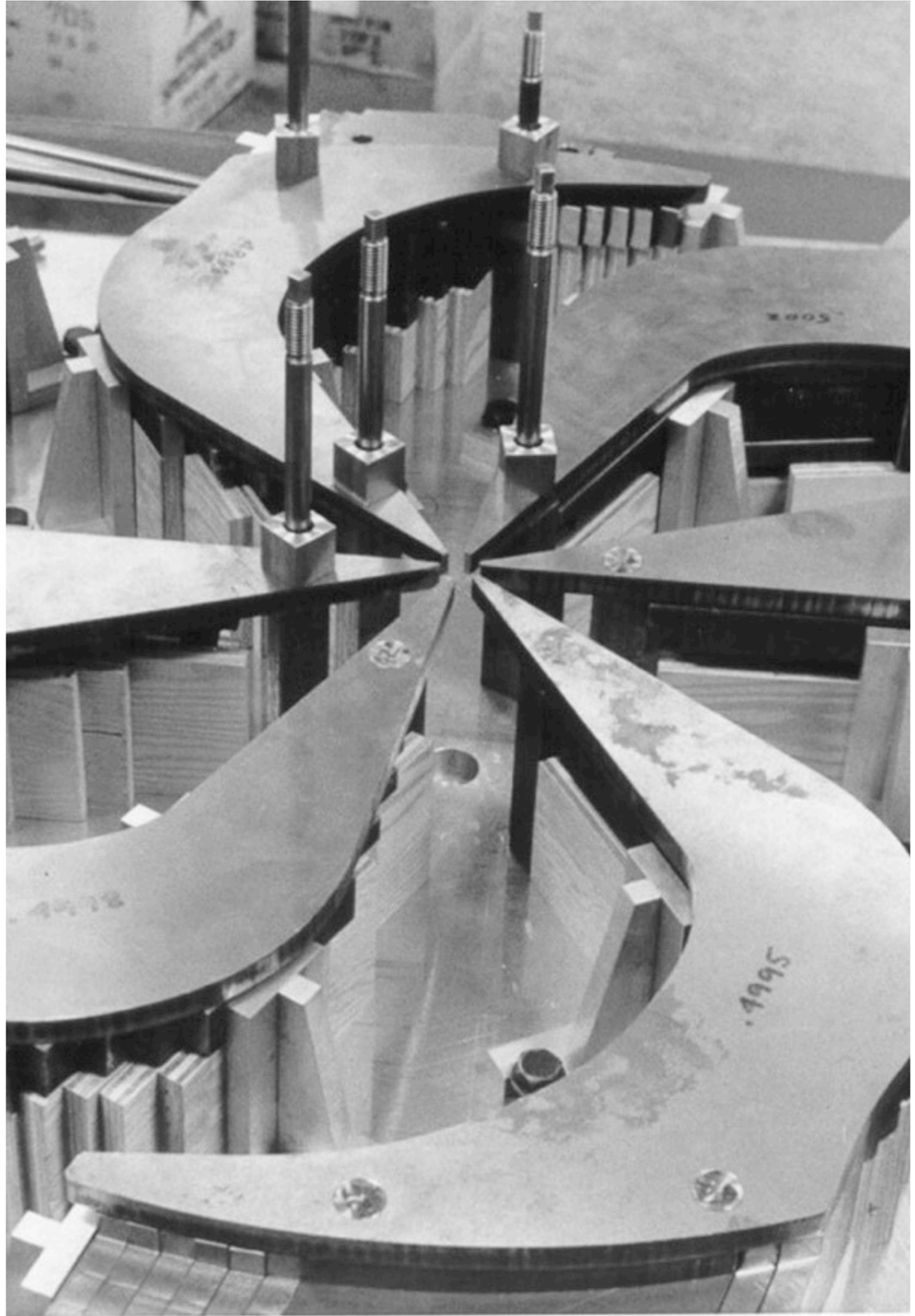
TRIUMF

Hyper-K and Hyper-K Activities at TRIUMF

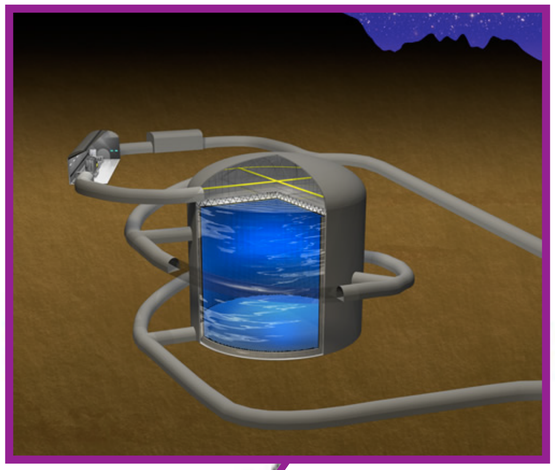
Mark Hartz

For the TRIUMF Neutrino Group



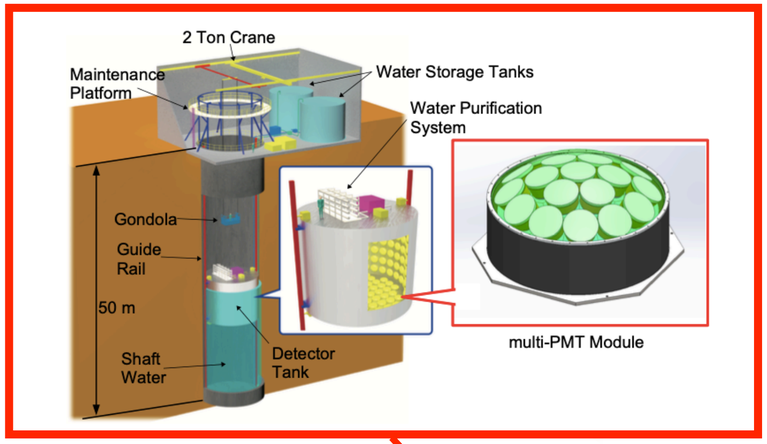
Discovery, accelerated

The Hyper-K Experiment

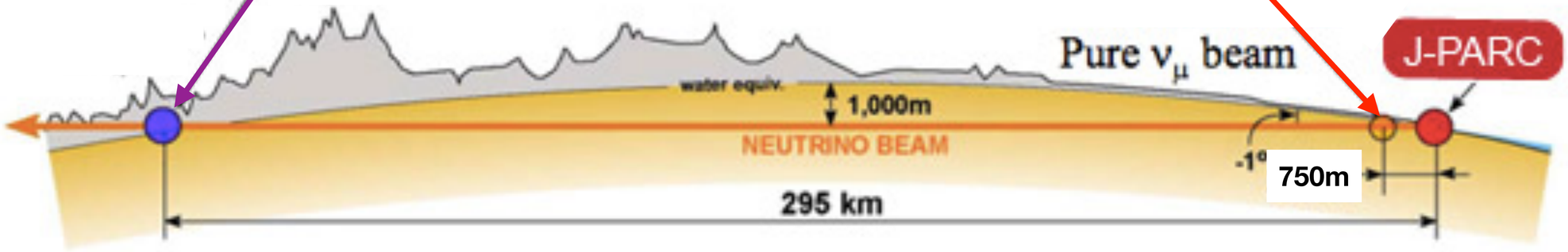


Hyper-Kamiokande Detector

~185 kton fiducial mass



Intermediate Water Cherenkov Detector



- Broad program to study neutrino oscillations (matter/antimatter asymmetry), proton decay, astroparticle physics and more
- Approved in Japan in 2020 (total project cost is ~600M USD)
- International collaboration with ~440 collaborators from 93 institutes in 19 countries

The Hyper-K Team at TRIUMF

- Mark Hartz (Research Scientist)
- Akira Konaka (Research Scientist)
- BAE search in progress
