Low energy neutrino observation and preparation for SK-Gd in Super-Kamiokande

Guillaume Pronost,

Kamioka Observatory, ICRR, The University of Tokyo

ICRR research Joint meeting, December 14th, 2019

(Supported by KAKENHI Grant-in-Aid
for Scientific Research
on Innovative Areas 26104008)

OUTLINE

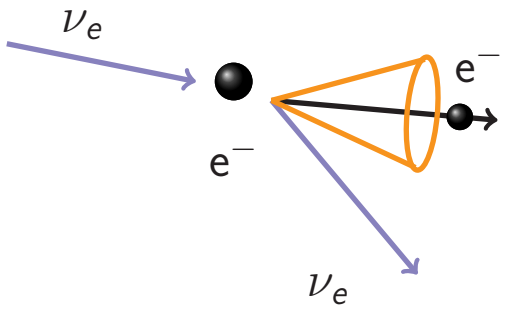
1 - Solar Neutrino in Super-Kamiokande

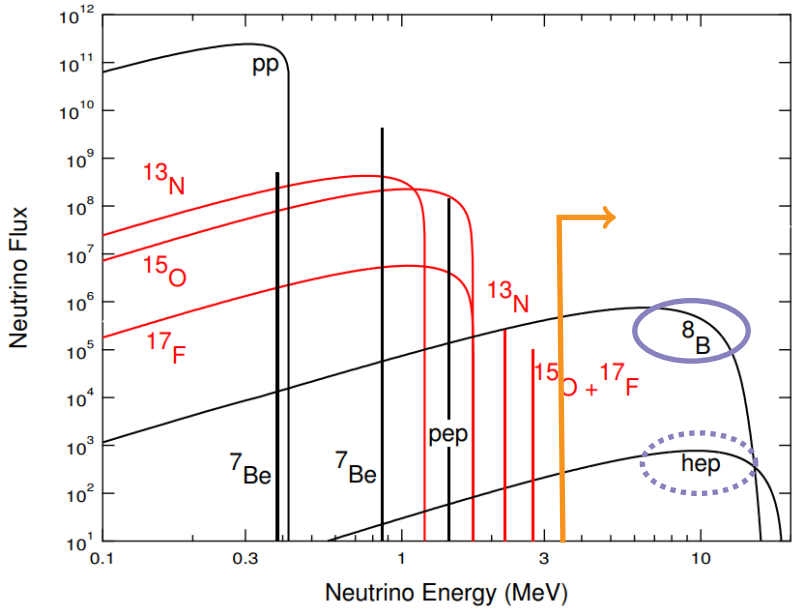
2 - Supernova Relic Neutrino

3 - Super-Kamiokande Gd project

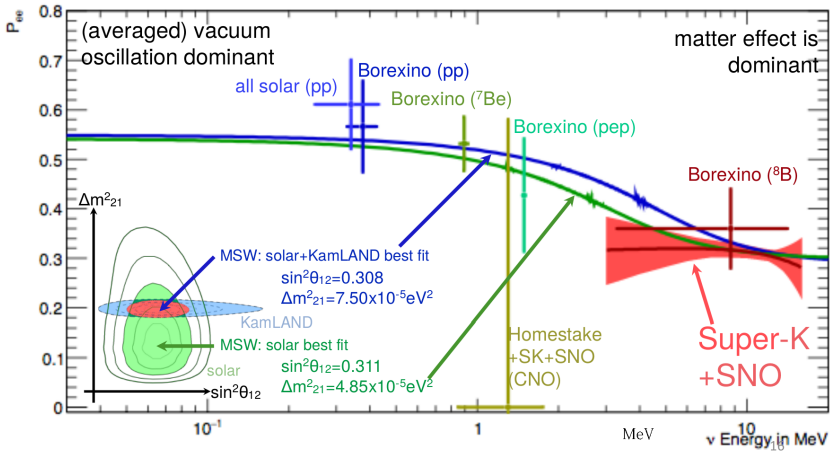
Solar ν in Super-Kamiokande

- Super-Kamiokande is looking at ν_e from Sun
  E_{thr} (SK-IV): 3.5 MeV $\rightarrow$ ^{8}B ν (and hep?)
- Detection channel: ν-e^- elastic scattering



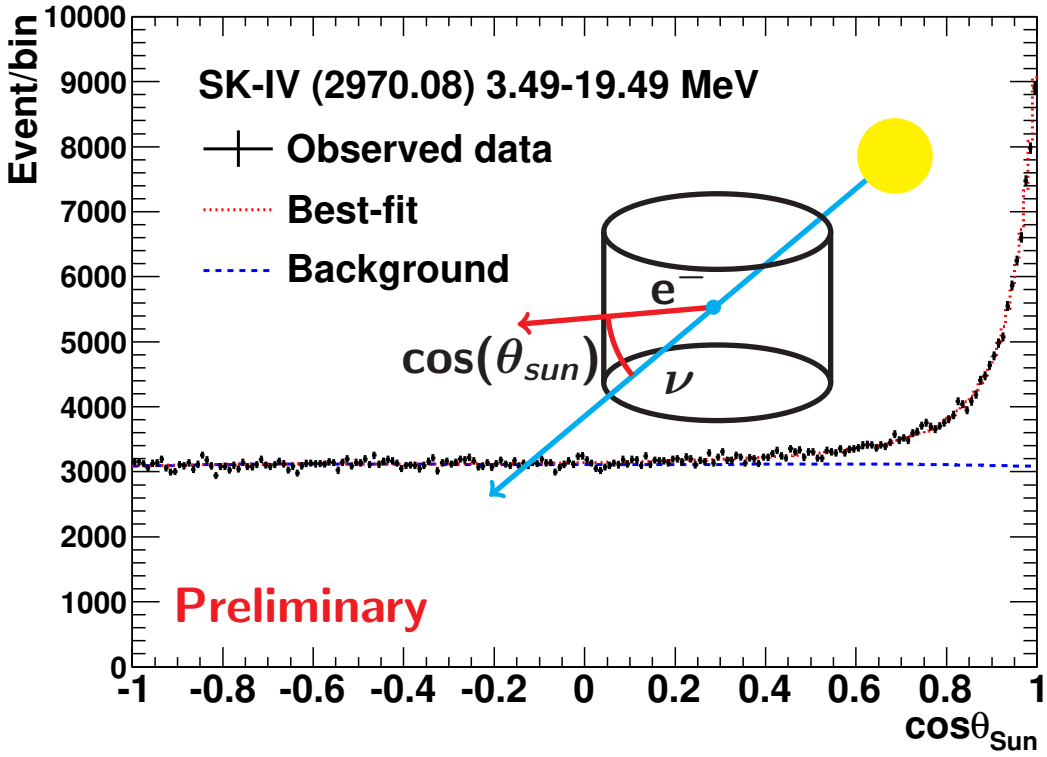


- Direction information used to select solar ν
- Analysis goals:
  - Probe the inside of the Sun
  - Earth matter effect (day/night asymmetry)
  - Observation of the transition region between vacuum and matter oscillations (up-turn?)



Recent results in solar ν analysis (1/2) [Preliminary]

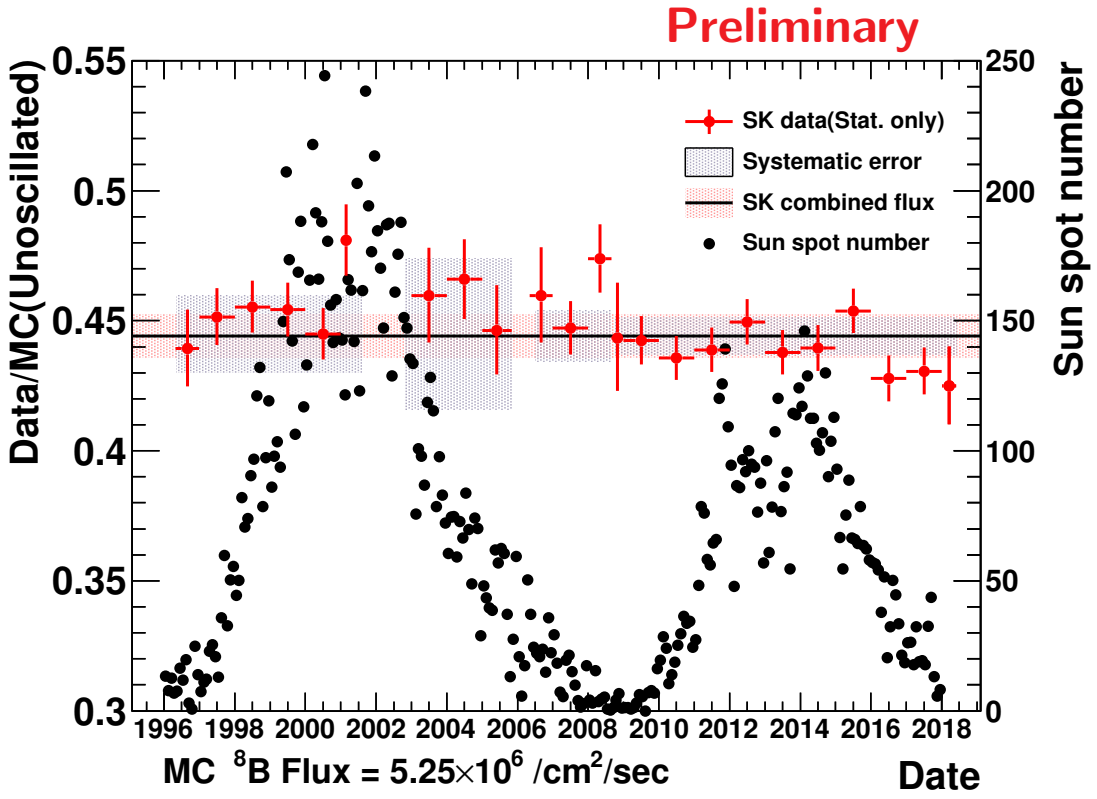
- Finalizing SK-IV analysis (Analyzed period Oct 2008 - May 2018)
- ^{8}B flux is coherent over the different periods of SK (22 years)



