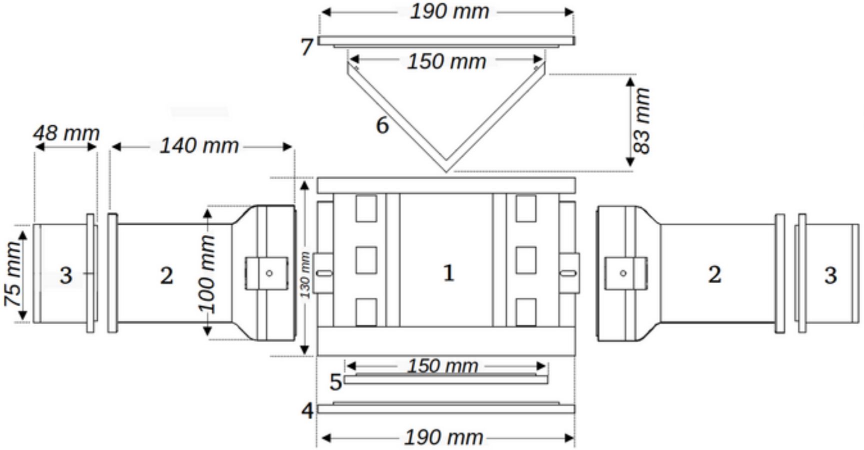


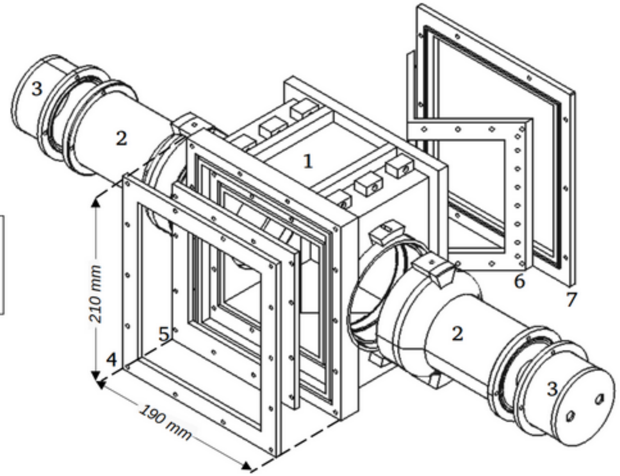


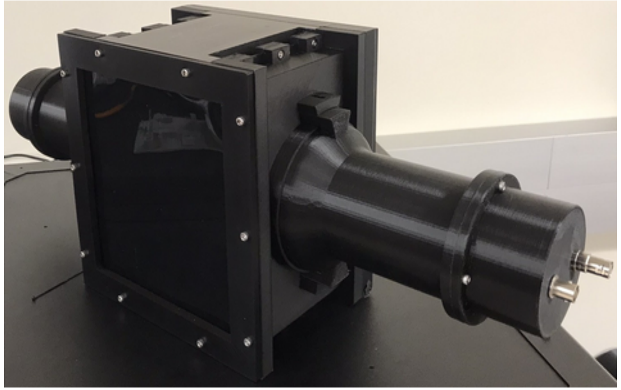


Aerogel Cherenkov Threshold (ACT)

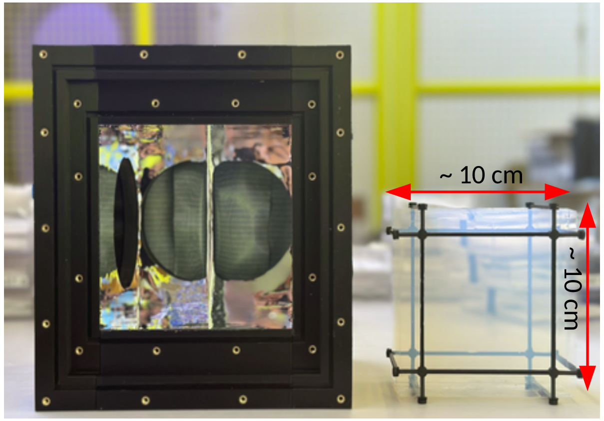
ACT detectors are intended for pion/muon separation and electron vetoing in the range of 0.2-1 GeV/c.

