Hyper-Kamiokande Project

Its Physics Potential

Astroparticle Physics 2014

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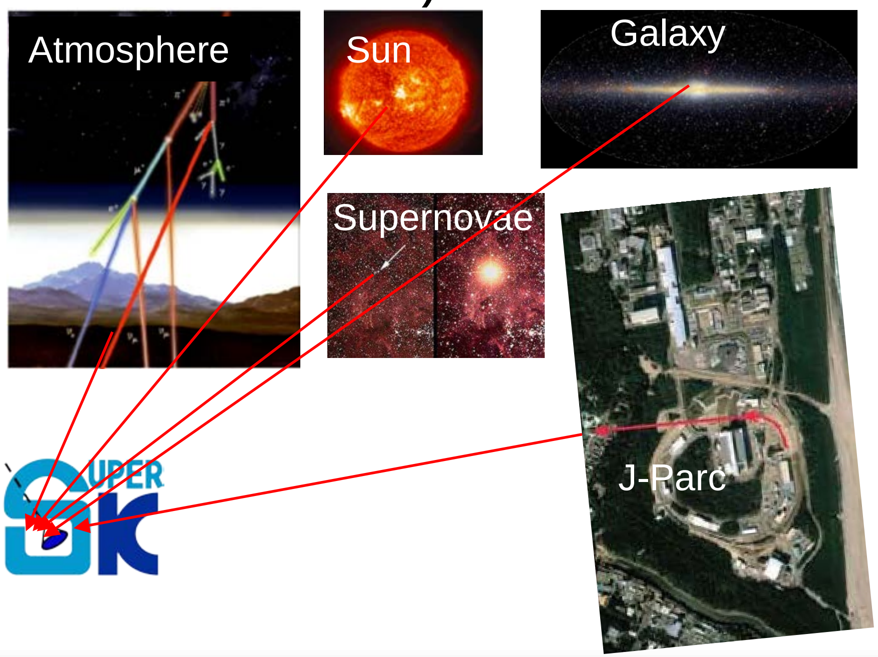
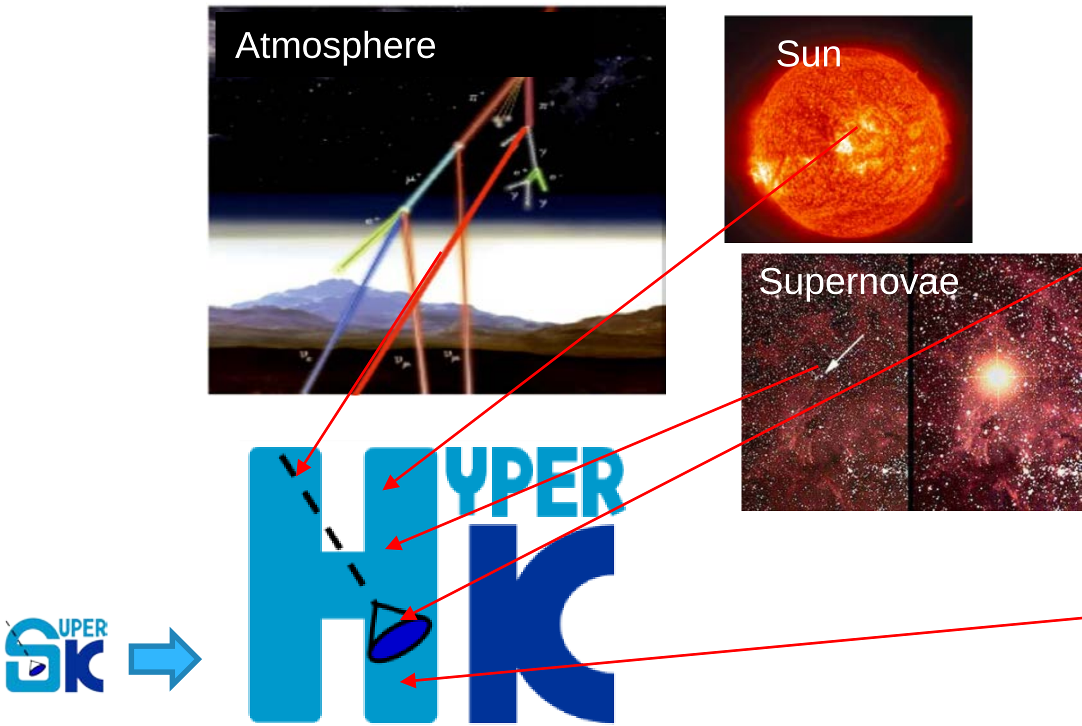
Remaining issues for

- Neutrino mixing parameters
  - CP phase δ, Mass hierarchy $|m_{32}{}^2|$, octant of θ_{23}
- Neutrinos as "astroparticles"
  - Solar neutrinos
    - Spectrum upturn(Solar matter effects, sterile?)
    - Day/night asymmetry (Earth matter effect)
  - Supernovae neutrinos
    - Burst(mechanism of SN)
    - DSNB(history of Universe)
  - High energy neutrinos from GC, Sun, earth…
    - Dark matter
- Proton decay



All of them are statistically limited!

Let's move on to "more than Super"



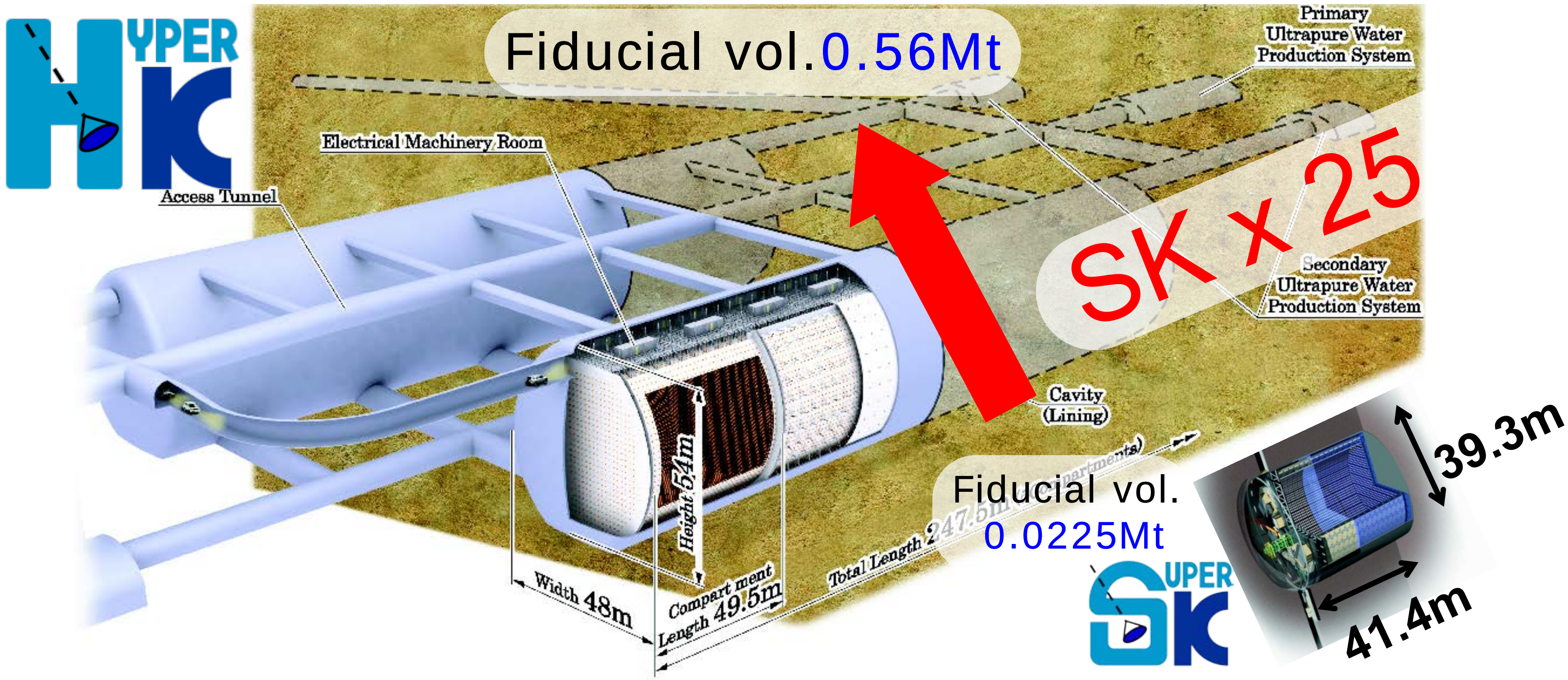
- Hyper-

(Wikipedia)

A prefix often used in scientific and technical words, to denote something above or beyond the usual, normal, expected, or healthy level. Sometimes used to mean *extreme* or specifically "more than super-".

