Super-Kamiokande/ Hyper-Kamiokande

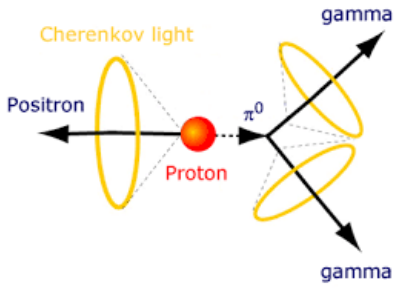
Byeongsu Yang (Chonnam National University)

2026.10.27

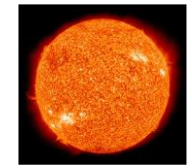
K-neutrino symposium 2026, Chung-Ang University

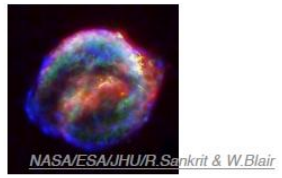
Research Topics

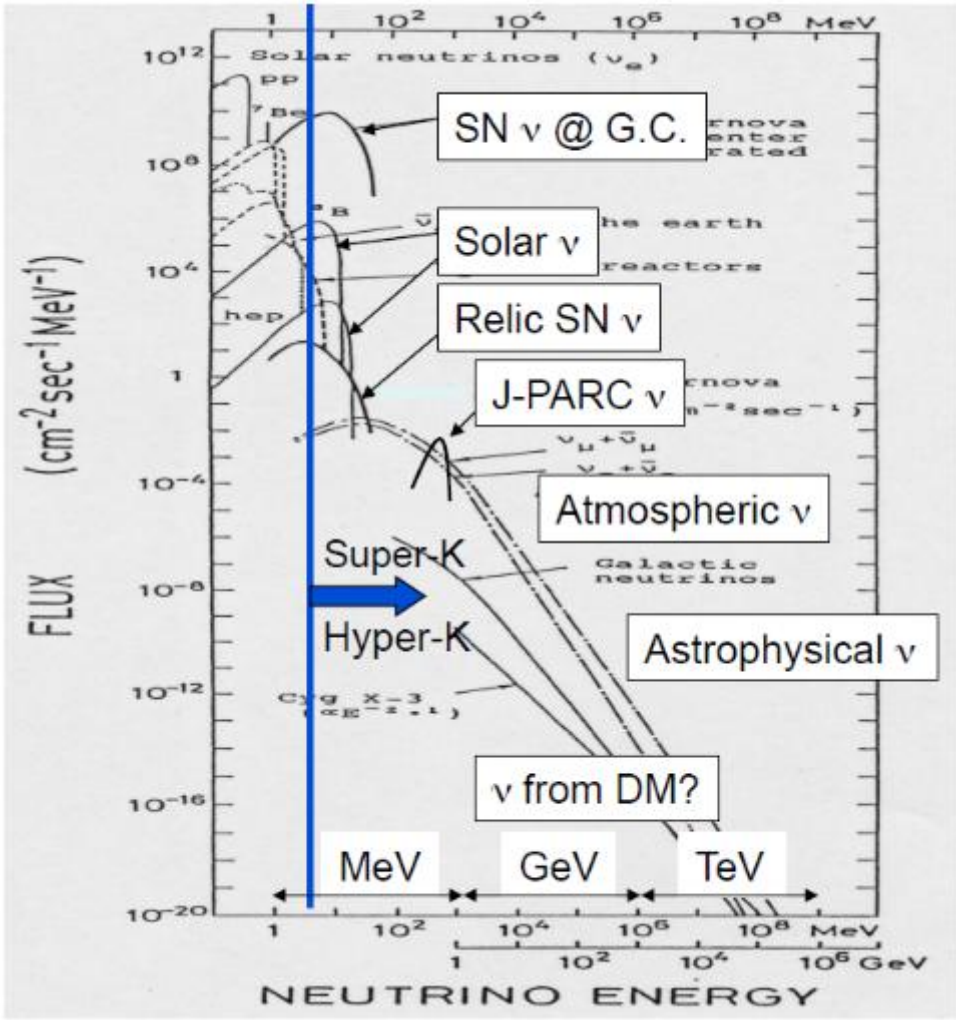
- Nucleon decay
- Neutrino physics
  - Accelerator and atmospheric neutrinos
  - Solar neutrinos
- Neutrino astronomy
  - Supernova, Sun, etc.
- Dark matter
- Sterile neutrino





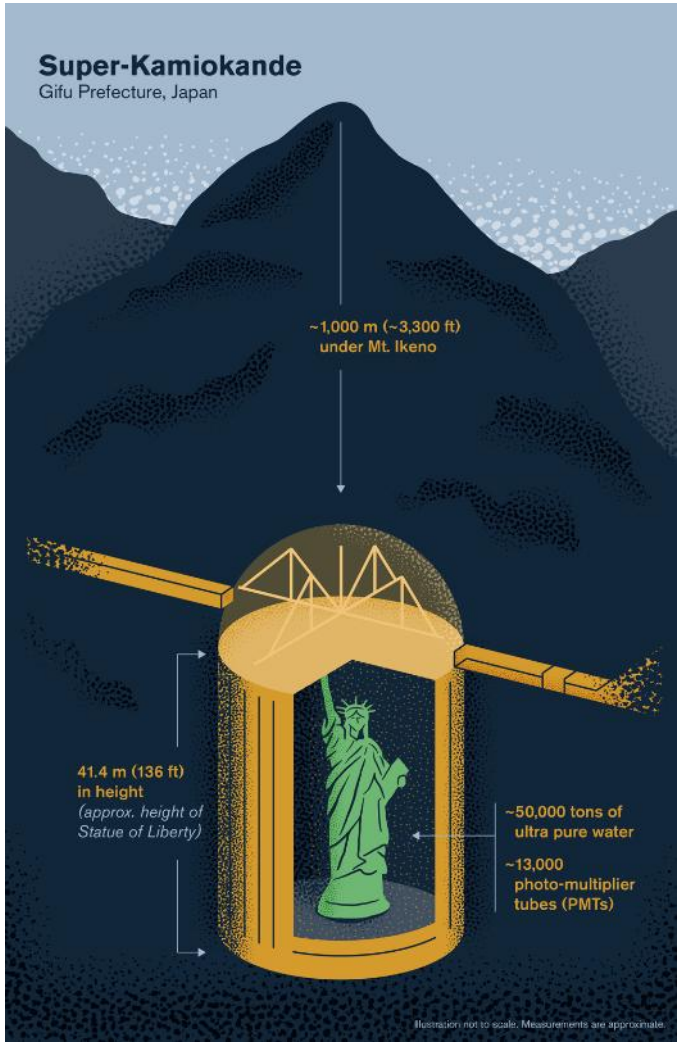






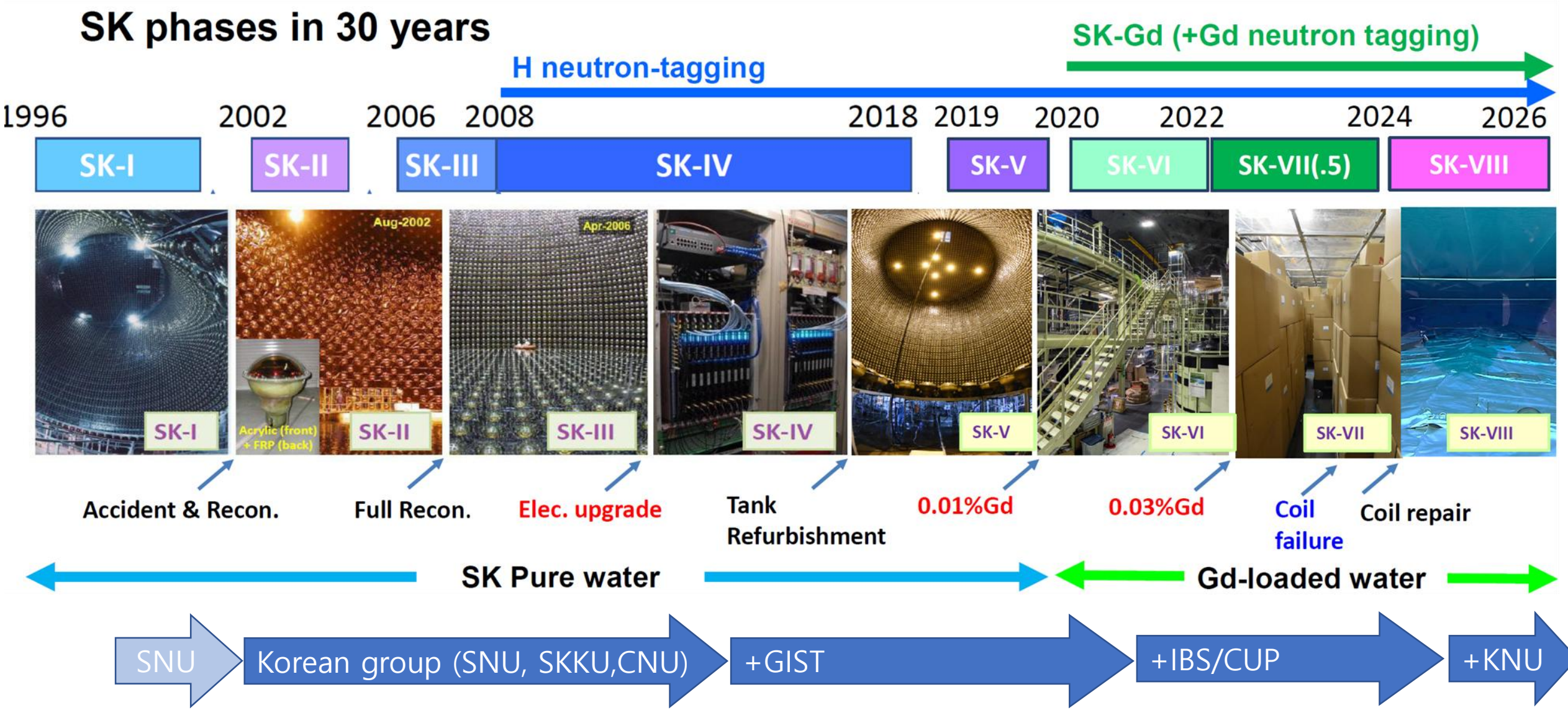
Super-Kamkiokande





The Super-Kamiokande is operated by an international collaboration of about 200 people and about 50 institutes from Japan, the United States, Korea, China, Poland, Spain, Canada, United Kingdom, Italy, France and Vietnam.

History of Super-Kamiokande



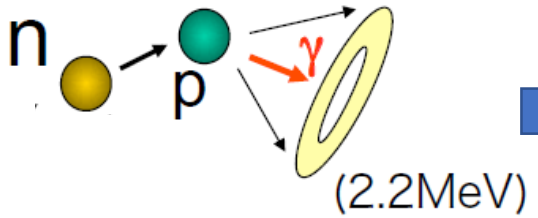
SNU → Korean group (SNU, SKKU,CNU) → +GIST → +IBS/CUP → +KNU


スーパーカミオカンデ観測30周年記念シンポジウム
Symposium for the 30th Anniversary of Super-Kamiokande
Super Kamiokande 30th anniversary symposium
SINCE 1996
30th
Super-Kamiokande
30th Anniversary
スーパーカミオカンデ観測30周年記念祝賀会
Super-Kamiokande 30th Anniversary Celebration
神代
神代
神代

SK-Gd

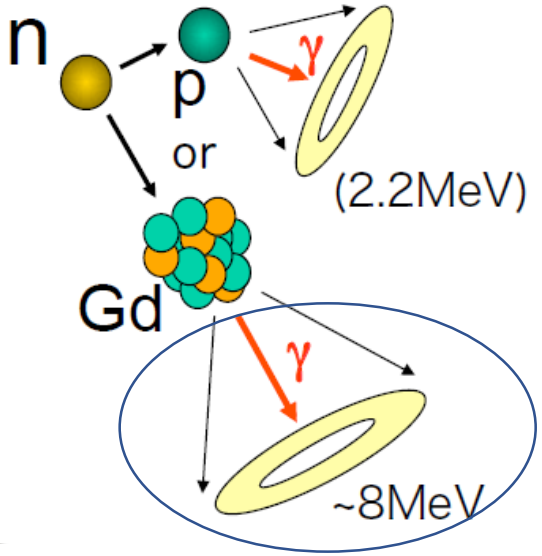
- Enhance neutron detection efficiency by adding Gd
  → Higher detection efficiency for neutron-producing reactions.