Period	Lifetime [day]	Extracted Signal	^{8}B flux [$\times 10^6$/cm^2/sec]
Last	2970	57844^{+369}_{-367}(stat)$\pm$925(syst)	2.30 ± 0.01(stat)$\pm$0.04(syst)
Previous	2860	55729^{+363}_{-361}(stat)	2.29 ± 0.02(stat)$\pm$0.04(syst)
SK-III	548	8148^{+133}_{-131}(stat)	2.40 ± 0.04(stat)$\pm$0.05(syst)
SK-II	791	7213^{+153}_{-151}(stat)	2.41 ± 0.05(stat)$^{+0.16}_{-0.15}$(syst)
SK-I	1496	22404 ± 226(stat)	2.38 ± 0.02(stat)$\pm$0.08(syst)

Recent results in solar ν analysis (2/2) [Preliminary]

- Finalizing SK-IV analysis (Analyzed period Oct 2008 - May 2018)
- ^{8}B flux is coherent over the different periods of SK (22 years)
- No correlation observed with the 11-years solar activity (62.8% prob. for constant flux)



Period	Lifetime [day]	Extracted Signal	^{8}B flux [$\times 10^6$/cm^2/sec]
Last	2970	57844^{+369}_{-367}(stat)$\pm$925(syst)	2.30 ± 0.01(stat)$\pm$0.04(syst)
Previous	2860	55729^{+363}_{-361}(stat)	2.29 ± 0.02(stat)$\pm$0.04(syst)
SK-III	548	8148^{+133}_{-131}(stat)	2.40 ± 0.04(stat)$\pm$0.05(syst)
SK-II	791	7213^{+153}_{-151}(stat)	2.41 ± 0.05(stat)$^{+0.16}_{-0.15}$(syst)
SK-I	1496	22404 ± 226(stat)	2.38 ± 0.02(stat)$\pm$0.08(syst)

Other solar neutrino studies

- **Solar flare's neutrinos**:
- In case of rear solar flares, D. Fargion (2003) predicts a detectable amount of neutrino in SK (~ 7 νs in case of 10^{32} erg's rear solar flares.)
- No signal observed in the different SK periods.
- High energy search is also performed (results are compatible with the BG level)
- Some other solar neutrino studies are on-going (like sun anti-neutrino or non-standard interaction searches).

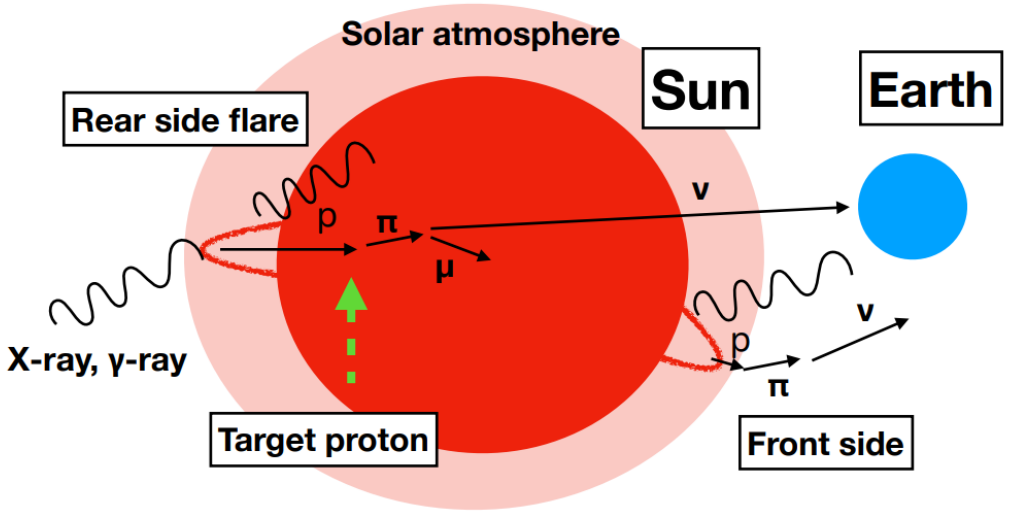
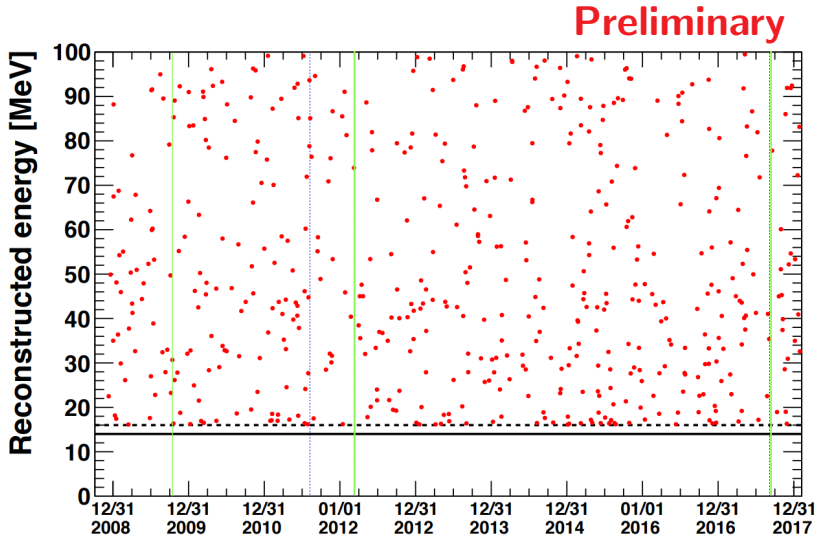


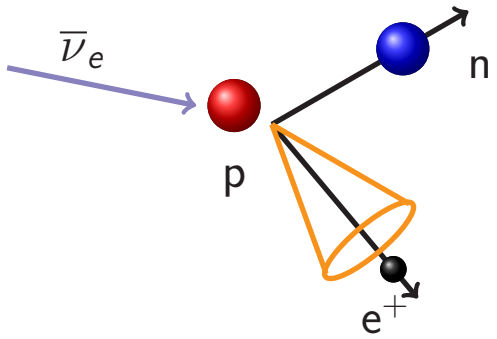
Figure from Okamoto-san (ICRR)

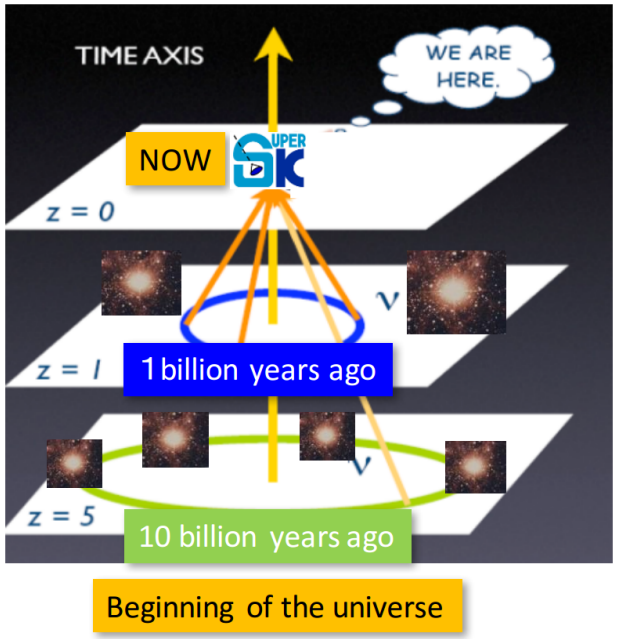
Low energy event search for Solar Flares in SK-IV:

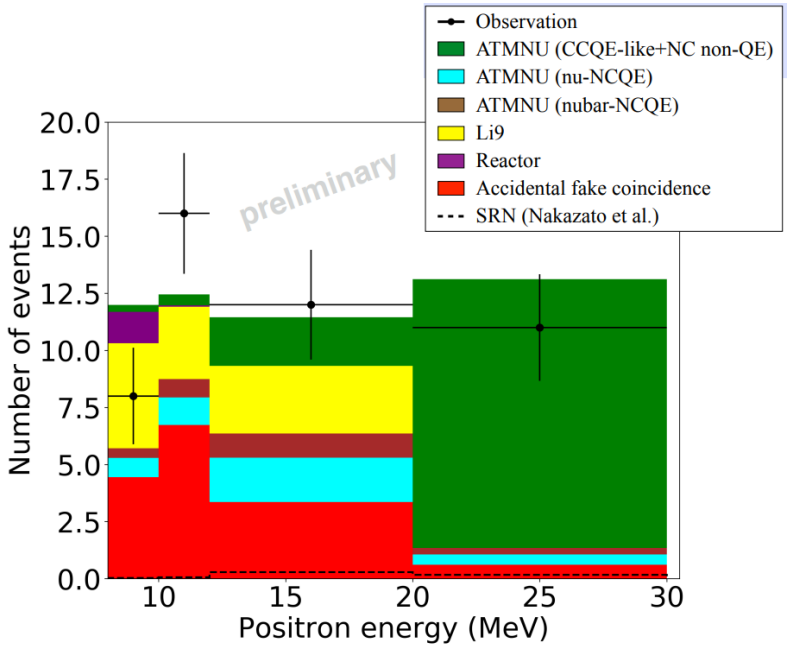


Supernova Relic Neutrino

- The Supernova Relic Neutrinos (SRN) or "Diffuse Supernova Neutrino Background" are an expected background of ν produced by all the past supernovae.
- Theoretical flux prediction :
  $0.3 \sim 1.5$ /cm^2/s (17.3MeV threshold)
- Signal: Inverse β decay reaction:





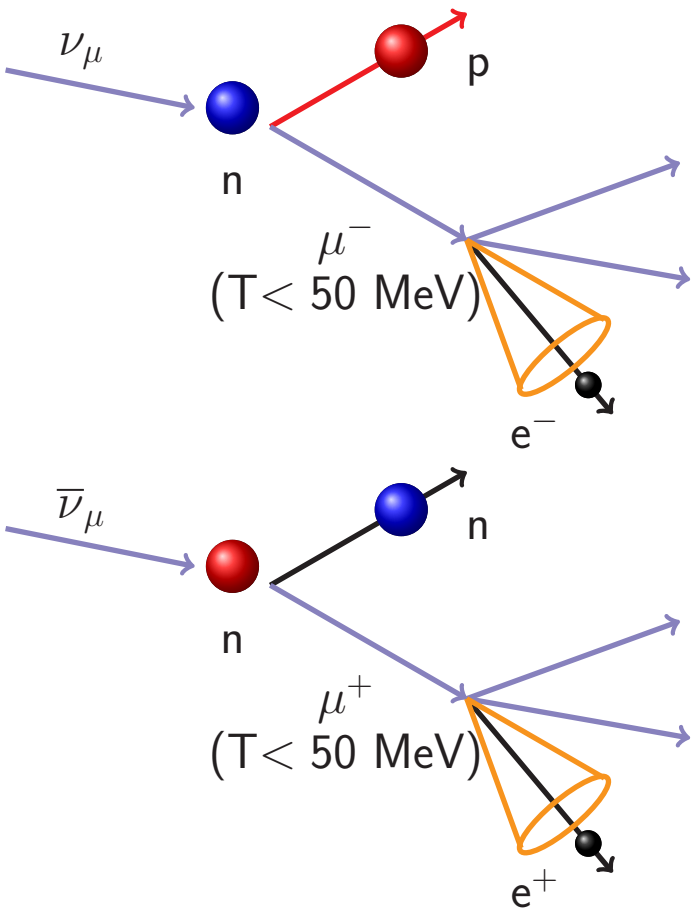


- Large background rate is affecting the analysis

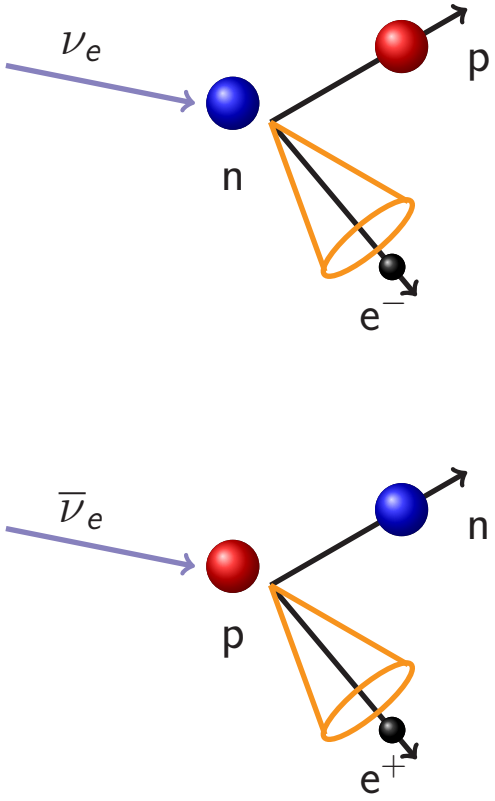
Backgrounds

- Difficult analysis due to large backgrounds

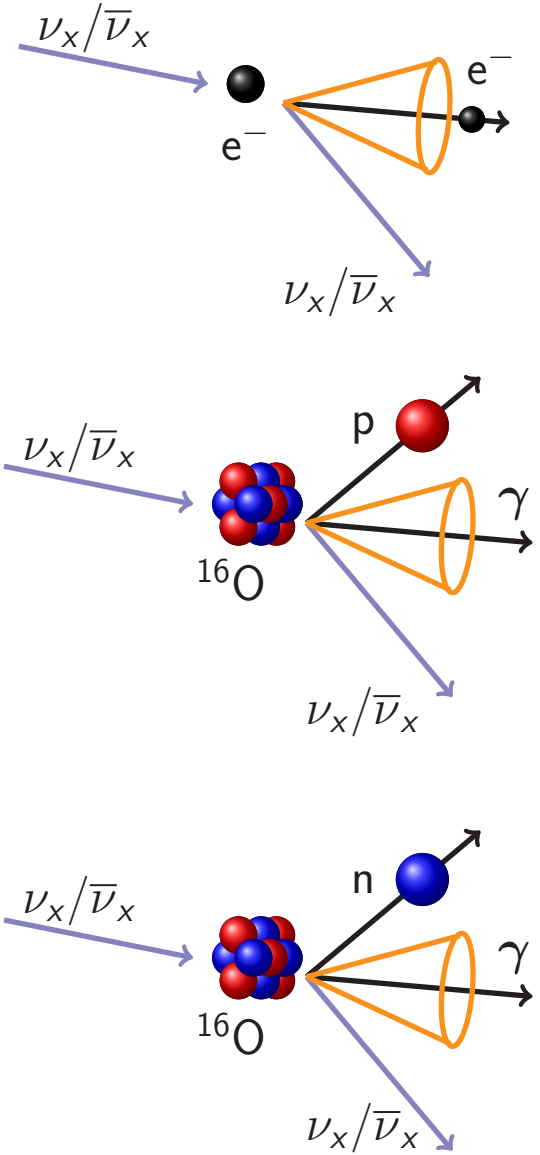
Atmospheric ν_μ CC



Atmospheric ν_e CC



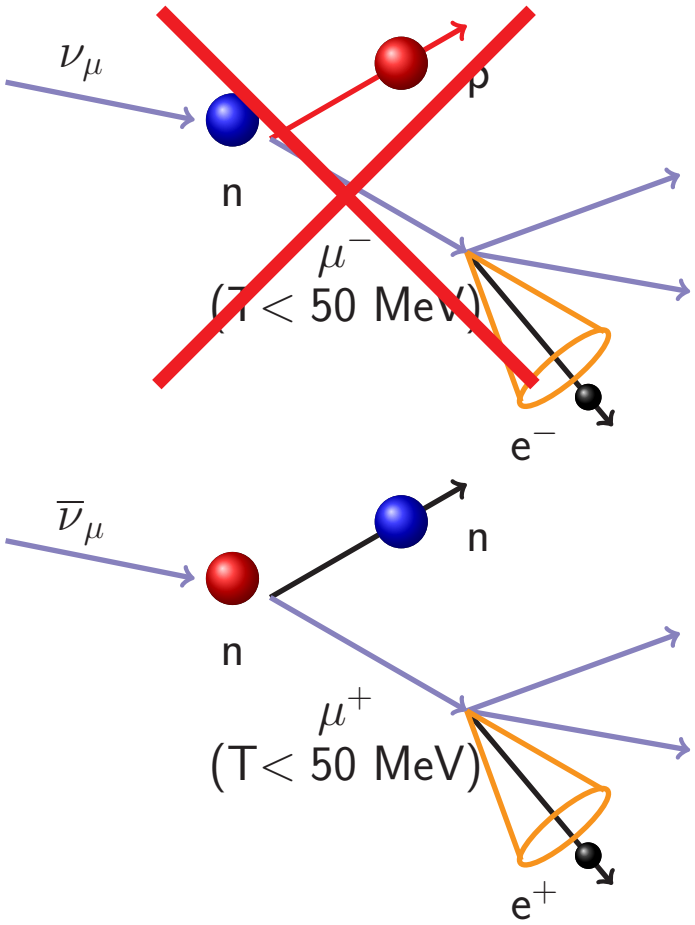
Atmospheric ν NC



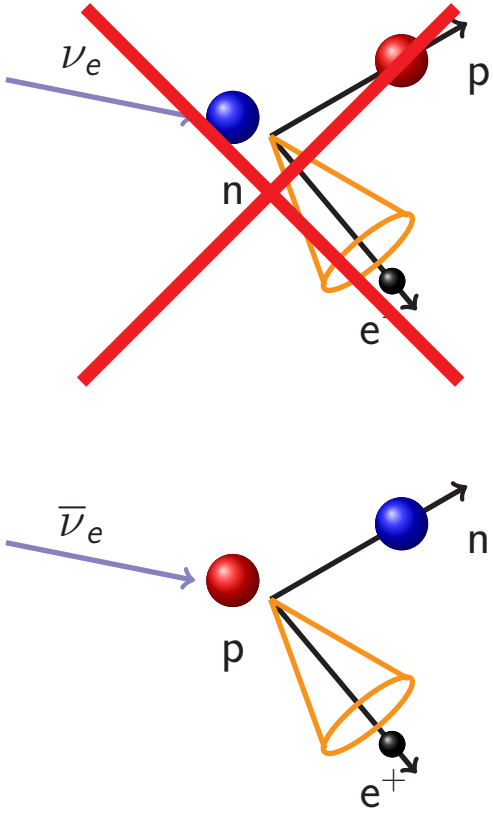
Backgrounds

- Signal produce one neutron, most BG interactions don't
- Neutron detection → BG reduction

