Directionality in neutrino detection

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Outline

Introduction	Our Goal	Neutrino Detectors
Directionality	Motivation	How to Measure
Development		
Summary	Future Prospects	Conclusions

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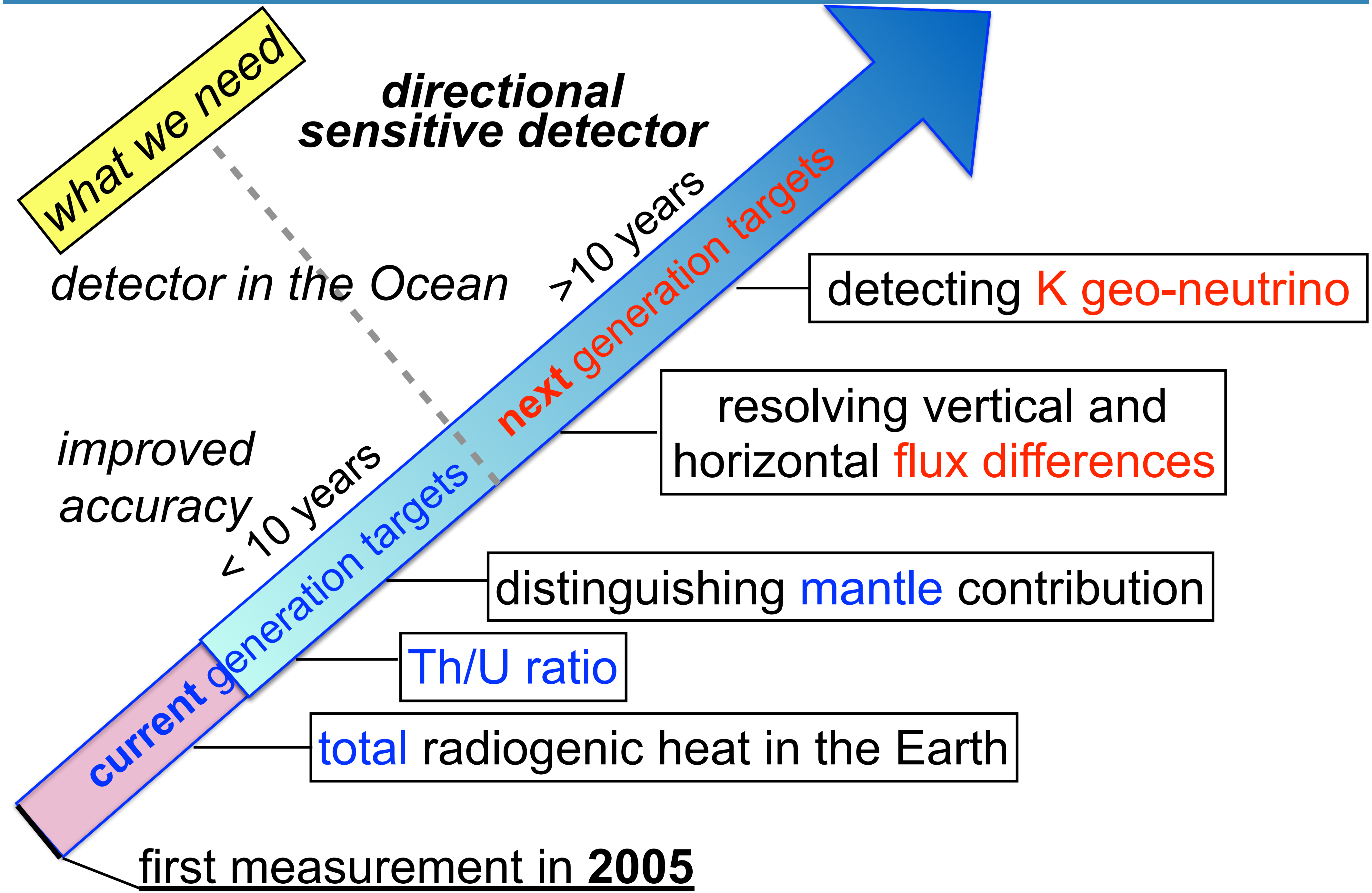
Where we are?


what we need
directional
sensitive detector
detector in the Ocean
>10 years
next generation targets
detecting K geo-neutrino
resolving vertical and
horizontal flux differences
improved
accuracy
< 10 years
current generation targets
distinguishing mantle contribution
Th/U ratio
total radiogenic heat in the Earth
first measurement in 2005

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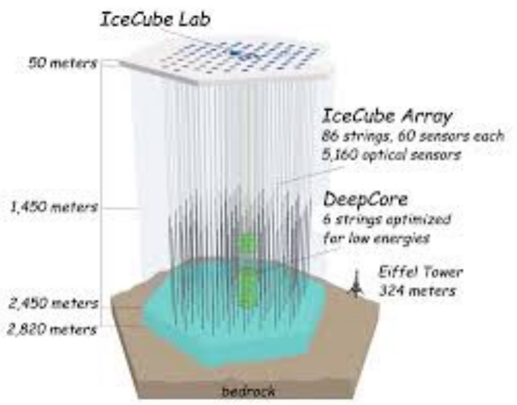
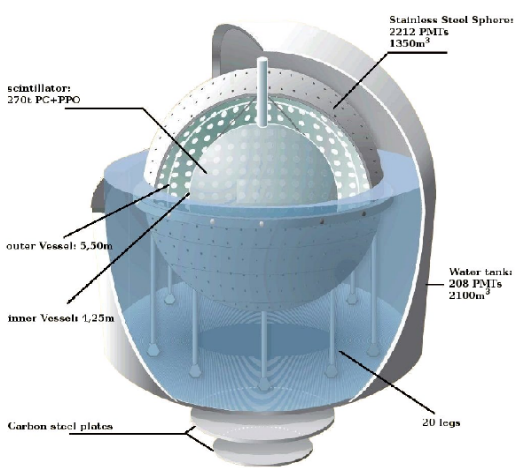
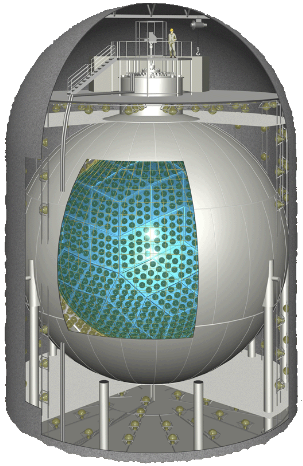
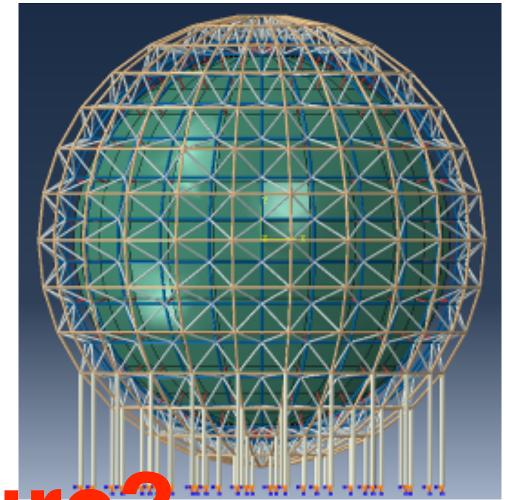
Neutrino Detectors

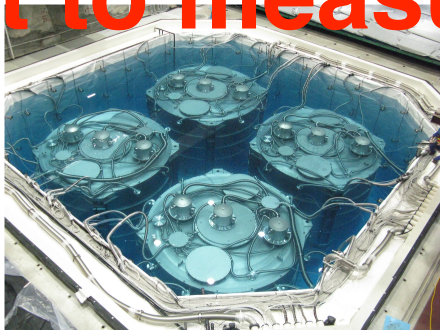


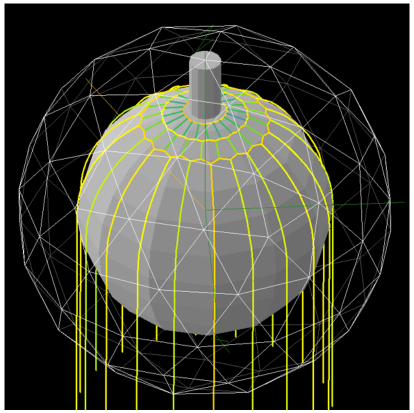


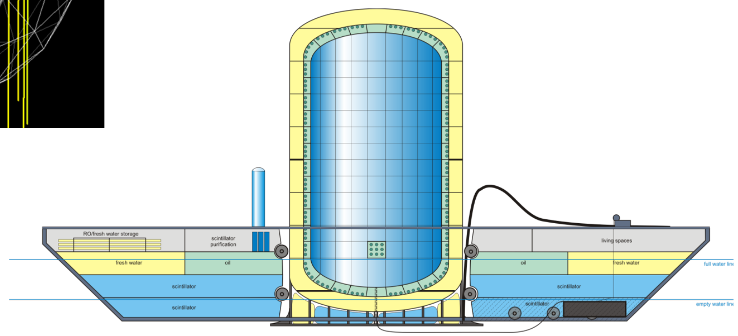


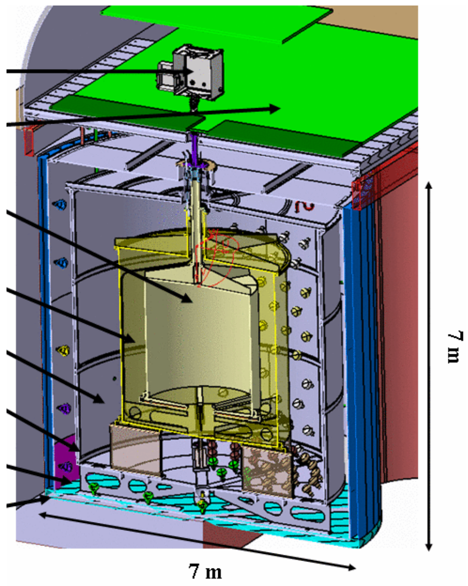


What do you want to measure?

