Overview of Large Volume Neutrino Experiments

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KPS DPF 2021 Annual Meeting

Thank Prof. Siyeon Kim, Prof. Carsten Rott and Prof. Jik Lee for providing slides

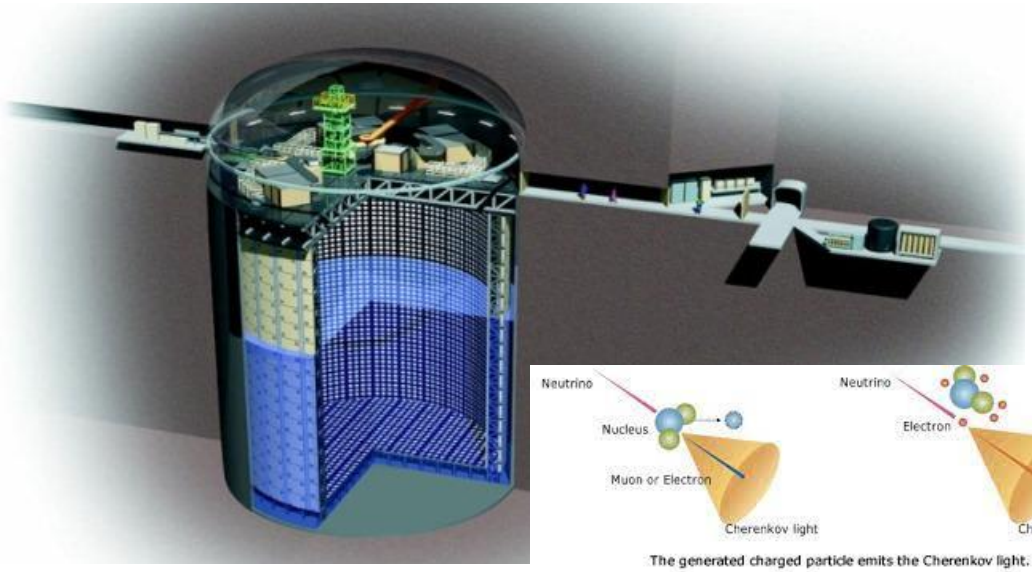
Part I.
Ongoing Experiments

Super-Kamiokande

IceCube

Super-Kamiokande Experiment

☐ Overview



- Large Water Cherenkov Detector (1996 ~ Present)
  → 50kton of pure water
  → 13,000 PMTs
  → 39m(D) X 42m(H)
  → detect neutrinos with an energy range of 5 MeV~ 10 GeV using Cherenkov radiation

- Discovery of Neutrino Oscillations (2015 Nobel Prize)

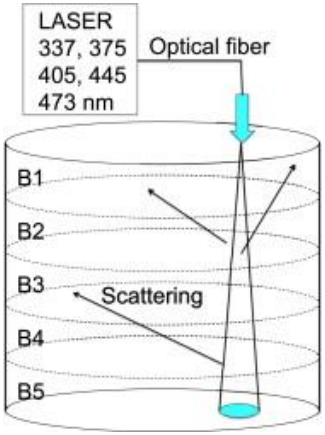
- Data Taking Periods (SK-I, II, III, IV, V, VI)
- Gd-loading (0.01%) between June 2020 and August 2020
  → Neutrons captured by Gd produce gammas (SN neutrinos, Proton decay..)
  → Additional Gd-loading (0.03%) is planned in 2022

Super-Kamiokande Experiment

☐ Status of Korea SK group

- Participating in SK since 1998
- 5 institutions (SNU, CNU, GIST, SKKU, IBS)
- Measurement of Water Parameters using Korean Laser Calibration system
- Researches on Solar Neutrinos (SNU) and Proton decays (SKKU) in progress

☐ Laser Calibration System



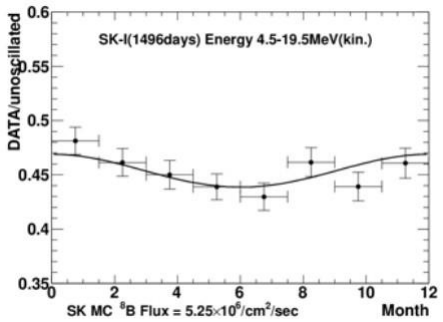
- Calibration of water parameters using laser injector system

  → water parameters (attenuation length, etc) are important in neutrino reconstruction
- Measurement of water parameters in 5 wavelengths
- Results are applied to Monte Carlo tuning

Super-Kamiokande Experiment

☐ Solar Neutrino Analysis

- Measurement of Seasonal Variations of Solar Neutrinos
- Seasonal Variations due to orbital motion and MSW effect
- Ph. D thesis analysis (SNU)
- Analysis of SK-I, II, III, IV data in progress



☐ Search for Proton Decays

- Search for $p \rightarrow e^+\pi^0\pi^0$

  → Current limit: 1.5×10^{32} years (IMB)
- Final state: eγγγγ (5 ring events)
- Data analysis of SK-I,II,III,IV in progress

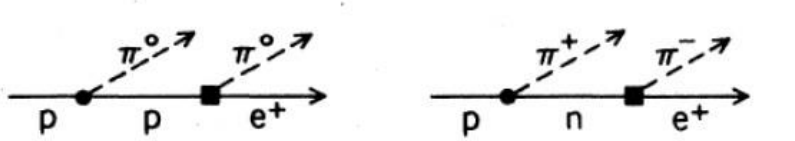
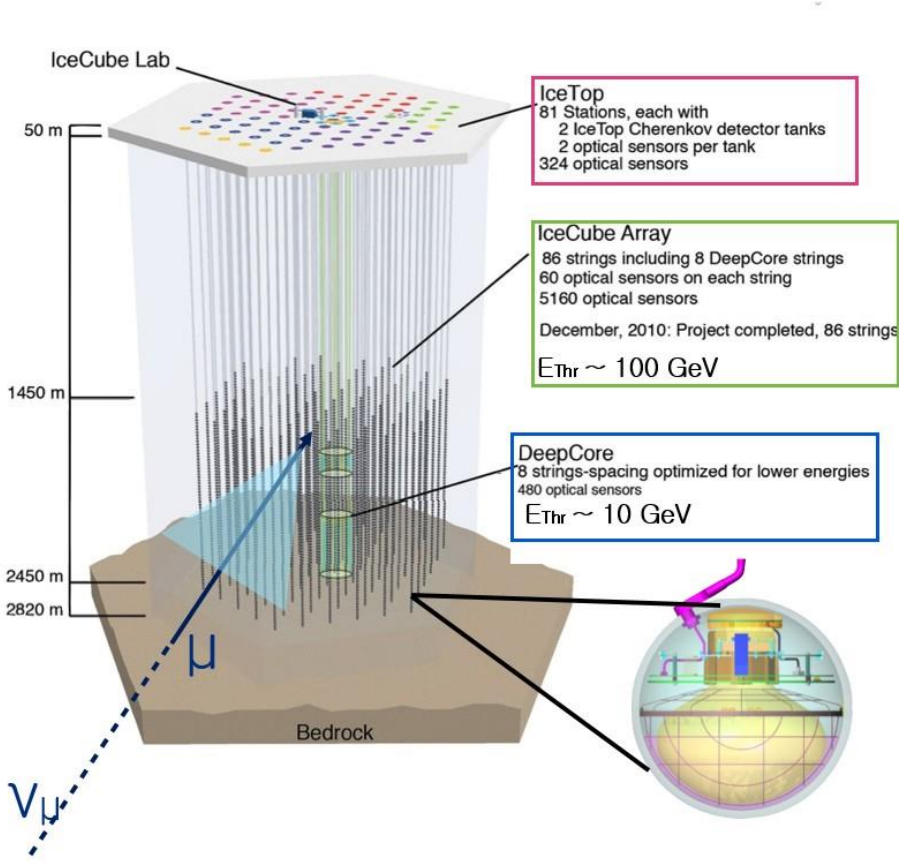


FIG. 1. Born or pole diagrams contributing to $p \rightarrow \pi\pi e^+$.

IceCube Experiment

☐ Overview



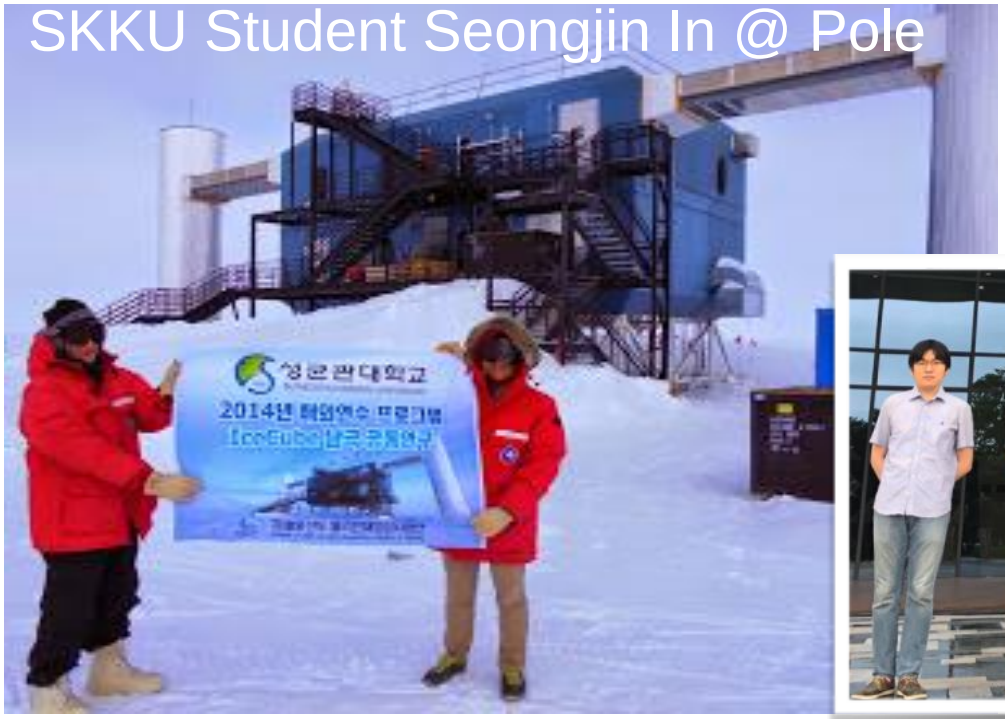
- Ice Cherenkov Detector at South Pole (2005 ~ Present)
  → Gigaton of Ice as medium
  → 5160 optical Modules (86 strings)
  → detect neutrinos with an energy range of 10 GeV~PeV using Cherenkov radiation
  → IceCube Upgrades (2022~23)
  → IceCube Gen2 (2026~)

- ~300 Collaborators from 54 Institutions (12 Countries)
- Discovery of High Energy Extragalactic Neutrinos (2018)

