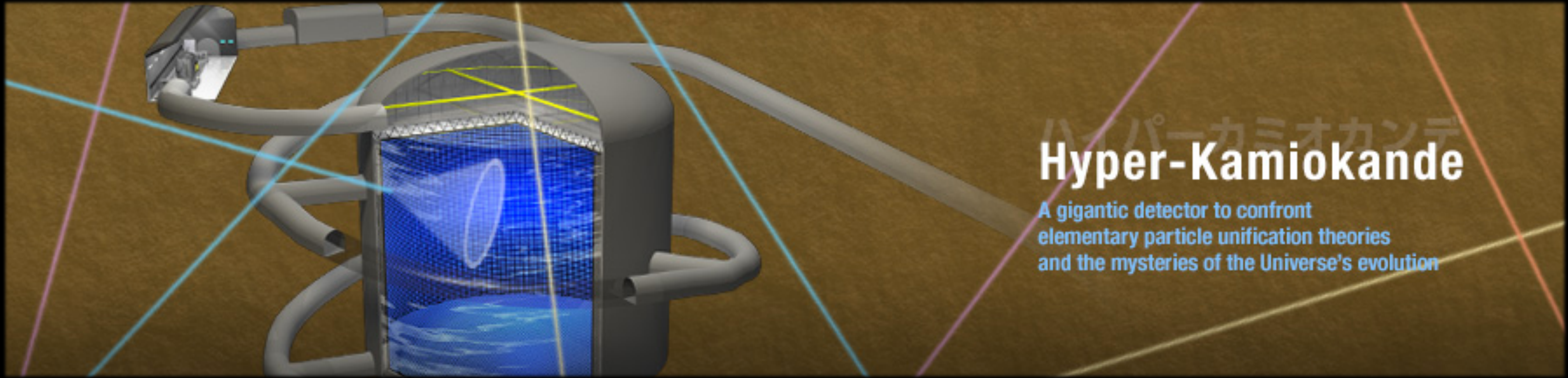
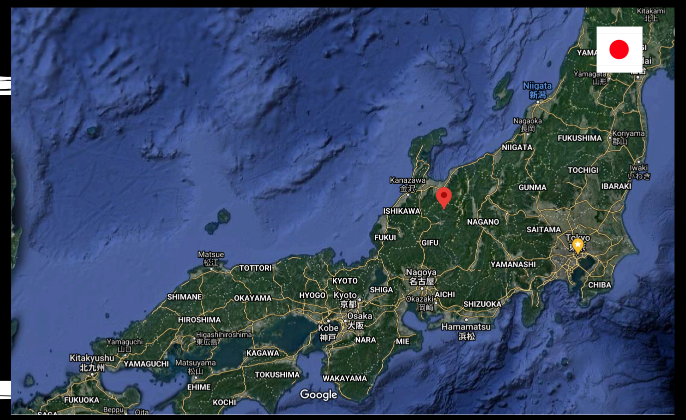


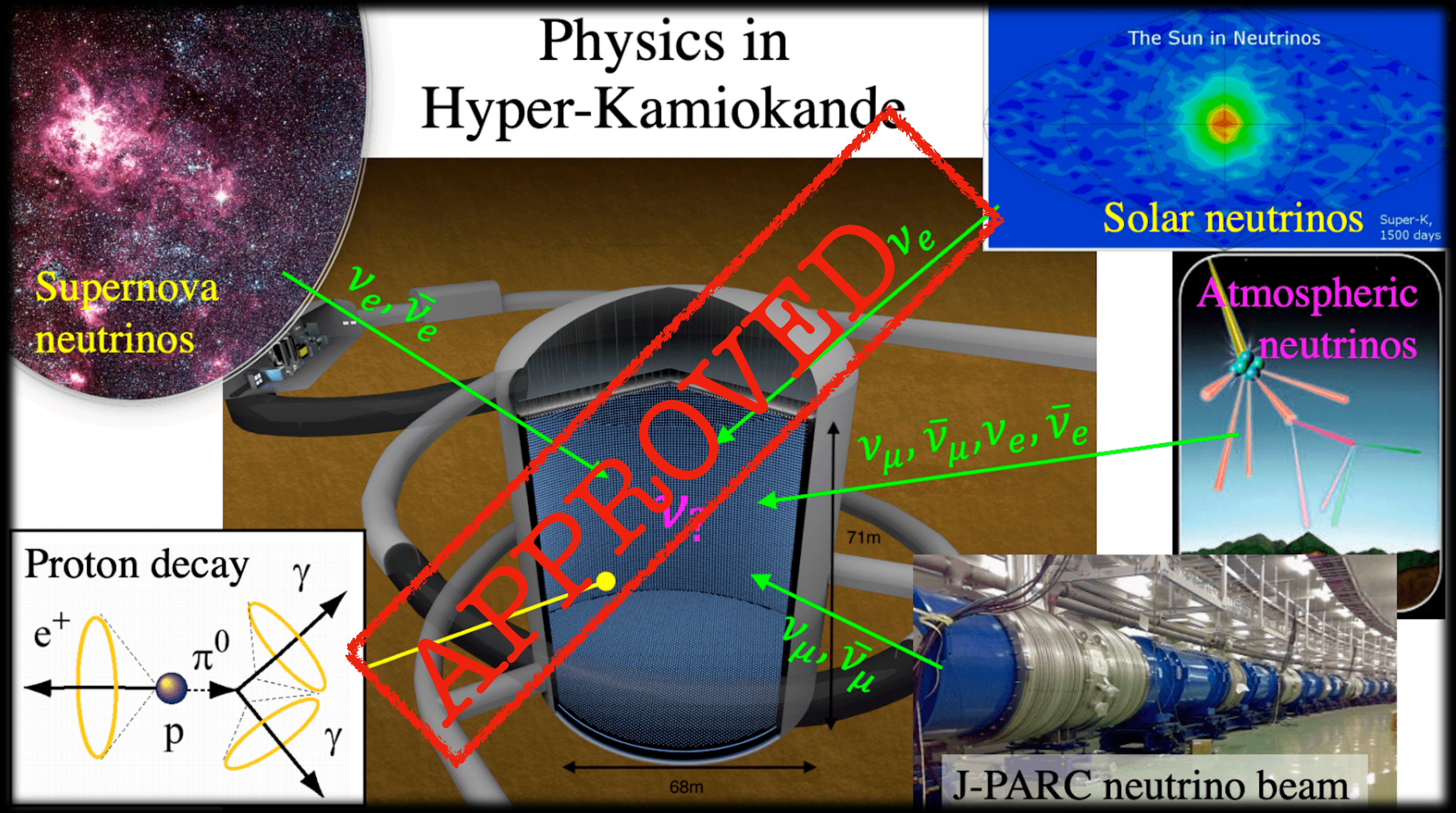
Hyper-Kamiokande Construction

Francesca Di Lodovico for the Hyper-Kamiokande Collaboration

TWENTIETH LOMONOSOV CONFERENCE ON ELEMENTARY PARTICLE PHYSICS
August, 19-25, 2021
MOSCOW STATE UNIVERSITY

The Hyper-Kamiokande Experiment

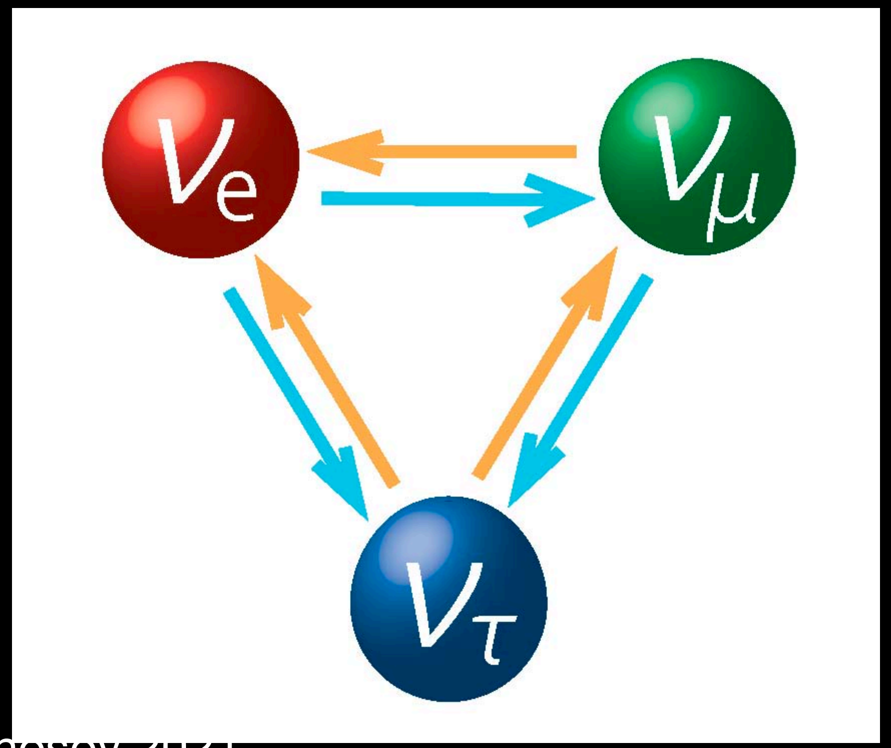




- Multi-purpose experiment
  - Beam physics
  - Astrophysical observatory
  - Rare (e.g.proton) decays

Neutrino Oscillations

Neutrino Oscillations will be measured based on **accelerator** and **atmospheric** neutrinos

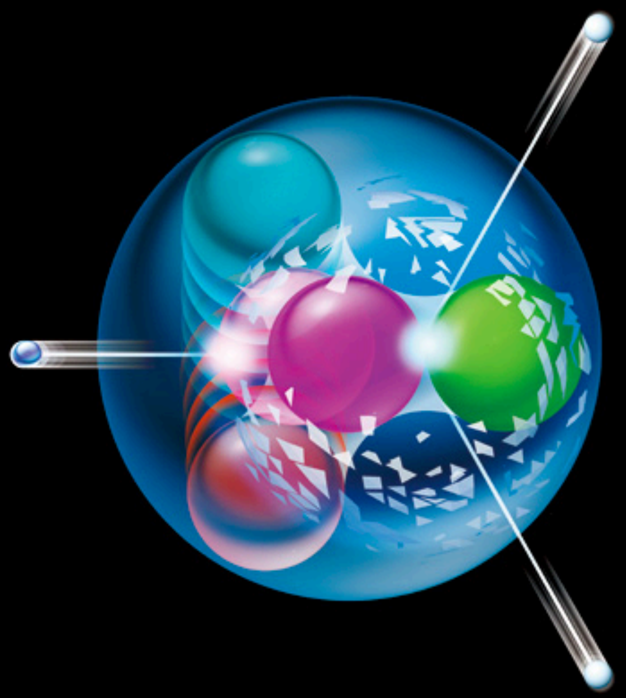


Astrophysical Neutrinos

Solar, **supernova**, and **supernova relic** neutrinos will be explored for astronomical research.

Rare Decays

Rare processes such as p**roton decay** or **neutron decay** processes that violate baryon number will be searched



Kamioka"NDE"

Nucleon Decay Experiment
Neutrino Detection Experiment

Kamiokande
(1983-1996)

3kton

20% coverage
with 50cm PMT

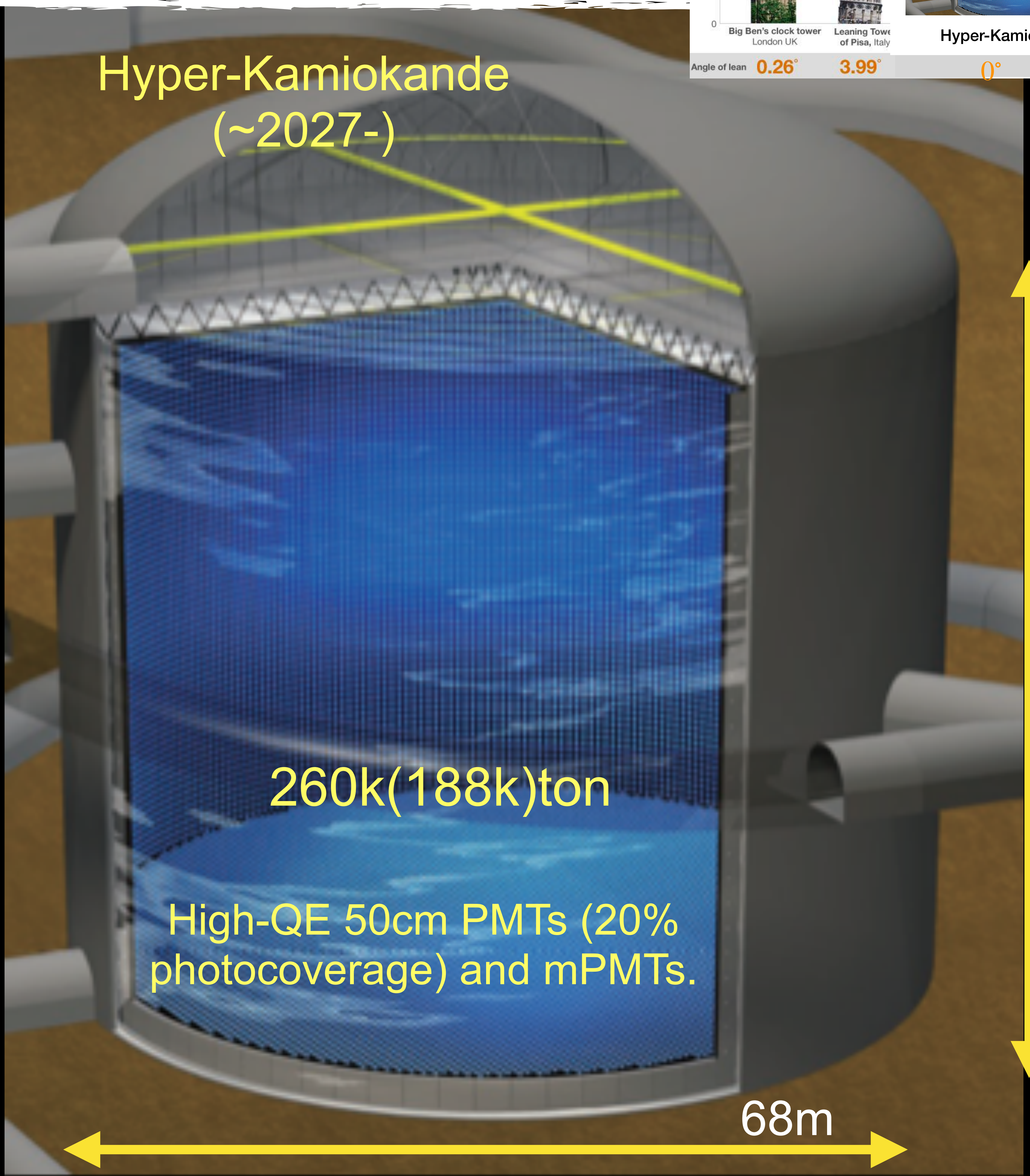
20x

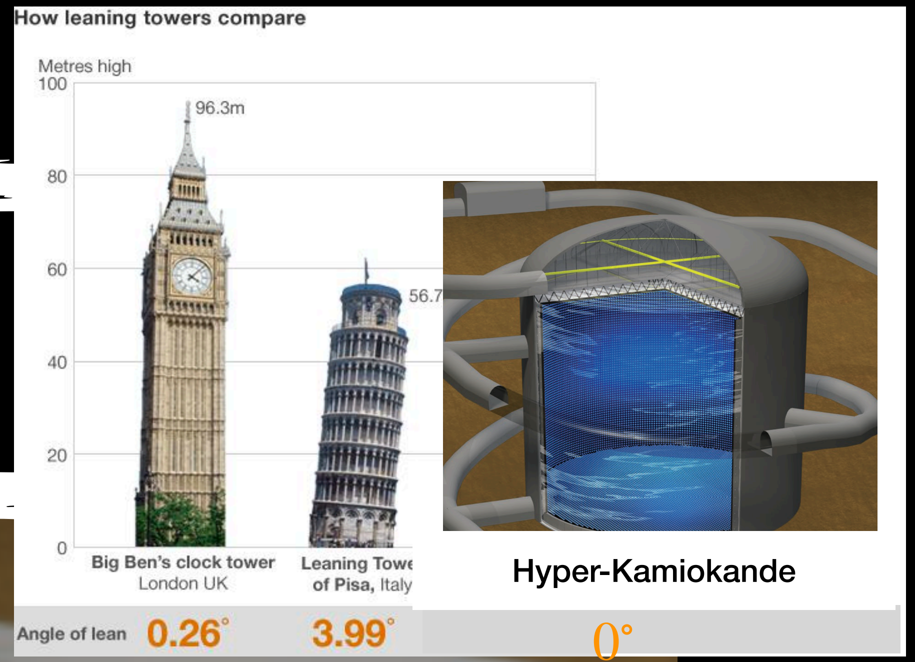
Super-Kamiokande
(1996-)

