Status of the Hyper-Kamiokande Experiment

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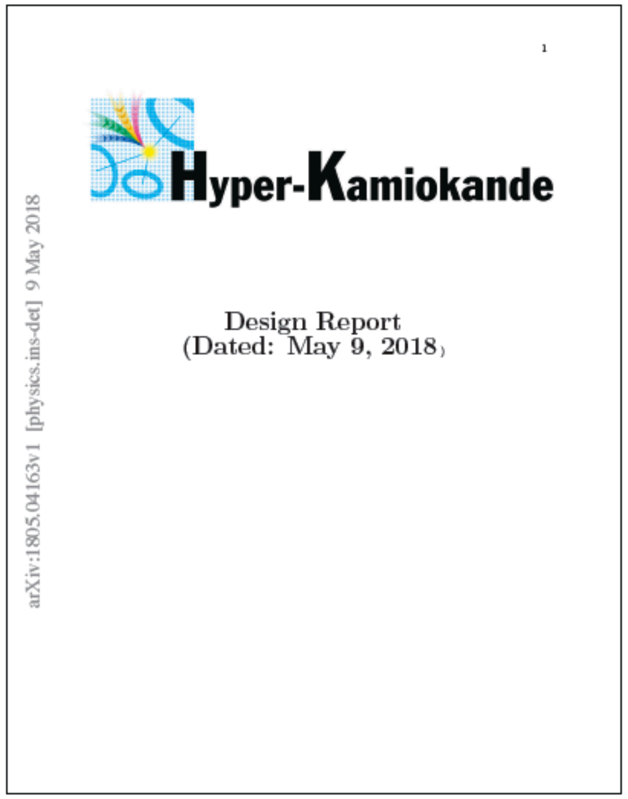
Outline

- Introduction to Hyper-K
- Overview of the detector
- Science goals
- Status
- Conclusions

Hyper-Kamiokande Proto-Collaboration

- International proto-collaboration was formed in 2015
- ~300 members from 15 countries, 73 institutes,
  - Korean members (16 members / 6 institutes)*
- Two host institutes:
  - University of Tokyo / ICRR
  - KEK / IPNS

Based on Design Report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Hyper-Kamiokande

Design Report
(Dated: May 9, 2018)

arXiv:1805.04163v1 [physics.ins-det] 9 May 2018

Documentation:

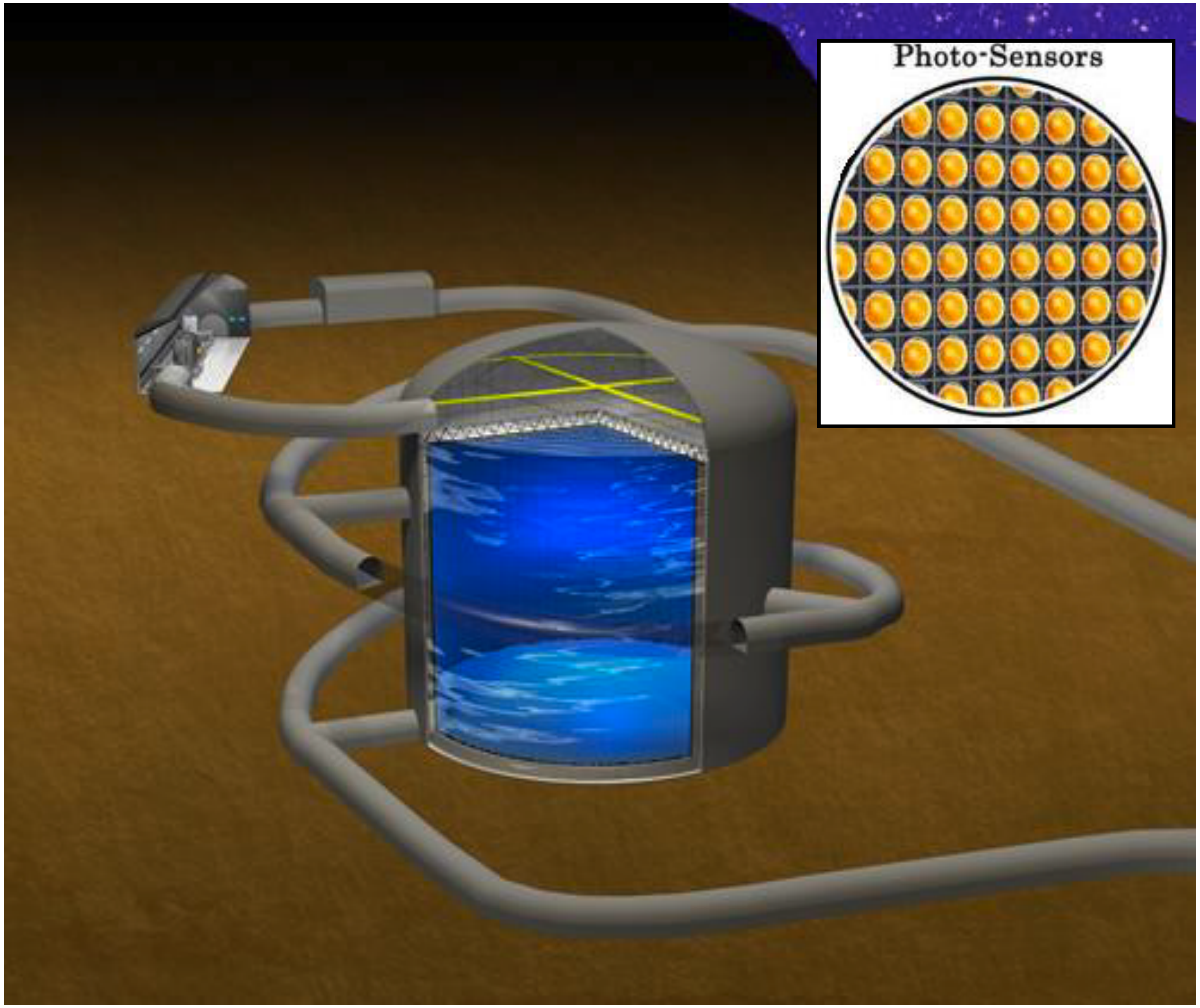
K. Abe et al. (Hyper-Kamiokande Collaboration),
Hyper-Kamiokande Design Report,
arXiV:1805.04163

K. Abe et al. (Hyper-Kamiokande Collaboration),
Physics potentials with the Second Hyper-Kamiokande detector in Korea,
PTEP 2018(2018) 6, 063C01

K. Abe et al. (Hyper-Kamiokande Working Group),
A Long Baseline Neutrino Oscillation Experiment Using J-PARC Neutrino Beam and Hyper-Kamiokande,
arXiv:1412.4673 [physics.ins-det]

K. Abe et al. **Letter of Intent: The Hyper-Kamiokande Experiment**,
arXiv:1109.3262 [hep-ex]

The Hyper-Kamiokande Project



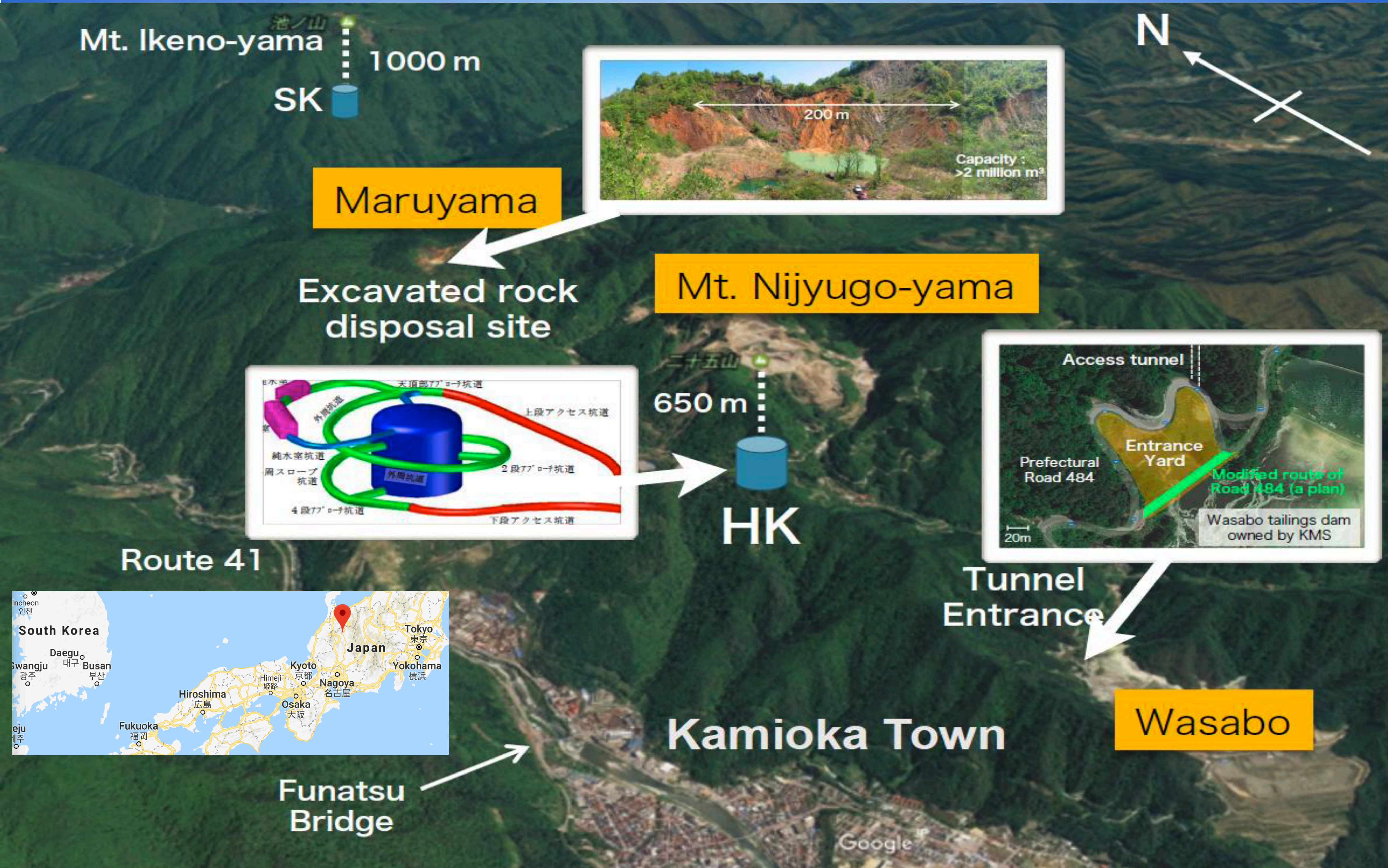
Size: 60 m(H)x74m(D)
Total volume: 260 kt
Fiducial volume: 190 kt
(~10xSuper-K)

Inner detector (ID):
40,000 x 20" PMTs
40**% photocoverage**

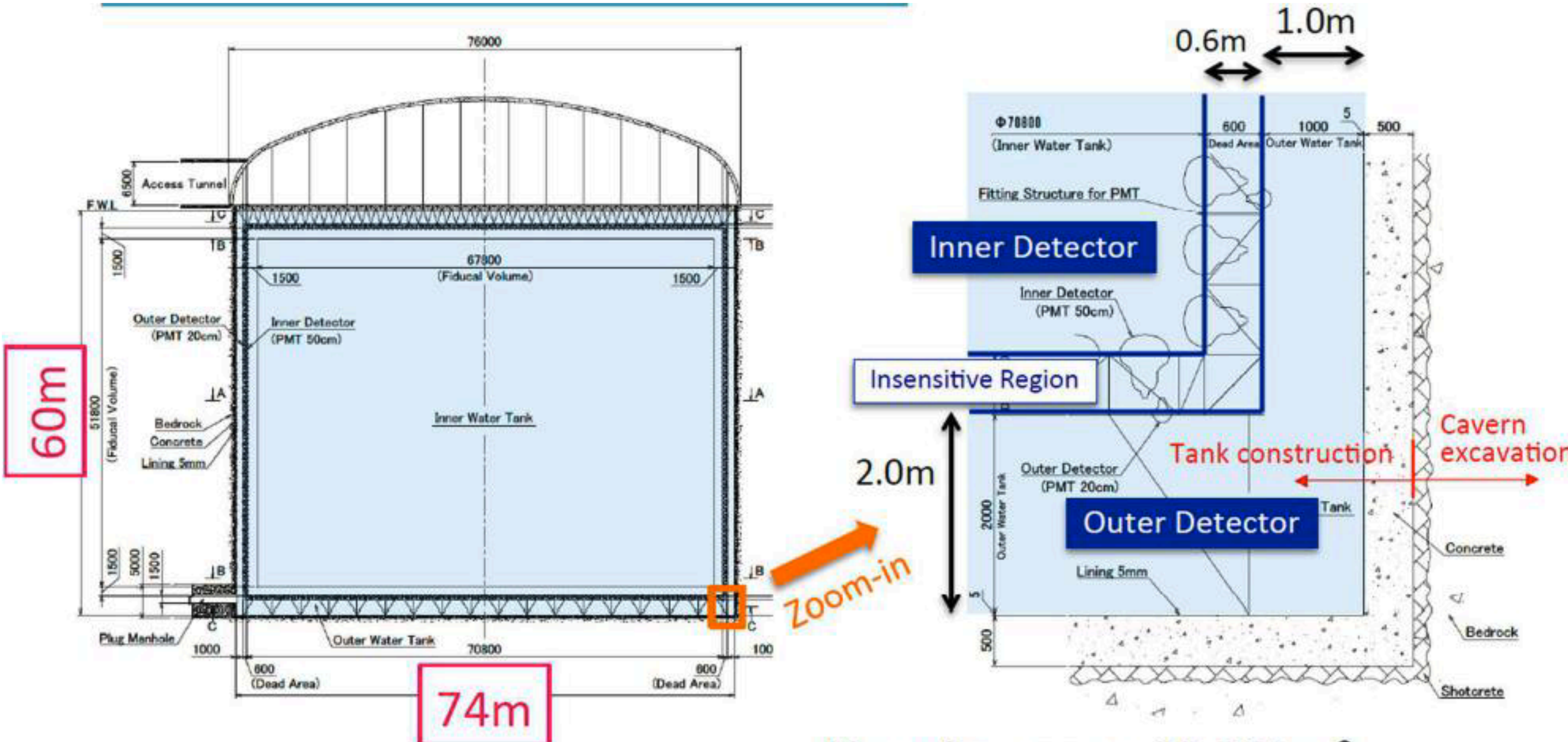
Outer detector (OD):
6700 x 8" PMTs
1% photocoverage
OD water thickness: 1m barrel,
2 m top and bottom

2nd tank construction in Korea
Construction of 2nd tank in Korea
(1-3 deg off axis, 2nd oscill. maximum) is under study - (see next talk)

Detector location



Water tank



Total : 258.1 kt/tank

Inner Detector : 215.7 kt/tank

Fiducial Volume: 187.0 kt/tank

ID surface area : 20,063 m^2

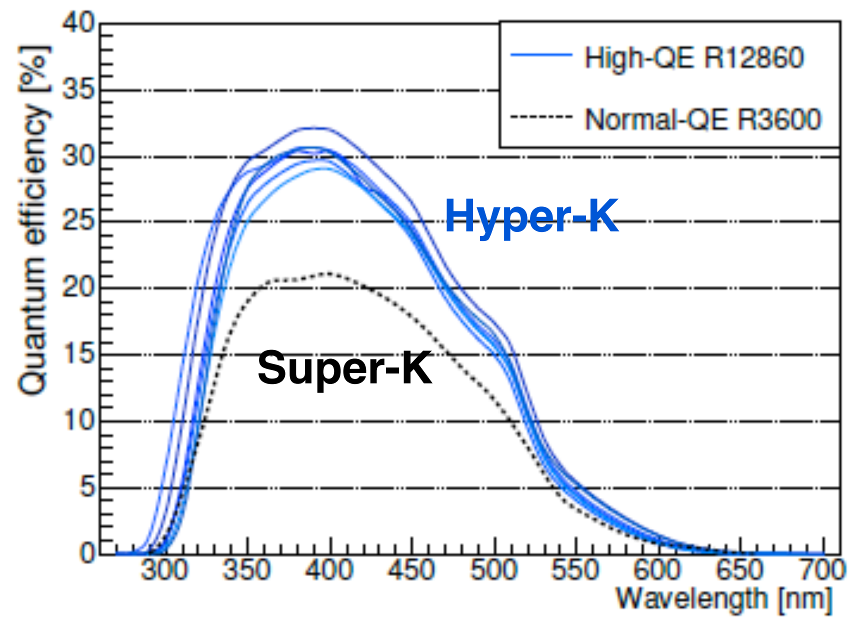
1 ID-PMT/0.5m^2 (40% coverage)

