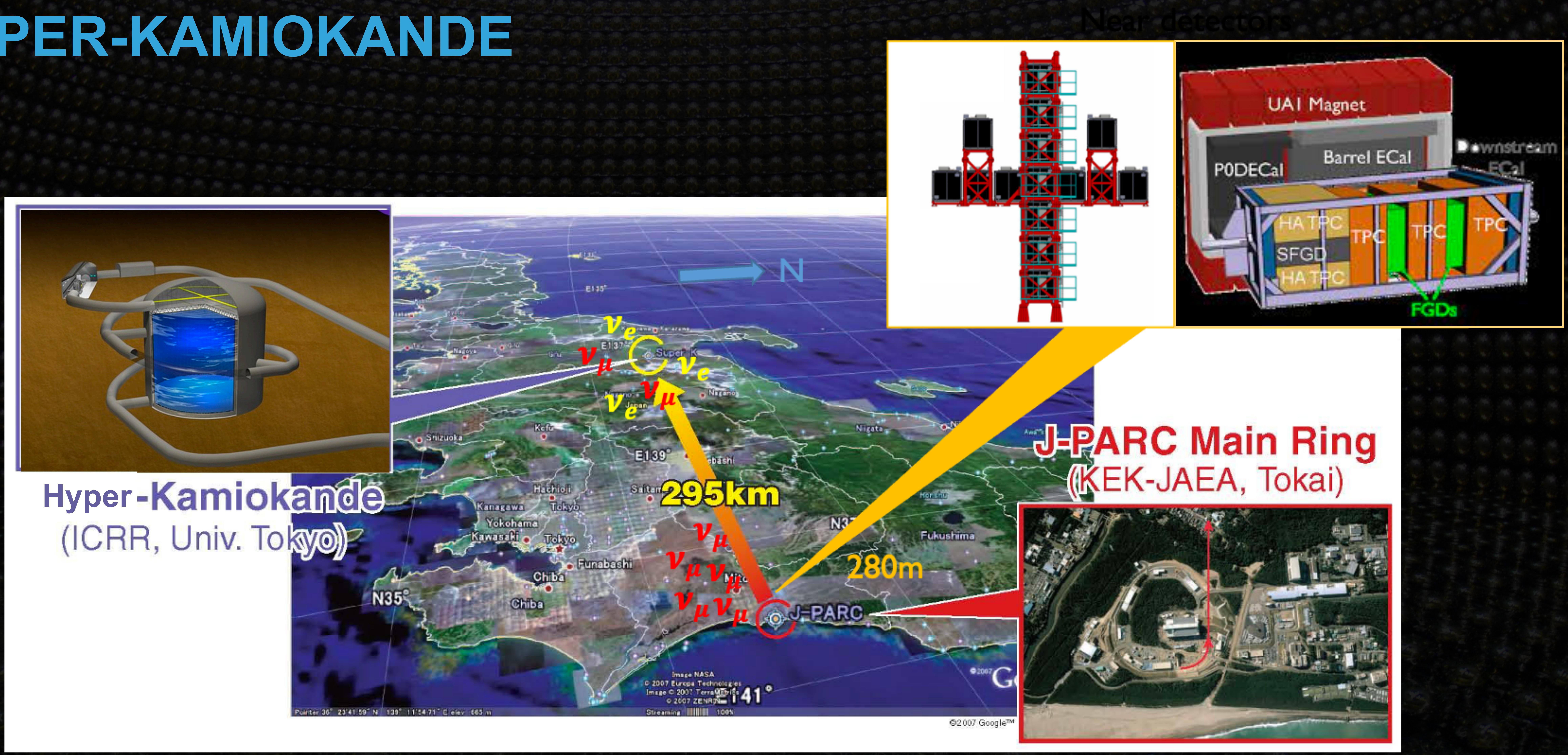
STATUS OF THE HYPER-KAMIOKANDE PROJECT

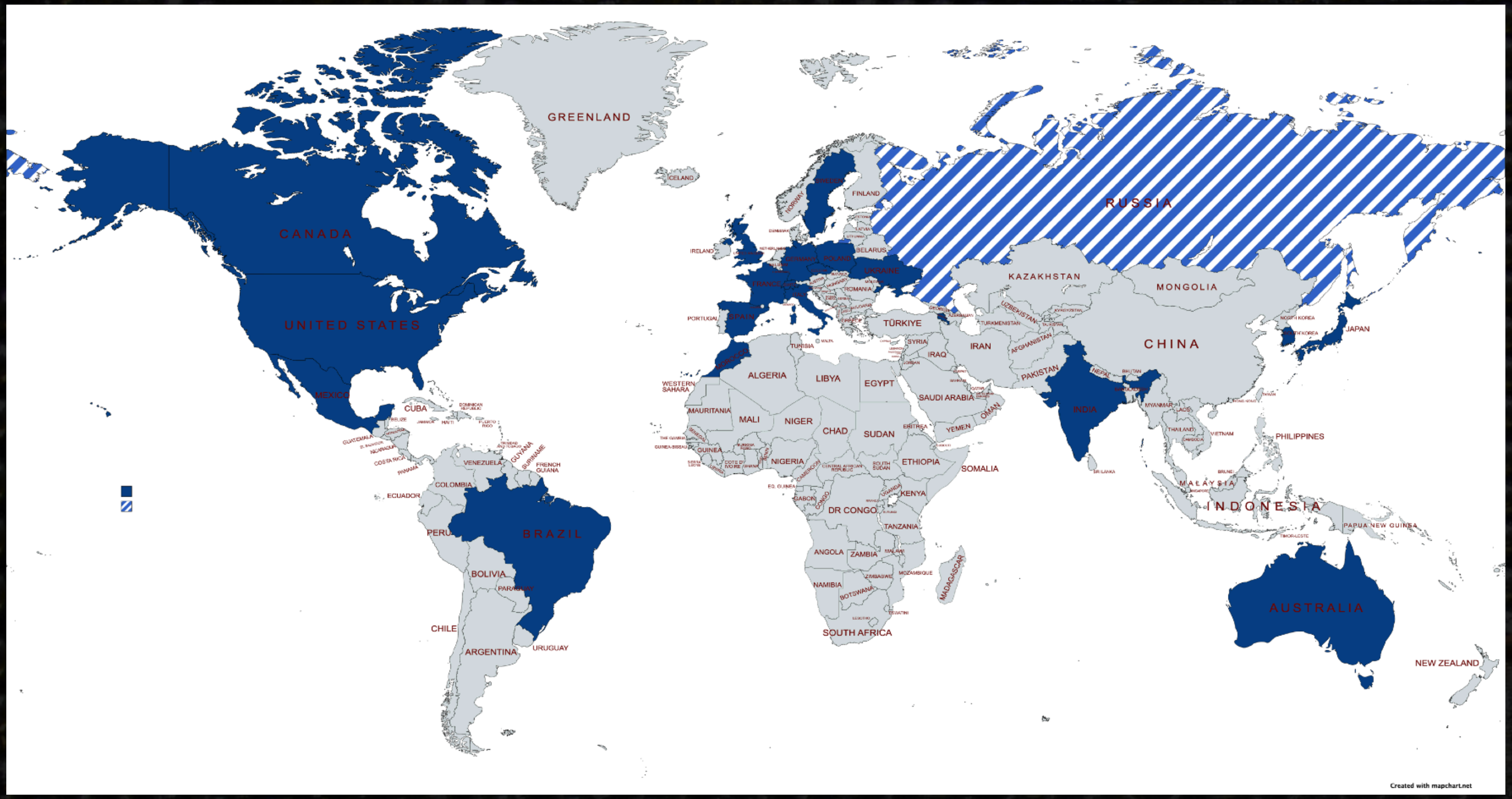
XIAOYUE LI
TRIUMF

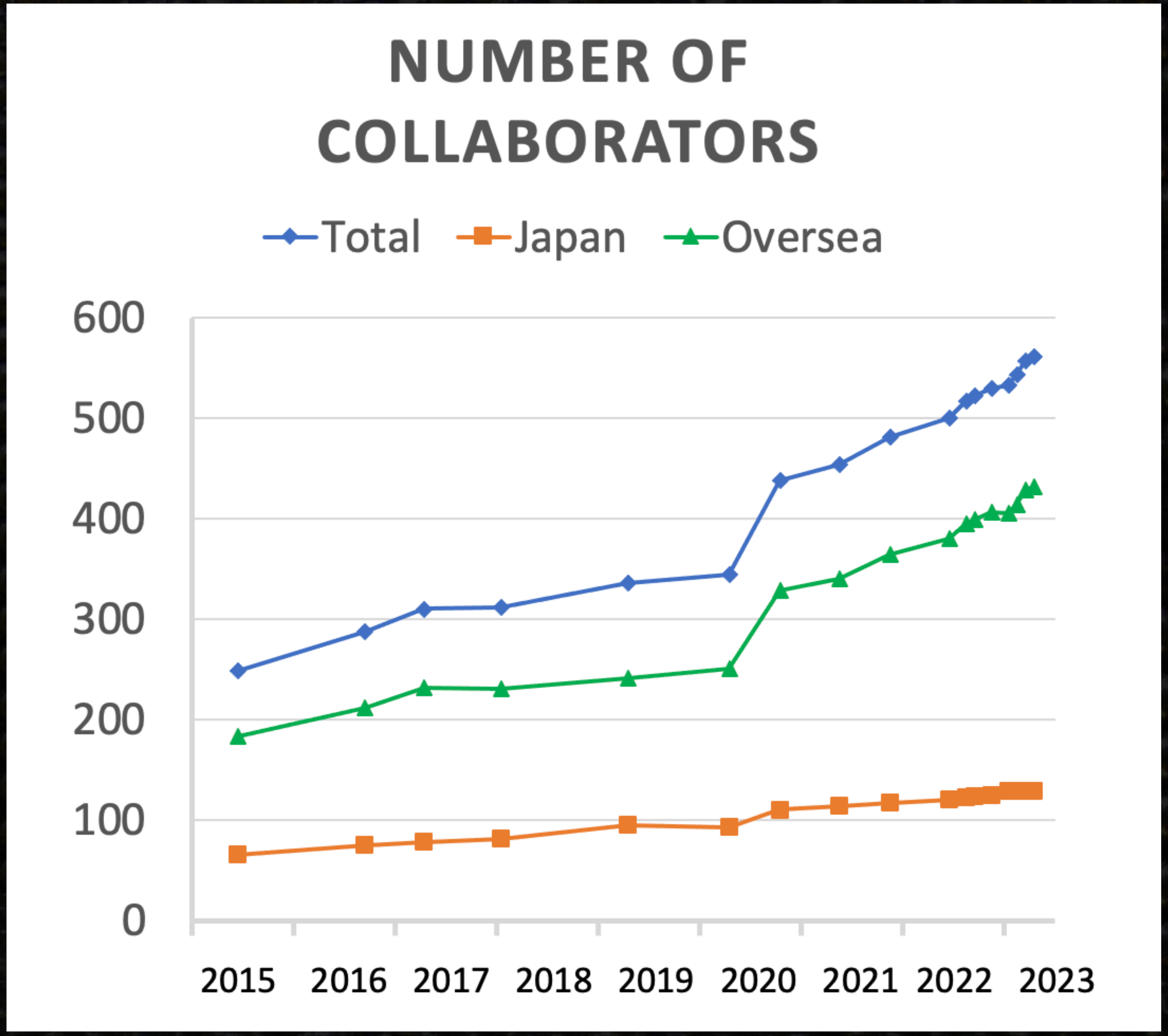
IPP ANNUAL GENERAL MEETING, FREDERICTON, NB
JUNE 23, 2023

HYPER-KAMIOKANDE



HYPER-K COLLABORATION





- ~560 collaborators from 21 countries and 101 institutes
- 25% Japanese/75% non-Japanese
- Two Host institutes: University of Tokyo and KEK
- Hyper-Kamiokande has become a CERN Recognized Experiment: RE45

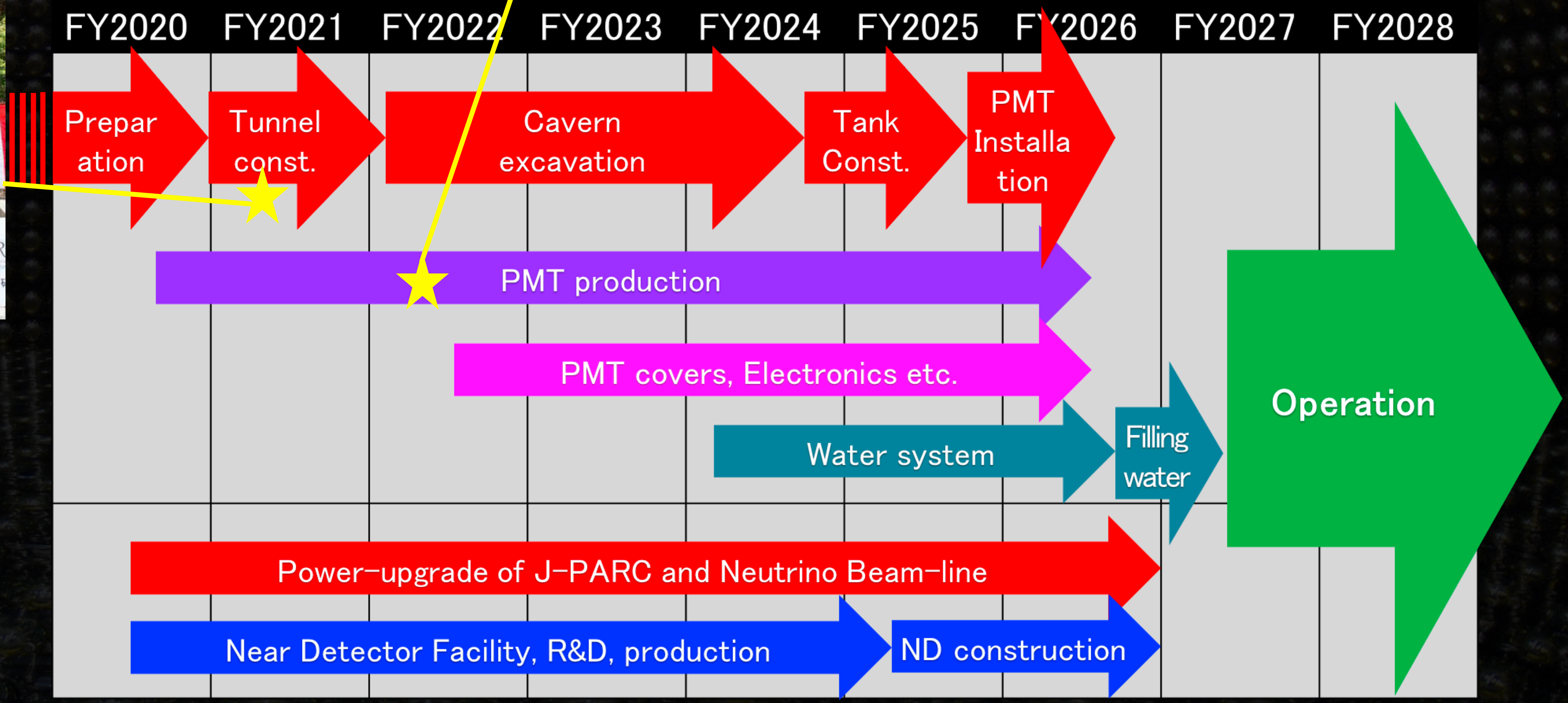
HYPER-K COLLABORATION

- First meeting in person (Toyama, 6-11 March 2023) of the collaboration after the Hyper-Kamiokande approval (2020) and pandemic.