- Thomas Lindner (Detector Scientist)
- Affiliated Scientists - P. De Perio (applied), B. Pointon, S. Bhadra
- Joint Scientists - R. Gornea, D. Karlen
- 4 Postdocs now, growing to 5-6
  - One postdoc will support T2K responsibility on the OTR proton beam monitor that is being transferred from YorkU/UToronto
- Ongoing searches for mechanical engineer (in training) and computer programmer
- Will soon have 6 graduate students at TRIUMF

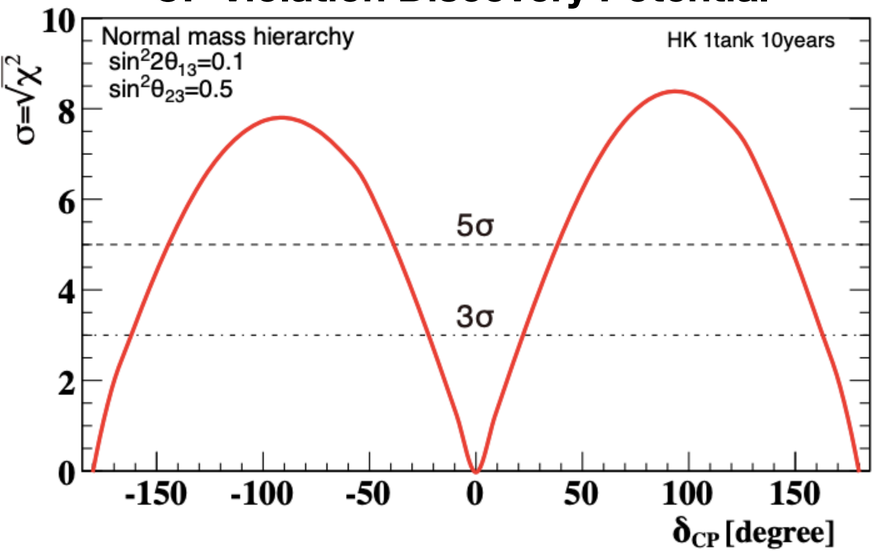
Neutrino Oscillations at HK

$$P_{\mu\to e}=\sin^2\theta_{23}\sin^2 2\theta_{13}\sin^2\left(\frac{\Delta m^2_{31}L}{4E_\nu}\right)\mp\frac{\sin 2\theta_{12}\sin 2\theta_{23}}{2\sin\theta_{13}}\sin^2 2\theta_{13}\sin\left(\frac{\Delta m^2_{21}L}{4E_\nu}\right)\sin^2\left(\frac{\Delta m^2_{31}L}{4E_\nu}\right)\sin\delta_{CP}+\ldots$$

