New Technologies for Gadolinium Loading Super-K

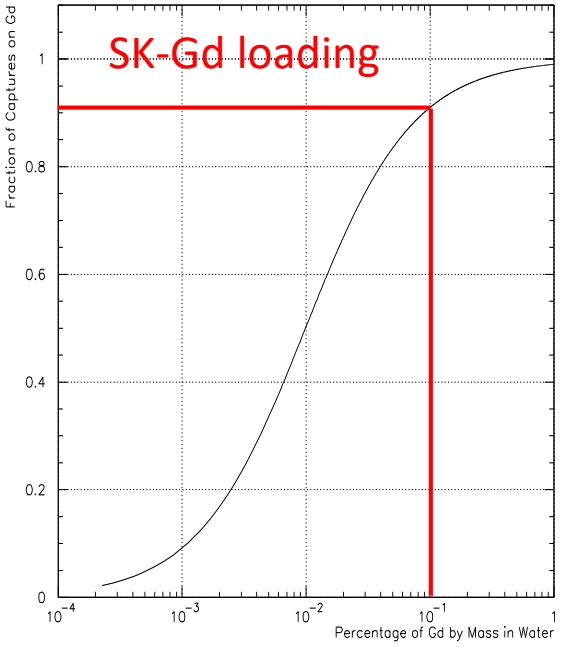
MATT MURDOCH

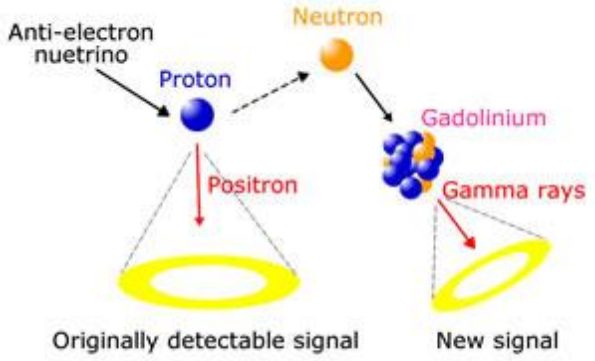
TAUP 2017 – NEW TECHNOLOGIES SESSION

2017/7/26

SK-Gd Overview

- Add 100 tons 0.2% $Gd_2(SO_4)_3$ to SK
  - Use neutrons to tag $\bar{\nu}$
  - > 90% of neutrons capture on Gd
- First proposed by Beacom and Vagins
  - PRL93,171101 (2004)
- New tech for new physics
  - Diffuse supernova background
  - Also improve existing signals



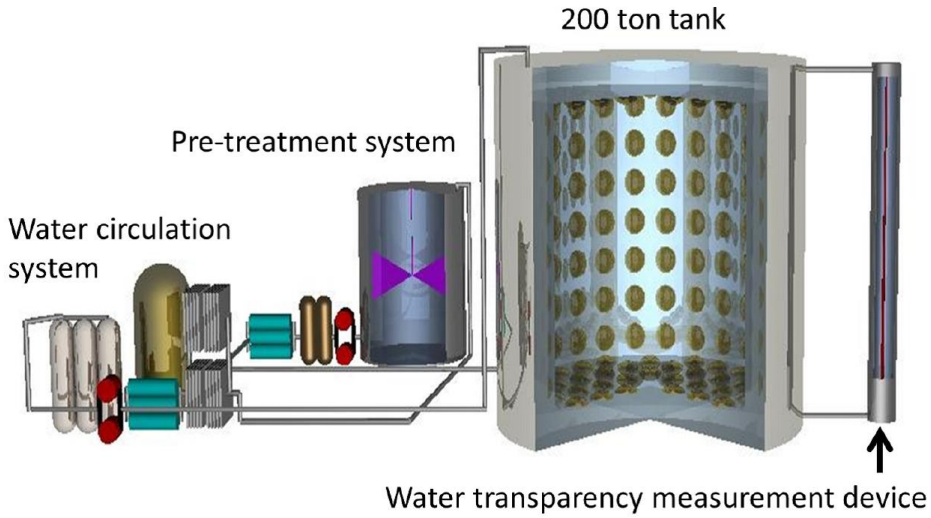


Challenges of Gd

- Add Gd while maintaining water transparency
  - New water circulation system
- Avoid erosion of detector components
  - Use only resistant materials
- Remove Gd when necessary
  - Resin based Gd capture
- High radiopurity – low contamination
  - Backgrounds for lowe analysis