Kamioka 3rd Generation

1Mt Water Cherenkov Detector



- 2 cylindrical tanks lying side-by-side (48m x 54m x 250m each)
- 5 compartments in each tank w/ photo-sensitive separation walls
- Each compartment is "twice the size of Super-Kamiokande II"
  - ✓ ID 20% photo-coverage with 99,000 20" PMTs
  - ✓ OD 2m layer with 25,000 8" PMTs

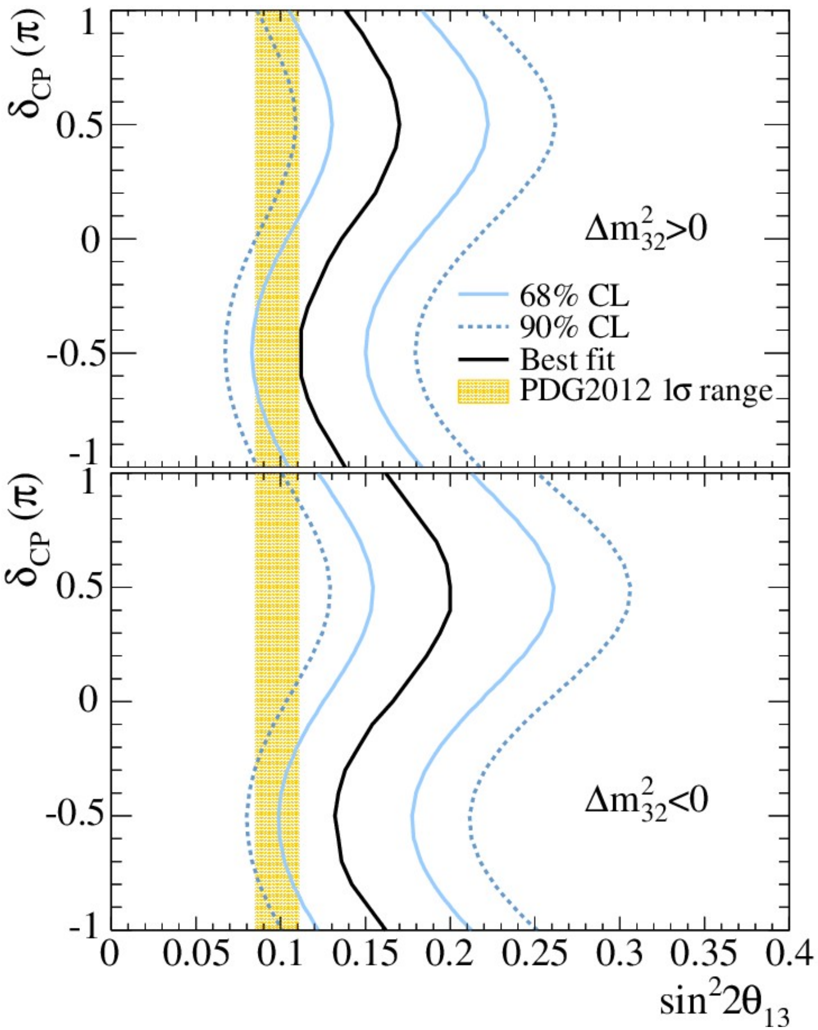
For solar neutrinos PMT must be doubled

Neutrino mixing parameters

Status of ν mixing parameters

- Recent results from T2K & reactor

Phys. Rev. Lett. 112, 061802 (2014)



ν_e appearance

T2K $\sin^2 2\theta_{13}$ = $0.140^{+0.038}_{-0.032}$ (NH)

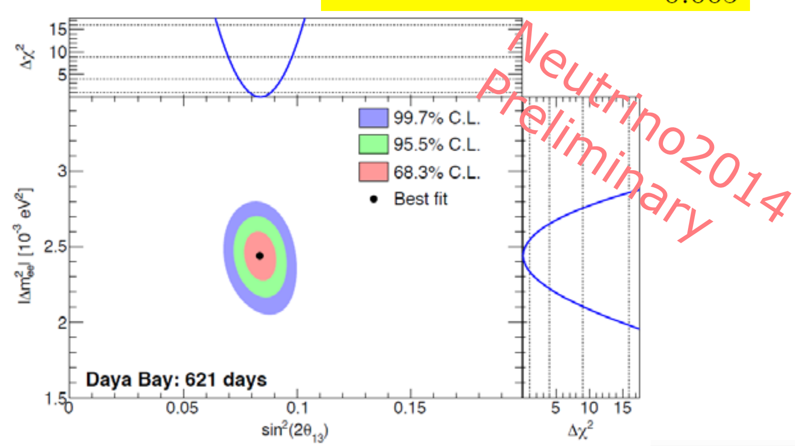
$0.170^{+0.044}_{-0.037}$ (IH)

is slightly larger than the ones from reactor experiments

→indication of non-zero δ_{cp} ?

The best overlap is for the Normal hierarchy with $\delta_{cp}=-\pi/2$!

c.f. Daya Bay $\sin^2 2\theta_{13} = 0.084^{+0.005}_{-0.005}$



The channel $\nu_\mu \rightarrow \nu_e$, $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

$$P(\nu_\mu \to \nu_e) = 4C_{13}^2 S_{13}^2 S_{23}^2 \cdot \sin^2 \Delta_{31}$$

Leading $\sin^2 2\theta_{13}$

$$+8C_{13}^2 S_{12} S_{13} S_{23} (C_{12} C_{23} \cos\delta - S_{12} S_{13} S_{23}) \cdot \cos\Delta_{32} \cdot \sin\Delta_{31} \cdot \sin\Delta_{21}$$

CPC

$$-8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin\delta \cdot \sin\Delta_{32} \cdot \sin\Delta_{31} \cdot \sin\Delta_{21}$$

CPV

$$+4S_{12}^2 C_{13}^2 (C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12} C_{23} S_{12} S_{23} S_{13} \cos\delta) \cdot \sin^2 \Delta_{21}$$

Solar

$$-8C_{13}^2 S_{13}^2 S_{23}^2 \cdot \frac{aL}{4E_\nu}(1 - 2S_{13}^2) \cdot \cos\Delta_{32} \cdot \sin\Delta_{31}$$

$$+8C_{13}^2 S_{13}^2 S_{23}^2 \frac{a}{\Delta m_{31}^2}(1 - 2S_{13}^2) \cdot \sin^2 \Delta_{31},$$

matter

Oscillation term

$$\Delta_{ij} = \frac{\Delta m_{ij}^2 L}{4E_\nu}$$

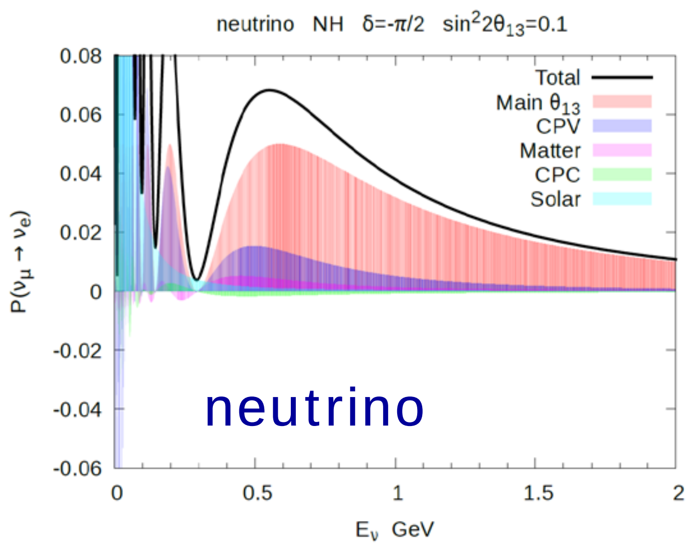
Measured angles

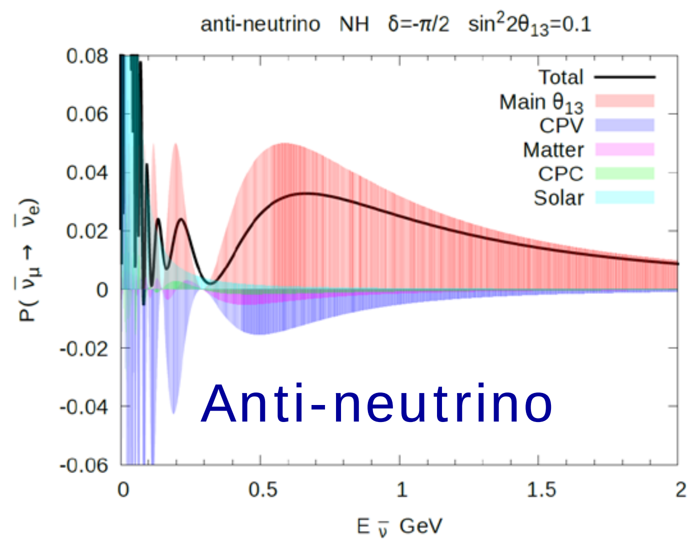
$$S_{23}^2 \sim 0.5 \quad S_{12}^2 \sim 0.3$$

$$S_{13}^2 \sim 0.03$$

$$P(\bar{\nu_\mu} \to \bar{\nu_e}) \quad a \to -a \quad \delta \to -\delta$$

- L=295km , ρ=2.6g/cm³ case (assuming NH, δ=-π/2)

