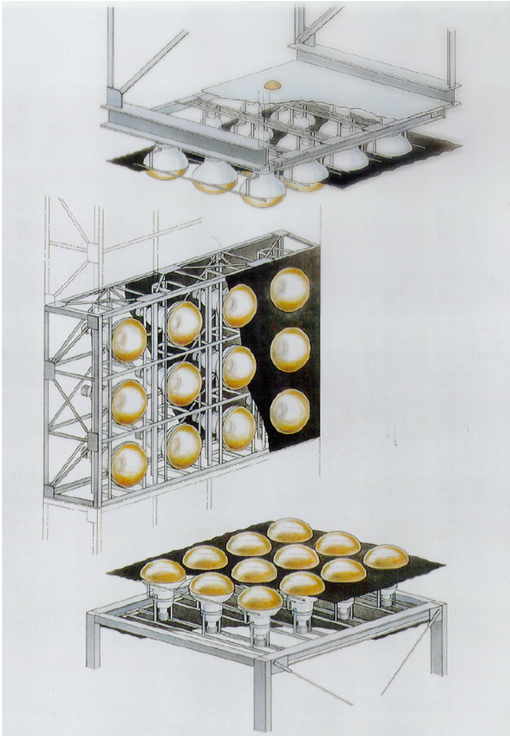
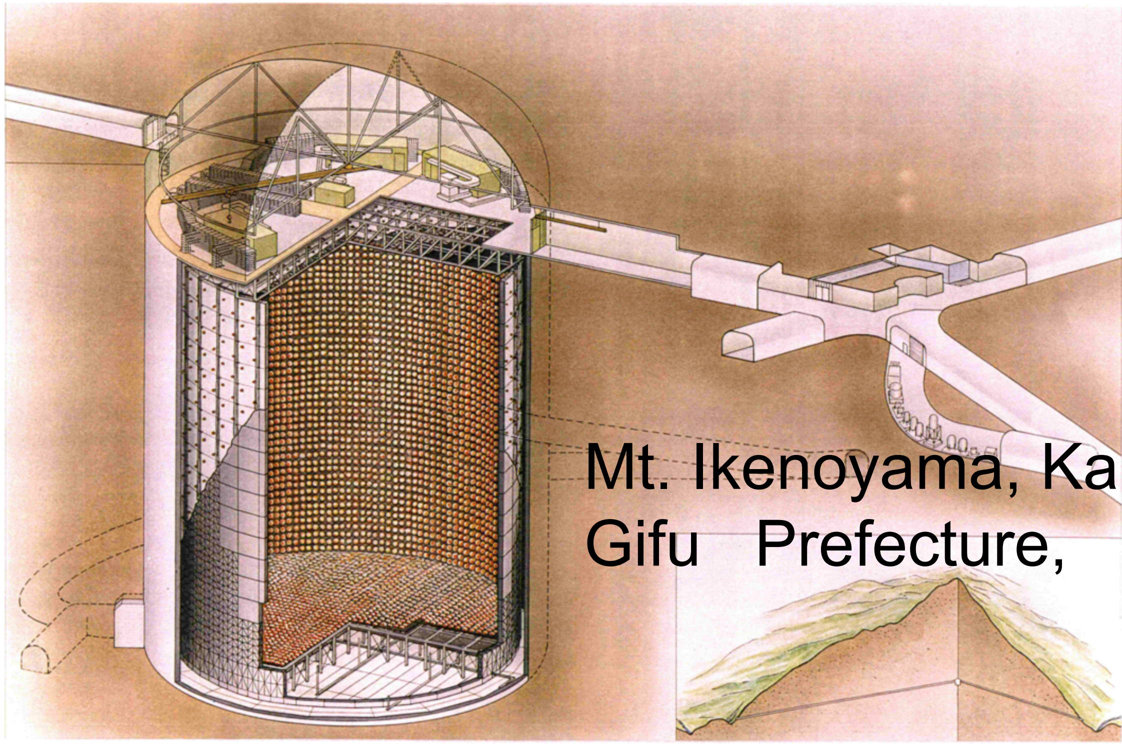
About a
Gd-doped
Water Cherenkov LAGUNA Detector

- WC detectors, Gd doping, *n*eutron tagging
- The gain from Gd, main reactions
- Status of SK's R&D on Gd-doping

Luis Labarga, University Autonoma Madrid
CSSP2010, Sinaia, July 1st 2010

Water Cherenkov detectors: *Super-Kamiokande*, the paradigm





Mt. Ikenoyama, Kamioka,
Gifu Prefecture, Japan

Total Volume		50 kton
Fiducial Volume		22.5 kton
No. PMTs	inner	[20’’] 11146
	outer	[8’’] 1885
Active Area		40 %

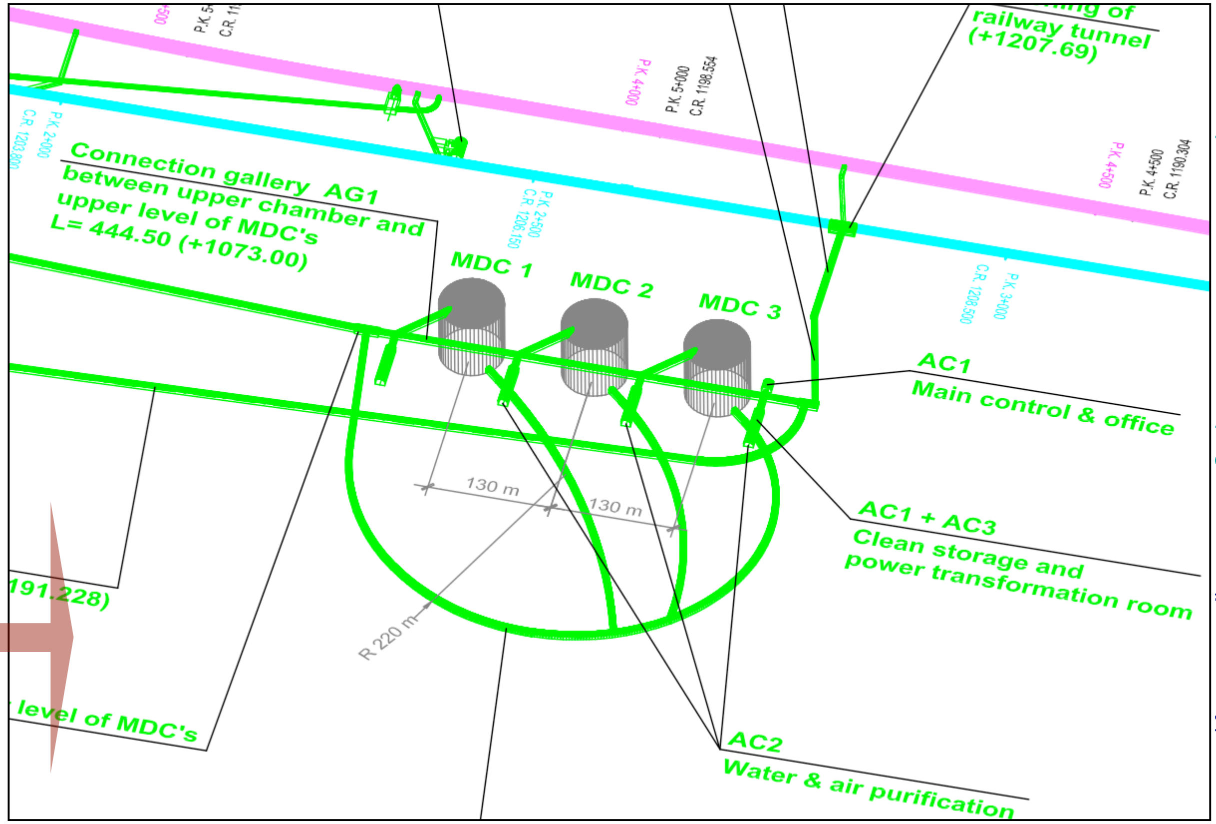
WC detectors:

LAGUNA **approach:**

MEMPHYS

A.de Bellefon et al., arXiv:hep-ex/0607026

MEMPHYS at the *Canfranc Underground Laboratory*



Feasibility Study for LAGUNA-MEMPHYS at the LSC (preliminary)
http://www.lsc-canfranc.es/pagina-279/

	SK	LAGUNA-MEMPHYS
Total Volume	50 kton	3 x 216 = 648 kton
Fiducial Volume	22.5 kton	~ 380 kton
No. PMTs inner	[20''] 11146	[12''] 3 x 76000 = 228000
outer	[8''] 1885	[8''] 3 x 5000 = 15000
Active Area	40 %	30 %

~1 / ~0.3 order of magnitude increase w.r.t. SK (total / per_tank)

WC detectors

Super-Kamiokande is currently the most powerful scientific apparatus for *p*-decay and ν physics

- ⇨ discovery of *Atmospheric*-ν oscillations
- ⇨ help solving *Solar*-ν problem
- ⇨ world's best limit on *p* lifetime
- ⇨ first long base ν experiment (K2K), currently T2K is running

- ⇨ precise measurement of leptonic mixing matrix parameters
- ⇨ discovery of SN1987a ν burst (Kamiokande)
- ⇨ world's best limit on relic Supernova ν,s

WC detectors; the Gd

- SK success largely due to detection technique: Water Cherenkov
- Caveat: no *n*eutron tagging
  - ⇨ no inverse β^- decay reaction (CCQE) measurement
  - ⇨ no anti-ν tagging at all
    - → *marginal sensitivity to "relic" Supernova-ν*
    - → *no sensitivity to reactor-ν*
    - → *no "others" ...*

- Solution: dissolve 0.2% (by mass) Gd compound in SK water

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)

key:

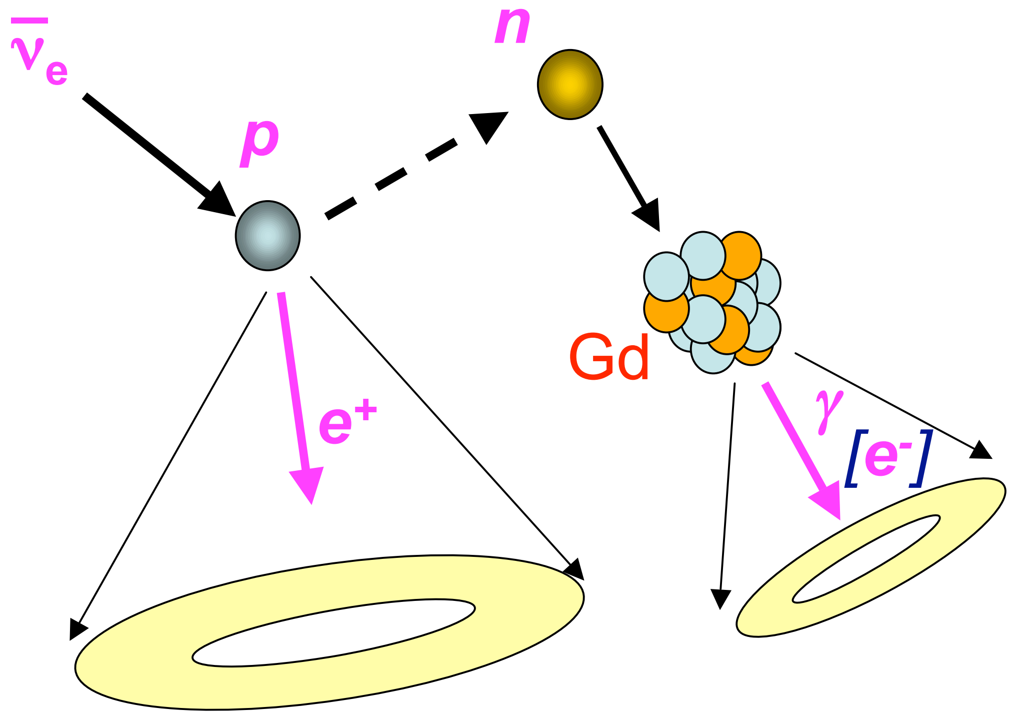
→ Gd has a very large cross-section for *n* capture,

→ 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 and "a must" for LAGUNA

(*) γ total Cross sections vs. E_γ

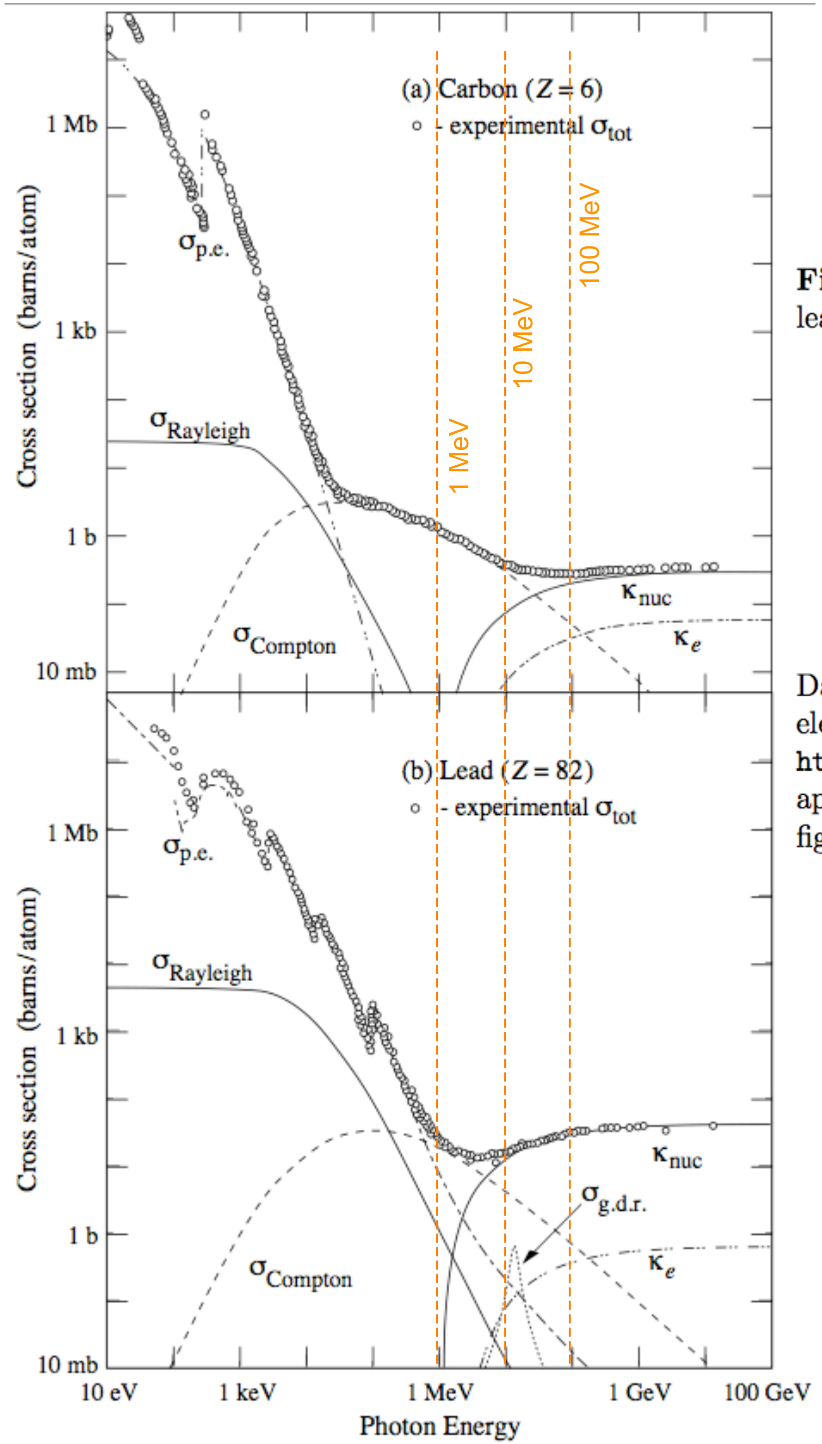


Figure 27.14: Photon total cross sections as a function of energy in carbon and lead, showing the contributions of different processes:

$\sigma_{\text{p.e.}}$ = Atomic photoelectric effect (electron ejection, photon absorption)

σ_{Rayleigh} = Rayleigh (coherent) scattering–atom neither ionized nor excited

σ_{Compton} = Incoherent scattering (Compton scattering off an electron)

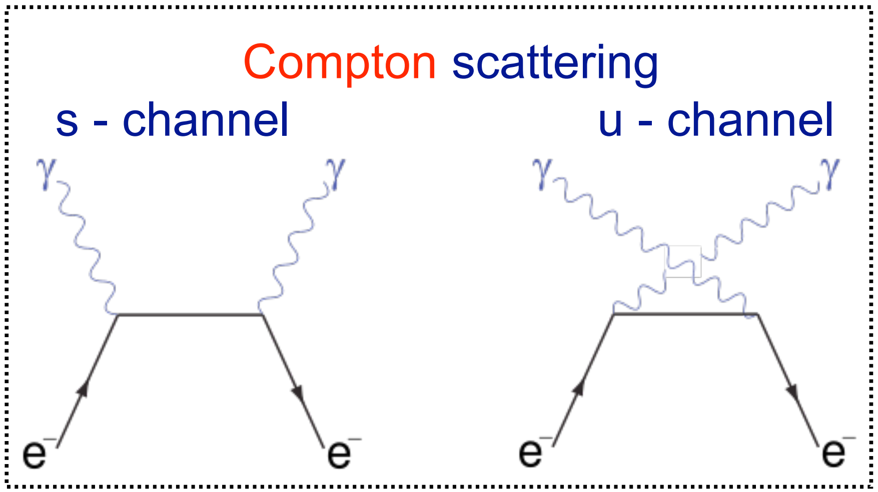
κ_{nuc} = Pair production, nuclear field

κ_e = Pair production, electron field

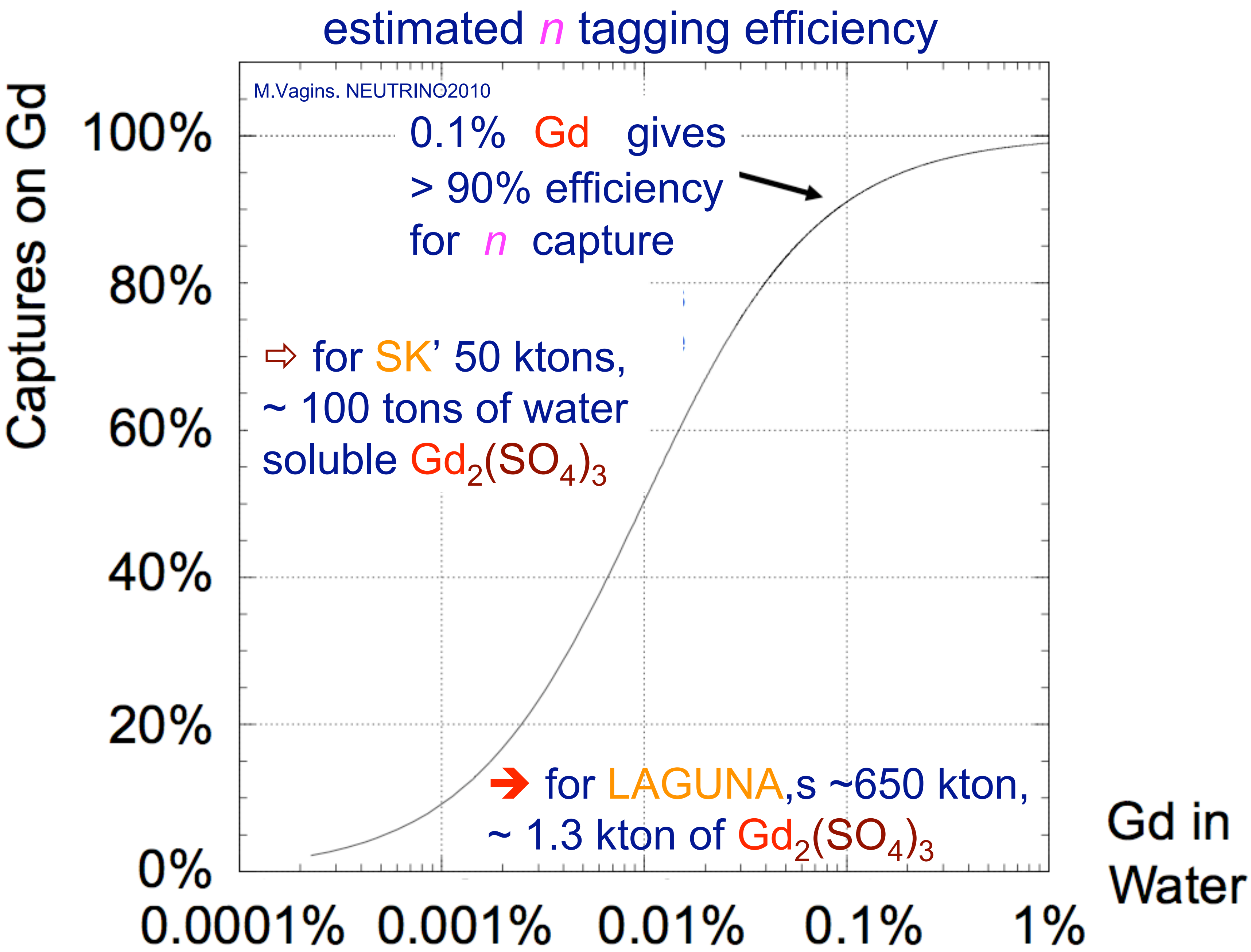
$\sigma_{\text{g.d.r.}}$ = Photonuclear interactions, most notably the Giant Dipole Resonance [46]. In these interactions, the target nucleus is broken up.

Data from [47]; parameters for $\sigma_{\text{g.d.r.}}$ from [48]. Curves for these and other elements, compounds, and mixtures may be obtained from `http://physics.nist.gov/PhysRefData`. The photon total cross section is approximately flat for at least two decades beyond the energy range shown. Original figures courtesy J.H. Hubbell (NIST).

August 30, 2006 15:40



WC-Gd detectors



R&D on WC-Gd detectors

SK has committed to bring Vagins' 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)

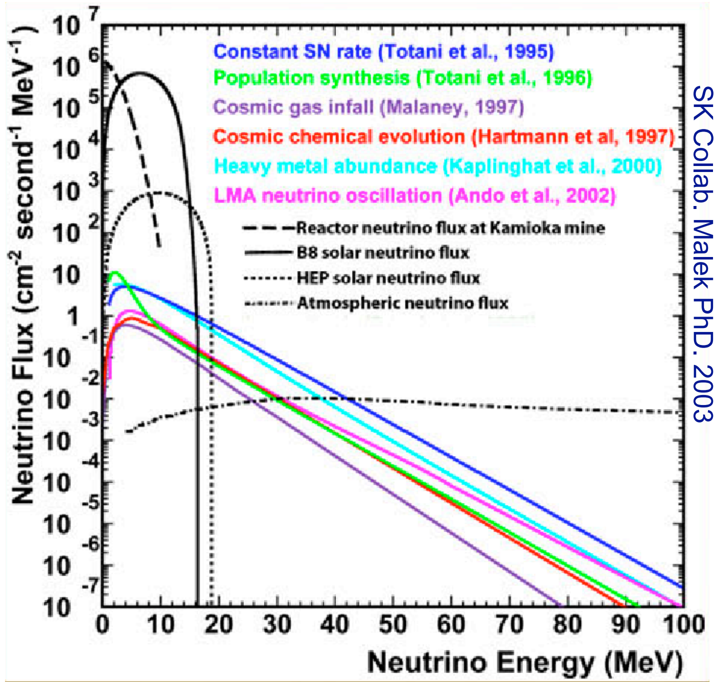
- The program is led by
  - M. Nakahata (ICRR - U. Tokyo)
  - M. Vagins (IPMU - U. Tokyo and UCI)

more in last part of the talk

The gain from Gd in WC detectors, Main Reactions

The known ν sources and their corresponding E_ν

- Inside of the Earth
- Nuclear Power reactors
- Sun
- Super-Nova explosions ("Relic" and nearby)
- Atmosphere (from MeV to TeV)
- Accelerators (~ GeV)



- *Other sources not yet known (e.g. DM-WIMP annihilation inside the Sun)*

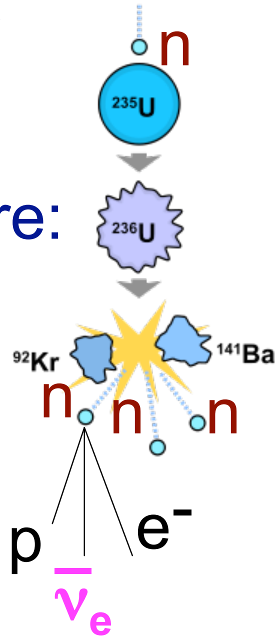
Also (¡!) p-decay

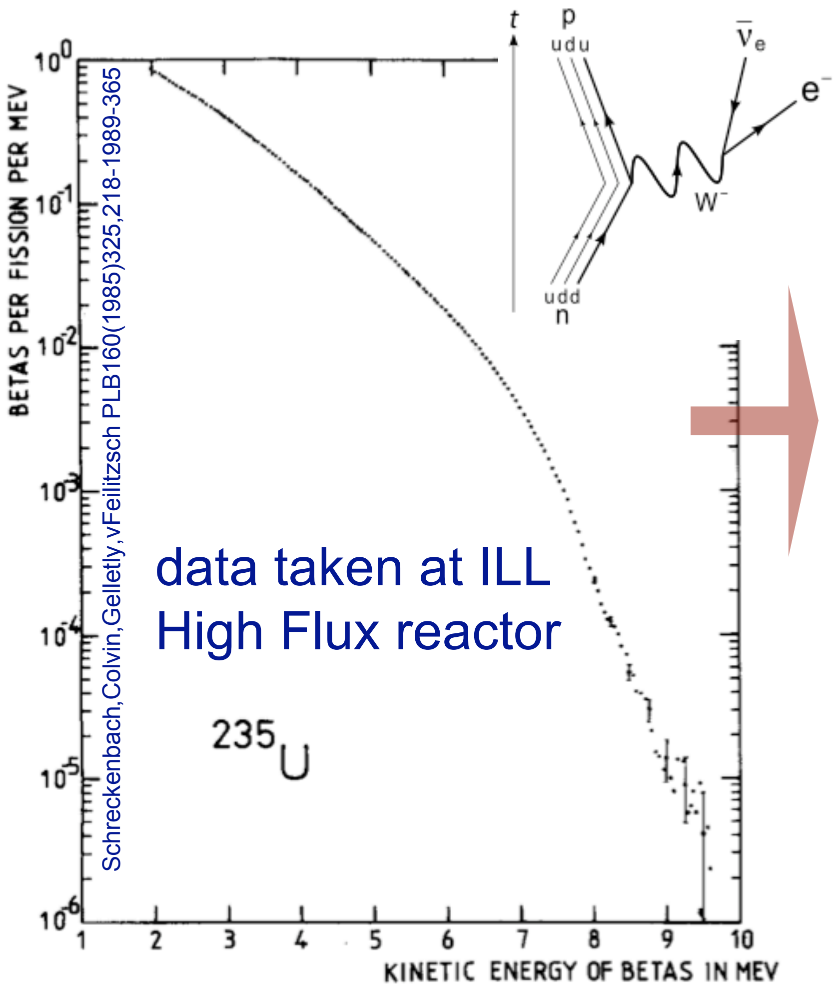
- typical energies of expected decay products are < GeV

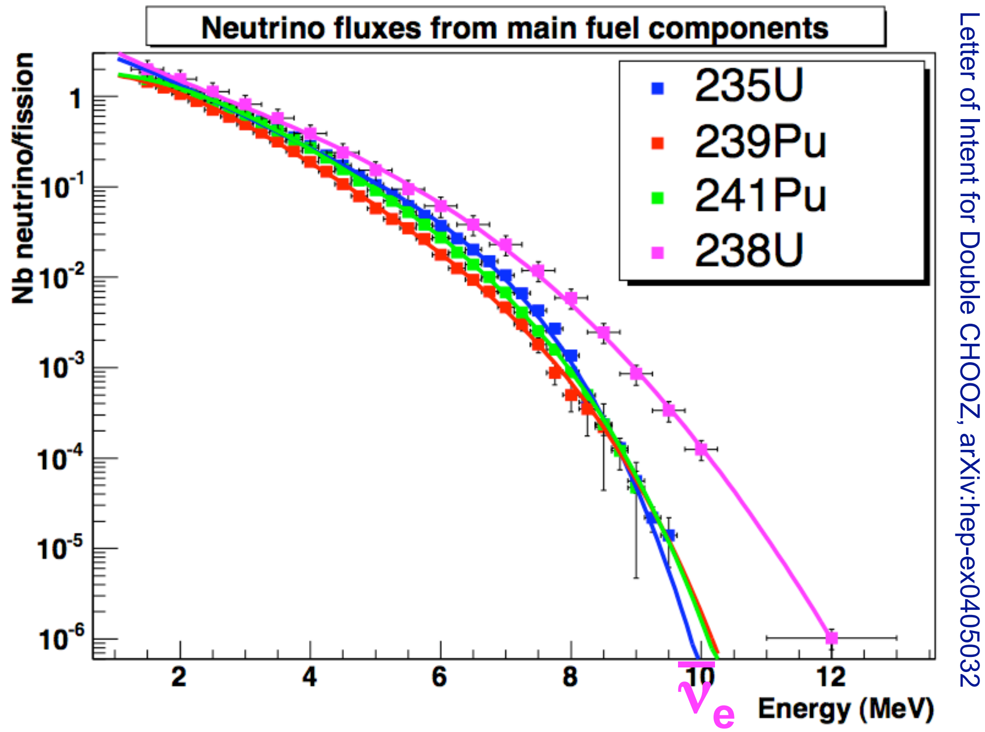
We will discuss here mainly those cases where inverse β process is the leading interaction

Nuclear Power Reactor ν's [$\bar{\nu}_e$ *to be precise ...*]

from β^- decay of fission products in the core:

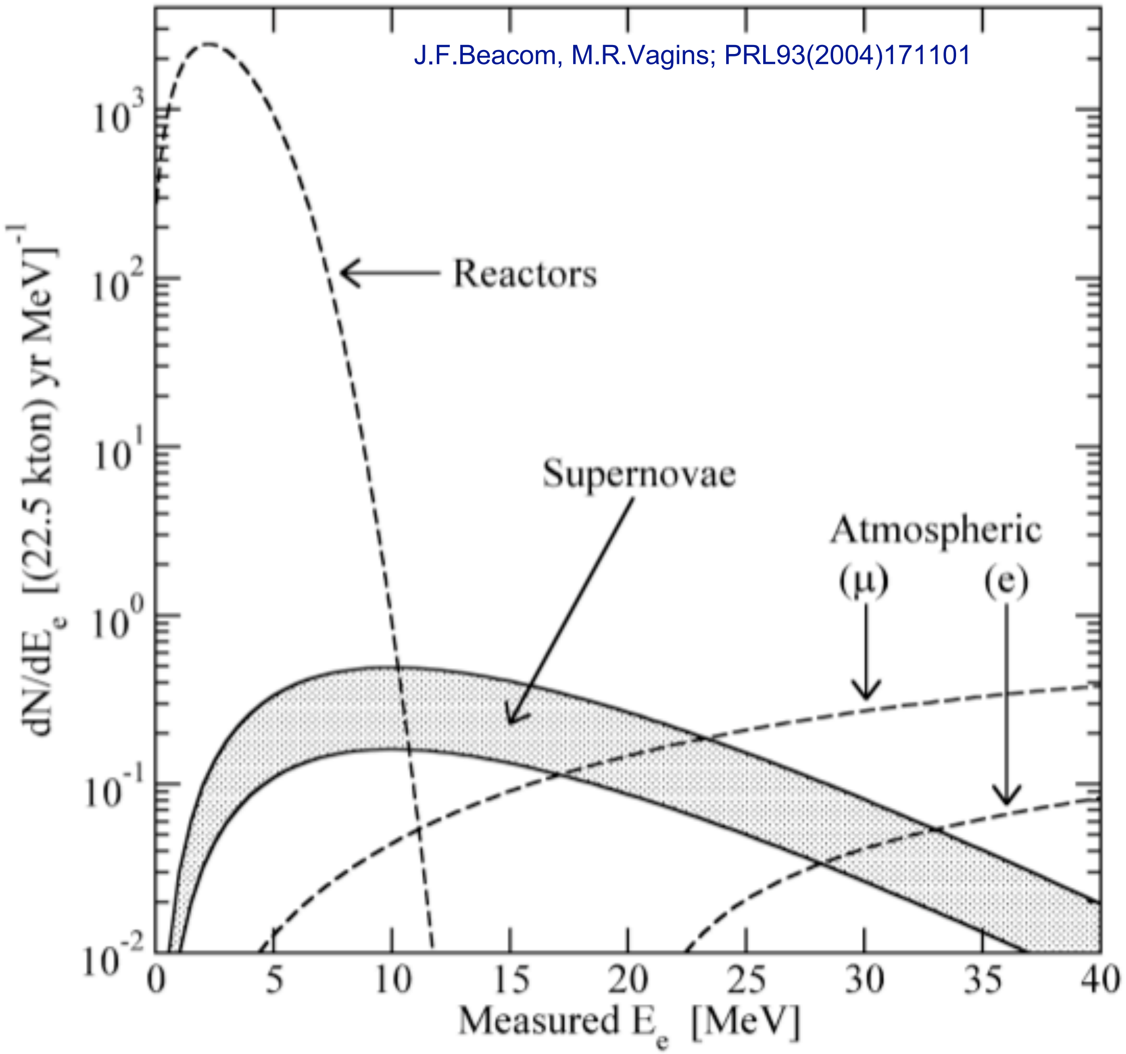






N.P. Reactor ν's

SK will pass from being slightly bothered by *NPR* ν's (those elastic scattered in the detector are an irreducible background to the solar ν measurement) to ...



measure the ν spectrum from Japan's *N*uclear *PR* with high-statistics, ~ 5,000 events / year,

$$\bar{\nu}_e p \rightarrow e^+ n$$

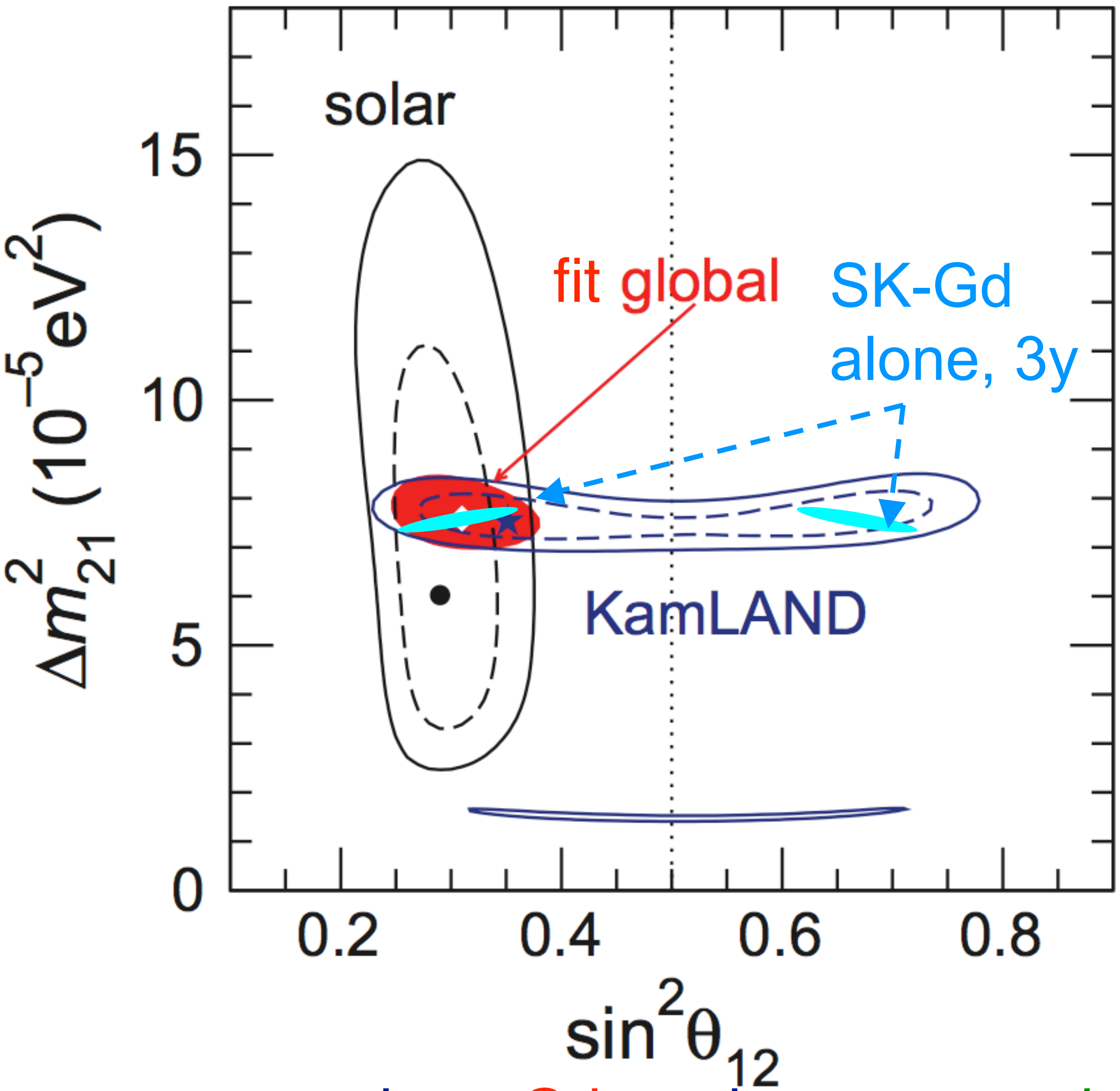
$$Gd \hookrightarrow \gamma\,[e^-]$$

.. almost background free due to the delayed coincidence between e^+ and γ

N.P. reactor ν's

⇨ SK may improve significantly the measurement of Δm^2_{21}

[Global/Solar/KamLAND plot from Schwetz,Tortola,Valle; New J, of Phys.10 (2008)113011]
[SK-Gd estimate translated from Choubey,Petcov; Phys. Lett. B594(2004)333]



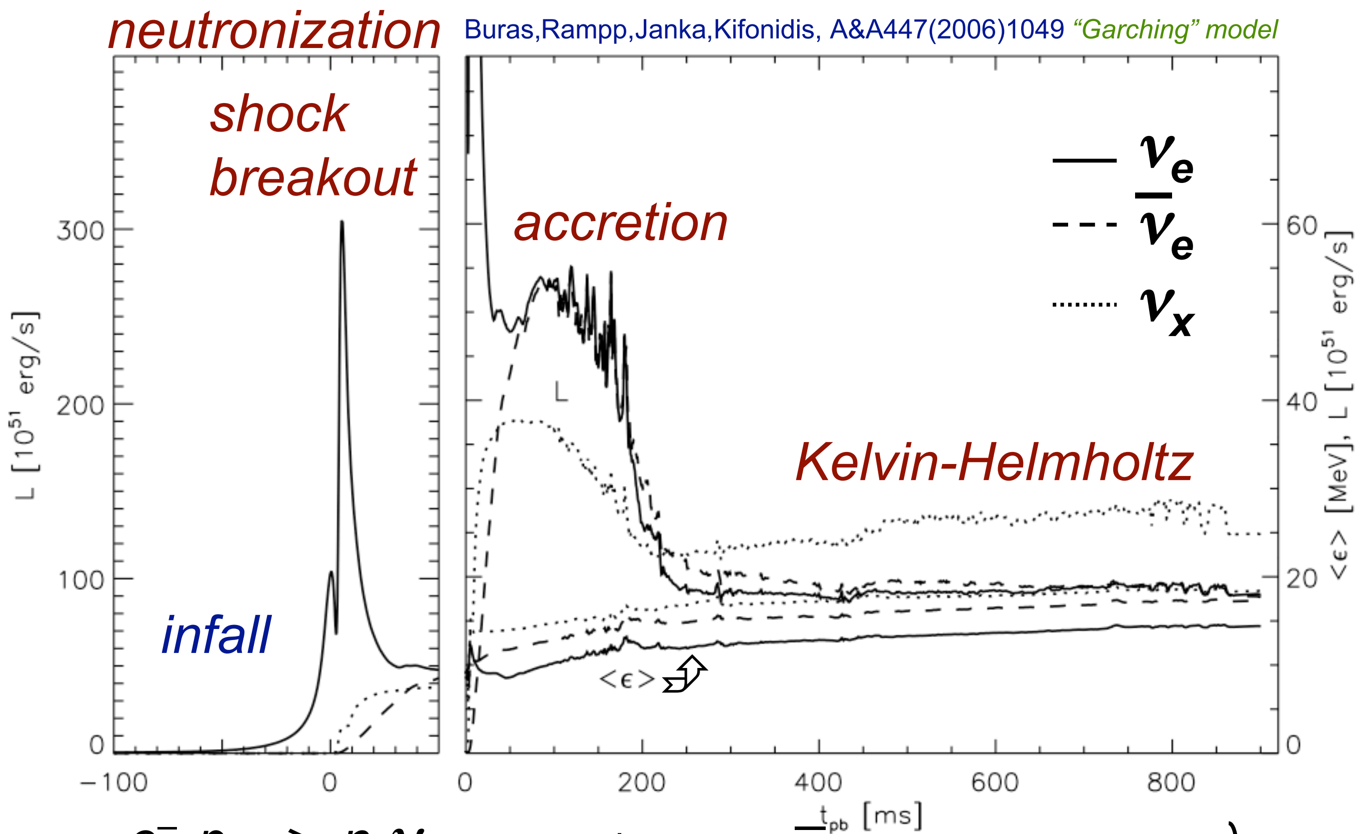
LAGUNA:

MEMPHYS - Gd
~ similar physics reach as *LENA*

⇨ here Gd produces a *very important* improvement

ν's from Super-Nova explosions

main phases:



$e^- p \rightarrow n \, \nu_e$

main reactions:

$e^+ n \rightarrow \bar{\nu}_e \, p$

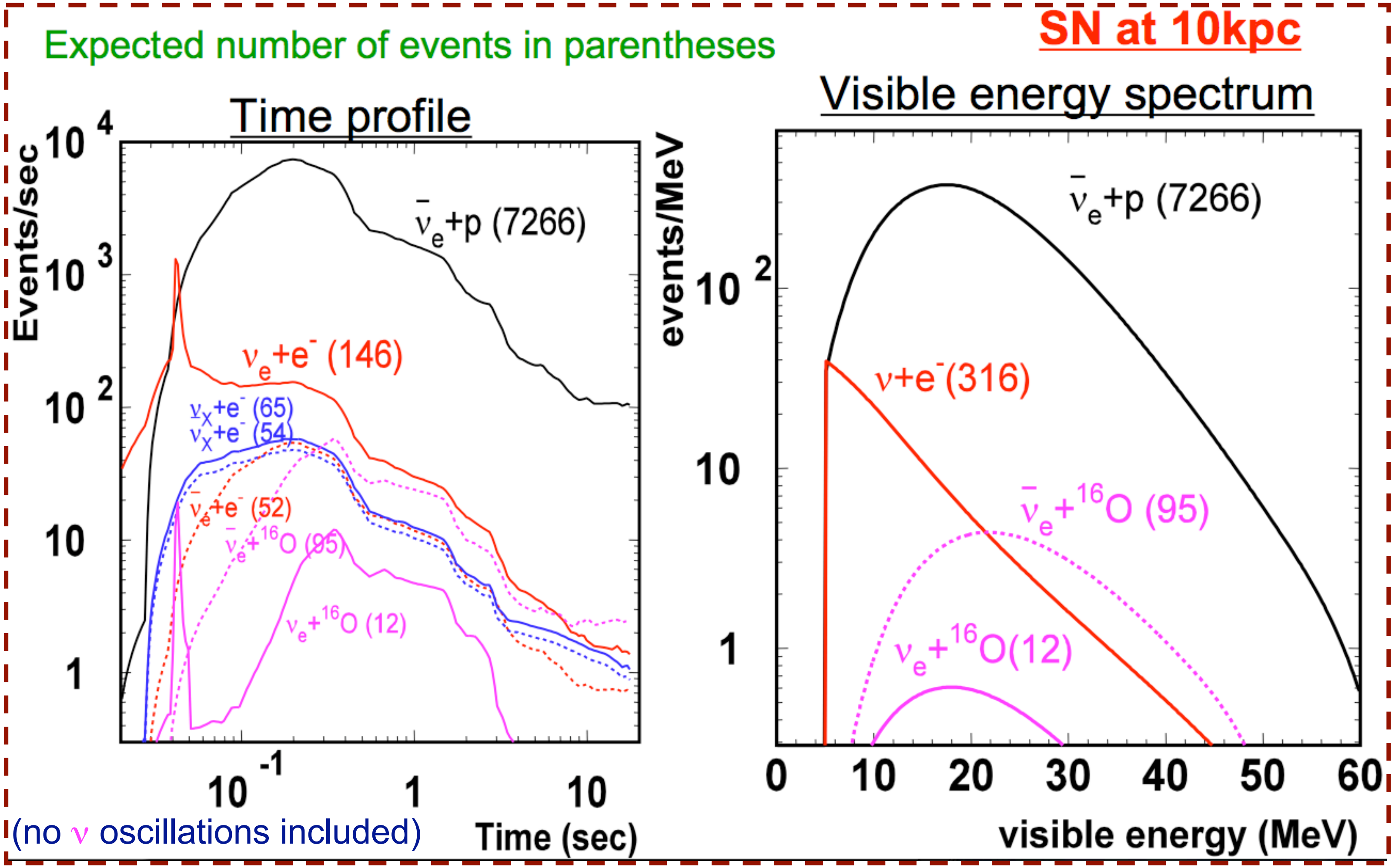
$e^- e^+ \rightarrow \nu_{e,\mu,\tau} \, \bar{\nu}_{e,\mu,\tau}$

$N \, N \rightarrow N \, N \, \nu_{e,\mu,\tau} \, \bar{\nu}_{e,\mu,\tau}$

access to these *reactions*, access to those *phases*

ν's from Super-Nova explosions

measurement expectations at SK

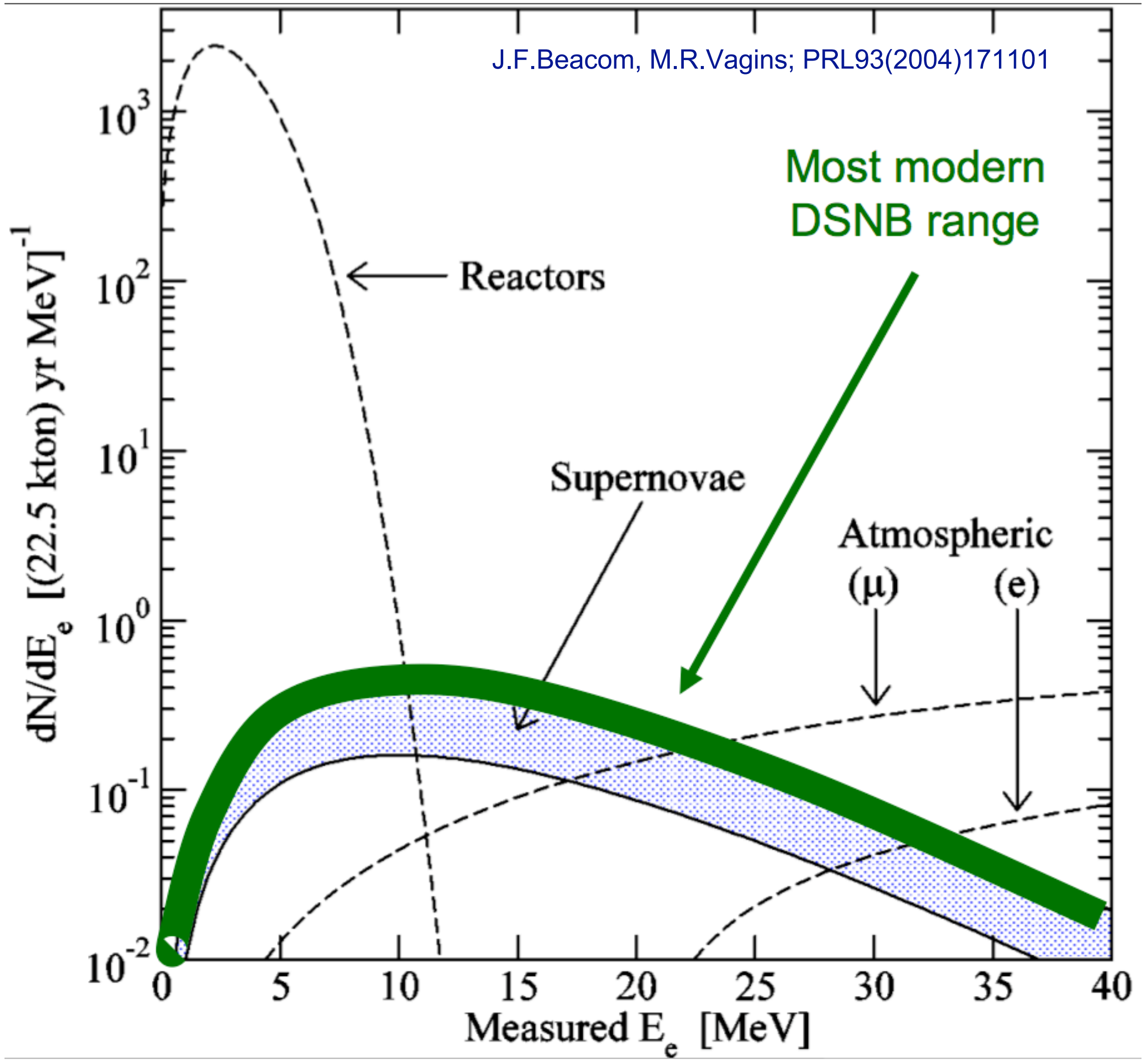


M. Nakahata (ICRR, U.Tokyo); Talk at LP2007
using *"Livermore" model:*
Totani,Sato,Dalhed,Wilson AJ496 (1998) 216

many low E $\bar{\nu}_e$; in principle a good place for Gd ...

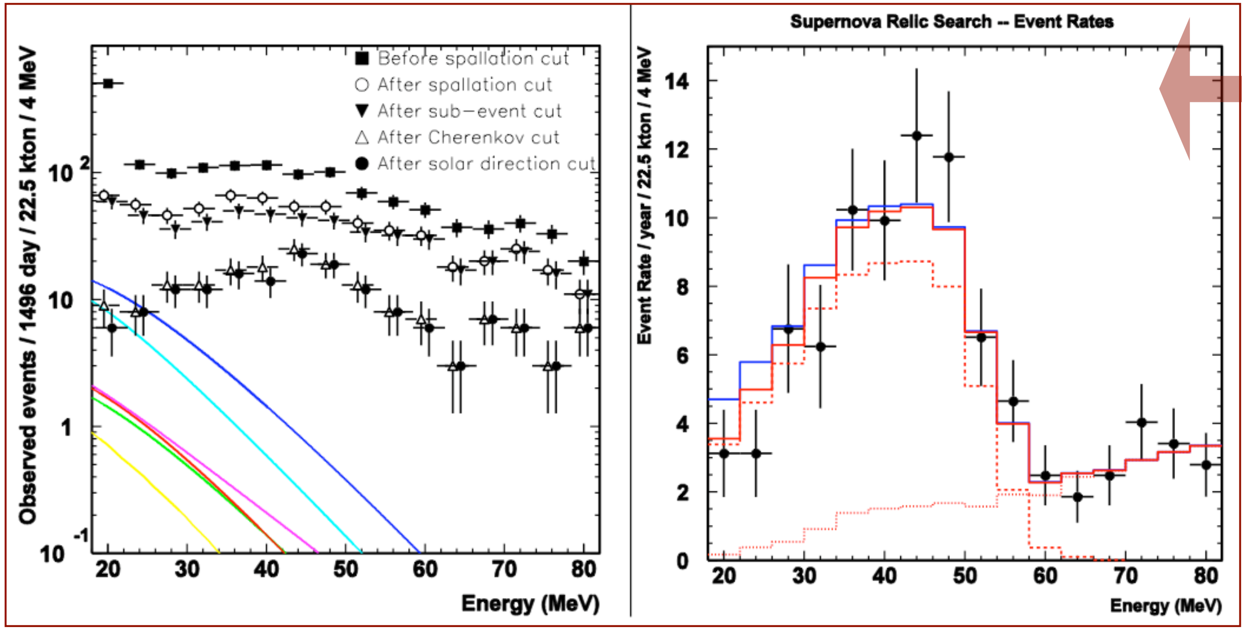
“relic” ν’s or Diffuse SN Neutrino Background (DSNB)

amount of coincident signals in SK-Gd will look like:



looks indeed promising, but what about backgrounds ?

“relic” ν’s or Diffuse SN Neutrino Background (DSNB)



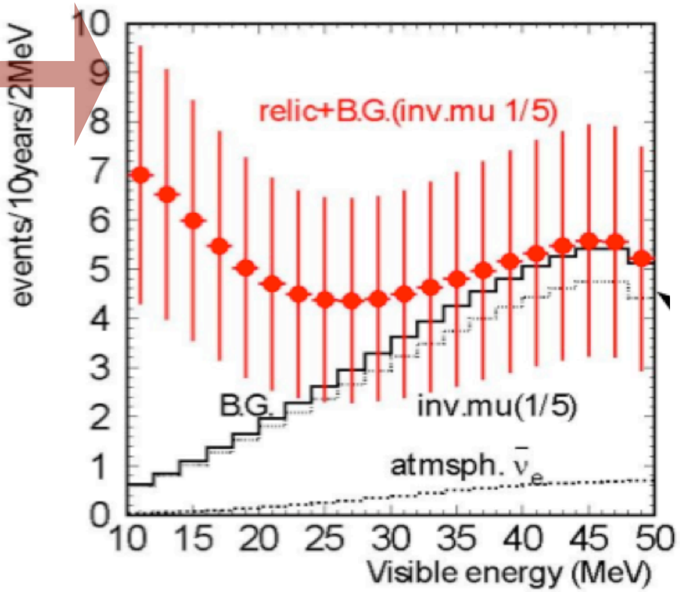
without delayed *n*-tag

world’s best limit (SK)

SK, M.Malek et al. PRL90(2003)061101

overwhelmed by the background

with delayed *n*-tag



Relic model:
AstropartPhys18(2003)307
with flux revised in NNN05

Assumptions:
- 67% detection efficiency
- Invisible μ can be reduced by a factor of 5

SK, 10y, 10-30 MeV
33 signal events
27 bkg. events

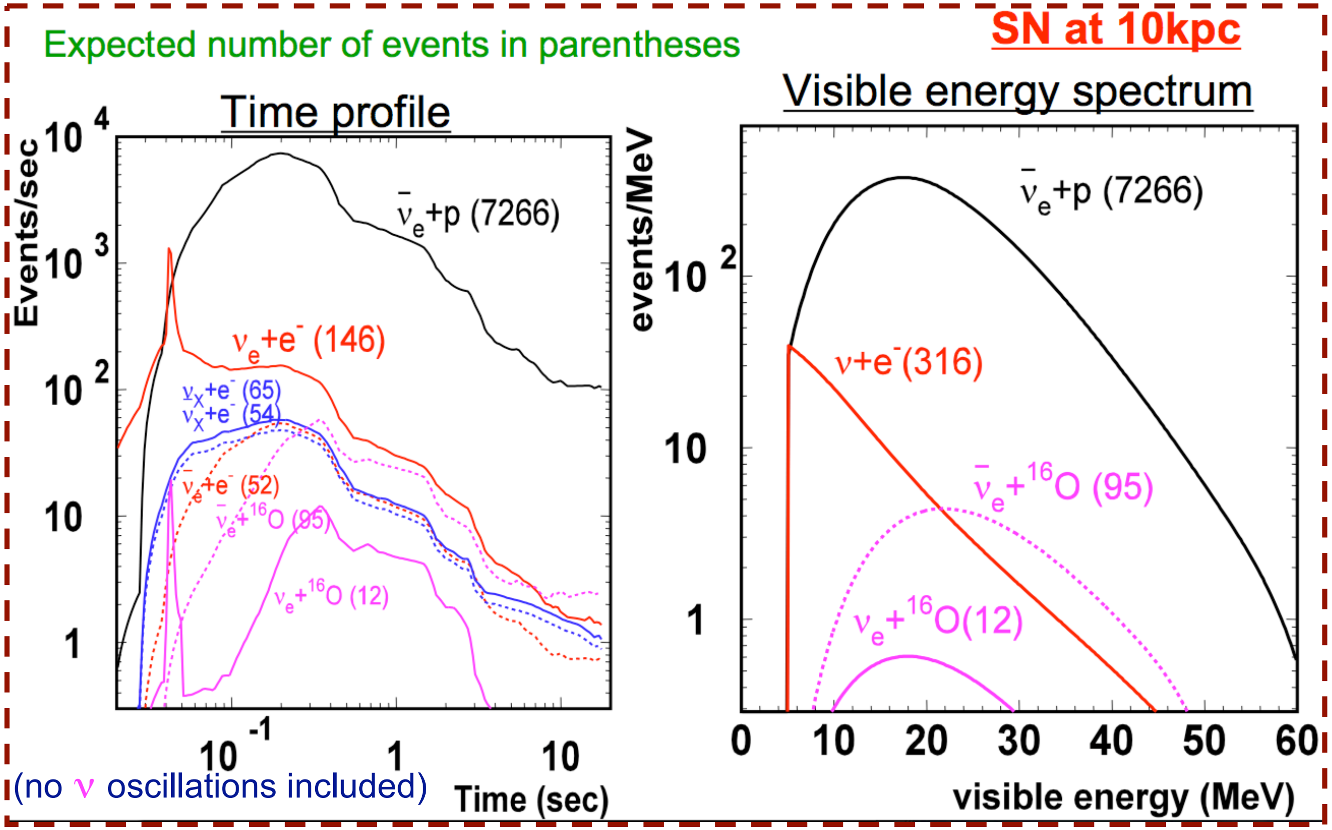
⇩ ⇩ ⇩

SK will *discover DSNB*

⇨ ~100 (60) / y at LAGUNA-WS

⇨ here Gd makes a *breakthrough* difference!

ν's from nearby or very close SN explosions



⇨ ~300000 events at *LAGUNA-WS* from Galactic SN at 10 Kpc

- The $\bar{\nu}_e$ inverse β reacting can be subtracted from the directional elastic scat. e^-, improving significantly the SN direction measurement
- The ^{16}O NC events and ^{16}O CC events no longer sit on a large background but are individually identifiable

⇨ here Gd certainly helps

WC-Gd, something else ?

Most surely yes, but it will come along the learning curve

Some promising ideas follows:

[courtesy of M.Vagins]

1. Early warning (hours or even days before the arrival of the SN ν wave) of large, relatively nearby SN would be possible via the observation of silicon-powered fusion in the dying stellar core
[See Odrzywodek,Misiaszek,Kutschera, *Astropart.Phys.*21(2004)303]
2. Background reduction for (free) *p* decay candidates since there should be no *n* captures seen after the decay of unbound *p*,s
3. Improvement on the limit on “wrong-sign” ν production in the Sun
4. Matter or anti-matter character of the interacting ν from T2K
5. A new, NC channel will likely be opened for the normalization of the total T2K ν flux at SK.
6. It may be possible to collect matter-enhanced and anti-matter-enhanced atmospheric ν samples and compare their oscillatory behavior as a test of CPT violation

⇨ Gd is a “must” at next generation ν detector (*LAGUNA*, *HK*, *DUSEL*); I can not conceive them without *n*-tagging

large guarantee physics output at a “reasonable” price (huge in absolute though), with a *hopefully* foolproof technique

⇨ rough comparison of *LAGUNA* detectors' performance

Table 12. Summary of the physics potential of the proposed detectors for astro-particle physics topics. The (*) stands for the case where gadolinium salt is added to the water of one of the MEMPHYS shafts.

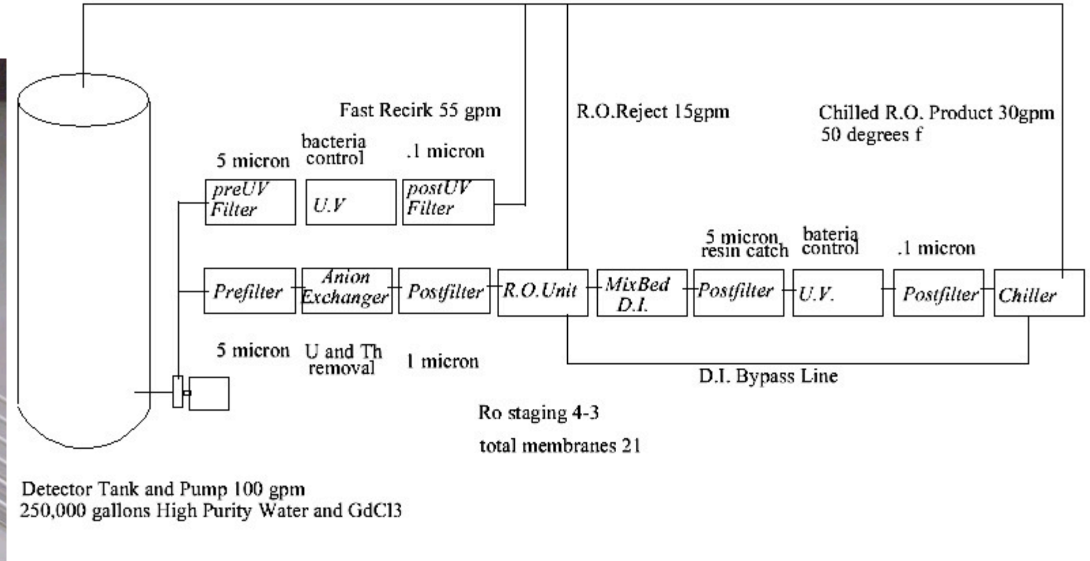
Topics	GLACIER 100 kton	LENA 50 kton	MEMPHYS 440 kton
Proton decay			
$e^+\pi^0$	0.5×10^{35}	—	1.0×10^{35}
$\bar{\nu}K^+$	1.1×10^{35}	0.4×10^{35}	0.2×10^{35}
SN ν (10 kpc)			
CC	$2.5 \times 10^4(\nu_e)$	$9.0 \times 10^3(\bar{\nu}_e)$	$2.0 \times 10^5(\bar{\nu}_e)$ (*)
NC	3.0×10^4	3.0×10^3	—
ES	$1.0 \times 10^3(e)$	$7.0 \times 10^3(p)$	$1.0 \times 10^3(e)$
DSNB ν (S/B 5 yr)	40–60/30	9–110/7	43–109/47 (*)
Solar ν (evts. 1 yr)			
^{8}B ES	4.5×10^4	1.6×10^4	1.1×10^5
^{8}B CC	—	360	—
^{7}Be	—	2.0×10^6	—
pep	—	7.7×10^4	—
Atmospheric ν (evts. 1 yr)	1.1×10^4	—	4.0×10^4 (1 ring only)
Geo ν (evts. 1 yr)	Below threshold	≈1000	Need 2 MeV threshold
Reactor ν (evts. 1 yr)	—	1.7×10^4	6.0×10^4 (*)
Dark matter (evts. 10 yr)	3 events ($\sigma_{ES} = 10^{-4}$, $M > 20$ GeV)	—	—

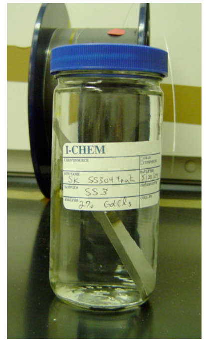
D. Autiero et al.; JCAP11(2007)011

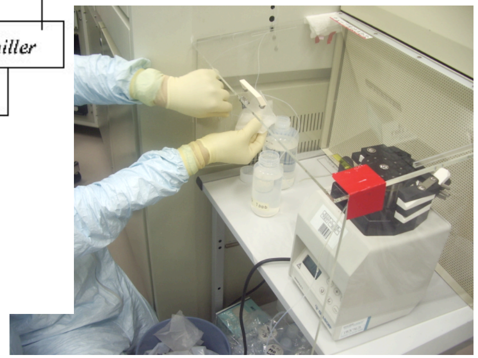
Status of SK R & D program towards dissolving a Gd compound in its water

Gadolinium
Antineutrino
Detector
Zealously
Outperforming
Old
Kamiokande
Super!

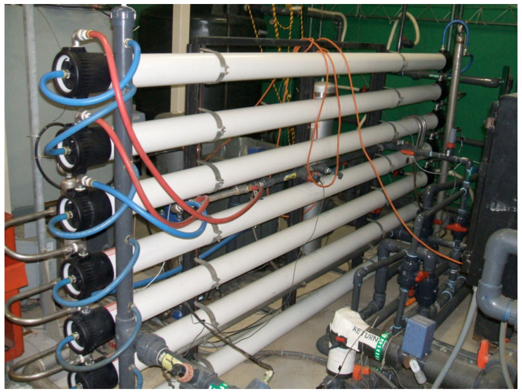
Over the last six years there have been a large number of Gd-related R&D studies carried out in the UCI and Japan:

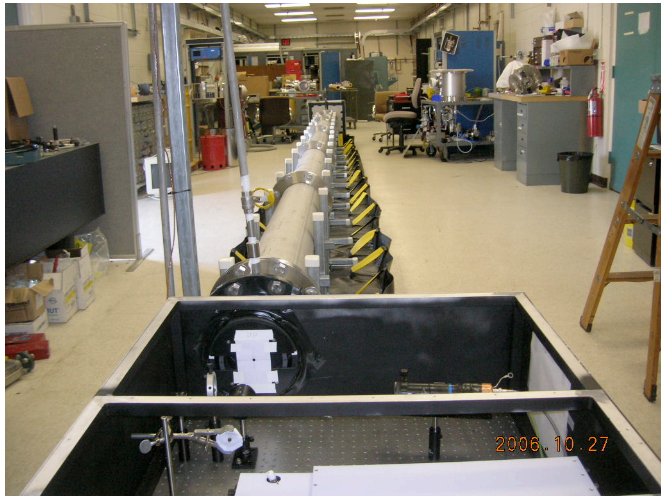






M. Vagins at NNN08 Paris, Sept. 2008






Astroparticle Physics 31 (2009) 320–328
Contents lists available at ScienceDirect
Astroparticle Physics
journal homepage: www.elsevier.com/locate/astropart

First study of neutron tagging with a water Cherenkov detector

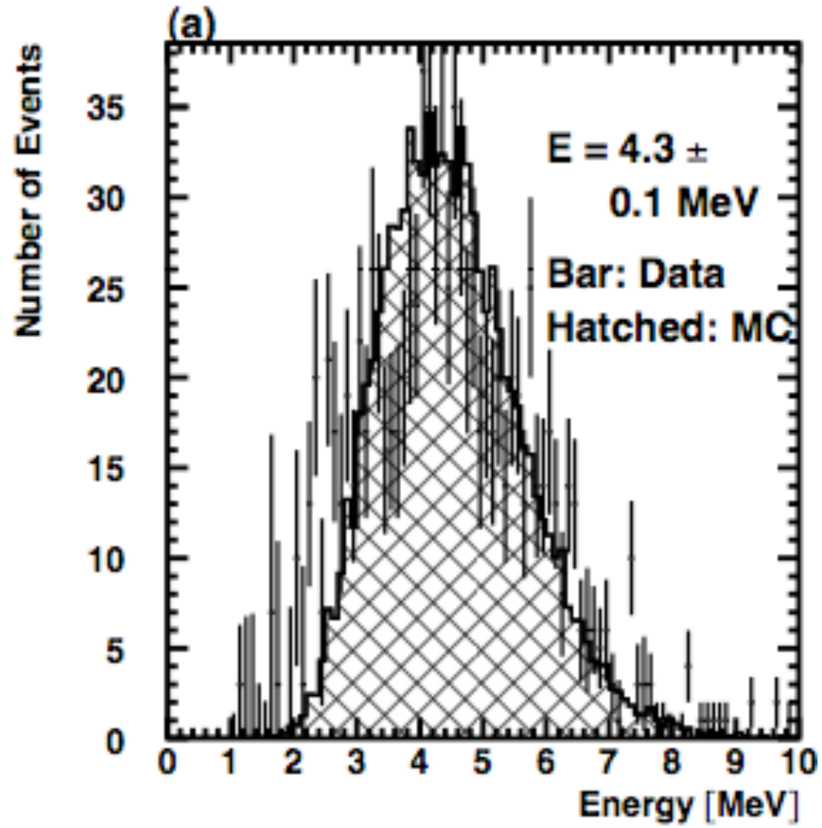
H. Watanabe [a,*], H. Zhang [af,*], K. Abe [a], Y. Hayato [a], T. Iida [a], M. Ikeda [a], J. Kameda [a], K. Kobayashi [a], Y. Koshio [a], M. Miura [a], S. Moriyama [a,ae], M. Nakahata [a,ae], S. Nakayama [a], Y. Obayashi [a], H. Ogawa [a], H. Sekiya [a], M. Shiozawa [a,ae], Y. Suzuki [a,ae], A. Takeda [a], Y. Takenaga [a], Y. Takeuchi [a,ae], K. Ueno [a], K. Ueshima [a], S. Yamada [a]
Y. Furuse, K. Nishijima, Y. Yokosawa, M. Koshiba, Y. Totsuka, M.R. Vagins, S. Chen, Z. Deng, G. Gong [af], Y. Liu [af], T. Xue [af], D. Kielczewska [ag], H.G. Berns [ah], K.K. Shiraishi [ah], E. Thrane [ah], R.J. Wilkes [ah], The Super-Kamiokande Collaboration
[a] Kamioka Observatory, Institute for Cosmic Ray Research, The University of Tokyo, Hida, Gifu 506-1205, Japan

Am / Be source:

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

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

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.

Next and ***"decisive"*** step is a dedicated Gd ***test-tank***, complete, with its own ***water-filtration*** system, 50*cm* PMT's, DAQ, etc.

⇨ ***EGADS*** facility
[Evaluating ***G***adolinium's ***A***ction on ***D***etector ***S***ystems***]***

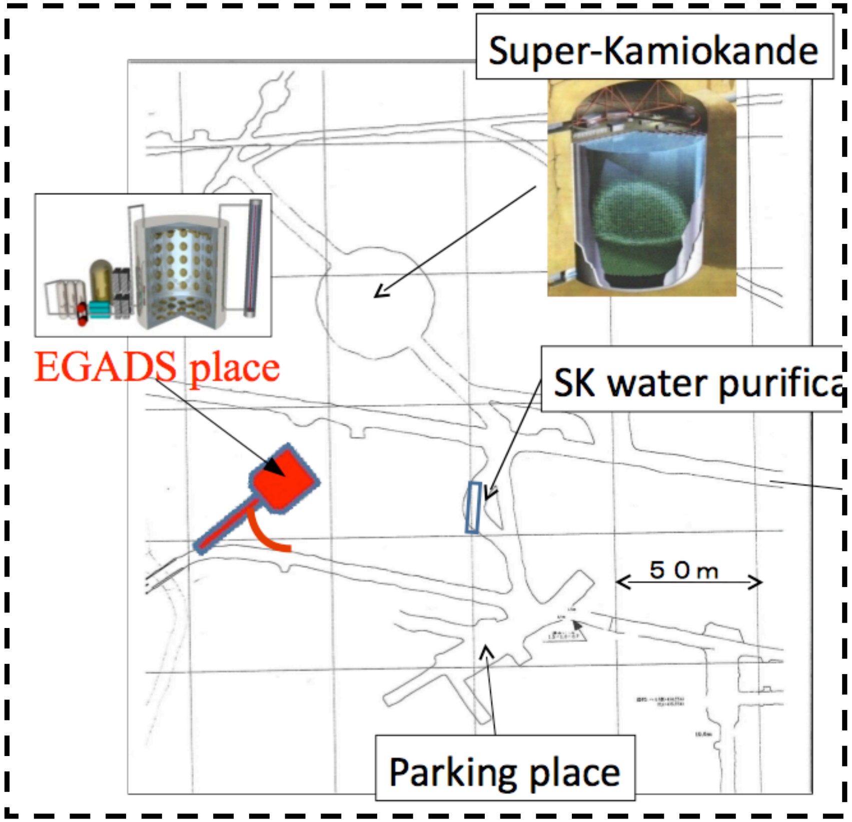
In June 2009 we got full funding (~ 400 M-*Yen*) for the project !

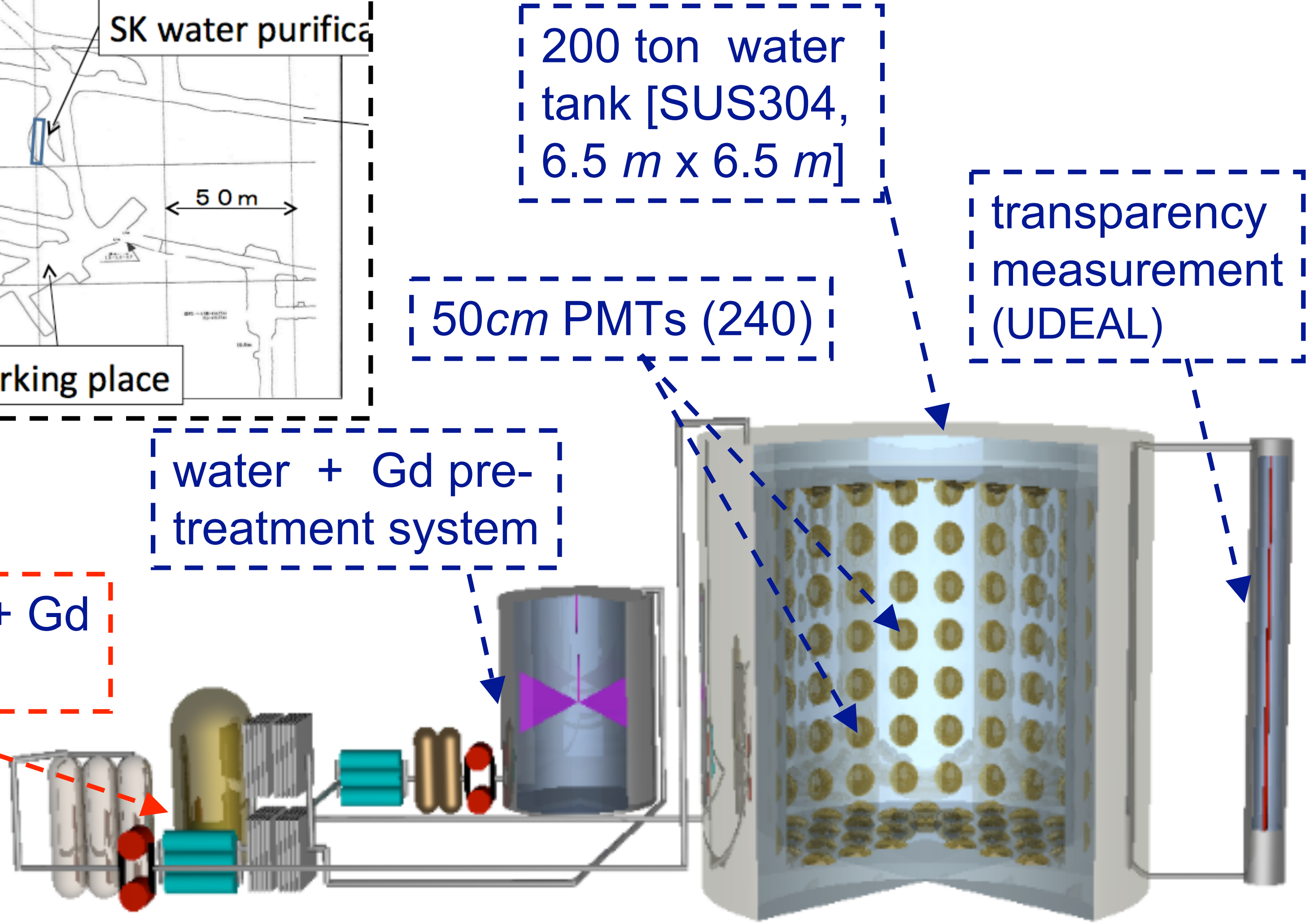
FY2009: Design and construction of test-tank and PMT-support structure ✓

FY2010: water-filtration system, water-attenuation-length measurement system, preparation + mounting of PMT's, installation of DAQ electronics and computers

FY2011 to FY2013: experimental program to address technical, reconstruction and background issues

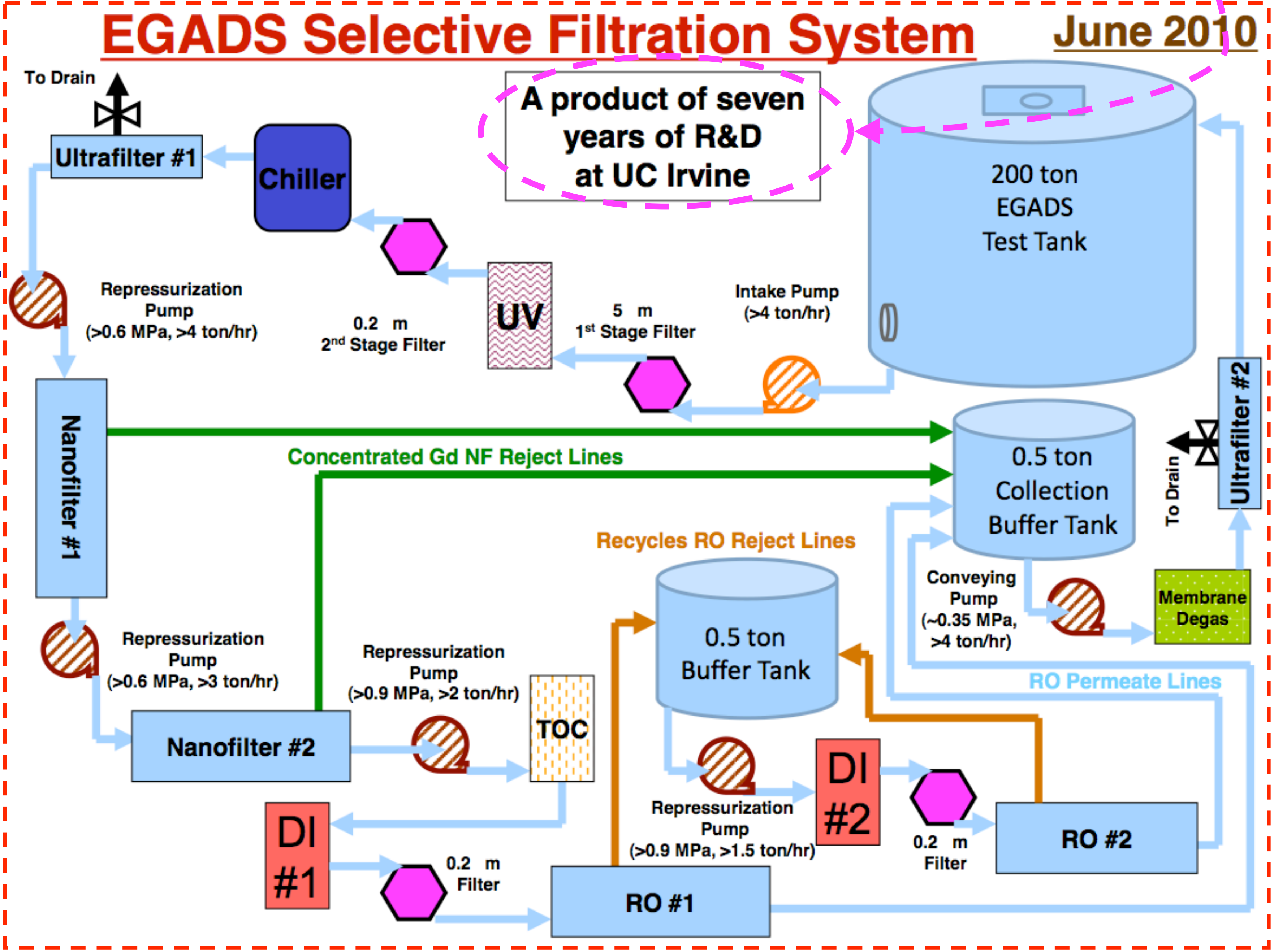
main characteristics of *EGADS*





A key ingredient:

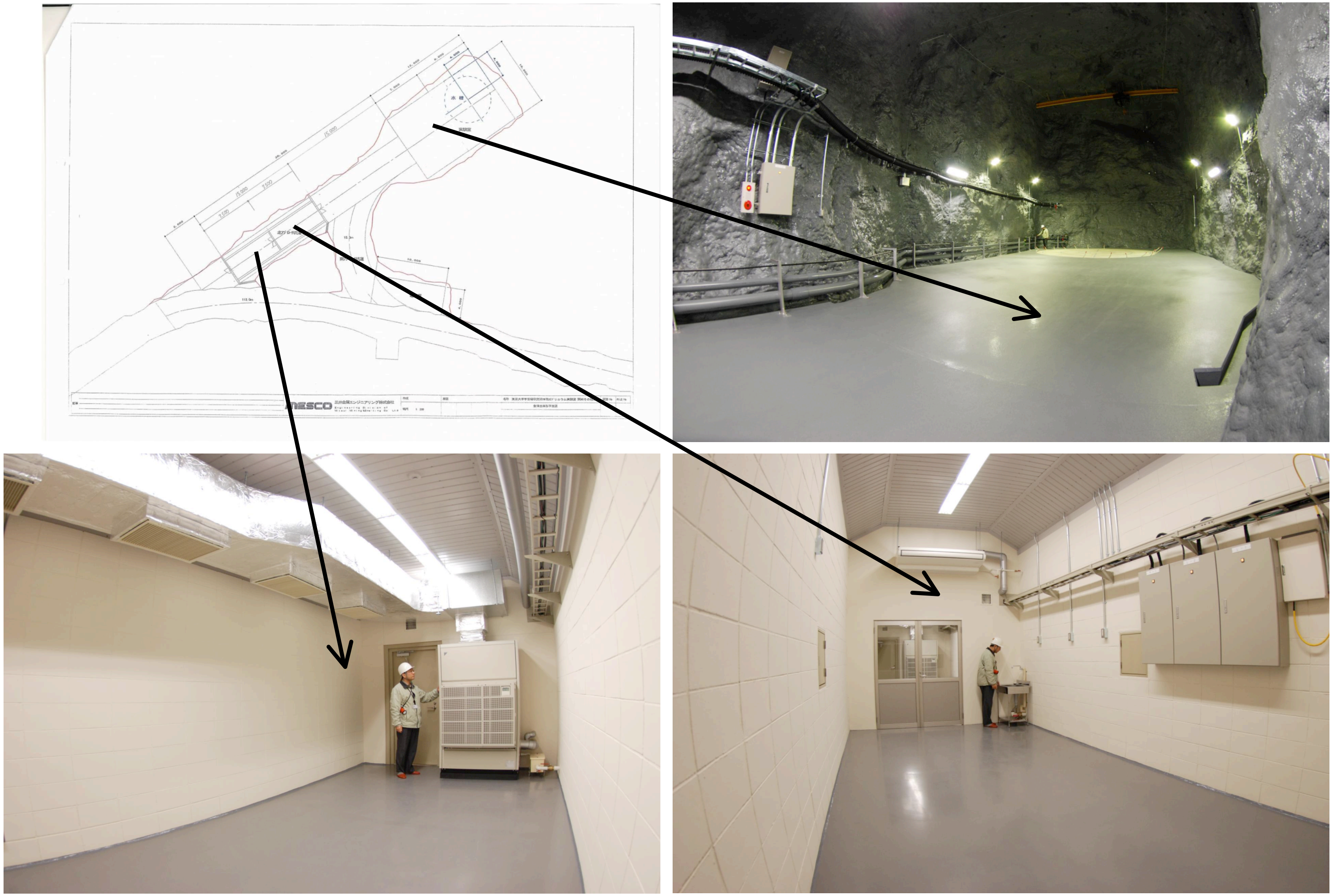
a truly pioneering work



M. Vagins at NEUTRINO 2010

A new underground experimental hall for EGADS

excavation started in September 2009 ....



the exp. hall was fully finished, with all services, by March 2010 ¡Bravo!

the EGADS tank

bidding process ended September 2009 ....

a through leak test was carried out last week-end ✓ ¡¡Bravo!!

Next:

→ mounting and commissioning of water-attenuation-length measurement system (UDEAL)

→ water-Gd pre-treatment system, selective-water-filtration system ...

→ preparation + mounting of PMT's, installation of DAQ electronics and computers

....

→ experimental program; long term stability assessment

....

... hopefully put the Gd in SK !

Thank you