→ ~40,000 ID-PMTs/tank

~6,700 OD-PMTs/tank

Photosensors

Inner Detector



Outer Detector

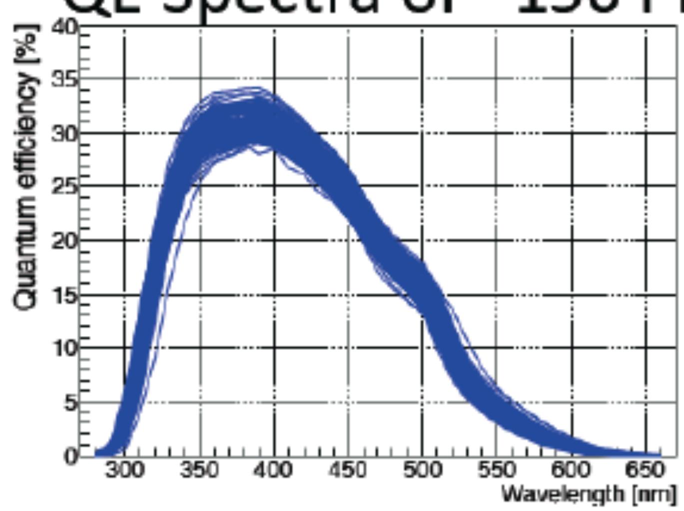
1 p.e. → time resolution 1.1ns
→ charge resolution 35%

Photosensor testing

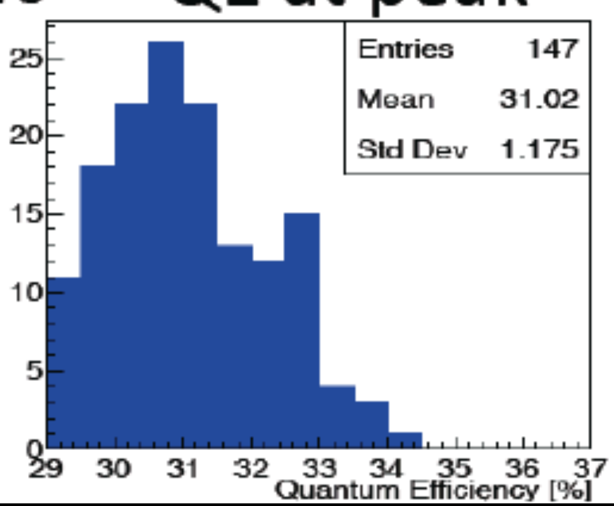
Y.Nishimura, talk at NEPTUNE2018

150 Box&Line 50 cm PMTs were manufactured
- all PMTs were tested at high pressure water ≤0.95 Mpa
- no damages were found

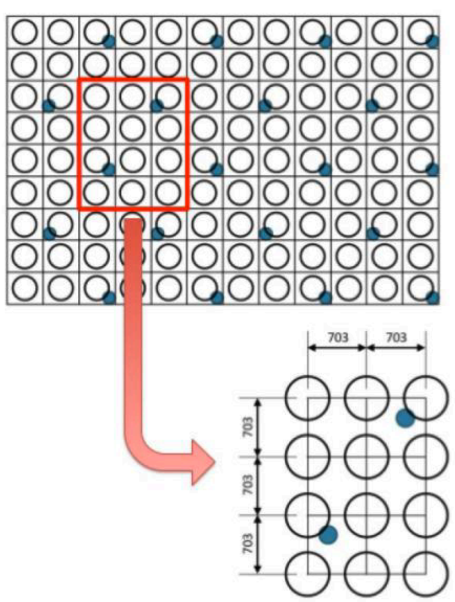
QE Spectra of ~150 PMTs



QE at peak



Box&Line



Alternative designs being discussed using multi-PMT modules, photon traps, …

Summary of Hyper-K parameters

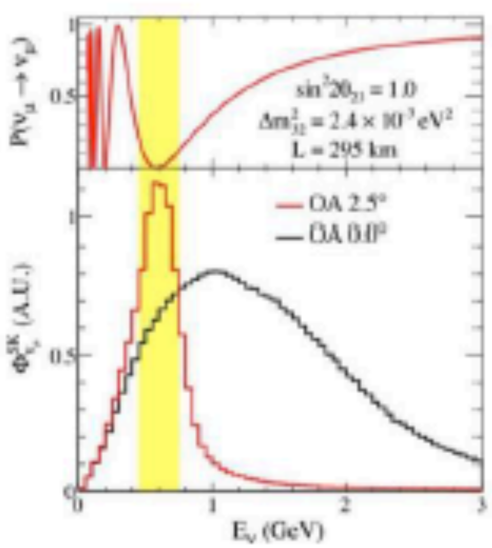
	Kamiokande	Super-K	Hyper-K
Depth	1,000 m	1,000 m	650 m
Dimensions of water tank			
diameter	15.6 m ϕ	39 m ϕ	74 m ϕ
height	16 m	42 m	60 m
Total volume	4.5 kton	50 kton	258 kton
Fiducial volume	0.68 kton	22.5 kton	187 kton
Outer detector thickness	$\sim$ 1.5 m	$\sim$ 2 m	1 $\sim$ 2 m
Number of PMTs			
inner detector (ID)	948 (50 cm ϕ)	11,129 (50 cm ϕ)	40,000 (50 cm ϕ)
outer detector (OD)	123 (50 cm ϕ)	1,885 (20 cm ϕ)	6,700 (20 cm ϕ)
Photo-sensitive coverage	20%	40%	40%
Single-photon detection efficiency of ID PMT	unknown	12%	24%
Single-photon timing resolution of ID PMT	$\sim$ 4 nsec	2-3 nsec	1 nsec

Tokai-to-Hyper-K Beam

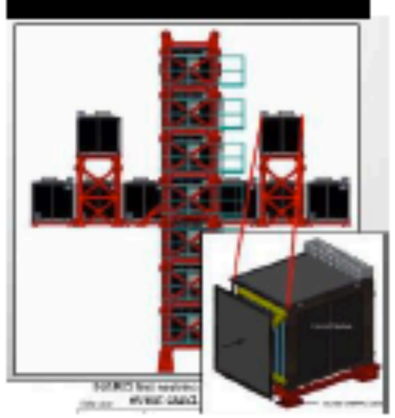
Hyper-K

J-PARC

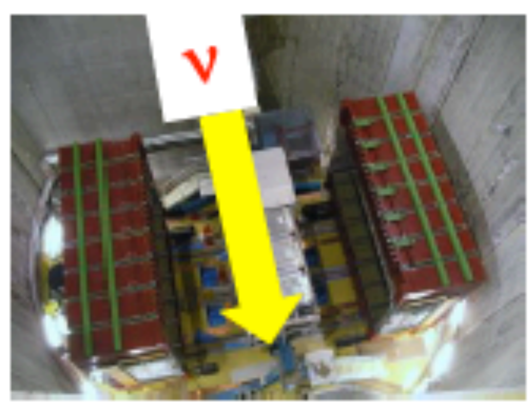
Off-axis neutrino beam



Neutrino monitor INGRID



Off-axis near neutrino detector



Decay tunnel

Horn

Target

Near neutrino detector at 280 m from target

Neutrino beam elements

J-PARC neutrino beam

2.5°off-axis, peak energy 600 MeV (oscillation maximum), current beam power 485 kW

Tokai-to-Hyper-K Beam

Power upgrade from ~0.5 to 1.3 MW

1st priority among projects which require new funding requests in KEK Project Implementation Plan (KEK-PIP)

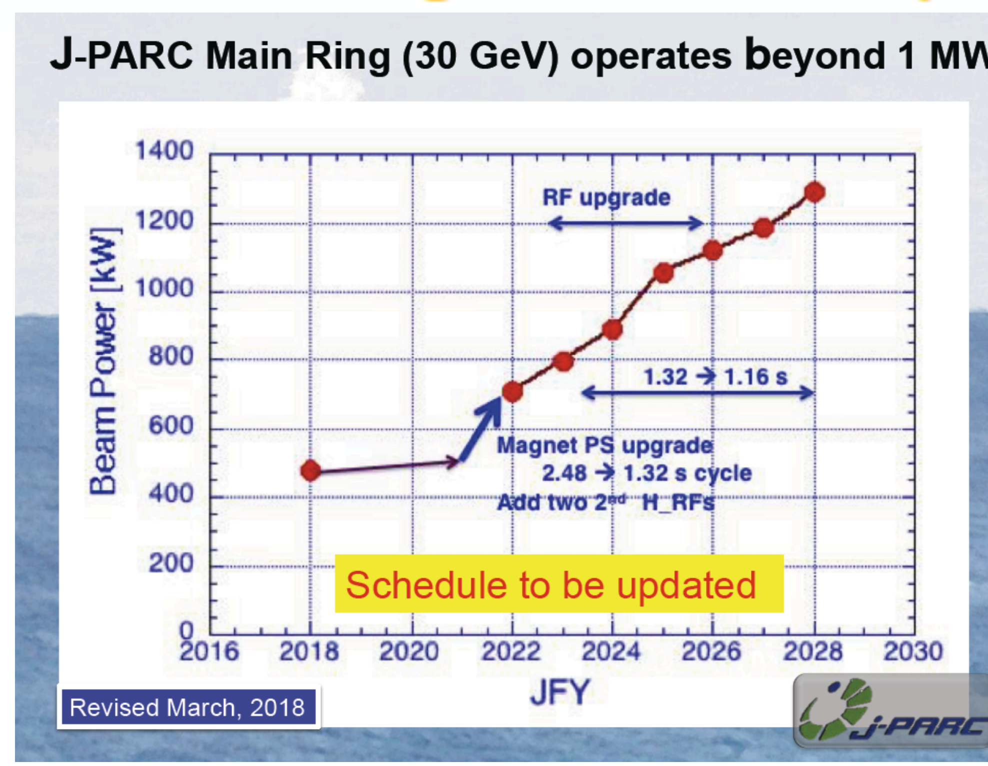
- Increase repetition rate: **Funding started**
  - MR magnet power supply upgrade
  - MR RF upgrade (High grad/PS)
  - MR Fast Extraction Kicker upgrade
- Higher #p/p
  - MR RF upgrade (PS)

Beam Power (kW)	485 (Achieved)	(940)	1,300 (Goal for T2K-II)
#p/p(10^{12})	250	250	310
Rep T (s)	2.48	1.28	1.16

+25%

Funding started

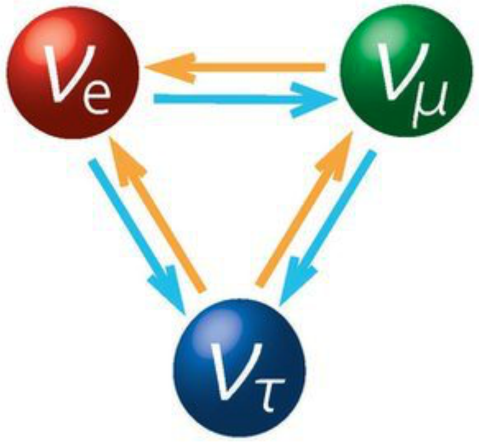
-10%

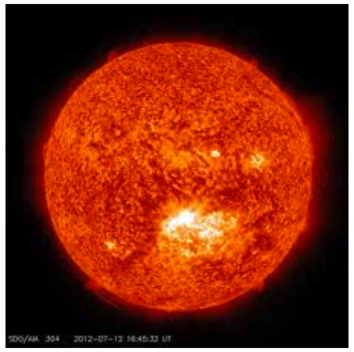


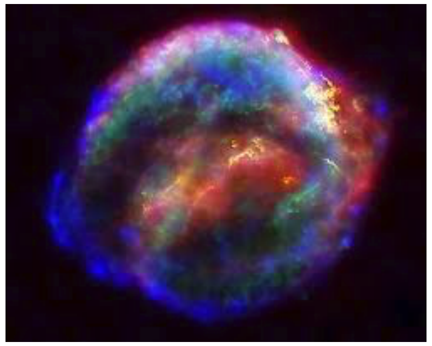
Hyper-K Science Program

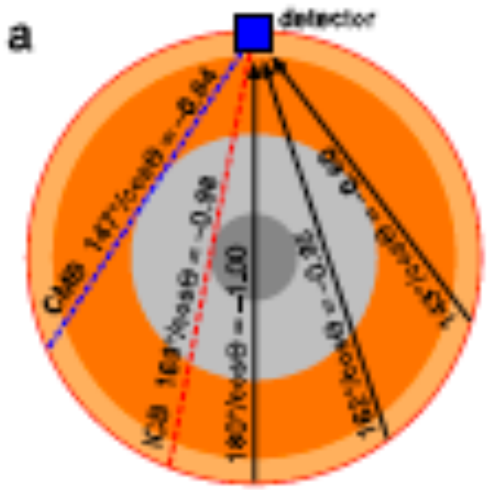
Hyper-K Science Program

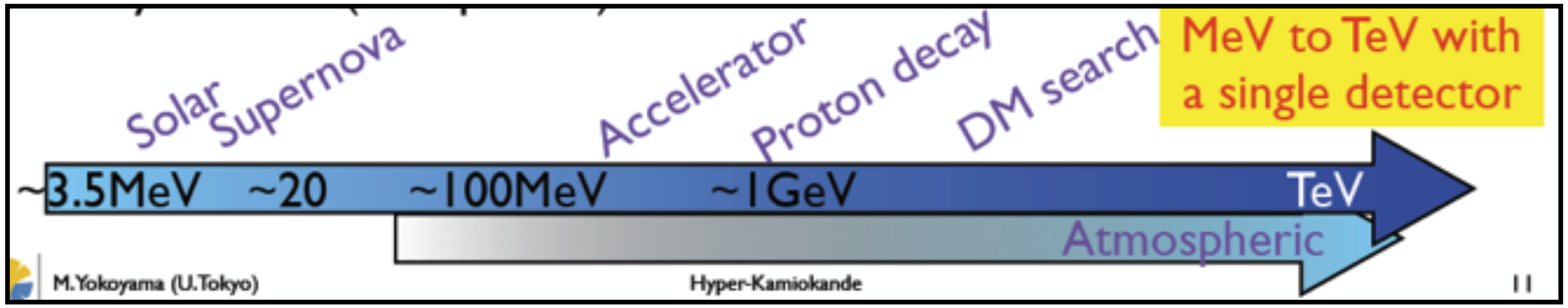
- Nucleon decays
- Comprehensive Neutrino Properties measurement program using Solar, Atm, and Accelerator ν's
  - $\theta_{12}, \theta_{23}, \theta_{13}, \Delta m^2_{21}, \Delta m^2_{32}$, CPδ
- BSM Physics
  - Dark matter, …
- Neutrino astronomy and astrophysics
  - Supernova burst neutrinos
  - DSNB - Diffuse supernova neutrino background
- Earth Science
  - Earth tomography









