Korea Neutrino Observatory (KNO) Report

Intae Yu

Sunkyunkwan University

Aug. 30, 2019

Kamiokande (1983-1996)

3000 ton

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

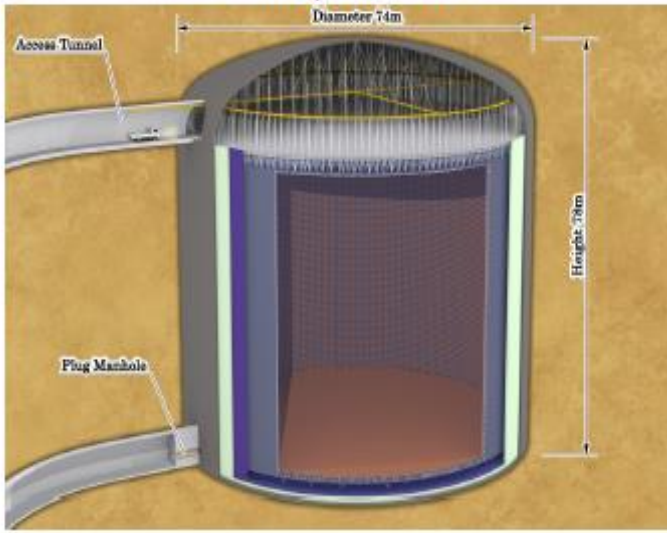
Super-Kamiokande (1996-)

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 (∼2026-)

2×260,000 ton

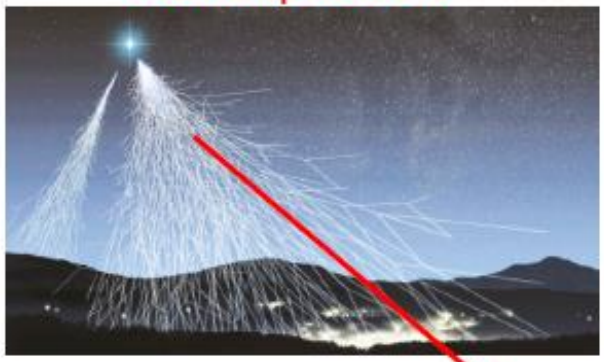


Physics programme:

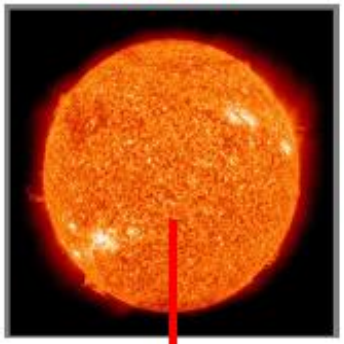
- Neutrino oscillations: Mass Hierarchy, Leptonic CP violation, θ_{23} Octant,...
- Nucleon decay: $p \to e^+\pi^0$, $p \to K^+\bar{\nu}$,...
- Neutrino astrophysics: Solar neutrinos, Supernova neutrinos, WIMP searches

Overview of Hyper-K Physics

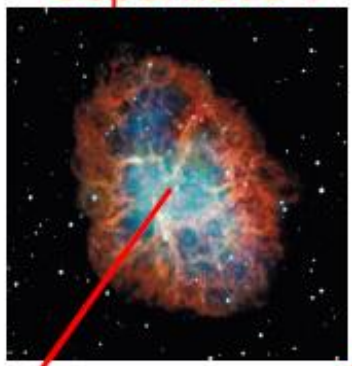
Atmospheric ν



Solar ν

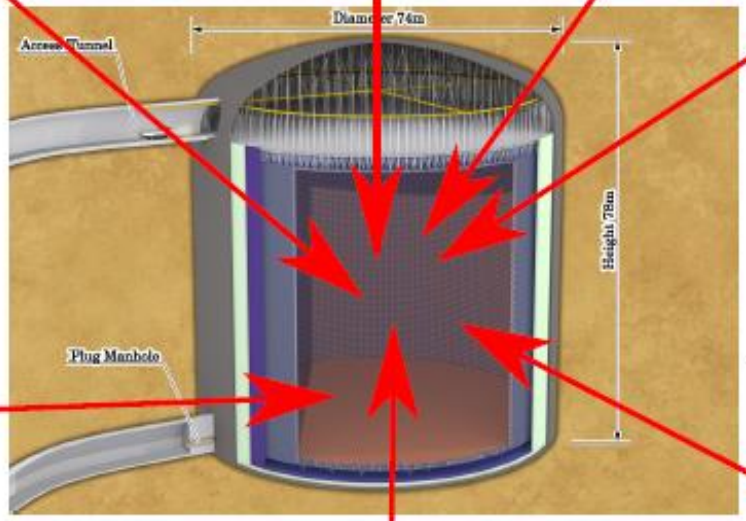


Supernova ν

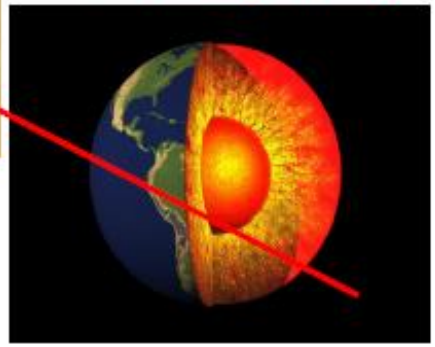


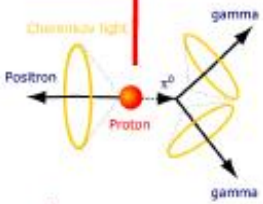
WIMP χχ -> νν

Beam ν



ν Tomography

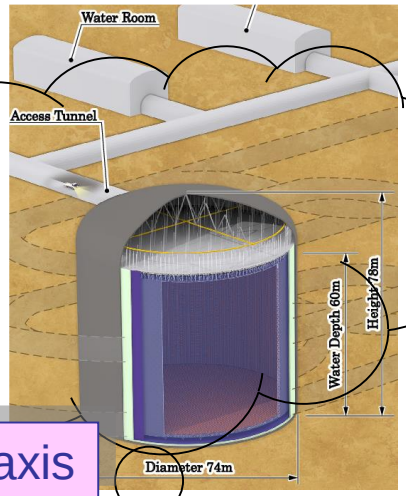




Nucleon Decay

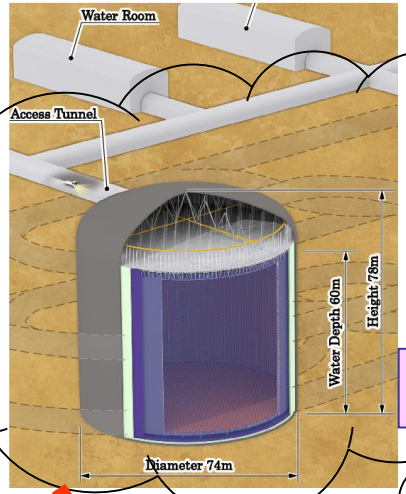
Neutrino Detector in Korea

KNO



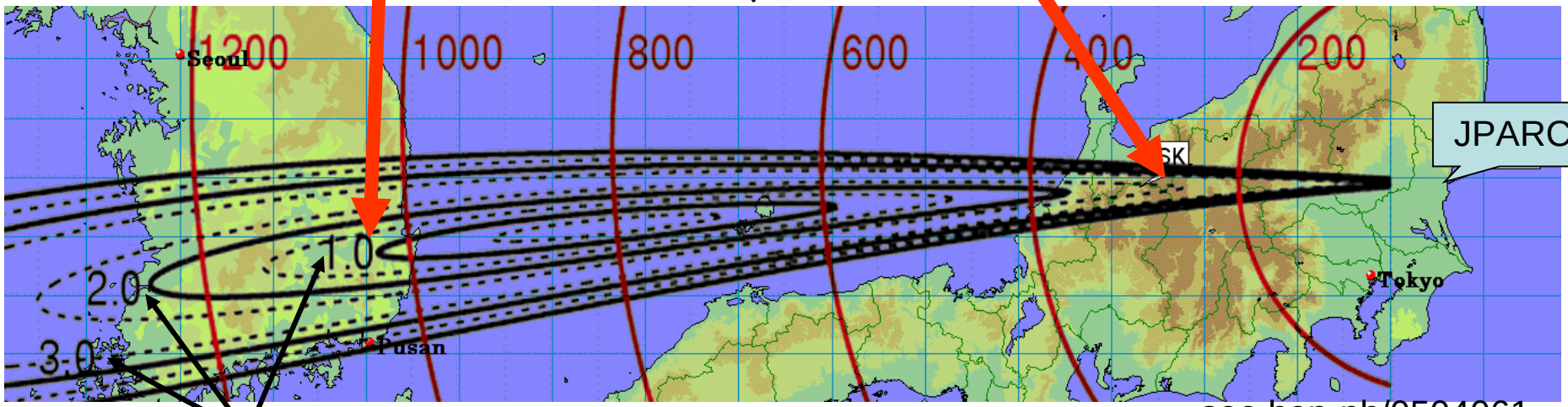
1.5 deg. off axis

Hyper-K



2.5 deg. off axis

The J-PARC ν_μ beam comes to Korea.



Off-axis angle

see hep-ph/0504061

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

Pros and Cons of KNO

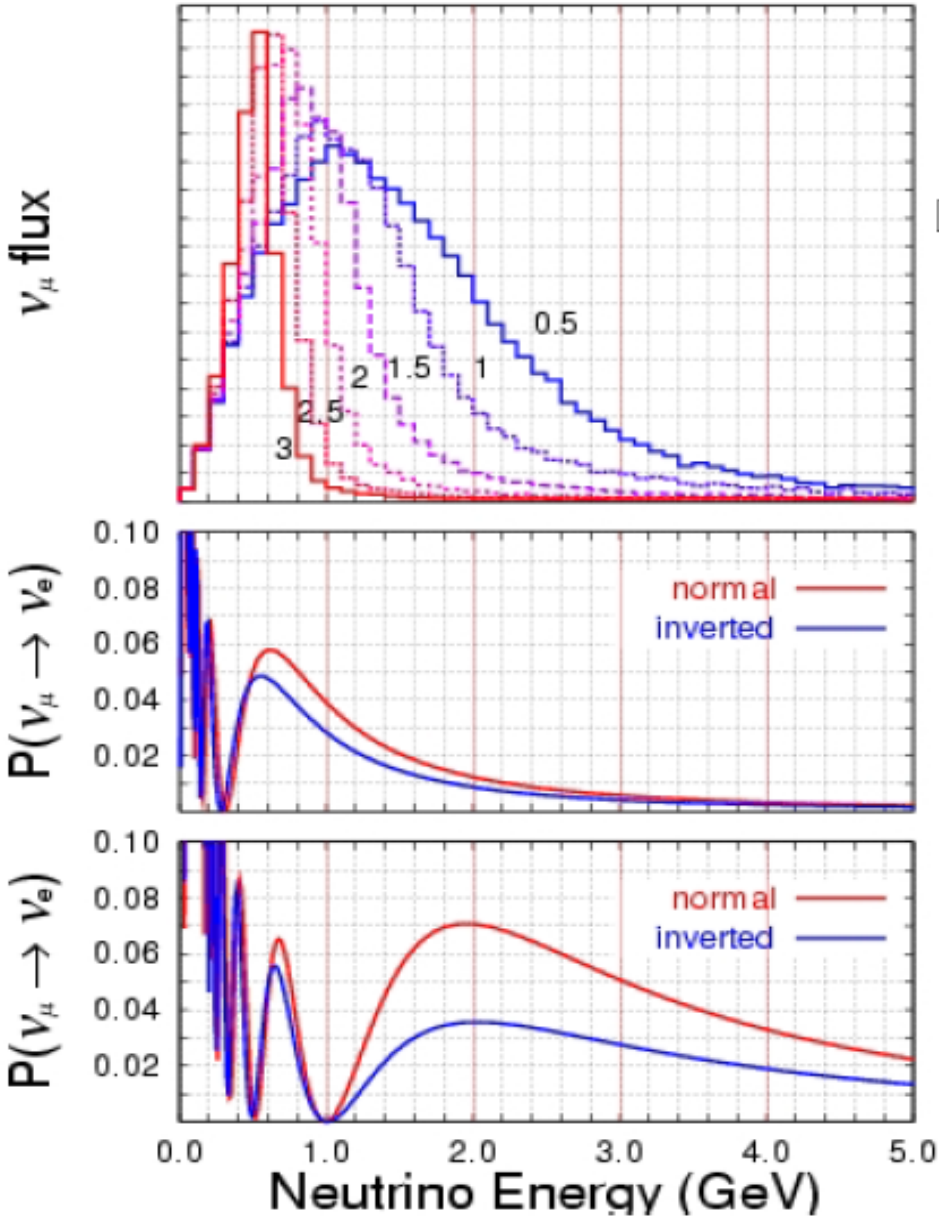
- Pros

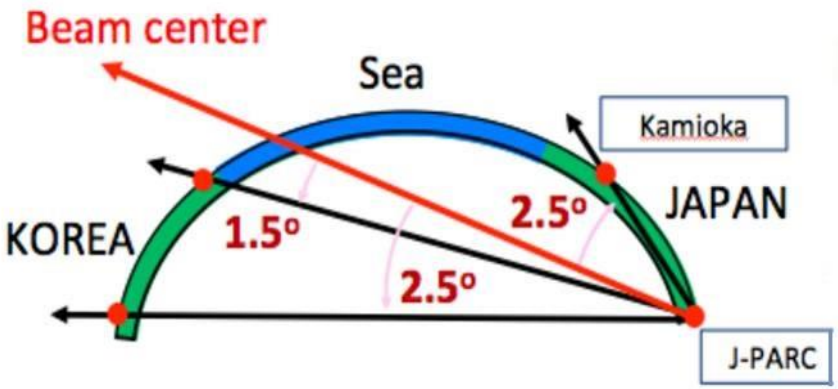
- 1st and 2nd oscillation maxima at KNO → more sensitive to leptonic CP violation
- Higher mass density and longer baseline (~1000 km) → better determination of neutrino mass hierarchy and better sensitivity to non-standard neutrino interactions
- Larger overburden (~1000 m) → better sensitivity to neutrinos 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



