The SuperK-gadolinium project

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On behalf of

The Super-Kamiokande Collaboration

- physics benefits
- the EGADS demonstrator
- implementation in Super-Kamiokande

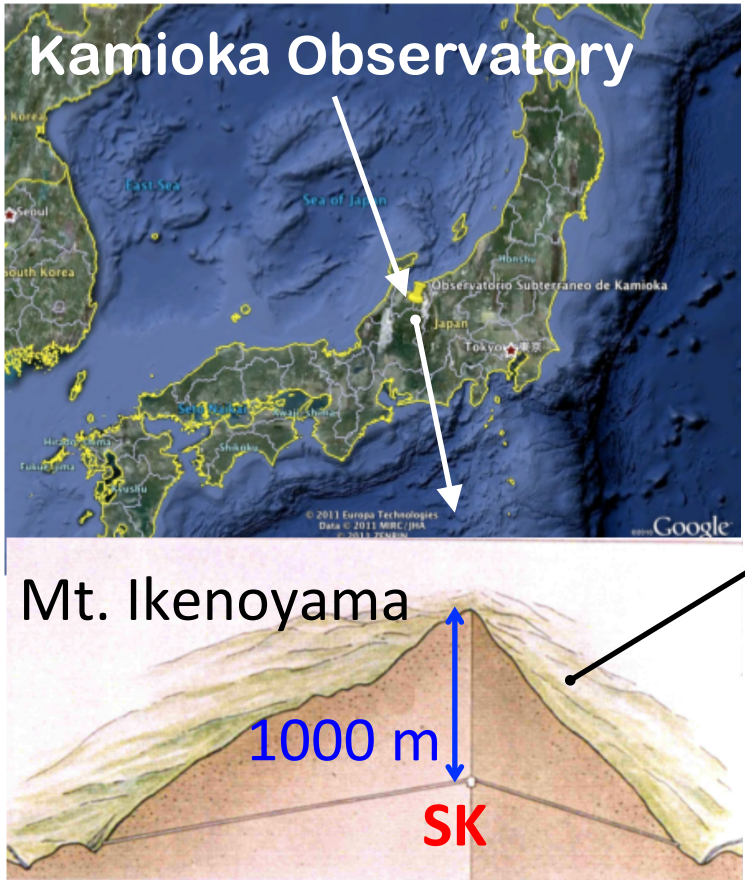
HQL-2016

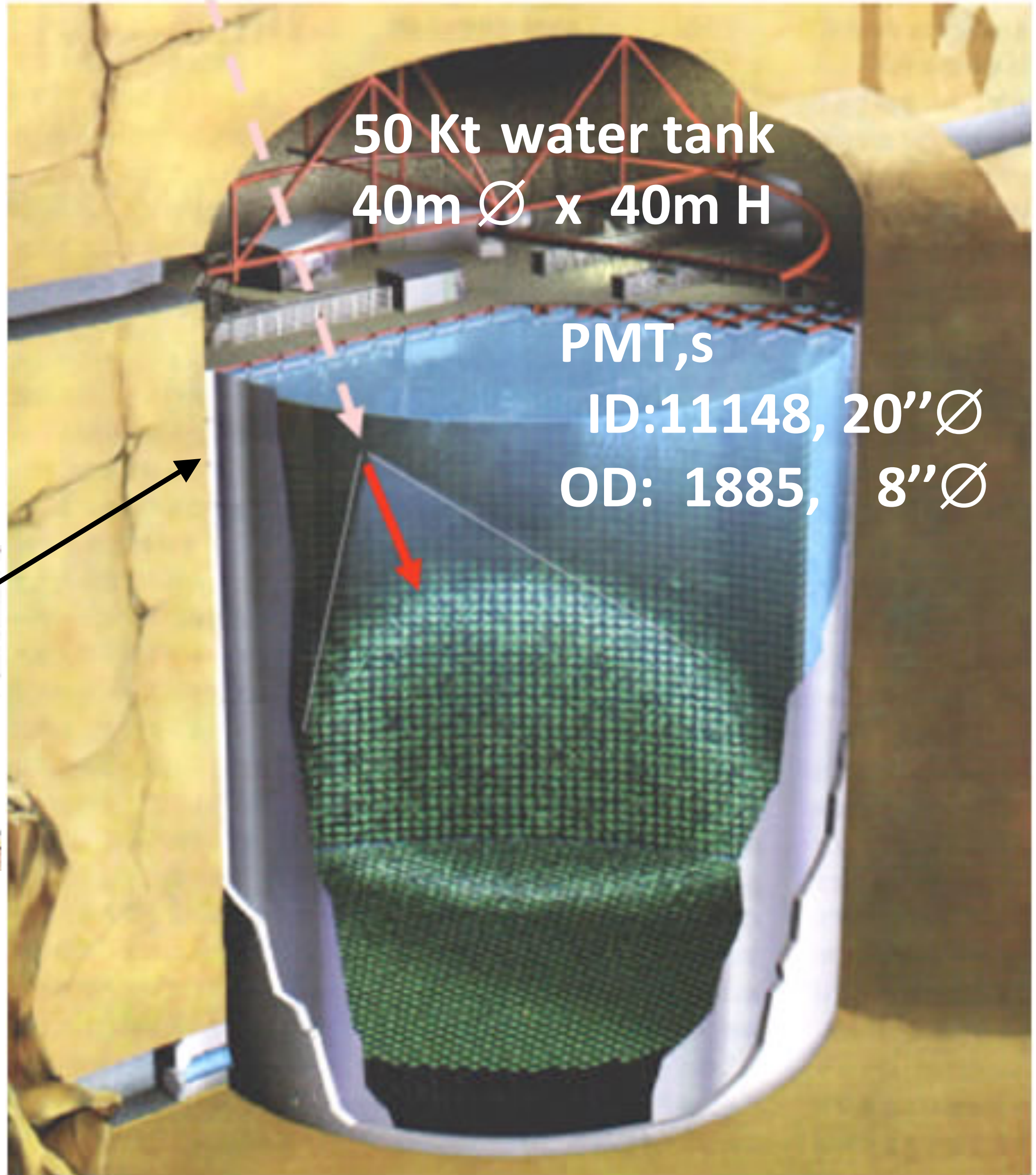
2016/04/15, Blacksburg, Virginia

MARIE CURIE ACTIONS

H2020-MSCA-RISE-2014-GA641540, SKPLUS

The *Super-Kamiokande* experiment at Kamioka Observatory





SK measures *Cherenkov radiation*

Super-K: superb physics thanks largely to **water-cherenkov technique**

- discovery of **ν** oscillations in the atmospheric sector
- key in the understanding of the solar-**ν** problem
- ....
- evidence for the appearance of atmospheric ν_τ
- first indication of terrestrial matter effects on solar-**ν**

most stringent limits on:

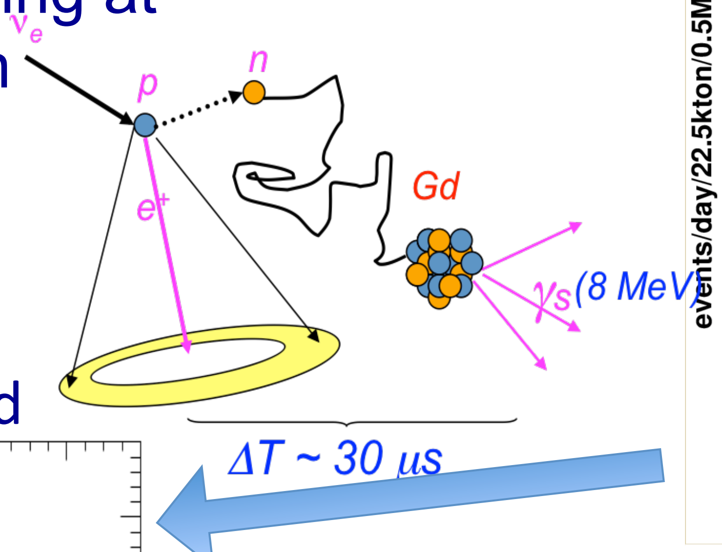
- nucleon decay
- WIMP-type **D**ark **M**atter from indirect search
- **D**iffuse **S**upernova **N**eutrino **B**ackground

