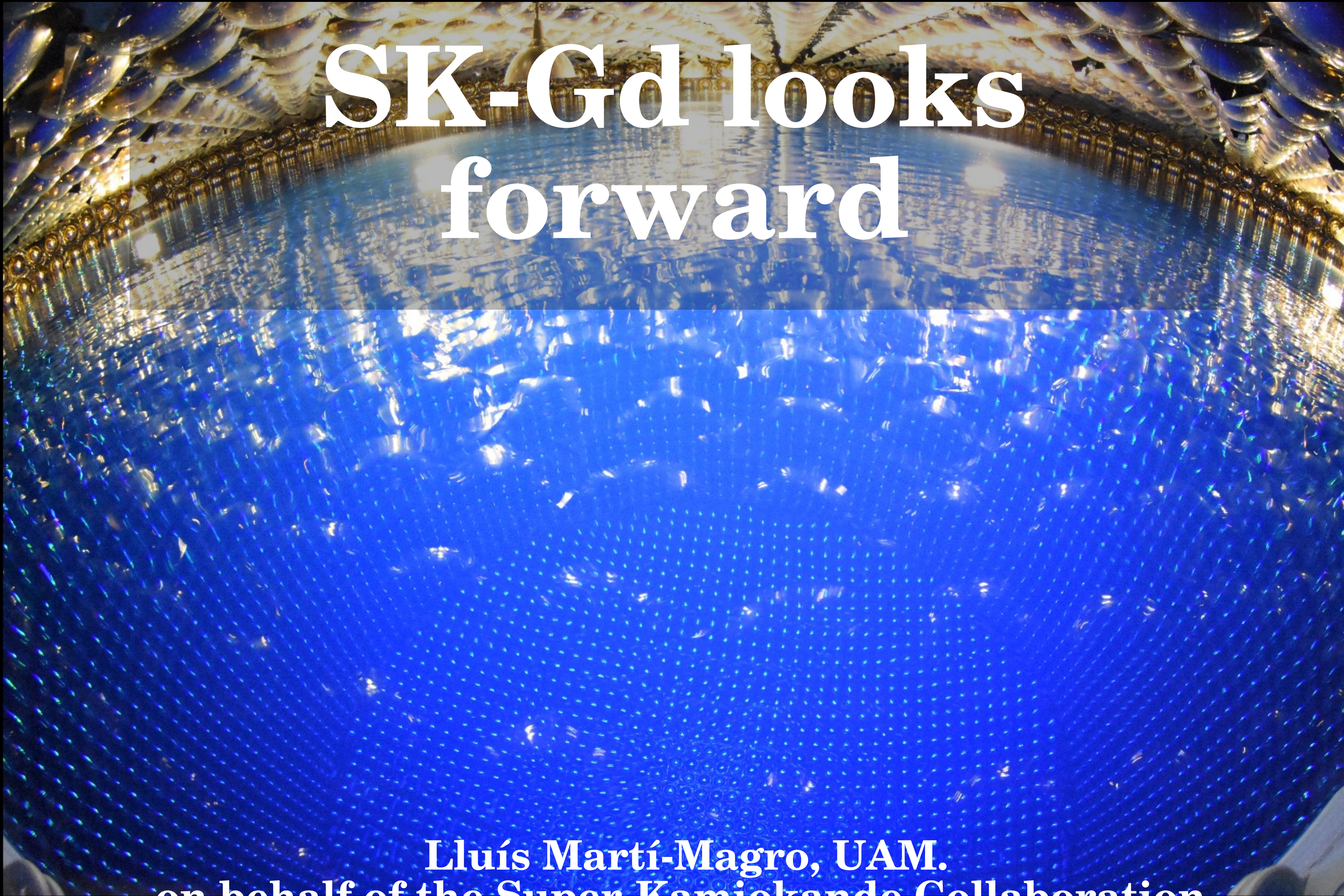

SK-Gd looks forward

Lluís Martí-Magro, UAM.
on behalf of the Super-Kamiokande Collaboration.

ICRC (online) July 20th, 2021. Berlin, Germany.