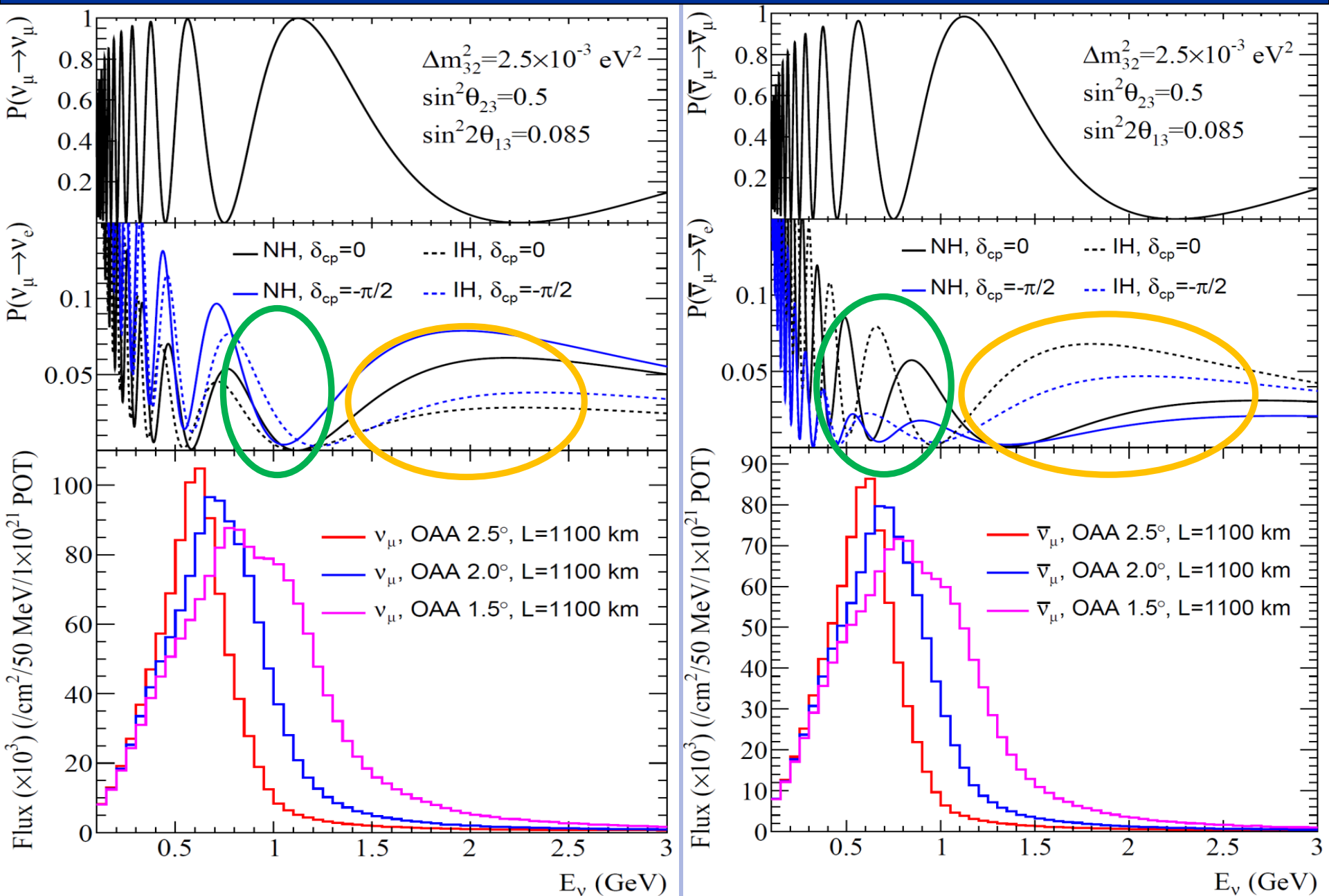


← Profile of off-axis beams

← $P(\nu_\mu \to \nu_e)$ at SK

← $P(\nu_\mu \to \nu_e)$ at Korea (L=1000km)

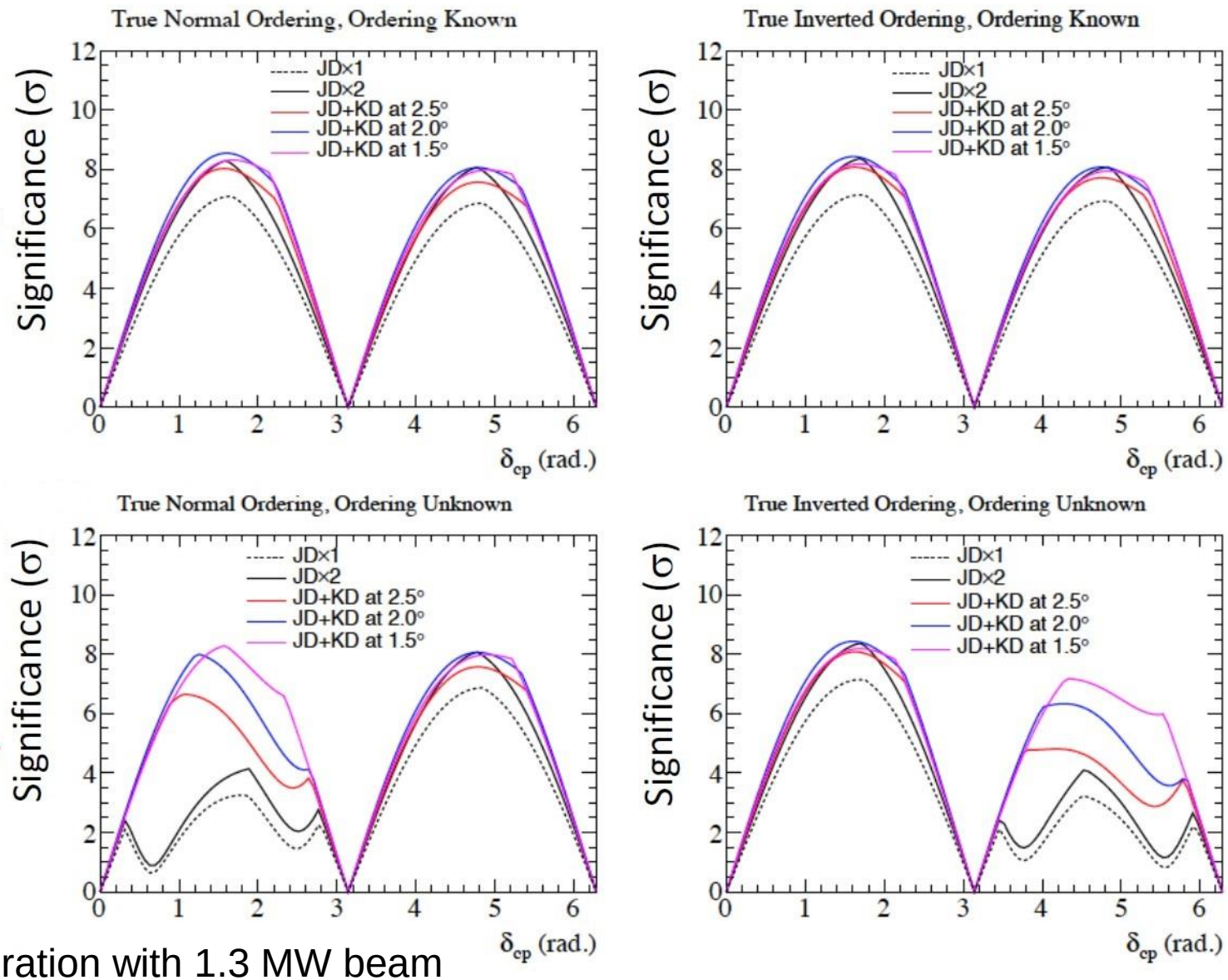
1st and 2nd Oscillation Maxima in Korea



Physics Potential at KNO: δ_{cp}

Known MO

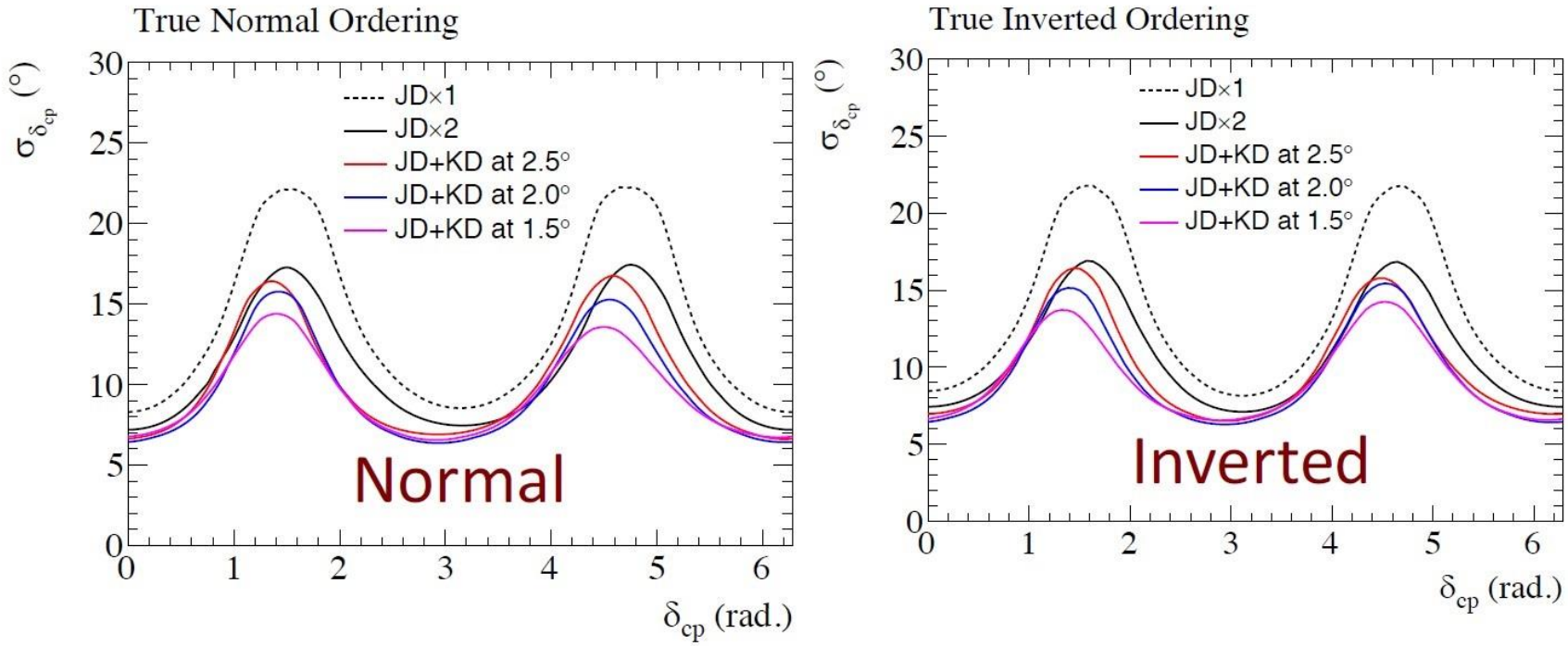
Unknown MO



10 years of operation with 1.3 MW beam

Physics Potential at KNO: δ_{cp} Precision

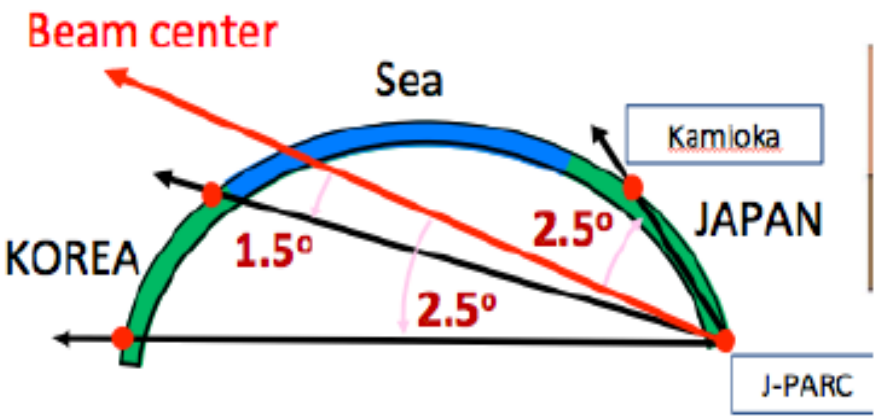
→ Very important for flavor symmetry model of neutrino mixing
S. Petcov in ICHEP 2018

