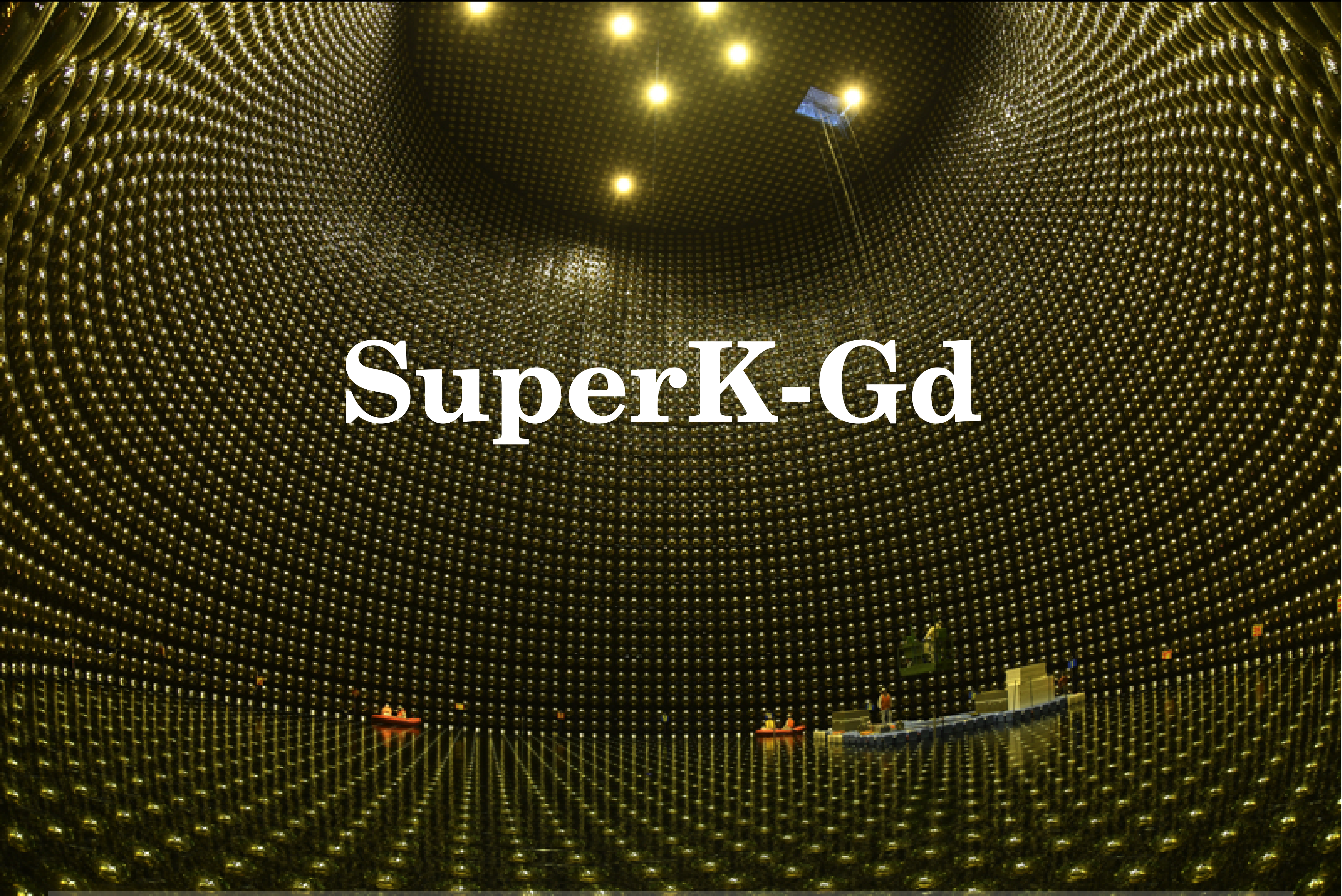


SuperK-Gd

Lluís Martí-Magro, ICRR

AAP2018 October 10th, 2018. Livermore, CA, USA.

Super-Kamiokande Detector in big numbers

Large variety of studies are conducted at SuperK:

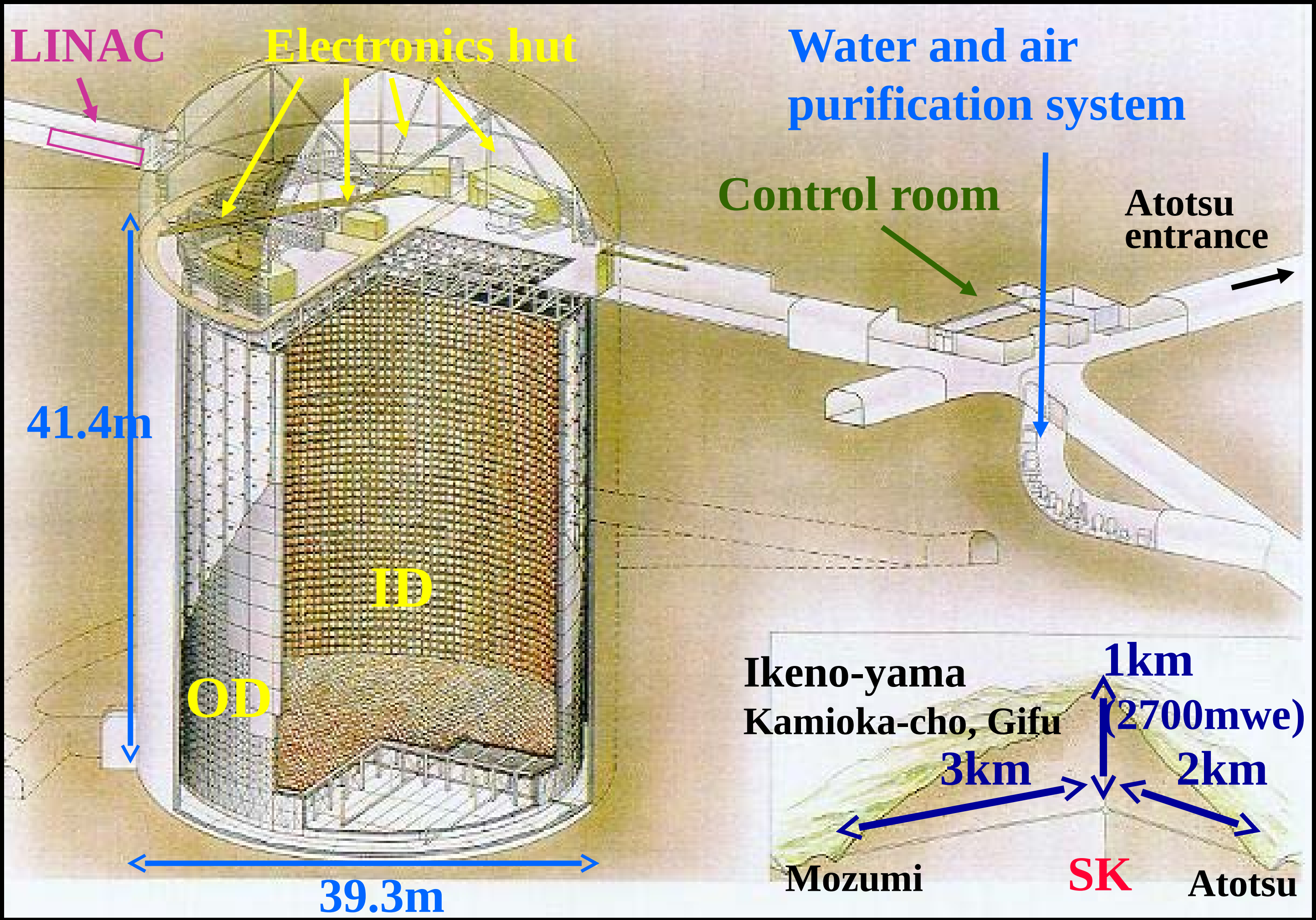
Solar neutrinos
Atmospheric neutrinos
Proton decay
Supernovae
Supernova Relic Neutrinos
Indirect search for DM
and more

10 countries
~45 institutions
~180 collaborators

Super-Kamiokande looks into the future:

SuperK-Gd

Super-Kamiokande Detector



- **50 kton water**
- **~2 m OD viewed by 8-inch PMTs**
- **32 kt ID viewed by 20-inch PMTs**
- **22.5 kt fid. vol. (2m from wall)**
- **Trigger efficiency: >99%@3.5 MeV E_{kin}**

Refurbishment work on-going !