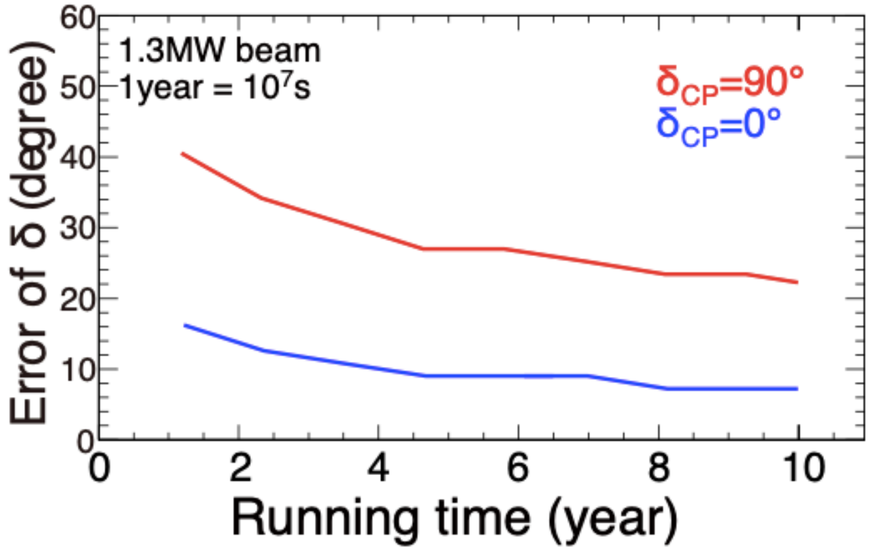
$$P_{\mu\to\mu}=1-\left(\sin^2 2\theta_{23}-\sin^2\theta_{23}\cos 2\theta_{23}\sin^2 2\theta_{13}\right)\sin^2\left(\frac{\Delta m^2_{32}L}{4E_\nu}\right)+\ldots$$

- Hyper-K will study neutrino oscillations with muon (anti)neutrino accelerator-produced beam and atmospheric neutrinos
- Major goal is the search for CP violation in neutrino oscillations
- Will also make measurements of parameters governing oscillations - θ_{13}, θ_{23}, Δm^2_{32}, δ_{cp}

