status of the Japanese Super-Kamiokande ν experiment; the participation of the U.A.M.

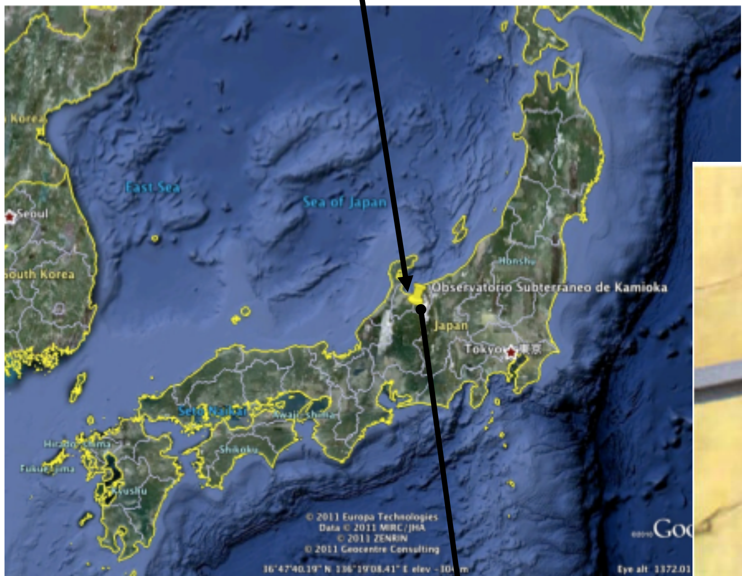
Luis Labarga, University Autónoma Madrid

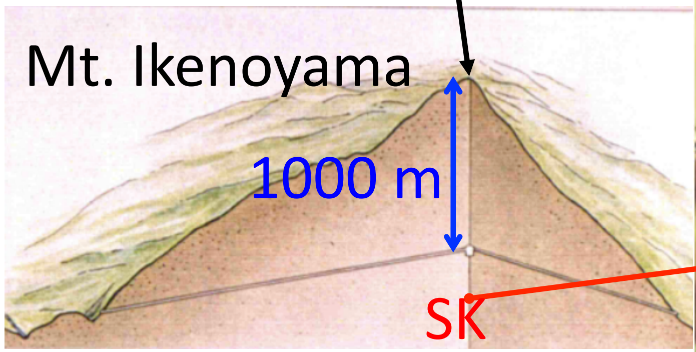
University Alcalá de Henares, December 11th 2013

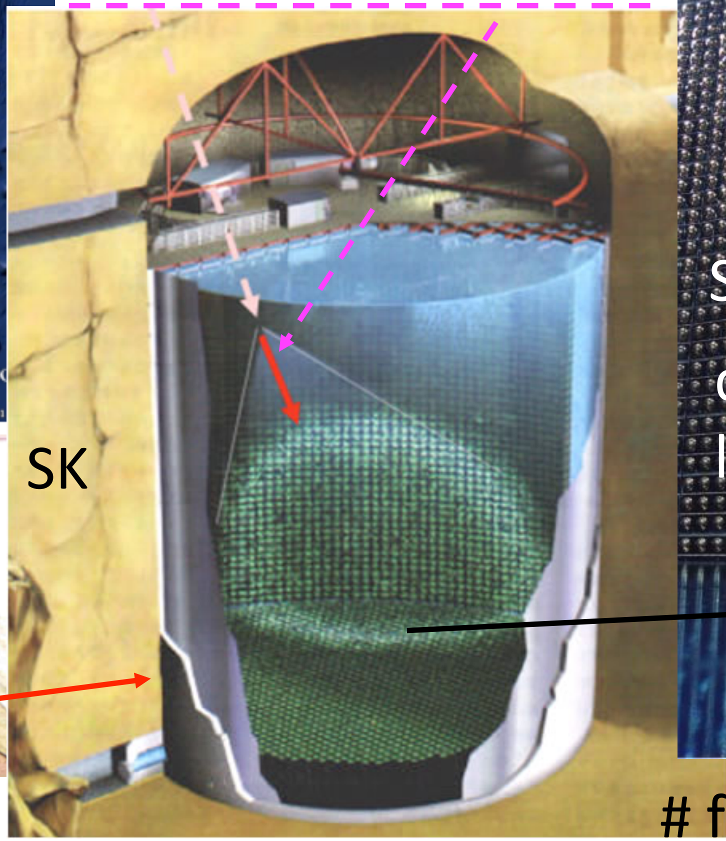
Super-Kamiokande (SK) paradigma de detector agua-Cherenkov

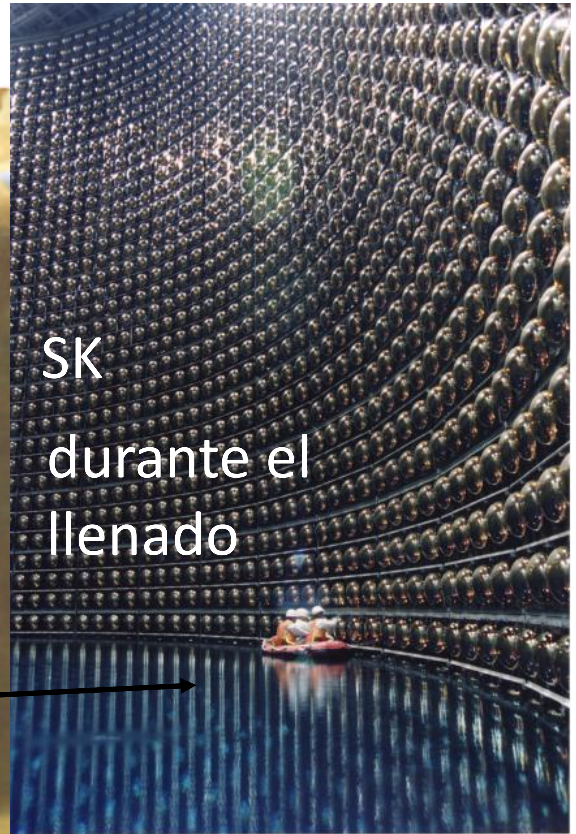
Observatorio de Kamioka
(Prefectura Gifu, Japón)

SK mide la radiación Cherenkov generada por las partículas con carga y alta energía









1000 m de tierra para apantallar muones de rayos cósmicos

$50.000\ m^3$ de agua
tanque: 40m ∅ x 40m H

fotomultiplicadores
11148 de 50 cm ∅
1885 de 20 cm ∅


viajando al laboratorio

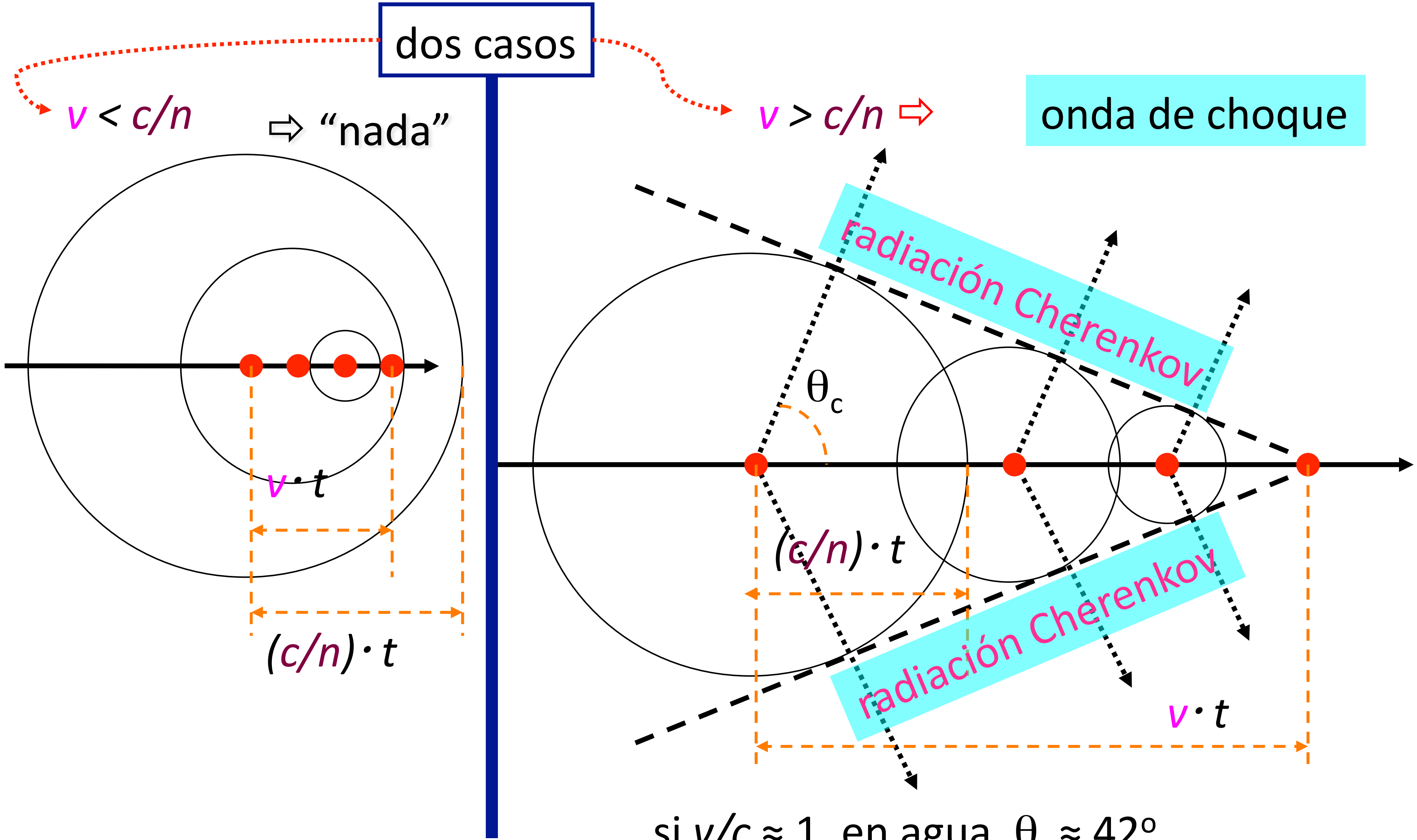

edificios de superficie:
la Residencia

de camino a la entrada del túnel


a la entrada del área
experimental

Básico de la radiación Cherenkov

una partícula cargada moviéndose en un medio con velocidad v
genera un campo EM que se propaga con velocidad c/n