Superk-Gd (GADZOOKS!) go further with **high efficiency neutron tagging**

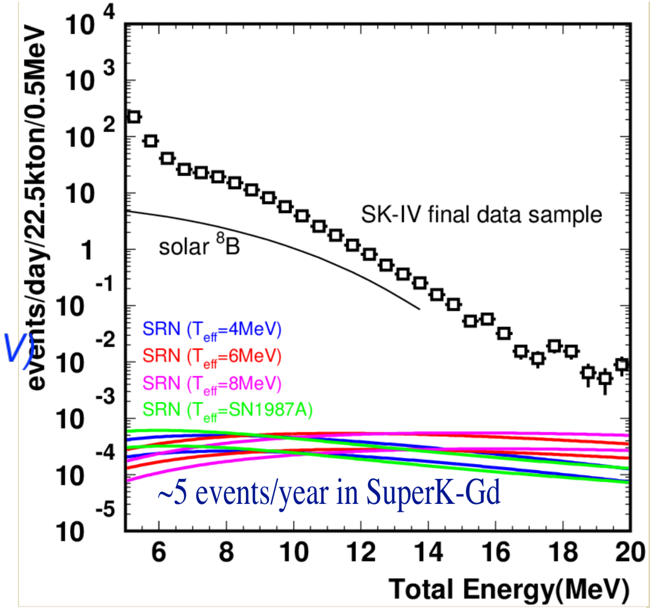
Beacom and Vagins PRL93,171101 (2004)

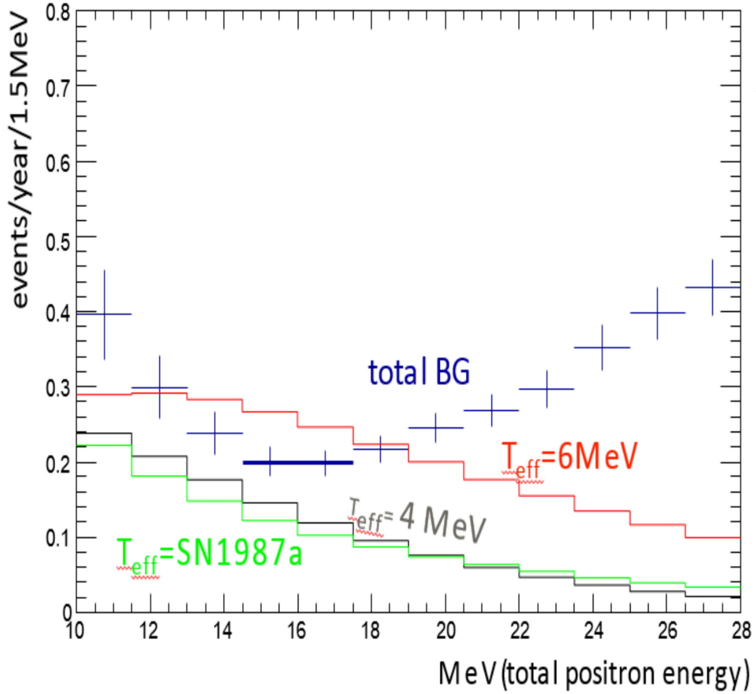
adding a 0.2 % by mass of a Gd compound, $Gd_2(SO_4)_3$, **to SK** water, the majority of final state **neutrons** produced in the interactions (90% captured × 90% reconstructed) will, after thermalized, be **captured by Gd** after ~30 μs and detected through the **8 MeV γ ray cascade** from its de-excitation

➔ anti-neutrino tagging at inverse β reaction



- be in position of discovering **DSNB** from the very much reduced background



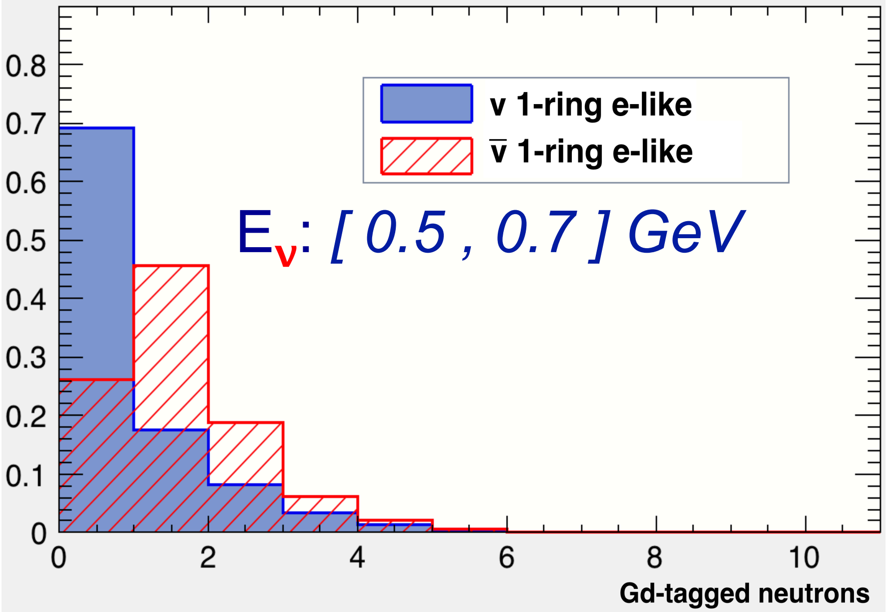


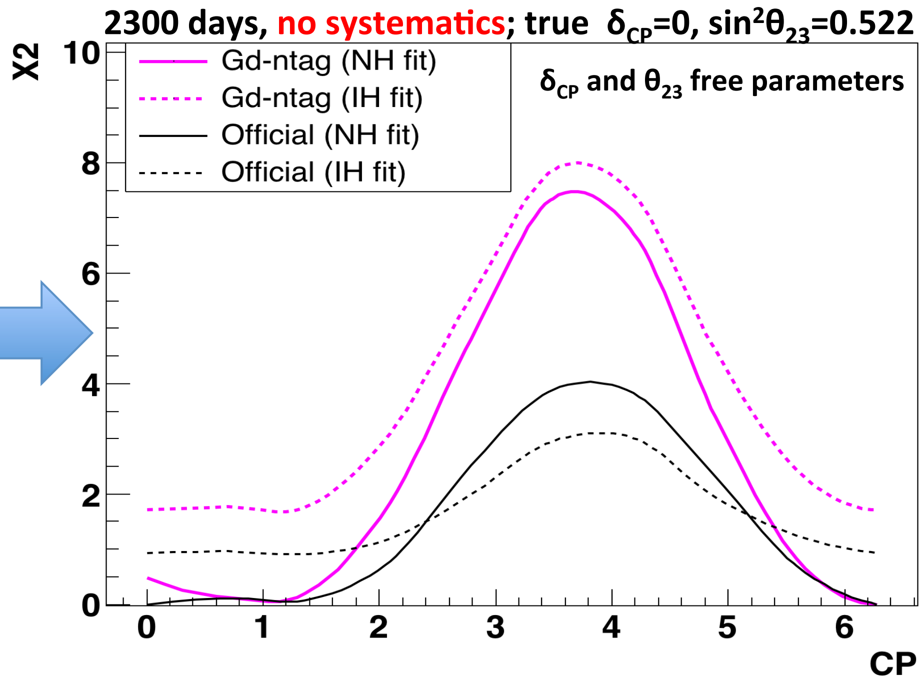
DSNB events number with 10 years observation

model	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	----

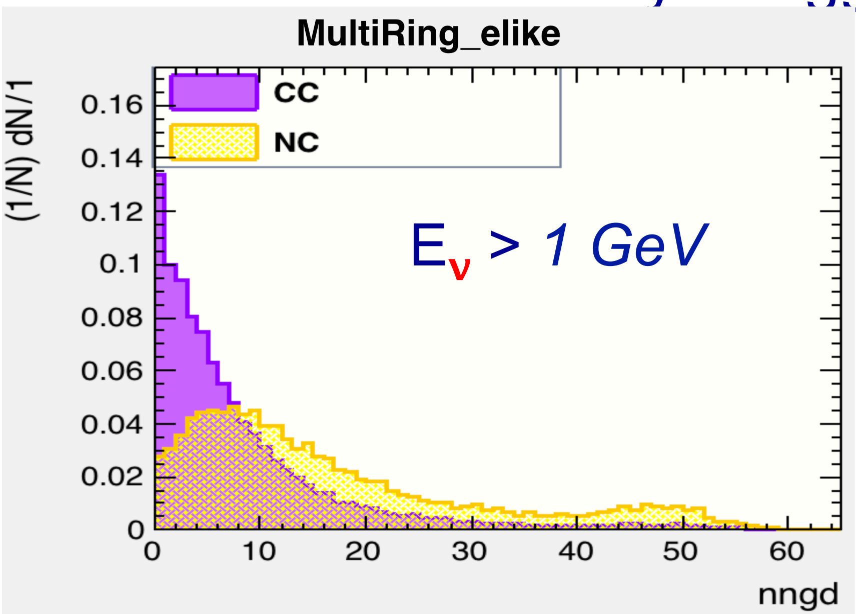
- improve pointing accuracy for Supernova
- Supernova early warning from Si burning **ν**s
- high precision solar- **ν**s elements from reactor **ν**s (if available)

