Overview of Korea Neutrino Observatory (KNO) Project

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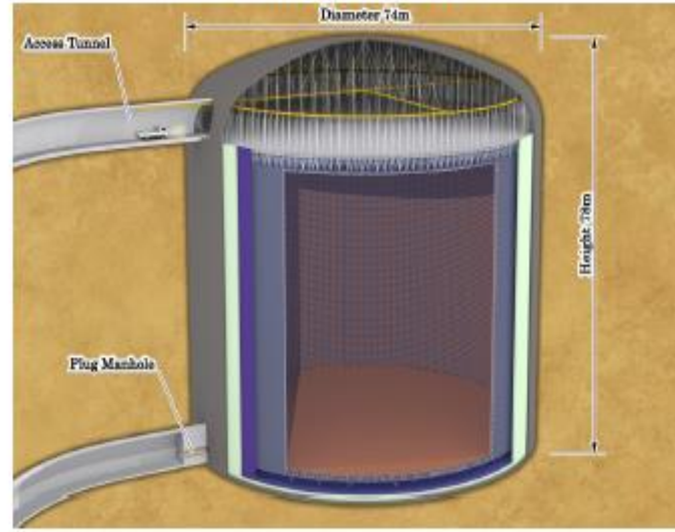
Kamiokande (1983-1996)
3000 ton

- Neutrinos from SN1987a.
- Atmospheric neutrino deficit.
- Solar neutrinos.

Super-Kamiokande (1996-)
50,000 ton

- Atmospheric neutrino oscillation.
- Solar neutrino oscillation with SNO.
- Far detector for KEK-PS (K2K) and J-PARC beam (T2K): electron neutrino appearance.
- World leading limit on proton lifetime $> 10^{34}$ years.

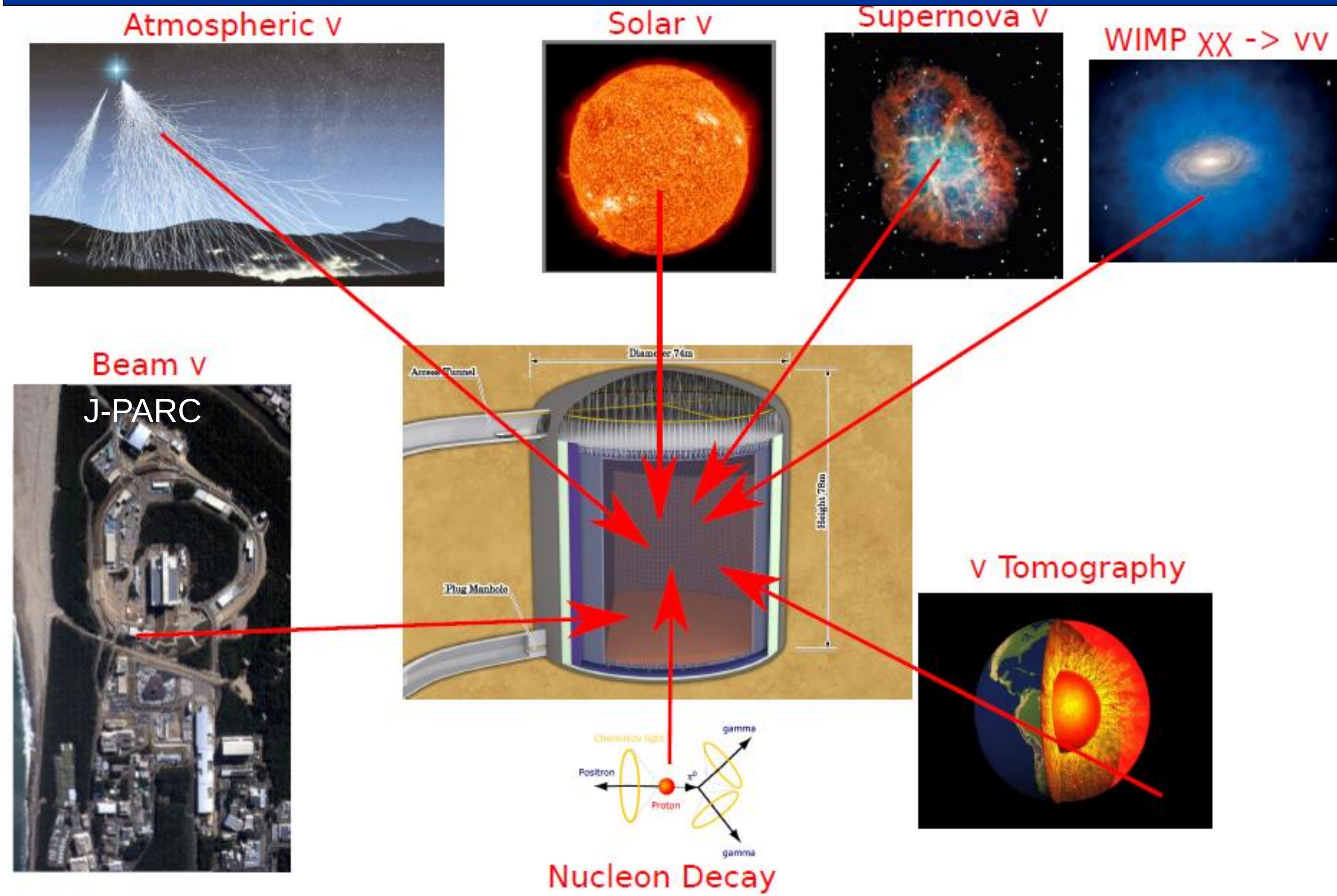
Hyper-Kamiokande ($\sim$2026-)
$2\times260{,}000$ ton



Physics programme:

- Neutrino oscillations: Mass Hierarchy, Leptonic CP violation, θ_{23} Octant,...
- Nucleon decay: $p\to e^{+}\pi^{0}$, $p\to K^{+}\bar{\nu}$,...
- Neutrino astrophysics: Solar neutrinos, Supernova neutrinos, WIMP searches

Overview of Hyper-K Physics

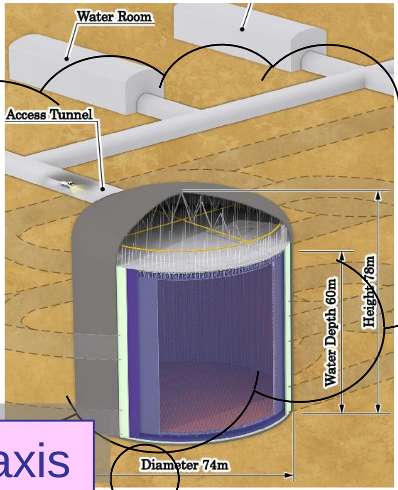


Status of Hyper-Kamiokande

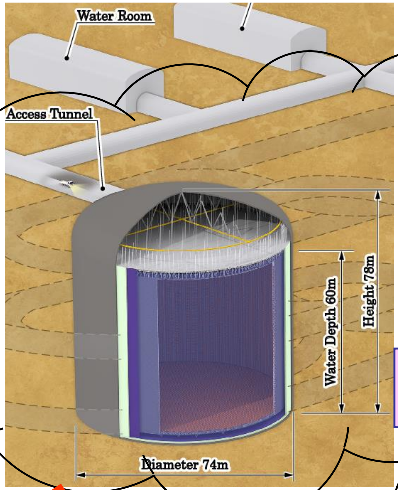
- Hyper-Kamiokande (HK) proto-collaboration was formed
- Two host institutions: U of Tokyo (ICRR), KEK (IPNS)
- Japanese funding agency (MEXT) provided a seed funding for Hyper-K in 2019. → standard process in Japan for large projects to begin with a year of seed funding
- U of Tokyo commitment ensures that the Hyper-K construction will begin in April, 2020.
- MEXT has made an official budget request in August according to Yomiuri newspaper (2019. 8. 21).

Neutrino Detector in Korea

KNO



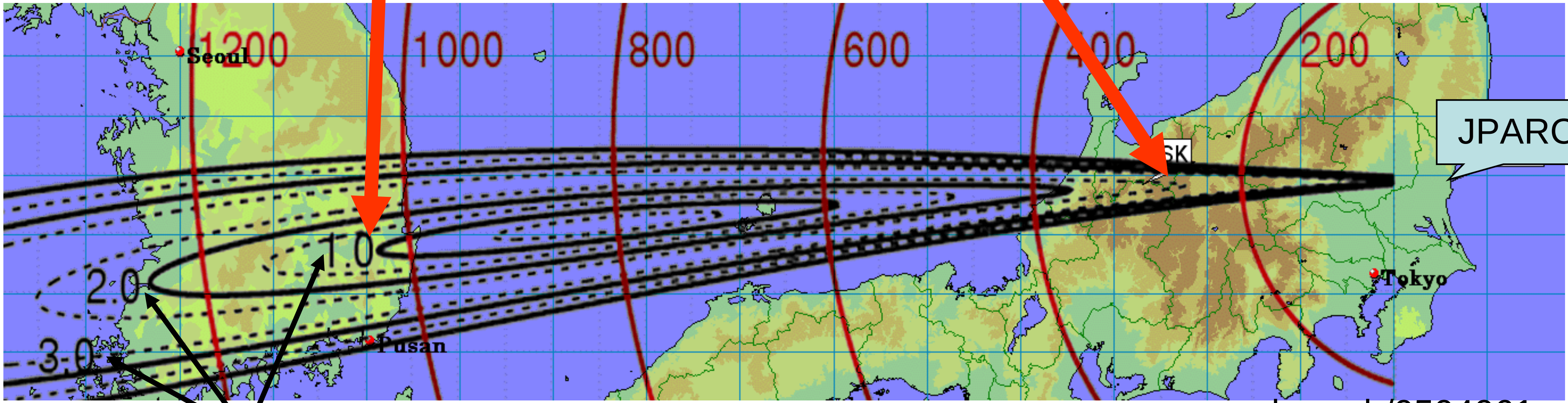
1.5 deg. off axis



Hyper-K

2.5 deg. off axis

The J-PARC ν_μ beam comes to Korea.