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ISEE, Nagoya University, Japan
Okayama University, Japan
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Tohoku University, Japan
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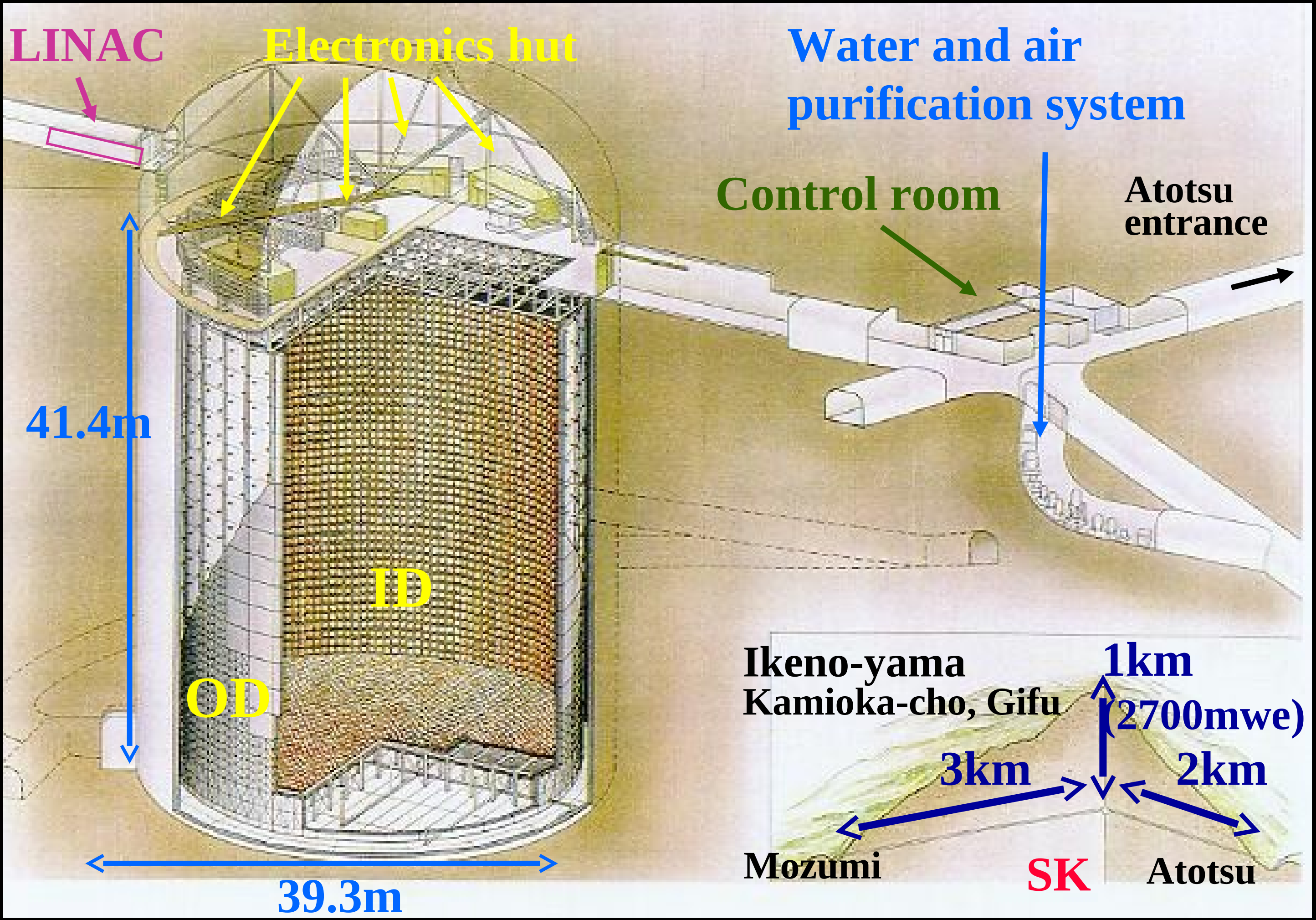
INFN Padova, Italy
INFN Roma, Italy

178 collaborators
52 Institutes
11 countries

Super-Kamiokande Detector

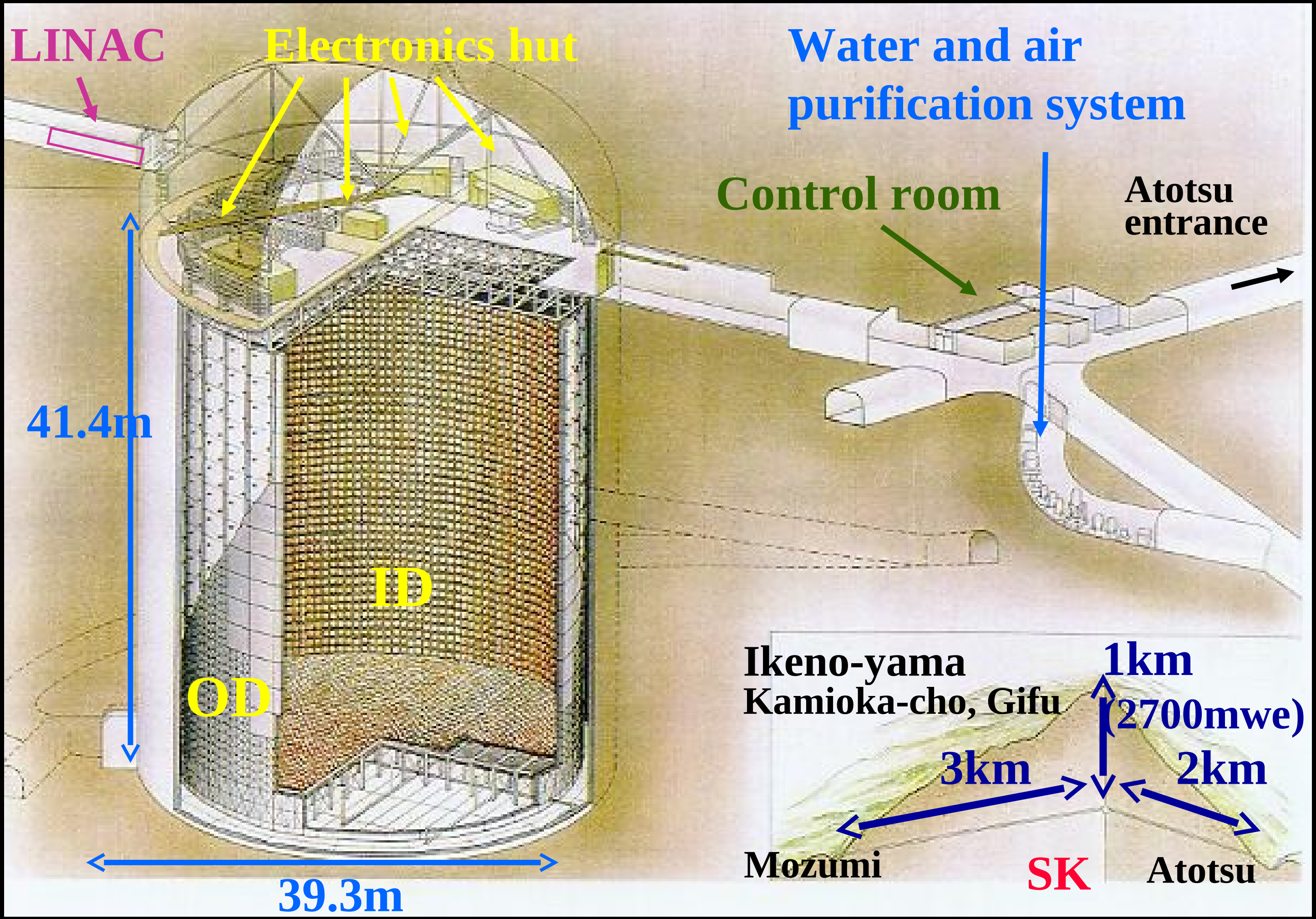


- 50 kton water
- 13 tons of Gd sulfate octahydrate
- ~2 m OD viewed by 8-inch PMTs
- 32 kt ID viewed by 20-inch PMTs

