The Future of Super-Kamiokande: SK-Gd

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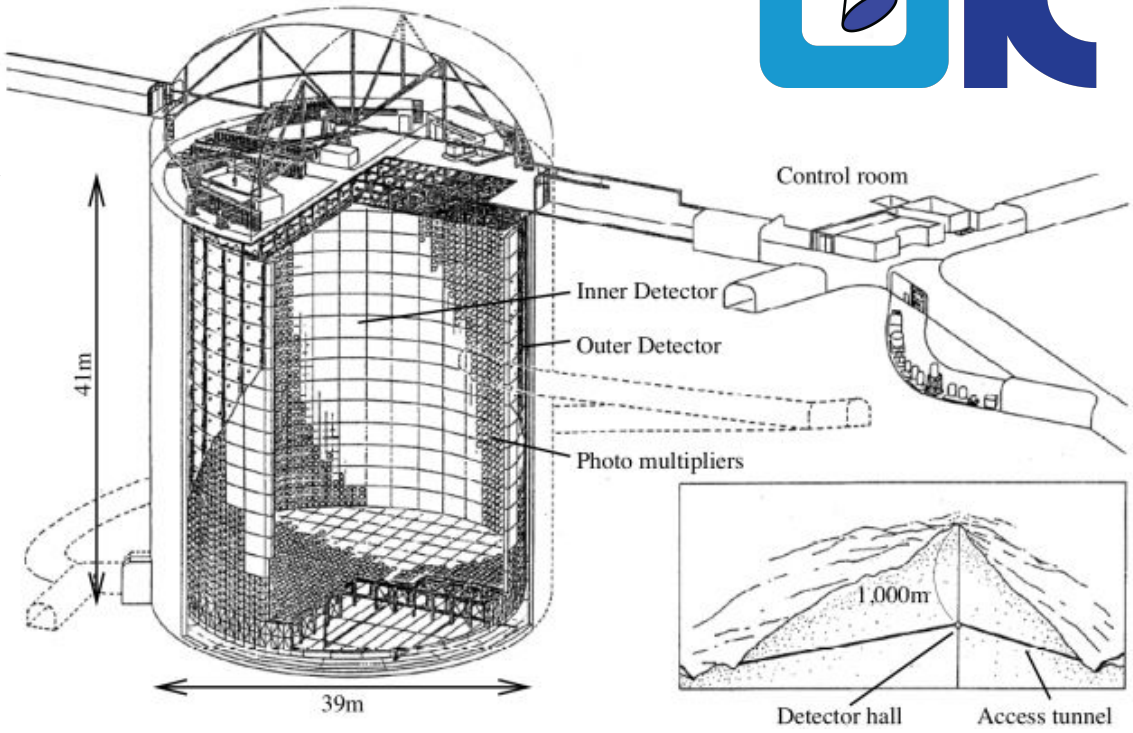
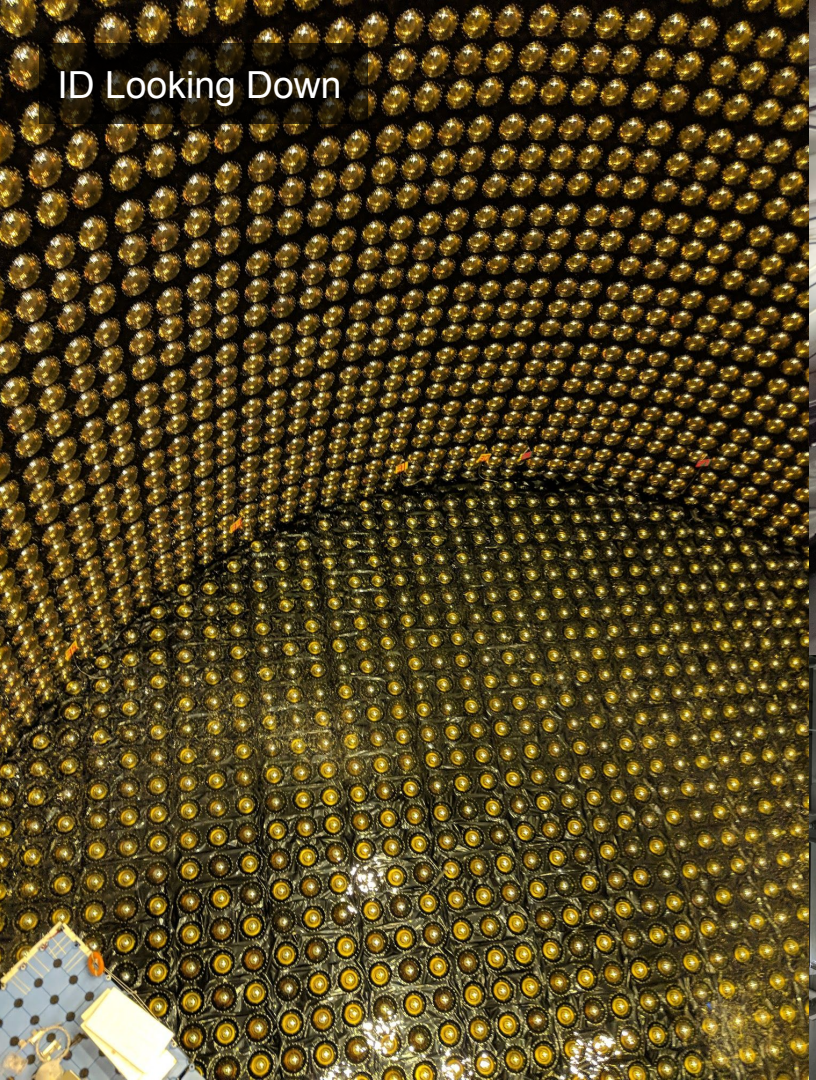
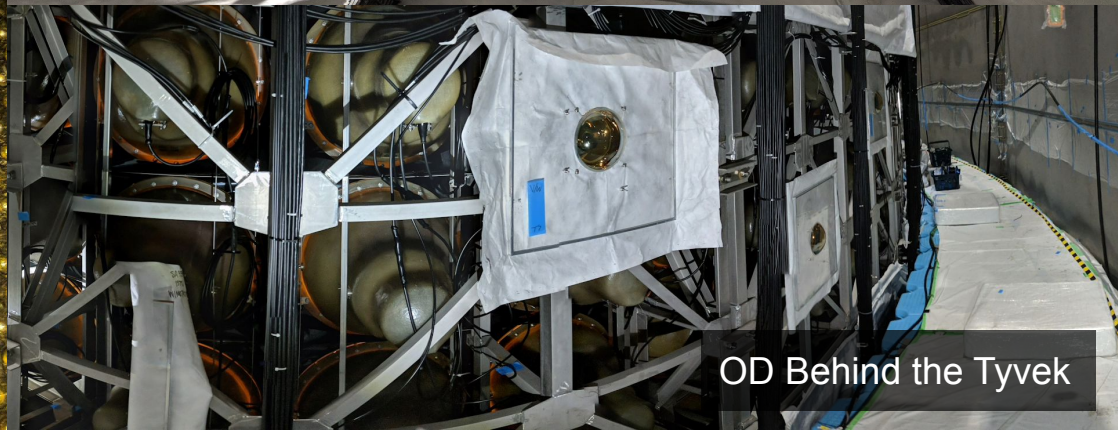
The Super-Kamiokande Neutrino Detector

