PSD (Pulse shape discrimination) power analysis for NaI crystal

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Han-wool Joo
Seoul National University
on behalf of the KIMS-NaI collaboration

Introduction

- **PSD power of NaI crystal**
- **Experimental setup**
- **Data analysis**
- **Result**
- **Summary and Plan**

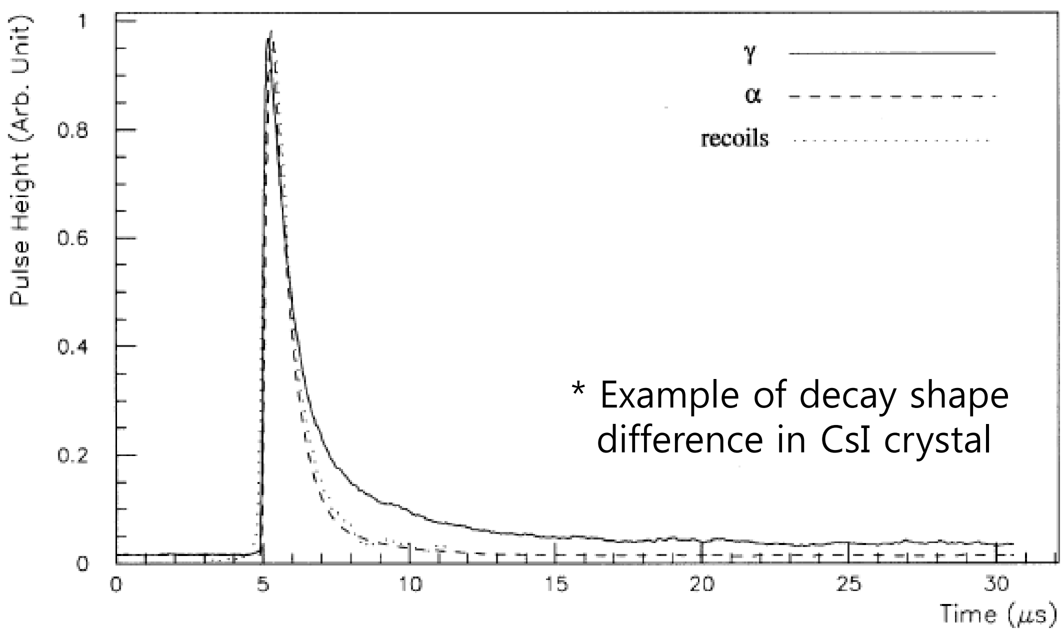
PSD power of NaI crystal

- **Different stopping power of nuclear recoils and electron recoils**

  - Higher stopping power of nuclear recoils than that of electron recoils

    -> Scintillation of nuclear recoils decays fasters than electron recoils

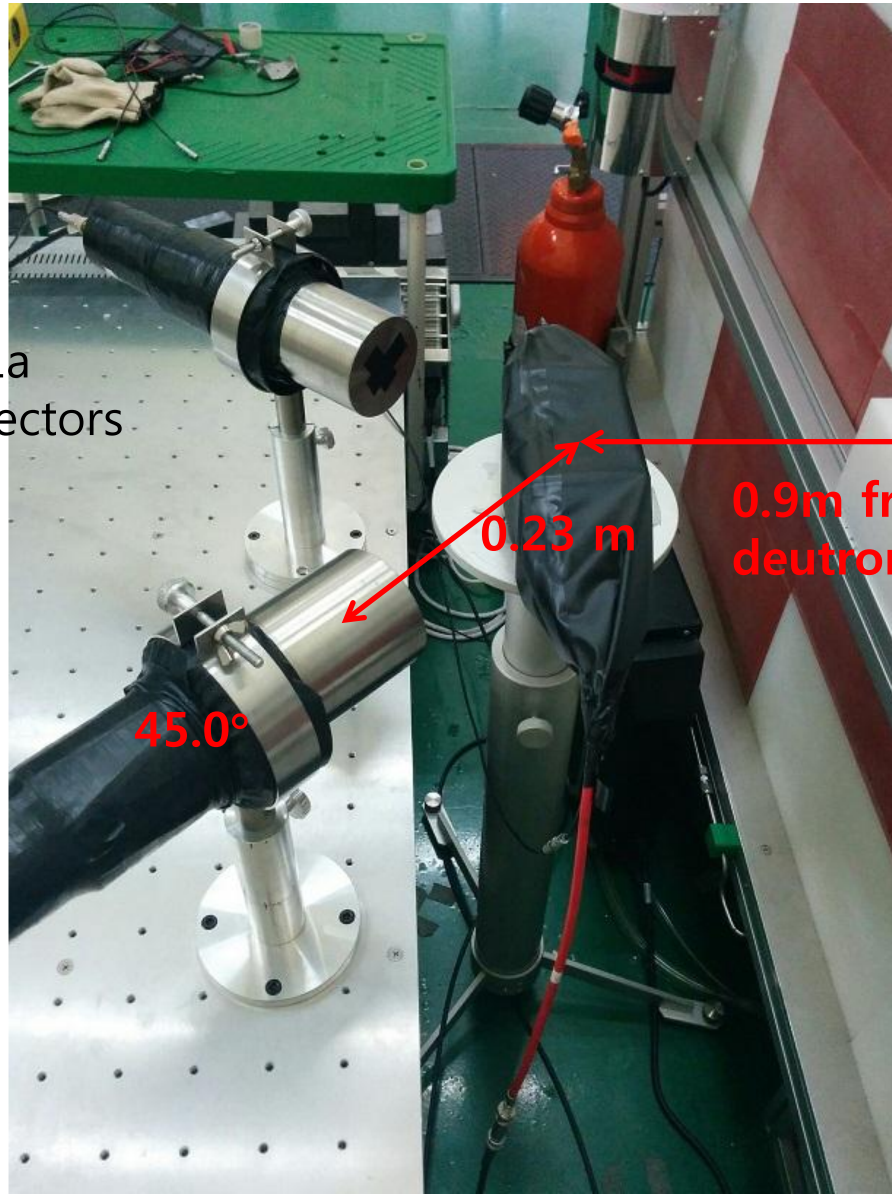
    -> Different shape of scintillation



- **Measurement of PSD power of NaI crystal is important for separating background events (induced by gammas) from expected dark matter induced events**

Experimental setup (for nuclear recoils)