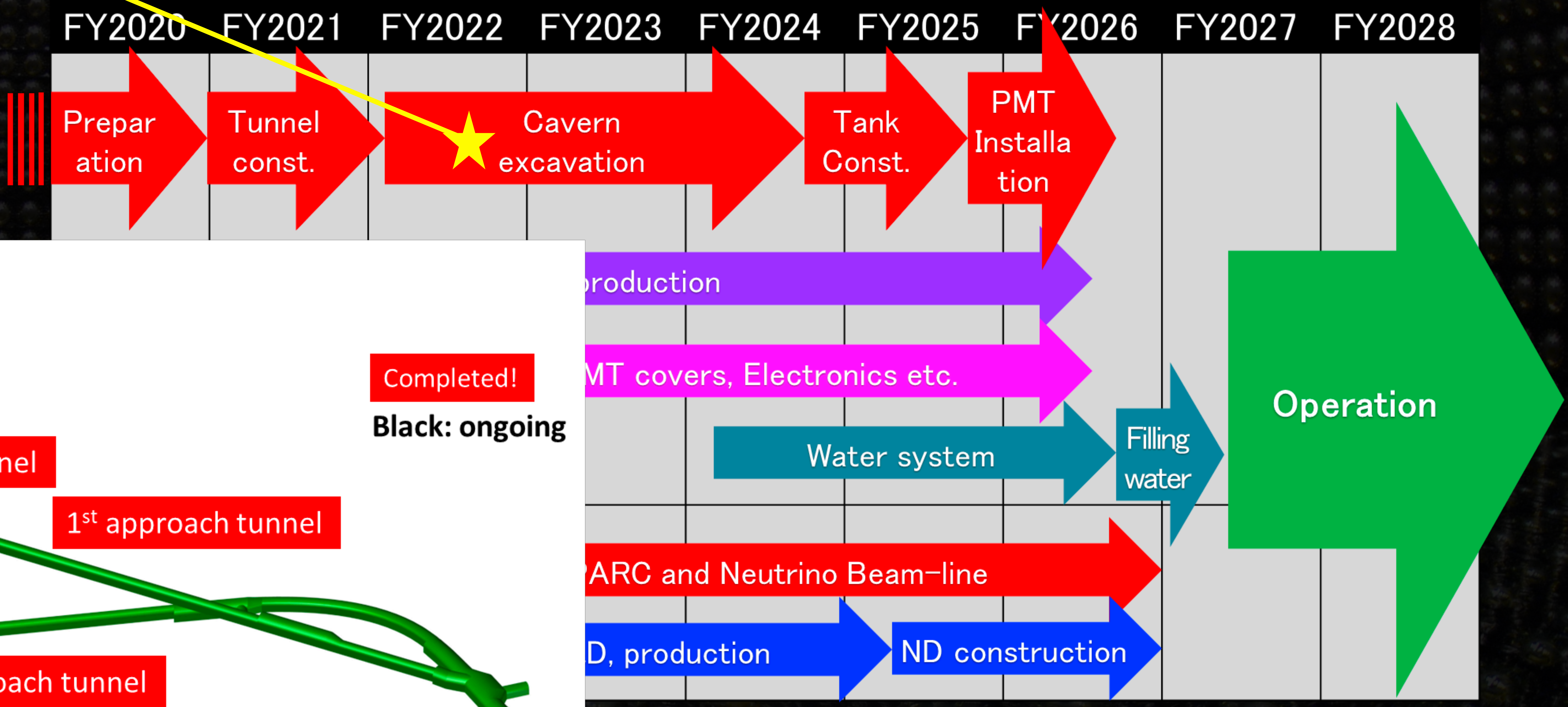
HYPER-K: RECENT PROGRESS

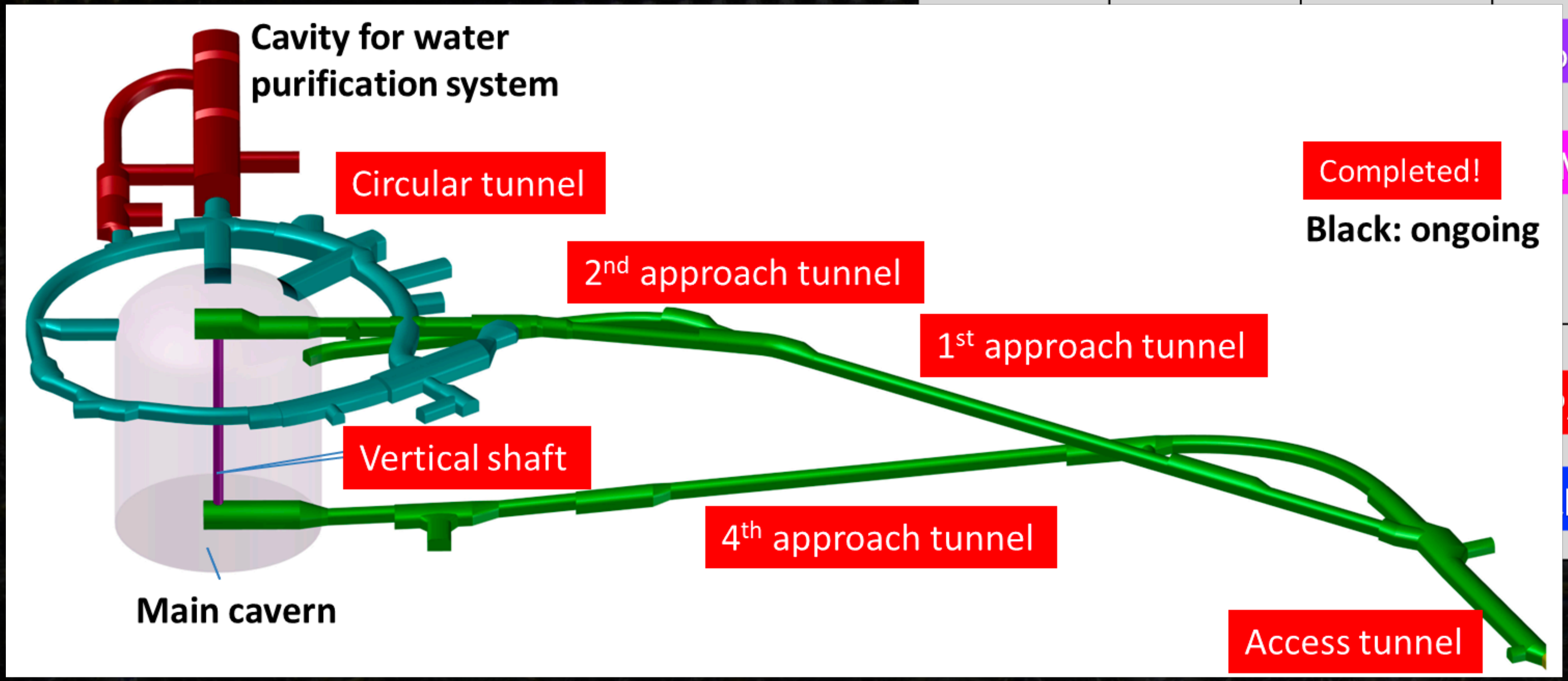
May 2021, Groundbreaking

Total of 3,772 PMTs (~20%) delivered by April 2022



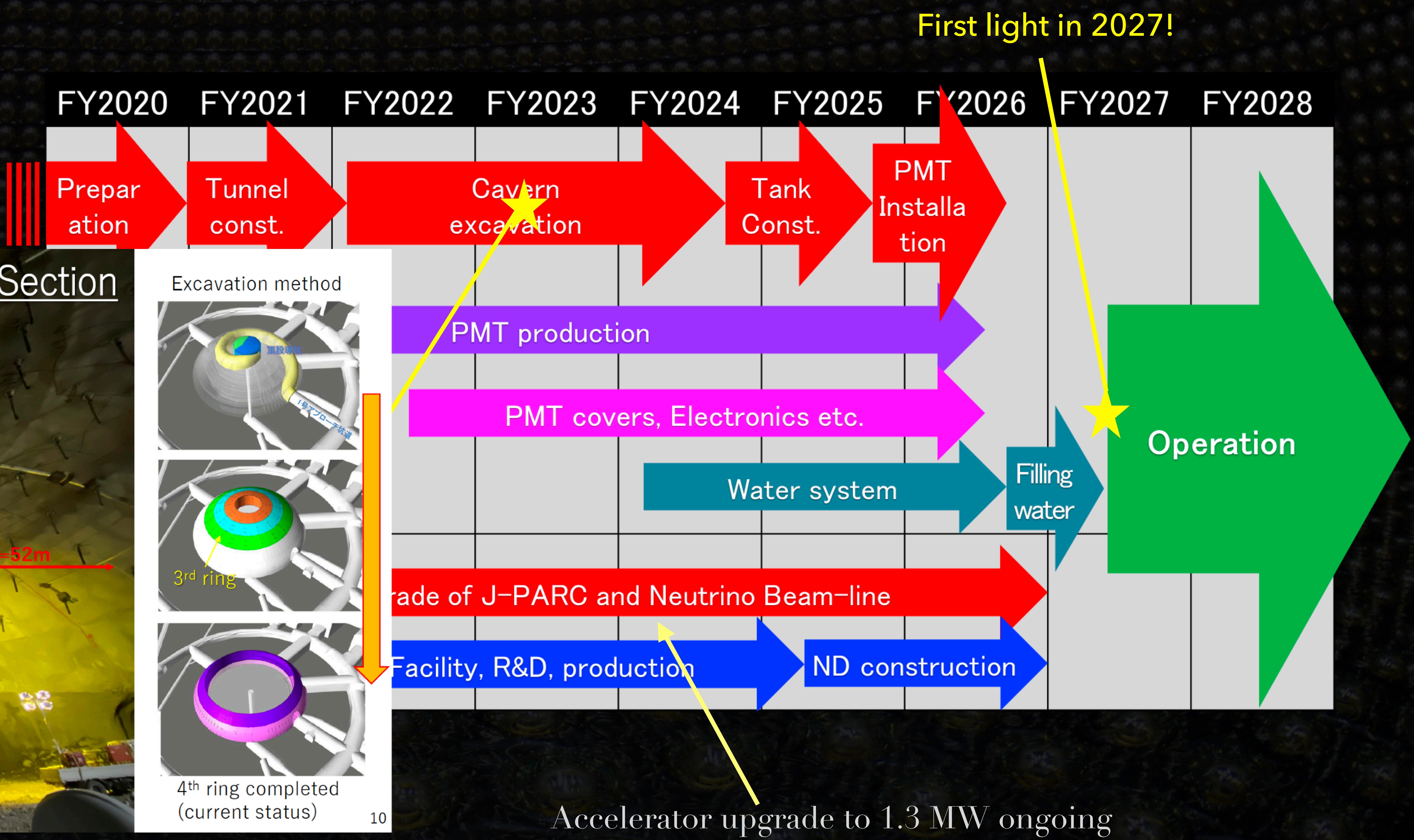
HYPER-K: RECENT PROGRESS

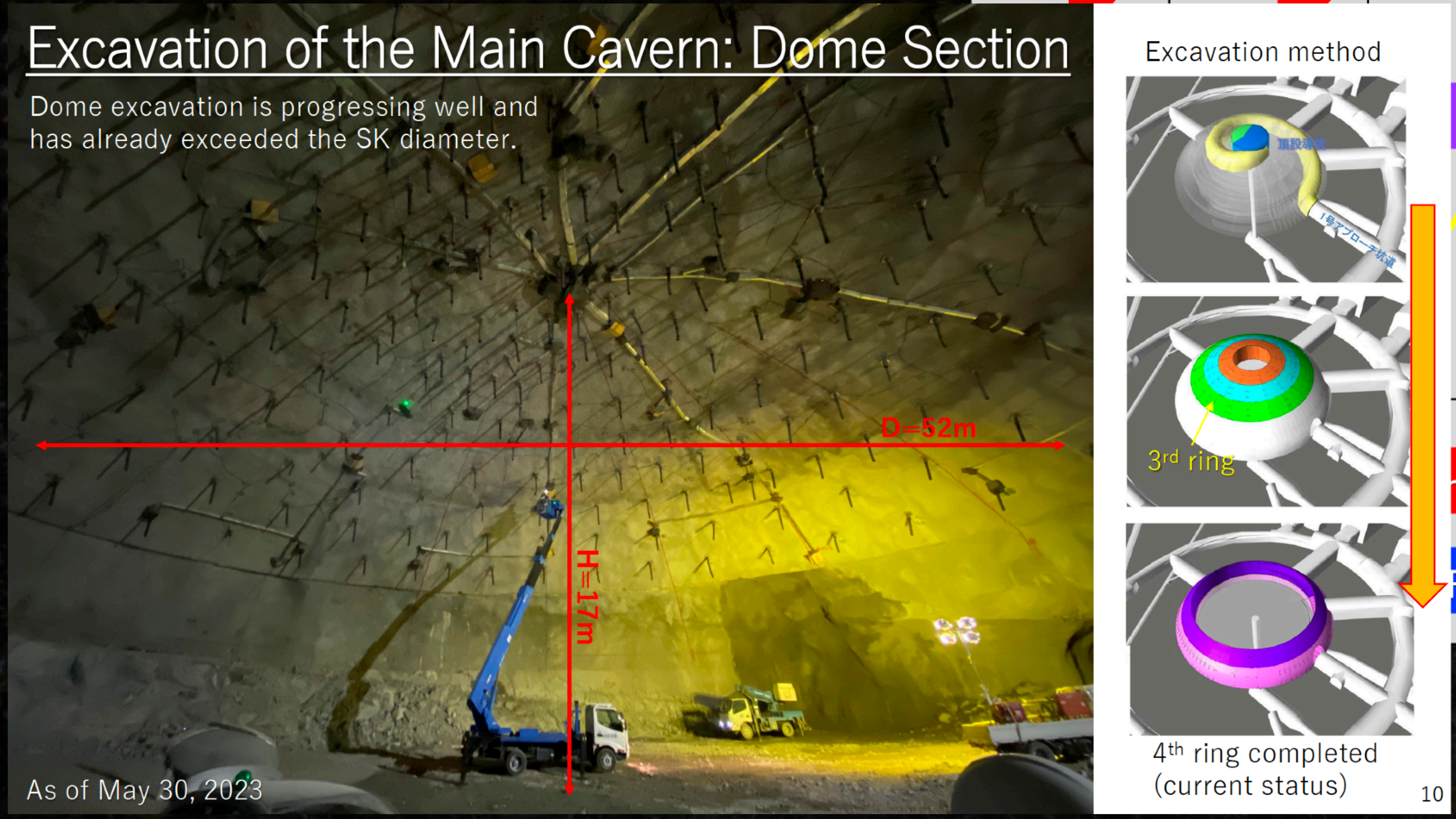




HYPER-K: RECENT PROGRESS

- Good progress in cavern excavation and accelerator upgrade





HYPER-K CANADA

Hyper-K Canada Collaborating Institutes

TRIUMF
University of Toronto
University of Victoria
York University
The University of Winnipeg
BCIT British Columbia Institute of Technology
Carleton University
University of Regina

Leadership roles

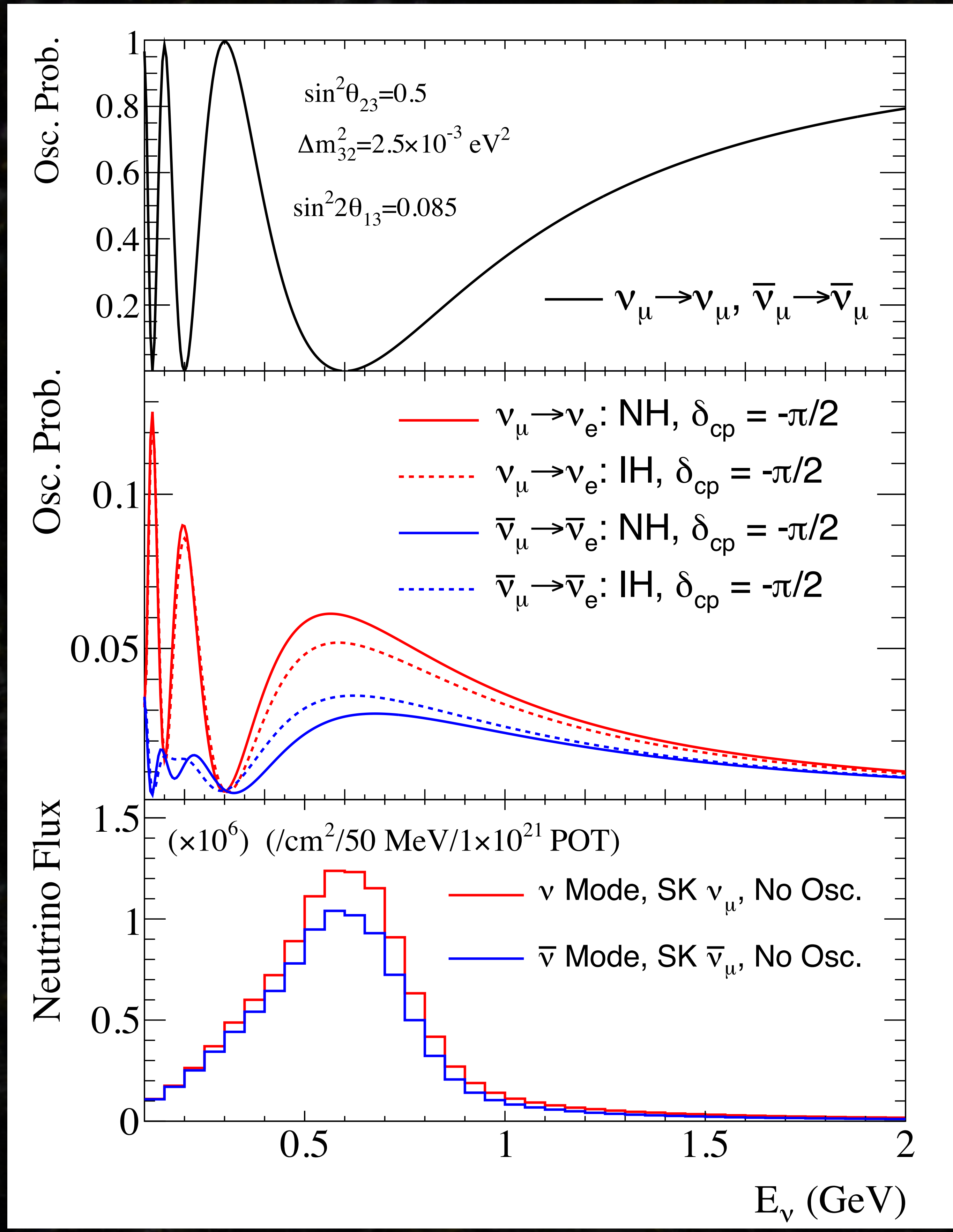
- M. Barbi (URegina)
- S. Bhadra (York)
- K. Graham (Carleton)
- R. Gornea (Carleton) → Hyper-K safety
- M. Hartz (TRIUMF) → WCTE/IWCD spokesperson
- B. Jamieson (UWinnipeg)
- D. Karlen (UVic)
- A. Konaka (TRIUMF)
- N. Kolev (URegina)
- X. Li (TRIUMF) → WCTE/IWCD calibration
- T. Lindner (TRIUMF) → mPMT
- J. Martin (UofT)
- B. Pointon (BCIT)

- Hyper-K Canada group formed in 2018
- Supported by NSERC Discovery grant - renewed
- Currently 13 investigators from 8 institutes, 4 postdocs, 9 graduate students

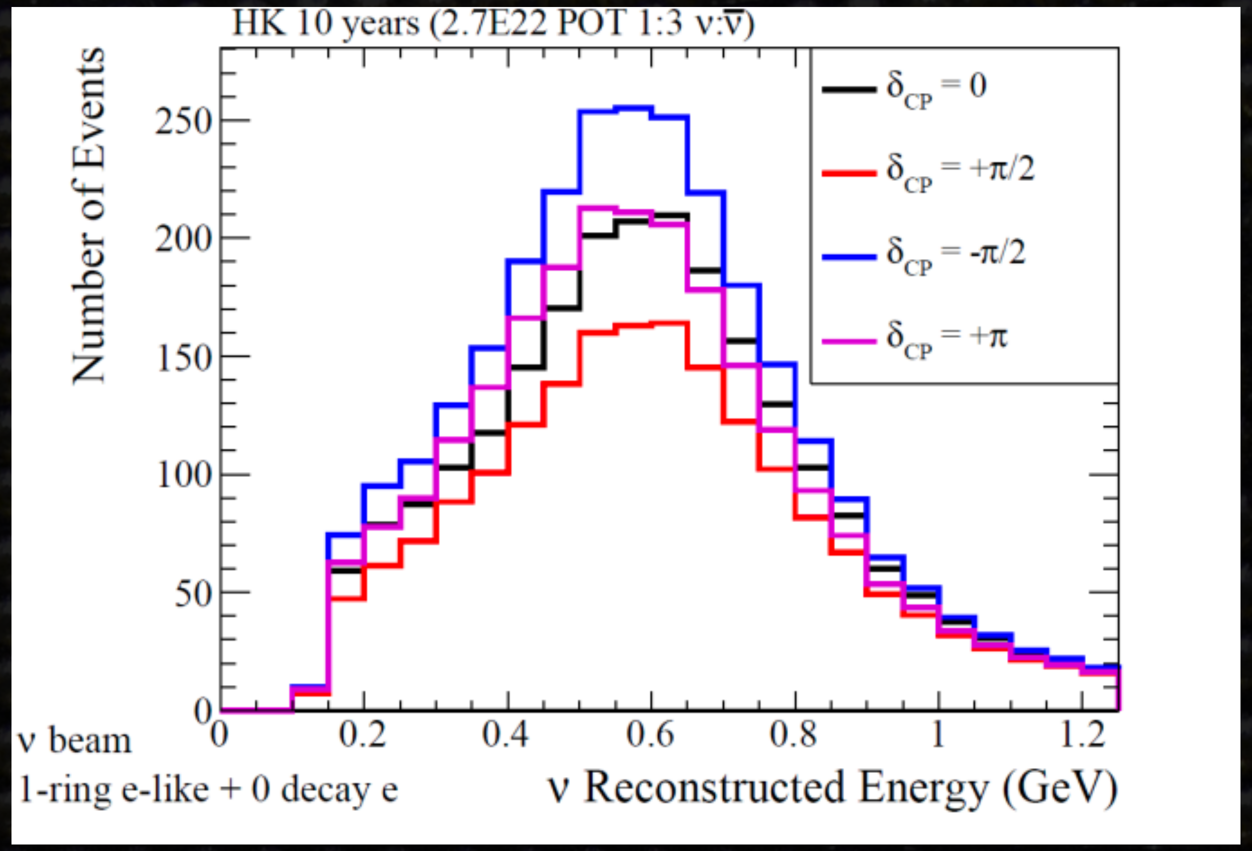
- Funding request in 2020 CFI-IF competition, $5.77M approved (including provincial funds)
- Bulk of matching funds are international contributions to the project
- New collaborators welcome!

