# The Hyper-Kamiokande Experiment

Mark Hartz for the

**Hyper-K Canada Collaboration**

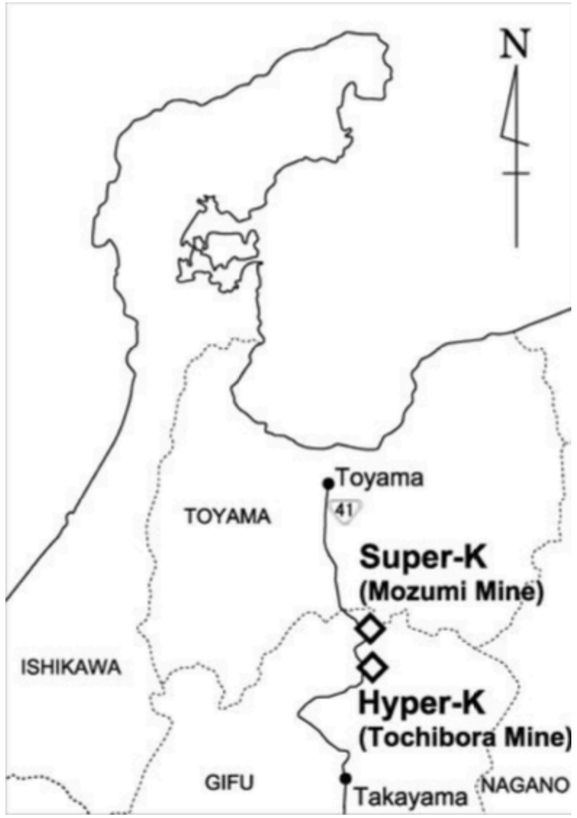
TRIUMF
UNIVERSITY OF TORONTO
University of Victoria
YORK UNIVERSITÉ UNIVERSITY
THE UNIVERSITY OF WINNIPEG
BCIT BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY
Carleton UNIVERSITY
University of Regina

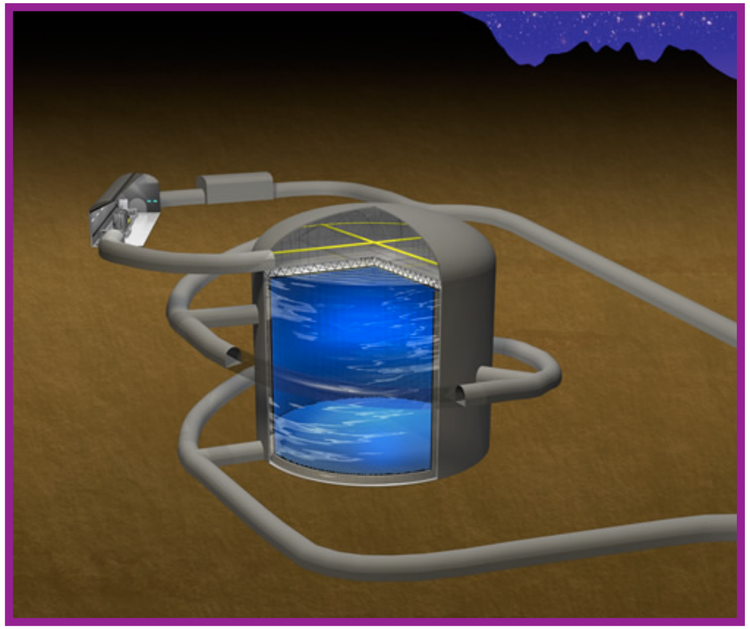
IPP Town Hall Meeting

July 16, 2020

# Hyper-Kamiokande Detector

- Hyper-Kamiokande Detector:
  - Water Cherenkov detector
  - 187 kton fiducial mass (8x larger than Super-Kamiokande)
- Broad Physics Program
  - Accelerator neutrinos
  - Proton decay searches
  - Supernova neutrino detection
  - Atmospheric neutrinos
  - Solar neutrinos
  - Dark matter searches
  - …

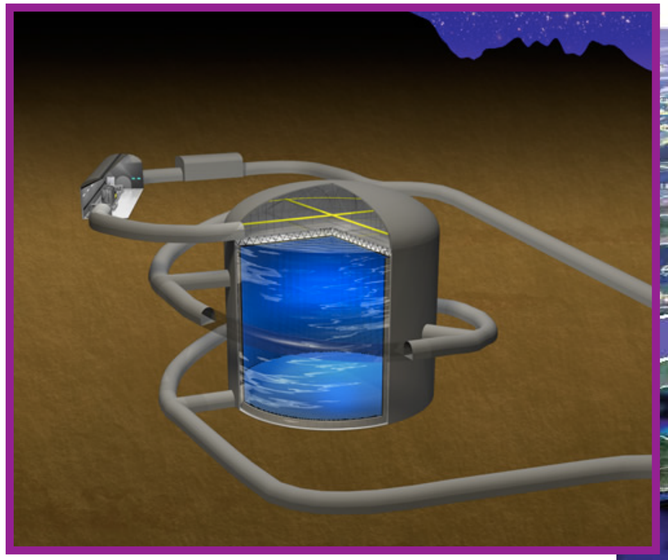


**Hyper-K approved in January 2020**

**Hyper-K Design Report: arXiv:1805.04163**

# Hyper-K Accelerator Program



Hyper-Kamiokande





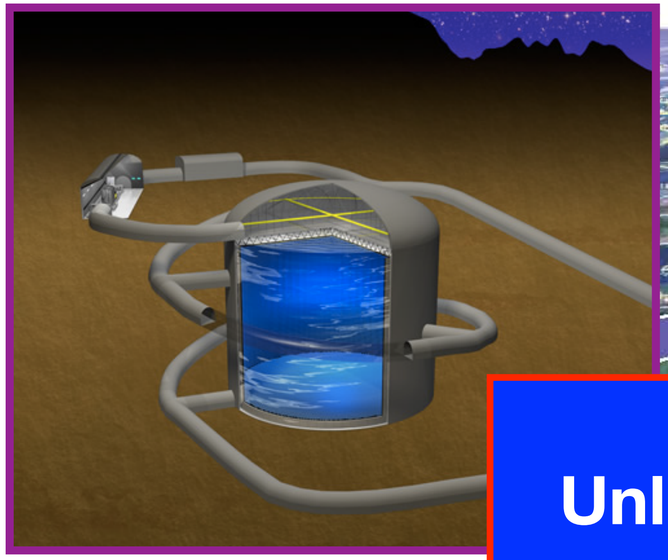
IWCD Detector

J-PARC Main Ring (KEK-JAEA, Tokai)

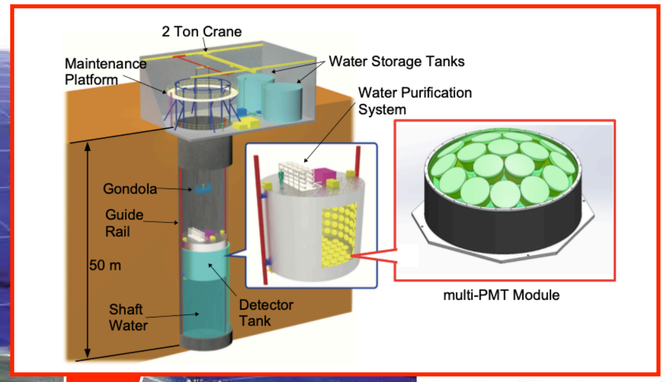


- Build on successful program of T2K
  - 8x larger detector
  - 2.5x higher beam intensity
  - New near detectors to reduce systematic uncertainties

# Hyper-K Accelerator Program



Hyper-Kamioka


IWCD Detector

**Unlike SK and T2K, accelerator and non-accelerator physics carried out by single Hyper-K experiment/collaboration**

J-PARC Main Ring
(KEK-JAEA, Tokai)

- Build on successful program of T2K
  - 8x larger detector
  - 2.5x higher beam intensity
  - New near detectors to reduce systematic uncertainties

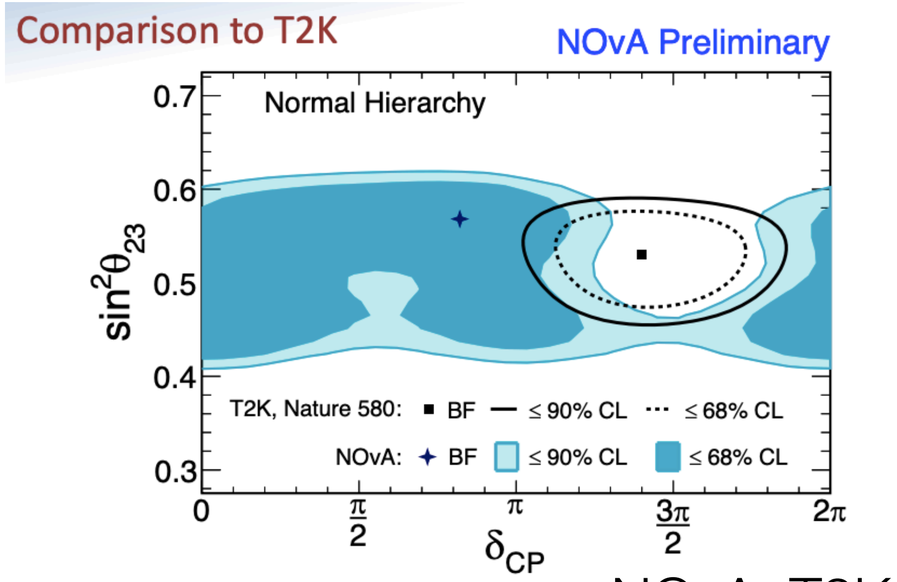
# Accelerator Neutrino: CP Violation Search