3 inch Bc501a
Neutron detectors



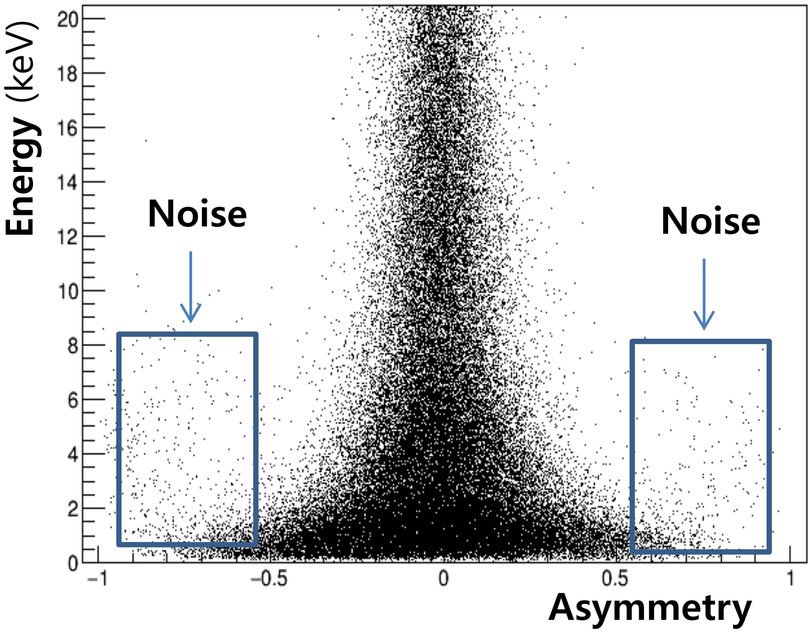
2x2x1.5 cm^3
NaI crystal with
two PMTs

2.43 MeV neutron beam from d-d fusion

0.9m from deutron target

Data analysis – noise rejection cuts for NaI

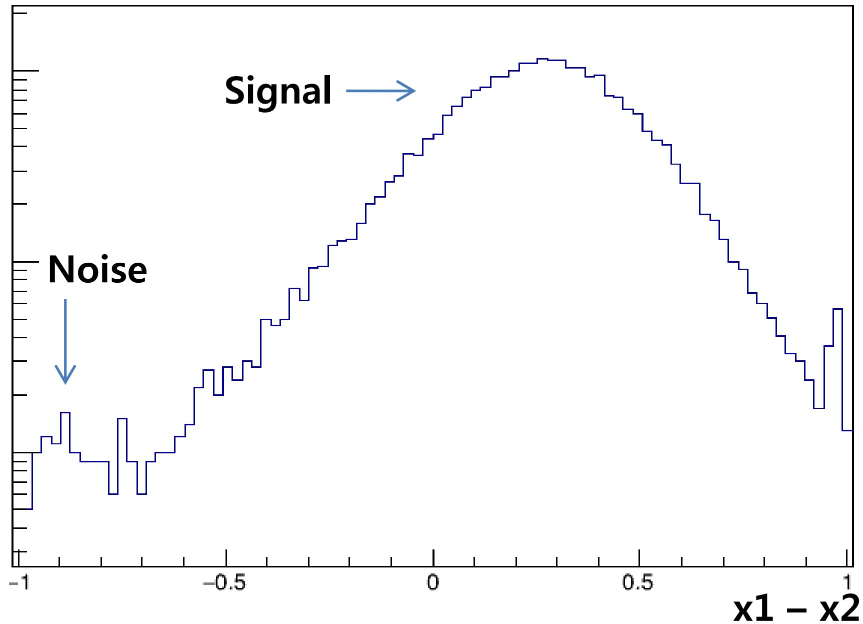
Charge asymmetry

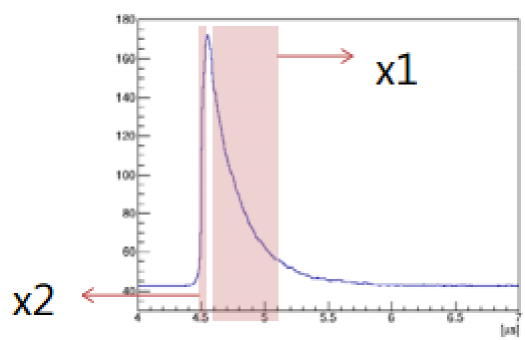


$$\textbf{Asymmetry} = \frac{Q_{PMT0} - Q_{PMT1}}{Q_{PMT0} + Q_{PMT1}}$$

$\boldsymbol{Q_{PMT}}$: charge sum of PMT signal

Charge ratio

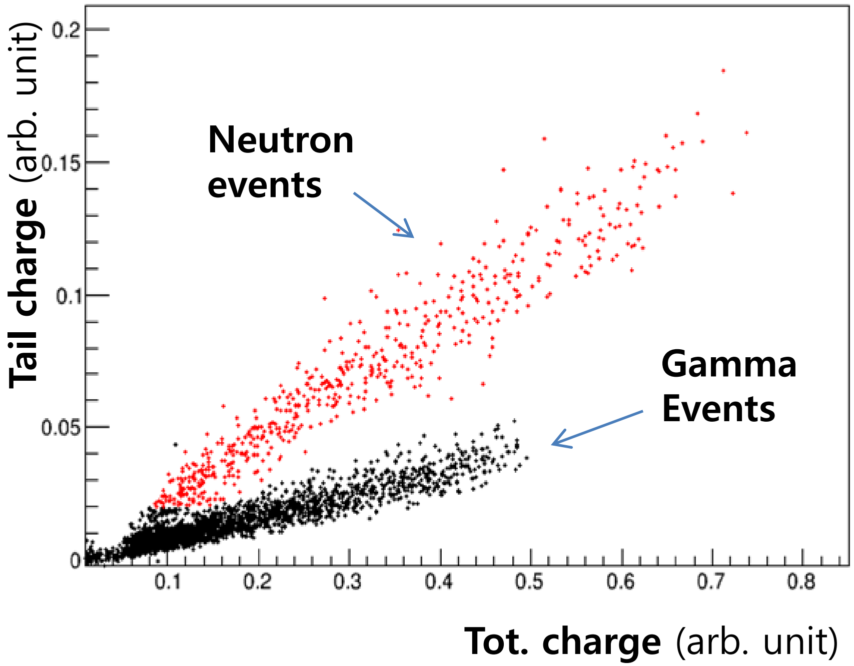




x1 : charge sum of slow component
x2 : charge sum of fast component

Data analysis – gamma background rejection cuts for Neutron detectors

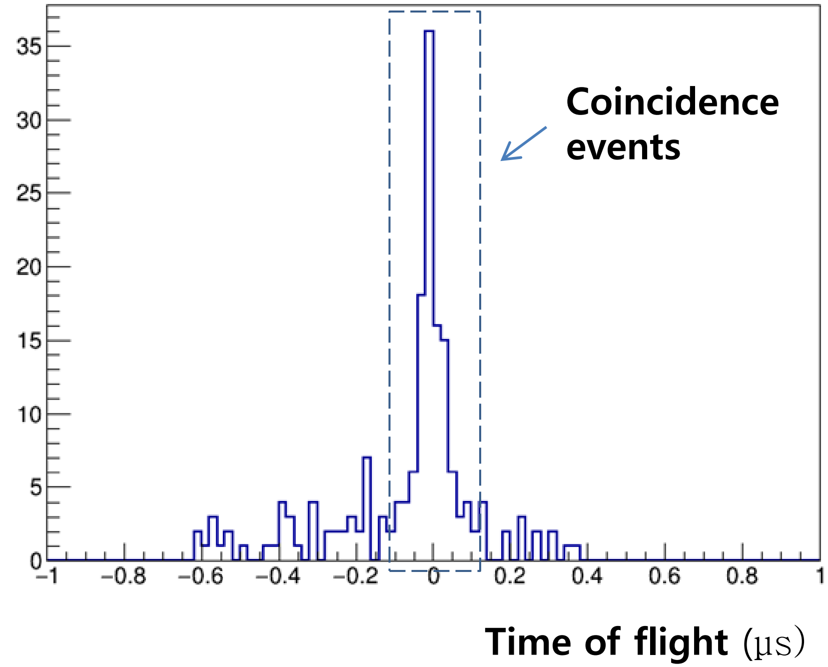
Neutron Detector(ND) PSD



Tot. charge : charge sum over 200 ns

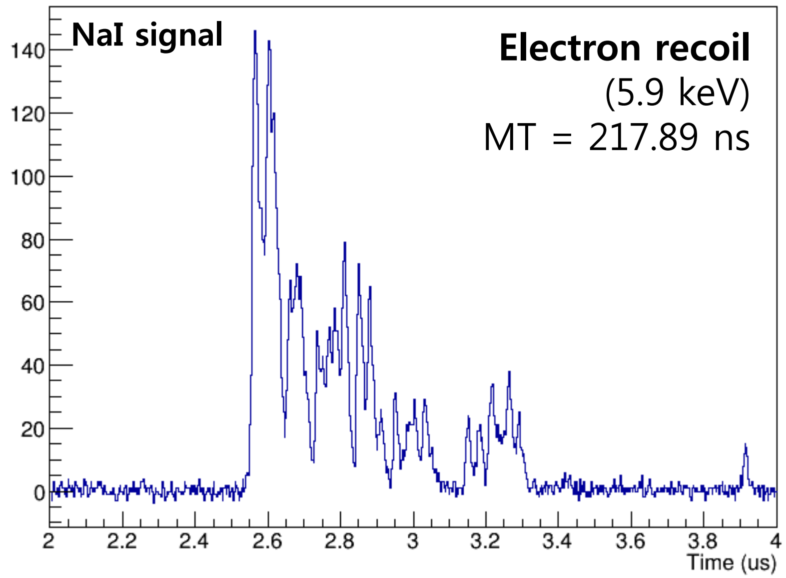
Tail charge : charge sum from 50 to 200 ns

