한국 중성미자 관측소

(Korea Neutrino Observatory: KNO)

Intae Yu

Sungkyunkwan University

2026. 10. 27

K-Neutrino Symposium

과학적 큰 질문

우주에서 왜 물질이 반물질보다 훨씬 많은가?

검증/성공신호

중성미자 진동확률과 반 중성미자의 진동확률의 차이 측정
진동확률 차이의 측정으로부터 중성미자 CP 위상각이 0°가 아님을 증명
중성미자 CP 위상각이 0°가 아닌 경우, 위상각의 정확한 측정

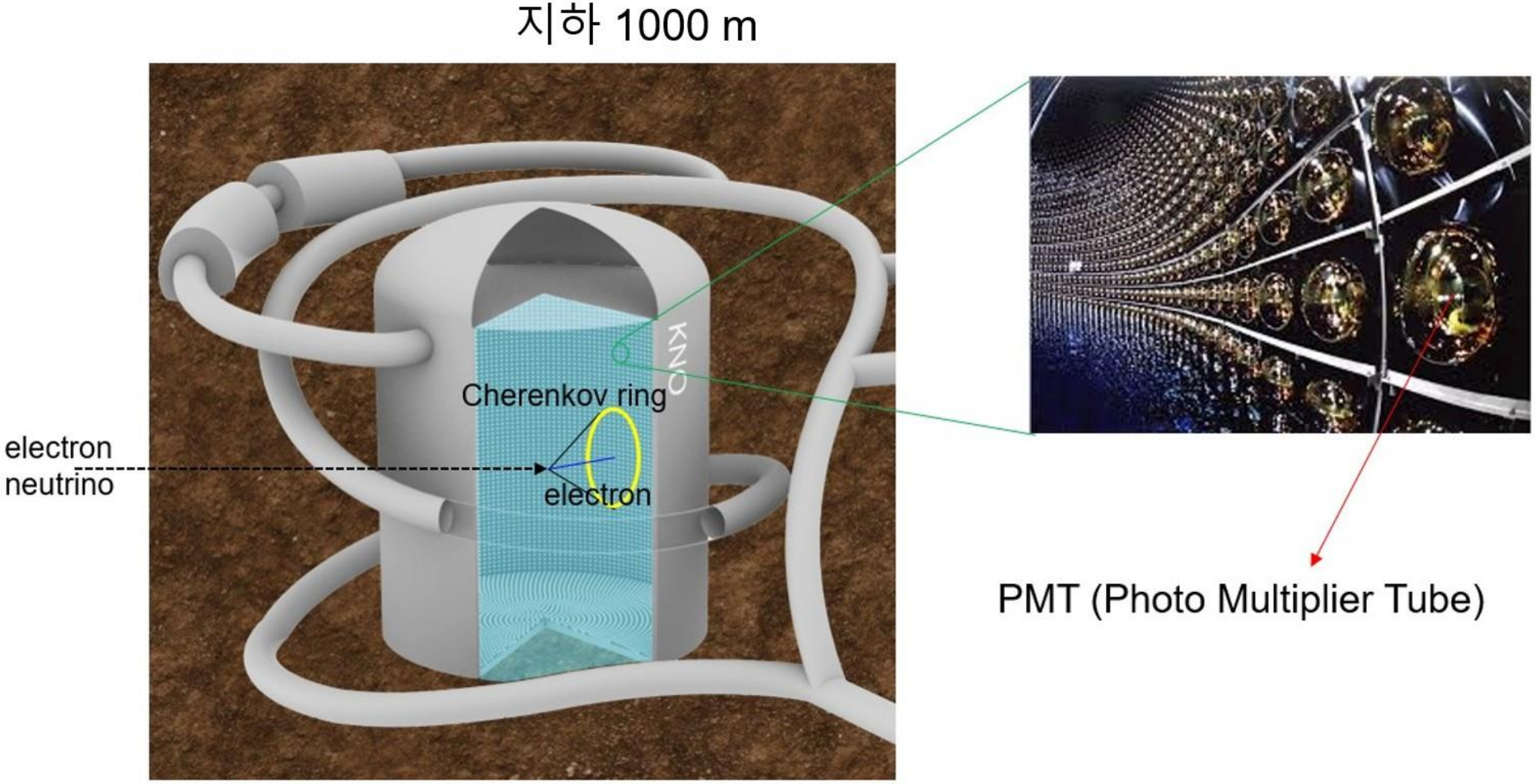
기대효과

CP 위상각의 정확한 측정을 통해 우주에서의 물질-반물질 비대칭 이해
세계최대규모의 지하중성미자 검출시설의 구축을 통한 한국기초과학 도약

필요한 국가연구기반

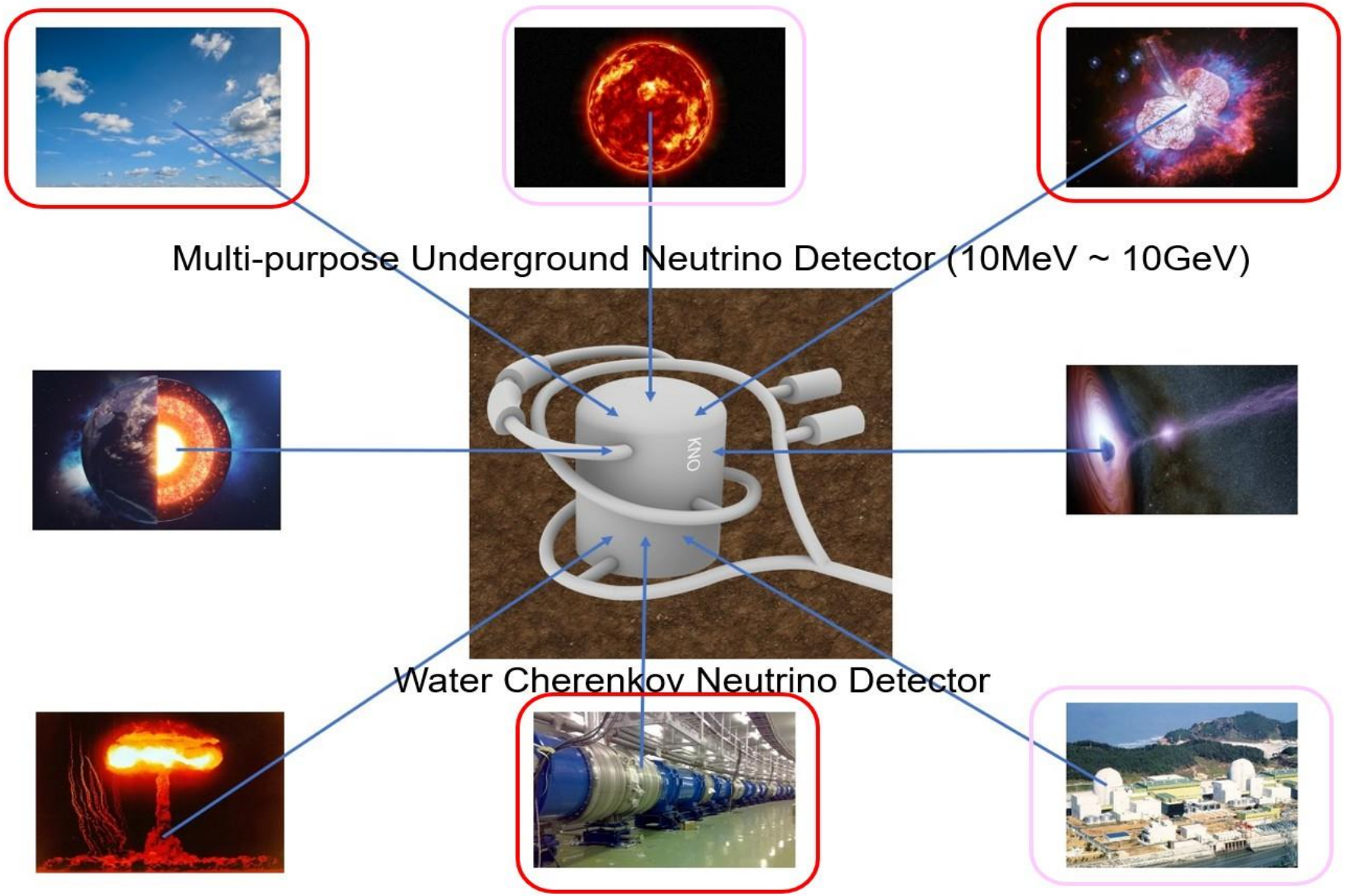
지하 깊이 위치한 수십만톤 규모의 물 체렌코프 중성미자 검출시설

Overview of Korea Neutrino Observatory (KNO)



- KNO will be the largest underground water cherenkov neutrino detector in the world

Overview of Korea Neutrino Observatory (KNO)



Main Physics Goals of KNO

- **Discovery of leptonic CP violation and precise measurement of CPV phase (δ_{cp})**
- Search for proton decays
- Observation of cosmic neutrinos : Neutrino Astronomy
- Search for BSM physics in the neutrino sector and many others

