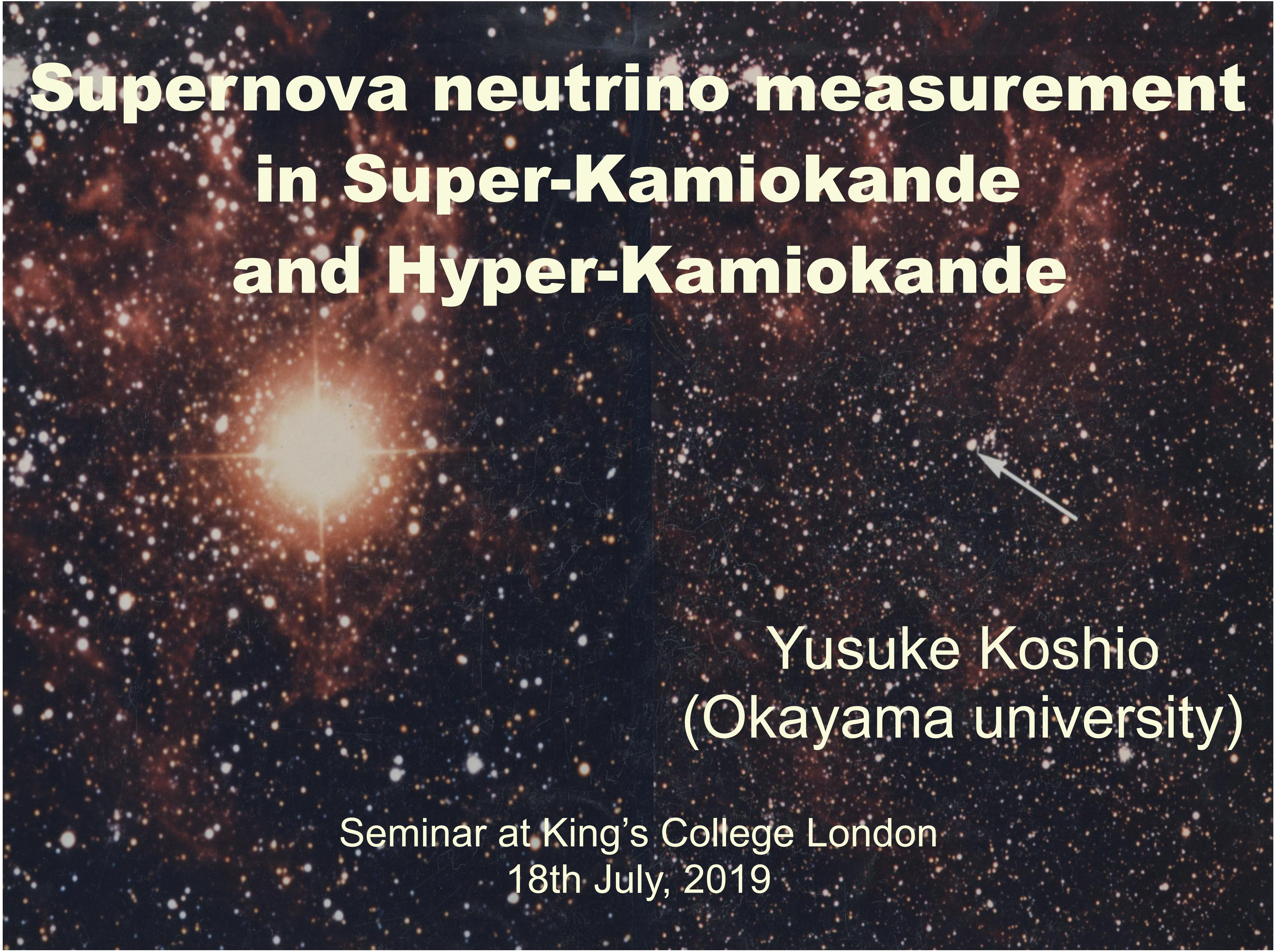


Supernova neutrino measurement in Super-Kamiokande and Hyper-Kamiokande

Yusuke Koshio
(Okayama university)

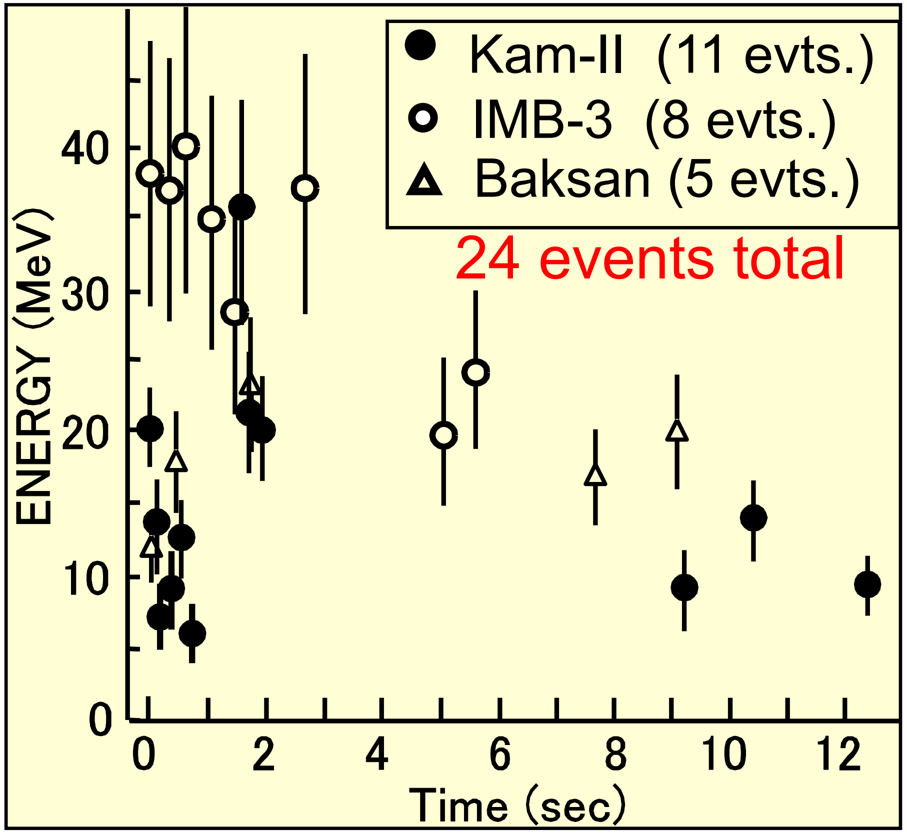
Seminar at King's College London
18th July, 2019

30 years anniversary of SN1987A

(in 2017)

Workshop at Koshiba hall in U.of.Tokyo
on February 12-13, 2017

http://www-sk.icrr.u-tokyo.ac.jp/indico/conferenceDisplay.py?confId=2935

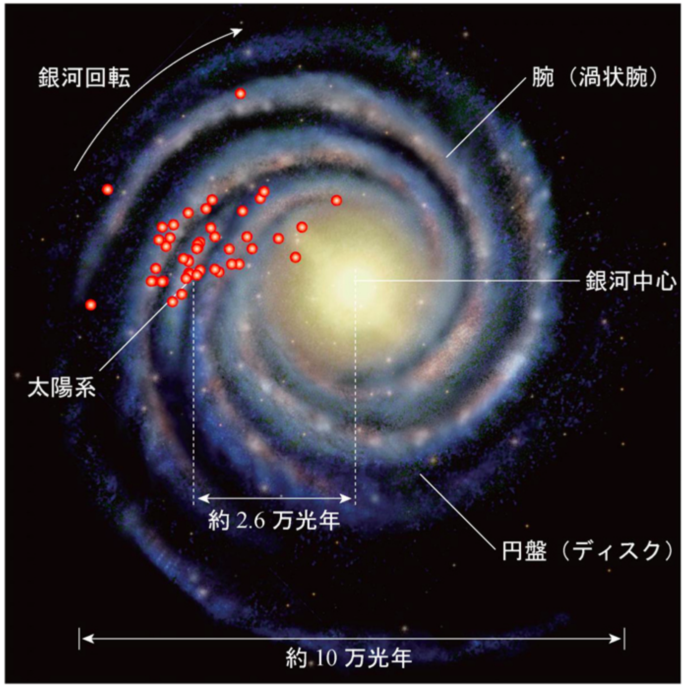


No Supernova neutrino detection since then..

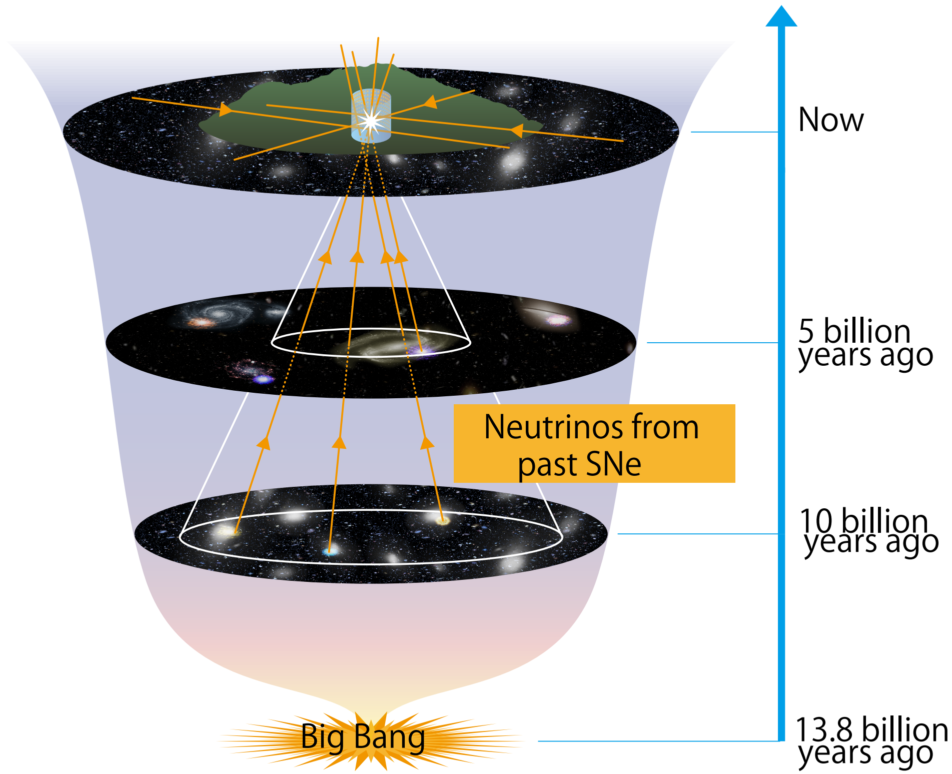
No chance for Supernova neutrino detection for next hundred's years?

We believe, yes!

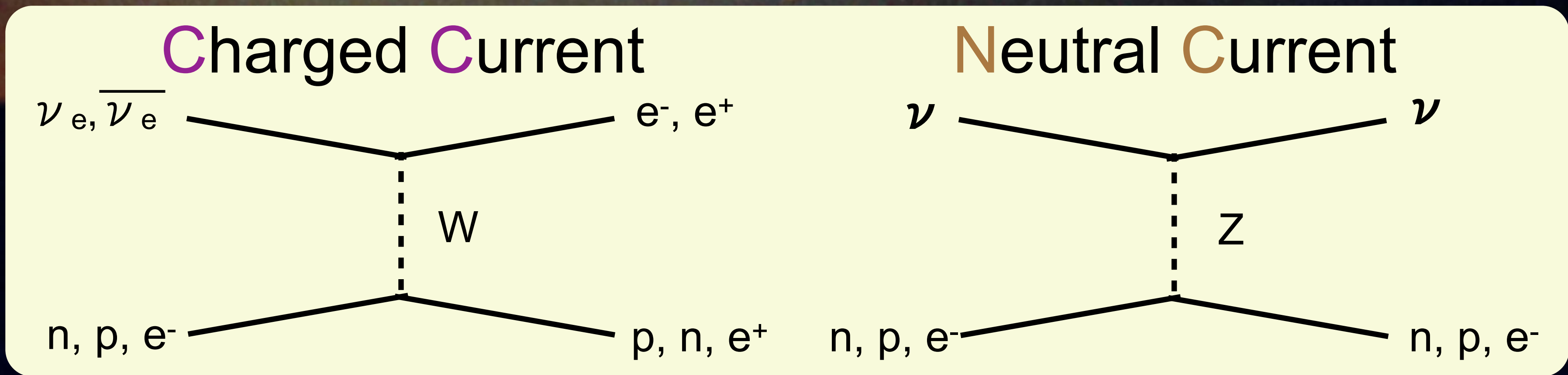
Galactic Supernova burst (a few per century)



Diffuse Supernova Neutrino Background



Neutrino interaction for supernova neutrino detection



Neutrino interaction for SN ν

Inverse beta decay

$\overline{\nu}_e + p \rightarrow e^+ + n$ (Charged Current interaction)

- ✓ Dominates for detectors with lots of free proton
  - Detect positron signal in water, scintillator, etc.
- ✓ $\overline{\nu_e}$ sensitive
- ✓ Obtain the neutrino energy from the positron energy
  - $E_e \sim E_\nu - (m_n - m_p)$, $E_\nu > 1.86\text{MeV}$
- ✓ Well known cross section
- ✓ Poor directionality
- ✓ Neutron tagging using delayed coincidence
  - $n + p \rightarrow d + \gamma$, $n + Gd \rightarrow Gd + \gamma$

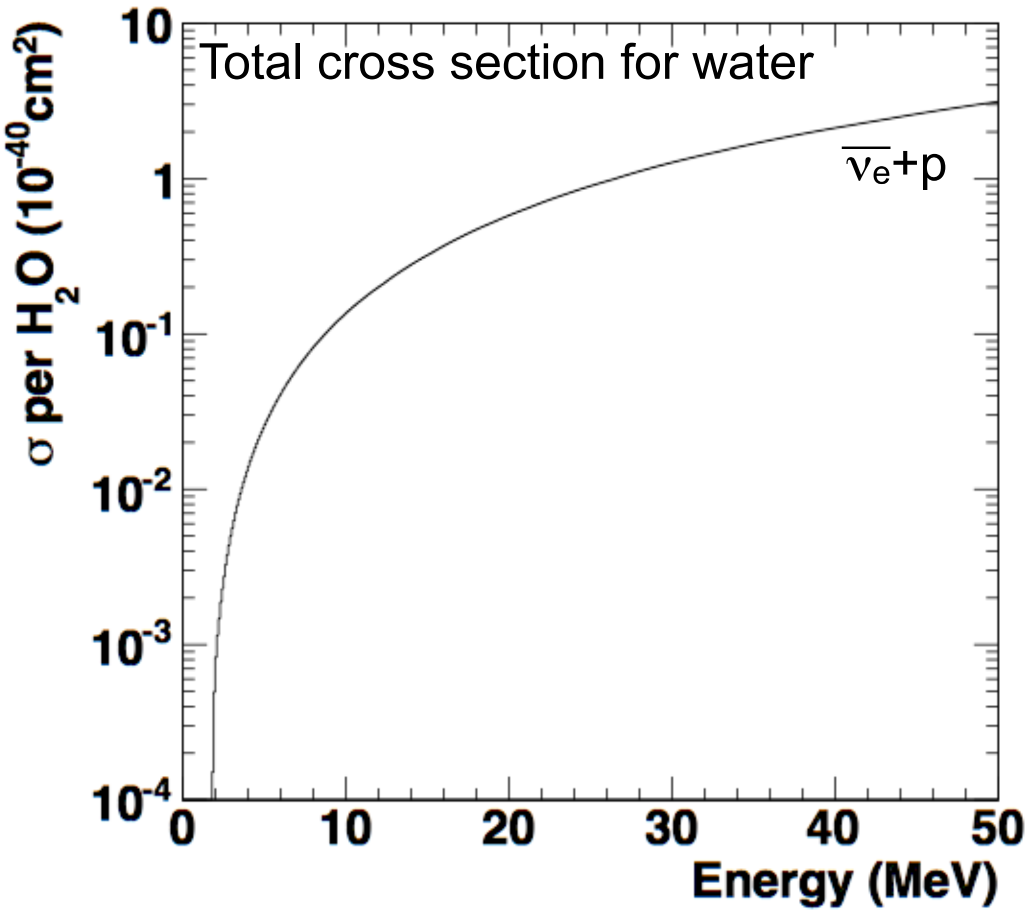
Neutrino interaction for SN ν

Strumia, Vissani
Phys. Lett. B564 (2003) 42

Inverse beta decay

$$\overline{\nu}_e + p \rightarrow e^+ + n$$

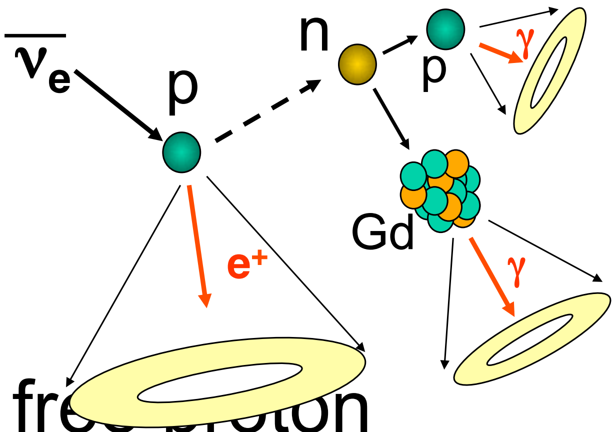
- ✓ Dominates for detectors w
  - Detect positron signal in w
- ✓ $\overline{\nu}_e$ sensitive
- ✓ Obtain the neutrino energ
  - $E_e \sim E_\nu - (m_n - m_p)$, $E_\nu > 1.$
- ✓ Well known cross section
- ✓ Poor directionality
- ✓ Neutron tagging using de
  - $n + p \rightarrow d + \gamma$, $n + Gd \rightarrow$ G



Neutrino interaction for SN ν

Inverse beta decay

$$\bar{\nu}_e + p \rightarrow e^+ + n$$



- ✓ Dominates for detectors with lots of free proton
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- ✓ Obtain the neutrino energy from the positron energy
  - $E_e \sim E_\nu - (m_n - m_p)$, $E_\nu > 1.86$MeV
- ✓ Well known cross section