IceCube Experiment

☐ Status of Korea IceCube group

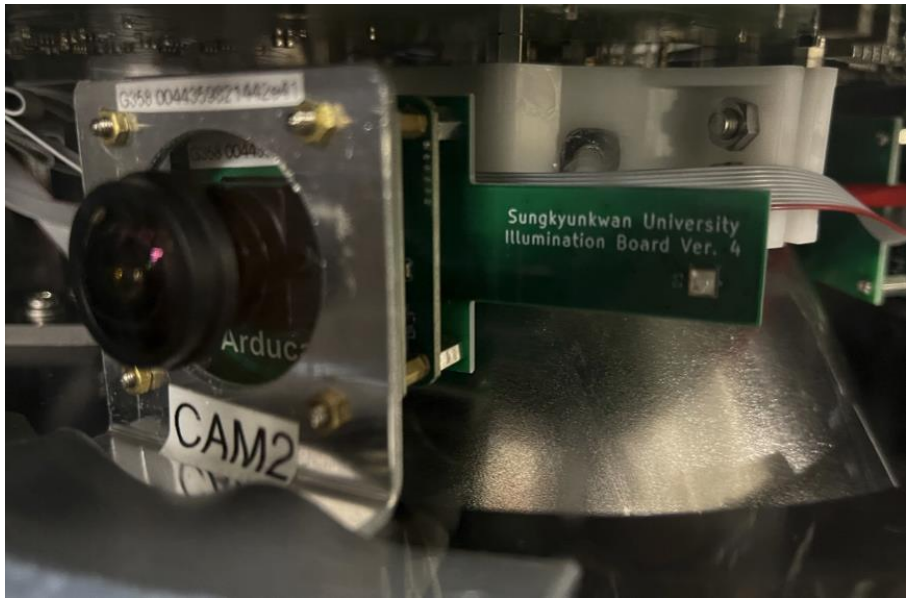
- SKKU participating in IceCube since 2013
- Development of Korean camera system to measure ice parameters
- Searches for Solar Atmospheric Neutrinos and Dark Matter Annihilation in the Sun

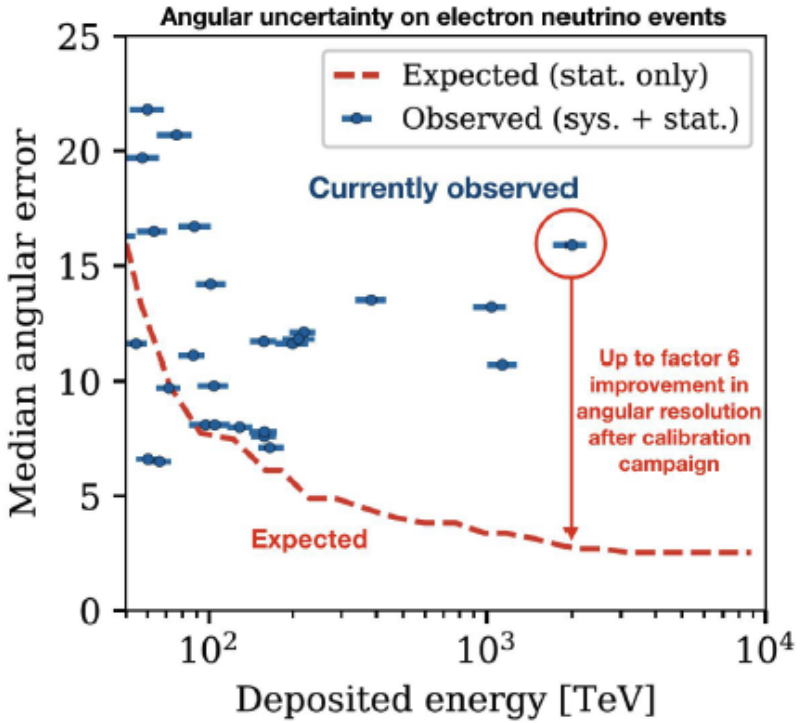


IceCube Experiment

☐ Korean Camera System for IceCube Upgrades

- Camera-based calibration system to precisely measure ice properties
- 2100 camera systems in total to be provided by SKKU
- 1200 systems were produced and shipped for tests

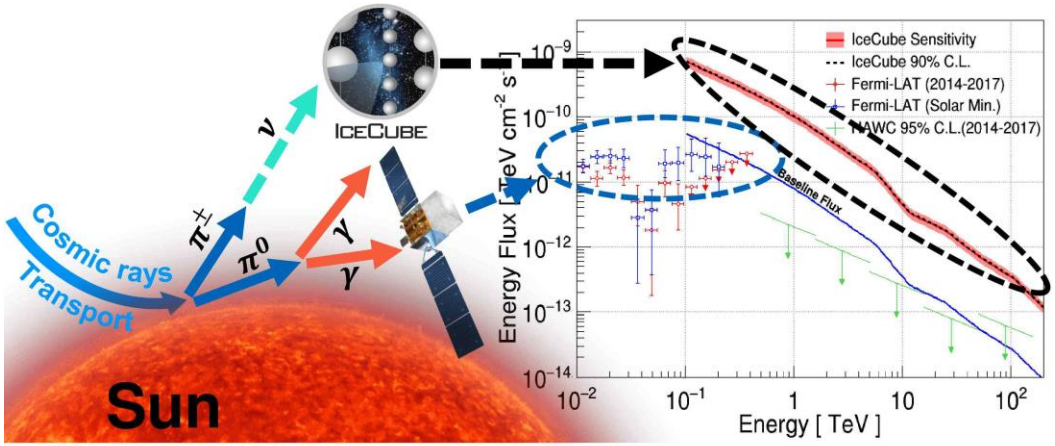


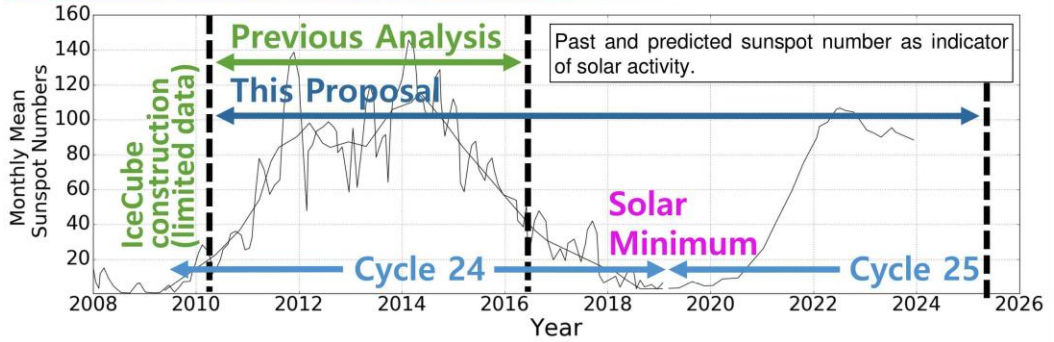


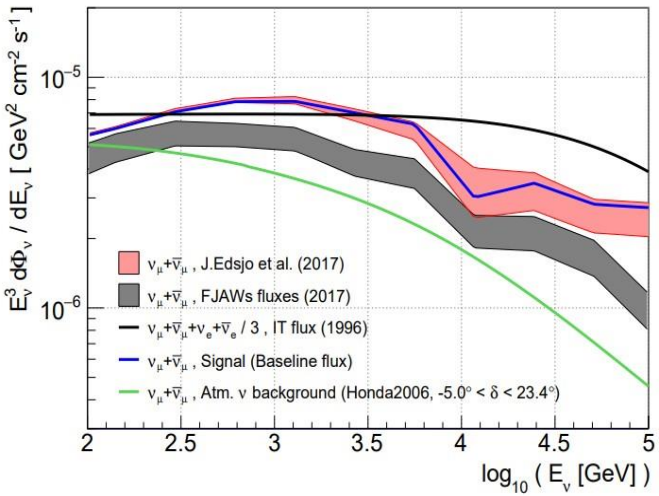
IceCube Experiment

☐ Search for Solar Atmospheric Neutrinos

- Neutrinos from Solar Atmosphere
- Published the first result in 2021 (Ph.D thesis)
- Analysis using 9 year data in progress (factor 4 improvement is expected)



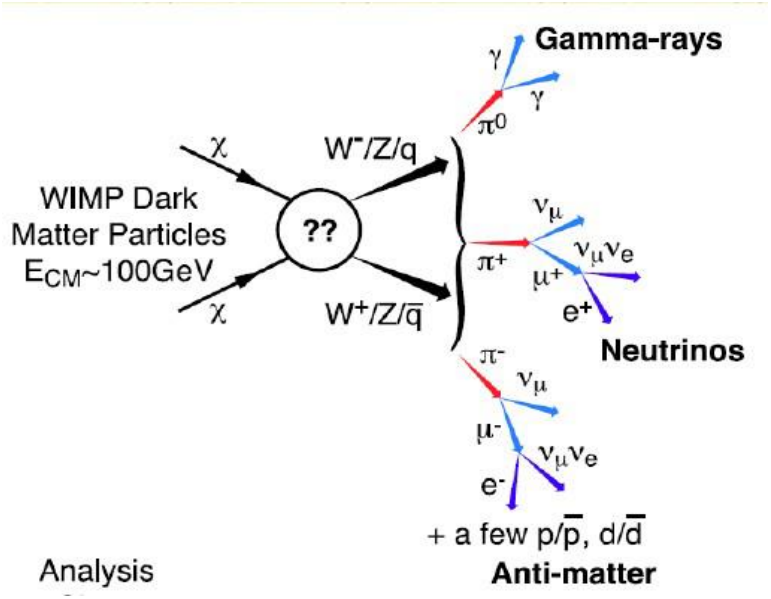


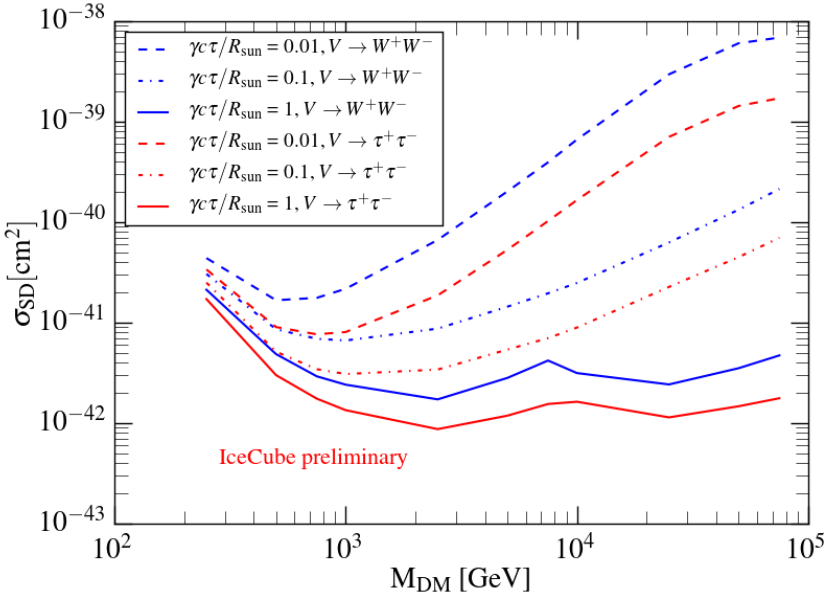


IceCube Experiment

☐ Search for Dark Matter Annihilations in the Sun

- Neutrinos from dark matter annihilations at the center of the Sun
- Dark matter capture/annihilation + neutrino propagation
- Analysis using 9 year data in progress (Ph. D thesis)