CP Violation in the Neutrino Sector

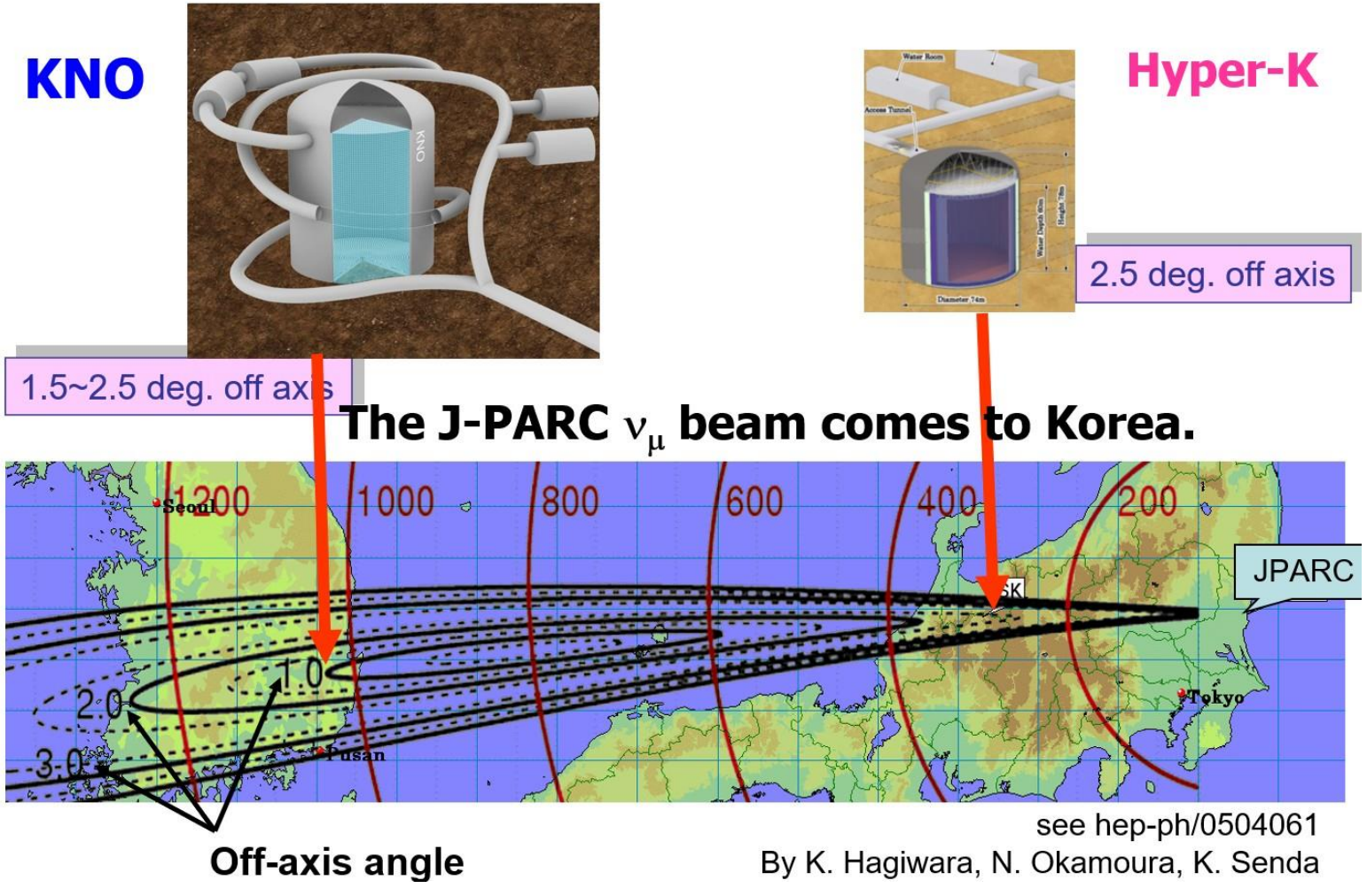
- Neutrino Oscillation Probabilities for ν_μ and $\overline{\nu_\mu}$

$$P(\nu_\mu(\bar{\nu}_\mu) \to \nu_e(\bar{\nu}_e)) \approx \sin^2\theta_{23}\ \sin^2 2\theta_{13}\ \sin^2(\frac{\Delta m^2_{31}L}{4E})$$
$$+ \sin 2\theta_{23}\sin 2\theta_{13}\sin 2\theta_{12}\cos\theta_{13}\sin(\frac{\Delta m^2_{31}L}{4E})\sin(\frac{\Delta m^2_{21}L}{4E})\cos(\frac{\Delta m^2_{31}L}{4E})\cos\delta$$
$$-(+)\sin 2\theta_{23}\sin 2\theta_{13}\sin 2\theta_{12}\ \cos\theta_{13}\sin^2(\frac{\Delta m^2_{31}L}{4E})\sin(\frac{\Delta m^2_{21}L}{4E})\sin\delta$$
$$+ \cos^2\theta_{13}\ \cos^2\theta_{23}\ \sin^2 2\theta_{12}\ \sin^2(\frac{\Delta m^2_{21}L}{4E}).$$

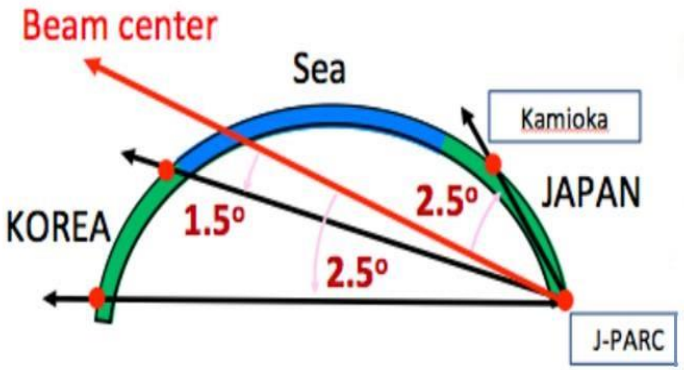
- CP violating phase : δ (δ_{CP}), Baseline : L
- **Non-zero sin δ_{CP}** gives different oscillation probabilities for ν_μ and $\overline{\nu_\mu}$ leading to CP violation in the neutrino sector
- For a fixed energy, CP violation is 3 times larger in the second oscillation maxima

CP Violation at KNO

- KNO plans to use ν_μ and $\overline{\nu_\mu}$ beams from J-PARC in Japan

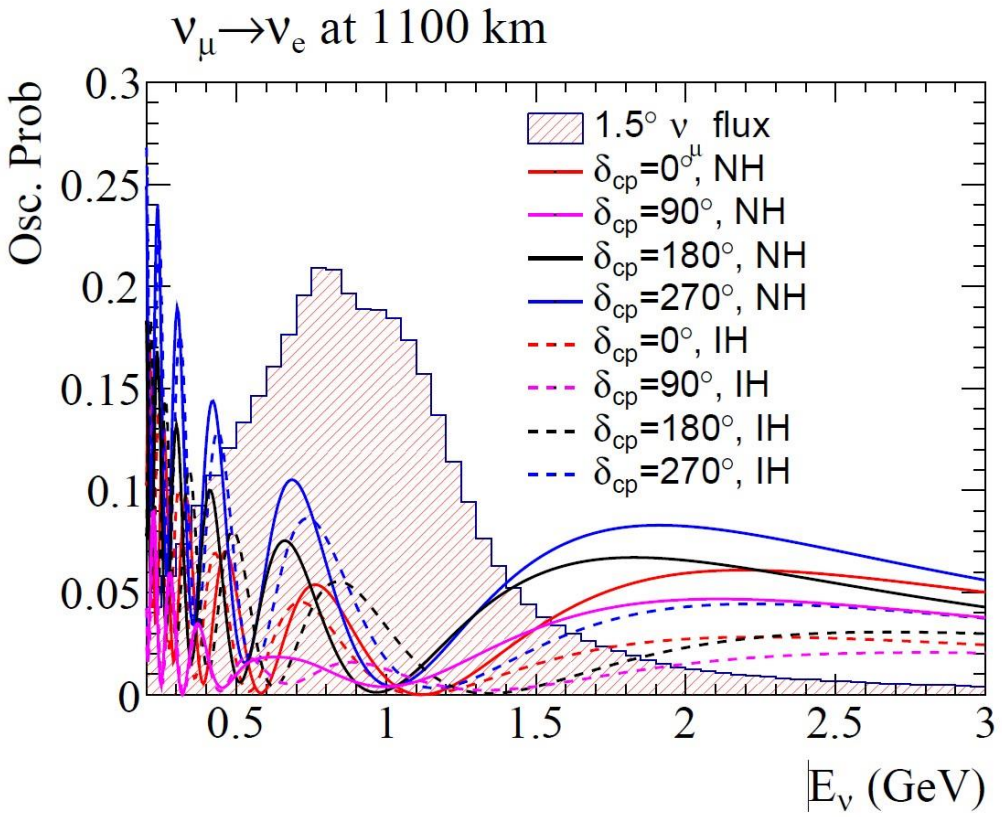


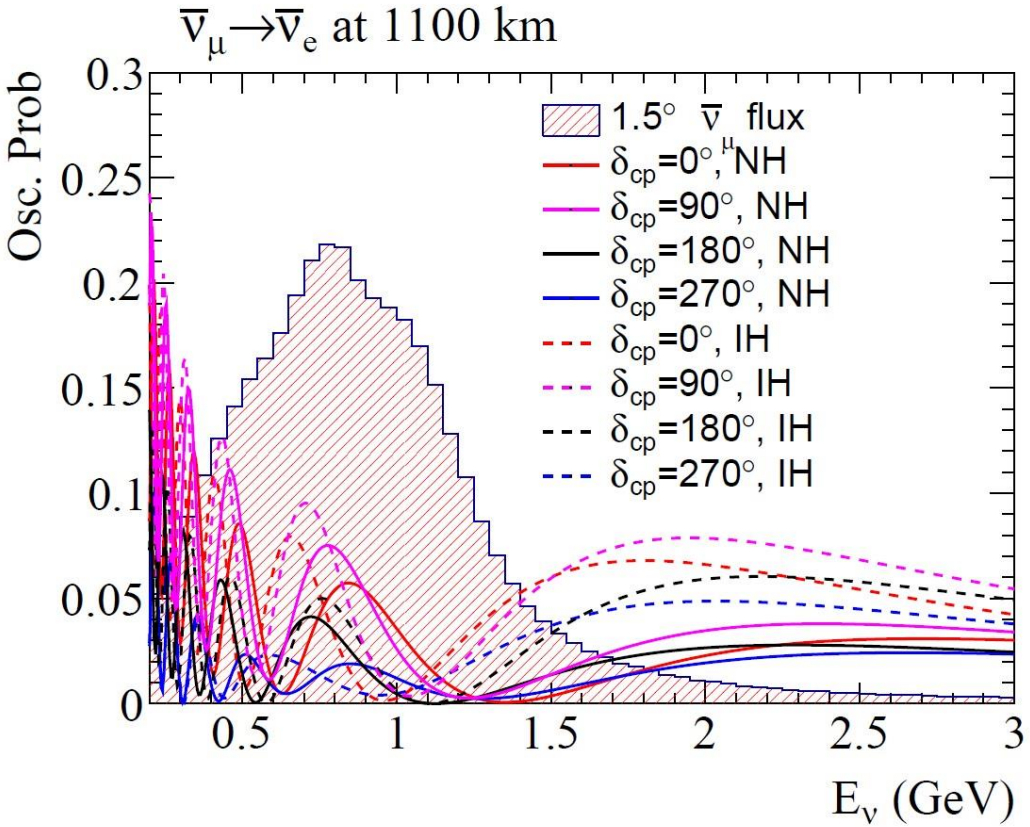
- KNO and HK share J-PARC beam
- Baseline from J-PARC to KNO is about 3 times longer than HK



