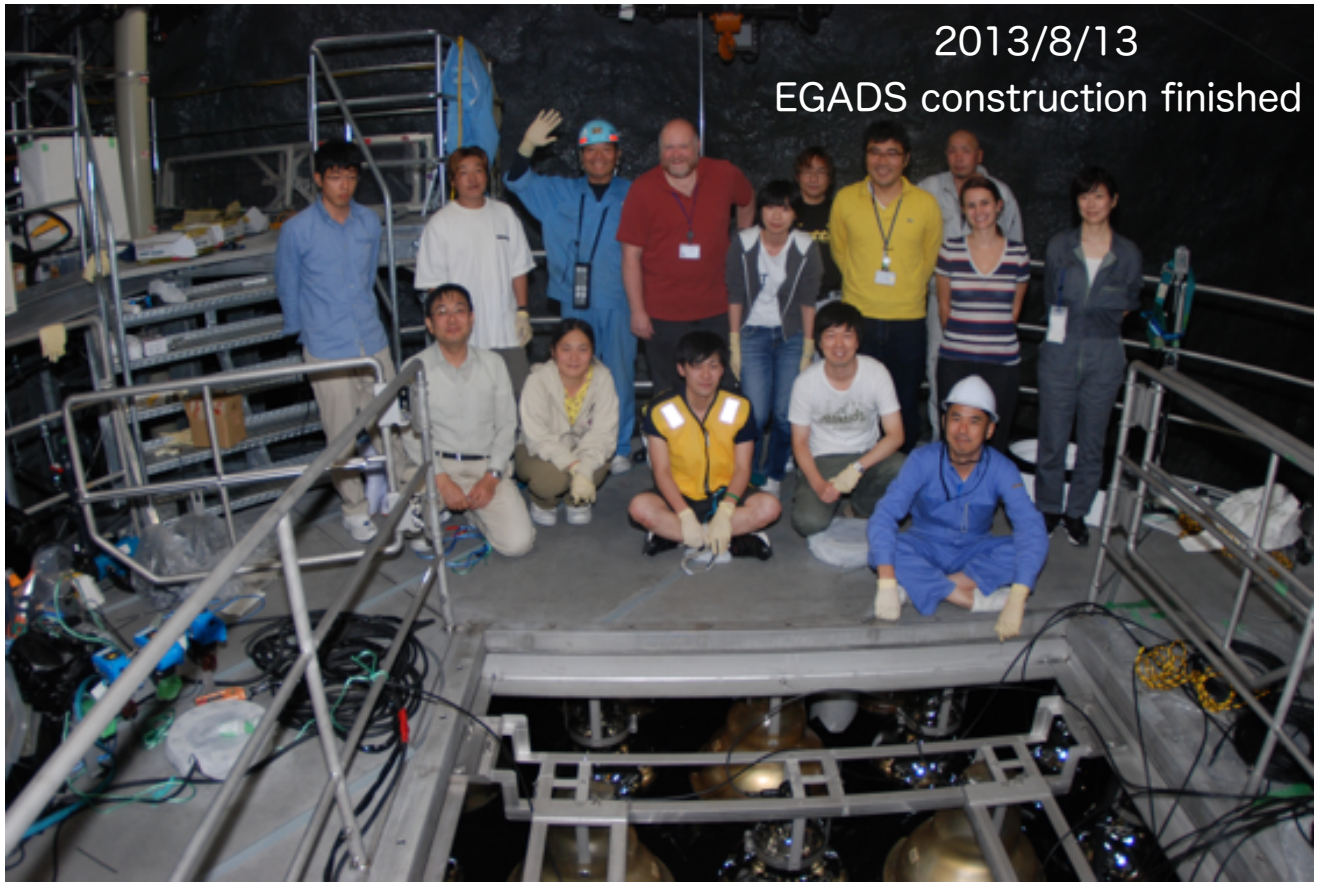
C02・Experiment
Super-K upgrade



Yusuke Koshio (Okayama U.)

Annual symposium of innovative area “GW-Genesis”
Kashiwa campus, University of Tokyo, 7th March, 2018

30 years anniversary of SN1987A

(2017)

Workshop at Koshiba hall in U.of.Tokyo
on February 12-13, 2017,
supported by the previous innovative area

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

Birthday cake

30 years anniversary of SN1987A

(2017)

Workshop at Koshiba hall in U.of.Tokyo
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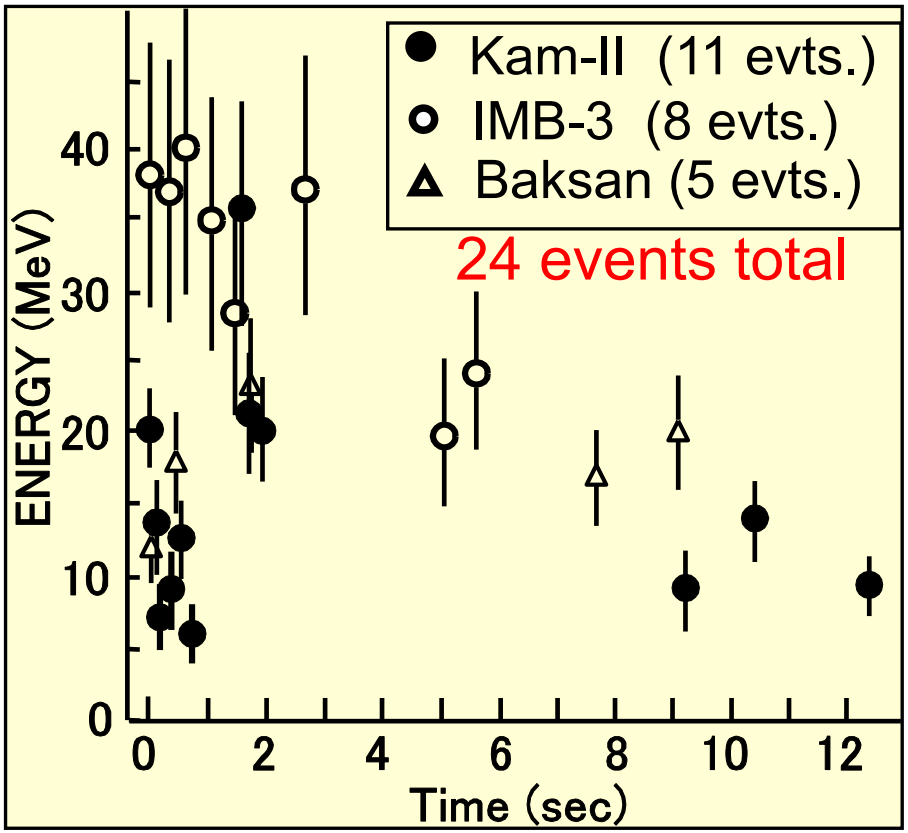


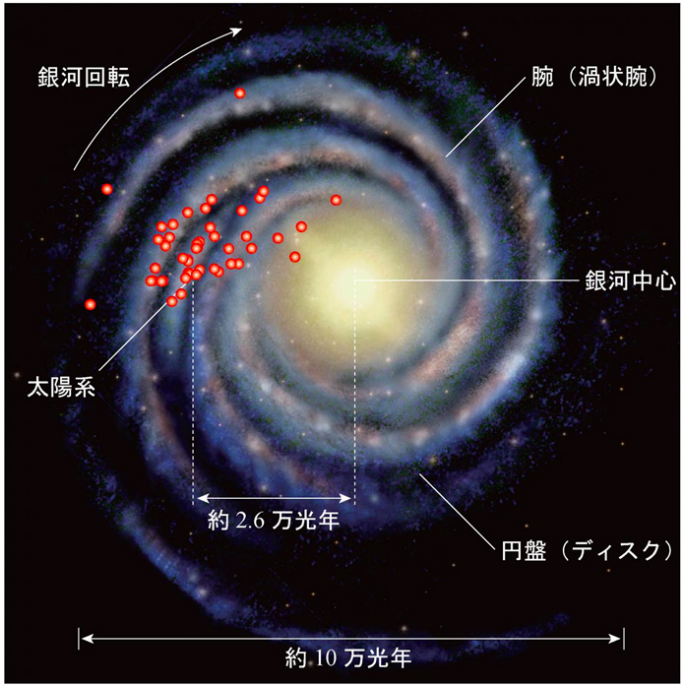
http://www-sk.icrr.u-tokyo.ac.jp/indico/conferenceDisplay.py?confId=2935

No Supernova neutrino detection since then..

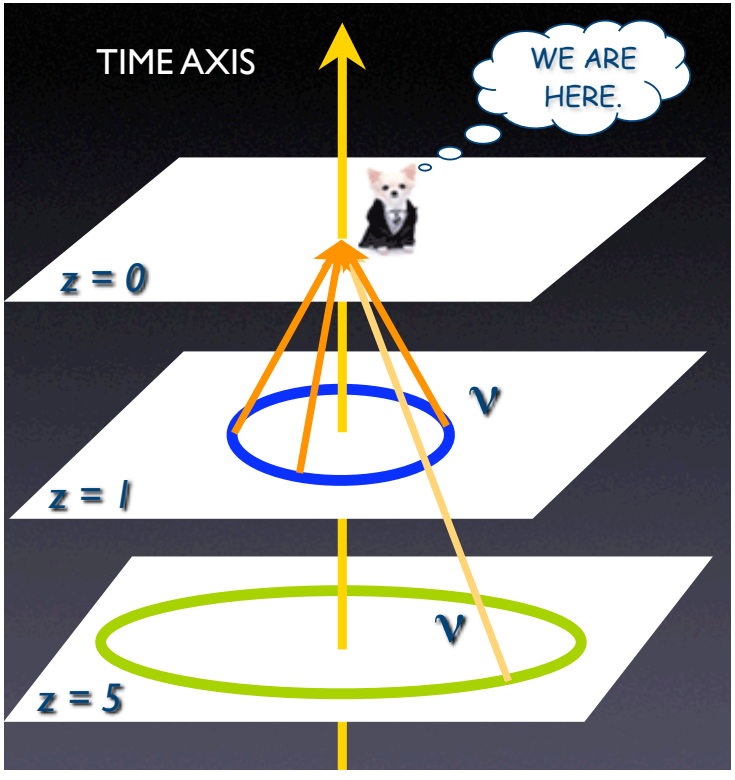
No chance for Supernova neutrino detection for next hundred's years?

We believe, yes!

Galactic Supernova burst (a few per century)