Hyper-Kamiokande

Sign flips between neutrino and antineutrino

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

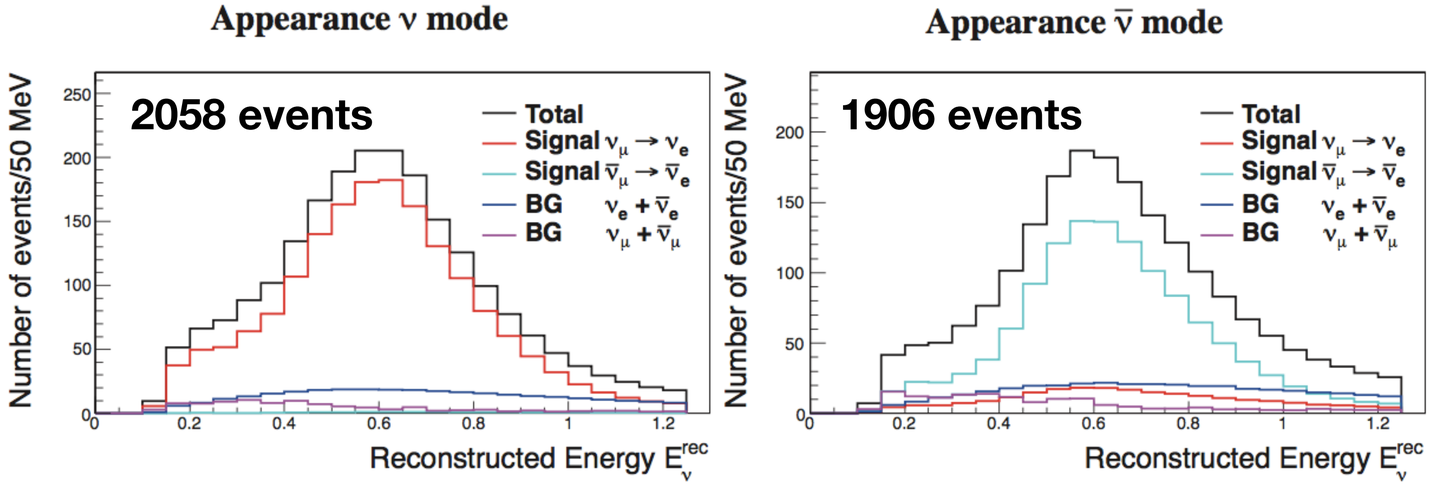
**NOvA Talk, Neutrino 2020**




| | NOvA | T2K |
|---|---|---|
| Neutrino Candidates: | 82 | 109 |
| Antineutrino Candidates: | 33 | 16 |

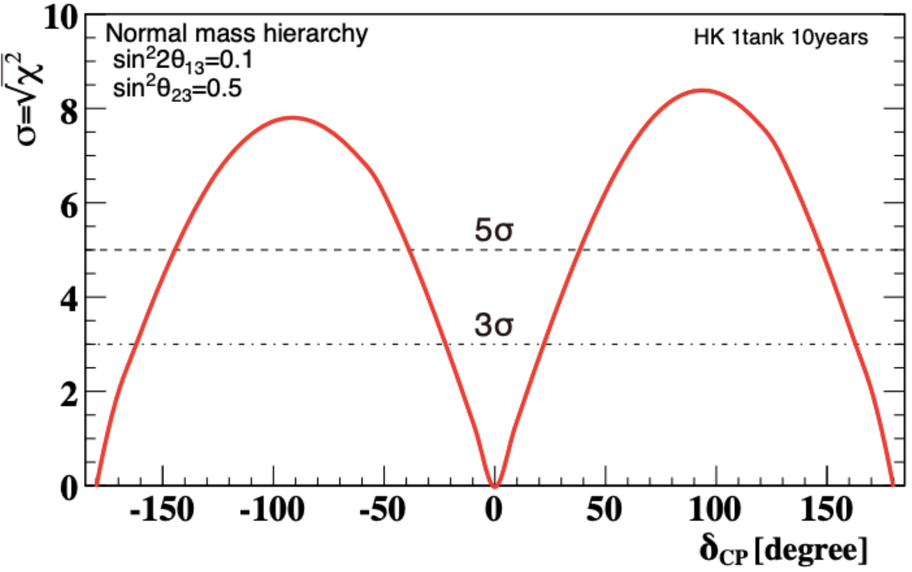
**No clear picture yet**

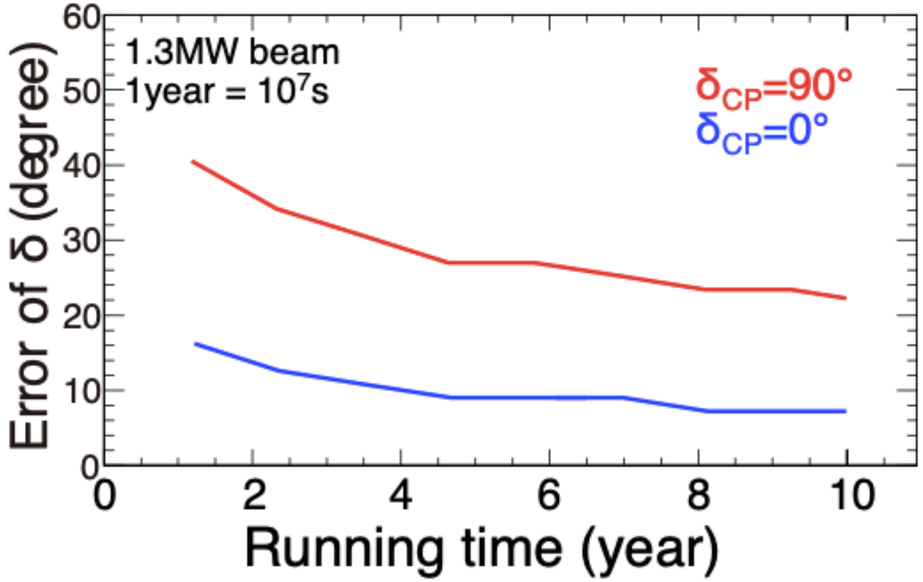
**Hyper-K, 10 years operation**



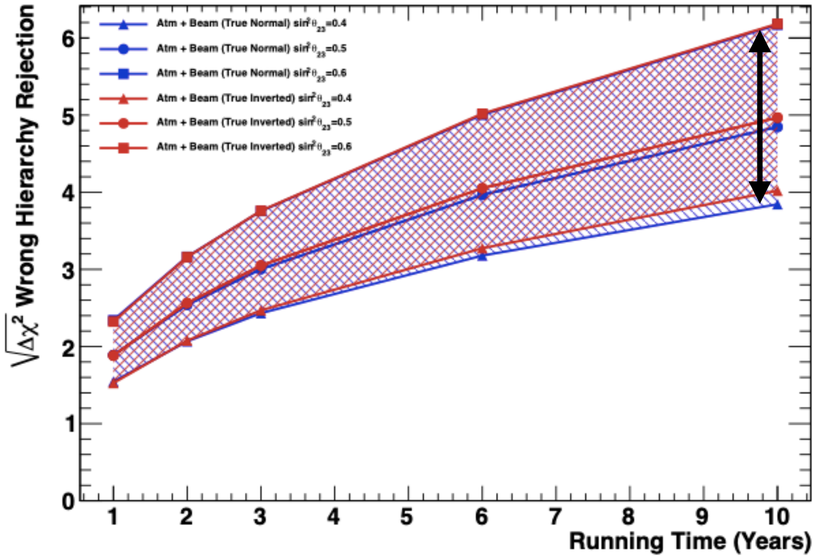

- Statistical errors on asymmetry measurement of ~3%
- Systematic error reduction is critical

# Oscillation Sensitivities




- For known mass hierarchy CP violation discovery for:
  - 76% of values at 3σ
  - 57% of values at 5σ
- CP phase can be measured with 7-20 degree precision
- 4σ sensitivity to mass hierarchy with atmospheric neutrinos