see hep-ph/0504061
By K. Hagiwara, N. Okamoura, K. Senda

Off-axis angle

Pros and Cons of KNO

- Pros

- 1st and 2nd oscillation maxima at KNO → more sensitive to leptonic CP violation

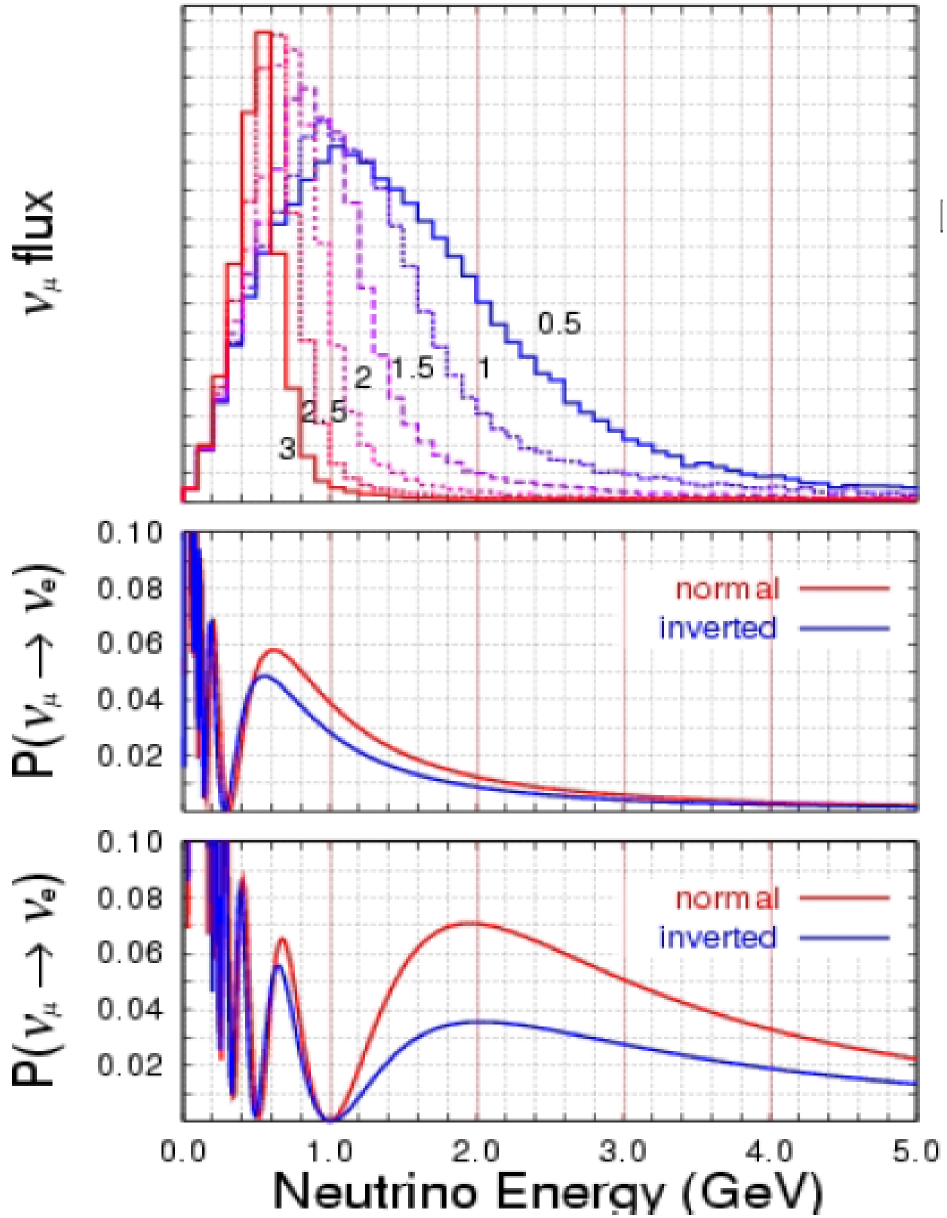
- Higher mass density and longer baseline → better determination of neutrino mass hierarchy and better sensitivity to non-standard neutrino interactions

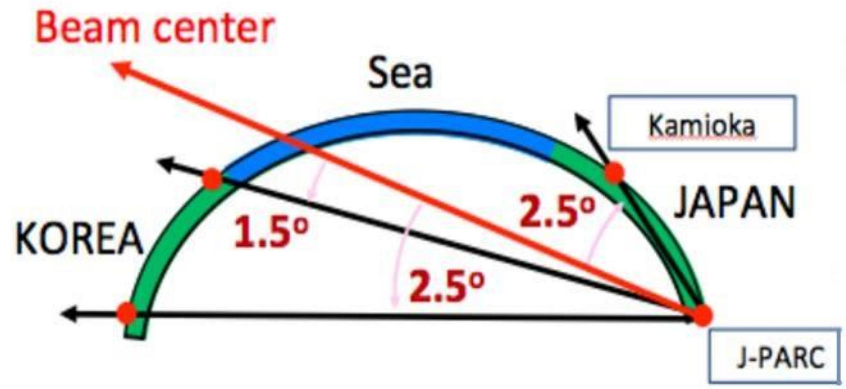
- Larger overburden (~1000 m) → better sensitivity to neutrinos of astronomical origin (solar/SN/galactic..)

- Cons

- Neutrino beam flux at KNO is ~ 10 times smaller than HK flux due to longer baseline

Neutrino Oscillations in Kamioka & Korea





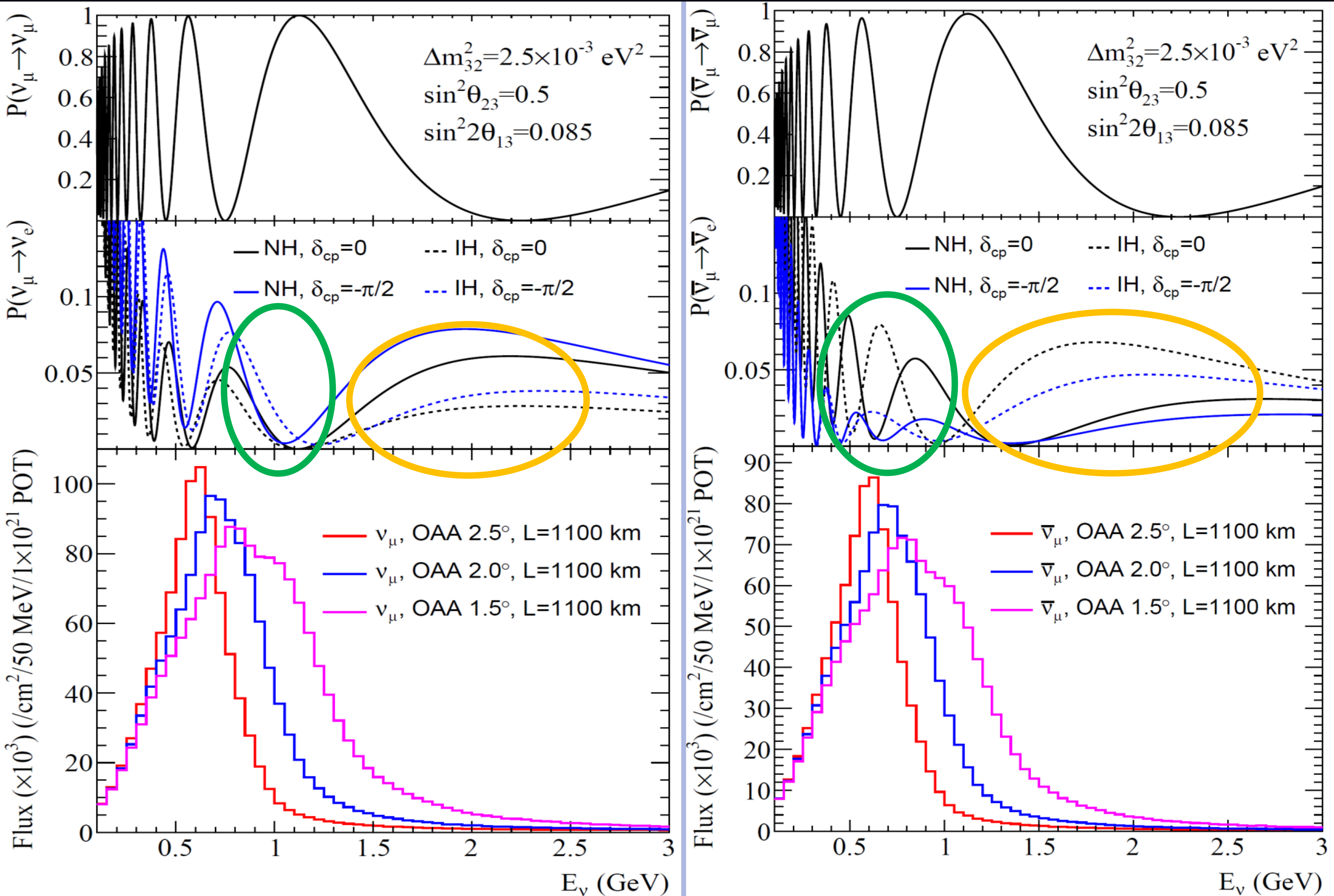
← Profile of off-axis beams

← $P(\nu_\mu \rightarrow \nu_e)$ at SK

← $P(\nu_\mu \rightarrow \nu_e)$ at Korea

(L=1000km)