Before Gd loading

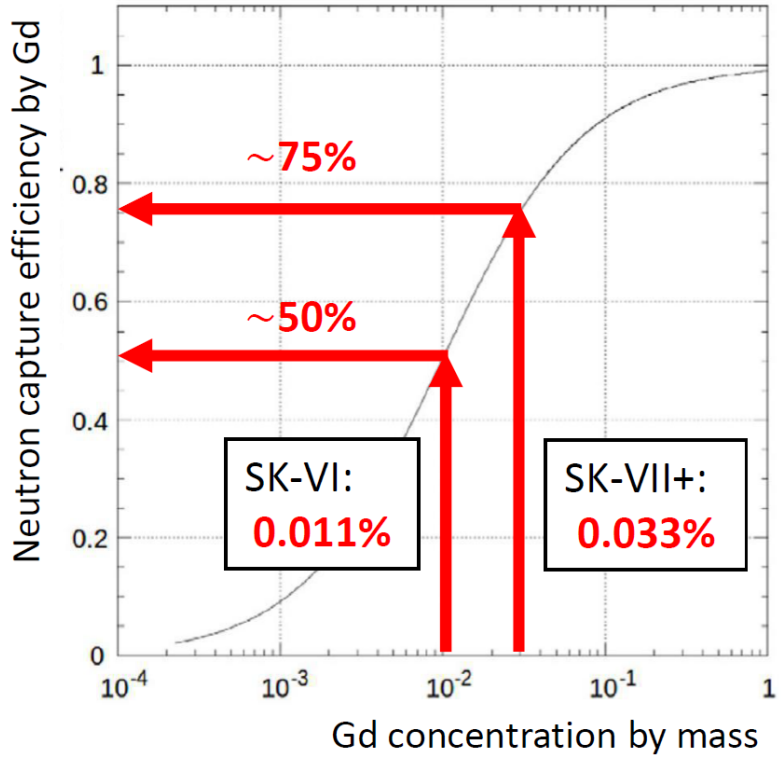


Too low energy to be efficiently detected in SK
Efficiency: 20–30%

After Gd loading



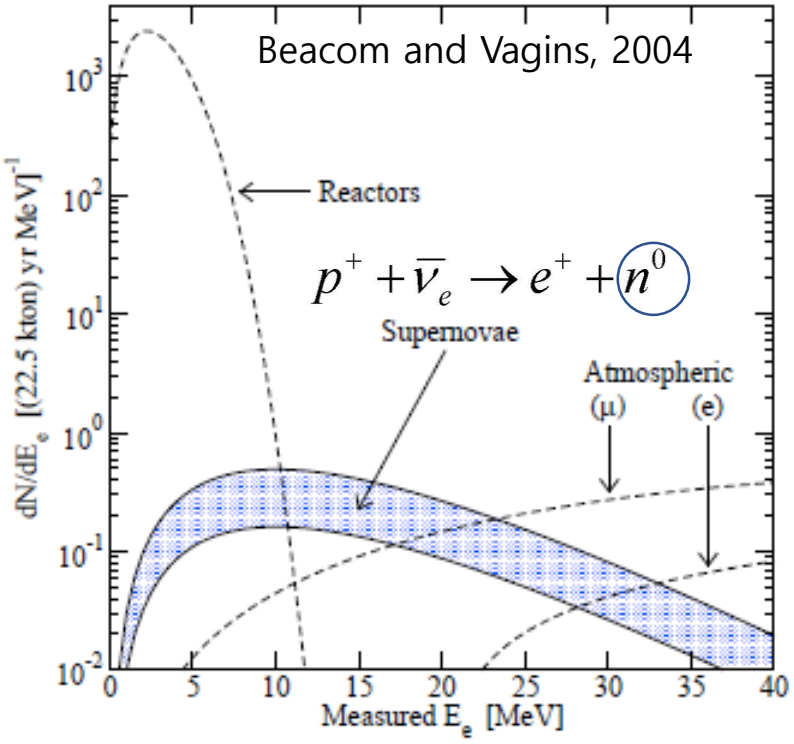
High efficiency



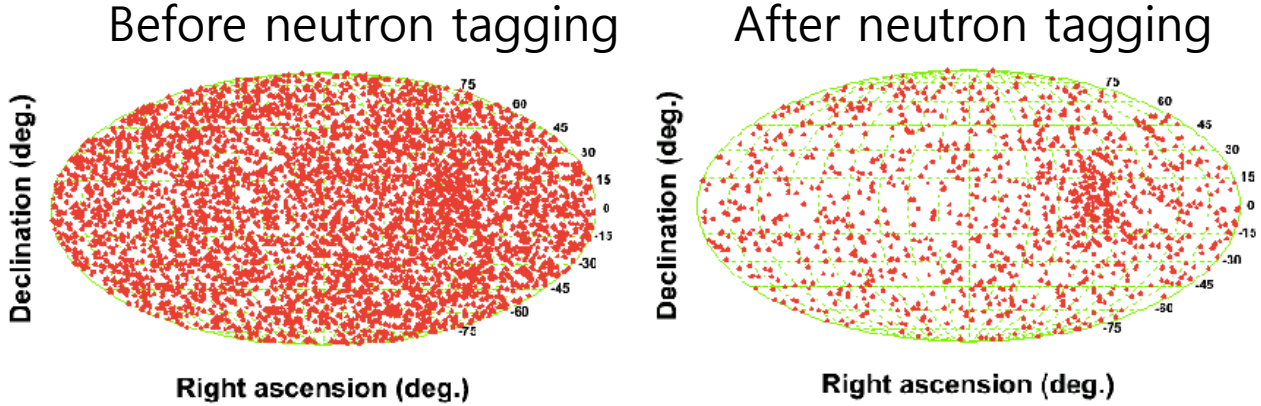
Expected Effects of Gd Loading

- Supernova Neutrinos: A large number of Inverse Beta Decay (IBD) reactions are expected.
  - Diffuse Supernova Neutrino Background (DSNB) / Supernova Relic Neutrino (SRN) Search
  - Real-time Supernova Neutrino Search
  - Increased sensitivity, directional resolution, reject IBD backgrounds

- Background rejection is improved in atmospheric neutrino, solar neutrino and proton decay analyses

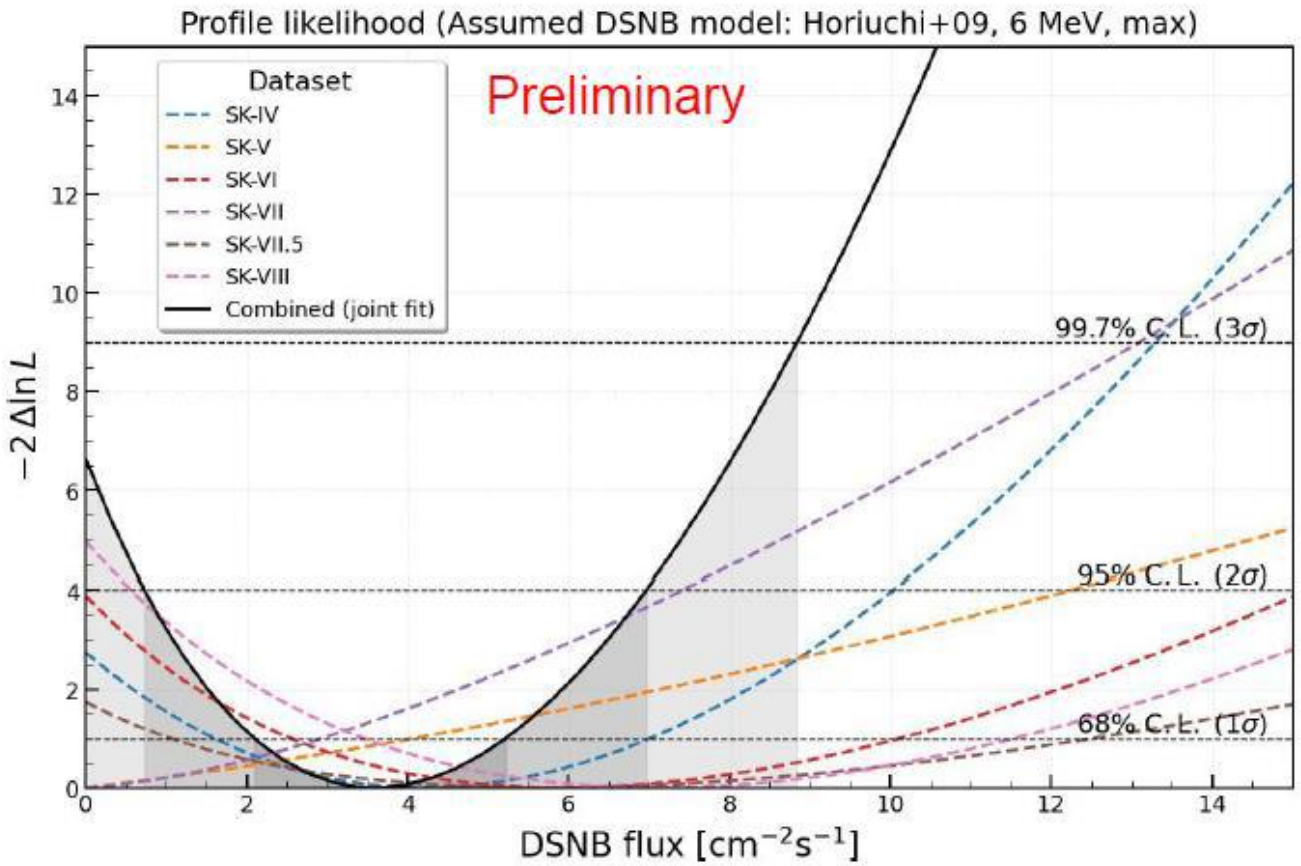


Angular Distribution of Reconstructed Neutrinos



The latest DSNB result

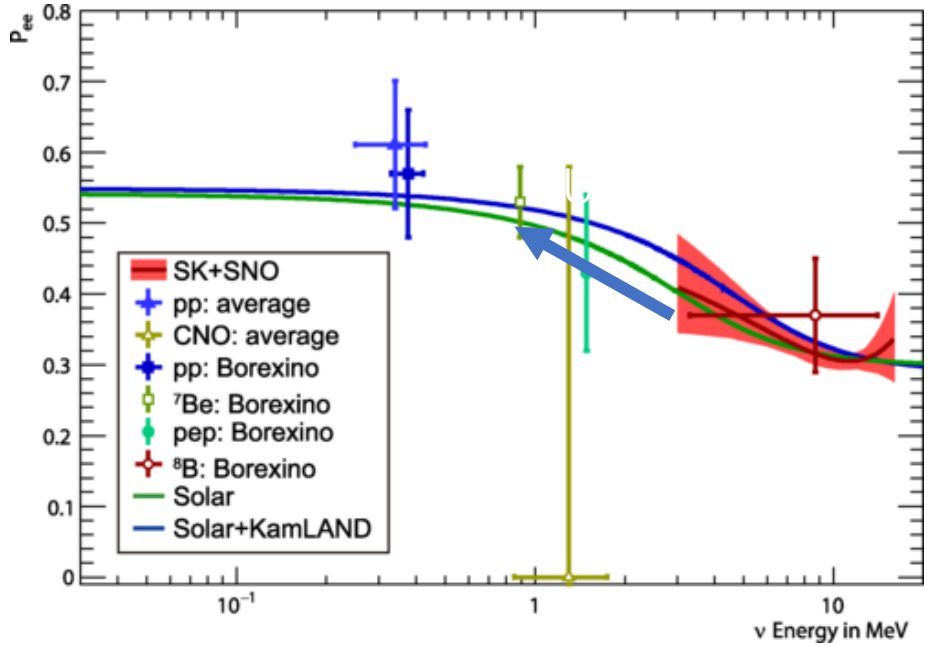
- DSNB $\bar{\nu}_e$ flux from all past core-collapse supernovae
- Super-K-Gd reports a 2.6σ preference for a DSNB component
- Neutron tagging is central to background suppression