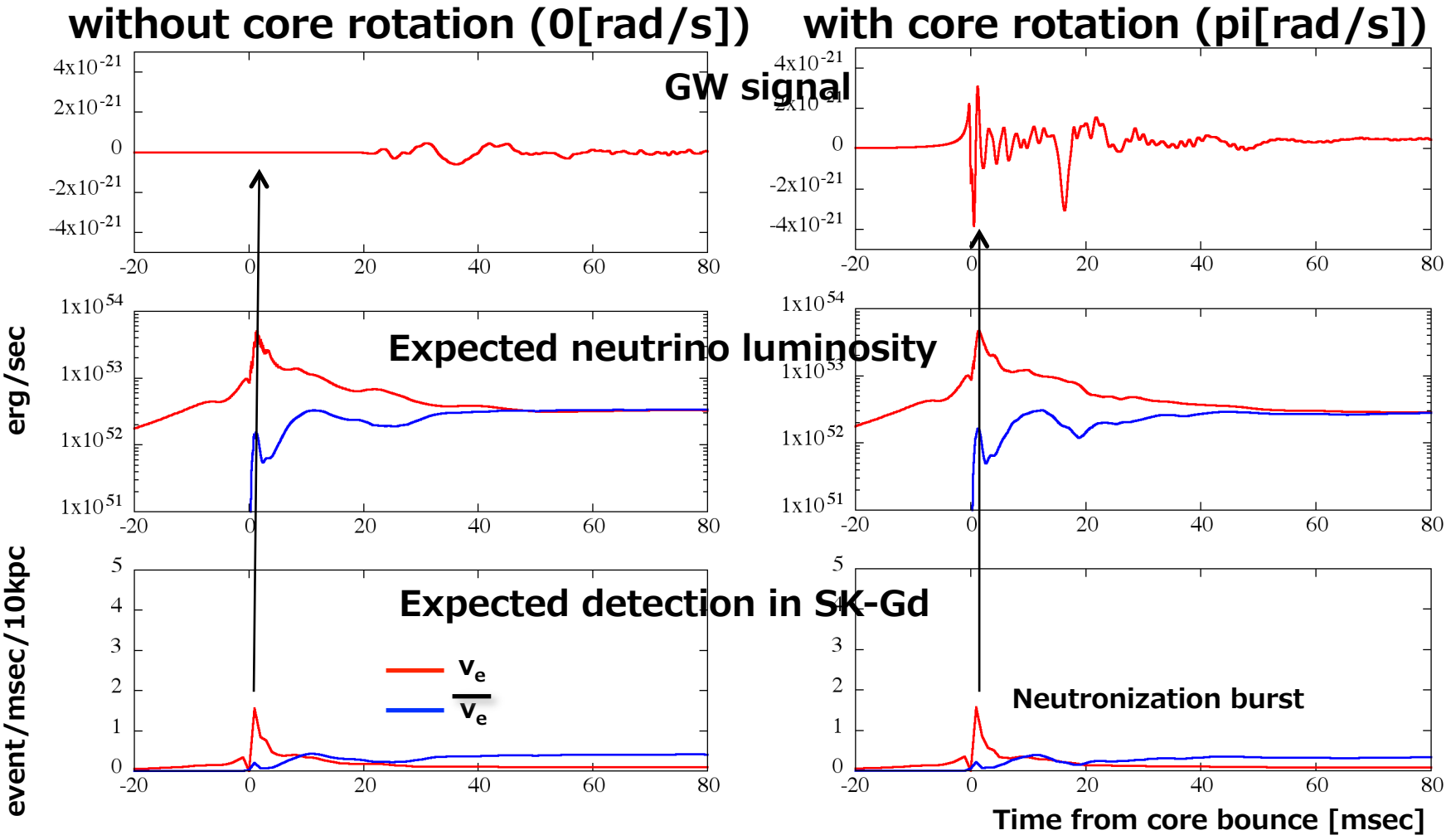


Diffuse Supernova Neutrino Background

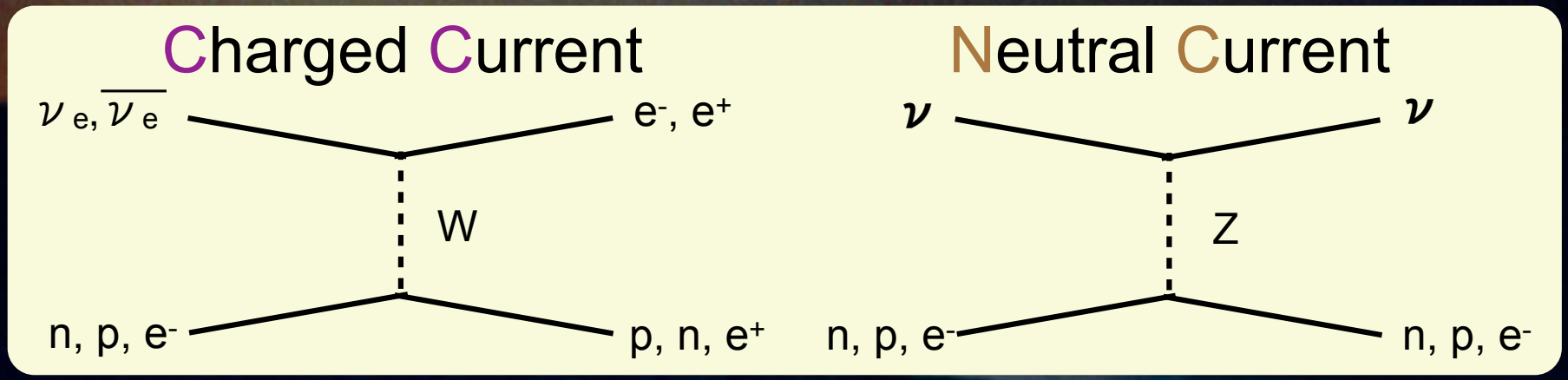


Why important for CCSNe?

ApJ 811, 86 (2015)



Neutrino interaction for supernova neutrino detection



Neutrino interaction for SN ν

Inverse beta decay

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

✓ Detect positron signal in water, scintillator, etc.

✓ $\overline{\nu}_e$ sensitive

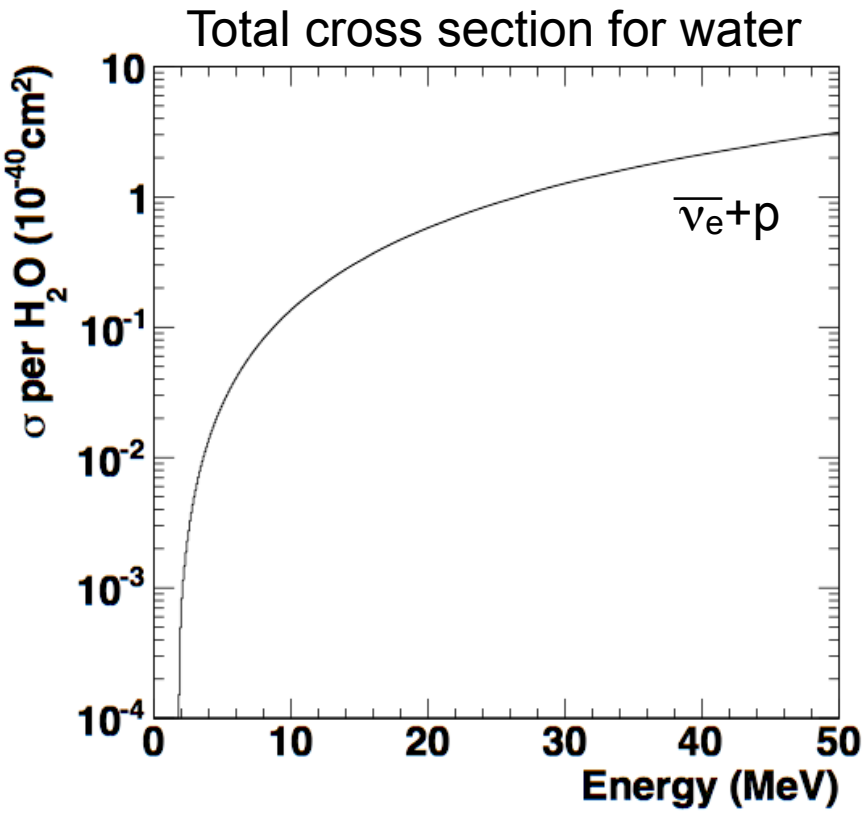
✓ Obtain the neutrino energy from the positron energy

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

✓ Well known and large cross section

✓ Neutron tagging using delayed coincidence

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



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

Neutrino interaction for SN ν

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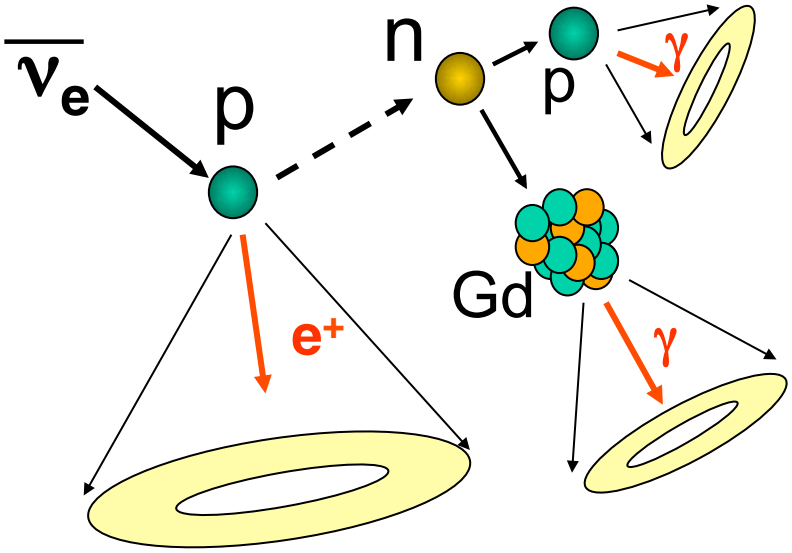


Neutrino interaction for SN ν

Elastic scattering

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

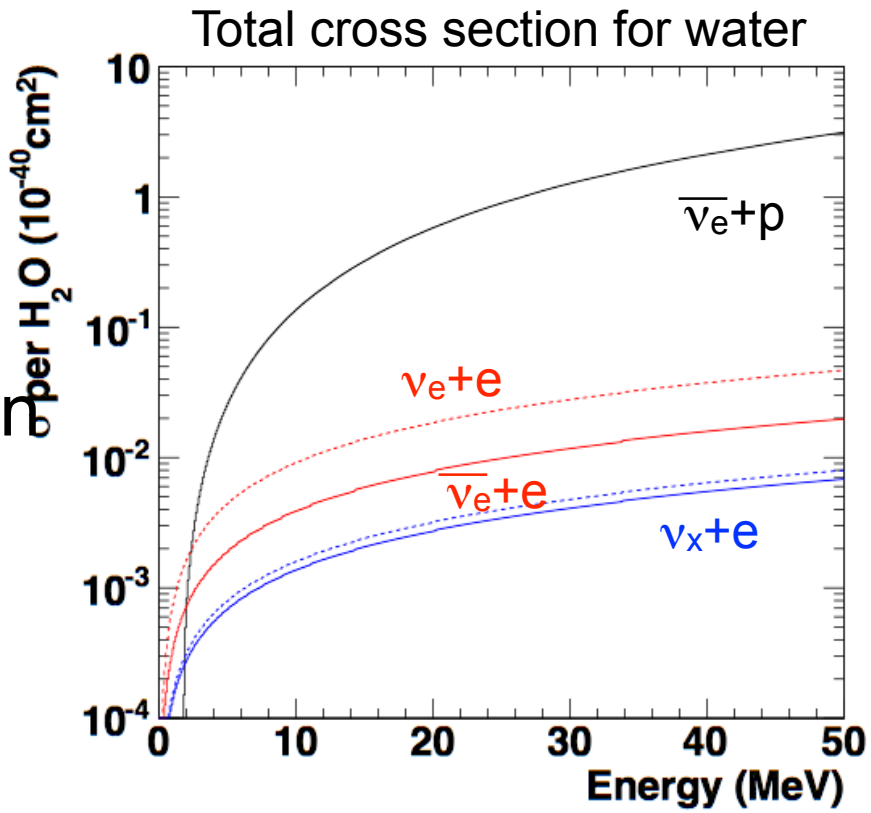
✓ Detect recoil electron signal in water, scintillator, etc.

✓ All neutrinos are sensitive

✓ Measurable for only recoil electron energy, not neutrino energy

✓ Well known cross section, few % of inverse beta decay

✓ Good directionality

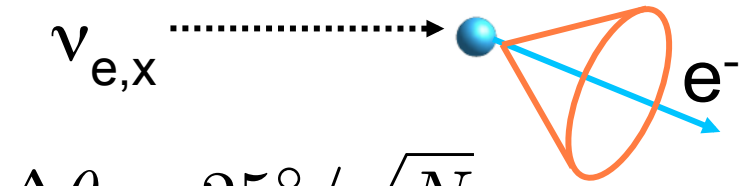


Neutrino interaction for SN ν

Elastic scattering

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

Water Cherenkov



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

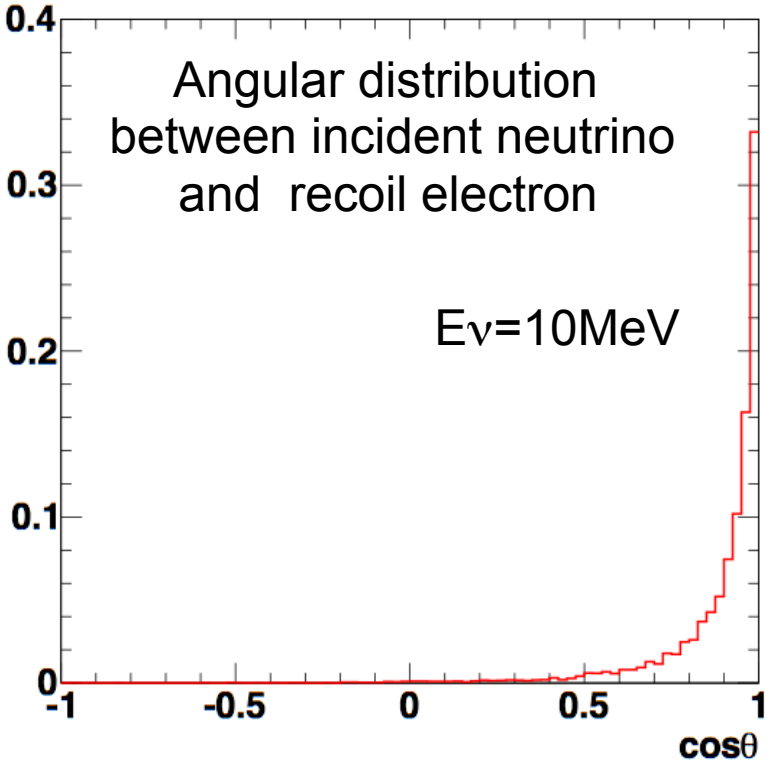
✓ Detect recoil electron signal in water, scintillator, etc.