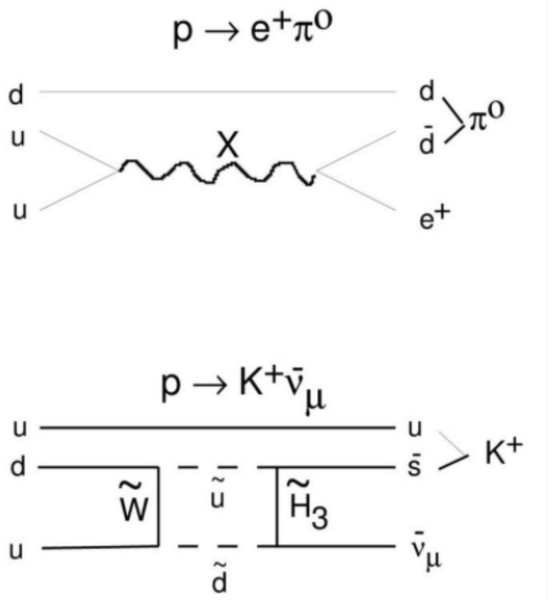


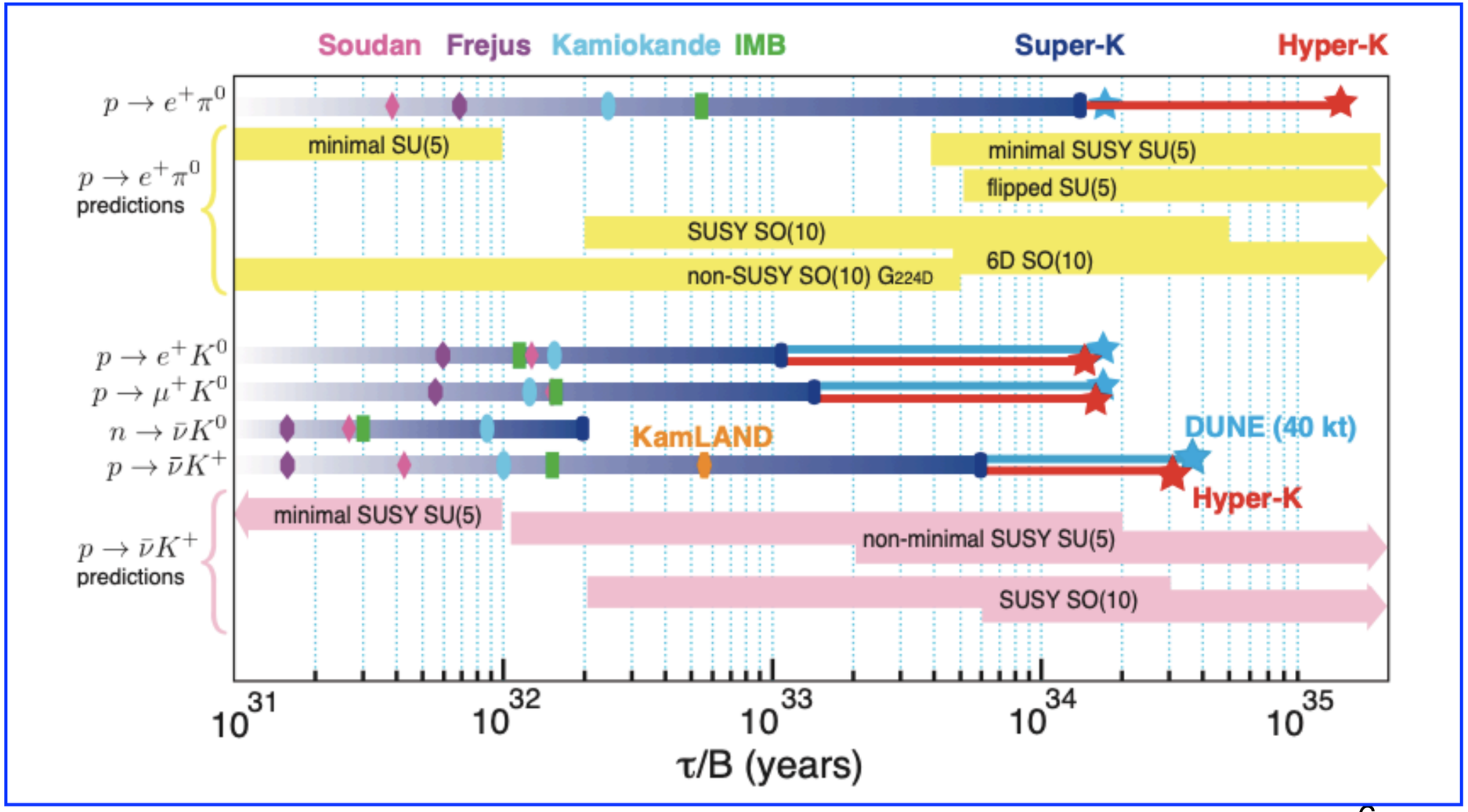

True $\theta_{23}$ value

# Proton Decay

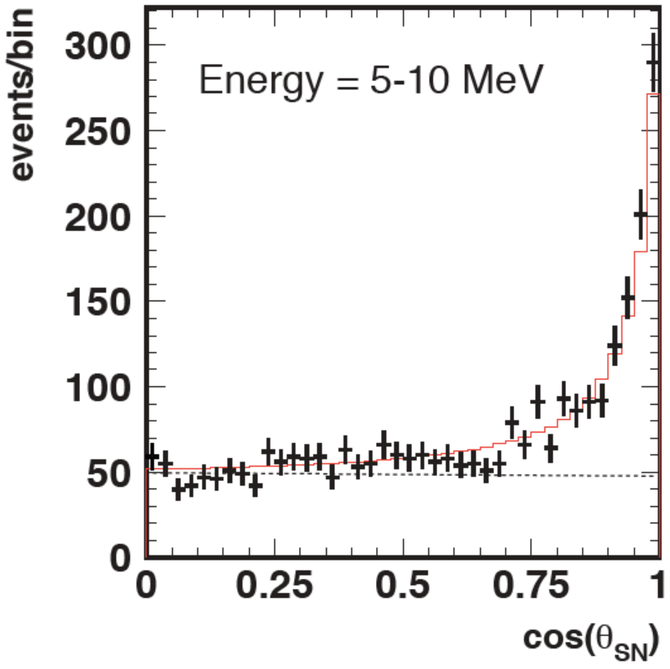
Hyper-Kamiokande

GUT theories unify quarks and leptons → predict proton (nucleon) decay

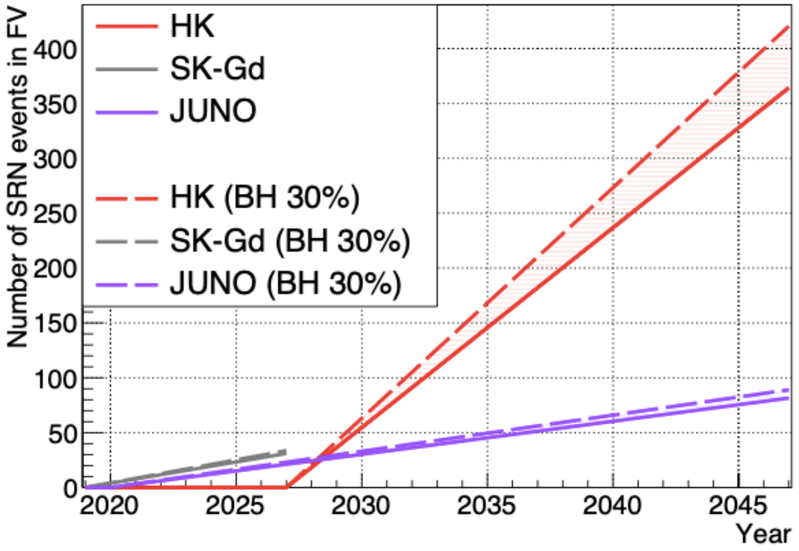


# Supernova Neutrinos

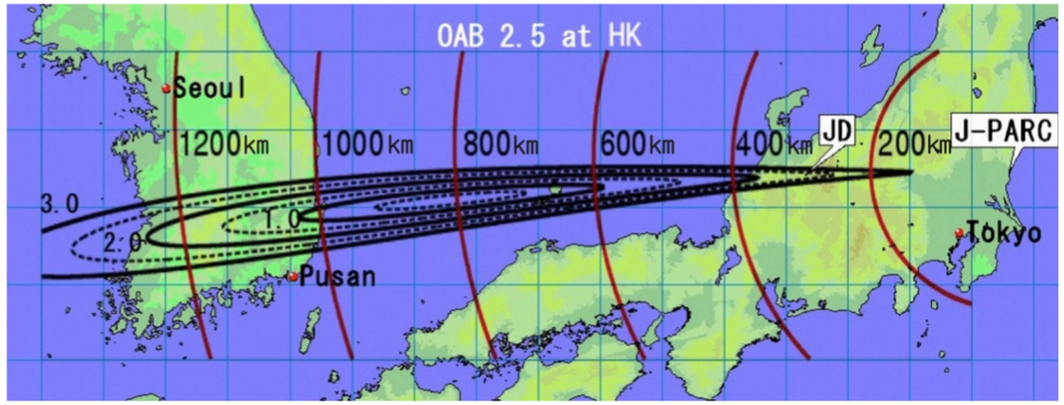


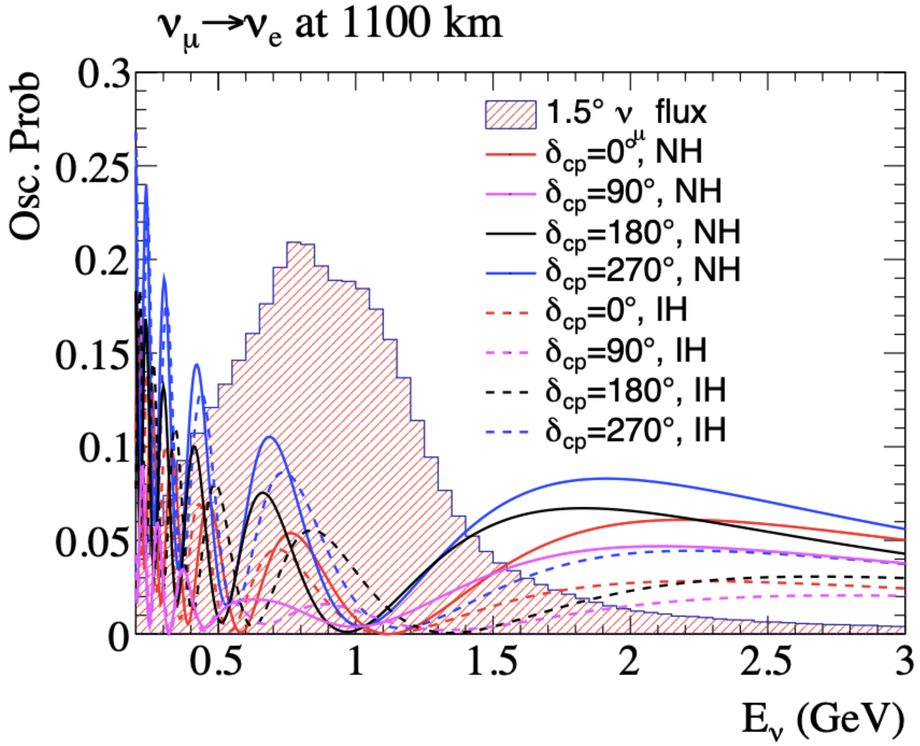

- 54k-90k events for 10 kpc distant supernova
- ~10 neutrino events for supernova in Andromeda
- Neutrino-electron scattering introduces pointing capability
- 1.0-1.3 degree accuracy for 10 kpc distant supernova




- There is a background of supernova neutrinos from all past supernovas
- Probes history of heavy element synthesis in stars

# Detector in Korea




- Opportunity to extend HK program with second detector in Korea
- Korean Neutrino Observatory (KNO) organization formed to develop this option
- Study **neutrino oscillations at the second oscillation maximum**
- **Deeper site than HK (~2700 m.w.e)**
- New large scale water Cherenkov detector
  - **Opportunity for development and application of new technologies**

