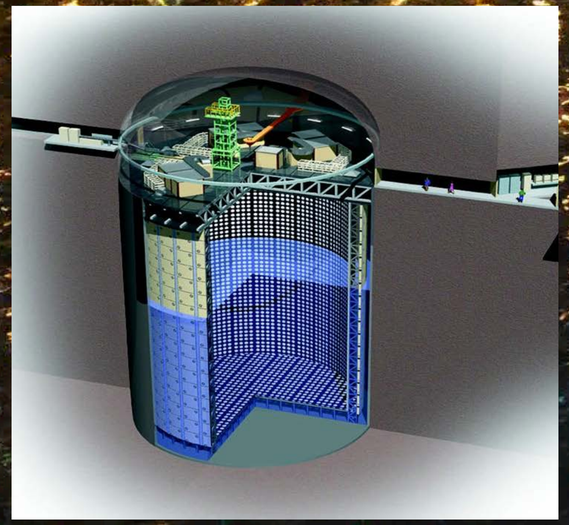
The 7th KMI International Symposium, Nagoya University

Novembet 11th, 2026

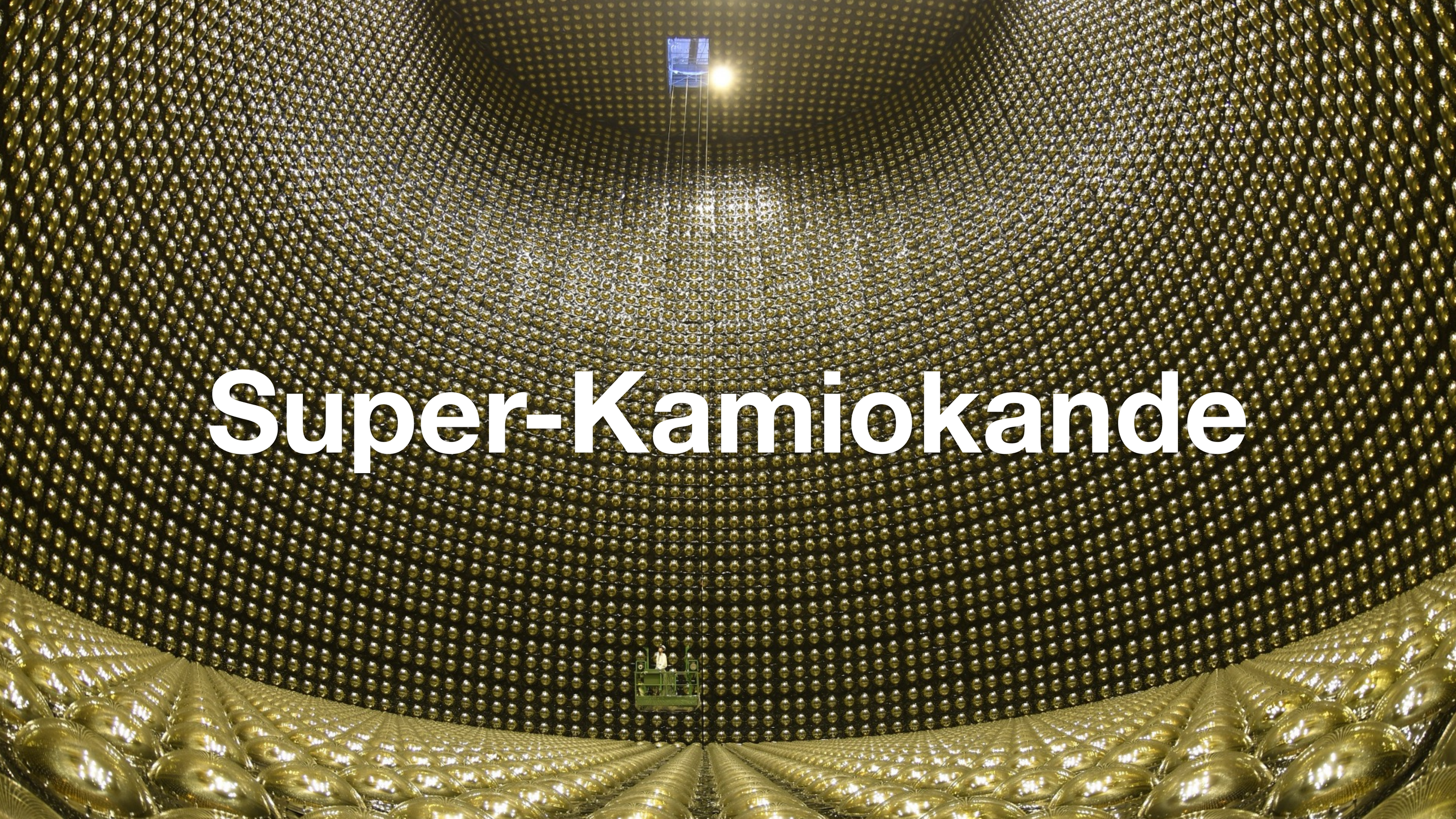


Latest results and status from Super- and Hyper-Kamiokande experiments

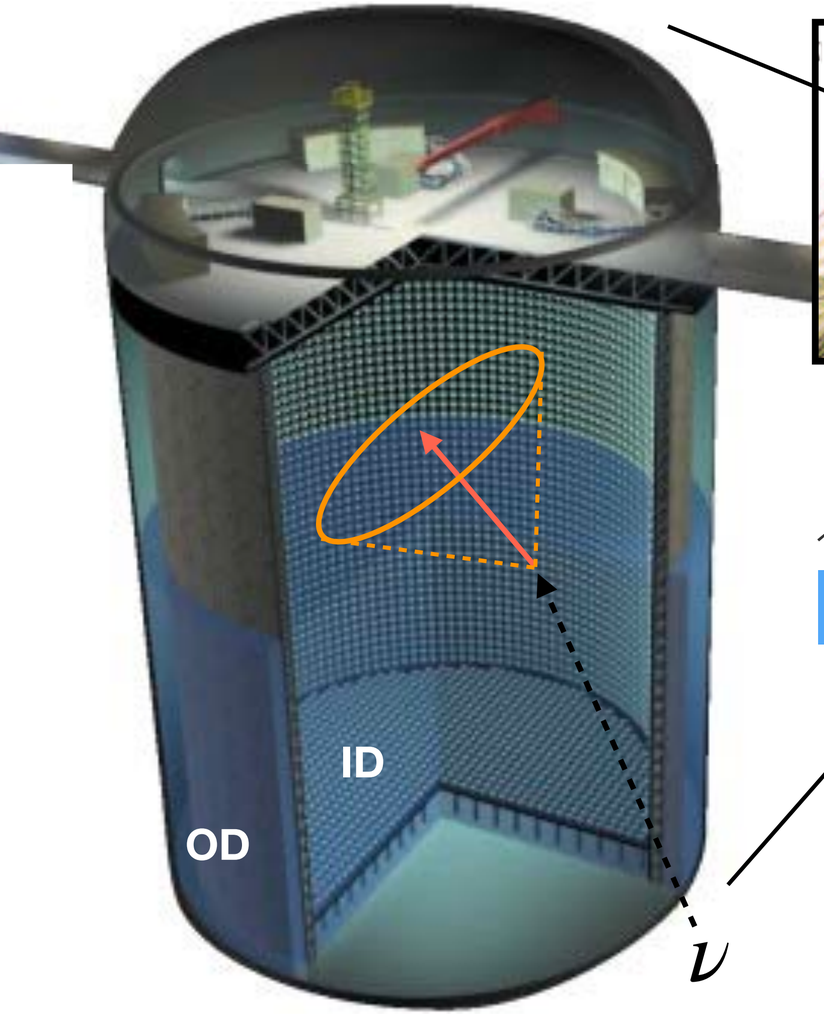


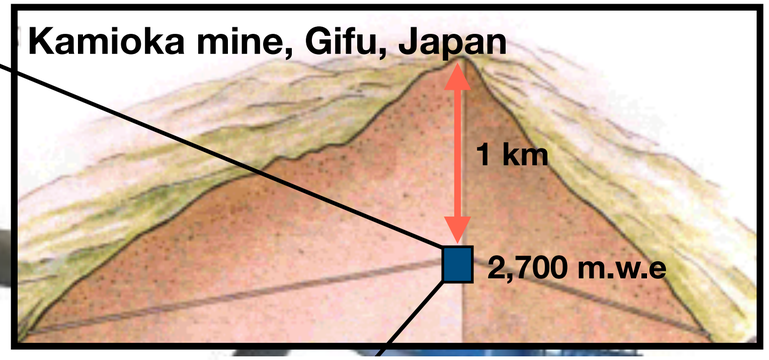
ASHIDA, Yosuke (Tohoku University)

芦田 洋輔 (東北大学)


Super-Kamiokande

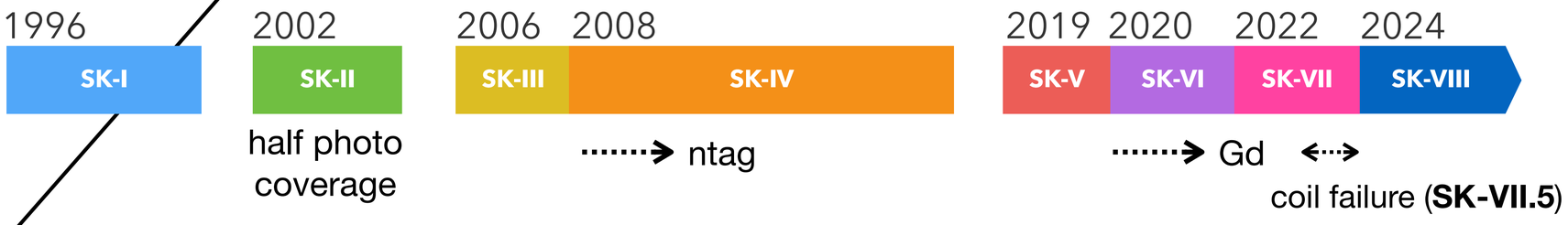
Super-Kamiokande





Atmospheric muon rate ~2 Hz

- 50 kton water (**22.5 kton** for analysis)
- **11,129** 20-inch PMTs (Inner Detector)
  → Physics event of interest
- **1,885** 8-inch PMTs (Outer Detector)
  → Background veto (muon etc)



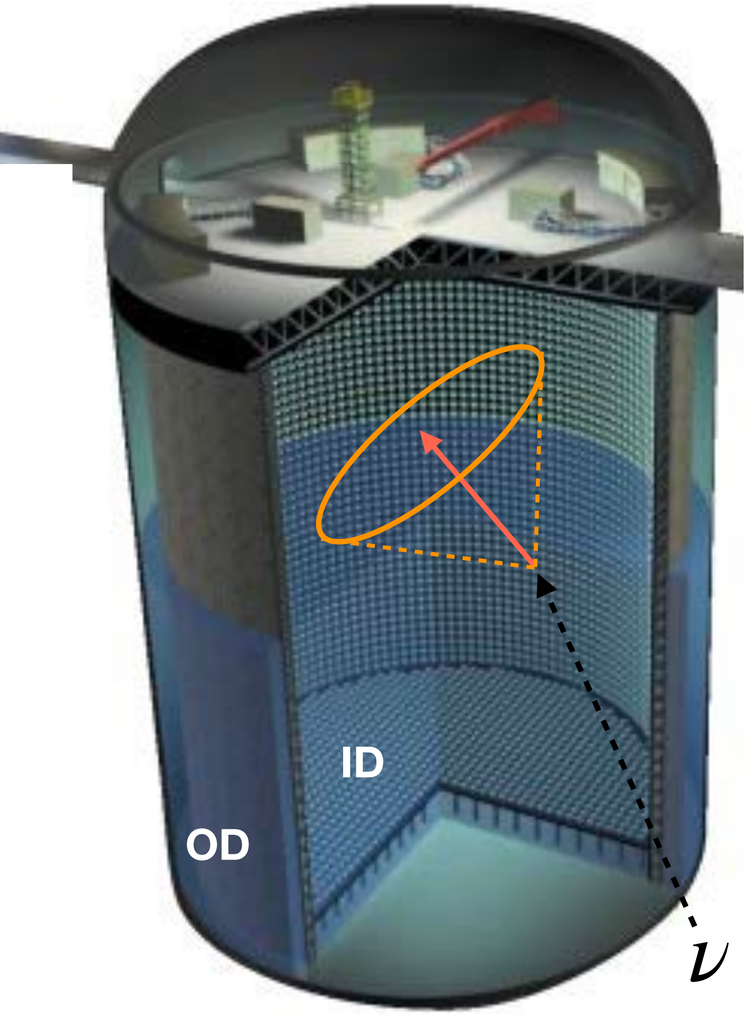
- 7 phases completed so far, and **SK-VIII** is on-going now.
- Huge accomplishments on many physics topics.
  - Neutrino oscillation measurements from various sources
  - Constraint on GUT from proton decay search
  - Neutrino astronomy
  - … etc

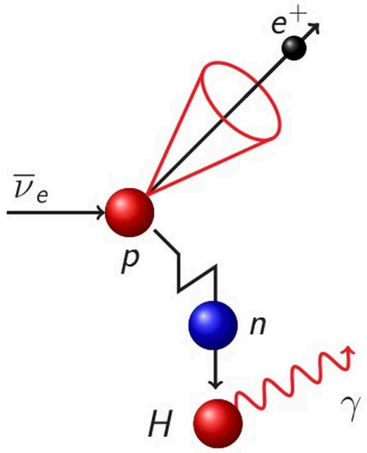


30 year anniversary!

Super-Kamiokande with *Gadolinium*

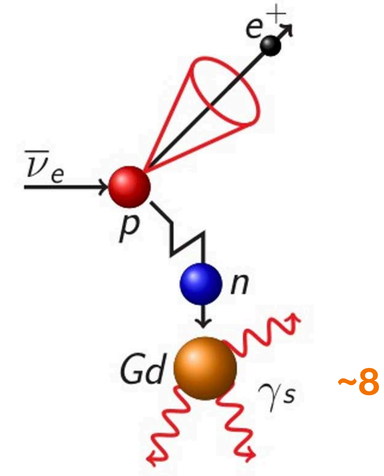
J. Beacom & M. Vagins, PRL 93, 171101 (2004)
K. Abe et al. (SK Collaboration), NIMA 1027, 166248 (2022)
K. Abe et al. (SK Collaboration), NIMA 1065, 169480 (2024)





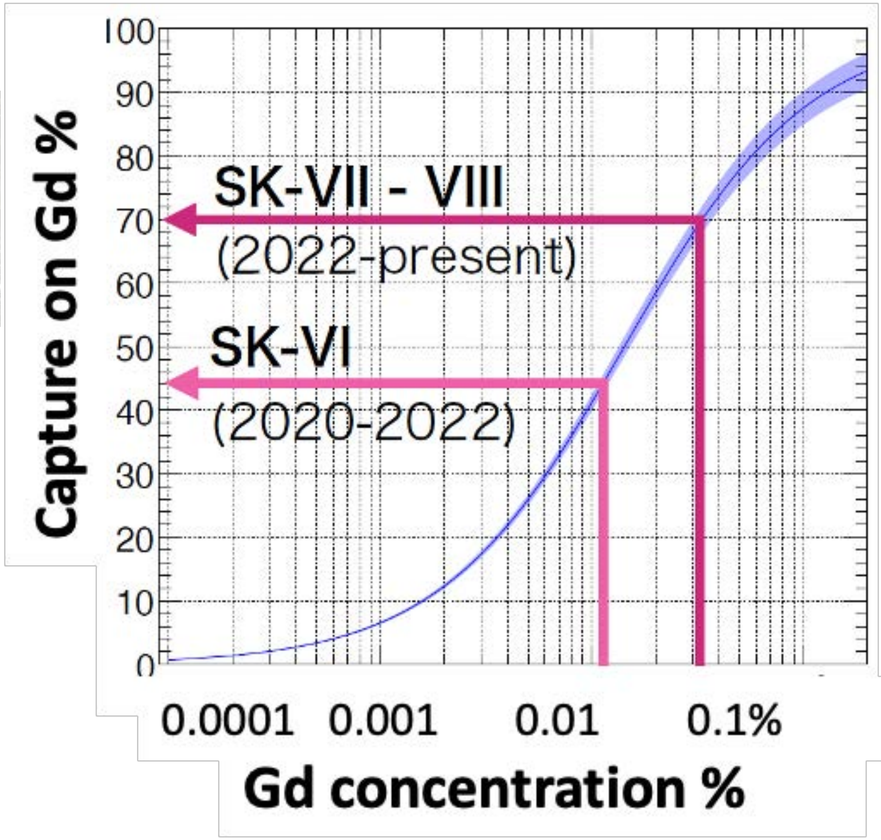
Upgrade



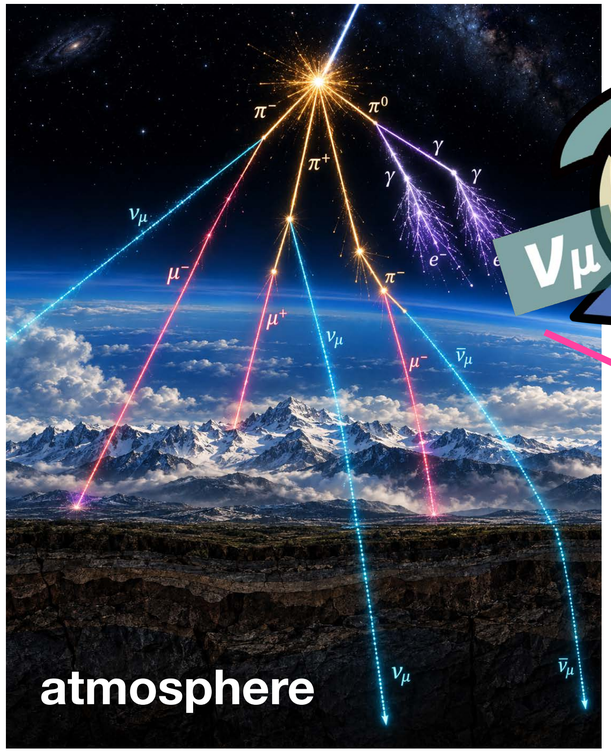


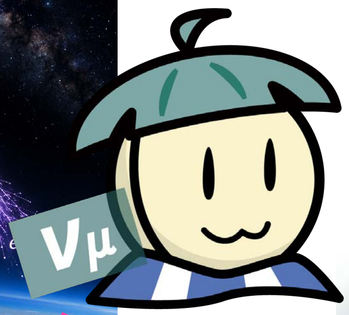
Gd loaded to improve neutron detection.

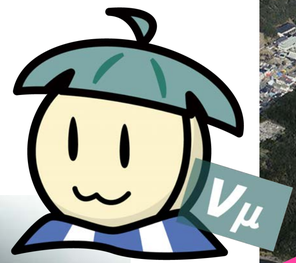
- Capture Xsec: 0.33 barn → **~49 kbarn**
- γ energy: 2.2 MeV → **~8 MeV**
- 0.011% (SK-VI), 0.033% (SK-VII~)



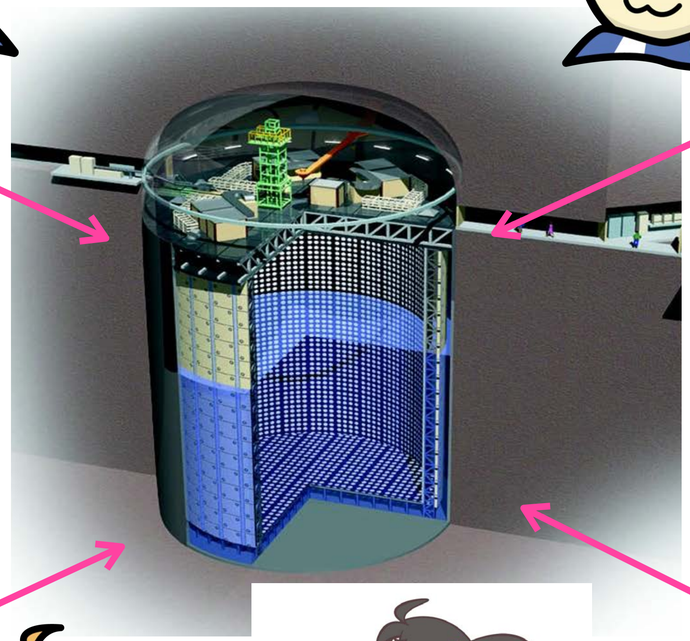
Oscillation Parameter Measurement



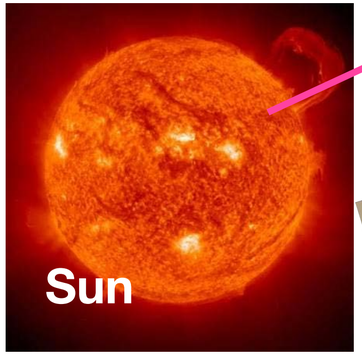








Many neutrino sources!