Gadolinium phase

	Phase	SK-I	SK-II	SK-III	SK-IV	SK-V	SK-VI
	Start - end	1996 Apr - 2001 Jul	2002 Oct - 2005 Oct	2006 Jul - 2008 Sep	2008 Sep - 2018 Mar	2019 Jan- 2020 Jul	2020 Jul- -
Number of PMTs	ID (coverage)	11146 **(40 %)**	5182 **(19 %)**	11129 **(40 %)**	11129 **(40 %)**	11129 **(40%)**	11129 **(40%)**
	OD	**1885**					

Super-Kamiokande Detector



Versatile detector:

Solar neutrinos,
Atmospheric neutrinos,
Proton decay,
Supernovae,
Supernova Relic Neutrinos,
Indirect search for DM and more

	Phase	SK-I	SK-II	SK-III	SK-IV	SK-V	SK-VI
	Start - end	1996 Apr - 2001 Jul	2002 Oct - 2005 Oct	2006 Jul - 2008 Sep	2008 Sep - 2018 Mar	2019 Jan- 2020 Jul	2020 Jul- -
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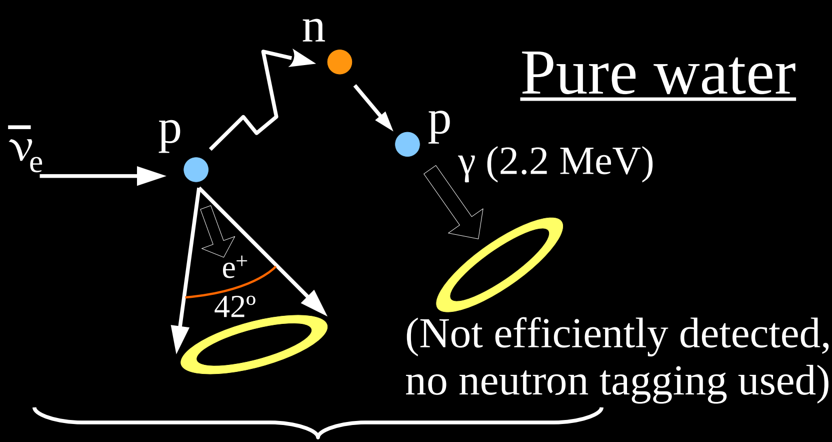
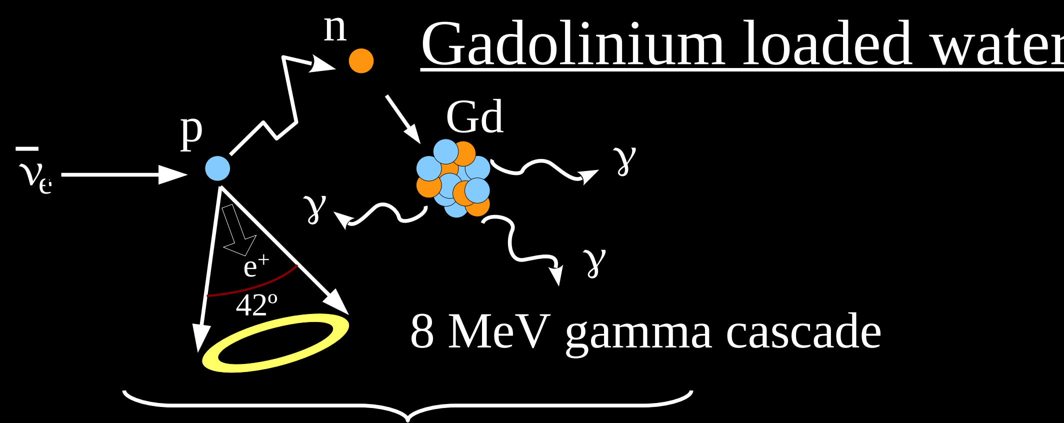
Efficient neutron tagging in water



$\Delta T \sim 200\ \mu s$



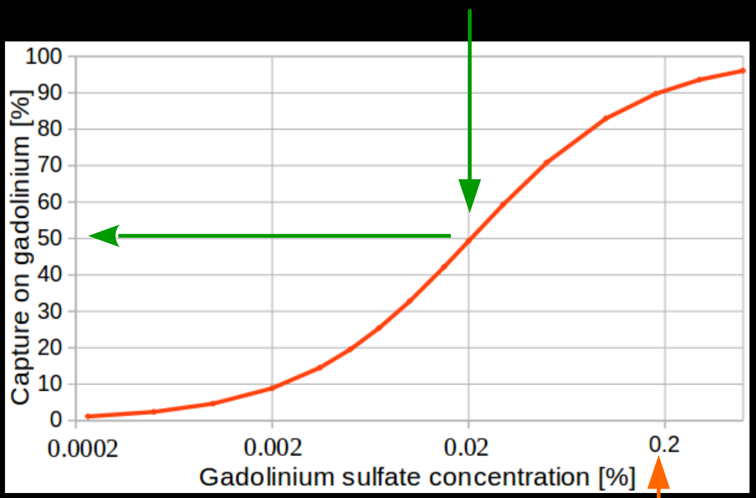
$\Delta T \sim 30\ \mu s$

Idea proposed as GADZOOKS!
by Beacom & Vagins PRL.93, (2004) 171101

With tight time and position coincidence between positron and neutron capture we will be able to tag neutrons with high efficiency

