Measurement of Quenching factor and PSD power of NaI crystal

2016. 7. 18.
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- What is Quenching Factor?
- Experimental setup
- Preliminary result
- Summary & Plans

- In scintillation crystals, the light yields from electron and nuclear recoils of the same energy are different.

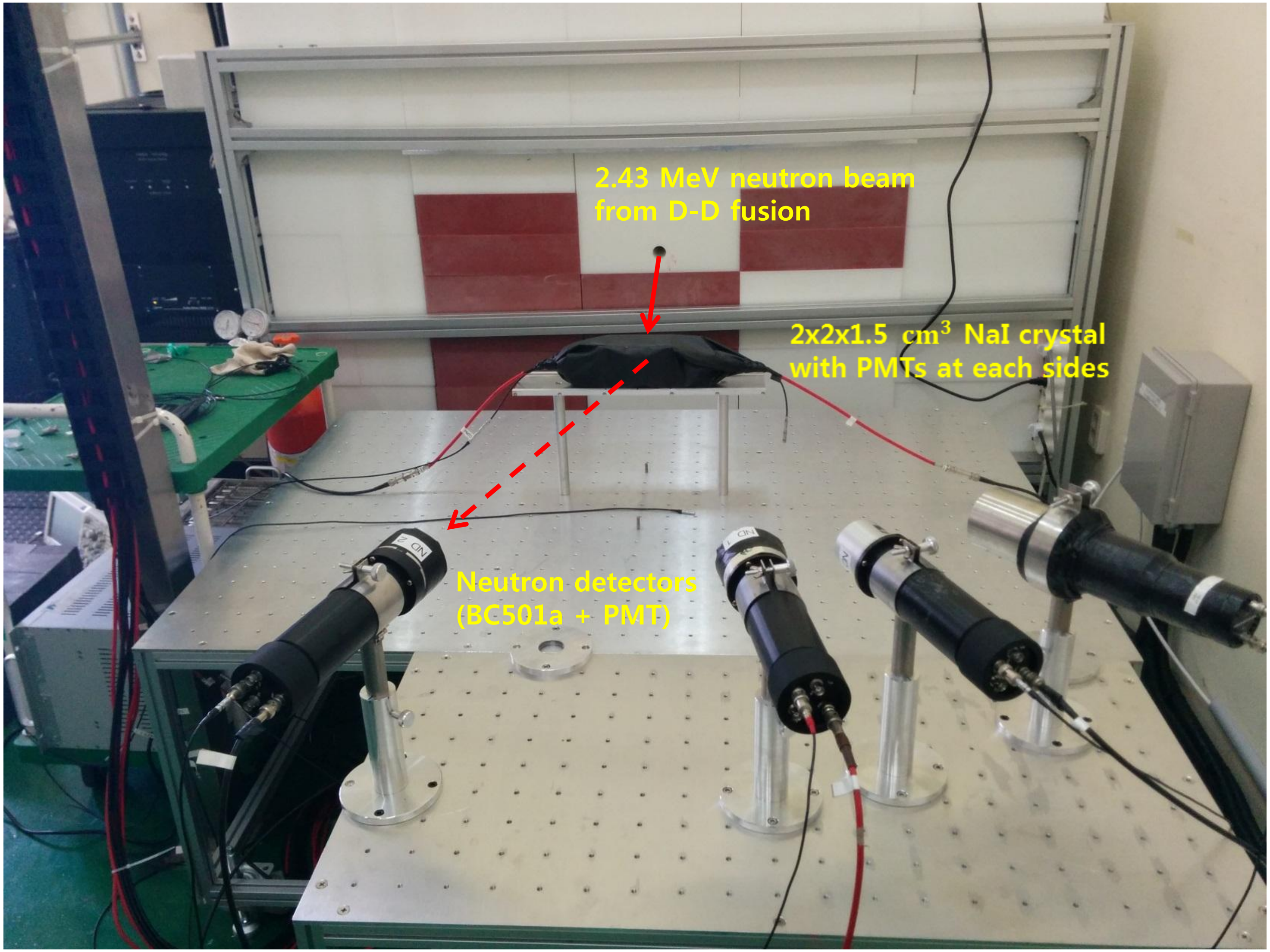
$$\text{Quenching Factor} = \frac{\text{Light yield from nuclear recoil}}{\text{Light yield from electron recoil}}$$

$$= \frac{\text{Measured energy from scintillation}}{\text{Nuclear recoil energy (Initial energy of scattered ion)}}$$