→ neutrino / anti-neutrino discrimination by neutron counting



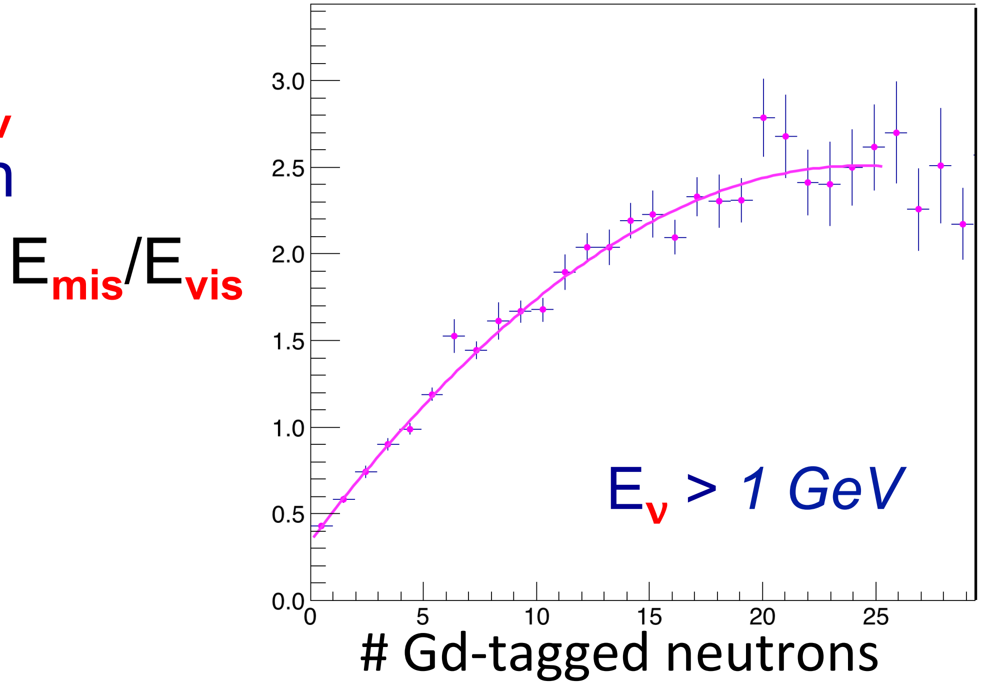


→ NC / CC discrimination by n-tagging

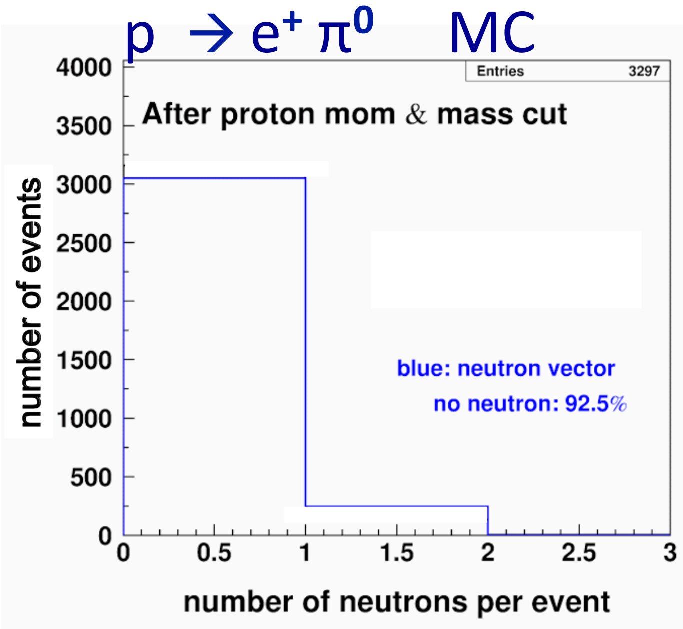


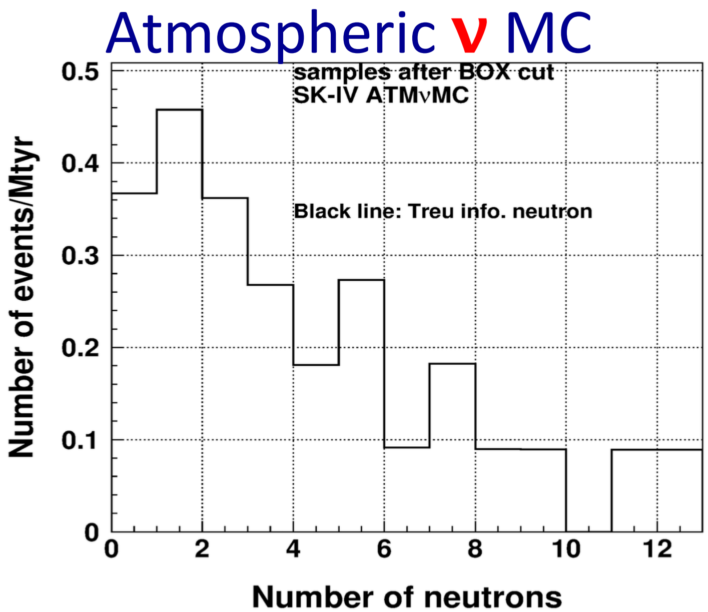
very significant increase in fraction of δ_{CP} over 90% CL

→ Improvement of E_ν reconstruction with tagged neutrons



→ neutron veto





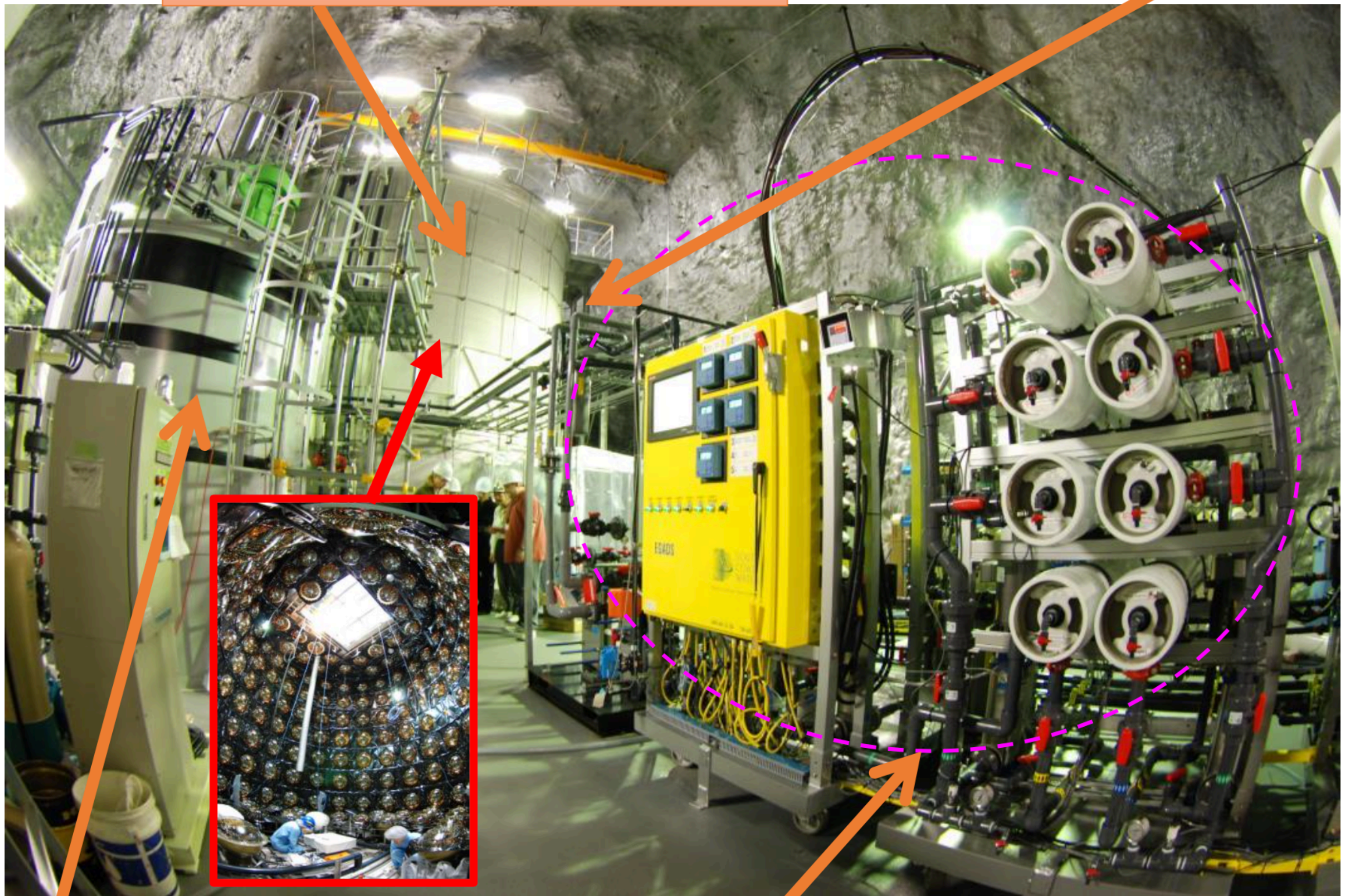
background probability reduced from 44% to 9%