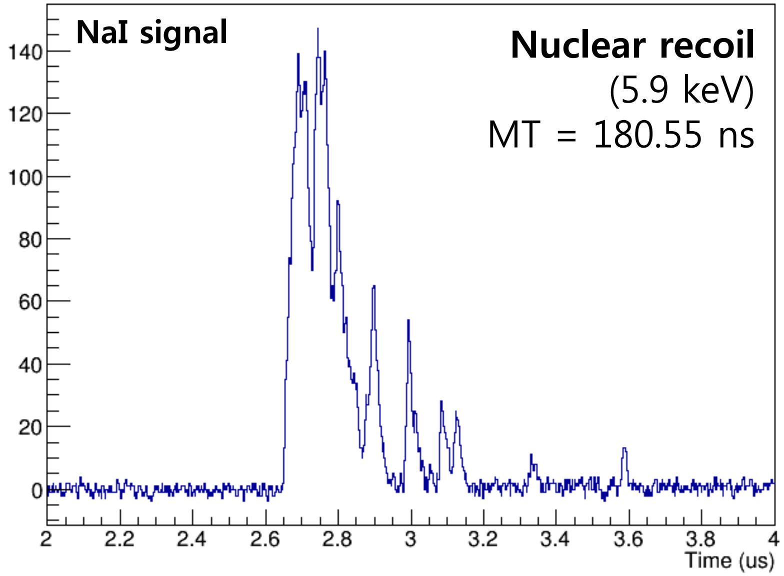
Time of flight



$$\mathbf{TOF} = T_{NaI} - T_{ND}$$

Calculate mean decay time of each signal





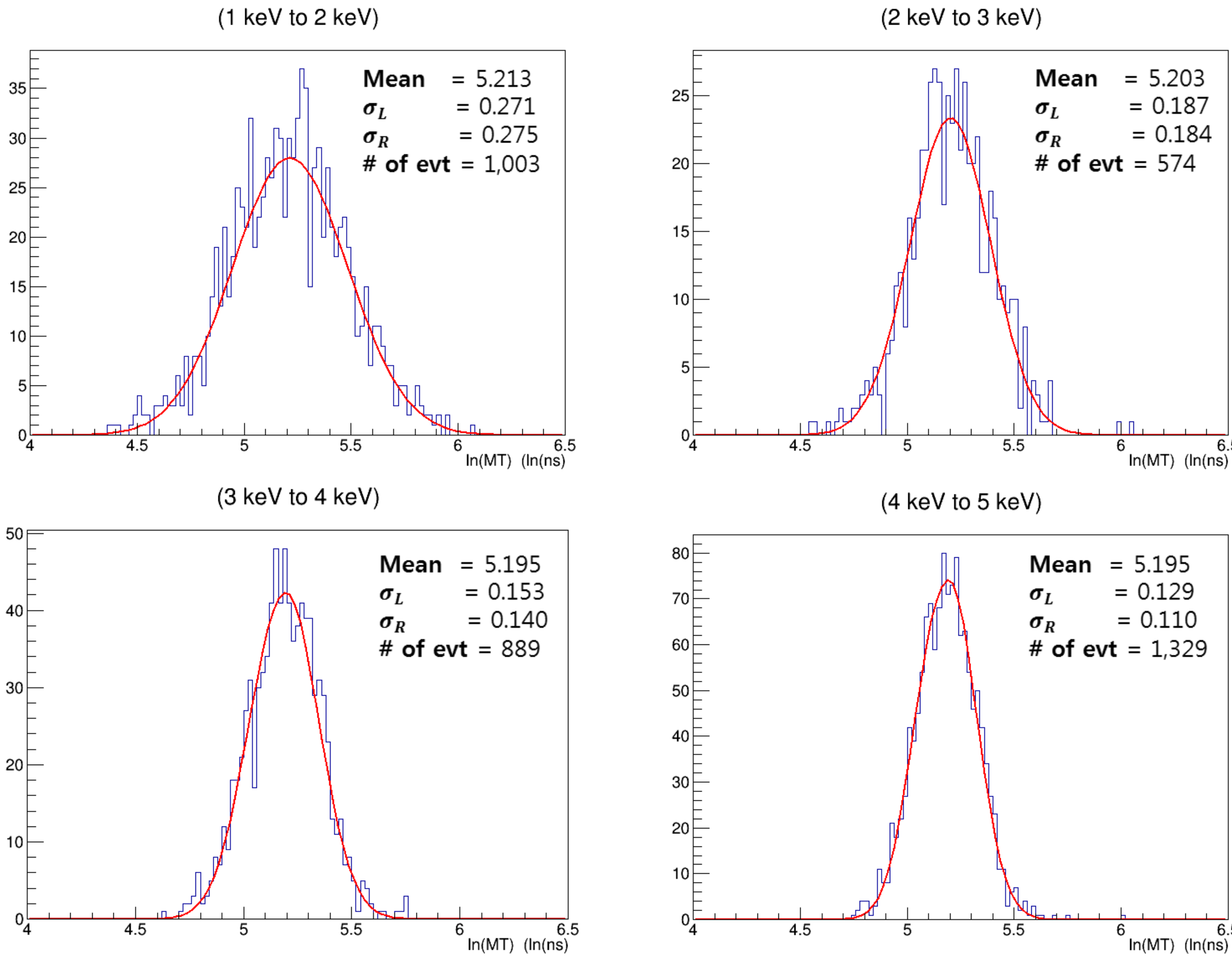
- **Discriminate nuclear recoils and electron recoils with natural logarithm of the mean decay time (MT)**

: $\ln(\mathrm{MT}) = \ln\left(\frac{\sum A_n t_n}{\sum A_n} - t_0\right)$

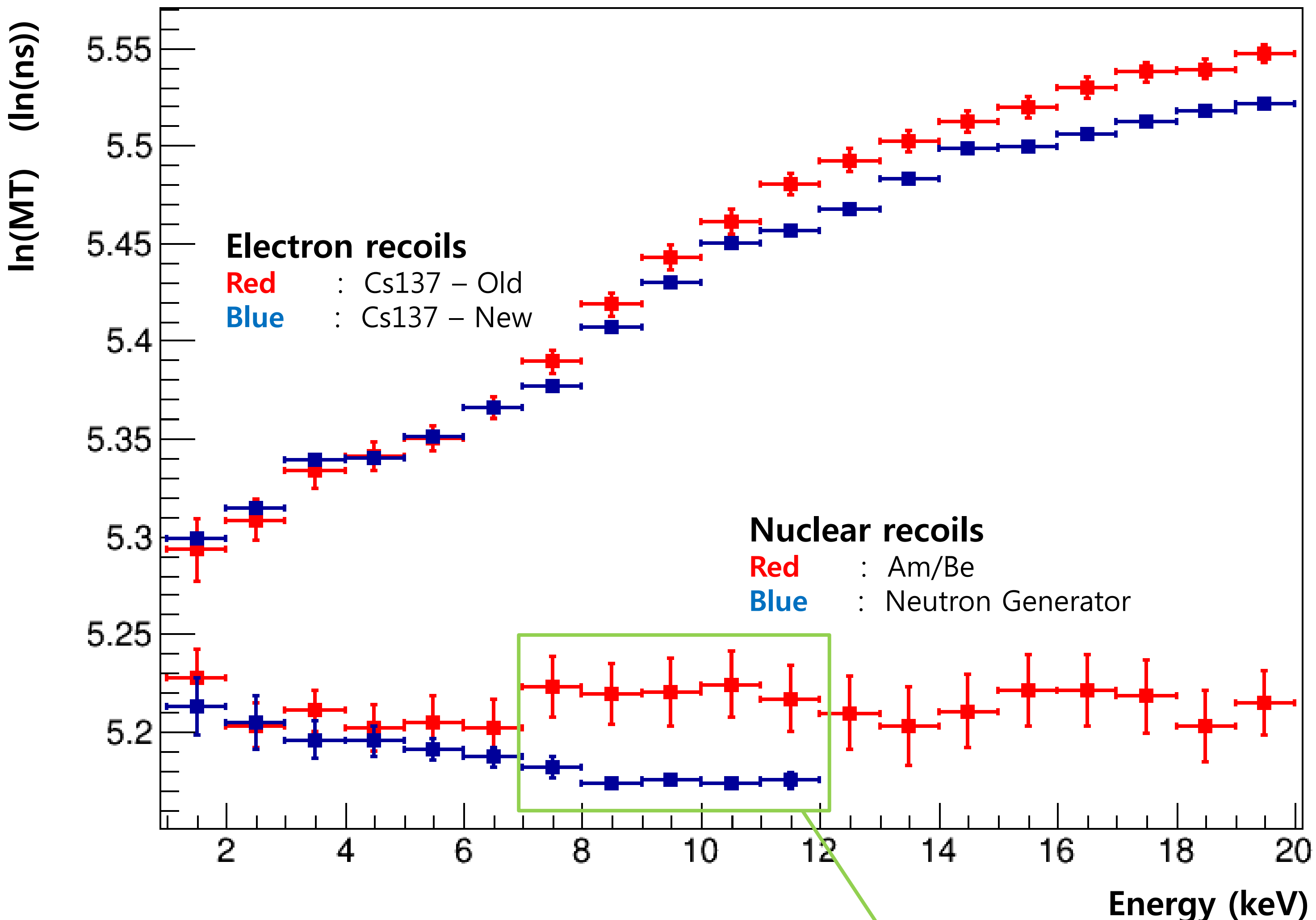
A_n : charge of n th cluster
t_n : time of n th cluster $(t_n - t_0 < 1.5\ \mathrm{us})$

