CCSN neutrino detection with Super-Kamiokande and Hyper-Kamiokande

Yusuke Koshio
(Okayama university)

Workshop on core-collapse supernova neutrino detection
Institut de Physique Nucleair d’Orsay
4th July, 2018

30 years anniversary of SN1987A

(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

Birthday cake

Promoted by Prof. Y. Suwa

30 years anniversary of SN1987A

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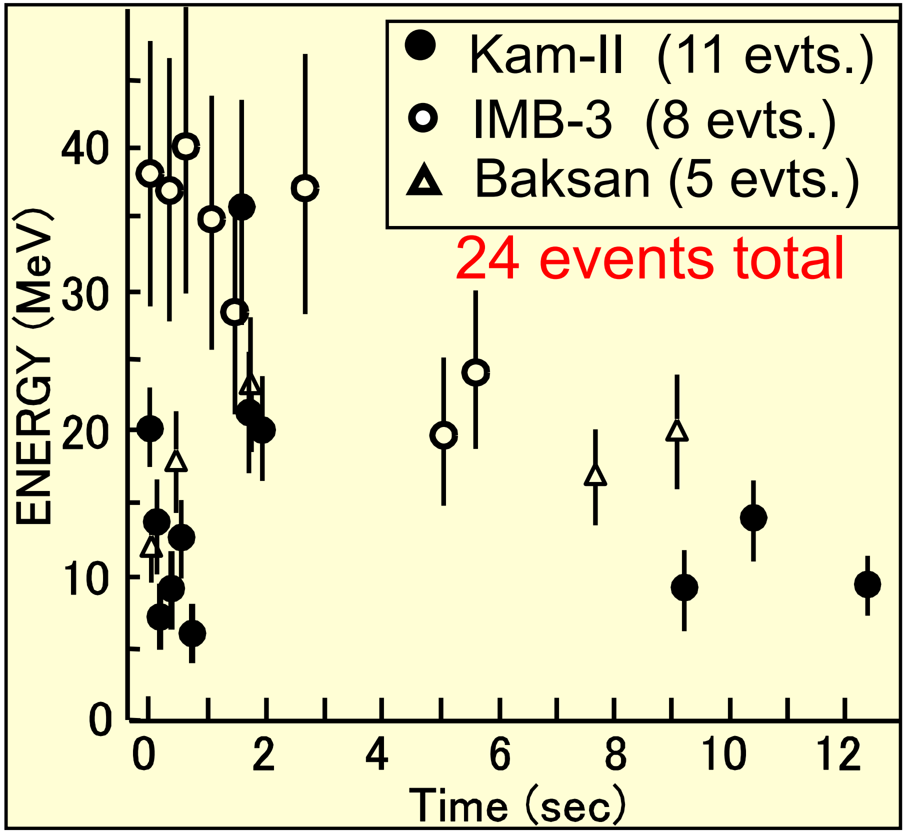
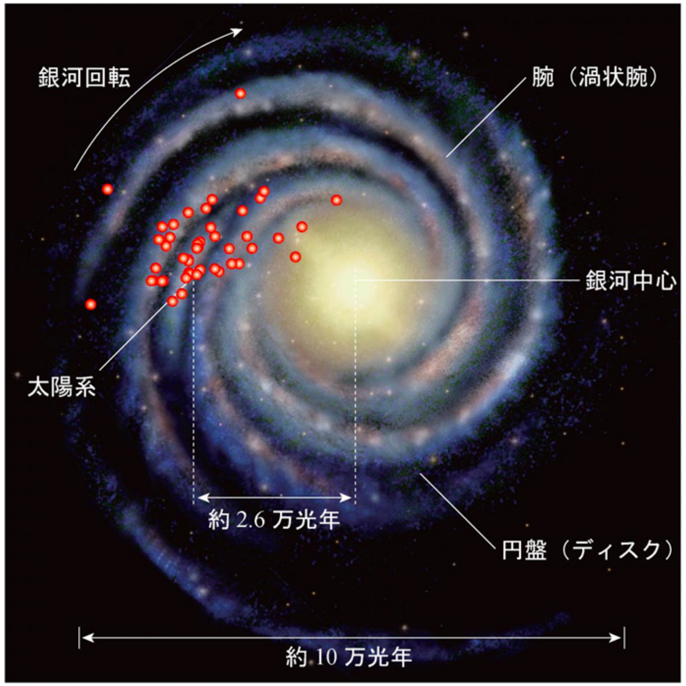


No Supernova neutrino detection since then..

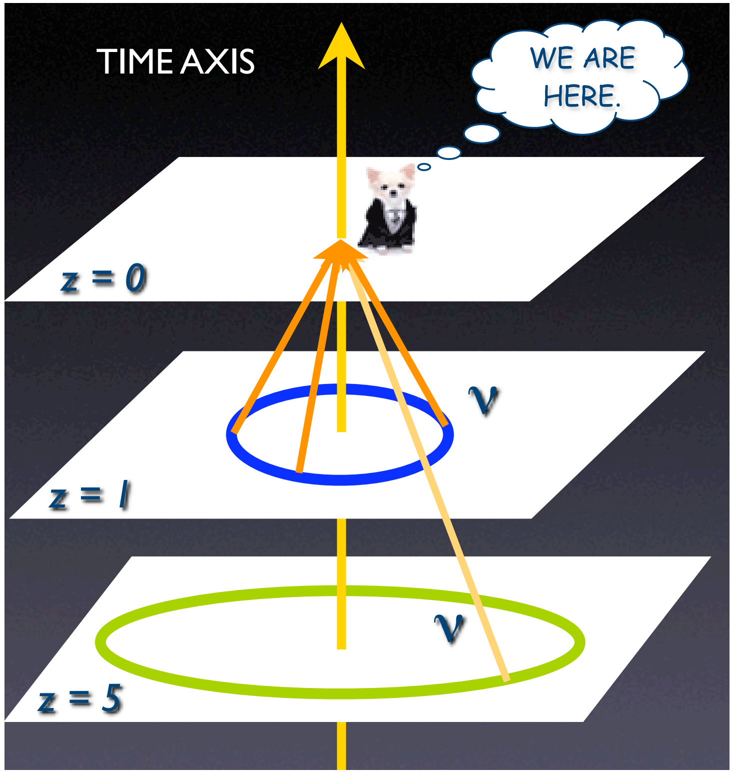
No chance for Supernova neutrino detection for next hundred's years?

We believe, yes!

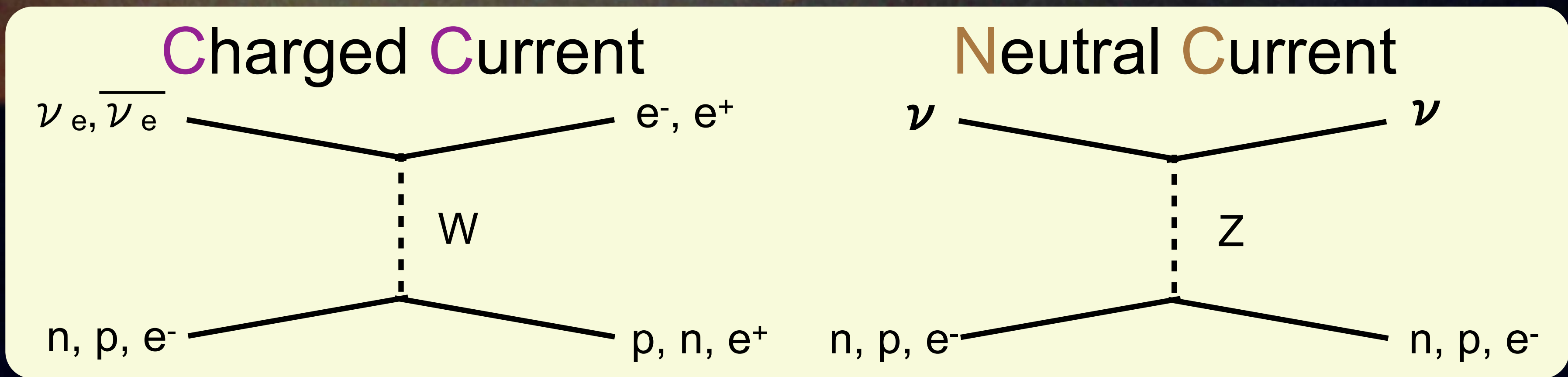
Galactic Supernova burst (a few per century)



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
- $E_e \sim E_\nu - (m_n - m_p)$, $E_\nu > 1.86$MeV

✓ Well known cross section

✓ Poor directionality

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

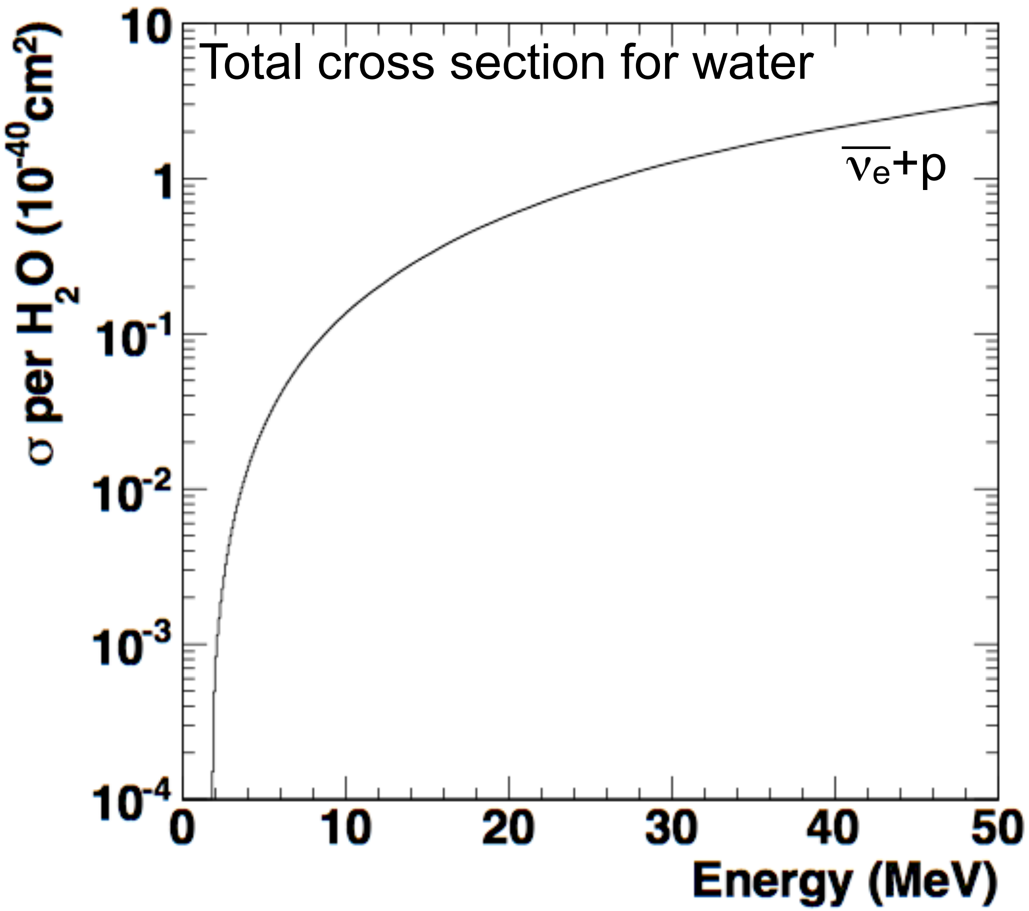
Neutrino interaction for SN ν

Inverse beta decay

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

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

- ✓ 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_ν > 1.
- ✓ Well known cross section
- ✓ Poor directionality
- ✓ Neutron tagging using de
  - n + p → d + γ, n + Gd → G



Neutrino interaction for SN ν

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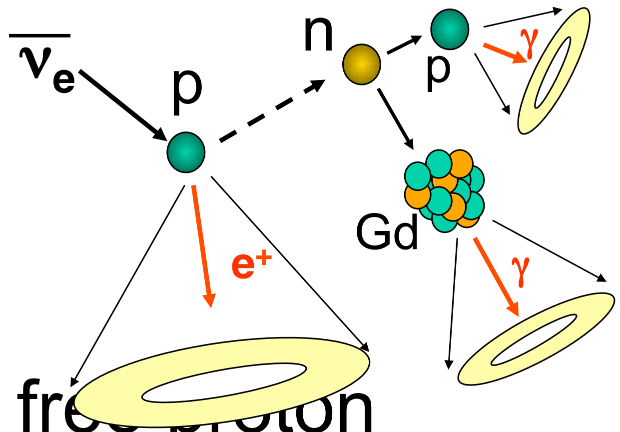

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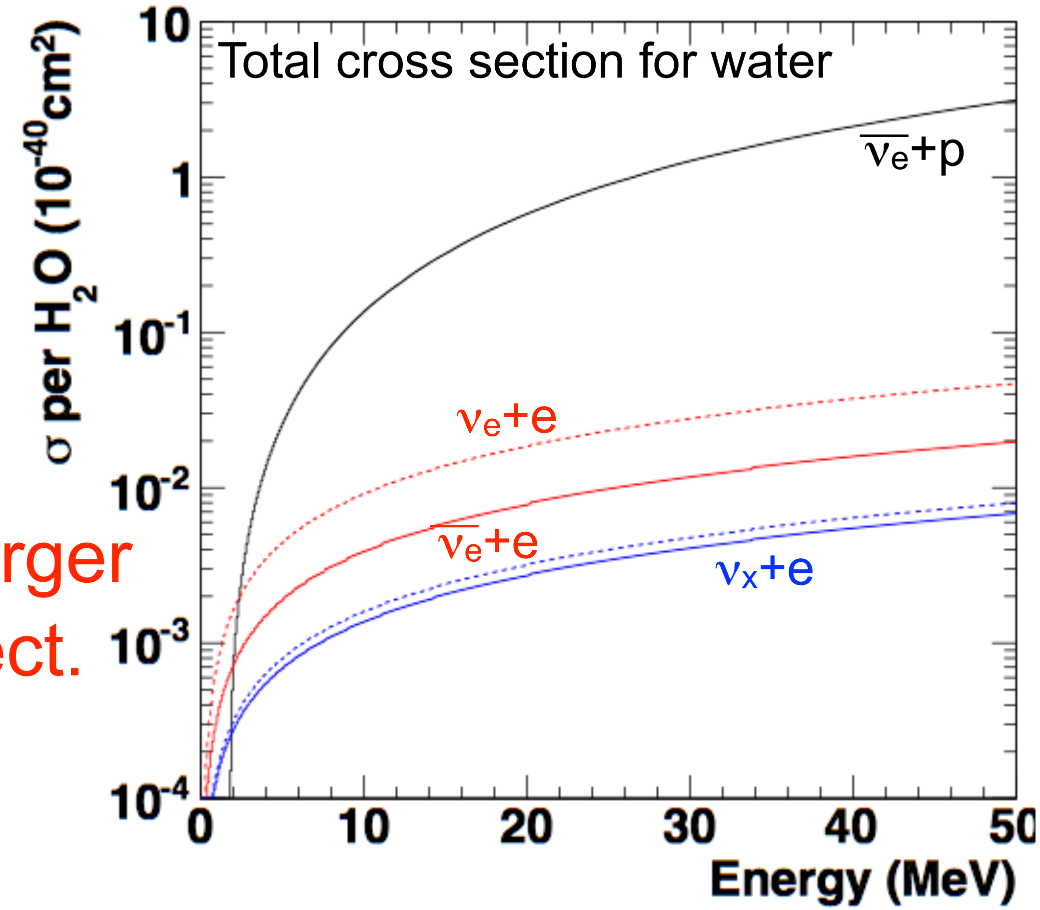
Possible to enhance this signal if Gd loaded