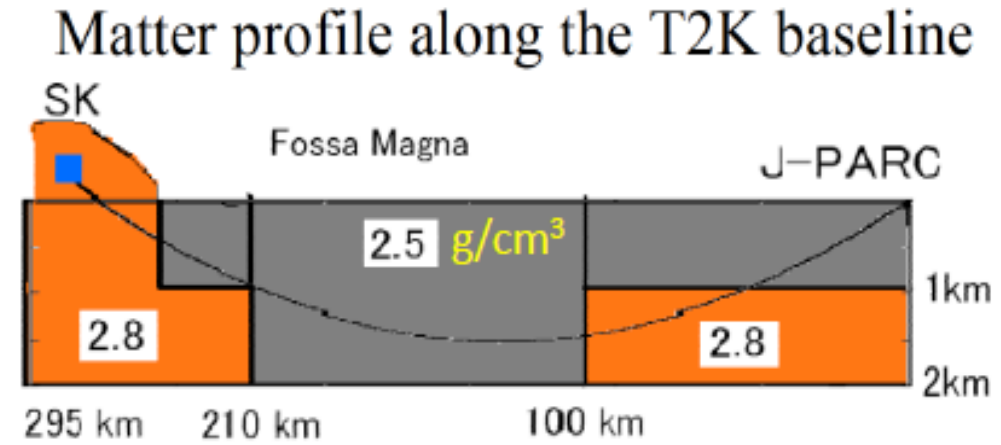


At maximum CP violation: JD+KD 1.5°: $\sigma(\delta_{CP})$ = 13~14 degree
JD x 2 : $\sigma(\delta_{CP})$ ~ 17 degree
JD x 1 : $\sigma(\delta_{CP})$ ~ 22 degree

10 years of operation with 1.3 MW beam

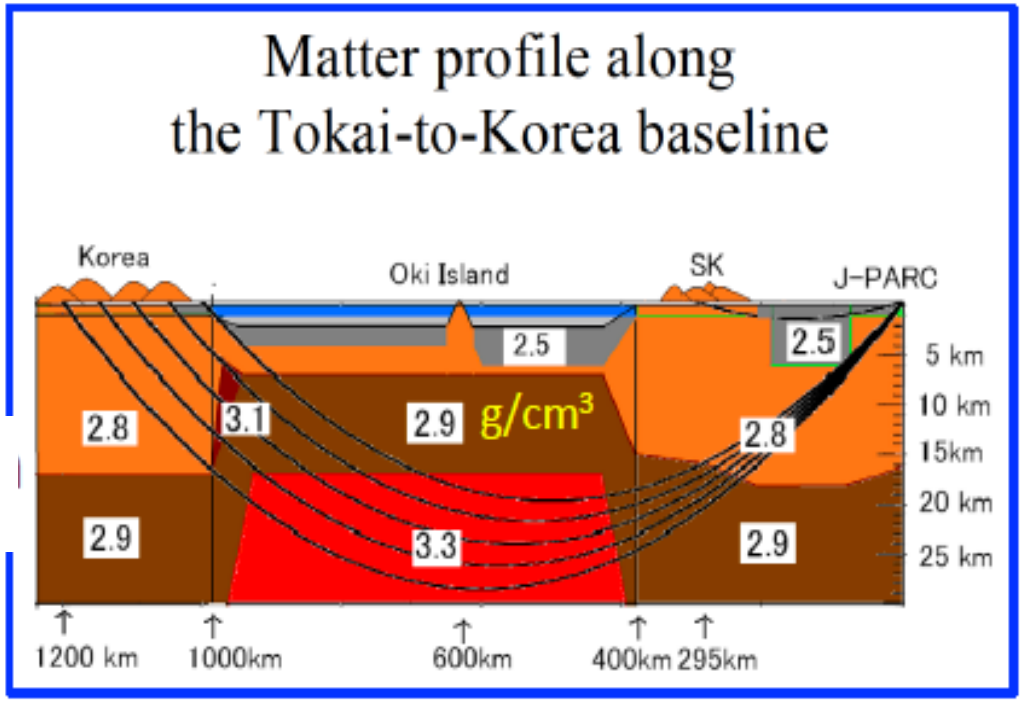
Matter Density Profile





Matter density:

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



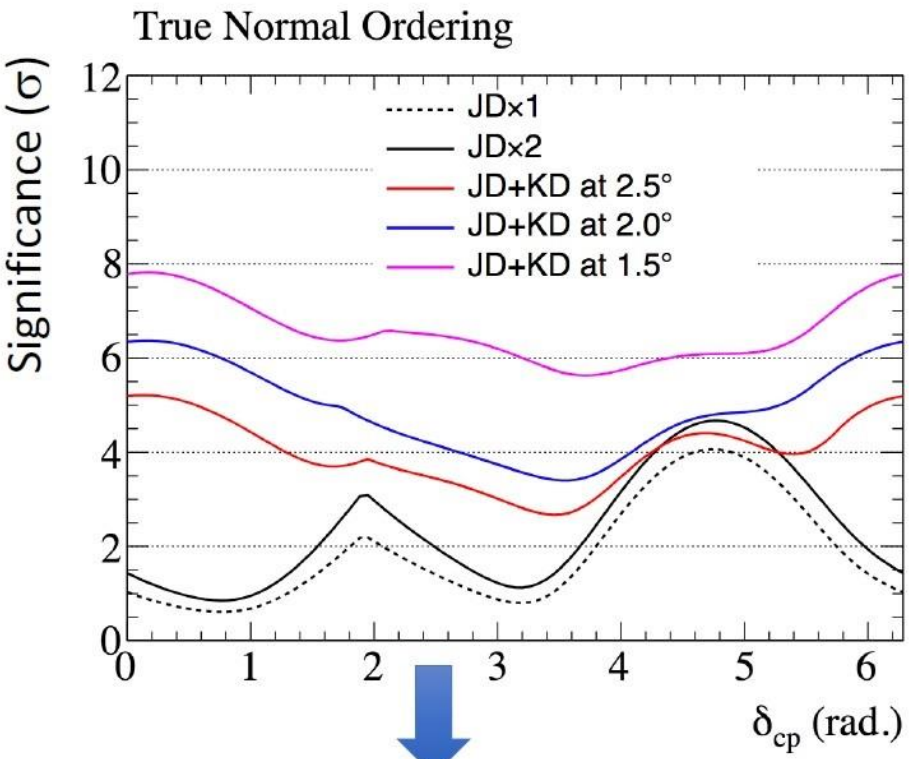
More matter effects

→ Better Measurement of Neutrino Mass Ordering

- Longer baseline
- Higher matter density
- Higher neutrino energy

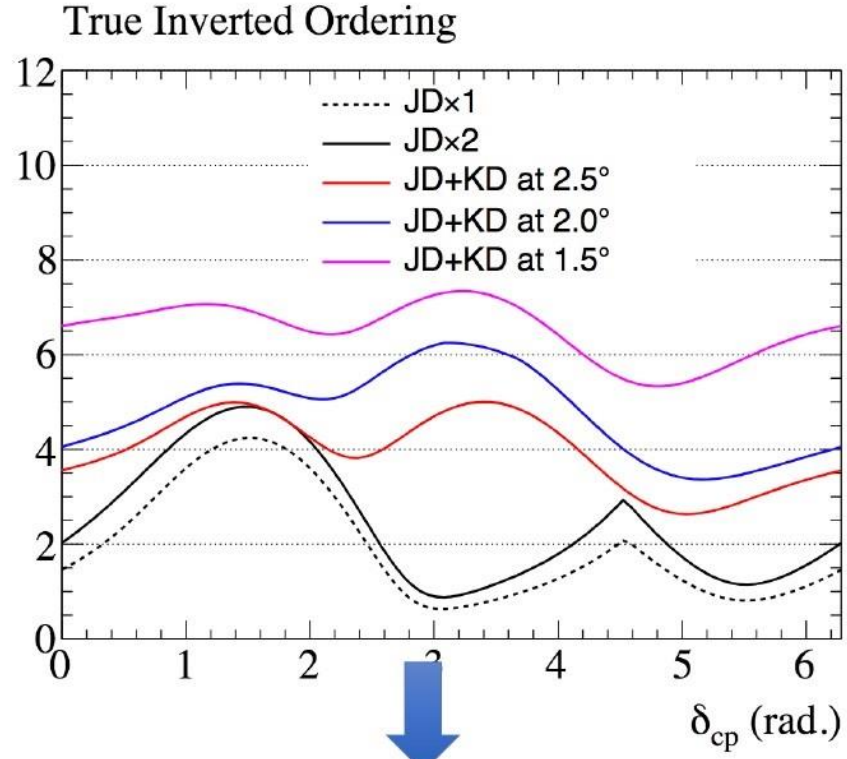
Physics Potential at KNO: Mass Ordering

Normal



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

Inverted

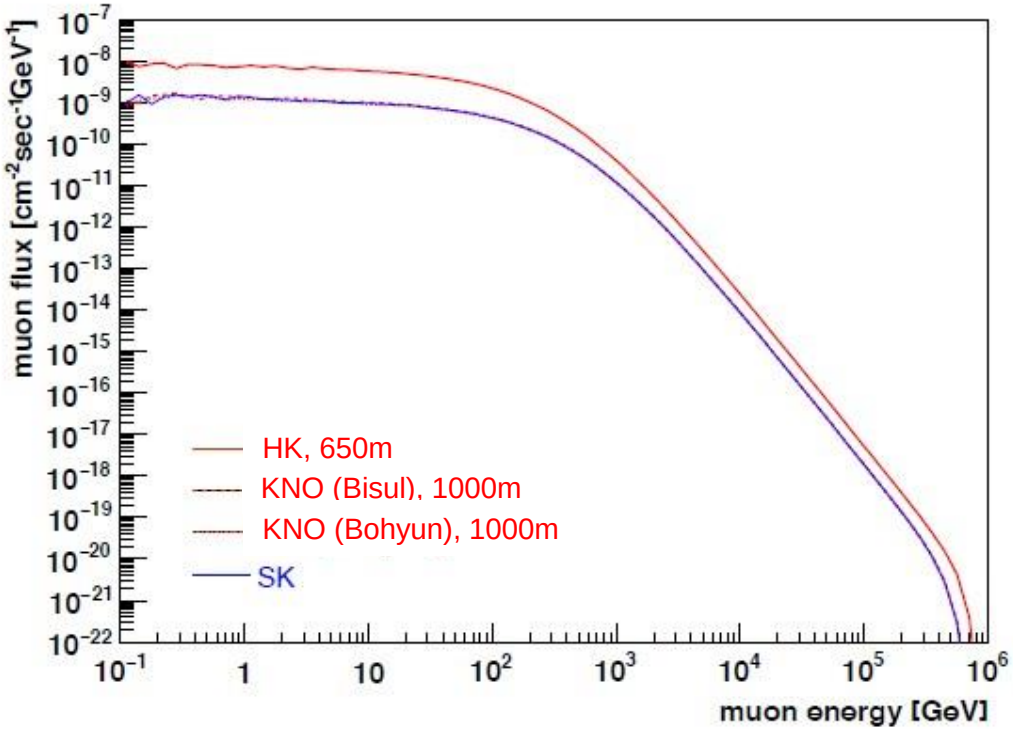


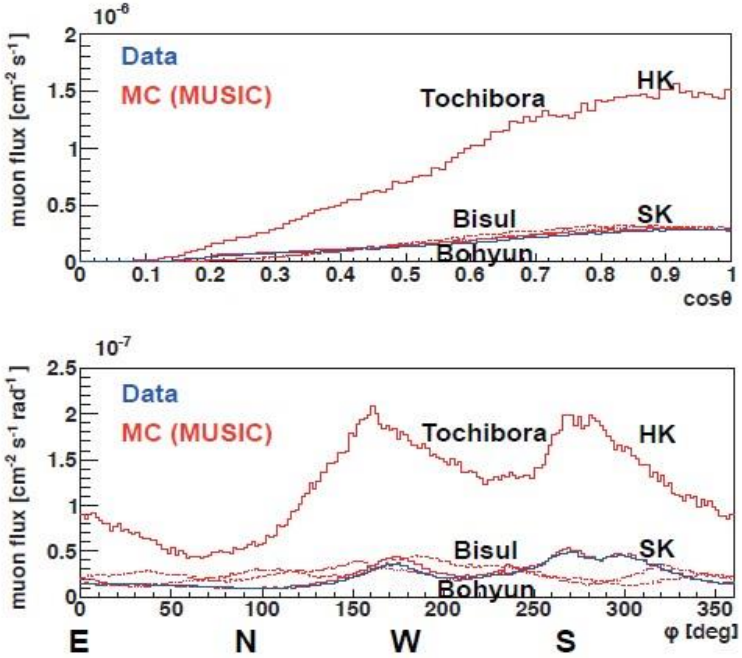
JD+KD 1.5°: 5.5 ~ 7 σ for all δ_{CP}
JD x2 : 1 ~ 5 σ for all δ_{CP}
(< 3 σ for most cases)

10 years of operation with 1.3 MW beam

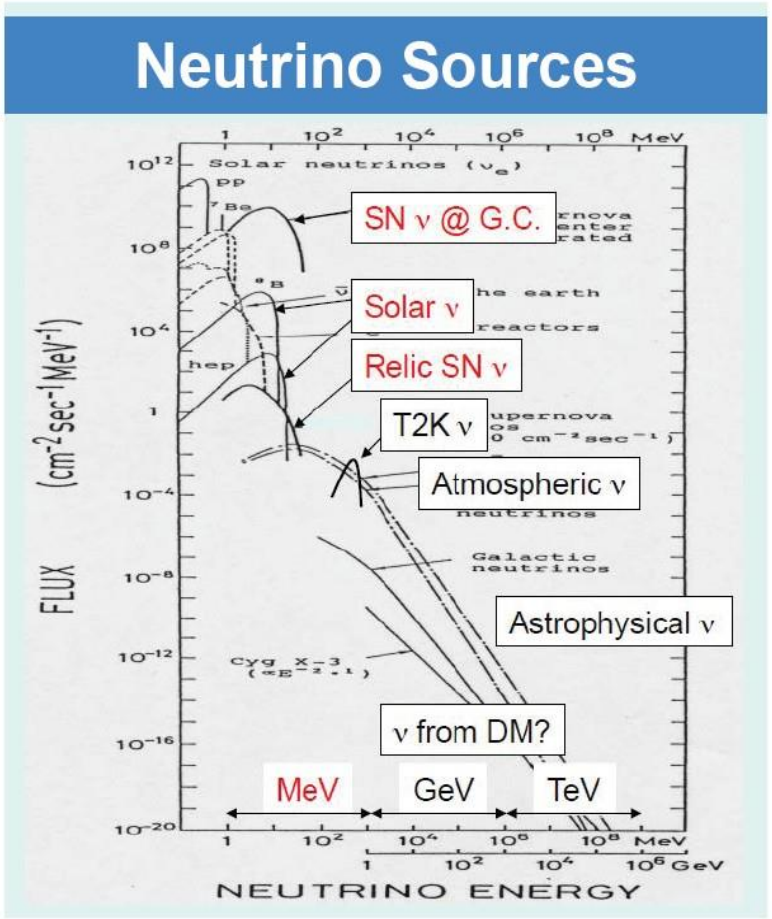
Cosmogenic Muon Flux

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

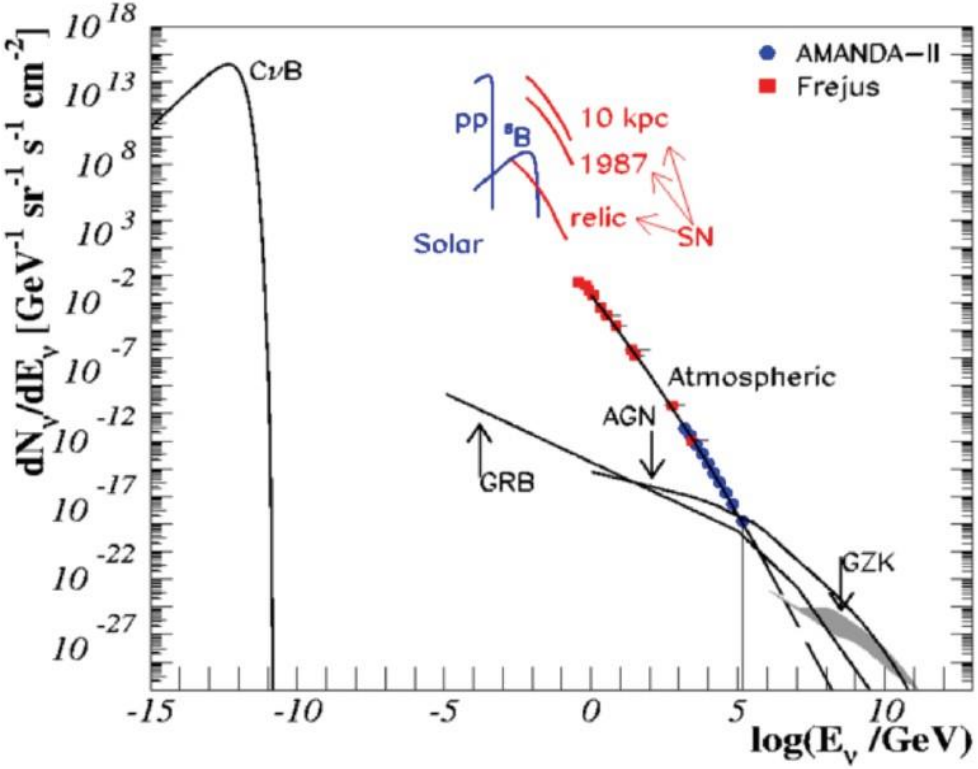




Neutrinos of Astronomical Origins



Astrophysical Neutrinos



GRB/AGN as neutrino sources in the energetic jet via

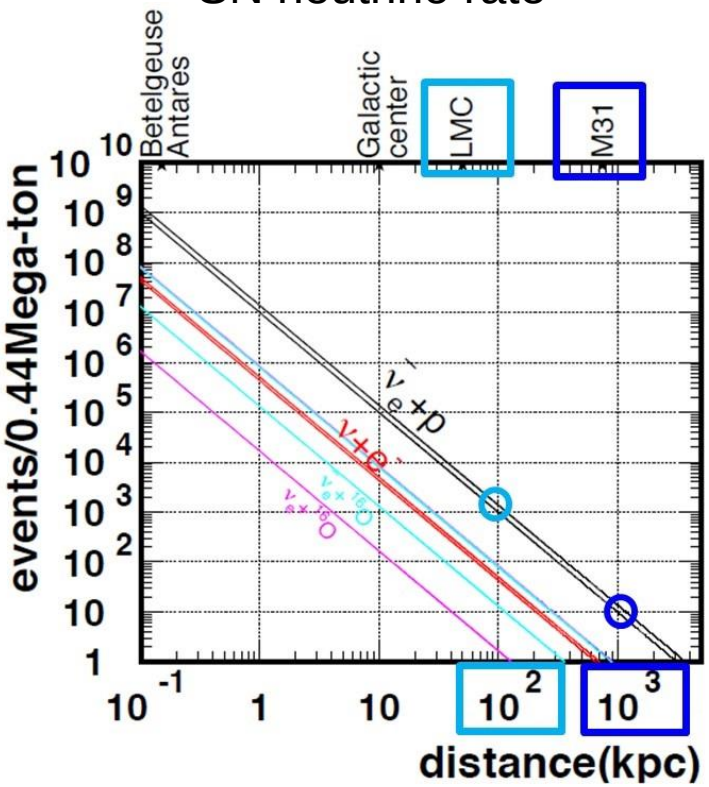
$$p + \gamma \rightarrow \Delta^+ \rightarrow \pi^+ + n \rightarrow e^+ + \nu_e + \bar{\nu}_\mu + \nu_\mu + n.$$

Halzen, Francis Nuovo Cim. C037 (2014) no.03, 117-132, Astron.Nachr. 335 (2014) 507

