Super Kamiokande-Gd

The Super Kamionade Gadolinium Project

TAUP2017 @Sudbury

JULY 26 2017

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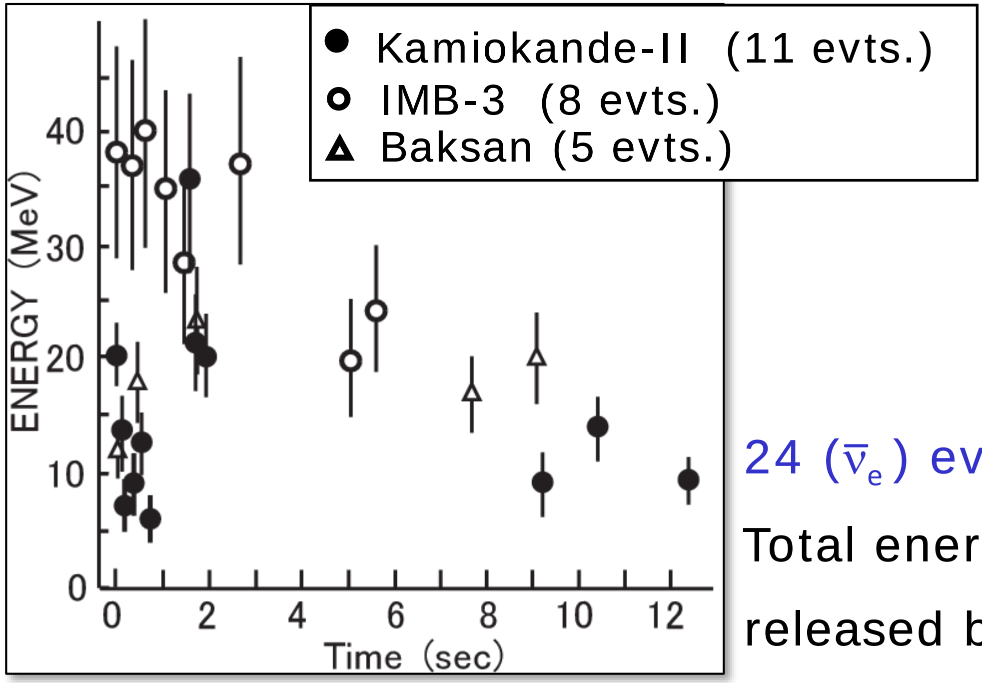
for the Super-K Collaboration

Total 24 pages

Supernova neutrinos from 1987A

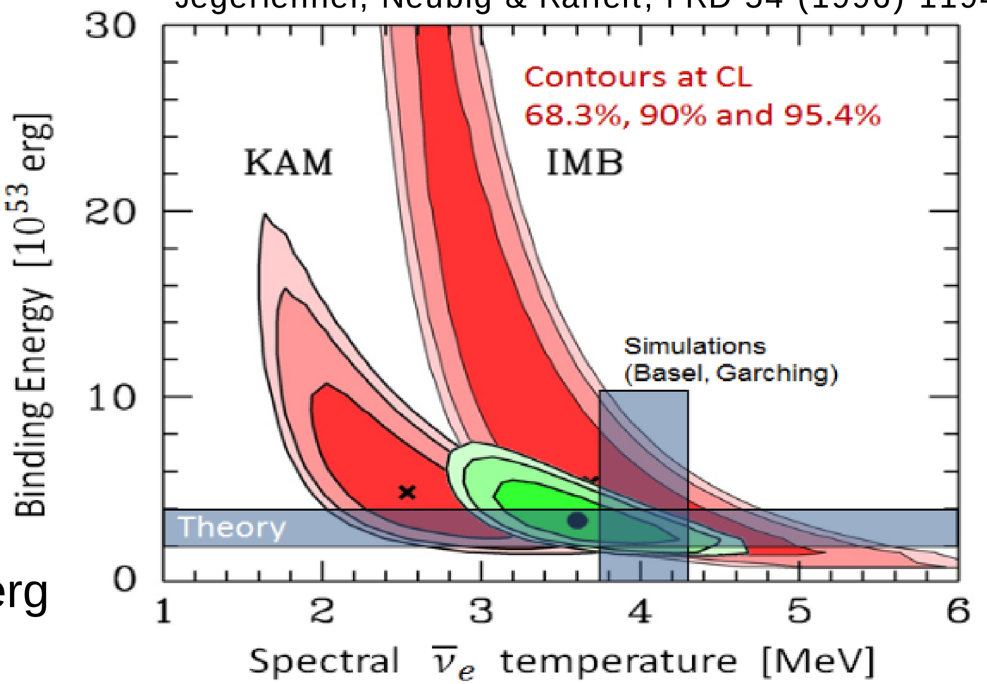
- The only detected SN neutrinos are from LMC(50kpc)



24 ($\bar{\nu}_e$) events in total.

Total energy released by $\bar{\nu}_e$: ~5x10^{52} erg

Jegerlehner, Neubig & Raffelt, PRD 54 (1996) 1194

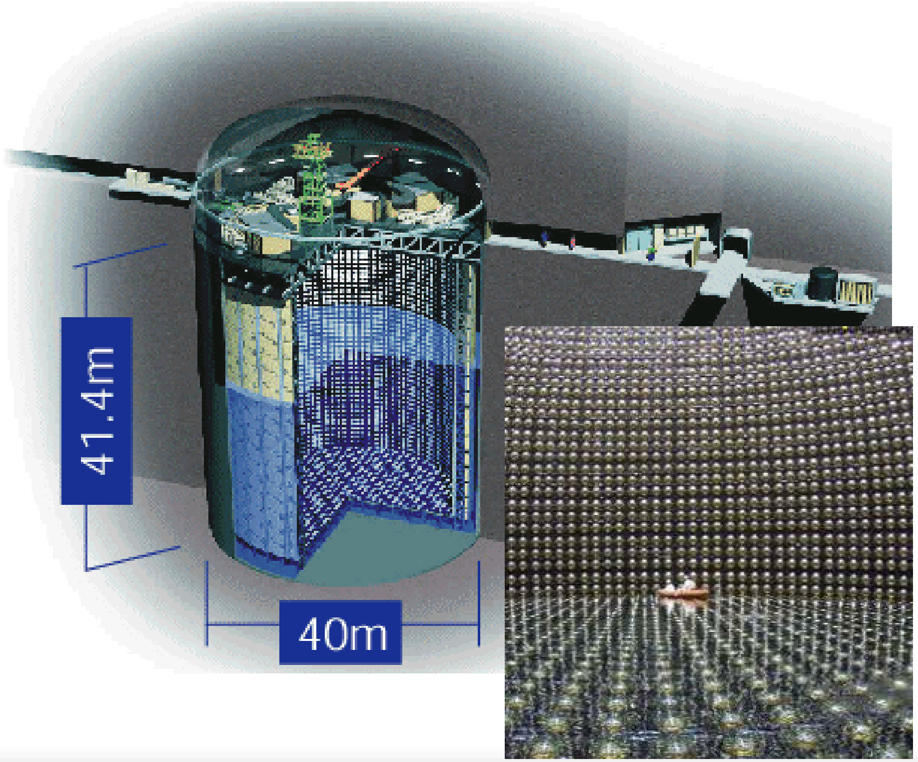


- The obtained binding energy is almost as expected, but large error in neutrino mean energy. No detailed information of burst process.
- We need energy, flavor and time structure.

The current detector

- **Super Kamiokande IV**
  - 32k ton FV > 4.5 $\mathrm{MeV}_{(kin)}$
  - 8.8k ton FV > 3.5$\mathrm{MeV}_{(kin)}$

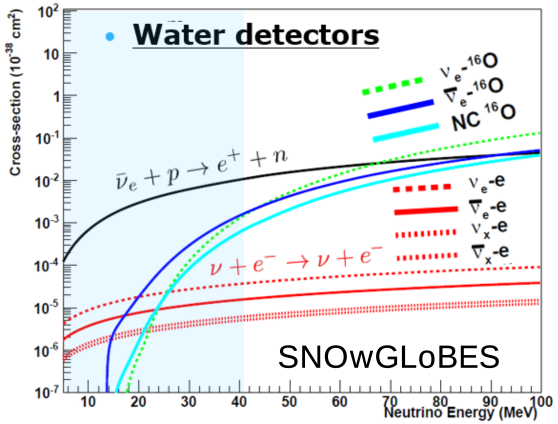
Basically $\bar{\nu}_e$detector via inverse beta decay



Supernova at 10 kpc
events in 32kton

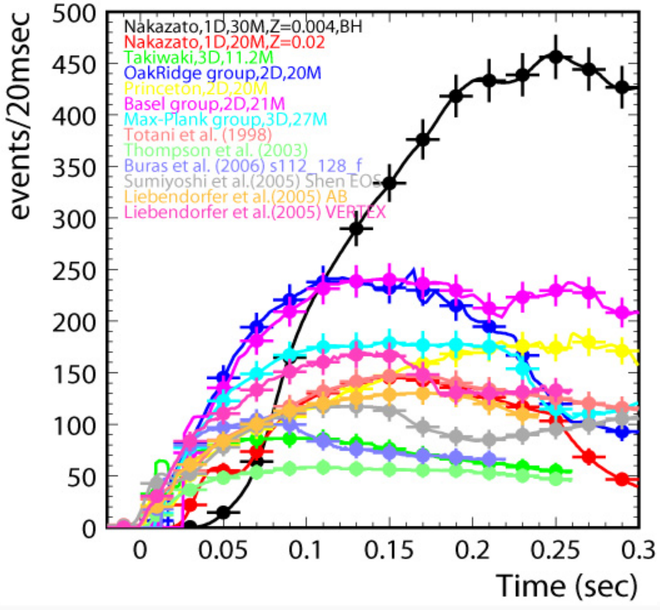
Nakazato:
ApJ.Suppl. 205 (2013) 2

	Nakazato
$\bar{\nu}_e p \rightarrow e^+ n$	3100
$\nu + e^- \rightarrow \nu + e^-$	170
^{16}O CC	60

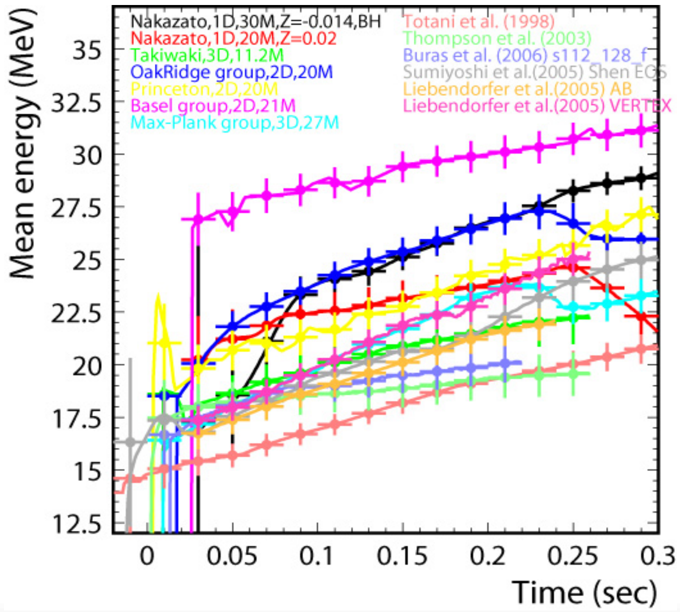


Enough statistics to discriminate models!

