**22nd ICEPP SYMPOSIUM @HAKUBA ( 2016.03.01 )**

# ニュートリノ物理のための中性子・酸素原子核反応によるガンマ線測定に向けた研究

# - 検出器開発の現状 -

**Research on Gamma-rays from the Interactions of Oxygen-nuclei and Neutrons for Neutrino Physics and Astronomy**

**YOSUKE ASHIDA**

Kyoto University High Energy Physics Group

Master-1st

# MOTIVATION

# NC-gamma MEASUREMENT

Neutrino's **NCQE** interaction is very important!!!

- **Supernova Relic Neutrino** search at Super-Kamiokande
- **Sterile Neutrino** search at T2K experiment
- **Dark Matter** search in the T2K beam

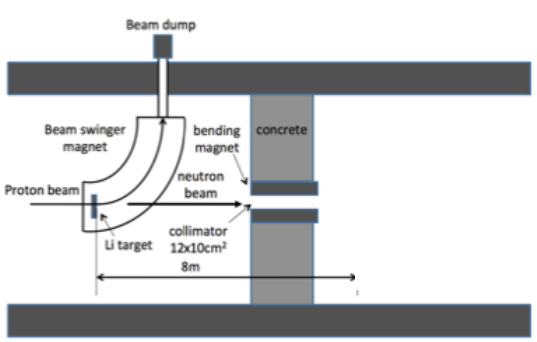
$$\boxed{<\sigma_{\mathrm{NCQE}}>= 1.55\times10^{-38}\pm0.395(\mathrm{stat.})^{+0.65}_{-0.33}(\mathrm{sys.})\ [\mathrm{cm}^2]}$$

**K.Abe et al. (The T2K Collaboration), Physical Review D 90, 072012 (2014)**

NCQE cross section was measured, but… **systematic uncertainty is large and expected to be dominant.**

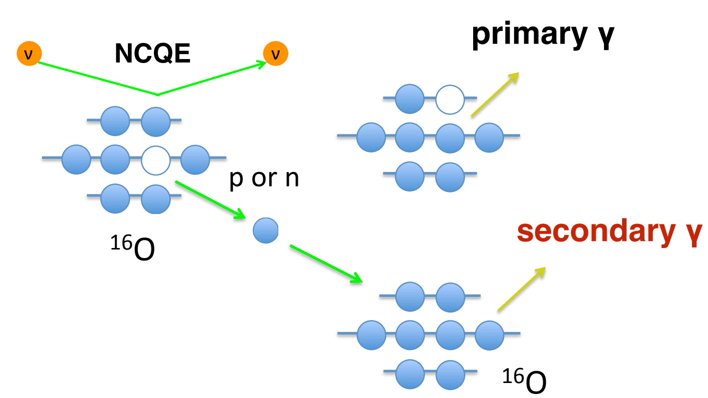
→ Main reason = "**secondary γ-rays**"

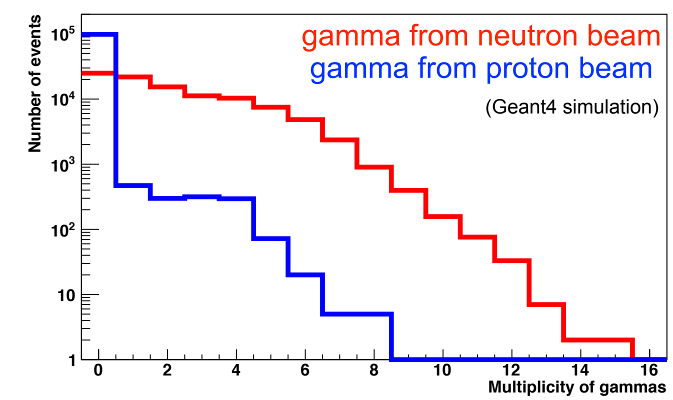
For the measurement of NCQE, only "primary γ-rays" are necessary but SK cannot distinguish these two…




RCNP N0 course

**γ-rays from de-excitation**



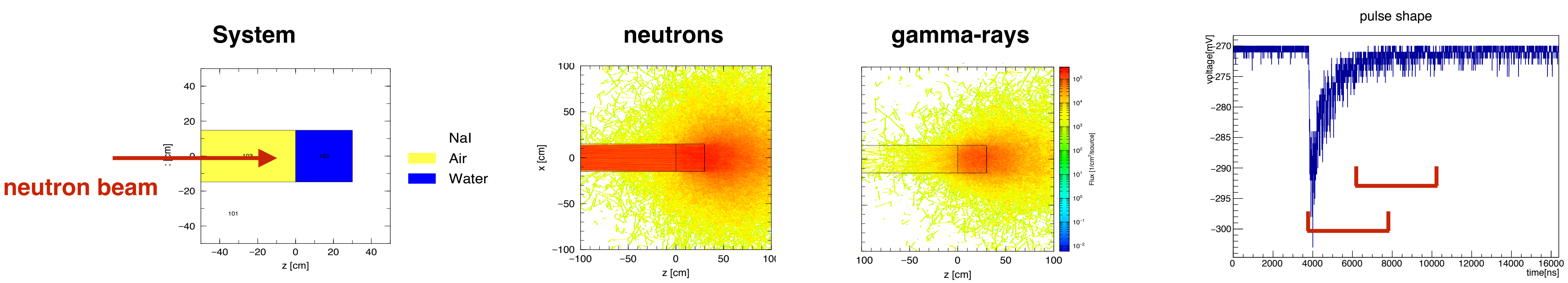

**The main particle that cause secondary processes is the neutron.**

We will measure **the multiplicity and the energy of gamma-rays from the interactions of oxygen-nuclei and neutrons** precisely **by using the RCNP's neutron beam ( ~80MeV ) that incident on the water target.**
( By this, we can pick out just "secondary processes" following the NCQE interactions. )

**4π covering detector!**

# NECESSITY OF n-γ SEPARATION

**Simulation by PHITS** K.Niita et al., Radiation Measurements 41 (2006)




**Pulse Shape Discrimination ( PSD )**

**Some scintillators have different pulse shapes for different incident particles.**

**Fast neutrons knock protons that have the larger dE/dx, and this leads to the smaller decay constant.**

Methods & Detectors

- Taking pulse shape data by using **Flash-ADC**, and analyse data later.
- Making the **“ratio” of full-range integration to decay-range one by ADC** ( like up-right )
- **CsI(Tl)** is a good candidate ( **good resolution & n-γ separation** ).

**We want to test this method for various scintillators, especially CsI(Tl) at the place where fast neutrons are coming.**

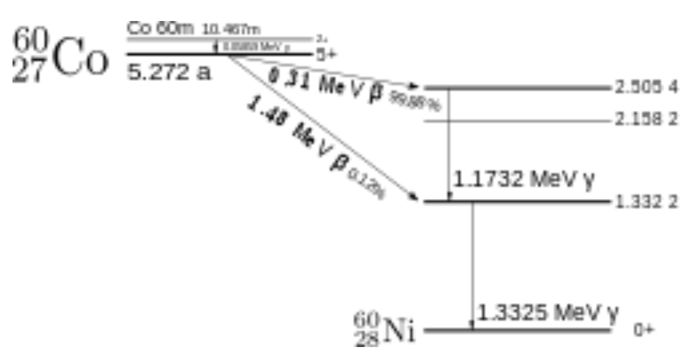
**J-PARC!!!**

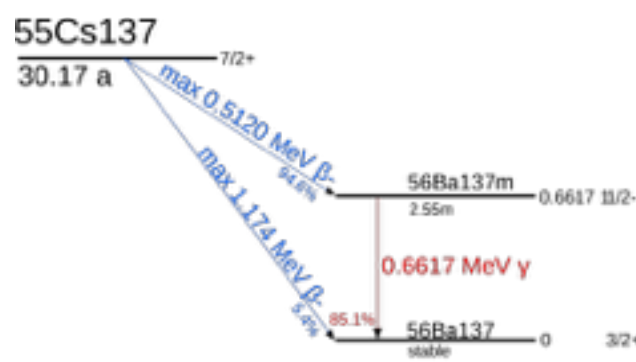
# TEST @KYOTO

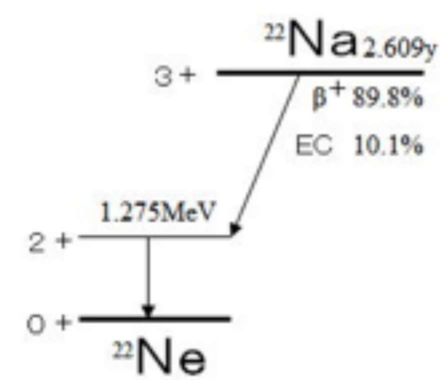
# TEST METHOD

- <u>Using some checking sources ( gamma-ray ), I tested response of some scintillators.</u>

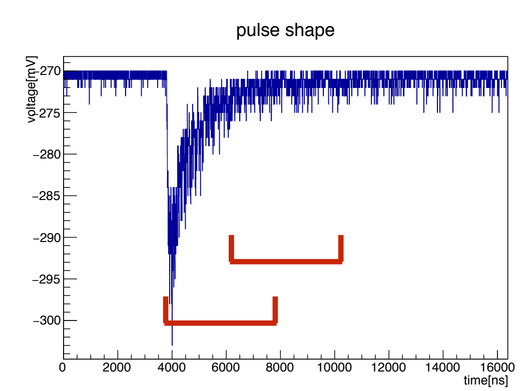
- **$^{60}$Co** : 1.17MeV, 1.33MeV, 2.5MeV[sum] photoelectric absorption peaks
- **$^{137}$Cs** : 0.662MeV photoelectric absorption peaks
- **$^{22}$Na** : 0.511MeV, 1.27MeV, 1.78MeV[sum] photoelectric absorption peaks
- BG ( no checking source ) : environmental gamma-rays, for example, 1.46MeV from **$^{40}$K**, 1.76MeV from **$^{214}$Bi**, 2.61MeV from **$^{208}$Tl**.