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

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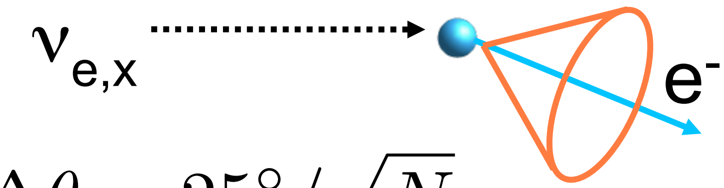
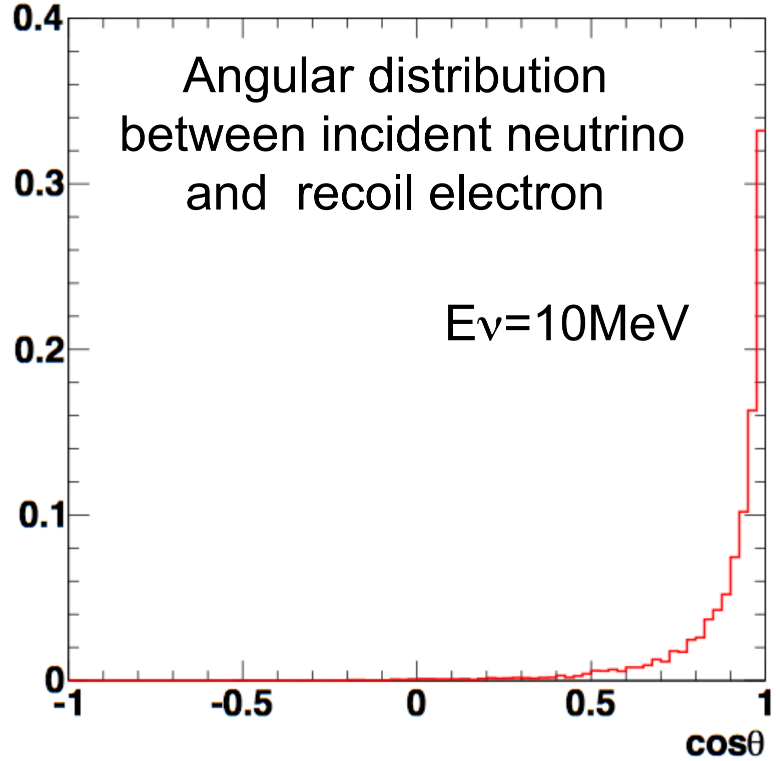
Water Cherenkov

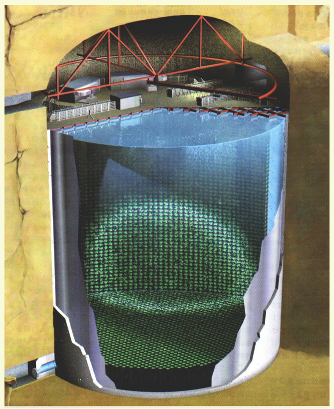


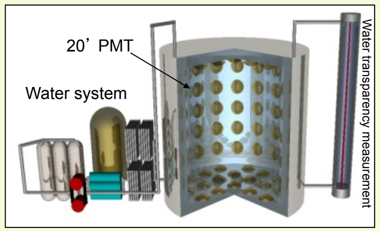
$$\Delta\theta \sim 25^\circ/\sqrt{N}$$

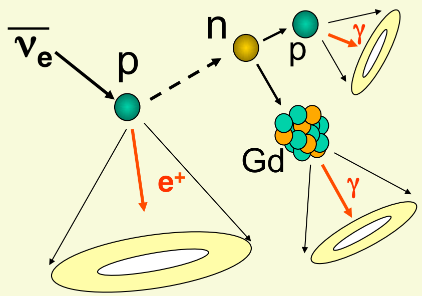


SN search at Super-Kamiokande

Super-K to SK-Gd



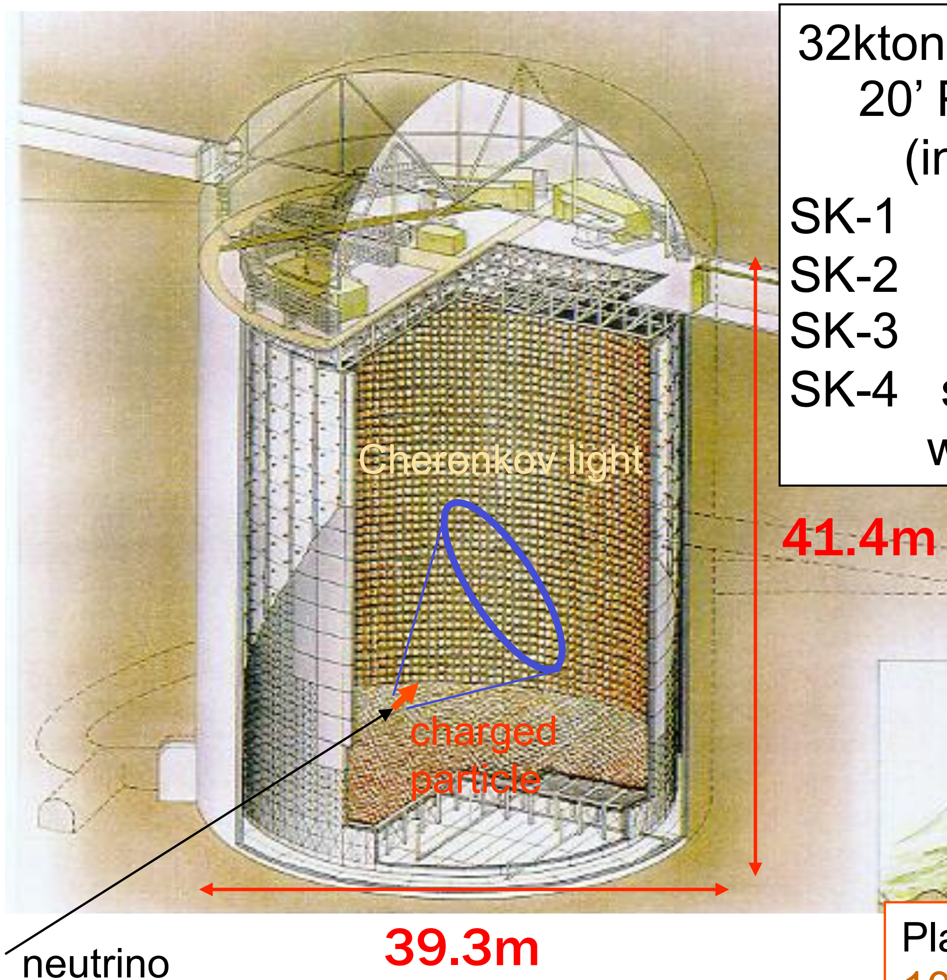




Kamioka underground detectors

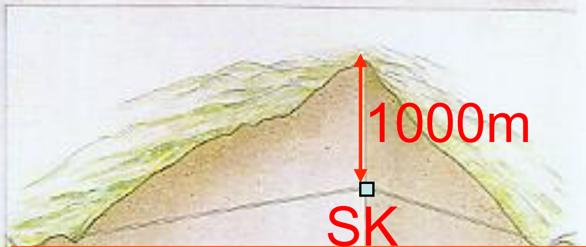
Super-Kamiokande

50kton Water Cherenkov detector

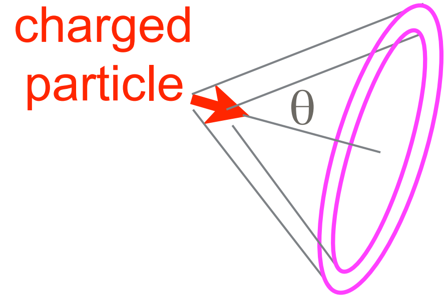


32kton fiducial volume for SN

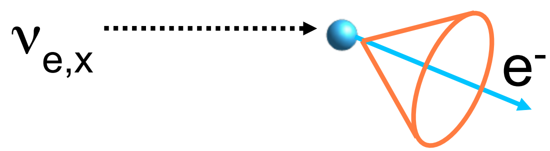
	20' PMT (inner)	photocathode coverage
SK-1	11,146	40%
SK-2	5,182	19%
SK-3	11,129	40%
SK-4	same as SK-3 with new electronics	



Placed inside the Kamioka mine
1000m underground

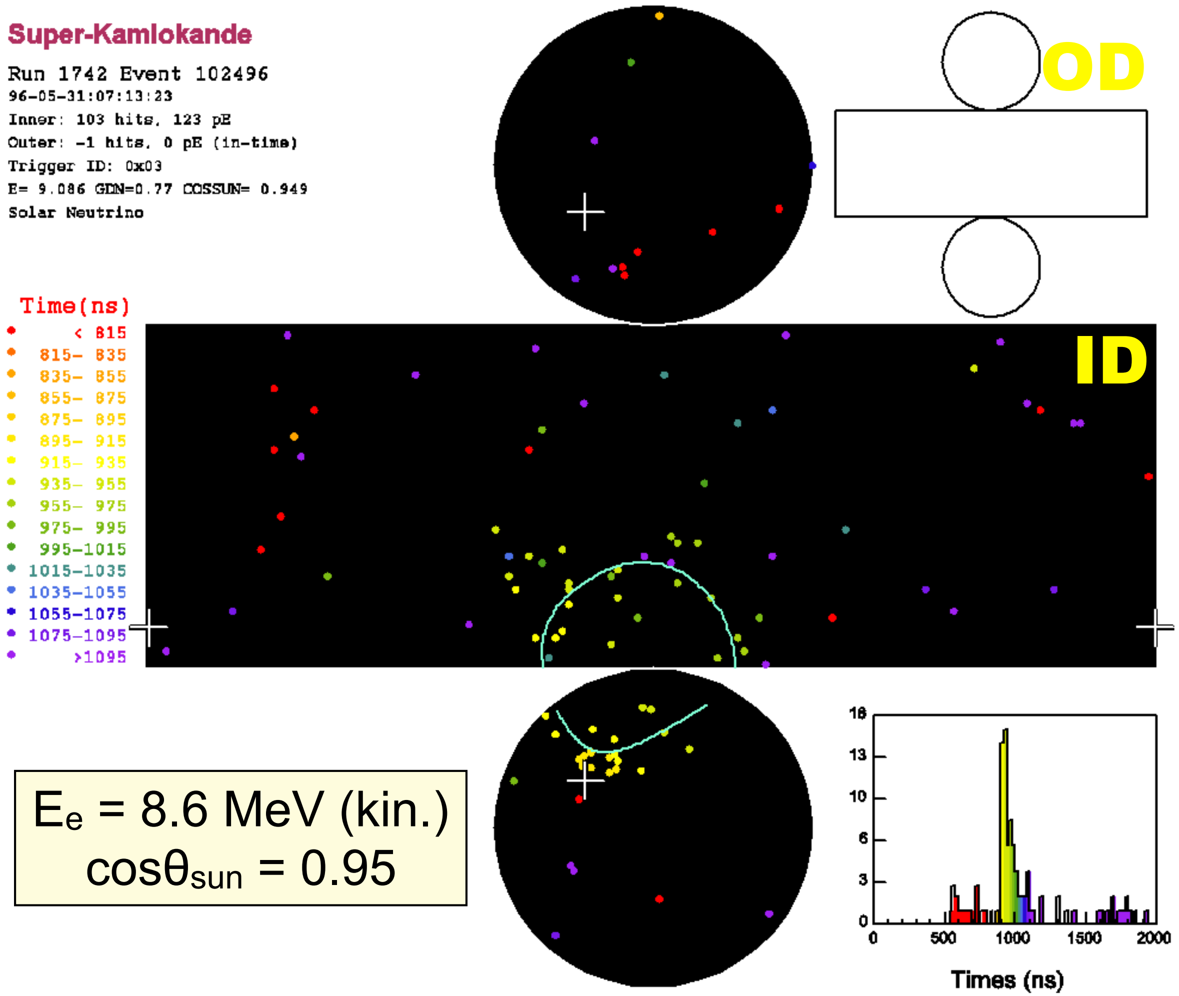


- ✓ Underground in Kamioka mine, (almost BG free)
- ✓ 3.5MeV energy threshold for recoil electron
- ✓ Dominant process is inverse beta decay
- ✓ Good directionality for νe elastic scattering



Super-Kamiokande

For supernova neutrinos (~MeV)



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

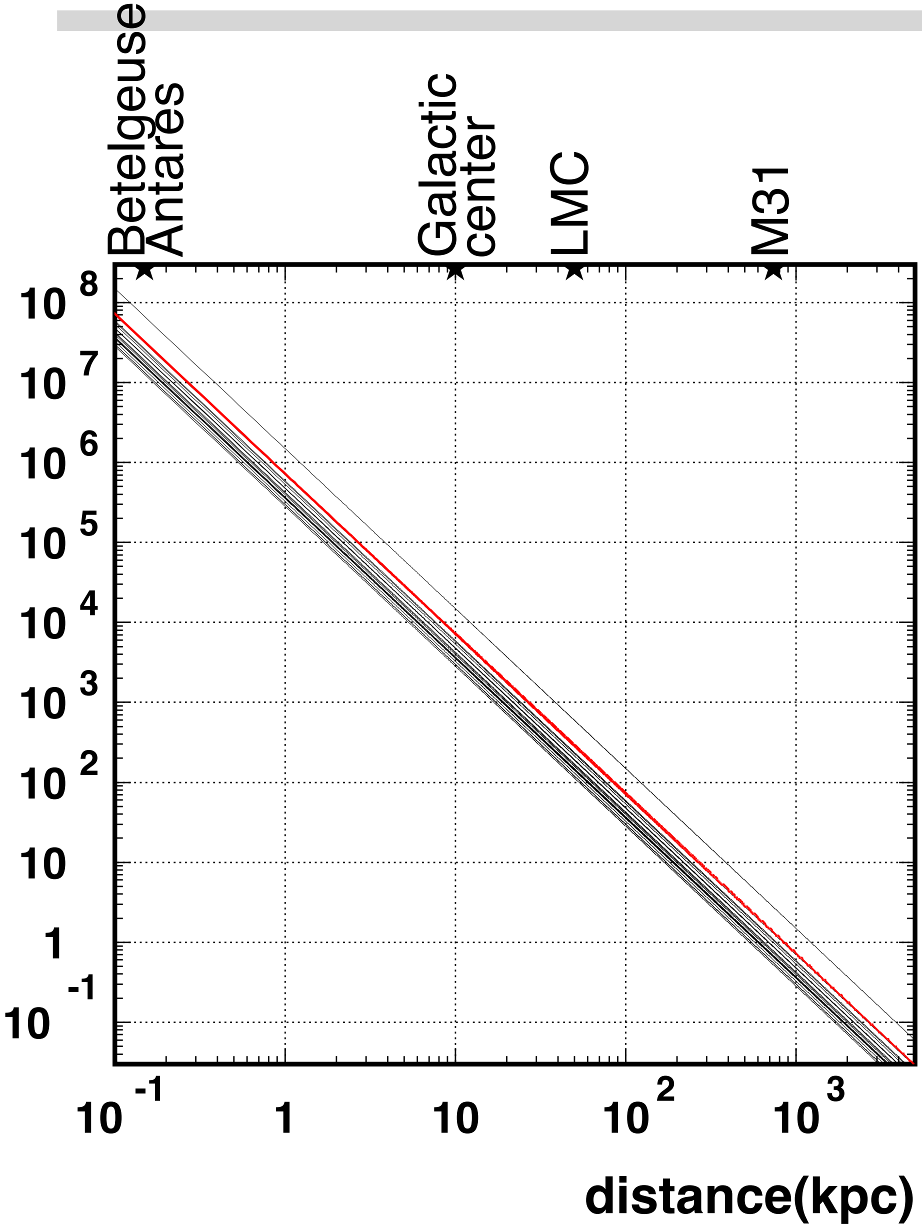
How to reconstruct?