Possible to enhance this signal if Gd loaded

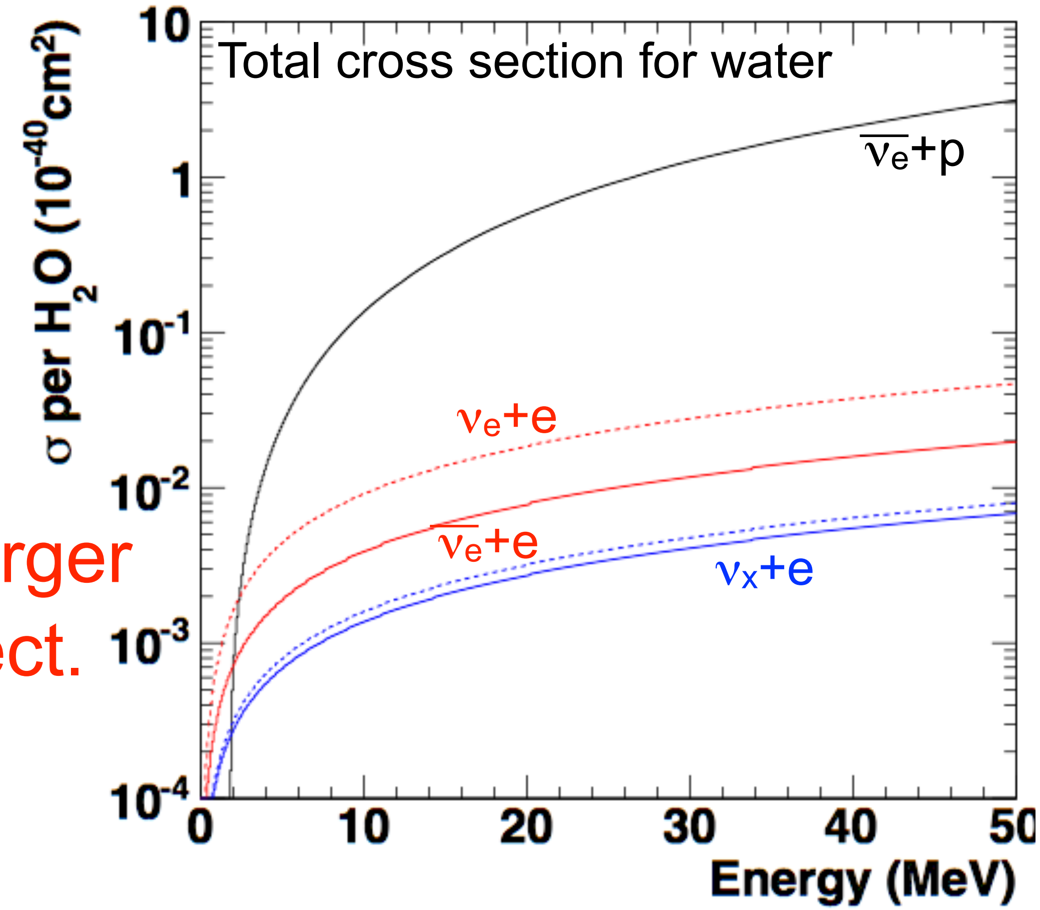
- ✓ Poor directionality
- ✓ Neutron tagging using delayed coincidence
  - $n + p \rightarrow d + \gamma$, $n + Gd \rightarrow Gd + \gamma$

Neutrino interaction for SN ν

Elastic scattering

$$\nu_{e,x} + e^- \rightarrow \nu_{e,x} + e^-$$

(Both Charged Current and Neutral Current interaction)



✓ All neutrinos are sensitive

✓ The cross section for ν_e is larger than others because of CC effect.

✓ Well known cross section.

- few % of inverse beta decay

✓ Good directionality

✓ Measurable for only recoil electron energy, not neutrino energy

Neutrino interaction for SN ν

Elastic scattering

$$\nu_{e,x} + e^- \rightarrow \nu_{e,x} + e^-$$

(Both Charged Current and Neutral Current interaction)

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✓ Well known cross section.

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✓ Good directionality

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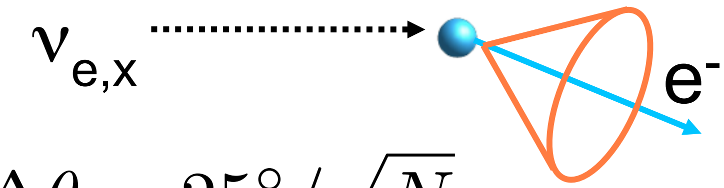
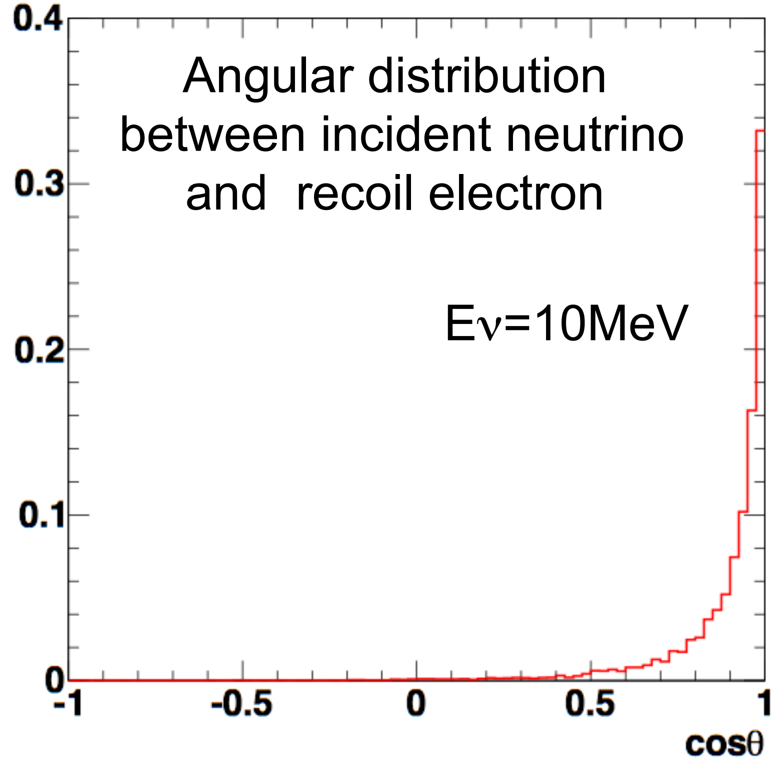
Water Cherenkov

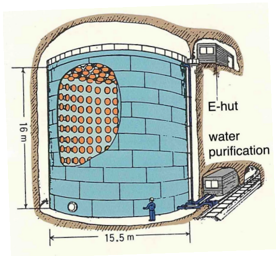


$$\Delta\theta \sim 25^\circ/\sqrt{N}$$

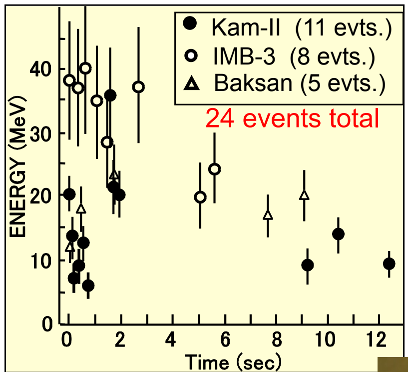


Three generations of "Kamiokande"

Kamiokande (1983-1995)

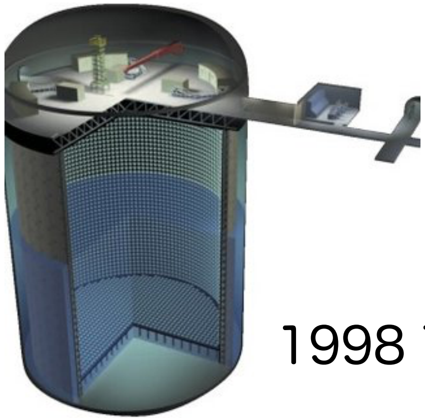


3kton
20% coverage
with 20' PMT



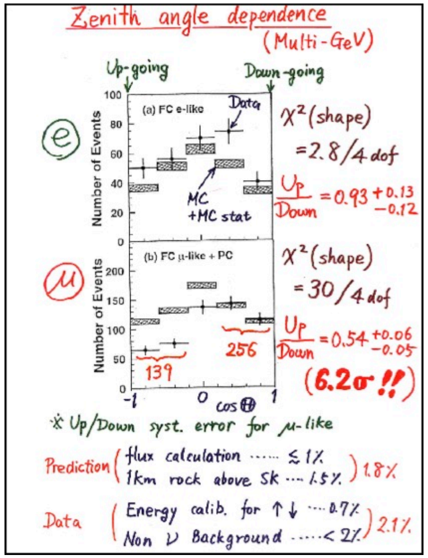
SN1987A

Super-Kamiokande (1996-)

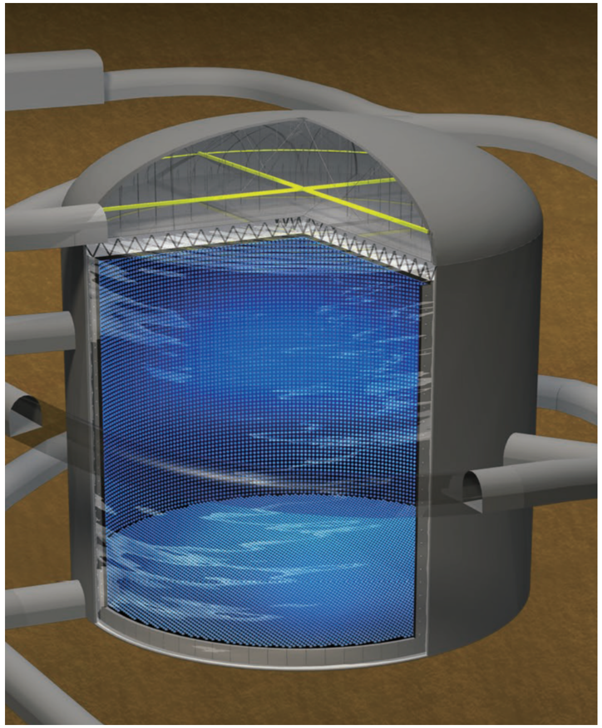


50k (22.5k) ton
40% coverage
with 20' PMT

1998 Takayama



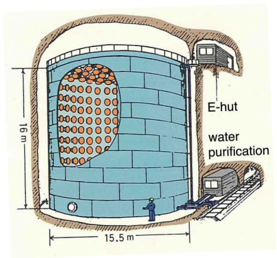
Hyper-Kamiokande (~2027-)



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

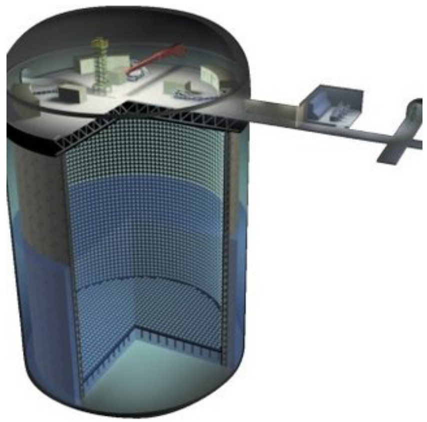
Three generations of “Kamiokande”

Kamiokande
(1983-1995)



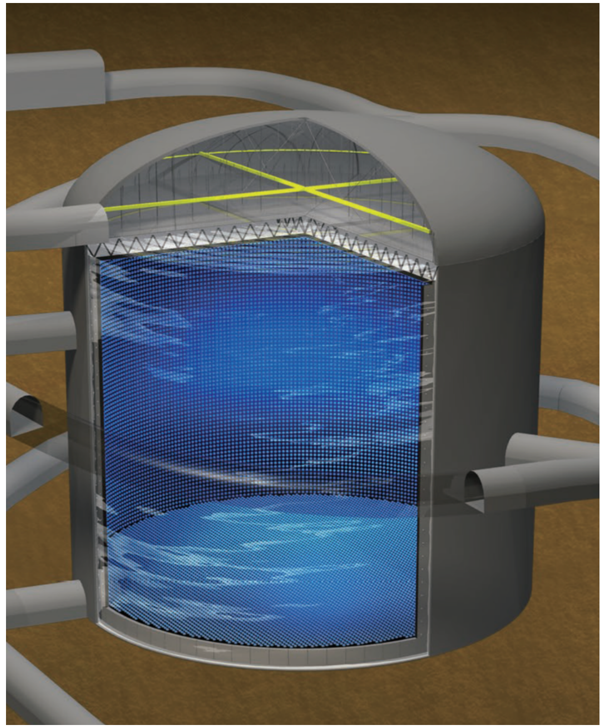
3kton
20% coverage
with 20’ PMT

Super-Kamiokande
(1996-)



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

Hyper-Kamiokande (~2027-)

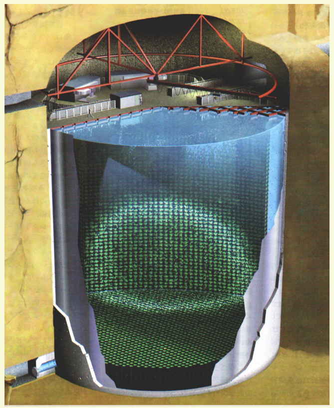


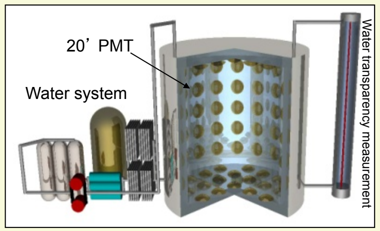
260k (190k) ton
40% coverage
with high-QE 20’ PMT

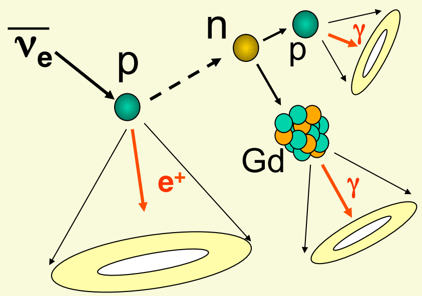
SuperK-Gd
(2020-)

SN search at Super-Kamiokande

Super-K to SK-Gd







Super-Kamiokande collaboration

Kamioka Observatory, ICRR, Univ. of Tokyo, Japan
RCCN, ICRR, Univ. of Tokyo, Japan
University Autonoma Madrid, Spain
University of British Columbia, Canada
Boston University, USA
University of California, Irvine, USA
California State University, USA
Chonnam National University, Korea
Duke University, USA
Fukuoka Institute of Technology, Japan
Gifu University, Japan
GIST, Korea

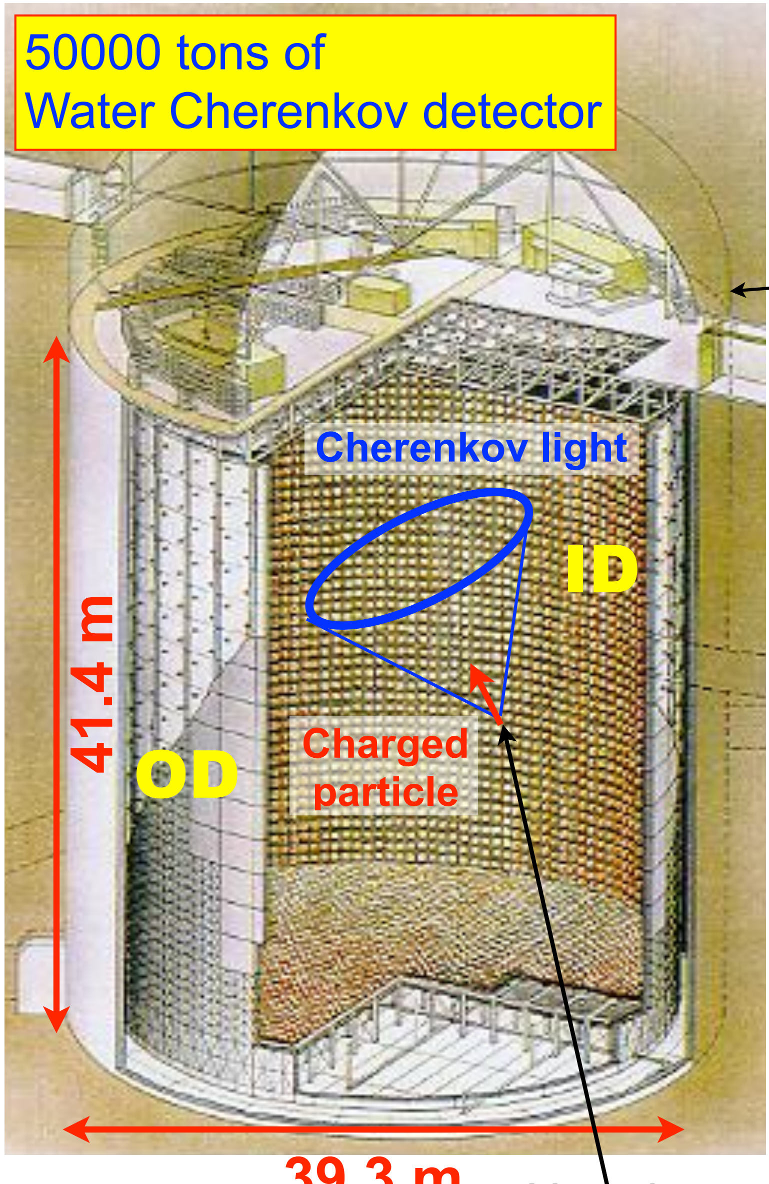
University of Hawaii, USA
Imperial College London, UK
NFN Bari, Italy
INFN Napoli, Italy
INFN Padova, Italy
INFN Roma, Italy
Kavli IPMU, The Univ. of Tokyo, Japan
KEK, Japan
Kobe University, Japan
Kyoto University, Japan
University of Liverpool, UK
LLR, Ecole polytechnique, France
Miyagi University of Education, Japan

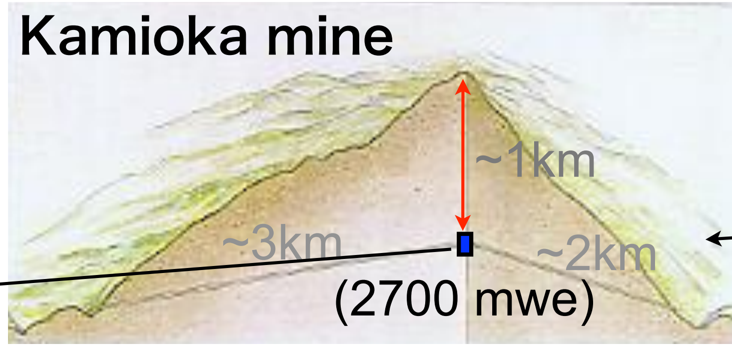
ISEE, Nagoya University, Japan
NCBJ, Poland
Okayama University, Japan
Osaka University, Japan
University of Oxford, UK
King's College London, UK
Seoul National University, Korea
University of Sheffield, UK
Shizuoka University of Welfare, Japan
Sungkyunkwan University, Korea
Stony Brook University, USA
Tokai University, Japan
The University of Tokyo, Japan