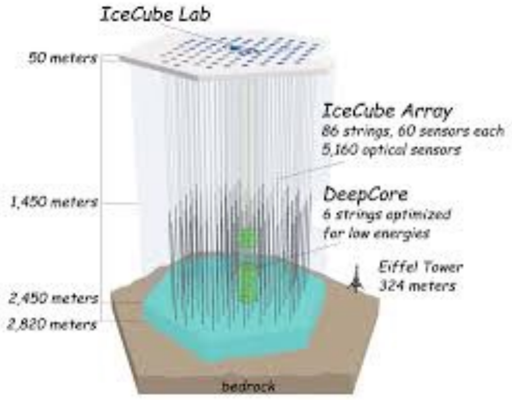


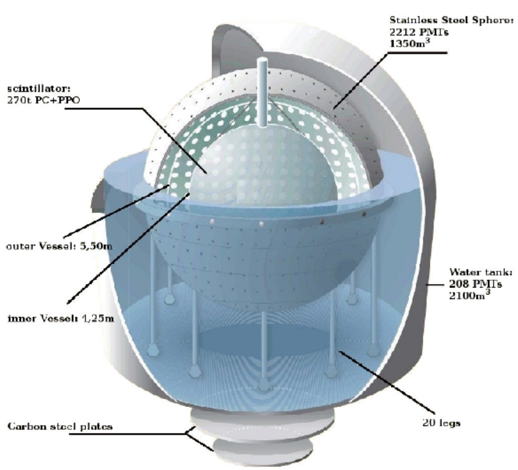


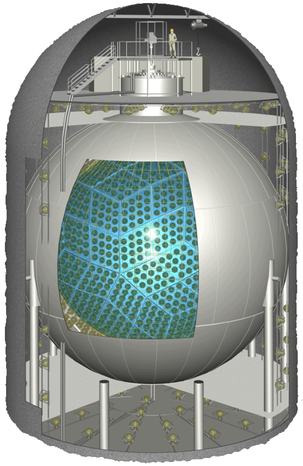


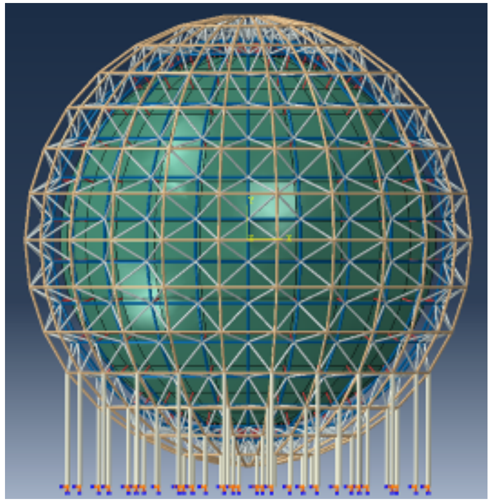


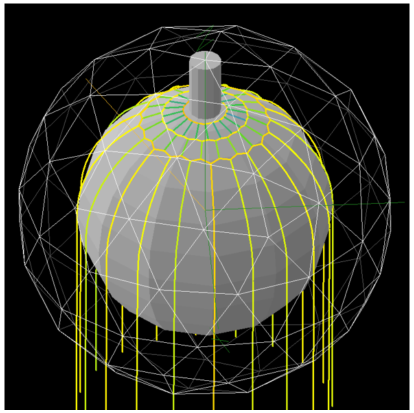
Neutrino Detectors

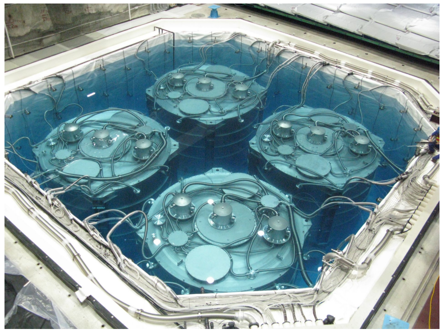


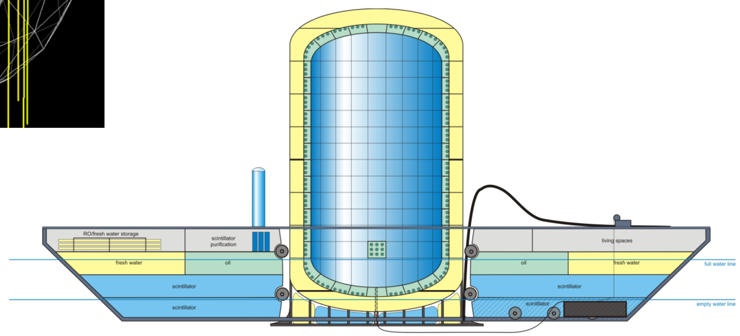


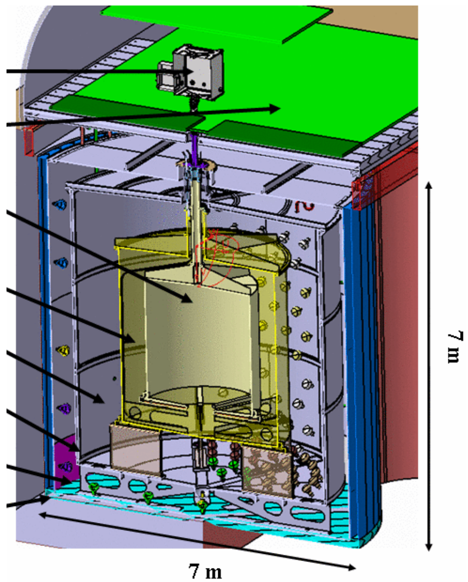




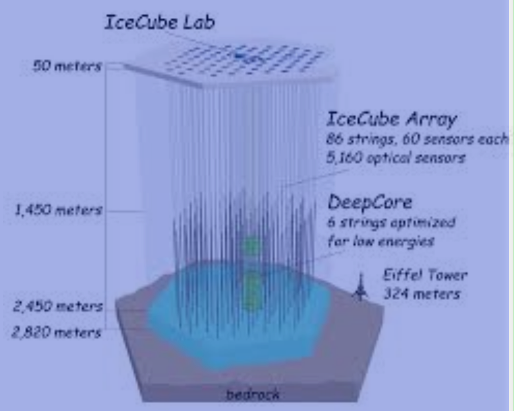




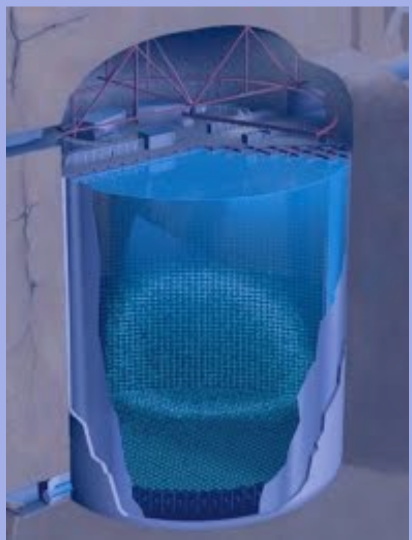


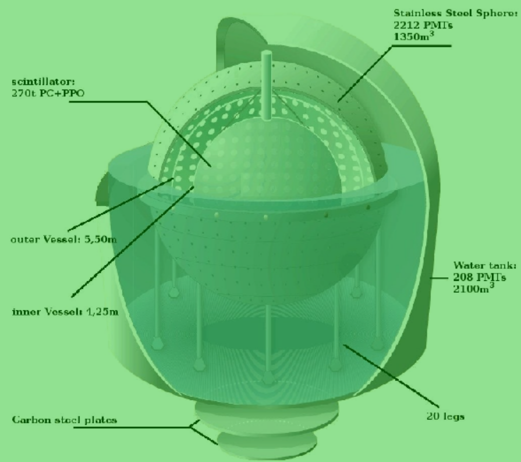


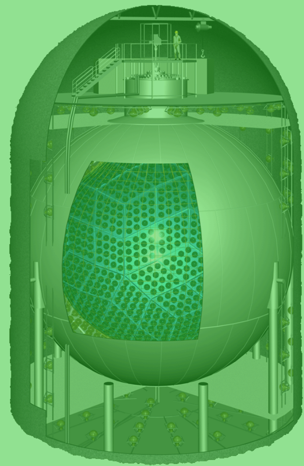
Neutrino Detectors : target

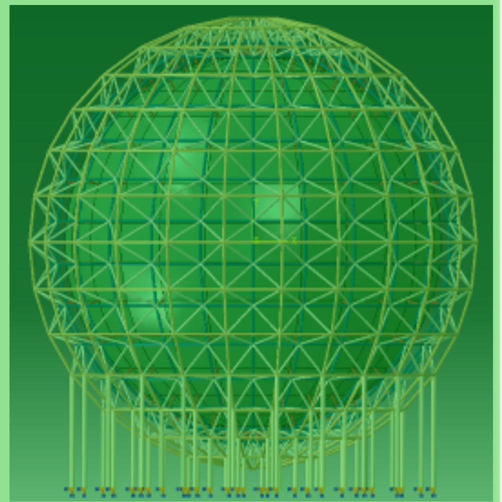


Water/Ice

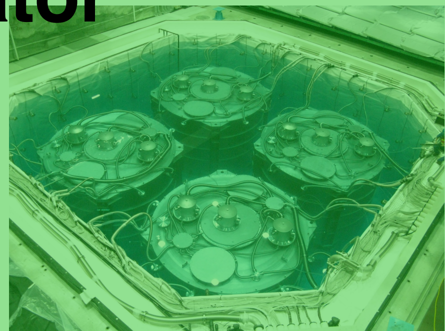


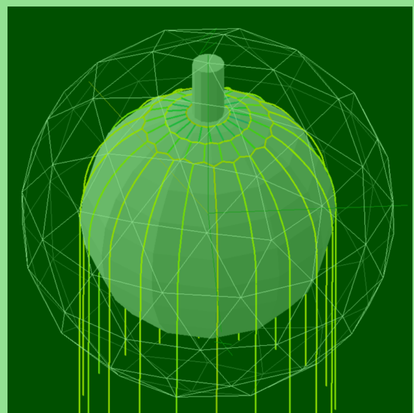


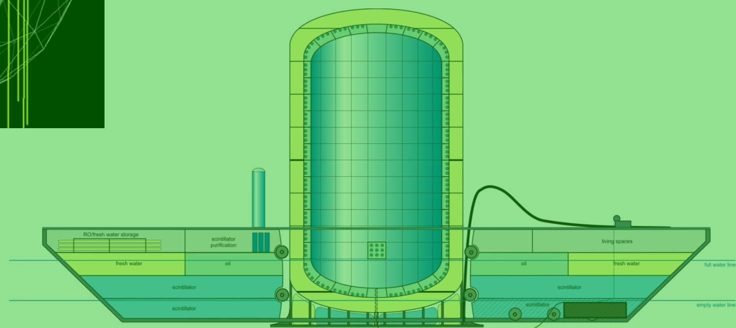


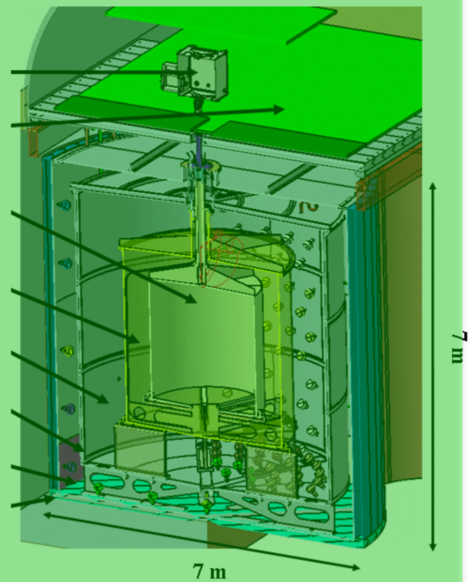


Liquid Scintillator

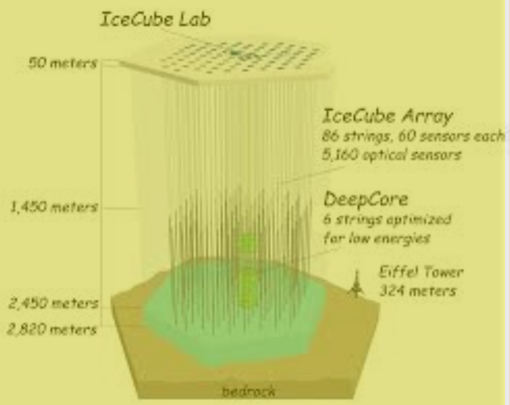




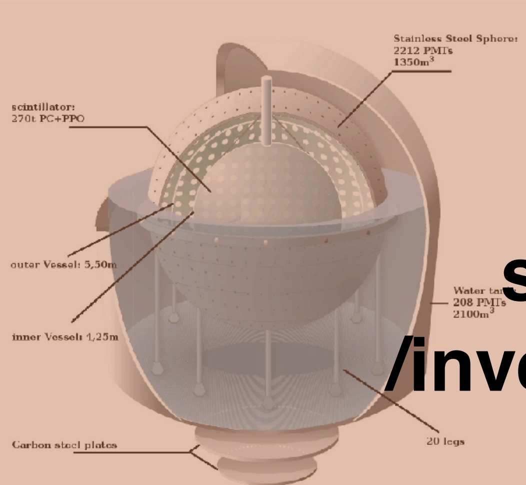


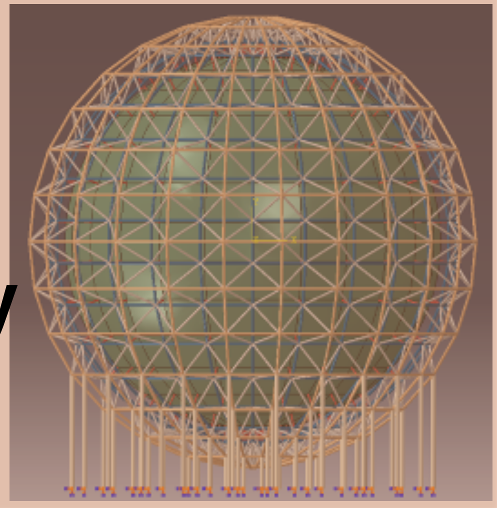


Neutrino Detectors : reaction

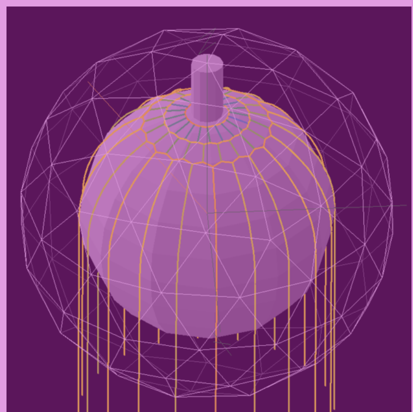


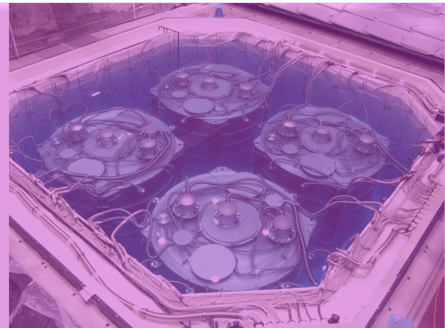
scattering



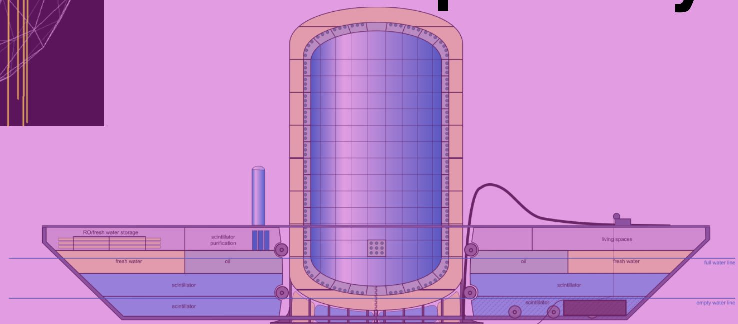


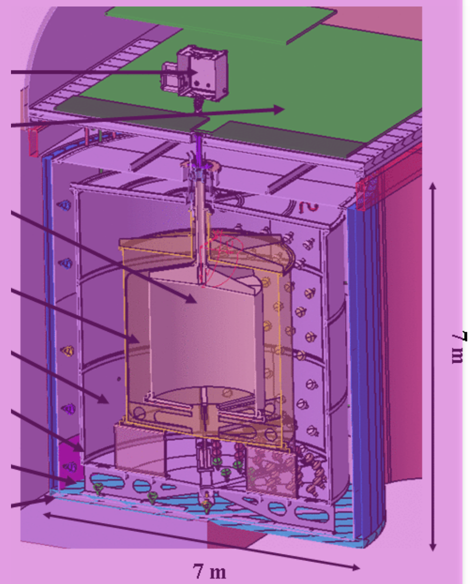
scattering /inverse β decay





inverse β decay



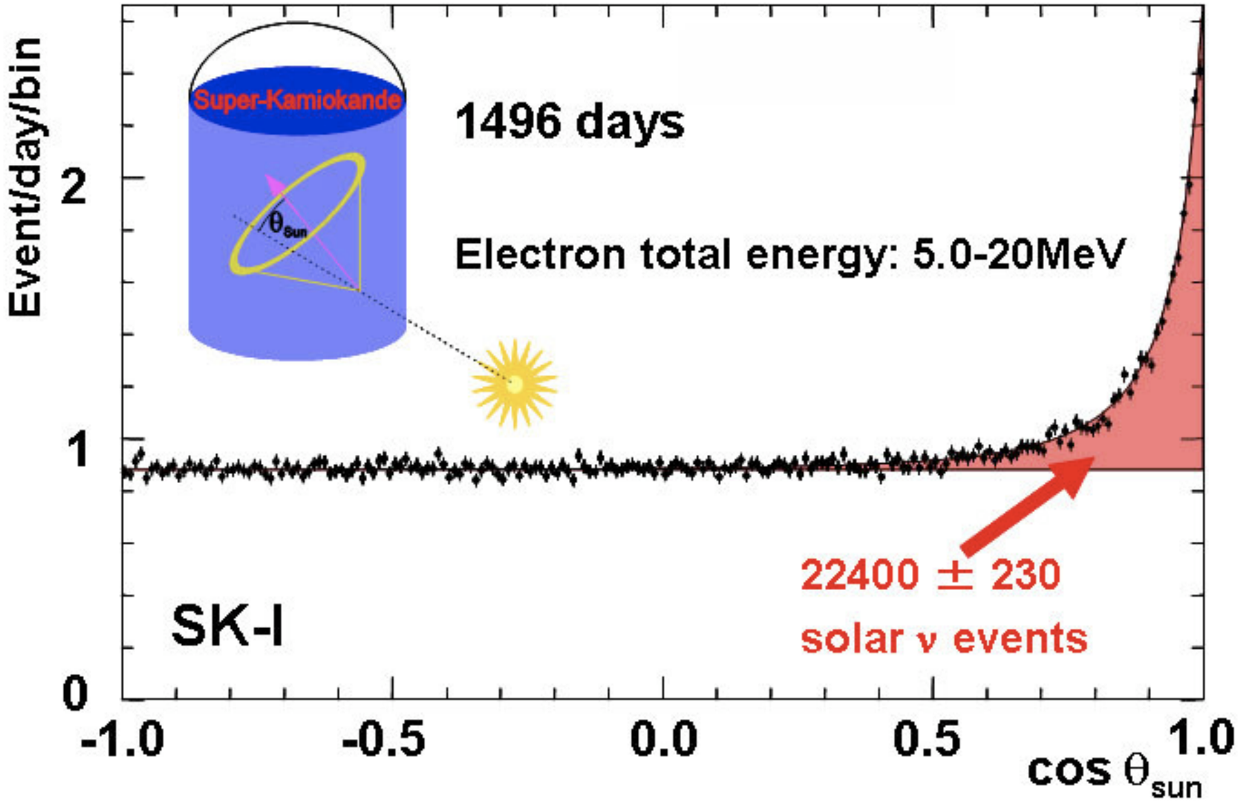


Water vs Liquid Scintillator

	Water	**Liquid Scintillator (LS)**
experiments	Super-K (Ice-Cube, etc.)	KamLAND (Borexino, SNO+, JUNO, etc.)
target volume	50,000 t larger	1,000 t
light	Cherenkov	Scintillation
light yield	6 p.e./MeV **higher energy**	400 p.e./MeV blighter **lower energy**
reaction	scattering	scattering/background reduction **inverse β decay**
directionality		

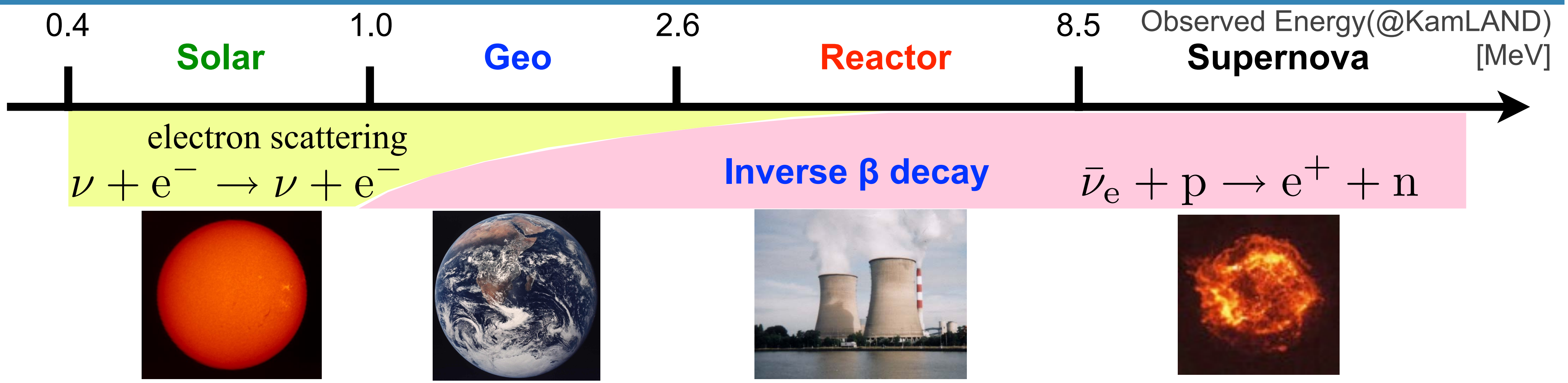
Directional Sensitivity in Water

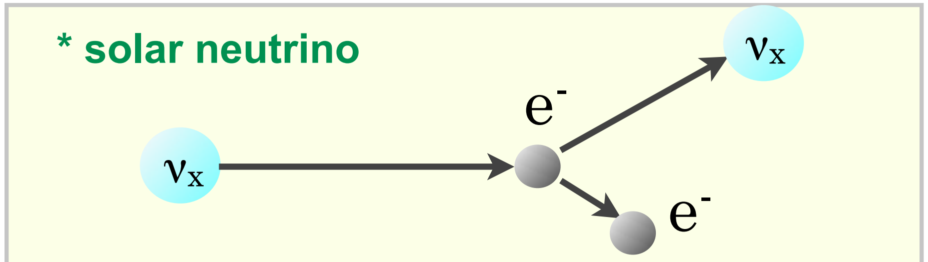
Solar neutrino measurement with **Super-Kamiokande**



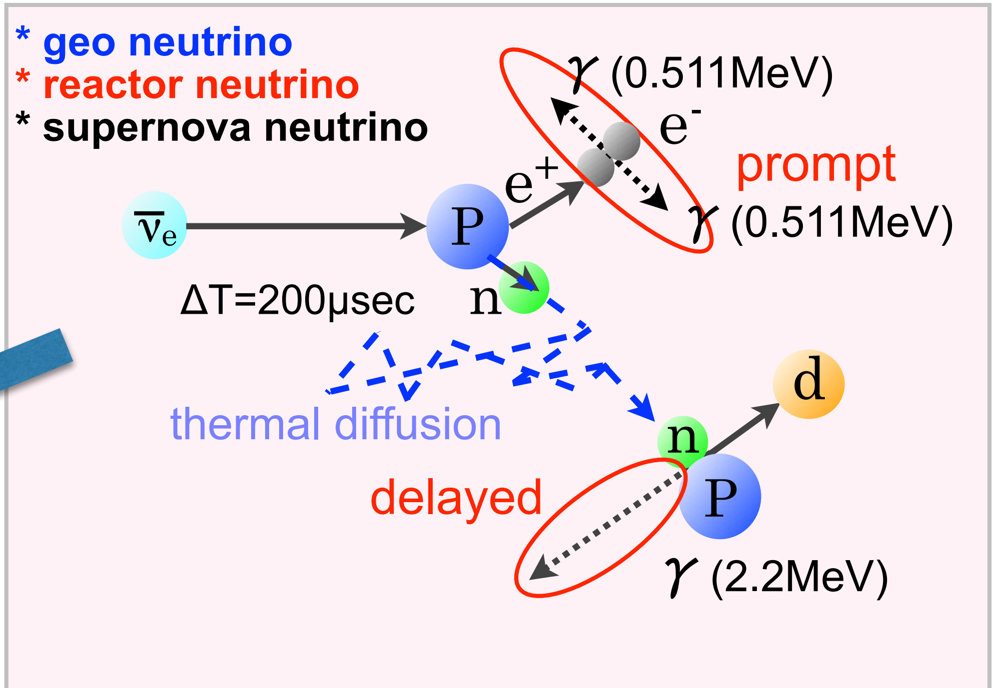
- Ling imaging water Cherenkov detector can have directional sensitivity.
- They can separate solar neutrino event from backgrounds.