50k(22.5k)ton

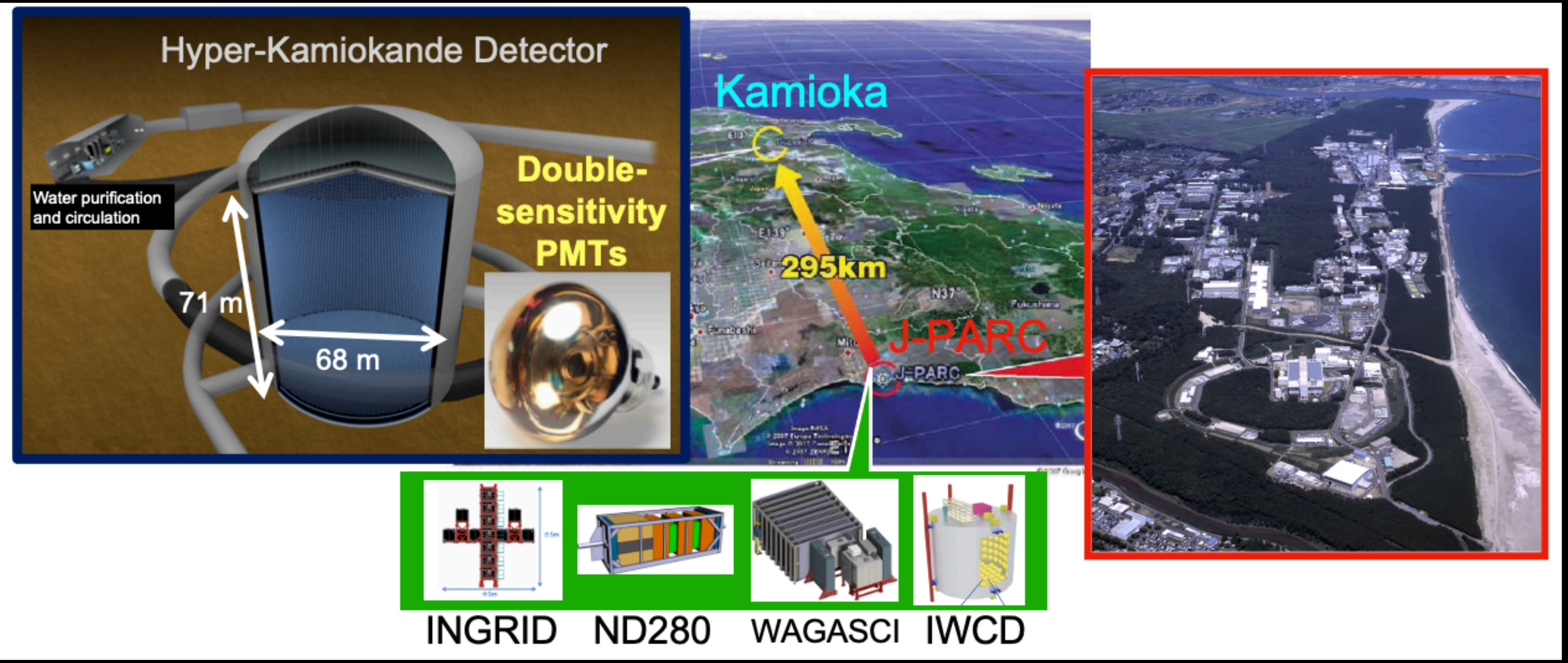
40% coverage
with 50cm PMT

8.4x

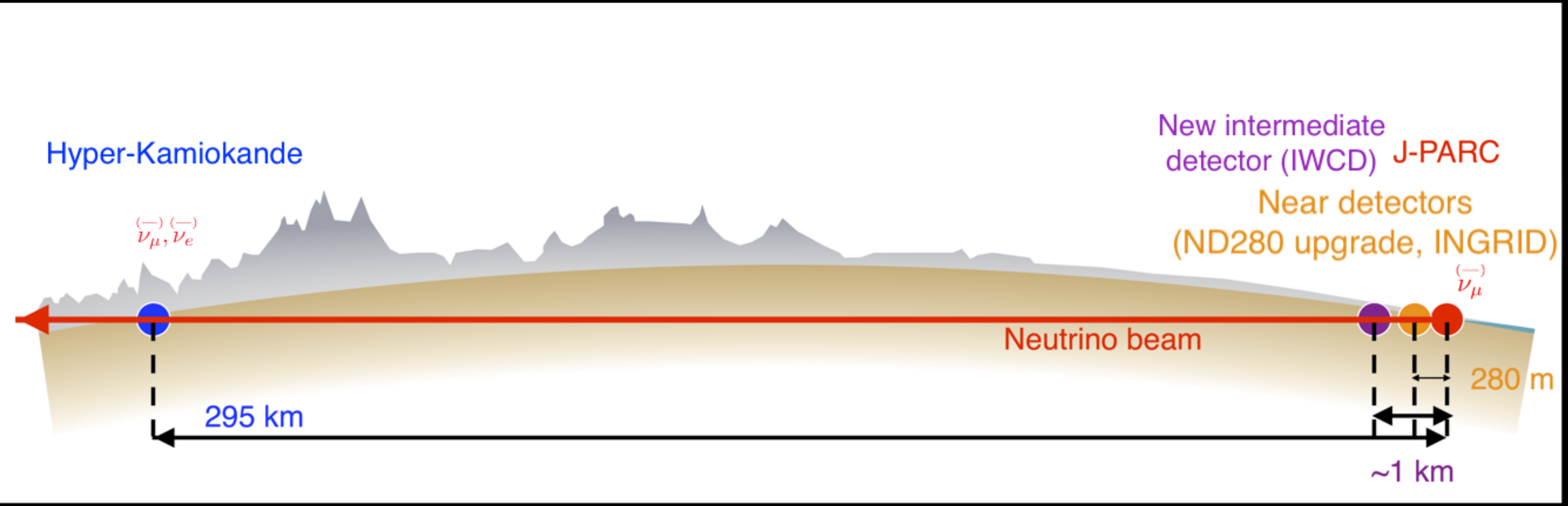


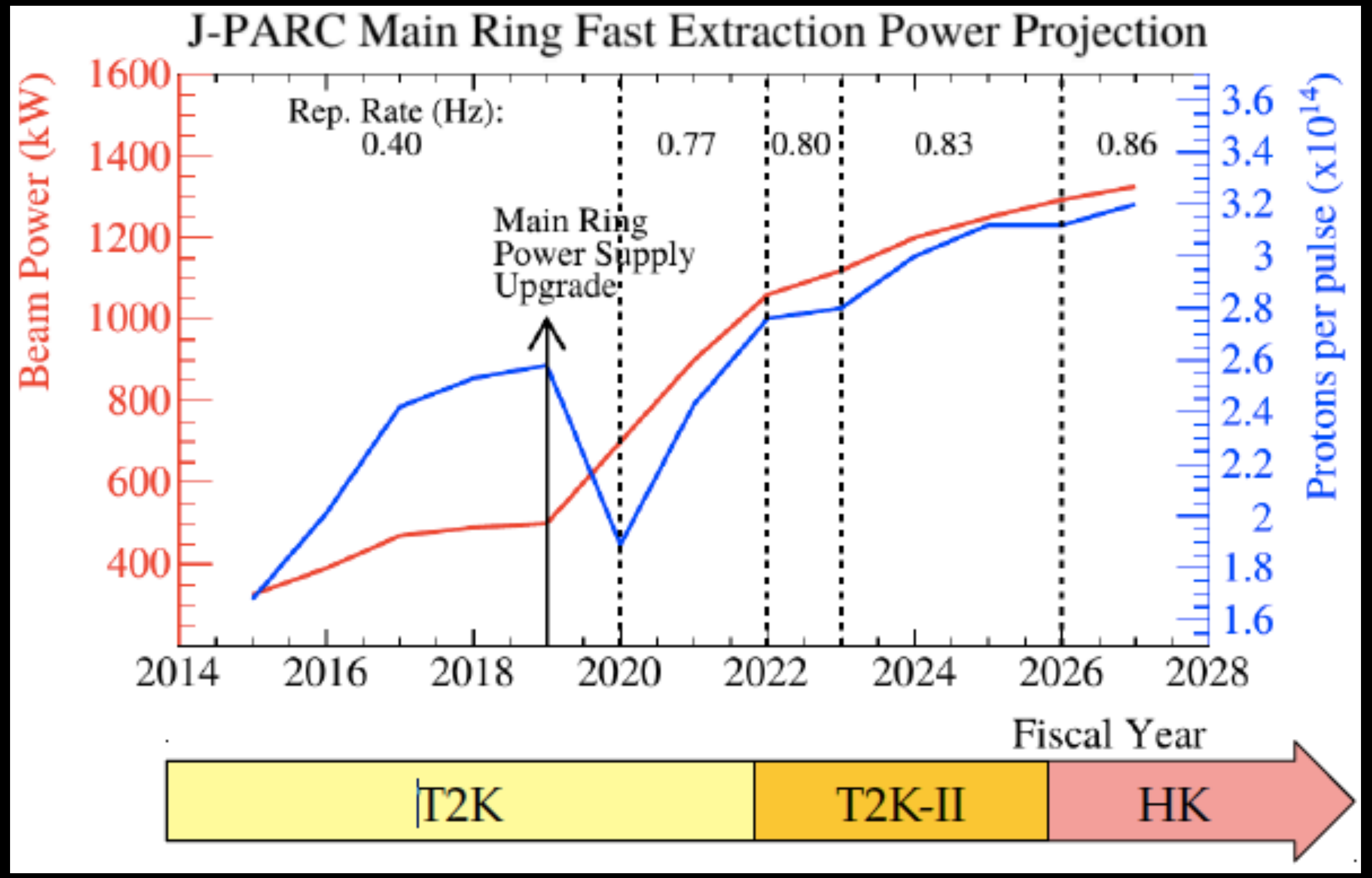


Hyper-Kamiokande Experiment



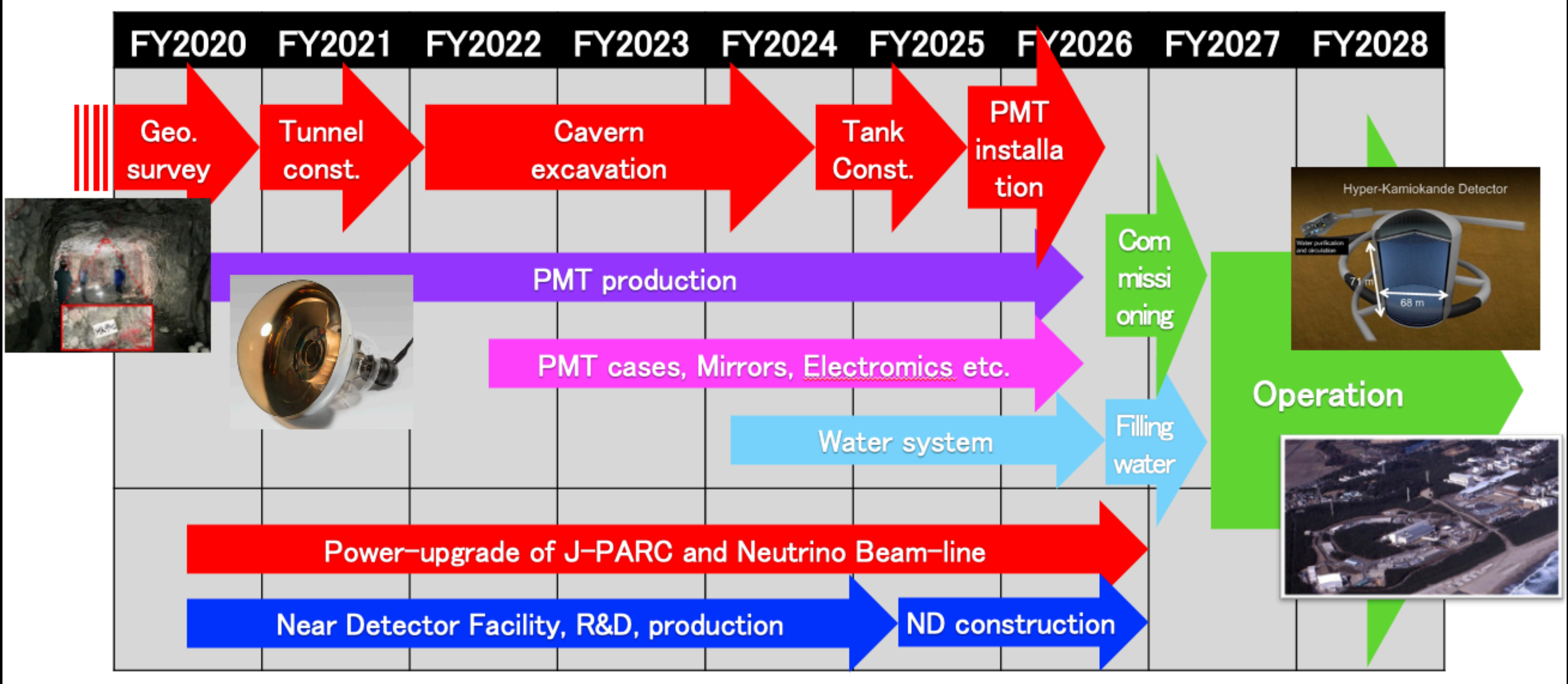
- Hyper-K detector with **8.4 times larger fiducial mass** (190 kiloton) than Super-K with **double-sensitivity PMTs**
- New (IWCD) and upgraded (@280m) near detectors to control systematic error.
- J-PARC neutrino beam will be upgraded from 0.5 to 1.3MW (**x2.5** higher than current T2K beam power)



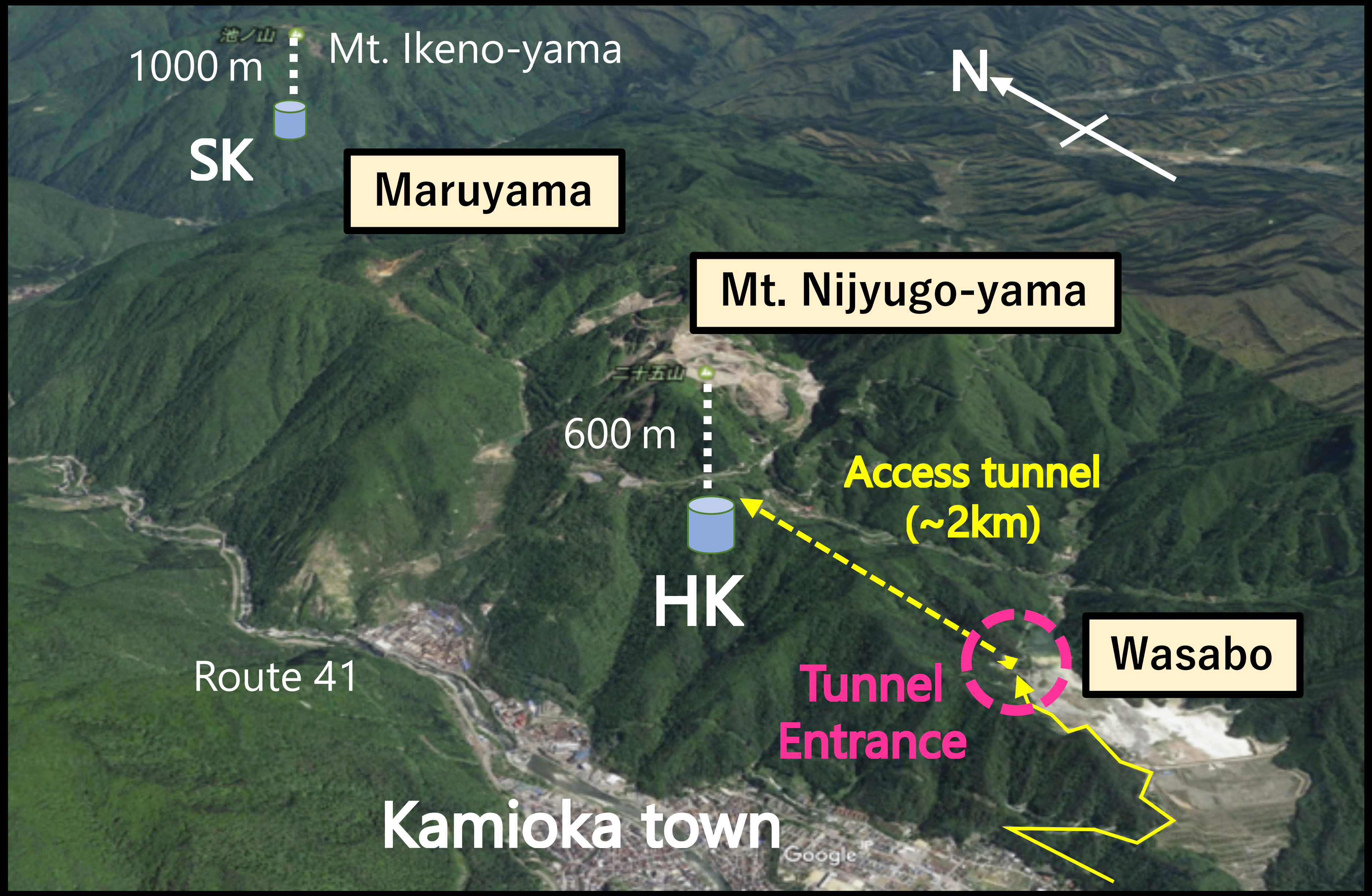


Hyper-K Schedule

- 7 years construction from year 2020; 5 years excavation + subsequent 2 years detector construction. Data taking from 2027.
- We will start water filling and detector commissioning in Dec.-2026.
- The participating countries need to be ready to start installation of their components by Dec.-2025 (We have ~5 years for preparation).



Entrance Yard Construction



- Construction of entrance yard in Wasabo is completed.
- Construction of the waste water treatment facility at the entrance yard.

Access Tunnel Excavation has Started!

- Cavern excavation started in May 2021
- Groundbreaking ceremony on May 28 2021
- Blasting started. Day/night excavation started

HYPER-K COLLABORATION:

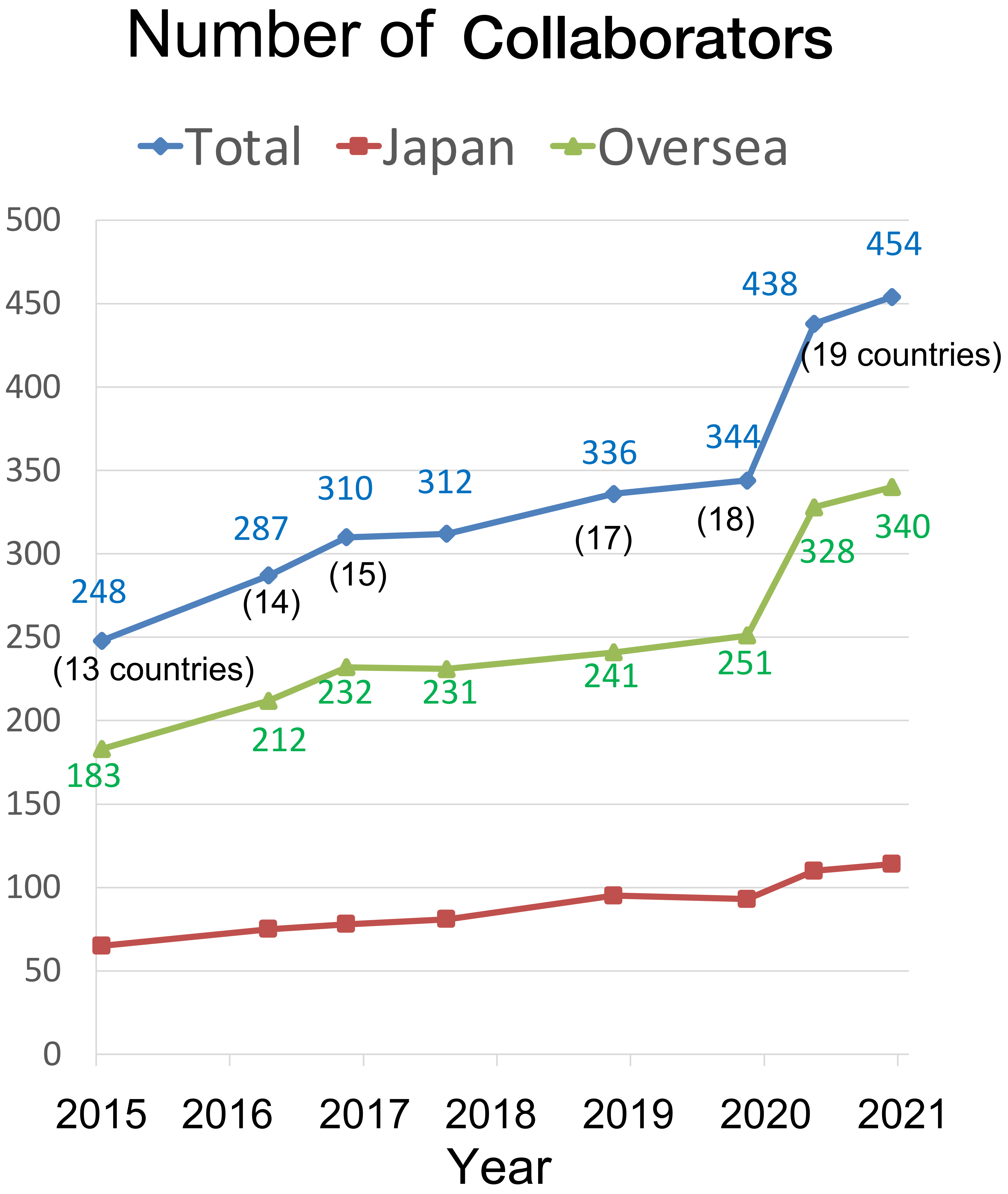
19 countries, 93 institutes, ~450 people as of May 2021, still growing

Collaborating Institutes

Europe	260 members
Armenia	3
Czech	3
France	28
Germany	1
Italy	53
Poland	37
Russia	21
Spain	26
Sweden	5
Switzerland	5
Ukraine	4
UK	74

Asia	142 members
India	10
Korea	18
Japan	114

Americas	52 members
Brazil	3
Canada	29
Mexico	11
USA	9



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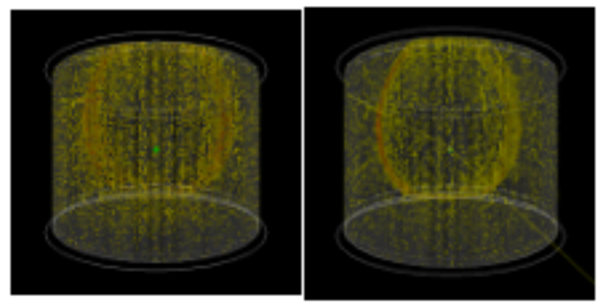
19 countries, 93 institutes, ~450 people as of May 2021, growing

Hyper-K Experiment (Far Detector)



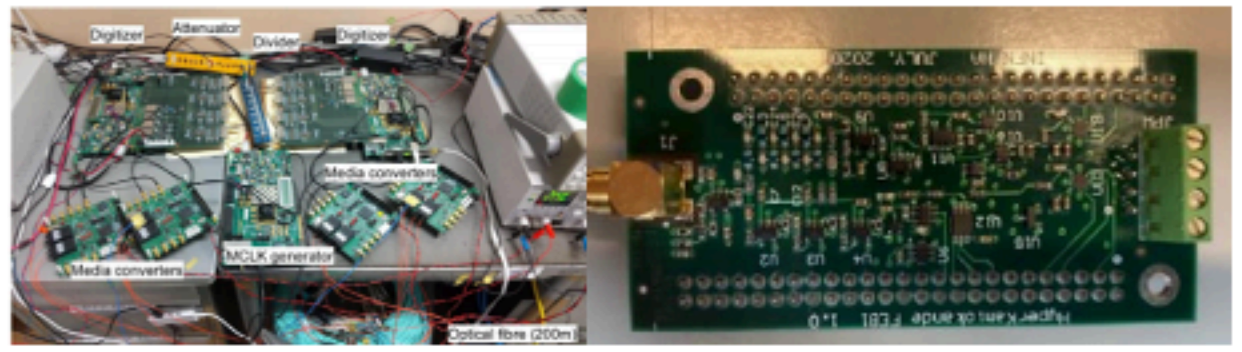
Neutrino interactions

Water system:
1st stage system
2nd stage system for 155 + 155 m^3/hour

Photosensors

Photosensors:
PMT
Cover
Light Collection
Coils…

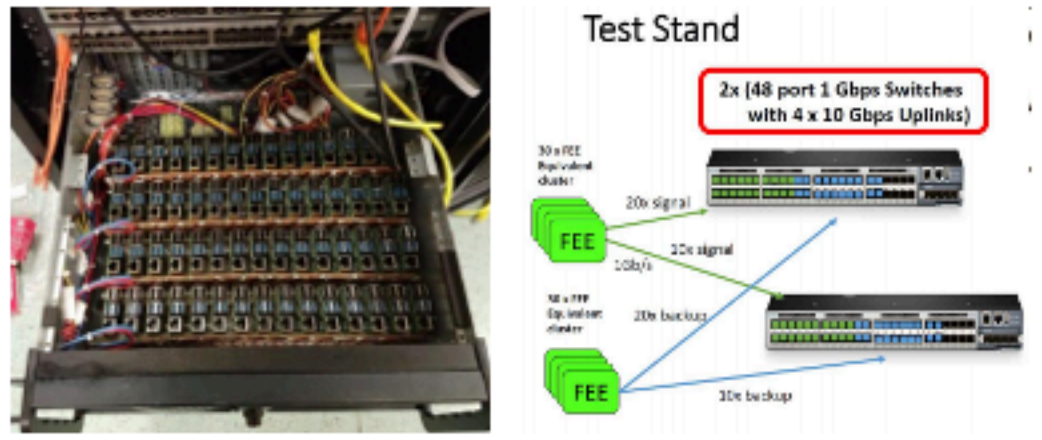
Half of ID PMTs



Electronics

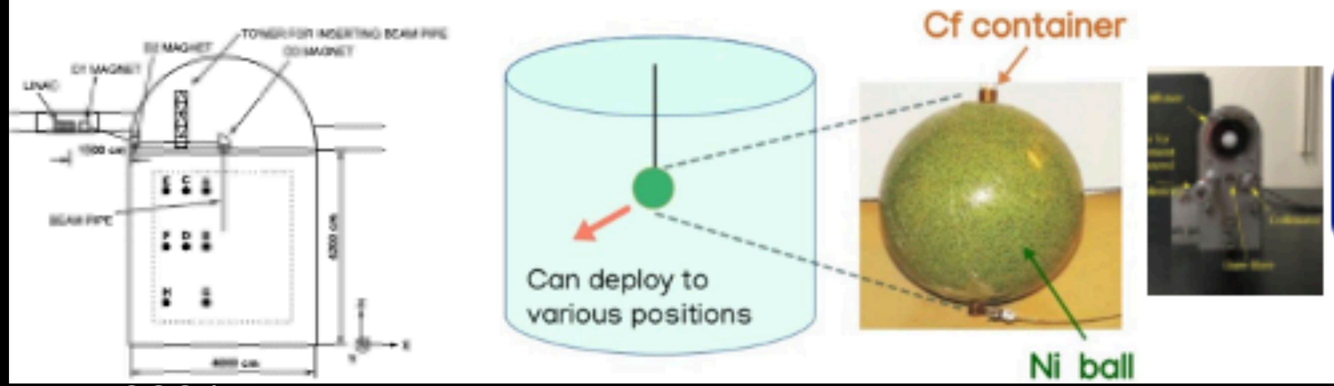
Electronics:
Digitizer
Boards
High Voltage Supply
Network
Waterproof'd box, connectors, cabling…

Part of ID Electronics



Data Acquisition and triggering

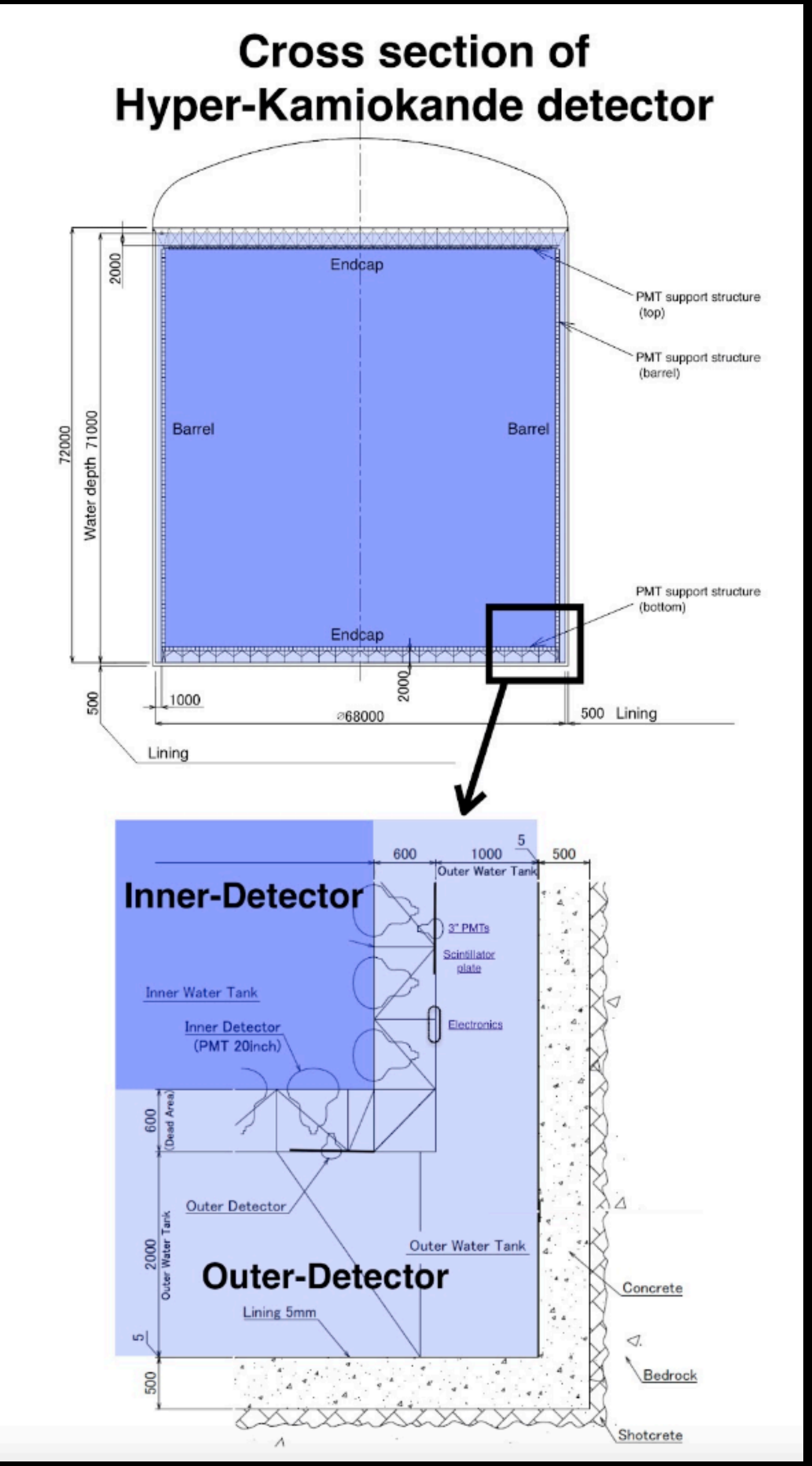
DAQ & Triggering:
Readout
Event builder
Software Triggers



