CdWO4 crystal in KamLAND for neutrino-less double beta decay research

Outline

1, Introduction
2, test measurement with CdWO4 crystal
3, deployment of CdWO4 crystal in KamLAND detector
4, Summary

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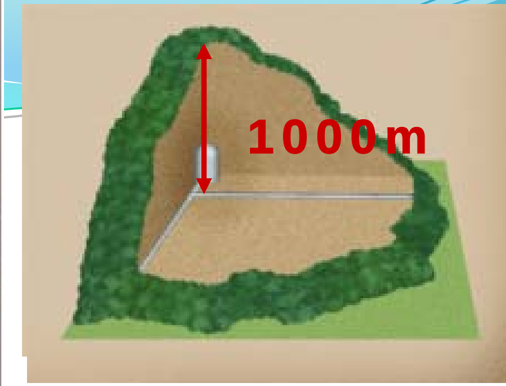
Nov. 17, 2011 @DBD11 in Osaka

1, Introduction

KamLAND detector (before KamLAND-zen)



Inner Detector

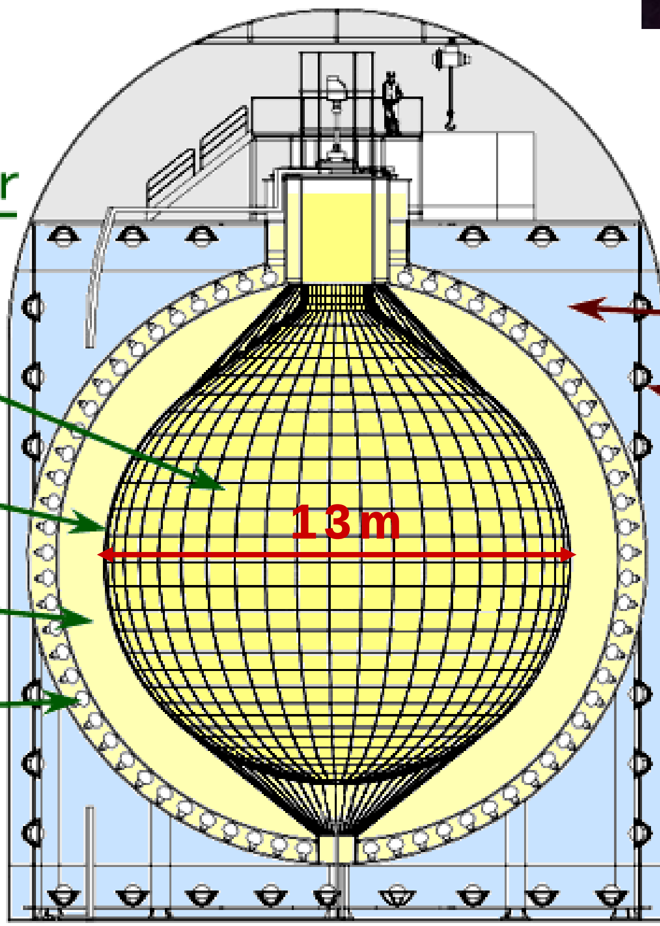
Liquid Scintilaltor (1kton)

Plastic Balloon

Mineral Oil (1800m³)

PMT

1879 PMTs
In total
(17inch & 20inch)



Outer Detector

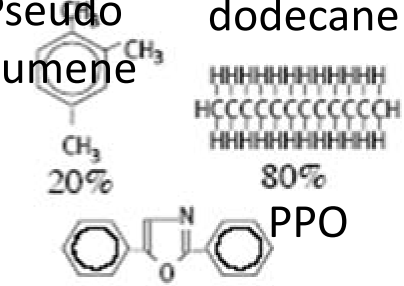
Water (3.2kton)

PMT (225 20inch PMTs)

LS

Pseudo cumene

dodecane



20%

80%

PPO

1.5g/l

$\rho = 0.78 g/cm^3$

$8,000 photons/MeV$

$\lambda \sim 10 m$

34% photo-coverage with 1325 17" and 554 20" photo-tubes

KamLAND for double beta decay measurement

- the radioactivity level inside the detector is very low
  - ^{238}U 7.3 × 10^{-19}[g/g]
  - ^{232}Th 1.5 × 10^{-17} [g/g]
  - ^{40}K < 1.5 [μBq/m³]
- The detector is capable of dissolving double beta decay material into Liquid Scintillator (KamLAND-zen),

or putting solid material inside the KamLAND balloon.

-> ^{116}Cd crystal in KamLAND is one of those options.

Isotope	Q-value [MeV]	Abundance [%]	2 ν half life (yr)
^{48}Ca	4.27	0.19	4.2×10^{19}
^{150}Nd	3.37	5.6	7.8×10^{18}
^{96}Zr	3.35	2.8	2×10^{19}
^{100}Mo	3.03	9.6	7.1×10^{18}
^{82}Se	3	9.2	9.2×10^{19}
^{116}Cd	2.8	7.5	2.9×10^{19}
^{130}Te	2.53	34	0.9×10^{21}
^{136}Xe	2.47	8.9	2.1×10^{21}
^{124}Sn	2.29	5.79	$>1 \times 10^{17}$
^{76}Ge	2.04	7.8	1.5×10^{21}

$CdWO_4$ crystal

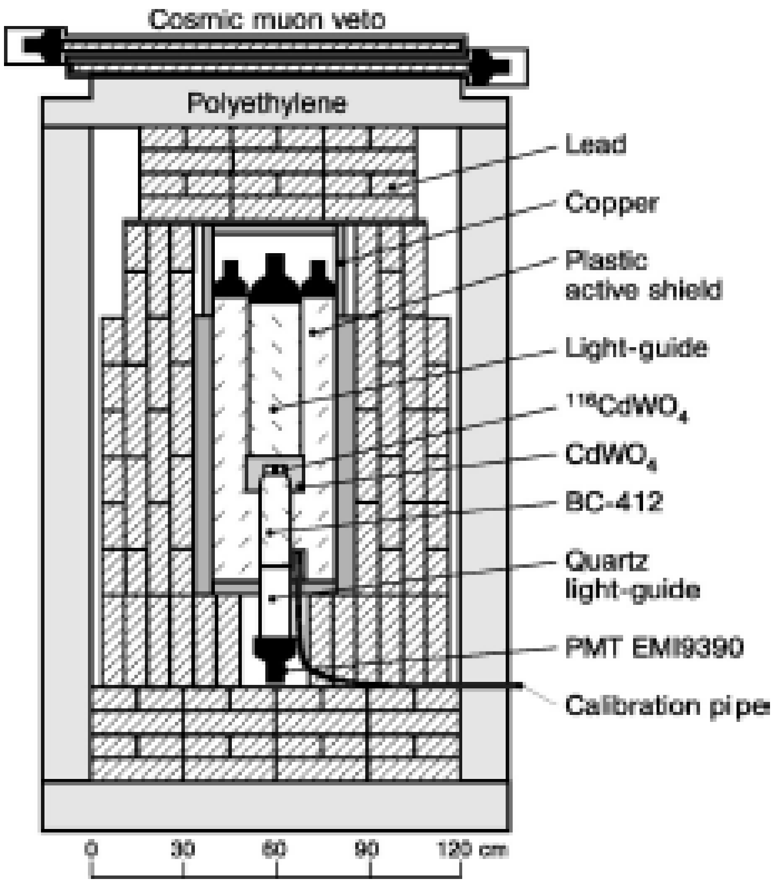
- Property of $CdWO_4$ crystal

Density:	7.9 g/cm^3
Melting point	1598 K
Hygroscopicity	absent
Chemically	inert
Max Emission Spectrum	470-540 nm
Refractive index	2.3
Light yield	~ 40% to NaI ?
Radio purity	< 10 µBq/kg
X_0	1.11 cm
λ	21.7 cm
Timing:	88.7% - 14.5 µsec
	8.7% - 4.6 µsec
	2.1% - 0.8 µsec
	0.5% - 0.15 µsec