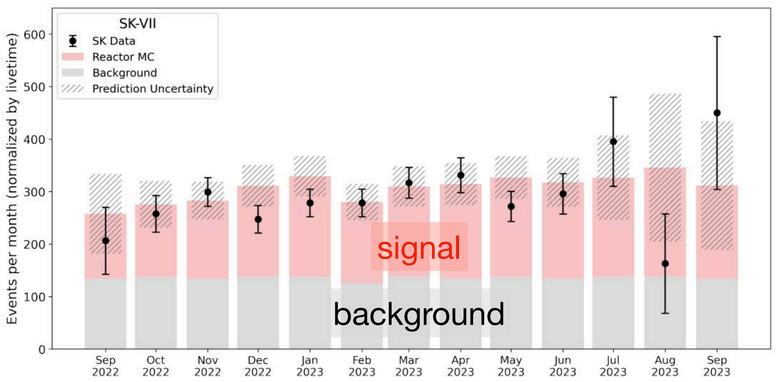
Oscillation Parameter Measurement

Atmospheric neutrinos

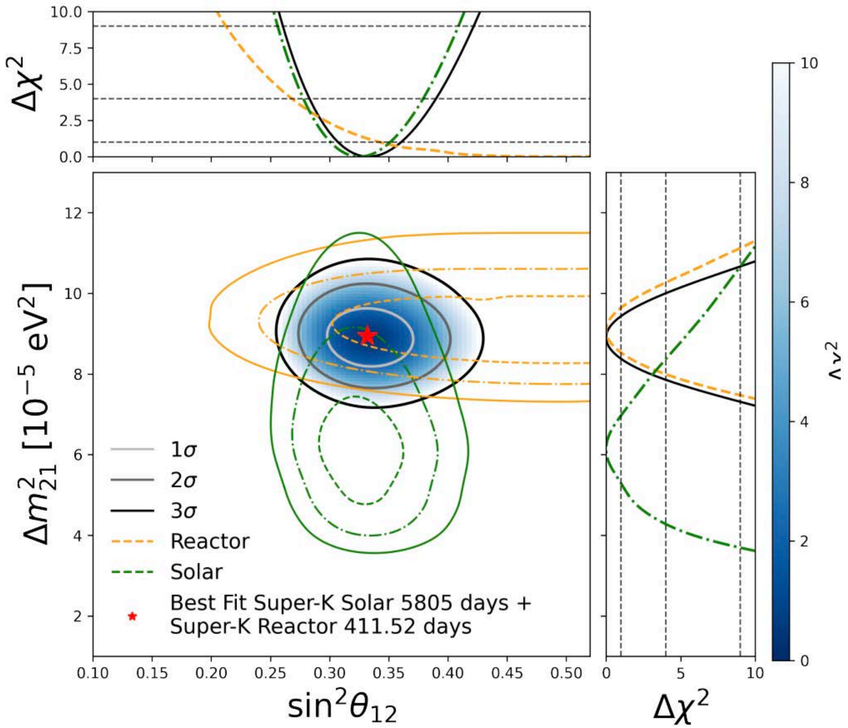
- Two analyses (zenith and L/E) are performed, setting different constraints.
- Excluded **IO** (inverted mass ordering) at ~**1.1σ**.
- Joint fit with beam neutrino data (T2K), showing a stronger constraint.

Reactor neutrinos

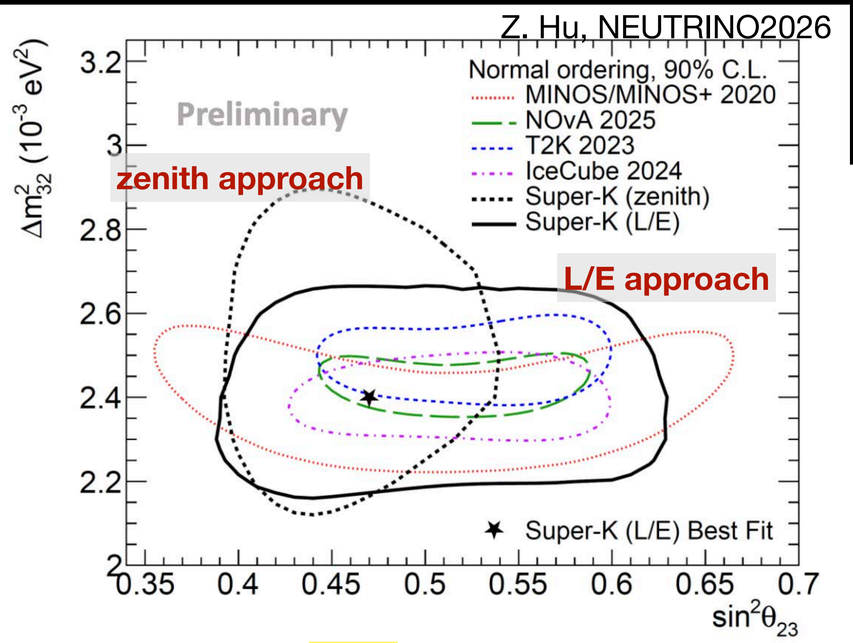
- Electron antineutrinos from reactors are observed for the first time due to Gd.
- Complementary sensitivity with solar neutrino oscillation measurements.



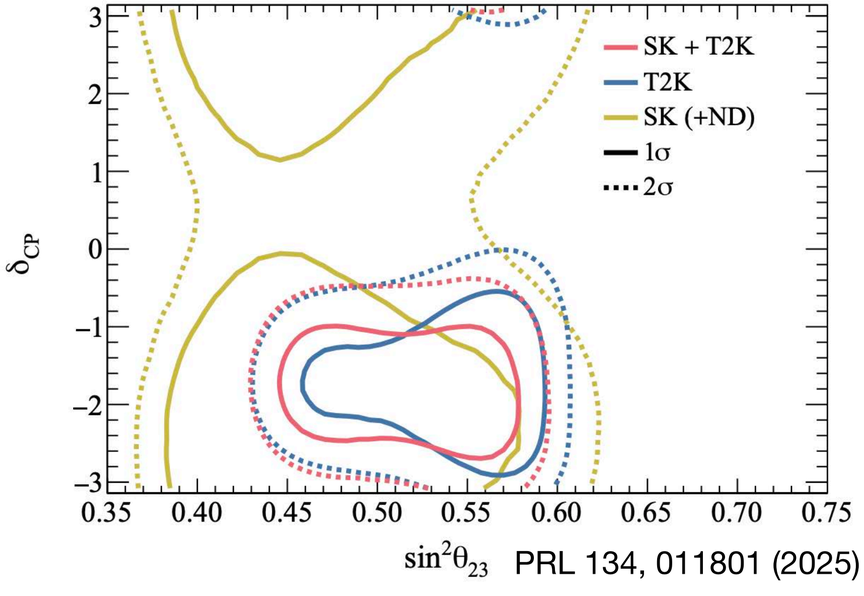
arXiv:2610.03143



Z. Hu, NEUTRINO2026



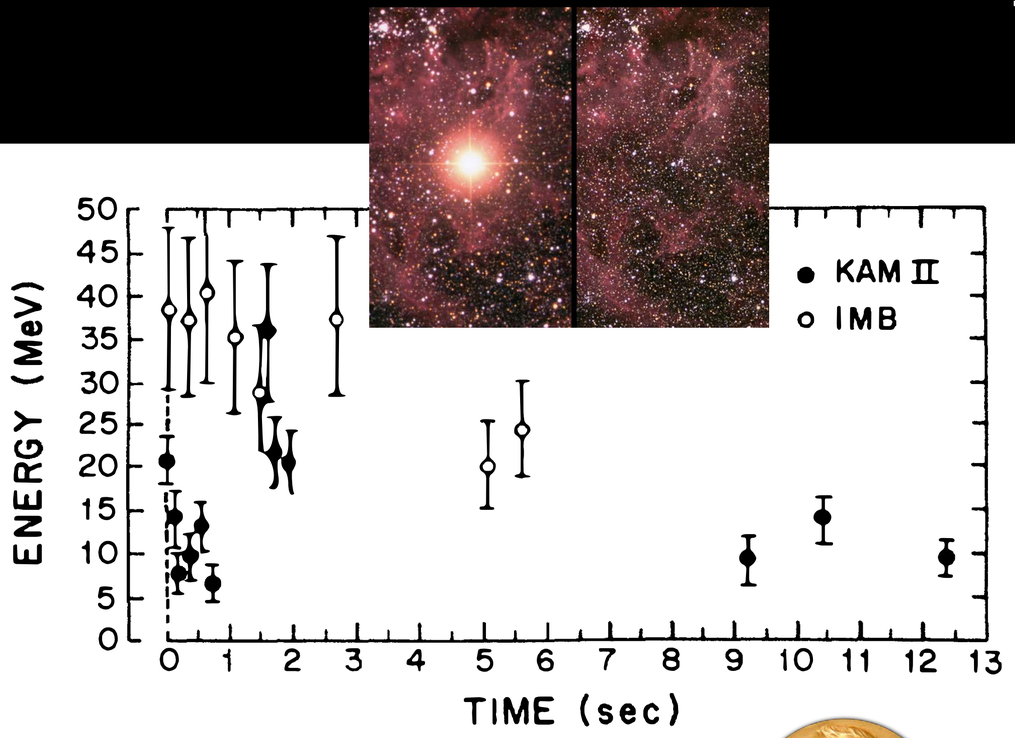
+ beam neutrinos

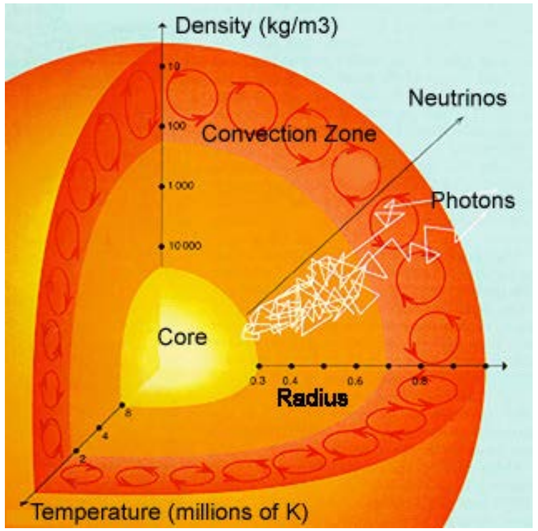


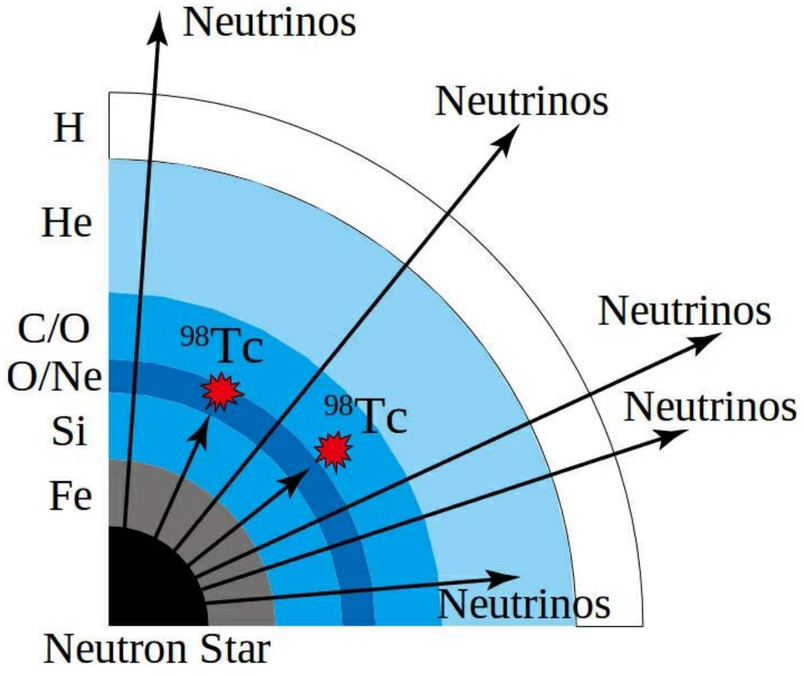
PRL 134, 011801 (2025)

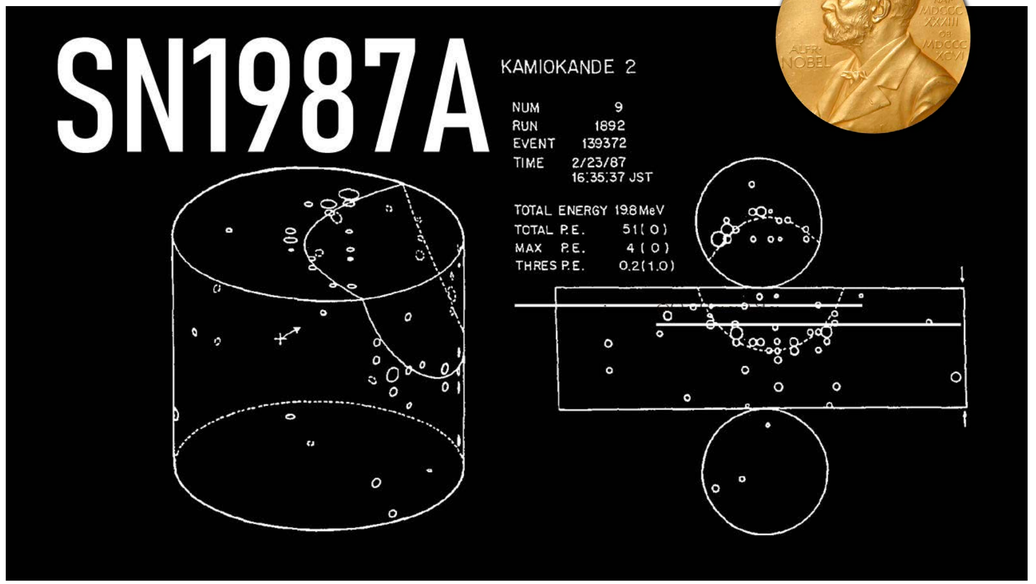
Astrophysics with Neutrinos

- Neutrinos are produced at the deep inside of heavy stars.
- Neutrinos from the **Sun** and **supernovae** (SNe) are a key probe of stellar physics.
- There is one observation from SN (**1987A**), which established a standard scenario of stellar core collapse.



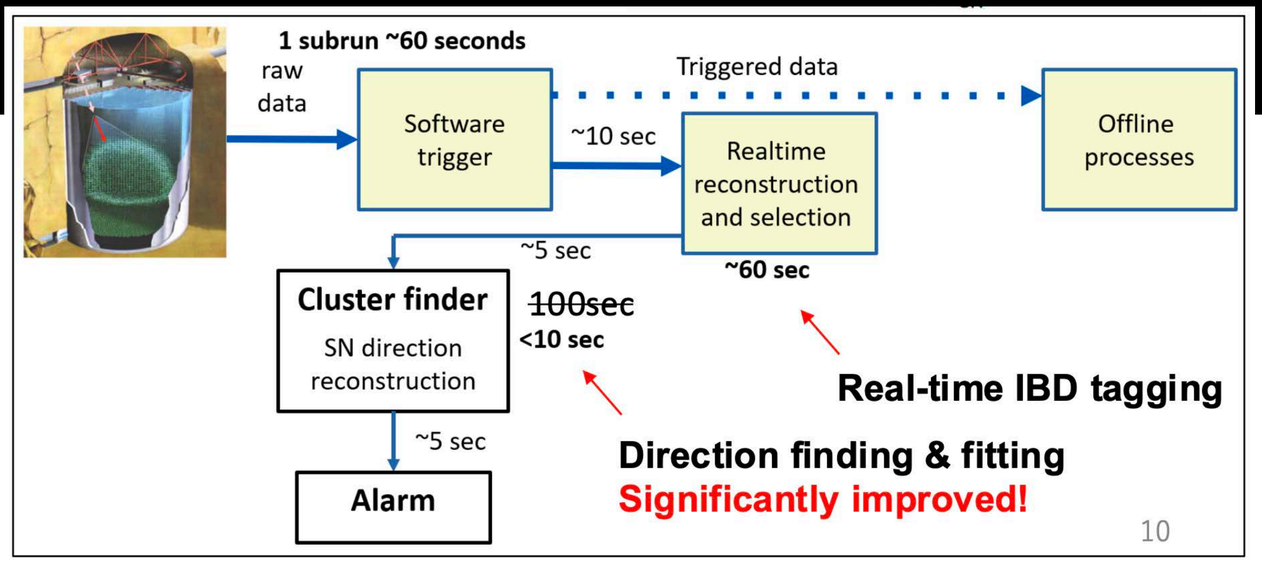






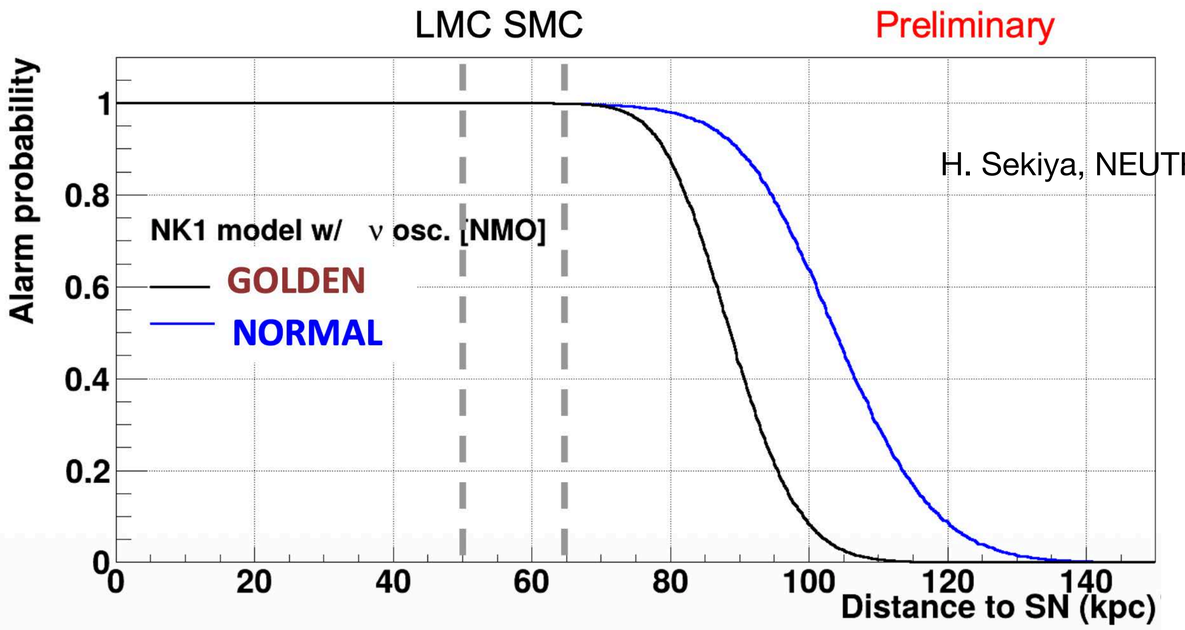
Alerting SN Detection

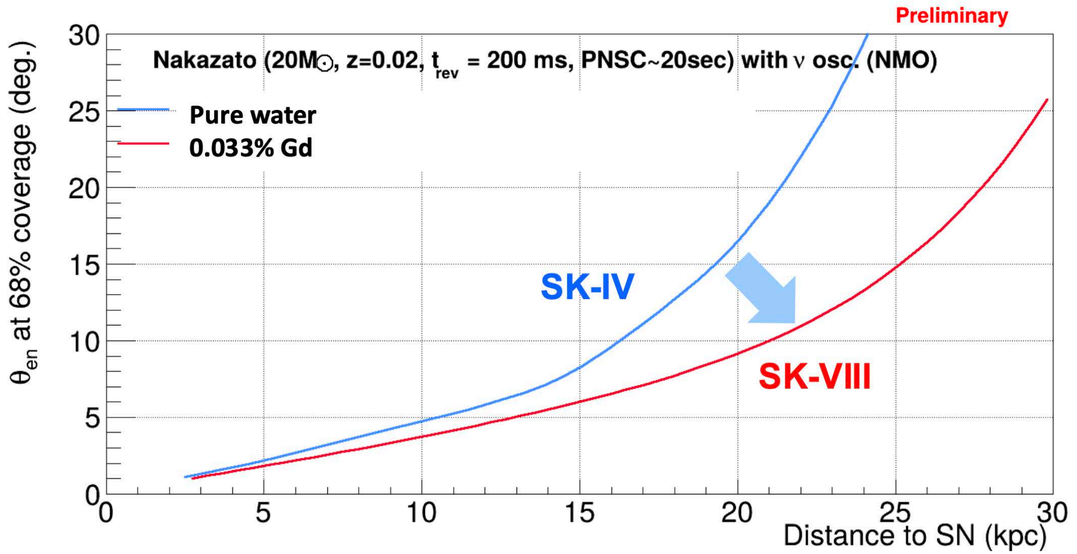
- We are ready to alert SN direction *quickly*!
- Our detector is sensitive enough to SNe in nearby galaxies and up to ~100 kpc.
- SK-Gd improves its pointing accuracy due to an efficient selection of **elastic scattering**.



