Status and Prospects of the Hyper-Kamiokande project

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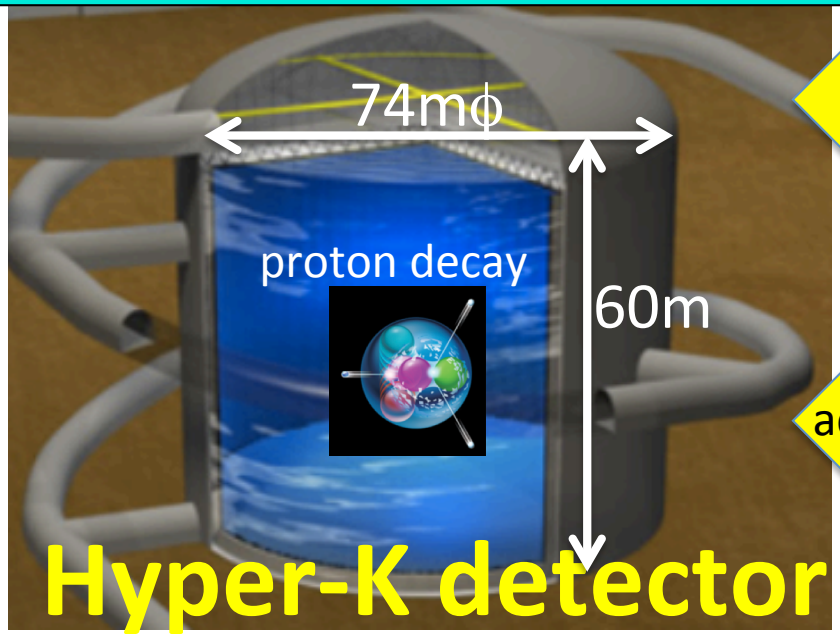
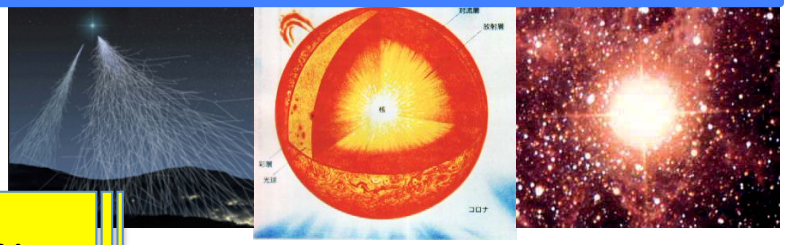
The Hyper-Kamiokande project

260kt Water Cherenkov
186 kt fiducual : 8x Super-K
Hi-QE PD w/ 40% (2x Super-K)

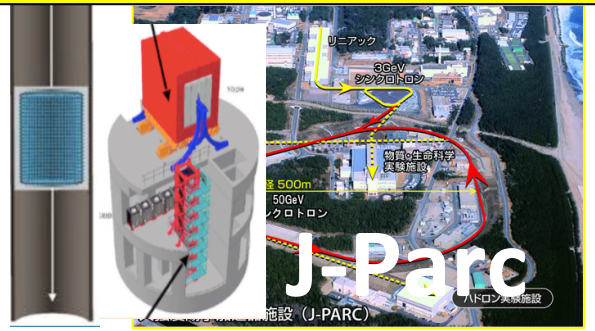


Atm-ν, Sol-ν, SN-ν, Astro-ν



natural-ν

1.3 MW beam (2 x T2K)
Upgraded ND/IWCD



accelerator-ν

Precision ν osc. with LBLE and atm-ν
Proton decay beyond 10^{35}yr
Precision Solar-ν osc.
Low-E ν astronomy SN-ν

→ This talk

→ PS2-132, T.Yano

→ PS2-120, E.O'Sullivan

Neutrino oscillations

Interferometer to explore lepton mixing

$\theta_{12}, \theta_{23}, \theta_{13}$

$+ \boxed{\delta(\text{CP-phase})}$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Δm^2_{21}

$\boxed{\Delta m^2_{32}}$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13} e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13} e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$\nu_\mu \rightarrow \nu_\tau$

atmospheric-ν

accelerator-ν

Δm_{32}^2

$\nu_e \rightarrow \nu_x$

reactor-ν (SB)

$\nu_\mu \rightarrow \nu_e$

accelerator-ν

Δm_{32}^2

$\nu_e \rightarrow \nu_x$

solar-ν

reactor-ν (LB)