Time variation of event rate



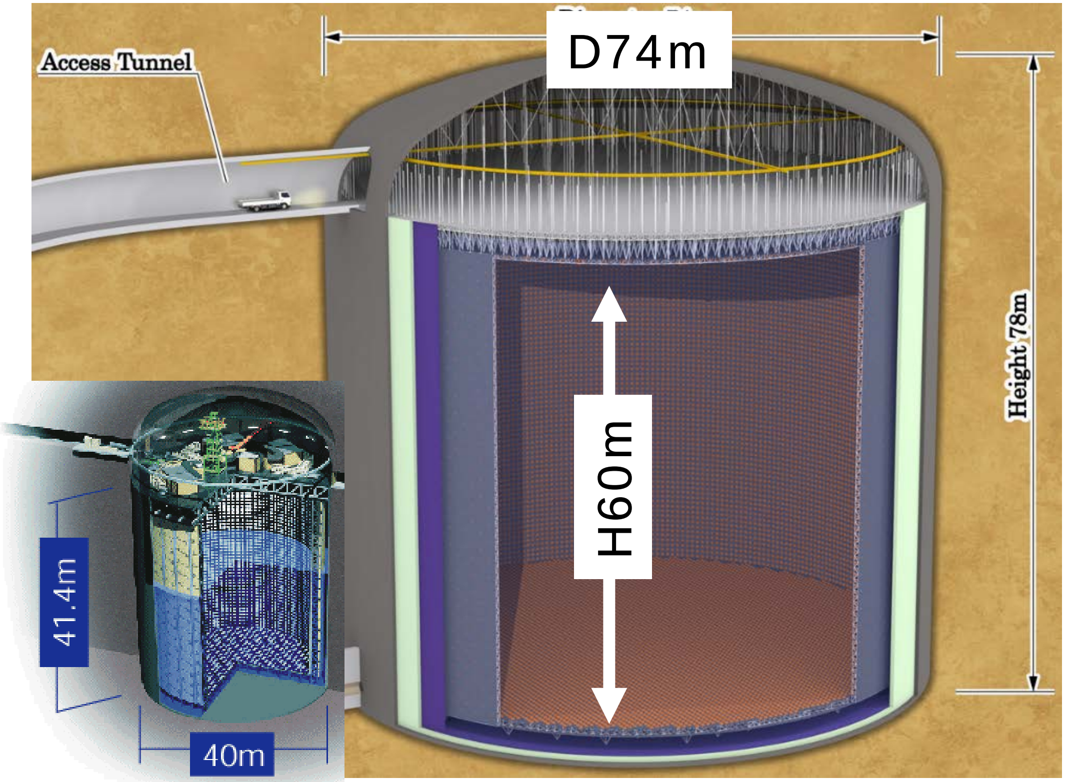
Time variation of mean energy



The coming detector

see coming T. Yano's talk

- **Hyper Kamiokande**
  - 260k ton total
  - 220k ton ID for SN observation



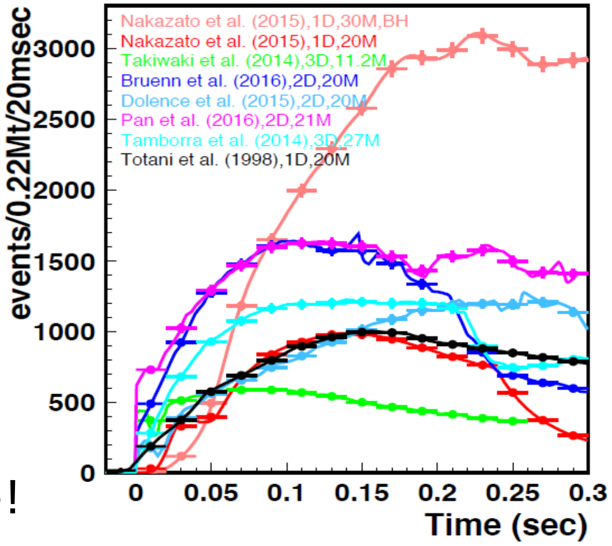
Supernova at 10 kpc
\# events in 220kton

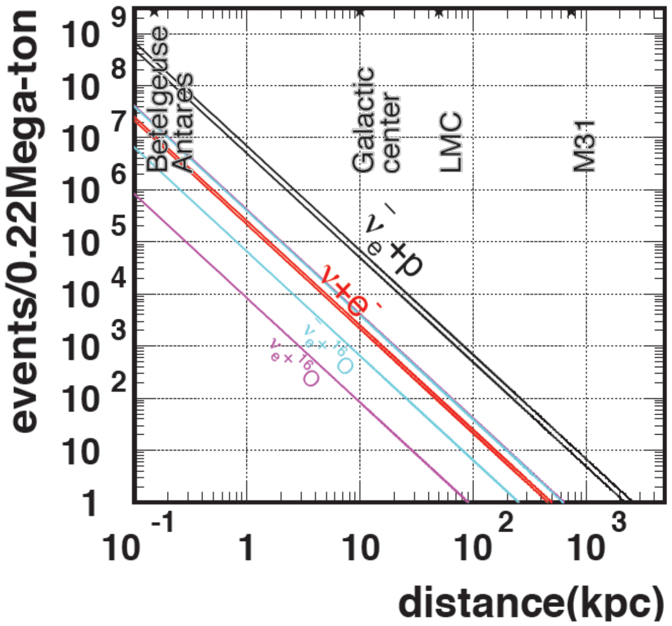
Nakazato:
ApJ.Suppl. 205 (2013) 2

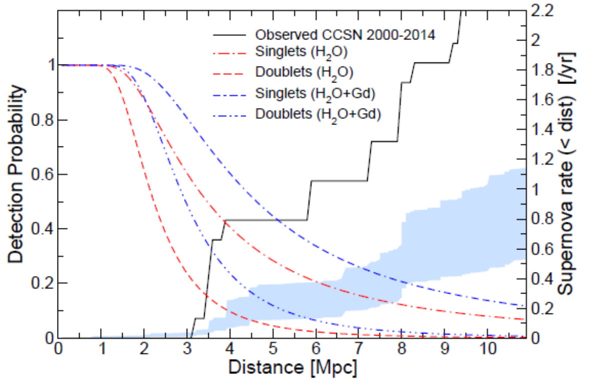
	Nakazato
$\bar{\nu}_e p \rightarrow e^+ n$	21300
$\nu + e^- \rightarrow \nu + e^-$	1200
^{16}O CC	410

statistical error invisible!

Time variation of event rate







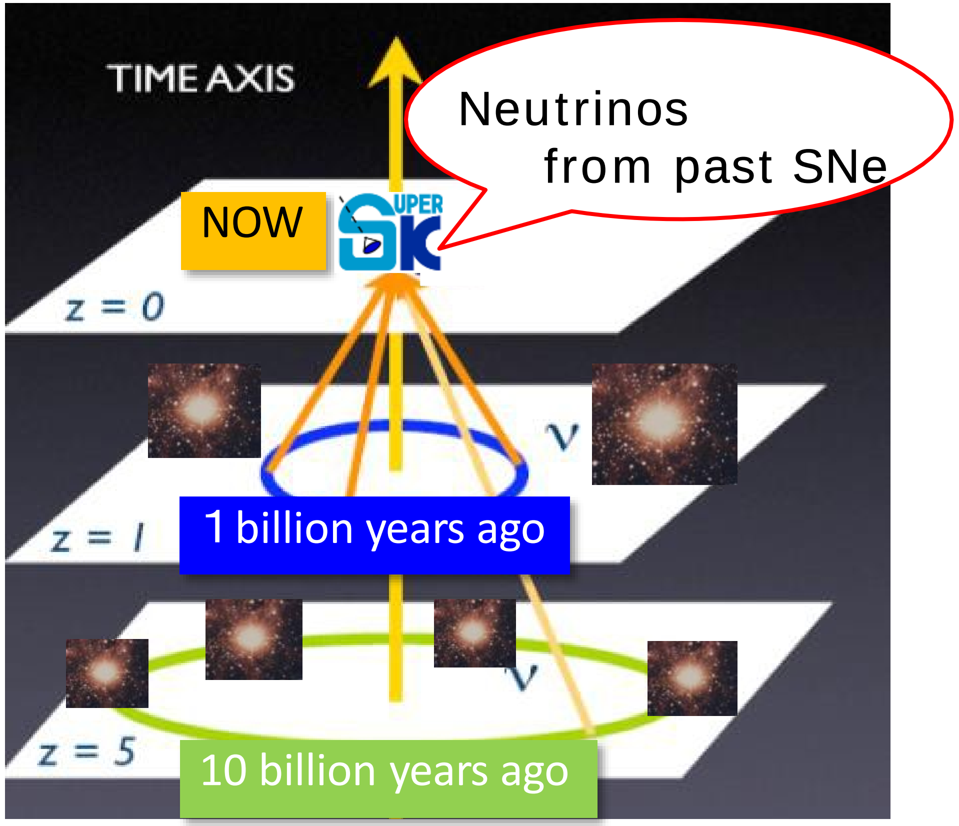
K. Nakamura MNRAS, 461, 3296 (2016)

20 year of operation
At least
~ 1 events < 10Mpc

Supernova neutrino from z=5

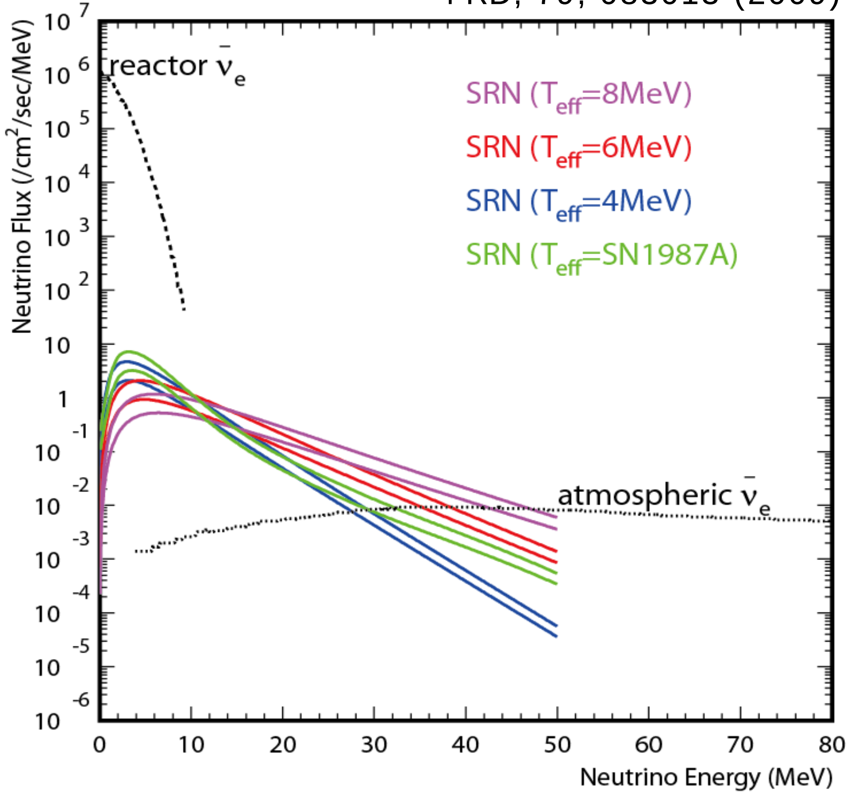
Diffuse Supernova Neutrino Background(DSNB)

- 10^{10} stellar/galaxy × 10^{10} galaxies × 0.3%(become SNe) ~*O*(10^{17})SNe



Beginning of the universe

Horiuchi, Beacom and Dwek, PRD, 79, 083013 (2009)