For example: L.Bardelli at all, nucl-ex/0608004v1, August 2006

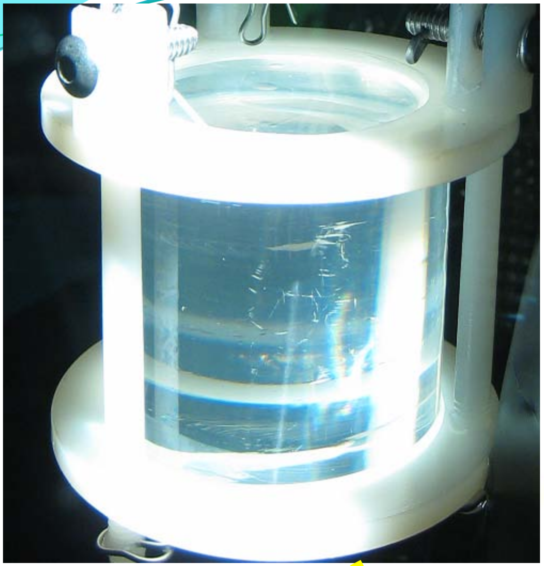
Past double beta decay experiment with $CdWO_4$ crystal

- F.A.Danevich at all. Phys Rev C68, 035501 (2003)
- Solotvina Underground Laboratory (1000 meters of equivalent)
- Four $CdW0_4$ crystals build with enriched up to 83% (Natural – 7.49%)
- Crystals mass – 330g → ^{116}Cd mass is 87 g.
- Crystals were viewed by 55 cm long light guide and background 5" EMI PMT
- Active shielding made of natural, CdW04, plastic scintillators
- Passive shielding: high purity cooper 3-6 cm, Lead 2 cm and 16 cm Polyethylene
- Cosmic veto: two plastic scintillators (120*130*3 cm installed above passive shield



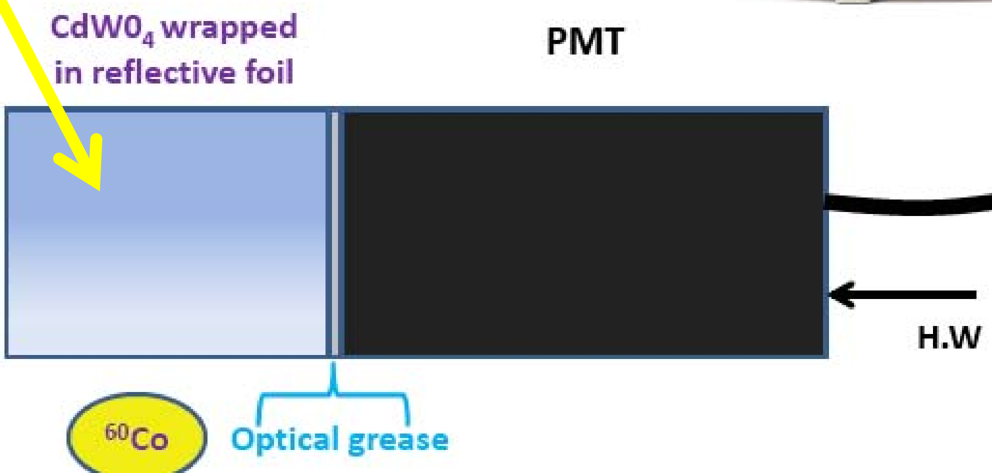
$T^{2\nu}_{1/2}$ = [2.9±0.06(stat) $^{+0.4}_{-0.3}$(sys)] ·10^{19} y was obtained

2, Test measurement of CdWO4's scintillation signal



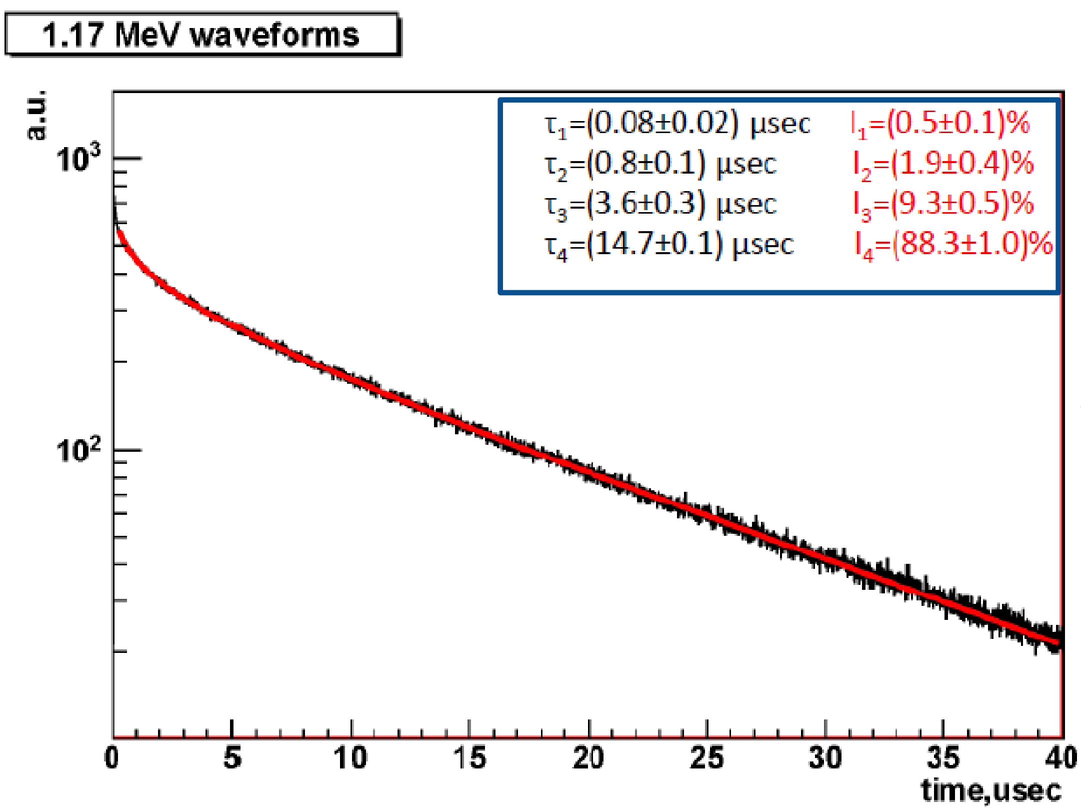
* Natural CdWO4 crystal (column shape)
Diameter = 39.65mm, height = 40.00mm
total mass = 390g
^{116}Cd mass = 9.4g

Record waveforms with a digital scope and store them in computer with following later analysis



Decay curve of scintillation light

Waveforms recorded by a digital oscilloscope were summed.