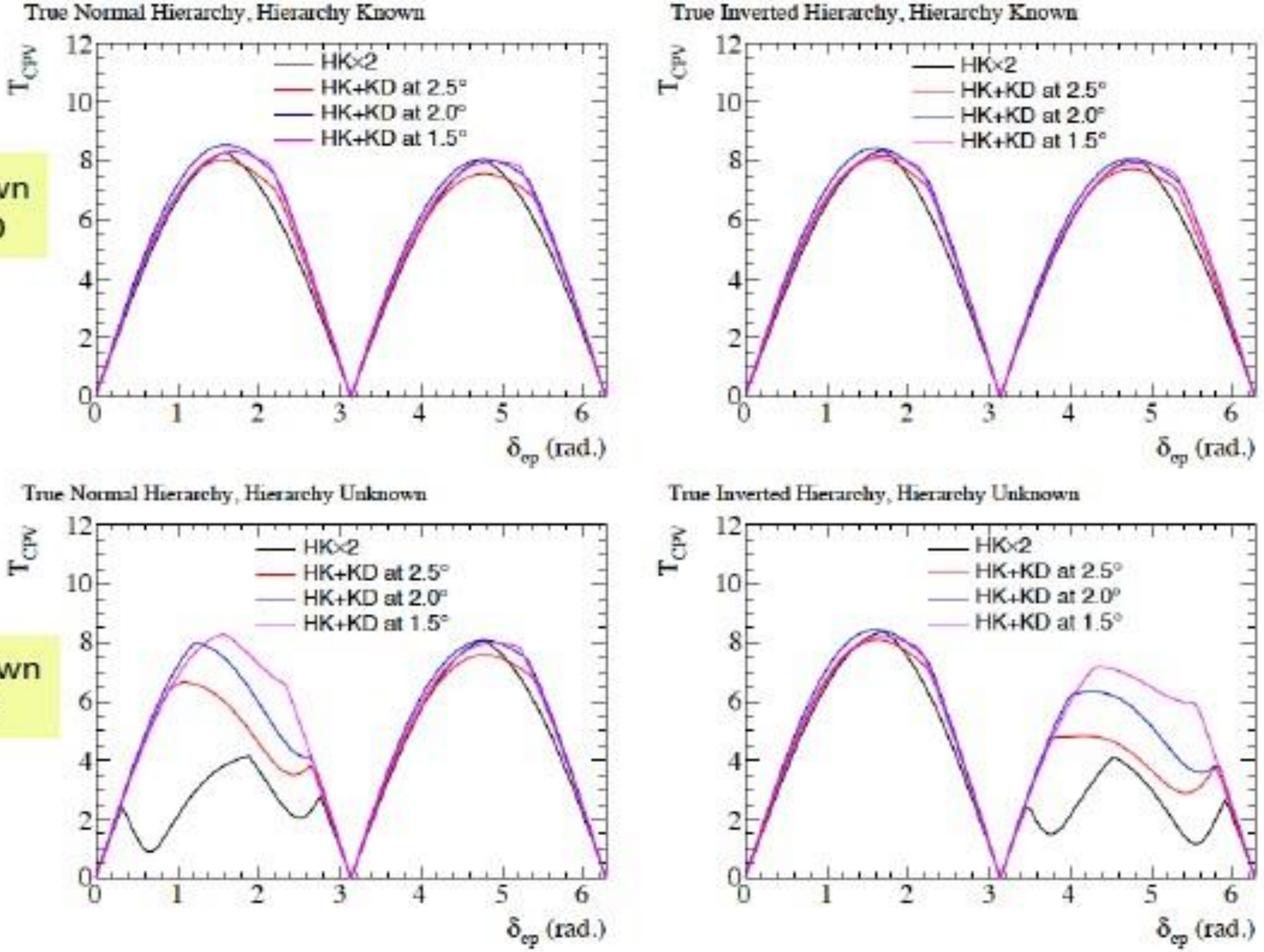
1st and 2nd Oscillation Maxima in Korea



Physics Potential at KNO: δ_{cp}

Known MO

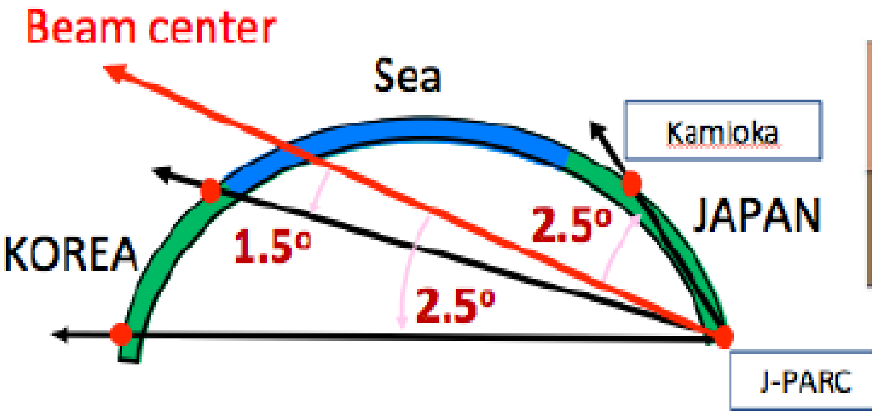
Unknown MO

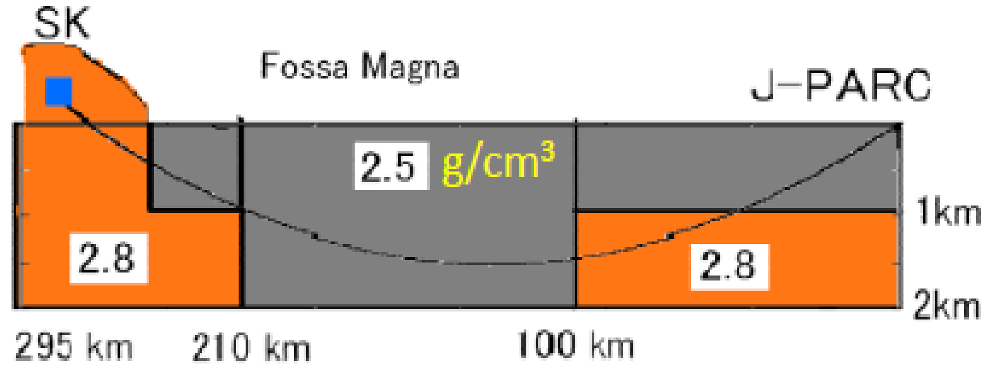


10 years of operation with 1.3 MW beam

For details, see S. Seo's talk

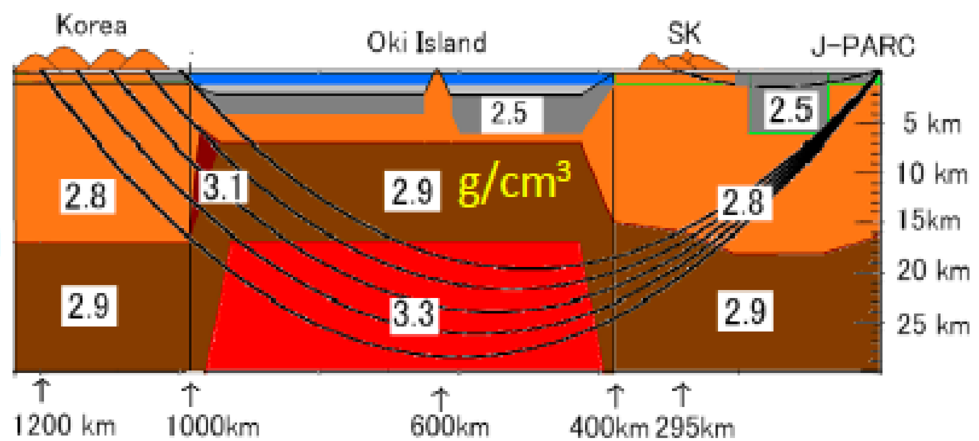
Matter Density Profile





Matter density:

$$r_A = 2\sqrt{2} G_F N_e E_\nu / \Delta m^2_{31}$$



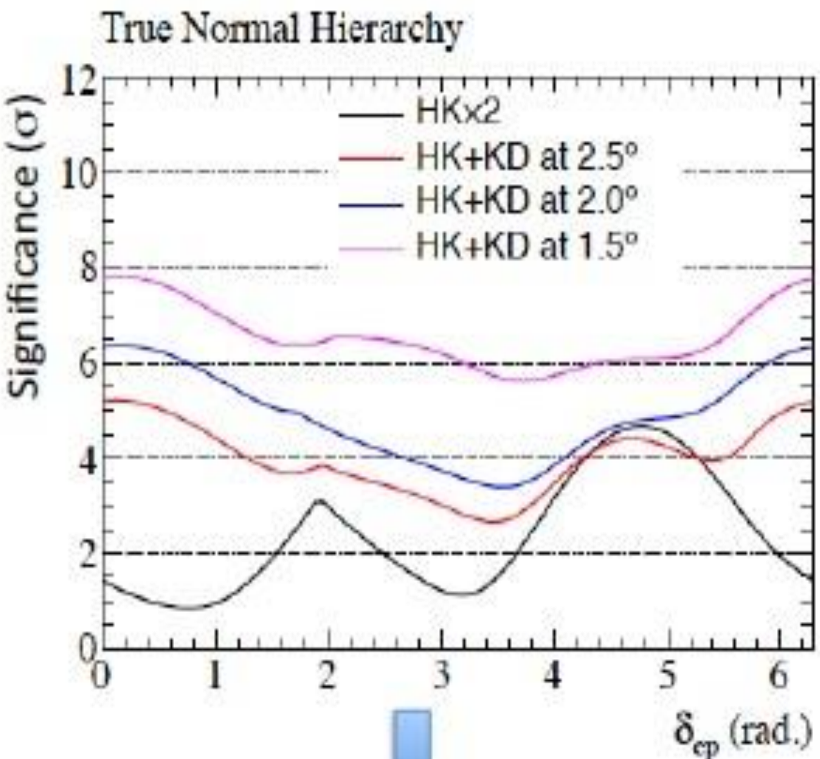
More matter effects

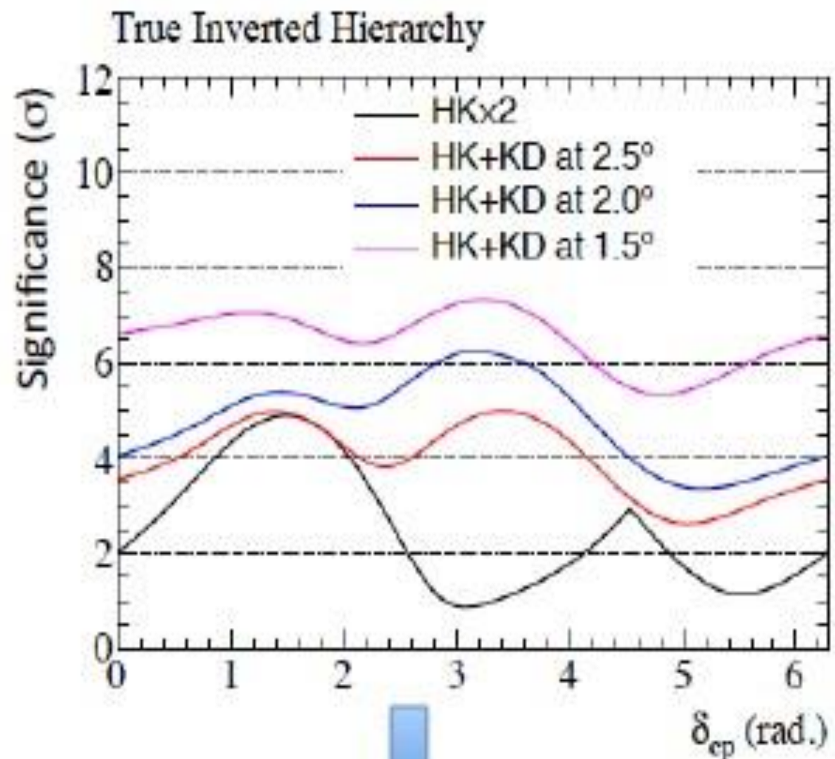
→ Better Measurement of Neutrino Mass Ordering

- Longer baseline
- Higher matter density
- Higher neutrino energy

Physics Potential at KNO: Mass Ordering

10 years of operation with 1.3 MW beam



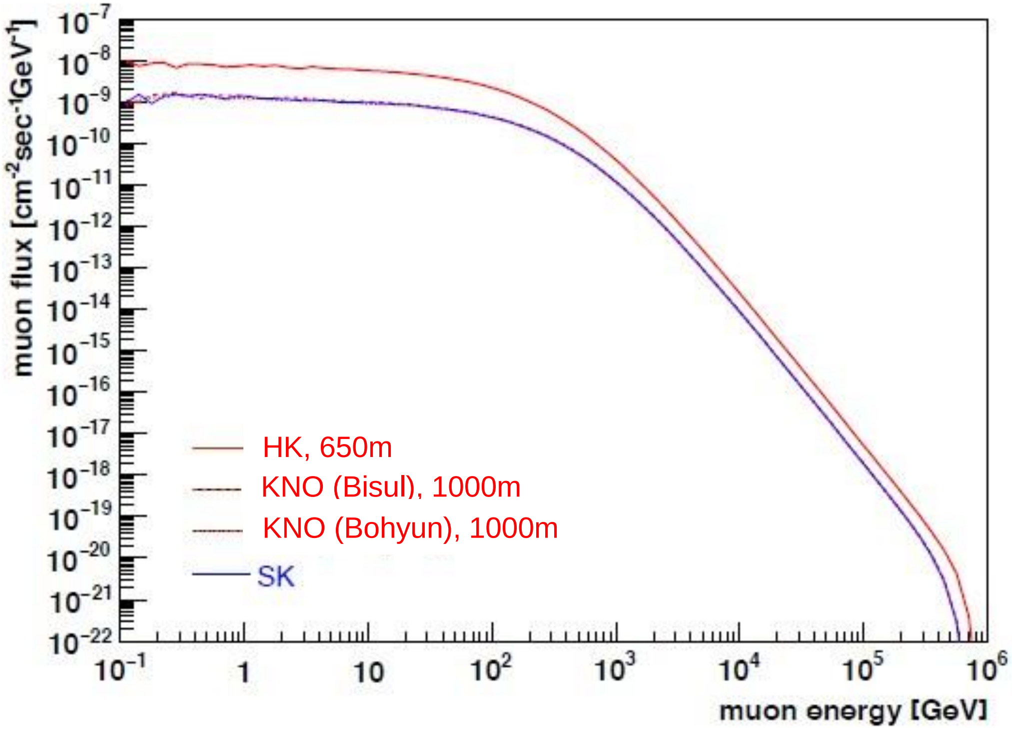


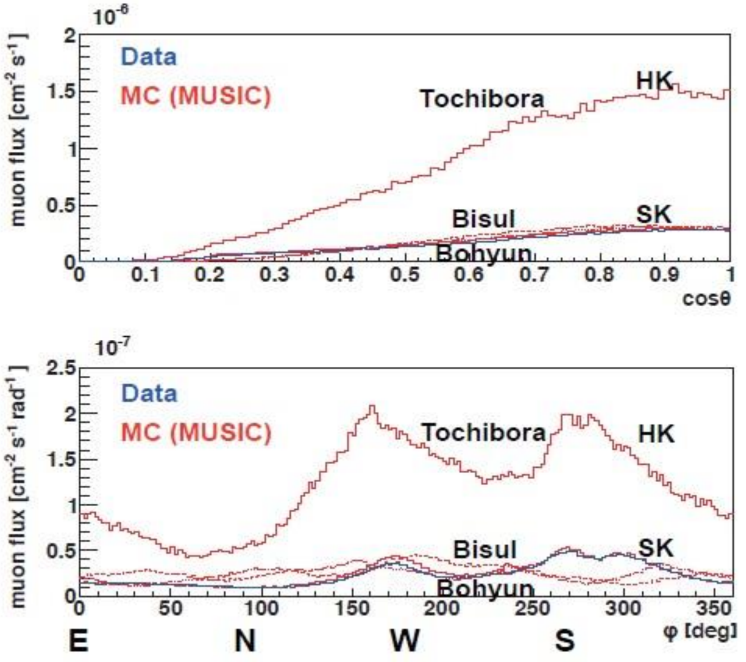
HK+KD 1.5°: 6 ~ 8 σ for all δ_{CP}
HK x2 : 1 ~ 4.5 σ for all δ_{CP}
(< 3 σ for most cases)

HK+KD 1.5°: 5.5 ~ 7 σ for all δ_{CP}
HK x2 : 1 ~ 5 σ for all δ_{CP}
(< 3 σ for most cases)

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

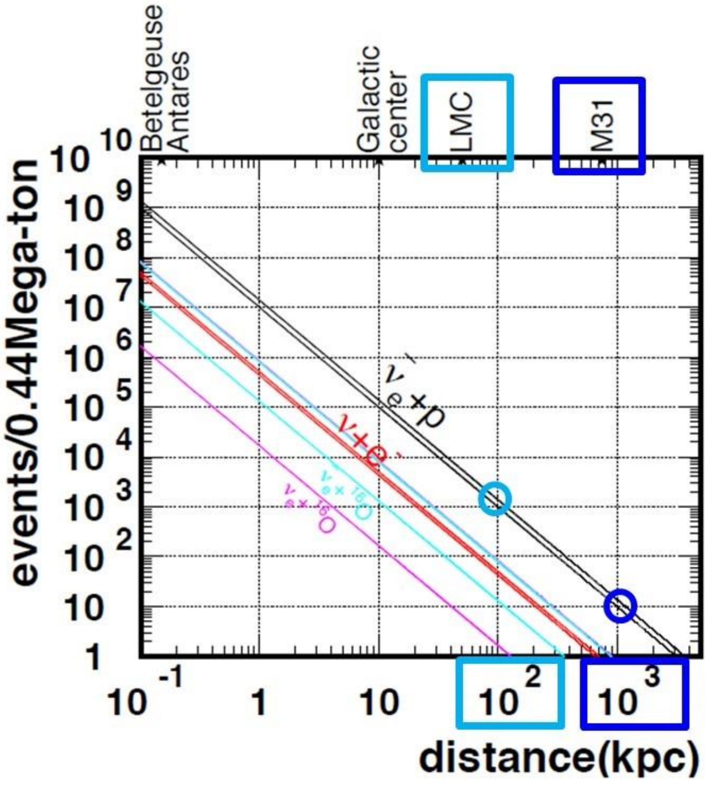




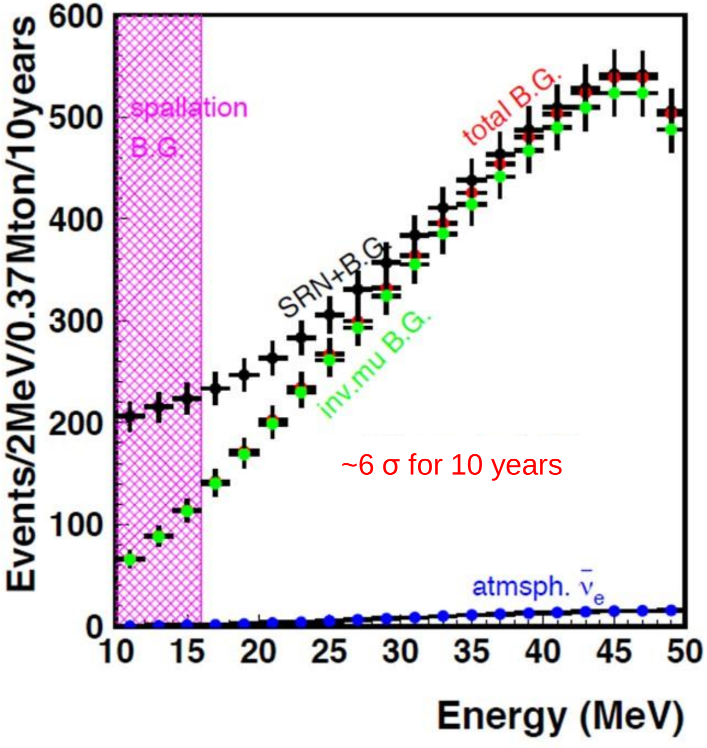
Neutrinos of Astronomical Origins

- Super Nova Neutrinos (SN)
- Super Nova Relic Neutrinos (SRN)