**PTEP 063C01, 2018**

# Hyper-K Canada

Hyper-Kamiokande

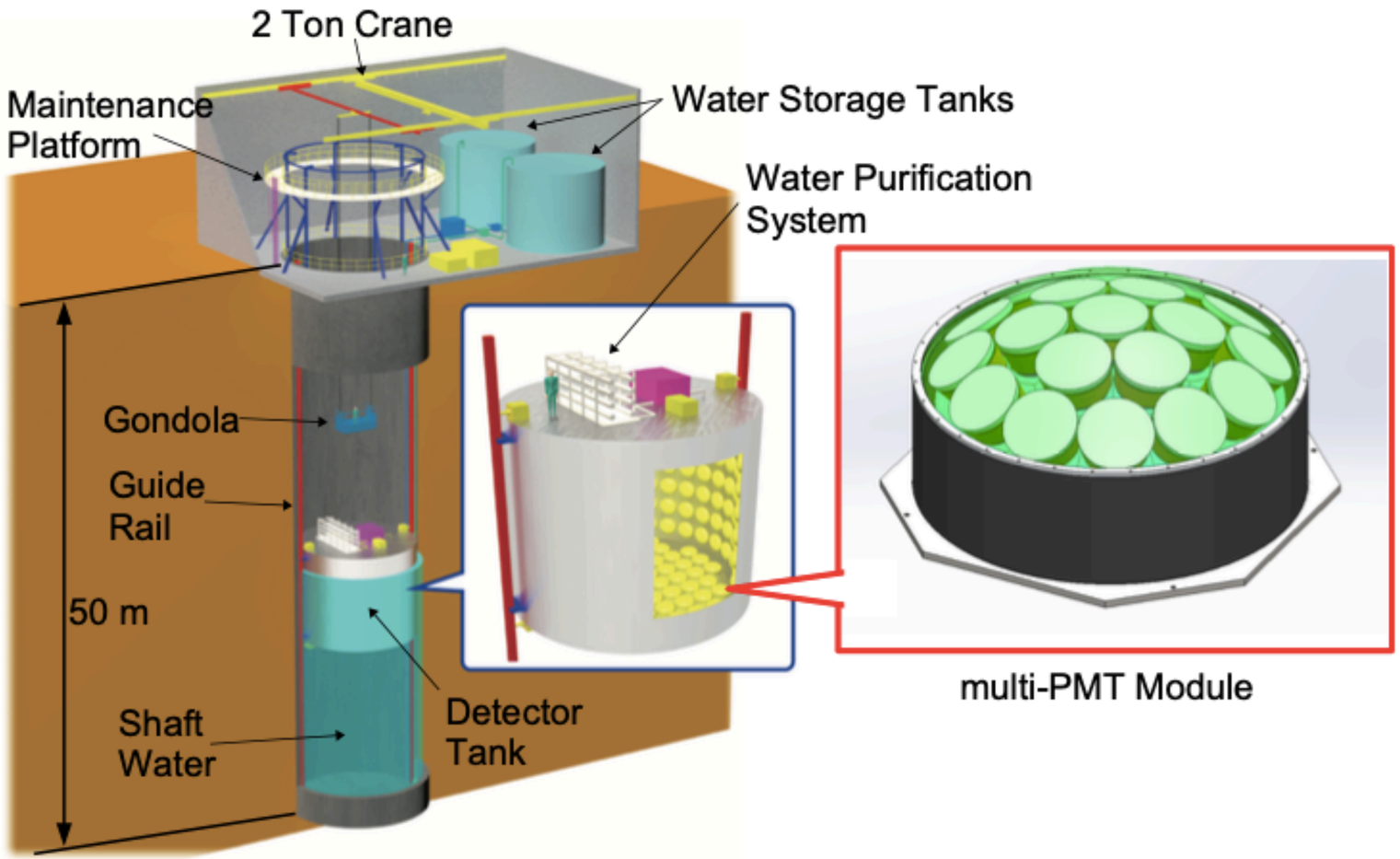
**Hyper-K Canada Collaboration**


- Hyper-K Canada group is formed at 8 institutes - room for growth!
- PIs: M. Barbi, S. Bhadra, P. de Perio, R. Gornea, M. Hartz, B. Jamieson, D. Karlen, N. Kolev, A. Konaka, T. Lindner, J. Martin, B. Pointon
- **4 postdocs (and growing), 6 graduate students (and growing), ~10 undergraduates per year (coop, CAPSTONE, senior thesis)**
- Currently funded through joint T2K+HK NSERC Discovery grant
- Research highlights on following slides

# Canadian Contribution: IWCD (NuPRISM)

Hyper-Kamiokande

- Intermediate detector for Hyper-K
- Located about 750 m from neutrino source
- 600 ton water Cherenkov detector
- Position can be moved to different off-axis angles
- Loading with Gd to enhance neutron detection
- Using new high resolution multi-PMT modules inspired by KM3NeT
- **Project conceived and led by Canadian institutes**



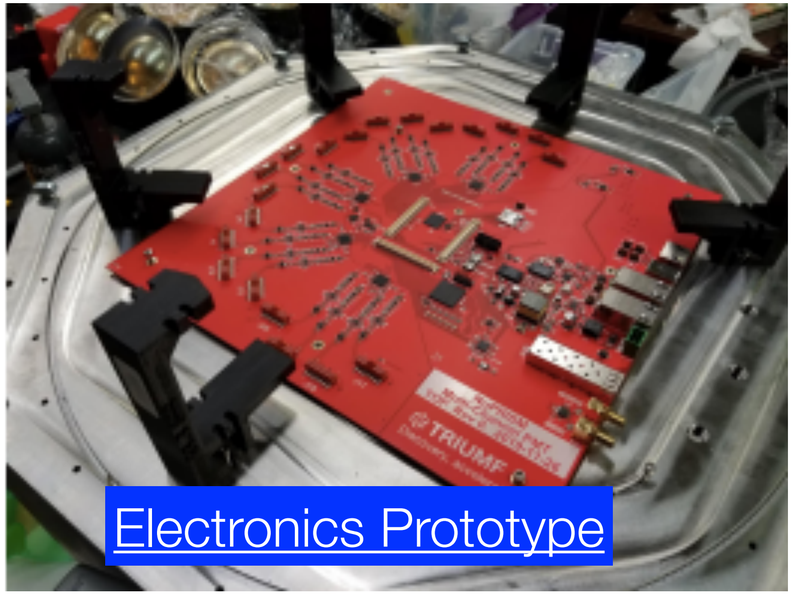

**Approved Hyper-K project includes IWCD**

**Stage-1 approval at J-PARC as E61**

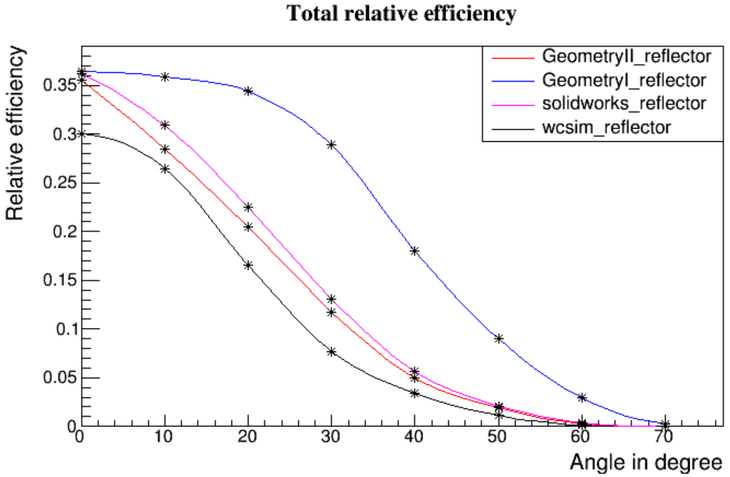
**https://j-parc.jp/researcher/Hadron/en/pac_1507/pdf/P61_2015-5.pdf**

# Multi-PMT (mPMT) Photosensor

mPMT prototype (Ashley Ferreira, TRIUMF Coop from Waterloo)



Electronics Prototype




Reflector optimization study
Purvaja Karthikeyan
(UVic Grad. Student)

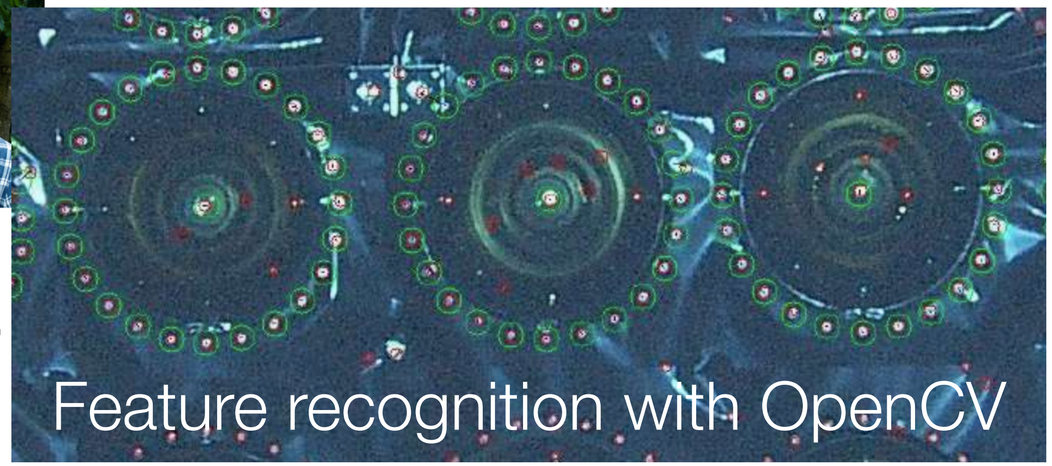
- 19 3-inch diameter PMTs integrated in module with high voltage and readout electronics
- Improved spatial and timing resolution for IWCD
- Considered as a photodetector for Hyper-K detector as well
- TRIUMF support for development, MRS support at Carleton, UVic, Univ. of Winnipeg
- **2020 CFI-IF submitted to build 250 modules for IWCD**
- **Consider future CFI-IF to build ~1000 for Hyper-K**