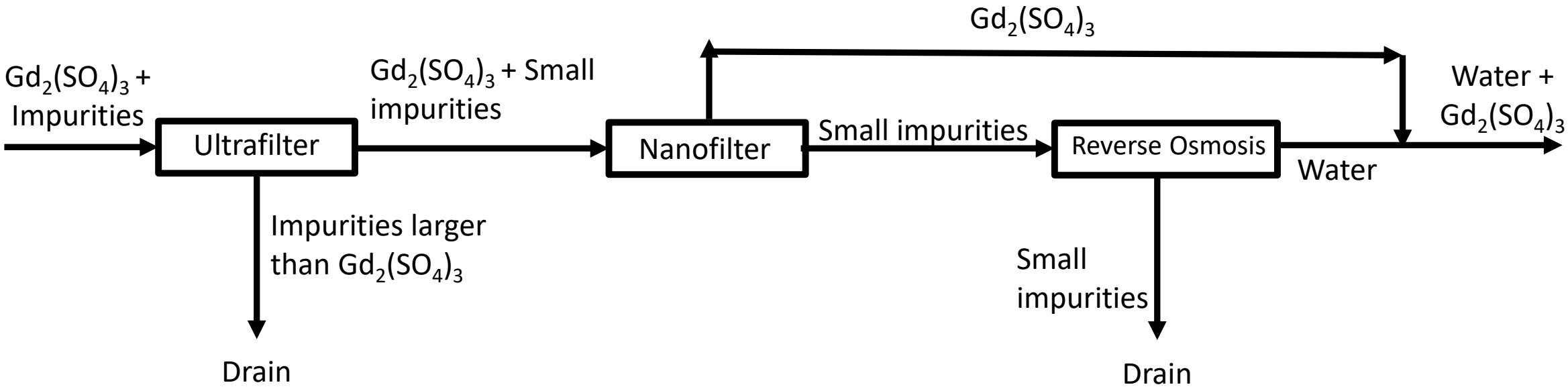
EGADS

- Evaluating Gadolinium's Action on Detector Systems
  - 200 ton, ~240 PMTS
  - 0.2% $Gd_2(SO_4)_3$
- Testbed for testing Gd technology
  - Runs in all configurations
  - Pure water & Gd water
  - With & without PMTs
- Currently taking data for > 2 years with PMTs at design Gd loading