- Calibration : use gamma source -> electron recoil

- Interaction with dark matter : Nuclear recoil

Experimental Setup

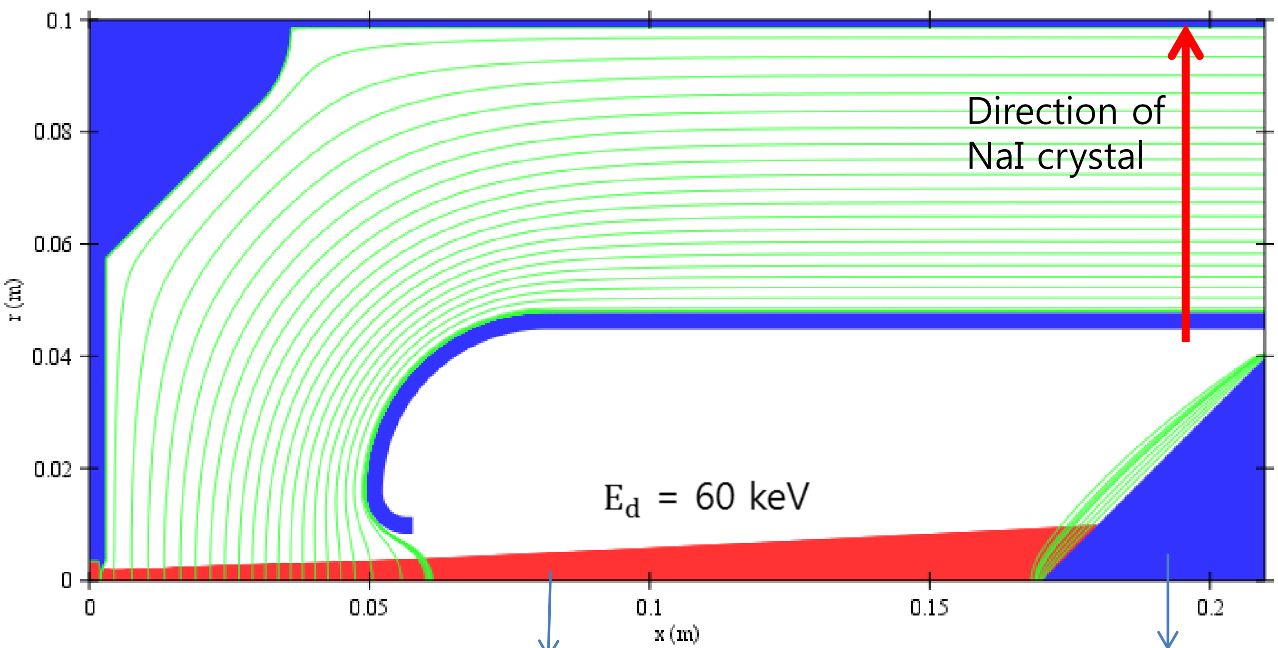


Neutron Generator

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

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

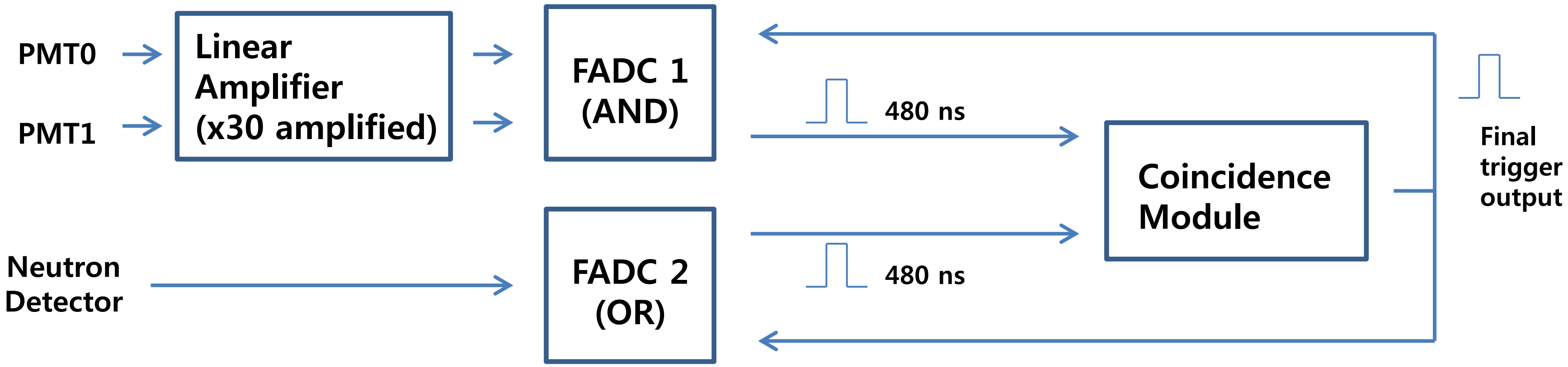
$$E_n^{1/2} = \frac{1}{M_{He}+M_n}\left[\sqrt{M_d * M_n * E_d} * \cos\theta + \sqrt{M_d * M_n * E_d * \cos^2\theta + (M_{He}+M_n)[(M_{He}-M_d)E_d + M_{He} * Q]}\right]$$



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

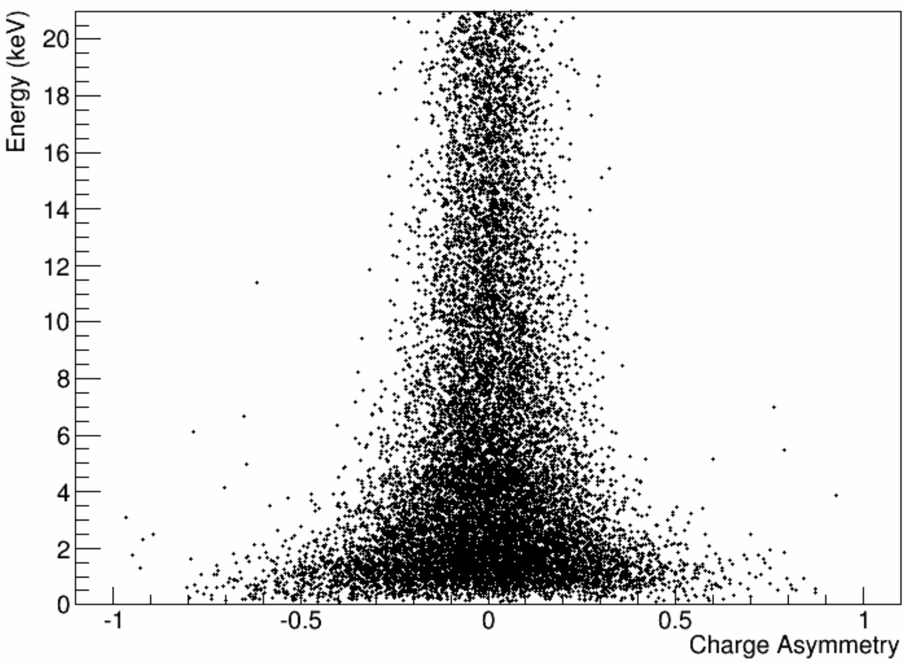
Pulse count trigger for NaI crystal

- 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)

