Hyper-Kamiokande project and its physics potential

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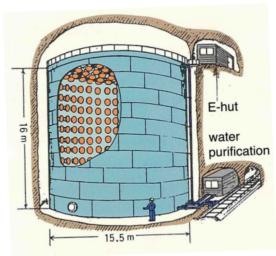
on behalf of Hyper-Kamiokande collaboration

International workshop on “Double Beta Decay and underground Science”
Hawaii, 22nd October, 2018

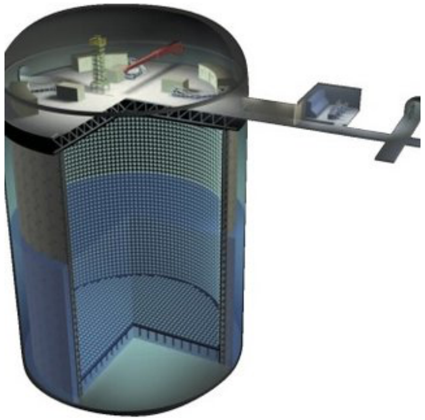
Three generations of "Kamiokande"

Kamiokande
(1983-1995)



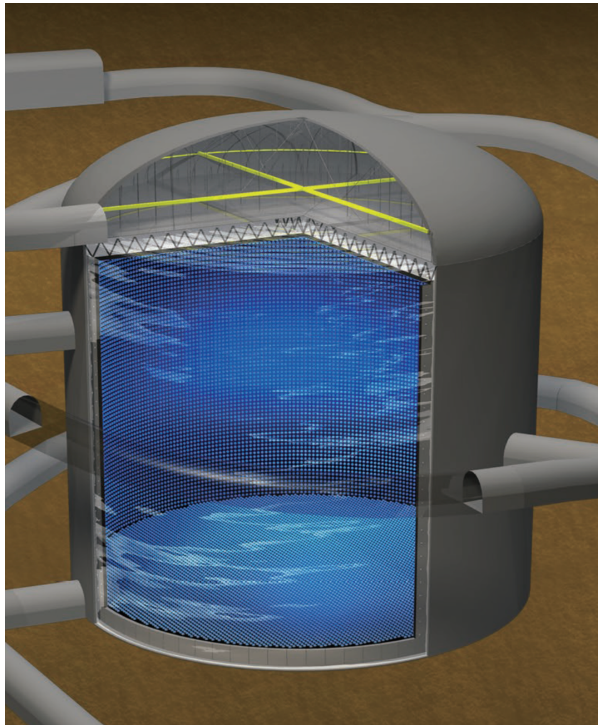
3kton
20% coverage
with 20' PMT

Super-Kamiokande
(1996-)



50k (22.5k) ton
40% coverage
with 20' PMT

Hyper-Kamiokande (~2027-)



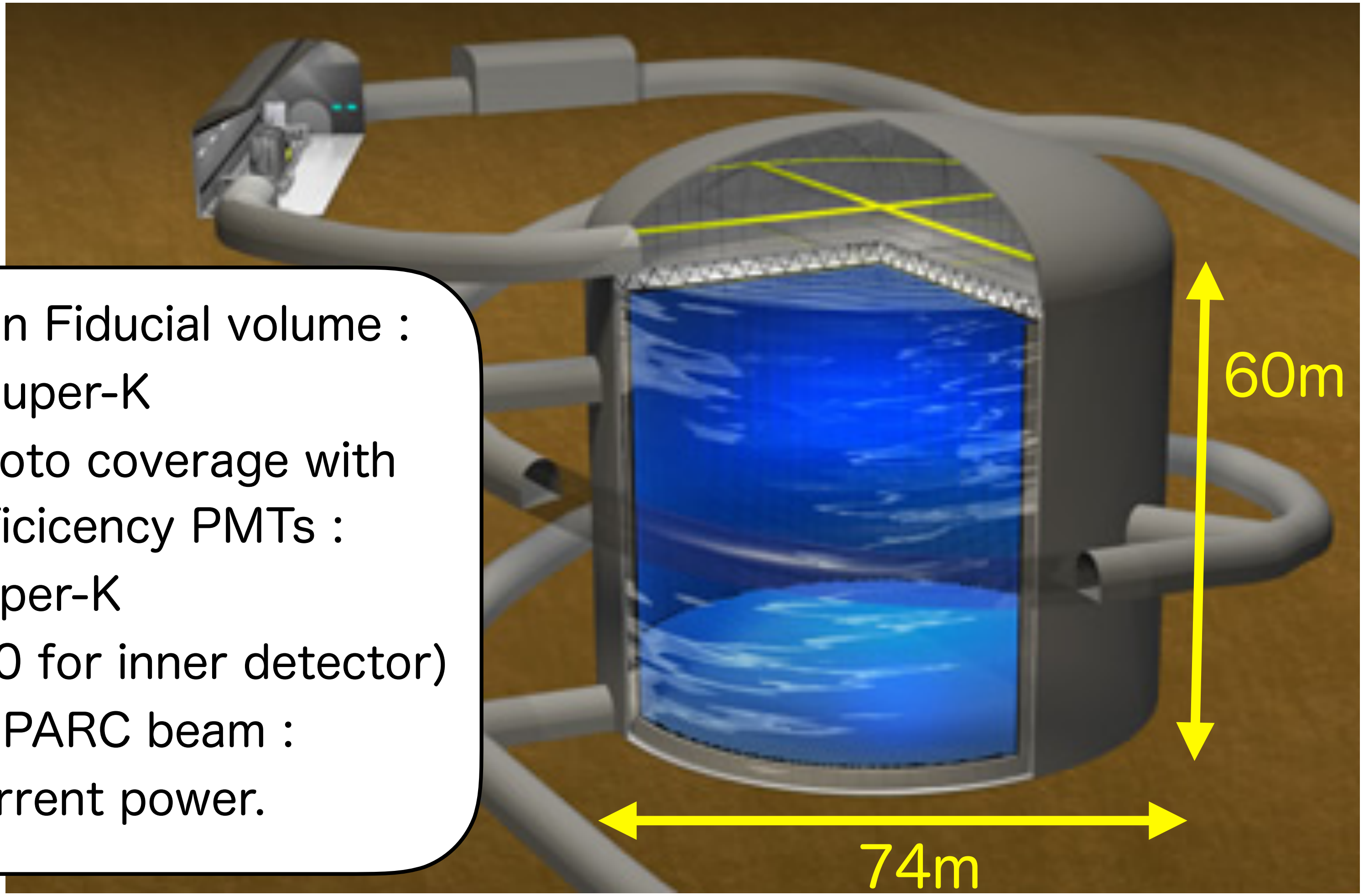
260k (190k) ton
40% coverage
with high-QE 20' PMT

SK-Gd
(2019-)

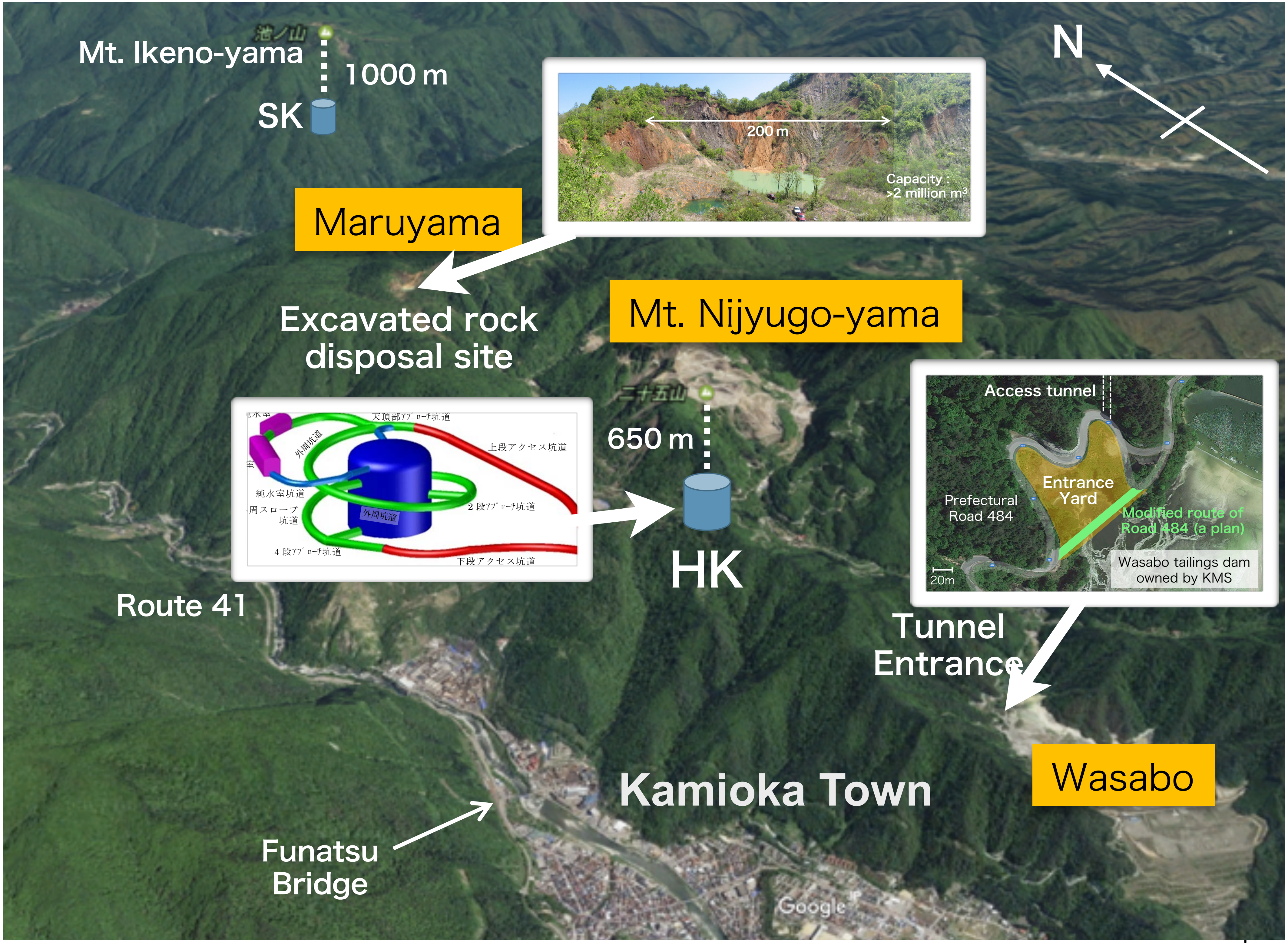
Hyper-Kamiokande

(See also “Hyper-Kamiokande Design Report”, arXiv : 1805.04163)

Next generation of large water Cherenkov detector for neutrino physics, astrophysics, nucleon decay, etc.



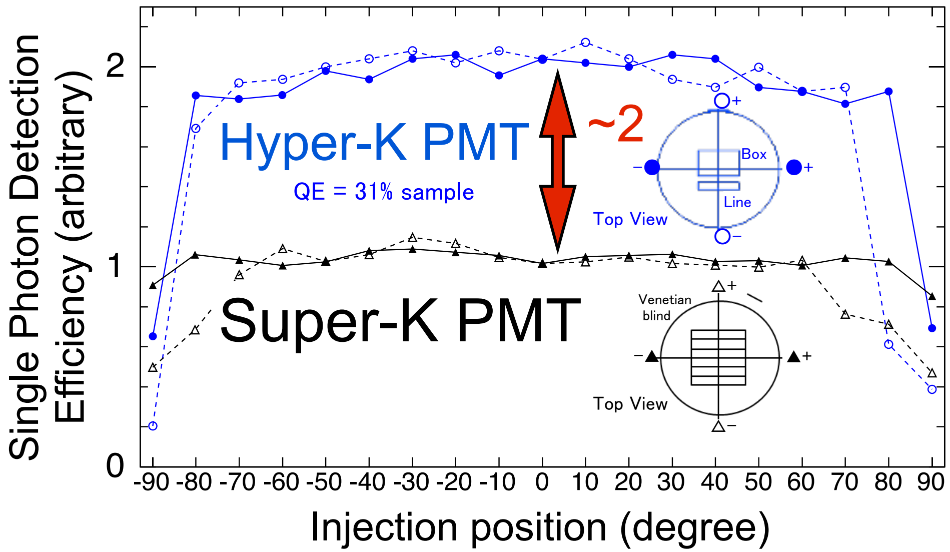
- 190kton Fiducial volume : ~10 x Super-K
- 40% photo coverage with high-efficicency PMTs : ~2 x Super-K (~40000 for inner detector)
- >MW J-PARC beam : ~3 x current power.