- 50,000 ton (22.5 kt fiducial) water Cherenkov detector in Gifu prefecture, Japan.
- More than 11,000 20” (~50 cm) diameter PMTs in inner detector.
- Further ~2,000 8” (~20 cm) PMTs in outer detector.
- Rich history of neutrino physics.
- Takaaki Kajita of SK awarded the 2015 Nobel Prize for discovery of neutrino oscillation.




ID Looking Down


OD Looking Up

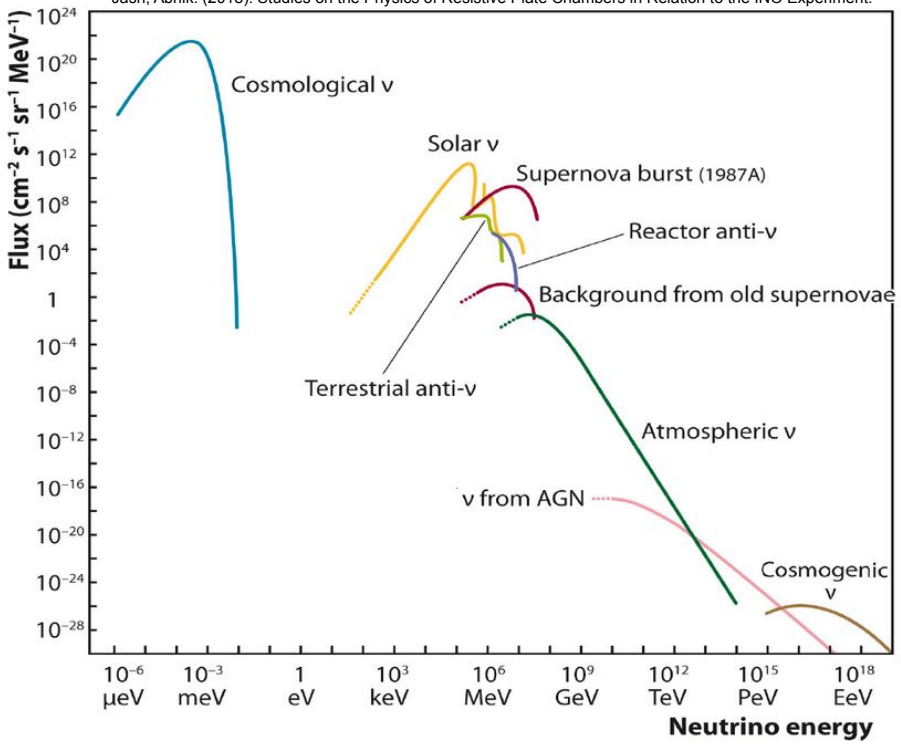

OD Behind the Tyvek

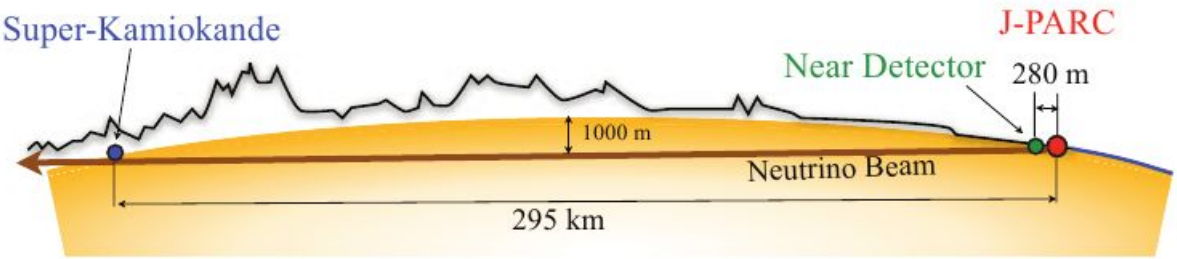
Neutrino Sources in SK

- Solar*
- Galactic supernova burst*
  - (Nobel Prize #1, Koshiba-san)
- Beam (T2K)
- Atmospheric
  - (Nobel Prize #2, Kajita-san)
- Nuclear reactors*
- Pre-supernovae*
- Relic supernovae*
  - (Nobel Prize #3 ???)

*Down to low energy
(below 10 MeV)