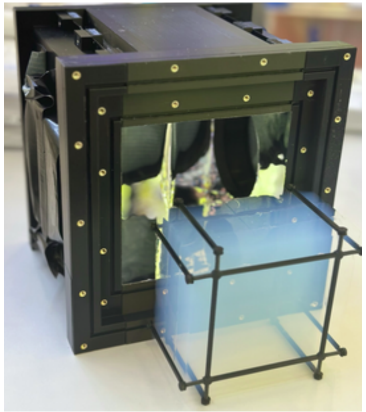


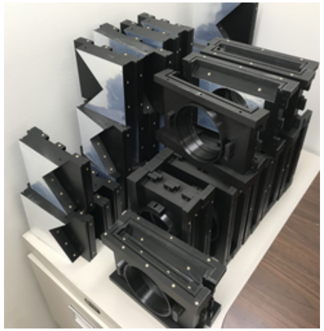




		Threshold momenta (GeV/c)			
n	Thickness (cm)	μ	π	K	p
1.006	8+8	0.9625	1.2578	4.4937	8.5499
1.01	6+6	0.7448	0.9733	3.4773	6.6161
1.015	6+6	0.6079	0.8028	2.8397	5.3953
1.02	6+6	0.5253	0.6865	2.4527	4.6667
1.03	4+6	0.4279	0.5592	1.9977	3.8009
1.047	8+8	0.3404	0.4449	1.5894	3.0240
1.06	4+6	0.3003	0.3925	1.4022	2.6680
1.11	2+2	0.2191	0.2864	1.0233	1.9469
1.13	2+2	0.2006	0.2622	0.9368	1.7825
1.15	2+2	0.1859	0.2430	0.8681	1.6517