CP Violation Discovery Potential



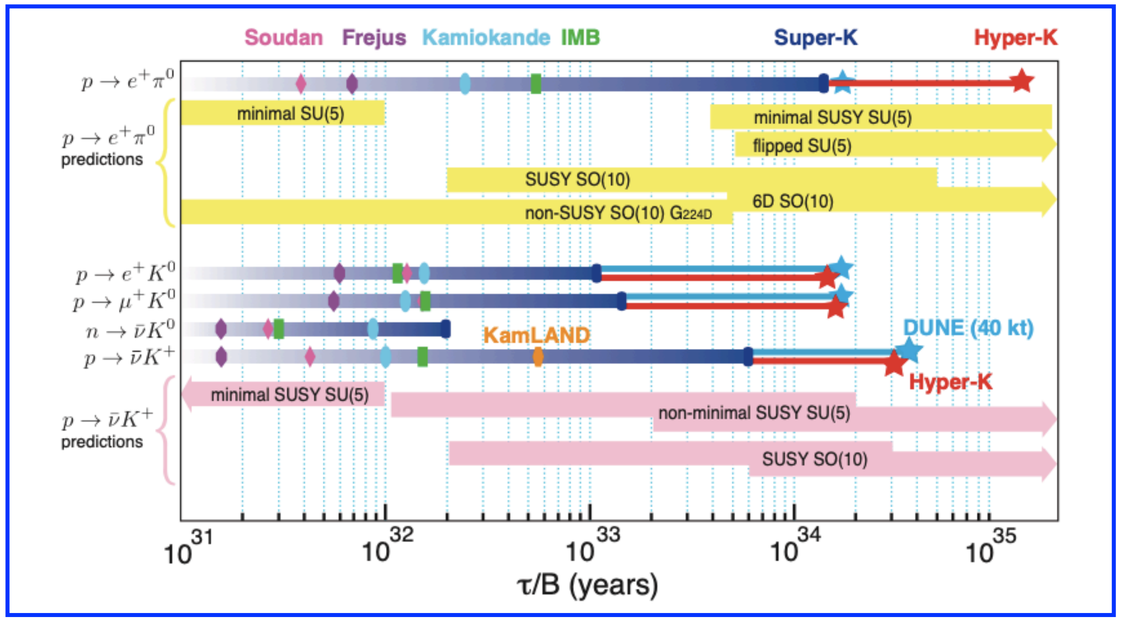
CP Phase Precision



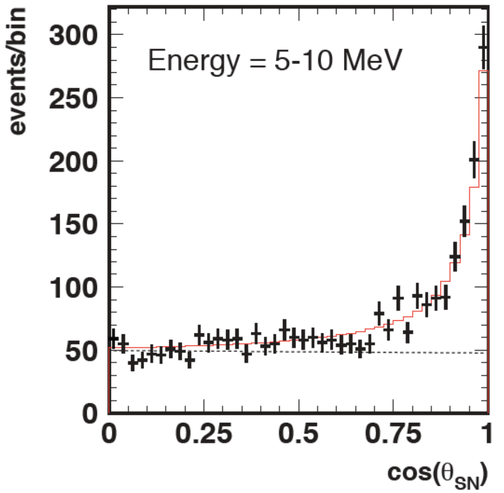
Other Physics at HK

- Hyper-K will have excellent sensitivity in many nucleon decay modes
  - Competitive with DUNE in lepton+kaon modes
- Supernova 10 kpc will produce 50k-90k events in Hyper-K
  - Unprecedented statistics to study supernova models and neutrino properties
  - ~1 degree accuracy for supernova direction reconstruction
- Will be able to detect diffuse neutrino background from past supernovas
- The higher energy neutrino signal can also be used to search for dark matter annihilation signals