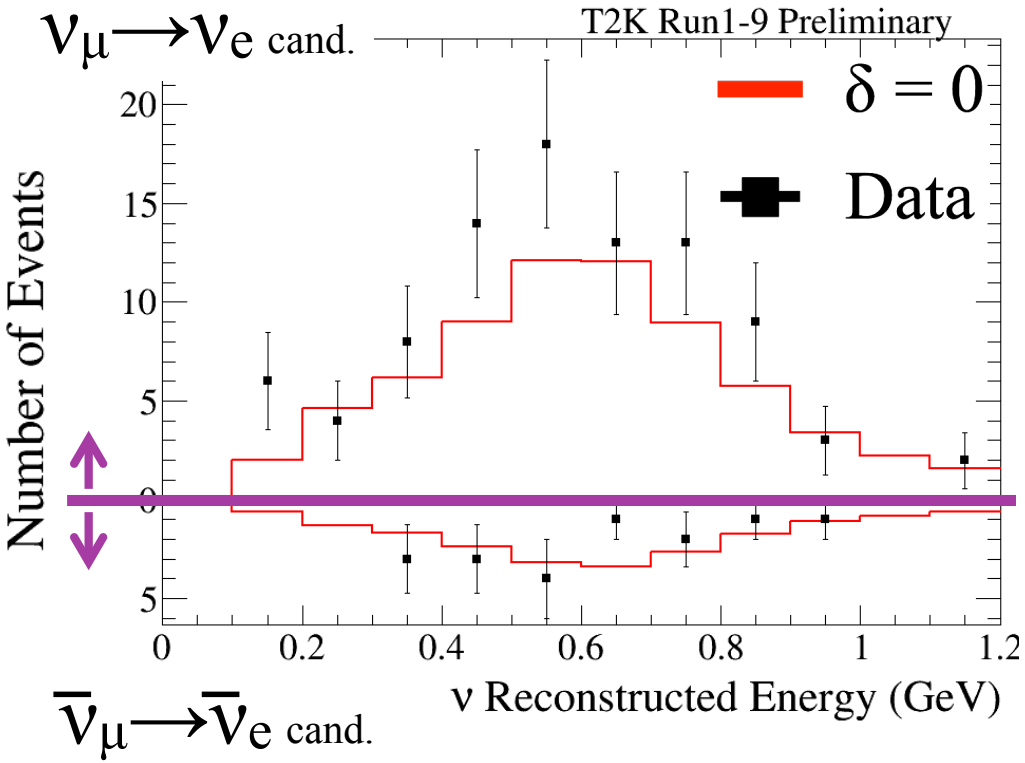
Δm_{21}^2

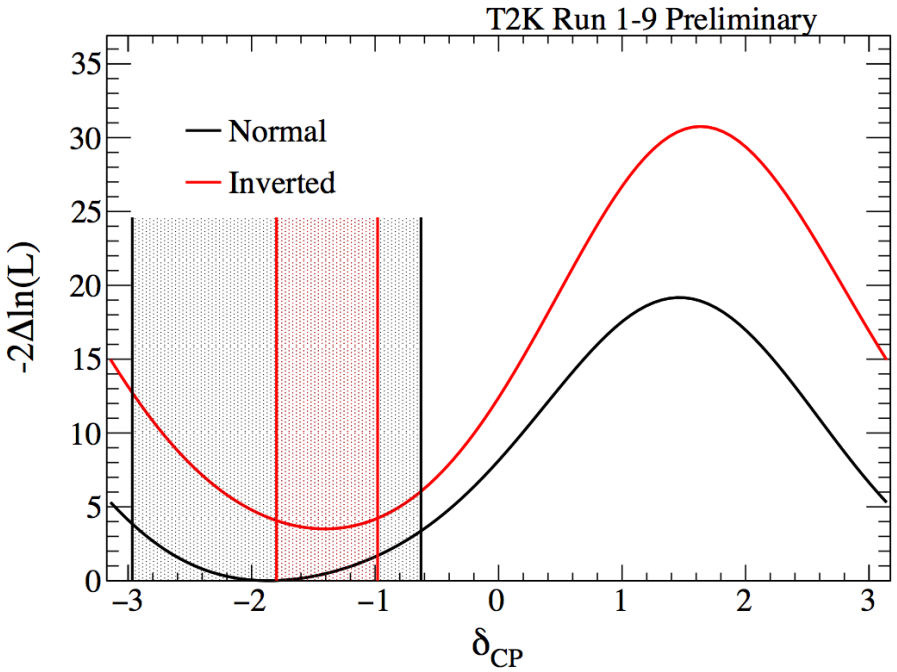
Latest T2K suggests maximum CPV

- **Results with all the data collected in 2010~2018**

	Obs.
$\nu_\mu \rightarrow \nu_e$ candidates	90
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ candidates	15

Expectation			
δ=-π/2	δ=π	δ=π/2	δ=0
81.4	68.6	55.5	68.3
17.1	19.3	21.7	19.4
CPV	CPC	CPV	CPC