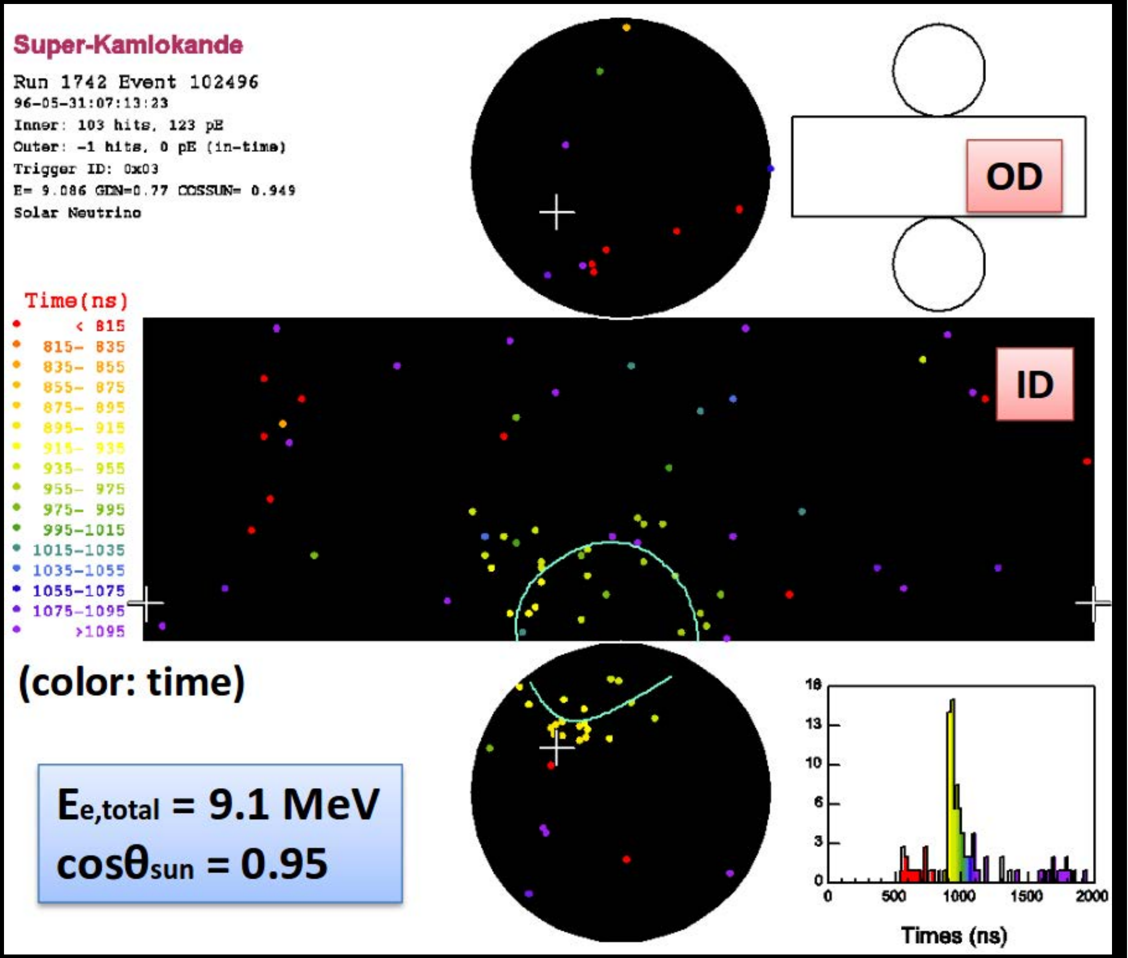
96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18

SK-I SK-II SK-III SK-IV

	Phase	**SK-I**	**SK-II**	**SK-III**	**SK-IV**
	Start -end	1996 Apr - 2001 Jul	2002 Oct - 2005 Oct	2006 Jul - 2008 Sep	2008 Sep - 2018 Mar
	Solar neutrino analysis live-time	1496 days	791 days	548 days	2860 days
	Kinetic energy threshold	1996 Apr - 2001 Jul	2002 Oct - 2005 Oct	2006 Jul - 2008 Sep	2008 Sep - 2018 Mar
Number of PMTs	ID (coverage)	11146 **(40 %)**	5182 **(19 %)**	11129 **(40 %)**	11129 **(40 %)**
	OD	**1885**			

Low energy event reconstruction

Solar neutrino: $\nu + e^- \rightarrow \nu + e^-$



Reconstruction:

- **Interaction vertex:**
  ⇨ Timing information

- **Electron direction:**
  ⇨ Cherenkov Ring pattern

- **Electron energy:**
  ⇨ Number of hit PMTs, N_{eff} , (~6 hit/MeV @ SK-I, III and IV)

Resolution (10 MeV electron case):

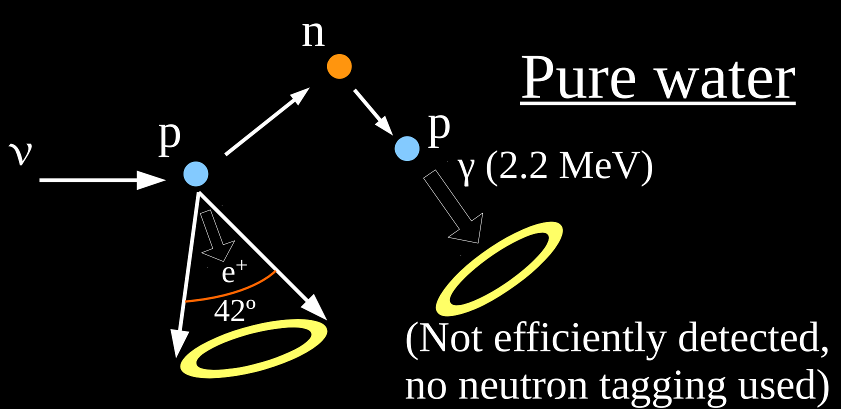
→ Energy 14% Vertex: 87 cm Direction: 26° ⟸ SK-I

→ Energy 14% Vertex: 55 cm Direction: 23° ⟸ Software improvement for SK-III & SK-IV

Next phase: SuperK-Gd

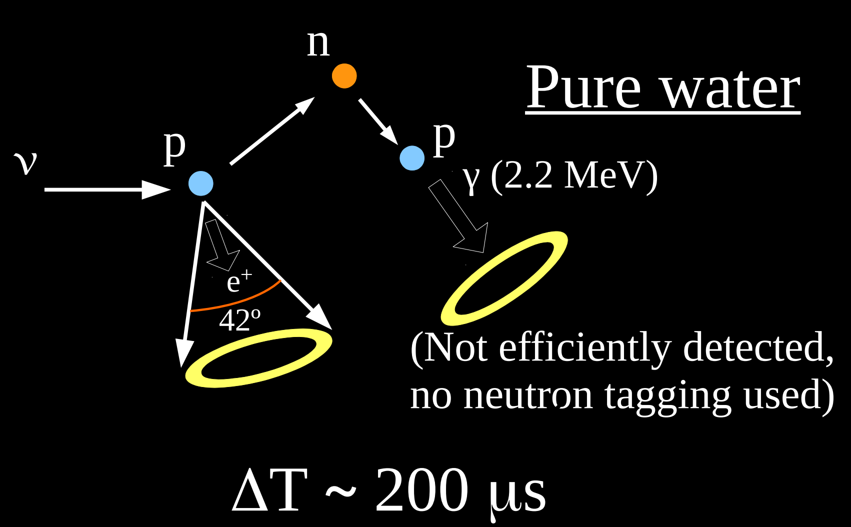
Enhancing the neutron tagging efficiency of SuperK

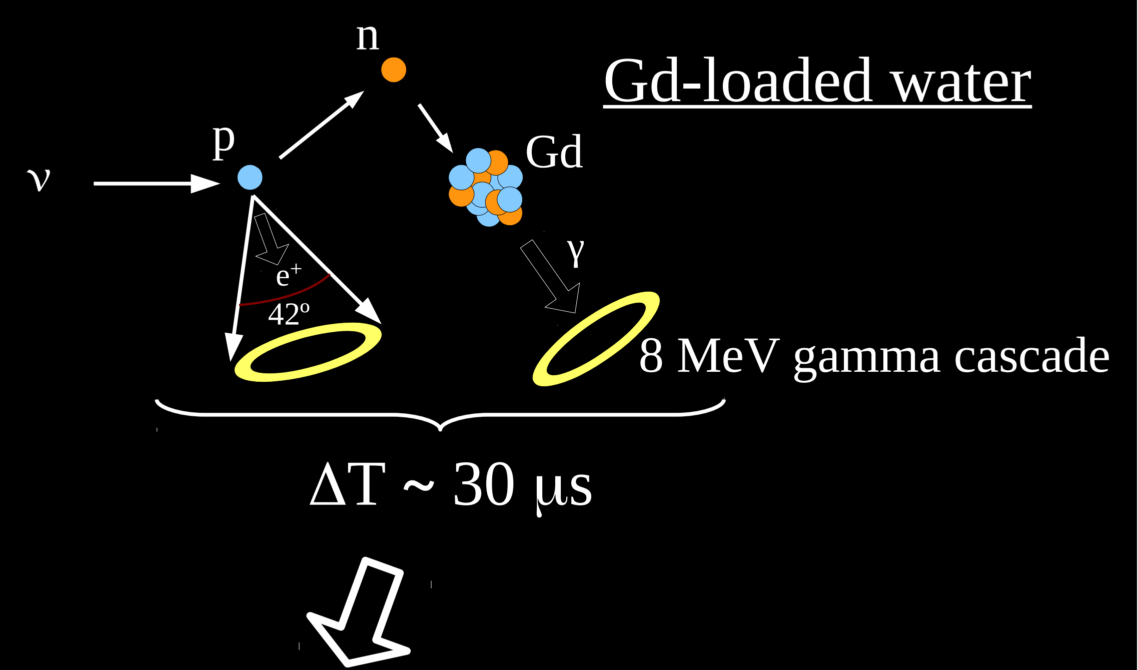
Neutron tagging with pure water



ΔT ~ 200 μs

Neutron tagging with Gd loaded water





With **tight time (delayed) and position coincidence** **between** **positron and neutron capture** (90% neutron capture on Gd with 0.2% $Gd_2(SO_4)_3$ concentration) we will be able to tag neutrons with high efficiency