Neutrino Detection in LS





neutrino detection by **electron scattering**



anti-neutrino detection by **inverse β decay**

Advantages

- 2 flashes have space and time correlations
- Eliminates background

Disadvantage

- No-directional information

Advantages of inverse β decay

Advantages 

- 2 flashes have <u>space and time correlations</u>
- <u>Eliminates background</u>

Advantages of inverse β decay

Advantages

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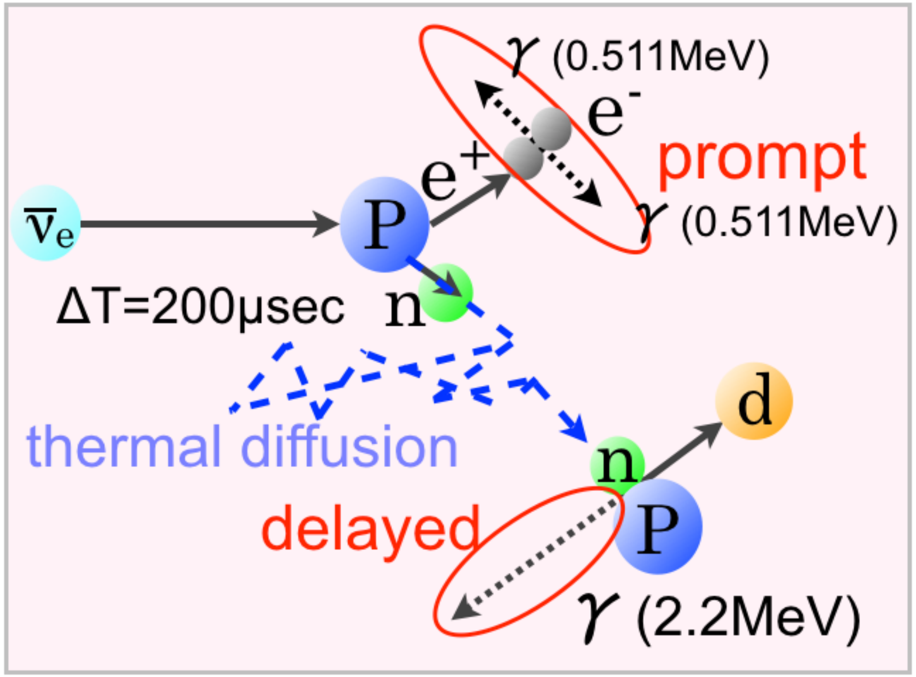
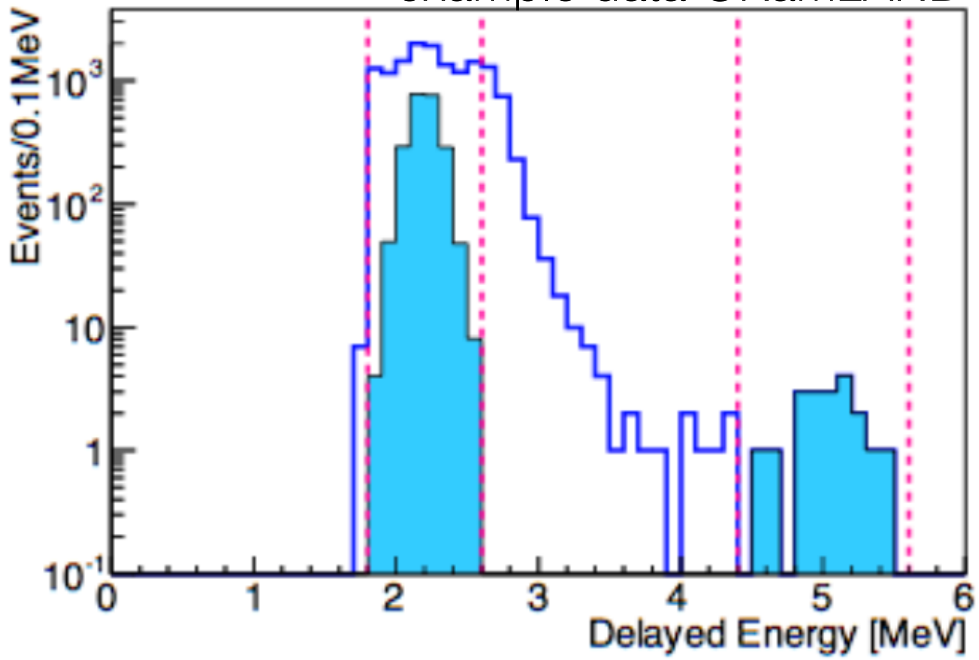


"delayed coincidence"

1. select delayed event

example data @KamLAND



fixed energy!

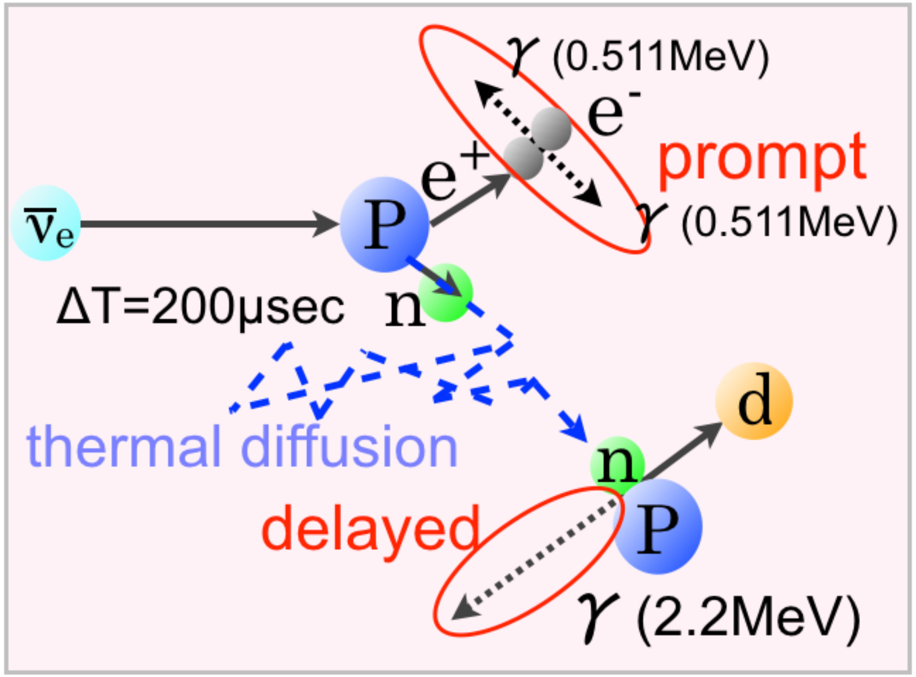
2.2 MeV(proton capture) or 4.9 MeV(^{12}C capture)

99.5% 0.5%

Advantages of inverse β decay

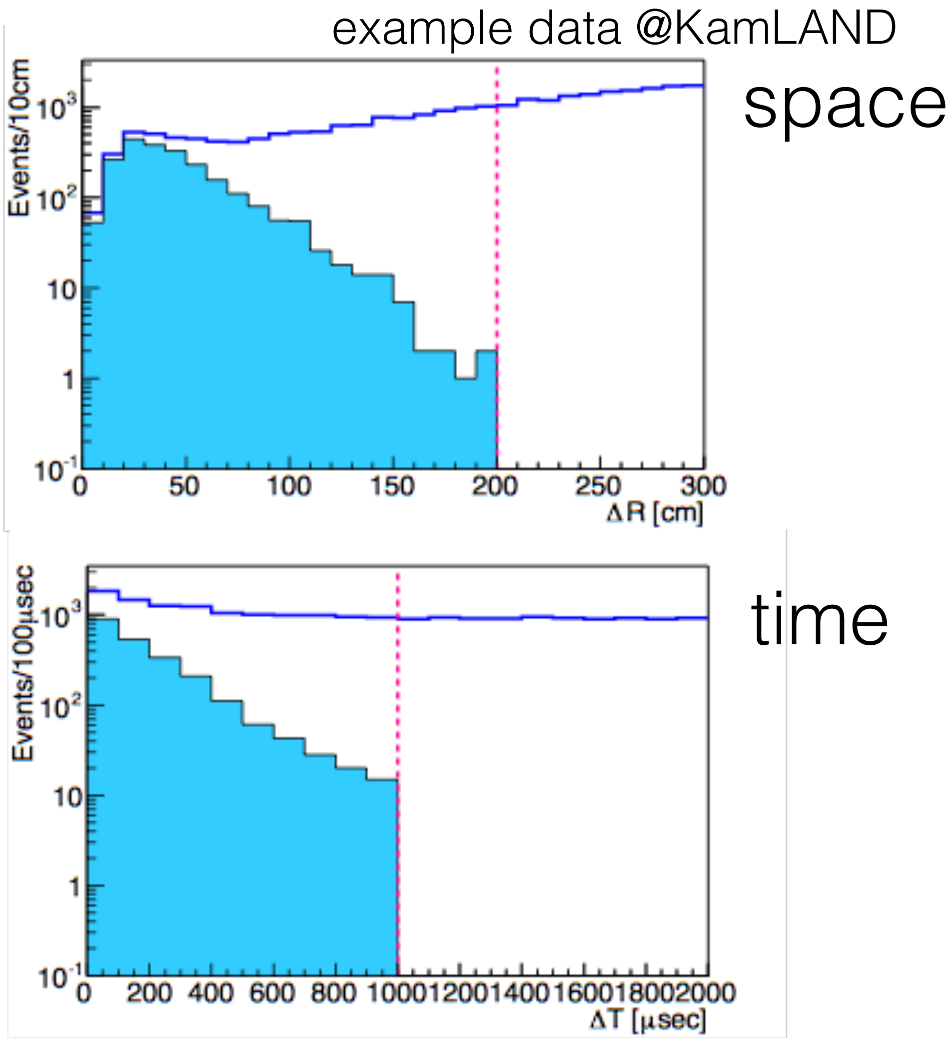
Advantages

- 2 flashes have space and time correlations
- Eliminates background



"delayed coincidence"

2. search prompt event

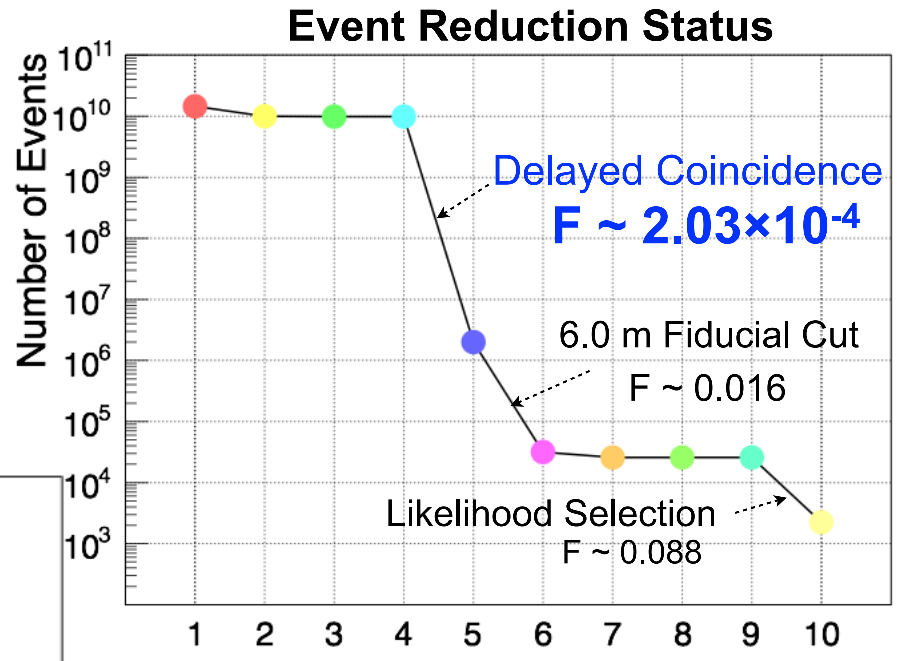


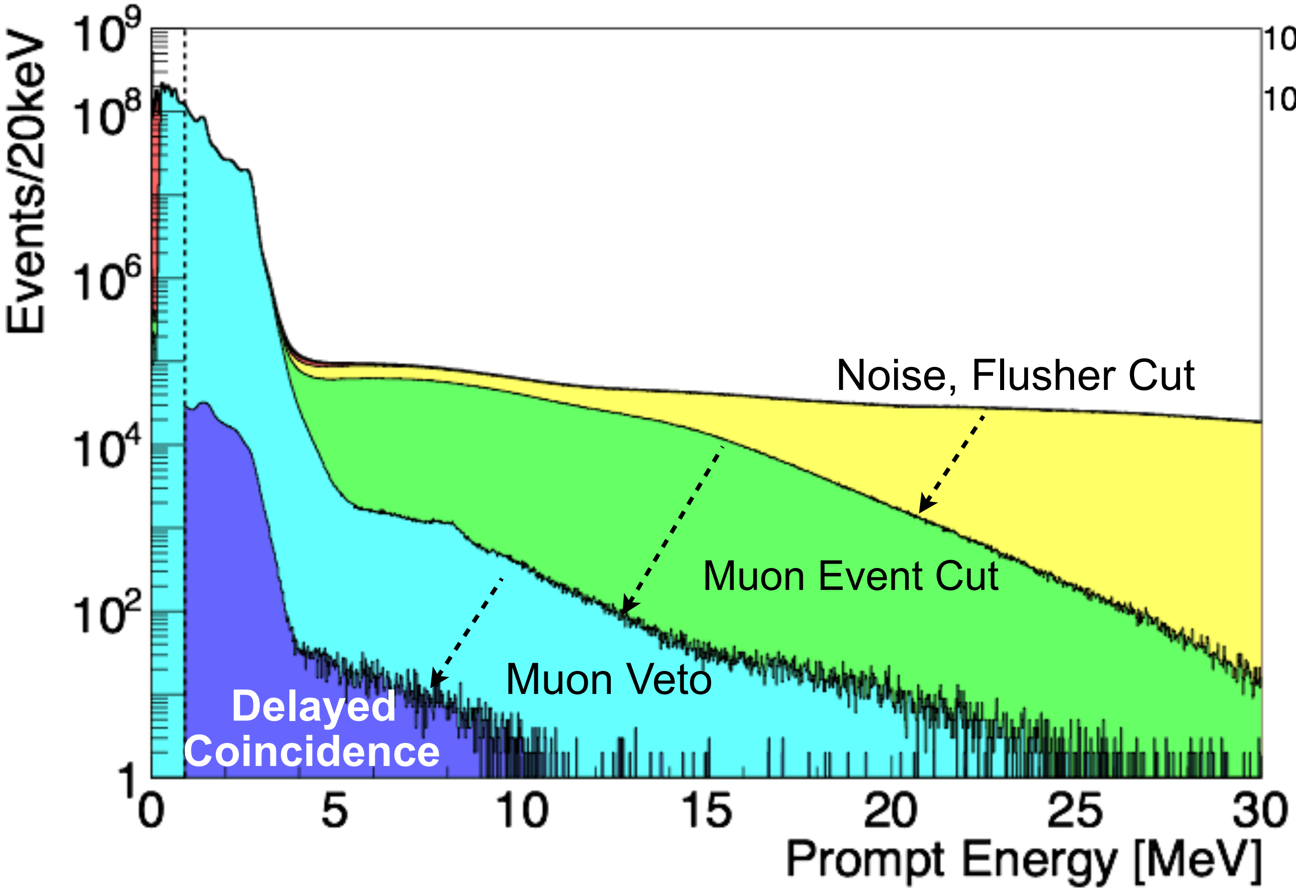
Advantages of inverse β decay

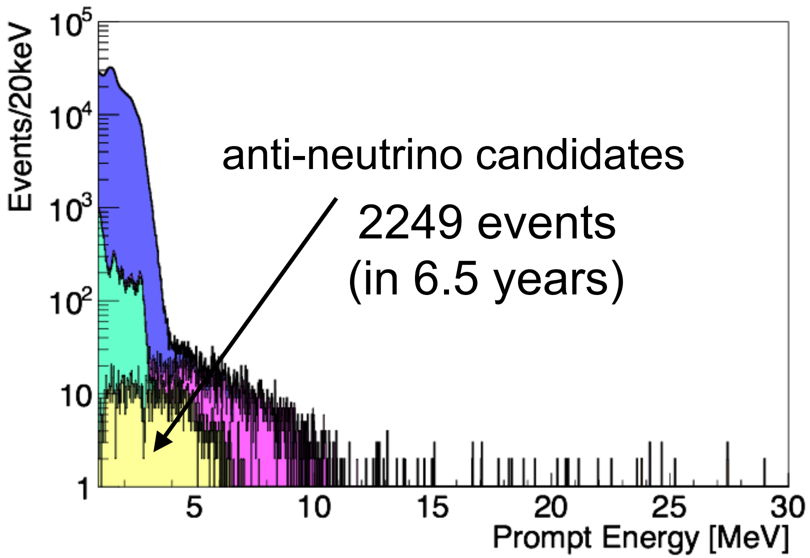
Advantages

- 2 flashes have <u>space and time correlations</u>
- Eliminates background

reduction factor ~10^{-4}







Directional Sensitivity in LS

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light yield	6 p.e./MeV **higher energy**	400 p.e./MeV blighter **lower energy**
reaction	scattering	scattering/background reduction **inverse β decay**
directionality		

- ✦ Make the impossible, possible!
- ✦ Breakthrough technology for “next generation” detector.

