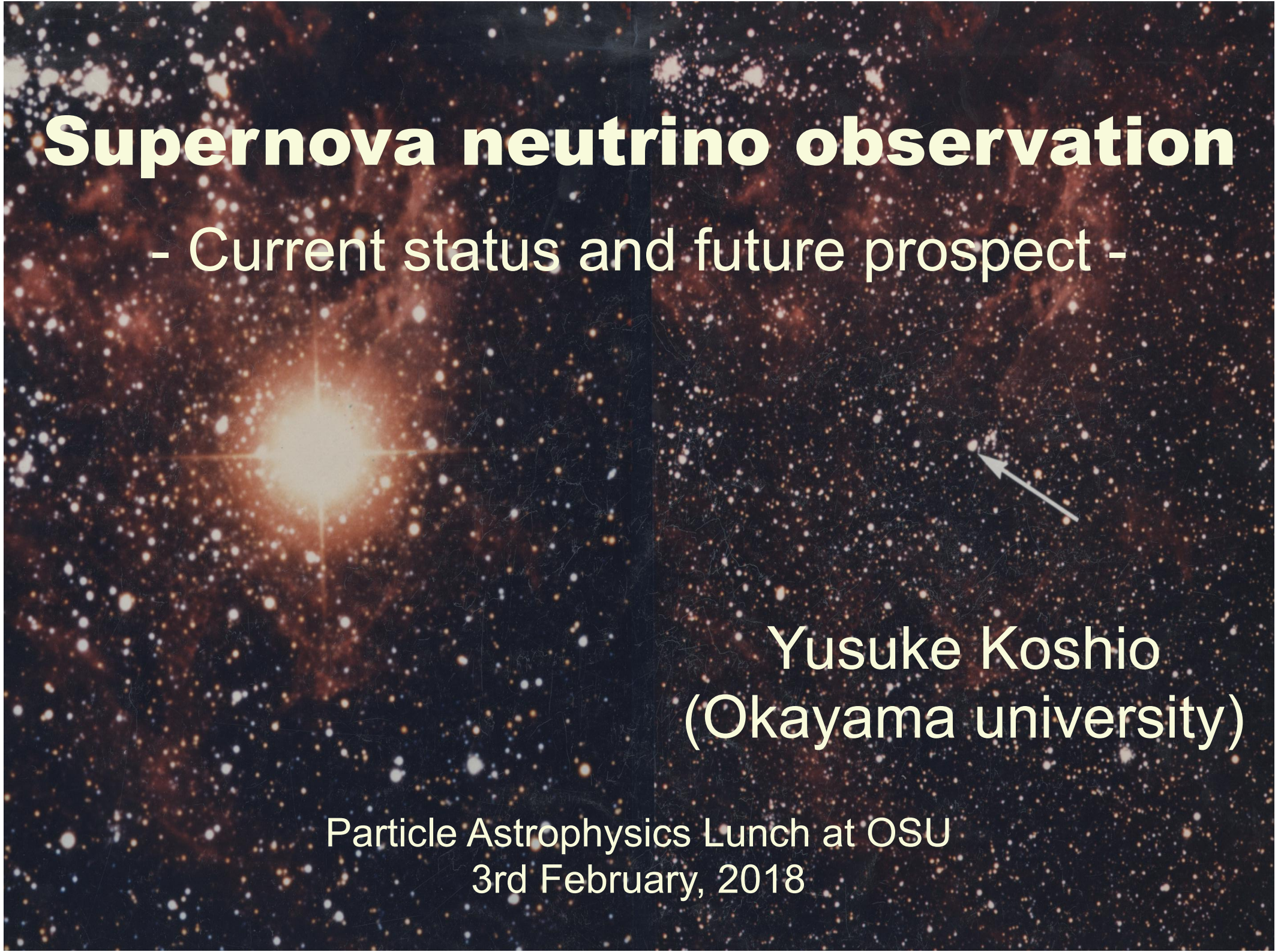

Supernova neutrino observation

- Current status and future prospect -

Yusuke Koshio
(Okayama university)

Particle Astrophysics Lunch at OSU
3rd February, 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

30 years anniversary of SN1987A

(2017)

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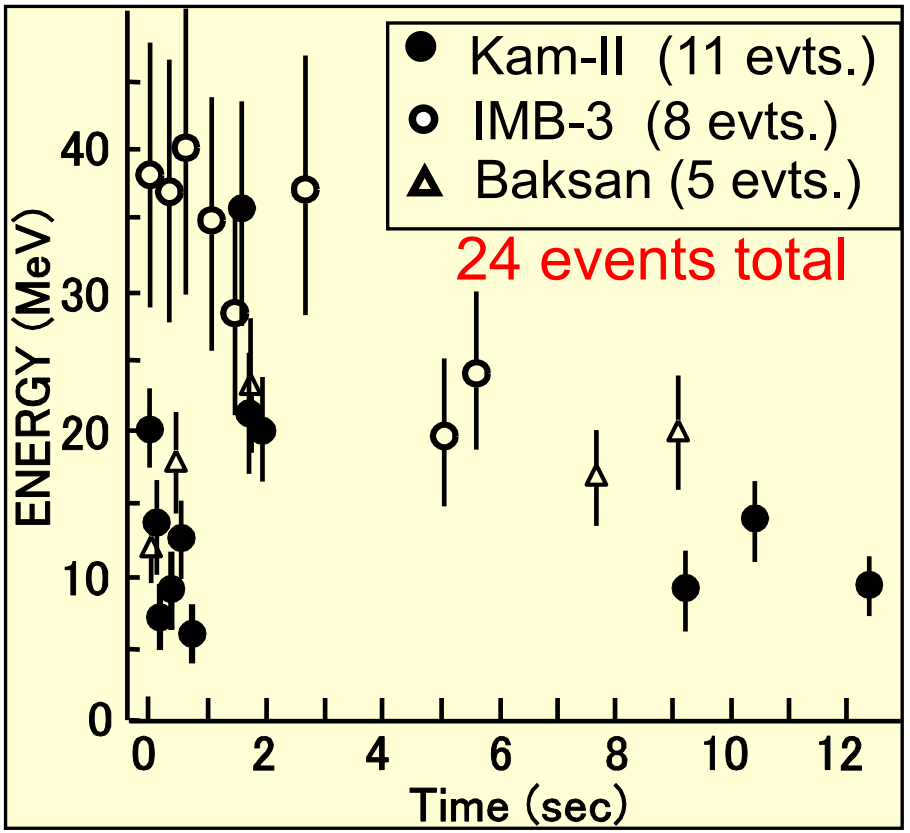
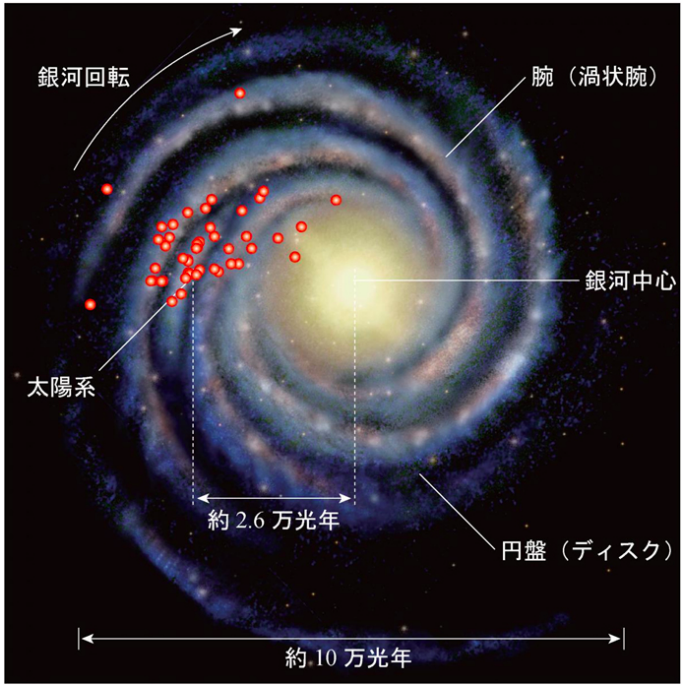


No Supernova neutrino detection since then..

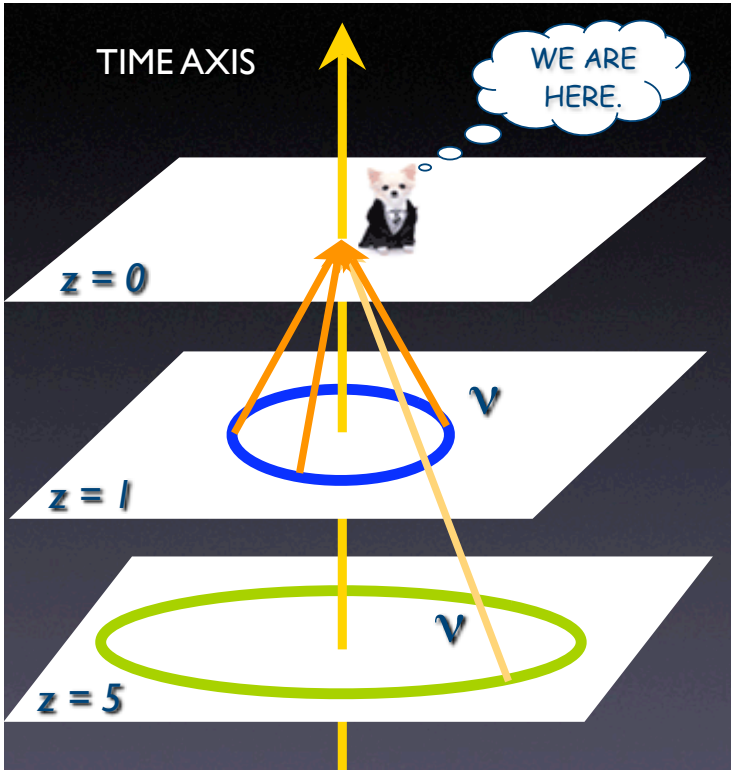
No chance for Supernova neutrino detection for next hundred's years?

We believe, yes!

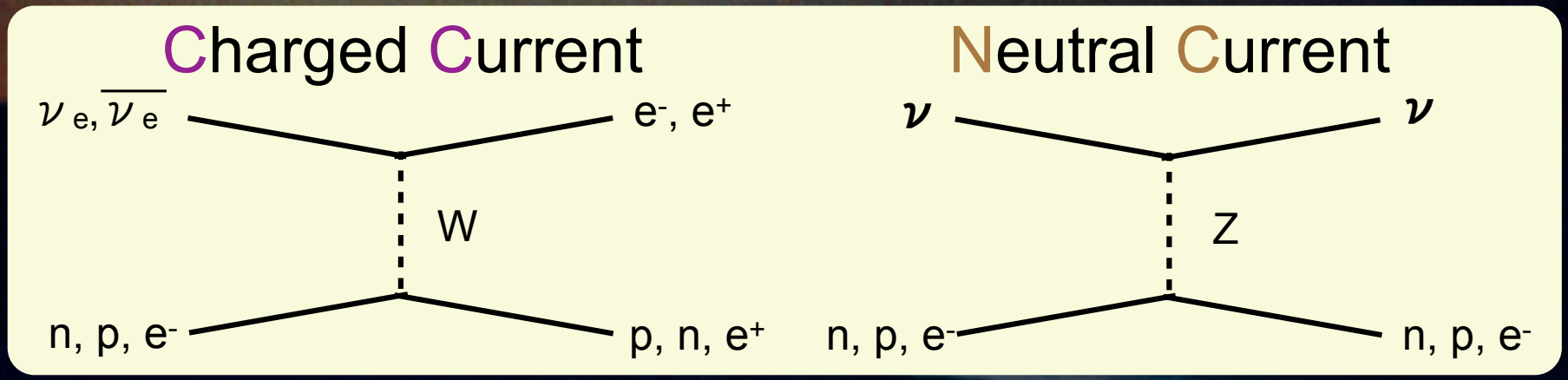
Galactic Supernova burst (a few per century)



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
  - $n + p \rightarrow d + \gamma$, $n + Gd \rightarrow Gd + \gamma$

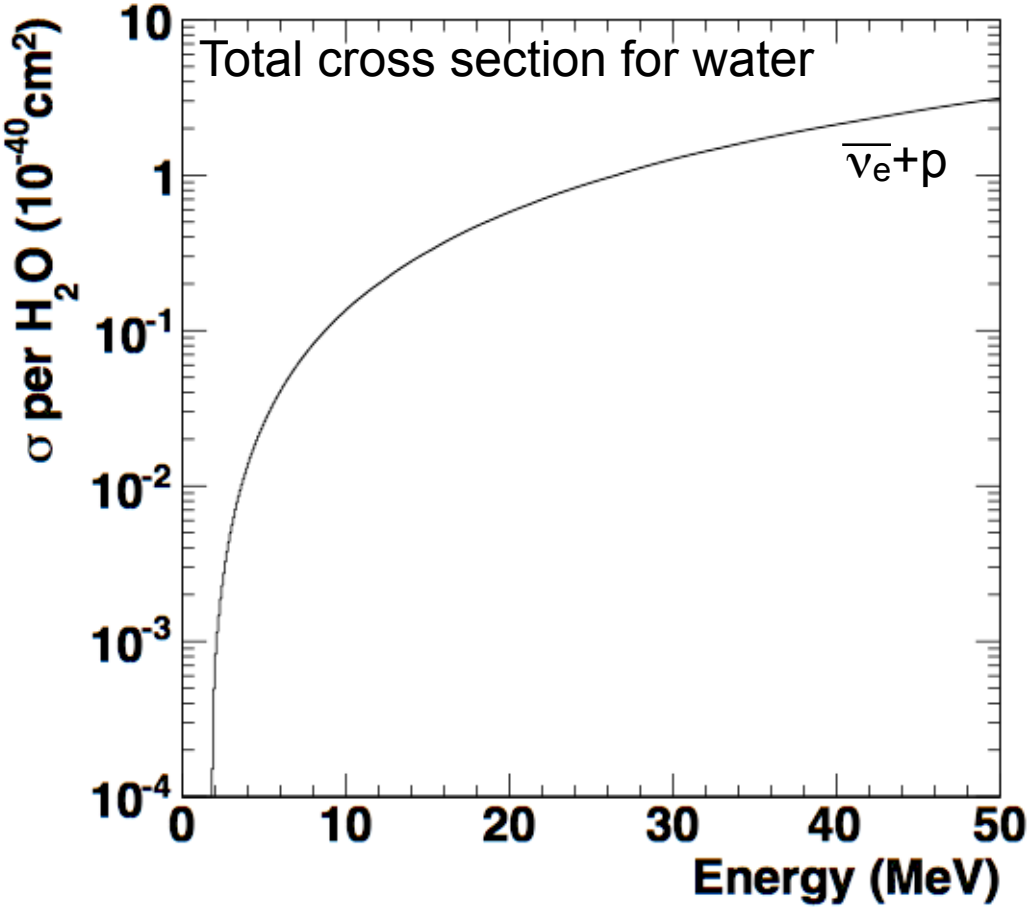
Neutrino interaction for SN ν

Inverse beta decay

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

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

- ✓ Dominates for detectors v
  - 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

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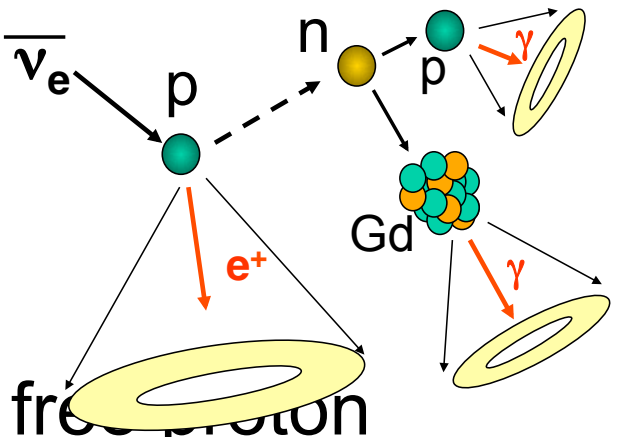

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- ✓ Poor directionality
- ✓ Neutron tagging using delayed coincidence
  - $n + p \rightarrow d + \gamma$, $n + Gd \rightarrow Gd + \gamma$