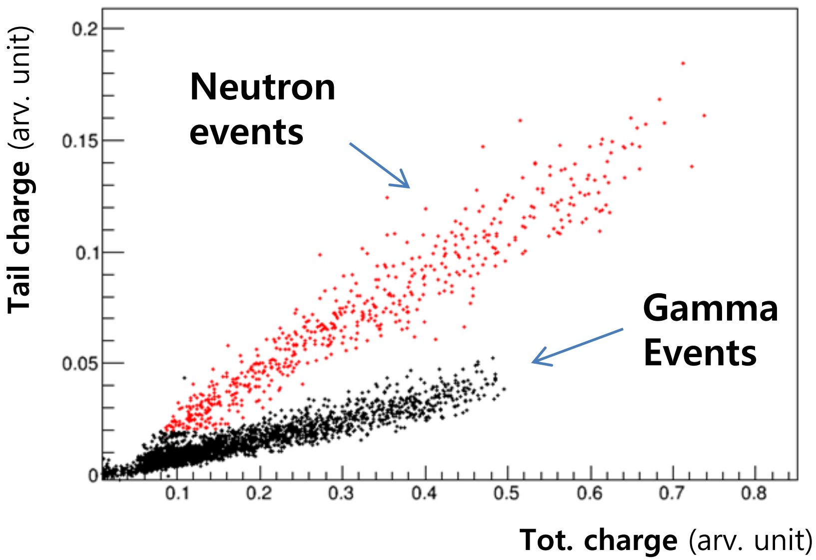
2. **Charge Asymmetry cut for PMTs** (-0.6 < charge asymmetry < 0.6)



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

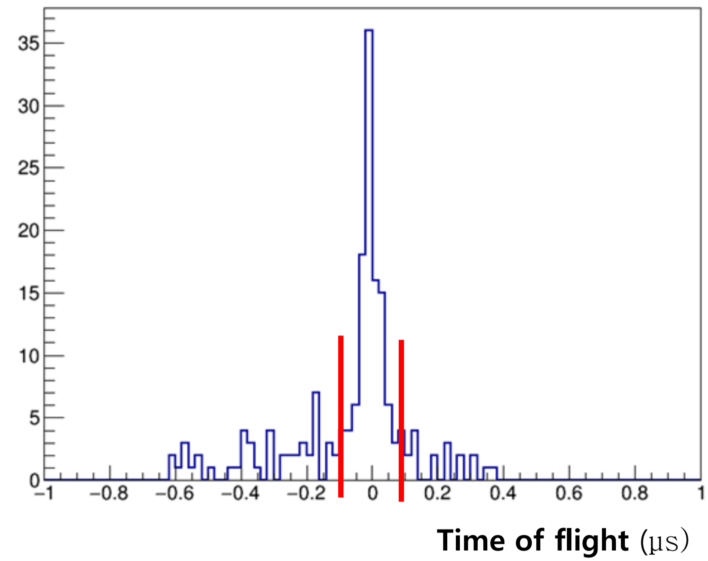
Event cut for analysis

3. Neutron Detector PSD



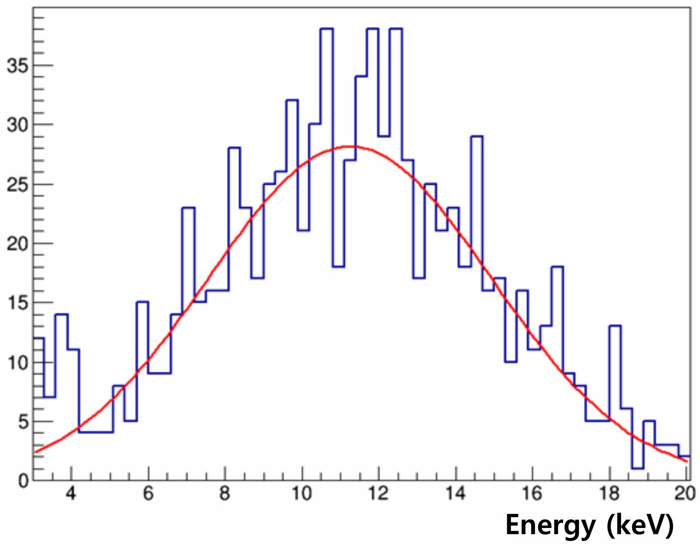
X axis : charge sum over 200 ns
Y axis : charge sum from 50 to 200 ns

4. Time of flight



X axis : Time difference between NaI signal and ND signal

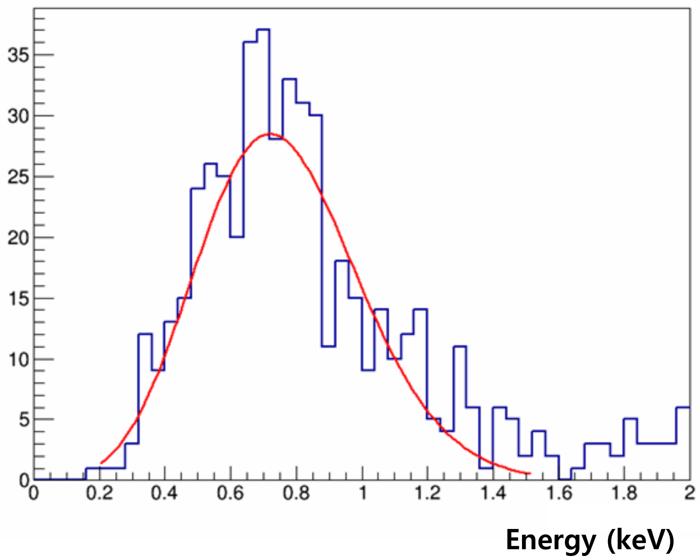
NaI deposit energy (when neutron is trigger by Neutron Detector at 45.0°)