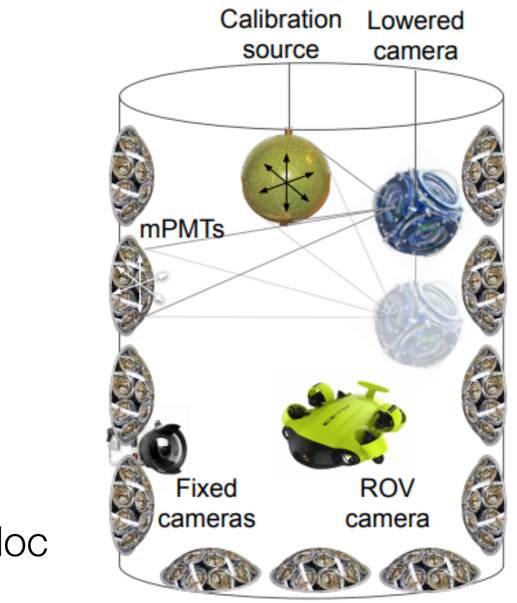
# Calibration

- IWCD and Hyper-K require precise position, energy, efficiency calibration
- **Hyper-K Canada leading photogrammetry system:**
  - Fixed cameras and remote operated submersible take pictures of the tank interior
  - Software able to build an accurate 3-D model of the detector
- Collaboration on Super-K: large scale deployment before Hyper-K



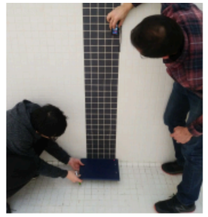
Tapendra BC & Michael Sekatchev, UofW and UBC undergrads

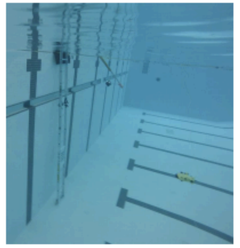


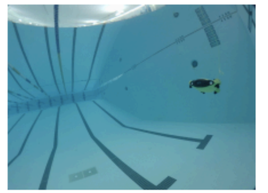



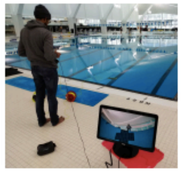

Former TRIUMF Postdoc Saul Cuen-Rochin (now faculty)

TRIUMF Postdoc Nick Prouse







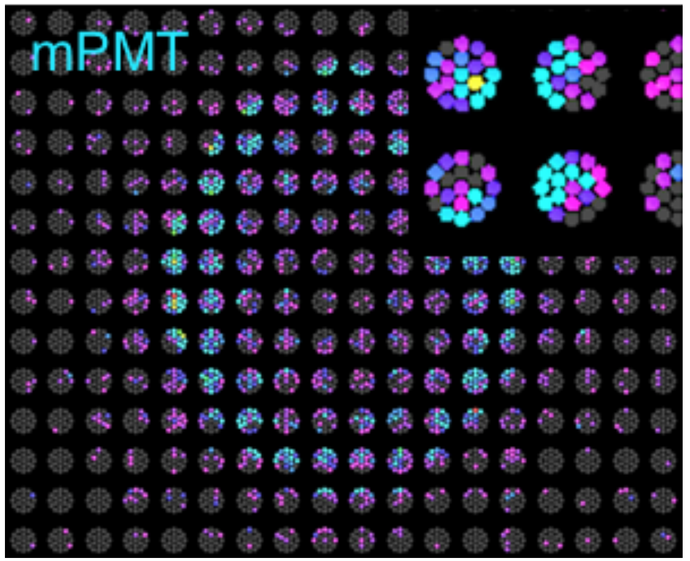


Testing at UBC Pool

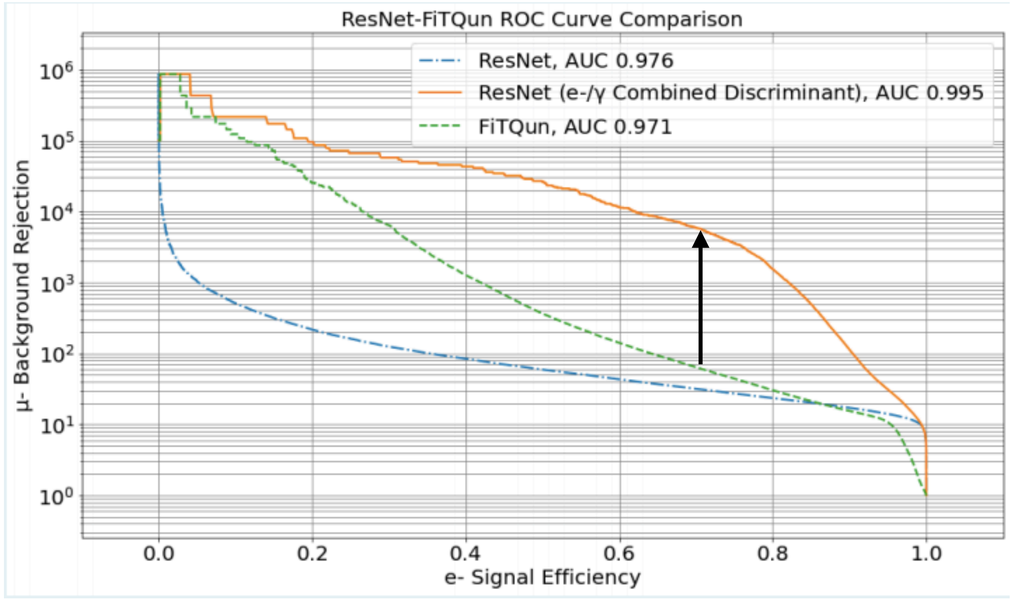
UBC CAPSTONE Students

# Machine Learning

- Improvements to water Cherenkov detectors → take advantage of additional/more precise data
- Application of machine learning to WC detectors led in Canada
- **Formation of WatChMaL group**
- Topics:
  - Multi-ring reconstruction
  - Multi-interaction reconstruction
  - **Electron/gamma/muon separation**




Tia Tuinstra
TRIUMF coop
(from Waterloo)

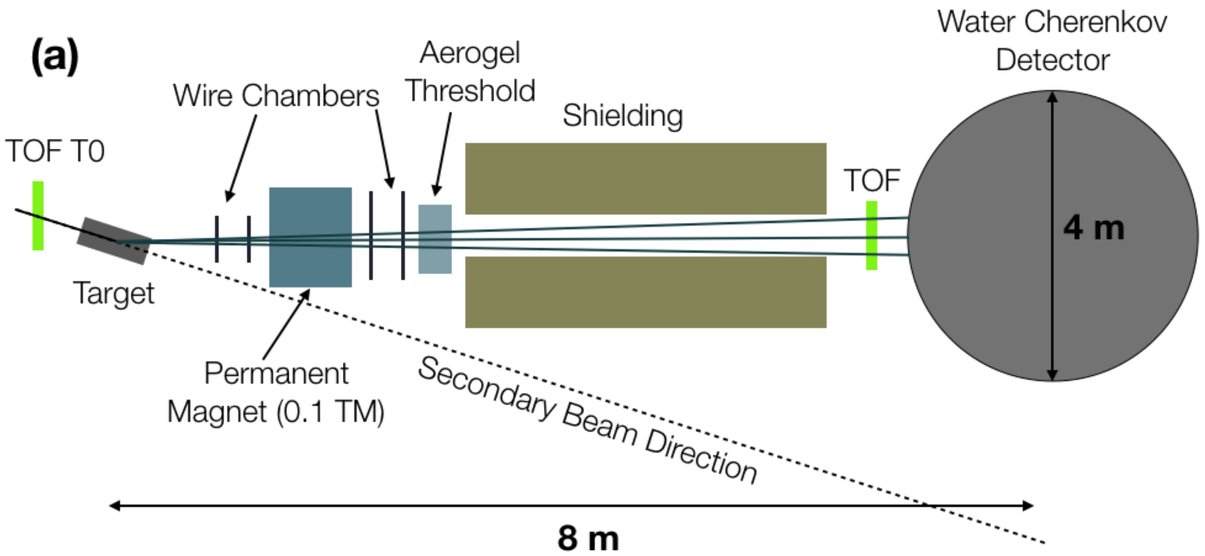


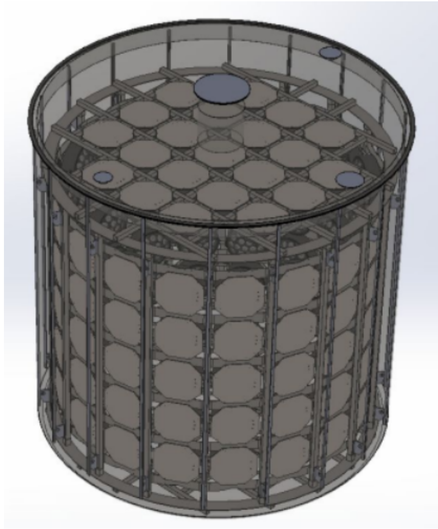

Callum Macdonald
TRIUMF coop
(from UBC)

# Water Cherenkov Test Experiment

- 50-ton scale water Cherenkov detector in particle beam at CERN
- **Platform for testing water Cherenkov hardware, calibration techniques, event reconstruction**
- Initial run focused on Hyper-K/IWCD, but potential for future operation with alternative configurations
- Canadian contribution funded through SAP-RTI
- Conceived and led by Canada