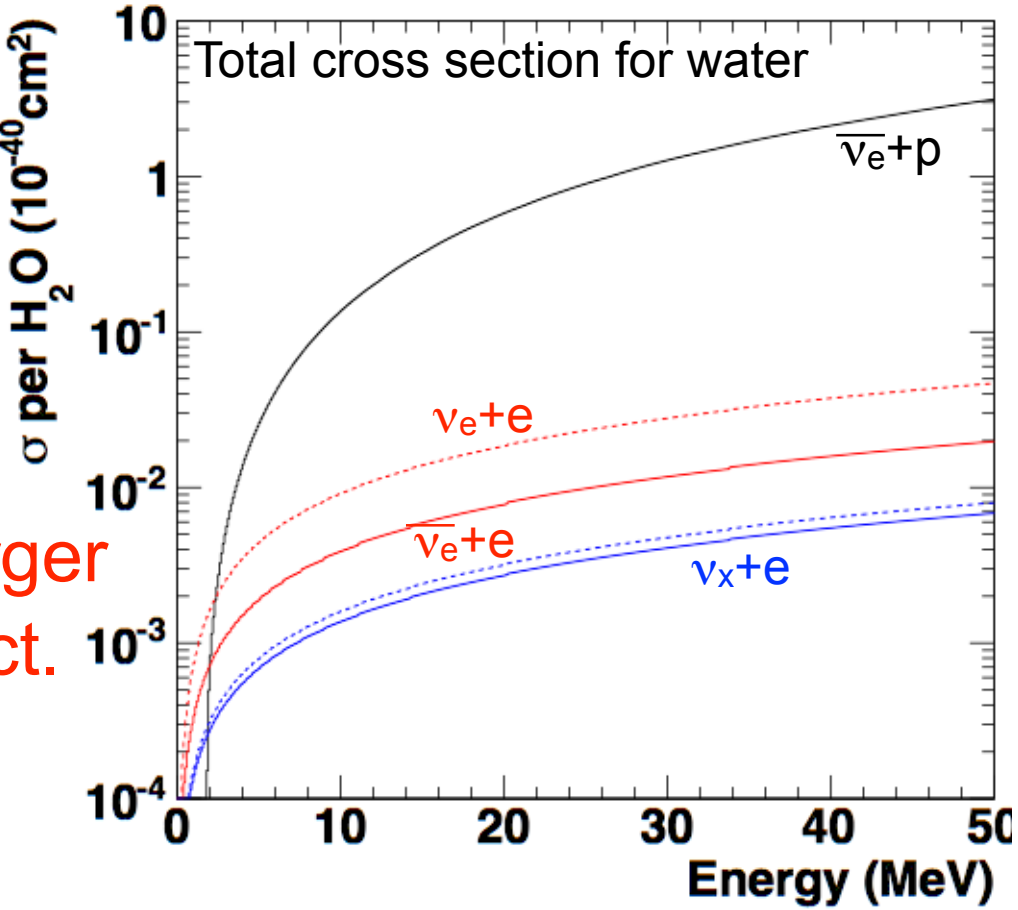
Possible to enhance this signal if Gd loaded

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

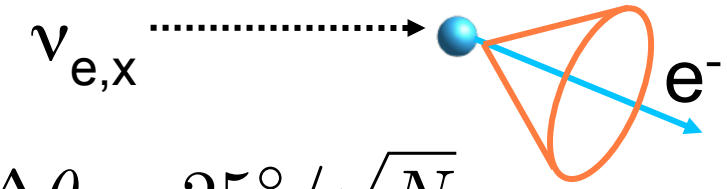
Neutrino interaction for SN ν

Elastic scattering

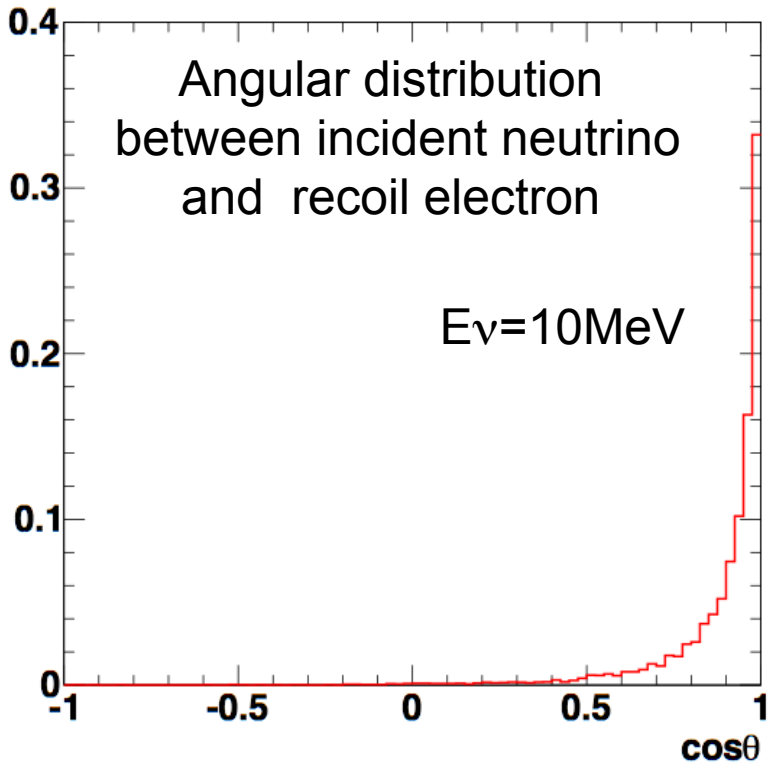
$$\nu_{e,x} + e^- \rightarrow \nu_{e,x} + e^-$$

(Both Charged Current and Neutral Current interaction)

Water Cherenkov



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



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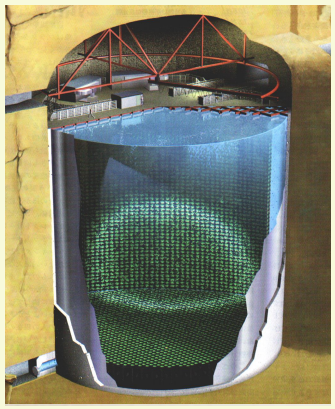
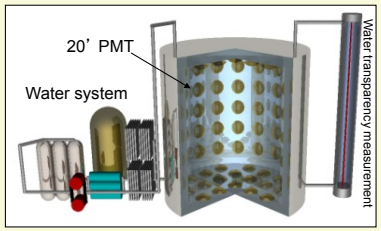
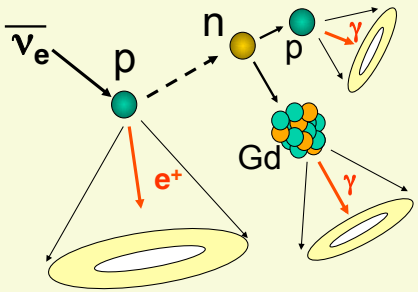
SN search at Super-Kamiokande

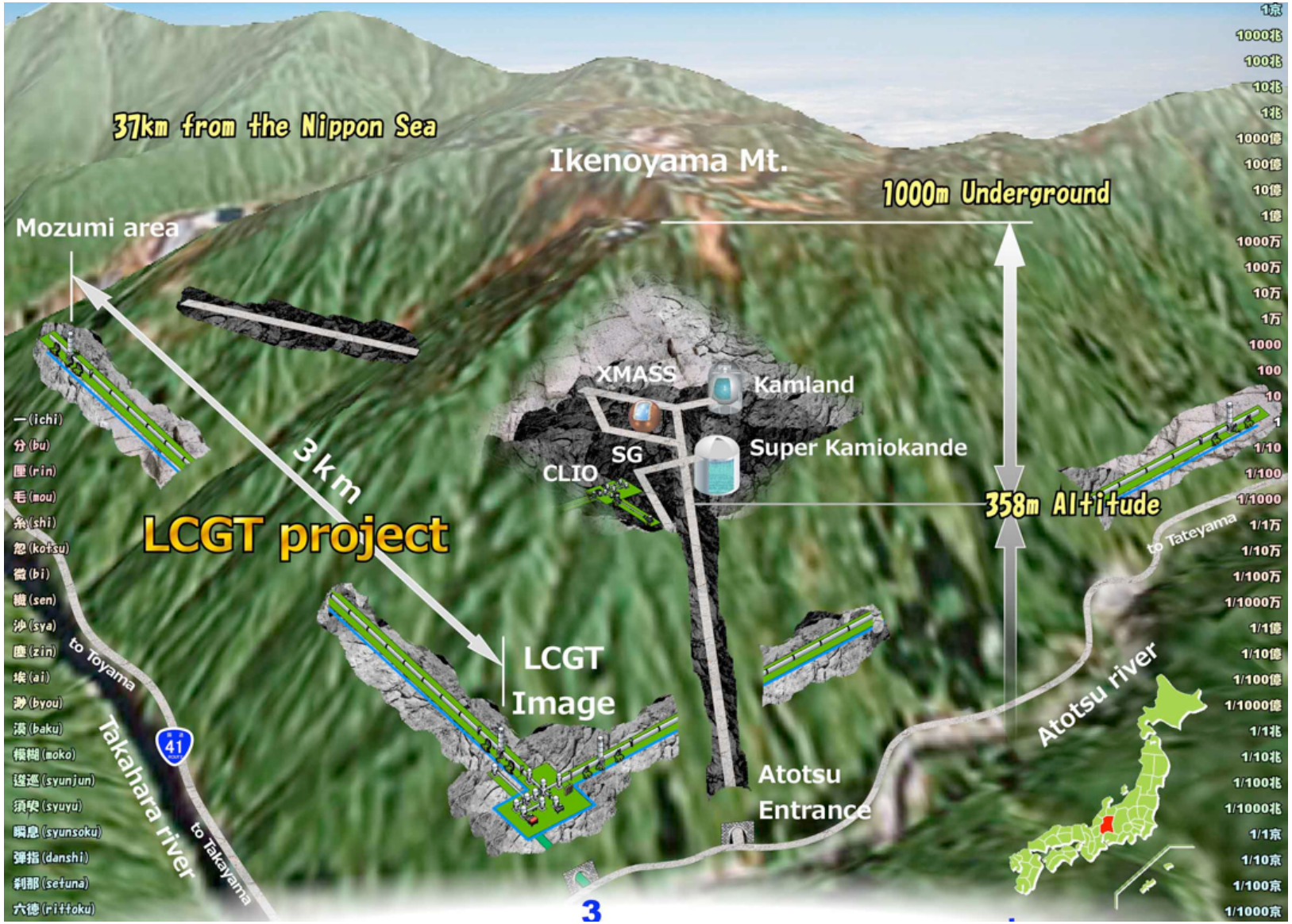
Super-K to SK-Gd





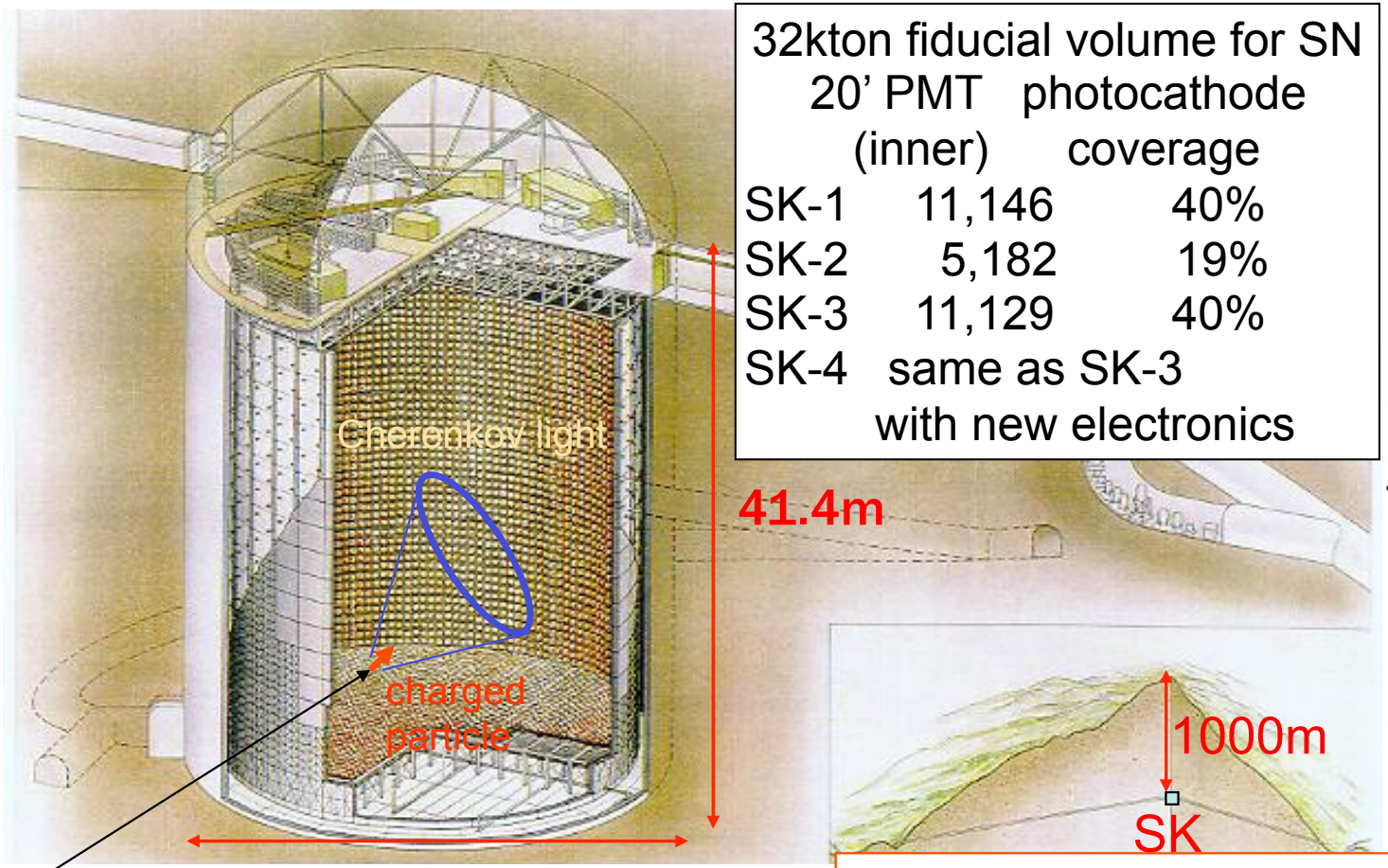


Kamioka underground detectors



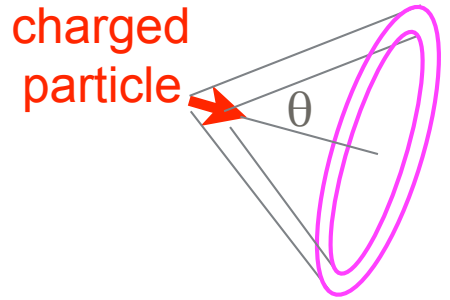
Super-Kamiokande

50kton Water Cherenkov detector

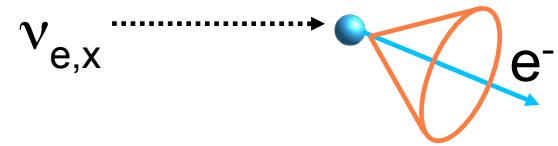


32kton fiducial volume for SN		
	20' PMT (inner)	photocathode coverage
SK-1	11,146	40%
SK-2	5,182	19%
SK-3	11,129	40%
SK-4	same as SK-3 with new electronics	