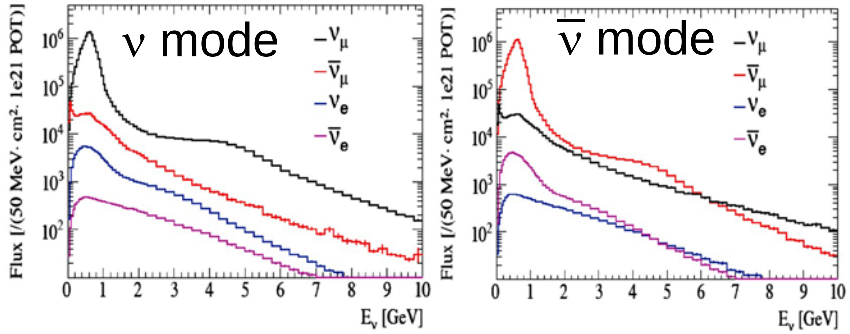




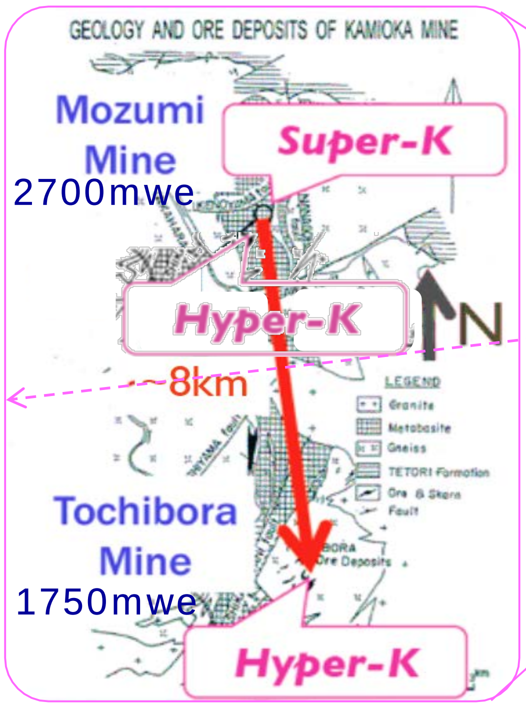
with J-PARC ν beam

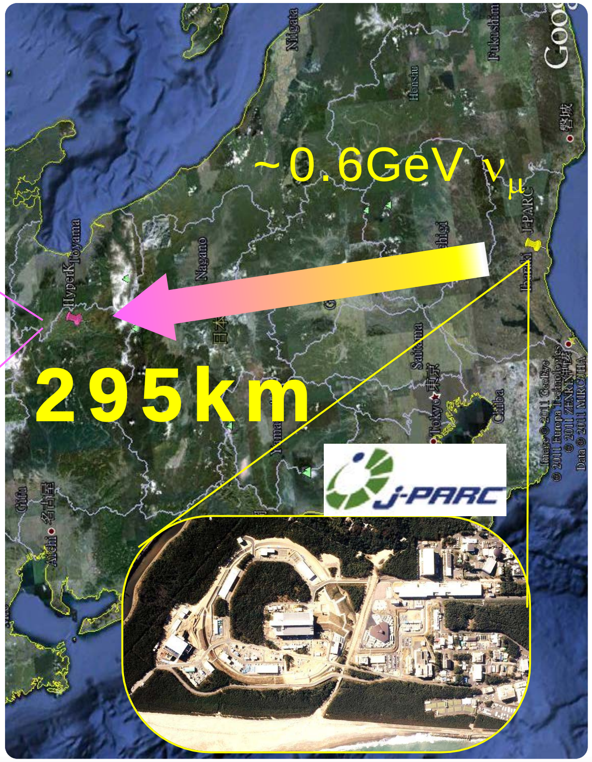
2.5º off-axis narrow band ν beam

- J-PARC 30GeV proton beam power will be upgrade to ＞0.75MW
- ＞1MW is under study



cite candidates in Kamioka





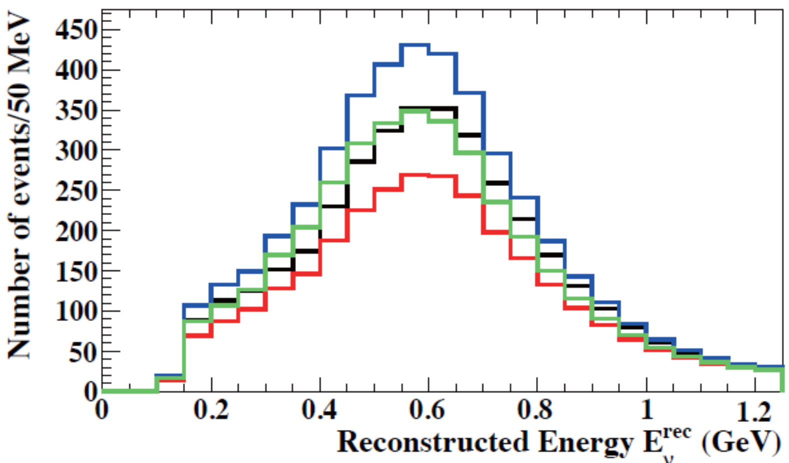
expected spectra (δ dependence)

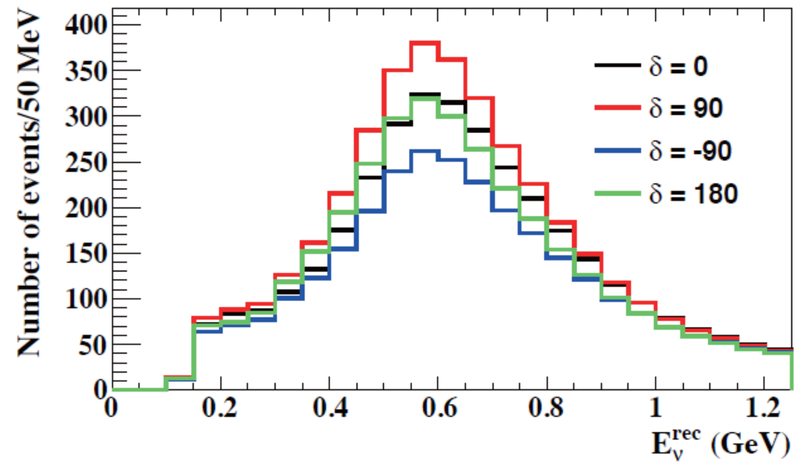
- Full MC based on T2K experience

beam BG , ν interaction, detector, reconstruction

Total 7.5×10^7 MW·sec (10 years) NH, $\sin^2 2\theta_{13}=0.1$, $\sin^2 2\theta_{23}=1.0$

ν mode 2.5 years $\bar{\nu}$ mode 7.5 years





Expected number of events

$\delta=0$

	Signal ($\nu_\mu \to \nu_e$ CC)	Wrong sign appearance	$\nu_\mu/\bar{\nu}_\mu$ CC	beam $\nu_e/\bar{\nu}_e$ contamination	NC
ν	3,016	28	11	523	172
$\bar{\nu}$	2,110	396	9	618	265

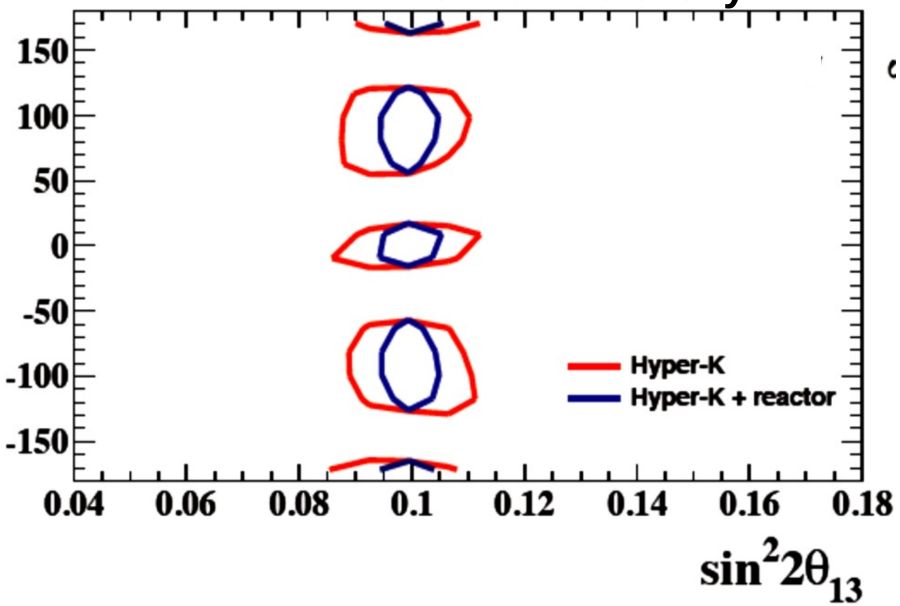
- WC PID is excellent→ ν_μ CC BG rejection > 99.9%
- π^0 rejection is established→NC π^0 is no longer dominant BG!

HYPER K sensitivity to δ_{CP}

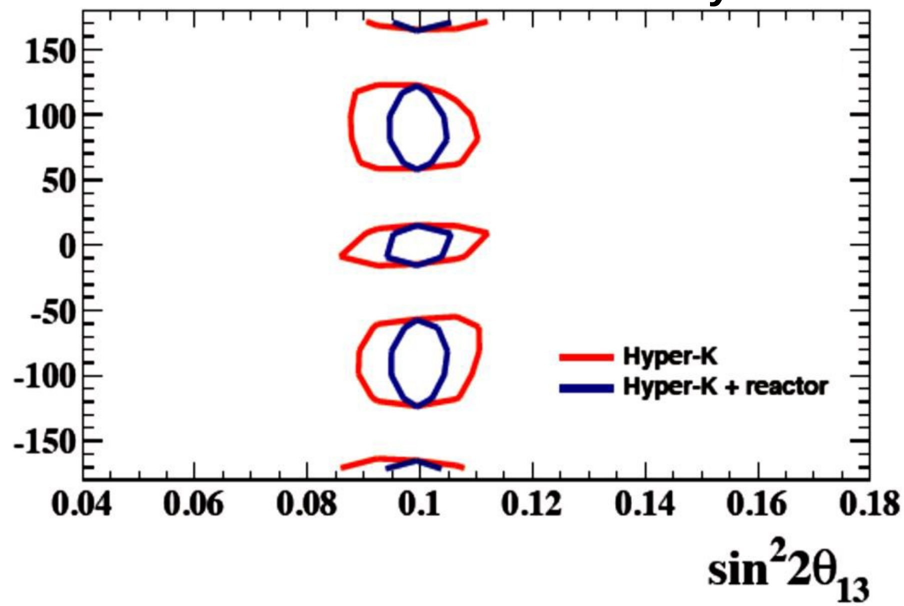
- Use both reconstructed energy spectra and number of observed events