Calculate ln(MT) for each keV

Fit with Bi-gaussian function



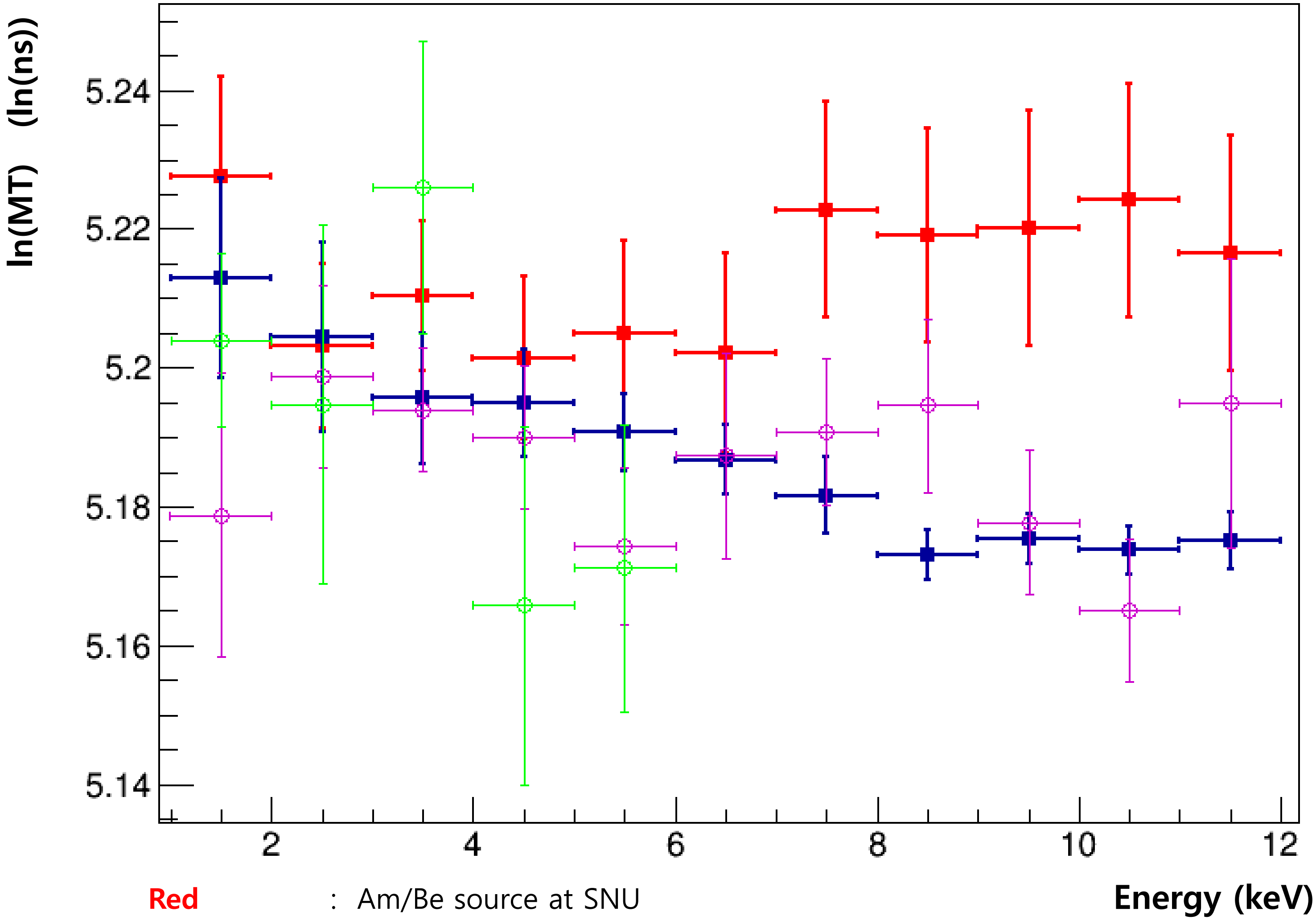
ln(MT) summary



X axis : deposit energy on NaI crystal
Y axis : mean decay time of NaI signal

~ 0.05 difference in ln(MT)
-> 10 ns difference

ln(MT)



Red : Am/Be source at SNU
Blue : Neutron generator, Quality Factor (45°)
Purple : Neutron generator, Quenching factor (Na recoils)
Light green : Neutron generator, Quenching factor (I recoils)

Summary and Plan

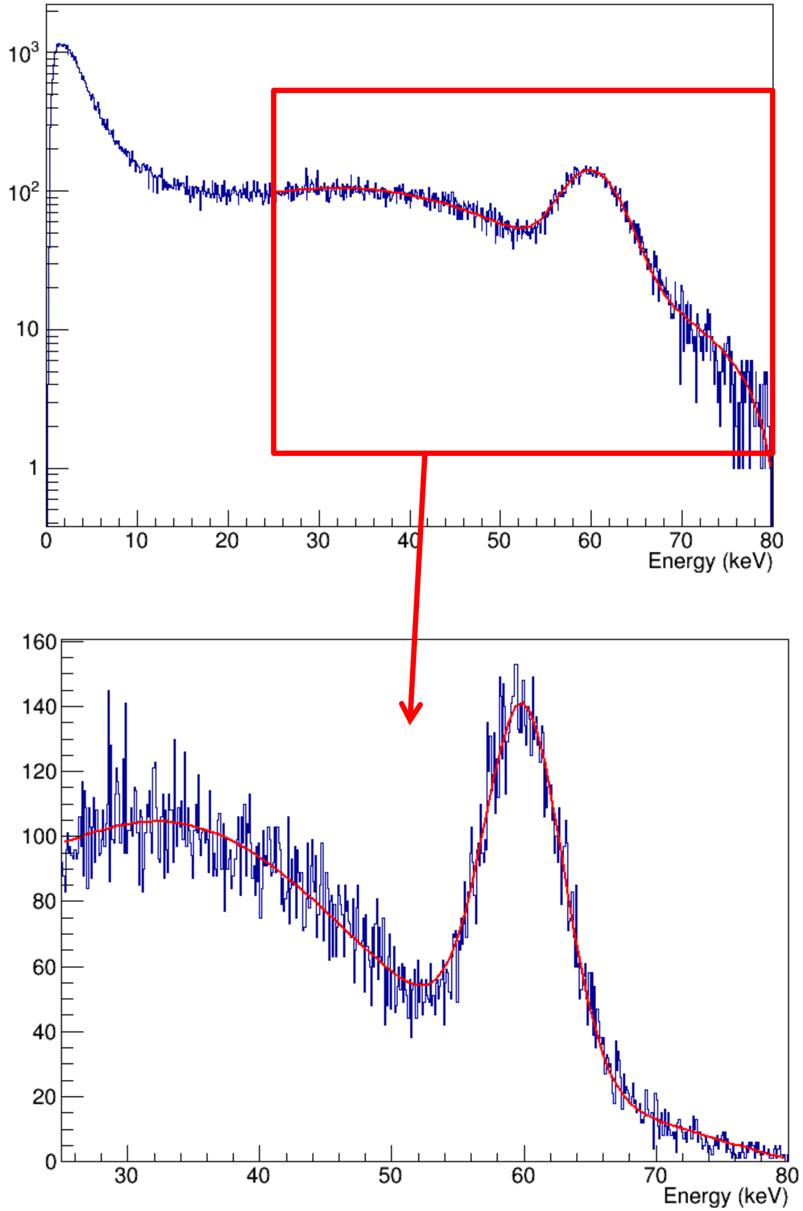
- **PSD power of NaI crystal was measured with mean decay time difference between electron recoil and nuclear recoil events**