Placed inside the Kamioka mine
1000m underground

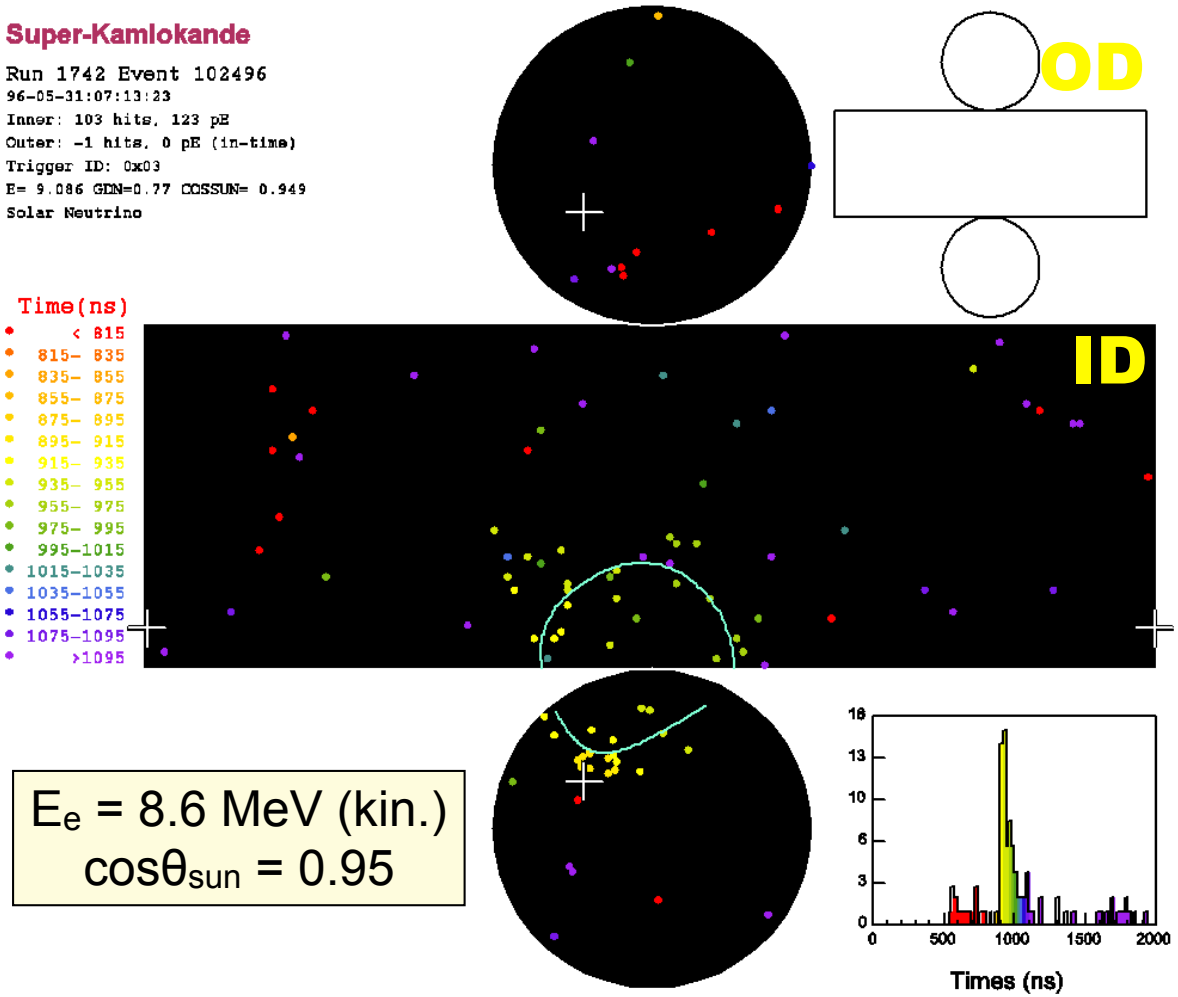


✓ Underground in Kamioka mine, (almost BG free)
✓ 3.5MeV energy threshold for recoil electron
✓ Dominant process is inverse beta decay
✓ Good directionality for νe elastic scattering



Super-Kamiokande

For supernova neutrinos (~MeV)



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

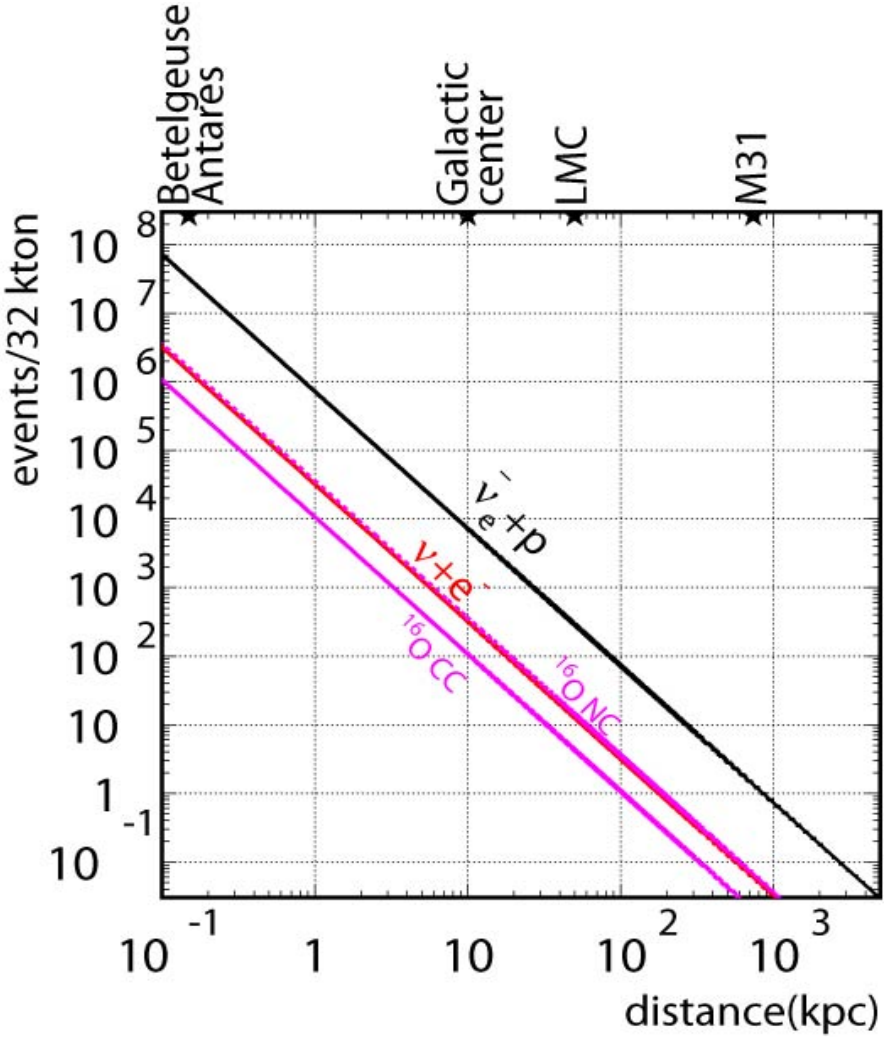
How to reconstruct?

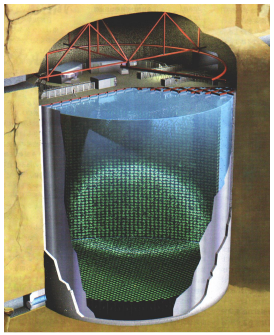
Detector performance

	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





Expected number of event

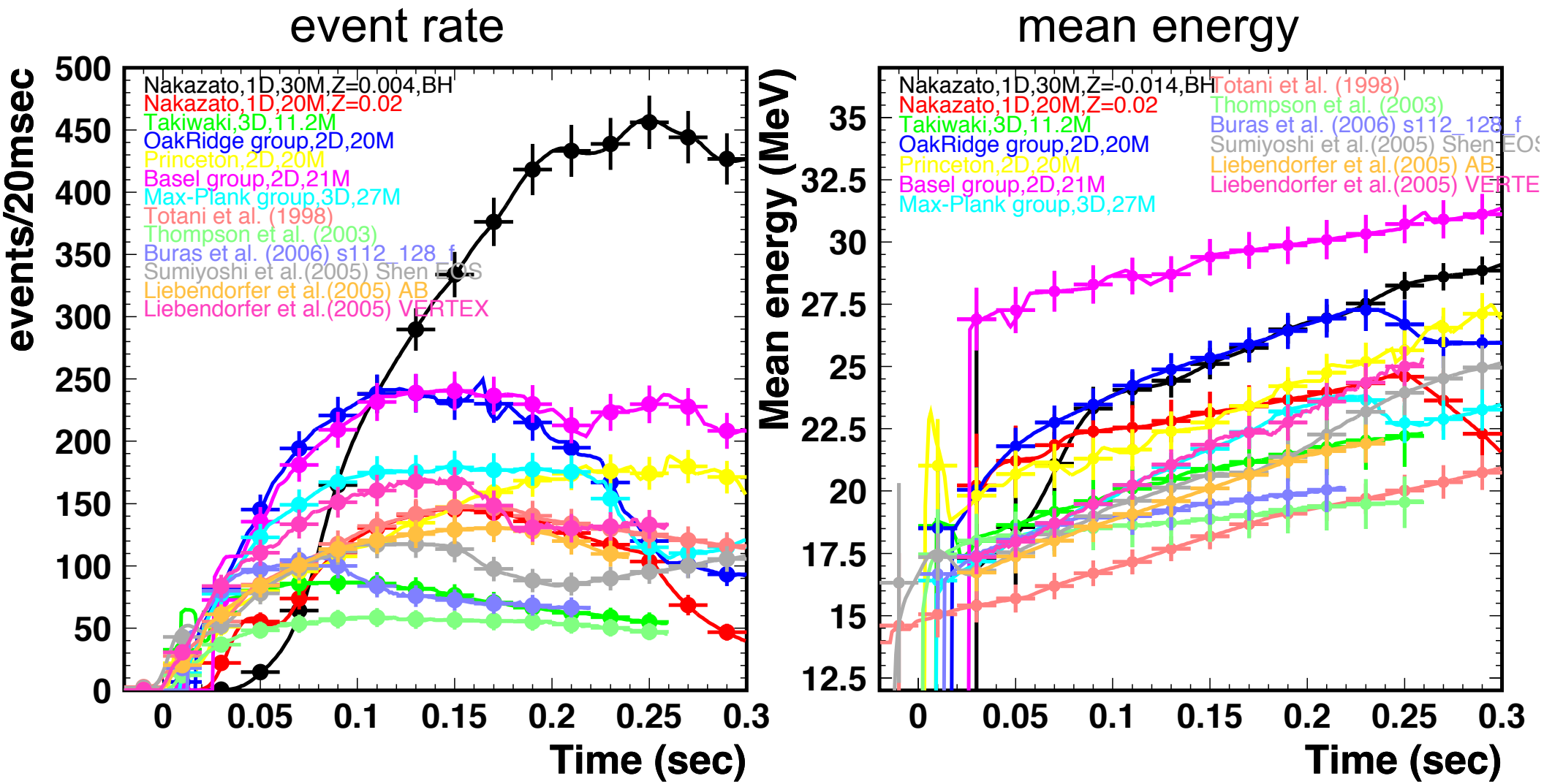
7.3k~10.2k ev (inverse beta decay)
320~380 ev (νe elastic scattering)
12~610 ev (ν_e CC)
95~580 ev ($\bar{\nu}_e$ CC)

at 10kpc, 4.5MeV energy threshold

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

Super-Kamiokande

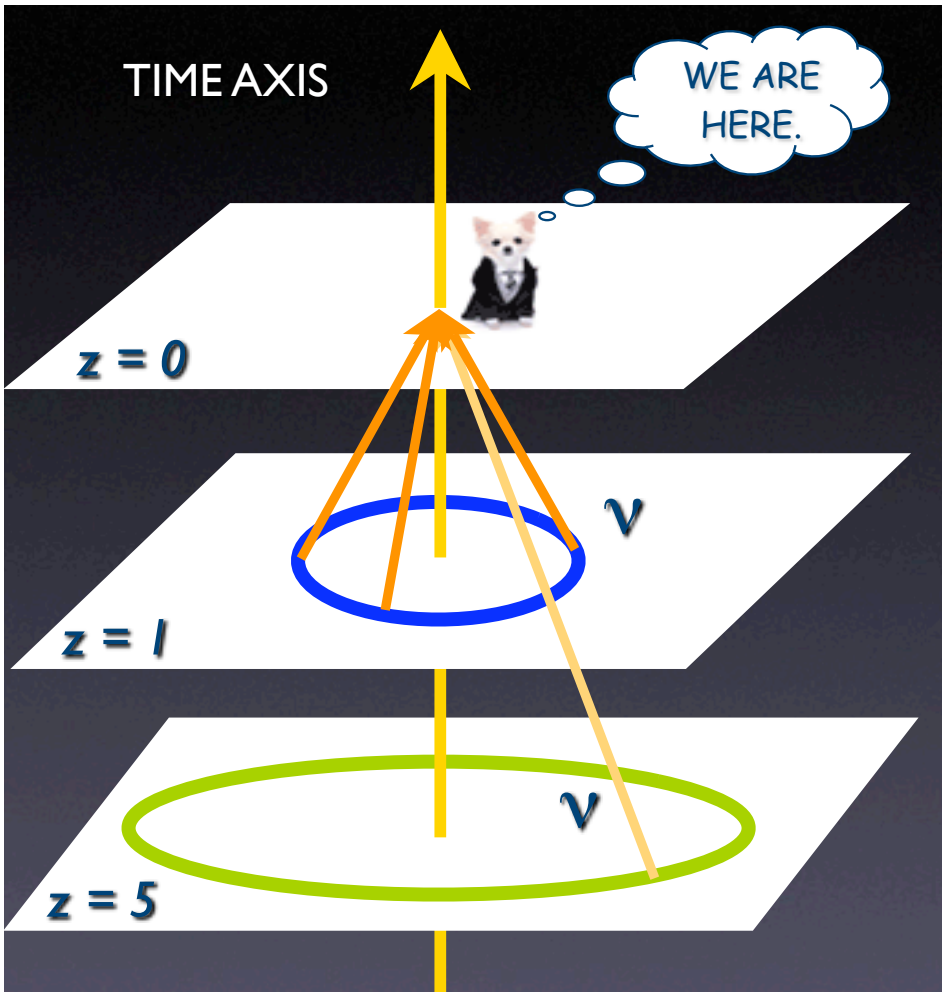
Time variation of $\overline{\nu_e}$+p at 10kpc

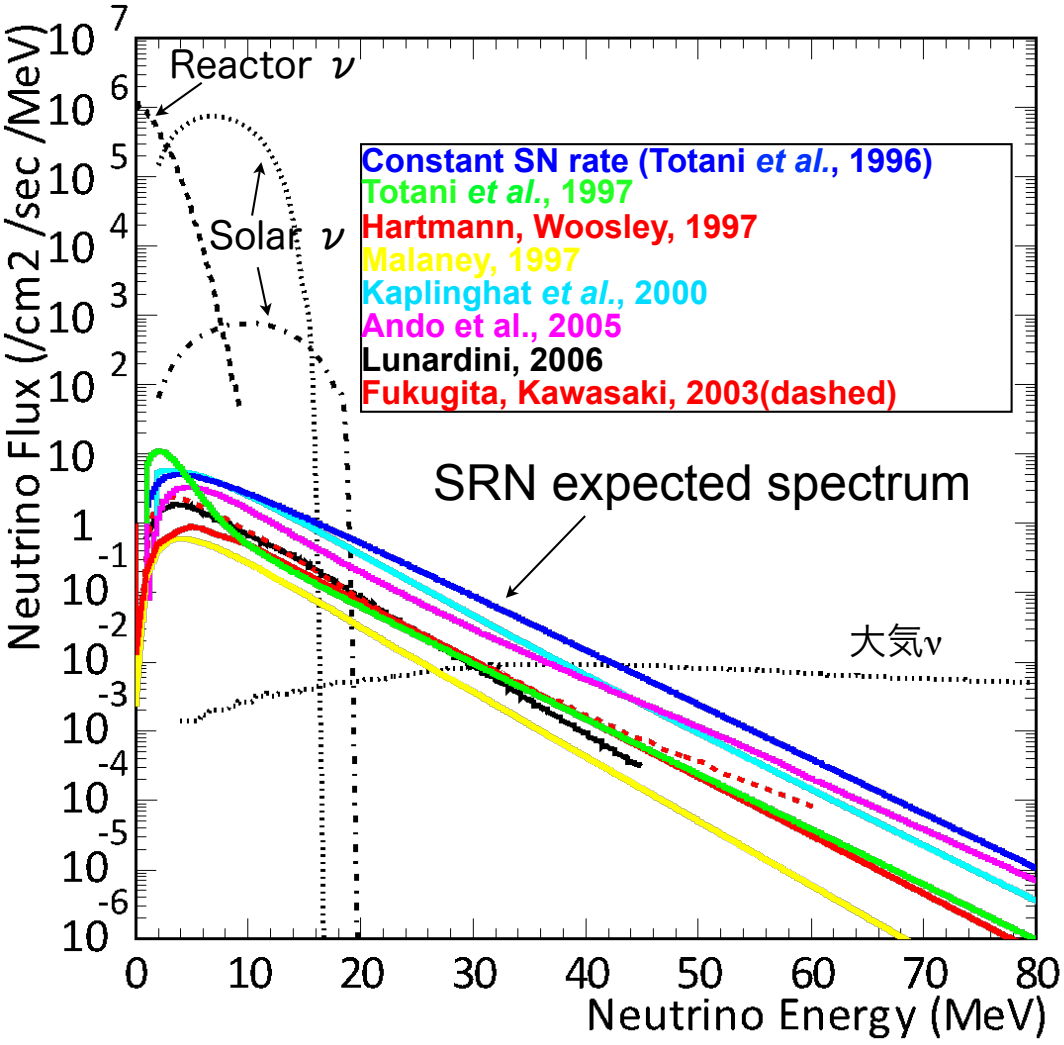


Diffuse Supernova Neutrino Background (DSNB)