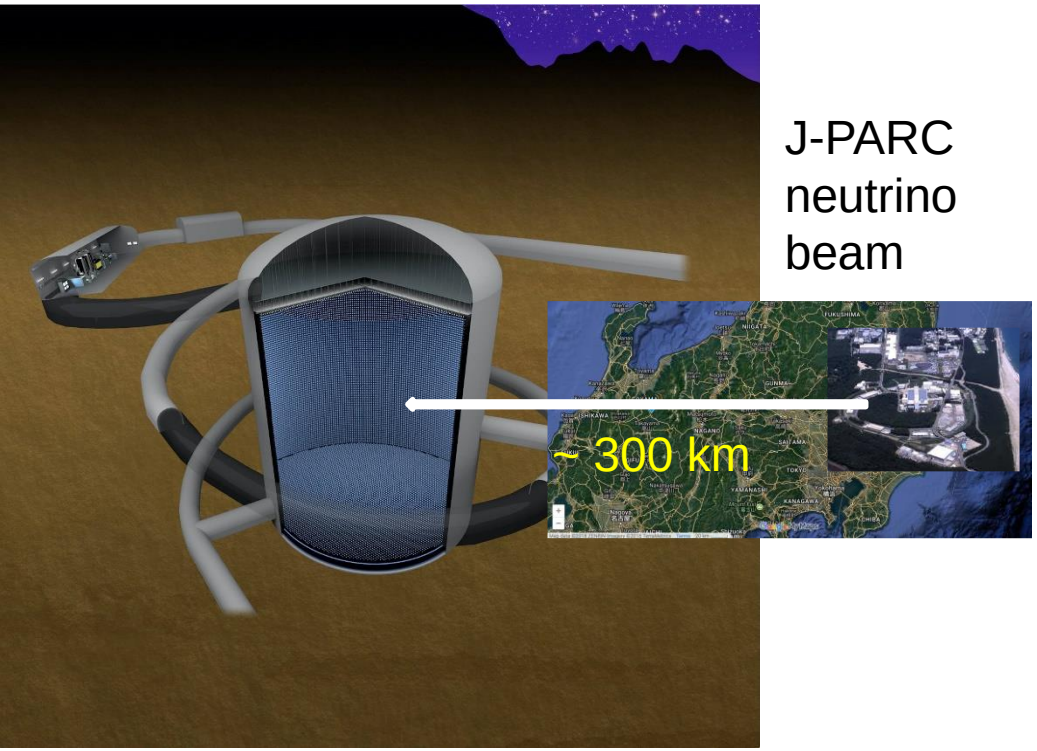
Part II.
Future Experiments

Hyper-Kamiokande

DUNE

Hyper-Kamiokande Experiment

☐ Overview



J-PARC neutrino beam

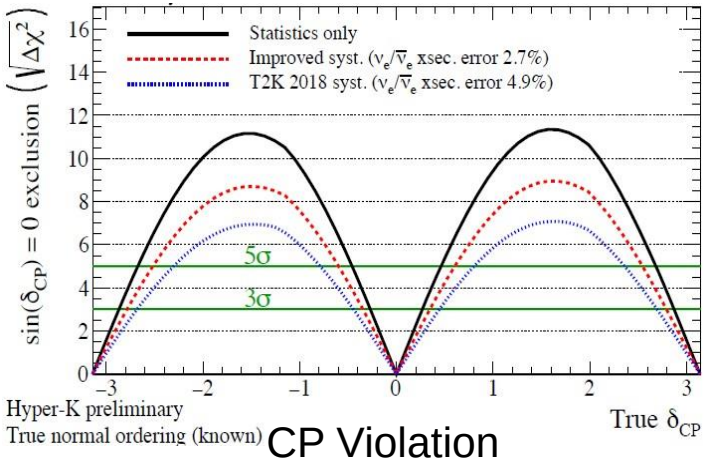
- Next generation Water Cherenkov Detector
  → 260kt of pure water
  → 40,000 PMTs
  → 68m(D) X 71m(H)
  → detect neutrinos with an energy range of 10 MeV~100 GeV using Cherenkov radiation

- Upgrade of J-PARC Neutrino Beam (0.5 MW → 1.3 MW)
- Upgrade of Near Detectors (ND280, IWCD)
- Physics Program: CP Violation, Mass Ordering, Precision Measurement of Neutrino Oscillations, Proton Decays, Neutrino Astrophysics

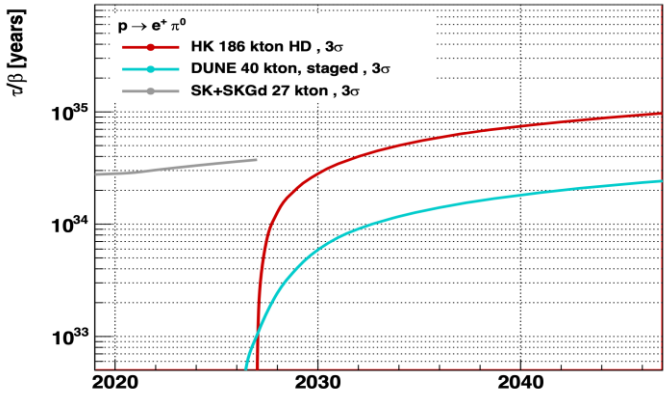
Hyper-Kamiokande Experiment

☐ Physics Goal

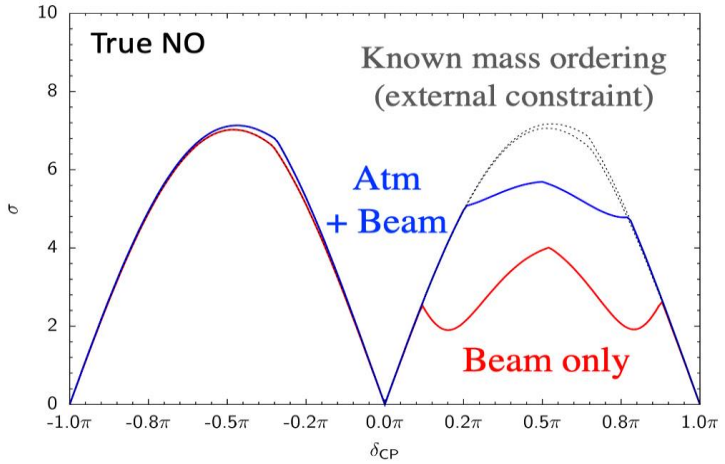
- Projections for 10-year data taking



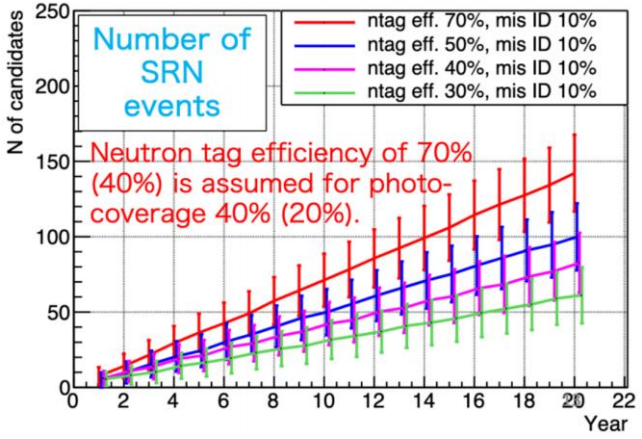
CP Violation



Proton Decay



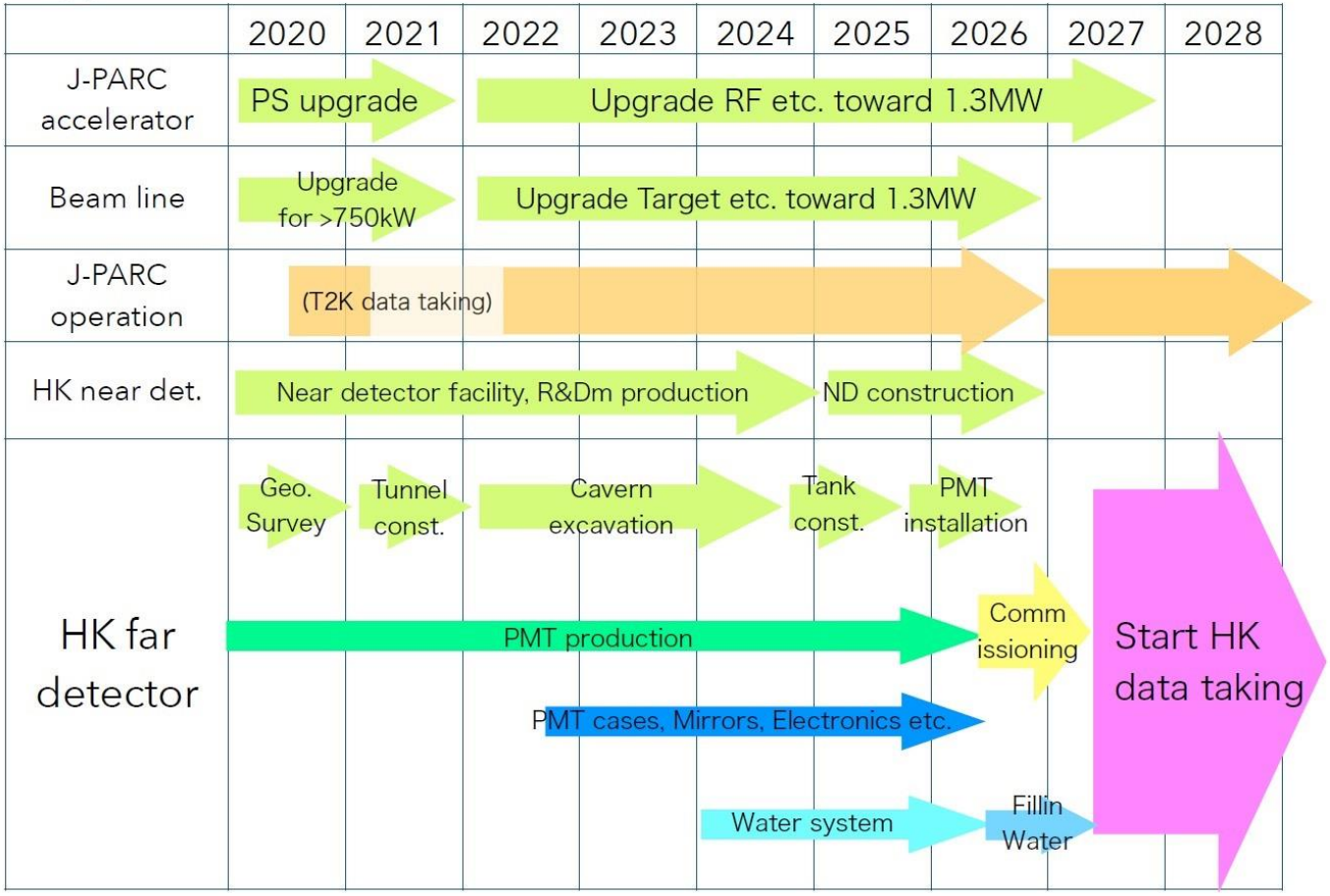
Mass Ordering

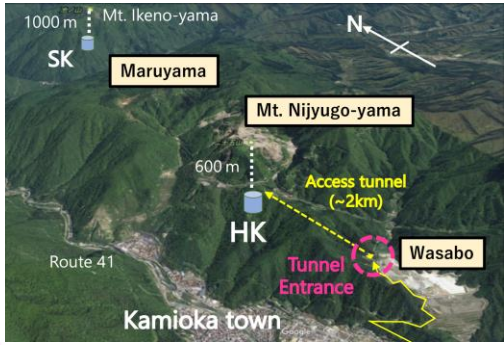


Supernova Relic Neutrino

Hyper-Kamiokande Experiment

☐ Hyper-Kamiokande Schedule





K. Sakashita. NUFACT 2021

Hyper-Kamiokande Experiment

☐ Hyper-Kamiokande (HK) Collaboration

- ~450 collaborators from 93 institutions (19 countries)