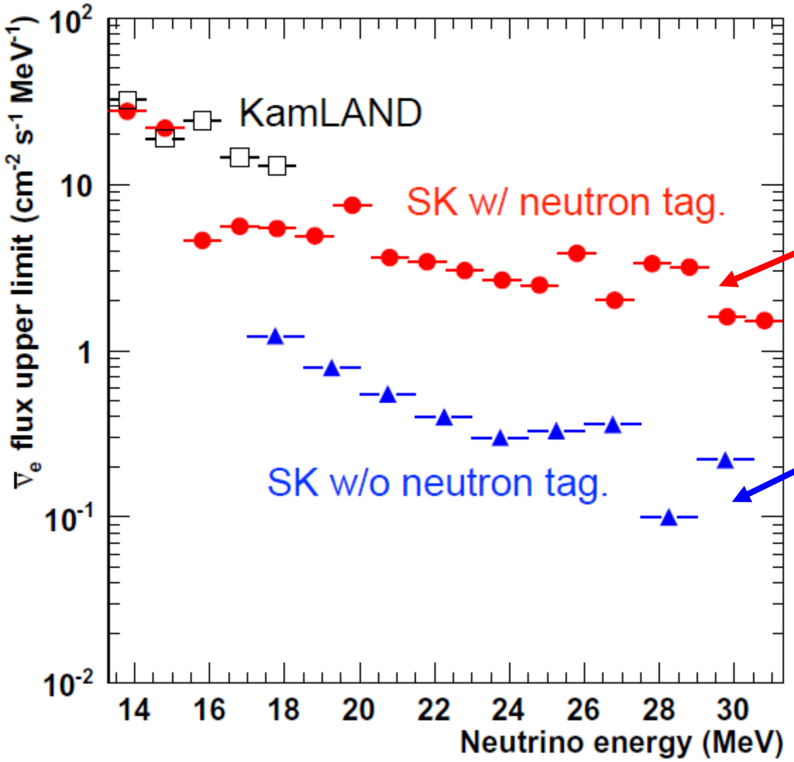


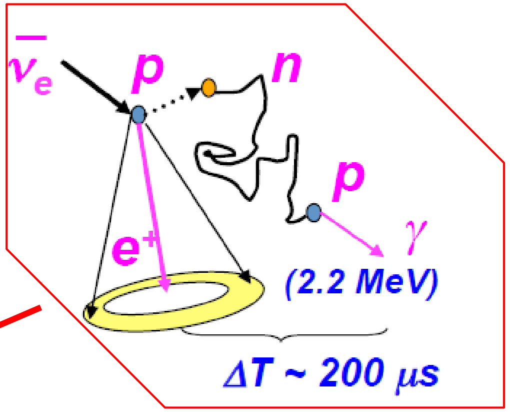
Search window for SK : From ~10MeV to ~30MeV

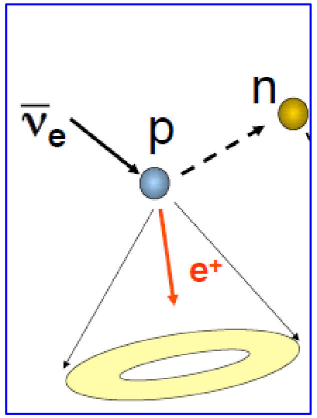
Status of DSNB search

Comparison with expected $\bar{\nu}_e$ signal

SK collaboration, Astropart. Phys. 60, 41-46 (2015)

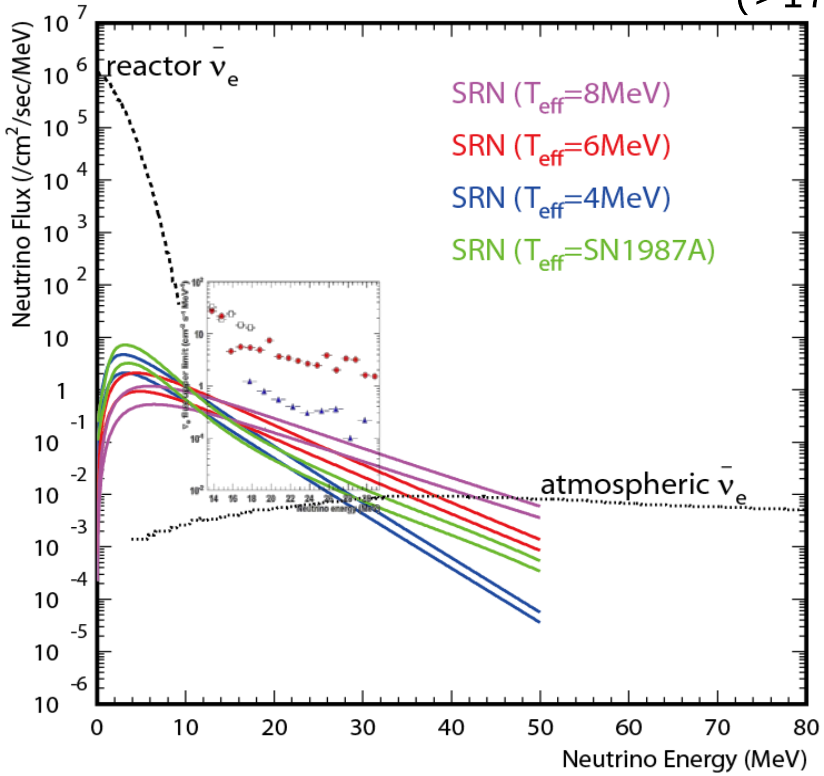






Theoretical flux prediction : 0.3~1.5 /cm²/s

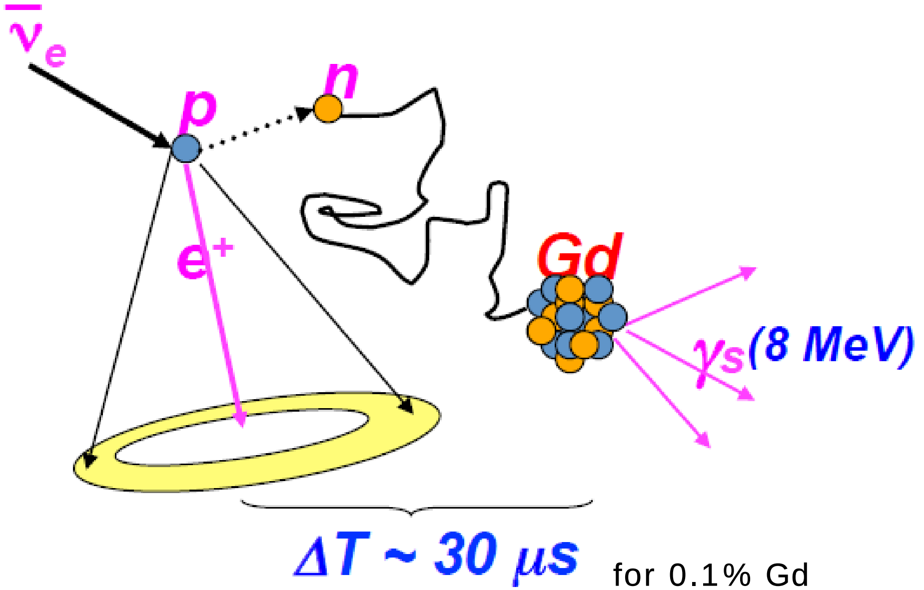
Current best limit by SK: 2.8~3.1 /cm²/s (>17.3MeV)



- Limited by backgrounds
  - More than 1 order BG reduction is needed!
  - Neutron tagging efficiency (by proton) is low... RI BG and low trigger efficiency

The Gadolinium project

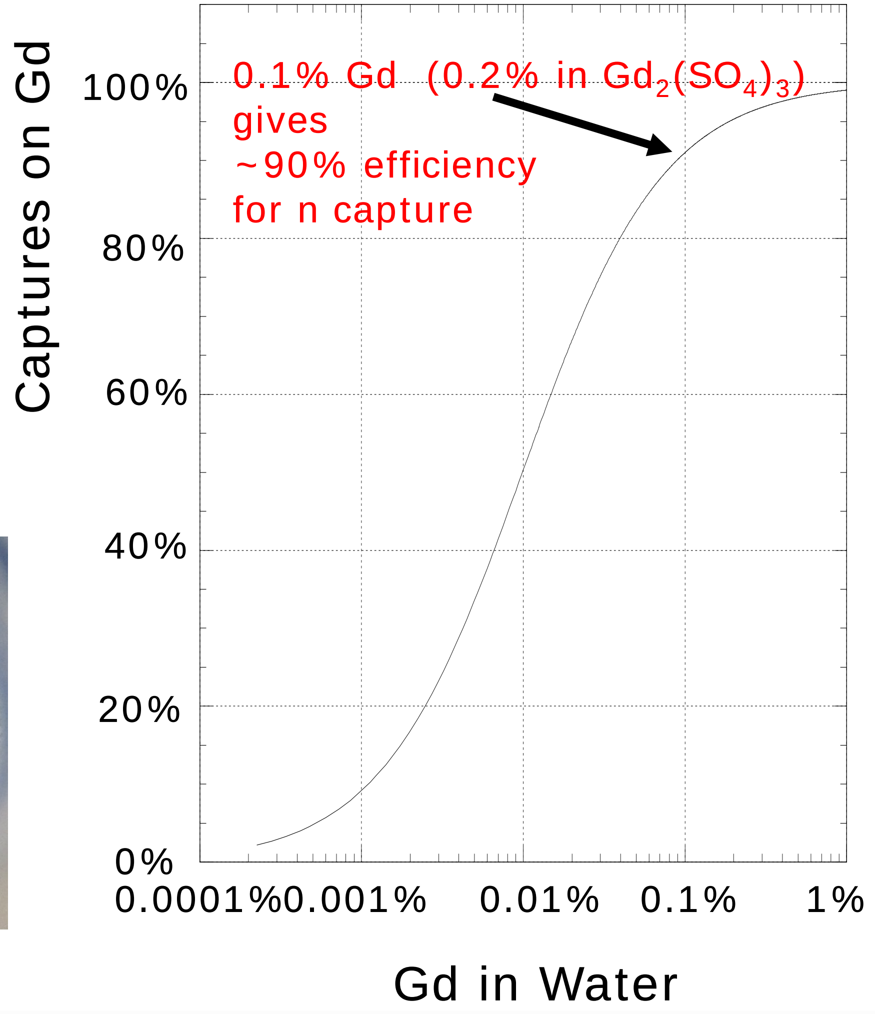
- To identify $\bar{\nu}_e p$ events by neutron tagging with Gadolinium.
- Large cross section for thermal neutron (48.89kb)
- Neutron captured Gd emits 3-4 γs in total 8 MeV
  - Well above most of BG from RIs and the SK trigger threshold
- 90% of Gd capture efficiency at 0.1% loading
- $Gd_2(SO_4)_3$ was selected to dissolve→0.2% loading
  - In Super-K, it corresponds to 100 tons of loading



for 0.1% Gd

$Gd_2(SO_4)_3$

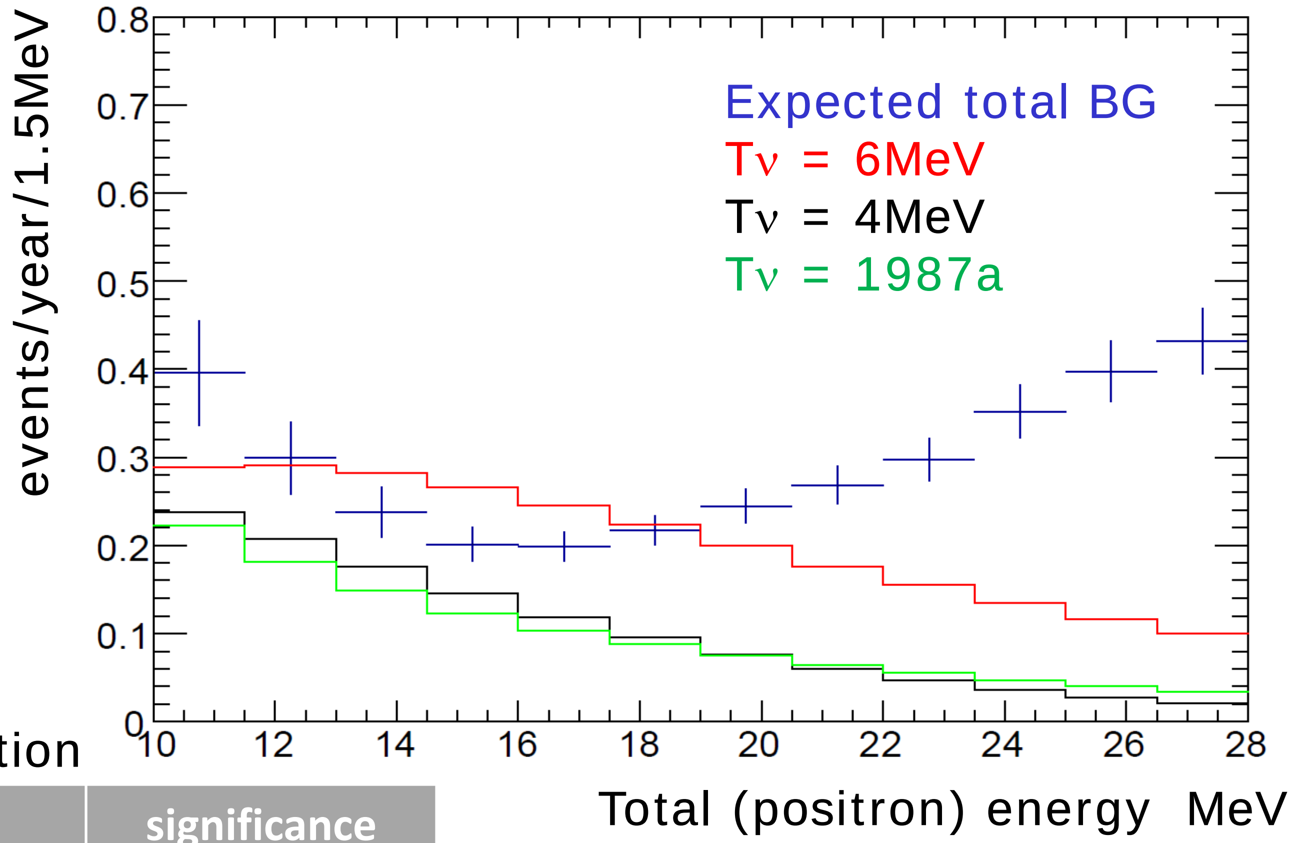
Beacom and Vagins PRL93,171101 (2004)



Expected signal

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

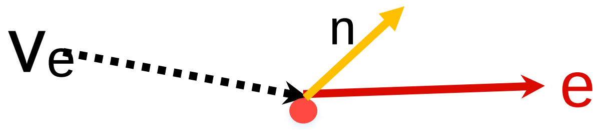
HBD models	10-16MeV (evts/10yrs)	16-28MeV (evts/10yrs)	Total (10-28MeV)	significance (2 energy bin)
T_{eff} 8MeV	11.3	19.9	31.2	5.3 σ
T_{eff} 6MeV	11.3	13.5	24.8	4.3 σ
T_{eff} 4MeV	7.7	4.8	12.5	2.5 σ
T_{eff} SN1987a	5.1	6.8	11.9	2.1 σ
BG	10	24	34	----

- First observation is within SK-Gd's reach!
- Further BG reduction with topological cuts are expected.

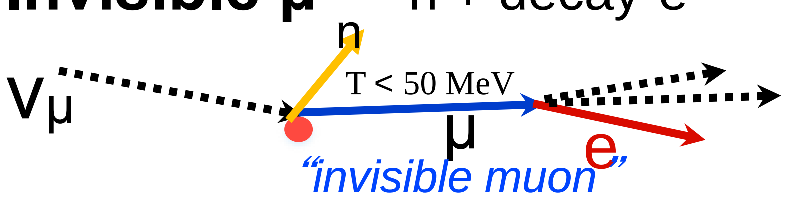
Remaining BG: atmospheric neutrino

- CC

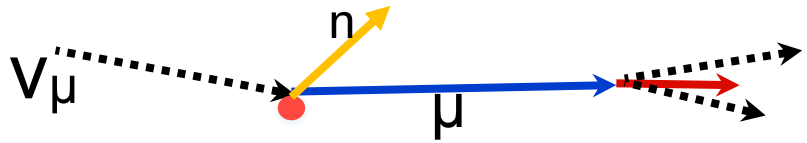
(anti-) ν_e CC



Invisible μ n + decay-e

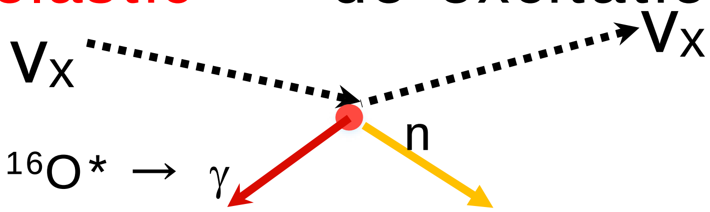


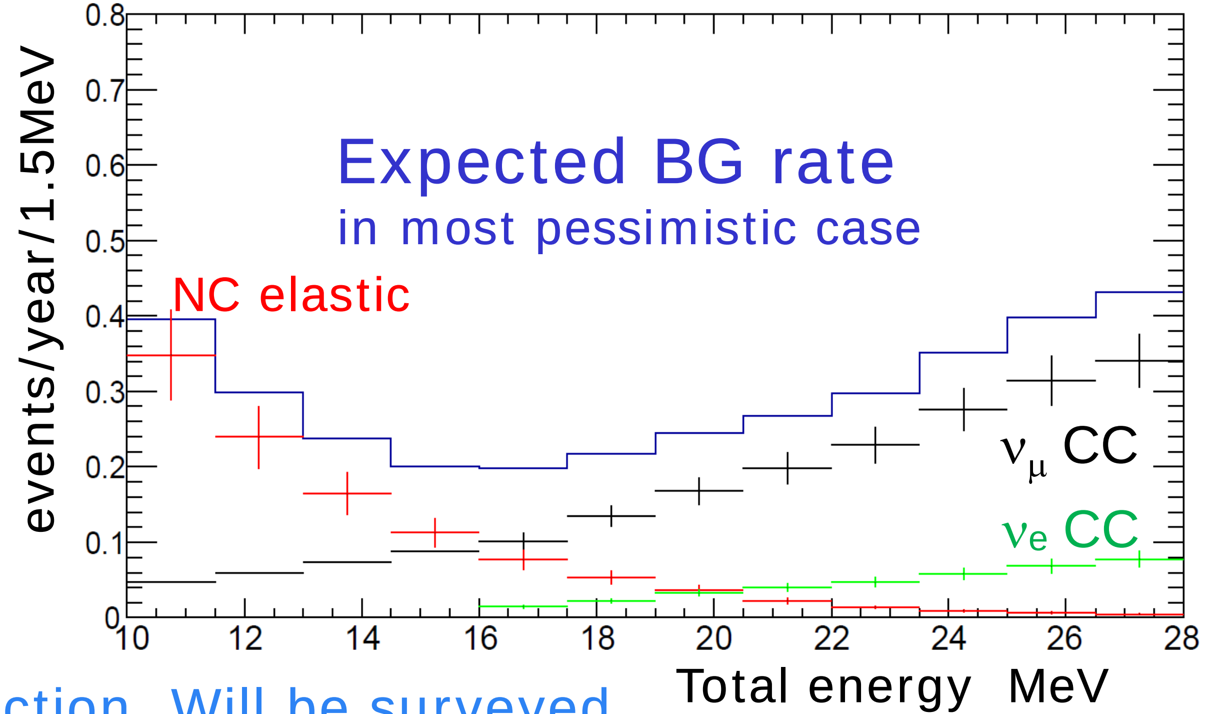
μ generation



- NC

NC elastic de-excitation γ



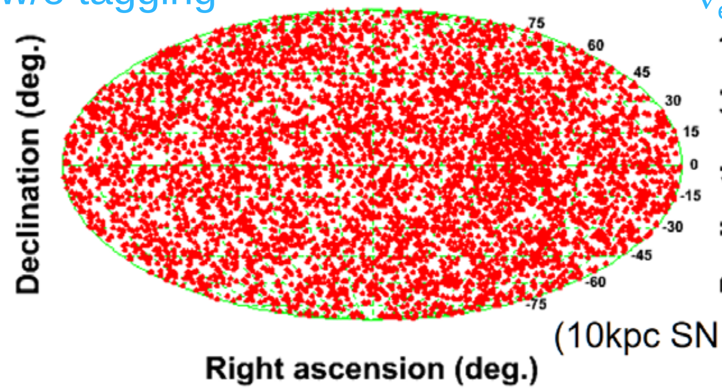


Vertex information gives further BG reduction. Will be surveyed.

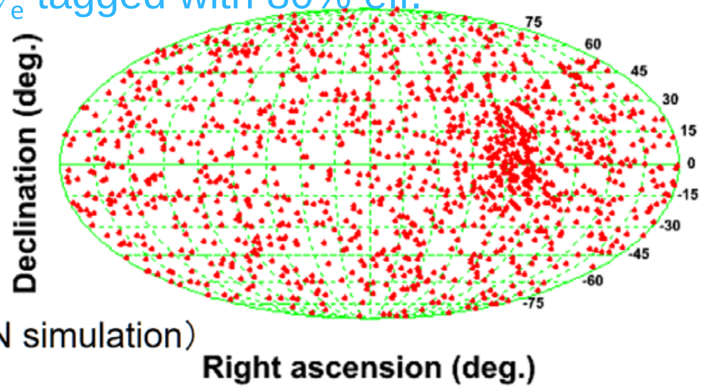
SK-Gd for SN burst

- If $\bar{\nu}_e$ can be tagged, directional events (ν+e scattering events) are enhanced. Pointing accuracy will be improved. For 10kpc SN ~5° → ~3° (@90%C.L.)

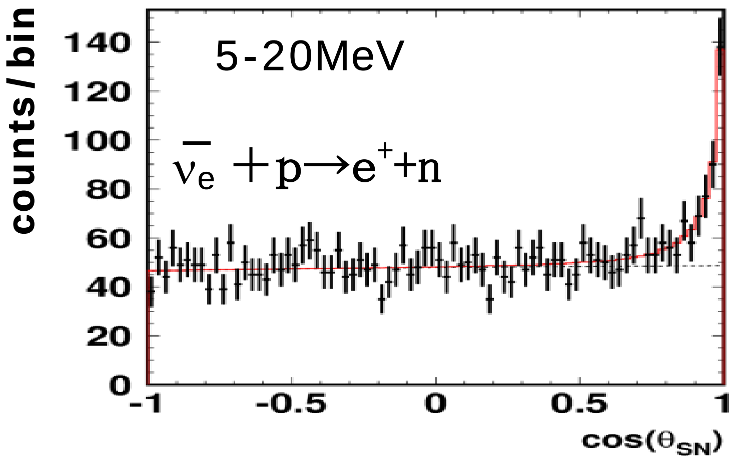
$\bar{\nu}_e$ w/o tagging

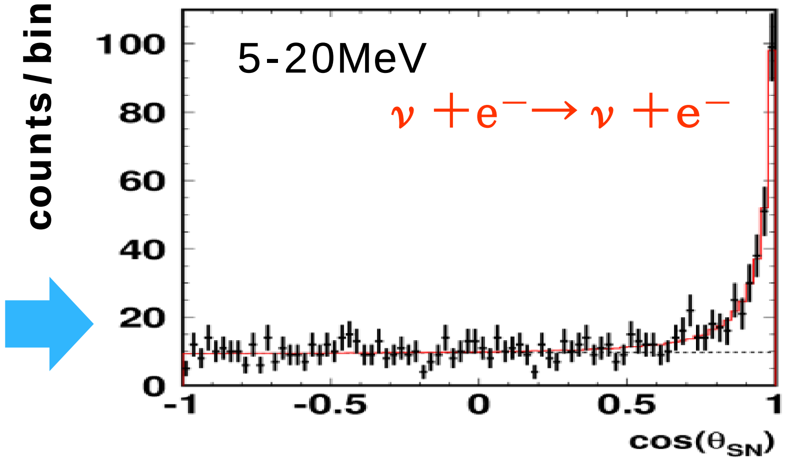


$\bar{\nu}_e$ tagged with 80% eff.