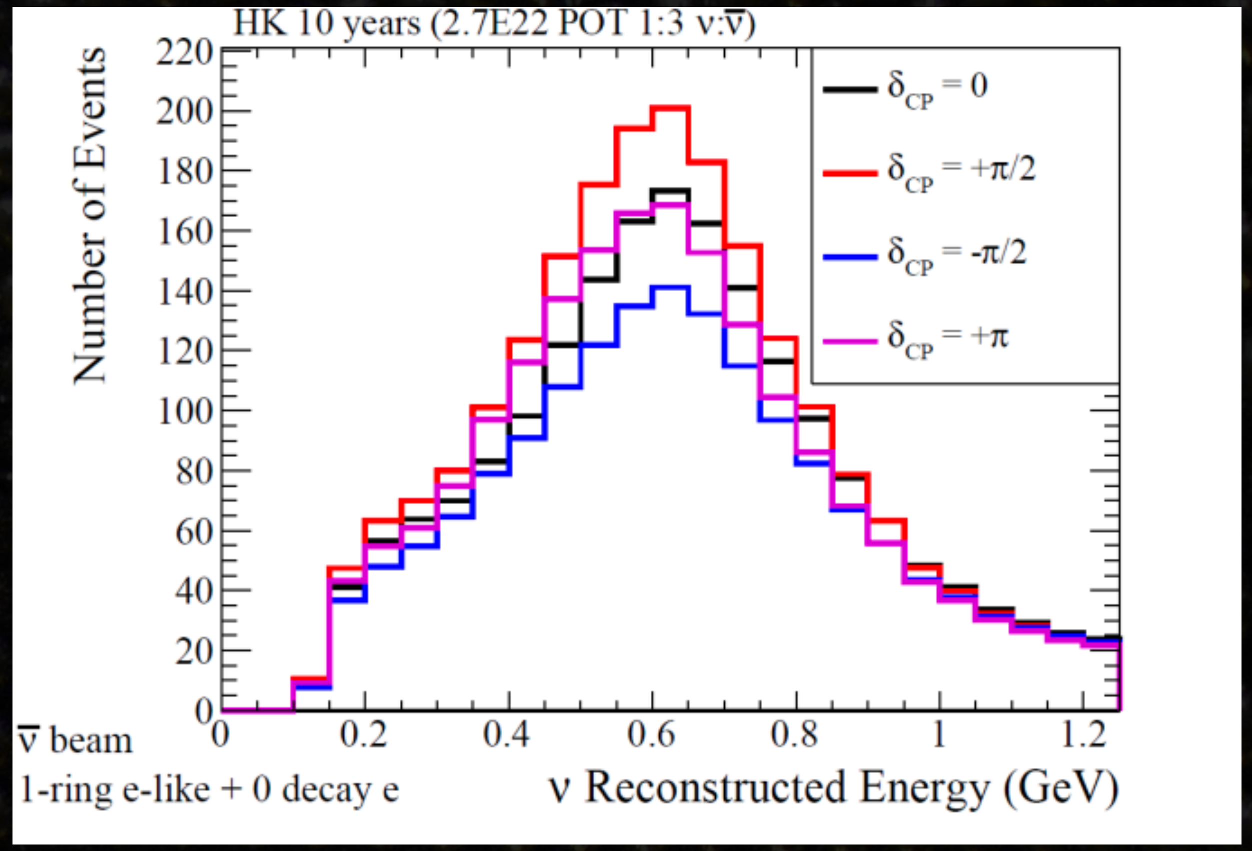
HYPER-K PHYSICS GOALS (1)

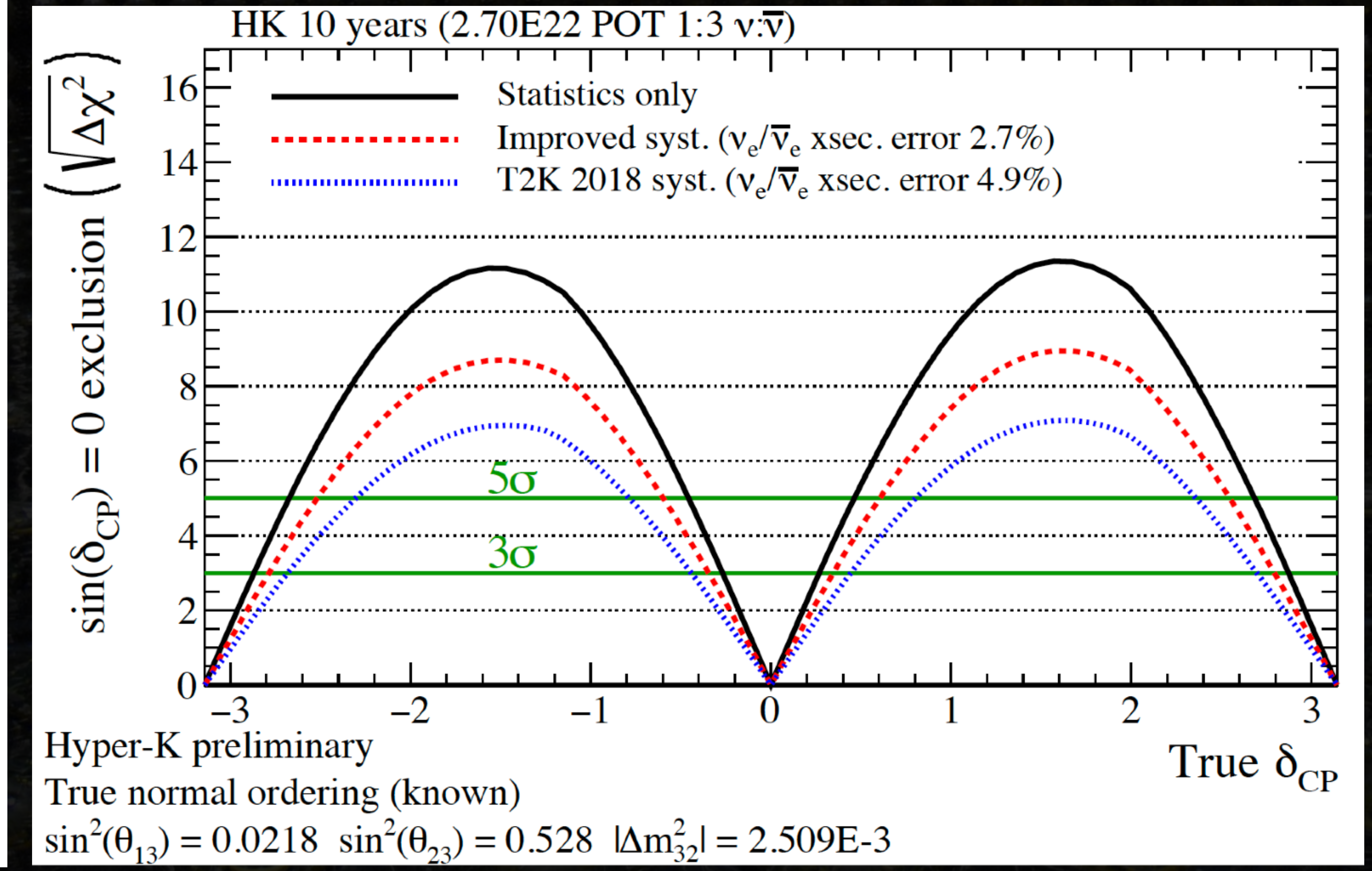
- Precision measurement of neutrino oscillation parameters