✓ All neutrinos are sensitive

✓ Measurable for only recoil electron energy, not neutrino energy

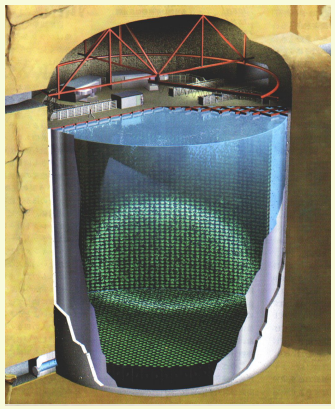
✓ Well known cross section, few % of inverse beta decay

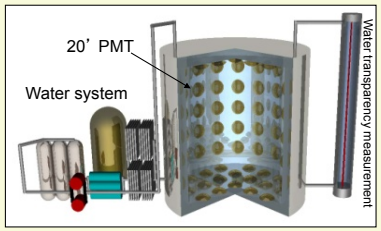
✓ Good directionality

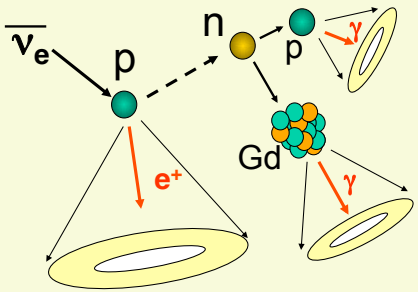


SN search at Super-Kamiokande

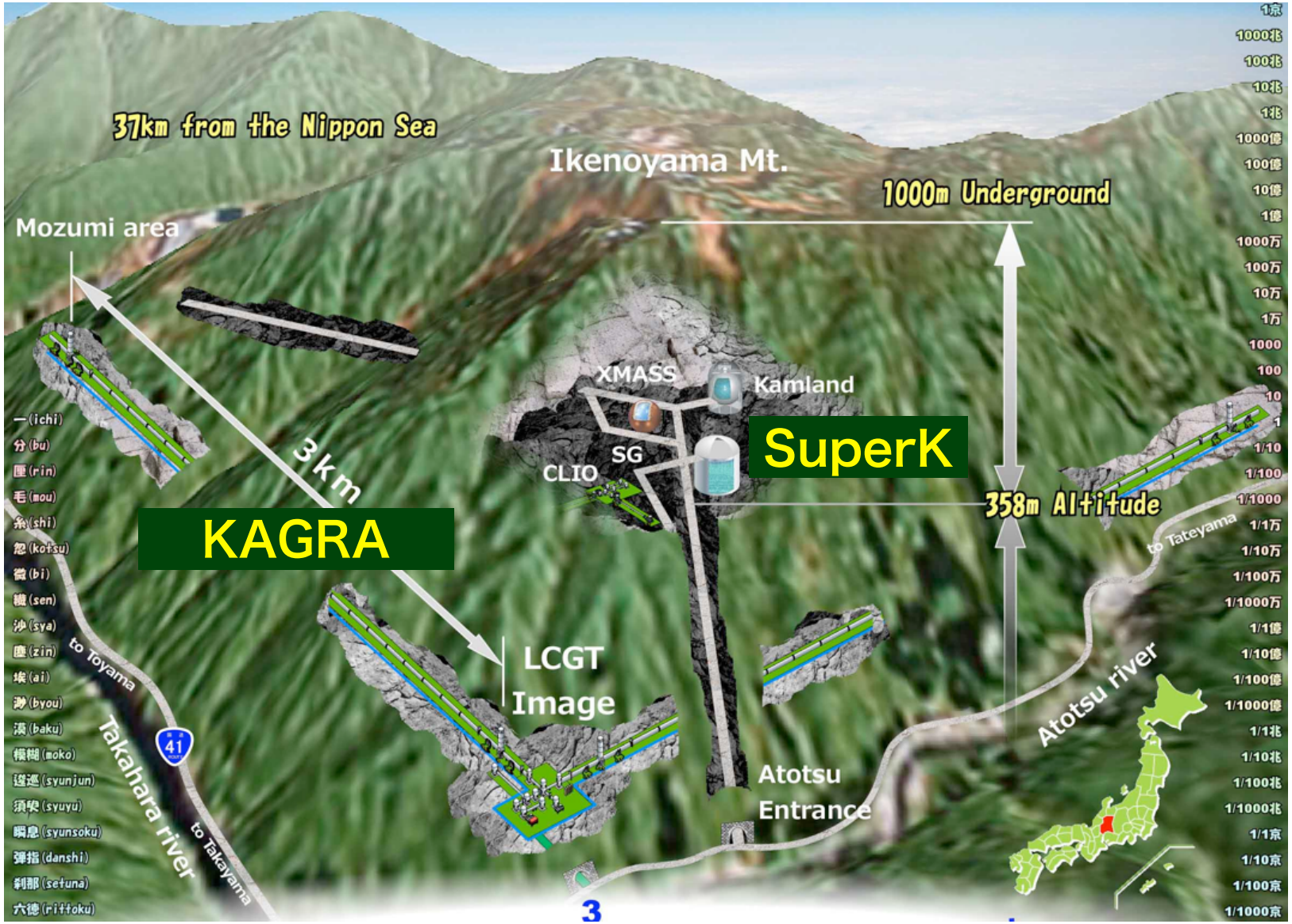
Super-K to SK-Gd





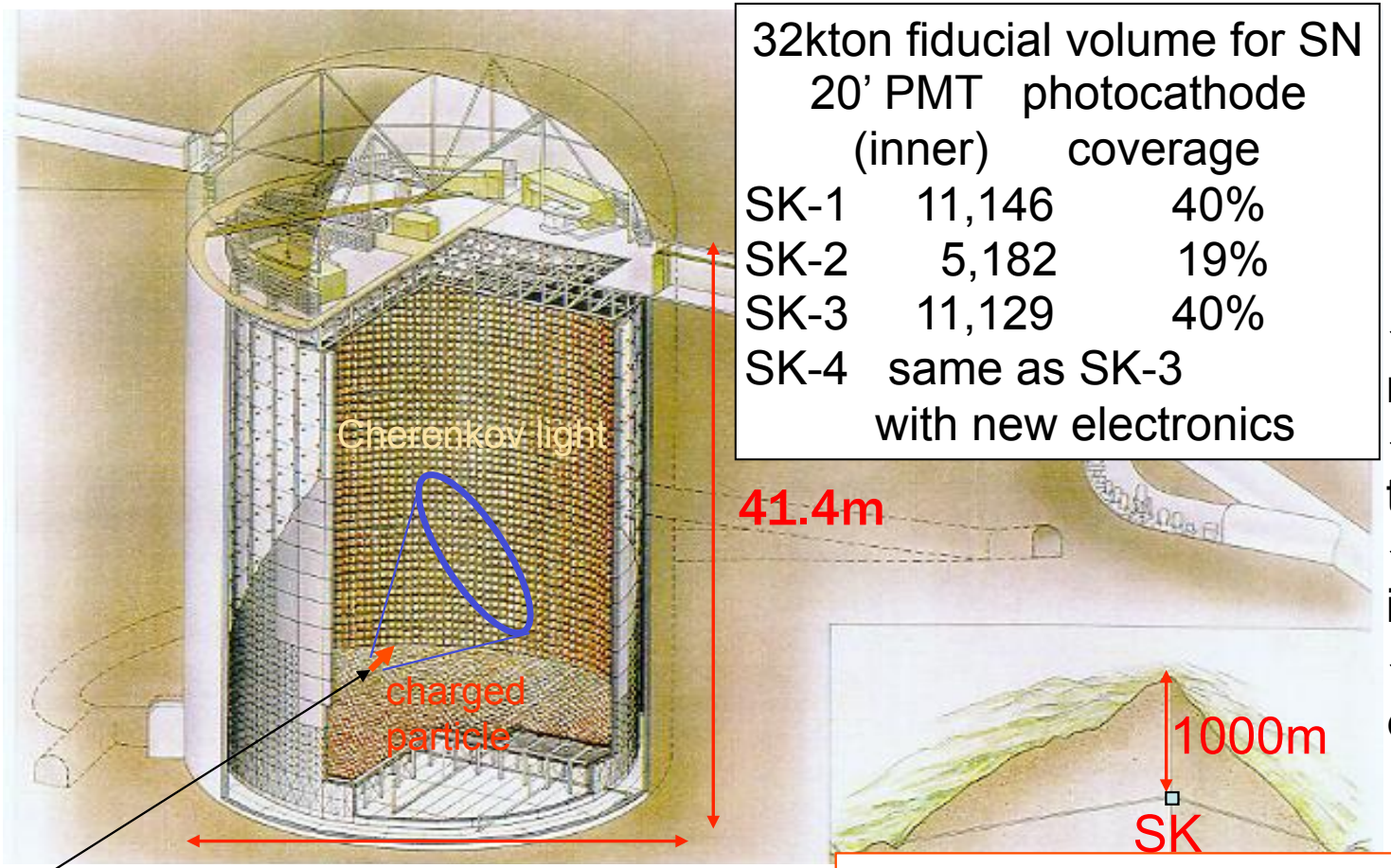


Kamioka underground detectors



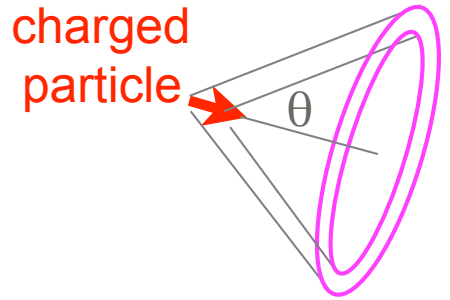
Super-Kamiokande

50kton Water Cherenkov detector

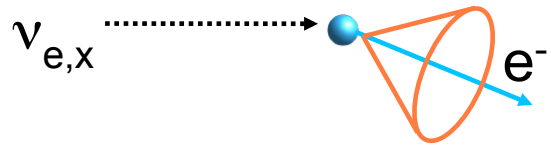


32kton fiducial volume for SN		
	20' PMT (inner)	photocathode coverage
SK-1	11,146	40%
SK-2	5,182	19%
SK-3	11,129	40%
SK-4	same as SK-3 with new electronics	