Calibration

Calibration:
Electron LINAC
Deployment system
Other RI sources, light sources et

Two components:
—Inner Detector (ID)
—Outer Detector (OD)



Hyper-K Detector Construction has Started

PMTs for the Inner Detector

	Super-K	Hyper-K
Number of PMTs	11,129 50cm PMTs	20,000 50cm PMTs (JPN) (+ additional PDs (Oversea))
Photo-sensitive Coverage	40 %	20 %
Single photon efficiency /PMT	~12%	~24%
Dark Rate /PMT	~4 kHz (Typical)	4 kHz (Average)
Timing resolution of 1 photon	~3 nsec	~1.5 nsec

2020/12 First six PMTs delivered to Kamioka

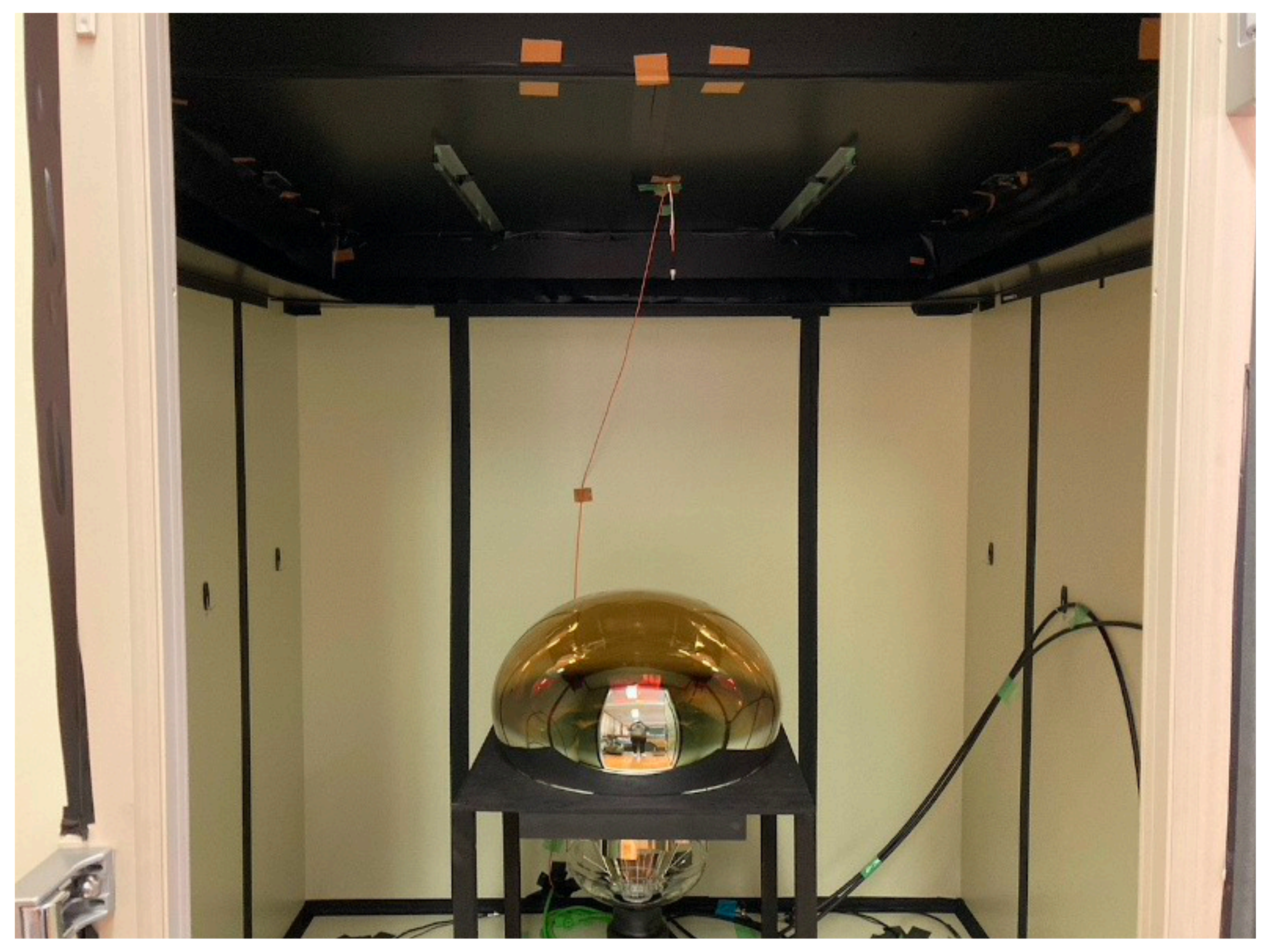
- Production has started on time for the 50cm PMTs with Box&Line dynode.
- 300 PMTs by March, 20,000 PMTs in total by 2026 according to the Japanese budget profile.

50cm PMT production

Storage

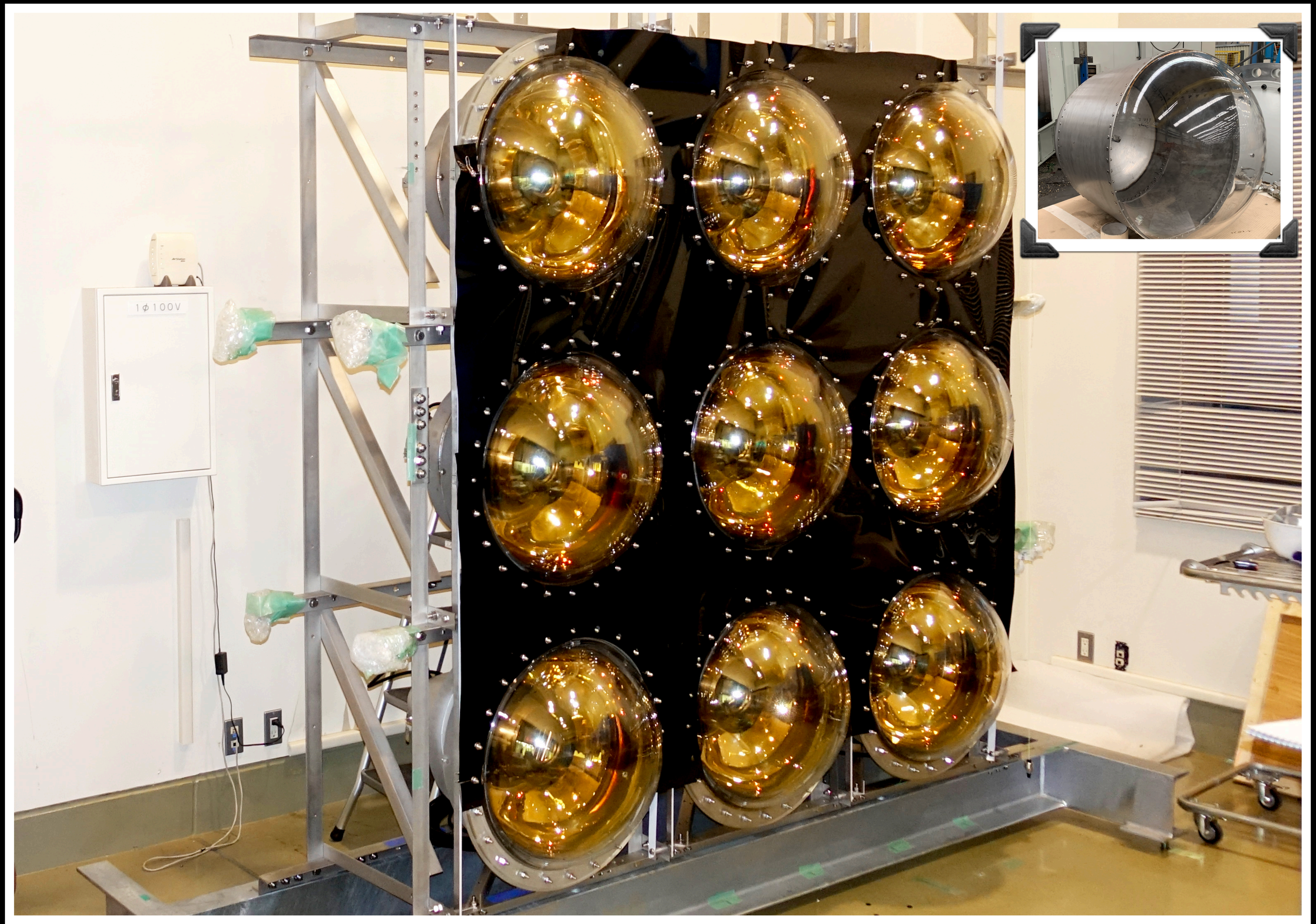
Visual inspection

Testing signal

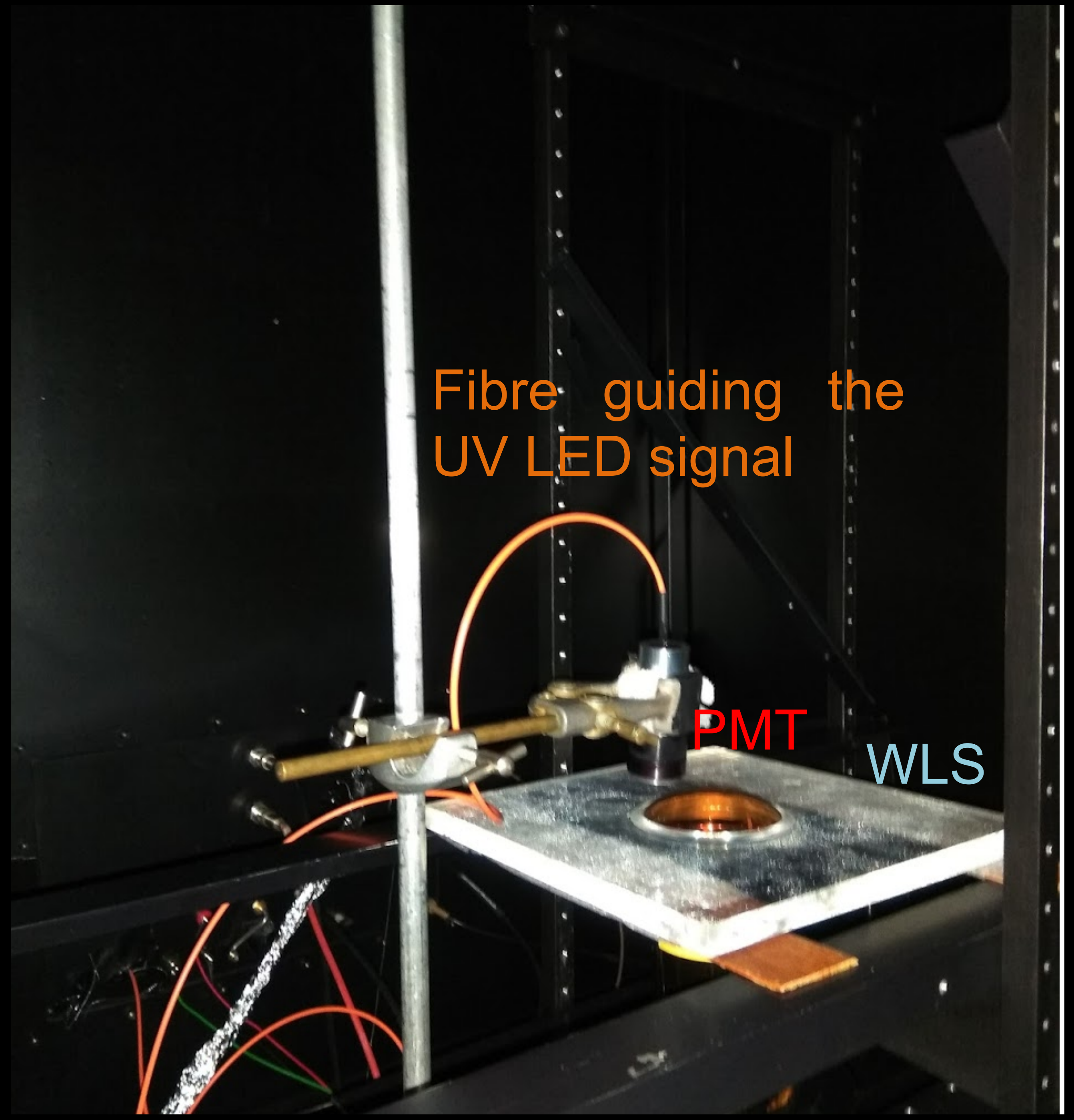


PMT Dark Rooms

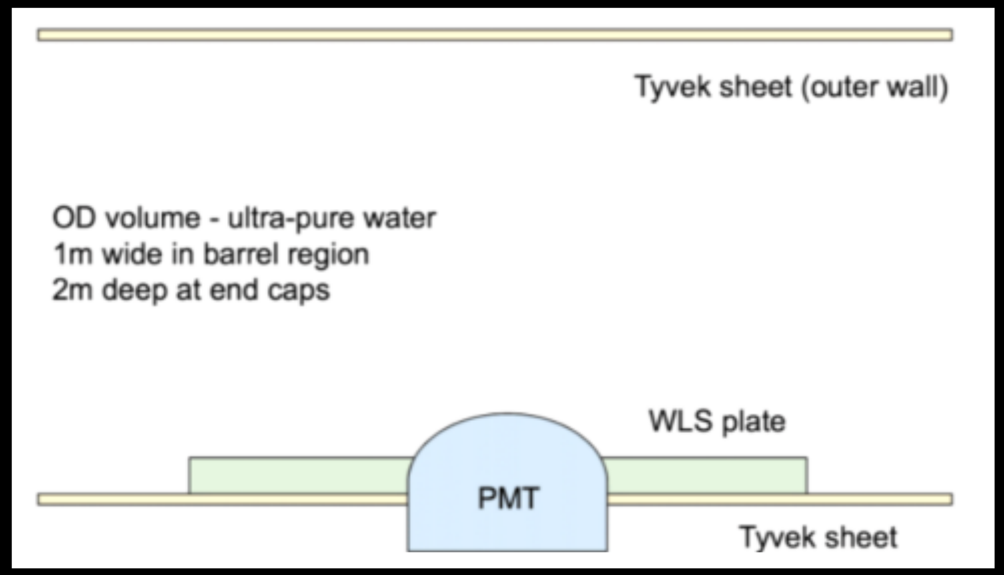
Photodetection System



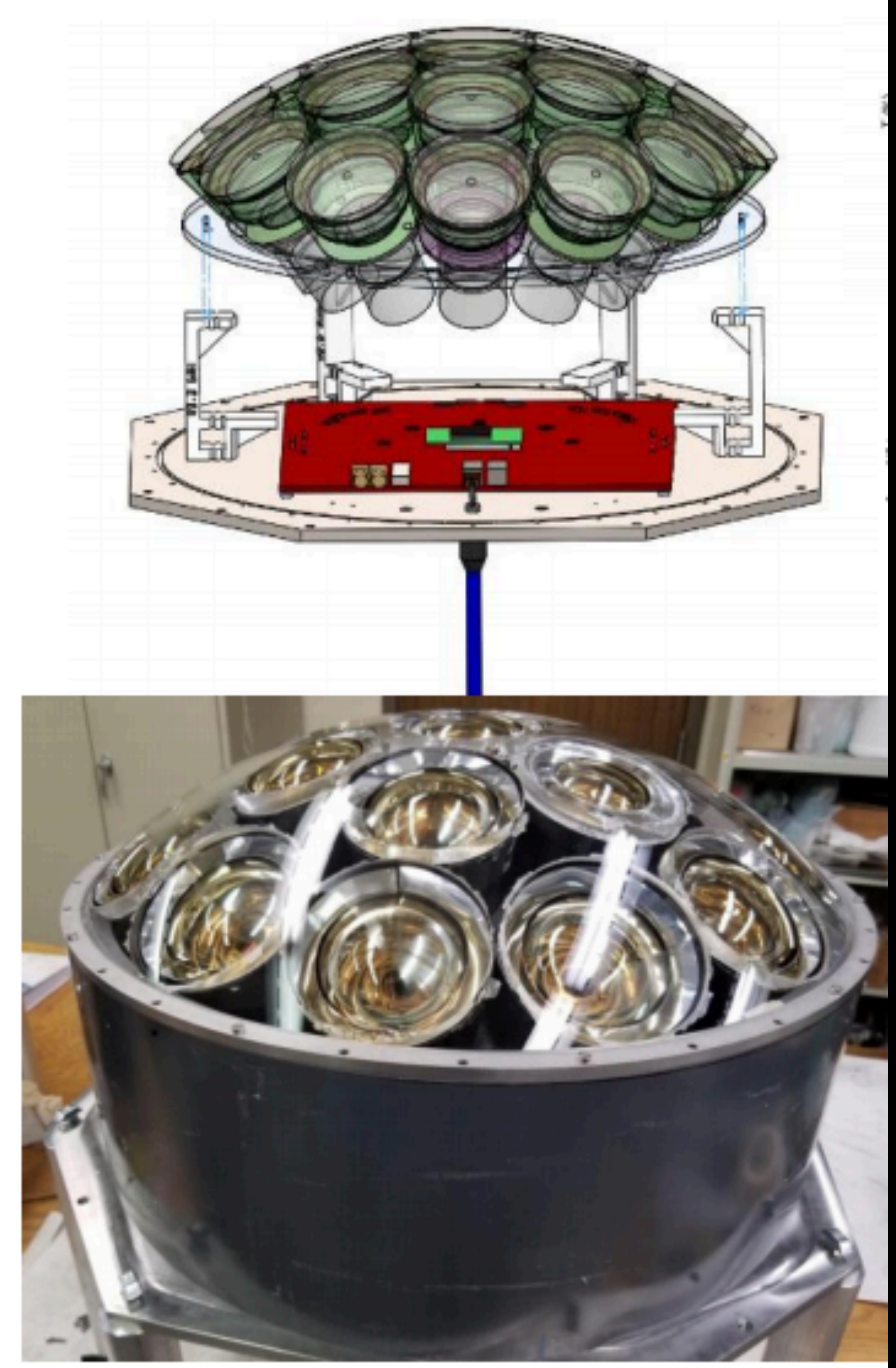
- 3 x 4 PMT frame mockup in Kashiwa from Jan/2020 to test installation
- Ongoing work on covers for 20” PMTs. Further R&D on material test, fabrication method, installation method, full validation under water pressure etc.