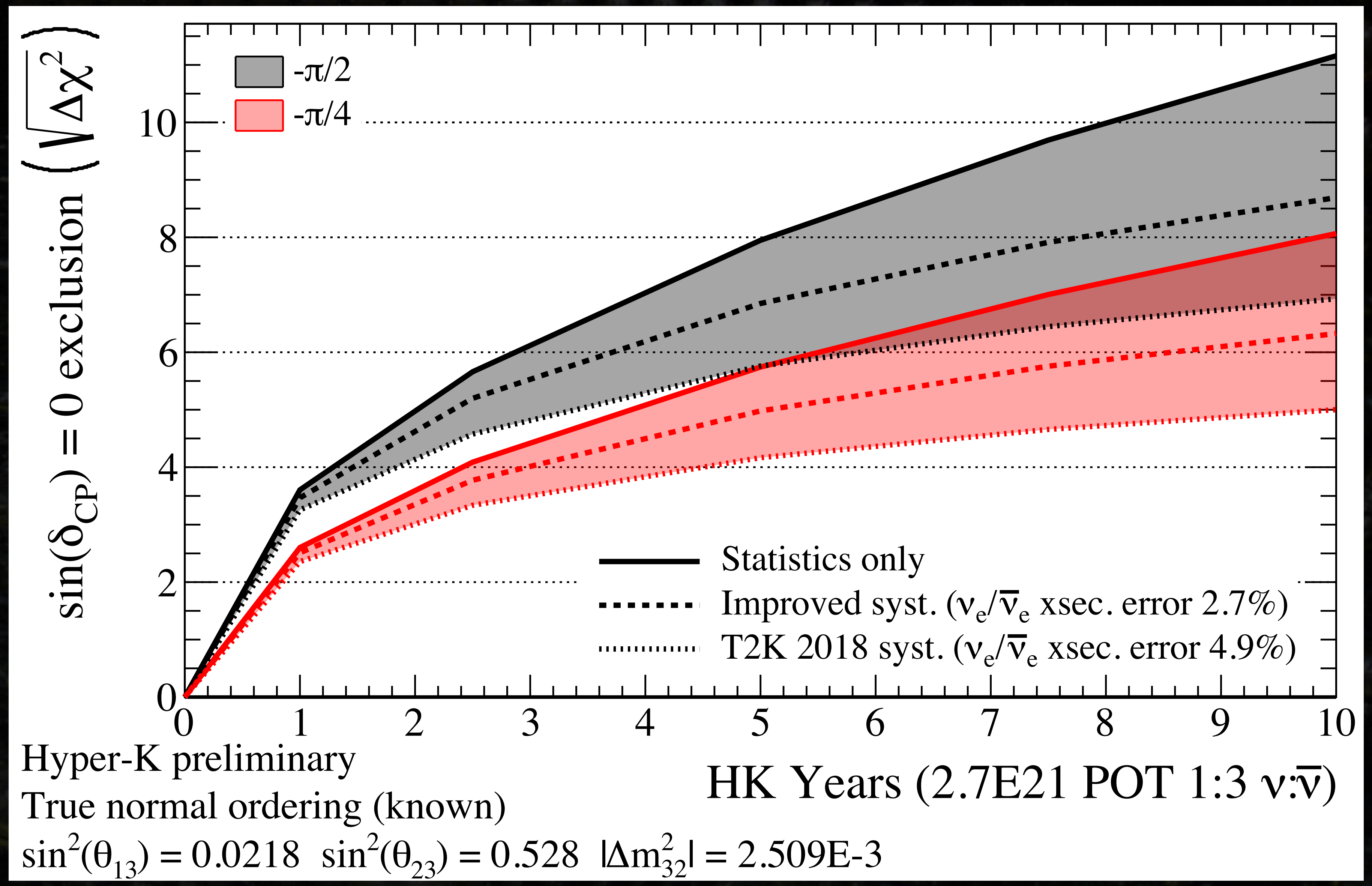


10 years running, 1:3 $\nu:\bar\nu$ run plan





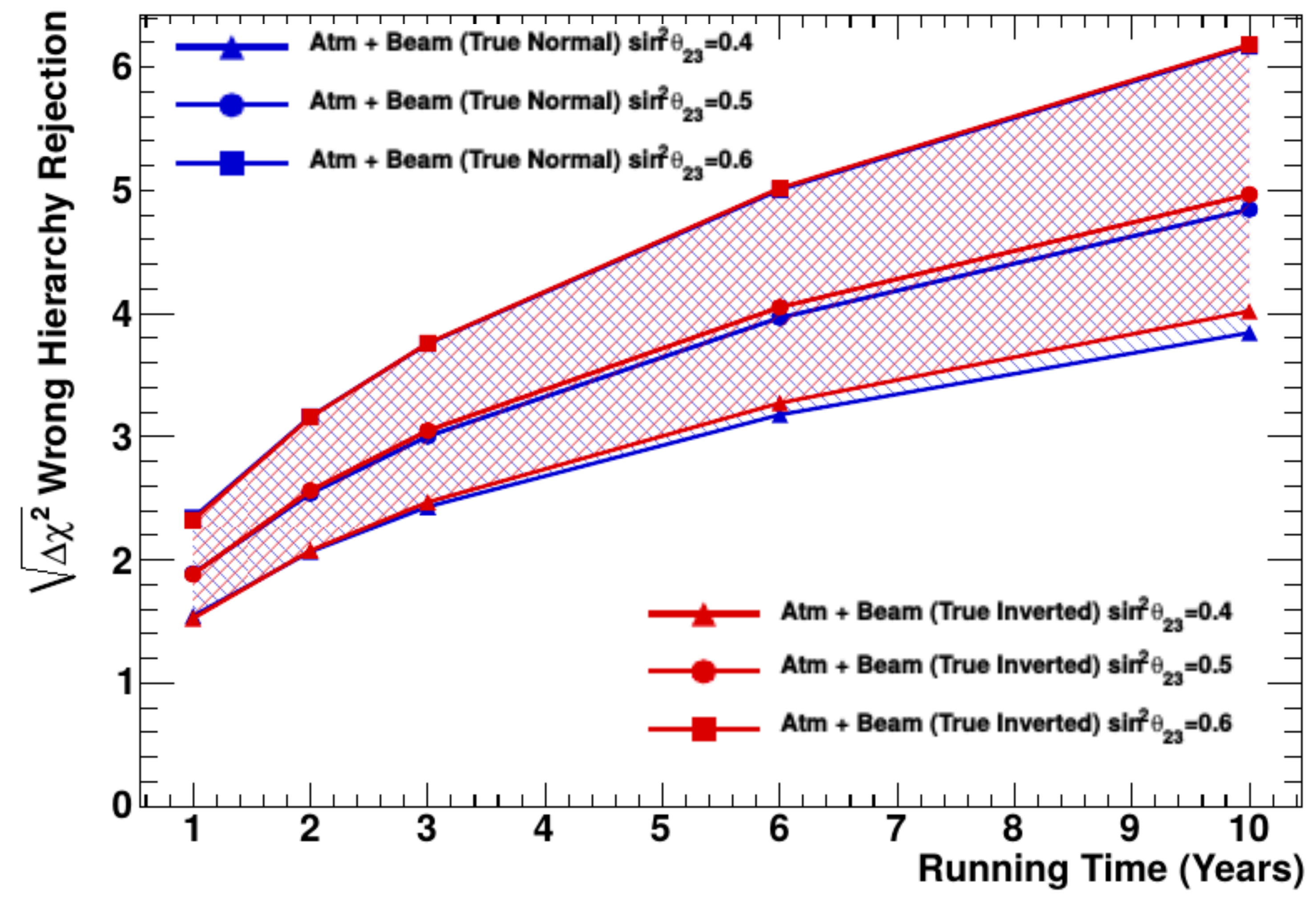




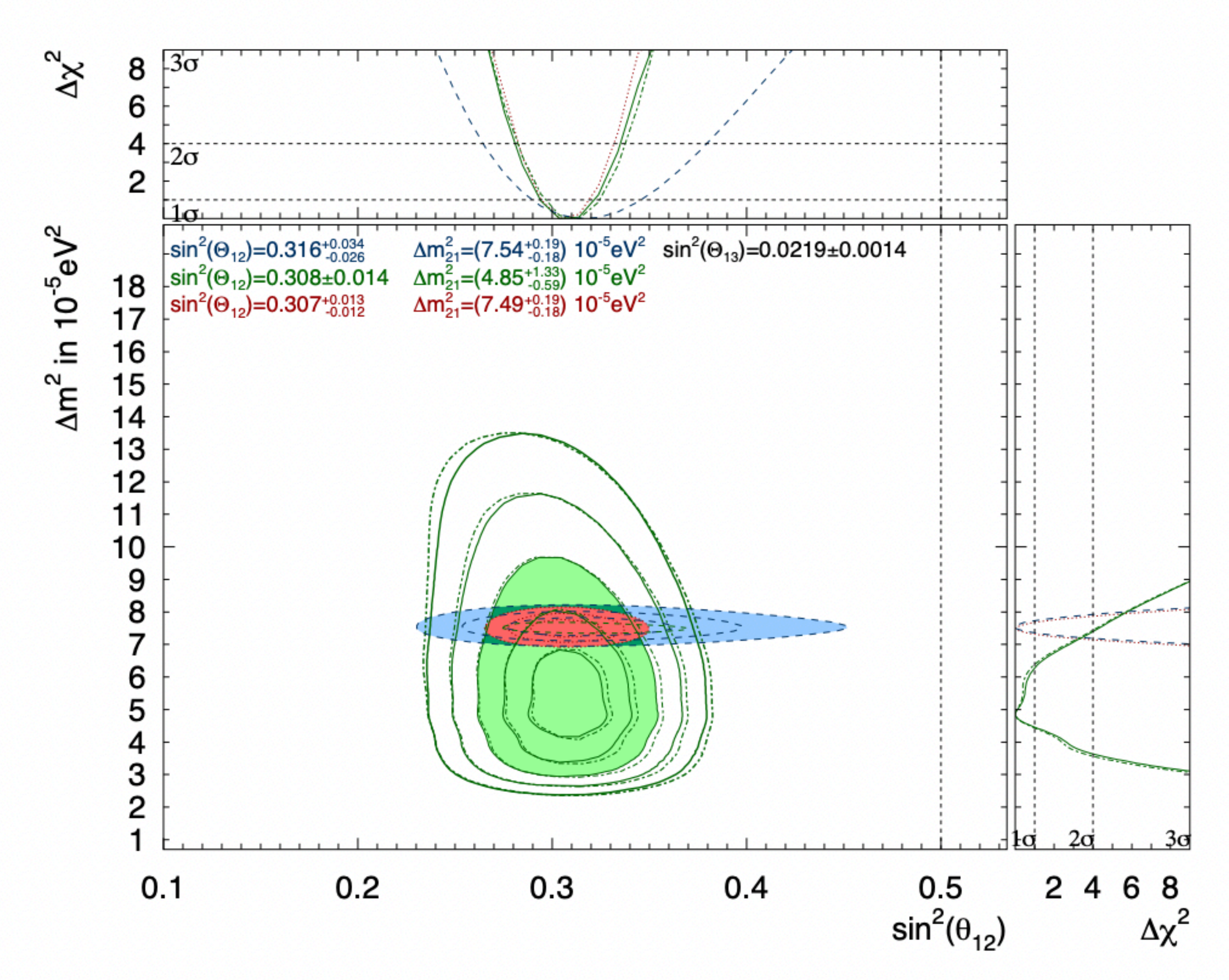
HYPER-K PHYSICS GOALS (2)

- Atmospheric neutrinos improve sensitivity to mass ordering
- $>4\sigma$ discovery potential for diffuse supernova neutrinos & supernova burst detectable up to 1 Mpc
- Resolve solar neutrino and KamLAND tension to $>4\sigma$

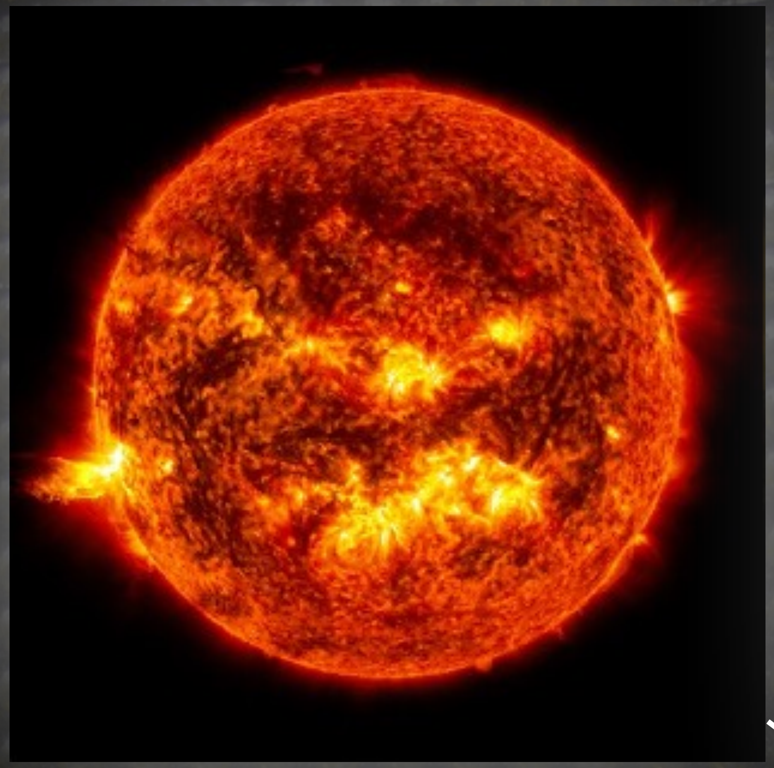
HK atmospheric + beam sensitivity to mass ordering