SN neutrino rate



SRN spectrum



Neutrinos of Astronomical Origins

- Neutrinos from active galactic nuclei and microquasars
- Neutrinos from interactions of cosmic protons and nuclei in the Galaxy
- Neutrinos from gamma-ray bursts (GRB)
- Neutrinos from clusters of galaxies
- Neutrinos from dark matter decays
- Solar Neutrinos

Multi-Messenger Astronomy

For details, see M.G. Park's talk

History of KNO/T2HKK

- Oct. 17, 2000: Another far detector using a JHF neutrino beam by S.B. Kim (KOSEF-JSPS Joint Seminar at KIAS)

- 2005/2006/2007: A large Cherenkov detector in Korea using a J-PARC neutrino beam (T2KK) by T. Kajita.
$\rightarrow$ 3 joint workshops supported by KOSEF and JSPS

- 2011: Proposal of 0.5 M ton water Cherenkov Hyper-Kamiokande detector at Kamioka (LOI as arXiv:1109.3262 and arXiv:1412.4673v2)

- 2015: Staged construction of two HK detectors of each 0.26 Mton at Kamioka

- July 10, 2016: The first T2HKK meeting in London
$\rightarrow$ present a proposal to the HK collaboration
$\rightarrow$ T2HKK working group (S. Seo)

Activities of KNO/T2HKK

- Sep. 2, 2016: First Workshop on T2HKK in Korea (SNU)
- Oct. 20, 2016: Pioneering Symposium at Korean Physical Society meeting (Gwangju)
- Nov. 2016: A white report on T2HKK released. It was published in Prog. Theor. Exp. Phys. 2018, 063C01.
- Nov. 21-22, 2016: International Workshop on 2nd Detector in Korea (SNU)
- Nov. 24, 2017: 1st KNO Workshop (KNU)
- Aug. 21, 2018: 2nd KNO Workshop (KASI)
- Nov. 2, 2018: 3rd KNO Workshop (KNU)
- Aug. 25, 2019: KNO Workshop with NUFACT 2019 (KNU)

Korean Efforts on KNO Realization

- 2018. 10. 20: Kick-off Meeting for KNO organization including physicists and astronomers
- Five working groups were formed in the meeting
- Each working group has held regular meetings
- Discussions with Korean government have been started
- Detector R&D work is in progress
- Several options for KNO detector are being considered
- Korean efforts are in very early stage

Working Groups of KNO Organization

- Government Relations Working Group

  contact and discussions with government and funding agency

- Detector R&D Working Group

  photo sensor, water purification, DAQ, and etc

- Science Working Group

  particle physics and astronomy subgroups

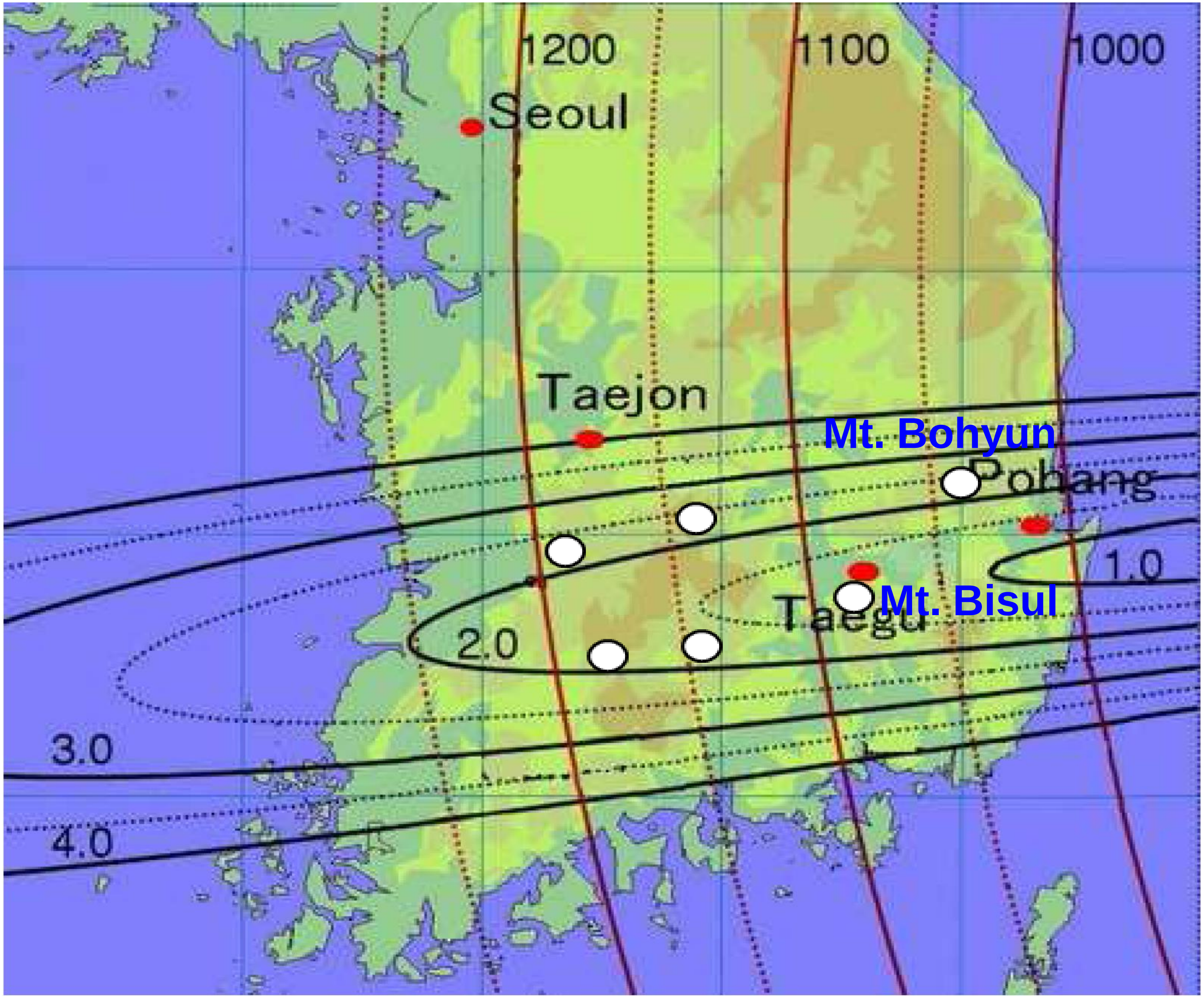
- Proposal Working Group

  preparation for KNO proposals

- International Relations Working Group

  foreign support and participation

KNO Candidate Sites



List of KNO Candidate Sites

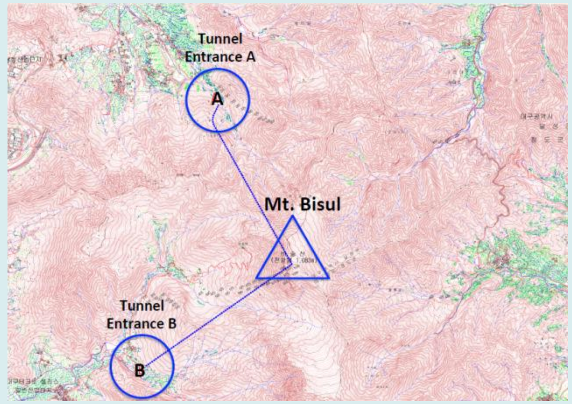
S. B. Kim (SNU)

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

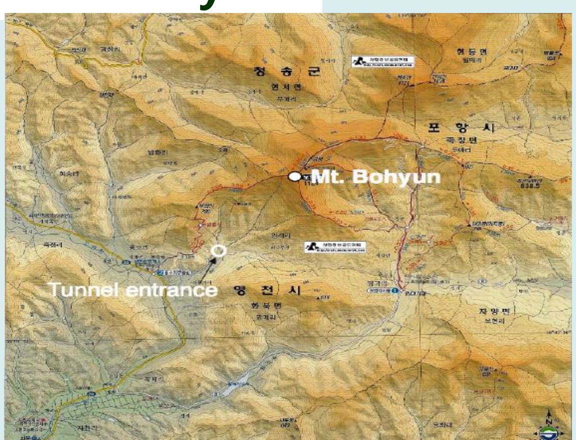
KNO Candidate Sites – Mt. Bisul and Mt. Bohyun

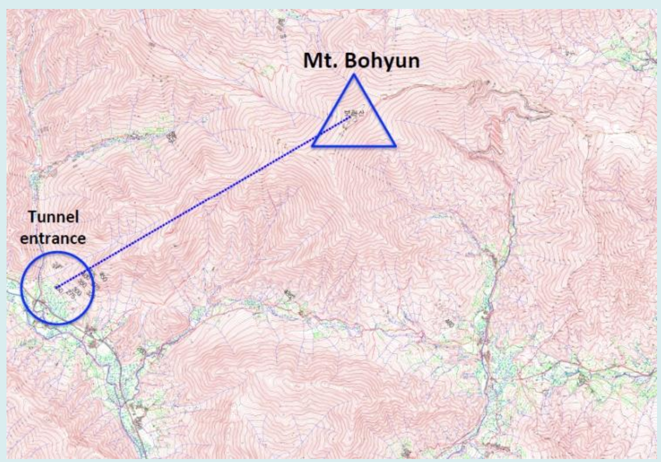
S. B. Kim (SNU)