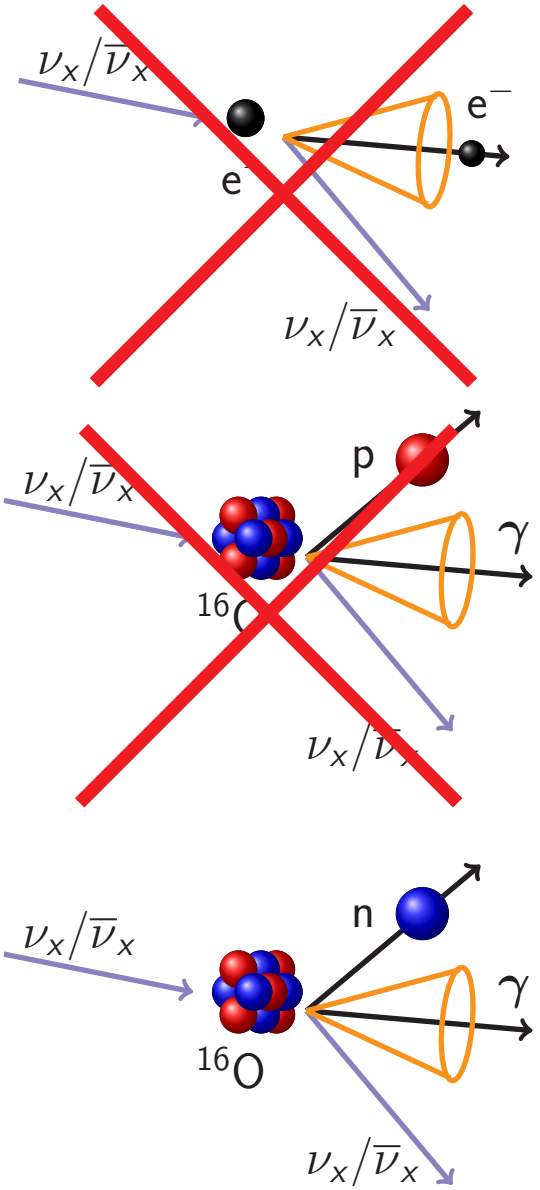
Atmospheric ν_μ CC



Atmospheric ν_e CC

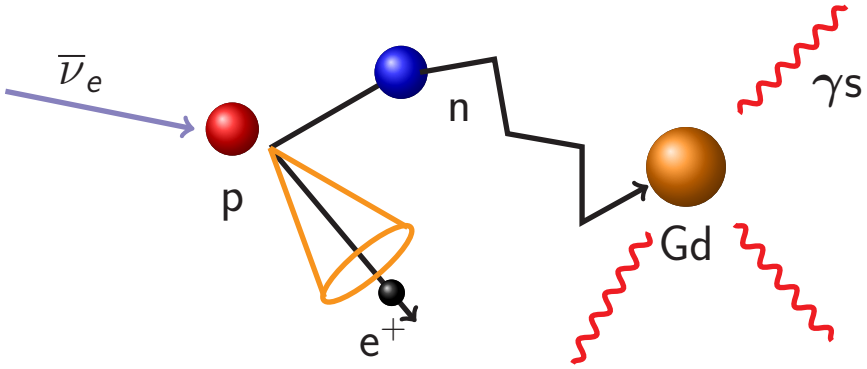


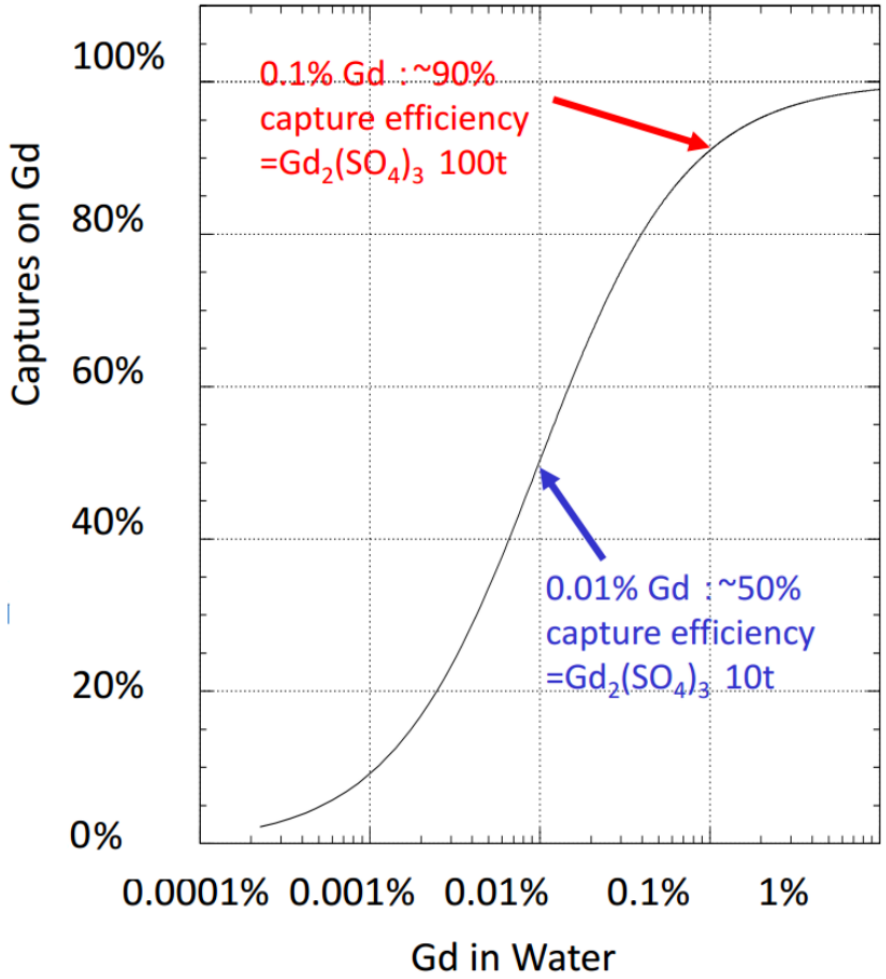
Atmospheric ν NC



Super-Kamiokande Gd project

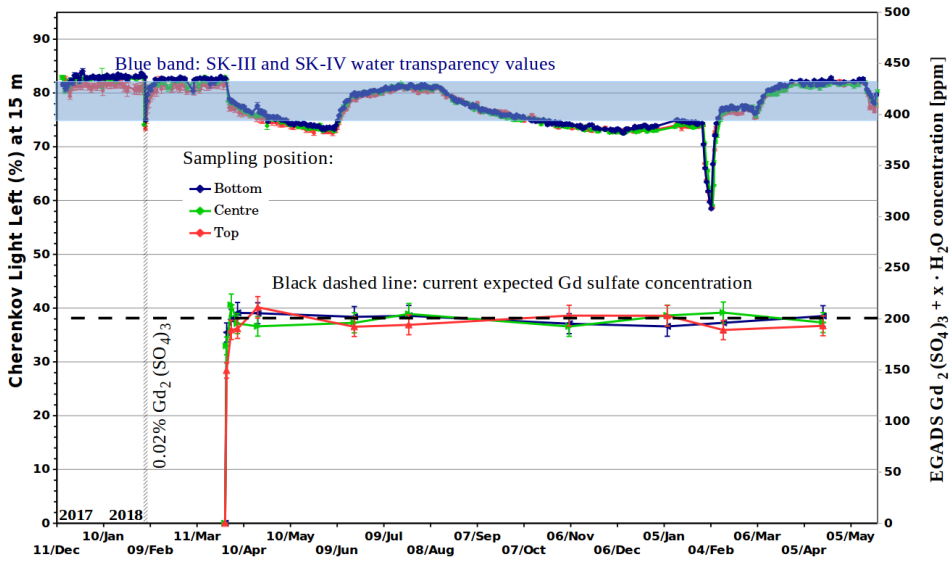
- Super-Kamiokande-Gd project (SK-Gd): load Gd in SK in order to detect neutrons from $\overline{\nu}$ interactions.
  - Gd: largest neutron capture cross-section among stable elements, and clear signal (γ cascade).
  - $\sim$ 80% of neutron tagging efficiency with 0.1% of Gd ($\sim$ 90% of Gd-n capture)
- Expect Supernova Relic Neutrino detection!



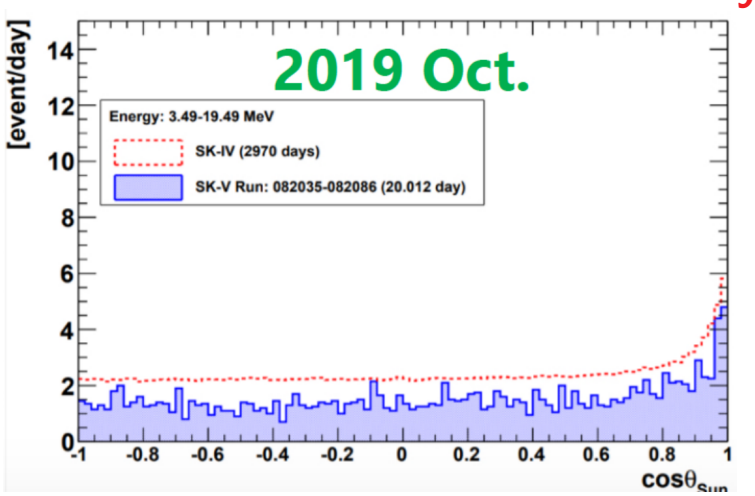


Super-Kamiokande Gd project status

- The SK-Gd was approved by the Super-Kamiokande collaboration in June 2015.
- In order to achieve it, we needed to:
  - Developed a water system able to keep good transparency with Gd-loaded water.
    → EGADS has been running as a demonstrator for SK-Gd since 2014, achieving good water transparency.
  - Fix the leak of the SK tank by at least a factor 10.
    → In summer 2018, we opened the SK tank for a extensive cleaning and maintenance of the detector.



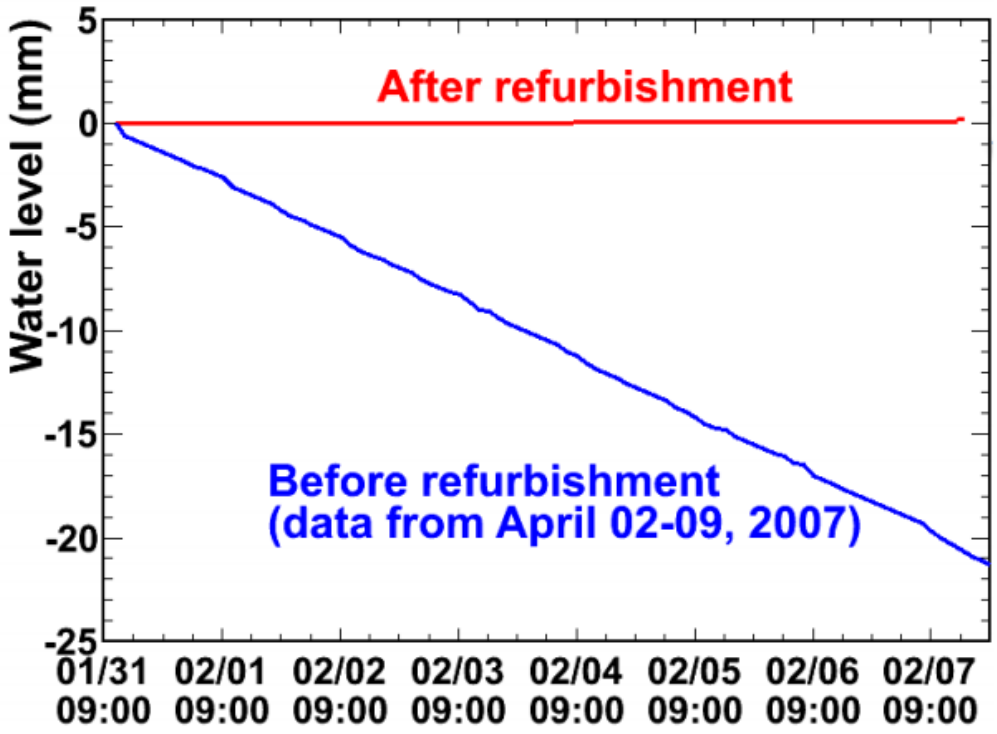
Preliminary



After the extensive cleaning of the detector, we even managed to reduce the BG of our LowE analysis!

Water leak status

- One of the main goal of the tank opening work was to fix the leak of SK.
- This is a critical condition before loading Gd in SK, in order to avoid letting Gd spreads in the environment.
- Several studies were performed since the end of the tank opening, allowing to determine the leak was reduced to be less than **0.017 tons per day**.
- The current SK water leakage has been reduced to less than 1/200th the rate during the period before tank refurbishment.



Success!

Gadolinium powder status

- 14tons of Gd sulfate have been delivered to Kamioka by the end of September
- Radioactivity screening is being performed on all the different lots in order to validate if the Gd-powder passes our requirements.
- 2/3 of the Gd powder have been screened in Kamioka (about half have been screened by Ge detectors outside Japan).
- So far, all the samples passed our requirements.

Chain	Isotope	Requirement (mBq/kg)
238U	238U	$< \mathbf{5}$
	226Ra	$< \mathbf{0.5}$
232Th	232Th	$< \mathbf{0.05}$
	228Ra	$< \mathbf{0.05}$
	228Th	$< \mathbf{0.05}$
235U	235U	$< \mathbf{30}$
	227Ac/Th	$< \mathbf{30}$

Water system status

- A dedicated Gd water system has been developed in order to allow the purification of Gd-loaded water in SK.
- The installation of new resin tanks, ultra filters, and UV system has been completed
- New plumbing for the new system has also been completed
- The anion exchange resin tanks has been completely filled since the beginning of this month.
- The 2/3 of cation exchange resin tanks has been filled in November. The remaining will be filled in February 2020.
- The system is operated and being flushed since October.

