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Workshop Towards Neutrino Technologies

13 - 17 July 2009

Toward low energy anti-neutrinos directional measurement; development of Li loaded liquid scintillator

Hiroko WATANABE

Tohoku University
Research Center for Neutrino Science
Aramaki Aza Aoba
Aobaku
Sendai 980-8578, Myagi, JAPAN

Toward low energy anti-neutrinos directional measurement

; development of Li loaded liquid scintillator

Workshop Toward Neutrino Technologies
Trieste - Italy, 13~17 July 2009

Hiroko Watanabe
RCNS, Tohoku University

Outline

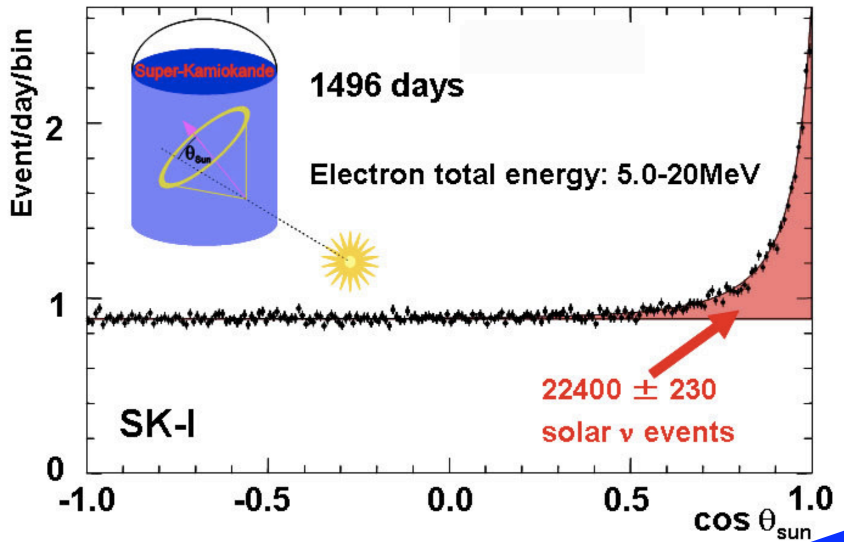
1. Directional Measurement
   - Physics Motivation
   - Detection Principal
2. Development of Liquid Scintillator
   - Reaction in Liquid Scintillator
   - Neutron Capture Nucleus
   - Li loaded Liquid Scintillator
   - Performance Estimation
3. Imaging Detector
   - Outline
   - Initial Development
   - Measurement Result
4. Application to Reactor Monitor
5. Summary

- Directional Measurement
  - Physics Motivation
  - Detection Principal

Directional Measurement

- Physics Motivation

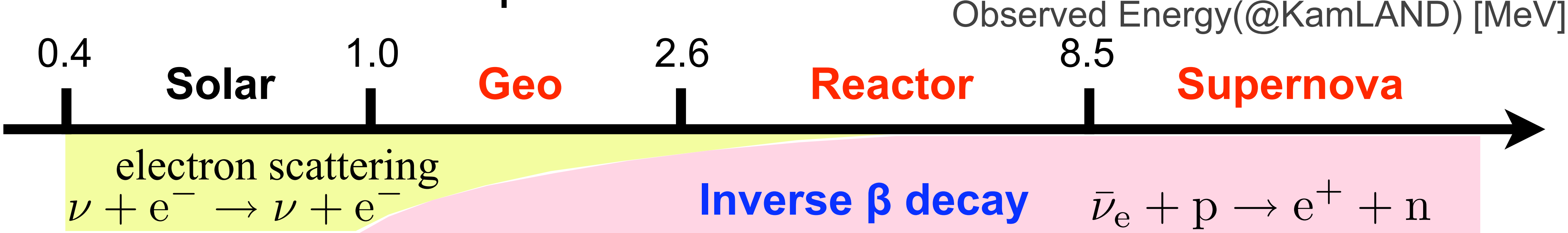
Ling imaging water Cherenkov detectors(Super Kamiokande, SNO, etc) can have directional sensitivity.



Super Kamiokande I

They can separate solar ν event from B.G.

Liquid scintillator detectors have good sensitivity to anti-neutrinos to use delayed coincidence.
It doesn't provide directional information.



We want to extract directional information from the liquid scintillator detectors.

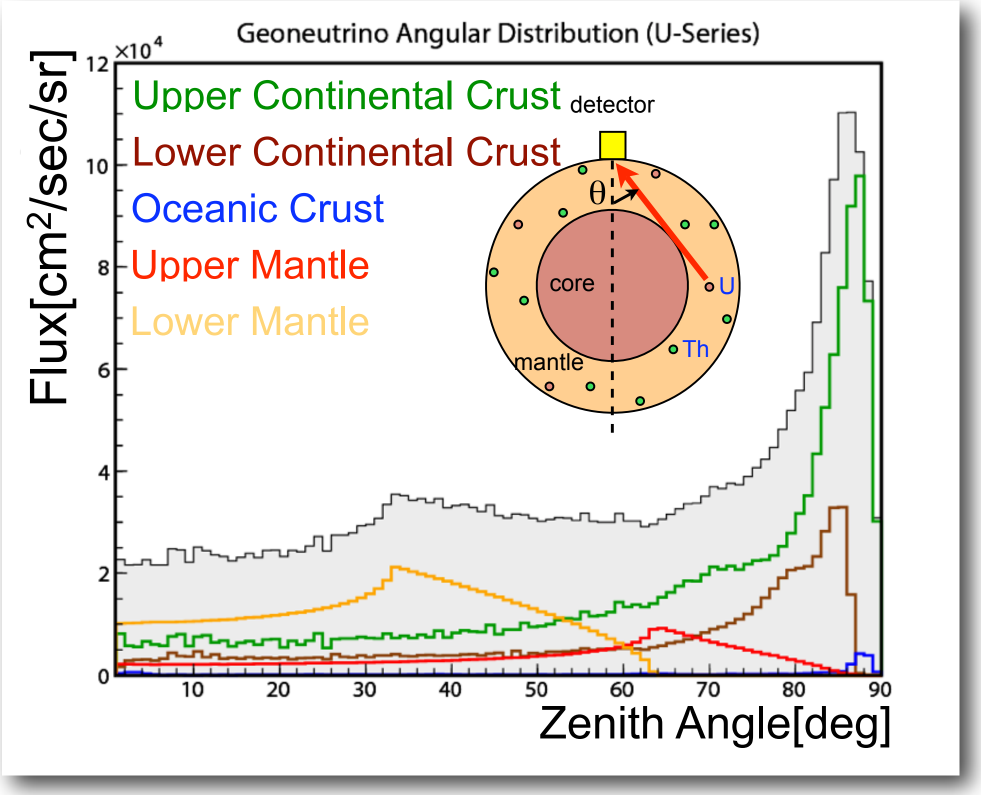
There are many physics motivations.

1kt size detector case

1. Geo anti-neutrinos

- Search for radiogenic heat source in the earth's deep interior

- Separation of reactor anti-neutrinos

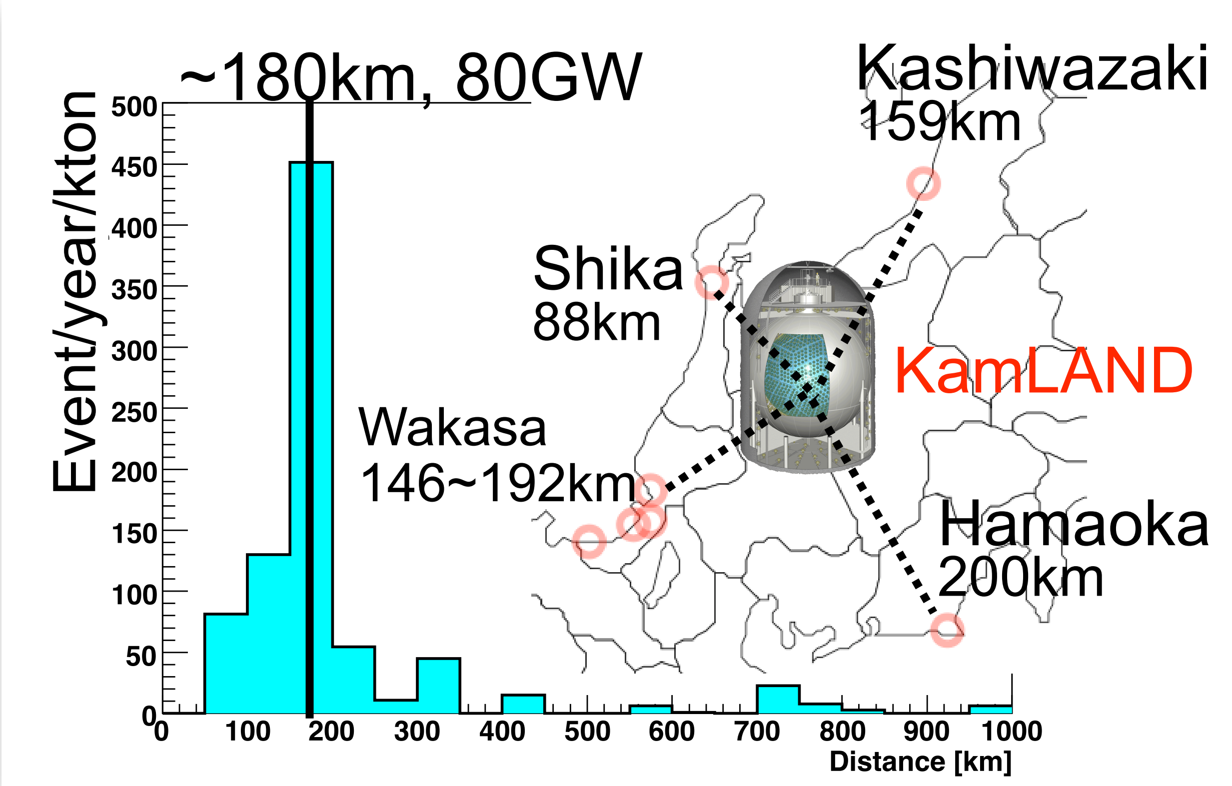


2. Supernova anti-neutrinos

- Early determination of SN direction

3. Reactor anti-neutrinos

- Improvement of oscillation sensitivity



200L size detector case

Application to reactor monitor

- monitoring system for combustion facilities
- discrimination based on directional information between B.G. and anti-neutrino

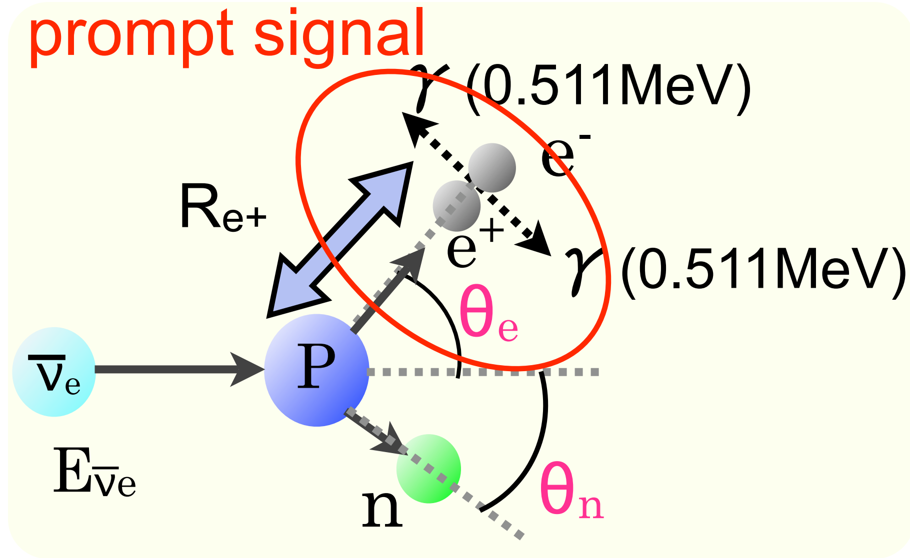
In the first stage, we target the development of ~200L size detector.

Detection Principal

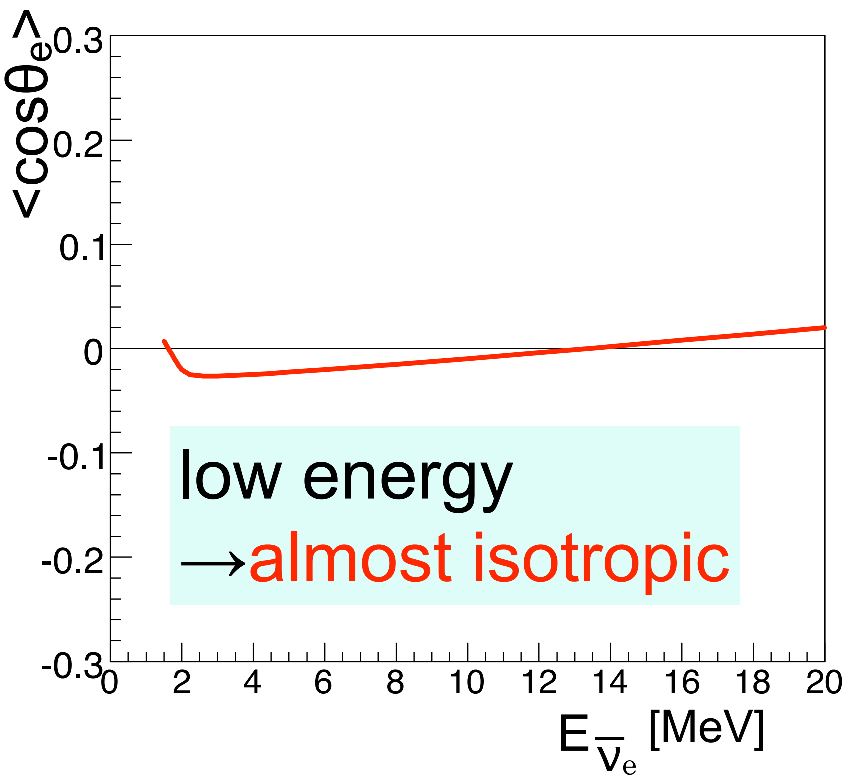
inverse β-decay

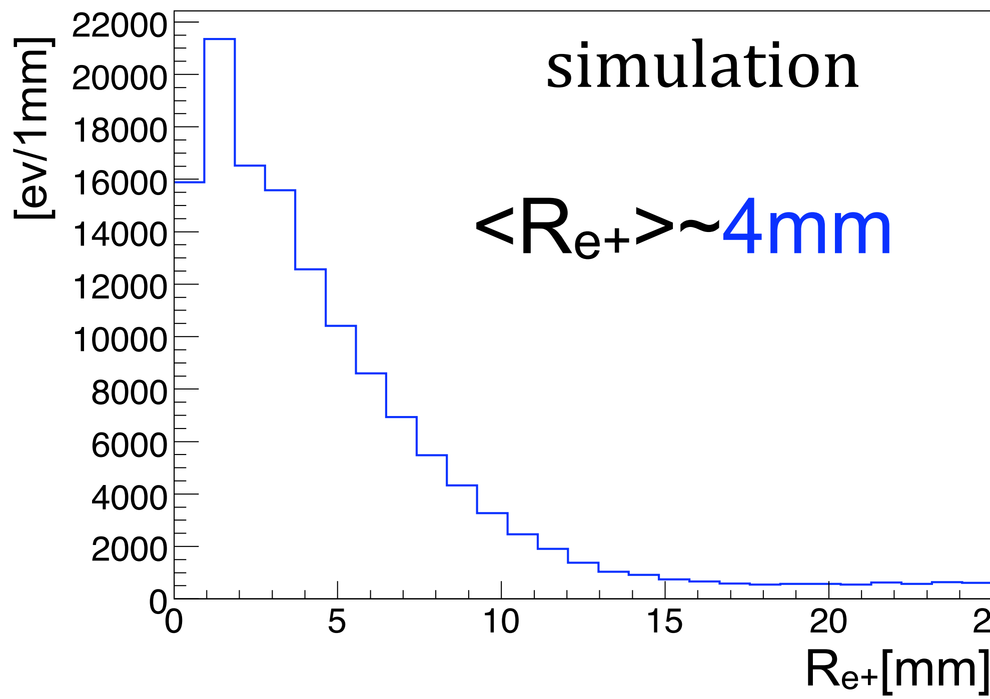
$$\overline{\nu}_e + p \rightarrow e^+ + n$$

This reaction is tagged by delayed coincidence.



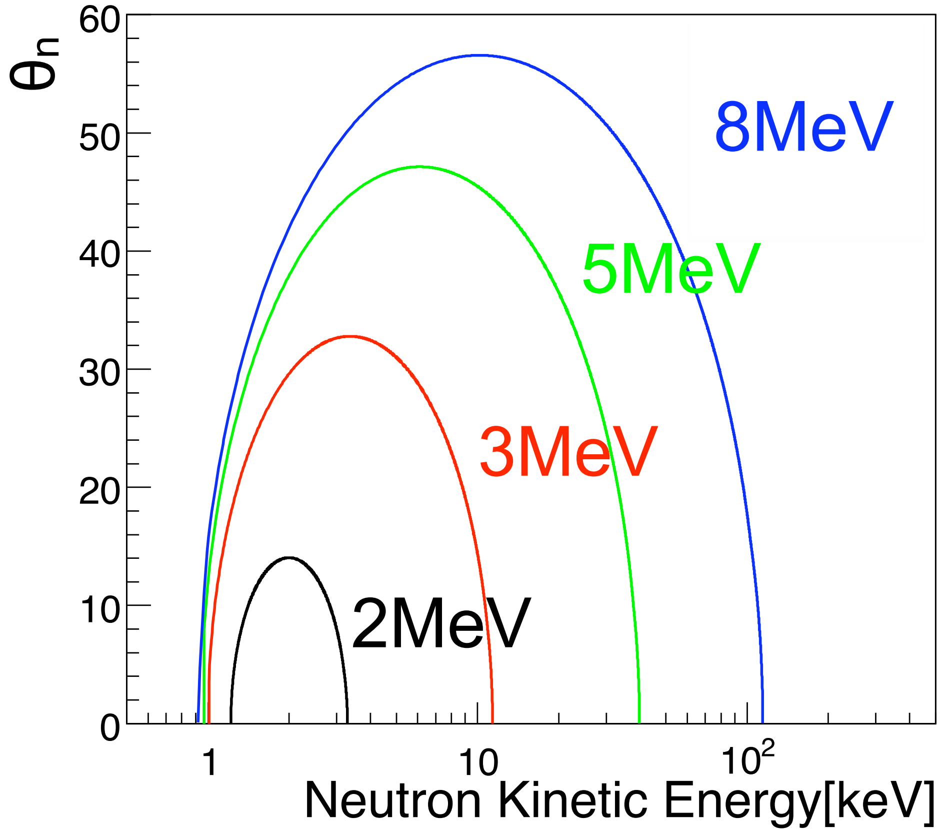
prompt : e^+ signal

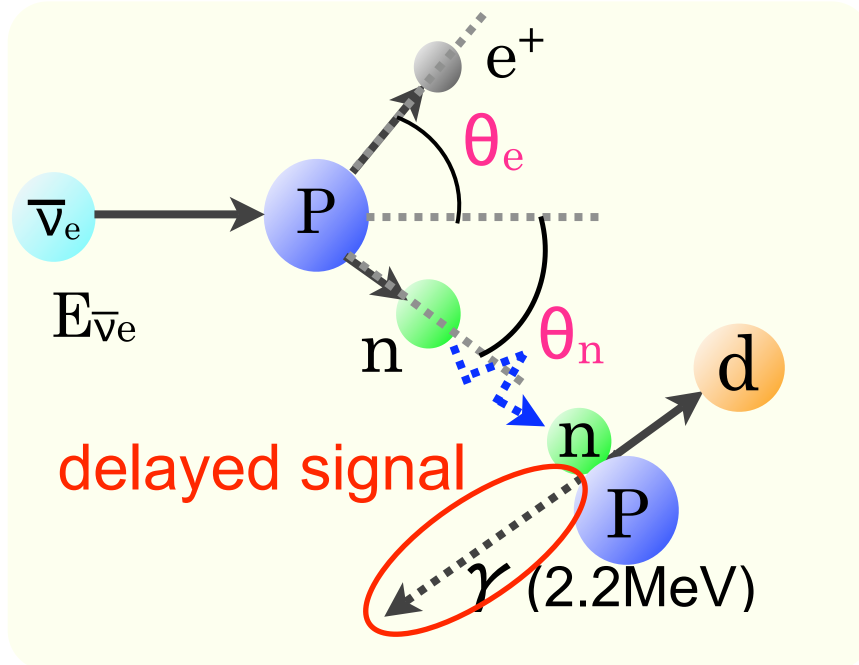




prompt signal retains information of $\overline{\nu}_e$ captured position

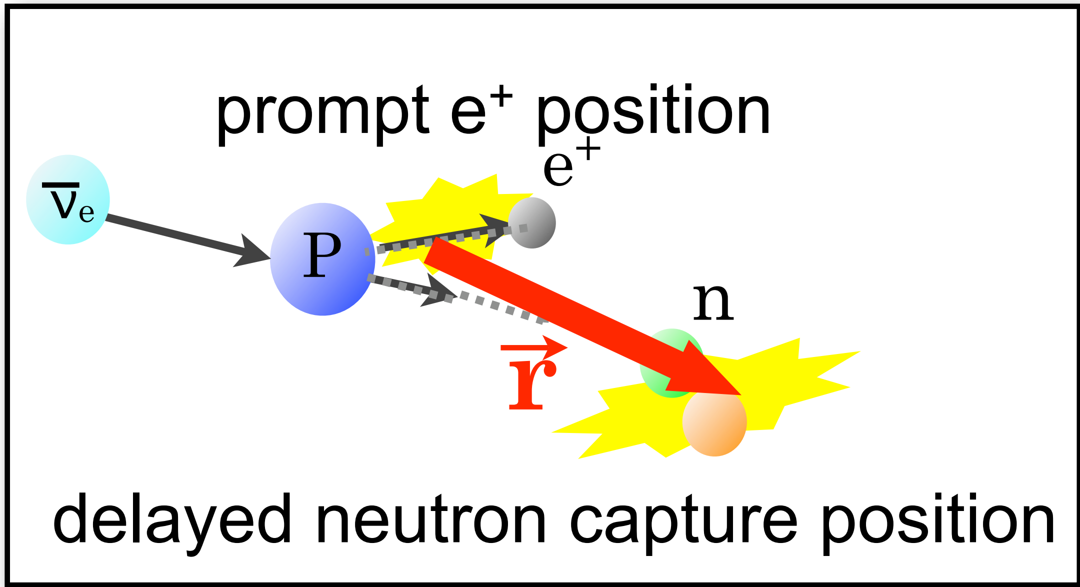
delayed : neutron capture signal





$E_{\bar{\nu}e} < 3MeV \rightarrow \theta_n < 35°$

forward recoil neutron retains information of the anti-neutrino direction



$\vec{r}$ correlates well with $\bar{\nu}_e$ direction

problems

- Current liquid scintillator doesn't have the sensitivity.
- Vertex resolution of PMT(~10cm) is not enough.

(The required resolution is about 10mm.)

To solve these problems, we aim at developing new measurement technology.

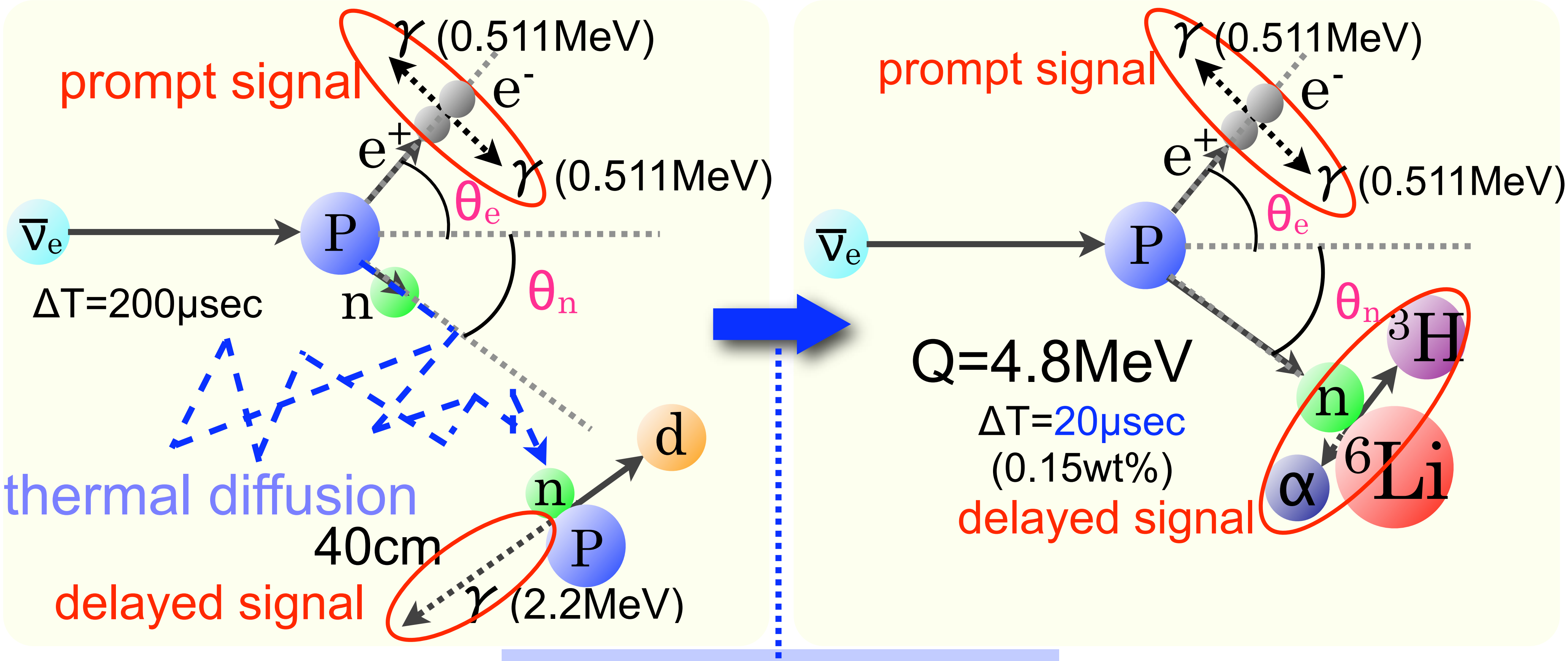
☑ Li loaded liquid scintillator
☑ Imaging detector

Development of Liquid Scintillator

- Reaction in Liquid Scintillator
- Neutron Capture Nucleus
- Li loaded Liquid Scintillator
- Performance Estimation

Development of Liquid Scintillator

Reaction in Liquid Scintillator



Problems

1.directional data is lost due to the thermal diffusion.

2. γ-ray travels 40cm

introduction of neutron capture nucleus

candidates: ^{6}Li, ^{10}B

✓large neutron capture cross section

✓(n,α)reaction

Improvement

1.minimize the thermal diffusion

2.α-ray can't travel long

Neutron Capture Nucleus

- Candidates

※ ^{1}H 0.3barn

① ^{10}B(3835barn)

$n + {}^{10}B \rightarrow {}^{7}Li^{*} + \alpha$ (BR=94%, Q=2.3MeV)

$\quad {}^{7}Li^{*} \rightarrow {}^{7}Li + \gamma$ (E_γ=0.48MeV)

$n + {}^{10}B \rightarrow {}^{7}Li + \alpha$ (BR=6%, Q=2.8MeV)

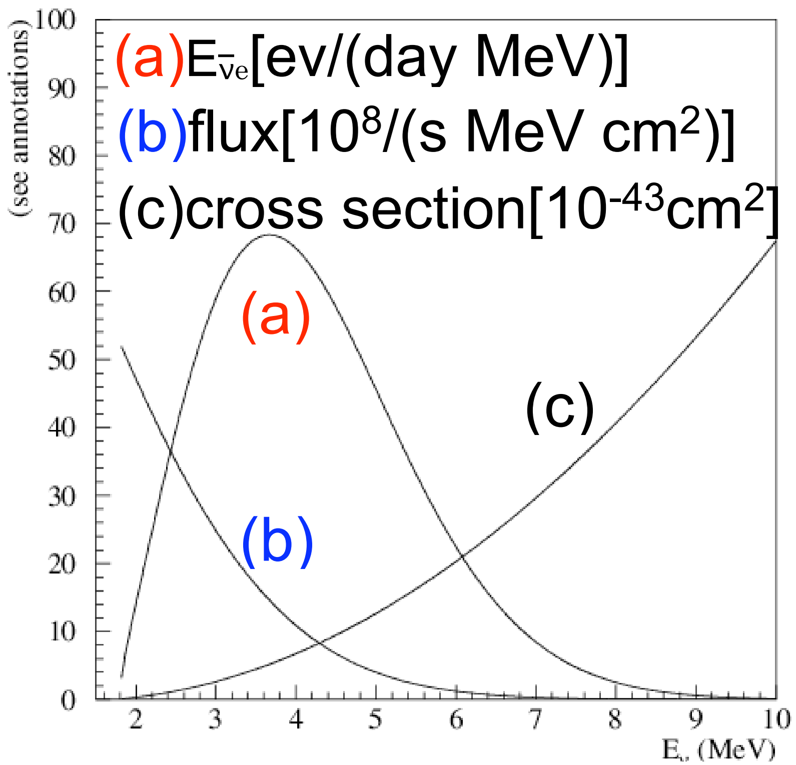
② ^{6}Li(940barn)

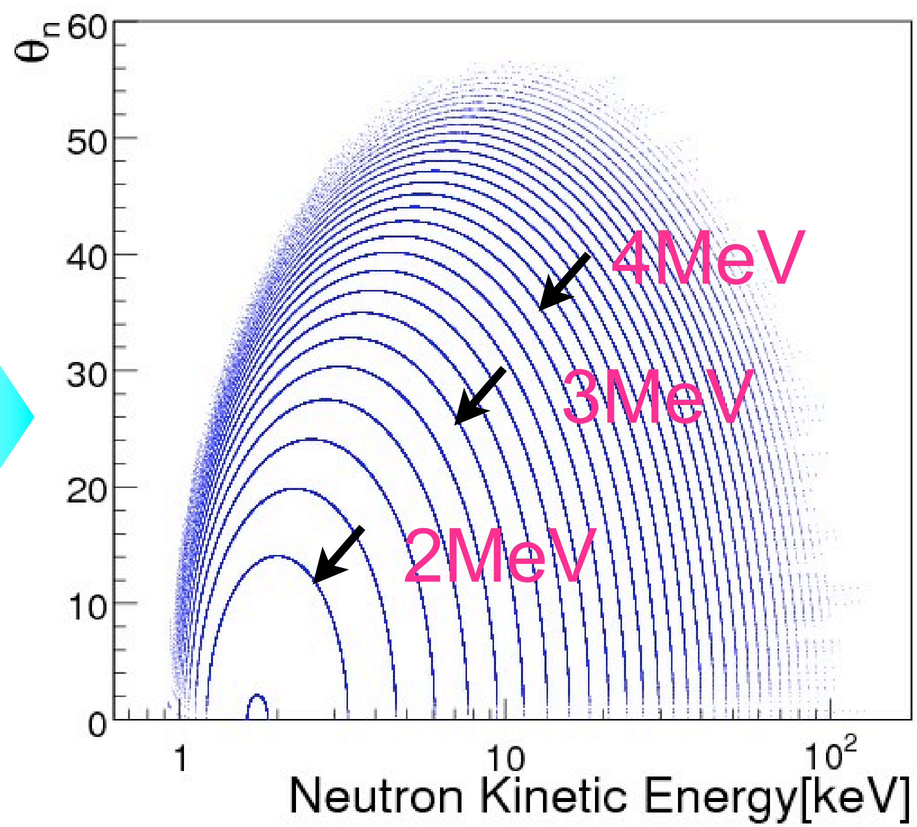
$n + {}^{6}Li \rightarrow \alpha + {}^{3}H$ (Q=4.8MeV)

- Simulation

- reactor anti-neutrinos energy range
- neutron kinetic energy < 100keV

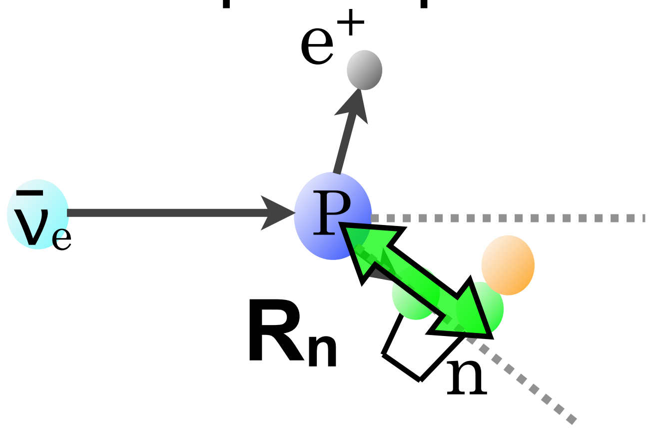
θn < 55°



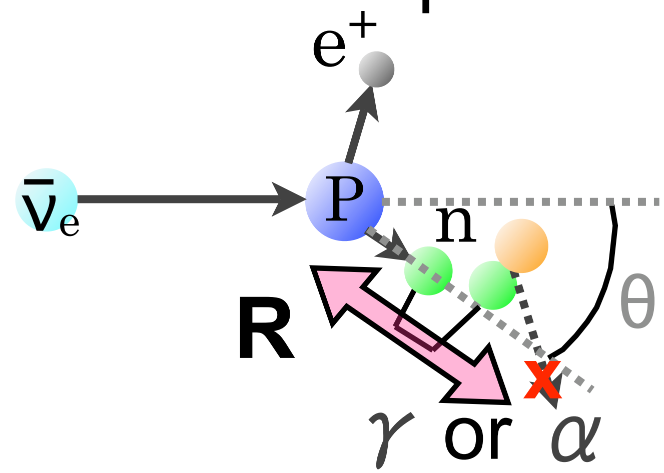


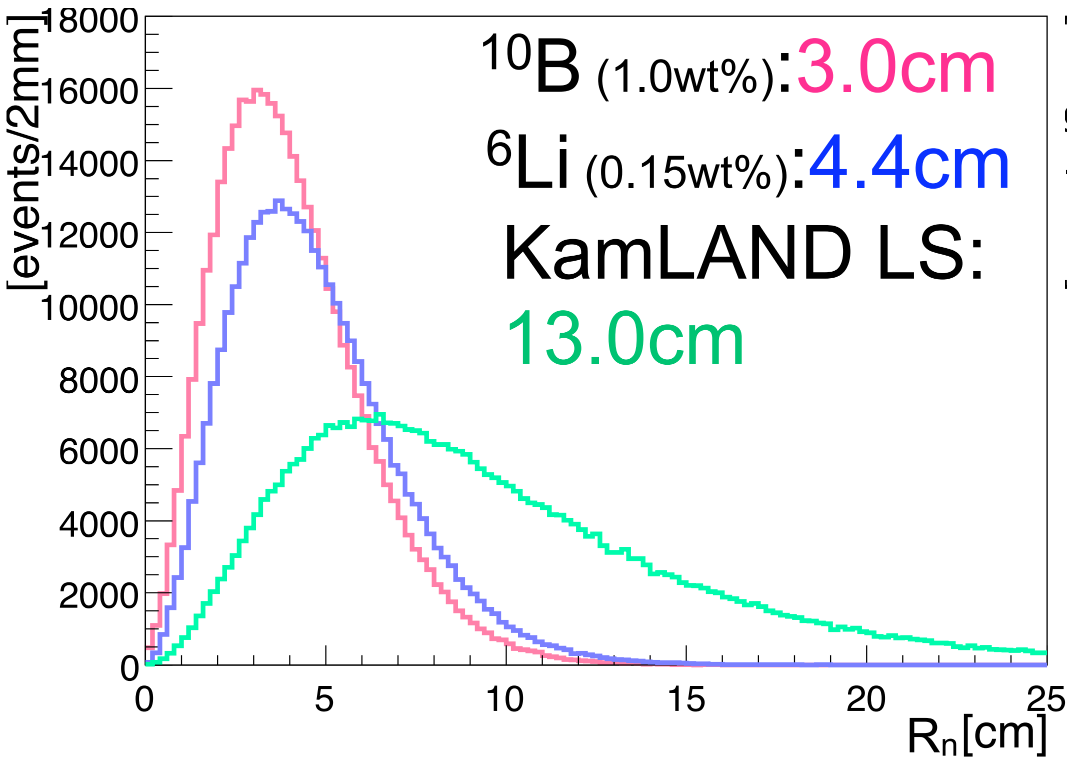
• ^{6}Li or ^{10}B

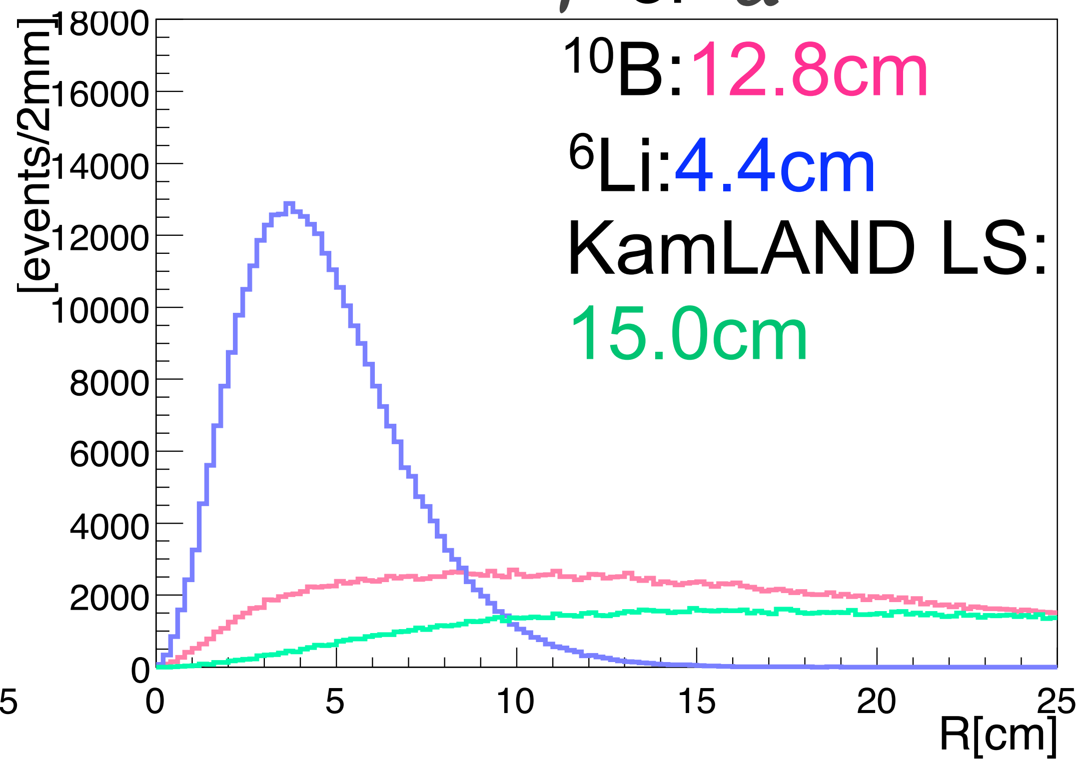
neutron capture point



reconstructed point



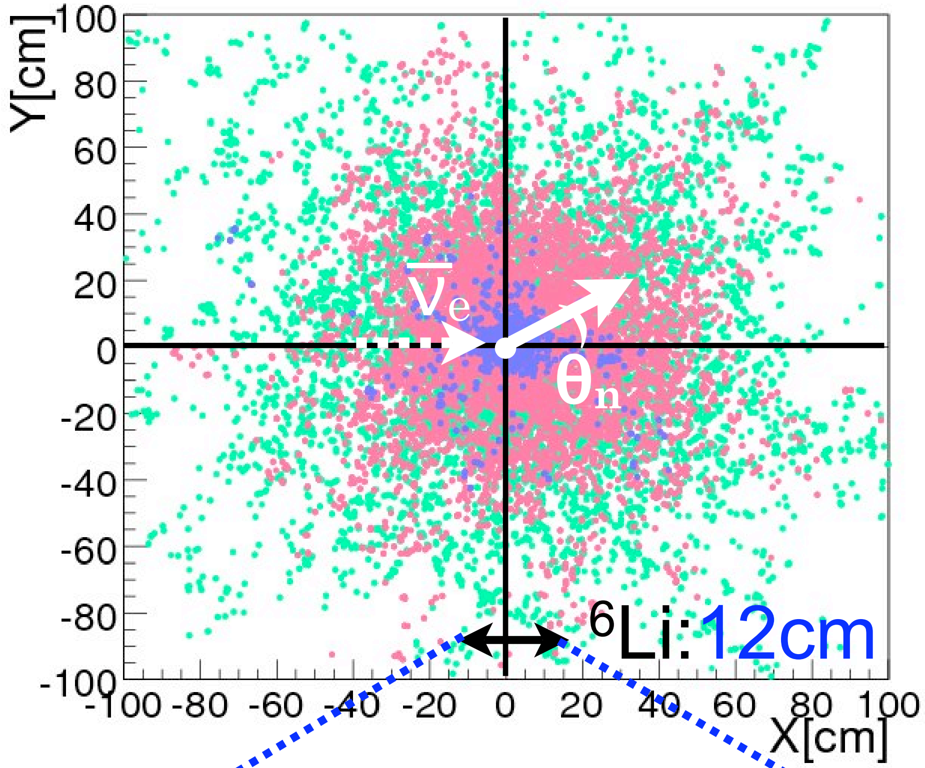


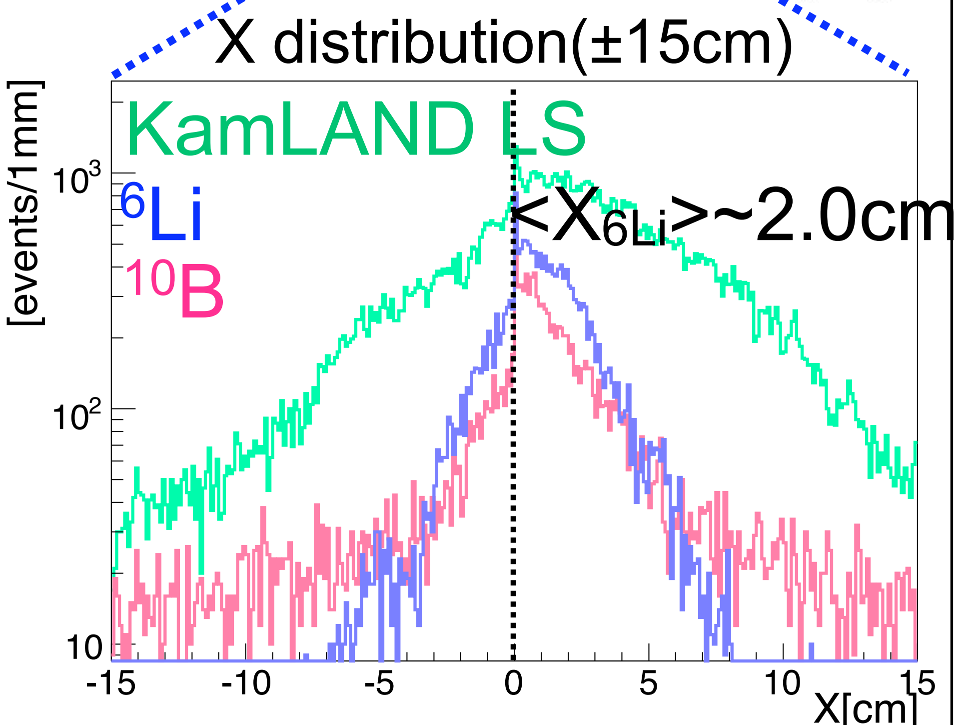


large neutron capture cross section is effective in minimizing the thermal diffusion

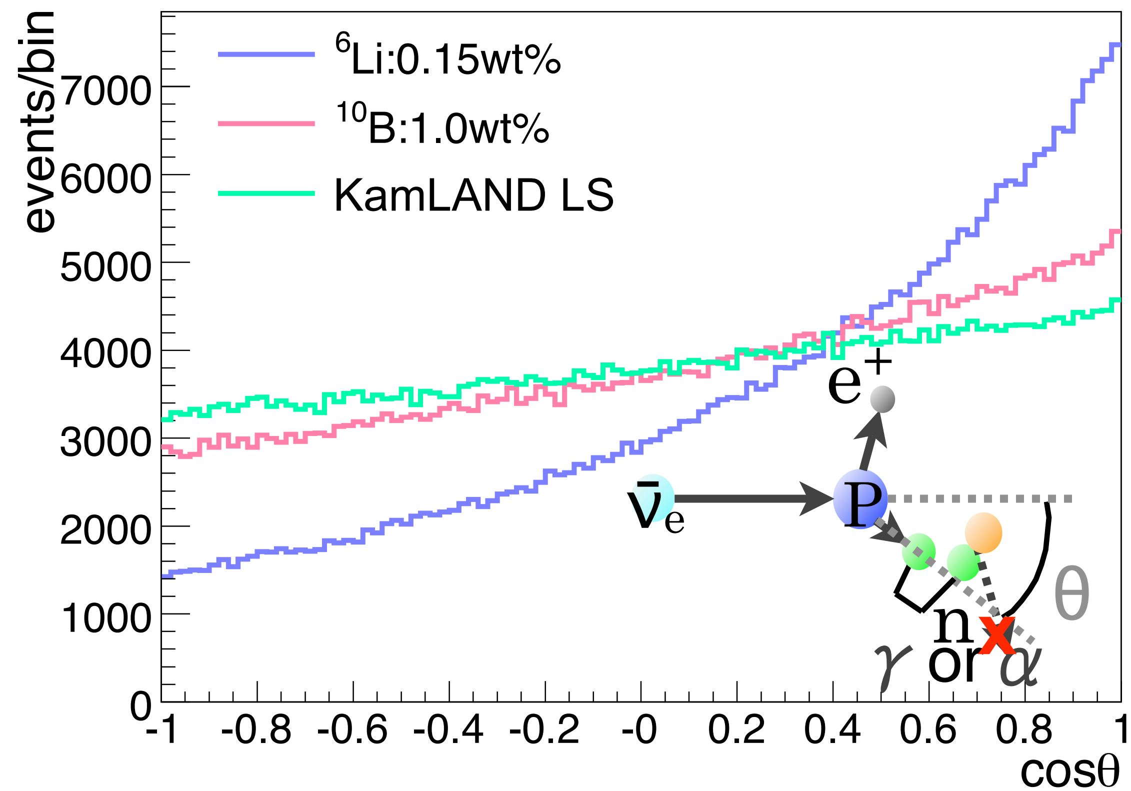
(n,α) reaction is effective in holding the neutron capture position information

neutron capture point





angler resolution



best

	Asymmetry	θ<45°
^{6}Li LS	0.391	27.7%
^{10}B LS	0.148	19.0%
KamLAND LS	0.079	17.0%

※ $\text{Asymmetry} = \frac{A_+ - A_-}{A_+ + A_-}$

A : number of event

A_+ $0 \leqq \cos\theta \leqq 1$

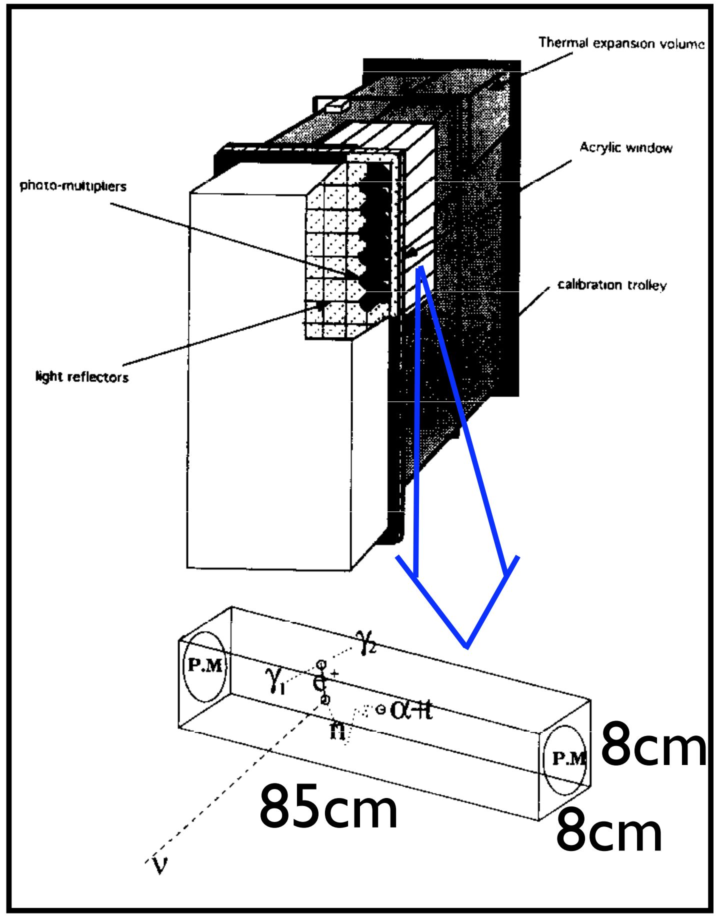
A_- $-1 \leqq \cos\theta \leqq 0$

Development of Li Loaded Liquid Scintillator

- previous experiment

Bugey (1991~1992)

They observed reactor anti-neutrinos using Li loaded liquid scintillator, NE320



NE320

- ^{6}Li 0.15wt%
- psudocumene base
- chemical instability led ~1% daily loss of detected light

We have to develop in our original way.

- Li compound

- Only ^{6}Li is necessary.

Isotope	Natural Abundance	Cross Section
^{6}Li	7.59%	940
^{7}Li	92.41%	0.0454

- Firstly, we tried to develop Li loaded liquid scintillator without enrichment.

  →couldn't get good result.

  low Li concentration, low light yield, no long-term stability, etc.

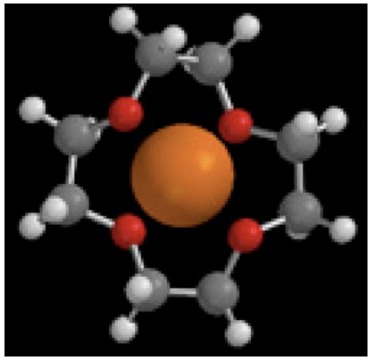
- Now, we already have enriched ^{6}Li compound.

  * 350g (we can develop small size detector, ~200L size)
  * ^{6}Li is commercial available.

- For large size detector, ~1kt size

  * We can employ an establish method by crown ether.

    0.5~1.5% enrich by 1 pass



•How to dissolve Li in LS?

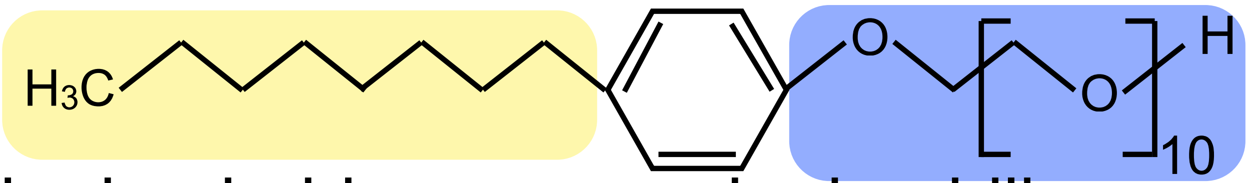
-behavior of Li component

① insolvable in oil

② solvable in water

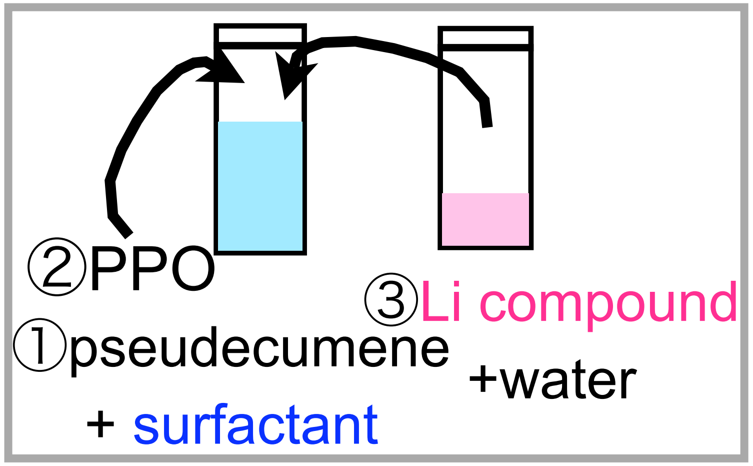
mix organic solvent and Li compound aqueous solution with surfactant

*surfactant : Triton X (product name)

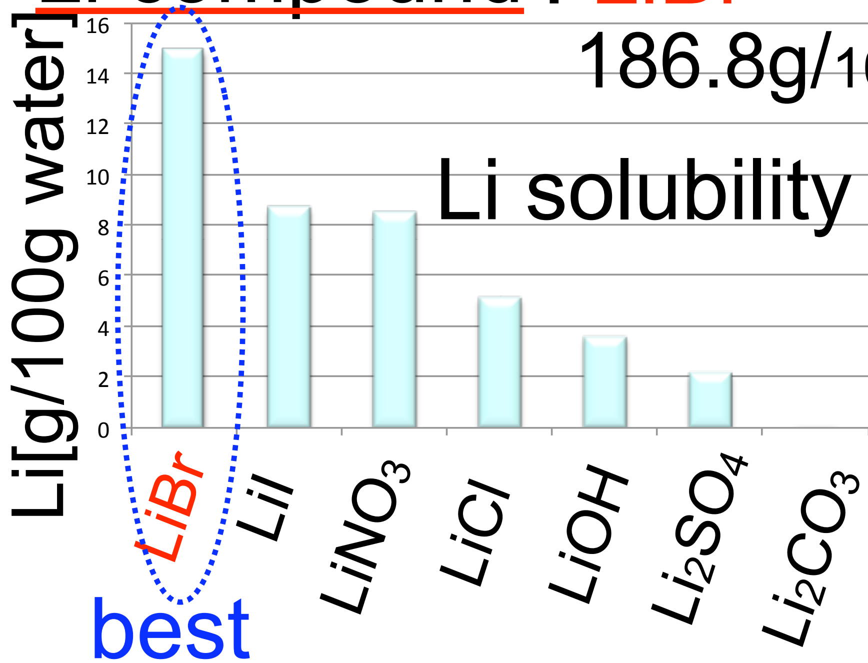


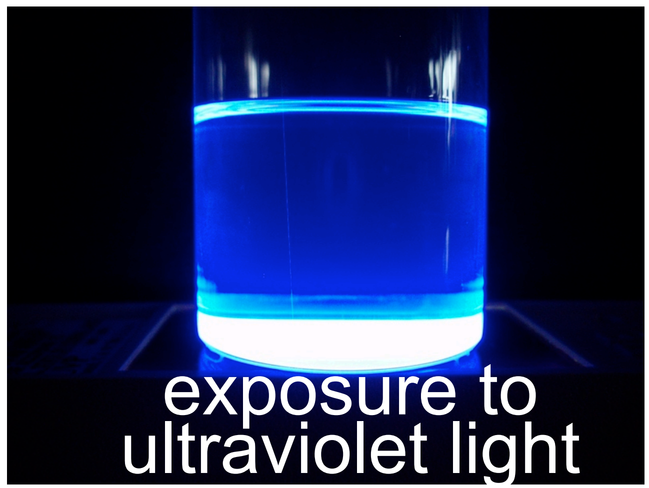
hydrophobic group hydrophilic group

Polyoxyethylene(10) Nonylephenyl Ether (POE)



*Li compound : LiBr





We have developed the ^{6}Li loaded LS by the original method.

- Progress of the method
  - toward 200L size detector(70cm cube)

※the proportion of KamLAND LS

		mixture ratio[%]		Li[wt%]	Transparency	light yield※
		PC	POE	^{6}Li[wt%]	[cm@400nm]	[%]
target value		-	-	2.0 0.15	≧70	≧100
conclusion	NOT enrich	50	50	1.04 0.078	64.6	46.1±0.4
	enrich	80	20	- 0.15 OK	**135** OK	**122±0.8** OK

- Necessary quantity of Li water solution is tenth of not enrich case.
- We have confirmed more than 2 years stability if use enriched ^{6}Li.

  ref) NOT enrich case, <4months

  NE320, 1% daily loss of detected light

Performance Estimation

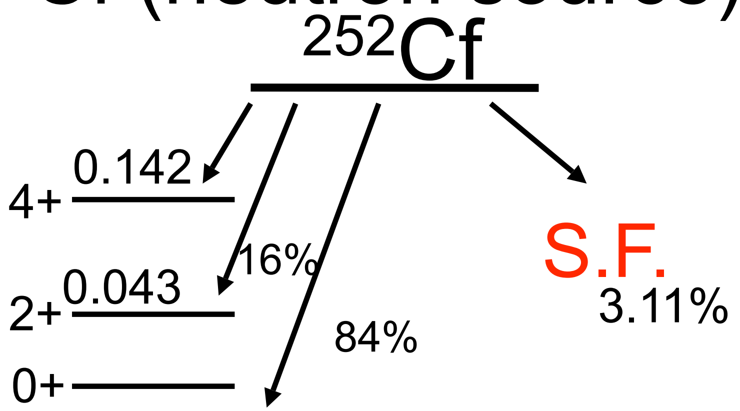
- Time of Fright

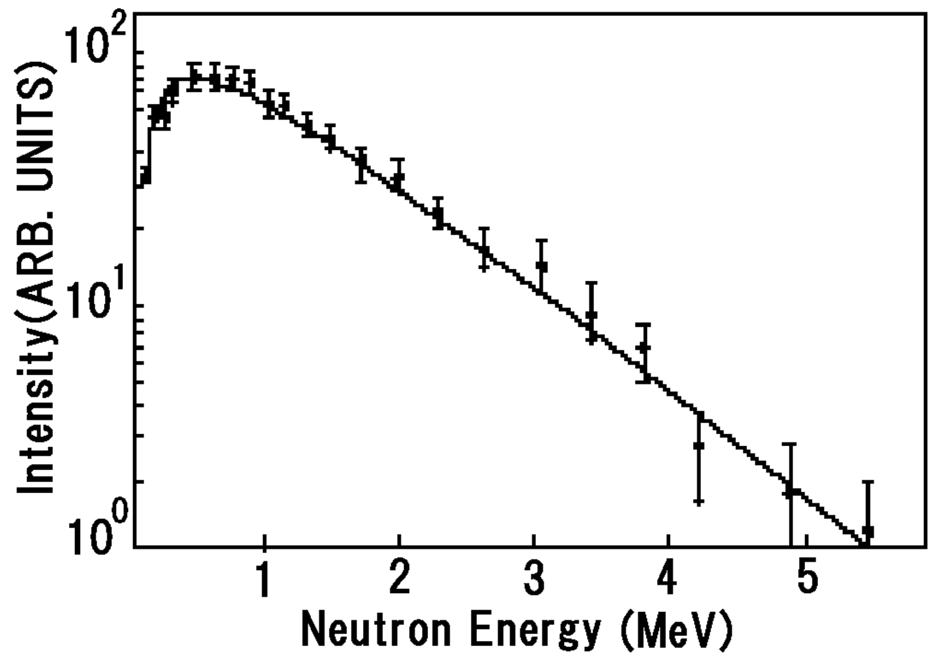
*We want to measure neutron capture event in the Li loaded LS.

- check peak on energy spectrum
- check capture time

*How to measure

- ^{252}Cf (neutron source)





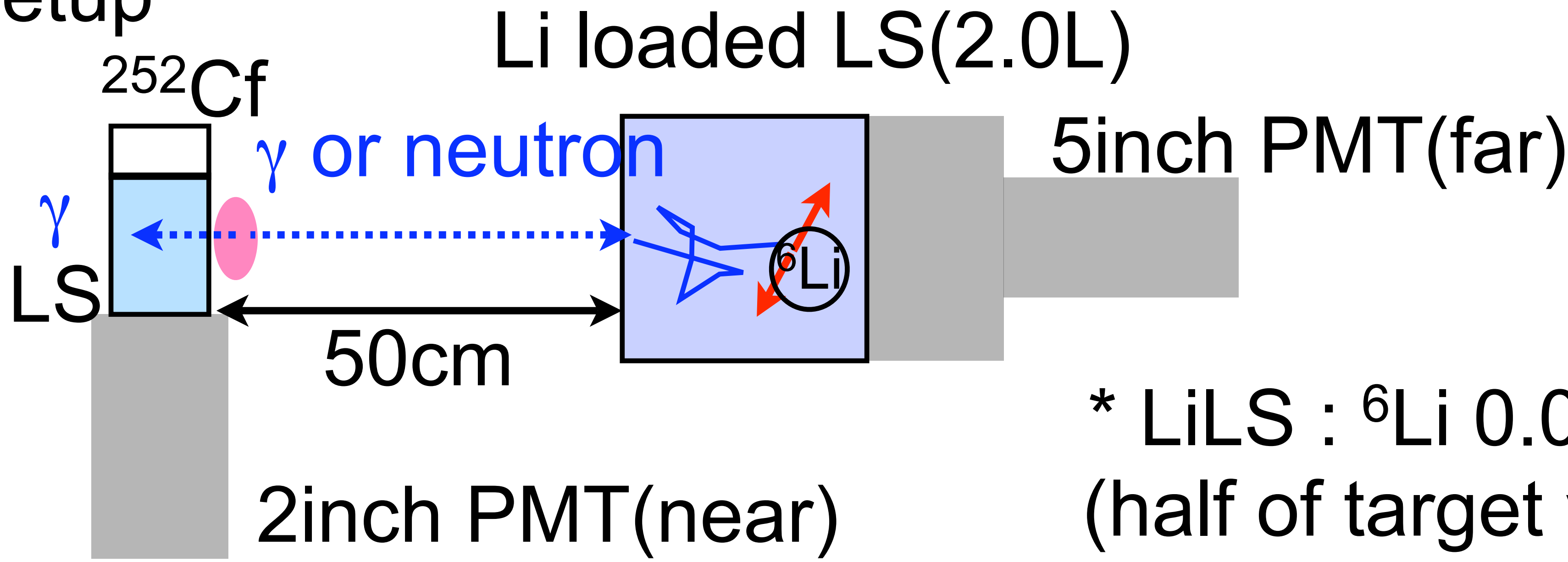
Spontaneous Fission

N_γ=7.8

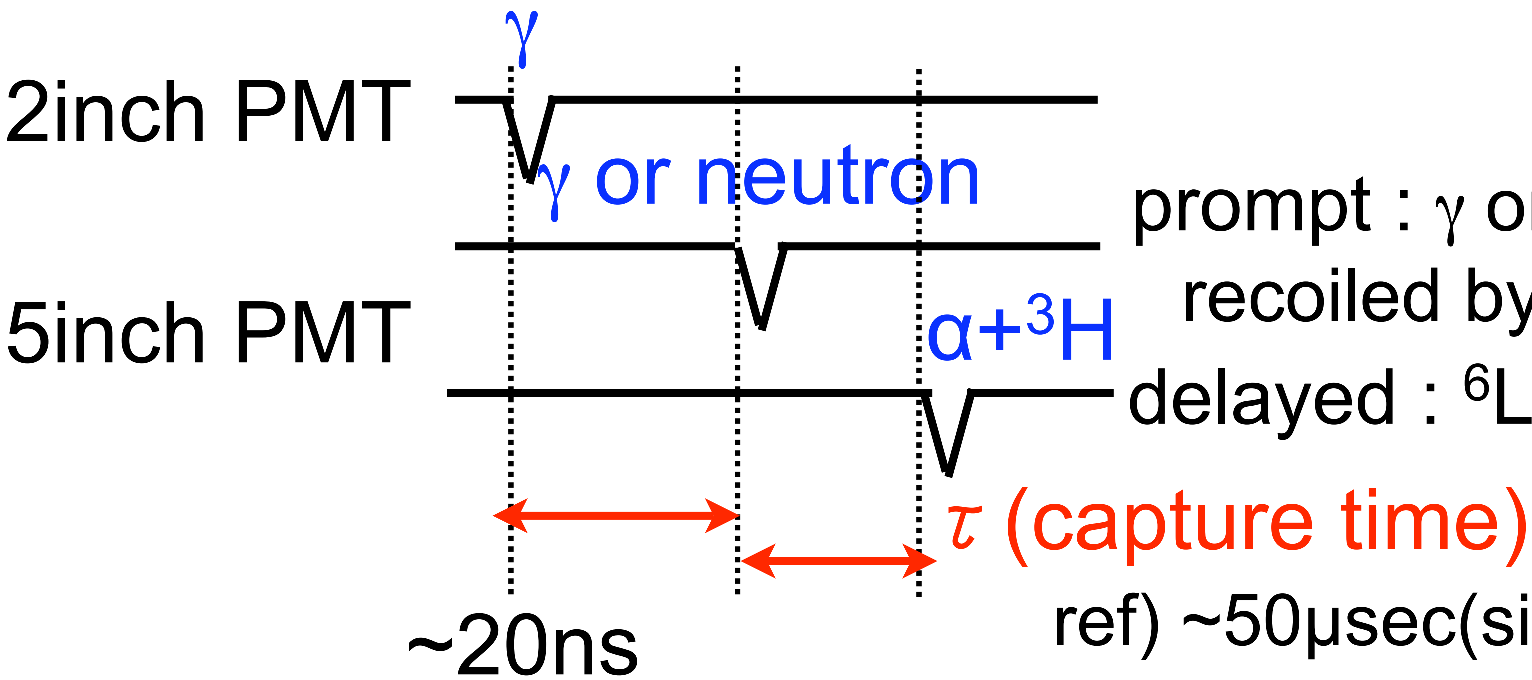
N_n=3.8

emitted at the same time

- setup



* LiLS : ^{6}Li 0.08wt%
(half of target value)



prompt : γ or neutron recoiled by proton

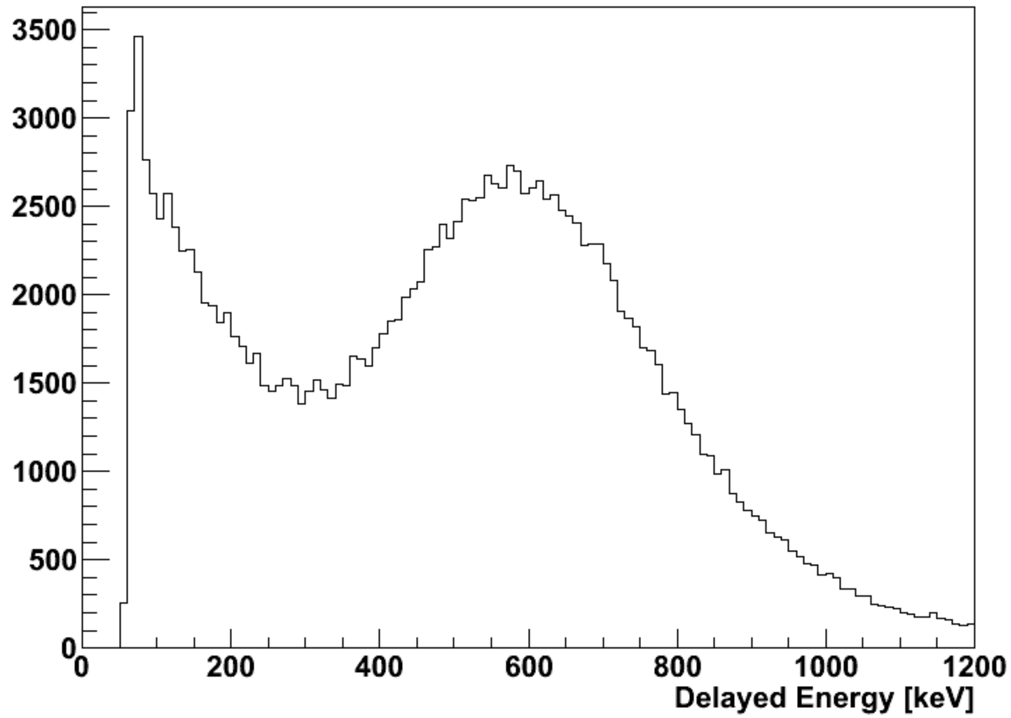
delayed : ^{6}Li capture event

ref) ~50μsec(simulation)

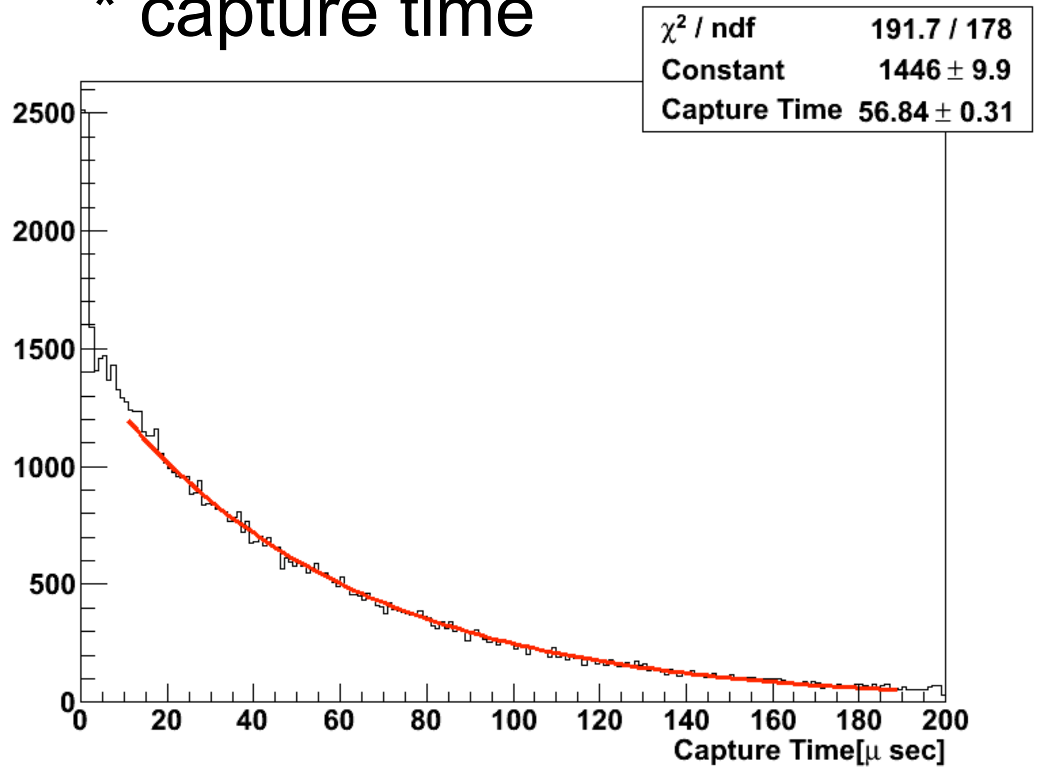
ref)^{252}Cf neutron ~ 2.5cm/ns

- result

*delayed signal energy spectrum



* capture time



We can see clear peak of neutron capture event.

capture time
56.84±0.31μsec

$n + {}^6Li \rightarrow \alpha + {}^3H$

$E_{visible}$ ~ 600keV

ref) E_{real} = 4.9MeV

ref) current liquid scintillator's capture time ~ 220μsec

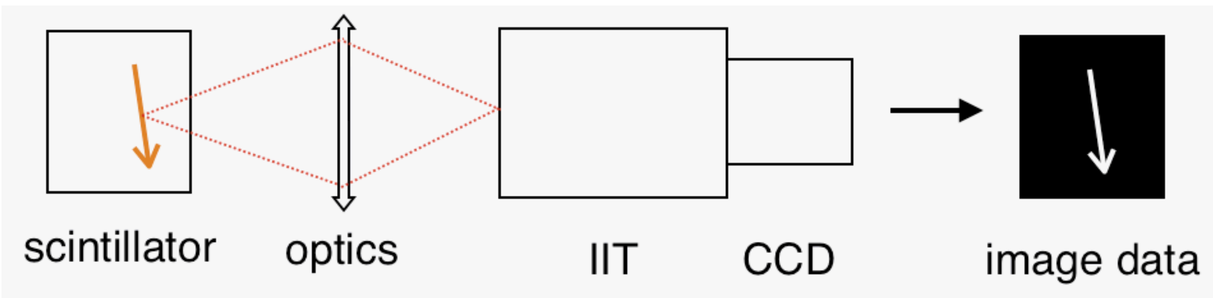
- Imaging Detector
  - Outline
  - Initial Development
  - Measurement Result

Imaging Detector

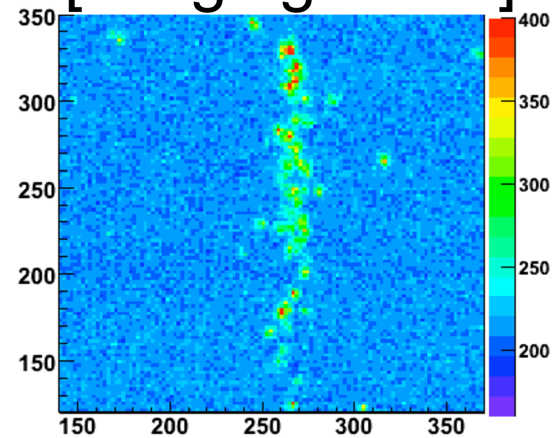
Outline

-The required position resolution is about 10mm.

-Precise measurement of energy deposit point with imaging devises.
(e.g.image intensifier(I.I.) and CCD camera)



[imaging result]



muon track

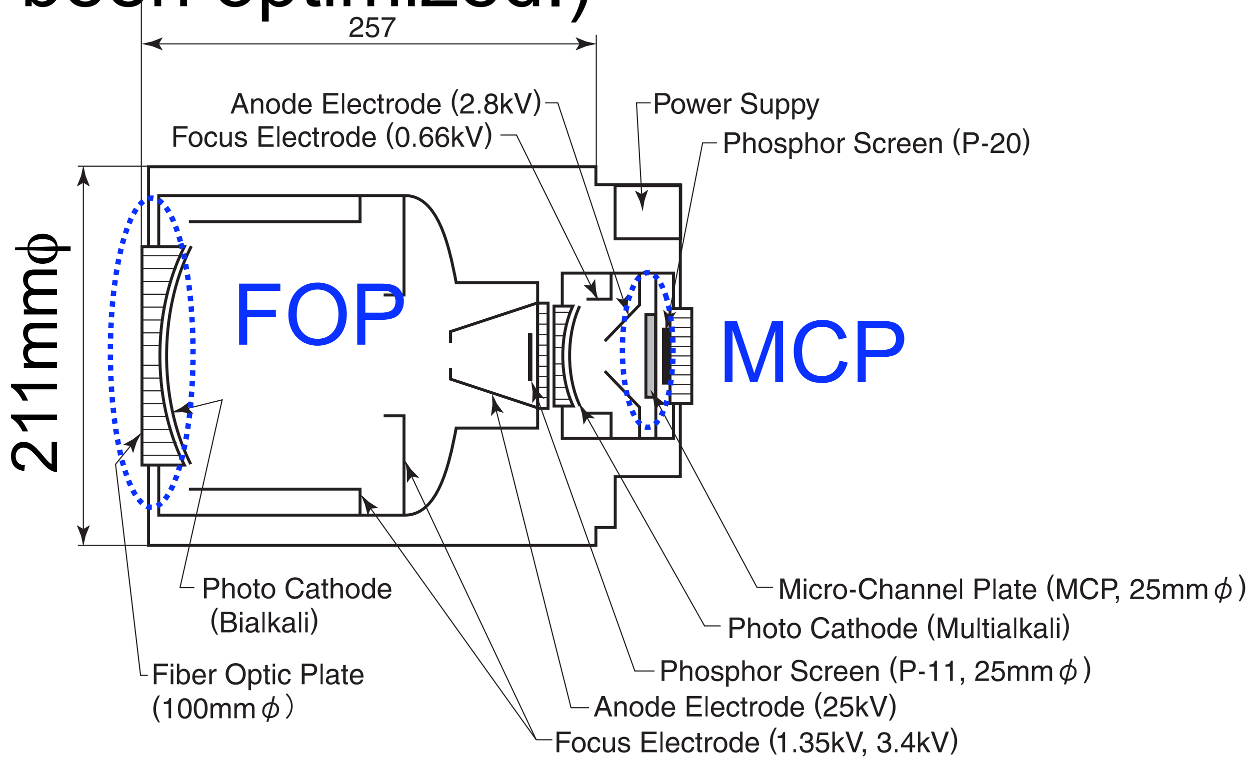
*advantage : can fix vertex with only 1 direct photon
*disadvantage : photon collection efficiency is low(0.31%)

small size detector→need several I.I.s and CCDs
large size detector→plan to use another device
e.g.) avalanche pixel photodiode

▶Initial development

- Image Intensifier

-We borrowed large diameter I.I. from SciFi experiment, and use it for initial development.
(It has not been optimized.)



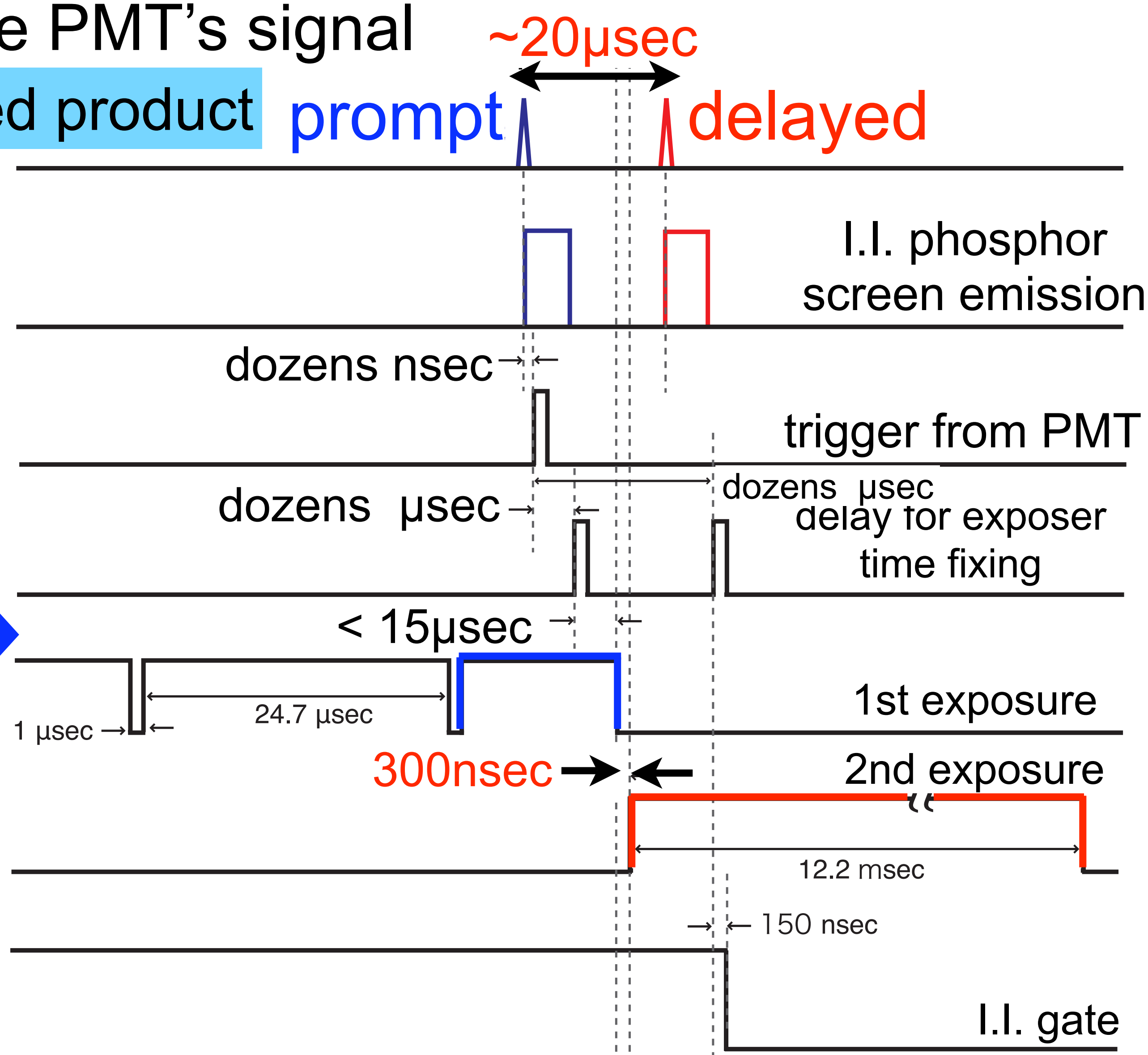
- acceptance surface(bialkali) 211mmϕ
- amplification mechanism (2stage)
  signal gain ~10^6
- quantum efficiency 12% @420nm

•CCD camera

CCD needs trigger to release the shutter
→ use PMT's signal

improved product

*for initial development



- flushing time < 1μsec
- exposure time > 33μsec
- number of pixel 480(H)×640(W)

we can not detect prompt and delayed signal individually.

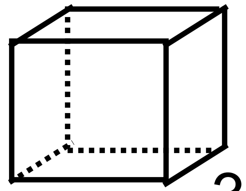
*We also have fast readout CCD (within 300nsec of each picture)

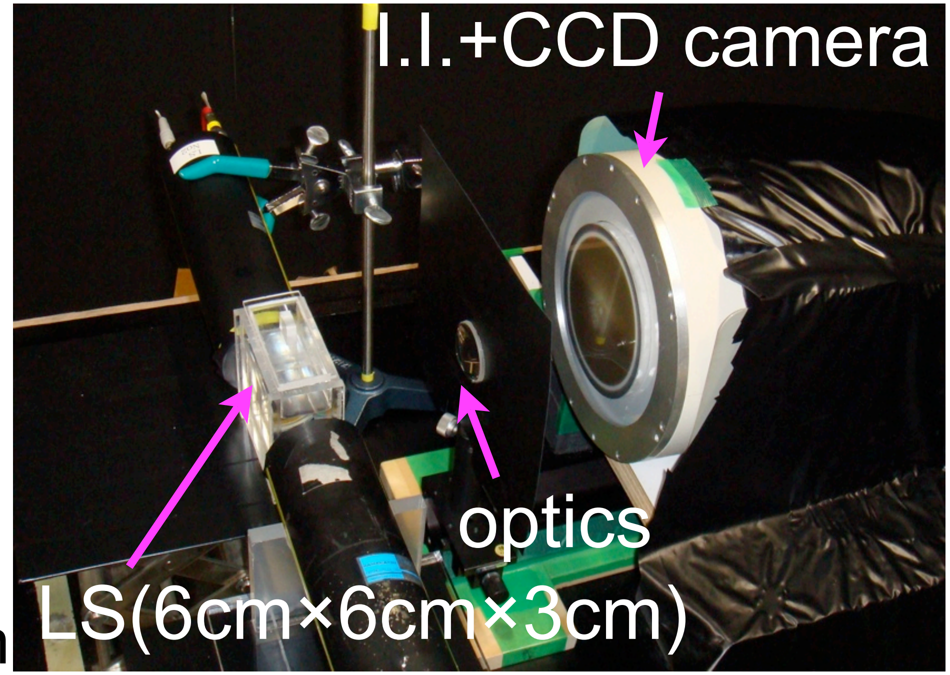
We are planning to use it to detect the neutron capture event in the ^{6}Li loaded LS.

- Liquid scintillator(LS)

pseudecumene : organic solvent
PPO(5.0g/l) : scintillating material
bis-MSB(0.1g/l) : wave length shifter

* λ : 370nm→420nm
for increase in light transmission and quantum efficiency.



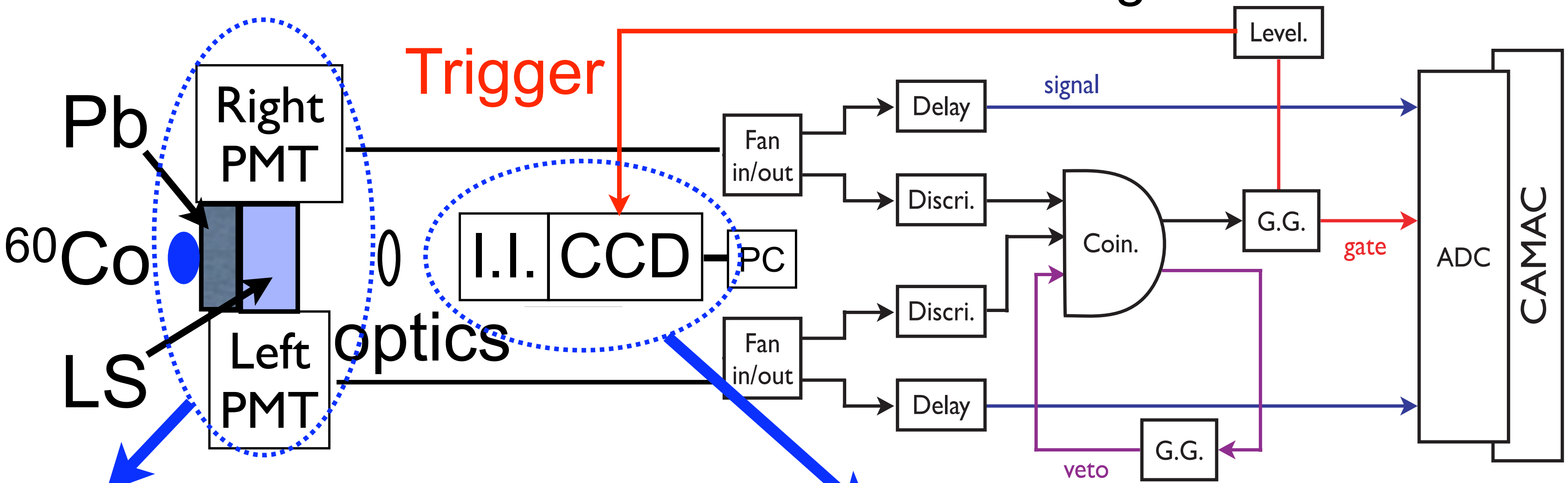


- Optics
  - Achromatic lens
    focal length : 60mm
    diameter : 40mm
  - photon collection efficiency 0.31%(@center)
    *we need several systems.
  - resolution σ < 3mm

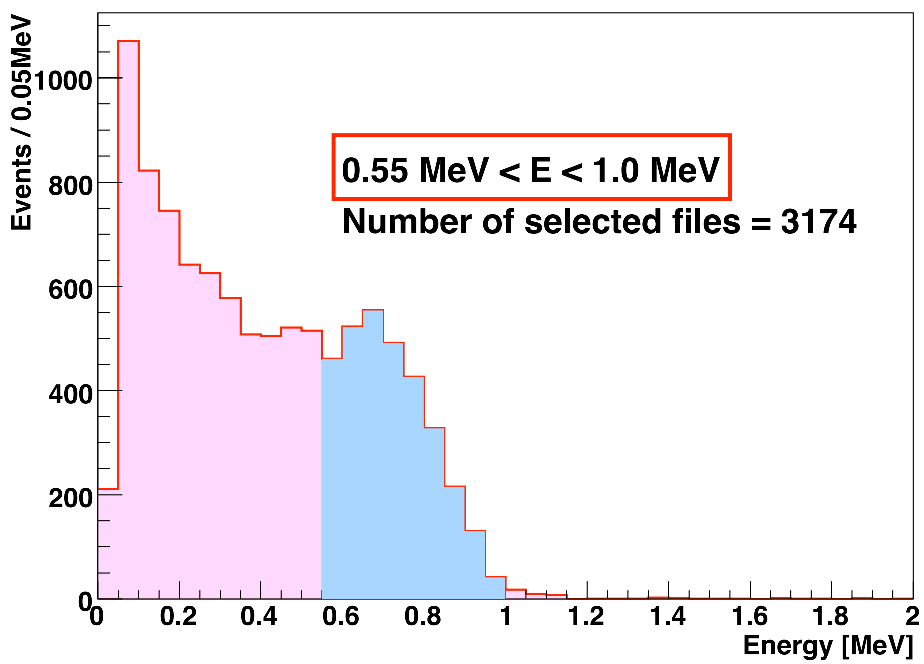
Measurement Result

- ^{60}Co bright spot measurement

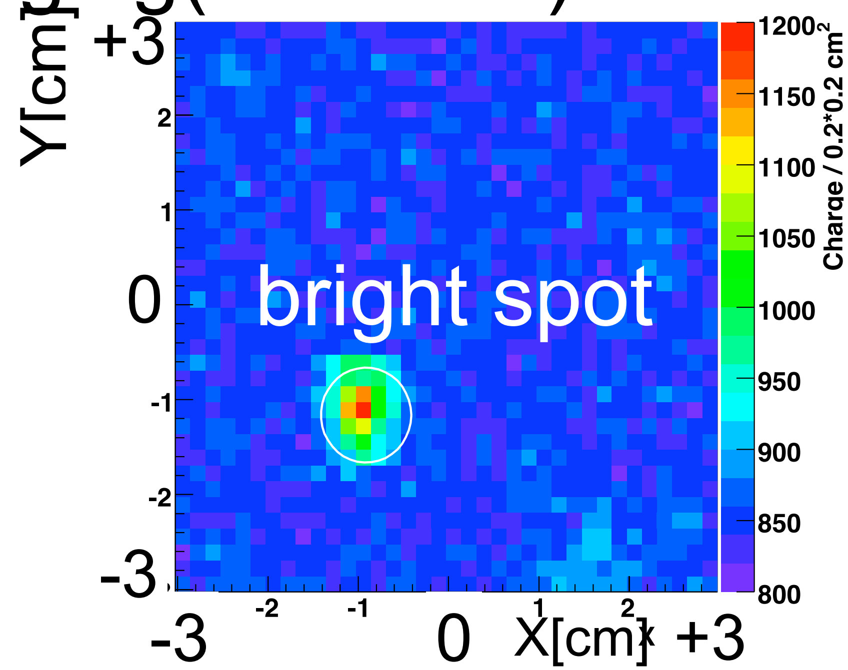
Trigger for CAMAC and CCD camera is left and right PMTs coincidence.



Energy(Left&Right PMTs)

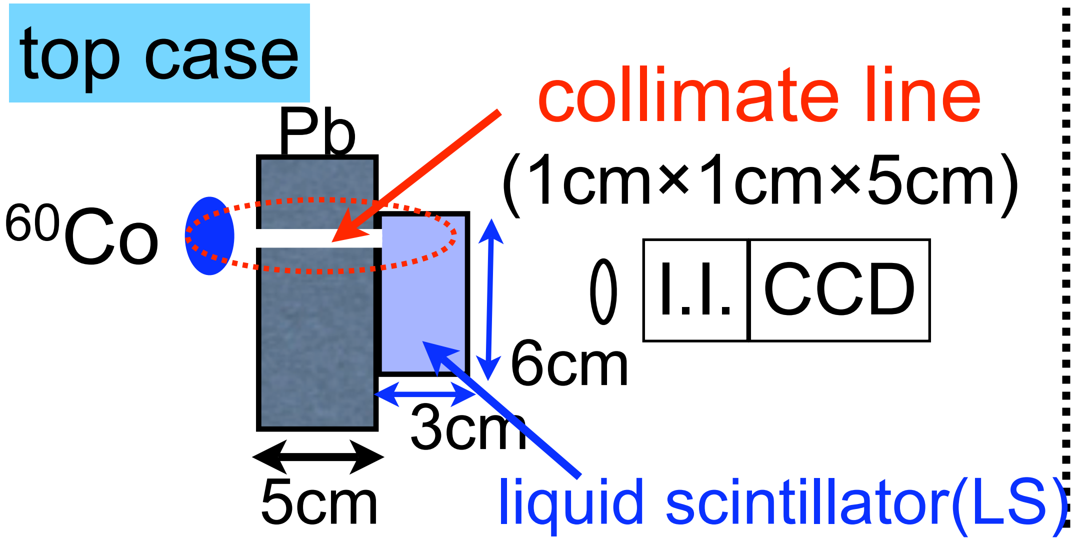


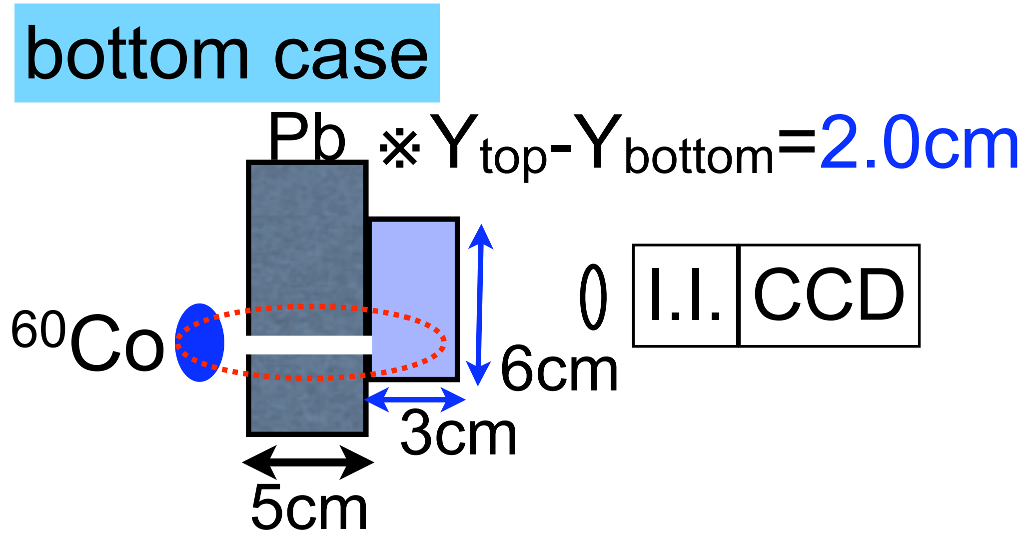
Imaging(I.I.&CCD)



^{60}Co γ-rays(1.173MeV, 1.333MeV) are collimated by Pb.

→We determined whether bright spots changed with ^{60}Co position.





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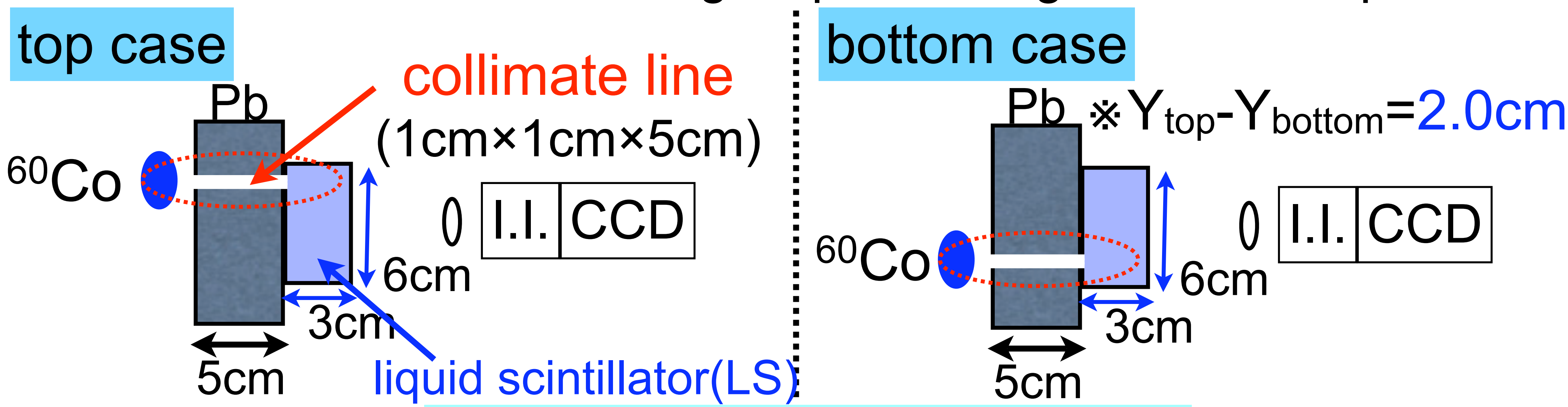
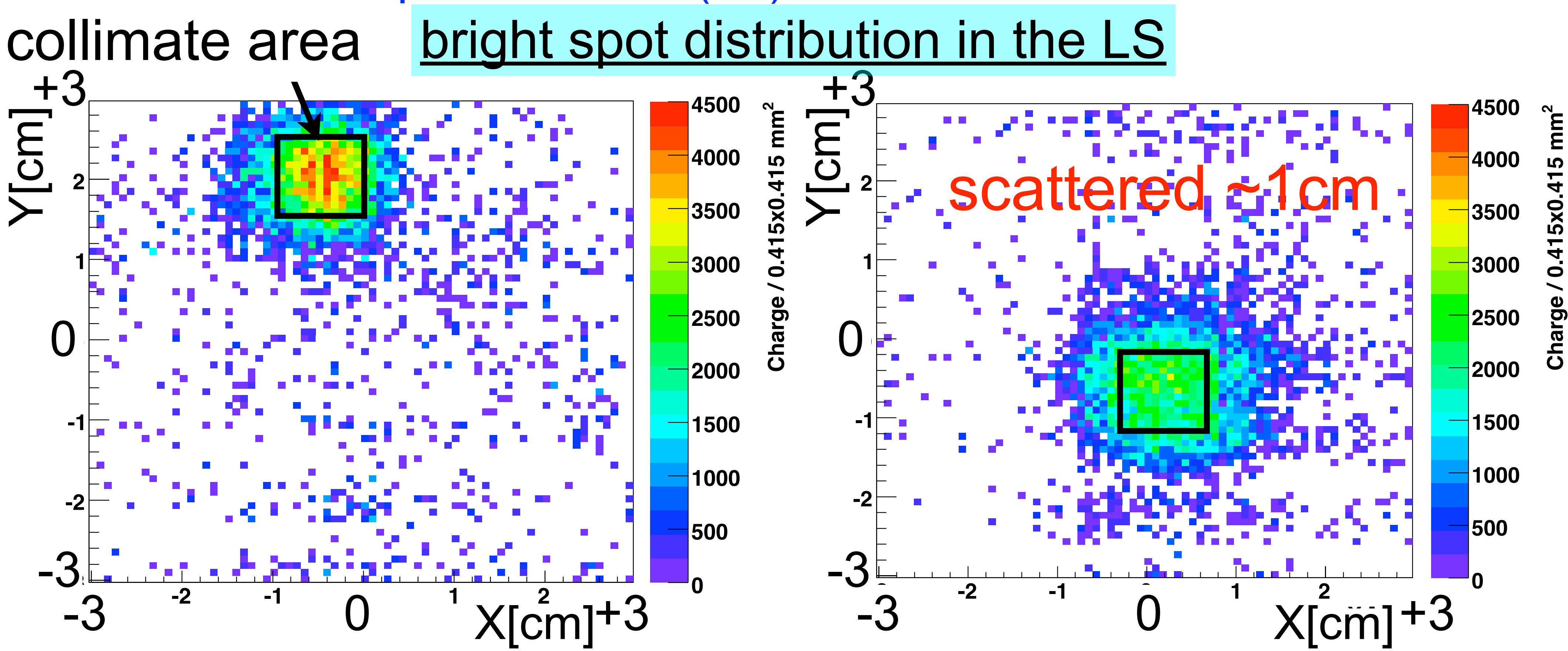
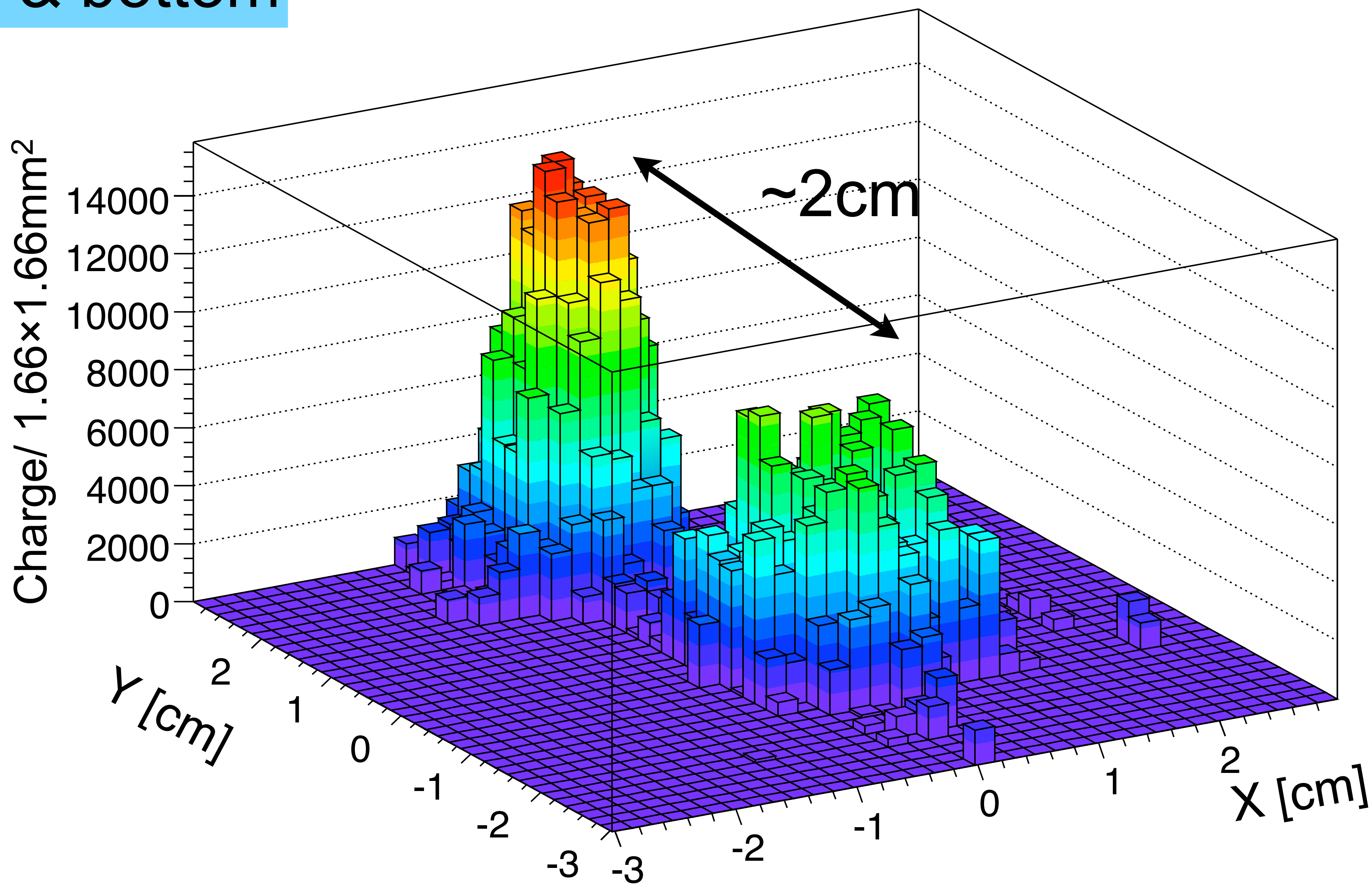




top & bottom



We can separate clearly.

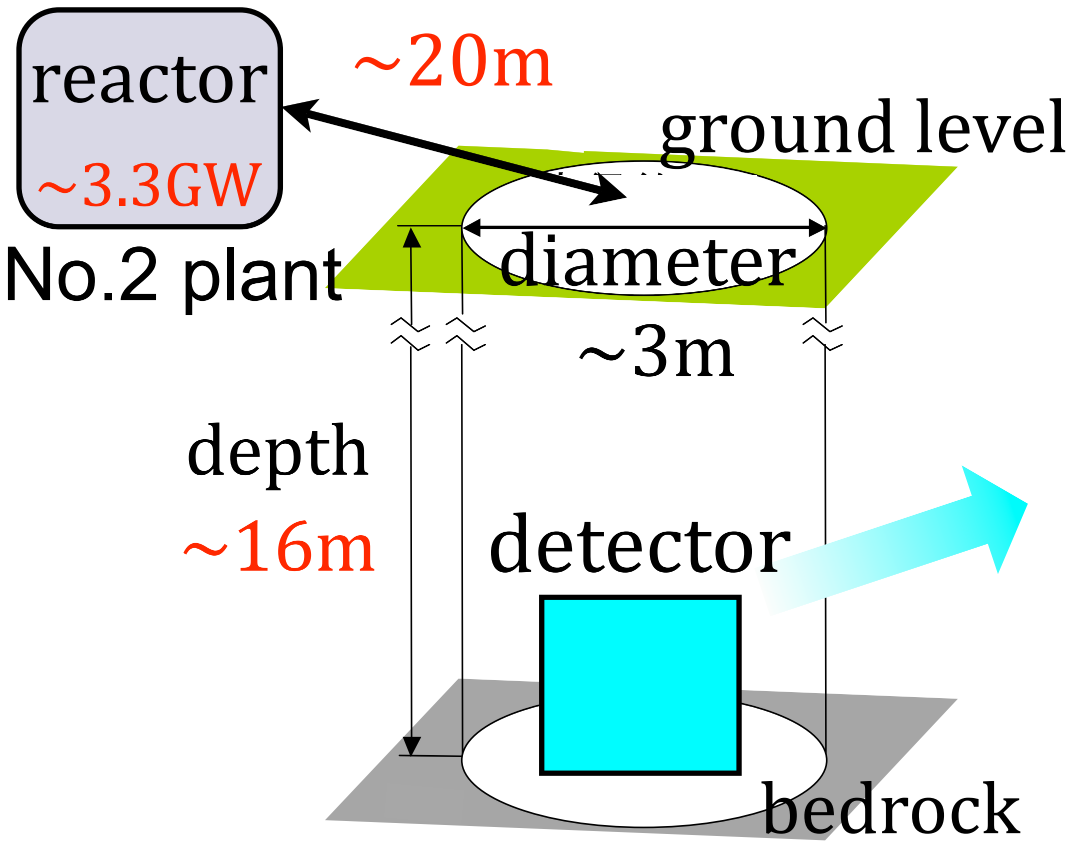
Application to Reactor Monitor

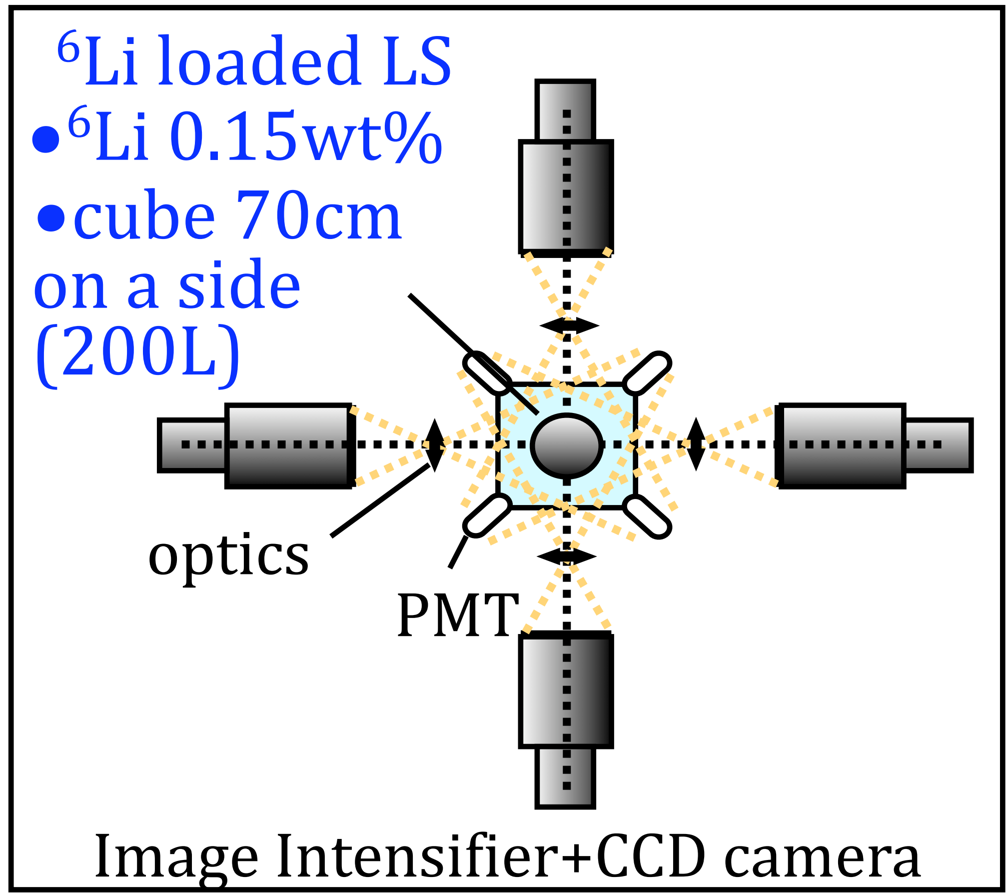
-at Kashiwazaki nuclear power plant, there have already been vertical shaft.

-1500 $\overline{\nu}_e$ events/day (200L size detector)

1. We will explore possibility of directional measurement at 16m under ground.
2. We are planning to try to measure above ground.

Li loaded liquid scintillator has good resistance for B.G. event.





Summary

▸ ^{6}Li loaded liquid scintillator can have good directional sensitivity.

- Li LS

▸ We have developed the ^{6}Li loaded LS by the original method.

▸ If we use enrich ^{6}Li compound, required performance for 200L size detector has been achieved.

- Imaging Detector

▸ We checked position resolution using I.I. and CCD camera.

- continue to R&D for prototype detector

▸ We are trying to explore possibility of pals shape discrimination.

▸ We want to measure energy deposit points in the ^{6}Li loaded LS with imaging detector.

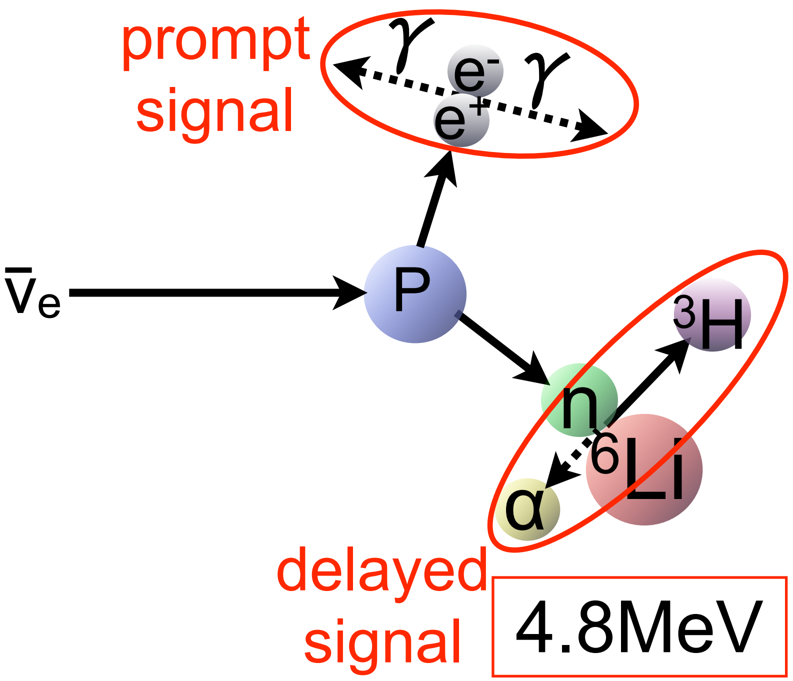
Backup

Performance Estimation

- α-quenching factor

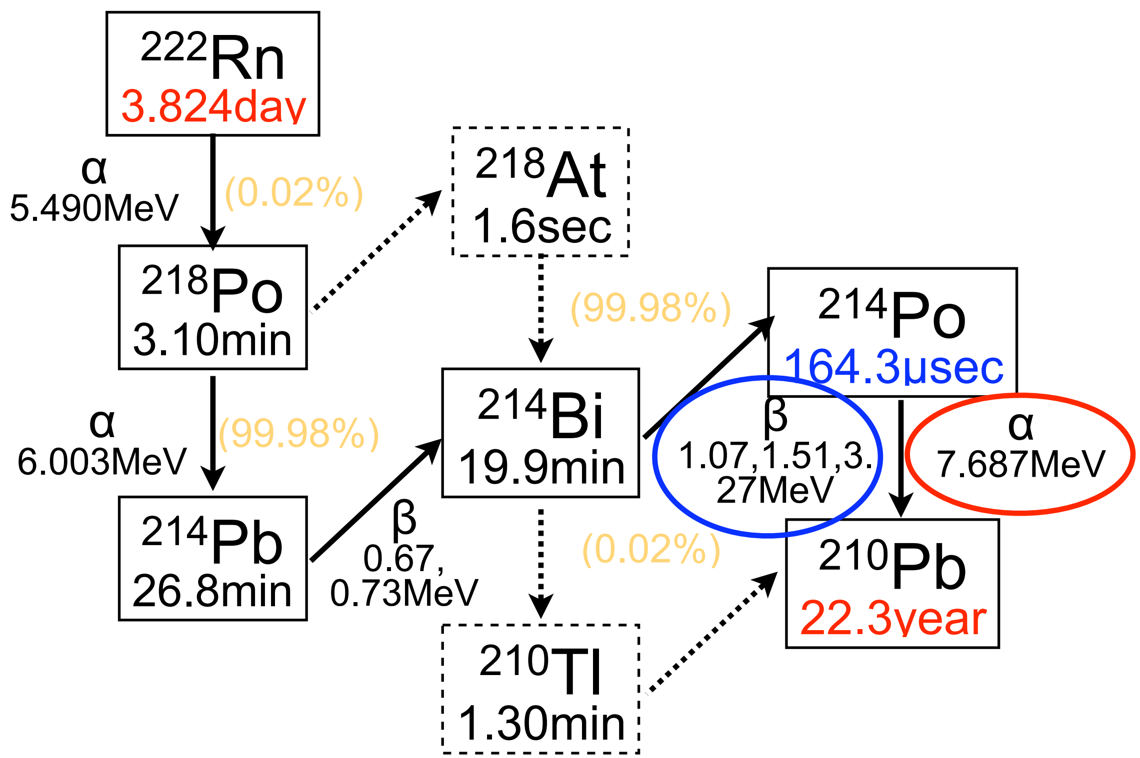
- We want to know the α-quenching factor for measuring delayed signal.

- How to measure
  - loaded ^{222}Rn in LS
  - ^{214}Po→^{210}Pb : α-ray(7.687MeV)
  - ^{214}Bi/^{214}Po delayed coincidence



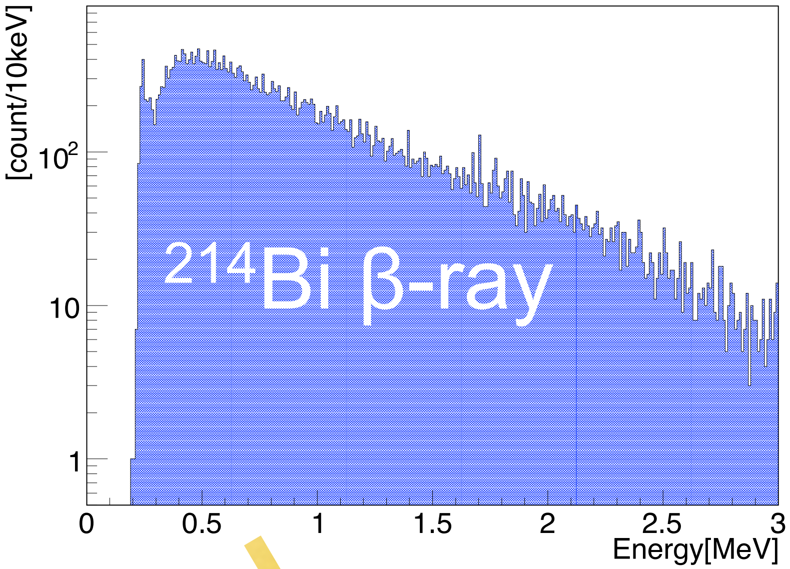
α 1.9MeV

^{3}H 2.9MeV

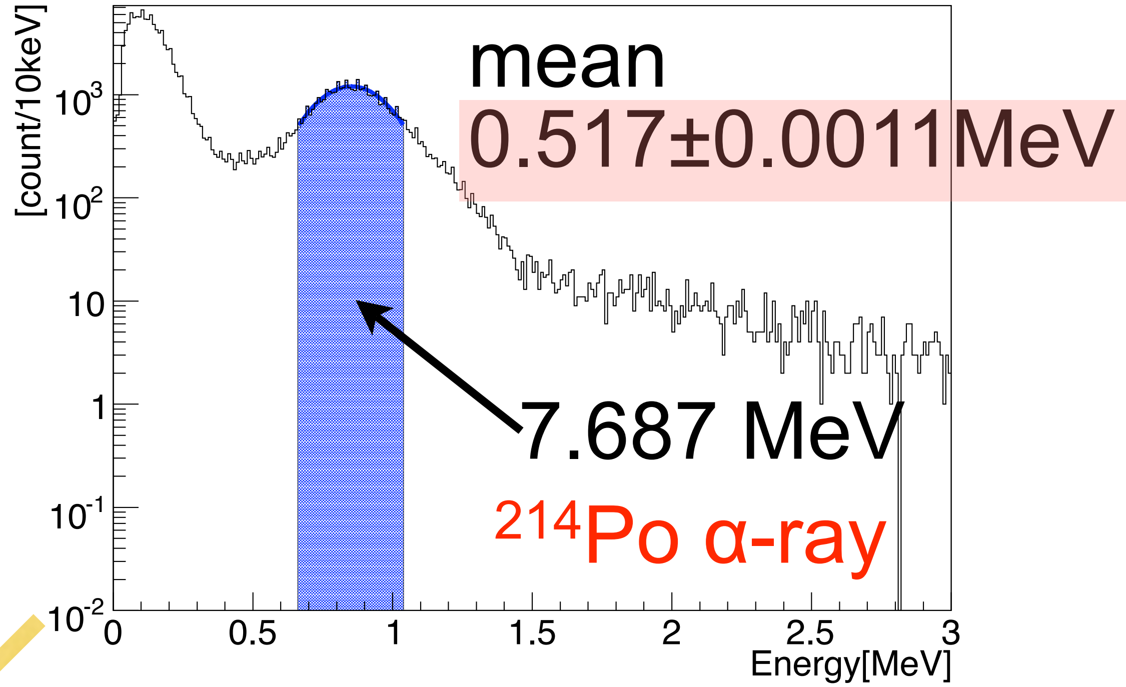


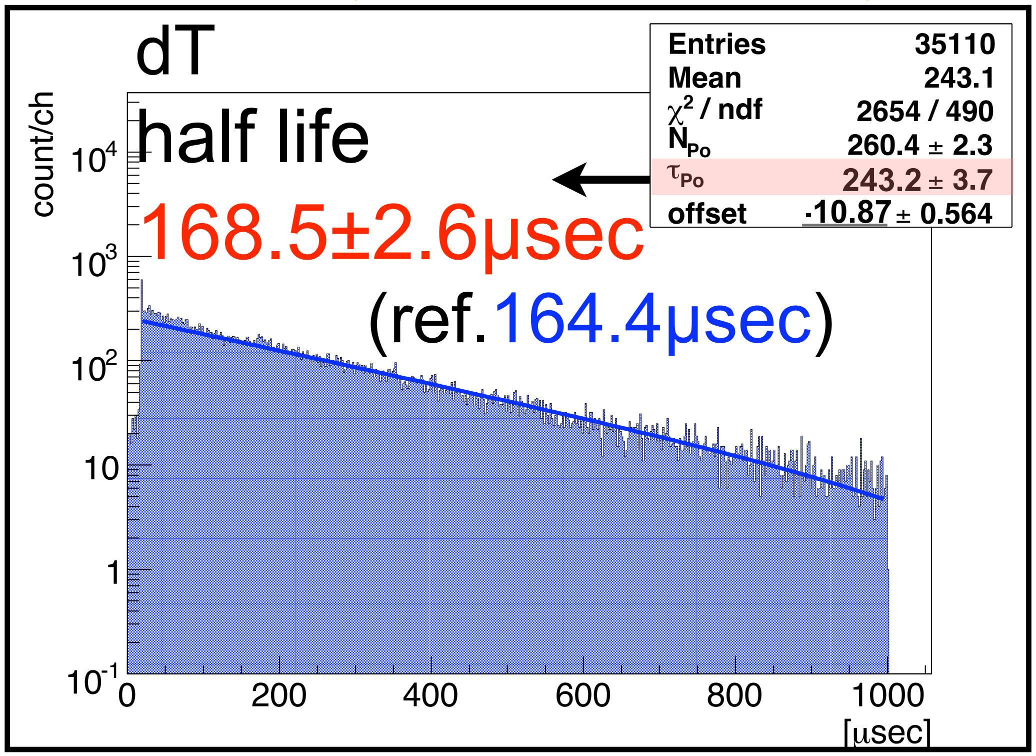
• result

prompt event



delayed event



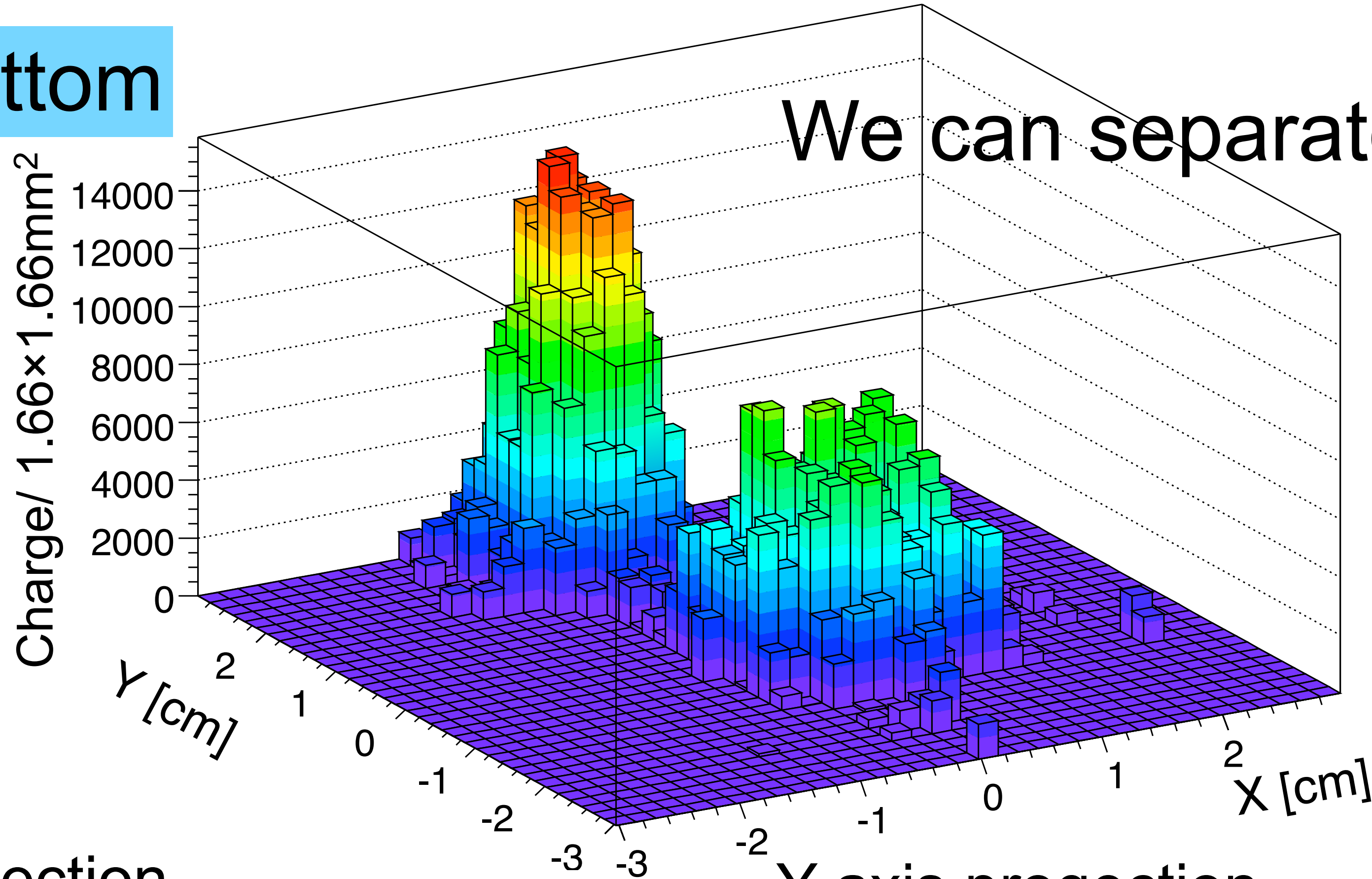


*^{214}Po α-ray quenching factor
LiLS 1/9
(ref.KamLAND 1/14
pseudecumene : dodecane = 1:4)

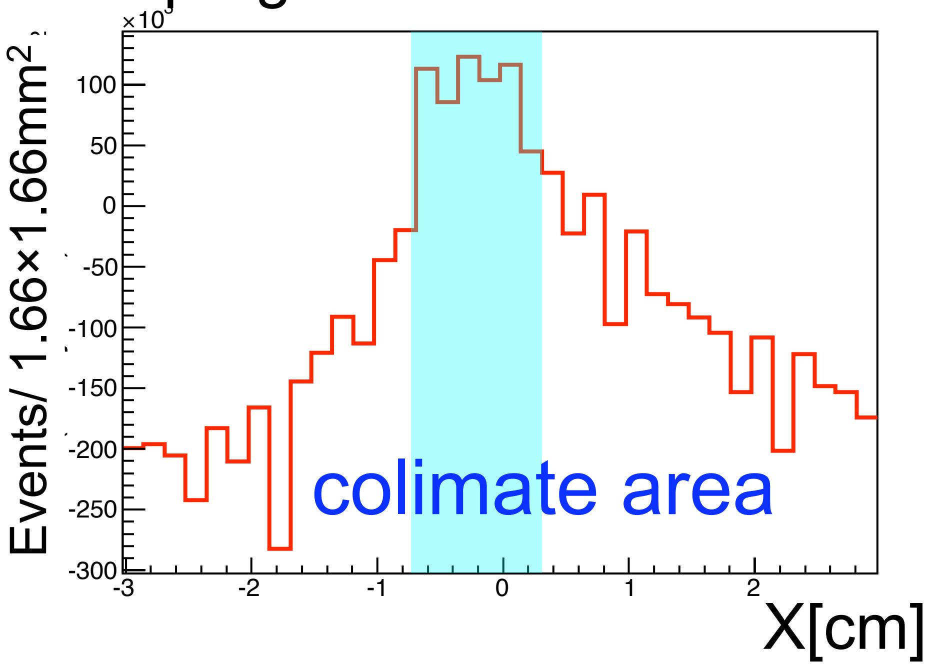
*high rate pseudecumene
minimize the quenching effect

top & bottom

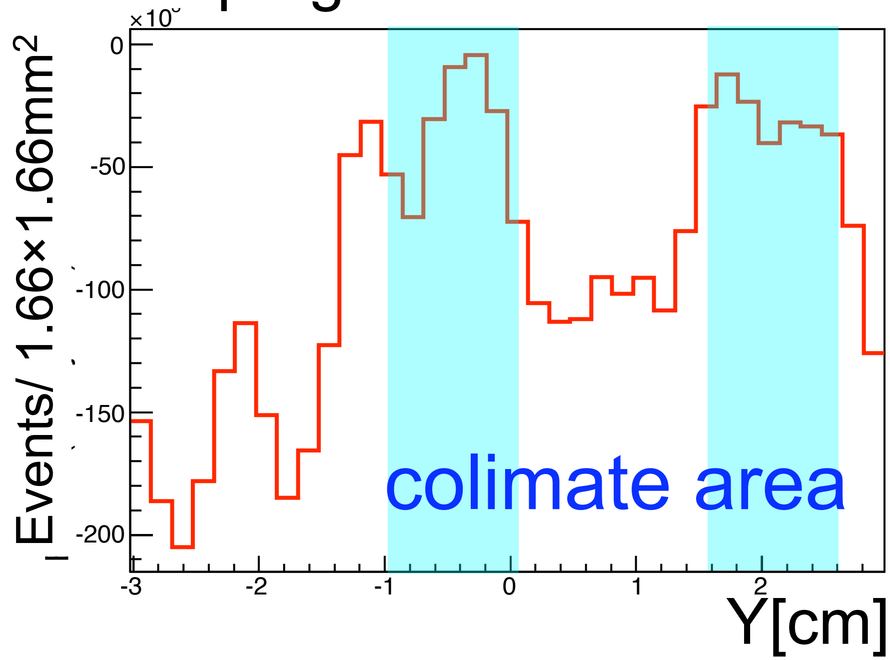
We can separate clearly.



X axis progection



Y axis progection



- ^{137}Cs measurement
  We checked if lower energy event was taken by CCD camera.
    - ^{137}Cs γ-ray 662keV