Placed inside the Kamioka mine
1000m underground

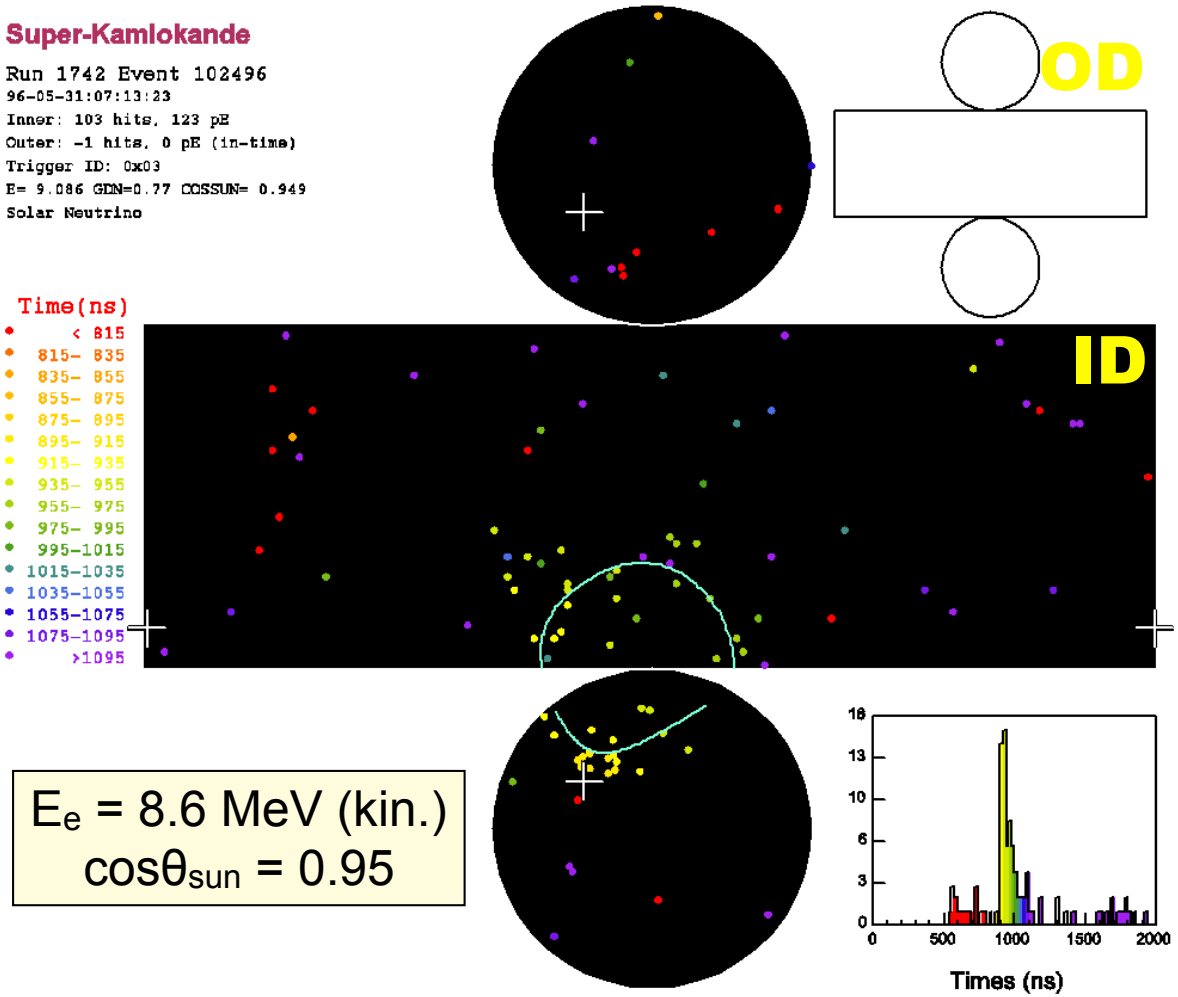


✓ Underground in Kamioka mine, (almost BG free)
✓ 3.5MeV energy threshold for recoil electron
✓ Dominant process is inverse beta decay
✓ Good directionality for νe elastic scattering



Super-Kamiokande

For supernova neutrinos (~MeV)



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

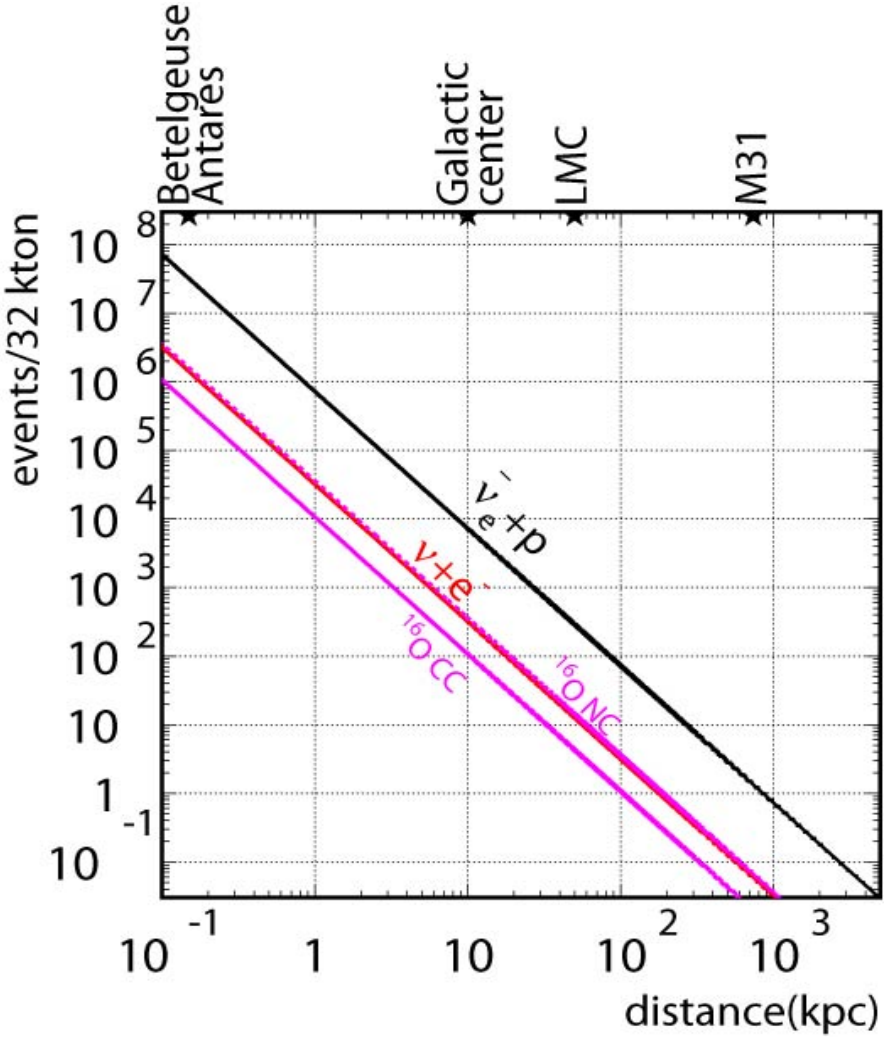
How to reconstruct?

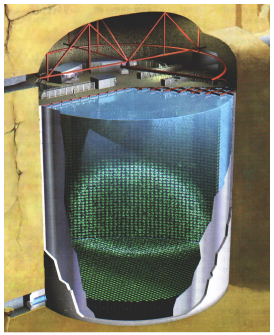
Detector performance

Information	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)

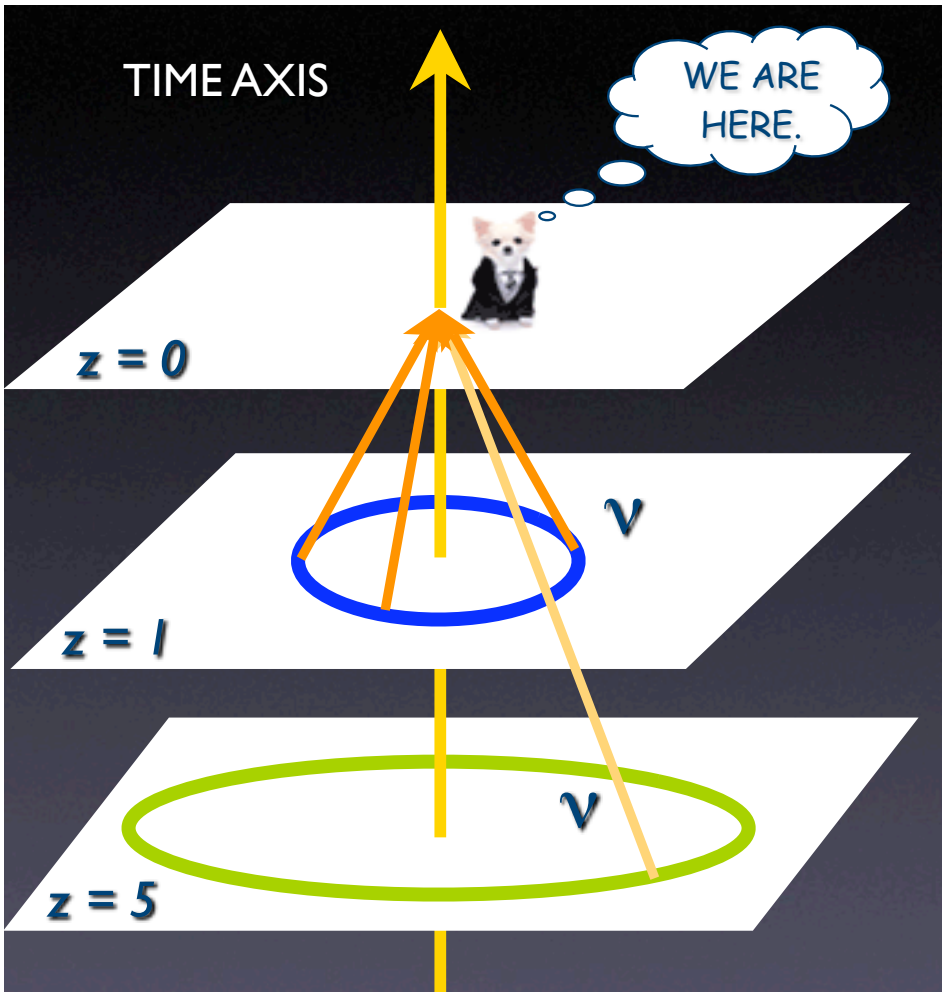
at 10kpc, 4.5MeV energy threshold

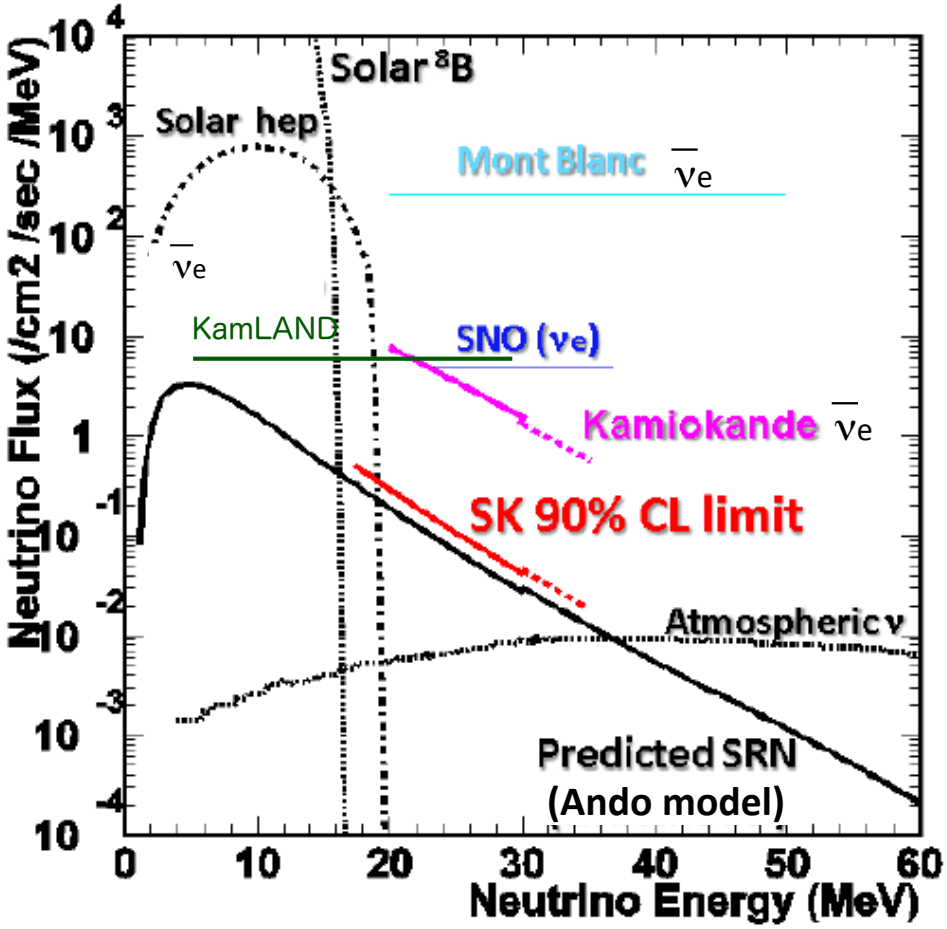
Livermore simulation
Totani, Sato, Dalhed, Wilson, ApJ. 496 (1998) 216

Diffuse Supernova Neutrino Background (DSNB)