Collaborating Institutes

Europe	260 members
Armenia	3
Czech	3
France	28
Germany	1
Italy	53
Poland	37
Russia	21
Spain	26
Sweden	5
Switzerland	5
Ukraine	4
UK	74

Asia	142 members
India	10
Korea	18
Japan	114

Americas	52 members
Brazil	3
Canada	29
Mexico	11
USA	9

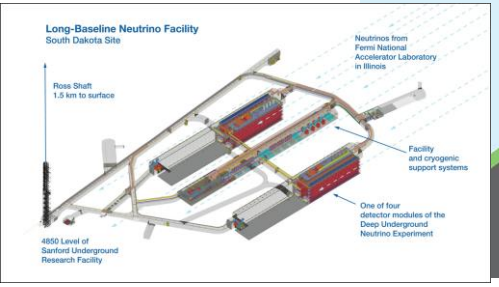
- 7 Korean Institutions participating in HK
  - → Chonnam National University
  - → Dongshin University
  - → GIST
  - → Kyungpook National University
  - → Seoul National University
  - → Sungkyunkwan University
  - → UNIST

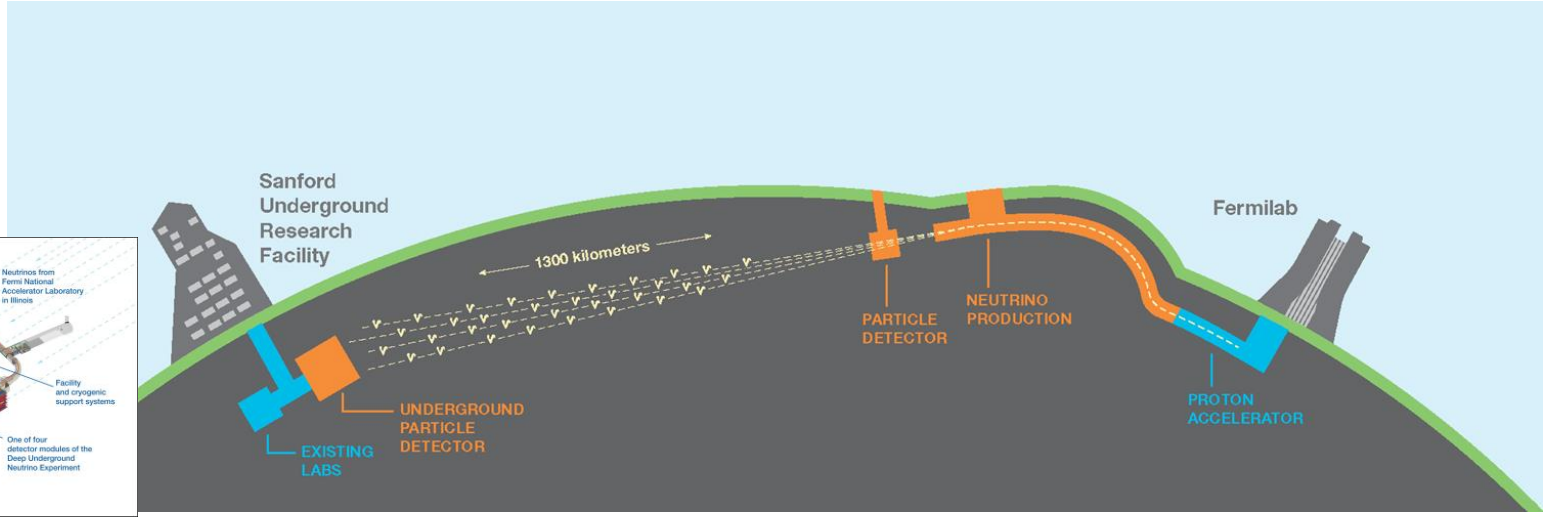
- Korean HK group plan to contribute to electronics and calibration systems

DUNE Experiment

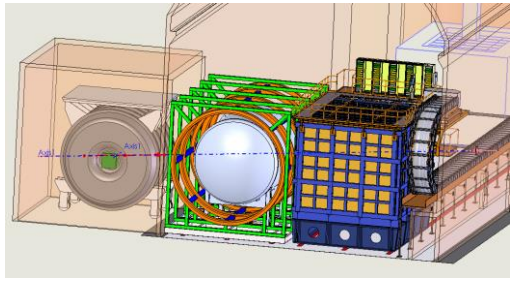
☐ Overview

Far Detector





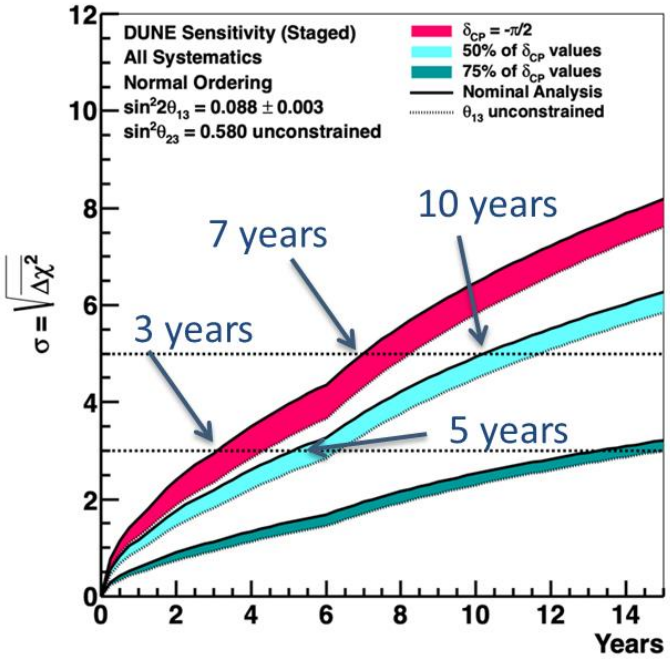
- 40 kton (4 X 10kton) of Liquid Argon Time Projection Chamber
- Fermilab LBNF Neutrino Beam (1.2 MW → 2.4 MW)
- Near Detectors Complex (Argon TPC, SAND, PRISM)



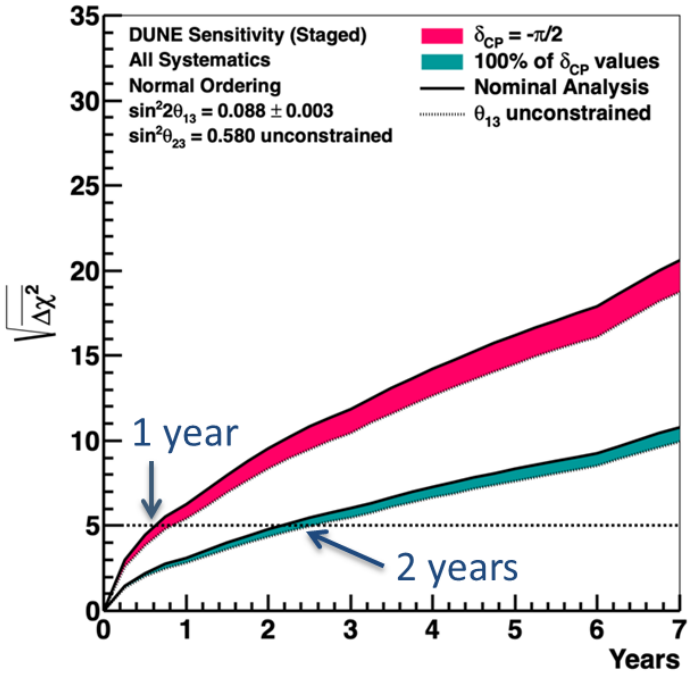
Near Detector

DUNE Experiment

☐ Physics Goal



CP Violation

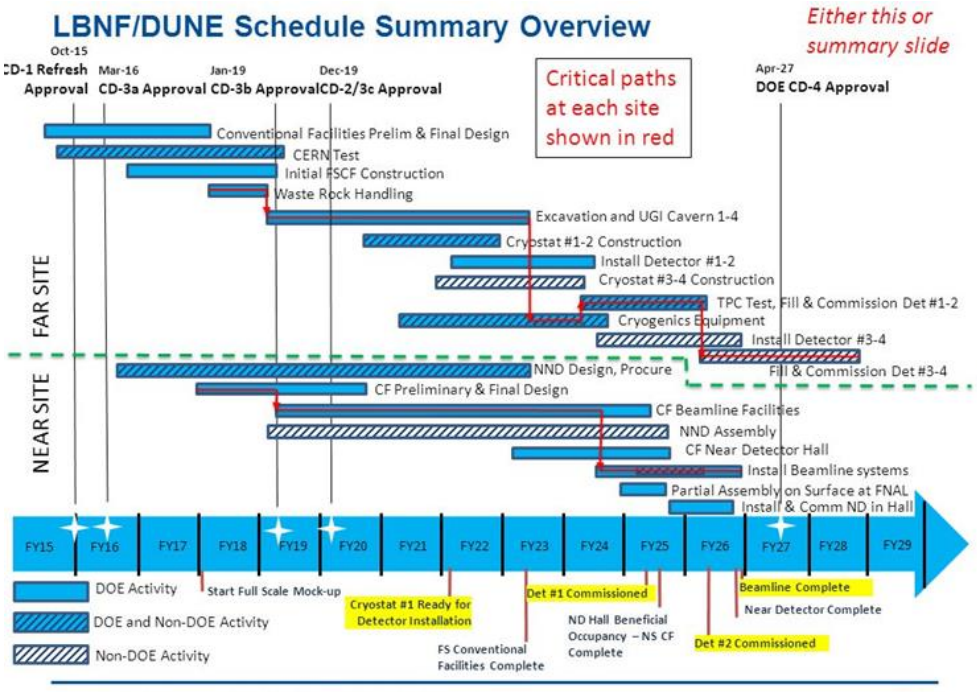


Mass Ordering

- Physics Program: CP Violation, Mass Ordering, Precision Measurement of Neutrino Oscillations, Proton Decays, Neutrino Astrophysics, and many others

DUNE Experiment

☐ DUNE Schedule



- Staged Construction

  (2026) 20kton, 1.2MW

  (2027) 30kton, 1.2MW

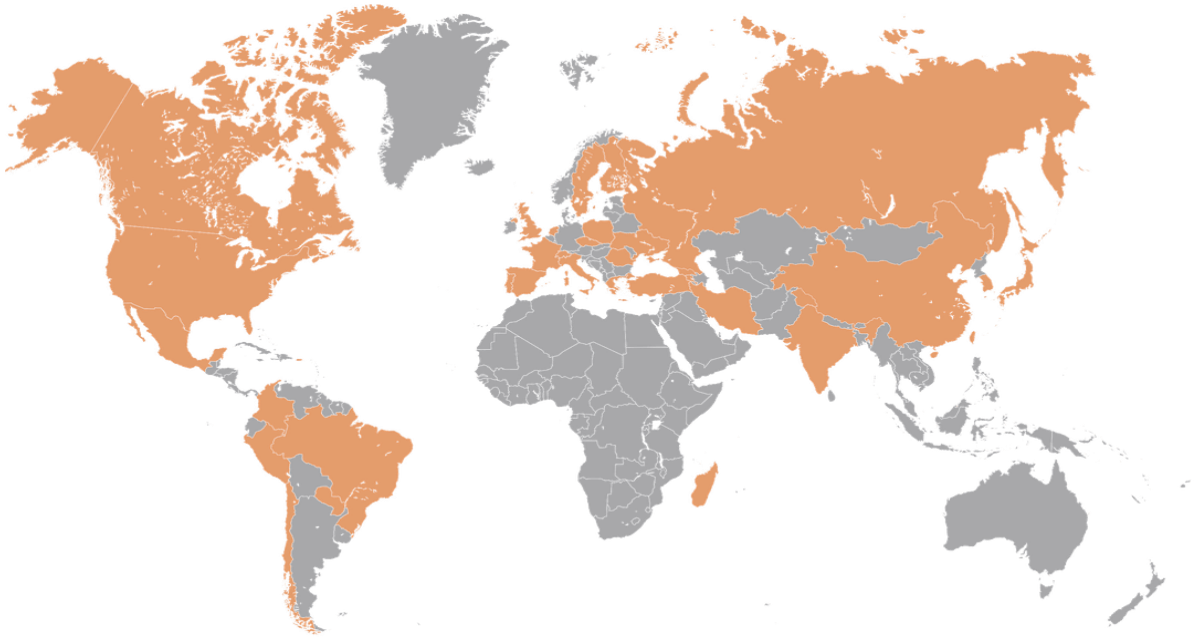
  (2029) 40kton, 1.2MW

  (2032) 40kton, 2.4MW

2018: ProtoDUNEs at CERN → 2019: FD TDR → 2020: Excavation starts → 2022: Installation of first module → First physics data: Atm, SN, & solar neutrinos. Proton decay. Calibration → 2026: ND & Neutrino beam available