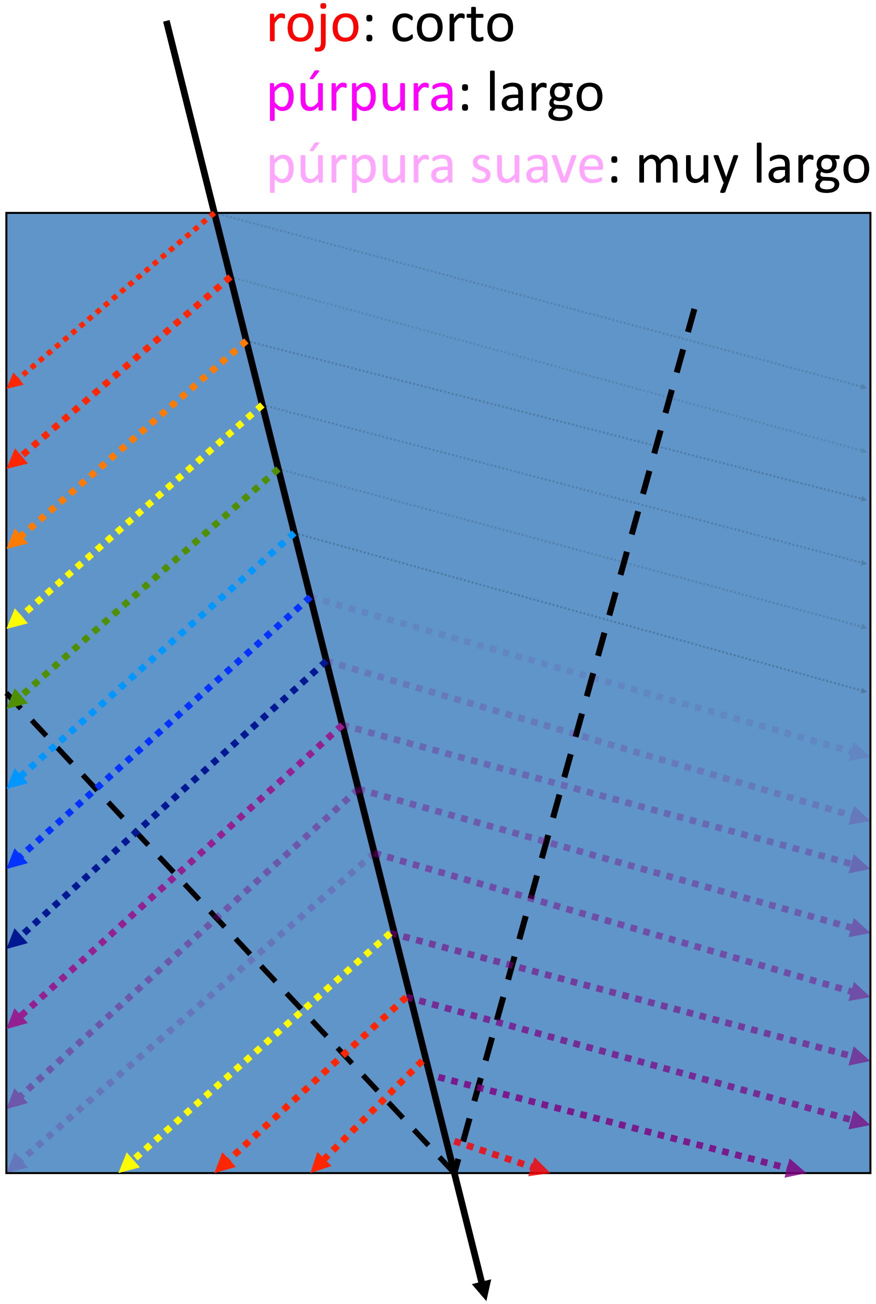


si $v/c \approx 1$, en agua, $\theta_c \approx 42^o$

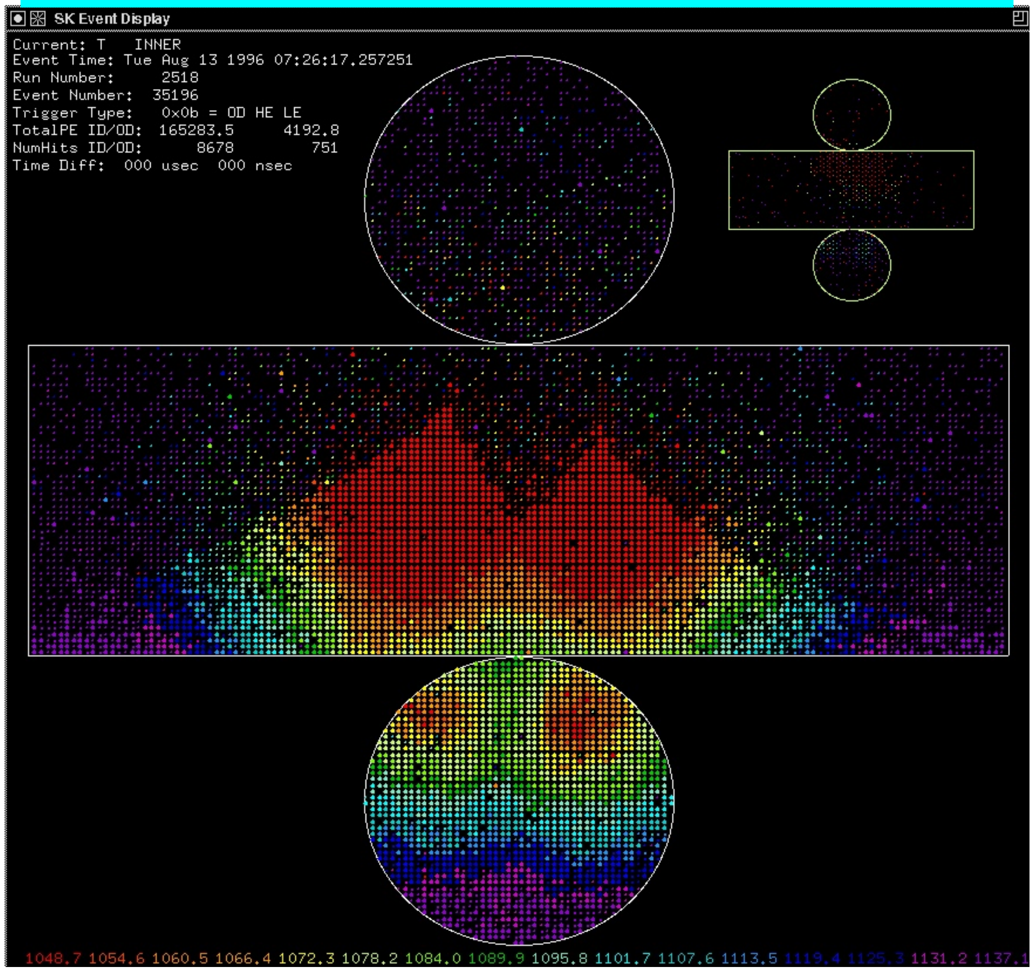
p.e.: la medida del tiempo que tarda la luz Cherenkov en llegar a los PMT’s

rojo: corto
púrpura: largo
púrpura suave: muy largo

nos permite reconstruir la trayectoria de las partículas …



suceso con 2 muones simultáneos; medida del tiempo



the origin of those detectors was the search for proton decay

- in the Standard Model the proton is absolutely stable. However
  - given the physics and mathematical structure of the SM
  - given those theoretical approaches for its evolution “realistic”
  - the current knowledge on the origin and evolution of the Universe

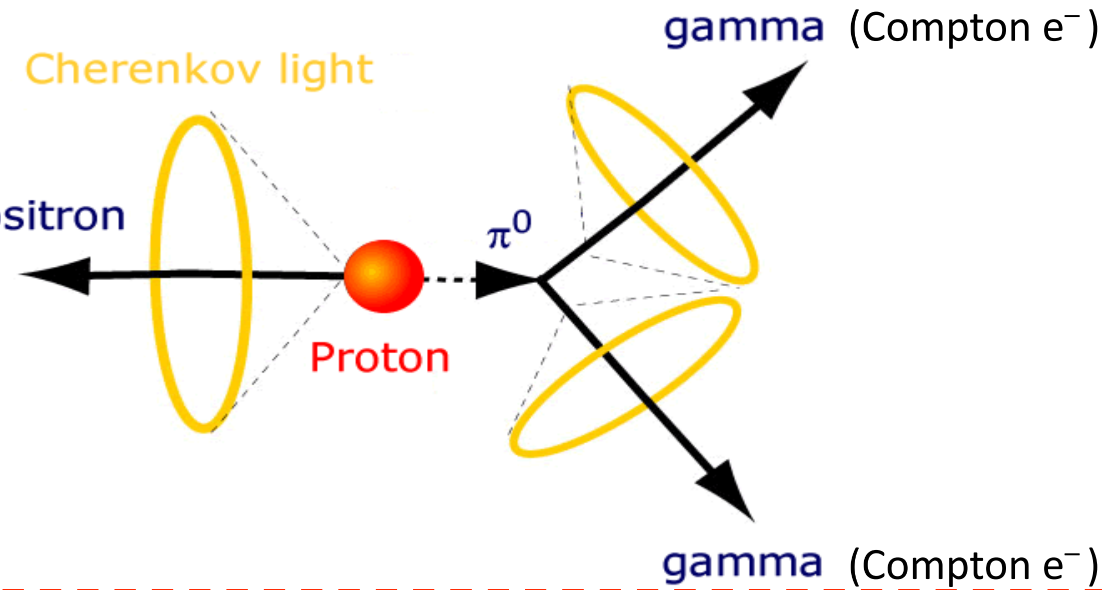
⇨ most of us believe that the proton is not stable, i.e. at some energy range quarks and leptons are basically the same type of particle

and WC detectors are the best way (known) for its search

f.i.: $p \rightarrow e^{+}\pi^{0}$

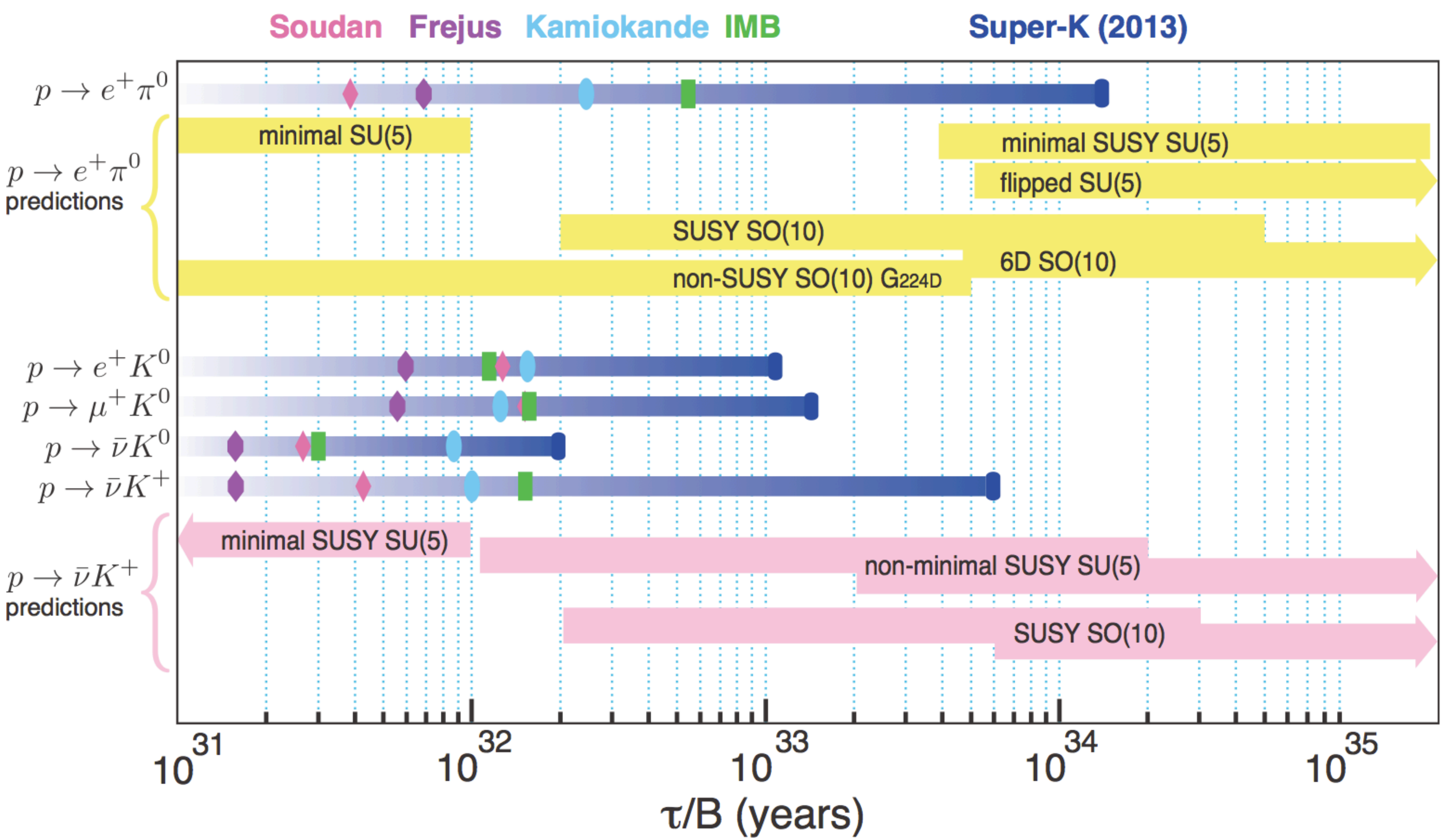
no candidate has been found so far

⇨ $\tau_p > 1.3 \times 10^{34}$ *years*



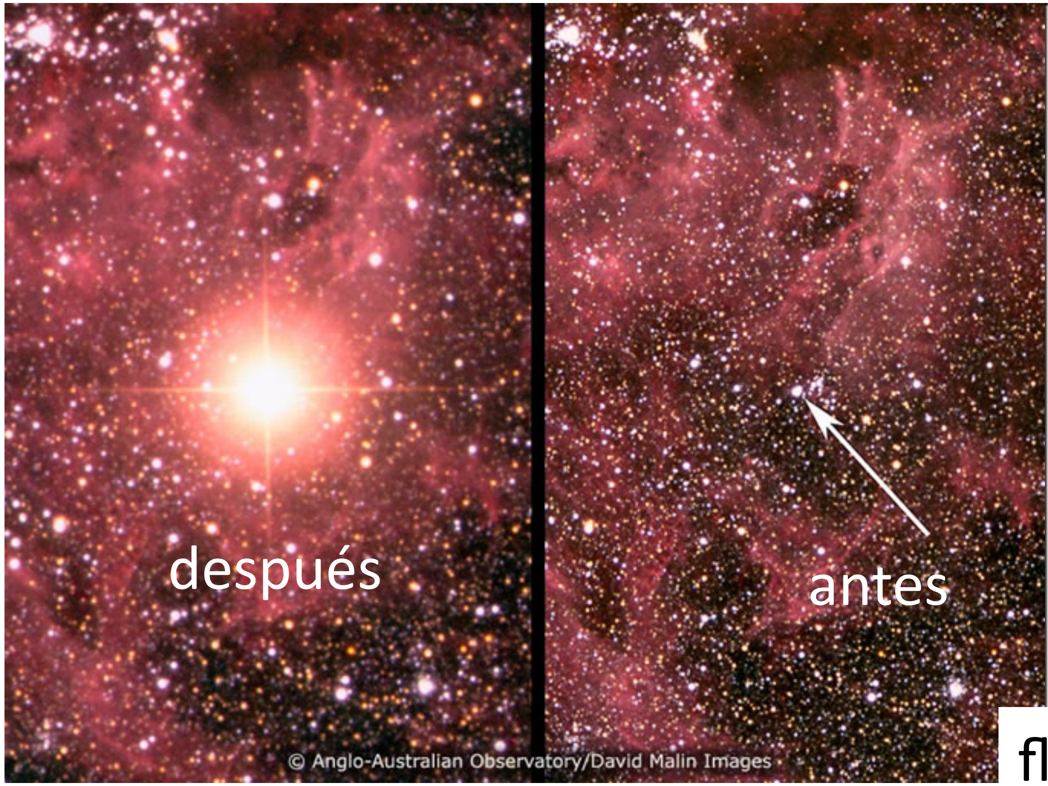
neutrino interactions in the detector was a very serious background