Neutrinos emitted from past supernovae

S.Ando

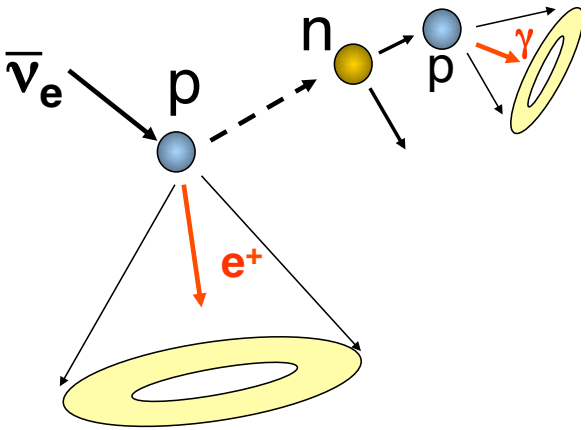




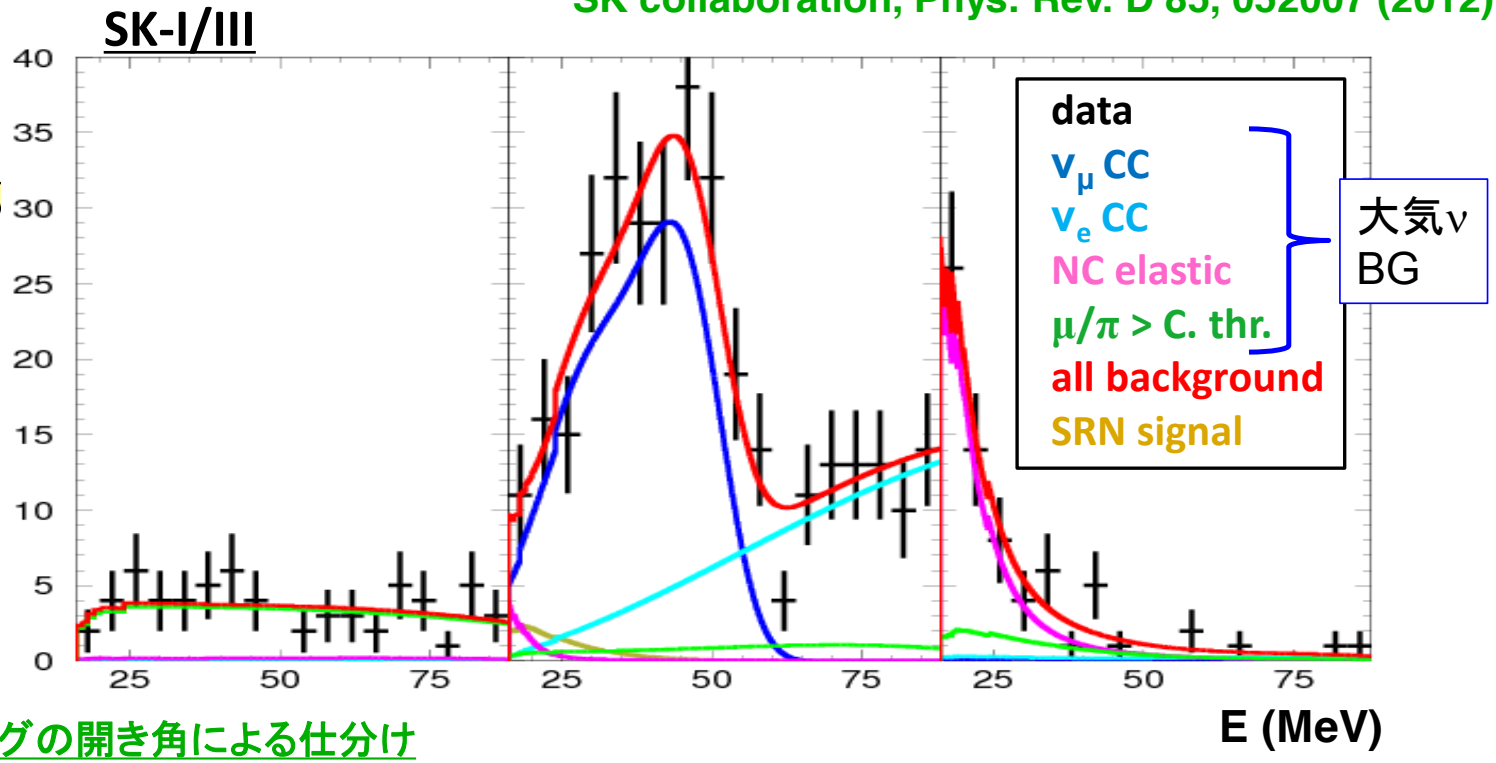
DSNB in Super-K

Current Super-K w/o neutron tagging

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

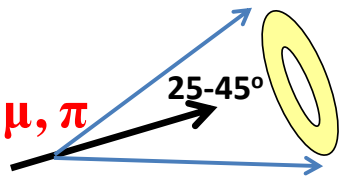


Only this signal

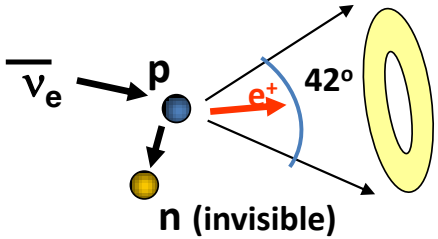


リングの開き角による仕分け

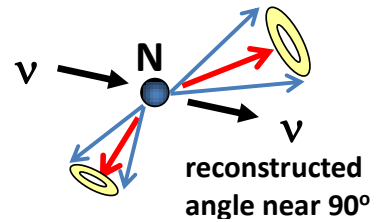
Low angle events



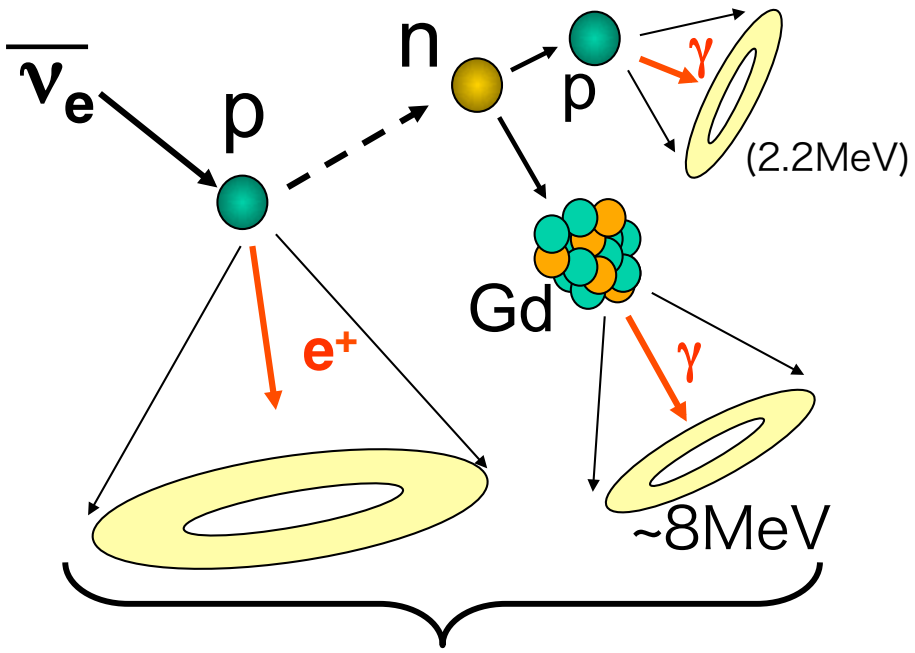
Signal Events



Isotropic Events



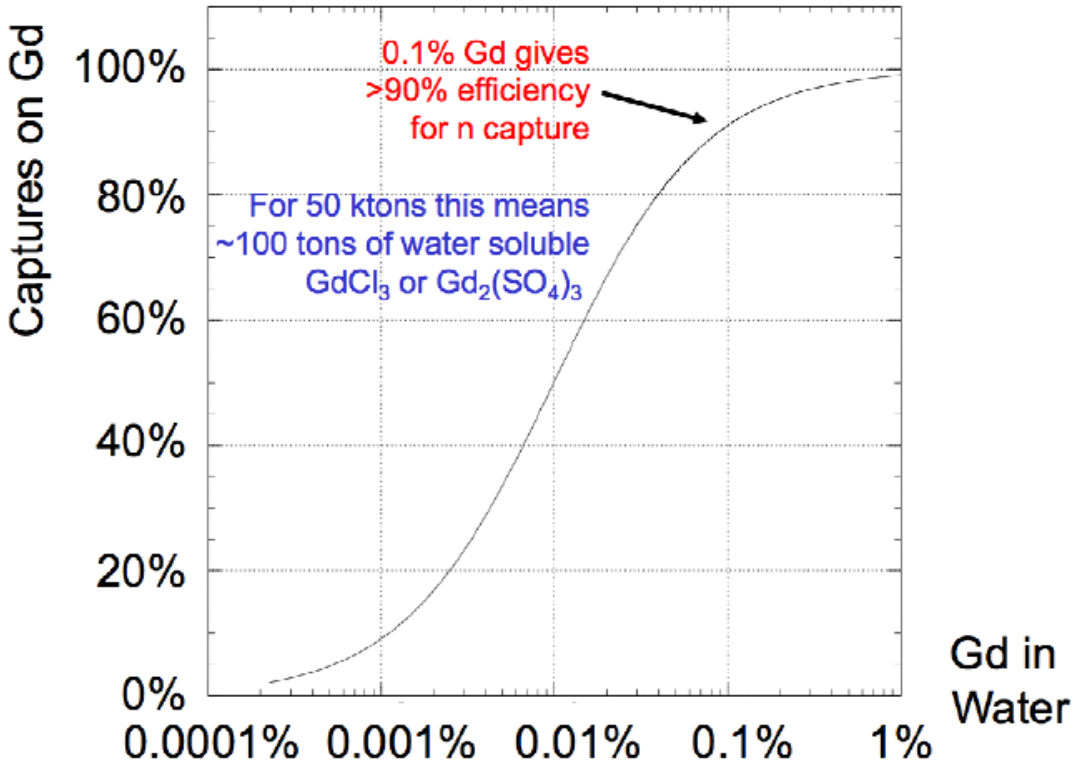
DSNB in upgraded Super-K



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

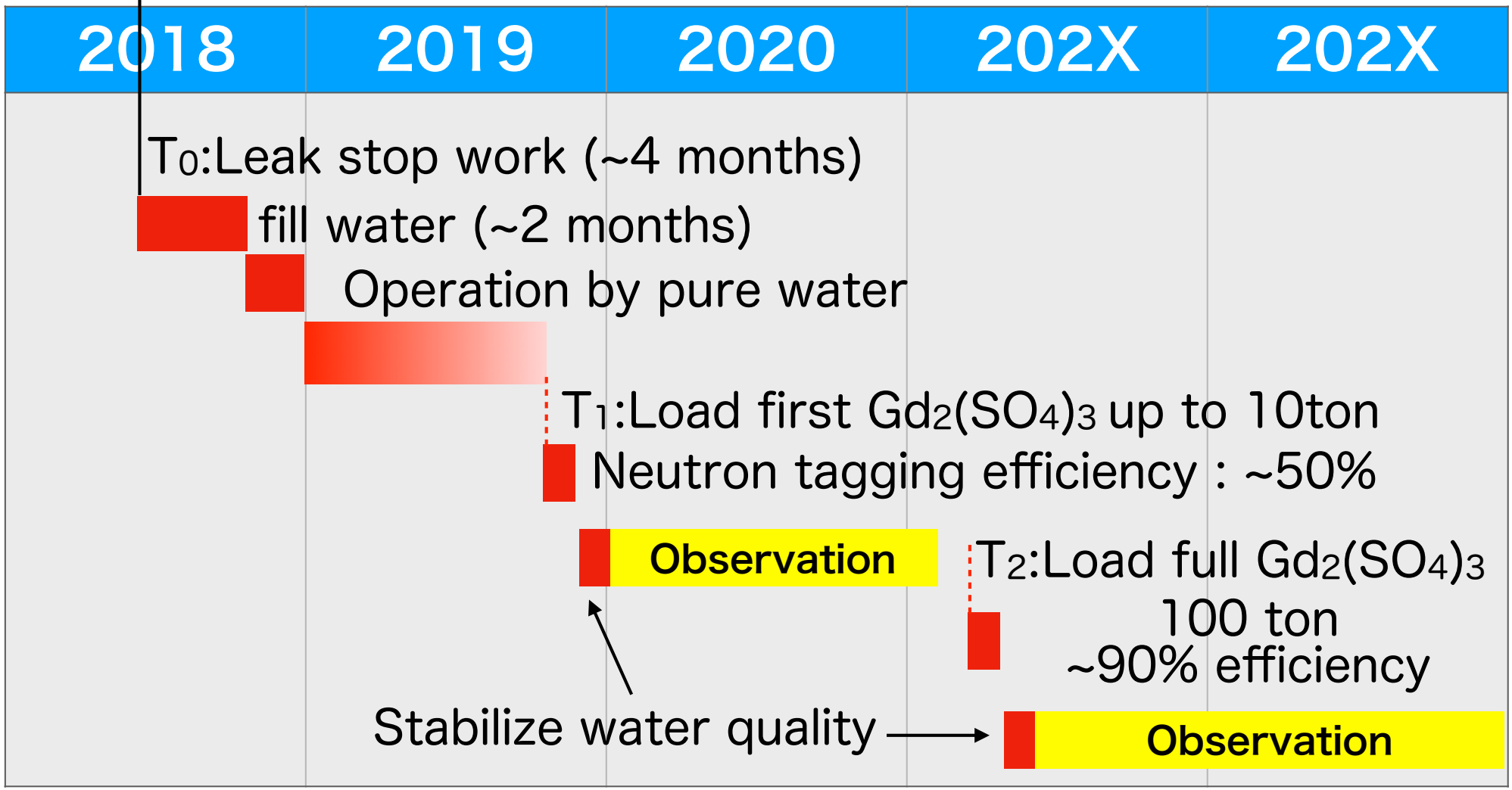
GADZOOKS!