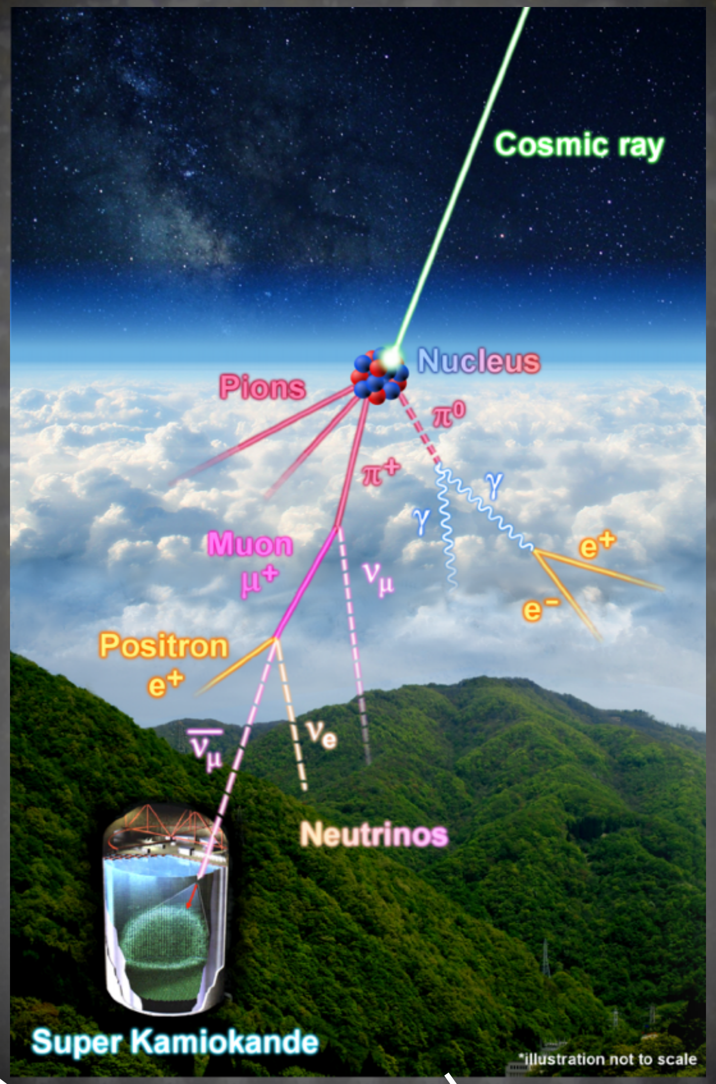
Δm^2_{21} tension



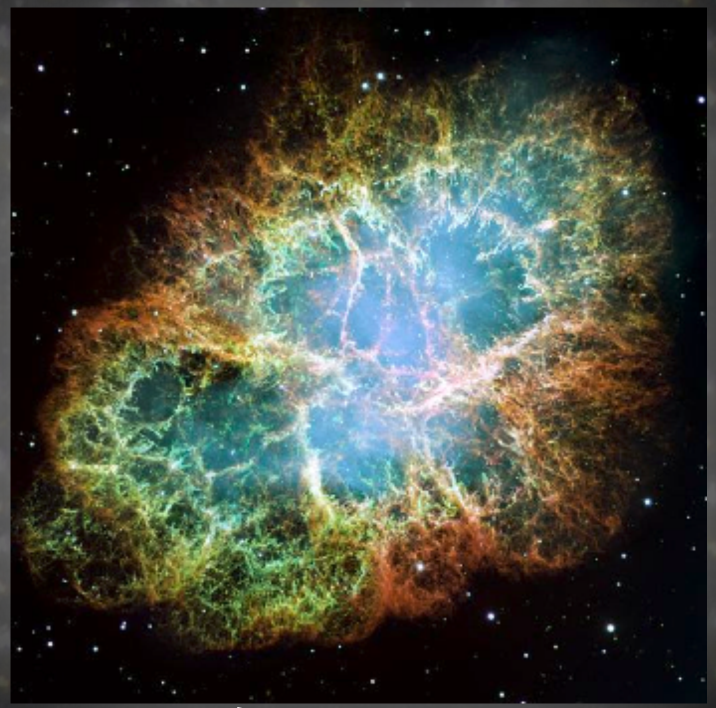
Solar neutrino

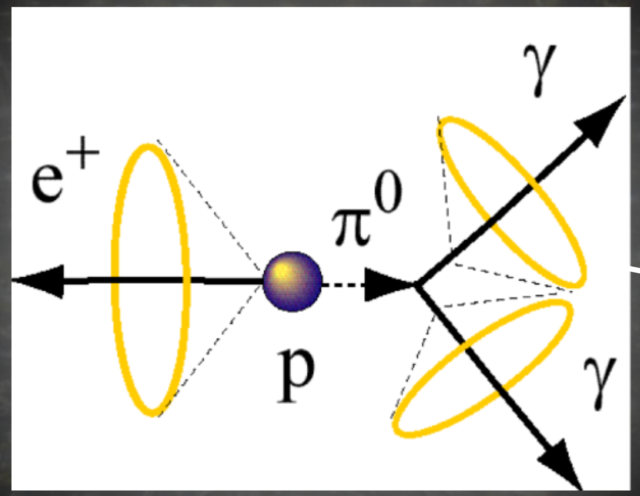


Atmospheric neutrino

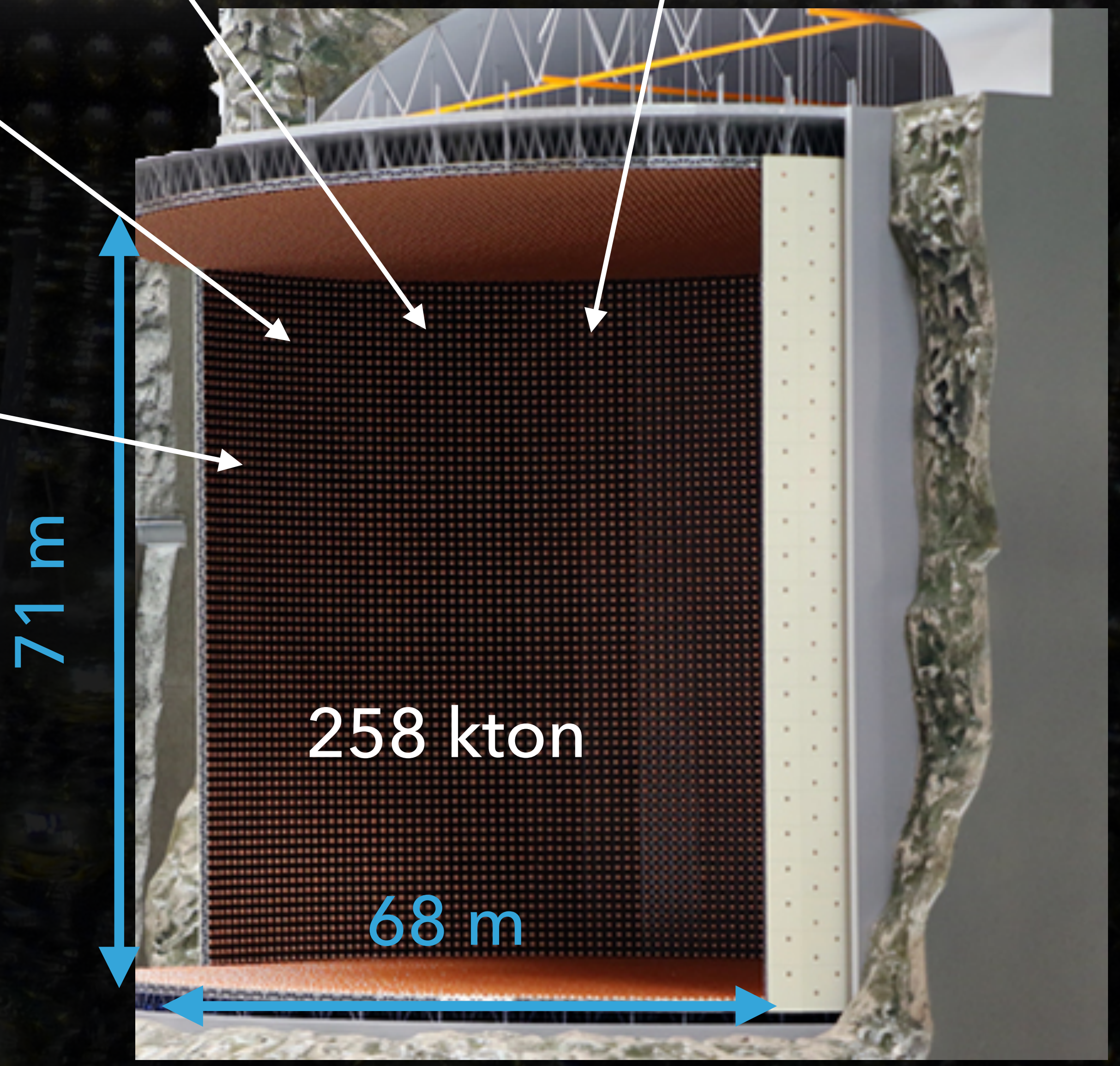


Supernova neutrino

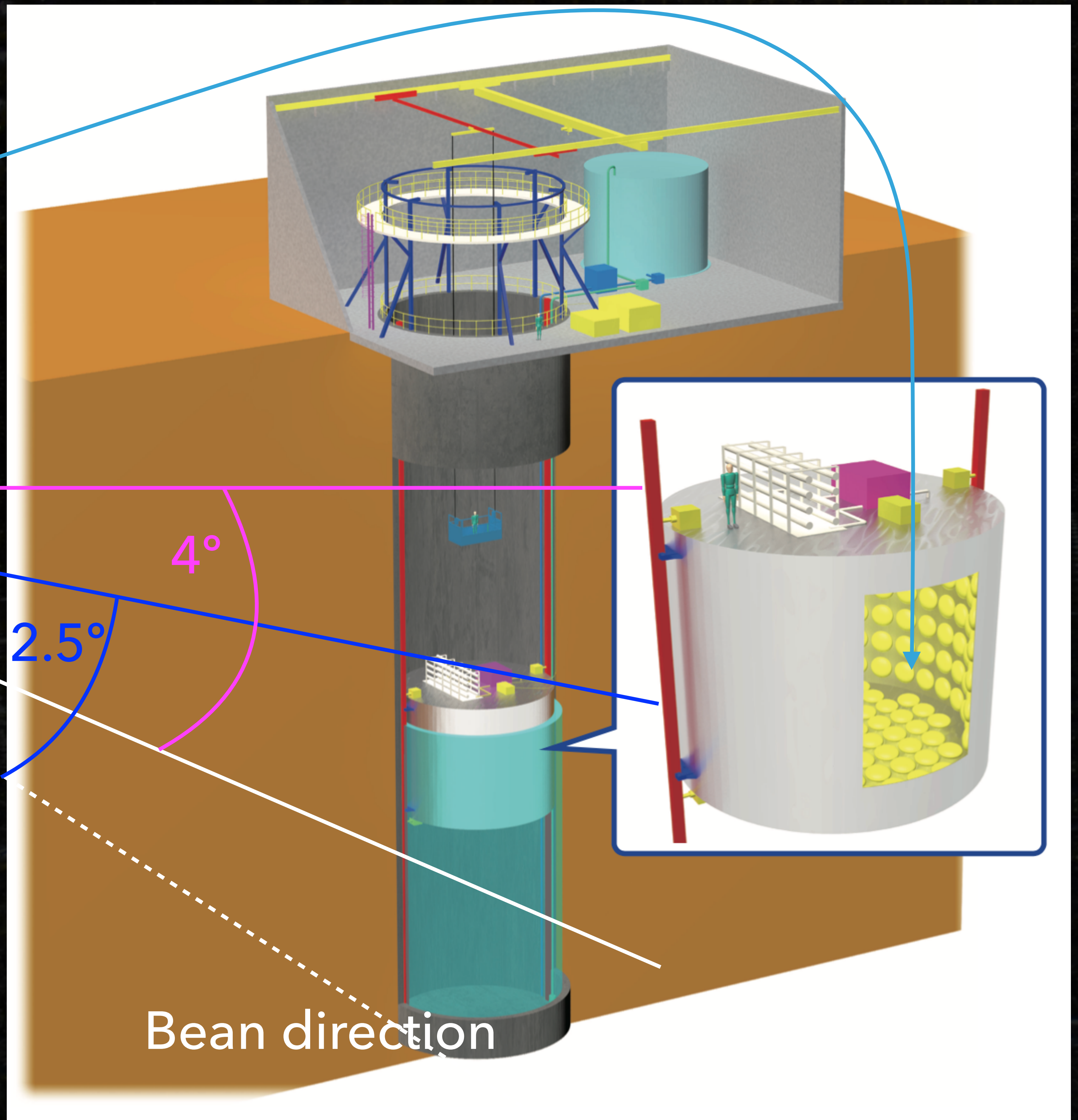


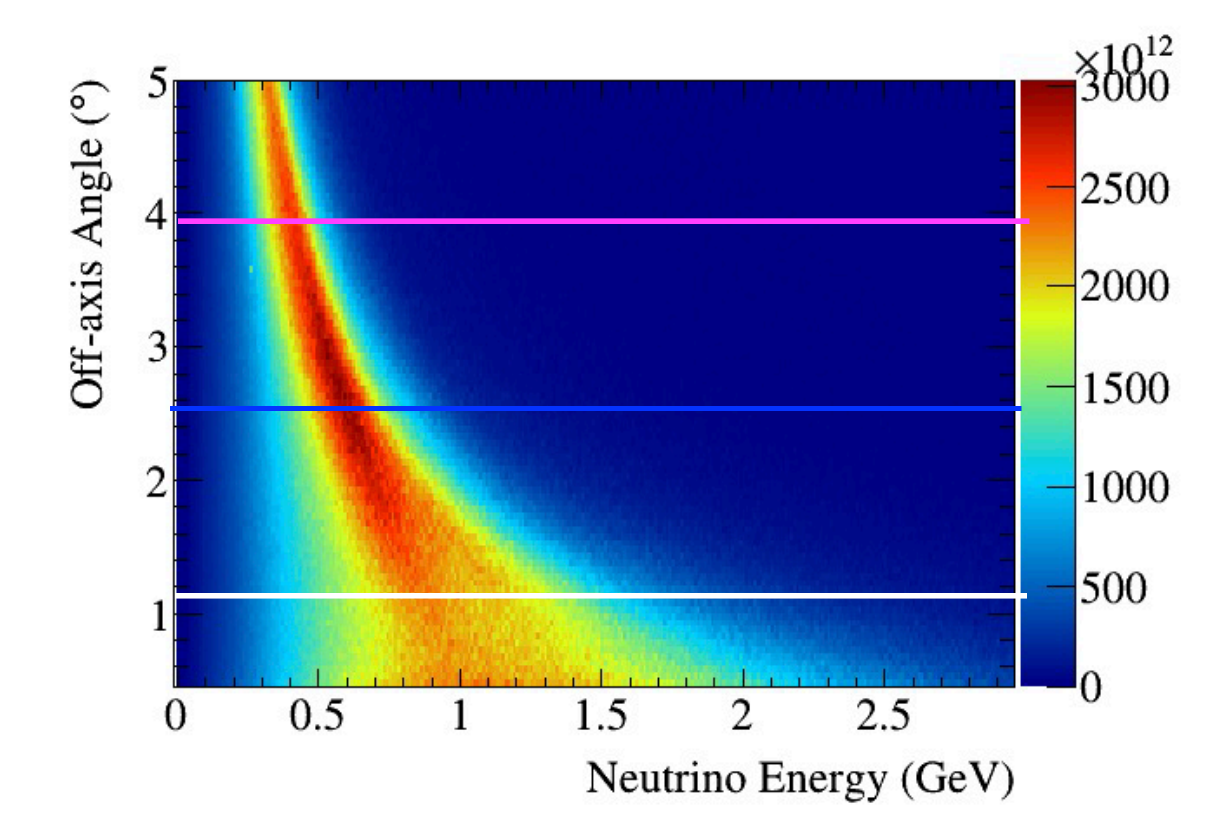


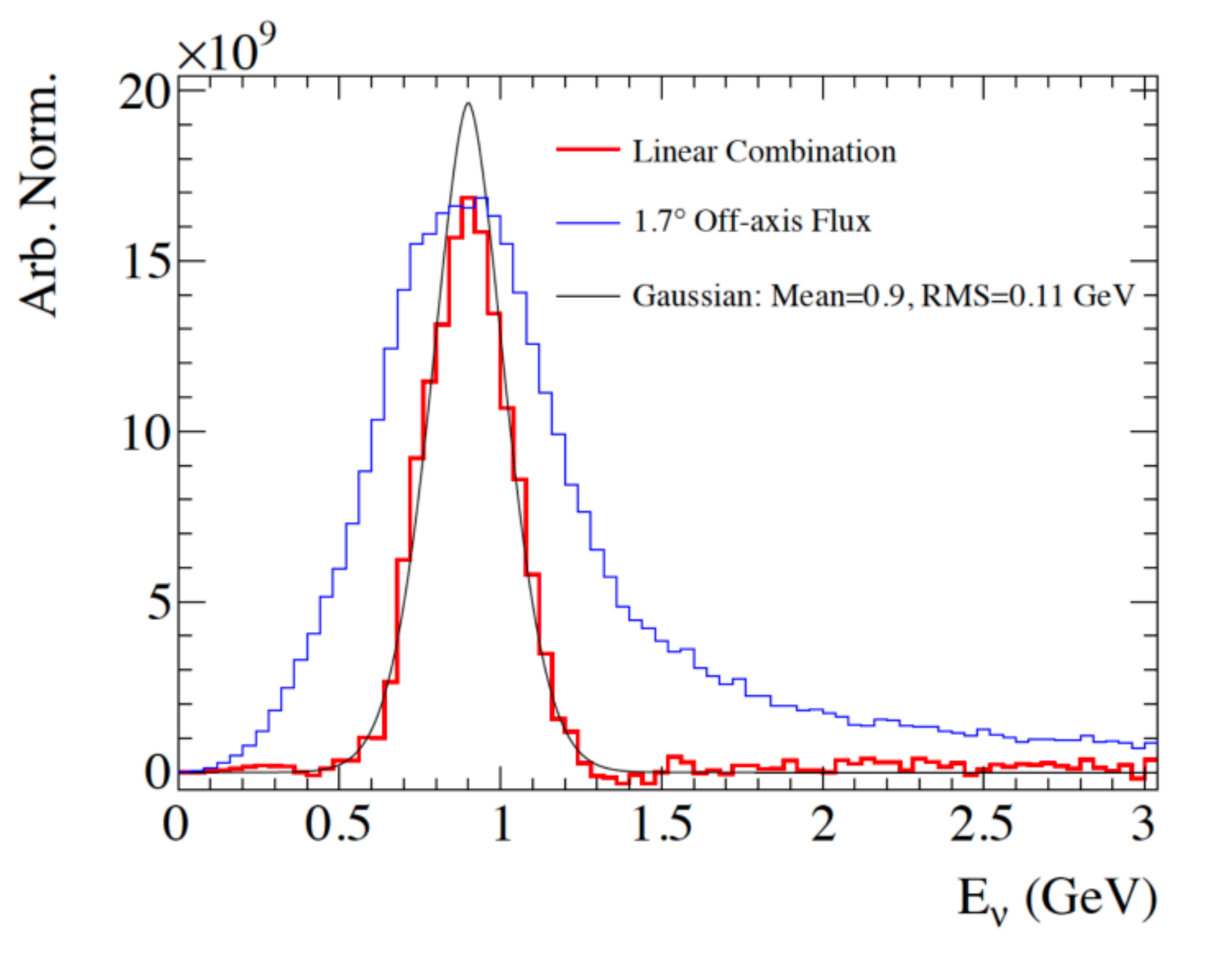
Proton decay



INTERMEDIATE WATER CHERENKOV DETECTOR (IWCD)

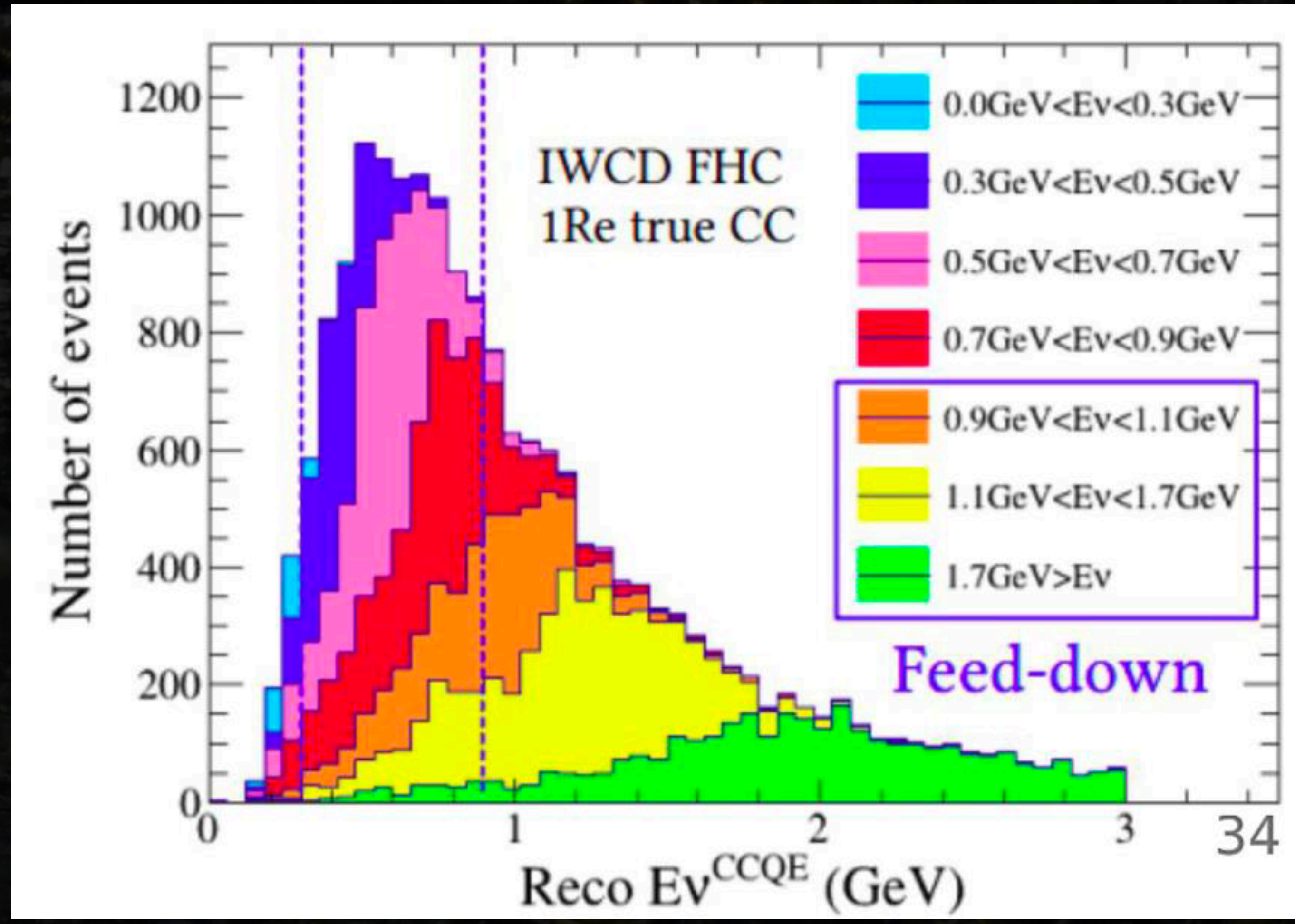






- $\nu_e/\bar{\nu}_e$ cross-section measurement can be improved due to better γ rejection than ND280
- Measure neutrino fluxes at different energies

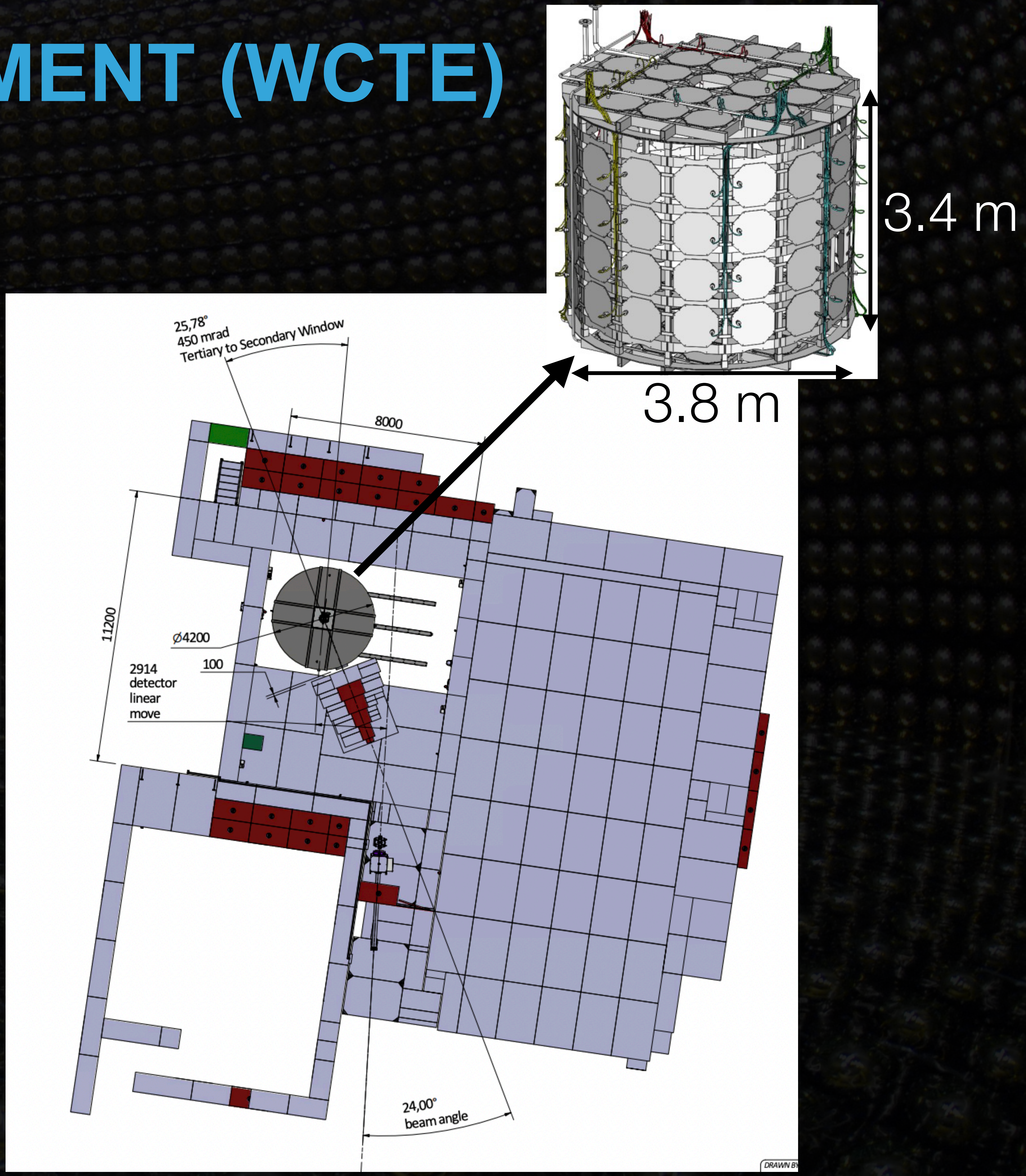
"Feed-down" effect in neutrino energy reconstruction



ND280 (280 m) ~1 km Hyper-K (295 km)

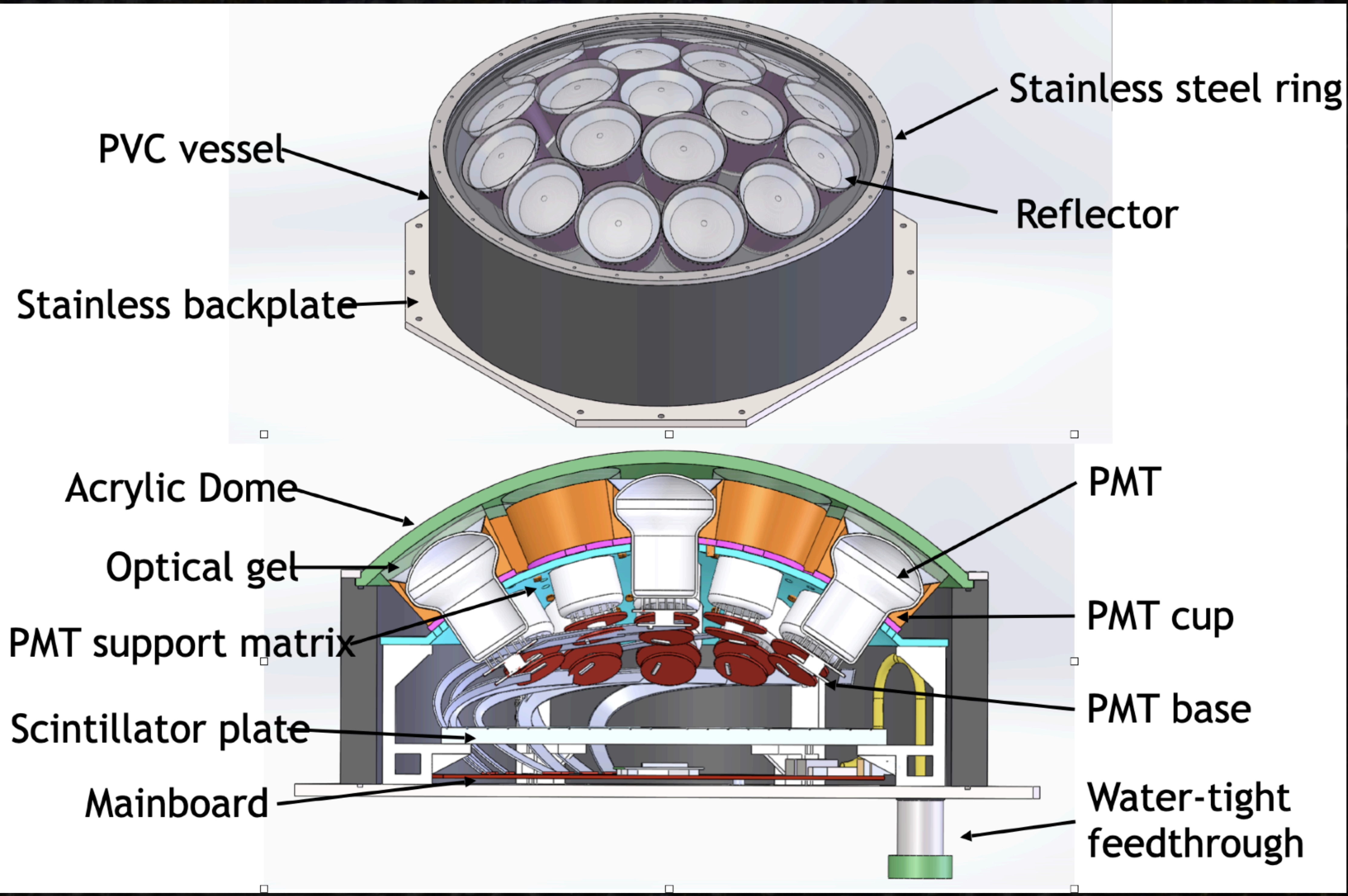
WATER CHERENKOV TEST EXPERIMENT (WCTE)

