R&D For A Water Cherenkov Detector With Gd Solution

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For Super-K Gd R&D Project

@HAνSE11 (DESY 2011.07.22)

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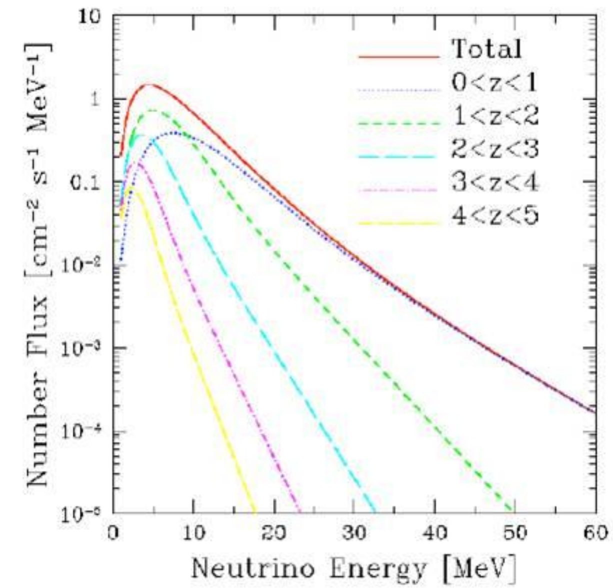
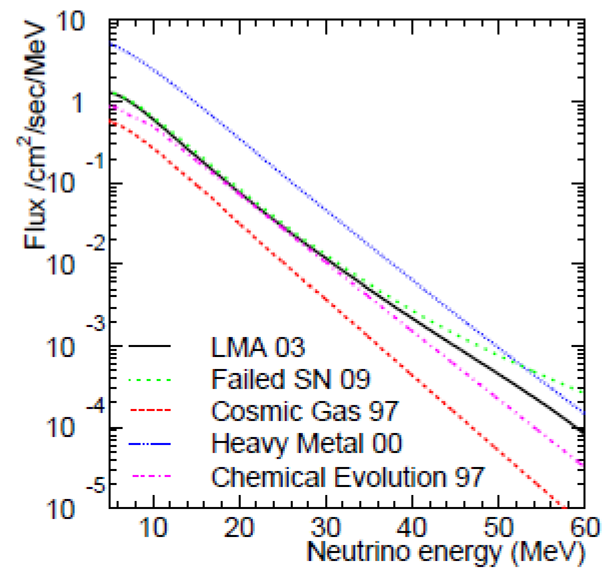
1. Supernova Relic Neutrinos (SRN)
(or Diffuse Supernova Neutrino Background, DSNB)

- Neutrinos produced from the past supernova explosion since the biginning of the formation of the stars (SRN or DSNB) are about to be seen. The predicted neutrino flux is still uncertain by ~10.



$$F(E_\nu) = c \int_0^{z_{\max}} R_{SN}(z) \left. \frac{dN_\nu(E_\nu^{'})}{dE_\nu^{'}} \right|_{E_\nu^{'}=(1+z)E_\nu} (1+z) \frac{dt}{dz} dz$$

- $R_{SN}(z)$:SN rate per unit comoving volume at redshift z.
  - SN rate = Star Formation History (Initial Mass Function) M>8Ms
  - SN rate = Metal Enrichment (Z>6) History

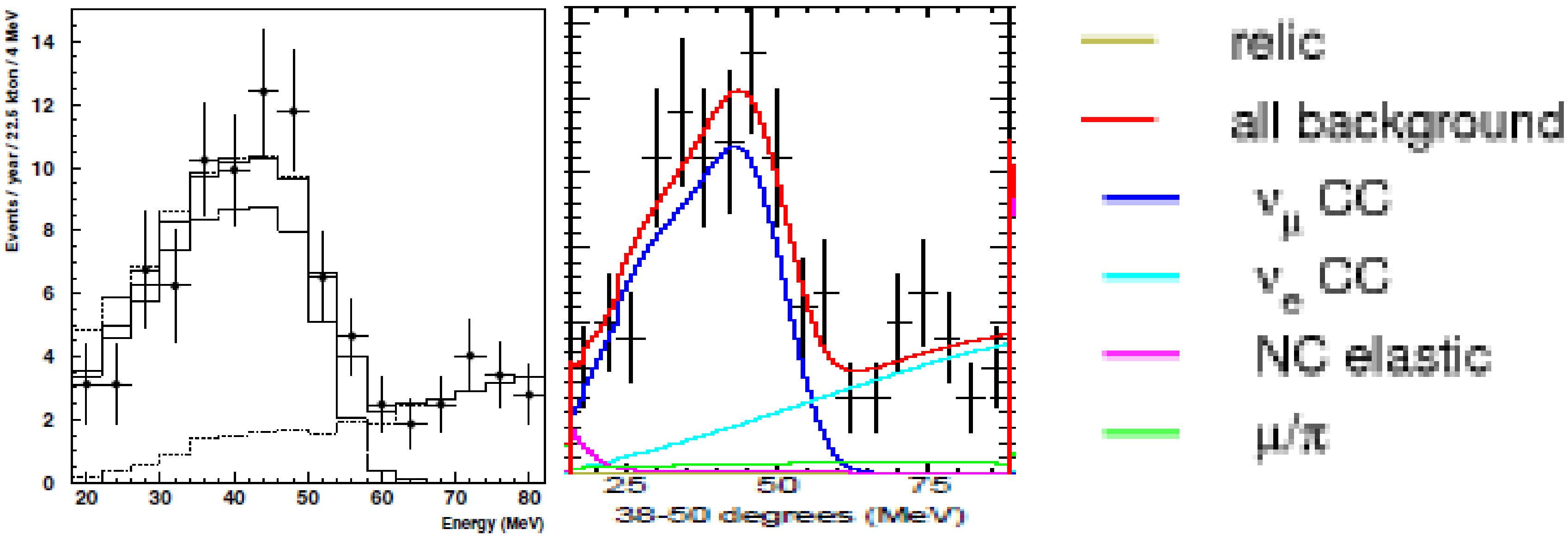


Super-K search for SRN

- Super-K ($\bar{\nu}_e + p \to e^+ + n$ Single tag): K.Bays etal.,(2011 Official) analysed SK-I,SK-II and SK-III data, and updated the result of Malek etal.,PRL90,061101,2003.
- Improvements: Spallation cut (E_{th}=16MeV←18MeV) and Cherenkov angle cut, Poisson statistics and MC calculations

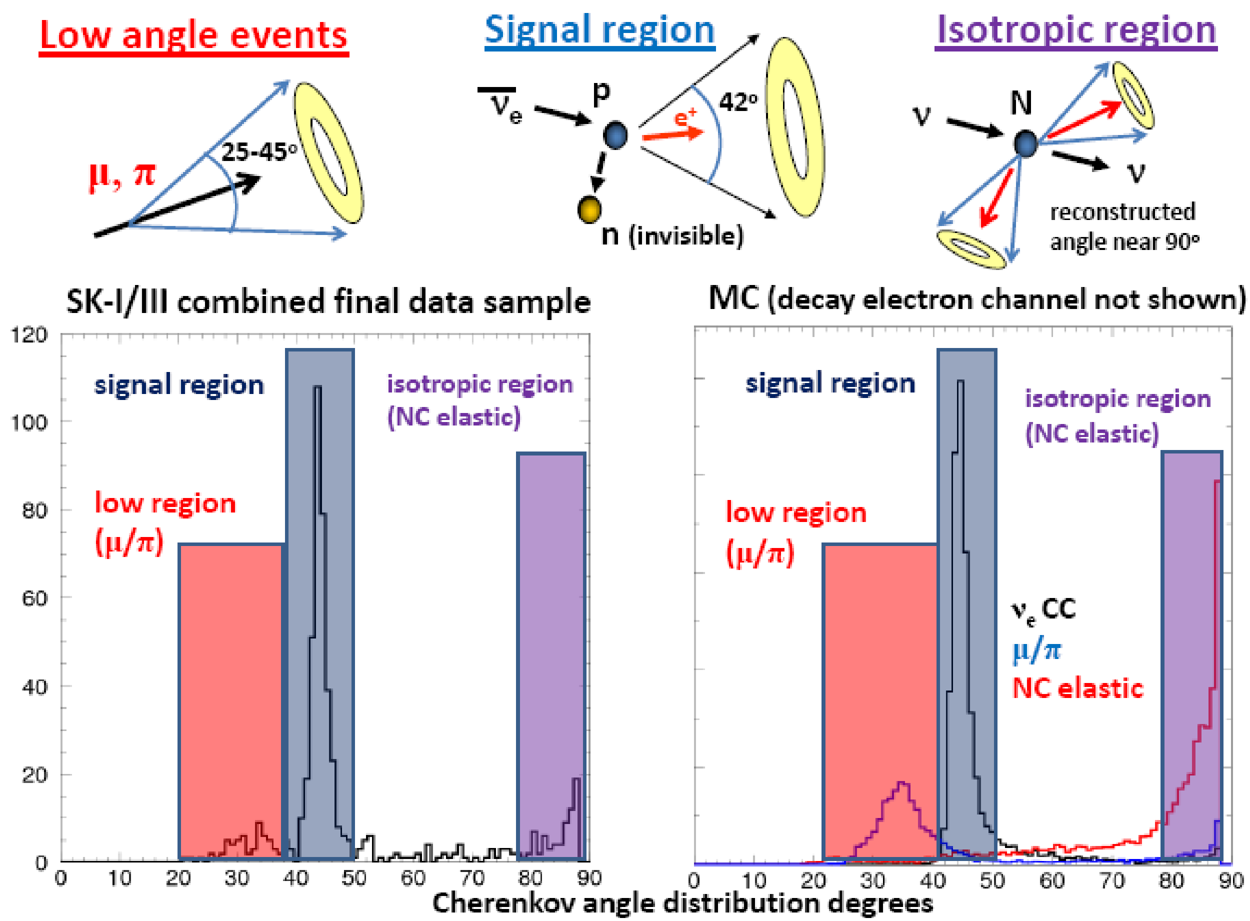
($\sigma(\bar{\nu}_e + p \to e^+ + n)$, ATMν NC elastic+primary/secondary γ's, pion absorption)

Malek et.al.(2003) Bays et.al.(2011)

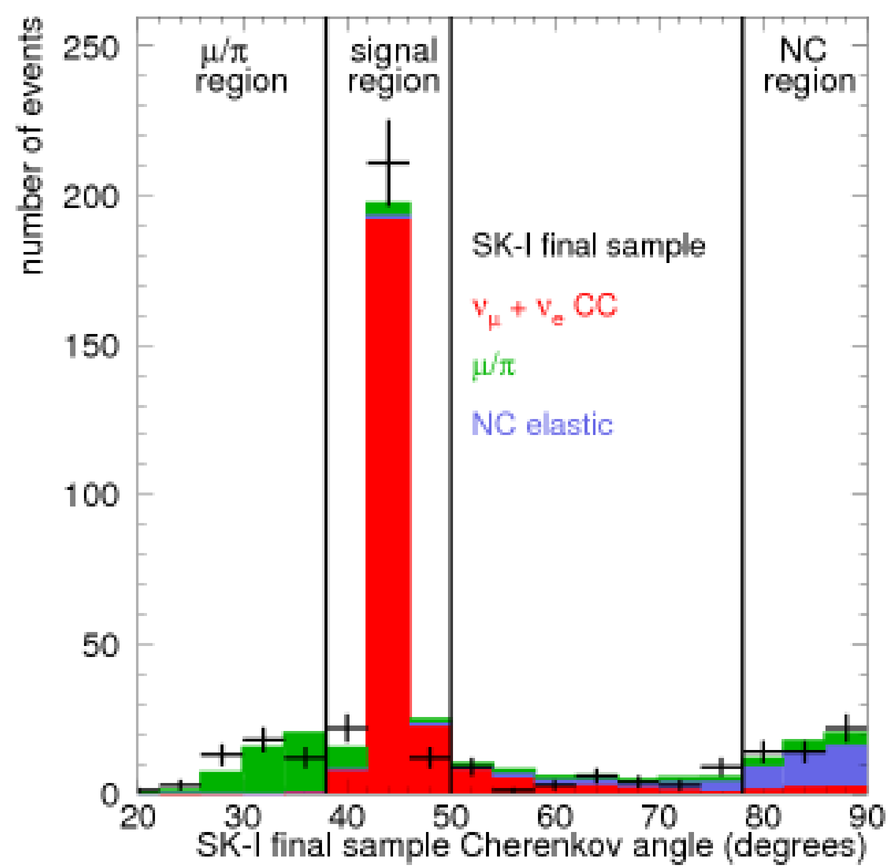


Cherenkov angle cut to discriminate event types

- Good agreement between data and MC



all relic cuts except C. angle applied



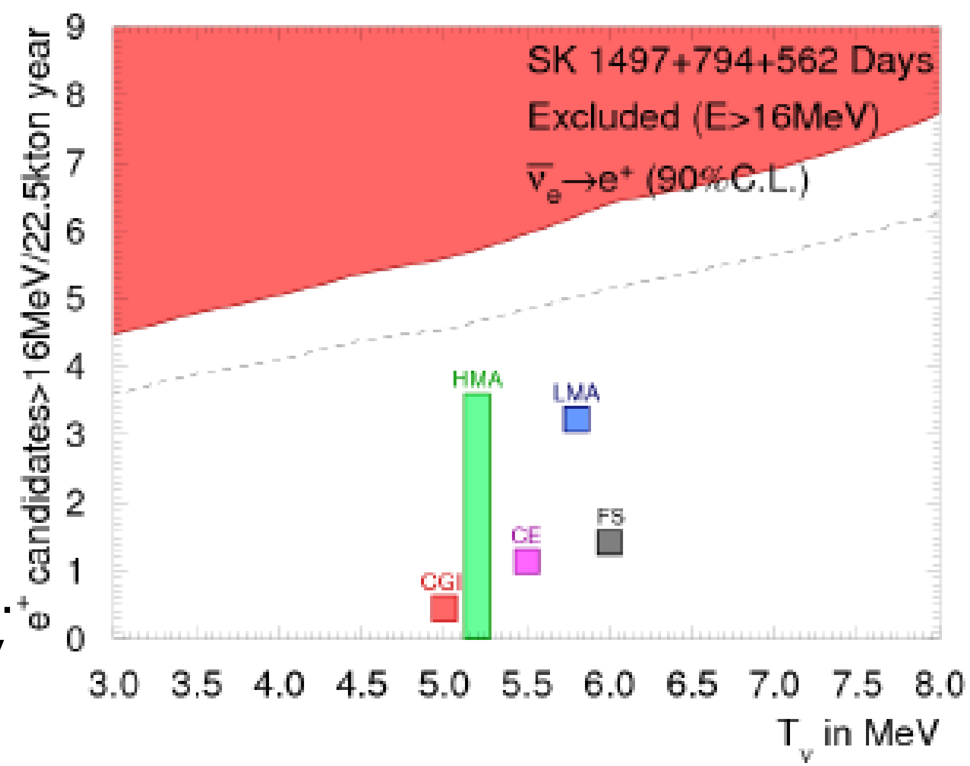
Super-K limit on SRN (2011)

Results: flux limits ($\bar{\nu}_e cm^{-2}s^{-1}$)

E_{e+} > 16 MeV	SK-I	SK-II	SK-III	Combined	Predicted
LMA (03)	2.46	7.65	8.03	2.86	1.7
Cosmic gas Infall (97)	2.10	7.45	7.82	2.75	0.3
Heavy Metal (00)	2.18	7.35	7.80	2.77	< 1.8
Failed Supernova (09)	2.36	7.95	8.44	2.95	0.7
Chemical Evolution (97)	2.22	7.23	7.84	2.80	0.6

Ando = Ando et al (LMA model)
KSW = Kaplinghat, Steigman, Walker (heavy metal abundance)
Mala = Malaney (cosmic gas infall)
Fail = Lunardini (failed SN model)
H/W = Hartmann/Woosley (chemical evolution)

Linear Scale!



This result: flux<2.9$\bar{\nu}_e$(1/cm²/sec) for E_e>16MeV @90%CL.

Malek(2003): flux<1.2 (1/cm²/sec) for E_e>18MeV
--Limit is not more stringent, but similar.

Unfortunately, just increasing statistics will not make us reach SRN.
We must reduce atmospheric neutrino background significantly. →Gd option.

Other experimental searches for $\bar{\nu}_e$ (SRN)

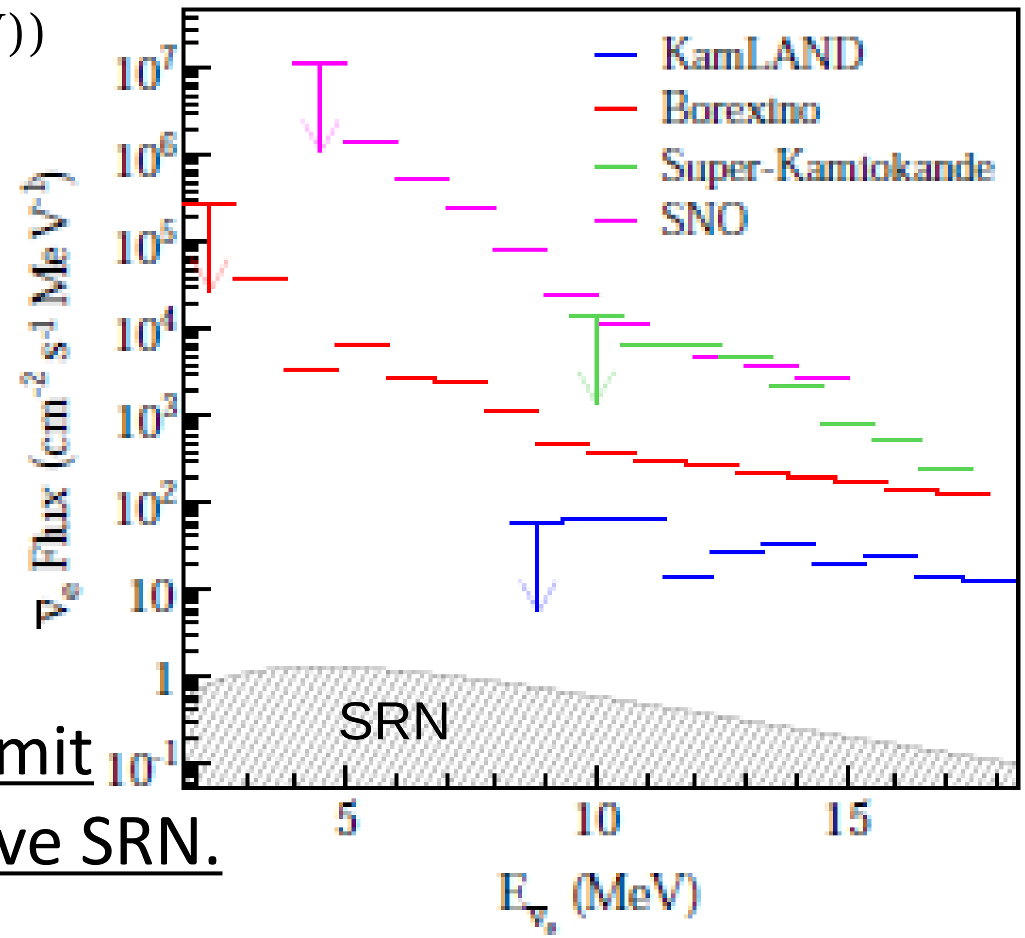
-All these liq.scinti detectors have delayed coincidence (double tag) for a signal.

- KamLAND: $\bar{\nu}_e + p \rightarrow e^+ + n \quad (n + p \rightarrow d + \gamma)$ (8.3MeV<E_ν<30.8MeV)
  - A.Gando etal.,arXiv:1105.3516.
- SNO: $\bar{\nu}_e + d \rightarrow e^+ + n + n \quad (n + d \rightarrow \gamma(6.25MeV))$
  $(4 < E_{\bar{\nu}} < 14.8MeV)$
  - Aharmim etal., PRD70,093014(2004).

  $\nu_e \quad (21 < E_\nu < 35MeV)$
  - Aharmim etal., APJ653,1545(2006)
- Borexino :

  $\bar{\nu}_e + p \rightarrow e^+ + n \quad (n + p \rightarrow d + \gamma)$
  - G.Bellini etal.,PLB696,191(2011)
- <u>Even KamLAND (4.53kton year) limit is still 2 orders of magnitude above SRN.</u>

Fig from KamLAND paper.



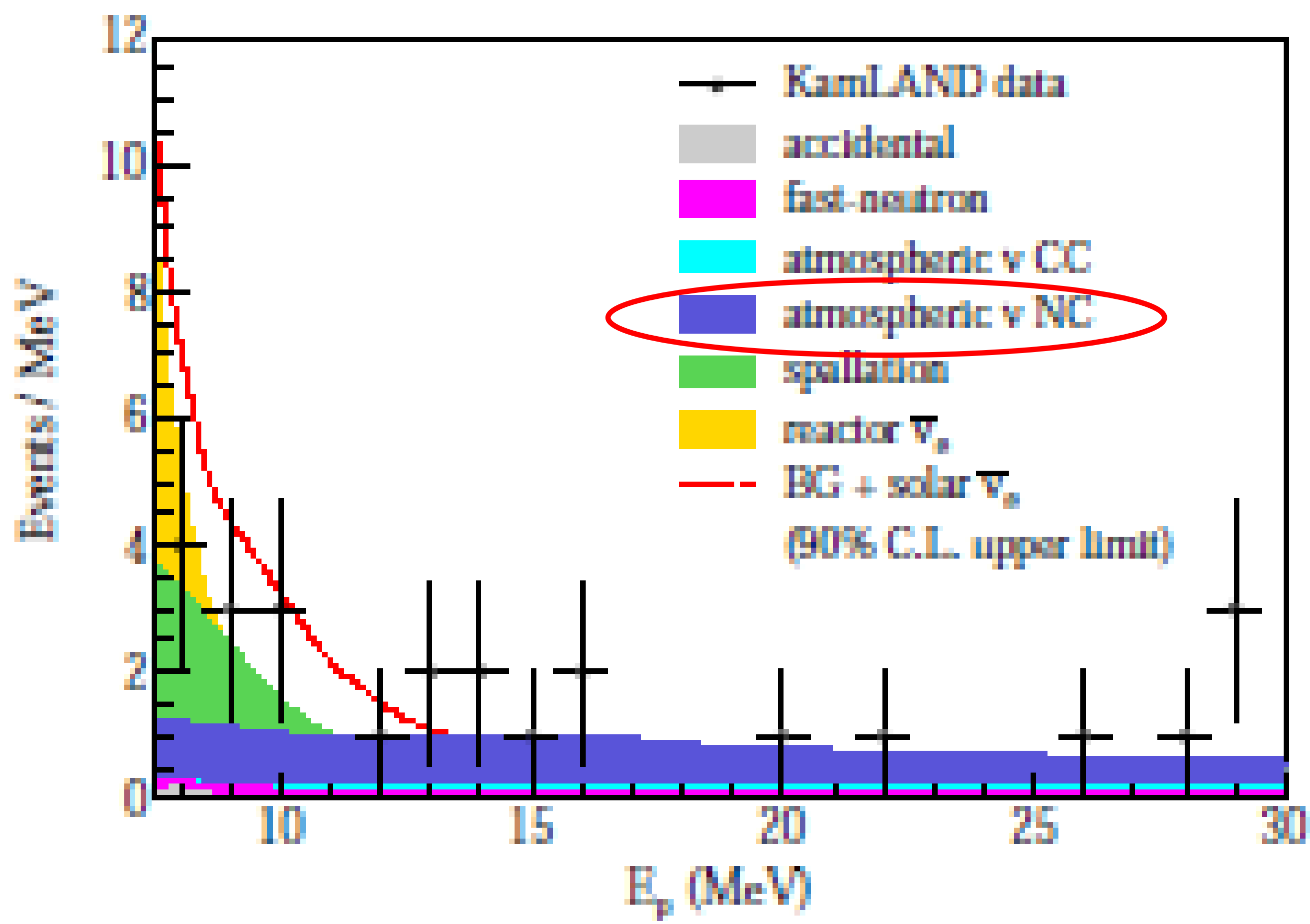
KamLAND's 25 $\overline{\nu}_e$ *Candidates* and MC estimation

A.Gando et al.,arXiv:1105.3516.

- They concluded that "Atmospheric ν NC background will be a challenge for future Large Liq.Scintillator detectors". Fig. from KamLAND paper.

arXiv:1105.3516.

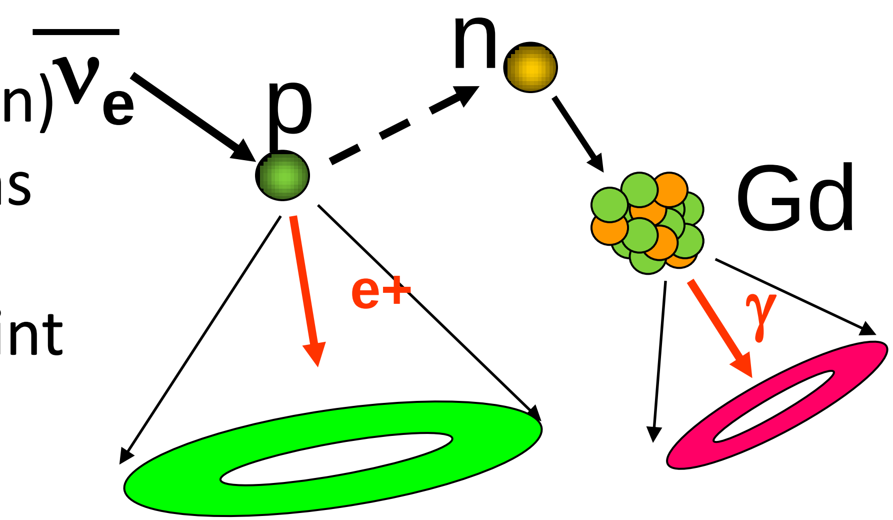
Background	Number of events
Random coincidences	0.22 ± 0.01
Reactor $\overline{\nu}_e$	2.2 ± 0.7
^{9}Li	4.0 ± 0.3
Atmospheric ν (CC)	0.9 ± 0.2
Atmospheric ν (NC)	16.4 ± 4.7
Fast-neutron	3.2 ± 3.2
Total	26.9 ± 5.7

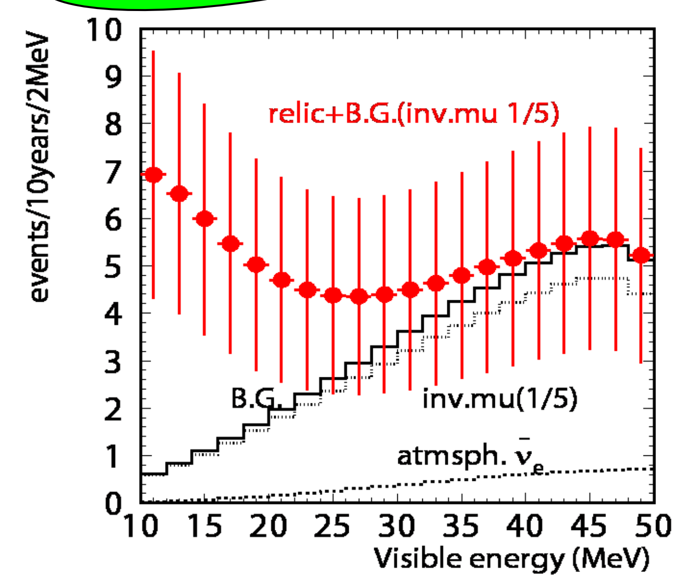


Possibility of a neutron tagging in SuperK

John F. Beacom and Mark R. Vagins, Phys.Rev.Lett. 93 (2004) 171101

- Large cross section of Gd for neutron capture
  - ~49,000 barns (0.3 barns on free proton)
  - neutron captured Gd emits 3-4 gammas in total energy 8MeV
- Delayed coincidence, same as other liq.Scint detectors
- This coincidence will lower analysis threshold down to 10 MeV. →x3 statistics.
  - Assuming Invisible muons be reduced by a factor of 5 and neutron eff.=67%.
  - Spallation events can be suppressed by 2×10^{-4}. – shown by data.





Expected number of SRN events: - 0.8 -5.0 events/year/22.5kton (10-30MeV)

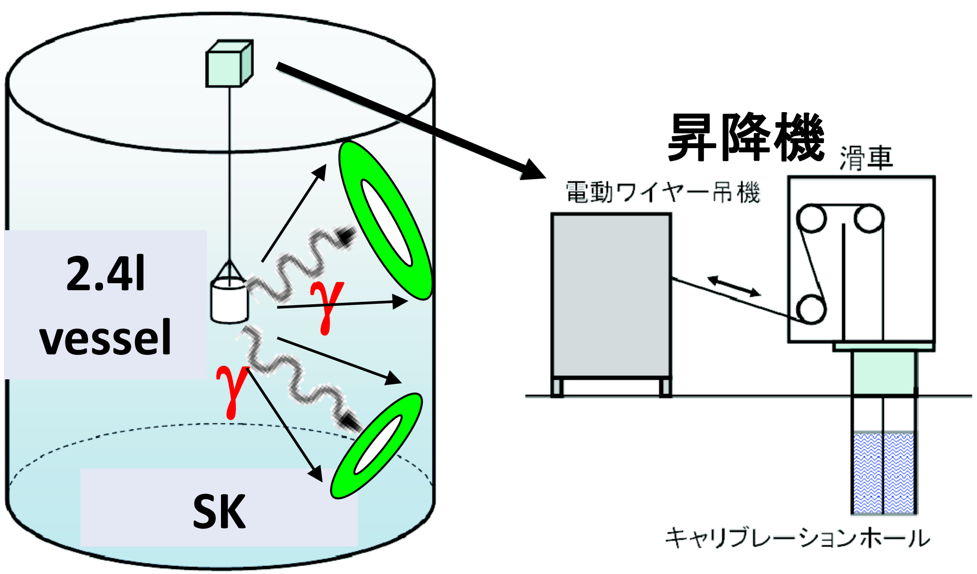
- 0.3 -1.9 events/year/22.5kton (18-30MeV)

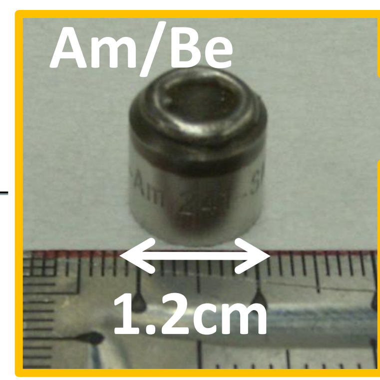
2. Test of Neutron Tagging Measurement at SK

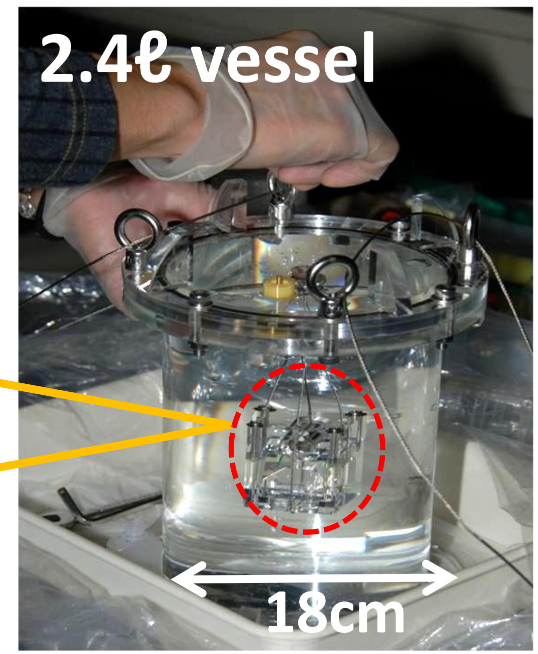
A test with 2.4litter vessel (0.2%$GdCl_3$) has worked.

H. Watanabe et al.(SK collab), Astropart., Phys. 31, 320 (2009)

- Am/Be source produces γ(4.43MeV) + neutron.
- The vessel was deployed in SK.





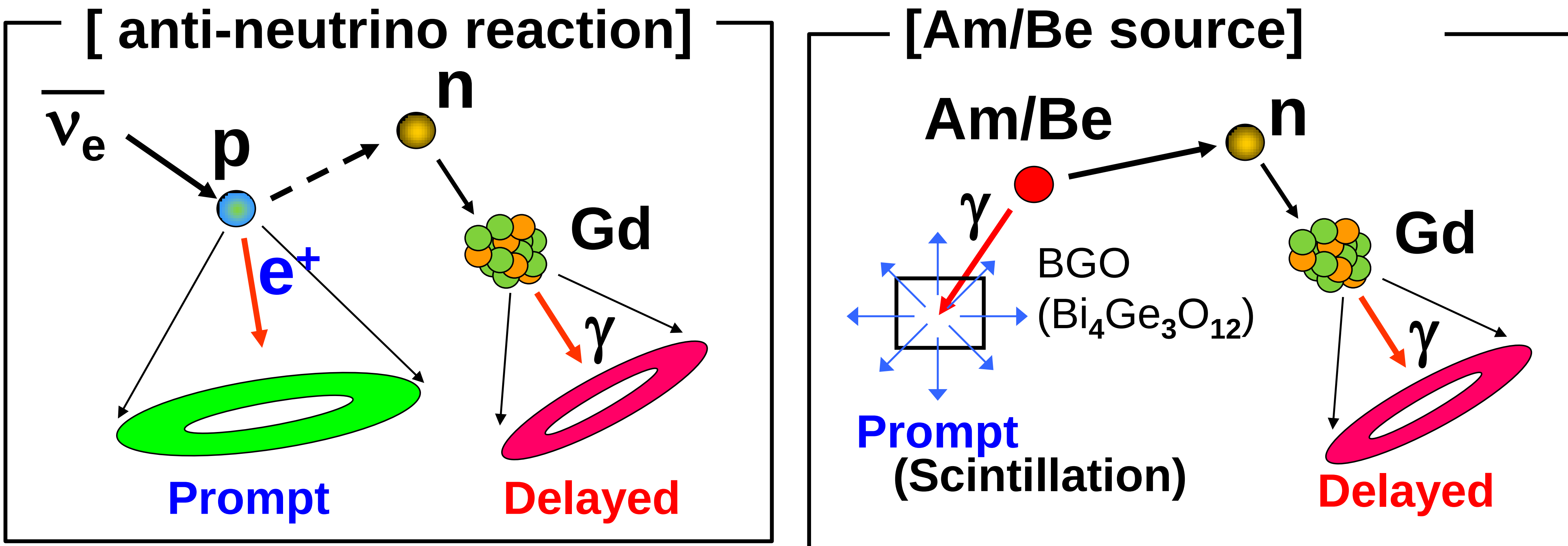


Am/Be source to mimic the inverse β decay

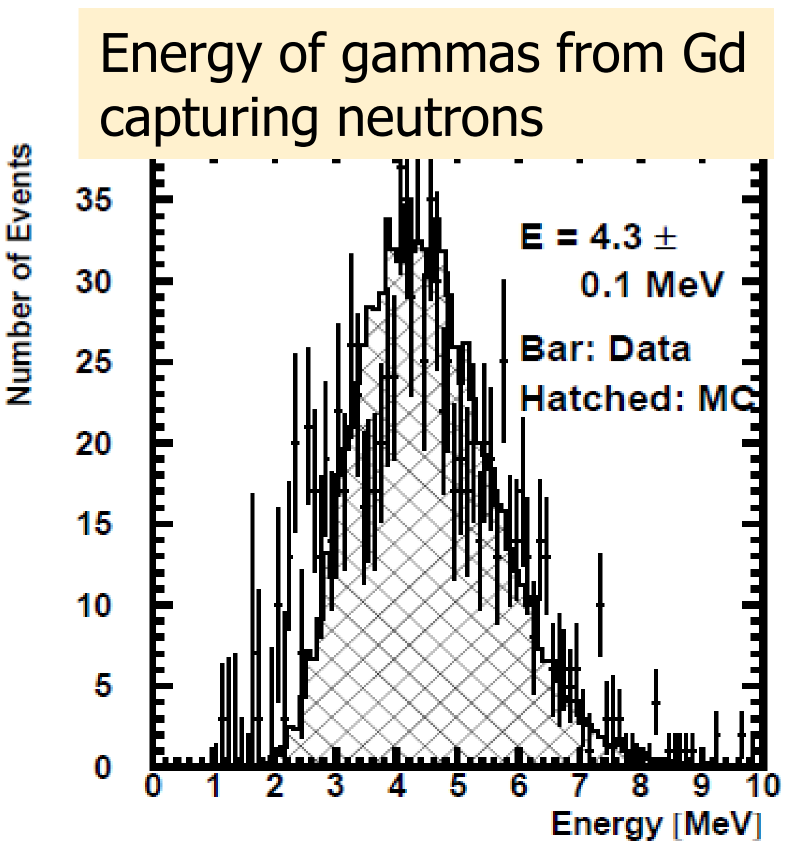
- 4MBq Am-α souce produces γ(4.4MeV)+n (a few MeV) at ~100Hz.

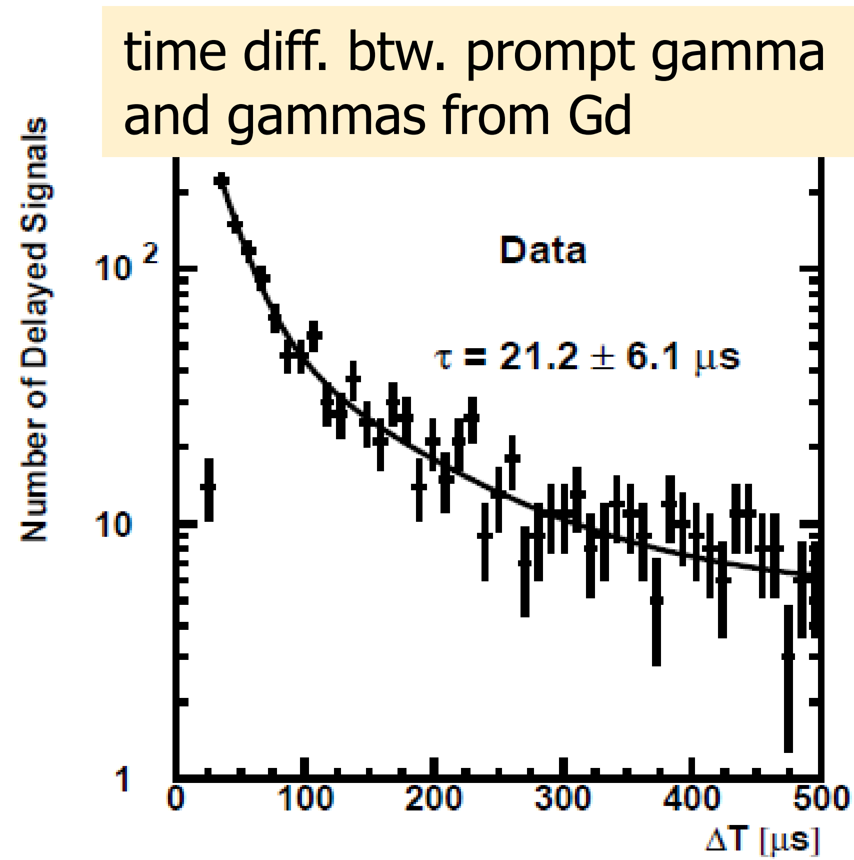
$$\alpha + {}^{9}Be \rightarrow {}^{12}C^{*} + n\ (2-6MeV)$$

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



Neutron Tagging Eff. Measurement at SK (cont'd)



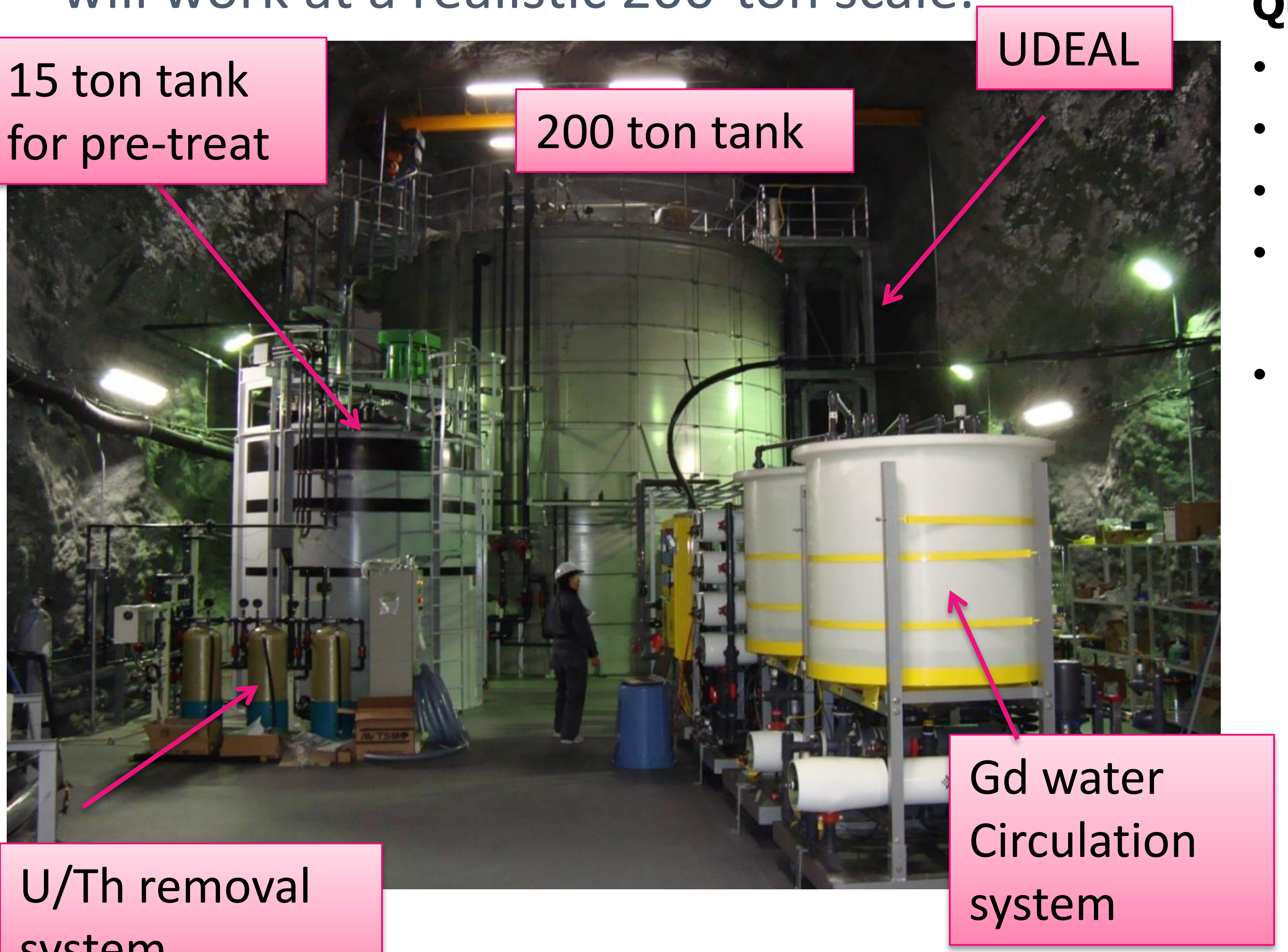


- The energy and time distributions are within expectations.
- The tagging efficiency is measured to be 66.7%.
  - Background reduction 2 x10^{-4} for E>10MeV is obtained using 3MeV threshold within 60μsec.

3. 200-ton Prototype Detector [EGADS] (2009-2013)

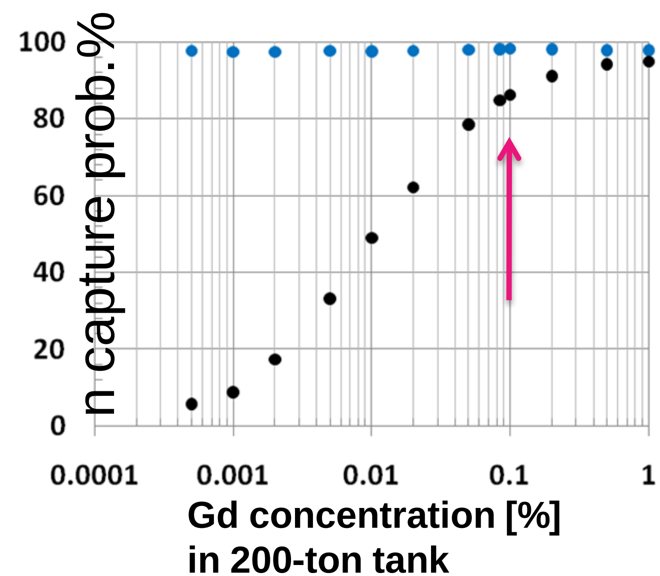
-Budget for 200-ton tank (EGADS) approved for 2009-2013 by JSPS (M.Nakahata,ICRR)

Purpose: Prove that a Gd-doped Water Cherenkov detector technology will work at a realistic 200-ton scale.



Questions to be answered:

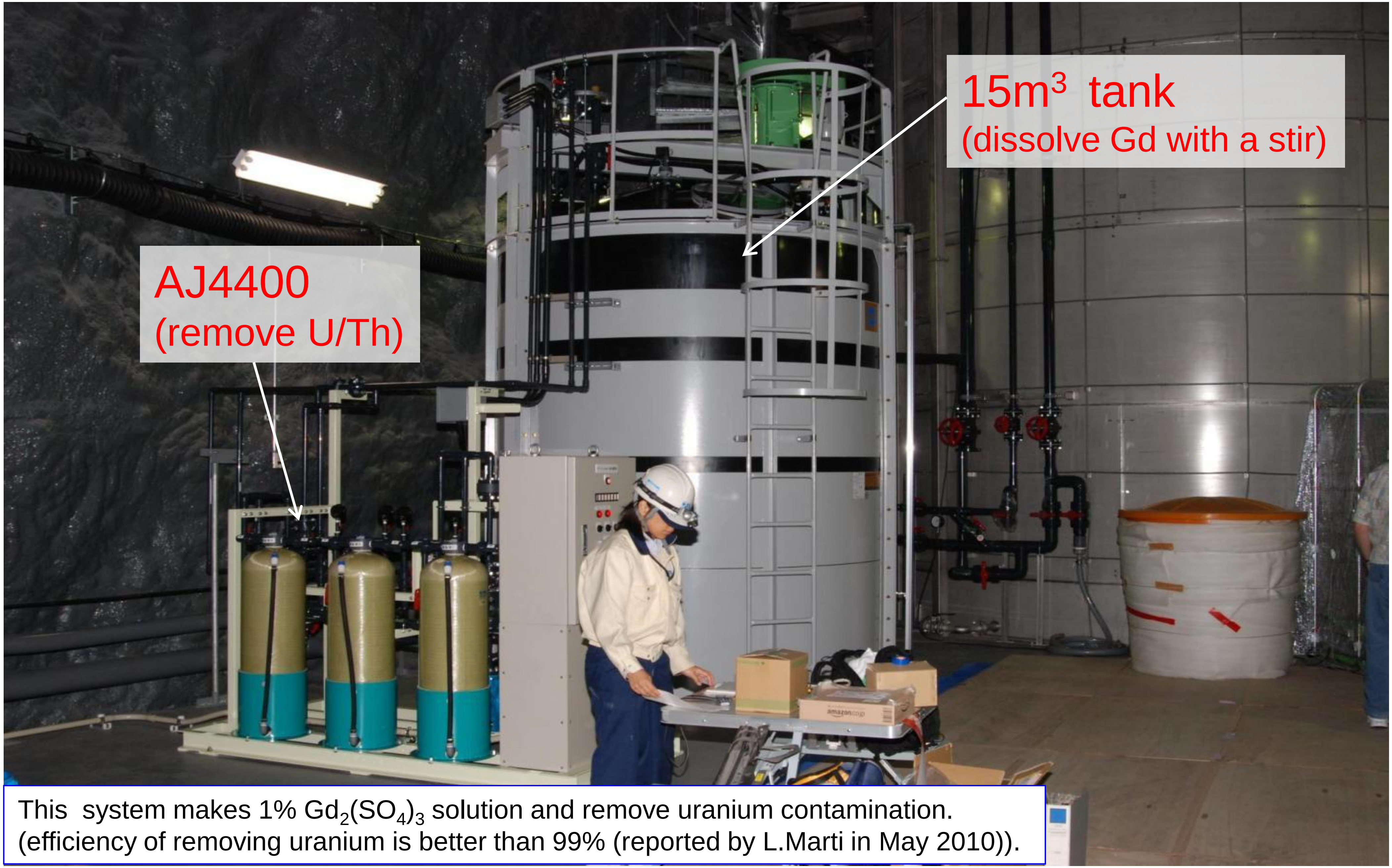
- **Effect on materials?**
- **Water transparency?**
- **mix/remove Gd in water?**
- **Neutron tag efficiency? <90%max.**
- **Background rejection?**



View from top of the tank

June 15, 2011

Pre-treatment system

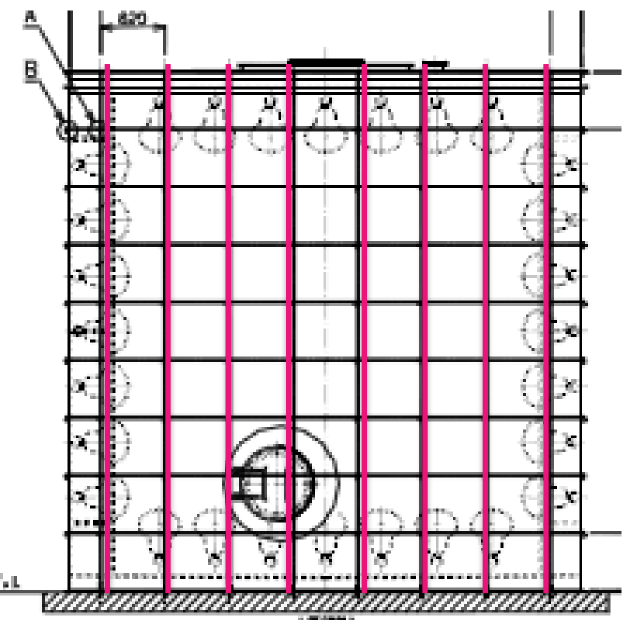


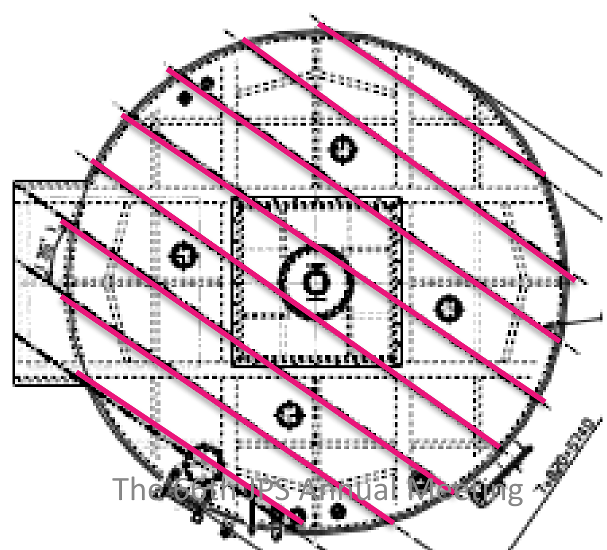
This system makes 1% $Gd_2(SO_4)_3$ solution and remove uranium contamination.
(efficiency of removing uranium is better than 99% (reported by L.Marti in May 2010)).

Installed in August 2010

Compensation Coil to keep the magnetic field in the tank <100mG

- Terrestrial B field=~400mG.
- By adjusting currents, the field inside the tank is <100mG.

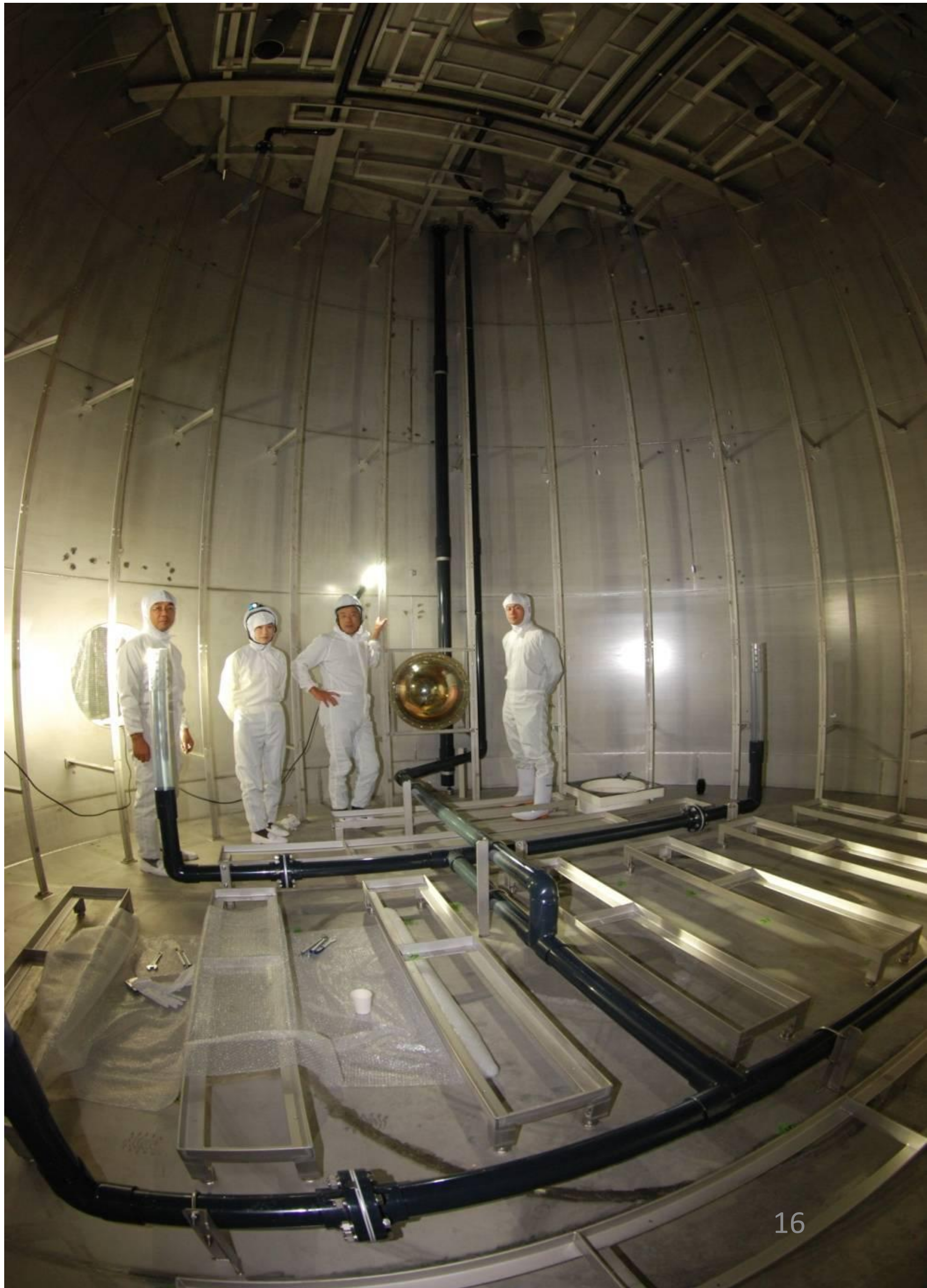




EGADS inside

Test of PMT mounting.

	PMT-only	PMT+FRP +acryl	PMT+FRP	PMT total
Top	18	16	2	36
Barrel	126	28	14	168
Bottom	18	16	2	36
	162	60	18	240



2010年9月4日現在

Summary

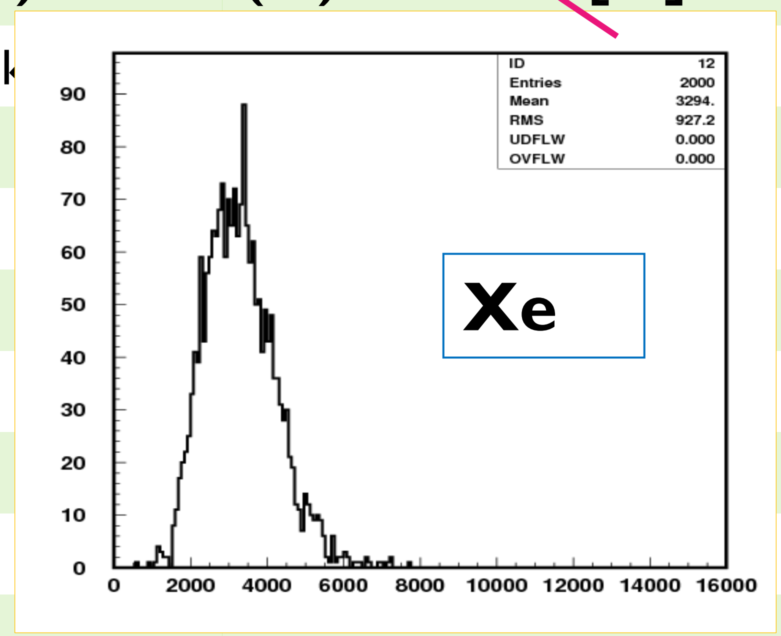
- H.Watanabe et al.(09) has shown that 2.4litters Gd solution worked. The next step (200-ton EGADS) started. 2 years later→
- All equipments for EGADS are ready in Lab-E hall.
- Quality check of all 240 PMTs (10 spares) was finished this week for dark rate, uniform response (within +-4%) and 1p.e.peak (gain).
- August: We will start circulation tests with Gd.
  First step: Circulate Gd water with 15m^3 tank
  Second step: Circulate Gd water with 200 m^3 tank without PMT)
- Third step: Mount PMTs in EGADS in December.
- Next March/April: Circulate Gd water with 200 m^3 tank with PMT.

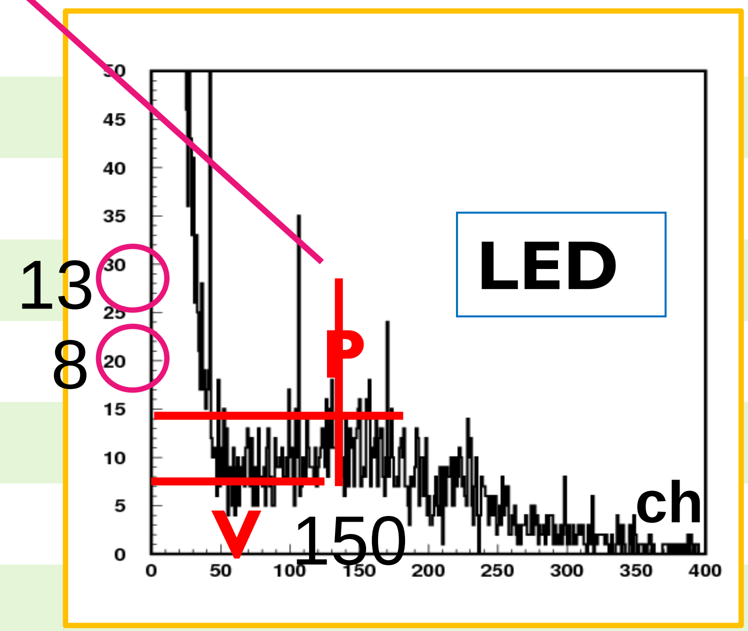
- In 2012-2013, we will have the complete proof-of-principle tests of a Gd-loaded Water Cherenkov technology using 200-ton EGADS.
- If it is proved to work, it will have an large impact on future large scale Supernova detectors and neutrino oscillation experiments (esp. reactor neutrino detectors).

Pre-calibration of 240 PMTs before installation
-Finished on July 20

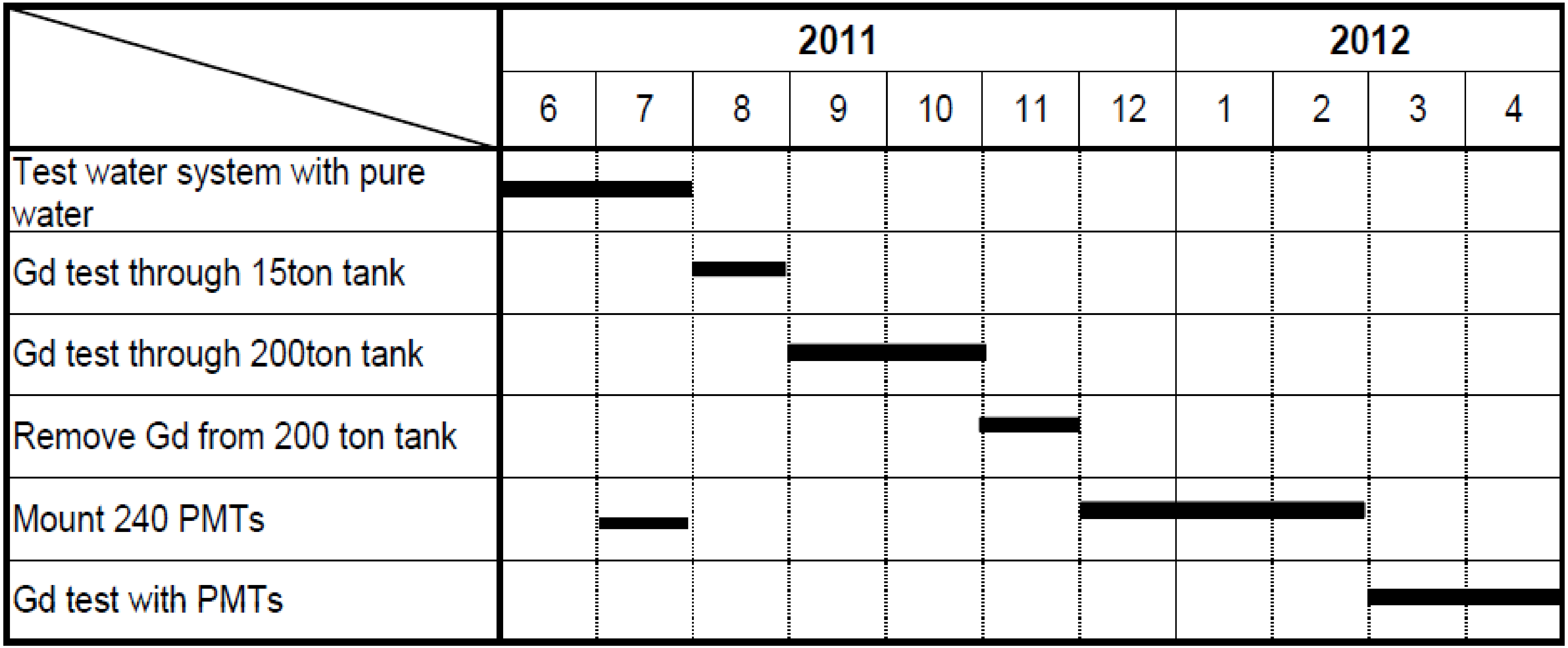
Check sheet

PMT ID	Dark rate (kHz)	Xe peak (ch)	1 p.e. peak [ch]	Peak value (counts)	Valley value (counts)
CD7963	30.5 k				



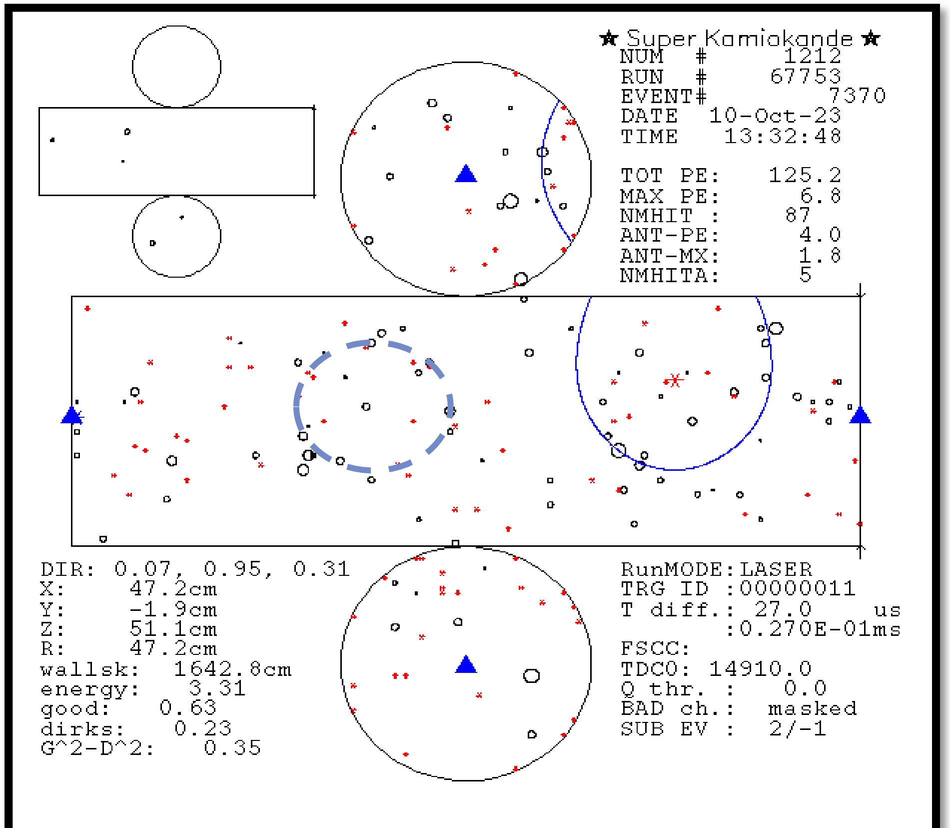


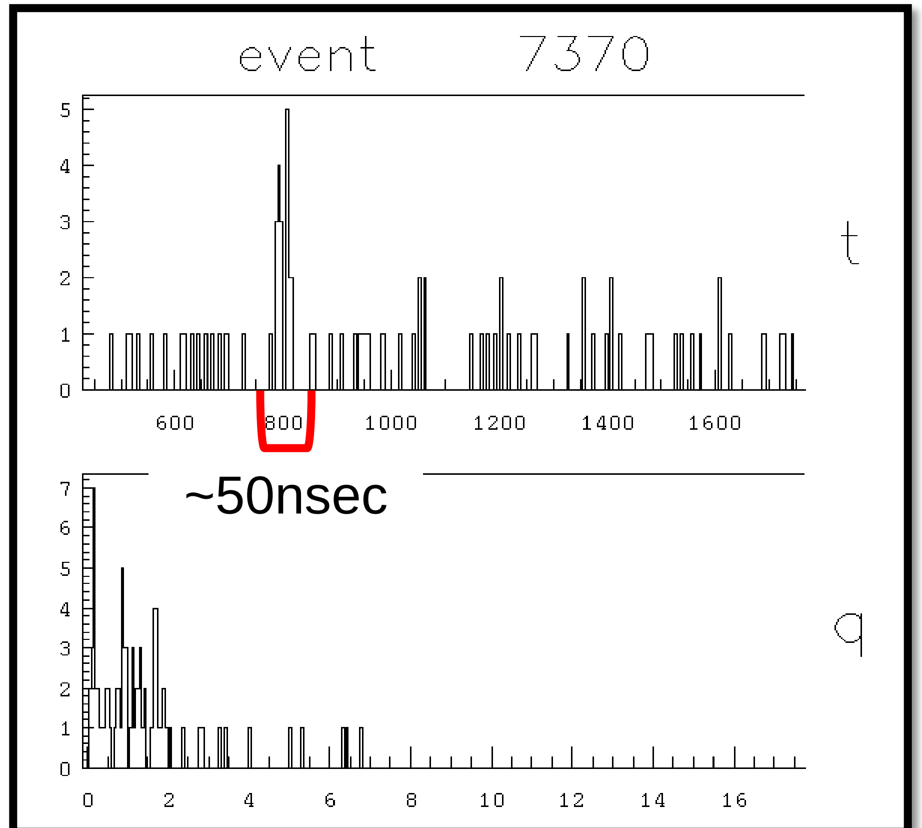
Schedule of EGADS from June



2.4 litter test in SK-IV

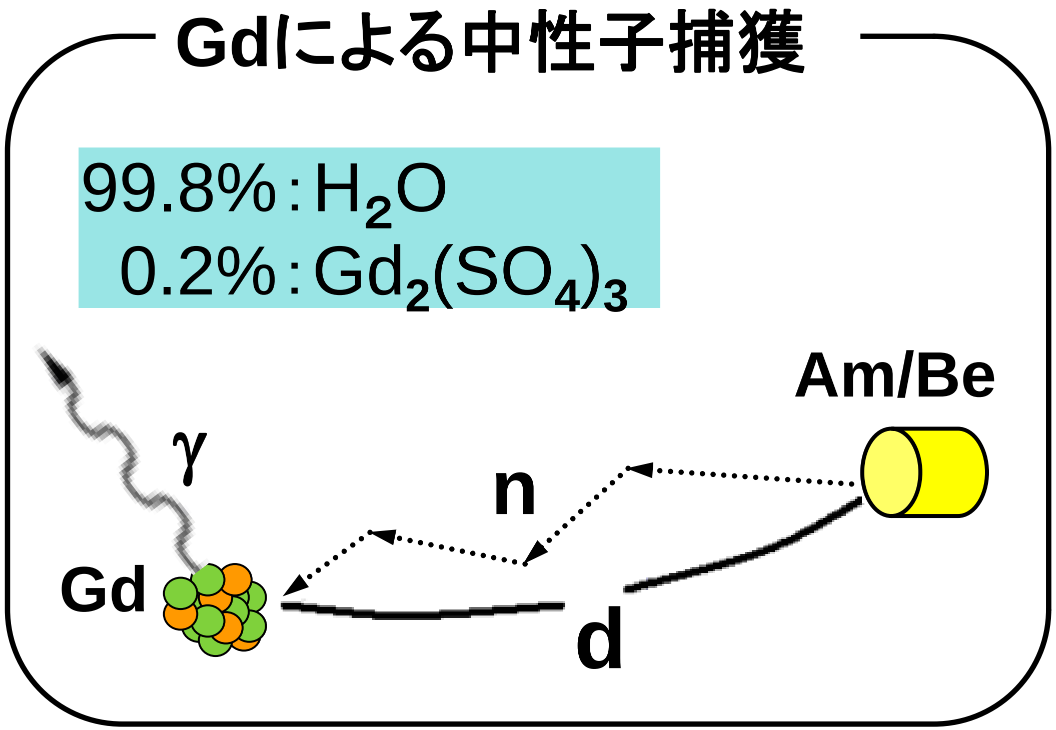
with $Gd_2(SO_4)_3$

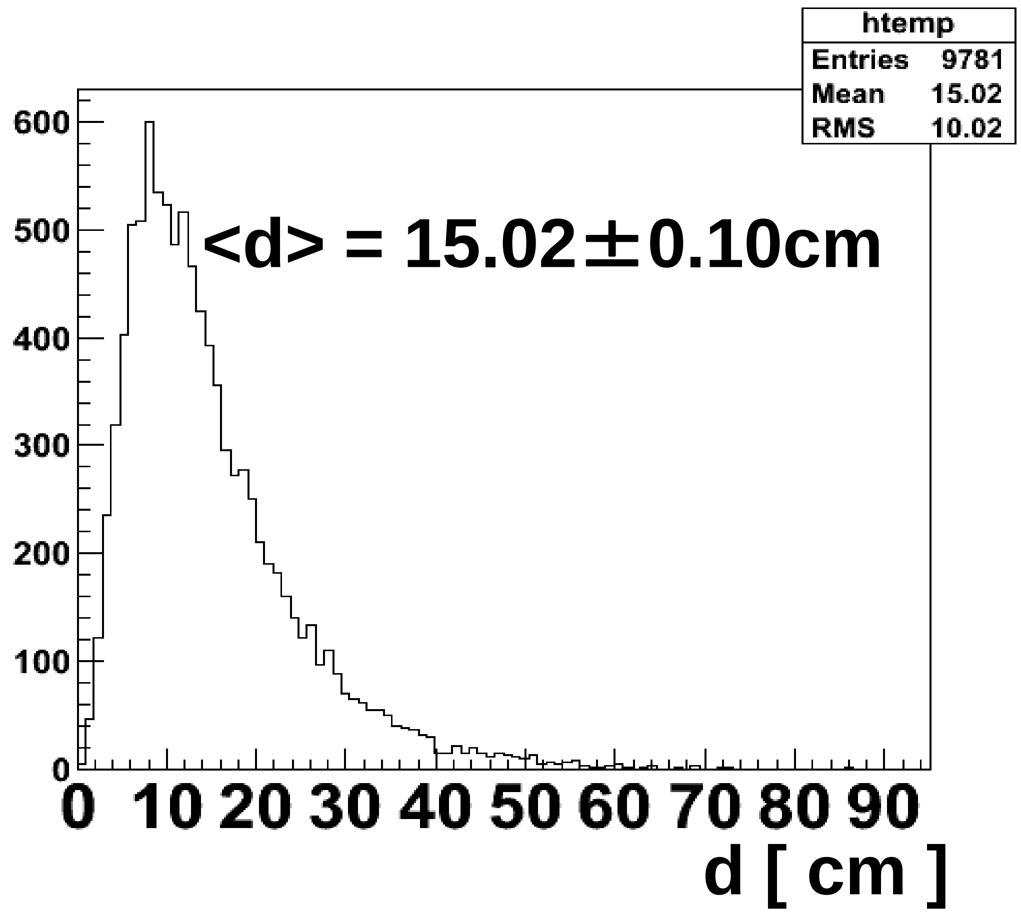




Gd水溶液中での中性子の反応

- Gd水溶液中において、Am/Beから出る中性子がGdに捕獲された位置をGeant4を用いたシミュレーションにより評価した。

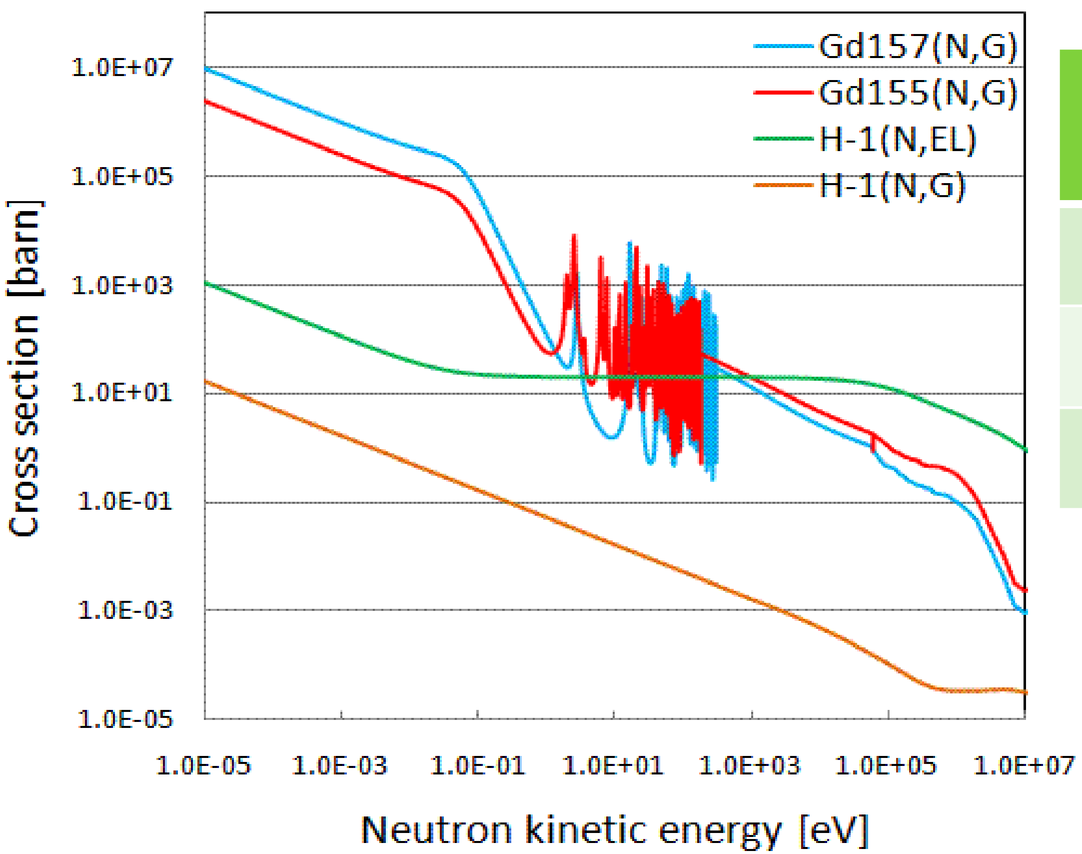




d = Am/Beの中心から中性子捕獲が起こった場所までの距離

中性子捕獲に関わる反応断面積

- eV領域まではnp 弾性散乱によりエネルギーを失う。
- 熱中性子化領域になるとnp 散乱断面積より、Gd捕獲断面積が大きくなり中性子捕獲が起きる。



0.2%$Gd_2(SO_4)_3$溶液中での反応

Capture	Cross sectio※[barn]	Fraction
Gd 155	46768.82	14.91%
Gd 157	203099.72	69.37%
Proton	0.26864	13.45%

※Thermal neutron cross section

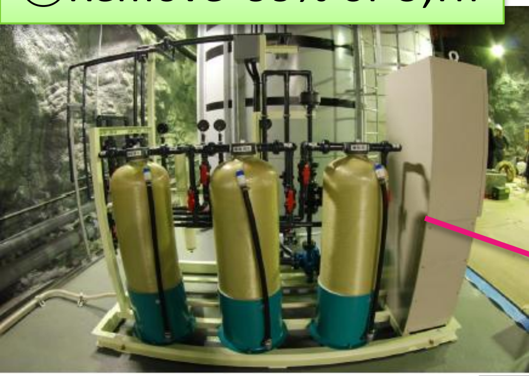
- (N,G) ：中性子捕獲(n,γ)
- (N,EL): np弾性散乱.

http://www.nndc.bnl.gov/exfor/endf.htm

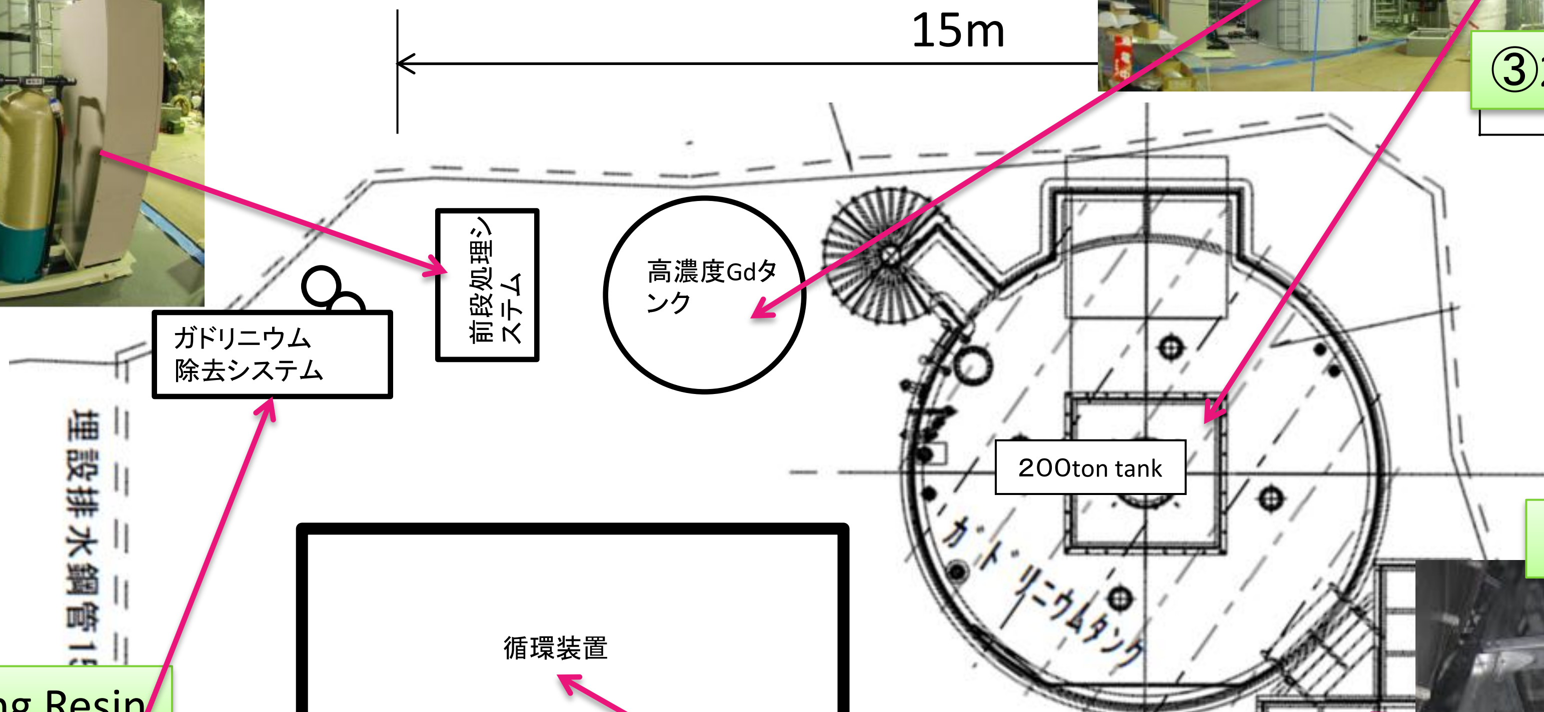
Lab-E Hall

②Mix Gd sulfate with water

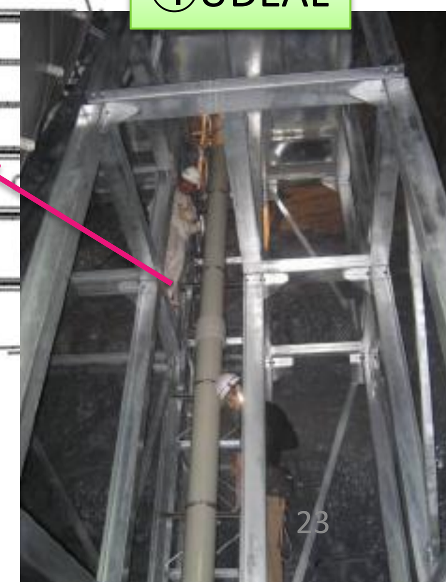
①Remove 99% of U,Th



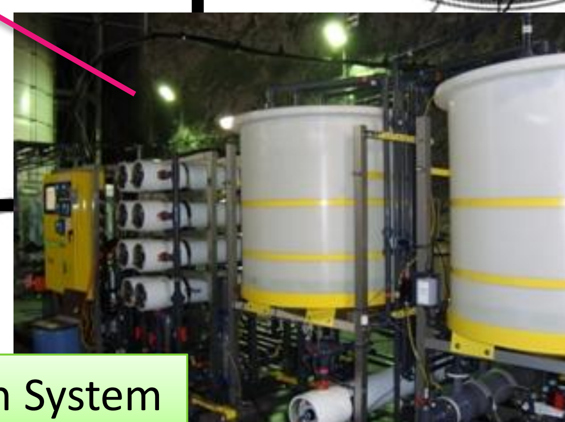
③200ton tank



④UDEAL



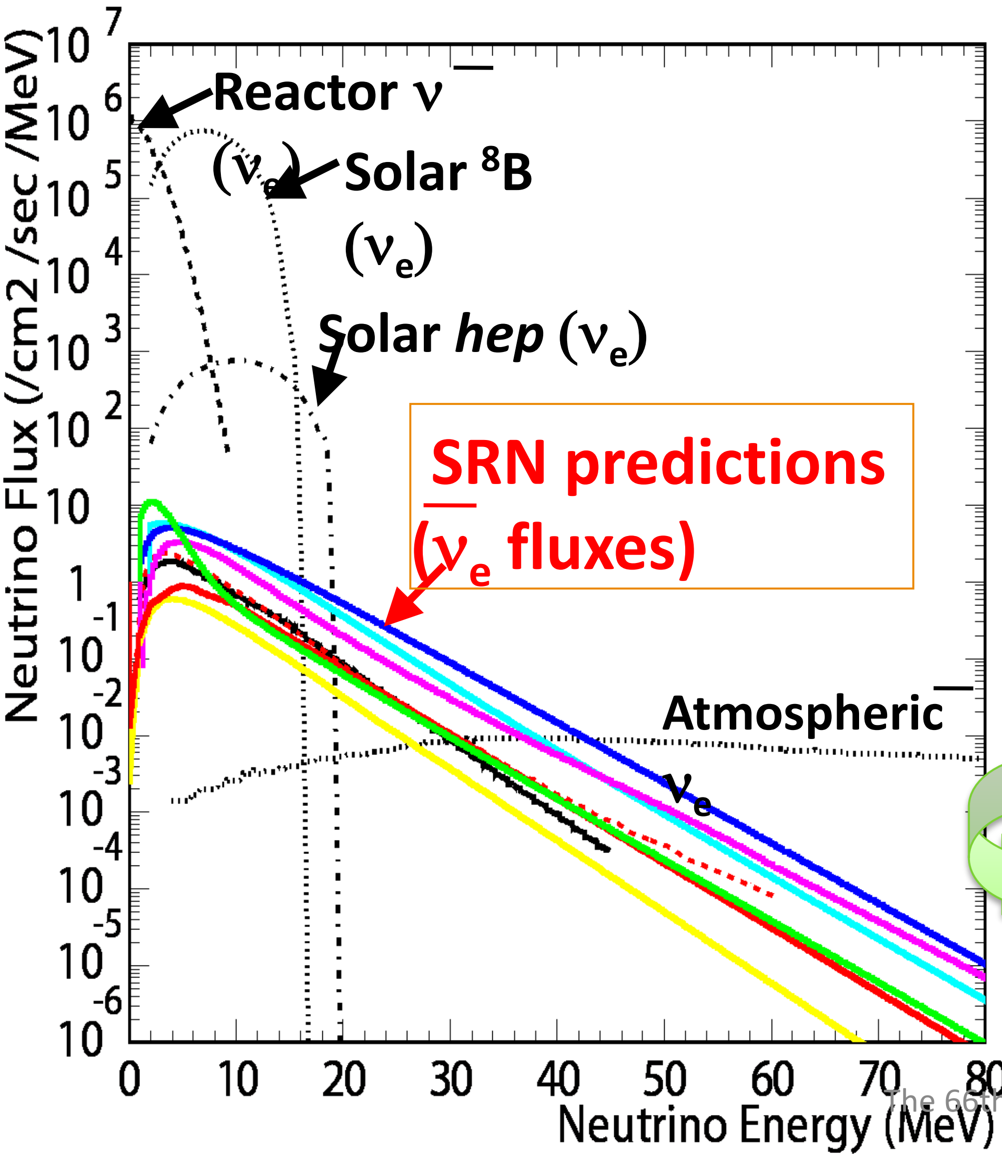
Remove Gd using Resin



⑤Water Circulation System

Introduction

Supernova Relic Neutrinos (SRN)



Expected number of SRN events:

- 0.8 -5.0 events/year/22.5kton (10-30MeV)
- 0.3 -1.9 events/year/22.5kton (18-30MeV)

How can we detect SRN?

- a large target mass
- high background reduction capability

Large cross section (~49,000 barn) of Gd for neutron capture may be our solution!