- Outer Detector: 3” PMTs, WLS plate, Tyvek

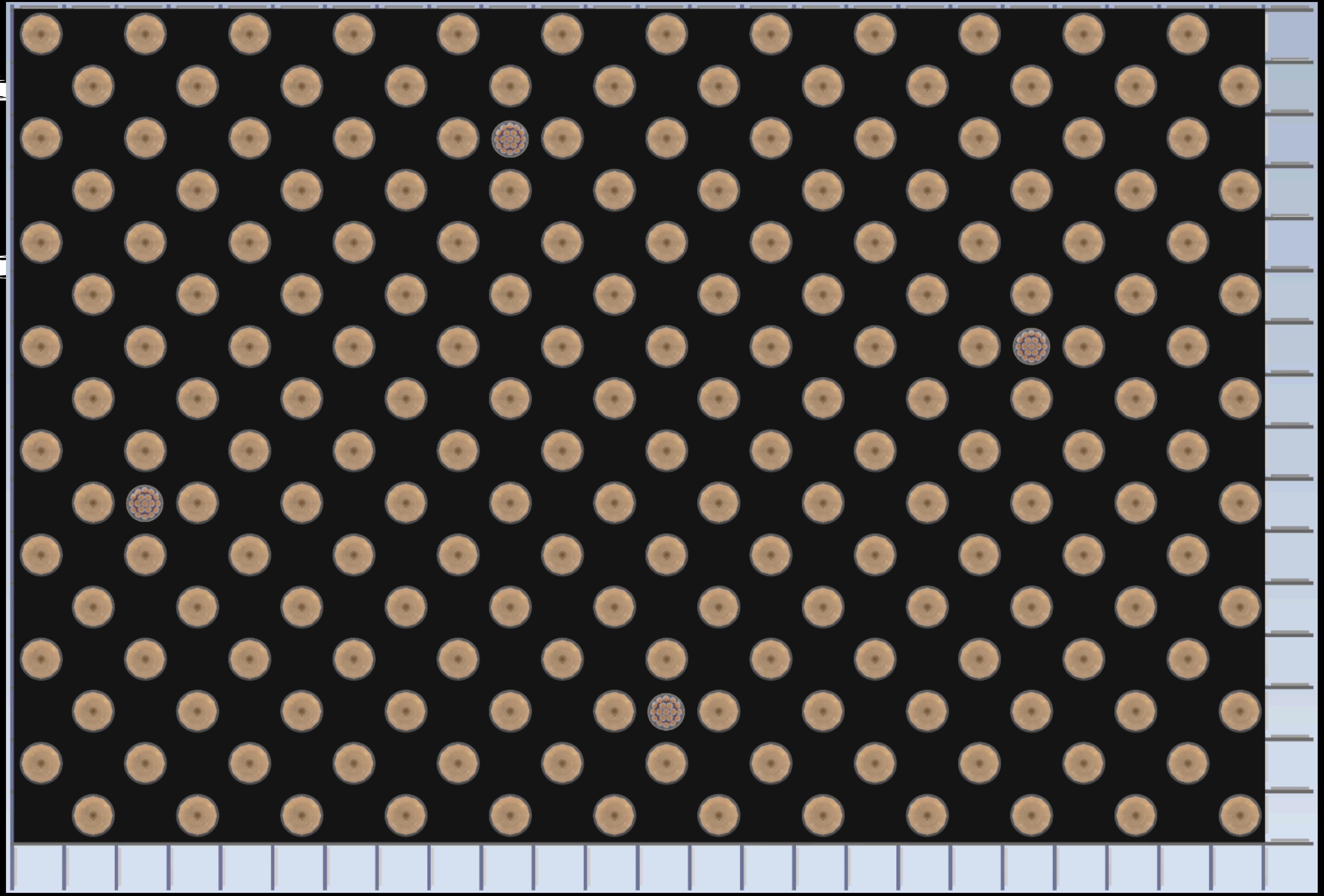


mPMTs



Prototype at TRIUMF

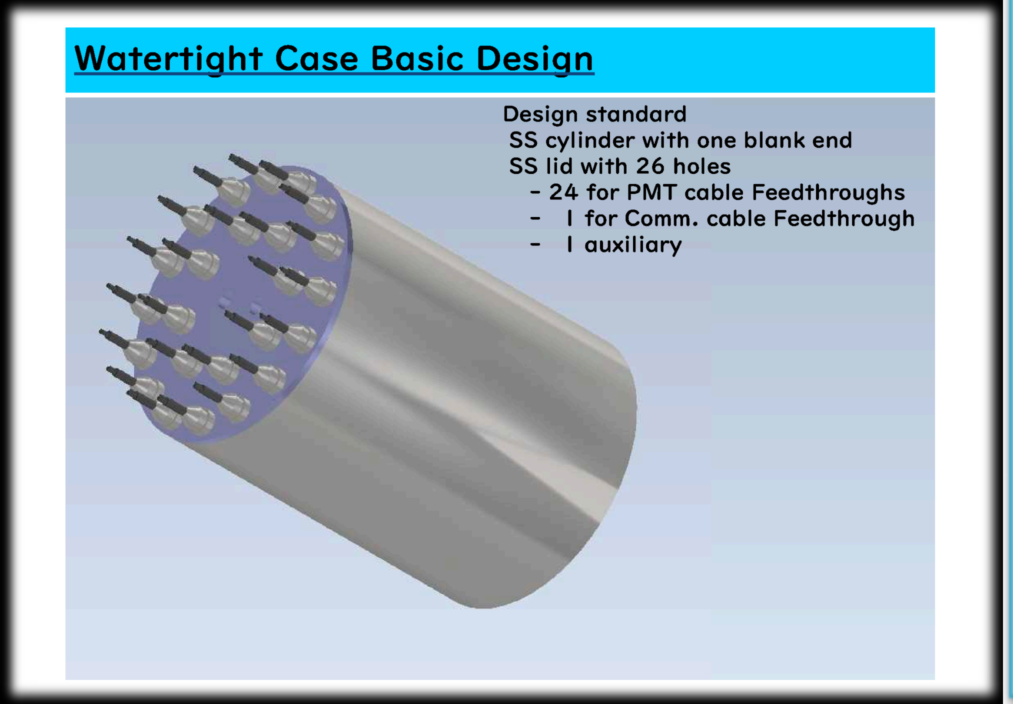
HK FD mPMT Electronics at INFN

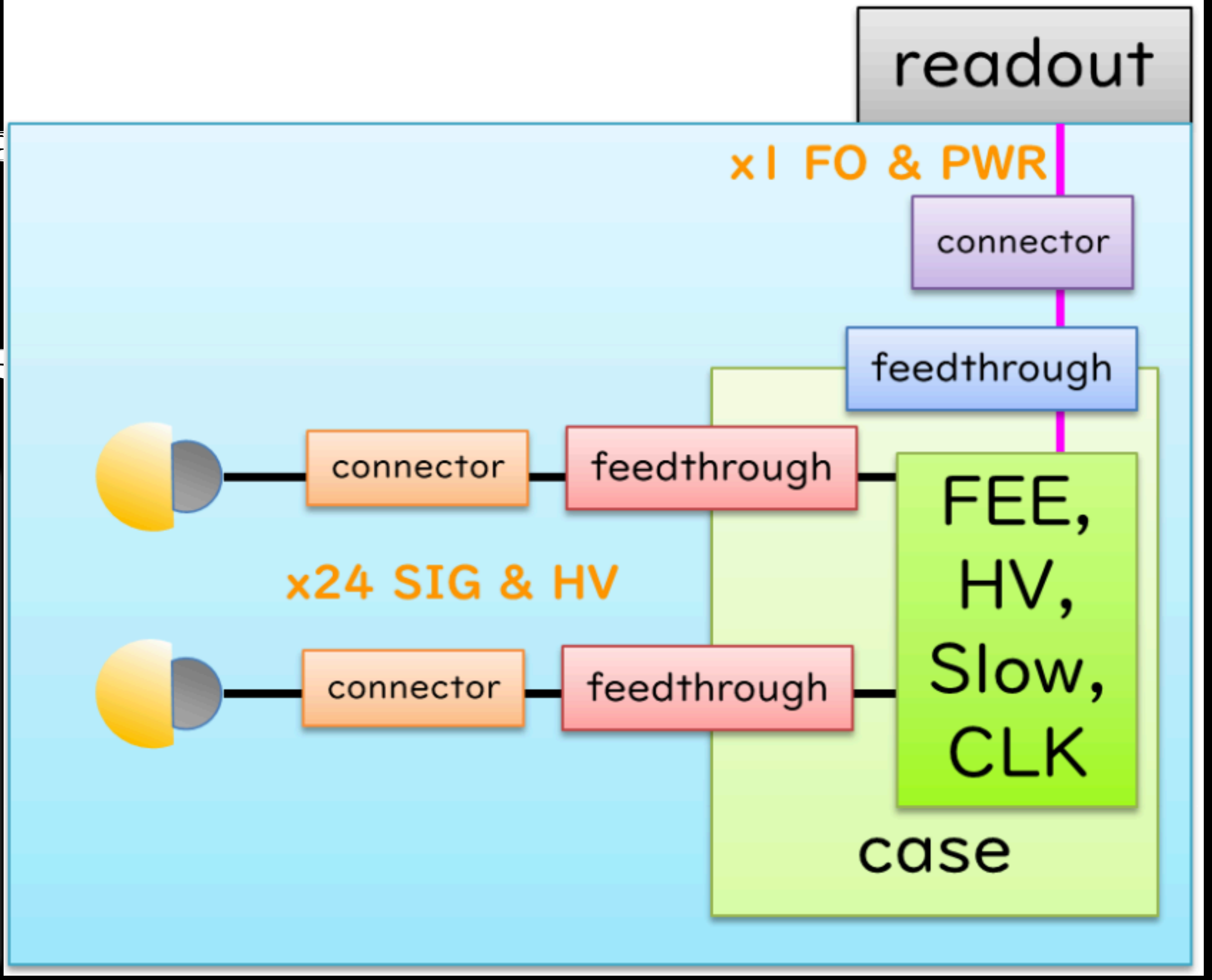


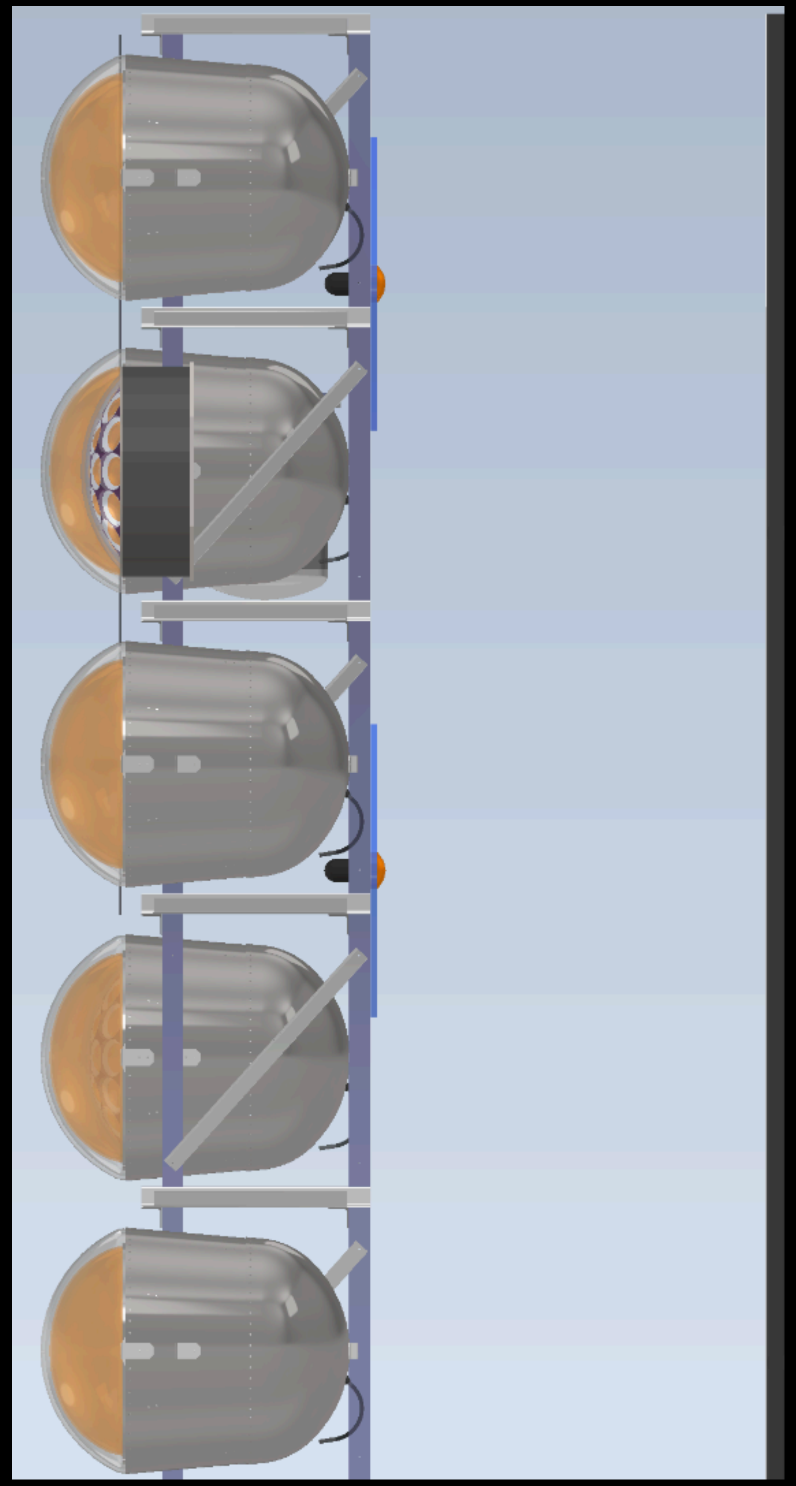
- Far Detector: hybrid configuration of 20” PMTs and mPMTs
- IWCD will be instrumented only with mPMTs.
- mPMT is a vessel which houses and protects an array of 19 3” PMTs:
  - improves the granularity and timing;
  - additional intrinsic directional information.
- Different constraints on far detector and IWCD mPMTs.

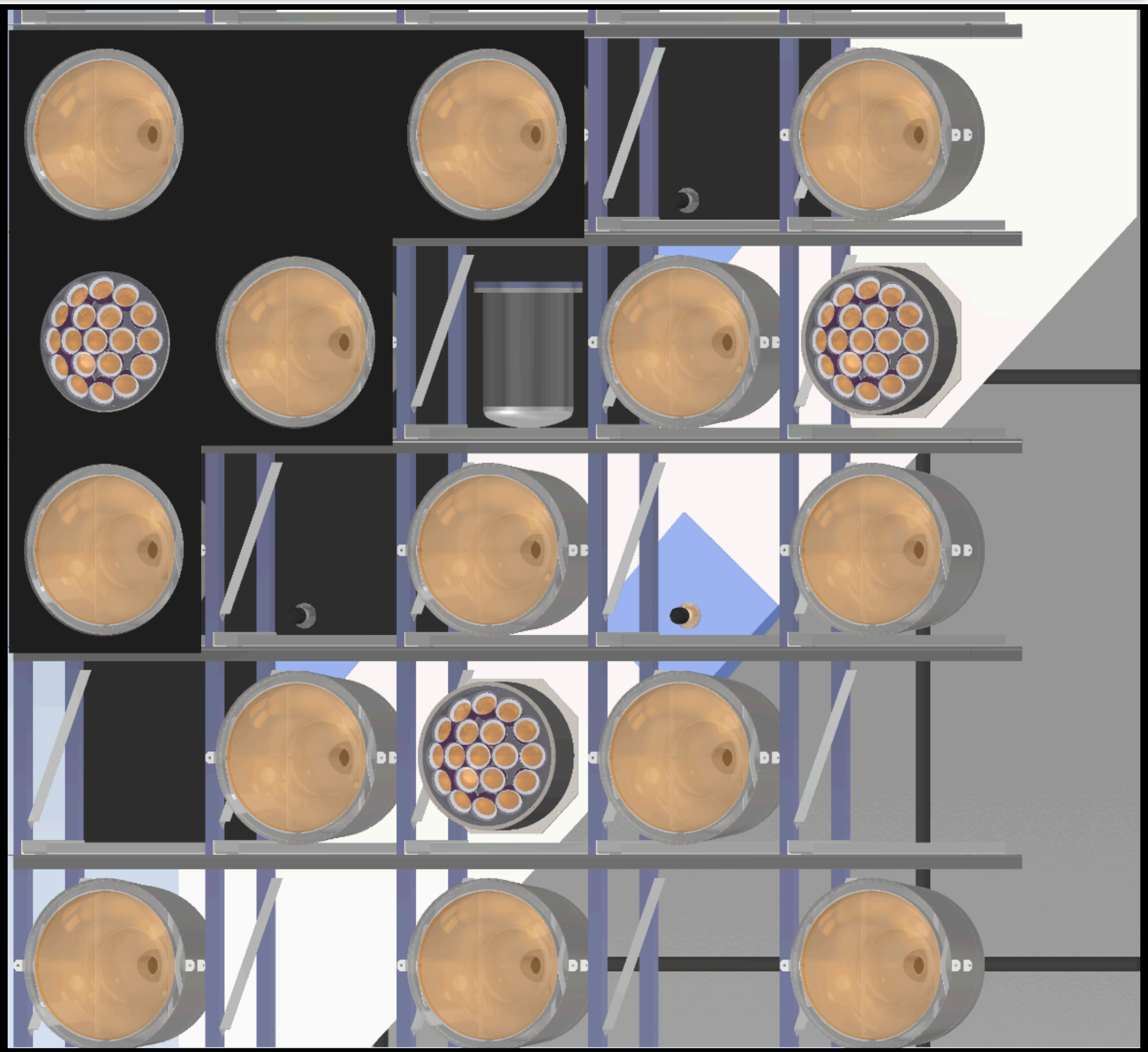
Electronics

- Critical components which define the HK detector performance and its systematics. There are many technical challenges as
  - Mechanical design of a box for water tightness
  - High performance, long life digitisers, high voltage PS, communication system, timing synchronisation system, and so on.



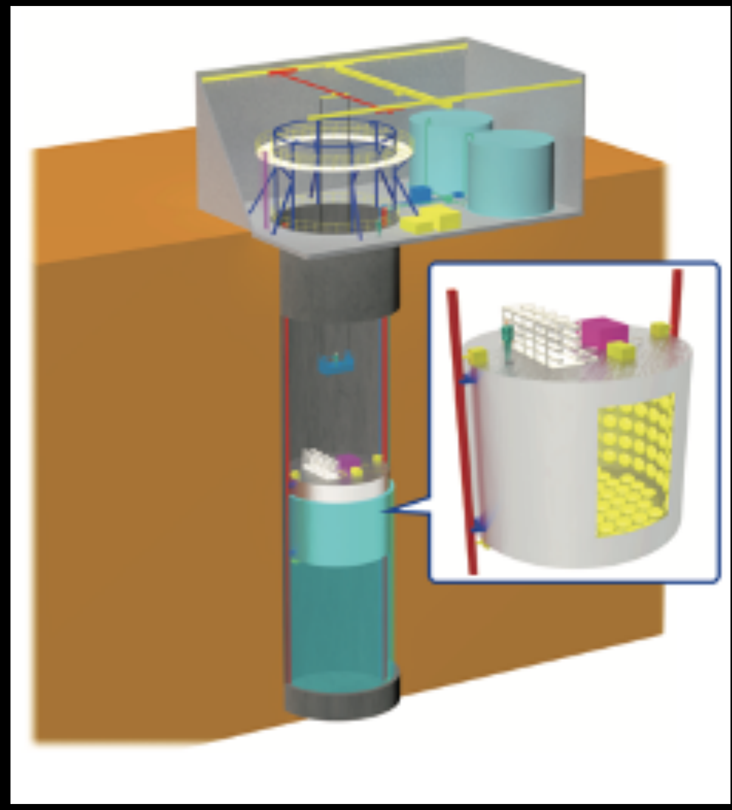






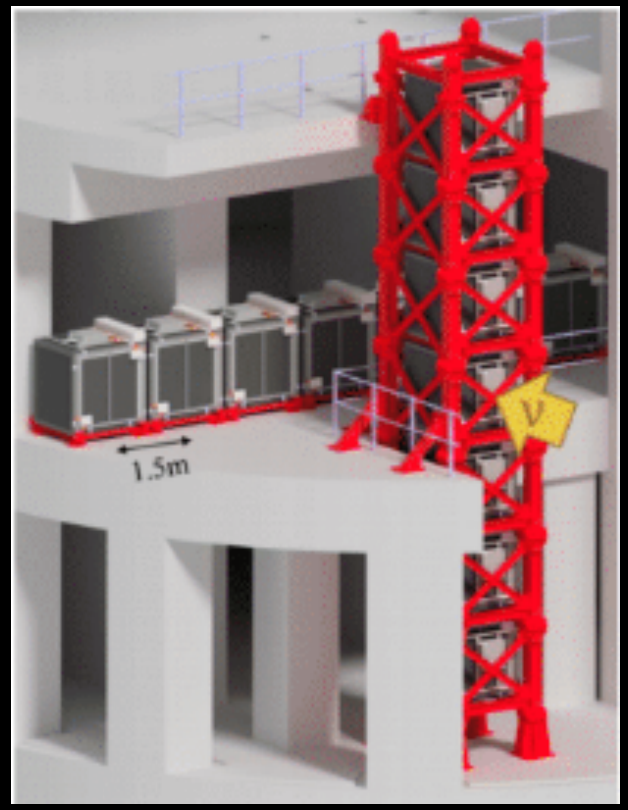
Suite of Near Detectors

- Critical components to precisely understand J-PARC beam and neutrino interactions.



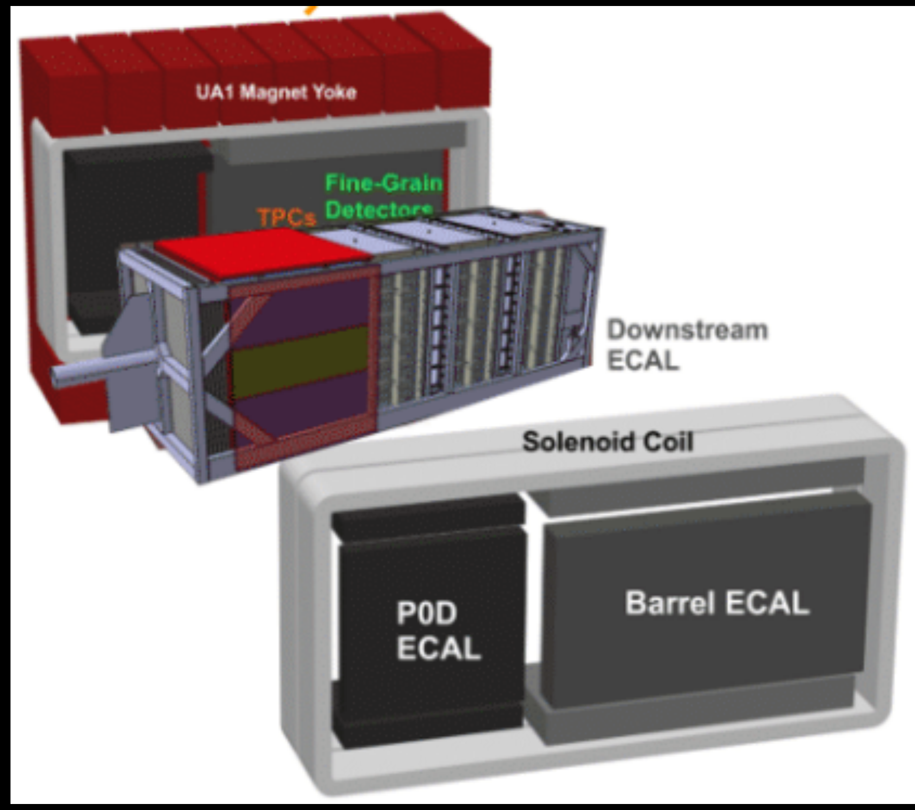
IWCD

Off-axis spanning water Cherenkov detector: intrinsic backgrounds, electron. (anti)neutrino cross-sections, E_ν vs. observables, H_2O target.



INGRID

On-axis detector: measure beam direction, monitor event rate.

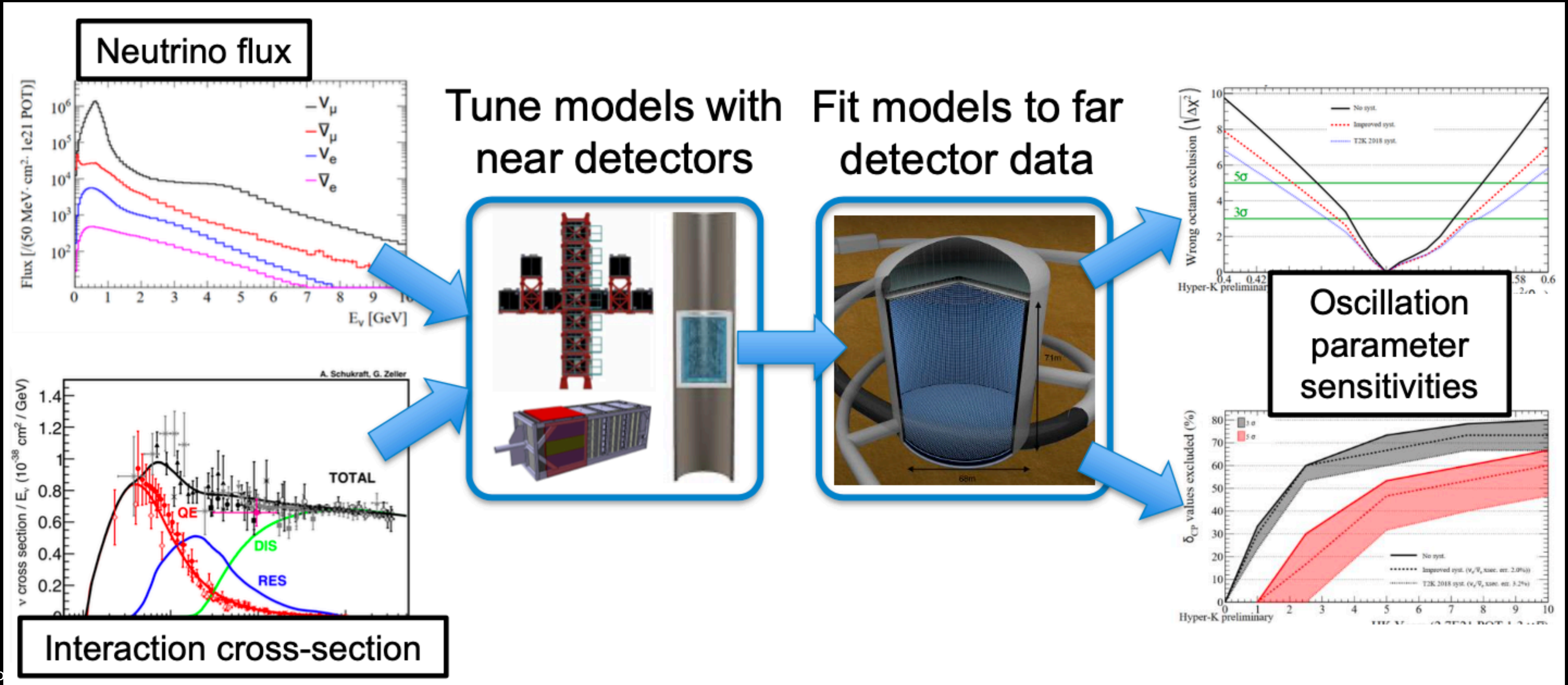


ND280

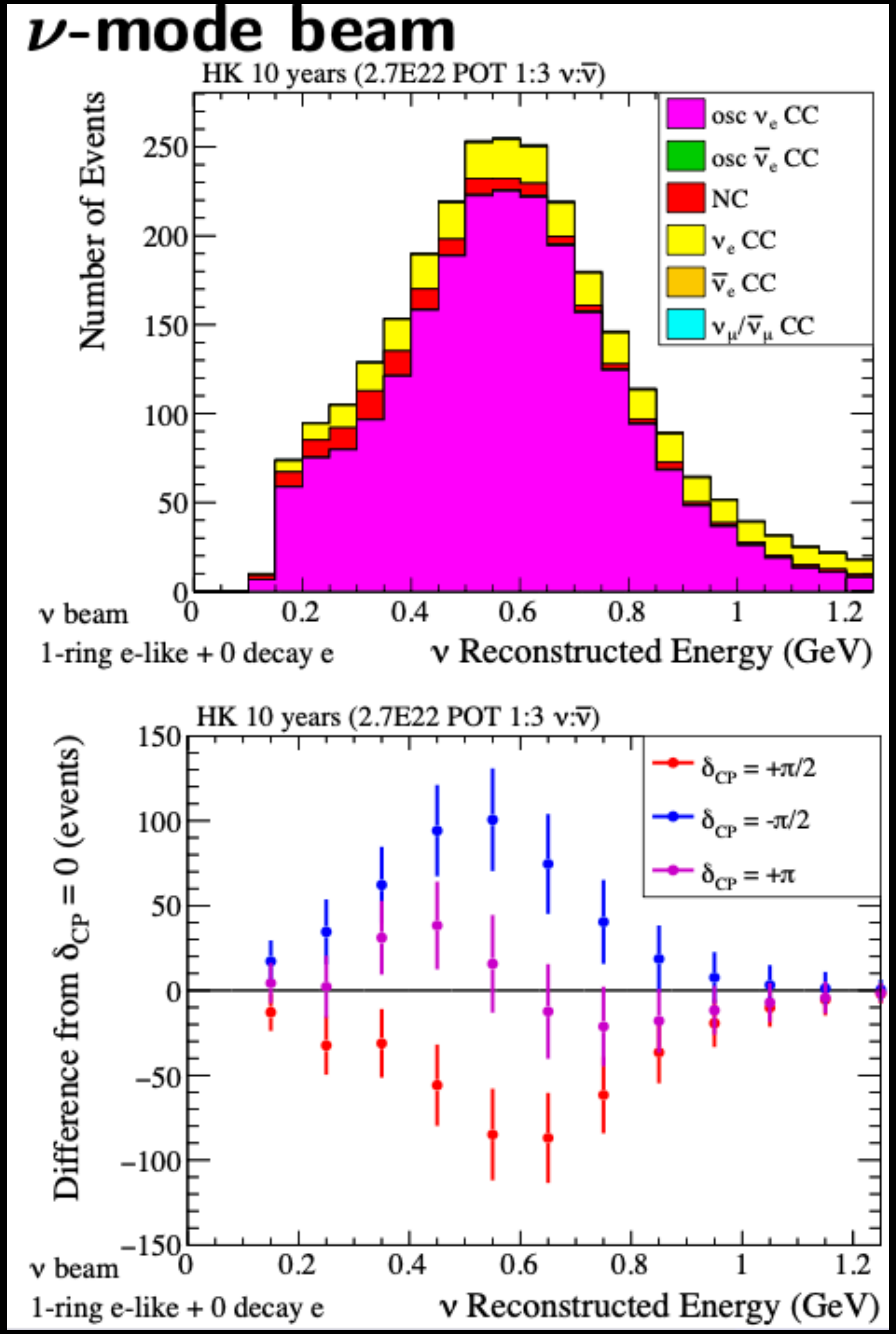
Off-axis magnetized tracker: charge separation (wrong-sign background), recoil system