Na recoil event

Gaussian fit (3 ~ 20 keV)

Mean = 11.26
Sigma = 3.67

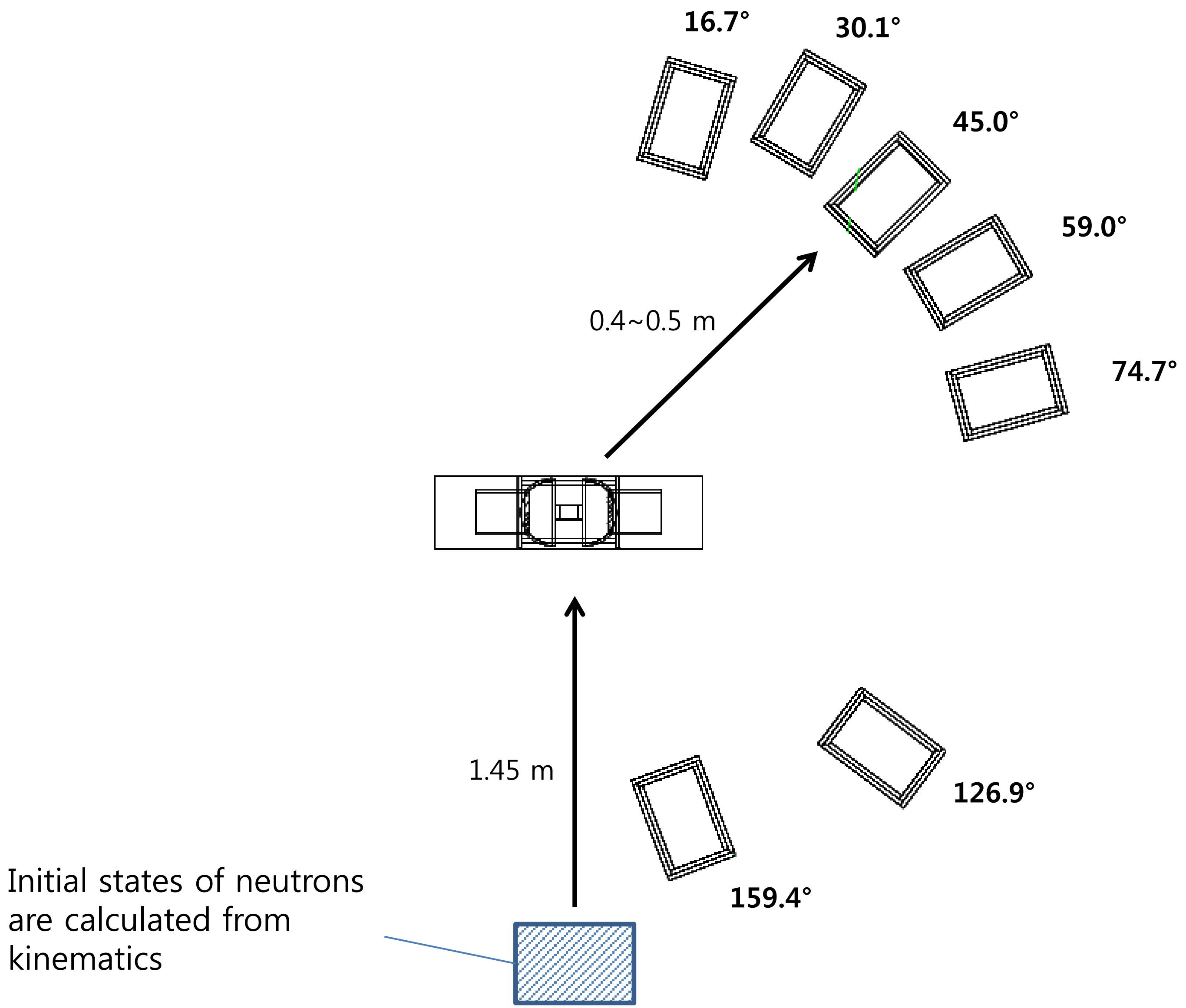


I recoil event

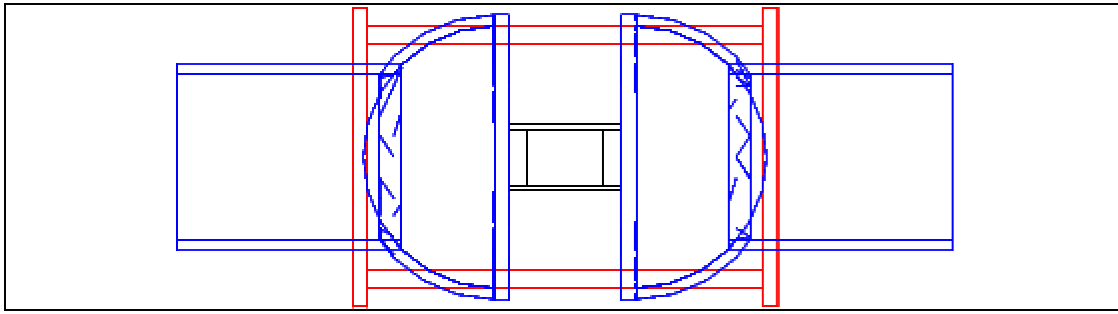
Poisson fit (0.2 ~ 1.5 keV)