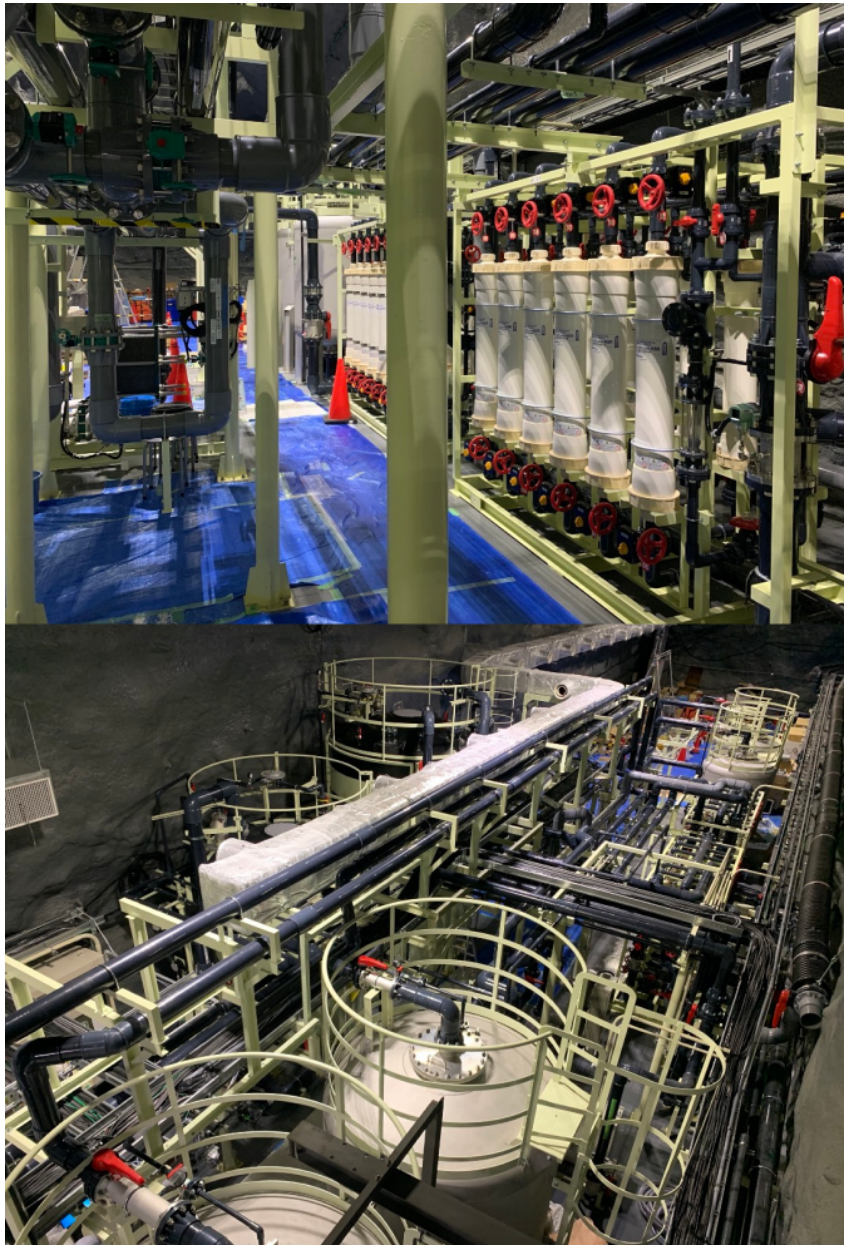
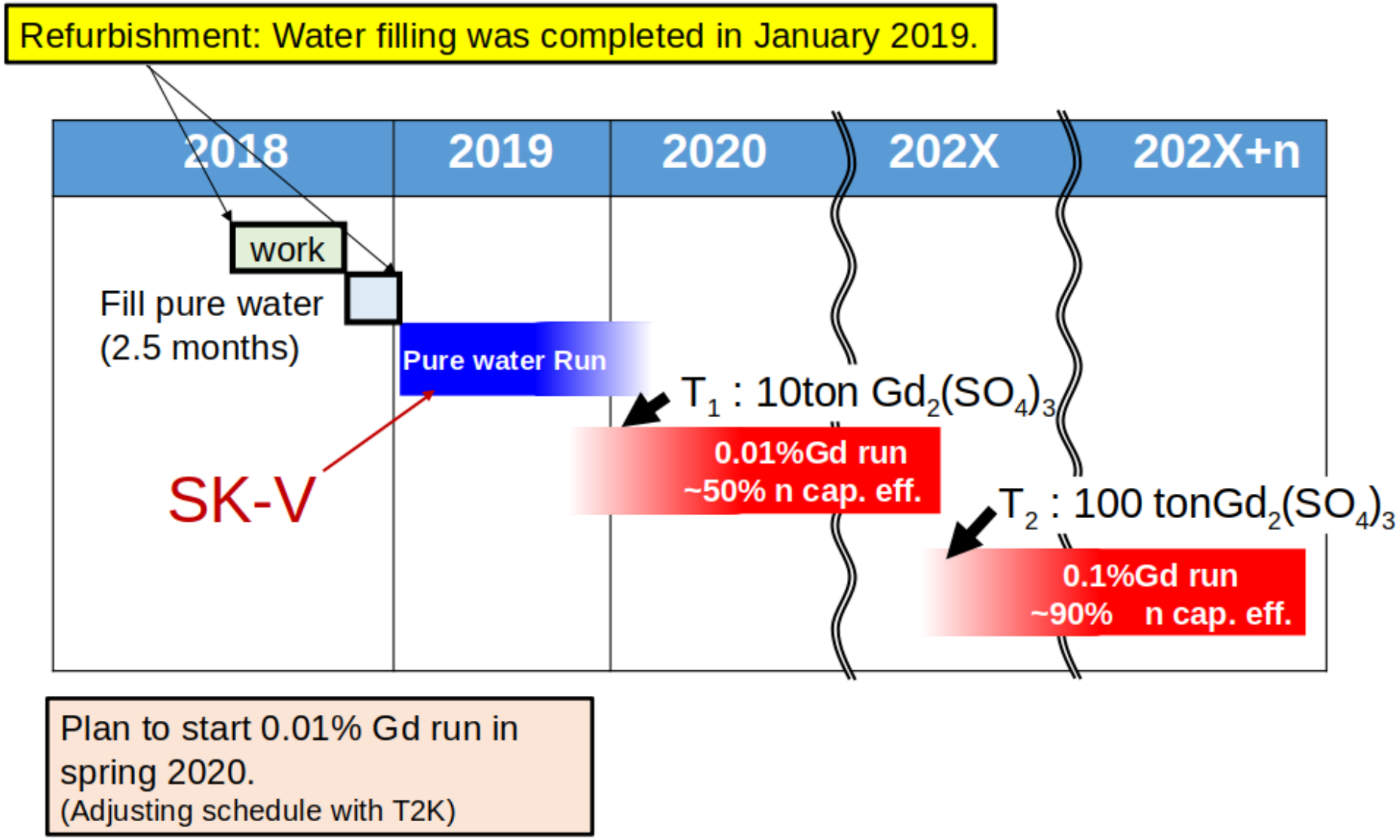


Photo from Nakajima-san

Gd loading plan



Publication in SK Low-Energy in 2019

- C. Simpson et al. (the Super-Kamiokande collaboration), *"Sensitivity of Super-Kamiokande with Gadolinium to Low Energy Antineutrinos from Pre-supernova Emission"*, The Astrophysical Journal, Volume 885, Number 2 (November 2019)
- LI. Marti et al. (EGADS group), *"Evaluation of Gadolinium's Action on Water Cherenkov Detector Systems with EGADS"*, submitted to NIM-A