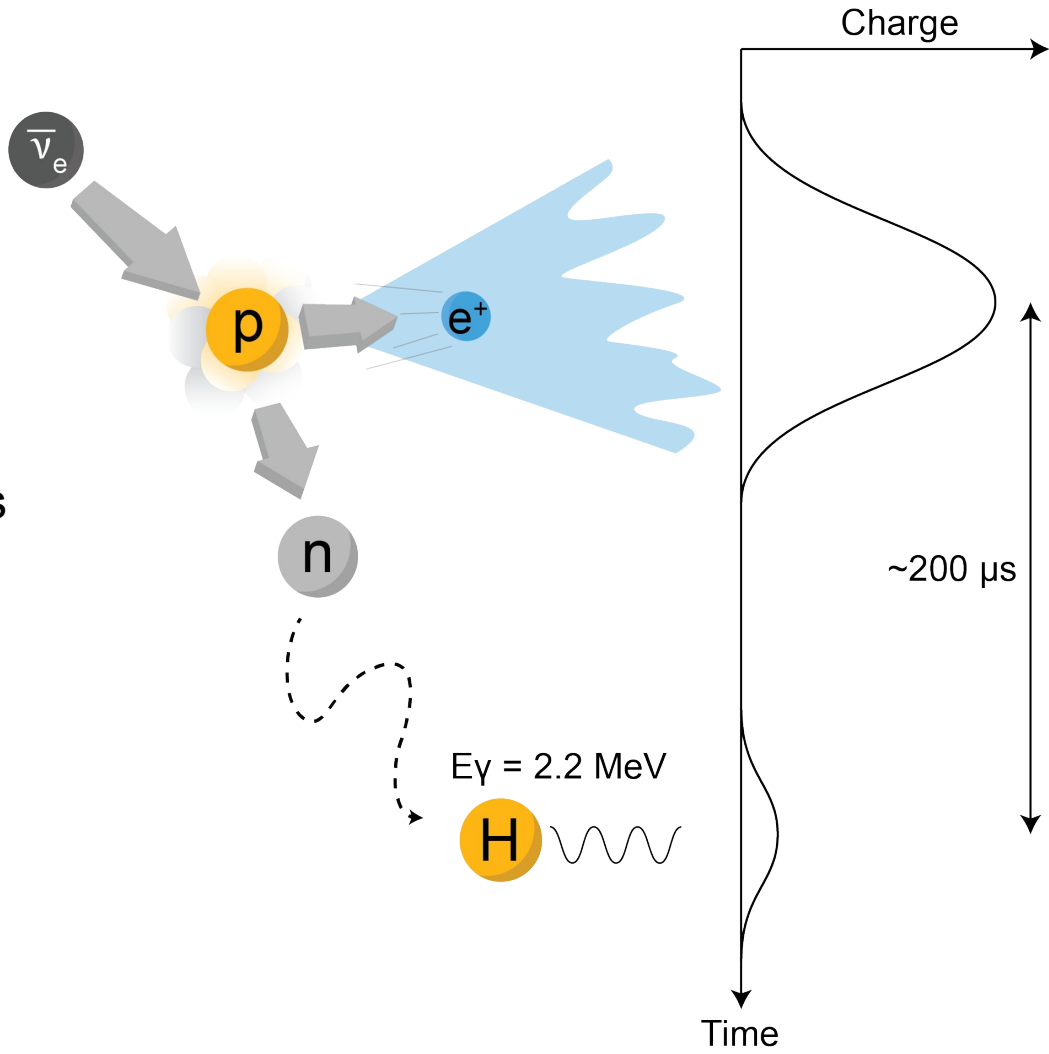
Jash, Abhik. (2018). Studies on the Physics of Resistive Plate Chambers in Relation to the INO Experiment.





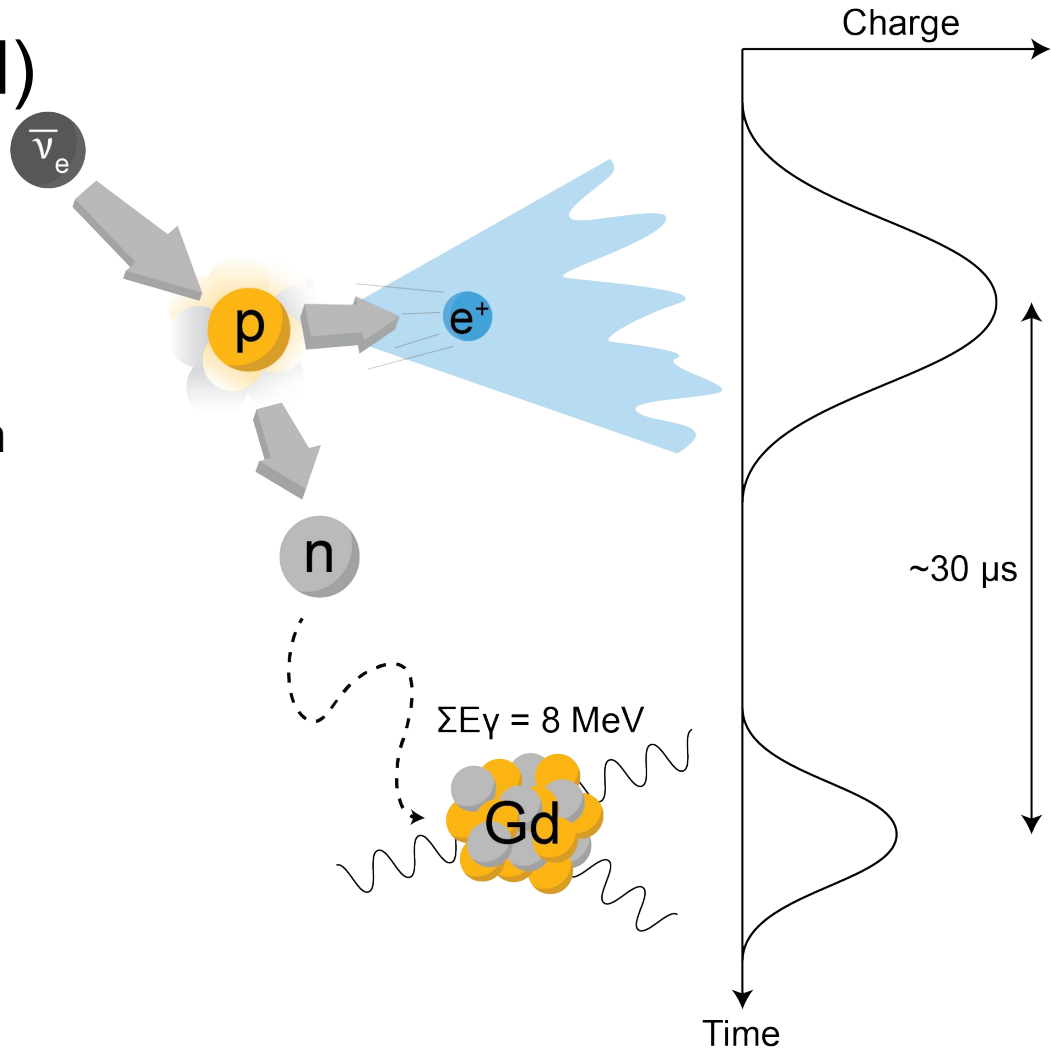
Inverse Beta Decay (H)

- Electron anti-neutrinos dominantly interact via IBD at lower energy.
- Prompt positron Cherenkov light detectable above a couple MeV.
- Delayed n capture on H releases a 2.2 MeV gamma.
- 2.2 MeV gamma very difficult to see in SK (~7 pe), lots of background.



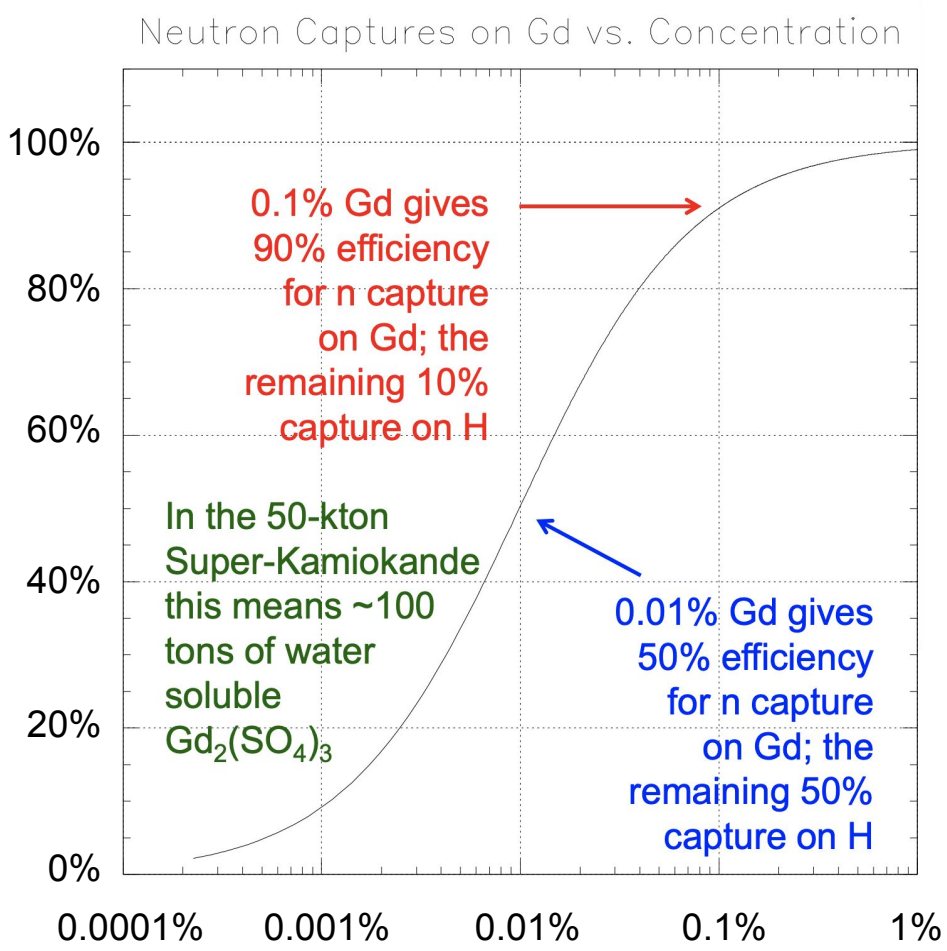
Inverse Beta Decay (Gd)

- Gd's n capture cross section is ~100,000 X that of H.
- Very distinct "heartbeat" signal.
- Released 8 MeV gamma cascade is much easier to see in SK (~23 pe, almost 100% efficient).
- More easily tag IBD, reducing background.



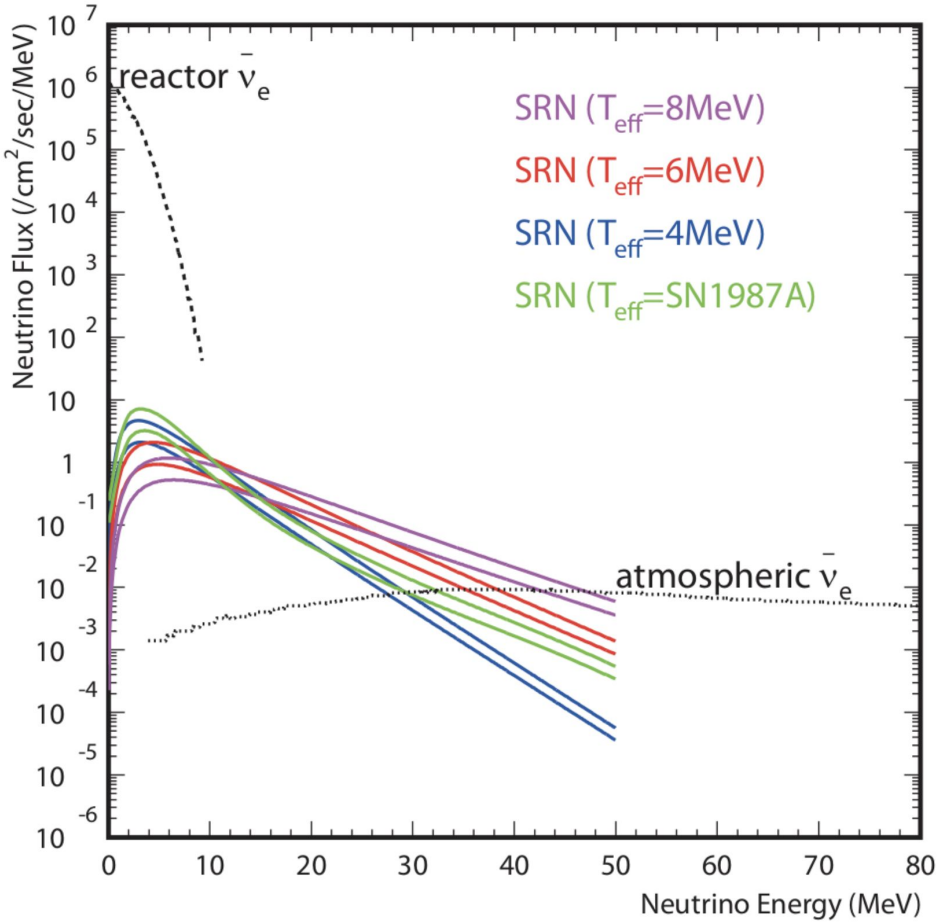
Gd in Super-K

- Let's load SK with Gd!
  - (Actually $Gd_2(SO_4)_3$)
- First proposed in 2003 by Beacom and Vagins (as GADZOOKS!).
- Lots of R&D and preparation in the lead up (EGADS).
- Two planned phases:
  - 0.01%, 0.1% Gd by mass.
- Balancing cost with n capture on Gd.
- Happening soon!



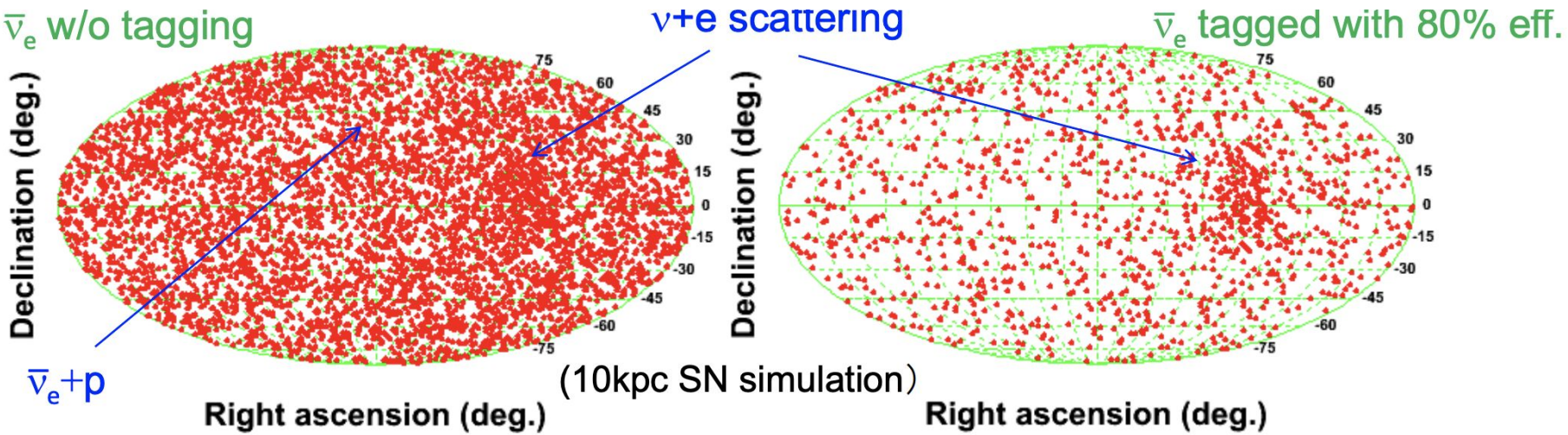
SRN in SK-Gd

- Energy window previously defined by reactor + atmospheric.
- With better tagging, reduces background.
- Expect to see up to 6 events a year.
- Never before detected.



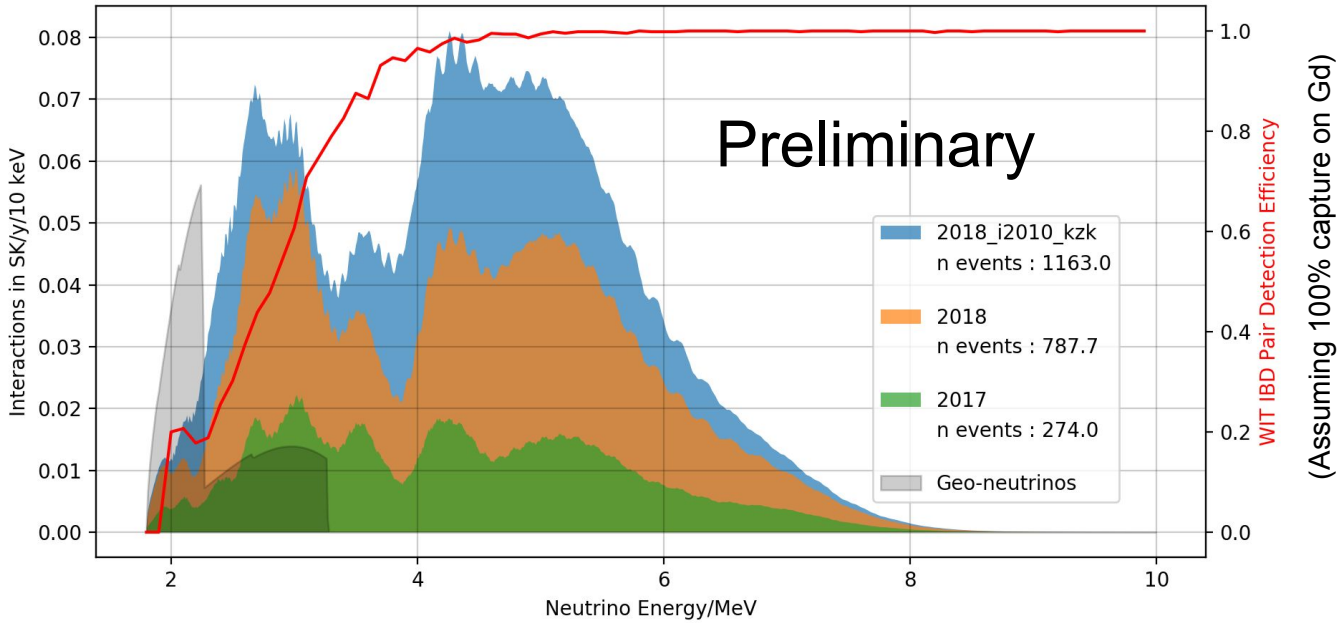
Supernova Burst

- Need to get pointing from elastic scattering (3% of all events).
- Electrons and positrons identical in SK.
- Tagging IBD reduces background to elastic scattering.
- Doubles pointing accuracy (reduces sky area by factor of 4).
- Can detect Si-burning pre-supernova neutrinos several hours before core collapse.