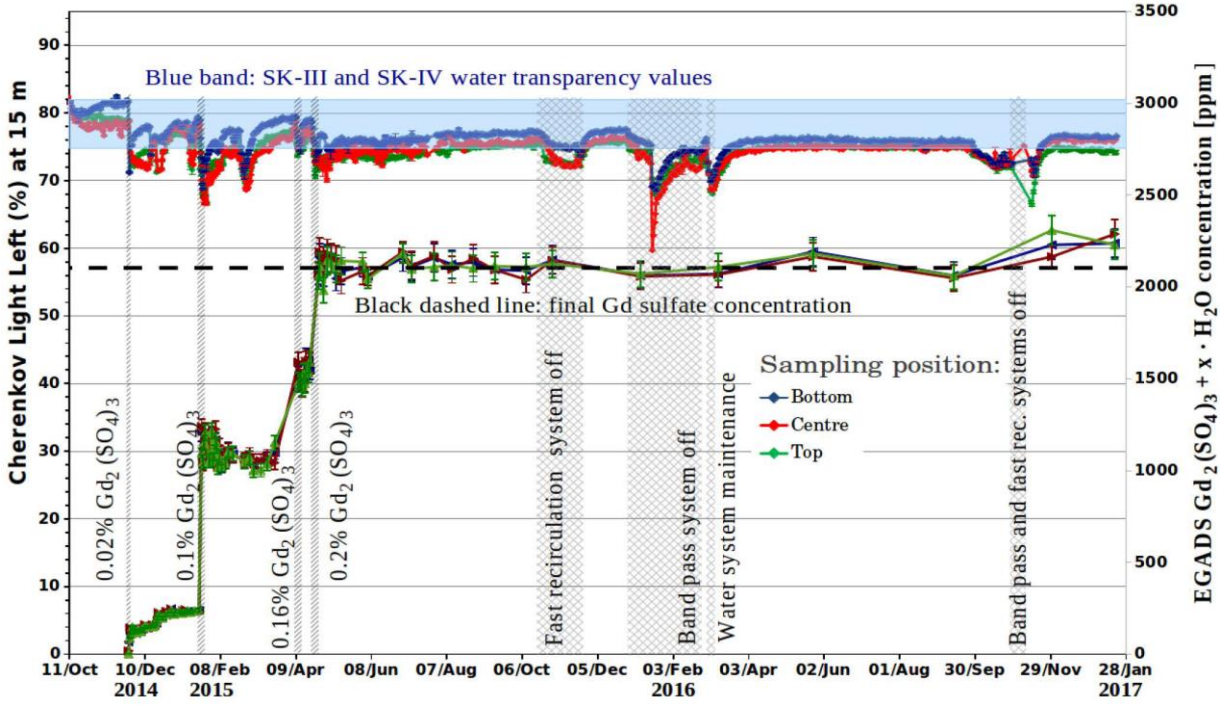
Water System

- Molecular band pass system
  - Selects & retains Gd, removes impurities

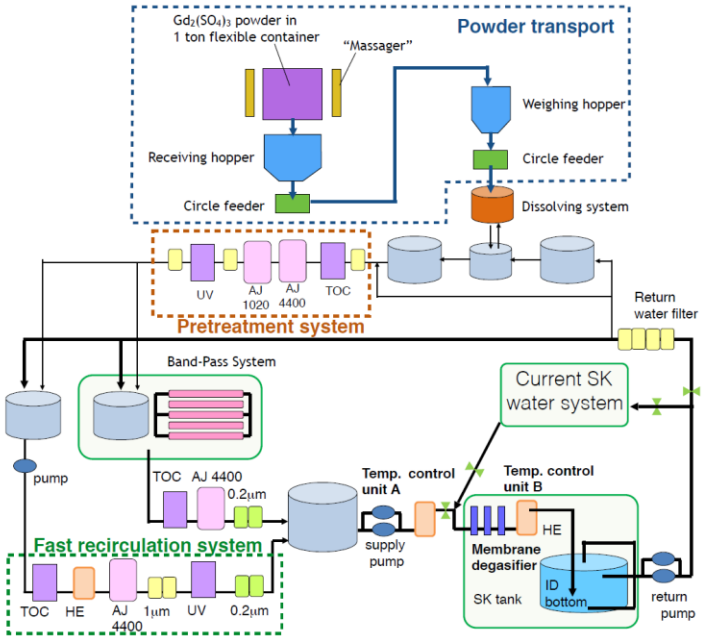


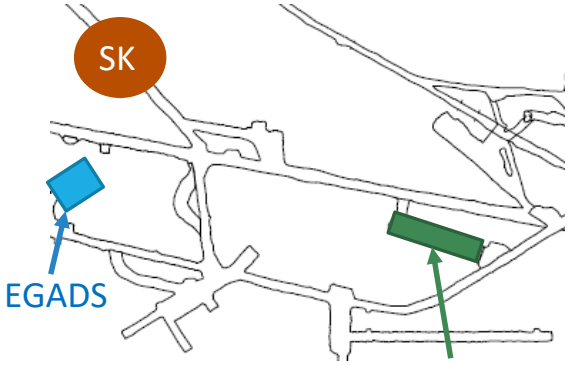
Water Quality

- Success!
- Maintains SK levels of water quality
- Great stability
- No observable $Gd_2(SO_4)_3$ loss after 2 years at design loading
  - >500 complete circulations