90%CL allowed regions for $\delta=-90^o, 0^o, 90^o, 180^o$

Normal hierarchy



Inverted hierarchy



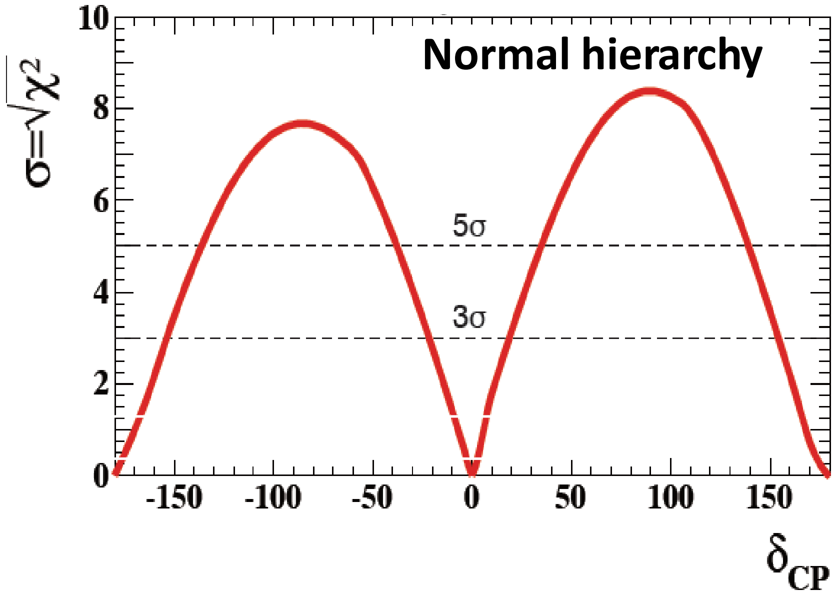
Determination power of δ_{CP} parameter:

1σ error of δ_{CP} is expected to be $8^o \sim 19^o$.

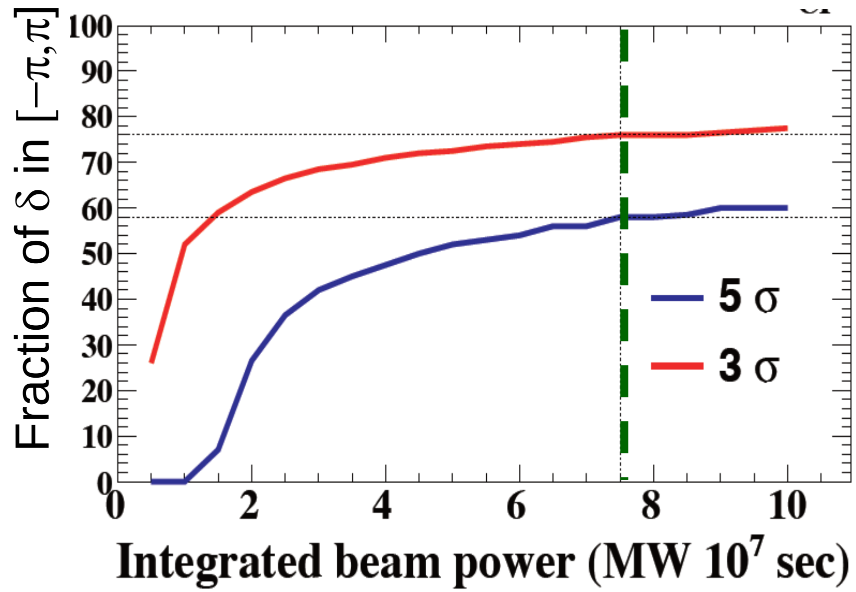
sensitivity to CPV

- sinδ=0 exclusion (CPV sensitivity)

7.5 x 10⁷ MW·sec (10 years)



Chance(%) to observe CP violation



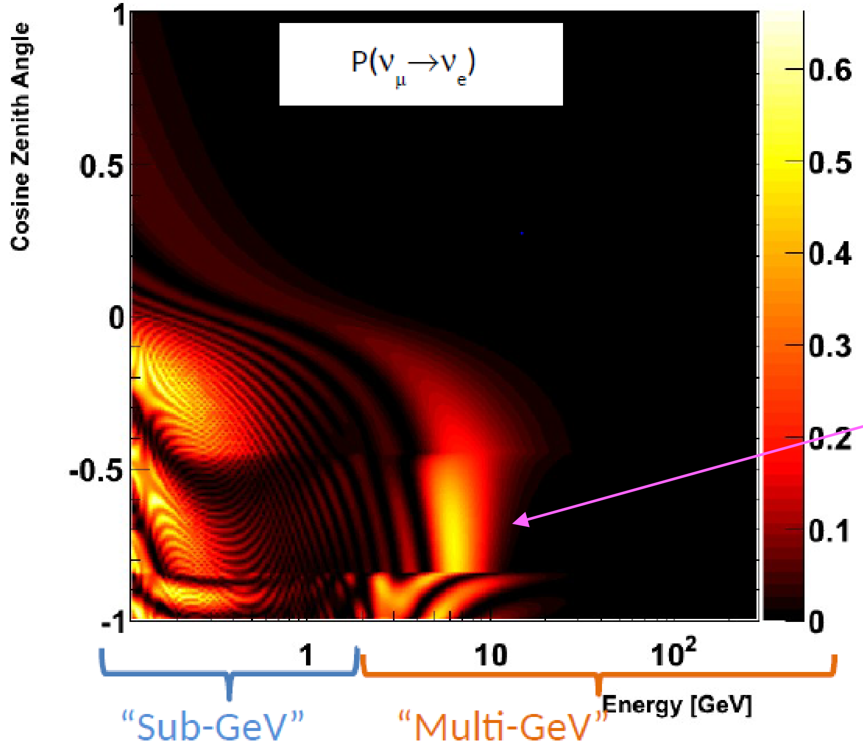
76% chance to observe CPV at 3σ

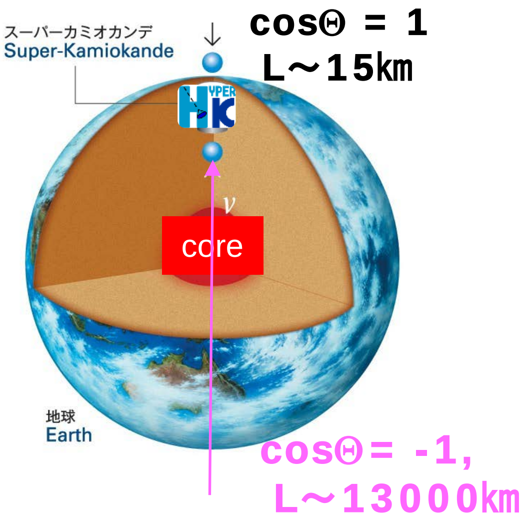
58% chance to observe CPV at 5σ

Mass hierarchy is assumed to be known

MH? atmospheric ν!

- ν_e appearance probability





Region of interest:
Multi-GeV, upward(Θ<0)

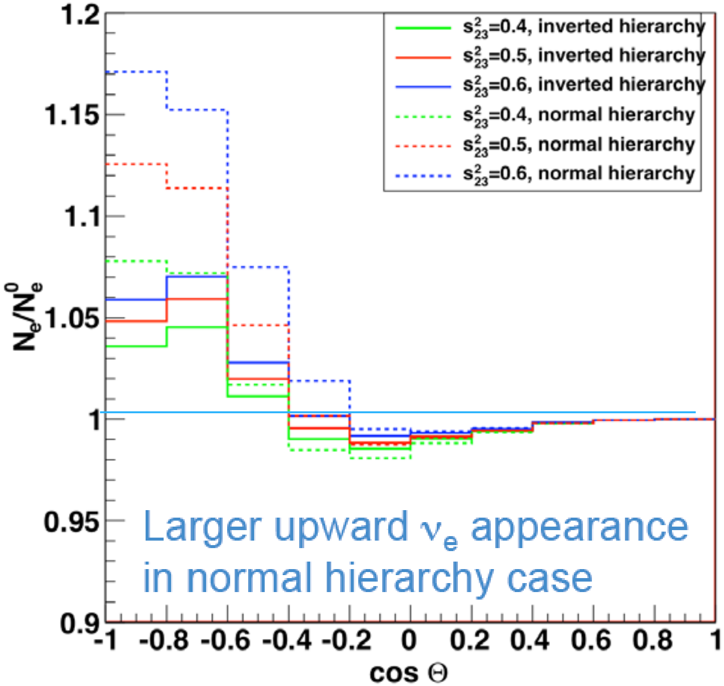
$\nu_\mu \rightarrow \nu_e$ resonance occurs in earth's core.
It is either ν_e or $\bar{\nu}_e$ depending on MH

Not only MH, but also has sensitivity to

- θ_{23} octant
- CP asymmetry

expected zenith angle distributions for N_e / N^0_e (MH, θ_{23} dependence)

Multi-GeV ν_e-like



10 years

Full MC

$\sin^2\theta_{23} = 0.4$
$\sin^2\theta_{23} = 0.5$
$\sin^2\theta_{23} = 0.6$

Inverted hierarchy (solid line)
Normal hierarchy (dotted line)