Beam design
Matej Pavin
TRIUMF postdoc



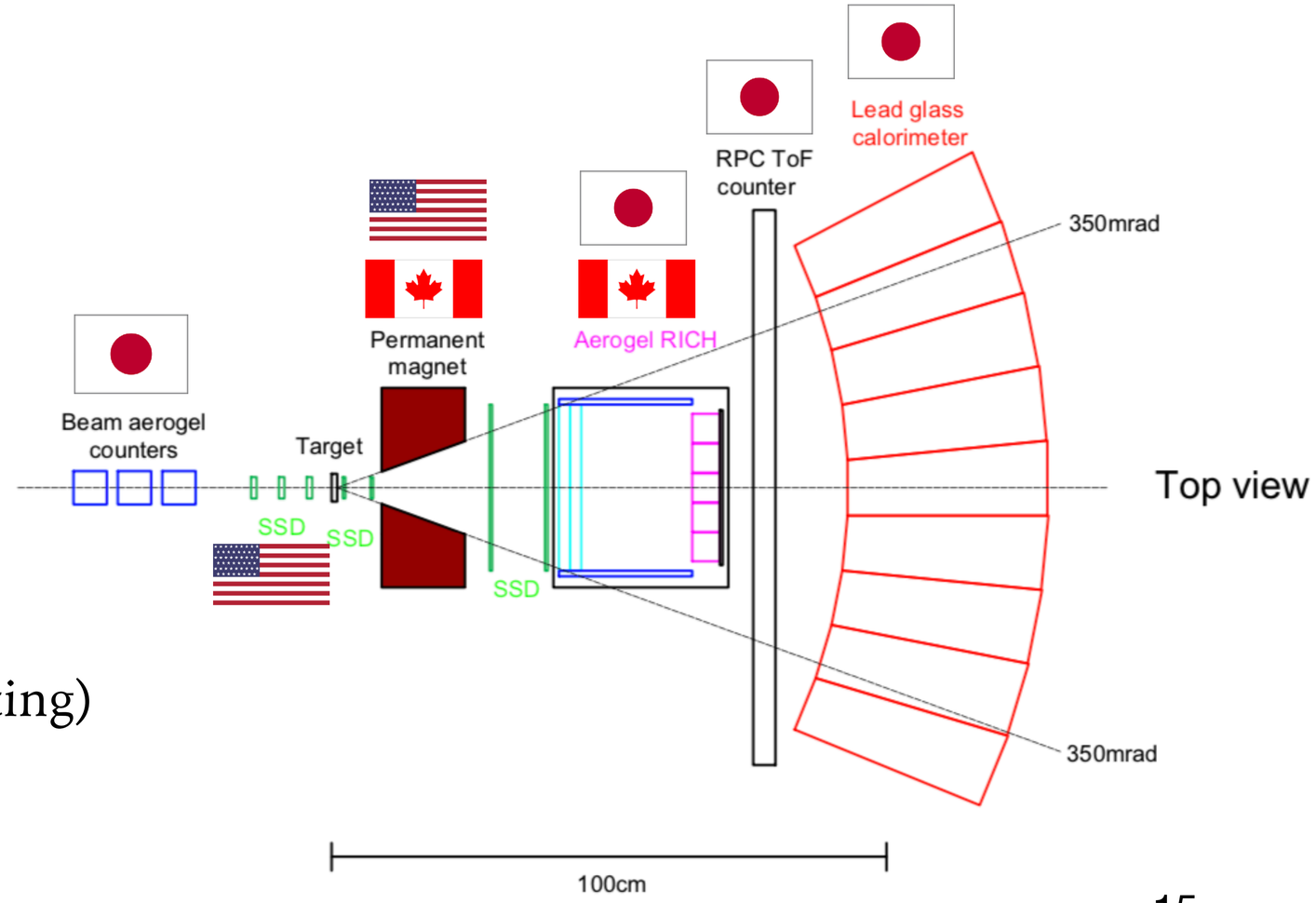
Mechanical Design
Shubham Garode
Visiting from VIIT

Location: CERN East Area

Proposal: CERN-SPSC-2020-005
Planned operation in 2022-2023

# EMPHATIC Experiment

- Table top hadron production experiment - improve neutrino flux simulation
- Unique application of technologies to hadron production measurements
  - Silicon strip tracking layers
  - Halbach array permanent magnet
  - Aerogel ring imaging Cherenkov detector for PID
- Operating in Fermilab MTEST beam line
  - 2018 - Pilot Run
  - 2020 - First Physics run with 100 mrad acceptance (COVID-19 permitting)
  - 2022 - Second physics run with 400 mrad acceptance



# Hyper-K Project Status

- Schedule:
  - 2020 - Approval and start of Hyper-K construction
  - 2022 - Operation of water Cherenkov test experiment at CERN
  - 2023 - Start of IWCD facility construction
  - 2025 - Hyper-K and IWCD detector assembly/installation
  - 2027 - Start of Hyper-K operation
- While project is advancing to construction, many areas where new contributions can be made:
  - Water system
  - Radon free air
  - Calibration
  - Beam line monitoring and maintenance
  - …

# Hyper-K Construction

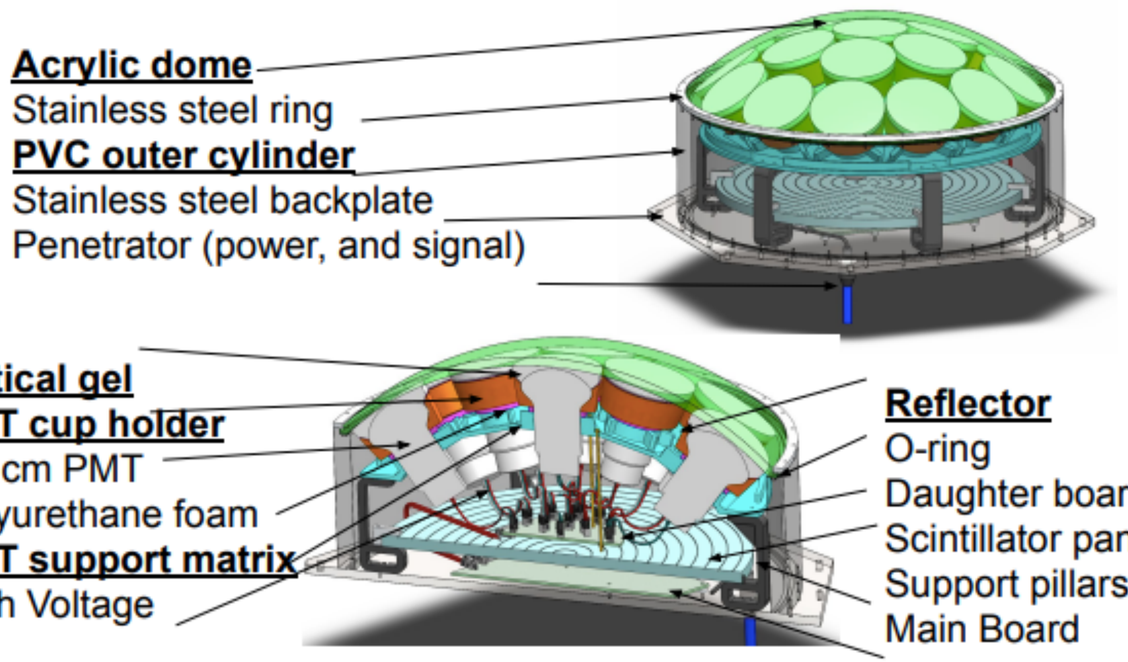
Construction of the entrance yard is proceeding!