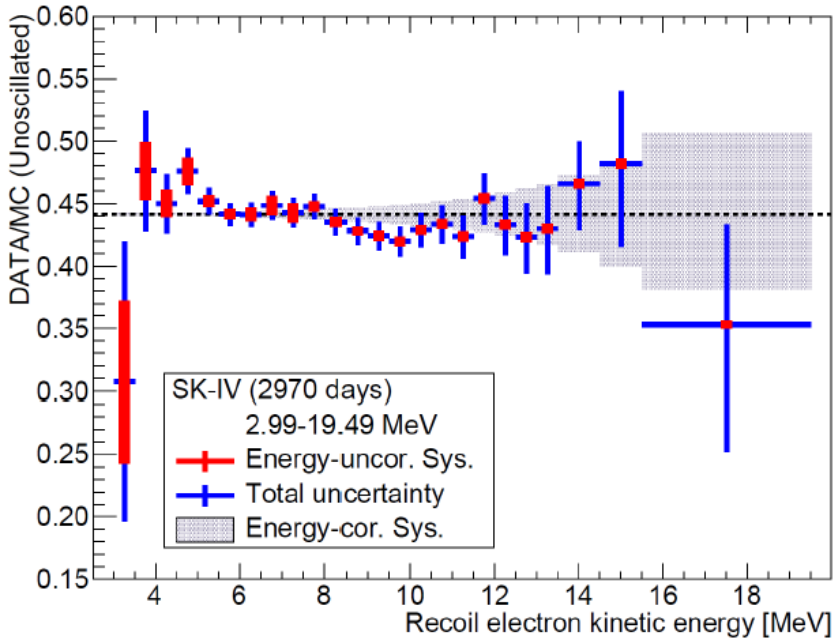
H. Sekiya, Neutrino 2026

Solar neutrinos

- Solar neutrinos probe oscillation over a broad energy range
- Current data are consistent with the MSW-LMA prediction
- The MSW transition region remains a key precision test



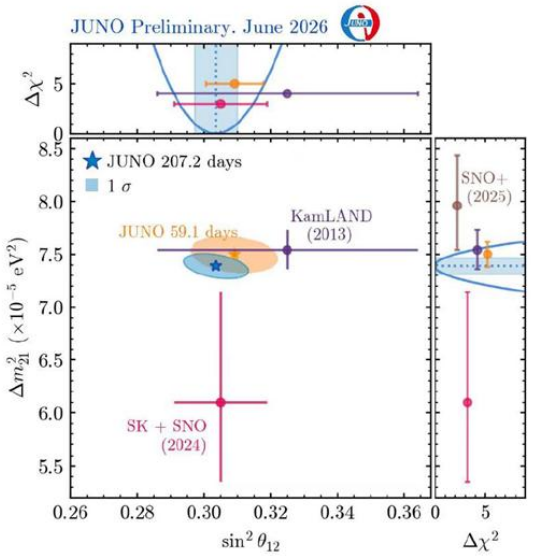
Phys. Rev. D 109, 092001 (2024)



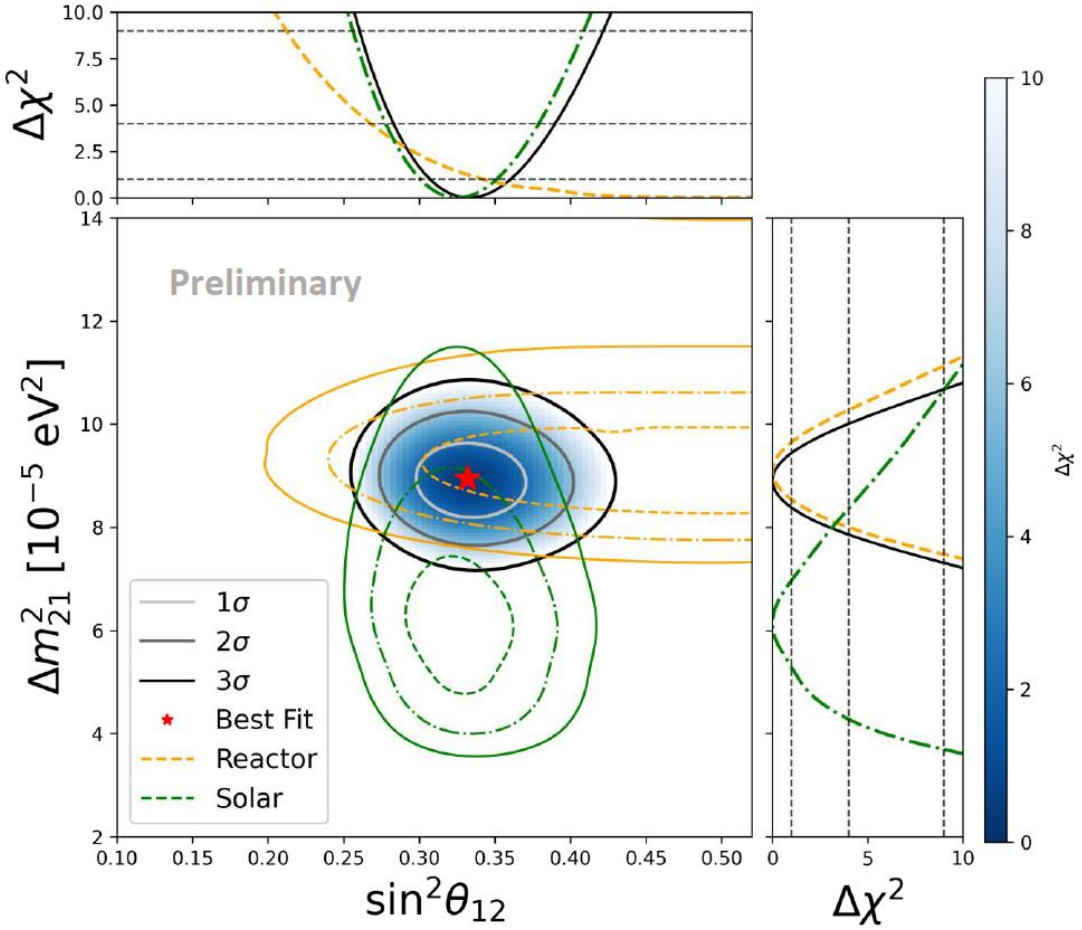
Phys. Rev. D 113, 112001 (2026)

Solar–Reactor Consistency Test with Super-Kamiokande

- SK solar (I–IV) vs. reactor (VI–VII): 1.94σ tension in Δm^2_{21}
- A common detector provides a valuable consistency cross-check



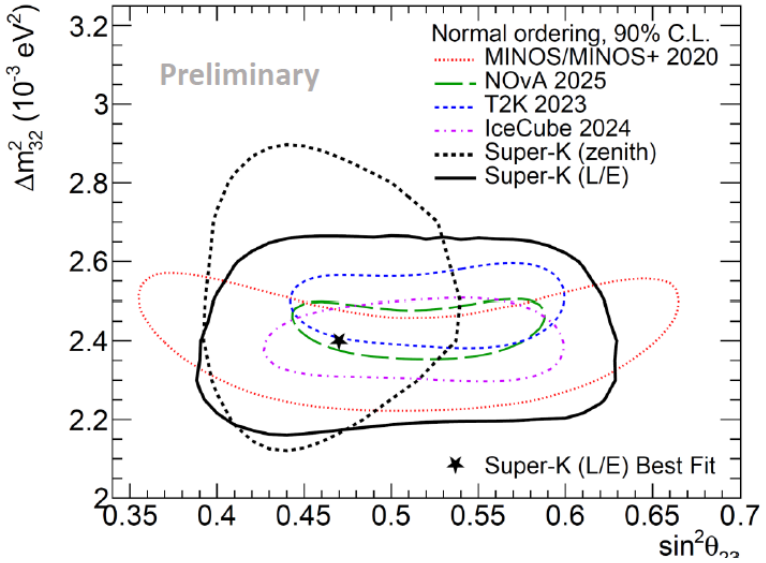
Ref. Y. Wang @ Neutrino 2026

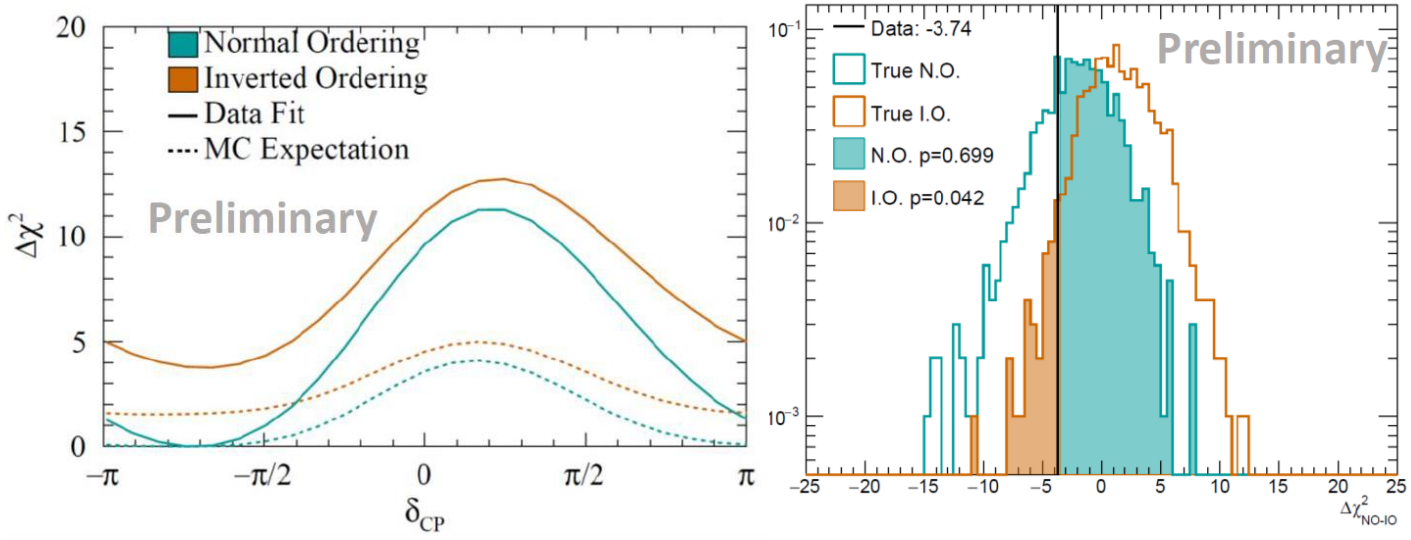


Z. Hu @ Neutrino 2026

Atmospheric neutrinos

- Updates for oscillation parameters and neutrino mass ordering tests, and so on.