→ more to come along the learning curve …

EGADS @ new hall near the SK area

Evaluating Gadolinium's Action on Detector Systems

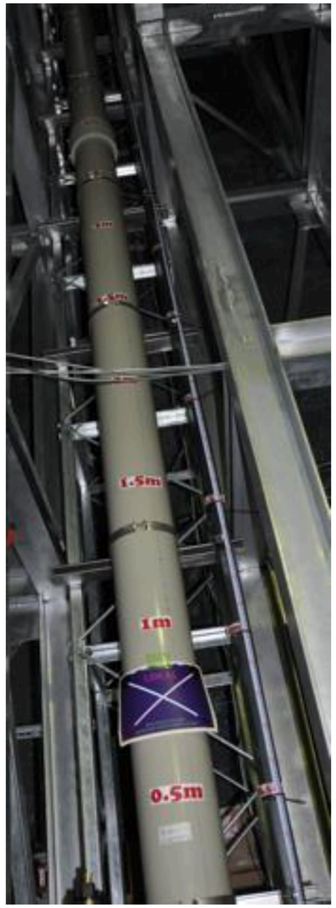
200 m^3 tank with 240 PMTs



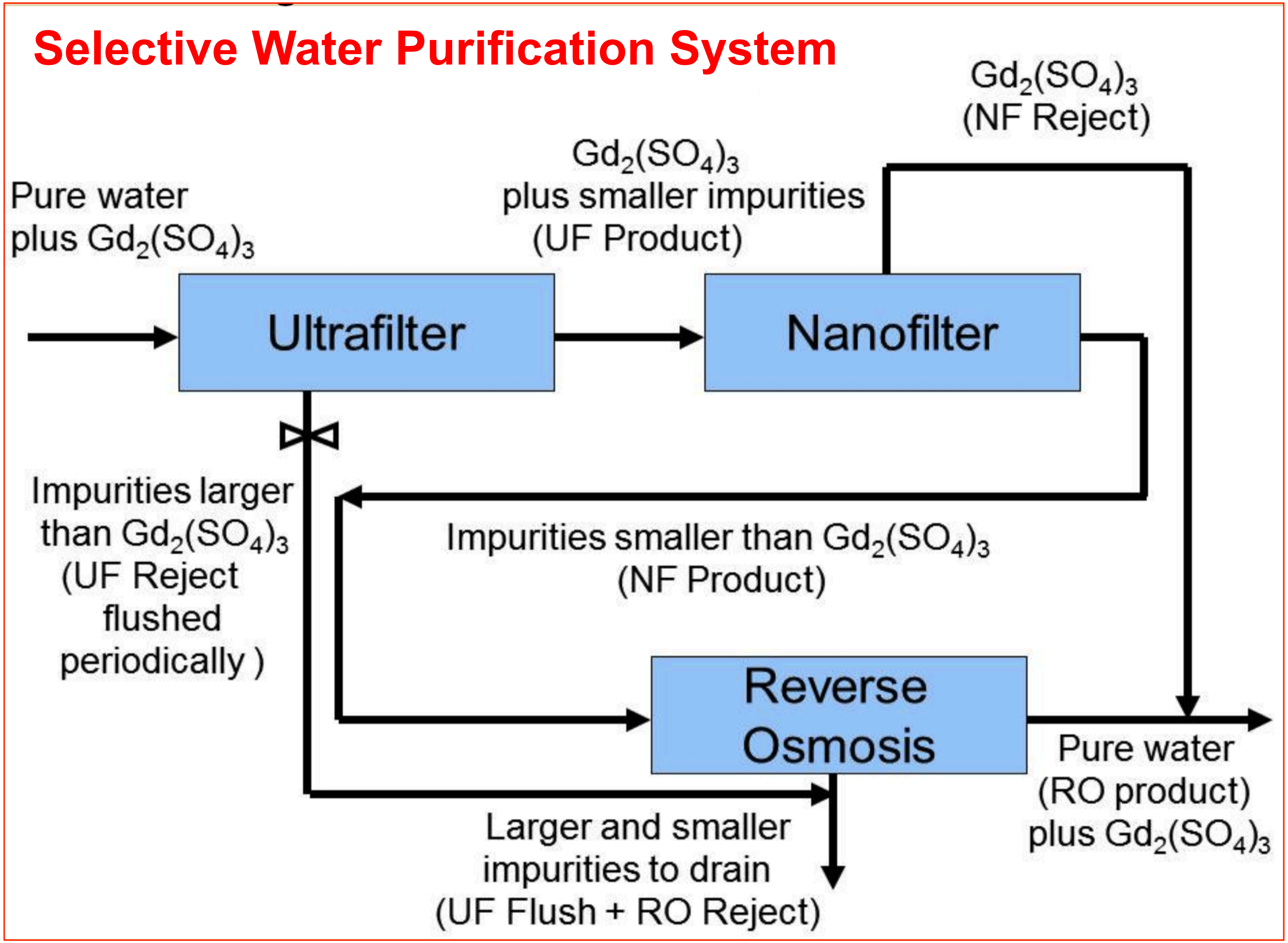
15m^3 tank to dissolve Gd

Gd water circulation system (purify water with Gd)

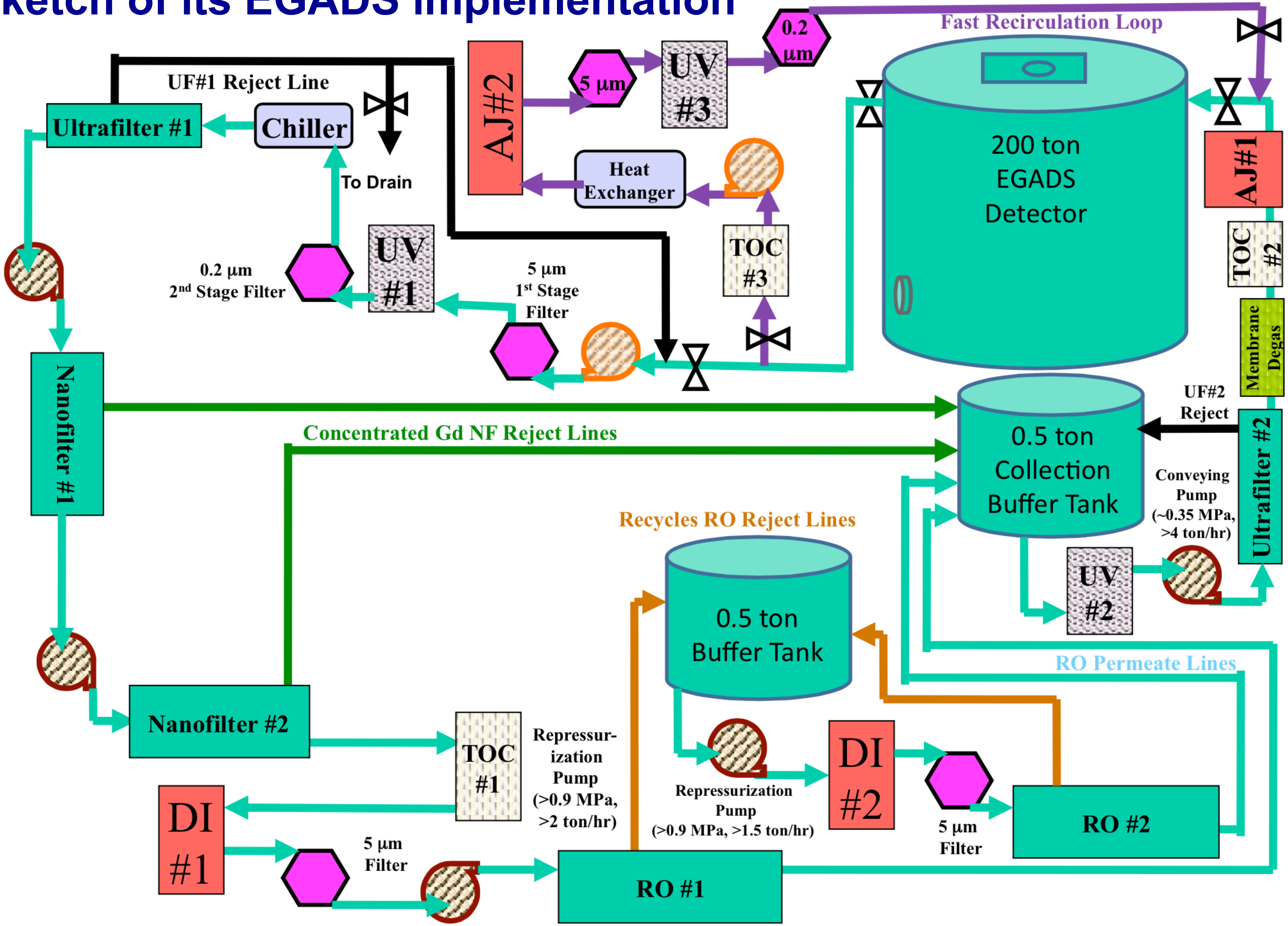
Transparency measurement (UDEAL)