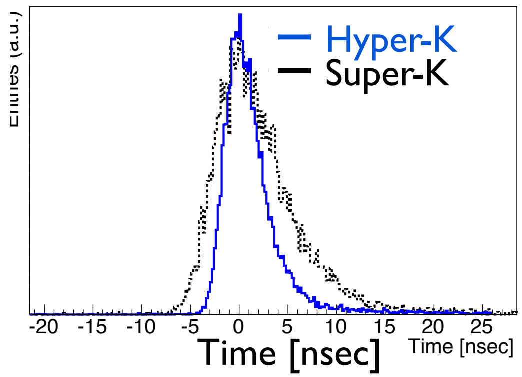
池ノ山
Mt. Ikeno-yama
1000 m
SK
N
200 m
Capacity :
>2 million m³
Maruyama
Excavated rock
disposal site
Mt. Nijyugo-yama
二十五山
650 m
HK
天頂部ｱﾌﾟﾛｰﾁ坑道
外周坑道
上段アクセス坑道
純水室坑道
2 段ｱﾌﾟﾛｰﾁ坑道
坑道
外周坑道
4 段ｱﾌﾟﾛｰﾁ坑道
下段アクセス坑道
Access tunnel
Entrance
Yard
Prefectural
Road 484
Modified route of
Road 484 (a plan)
Wasabo tailings dam
owned by KMS
20m
Route 41
Tunnel
Entrance
Wasabo
Kamioka Town
Funatsu
Bridge
Google

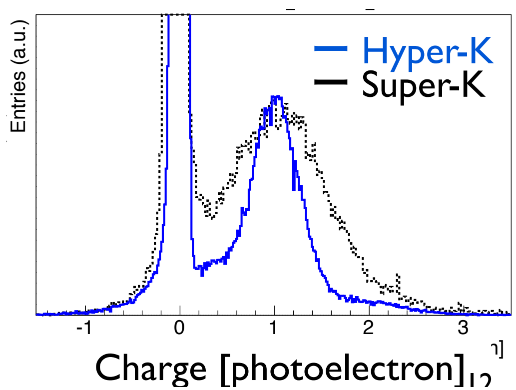
New developed photo-sensor

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



~140 new PMTs have been installed in SK this summer. Performance will be checked with Cherenkov light for years.

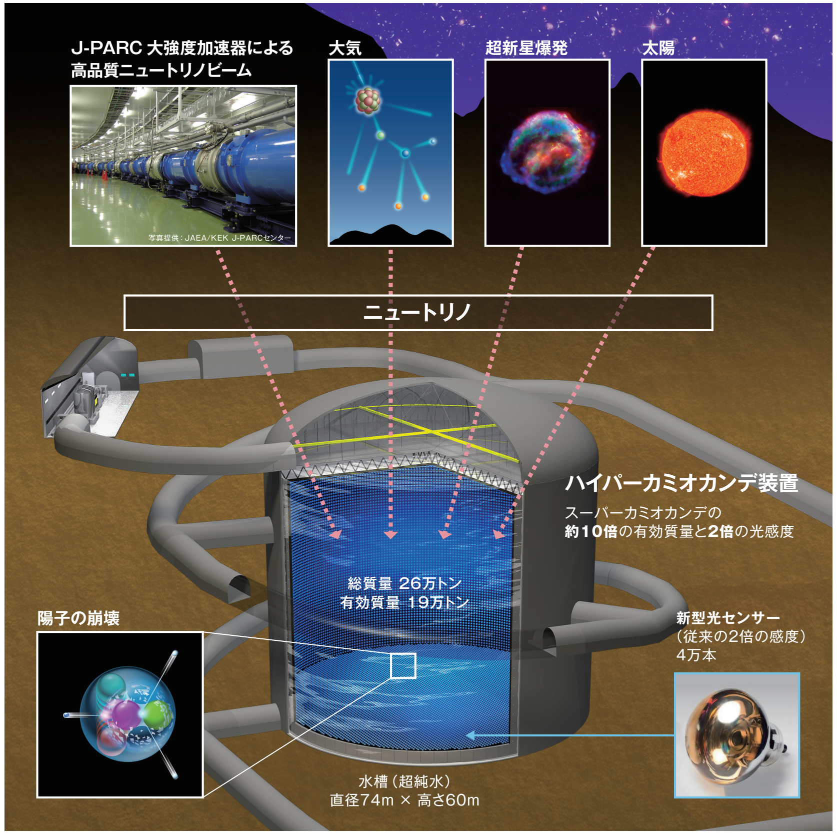


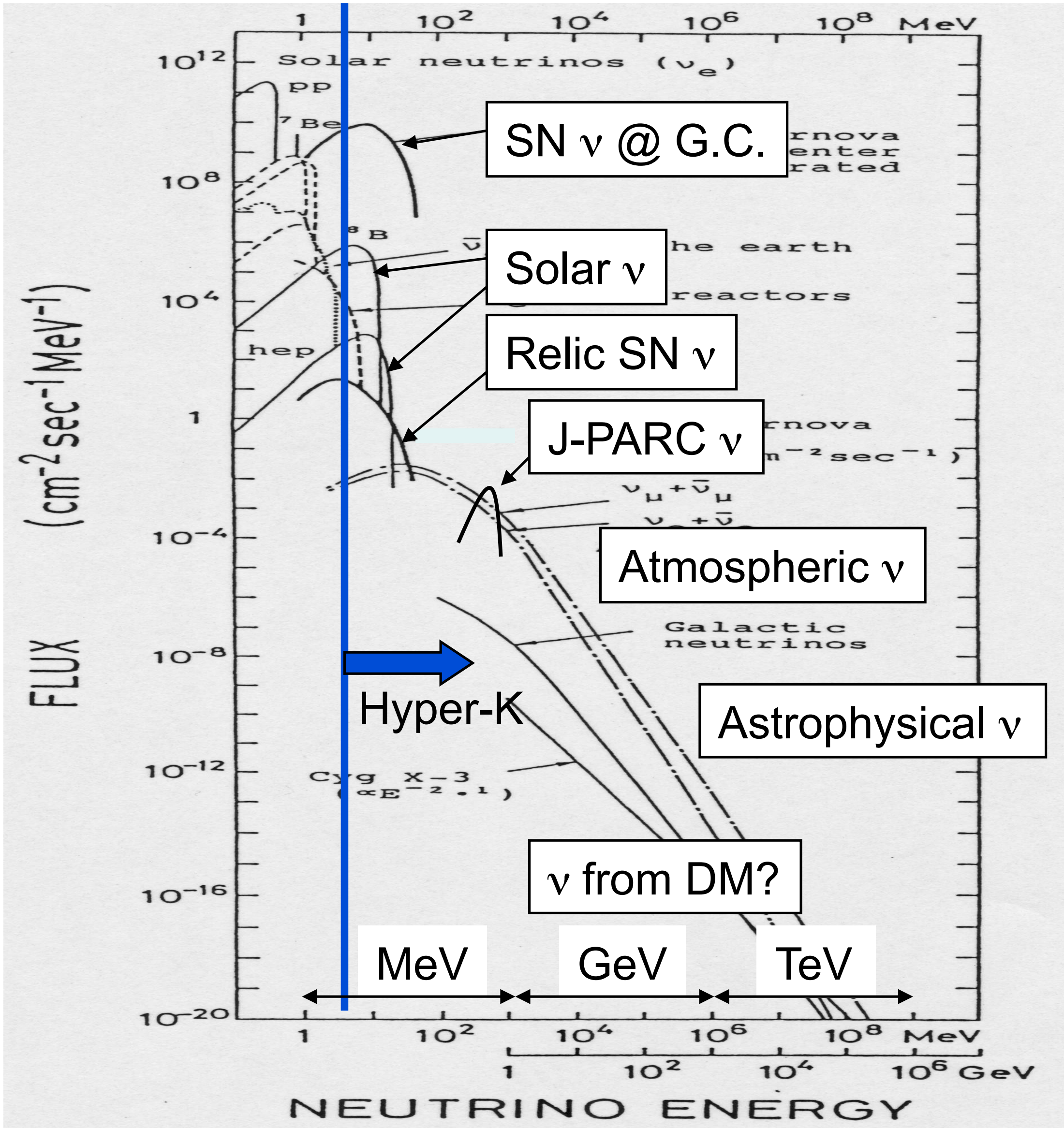


Continuous effort for improvements, e.g. noise reduction, cover design, light concentrator, etc.

Multi-purpose detector

Broad scientific program with wide energy range (MeV~TeV)





Neutrino oscillation

Mixing angle : Maki-Nakagawa-Sakata Matrix

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

Atm. and Acc.	Reactor and Acc.	Solar and KamLAND
$\theta_{23} \sim 45 \pm 5^\circ$	$\theta_{13} \sim 9^\circ$	$\theta_{12} \sim 34 \pm 3^\circ$
$\lvert\Delta m^2_{32}\rvert = 2.4 \times 10^{-3}\mathrm{eV}^2$		$\Delta m^2_{21} = +7.6 \times 10^{-5}\mathrm{eV}^2$

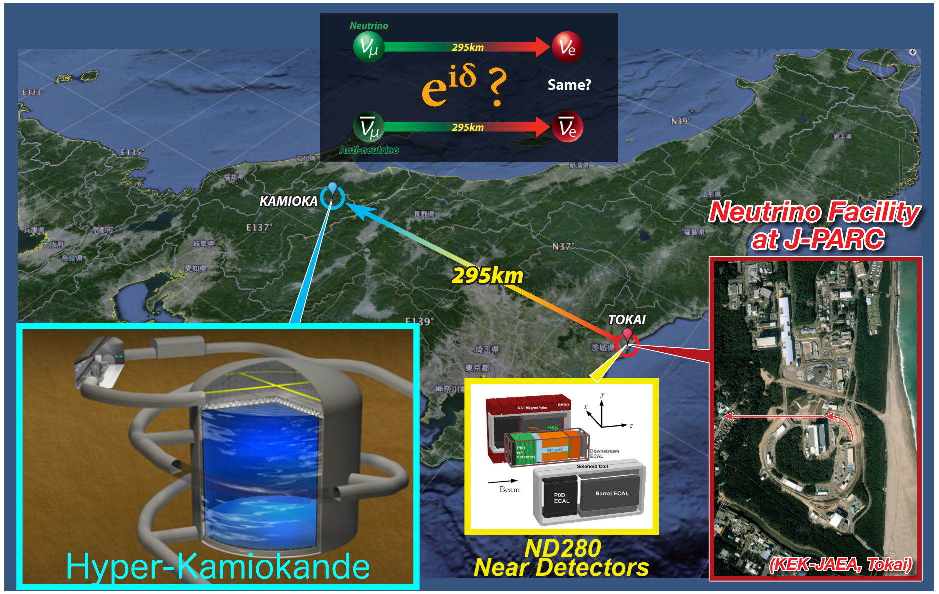
δ cp and Mass hierarchy of 2-3 are not determined

Atmospheric, Accelerator, Reactor

Accelerator, Atmospheric and Solar neutrinos are main targets of Hyper-Kamiokande

Accelerator neutrino

Neutrino beam from J-PARC



Same beamline as T2K

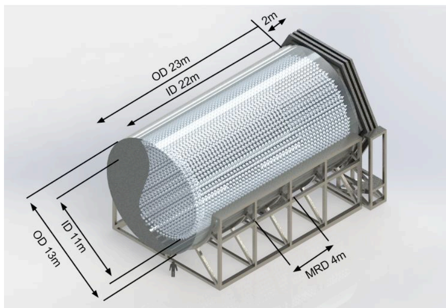
30GeV, 485kW in 2018

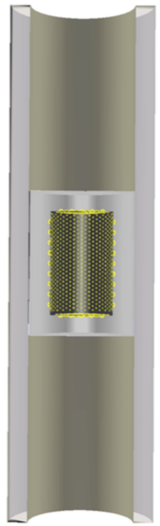
>1.3MW by upgrade

Reduce rep. cycle with new power supplies

Near detectors

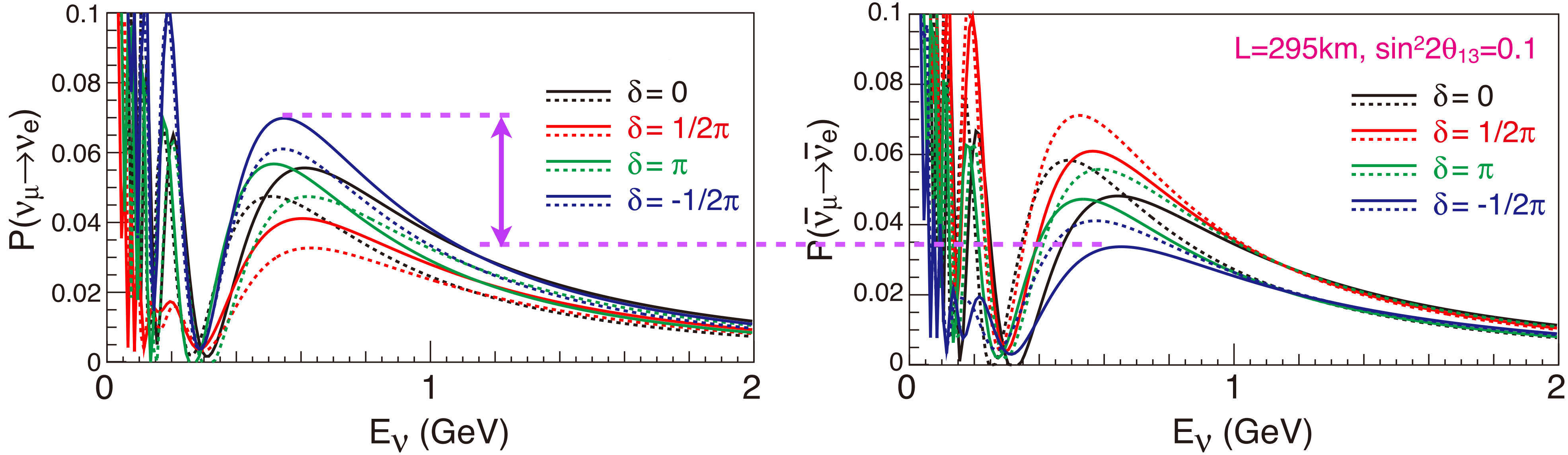
- Based on experience in T2K, with new ideas
- Upgrade ND280 off-axis detectors
  - Upgrade proceeding for T2K-II
- Intermediate (1~2km) Water Cherenkov Detector
  - Off-axis spanning, with Gd loading