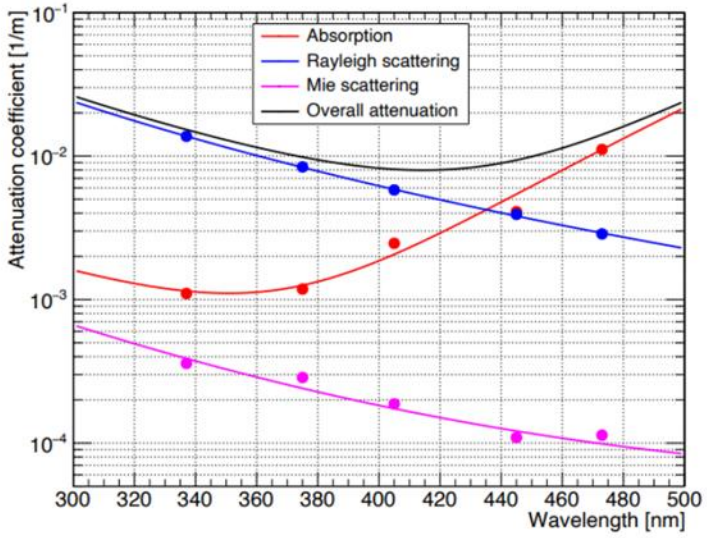
Z. Hu @ Neutrino 2026

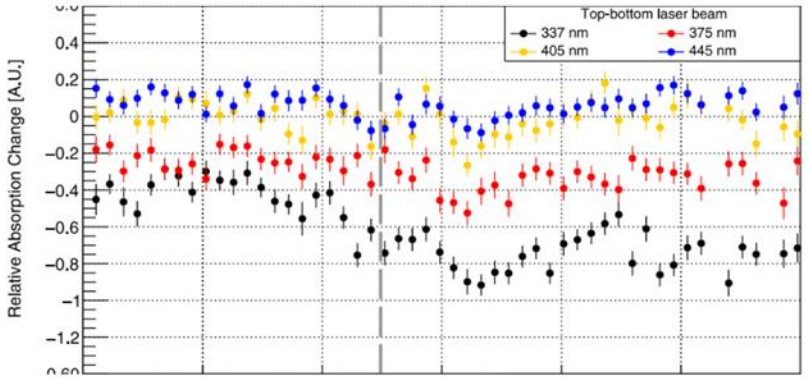
SK-Korean group: 6 institutes, 19 researchers

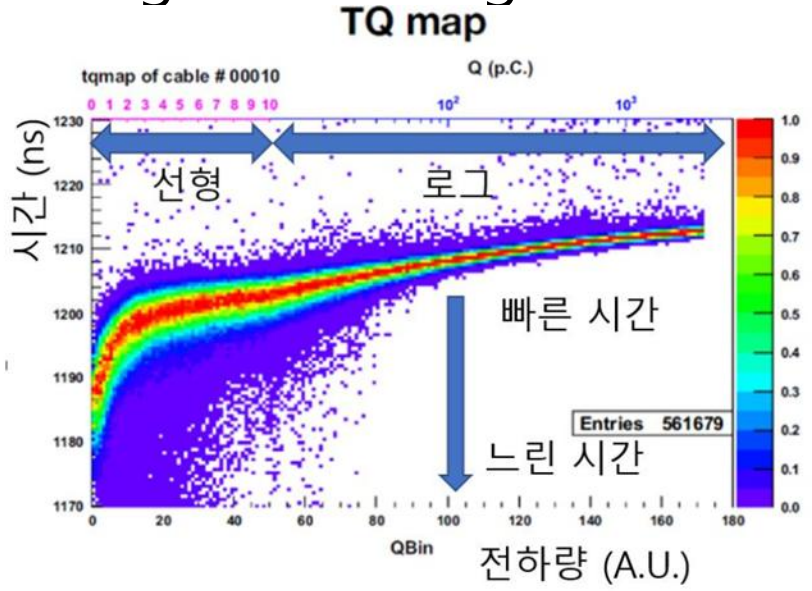
- CNU
  - D.E. Jung
  - D.H. Moon
  - R.G. Park
  - B.S. Yang: A co-convener of calibration group
- GIST
  - J.S. Jang
- IBS/CUP
  - K. Choi
- KNU
  - J.S. Park
  - 1 graduate student
- SNU
  - J.H. Yoo: Country Board
  - 5 graduate students
- SKKU
  - E.H. Kwon
  - J.W. Seo
  - I.T. Yoo
  - 2 graduate students

Korean contribution for Super-K

- Calibration
  - Water parameter measurement
  - Monitoring attenuation length of Gd-loaded water
  - PMT timing-charge (time walk) calibration and timing monitoring







Korean contribution for Super-K

- Physics
  - Search for $p \to e^+\pi^0\pi^0$, $p \to \mu^+\pi^0\pi^0$: Seo Ji-Woong, Kwon Eunhyang (SKKU)
    - Accepted. (arXiv:2604.10975)

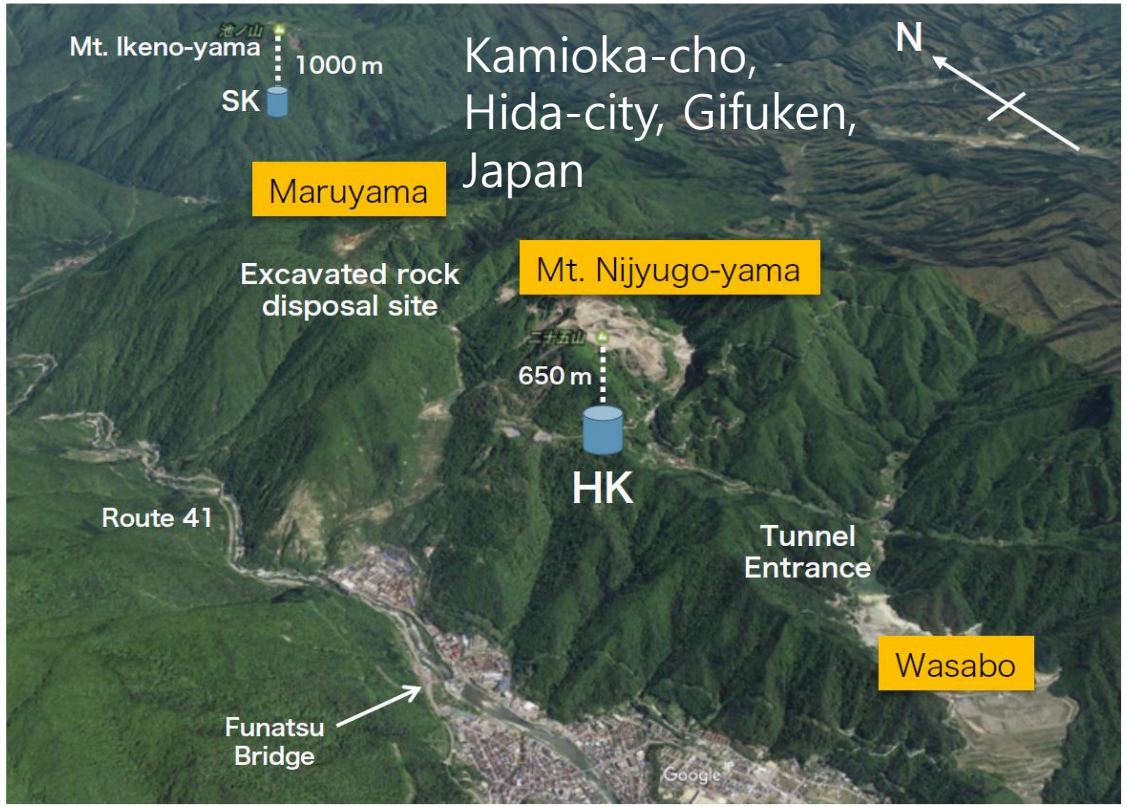
$$p \to e^+\pi^0\pi^0 \quad 7.2 \times 10^{33} \text{ years}$$
$$p \to \mu^+\pi^0\pi^0 \quad 4.5 \times 10^{33} \text{ years}$$

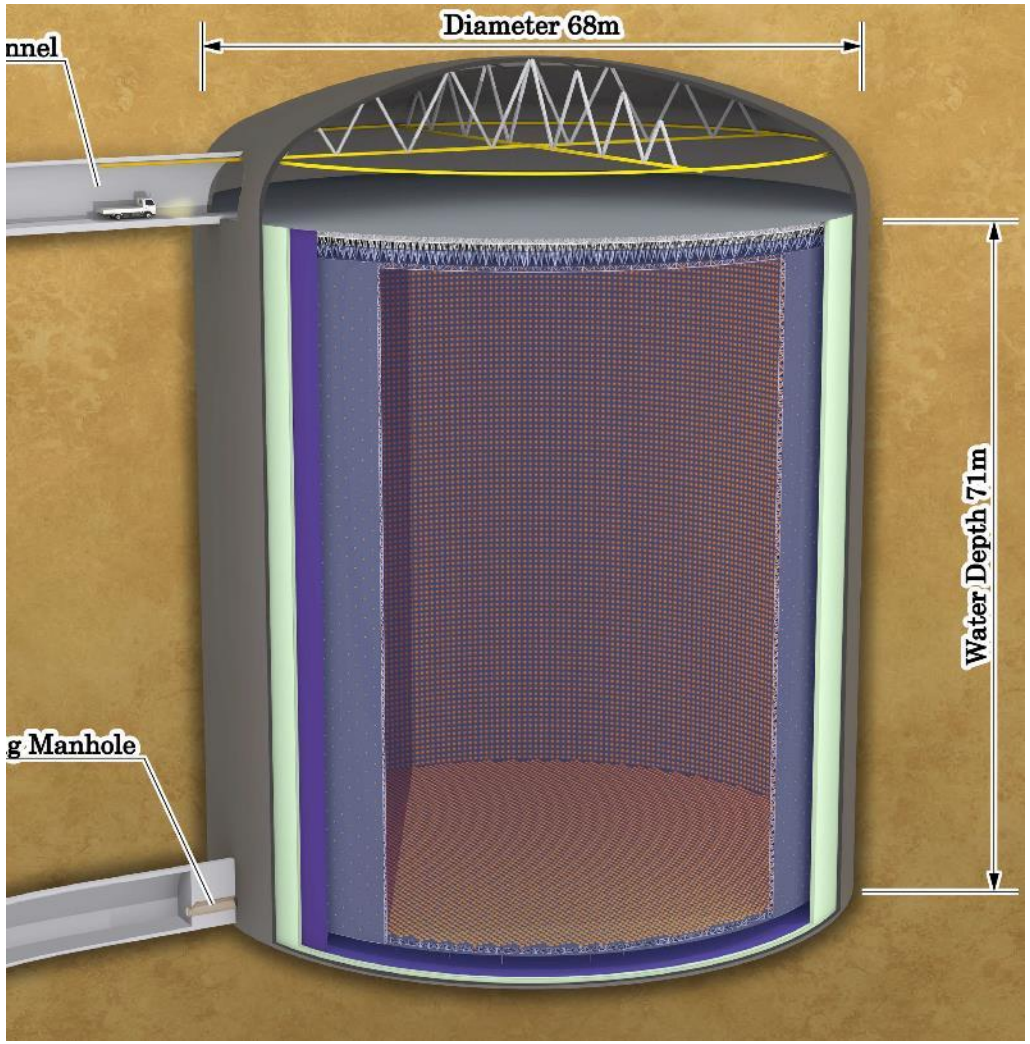
  - Search for $n \to \nu\pi^0$, $p \to \nu\pi^+$: Seunghyun Jung
    - Published: Phys. Rev. D 113, 012015 (2026)

$$3.5 \times 10^{32} \text{ yr for } p \to \nu\pi^+$$
$$1.4 \times 10^{33} \text{ yr for } n \to \nu\pi^0$$