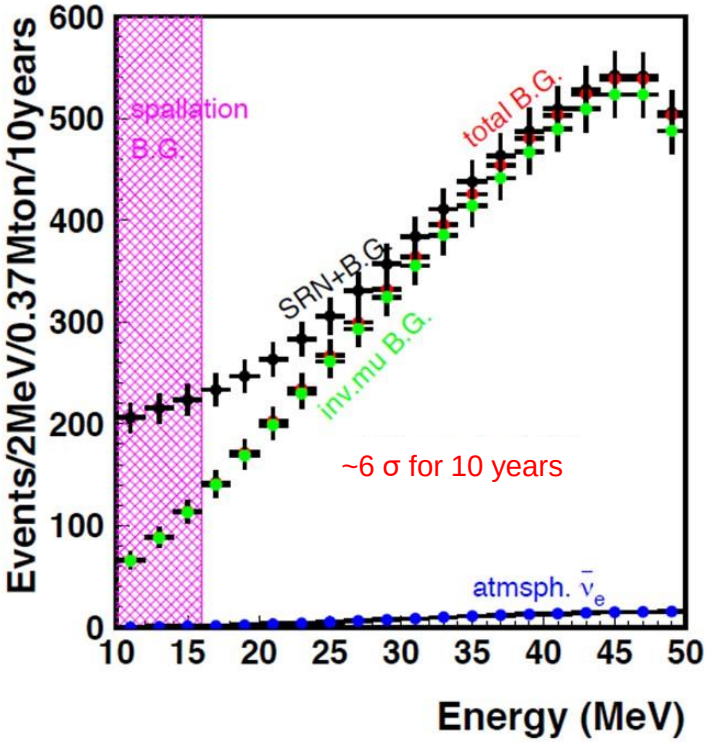
Neutrinos from Super Nova

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

SN neutrino rate



SRN spectrum

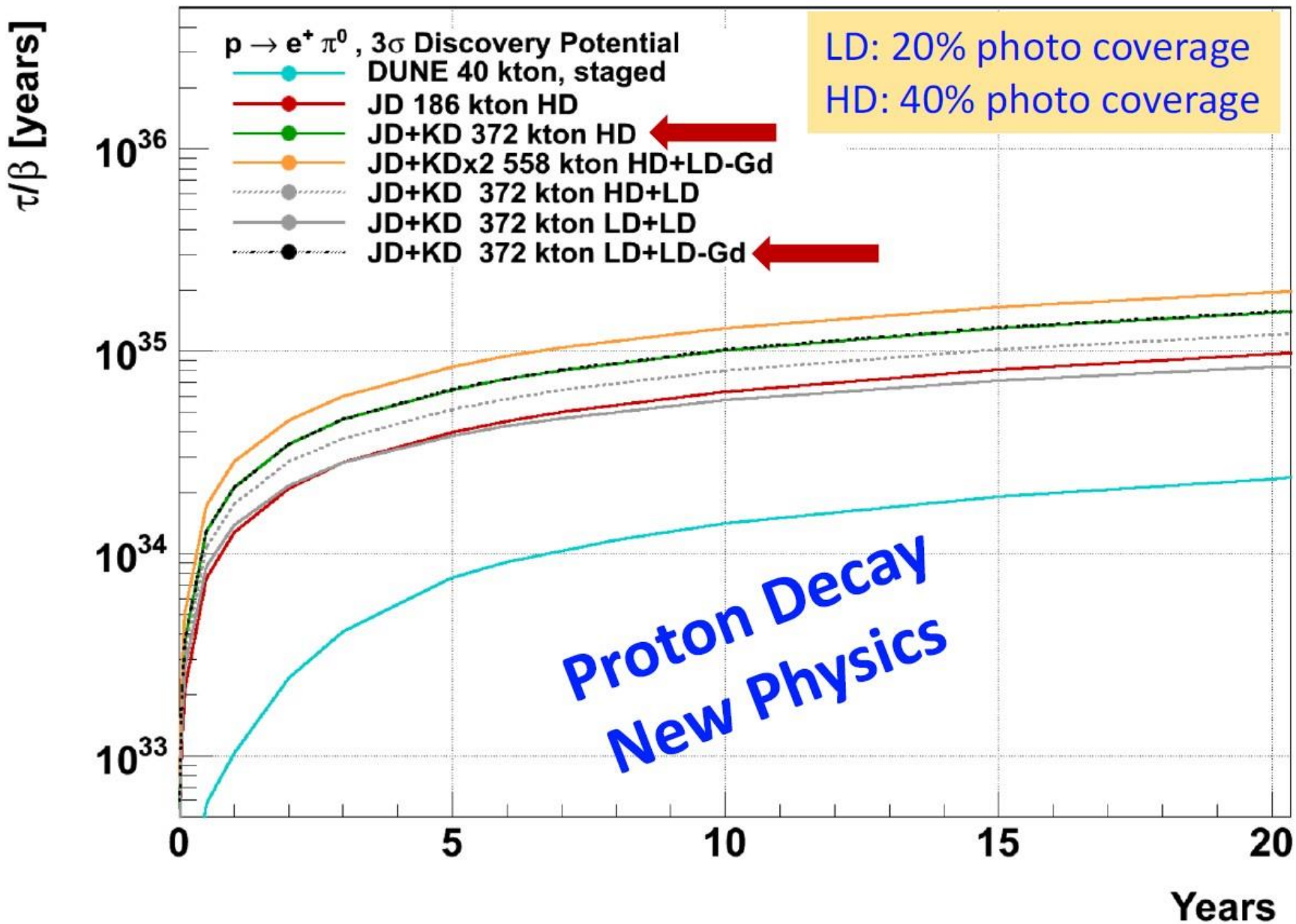


Neutrinos from Other Astronomical Sources

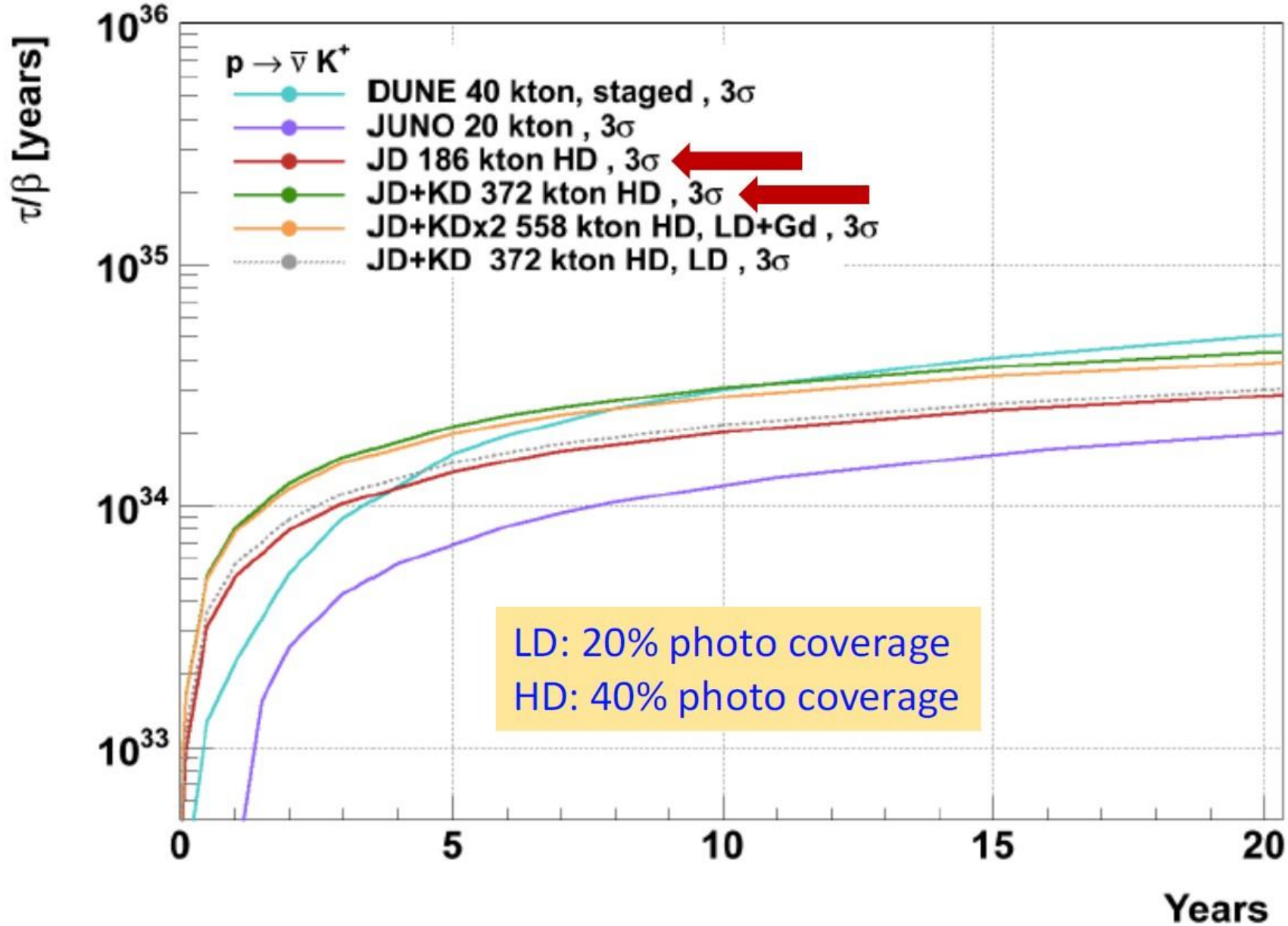
- Neutrinos from active galactic nuclei and microquasars
- Neutrinos from interactions of cosmic protons and nuclei in the Galaxy
- Neutrinos from gamma-ray bursts (GRB)
- Neutrinos from clusters of galaxies
- Neutrinos from dark matter decays
- Solar Neutrinos

Multi-Messenger Astronomy

Discovery Potential for $p \rightarrow e^+\pi^0$ Decay



Discovery Potential for p → νK Decay



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.
→ 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
→ present a proposal to the HK collaboration
→ 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: 4th KNO Workshop @ NUFACT 2019 (KNU)

KNO Workshop : Satellite Meeting of NUFACT 2019 (2019. 8.25)

12:00	**Registration: (KNO Workshop)**	*1F Lobby , The Grand Hotel Daegu*	12:00 - 12:50
	Opening Remarks	*Dongchul Son*	
	Regency Hall (LL/B1F), The Grand Hotel Daegu		12:50 - 13:00
13:00	**Review of Neutrino Experiments in Korea**	*Kyung Kwang Joo*	
	Regency Hall (LL/B1F), The Grand Hotel Daegu		13:00 - 13:30
	Overview of Korean Neutrino Observatory (KNO) Project	*Intae Yu*	
	Regency Hall (LL/B1F), The Grand Hotel Daegu		13:30 - 14:00
14:00	**Hyper-Kamiokande Project**	*Carsten Rott*	
	Regency Hall (LL/B1F), The Grand Hotel Daegu		14:00 - 14:30
	Tea Time		
	Dynasty hall (2F), The Grand Hotel Daegu		14:30 - 14:50
	Particle Physics at KNO	*Seon-Hee Seo*	
15:00	*Regency Hall (LL/B1F), The Grand Hotel Daegu*		14:50 - 15:20
	Astronomy at KNO	*Myeong-Gu Park*	
	Regency Hall (LL/B1F), The Grand Hotel Daegu		15:20 - 15:50
	KNO Detector R&D	*HongJoo Kim*	
16:00	*Regency Hall (LL/B1F), The Grand Hotel Daegu*		15:50 - 16:20
	Tea Time		
	Dynasty hall (2F), The Grand Hotel Daegu		16:20 - 16:40
	Panel Discussion for Future Efforts and Plans		
17:00	*Regency Hall (LL/B1F), The Grand Hotel Daegu*		16:40 - 17:30

Korean Efforts on KNO Realization

- 2018. 10. 20: Kick-off Meeting for KNO organization
- Five working groups were formed in the meeting
- Geological surveys were done for KNO candidate sites
- Detector R&D work is in progress
- Several options for KNO detector are being considered
- Discussions with Korean government have been started
- Korean efforts are in very early stage

Working Groups of KNO Organization

- Government Relations Working Group
  contact and discussions with government and funding agency

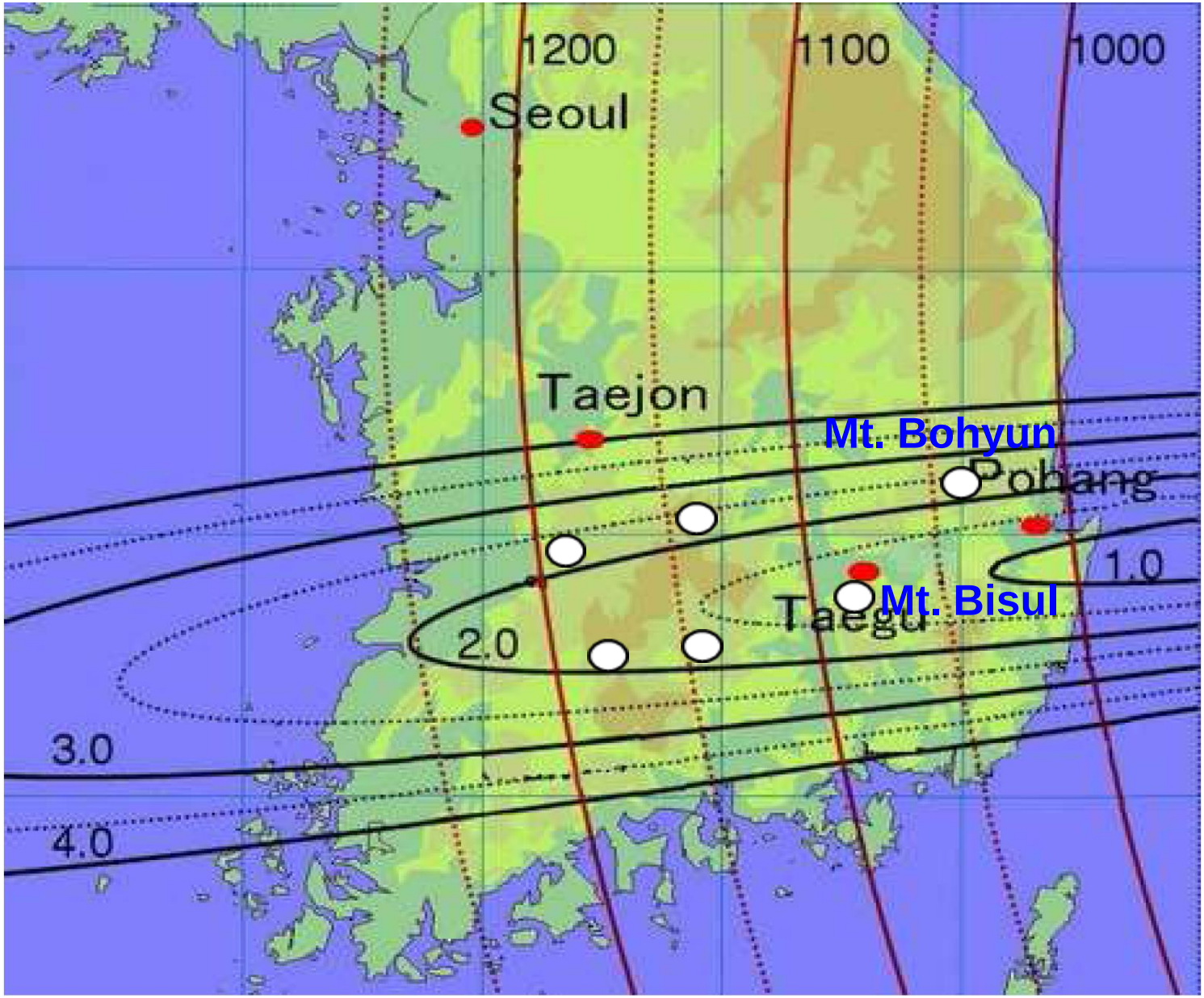
- Detector R&D Working Group
  photo sensor, water purification, electronics, and etc