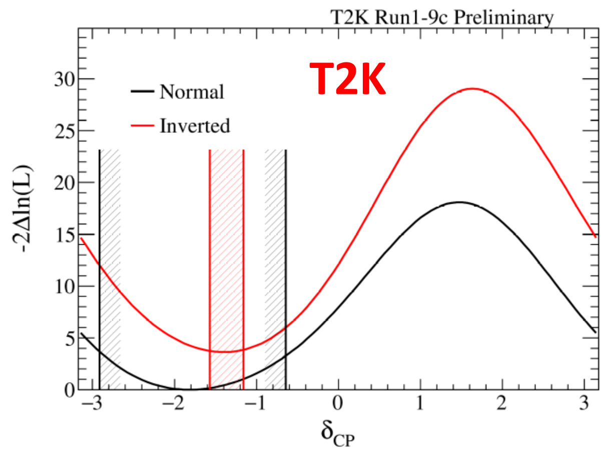
Search for CP violation

Neutrino　　　　　　　　　　Anti-Neutrino



- Hint on maximal CP violation, however, need more statistics, O(1000), for definite measurement,

  cf. current T2K : 89 ν_e and 7 ν_e

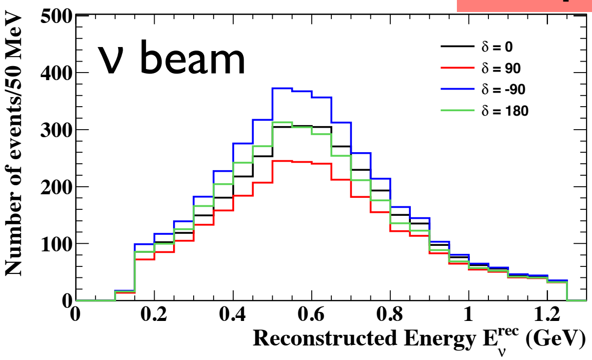


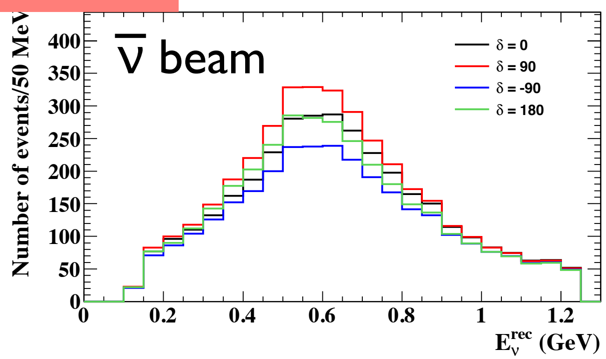
- Control of systematics is crucial,
  - Neutrino beam, interaction and detector.
  - Assigned 6-7% in current T2K.

Expected events at HK

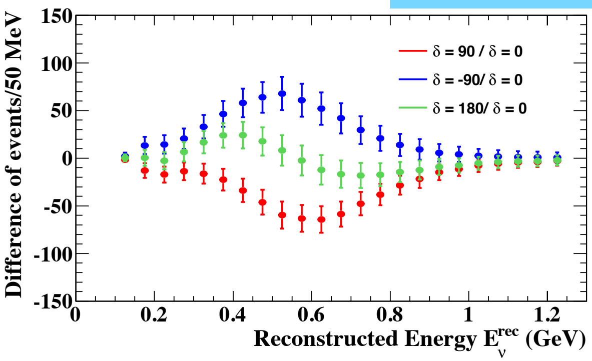
10 years (10yrs×1.3MW×10^7s), ν : νbar = 2.5yrs : 7.5yrs

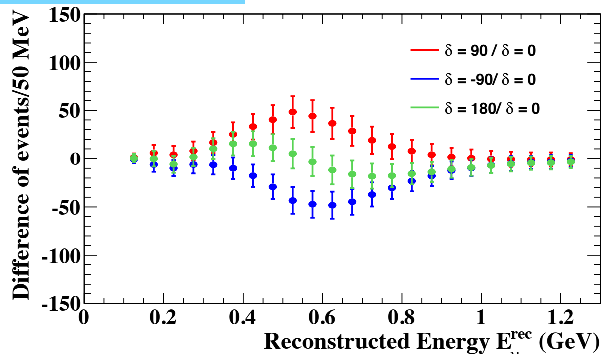
ν_e appearance





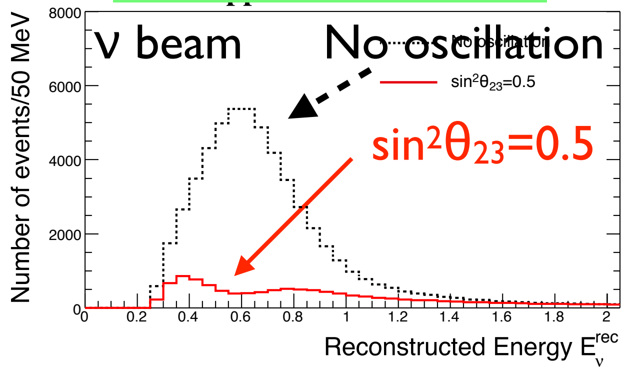
Difference from δ_{CP}=0

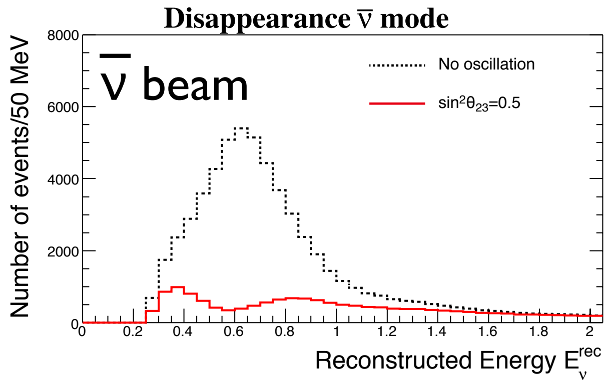




for δ=0	Signal ($\nu_\mu \to \nu_e$ CC)	Wrong sign appearance	$\nu_\mu/\bar{\nu}_\mu$ CC	beam $\nu_e/\bar{\nu}_e$ contamination	NC
ν beam	1,643	15	7	159	134
$\bar{\nu}$ beam	1,183	206	4	317	196

ν_μ disappearance

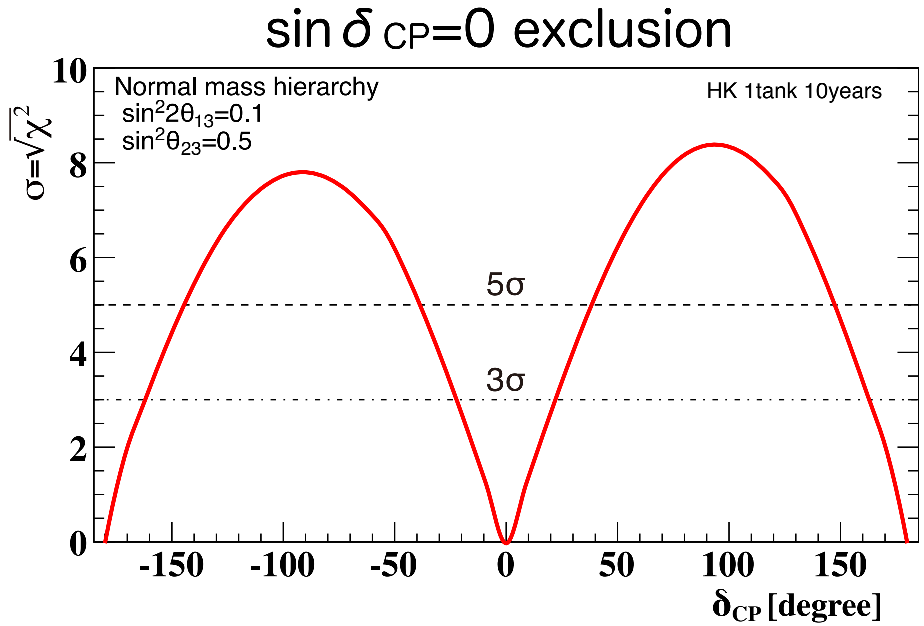


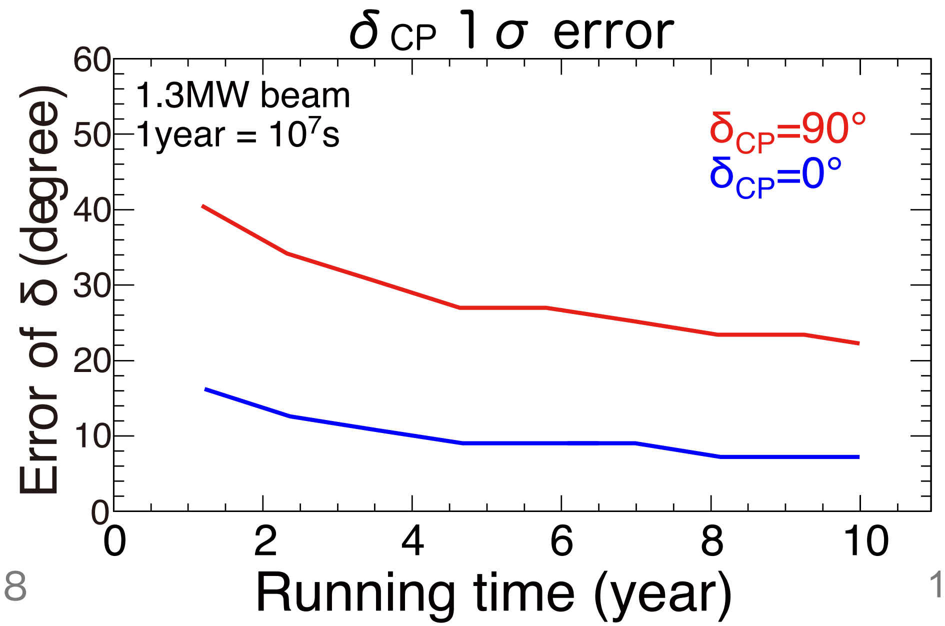


	$\nu_\mu+\bar{\nu}_\mu$ CCQE	ν_μCC nonQE	Others
ν beam	6,391	3175	515
$\bar{\nu}$ beam	8,798	4315	614

CP violation sensitivity

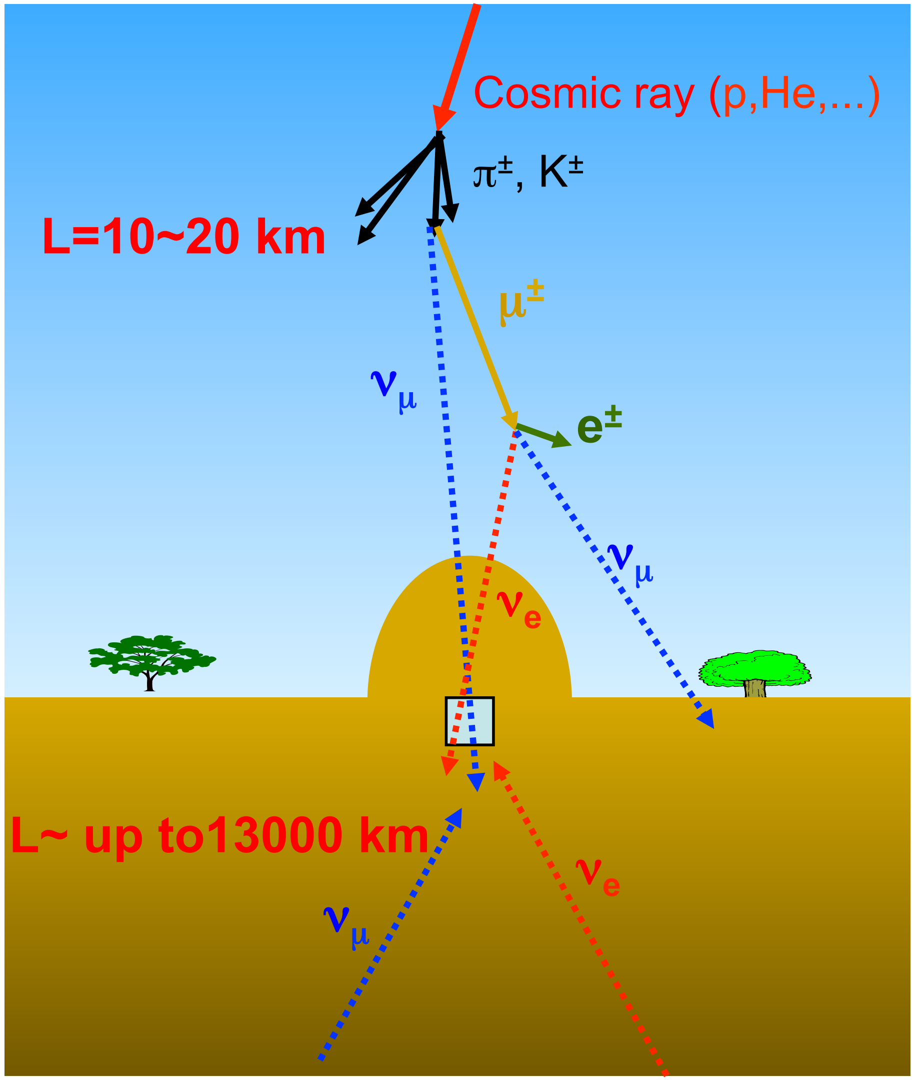
- Exclusion of sin δ_{CP}=0
  - 8σ (6σ) for δ=-90° (±45°)
  - 76% (58%) coverage of parameter space for CPV discovery w/ >3σ (>5σ)
- δ_{CP} precision measurement
  - 22° for δ=±90°
  - 7° for δ=0° or 180°
- Enhanced further by combination with atmospheric ν