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Directionality	Motivation	How to Measure
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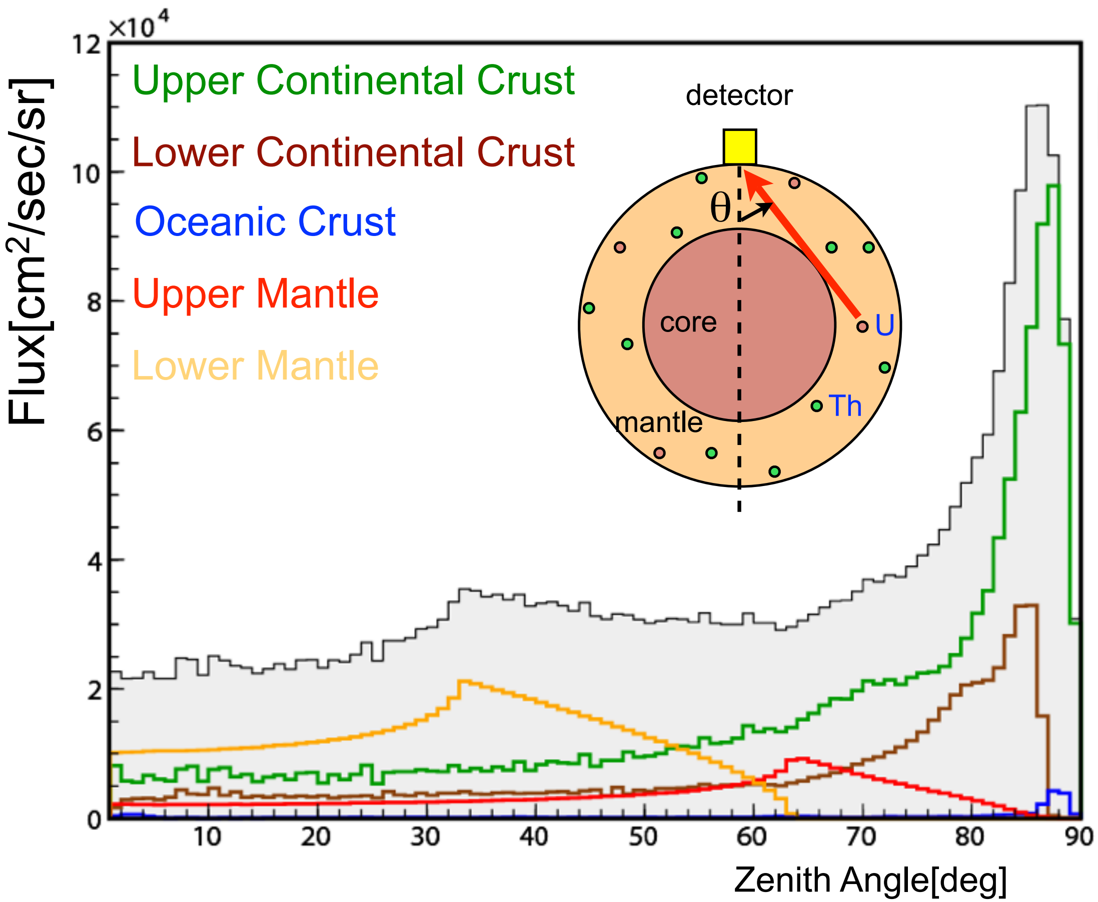
What we can measure?

1. large size detector (1kt~)

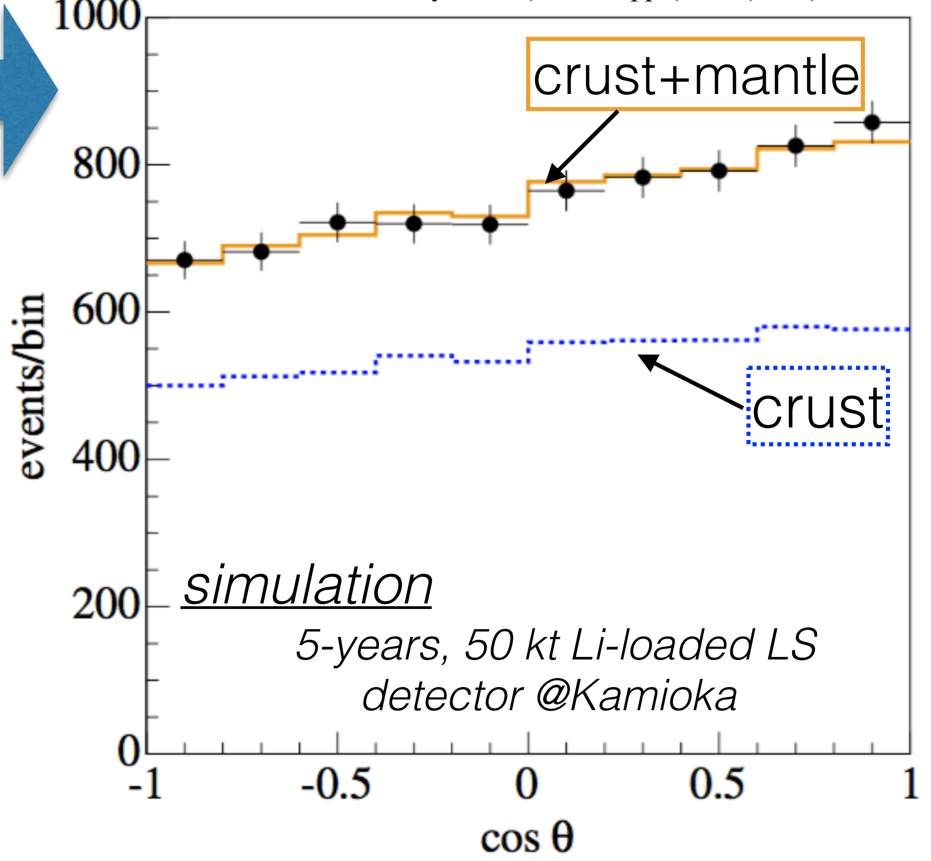
<u>geo-neutrino</u>

- distinguish mantle from crust contributions
- separate reactor anti-neutrinos

geo-neutrino angular distribution @Kamioka



I. Shimizu, Nuclear Physics B (Proc. Suppl.) 168 (2007) 147–149



What we can measure?

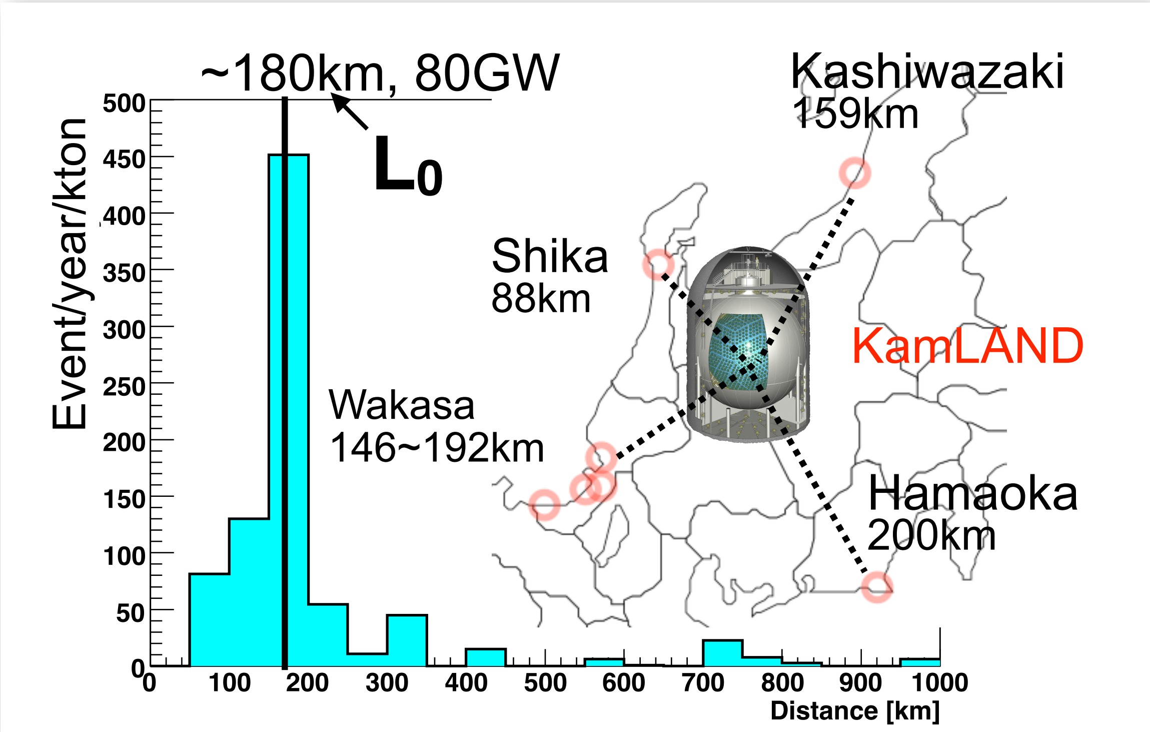
1. large size detector (1kt~)

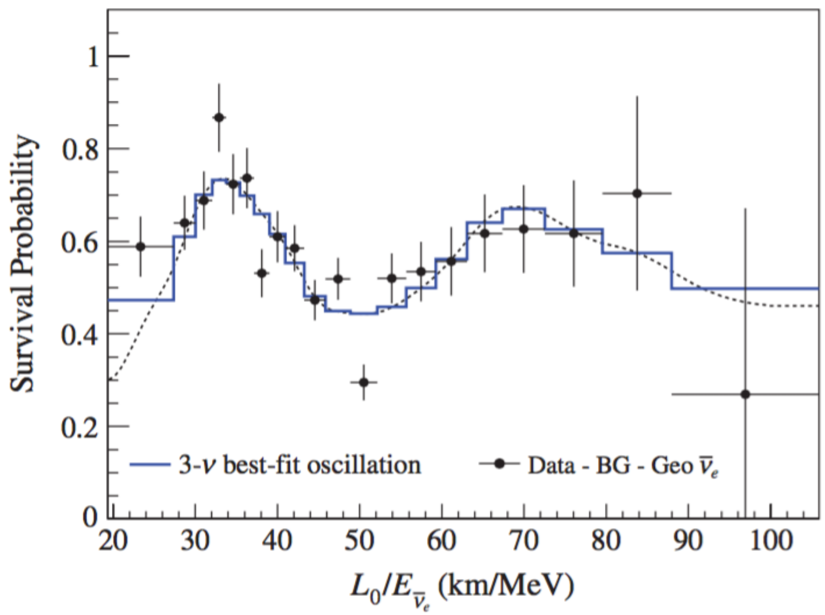
<u>supernova neutrino</u>

- early determination of supernova detection

<u>reactor neutrino</u>

- improvement of oscillation parameter measurement



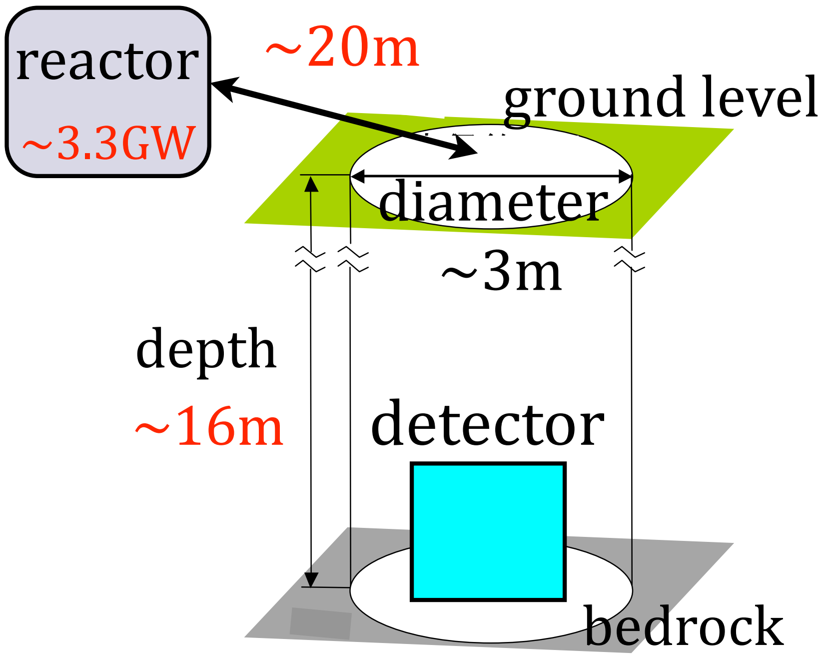


What we can measure?

2. small size detector (~200kg) our first target

- establishment of new technology using anti-neutrino sources (reactor neutrino, radioactive source)
- application to reactor monitor

example) Japan @Kashiwazaki-Kariwa nuclear power plant



1500 $\overline{\nu}_e$ events/day

Outline

- Introduction
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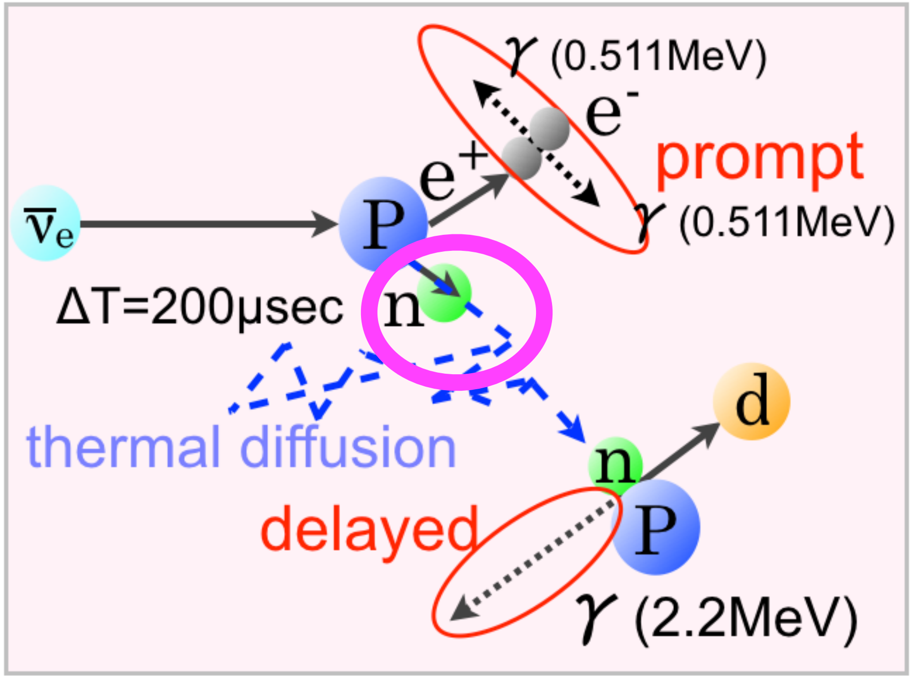
  - Neutrino Detectors
- Directionality
  - Motivation
  - How to Measure
- Development
- Summary
  - Future Prospects
  - Conclusions

How to measure? : key point

inverse β decay



<u>key point</u>

“neutron” retains information of anti-neutrino direction

How to measure? : theoretical calculation

PHYSICAL REVIEW D, VOLUME 60, 053003

Angular distribution of neutron inverse beta decay, $\bar{\nu}_e + p \rightarrow e^+ + n$

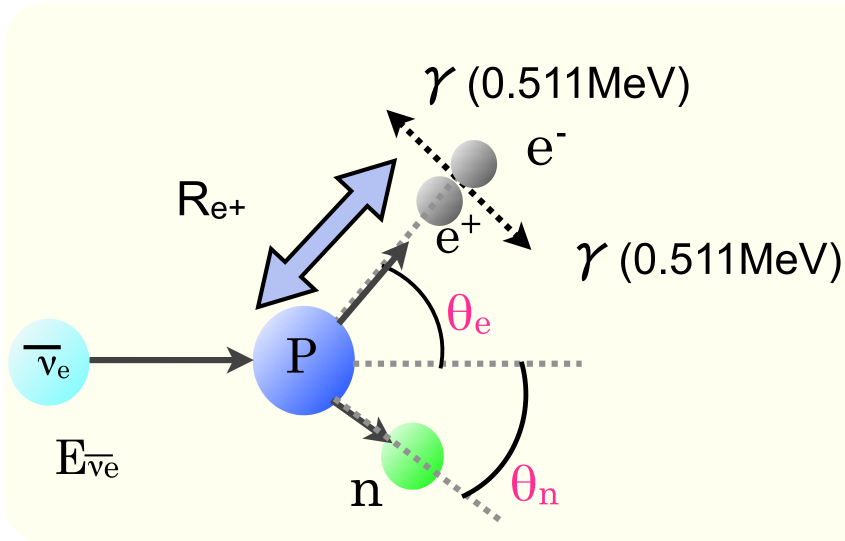
P. Vogel* and J. F. Beacom†
Physics Department 161-33, California Institute of Technology, Pasadena, California 91125
(Received 1 April 1999; published 27 July 1999)

Improved estimate of the cross section for inverse beta decay

Artur M. Ankowski*
Center for Neutrino Physics, Virginia Tech, Blacksburg, Virginia 24061, USA
(Dated: January 26, 2016)
arXiv:1601.06169

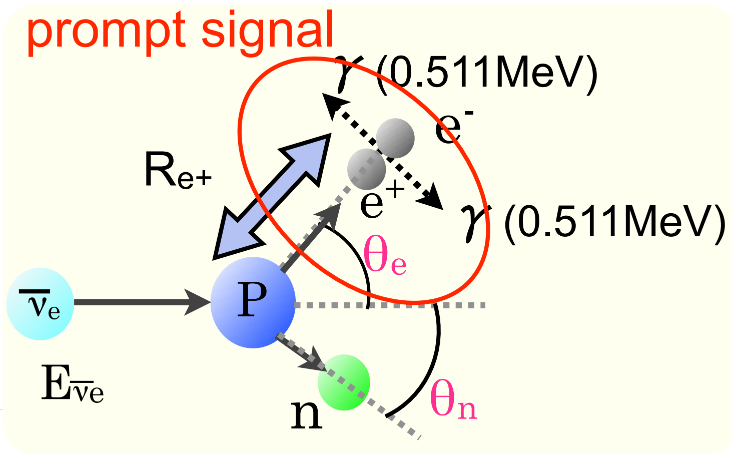
Theoretical calculation gives us "**θe**".