First loading (0.02% in mass):

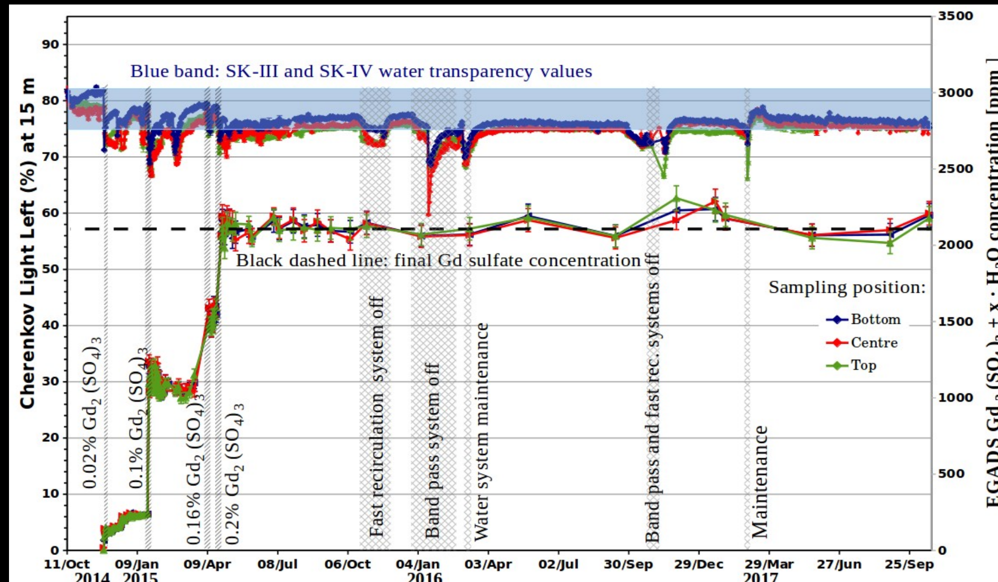
50% neutron capture on Gd



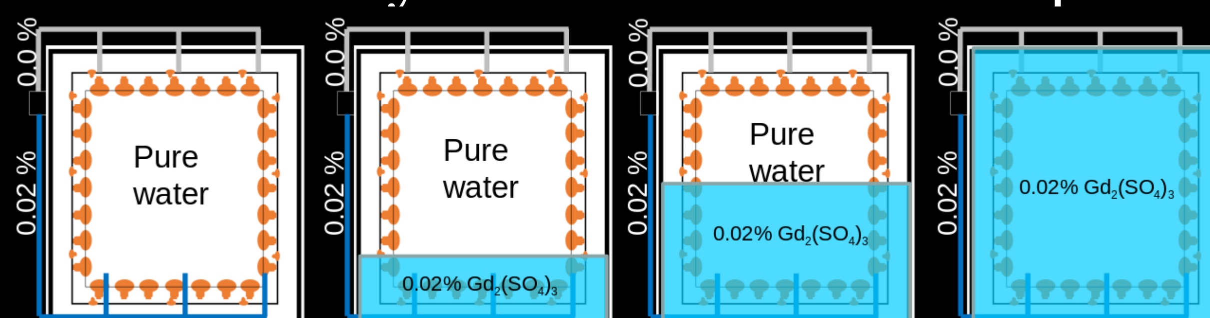
Final target

The road (so far) to efficient neutron tagging

- Dilution, material tests, water transparency tested in EGADS[1]



- SK tank refurbished in summer 2018.
- In 2020, diluted 13 tons Gd sulfate octahydrated to 0.02% in mass[2]:
  - Supply 0.02% Gd sulfate to the bottom of SK tank.
  - Supply flow was 60 tons/hour → 35 days were needed to complete Gd loading.
  - Pure water return from top of SK tank.