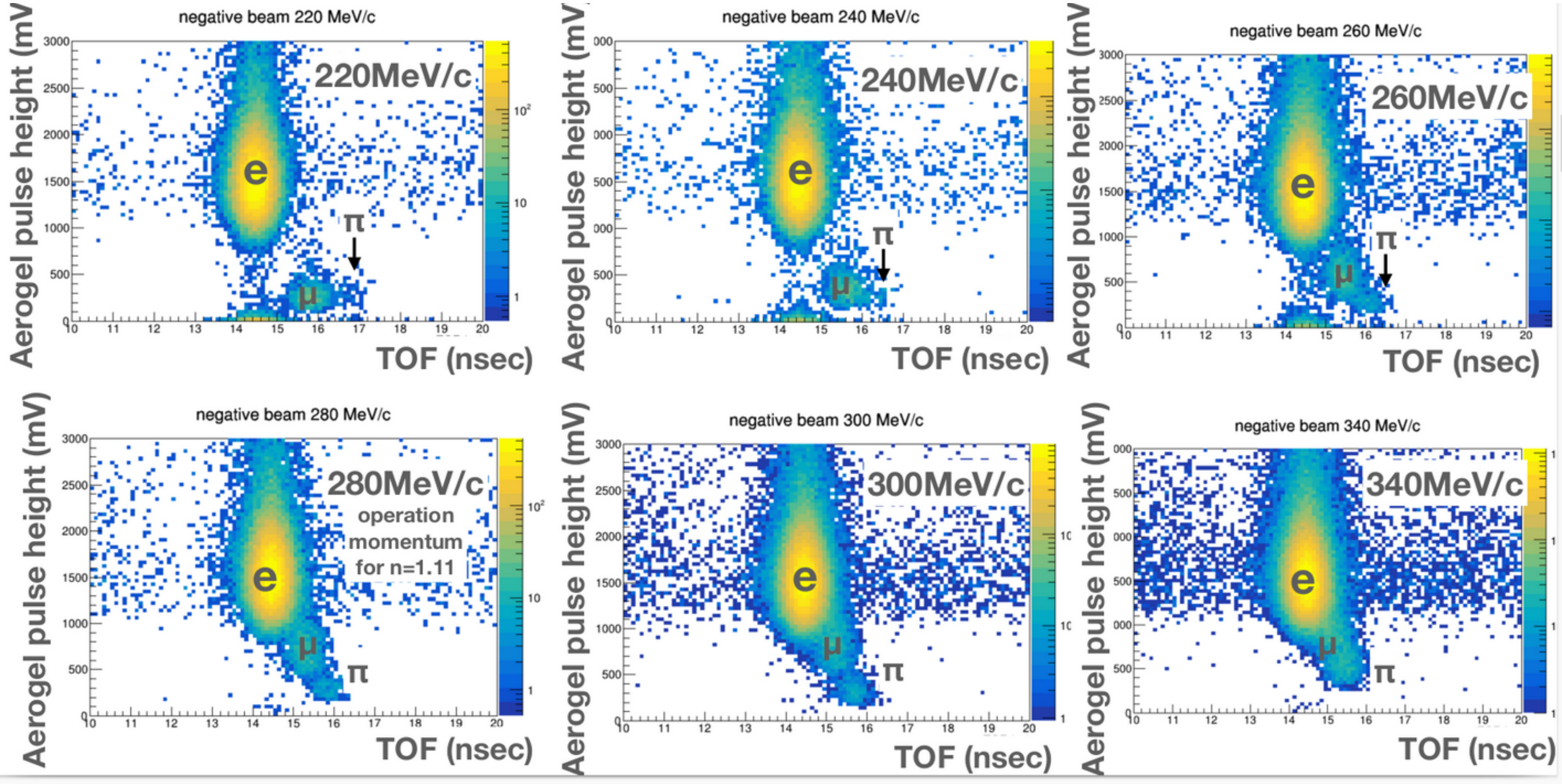






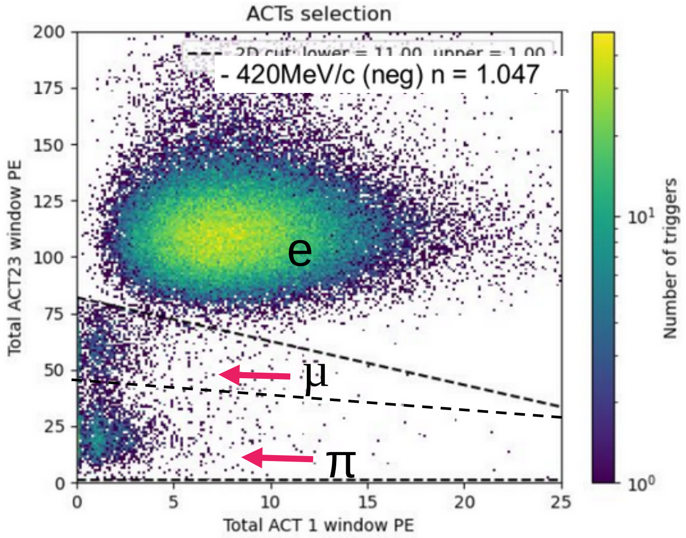
n=1.13: $p_{th}(\pi)$=0.262GeV/c, $p_{th}(\mu)$=0.200GeV/c

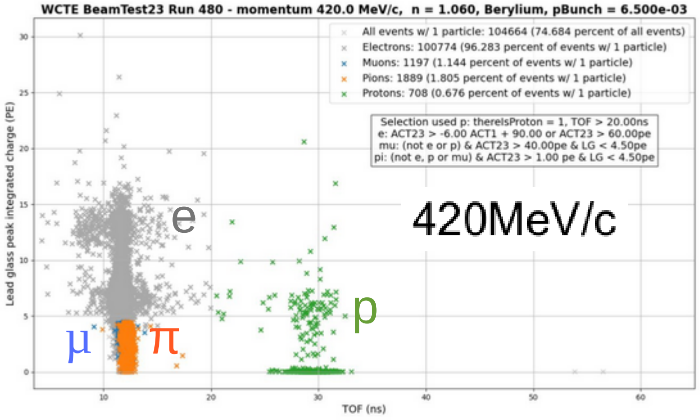
Measurements are done around the pion cherenkov threshold.