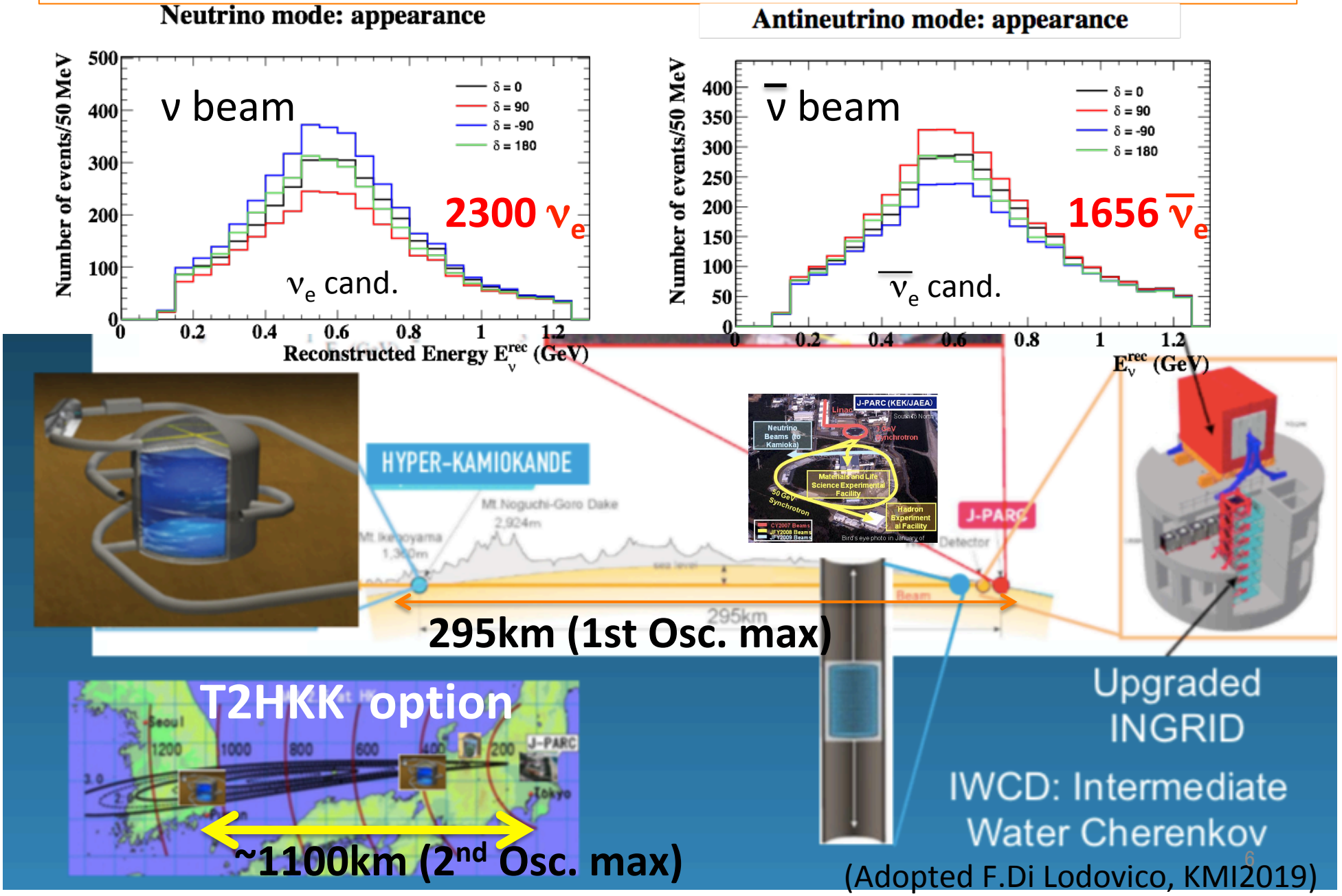




Null δCP excluded by 2 σ level

Precision ν oscillation

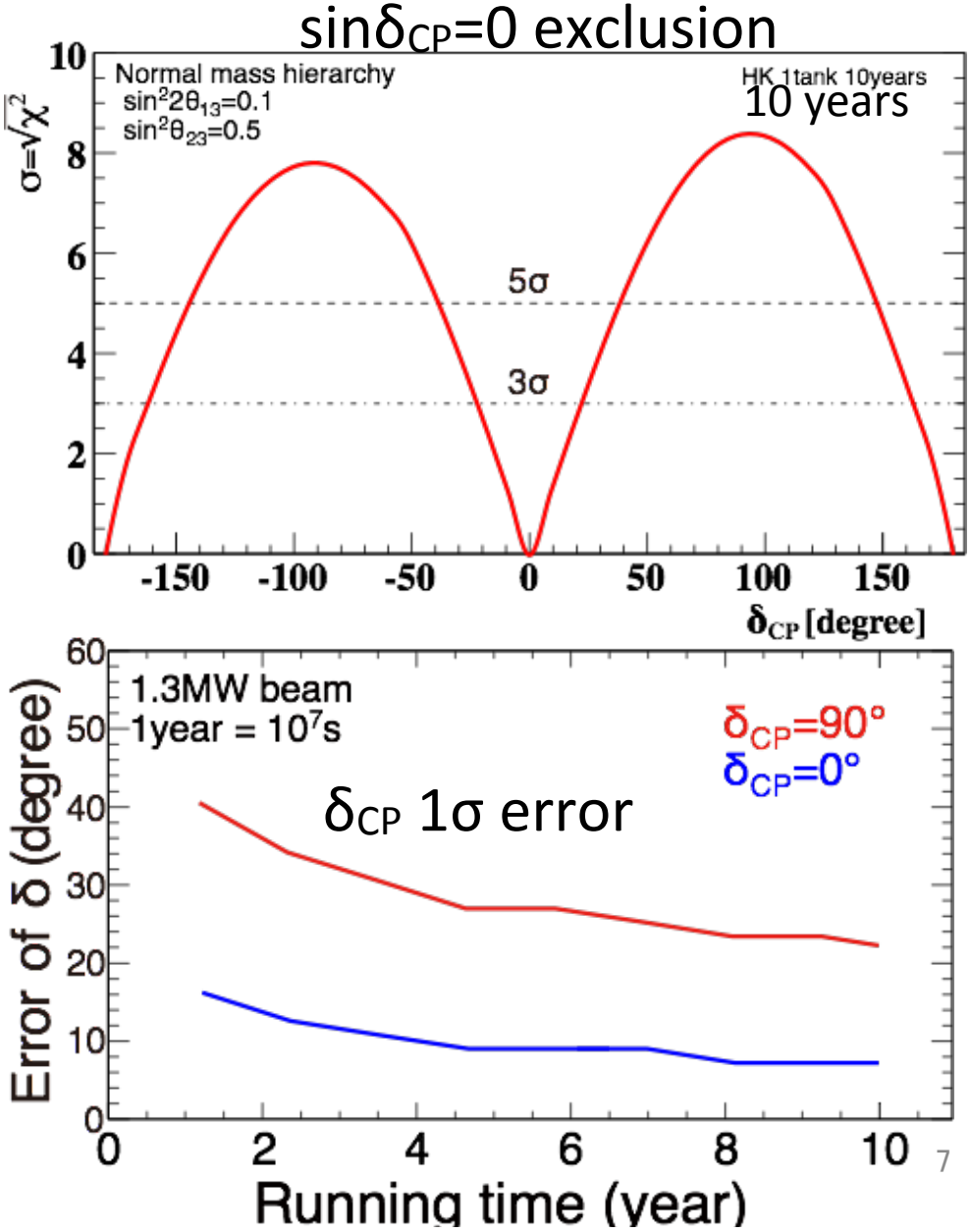
T2HK (Tokai to HK)



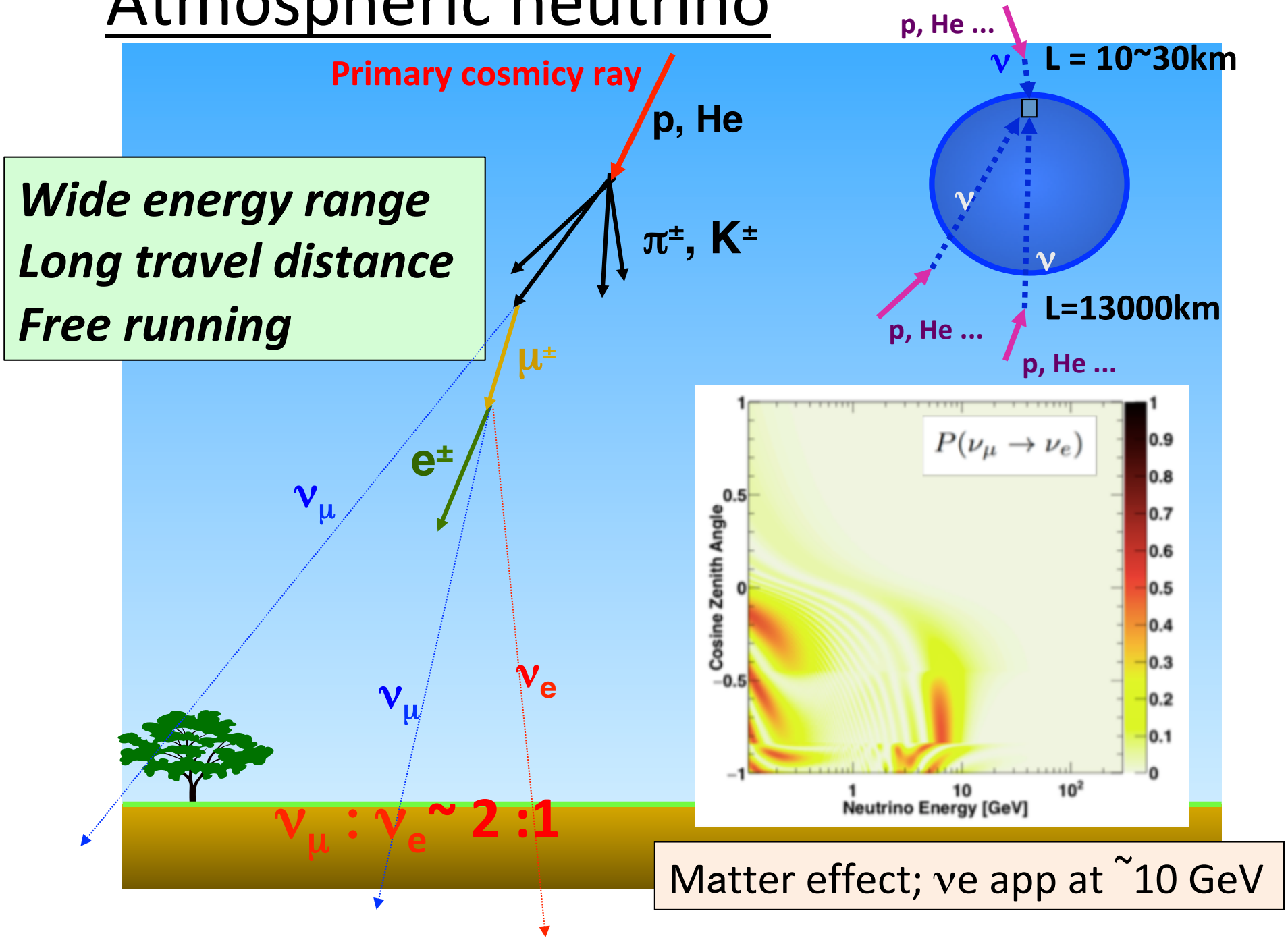
(Adopted F.Di Lodovico, KMI2019)