- T9 test beam @ CERN
- 0.3 - 1.1 GeV π, p, e, μ and tagged γ beam
- Prototype of IWCD: test of mPMT and calibration techniques
- Detector construction to start in November 2023
- Data taking in April 2024
- Lots of interesting physics to come with WCTE
  - Control samples for event reconstruction
  - Precision study of water Cherenkov detector response
    - Muon Cherenkov emission profile
  - Study of pion scattering
  - Neutrino interaction model tuning using e/μ scattering
  - … …



MULTI-PMT DEVELOPMENT

TRIUMF
THE UNIVERSITY OF WINNIPEG
YORK UNIVERSITÉ UNIVERSITY
University of Regina
Carleton UNIVERSITY
University of Victoria



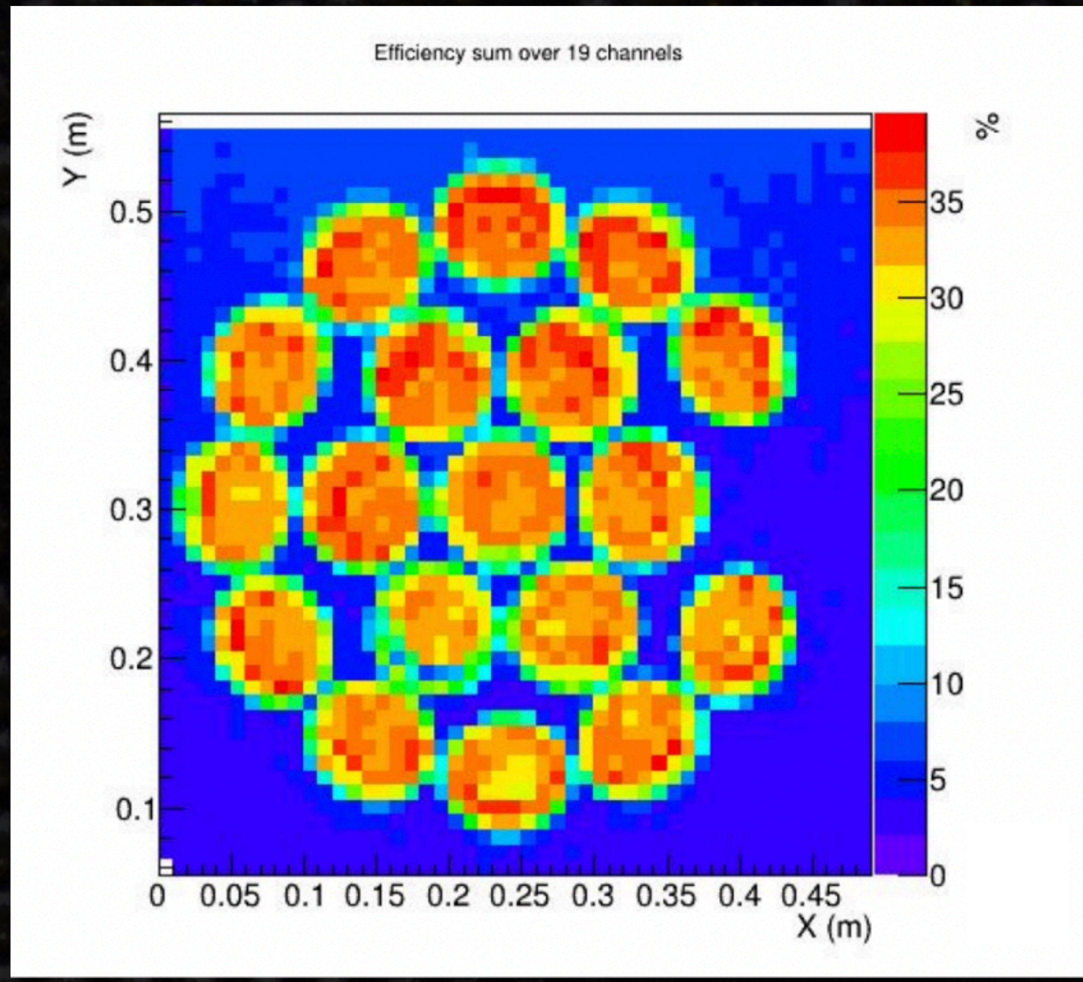
- 19 3-inch diameter PMTs integrated in module with high voltage and readout electronics
- 8-cm diameter PMTs have excellent timing resolution (~1.6 ns FWHM) with good spatial resolution
- High voltage circuits and electronics mainboard are integrated in the module
- Will build 250 modules for IWCD with CFI-IF funding
  - 50 WCTE mPMTs will be reused in IWCD

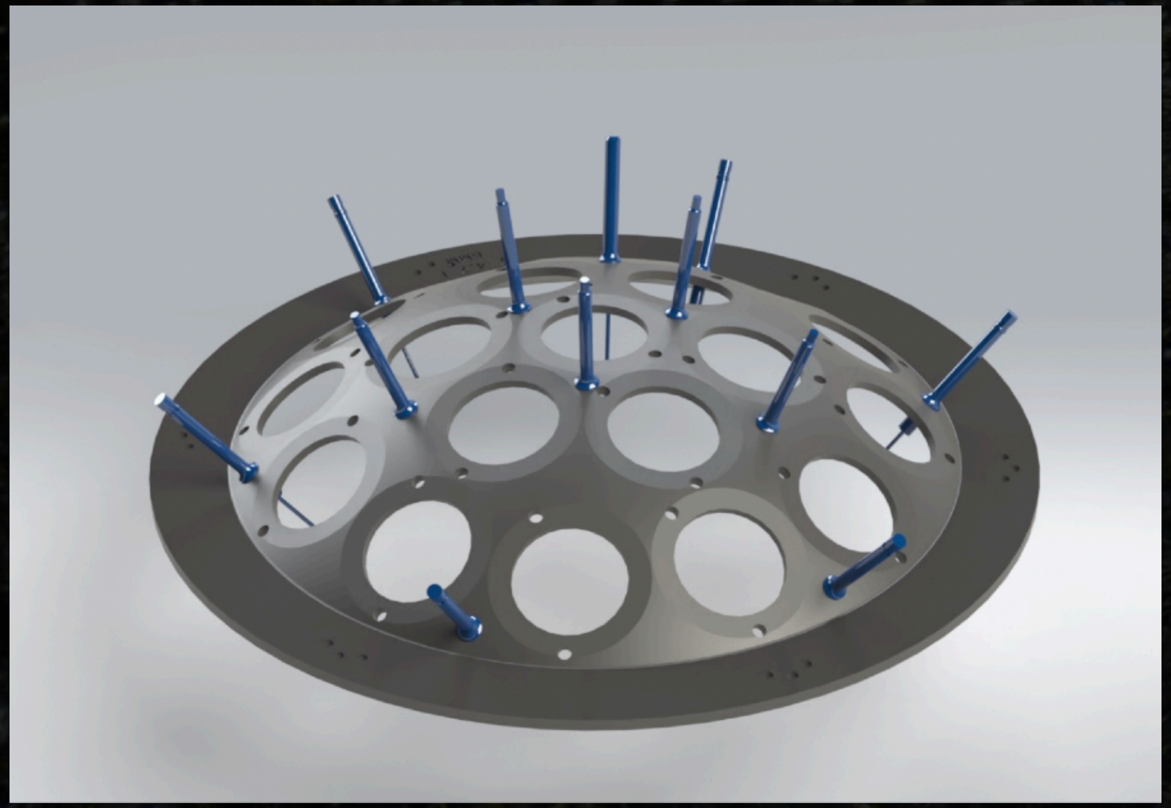
MULTI-PMT FOR WCTE

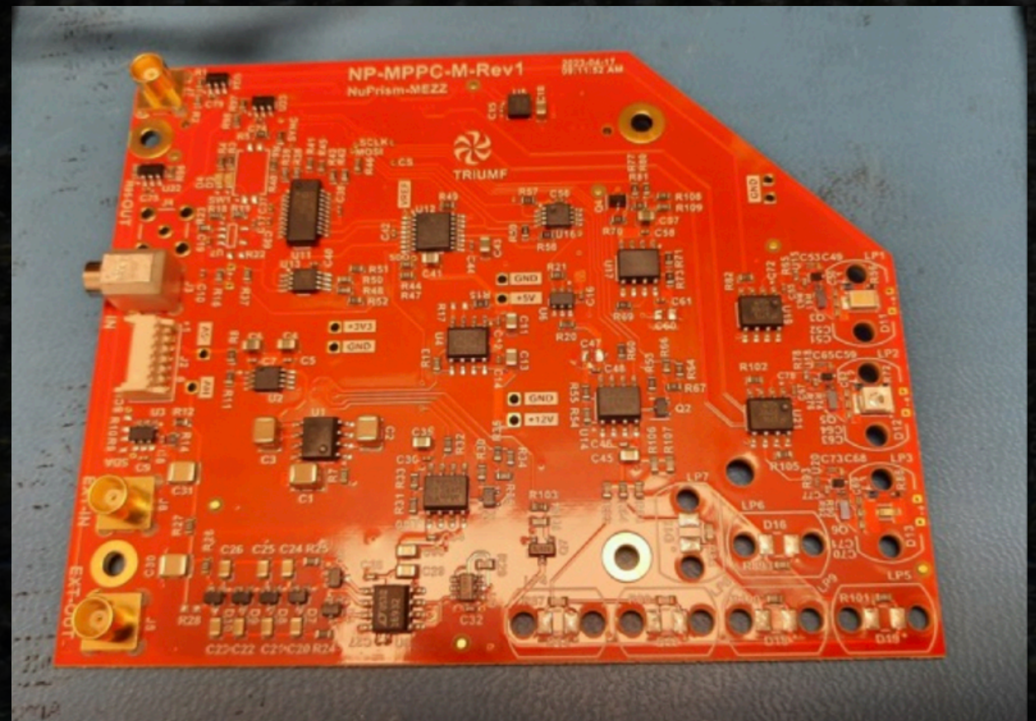
- Production of 50 WCTE mPMTs will start in July
  - Will use the experience of WCTE mass production to make the final decision about the mPMT assembly strategy.
  - Choice between in-situ vs ex-situ gelling strategy will be made after WCTE mPMT production
- 3 sub-ns pulsed LEDs per mPMT for detector calibration & 6 continuous LEDs as photogrammetry targets

Ex-situ gelling mPMTs @ TRIUMF

Measured mPMT relative efficiency







Light pulser card

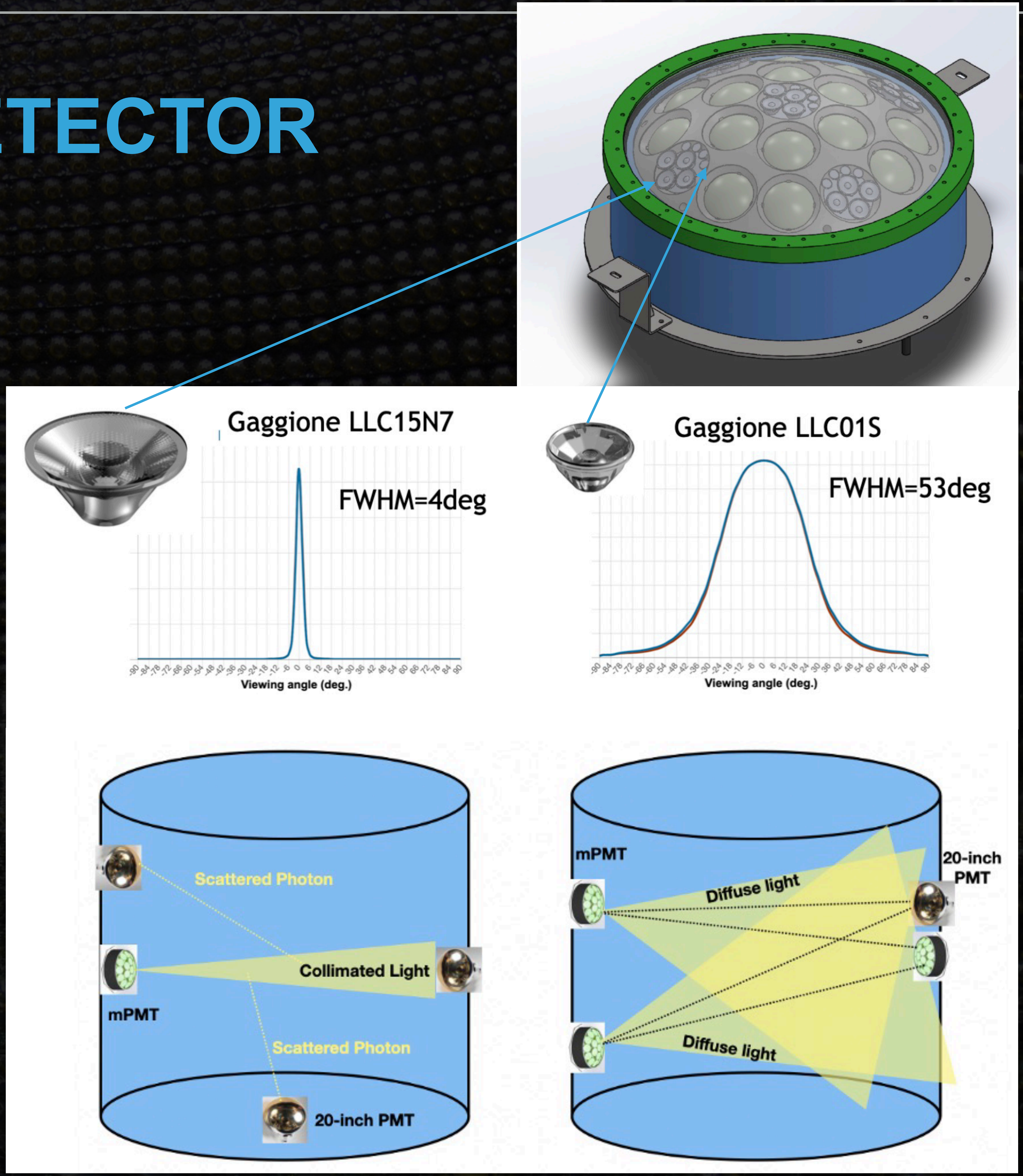
In-situ gelling mPMTs @ Carleton

Machined XPS foam matrix in Ottawa

Assembled mPMT w/ XPS foam matrix

MULTI-PMT FOR HYPER-K FAR DETECTOR

- CFI-IF 2023 funding competition to build 200 mPMTs for Hyper-K detector for calibration purposes
  - For 200 mPMTs we would replace 5 PMTs with LED units
  - Each of the five LED units will have 8 LEDs with LEDs of 290, 365, 405, 475nm wavelength
  - A narrow and wide collimator for each wavelength
    - Photon scattering/absorption & PMT timing, angular response calibration
- mPMT can help break the degeneracy between water quality and PMT angular response -> reduce energy-scale error