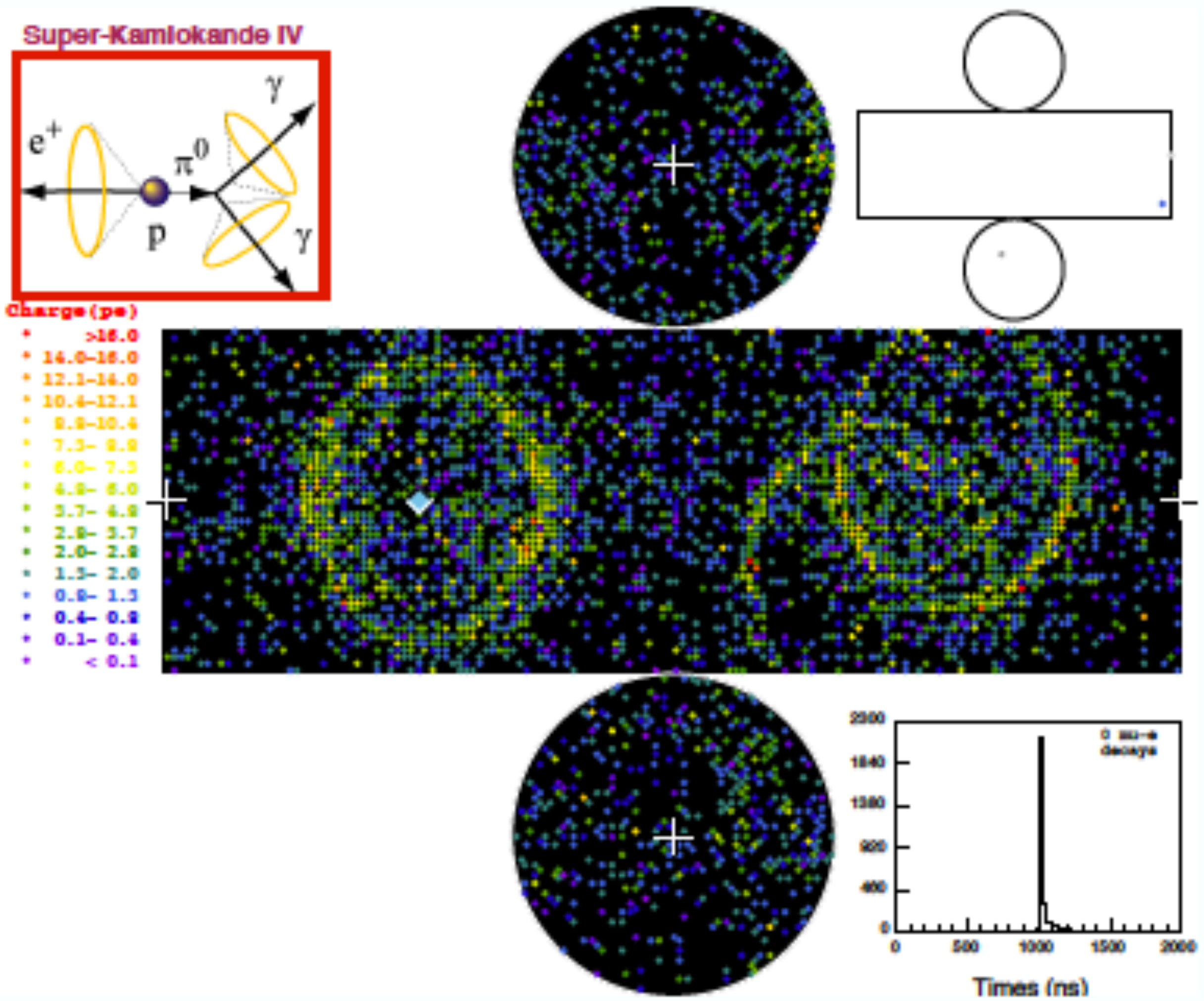


Nucleon decay

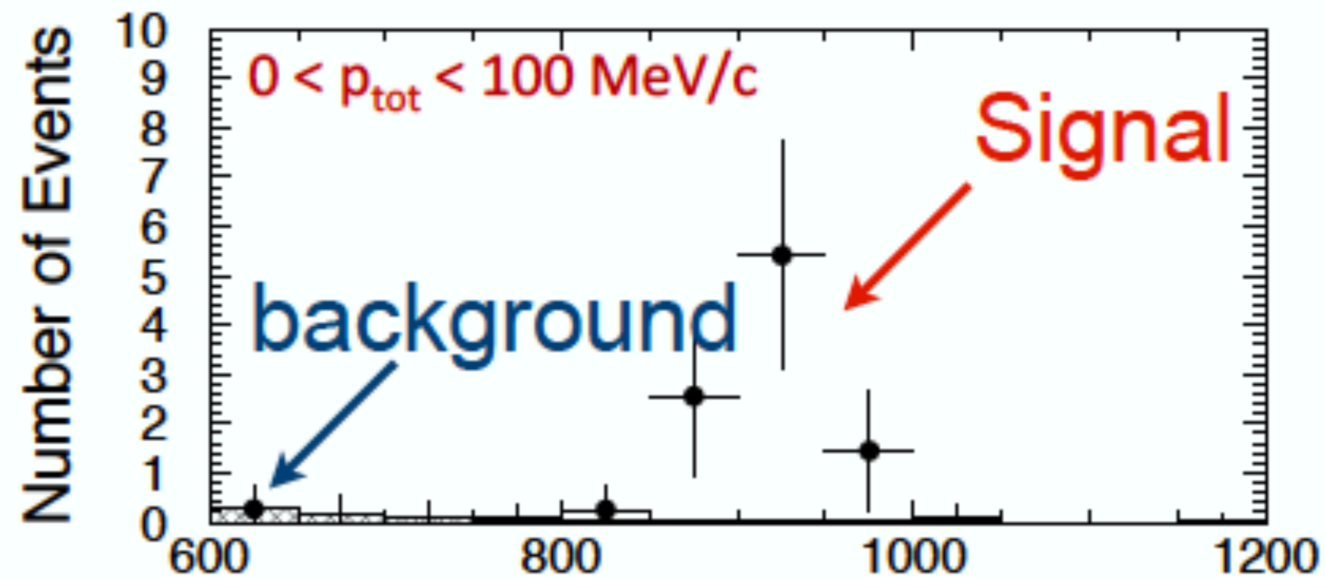
Nucleon Decay

World-leading searches from Super-K to Hyper-K

Cherenkov ring image in Super-K



Hyper-K 10 years operation assuming
τ_{proton}=1.7×10^{34}years (SK limit)

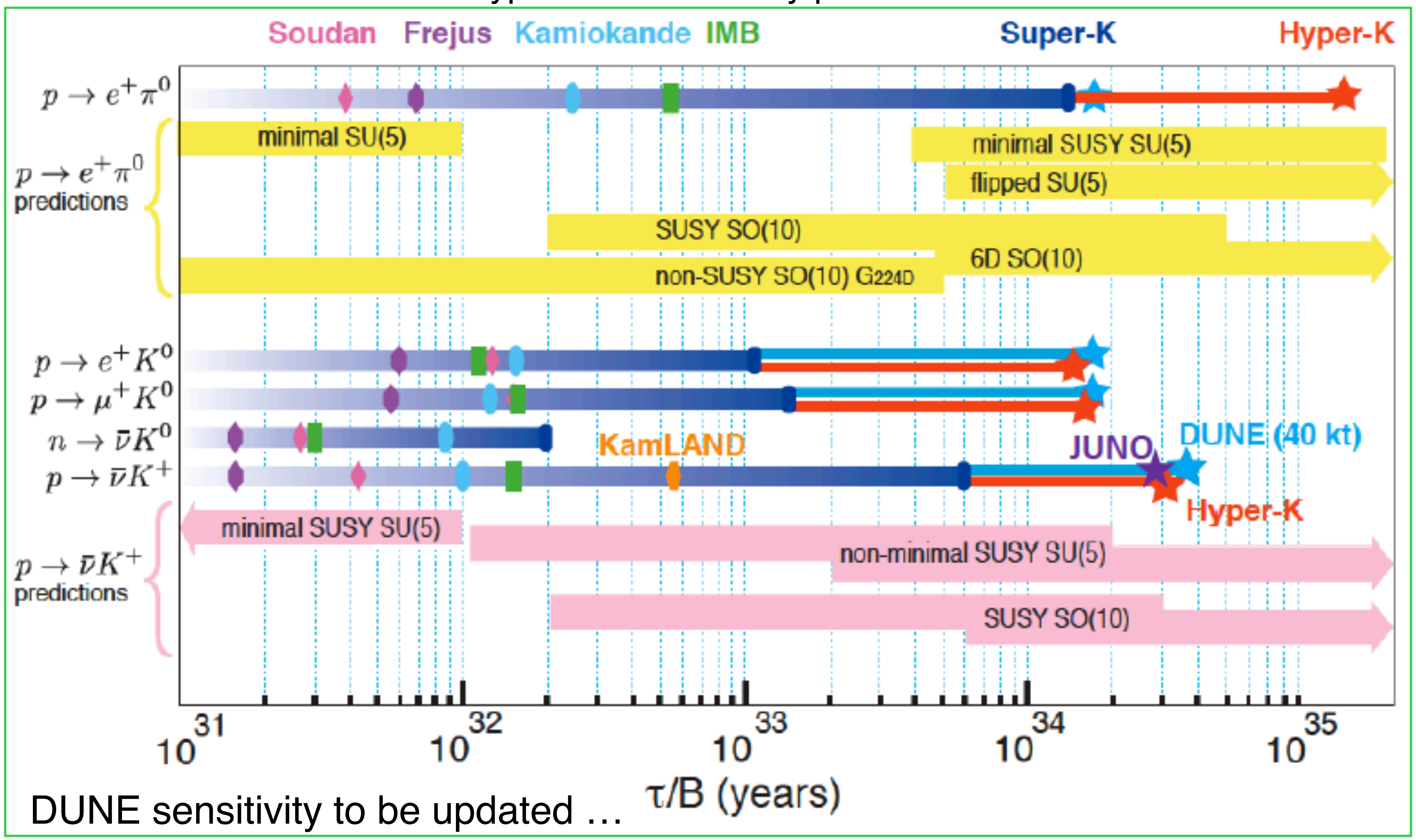


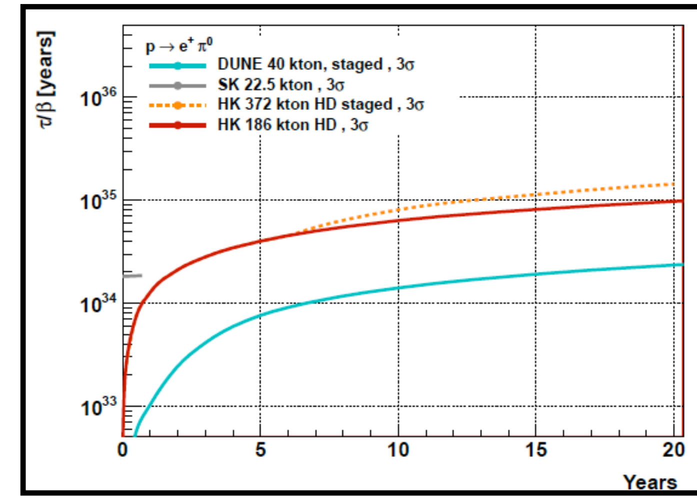
3σ reach to 10^{35} yrs

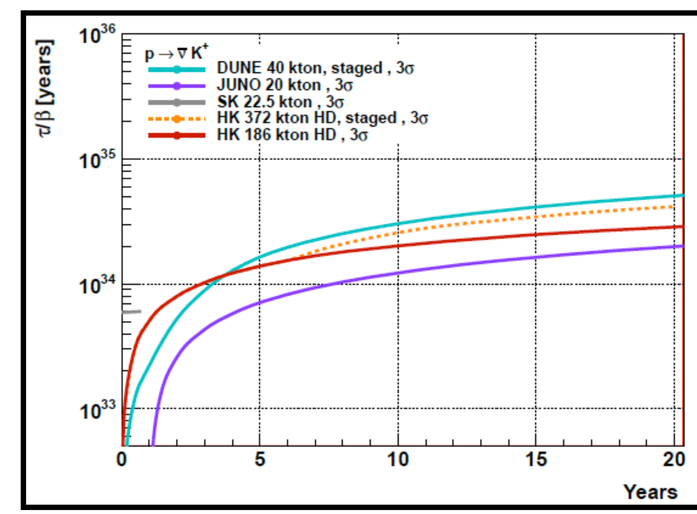
Neutron tagging is a key to further reduce the atmospheric neutrino backgrounds associated with

Nucleon Decay

Hyper-K 3σ discovery potential







	material	Fiducial Mass (kton)
Super-K	Water	22
Hyper-K	Water	190
Dune	Argon	40
JUNO	Liq. Scinti	20

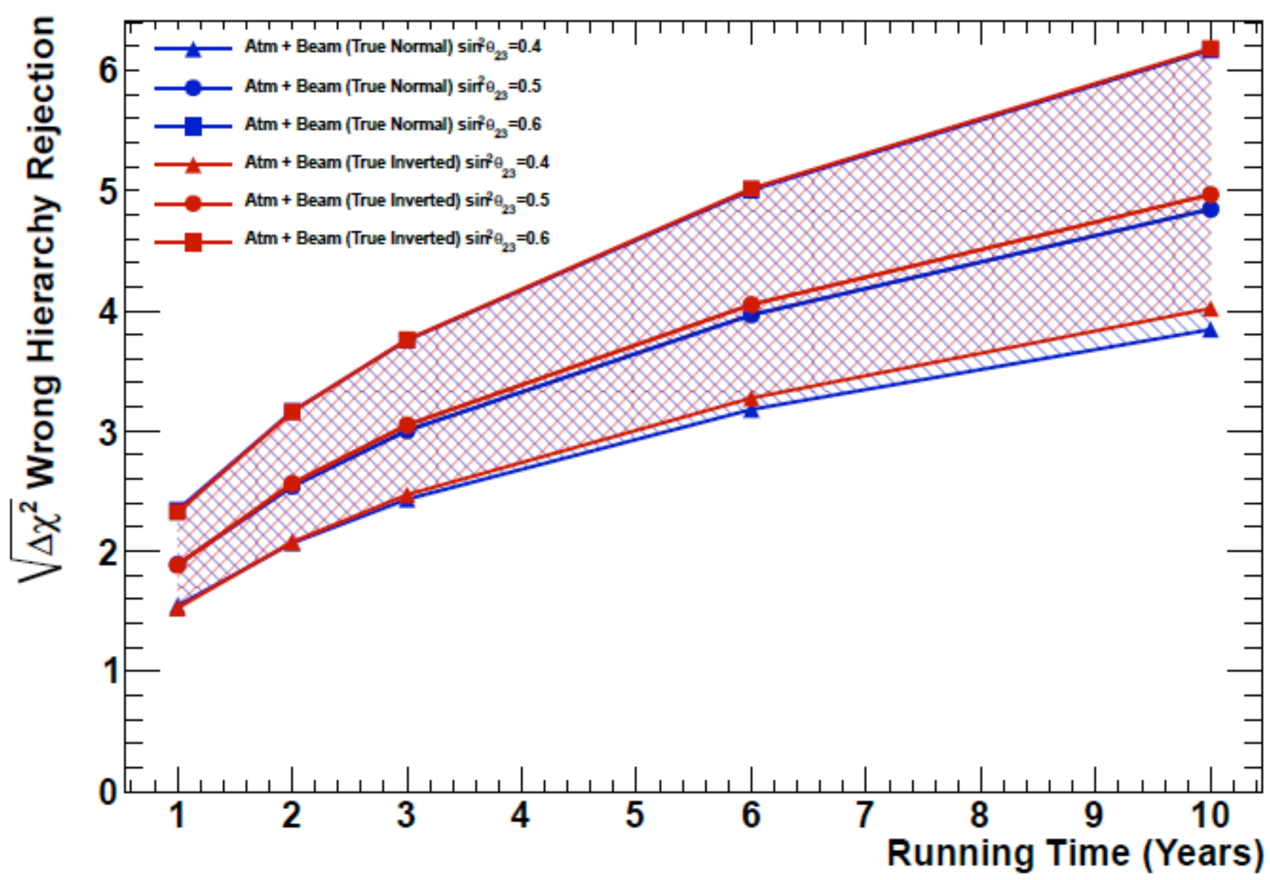
- Proton decay discovery potential for many decay mode
  - **$p \to e^+\pi^0$; 1×10^{35} yrs with 3σ CL**
  - **$p \to \nu K^+$; 3×10^{34} yrs**