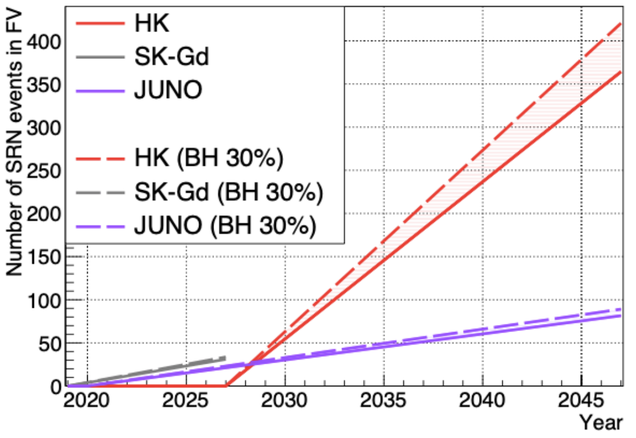
Nucleon Decay Sensitivity



Supernova Directionality

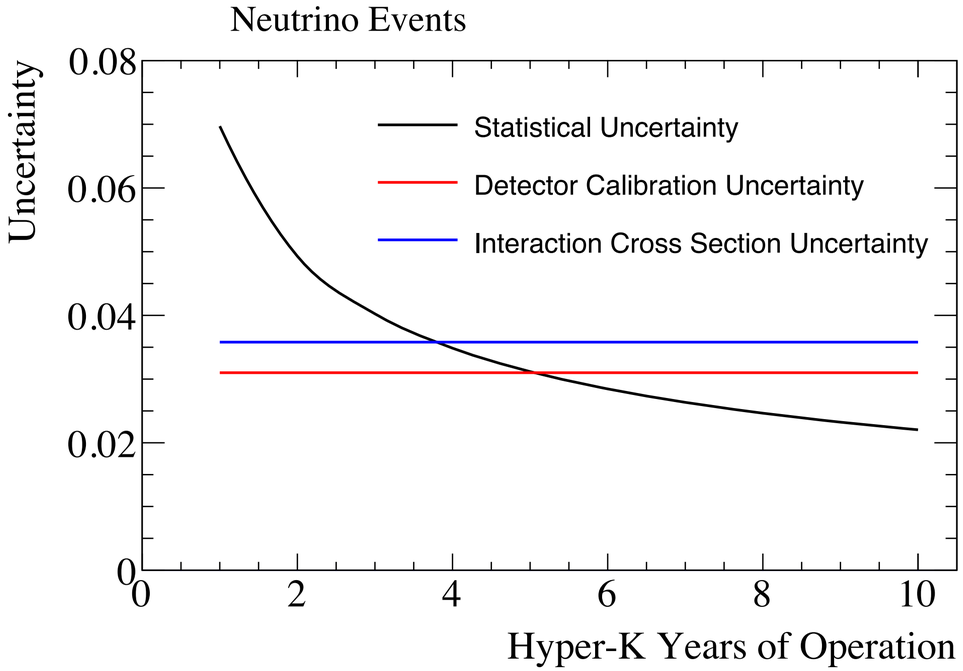


Diffuse Supernova Background

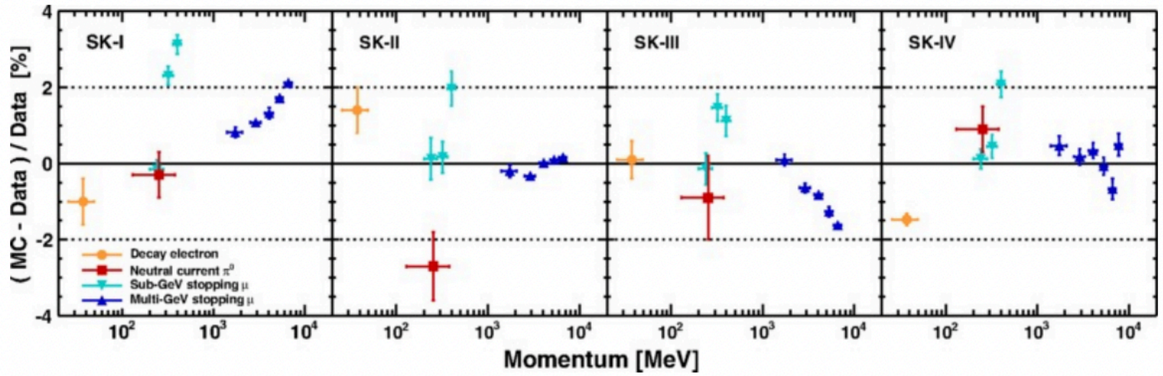


Systematic Uncertainties

- Systematic errors will dominate many HK measurements if not reduced
- For CP violation, the Hyper-K statistical error will quickly drop below the current dominant errors in T2K measurements (left)
- For parameter measurements, energy scale uncertainty is ~2% and needs to be reduced to <1%
- Neutrino interaction modeling - addressed by the Intermediate Water Cherenkov Detector
- Detector calibration - Addressed by mPMT and photogrammetry based calibration



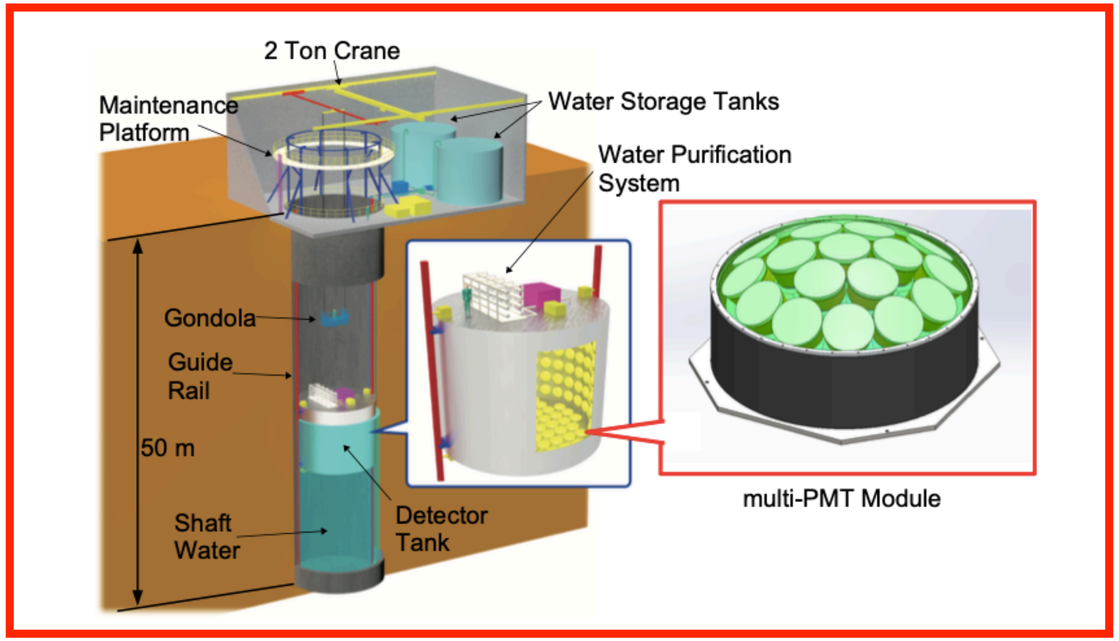
electrons: decay e, π^0 invariant mass
muons: opening angle, range