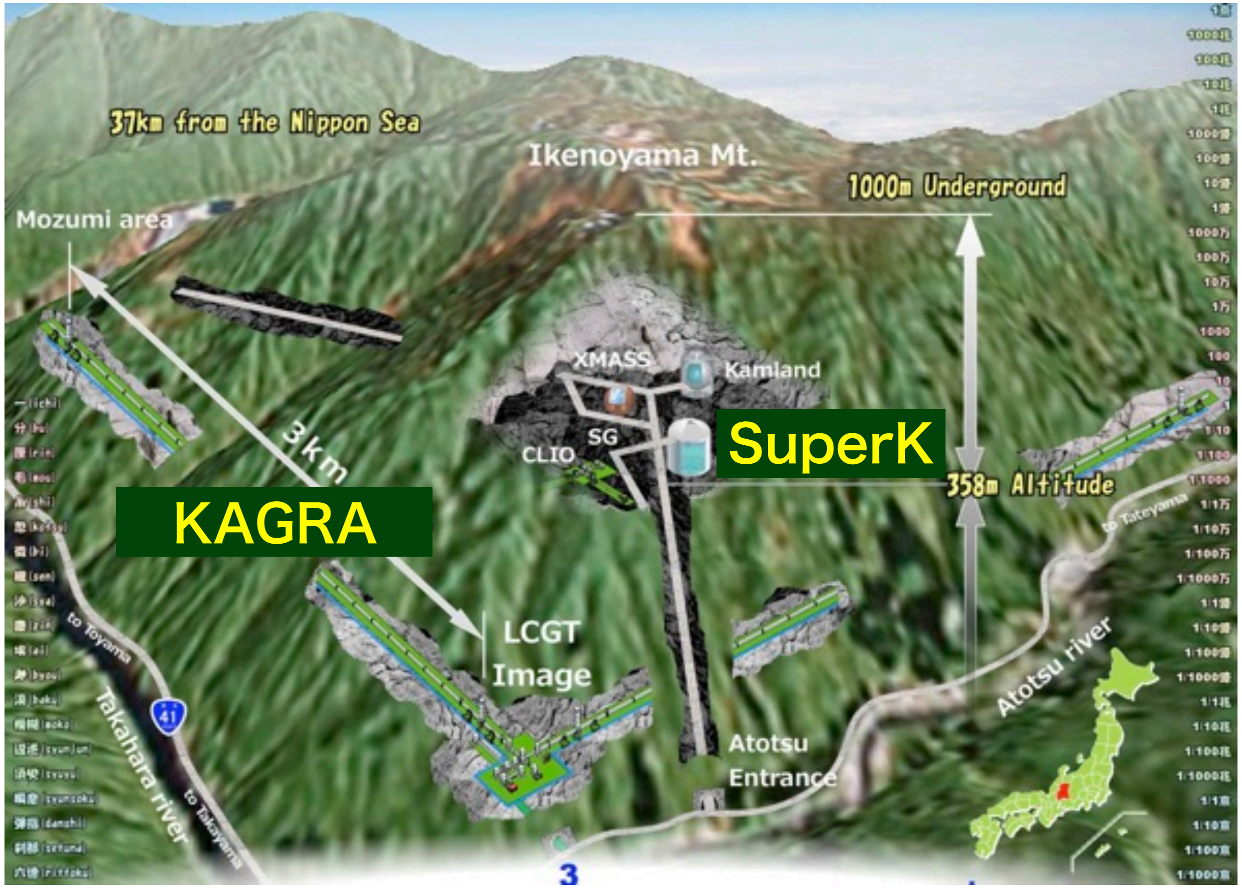
Tokyo Institute of Technology, Japan
Tokyo University of Science, japan
University of Toronto, Canada
TRIUMF, Canada
Tsinghua University, Korea
The University of Winnipeg, Canada
Yokohama National University, Japan

178 collaborators
from 45 institutes
10 countries

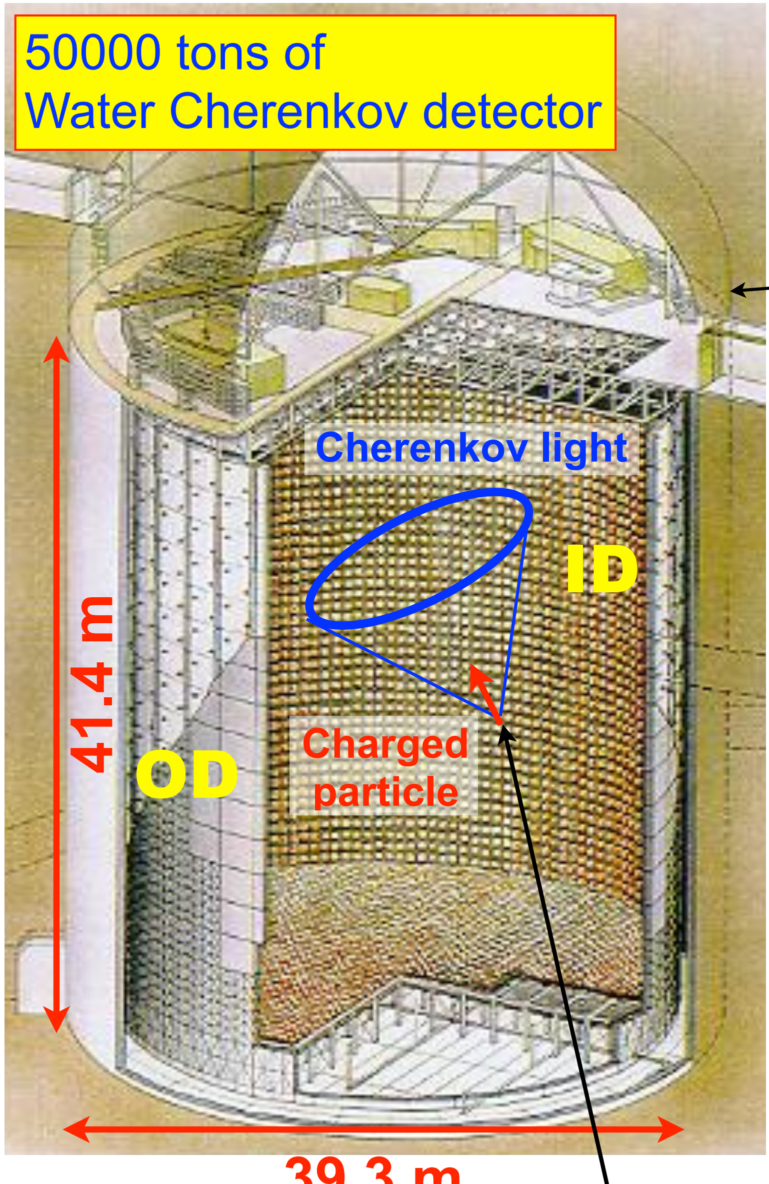
Super-Kamiokande

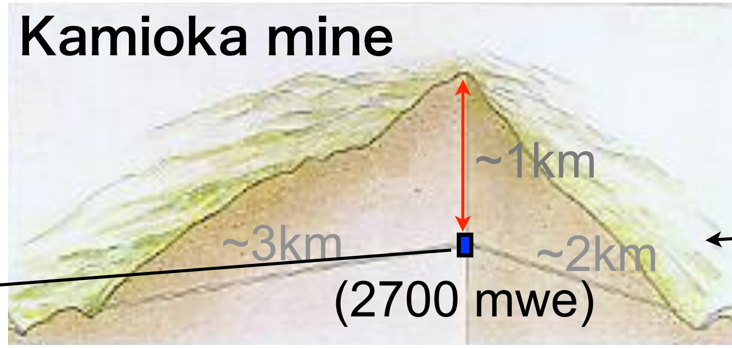






Super-Kamiokande





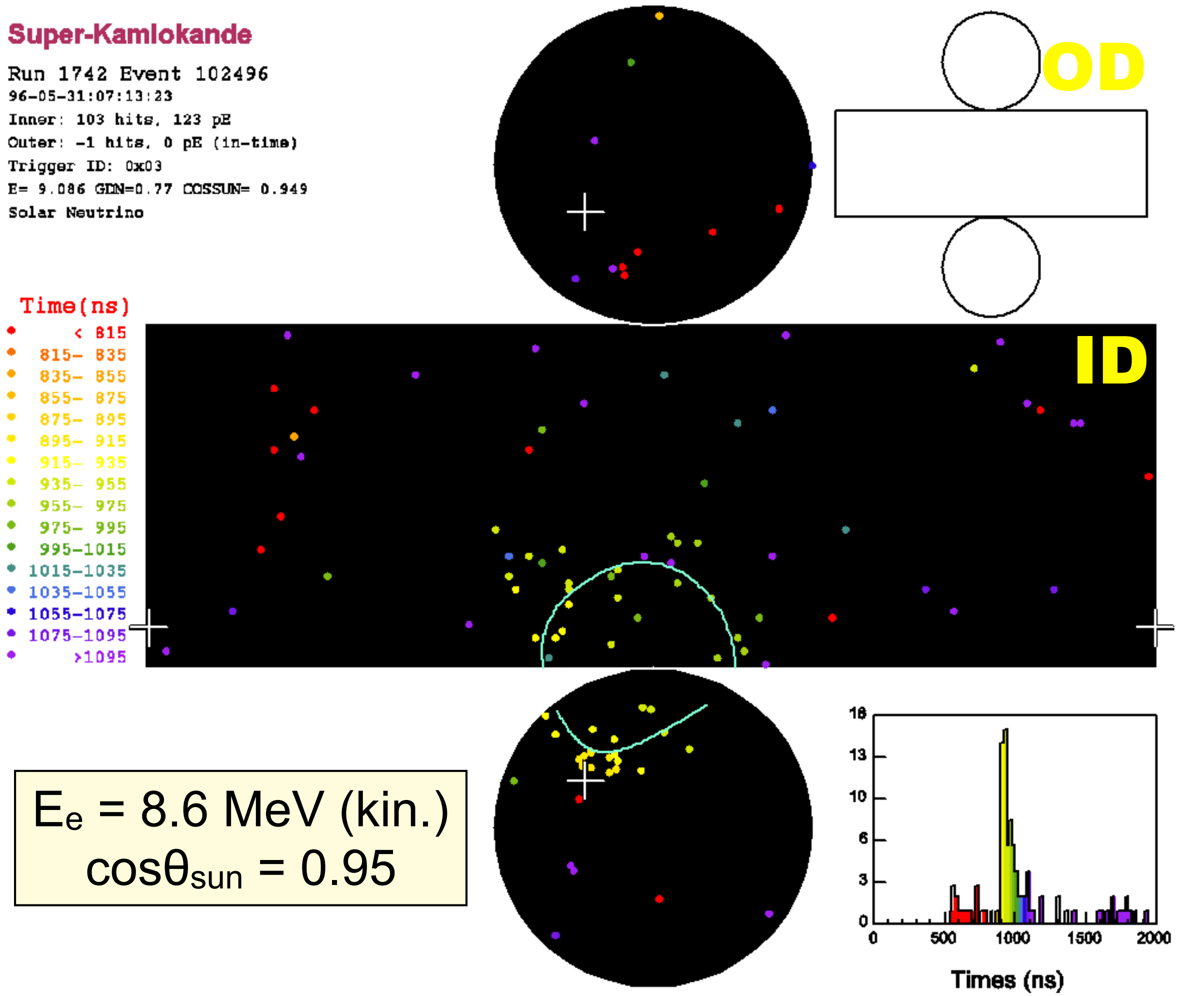
Phase	Period	Fiducial vol. (kton)	# of PMTs	Energy thr.(MeV)
SK-I	1996.4 ~ 2001.7	22.5	11146 (40%)	4.5
SK-II	2002.10 ~ 2005.10		5182 (20%)	6.5
SK-III	2006.7 ~ 2008.8	22.5 (>5.5MeV) 13.3 (<5.5MeV)	11129 (40%)	4.5
SK-IV	2008.9 ~ 2018.5	22.5 (>5.5MeV) 16.5 (4.5<E<5.5) 8.9 (<4.5MeV)		3.5
SK-V	2019.1 ~	just started!		

(coverage) (Kin. energy)

Running and improvements over 20 years

Super-Kamiokande

For supernova neutrinos (~MeV)



E_e = 8.6 MeV (kin.)
$\cos\theta_{sun}$ = 0.95

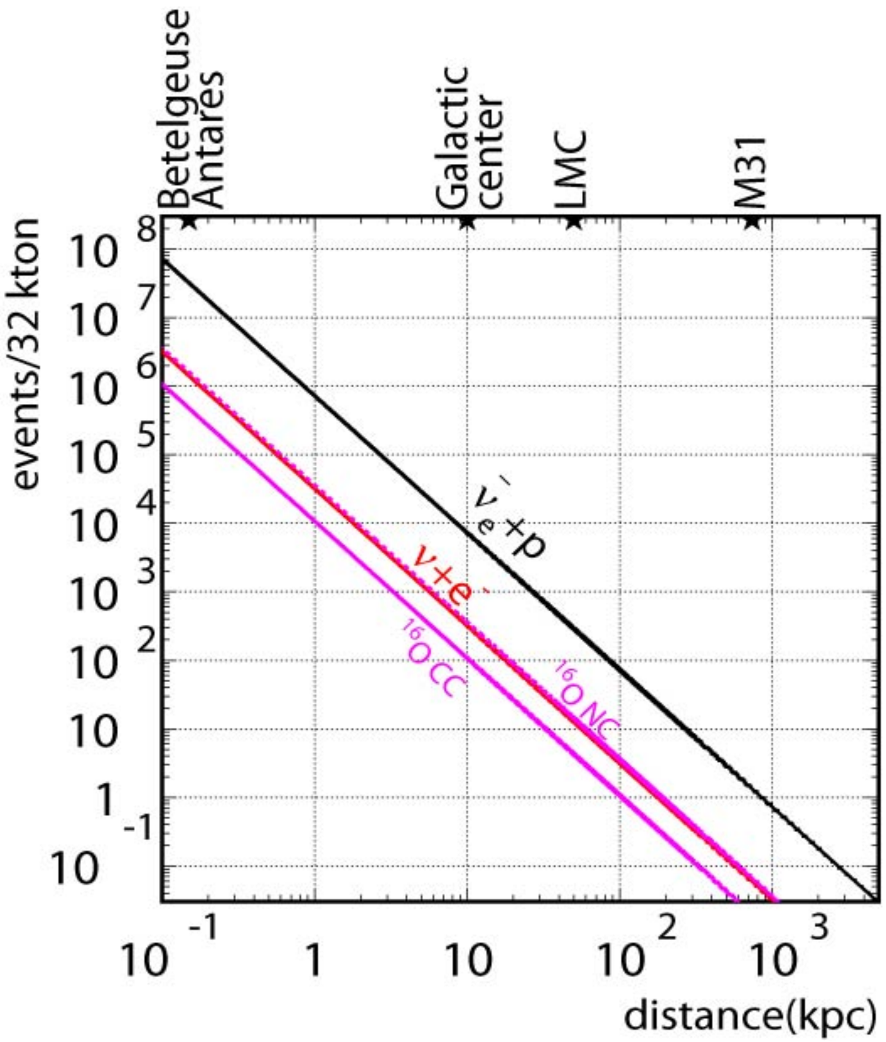
How to reconstruct?

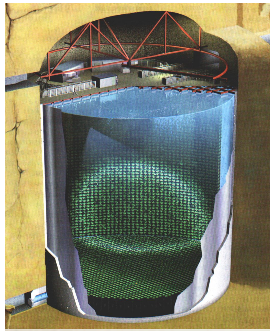
Detector performance

	Resolution@10MeV	Information
vertex	55cm	hit timing
direction	23deg.	hit pattern
energy	14%	# of hits.