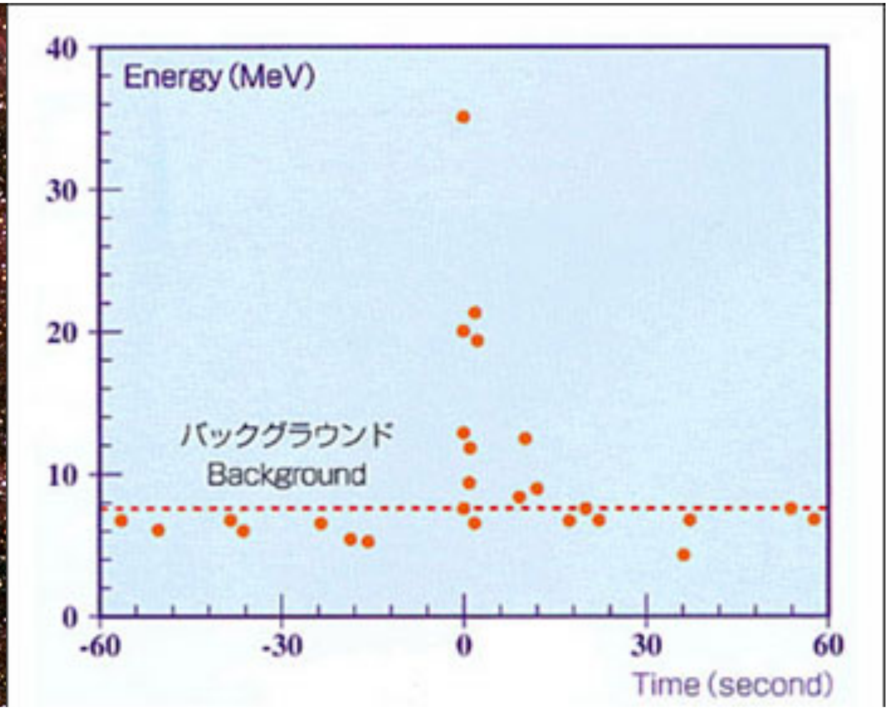
limits on proton decay as of today



pero la propia Naturaleza nos hizo descubrir que este tipo de detectores son extraordinarios *telescopios de neutrinos*

explosión SuperNova SN1987A

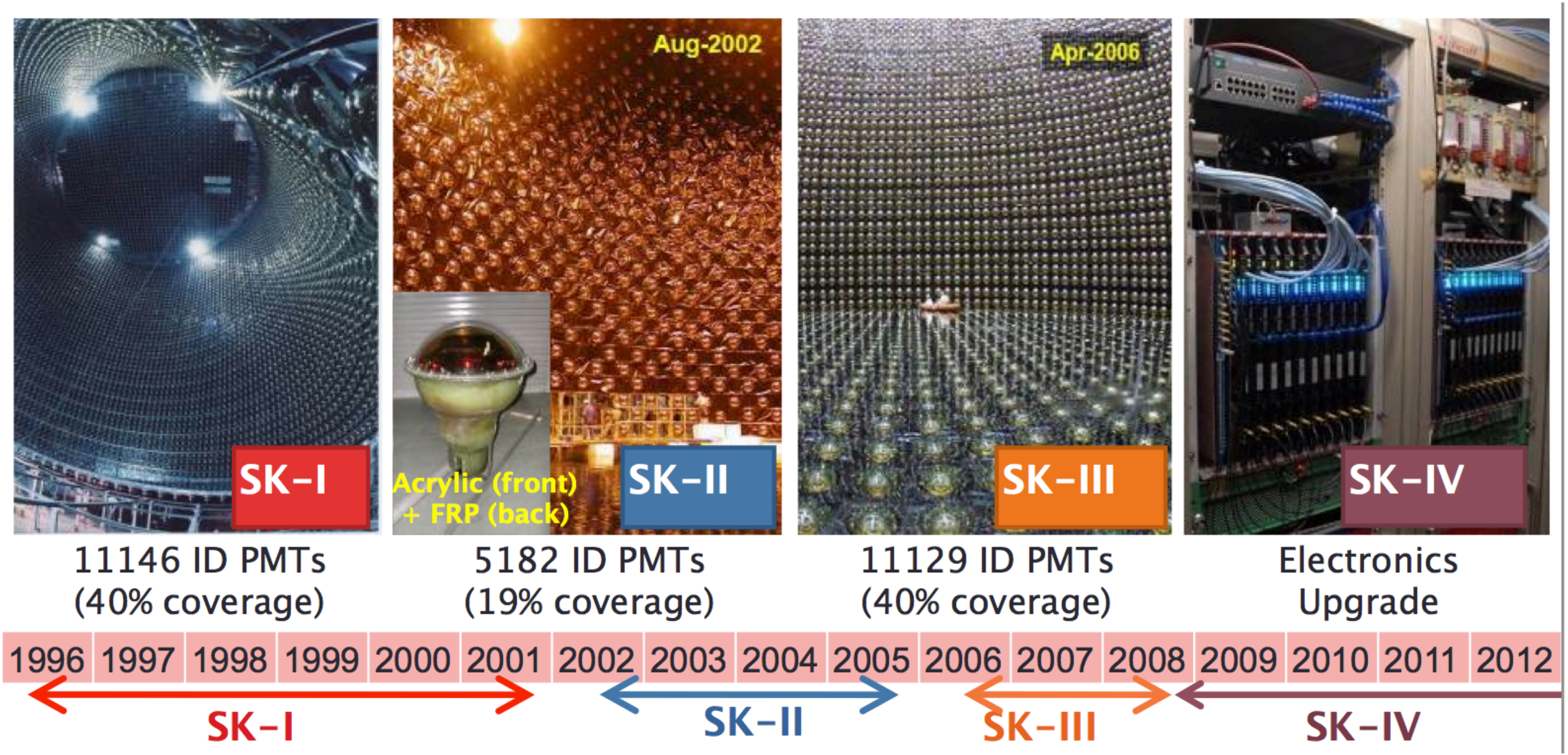




flujo y espectro de ν's medido por Kamiokande (precursor de SK)

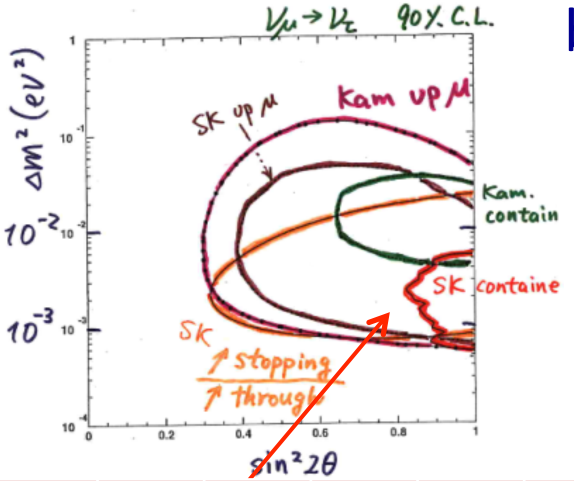
detectores con los que, además de éste (Nobel 2002), se han hecho otros descubrimientos fundamentales

history of Super-Kamiokande

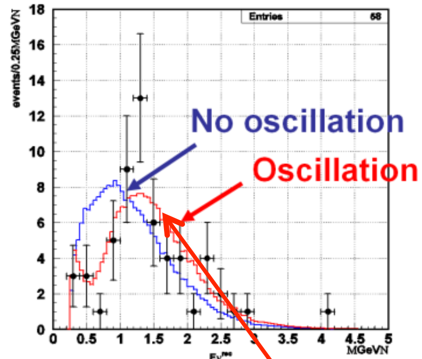


physics achievements with Super-Kamiokande

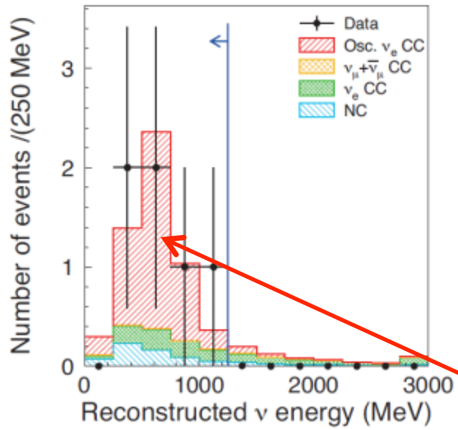
Atmospheric ν oscillations



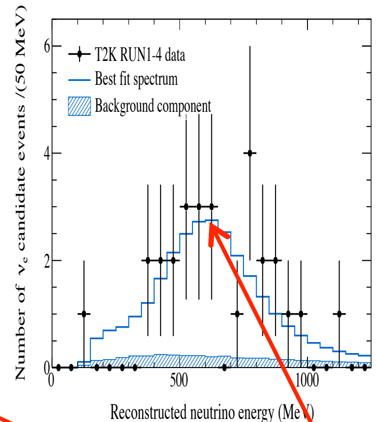
K2K confirmed atmospheric osc. by long baseline ν



indication θ_{13} by T2K

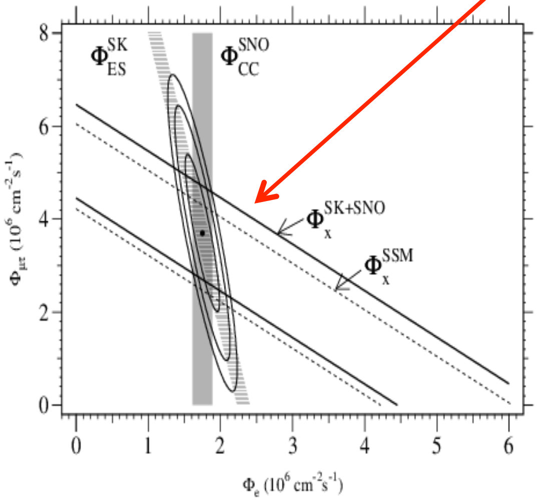


observation θ_{13} by T2K

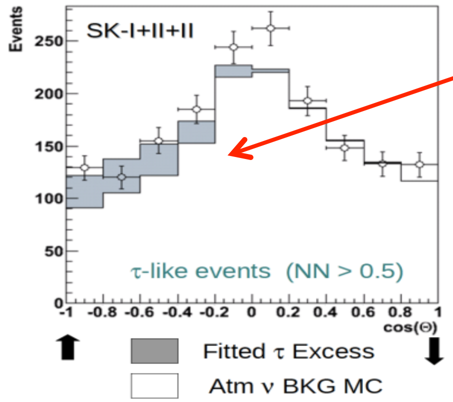


96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13

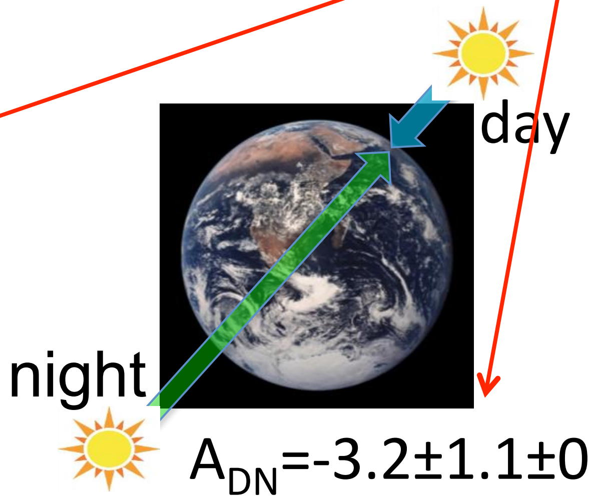
Solar ν oscillations



ν_τ appearance in atmospheric ν



Solar day/night asymmetry



A_{DN}=-3.2±1.1±0.5 %

SK and WC detectors; the Gd

- SK success largely due to detection technique: Water Cherenkov

- Caveat: no anti-ν tagging at all
  no *n*eutron tagging
  no inverse β^- decay reaction (CCQE) measurement
  → *marginal sensitivity to "relic" Supernova-ν*
  → *no sensitivity to reactor-ν*
  → *no "others" ...*