@10kpc (Nakazato 20$M_\odot$, PNSC 20sec)

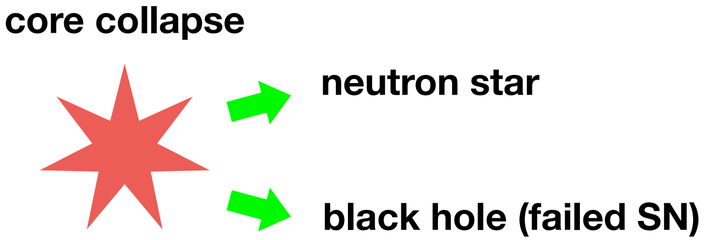
3.78±0.04° (1σ) **5.52 ± 0.06° (90%C.L.)**

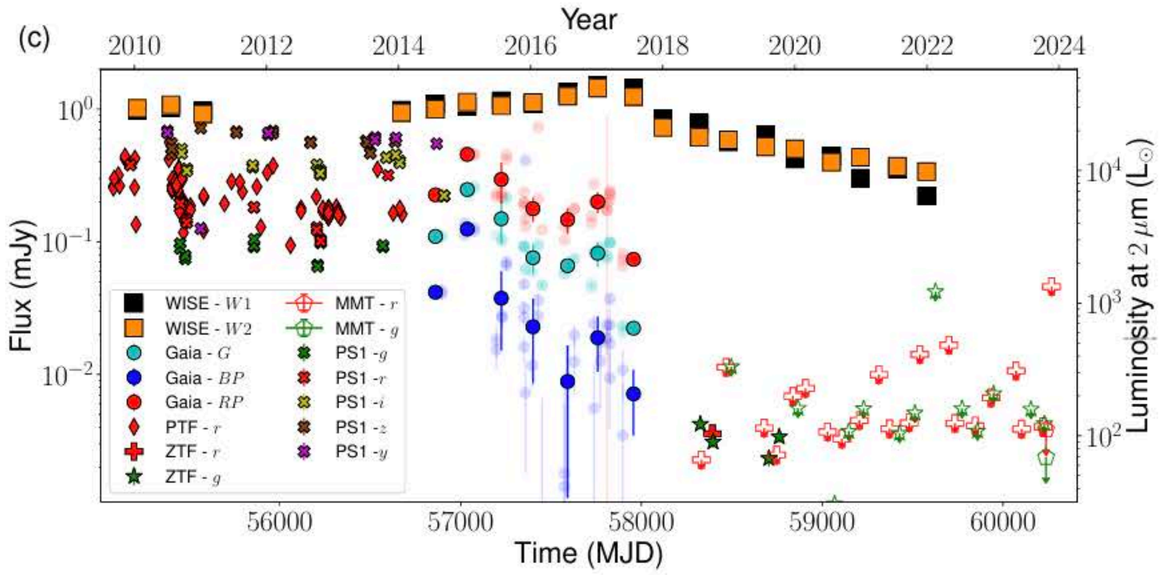




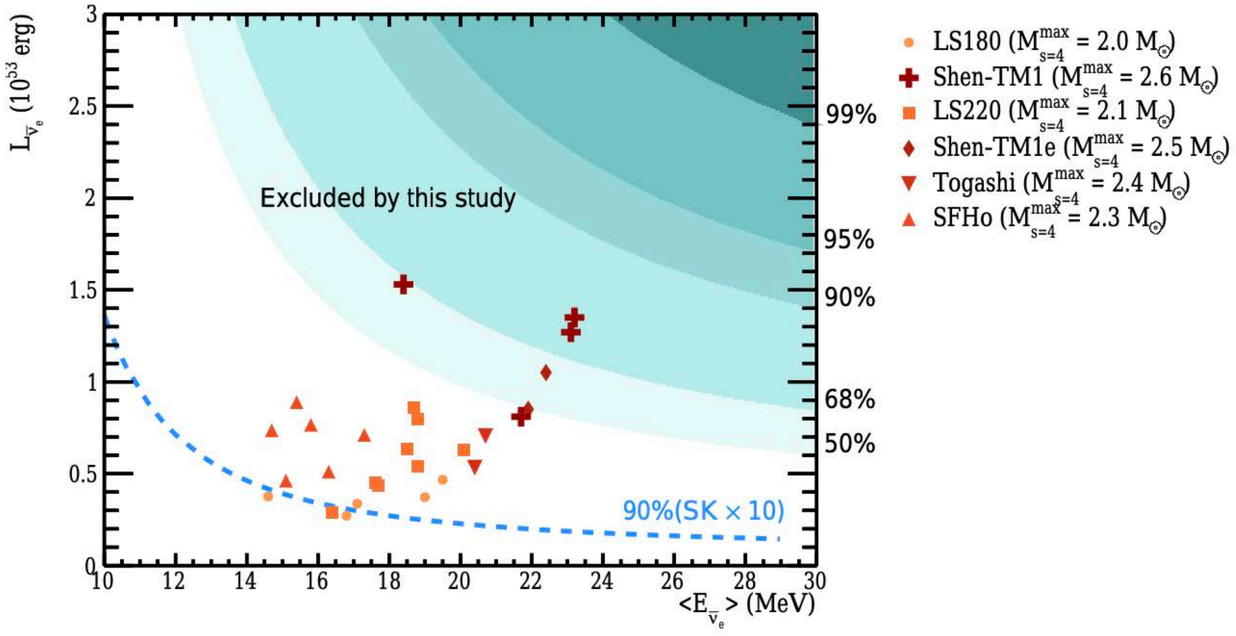
Neutrinos from “Failed” Explosion

- Observation of **a failed SN in Andromeda, M31 (~780 kpc)** was reported.
- Super-K data in the corresponding period didn’t find any cluster events.
- Numerical models on failed SNe are constrained from this *non*-detection.





K. De et al., Science Vol 391, Issue 6786 (2026)



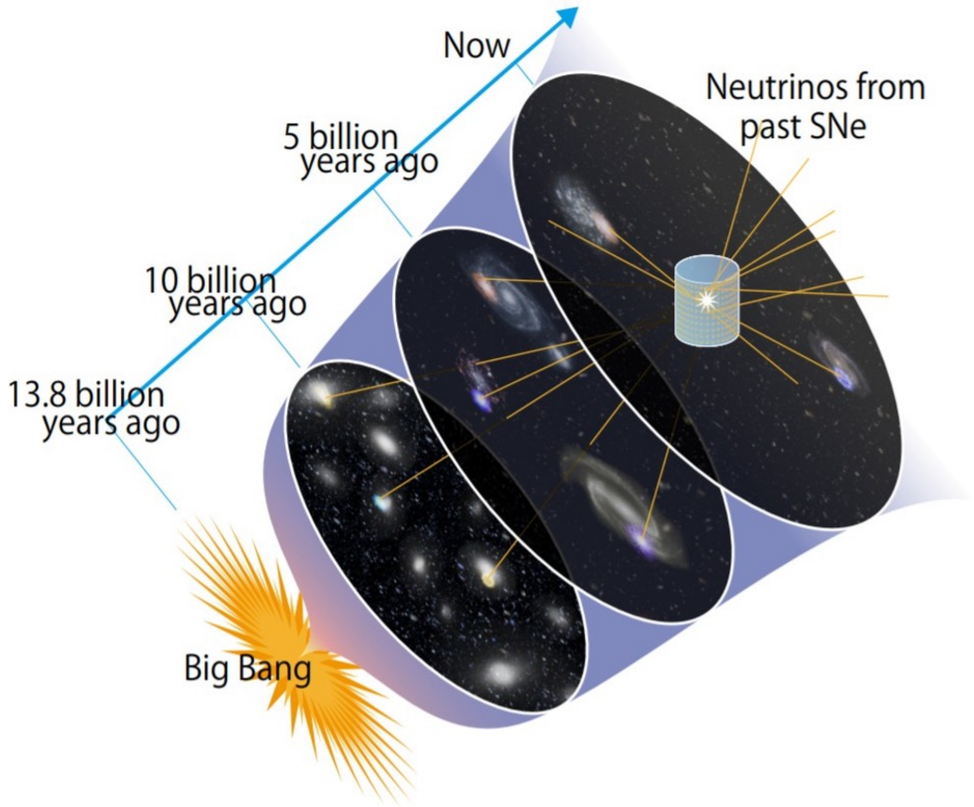
Y. Suwa et al., The Open Journal of Astrophysics, Volume 8 (2025)

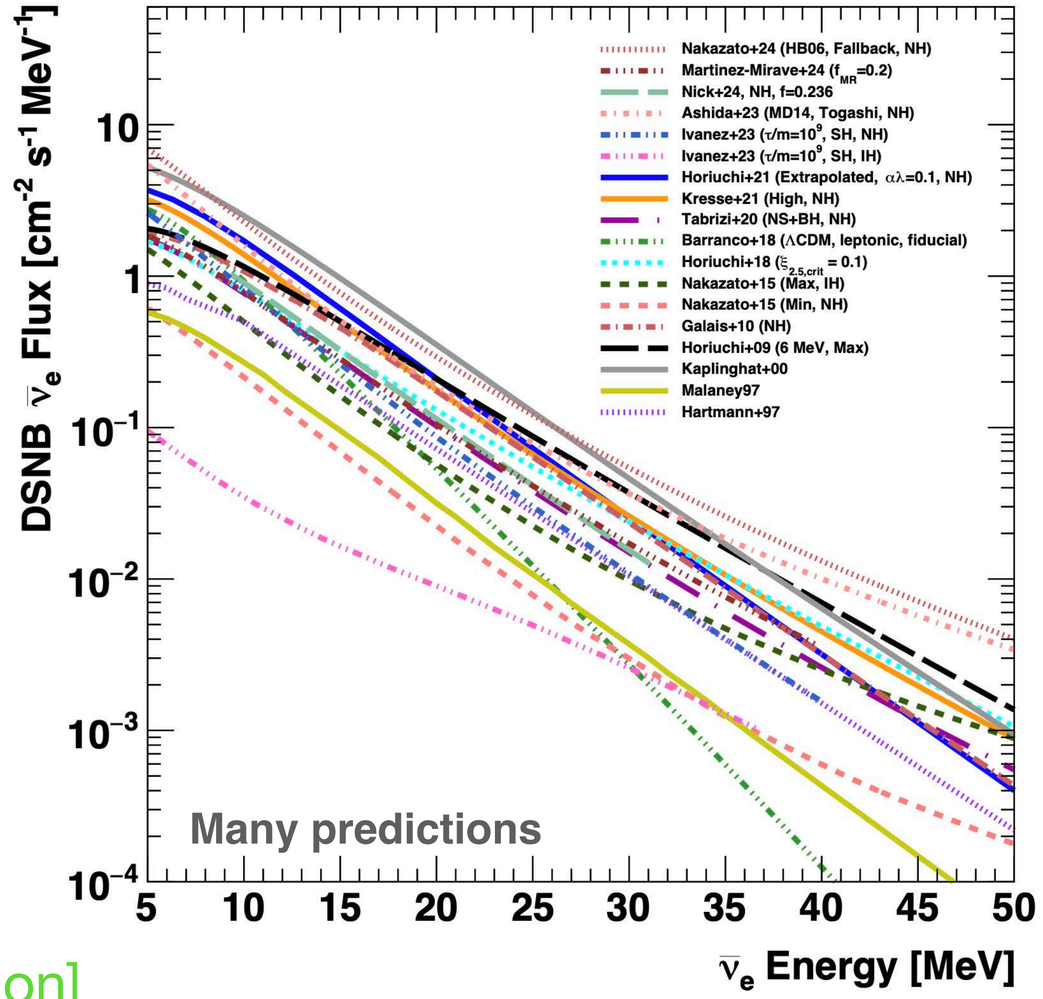
F. Nakanishi et al. (Super-Kamiokande Collaboration), ApJL 997, L9 (2026)

Message from Stars in the Past

The accumulated flux of neutrinos released from stellar core collapse over the cosmic history

= **Diffuse Supernova Neutrino Background (DSNB)**

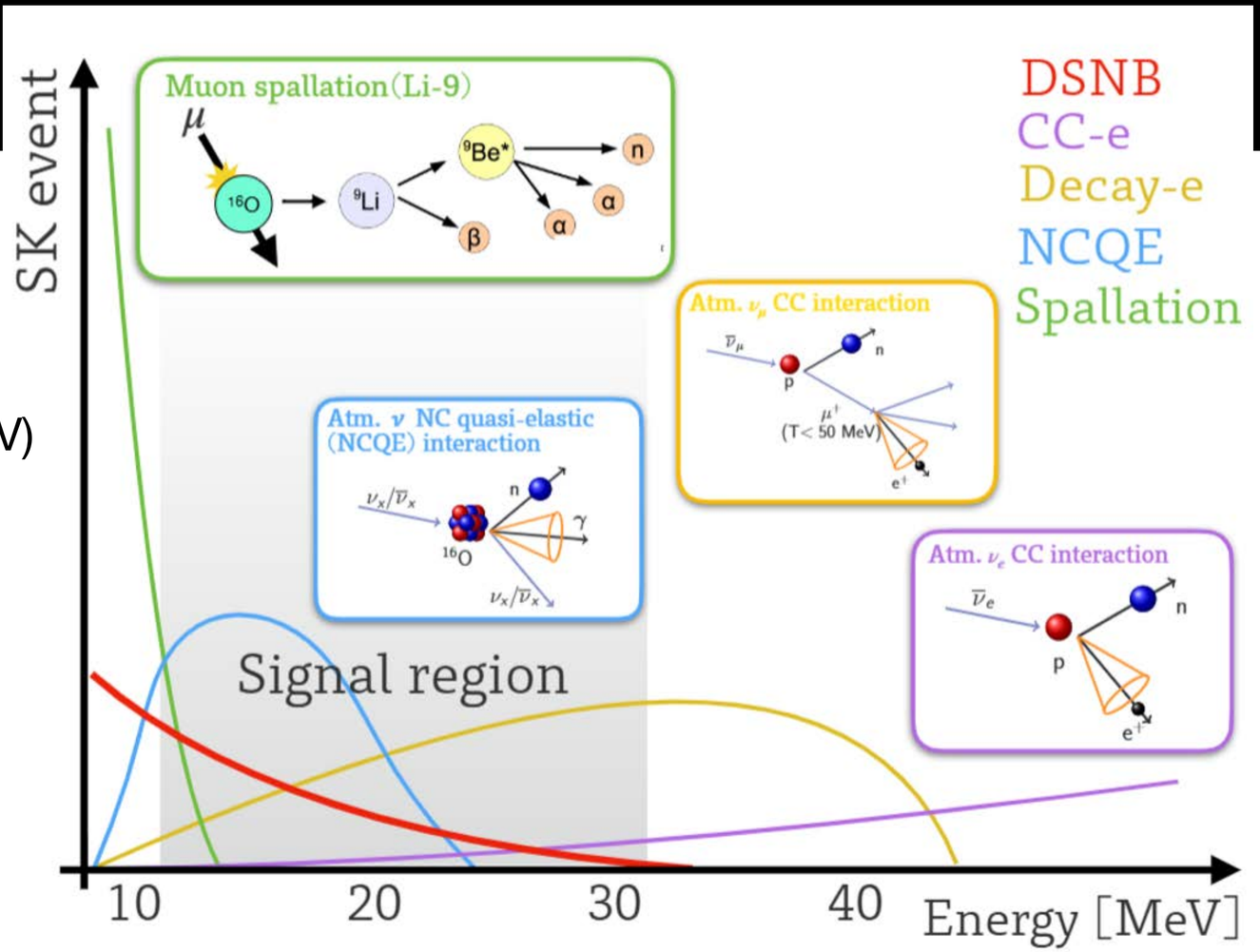




$\Phi = \int$ [ν emission] ⊗ [Star formation] ⊗ [Universe expansion]

Latest DSNB Analysis

- **Additional dataset** (5003 days in total)
- **Refined event selections** (ML-based)
- **Lowered threshold** (E_ν = 17.3 MeV → 13.3 MeV)
- **Improvements on systematic uncertainties**
- **Joint fit for SK-IV through SK-VIII**



Phase	Period	Livetime [days]	Water Status
SK-IV	Oct. 2008 - Feb. 2018	2970.1	Pure-water
SK-V	Feb. 2019 - Jul. 2020	379.2	Pure-water
SK-VI	Aug. 2020 - Jun. 2022	552.2	Gd-water (0.01w%)
SK-VII	Jul. 2022 - Oct. 2023	404.0	Gd-water (0.03w%)
SK-VII.5	Dec. 2023 - Jul. 2024	191.8	Gd-water (0.03w%)
SK-VIII	Sep. 2024 - Mar. 2026	505.7	Gd-water (0.03w%)

New analysis with a 5003-day dataset =
~3350-day pure water + ~1650-day Gd water

Spectral Fitting

- 1 signal + 6 background components considered.
- 6 panels prepared based on $\boldsymbol{\theta_C}$ and $\boldsymbol{N_n}$.

$$\mathcal{L}\left(\mathrm{Data}\,|\,N_s,\,\vec{N}_b,\;\eta_s\,,\,\vec{\eta}_b\right) = \mathcal{L}\left(\vec{0}\,|\,\eta_s,\,\vec{\eta}_b\right) \times e^{-\left(\varepsilon_s(\eta_s)N_s\,+\,\sum_{j\in\vec{b}}N_j\right)} \times \prod_{i=1}^{N_{\mathrm{data}}}\left[\varepsilon_s(\eta_s)N_s\cdot\mathrm{PDF}_s\left(E^i,\,\theta_C^i,\,N_{\mathrm{n}}^i\right) + \sum_{j\in\vec{b}}N_j\cdot\mathrm{PDF}_j\left(E^i,\,\theta_C^i,\,N_{\mathrm{n}}^i\,|\,\vec{\eta}_b\right)\right],$$

pull term for nuisance parameters

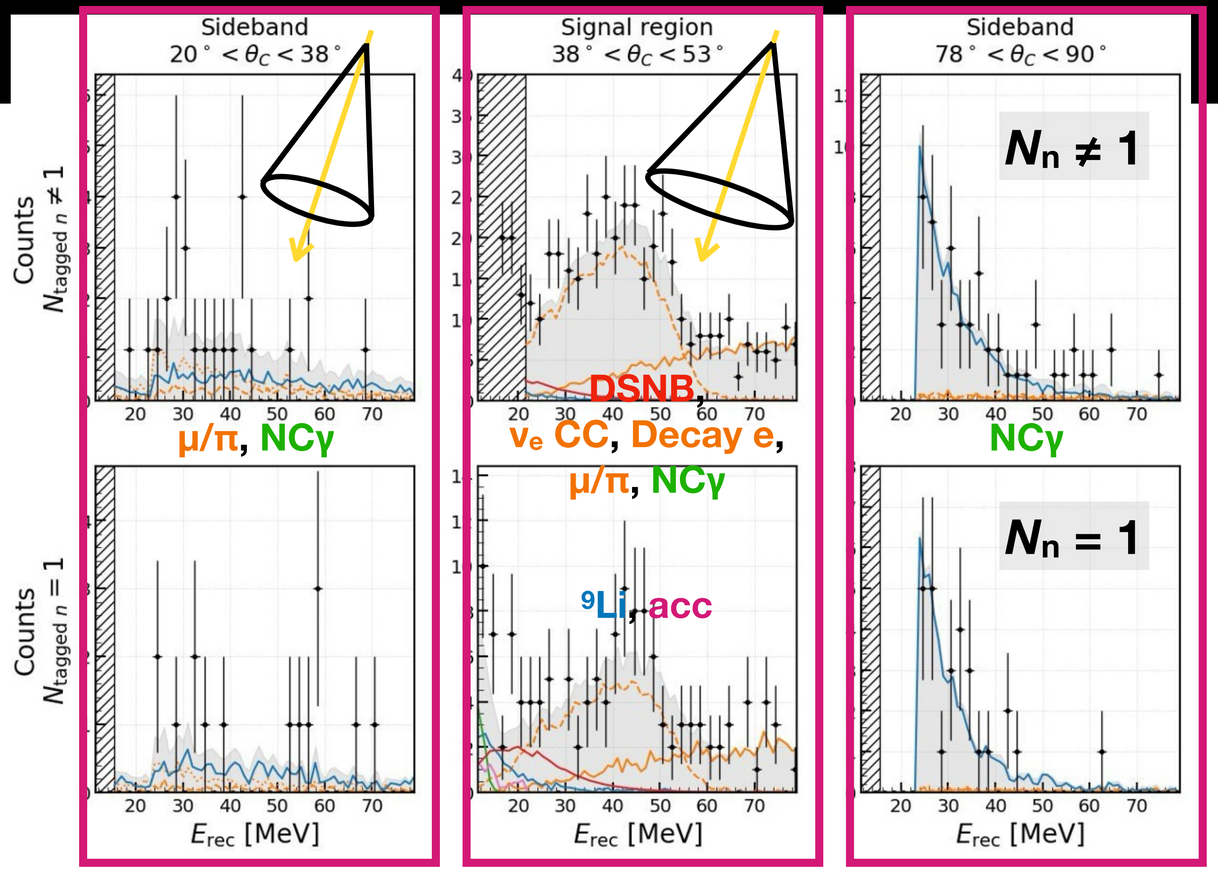
×

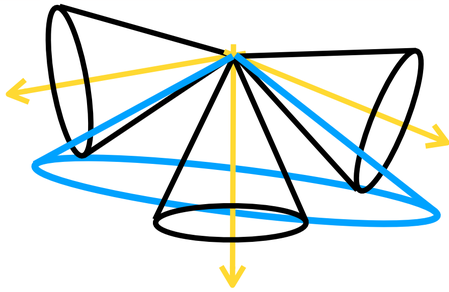
Signal-related PDF

+

BG-related PDFs
Shape depending on nuisance parameters.