CP Violation at KNO

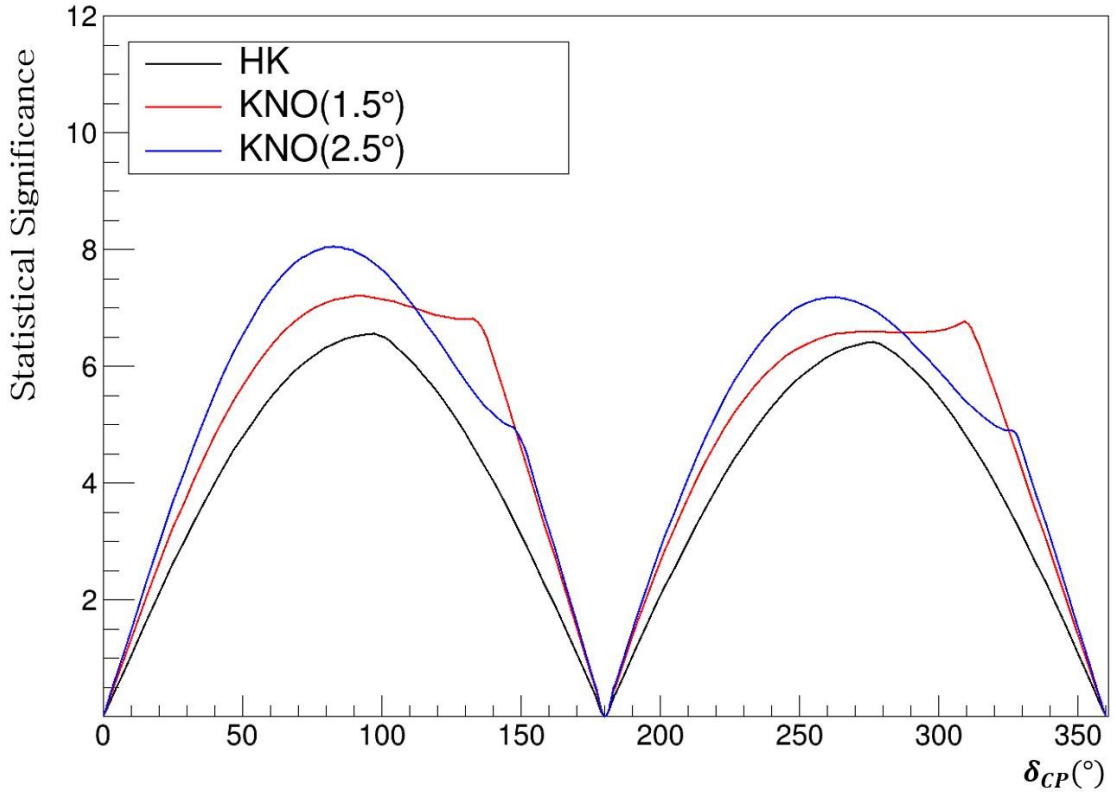
- ν_μ and $\overline{\nu_\mu}$ Energy Spectrum and Oscillation Probabilities at KNO

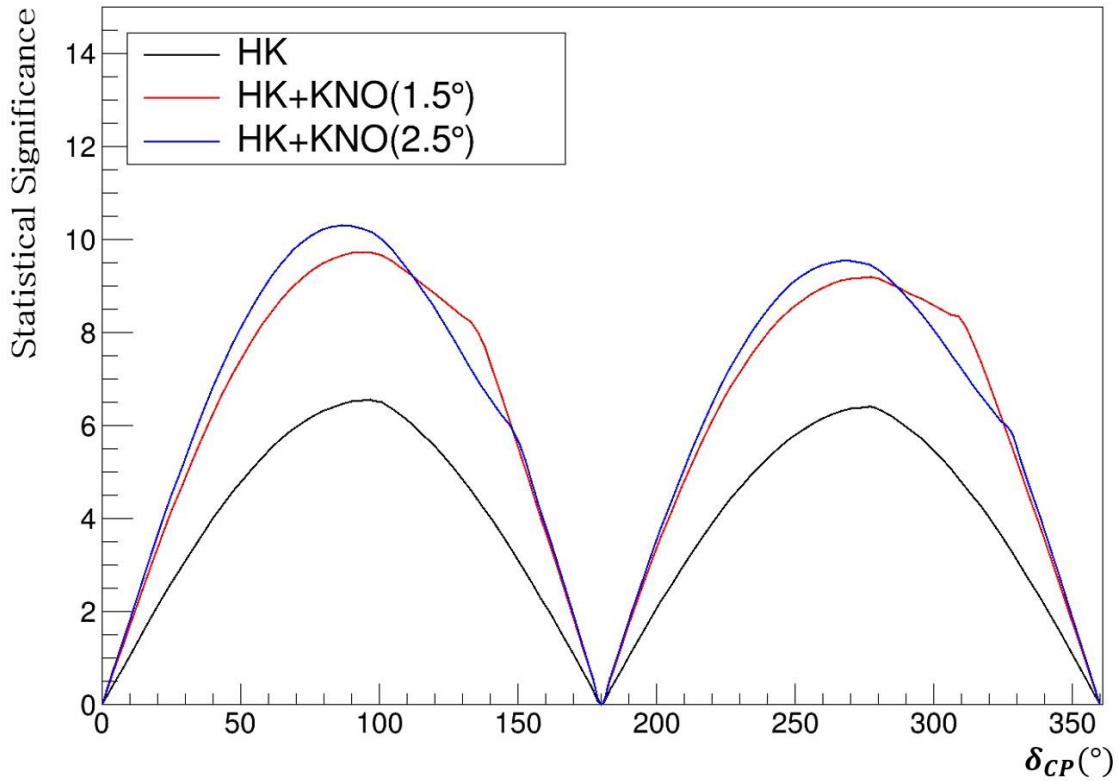




CP Violation at KNO

- Significance of CP Violation Measurement at KNO



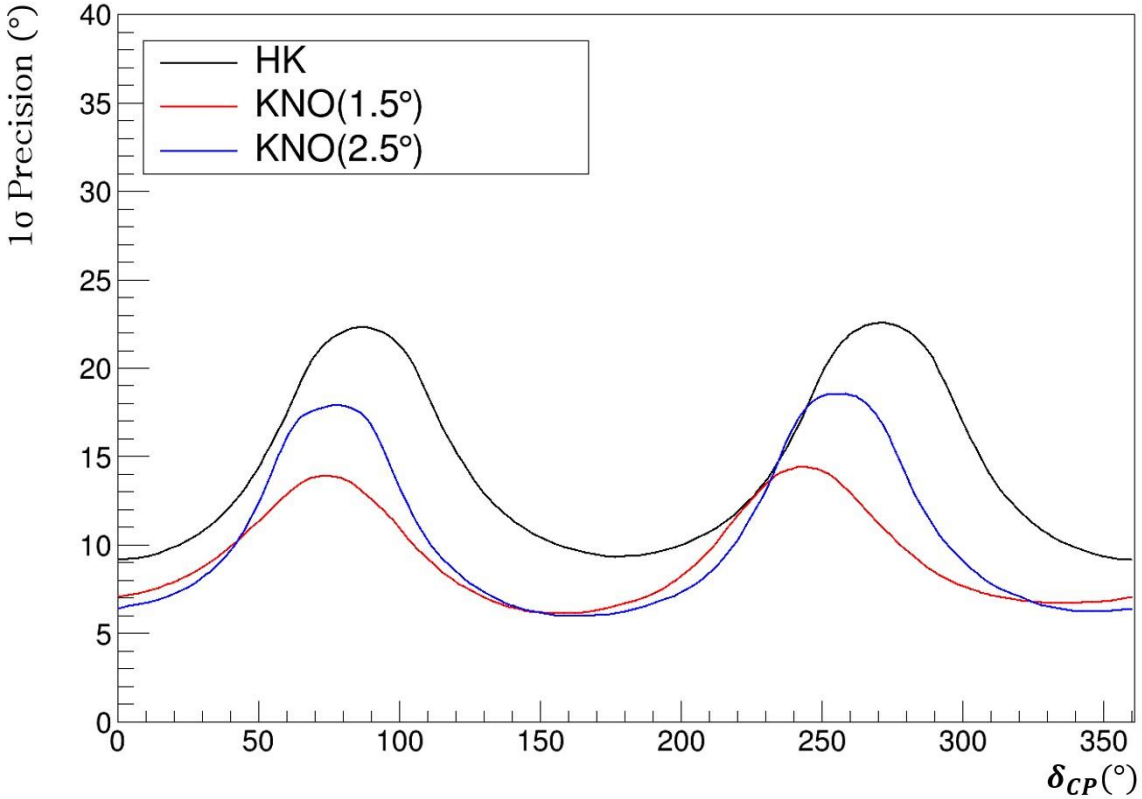


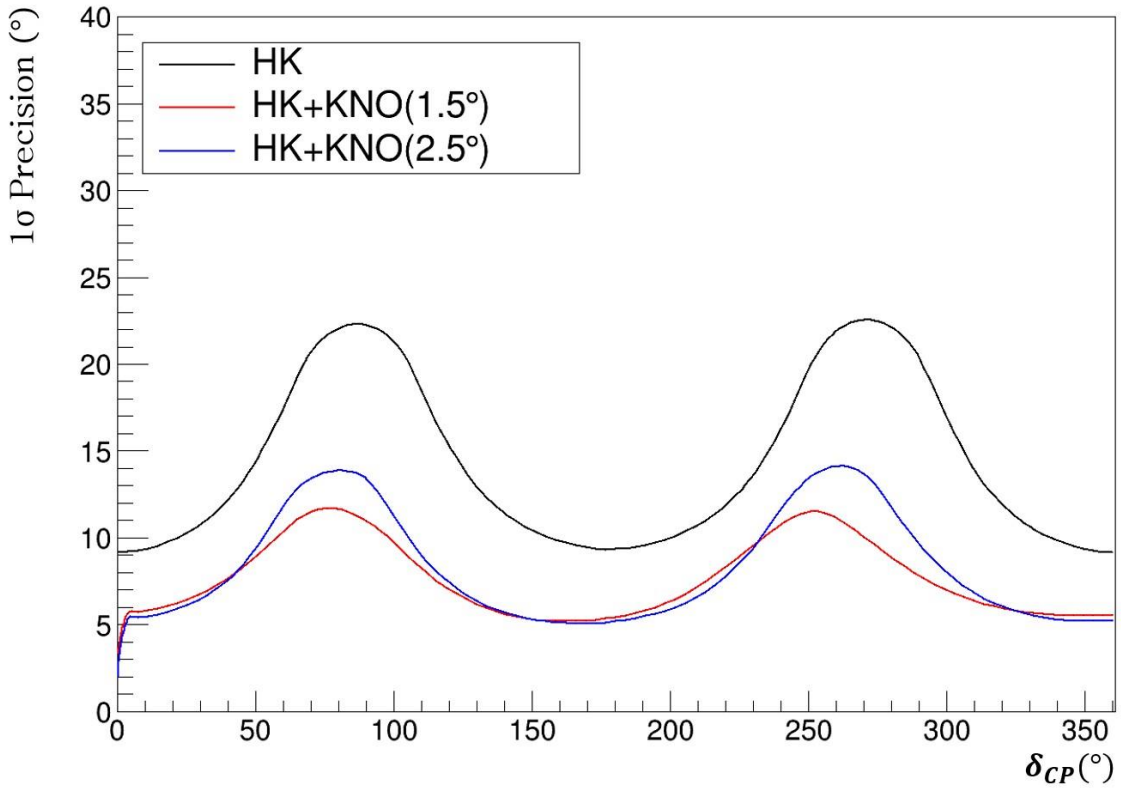
✓ 10 years of Operation with 1.3 MW of J-PARC Beam