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

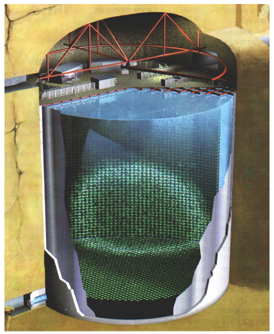


Nakazato et.al. ApJ.Suppl. 205 (2013) 2

http://asphwww.ph.noda.tus.ac.jp/snn/index.html

M_{init}	Z	Supernova models			BH models
		t_{revive}= 100ms	t_{revive}= 200ms	t_{revive}= 300ms	
13M_{solar}	0.02	258kB	257kB	256kB	---
20M_{solar}		258kB	257kB	257kB	
30M_{solar}		257kB	257kB	255kB	
50M_{solar}		257kB	256kB	256kB	
13M_{solar}	0.004	258kB	257kB	257kB	
20M_{solar}		258kB	257kB	256kB	
30M_{solar}		---			4.97MB (Shen)
					2.69MB (LS220)
50M_{solar}		259kB	258kB	257kB	---

at 10kpc, 4.5MeV energy threshold



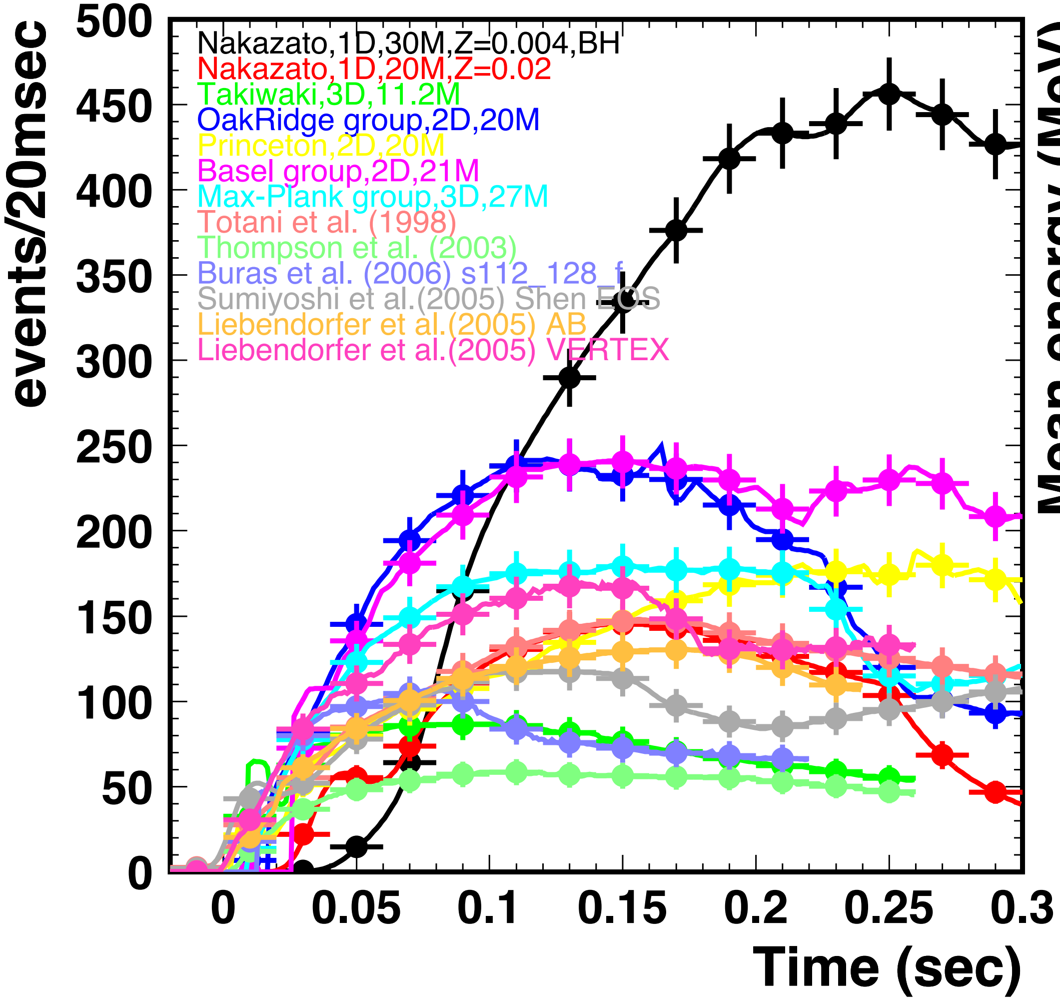
2.8k~15k ev

(inverse beta decay
7.3k events for
Livermore model)

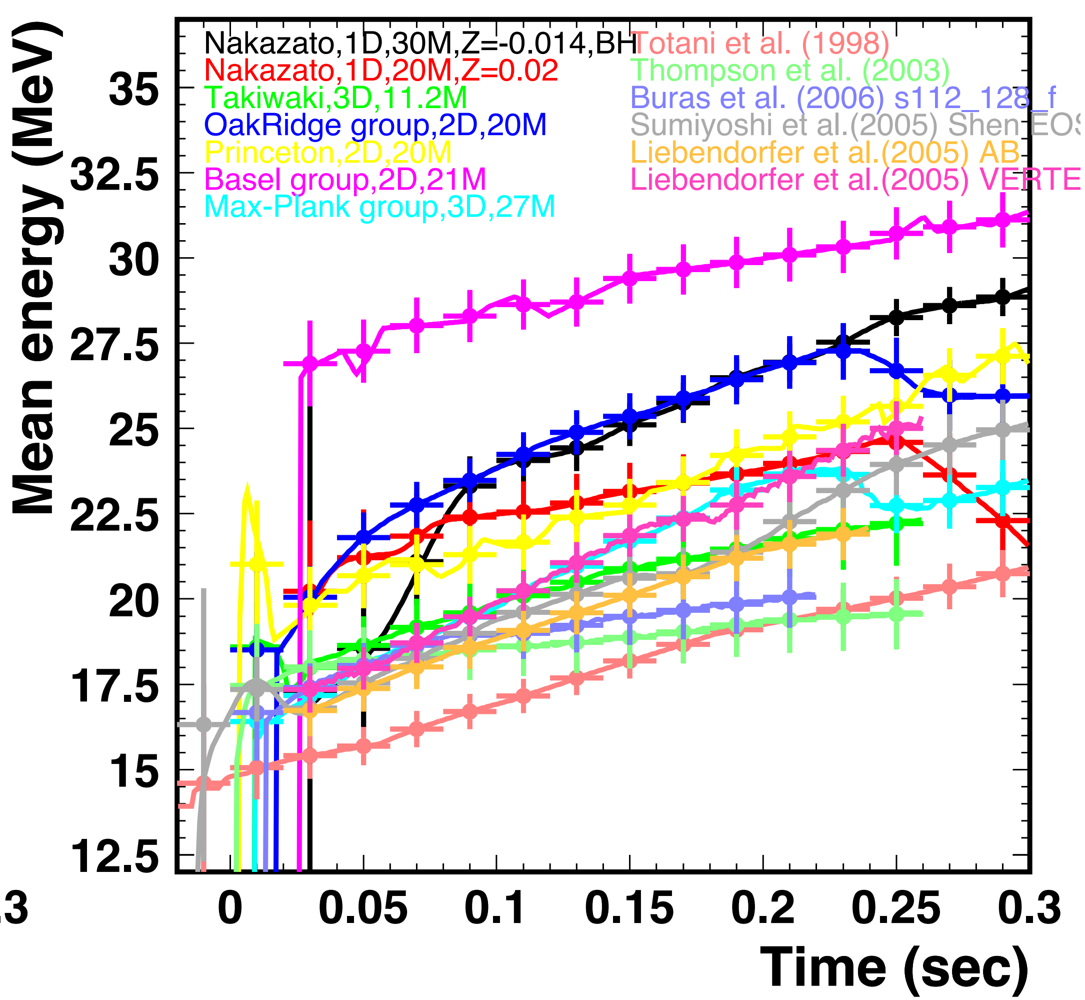
Super-Kamiokande

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

event rate



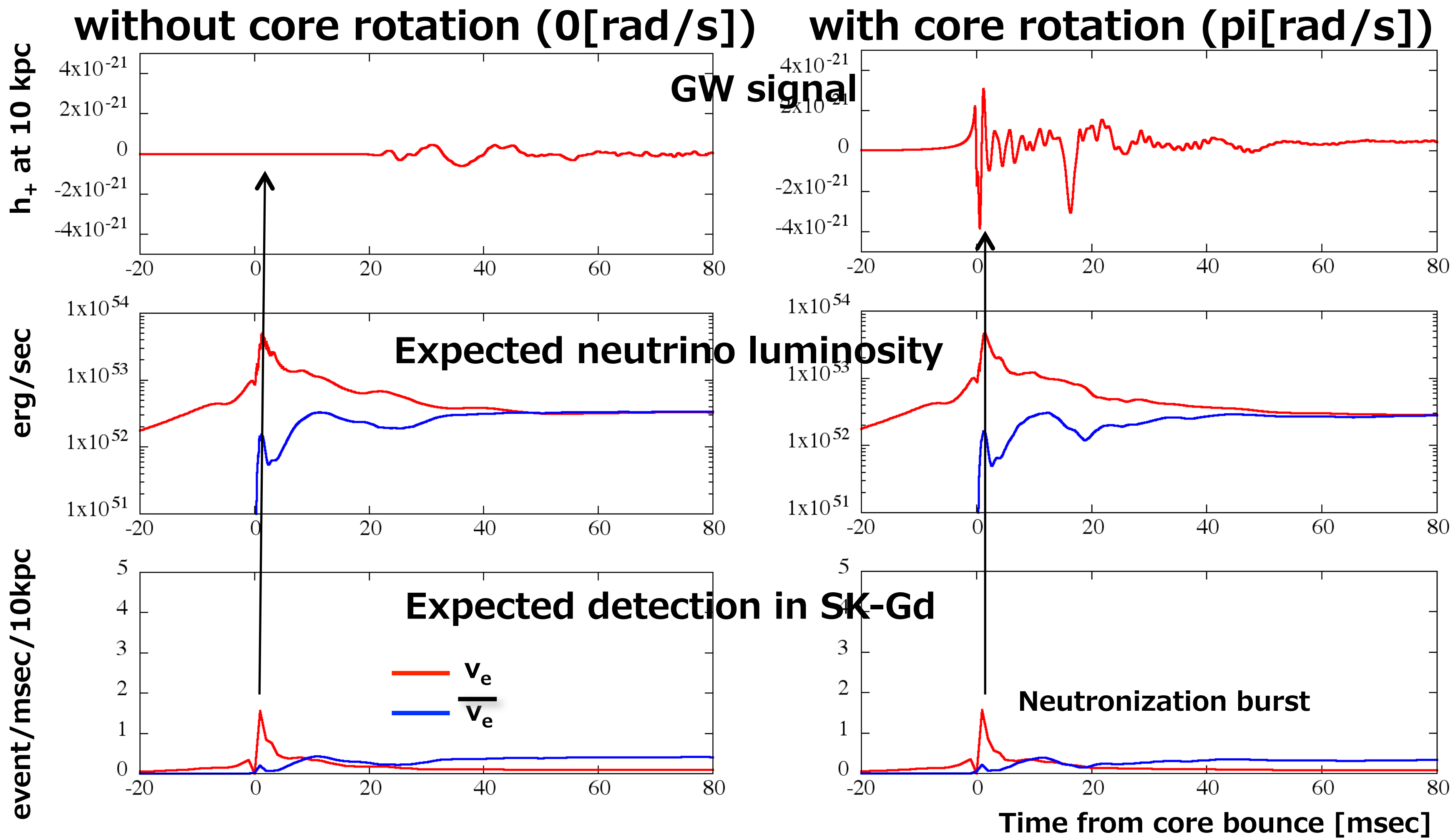
mean energy



Super-Kamiokande

Neutrino and Gravitational Wave

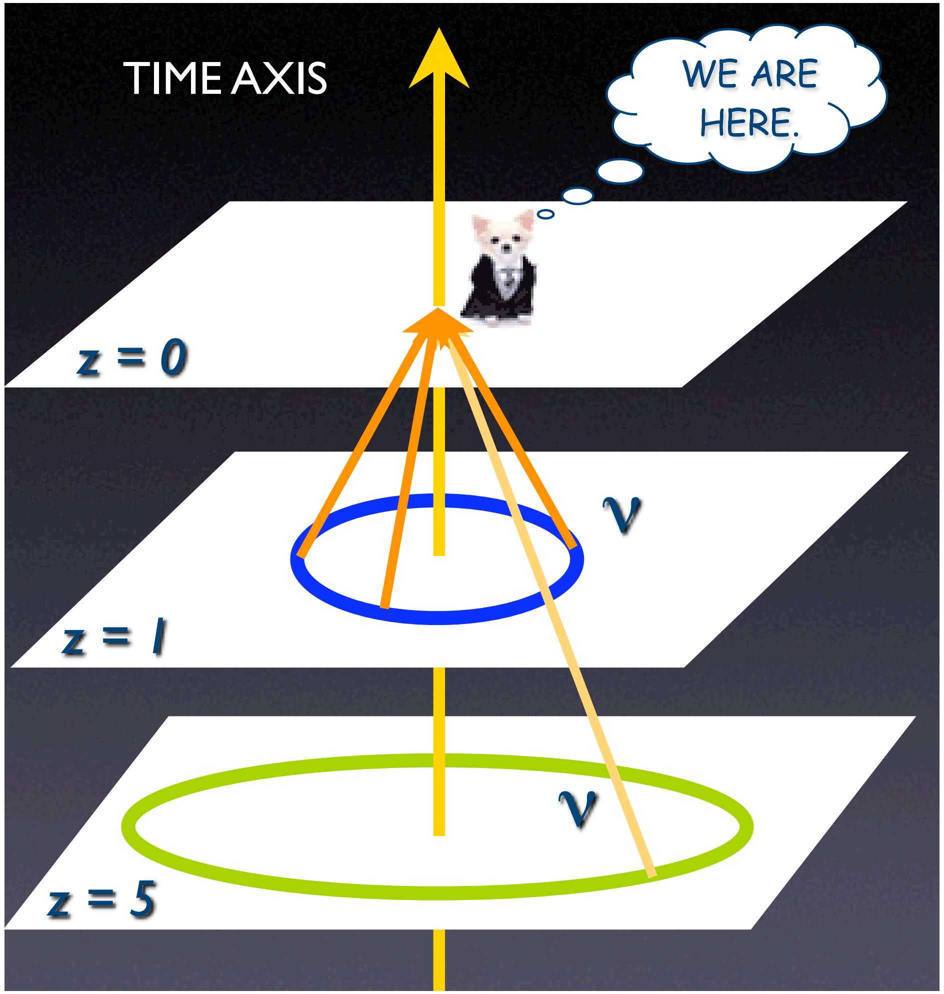
ApJ 811, 86 (2015)