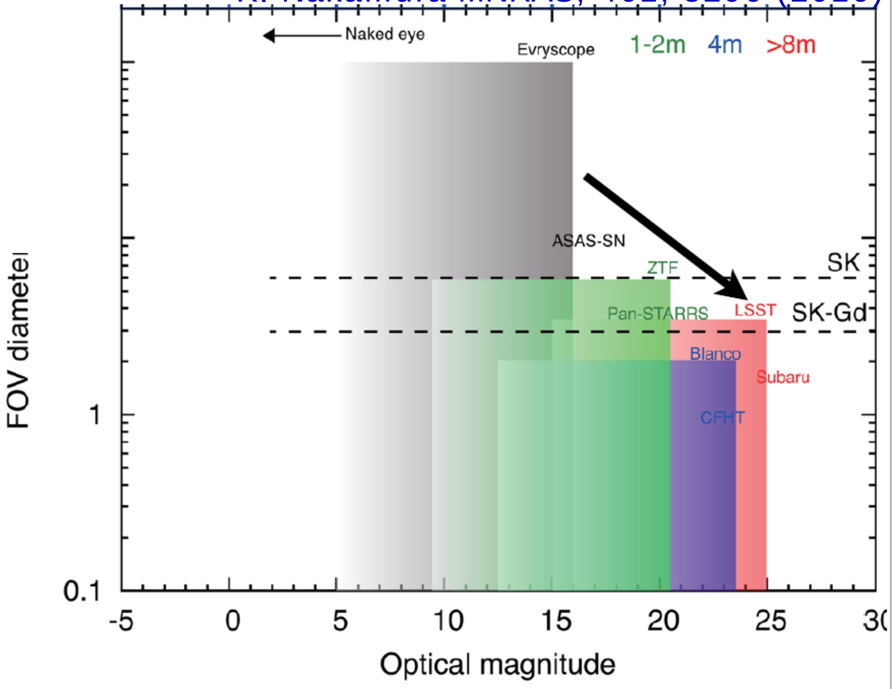
(10kpc SN simulation)





It helps the large optical telescope!

K. Nakamura MNRAS, 461, 3296 (2016)



R&D items and recent progresses

1st level
Environmental Safety

2nd level
Minimize negative impacts to current physics programs at SK

3rd level
Further investigate physics capability with n-tagging

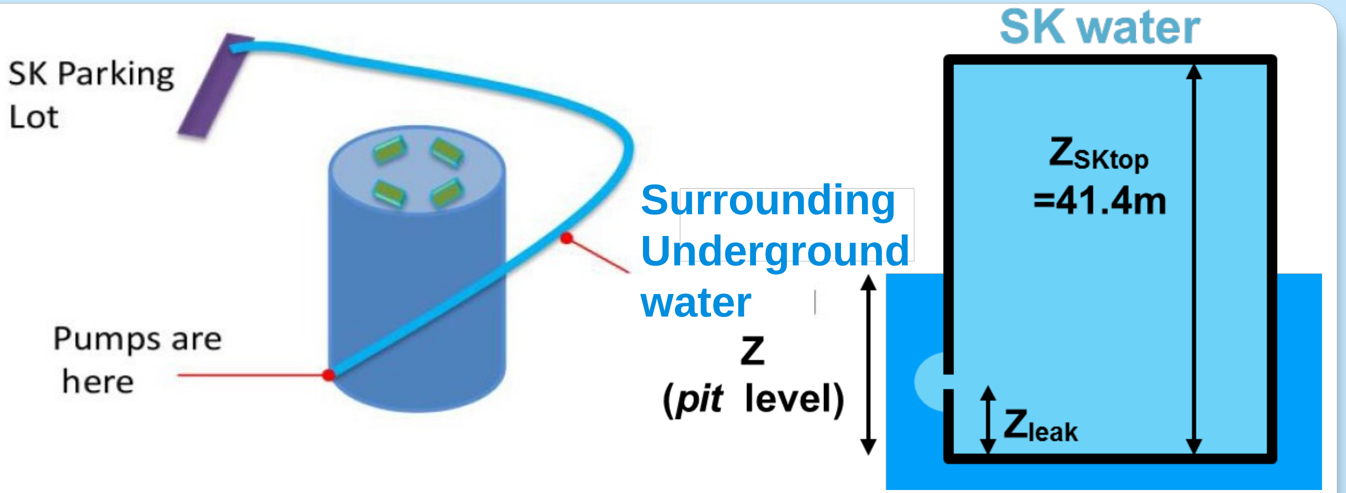
- Stopping the SK leakage
  - Estimation of the leak location
  - Development of leak-fixing method
- Reduction of RIs from $Gd_2(SO_4)_3$ powder
  - Test of Ra removal raisins
  - Material screening with HP-Ge detectors
  - High sensitivity measurement with ICP-MS
- Test with the EGADS demonstrator
  - Continuous monitoring of the water quality
  - Continuous monitoring of Gd concentration
  - Demonstration of Gd-captured neutron signal/QBEE upgrade
- Construction of the new water system
- Gd gamma measurements and improved simulation of Gd capture

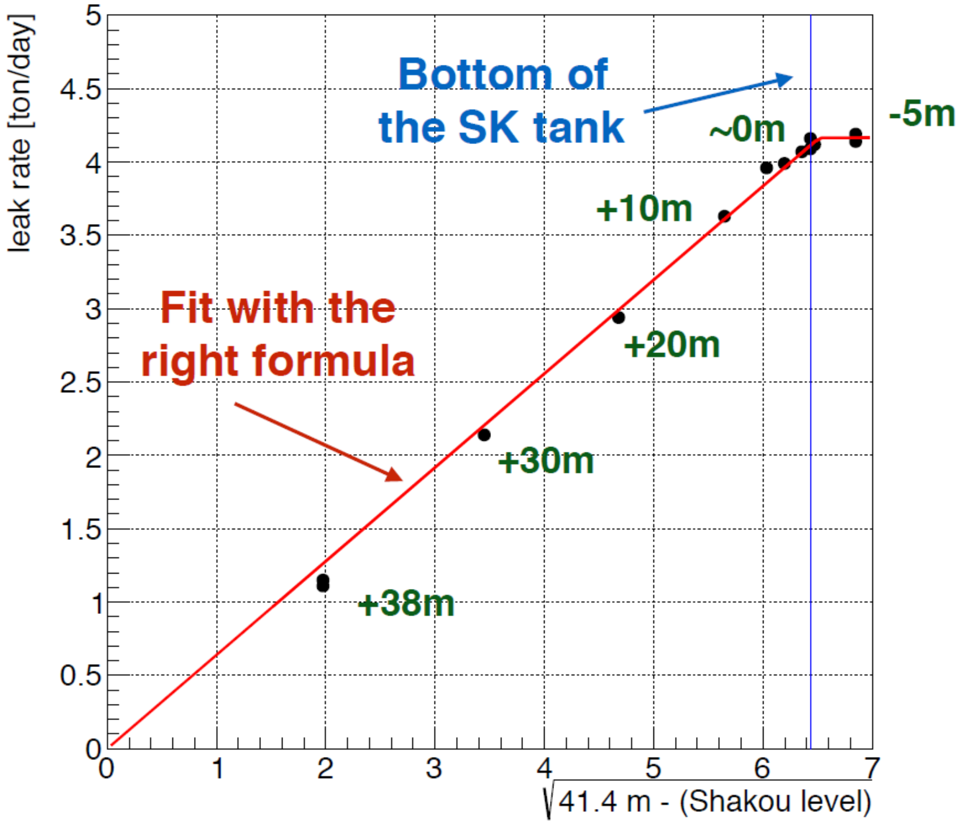
SK water leakage

- SK water is leaking at ~1 ton/day.
- In order to survey the location of the leakage, by changing the water level of the inclined pit (access tunnel to the bottom of SK), water leak rate was precisely measured from Nov. 2016 to Mar. 2017
  - Changes water pressure to the tank
- Assuming just one leakage point,

$$\Phi_{leak}(z) = \begin{cases} a \times \sqrt{z_{SKtop} - z} & (z > z_{leak}) \\ a \times \sqrt{z_{SKtop} - z_{leak}} & (z < z_{leak}) \end{cases}$$

Data indicates that the leak location is near the bottom of SK detector





Leak-fixing method

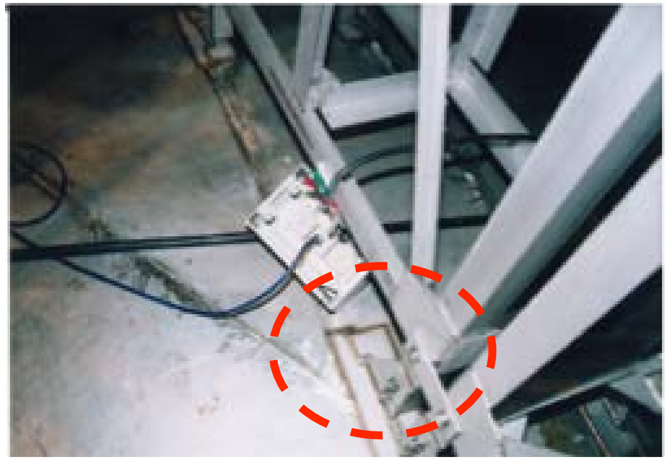
- Paint all the welding lines with 2 sealing materials
  - **Bio-seal 197**:
    Fill pinholes and cracks in steel plates
  - **Poly-urea based sealant**:
    Newly-developed, flexible and low-background
- Tests for the new sealant:

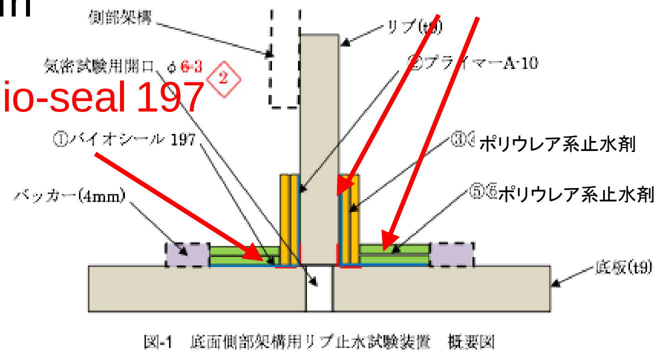
  Mechanical strength
  - No problem after applying 5 atm pressure in Gd-loaded water for 6 months so far.
  - Passed the JIS standard for attachment