T2HK CP sensitivity

- Exclusion of $\sin\delta_{CP}=0$
  - 8σ for δ=-90° (T2K best fit)
  - 80% coverage of δ parameter space for CPV discovery w/ >3σ
- δ_{CP} precision measurement
  - 22° for δ=-90°
  - 7° for δ=0°

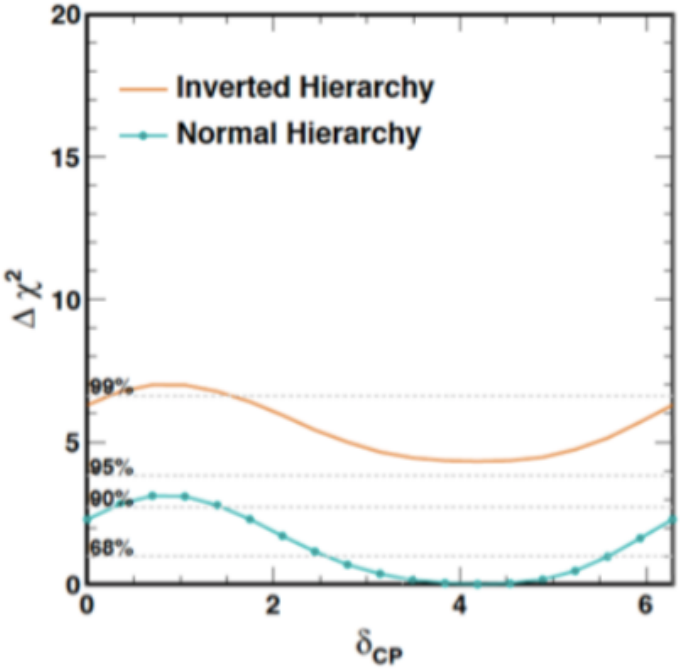


Atmospheric neutrino



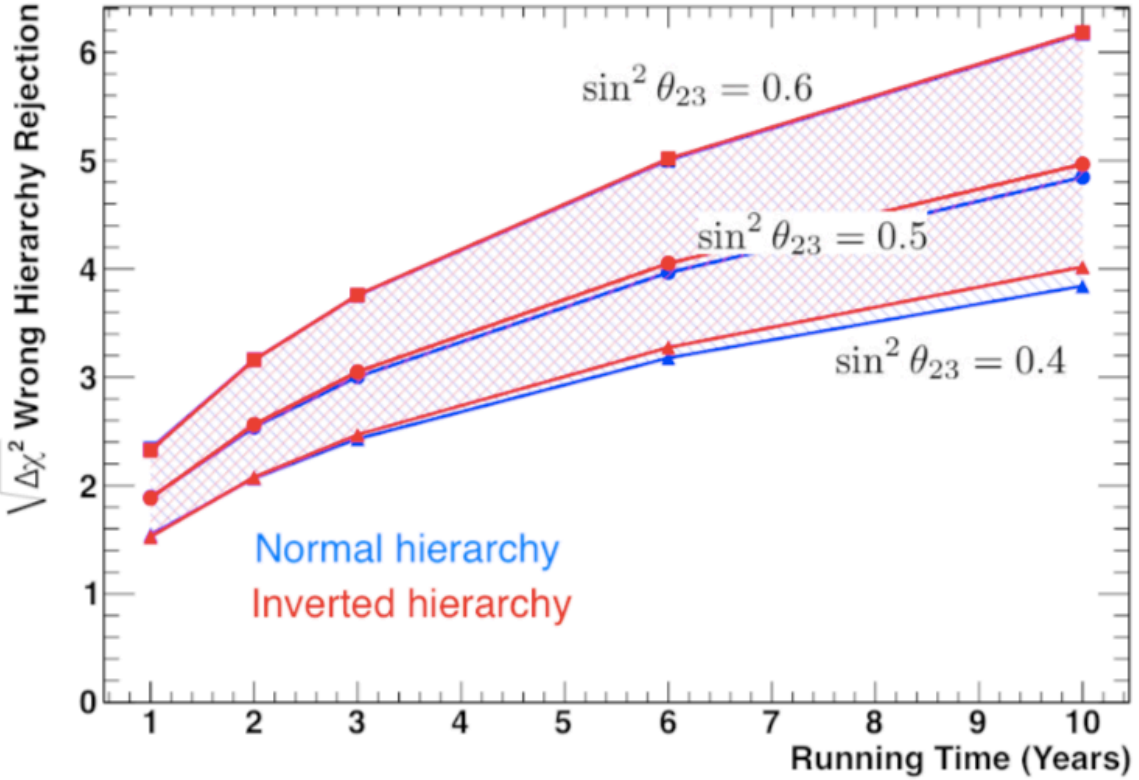
Wrong mass hierarchy rejection by atm-ν

Current SK atm-ν



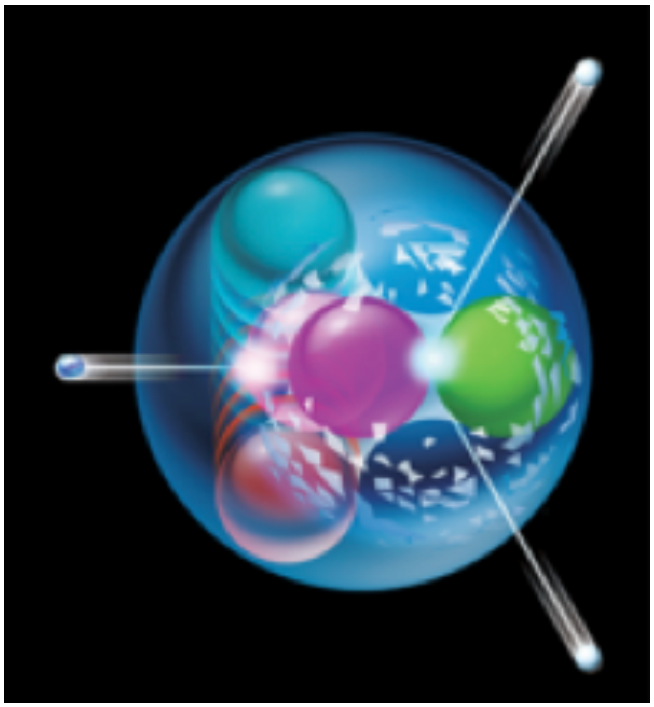
Super-K suggests normal hierarchy (~2σ)

T2HK+atmν 10 yrs:

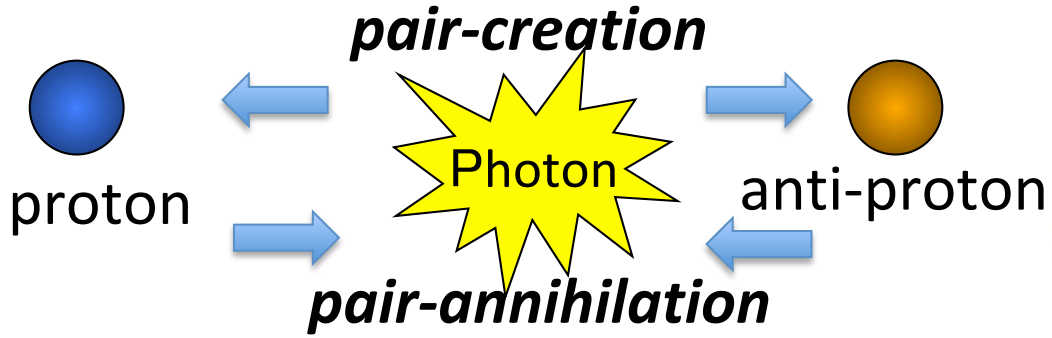


3-5 σ by Hyper-K 10 yrs w/ T2HK

Proton Decay



Hint for Baryon asymmetry



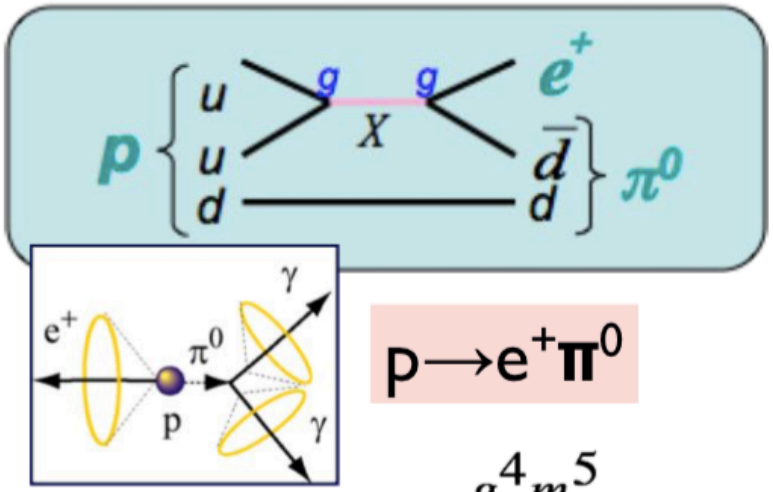
$$\underbrace{10{,}000{,}000{,}001}_{\text{proton}} + \underbrace{10{,}000{,}000{,}000}_{\text{anti-proton}} = \underbrace{1}_{\text{proton}}$$

- Sakharov's 3 conditions for baryon asymmetry
  - C and CP-violating processes
  - Baryon number violation processes
  - Non thermal-equilibrium condition

A gigantic ν detector can account for ν CP and proton decay !

Current proton decay searches in Super-K

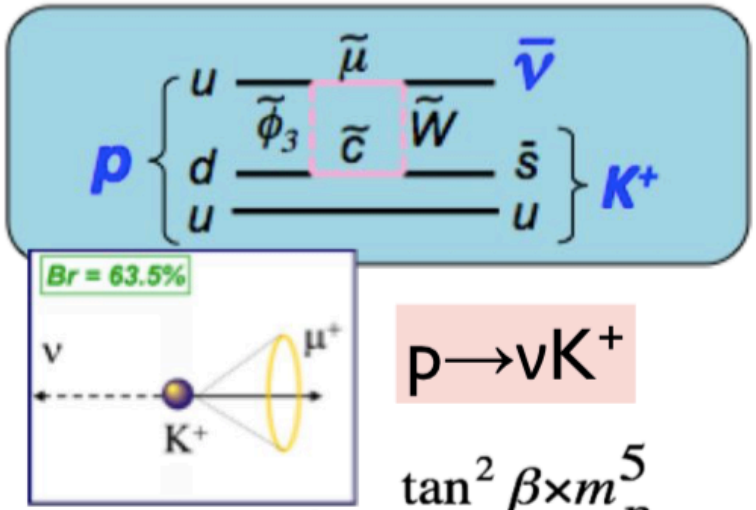
Mediated by gauge bosons



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

$$\Gamma(p \rightarrow e^+\pi^0) \sim \frac{g^4 m_p^5}{M_X^4}$$

SUSY mediated



$p \rightarrow \nu K^+$

$$\Gamma(p \rightarrow \bar{\nu}K^+) \sim \frac{\tan^2\beta \times m_p^5}{M_{\tilde{q}}^2 \times M_3^2}$$

Current Super-K lifetime limit (90% CL,365kton·yr)

$p \rightarrow e^+\pi^0$: > 2.0×10^{34} years (0 cand./ 0.63 BG)

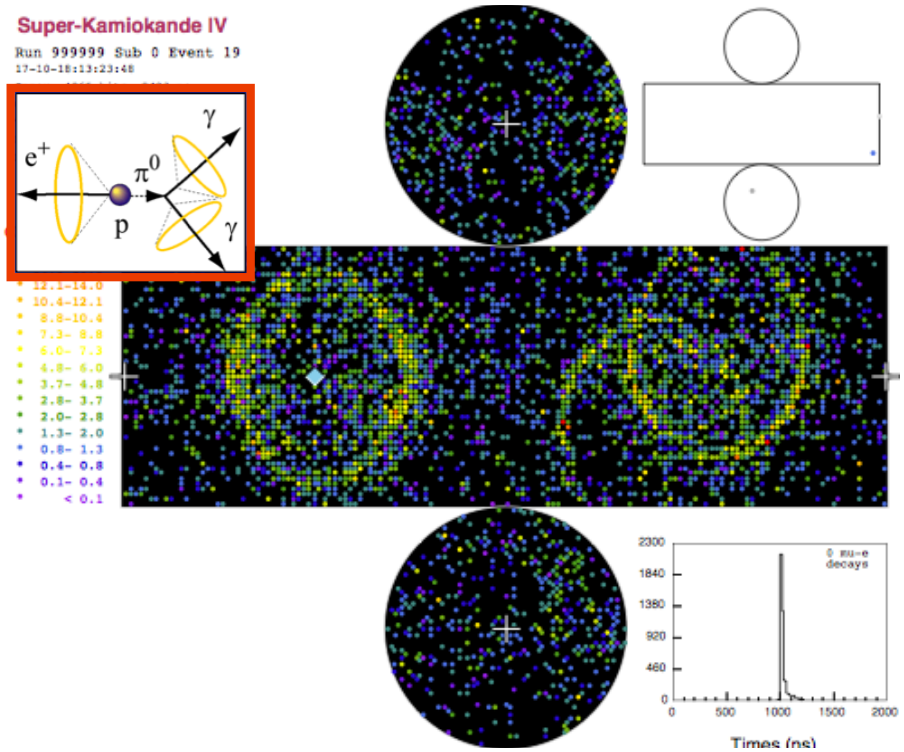
$p \rightarrow \mu^+\pi^0$: > 1.2×10^{34} years (1 cand. / 0.72 BG)

$p \rightarrow \nu K^+$: > 8.2×10^{33} years (0 cand./ 0.91 BG)