Mean = 0.76
Sigma = 0.87

Simulation with Geant4

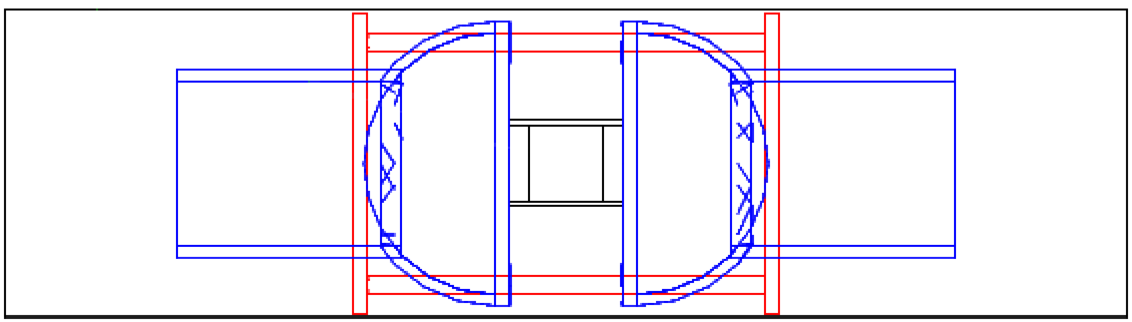


Simulation with Geant4

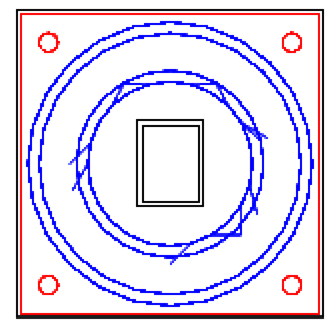


1 mm Black sheet

Upper View



Front View

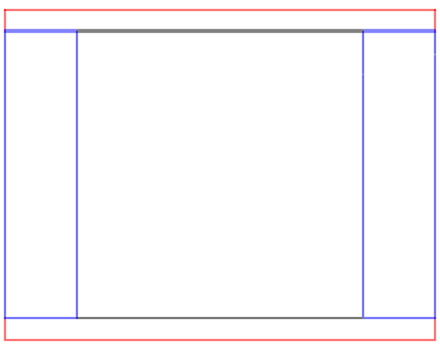


Side View

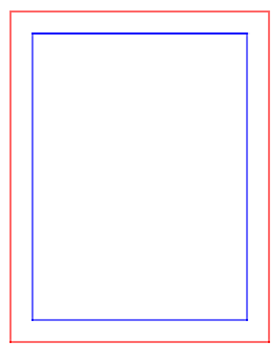
Blue : PMT (R12669)
Red : PMT Holder (with Al Plate x2 & Al Stick x4)

NaI Crystal

Upper View



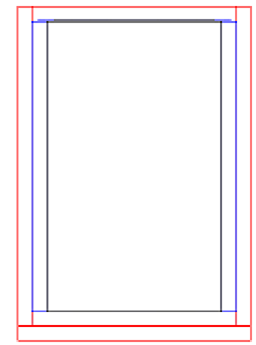
Front View



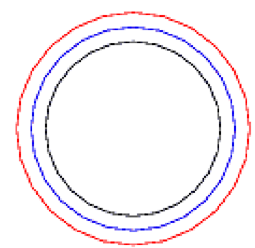
Side View

Blue : Quartz (5 mm thickness)
Red : Aluminum Housing (2 mm thickness)
Black : NaI Crystal (2x2x1.5 cm^3)

Neutron Detector



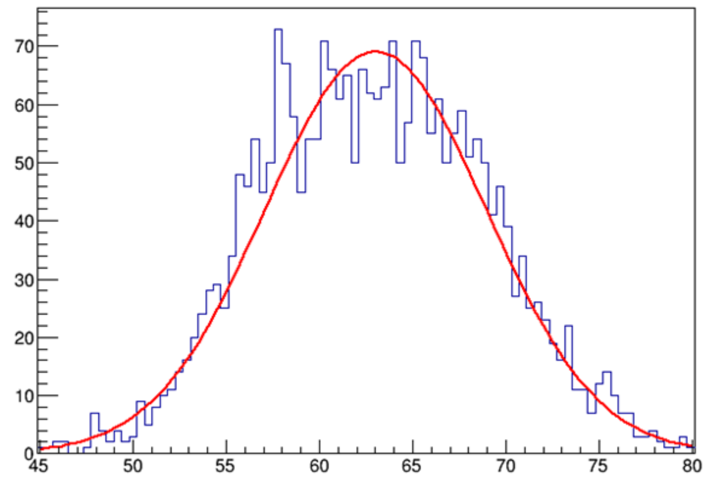
Upper View



Front View

Blue : Stainless Steel (5 mm thickness)
Red : Teflon (5 mm thickness)
Black : Bc501a (6 cm diameter)

Nuclear recoil energy (when neutron is trigger by Neutron Detector at 45.0°)