Neutrino Oscillations

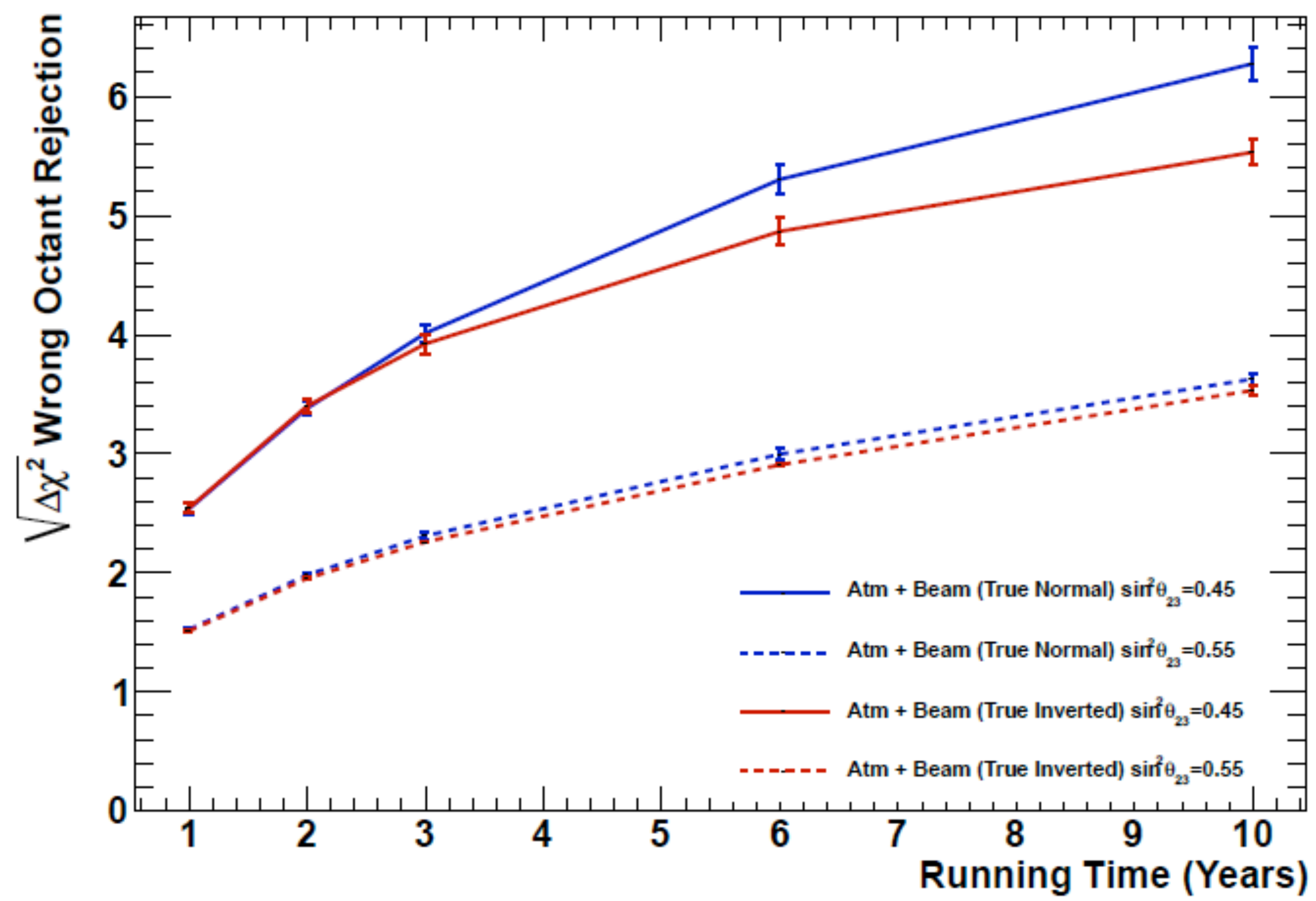
Atmospheric Neutrinos

Joint analysis of atmospheric and accelerator neutrinos

Sensitivity to mass hierarchy



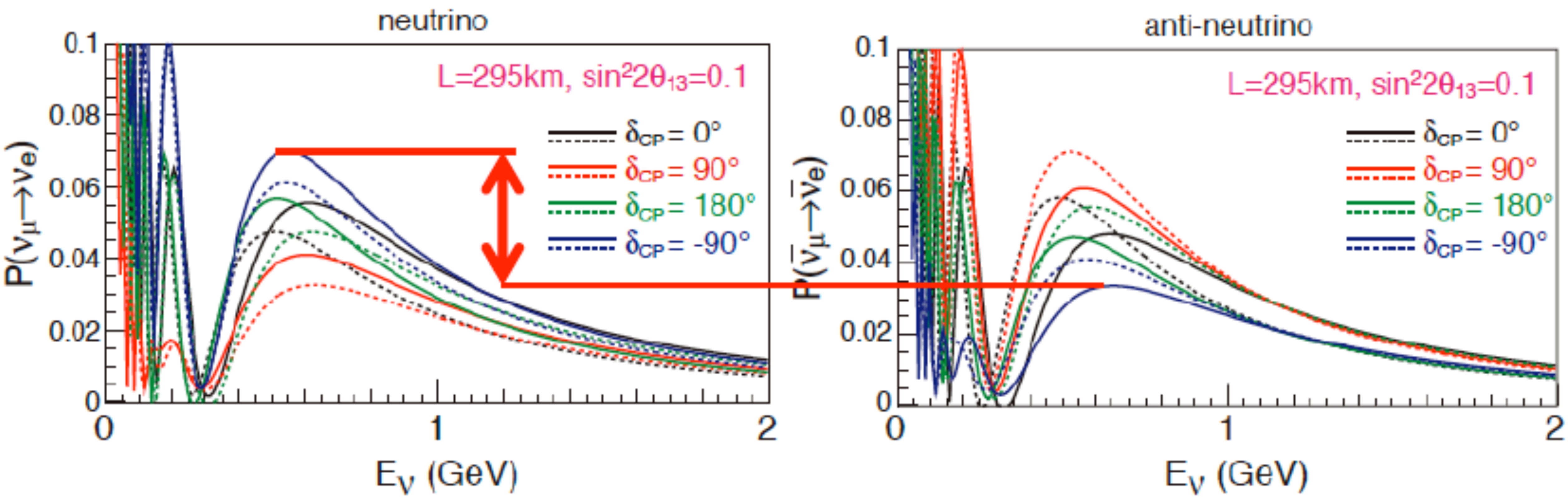
Octant sensitivity



1 Hyper-K tank 3σ rejection of wrong hierarchy with 10 year data

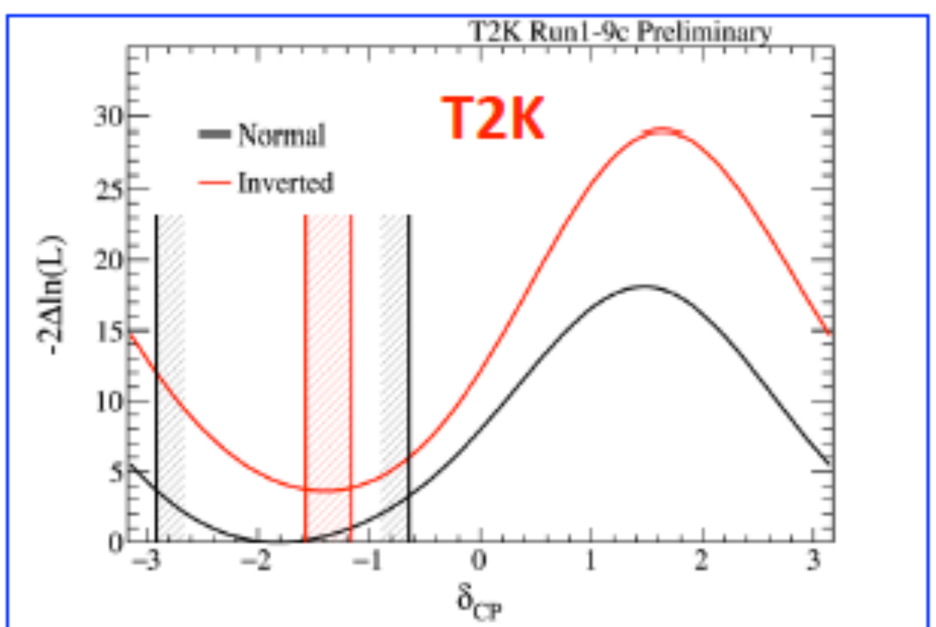
1 Hyper-K tank can resolve octant at 3σ, for $|45^0 - \theta_{23}| \geq 2.3$ deg

CP violation



$$L = 295\,\mathrm{km},\ \sin^2 2\theta_{13} = 0.1,\ \sin^2 2\theta_{23} = 1.0,\ \delta_{CP} = -90^\circ$$

Hint on maximal CP violation, δ ~ -π/2



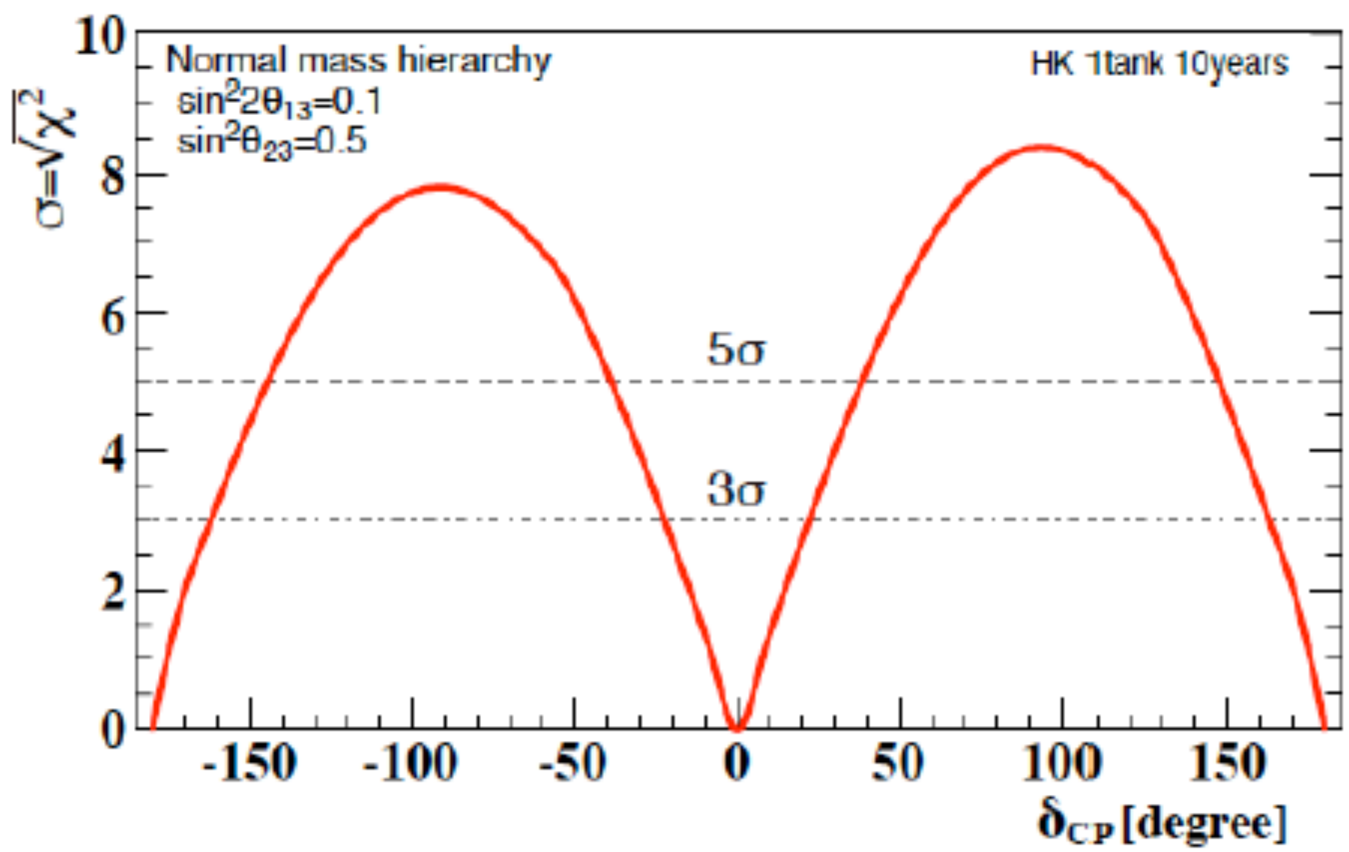
E = 0.6 GeV, $\Delta m^2_{32} L/4E \approx 1$

$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)}$$

For δ = - π/2
→ CP violation effect A_{CP} ~ 28%, matter effect ~8%

Hyper-K CP sensitivity

Integrated beam power 1.3 MW x 10^8 s
→ 2.7 x 10^{22} POT with 30 GeV proton beam
$\nu : \bar{\nu} = 1:3$ $\sin^2 2\theta_{13} = 0.1$



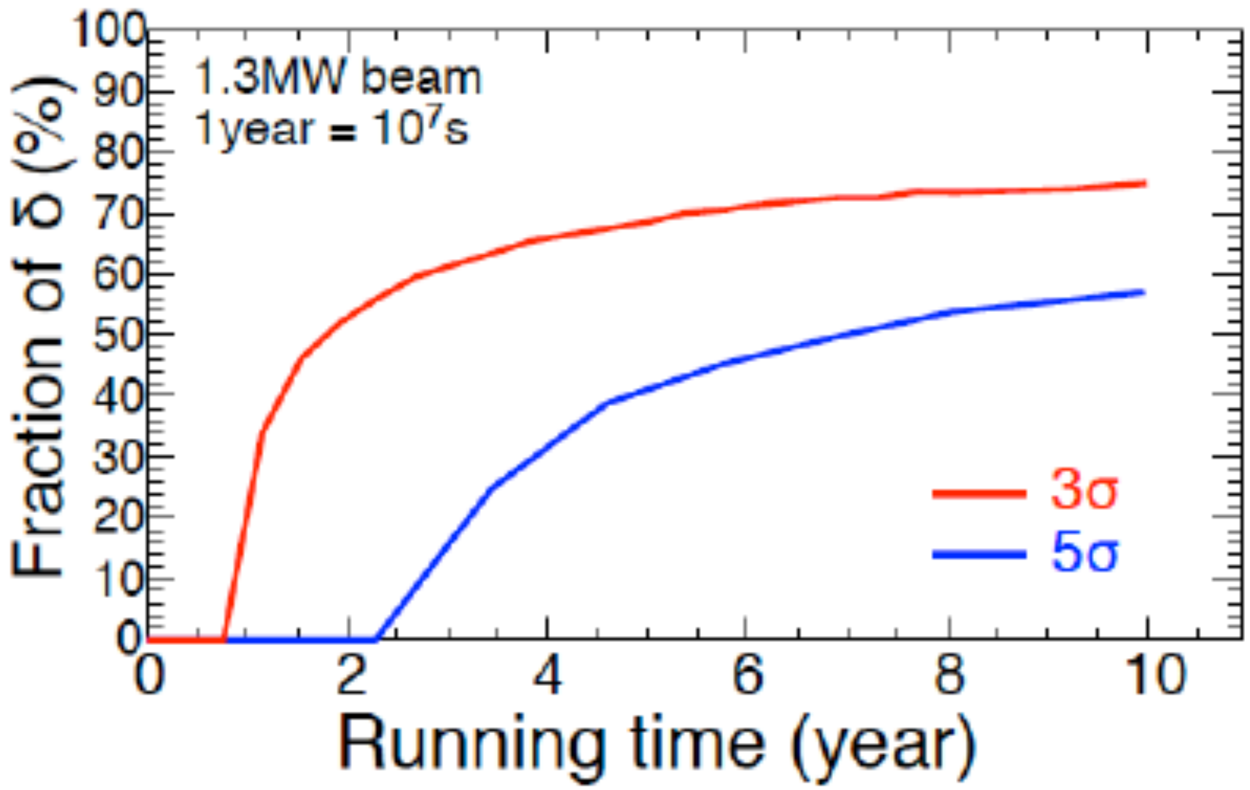
Hyper-K: uncertainties of expected number events

$\nu_\mu \rightarrow \nu_e$	3.2%
$\nu_\mu \rightarrow \nu_\mu$	3.6%
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	3.9%
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$	3.6%

T2K systematic uncertainties **5-6 %**

Exclusion of δ=0 at 8σ (for δ= -π/2)
5σ (3σ) significance for 57 (80)% of possible δ values