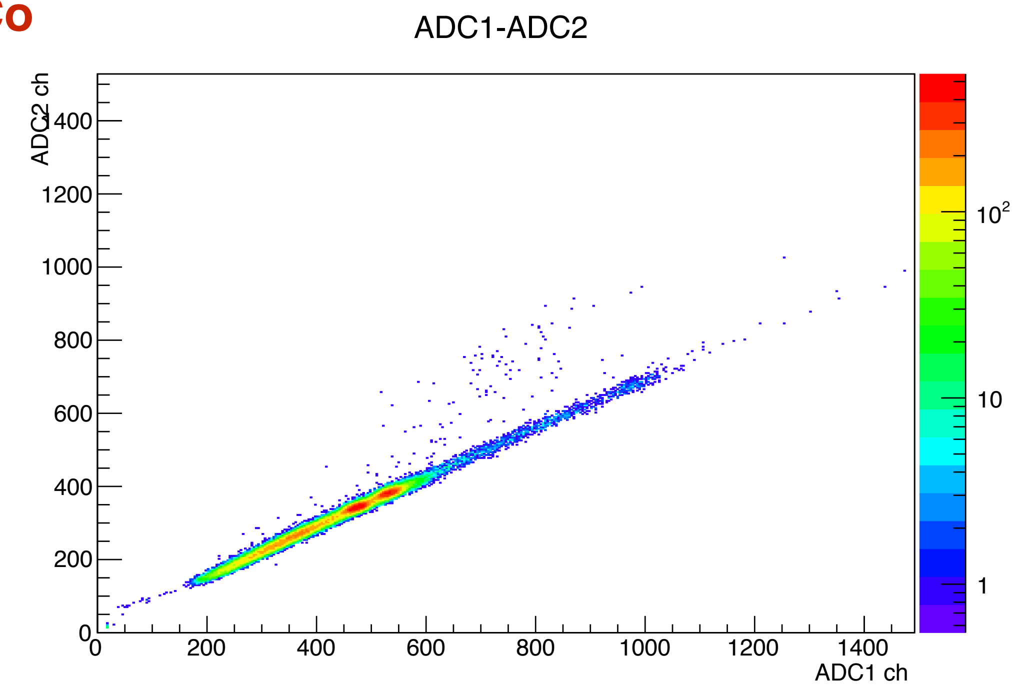

- As for NaI(Tl) and CsI(Tl), I took data of both **full and decay components** of pulse shapes, and made ratios of these two.