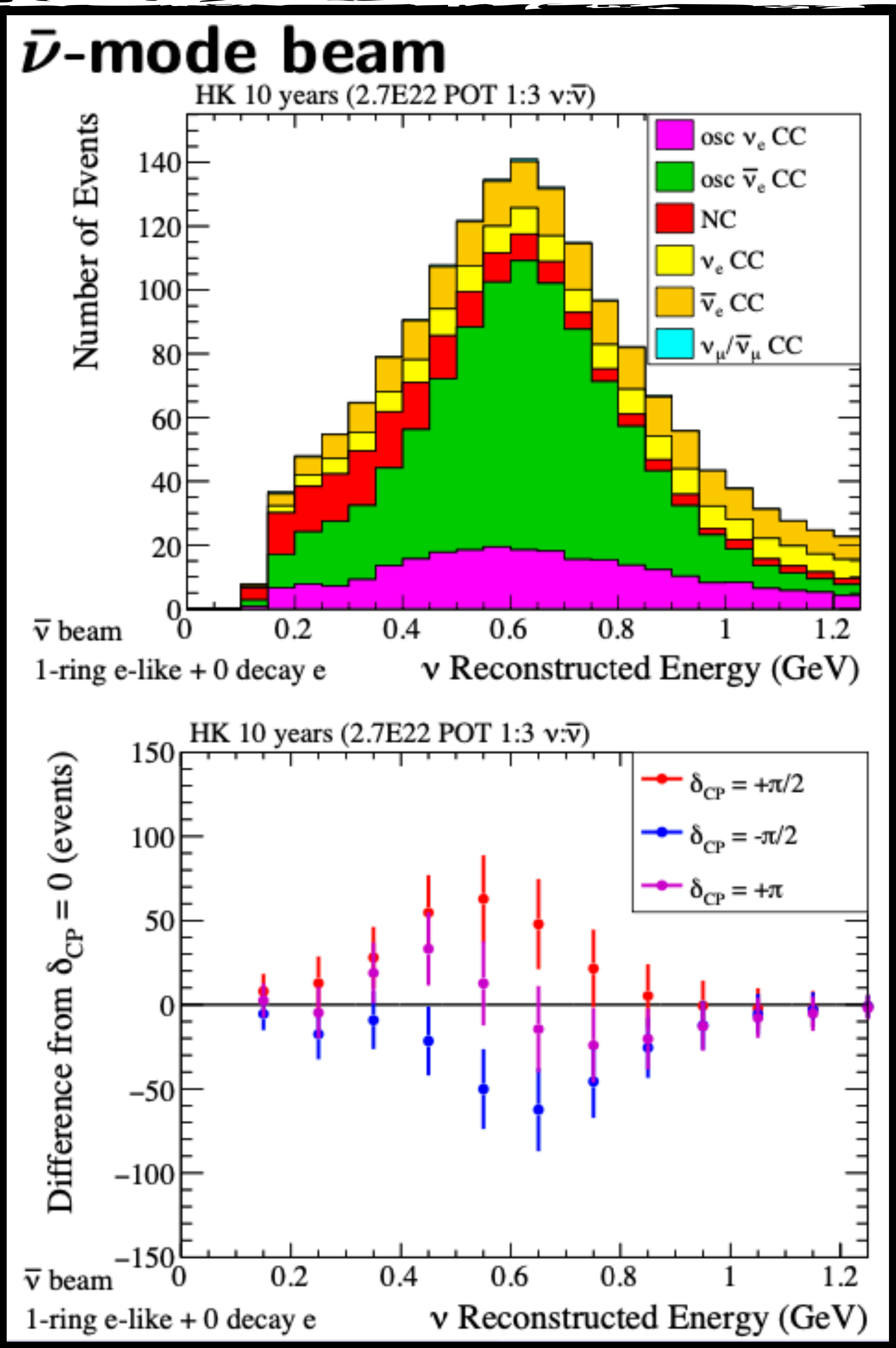
Hyper-K Beam Oscillation Analysis

- Based on T2K oscillation method.



Hyper-K Beam Oscillation Analysis





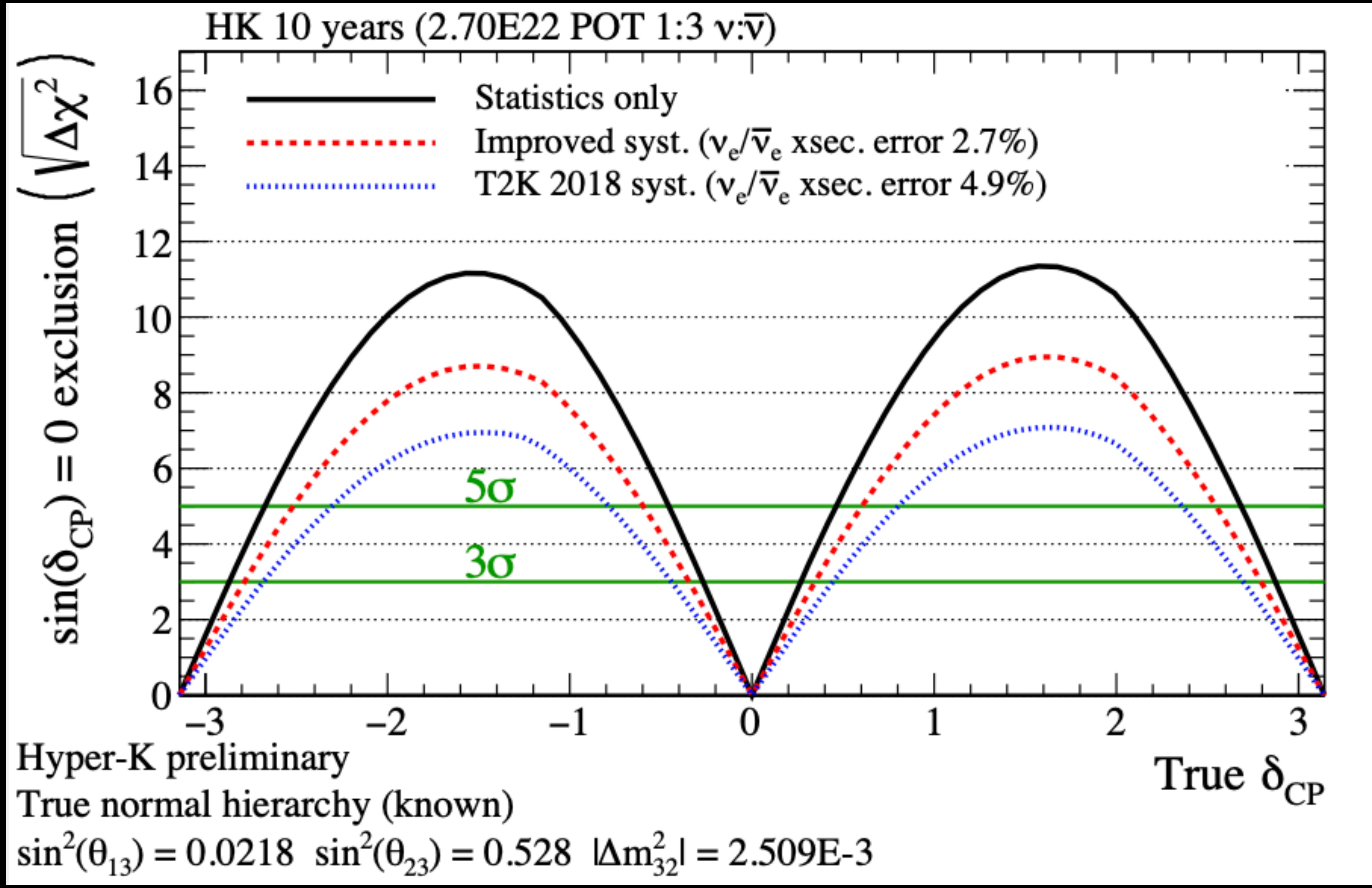
10 years (2.7E22 POT),
$\nu : \bar{\nu} = 1 : 3$

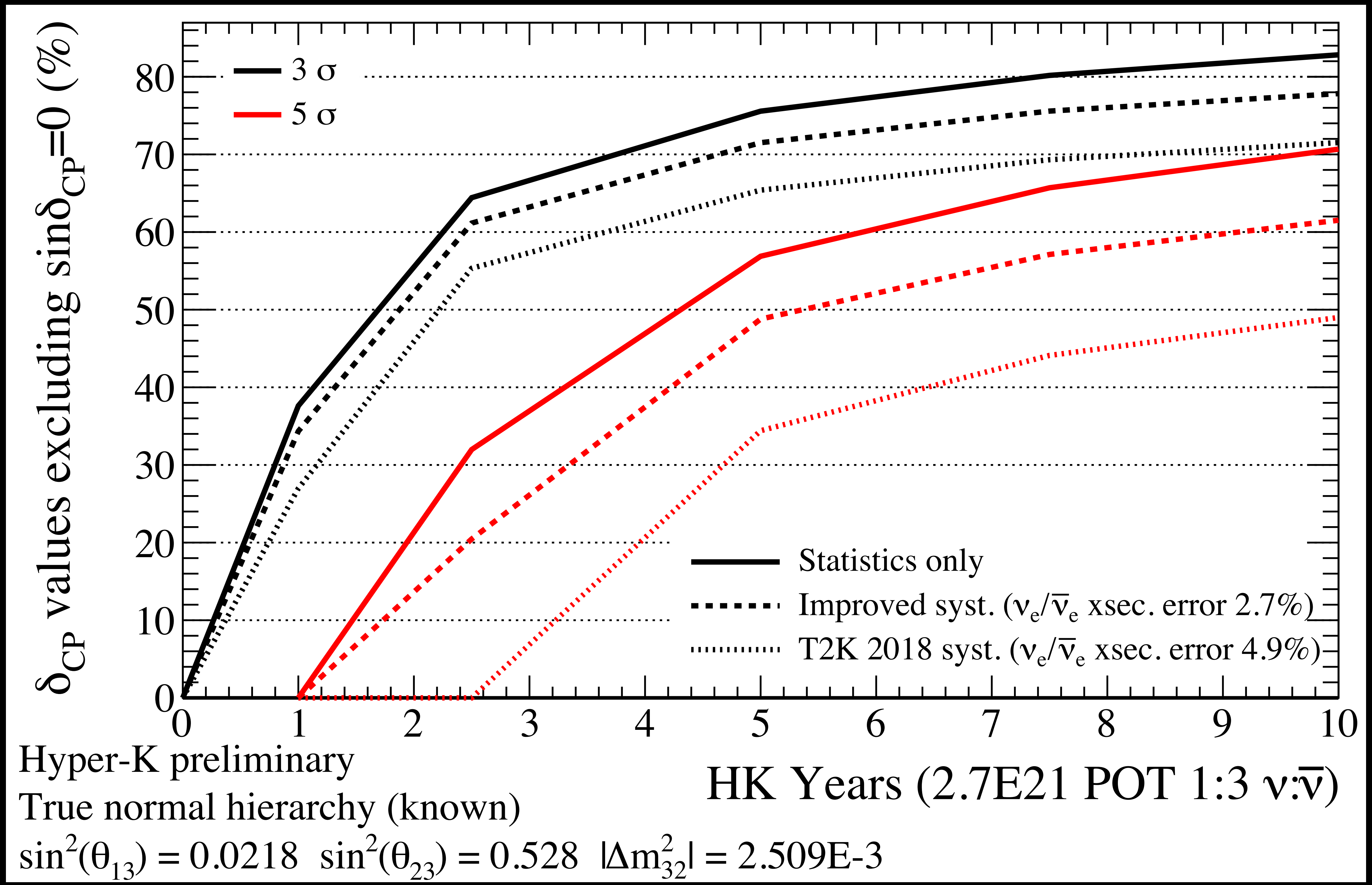
- Use Super-K MC, scaled to HK volume and exposure
- Expect approx:
  - 2300 ν_e events
  - 1900 $\bar{\nu}_e$ events
  - Assuming $\sin(\delta_{CP}) = 0$
- Difference between neutrino and antineutrino rates gives δ_{CP}

$\sin\delta_{CP} \neq 0$ *Sensitivity*

CP violation sensitivity with different assumptions of mass hierarchy knowledge. T2K 2018 systematic error is assumed.

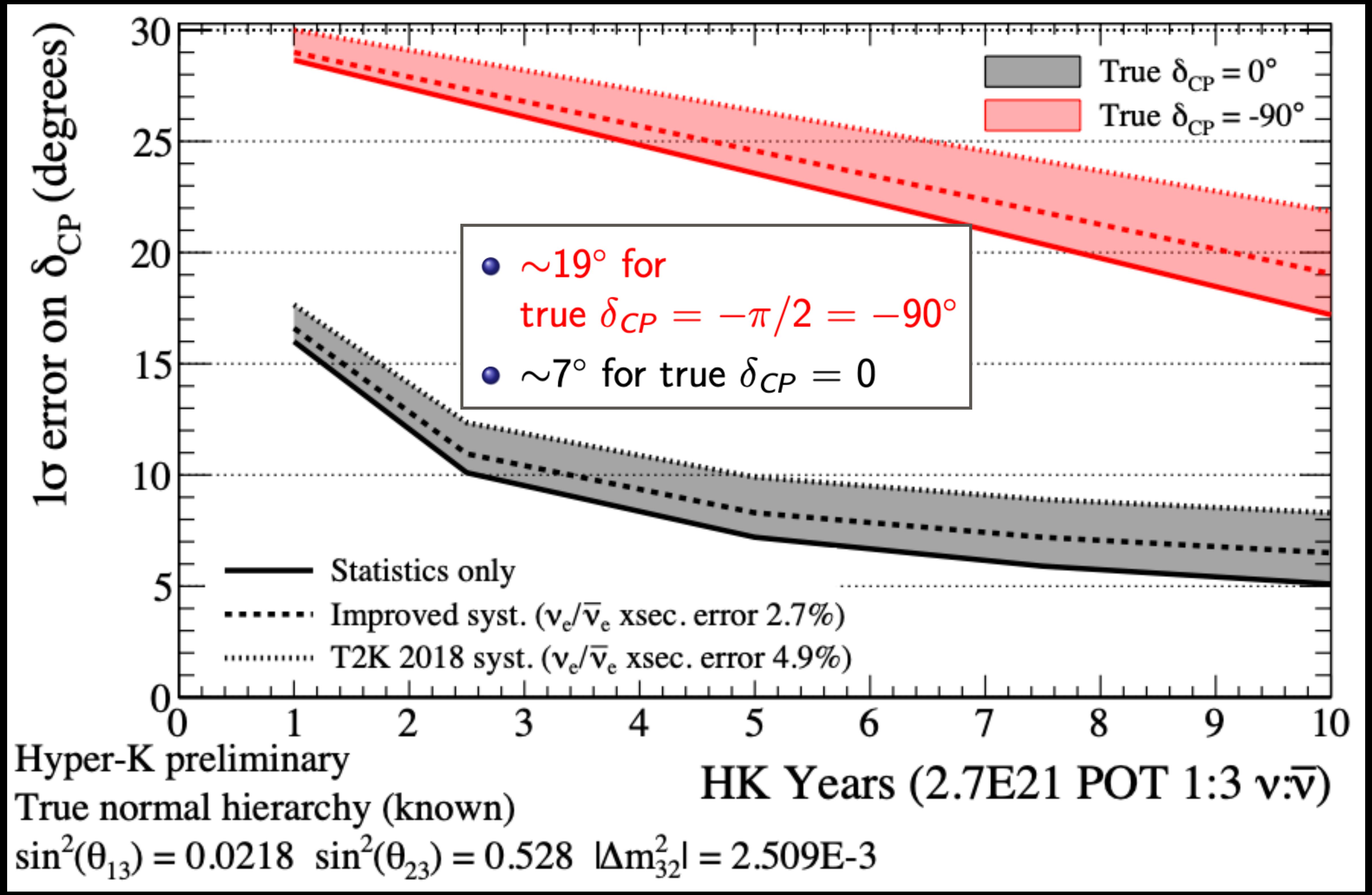
CP violation projected exclusion sensitivity as a function of operation years with different assumptions of systematic errors



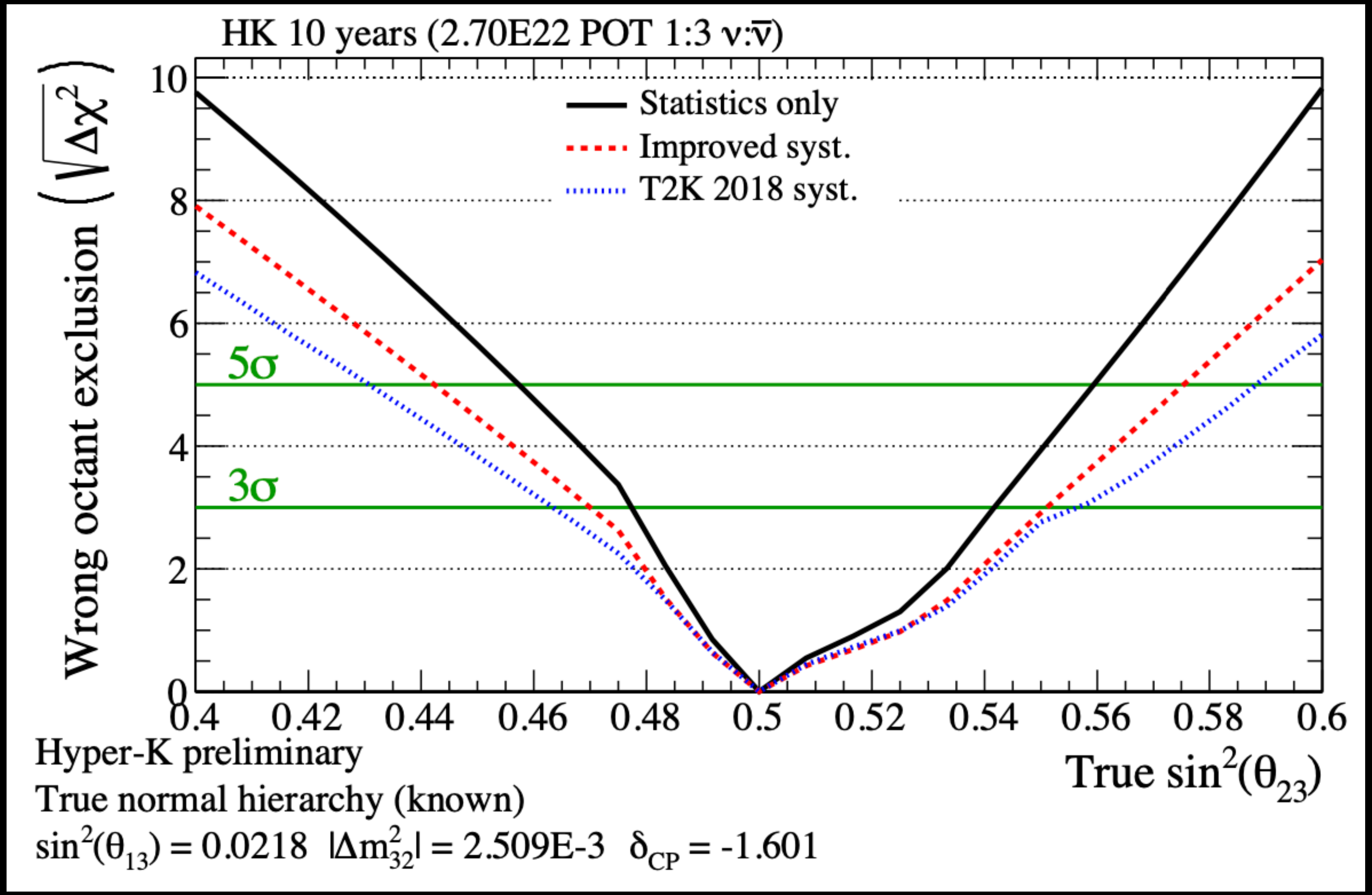


Resolution on δ_{CP} and measurement of $\sin^2\theta_{23}$

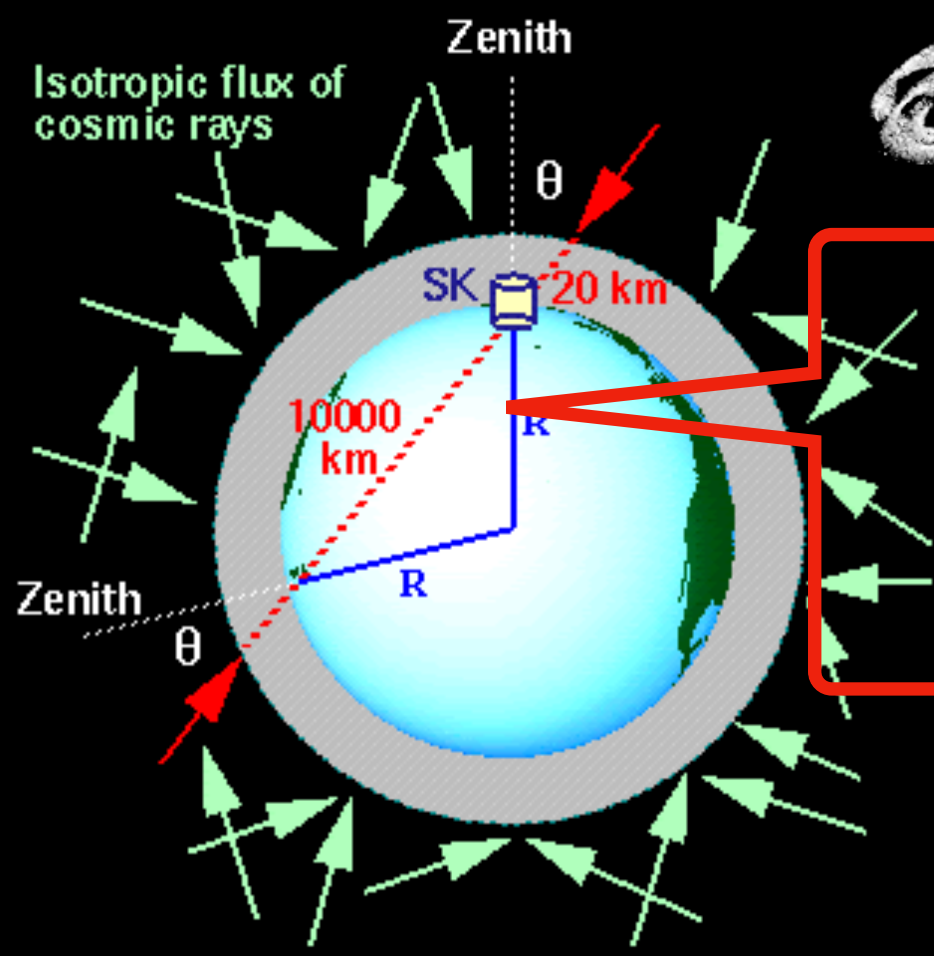
- How accurately can we measure the value of δ_{CP}?