- **Difference in mean decay time at >8keV in Am/Be data and neutron generator data**

- **Additional PSD power measurement with another NaI crystal**

Backup Slides

Number of 60 keV gamma events in Am/Be data

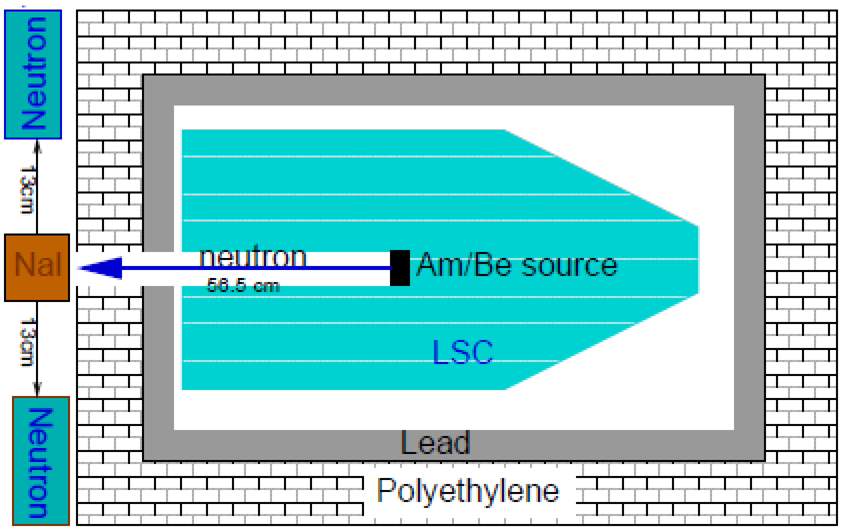


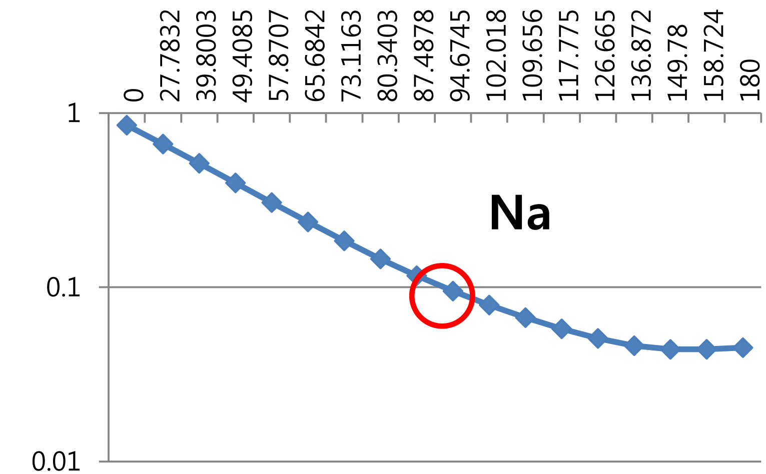
Fitting Function (Linear + two gaussian)
: **p0** + **p1** * x
+ **p2** * Gaus(**p3**, **p4**)
+ **p5** * Gaus(**p6**, **p7**)

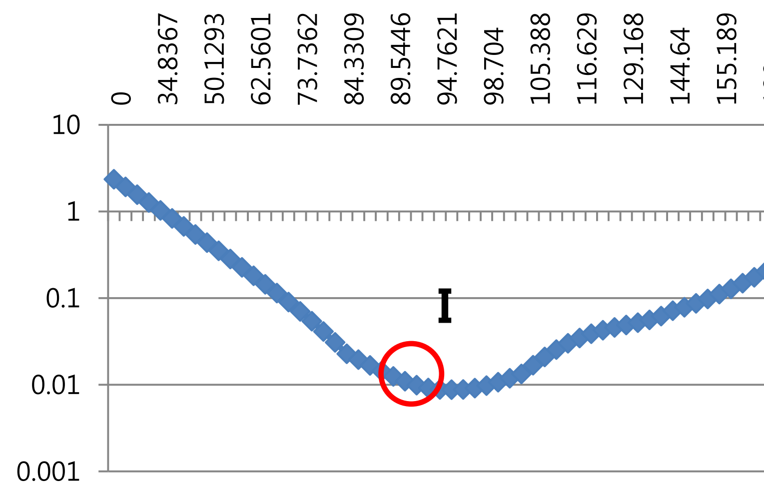
p0 : 90.30
p1 : - 1.12
p2 : 52.12
p3 : 35.28
p4 : 11.77
p5 : 119.28
p6 : 59.98
p7 : 2.99

Estimated number of 60keV gamma events from alpha-decay of Am source
(by integration of gaussian function)
: ~9,000 events