The key to Superk-Gd:



Selective Water Purification System: sketch of its EGADS implementation

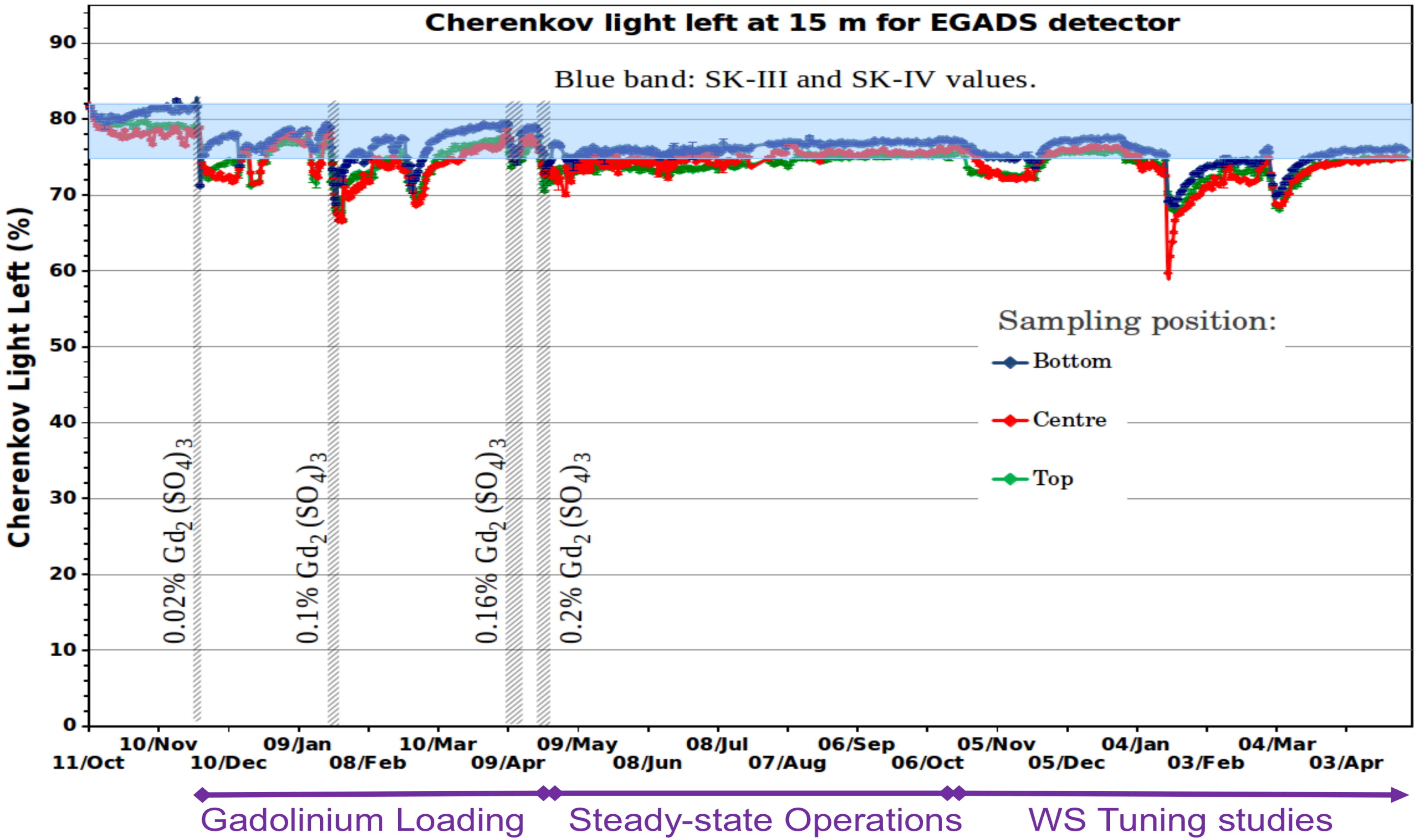


water transparency

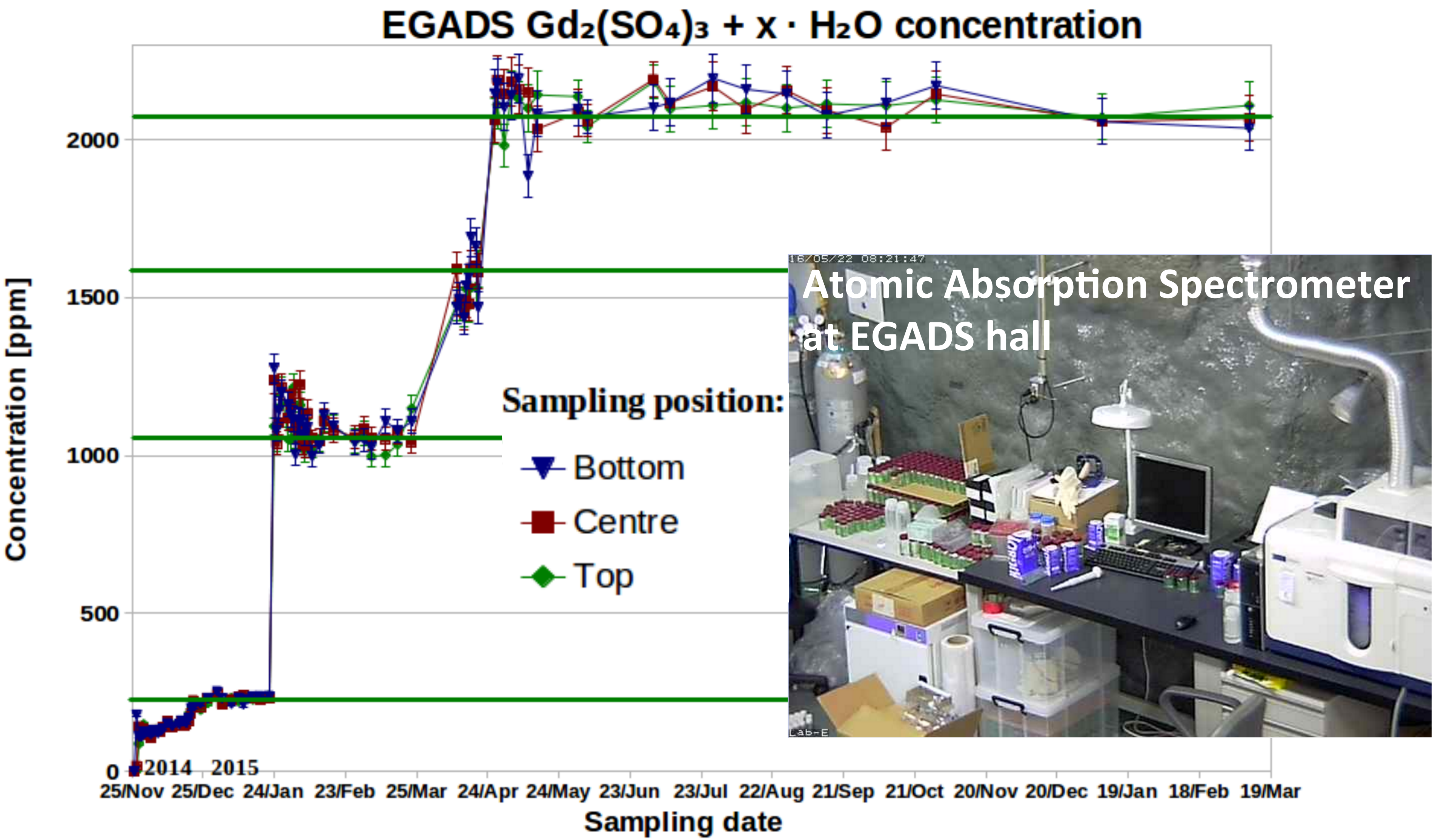
UDEAL measures absolute attenuation lengths at 7 wave-lengths:

in **nm** (its contribution to Cherenkov light is indicated in brackets)