An unbinned maximum likelihood fit

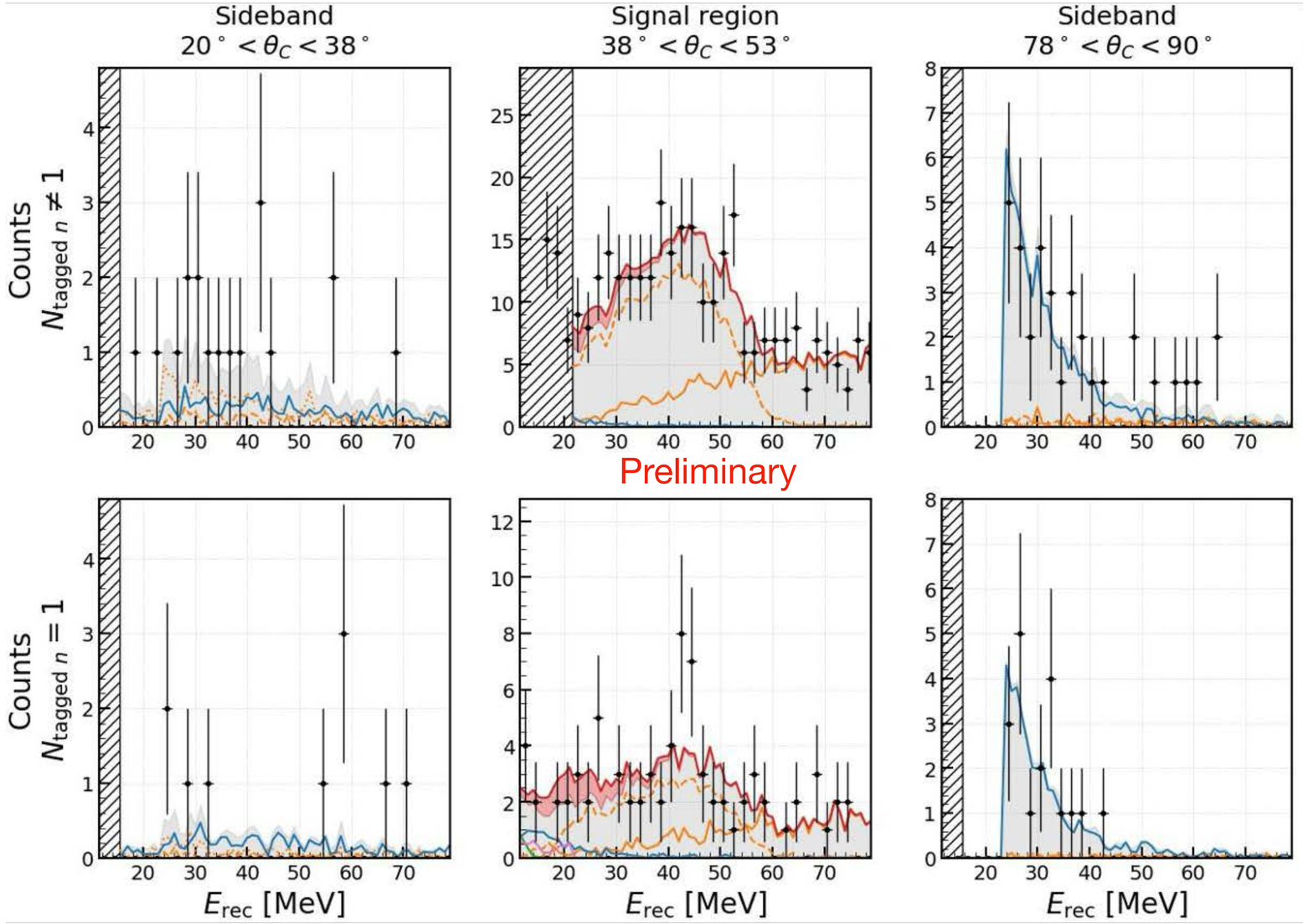




- **Signal**: Horiuchi+09, 6 MeV Max (“**DSNB**”)
- **Background**
  - atmospheric ν_e CC (“**ν_e CC**”)
  - invisible muon/pion from atmospheric ν_μ CC, NC1π etc (“**Decay e**”)
  - visible muon/pion from atmospheric ν CC, NC1π etc (“**μ/π**”)
  - nuclear deexcitation gamma rays from atmospheric ν NCQE, NC1π etc (“**NCγ**”)
  - atmospheric muon spallation induced isotope with neutron (“**spall ^{9}Li**”)
  - accidental coincidental events (“**acc**”)

Fit Result for SK-IV~V (Pure Water Period)

arXiv:2610.35619





1.4σ

IBD event rate for E_ν > 13.3 MeV (E_{rec} > 11.5 MeV)

Best-fit: 4.4 +3.5/-3.2 events/yr

Predicted: 2.9 - 5.2 events/yr

(Horiuchi+09, 6MeV, min - max)

DSNB flux for E_ν > 13.3 (E_{rec} > 11.5 MeV)

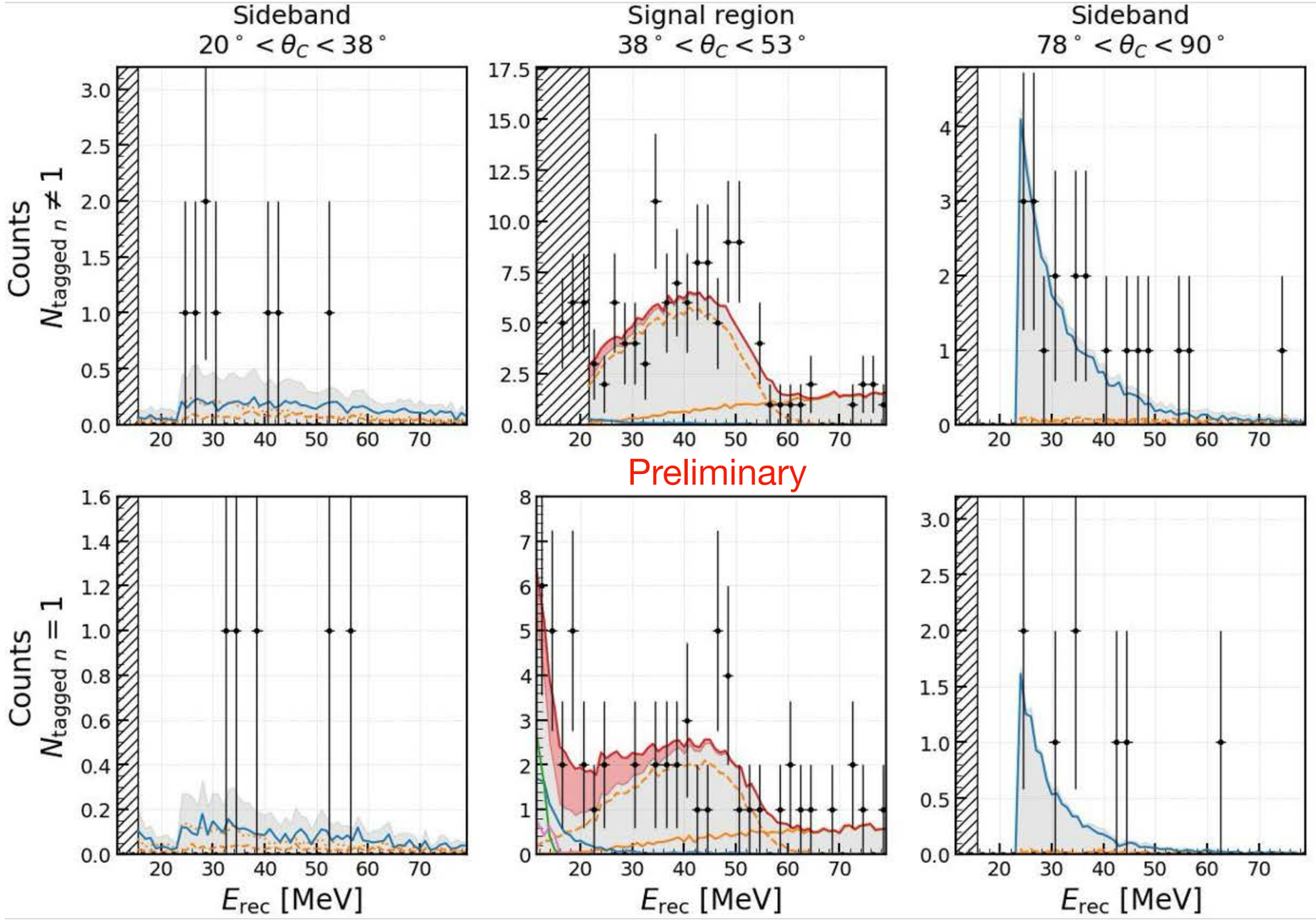
Best-fit: 3.3 +2.6/-2.4 cm^{-2} s^{-1}

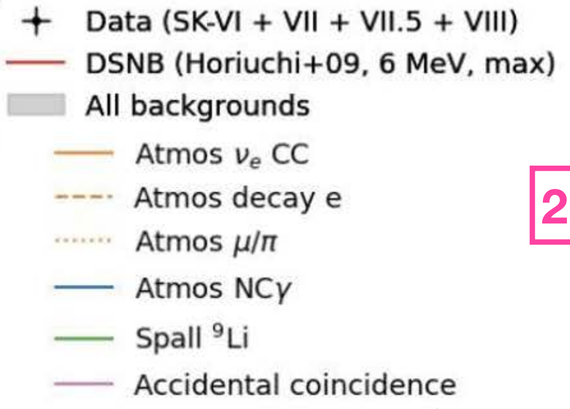
Predicted: 2.1 - 3.9 cm^{-2} s^{-1}

(Horiuchi+09, 6MeV, min - max)

Fit Result for SK-VI~VIII (Gd Water Period)

arXiv:2610.35619





2.2σ

IBD event rate for E_ν > 13.3 MeV (E_{rec} > 11.5 MeV)

Best-fit: 5.2 +2.9/-2.6 events/yr

Predicted: 2.9 - 5.2 events/yr

(Horiuchi+09, 6MeV, min - max)

DSNB flux for E_ν > 13.3 (E_{rec} > 11.5 MeV)

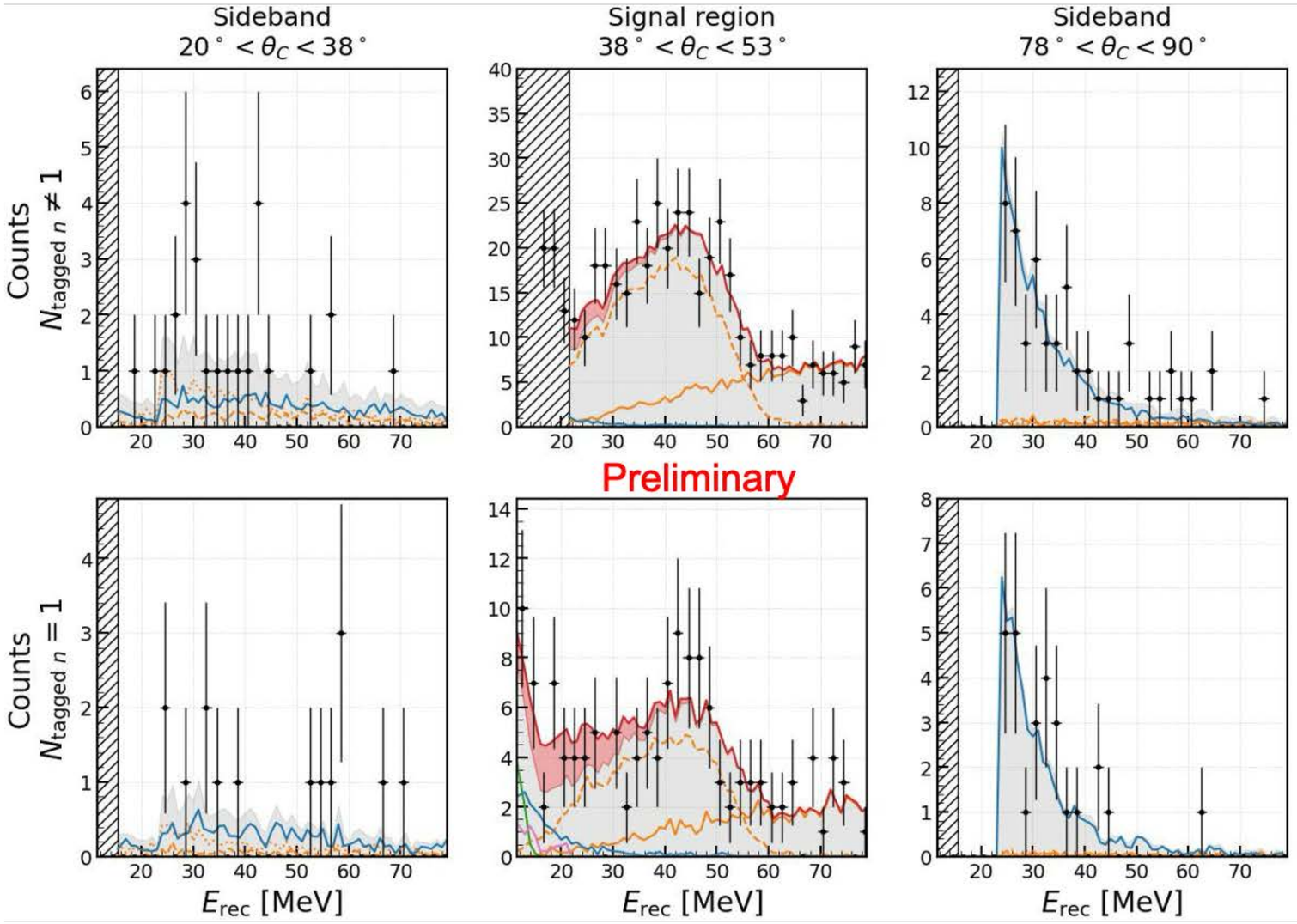
Best-fit: 3.9 +2.2/-1.9 cm^{-2} s^{-1}

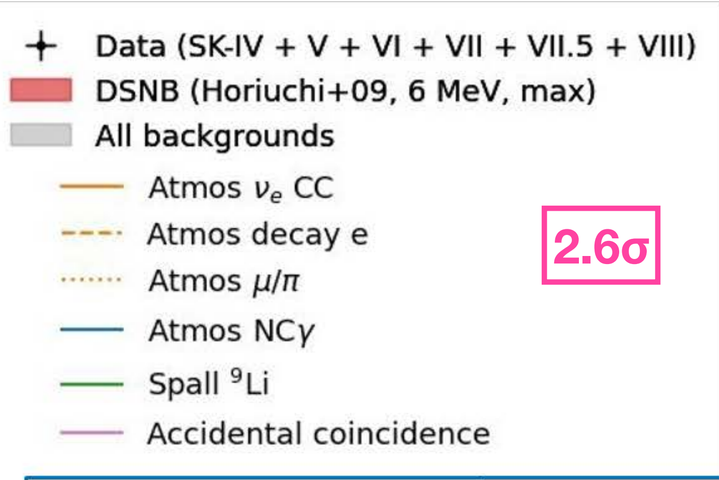
Predicted: 2.1 - 3.9 cm^{-2} s^{-1}

(Horiuchi+09, 6MeV, min - max)

Fit Result for SK-IV~VIII (Entire NTag Period)

arXiv:2610.35619





2.6σ

IBD event rate for E_ν > 13.3 MeV (E_{rec} > 11.5 MeV)

Best-fit: 4.8 +2.2/-2.0 events/yr

Predicted: 2.9 - 5.2 events/yr

(Horiuchi+09, 6MeV, min - max)

DSNB flux for E_ν > 13.3 (E_{rec} > 11.5 MeV)

Best-fit: 3.6 +1.6/-1.5 $\text{cm}^{-2}\ \text{s}^{-1}$

Predicted: 2.1 - 3.9 $\text{cm}^{-2}\ \text{s}^{-1}$

(Horiuchi+09, 6MeV, min - max)

Fit Summary

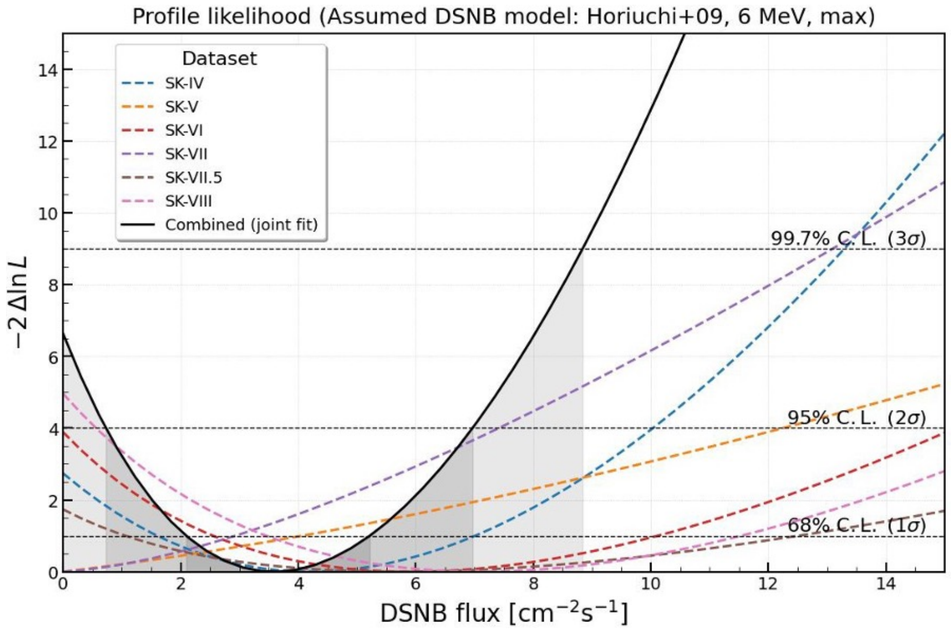
arXiv:2610.35619

- Joint fit result gives a **2.6σ** significance (excludes a null DSNB hypothesis at **99.5% C.L.**).
  - Most significant phase is SK-VIII (~2.2σ).
  - 1.4σ (pure water phase only), 2.2σ (Gd water phase only)
- **This is the first *indication* of the DSNB electron antineutrino signature!**