- 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

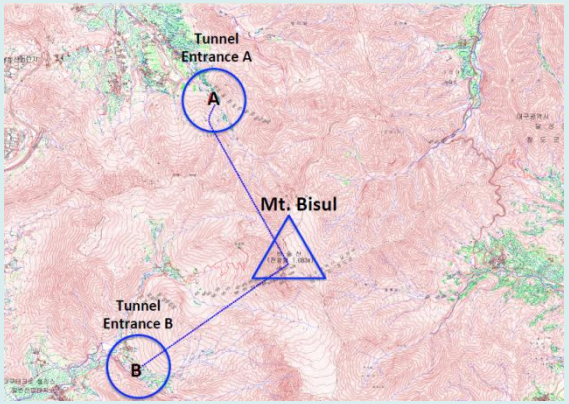
S. B. Kim (SNU)

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

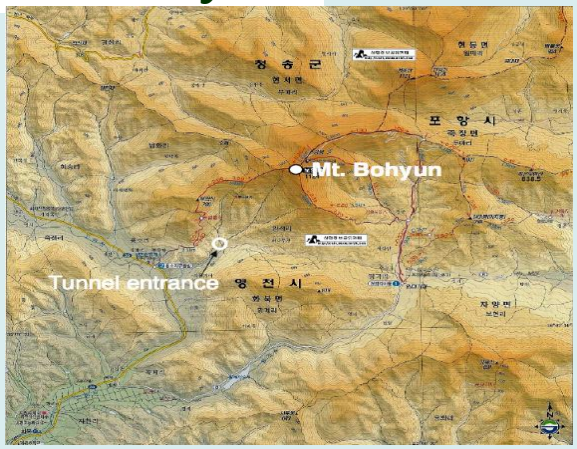
KNO Candidate Sites – Mt. Bisul and Mt. Bohyun

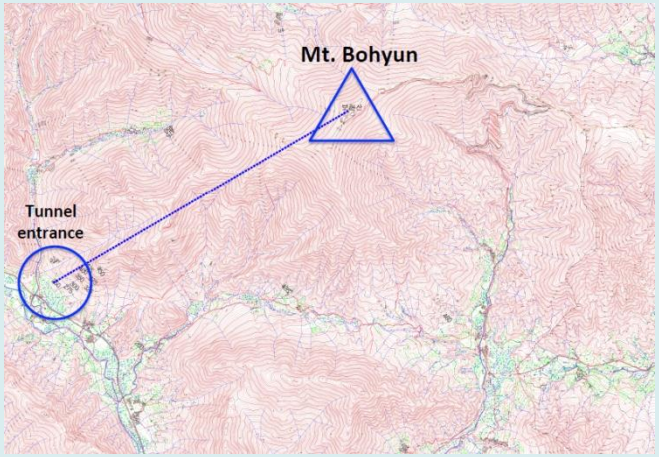
S. B. Kim (SNU)

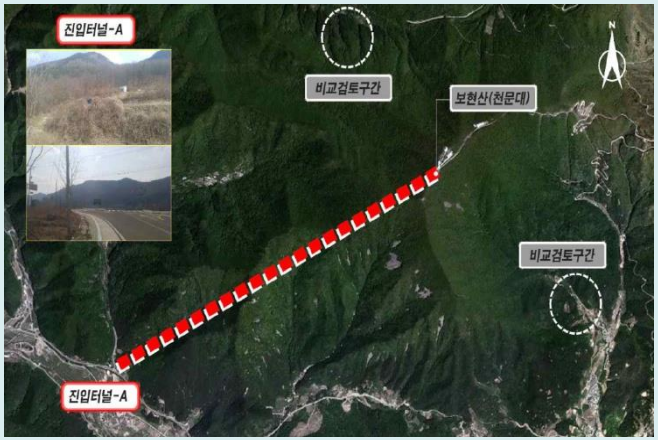
Mt. Bisul



Mt. Bohyun

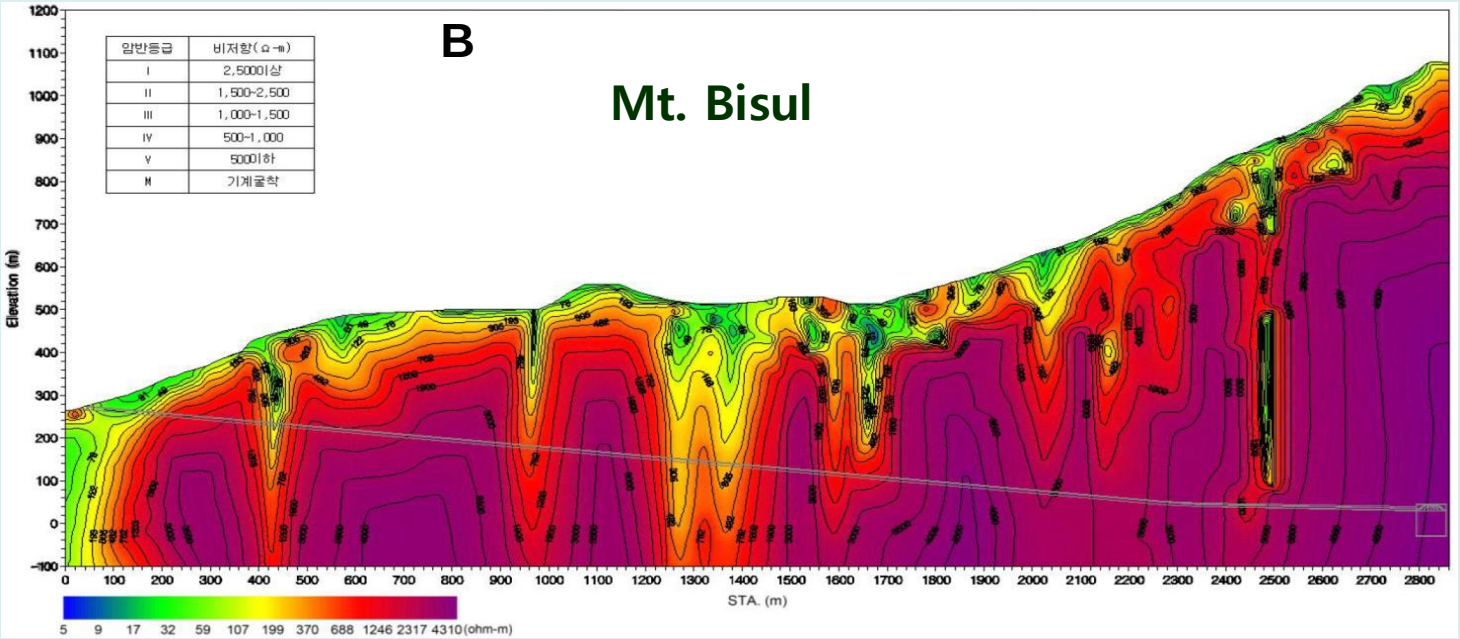


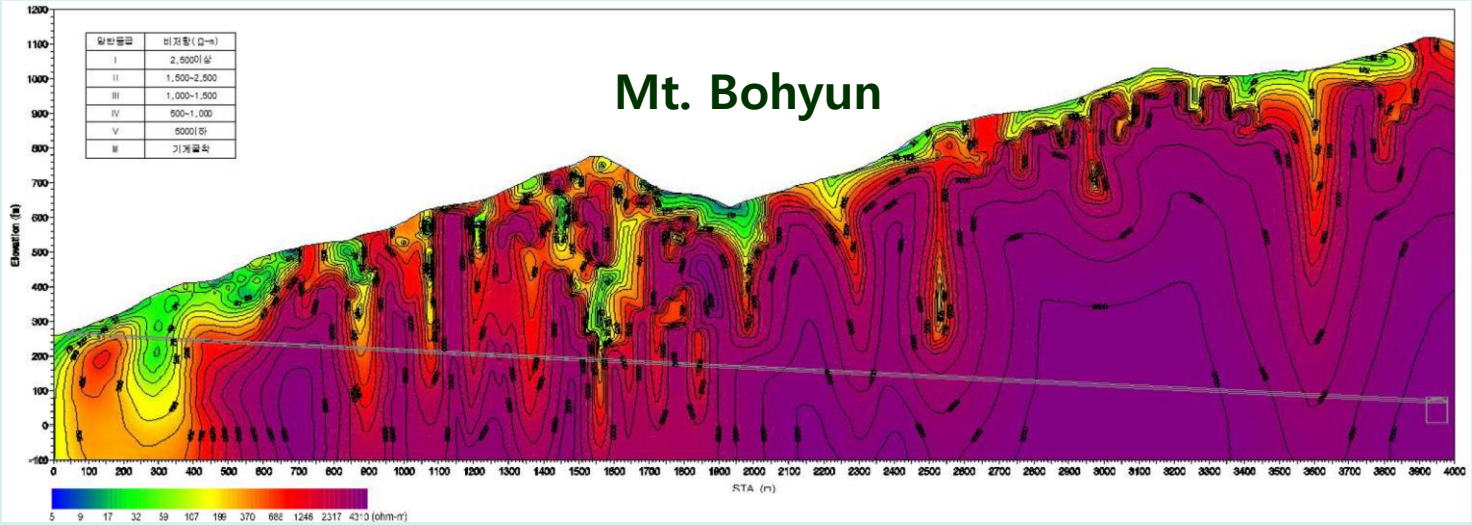




Bedrock Investigation of KNO Sites

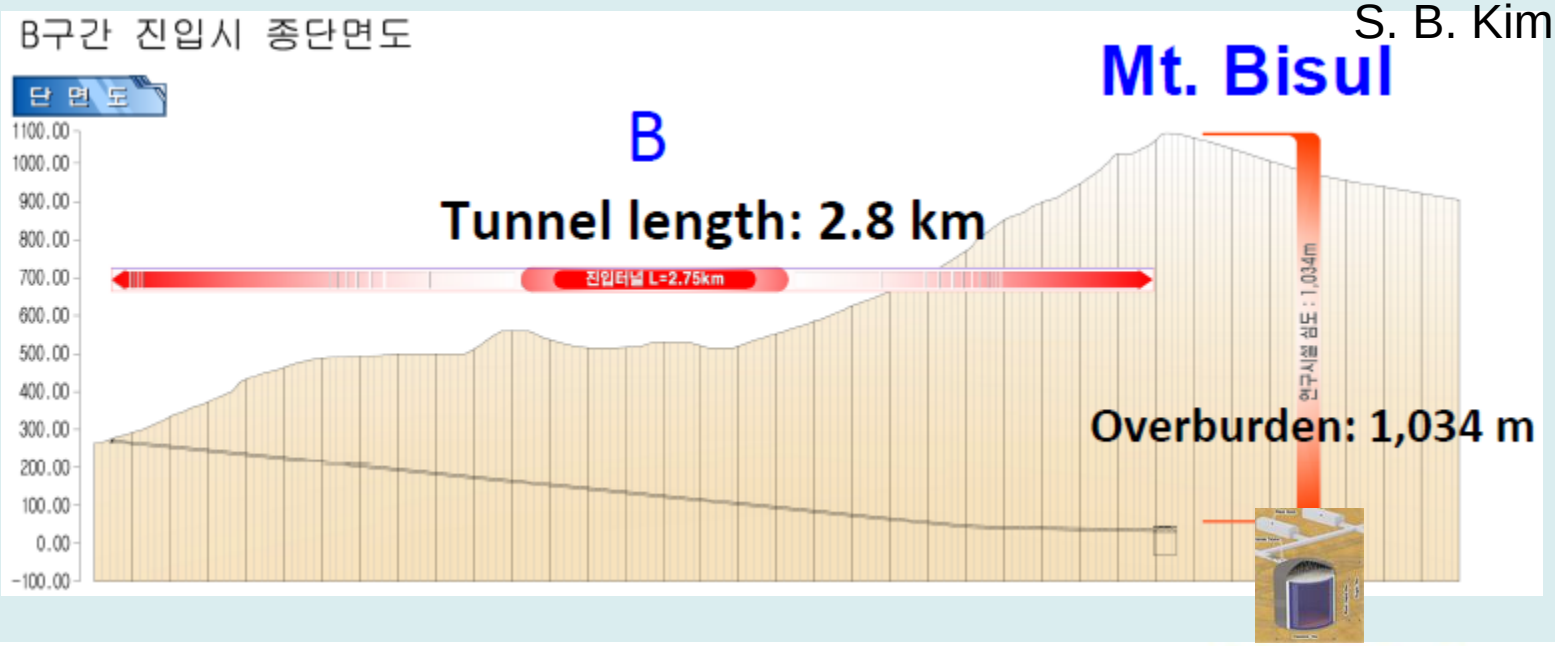
S. B. Kim (SNU)