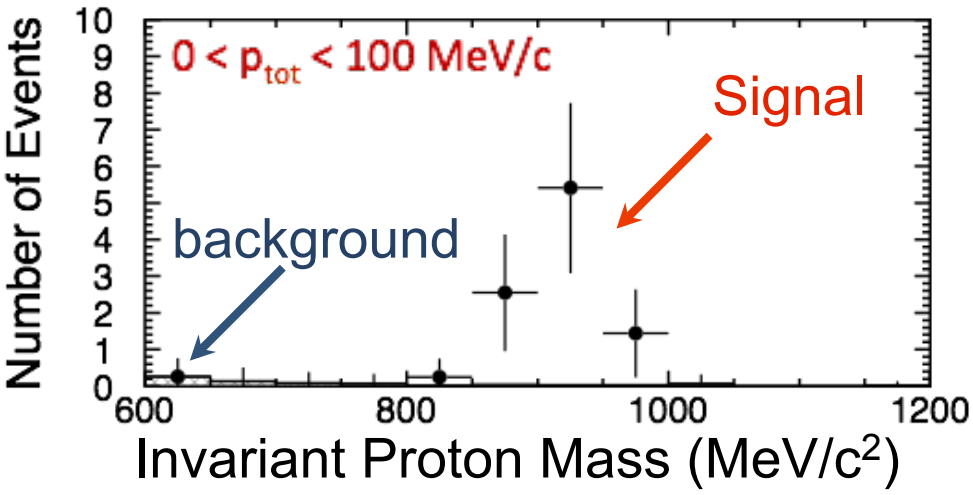
Larger FV (x8) & stringent BG cuts in Hyper-K (ex. n-tag)

Proton decay $p \rightarrow e\pi^0$ at Hyper-K

Towards 10^{35} year lifetime (3σ)

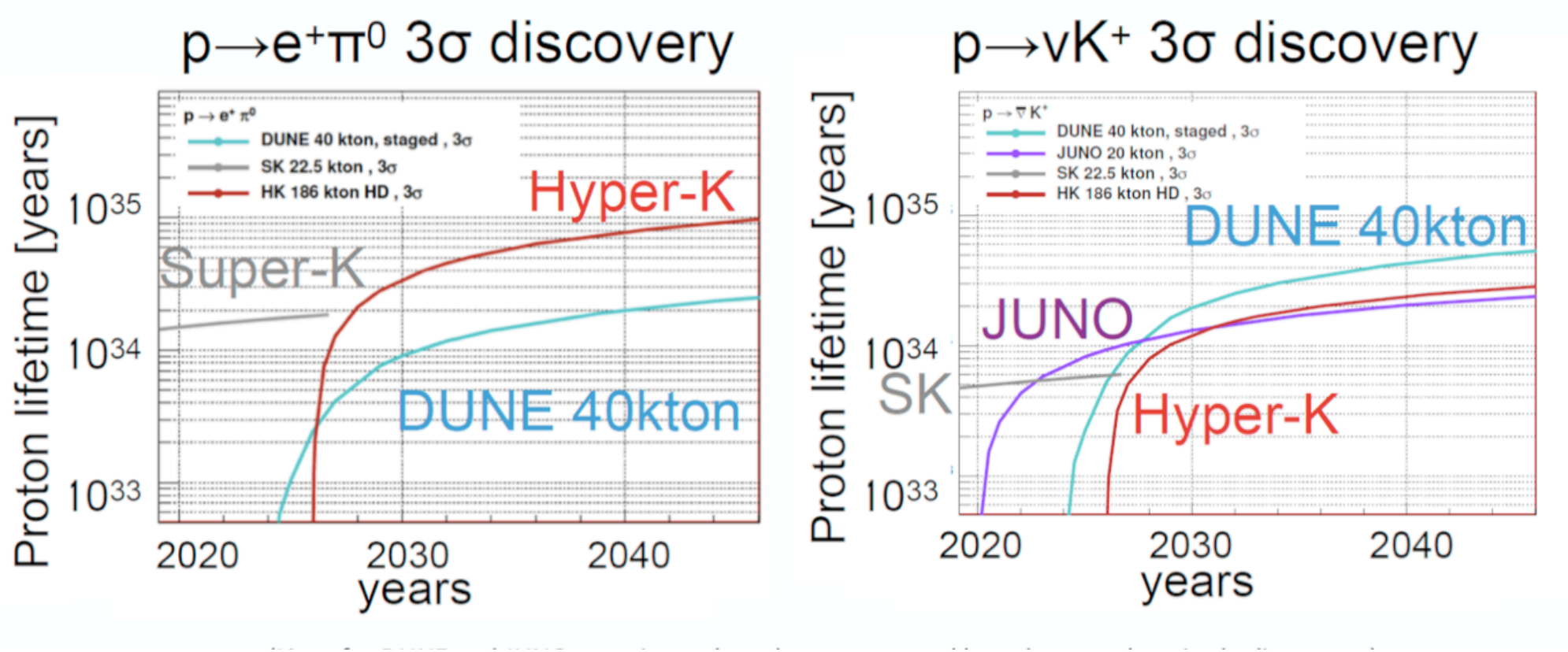


Hyper-K 10 years operation assuming $\tau_{proton}=1.7\times10^{34}$years (near current SK limit)



- High statistics (~8 × Super-K) **380 kt yr = 2years !**
- Neutron tagging will significantly reduce atmospheric neutrino backgrounds associated with neutrons.

HK proton decay sensitivity



In the next decade, proton decay searches will be improved by O(10) out by next generation ν-detectors, and maybe discovery ...