✓ KNO (0.5Mt) and HK (0.26Mt)

CP Violation at KNO

- Precision of δ_{CP} Measurement at KNO



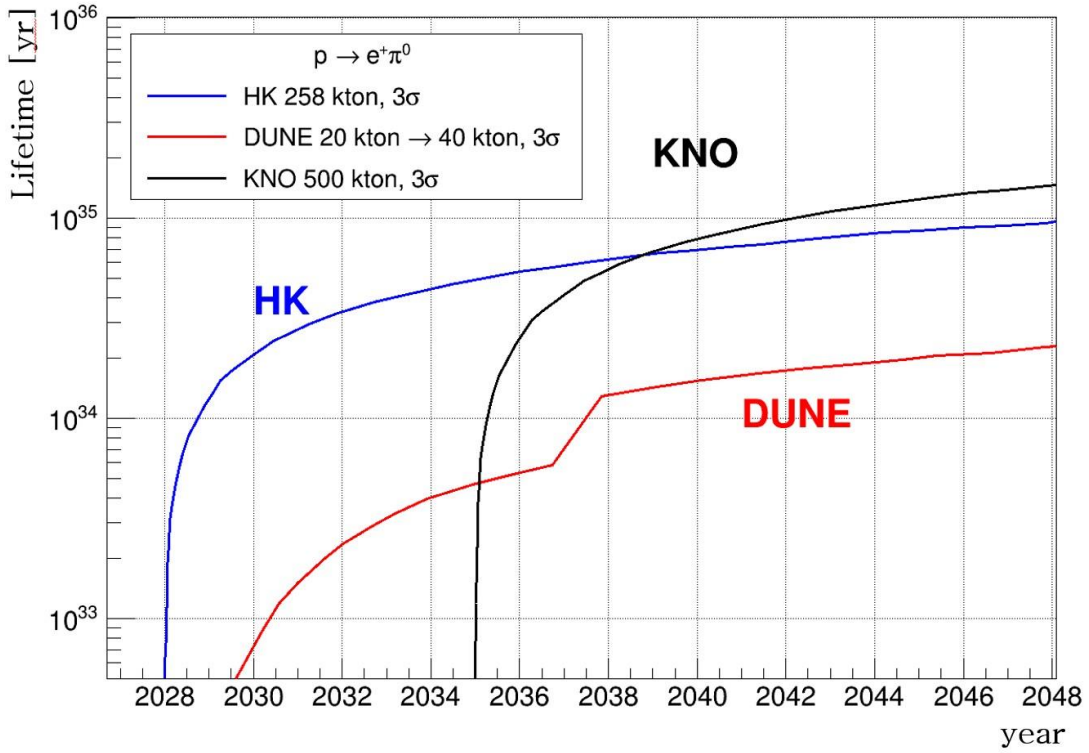


- ✓ 10 years of Operation with 1.3 MW of J-PARC Beam
- ✓ KNO (0.5Mt) and HK (0.26Mt)

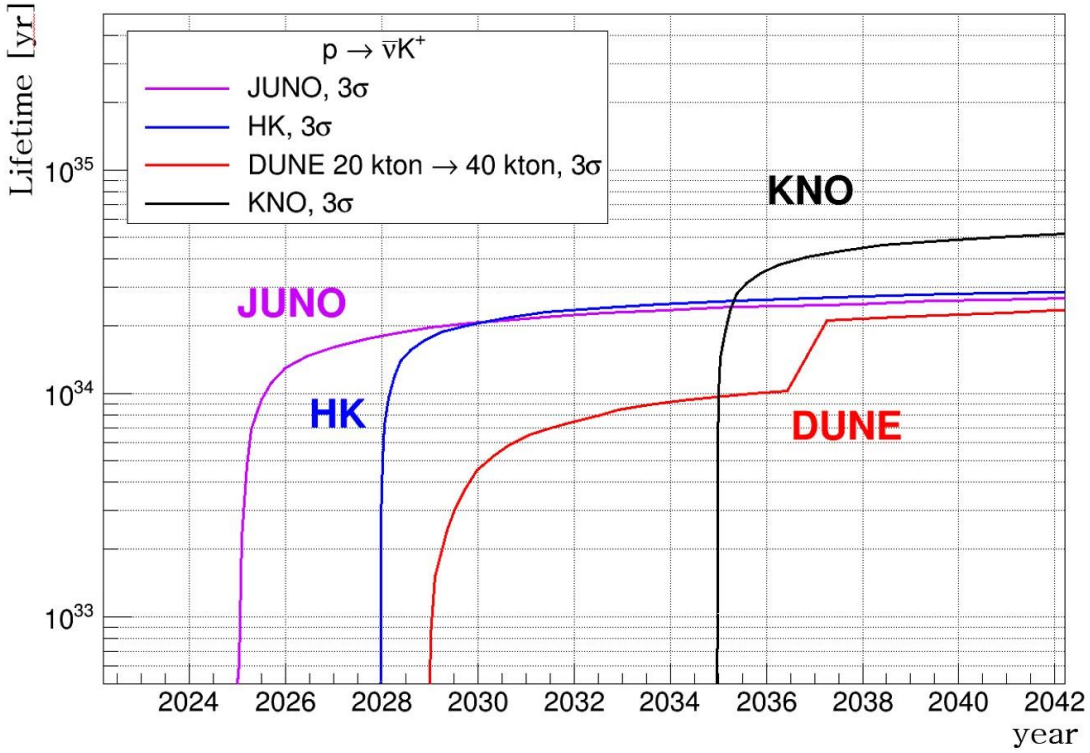
Proton Decays at KNO

- Search for Proton Decays at KNO

$p \to e^+\pi^0$



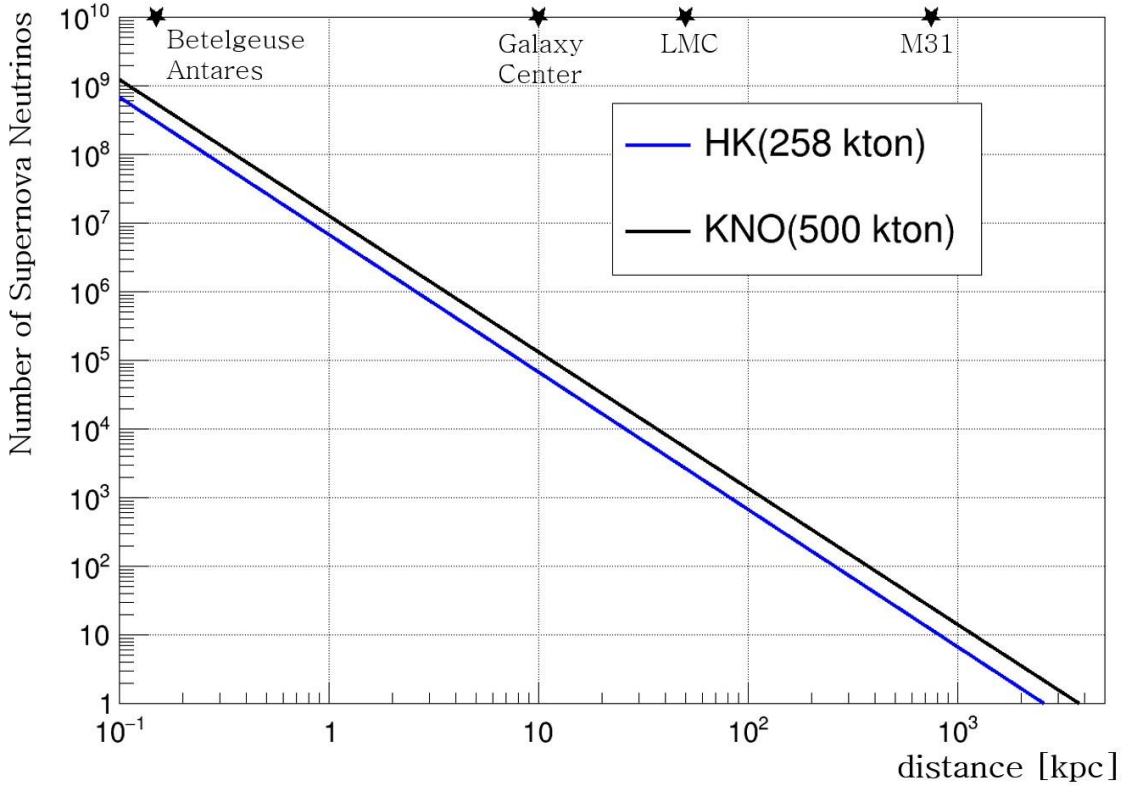
$p \to \bar{\nu}K^+$

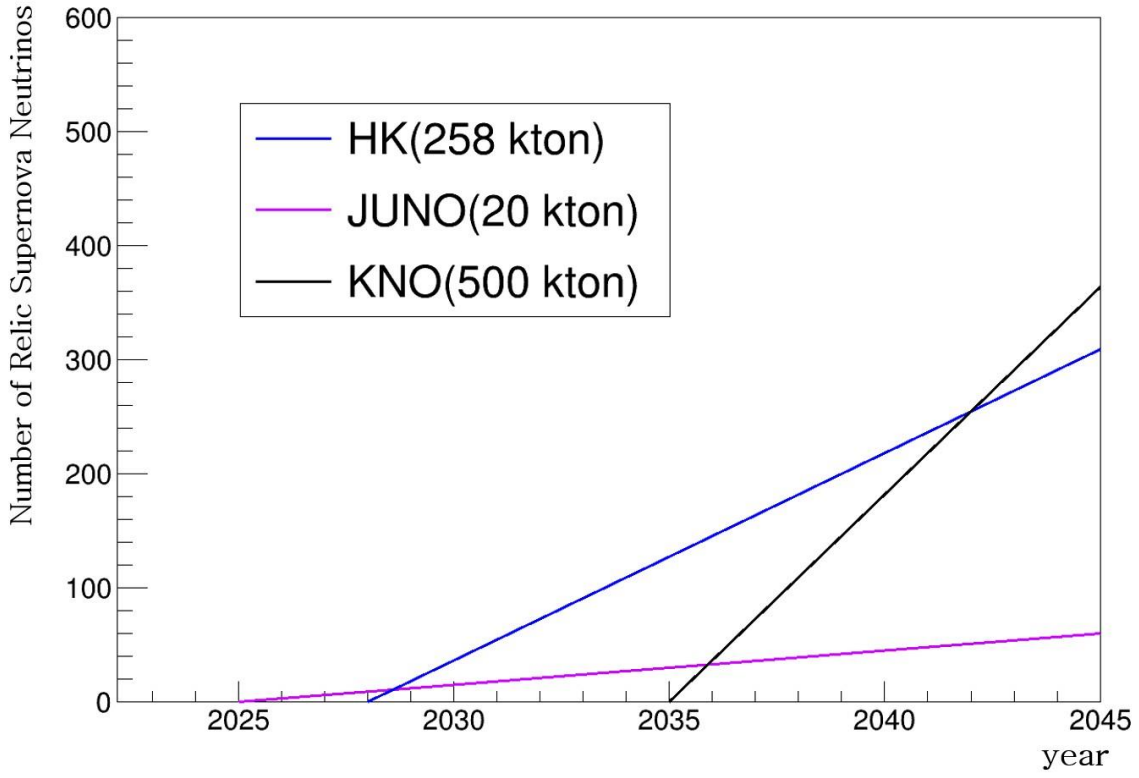


✓ KNO (0.5Mt) and HK (0.26Mt)