Neutrinos emitted from past supernovae

S.Ando

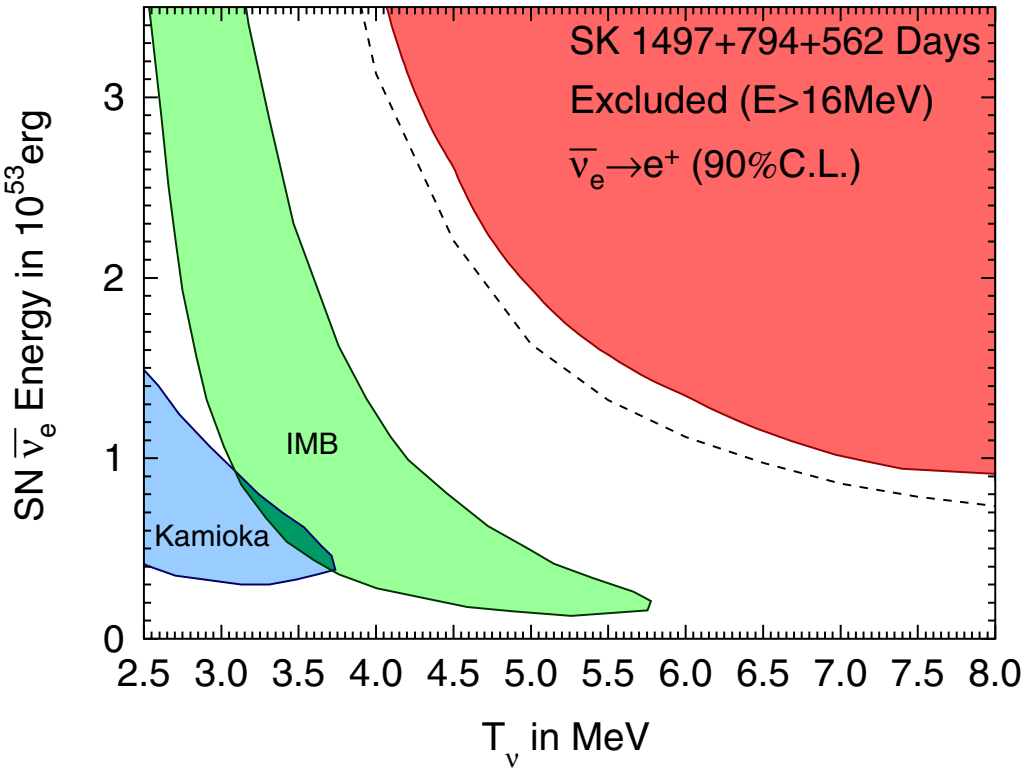


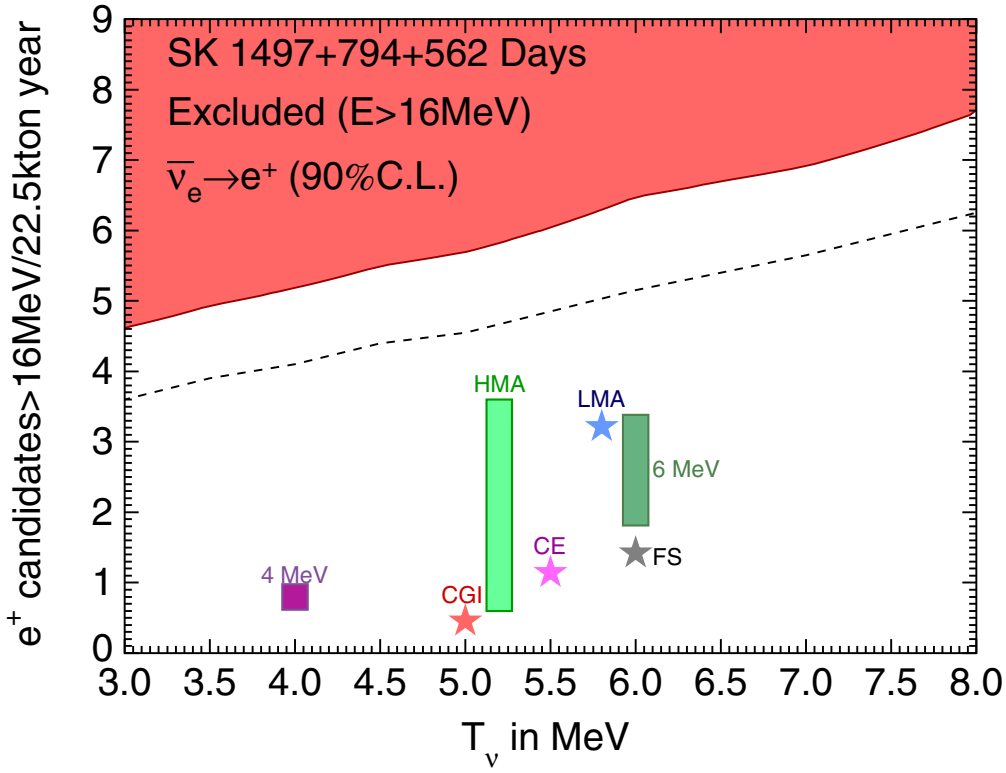


DSNB in Super-K

Upper limit from Super-K

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

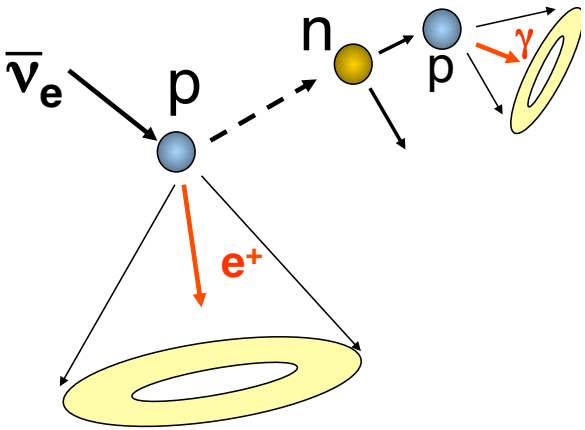




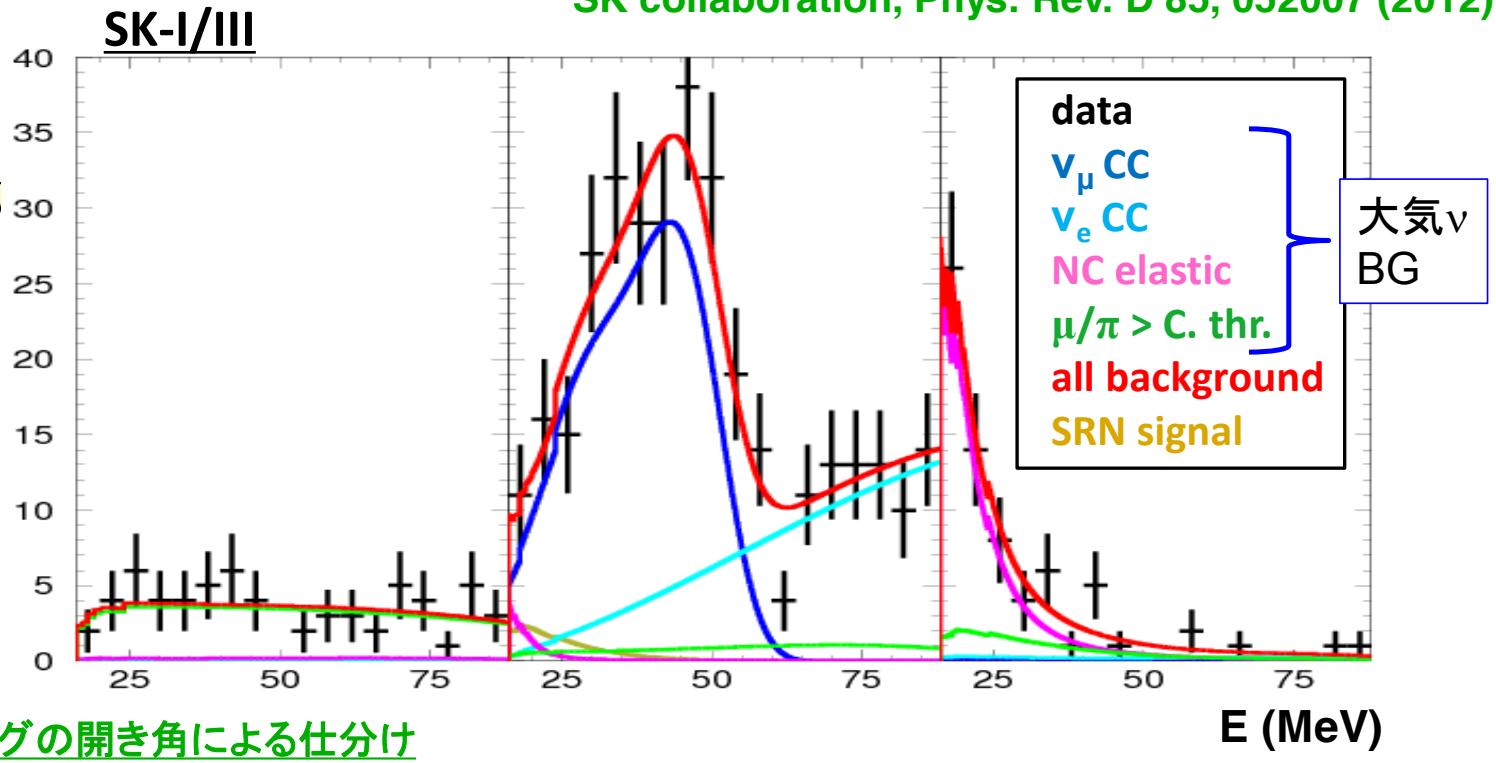
DSNB in Super-K

Current Super-K w/o neutron tagging

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

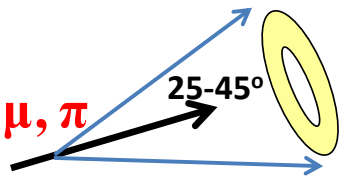


Only this signal

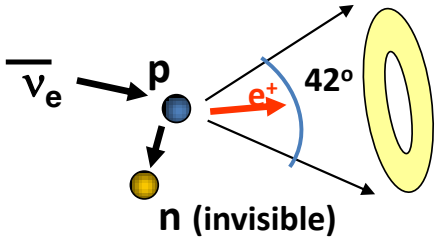


リングの開き角による仕分け

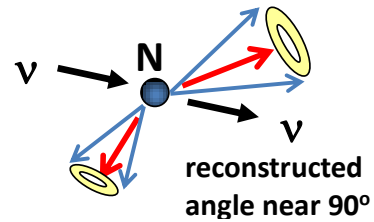
Low angle events



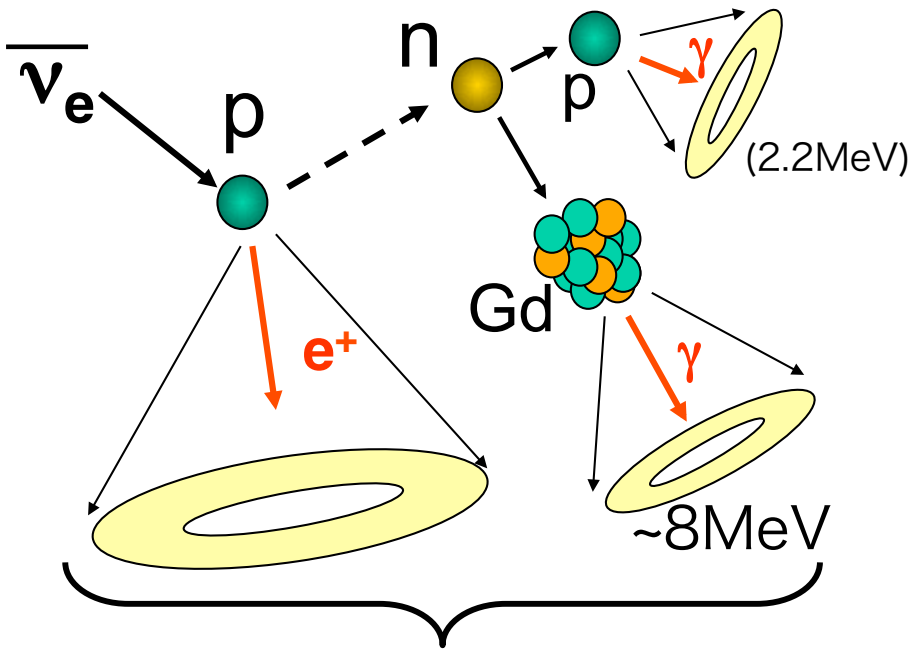
Signal Events



Isotropic Events



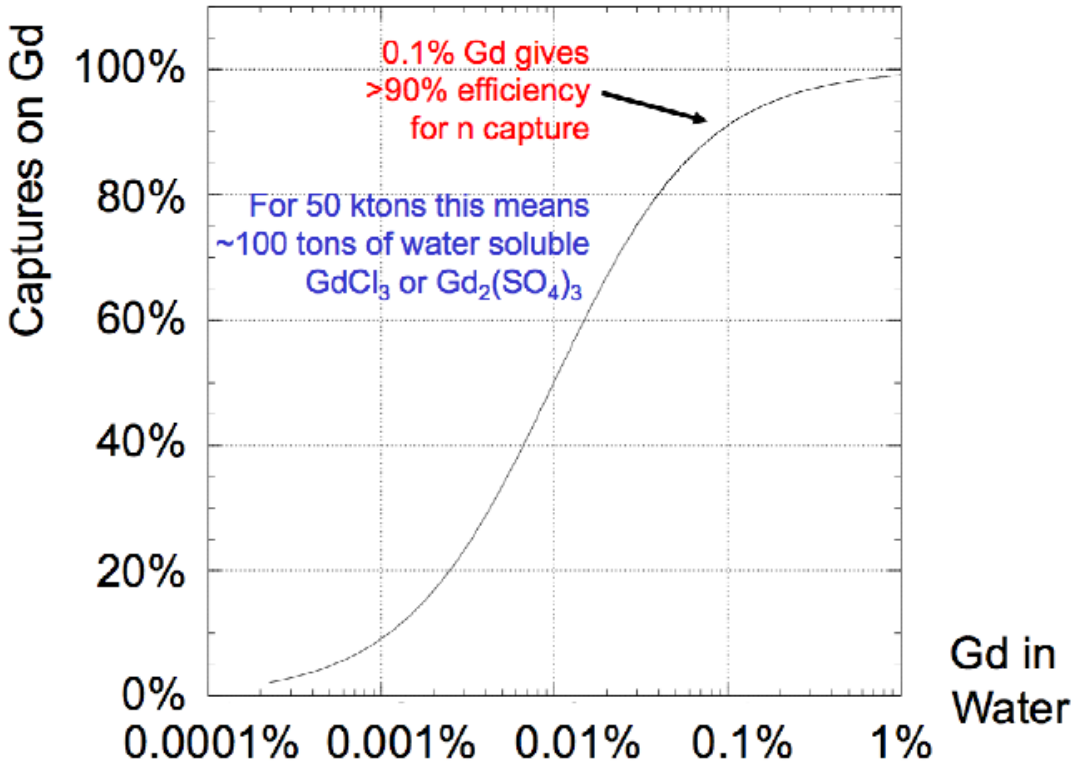
DSNB in upgraded Super-K



- 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

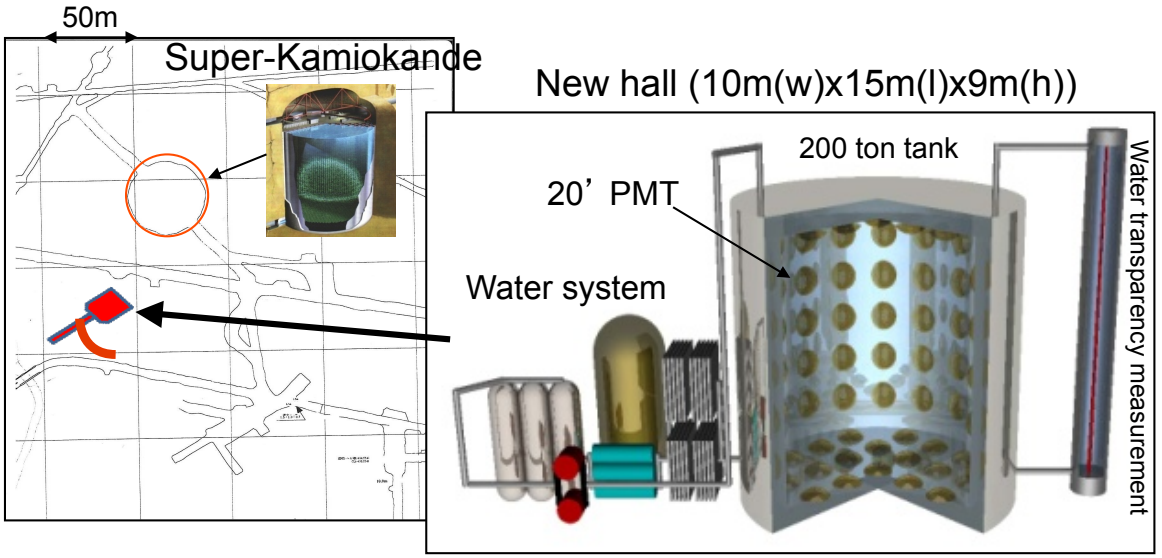
✓How to introduce and remove

✓Effect on detector

✓Effect from environment neutrons

✓etc.