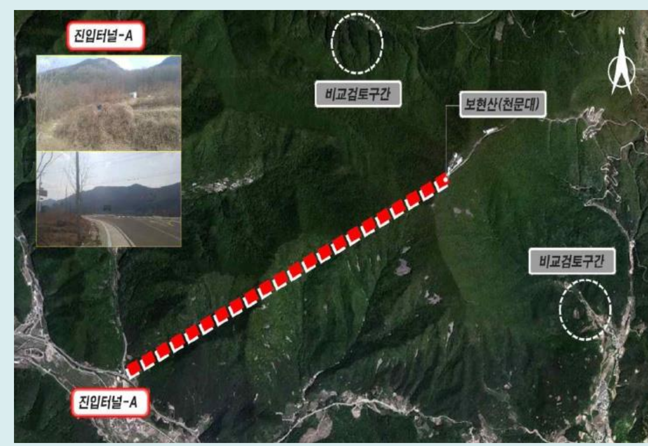
Mt. Bisul



Mt. Bohyun

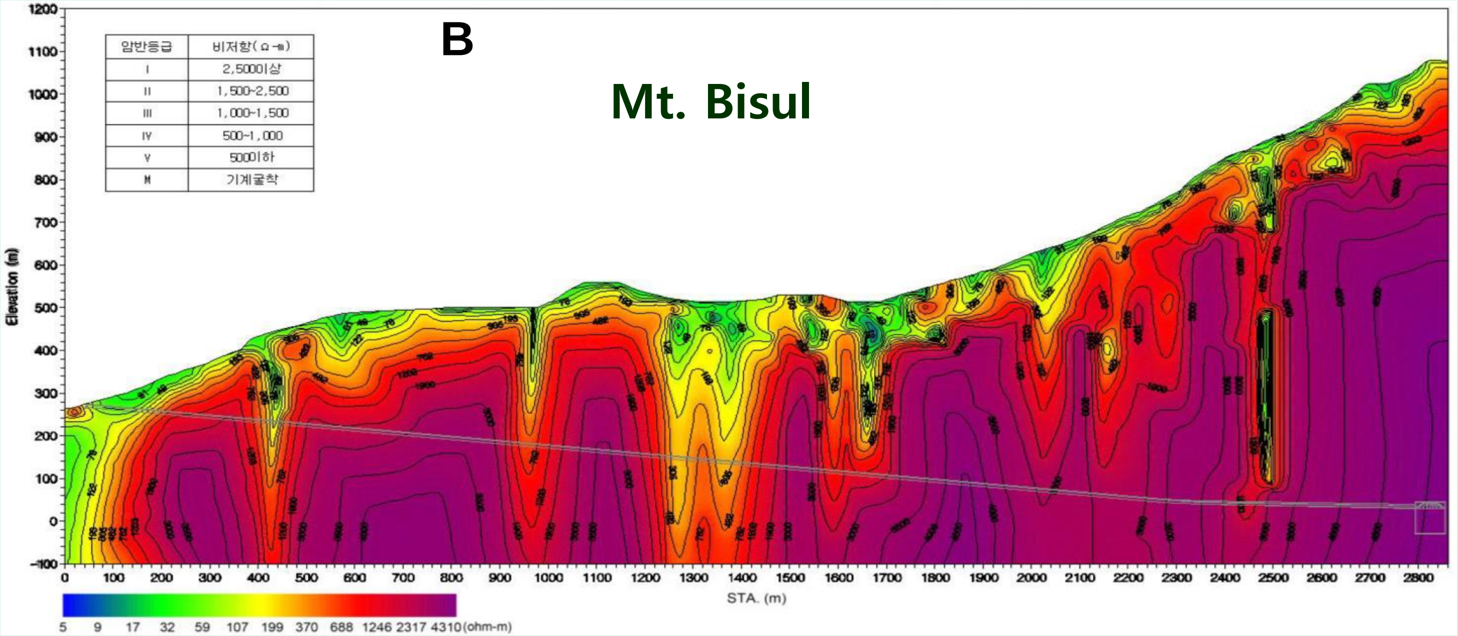


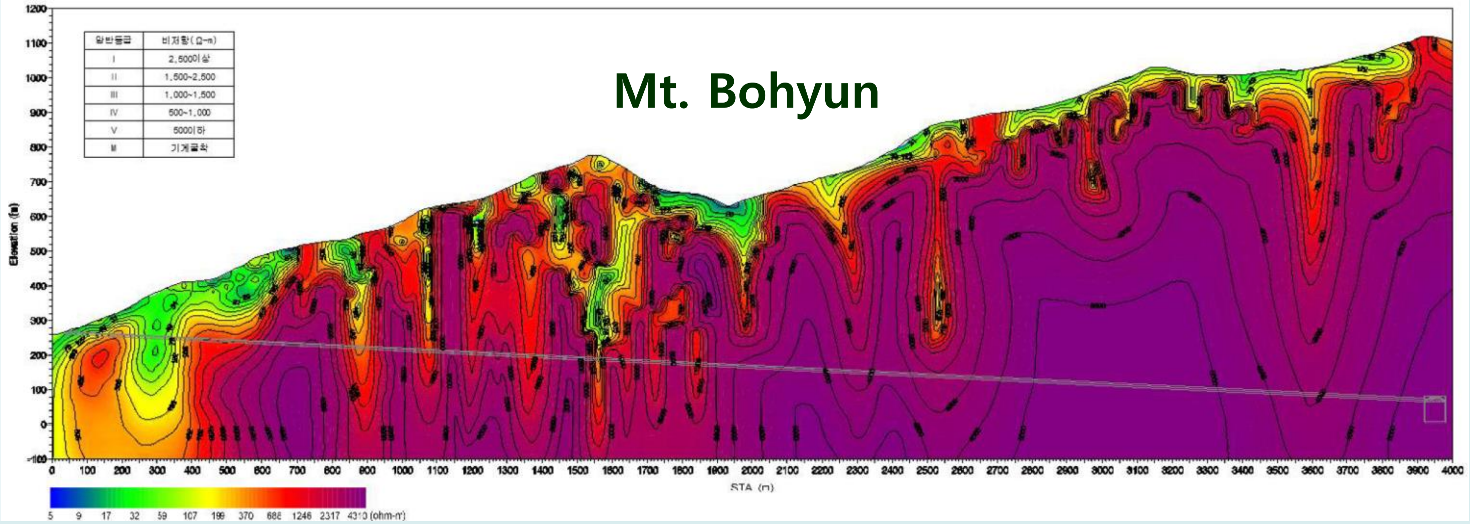




Bedrock Investigation of KNO Sites

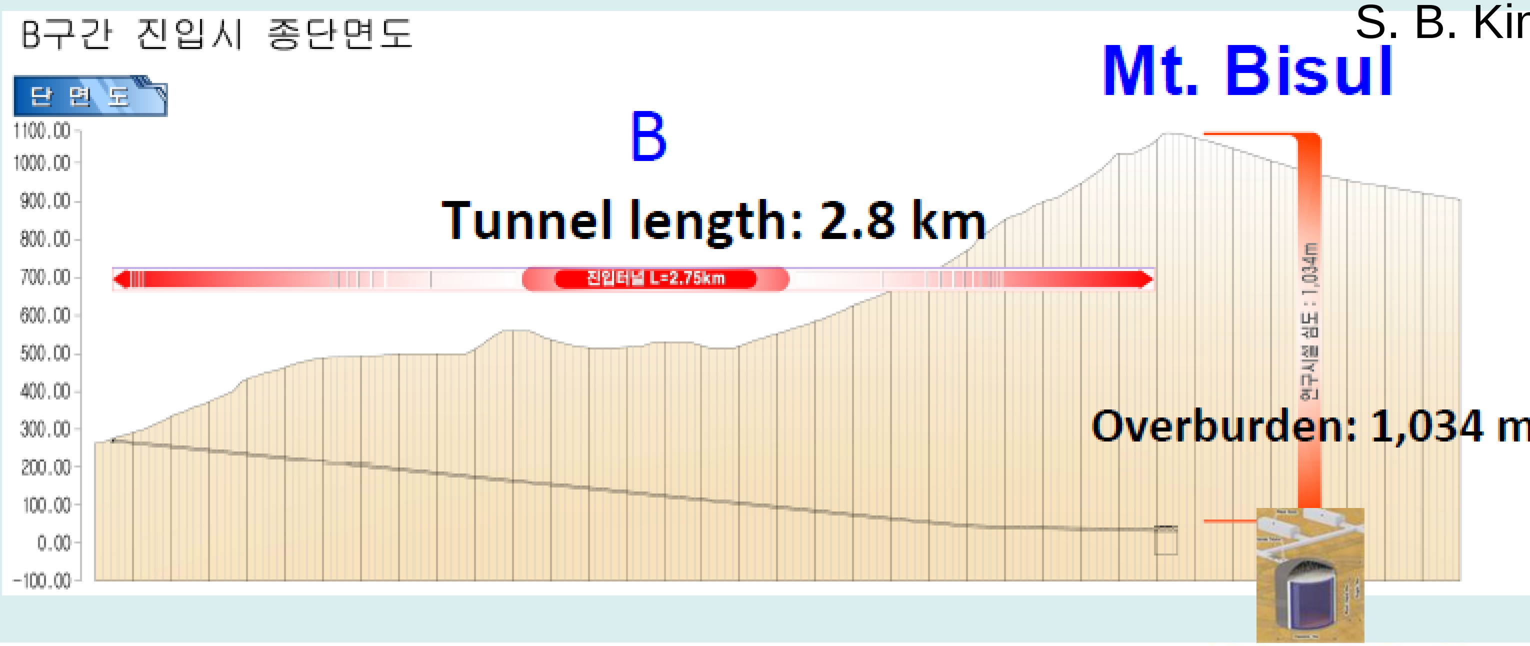
S. B. Kim (SNU)