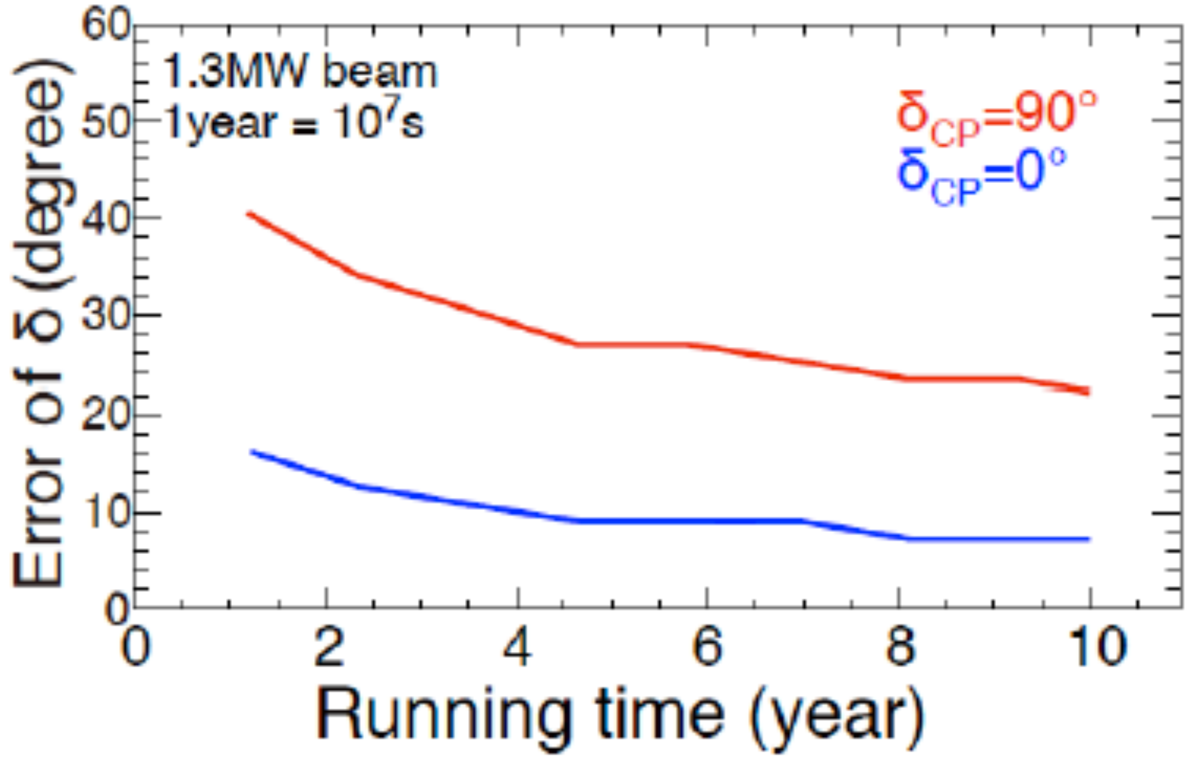
Hyper-K CP sensitivity

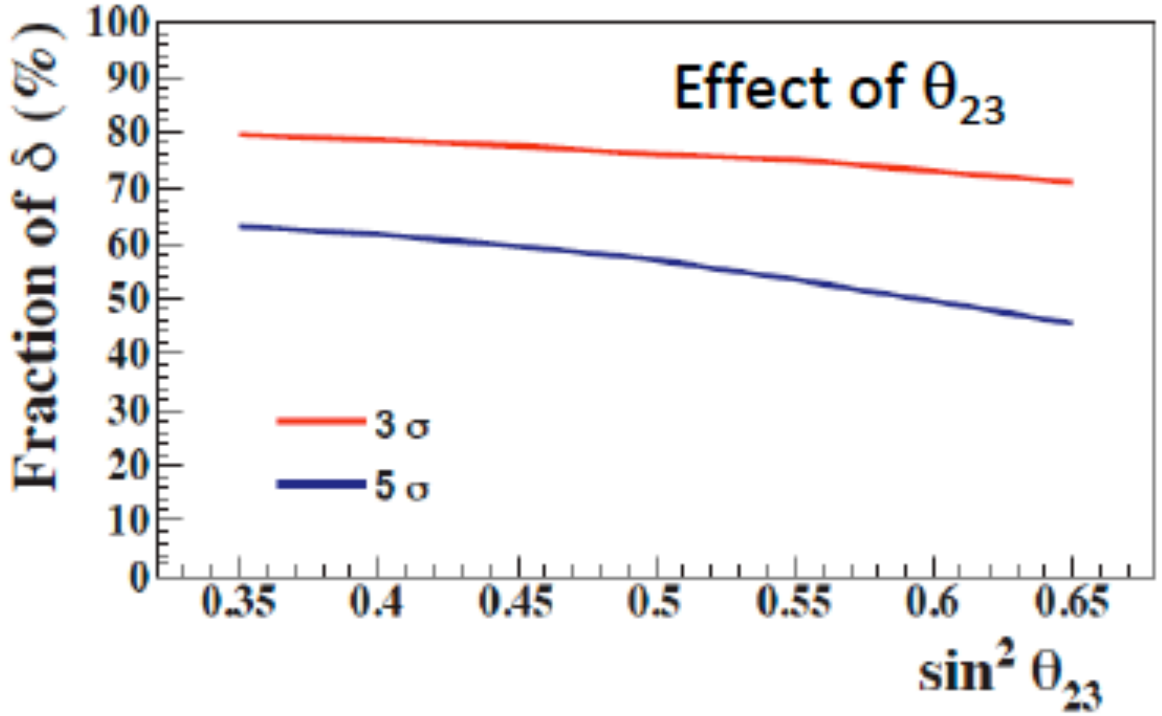


Measurement of δ

δ = 90 deg σ = 23 deg

δ = 0 deg σ = 7 deg





CPV Global Picture

arXiv:1805.04163

Hyper-K
- Single tank
- Normal hierarchy
- Systematics 3-4%

$\nu : \bar{\nu} = 1:3$

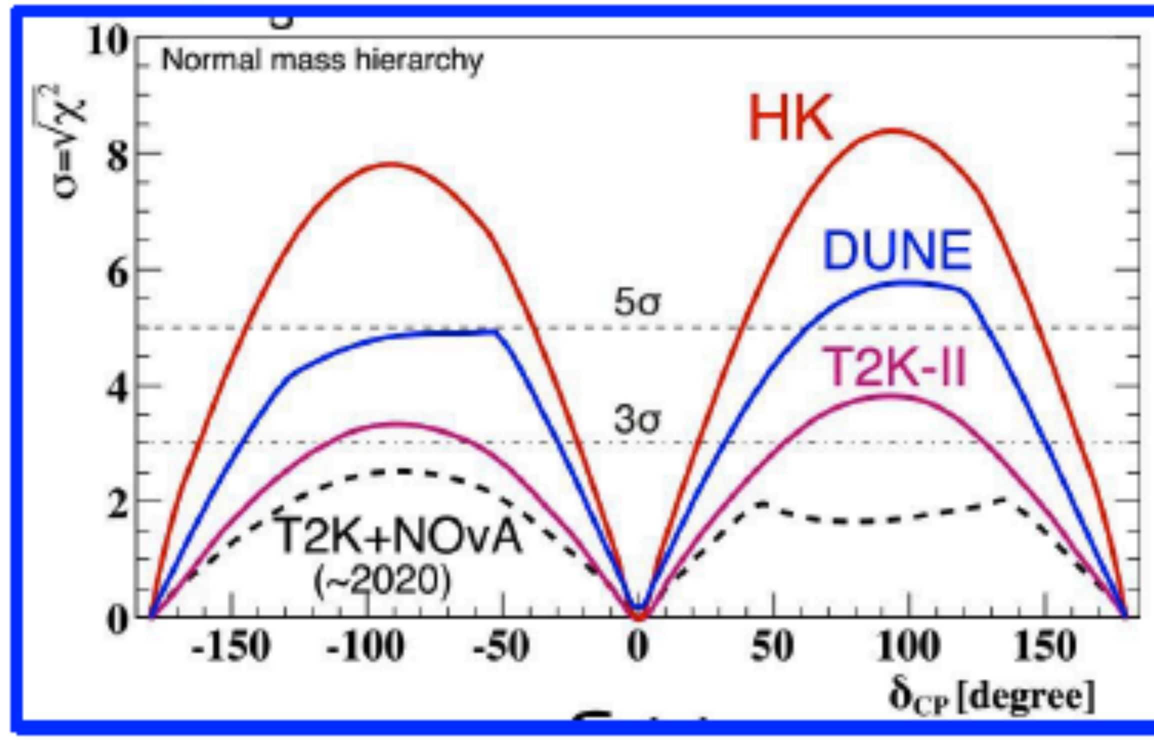
- CPV (δ = -90 deg, 5σ)
  → 1.3MW x 4 years

arXiv:1807.10334

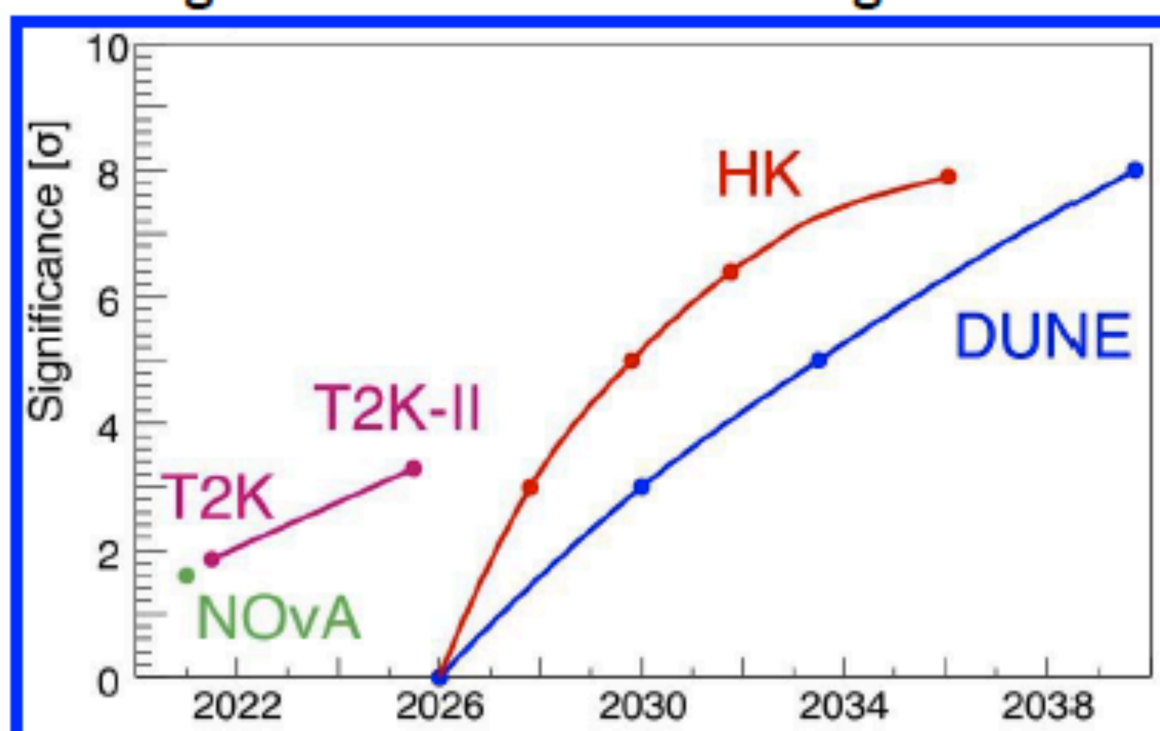
DUNE
- Staging plan
- Normal hierarchy
  $\nu : \bar{\nu} = 50\% : 50\%$
- CPV (δ = -90 deg, 5σ) 253 kt·MW·year
  → 6.5 years

Combination T2K-II and NOvA can reach ~4.5σ for δ = -90 deg by 2026

Significance for δ = 0 exclusion



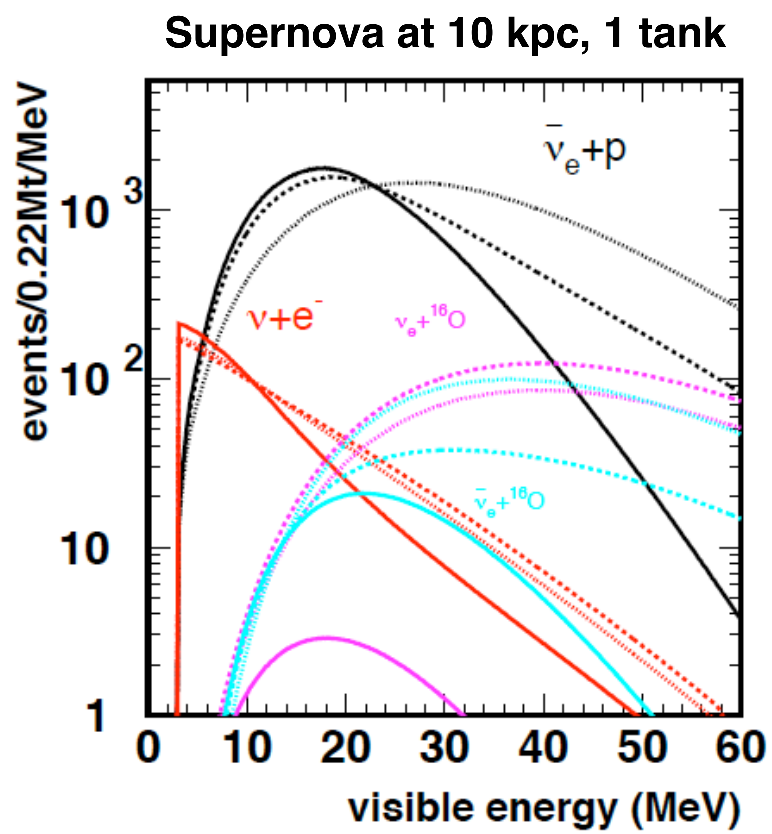
Significance for δ = -90 deg

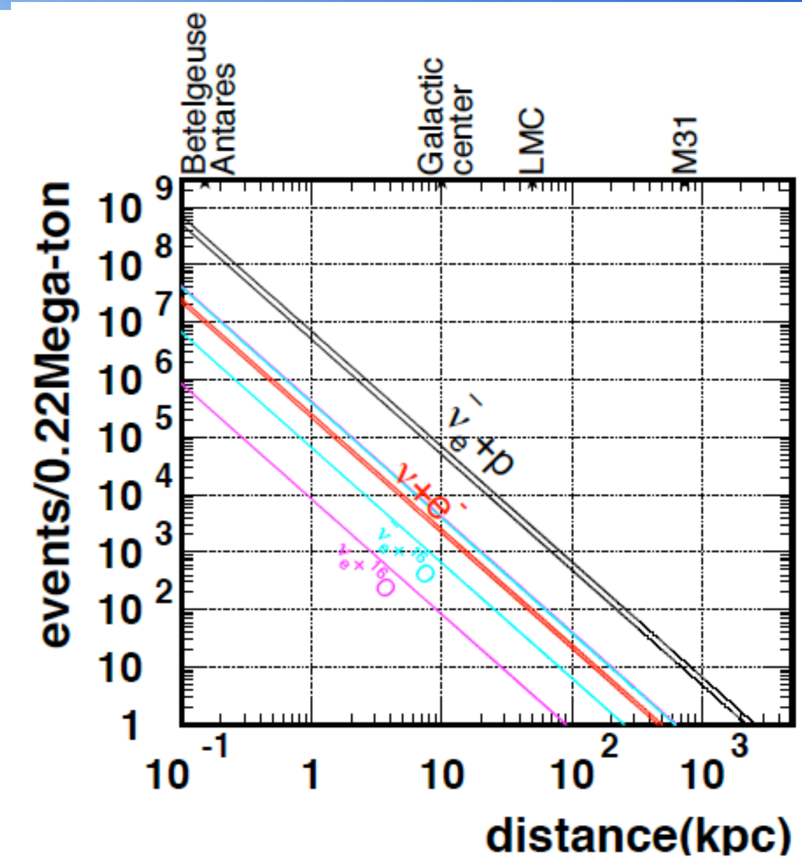


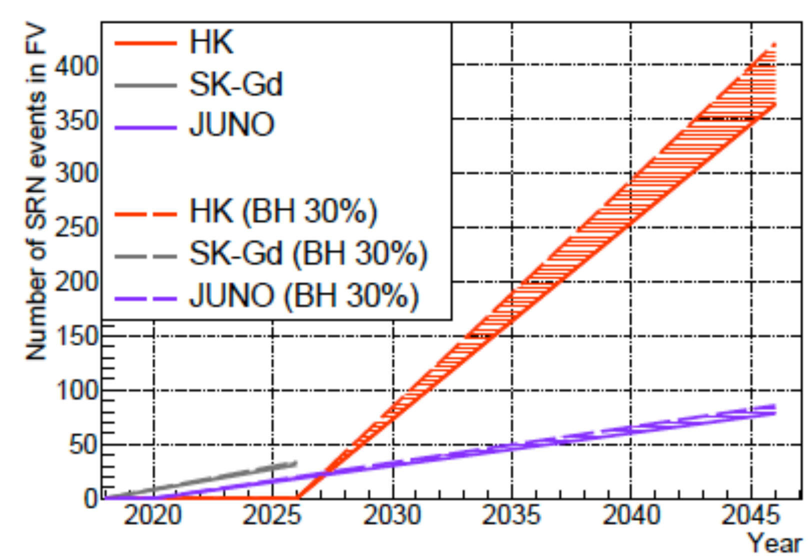
Supernova Neutrinos

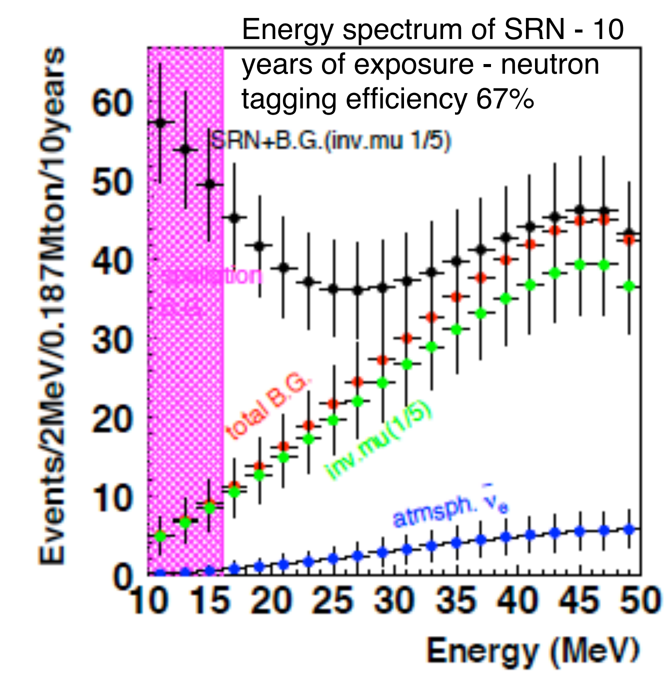
Supernova Neutrinos

- **Supernova burst**
  - Sensitive to even SNe in Andromeda
  - 50-80 k events / SN @10 kpc
  - Time and energy profile with high statistics
    - Explore dynamics of SN central engine
    - Explosion mechanism, NS/BH formation
  - 1° pointing for SN alerts - Multi-messenger (Optical, GW, …)
- **DSNB - Diffuse Supernova ν**
  - Super-K-Gd expected to observe first
  - HK will measure the spectrum
    - History of star/BH formation