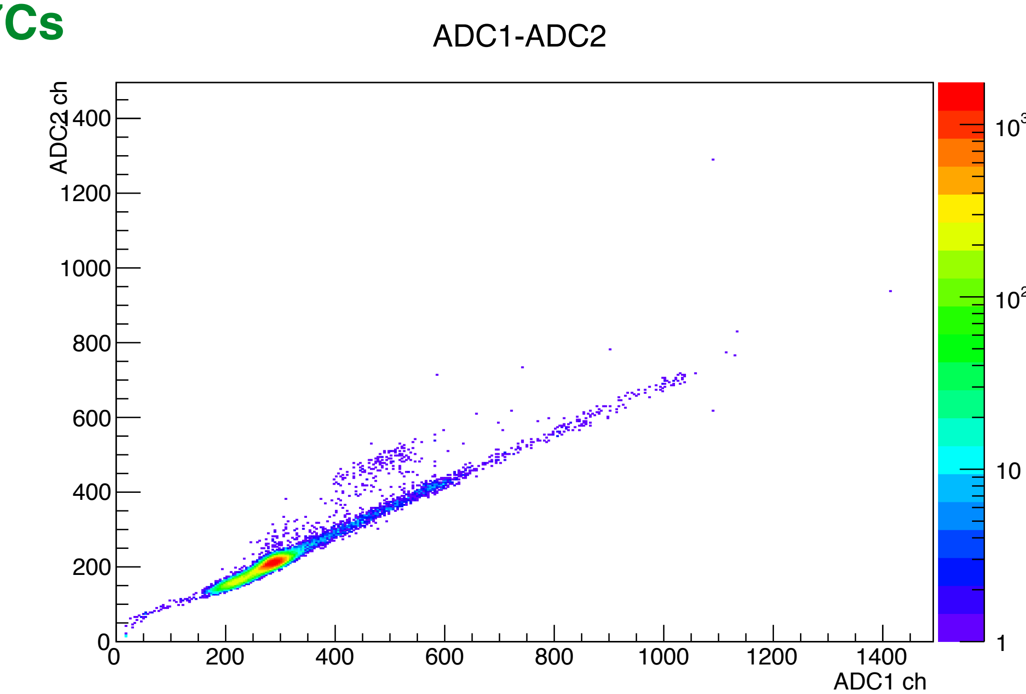
# RATIO MEASUREMENT

**NaI(Tl) : ADC1 ( full component ) vs ADC2 ( decay component )**

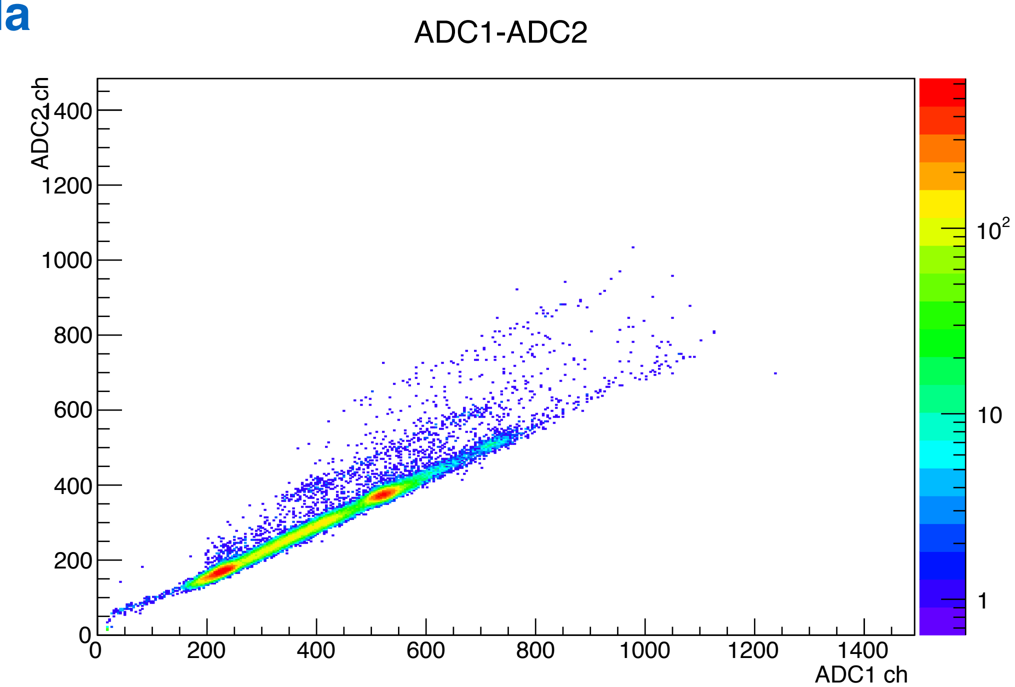
$^{60}$Co



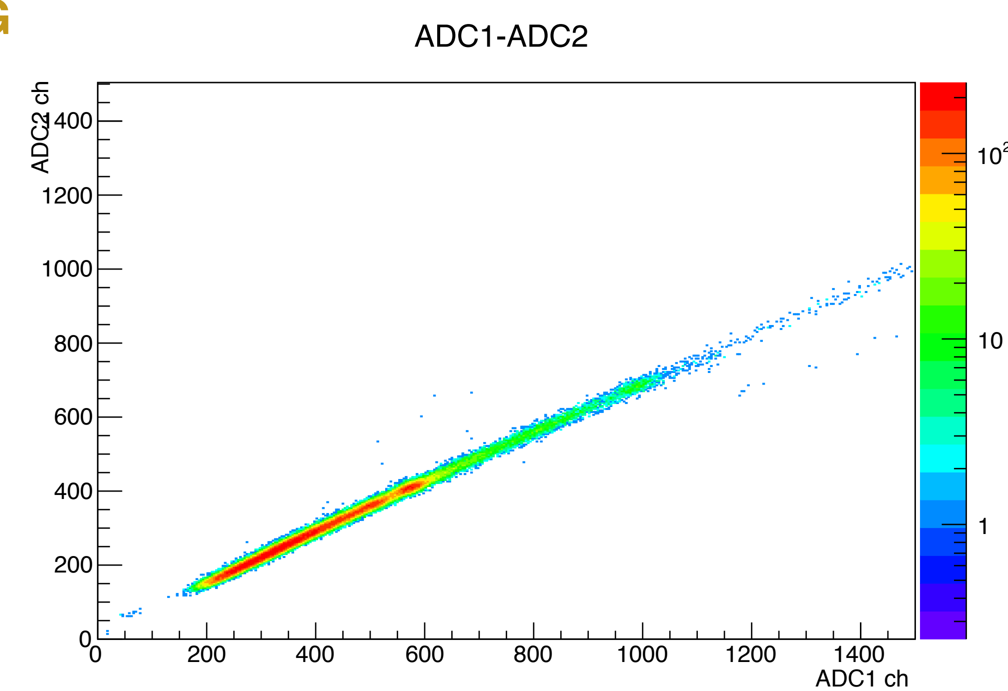

$^{137}$Cs




$^{22}$Na



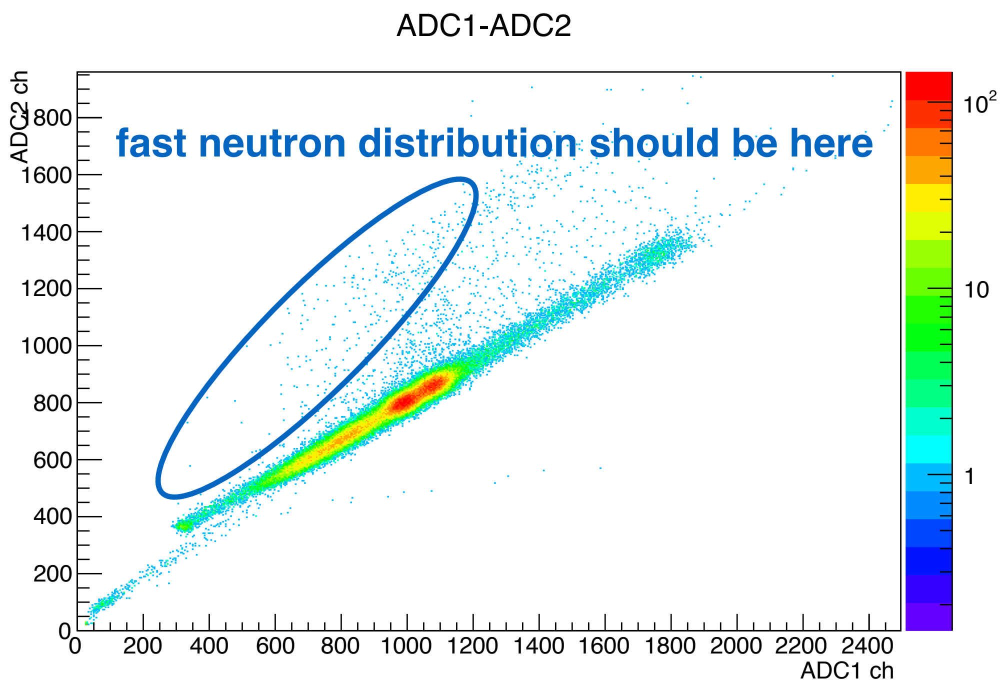

BG



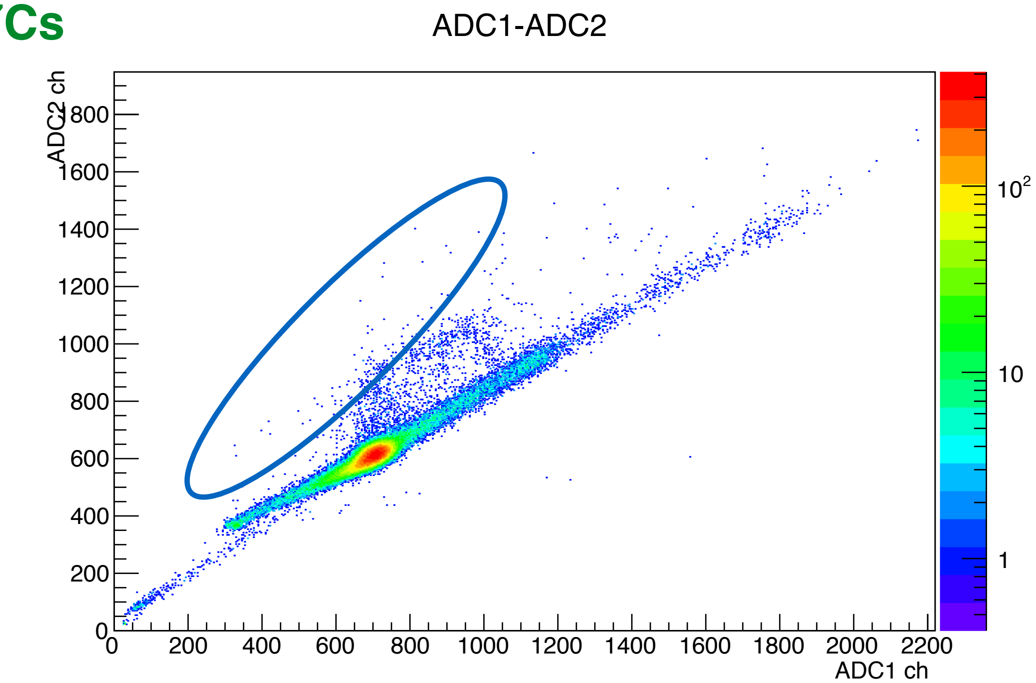
# RATIO MEASUREMENT

**CsI(Tl) : ADC1 ( full component ) vs ADC2 ( decay component )**

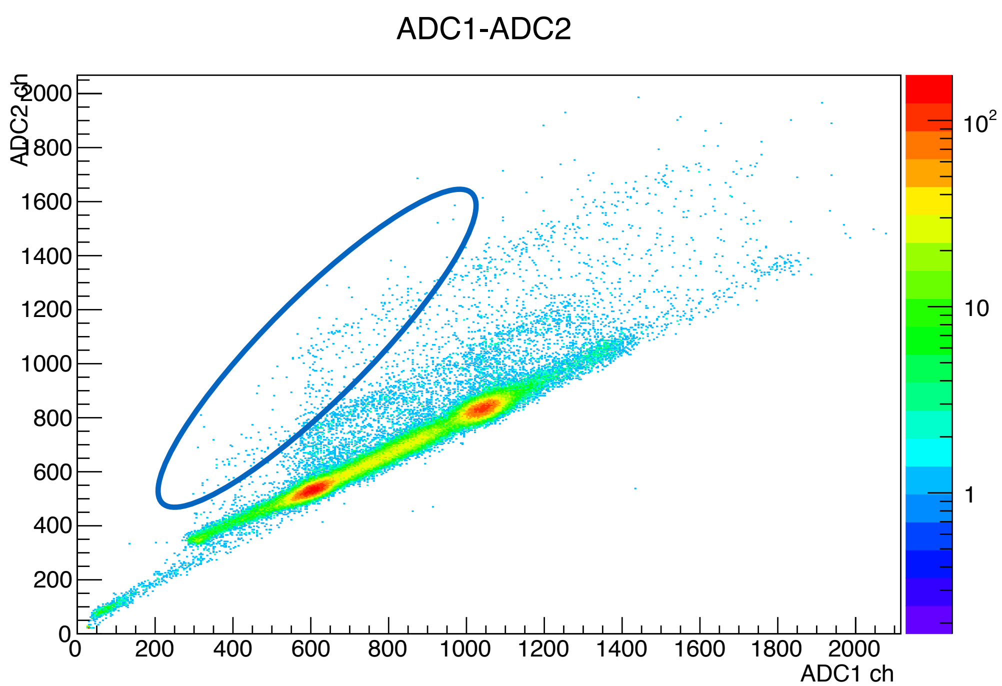
**$^{60}$Co**



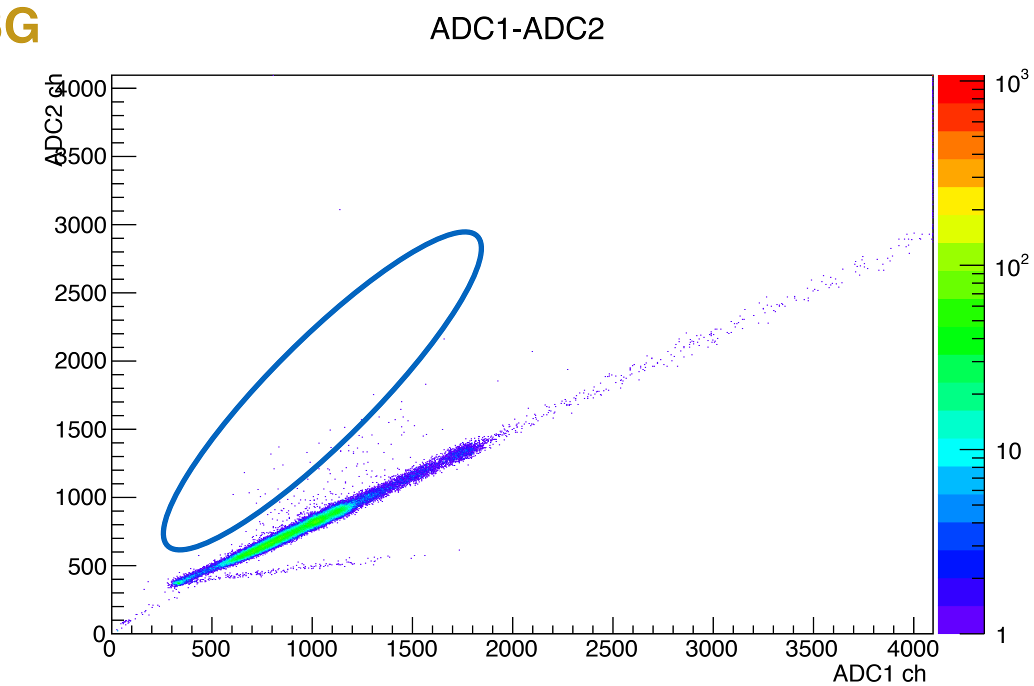

**$^{137}$Cs**




**$^{22}$Na**




**BG**



# T64 EXPERIMENT @J-PARC

# PURPOSE

- **J-PARC B2 Hall** Y.Hayato, Acta Phys.Polon. B40 (2009)

- According to the NEUT simulation by the INGRID group, **there are fast neutrons, gamma-rays and muons originated from the T2K beam here at B2 Hall.**
- This is good for our purpose to test n-γ discrimination.