New Water System for SK

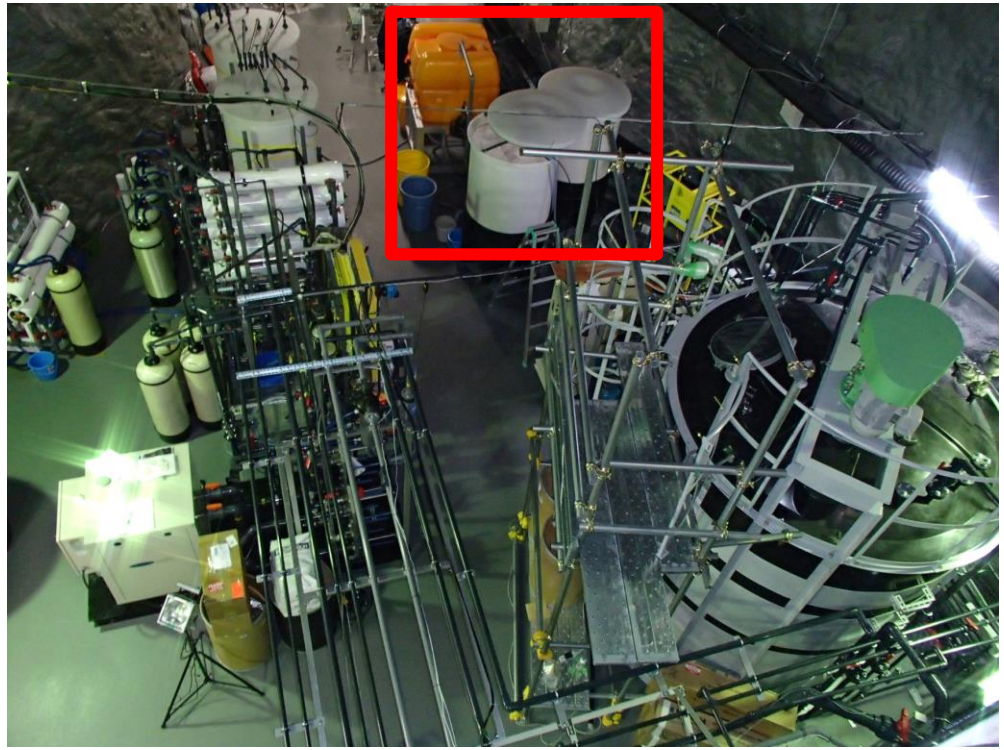




Gd Removal

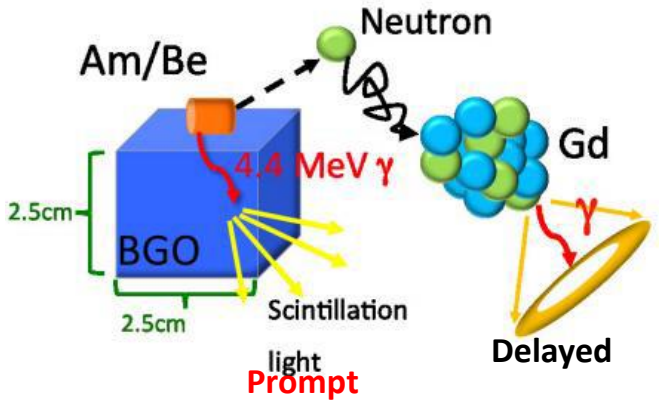
- Need ability to remove Gd
  - Maintenance, end of experiment, etc.
- Pass water through cation ion-exchange resin
  - Simple and effective
- Tested several times in EGADS
  - << 1ppm $Gd_2(SO_4)_3$ remains after treatment
- Enlarged system designed for SK

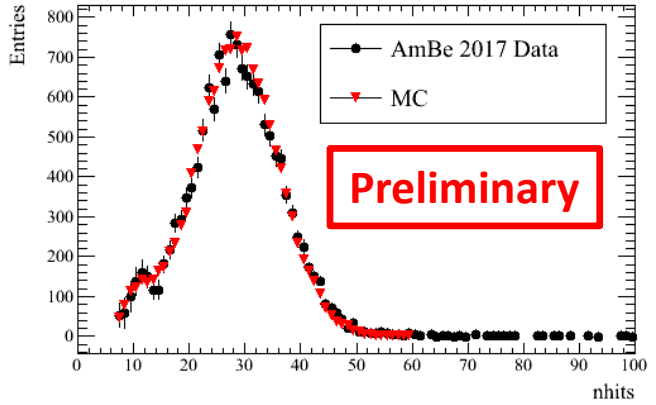
Resin removal system



EGADS Data

- AmBe neutron source and Geant4 MC
  - Good agreement
- Monitor detector response over time
  - Capture time sensitive to Gd concentration
  - Stable over time
  - No observable Gd loss
  - Cross check water quality