$\Delta m^2_{12} = 7.6 \times 10^{-5}\ eV^2$
$\Delta m^2_{23} = 2.4 \times 10^{-3}\ eV^2$
$\sin^2\theta_{12}=0.31$
$\sin^2\theta_{13}=0.025$
$\delta_{CP}=40°$

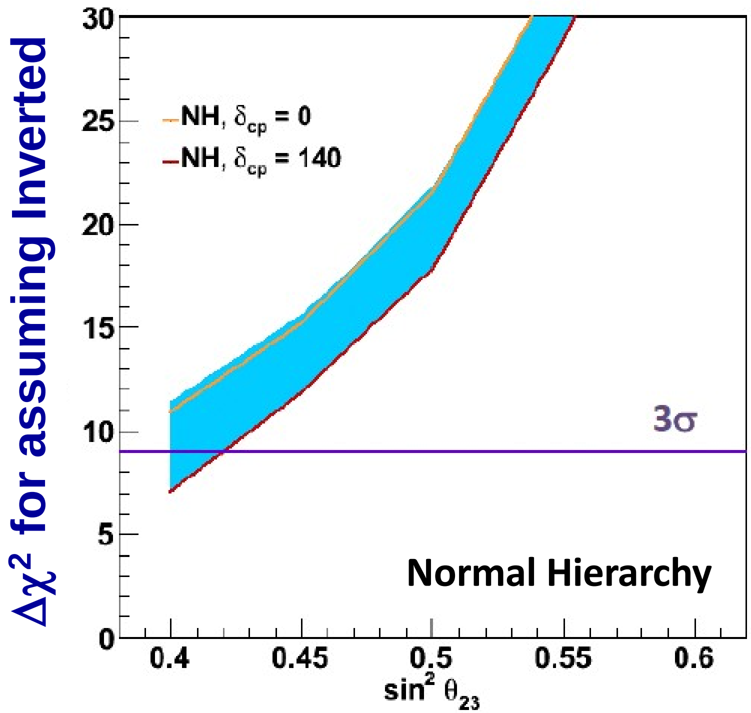
- MH difference (and θ_{23} octant difference) are clearly visible.

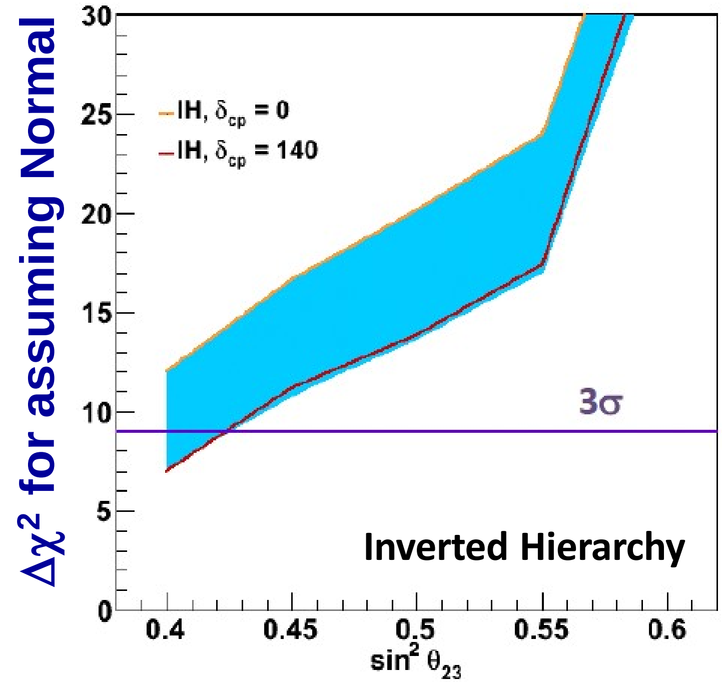
sensitivity to MH

- Significance ≡ $\Delta\chi^2$ for wrong MH rejection

$\sin^2 2\theta_{13} = 0.1$
HK 10 years operation

Band : range of CP





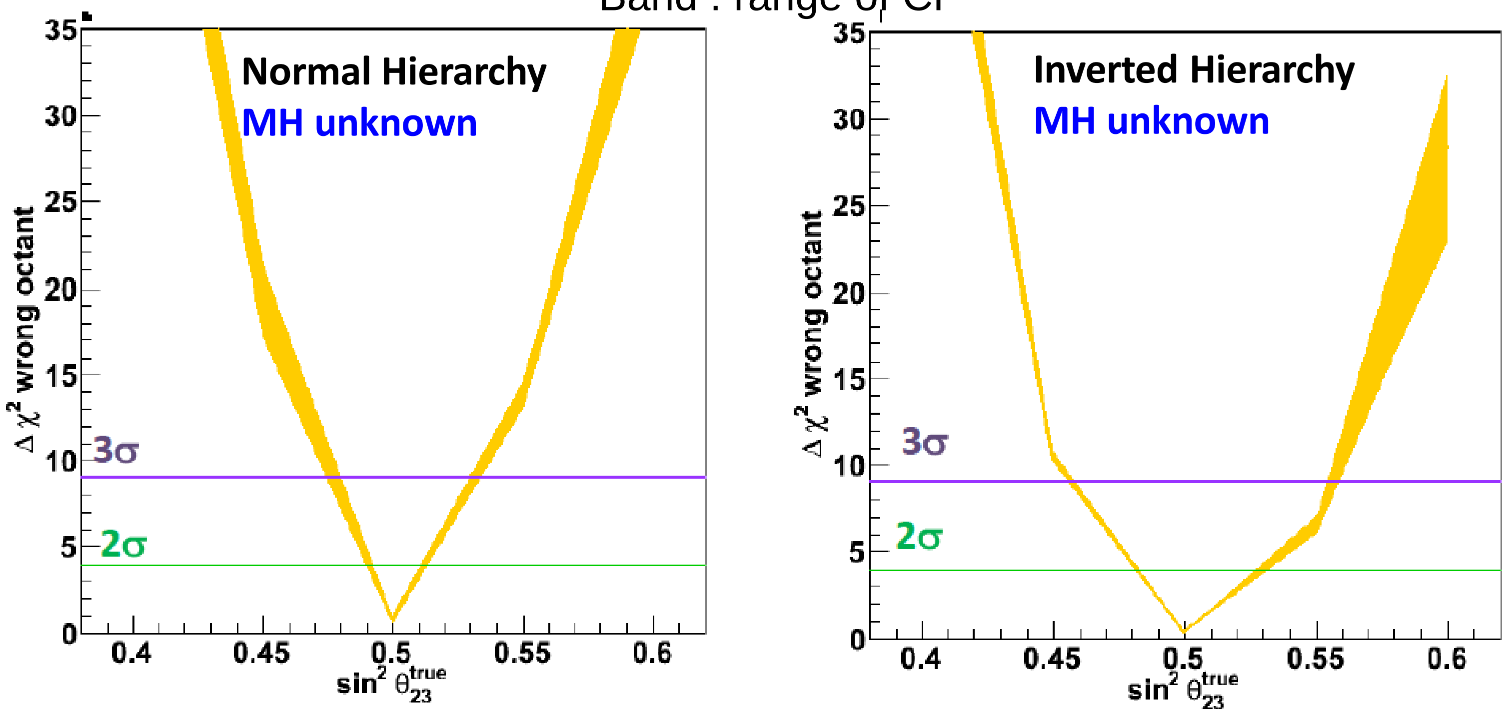
Sensitivity depends on θ_{23}, but for most cases MH can be determined >3σ

HK sensitivity to θ_{23} octant

- Significance ≡ $\Delta\chi^2$ for wrong octant rejection

$\sin^2 2\theta_{13} = 0.1$
HK 10 years operation

Band : range of CP



Octant can be determined >3σ

if $\sin^2\theta_{23}$ < 0.47 and $\sin^2\theta_{23}$ > 0.53 for NM

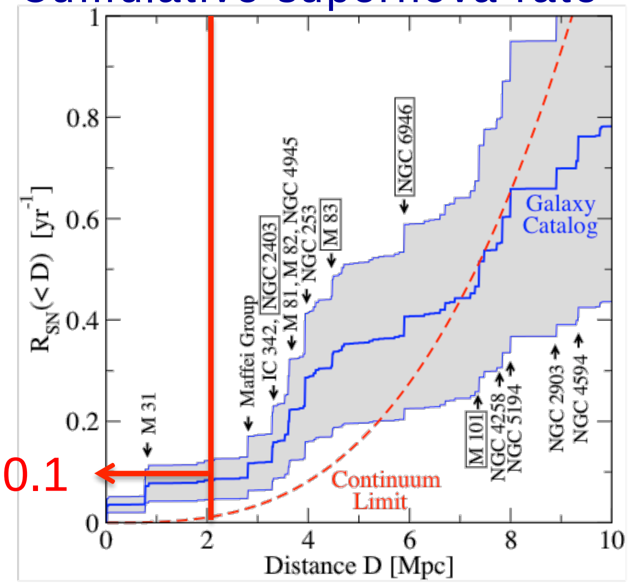
if $\sin^2\theta_{23}$ < 0.45 and $\sin^2\theta_{23}$ > 0.56 for IM