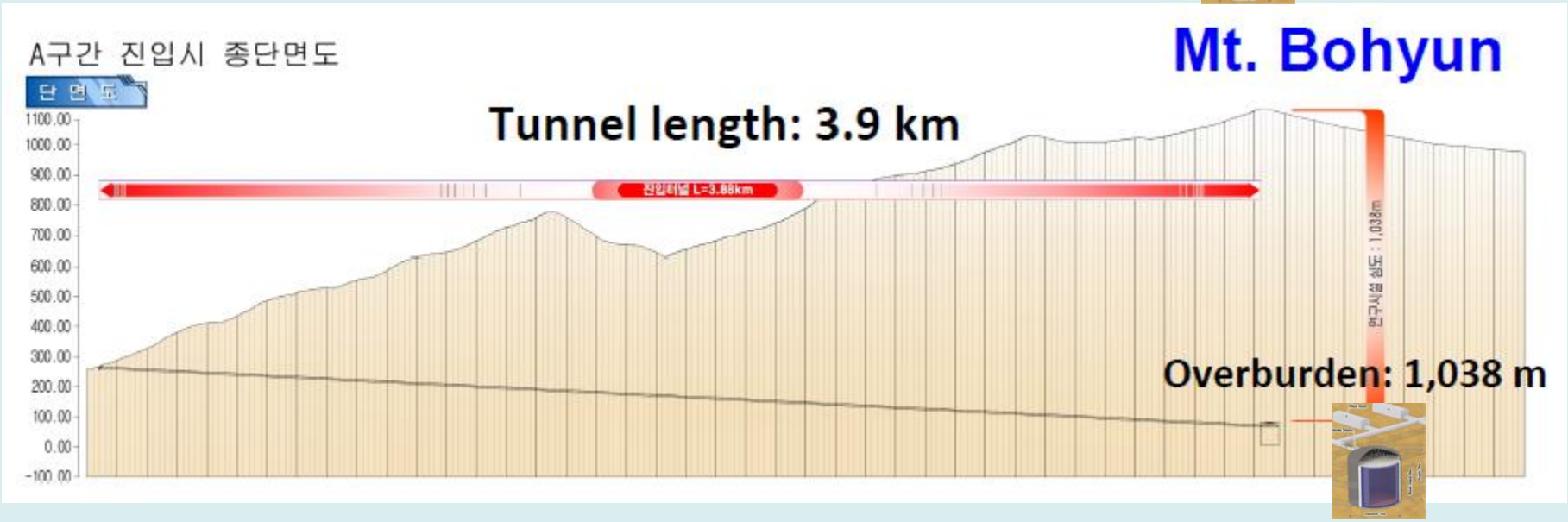




Conceptual Design of KNO Tunnel

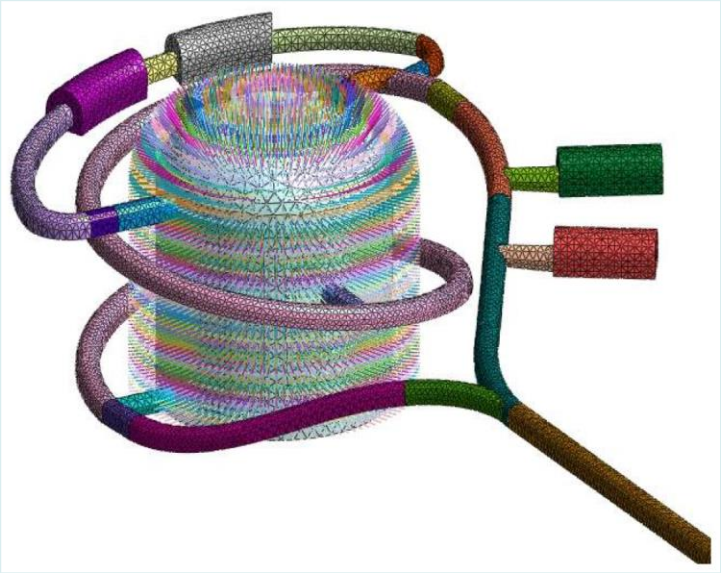
S. B. Kim (SNU)

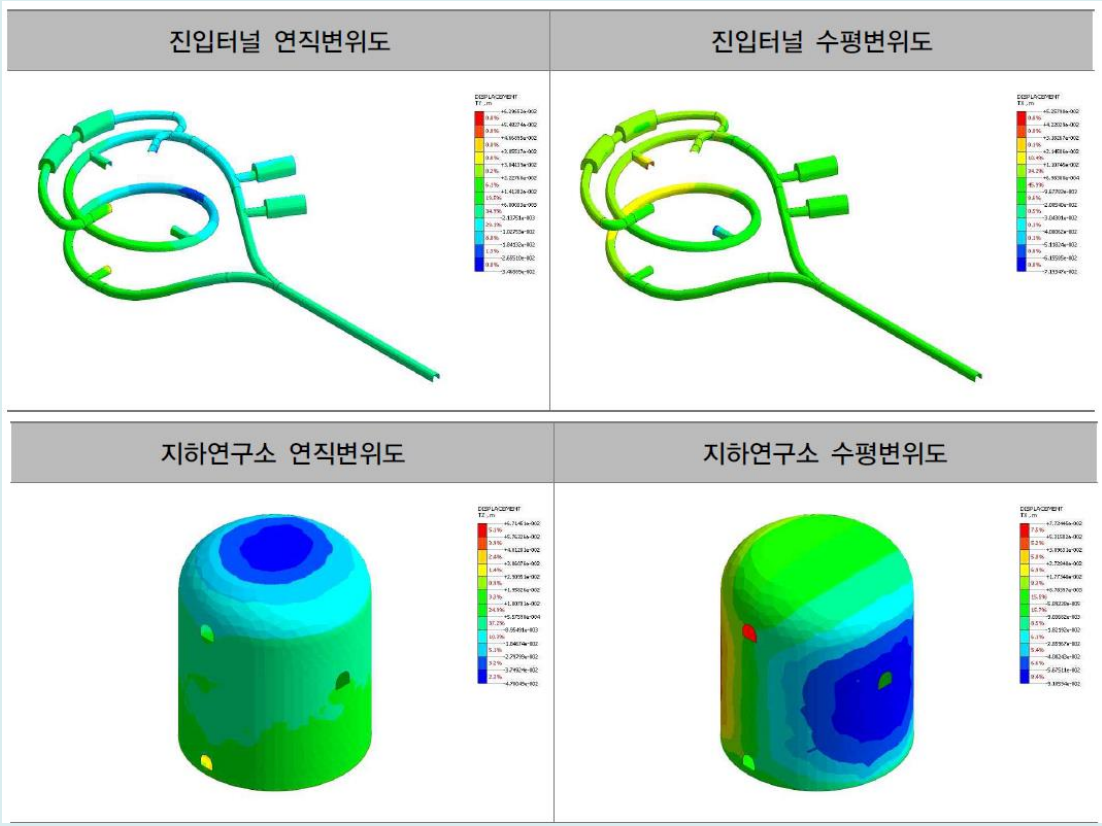


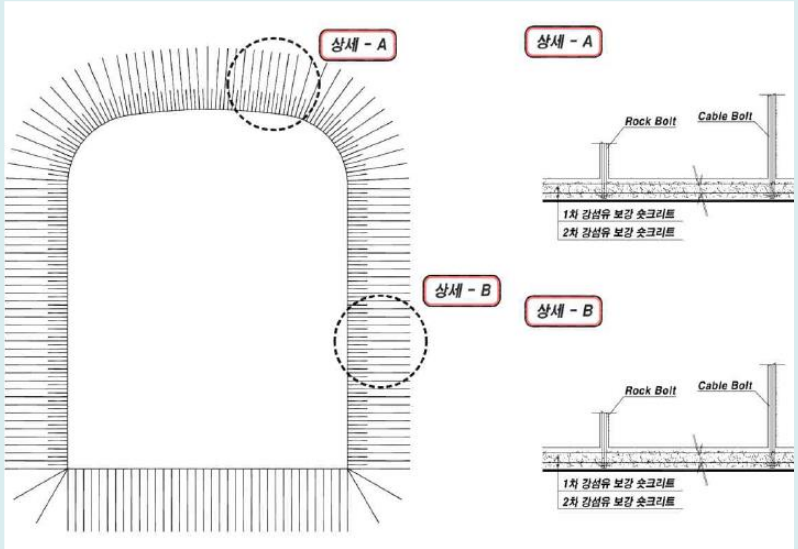


Stress Analysis and Reinforcement

S. B. Kim (SNU)







- Construction Period : 4 ~ 5 years
- Cost: much lower than HK

Activities on Detector R&D

KNO Detector R&D Lists

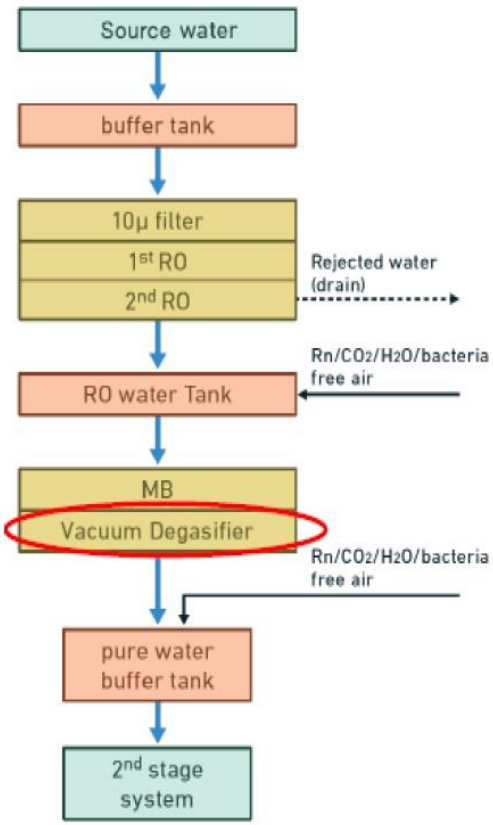
1) Detector hardware performance simulation
   Detector configuration, energy threshold, energy resolution optimization.
2) Detector materials
   Water purification LSC or Gd-doping option
3) Photo Detector:
   PMT or SiPMT
4) Electronics & DAQ
5) Proto-type
6) Tank and mechanical design
7) Detector calibration (source, LED, laser)
8) Computing, software, DB
9) Monitoring, safety etc
   Radon monitoring system