337 (0.25), **375** (0.25), **405** (0.21), **445** (0.14), **473** (0.11), **532** (0.04), **595** (.003)

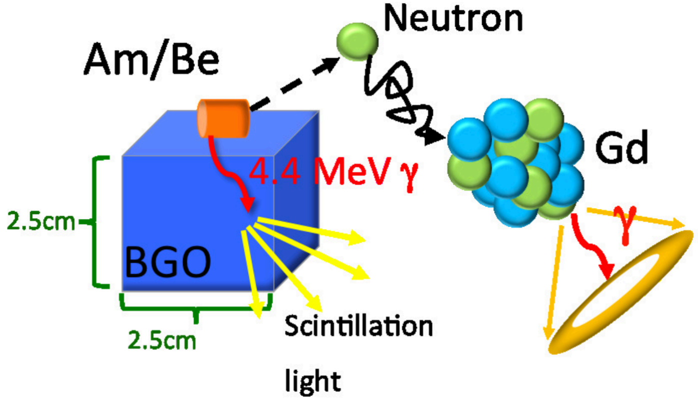


$Gd_2(SO_4)_3$ concentration: uniformity along volume, time stability



→ Our Gd-capable water system is lossless (>99.99%)
[the fully-loaded EGADS tank has been turned over 200 times so far]

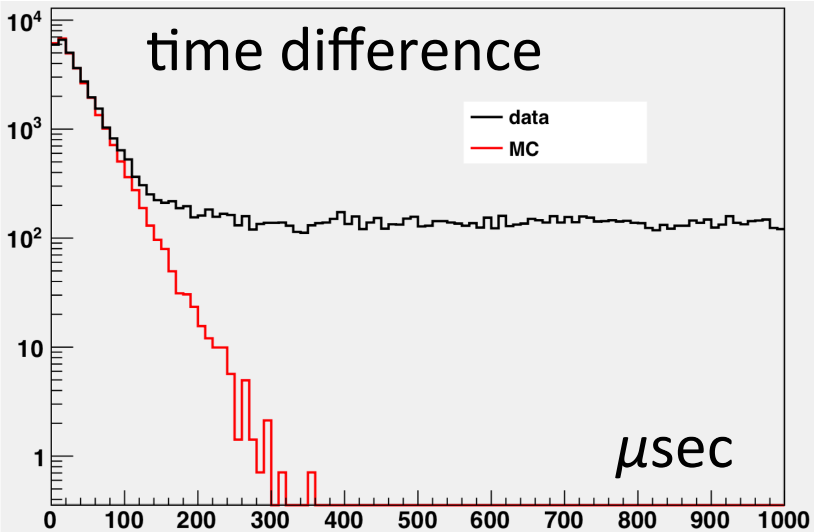
Some calibration results: mimicking inverse β decay signals with an Am/Be source and BGO scintillator

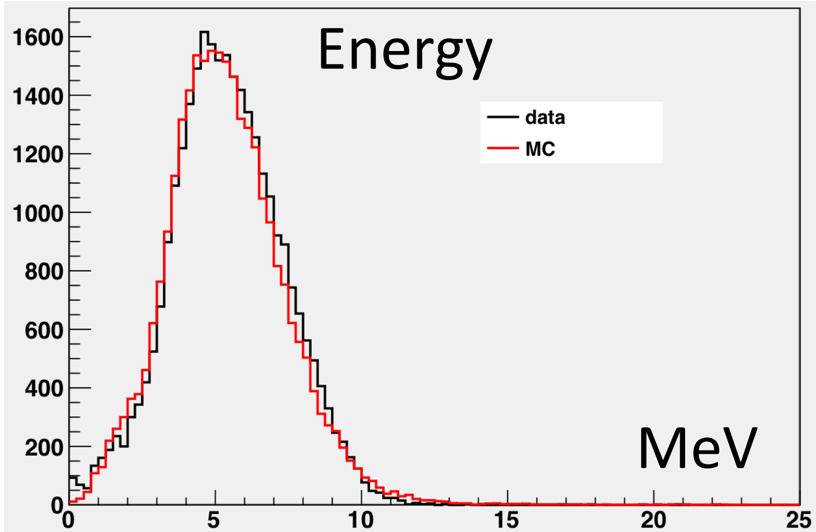


$$^{241}Am \rightarrow {}^{237}Np + \alpha$$

$$\alpha + {}^{9}Be \rightarrow {}^{12}C^{*} + n, {}^{12}C + n$$

$$^{12}C^{*} \rightarrow {}^{12}C + \gamma(4.43MeV)$$





Gadolinium Sulfate Octahydrate Concentration

	2178 ± 76 ppm	1055 ± 37 ppm	225 ± 8 ppm
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

mean capture time of neutron (μsec)

Radioactivity Contaminations at $Gd_2(SO_4)_3$ seriously assessed
[they are sources of background signals all along the FV]

		Measured radioactivity in mBq/kg for the $Gd_2(SO_4)_3$ batches purchased to date June 2015								
Chain	**Sub-chain**	**Standford Materials** 09/04	**Standford Materials** 10/08	**Beijing Jinghonganxin** 12/08	**Changshu Huanyu** 13/02	**Beijing Jinghonganxin** 13/03	**Standford Materials** 13/08	**HK Tai Kun** 13/07a	**HK Tai Kun** 13/07b	**Standford Materials** 14/12
^{238}**U**	^{238}**U**	51 ± 21	< 33	292 ± 6	74 ± 28	242 ± 6	71 ± 20	47 ± 26	73 ± 27	< 76
	^{226}**Ra**	8 ± 1	2.8 ± 0.6	74 ± 2	13 ± 1	13 ± 2	8 ± 1	5 ± 1	6 ± 1	< 1.4
^{232}**Th**	^{228}**Ra**	11 ± 2	270 ± 16	1099 ± 12	205 ± 6	21 ± 3	6 ± 1	14 ± 2	3 ± 1	2 ± 1
	^{228}**Th**	28 ± 3	86 ± 5	504 ± 6	127 ± 3	374 ± 6	159 ± 3	13 ± 1	411 ± 5	29 ± 2
^{235}**U**	^{235}**U**	< 32	< 32	< 112	< 25	< 25	< 32	< 12	< 30	< 1.8
	^{227}**Ac**	214 ± 10	1700 ± 20	2956 ± 30	1423 ± 21	175 ± 42	295 ± 10	< 6	< 18	190 ± 6
Others	^{40}**K**	29 ± 5	12 ± 3	101 ± 10	60 ± 7	18 ± 8	3 ± 2	3 ± 2	8 ± 4	< 5
	^{138}**La**	8 ± 1	$<$	683 ± 15	3 ± 1	42 ± 3	5 ± 1	< 1	< 2	23 ± 1
	^{176}**Lu**	80 ± 8	21 ± 2	566 ± 6	12 ± 1	8 ± 2	30 ± 1	1.6 ± 0.3	< 2	2.5 ± 0.6

work done mostly at the *Canfranc Underground Laboratory*

- salts from different providers have in general similar contaminations
- some improvement along time seen
- in any case, Superk-Gd can not afford those amounts of RIs

Radioactive contamination in $Gd_2(SO_4)_3$ might add background to the ^{8}Be solar **ν** spectrum:

Typical activities of salts in the market:

Radioactive chain	Part of the chain	mBq/kg
^{238}U	^{238}U	50
	^{226}Ra	5
^{232}Th	^{228}Ra	10
	^{228}Th	100
^{235}U	^{235}U	32
	^{227}Ac / ^{227}Th	300

For DSNB

Expected signal ~5 events/year/FV

- ^{238}U Spontaneous Fission:

  ~ 5.5 [γ(Eγ>10.5 MeV) + 1n] / year / FV

  x10 reduction desirable

For solar neutrino

Current BG ~200 events/day/FV

- U (n) ~320events/day/ FV

  x10 reduction desirable

- Th/Ra (β,γ)~3 x 10^{5} events/day/ FV

  x10^{3} reduction needed

Two approaches **to reduce RIs** are being followed

- Remove RIs from normal $Gd_2(SO_4)_3$ ourselves [a lot of work being done in Kamioka, not discussed here]
- Cooperative development of pure salts with chemical Co.

we are cooperating with the following companies:

Molycorp, *Shin-Etsu Chemical Co. Ltd.* , *Kanto Chemical Co. Inc.*, *Wako Pure Chemical Ind. Ltd.*, and *Nippon Yttrium Co. Ltd.*