300 mCi Am/Be experimental setup and cross section of Na and I





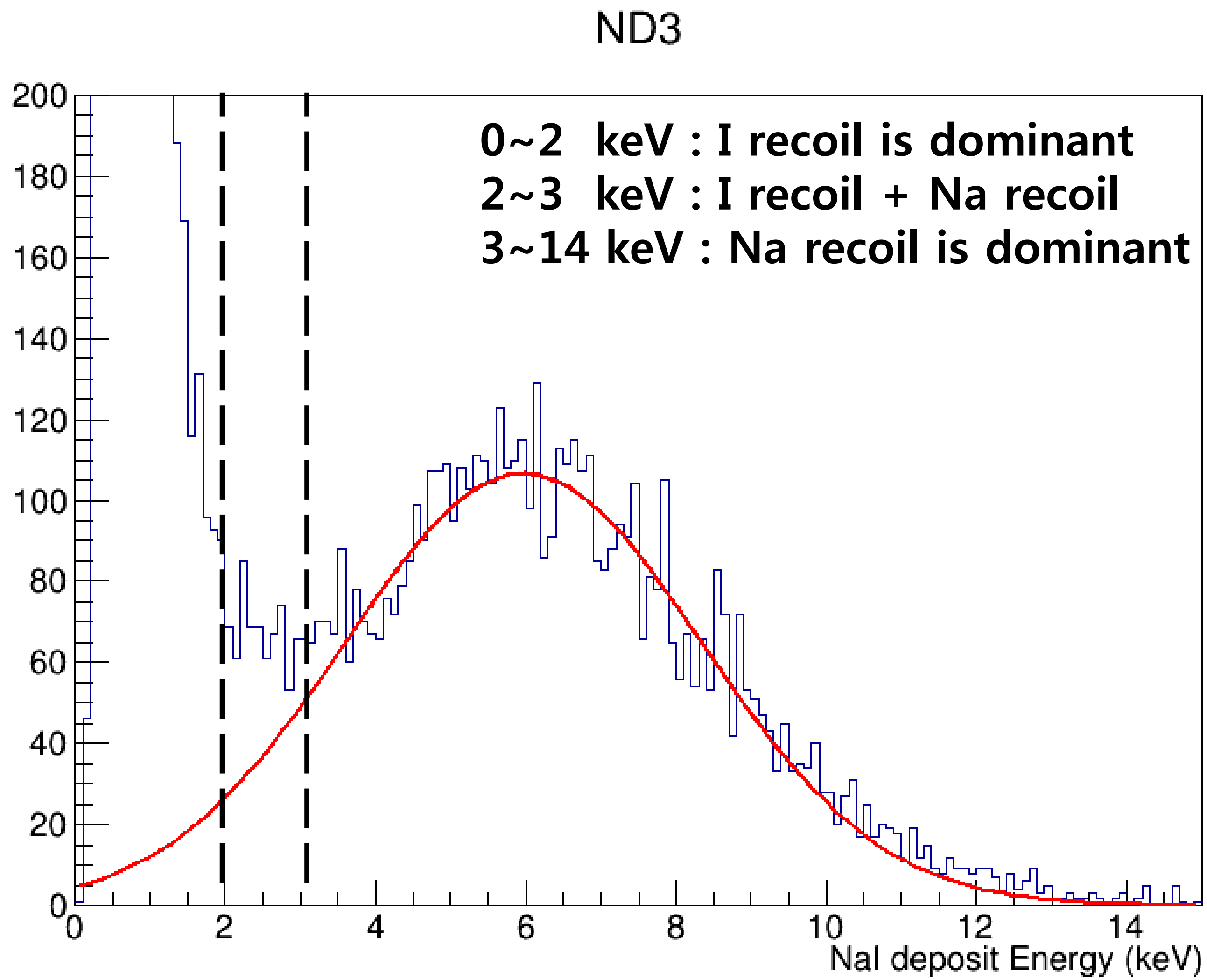


Calculated visible energy of I recoil events < 10 keV

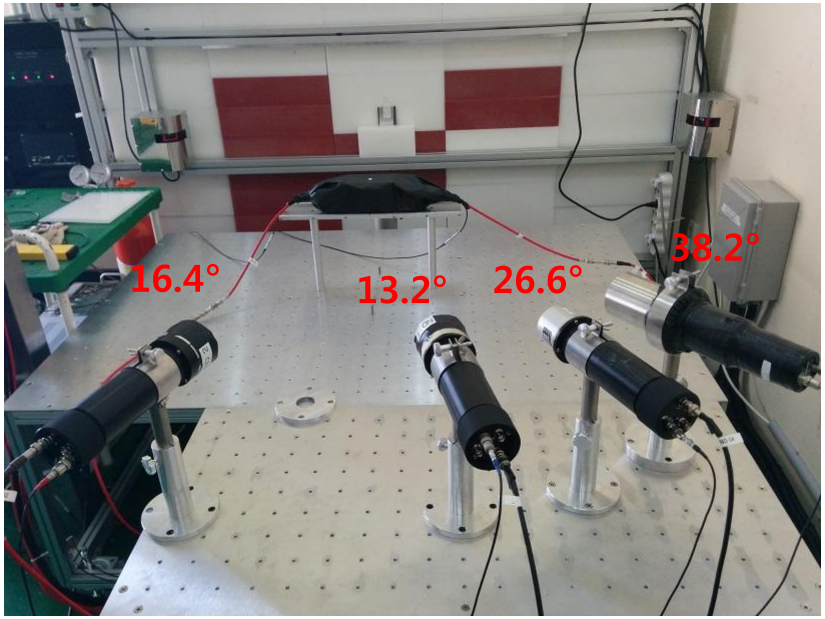
(energy of neutron < 8 MeV)

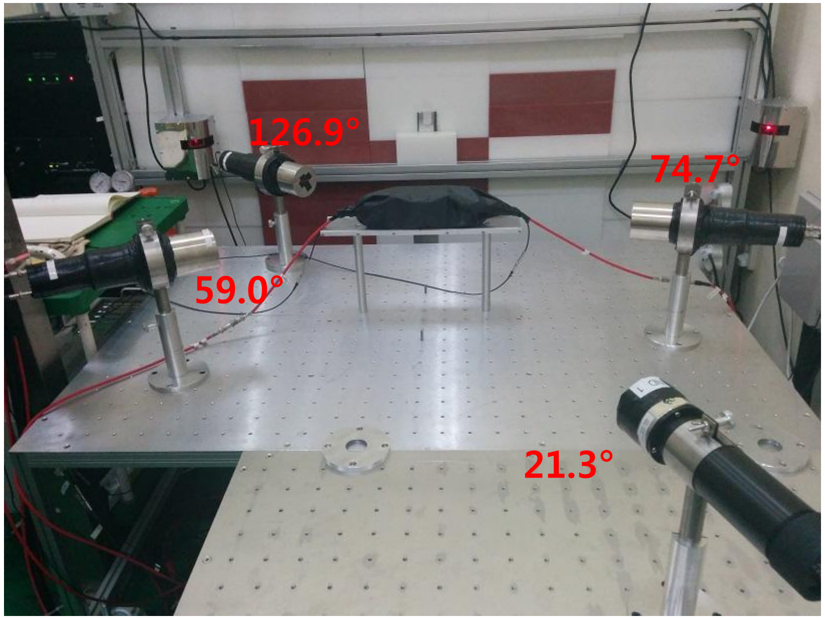
X axis : Neutron scattering angle
Y axis : Cross secion
(data from ENDF)

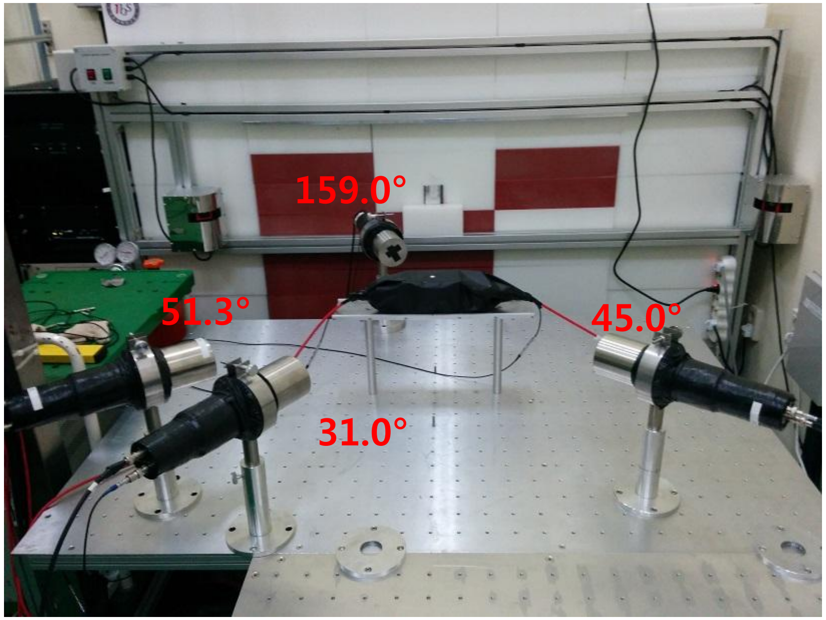
Deposit energy on NaI



Experimental setup for quenching factor measurement





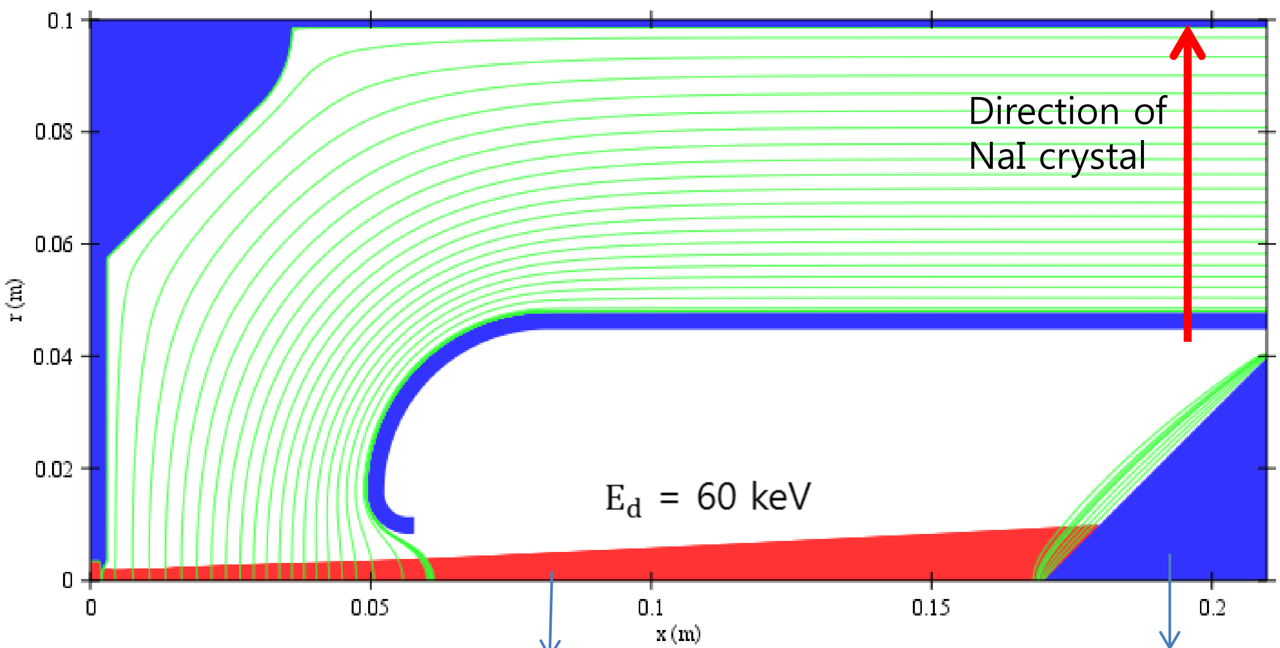


Neutron Generator

- The fusion process of making neutrons (1x10^8 /s)

  D + D $\longrightarrow$ n + ^{3}He (Q = 3.27 MeV)