  TOC Elusion
  - Effect in light yield less than 2.4%

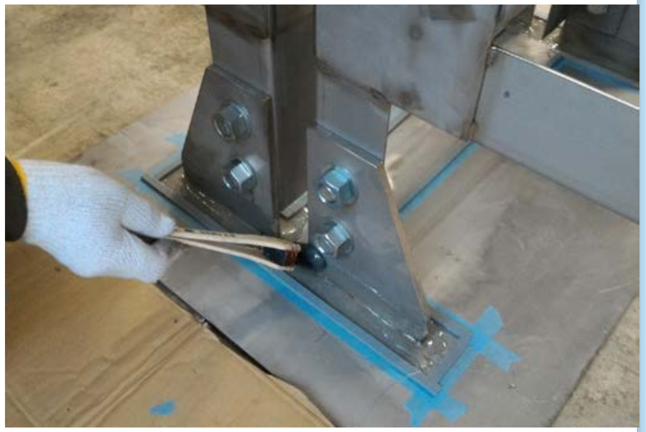
  Radon emanation
  - ~0.3 mBq/m^2, less than the 20 inch PMTs
  - No problem for solar neutrino measurement

Most suspicious;
Anchors of the PMT frame





Mock-up simulation



Low RI $Gd_2(SO_4)_3$ development

- For solar ν measurement, U (spontaneous n fission), Th/Ra(β,γ) must be removed.
- We are intensively developing pure powder with several companies.
- Evaluation ~1 mBq/kg : Ge detectors in Canfranc, Boulby and Kamioka
- ~0.1mBq/kg ICP-MS in Kamioka

Chain	^{238}U			^{232}Th			^{235}U	
	^{238}U		^{226}R	^{232}Th	^{228}Ra	^{228}Th	^{235}U	$^{227}Ac/^{227}Th$
Typical	50		5	100	10	100	30	300
Goal*	**< 5**		**< 0.5**	**< 0.05**	**< 0.05**	**< 0.05**	**< 3**	**< 3**
Detector	Ge	ICPMS	Ge	ICPMS	Ge	Ge	Ge	Ge
Company A	< 13	0.2	0.7±0.4	0.3	< 0.39	1.7±0.4	< 1.3	< 3.1
Company B	< 25	0.2	< 0.6	0.2	< 0.7	0.9±0.3	< 3.1	< 6.1
Company C	< 13	0.1	< 0.3	0.2	< 0.3	< 0.4	< 0.6	< 1.9

*Goal for 0.2% Gd-sulfate loading

unit [mBq/kg $(Gd_2SO_4)_3$)]

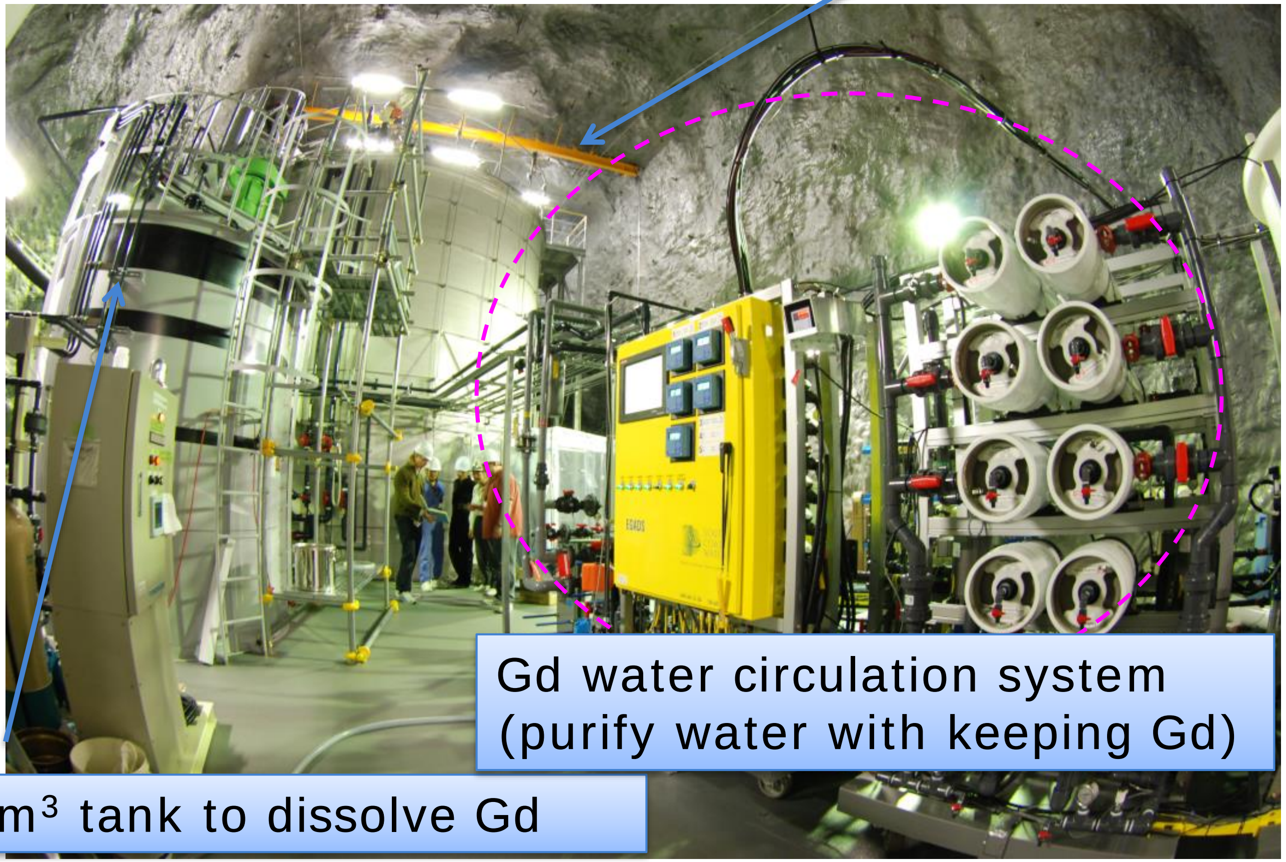
U : Achieved our goal. Th/Ra: further factor 4 (0.05% loading is OK)

EGADS

M. Murdoch's talk an hour ago

Evaluating Gadolinium's Action on Detector Systems

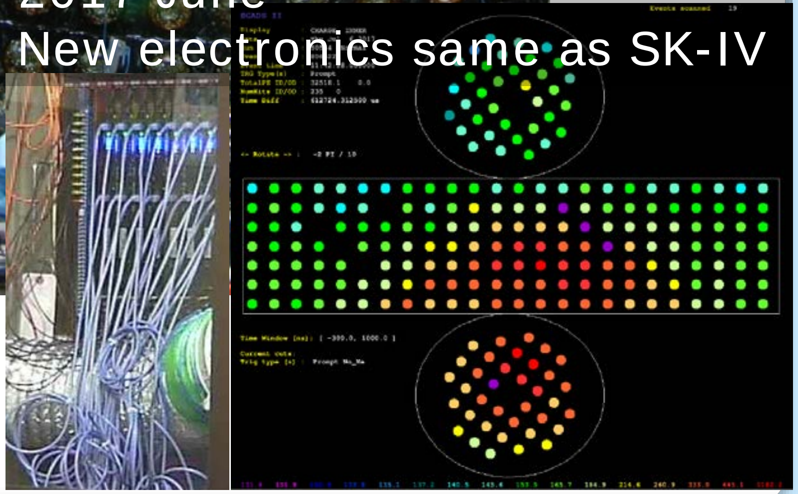
- To study the Gd water quality with actual detector materials.
- The detector fully mimic Super-K detector;
  SUS frame, PMT and PMT case, black sheets, etc.
- Tests for Hyper-K; 13 HPDs



15m^3 tank to dissolve Gd

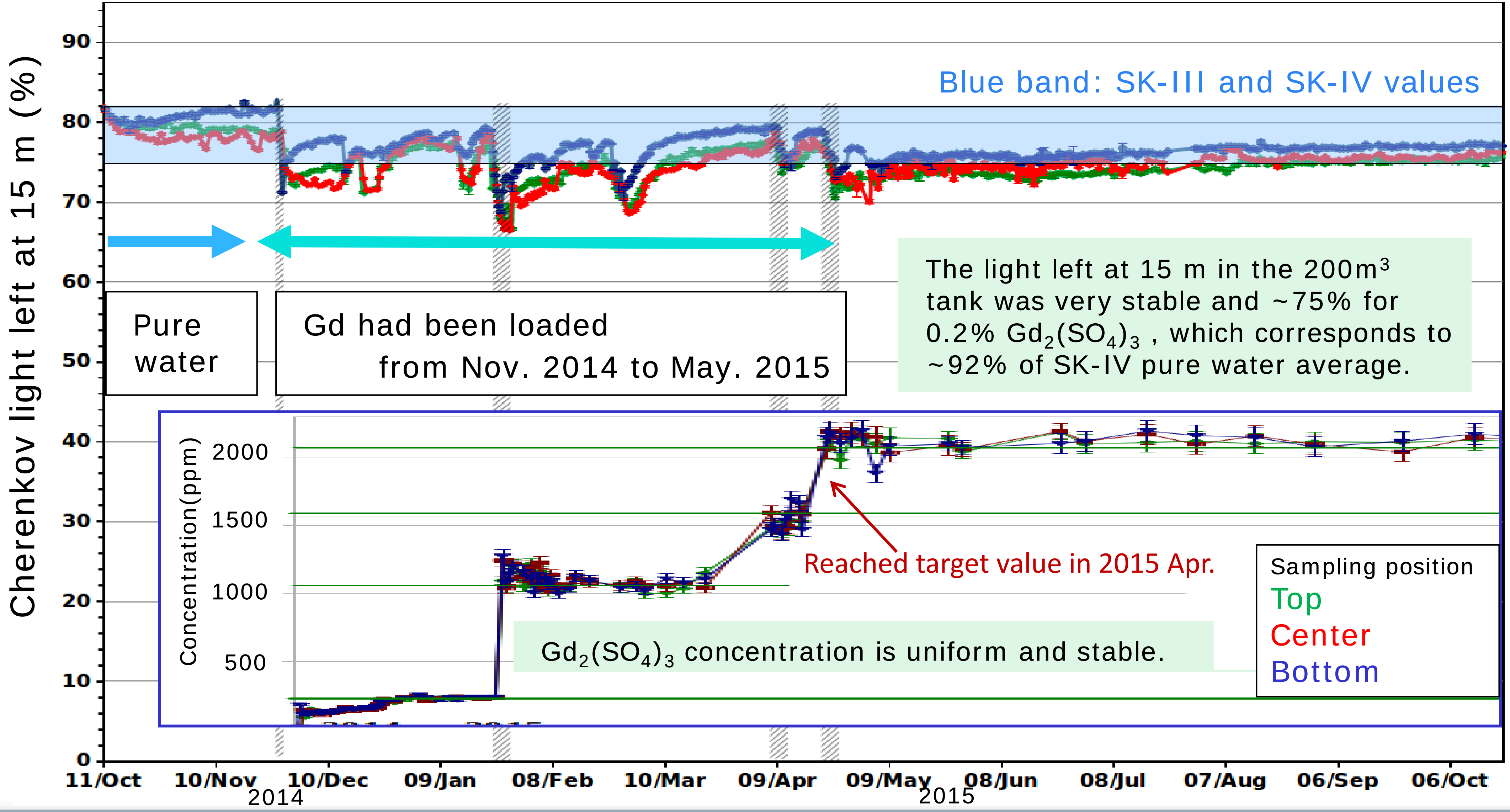
Gd water circulation system
(purify water with keeping Gd)

200 m^3 tank with 240 PMTs

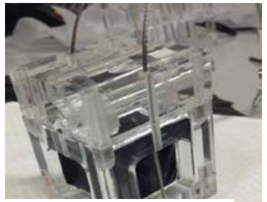


2017 June
New electronics same as SK-IV

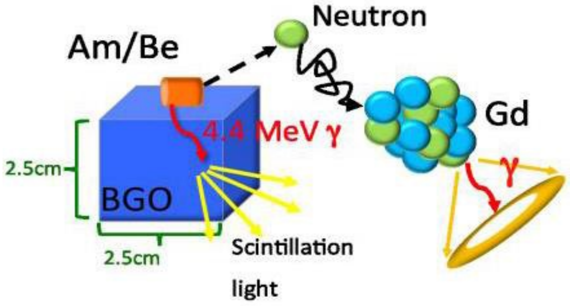
Water quality and $Gd_2(SO_4)_3$ concentration in EGADS