Very promising results: already x50 reduction of ^{228}Th

		units: mBq/kg			limits: @ 95 %		
Chain	**Main sub-chain isotope**	$Gd_2(SO_4)_3$ Co. A	Gd_2O_3 Co. A		Gd_2O_3 Co. B Sample 1	Gd_2O_3 Co. B Sample 2	Gd_2O_3 Co. B Sample 3
^{238}U	^{238}U	< 139	< 280		< 68	< 130	< 36
	^{226}Ra	< 2.1	< 4		< 0.9	< 1.0	< 1.4
^{232}Th	^{228}Ra	2.8 ± 1.9	< 10		< 2.7	< 2.3	< 1.4
	^{228}Th	1.8 ± 0.9	< 9		< 2.5	< 1.4	< 0.8
^{235}U	^{235}U	< 2.4	< 7		< 1.6	< 0.8	< 1.0
	^{227}Ac/^{227}Th	< 10	< 11		< 4.3	-	-
	^{40}K	< 14	< 11		< 4.6	< 5.3	< 3.4
	^{138}La	< 1.9	< 1.7		< 0.6	< 0.7	< 0.7
	^{176}Lu	< 1.6	< 2.6		< 0.8	< 0.7	< 1.6
	^{134}Cs	< 0.9	< 0.8		< 0.24	< 0.4	< 0.23
	^{137}Cs	< 0.9	< 0.8		< 0.3	< 0.34	< 0.30

Intensive work at
- Canfranc Underground Laboratory
- Kamioka Observatory
- Boulby Underground Observatory (recently joined)

On 2015/06/27 **Super-Kamiokande approved the Superk-Gd project**

- a T2K+SK joint protocol to take decision about when to trigger it
- takes into account the needs of both experiments, readiness of SK-Gd project, T2K schedule, J-PARC MR power upgrade, others
- from the above, **current expected time of refurbishment is 2018**

➔ ***3**-phase procedure:*

T_0 drain + leak stop work

fill + purify water

pure water circulation

6 months

T_1 load $Gd_2(SO_4)_3$ up to 0.02%

stabilize water transparency

meas.

3 months

T_2 full $Gd_2(SO_4)_3$ up to 0.2%

stabilize water trans.

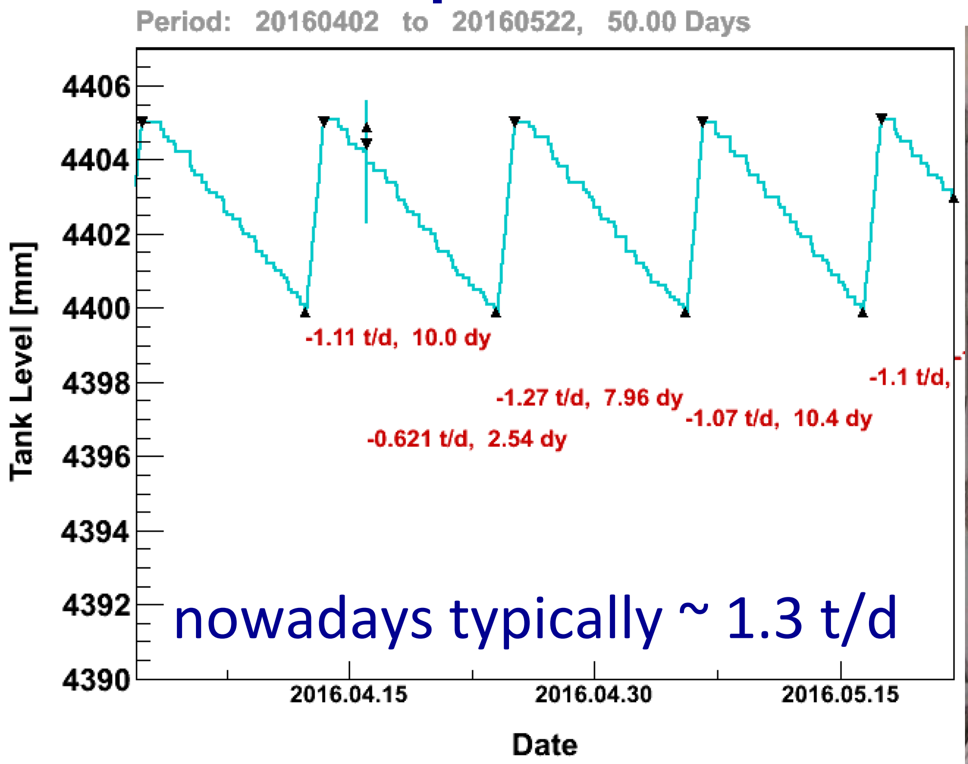
measurement

3 months

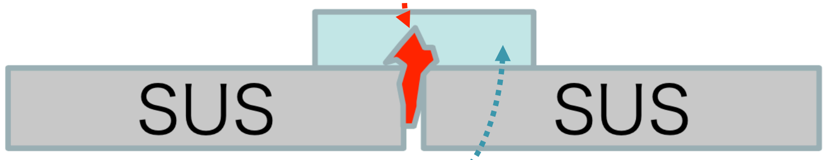
Further key items:

- refurbishment / leak stop
- the new water system

leak at the Super-Kamiokande tank: technique



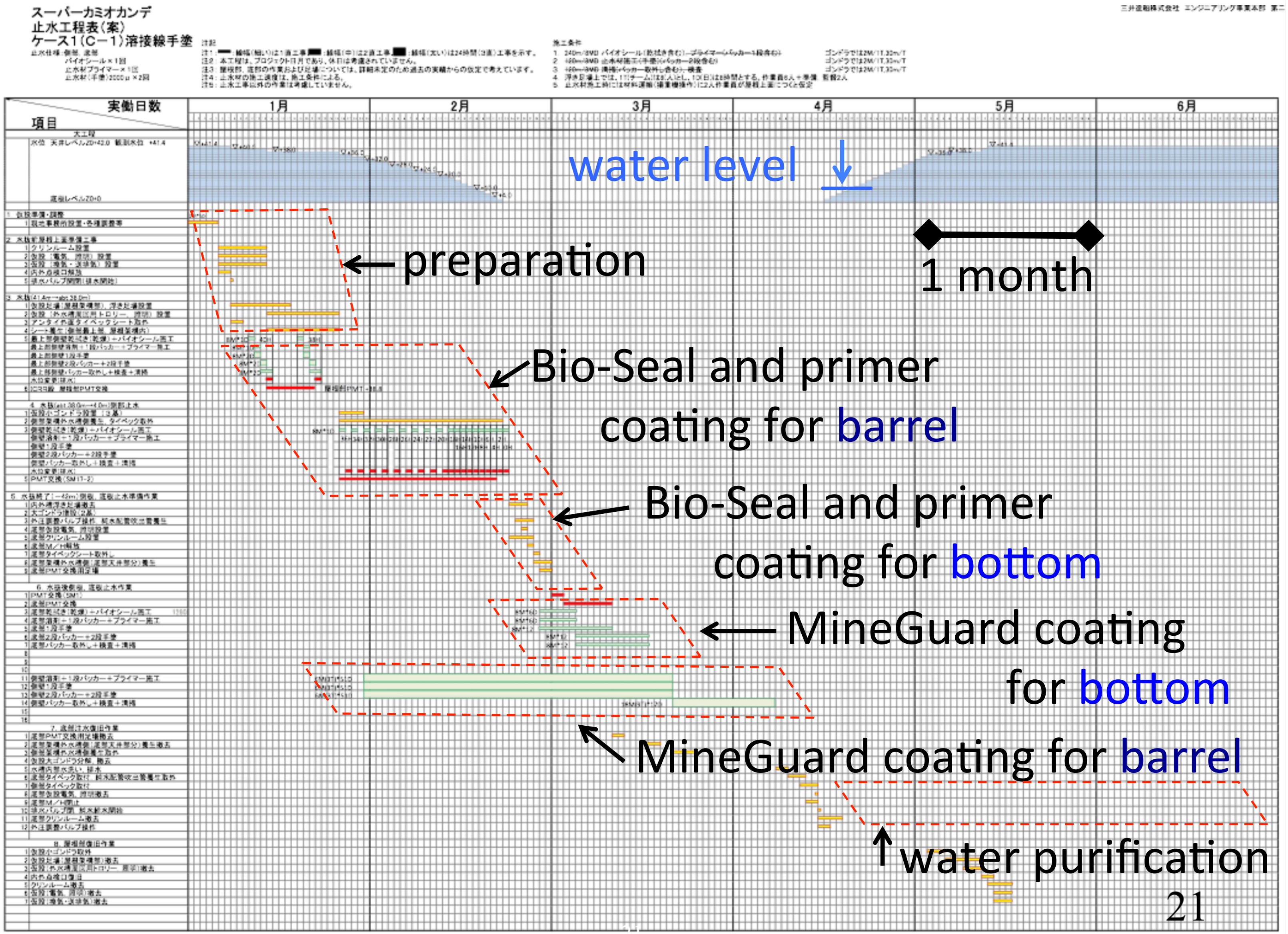
- double coating with
  1. BIO-SEAL 197 epoxy resin:
     sneaks into small gaps
  2. Mine Guard C viscous material:
     allows more displacement (less penetration though)