- For a true value of $\sin^2\theta_{23}$, how much can we exclude the wrong octant? ($\sin^2\theta_{23}$ < or > 0.5)



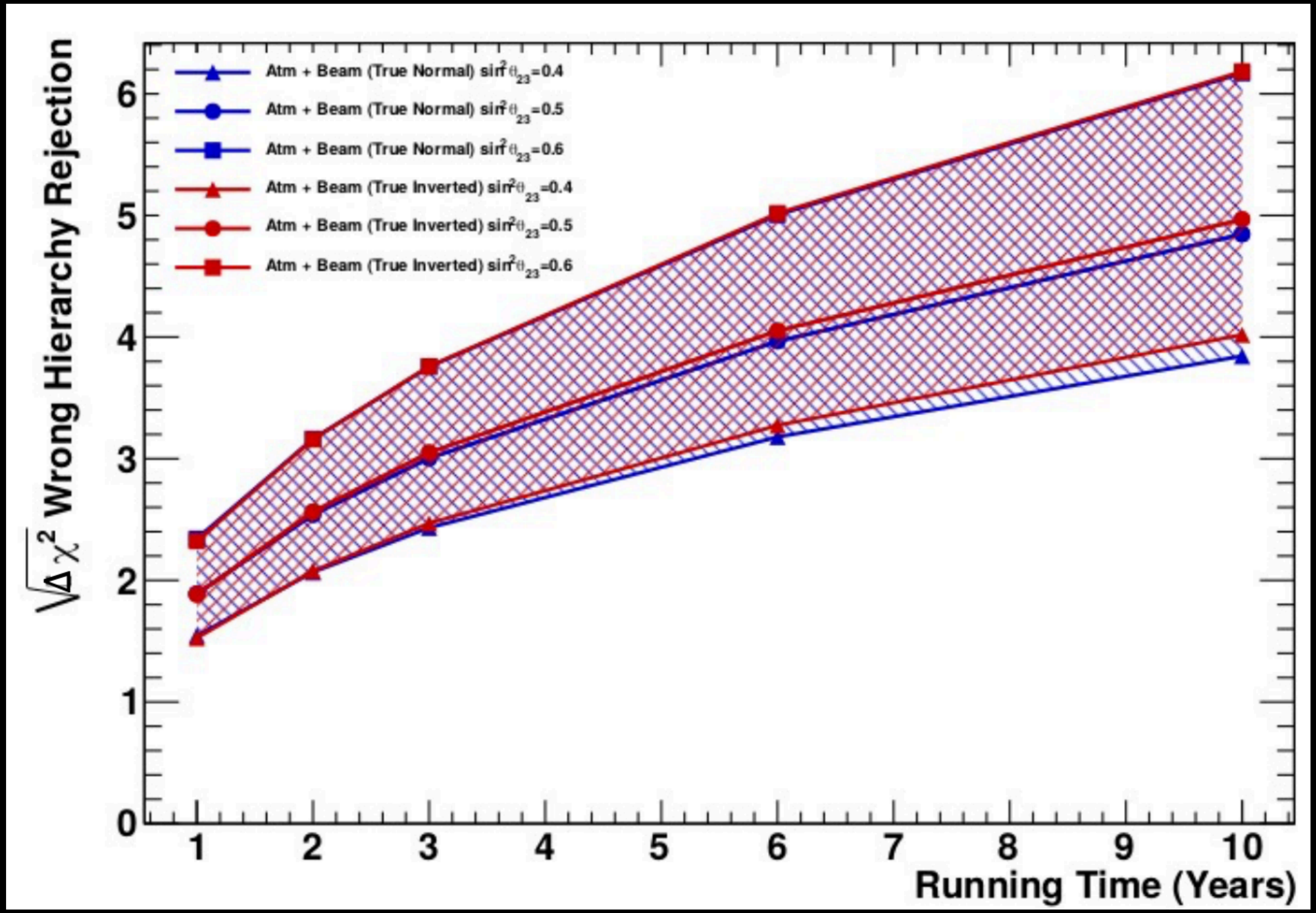
Adding Atmospherics



- Neutrinos penetrating the earth are affected by the mass effect.
  - Normal mass ordering : $\nu_\mu \rightarrow \nu_e$ is enhanced
  - Inverted mass ordering: $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ is enhanced

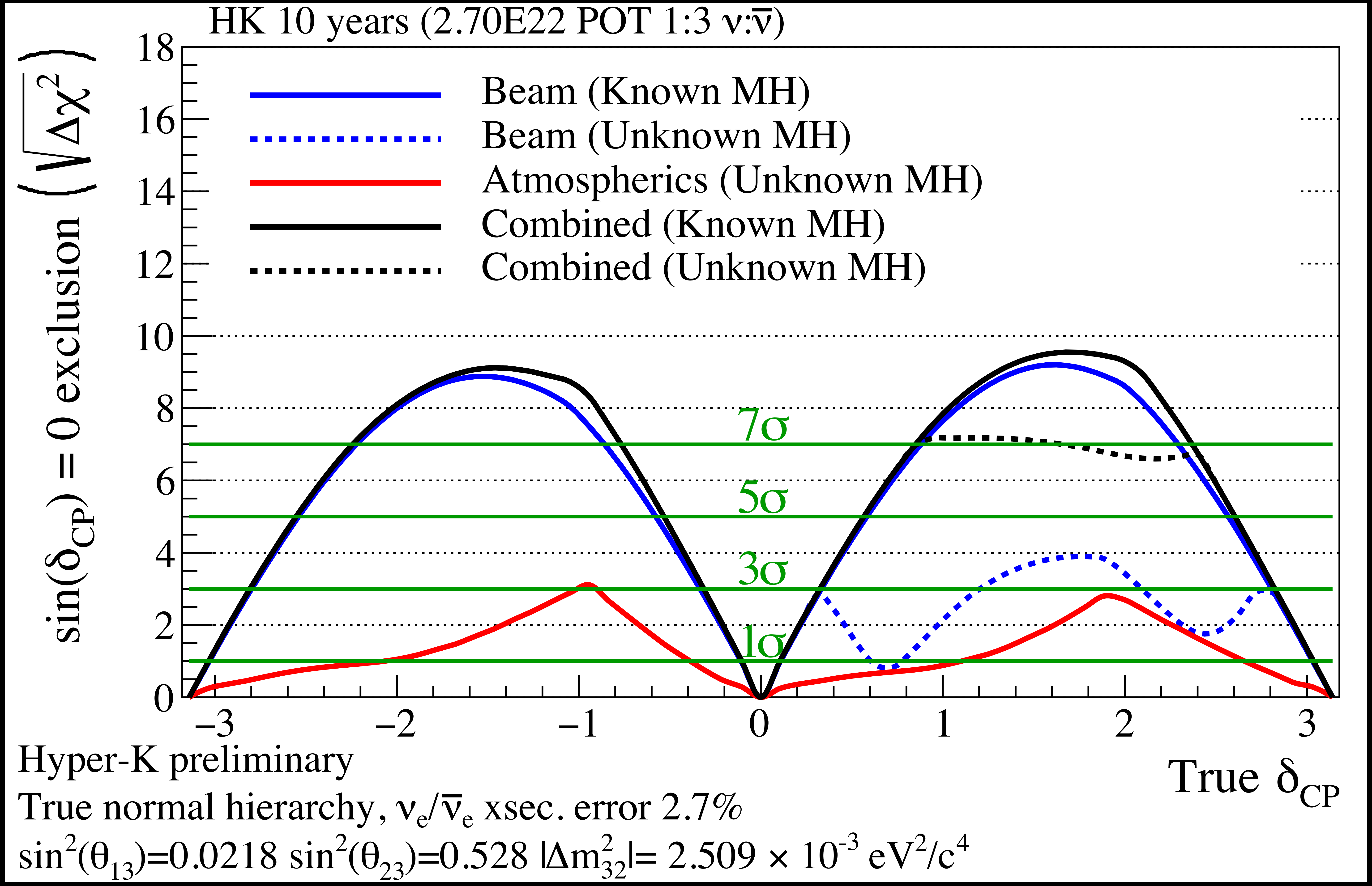
- Comparison between neutrinos and antineutrinos oscillations can be used to determine the hierarchy.

- Can exclude incorrect mass ordering at $\mathbf{4-6\sigma}$ significance (depending on value of $\sin^2\theta_{23}$)



Adding Atmospherics

- If mass ordering unknown, beam analysis less sensitive for some values of δ_{CP}.
- Joint atmospheric and beam analysis increases sensitivity above 5σ
- CP violation sensitivity with different assumptions of mass hierarchy knowledge:



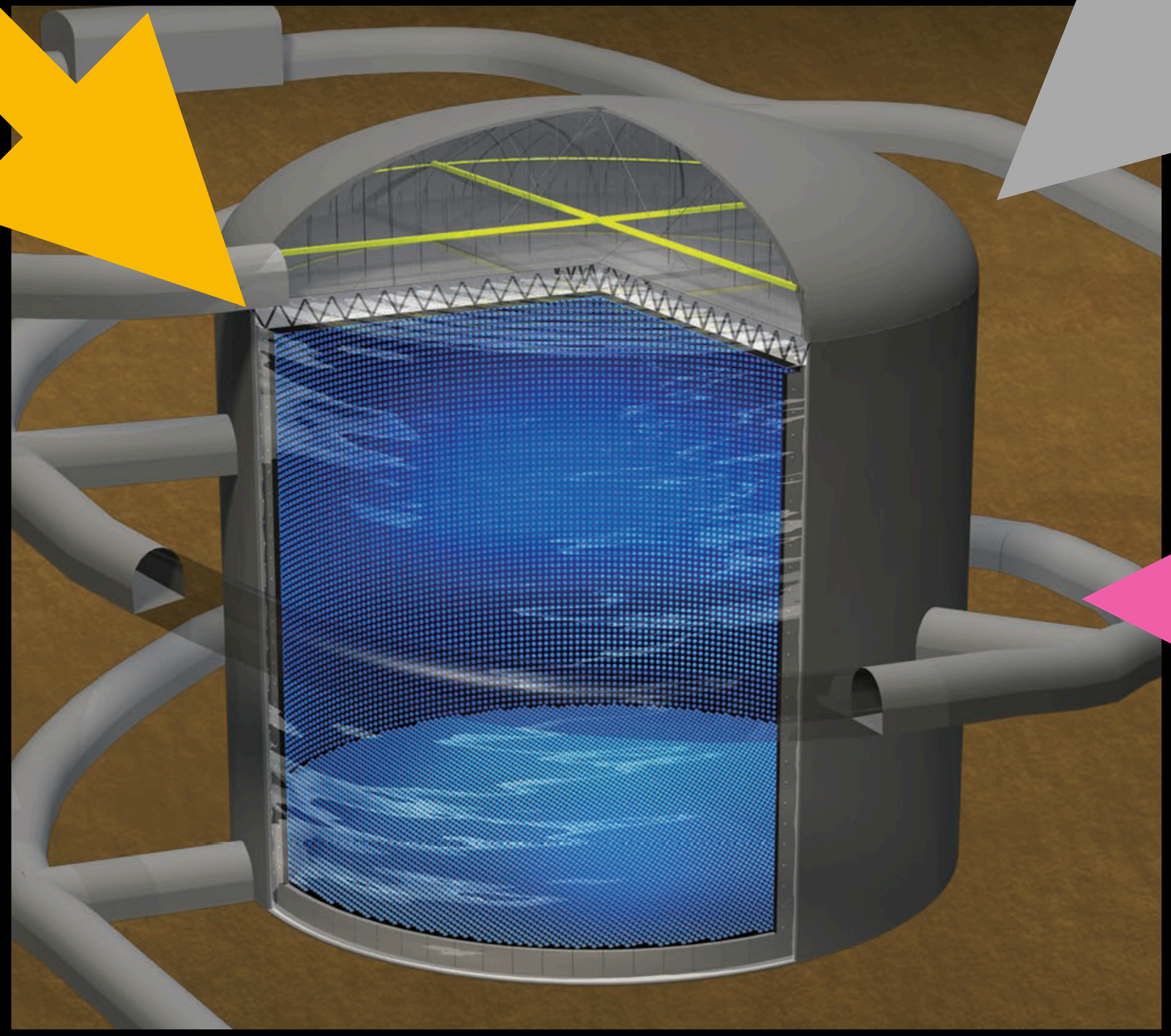
Astrophysics Neutrinos at Hyper-K

Solar Neutrinos

- Burning processes, modelling of the Sun
- Property of neutrino

Supernova Neutrinos

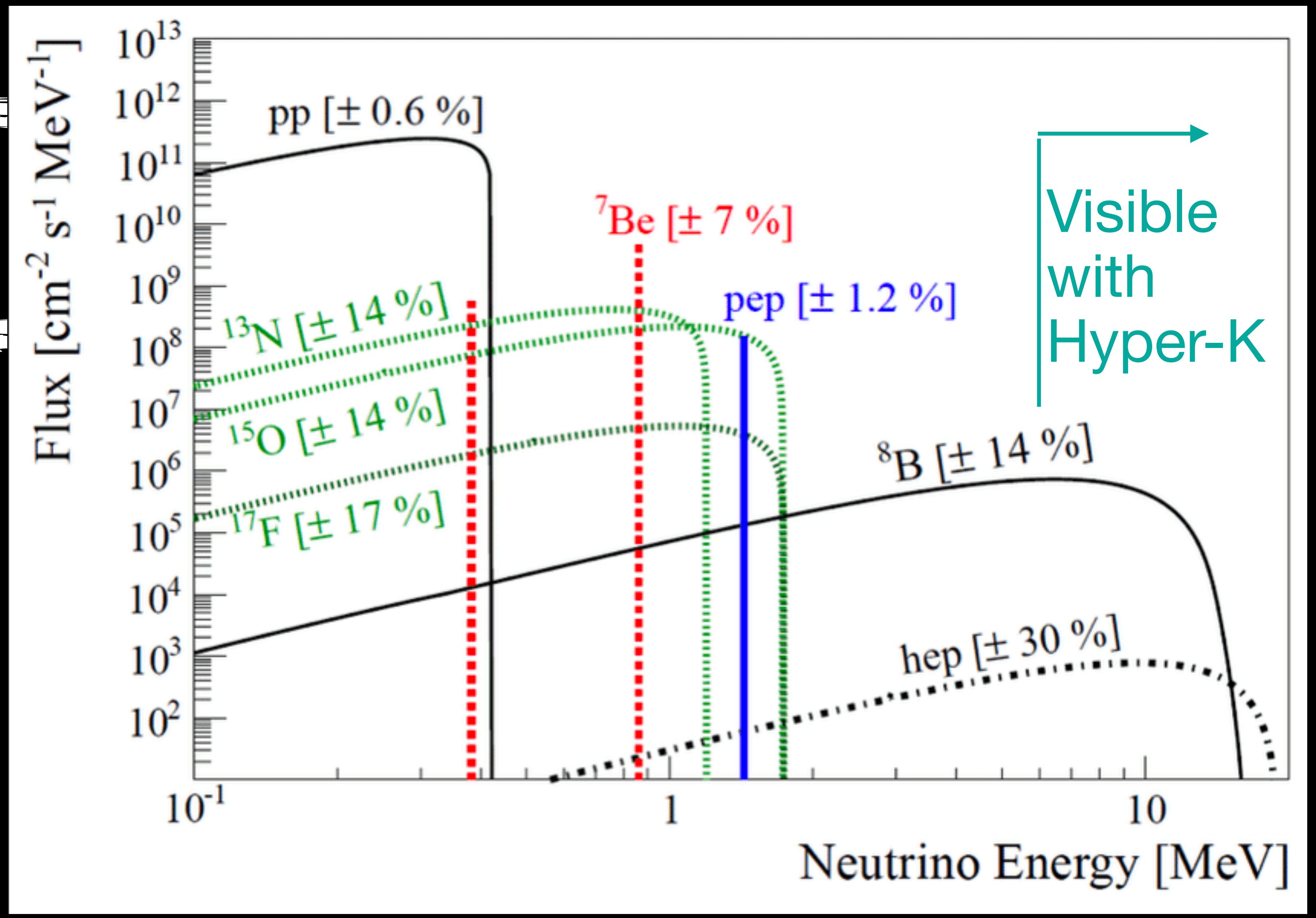
- SN explosion mechanism
- SN monitor
- Nucleosynthesis



Supernova Relic Neutrinos

- SN mechanism
- Star formation history
- Extraordinary SNe

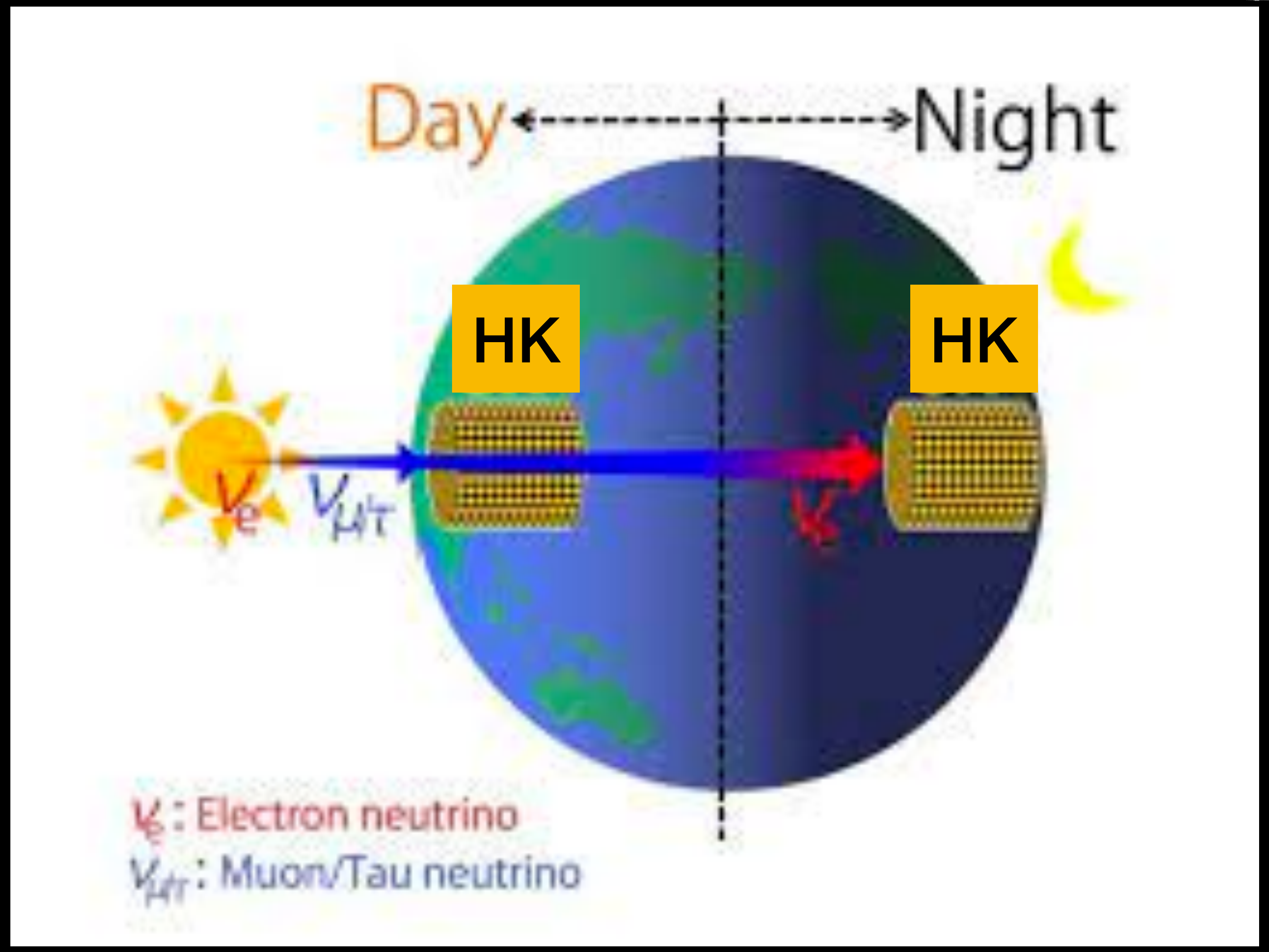
Solar Neutrinos



- Solar neutrinos are the neutrinos originated from the nuclear reactions in the Sun.
- Large statistics: 130 ν ev./day/tank, E_{vis}>4.5MeV
- Highlights of solar ν measurements:

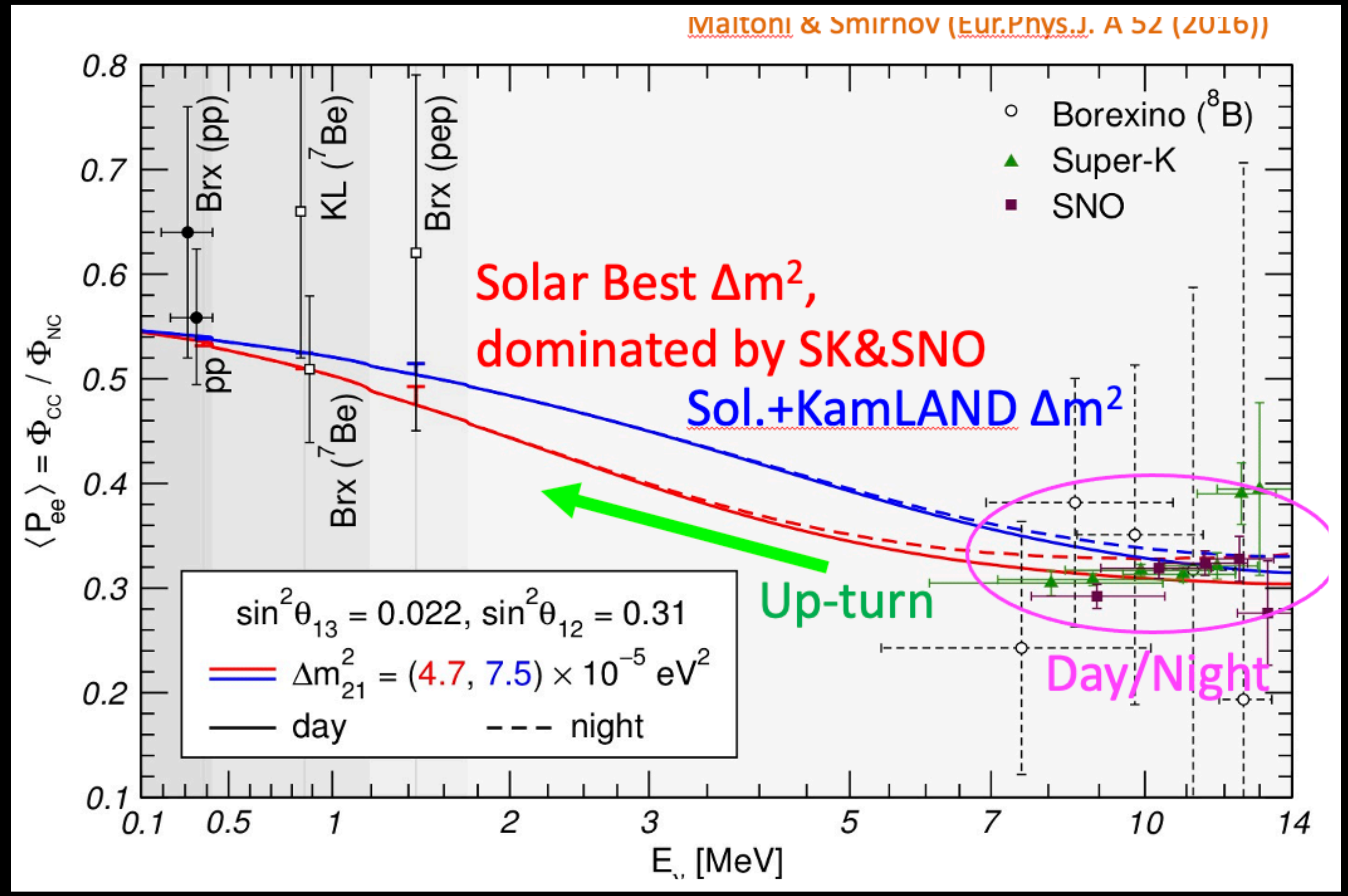
Day/Night (D/N) Asymmetry

- The terrestrial matter effect can result in **D/N asymmetry**.
- This can affect Δm^2_{12} measurement.