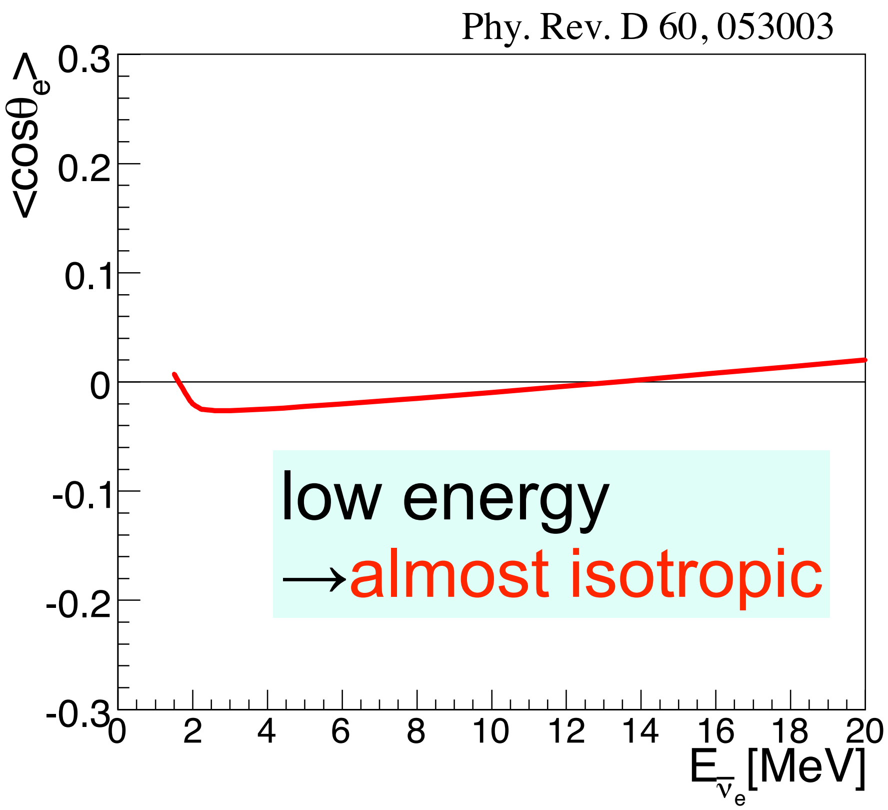
→"**θn**" is determined by the conservation of momentum.

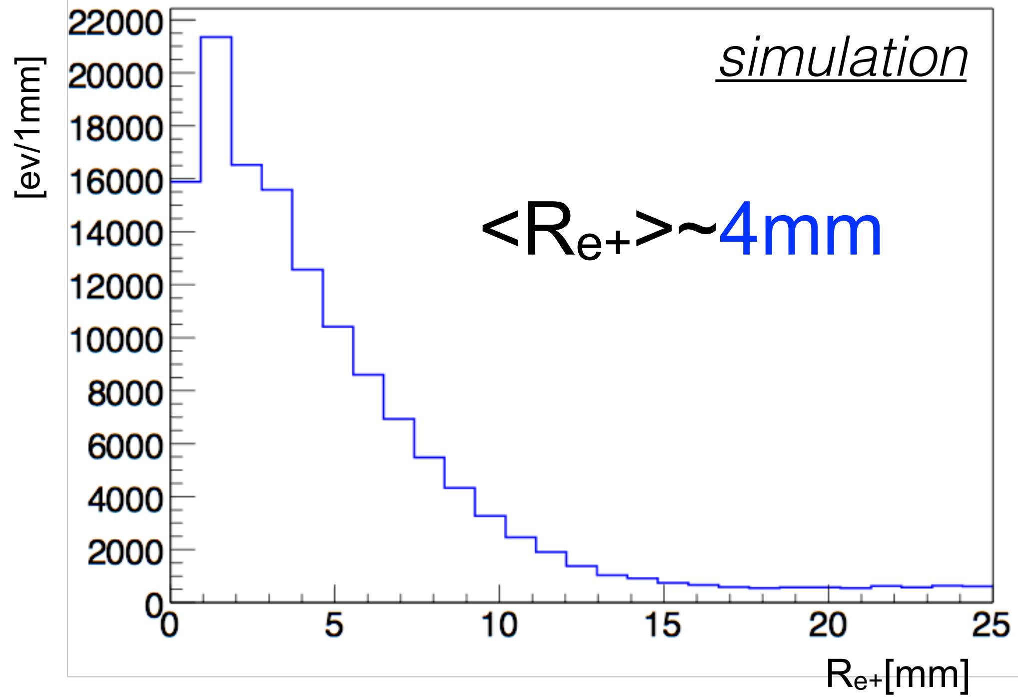


How to measure? : prompt signal

prompt : e^+ signal



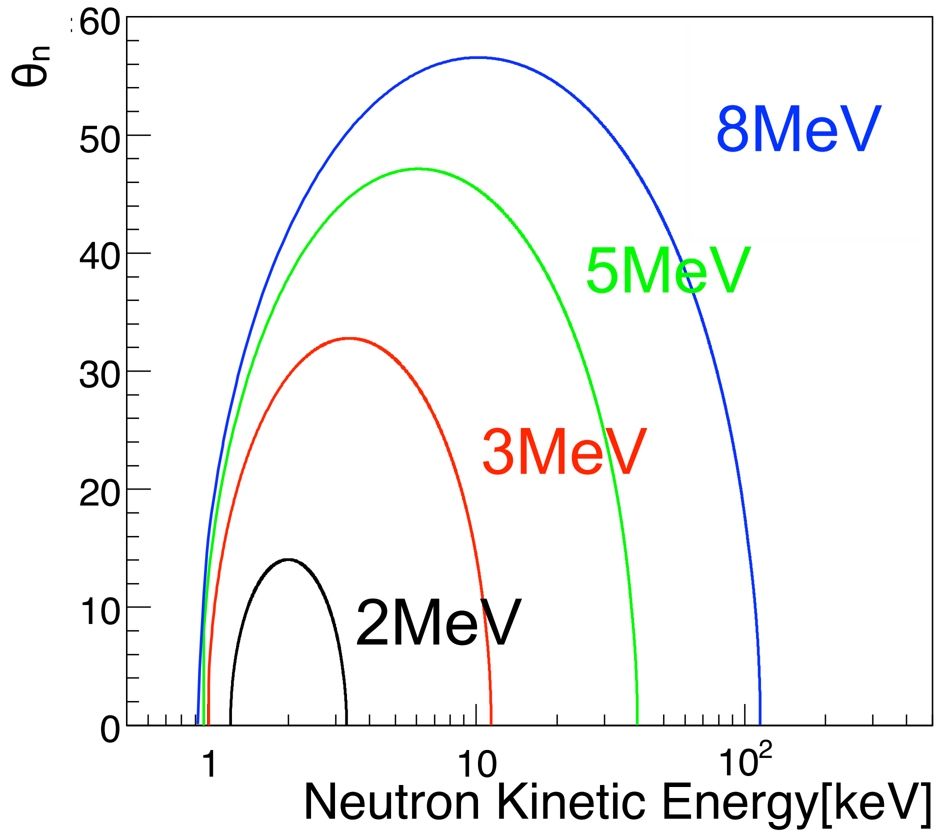




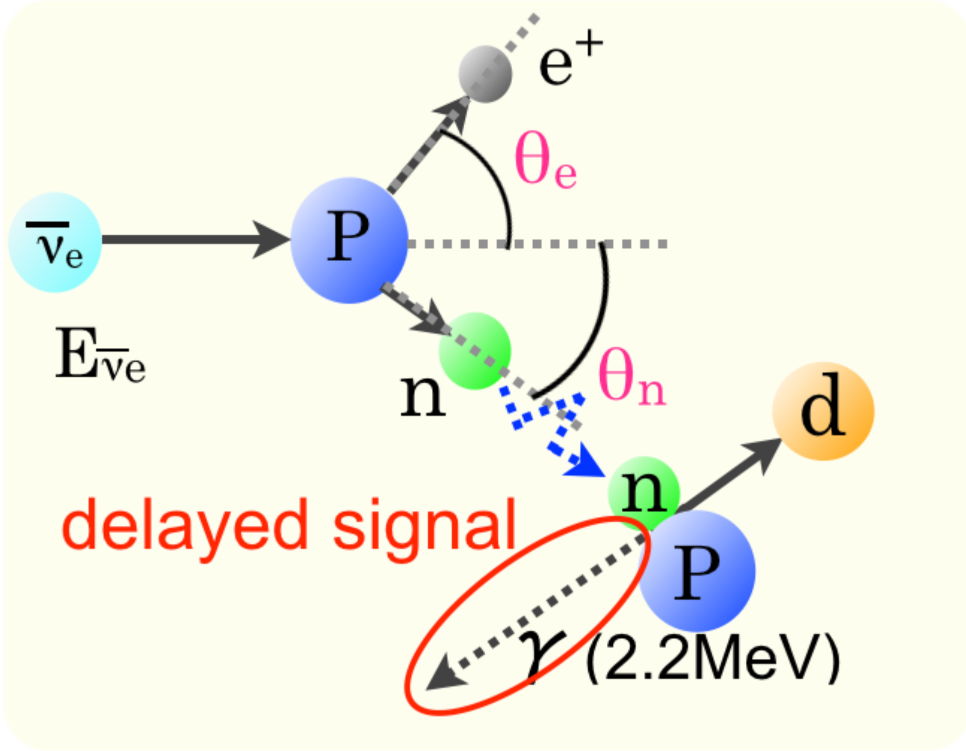
prompt signal retains information of $\overline{\nu}_e$ captured position

How to measure? : delayed signal

delayed : neutron capture signal

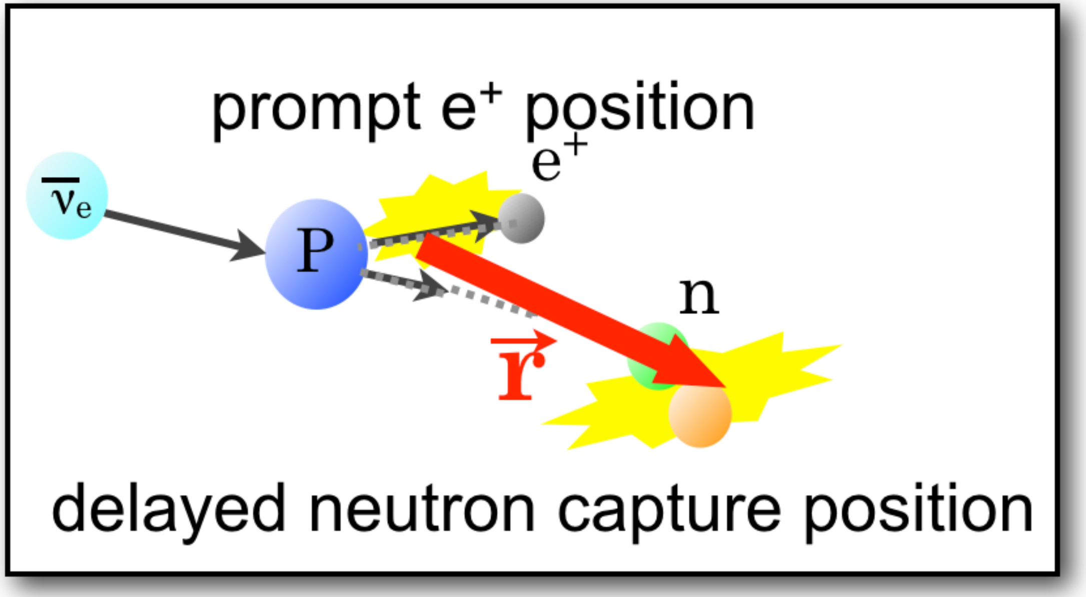


$E_{\bar{\nu}e} < 3\text{MeV} \rightarrow \theta_n < 35°$

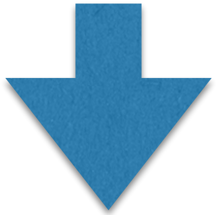


forward recoil neutron retains information of the anti-neutrino direction

How to measure? : answer!

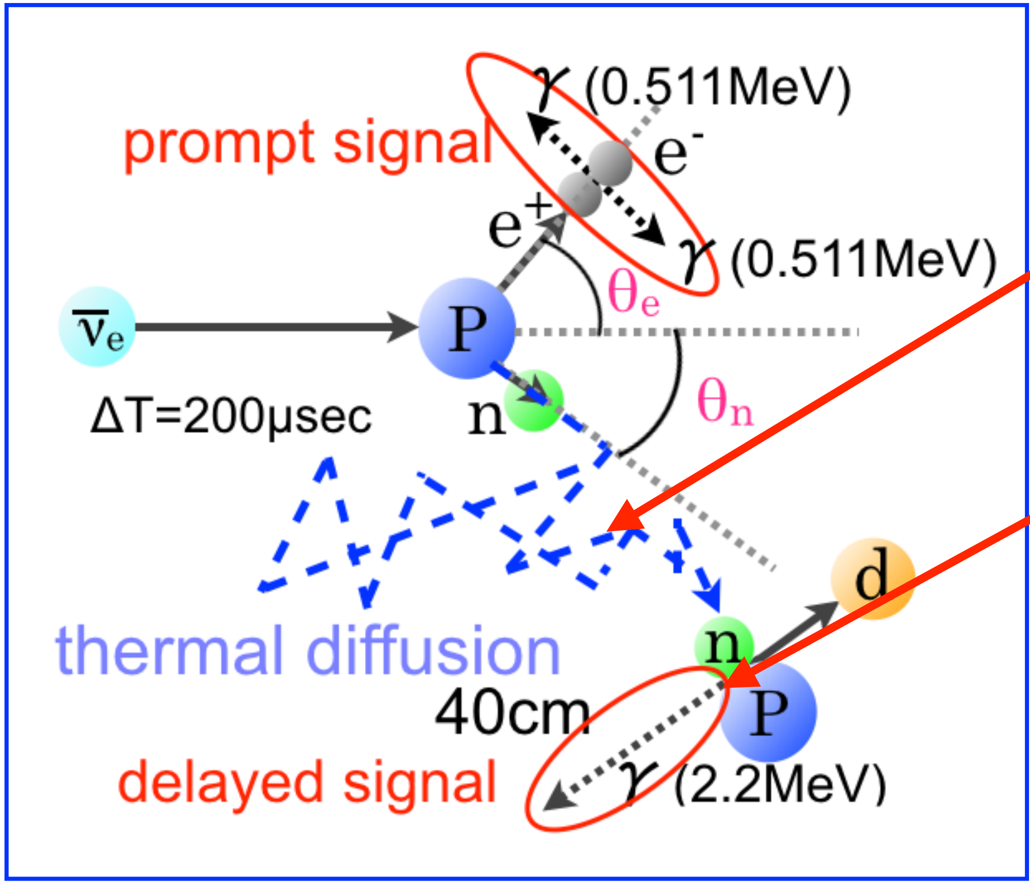


$\vec{r}$ correlates well with $\overline{\nu}_e$ direction



measure neutron capture position
before neutron loses directional information

Problems of current LS



Problems

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

2. γ -ray travels 40cm
   we can not decide detection point.

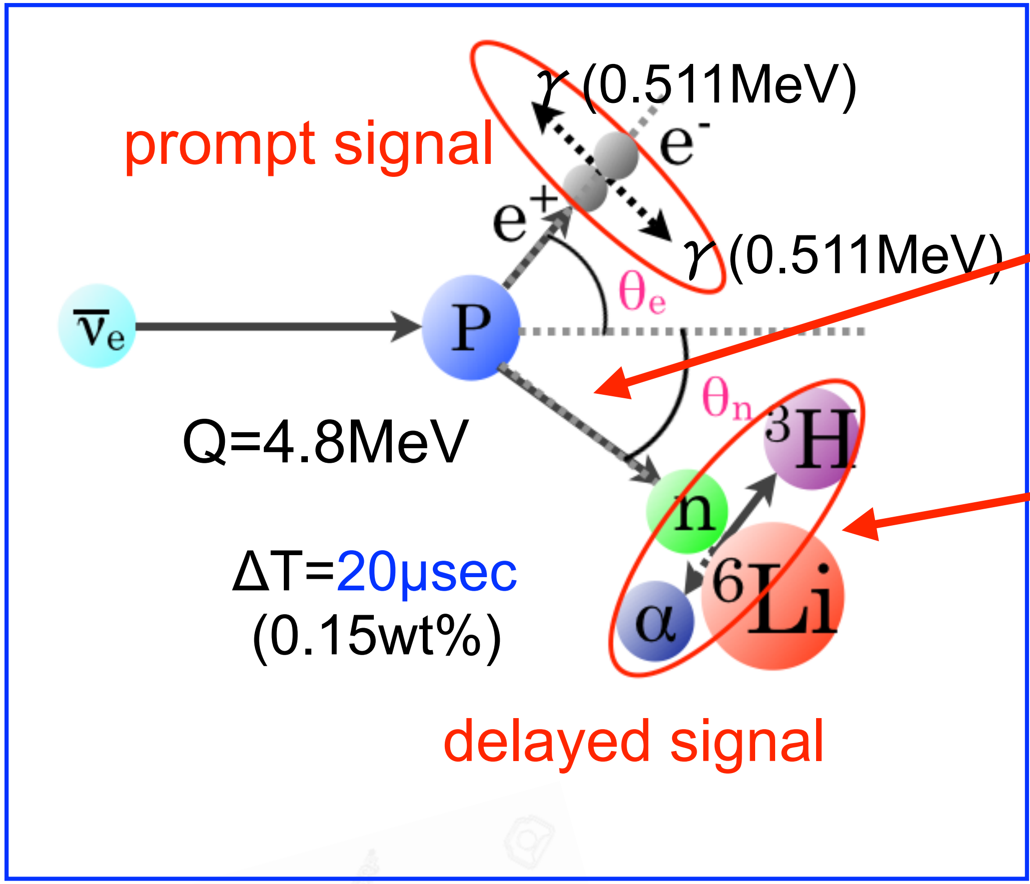
introduction of neutron capture nucleus

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

✓ large neutron capture cross section

✓ (n,α)reaction

Improvements



Improvements

1. minimize the thermal diffusion

2. α-ray can not travel long

- ☑ neutron capture nuclei loaded liquid scintillator
- ☑ high vertex resolution detector

^{6}Li or ^{10}B

ref) proton 0.3 barn

	① ^{10}B	② ^{6}Li
neutron capture cross section	3835 barn	940 barn
natural abundance	19.9 %	7.5 %

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

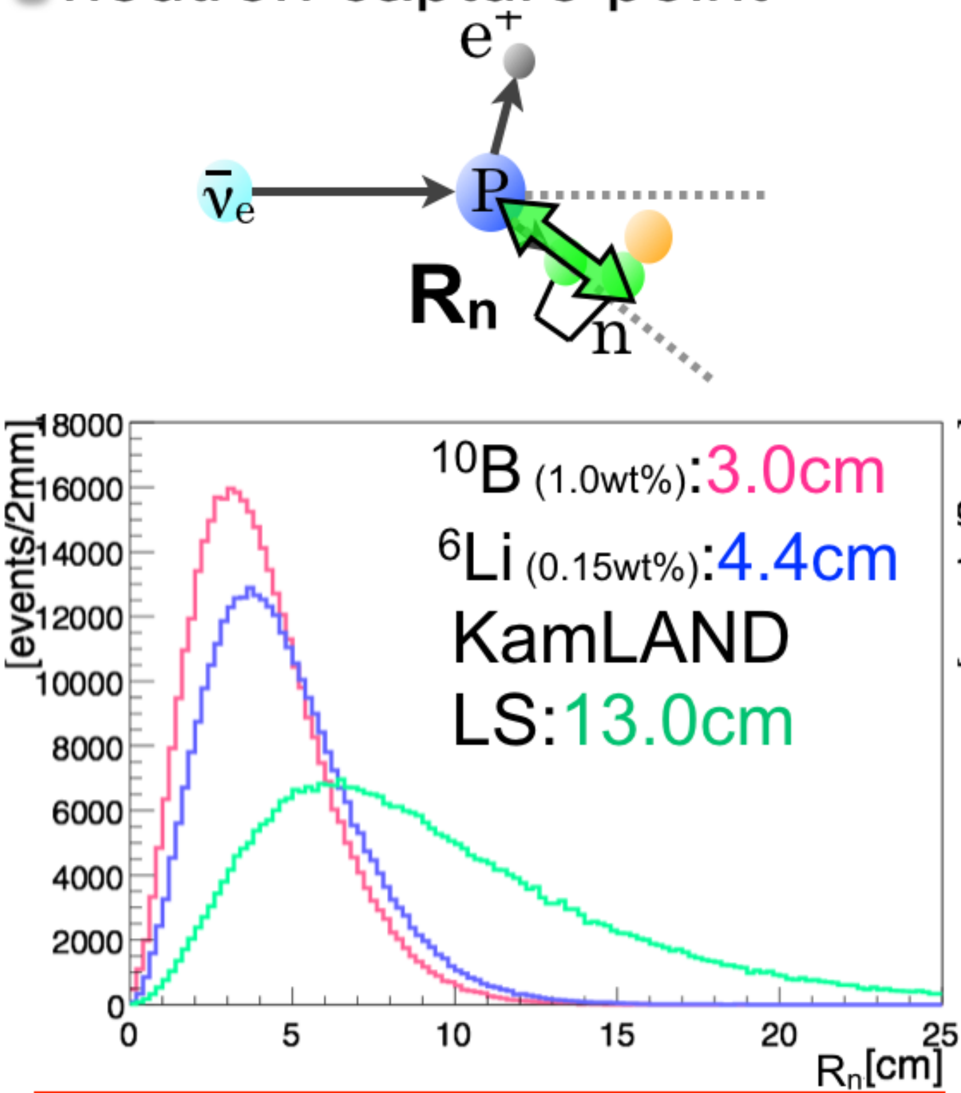
$$^{7}Li^{*} \rightarrow {}^{7}Li + \gamma \ (E_{\gamma}=0.48MeV)$$

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

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

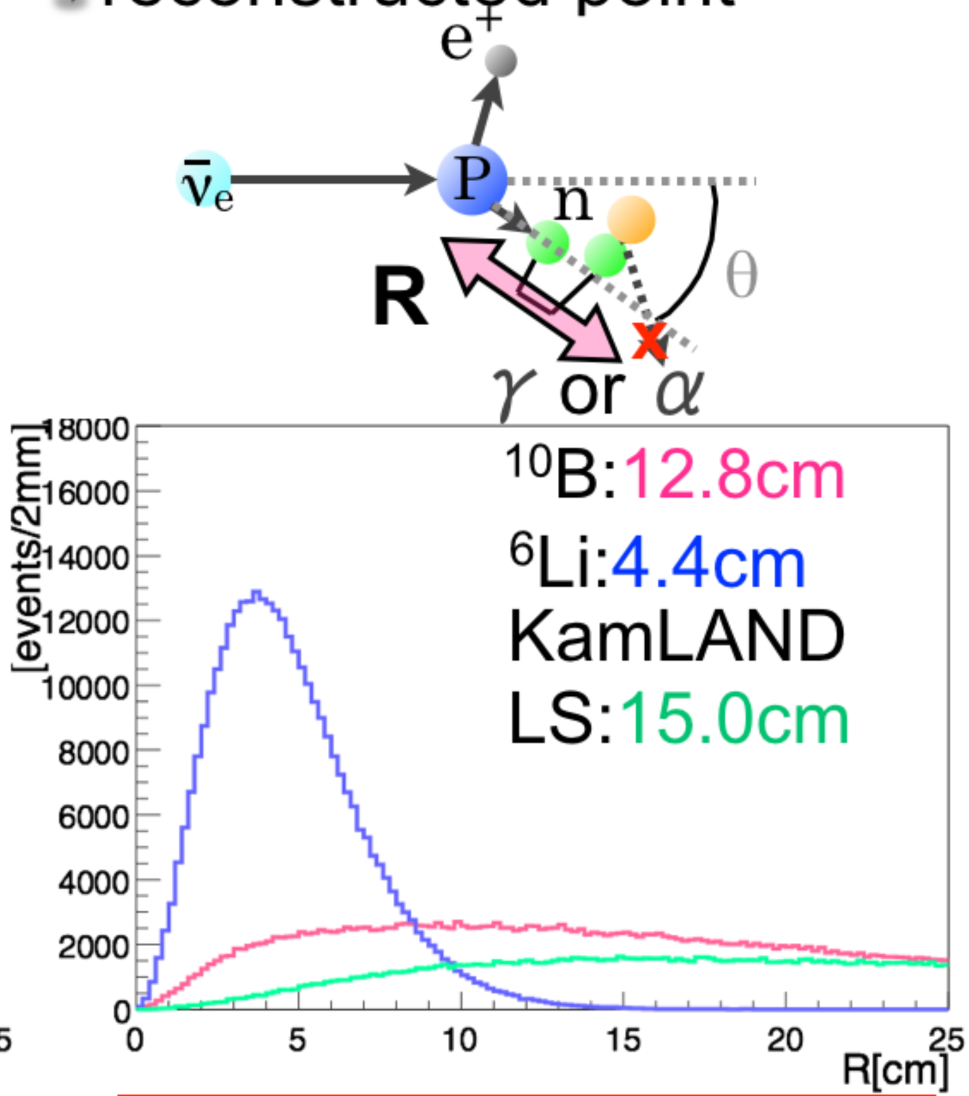
^{6}Li or ^{10}B : simulation

- neutron capture point



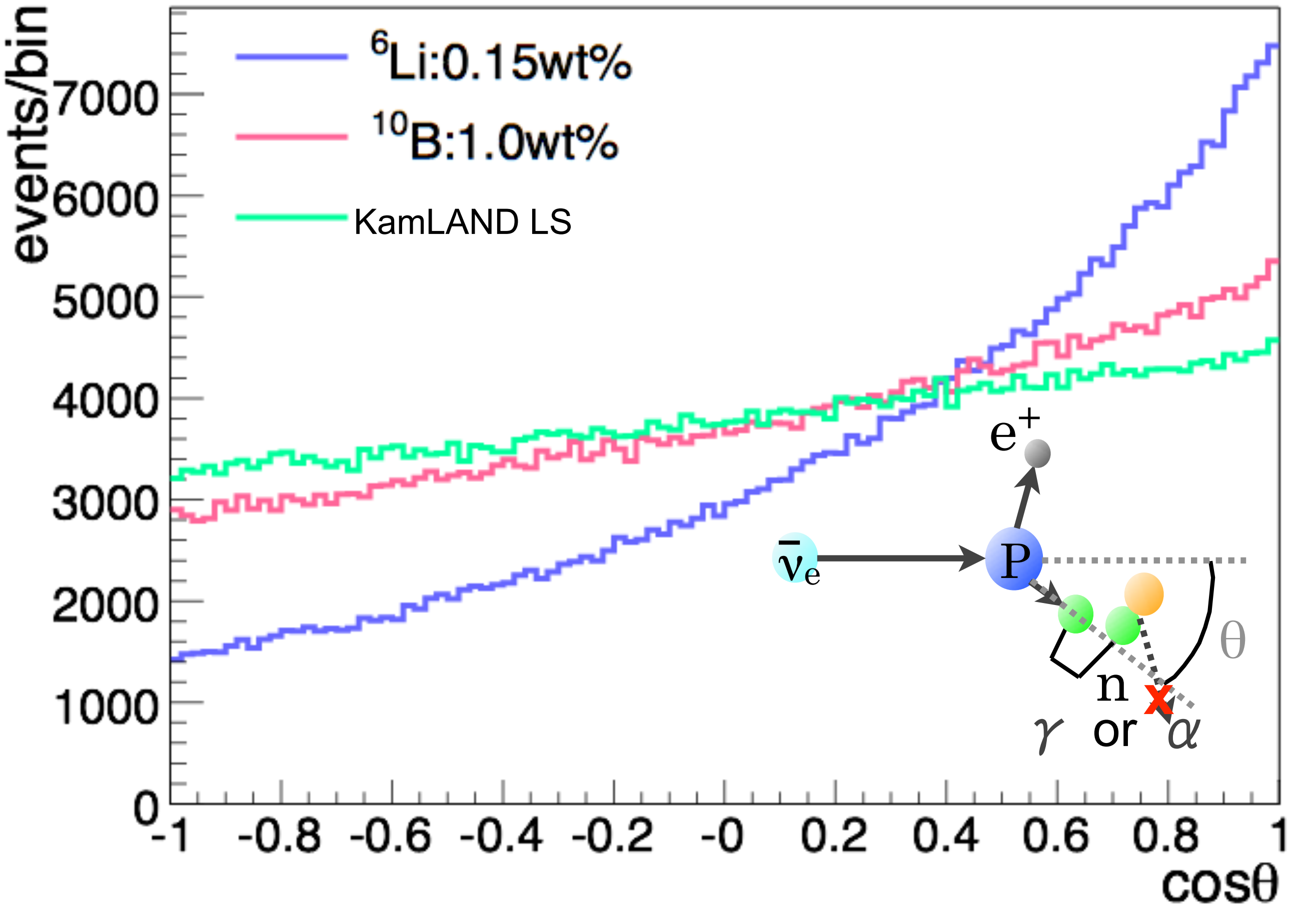
large neutron capture cross section is effective in minimizing the thermal diffusion

- reconstructed point



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

Angular Resolution



best

	Asymmetry	miss-identification rate (θ>90°)
^{6}Li LS	0.391	30.4%
^{10}B LS	0.148	42.6%
KamLAND LS	0.079	46%

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

A : number of event

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

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

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- Motivation
- How to Measure

Development

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Developments

- ^{6}Li loaded liquid scintillator
- high vertex resolution detector

Developments: status

- ^{6}Li loaded liquid scintillator →(almost) completed!
- high vertex resolution detector →ongoing

^{6}Li loaded liquid scintillator
+
high vertex resolution detector →ongoing

Developments: status

- ☑ ^{6}Li loaded liquid scintillator →**(almost) completed!**
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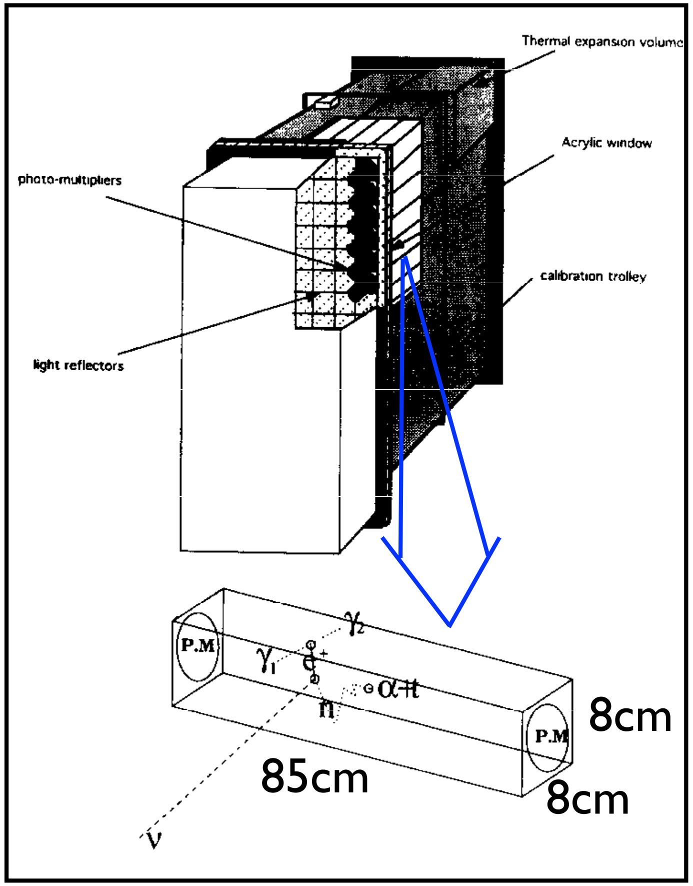
^{6}Li loaded liquid scintillator
\+
high vertex resolution detector →**ongoing**

^{6}Li loaded LS : 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

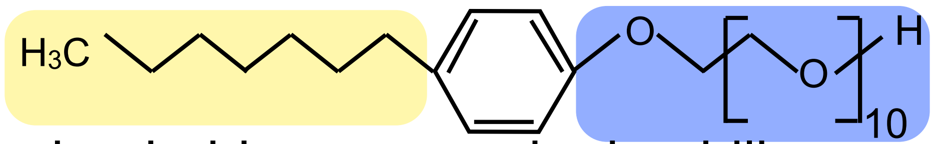
We have to develop in our original way.

^{6}Li loaded LS : our method

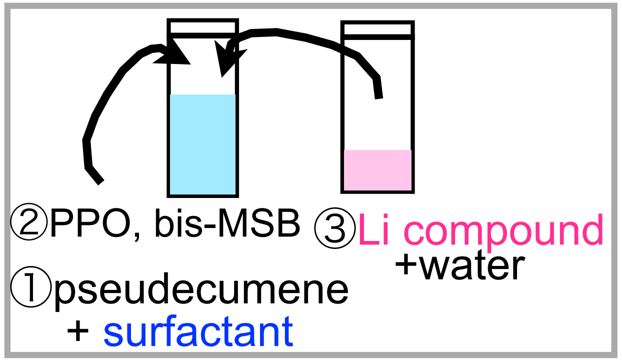
- behavior of Li component
  - ① insolvable in oil
  - ② solvable in water

→ mix organic solvent and Li compound aqueous solution with surfactant

*surfactant : POE(10) octyl-phenyl-ether

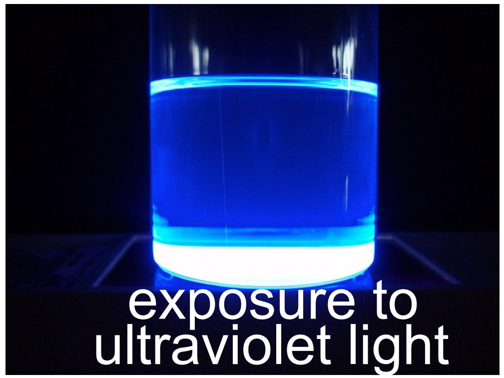


hydrophobic group hydrophilic group



- our recipe

Pseudecumene	82 wt%
POE(10) octyl-phynyl-ether	18 wt%
LiBr	31 g/L
PPO	5.4 g/L
bis-MSB	0.1 g/L



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

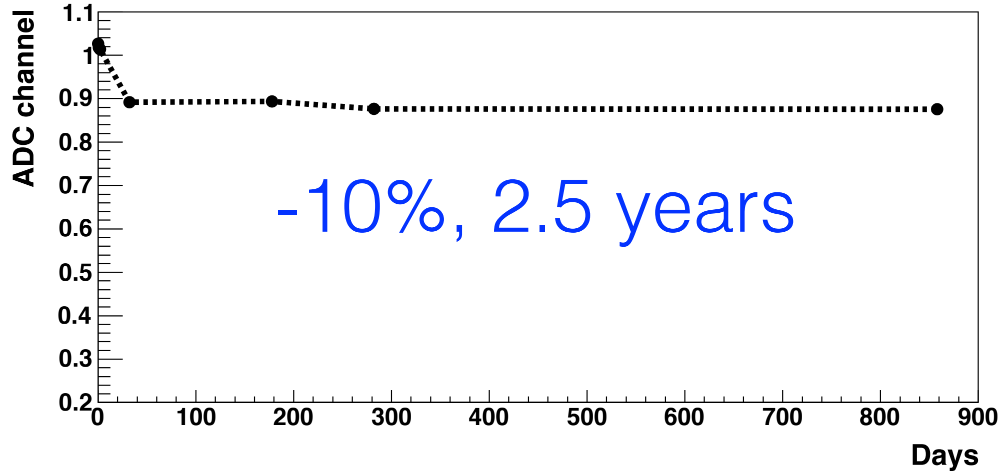
^{6}Li loaded LS : progress of our method

Y.Shirahata Master Thesis

	^{6}Li	Light yield (KamLAND LS = 1)	Transparency @400nm	Delayed energy
target	> 0.15 wt%	> 1.0	> 100 cm	better than KamLAND
our study	0.16 wt%	1.03 ± 0.03	167.9 ± 4.3 cm	540 ± 14.9keV