~ 6 hits/MeV
well calibrated by LINAC / DT within 0.5% precision

Super-Kamiokande





Expected number of event

7.3k~10.2k ev (inverse beta decay)
320~380 ev (νe elastic scattering)
12~610 ev (ν_e CC)
95~580 ev ($\bar{\nu}_e$ CC)

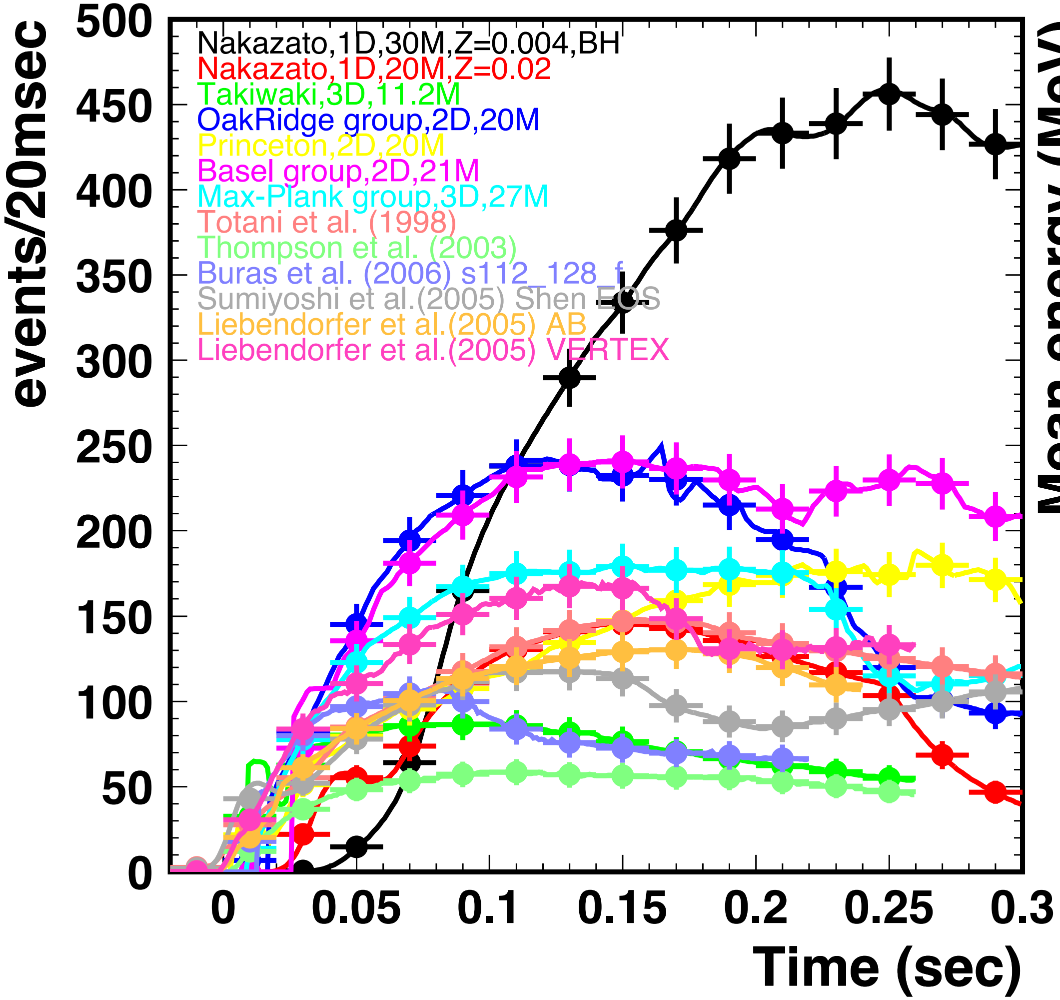
at 10kpc, 4.5MeV energy threshold

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

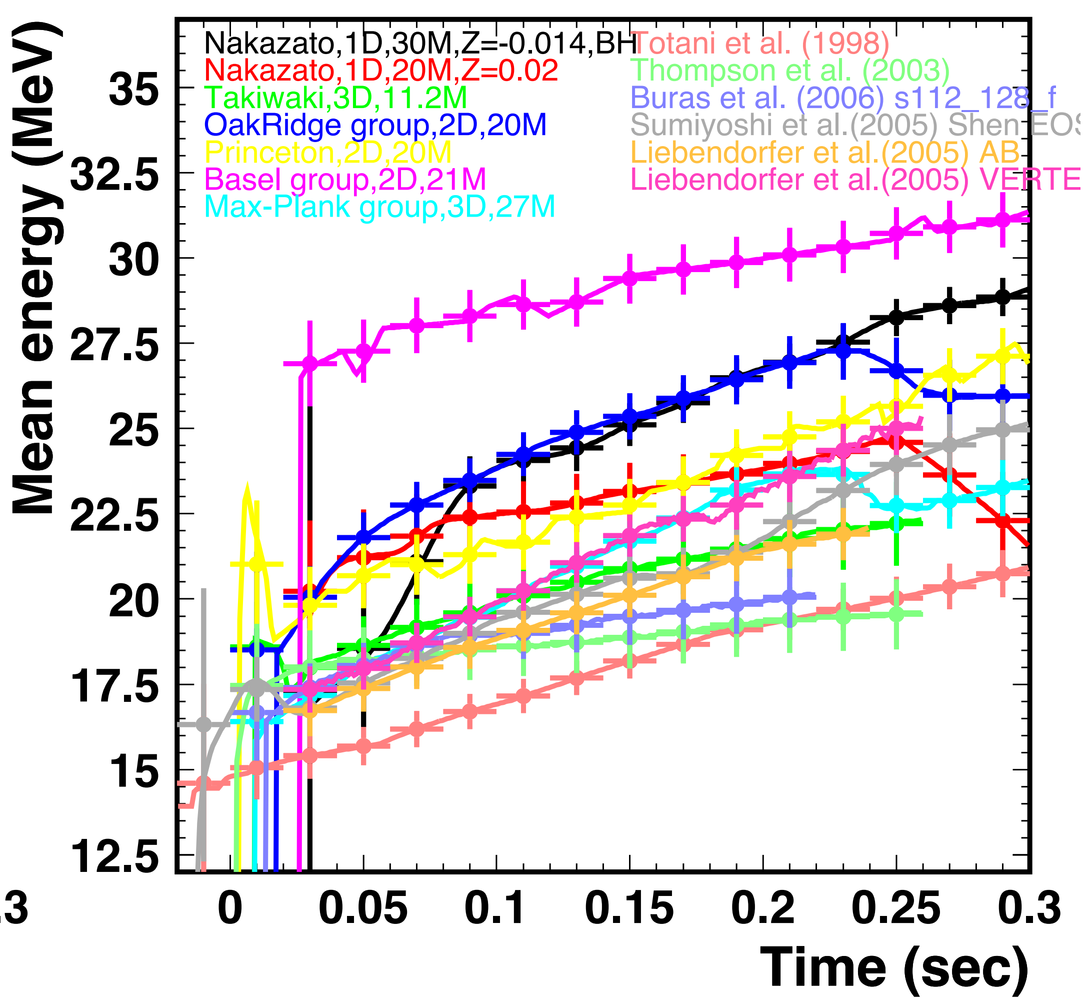
Super-Kamiokande

Time variation of $\overline{\nu_e}$+p at 10kpc

event rate

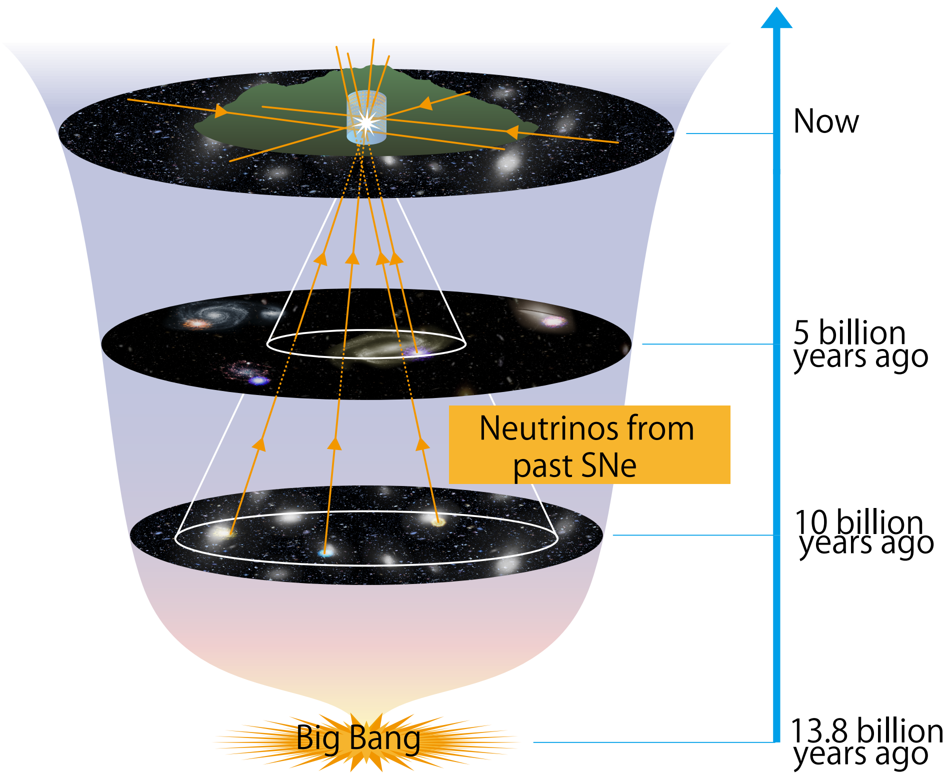


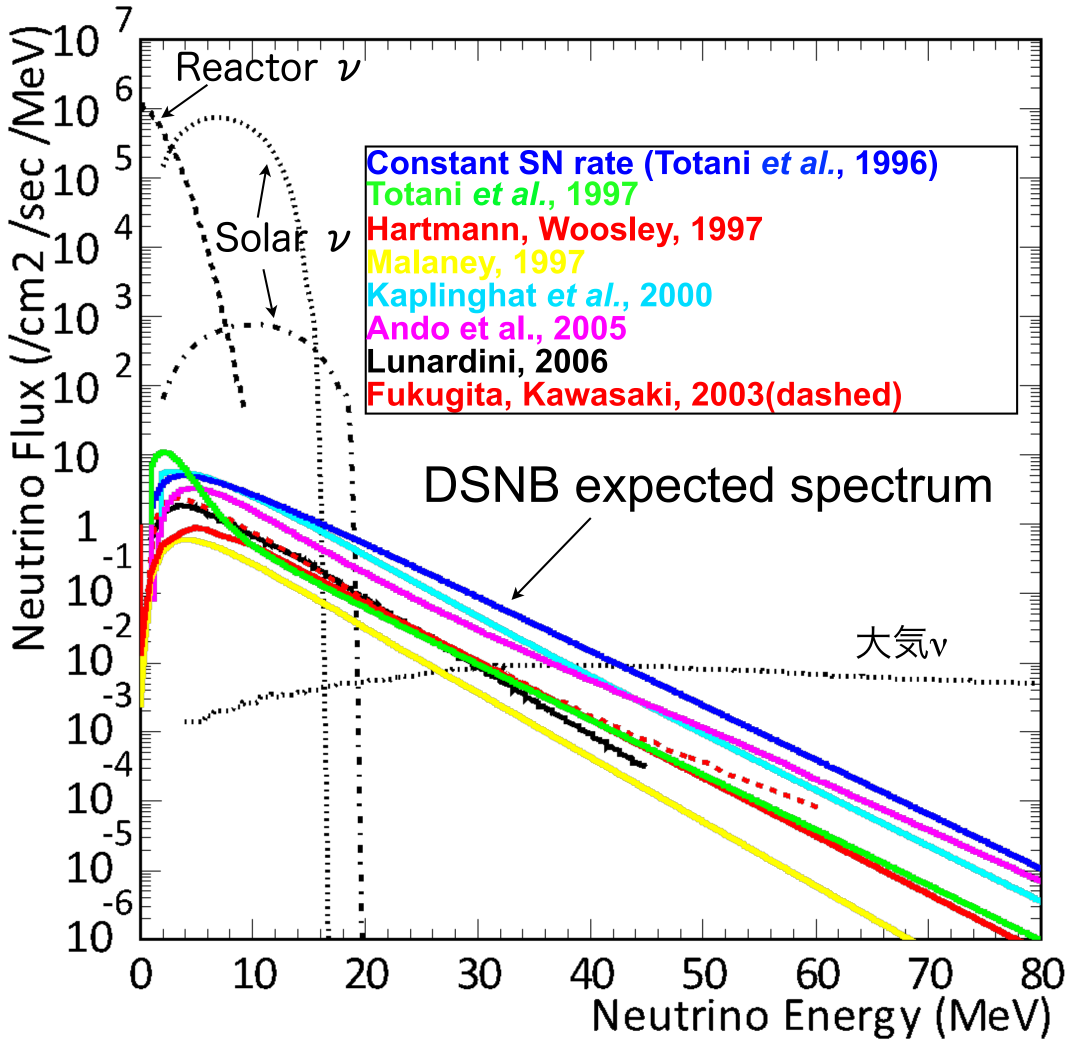
mean energy



Diffuse Supernova Neutrino Background (DSNB)

Neutrinos emitted from past supernovae

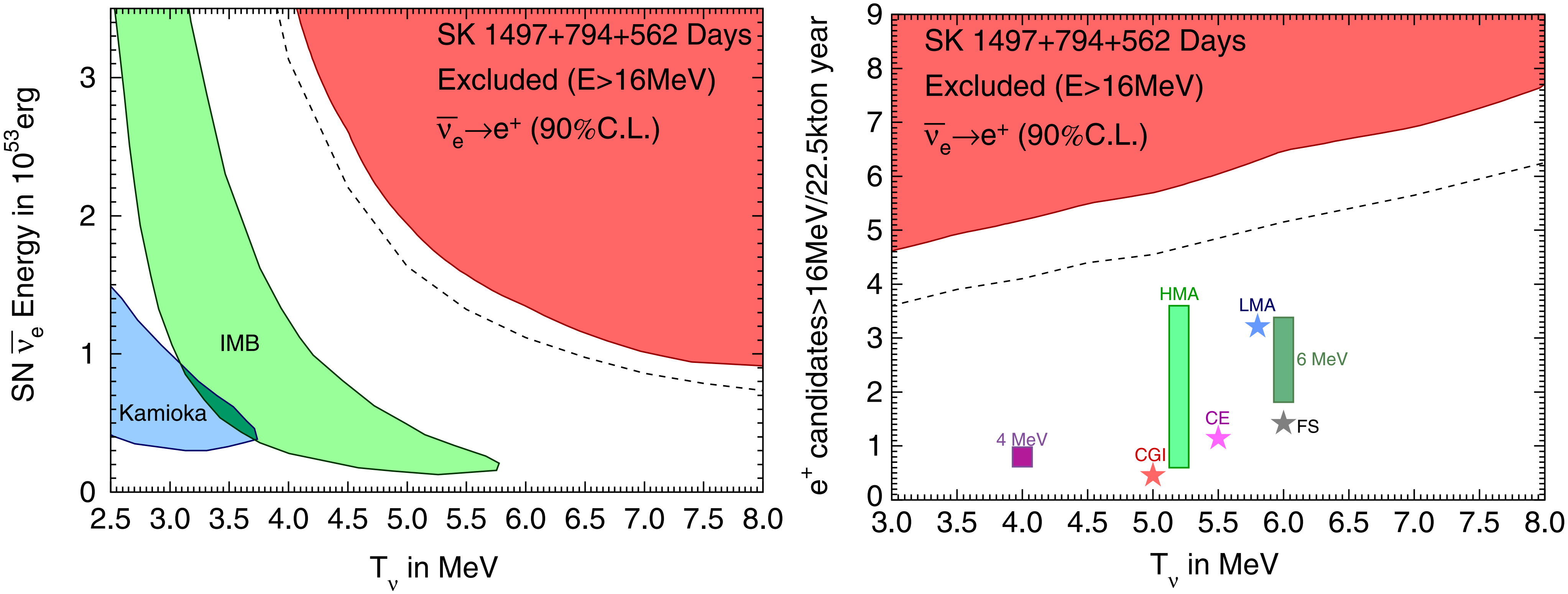




DSNB in Super-K

Upper limit from Super-K

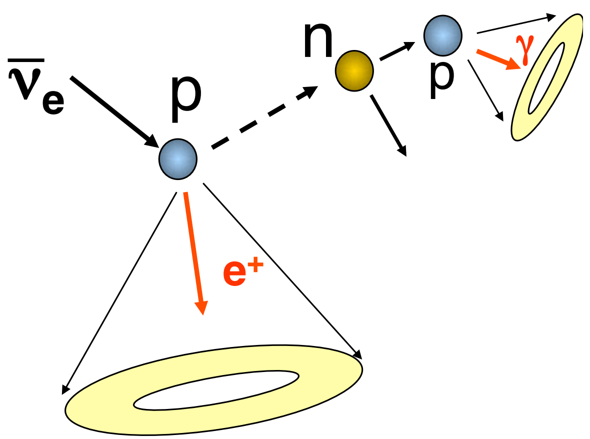
SK collaboration, Phys. Rev. D 85, 052007 (2012)



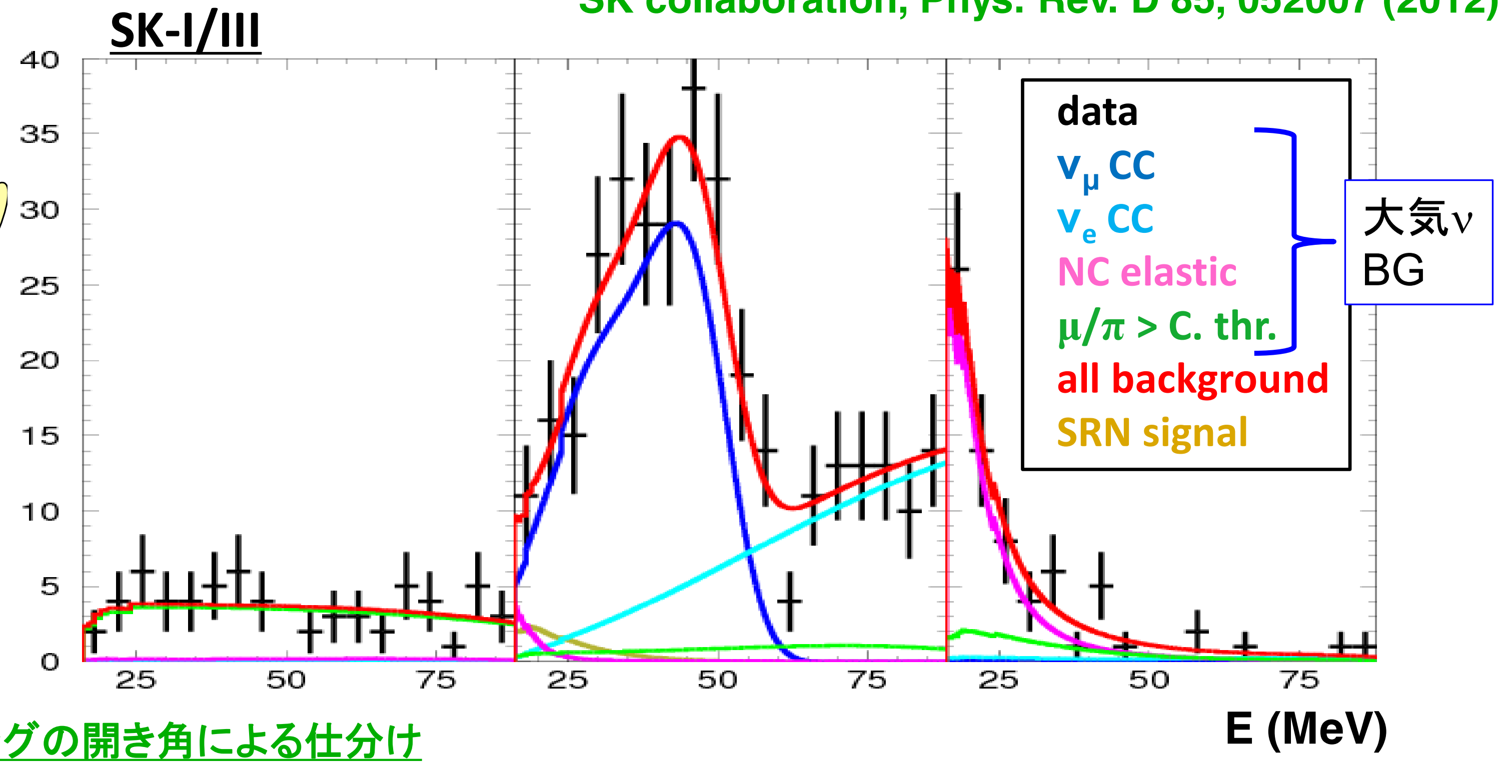
DSNB in Super-K

Current Super-K w/o neutron tagging

SK collaboration, Phys. Rev. D 85, 052007 (2012)