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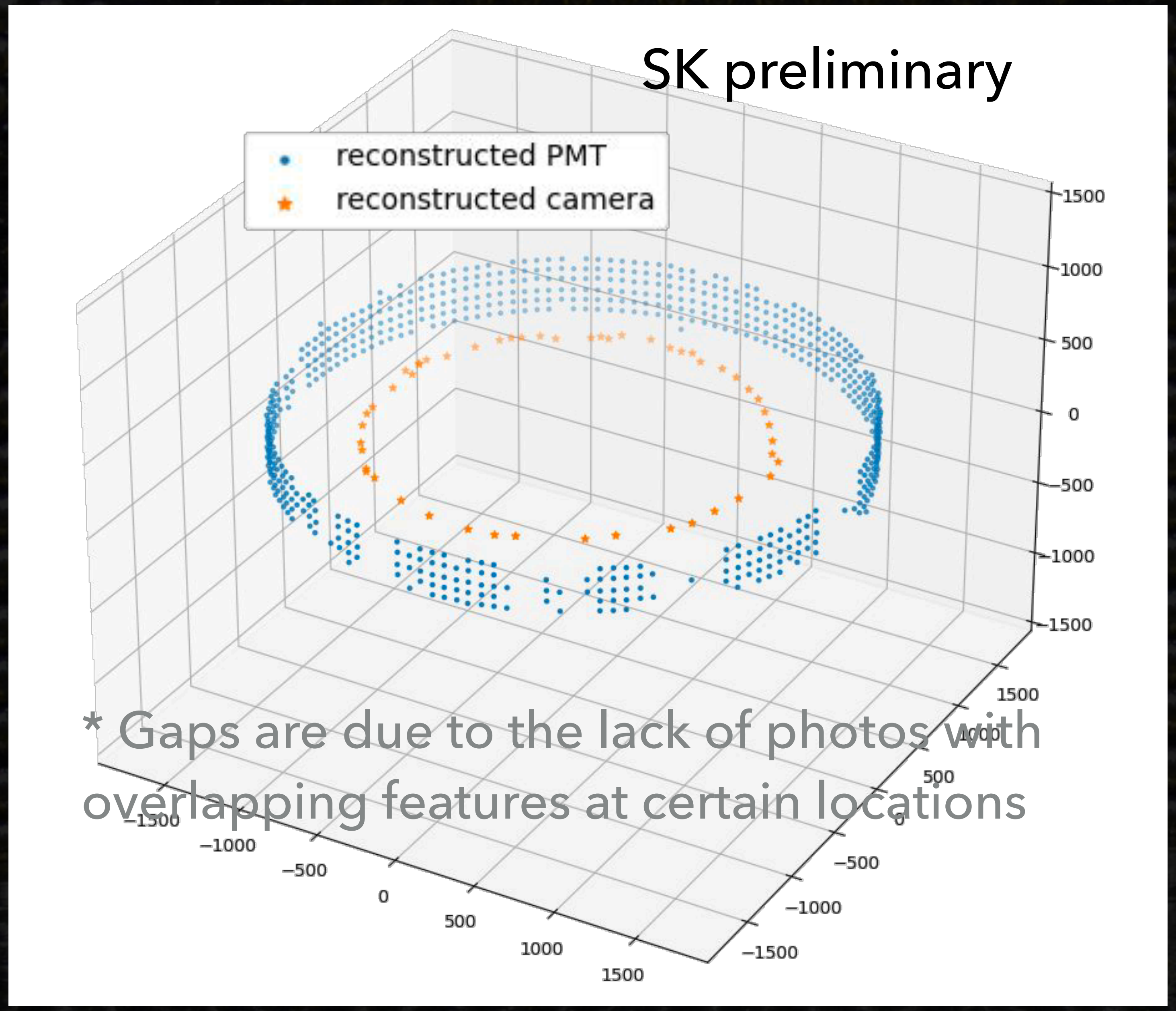
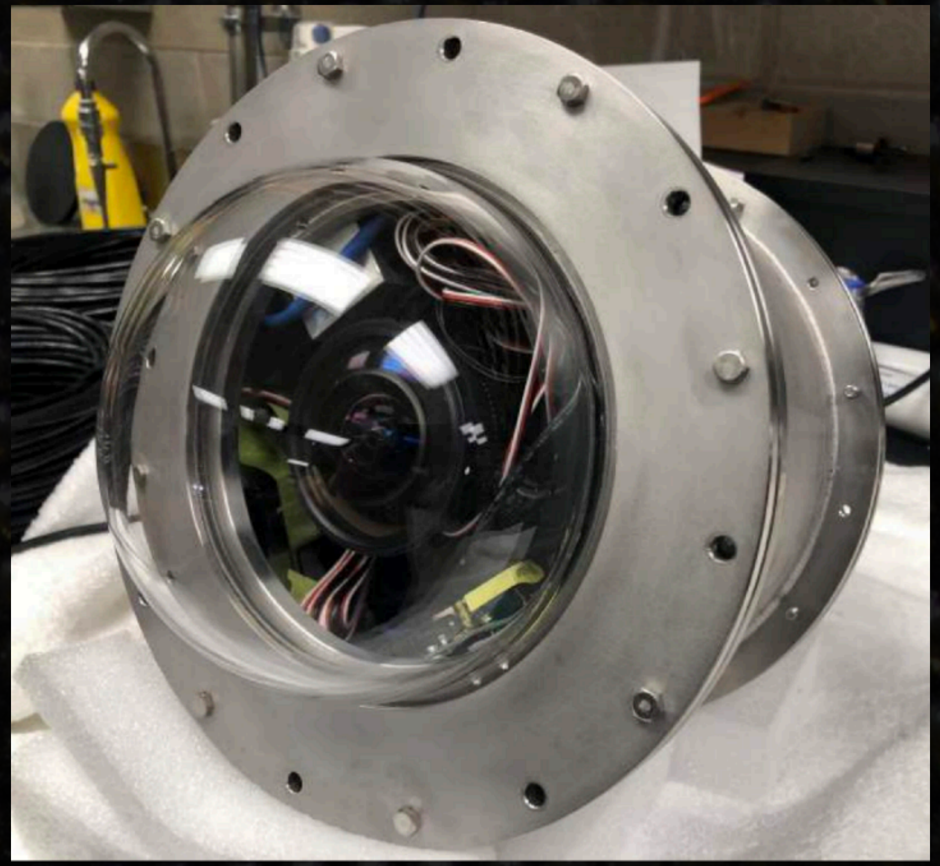
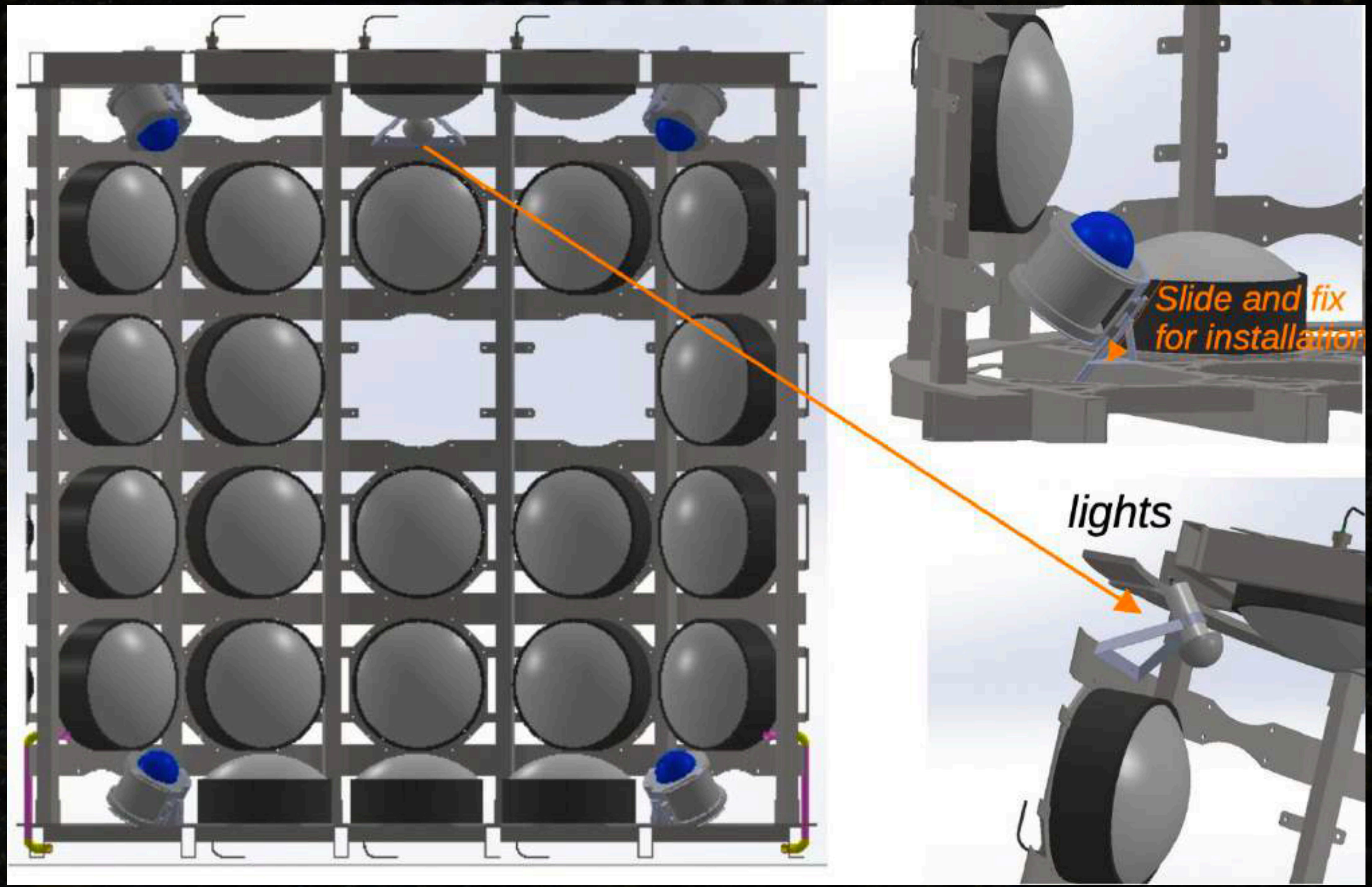
PHOTOGRAMMETRY GEOMETRY CALIBRATION



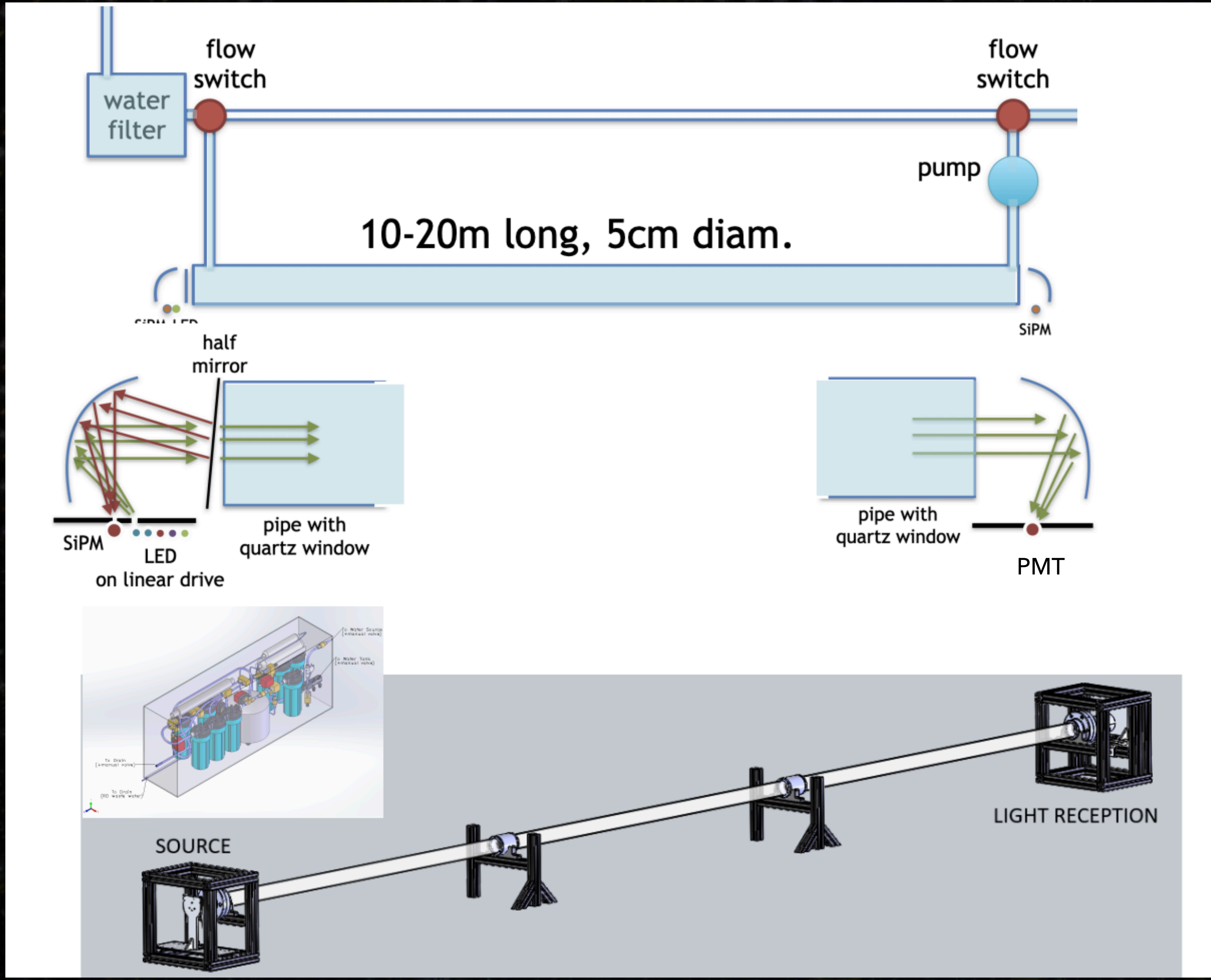
First assembled camera module @UWinnipeg



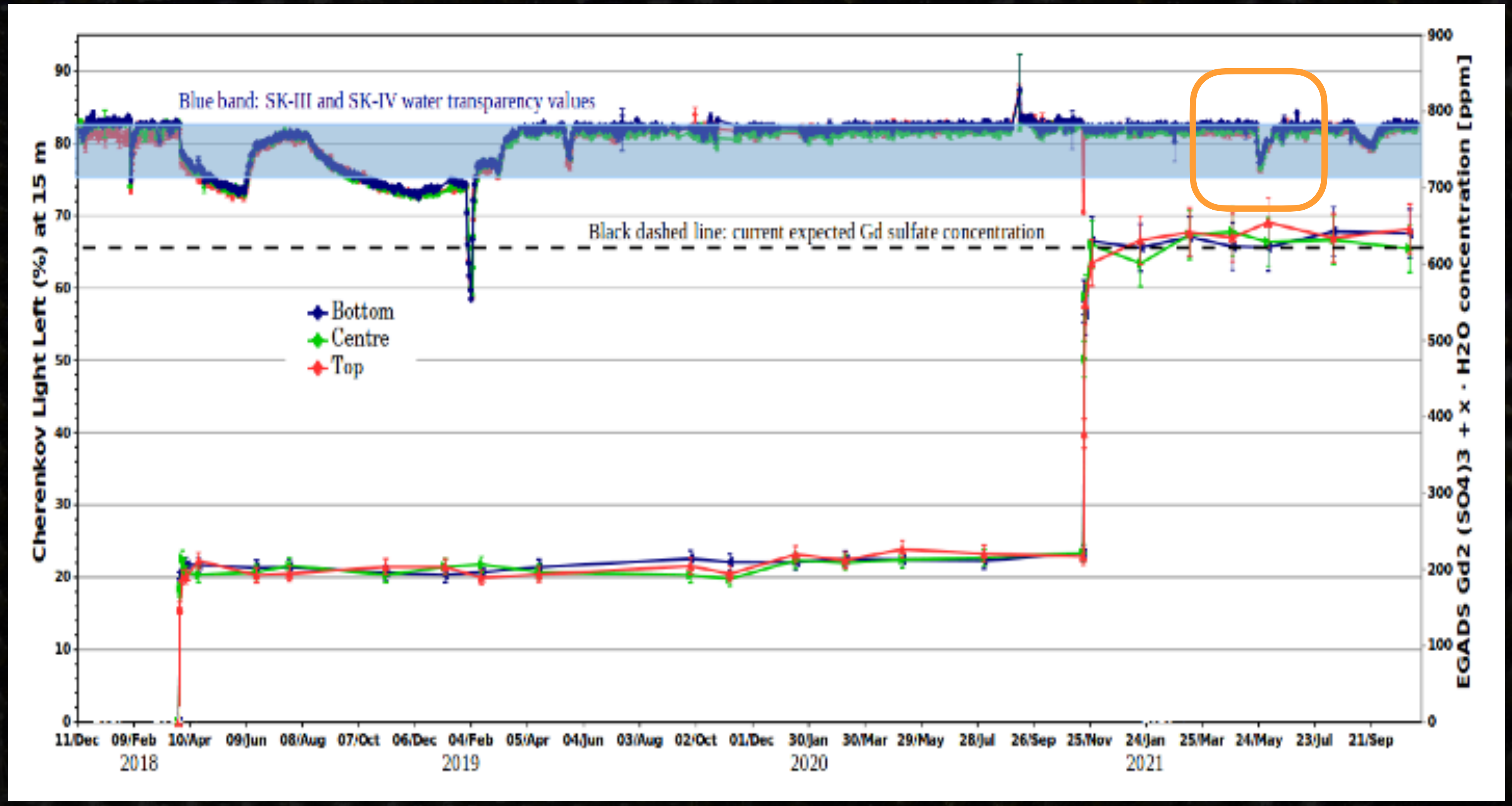


- Use photogrammetry to measure the position of PMTs and calibration sources in-situ
  - The first survey was done in SK using underwater ROV
  - WCTE and IWCD will utilize fixed cameras
  - Reduce fiducial volume error

WATER MONITORING SYSTEM



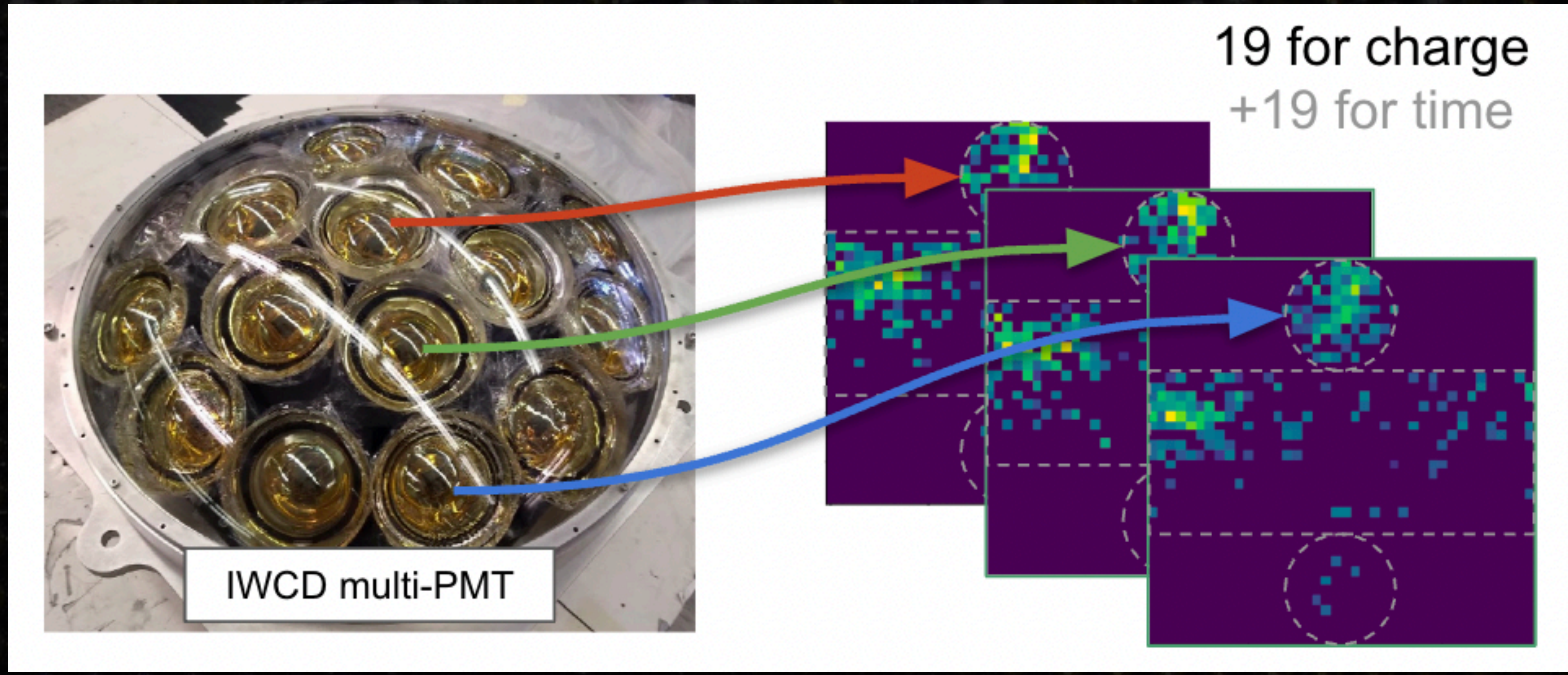
Light transmission through 15 m of water