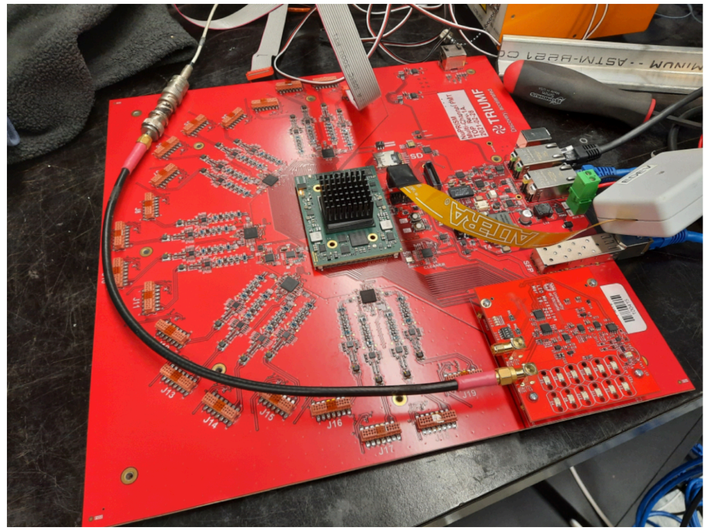


Energy scale bias for control samples in SK

IWCD - mPMT

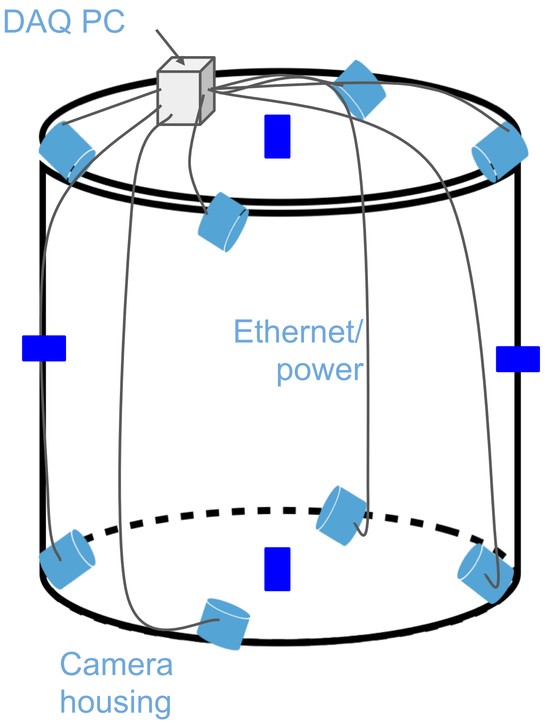
- 250 mPMTs will be produced in Canada, funded by CFI-IF
- multi-PMT photosensors, TRIUMF role:
  - Complete mechanical and electronics design
  - Complete assembly/testing procedure and equipment design
  - Support setup of production line at UVic
  - Electronics production and testing during production