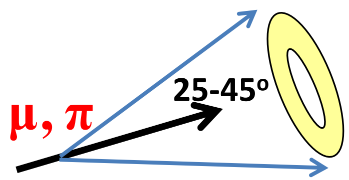


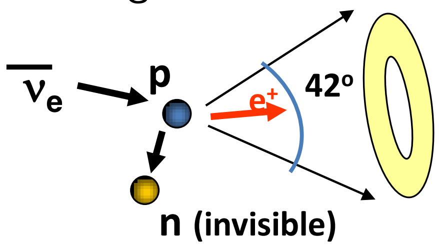
Only this signal

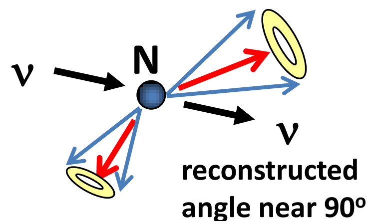


リングの開き角による仕分け

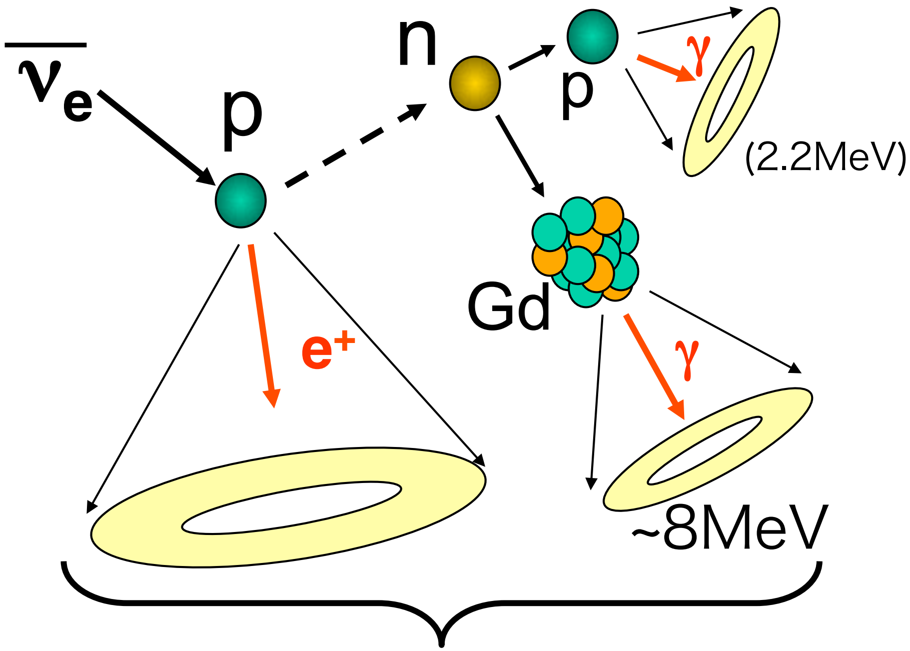
Low angle events | Signal Events | Isotropic Events







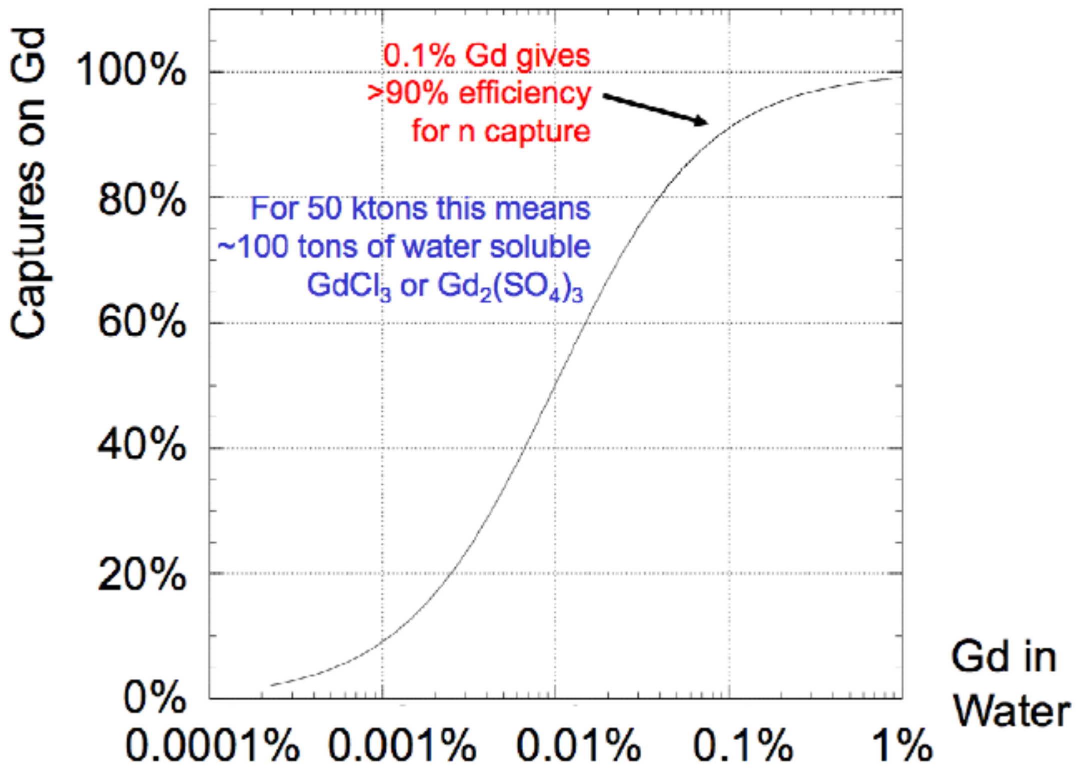
DSNB in upgraded Super-K



- Delayed coincidence
  - Suppress B.G. drastically for $\overline{\nu}_e$ signal
  - ΔT~20μsec
  - Vertices within ~50cm

GADZOOKS!

Dissolve Gadolinium into Super-K
J.Beacom and M.Vagins, Phys.Rev.Lett.93 **(2004)** 171101



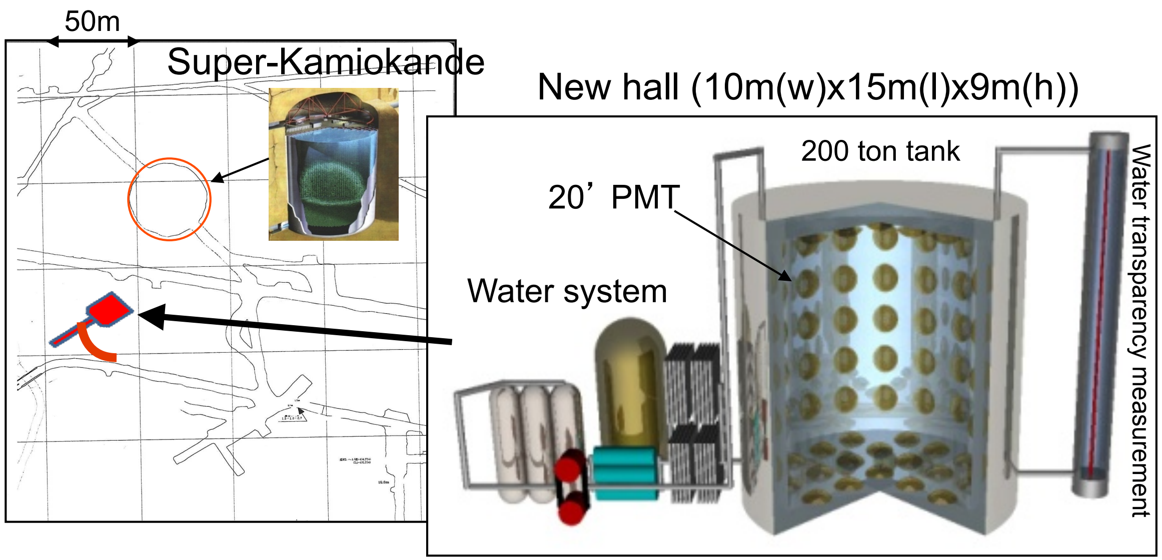
Proposed in 2004,
but not so easy..

EGADS as R&D

(Evaluating Gadolinium's Action on Detector Systems)

Purpose
- ✓Water transparency
- ✓How to purify
- ✓How to introduce and remove
- ✓Effect on detector
- ✓Effect from environment neutrons
- ✓etc.

R&D for Gd test experiment



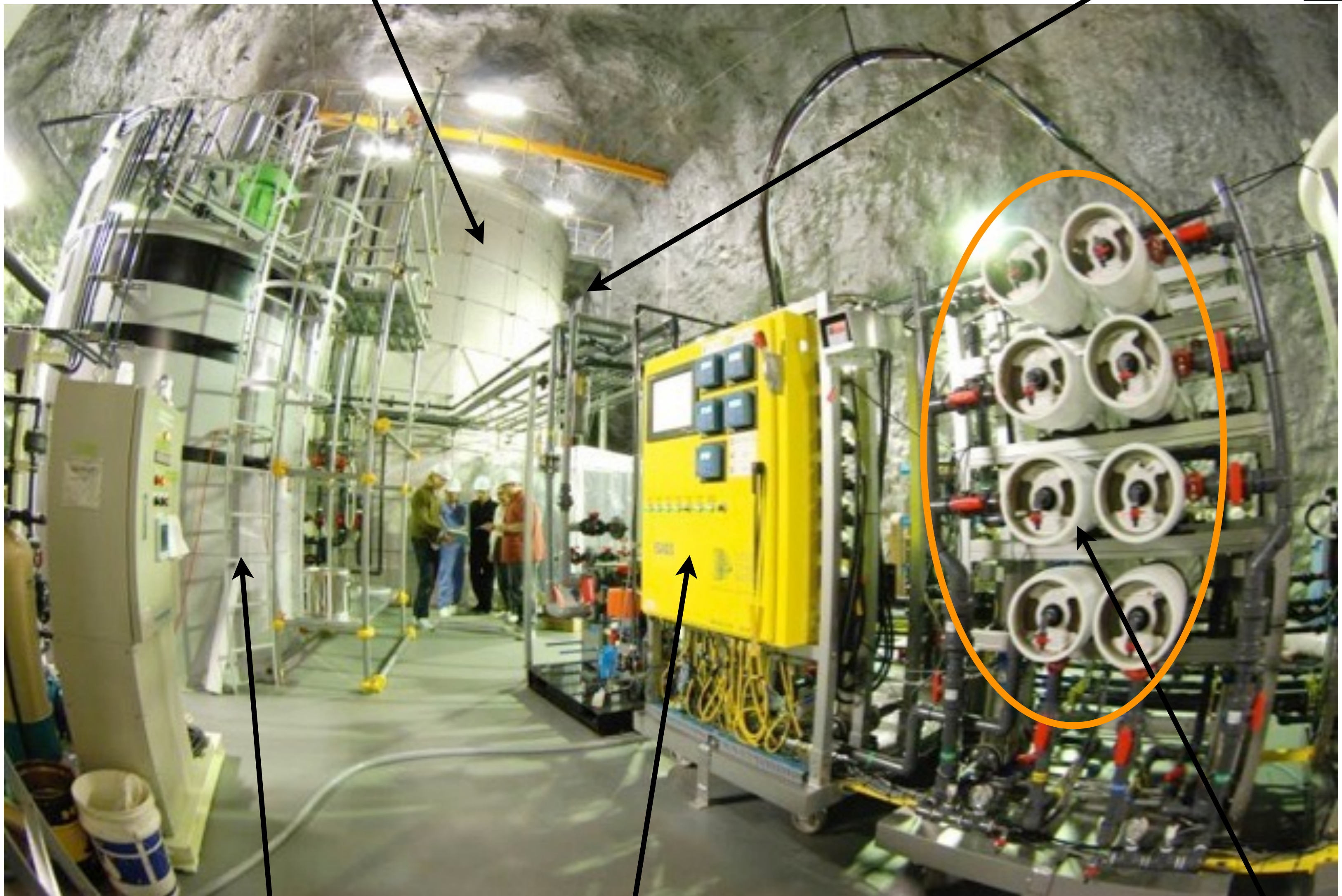
Now working well

EGADS as R&D

UDEAL

water transparency measurement

200 ton tank

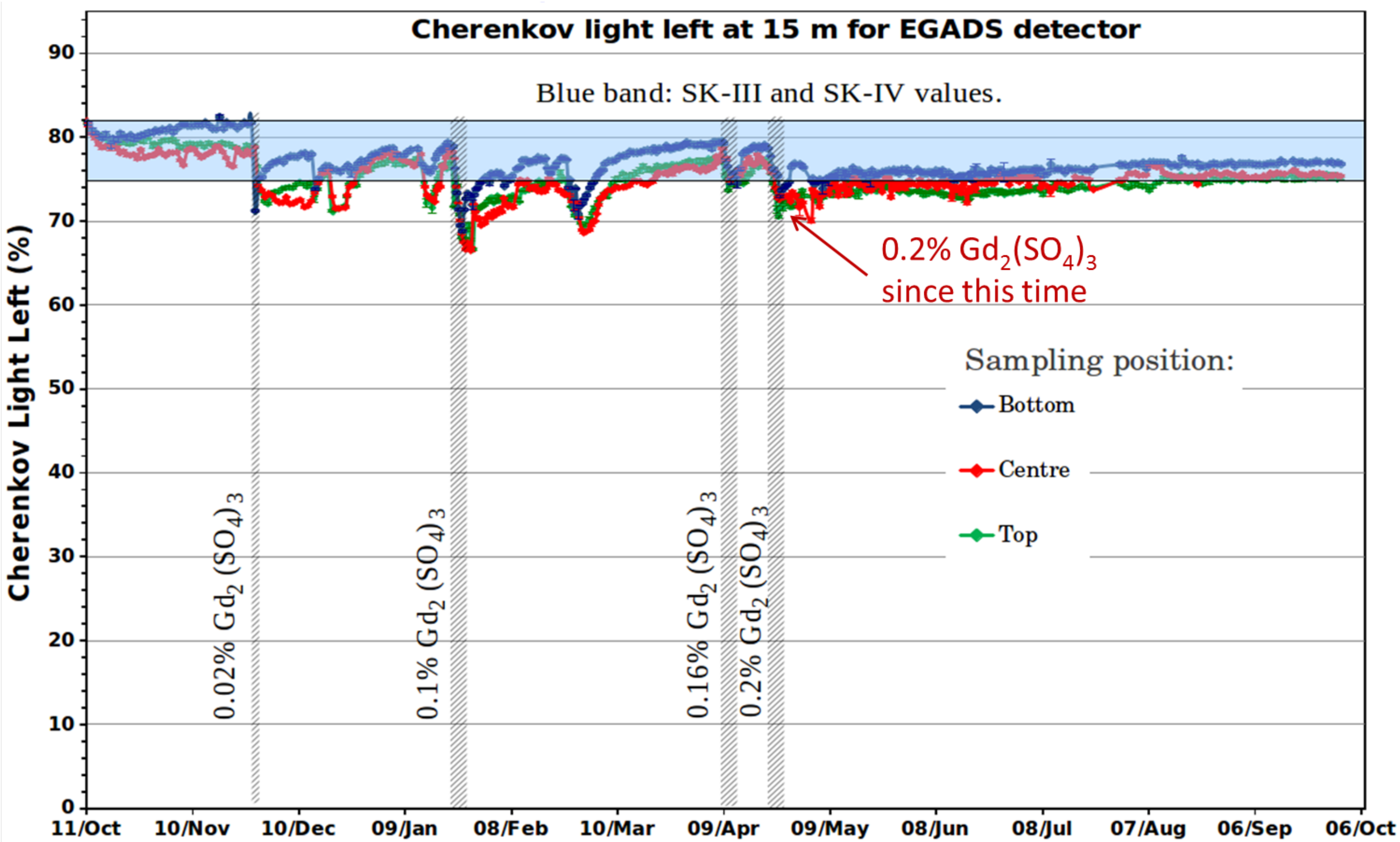


15 ton buffer tank

Control panel of circulation system

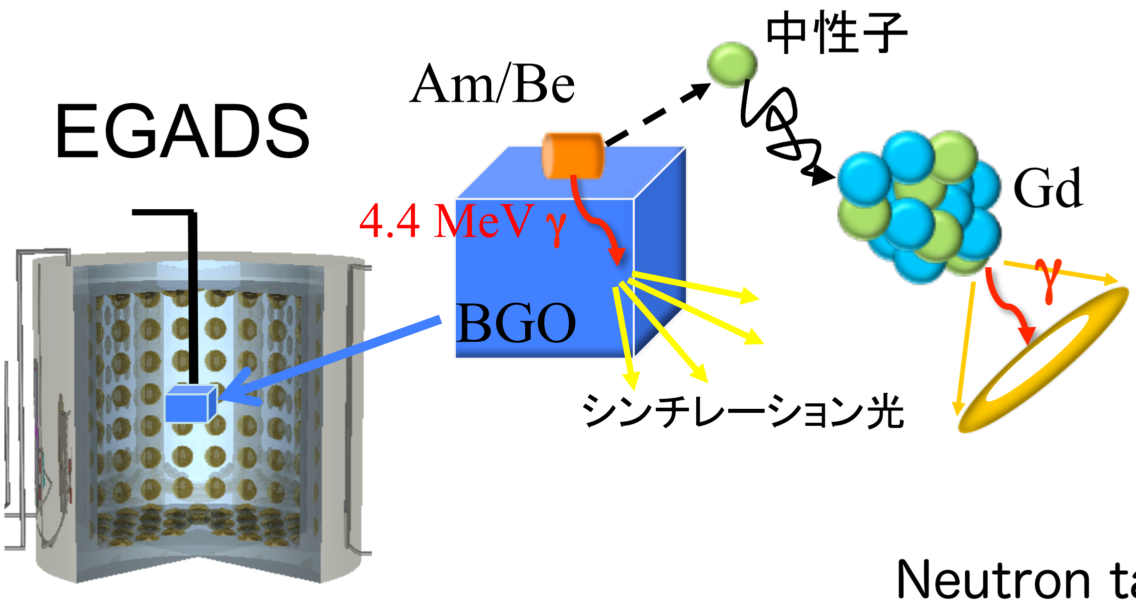
Filter

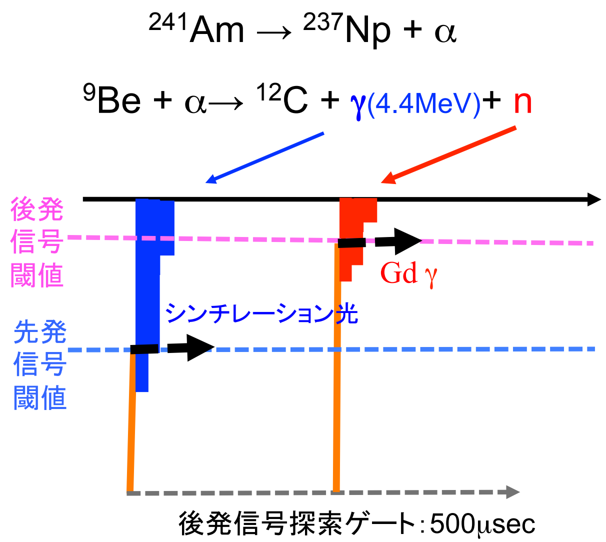
EGADS as R&D



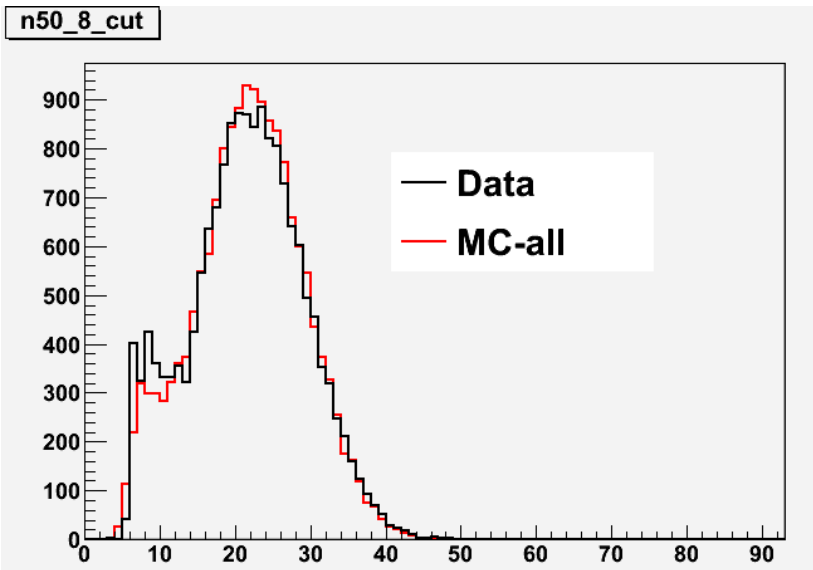
Very stable and continuous data taking

Neutron tagging efficiency





Neutron tagging with delayed coincidence



Neutron capture time

	2178±44ppm	1055±21ppm	225±5ppm
Data	29.89±0.33	51.48±0.52	130.1±1.7
MC	30.03±0.77	53.45±1.19	126.2±2.0