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

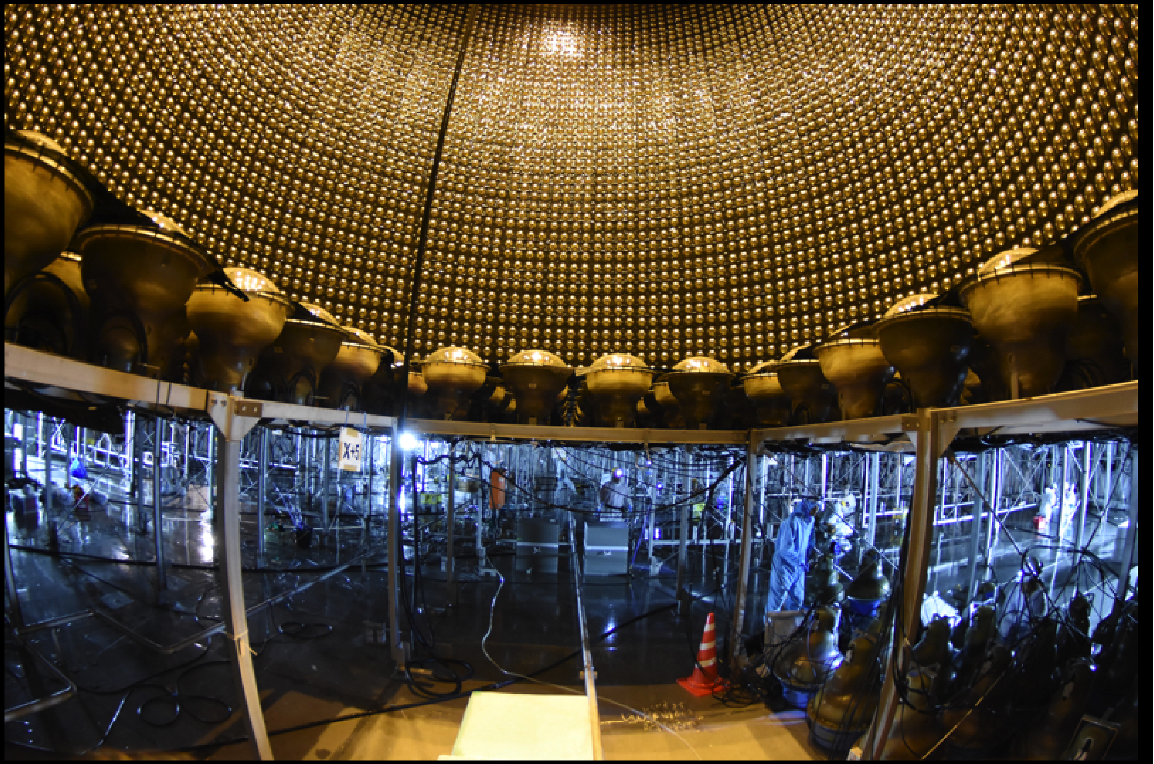
SuperK-Gd: Why? How? When?

Why? - Physics targets

- Supernovae:
  - Supernova relic neutrinos: SN neutrinos from all the past SNe in the universe
  - Improve pointing accuracy
  - Early warning for nearby SN
  - Late black hole formation
- Reduce background in proton decay
- Enhance $\boldsymbol{\nu}$ anti-$\boldsymbol{\nu}$ in atm and T2K analyses

How? - SuperK refurbishment

- Fix water leak
- Replace ID and OD dead PMTs
- Improve water flow in SuperK
- Improve HV



When?

- June-Dec. 2018 refurbishment
- Jan. 2019: pure water
- 20XX (T1): 0.02% Gd sulfate
- 20XX (T2): 0.2% Gd sulfate

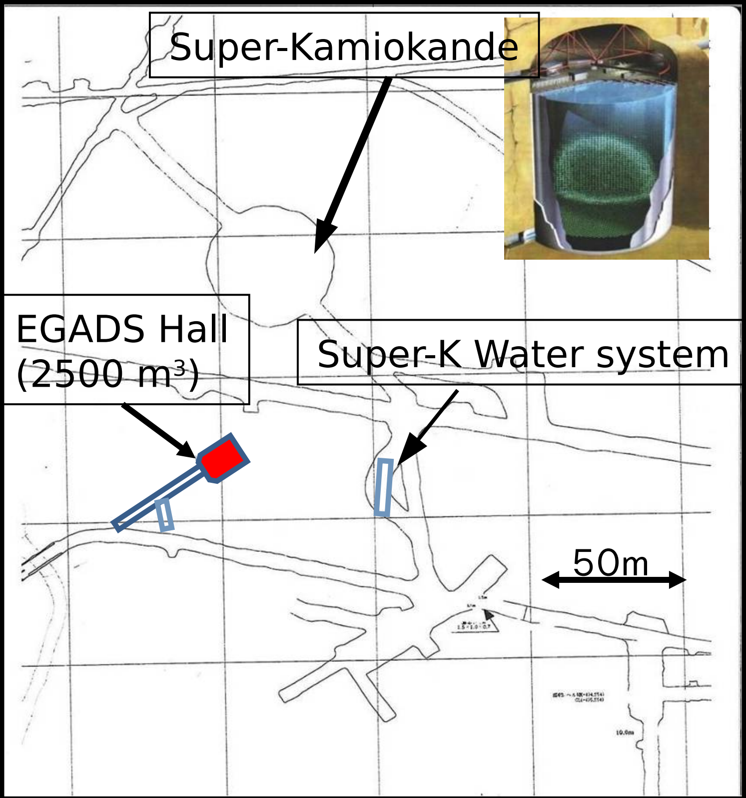
The road to SuperK-Gd: EGADS

Because of all the exciting possibilities, in June 2009 the SuperK collaboration launched the EGADS project

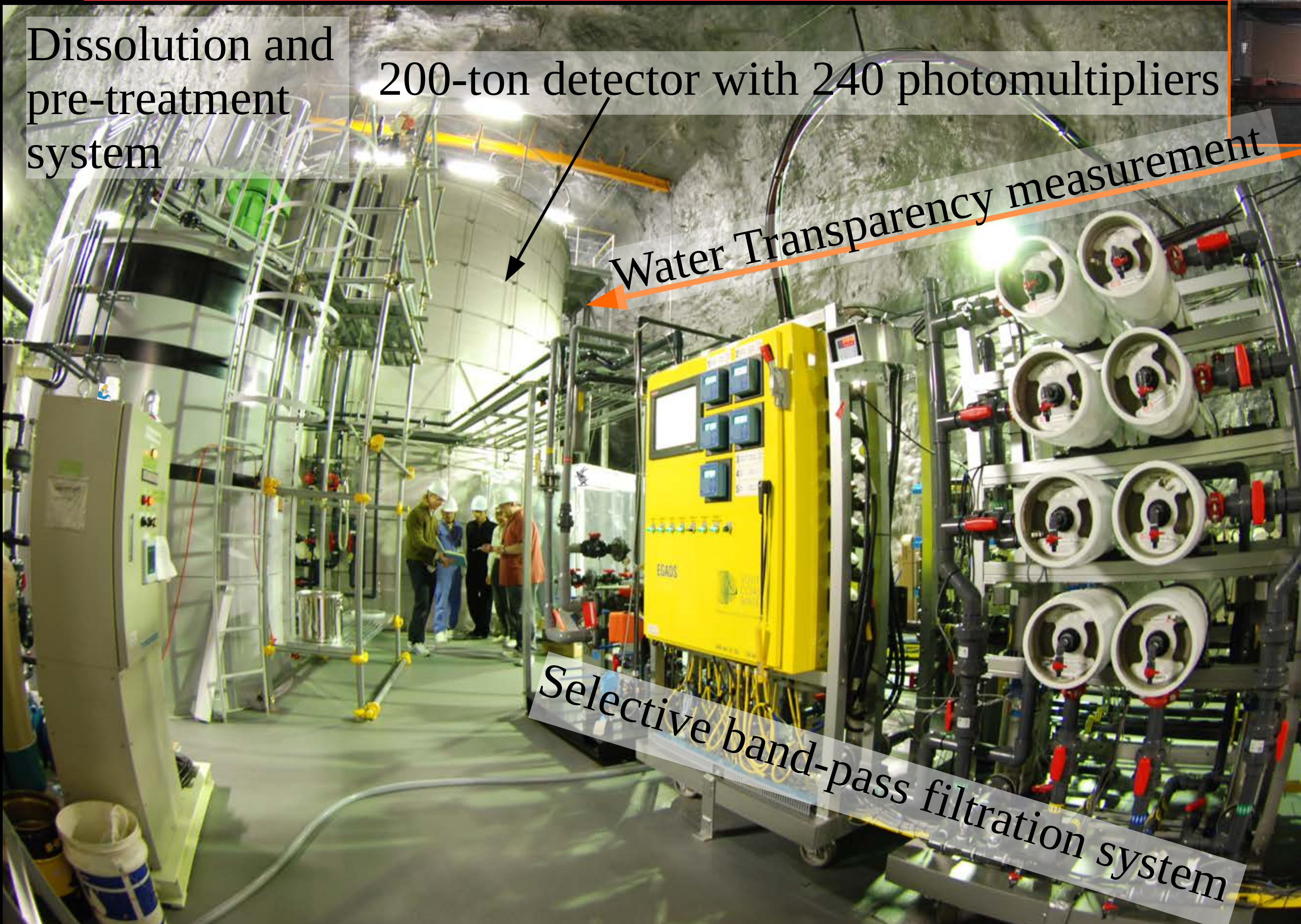
Evaluating **G**adolinium's **A**ction on **D**etector **S**ystems

Our Goals:

- ✔ Water purification system
- ✔ Monitor the water transparency
- ✔ Effects on detector components
- ✔ Adding/removing Gd
- ✔ Neutron background