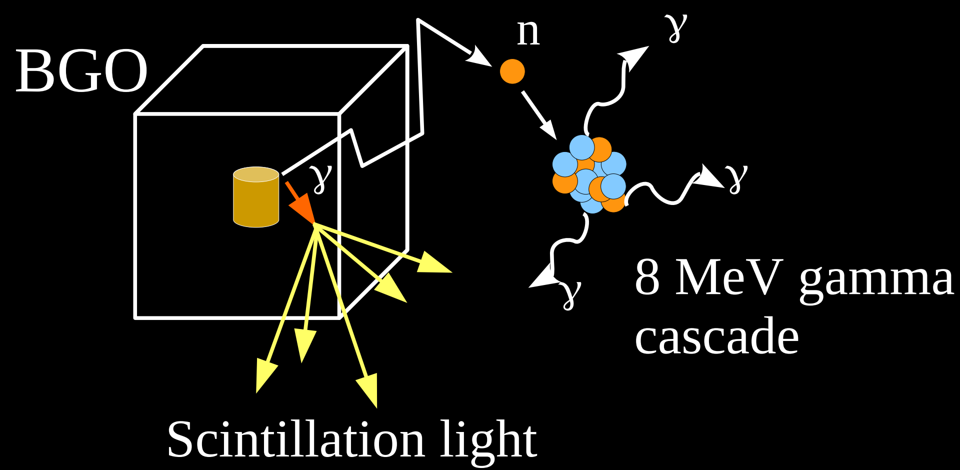


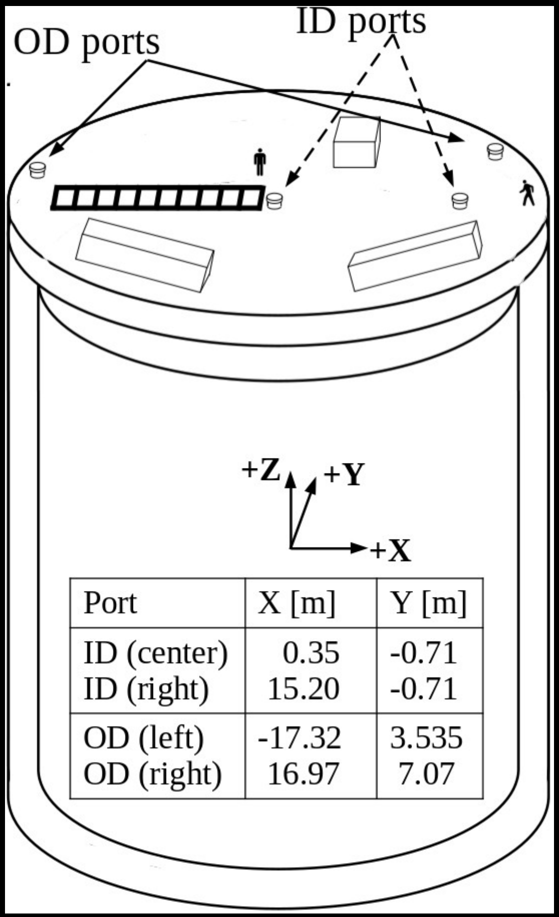
[1] Nucl. Instrum.Meth. A 959 (2020) 163549
[2] to be submitted soon

Gd concentration monitoring: Am/Be

- **Am/Be** source + BGO crystal:
  - ^{241}Am is an α source: $^{241}\mathrm{Am} \rightarrow {}^{237}\mathrm{Np} + \alpha$

    $\mathrm{Be} + \alpha \rightarrow {}^{12}\mathrm{C} + \gamma\ (4.4\ \mathrm{MeV}) + n$
  - The Am/Be source is inside a BGO crystal: γ (4.4 MeV) produces scintillation light that triggers a prompt event
  - Neutron candidates are then searched
  - From ID (center), mainly from: **Z**=+12m, 0m and -12 m

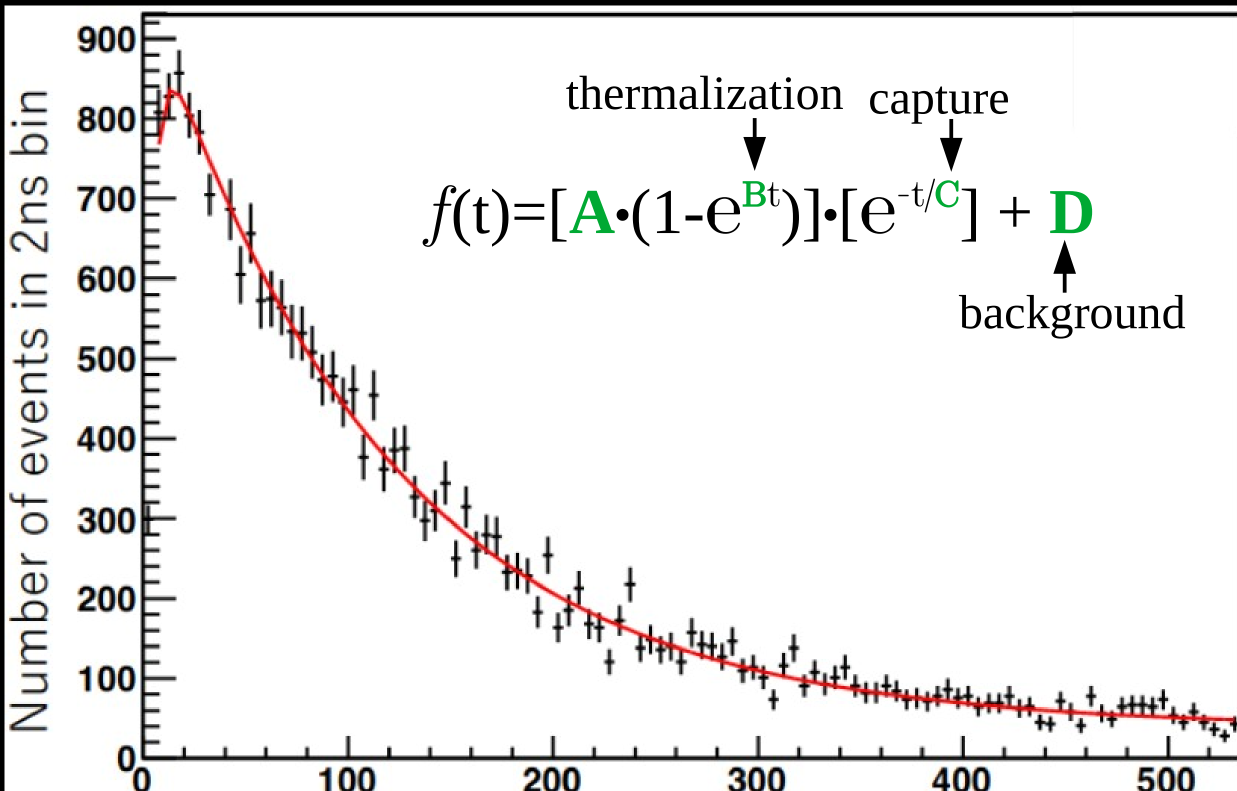




Port	X [m]	Y [m]
ID (center)	0.35	-0.71
ID (right)	15.20	-0.71
OD (left)	-17.32	3.535
OD (right)	16.97	7.07