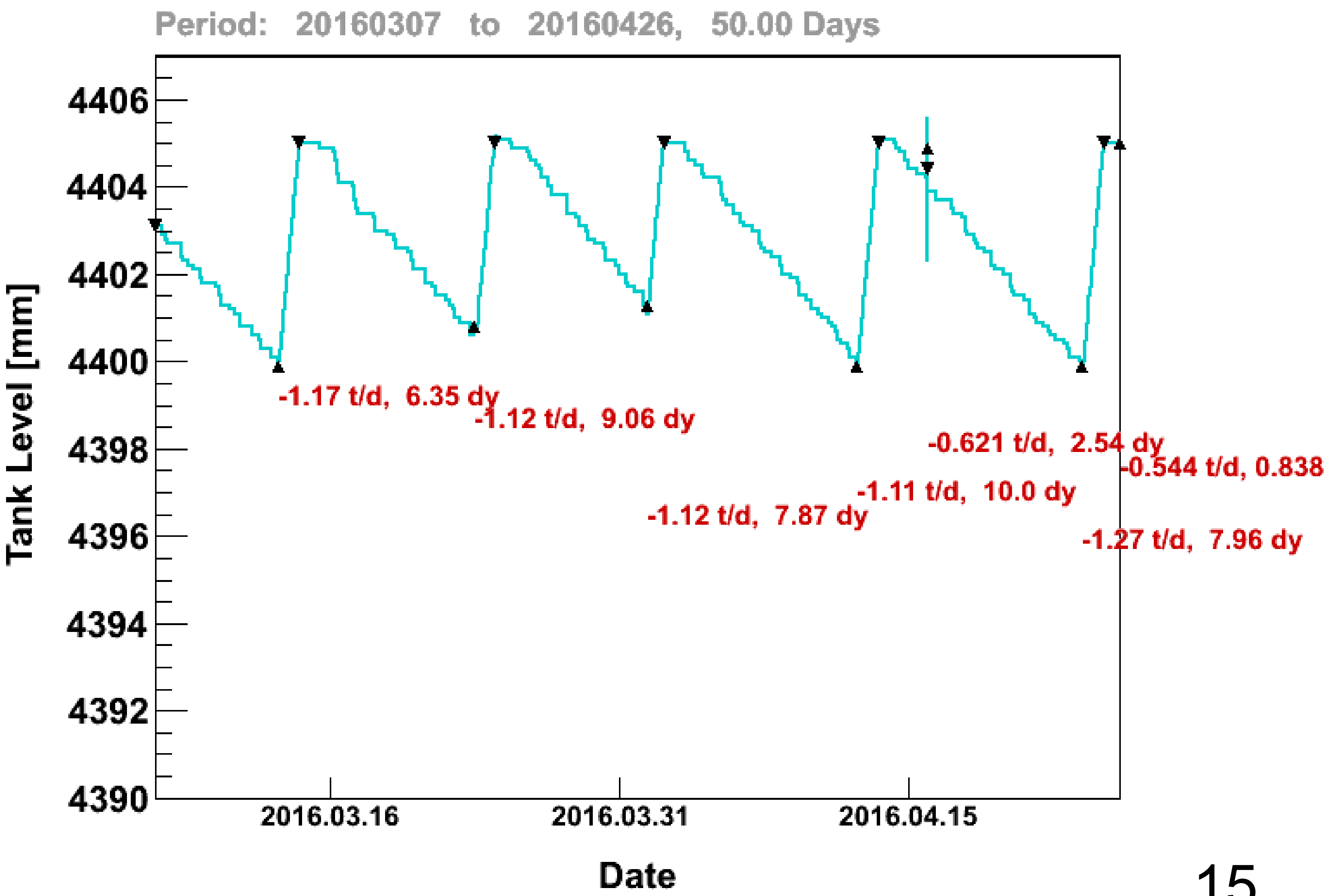
Neutron capture efficiency

Data	MC
84.36± 1.79%	84.51±0.33%

Approved this project by the Super-K collaboration in 2015 as “Super-K Gd”

Big work toward
SK-Gd in last year

Water leakage from SK tank

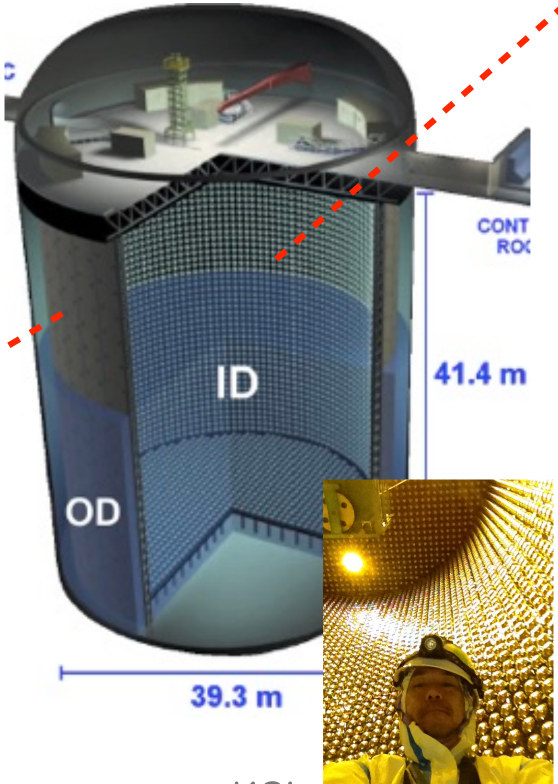


15

Super-K tank refurbishment

- Stop water leak (~3ton/day)
- Change bad PMTs
- Install new water pipe for better water control
- Cleaning

Change bad PMTs

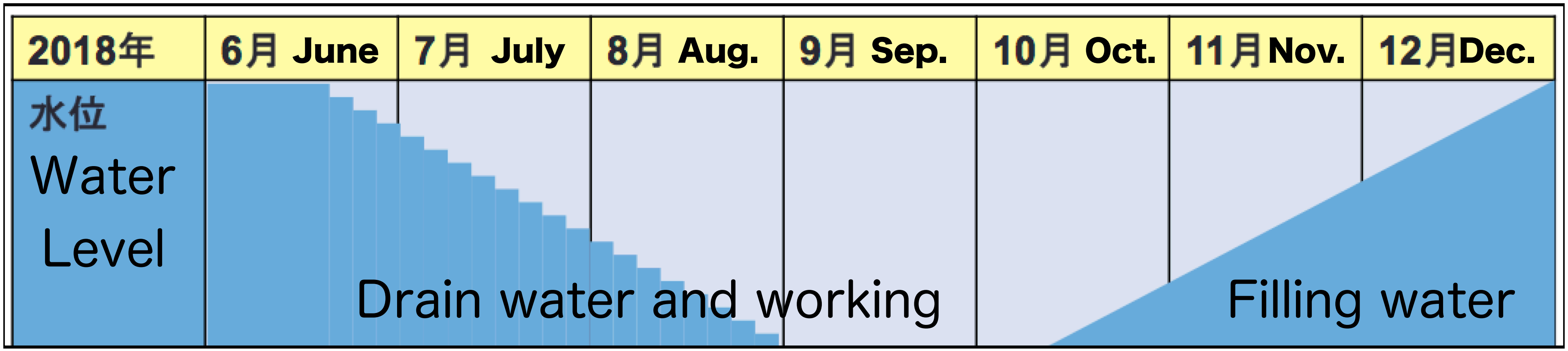


Seal whole welding lines

Install new water pipe

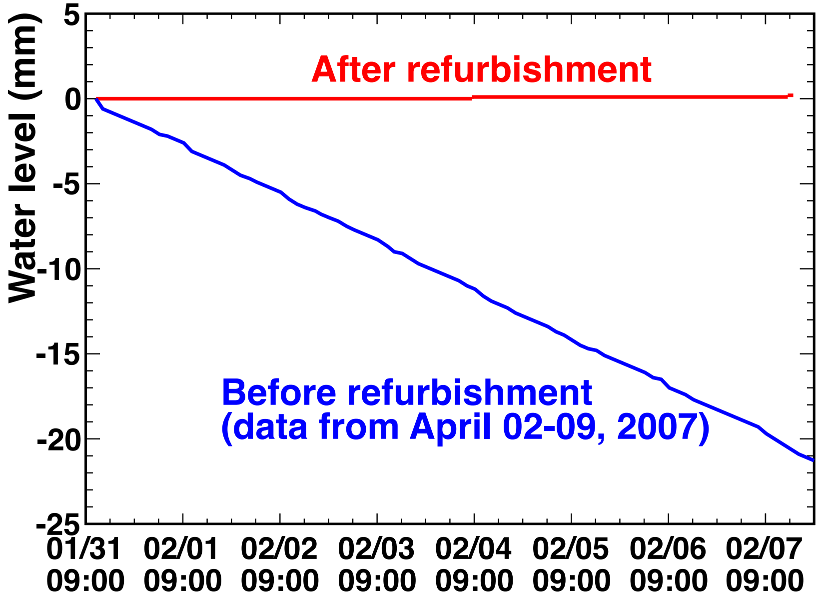
Super-K tank refurbishment

- Start on 31st May, 2018, work on barrel part draining water. After complete draining in the end of August, working on bottom part.
- Start filling water in the middle of October, 2018.
- After complete filling water on 29th January, 2019, resume the data taking as SK-V.



Water leakage from SK tank

After filling the tank completely with water, we started the water leakage measurement from 11:30 on 31st January to 15:52 on 7th February, 2019. (7 days 4 hours 22 minutes in total)



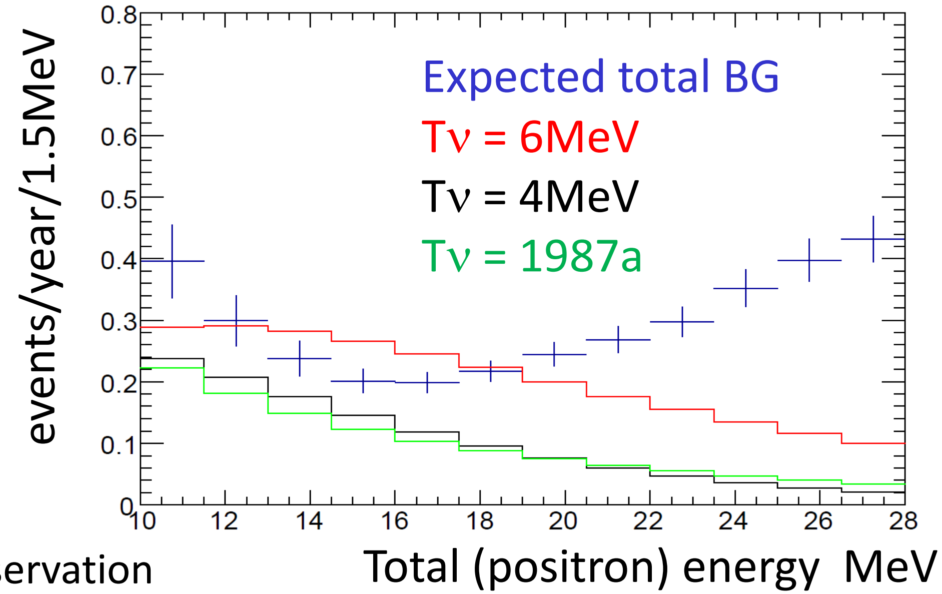
- Currently we do not observe any water leakage from the SK tank within the accuracy of our measurement, which is less than 0.017 tons per day.
- This is less than 1/200th of the leak rate observed before the tank refurbishment.

We are ready to introduce Gadolinium to Super-K

Physics expectation in SK-Gd

DSNB flux:
Horiuchi, Beacom and Dwek,
PRD, 79, 083013 (2009)

- It depends on typical/actual SN emission spectrum

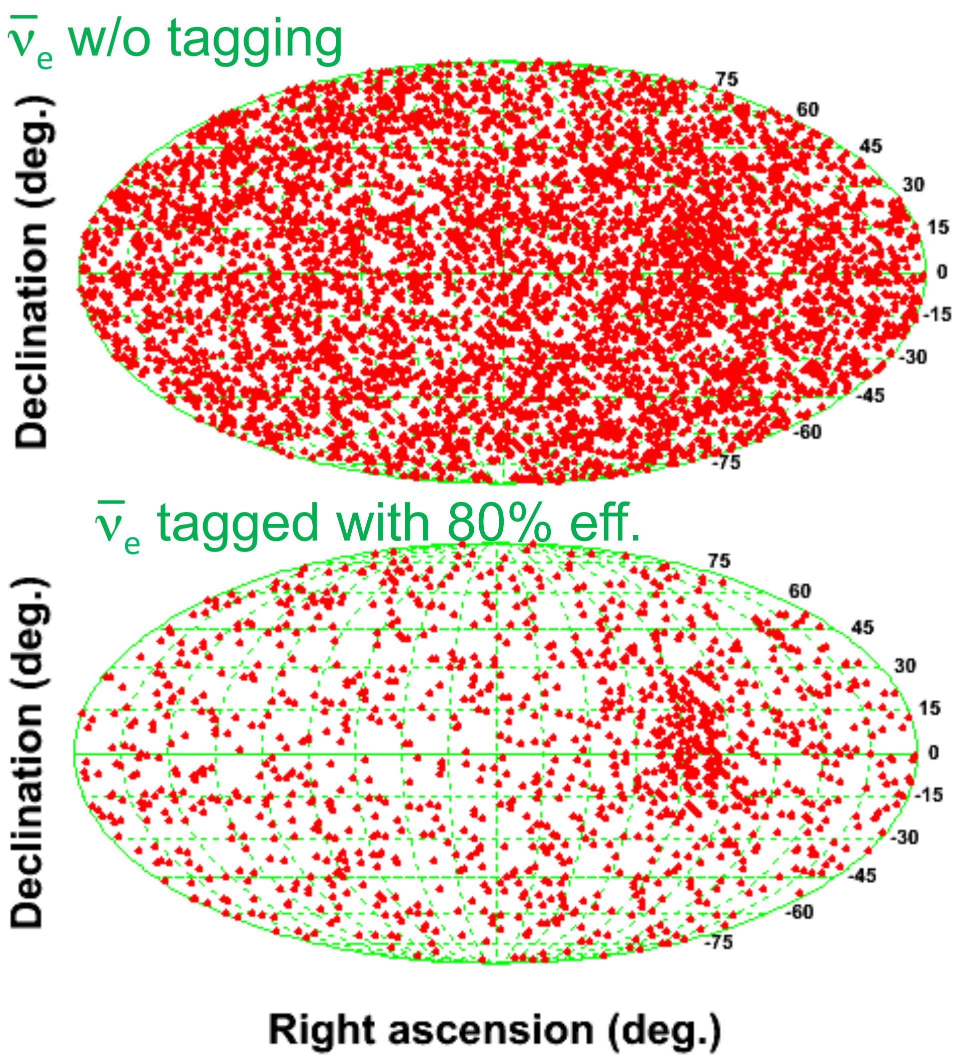


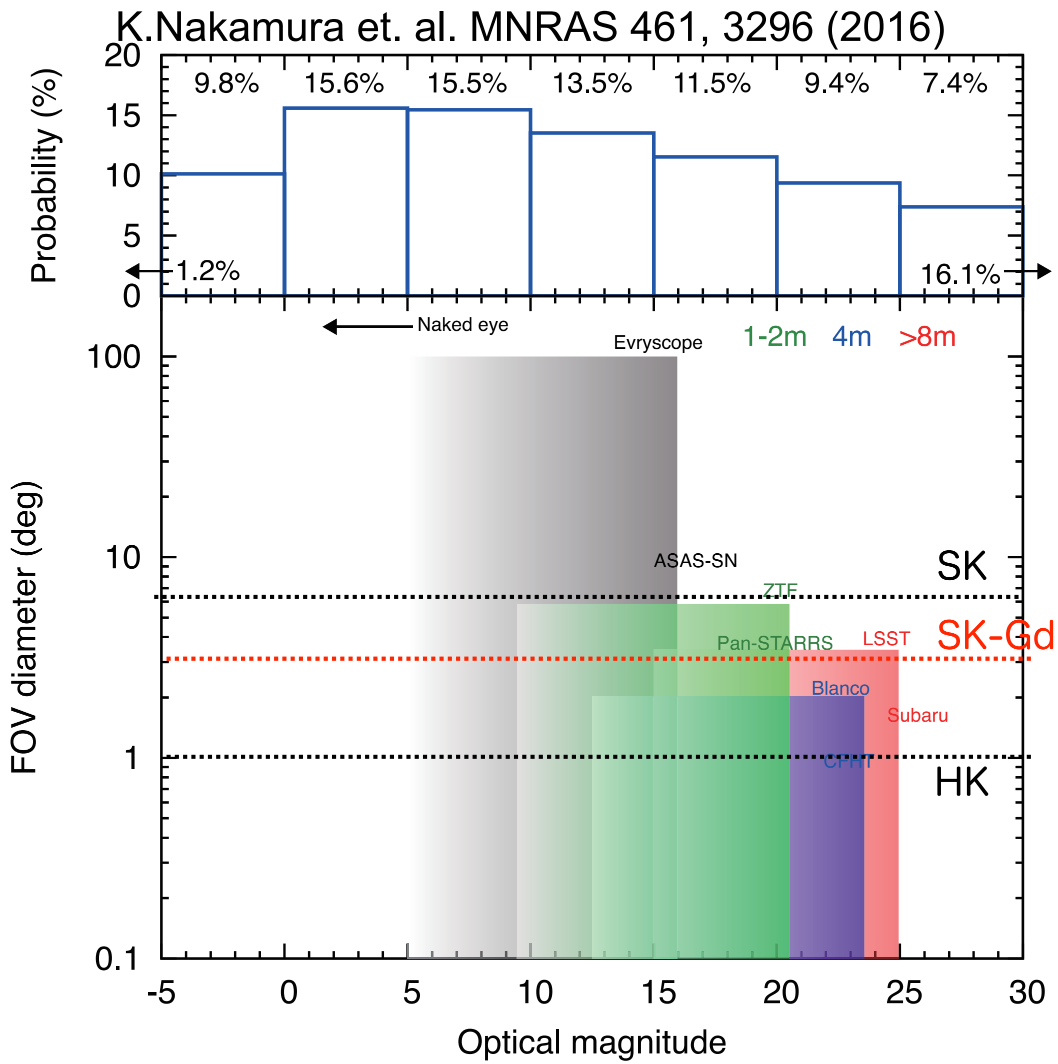
DSNB events number with 10 years observation