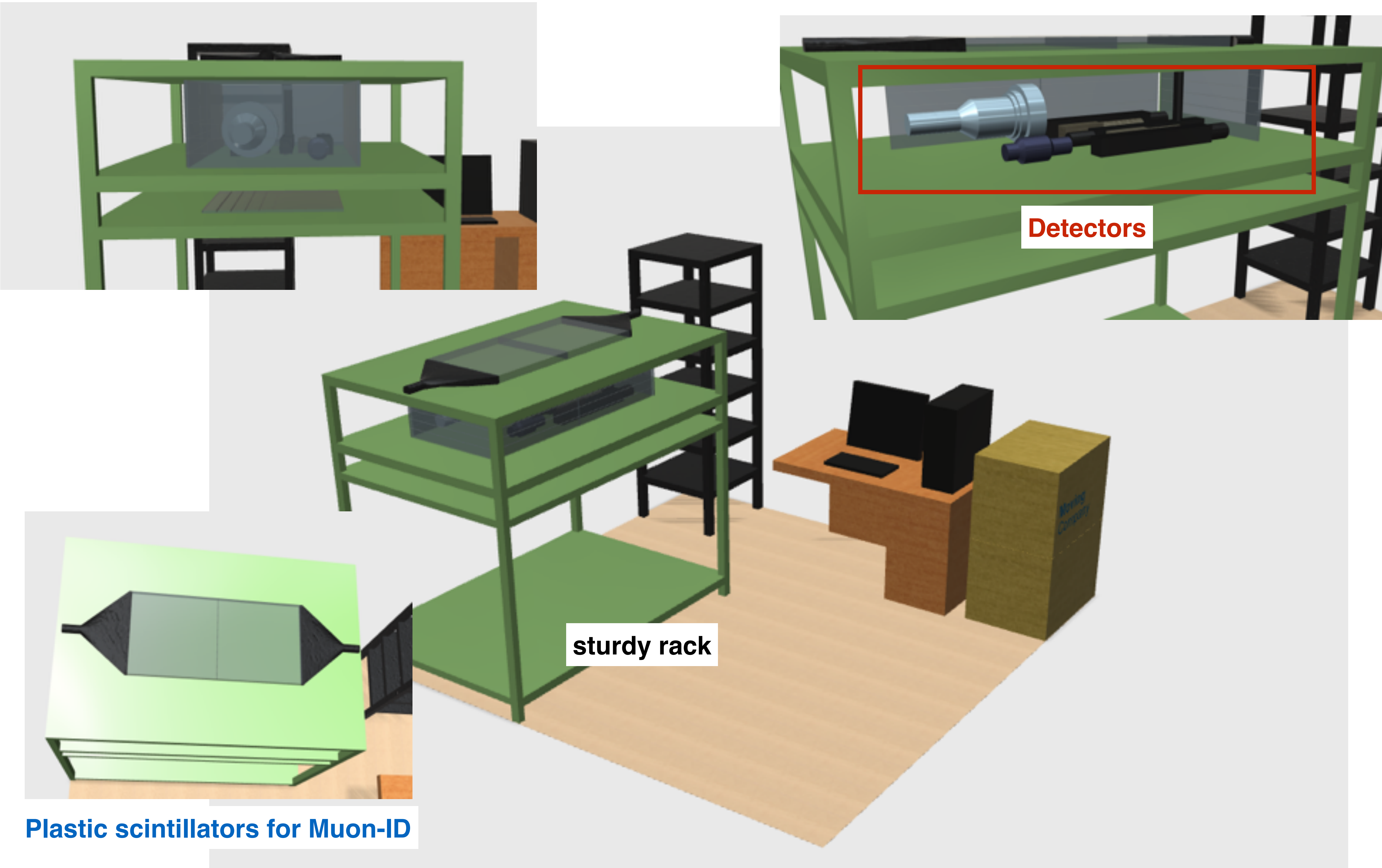
- **Purpose**

- **testing the PSD method for various detectors.** K.Abe et al. (The T2K Collaboration), Nucl. Instr. and Meth. A, Volume 694 (2012)
- **estimating the background at J-PARC B2 Hall.** ( Here INGRID and WAGASCI are also being done, and **the background estimation is important for these groups.** ) T.Koga et al., JPS Conf. Proc. 8, 023003 (2015)

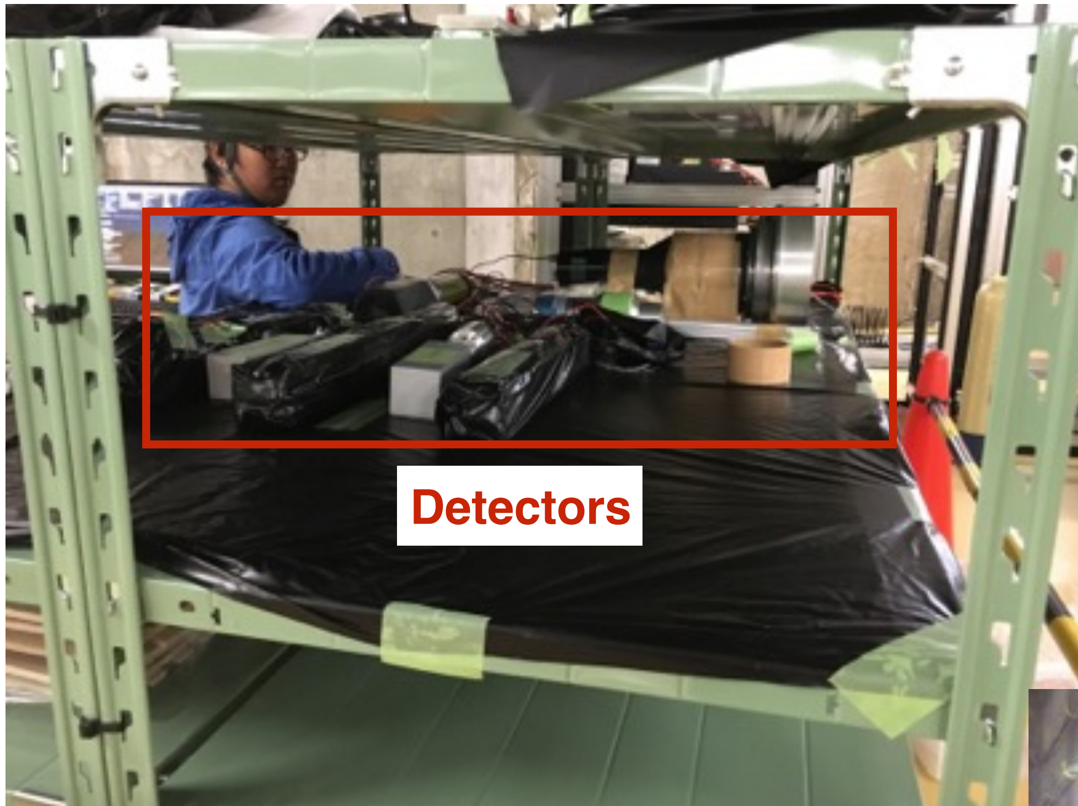
**Our proposal has been approved by J-PARC !!!**

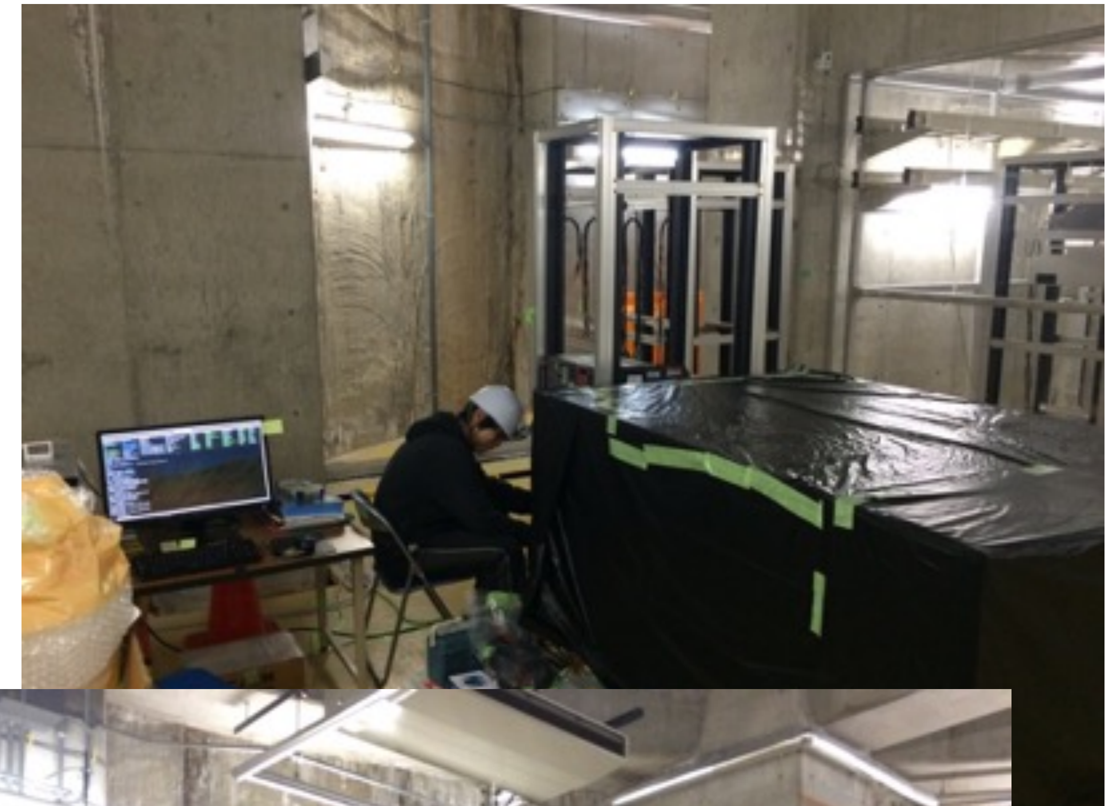
→ **"T64" experiment**

# EXPERIMENTAL SETUP



# EXPERIMENTAL SETUP



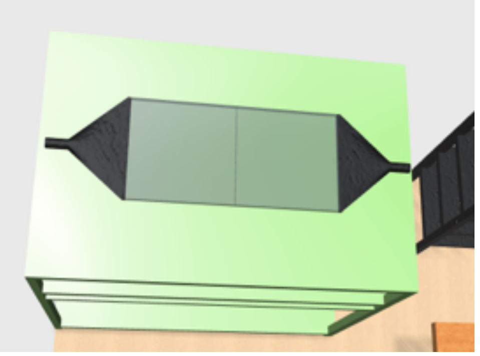



# DETECTORS

**Detectors**

| Detector | Details ( rough ) | Number | Use |
|---|---|---|---|
| CsI(Tl) | 6.5cm×6.5cm×60cm | 3 | neutron and gamma-ray measurement |
| NaI(Tl) | 5.8cm×5.8cm×35cm | 2 | neutron and gamma-ray measurement |
| $LaBr_3$ | $\phi$8.5cm×22.8cm | 1 | neutron and gamma-ray measurement |
| Liquid | $\phi$22cm×45.5cm | 1 | neutron and gamma-ray measurement |
| $BaF_2$ | $\phi$10cm×30cm | 1 | neutron and gamma-ray measurement |
| Plastic Type.A | 1.0cm×5.0cm×60.0cm | 46 | Muon-ID |
| Plastic Type.B | 50cm×50cm×5.0cm | 3 | Muon-ID |