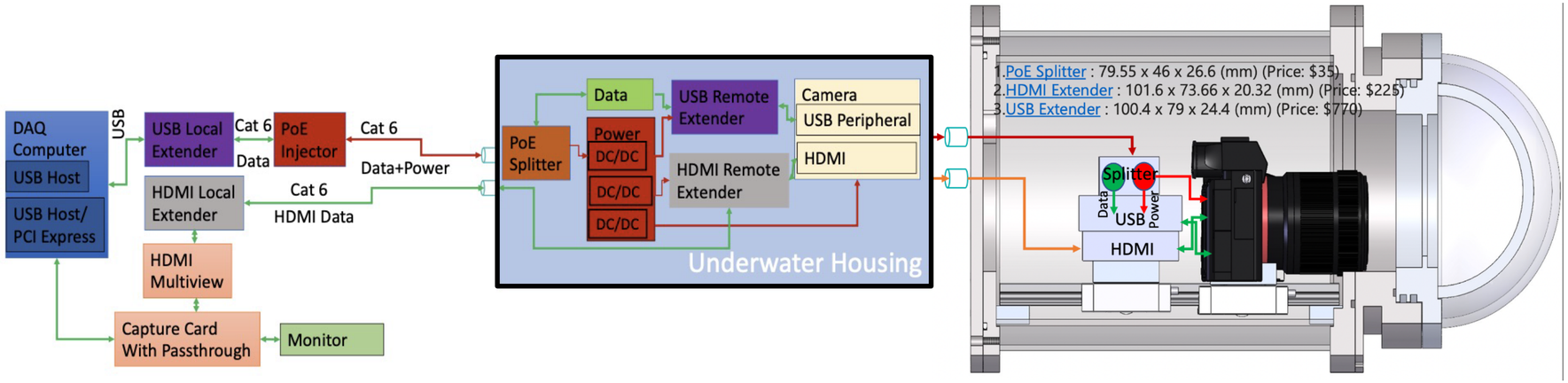




IWCD - Photogrammetry

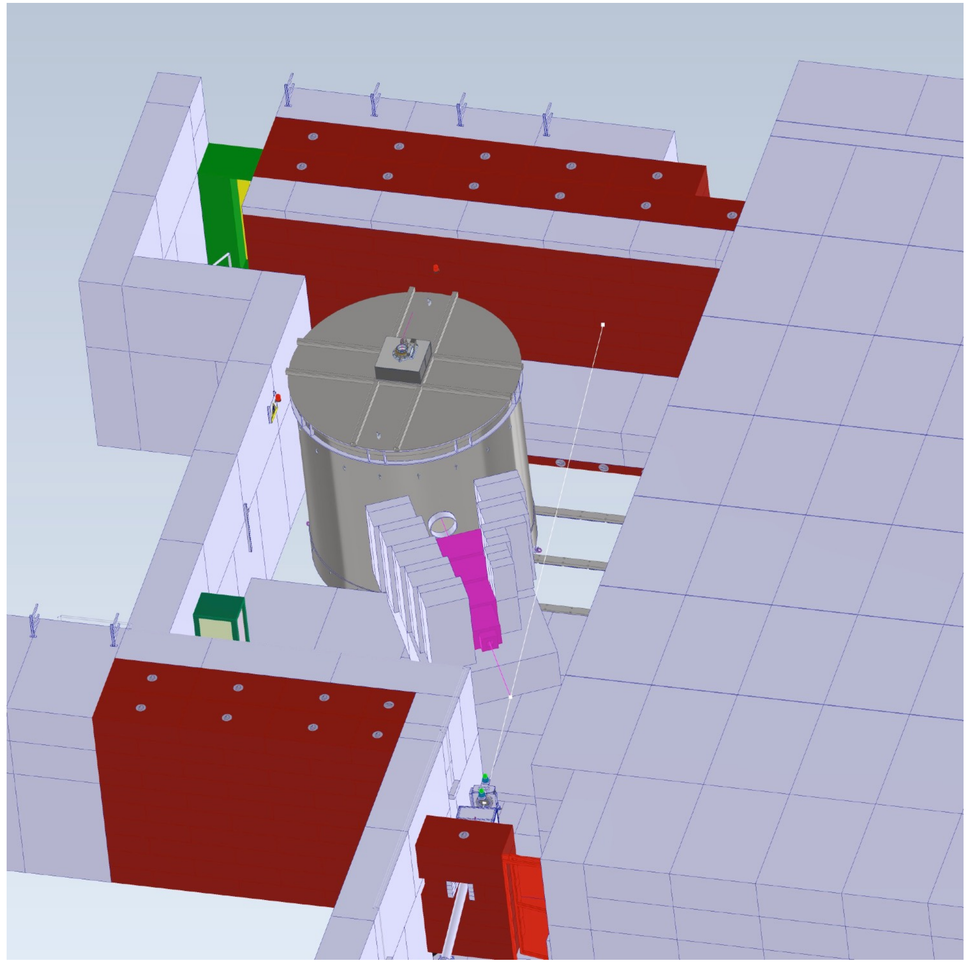
- ~8 photogrammetry cameras will be produced in Canada, funded by CFI-IF
- Photogrammetry, TRIUMF role:
  - Design and testing of the water-tight vessel
  - Design of mounting system
- U. Winnipeg is developing the camera readout and control





Water Cherenkov Test Experiment

- Scaled prototype of IWCD with ~1/2 diameter and 1/2 the height
- Will operate in the CERN T9 test beam, in 2024
- Approved by CERN Research Board
- TRIUMF roles:
  - Build, install and operate 50 mPMT modules (pilot production)
  - Design and purchase Halbach array permanent magnets for the spectrometer
  - General leadership on the project



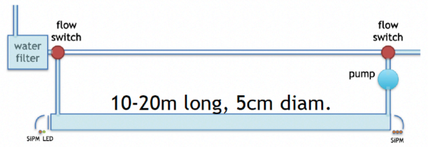
Hyper-K Detector Contributions

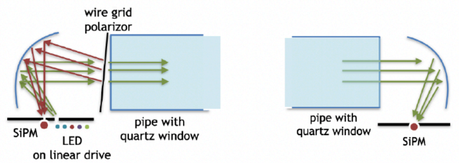
- Plan contributions to Hyper-K detector funded through CFI-IF 2023 competition
- 200 mPMT modules used for calibration
  - Some PMTs are replaced by pulsed LED light injection system for water/PMT response calibration
- Photogrammetry system will be built for HK as well
- Ex-situ light attenuation and scattering measurement devices to be built
  - See Akira's talk for more details

Updated Concept

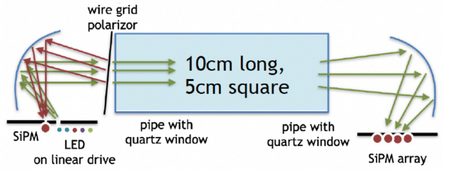
diffused LED light
collimated & polarized light
photogrammetry LED light

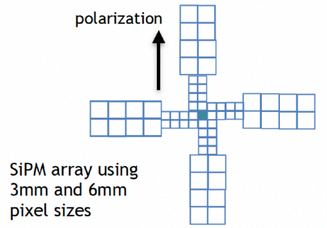
Transmission





Scattering





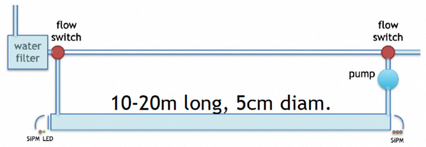
Hyper-K Detector Contributions

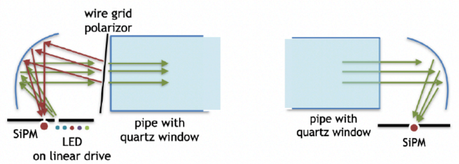
- TRIUMF's role:
  - Basic design of light attenuation/scattering devices to be carried out through NSERC Alliance grant
  - Design of the mechanical systems for integration of LEDs into mPMT module
  - Electronics design of LED driver integration with electronics main board
  - HK collaborators at INFN are leading update of mPMT electronics and vessel design
    - Significant TRIUMF involvement is risk if they cannot deliver
  - Photogrammetry design should be the same
- mPMT production planned at Carleton

Updated Concept

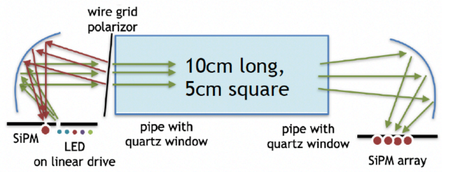
diffused LED light
collimated & polarized light
photogrammetry LED light