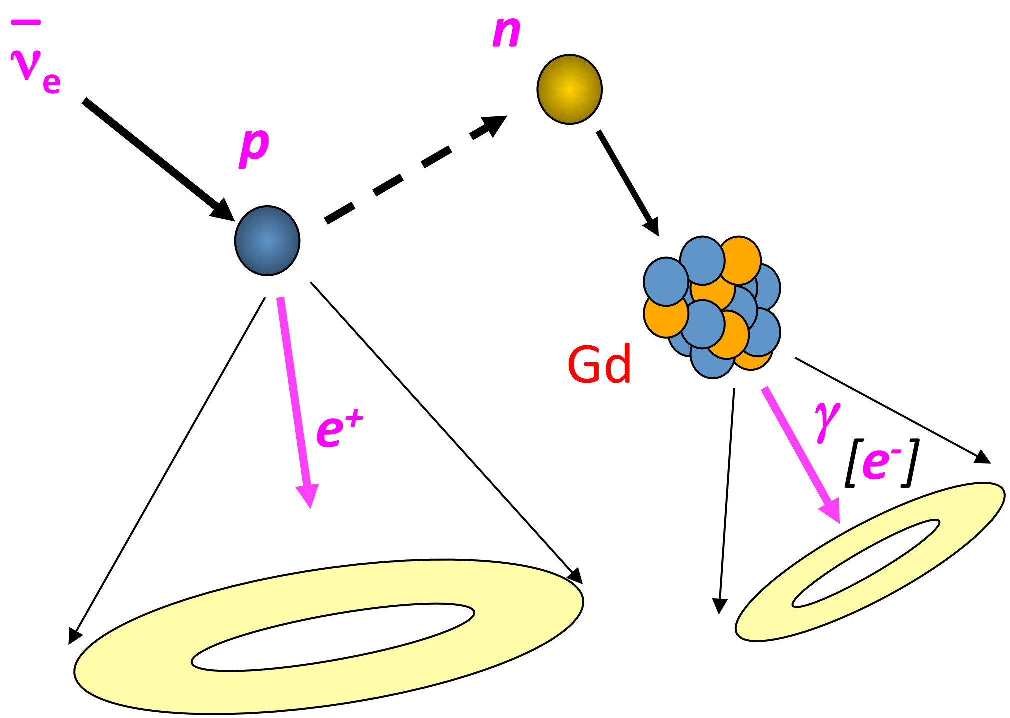
- Solution: dissolve 0.2% (by mass) Gd compound in SK water
  [Beacom and Vagins, Phys. Rev. Lett., 93:171101, 2004]

key:
→ Gd has a very large cross-section for *n* capture,
→ in the process it emits a few γ,s with total energy 8 MeV

WC-Gd detectors

neutron tagging in Gd-enriched Water-Cherenkov detectors

basic reaction is inverse β process

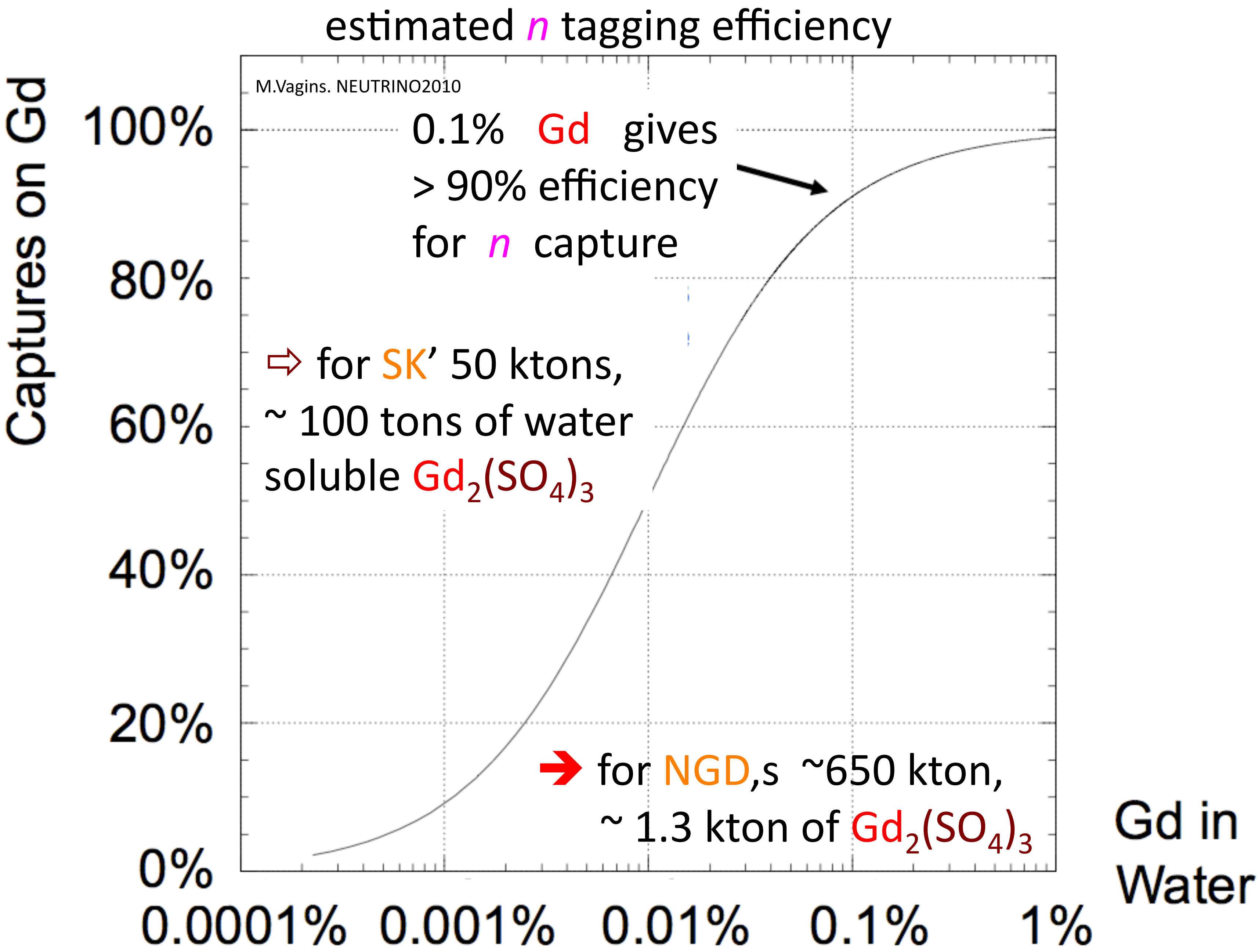


→ e^+ is detected
→ n wanders around for ~12μs until thermalises
→ ~20μs [50cm] until Gd-capture
→ 8MeV γs
→ an e^- is Compton-scat. off the γ and detected

⇨ $\bar{\nu}_e$ is identified by the coincidence between the e^+ and the *delayed* e^-, with high efficiency (> 80%)

⇨ fantastic consequences for SK & "a must" in Next Generation Detectors

WC-Gd detectors



R & D on WC-Gd by Super-Kamiokande

SK has committed to bring this idea into reality
⇨ strong SK R&D program

- The institutes involved are principally:
  - *Institute for Cosmic Ray Research* (ICRR) - Uni. Tokyo
  - *Institute for the Physics and Mathematics of the Universe* (IPMU) - Uni. Tokyo
  - *University California Irvine* (UCI)
  - *University of Okayama*
  - *University Autonoma Madrid* (UAM)

- The program is led by
  - M. Nakahata (ICRR - U. Tokyo)
  - M. Vagins (IPMU - U. Tokyo and UCI)

Antineutrino tagging will have a profound impact in experimental neutrino physics.

Remarkably, SK will be in the position of **discovering** the Difusse Supernova Neutrino Background, and the next generation will measure its energy spectrum: the red-shifted sum of the contribution of supernova neutrino from every epoch of the Universe

In addition

– precise measurement of the solar elements in the leptonic mixing matrix from nuclear reactor electron antineutrinos,
– a much increased sensitivity to the neutrino MH from atmospheric neutrinos and antineutrinos traversing the earth before interacting in SK
– increase the sensitivity for proton decay searches
– others coming along the learning curve

Status of SK R & D program towards dissolving a Gd compound in its water

***G**adolinium*
***A**ntineutrino*
***D**etector*
***Z**ealously*
***O**utperforming*
***O**ld*
***K**amiokande*
***S**uper!*

Gd inside SK

2007: 0.2 % $GdCl_3$

[SK Coll., Astropart. Phys. 31 (2009) 320]

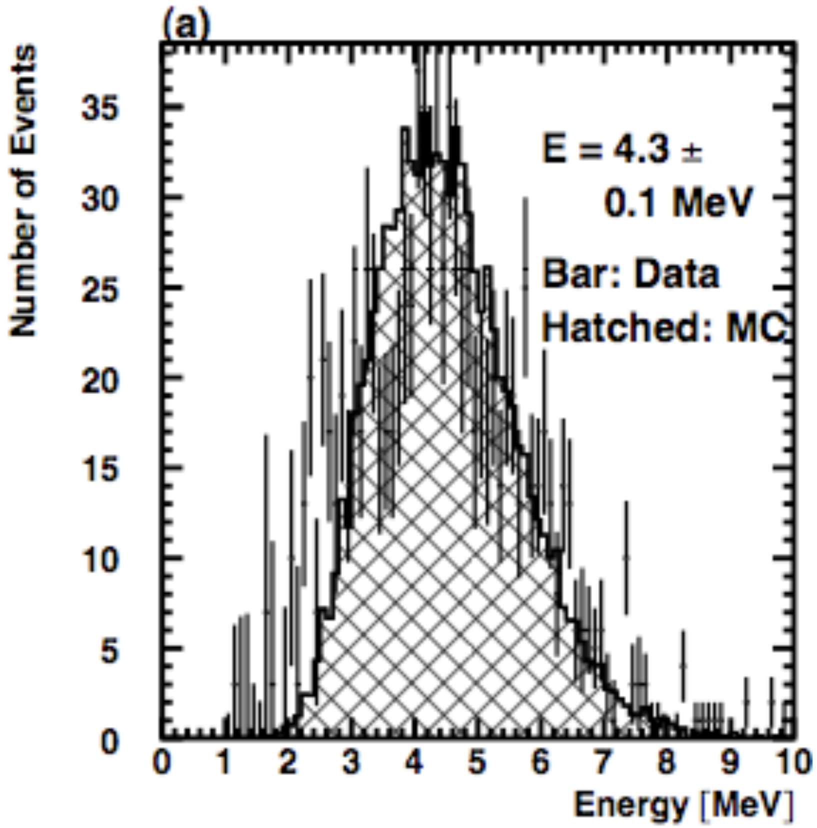
2010: 0.2% $Gd_2(SO_4)_3$

Am / Be source:

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

$\hookrightarrow {}^{12}C + \gamma(4.4\ MeV)$

inside a BGO crystal array,
in 2 liters of 0.2% $GdCl_3$ solution



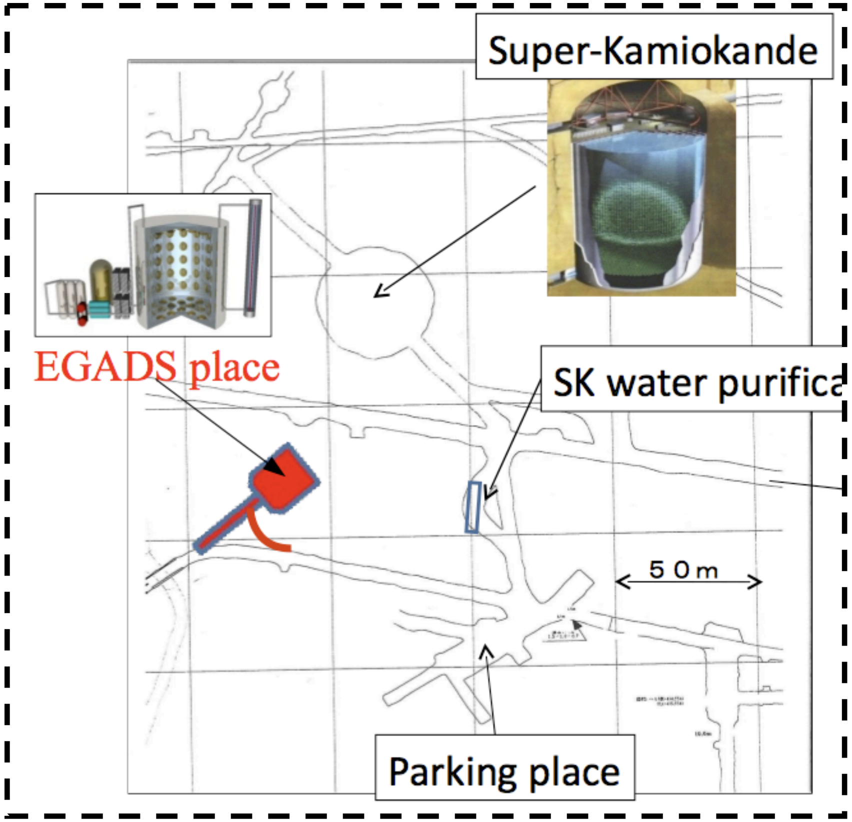
first observation of 8 MeV γ cascade from Gd in a large WC det.