**We will cover detectors with two types of plastic scintillators to identify muon events.**



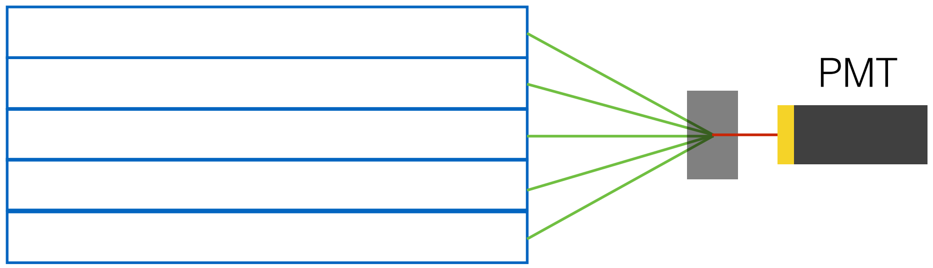
Type.B

## Type.A

- auxiliary plastic scintillators for INGRID
- for read-out, use wave length shift ( WLS ) fibers.
- make sets of detectors and read some fibers together by PMTs.

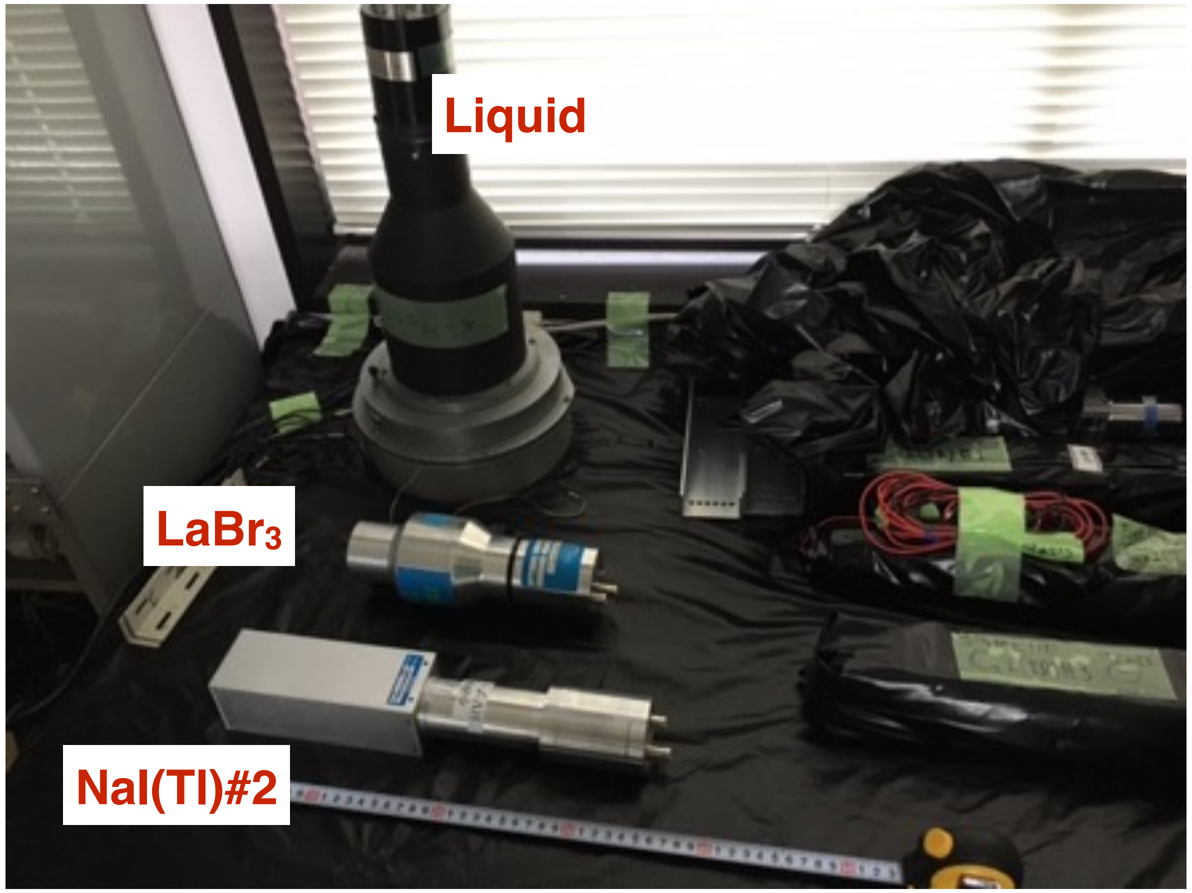
## Type.B

- attached with light-guides and PMTs.