2.6σ

shared parameters
separate parameters

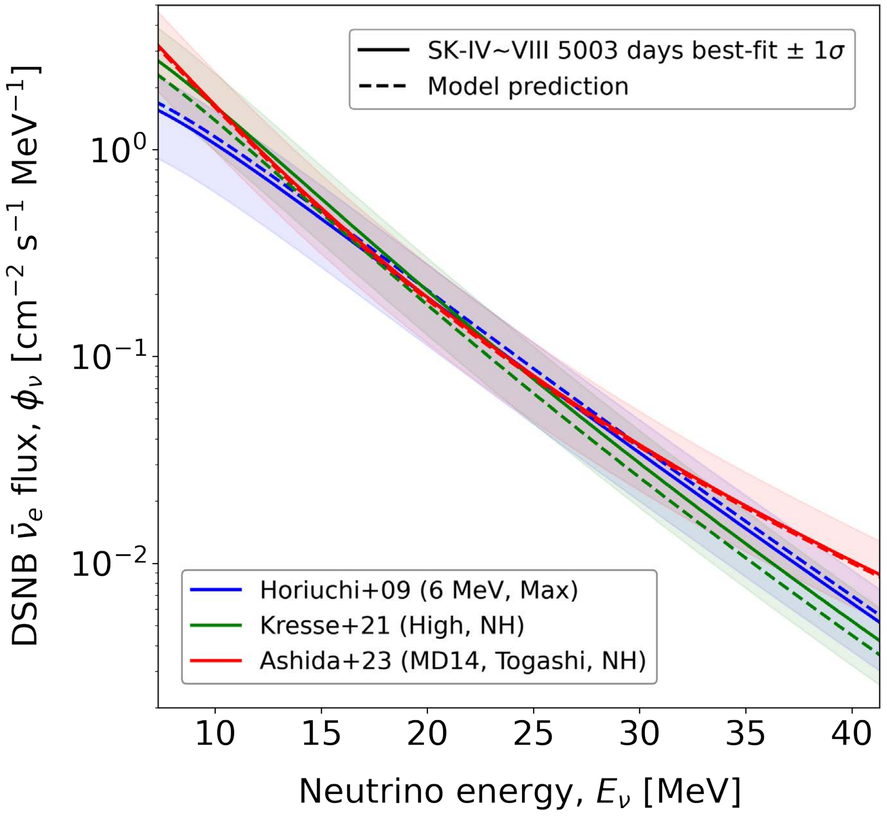
	Parameter	Units	Joint	SK-IV	SK-V	SK-VI	SK-VII	SK-VII.5	SK-VIII
Signal	N_s	rate	4.8	5.6	0	7.9	0	7.6	9.5
Background: atmospherics	N_nue (νe CC)	scale on MC	1.1	1.3	1.3	0.8	0.8	1.0	0.8
	N_numu (decay-e)	scale on MC	1.2	1.2	1.2	1.2	1.3	1.2	1.0
	N_mupi (μ/π)	scale on MC	1.2	1.3	1.0	1.0	0.9	1.1	1.1
	N_ncqe (NCγ)	scale on MC	1.1	1.0	1.2	1.1	1.3	0.9	0.9
Background: spallation	N_spall (^{9}C/^{8}B/^{8}He)	scale on MC	0 (inactive)	0 (inactive)	0 (inactive)	0 (inactive)	0 (inactive)	0 (inactive)	0 (inactive)
	N_li9 (^{9}Li)	scale on MC	1.1	1.0	1.0	1.0	1.0	1.0	1.0
Background: accidentals	N_acc_coinc	rate	Per-phase	0.2	0.5	0.2	0.3	0.3	0.1
Nuisances	epsilon_ntag_cc	σ units on unc	-0.2	0.0	-1.1	-1.3	-0.9	0.0	1.1
	epsilon_ntag_nc	σ units on unc	0.8	0.2	0.7	0.3	0.4	0.0	0.2
	epsilon_ntag_sig	σ units on unc	Per-phase	0.2	0.0	0.1	0.0	0.0	0.2
	epsilon_eff_sig	σ units on unc	Per-phase	0.0	0.0	0.0	0.0	0.0	0.0
	f0_spall	iso fraction	0 (inactive)	0 (inactive)	0 (inactive)	0 (inactive)	0 (inactive)	0 (inactive)	0 (inactive)
	f1_spall	iso fraction	0 (inactive)	0 (inactive)	0 (inactive)	0 (inactive)	0 (inactive)	0 (inactive)	0 (inactive)
	epsilon_li9	σ units on unc	0.1	0.1	0.0	0.0	0.0	0.0	-0.1



Fitting with Other DSNB Models

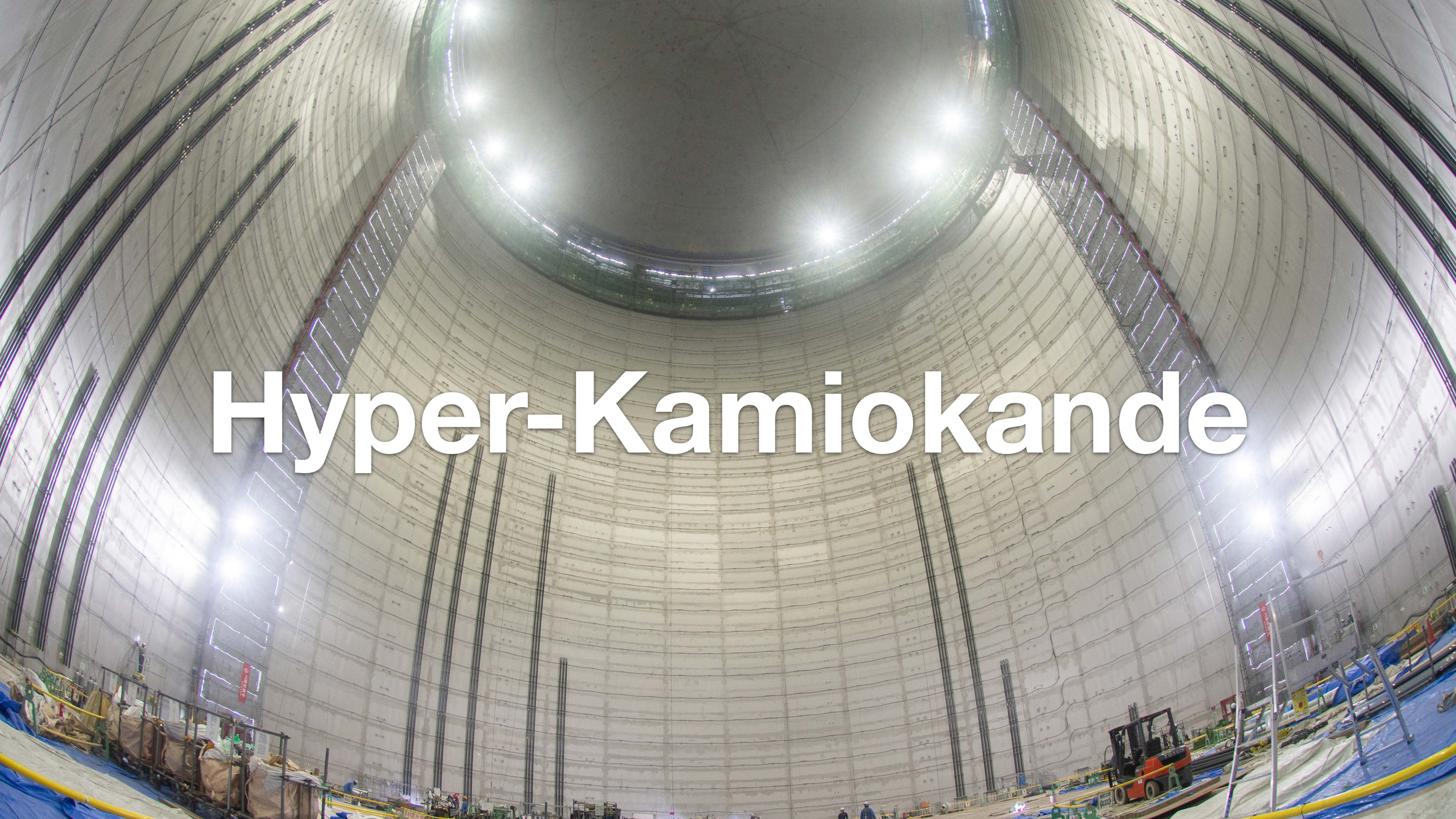
arXiv:2610.35619

- Three models (which have different shapes) were tested.
- The fitting consistently shows a significance of ~2.6σ against the null DSNB hypothesis.
- Our analysis is not capable of model discrimination yet.



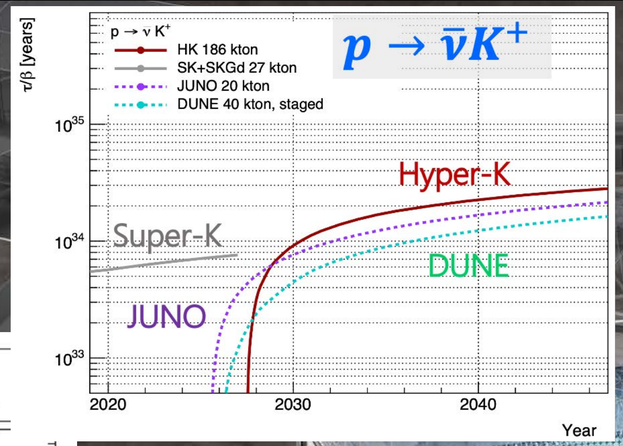
Preliminary

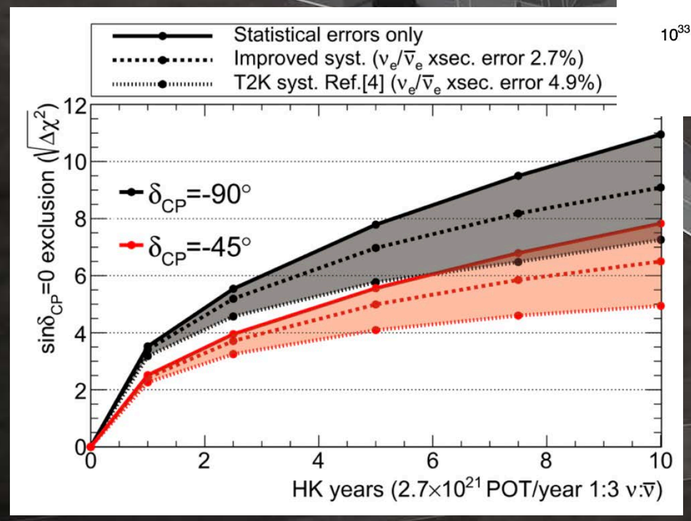
	IBD event rate [events/year]		DSNB flux [cm^{-2} s^{-1}]		Significance (SK-IV ~ VIII joint fit)	Maximum Likelihood Value
	Best-fit	Pred	Best-fit	Pred		
Horiuchi+09 6 MeV, max	4.8 +2.2/-2.0	5.2	3.6 +1.6/-1.5	3.9	2.6σ	1226.1
Kresse+21	5.1 +2.2/2.0	4.3	4.1 +1.8/-1.6	3.5	2.7σ	1225.3
Ashida+23	5.7 +2.5/-2.3	5.5	4.0 +1.8/-1.6	3.9	2.6σ	1225.9


Hyper-Kamiokande

Hyper-Kamiokande Project

260 kton (8.4× SK) + 1.3 MW beam

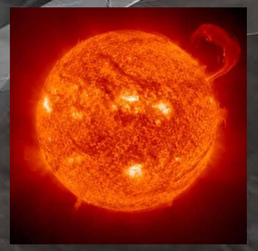




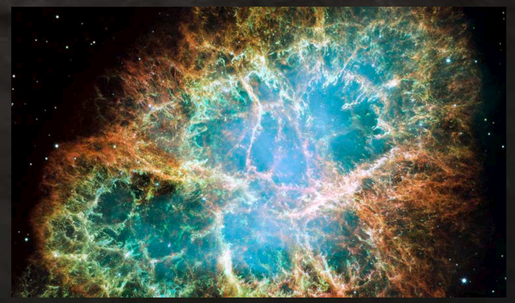
Rushing construction work for the operation in **2028**!

Components

- Beam (J-PARC)
- Near detector (ND280, INGRID)
- Intermediate detector (IWCD)
- Far detector (Hyper-K)





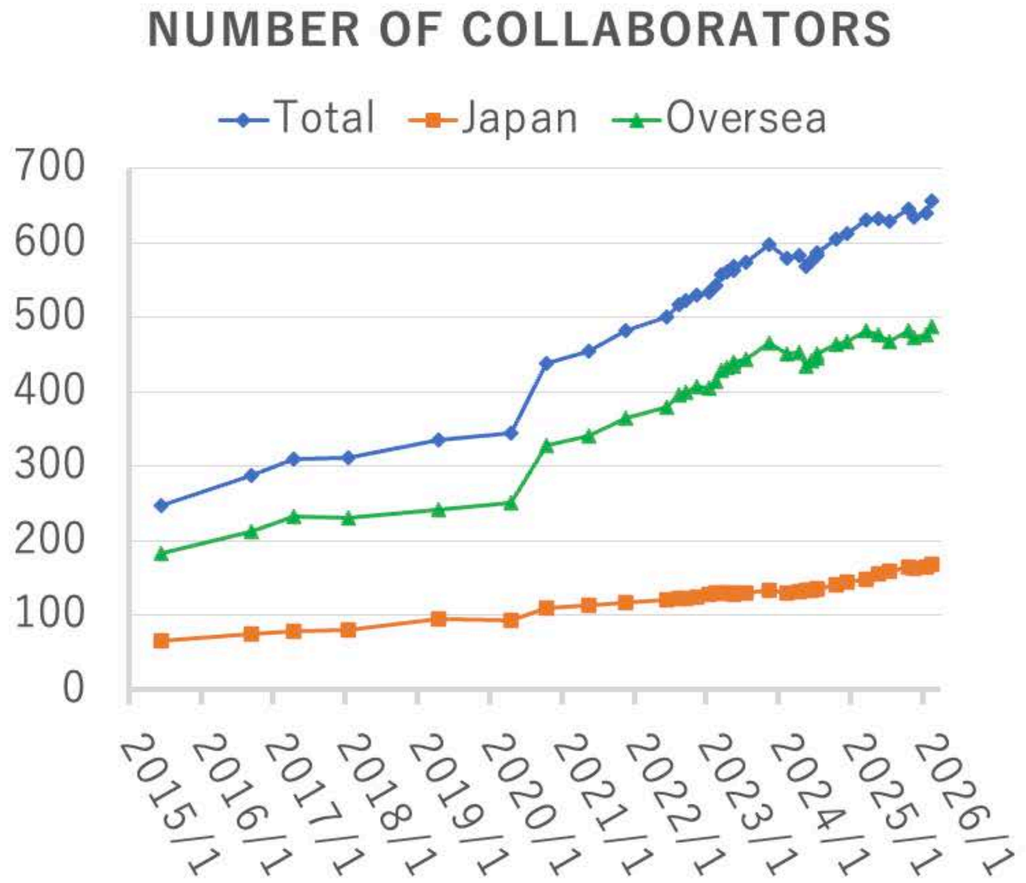


Fruitful science topics

- Leptonic CP violation with beam+atmospheric oscillations
- Test of GUT via proton decay search
- Neutrino astronomy (DSNB, MeV~GeV astrophysical neutrinos)
- Indirect dark matter search, etc…