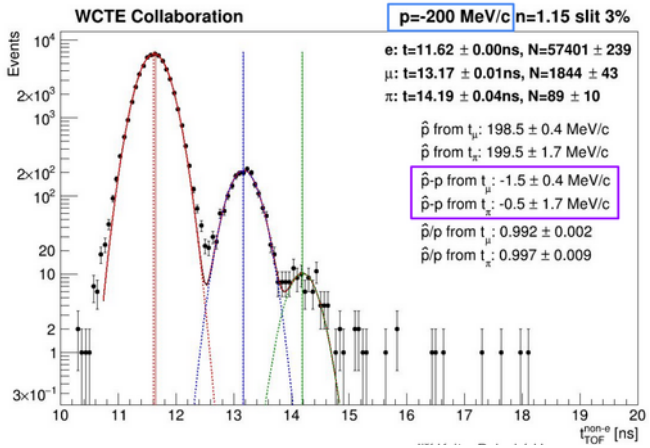


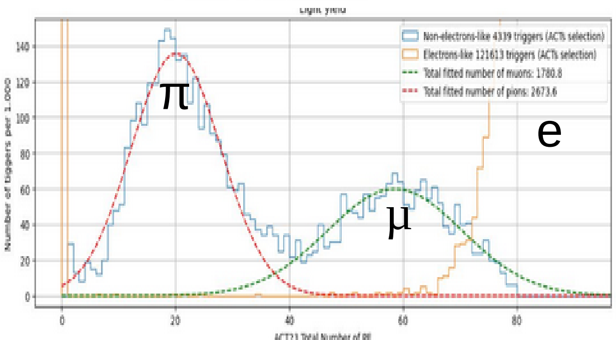
Analysis approach

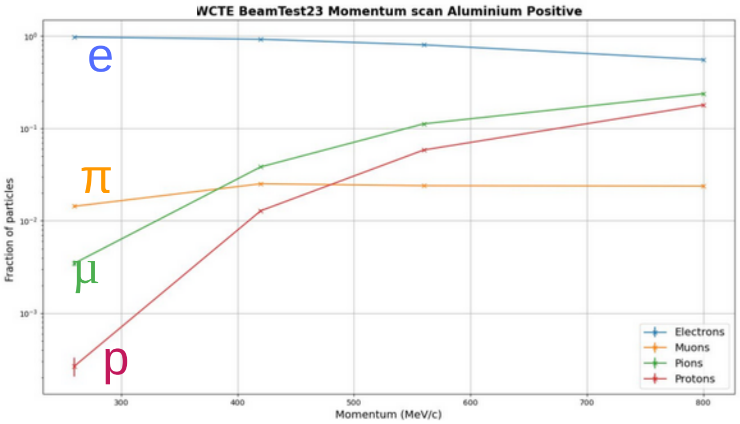
- The TOF current resolution is around 240 ps, allowing separation up to 280 MeV/c.
- TOF cut to separate protons, 2D cuts in ACT23 vs ACT1 to separate e, mu, pi.