Astroparticle Neutrinos

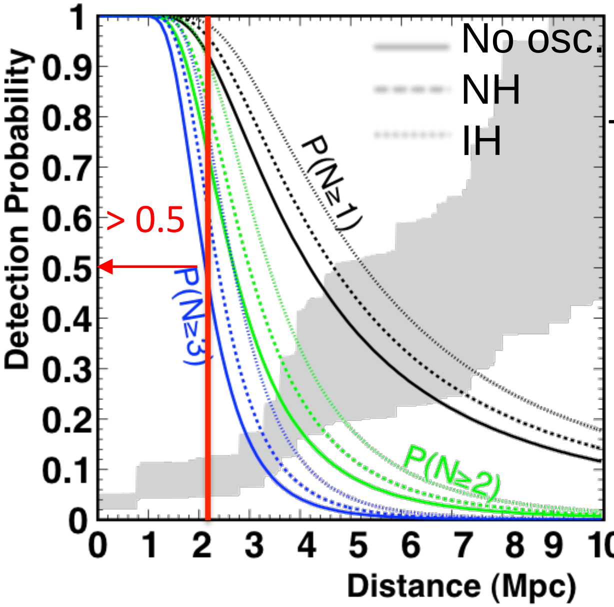
Hyper-K sensitivity to SN burst ν

- SN in nearby galaxies

Cumulative supernova rate



Hyper-K detection probability



1 SN about every 10 years is expected within 2 Mpc.
>50% chance for signal multiplicity of 3 for SN at 2 Mpc

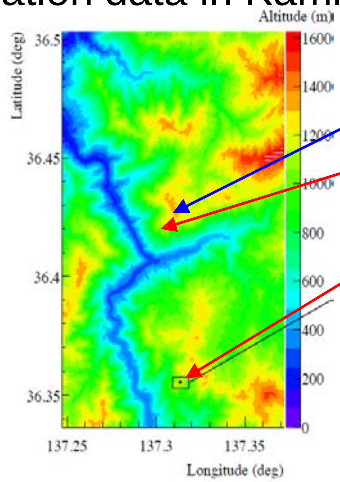
- SN in our galaxy

Huge statistics ~250k events @ 10kpc
Sensitive to MH

HYPER K sensitivity to DSNB (SN relic neutrino)

- Sensitivity depends on spallation BG by cosmic μ

Elevation data in Kamioka



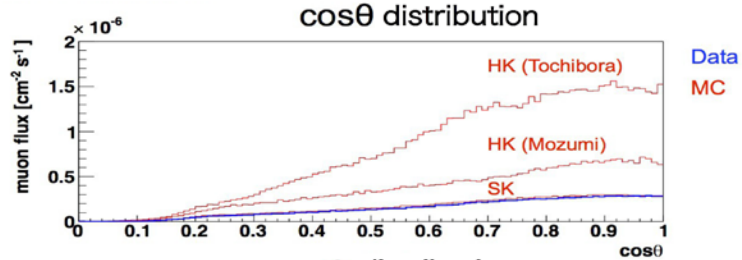
SK Mozumi

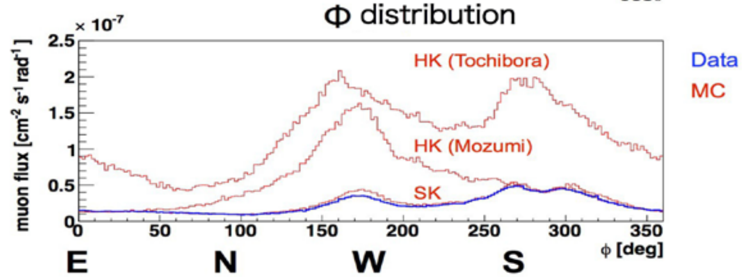
HK Mozumi

HK Tochibora

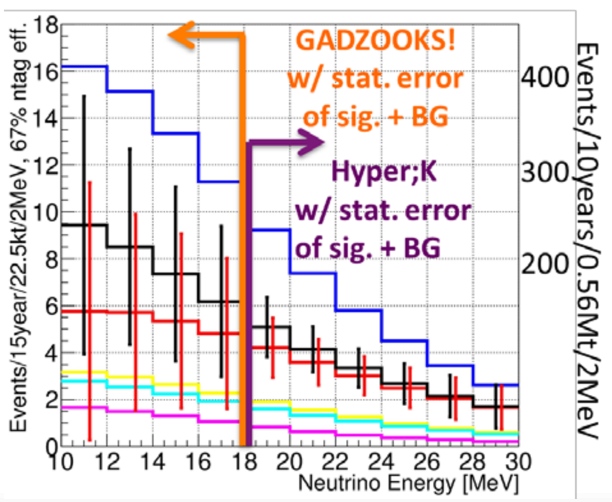
At Tochibora,
SK x 4 spallation BG

μ flux

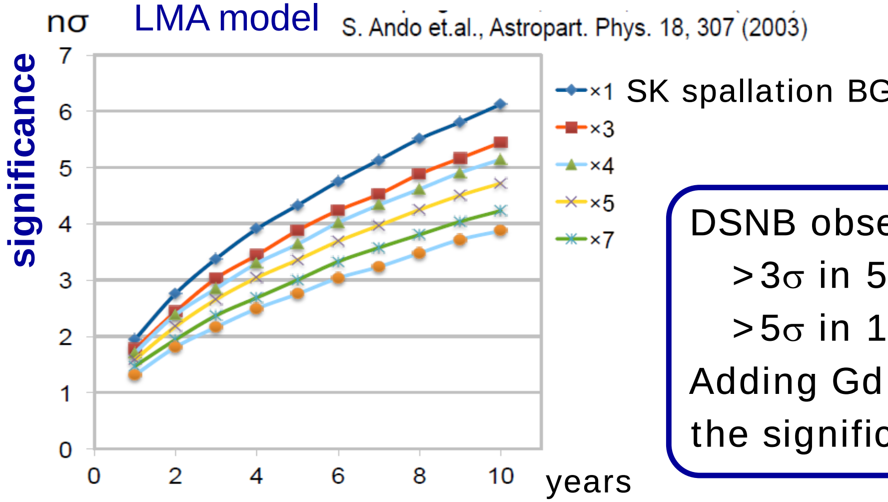




Expected DSNB spectra for various models



LMA model S. Ando et.al., Astropart. Phys. 18, 307 (2003)



DSNB observation
> 3σ in 5 years
> 5σ in 10 years
Adding Gd increases the significance

WIMP annihilations

- Possible annihilation channels
  - $\chi\chi \rightarrow qq, gg, cc, ss, bb, tt, W^+W^-, ZZ, \tau^+\tau^-, \mu\mu, \nu\nu, e^+e^-, \gamma\gamma$

Few neutrinos

"high energy neutrinos" in decay

Dominant decay into hadrons

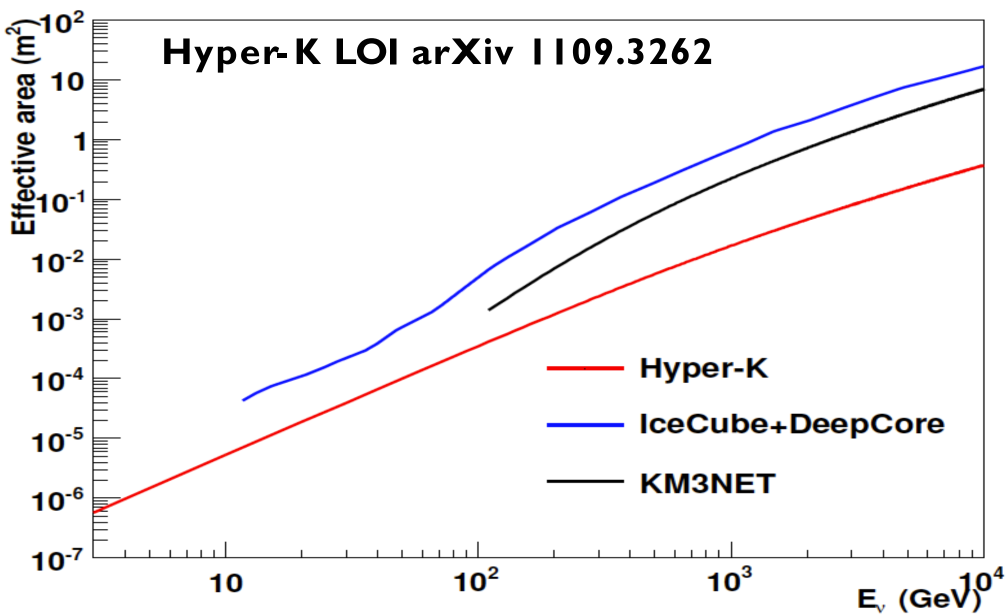
Charged pions decay producing neutrinos up to E=52.8MeV