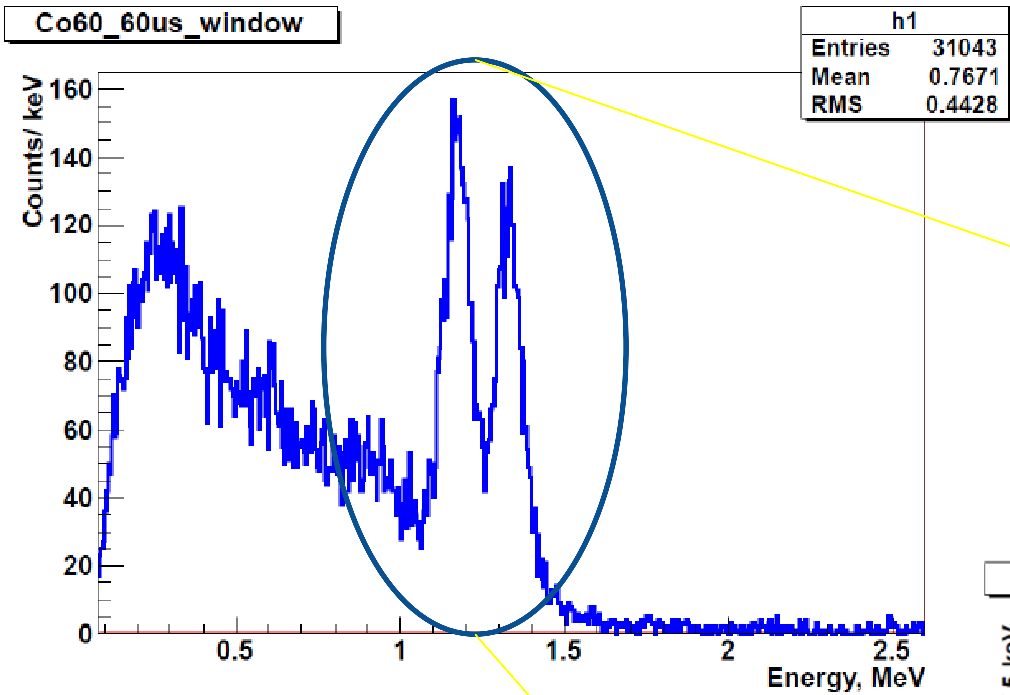
From the area of the waveform,
2300 p.e. @1MeV was obtained.