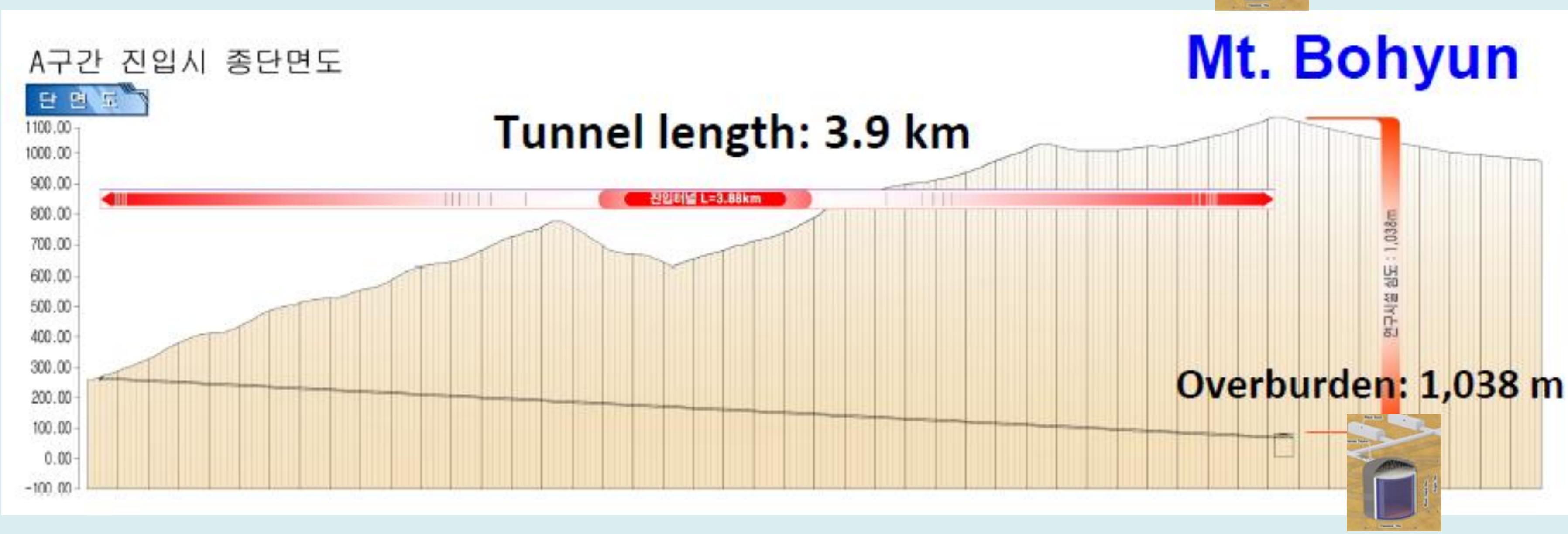




Conceptual Design of KNO Tunnel

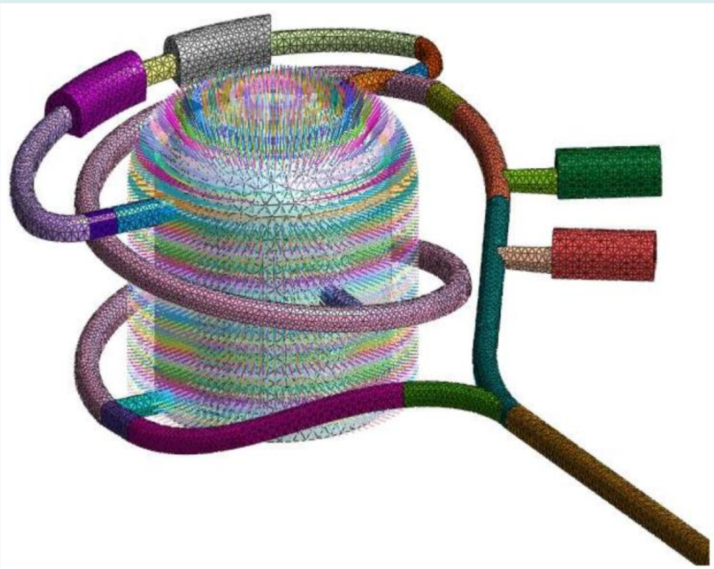
S. B. Kim (SNU)

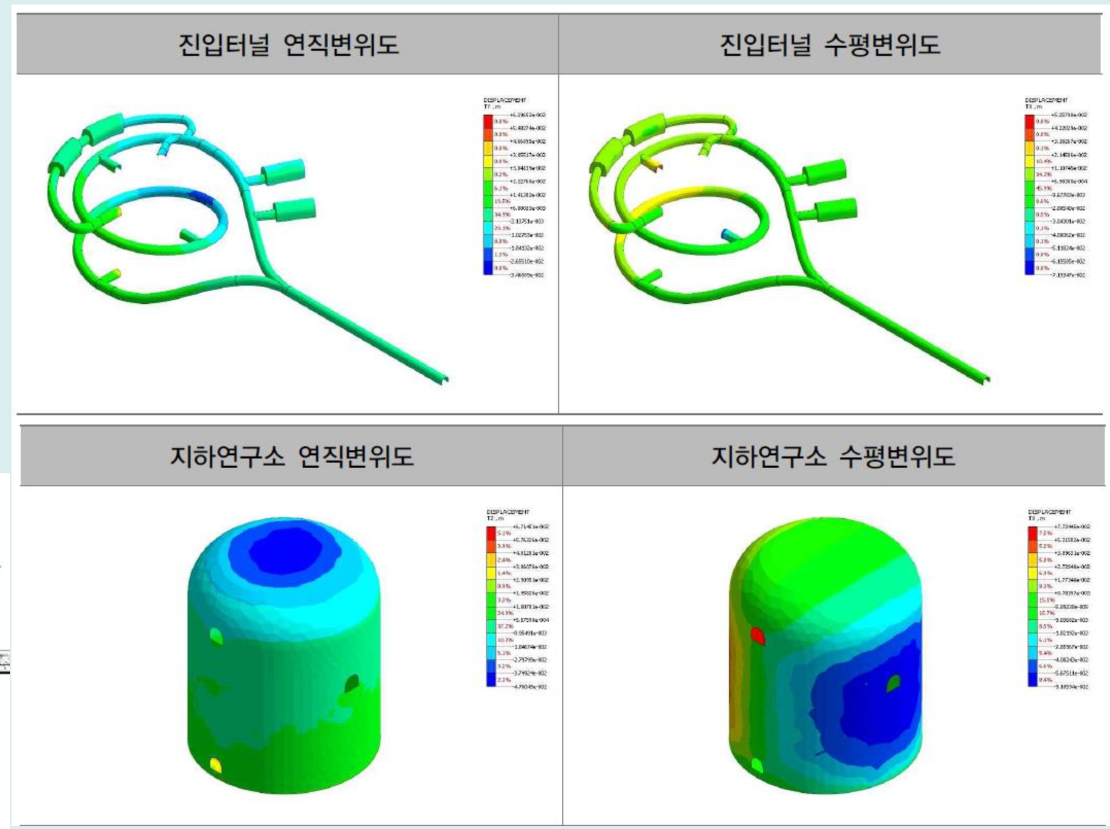


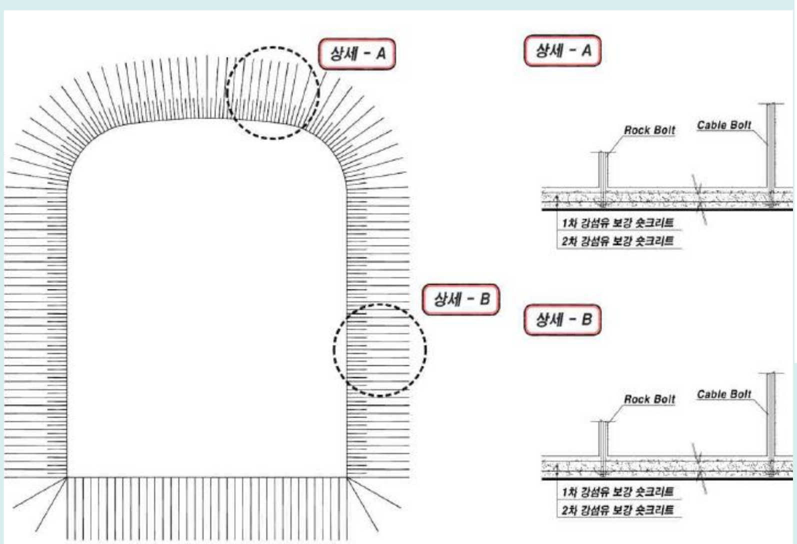


Stress Analysis and Reinforcement

S. B. Kim (SNU)







Activities on Detector R&D

- Two independent approaches of photo sensor R&D

- Development of conventional PMT
  - University of Seoul in collaboration with Korean company MECARO
  - Work on 3 inch PMT first and move to larger PMT

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

For details, see H.J. Kim's talk

Activities on Detector R&D

- Development of water purification system
  - Seoul National University in collaboration with Korean company DICOTECH
  - prototype construction of radon vacuum degassifier
  - development of high-sensitive radon measurement device

- Frontend electronics R&D
  - Korean company NOTICE sells FADC modules
  - preliminary evaluation in progress

For details, see H.J. Kim's talk

Activities on KNO Science

- Particle physics subgroup identifies potential KNO physics topics through workshops and seminars
  - organize Korean neutrino meetings
  - carry out sensitivity studies using simplified simulations (published in PTEP 2018)

- Astronomy subgroup is preparing for a white paper on KNO astronomy
  - list of potential KNO astronomy topics
  - emphasis on multi-messenger astronomy using neutrinos