<u>Our Li LS has required quality for small size detector</u>

<u>Light yield, long term stability</u>

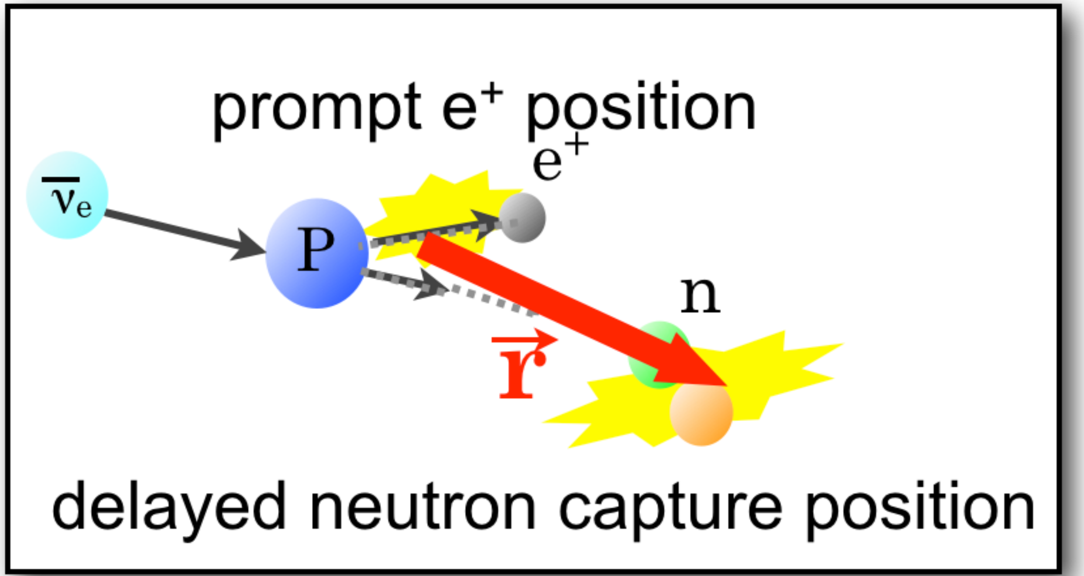


Developments: status

- ^{6}Li loaded liquid scintillator →**(almost) completed!**
- high vertex resolution detector →**ongoing**

^{6}Li loaded liquid scintillator
+
high vertex resolution detector →**ongoing**

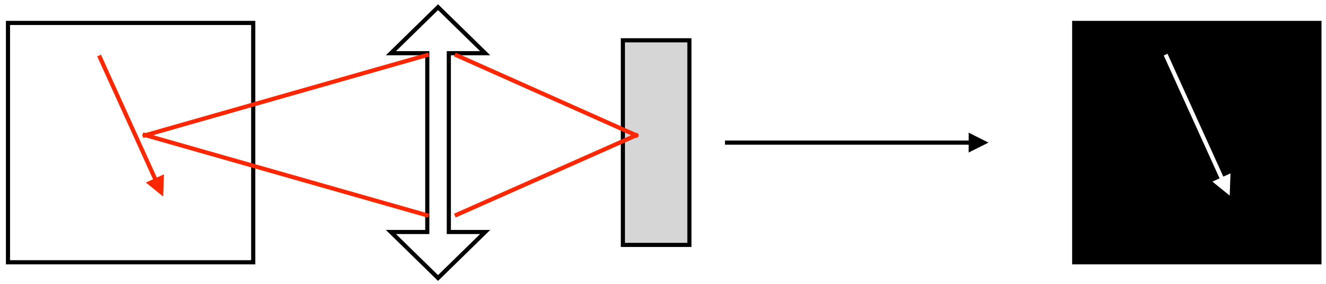
High vertex resolution detector



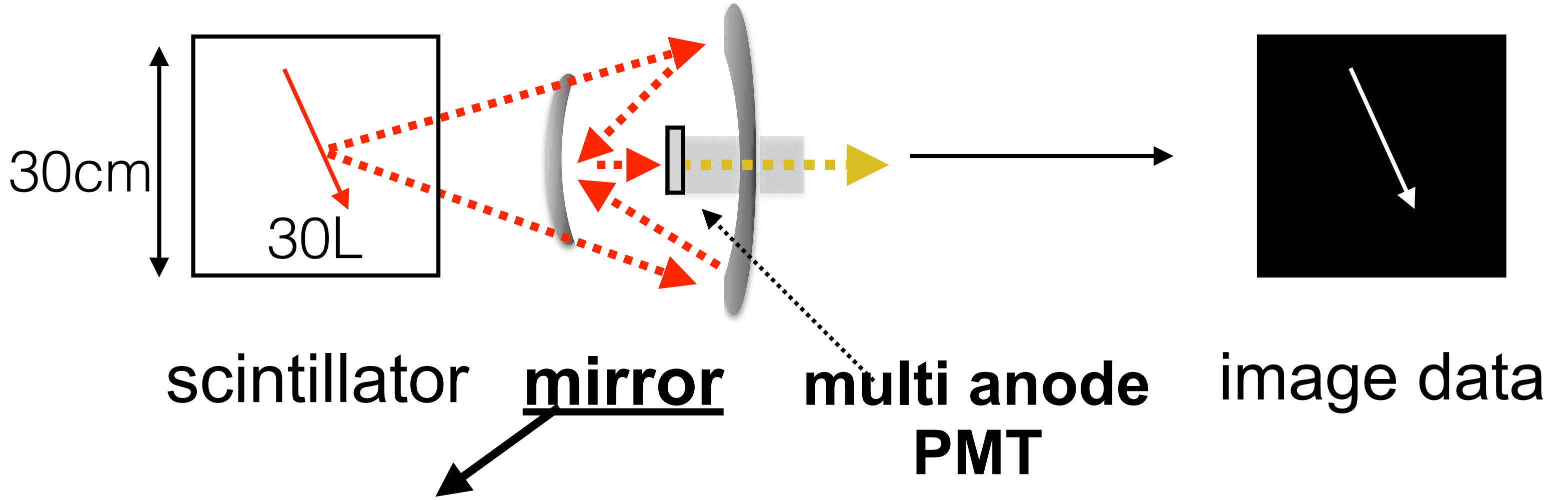
- We need high vertex resolution to separate **2 vertexes**.

- required resolution : **~1.5cm**
  (ref: Photo Multi Plire (PMT) ~10cm)

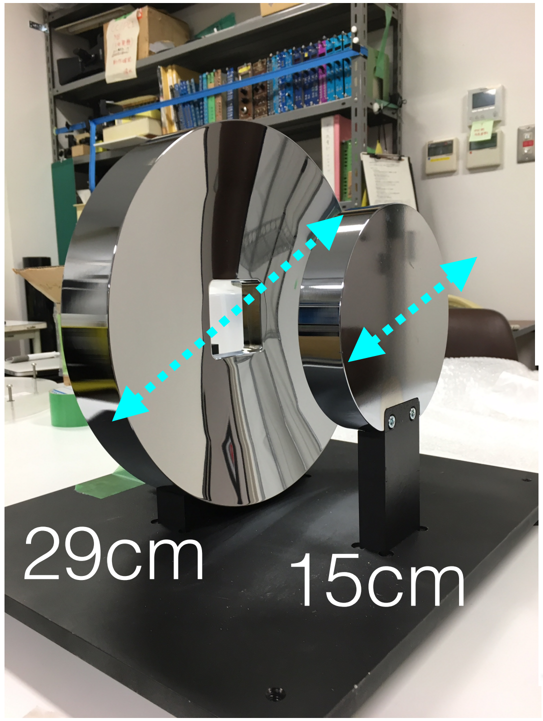
"Imaging Detector"

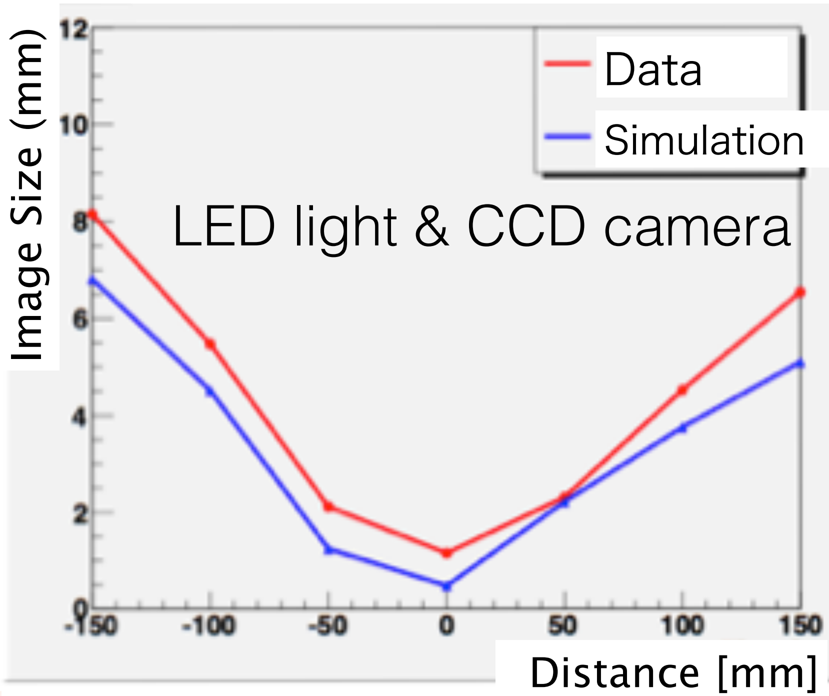


Imaging Detector



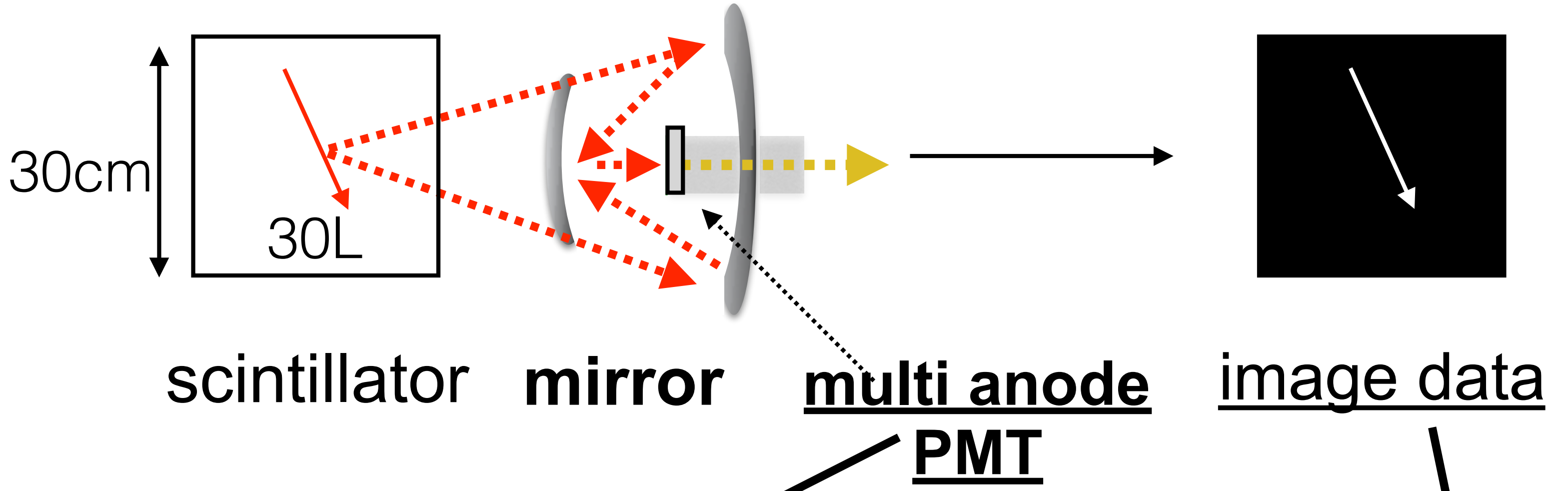
We designed mirror for 30L detector.



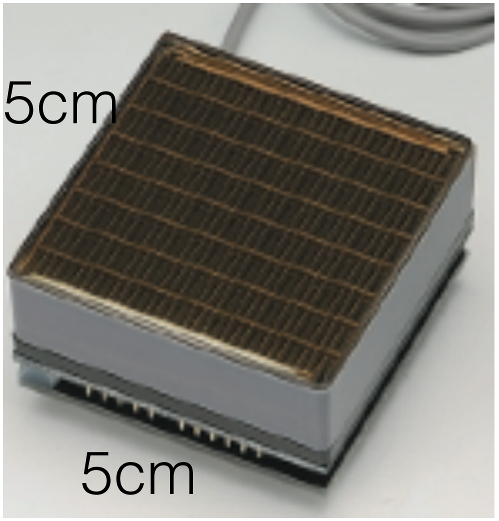


- consistent with simulation
- vertex resolution **< 8mm**
  (required : < 15mm)

Imaging Detector

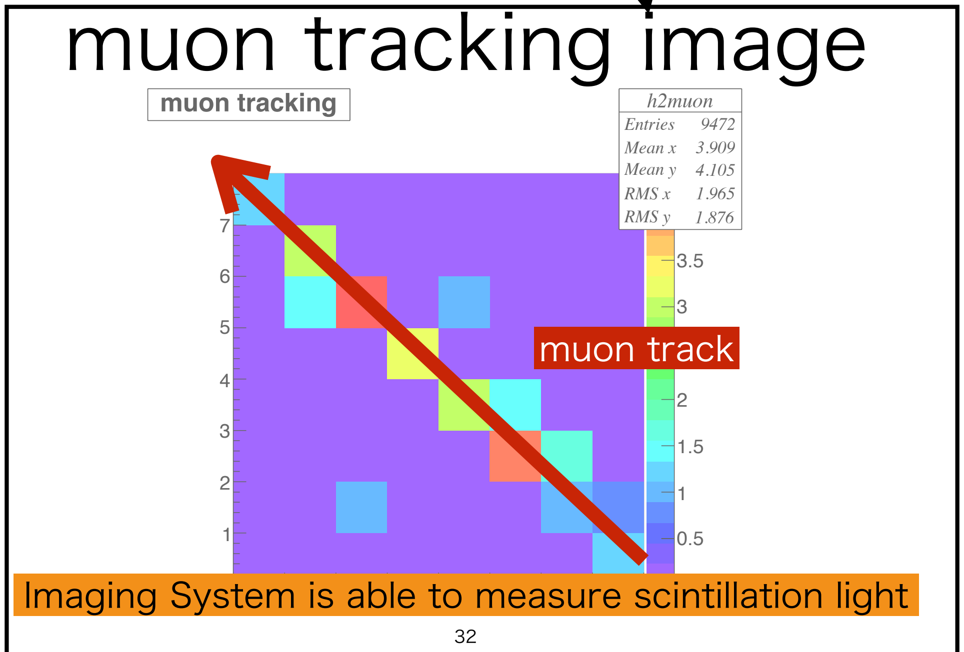


Hamamatsu H12700



- “pixelated” PMT (64 channels)
- required to measure 1 p.e.

muon tracking image



Developments: status

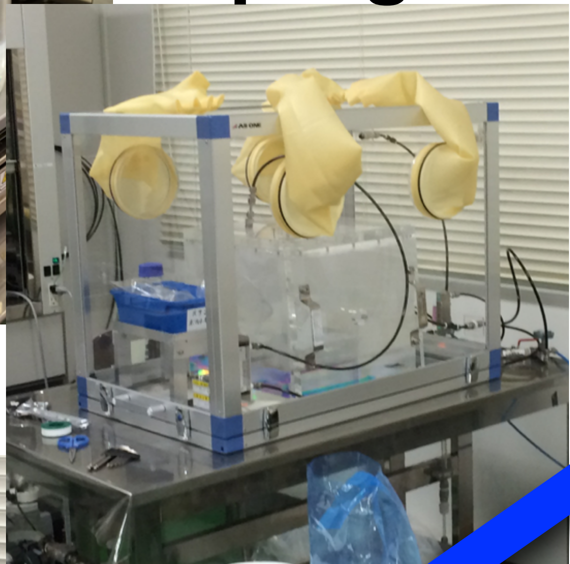
- ☑ ^{6}Li loaded liquid scintillator →**(almost) completed!**
- ☑ high vertex resolution detector →**ongoing**

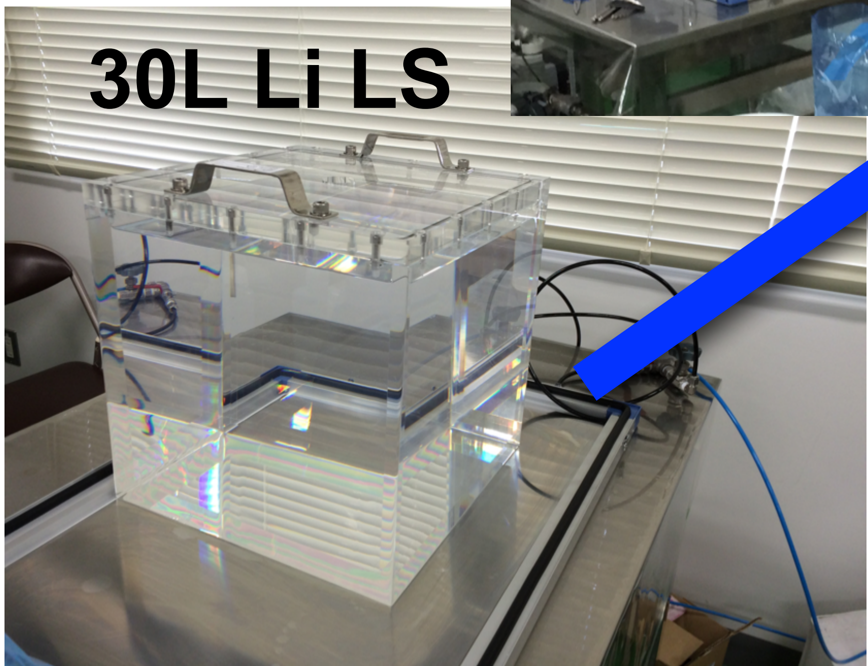
^{6}Li loaded liquid scintillator
+
high vertex resolution detector
→**ongoing**