R&D for Gd test experiment



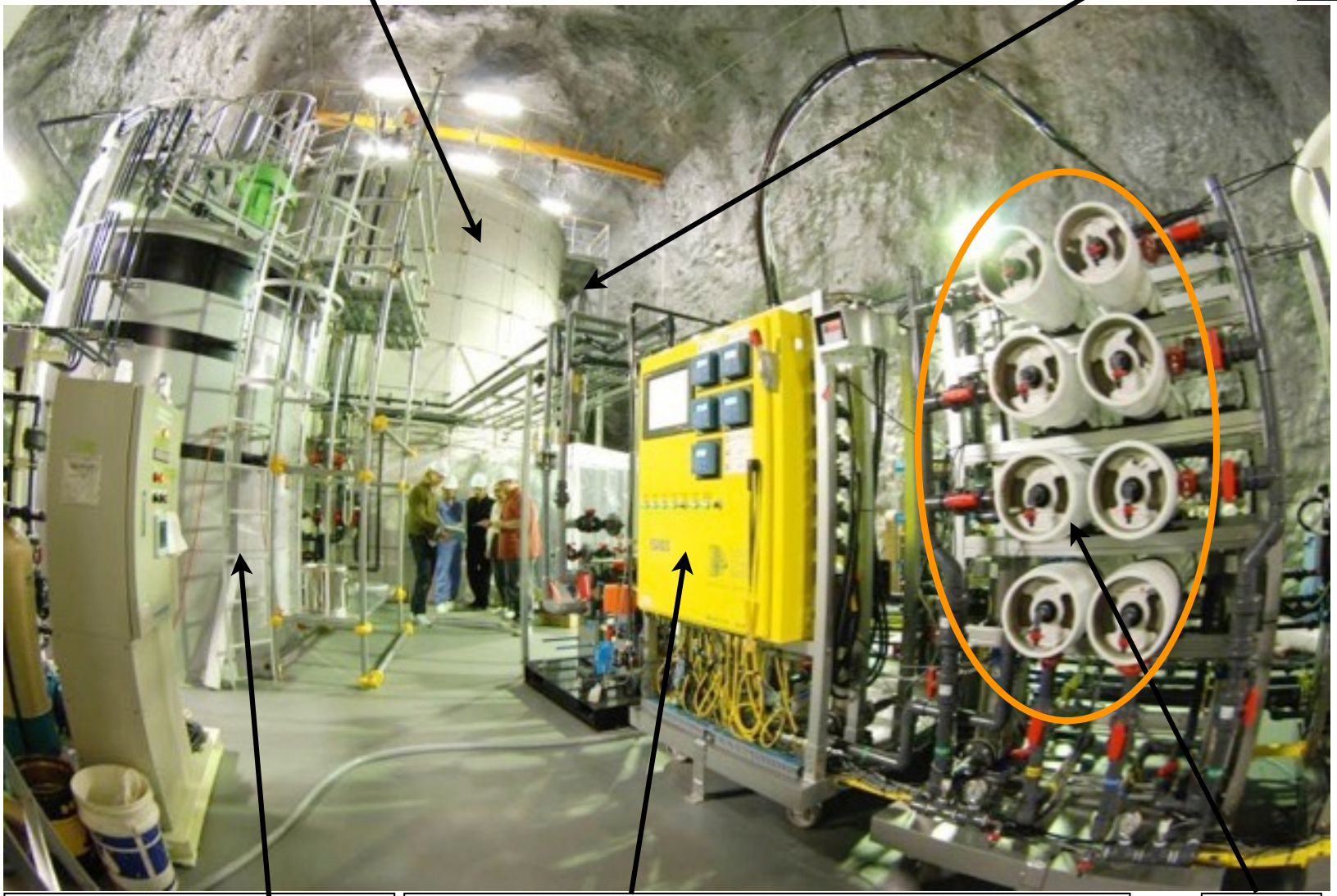
Now working well

EGADS as R&D

200 ton tank

UDEAL

water transparency measurement

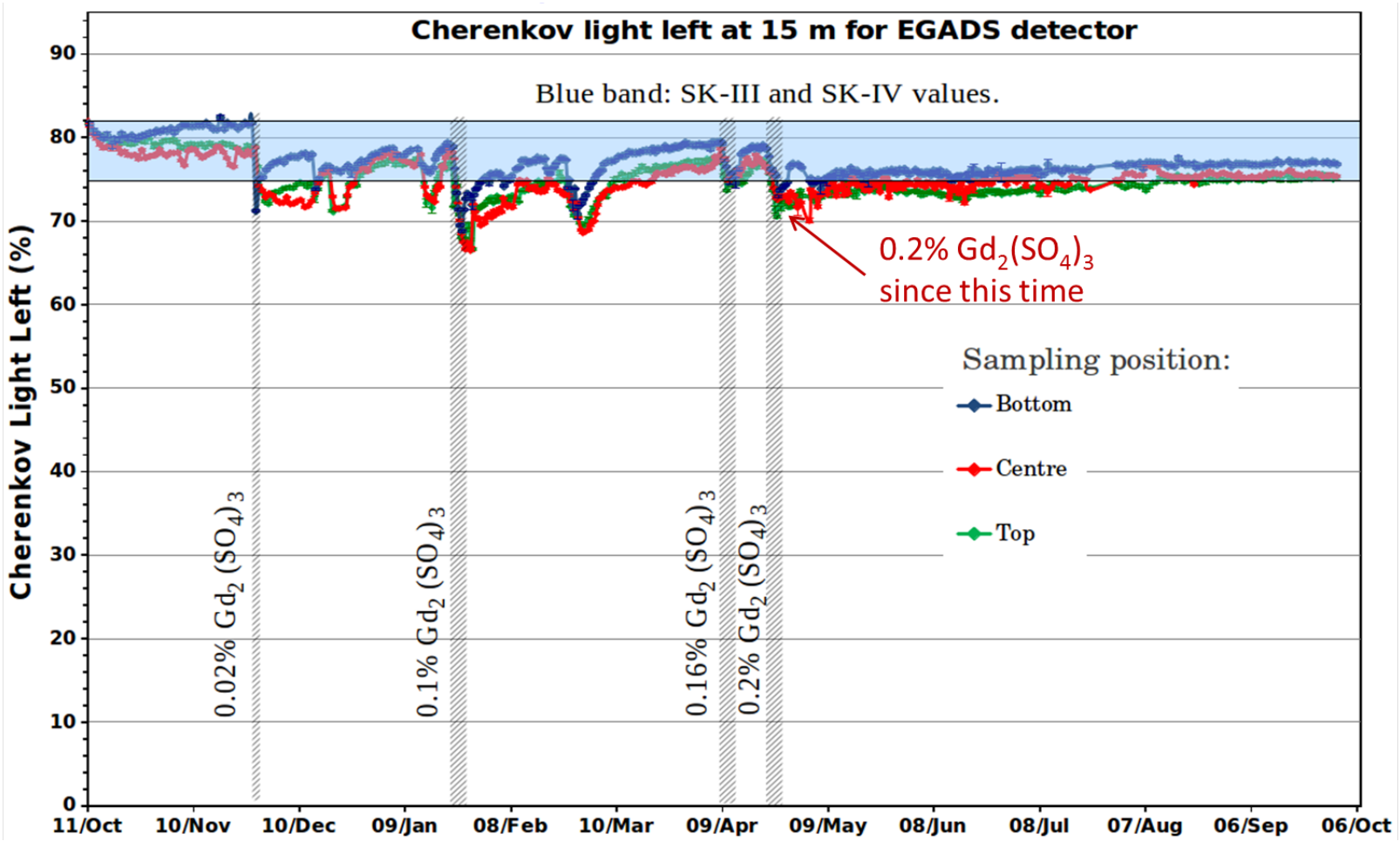


15 ton buffer tank

Control panel of circulation system

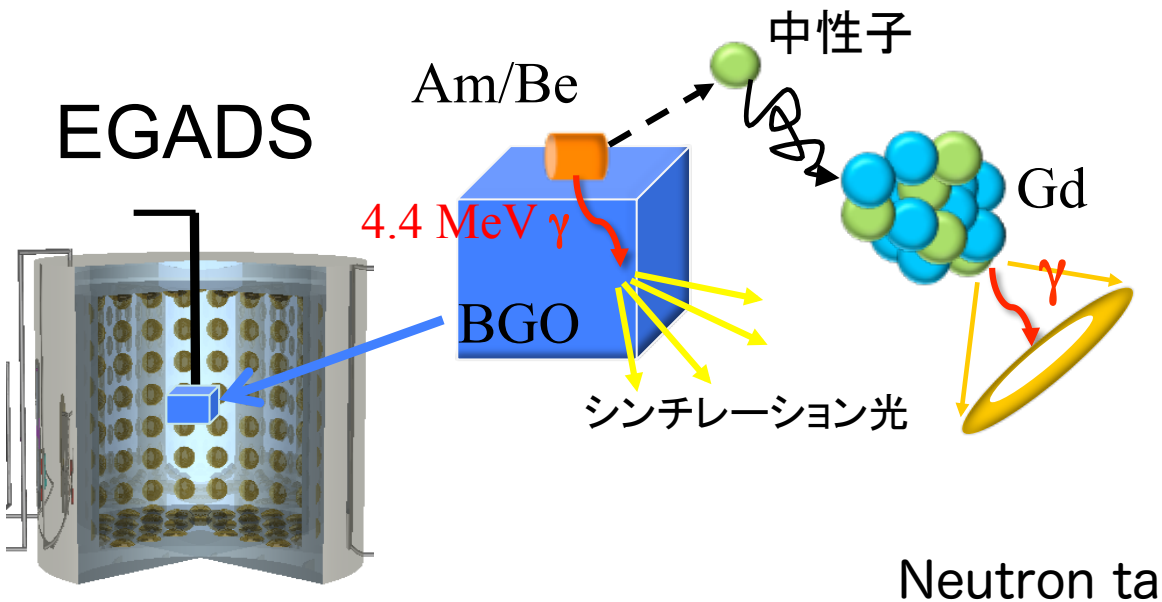
Filter

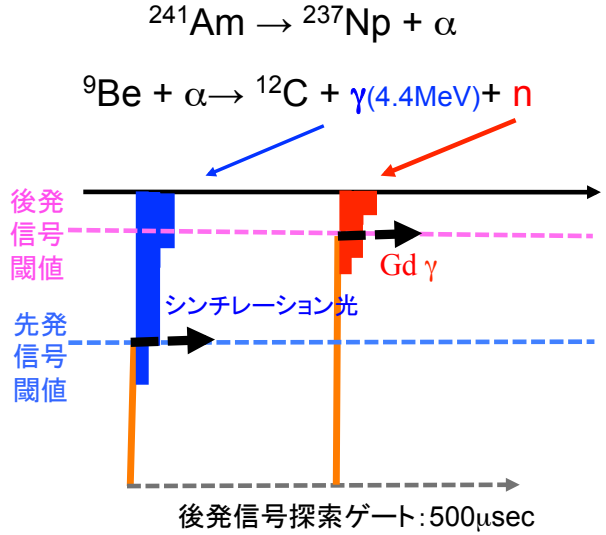
EGADS as R&D

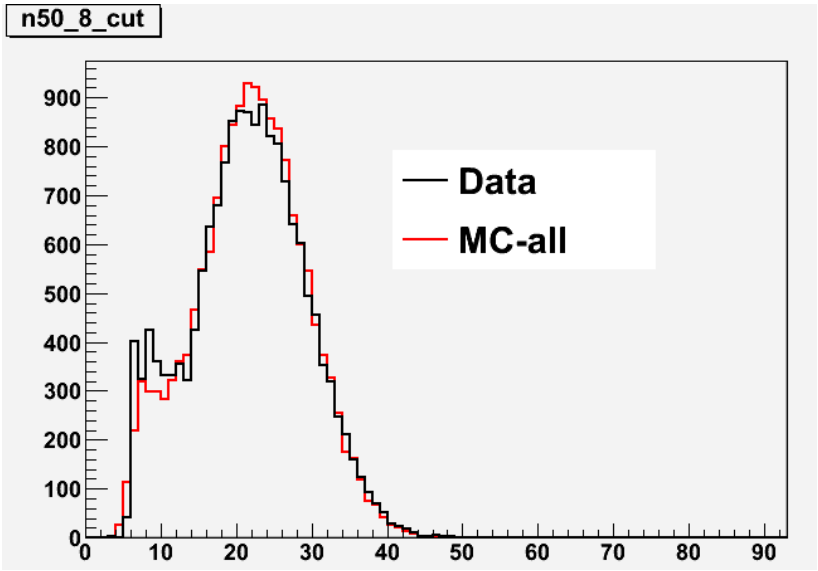


Very stable and continuous data taking

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

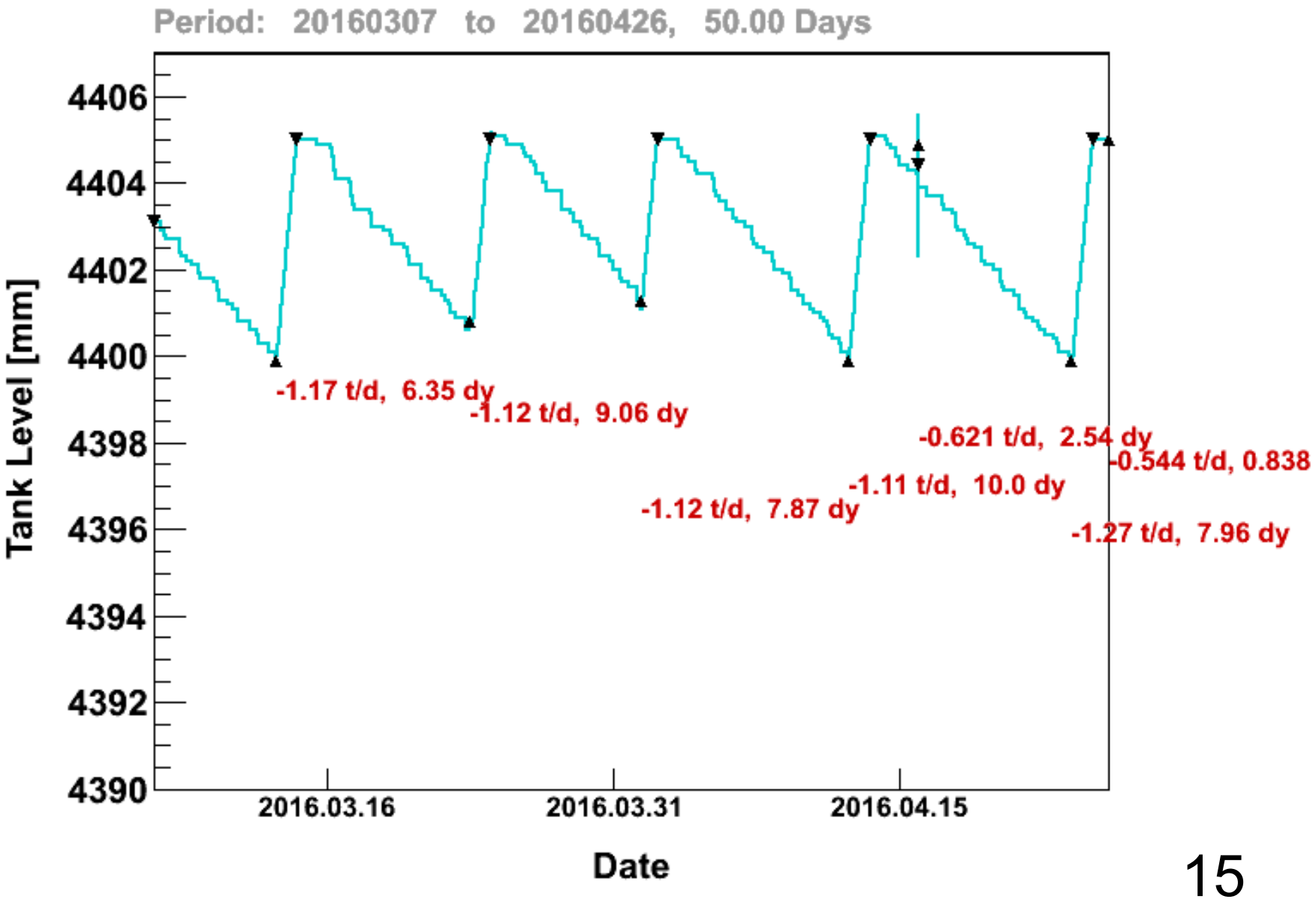
Neutron capture efficiency

Data	MC
84.36± 1.79%	84.51±0.33%

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

Remaining work toward SK-Gd

Leak fixing



15

Leak fixing

Cover all the welded places with sealing materials