Atmospheric neutrino

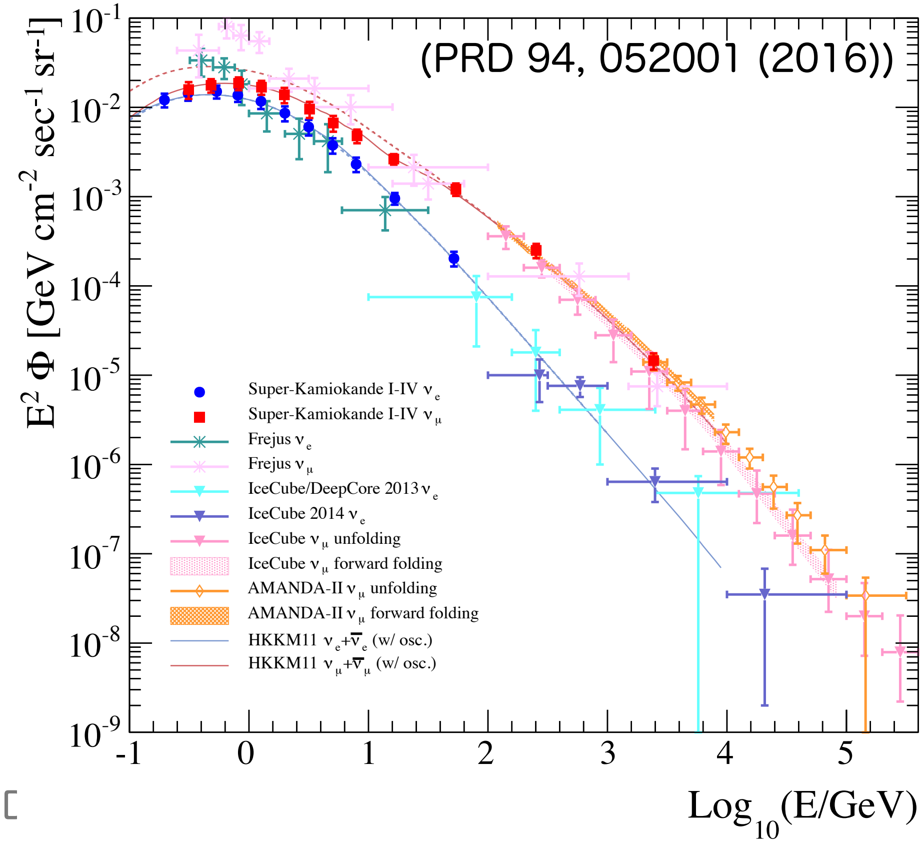
Atmospheric neutrinos



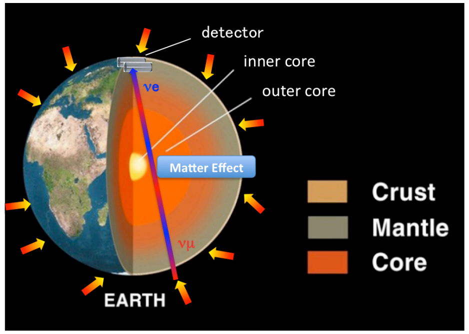
Cosmic rays strike air nuclei and the decay of the out-going hadrons gives neutrinos.

✓ Flux measurement by SK

✓ Model calculation is consistent with data.



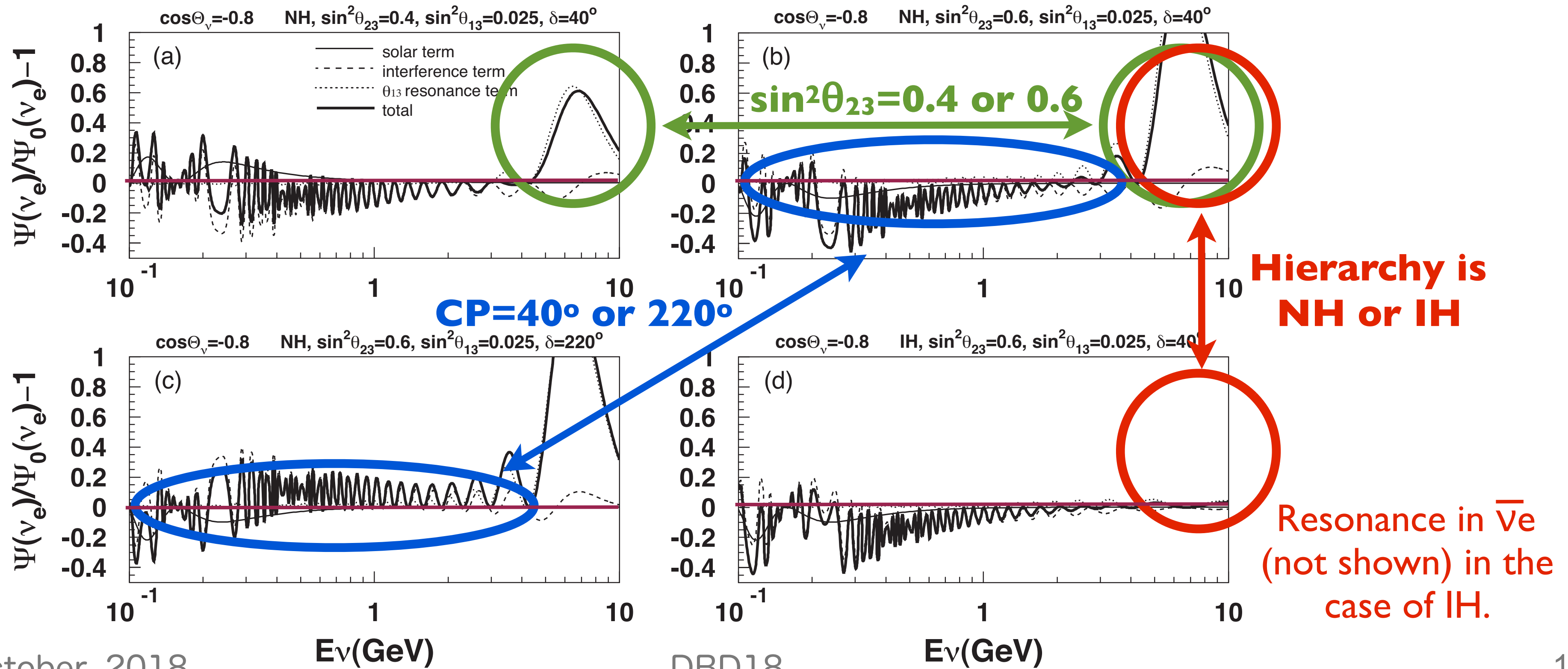
Neutrino oscillation in Atm. ν



Consider all the sub-leading effects (Δm^2_{21}, matter)

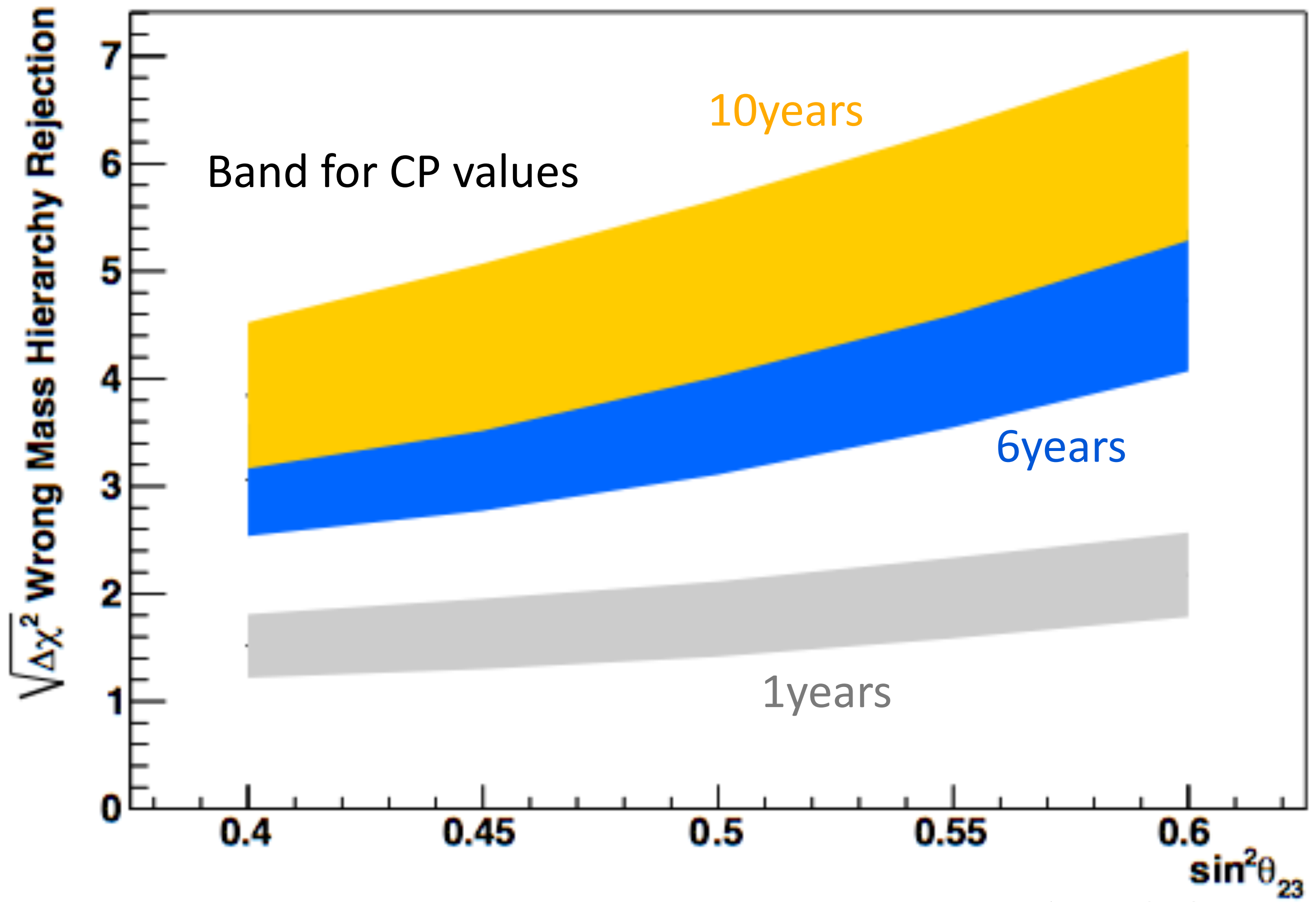
- Mass hierarchy : resonance in multi-GeV ν_e or $\bar{\nu}_e$
- Octant θ_{23} : magnitude of the resonance
- δ_{CP} : interference btw two Δm^2 driven oscillation

Fractional change of upward ν_e flux ($\cos\theta_{zenith}$ = -0.8)



Sensitivity

Mass hierarchy

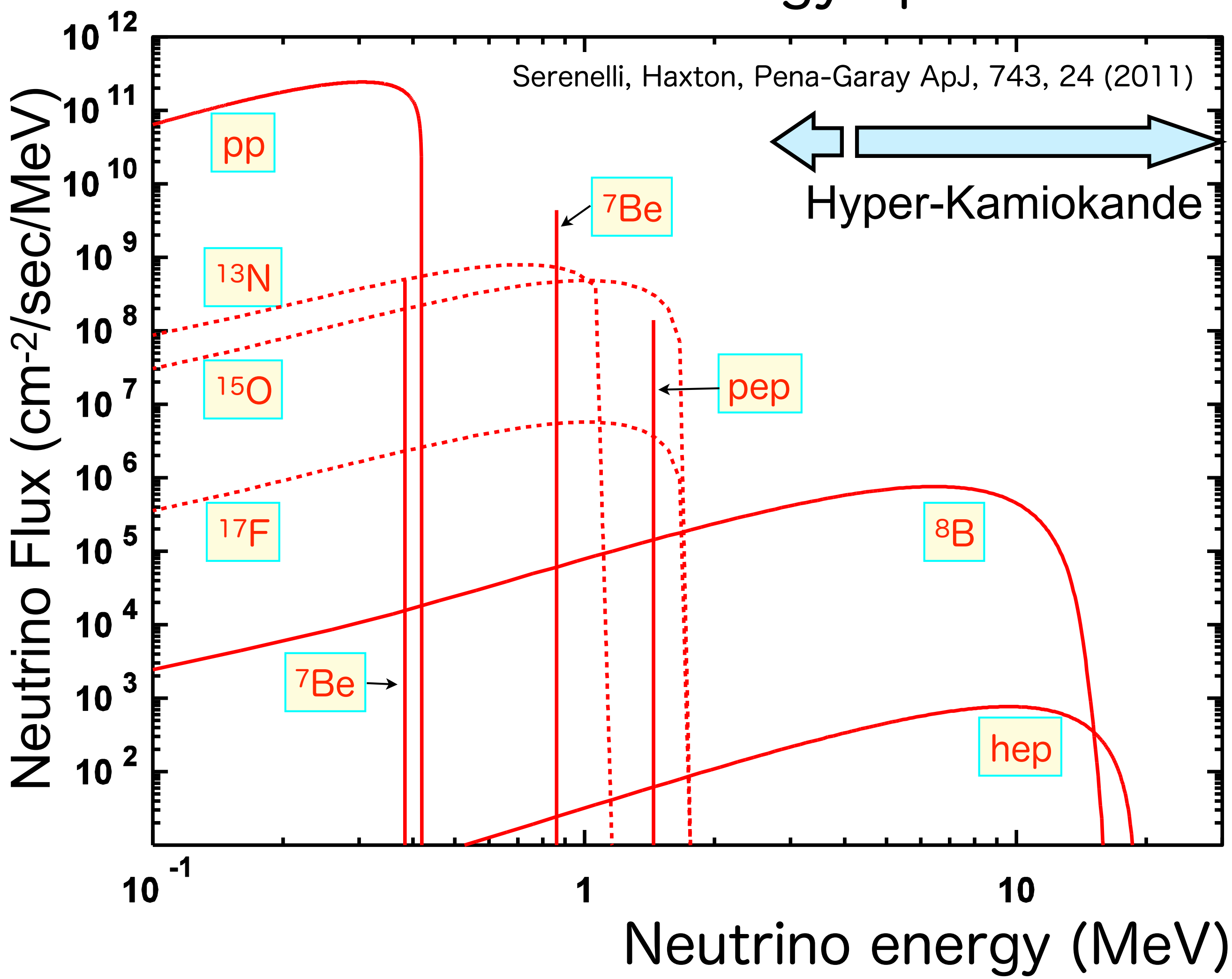


Determination possible by ~5 years ($\sin^2\theta_{23}$=0.5)

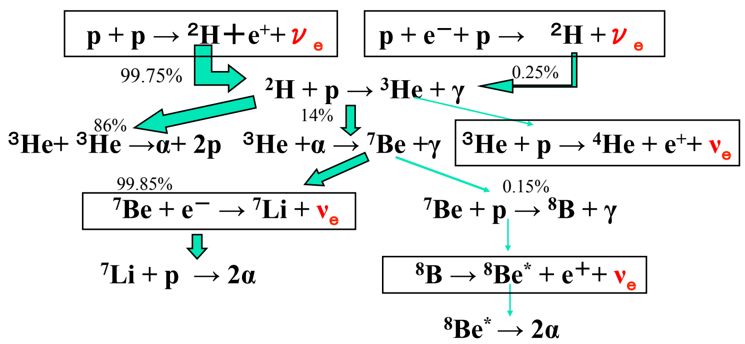
Solar neutrino

Solar neutrinos

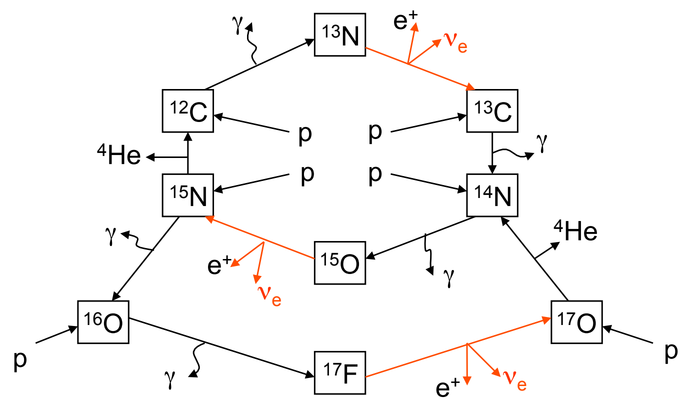
Solar neutrino energy spectrum



pp-chain

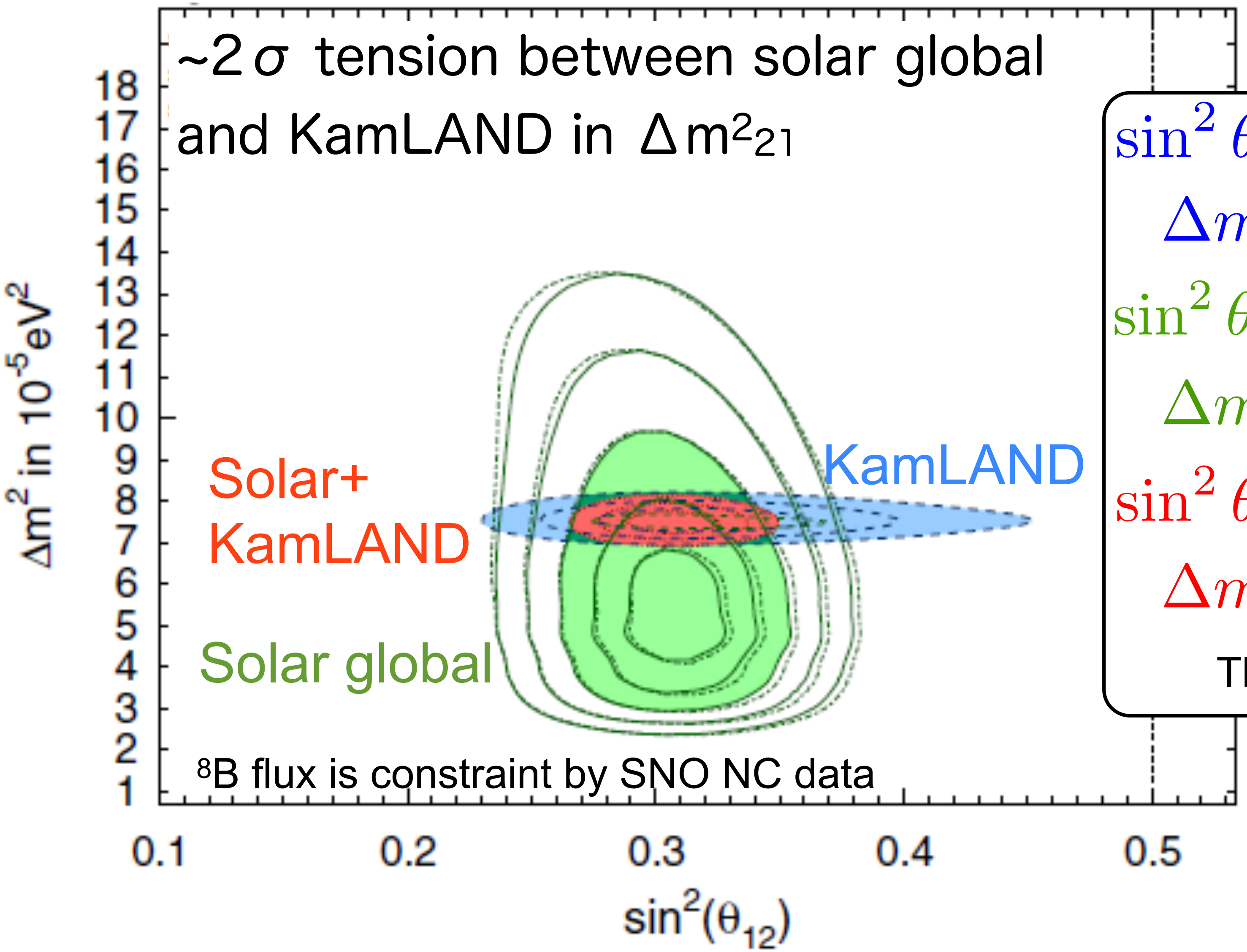


CNO cycle



Neutrino oscillation in Solar ν

PRD94, 052010 (2016)



$$\sin^2\theta_{12} = 0.316^{+0.034}_{-0.026}$$
$$\Delta m^2_{21} = 7.54^{+0.19}_{-0.18}$$
$$\sin^2\theta_{12} = 0.308 \pm 0.014$$
$$\Delta m^2_{21} = 4.85^{+1.33}_{-0.59}$$
$$\sin^2\theta_{12} = 0.307^{+0.013}_{-0.012}$$
$$\Delta m^2_{21} = 7.49^{+0.19}_{-0.18}$$

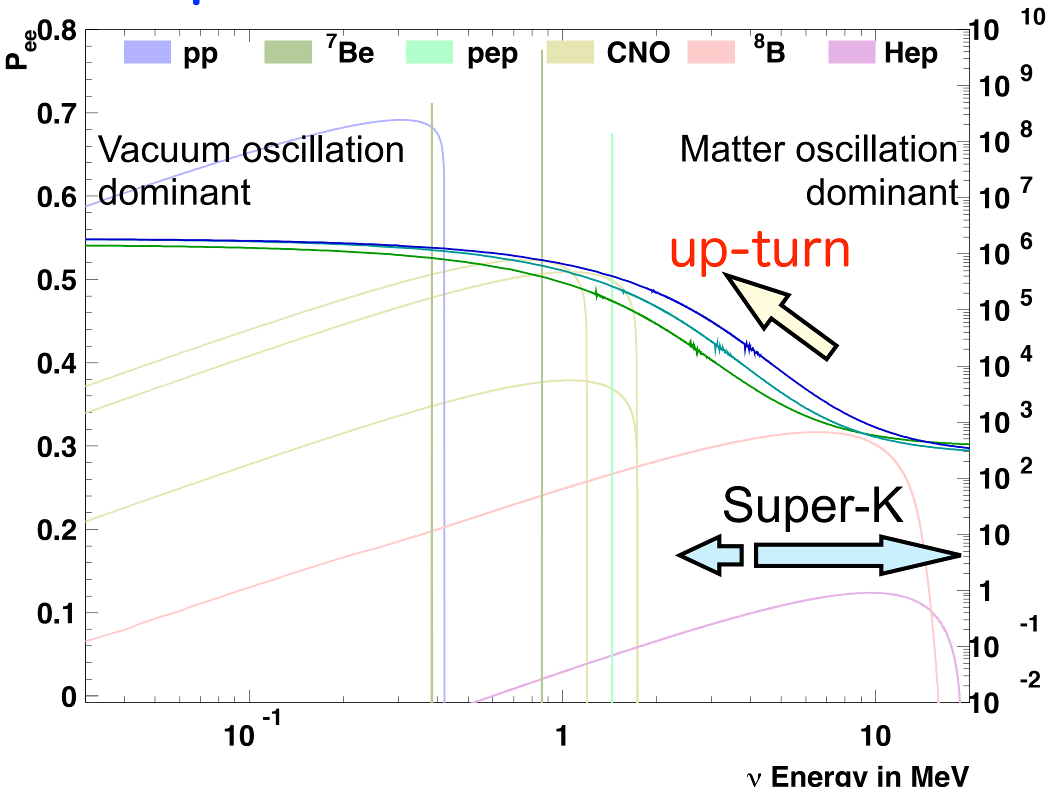
The unit of Δm^2_{21} is 10^{-5} eV^2

$\sin^2\theta_{13}=0.0219\pm0.0014$

Neutrino oscillation in HK

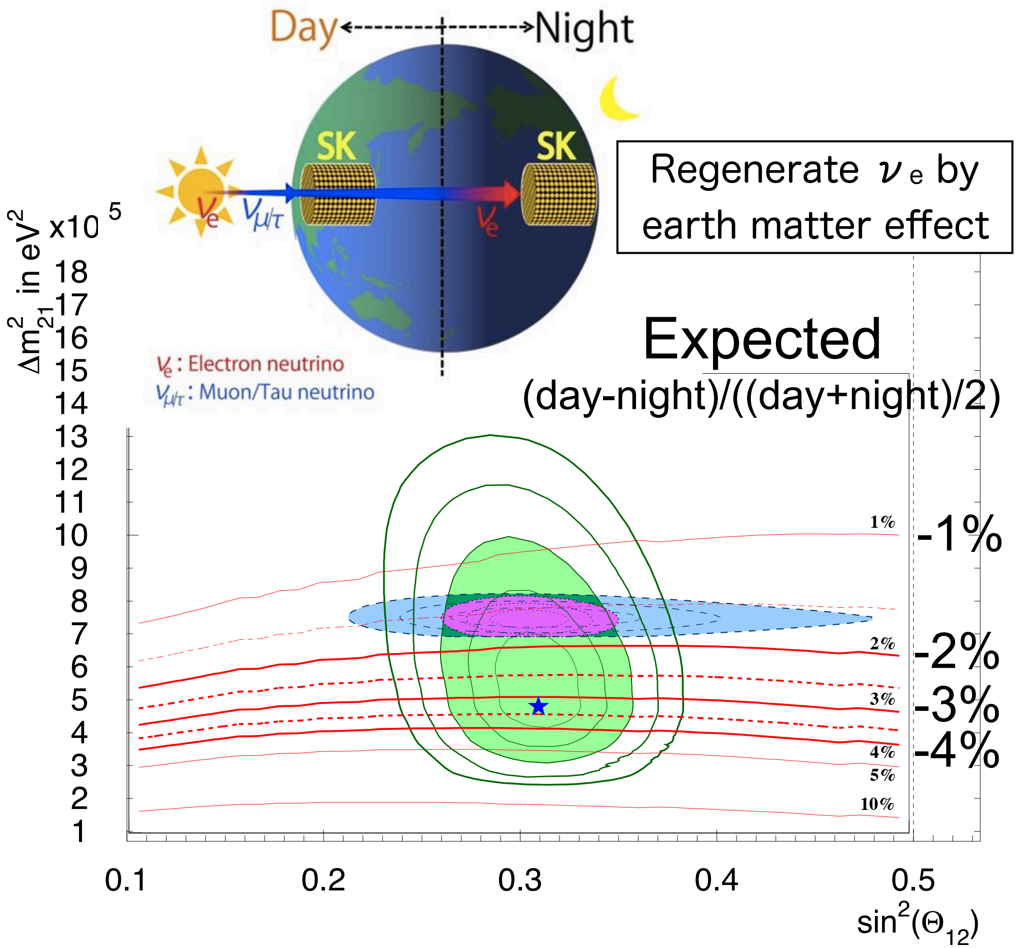
See the neutrino oscillation MSW effect directly