  - Several on-going analyses

Hyper-Kamkiokande



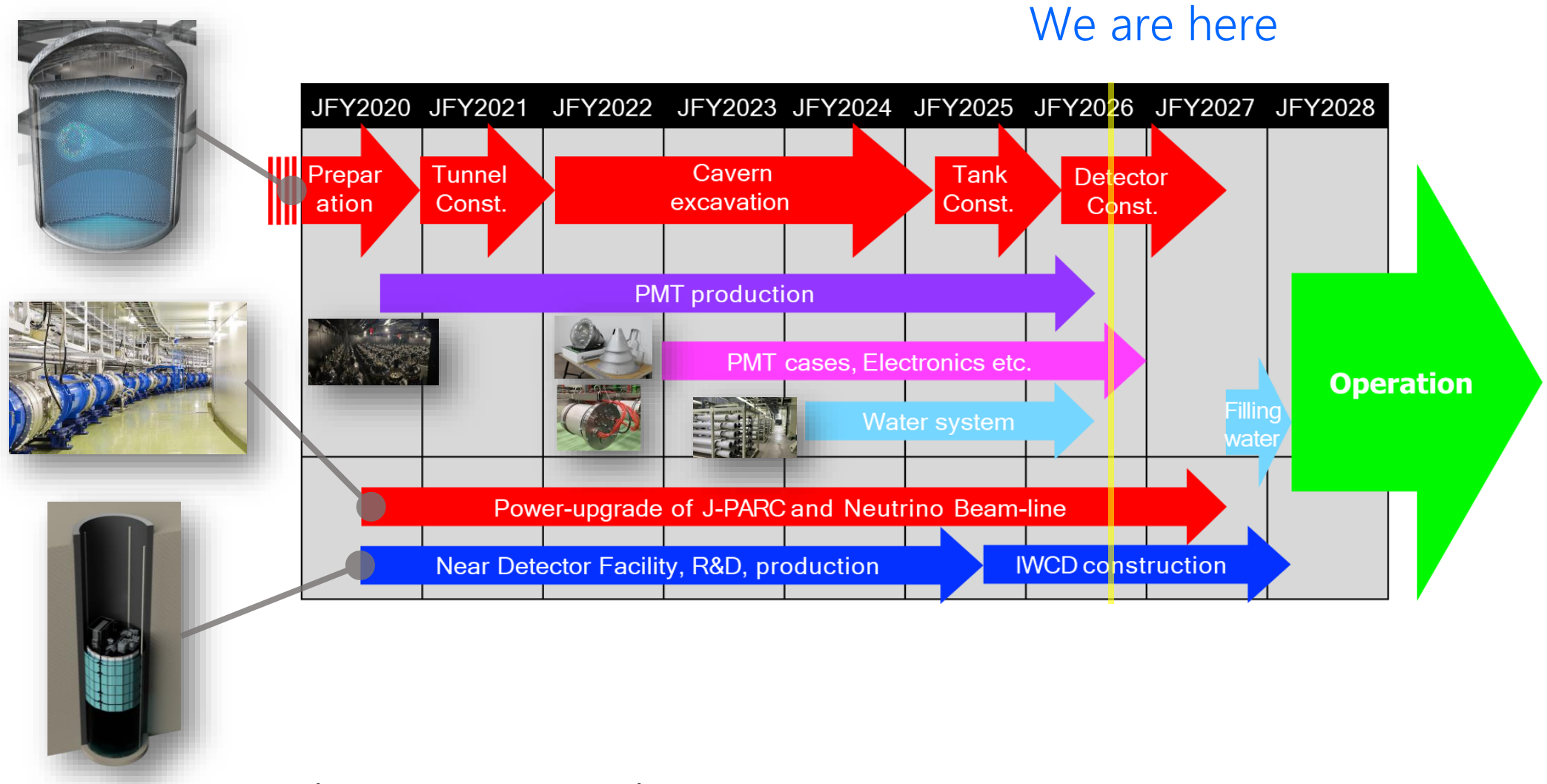


- about 600 researchers from 22 countries have participated in the experiment



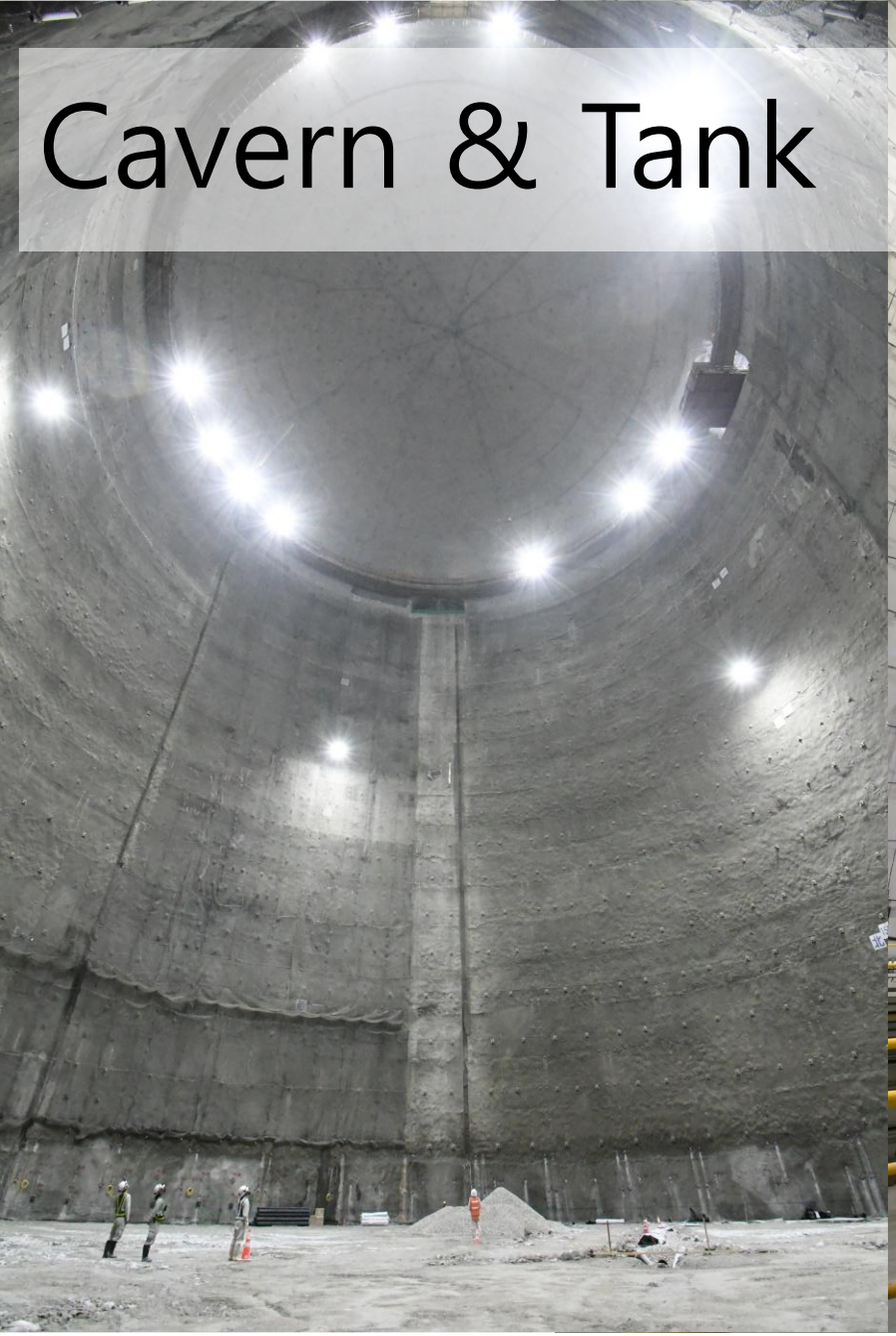
260 kton ultrapure water
~20,000 PMTs

Timeline of Hyper-Kamiokande



Note: JFY=Japanese Fiscal Year starts on April 1st

Cavern & Tank

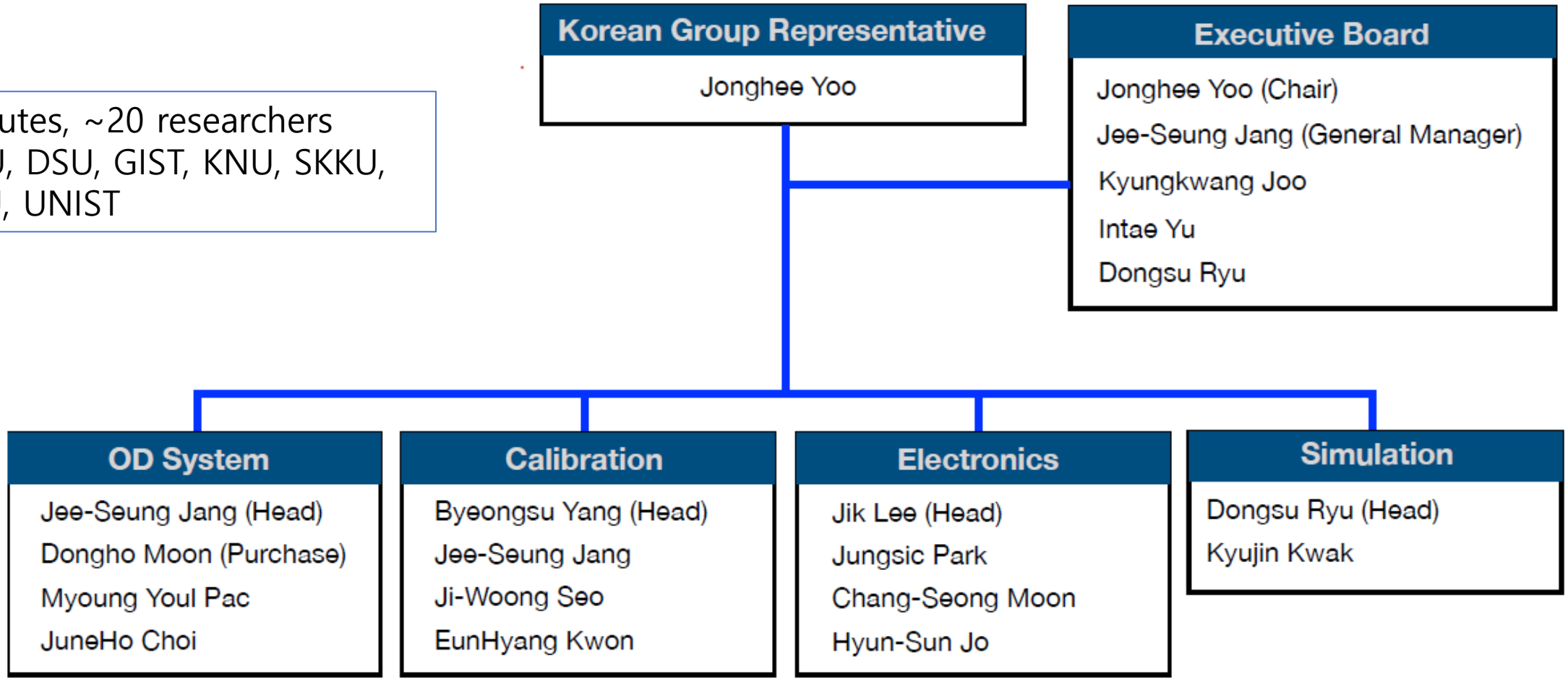




- Excavation of world's largest human-made cavern was completed in 2025
- Tank lining work is about to be completed

Korean group

7 institutes, ~20 researchers
- CNU, DSU, GIST, KNU, SKKU, SNU, UNIST



Korean contribution

- OD electronics
- Inner PMT pre-calibrations
- Laser calibration system

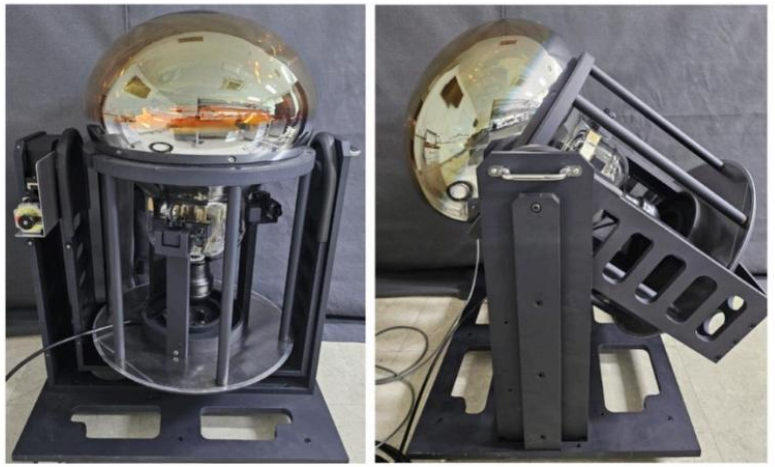
- Most are covered by CPNR (Center for precision neutrino research), CNU.

Korean contribution: PMT pre-calibration

- PMT test before installation
  - Measure position dependence of QE×CE, gain, timing, charge, SPE response
  - Study QE dependence on angle, polarization, wavelength
- Collaboration among Japan, Korea, and Australia
  - Calibration devices developed by Korean and Australian groups
  - Tested in CNU and the device being installed in Jikkento (Kamioka-Cho)
  - Pre-calibration will start for ~400 PMTs.

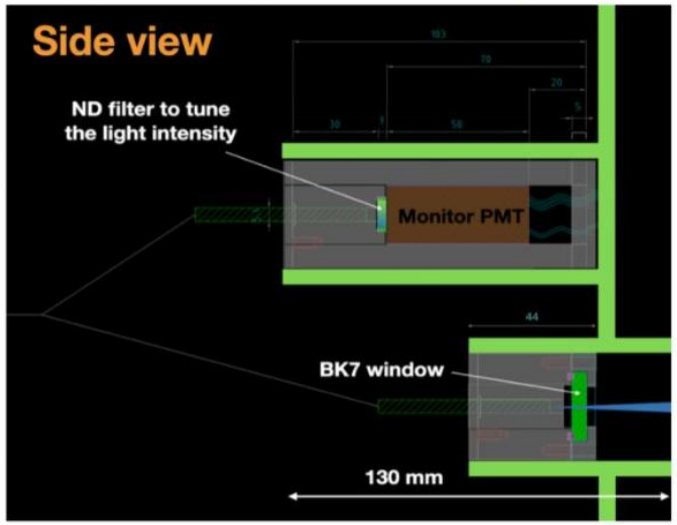


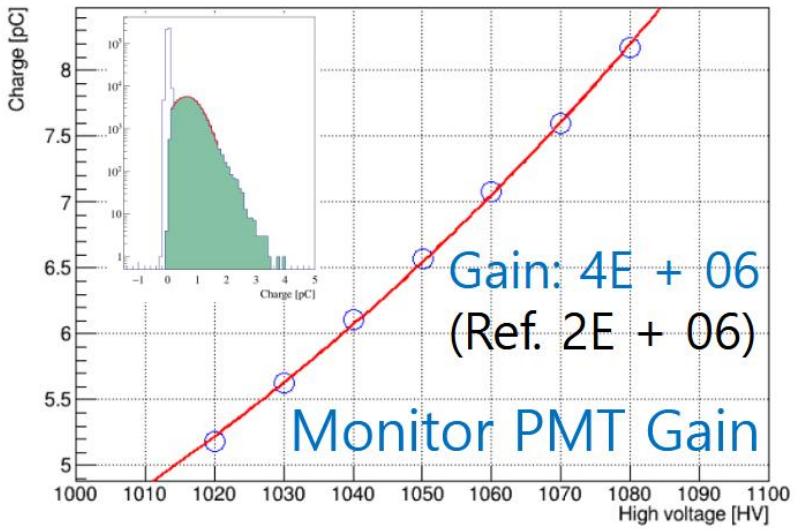


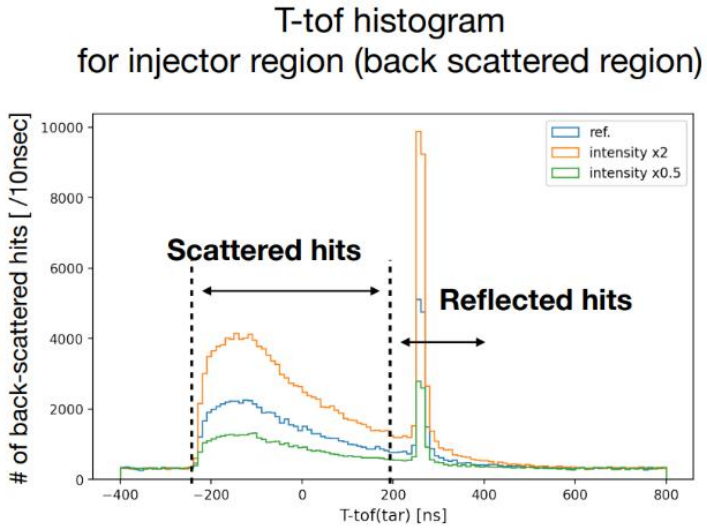


Korean contribution: calibration

- Water parameter measurement same as Super-K
  - Laser injector design: finished.
  - Testing monitor PMT (NNVT and Hamamatsu) and fiber coupler: on-going
  - Laser simulation: on-going

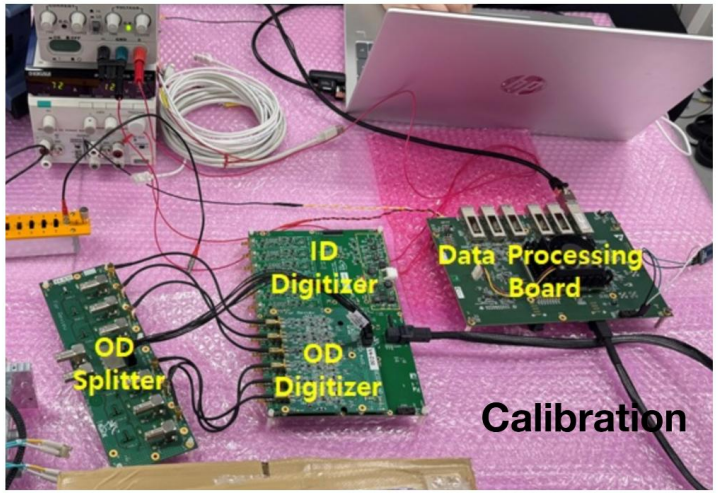


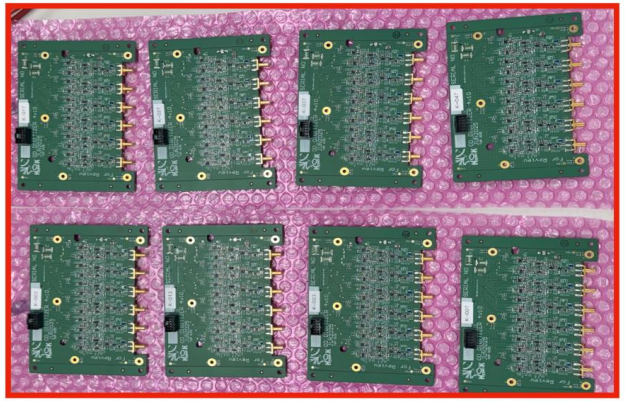


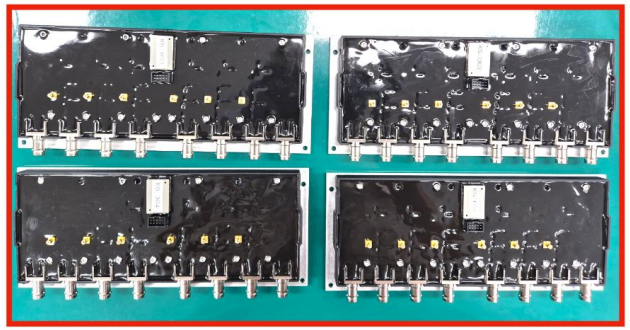


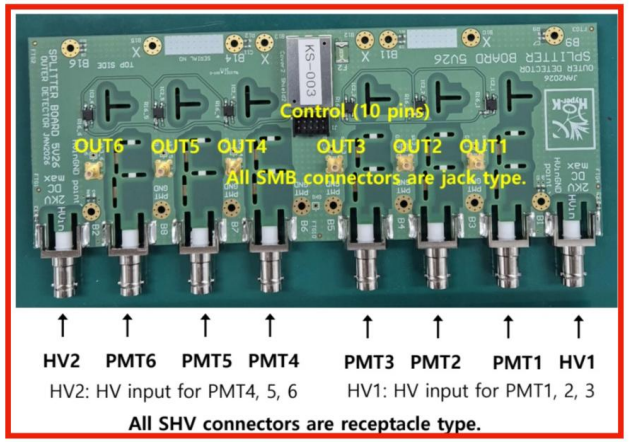
Korean contribution: Electronics and OD

- Electronics
  - KNU has completed the development of a signal switcher for calibration.
- Outer Detector (OD)
  - 3-inch NNVT test is done
  - All outer detector electronics will be produced in Korea









Summary

- Continued Updates from Super-K
  - Adding new results to the established baseline of neutrino and nucleon decay data.
  - Sustaining steady research output during the transition to the next-generation phase.
- On Track for Hyper-K Operation in 2028
  - Shifting focus to detector construction following the successful completion of cavern excavation.
- Expanding Scope of Korean Contributions
  - Super-K: Actively engaging in detector calibration and core physics analyses.
  - Hyper-K: Taking ownership of pre-calibration, optical measurements, electronics, and outer detector systems.

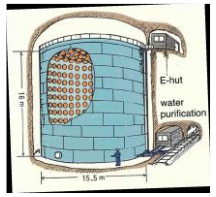
보충자료

Generation of Kamiokande Experiments

Water Cherenkov Detectors

Kamiokande (1983-1995)

16m



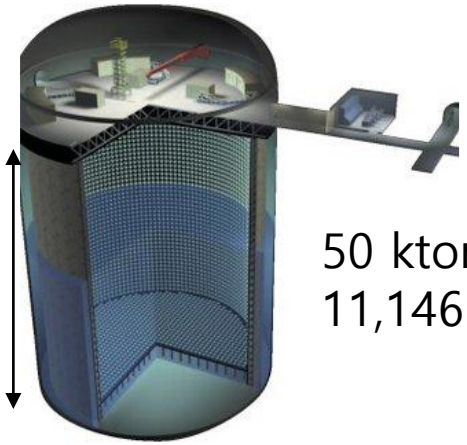
3 kton ultra pure water
948 PMTs



KOSHIBA
Masatoshi
2002 Nobel Prize

Super-Kamiokande (1996-)

41m



50 kton ultra pure water
11,146 PMTs



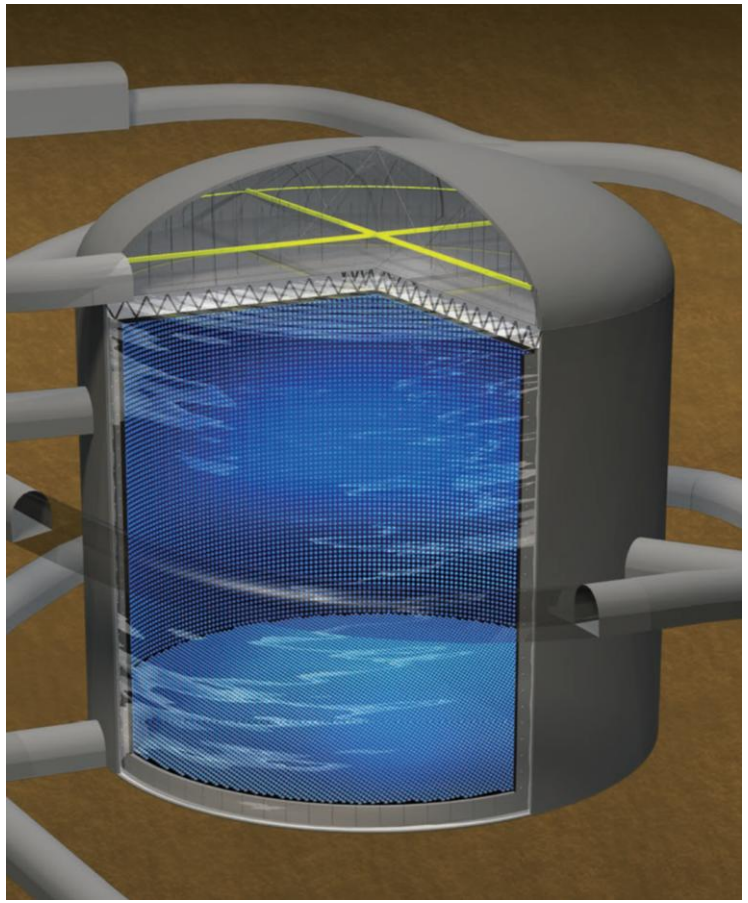
KAJITA
Takaaki
2015 Nobel Prize

Foundation of Neutrino Astronomy
- Supernova (SN1987A) neutrinos
- B8 Solar neutrinos

Discovery of Neutrino Oscillation
- Atmospheric Neutrinos

Hyper-Kamiokande (2028-)

71m



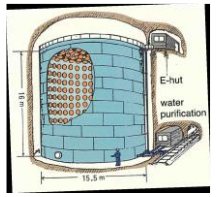
260 kton ultra pure water
~20,000 PMTs

Generation of Kamiokande Experiments

Water Cherenkov Detectors

Kamiokande (1983-1995)

16m

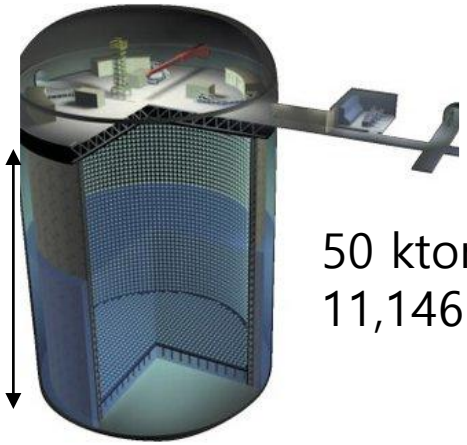


3 kton ultra pure water
948 PMTs

No Korean group
A few Korean researchers

Super-Kamiokande (1996-)

41m

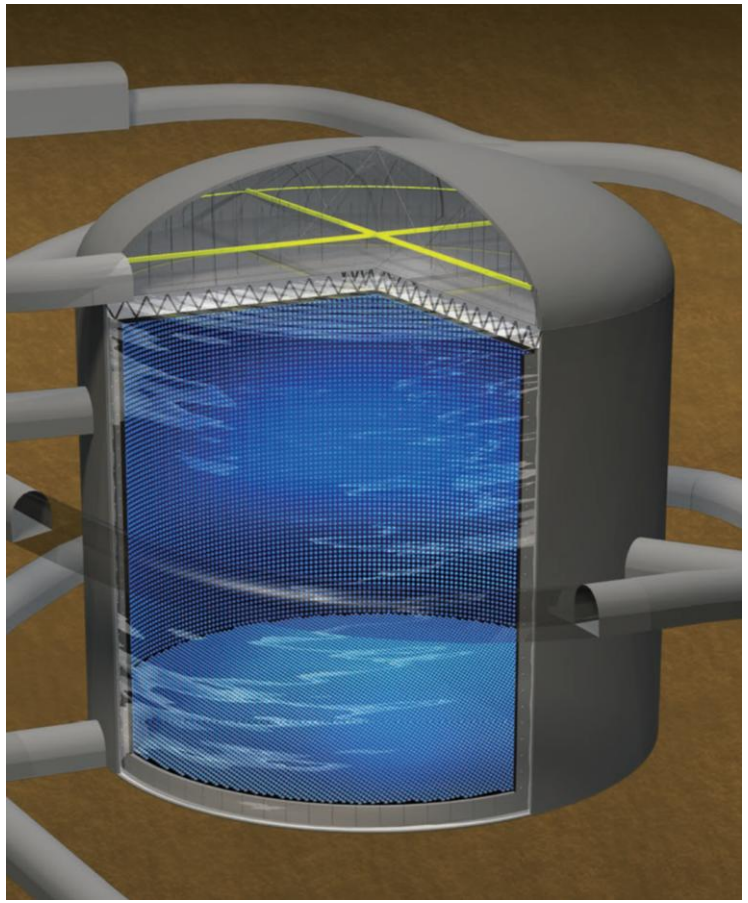


50 kton ultra pure water
11,146 PMTs

5 Korean institutions
About 20 researchers

Hyper-Kamiokande (2028-)

71m



7 Korean institutions
About 20 researchers

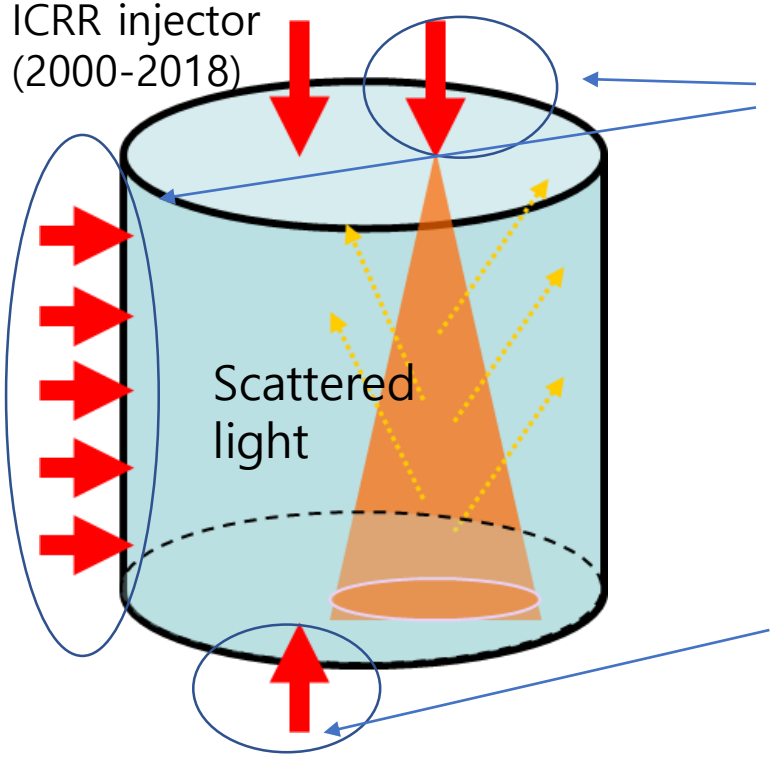
260 kton ultra pure water
~20,000 PMTs

Expected Effects of Gd Loading

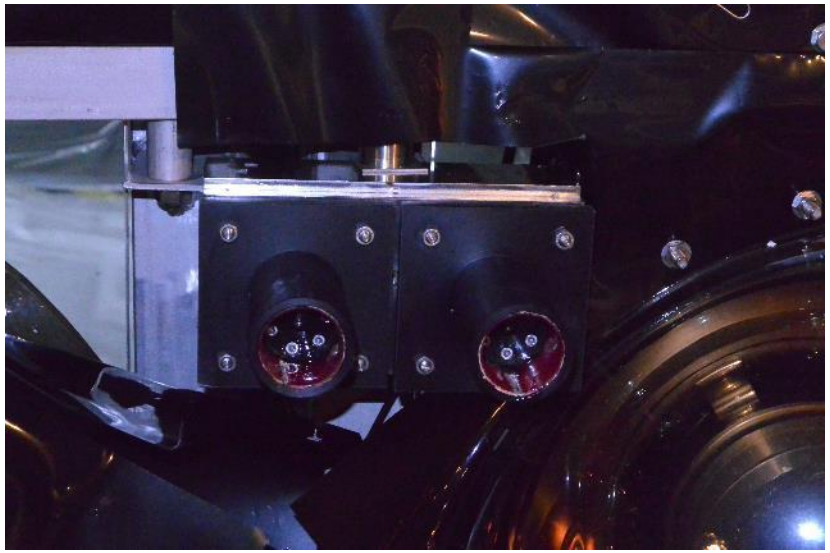
- Atmospheric Neutrinos
  - Improved neutrino/antineutrino discrimination
- Proton Decay
  - Enhanced atmospheric neutrino background rejection
- Solar Neutrinos
  - Improved cosmic-ray spallation background rejection

Contribution of Korean group

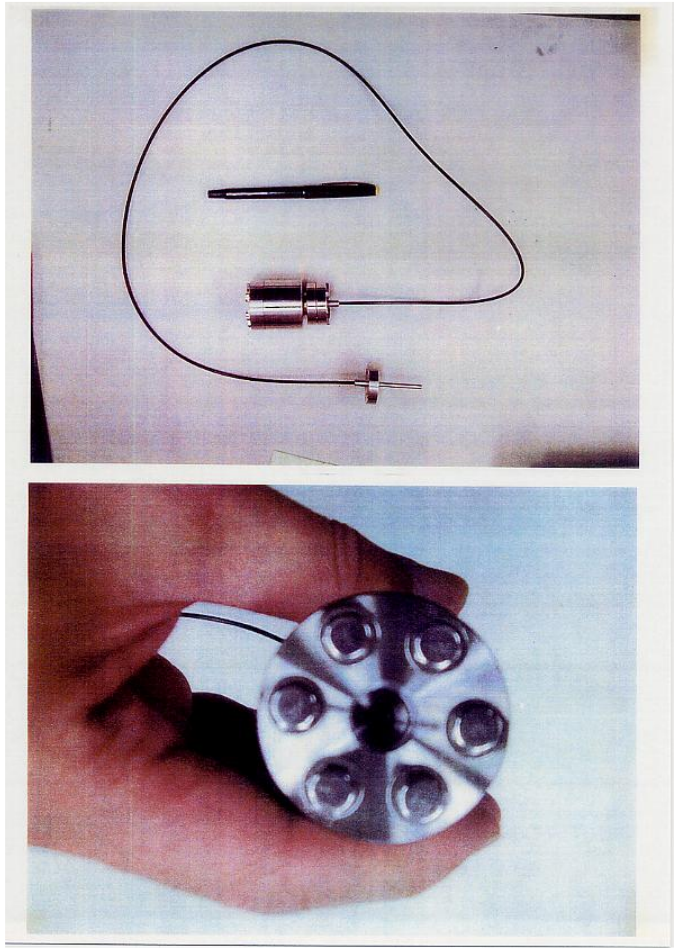
ICRR injector
(2000-2018)



Korean group injectors

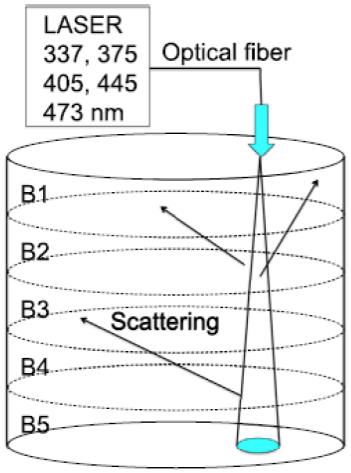


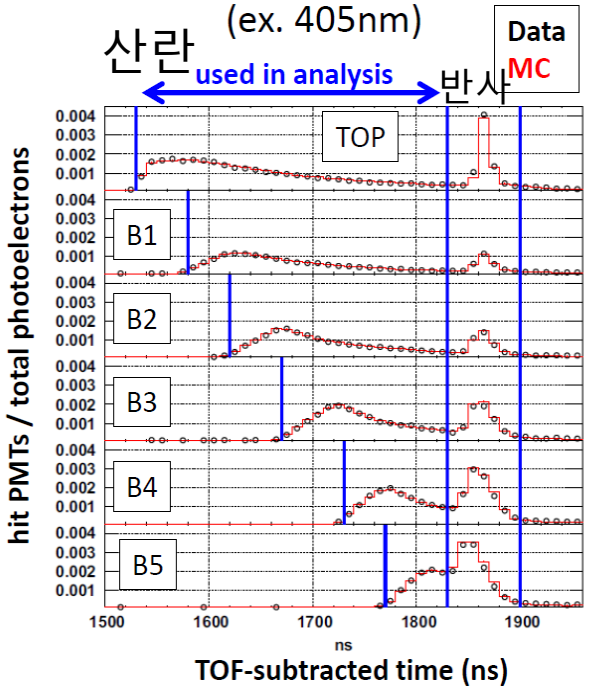
Korean group
injectors ‘2002 -

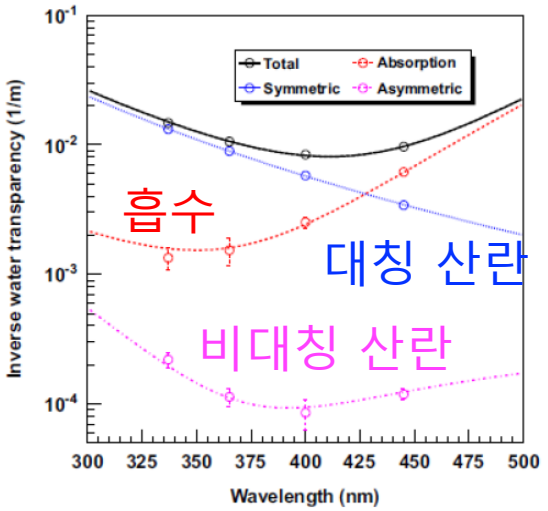


한국 그룹의 기여: 캘리브레이션

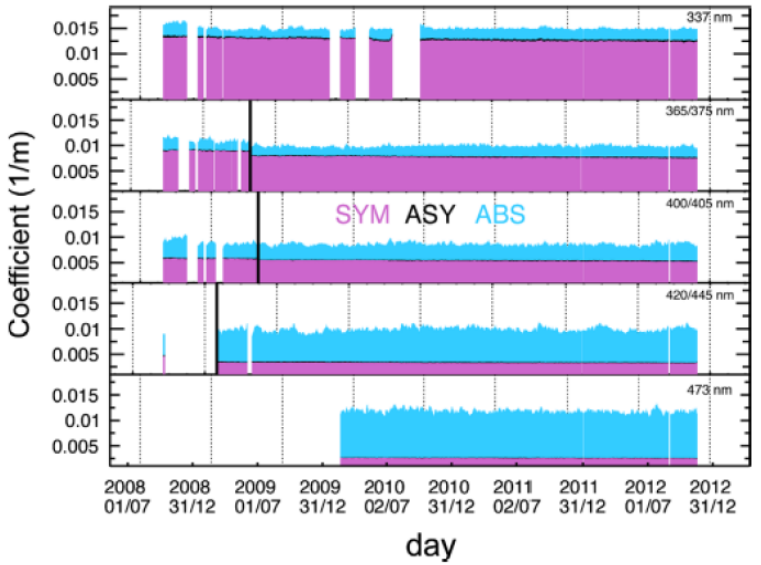
- 검출기 윗 면에 설치된 인젝터로 입사한 빛이 산란되어 PMT에 도달한 시간을 사용하여 다섯 파장에 대한 산란률과 흡수율을 측정.
- 이를 사용하여 SK 시뮬레이션에 파장에 따른 산란률과 흡수율의 모형을 결정.
- 산란률과 흡수율의 시간에 따른 변화를 감시
- Gd 두 번째 용해 후 SK-VII에서 빛의 산란/흡수 계수 측정 완료