DUNE Experiment

☐ DUNE Collaboration

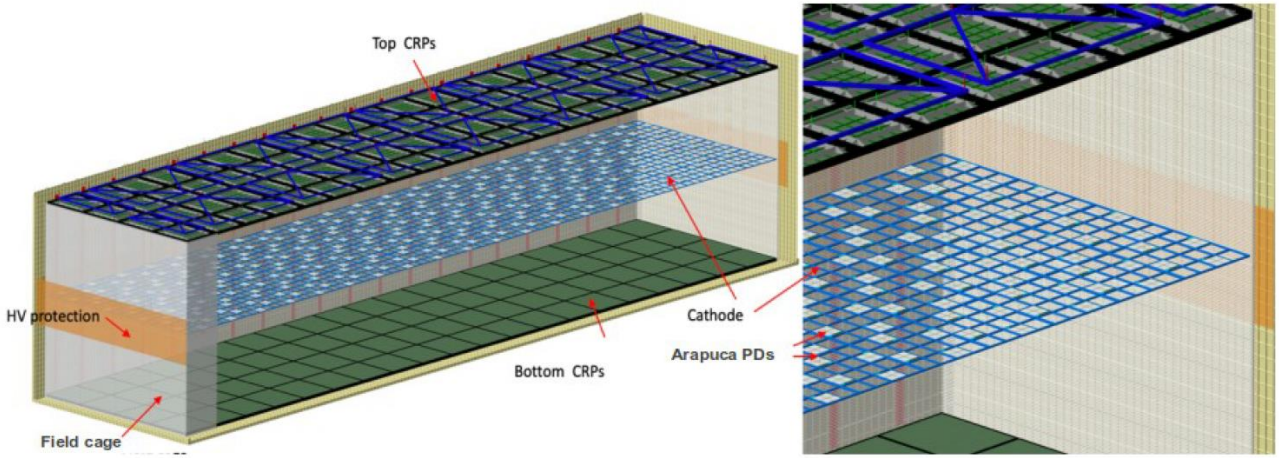


- ~1300 Collaborators from ~200 Institutions (30 Countries)
- 4 Korean Institutions participating in DUNE
  → Chung-Ang University
  → Jeonbuk National University
  → UNIST
  → KISTI

DUNE Experiment

☐ Korean DUNE Group

- Participating in Near Detector Project
  → Conceptual Design Report
  → Muon Antineutrino Studies
- BSM Physics (Boosted Dark Matter) Studies
- Participating in Neutrino Beam Accelerator Project
- Participating in Photon Detection System Project for the Far Detector

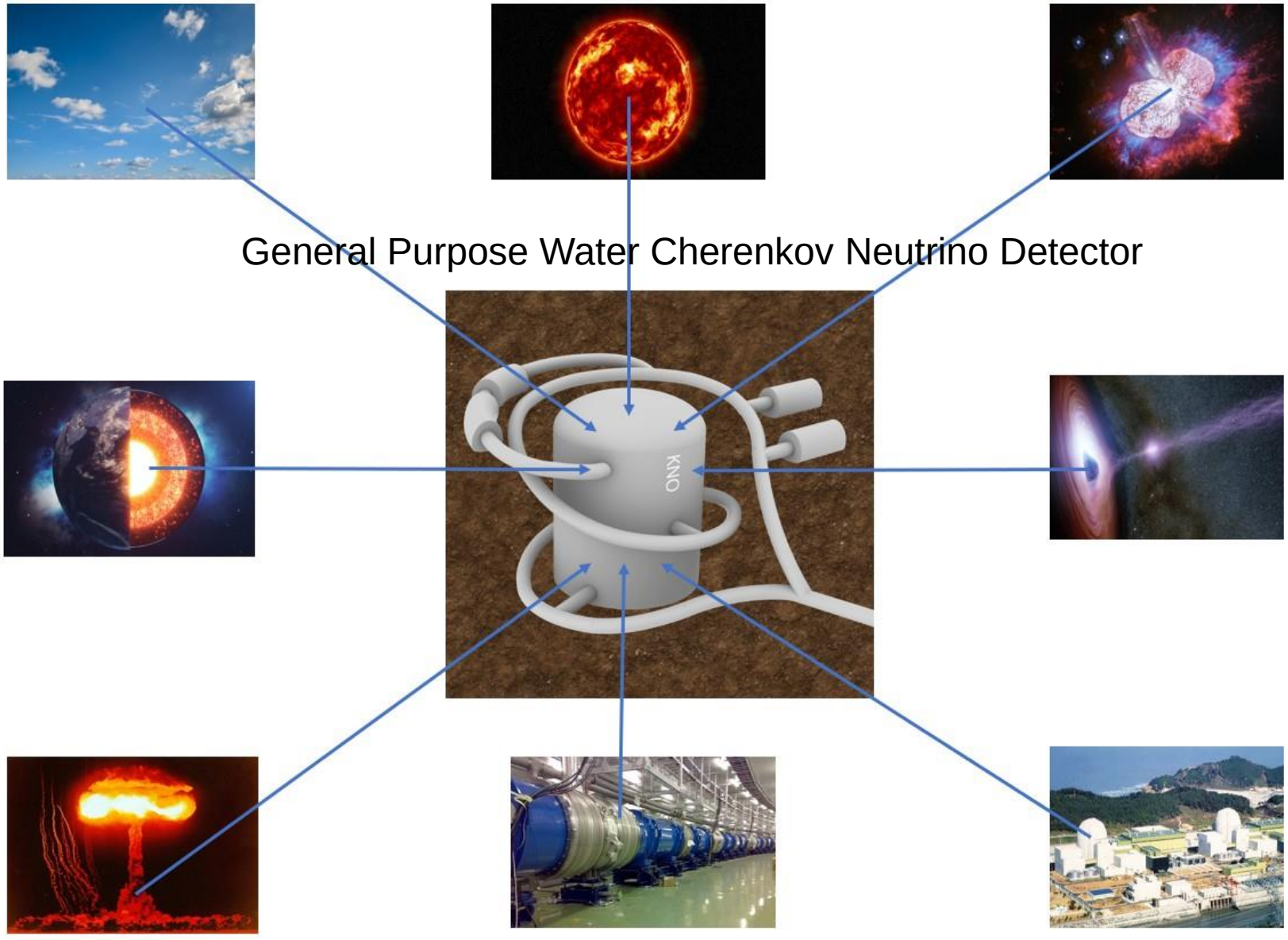


Part III.

Future Project

Korean Neutrino Observatory (KNO)

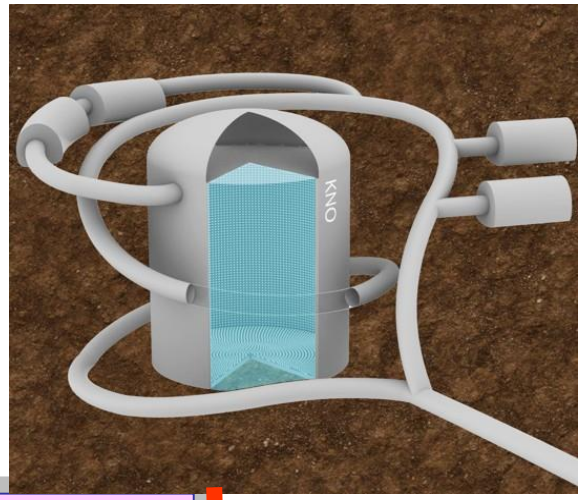
KNO Science

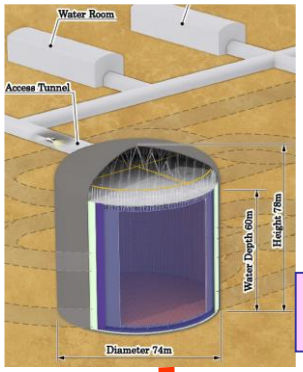


Far Detector to J-PARC beam

KNO

0.5Mt?





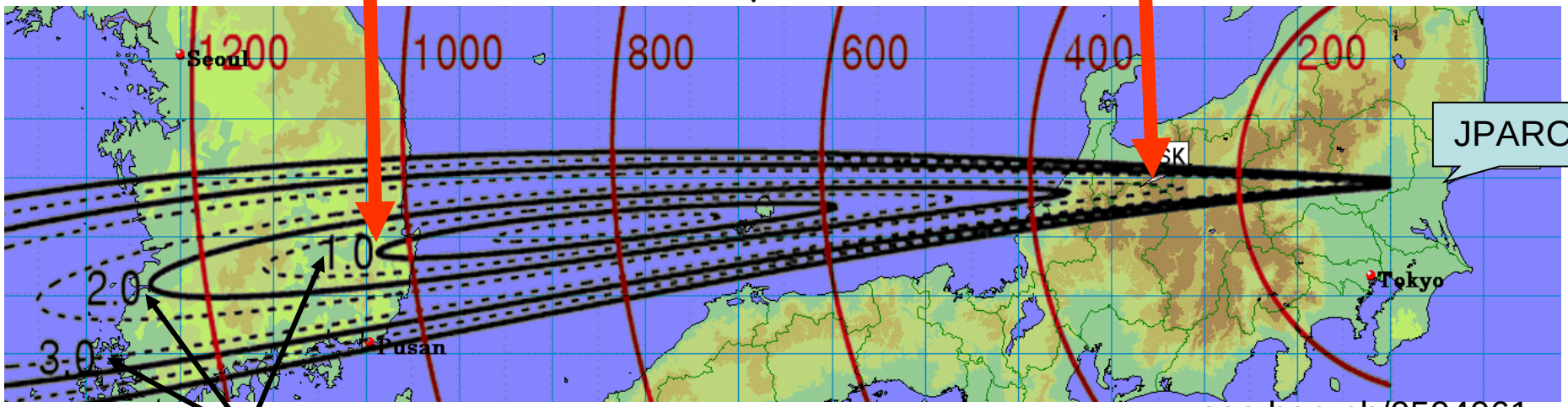
Hyper-K

0.26Mt

2.5 deg. off axis

~1.5 deg. off axis

The J-PARC ν_μ beam comes to Korea.