Neutron calibration in EGADS

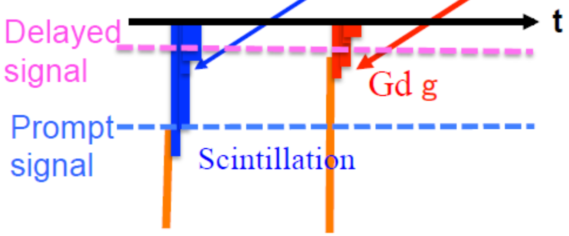


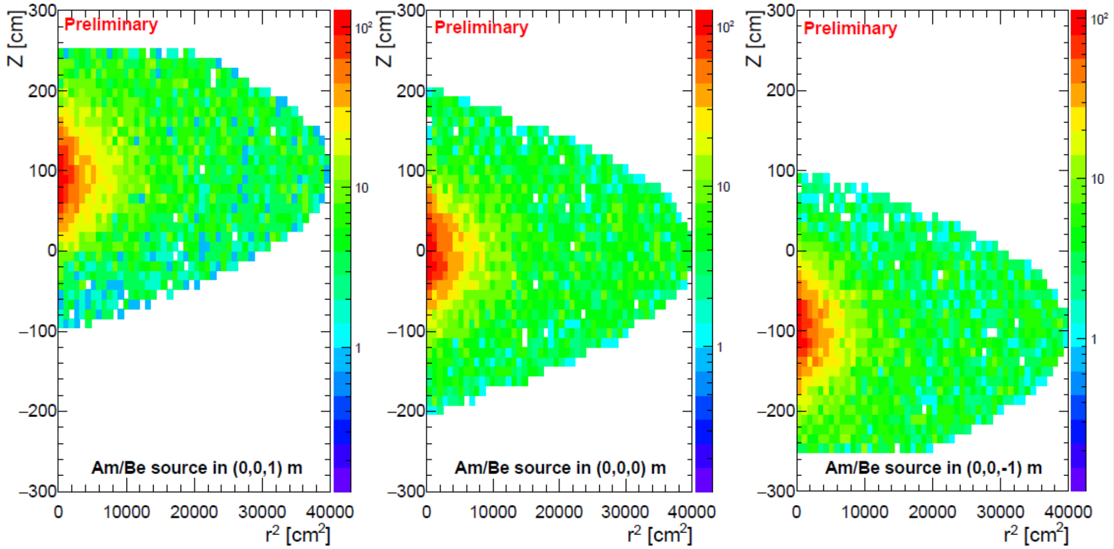
- Am/Be + BGO deployed in EGADS



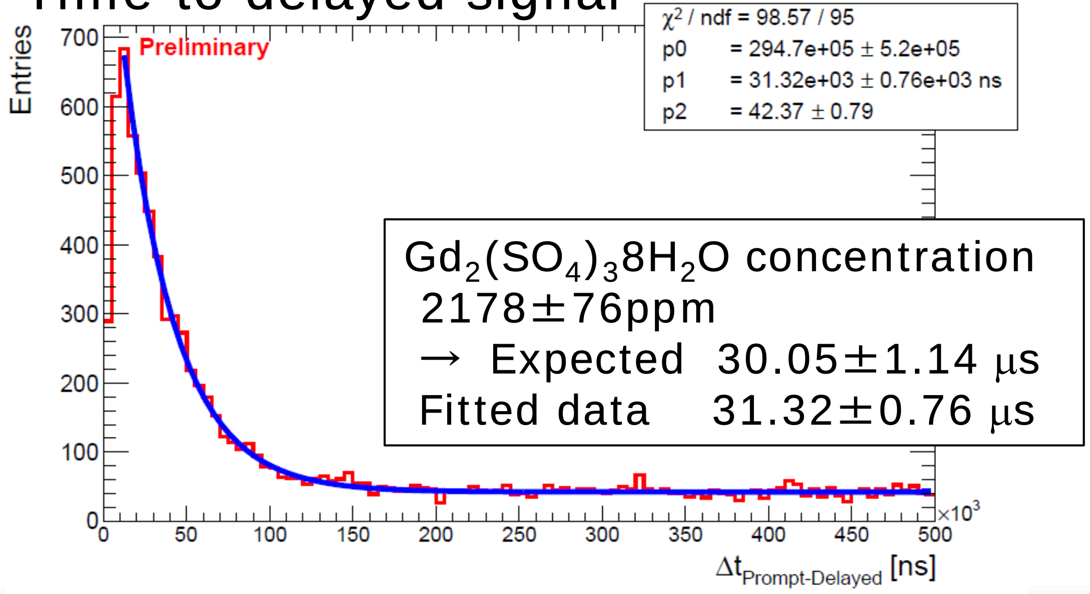
$^{241}Am \rightarrow {}^{237}Np + a$

$^{9}Be + a \rightarrow {}^{12}C + g(4.4MeV) + n$



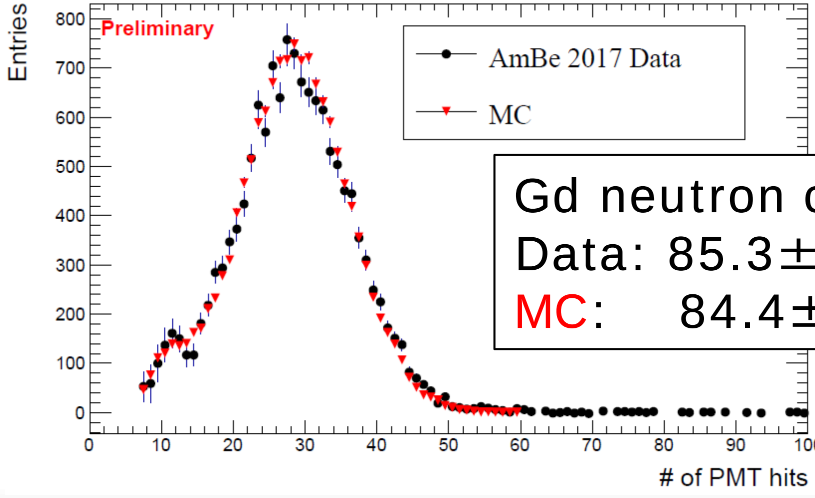


Time to delayed signal



$Gd_2(SO_4)_3 8H_2O$ concentration
2178±76ppm
→ Expected 30.05±1.14 μs
Fitted data 31.32±0.76 μs

Delayed signal spectrum



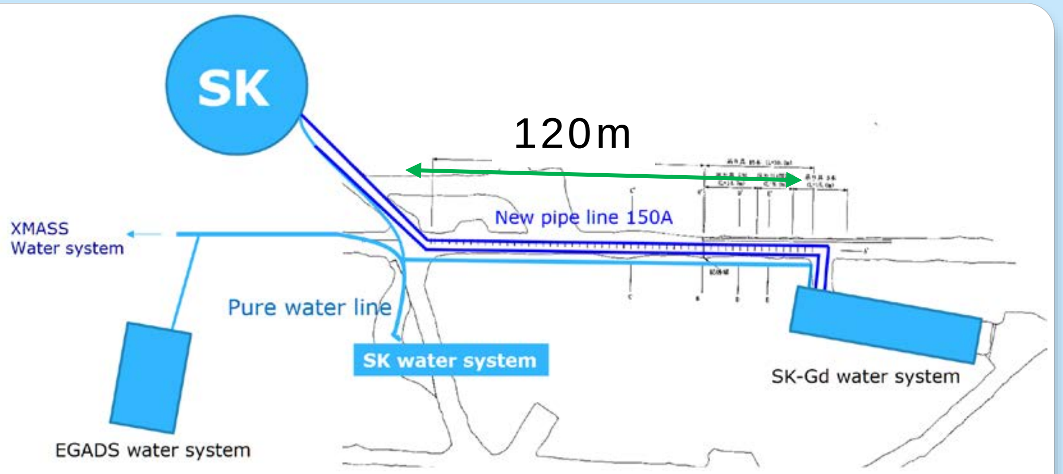
Gd neutron capture efficiency
Data: 85.3±0.9% (stat)
MC: 84.4± 0.3% (stat)

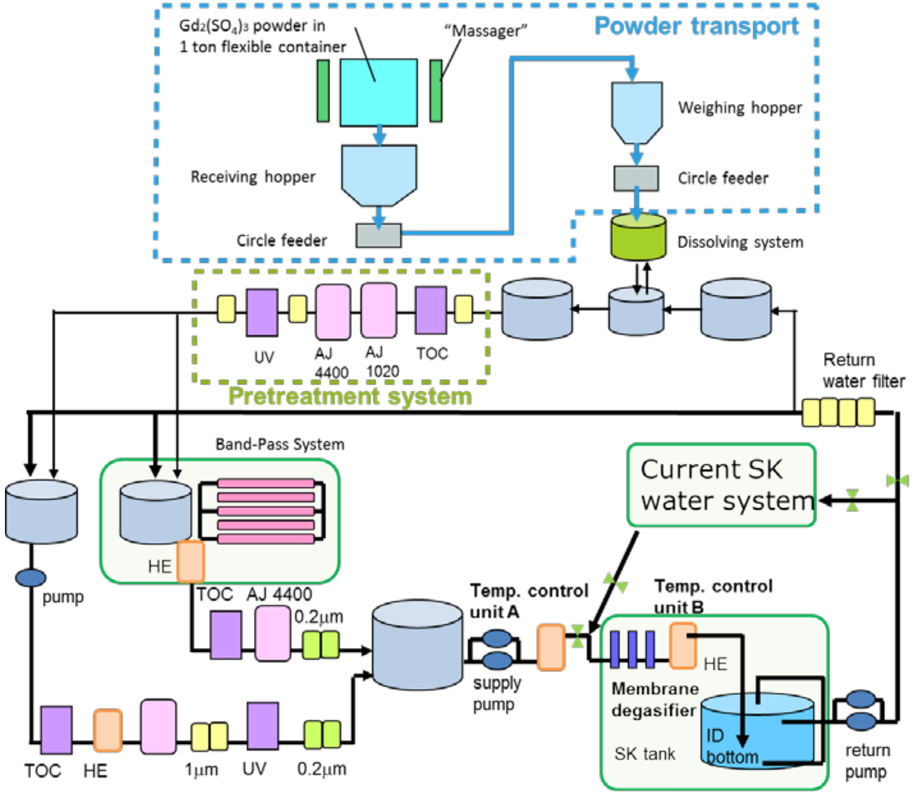
Eye inspection after 2.5 years operation