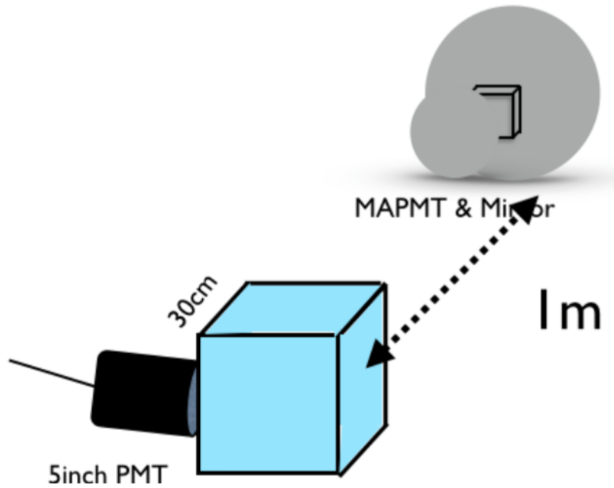
30L Detector : LiLS + Imaging Detector

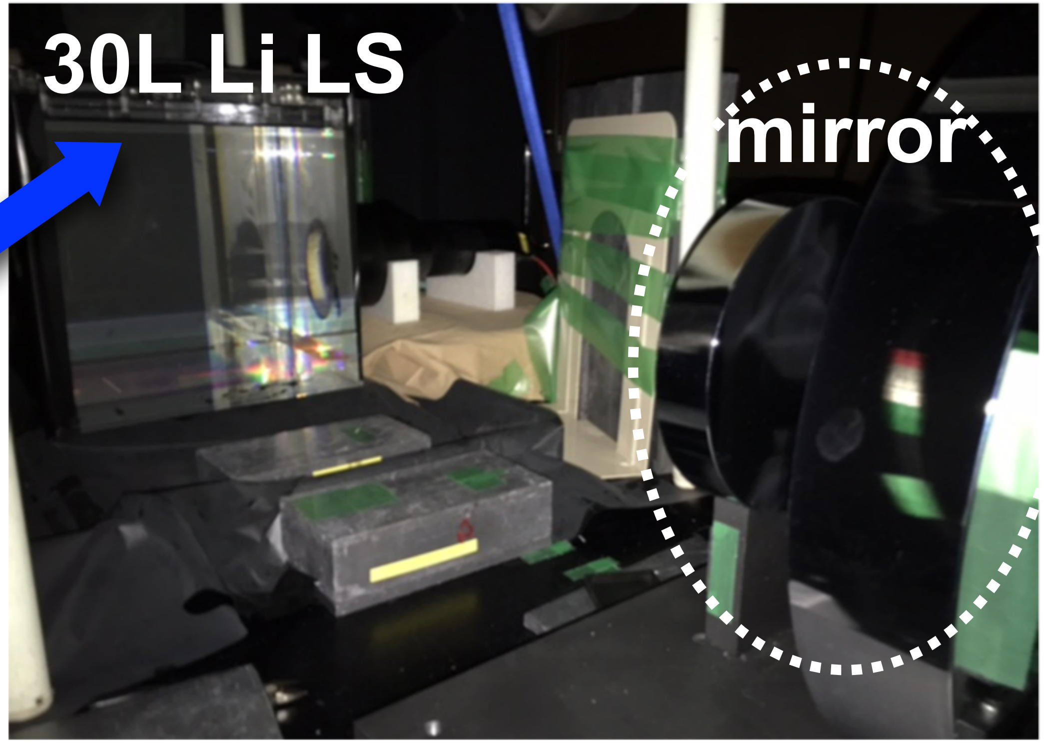
Li LS

N$_2$ purge



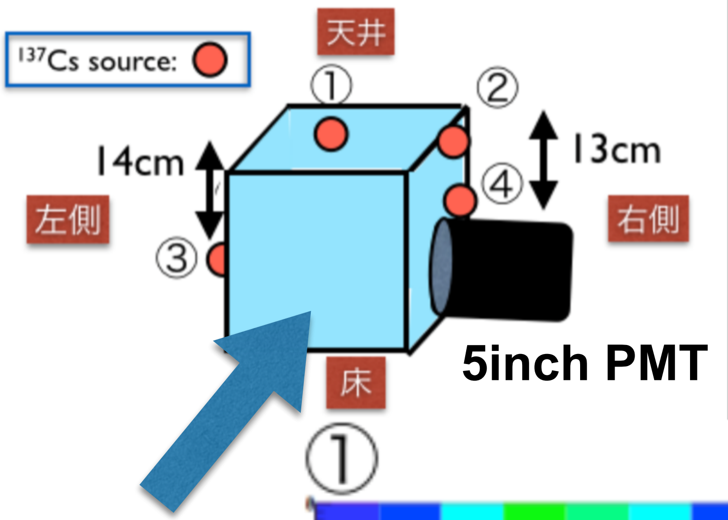


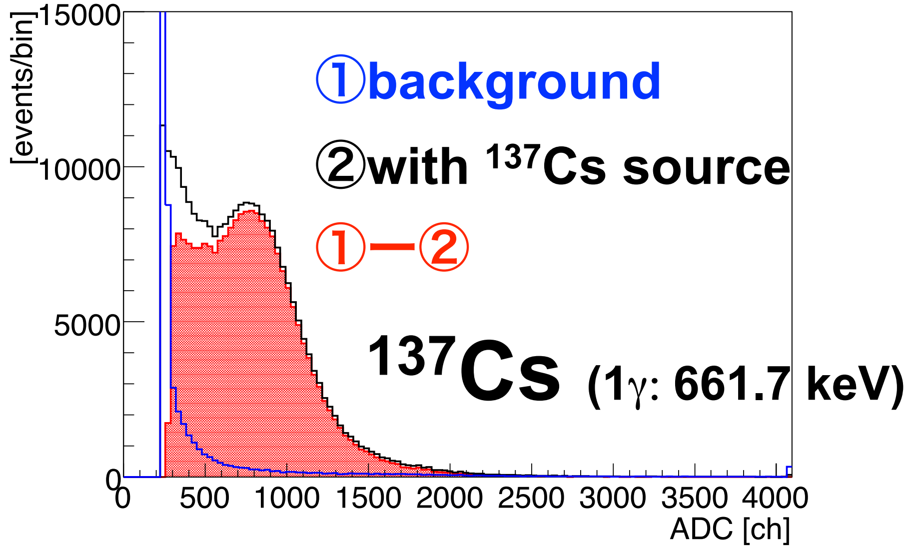


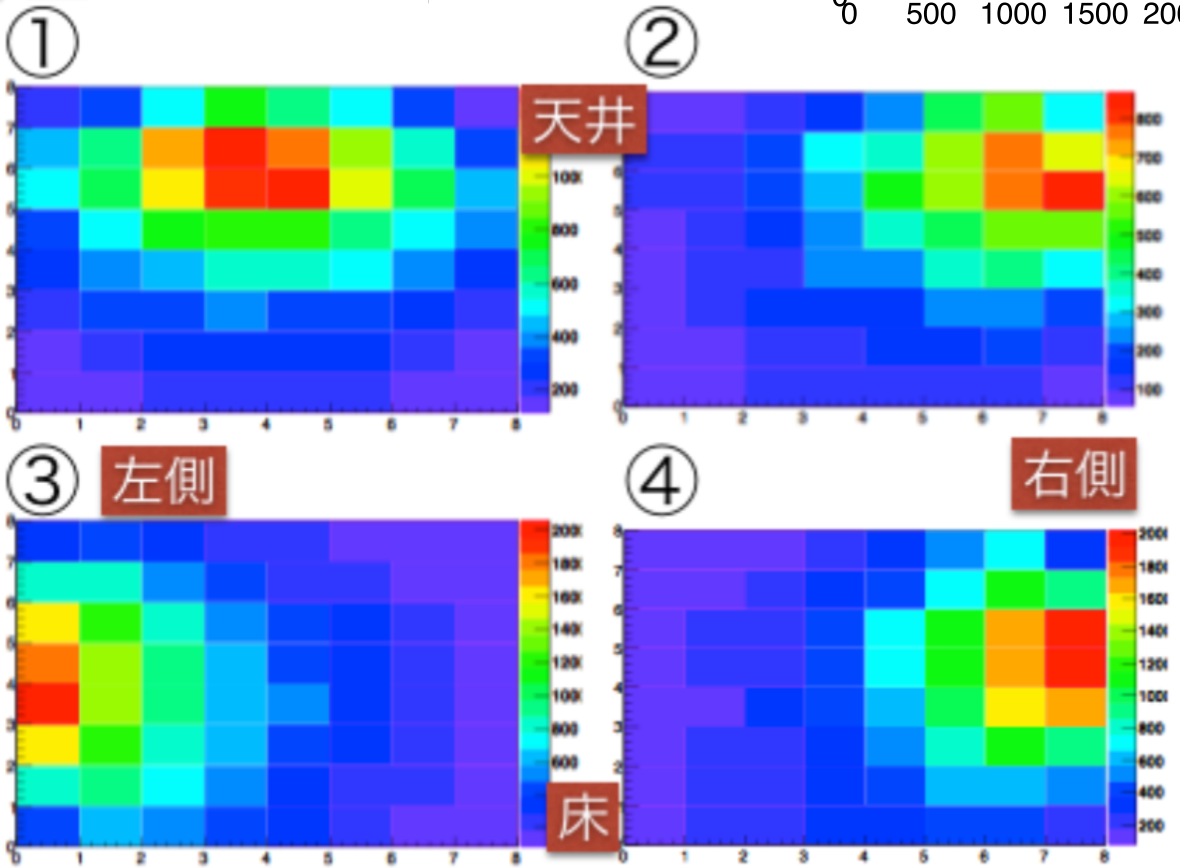


30L Detector : LiLS + Imaging Detector

Image measurement with γ-ray source



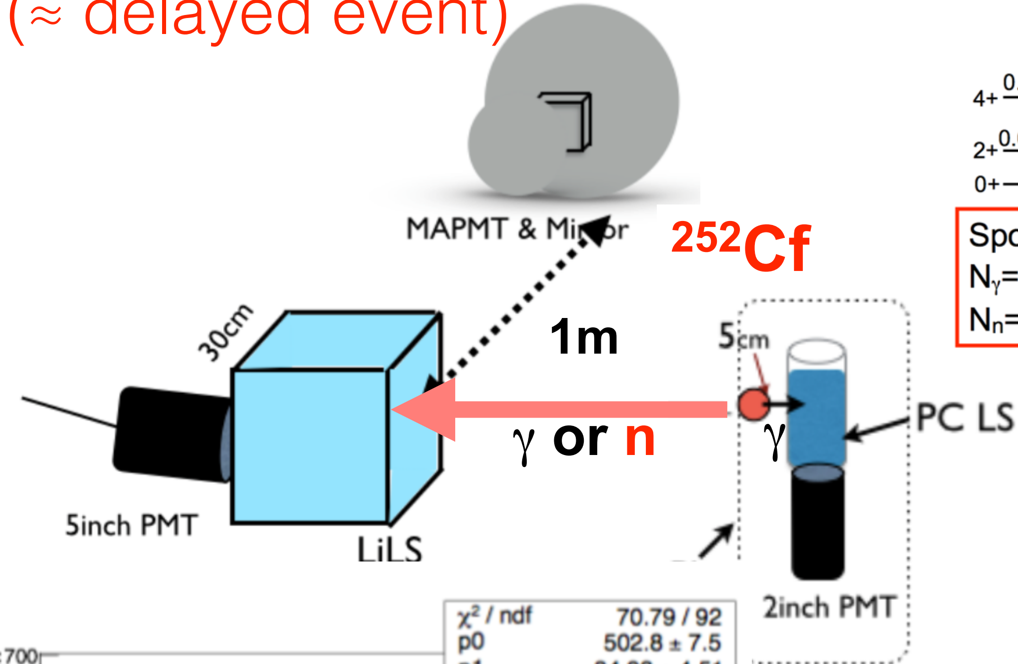


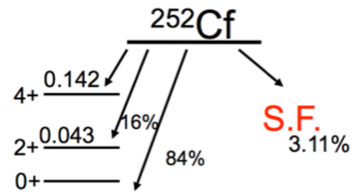


30L Detector : LiLS + Imaging Detector

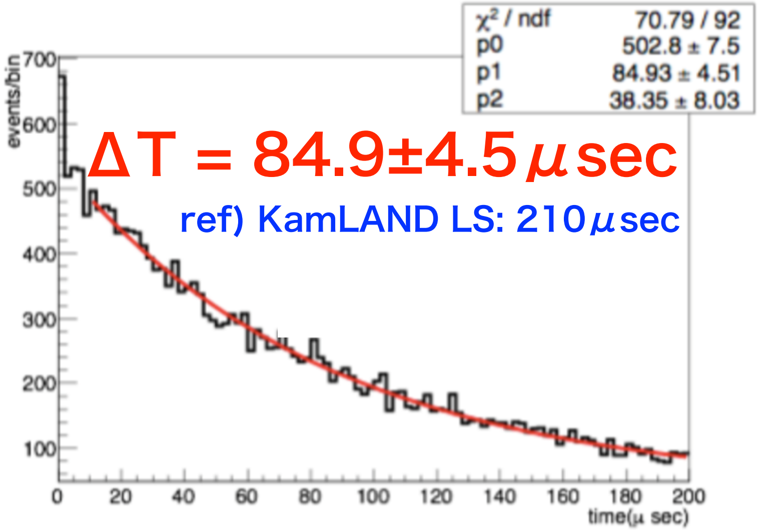
Image measurement with neutron source

(≈ delayed event)



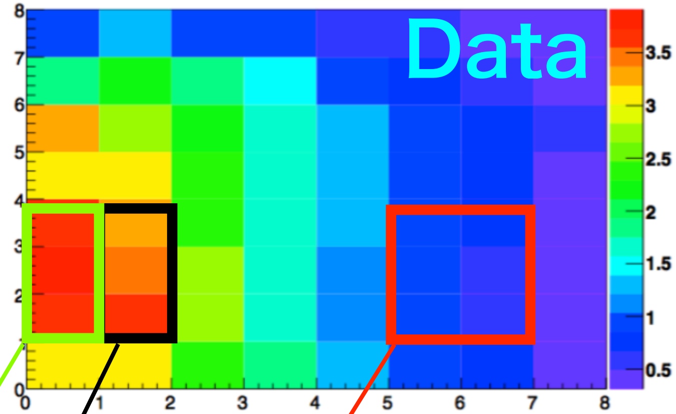


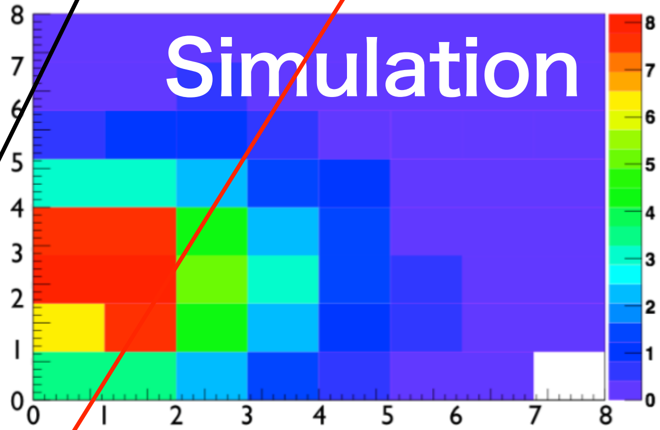
Spontaneous Fission
N_γ=7.8
N_n=3.8
emitted at the same time



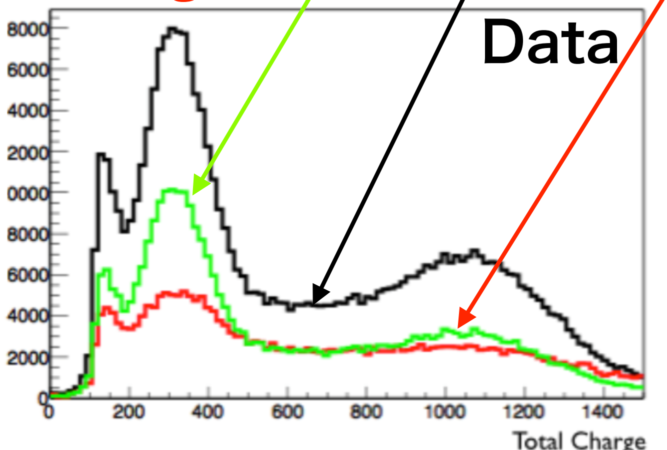
ΔT = 84.9±4.5μsec

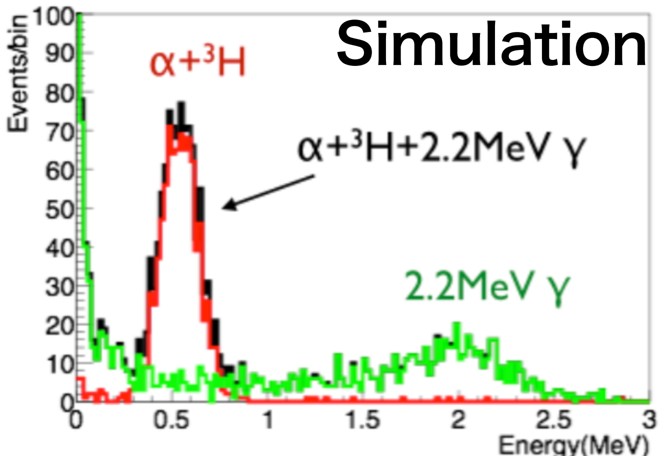
ref) KamLAND LS: 210μsec





Charge





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Future Prospects

	< 3 years	< 10 years	>10 years
size	30 L	~200 L	> 1kt
source	neutron	reactor neutrino	**geo-neutrino**
goal	①	②	③

① demonstration of new technology

② directional measurement of high rate neutrino sources

③ directional measurement of geo-neutrino

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Conclusions

▸Directional sensitivity will be efficient technology for anti-neutrino measurement, especially geo-neutrino measurement.

▸New measurement technologies:

* ^{6}Li loaded liquid scintillator can have good directional sensitivity.
  - We have developed the ^{6}Li loaded LS by the original method.
* 30L detector : test of detection technology
* <5 years : Reactor neutrino directional measurement with ~200L size detector

✦ Make the impossible, possible!

✦ Breakthrough technology for “next generation” detector.