Access tunnel construction to start in FY2021

Access tunnel entrance

# Thank You

# Multi-PMT (mPMT) Photosensor

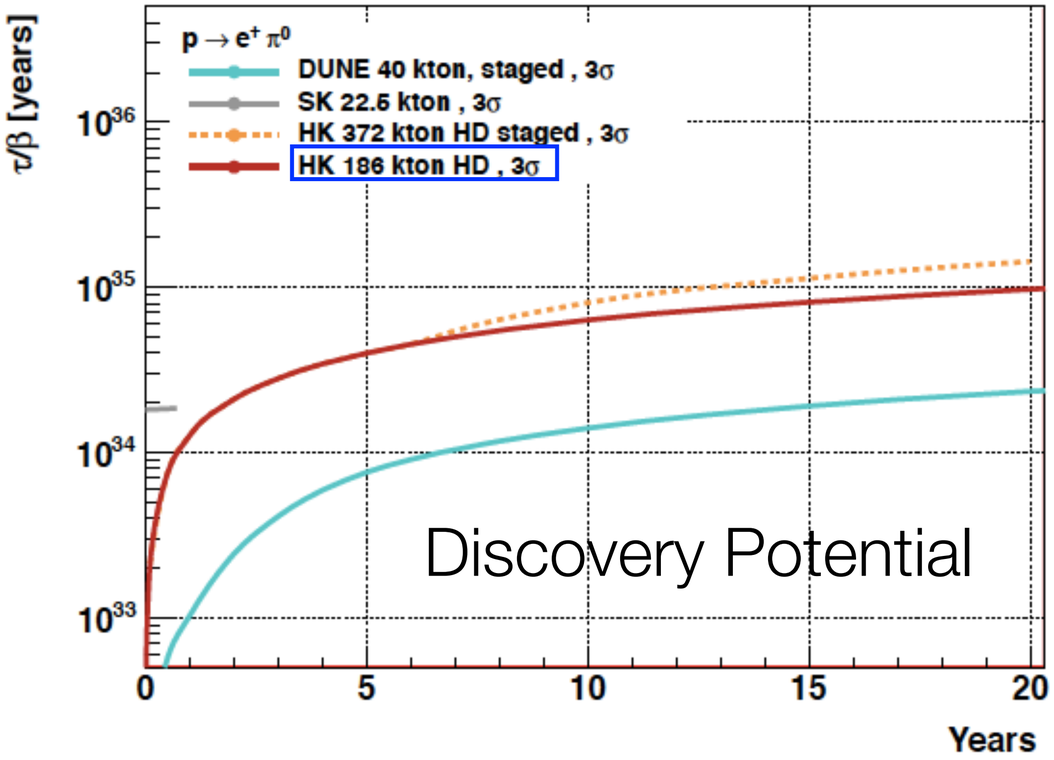




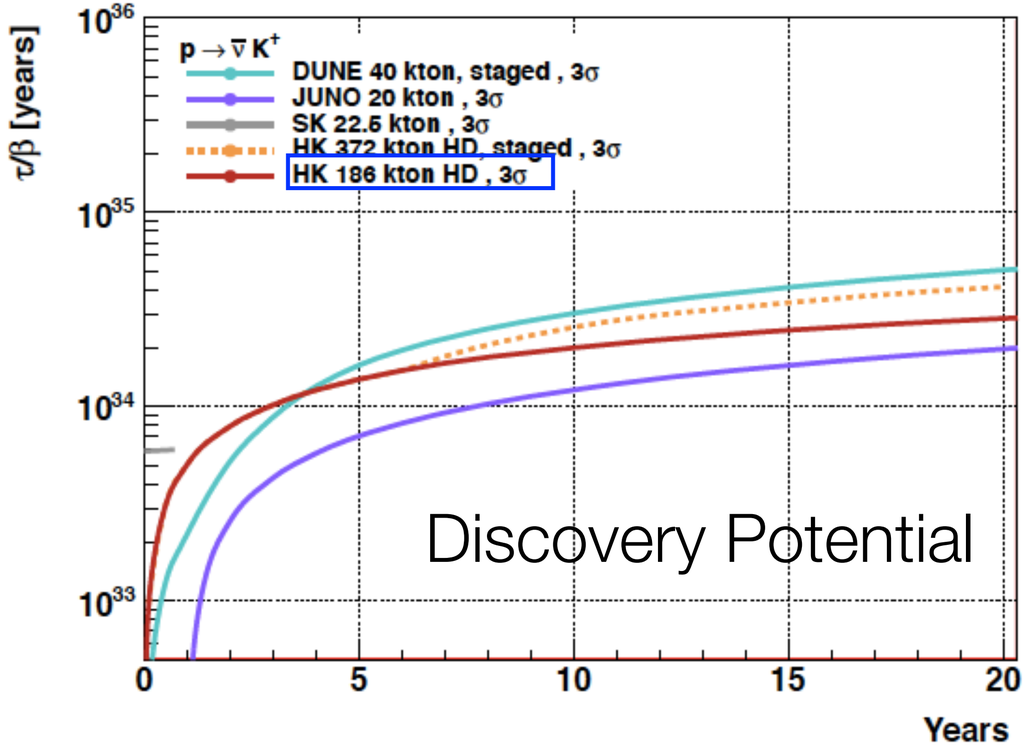
- 19 3-inch diameter PMTs integrated in module with high voltage and readout electronics
- Improved spatial and timing resolution compared to 20-inch PMTs is necessary for detector of IWCD size
- Considered as a photodetector for Hyper-K detector as well
- 2020 CFI-IF submitted to build 250 modules for IWCD
- Future CFI-IF to build ~1000 for Hyper-K planned

# Proton Decay

GUT theories unify quarks and leptons → predict proton (nucleon) decay

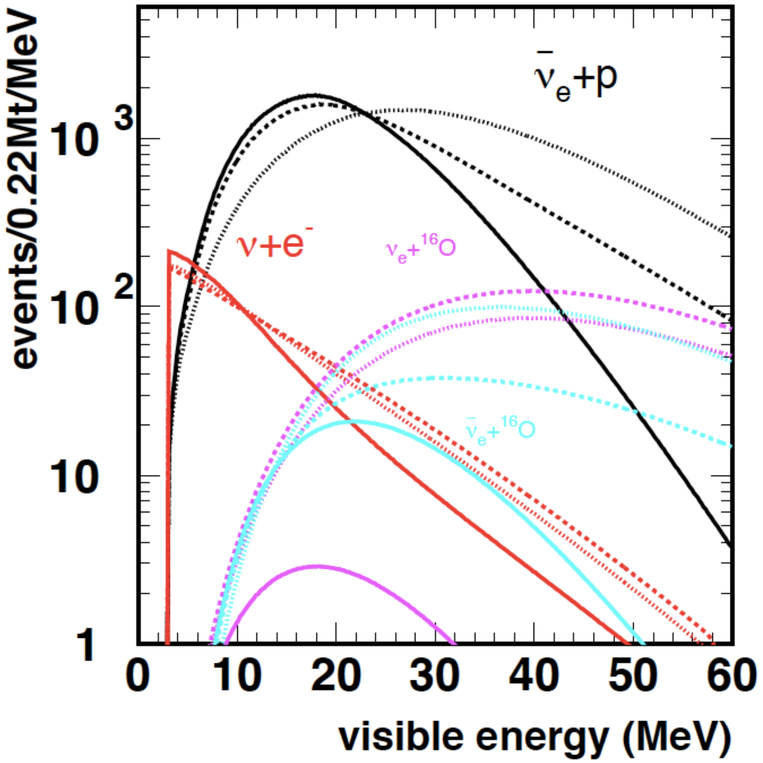



- Hyper-K excels in the $p \rightarrow e^+\pi^0$ channel, very high efficiency
- Largest fiducial mass

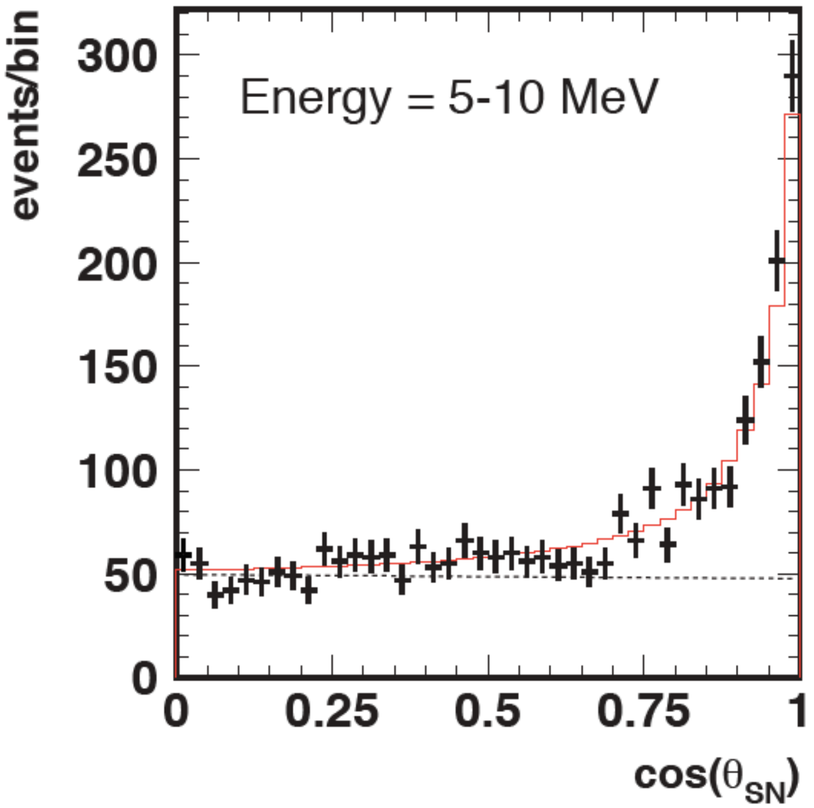



- Hyper-K is competitive $p \rightarrow \nu K^+$ channel, very high efficiency
- DUNE has potential for better efficiency since kaon is visible

# Supernova Burst Neutrino



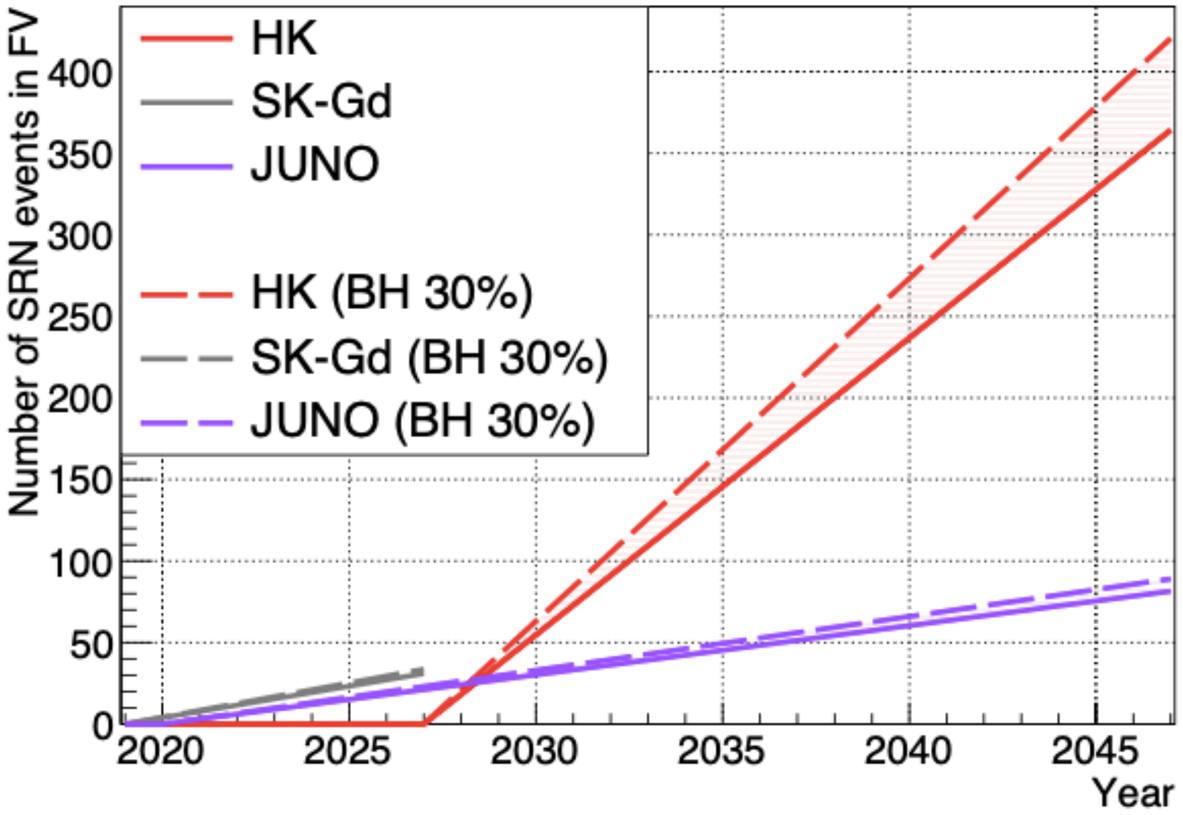

- Inverse beta decay and neutrino-electron scattering channels
- 54k-90k events for 10 kpc distant supernova
- ~10 neutrino events for supernova in Andromeda