targets of usual indirect search

"low energy neutrinos" → Unique targets for SK/HK

C.Rott et al., arXive:1208.0827

- Up-going ν_μ effective area



HK Fiducial vol.: 25 x SK

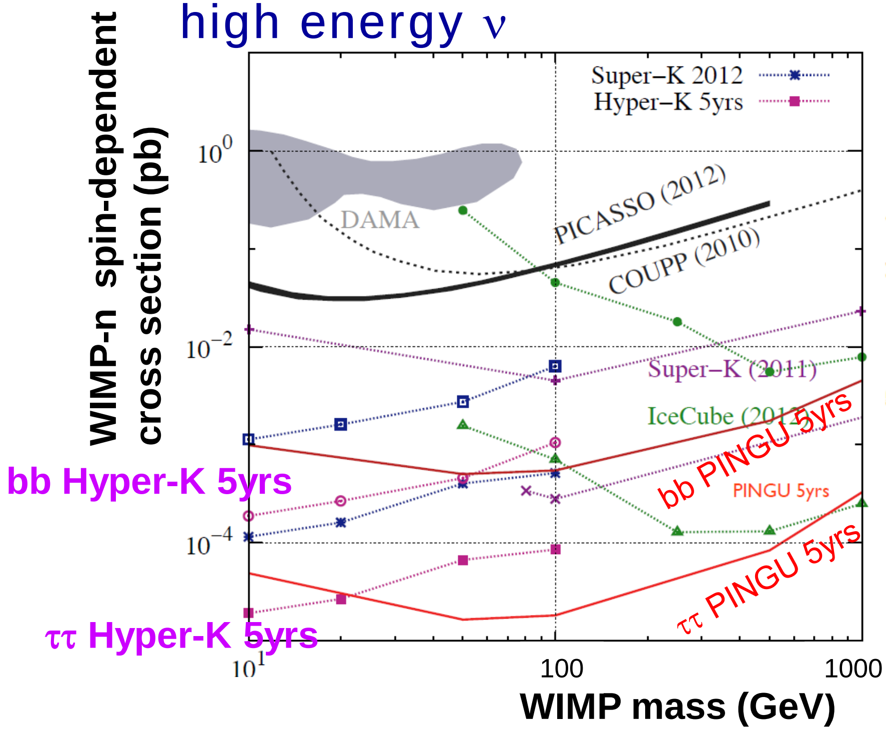
HK Effective area: ~18 x SK

sensitivity 3~6 x SK

Hyper-K sensitivity to WIMPs

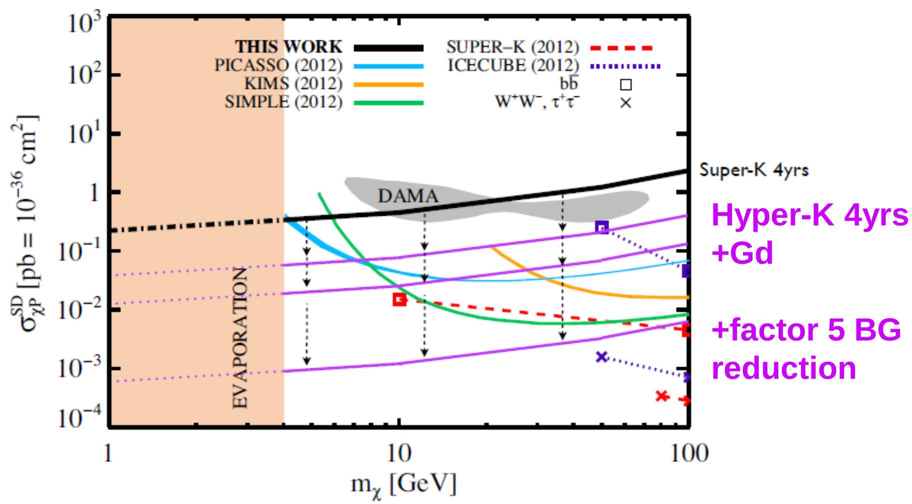
- In the Sun

high energy ν



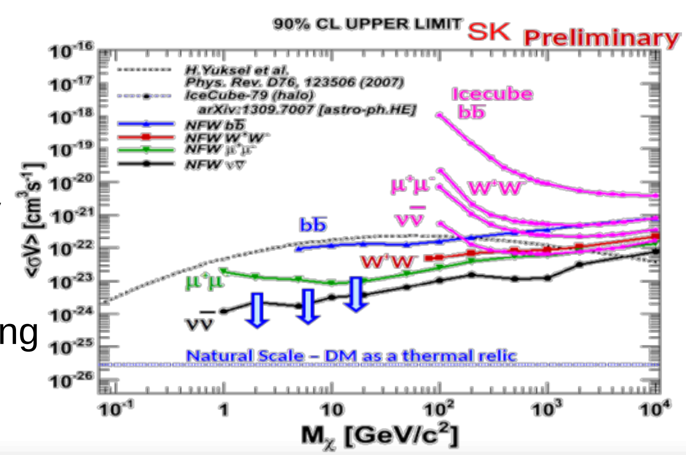
low energy ν

Model the full hadronic shower in the Sun.
Minimal dependence on channels.



- In the Galaxy

Studies on Hyper-K sensitivity are on going

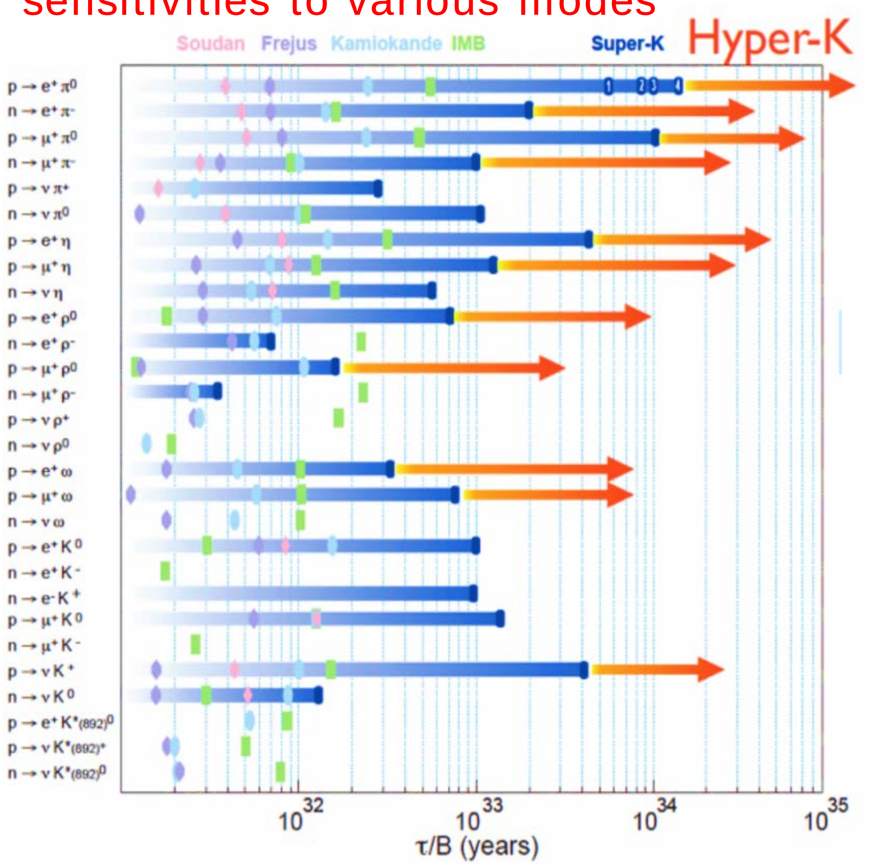


In low mass region
Hyper-K will be the best!

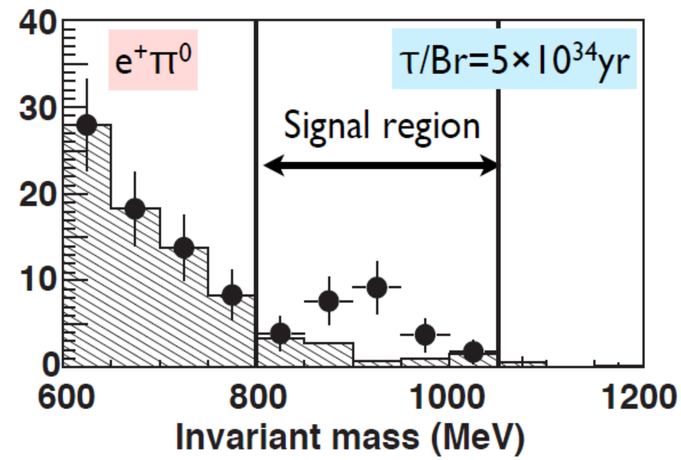
HYPER K sensitivity to proton decay

- 10 times better sensitivity than Super-K
  - Only realistic plan to go beyond 10^{35} years for $p \rightarrow e^+\pi^0$

Hyper-K 10years
sensitivities to various modes



In lucky case, 3σ discovery is possible!



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

1.3×10^{35} years (90%CL)

5.7×10^{34} years (3σ discovery)

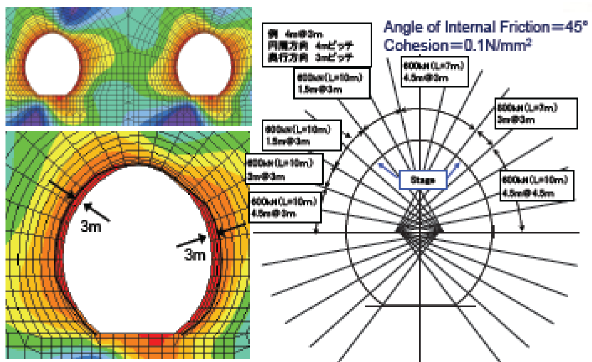
$p \rightarrow \nu K^+$ SUSY favored

3.2×10^{34} years (90%CL)

1.2×10^{34} years (3σ discovery)