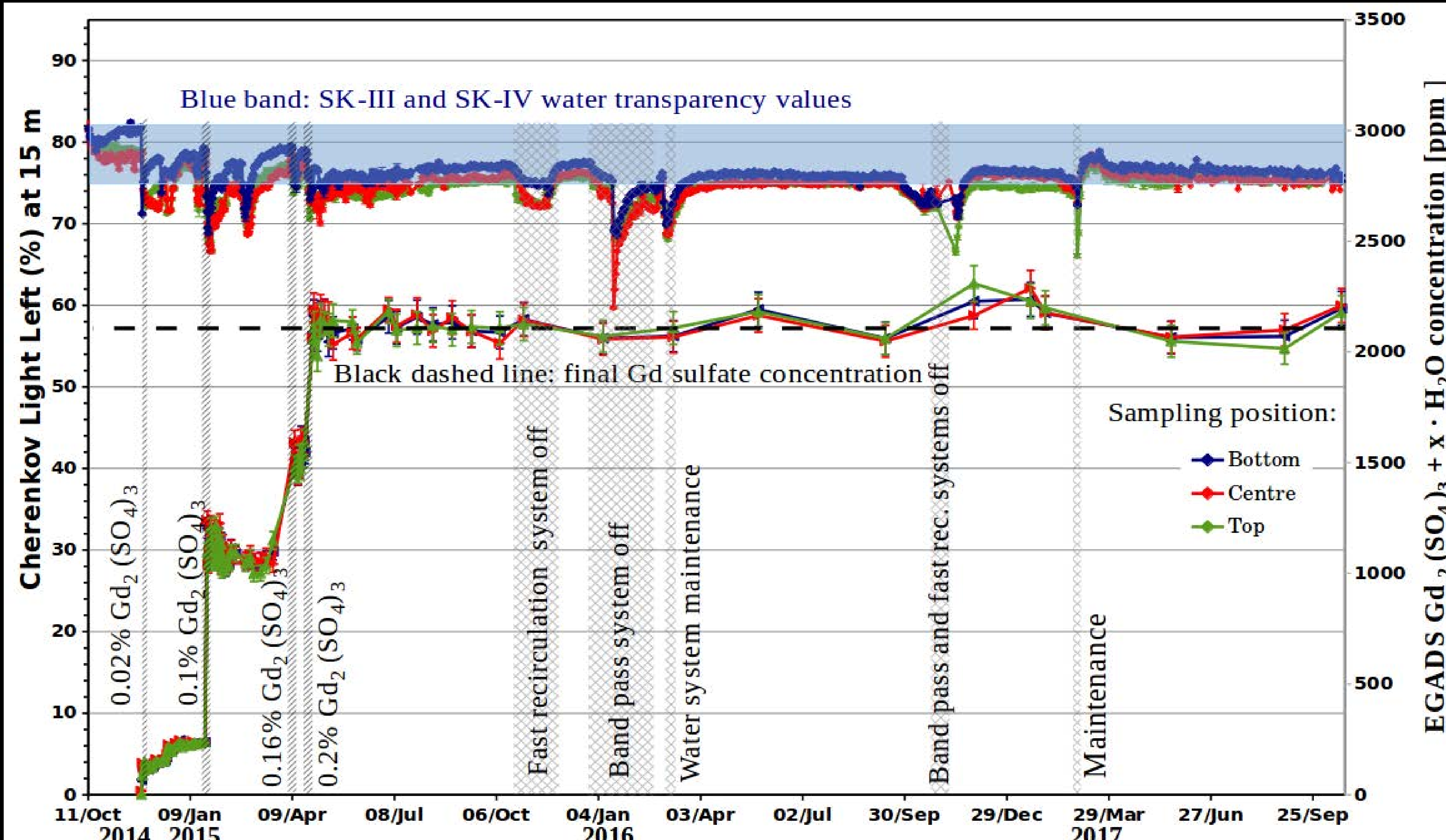


The road to SuperK-Gd: EGADS



The EGADS detector was build using the same materials as in SuperK

EGADS' main result

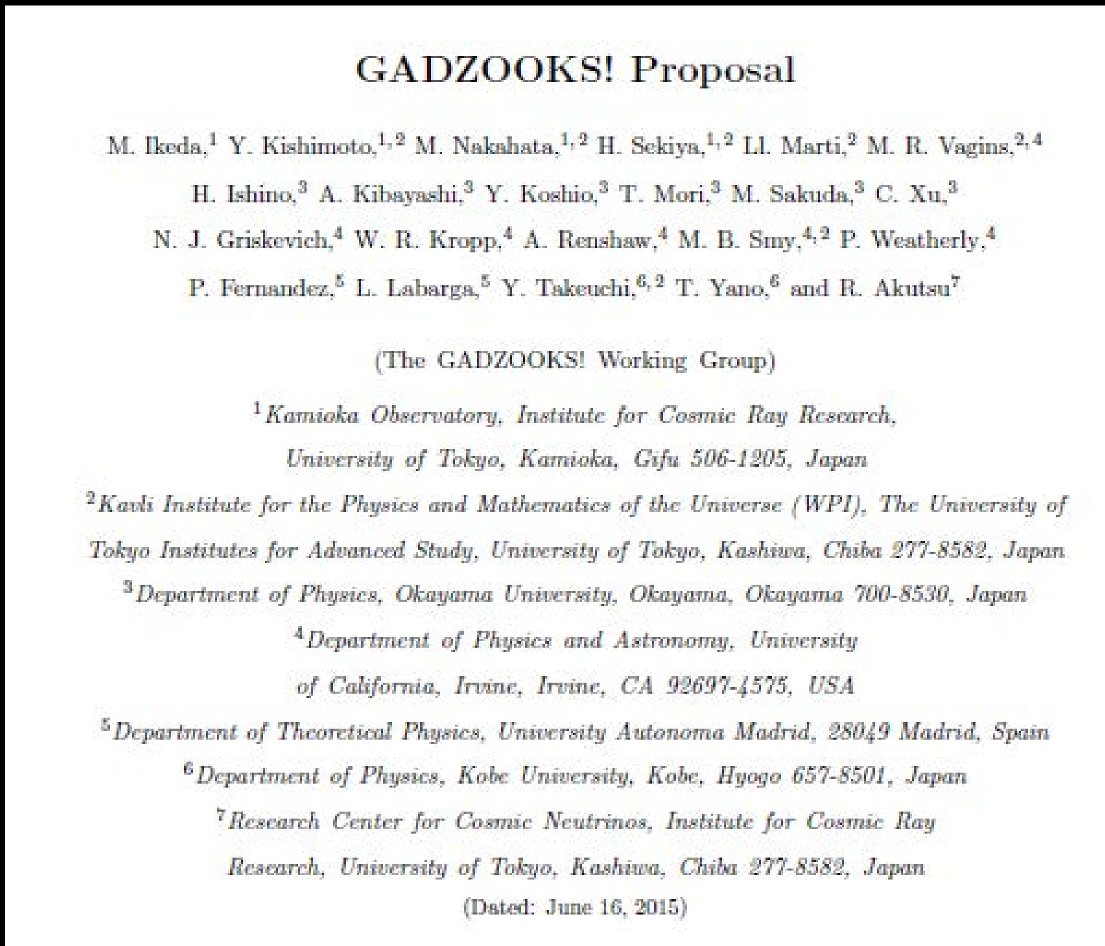


0.2 % Gd sulfate is as transparent to Cherenkov light as pure-water

Our water system achieves the above with no Gd losses

Gd concentration is homogeneous in our detector

The road to SuperK-Gd



GADZOOKS! Proposal

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N. J. Griskevich,[4] W. R. Kropp,[4] A. Renshaw,[4] M. B. Smy,[4,2] P. Weatherly,[4]
P. Fernandez,[5] L. Labarga,[5] Y. Takeuchi,[6,2] T. Yano,[6] and R. Akutsu[7]

(The GADZOOKS! Working Group)

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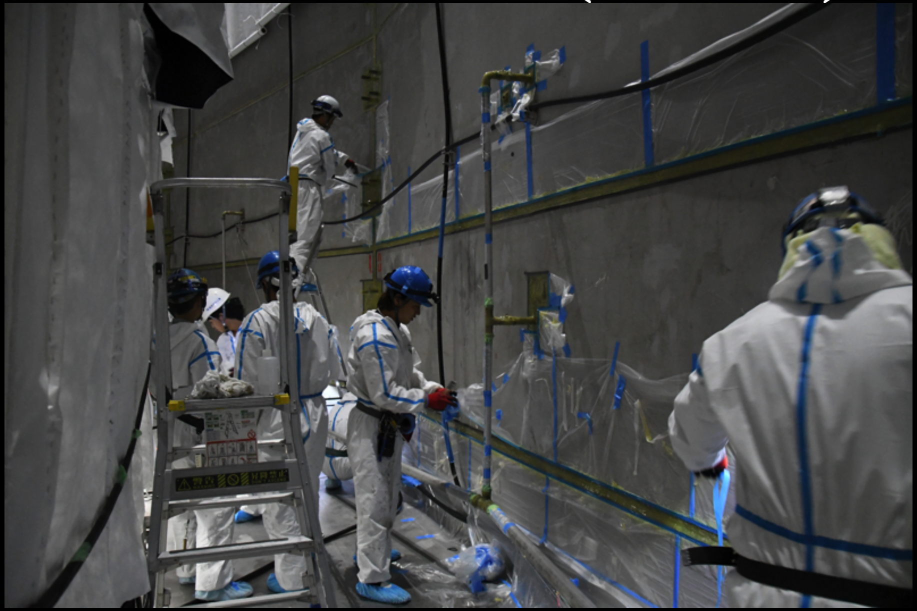
(Dated: June 16, 2015)

On June 27, 2015, the Super-Kamiokande collaboration approved the SuperK-Gd project