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

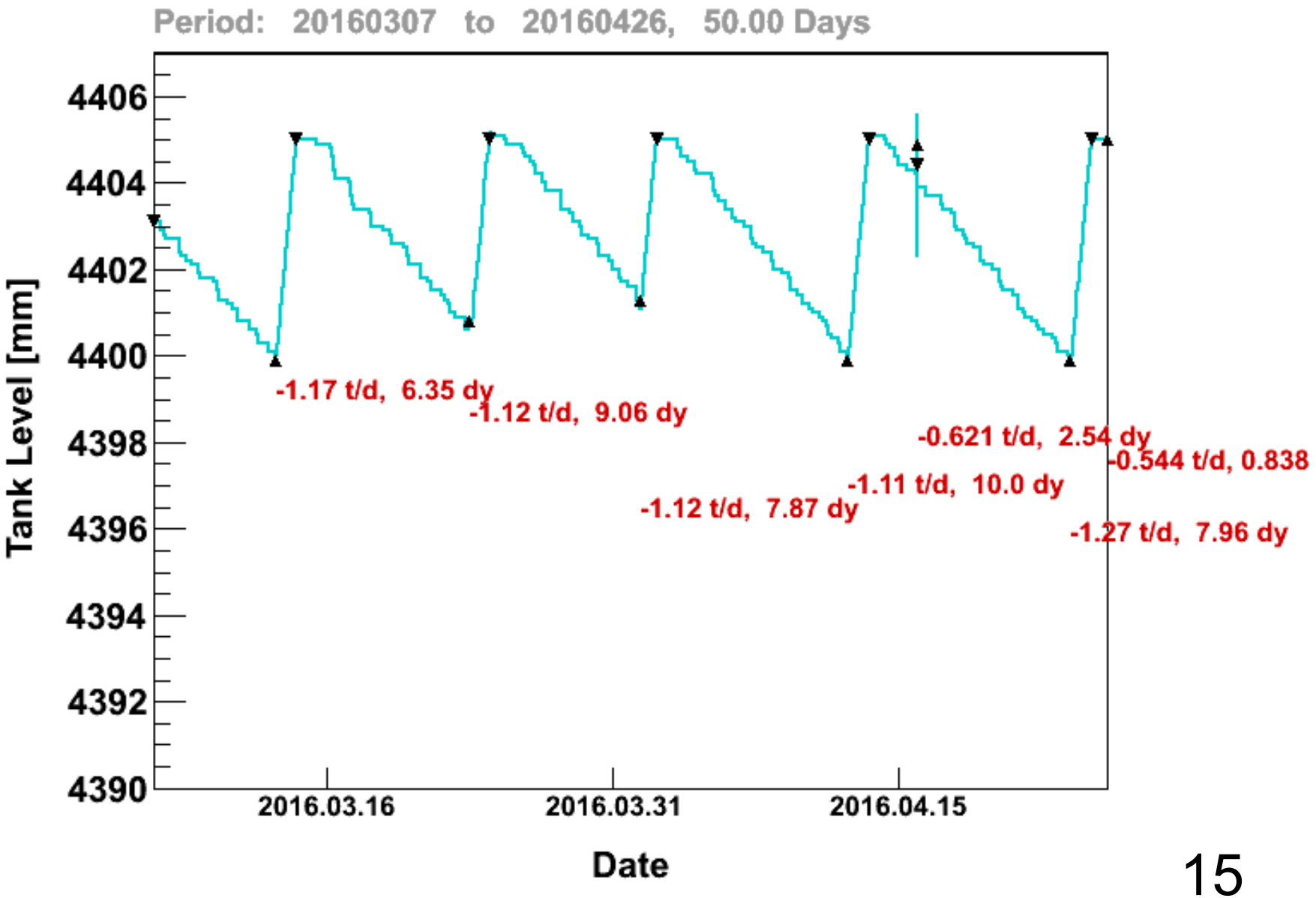


Schedule of the Super-K Gd

Start refurbishment of Super-K on 1st June, 2018



Leak fixing


Period: 20160307 to 20160426, 50.00 Days
Tank Level [mm]
4406
4404
4402
4400
4398
4396
4394
4392
4390
2016.03.16
2016.03.31
2016.04.15
Date
-1.17 t/d, 6.35 dy
-1.12 t/d, 9.06 dy
-1.12 t/d, 7.87 dy
-0.621 t/d, 2.54 dy
-1.11 t/d, 10.0 dy
-0.544 t/d, 0.838
-1.27 t/d, 7.96 dy

Leak fixing

Cover all the welded places with sealing materials

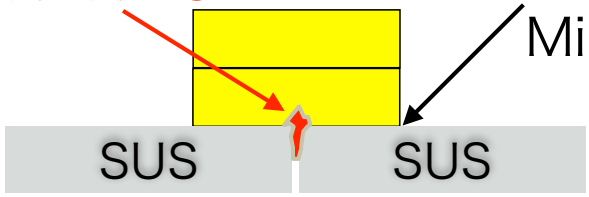
Cover with two materials.
One is BIO-SEAL 197 (epoxy resin) which sneak into small gaps, the other is 'Material' (poly-urea) which allows more displacement.

Need to wait several hours to the next step

BIO-SEAL 197

'Material' (two layers)

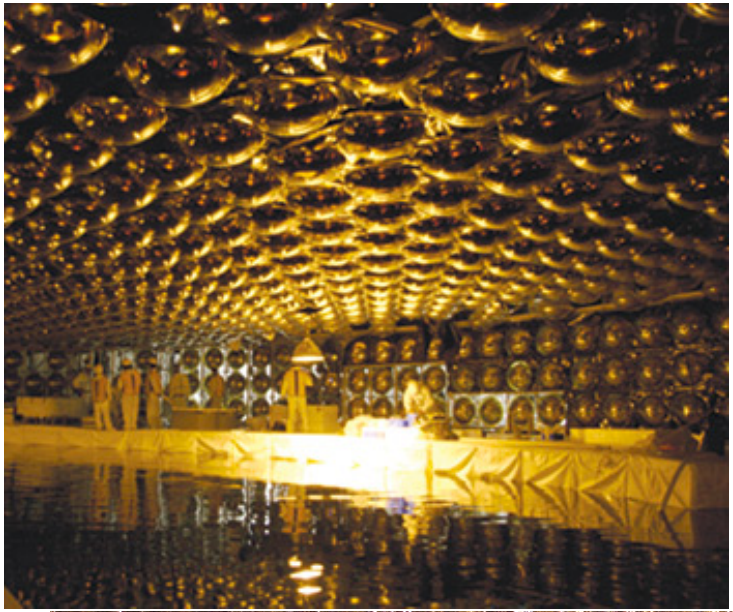
Primer between MineGuard and SUS

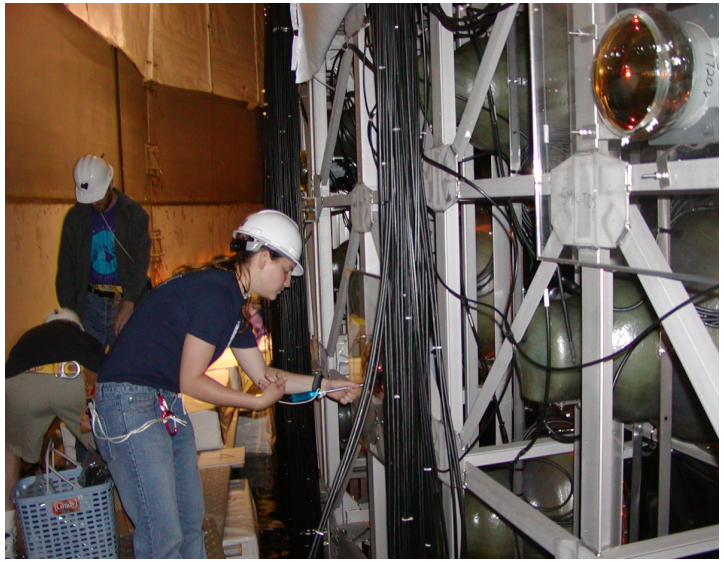


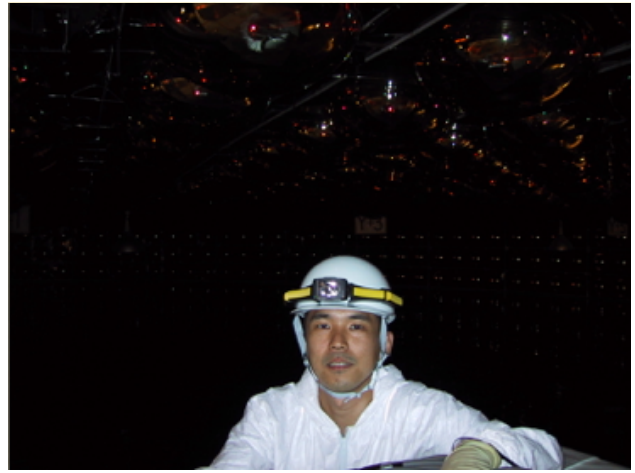
Backer as a bank to keep the coating region