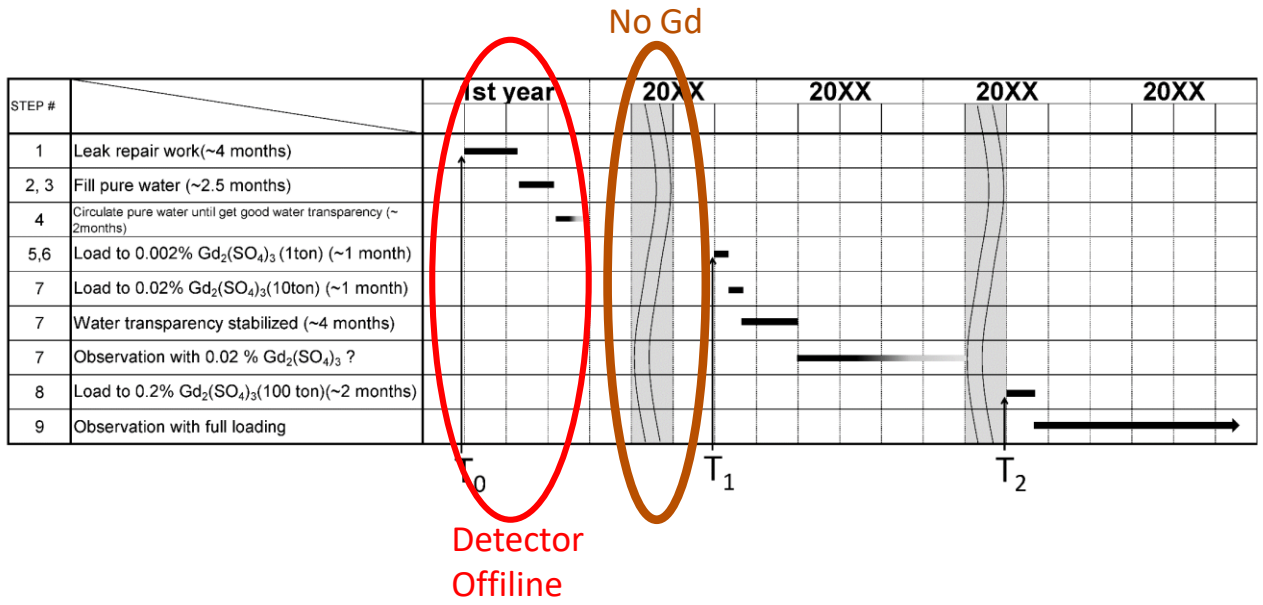
Preliminary	2015 Data	2016 Data	2017 Data	EGSIM
Efficiency (Gd n-capture)	84.2 ± 1 %	85.3 ± 0.7 %	85.3 ± 0.9 %	84.4 ± 0.3 %
Lifetime (μs)	30.9 ± 0.4	31.1 ± 0.3	31.04 ± 0.4	31.06 ± 0.1

Preliminary

* N.B. Lower than expected SK efficiency due to neutron containment/small fiducial volume

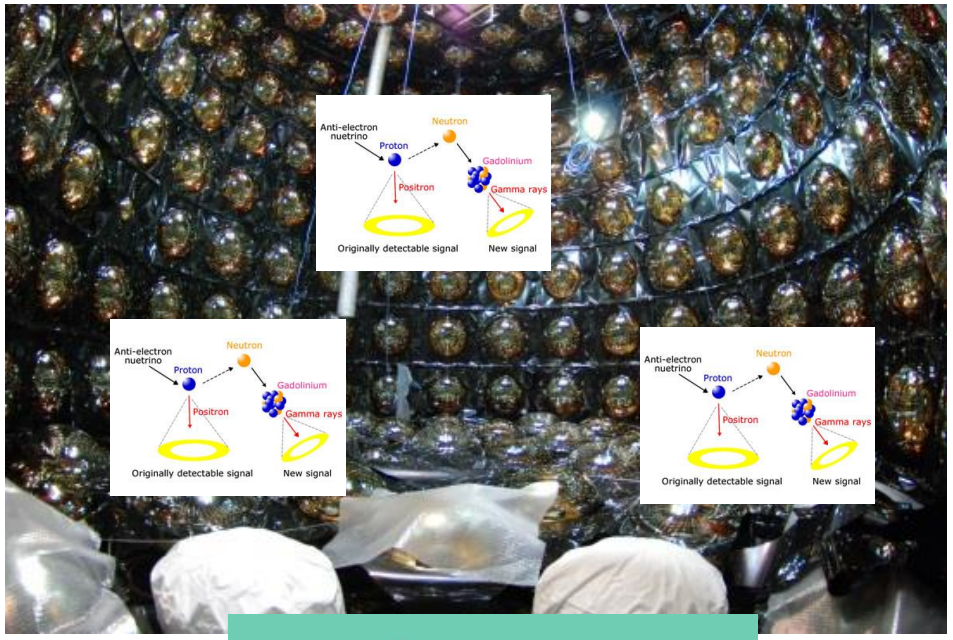
SK-Gd

- EGADS demonstrated feasibility of Gd doped water Cherenkov technology
- Based on the success of EGADS, plan to add Gd to SK
  - Planned T_0 = 2018
- SK tank will be drained for repair work
  - Non-operational for 6-9 months
  - No Gd until after T1
- Need some supernova contingency!