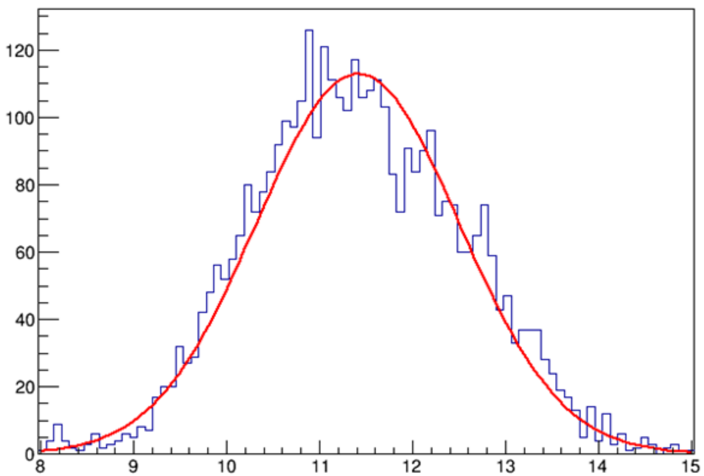


Energy (keV)

Na recoil event

Gaussian fit (45 ~ 80 keV)

Mean = 63.05
Sigma = 5.93



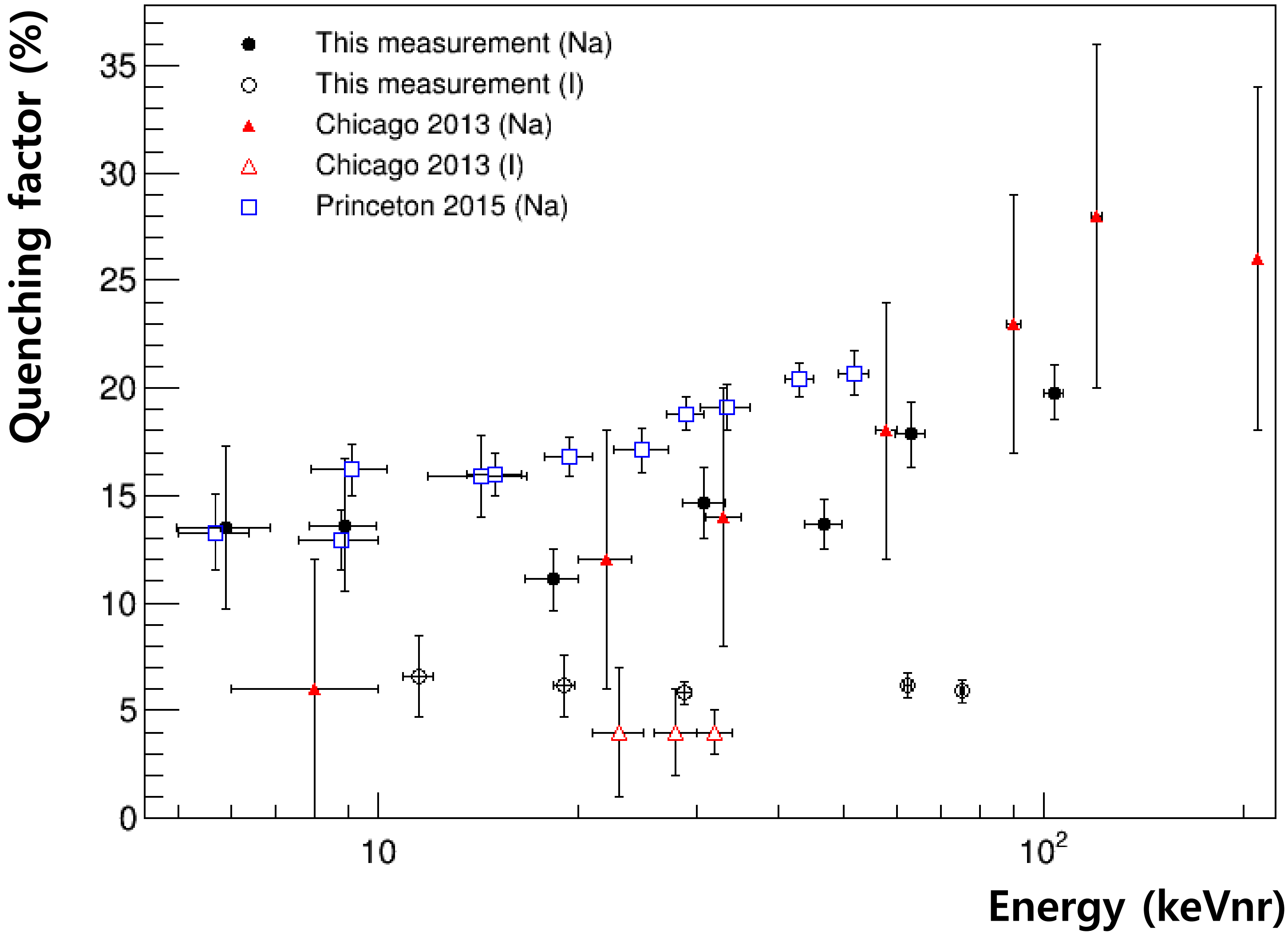
Energy (keV)