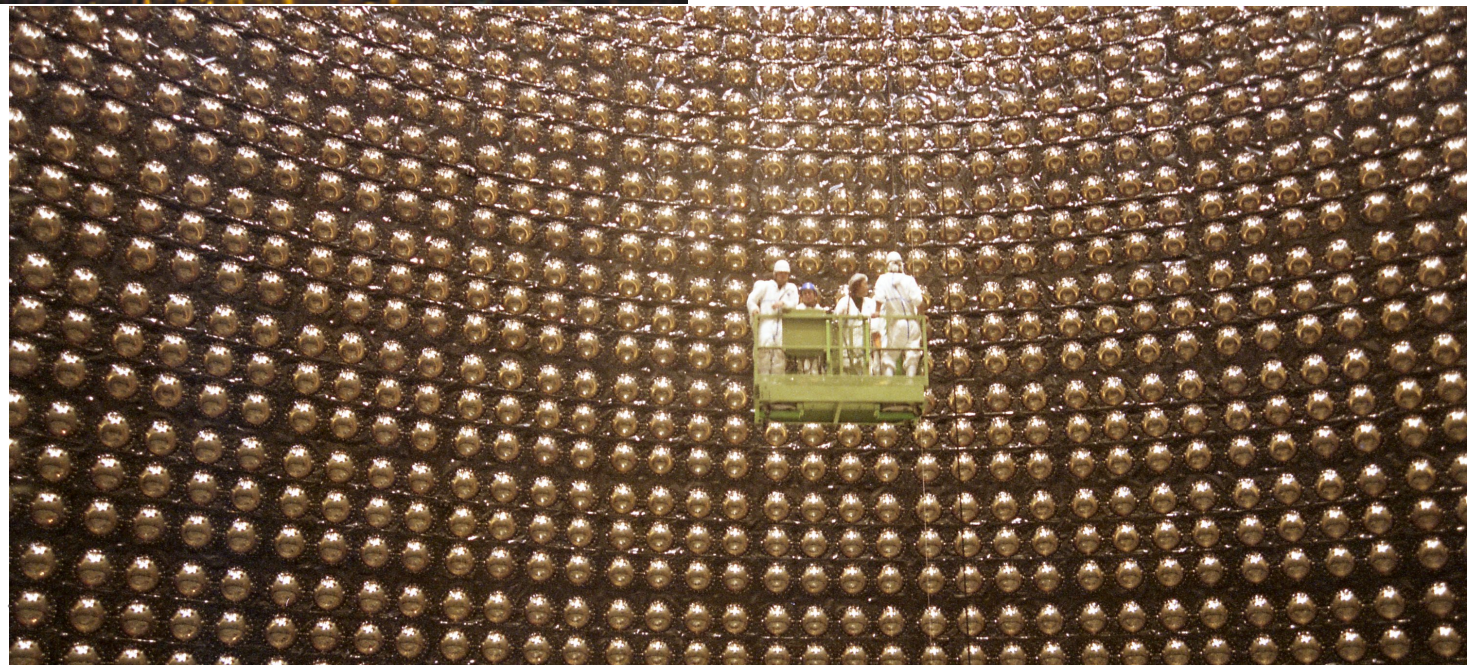
Mock-up test in the underground

Working inside the Super-K





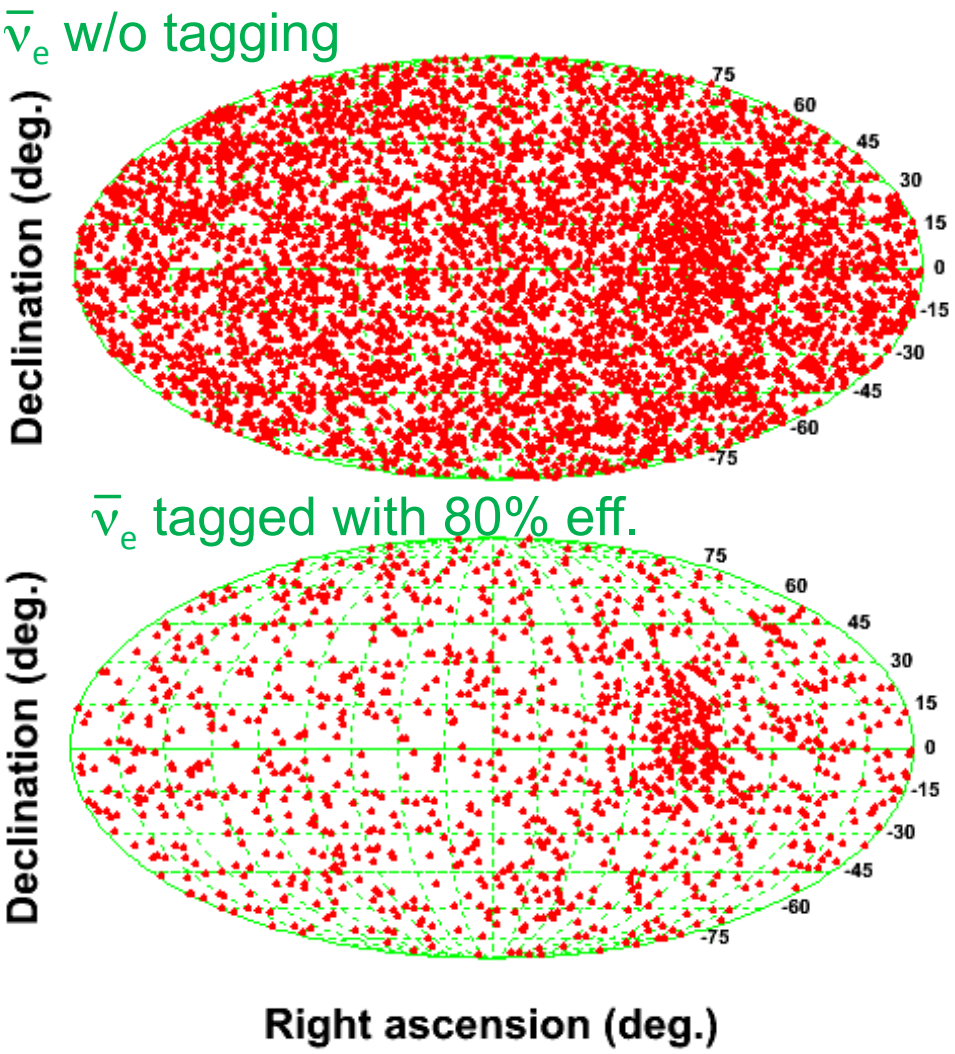


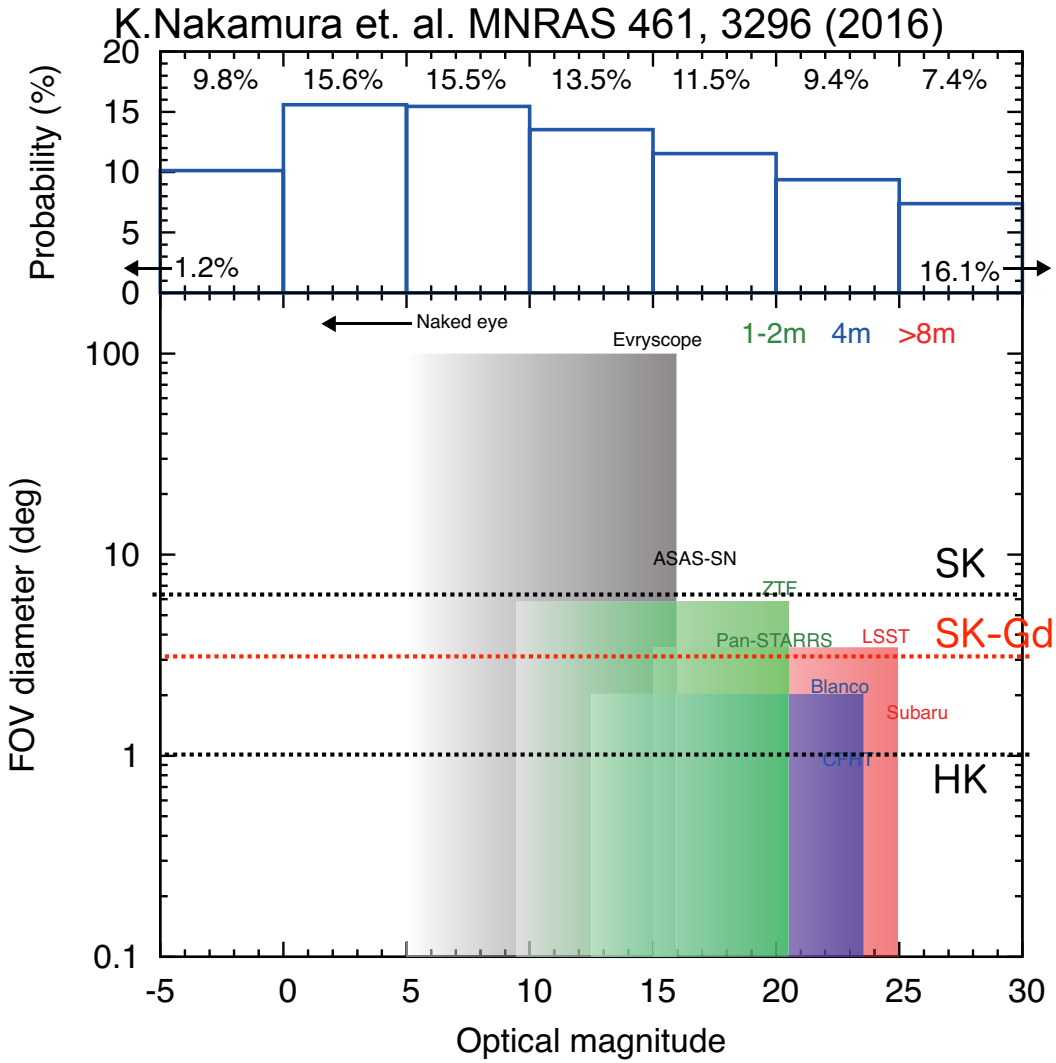



Summary
Ready for the first discovery of the DSNB!
Thanks

Physics expectation in SK-Gd

For Supernova burst neutrinos

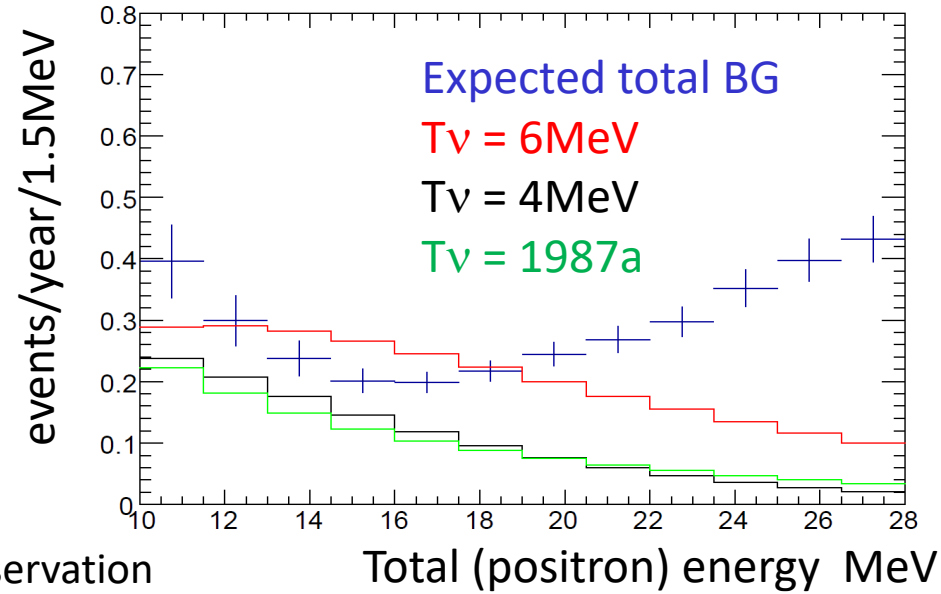




Physics expectation in SK-Gd

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	----

Proposed in 2004,
but not so easy..

EGADS as R&D

(Evaluating Gadolinium's Action on Detector Systems)

Purpose

✓Water transparency

✓How to purify

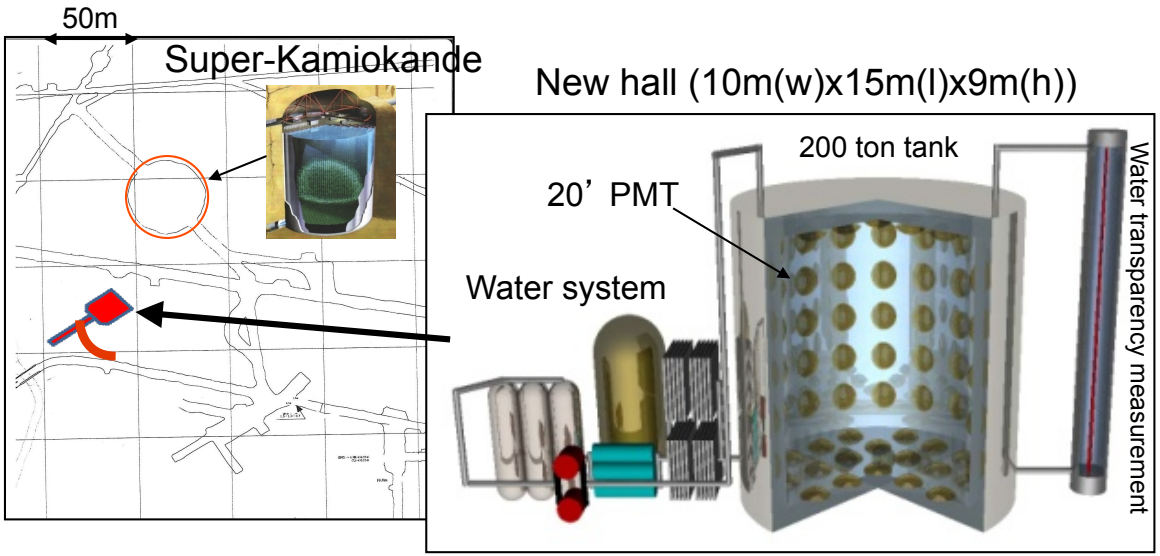
✓How to introduce and remove

✓Effect on detector

✓Effect from environment neutrons

✓etc.