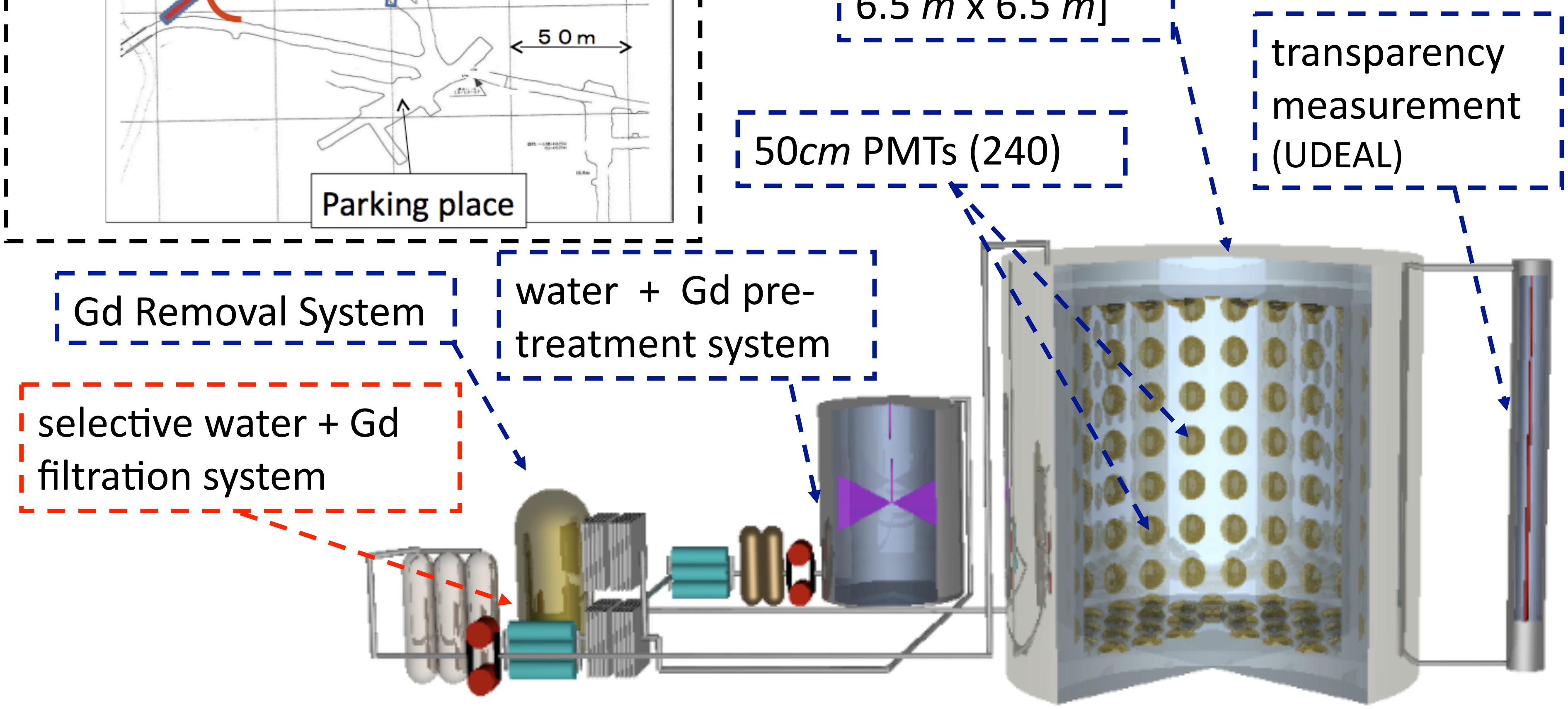
- Many studies have been ongoing in both the US and Japan over the last 10 years
- Current and ***"decisive"*** step is a dedicated Gd ***test-tank***, complete, with its own ***water-filtration*** system, 50*cm* PMT's, DAQ, etc.

→ EGADS (Evaluating Gadolinium's Action on Detector Systems)

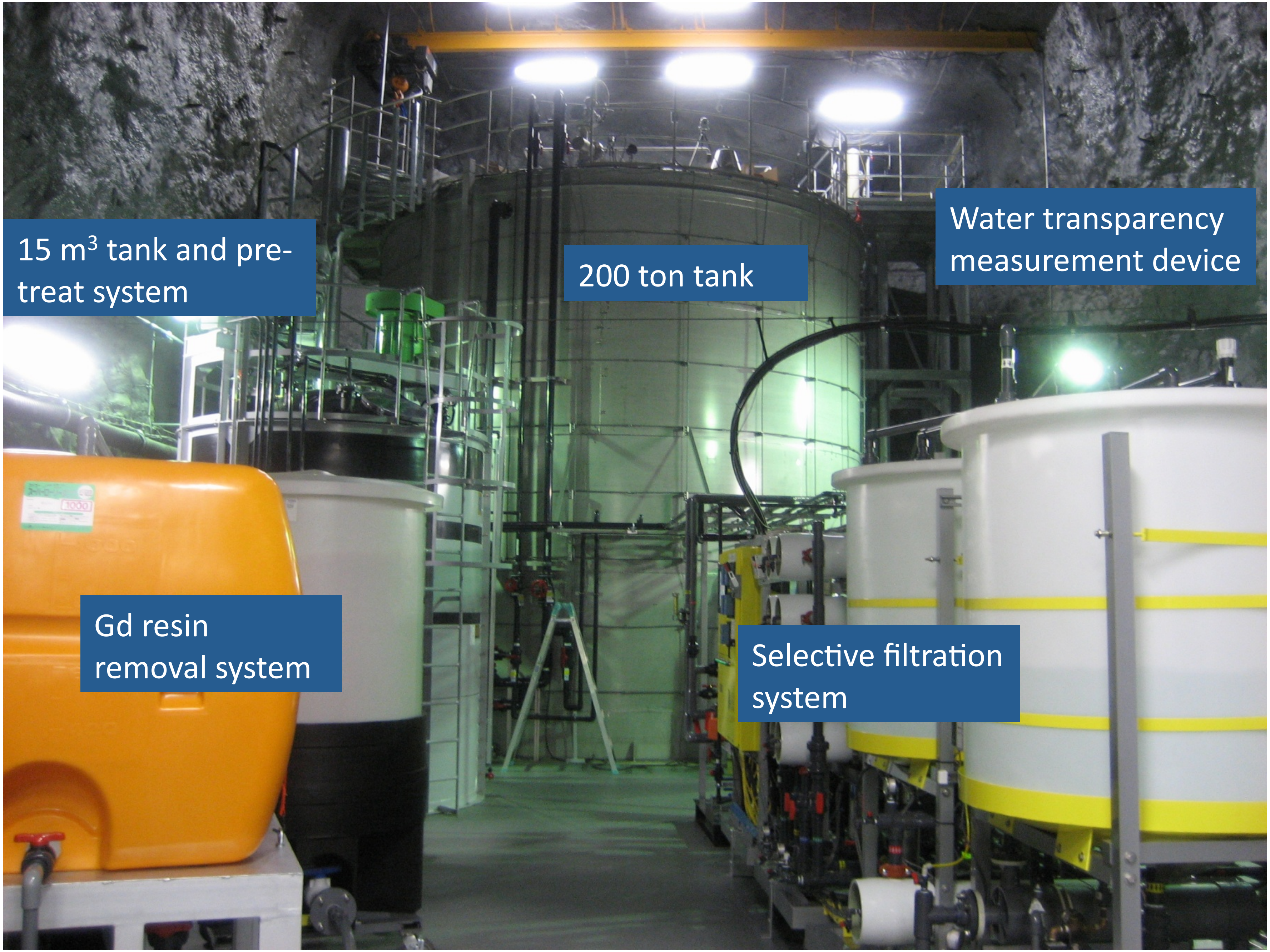
- New dedicated, multi-million dollar test facility
- Kamioka mine (near SK)
- Will address all issues of the GADZOOKS! principle.

main characteristics of EGADS





the EGADS lab



what is being studied ?

Compound to be used

Effects on detector components

Introduction and removal

Introduction of new backgrounds for new and existing analysis

Keep Gd inside the SK tank

Maintaining ultrapure doped water

Effect on water transparency

which compound to use ?

Three choices investigated thus far:

$Gd(NO_3)_3$

Easily dissolved

Nitrate opaque in the UV (very bad for Cherenkov light)

$GdCl_3$

Easily dissolved

Chloride highly corrosive (not good for components)

$Gd_2(SO_4)_3$

Octahydrate form dissolves easily

Good water transparency

Gadolinium sulfate is the compound being tested at EGADS

materials effects

31 materials present in the SK tank have been long-term soak tested in $Gd_2(SO_4)_3$ solution to check for corrosion.

Only affected material is a rubber used for the FRP/acrylic cases.

Further studies with this rubber show the effect is comparable to pure water if temperature is kept below 15°C.

Final soak study of SK materials will be done with components installed inside EGADS detector