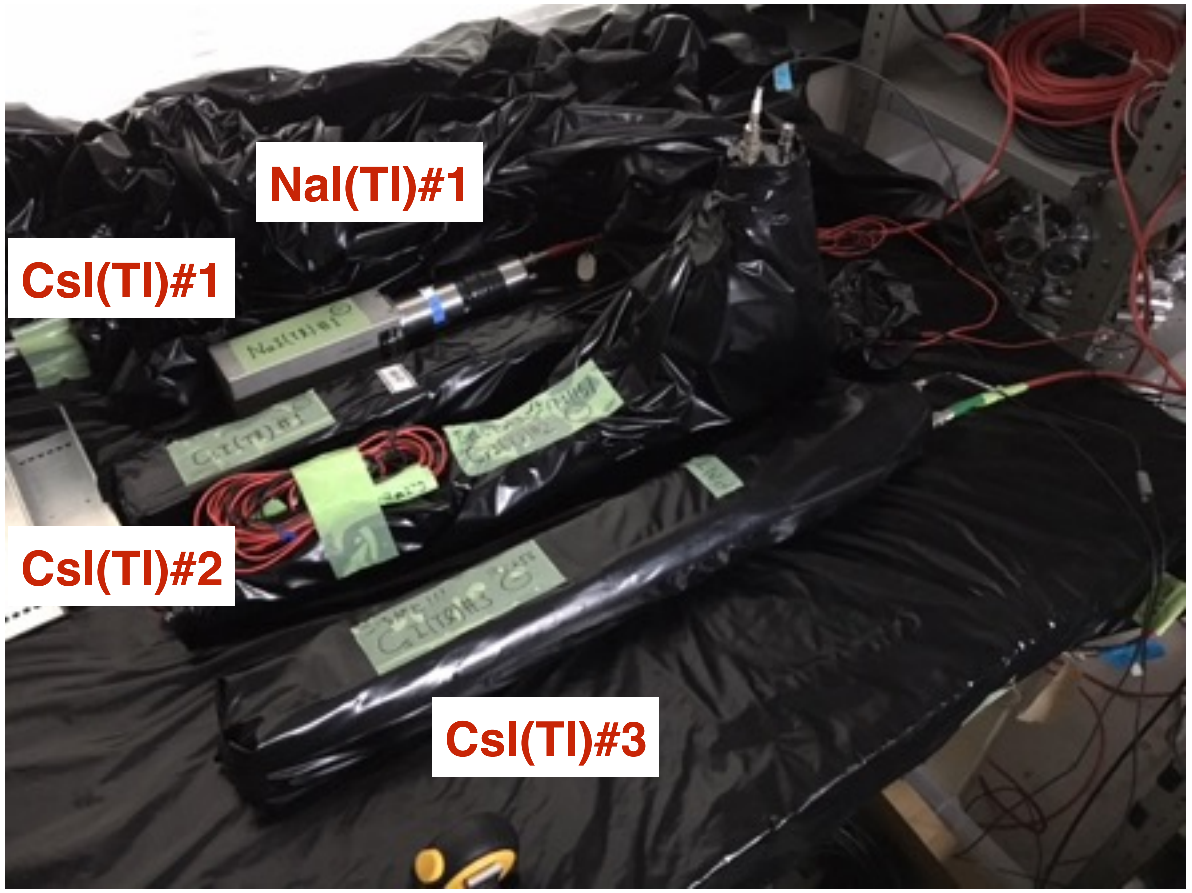



Type.A read-out system

# DETECTORS

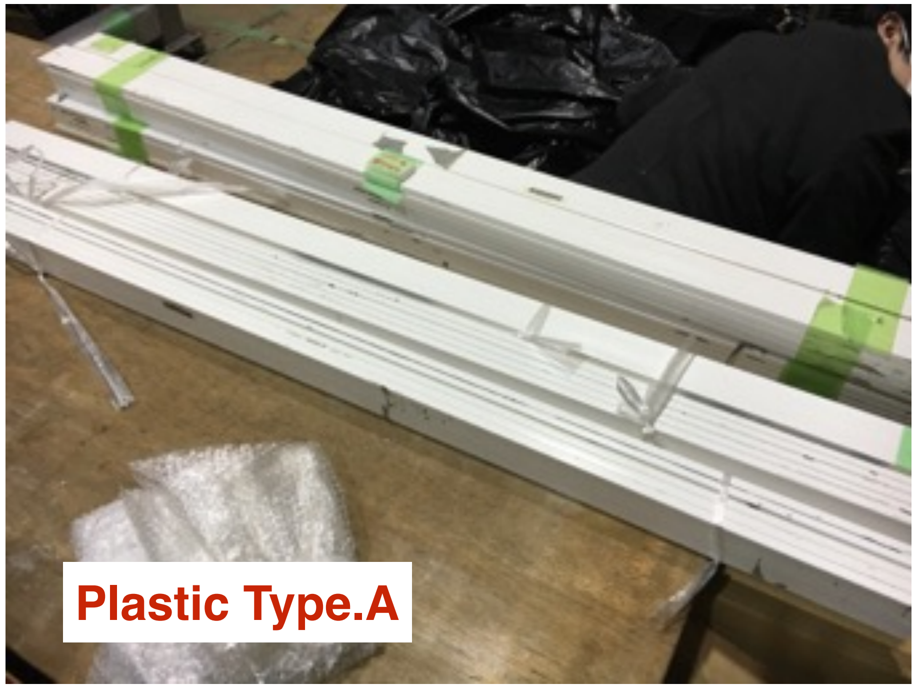


Liquid
LaBr3
NaI(Tl)#2

NaI(Tl)#1
CsI(Tl)#1
CsI(Tl)#2
CsI(Tl)#3


BaF2

Plastic Type.A

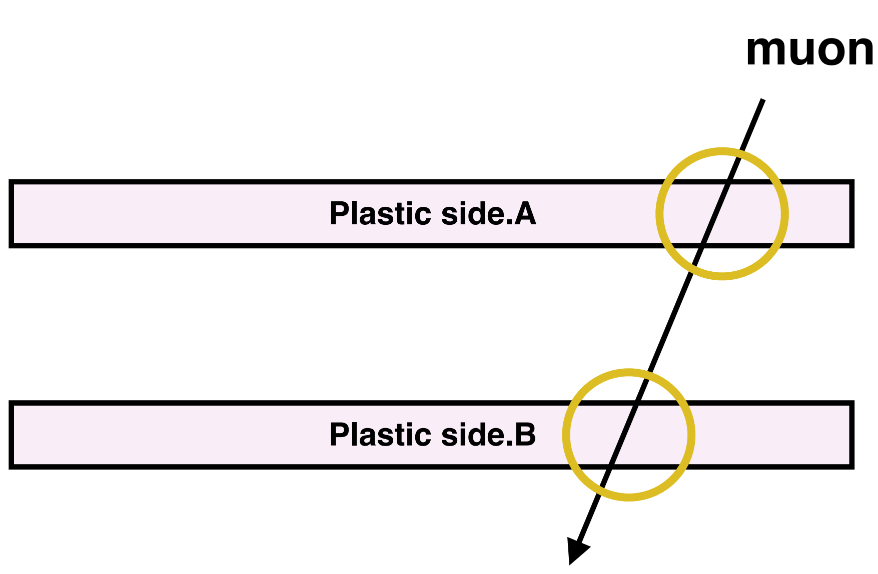
# MUON-ID SYSTEM

“**Muon-ID**” is done by using plastic scintillators.

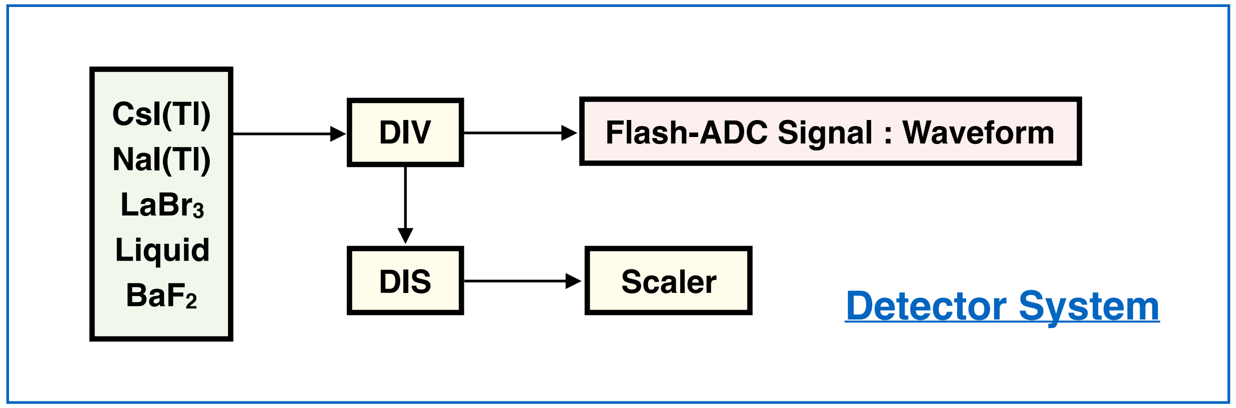
- Pick out two sides of 6-planes ( for example, “front” and “back” ), and bundle the signals from these two sides and insert together into one channel of “COINCIDENCE” module.

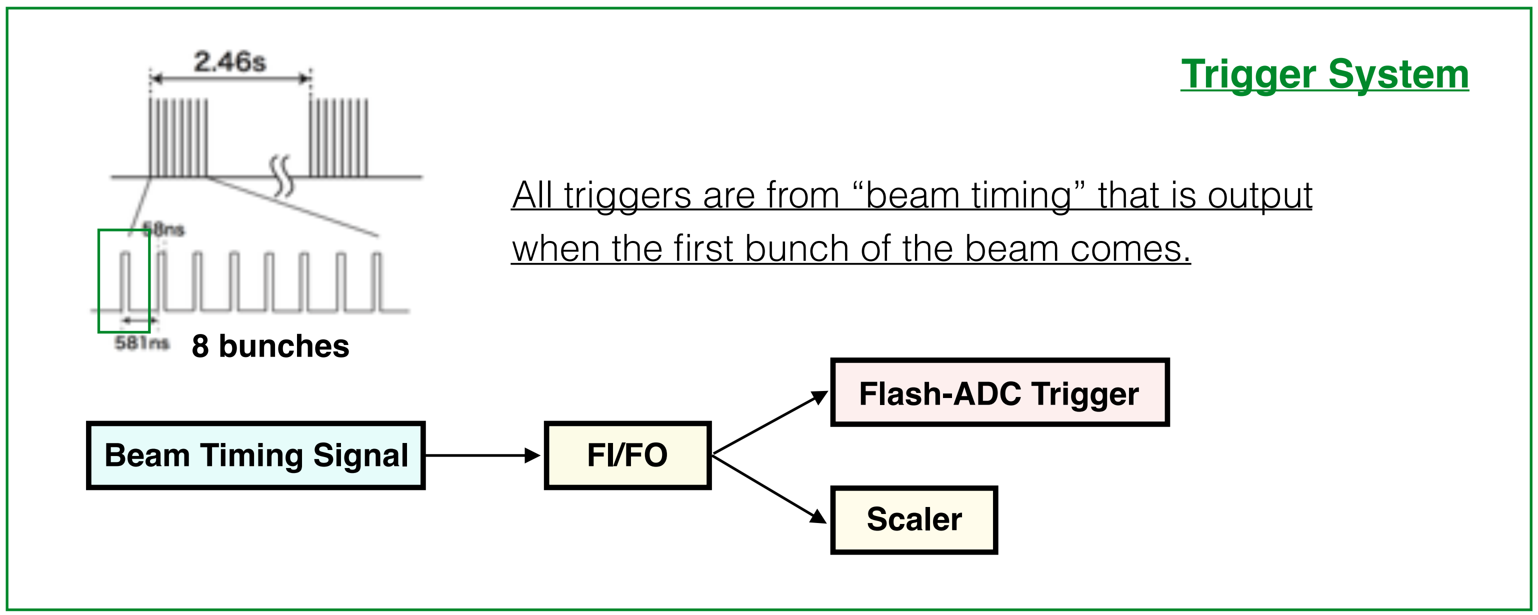
- This is done for several combinations of sides ( “front+back”, “up+down”, “right+left”, … ), and insert all together into “FI/FO” module ( **“OR” logic** ).

- The width of the digital signal that goes into “COINCIDENCE” module from “DISCRIMINATOR” module is set to have time width ~ few ns in order to use for both directions such as “front to back” and “back to front”.



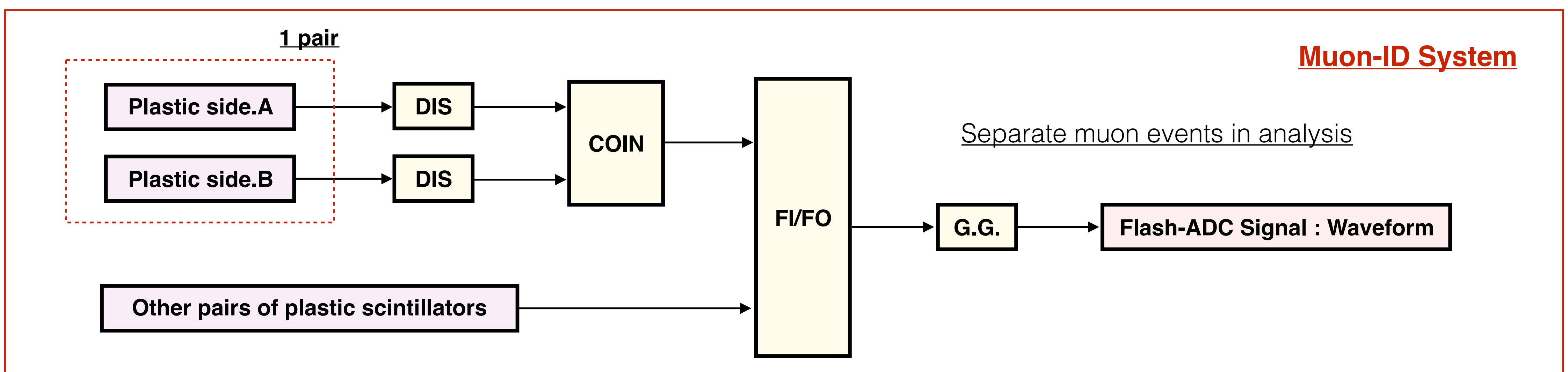
# DATA ACQUISITION SYSTEM




NIM Modules
- DIV: Divider
- DIS: Discriminator
- G.G.: Gate Generator
- DLY: Delay
- FI/FO: Fan In / Fan Out
- COIN: Coincidence
- Scaler