NIKKEN SEKKEI

Growing Collaboration



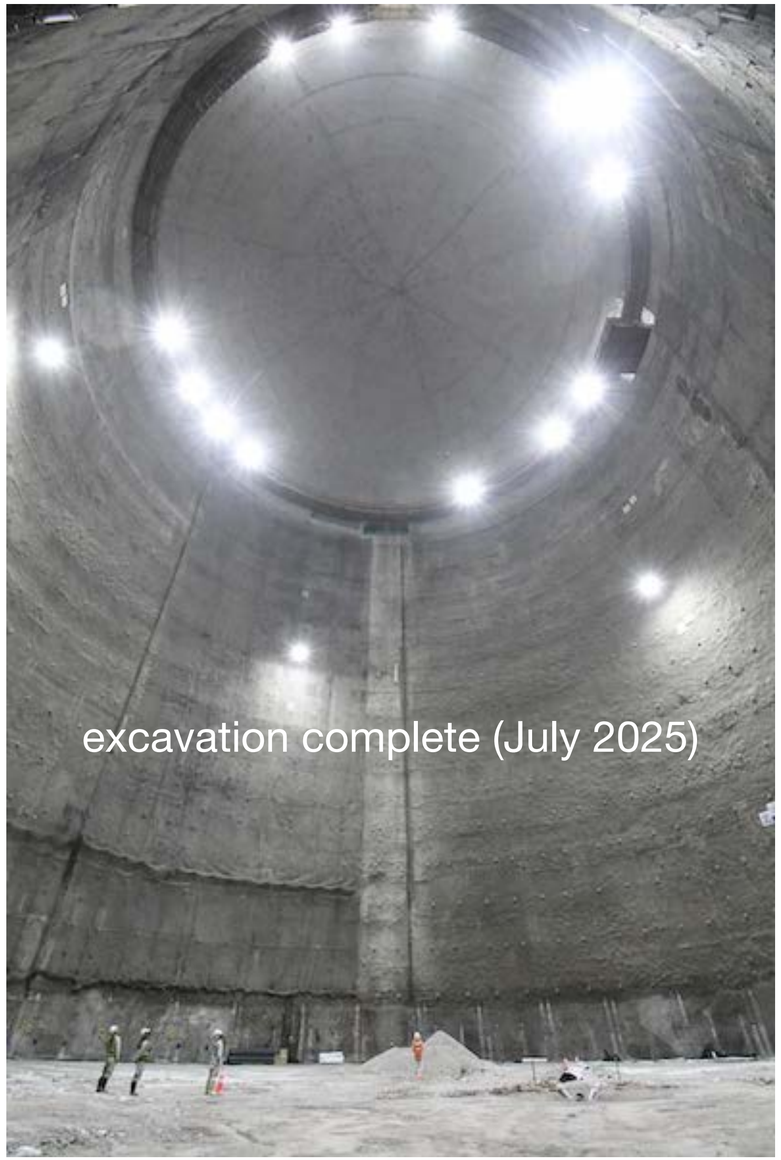


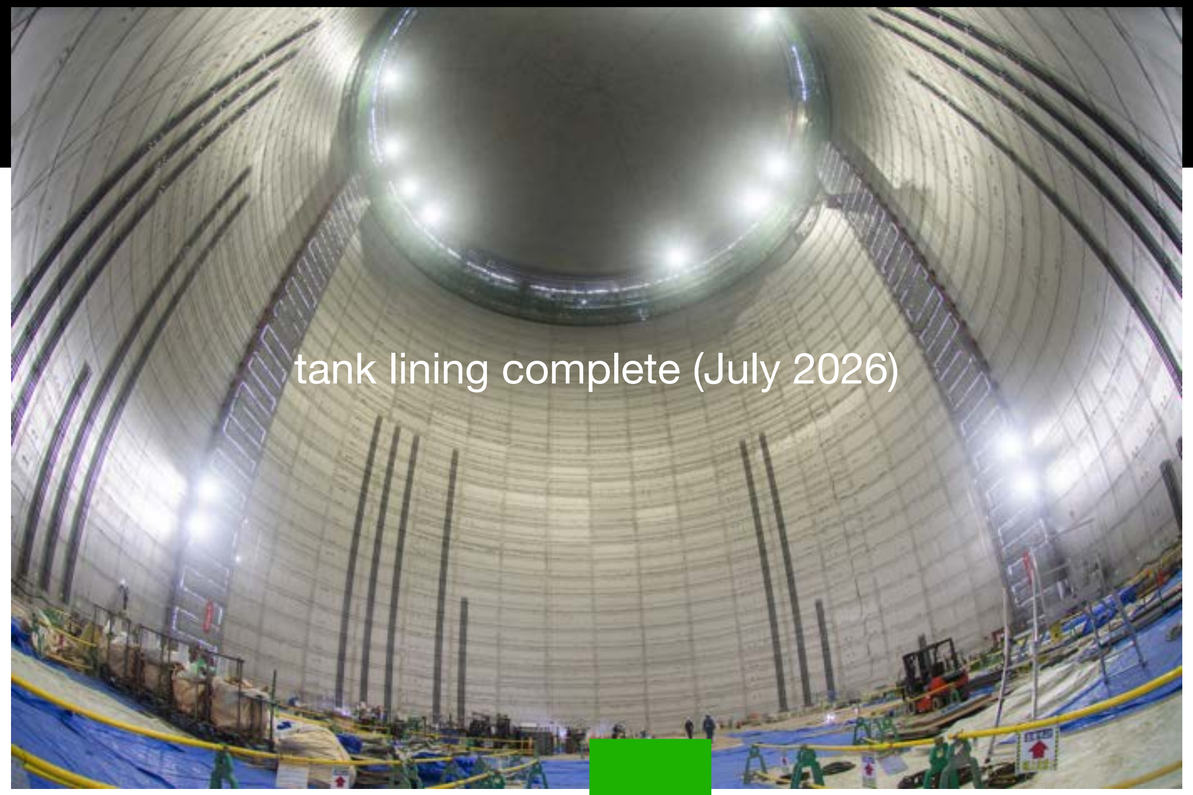


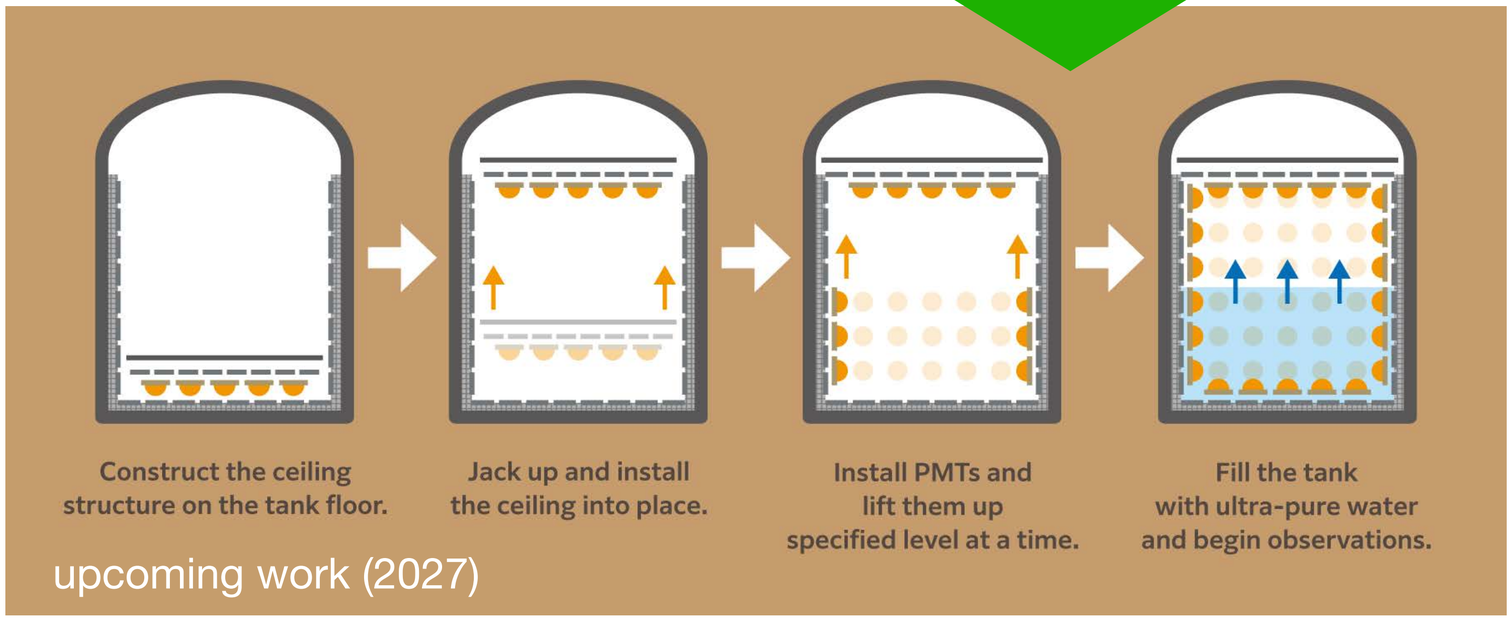
- ~660 members from 23 countries and ~100 institutes
- Still growing linearly

R. Akutsu, NEUTRINO2026

Tank Construction







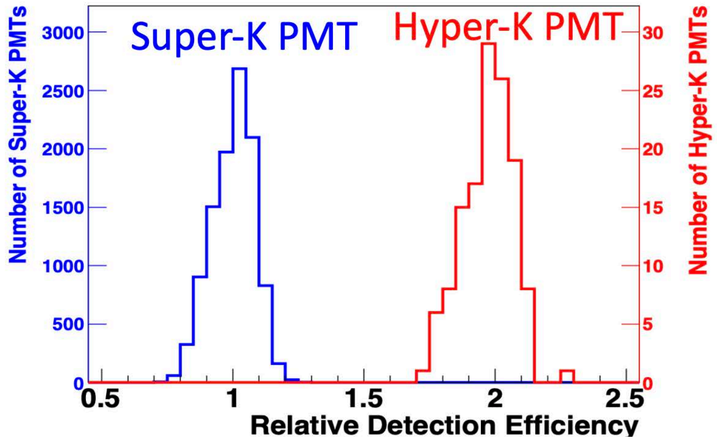
Photosensors

20,000 50-cm PMTs for ID



R12860 Hamamatsu Photonics K.K.

Relative Detection Efficiency at single p.e.

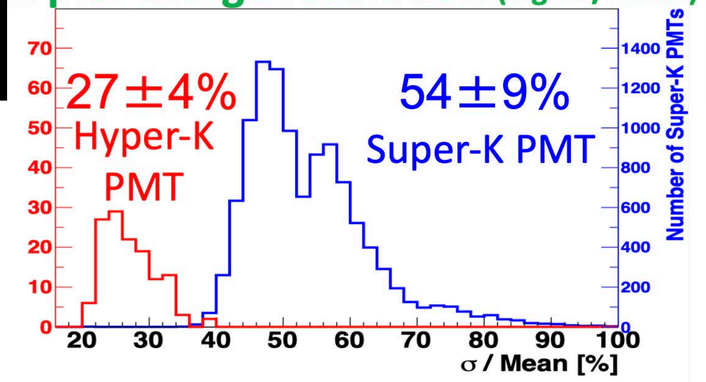


= ×1.4 QE ×1.4 CE from Super-K PMTs

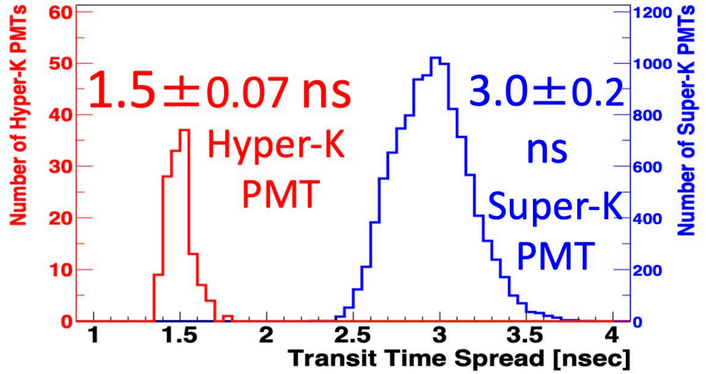
QE : Quantum efficiency

CE : Collection efficiency

1 p.e. charge resolution (Sigma/Mean)



Time resolution [Sigma]



2× performance than SK PMTs

Y. Nishimura, ICHEP2026



800 mPMTs (19 of 8-cm PMTs) for ID

Sensor performance tests are on-going!

3,600 8-cm PMTs for OD



8-cm PMT

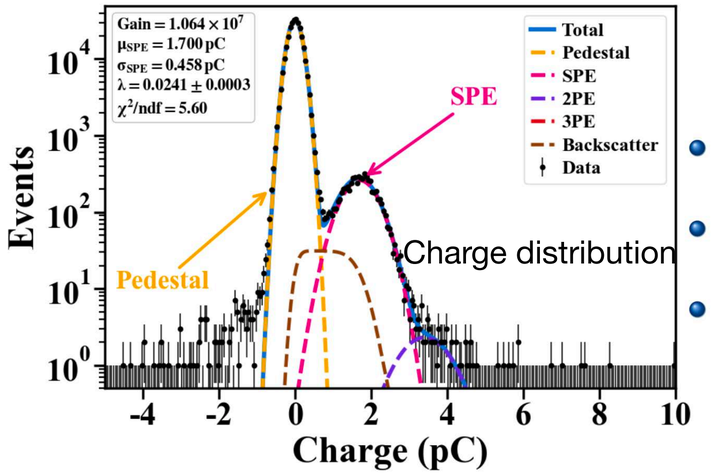
(Hamamatsu R14374)

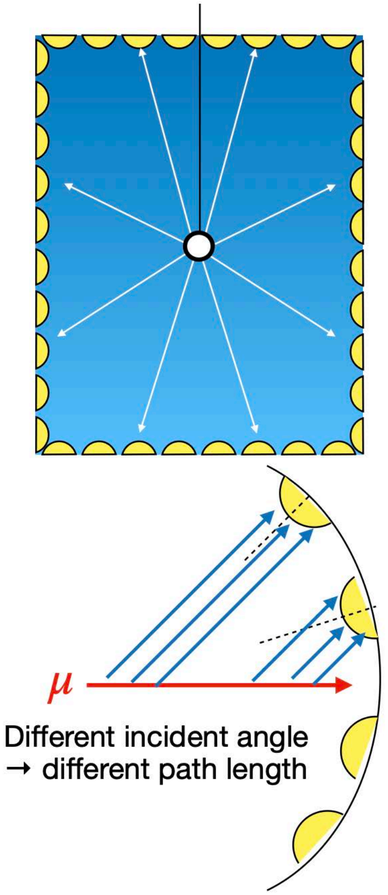


+ Wavelength shifting plate

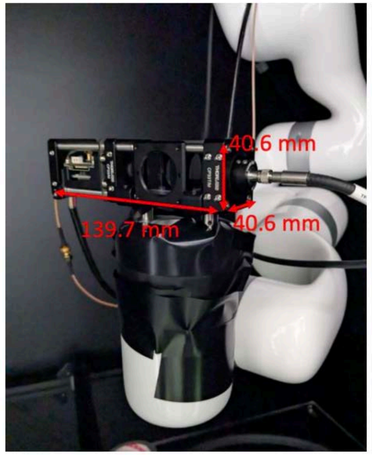
ID PMT Pre-calibration

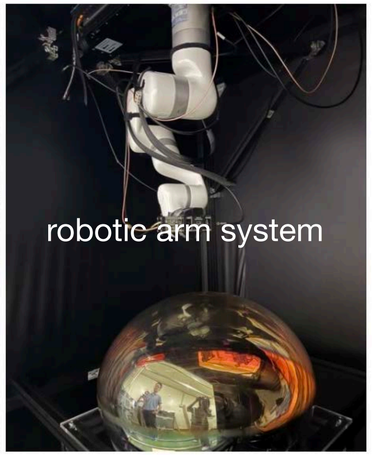
- Performance of ~400 PMTs as a function of light injection angles are measured before installation into the tank.
  - **Detection efficiency**
  - Charge resolution
  - Time response (time offset, **TTS**)
- Various dependences are also investigated.
  - **Wavelength** (375, 405, 450, 473 nm)
  - **Magnetic field**
  - **Electronics** (waveform digitizer vs. HK electronics
  - Cross checked between two independent systems.

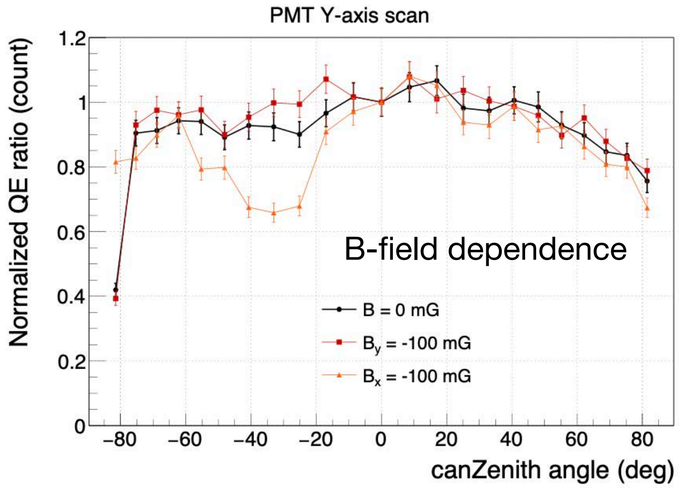






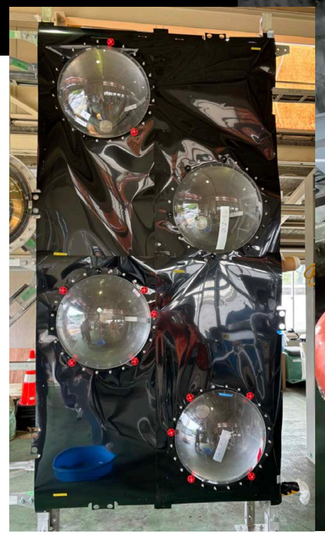




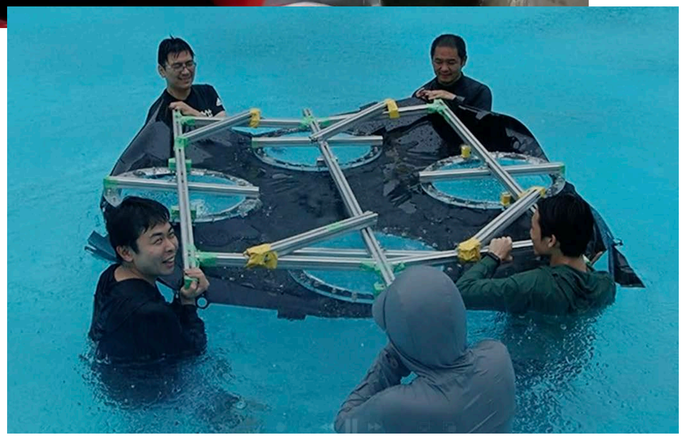


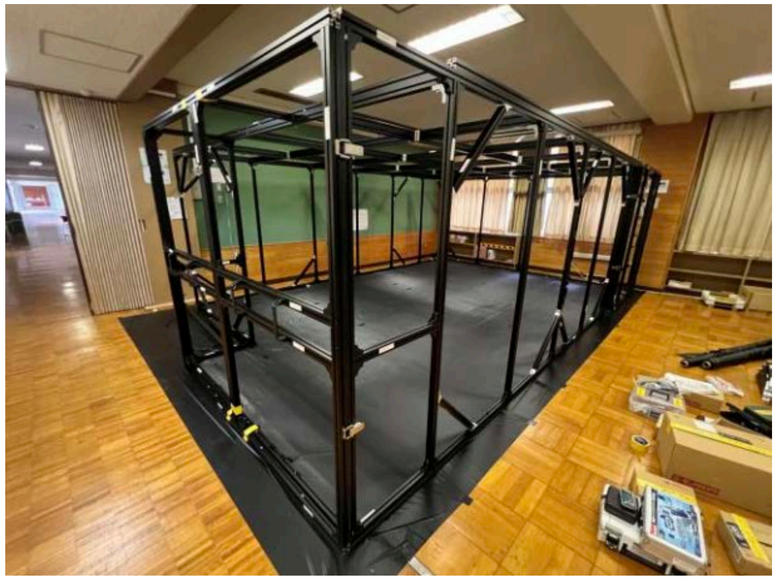
Other Far Detector Work…

- ID blacksheet
- ID PMT signal check before assembly
- ID PMT+Cover assembly
- OD PMT quality assuarance test
- mPMT in-water performance measurement
- In-water electronics development
- … etc