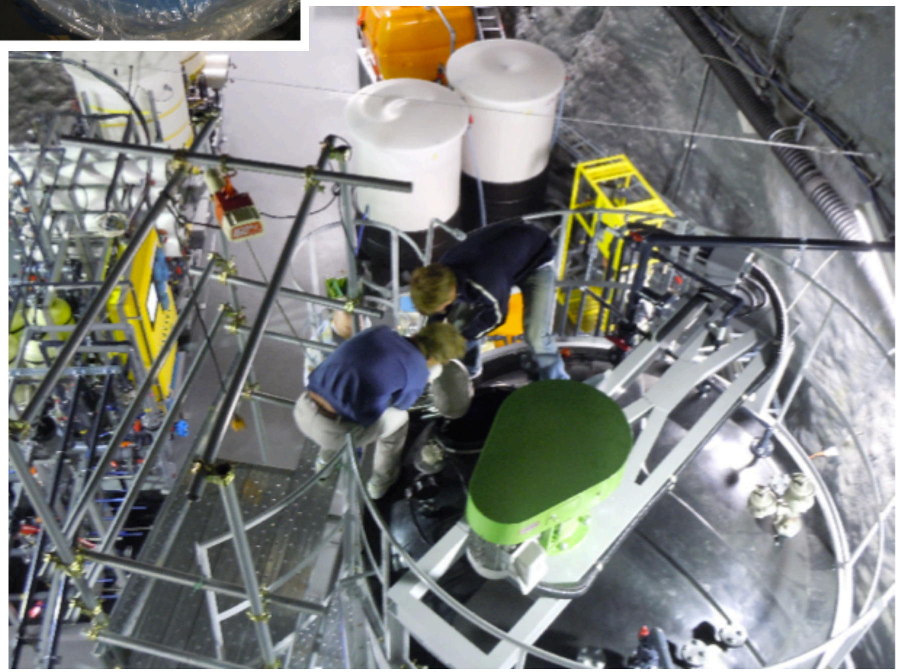
Gd Pre-Treatment System

$Gd_2(SO_4)_3$ is soluble up to 2% by mass

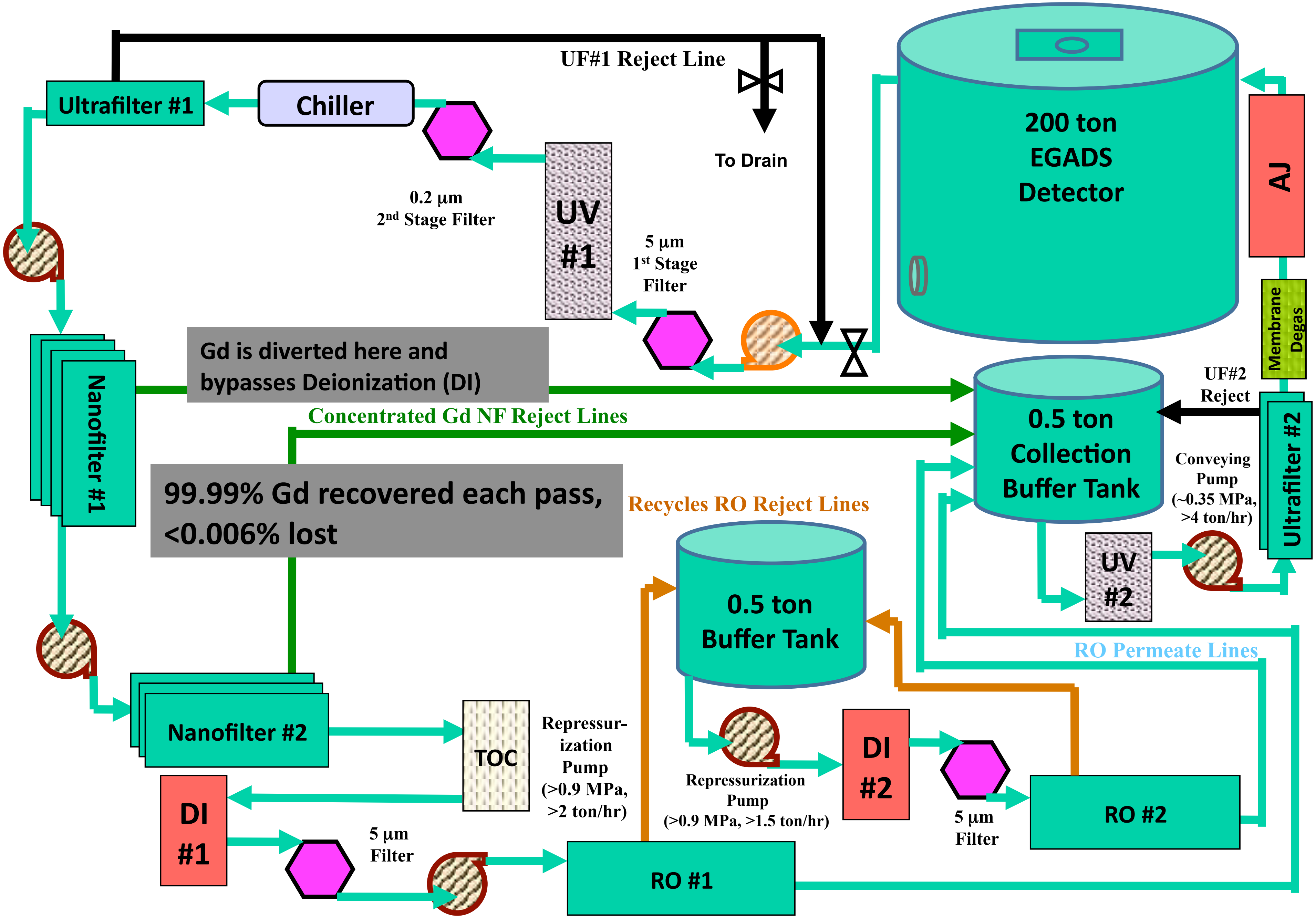
15 m^3 tank to dissolve Gd

Make concentrated solution and then add to detector in steps

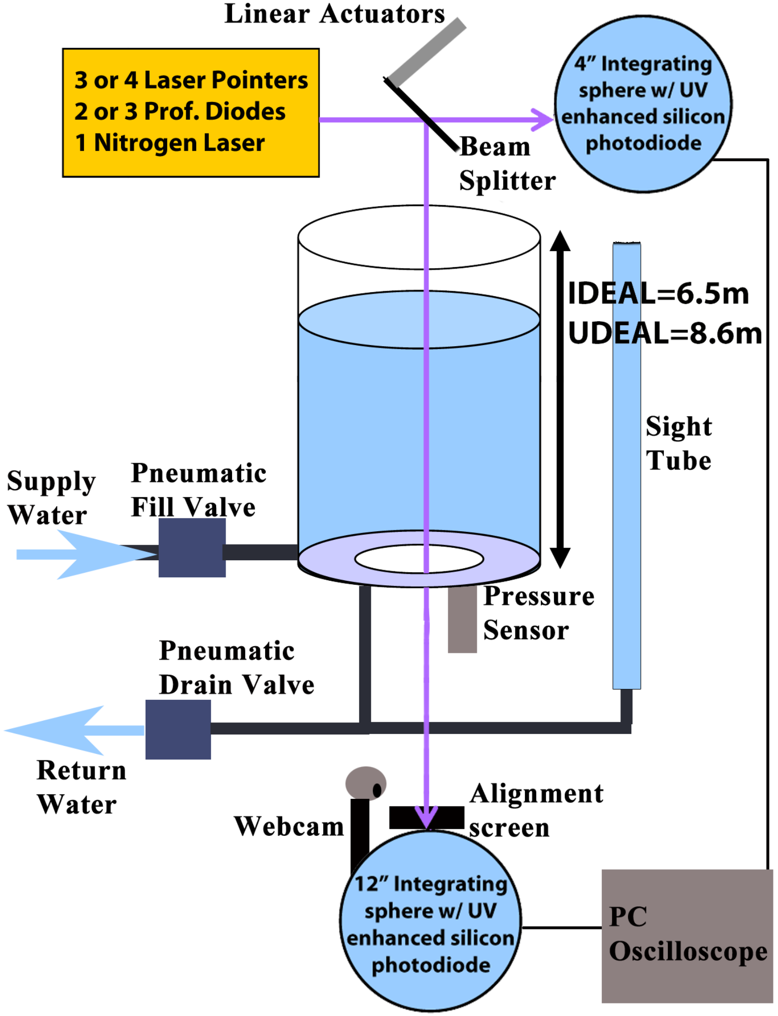
Simple water system with uranium removing resin tanks



key: *EGADS selective filtration system* *a truly pioneering work*



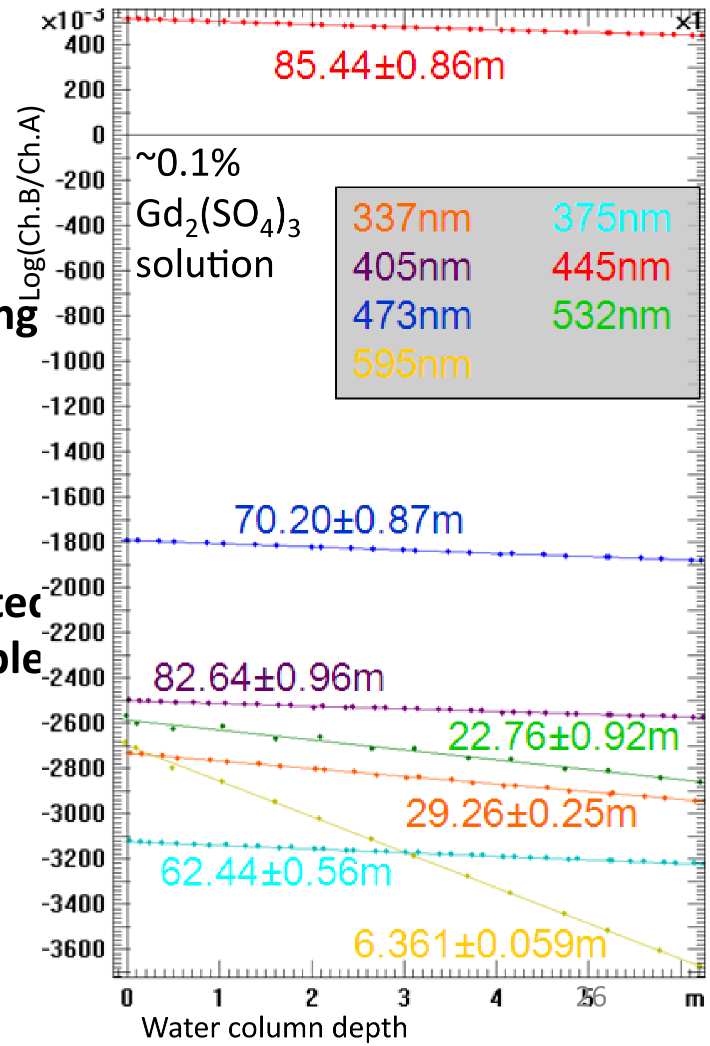
water transparency monitoring



Precision measurements of attenuation lengths >100 m

Monitor relevant Cherenkov region using multiple lasers

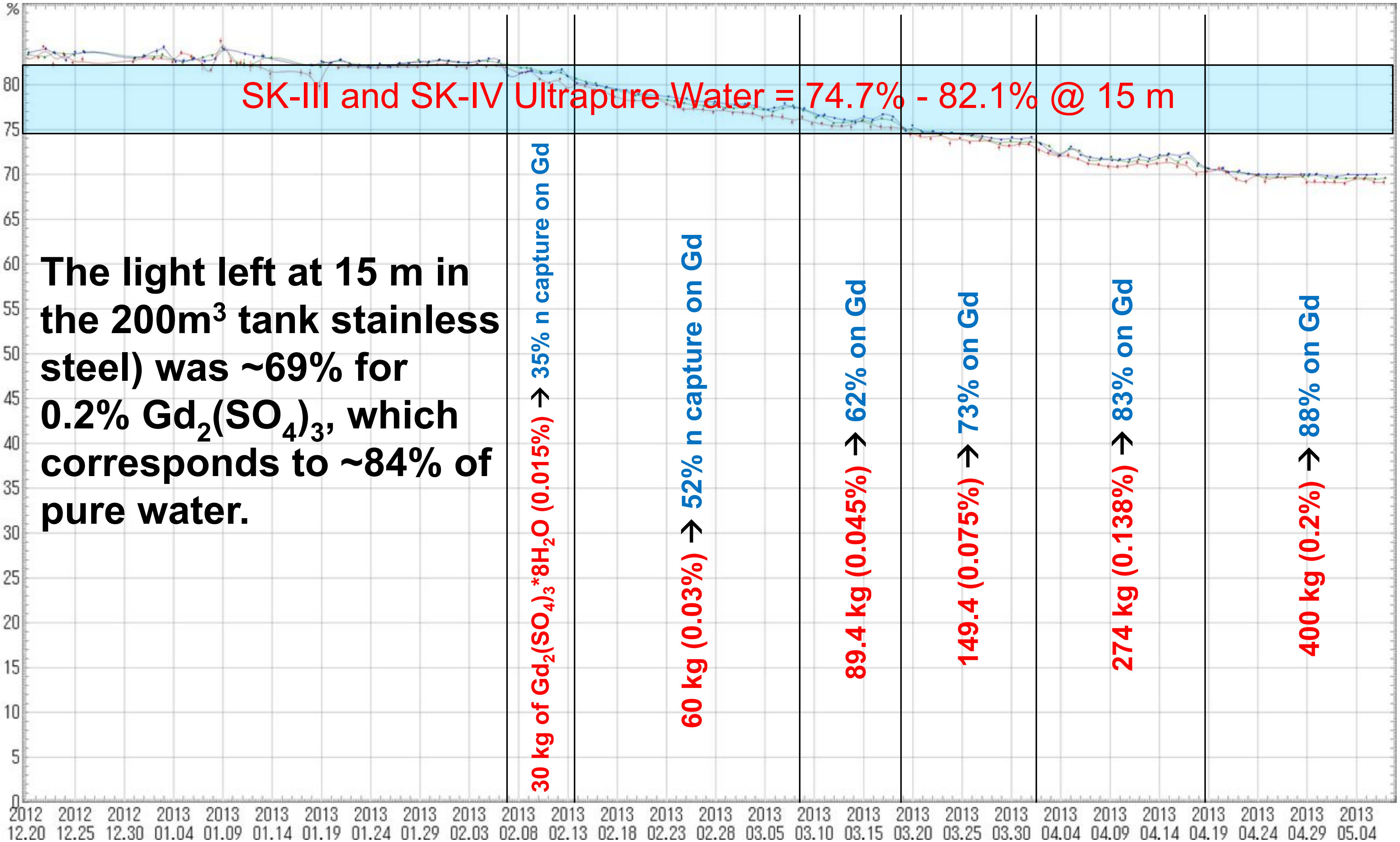
Devices fully automated running is rather simple and quick