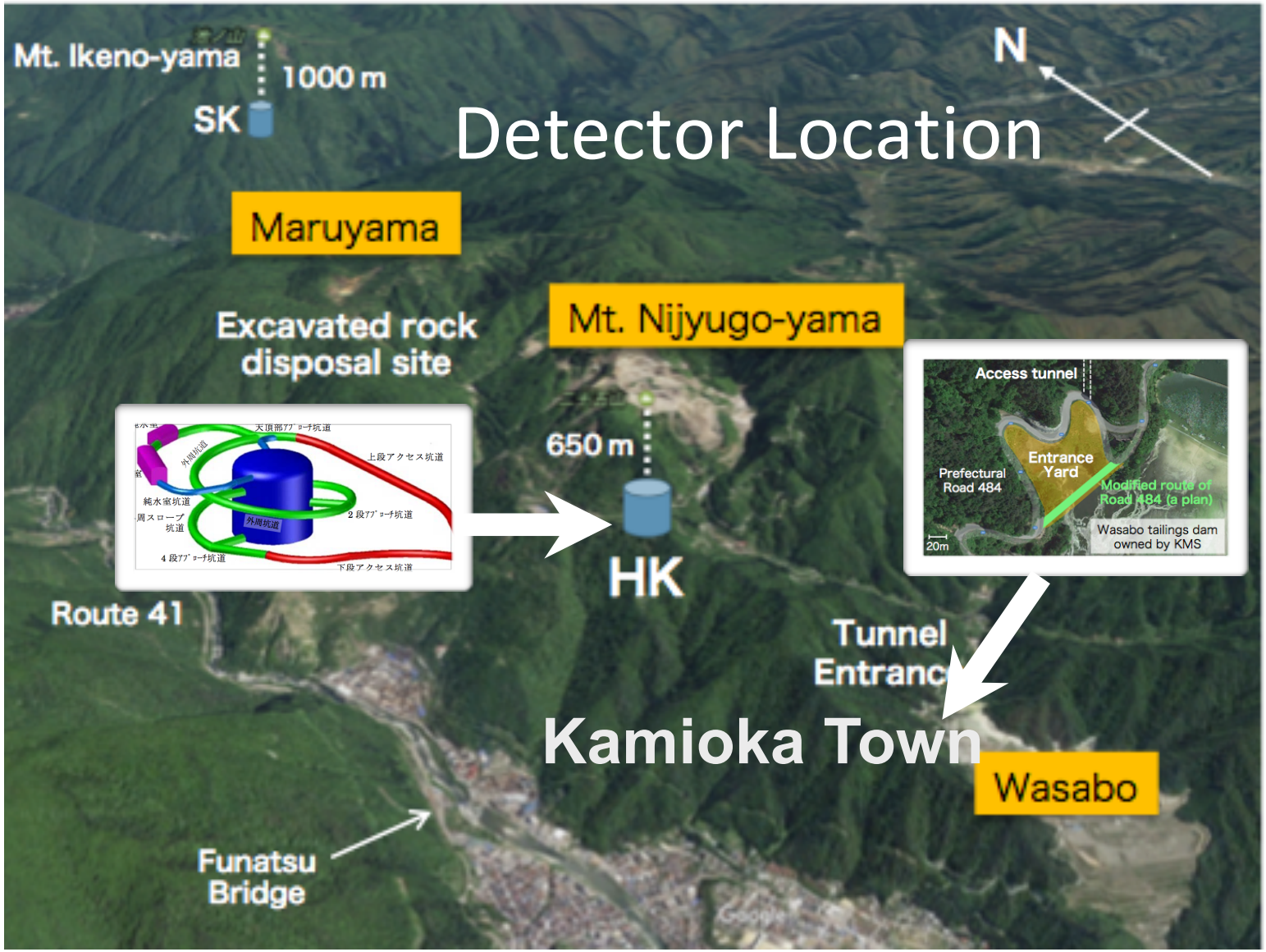
Project status

2nd Hyper-K Financial Forum (July 27, 2019 @ U.Tokyo)

International Hyper-K proto-collaboration

15 + 2 countries, ~80 institutes, ~300 members

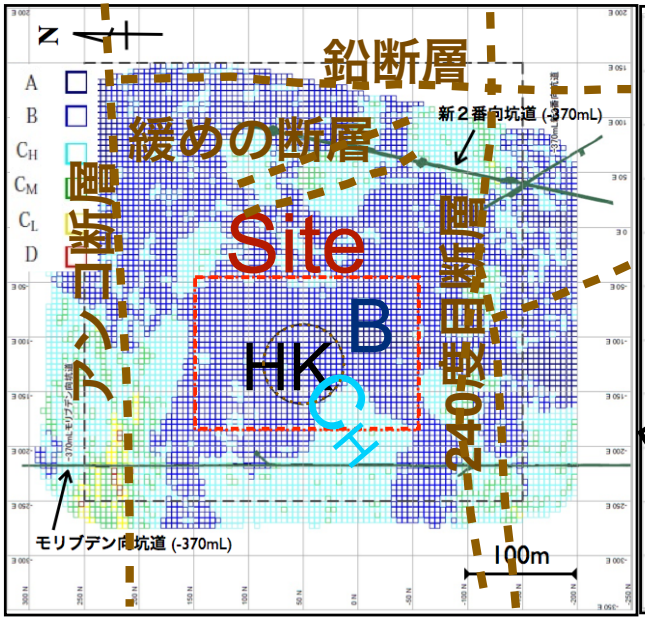
- 8km south of Super-K
- 295km from J-PARC and 2.5 deg. off-axis (same as Super-K)
- 650m rock overburden



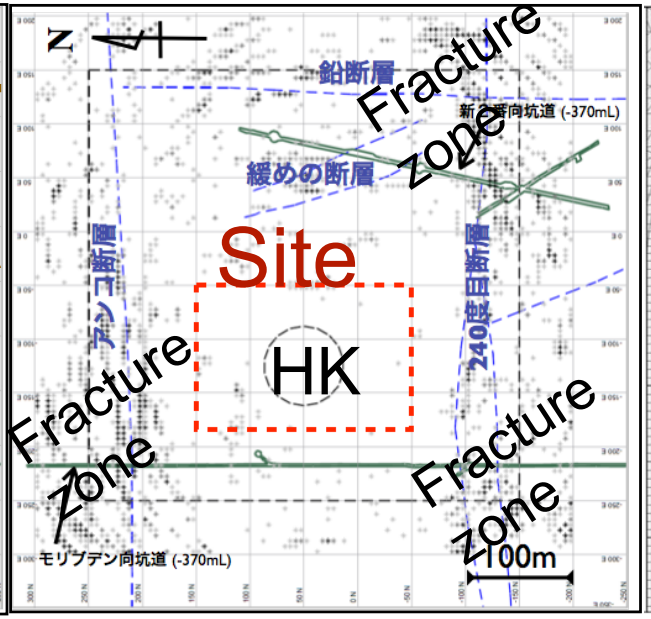
Cavern study

(2017.8)HK Advisory committee concluded:
"The level of feasibility of cavern and tank construction is now satisfactory."

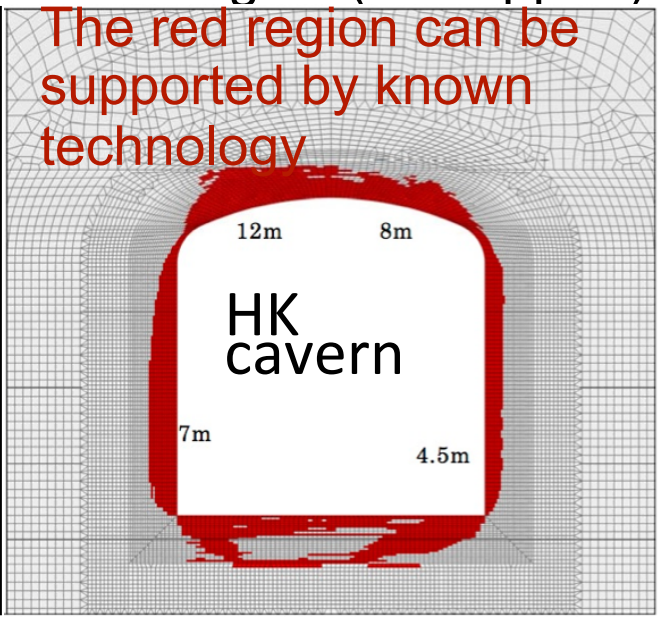
3D Rock class dist.