I recoil event

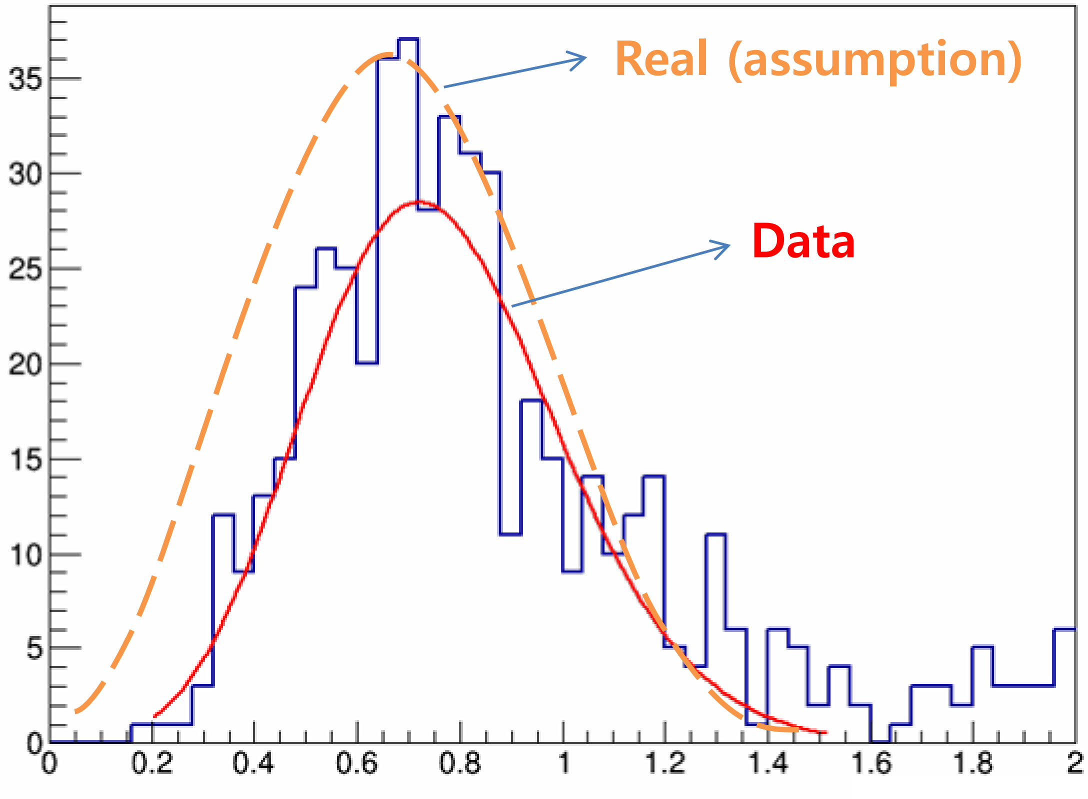
Poisson fit (8 ~ 15 keV)

Mean = 11.42
Sigma = 1.09

Preliminary Result

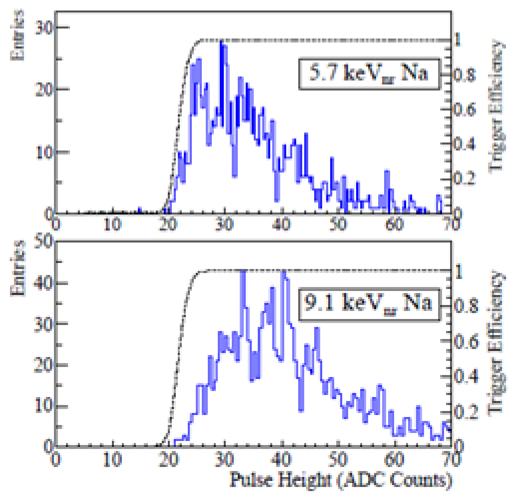


Trigger efficiency



Some events with low energies can be thrown away by trigger condition

-> Estimated quenching factor is large than real value.