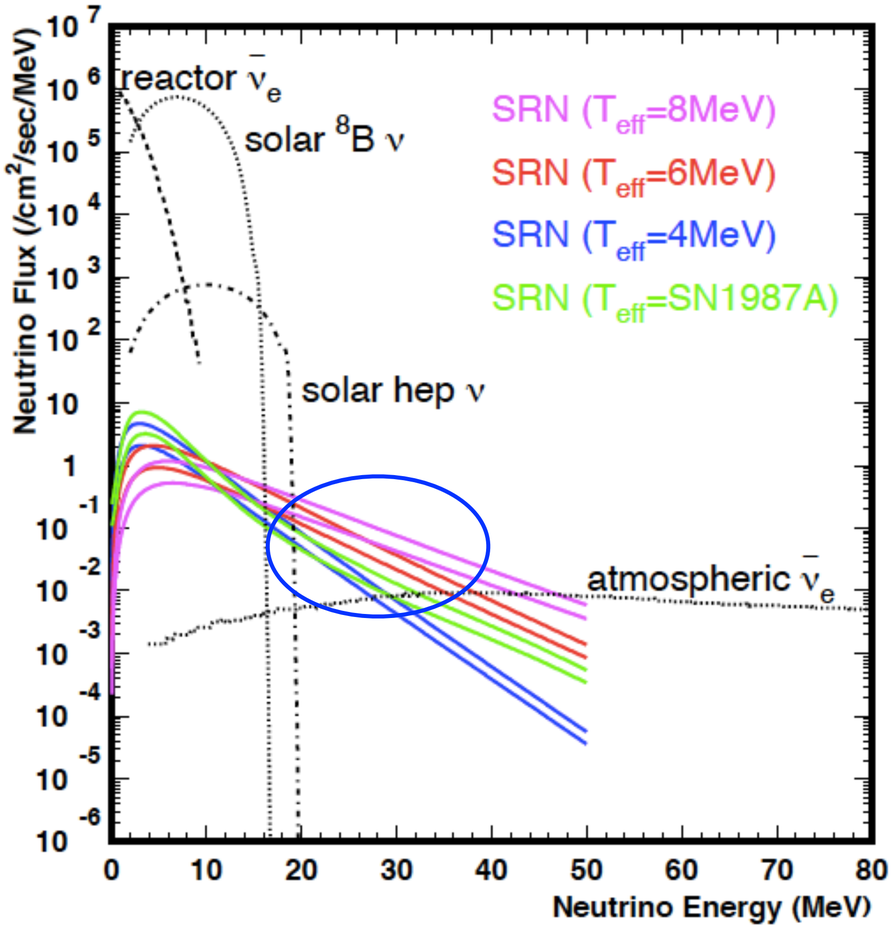



- Neutrino-electron scattering introduces pointing capability
- 1.0-1.3 degree accuracy for 10 kpc distant supernova

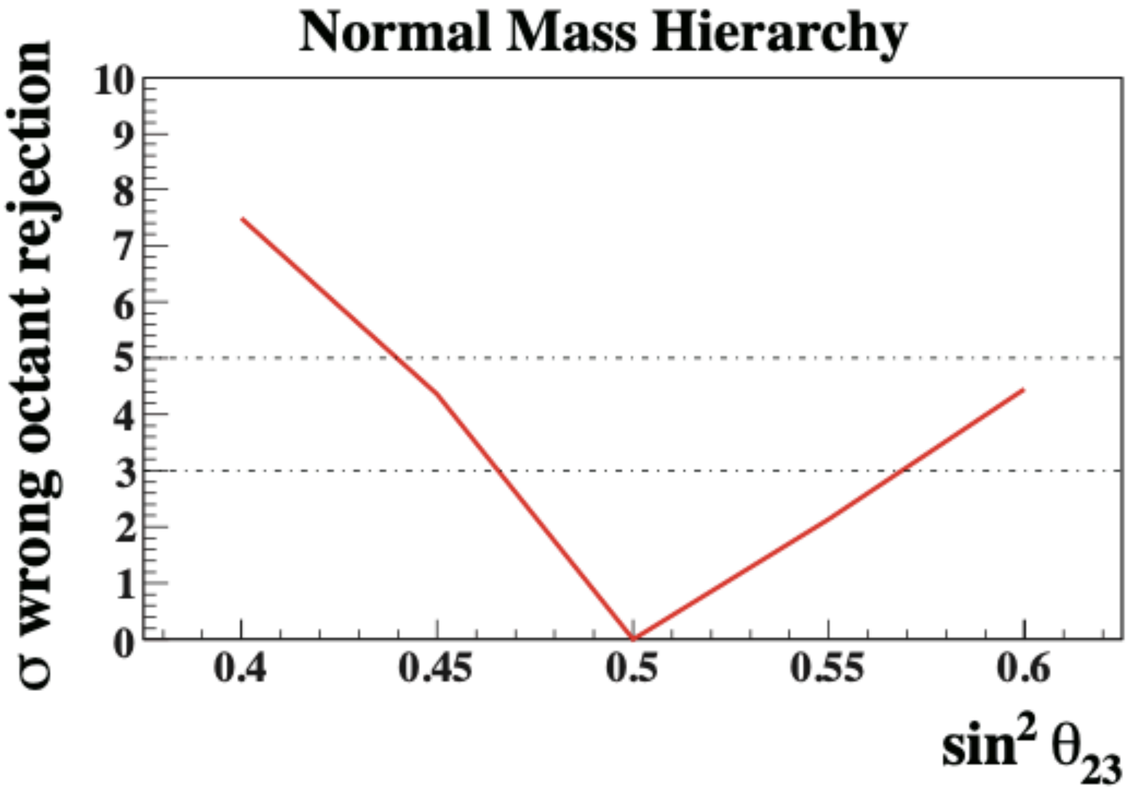
# Relic Supernova Neutrinos

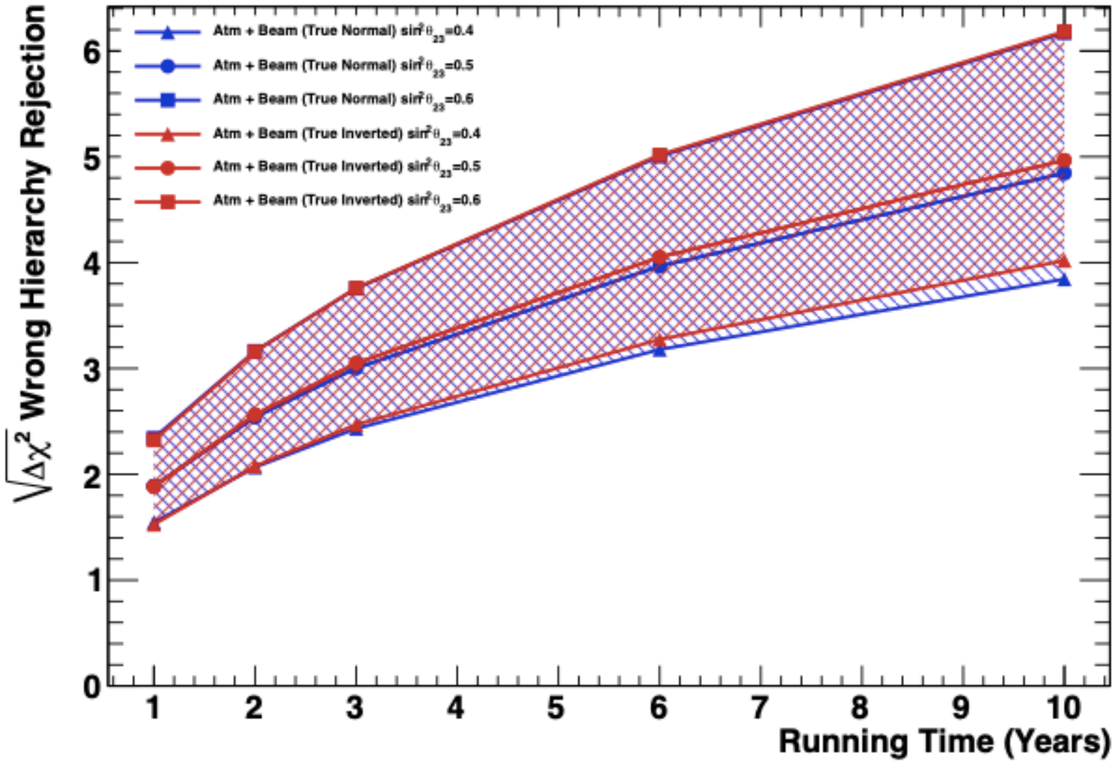
- There is a background of supernova neutrinos from all past supernovas
- Can learn about the history of heavy element synthesis in stars



# Other Oscillation Parameters




- Determine if $\theta_{23}$ mixing angle is <, > or consistent with 45° (symmetry?)
- Combination of atmospheric and accelerator neutrinos gives >4σ wrong mass ordering rejection