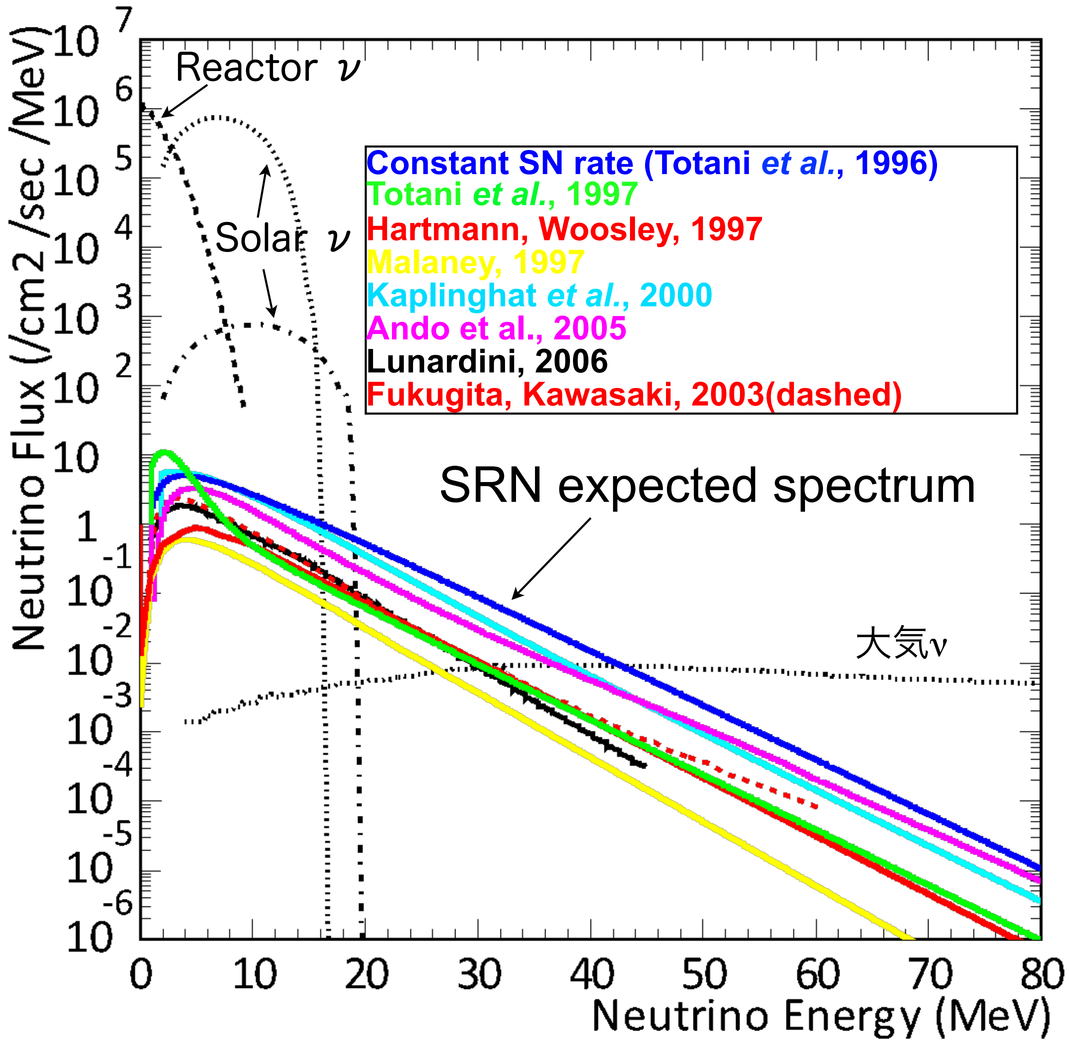


Diffuse Supernova Neutrino Background (DSNB)