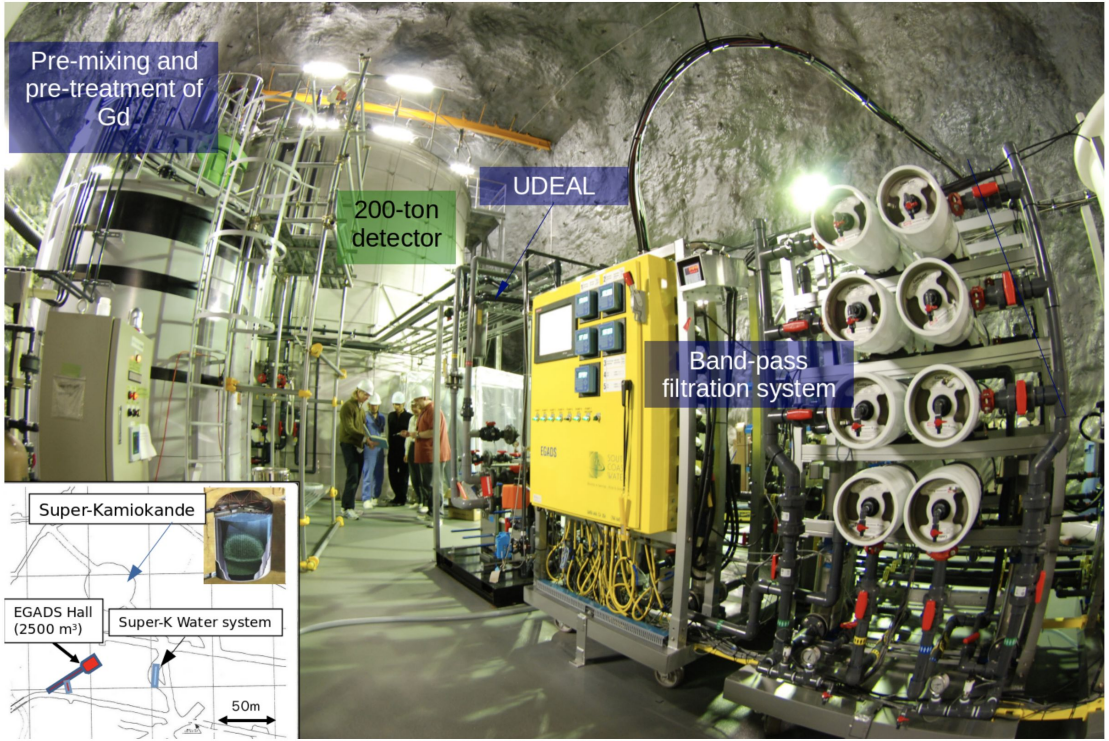
Reactor Neutrinos

- Since 2011, majority of Japanese nuclear reactors have been turned off.
- Kashiwazaki reactor (161 km) planned to restart April 2020.
- Can detect restart with SK-Gd.
- Would be first reactor neutrinos detected in WC detector.



EGADS: Baby SK

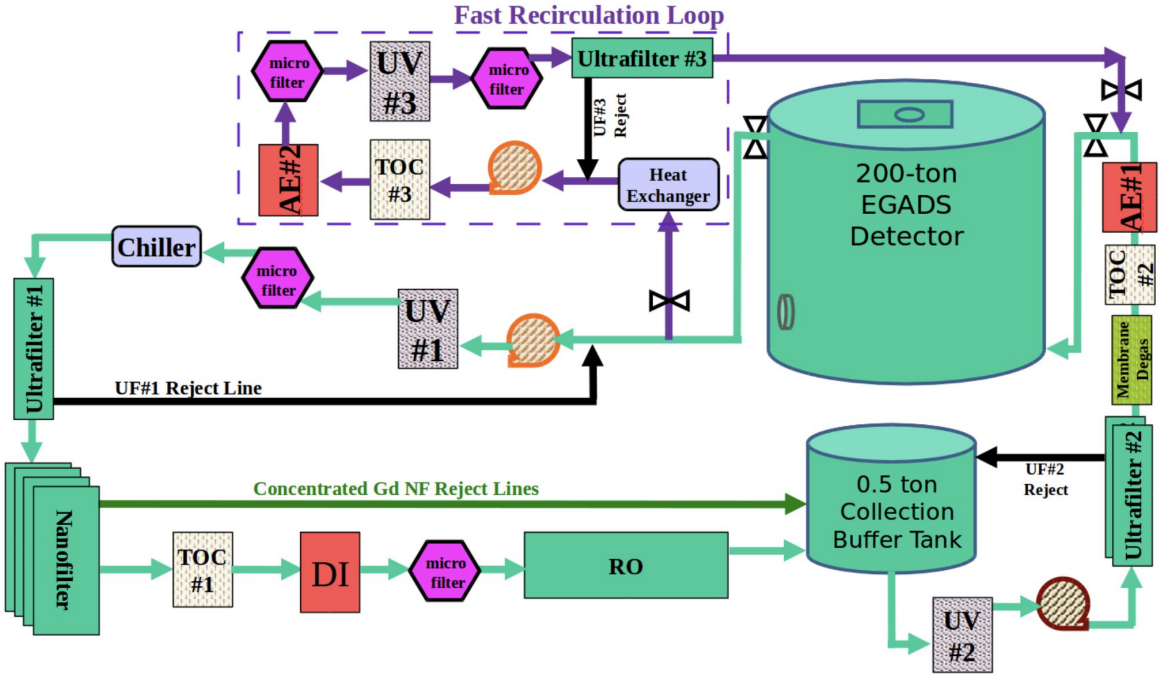
- **E**valuation of **G**adolinium's **A**ction on **D**etector **S**ystems.
- Test bed for SK-Gd, same style detector, same mine.
- 200 t, 240 PMTs (227 SK style, 13 of various potential Hyper-K styles).
- Need to test water systems, water transparency, effects of Gd on detector components.
- Strong detector in its own right!