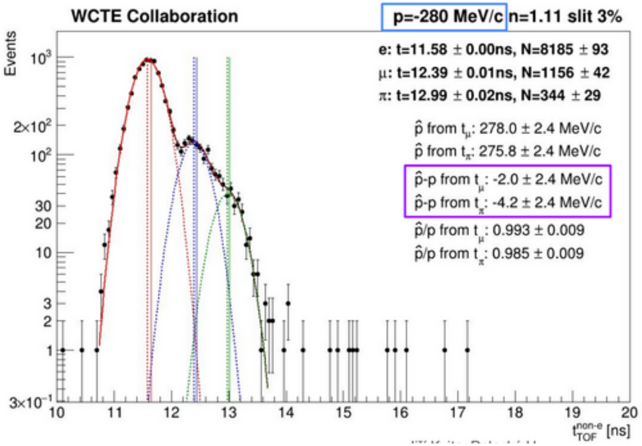






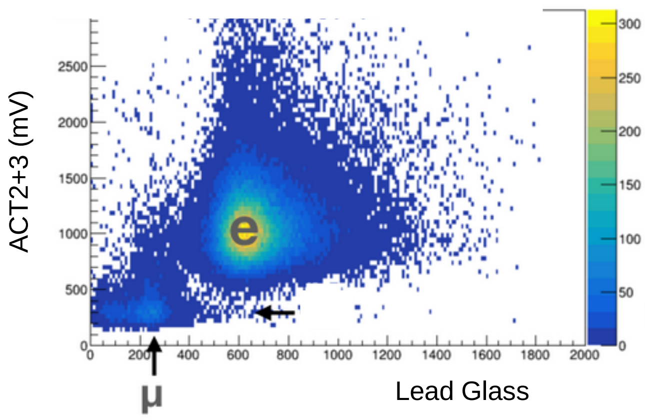




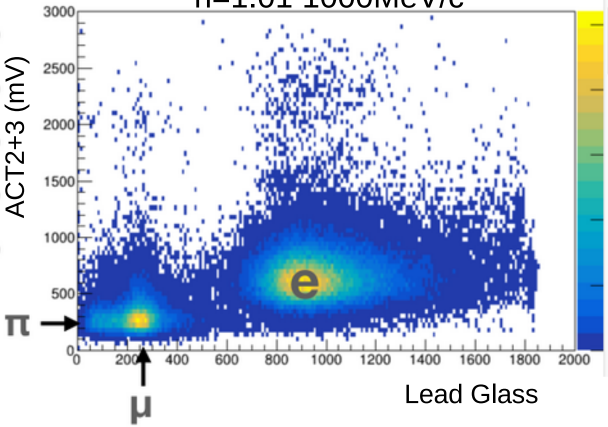


No proper separation at low indices

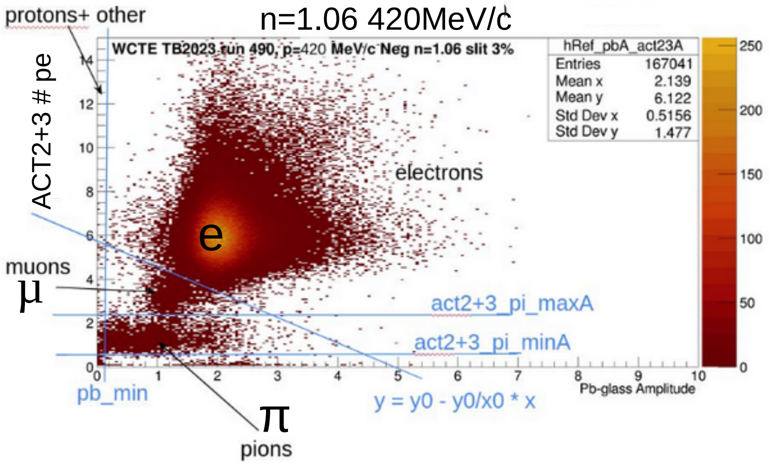
n=1.02 700MeV/c



n=1.01 1000MeV/c



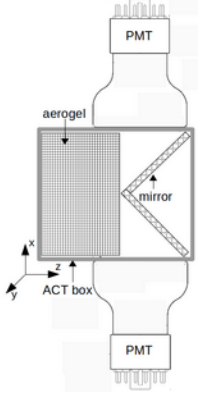
n=1.06 420MeV/c



- The amount of detected light at low indices is low, so proper separation is not achieved. Need to increase the number of corresponding detectors to improve light collection efficiency.