Neutrinos emitted from past supernovae

S.Ando

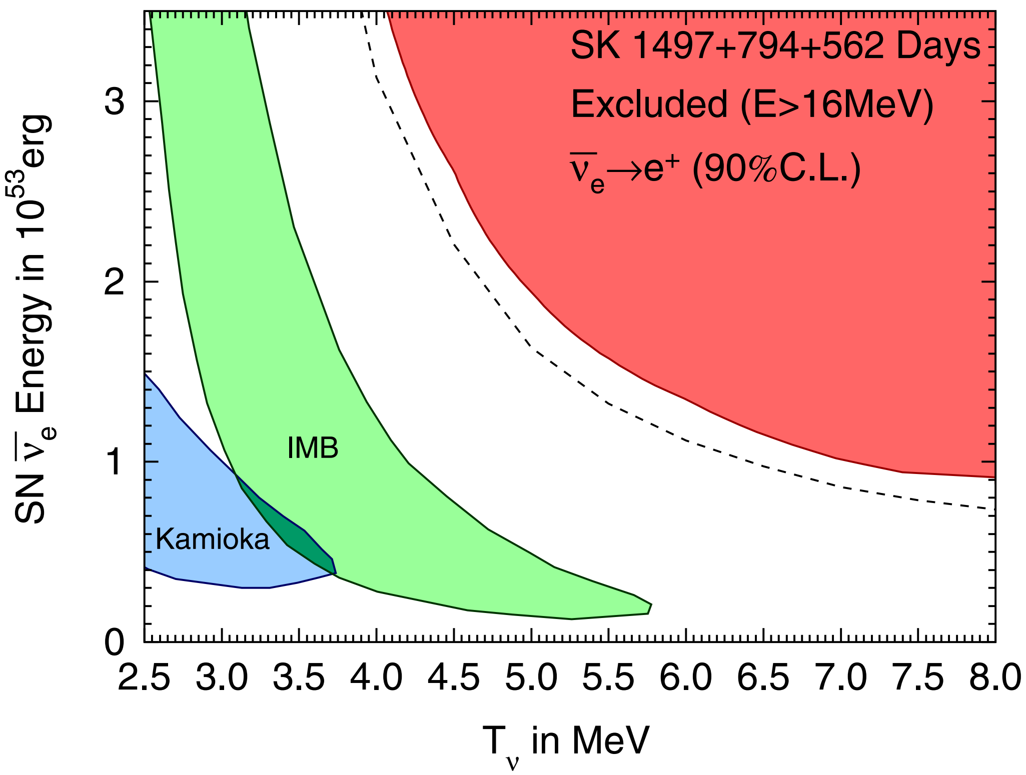


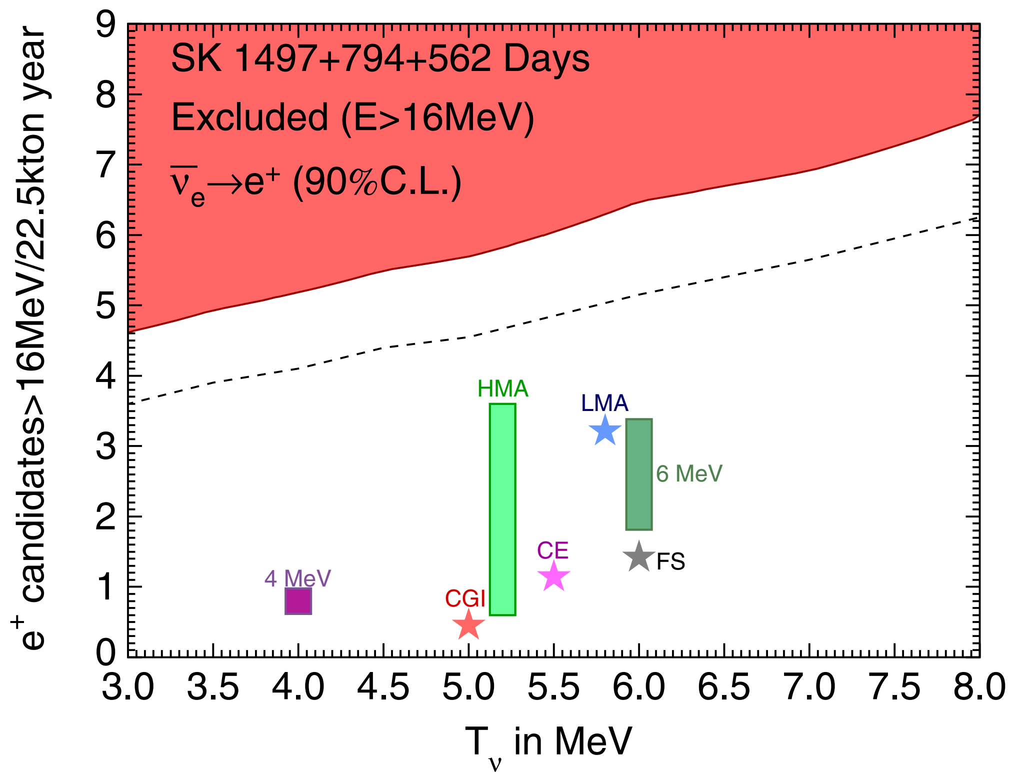


DSNB in Super-K

Upper limit from Super-K

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

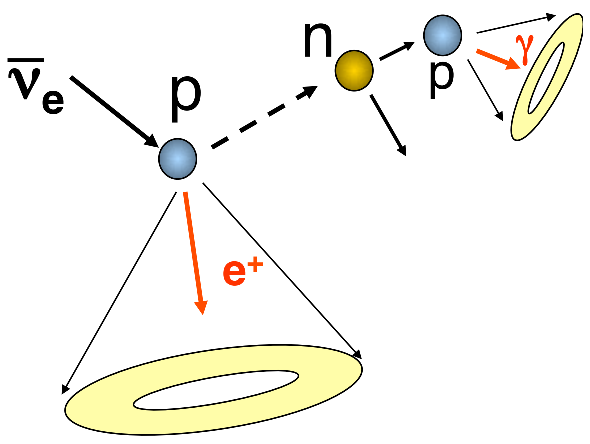




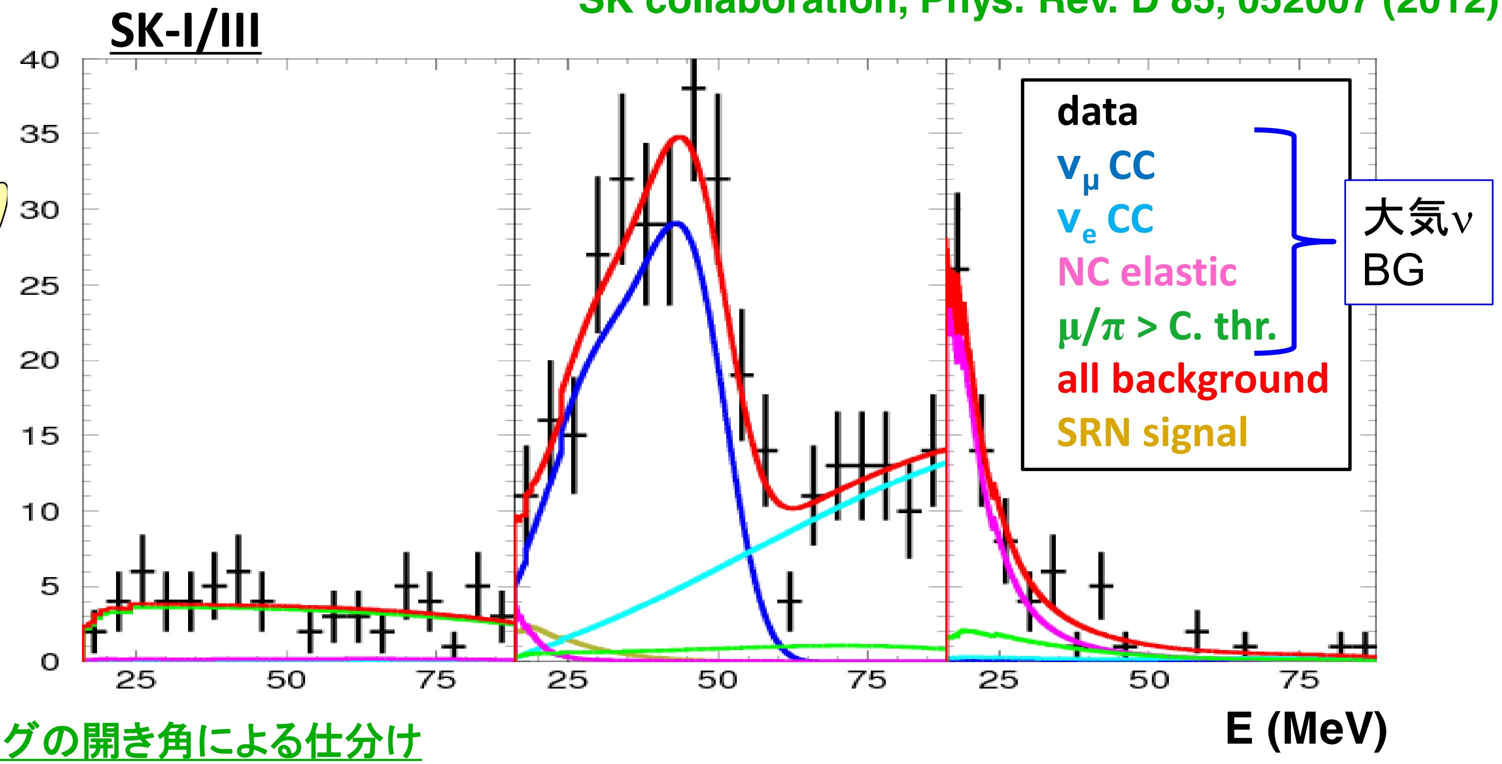
DSNB in Super-K

Current Super-K w/o neutron tagging

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

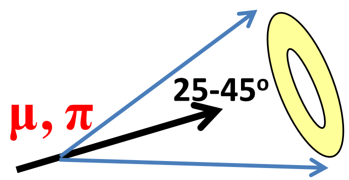


Only this signal

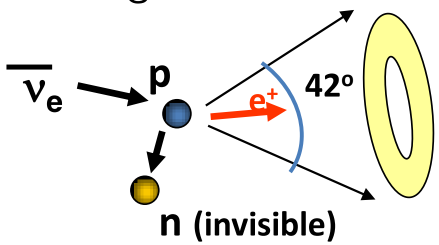


リングの開き角による仕分け

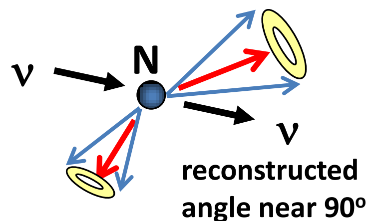
Low angle events



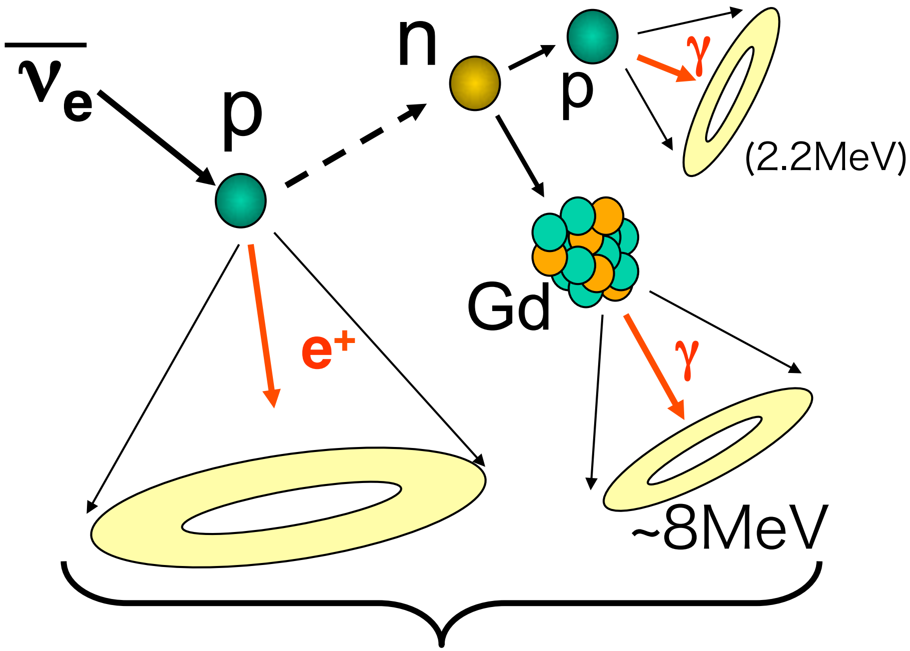
Signal Events



Isotropic Events



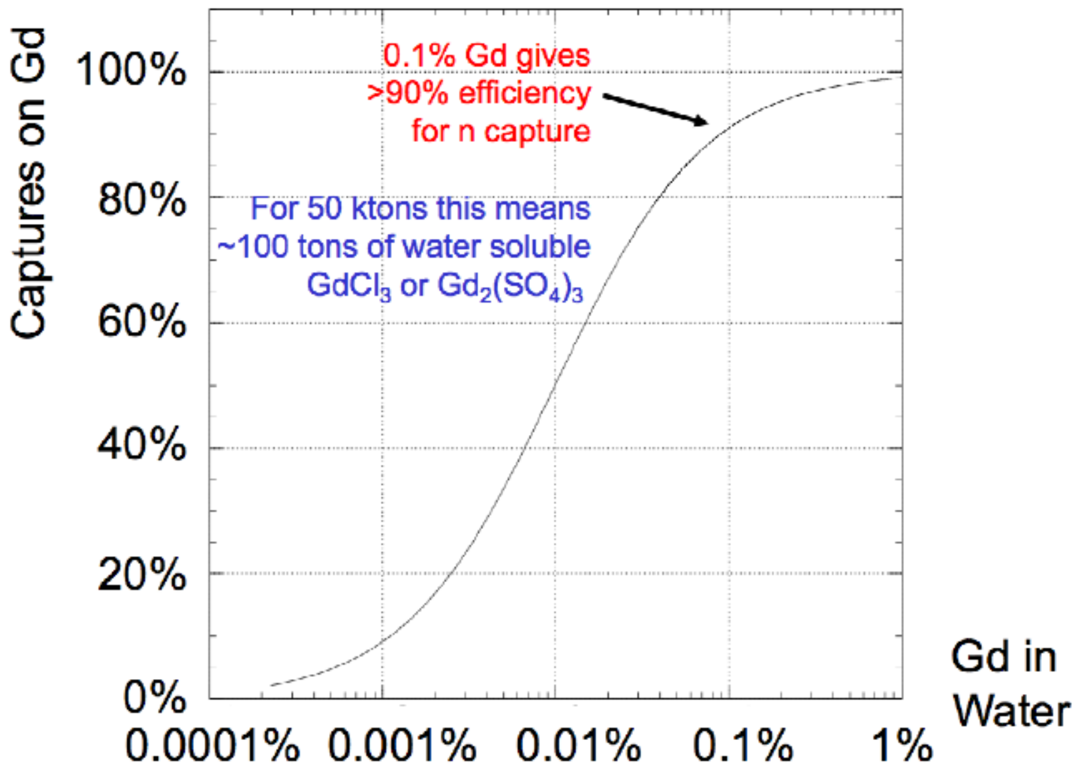
DSNB in upgraded Super-K



- 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



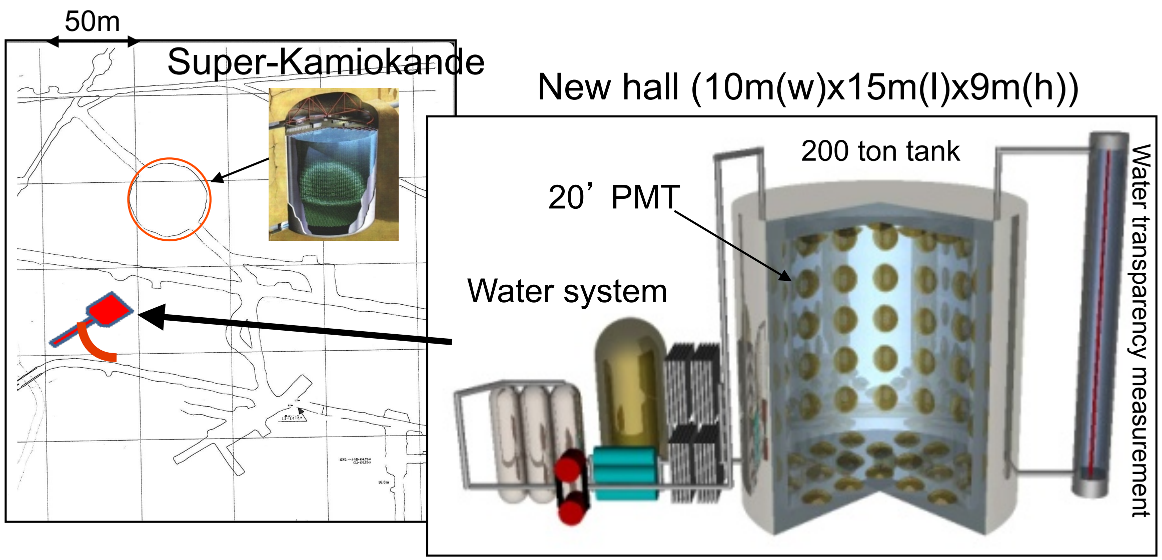
Proposed in 2004,
but not so easy..