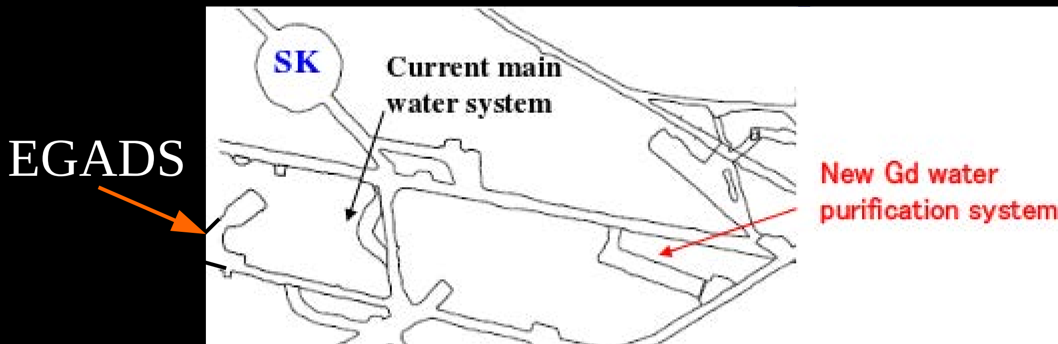
Leak fix

Two types of sealant materials: BIO-SEAL 197 (strong but rigid) and MineGuard-C (flexible)



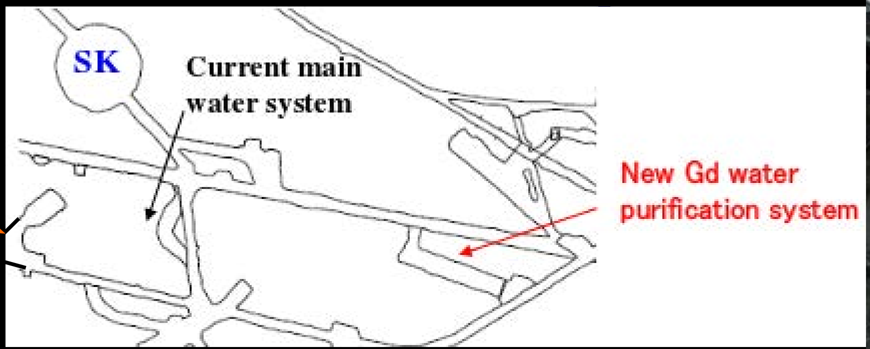
Seal all submerged welded areas

New Water System for SuperK-Gd



New Water System for SuperK-Gd

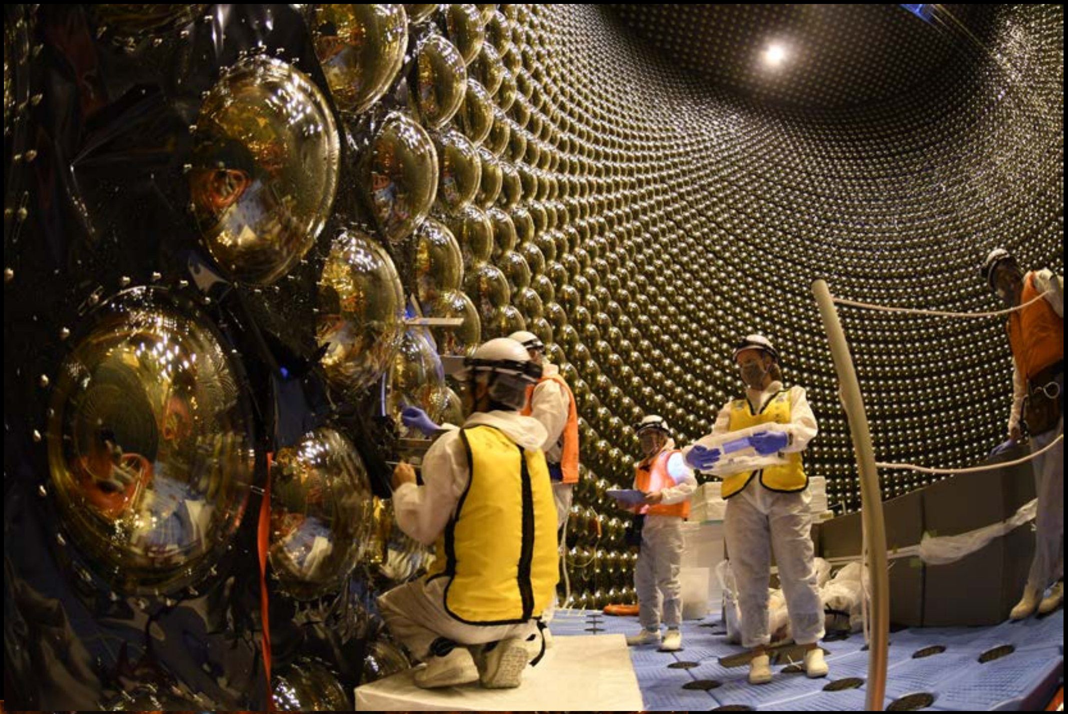
EGADS



Cavern for the new water system has been excavated

Equipment has been already installed (Gd solution, etc)

ID PMT replacement



About 140 ID PMTs have been replaced

Cables and connections of problematic PMTS were checked

OD work

- About 200 OD PMTs have been replaced (about 100 on the top)

- Tyvek replacement: B-W and W-W Tyvek

Summary

SuperK-Gd: Adding Gd sulfate at 0.2% in mass will add neutron tagging capabilities to Super-Kamiokande

EGADS has shown its feasibility: we can remove impurities and maintain high transparency water, with basically no Gd losses, we can remove Gd efficiently when needed, etc

Faulty OD and ID PMTs are being replaced

Detector structure being refurbished:

We are fixing the leak at SuperK using two sealants: BIO-SEAL 197 and MineGuard-C

Summary

SuperK-Gd: Adding Gd sulfate at 0.2% in mass will add neutron tagging capabilities to Super-Kamiokande

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Detector structure being refurbished:

We are fixing the leak at SuperK using two sealants: BIO-SEAL 197 and MineGuard-C

Thank you for your attention!!

Backgrounds

Relevant radioactive contamination, typical impurities in untreated Gd sulfate and our requirements from our physics goals:

Chain	Part of the chain	Typical (mBq/Kg)	SRN (mBq/Kg)	Solar (mBq/Kg)
^{238}U	^{238}U	50	< 5	-
	^{226}Ra	5	-	< 0.5
^{232}Th	^{232}Th	10	-	< 0.05
	^{228}Th	100	-	< 0.05
^{235}U	^{235}U	32	-	< 3
	$^{227}Ac/^{227}Th$	300	-	< 3

Backgrounds

Relevant radioactive contamination, typical impurities in untreated Gd sulfate and our requirements from our physics goals:

Chain	Part of the chain	Typical (mBq/Kg)	SRN (mBq/Kg)	Solar (mBq/Kg)	Company A	Company B	Company C
^{238}U	^{238}U	50	< 5	-	< 0.04	< 0.04	< 0.04
	^{226}Ra	5	-	< 0.5	< 0.2	< 0.2	~ 1
^{232}Th	^{232}Th	10	-	< 0.05	0.02	0.06	0.09
	^{228}Th	100	-	< 0.05	< 0.3	< 0.26	~ 2
^{235}U	^{235}U	32	-	< 3	< 0.4	< 0.3	< 1.3
	$^{227}Ac/^{227}Th$	300	-	< 3	< 1.5	< 1.2	< 3.1

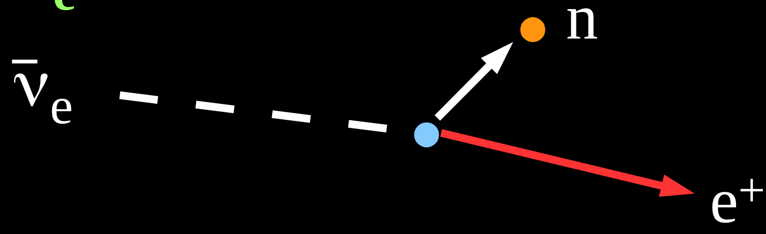
We plan to use resins AJ4400 and AJ1020 to further remove U and Ra after dissolving Gd sulfate