Neutrino Astronomy at KNO

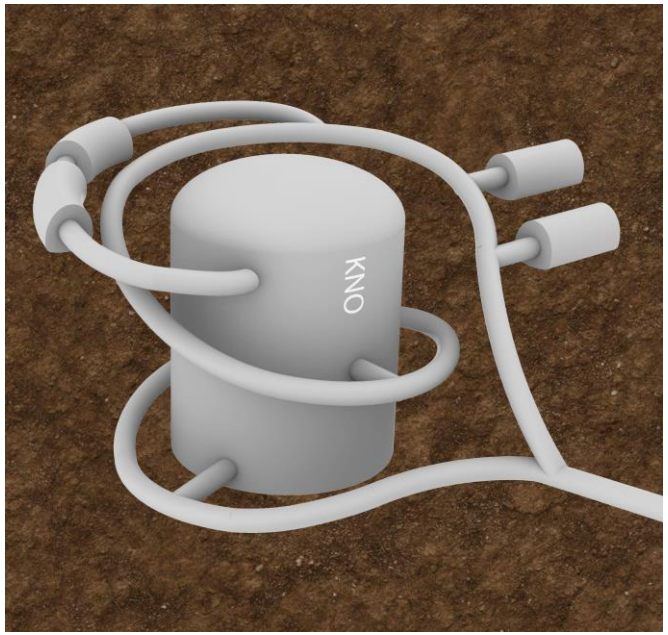
- Observation of Supernova Neutrinos at KNO





✓ KNO (0.5Mt) and HK (0.26Mt)

KNO, HK, and DUNE

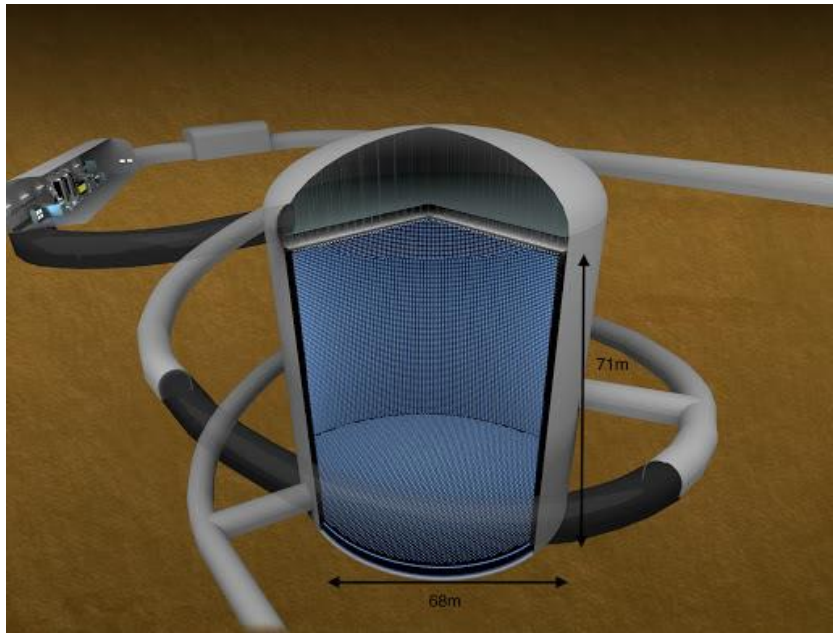


Water Cherenkov Detector

500 kt

1000m

2035~

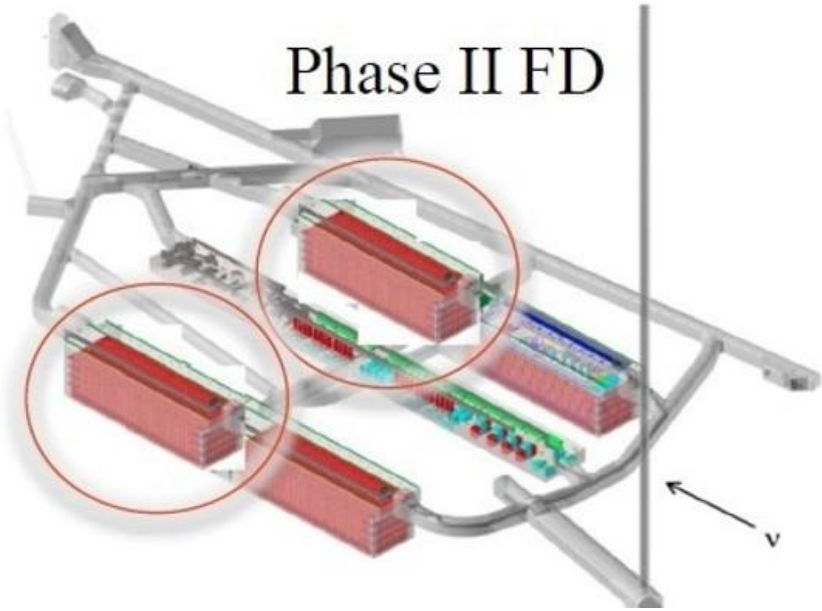


Water Cherenkov Detector

260 kt

650m

2028~



Liquid Argon Detector

70kt

1500m

phase 1: 2032~

History of KNO

- 2005~2007: Proposal on a far detector in Korea to J-PARC neutrino beam by Prof. T. Kajita and Prof. S.B. Kim et al
- 2017: Preliminary geological surveys were done for KNO candidate sites
- 2018: White report on the Korea detector published (PTEP)
- 2018. 10 : Kick-off meeting for KNO organization
- 2023~2024: **기획연구보고서 "한국 중성미자 관측소 구축사업" 과기부 제출**
- 2026. 8: **과기부 구축형 R&D 사업 지원**

KNO Organization

- KNO working groups have been organized
- Currently 14 institutions are participating in KNO project



Kyungpook National University

Kyung Hee University

Dongsin University

Seoul National University

Sejong University

Sungkyunkwan University

Chonnam National University

Chung-Ang University

Chungnam National University

Jeonbuk National University

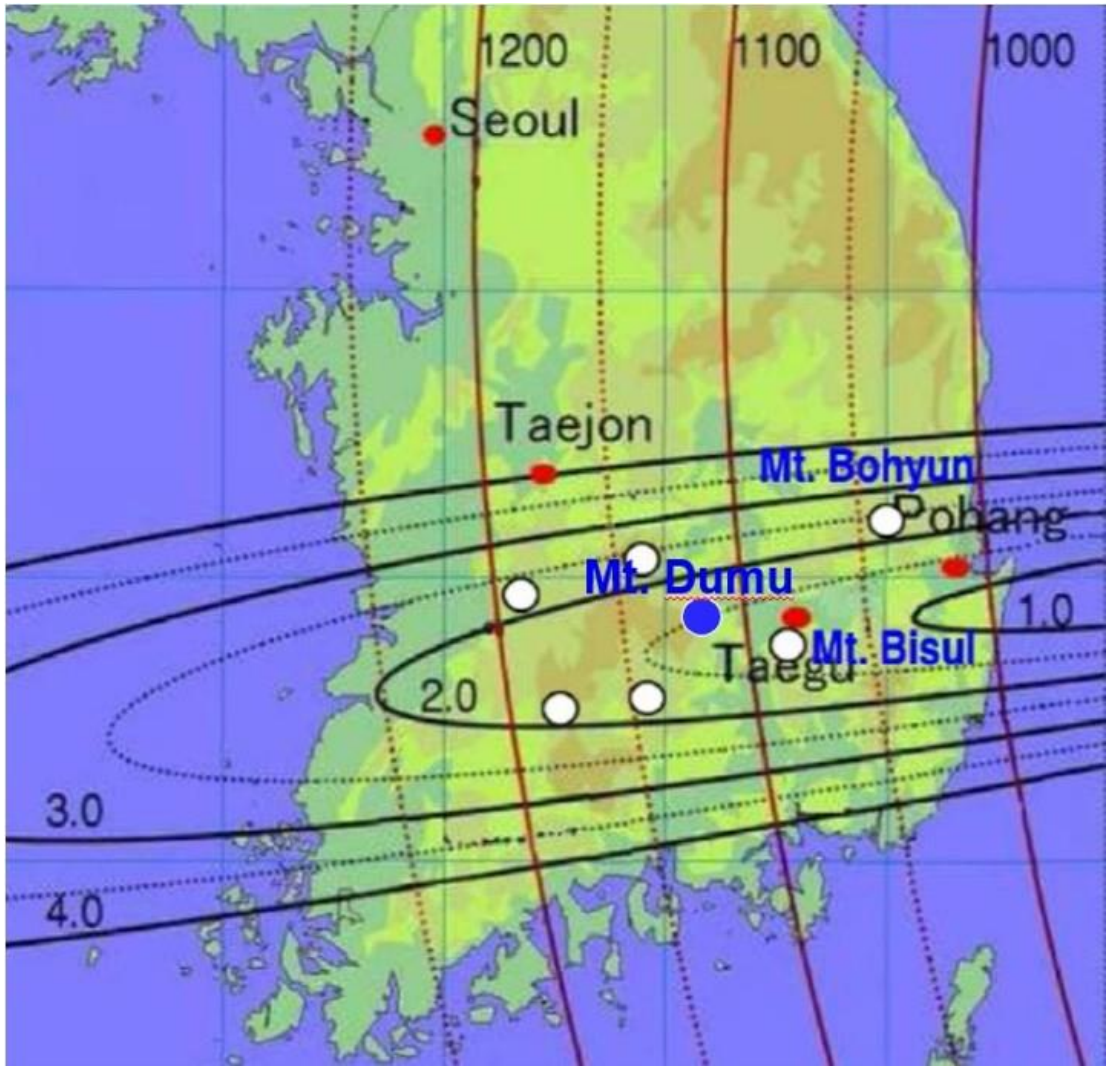
Korea Astronomy and Space Science Institute

Seoul University of Science and Technology

GIST

UNIST

KNO Candidate Sites



- J-PARC 중성미자

  빔으로부터 1.5°~2.5°
- 1000m 높이의 산
- 견고한 지하암반
- 풍부한 지하수
- 우수한 접근성
- 후보지:

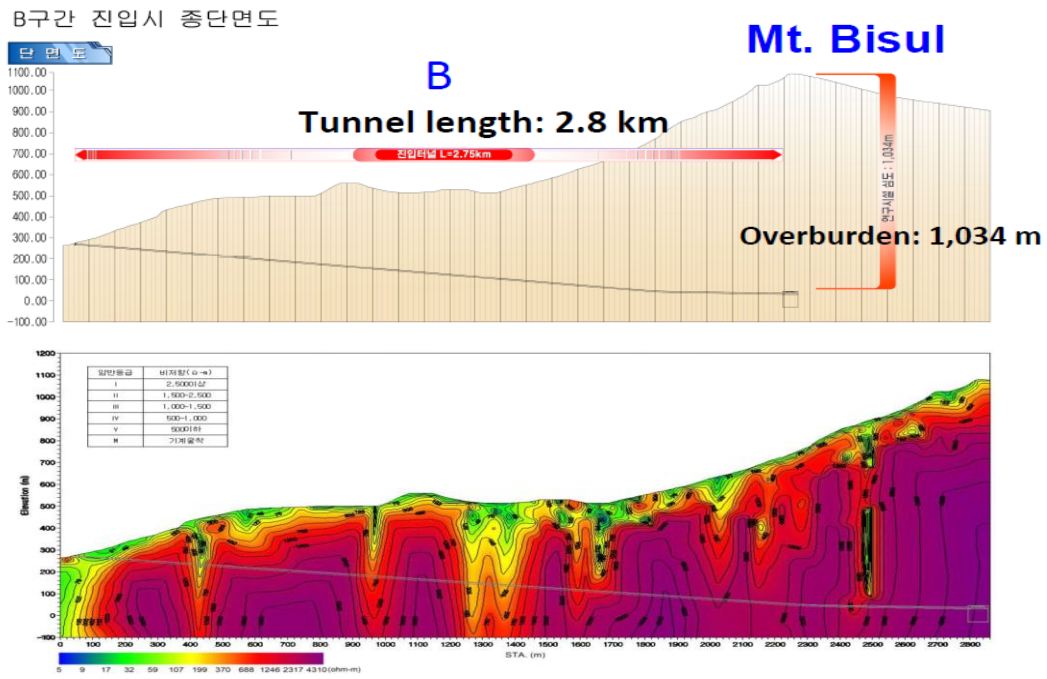
  두무산 (합천)

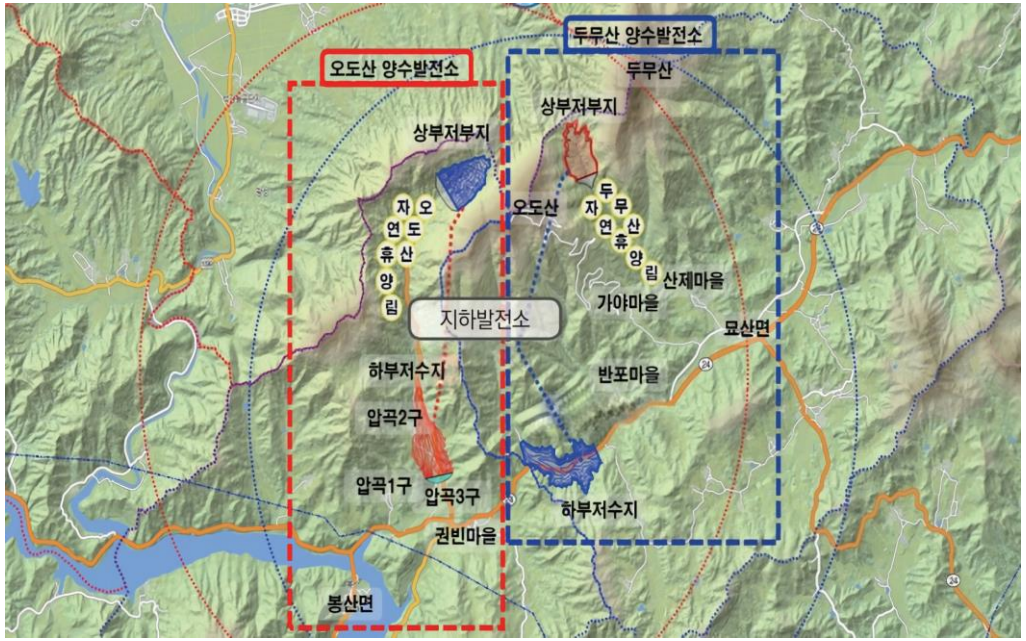
  비슬산 (달성)

  보현산 (영천)

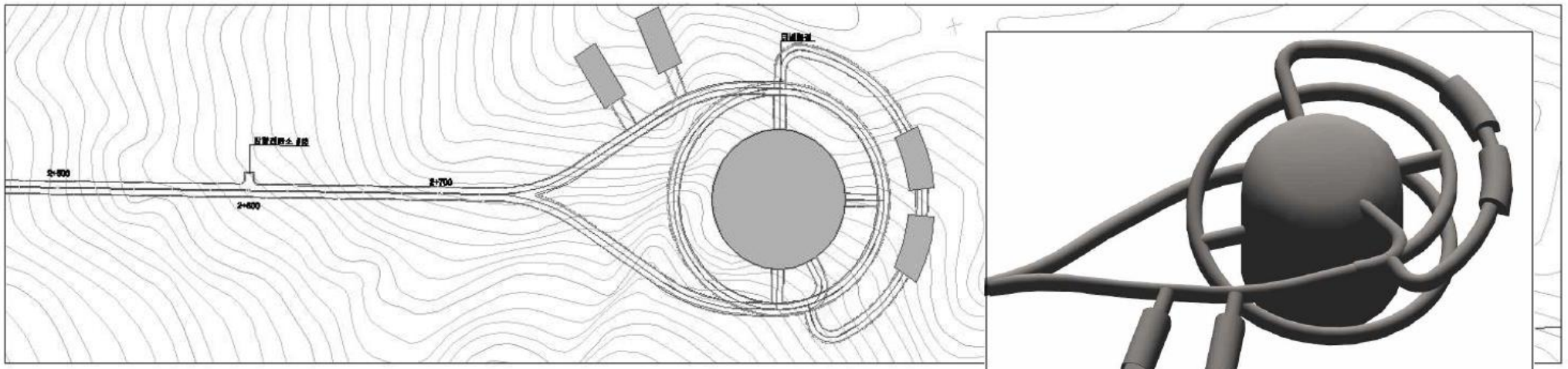
KNO Candidate Sites

- 비슬산, 보현산 후보지에 대한 지질조사와 지하시설 기초설계 완료
- 두무산 후보지의 경우 근처에 두무산 지하양수발전소가 건설될 예정이며 KNO와 시너지 효과를 거둘 수 있을 것으로 기대