Spectrum distortion



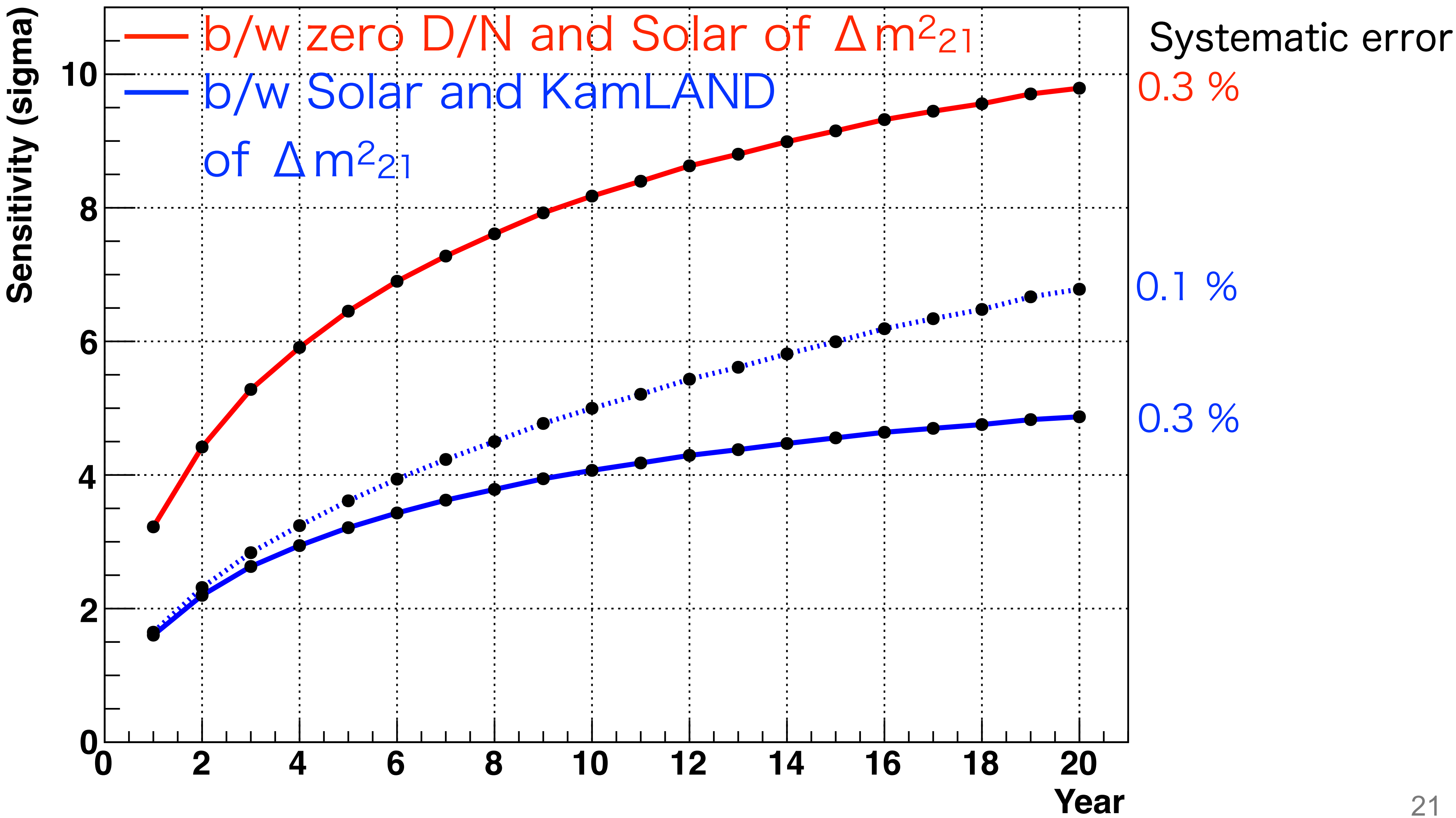
Super-K can search for the spectrum "upturn" expected by neutrino oscillation MSW effect

Day-Night flux asymmetry



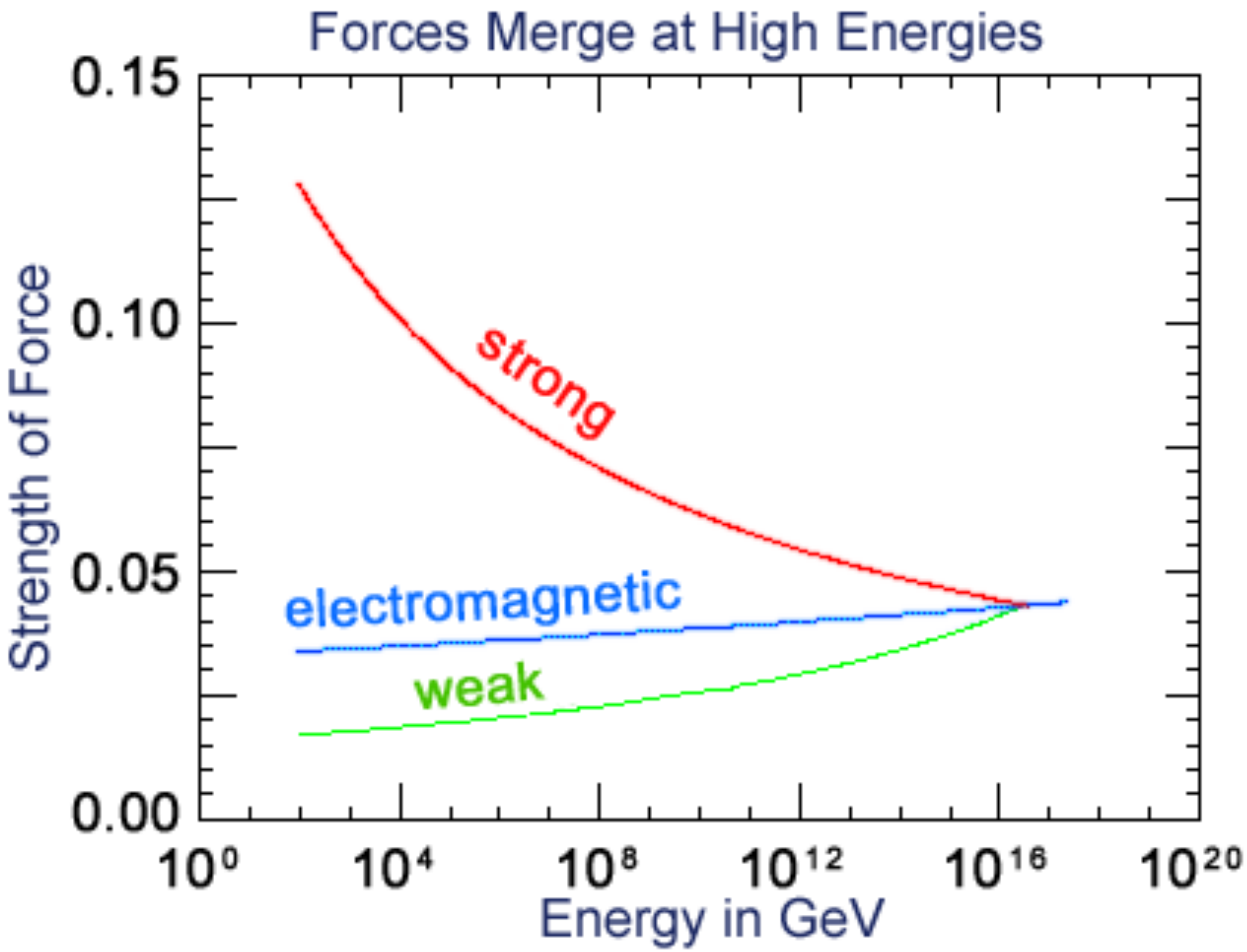
Sensitivity

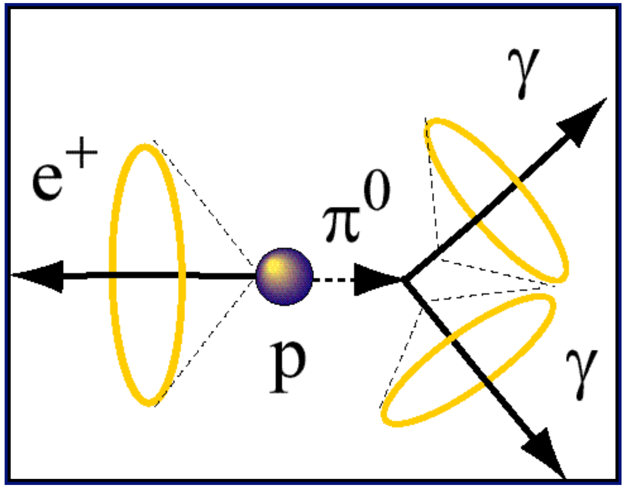
Day/Night flux asymmetry



Nucleon decay

Motivation



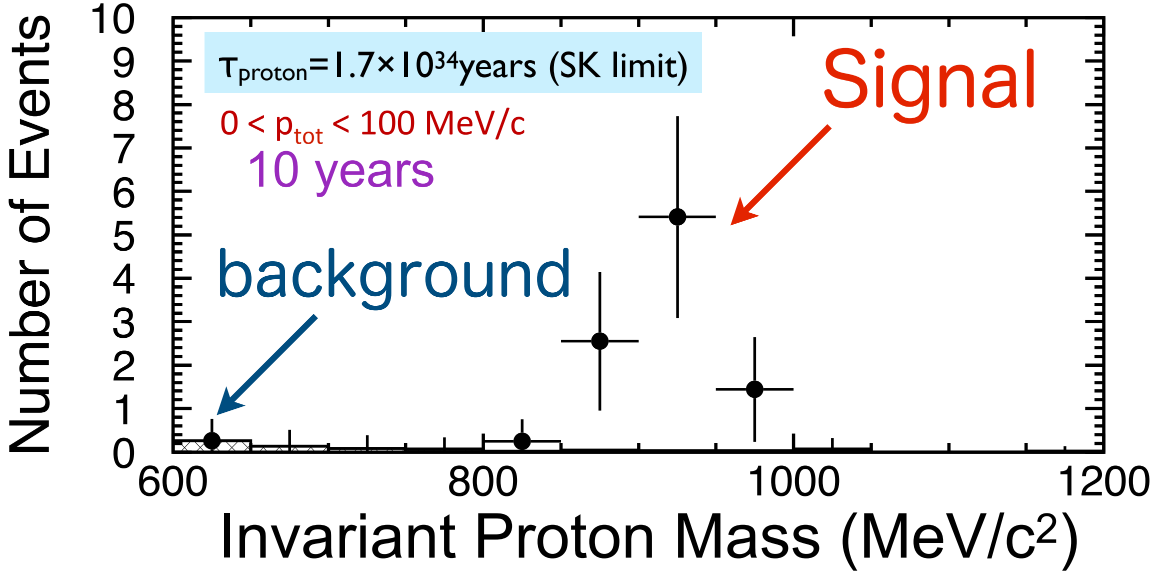


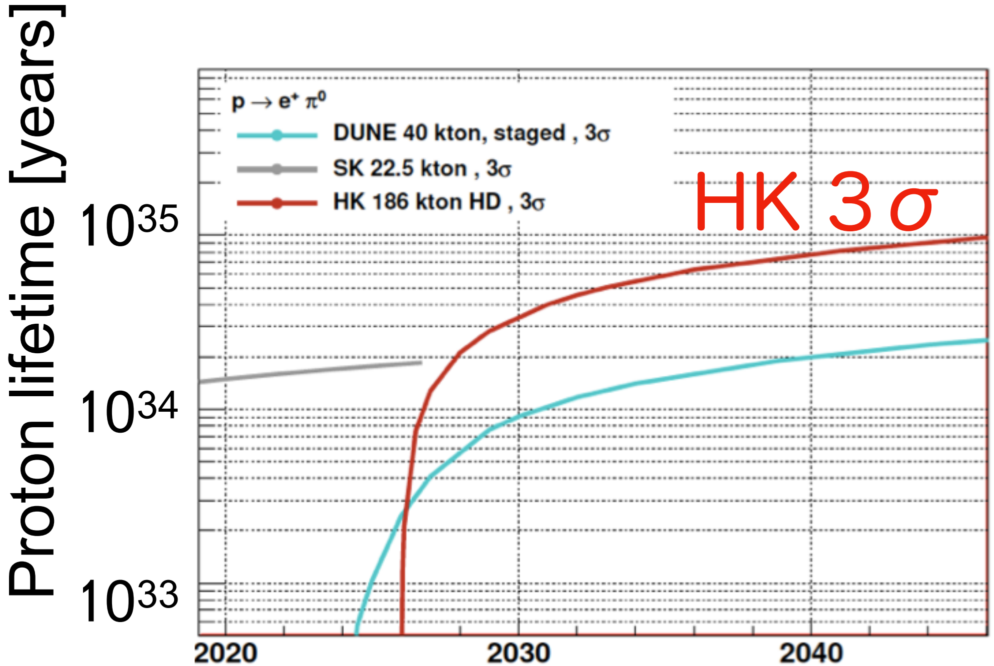
Only possible to directly prove the grand unification