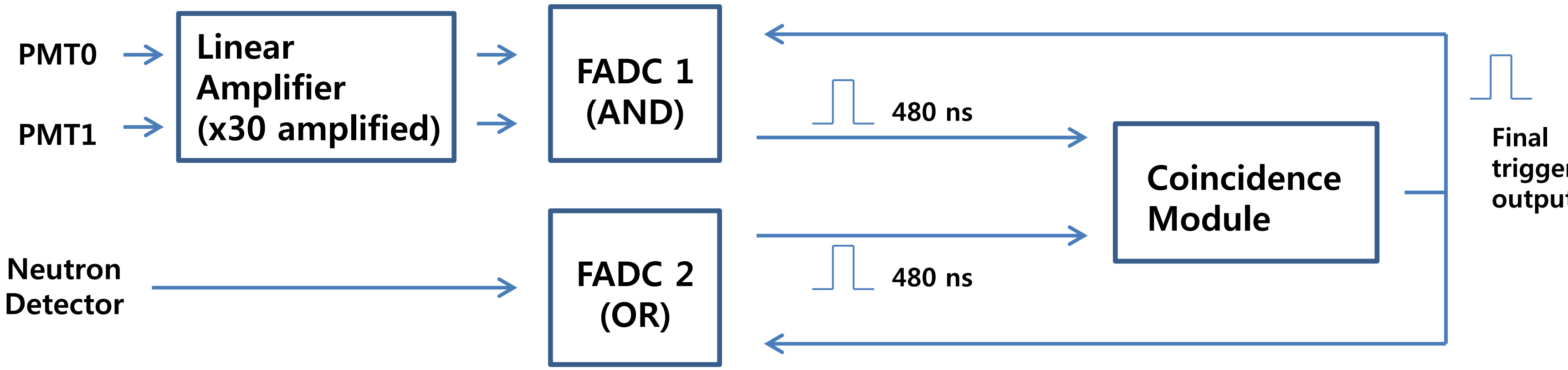
$$E_n^{1/2} = \frac{1}{\mathrm{M_{He}+M_n}}\left[\sqrt{\mathrm{M_d * M_n * E_d}} * \cos\theta \right.$$
$$\left. + \sqrt{\mathrm{M_d * M_n * E_d} * \cos^2\theta + (\mathrm{M_{He}} + \mathrm{M_n})[(\mathrm{M_{He}} - \mathrm{M_d})\mathrm{E_d} + \mathrm{M_{He}} * \mathrm{Q}]}\right]$$



Spread Deuterium Beam

Deuterium Target
(Flat & 45° leaned)

Trigger logic



Threshold voltage

- PMT : 10 mV
- Neutron Detectors : 50 mV

Pulse width trigger for neutron detector

- Neutron detectors : 10 ns

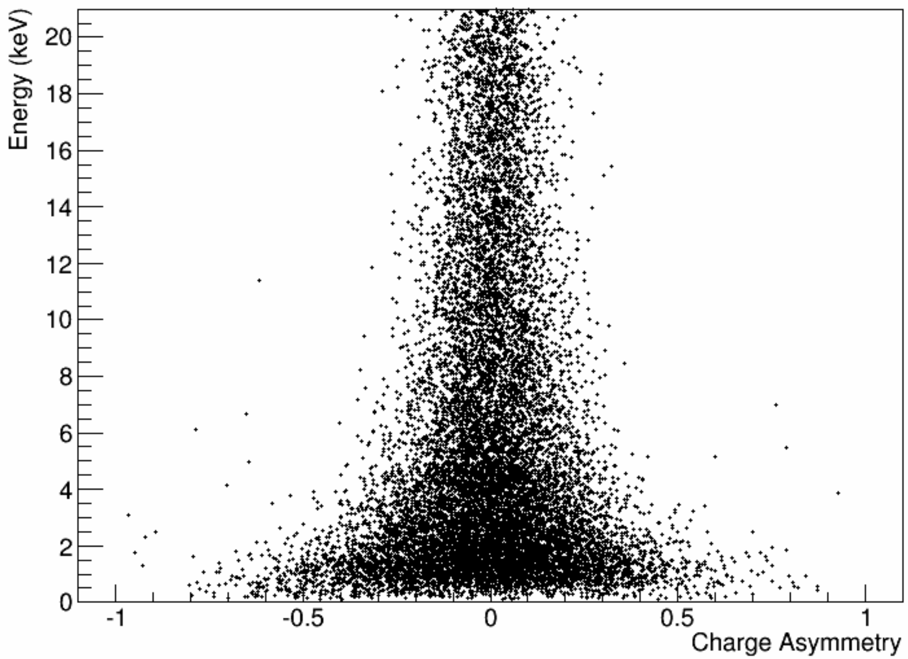
Pulse count trigger for NaI crystal

- Two or more pulses in each PMT
  & Sum of pulse count of PMTs is larger than four within 400 ns

Event cut for analysis

1. **Timing cut for PMTs**
   - Time difference between two PMTs < 0.2 (μs)
   - Start position of signal > 2.0 (μs)　　　(Trigger Position : 3 μs)

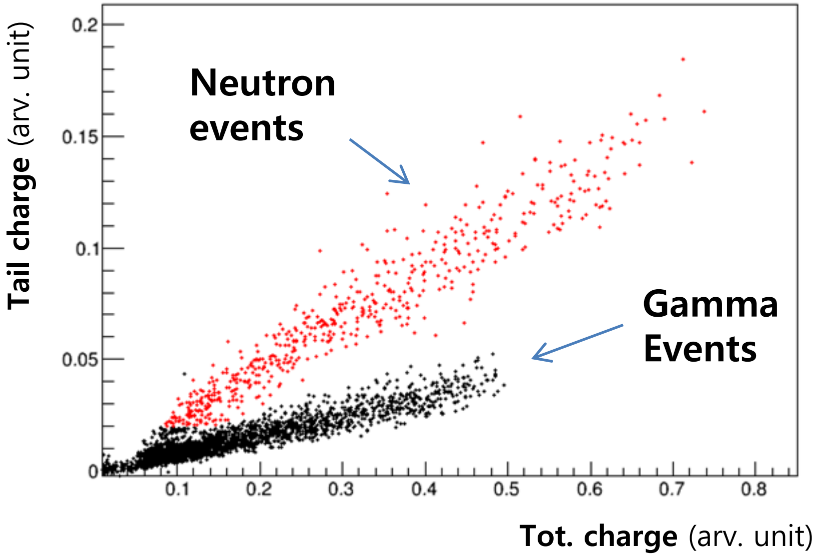
2. **Charge Asymmetry cut for PMTs** (-0.6 < charge asymmetry < 0.6)



$$\left(= \frac{\text{QC of left PMT} - \text{QC of right PMT}}{\text{QC of left PMT} + \text{QC of right PMT}} \right)$$