HBD models	10-16MeV (evts/10yrs)	16-28MeV (evts/10yrs)	Total (10-28MeV)	significance (2 energy bin)
T_{eff} 8MeV	11.3	19.9	31.2	5.3 σ
T_{eff} 6MeV	11.3	13.5	24.8	4.3 σ
T_{eff} 4MeV	7.7	4.8	12.5	2.5 σ
T_{eff} SN1987a	5.1	6.8	11.9	2.1 σ
BG	10	24	34	----

Physics expectation in SK-Gd

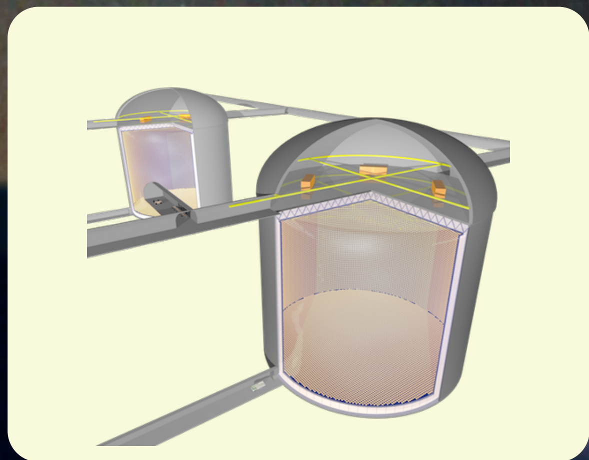
For Supernova burst neutrinos





SN search at Hyper-Kamiokande

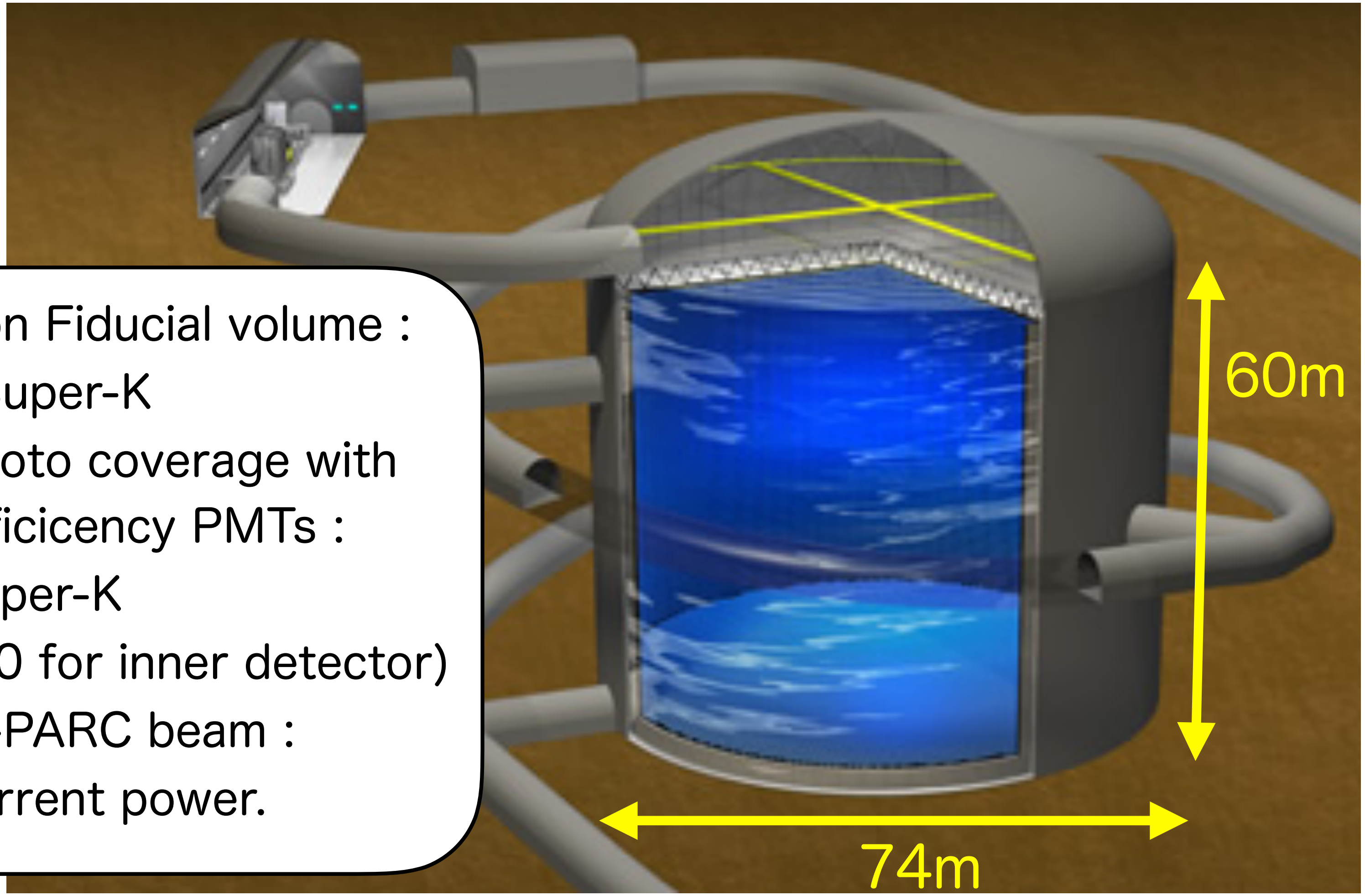
Precise measurement



Hyper-Kamiokande

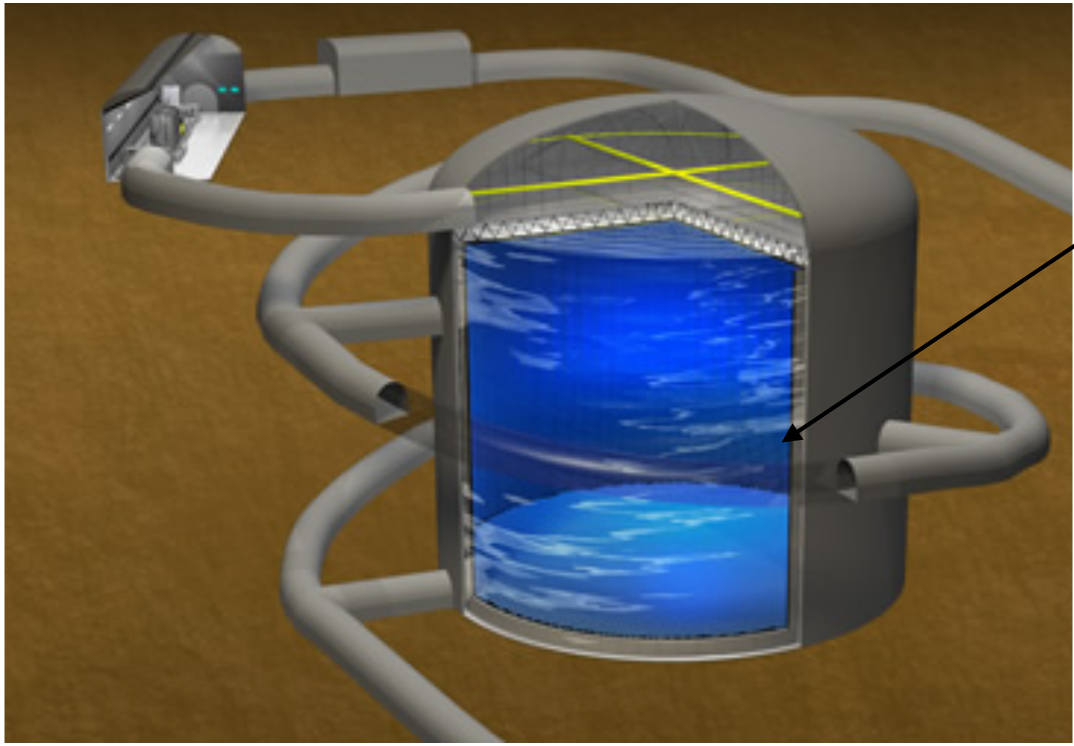
(See also "Hyper-Kamiokande Design Report", arXiv : 1805.04163)

Next generation of large water Cherenkov detector (~2027 -)



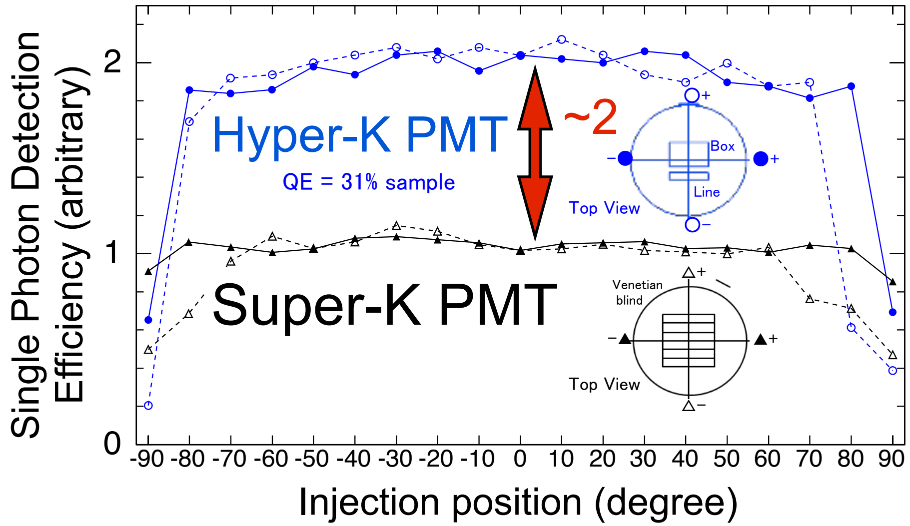
- 190kton Fiducial volume : ~10 x Super-K
- 40% photo coverage with high-efficicency PMTs : ~2 x Super-K (~40000 for inner detector)
- >MW J-PARC beam : ~3 x current power.

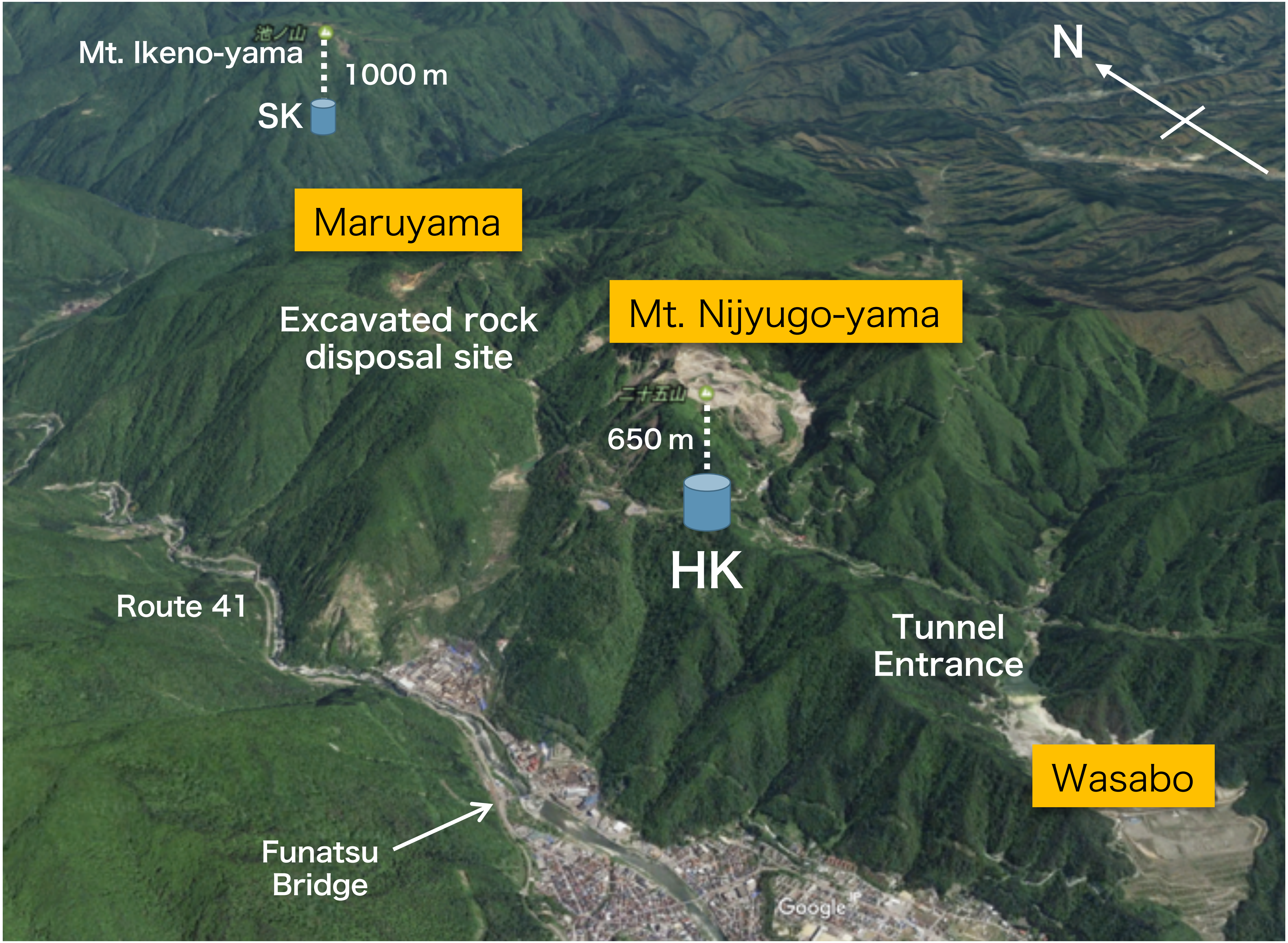
Hyper-Kamiokande



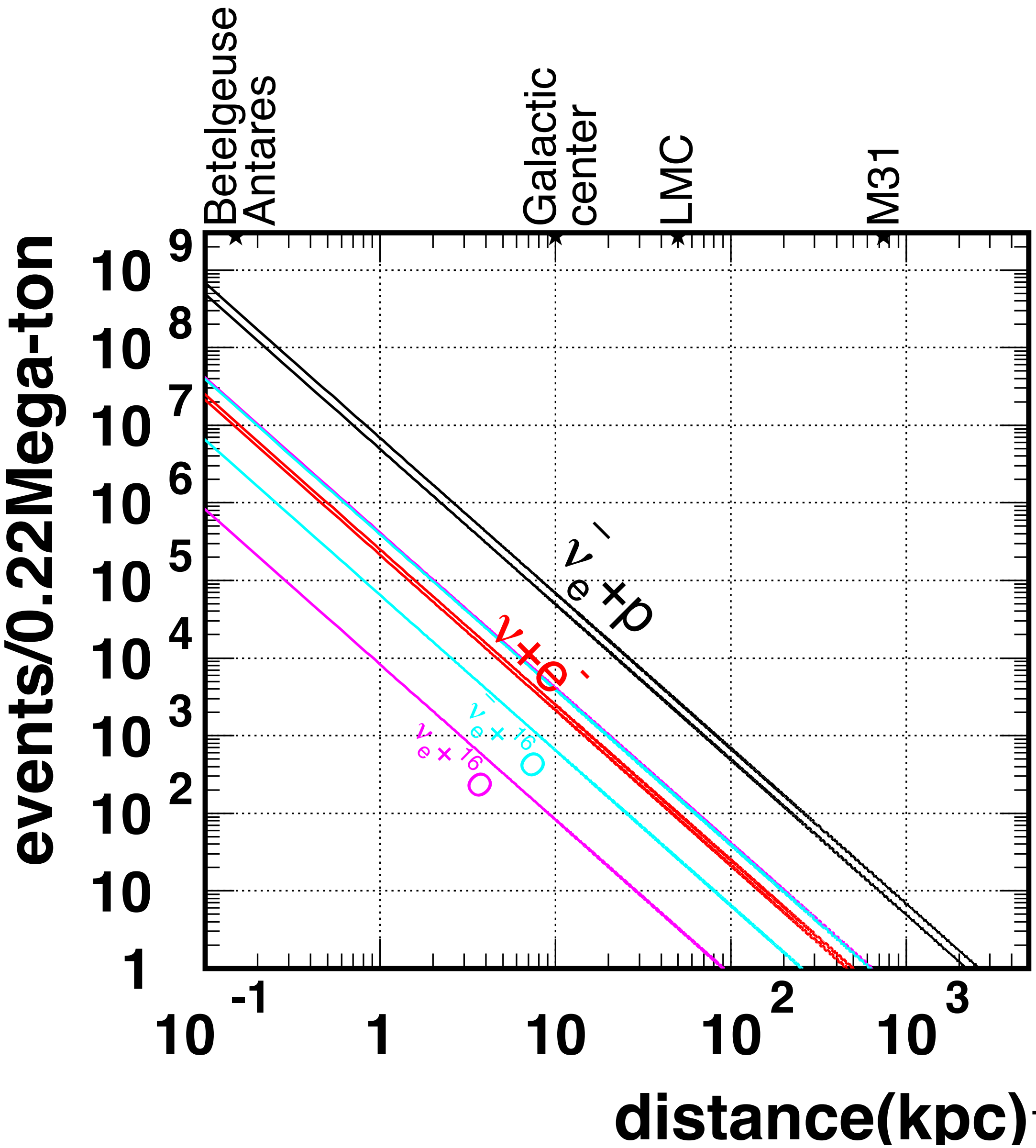
~40000 PMT / tank

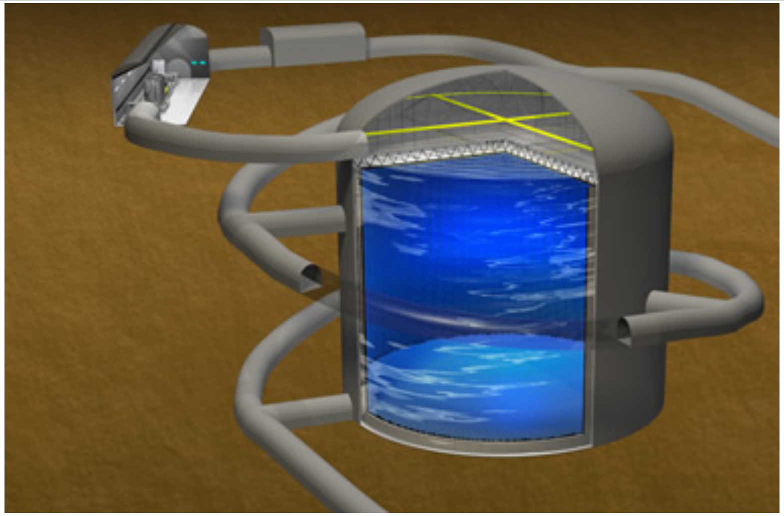
New photo-censer which has twice sensitivity than Super-K