Gd concentration monitoring: Am/Be

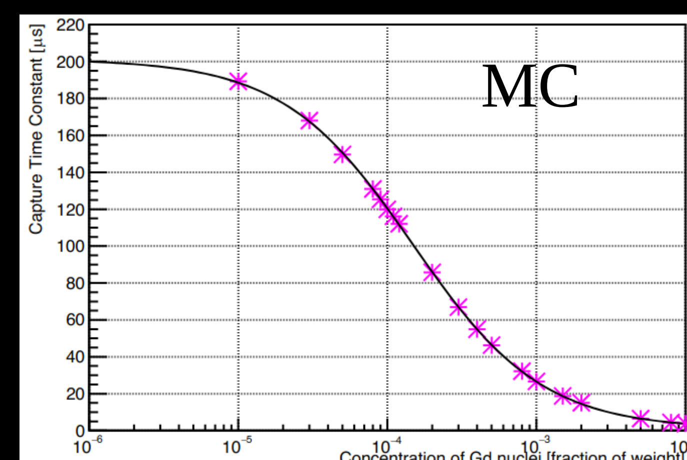
- Example of neutron candidate capture time from the prompt event



Neutron candidate capture time [μs]

Capture time	21st Jan (example)
Z=+12 m	113.9 ± 2.5μs
Z= 0 m	113.4 ± 2.4μs
Z=-12 m	118.7 ± 2.3μs

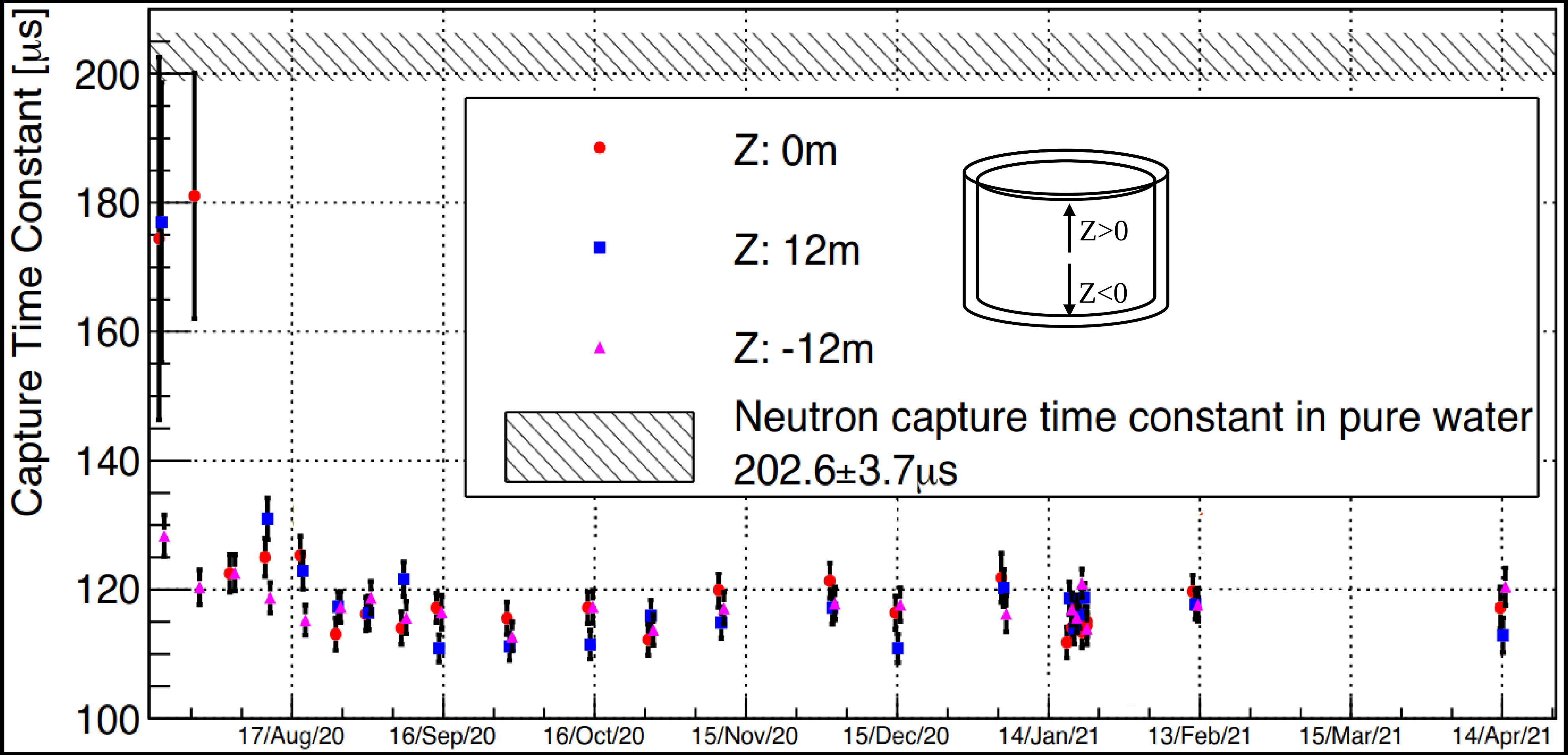
Average all days:
116.2 ± 0.4 μs



MC derived Gd concentration
from the measured capture time:
105 ± 2 ppm

Gd concentration monitoring: Am/Be

- Capture time history:

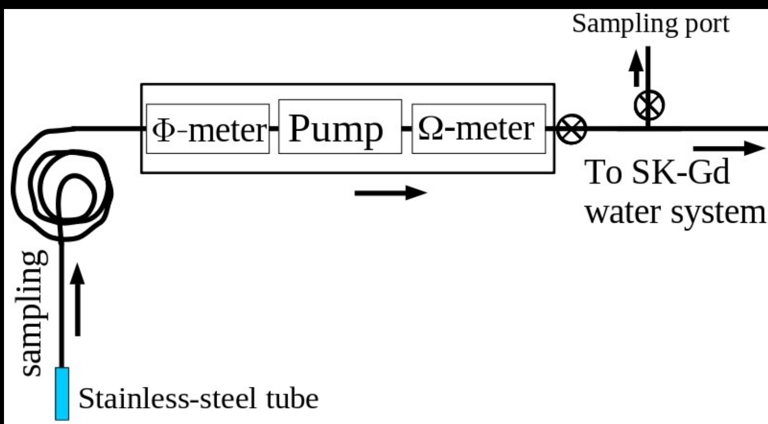


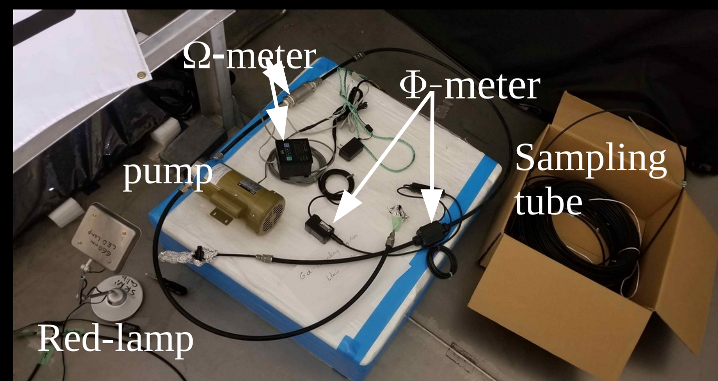
After Gd loading:
- The capture time is homogeneous at different depths (Z)
- The capture time remains constant since the end of the Gd loading

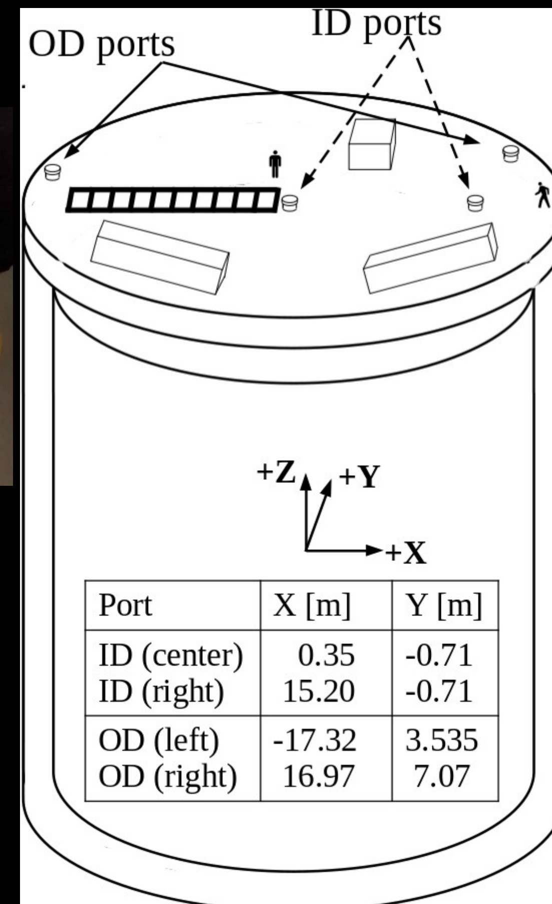
Gd concentration monitoring: direct sampling

- Direct sampling: sample from different ports both in the ID and the OD at different depths (Z).

→ Measure both the conductivity and the Gd sulfate octahydrate with an Atomic Absorption Spectrometer.







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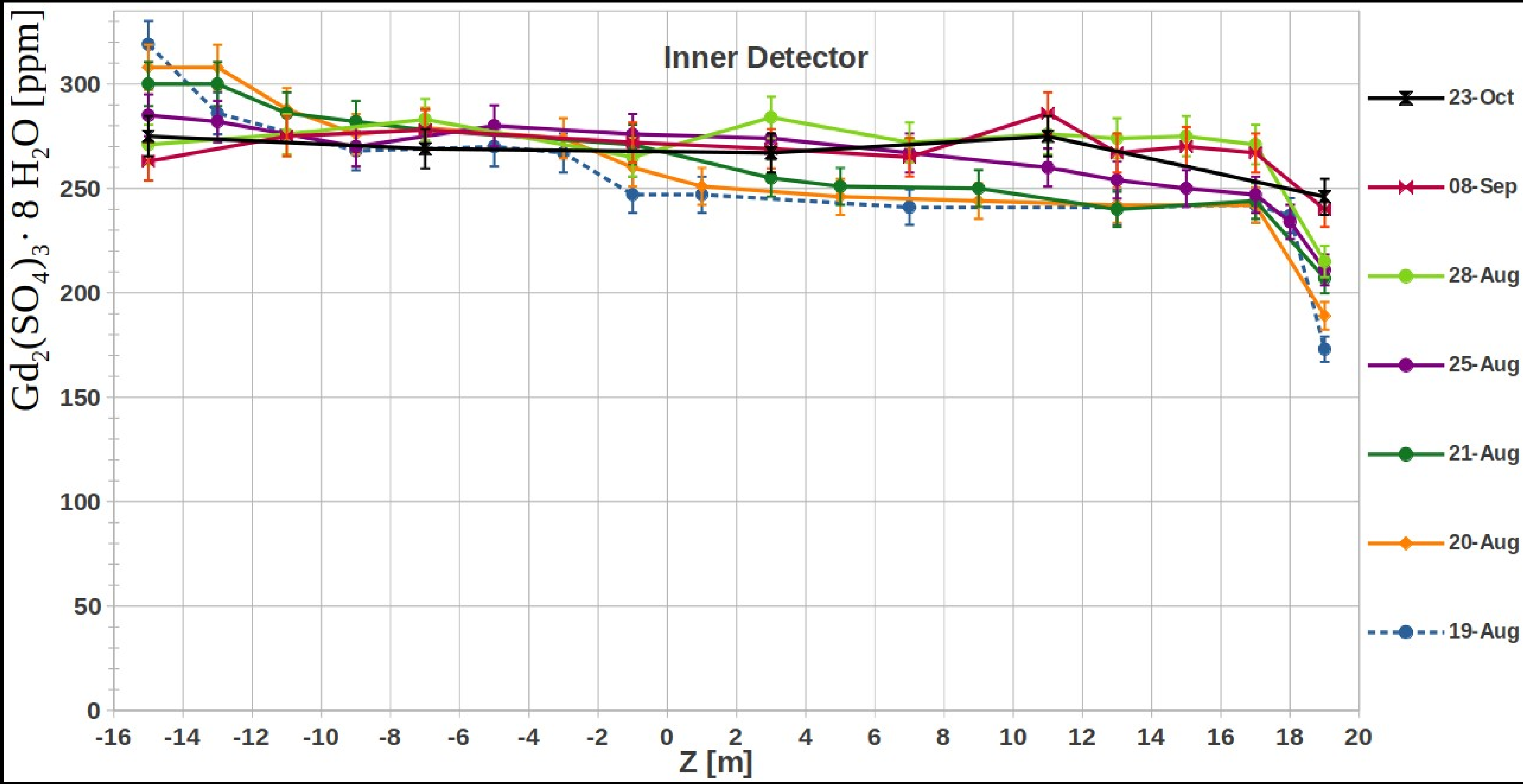