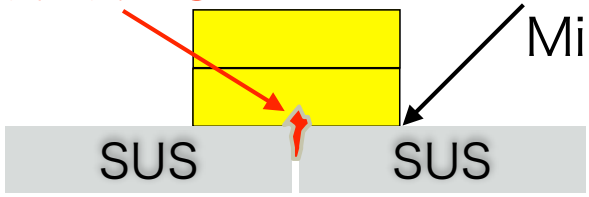
Cover with two materials.
One is BIO-SEAL 197 (epoxy resin) which sneak into small gaps, the other is 'Material' (poly-urea) which allows more displacement.

Need to wait several hours to the next step

BIO-SEAL 197

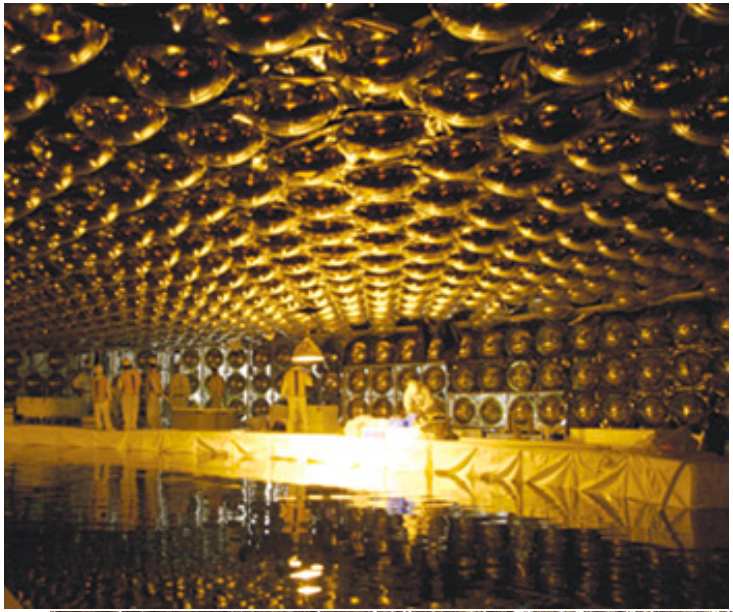
'Material' (two layers)

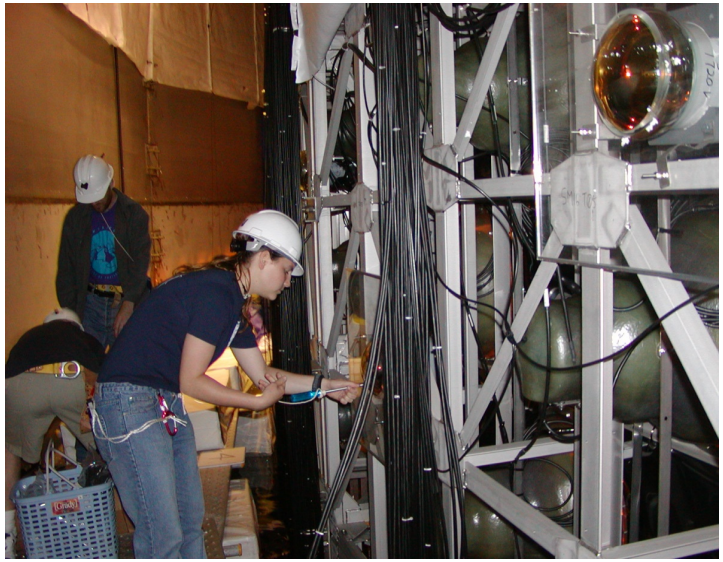
Primer between MineGuard and SUS

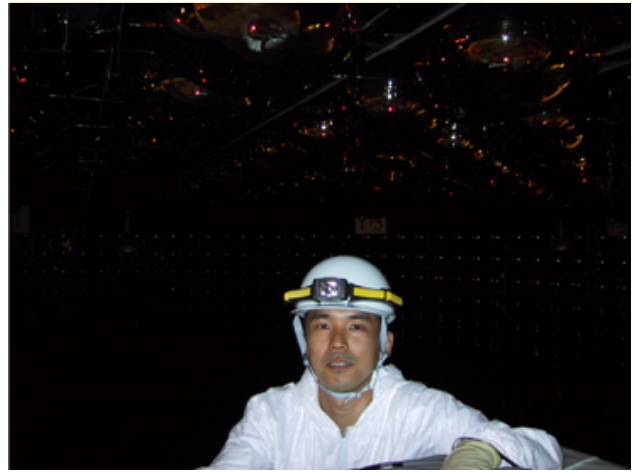


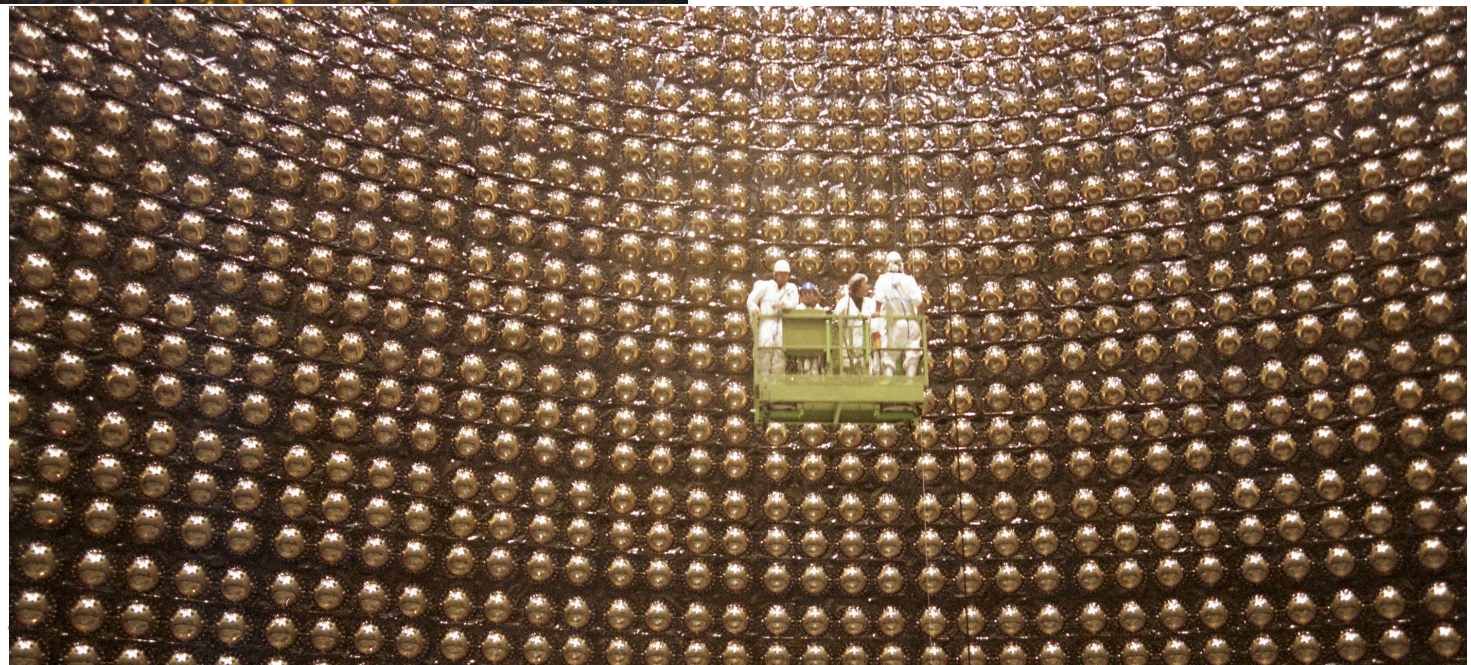
Backer as a bank to keep the coating region

Working inside the Super-K





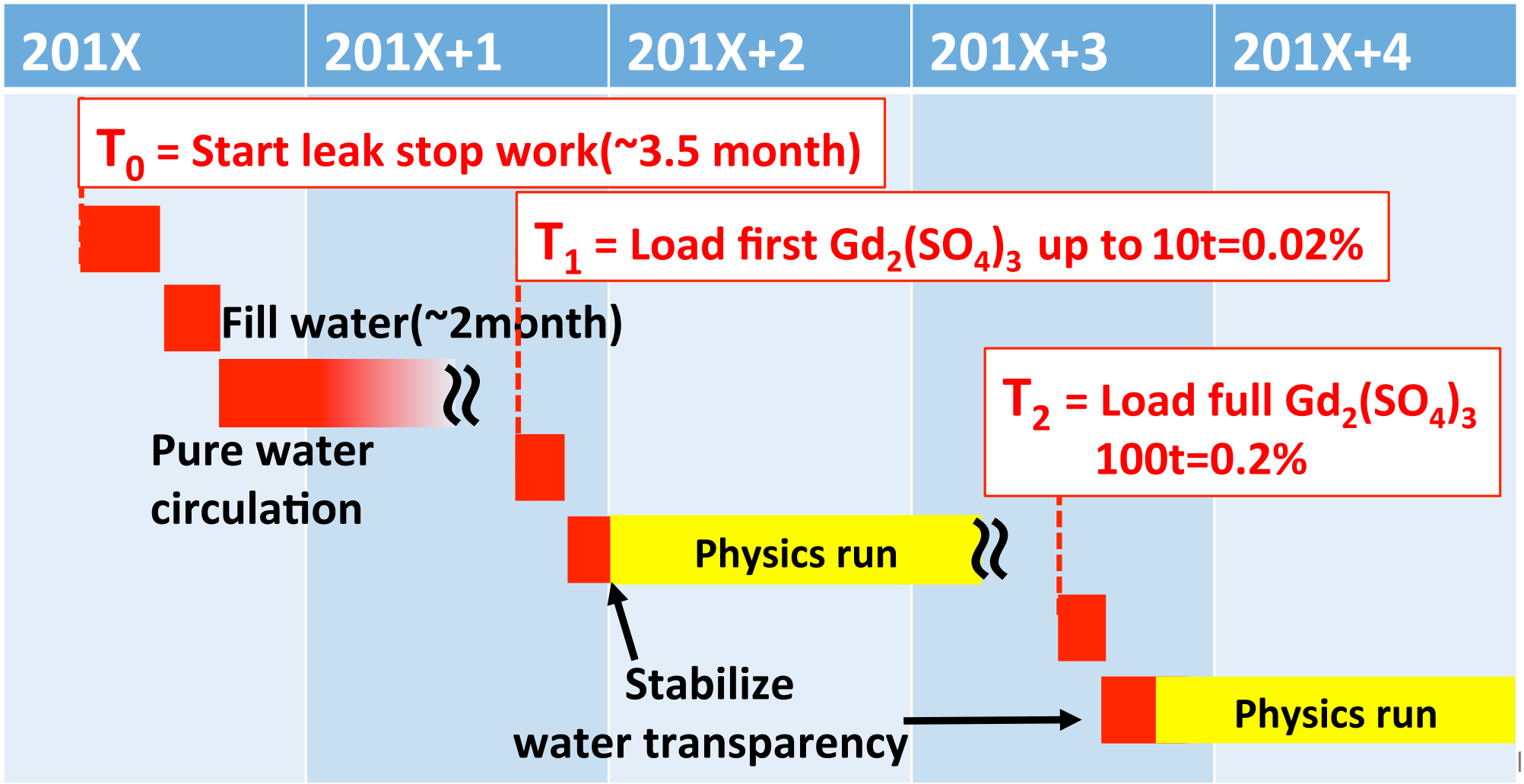




‘Super-K Gd’ or ‘SK Gd’

Time line

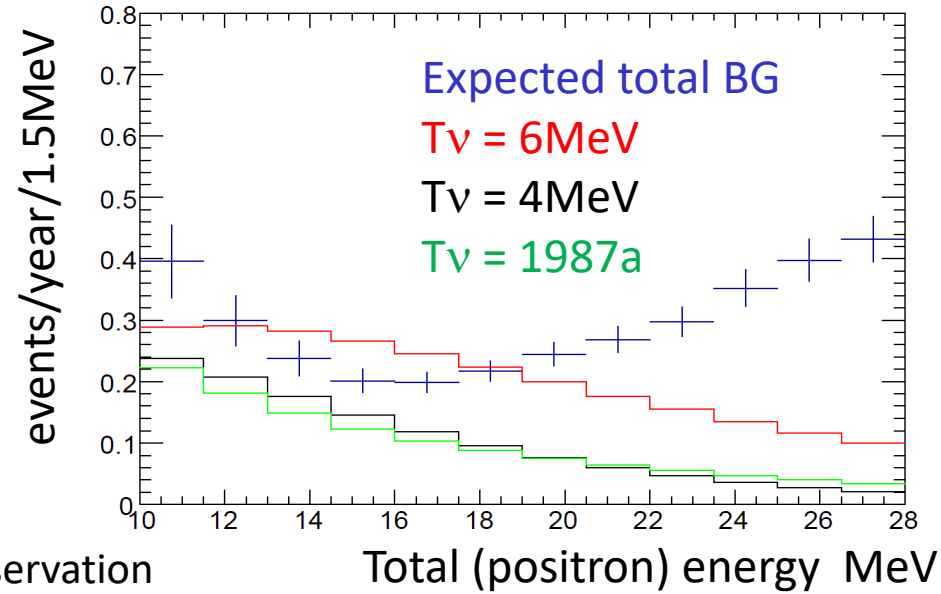
Given the current anticipated schedules, the expected time of the refurbishment is 2018.