EGADS Tests

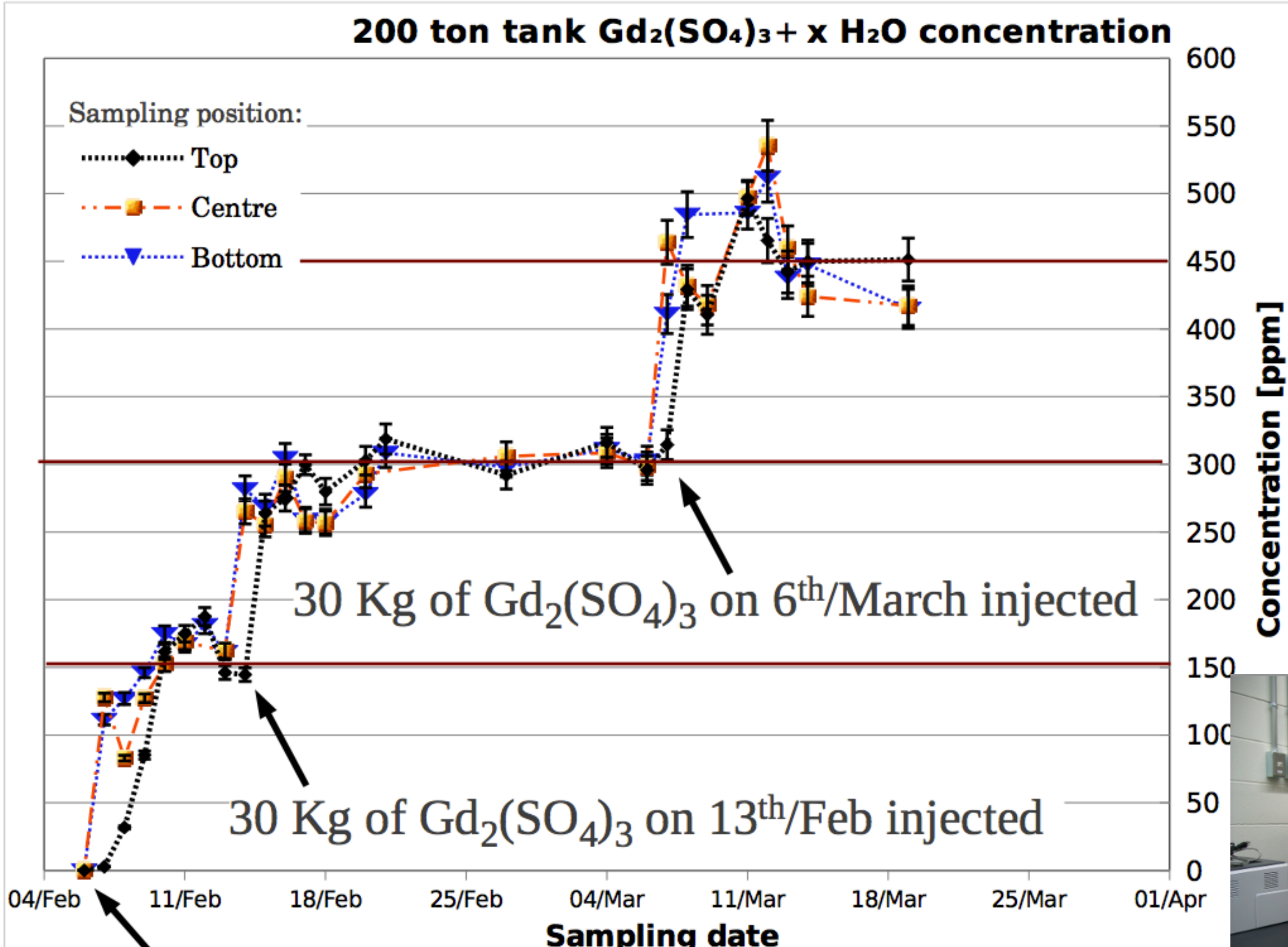
- ☑ Pure water in 200 ton tank (no PMTs)
- ☑ Gd water in 15 m^3 tank
- ☑ Gd water in 200 ton tank (no PMTs)
- ☐ Pure water in 200 ton detector (with PMTs)
  - Ongoing now
- ☐ Gd water in 200 ton detector (with PMTs)

EGADS 200 Ton Tank Gd-Water Transparency



measurement of Gd concentration using atomic absorption spectrometry

Concentration measurement @ 200 ton tank



Right after injecting 30 Kg of $Gd_2(SO_4)_3$ on 6th/Feb.

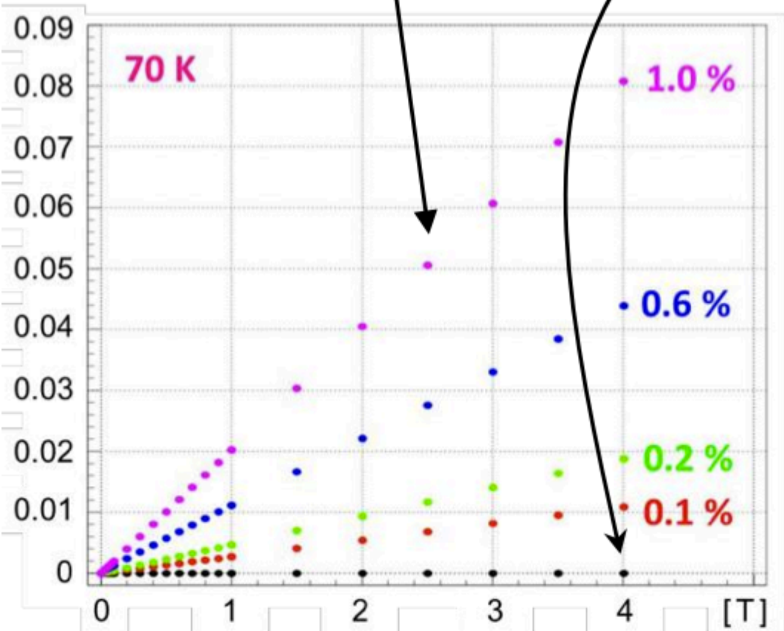
$Gd_2(SO_4)_3$ is **homogeneously dissolved** within 3-4 days

Lluis Marti

measurement of Gd concentration using its magnetic susceptibility

To test this idea, Prof. Luis Labarga (Univ. Autonoma Madrid, Spain) conducted a series of measurements with a SQUID with a blank sample (black on figure) and 0.1%, 0.2%, 0.6% and 1% concentrations. The susceptibility of blank has been subtracted (blank black dots lie on zero).

A linear correlation for each sample is seen as a function of the magnetic field. **The slope is clearly correlated to the Gd concentration** too although not perfect due to problems with the sample container.



Magnetic susceptibility as a function of the applied magnetic field.

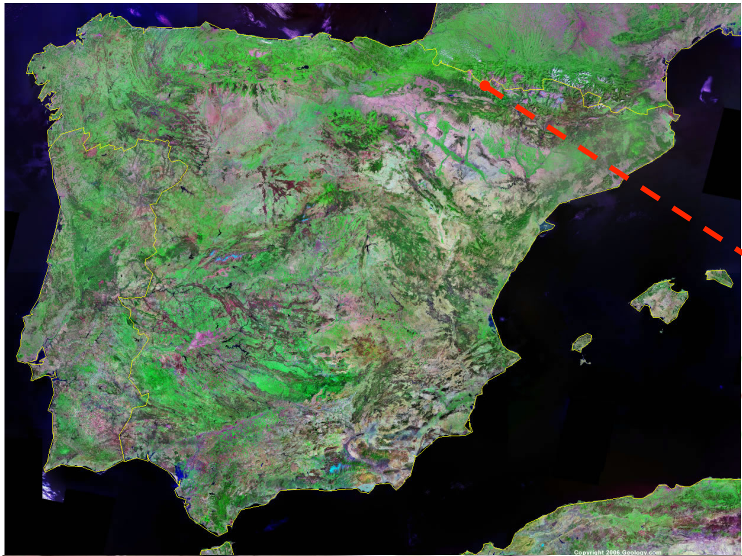
The sample container must be of a low diamagnetic material (ideally it should not interfere with the magnetic field at all) and completely seal our fluid samples to avoid water evaporation.

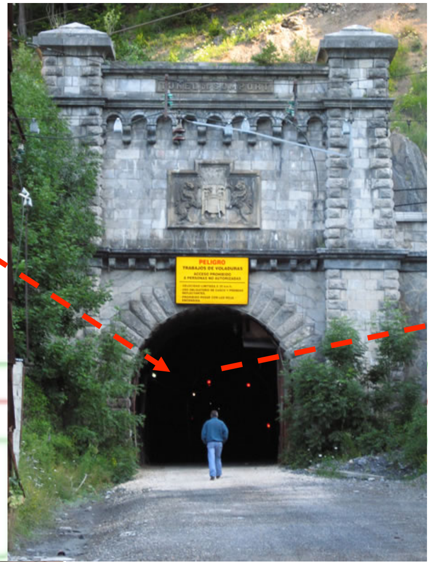
In the first half of FY2014 we will have the design of the sample container and perform the same test as above to confirm the perfect correlation between slope and Gd concentration. Once this is confirmed, we will work on the final design of a device that can be actually used to measure Gd concentrations. This device will feature: **good precision and reproducibility, no dilution or major human intervention** as to allow permanent Gd concentration monitoring.

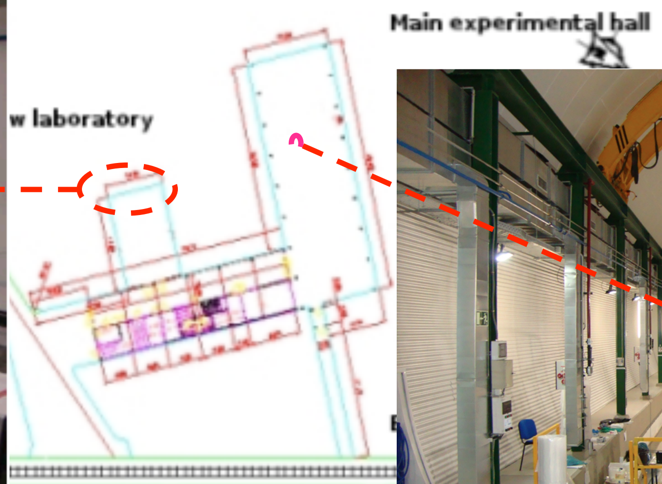
By the end of FY2014, we should have a design and purchased the necessary material to build it. Eventually, and if on schedule, perform a series of first tests in the laboratory.

radioactive contamination of materials

[***LSC***, *Laboratorio Subterráneo de Canfranc*]

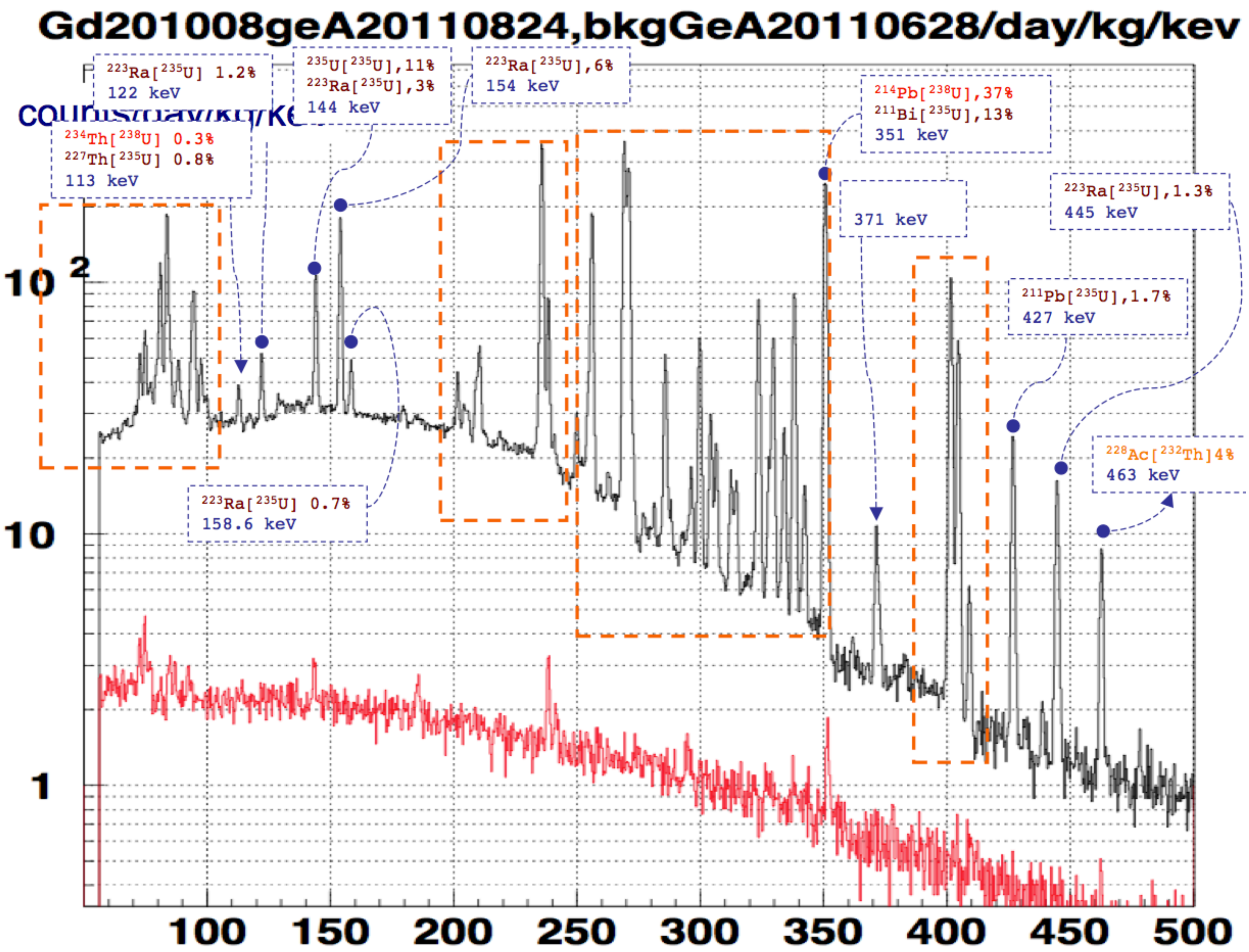






HPGe detector farm

main Hall: *ArDM*, *Next* ...