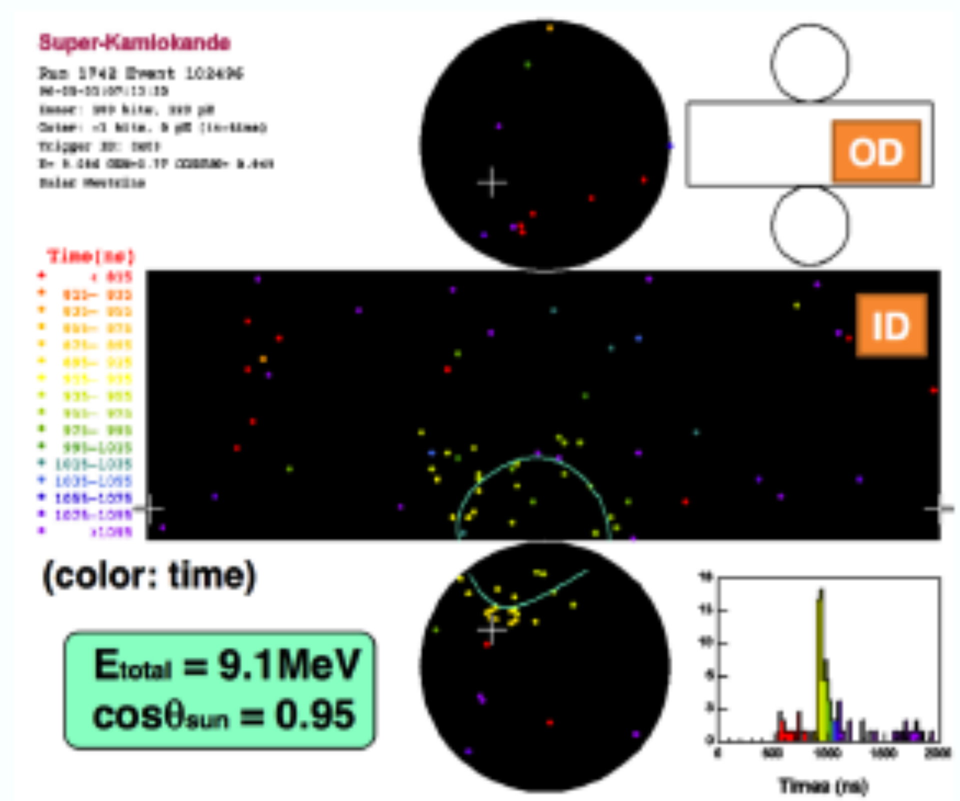


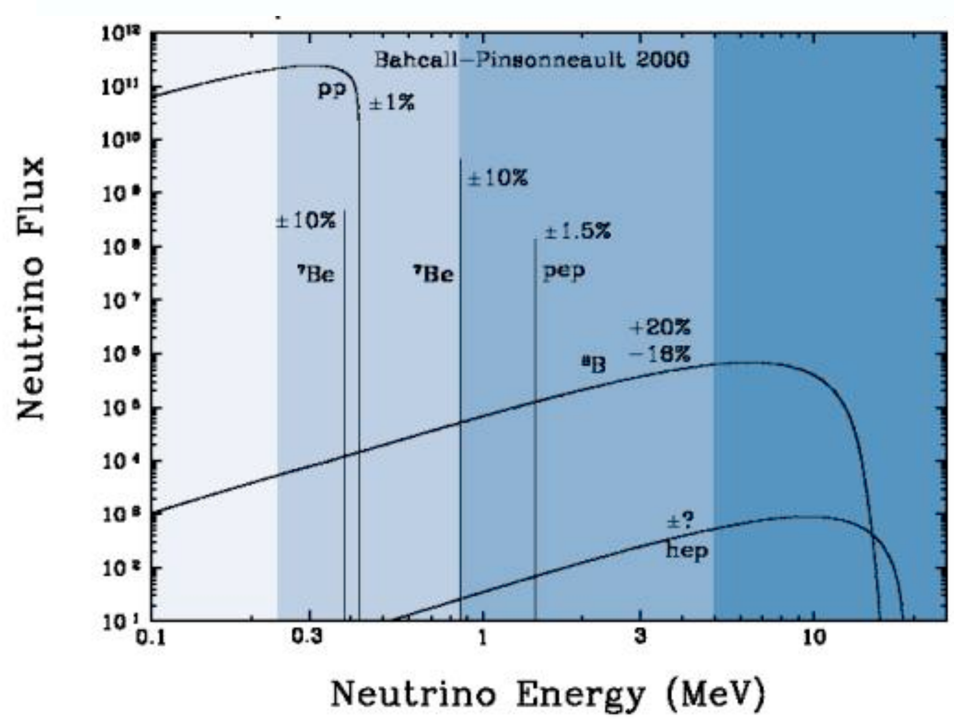


Solar Neutrinos

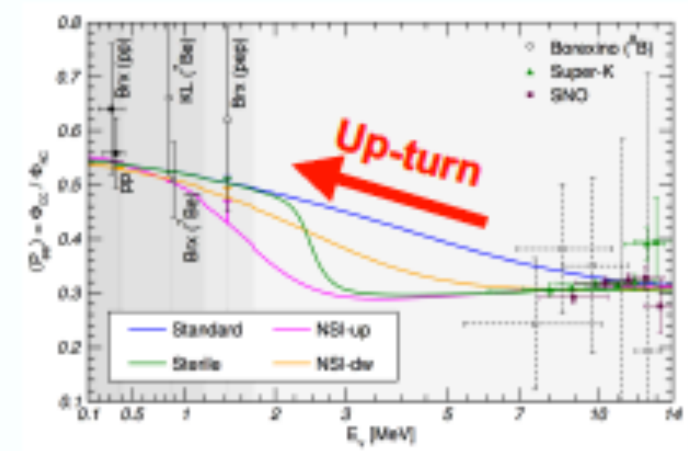
Solar Neutrinos

Cherenkov ring image in Super-K





survival probability of electron solar neutrinos



- **Neutrino oscillation study**
  - Precision measurements of spectrum and day/night flux asymmetry (test of standard matter effect or exotic scenario?)
- **Solar physics**
  - First observation of Hep ($^3He+p \rightarrow {}^4He+e^++\nu_e$) neutrinos

⇒ Low energy threshold,

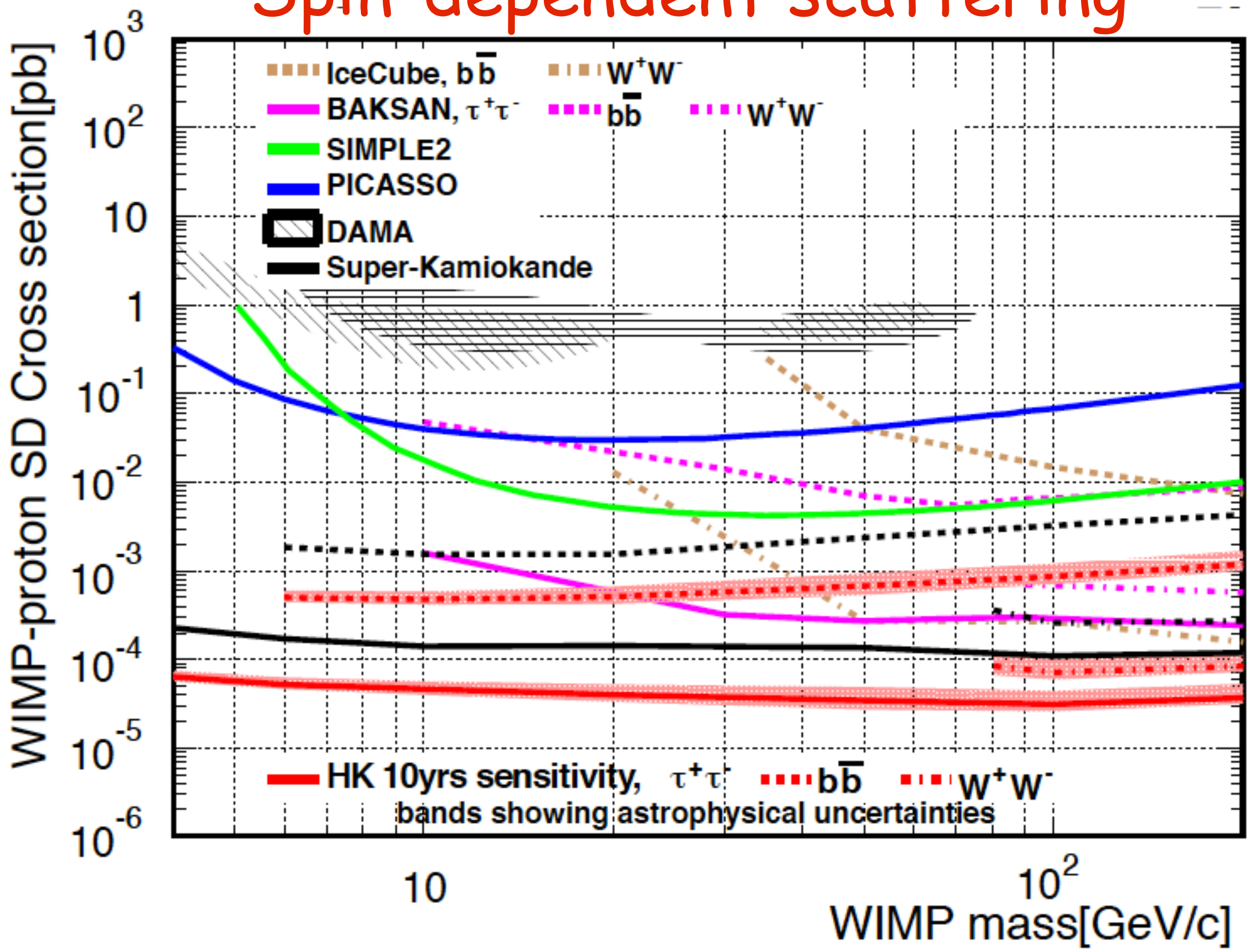
high resolution reconstruction, and low background are critical