Physics expectation in SK-Gd

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

- It depends on typical/actual SN emission spectrum

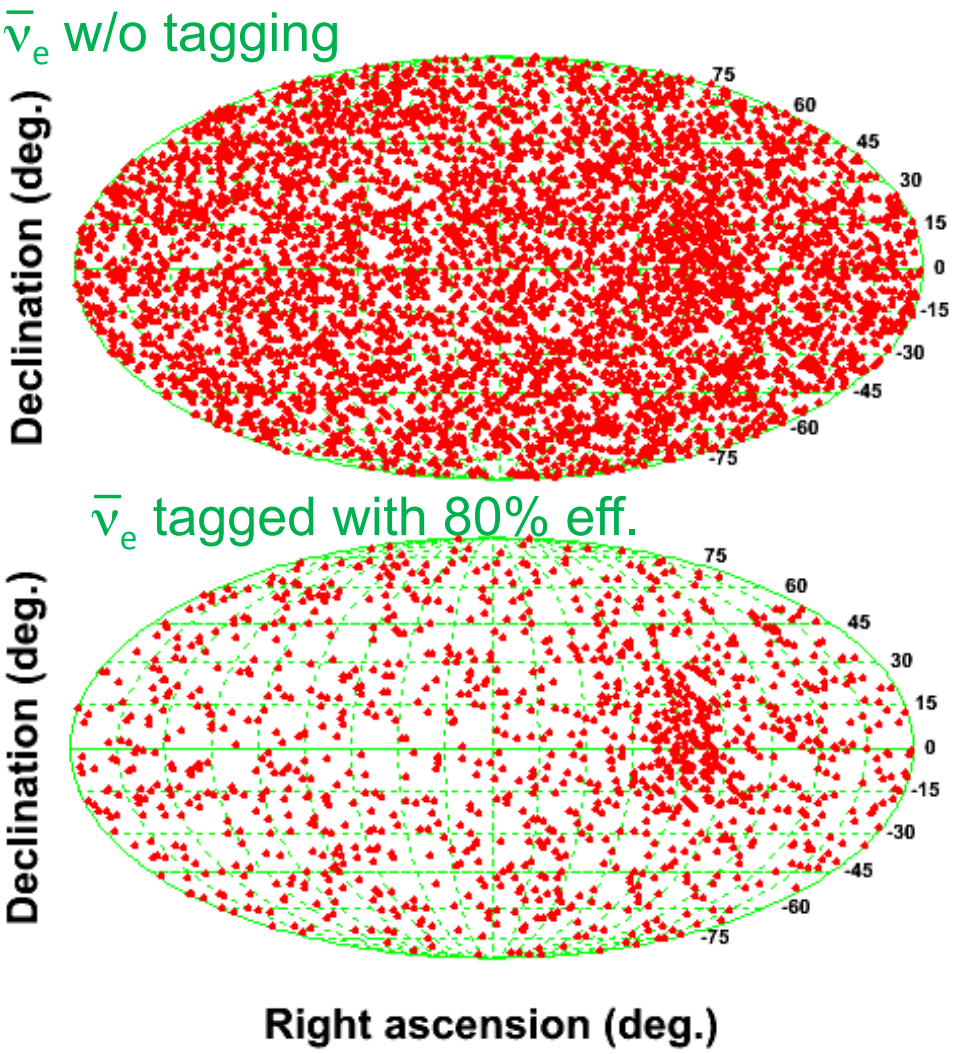


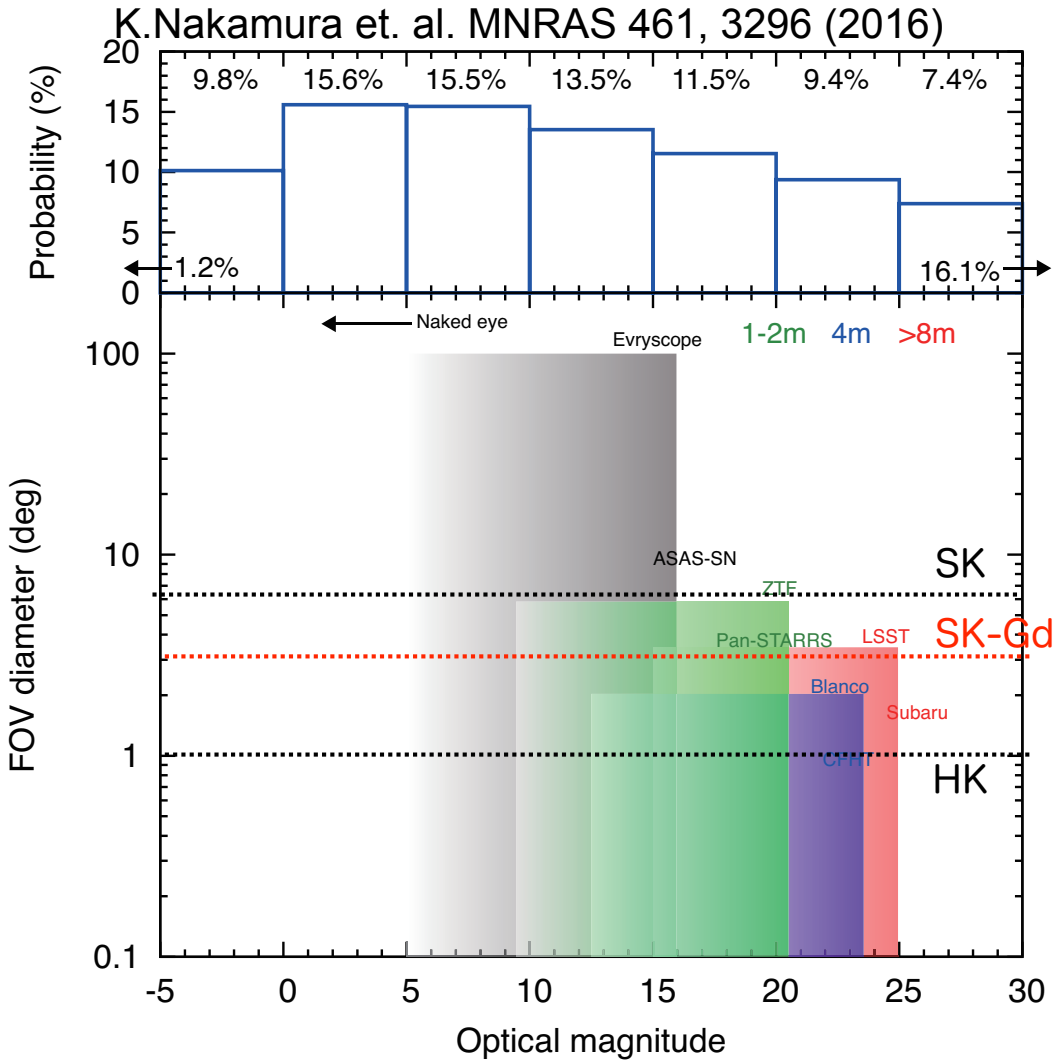
DSNB events number with 10 years observation

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



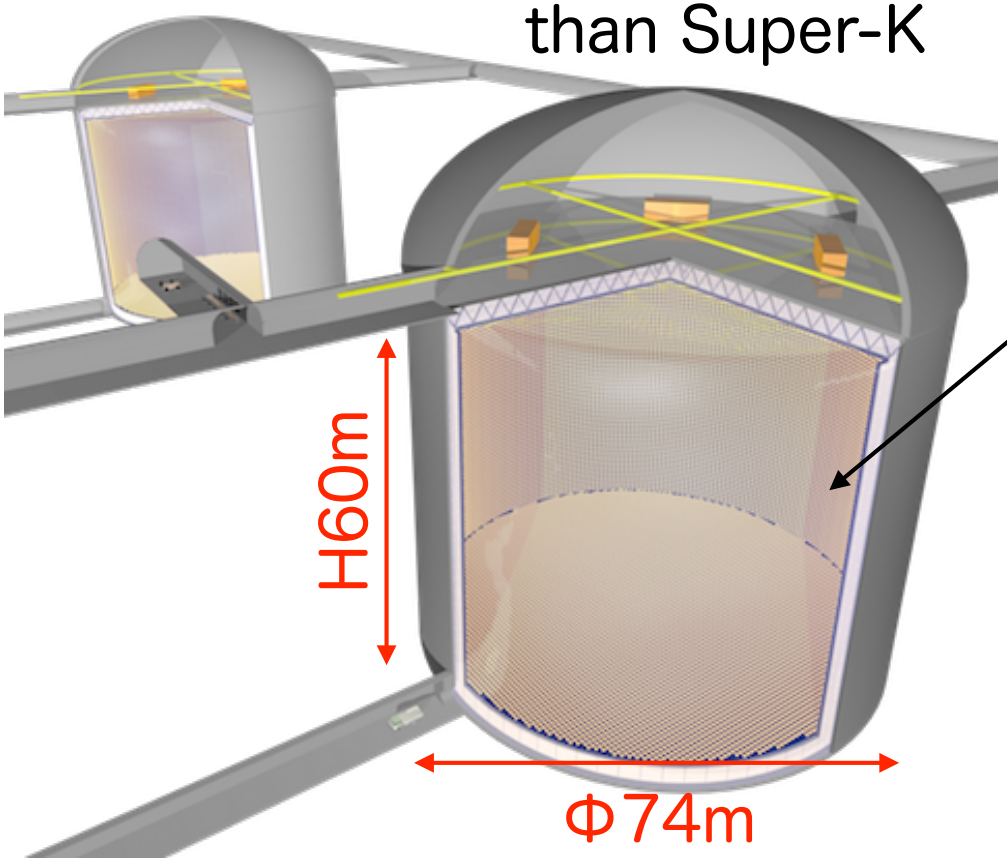


In future

Hyper-Kamiokande

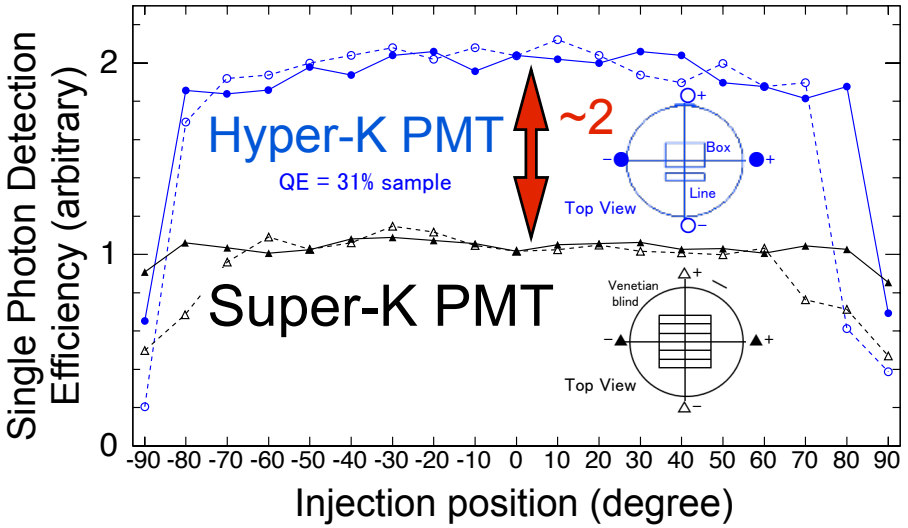
2 tanks x
with staging

~10 times larger volume
than Super-K

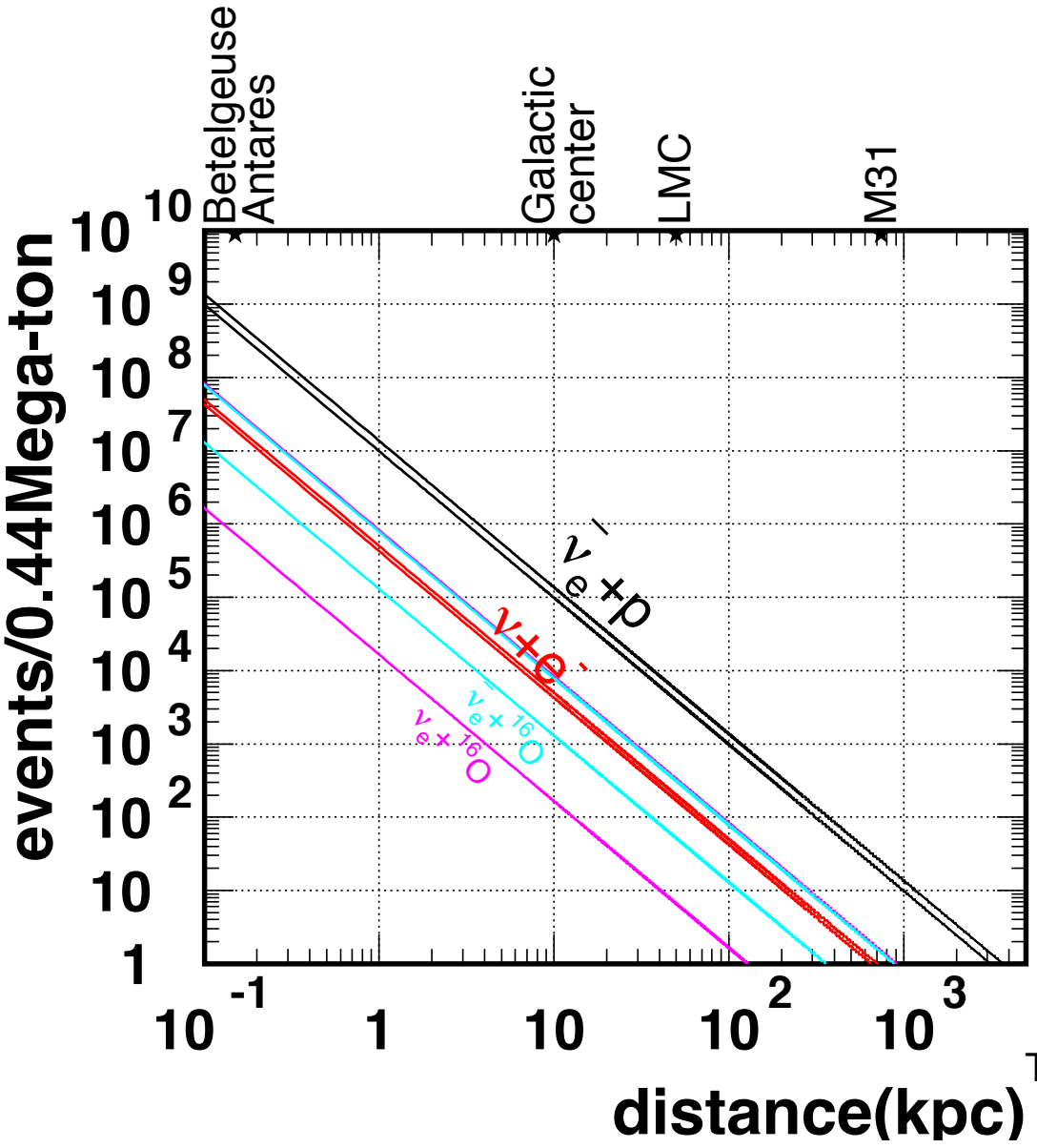


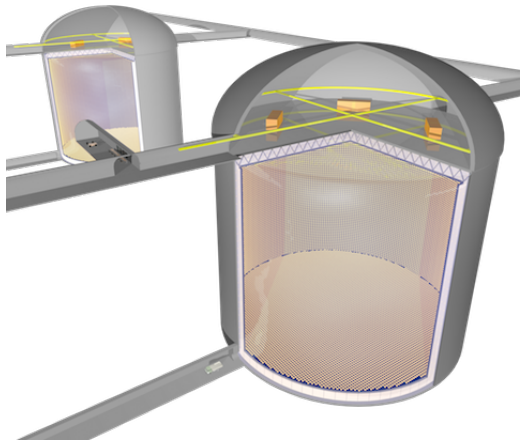
~40000 PMT / tank

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



Hyper-Kamiokande





Expected number of event

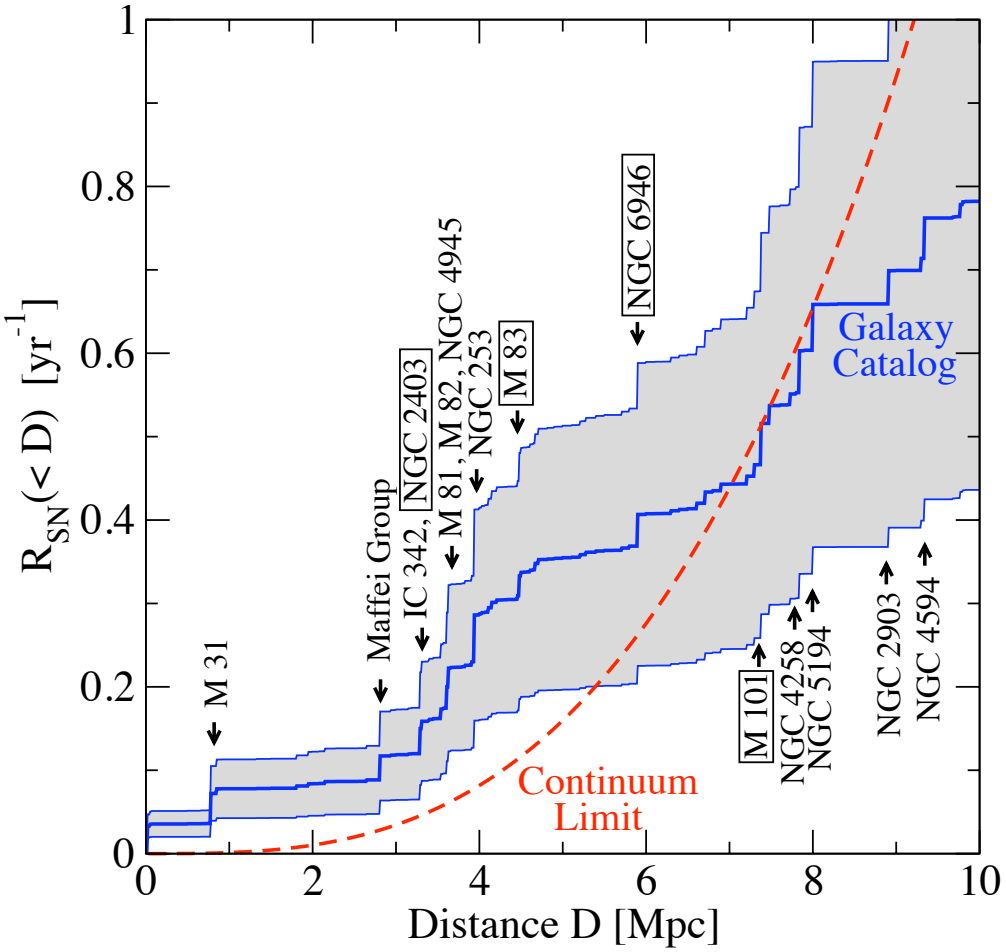
98k~136k ev (IBD)
4.2k~5k ev (νe ES)
(12~80 for neutronization)
160~8200 ev (ν_e CC)
1300~7800 ev ($\bar{\nu}_e$ CC)

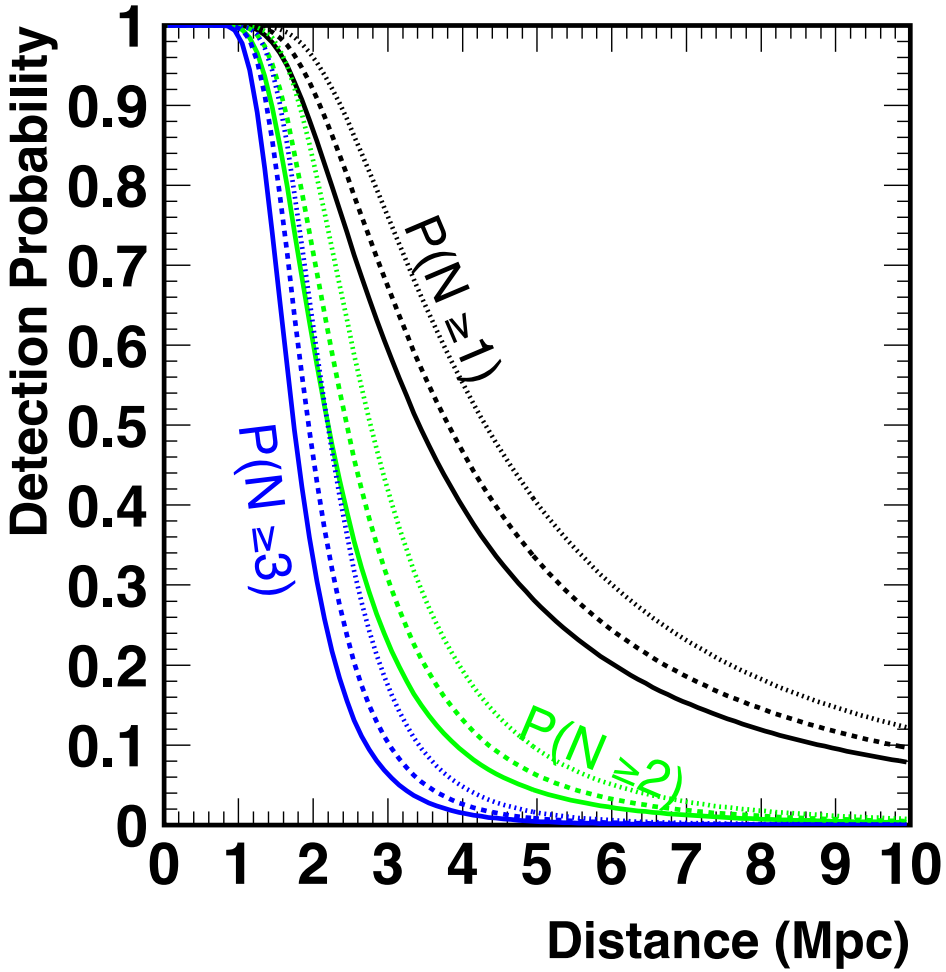
at 10kpc

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

Hyper-Kamiokande

Cumulative calculated supernova rate





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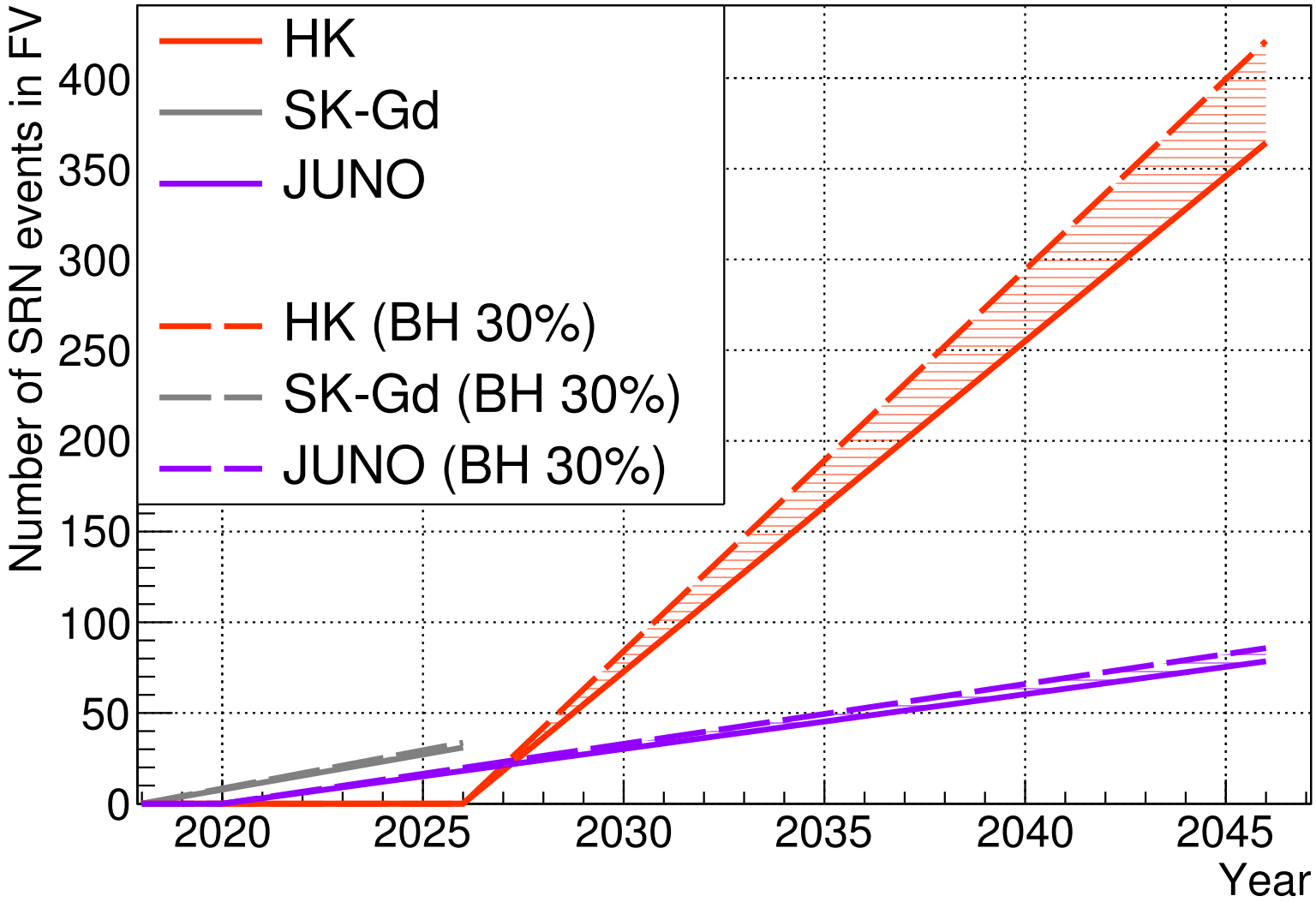
DSNB at Hyper-K

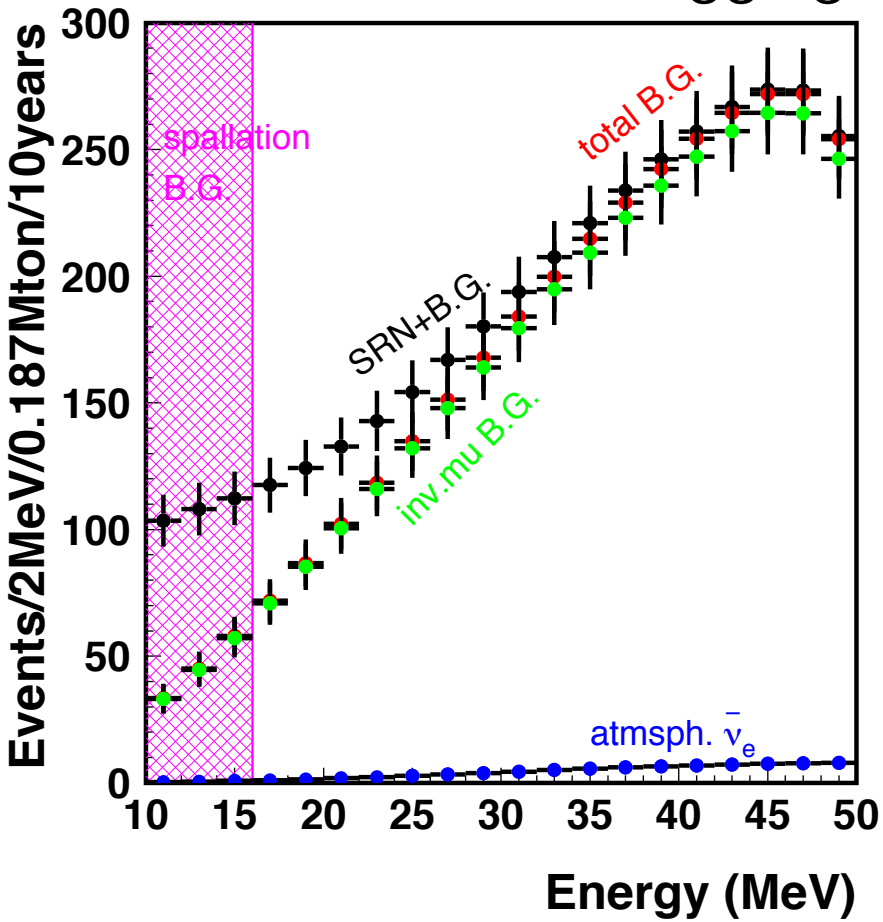
expected number of events



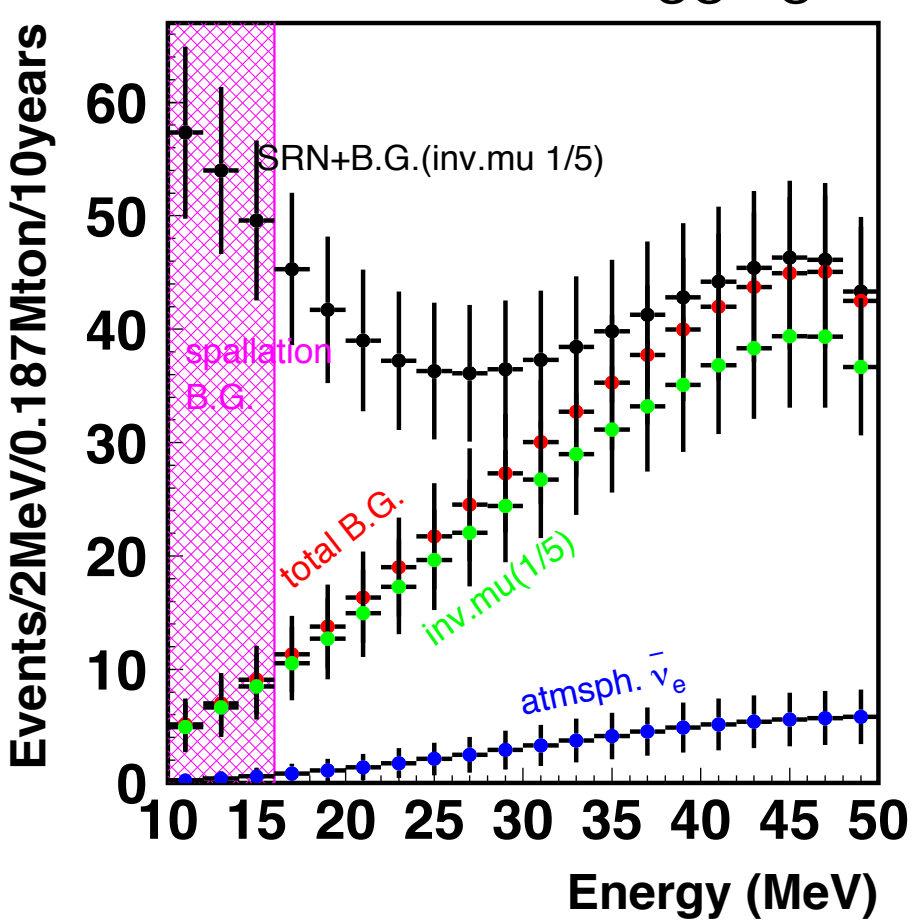
DSNB at Hyper-K

expected spectrum

without neutron tagging

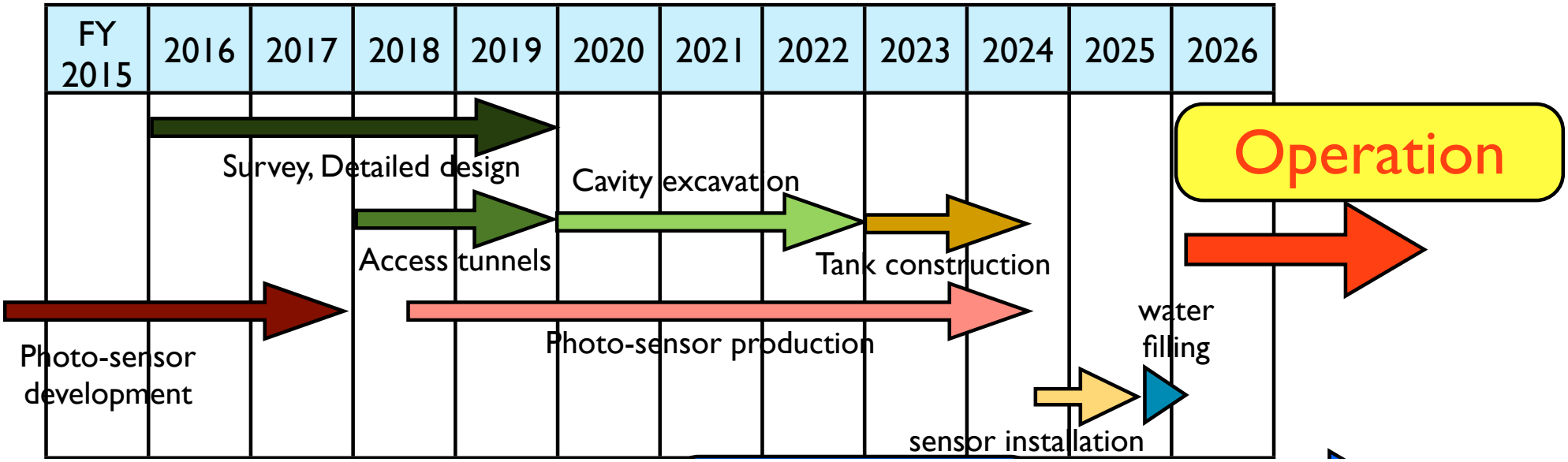


with neutron tagging



Hyper-Kamiokande

Notional timeline (1st tank)



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.


Summary
Let’s go supernova!
Thanks