R&D for Gd test experiment



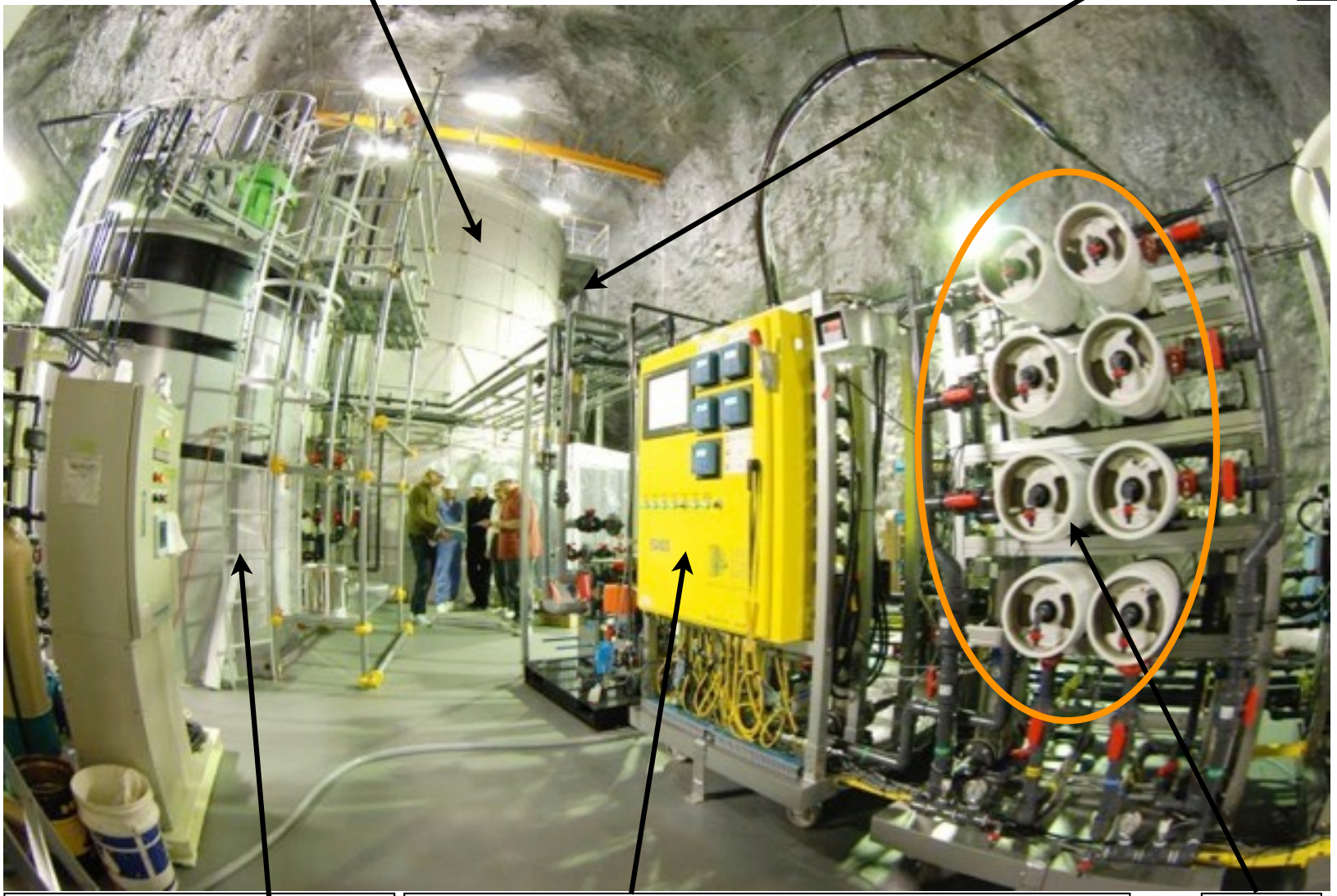
Great success by the previous innovative area!

EGADS as R&D

200 ton tank

UDEAL

water transparency measurement

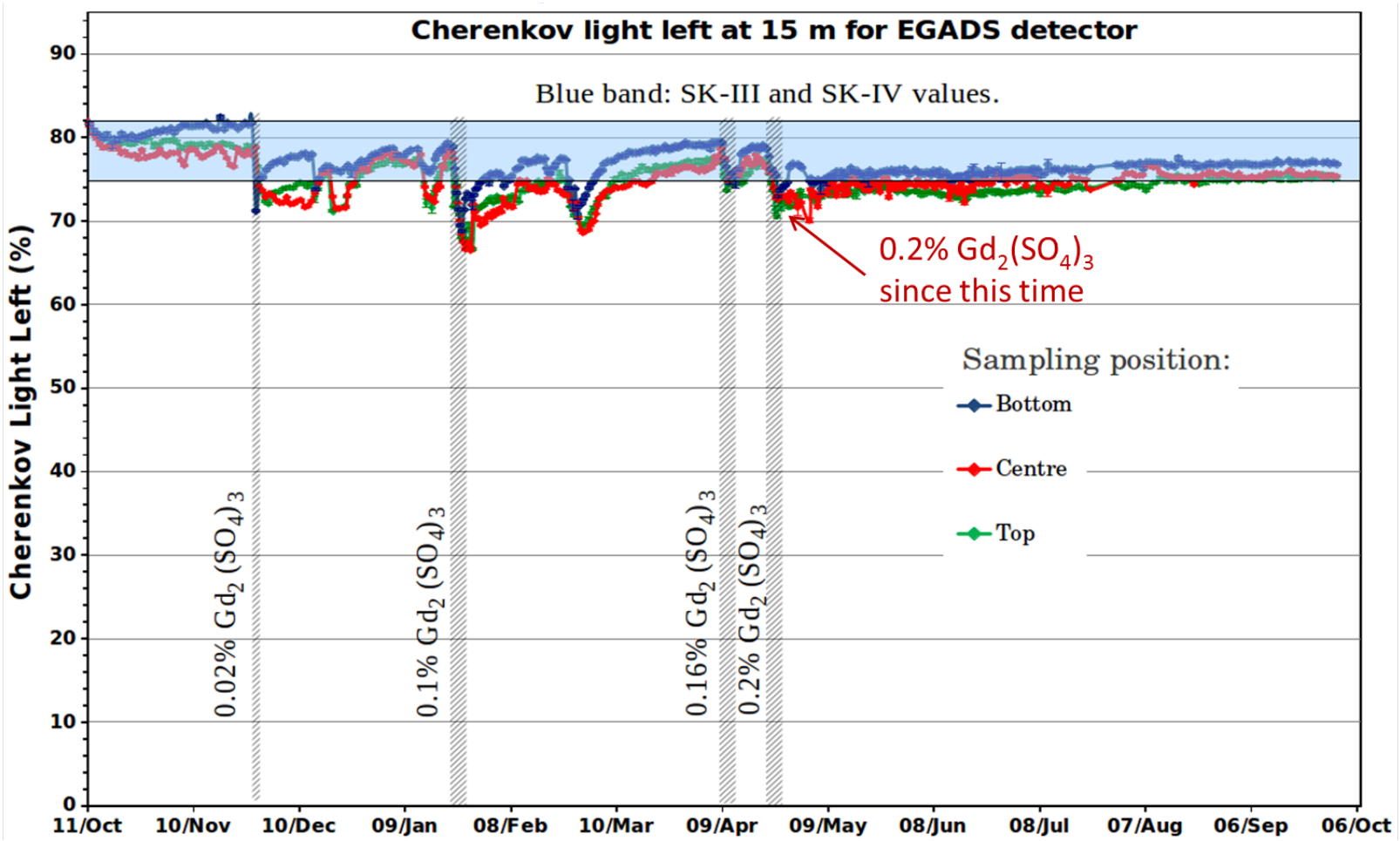


15 ton buffer tank

Control panel of circulation system

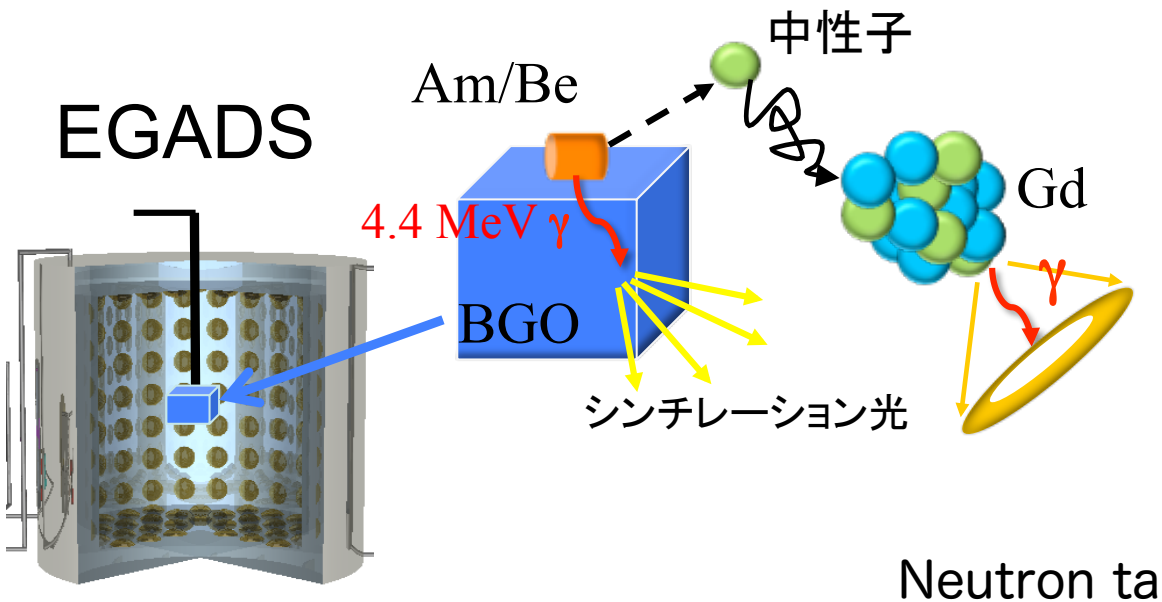
Filter

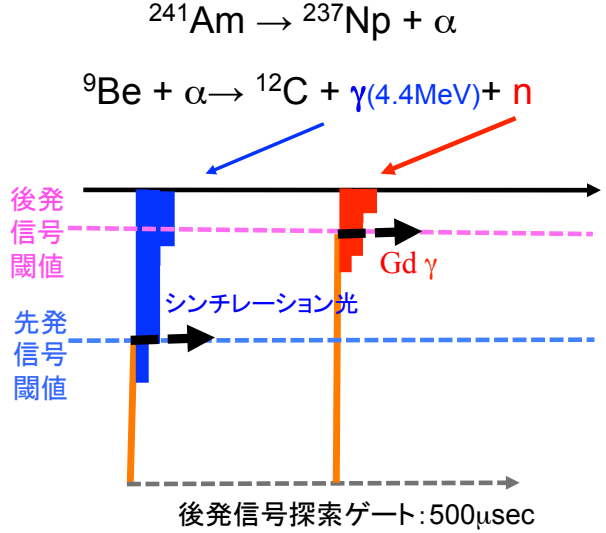
EGADS as R&D

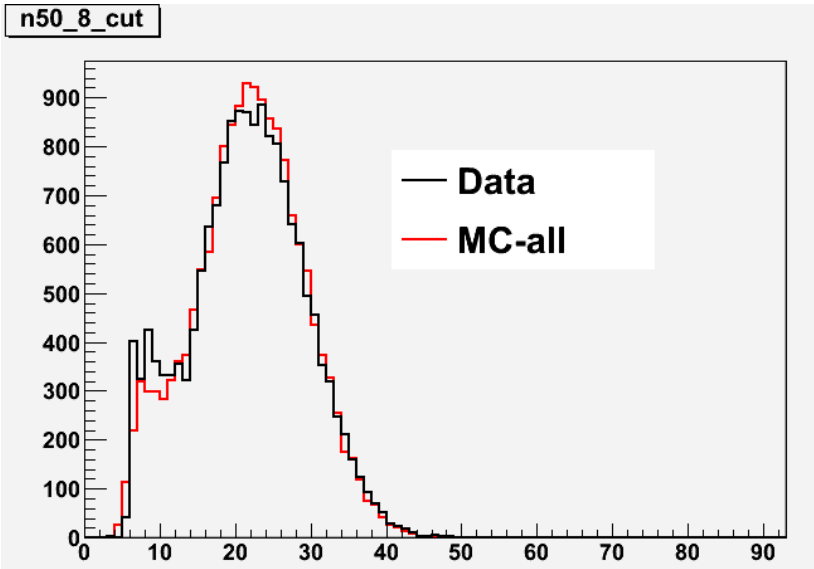


Very stable and continuous data taking

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%

DSNB in Super-K

Upper limit from Super-K

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