Fracture zone



Plastic region (no support)

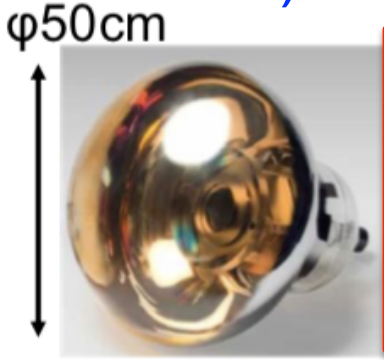


Large enough stable rock site is now identified and verified.
Japan (U.Tokyo) takes responsiblity for site construction.

Many R&D on new photo-detectors

HPK B&L-PMT (ID baseline)

- **20% coverage (=20k) by Japan**
- Equivalent p.e./MeV as Super-K
- 100 PMT's installed in Super-K (2018)
- Ready to produce

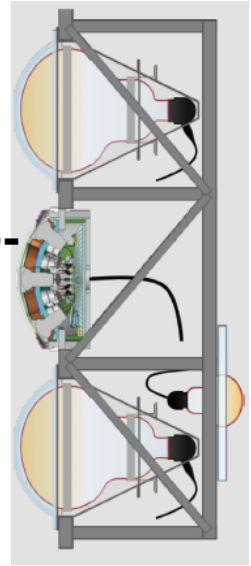


- sensitivity: 2 x SK
- Time resolution: 1/2 x SK
- Pressure: 2 x SK

Outer-detector system

(Overseas contribution)

Open for photo-sensor type, density, light-concentrator, deployment method



Other ID candidates

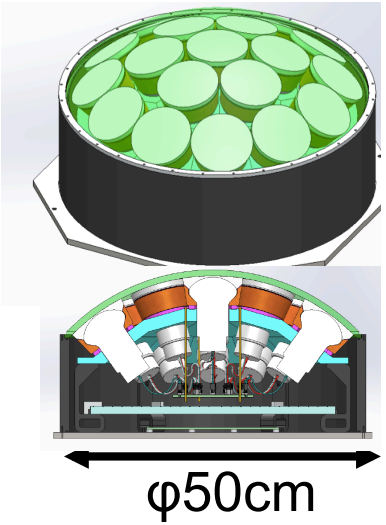
(Overseas contribution)

MCP-PMT

Ongoing R&D to improve timing, reduce dark rate, water-proofing, cover etc

Multi-PMT module

Many R&D are needed on module/ assembly, acrylic vessel, electronics, simulation&reconstruction etc



Still seek for new contributors...

Hyper-K Design Report

arXiv:1805.04163

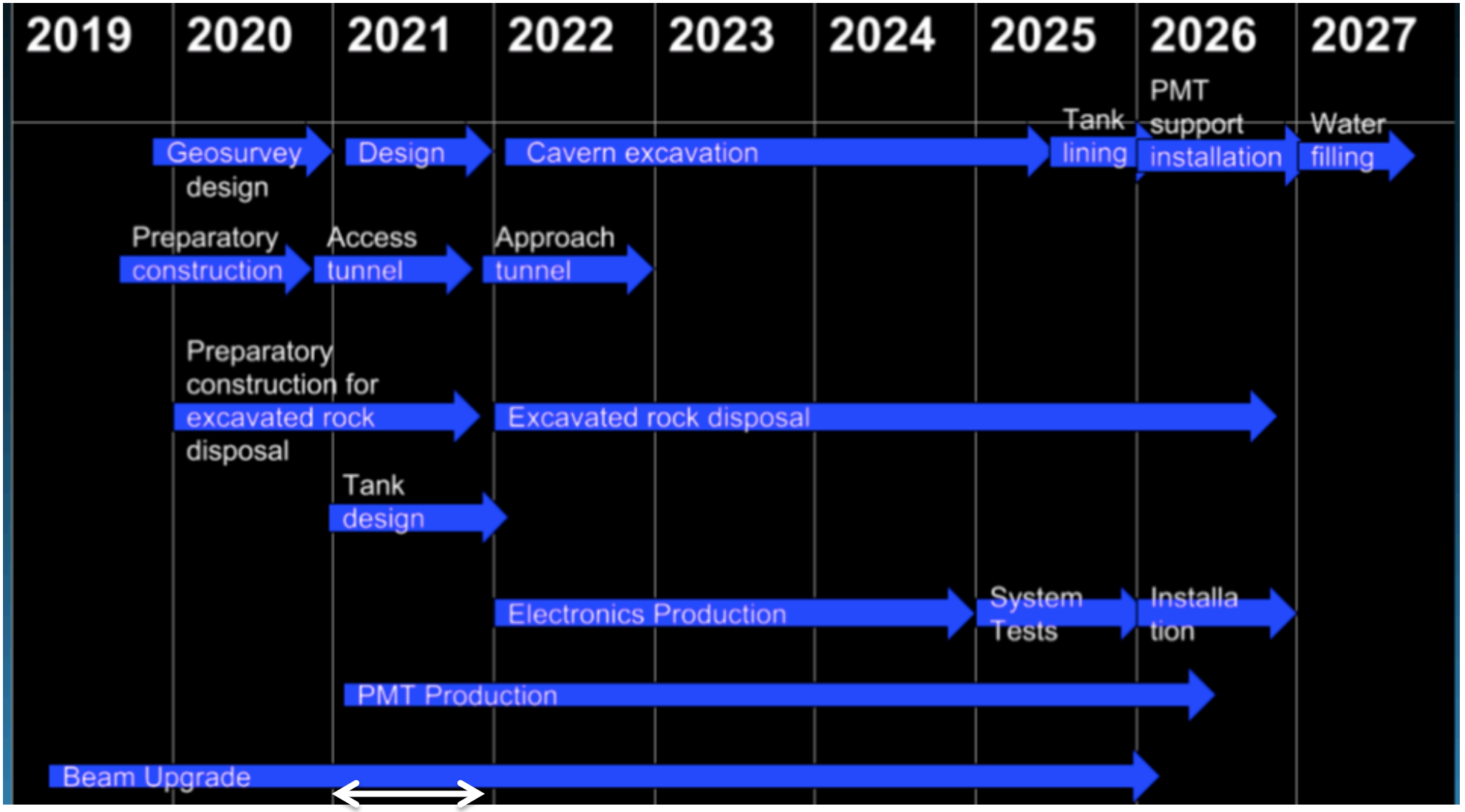
Hyper-Kamiokande

Design Report
(Dated: May 9, 2018)

Now technical detail is being finalized
in Hyper-K Technical Report 2019

Construction time line

Seed funding now



J-PARC MR shutdown
for upgrade work

Summary

- Hyper-K project is a next generation ν/pdk experiment with
  - 186kt FV as one order larger than Super-K
  - Strong 1.3 MW low-E off-axis ν beam
  - Upgraded near detector system
- Hyper-K multi-purpose project covering
  - Precision neutrino oscillations aiming neutrino CP
  - Proton decay $e^{+}\pi^{0}$ with 10^{35} yr
  - Rich program in low-E ν astronomy also
- Construction shall start in 2020 aiming operation in 2027
  - Initiative by U.Tokyo and KEK with strong support of world-wide neutrino/astroparticle communities
- New participation is highly welcome !!