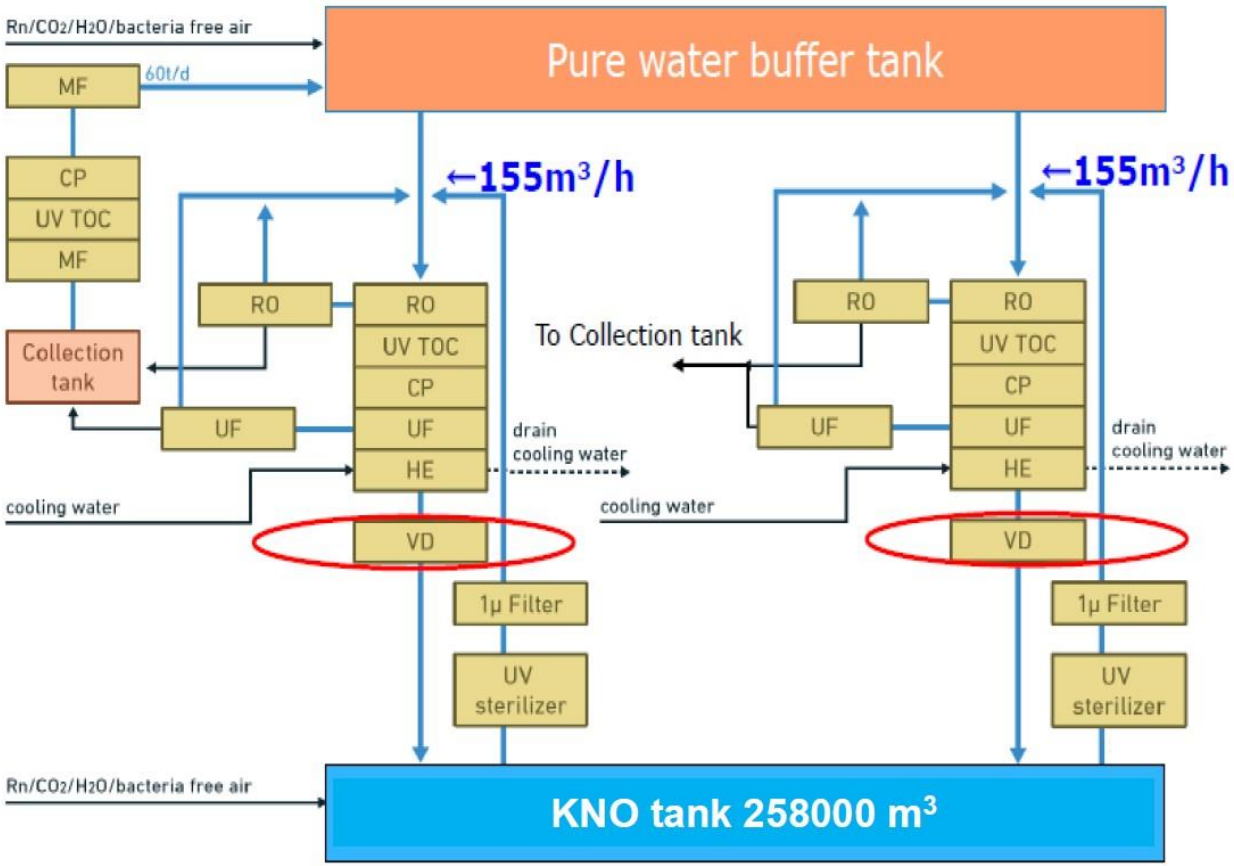
Activities on Detector R&D : Water Purification

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

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

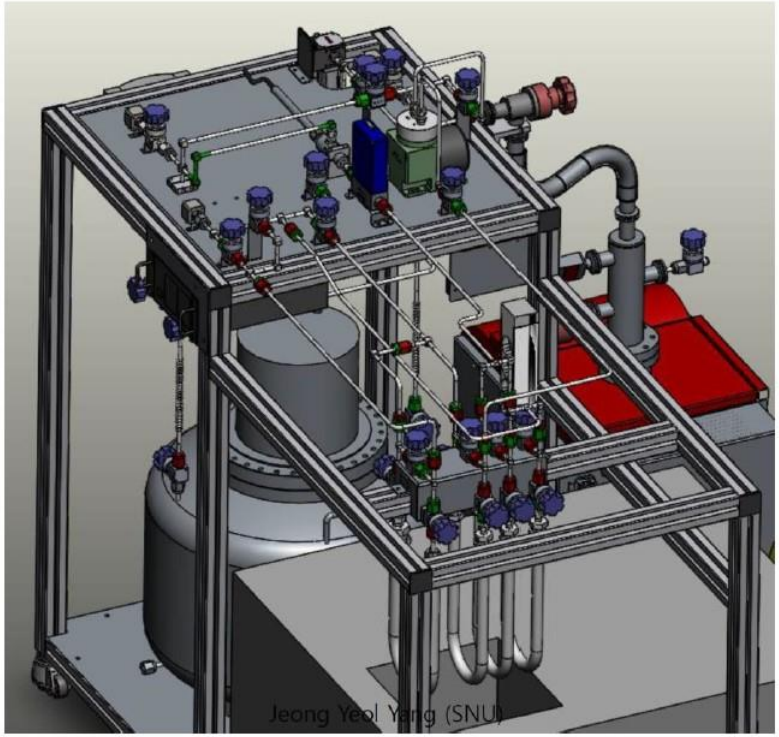
Design of Water Purification System





- Cost estimation of water purification system with DICOTECH Co. and SNU (Help provided by HK)
- Initial supply of ultra-pure water: 78 m^3/hr, circulation supply : 310 m^3

Development of High-sensitive Radon Measurement Device



Designed radon measurement device at SNU

Assembled radon measurement device at SNU

- Developing a radon removal tower from water with DICOTECH Co. in order to measure radon content in water
- Ready for calibration and radon measurement

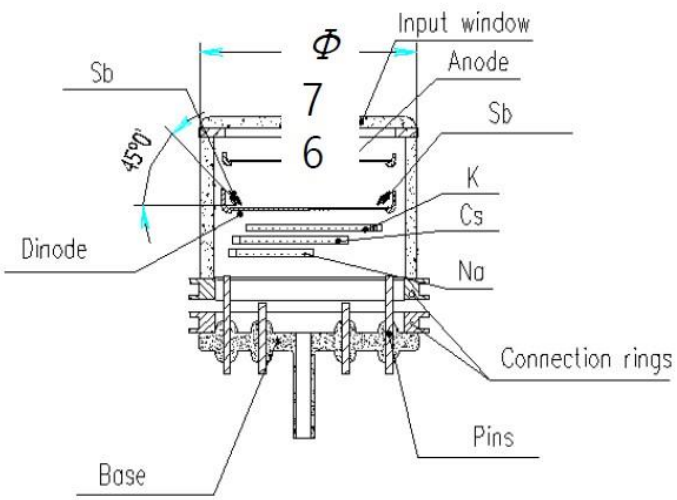
Activities on Detector R&D : Photo sensor

- Two independent approaches of photo sensor R&D

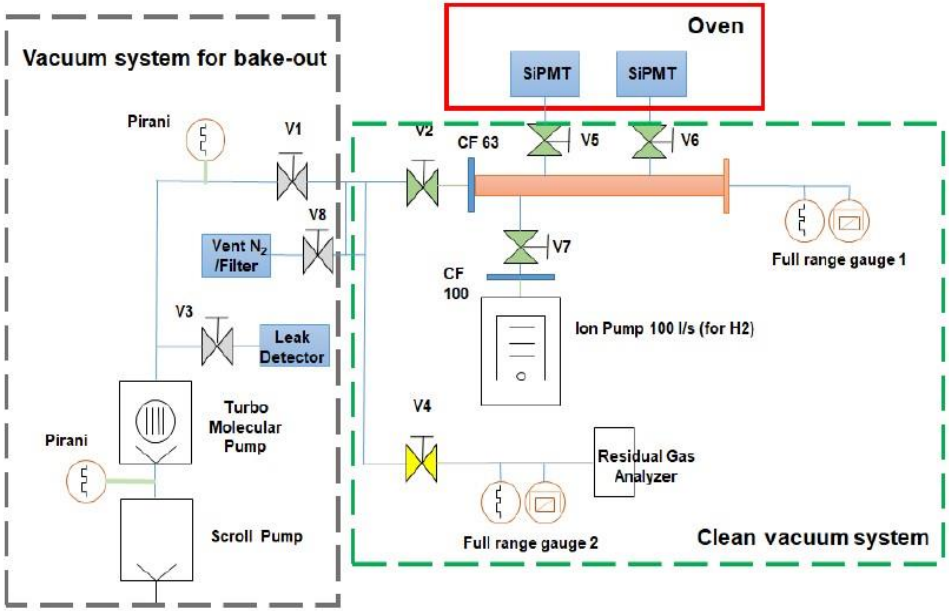
- Development of conventional PMT
  - University of Seoul in collaboration with Korean company MECARO
  - Work on 3 inch PMT first and move to larger PMT

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

Schematics for photocathode fabrication



Scheme for photocathod fabrication



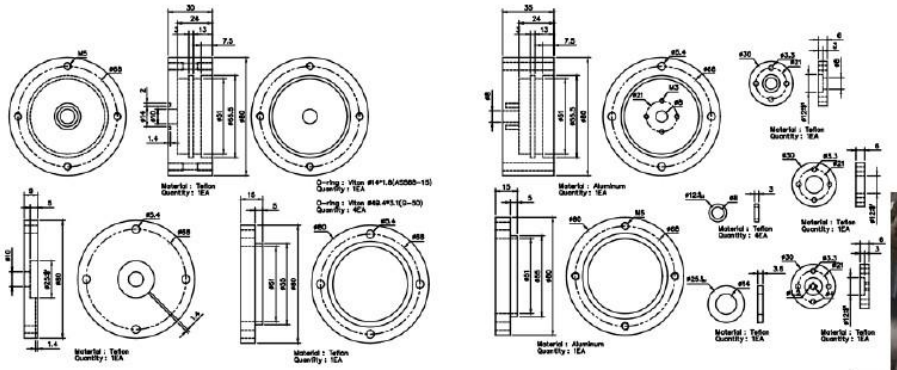
Schematic for photocathod fabrication setup

Scheme for assembling photocathode, scintillator and SiPM in SiPMT is being designed.

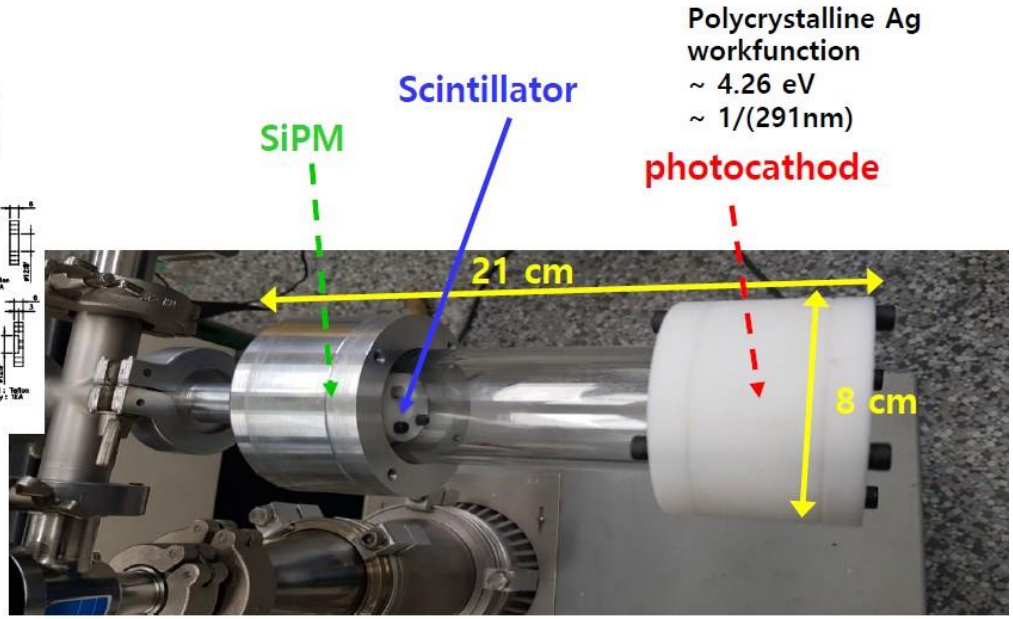
Demonstrator for SiPMT

- Demonstrator Design & Production
  - Vacuum Tube: ~10^{-5} Torr
  - photocathode(Ag), Scintillator & SiPM installed to prove the principle of SiPMT

Vacuum Tube Design



Manufactured Demonstrator



Prospect for KNO

- KNO has great physics potential and korean physicists are very serious about the project
- Korea has had strong neutrino physics programs such as RENO, NEOS, and foreign experiments (SK, K2K,T2K)
- KNO may be a latecomer compared to Hyper-K and DUNE but KNO has some advantages such as lower cost and shorter construction period
- There will be Korea HEP general meetings to discuss long-range strategies including KNO this year
- The first step will be to get a seed funding from Korean government in 2020.
- Strong international collaboration will be essential especially for detector R&D and construction

Summary

- 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

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

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:

$$|\Delta m^2_{32}| = 2.5 \times 10^{-3}\ \text{eV}$$
$$\sin^2\theta_{23} = 0.5$$
$$\sin^2 2\theta_{13} = 0.085$$
$$\Delta m^2_{21} = 7.53 \times 10^{-5}\ \text{eV}$$
$$\sin^2\theta_{12} = 0.304$$
$$\delta_{cp} = 0, \pi/2, \pi, 3\pi/2$$

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)

	Percent Error (%)				
Error Source	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	–

KNO Strategy