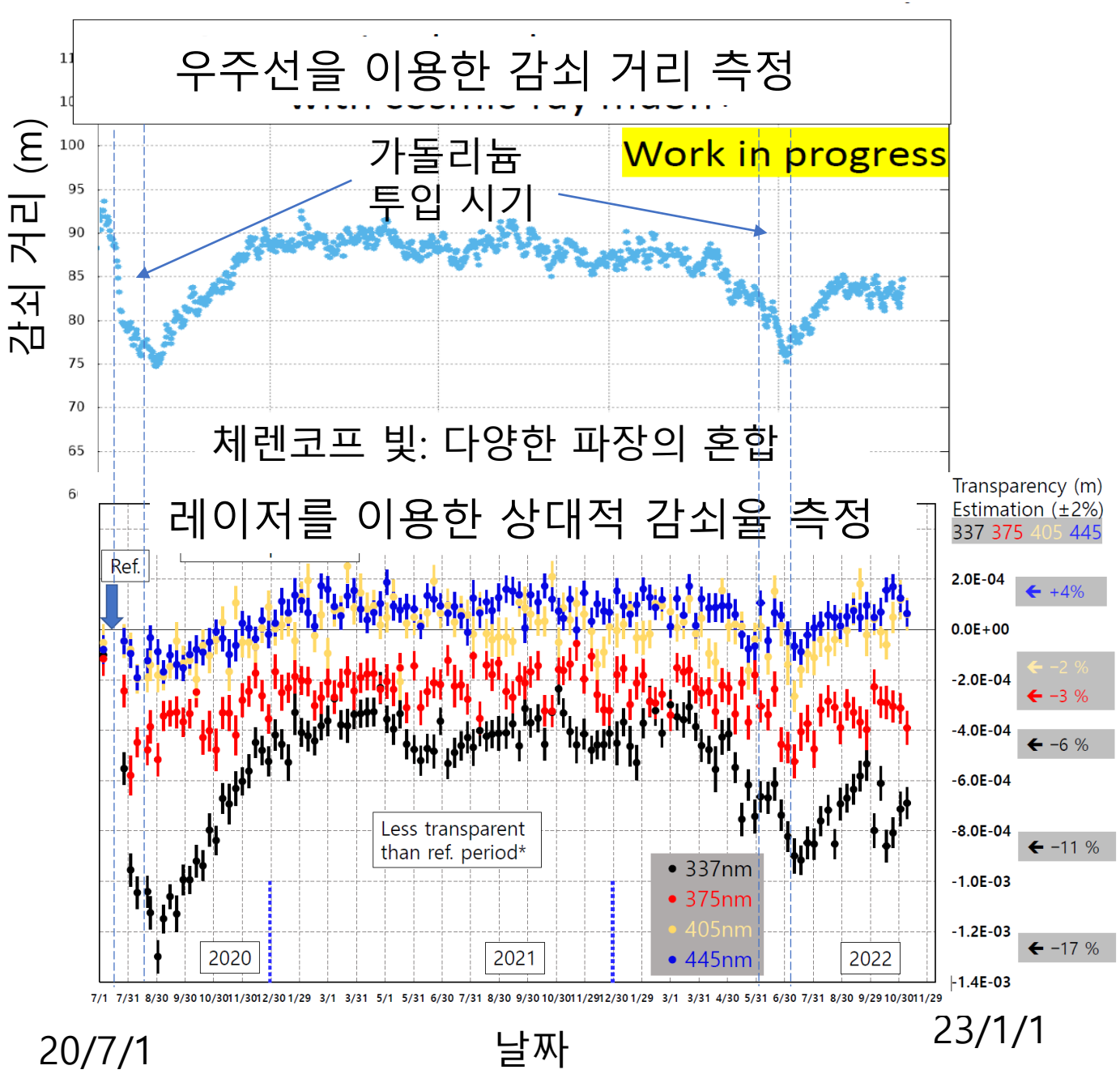
Data points (April 2009) fitted with empirical functions used in SKDETSIM



RMS/mean (Aug. 2008 – Nov. 2012):
~3% for symmetric scattering
20-40% for absorption

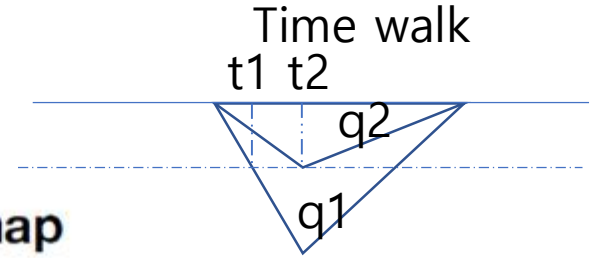
한국 그룹의 기여: 캘리브레이션 SK-Gd 물 투명도 변화 측정

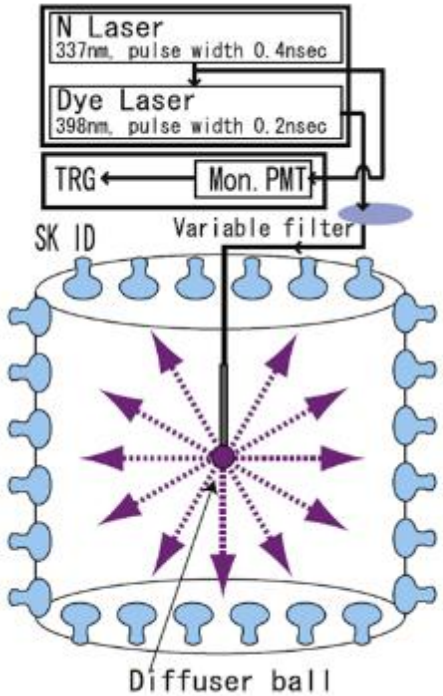
- 광원 : 우주선(뮤온)에 의한 체렌코프 빛, 레이저, 제논 램프 등
- 가돌리늄 투입 동안 투명도 감소. 회복에 약 5개월.
- 짧은 파장에 큰 영향

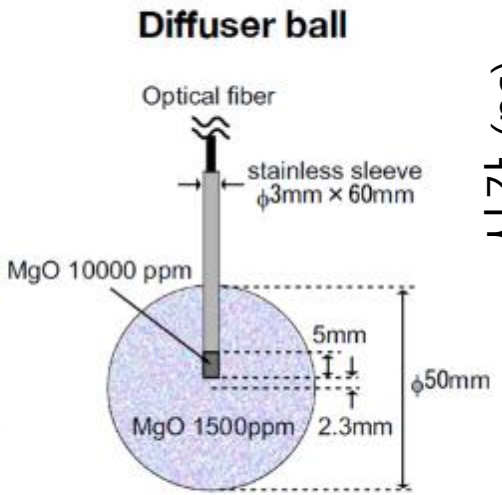


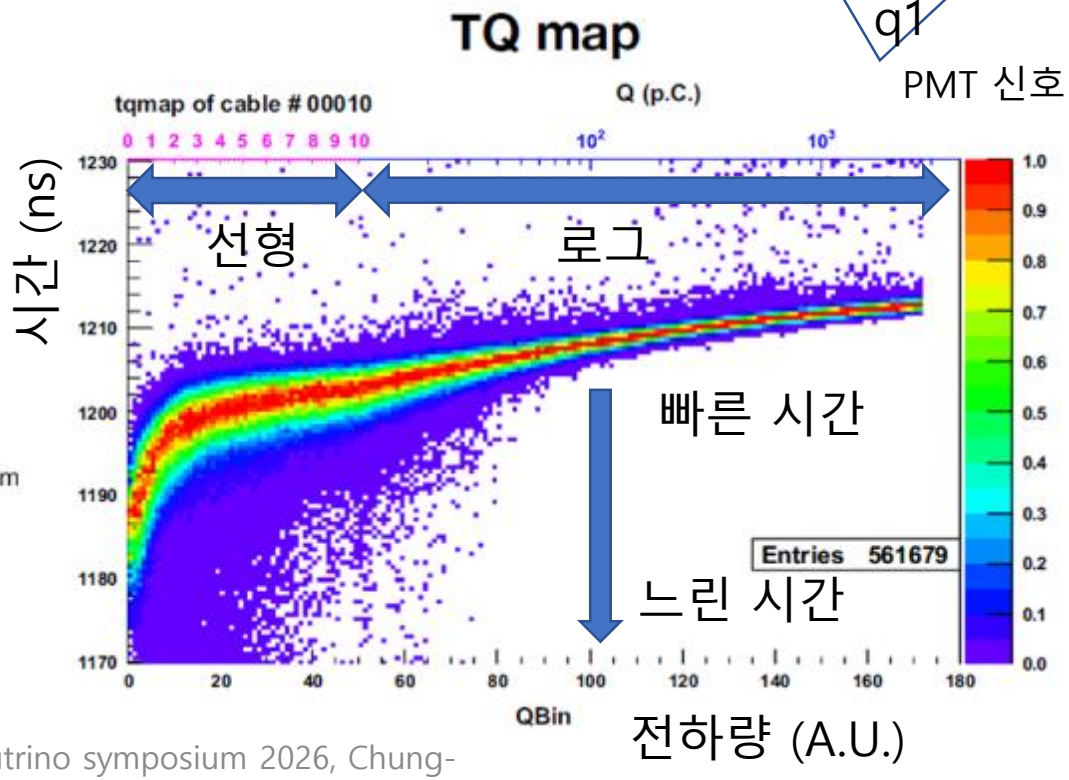
한국 그룹의 기여: 캘리브레이션

- 검출기 중심에서 퍼지는 레이저 빛을 사용하여, 전하량에 따른 PMT의 빛 검출시간 (PMT 신호의 discriminator 문턱 전압 넘는 시간)을 보정
- 2021년 12월부터 한국 그룹에서 담당









Hyper-K Korean group: 7 institutes, ~20 researchers

- KNU
  - C.S. Moon
  - J.S. Park
  - J. Lee
  - H.S. Jo
- GIST
  - J.S. Jang
- DSU
  - M.Y. Park
  - J.H. Choi
- SNU
  - J.H. Yoo: Country Board
  - S.H. Jeon
- SKKU
  - E.H. Kwon
  - J.W. Seo
  - I.T. Yoo
- UNIST
  - K.J. Kwak
  - D.S. Ryu
- CNU
  - D.H. Moon
  - B.S. Yang
  - K.K. Joo
  - D.E. Jung