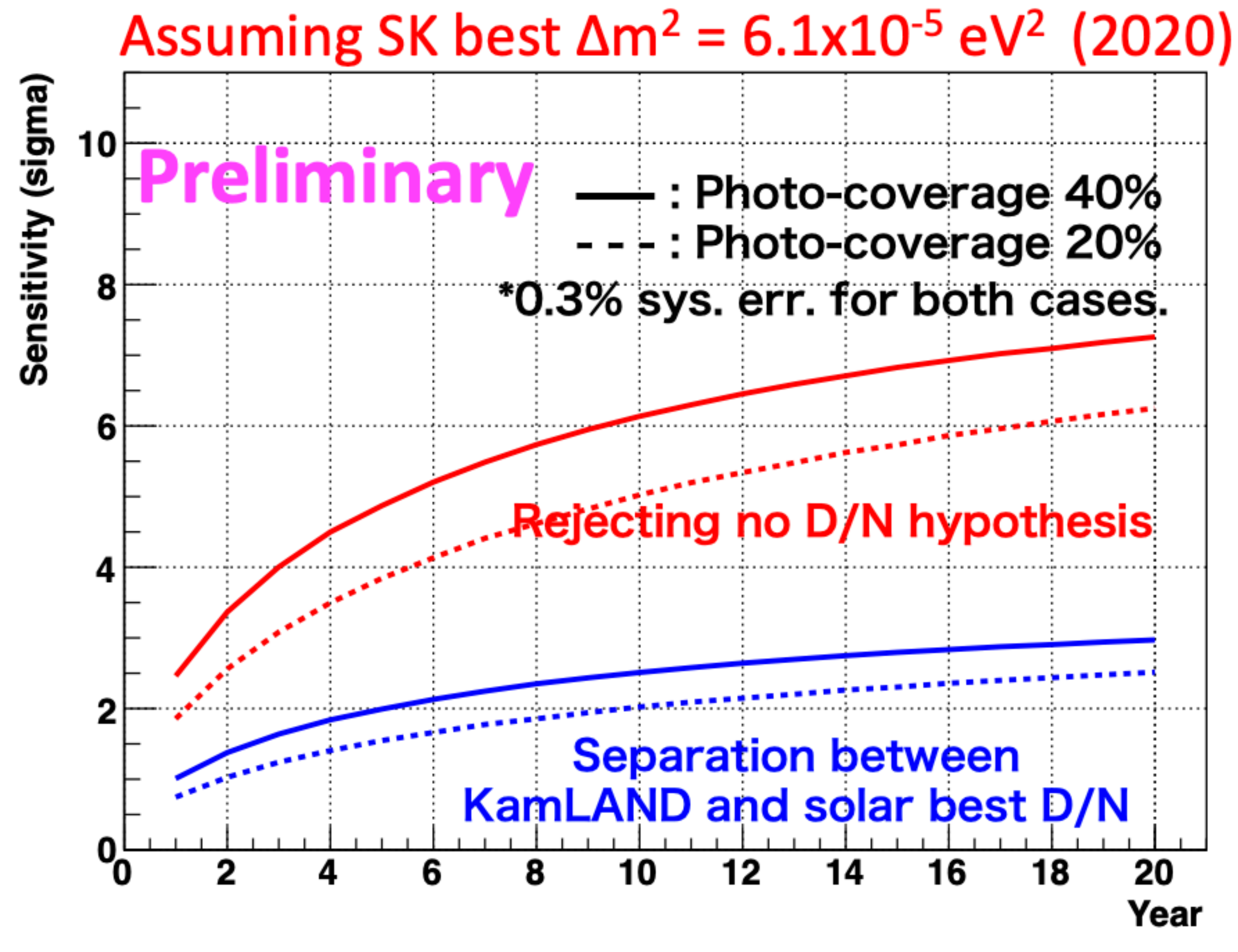
Upturn of the spectrum

- Upturn is the variation of the oscillation probability between the vacuum and MSW dominated energy region.

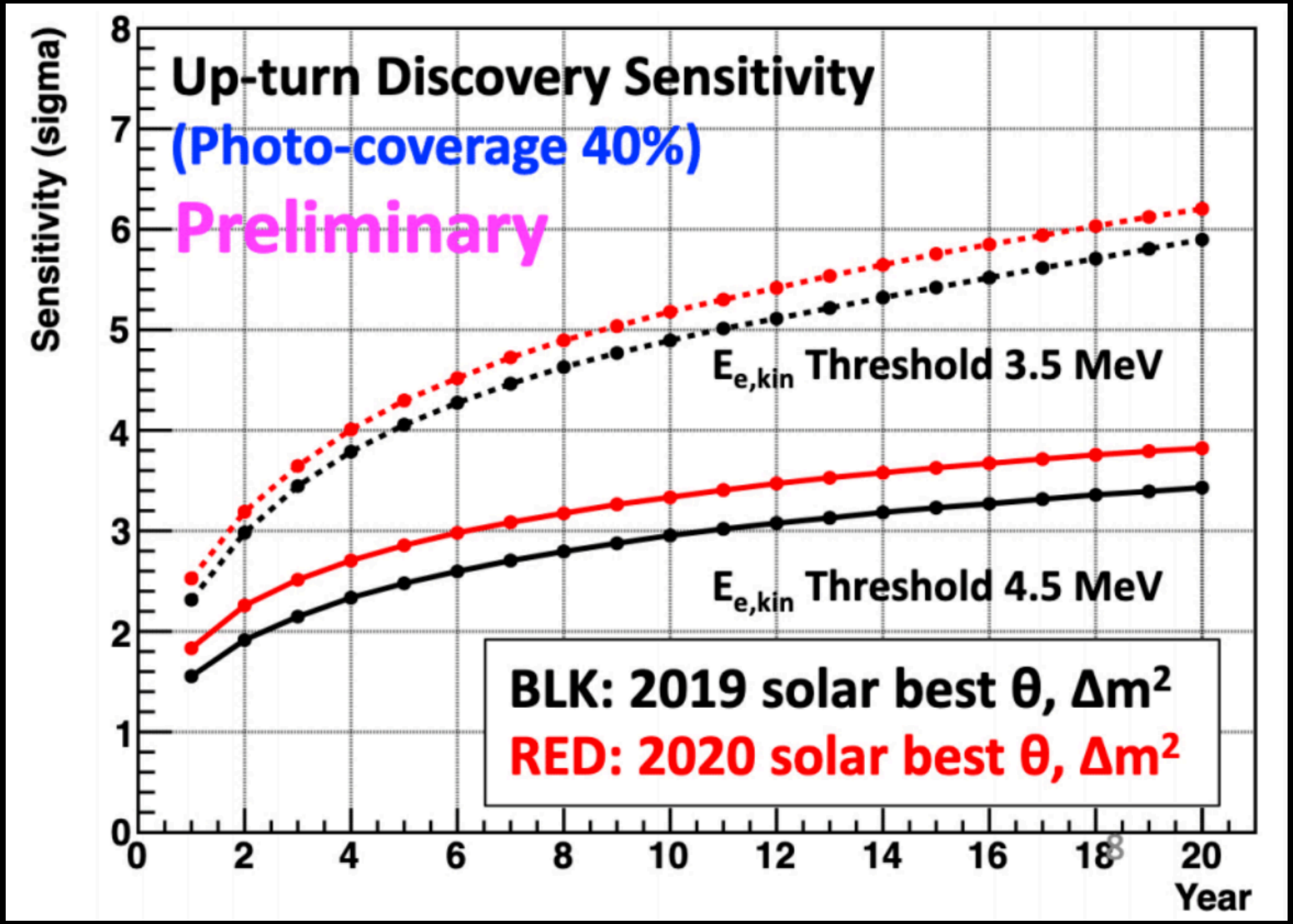


- Upturn not observed yet.

Solar Neutrinos



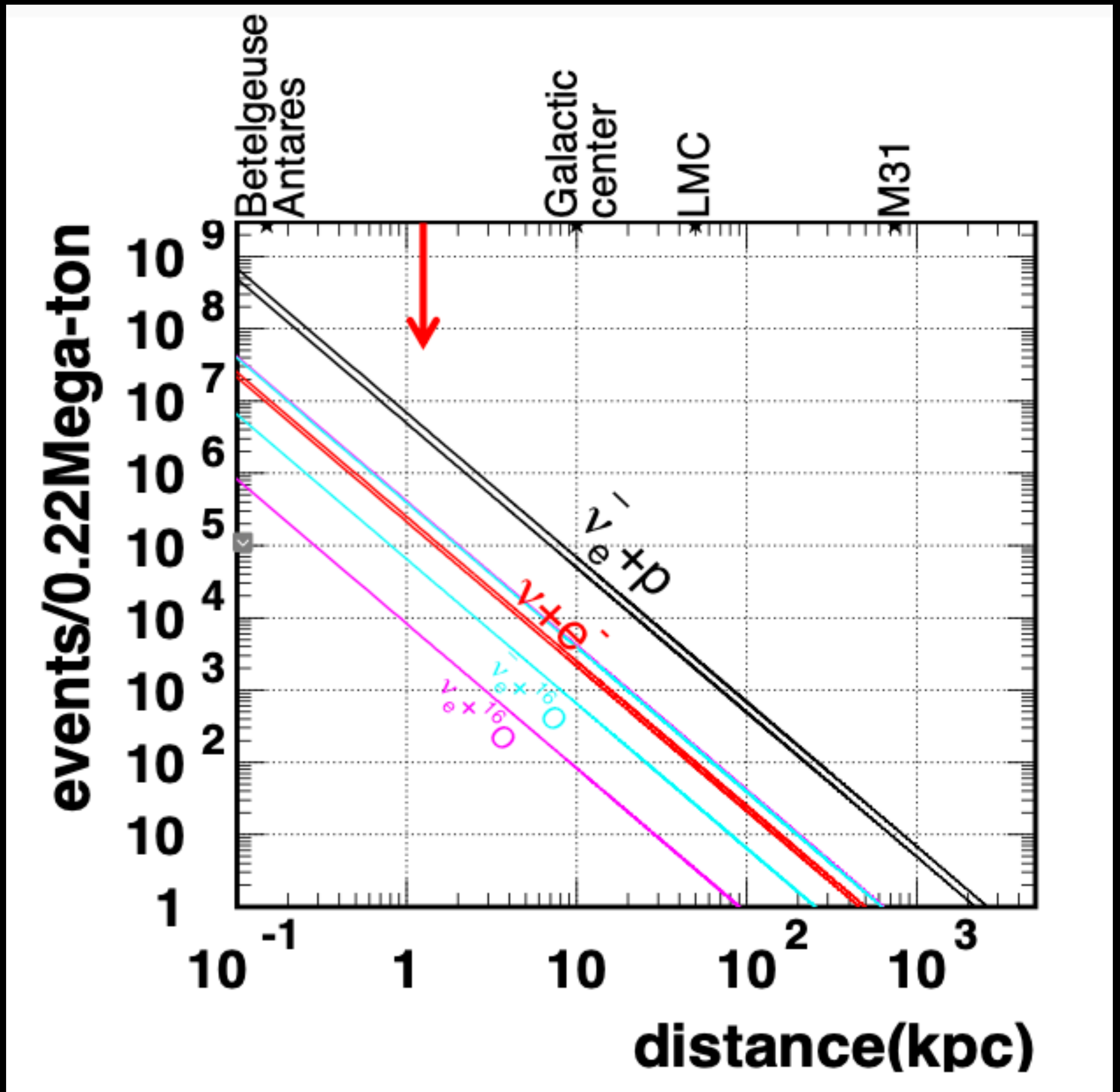
- Large D/N asymmetry is expected to be observed with $> 5\sigma$ after 10 years of operation



- In the upturn analysis, it is expected that **the sensivity exceeds** $3(5)\sigma$ after 10y operation with the threshold of 3.5(4.5 MeV)

Supernova Neutrinos

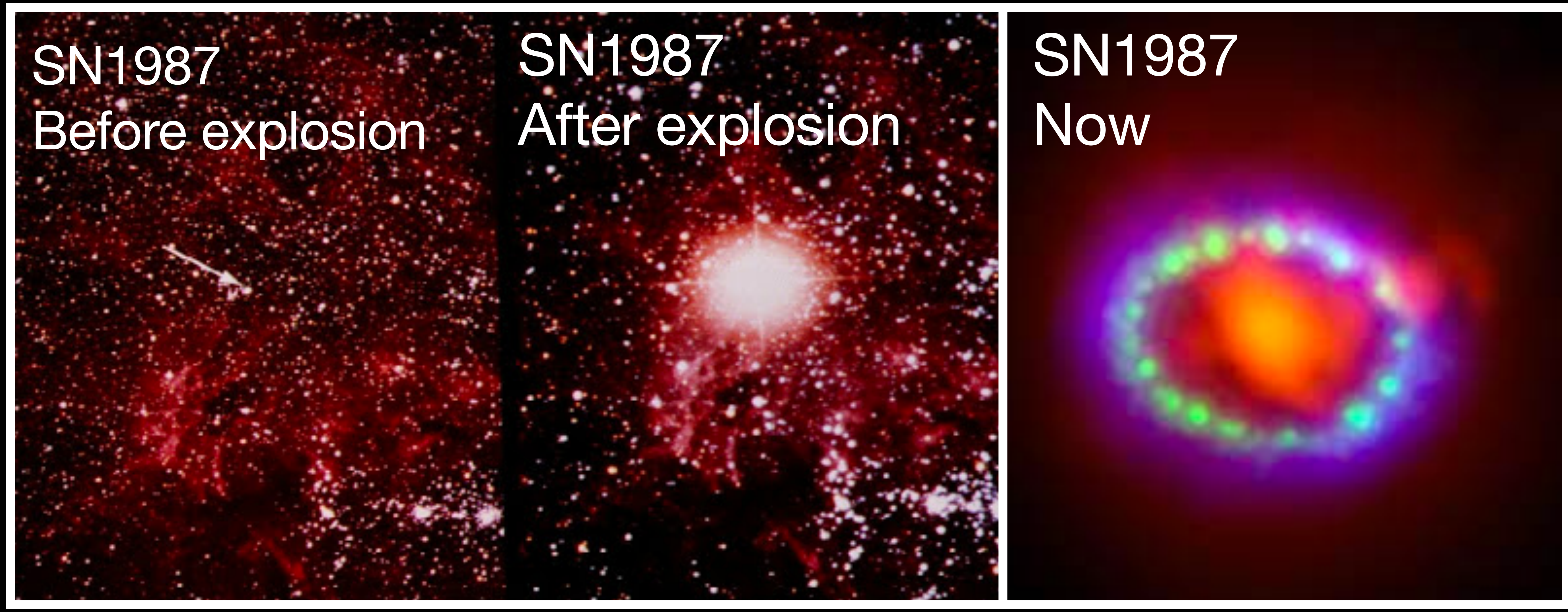
- Supernova neutrino observation:
  - 54-90k events for SN at 10 kpc (most sensitive to $\bar{\nu}_e$)
  - Precise Neutrino Time profile
  - Precise spectrum measurement
  - Investigation of the SN mechanism (SASI/ Rotation/Convection)

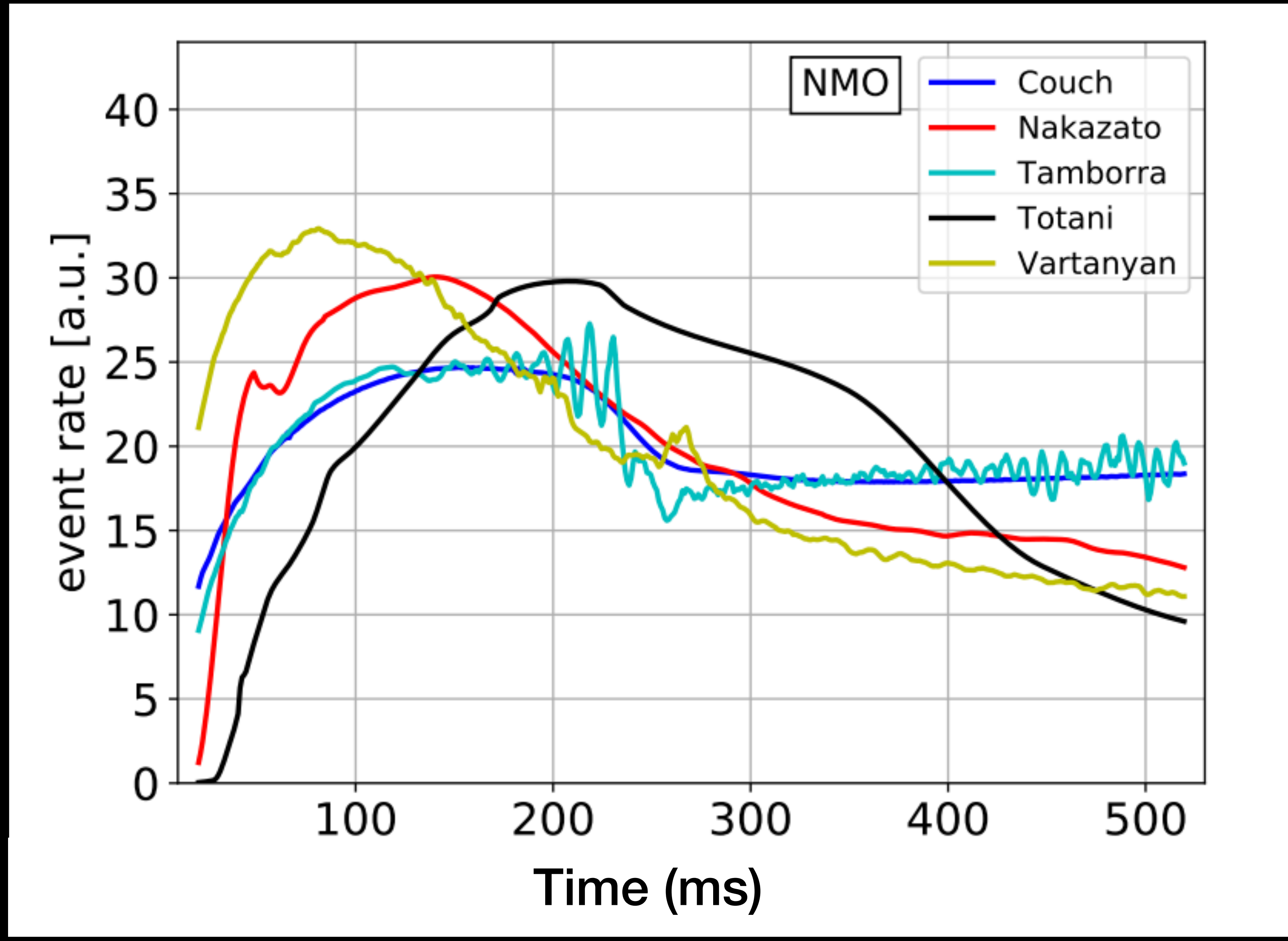


- Models by different groups, using various approximations ➔ telling models apart can help understand the explosion mechanism

Supernova paper

- First Hyper-K paper!
- Published by *Astrophysical Journal* on April 13, 2021.
- arXiv:2101.05269 [astroph.IM]
- Hyper-K has the potential to have a large statistics if there is a supernova burst
- Hyper-K can distinguish between different explosion mechanism models.

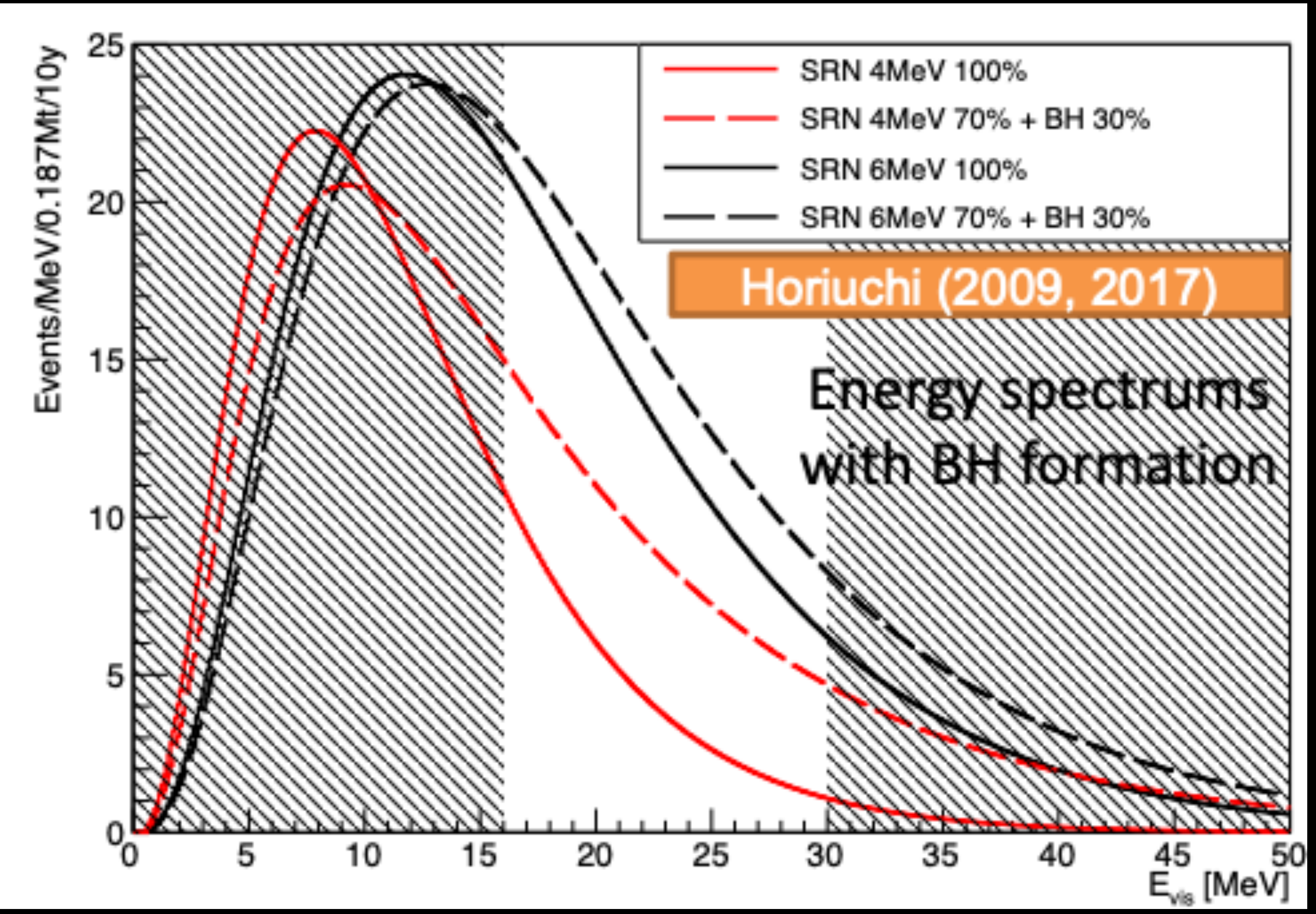




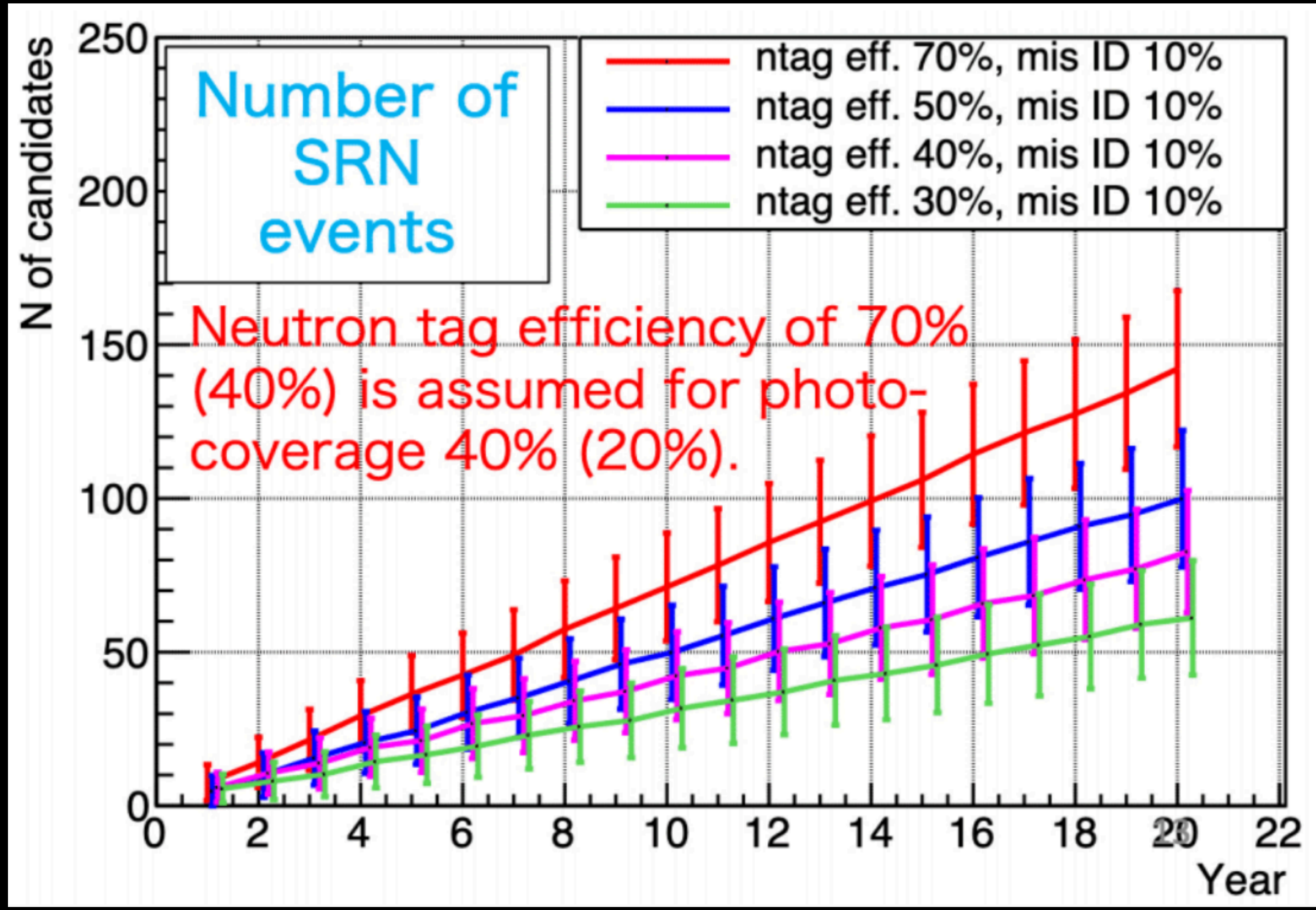
Event rate in Hyper-K from supernova burst for different explosion models

Supernova Relic Neutrinos

- Supernova Relic Neutrino (SRN)
- Diffused neutrinos coming from all past supernovae.
- Not discovered but promising extra-galactic ν.
- SRN can be observed by HK in 10y with ~70±17 events. It is > 4σ for SRN signal.