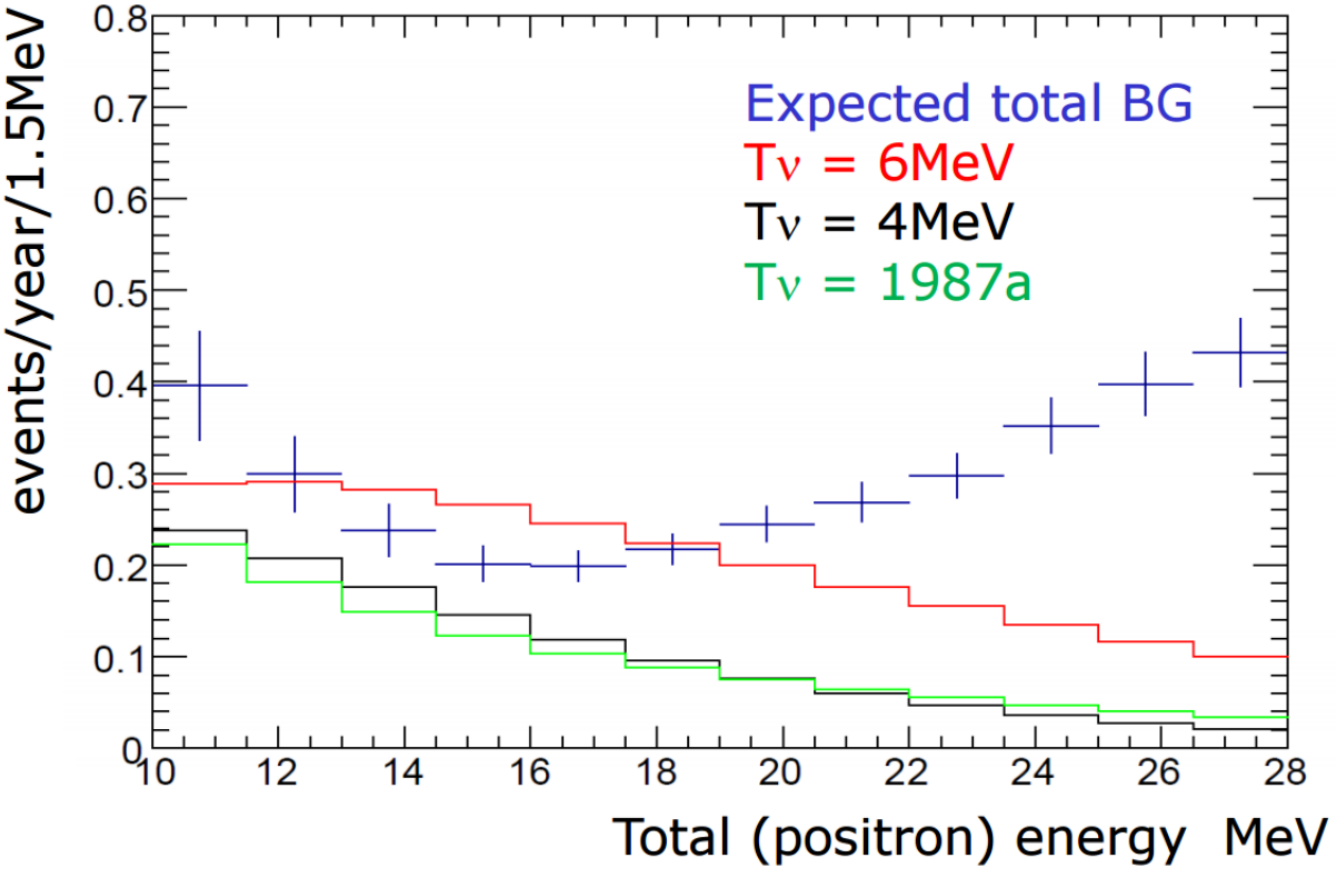
- Paper in SK LowE starts to be more "Gadolinium related" as SK-Gd approach. There is good hope it will increase in a near future!

Summary

- Solar neutrino:
  - We are finalizing the analysis of SK-IV data.
- SK-Gd:
  - Following the tank opening work in 2018, we managed to reduce the internal BG of the detector.
  - Currently no significant leak is observed with the upper limit of **0.017 tons per day** (better than our requirements for the Gd loading)
  - The Gd powder is currently in Kamioka, with an on-going screening of its radioactivity.
  - The final preparation for the Gd-loaded water purification system are on-going.
- **We expect to load 10 tons of Gd powder in SK in the next 4 to 6 months!**

Backup

Supernova Relic Neutrino in SK-Gd



HDB*	10-16 MeV	16-28 MeV	Total	significance
T_{eff} 8 MeV	11.3	19.9	31.2	5.3 σ
T_{eff} 6 MeV	11.3	13.5	24.8	4.3 σ
T_{eff} 4 MeV	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	–

Dependence on the typical SN emission spectrum

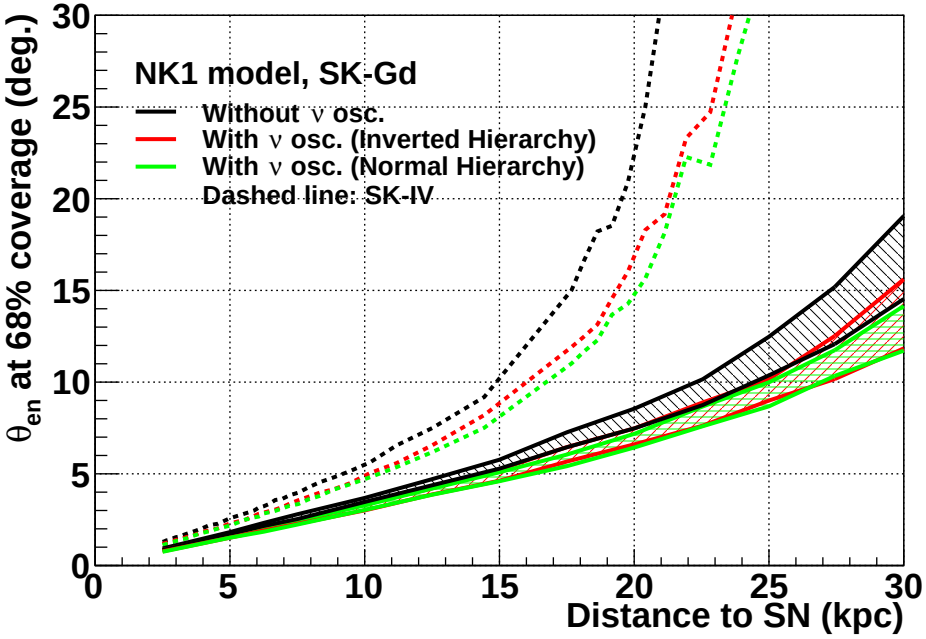
In events/10years

Significance is determined with 2 energy bins

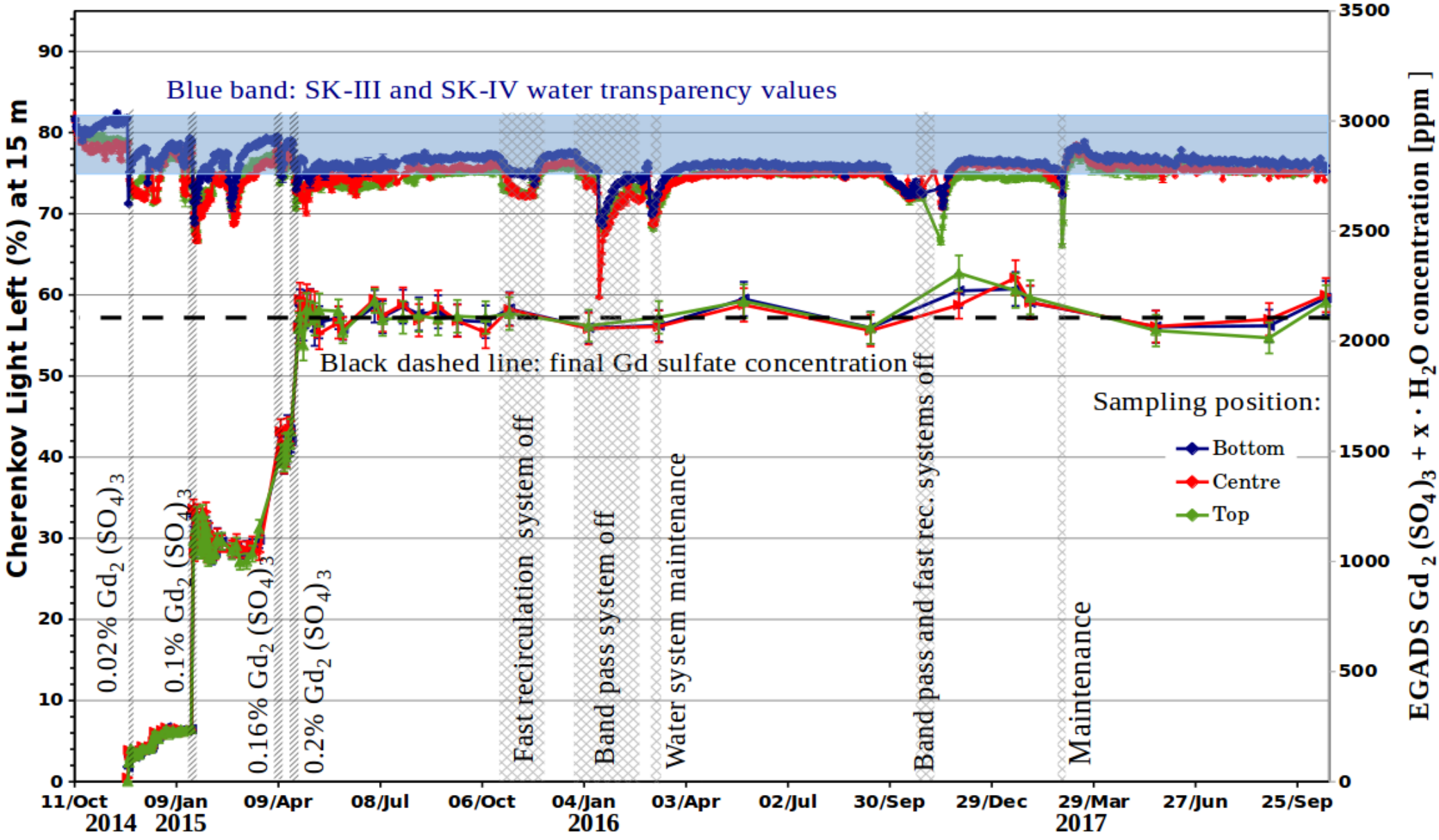
* Horiuchi, Beacom and Dwek, Phys Rev D 79 083013 (2009)