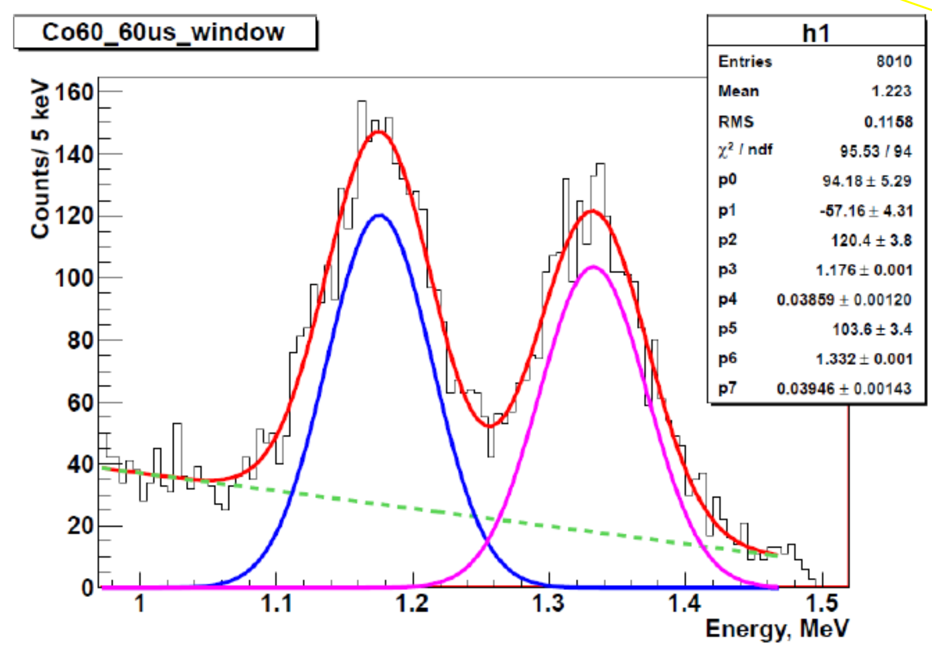
Consistent with
the past measurement

decay time [μs]	ratio [%]
14.5	88.7
4.6	8.7
0.8	2.1
0.15	0.5

nucl-ex/0608004v1, August 2006

Energy spectrum of ^{60}Co source

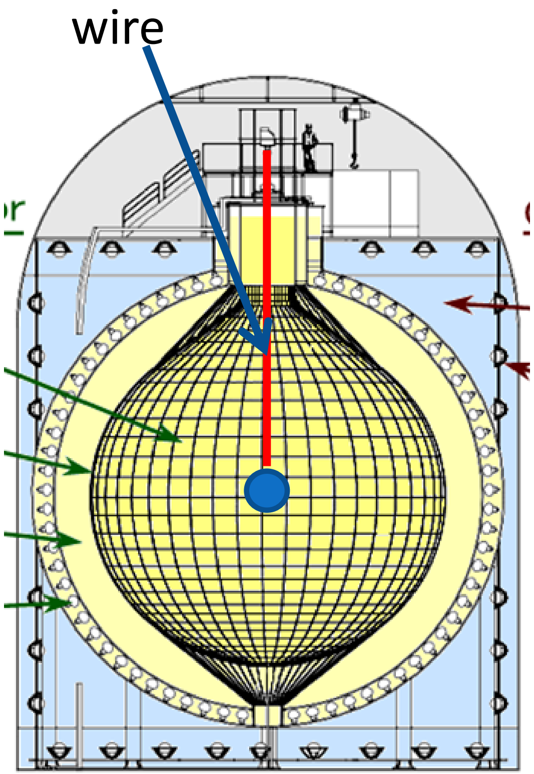


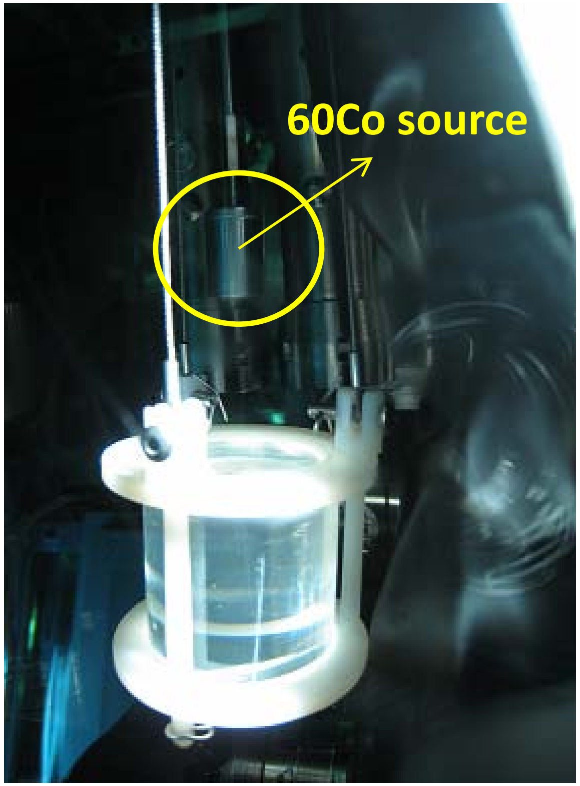


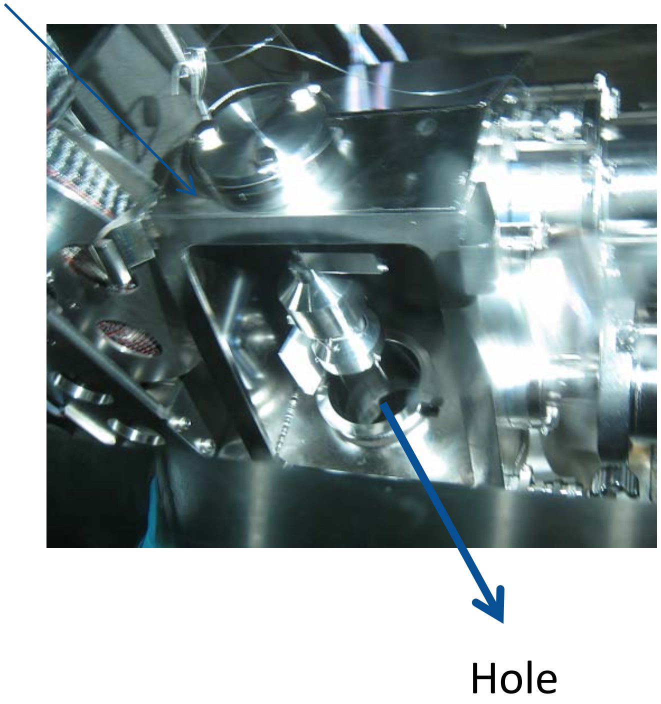
Resolution δ:
for 1.17 MeV 3.28%
for 1.33 MeV 2.97%

3, Installation of $CdWO_4$ crystal in KamLAND

Put the Cd crystal in the center position using a calibration source deployment system(MiniCAL) .







Measurement was done
- with Cd crystal and ^{60}Co source
- with Cd crystal only
- with nothing inside the balloon other than LS

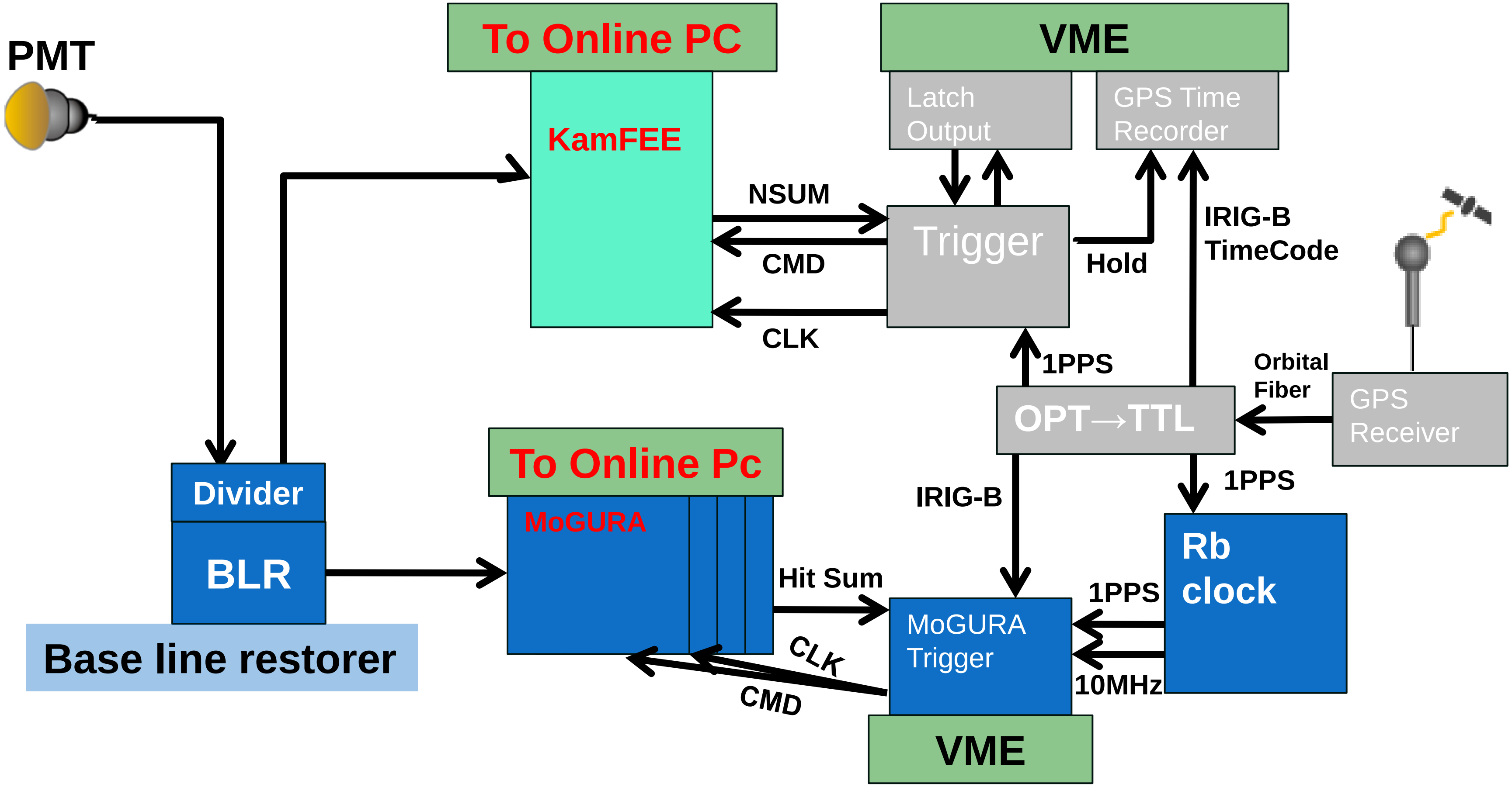
KamLAND DAQ

To measure scintillation light from Cd Crsytal, front-end electronics continue taking data for more than a few tens of micro second.

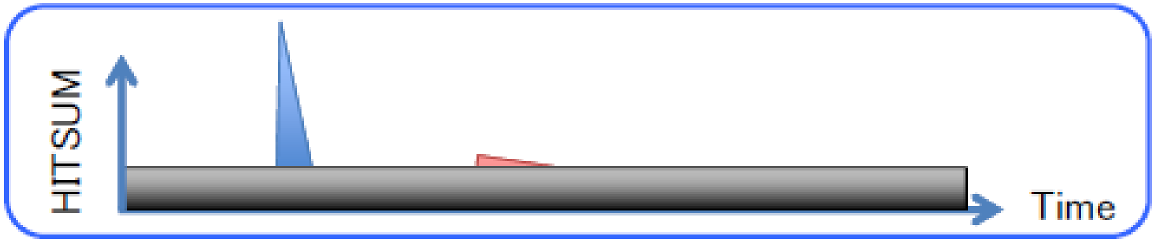
Signals are processed by two types of electronics.

* KamFEE : 30μs is needed to digitize waveform
* MoGURA : dead time free new electronics. Not covered all PMTs.