Measurements done at Canfranc, Boulby and Kamioka
Company names hidden

Atmospheric ν backgrounds

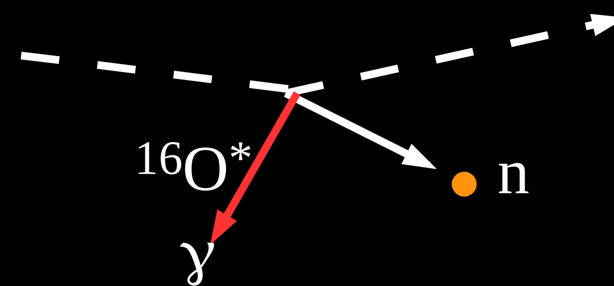
- **Charge Current:**

$\bar{\nu}_e$ CC

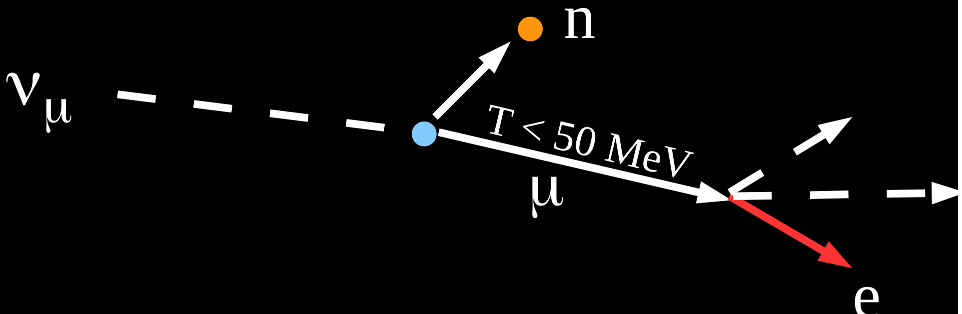


- **Neutral Current:**

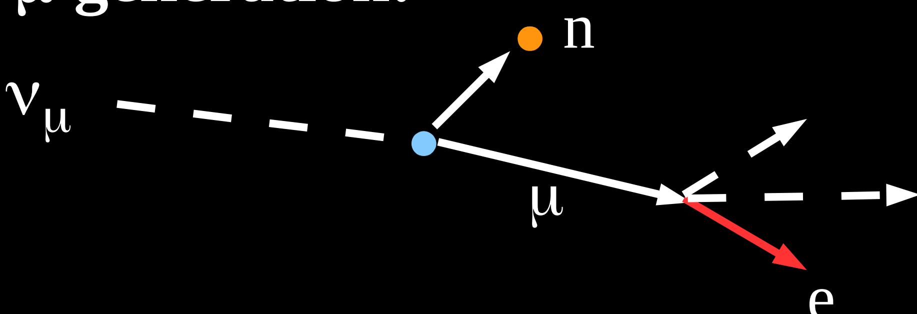
NC elastic

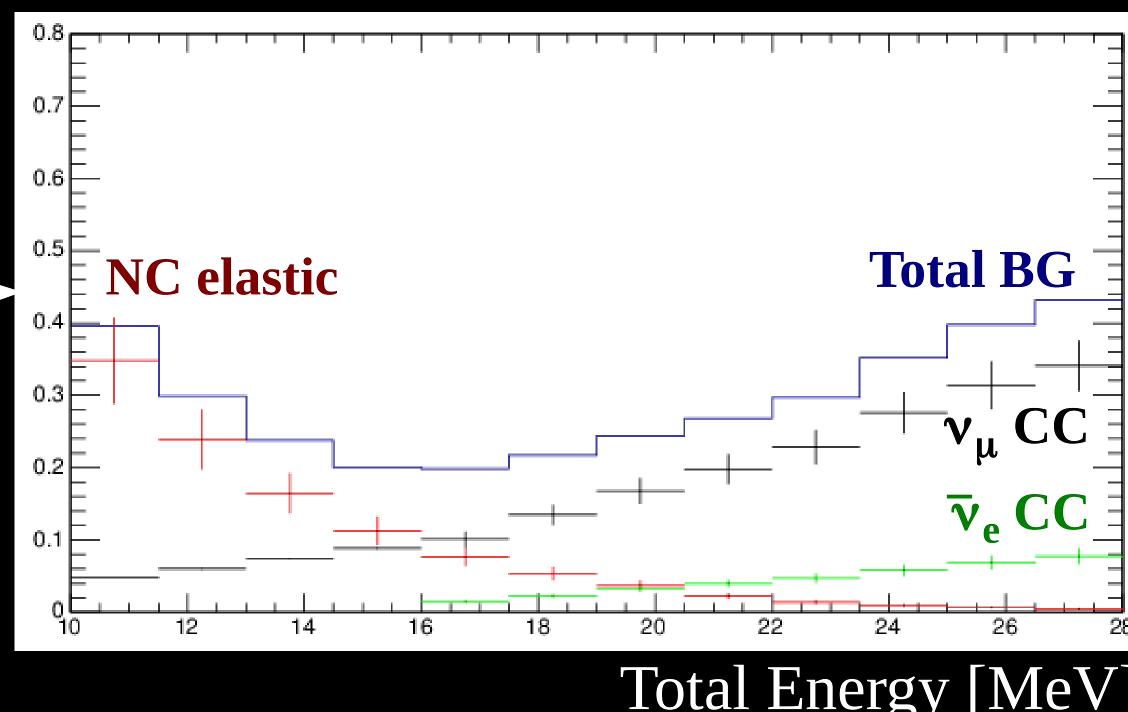


Invisible μ:



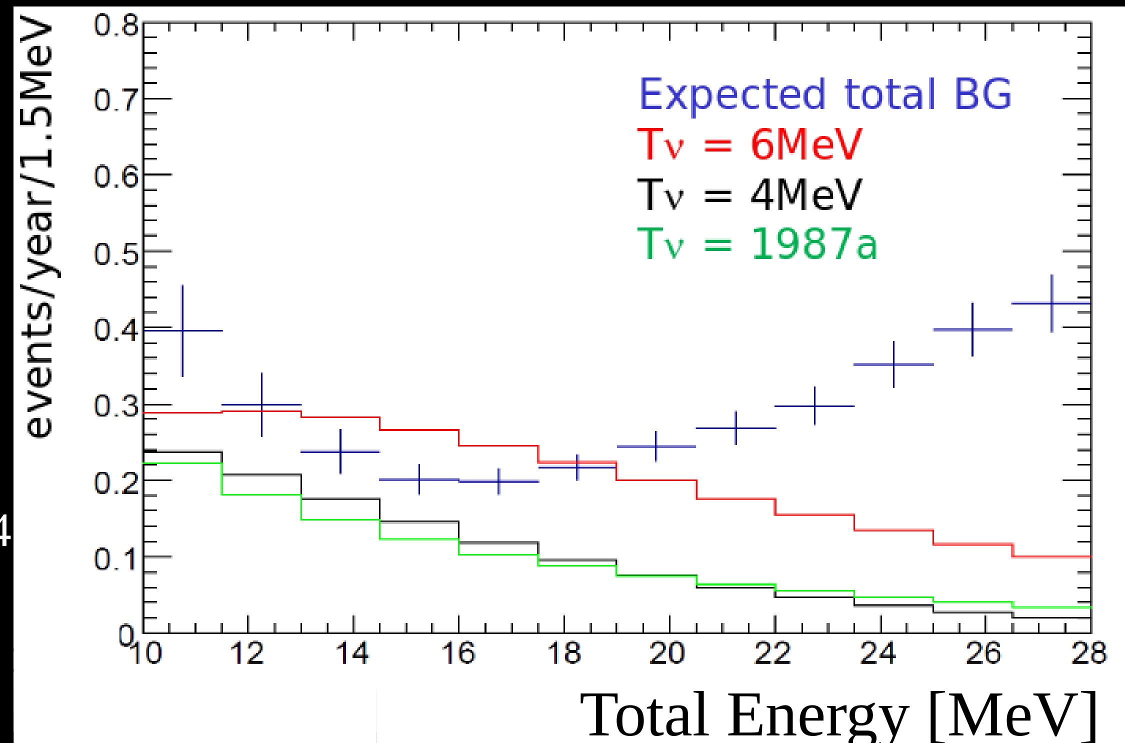
μ generation:





Background vs expected signal

SRN flux:
Horiuchi, Beacom, Dwek
PRD, 79, 083013 (2009)



The detection of SRN depends on the typical SN emission spectrum

$T_\nu \sim 5\,(M_{NS}/1.4M_\odot)^{1/3}\,(R_{NS}/10km)^{-3/4}$

SRN number of expected events after 10 years of observation

HBD models	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	----

With SuperK-Gd the first SRN observation is within our reach!!

The road to SuperK-Gd: how it started

Once upon a time…

VOLUME 93, NUMBER 17 PHYSICAL REVIEW LETTERS week ending 22 OCTOBER 2004

Antineutrino Spectroscopy with Large Water Čerenkov Detectors

John F. Beacom[1] and Mark R. Vagins[2]

[1]*NASA/Fermilab Astrophysics Center, Fermi National Accelerator Laboratory, Batavia, Illinois 60510-0500, USA*
[2]*Department of Physics and Astronomy, 4129 Reines Hall, University of California, Irvine, California 92697, USA*

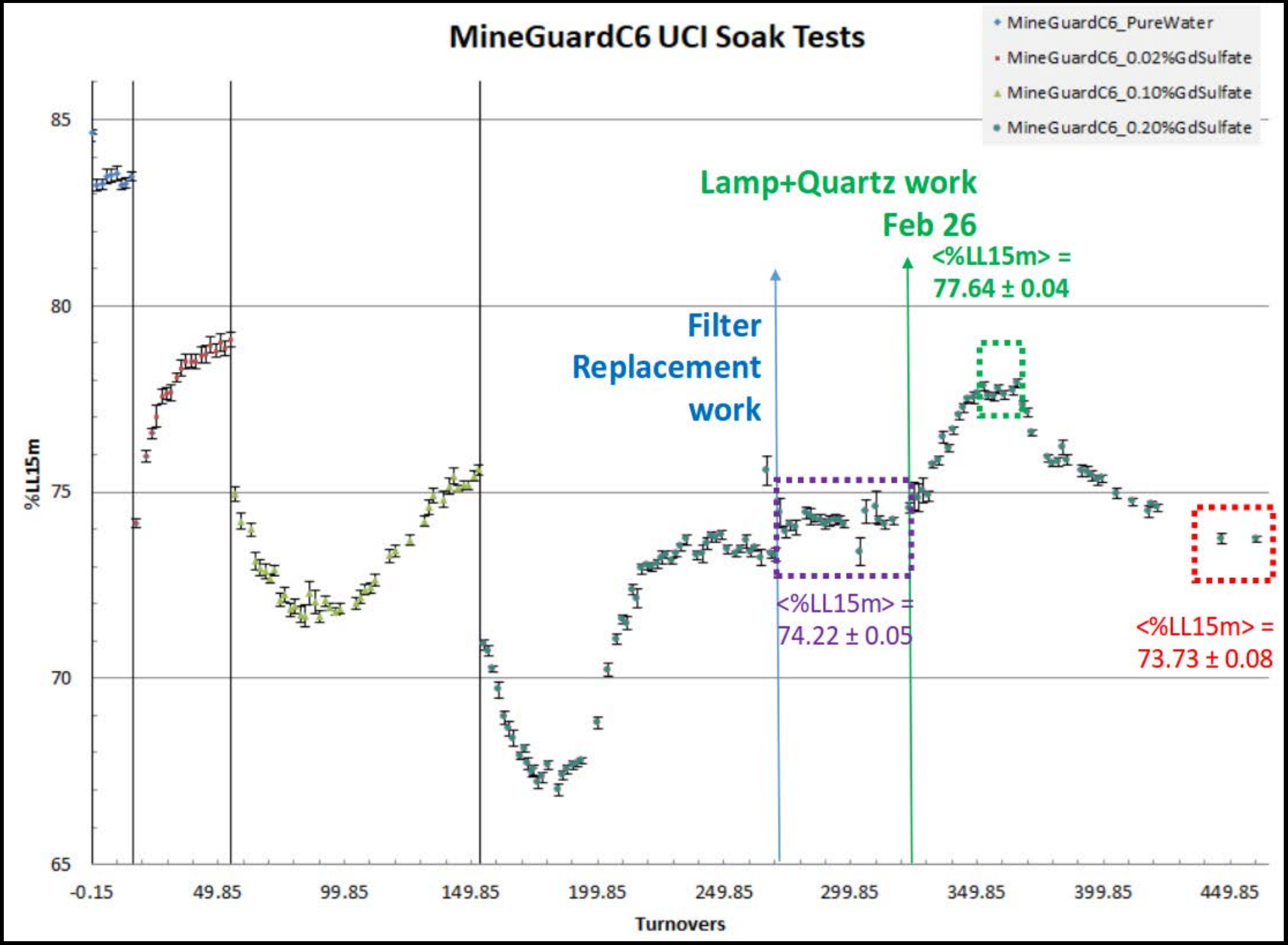
(Received 25 September 2003; published 20 October 2004)