$p \to e^+\pi^0$ discovery potential

- Look at an invariant proton mass
- Possible BG free search (0.06 BG/Mton year)
- Discovery potential reach to 10^{35} years

p_{tot}<100MeV/c		100<p_{tot}<250MeV/c	
Sig. ε(%)	Bkg (/Mtyr)	Sig. ε(%)	Bkg (/Mtyr)
18.7	0.06	19.4	0.62

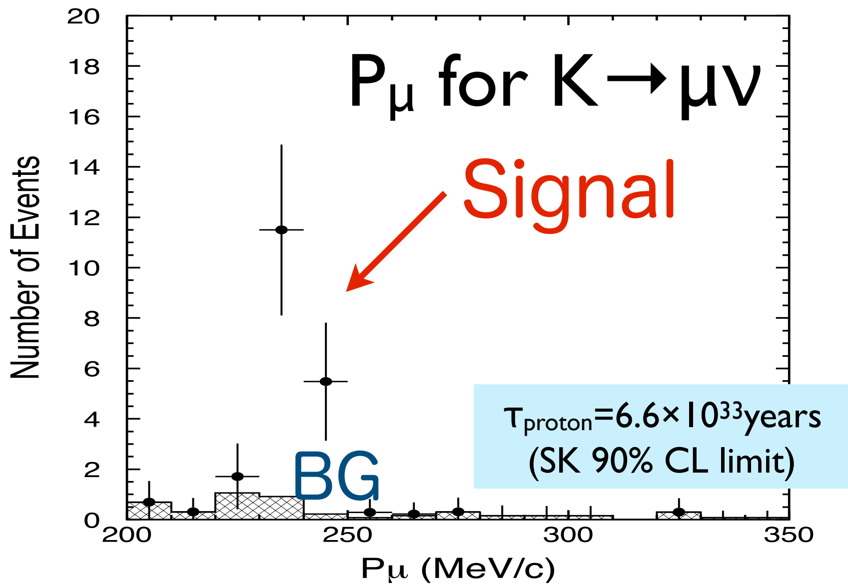


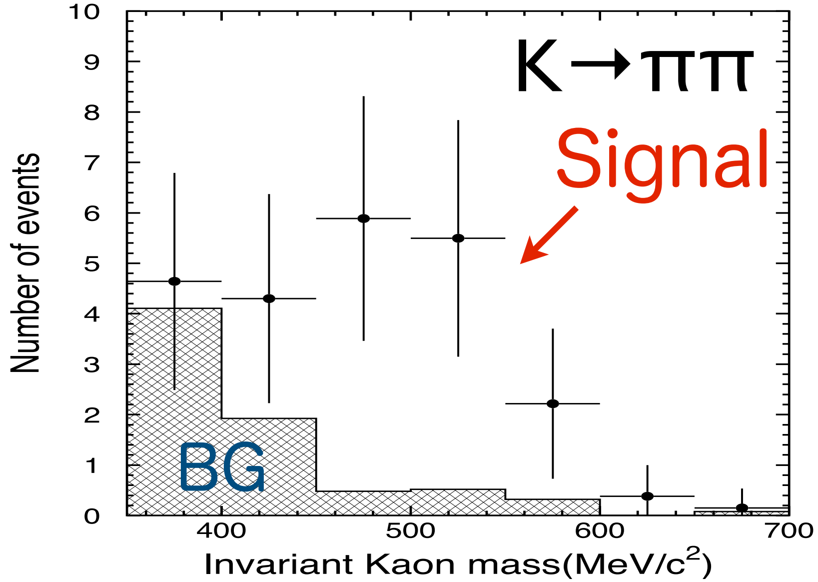


$p \rightarrow \nu K^+$ discovery potential

- K is invisible, so it is identified by daughter particles;
  - Monochromatic muon (236 MeV/c) for $K \rightarrow \mu \nu$
  - $K \rightarrow \pi^+ \pi^0$
- Possible BG free search (0.06 BG/Mton year)
- Discovery potential reach to > 3 x10^{34} years

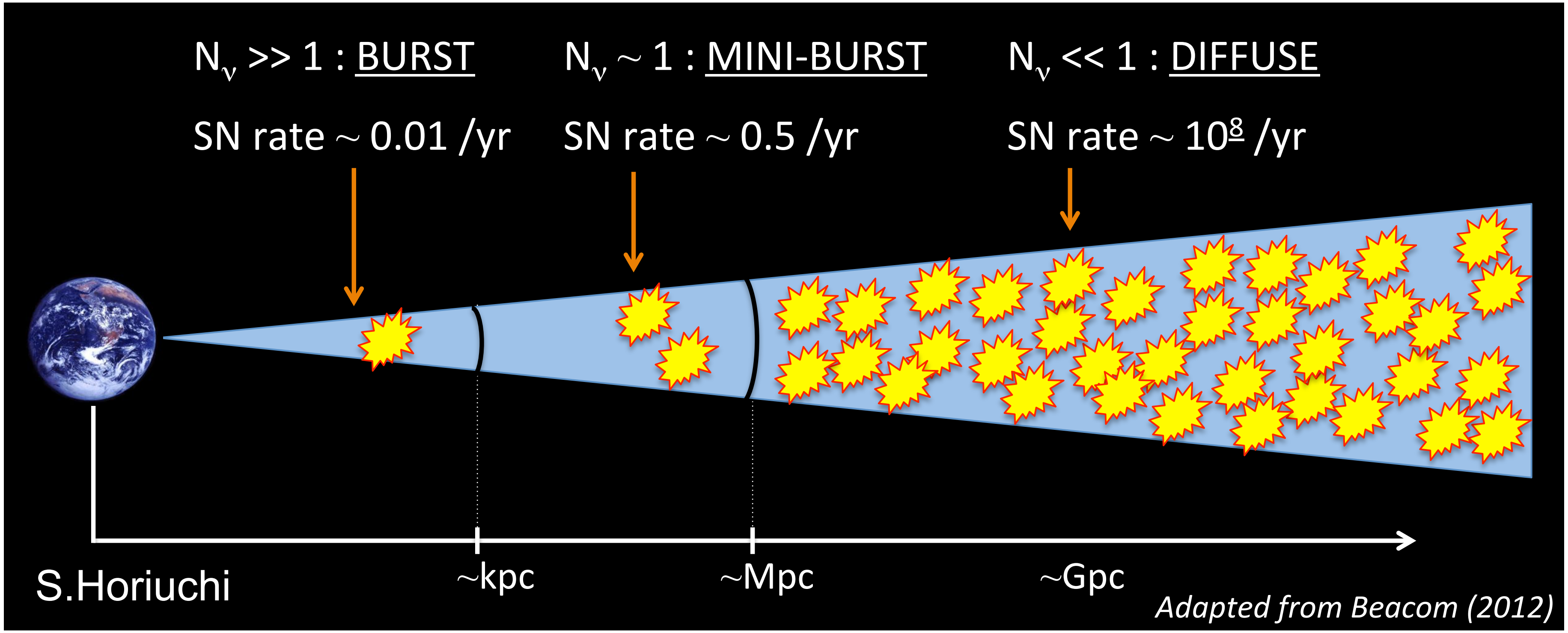
prompt-γ & $K^+ \rightarrow \mu^+ \nu$		$K^+ \rightarrow \pi^+ \pi^0$	
Sig. ε(%)	Bkg (/Mtyr)	Sig. ε(%)	Bkg (/Mtyr)
12.7	0.9	10.8	0.7

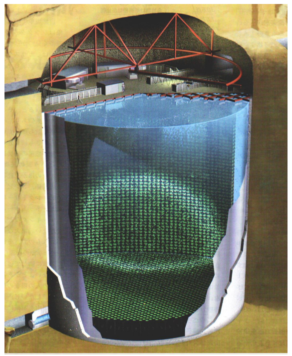


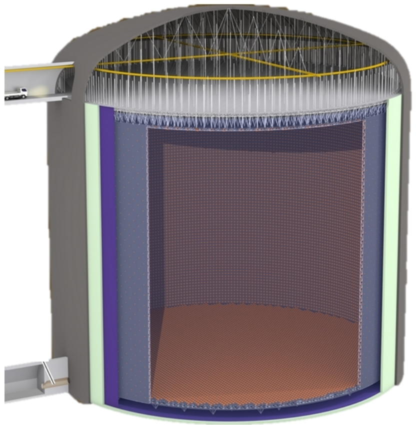


Supernova Neutrino

Supernova neutrino







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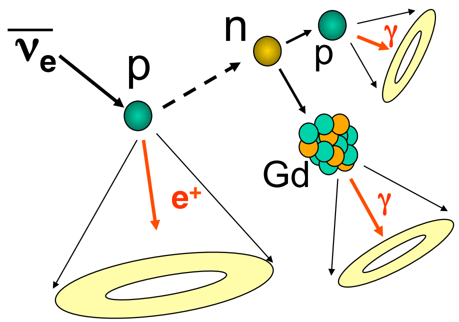
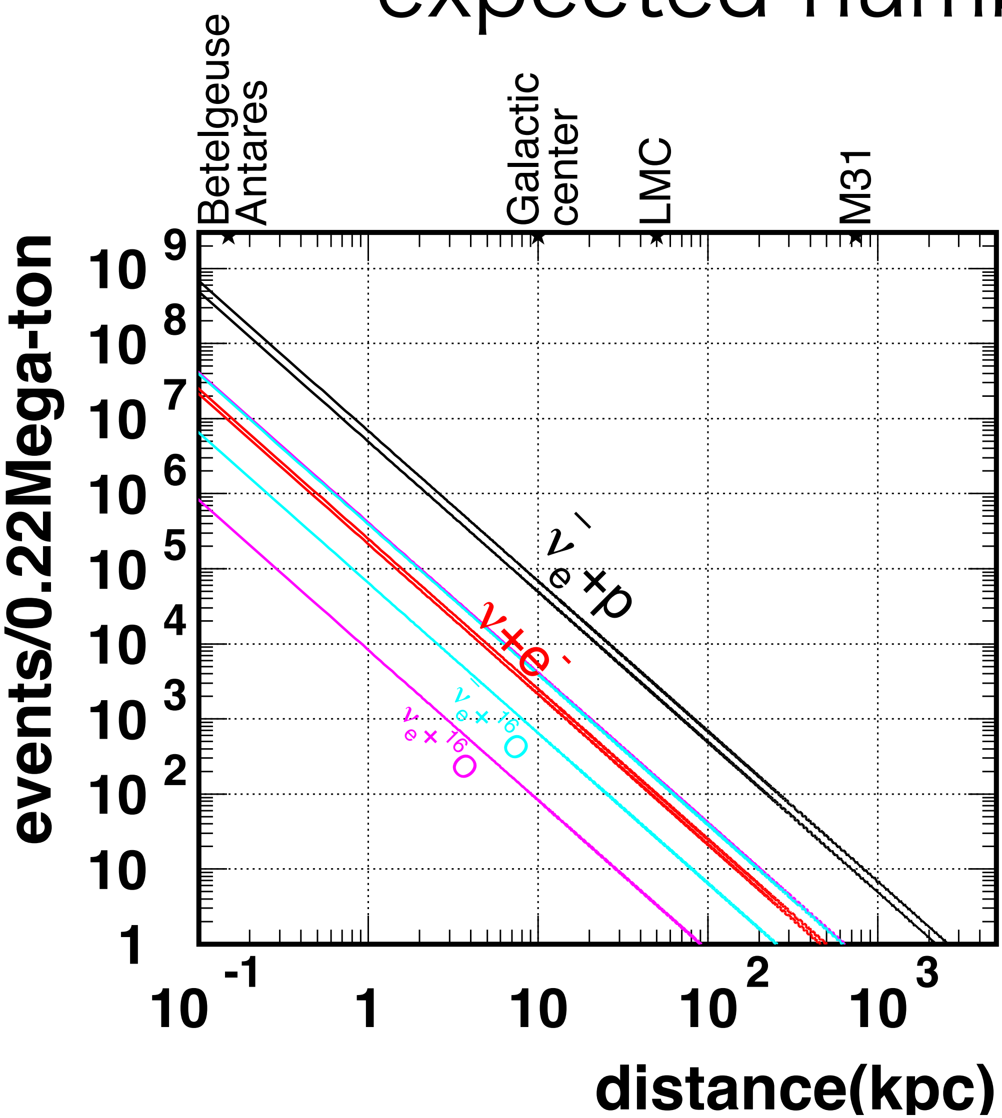
neutron tagging technique