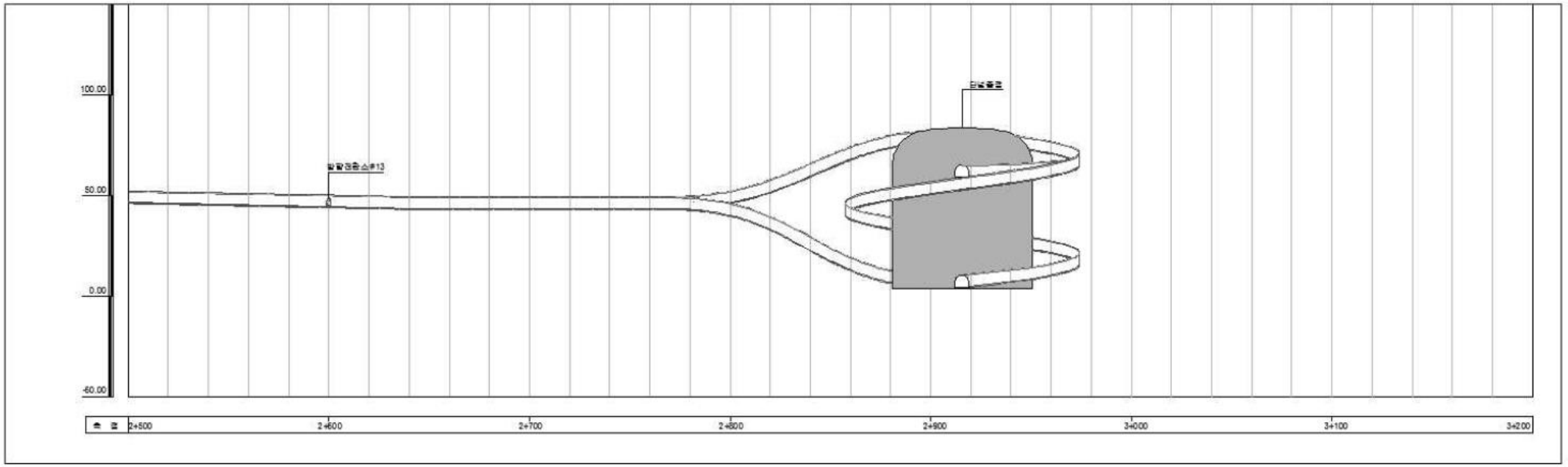




KNO 지하시설 개념도



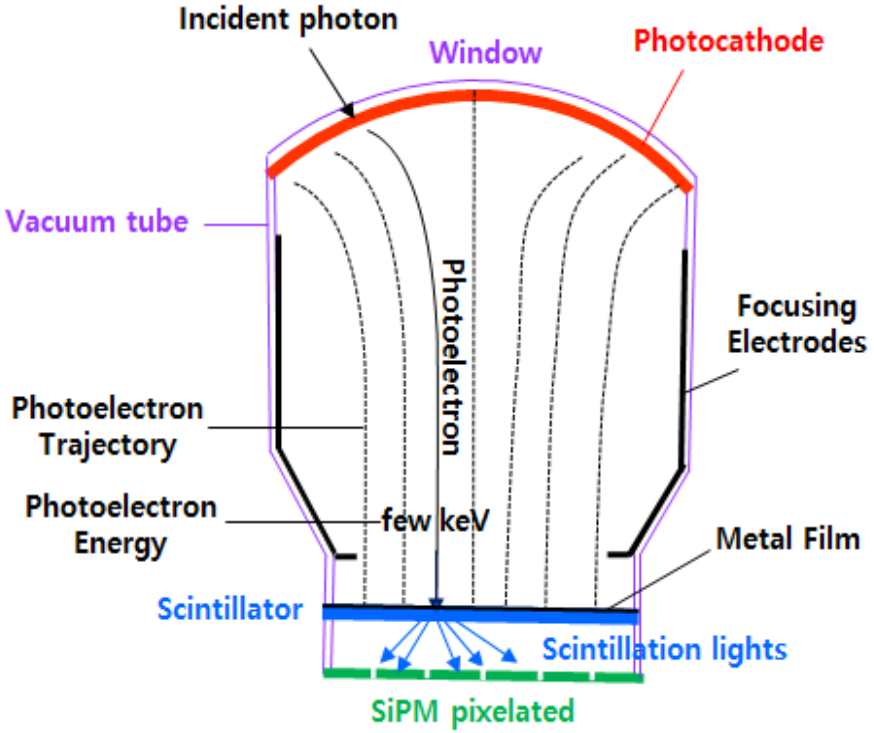
종단면도

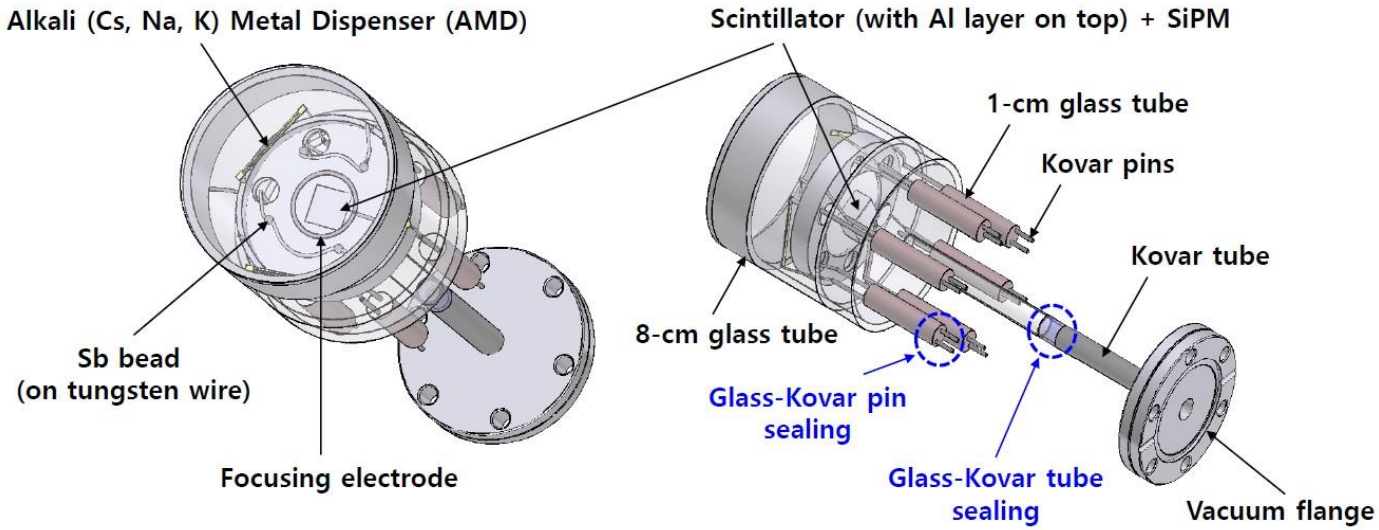


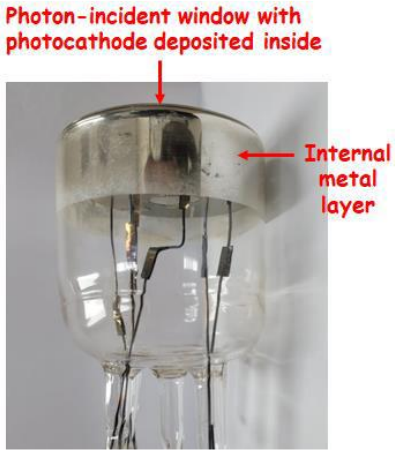
Activities on Detector R&D

- Development of Silicon PMT (SiPMT)
  - Kyungpook National University
  - Hybrid PMT using photocathode, scintillator, and SiPM
- Design of Water Purification System
  - Seoul National University and Chonnam National University in collaboration with DICOTECH co
- Development of Radon System
  - Seoul National University
  - Radon Degasifier (DICOTECH), Highly Sensitive Radon detector (DAON)
- Development of KNO Software
  - Sejong University, Sungkyunkwan University, UNIST
  - KNO event reconstruction package

Detector R&D on PMT



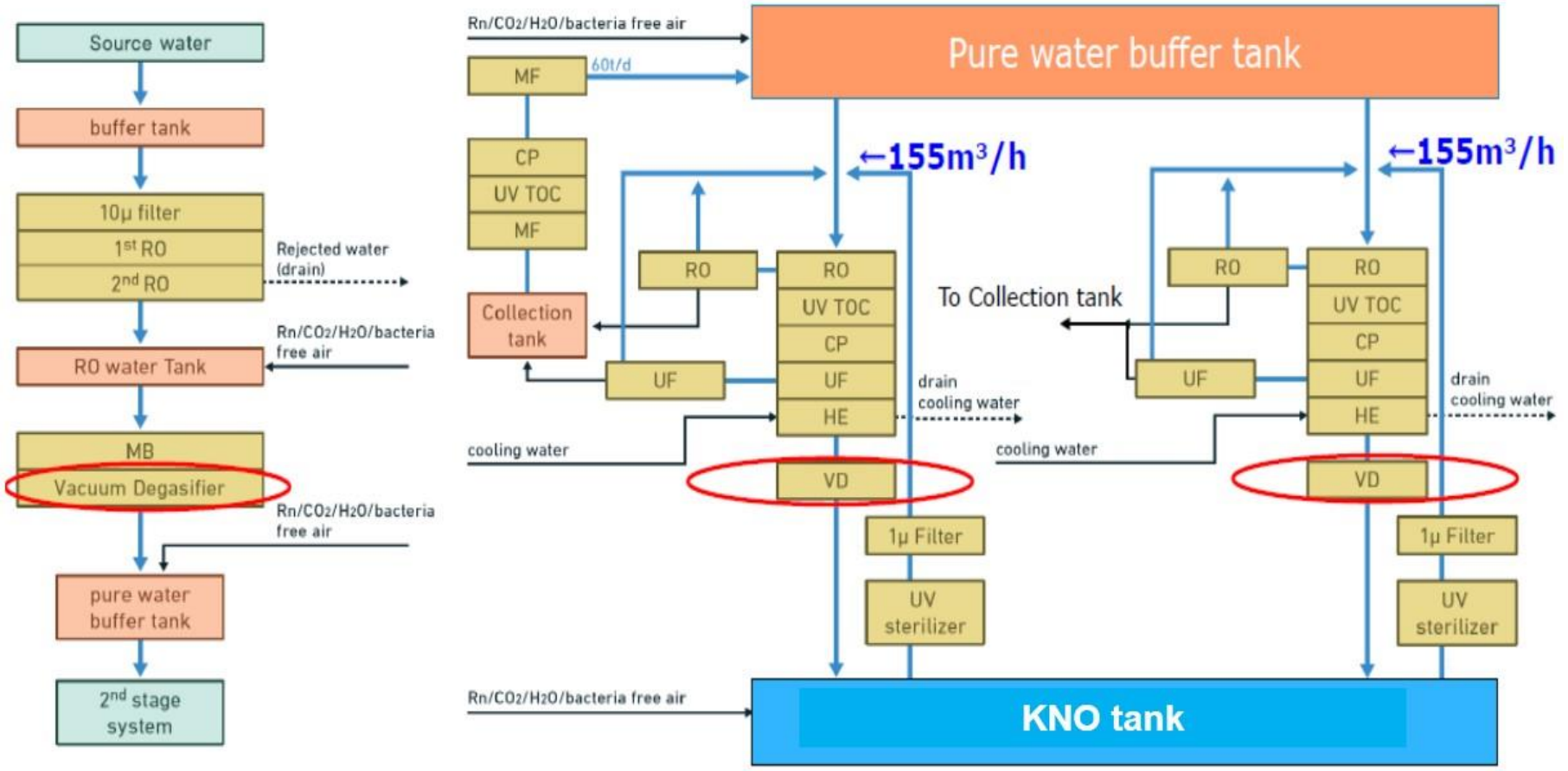




- ✓ Fast response time : ~ few ns
- ✓ Large detection area
- ✓ High multiplication : 2×10^7

- ✓ Design and fabrication of 3 inch PMT in progress
- ✓ KNO outer detector needs O(1000) small PMTs

Design of Water Purification System



- ✓ Based on SK/HK system
- ✓ Designed by DICOTECH

Detector R&D on Radon System

radon degasifier prototype



radon detector

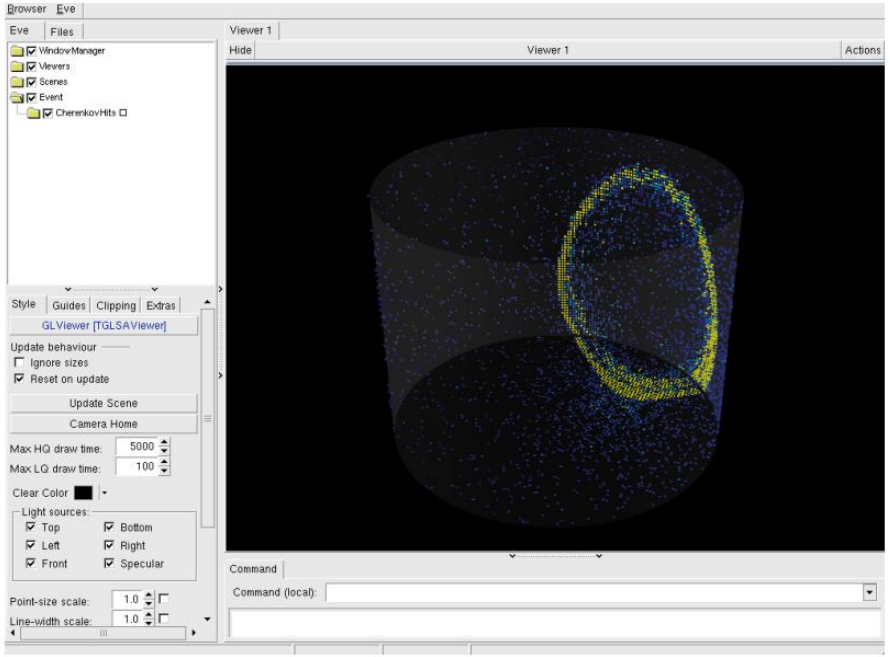


- ✓ Radon Vacuum Degasifier (DICOTECH) for radon removal
- ✓ Highly Sensitive Radon Detector (DAON)