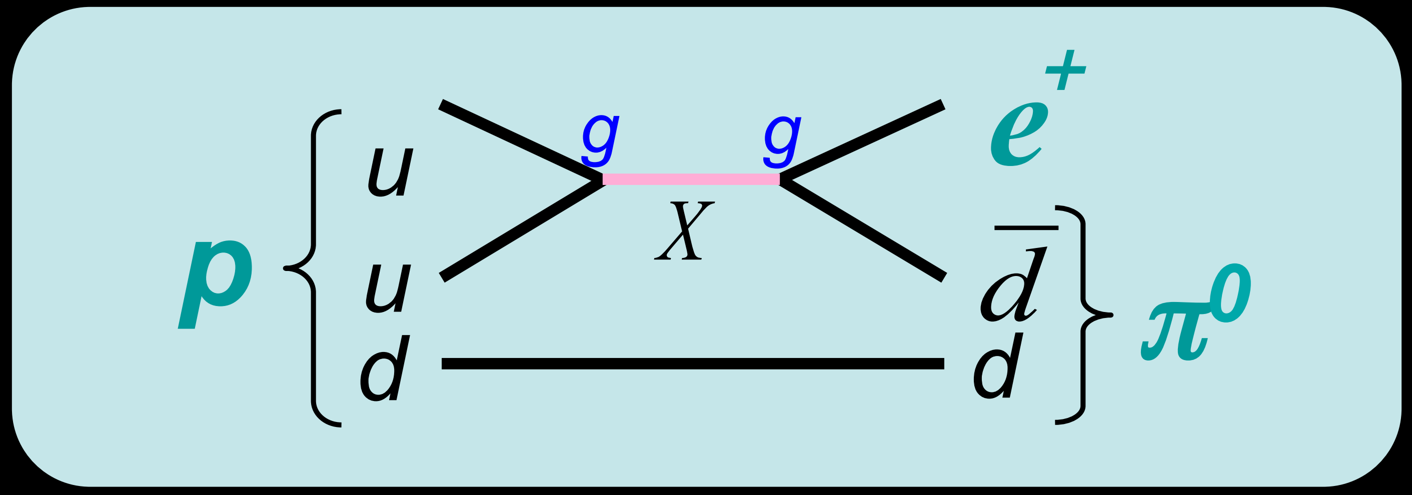


- The number of detected SRN events is predicted for various neutron-tagging configurations.
- In the case of 70% efficiency, ~70 events will be observed within 10 operation years. This corresponds to 4σ **sensitivity**

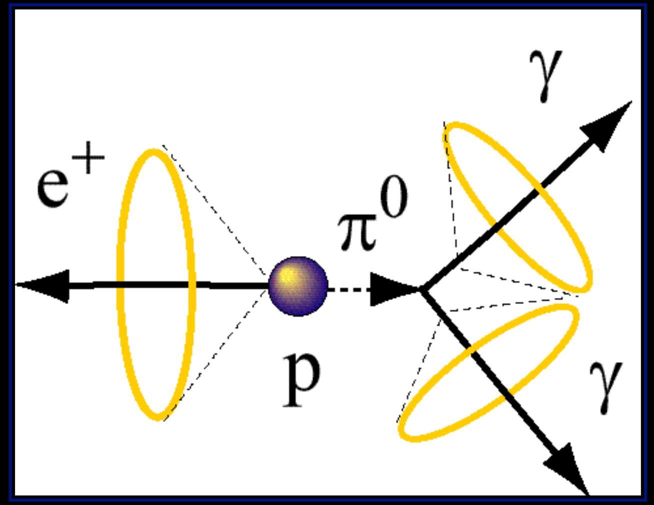


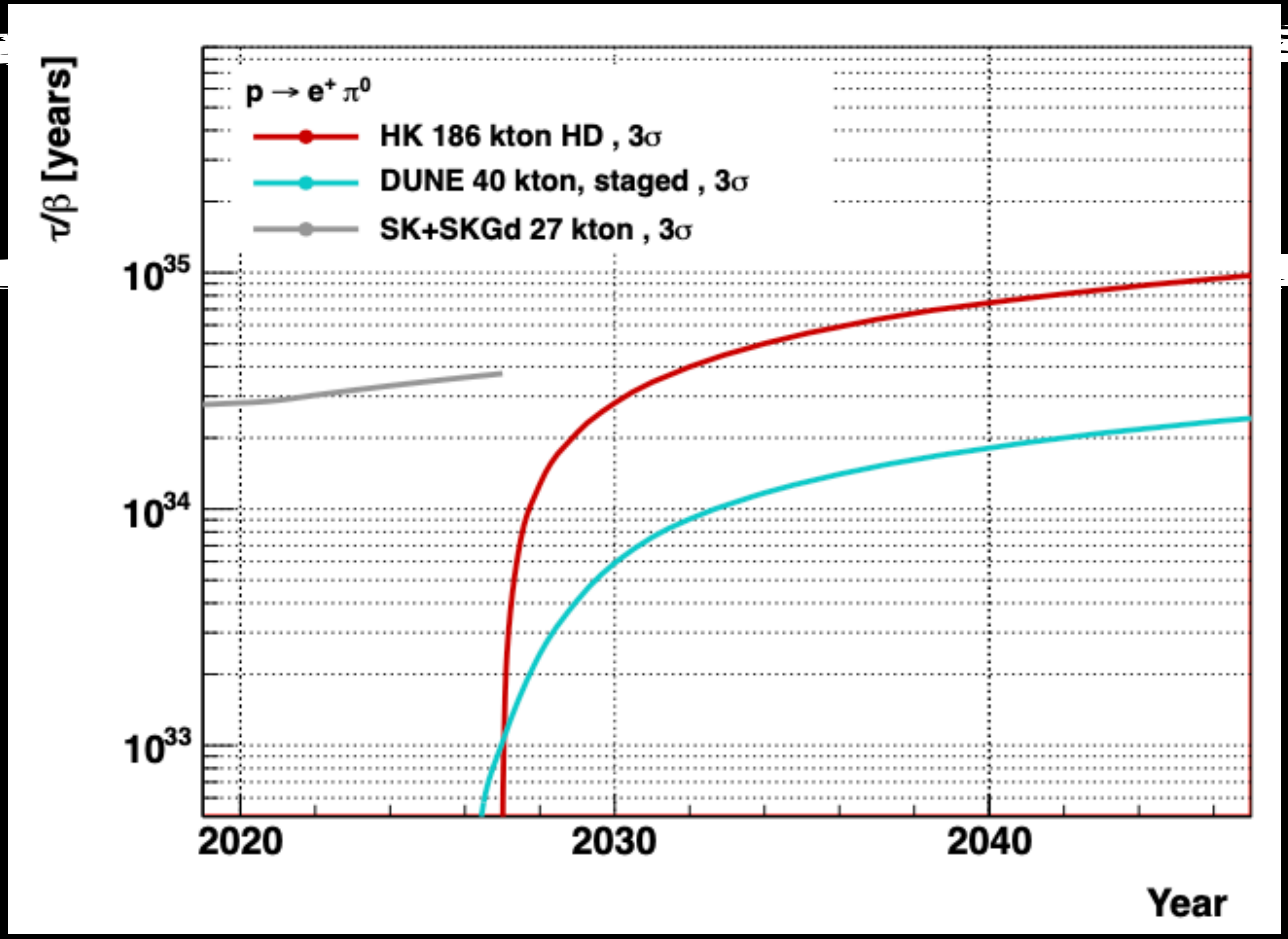
Proton Decay Searches

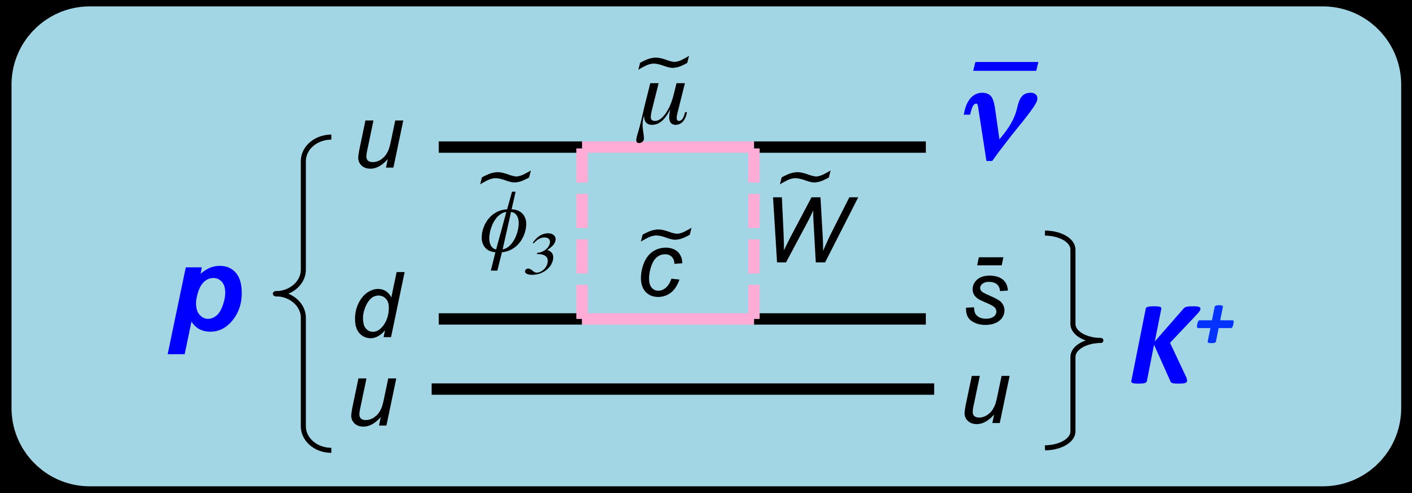
- Two major modes predicted by many models



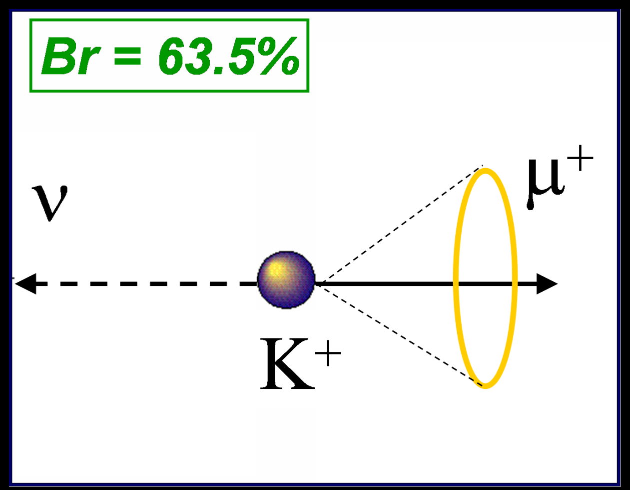
p→e⁺π⁰

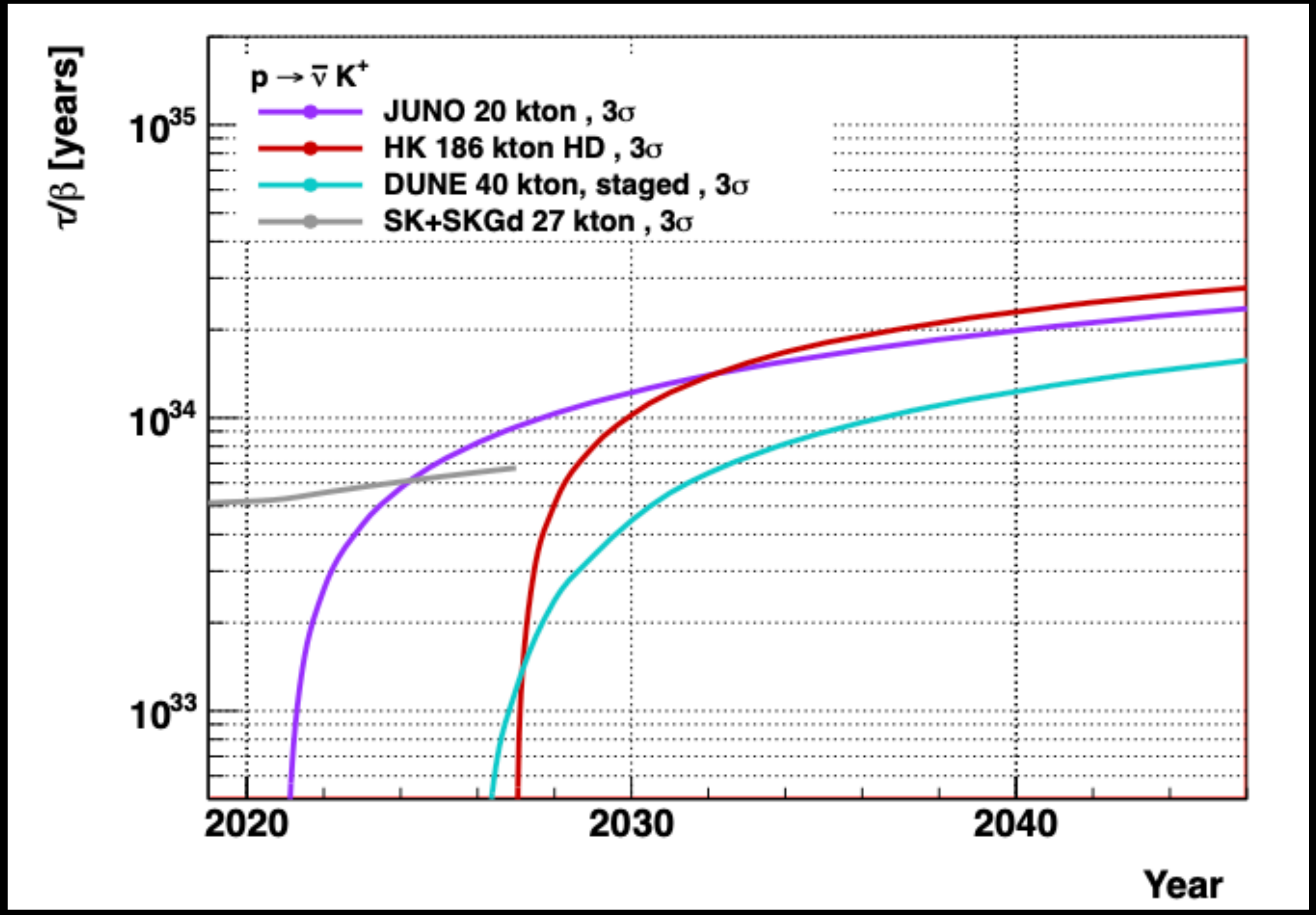






p→ν̄K⁺





- Hyper-K is able to pursue these and other final states with the highest precision.

Conclusion

- A groundbreaking experiment is being built in Japan.
- It will address major open questions in science!
- HK is expected to have sensitivity to conclude various physics questions within ~10 years of operation
  - δ_{CP} and mass hierarchy in neutrino oscillation
  - $O(10^{34})$ years of proton lifetime
  - D/N asymmetry and upturn in solar neutrinos.
  - Existence of SNR neutrinos
- HK has an ability to observe the SN neutrinos if the SN burst occurs in our galaxy
- It will start to take data in 2027!!

Backup Slides

- Additional slides for perusal

New Research Building in Kamioka

New research building at Kamioka

- It is now being constructed. It will be completed by next summer.
- It has 4 floors and 3,050 m^2 total floor area.

Dormitory rooms.

Dinning rooms.

Many visiting researcher's Rooms in 2^{nd} and 3^{rd} floors.

Lab. Rooms to construct detector components.

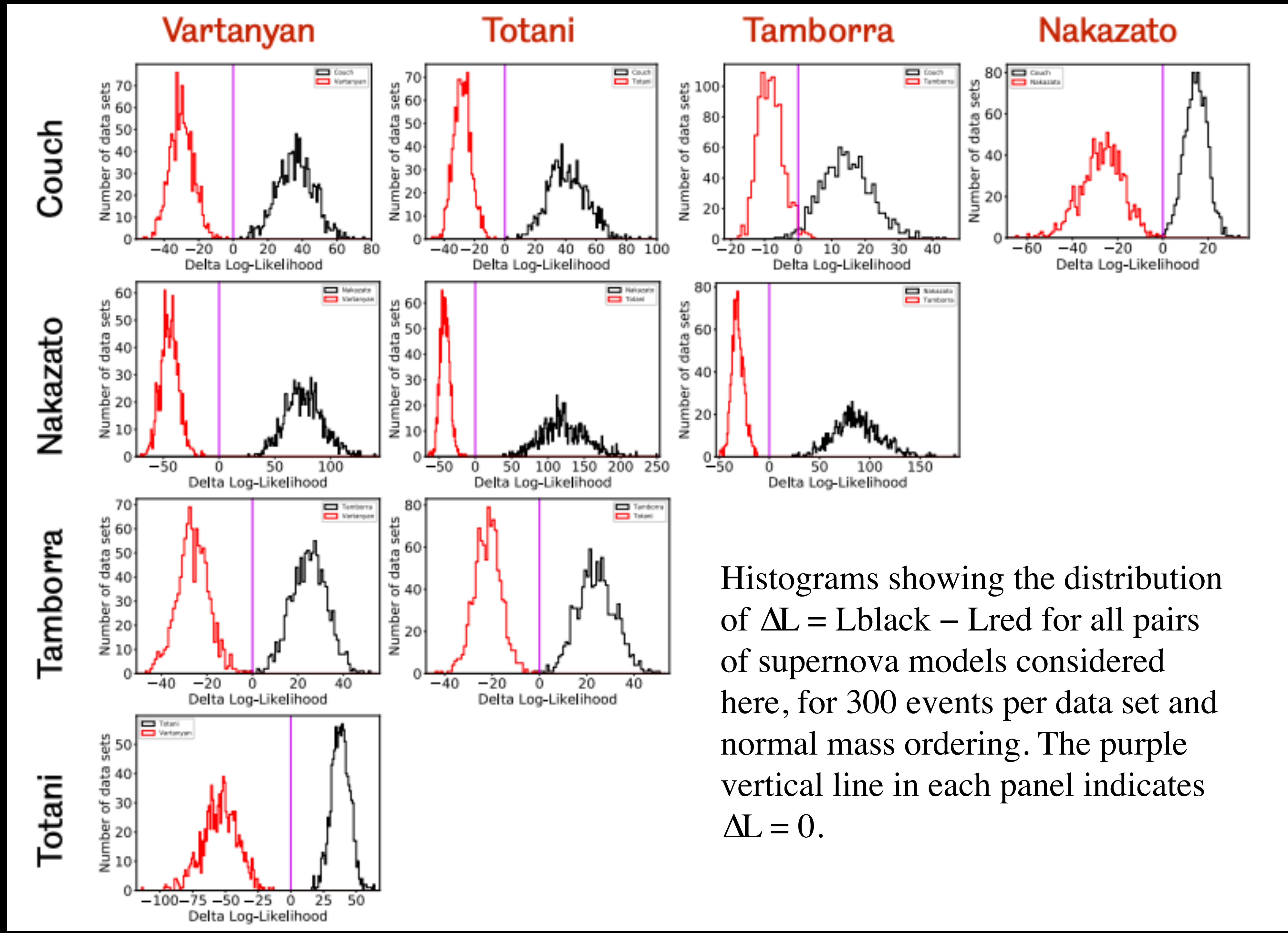
Big hall to accommodate about 150 people on the 1^{st} floor.

Many physicists and engineers will come to Kamioka during the HK construction. They can use this research building.

Image of new research building

Supernova Neutrinos

- Supernova Model Discrimination with Hyper-Kamiokande
- e-Print: 2101.05269 [astro-ph.IM]



Histograms showing the distribution of ΔL = Lblack − Lred for all pairs of supernova models considered here, for 300 events per data set and normal mass ordering. The purple vertical line in each panel indicates ΔL = 0.

Accuracy with which the true model can be identified, for 300 events per data set

Normal mass ordering.

True Model: Normal	Reconstructed Model: Couch	Nakazato	Tamborra	Totani	Vartanyan
Couch	**98.2**	0.2	1.6	0.0	0.0
Nakazato	0.1	**99.9**	0.0	0.0	0.0
Tamborra	1.6	0.0	**98.0**	0.2	0.2
Totani	0.0	0.0	0.0	**100.0**	0.0
Vartanyan	0.0	0.0	0.0	0.0	**100.0**

Inverted mass ordering.

True Model: Inverted	Reconstructed Model: Couch	Nakazato	Tamborra	Totani	Vartanyan
Couch	**99.9**	0.1	0.0	0.0	0.0
Nakazato	0.0	**100.0**	0.0	0.0	0.0
Tamborra	0.0	0.0	**97.4**	0.1	2.5
Totani	0.0	0.0	0.0	**100.0**	0.0
Vartanyan	0.0	0.0	0.8	0.0	**99.2**

- With 300 events, corresponding to SN at 60-100 kpc, >97% identification is realized.