Other physics improvement of SK-Gd

- Gd loading will have other impact on the physics capability of SK:
  - Improvement of the pointing accuracy for galactic supernova: By a factor $\sim$ **2** at at 10 kpc
  - Detection of pre-Supernova Si-burning neutrinos
  - Reduction of the proton decay background
  - Neutrino/anti-neutrino discrimination
  - Detection of reactor neutrinos



EGADS water transparency



Gd powder radioactivity reduction

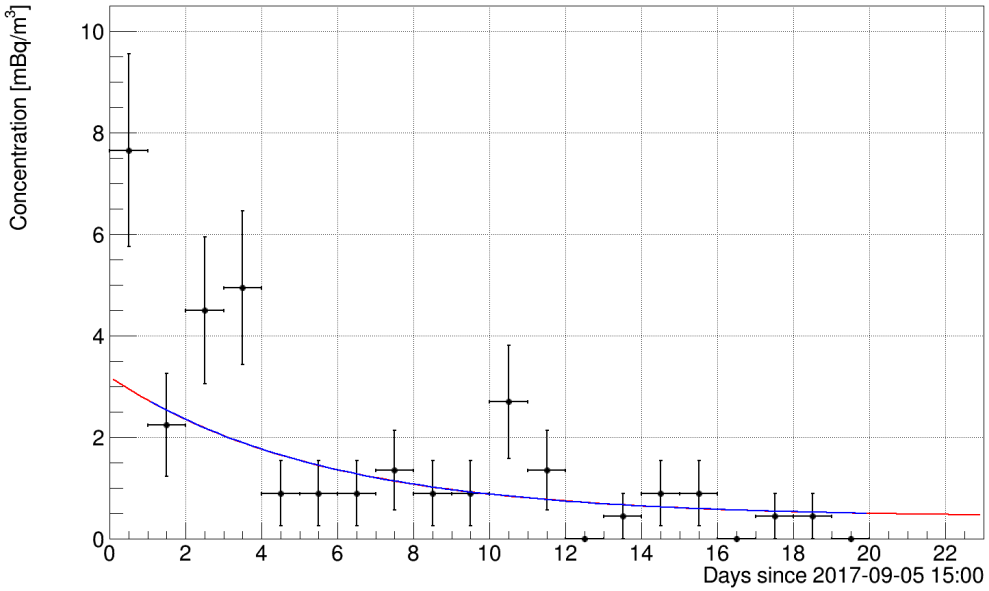
- In order to reduce the background in the SRNs and Solar ν analysis, the radioactivity background from Gd powder needs to be minimized
- New radio-purity measurement method developed in order to obtains more precise values

Chain	Isotope	Goal (mBq/kg)	Company A		Company B		Company C	
			Ge	ICPMS	Ge	ICPMS	Ge	ICPMS
238U	238U	$<$ **5**	..	$\sim$ **0.04**	$<$ 10	$<$ **0.04**	$<$ 11	$<$ **0.04**
	226Ra	$<$ **0.5**	..	–	$<$ **0.2**	–	$<$ **0.2**	–
232Th	232Th	$<$ **0.05**	–	$\sim$ 0.09	–	$\sim$ 0.06	–	$\sim$ **0.02**
	228Ra	$<$ **0.05**	..	–	$<$ 0.2	–	$<$ 0.3	–
	228Th	$<$ **0.05**	..	–	$<$ 0.3	–	$<$ 0.3	–
235U	235U	$<$ **3**	..	–	$<$ **0.3**	–	$<$ **0.4**	–
	227Ac/Th	$<$ **3**	..	–	$<$ **1.2**	–	$<$ **1.7**	–

- Thanks to the work with the different companies, we are close to our goal.
- EGADS prototype has been filled with Company C best sample to test it.

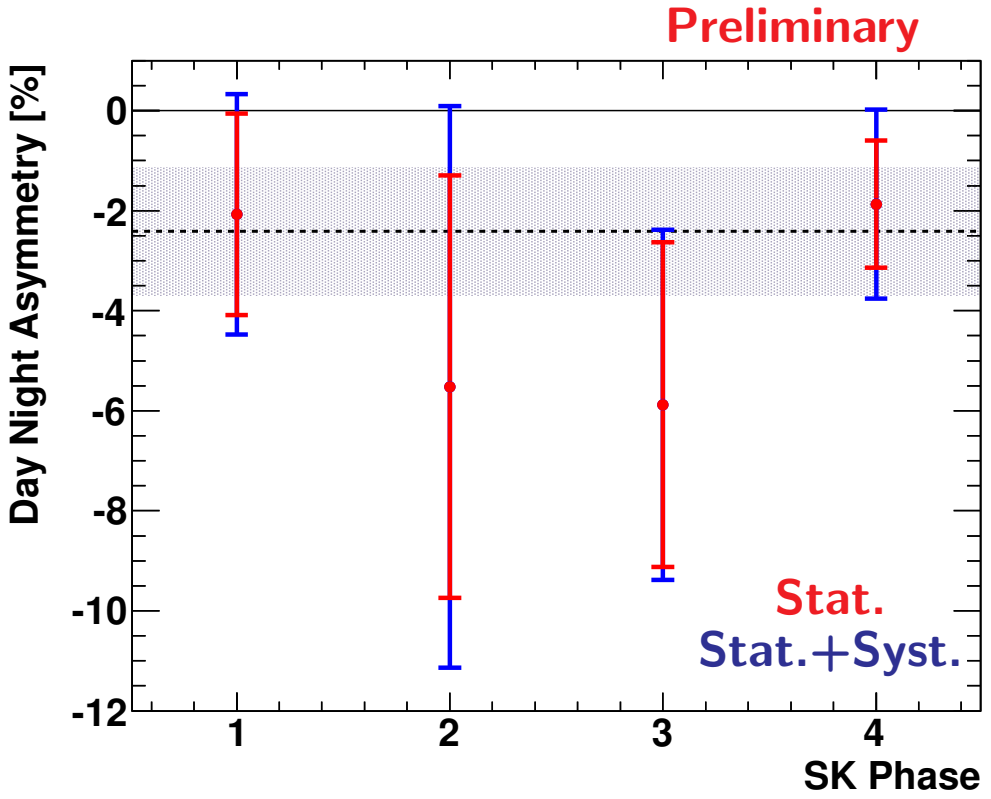
Gd Water system

- Dedicated water purification system for Gd-water
- The radon emissions from the different part of the system will be checked:
  - Some parts were tested with Gd water $\rightarrow$ ex: membrane de-gasifier: Rn emission compatible with measurement system BG expectations (0.5 ± 0.3 mBq/m^3)
- After the tank opening, the system will be used in order to improve the water quality early right after the filling (first real test of the system).



Recent results in solar ν analysis (3/3) [Preliminary]

- The existence of day-night asymmetry on the ν flux is expected from the MSW effect
- Last day-night asymmetry significance from SK is 1.9σ from 0 (combined measurement)



Period	Lifetime [day]	Day Night Asymmetry [%]	Significance
Combined	5805	$-2.4 \pm 1.0 \pm 0.8$	1.9σ from 0
SK-IV	2970	$-1.9 \pm 1.3 \pm 1.4$	1.0σ from 0
SK-III	548	$-5.9 \pm 3.2 \pm 1.3$	1.7σ from 0
SK-II	791	$-5.5 \pm 4.2 \pm 3.7$	1.0σ from 0
SK-I	1496	$-2.1 \pm 2.0 \pm 1.3$	0.9σ from 0