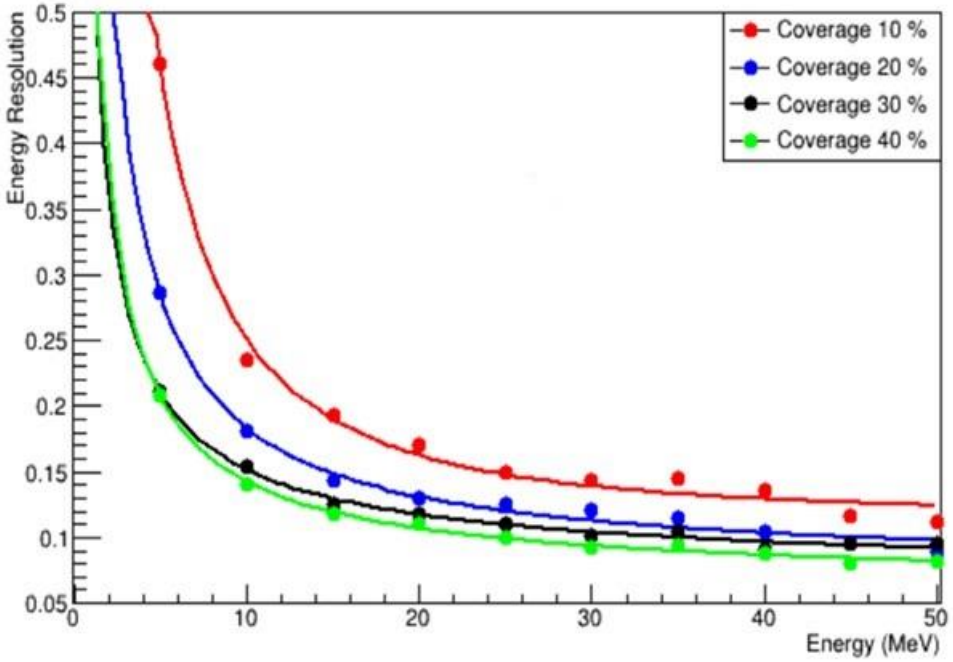
KNO Software Development

- Develop KNO reconstruction packages which can be used to study physics sensitivities and to optimize the detector design
- 1st version of KNO reconstruction package based on goodness fit developed and 2nd version of KNO reconstruction package based on likelihood fit being developed

3D event display with EVE tool



Energy resolution



KNO 구축예산 (추정치)

● **추정 예산은 과기부 기획보고서 자료(2024년)를 참조**

부문	세부내역	부문별 예산(원)
지하시설	지하터널, 지하공동 등	1600억
검출기 구조물 및 수조	콘크리트 수조 덮개구조물 및 크레인 광센서 구조물	600억
초순수 정수장치	78 m^3/h 용량 초순수 정제 장치 2대	400억
광센서	내부 검출기 광센서 (대구경 PMT 30000개) 외부 검출기 광센서 (소구경 PMT 10000개)	2000억
전자 모듈 및 고전압 모듈	전자 모듈 고전압 모듈 및 케이블	200억
전력설비, 연구동 및 기타	2MW급 전력설비 연면적 5000m^2 지상 연구동 기타 부대시설	200억
총 예산		5000억

Conclusion

- KNO는 차세대 중성미자 연구를 주도할 수 있는 한국 주도의 대형연구 시설이며 향후 수십년 동안 한국을 대표하는 기초과학시설이 될 수 있음
- 국내 중성미자 학계는 RENO 실험 등을 통해 세계적인 연구성과를 도출하는 등 KNO를 성공적으로 추진할 수 있는 역량 보유
- KNO에 대한 과학적, 기술적 선행 연구가 상당한 정도로 진행되고 있어 KNO의 성공 가능성을 높이고 있음
- KNO는 과기부의 새로운 구축형 R&D 제도에 적합한 사업으로, KNO의 성공을 통해 한국 기초과학의 위상을 제고하는 동시에 발전적인 대형기초과학시설 구축프로세스를 정립하는 데 기여할 것으로 예상

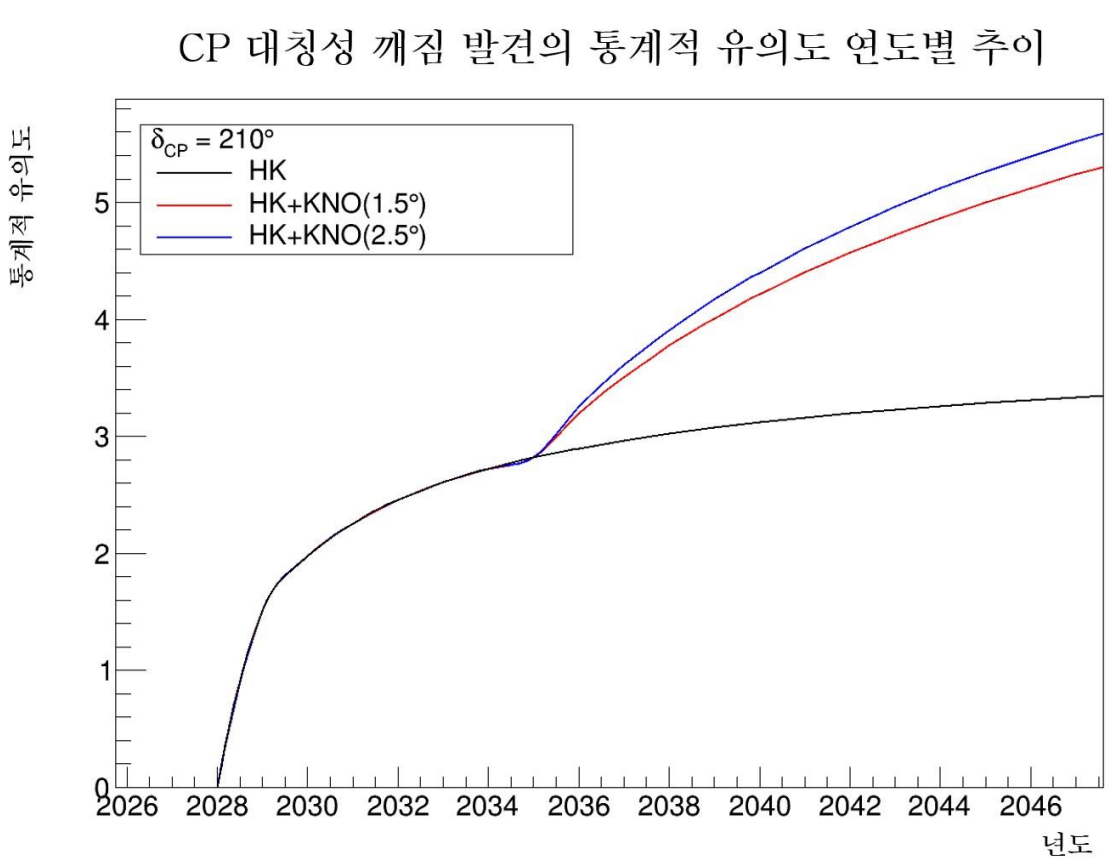
감사합니다

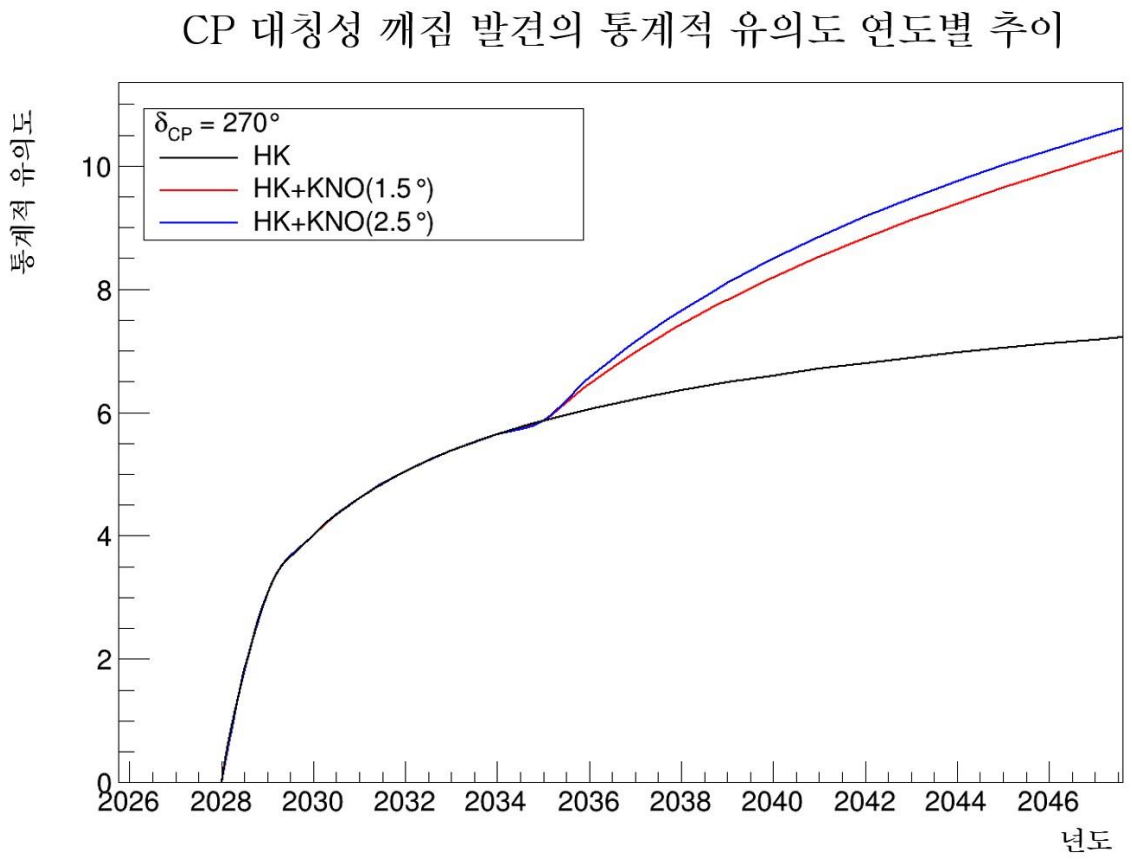
KNO Collaboration

- 현재 약 120여명의 연구자가 중성미자 분야에서 활동하고 있으며 대다수의 연구자가 KNO에 참여의사를 표명 (기획보고서 자료)
- 2023년 물리학회를 통해 실시된 KNO 수요조사에서 97%의 응답자가 KNO 구축의 필요성에 동의한다고 응답 (기획보고서 자료, 237명 중 229명이 동의)
- KNO가 구축되는 경우, 200~300여명의 국내연구자가 참여할 것으로 기대되며 해외연구자들을 포함하면 500~600여명의 그룹이 될 것으로 예상
- KNO와 HK는 J-PARC neutrino beam을 공동으로 사용하게 되어 HK와의 국제공동연구를 추진할 계획

CP Violation in KNO and HK

- **CP phase δ_{cp} = 0~54°, 112~360° from Nature (2025) by T2K and NOνA**





CP Violation in KNO and HK

- **CP phase δ_{cp} = 0~54°, 112~360° from Nature (2025) by T2K and NOνA**