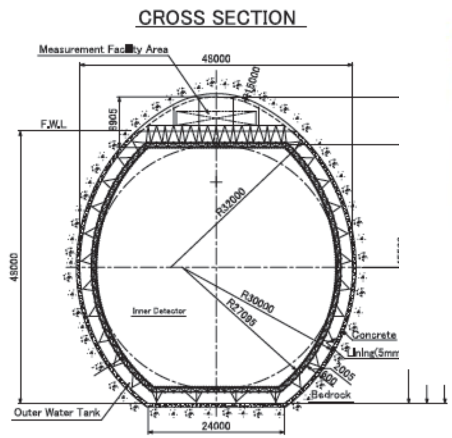
Technical R&D

- Large cavern excavation

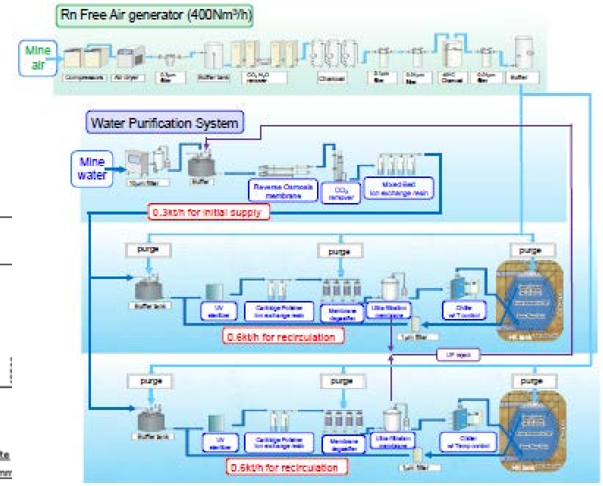


(Section G:3m of Max Loosened Zone)

- Water tank

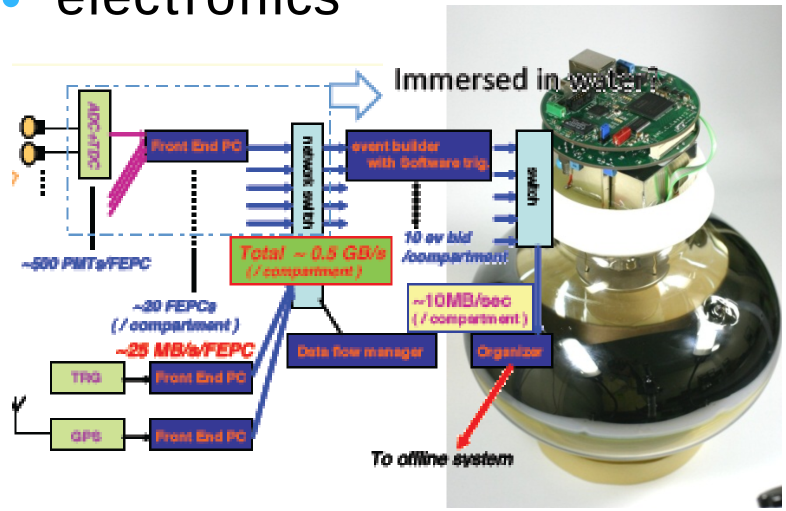


- Water purification system



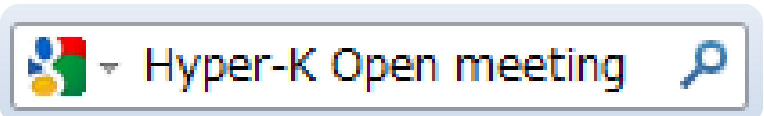
- Photo sensor
  - High QE 20'' BL-dynode PMTs and high QE 20'' HPDs will be tested in water.

- electronics



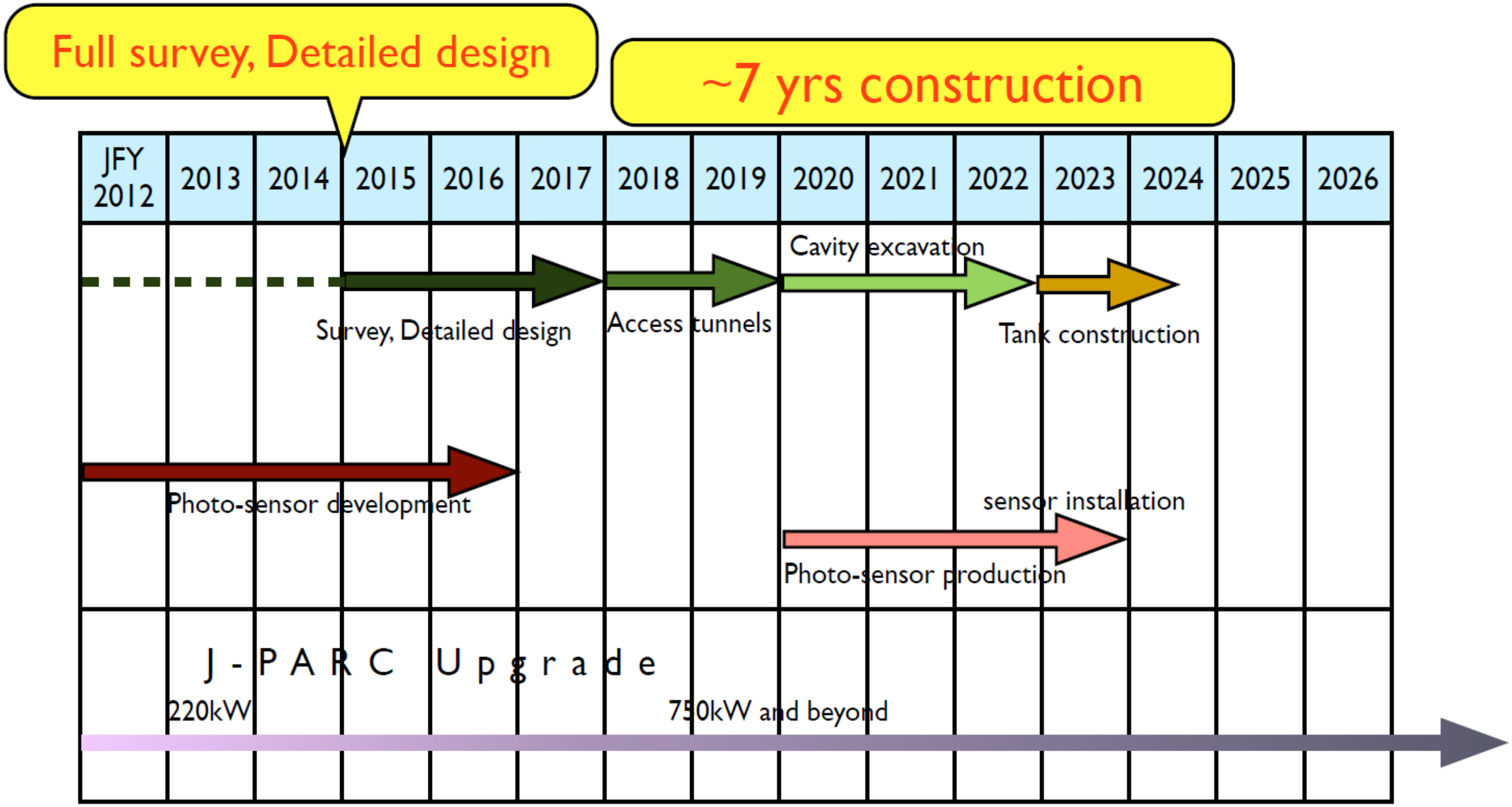
Conclusion

- Hyper-K has great potential for wide range of Physics.
  - Neutrino mixing parameters
    - Discovery potential of CPV(δ_{CP}) for 76% of the region with 3σ.
    - Determine Mass hierarchy and θ_{23} octant with 3σ.
  - Astrophysical neutrinos
    - Burst Supernovae sensitivity Nν>3 at 2Mpc
    - SRN >3σ in 5 year w/o Gd
    - Best sensitivity to Low mass WIMPs
  - Proton decay
    - sensitivity o(10^{35})years for $p \rightarrow e^{+}\pi^{0}$
  - Other physics including unexpected
    - ex. sterile/ν mass: KOHRI's talk on Friday at 18:10
- Preparation works are in progress.
- Hyper-K is open to the international community.
  - 5^{th} Open Hyper-K meeting in Vancouver
    July 19-22 at UBC/TRIUMF



Extra slides

Timeline



-2015 Full survey, Detailed design (3 years)
-2018 Excavation start (7 years)
-2025 Start operation

Political Status

- ~2013
  - HEP and CRC communities endorse Hyper-K.
  - Budget for Hyper-K R&D is available.
    - building One kton proto-type detector.
- 2014
  - IBR (International Board of Representative) committee is formed.
    - Brazil, Canada, France, Italy, Japan, Korea, Poland, Portugal, Russia, Spain, Switzerland, UK, and US.
  - Science Council of Japan announced "Japanese Master Plan of Large Research Projects". New
    - http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-22-t188-1.pdf
    - Top 27 projects out of 192 are selected in all science area. The Hyper-K is one of the top projects to be pursued in Japan.

HYPER K

Home | For Public | For Scientists | For Collaborators

Home › Getting Involved

Hyper-K IBR

Getting Involved

If you would like to get involved in the project, please contact the IBR member of your own Country:

Attendees of the 4th open Hyper Kamiokande meeting

Brazil: H. Nunokawa (Rio de Janeiro)

Canada: S. Bhadra (York), A. Konaka (TRIUMF)

France: M. Gonin (Ecole Polytechnique)

Italy: M.G. Catanesi (INFN-Bari)

Japan: T. Kobayashi (KEK), T. Nakaya (Kyoto), M. Shiozawa (ICRR)

Korea: K.K. Joo (CNU)

Poland: E. Rondio (NCBJ, Warsaw)

Portugal: J. Maneira (LIP, Lisbon)

Russia: Y. Kudenko (INR)

Spain: L. Labarga (Madrid)

Switzerland: A. Blondel (Geneva)

UK: F. Di Lodovico (QM London), D. Wark (STFC, RAL-PPD, Oxford)

USA: E. Kearns (Boston), C. Walter (Duke)

If your Country is not among the ones above, please contact:

T. Nakaya (Kyoto), M. Shiozawa (ICRR)

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14年3月18日火曜日