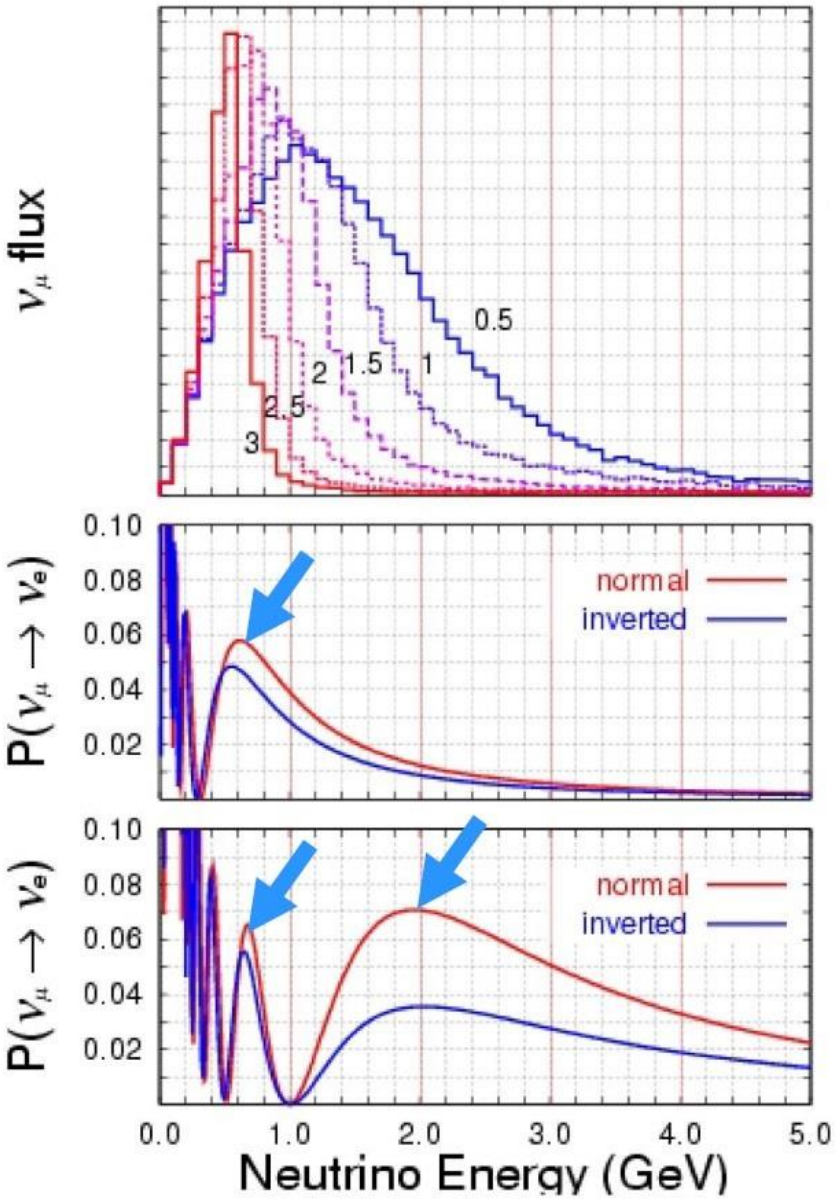


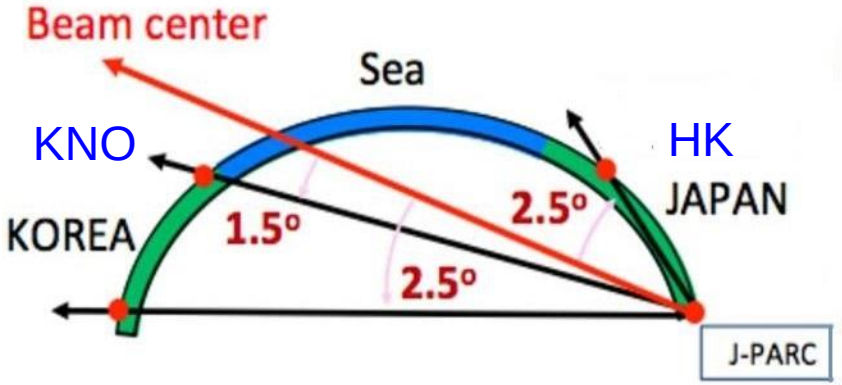
Off-axis angle

see hep-ph/0504061

By K. Hagiwara, N. Okamoura, K. Senda

Neutrino Oscillations in KNO & Kamioka



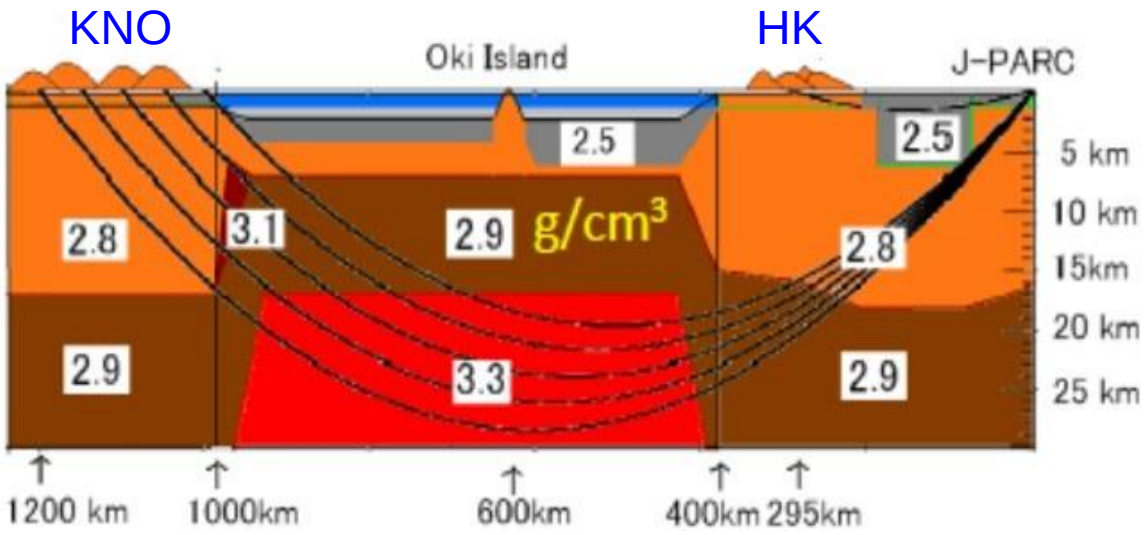


← Profile of off-axis beams

← $P(\nu_\mu \rightarrow \nu_e)$ at SK
(L=300 km) → 1st osc. max. only

←$P(\nu_\mu \rightarrow \nu_e)$ at Korea
(L=1100 km) → 1st and 2nd osc. max.

Matter Density Profile

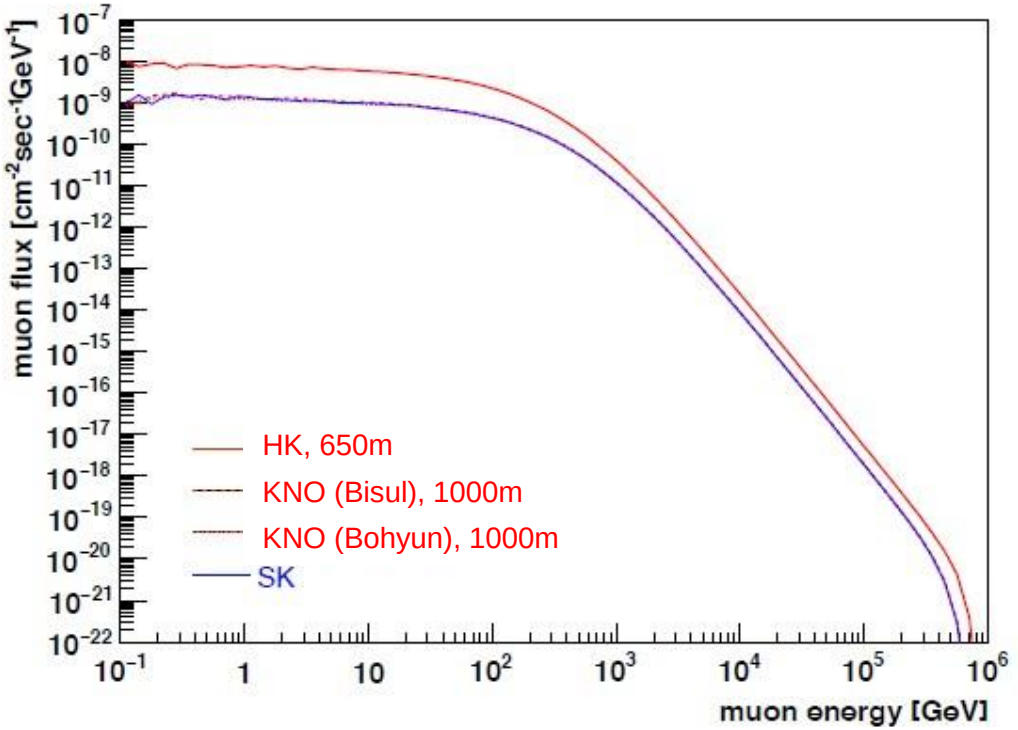


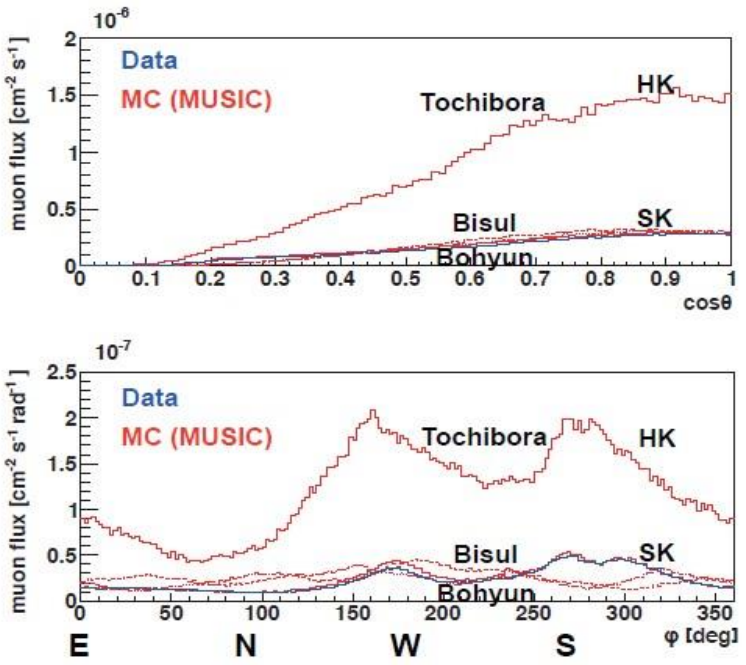
- Higher mass density and longer baseline at KNO
  → Enhanced Mass effect (MSW effect)

- Better measurement of neutrino mass ordering and enhanced sensitivity to non-standard interaction with matter

Cosmogenic Muon Flux

- Overburden of KNO site ~ 1000 m (HK: 650 m)
- Muon flux at KNO is 5 times smaller than HK flux
  → less cosmogenic backgrounds
  → better sensitivity to astrophysical neutrinos