池ノ山
Mt. Ikeno-yama
1000 m
SK
N
Maruyama
Excavated rock
disposal site
Mt. Nijyugo-yama
二十五山
650 m
HK
Route 41
Tunnel
Entrance
Wasabo
Funatsu
Bridge
Google

Hyper-Kamiokande





<u>Expected number of event</u>

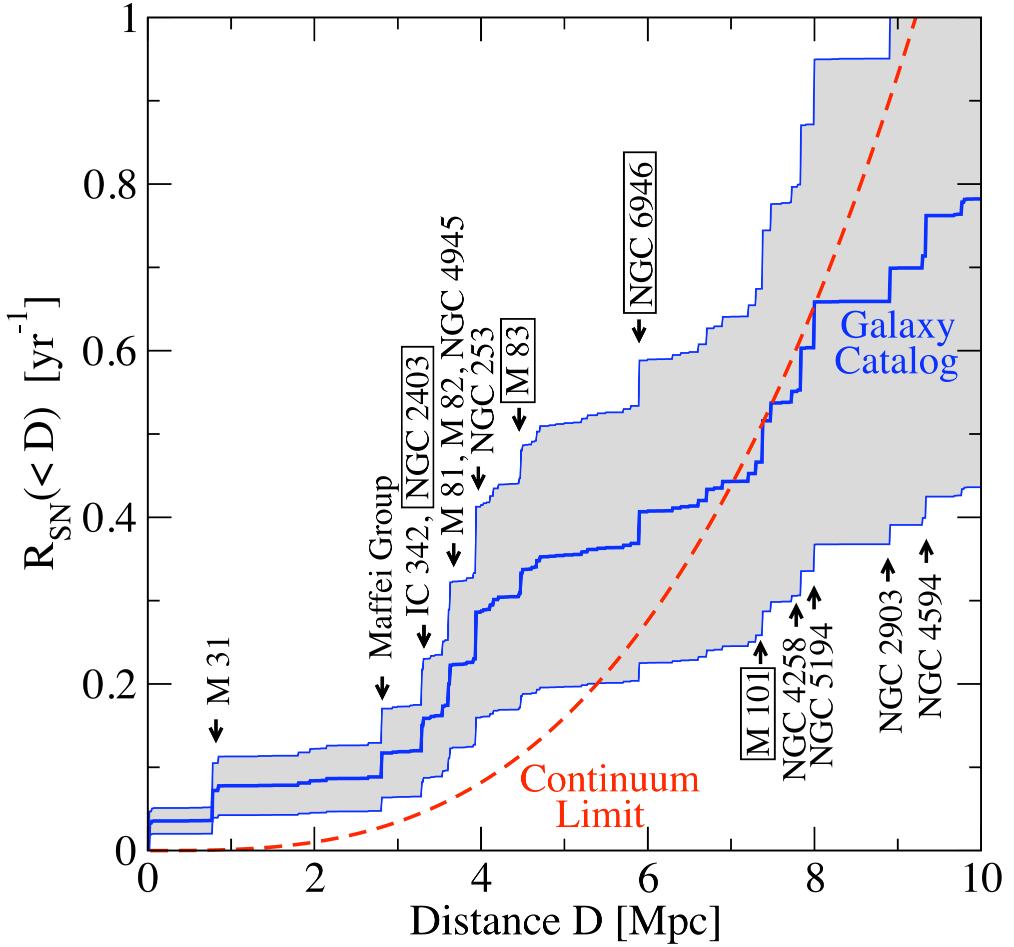
49k~68k ev (IBD)
2.1k~2.5k ev (νe ES)
(6~40 for neutronization)
80~4100 ev (ν_e CC)
650~3900 ev ($\overline{\nu_e}$ CC)

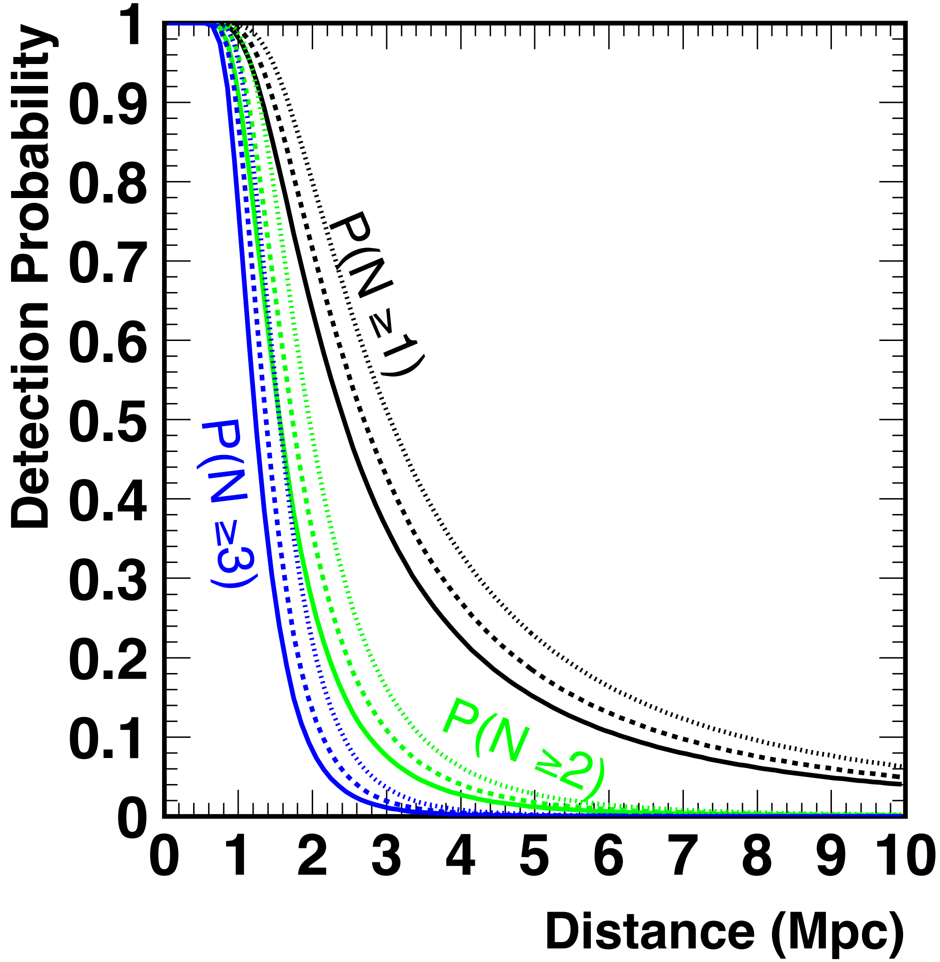
at 10kpc

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

Hyper-Kamiokande

Cumulative calculated supernova rate

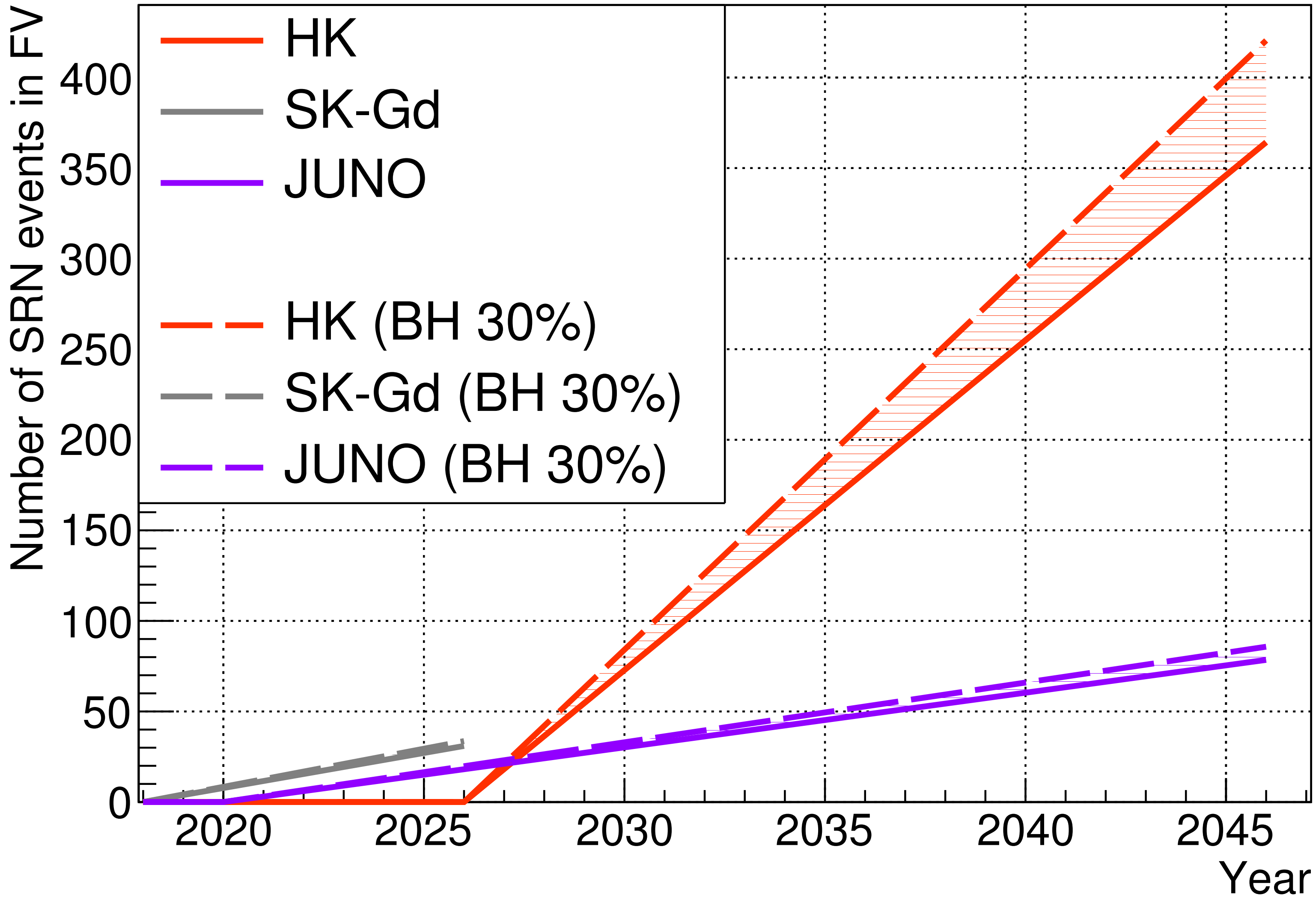




S. Horiuchi et.al.

DSNB at Hyper-K

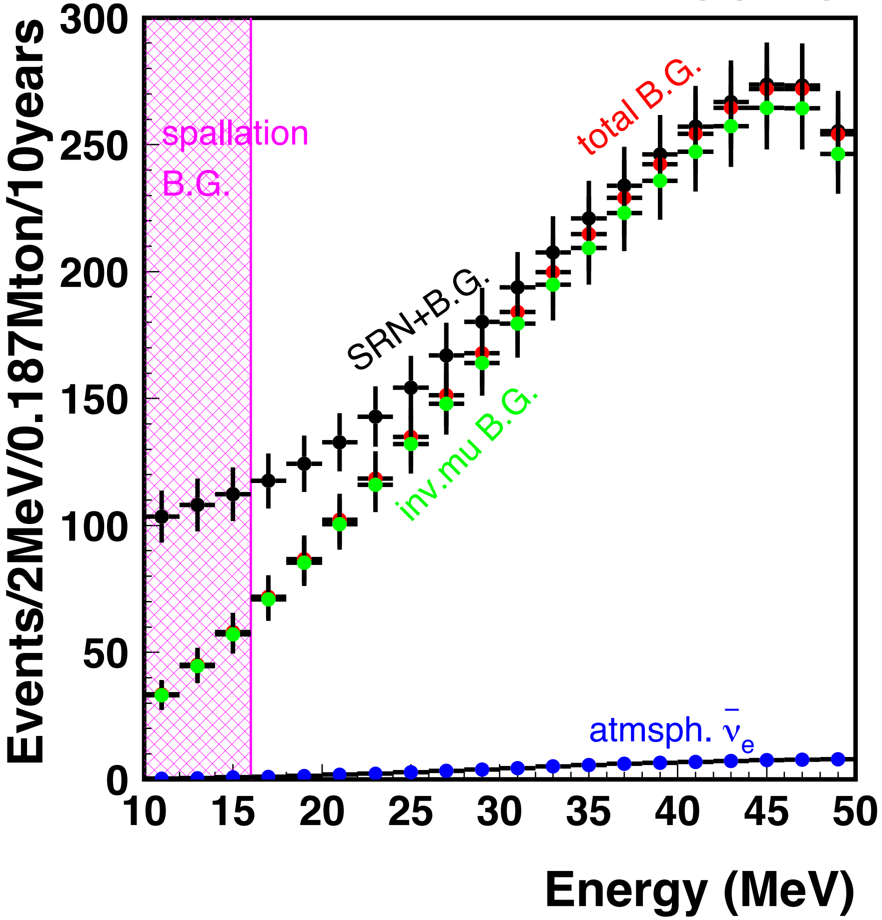
expected number of events



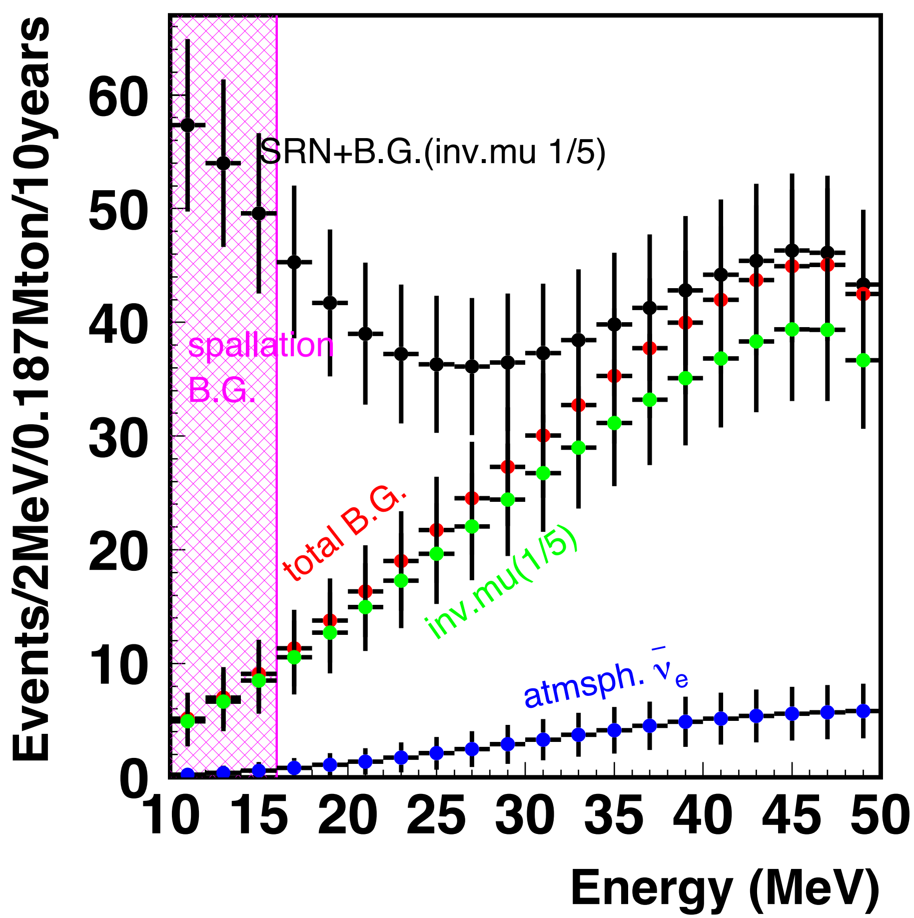
DSNB at Hyper-K

expected spectrum

without neutron tagging



with neutron tagging



Status of the project

- 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 in June 2019

Hyper-K meeting@Madrid, March 2018

Inaugural Symposium@Kashiwanoha, January 2015

NNSO Inaugural Ceremony@Kamioka, October 2017

Summary

Let's go supernova!

Thanks