more Science …

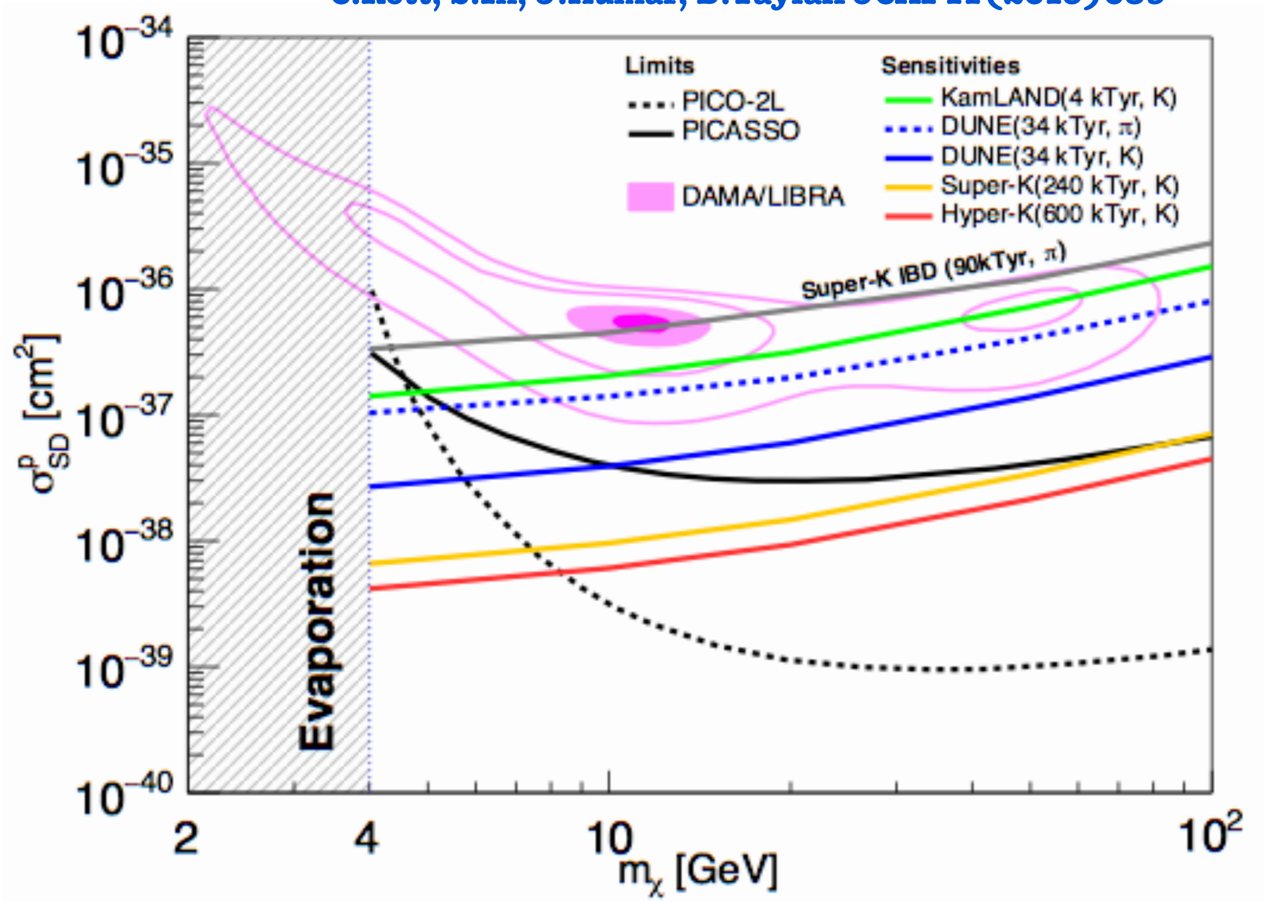
more science (Dark Matter)…

Solar Dark Matter

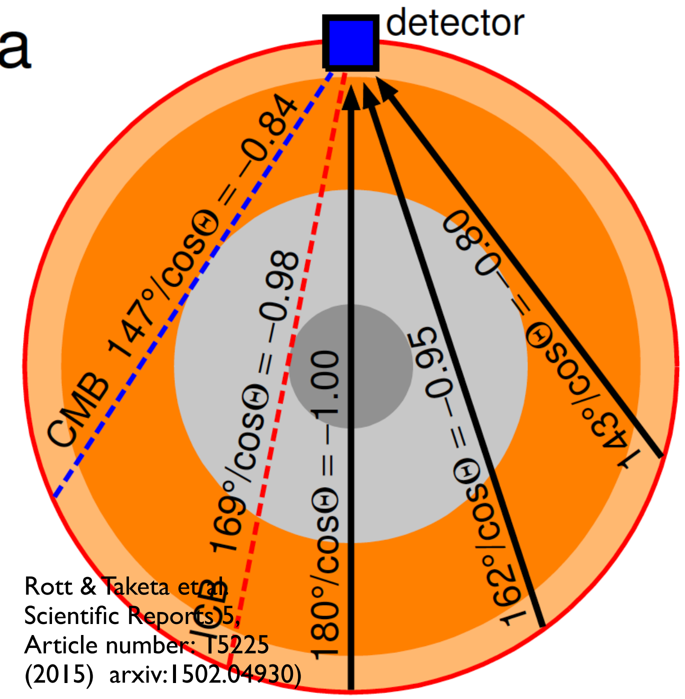
Spin-dependent scattering

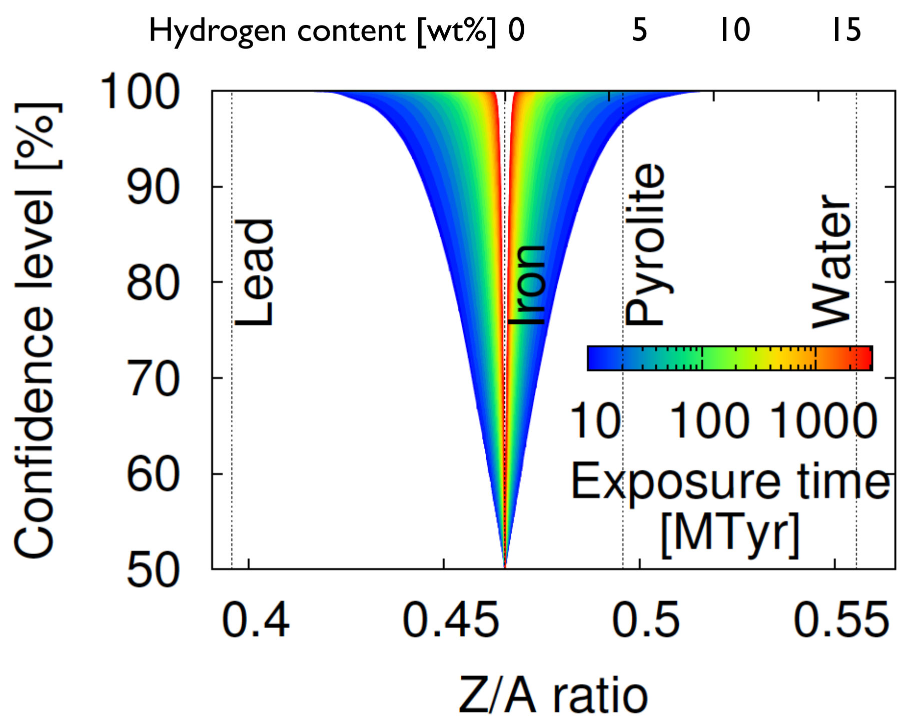


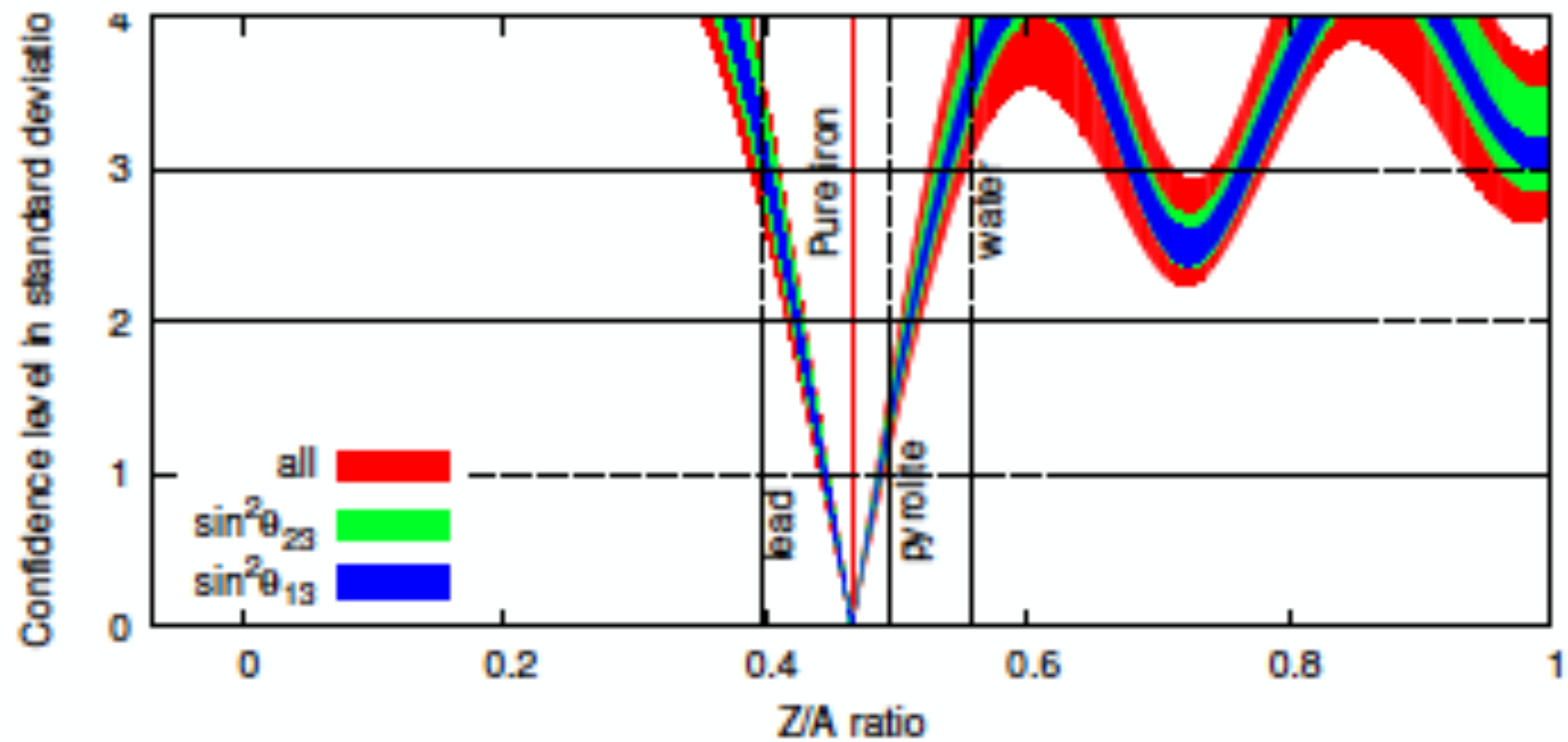
C.Rott, S.In, J.Kumar, D.Yaylali JCAP11(2015)039

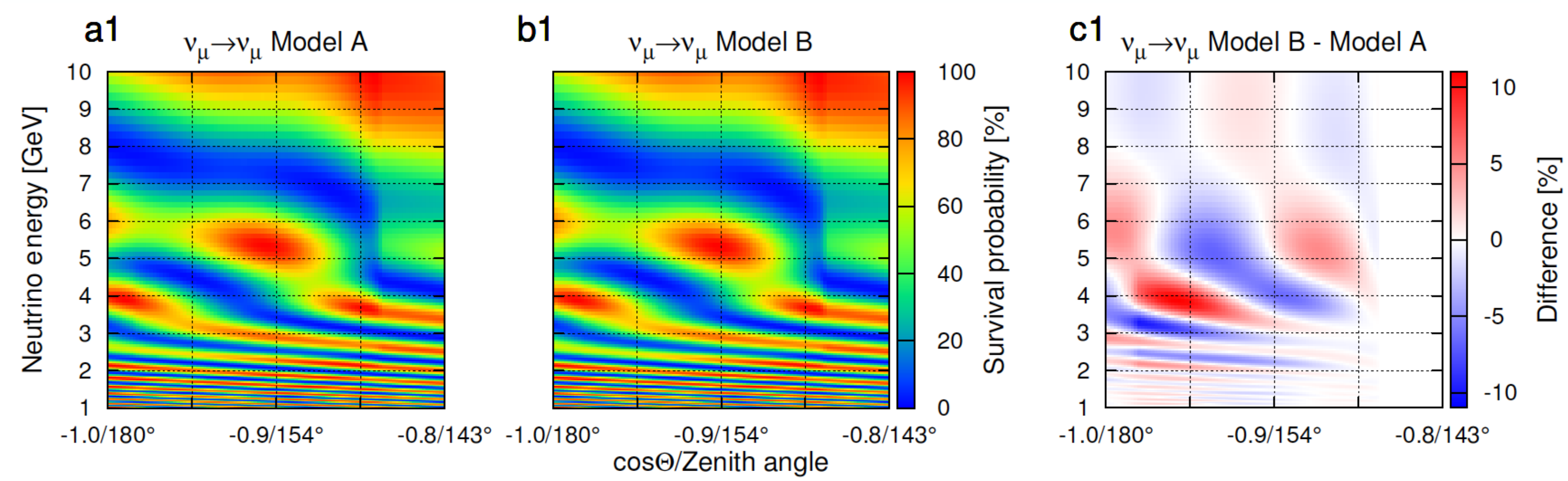


Neutrino Tomography









- Sensitivity to the outer Earth core composition
- Constrain the hydrogen content of the outer Earth core to a few wt%

Status

Hyper-K Status in Japan

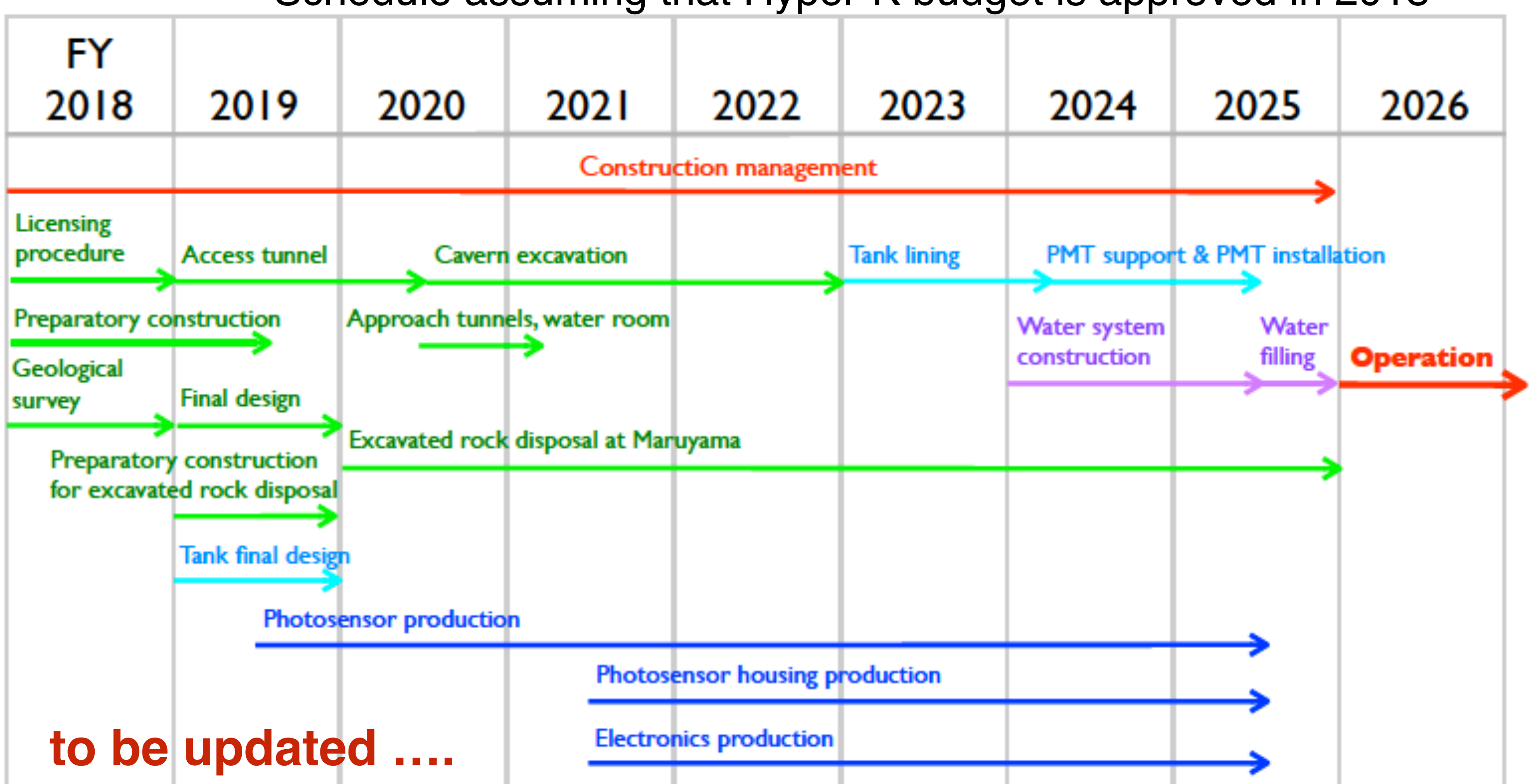
- In the end of Aug. 2018, MEXT has decided to request the budget to Ministry of Finance for "funding for feasibility study."
- In the Japanese system, "funding for feasibility study" implies "seed funding". For example;
  - Super-Kamiokande received the "funding for feasibility study" in 1990, and the construction budget was approved in 1991.
  - Other examples include: Subaru telescope (8m telescope at Hawaii), ALMA telescope in Chili (for 2 years), and TMT (30 meter telescope in Hawaii).
- Then, the President of the Univ. of Tokyo, in recognition of both the project's importance and value both nationally and internationally, pledged to ensure construction of the Hyper-Kamiokande detector commences as scheduled in April 2020.

Hyper-K excavation will begin in 2020!
(will begin observation in ~2027)

Hyper-K Status

- International Hyper-Kamiokande proto-collaboration has been formed
- Two host institutions: U Tokyo/ICRR and KEK/IPNS
- U Tokyo has created a new institution for Hyper-K construction: Next generation Neutrino Science Organization (NNSO)
- Hyper-Kamiokande was selected to be listed on the Large Projects Roadmap of the Japanese Ministry of Education, Culture, Sports, Science (MEXT) (August 4, 2017)
- Statement from the President of The University of Tokyo Concerning the Start of Hyper-Kamiokande (September 12, 2018)
- Hyper-Kamiokande Experiment to begin construction in April 2020 (September 19, 2018)

Schedule assuming that Hyper-K budget is approved in 2018



Press Release

Hyper-Kamiokande Experiment to Begin Construction in April 2020
(press release September 19, 2018)

- Last week at the 7th Hyper-Kamiokande proto-collaboration meeting, a statement was issued by the University of Tokyo recognizing the significant scientific discoveries which the planned Hyper-Kamiokande experiment would enable.
- It states that, based on these exciting prospects, the University of Tokyo will ensure that construction of the experiment will begin in 2020. Hyper-Kamiokande now moves from planning to a real experiment.
- The Hyper-Kamiokande proto-collaboration welcomes this exciting endorsement of the project and the boost it will give to increasing even further the international contributions and participation in the experiment. Introducing the statement, Professor Takaaki Kajita, Director of the Institute for Cosmic Ray Research at the University of Tokyo and 2015 Nobel Laureate in Physics, pointed out that the Japanese funding agency MEXT has included seed funding for Hyper-Kamiokande in its JFY 2019 budget request. He illustrated with many examples that it is standard in Japan for large projects to begin with a year of seed funding, and said that in any case the **University of Tokyo commitment meant that Hyper-Kamiokande construction will begin in April 2020**.
- The Hyper-Kamiokande Proto-Collaboration will now work to finalize designs, and is very open to more international partners to join in this far-reaching new experiment.

http://www.hyperk.org/?p=387

Organization

Hyper-K Organization

Hyper-Kamiokande Governance Structure

http://www.hyperk.org/?page_id=67

Leadership
Project leader: M. Shiozawa (Japan)
Project co-leader: F. Di Lodovico (UK)

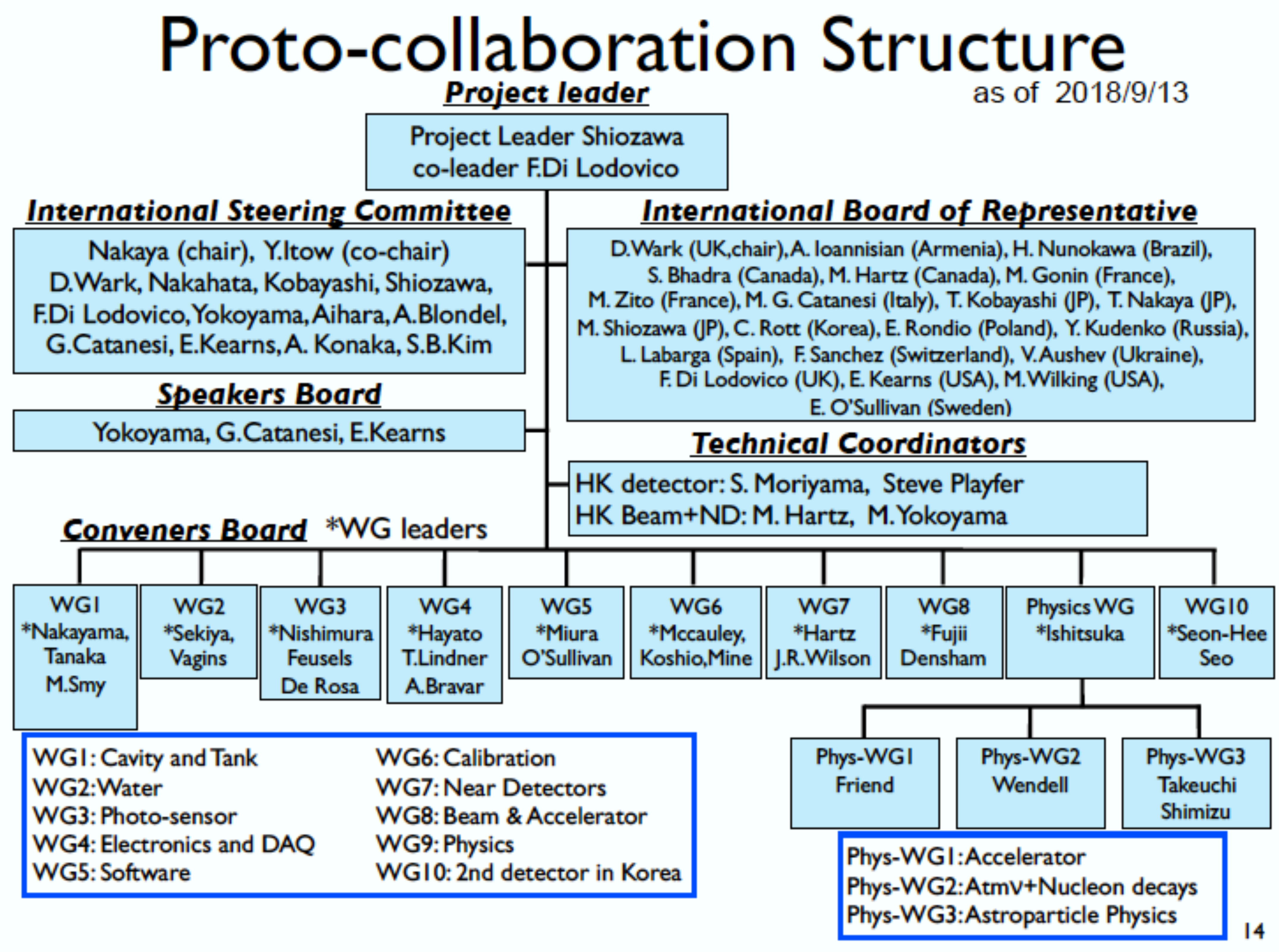
Working Groups

Working Group	Topic
1	Cavern and Tank
2	Water
3	Photosensors
4	Electronics and DAQ
5	Software
6	Calibration
7	Near Detector
8	Beam
9	Physics*
10	Second tank in Korea

*Physics Working Group (WG9) sub-divided in:
- Phys-WG1 (Accelerator)
- Phys-WG2 (Atmospheric neutrinos & Nucleon Decays)
- Phys-WG3 (Astroparticle Physics)
- Phys-WG4 (2nd detector in Korea)

- (International) Steering Committee (**iSC**):
  - *Charged with the management of the Hyper-Kamiokande project*
- International Board Representative (**IBR**)
  - *Charged with collaboration governance, steering, and the promotion of funding requests internationally*
- Technical Coordinator (**TC**)
- Conveners Board (**CB**)
  - *Coordinates the research and development of the hardware, software, and physics potential of the full experiment.*
- Speakers Board (**SB**)