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



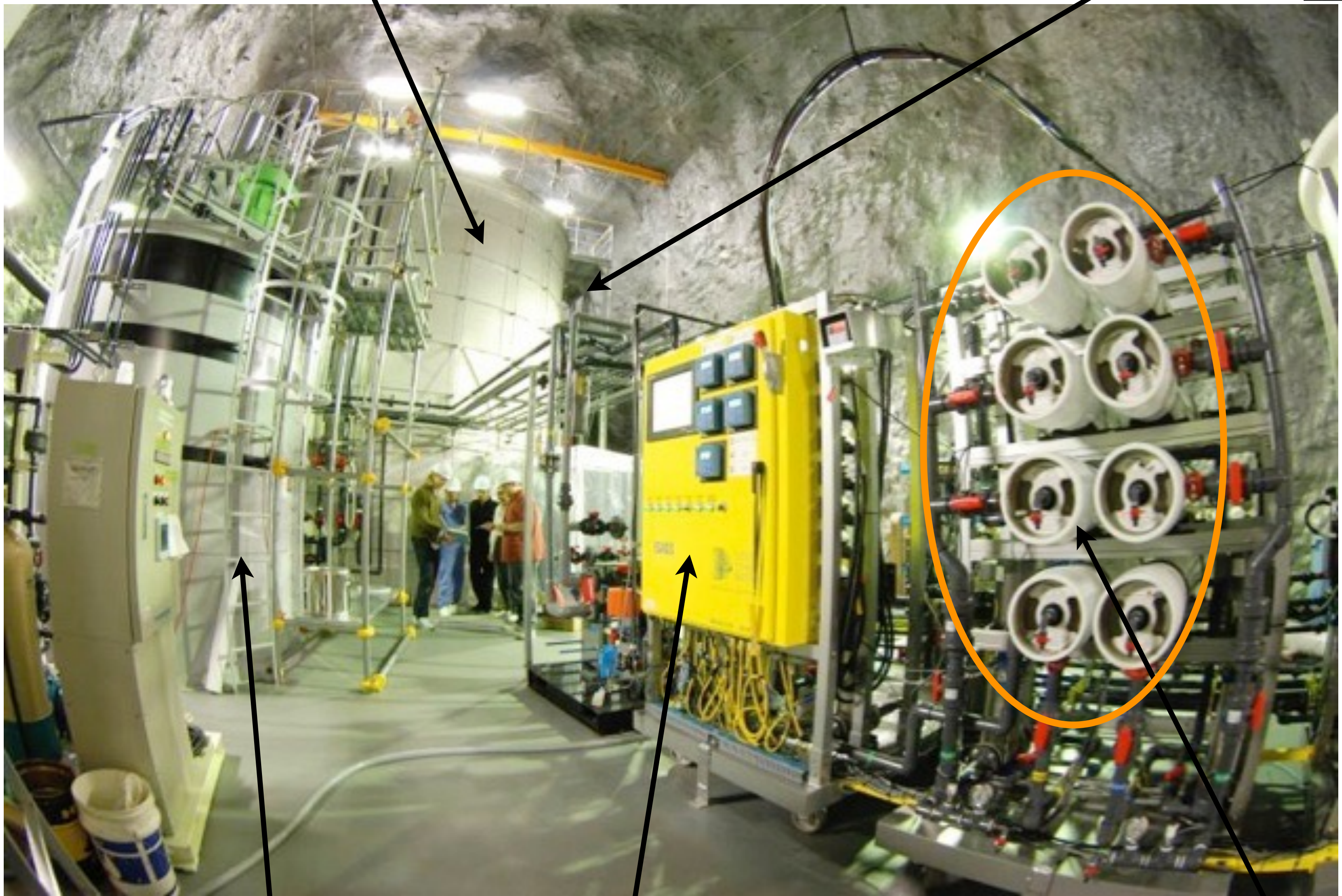
Now working well

EGADS as R&D

UDEAL

water transparency measurement

200 ton tank

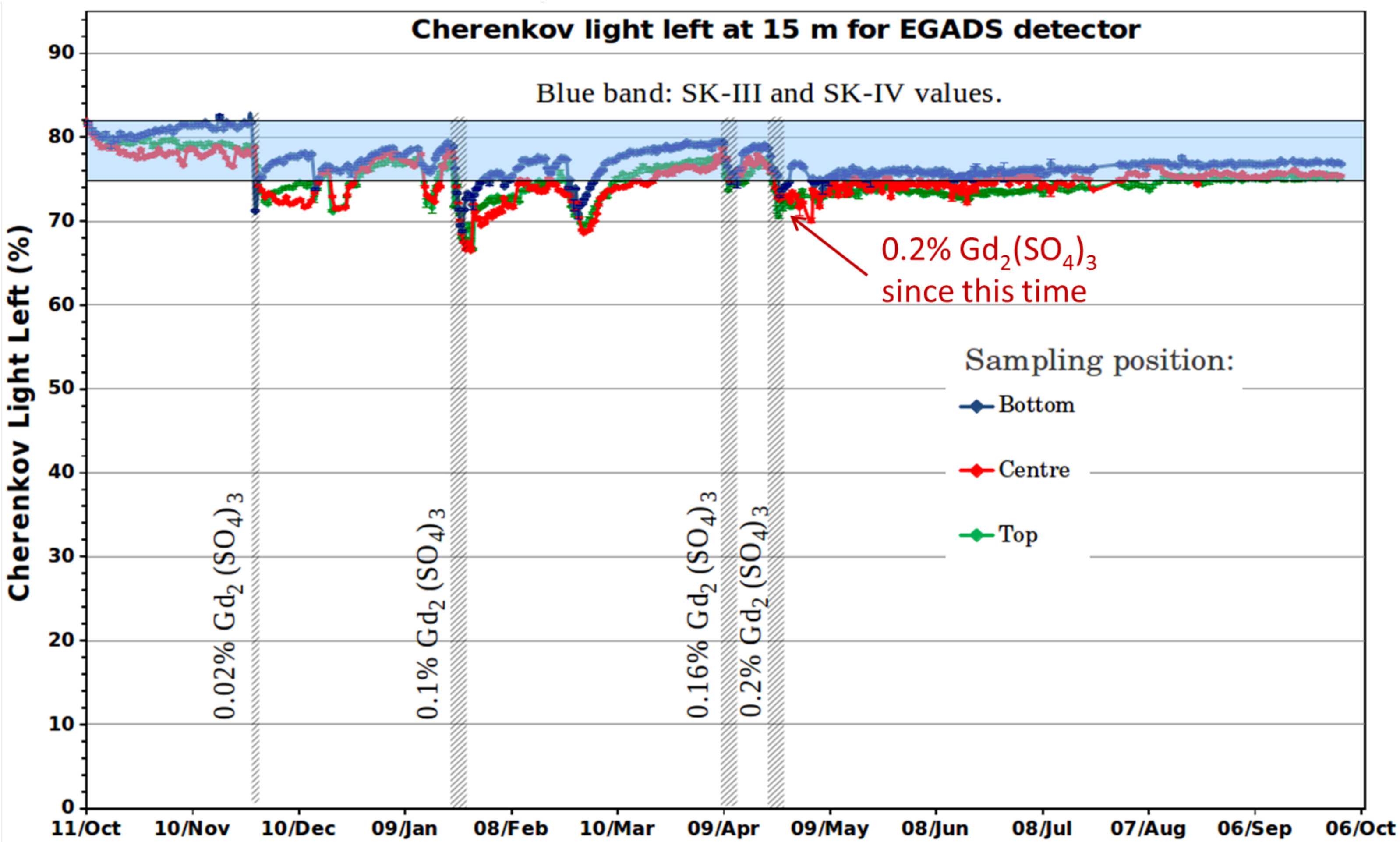


15 ton buffer tank

Control panel of circulation system

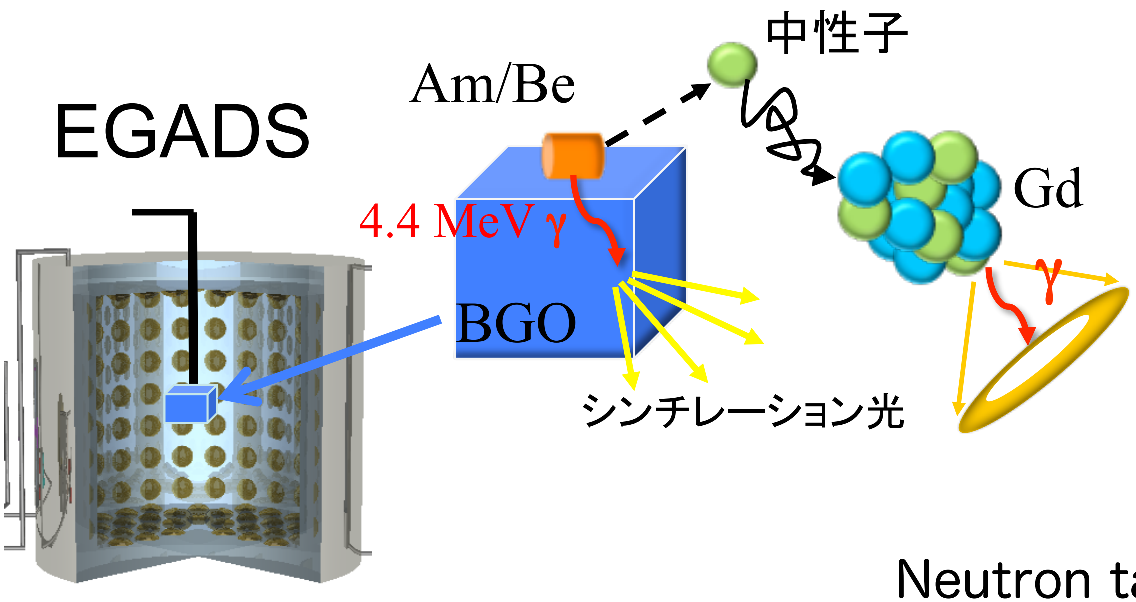
Filter

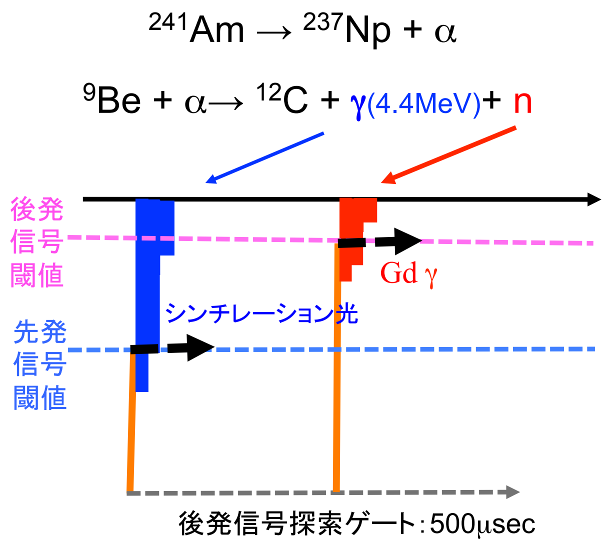
EGADS as R&D



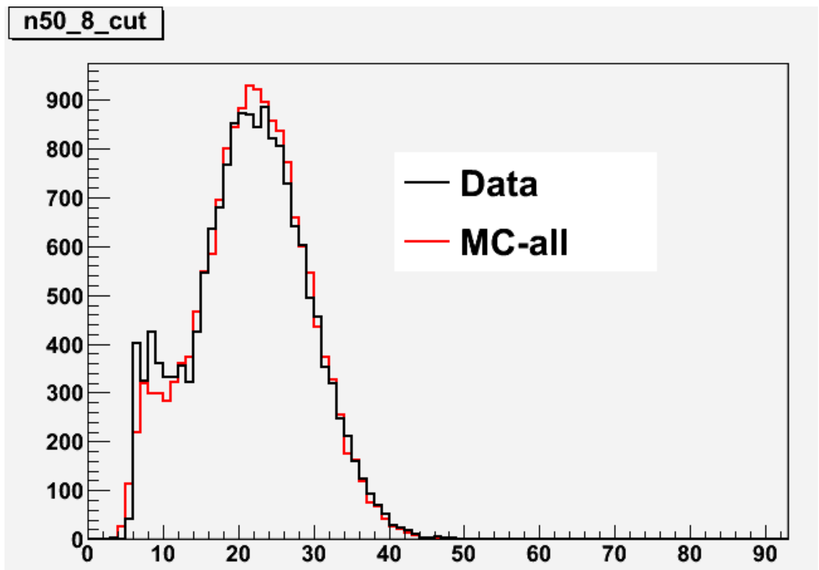
Very stable and continuous data taking

Neutron tagging efficiency





Neutron tagging with delayed coincidence



Neutron capture time

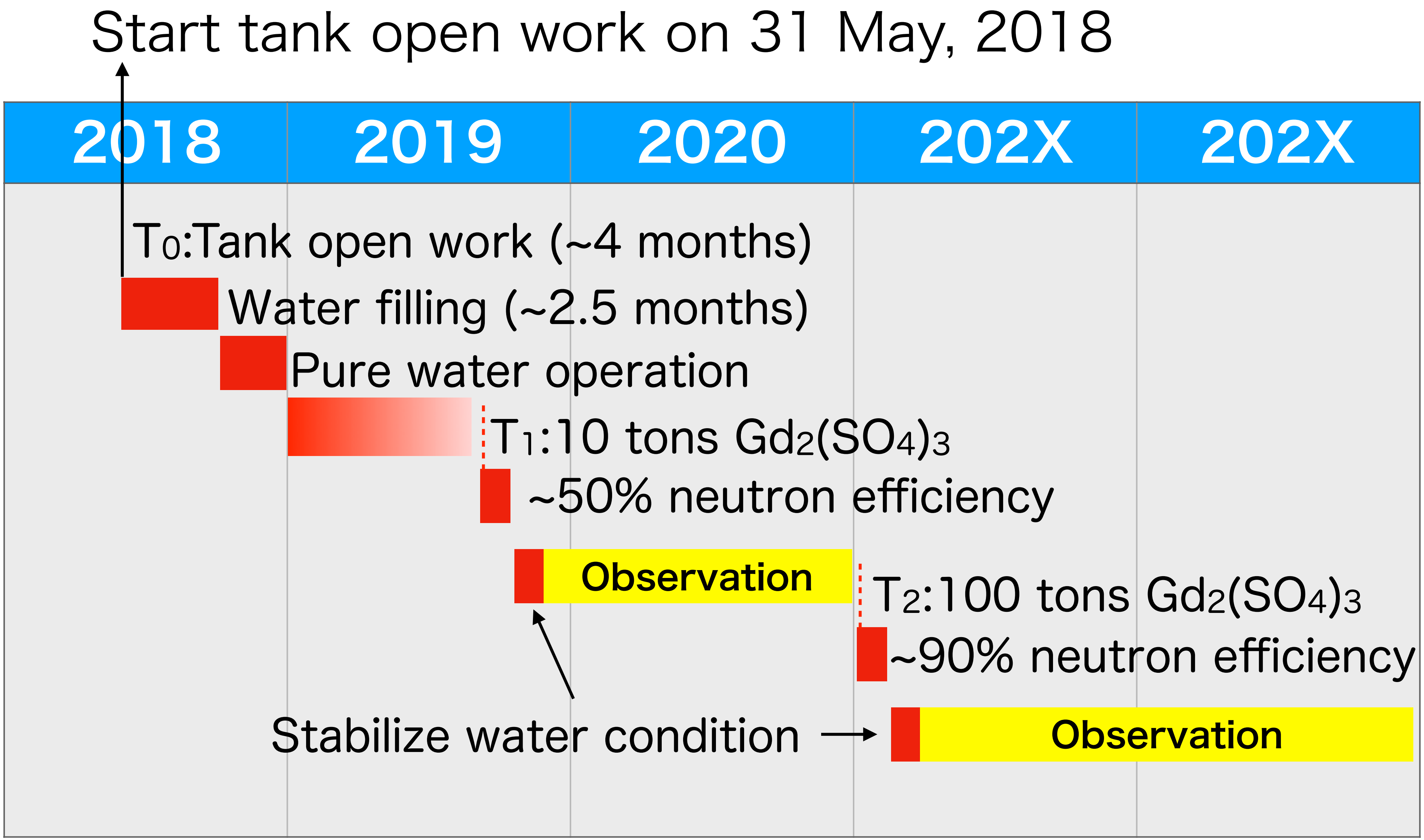
	2178±44ppm	1055±21ppm	225±5ppm
Data	29.89±0.33	51.48±0.52	130.1±1.7
MC	30.03±0.77	53.45±1.19	126.2±2.0

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”

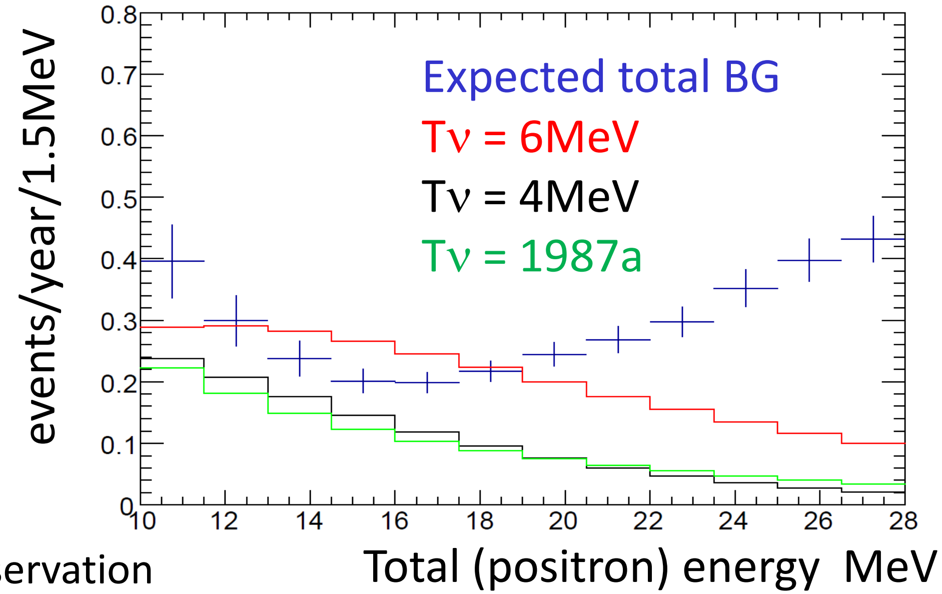
Time line toward SK-Gd



Physics expectation in SK-Gd

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

- It depends on typical/actual SN emission spectrum

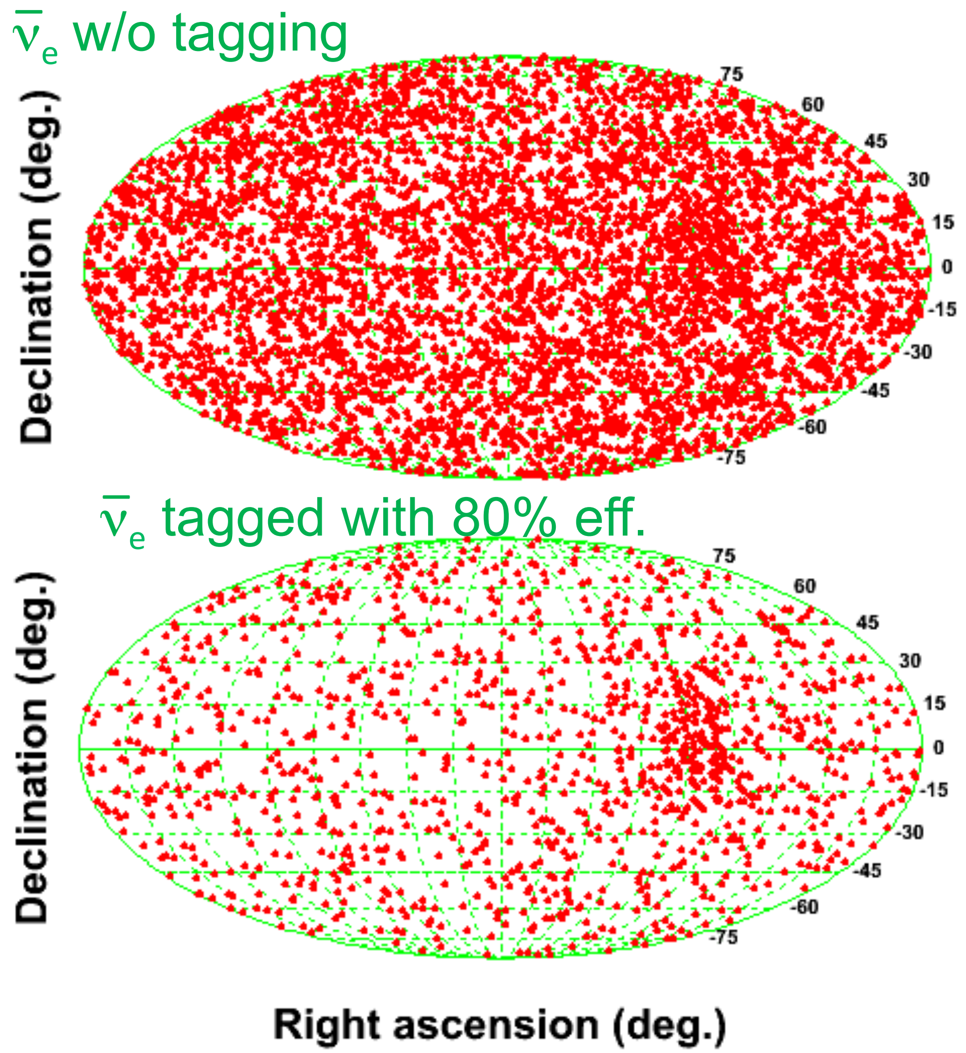


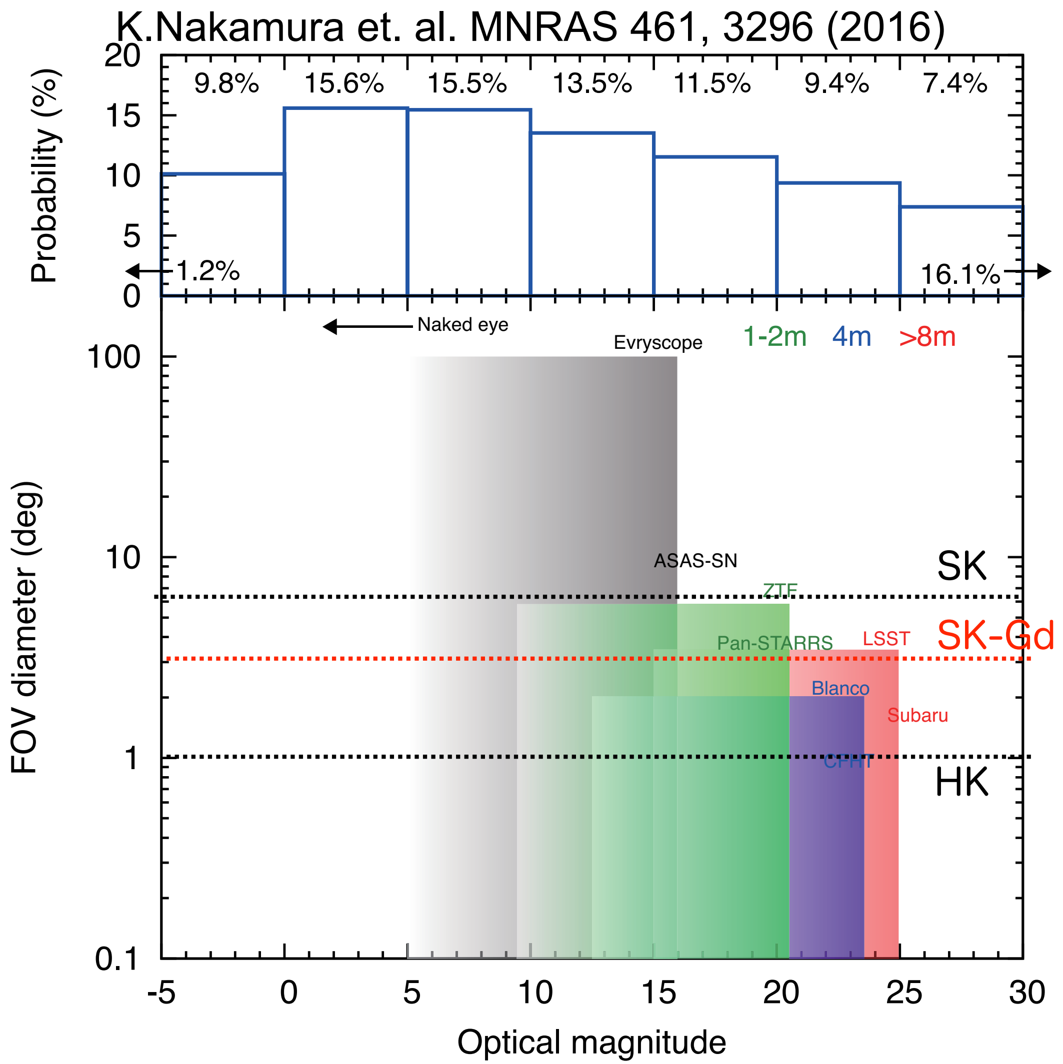
DSNB events number with 10 years observation