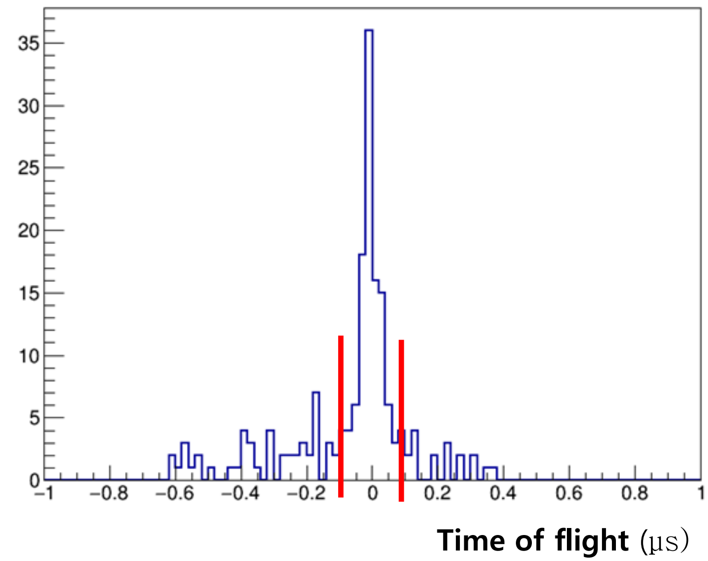
Event cut for analysis

Neutron Detector PSD



X axis : charge sum over 200 ns
Y axis : charge sum from 50 to 200 ns

Time of flight



X axis : Time difference between NaI signal and ND signal

ln(MT) calculation with clustering algorithm

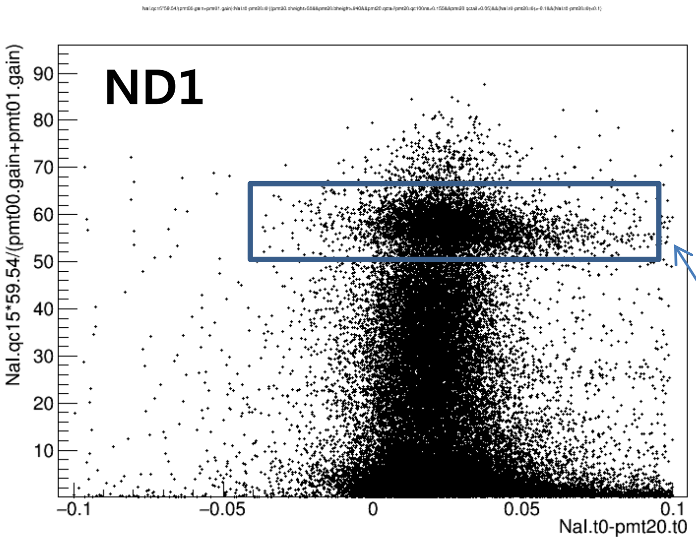
For clusters with time0x[n] < det0.t0 + 1.5

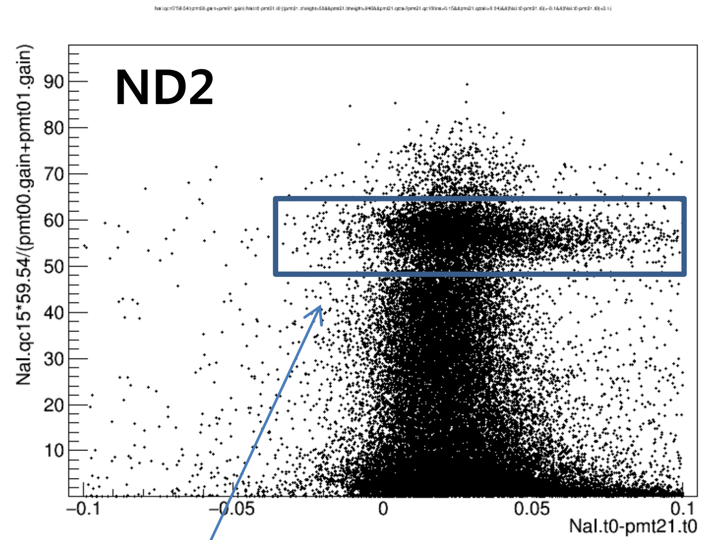
$$MT = \frac{1}{2} * \left(\frac{\sum clust00[n] * (time00[n] - det0.t0)}{\sum clust00[n]} + \frac{\sum clust01[n] * (time01[n] - det0.t0)}{\sum clust01[n]} \right)$$

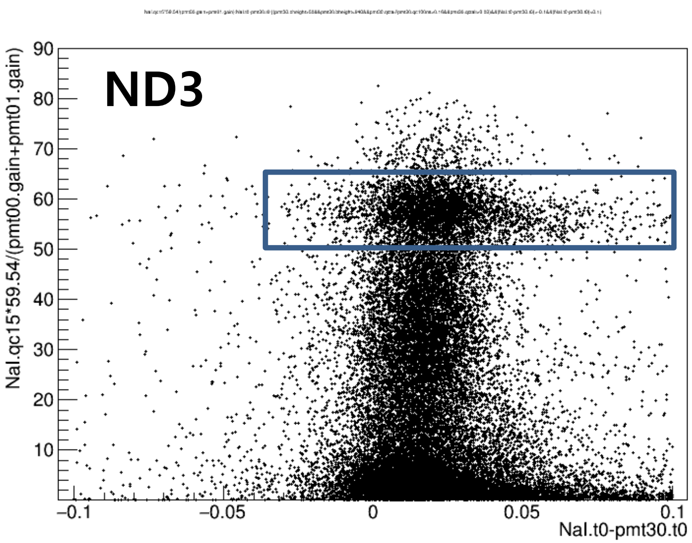
$$= \frac{1}{2} * \left(\frac{\sum clust00[n] * time00[n]}{\sum clust00[n]} + \frac{\sum clust01[n] * time01[n]}{\sum clust01[n]} \right) - det0.t0$$

clust0x[n] : charge sum of n th cluster of PMT x
time0x[n] : mean time of n th cluster of PMT x
det0.t0 : mean time of 1st cluster of NaI signal

NaI deposit energy vs. ToF (NaI~ND / SNU Am/Be)

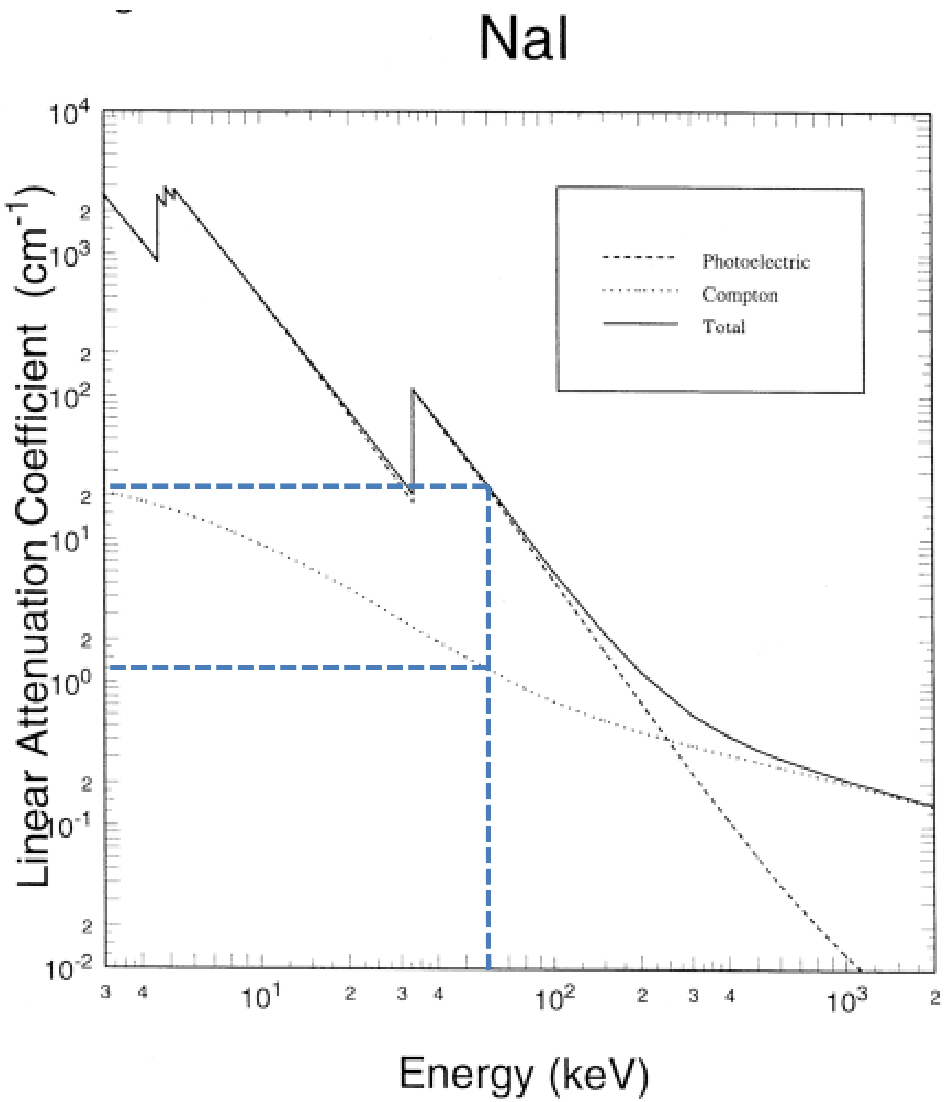






60 keV gamma ray events from Am source are remains after all cuts are applied.

Gamma ray absorption in NaI



Compton : ~5% of Photoelectric

& assuming scattered gamma is uniformly distributed in 0~40 keV

-> There are only 11 gamma events per 1 keV (~1 %) (9,000 * 0.05 * 0.025)

Not sufficient to explain difference in SNU and KRISS result