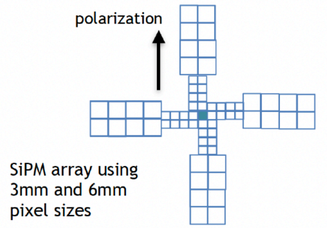
Transmission





Scattering

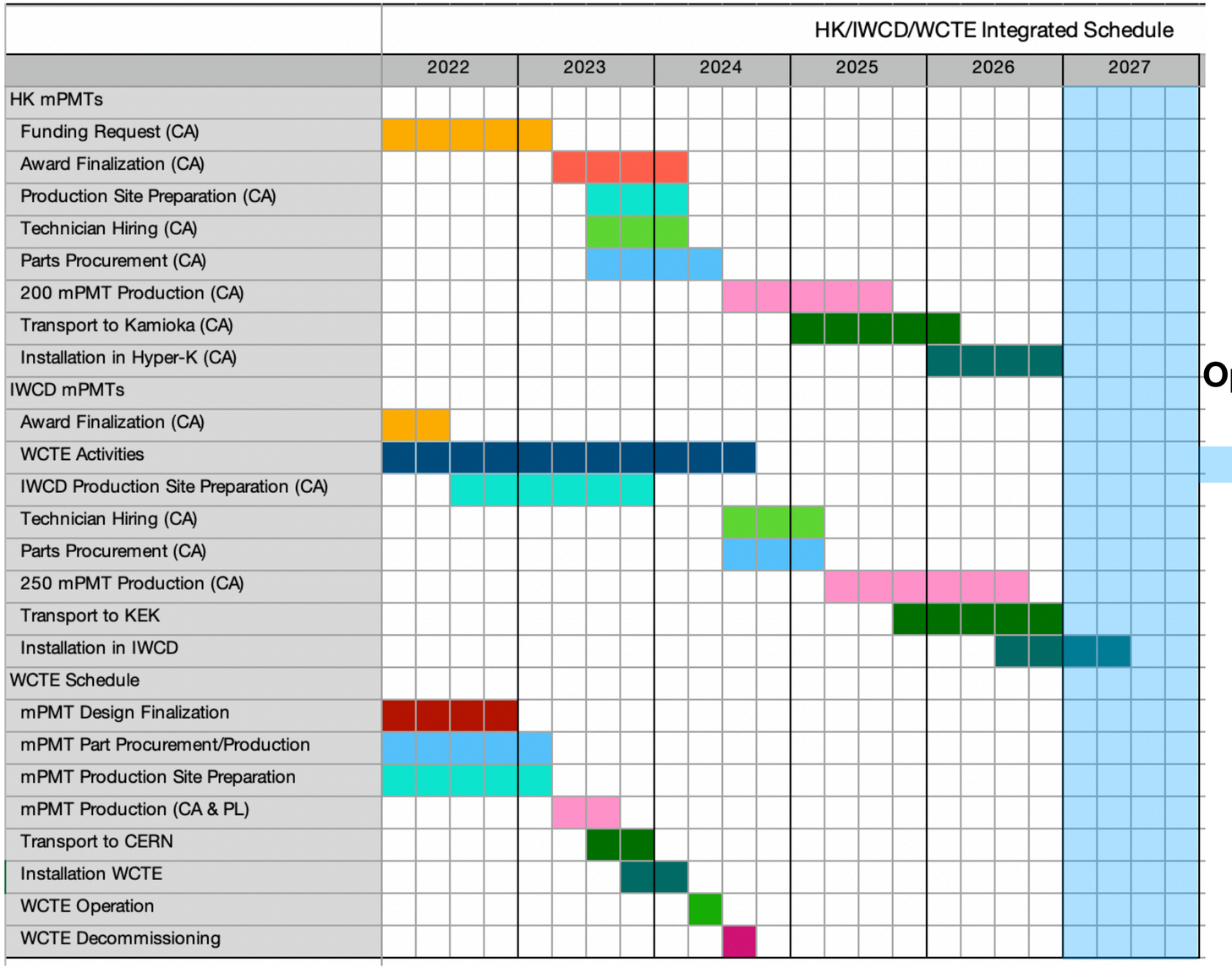




TRIUMF Resources

- WCTE:
  - Space for assembly, testing and storage of 50 mPMT pilot production run
  - ~51 FTE months of technical personnel, including T. Lindner's time (numbers should be checked)
- IWCD:
  - Space for electronics testing
  - ~60 FTE months of technical and project management personnel
- Hyper-K:
  - Space for electronics testing
  - ~72 FTE months of technical and project management personnel
- We are making a mechanical engineer (in-training) hire to support these projects (included in total technical support numbers)

Schedule



HK Operation

- COVID and supply chain issues are causing delays to mPMT/WCTE schedules
- HK start is still planned for JFY2027 (no significant impact of COVID on schedule in Japan yet)