We propose modifying large water Čerenkov detectors by the addition of 0.2% gadolinium trichloride, which is highly soluble, newly inexpensive, and transparent in solution. Since Gd has an enormous cross section for radiative neutron capture, with $\sum E_\gamma = 8$ MeV, this would make neutrons visible for the first time in such detectors, allowing antineutrino tagging by the coincidence detection reaction $\bar{\nu}_e + p \to e^+ + n$ (similarly for $\bar{\nu}_\mu$). Taking Super-Kamiokande as a working example, dramatic consequences for reactor neutrino measurements, first observation of the diffuse supernova neutrino background, galactic supernova detection, and other topics are discussed.

DOI: 10.1103/PhysRevLett.93.171101 PACS numbers: 95.55.Vj, 29.40.Ka

...it was proposed to add **gadolinium** to the ultra-pure water of SuperK. Adding Gd would **make neutrons visible**, which would allow the detection of neutrons with high efficiency.

Mine-guard-C soak tests

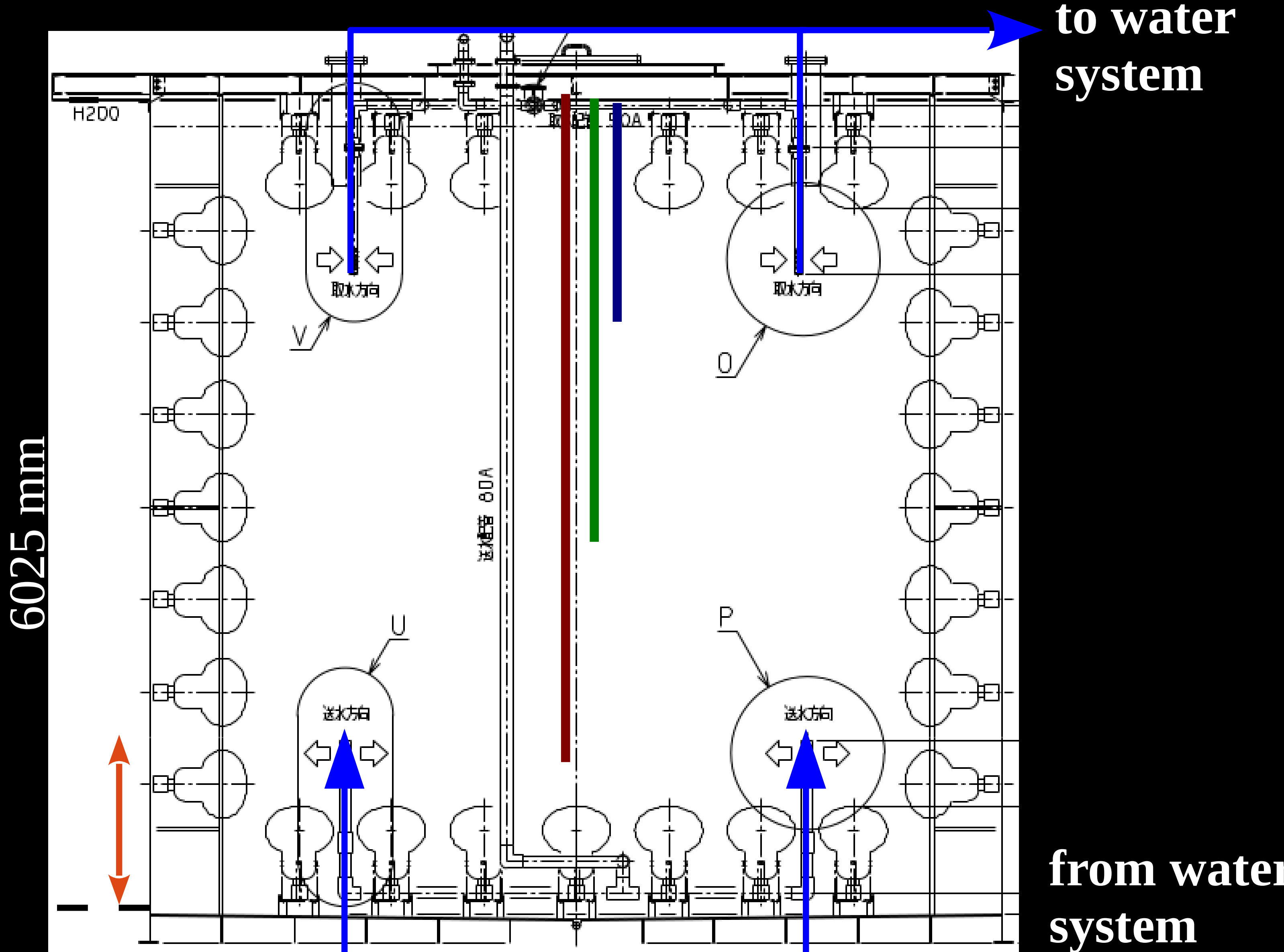


Soaked Mine-guard-C in Gd loaded water with good results: Cherenkov ilght loss in 15 m is 77.64 % (well within the typical SK-III SK-IV values)

EGADS detector

Sampling positions at 1660 mm, 3320 mm and 4990 mm from top of the tank (for water transparency, UDEAL, and Gd concentration measurements)

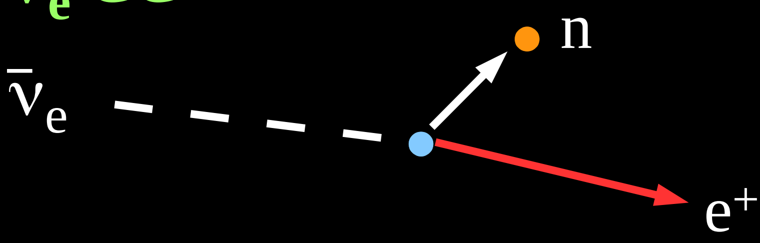
240 PMTs were installed in summer 2013



Atmospheric ν backgrounds

- **Charge Current:**

$\bar{\nu}_e$ CC



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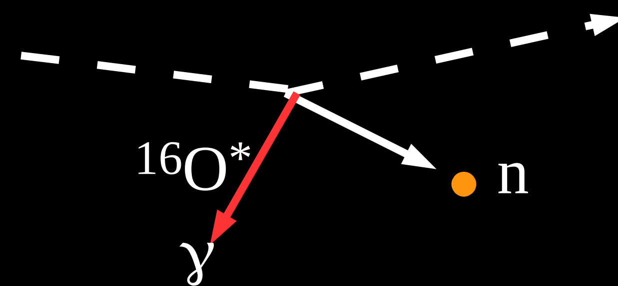

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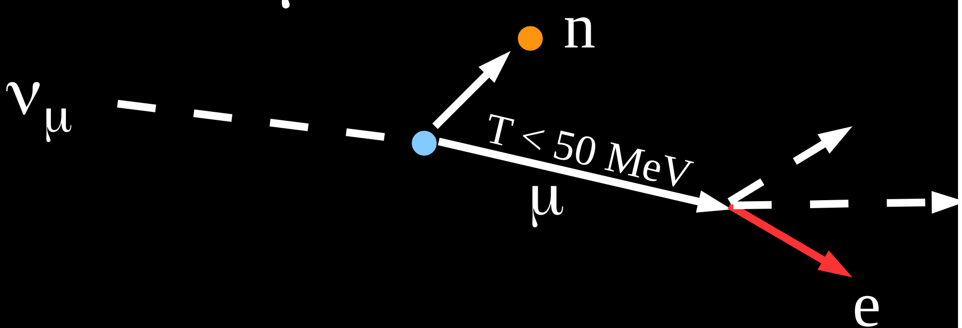