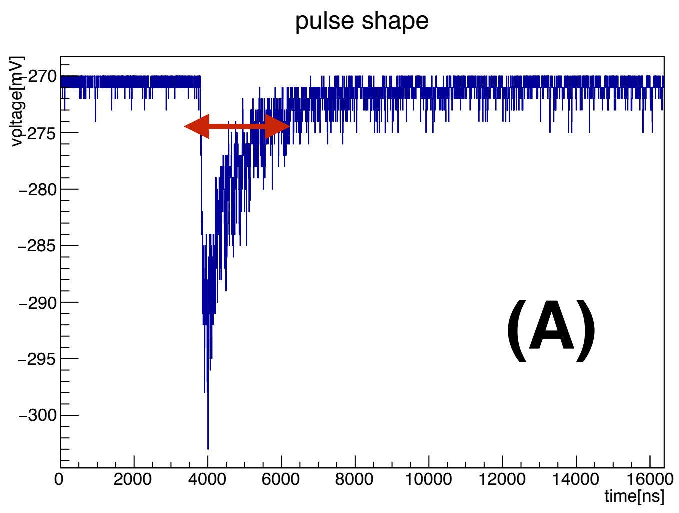
VME Modules
- Flash-ADC: CAEN V1720 ( **250MHz, 4096 sampling** )

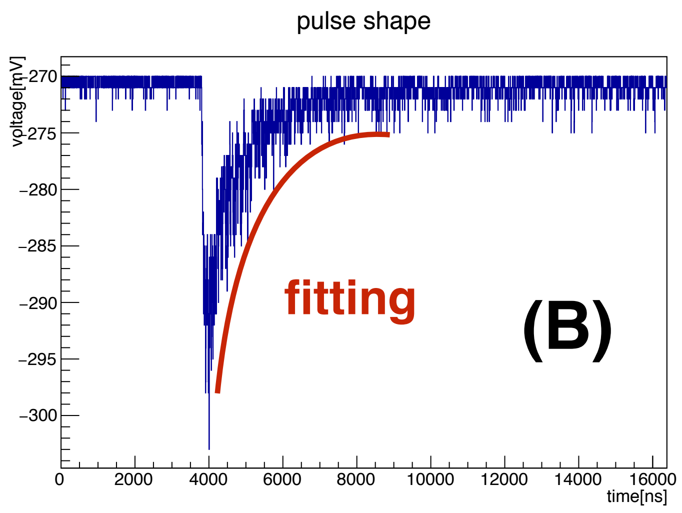


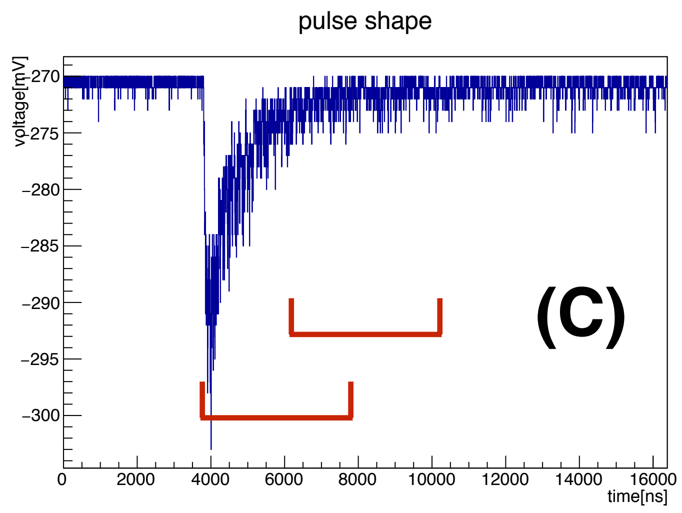
# ANALYSIS

Now I consider three ways to categorize events into neutron / gamma-ray.

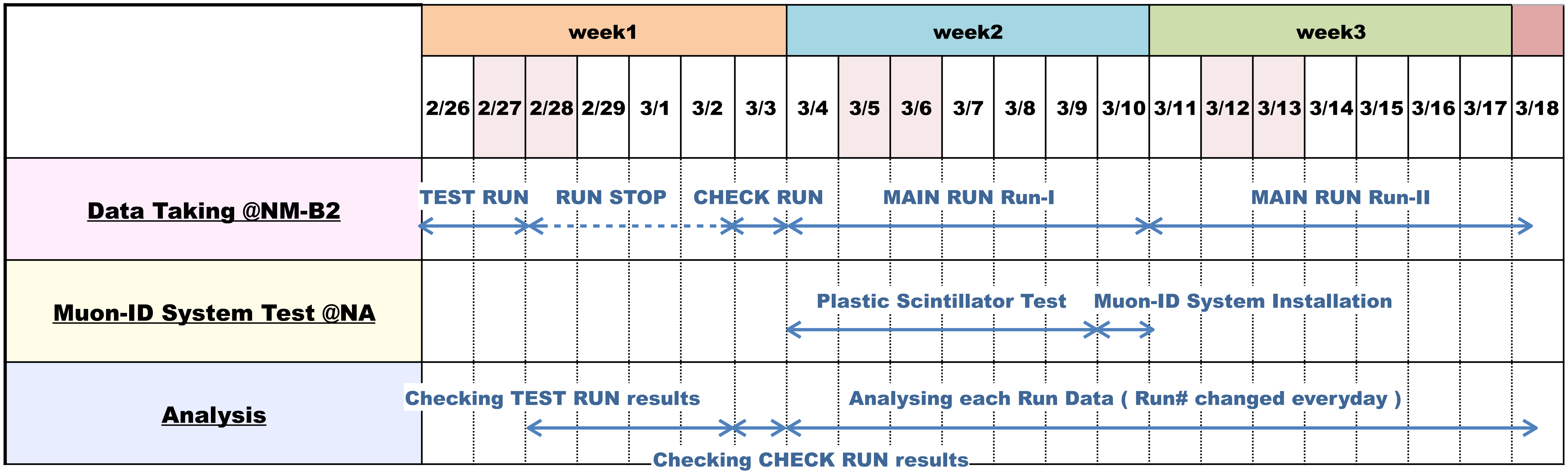
A. Use **pulse height** information
B. Fitting **decay curve** and extract parameter
C. Make **a ratio of full to decay component** ( **offline-ADC** )



# SCHEDULE




- **TEST RUN** : modules, detectors' signal and beam-timing signal check
- **CHECK RUN** : Some modulations on DAQ system & final check
- **MAIN RUN Run-I** : data taking without Muon-ID system
- **MAIN RUN Run-II** : data taking installed with Muon-ID system
- **MAIN RUN Run-III** : more data taking after 22nd of March…?

# CURRENT STATUS

- We have completed set-up of detector system except for plastic scintillators.
- We have finished **TEST RUN**, and it seems OK ( now checking ).

- **Next week we will start the measurement !!!**

**Results will be at JPS conference in March…**

# SUMMARY & OUTLOOK

- Neutrino's NCQE interaction is very important in some physics and astronomy, but "secondary gamma-ray" is the main reason for the large systematic uncertainty.
- We started the project to study "secondary gamma-ray", and for this the detector that has both n-γ separation ability and good energy resolution is necessary.
- We will test n-γ separation at J-PARC B2 Hall ( T64 experiment ).
- By the next beam time at RCNP ( maybe in June ), we will simulate some ideas and determine DAQ system.

Outlook

# APPENDIX

# COLLABORATORS

**Y.Ashida**, T.Nakaya, K.Huang

from *Kyoto University*

H.Nagata, **Y.Koshio**☆, T.Shirahige, D.Fukuda

from *Okayama University* ☆**Spokesperson**

A.Konaka

from *TRIUMF*

Corina Nantais

from *University of British Columbia*

A.Suzuki, Y.Takeuchi, T.Yano

from *Kobe University*

Special Thanks:

T.Namba from *ICEPP, University of Tokyo* for CsI(Tl) scintillators

T.Kawabata from *Kyoto University* for Liquid scintillator

Y.Watanabe from *Saint Gobain* for $LaBr_3$ scintillator

G.Collazuol from *University of Padova* for $BaF_2$ scintillator

T.Hayashino from *Kyoto University* for some simulations

# SUPERNOVA RELIC NEUTRINO

- **SUPERNOVA** = explosion at the end of the star life

- **99% of the energy ( ~$10^{46}$J ) is taken by the neutrino !!!**
- Most theoretical models predict it occurs **2~3 times per century** in one galaxy ( i.e. Milky Way ).

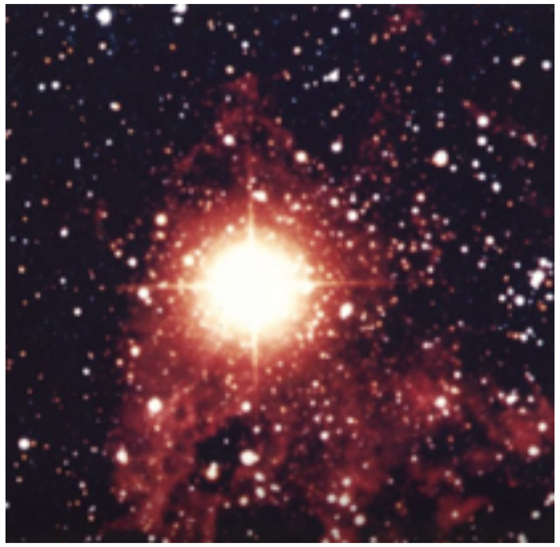
→ **There should be relic neutrinos from supernovae since the beginning of the universe.**

= **Supernova Relic Neutrino** ( SRN )

- **Supernova is important not in Cosmology but in Nuclear and Particle Physics.**

→ There are a lot of models for supernova.