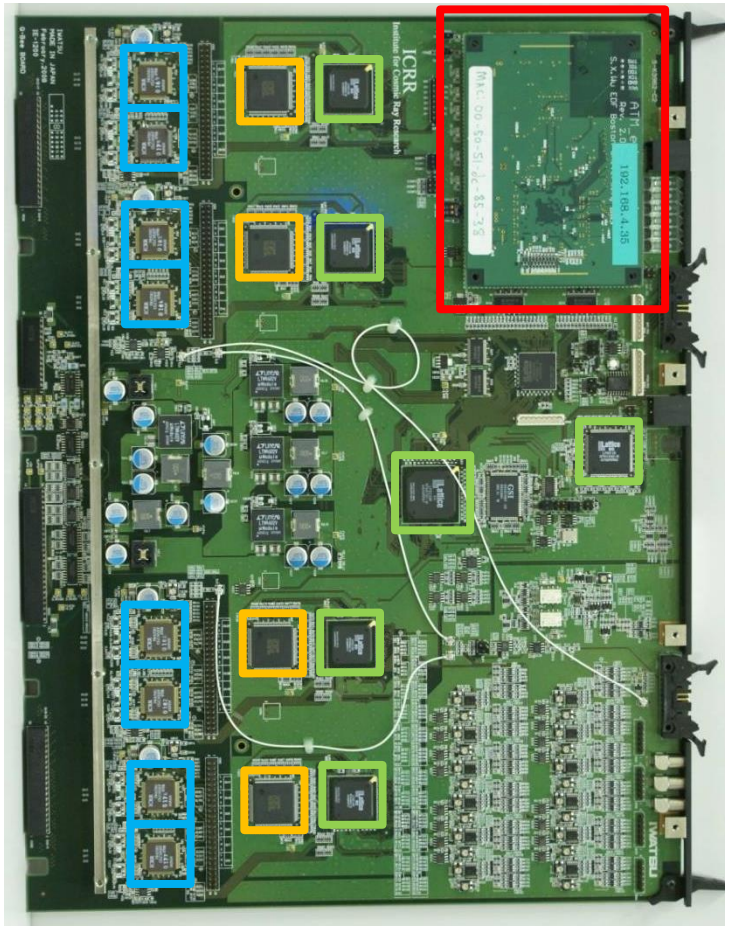
EGADS for Supernova

- Repurpose EGADS as supernova detector
- Employing Gadolinium to Autonomously Detect Supernovae
  - ~90,000 events for Betelgeuse SN
- Replace old (old) ATM electronics
  - SK I, II, III
- New (old) QBEE electronincs
  - SK IV
  - In SK since 2008
- Create 0 deadtime**, autonomous** supernova detector



QBEE Board

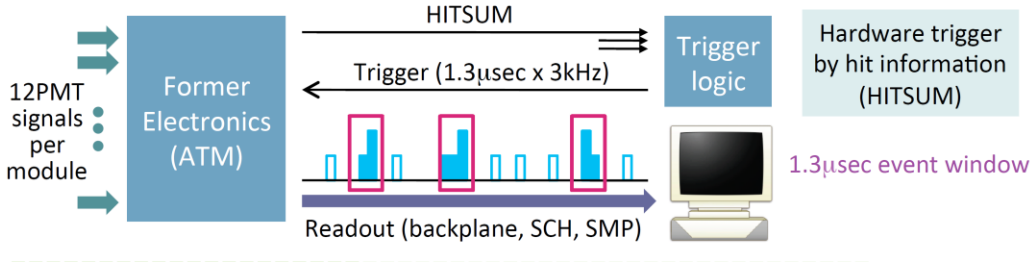
- QTC Based Electronics with Ethernet
- 24 inputs (PMTs) per board
- QTCs – time to charge converters
  - 3 gain stages for high dynamic range
- Multi-hit TDCs
  - Dead time free system
- Ethernet readout daughter board
- 60MHz master clock supplies 60kHz global trigger to QBEEs



DAQ Upgrade

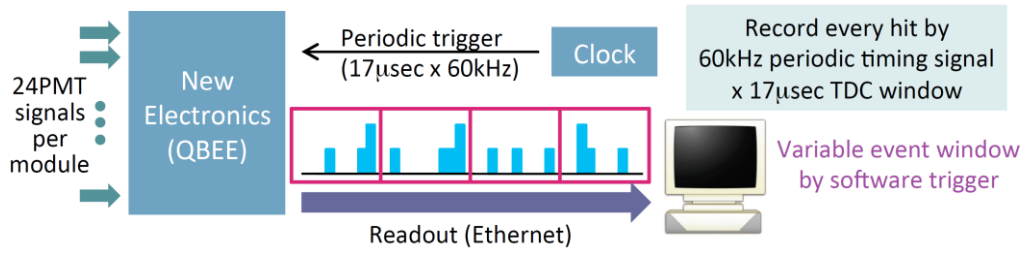
ATM

- Significant deadtime
- Hardware Trigger
  - Only hits in trigger window recorded
- Capable of ~300 Hz readout
- Moderate dynamic range