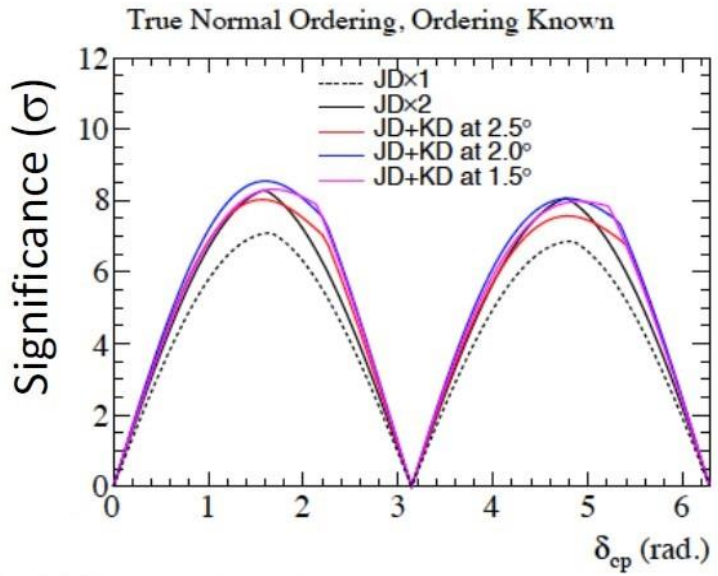


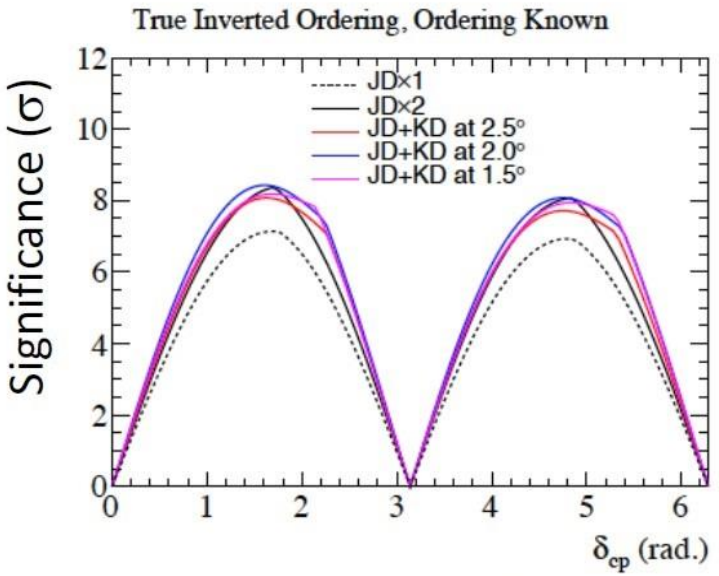
Physics Potential at KNO: δ_{cp}

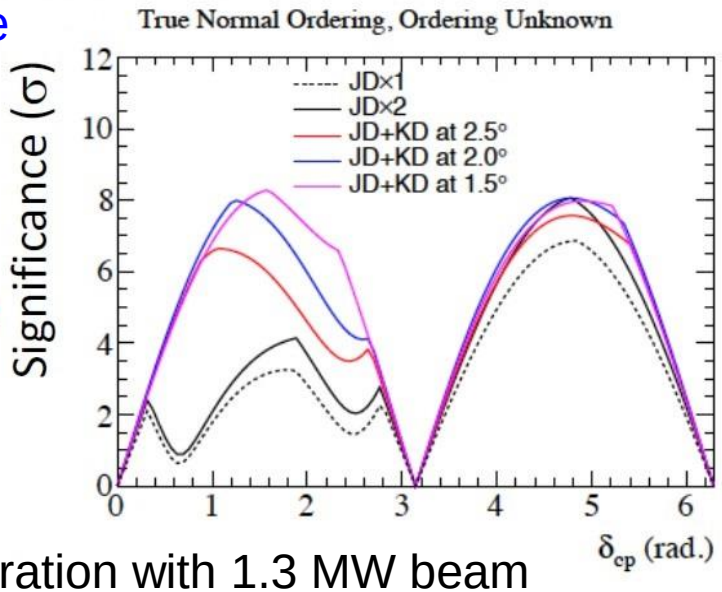
Known MO

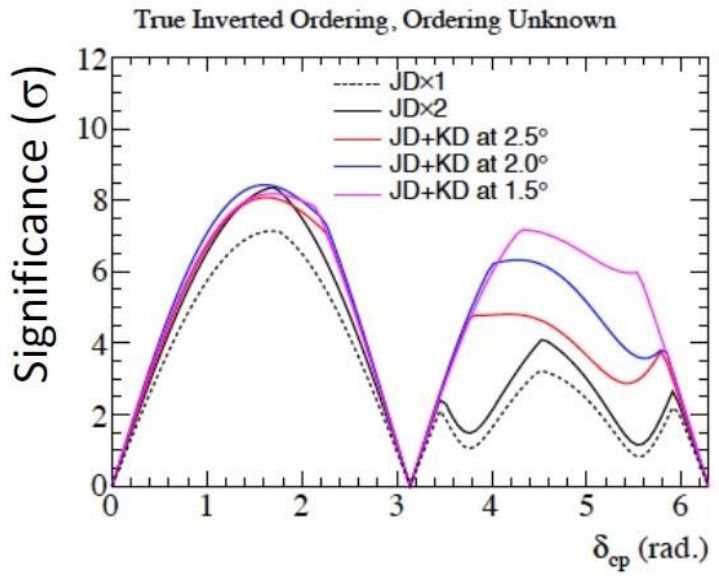
Unknown MO

KNO, HK
0.26 Mton
40% coverage



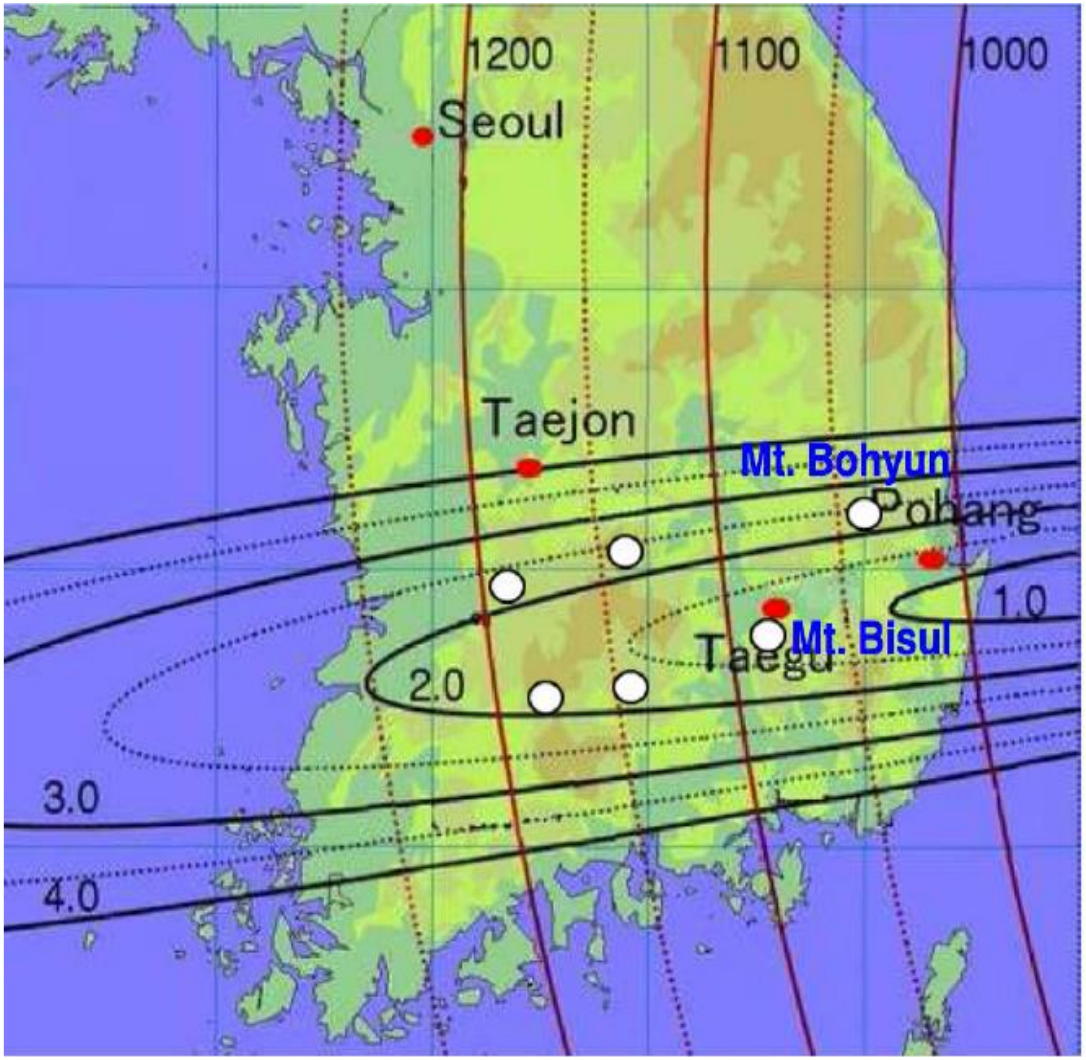






10 years of operation with 1.3 MW beam

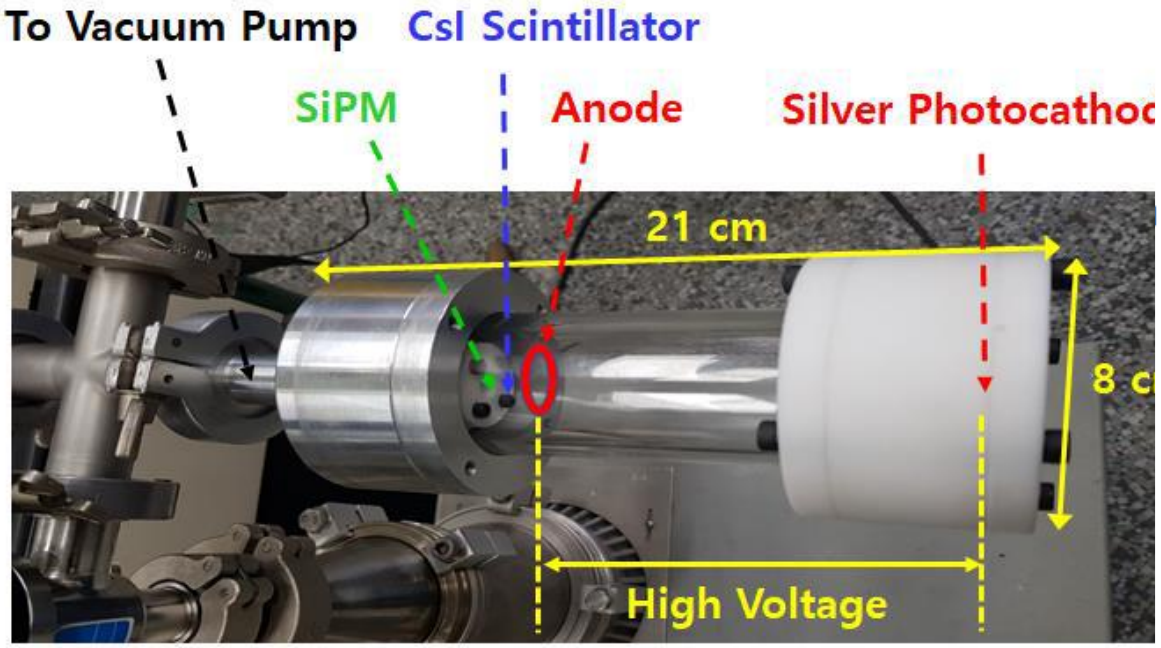
KNO Candidate Sites

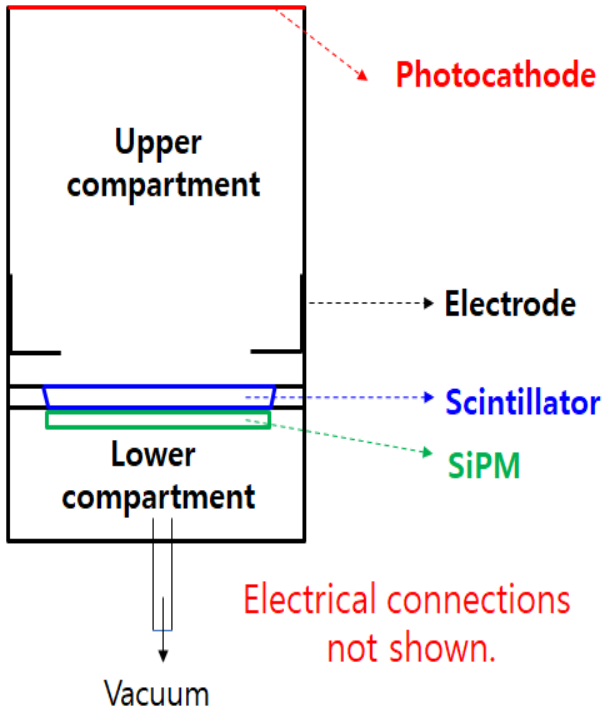


Site	Height (m)	Baseline (km)	Off-axis angle (degree)	Elements of rock
Mt. Bisul	1084	1088	1.3°	Granite porphyry, Andesitic breccia
Mt. Hwangmae	1113	1140	1.8°	Flake granite, Porphyritic gneiss
Mt. Sambong	1186	1180	1.9°	Porphyritic granite, Biotite gneiss
Mt. Bohyun	1124	1040	2.2°	Granite, Volcanic rocks, Volcanic breccia
Mt. Minjuji	1242	1140	2.2°	Granite, Biotite gneiss
Mt. Unjang	1125	1190	2.2°	Rhyolite, Granite porphyry, Quartz porphyry

Activities on Detector R&D : PMT

- Development of Silicon PMT
  - Kyungpook National University in collaboration with Russian group
  - Hybrid PMT using photocathode, scintillator, and SiPM

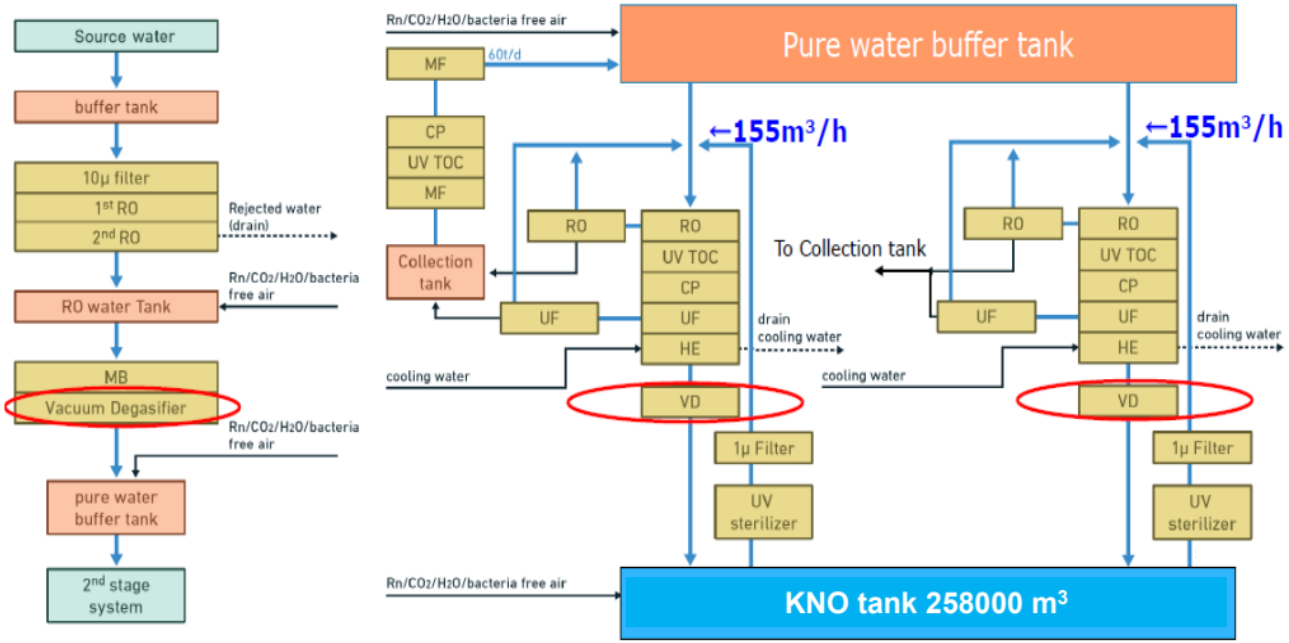




More Activities on Detector R&D

- R&D on Water purification system
  - Seoul National University in collaboration with Korean company DICOTECH
  - design of water purification system of KNO