- Everything looked beautiful and shiny with 0.2% $Gd_2(SO_4)_3$ water

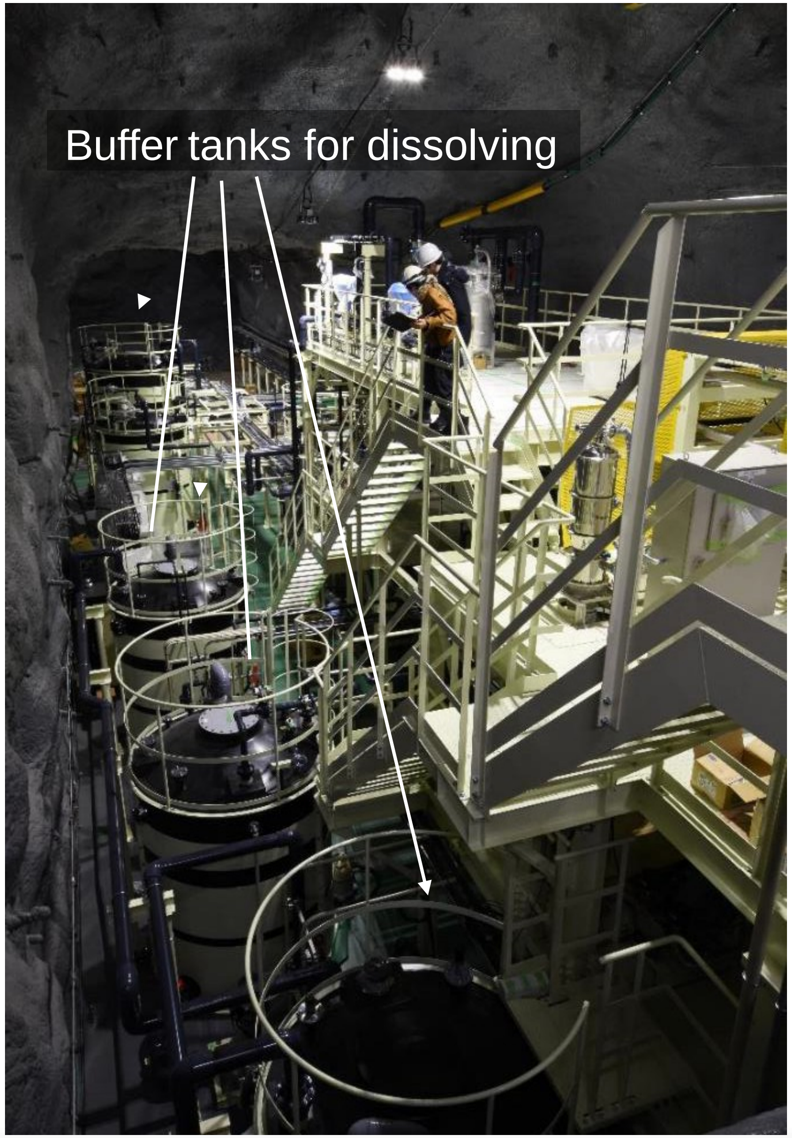
SK-Gd water system

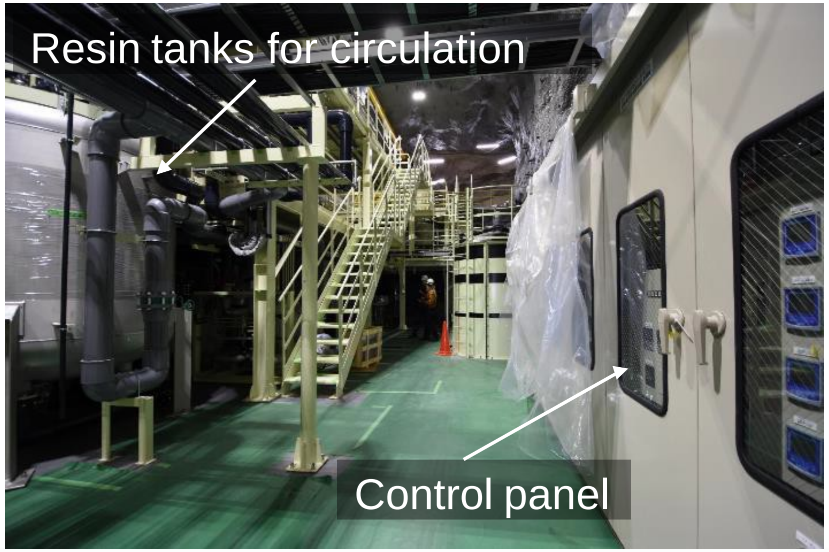
- Dissolving system
- Pretreatment system
- Re-circulation system





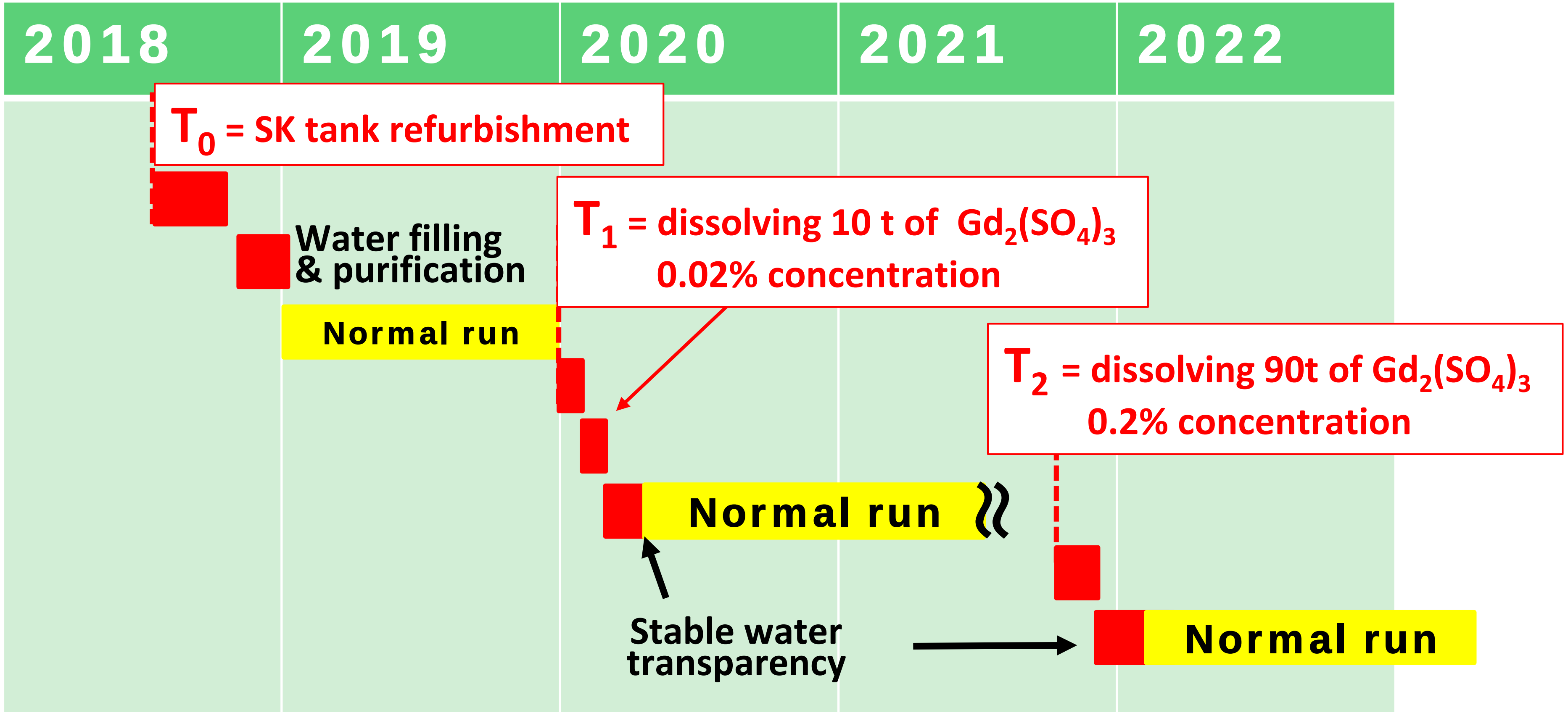
SK-Gd water system





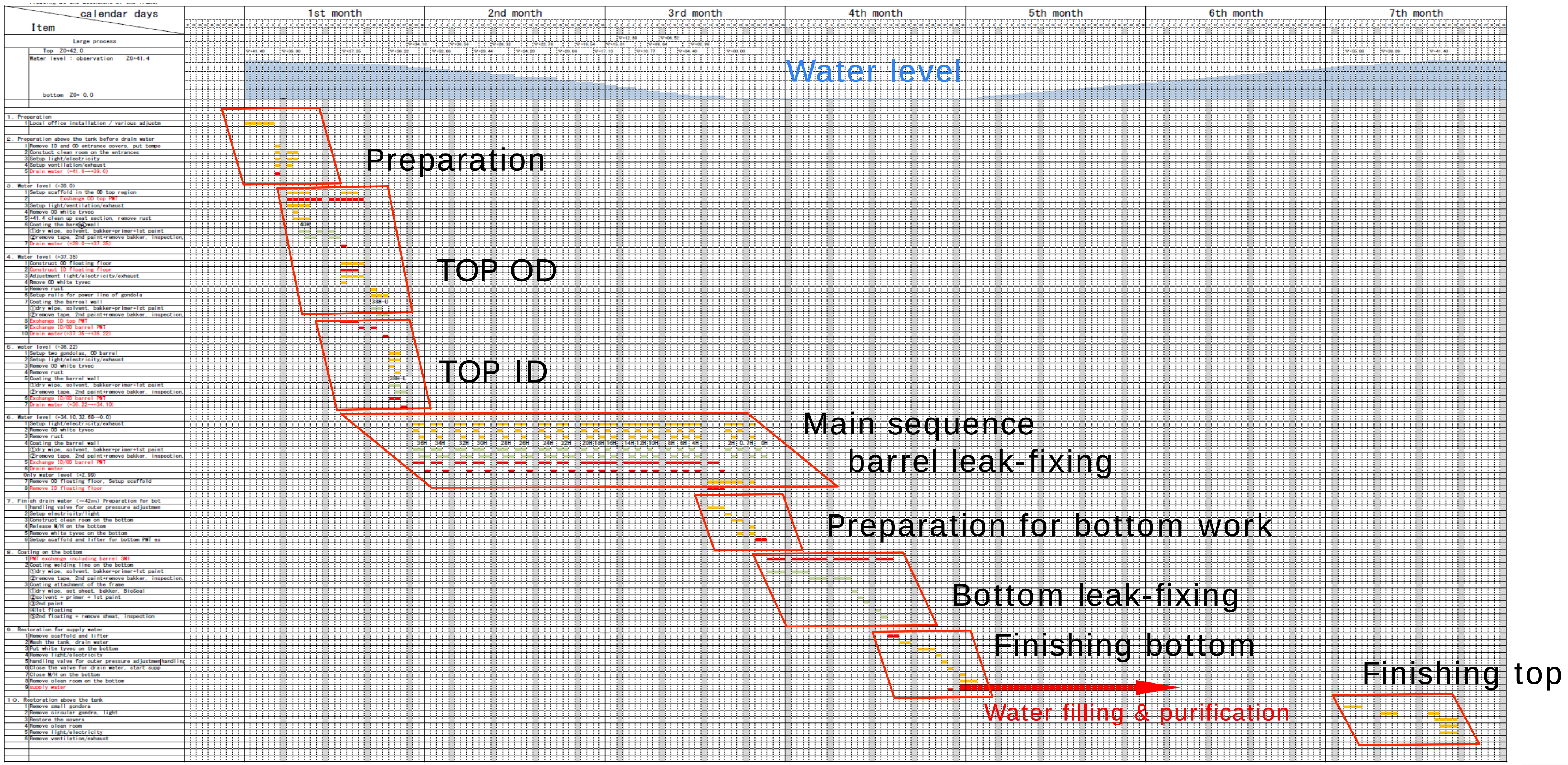
Timeline

- 3 steps (T_0,T_1,T_2) to get 0.2% concentration
- T2K and SK agreed to set T_0 in 2018
  - In JPARC PAC meeting in this morning, T_0 was decided on June. 1st 2018.



Detailed schedule of SK refurbishment

- Day-by-day schedule … In total, 6.5 months are required to resume SK physics run.



Conclusion

- SK-Gd project tries to catch neutrinos from past SNe before Hyper-K running.
- A lot of progresses made recently on leak fixing, background reduction and water system construction, and further preparation is ongoing for the SK refurbishment in 2018.