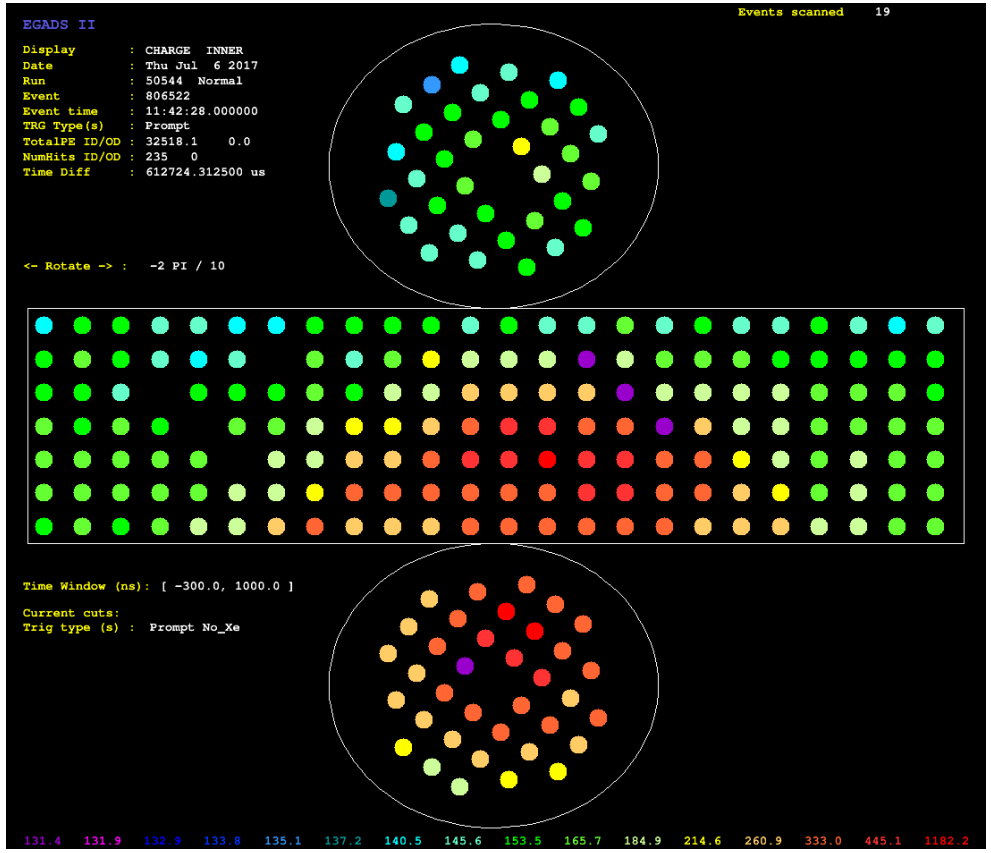
QBEE

- No deadtime
- Software trigger
  - All hits recorded
- Capable of >10 kHz readout
- Large dynamic range (ATM x 5)



Upgrade Progress

- QBEEs installed
- DAQ being tested
  - Taking data
  - Finalising setup
- Calibration campaign before physics data-taking



Cosmic ray in EGADS with QBEE electronics

Real Time Alert

- Implement Intelligent Trigger system from SK
  - Real time event reconstruction
- With Gd we can identify Inverse Beta events with low background
  - Prompt positron
  - Delayed neutron (~0-300 μs later)
- Multiple IB events in 1ms can only be from a SN burst!
  - No need for cross-checks/human intervention
  - Autonomously alert within 1 s of neutrino arrival

Summary

- Viability of Gd doped Water Cherenkov technology demonstrated
  - Developing several other new technologies on the way
- EGADS will now be repurposed to autonomously detect nearby supernova
  - Most advanced supernova detector
- Gadolinium revitalising a many decades young technology in pursuit of new physics
  - While enhancing old searches

Matthew.Murdoch@ipmu.jp

Backups

Radioisotope Reduction

- Significant contamination in untreated Gd powder
  - In terms of backgrounds for low energy analyses
  - Solar has most stringent requirements
- Reduction through:
  - Pre-treatment by suppliers
  - Removal via ion-exchange resins