Gd201008geA20110824,bkgGeA20110628/day/kg/kev
counts/day/kg/keV
223Ra[235U] 1.2%
122 keV
235U[235U],11%
223Ra[235U],3%
144 keV
223Ra[235U],6%
154 keV
214Pb[238U],37%
211Bi[235U],13%
351 keV
234Th[238U] 0.3%
227Th[235U] 0.8%
113 keV
371 keV
223Ra[235U],1.3%
445 keV
211Pb[235U],1.7%
427 keV
228Ac[232Th]4%
463 keV
223Ra[235U] 0.7%
158.6 keV
10 2
10
1
100
150
200
250
300
350
400
450
500

radioactive contamination of materials

Grand summary of all $Gd_2(SO_4)_3$ batches measured @ Canfranc

Chain	Main sub-chain isot.	Gd-0904	Gd-1008	Gd-1208	Gd-1302	Gd-1303	Gd-1308	Gd-1307a	Gd-1307b
^{238}U	^{238}U	51±21	< 33	292±67	74±28	242±60	71±20	--	--
	^{226}Ra	8±1	2.8±0.6	74±2	13±1	13±2	8±1	*seen*	*seen*
^{232}Th	^{228}Ra	11±2	270±16*	1099±12	205±6	21±3	6±1	--	*seen*
	^{228}Th	28±3	86±5	504±6	127±3	374±6	159±3	*seen*	--
^{235}U	^{235}U	< 32	< 32	< 112	< 25	< 25	< 32	--	--
	^{227}Ac/ ^{227}Th	214±10	1700±20	2956±30	1423±21	175±42	295±10	--	--
Other	^{40}K	29±5	12±3*	101±10	60±7	18±8	3±2	*seen*	*seen*
	^{138}La	8±1	<	683±15	3±1	42±3	5±1	--	*seen*
	^{176}Lu	80±8	21±2	566±6	12±1	8±2	30±1	*seen*	--

Very preliminary

learning about relative isotope abundance of Gd and radioactive isotope contaminations using mass spectroscopy

measurement of contamination of ^{238}U and ^{232}Th isotopes in a sample of $Gd_2(SO_4)_3$ with an old ICPMS in Kamioka

current measuring program
- relative isotope abundance
- long lived radioactive isotopes

at "Laboratorio de ICP-MS" from SIDI-UAM

Gd Removal

Method 1: Ion exchange resin

- Test shows Gd levels ~1000 ppm to less than 0.5 ppb
- Resin will saturate, ok for small scale

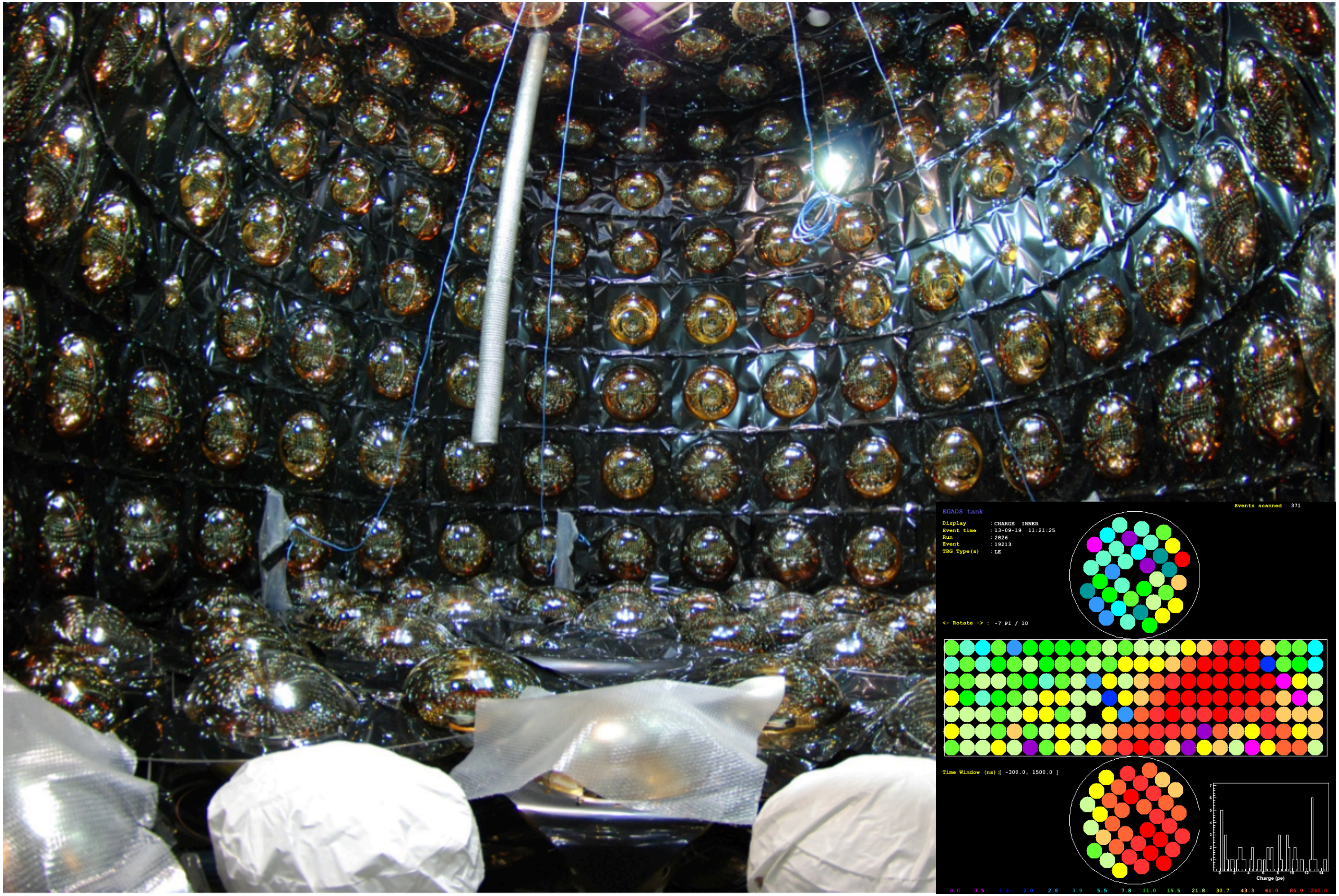
Method 2:
Removal system and filtering

pH up -> Gd out of solution
- Filter with a mechanical filter
- Settling tanks may be more useful than filter press

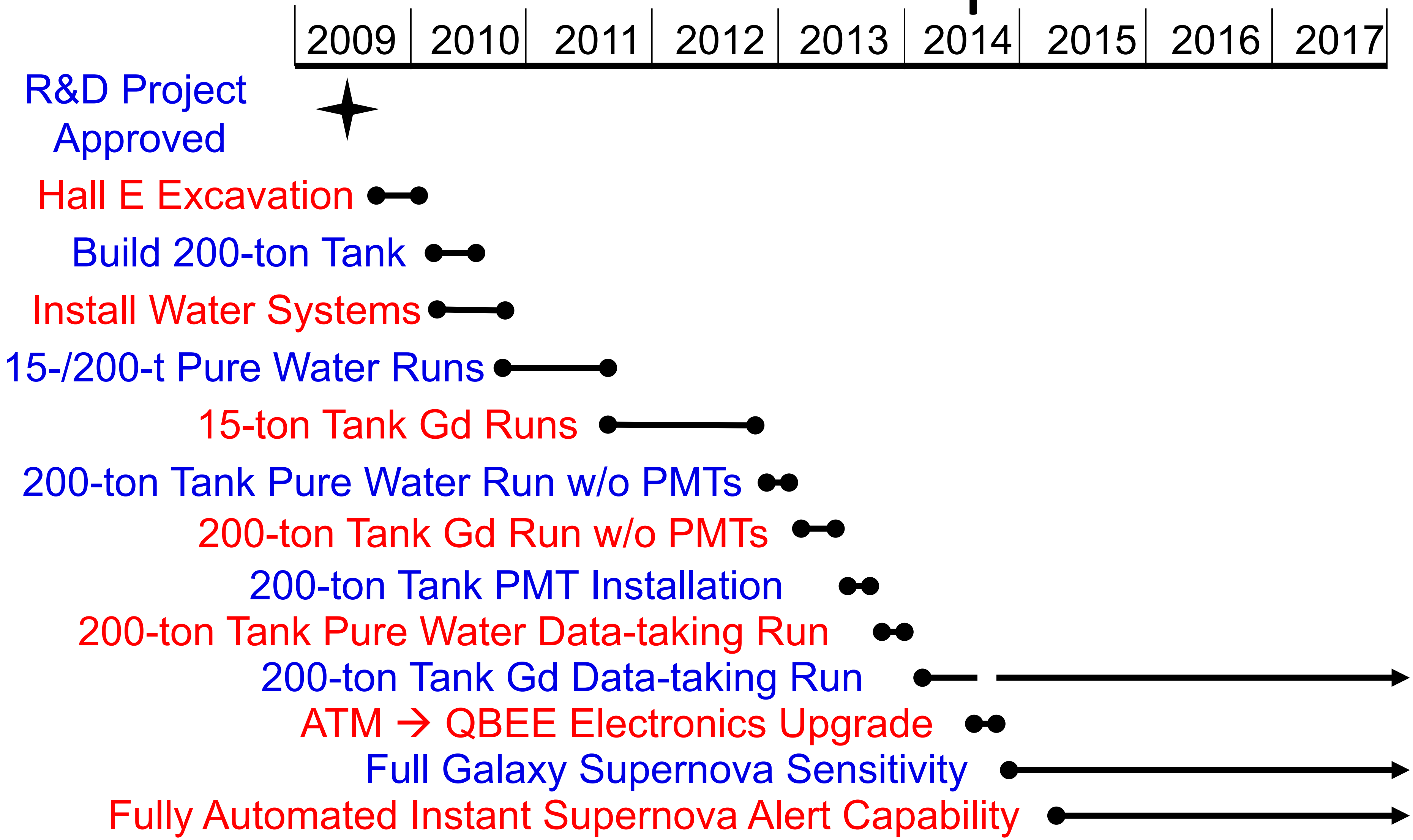
First method used at EGADS

the 240 PMTs were installed this summer

EGADS tank fully instrumented; already taking data



EGADS Roadmap



[M. Vagins]

road path to GADZOOKS!

Water in 200 ton detector currently 17.4 MΩ-cm, will soon remove extra DI unit from system

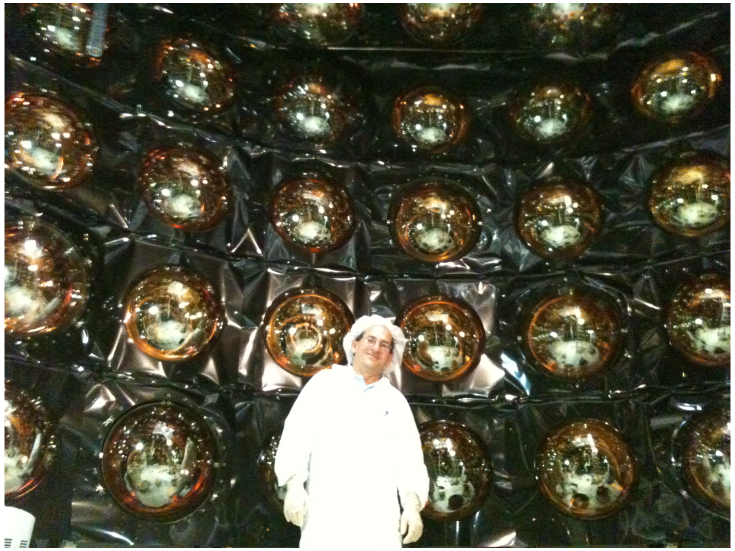
Add Gd to EGADS detector in January 2014

Run EGADS Gd detector as final proof of principle test

Full SK MC studies with additional information of scattering and absorption of Gd

May 2014 -> SK to decide on GADZOOKS!

Thank you



Additional Material: