KamLAND & KASKA Prototype

(In view of safeguards)

F.Suekane

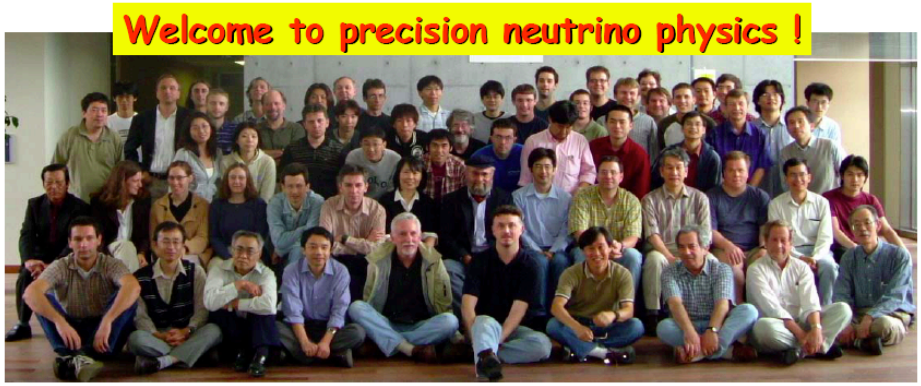
Research Center for Neutrino Science

Tohoku University

suekane@awa.tohoku.ac.jp

Applied Antineutrino Physics Workshop
@Laurence Livermore National Lab., CA, USA
2006.9.24-26

KamLAND Collaboration



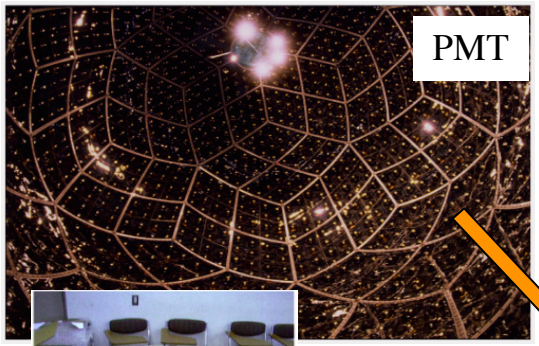
T. Araki,[1] K. Eguchi,[1] S. Enomoto,[1] K. Furuno,[1] K. Ichimura,[1] H. Ikeda,[1] K. Inoue,[1] K. Ishihara,[1,*] T. Iwamoto,[1,†] T. Kawashima,[1] Y. Kishimoto,[1] M. Koga,[1] Y. Koseki,[1] T. Maeda,[1] T. Mitsui,[1] M. Motoki,[1] K. Nakajima,[1] H. Ogawa,[1] K. Owada,[1] J.-S. Ricol,[1] I. Shimizu,[1] J. Shirai,[1] F. Suekane,[1] A. Suzuki,[1] K. Tada,[1] O. Tajima,[1] K. Tamae,[1] Y. Tsuda,[1] H. Watanabe,[1] J. Busenitz,[2] T. Classen,[2] Z. Djurcic,[2] G. Keefer,[2] K. McKinny,[2] D.-M. Mei,[2,‡] A. Piepke,[2] E. Yakushev,[2] B.E. Berger,[3] Y.D. Chan,[3] M.P. Decowski,[3] D.A. Dwyer,[3] S.J. Freedman,[3] Y. Fu,[3] B.K. Fujikawa,[3] J. Goldman,[3] F. Gray,[3] K.M. Heeger,[3] K.T. Lesko,[3] K.-B. Luk,[3] H. Murayama,[3,§] A.W.P. Poon,[3] H.M. Steiner,[3] L.A. Winslow,[3] G.A. Horton-Smith,[4,¶] C. Mauger,[4] R.D. McKeown,[4] P. Vogel,[4] C.E. Lane,[5] T. Miletic,[5] P.W. Gorham,[6] G. Guillian,[6] J.G. Learned,[6] J. Maricic,[6] S. Matsuno,[6] S. Pakvasa,[6] S. Dazeley,[7] S. Hatakeyama,[7] A. Rojas,[7] R. Svoboda,[7] B.D. Dieterle,[8] J. Detwiler,[9] G. Gratta,[9] K. Ishii,[9] N. Tolich,[9] Y. Uchida,[9,**] M. Batygov,[10] W. Bugg,[10] Y. Efremenko,[10] Y. Kamyshkov,[10] A. Kozlov,[10] Y. Nakamura,[10] C.R. Gould,[11] H.J. Karwowski,[11] D.M. Markoff,[11] J.A. Messimore,[11] K. Nakamura,[11] R.M. Rohm,[11] W. Tornow,[11] R. Wendell,[11] A.R. Young,[11] M.-J. Chen,[12] Y.-F. Wang,[12] and F. Piquemal[13]

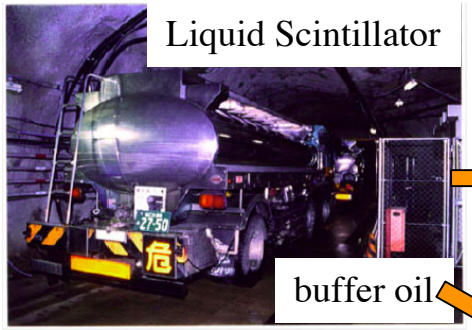
(The KamLAND Collaboration)

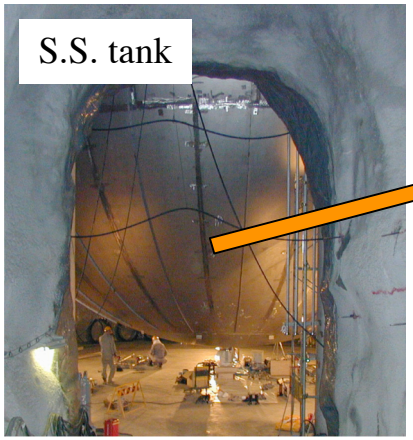
[1]*Research Center for Neutrino Science, Tohoku University, Sendai 980-8578, Japan*
[2]*Department of Physics and Astronomy, University of Alabama, Tuscaloosa, Alabama 35487, USA*
[3]*Physics Department, University of California at Berkeley and Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
[4]*W. K. Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California 91125, USA*
[5]*Physics Department, Drexel University, Philadelphia, Pennsylvania 19104, USA*
[6]*Department of Physics and Astronomy, University of Hawaii at Manoa, Honolulu, Hawaii 96822, USA*
[7]*Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803, USA*
[8]*Physics Department, University of New Mexico, Albuquerque, New Mexico 87131, USA*
[9]*Physics Department, Stanford University, Stanford, California 94305, USA*
[10]*Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA*
[11]*Triangle Universities Nuclear Laboratory, Durham, North Carolina 27708, USA and Physics Departments at Duke University, North Carolina State University, and the University of North Carolina at Chapel Hill*
[12]*Institute of High Energy Physics, Beijing 100039, People's Republic of China*
[13]*CEN Bordeaux-Gradignan, IN2P3-CNRS and University Bordeaux I, F-33175 Gradignan Cedex, France*

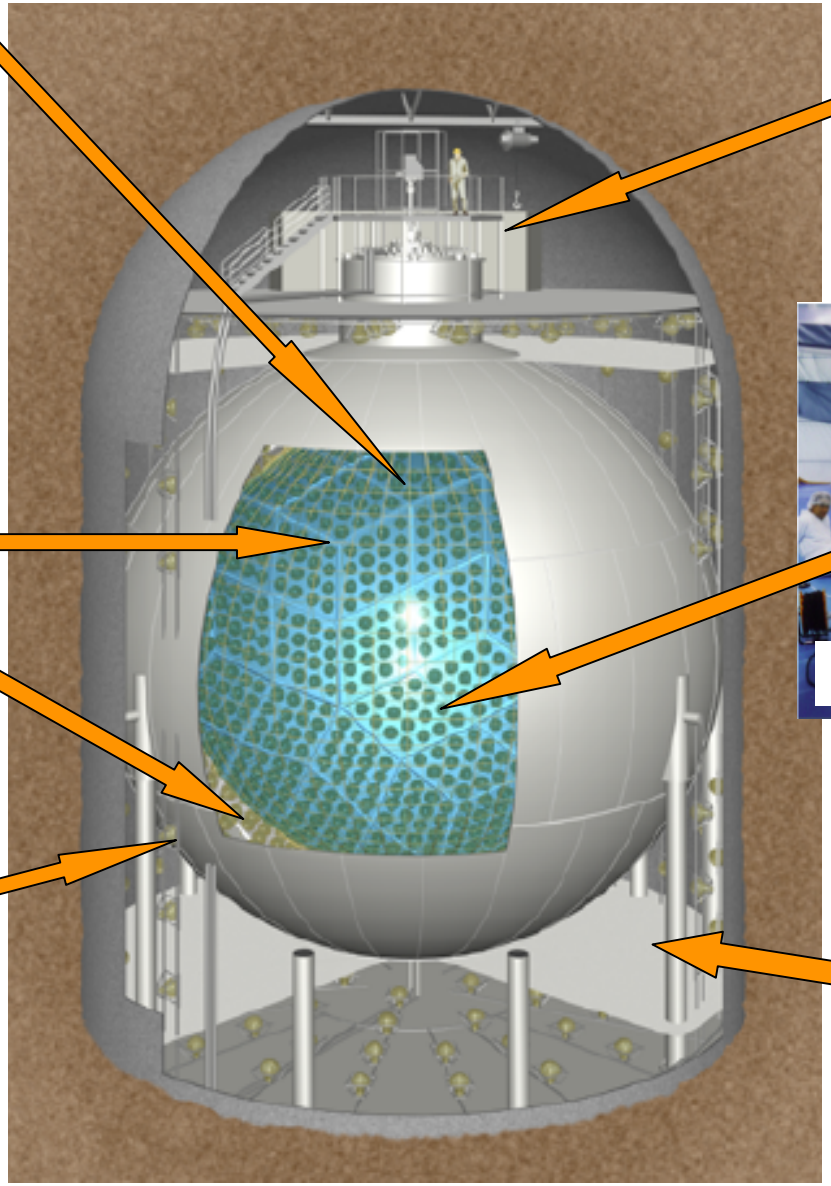
(Dated: November 1, 2004)

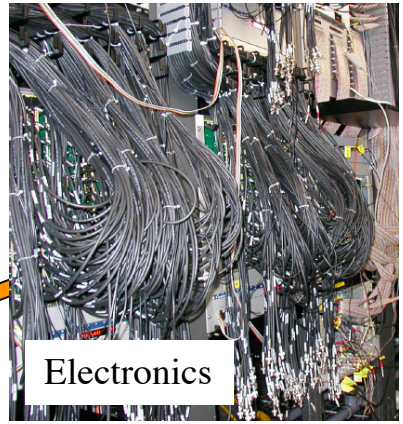
KamLAND Detector

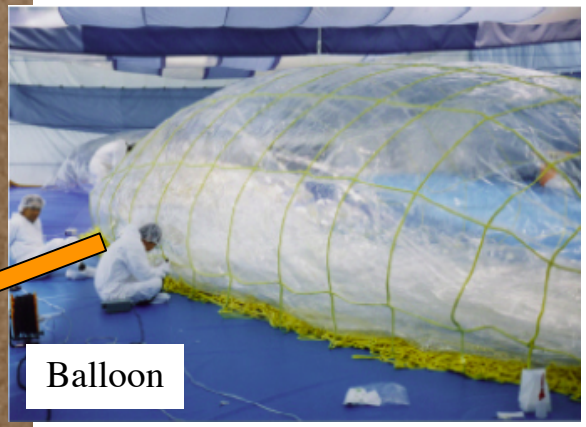




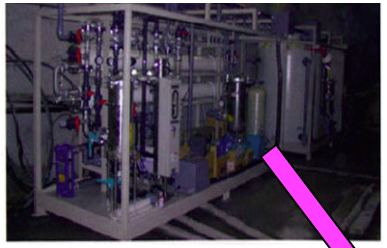




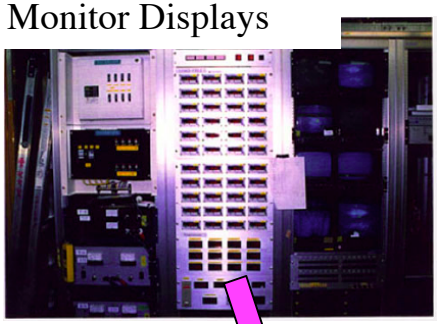


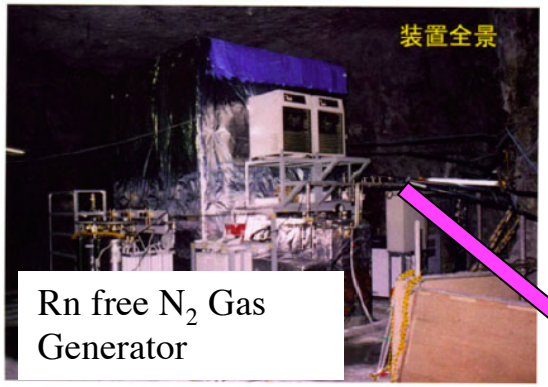


Water Purification system

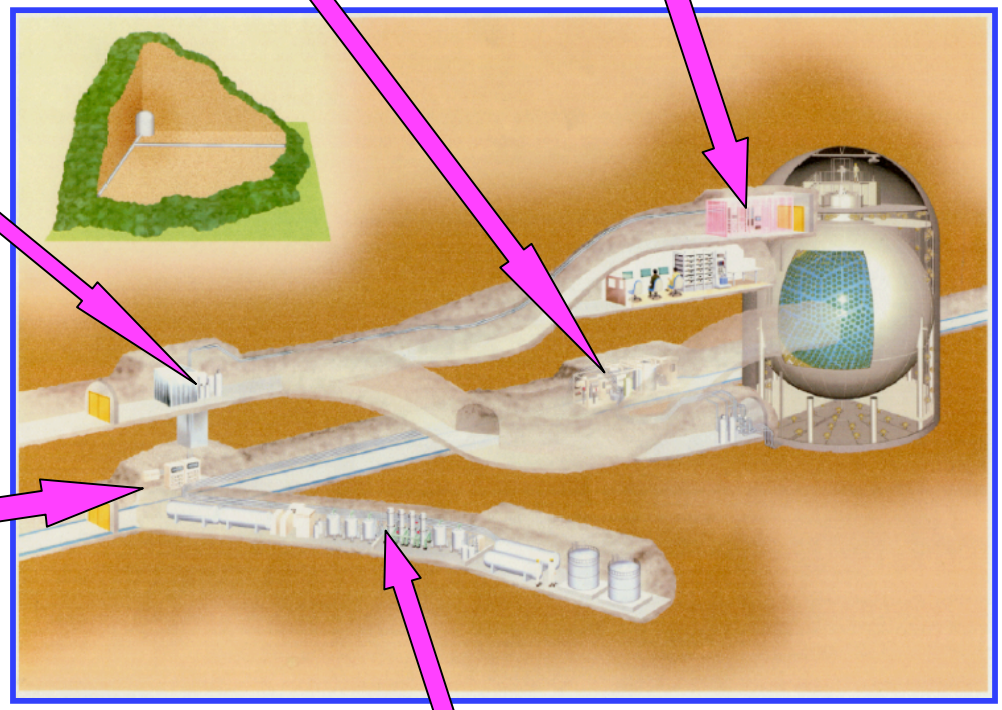


Monitor Displays





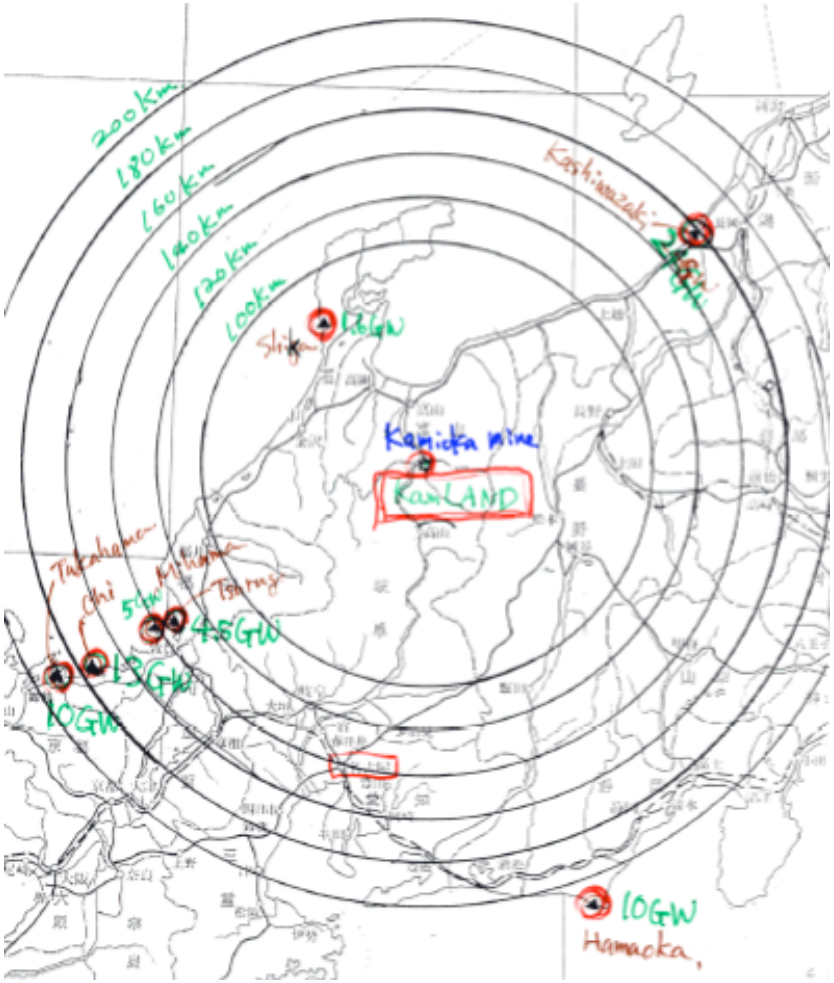
Rn free N_2 Gas Generator



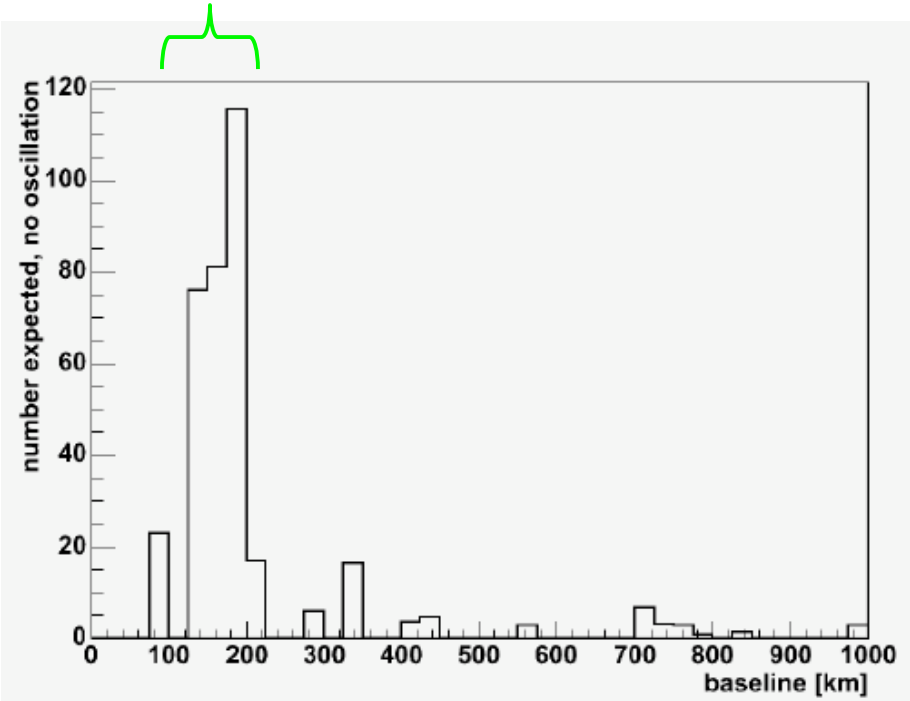
Corridor to detector

Oil Purification system

KamLAND; Distance to Reactors



68GW$_{th}$



$<L>\sim 180\text{km} \Rightarrow \sqrt{\square m^2} \sim 0.01eV$

Issues for KamLAND Detector Design

Event rate ~ only 1/day/kt (or 1/3years/t)

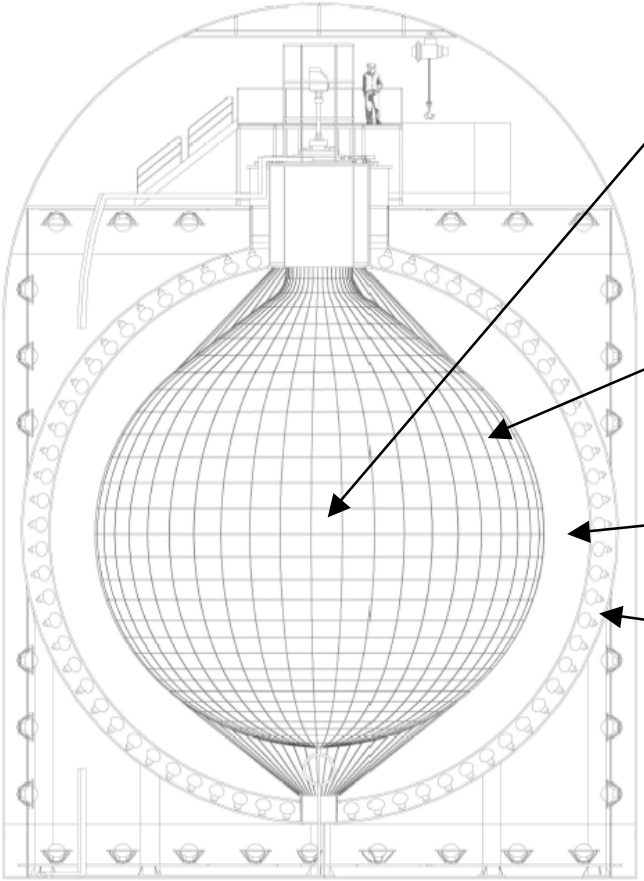
=> Background reduction is essential

- Large overburden to shield cosmic-rays:
  @2700mwe, cosmic-rar rate=10^{-5} of surface
- Extremely radio-pure liquid scintillator:
  Purification system -> U/Th/^{40}K <10^{-10}ppm
- Thick Shields:
  at least 50cm of water + 2.5m of Buffer Oil
- Delayed coincidence

Large Liquid Scintillator (M~1kton)

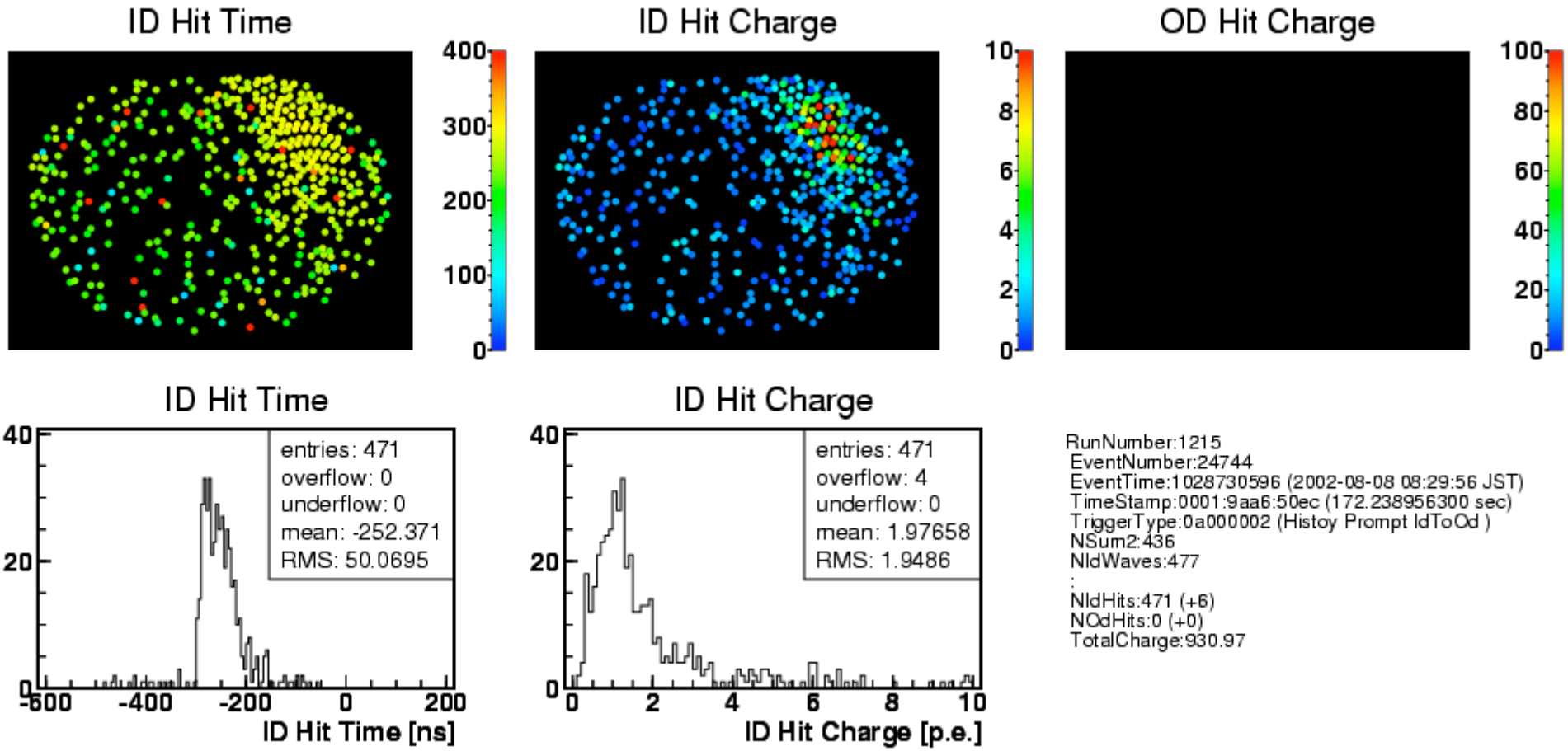
- Transparency and stability is essential
- Simple is better

Key Detector Elements



- Liquid Scintillator: (1150m^3)
  Dodencane(80%)+PC(20%)+PPO(1.5g/L)
  Light output >8,000photons/MeV, $\Lambda_{att.}$>10m
  (Gd is not used)
- Balloon: 13m diam. 135μmt Nylon/EVOH multilayer film. Held by Kevlar mesh.
- Buffer Oil: (1700m^3) 2.5mt. n-Dodecane+Isoparaffin
- PMT: 1325 17" aperture PMT
  + 554 20" aperture => 34% photo-coverage
- Purification system:
  Water extraction + N_2 bubbling
  U =>3.5x10^{-18}g/g

Event Display: Low Energy Event



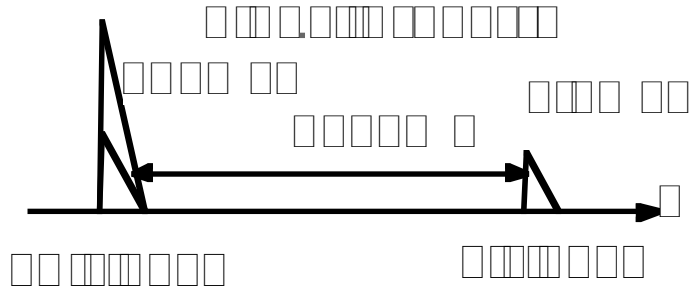
$\bar{\nu}_e$ identification

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

$$e^+ + e^- \rightarrow 2\gamma$$

$$(E_\gamma = 0.8MeV)$$

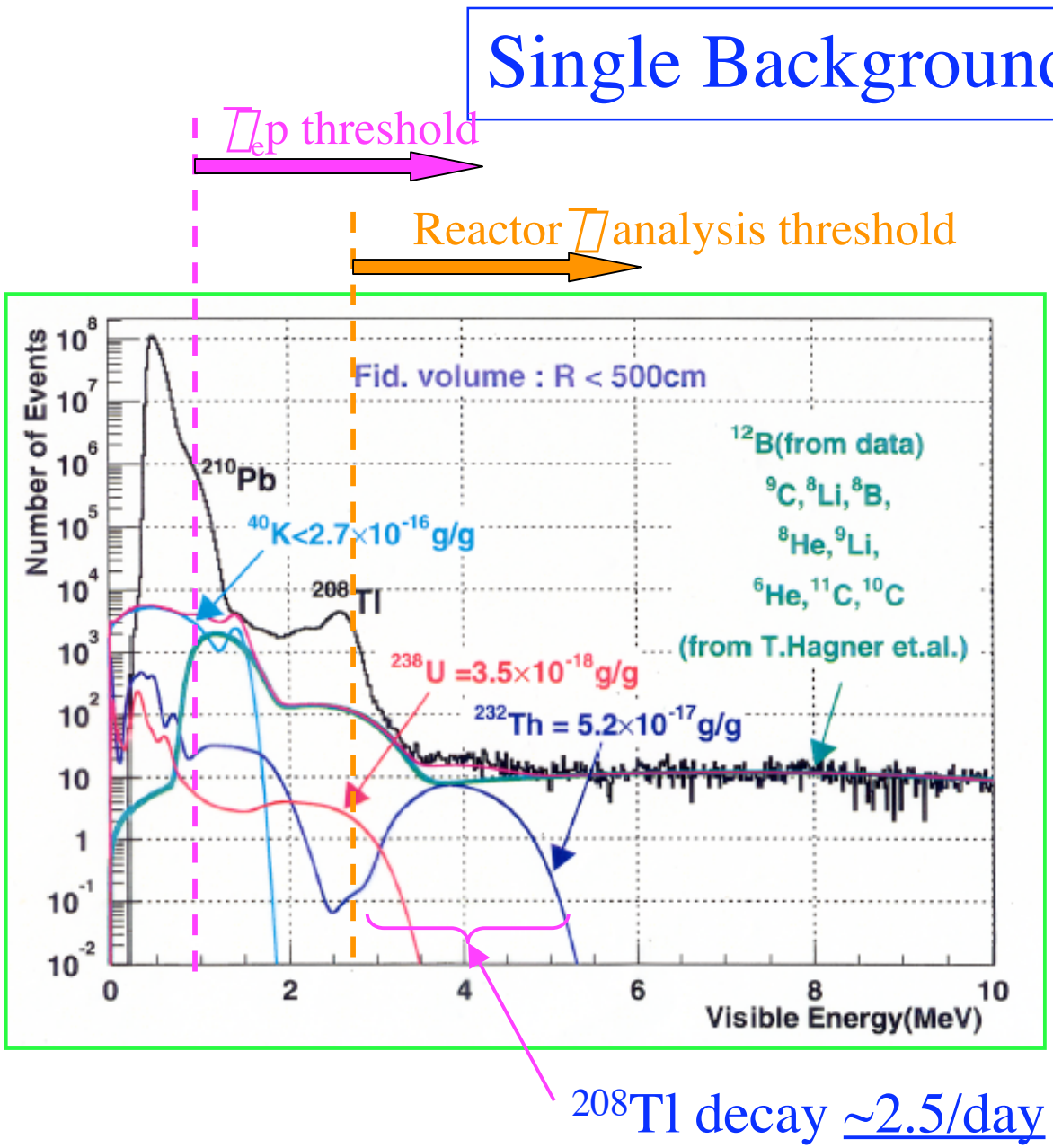
$$n + p \rightarrow d + \gamma(2.2MeV)$$



($\bar{\nu}_e$p -> e$^+$n); an ideal reaction, because

- Only $\bar{\nu}_e$ contributes (no background from other neutrino species)
- Low threshold Energy (1.8MeV)
- Large cross section (~100σ_{ν_e})
- p is abundant in LS
- Cross section precisely known ($\Delta\sigma/\sigma$=0.2%)
- $\bar{\nu}_e$ energy can be measured (E_ν=$E_{visible}$+0.8MeV)
- Delayed Coincidence -> powerful background rejection

Single Backgrounds



^{208}Tl decay ~2.5/day

^{238}U/^{222}Rn: 3.5x10^{-18}g/g
= 2decay/day

^{232}Th: 5.2x10^{-17}g/g
=10decay/day

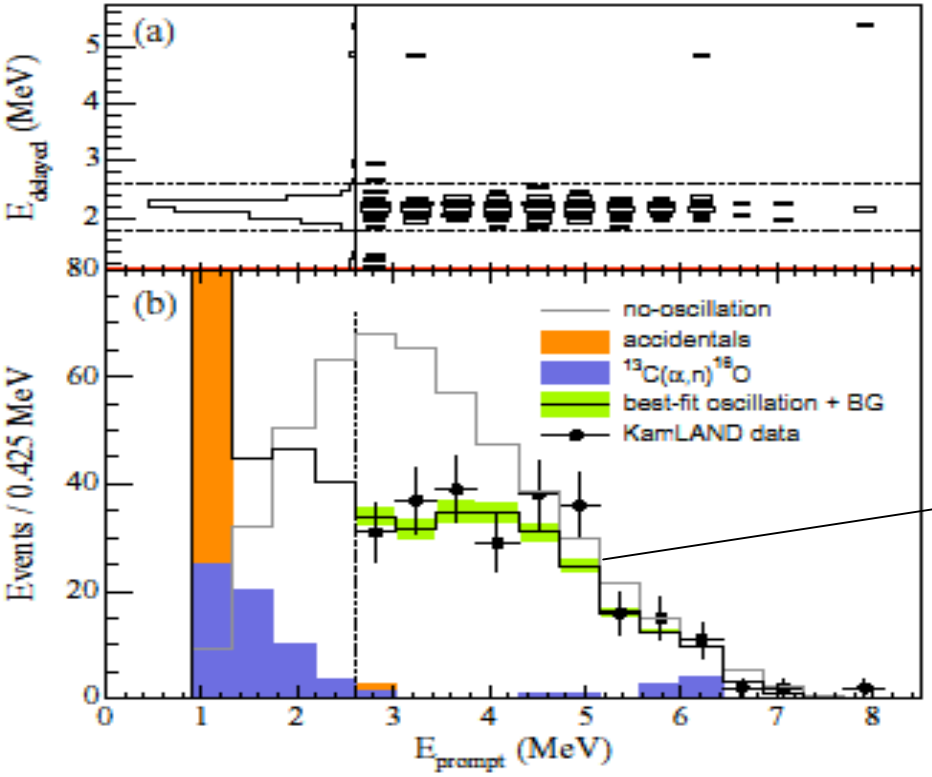
^{40}K: <2.7x10^{-16}g/g
<4000decay/day

Cosmic-ray=0.3Hz

(cf: sea water contains10^{-9}g/g of U.)

Neutrino Event Spectrum

Very Good S/N



$$N(E_\nu) = N_0(E_\nu)\left[1 - \sin^2 2\theta \sin^2 \frac{\Delta m^2 L}{4E_\nu}\right]$$

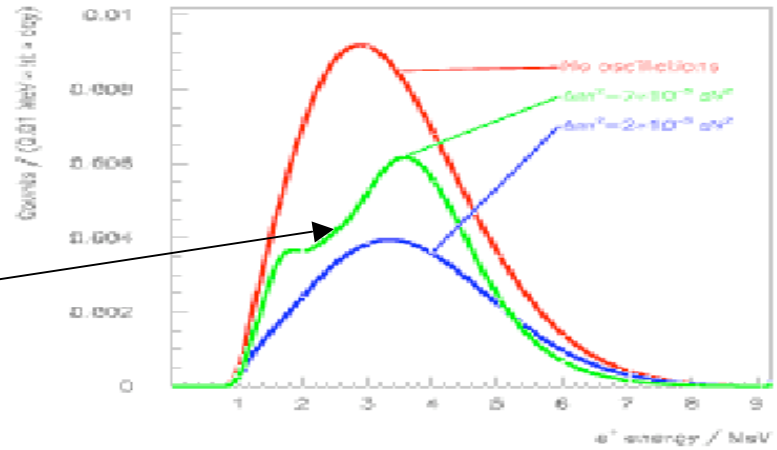
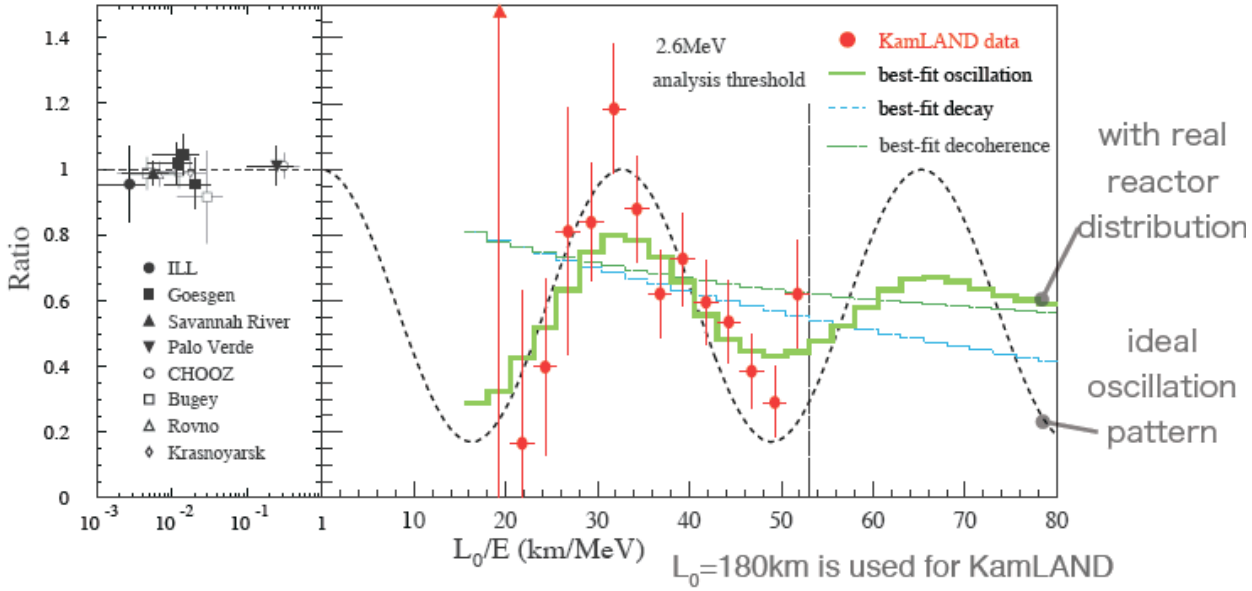
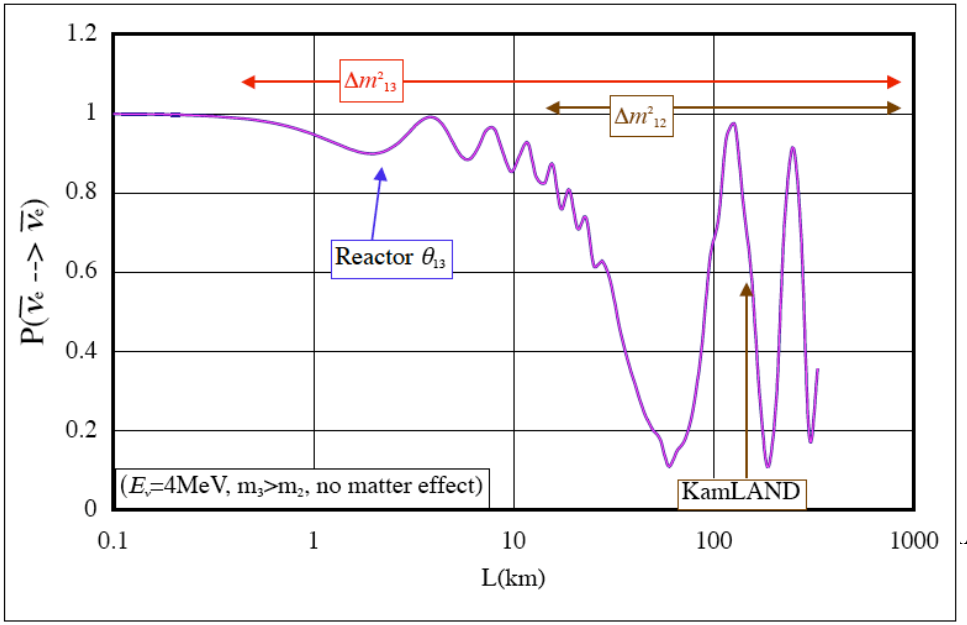


FIG. 37. Positron energy spectra expected at KAMLAND for no oscillations and oscillations with indicated parameters Δm^2 and $\sin^2 2\theta = 0.75$ in the MSW LMA solar neutrino solution.

Reactor neutrino oscillation does exist

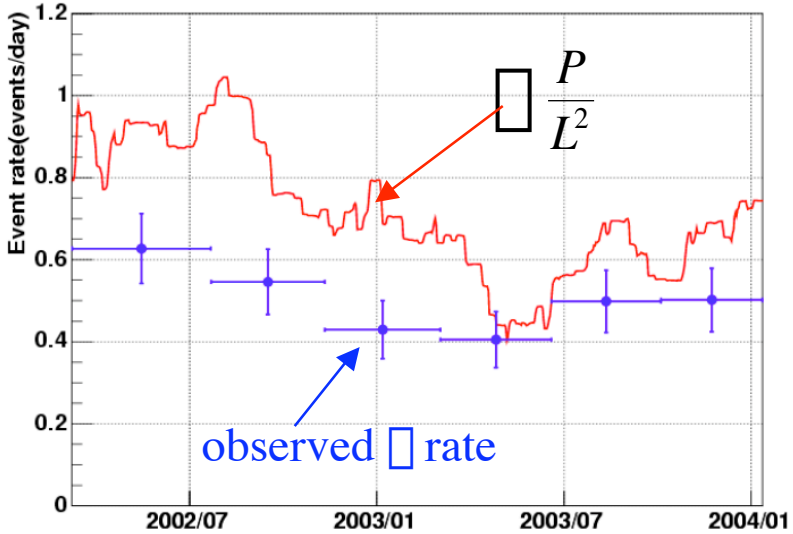




Long range detection has to take into account the effect of the neutrino oscillation

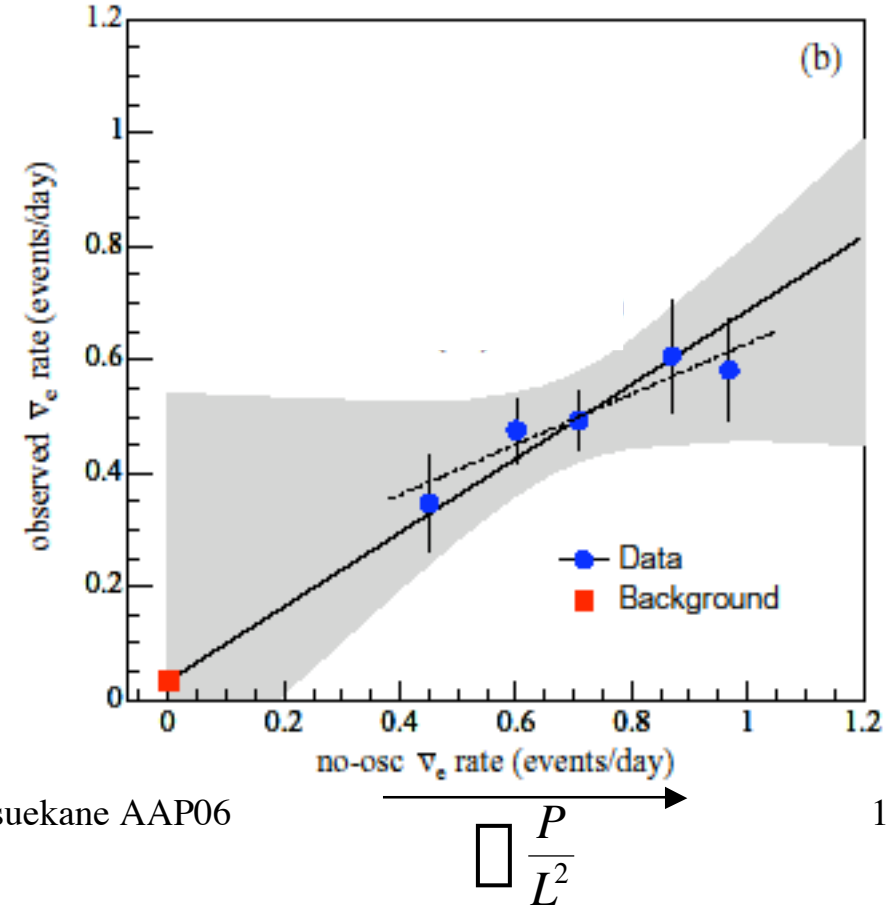
=> Avoid L=50km

Reactor Power Variation



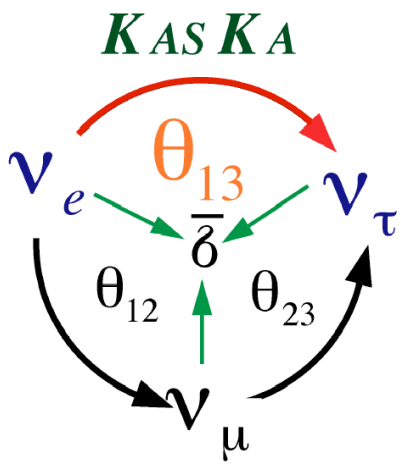
KamLAND is already monitoring gross reactor opeartion in Japan

In 2003, many power reactors stopped.



KASKA Prototype

Neutrino Experiments at Kasniwazaki-Kariwa Nuclear Power Station



KASKA Members

Niigata University: N.Tamura, M.Tanimoto, H.Miyata, H.Nakano T.Kawasaki, M.Katsumata, T.Iwabuchi, M.Aoki, N.Nakajima, K.Sakai
Tohoku University: F.Suekane, Y.Sakamoto, S.Tsuchiya, H.Tabata
Tokyo Metropolitan University: T.Sumiyoshi, H.Minakata, O.Yasuda , K.Sakuma
Tokyo Institute of Technology: M.Kuze, K.Nitta, H.Furuta, J.Maeda, Y.Funaki
Kobe University: T.Hara
KEK: N.Ishihara, H.Sugiyama
Miyagi University of Education: Y.Fukuda, Akiyama
Hiroshima Institute of Technology: Y.Nagasaka
Osaka University: Nomachi

~30people

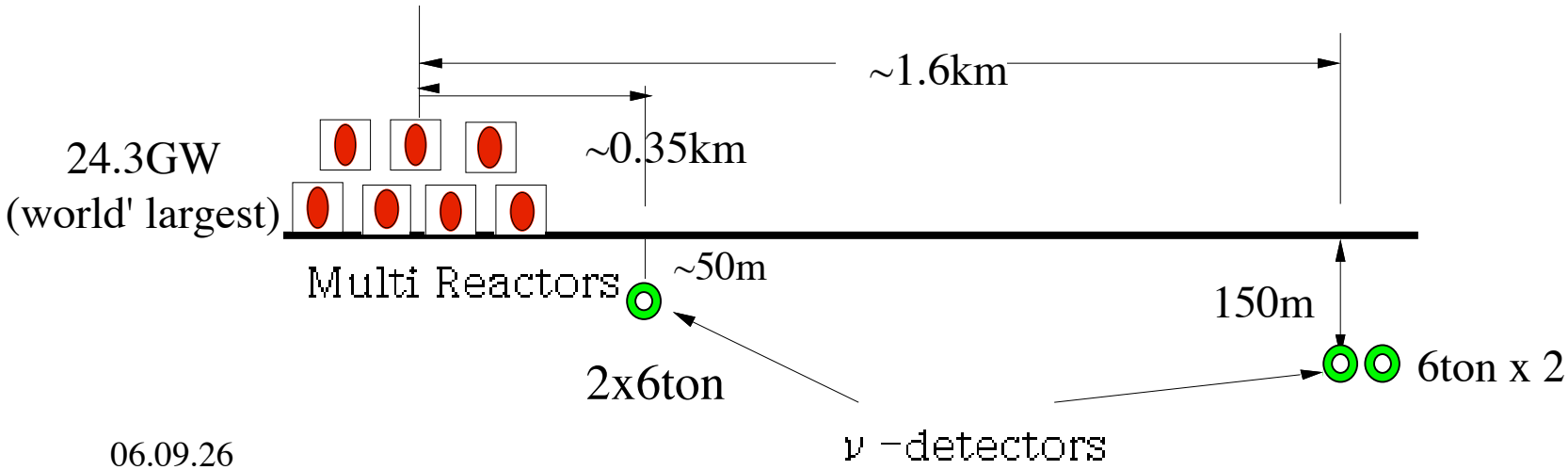
06.09.26

KASKA-θ_{13}

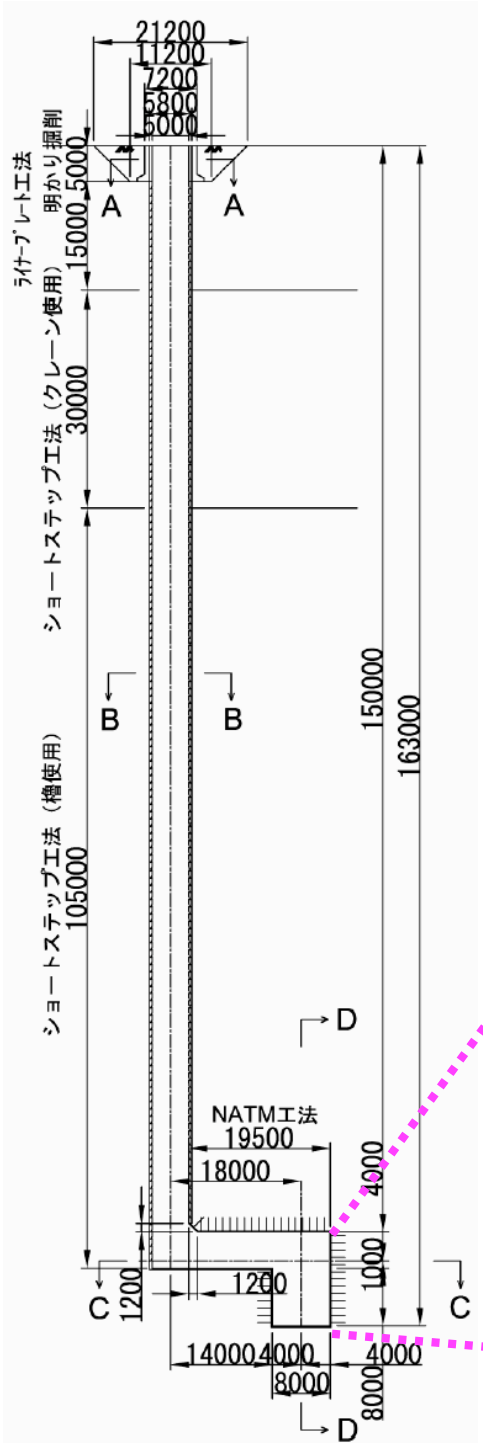
L=1.6km

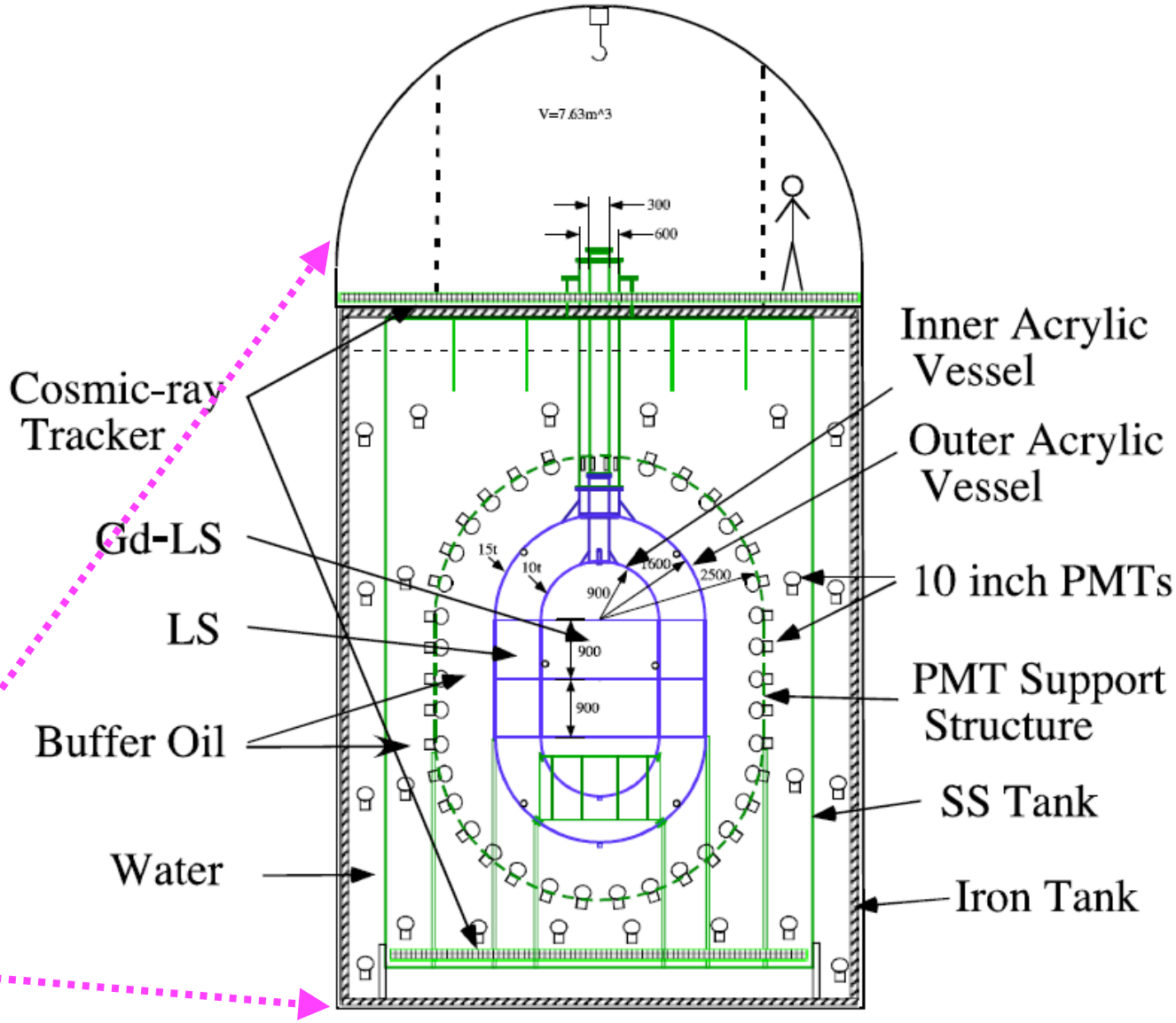
Kashiwazaki-Kariwa Nuclear Power Station

$\sin^2 2\theta_{13} < 0.015$



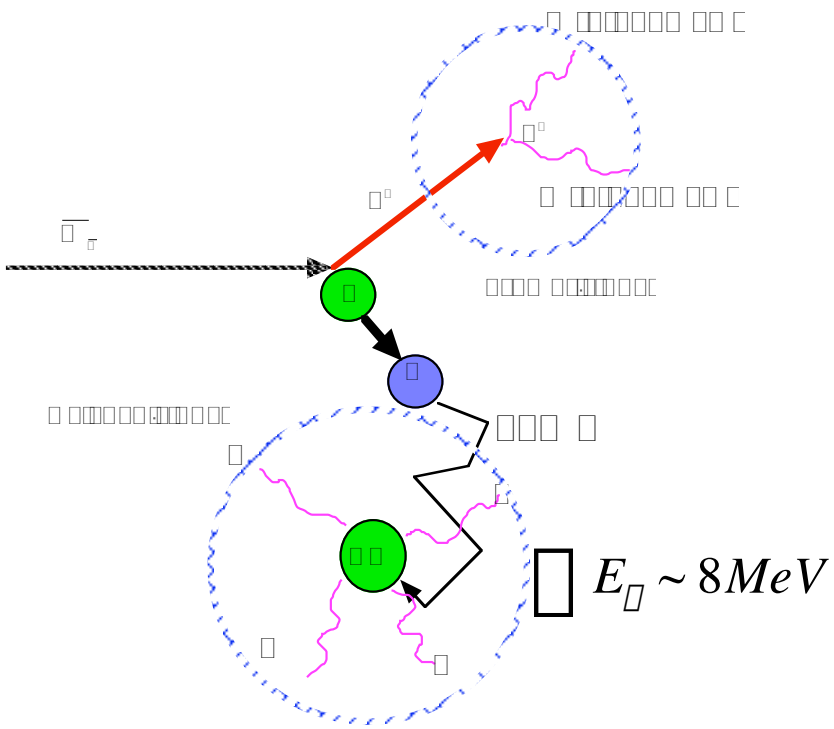
Detector & Shaft Hole





Neutrino Detection

=> use Gd

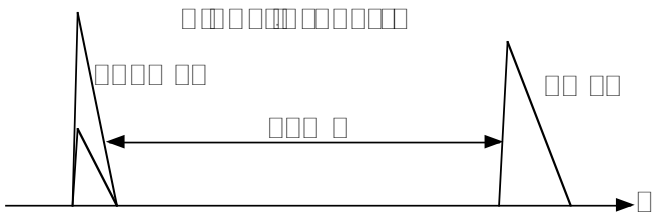


$$\bar{\nu}_e + p \rightarrow e^+ + n$$

Then

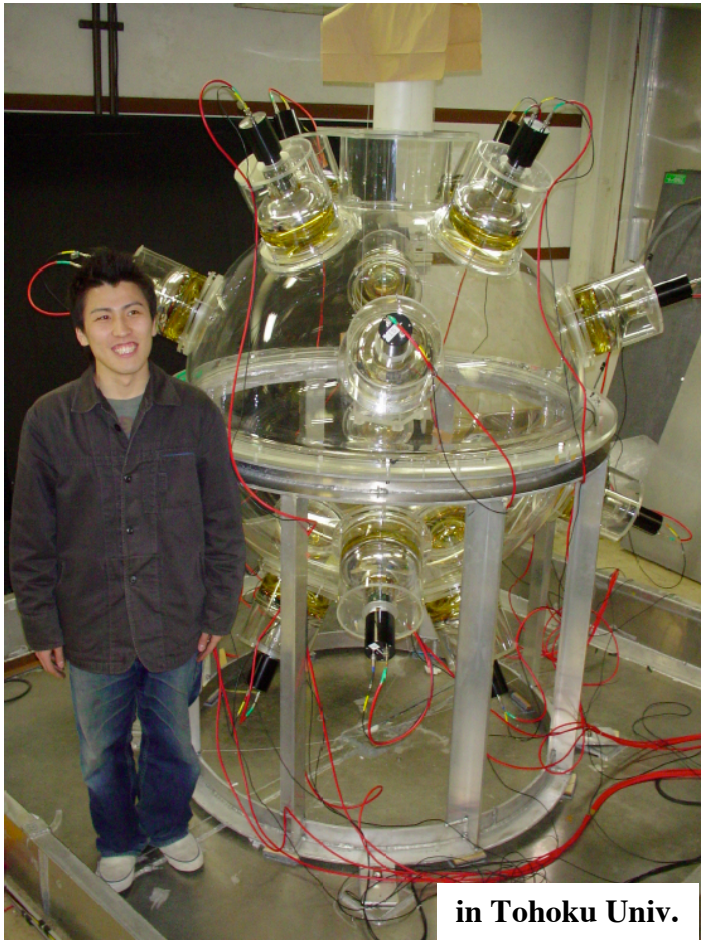
$$e^+ + e^- \rightarrow 2\gamma (2 \times 0.511 MeV)$$

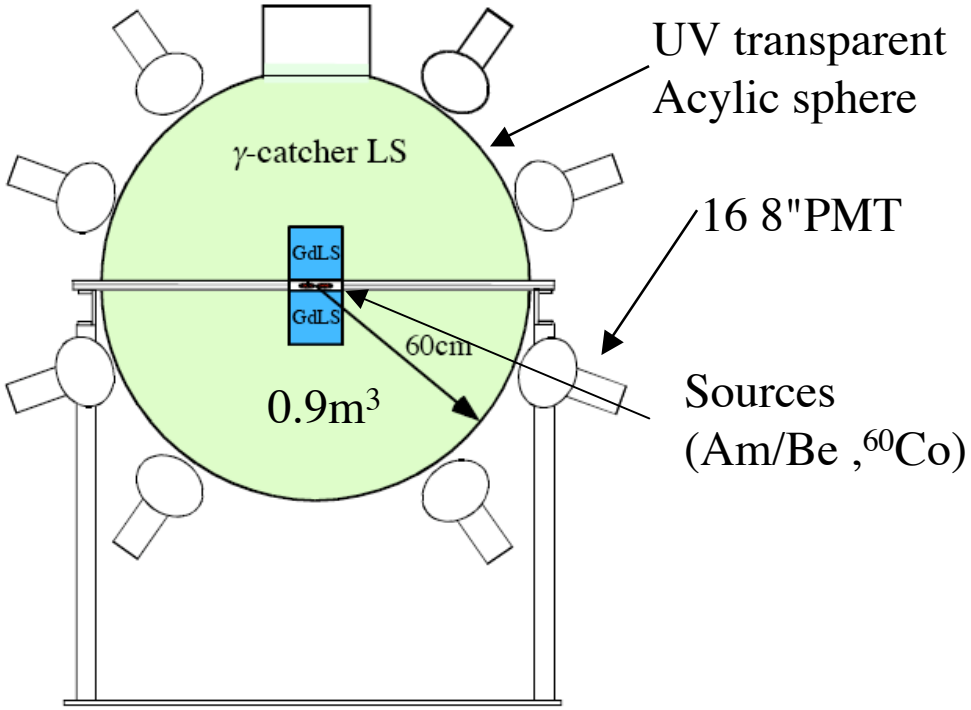
$$n + Gd \rightarrow Gd' + \gamma s \left(\sum E_{\gamma} \sim 8MeV \right)$$



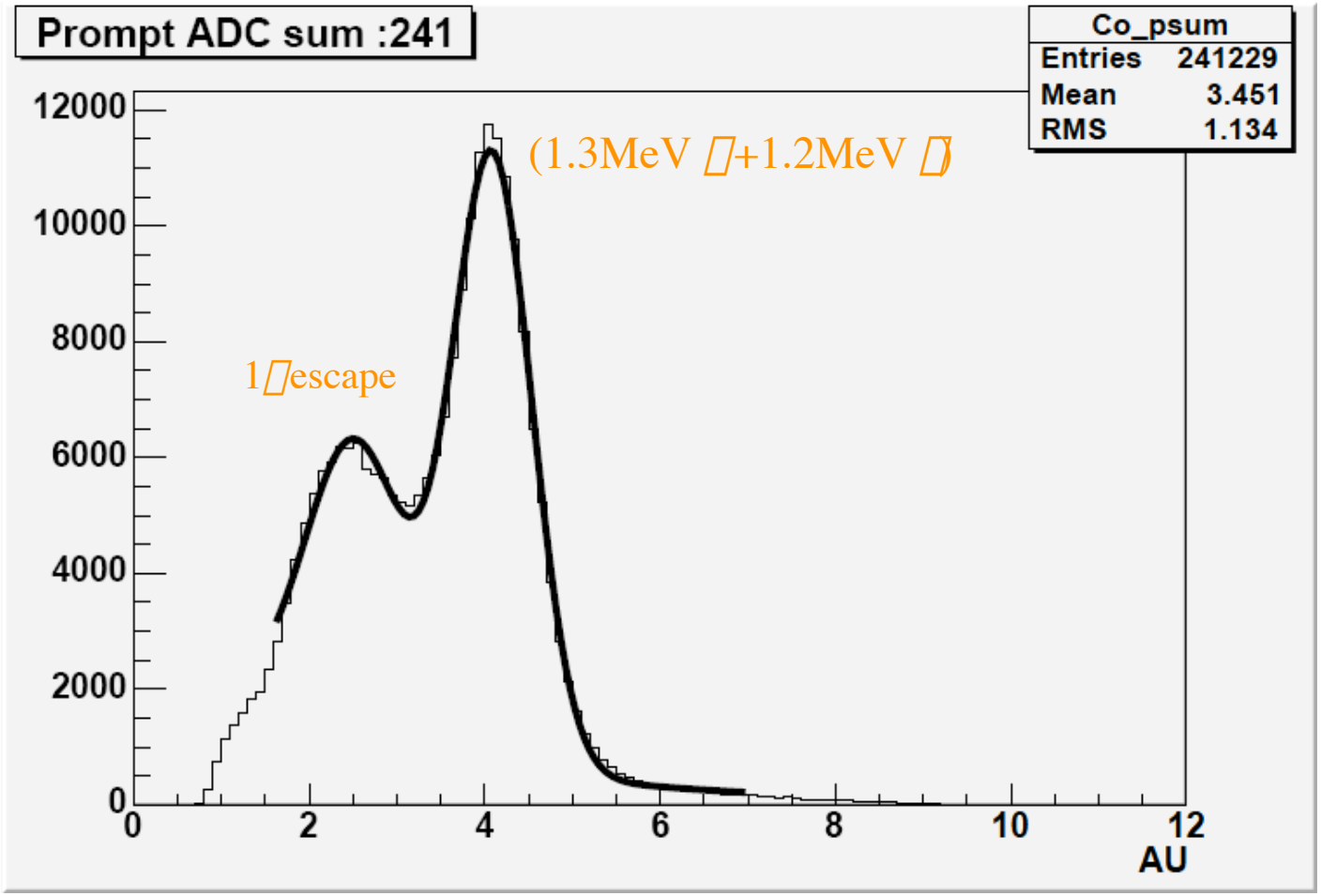
KASKA Prototype

* Test of γ-catcher.
* Am/Be $\bar{\nu}_e$ like signal.
$\bar{\nu}_e$ detection at research reactor.
*Magnetic shield test
•MC development
•LS handling

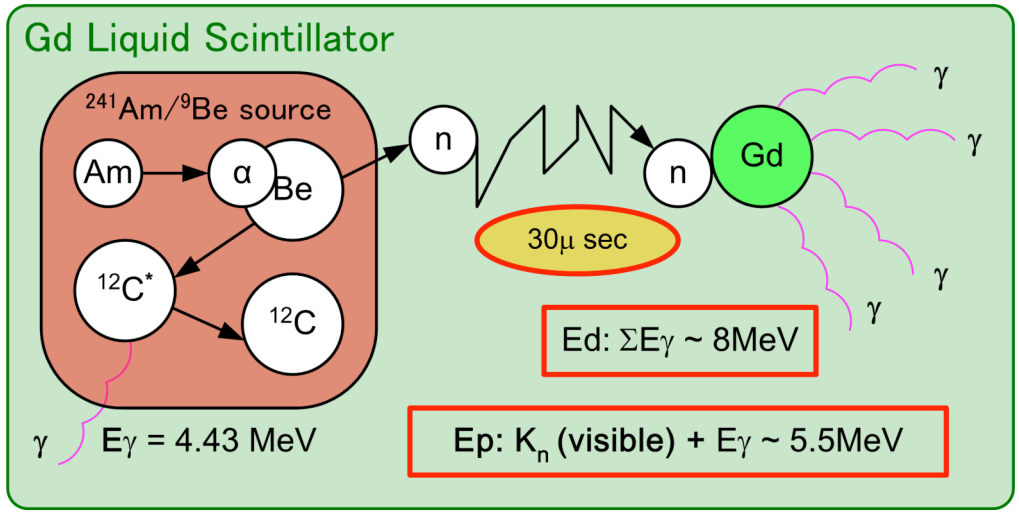




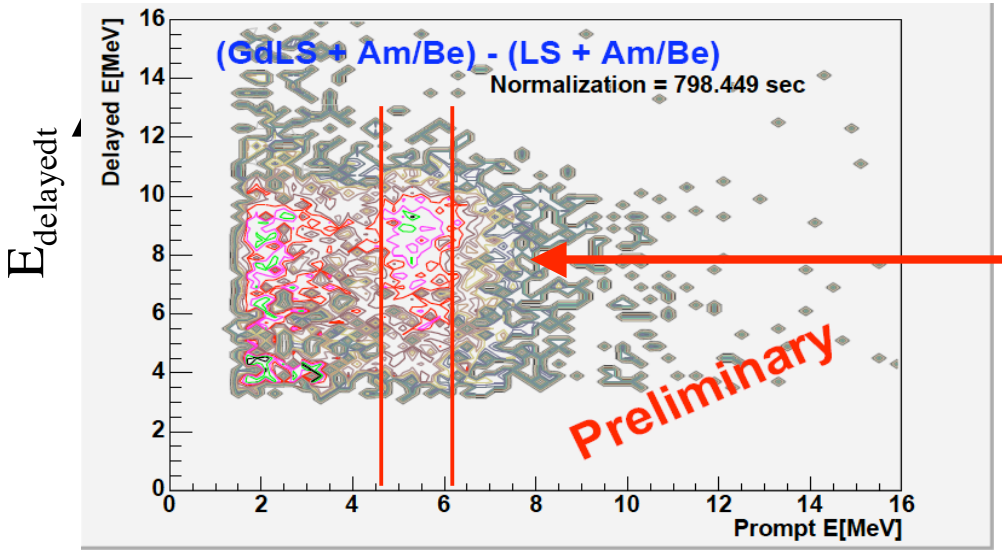
^{60}Co signal


Prompt ADC sum :241
Co_psum
Entries 241229
Mean 3.451
RMS 1.134
(1.3MeV γ+1.2MeV γ)
1γescape
12000
10000
8000
6000
4000
2000
0
0
2
4
6
8
10
12
AU

Am/Be signal

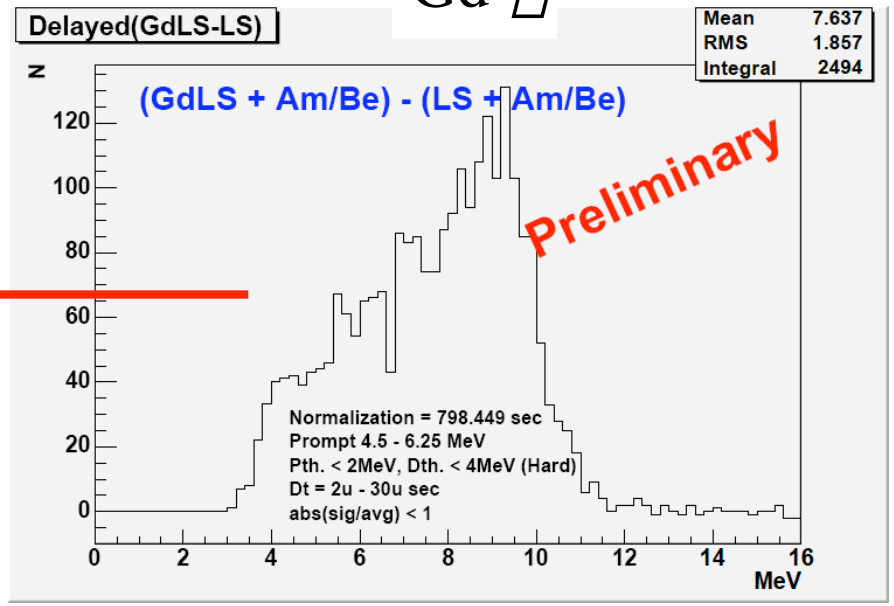


Gd-

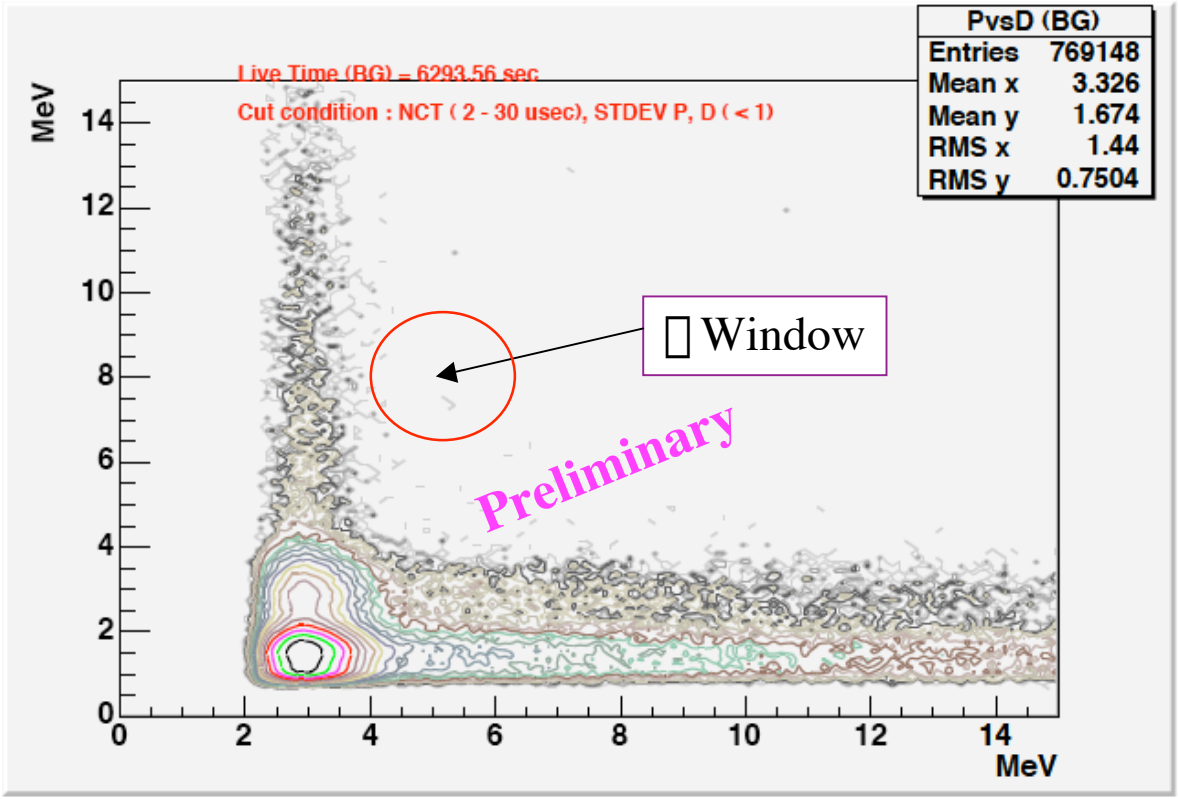


$E_{delayedt}$

E_{prompt}

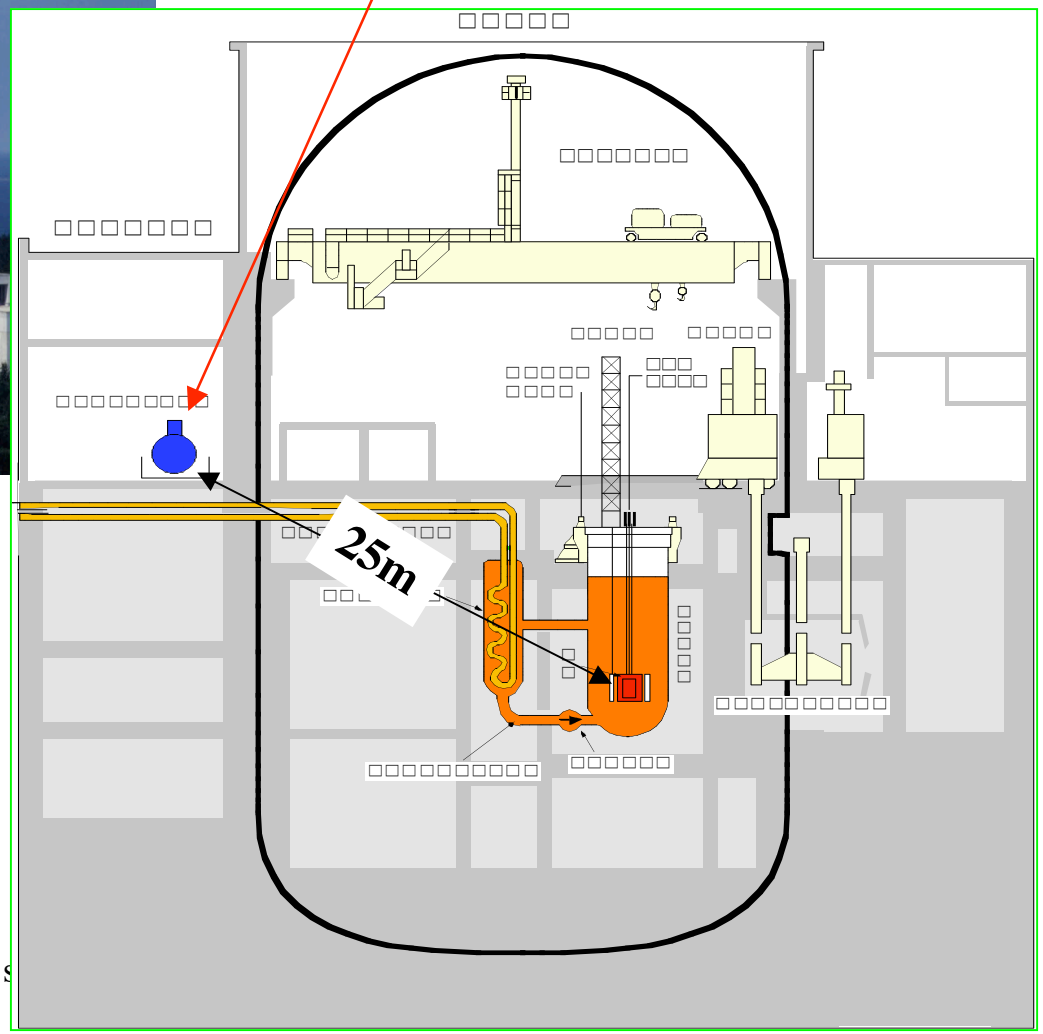


Background for reactor □



Prototype@Joyo research reactor

Purpose: Not for safegard R&D, just to see reactor ON/OFF for demonstration.



Fast Reactor (Pu rich)

P_{th}=140MW

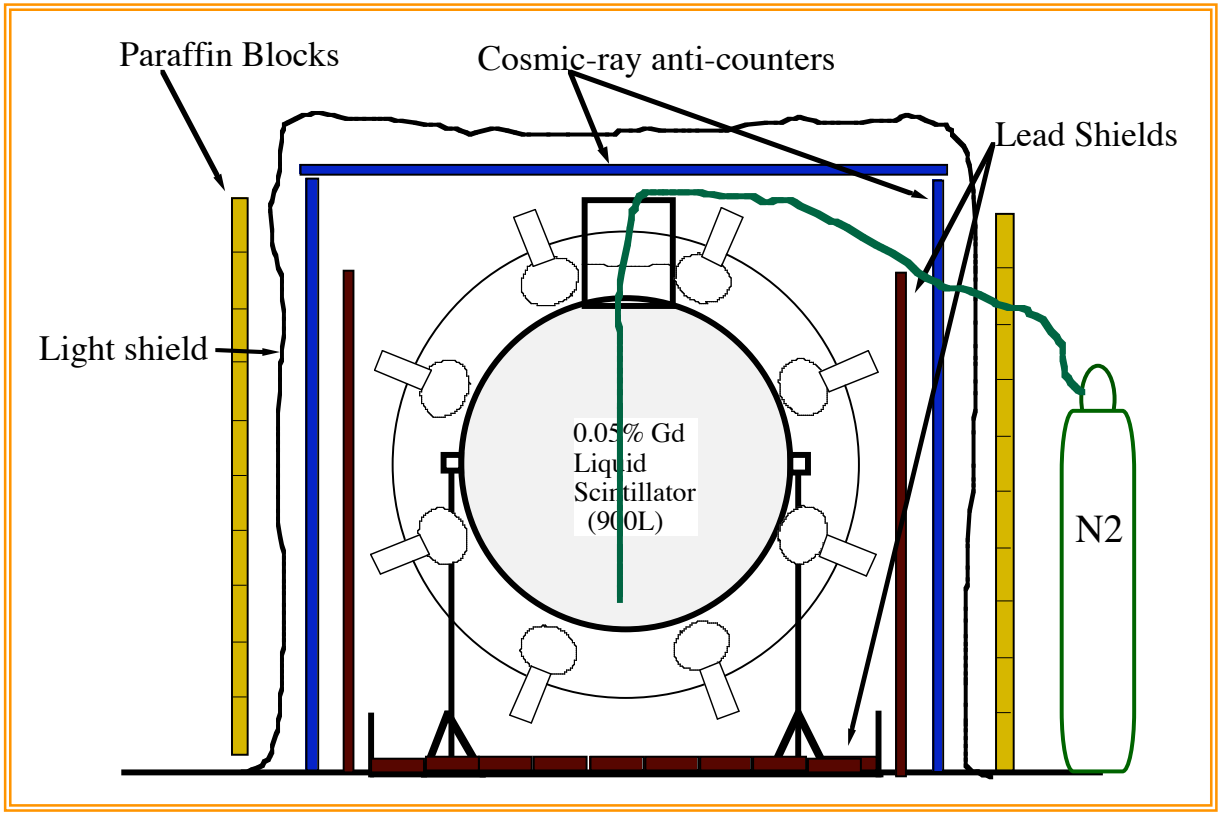
Frequent ON/OFF

L~25m

~150 [p]>e^+n reaction/day

Some modification for Joyo experiment

* 0.05% Gd LS(10%BC521+15%PC+75%isoParaffin oil)
* Lead shield,
* Cosmic-ray anti counter
* Paraffin Blocks
* *n*/γ pulse shape discrimination(PSD)



Event Selections

- 3.5MeV<Ep<6MeV
- 6MeV<Ed<9MeV
- ΔT<50μs
- Fiducial cuts(R<45cm)
- PSD cut

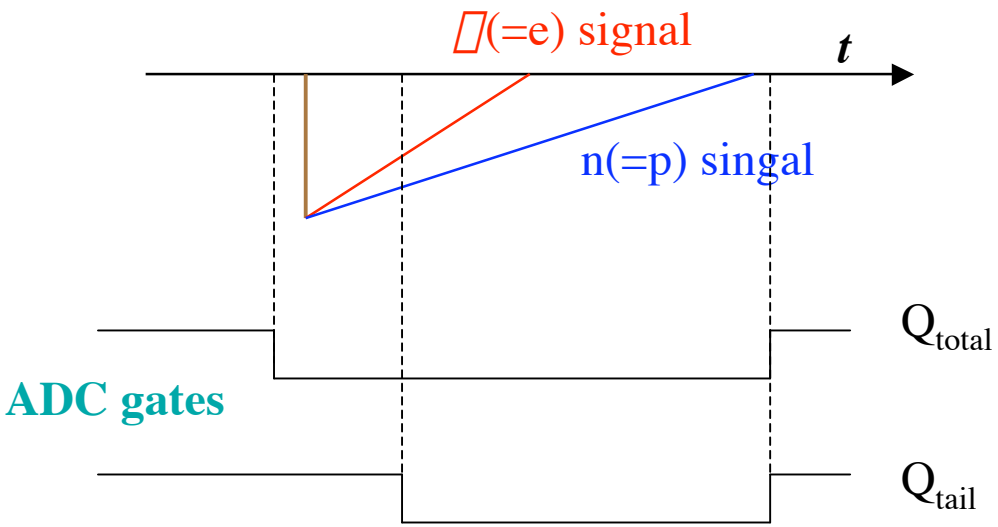
=> efficiency ~5%

=> S/N~1/a few x10

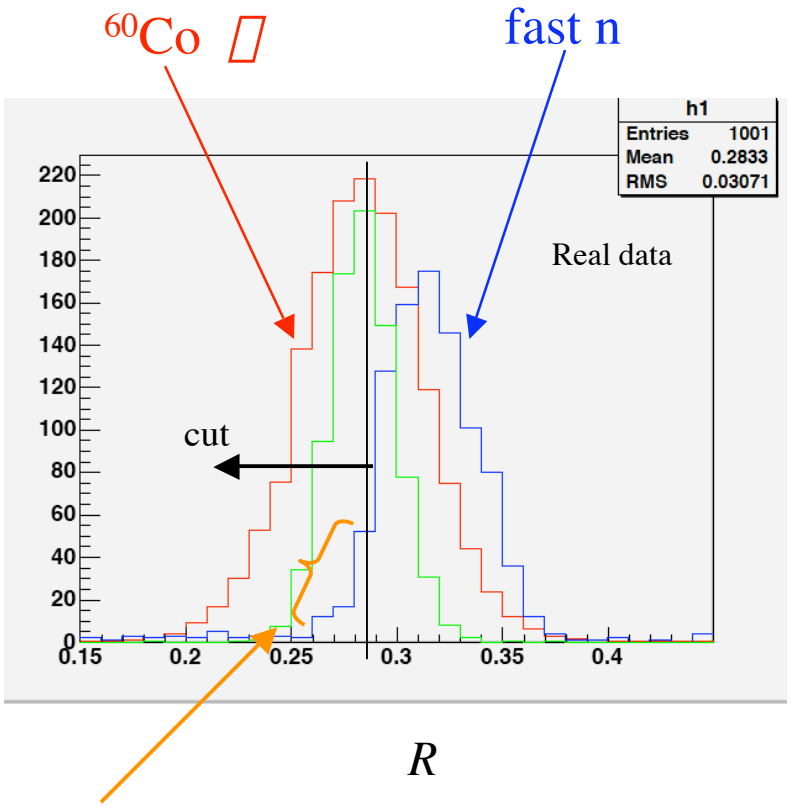
Not to scale

n/γ PSD with prototype LS

The most sever BKG on surface is fast neutron.
=> n/γ separation will be essential

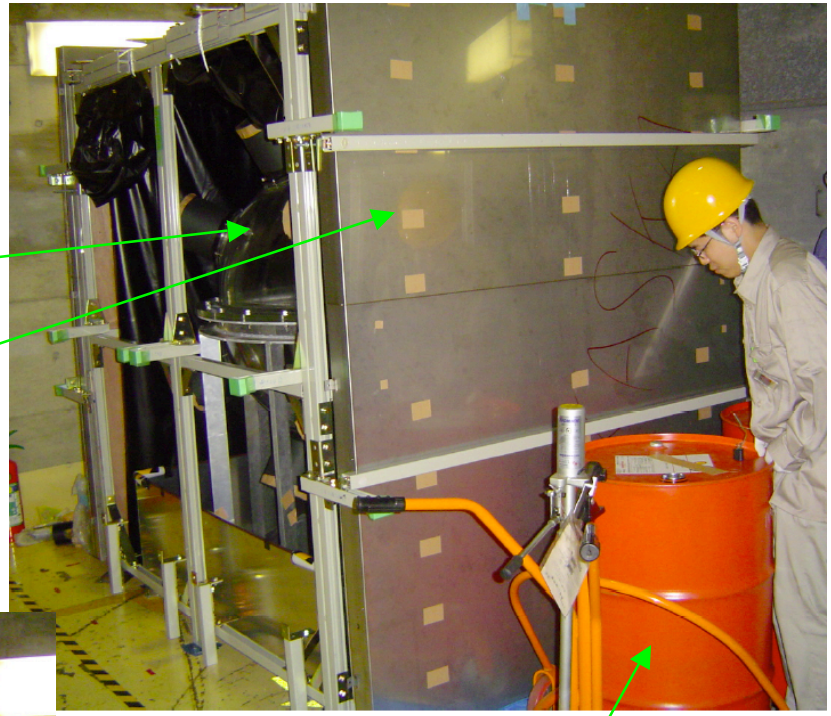


$$R \equiv \frac{Q_{tail}}{Q_{total}}$$ is different for γ and n



For 50% of γ efficiency, n rejection rate >90% => S/N becomes more than 5 times better

2006.8.30

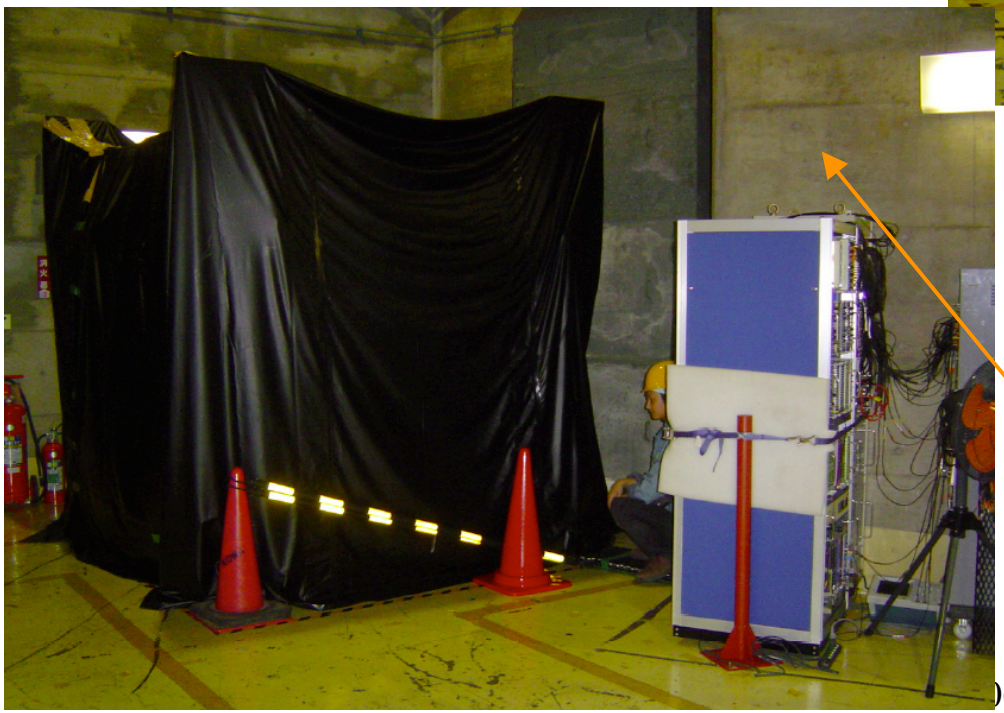


Acrylic sphere

Cosmic-ray
Anti counter

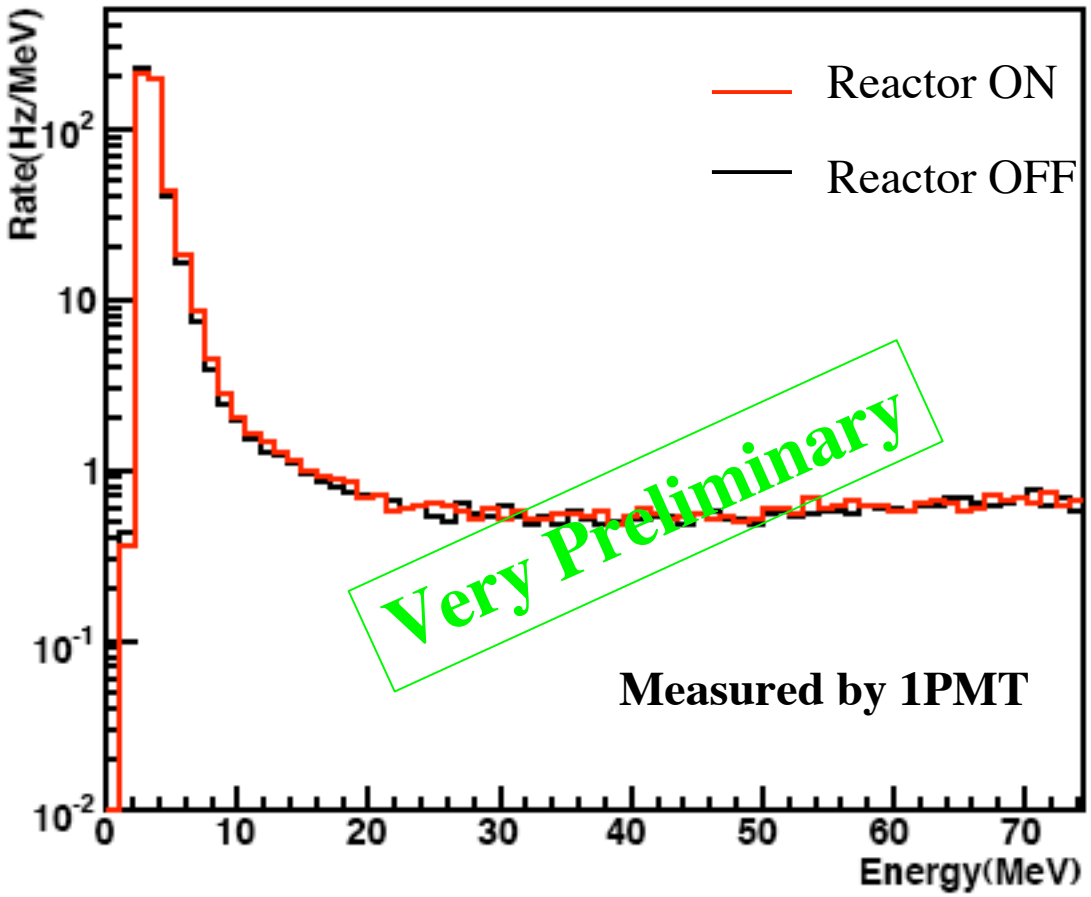
Gd-LS

2006.9.20



Reactor is behind the wall

Energy spectrum of singles (no cuts)



Just starting data taking.

Possible Improvements

*** More PMT Coverage: => Better PSD**
=> Less leakage from low energy BKG

*** Better Shield: Thicker lead & paraffin block shields,**
Double acrylic sphere (buffer region)

*** Better Anticounter coverage: => Cosmic-ray related BKG**

*** Higer reactor power: Monju(fast reactor) => x5**
High Power ABWR => x30

*** Shorter distance: => ~ $1/L^2$**

Simple Summary

- **KamLAND successfully measures reactor neutrinos at distance hundreds of km from reactors.**

- **KASKA prototype is going to take fast reactor data shortly**