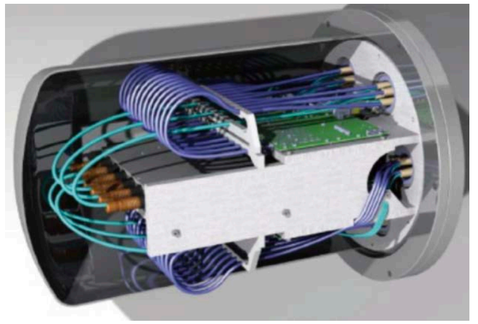






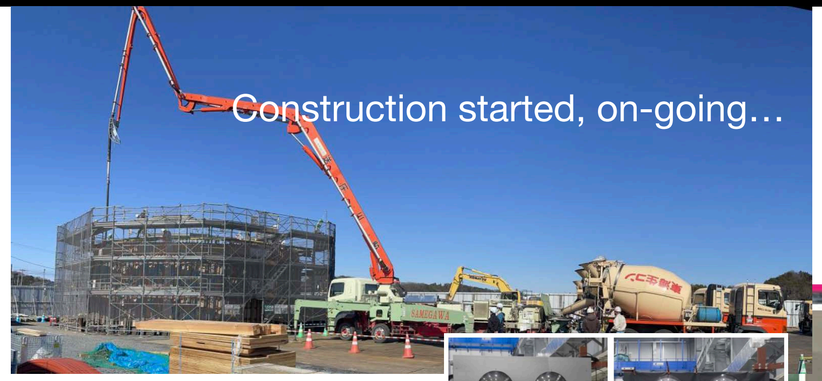




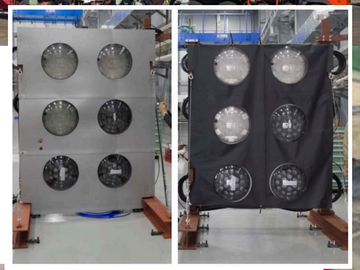


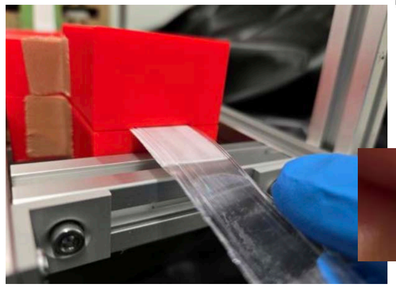
Progress in J-PARC

Many upgrades for the 1.3 MW operation



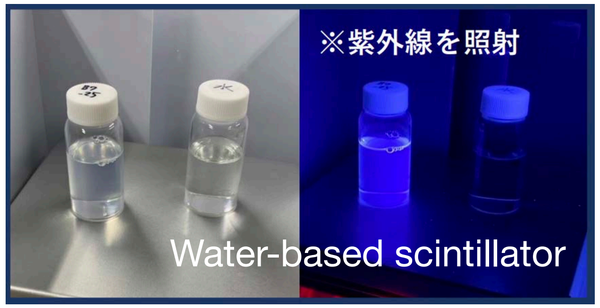
Mockup test

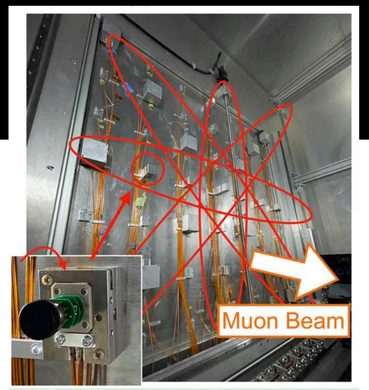


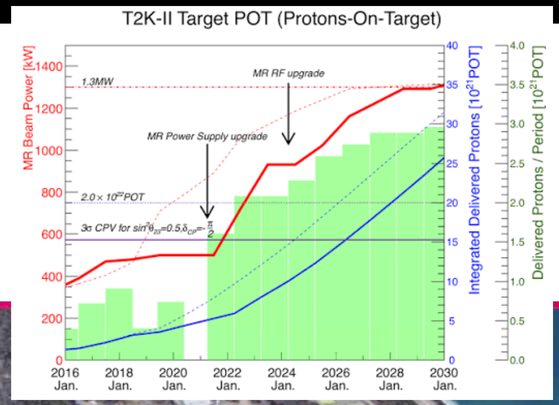




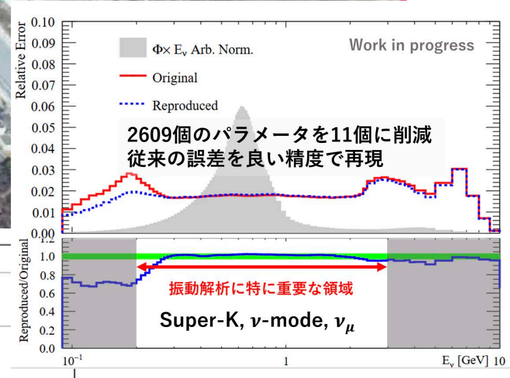
Fiber tracker R&D

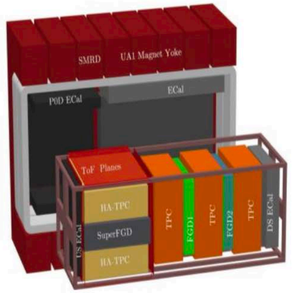




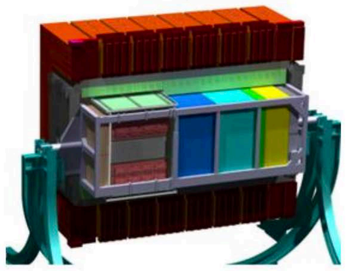




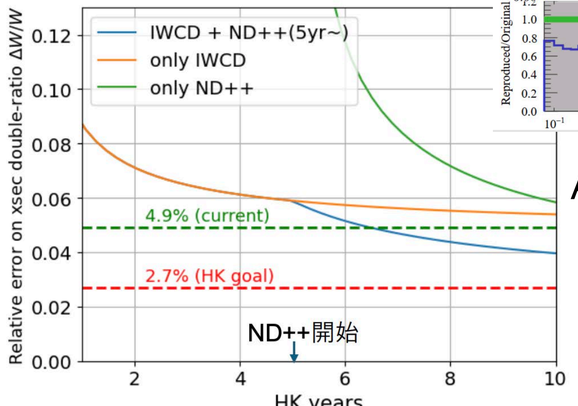




ND280

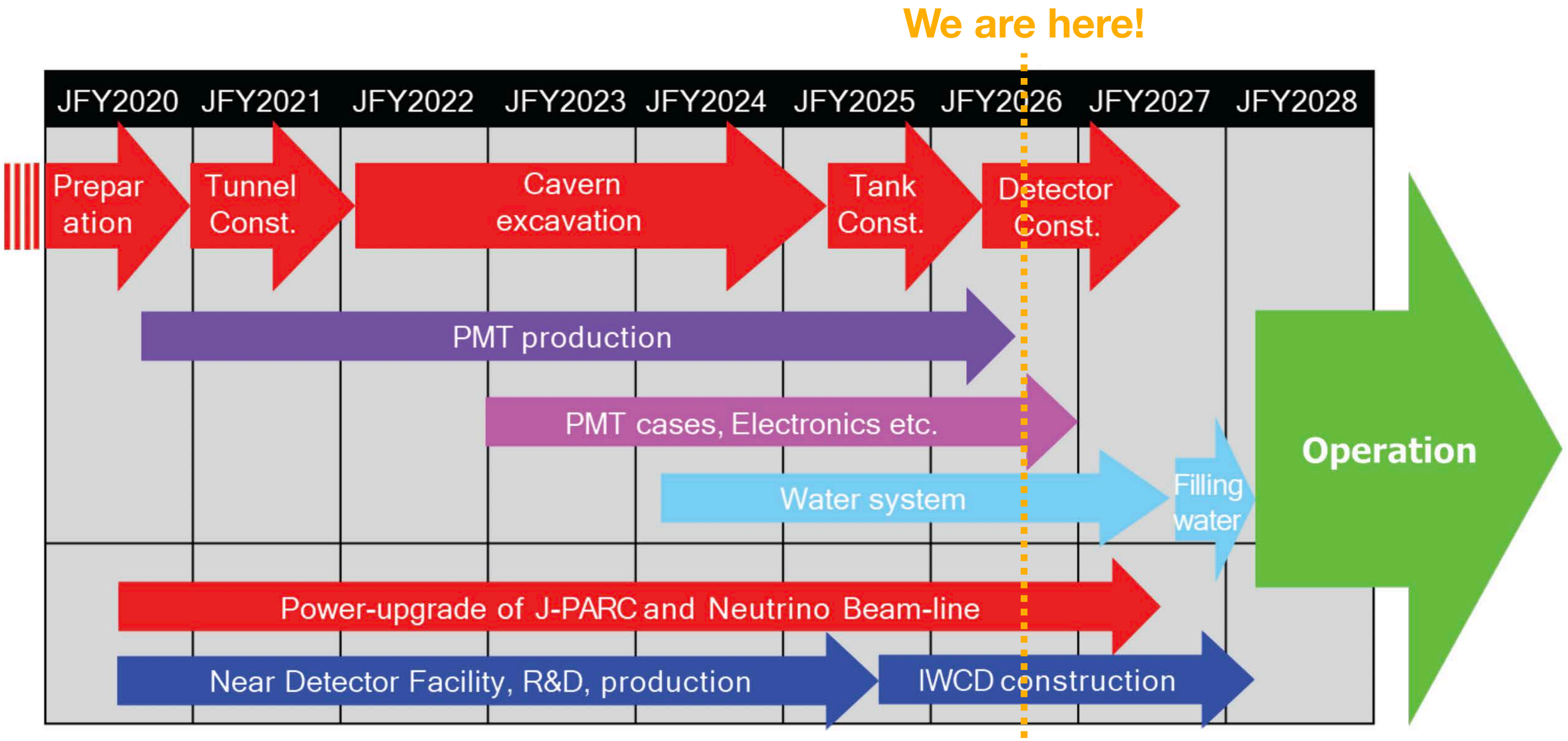


ND280++



Analysis improvements for multiple detectors

Schedule


We are here!
JFY2020
JFY2021
JFY2022
JFY2023
JFY2024
JFY2025
JFY2026
JFY2027
JFY2028
Prepar ation
Tunnel Const.
Cavern excavation
Tank Const.
Detector Const.
PMT production
PMT cases, Electronics etc.
Water system
Filling water
Operation
Power-upgrade of J-PARC and Neutrino Beam-line
Near Detector Facility, R&D, production
IWCD construction

Summary

- **Super-K has been leading particle physics and astrophysics fields for 30 years!**
  - Comprehensive understanding of neutrino oscillation from various source measurements.
  - Recent Gd loading has improved the sensitivity to IBD and SN pointing accuracy.
  - First indication of the DSNB signature is reported (arXiv:2610.35619).

THANK YOU FOR YOUR ATTENTION!



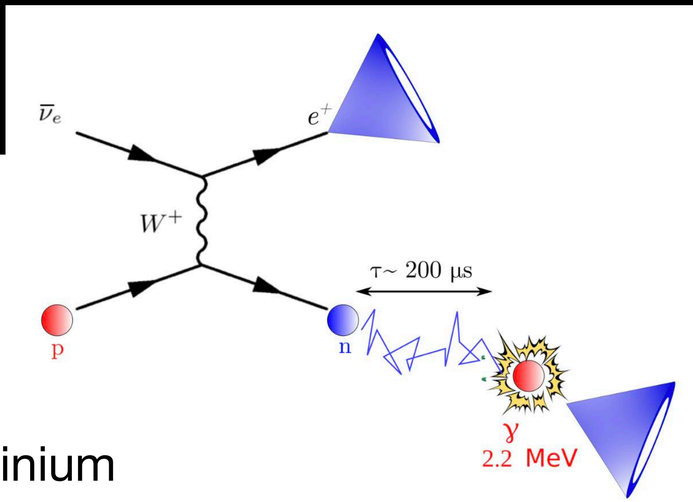
SK-san (Higgstan)

- **Hyper-K is under construction, and expects to begin in 2028!**
  - Tank construction is going well, now ready for accepting PMT installation.
  - ID PMT+Cover assembly and installation into the tank are coming next year.
  - PMT testing and performance evaluation campaigns are starting soon/now.
  - Intensive activities are made also on the J-PARC side.

Stay tuned for exciting moments!

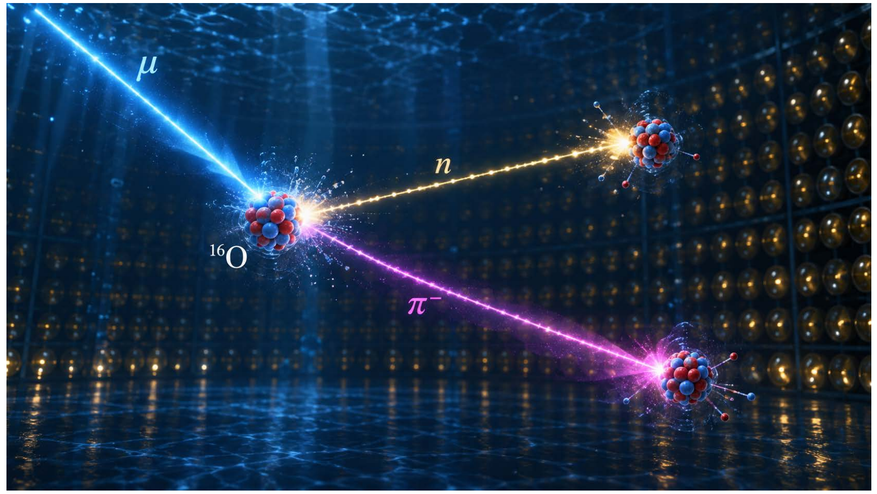
Supplements

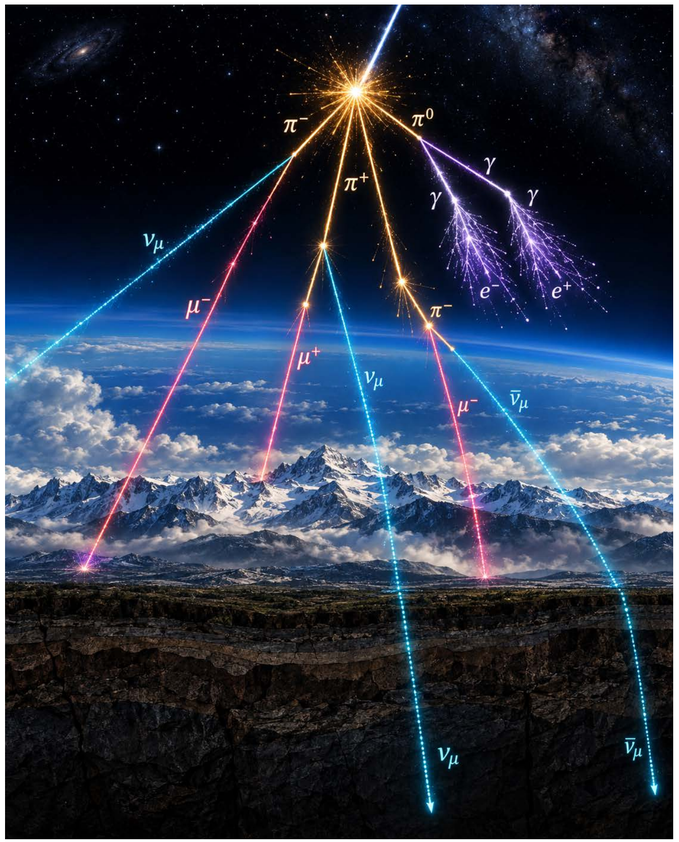
Search Strategy



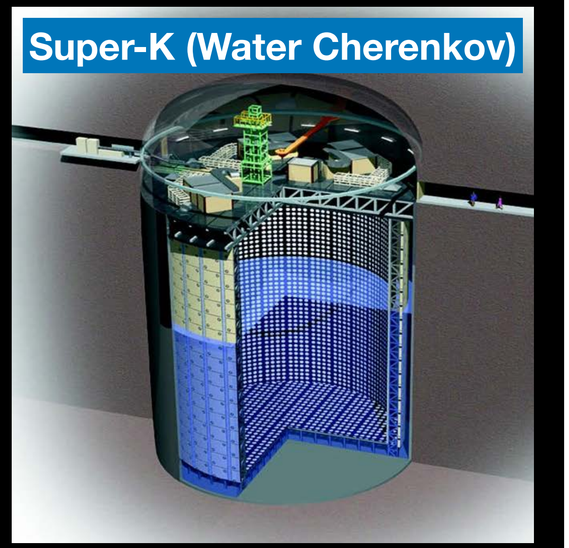
- Signal = **inverse beta decay (IBD)**, $\bar{\nu}_e + p \rightarrow e^+ + n$ (dominant channel)
  - e^+ = "*prompt*" signal (main energy range: **O(1–10) MeV**)
  - **n** = "*delayed*" signal via **γ-ray(s)** from thermal capture on hydrogen or gadolinium

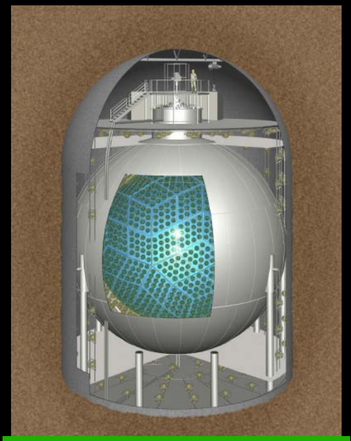
- Many types of backgrounds mimicking this signature.
  - Atmospheric neutrinos (CC, NC) — **Major backgrounds**
  - Radioactive isotopes and neutrons produced by atmospheric muons
  - Solar neutrinos (ES)
  - Reactor neutrinos (IBD)



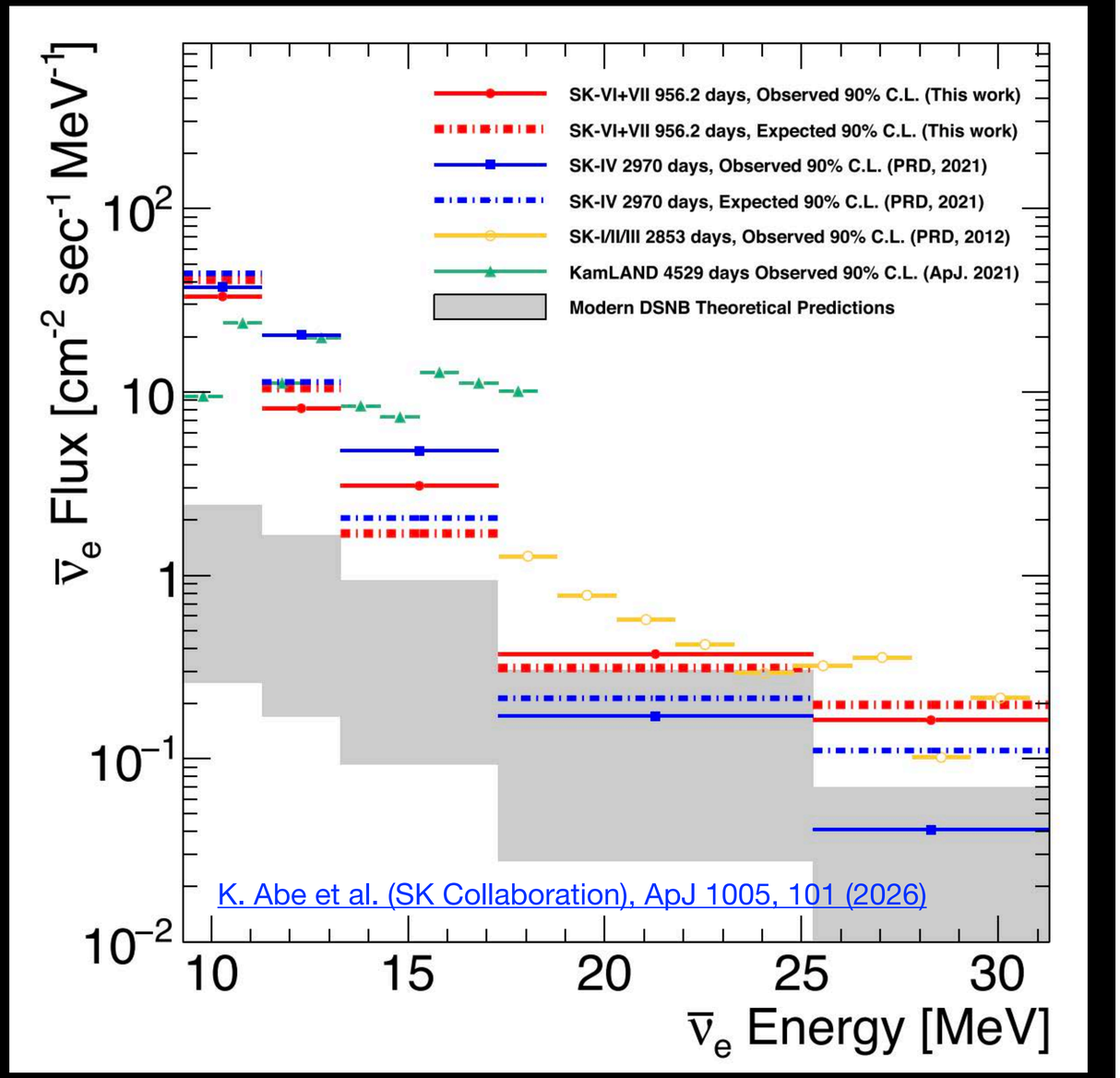


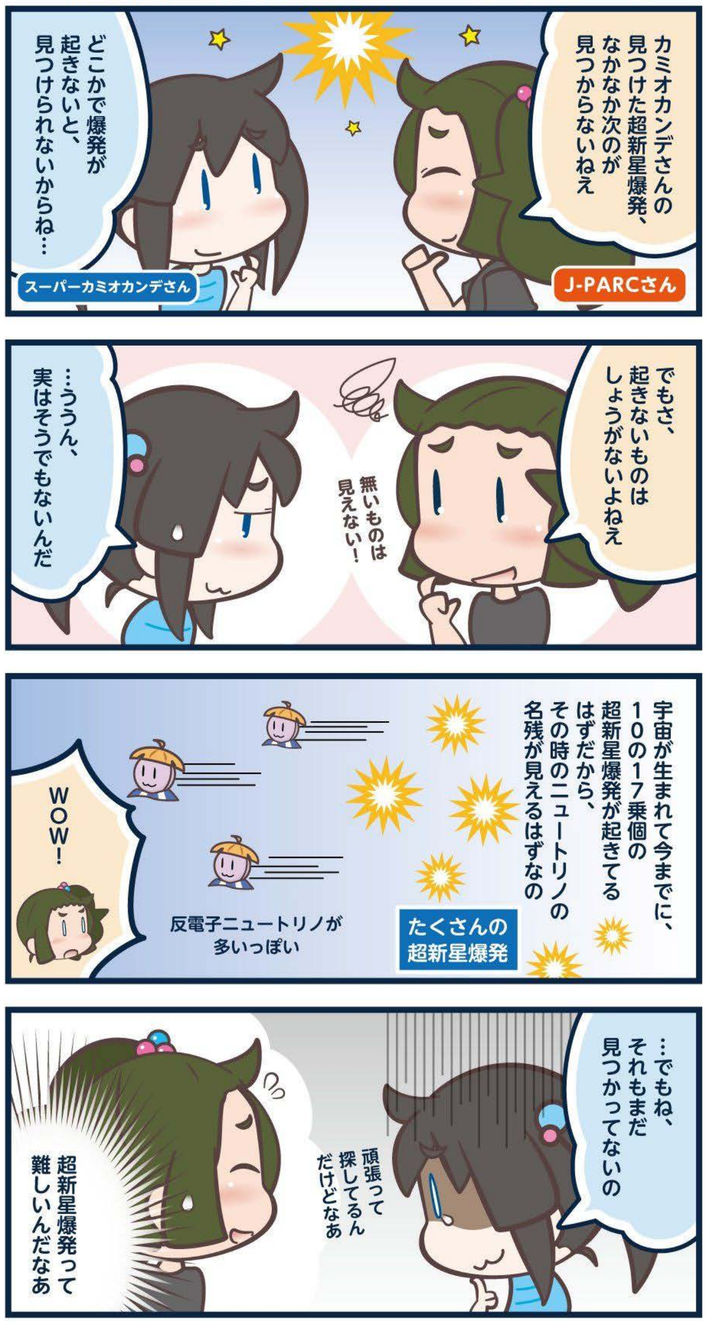
Before *This* Summer…





KamLAND
(Liquid Scintillator)