-> MoGURA was used for the detection of signals from Cd crystal



Expected timing distribution of hits



LS signal

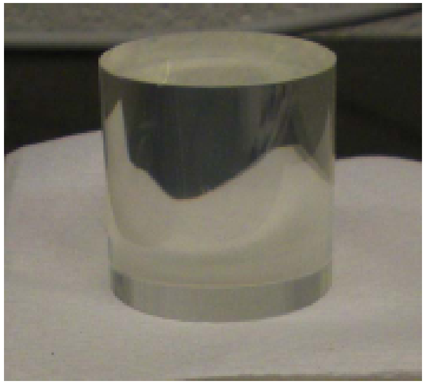
Event Rate	~ 80 Hz (@Th = 120 NHITs)
HIT Distribution	~ 100 nsec
NHITs	~ 200 HIT/MeV (for 17')

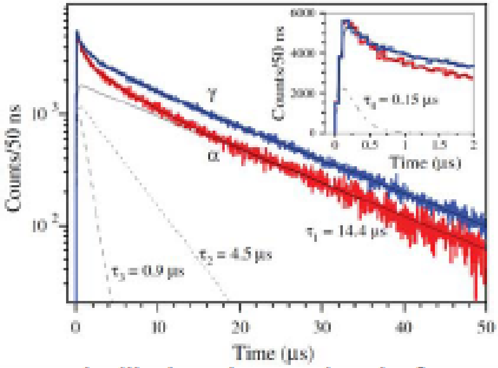
Dark signal

Dark Rate	~ 1.5 HIT/CLK

Crystal signal

Event Rate	~ Hz
Decay Constant	~ 14.5 usec
Light Emission	~ 15 k photons/MeV
Visible p.e.	~ 500 p.e./MeV
HITs	~ 1.9 HIT at the 1st CLK @ 2.8MeV
	~ 0.69 HIT at the 1st CLK @ 1.1 MeV

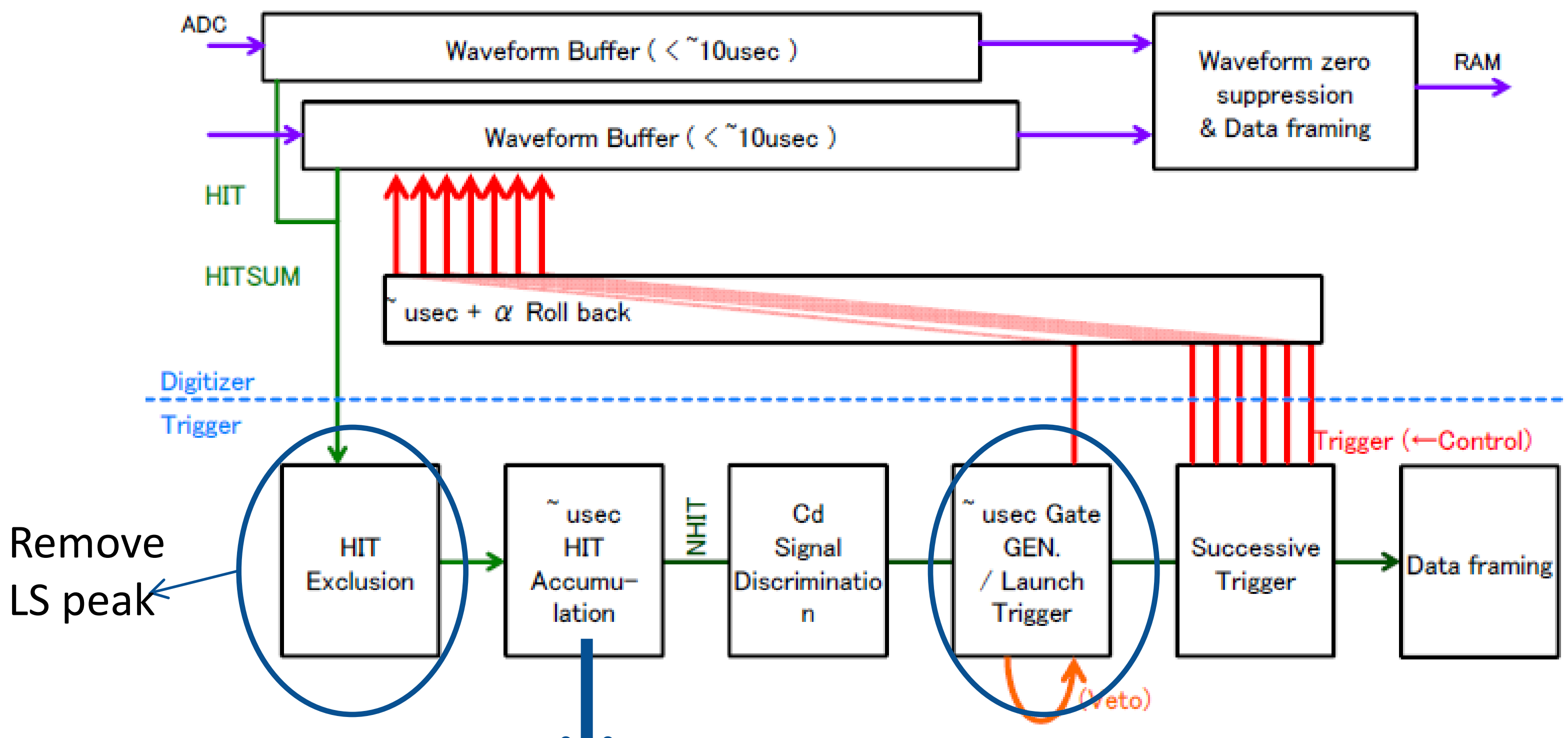




scintillation decay signal of similar CdWO4 crystal

: L.Bardelli et al. NIMA 569 (2006) 743-753

New trigger logic for Cd signal

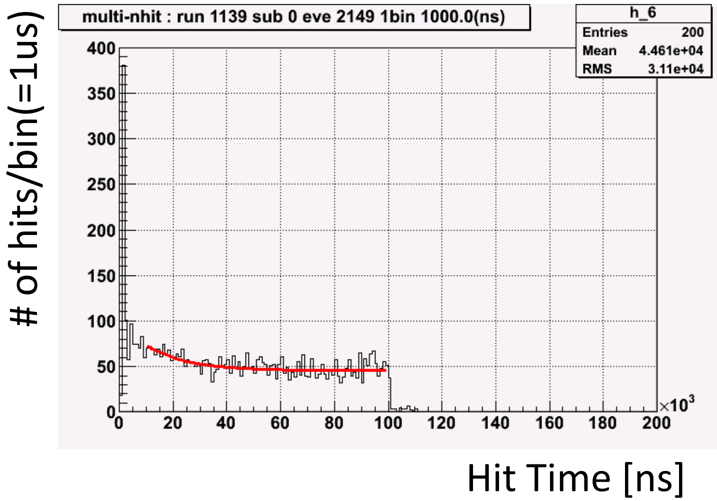


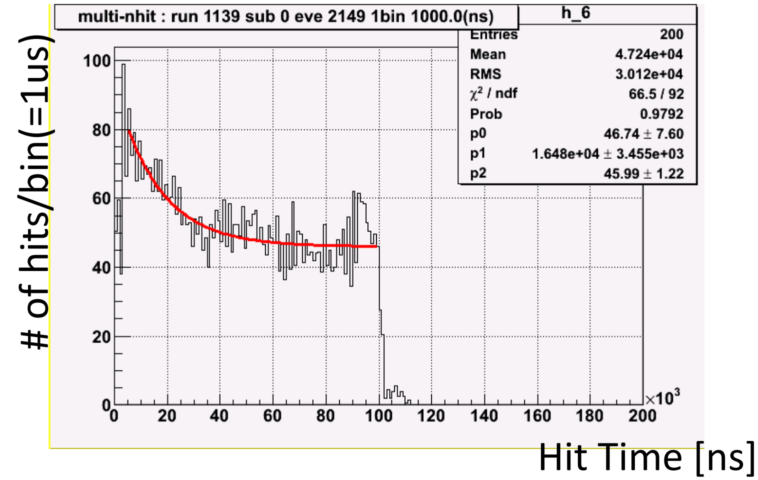
Hit accumulation Window length for trigger :
Normal run -> 120ns
Cd trigger -> 7 micro sec

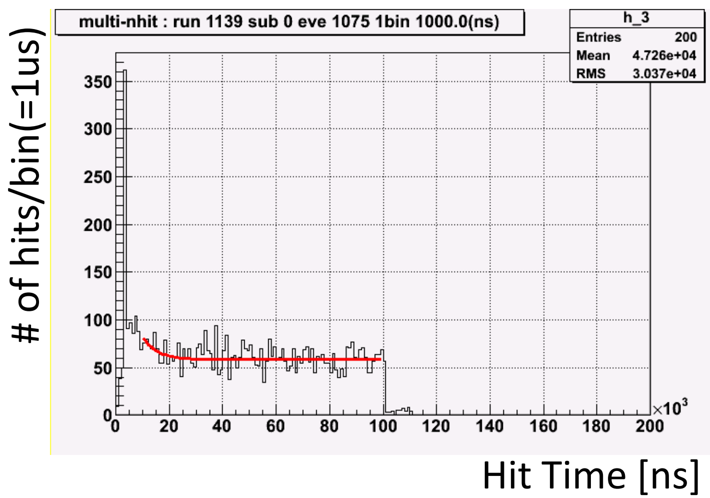
Hit distribution in one event

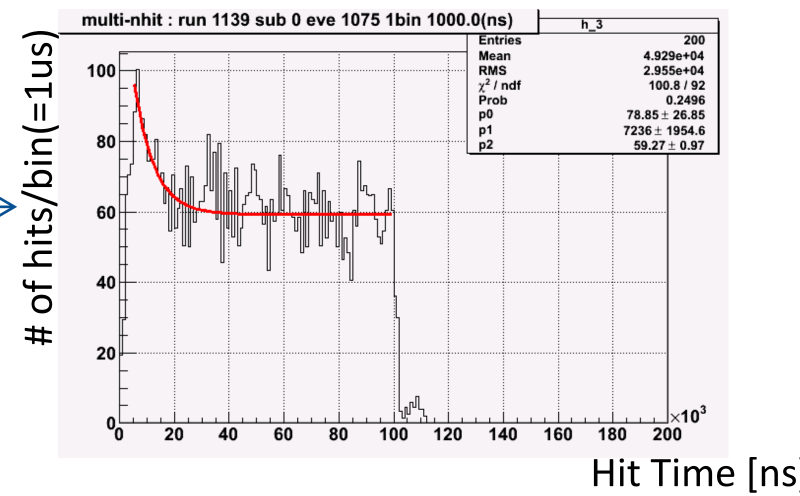
Raw Data

Remove a peak(hits/bin>200)
and fit a exponential curve to the data





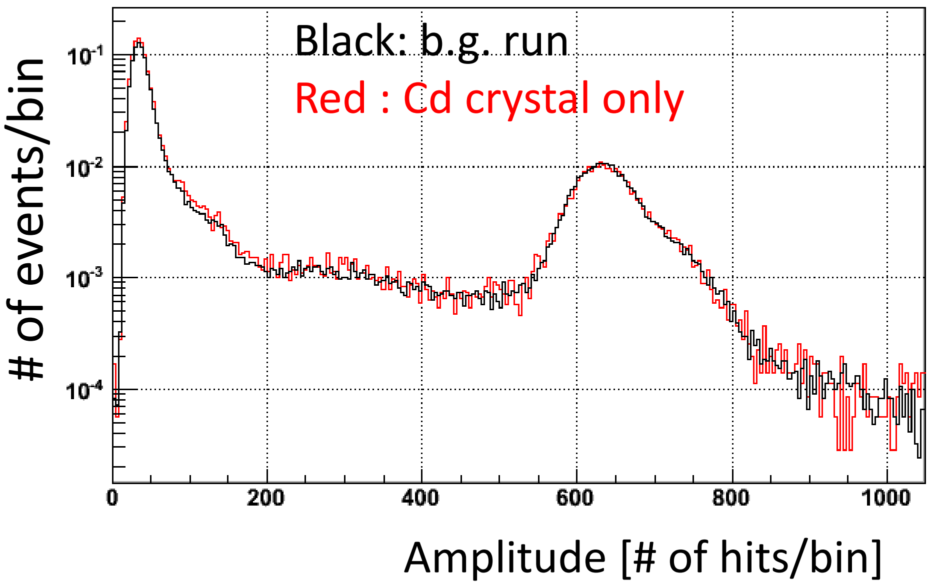


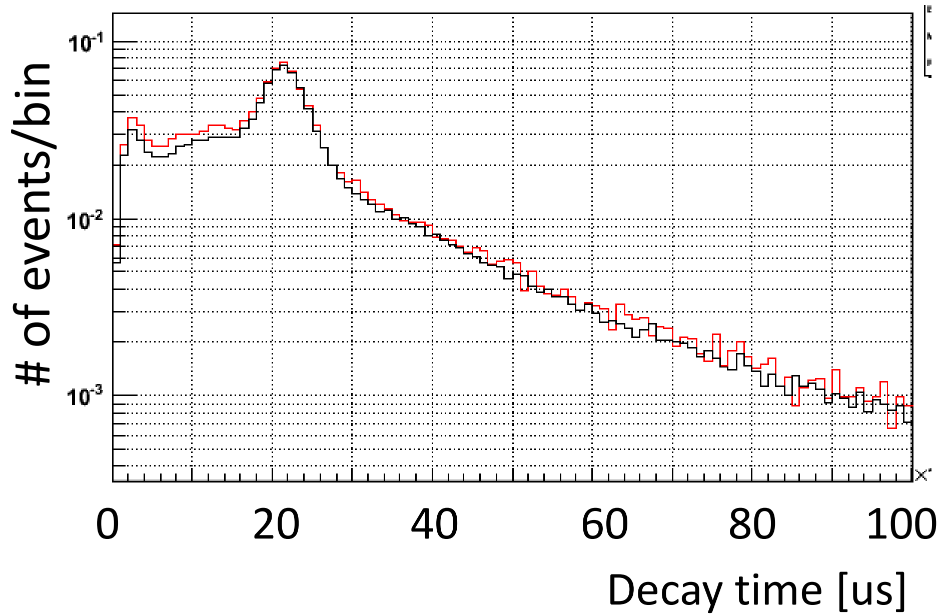


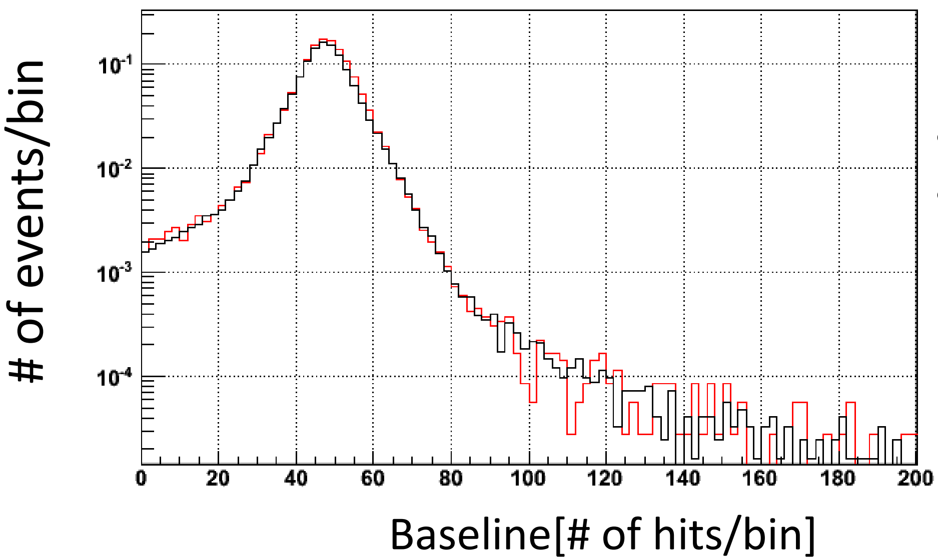
Fitting curve : f(t) = amplitude * exp(- t/decaytime) + baseline

background and Cd-only run

Distributions of fitting parameters

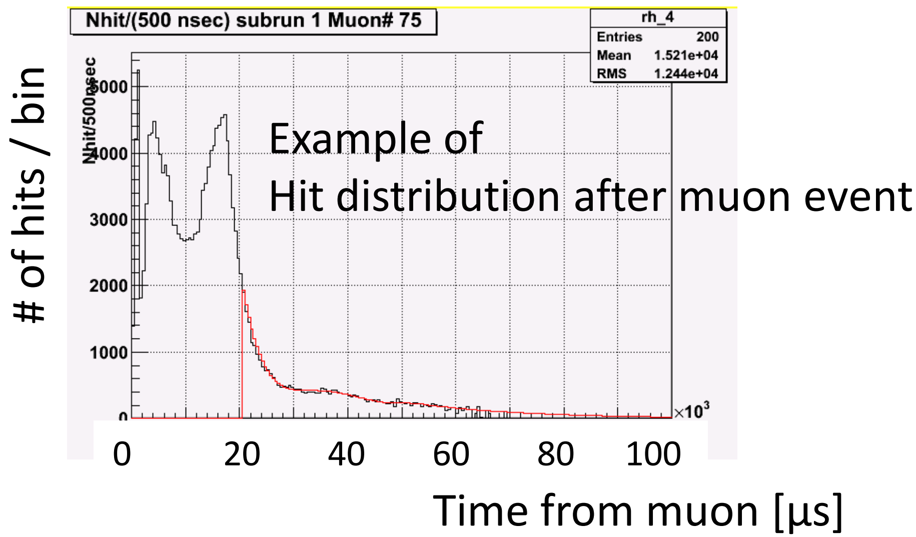




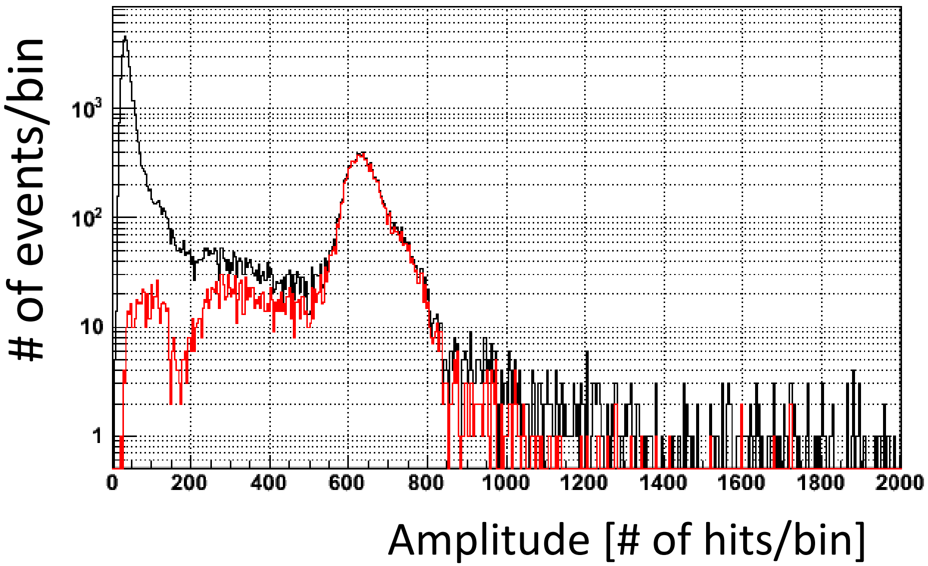


- Two peaks in Amplitude distribution
- b.g. events tend to take decay time of around 22us

Muon subtraction



After pulses after muon event mimic Cd signals.



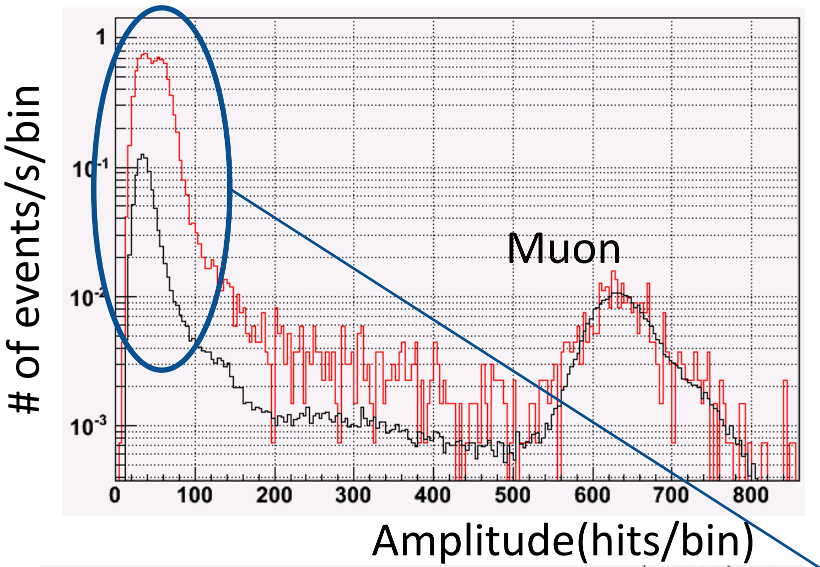
Comparing the Cd-triggered evens with the FBE electronics data, we can subtract muon.
Then higher peak can be removed.