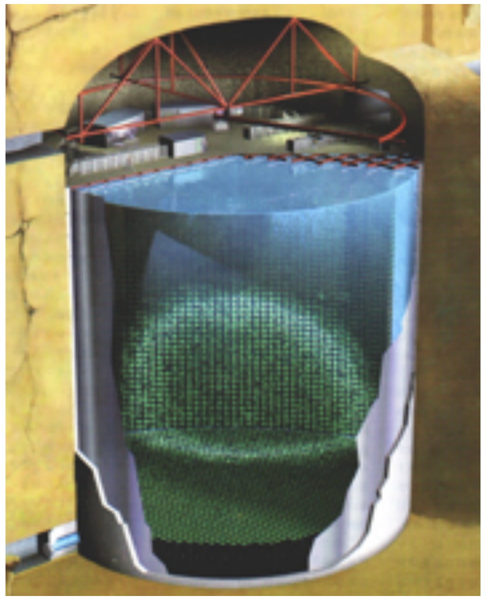
- the mechanism of explosion
- the equation of state of the neutron star
- dark matter
- dark energy
- etc…



# SK-Gd PROJECT

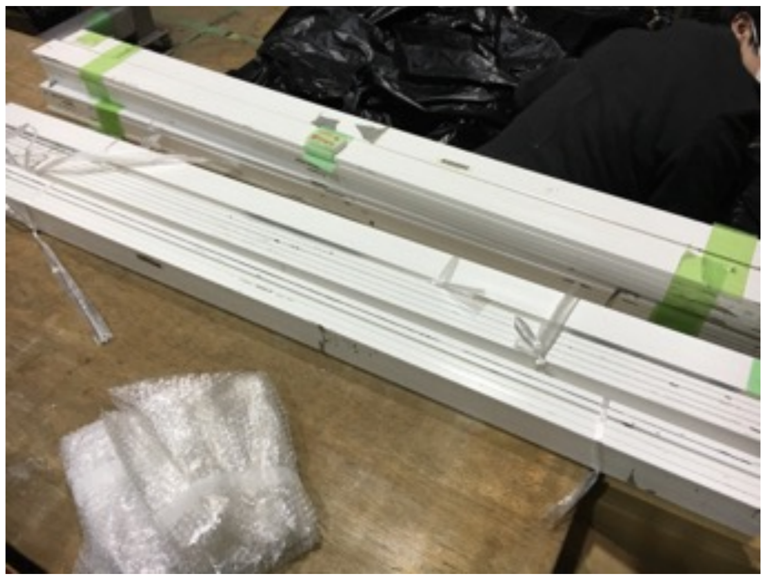
- At **Super-Kamiokande** ( SK ), SRN search is being done.
- Main signal = **inverse β-decay** : $\bar{\nu}_e + p \rightarrow n + e^+$
- The next leading-order mode is two order less than this mode ( anti-electron neutrinos have the largest cross section with water ).

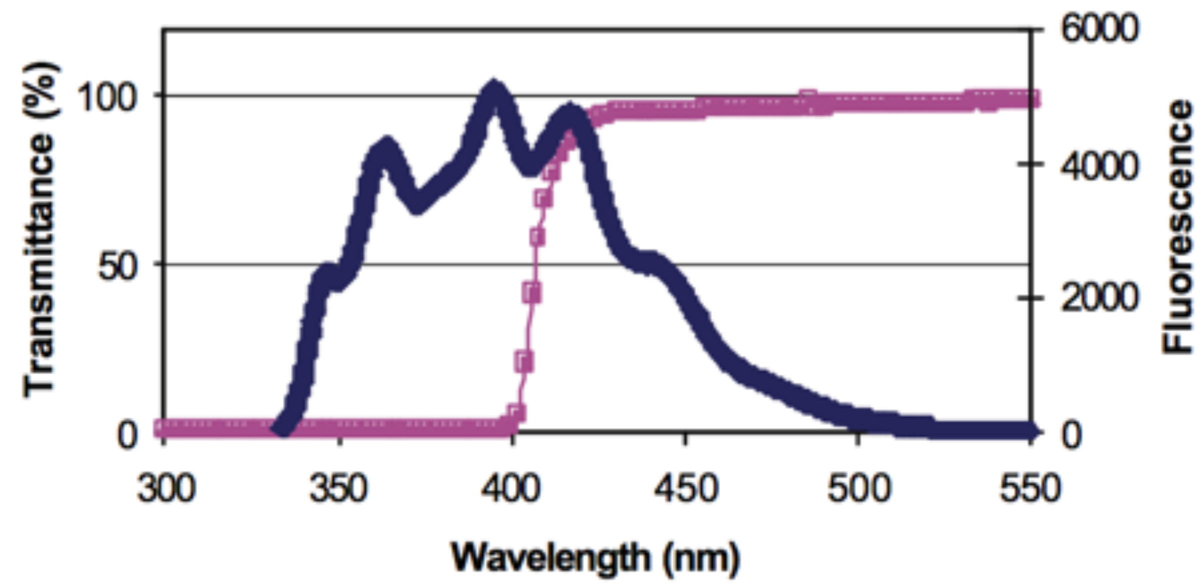
- In **SK-Gd** project, the sensitivity to this mode will be improved by using **gadolinium ( Gd ) ability to capture neutrons.**
- after neutrons captured by Gd, de-excitation gamma-rays will be emitted.
- **The secondary gamma-rays from the atmospheric neutrino's NCQE interaction will be background in this search.**



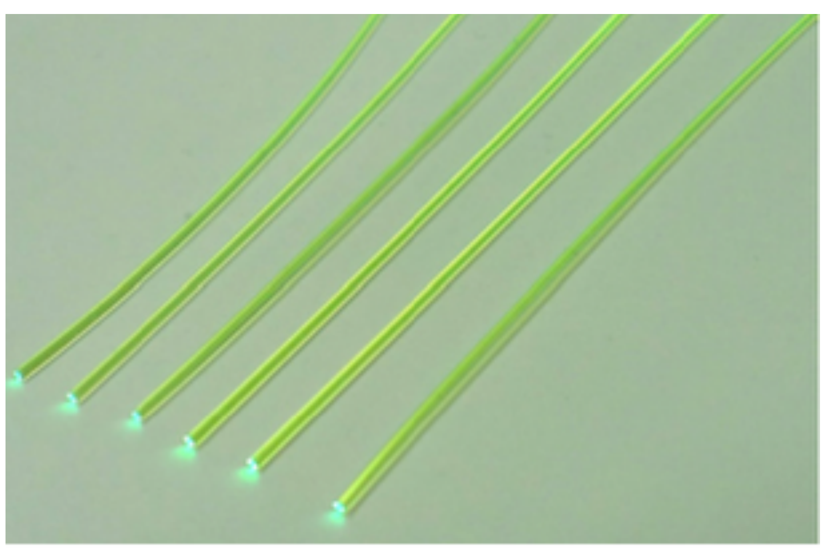
K. Bays et al. (Super-Kamiokande Collaboration), Phys. Rev. D 85, 052007 (2012)

# INGRID PLAS-CIN & WLS FIBER

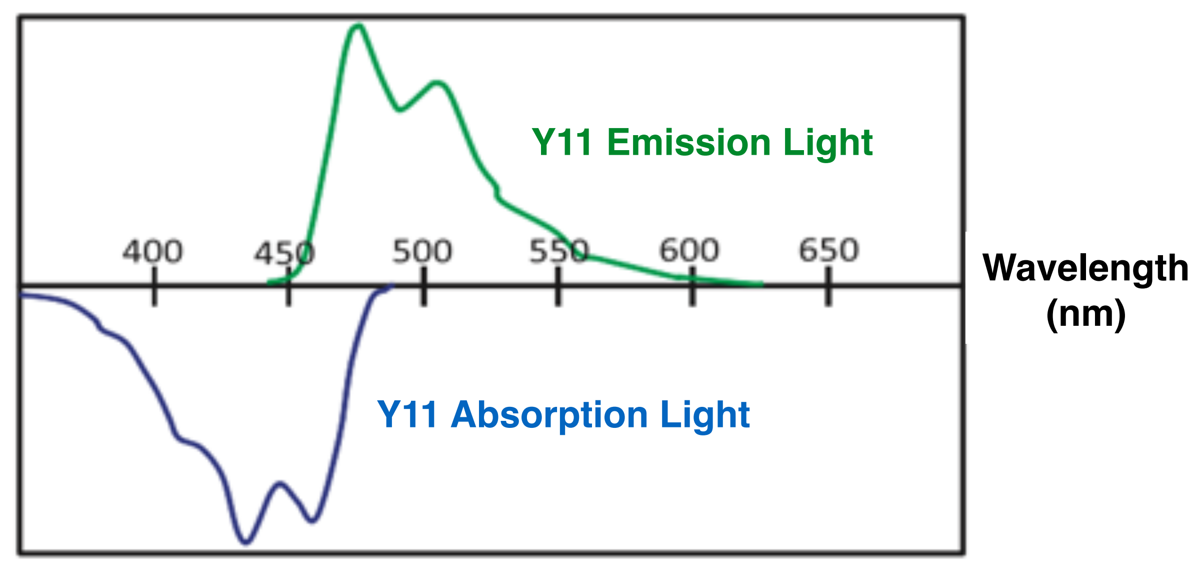





Wavelength of Scintillation Light from the INGRID Plastic Scintillator



Wave Length Shift Fiber Y11(200)MS for Read-out




T.Kikawa, Master Thesis, Ktoto Univ. (2010)

# EVENT ESTIMATION OF T64

- NEUT simulation by INGRID group
- $1.0 \times 10^{21}$ POT statistics
- INGRID assumed as 1m cubic