Chain	**Part of Chain**	**Typical (mBq/kg)**	**Goal (mBq/kg)**	**Analysis**
^{238}U	^{238}U ^{226}Ra	50 5	< 5 < 0.5	DSNB Solar
^{232}Th	^{228}Ra ^{228}Th	10 100	< 0.05 < 0.05	Solar Solar
^{235}U	^{235}U ^{227}Ac/^{227}Th	32 300	< 3 < 3	Solar Solar

Radioisotope Reduction - Pretreatment

- Orders of magnitude reductions compared to typical sample
- Goals met for U
- Well on the way to Ra/Th goals

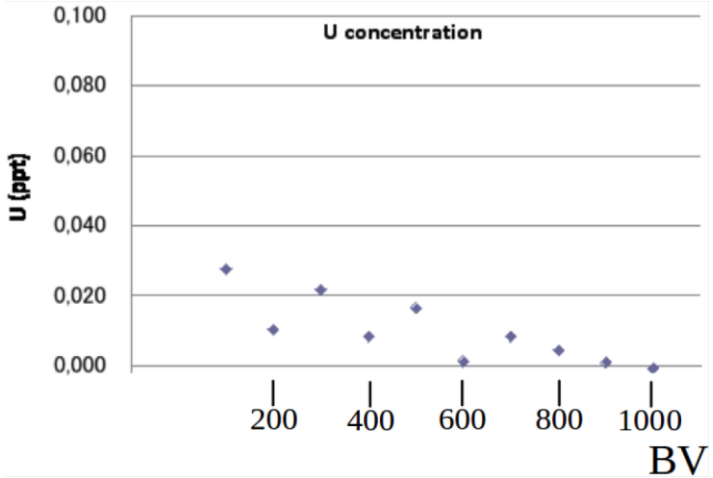
Chain	Part of Chain	Typical (mBq/kg)	Goal (mBq/kg)	Company A (mBq/kg)	Company B (mBq/kg)	Company C (mBq/kg)
^{238}U	^{238}U ^{226}Ra	50 5	< 5 < 0.5	3 < 9	2.7 < 0.6	2.1 < 0.3
^{232}Th	^{228}Ra ^{228}Th	10 100	< 0.05 < 0.05	< 5.9 < 5.9	< 0.7 0.9	< 0.3 < 0.4
^{235}U	^{235}U ^{227}Ac/^{227}Th	32 300	< 3 < 3	< 35 < 35	< 3.1 < 6.1	< 0.6 <1.9

Radioisotope Reduction - U

- Further U reduction demonstrated

- Use Amberjet (AJ) 4400
  - Ion exchange resin

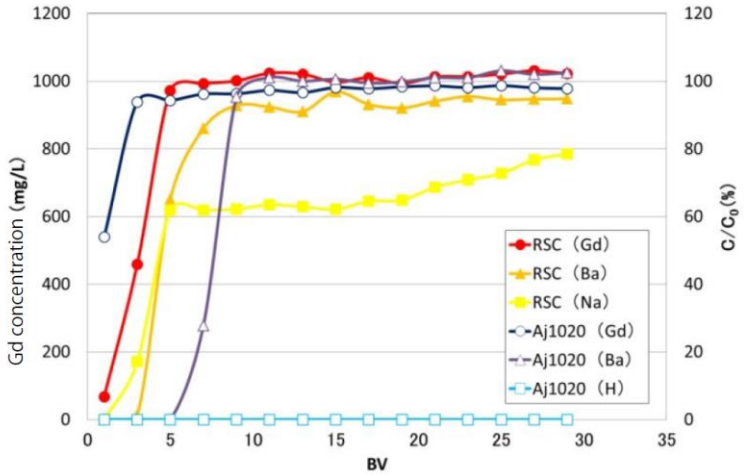
- Deployed & tested in EGADS
  - Initial loading 10 ppt
  - Reduces U to < 1% initial level
  - No Gd loss observed



BV = bed volume = ~150 litres of water

Radioisotope Reduction - Ra

- Use cation-exchange resin
  - Ra: DOWTEX Radium Selective Complexer (RSC)
  - Amberjet 1020
- DOWTEX Exchanges Na^{+} for Ra^{2+}
  - AJ uses H^{+}
  - Will absorb Gd^{3+}
- Replace Na/H with Gd
- Difficult to measure Ra directly
  - Measure daughter, Rn
- New Rn system developed
  - Use Rn detector developed for SK
  - NIMA 867, pg 108-114, 2017
- Tests will begin shortly



Initial binding of Gd by the resin. Modified resins stop absorbing Gd after several BV