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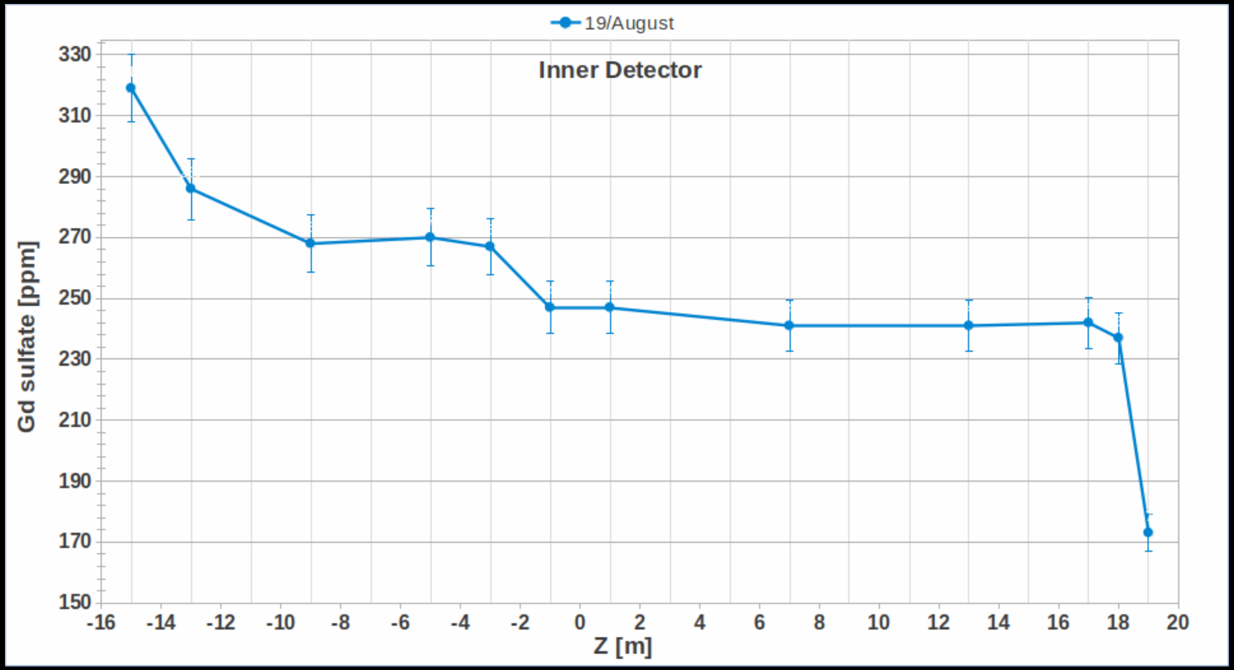

Next steps: Production of Gd sulfate

- During 2020' Gd loading, every lot was checked (Kamioka, Canfranc & Boulby)

- ^{228}Ra concentration was found to be higher in the second half due to its higher concentration the feedstock (Gd oxide)

→ Search for a cleaner feedstock
→ Improve purification methods

Chain	Chain section	SRN (mBq/Kg)	Solar (mBq/Kg)
^{238}U	^{238}U	< 5	-
	^{226}Ra	-	< 0.5
^{232}Th	^{228}Ra	-	< 0.05
	^{228}Th	-	< 0.05
^{235}U	^{235}U	-	< 3
	^{227}Ac/^{227}Th	-	< 3

Next steps towards adding more Gd

Other preparations for the next loading:

→ Test of new resins to replace the production of discontinued lines→ Ongoing.

→ Improvement of the dissolving system: from packing to improving Gd powder injection and mixing.

→ We must be capable of removing this Gd from SK. Increase the stock of Gd removal resin in the mine.

- Production of Gd sulfate started (~3 ton/month).

- **Plan:** Add **26 tons of $Gd_2(SO_4)_3 \cdot H_2O_2$** (39 tons total) in May 2022

Summary

In 2020 Super-Kamiokande diluted 13 tons of $Gd_2(SO_4)_3 \cdot H_2O_2$ to achieve efficient neutron tagging.

The concentration of Gd is being periodically monitored using two methods:

→ Searching for neutrons from an Am/Be source
→ Direct sampling from the SK tank

→ Homogeneous Gd concentration

Preparations for the next loading ongoing:
→ Radio-purity of the Gd sulfate powder
→ Improvement of several aspects of its dilution and injection
→ Upgrade of the Gd removal system

We expect to load 26 tons of $Gd_2(SO_4)_3 \cdot H_2O_2$ in May 2021