Supernova burst

expected number of events

arXiv : 1805.04163



Expected number of event

49k~68k ev (IBD)
2.1k~2.5k ev (νe ES)
(6~40 for neutronization)
80~4100 ev (ν_e CC)
650~3900 ev ($\bar{\nu}_e$ CC)

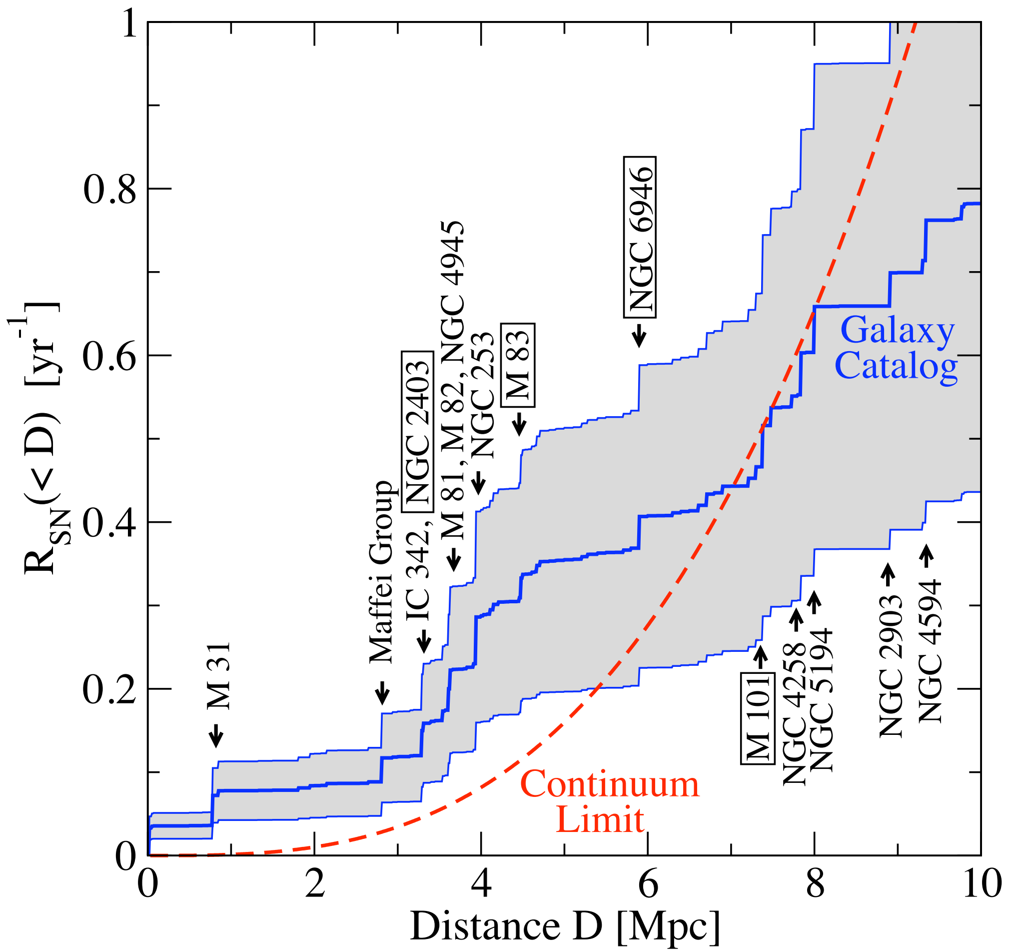
at 10kpc

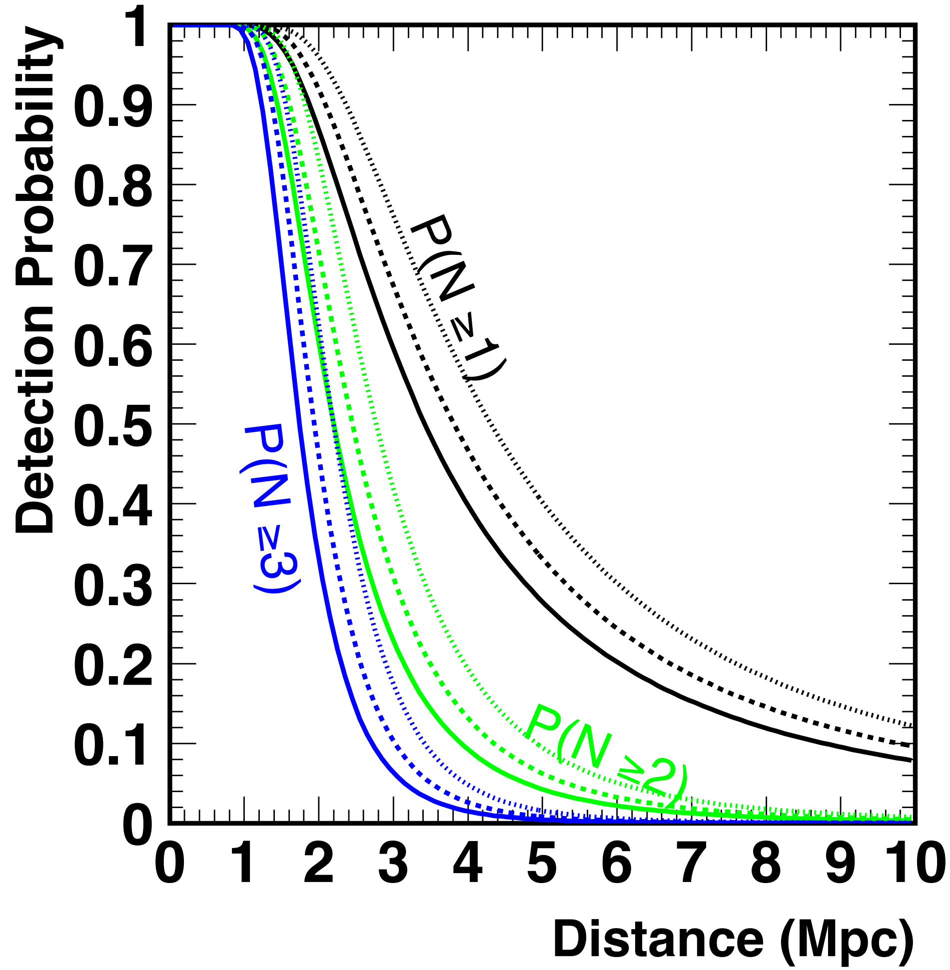
Livermore simulation

Totani, Sato, Dalhed, Wilson, ApJ. 496 (1998) 216

Nearby galaxy

Cumulative calculated supernova rate



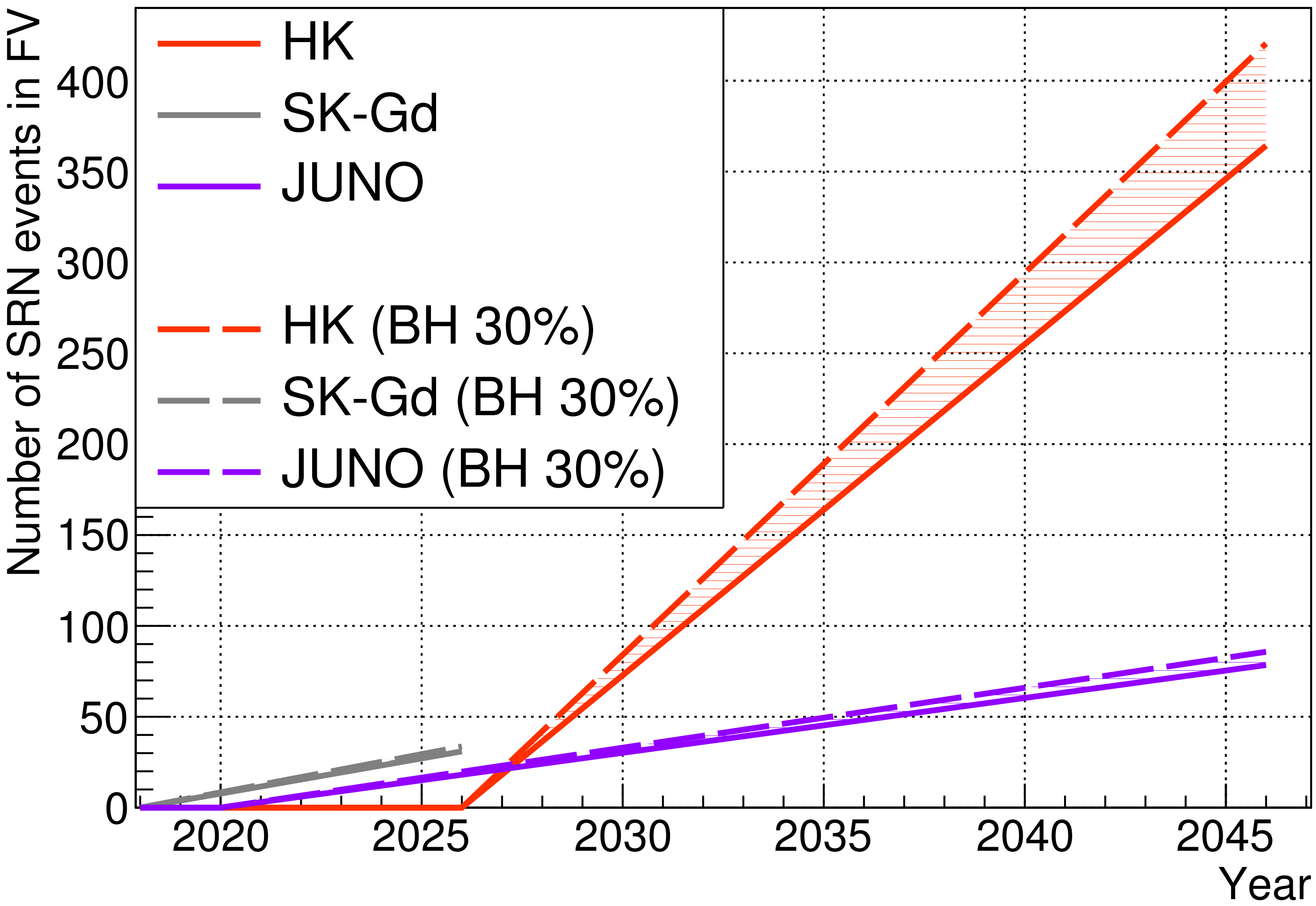


S. Horiuchi et.al.

Diffuse Supernova Neutrino background

expected number of events

(detection efficiency is not considered)



Status of the project

International organization

- International Hyper-Kamiokande proto-collaboration
  - 15 countries, 73 institutes, ~300 members, ~75% from abroad
- 2 host institutes: UTokyo/ICRR and KEK/IPNS
- UTokyo launched an institute for HK construction: Next-generation Neutrino Science Organization (NNSO)
- External review by Advisory Committee

Hyper-K meeting@Madrid, March 2018

Inaugural Symposium@Kashiwanoha, January 2015

NNSO Inaugural Ceremony@Kamioka, October 2017

Toward construction start

- MEXT (Ministry of Science in Japan) lists the Hyper-K in its Roadmap2017 as a priority big project
- UTokyo is making all efforts to get funded with strong leadership of the president Gonokami.
  - Hyper-K is requested to MEXT as a top priority project
  - UTokyo launched "Next-Generation Neutrino Science Organization" to host Hyper-K
- Seed funding has been allocated within MEXT budget request for JFY2019
  - It usually led to full funding in the following year, as it was the case for the Super-Kamiokande

Statement of the president of UTokyo

September 12th, 2018

https://www.u-tokyo.ac.jp/focus/ja/articles/z0208_00006.html

The University of Tokyo pledges to ensure construction of the Hyper-Kamiokande detector commences as scheduled in April 2020.

September 12th, 2018

Concerning the Start of Hyper-Kamiokande

Seed funding towards the construction of the next-generation water Cherenkov detector Hyper-Kamiokande has been allocated by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) within its budget request for the 2019 fiscal year. Seed fundings in the past projects usually lead to full funding in the following year, as it was the case for the Super-Kamiokande project.

The University of Tokyo pledges to ensure construction of the Hyper-Kamiokande detector commences as scheduled in April 2020. The University of Tokyo has made this decision in recognition of both the project's importance and value both nationally and internationally.

The neutrino research that lead to Nobel prizes for Special University Professor Emeritus Koshiba and Distinguished University Professor Kajita has entered a new era. The international community has demonstrated the need for Hyper-Kamiokande. The considerable expertise and achievements of the University of Tokyo and Japan, and unique and invaluable contributions from national and international collaborators will ensure the project will make significant contributions to the intellectual progress of the world.

Makoto Gonokami

Makoto Gonokami
President, The University of Tokyo

Summary

- Next generation of the water Cherenkov detector, Hyper-Kamiokande, has unique opportunities for future physics program
  - Neutrino oscillation by beam, atmospheric, solar neutrinos
  - Search for proton decay
  - Neutrino astrophysics
- Based on the experiences from Kamiokande and Super-Kamiokande, also with new ideas and technologies.
- Many efforts are on going for starting construction in 2020, and operation from ~2027.