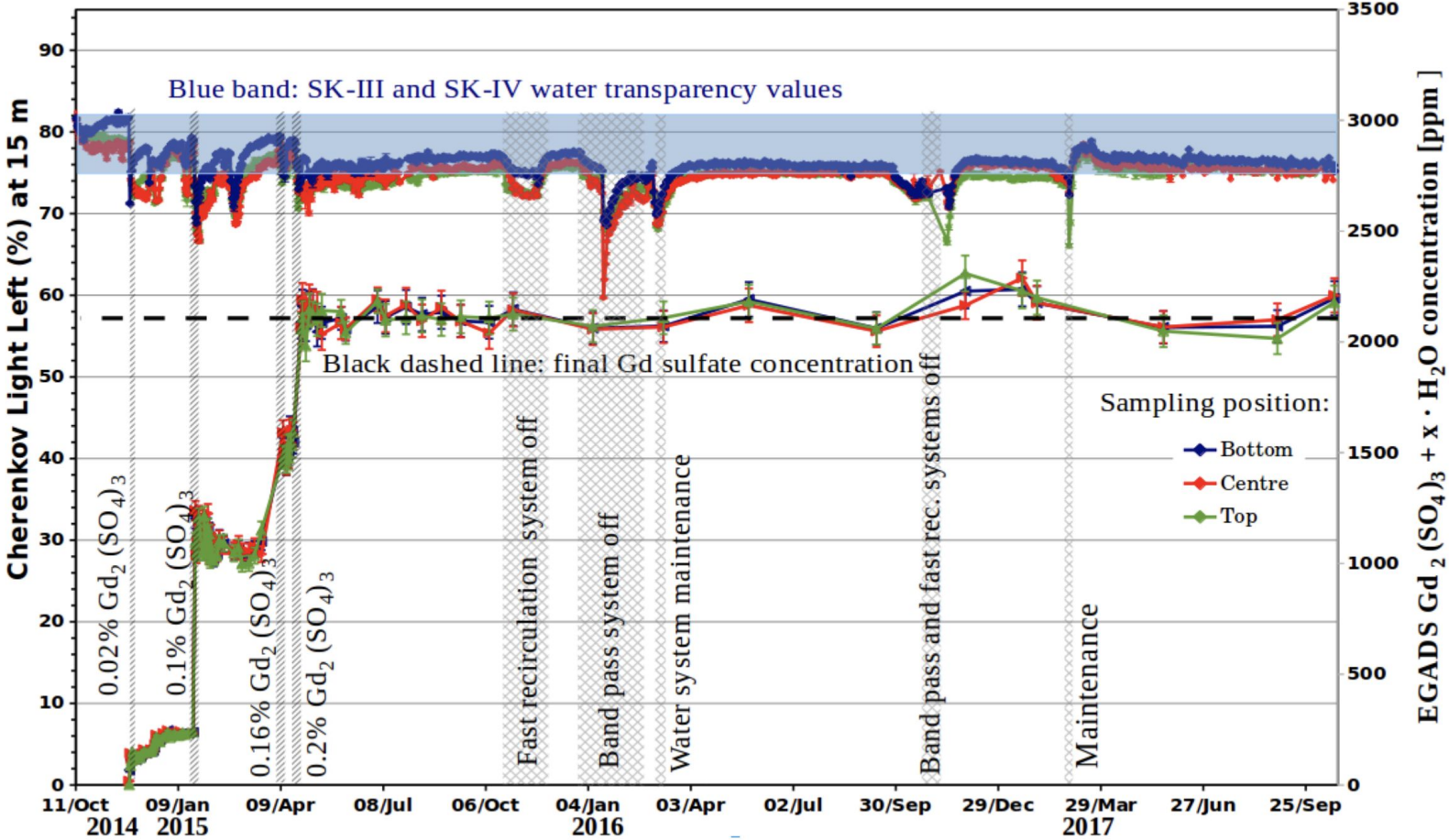

Lab E (On top of the EGADS tank)

Water System

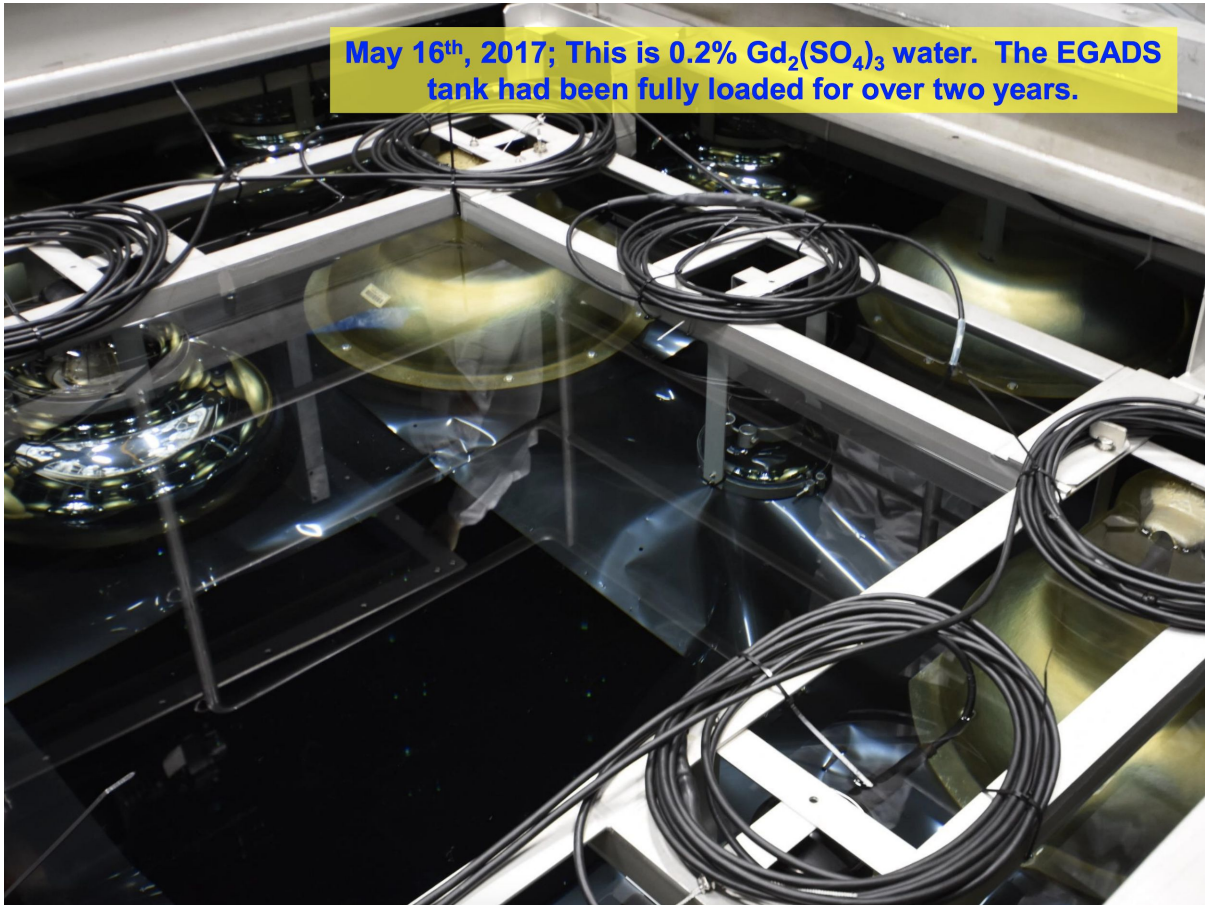
- SK's water purifier would clear out $Gd_2(SO_4)_3$.
- Need system to keep water pure while preserving Gd.
- Introduce the "molecular band-pass" system, purifying the Gd-less water separately to Gd water.



EGADS Water Transparency (UDEAL)



Gd's Effect on EGADS Hardware



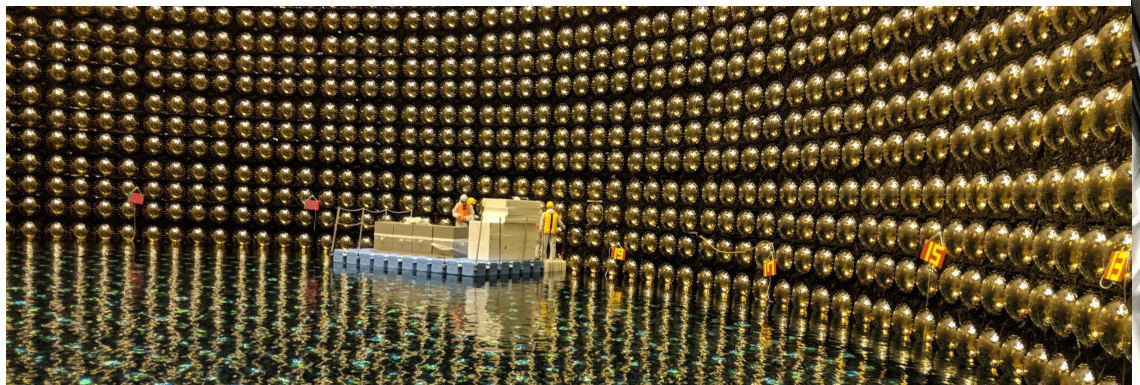
- Used SK building materials: stainless steel frame/fixings, acrylic PMT covers, waterproof cabling etc.
- 2 years of full Gd loading.
- All looks good!

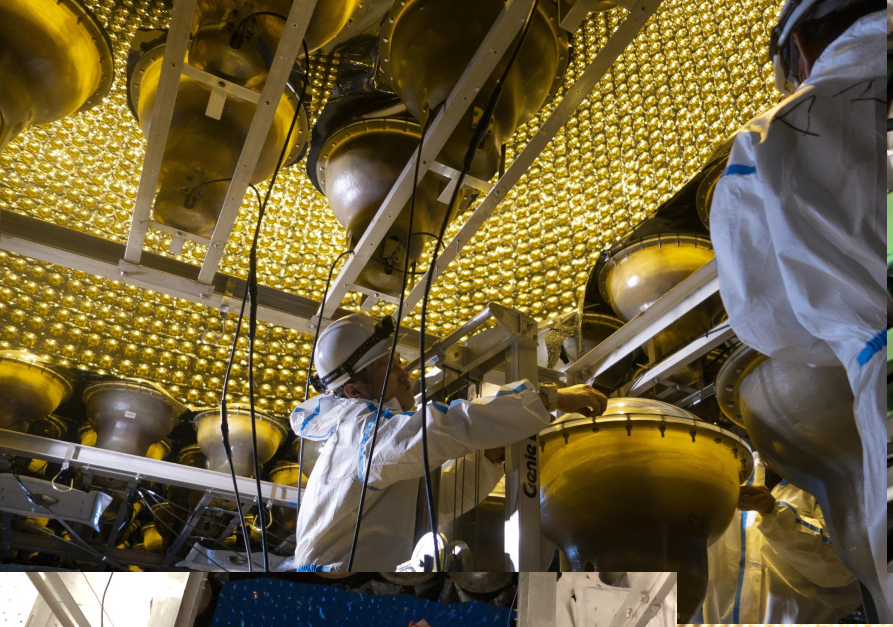
Water System (SK)

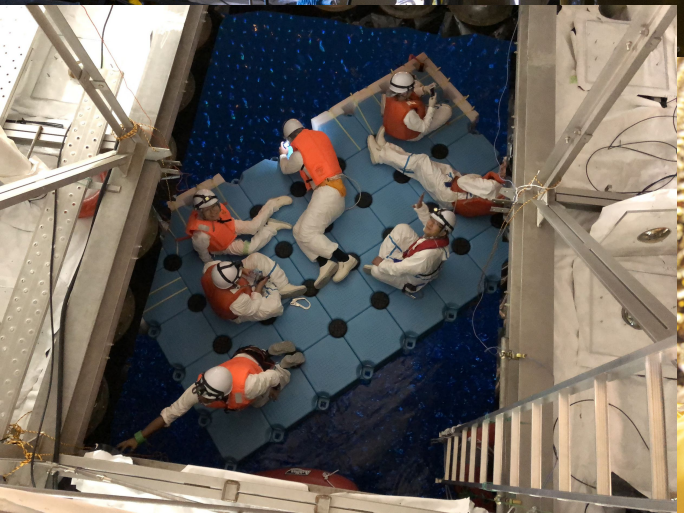
- New hall blasted in Kamioka mine for new water systems.
- Gd mixing/loading/ removal systems installed and ready for SK.
- Band-pass system hopefully installed soon.

SK Refurbishment 2018

- SK opened in summer 2018, first time in 12 years!
- Combined efforts of SK and T2K collaborators.
- Dead PMTs replaced, structure cleaned, tyvek replaced, water system upgraded, no detectable leak (<15 kg a day).
- Ready for SK-Gd!






Summary

- Many neutrino sources produce relatively low energy anti-neutrinos.
- SRN/DSNB for example.
- These dominantly interact via inverse beta decay.
- Super-Kamiokande suffers from high backgrounds for these events.
- Doping the detector with gadolinium provides efficient neutron tagging.
- Opens up many new avenues of research.
- SK-Gd happening soon!

Backup

Pre-SN E and L Before Core Collapse