- many test passed: tension, leakage, Radioactivity contamination, …
- mass production is realistic

fixing the leak at SK tank

detailed, day-to-day schedule prepared by *Mitsui & Co. Ltd*:



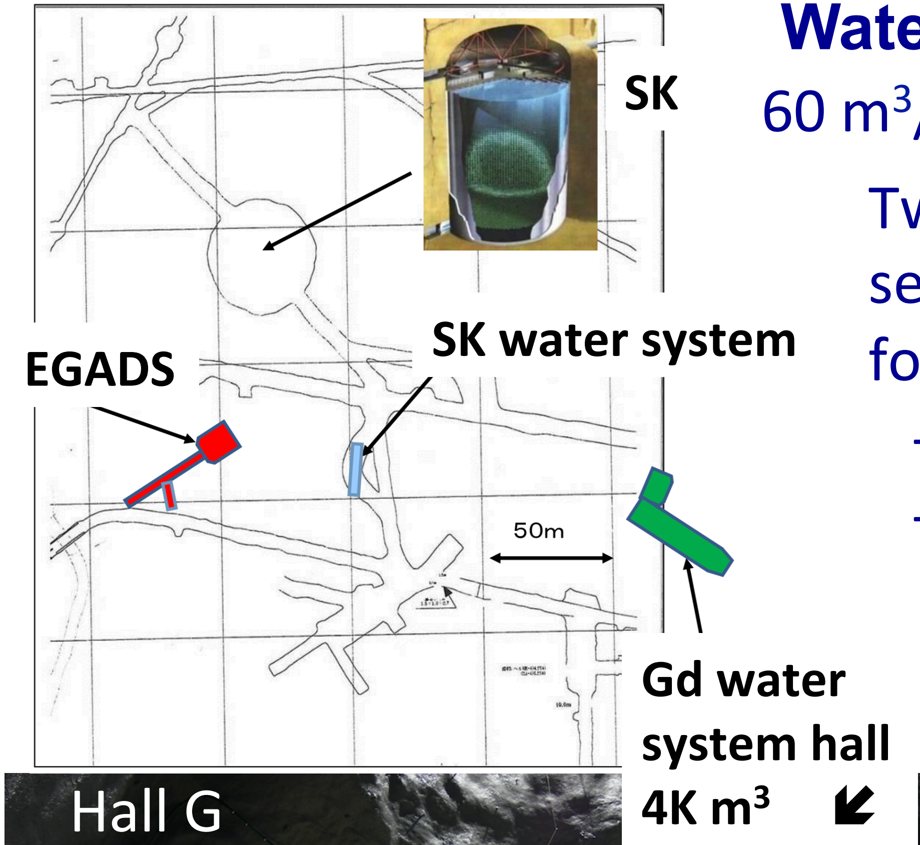
In total: ~ 6 months needed for the job

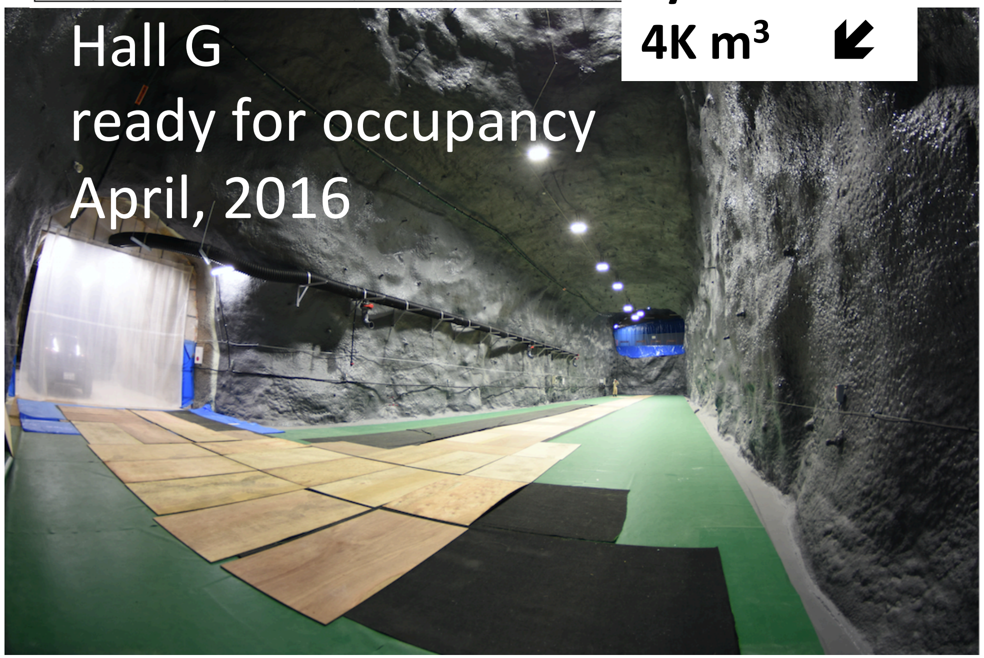
Water system for Superk-Gd

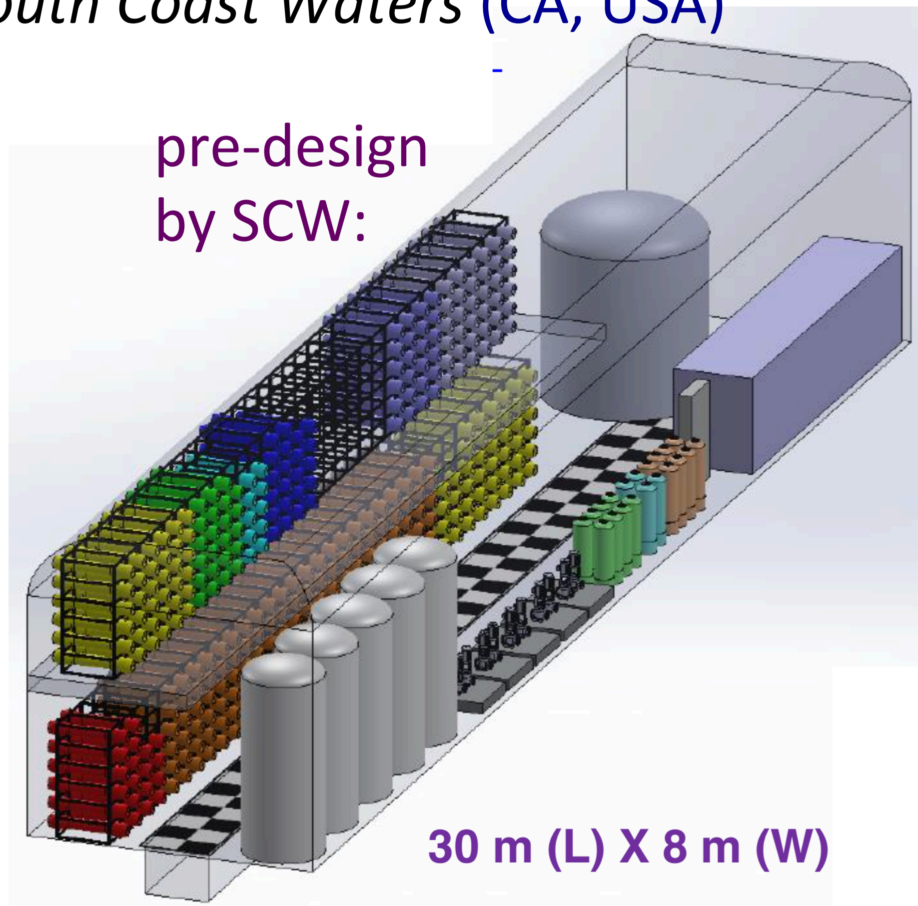
60 m³/hr selective filtration system

Two companies have already made serious preliminary design/proposal for Superk-Gd:

- *Organo Corporation* (Japan)
- *South Coast Waters* (CA, USA)







Summary / Conclusions / Outlook

- Superk-Gd enlarges significantly the window of SK's physics measurements
- EGADS has demonstrated its viability and reliability
- Superk-Kamiokande has endorsed Superk-Gd; its implementation is expected to begin in 2018