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	----

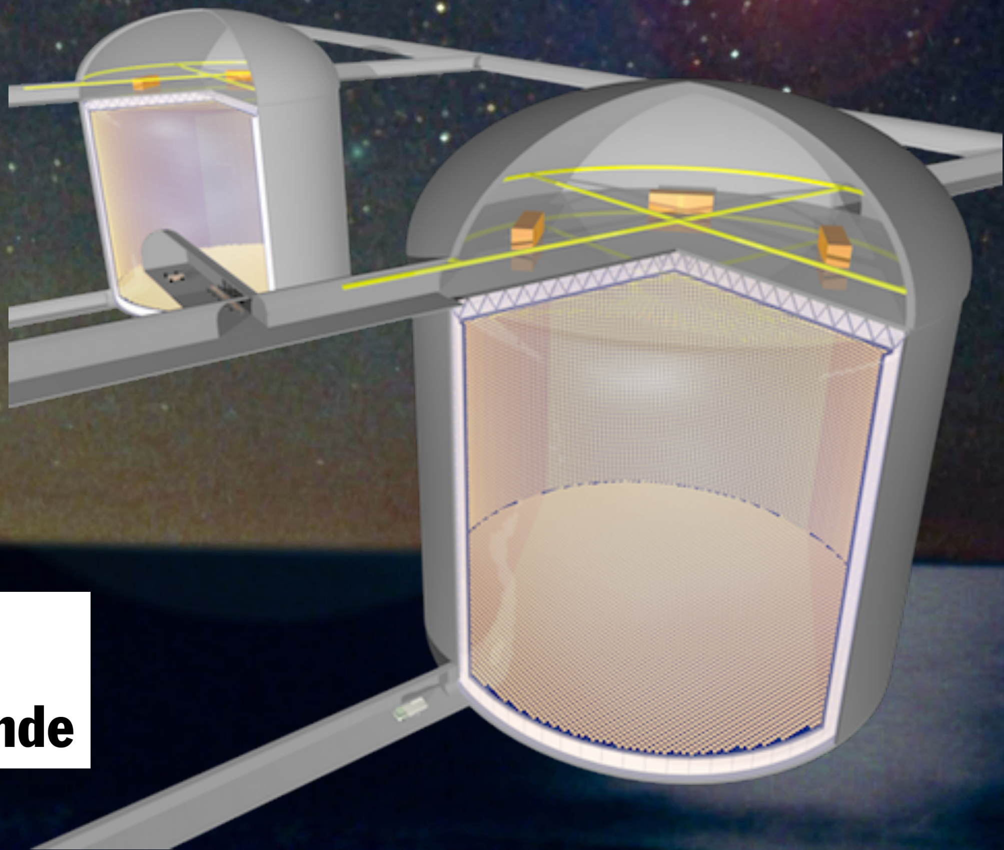
Physics expectation in SK-Gd

For Supernova burst neutrinos





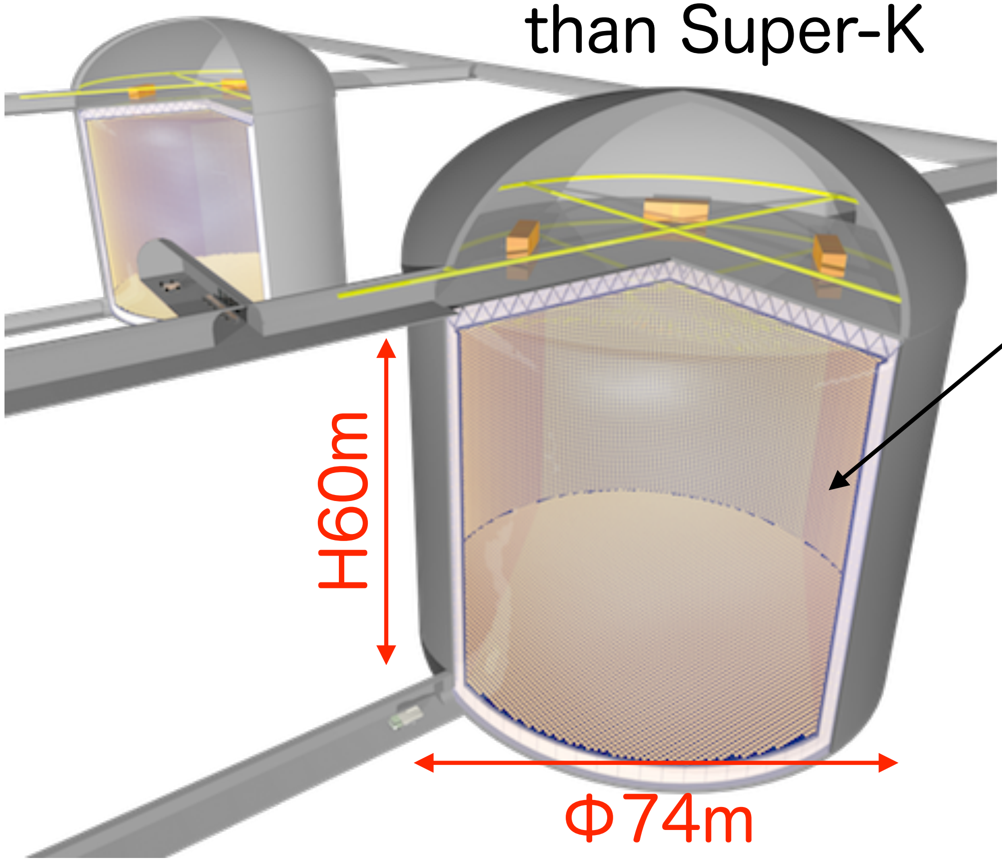
SN search at Hyper-Kamiokande



Hyper-Kamiokande

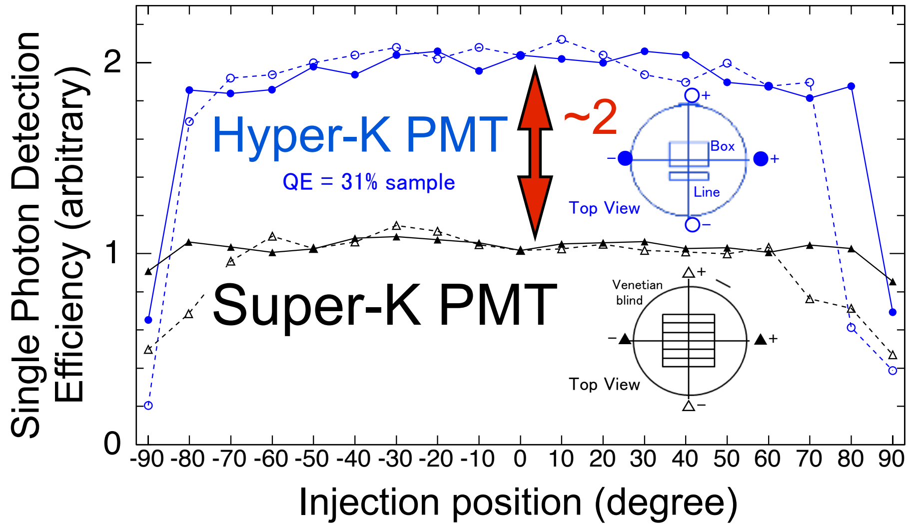
2 tanks x

with staging ~10 times larger volume than Super-K

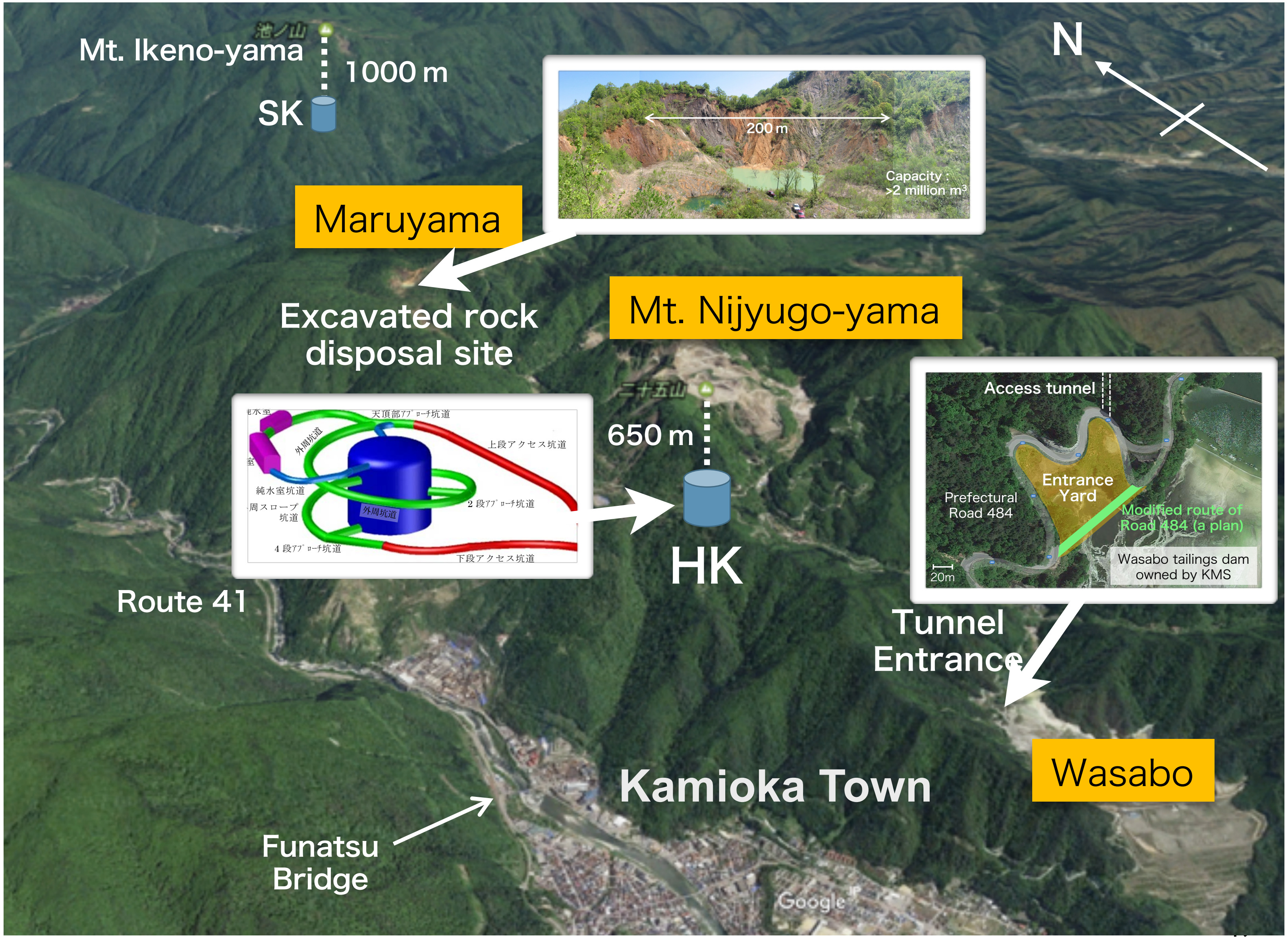


~40000 PMT / tank

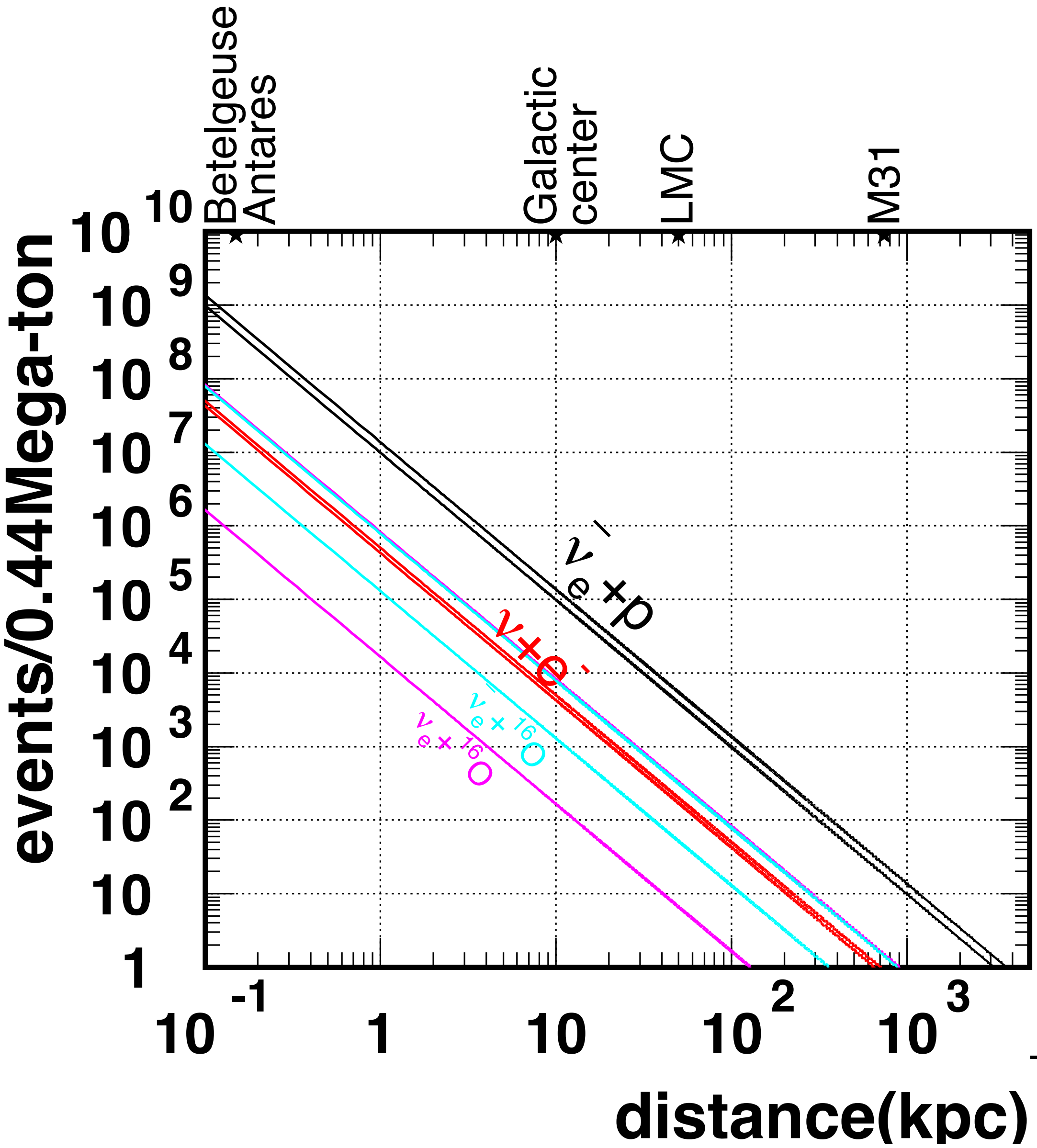
New photo-censer which has twice sensitivity than Super-K

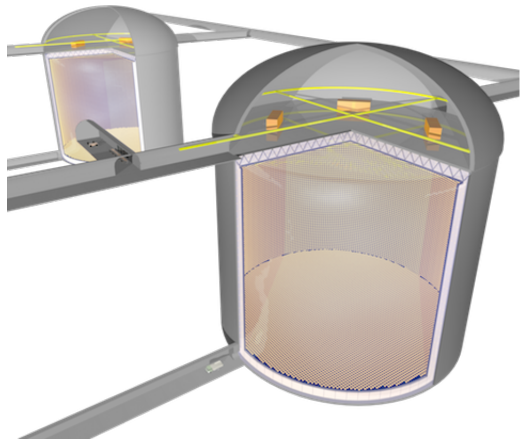


Hyper-Kamiokande



Hyper-Kamiokande





Expected number of event

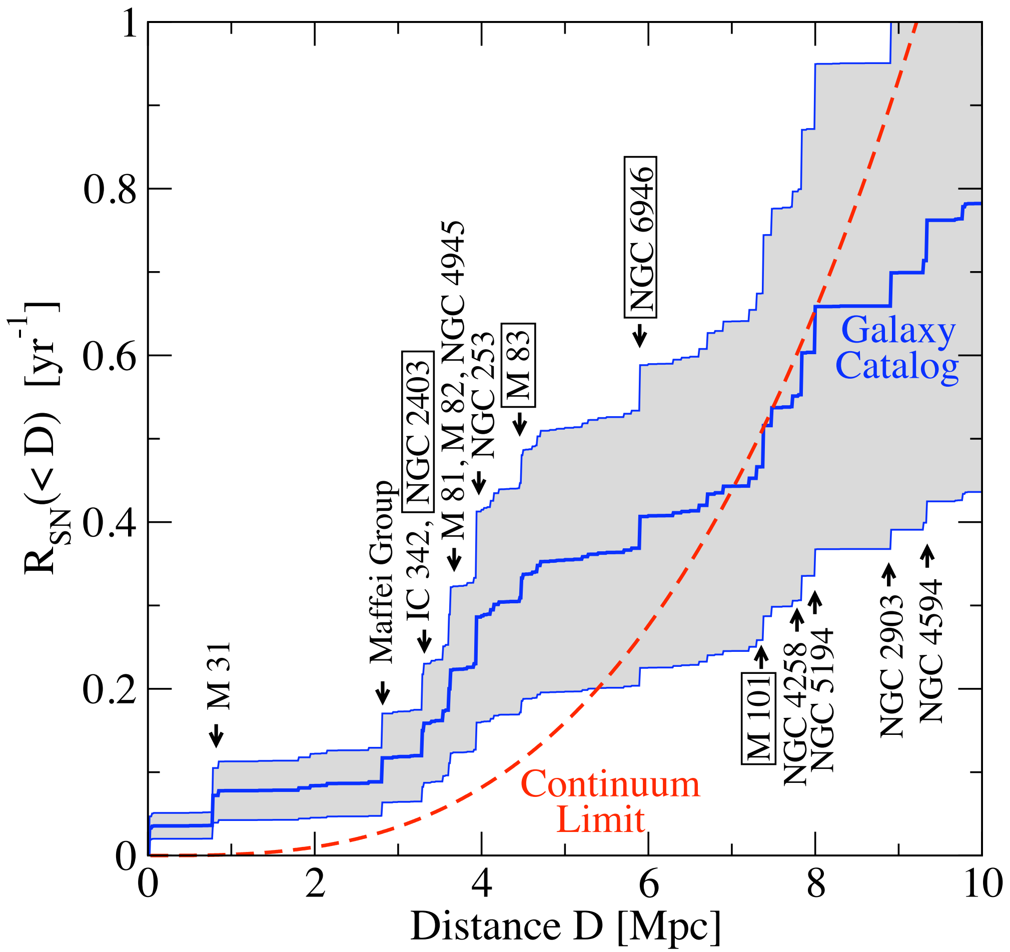
98k~136k ev (IBD)
4.2k~5k ev (νe ES)
(12~80 for neutronization)
160~8200 ev (ν_e CC)
1300~7800 ev ($\overline{\nu}_e$ CC)