  - prototype construction of radon degasifier

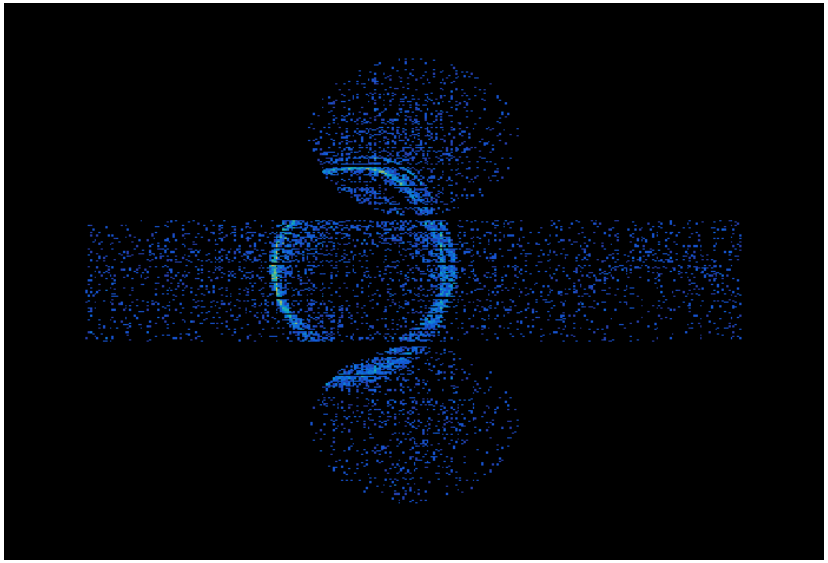
blueprint of water purification system



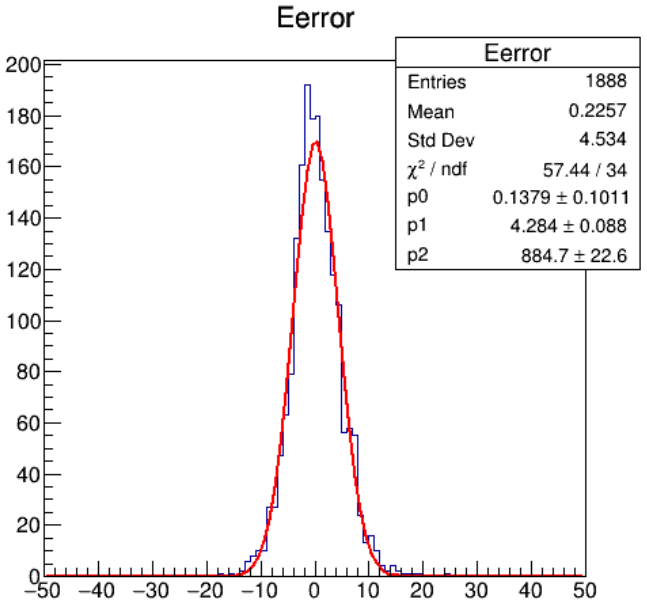
radon degasifier prototype

KNO Software Development

- Develop KNO simulation/reconstruction package which can be used to study sensitivities and to optimize the detector design
- 1st Version of KNO reconstruction package is available
- 2nd Version of KNO reconstruction package is being developed



Neutrino Event Display

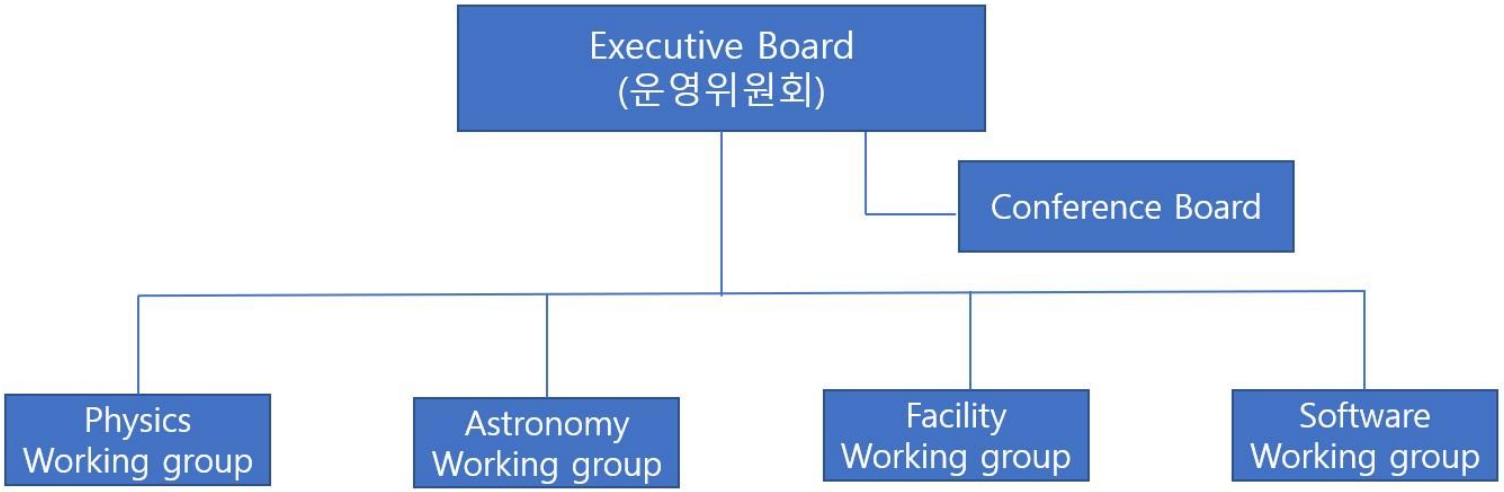


Energy Resolution

KNO Organization

- KNO working groups (~60 members from 10 institutions) have been organized
- 10 KNO domestic/international workshops have been held since 2016
- KNO web site is open (www.kno.or.kr)

KNO Organization Chart



Summary

- Korean Groups are actively participating in Super-Kamiokande and IceCube experiments which are the leading neutrino experiments

- The next-generation experiments - Hyper-Kamiokande and DUNE are expected to make breakthroughs in the field of neutrino physics for the next decades. The significant contributions of Korean groups to these experiments are necessary for the future of high energy physics in Korea

- KNO can be a leading next-generation neutrino experiment if realized and the flagship project for Korean HEP for the next decades

Thank you