For details, see M.G. Park's talk

Summary and Prospect

- KNO greatly enhances physics sensitivities in the measurements of leptonic CP violation, mass ordering, proton decay, NSI, and many others
- KNO also serves as a powerful neutrino telescope for multi-messenger astronomy
- KNO organization and working groups are formed and active
- Efforts on detector R&D and science are in progress
- KNO can be a flagship project for Korean HEP for the next 10 years

Thank you

BACK UP

Physics Sensitivity Studies

Simulation parameters

- 2.7×10^{22} POT with $\nu : \bar{\nu} = 1 : 3$ operation ratio

  → 10 years of operation with 1.3 MW beam

- 187 kton fiducial volume (compared to 22.5 kton for SK)
- Baseline to Korea is 1100 km
- Off-axis beam: 1.3°, 1.5°, 2.0°, 2.5°
- Oscillation parameters: →

$$|\Delta m^2_{32}| = 2.5\times10^{-3}\ \text{eV}$$
$$\sin^2\theta_{23} = 0.5$$
$$\sin^2 2\theta_{13} = 0.085$$
$$\Delta m^2_{21} = 7.53\times10^{-5}\ \text{eV}$$
$$\sin^2\theta_{12} = 0.304$$
$$\delta_{cp} = 0, \pi/2, \pi, 3\pi/2$$

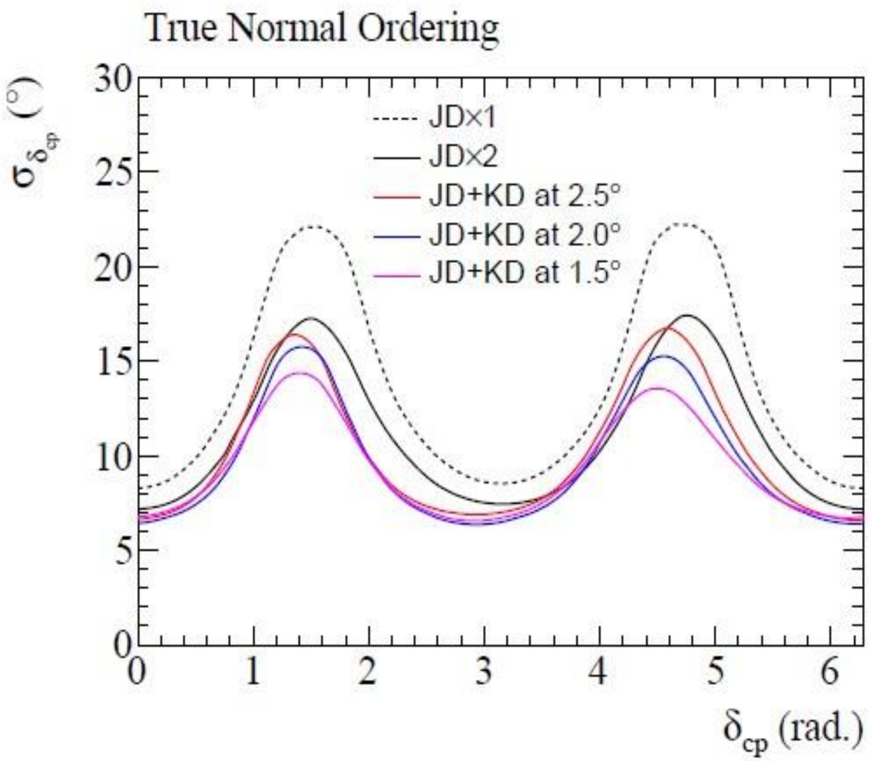
Systematic Error Model

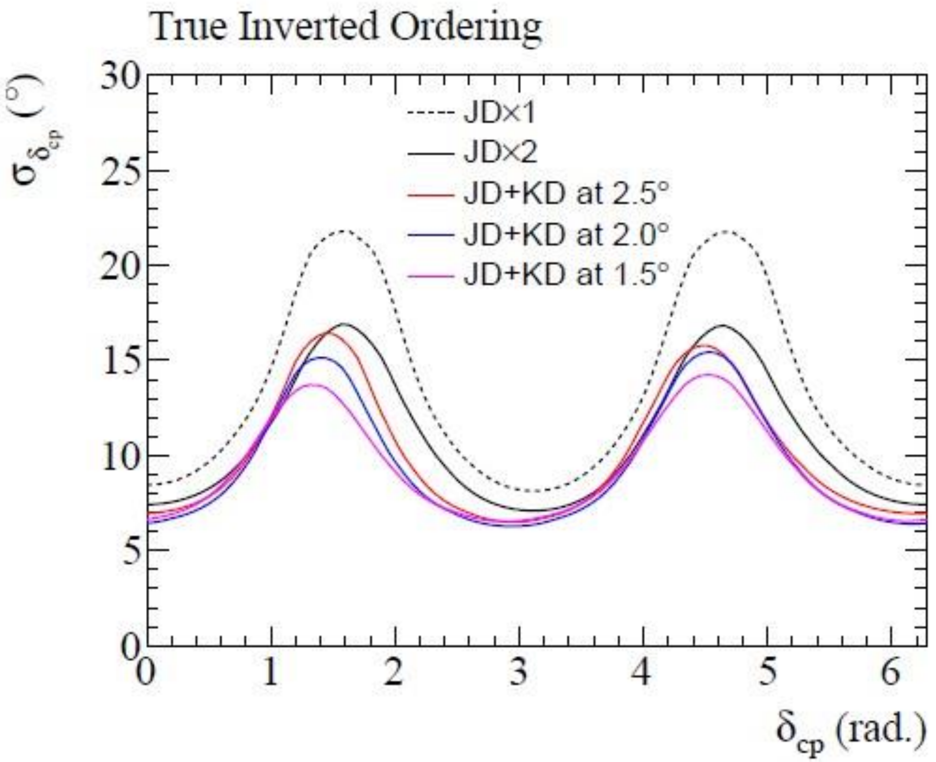
- Use a simplified error model in the simulation

- Total error is slightly larger than those in the Hyper-K design report.
(KEK Preprint 2016-21)

Error Source	Percent Error (%)				
	ν 1Rμ	$\bar{\nu}$ 1Rμ	ν 1Re	$\bar{\nu}$ 1Re	(ν 1Re)/($\bar{\nu}$ 1Re)
OAA=2.5°, $L = 1100$ km					
$\sigma_{\nu_e}/\sigma_{\nu_\mu}$, $\sigma_{\bar{\nu}_e}/\sigma_{\bar{\nu}_\mu}$	0.00	0.00	2.10	1.68	3.12
Energy Scale	0.02	0.02	0.01	0.01	0.01
Matter Density	0.04	0.08	0.43	0.09	0.53
NCπ^+ Bgnd.	1.28	1.25	0.00	0.00	0.00
ν_e & NCπ^0 Bgnd.	0.00	0.00	1.32	1.41	1.88
CC non-QE Fraction	2.76	1.88	1.98	1.29	2.35
Extrapolation	2.70	2.60	2.44	3.06	1.95
Far Detector Model	2.64	2.64	2.08	2.08	0.00
Total	4.69	4.16	4.54	4.47	4.86
OAA=2.0°, $L = 1100$ km					
$\sigma_{\nu_e}/\sigma_{\nu_\mu}$, $\sigma_{\bar{\nu}_e}/\sigma_{\bar{\nu}_\mu}$	0.00	0.00	2.01	1.67	3.07
Energy Scale	0.02	0.01	0.01	0.01	0.01
Matter Density	0.02	0.06	0.55	0.12	0.67
NCπ^+ Bgnd.	1.47	1.29	0.00	0.00	0.00
ν_e & NCπ^0 Bgnd.	0.00	0.00	1.26	1.29	1.76
CC non-QE Fraction	0.87	0.82	1.24	0.76	1.51
Extrapolation	2.68	2.68	2.38	3.00	1.92
Far Detector Model	2.64	2.64	2.08	2.08	0.00
Total	3.89	3.83	4.18	4.27	4.39
OAA=1.5°, $L = 1100$ km					
$\sigma_{\nu_e}/\sigma_{\nu_\mu}$, $\sigma_{\bar{\nu}_e}/\sigma_{\bar{\nu}_\mu}$	0.00	0.00	1.72	1.41	2.67
Energy Scale	0.01	0.01	0.01	0.01	0.01
Matter Density	0.01	0.06	0.24	0.28	0.53
NCπ^+ Bgnd.	1.61	1.30	0.00	0.00	0.00
ν_e & NCπ^0 Bgnd.	0.00	0.00	1.42	1.37	1.93
CC non-QE Fraction	0.44	0.30	0.52	0.37	0.75
Extrapolation	2.67	2.60	2.23	2.88	1.84
Far Detector Model	2.64	2.64	2.08	2.08	0.00
Total	3.83	3.81	3.84	4.11	3.91
OAA=2.5°, $L = 295$ km					
$\sigma_{\nu_e}/\sigma_{\nu_\mu}$, $\sigma_{\bar{\nu}_e}/\sigma_{\bar{\nu}_\mu}$	0.01	0.00	2.44	1.82	3.53
Energy Scale	0.04	0.03	0.42	0.63	0.21
Matter Density	–	–	–	–	–
NCπ^+ Bgnd.	2.33	1.79	0.00	0.00	0.00
ν_e & NCπ^0 Bgnd.	0.00	0.00	0.94	1.22	1.51
CC non-QE Fraction	1.68	1.72	2.07	1.00	2.25
Extrapolation	2.60	2.56	2.51	3.05	1.96
Far Detector Model	2.64	2.64	2.08	2.08	0.00
Total	4.13	4.15	4.71	4.47	4.90
OAA=2.5°, $L = 295$ km (Hyper-K Design Report)					
Total	3.6	3.6	3.2	3.9	–

Physics Potential at KNO: $\sigma_{\delta cp}$





JD+KD at 1.5° gives the best precision on δ_{cp} measurement

KNO Strategy