geometrical reason

Short Rayleigh scattering length: ~2-3 cm +



→ no proper separation

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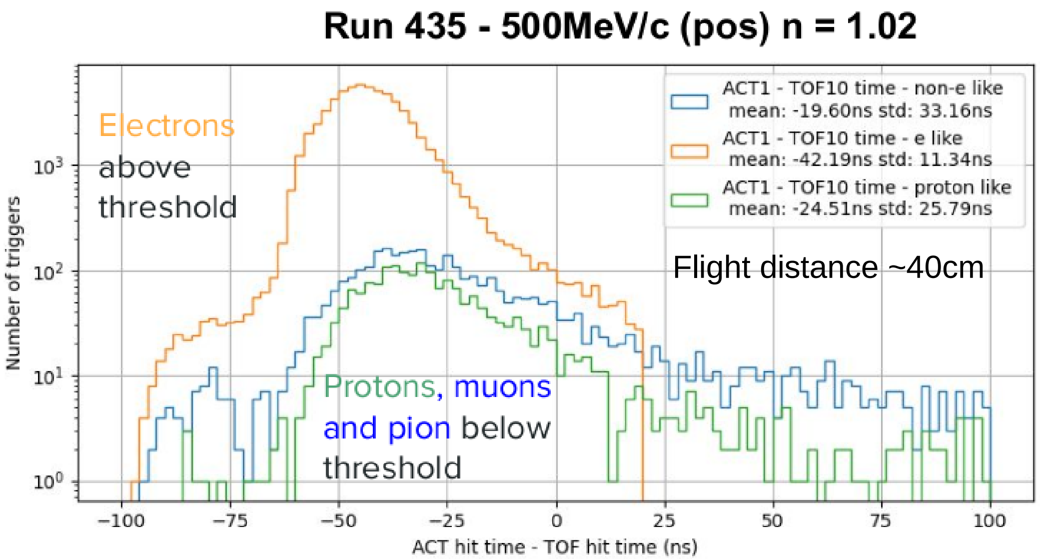
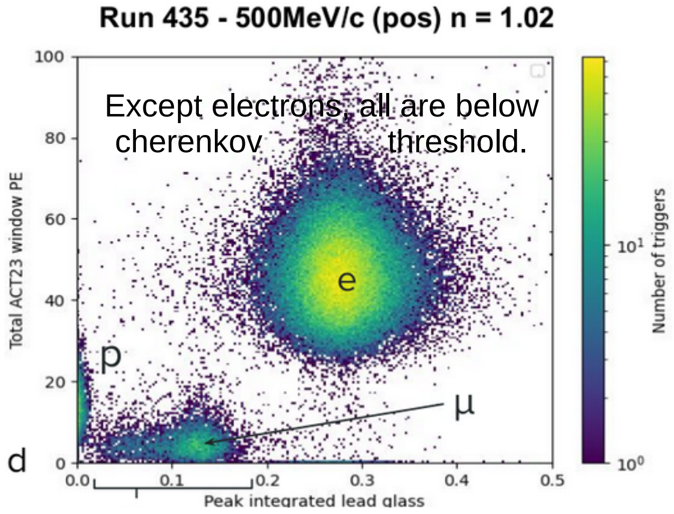
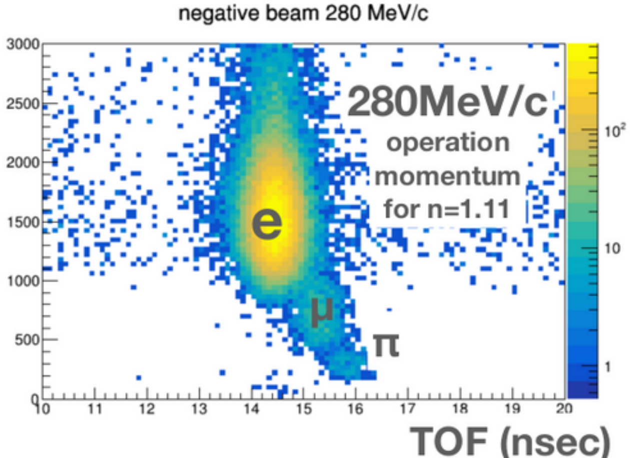
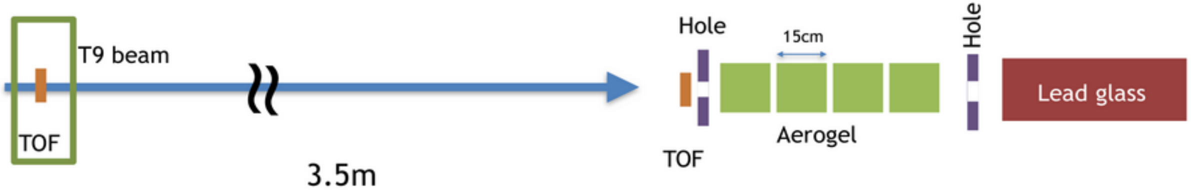
Scintillation from reflector material of ACTs

- Life time of the scintillation light is tens of nsec.
- Light emission below Cherenkov threshold, more for protons due to larger dE/dx..









Summary

- Hyper-K is a long baseline neutrino observatory aiming to improve neutrino oscillation studies.
- Canada group developed multi-PMTs for Hyper-K.
- WCTE will be major milestone towards delivery of mPMTs for IWCD!
- WCTE beam monitors enables sub-GeV π/μ separation by Aerogel Cherenkov (ACT) and TOF.

End of Slides

Momentum measurement

Compare separation as a function of energy.
Energy bias mainly in positive range (antiparticles)