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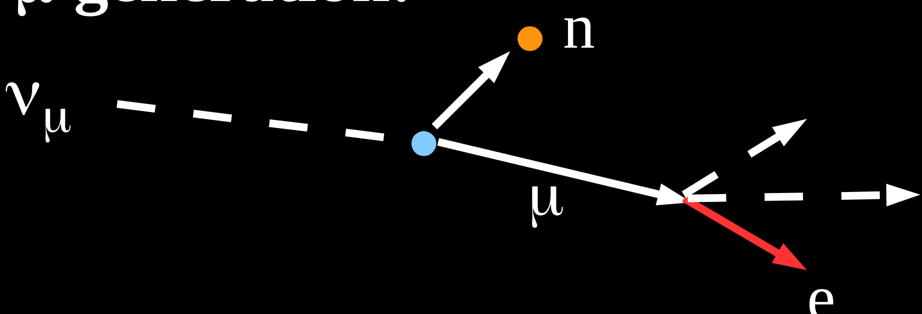

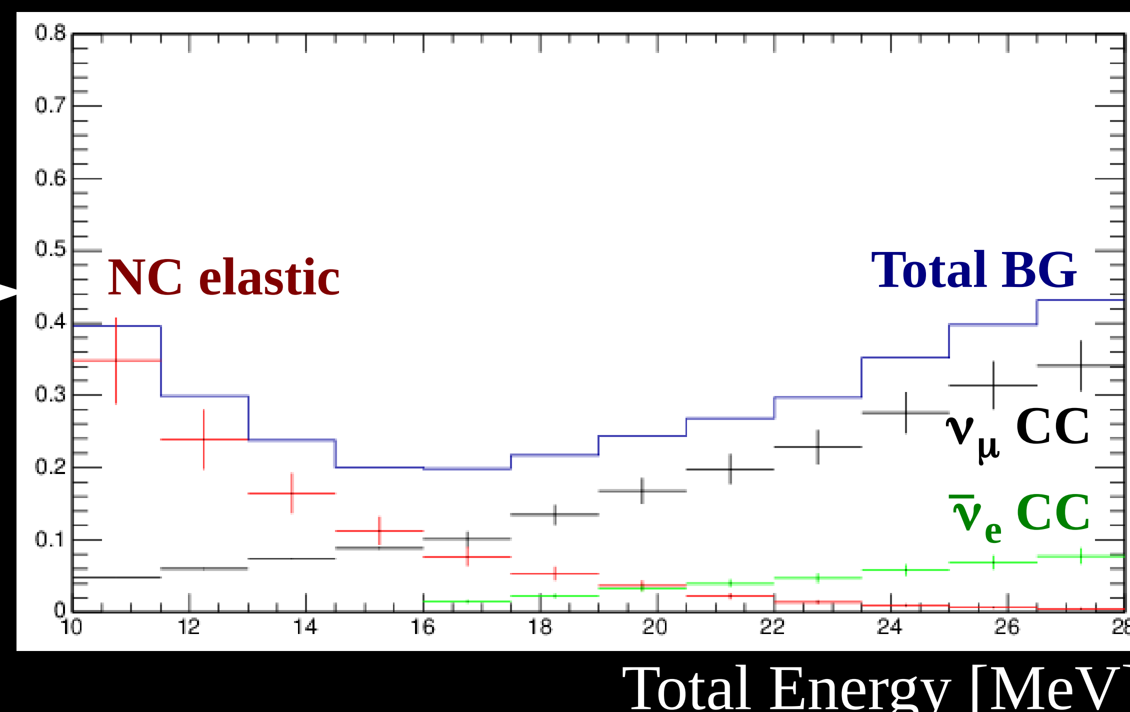

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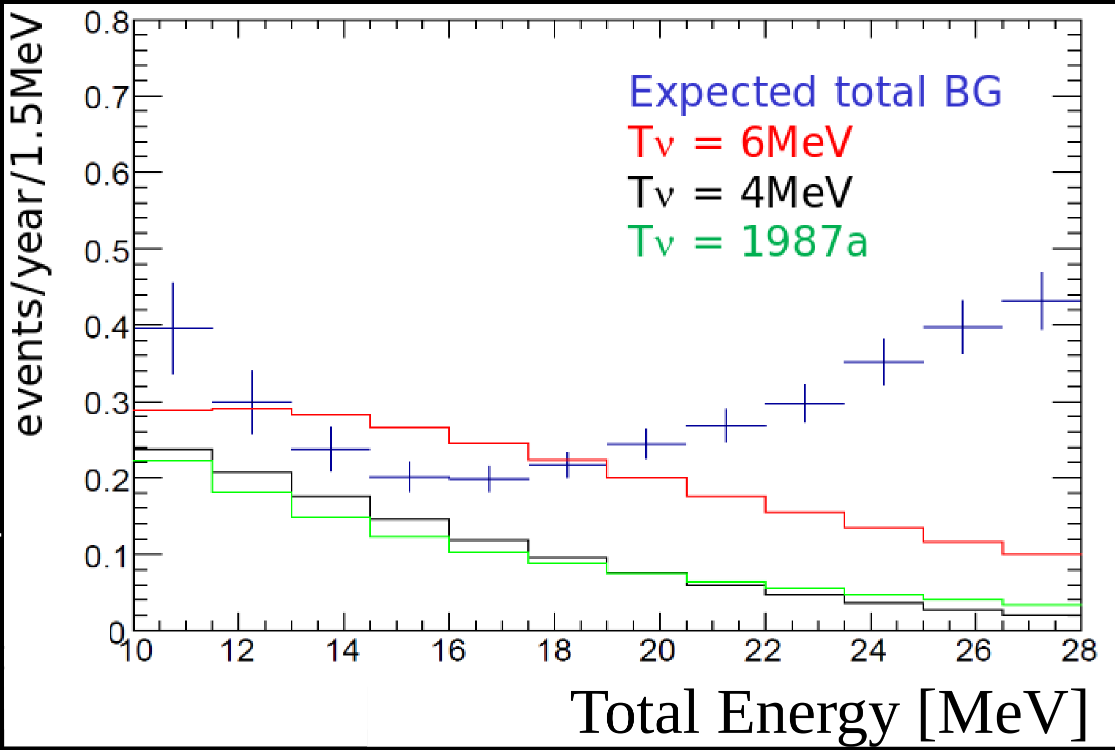

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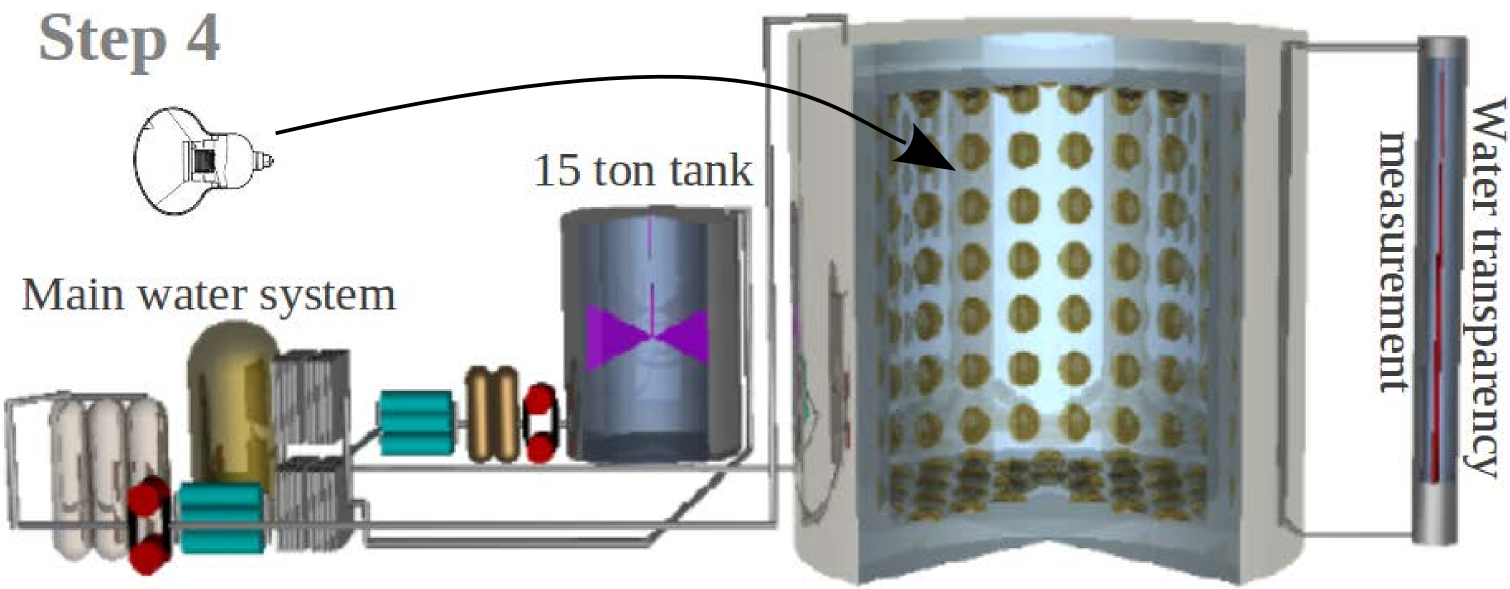
With SuperK-Gd the first SRN observation is within our reach!!

Step 4: EGADS Detector



- **Step 1:** Circulation through the 200 ton tank with pure water (first half 2011 pure water circulation) **Done!**
- **Step 2:** Circulation through the 15 ton tank with $Gd_2(SO_4)_3$ (from middle 2011 to end 2012) **Done!**
- **Step 3:** Circulation though the 200 ton tank with $Gd_2(SO_4)_3$ **Done!**
- **Step 4:** PMT mounting (240 in total). **Done!**
- **Step 5:** Full realization of the EGADS project **Done!**