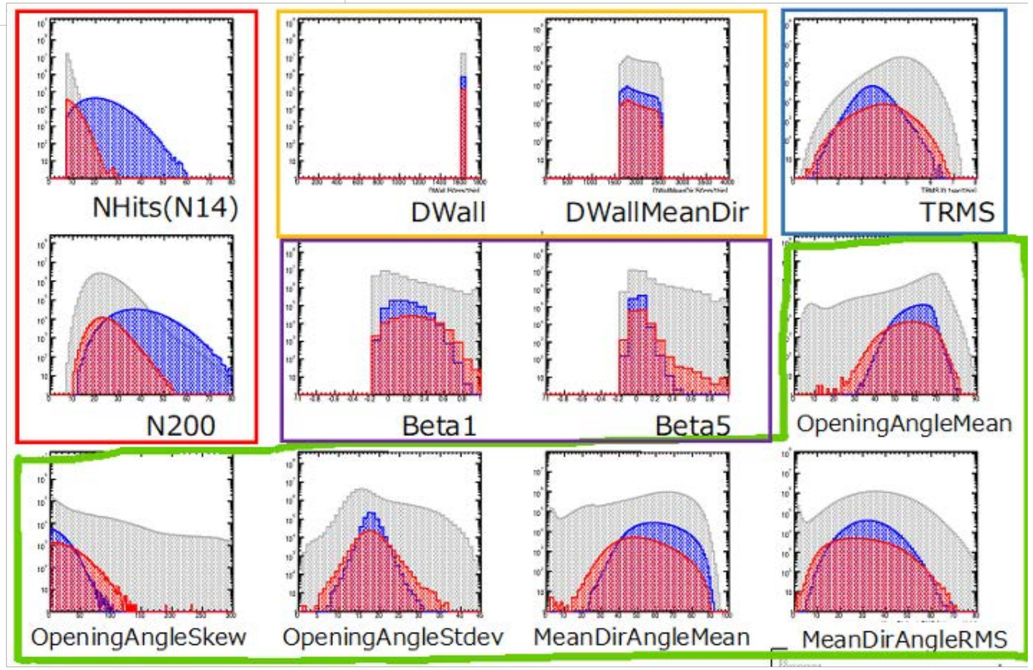


©Yuki A., higgstan.com

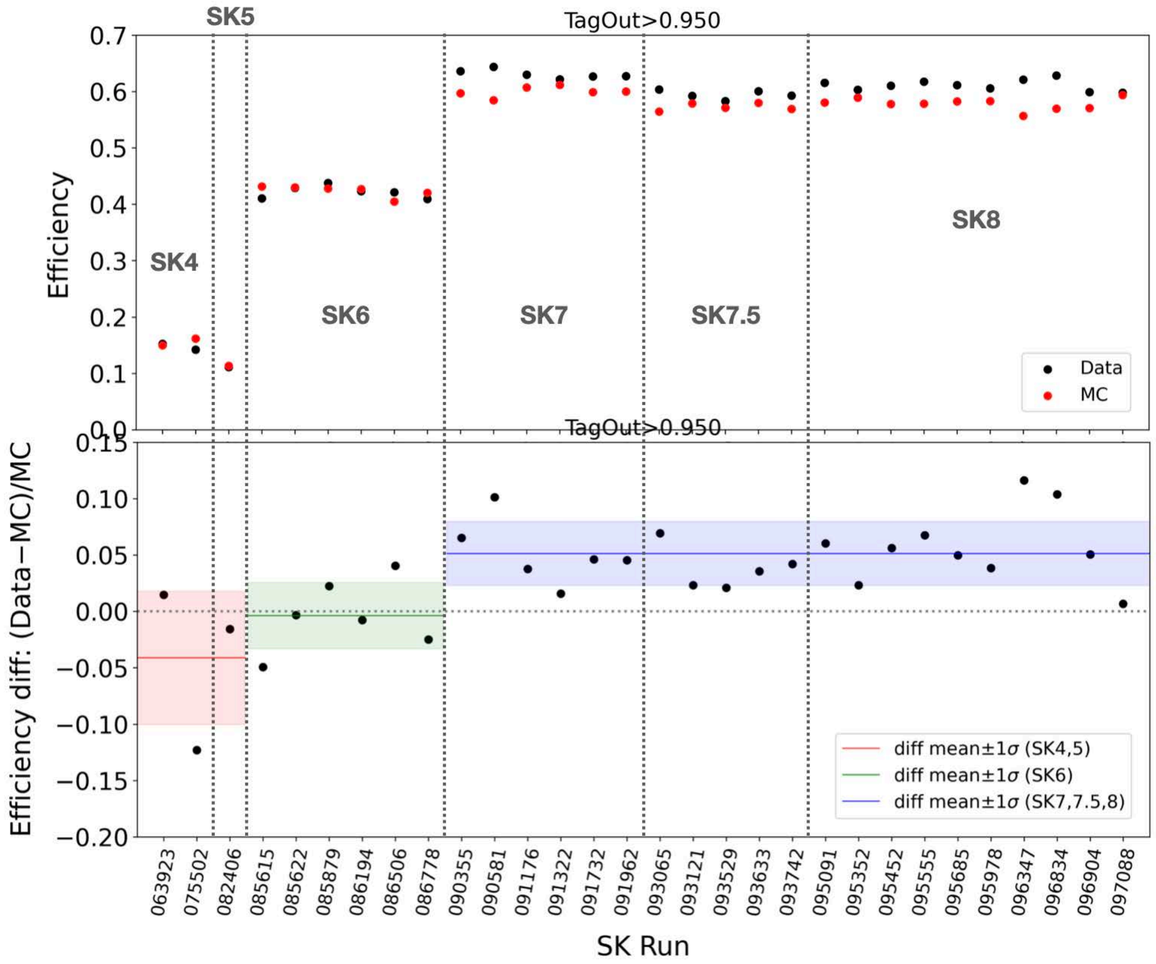
Neutron Tagging

- **Neural Network** (TMVA-MLP) structured based on 12 variables with spacial and temporal hit patterns.
- **Am/Be** neutron source is used to validate the employed method.
  - **SK-IV, V**: (sig eff) ~10%, (syst) ±10%
  - **SK-VI**: (sig eff) ~40%, (syst) ±3%
  - **SK-VII, VII.5, VIII**: (sig eff) ~60%, (syst) ±5%

PMT hits
Mean direction/Distance from SK ID
Timing info
Harmonic Beta parameters
Hit patterns

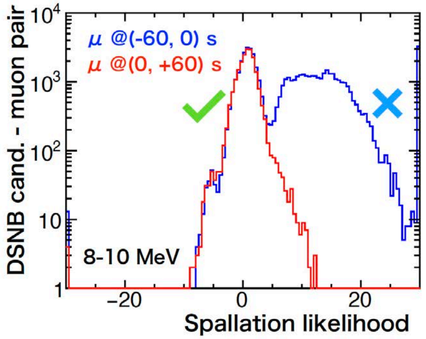


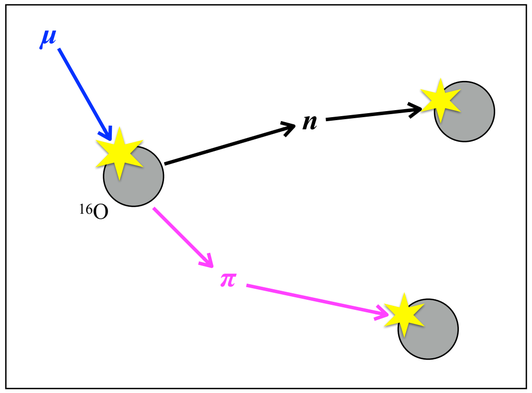
$$^{9}Be + \alpha(\text{from}\,^{241}\text{Am}) \rightarrow ^{12}C^{*} + \gamma(4.4MeV) + n$$

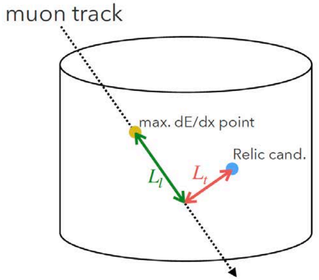


Spallation Background

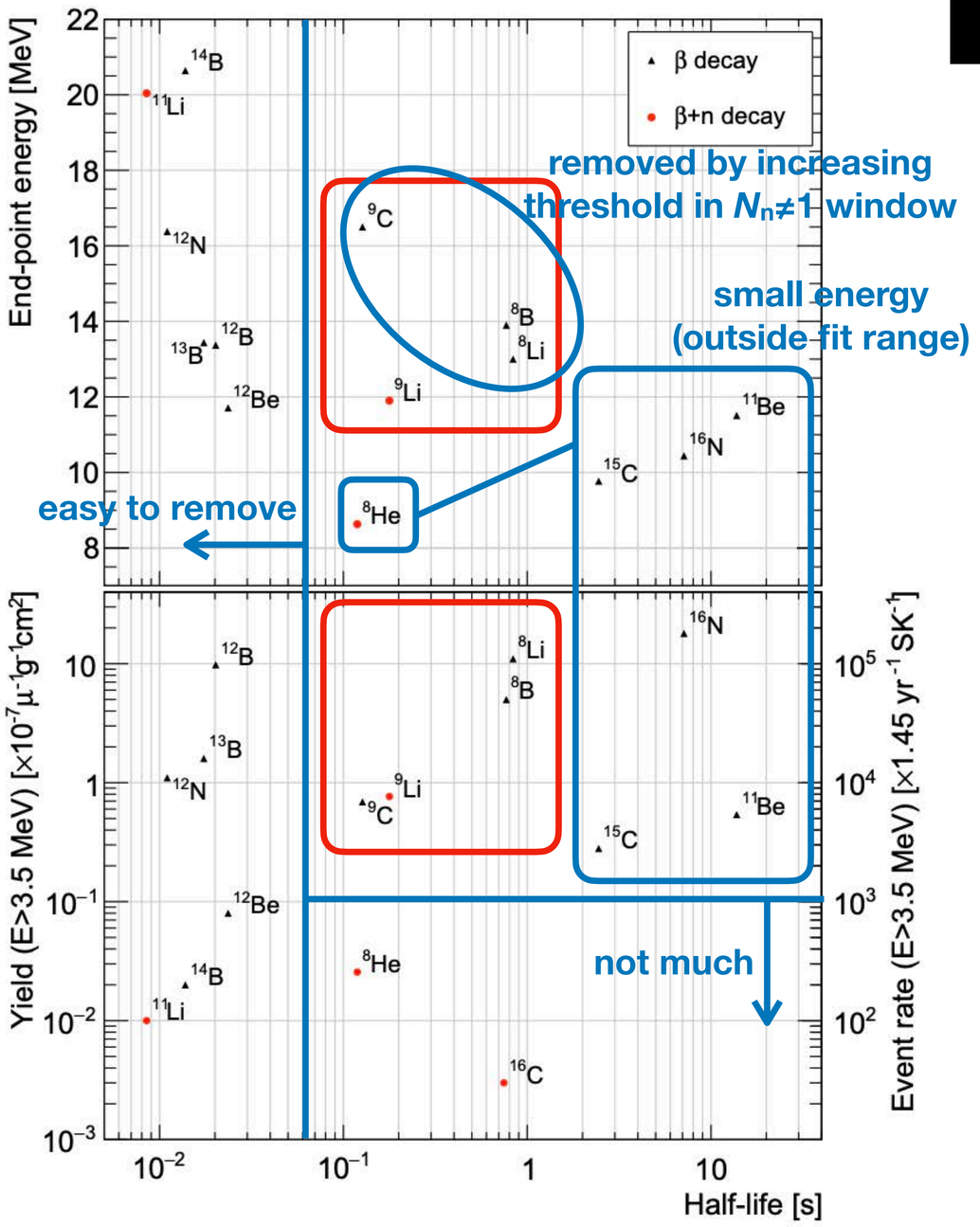
- Optimized selection in a data-driven way, by calculating spallation likelihood for muons collected *before/after* each candidate event.
- In the golden window (N_n=1), consider ^{9}Li and accidental coincidence events.
  - **^{9}Li**: estimated by toy samples with replaced *dt*
  - **acc**: estimated by mistag rate





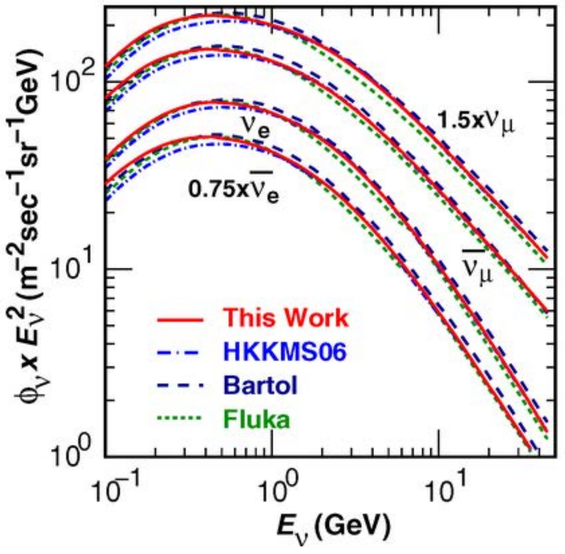


$$\mathscr{L} = \log \prod_{i \in vars} \frac{\mathrm{PDF}_i^{\mathrm{spall}}(x)}{\mathrm{PDF}_i^{\mathrm{random}}(x)} \quad (vars = dt, dlt, dll, qtot, resq)$$



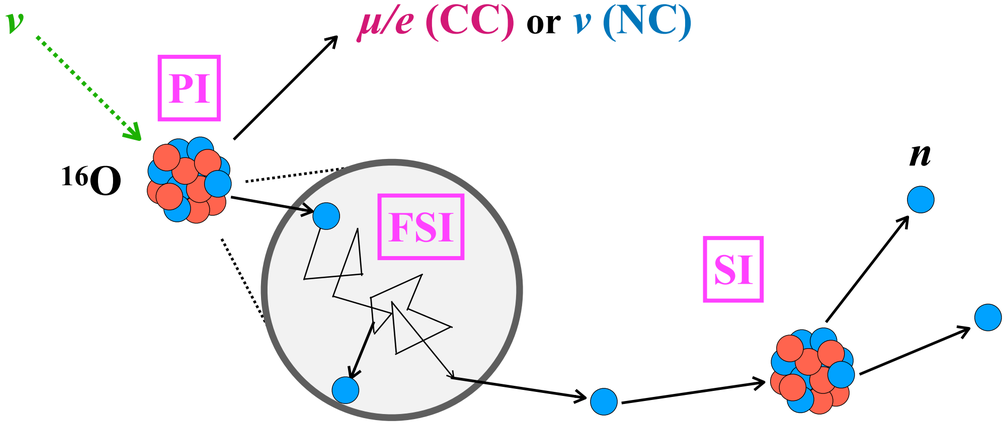
Atmospheric Neutrino Background

Neutrino flux (HKKM2011)



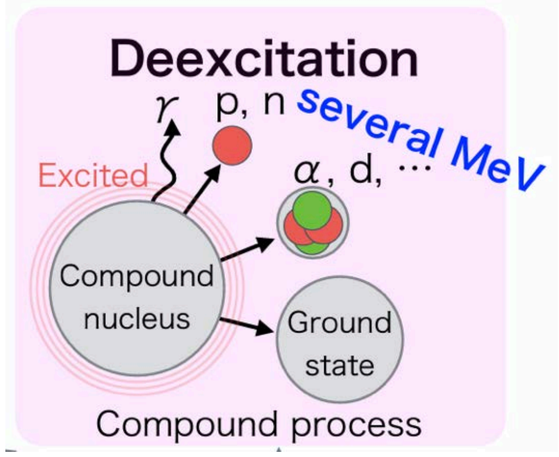
+

Neutrino primary & final state interaction (NEUT) + in-detector secondary interaction (GEANT4)



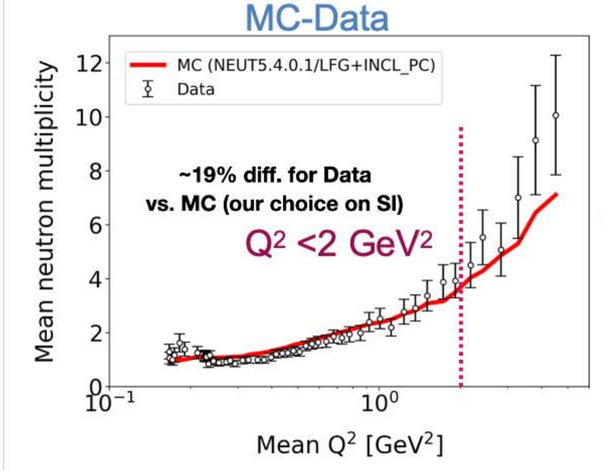
+

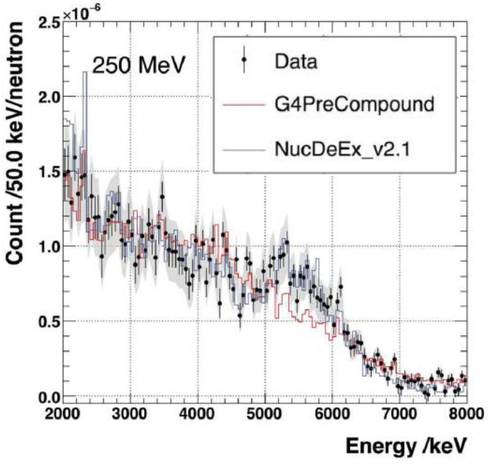
Nuclear final state



Systematics about complex final states are constrained in many ways.

- **Flux**: Honda flux (HKKM2011)
- **Interaction** (xsec, final state kinematics)
  - Model choice based on external beam test results.
  - CC: NEUT xsec + GEANT4 simulation
  - NC: T2K measurement for xsec + final state gamma
  - Neutron multiplicity: Super-K measurement





Fitting Parameters

Shared parameters (correlated over phases)

- Signal and background scales
- Atmospheric neutron multiplicity
- ^{9}Li spectrum shape

Per-phase parameters (independent)

- Accidental coincidence scale
- Signal efficiency
- Ntag efficiency

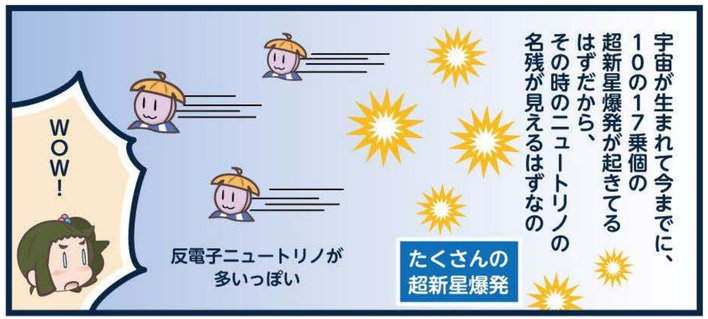
9 + (3 × 6 phases) = 27 parameters

	Parameters	Sharing
Signal	DSNB signal rate	Shared
Backgrounds	atmospheric ve CC scale on MC	Shared
	atmospheric decay-e scale on MC	Shared
	atmospheric NCγ scale on MC	Shared
	atmospheric μ/π scale on MC	Shared
	^{9}Li spallation scale on MC	Shared
	accidental coincidence rate	Per-phase
Nuisances	atmospheric bkg ntag migration (CC)	Shared
	atmospheric bkg ntag migration (NCγ)	Shared
	ntag efficiency uncertainty	Per-phase
	signal efficiency uncertainty	Per-phase
	^{9}Li spectral shape	Shared

超新星背景ニュートリノ！







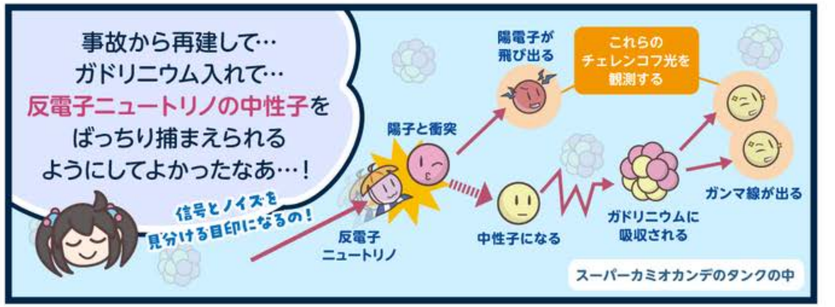


©Yuki A., higgstan.com

「かすかなささやき」見つけた？超新星背景ニュートリノ！









©higgstan.com