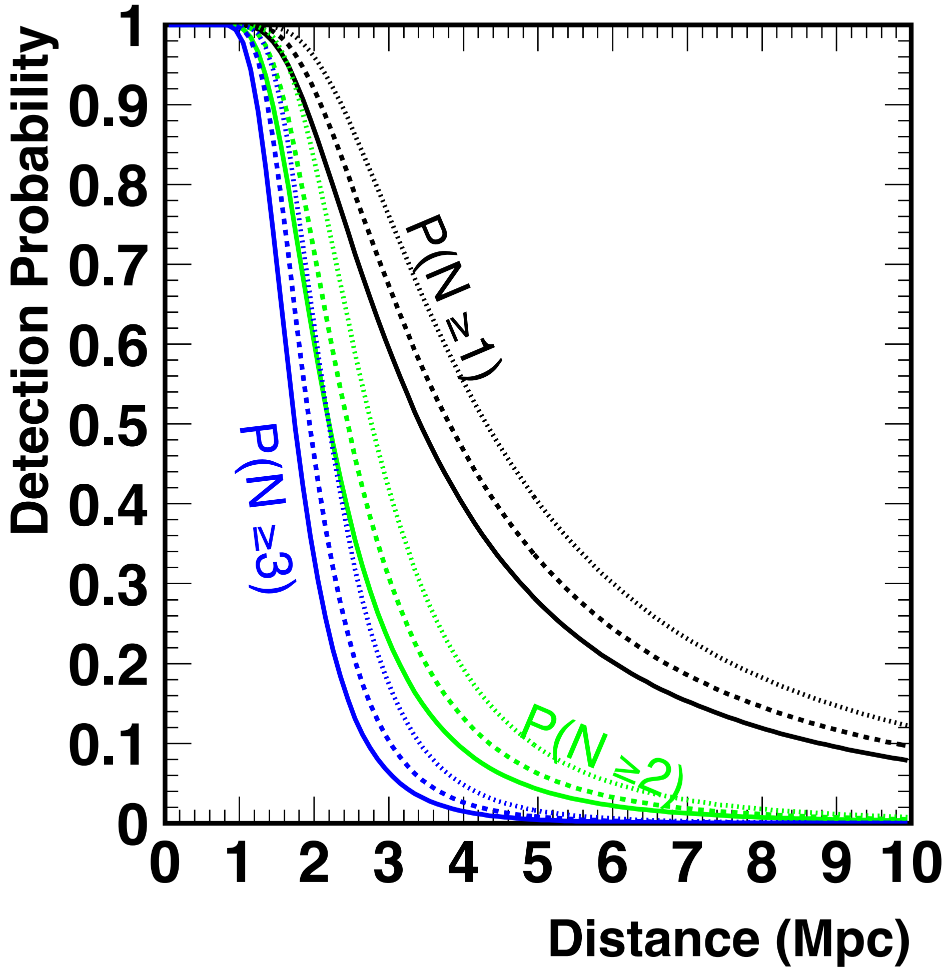
at 10kpc

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

Hyper-Kamiokande

Cumulative calculated supernova rate

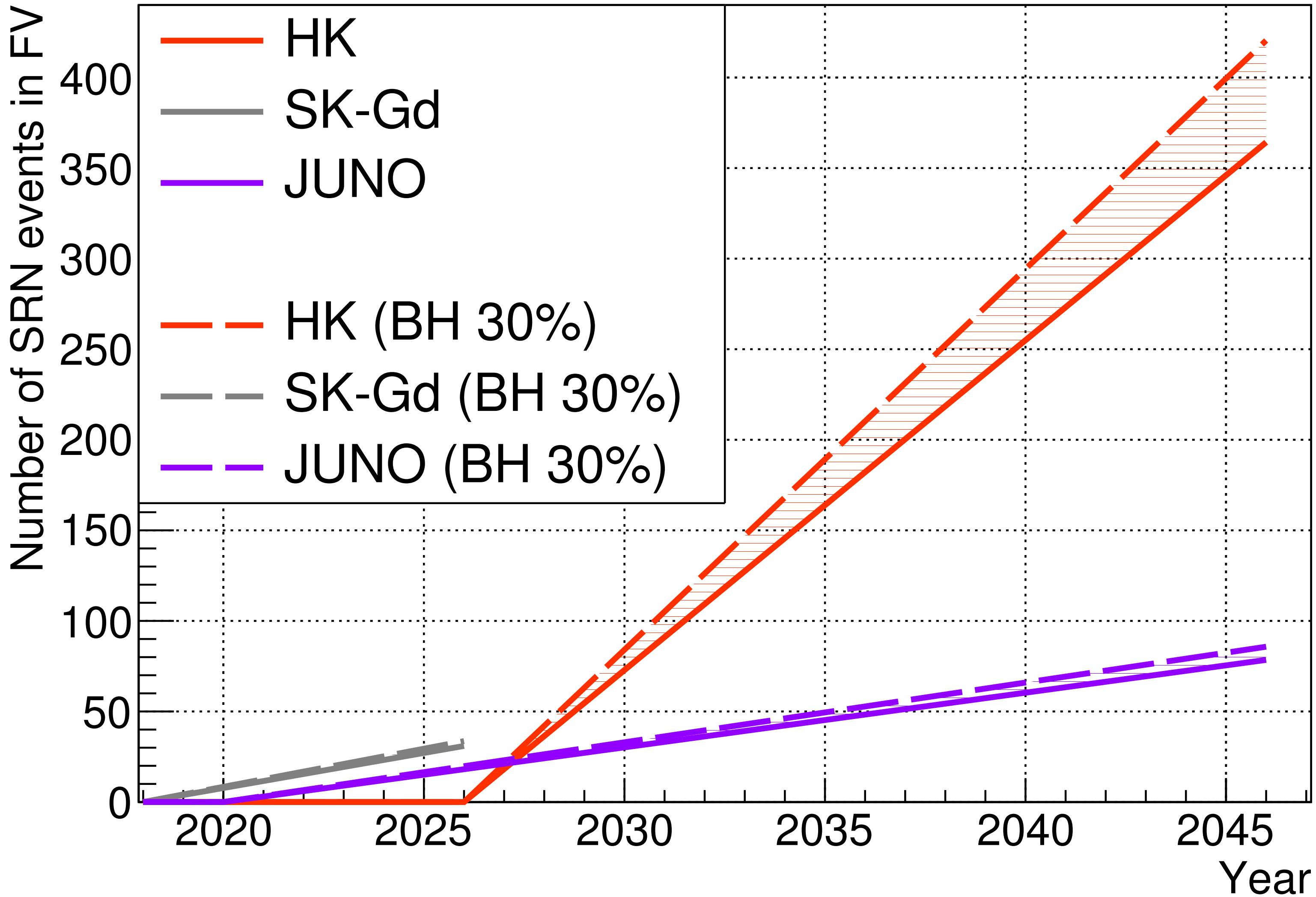




S. Horiuchi et.al.

DSNB at Hyper-K

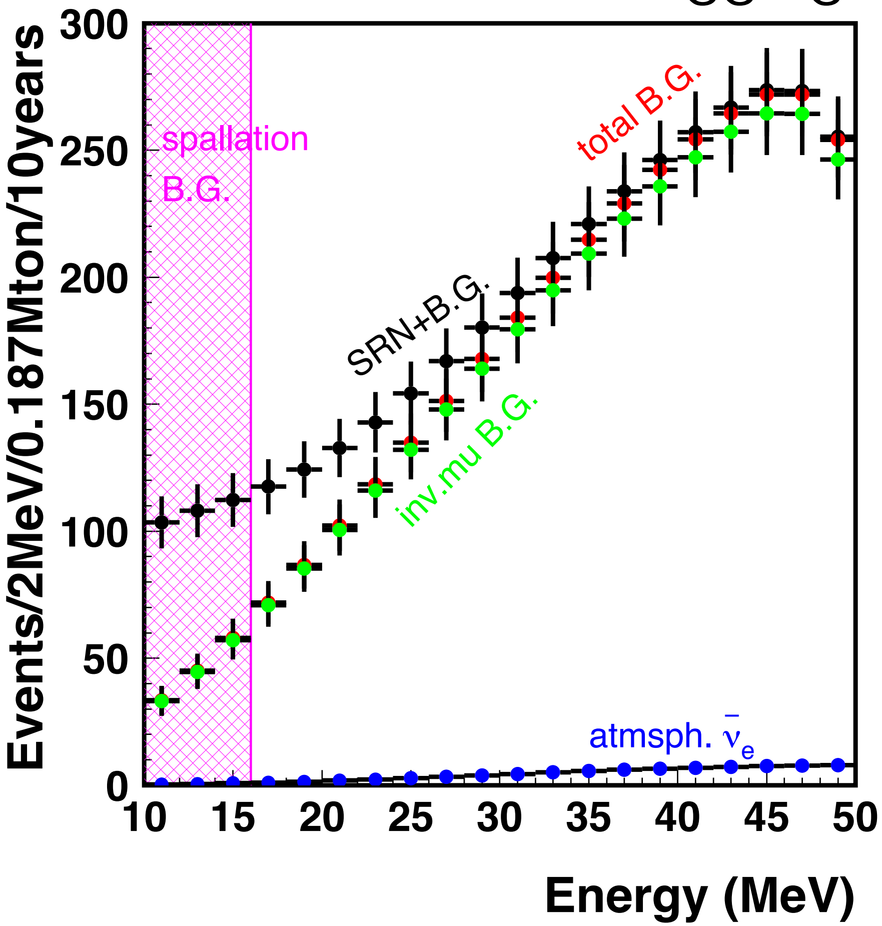
expected number of events



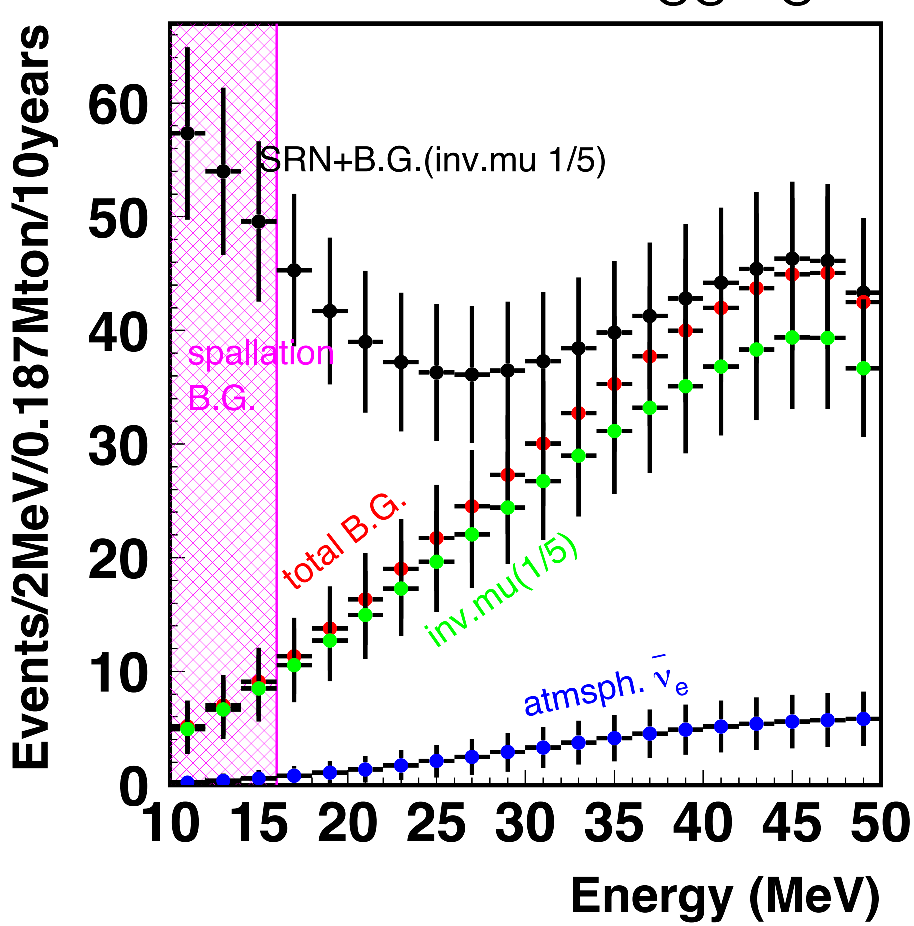
DSNB at Hyper-K

expected spectrum

without neutron tagging



with neutron tagging



Hyper-Kamiokande

- International proto-collaboration
    - 15 countries, 73 institutes, ~300 members, ~75% from abroad
- 'Hyper-Kamiokande Design Report' arXiv:1805.04163, May 9, 2018. 333pp.
- Selected 'Roadmap 2017' in MEXT (Japanese funding agency) as one of the 17 highest-priority large-scale projects in Japan.
- We are aiming to start observation in 2026.

Welcome to join us!

Workshop held near Kamioka

8-10 October, 2018

Deciphering multi-Dimensional nature of core-collapse SuperNovae via Gravitational-Wave and neutrino signatures (SNeGWv2018)

8-10 October 2018
Toyama International Conference Center
Japan timezone

- Overview
- Scientific Programme
- Timetable
- Contribution List
- Author List

The aim of the workshop is to create an environment in which to gather experts on the explosion physics of core-collapse supernovae (CCSNe) and to then have exciting discussions with world-leading astronomers (with an intense focus on gravitational-wave (GW) and neutrino signals). Such an exciting encounter is intended to strengthen further collaboration between the CCSN theory and the CCSN multi-messenger observation communities. Held in close proximity to the sites of Super-Kamiokande and KAGRA, this workshop will take place in Toyama and provide a special opportunity to start new collaborations. It is also expected to impart significant new momentum toward deciphering the as-yet uncertain multi-dimensional and multi-physics nature of CCSNe via synergistic observations of the CCSN multi-messenger signatures.

http://www-sk.icrr.u-tokyo.ac.jp/indico/event/3586/


Summary
Let's go supernova!
(Hope after Super-K tank open work is finished..)
Thanks