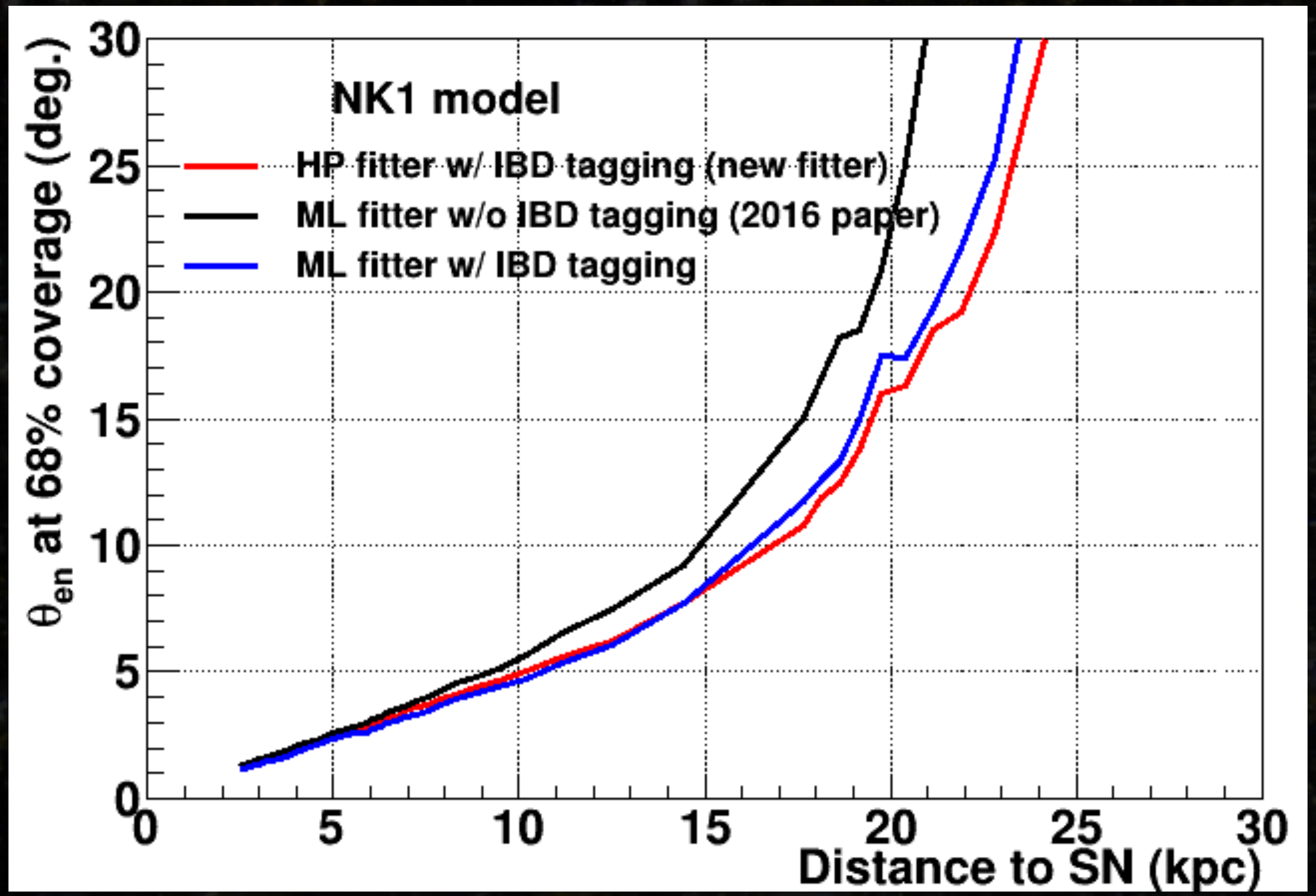
- Light propagation in water needs to be precisely calibrated and monitored
- Pulsed LED (230 - 700 nm) with <1 ns width
  - Same LED driver design as mPMT
- Applications in drinking water monitoring
- First mechanical prototype built @ TRIUMF

MACHINE LEARNING EVENT RECONSTRUCTION

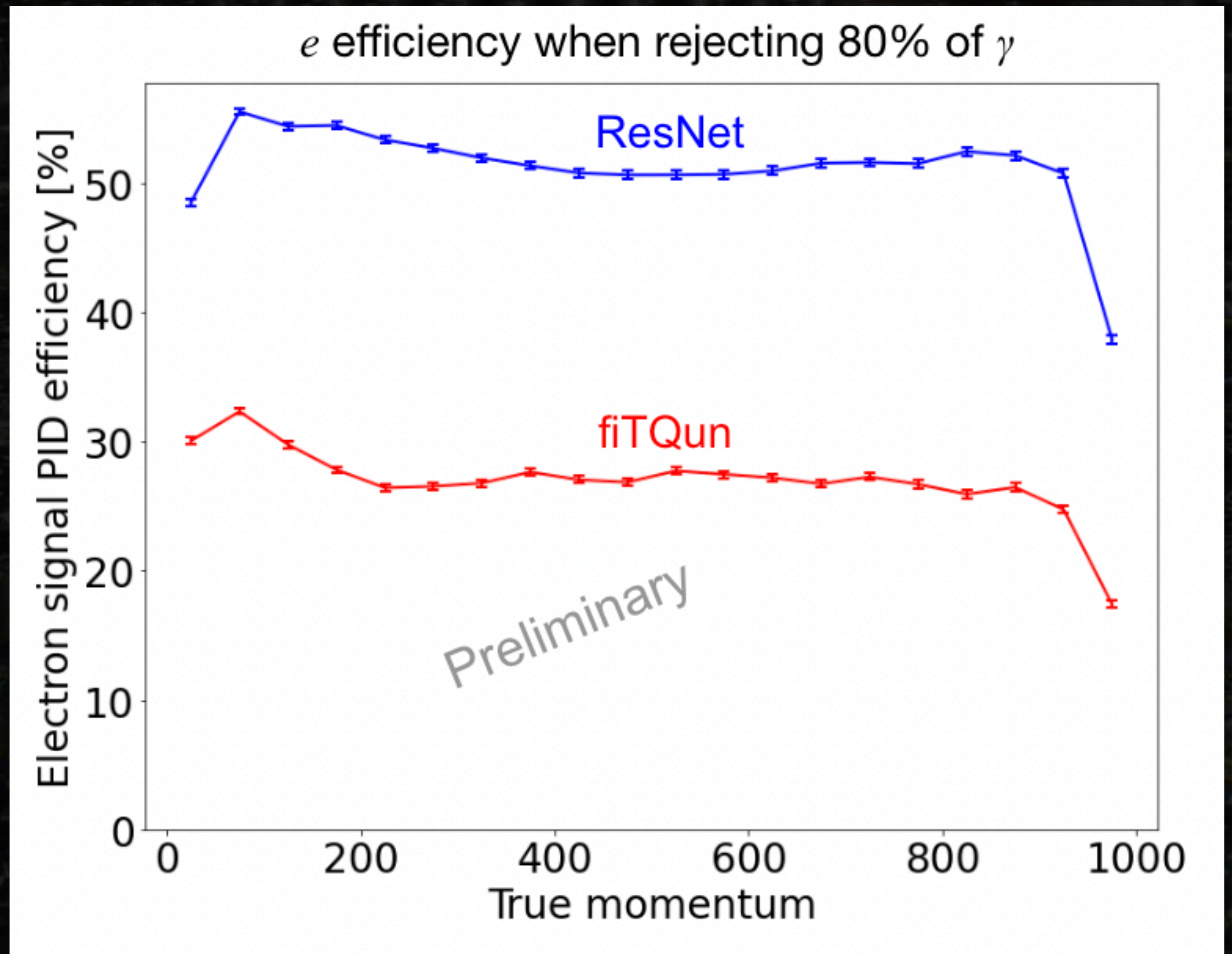
- Machine learning techniques have been applied to event reconstruction in IWCD and Hyper-K
  - Encouraging improvements from traditional method
- Improve supernova direction finding

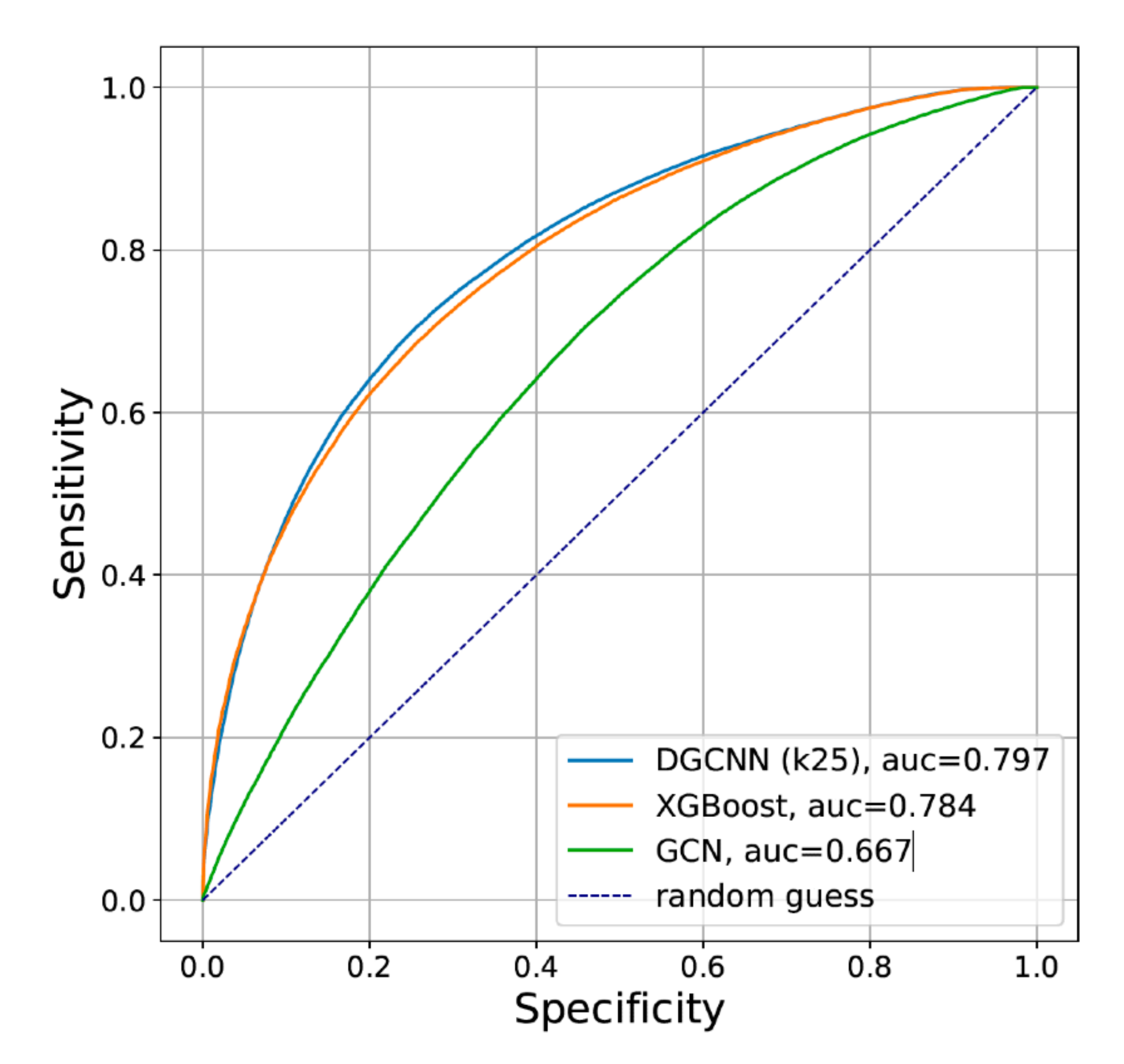


SN direction in Super-K



e/γ separation in IWCD



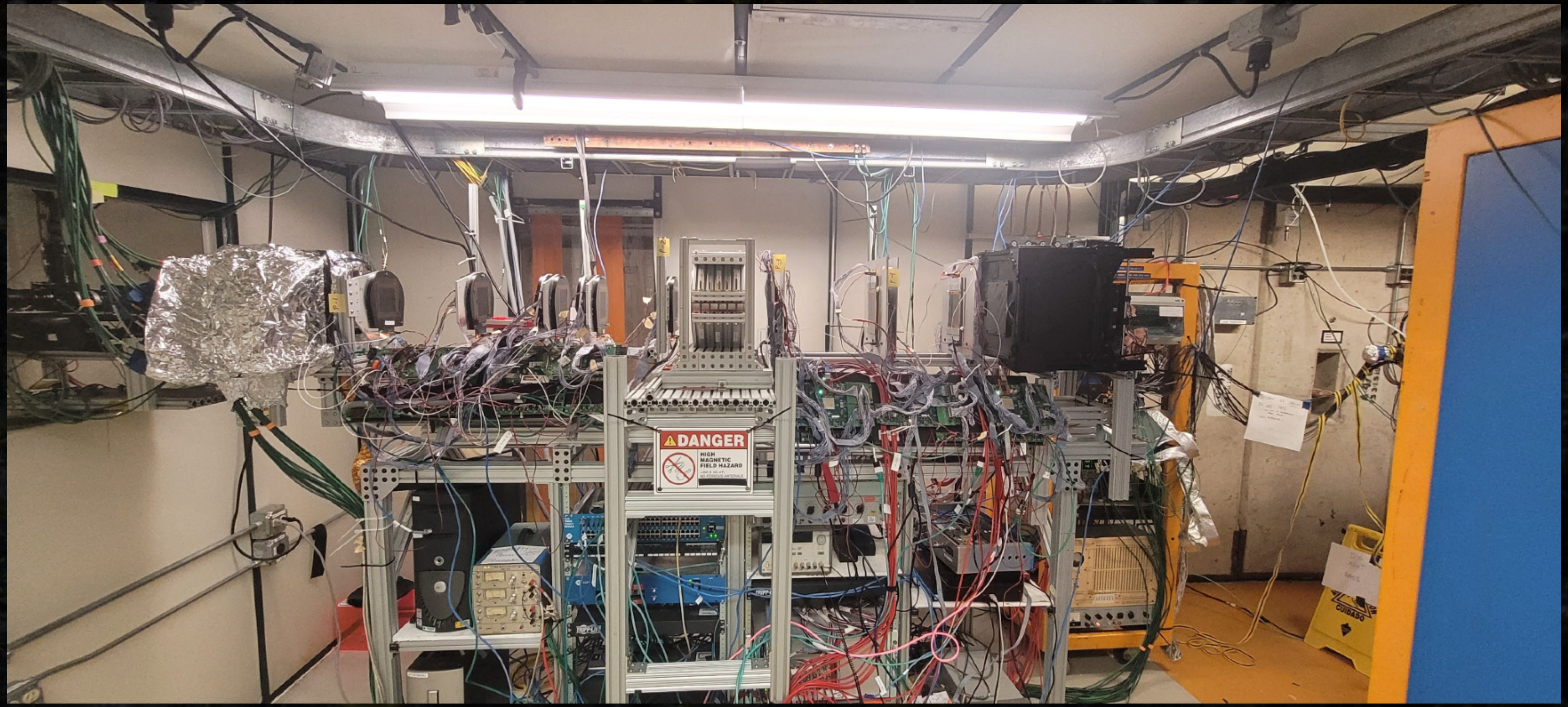


Neutron tagging

"*Using Machine Learning to Improve Neutron Identification in Water Cherenkov Detectors*", Front. Big Data, 30 September 2022 (https://doi.org/10.3389/fdata.2022.978857)

EMPHATIC

- Experiment to Measure the Production of Hadrons At a Test beam In Chicagoland
- Collection of small detectors to track particles that fits within 4 meters with high precision before and after a target using SSDs, ARICH, TOF, calorimeter and a permanent magnet.
- Located at the test beam facility in Fermilab.
- Uses the Beam momentum: ± 2, 4, 8, 12, 20, 30, and 120 GeV/c, going lower than the NA61/SHINE.
- Phase 0 (2018) : Proof of concept run of proton-carbon forward scattering with results published: https://doi.org/10.1103/PhysRevD.106.112008
- Phase 1 (2019-2023) : Full spectrometer assembled, data taking with a large collection of thin targets: Aluminum, graphite, iron, water, CH2. Analysis on the way.
- Phase 2 (2024-...) : Larger angular acceptance spectrometer in construction, permanent location at Fermilab, thin and replica target measurements plans.



SUMMARY AND OUTLOOK

- Hyper-K Canada group is focussed on detectors and detector systems necessary to control critical systematic effects for neutrino interaction and detector modeling in Hyper-K
  - Novel multi-PMT photosensor development
  - WCTE will take data in April 2024 and will yield interesting physics results
  - IWCD will constrain key cross section uncertainties and enable oscillation parameter measurement more independent of neutrino cross section modeling
  - New detector calibration techniques
  - Reducing neutrino production modeling uncertainties with hadron production measurements
- CFI-IF 2020 award funds mPMTs and photogrammetry for the IWCD
- CFI-IF 2023 award will fund mPMTs and photogrammetry for the Hyper-K detector