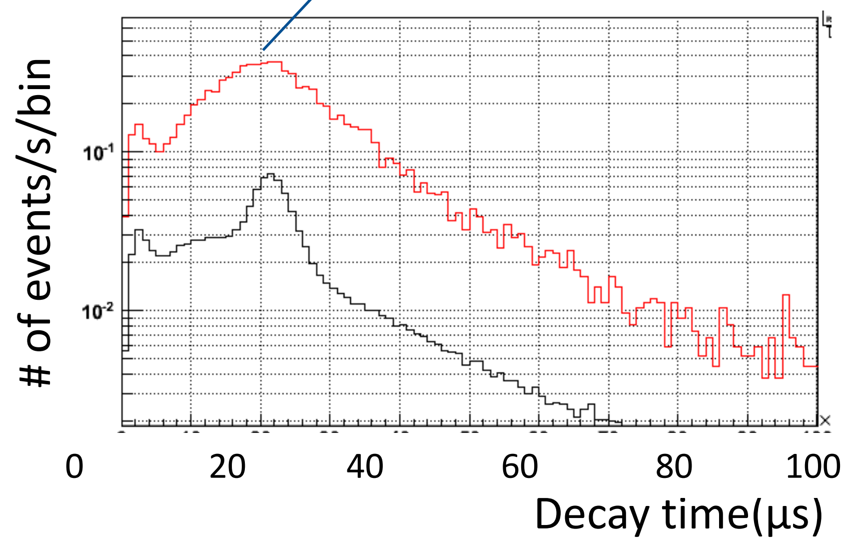
Cd crystal and ^{60}Co source run

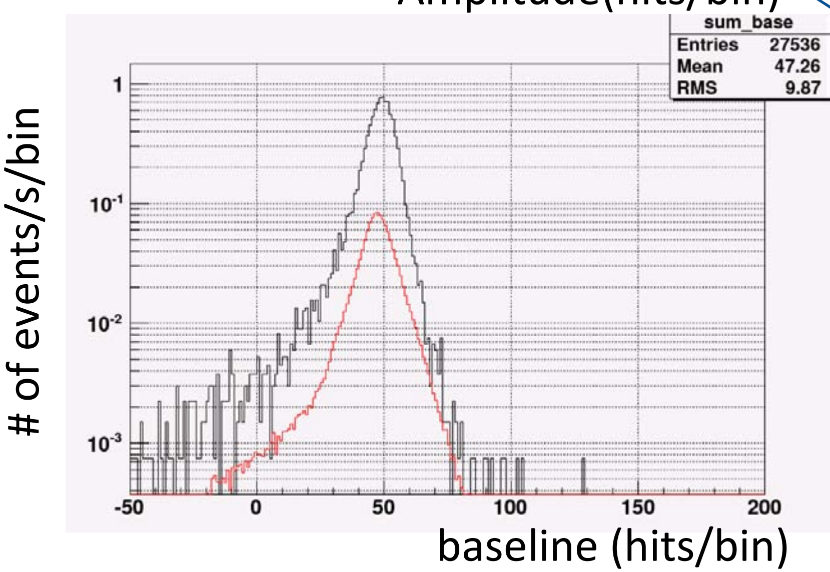
Red : $CdWO_4$ + ^{60}Co run

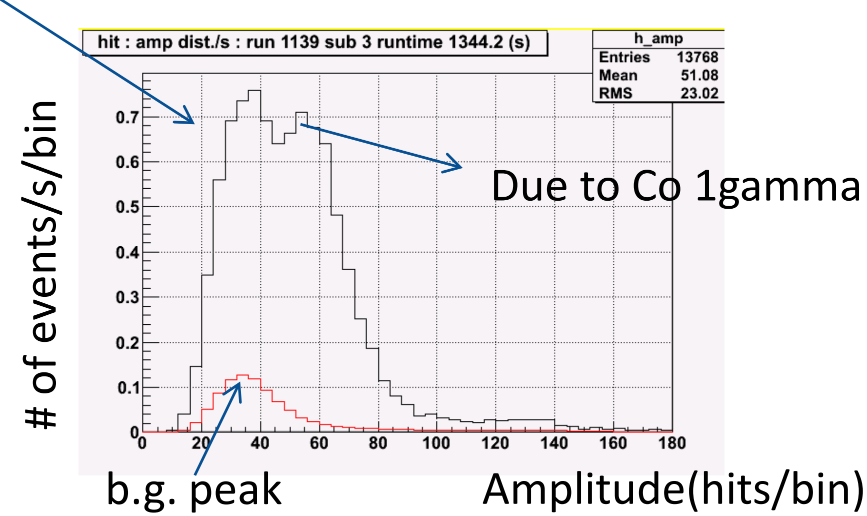
Black : background run

Decay time Is
Larger than 14us



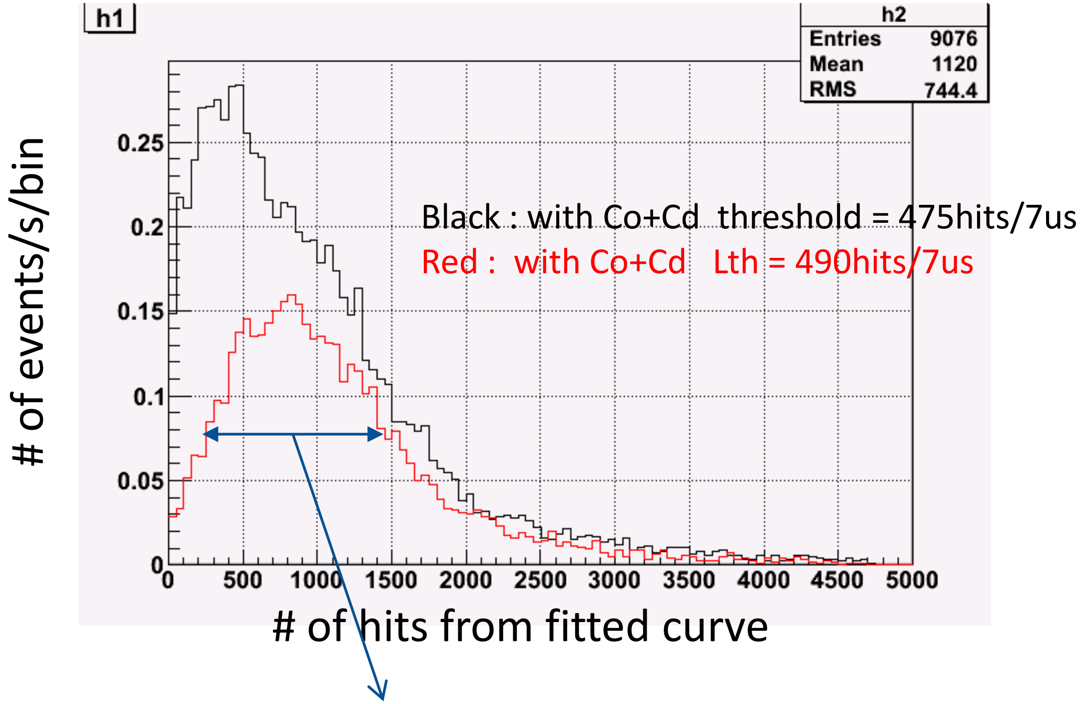






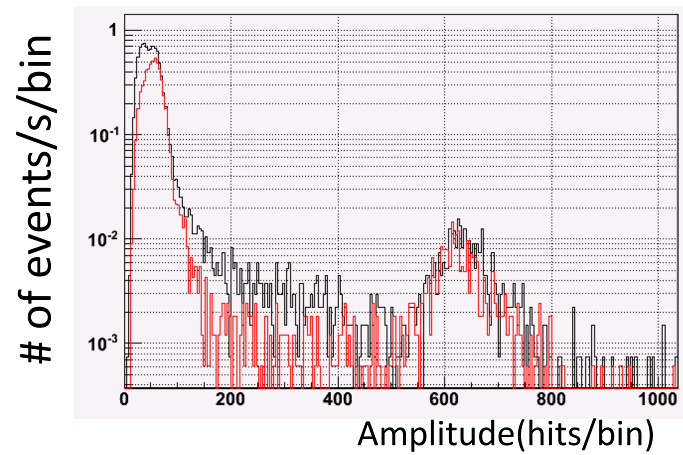
Rough estimation of the Resolution

Integrate "f(t) = **amplitude** * exp(- t/**decaytime**) + **baseline**" and obtain # of hits



FWHM of the peak is broad.

Increase the trigger threshold



Black : with Co+Cd threshold = 475hits/7us

Red : with Co+Cd Lth = 490hits/7us

4, Summary

* Natural $CdWO_4$ crystal was prepared and the property of scintillatoin light was measured.

    * Crystal was directly connected with PMT and about 3% energy resolution @ 1MeV was obtained.

* $CdWO_4$ crystal was deployed in KamLAND together with ^{60}Co source.

    * new Trigger logic detected Cd scintillation signals
    * Obtained peak from ^{60}Co's one gamma ray was rather broad.
    * To investigate the result further, detailed simulation or measurement with other sources will be needed.