Proto-collaboration Structure



Conclusions

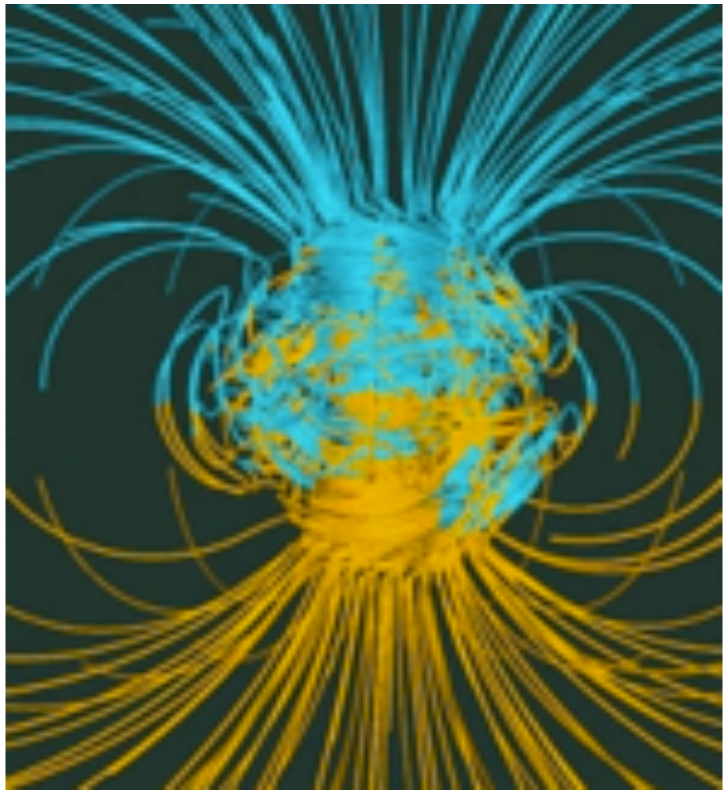
Conclusions

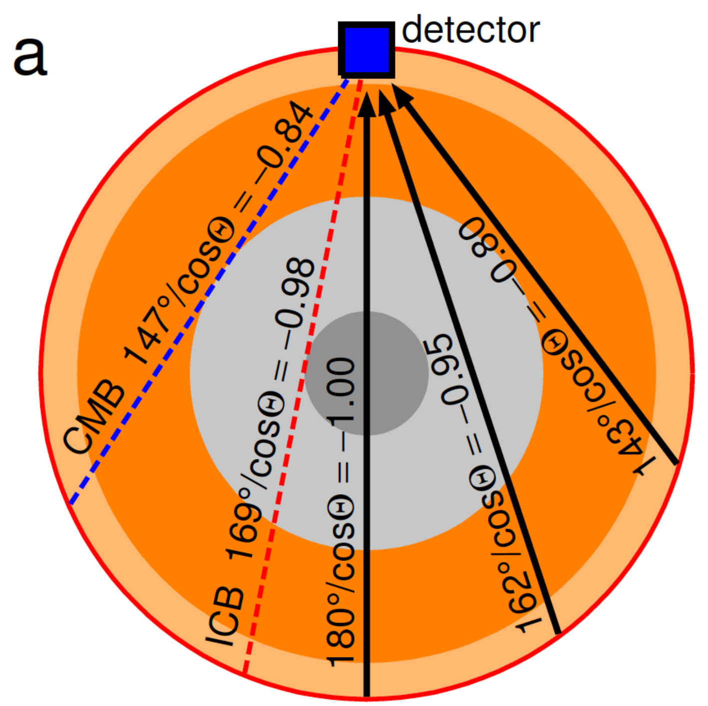
- Hyper-Kamiokande will offer an extremely broad science program with the prospects of major breakthrough discoveries
  - Search for CP violation in neutrino oscillations
  - Proton decay
  - Rich program with atmospheric and solar neutrinos
  - Supernova neutrinos
- Timeline & Status
  - Hyper-Kamiokande construction to start in April 2020
  - Seed funding provided by MEXT
  - Formation of the international collaboration
  - Expect to start operations in 2027

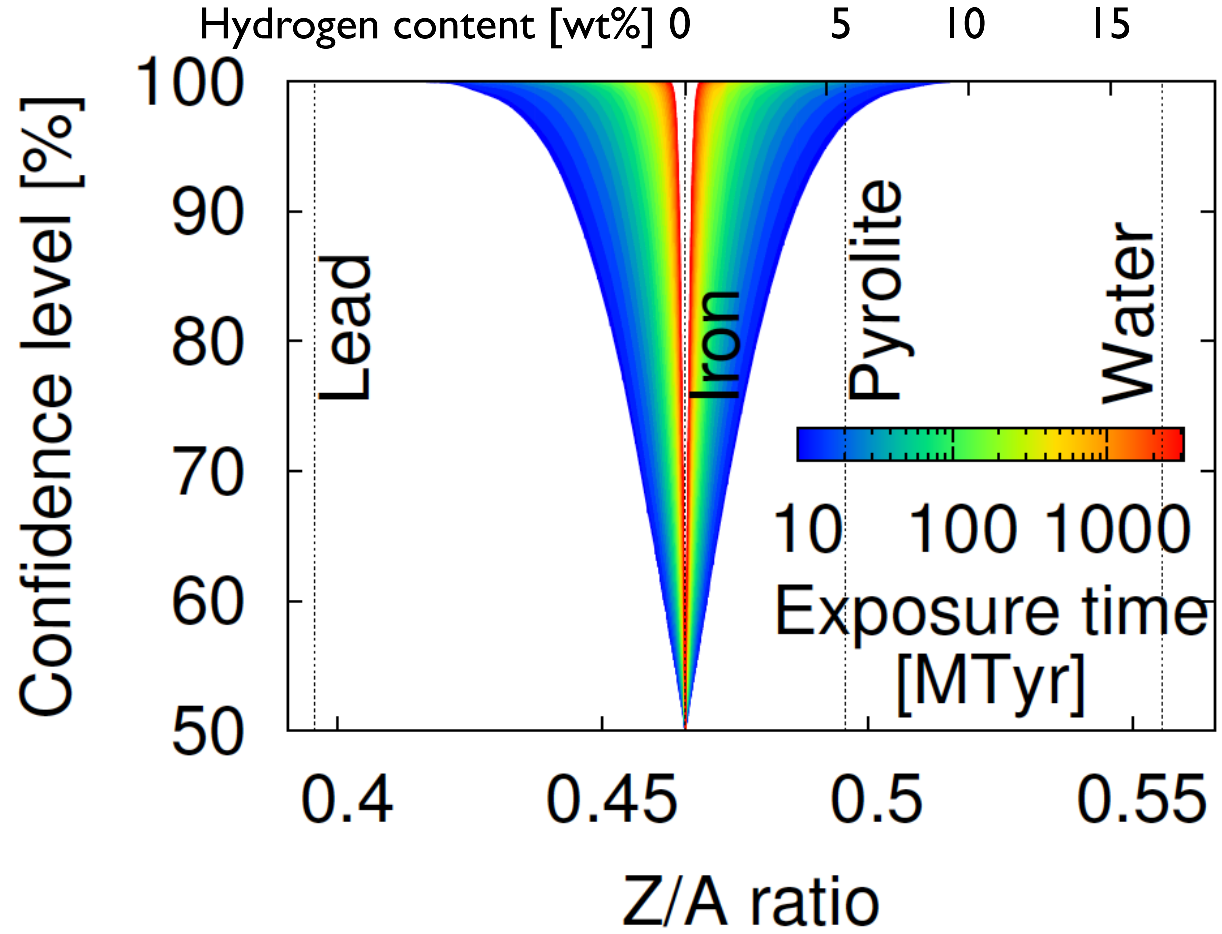

Thanks !

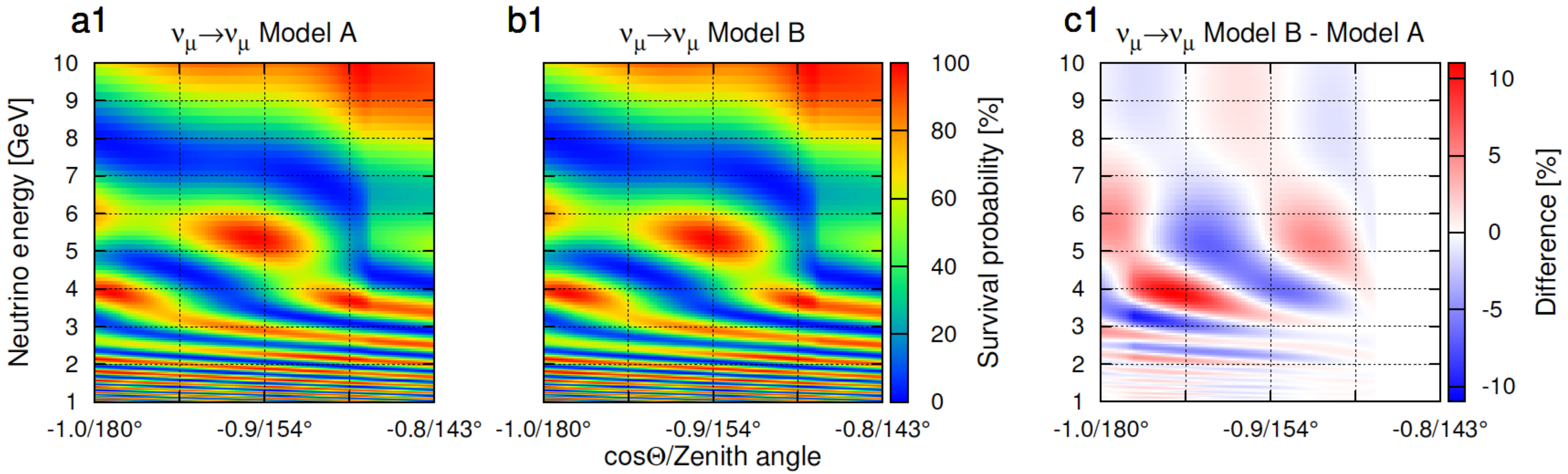
Rott & Taketa et al. Scientific Reports 5, Article number: 15225 (2015) arxiv:1502.04930)

Neutrino Tomography

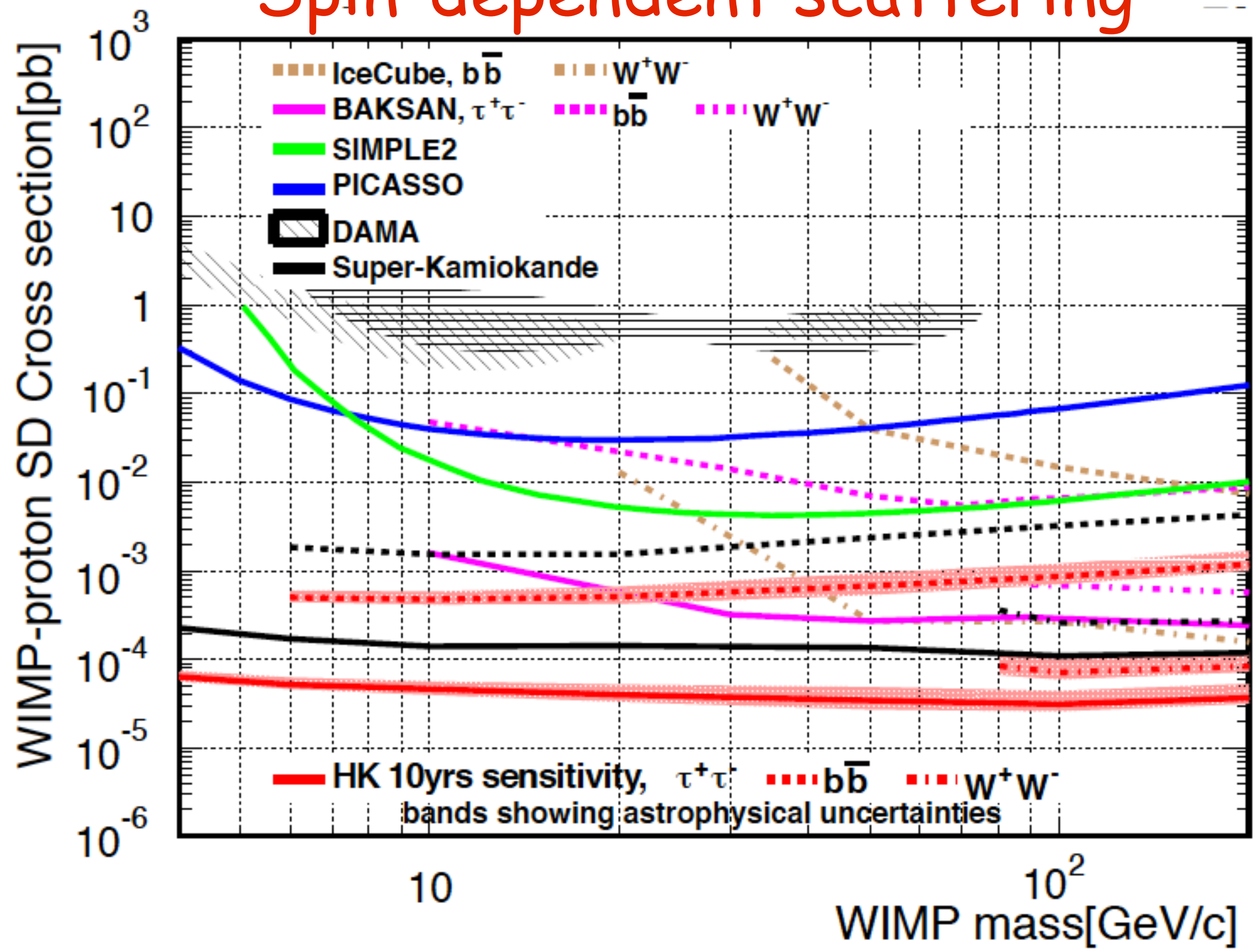




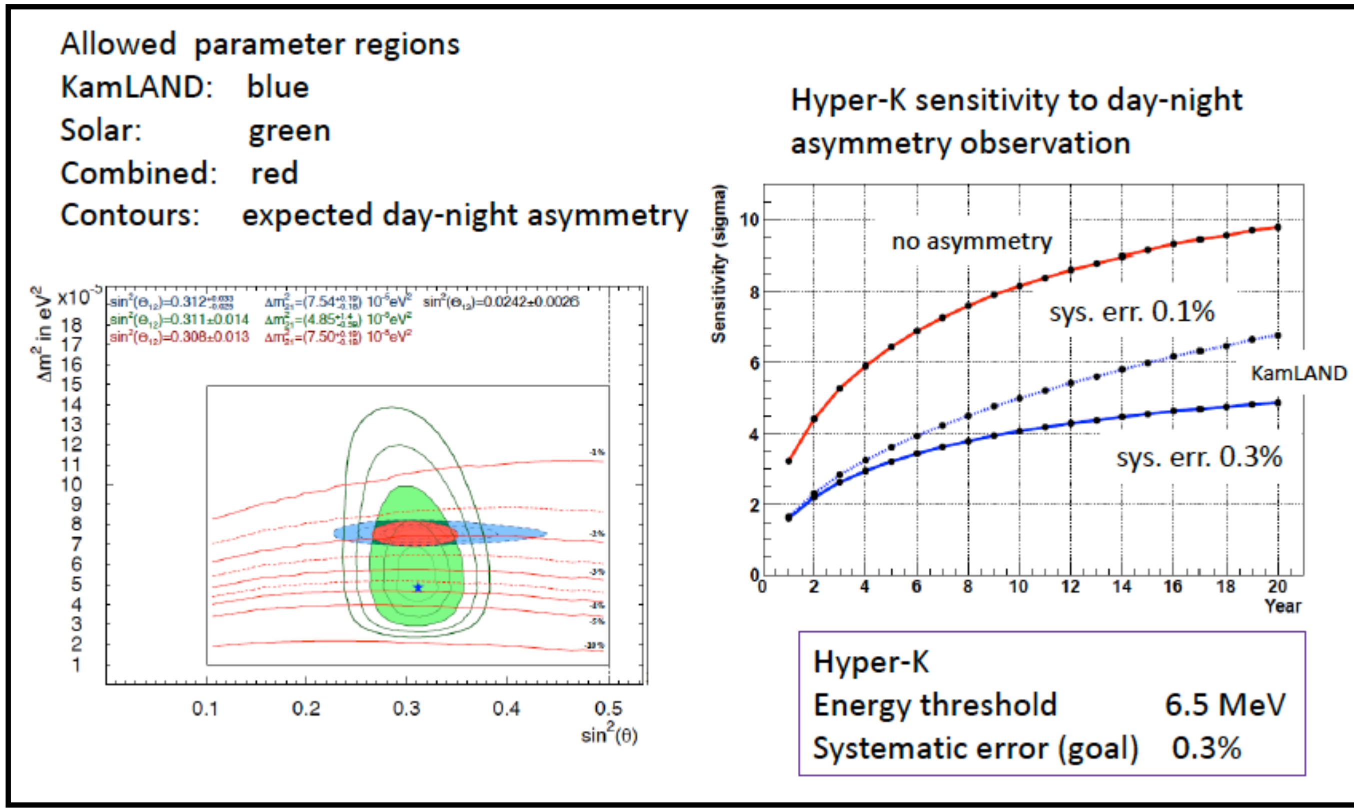




Solar Dark Matter
Spin-dependent scattering



Solar Neutrinos



- more science:
  - Neutrino Oscillation tomography - determination of the Earth core composition
  - ...

Near detectors