arXiv:1503.07212v1

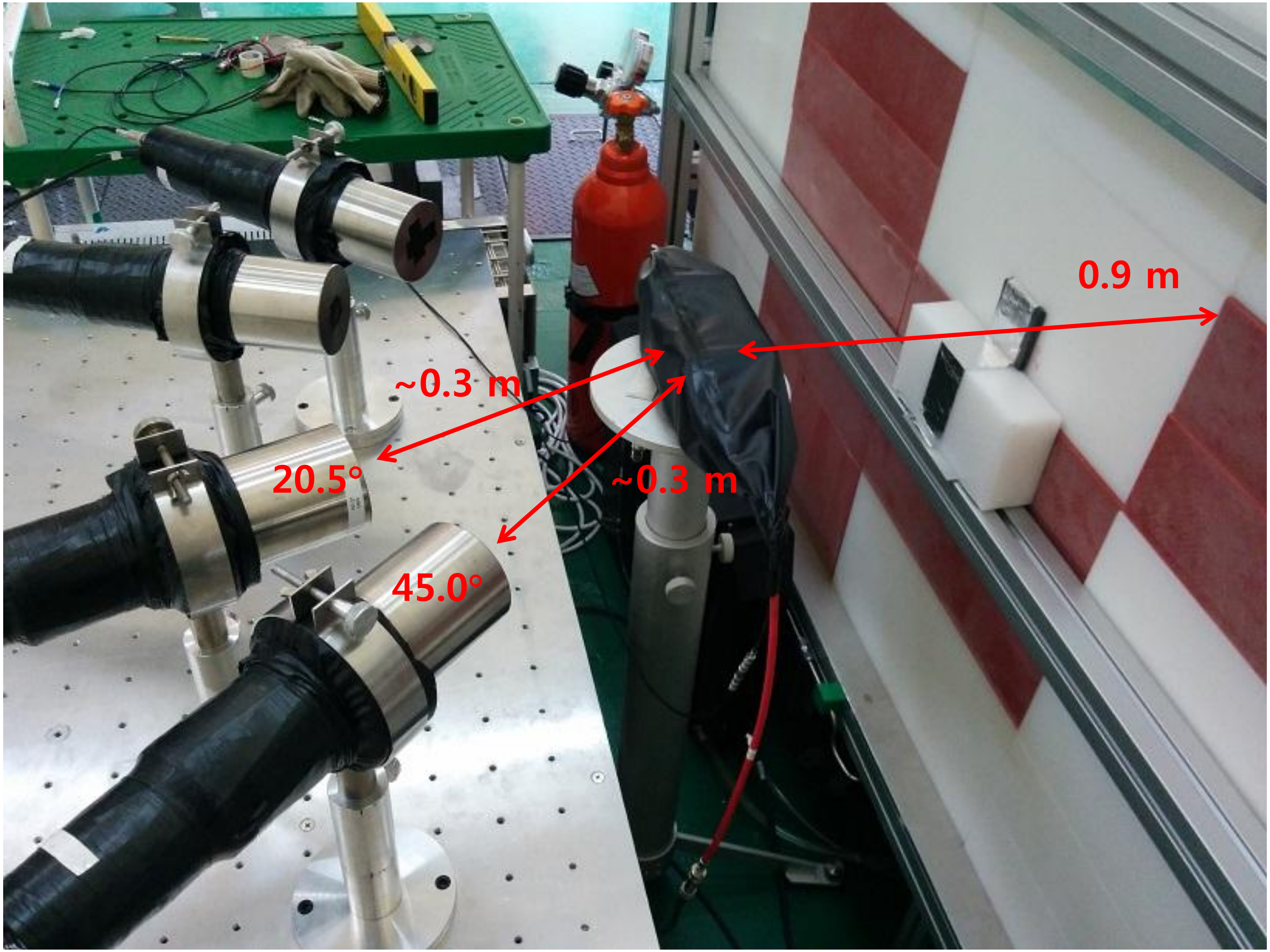
Summary & Plans

- **Quenching factor for NaI crystal was measured for recoiled sodium from 10 to 100 keVnr (14~20%) and for recoiled iodide from 10 to 75 keVnr (5~7%)**

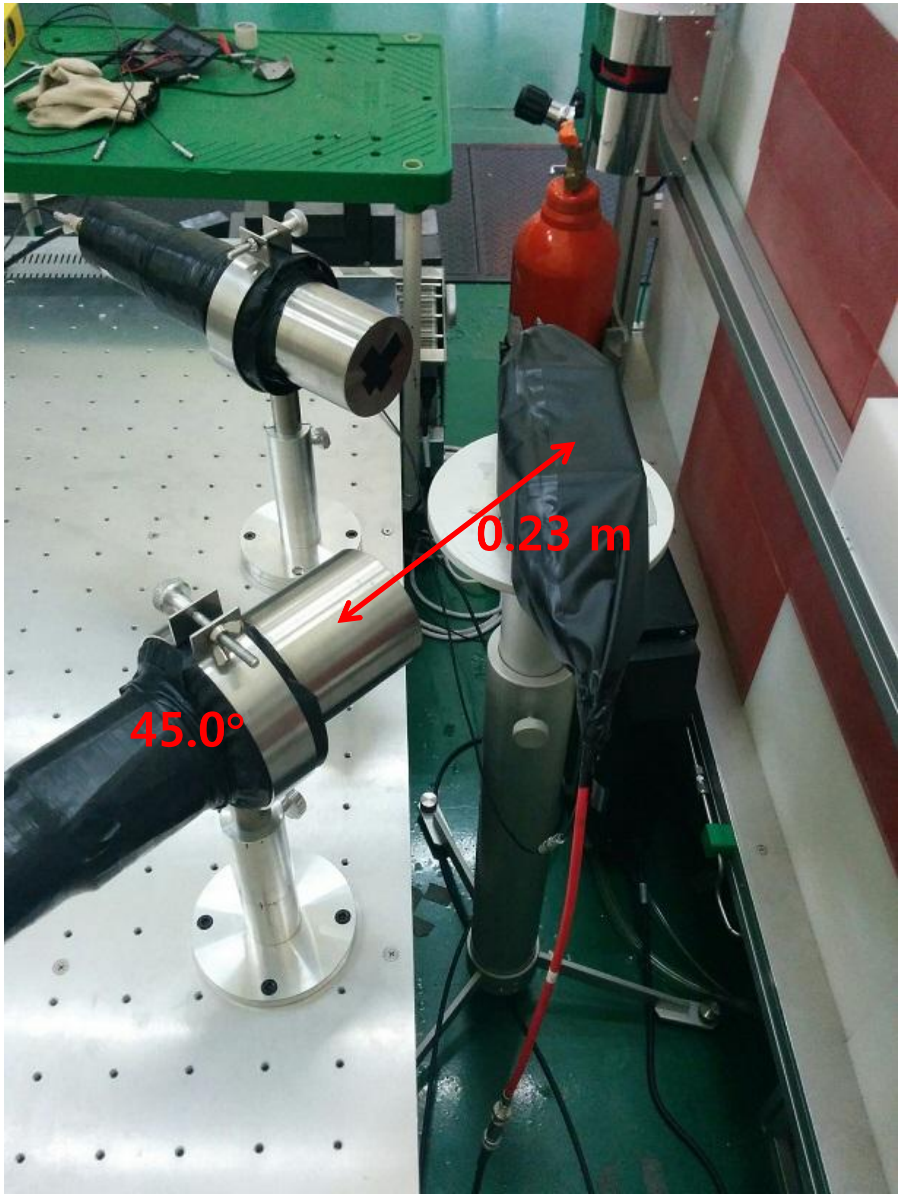
- **Additional analysis**
  - Trigger efficiency for NaI signals at low energy region

- **Additional measurement with other crystals**
  - With different dopant, size, etc…

Setup to measure Quality factor of NaI crystal



Setup to measure Quality factor of NaI crystal (set2)



ln(MT)

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

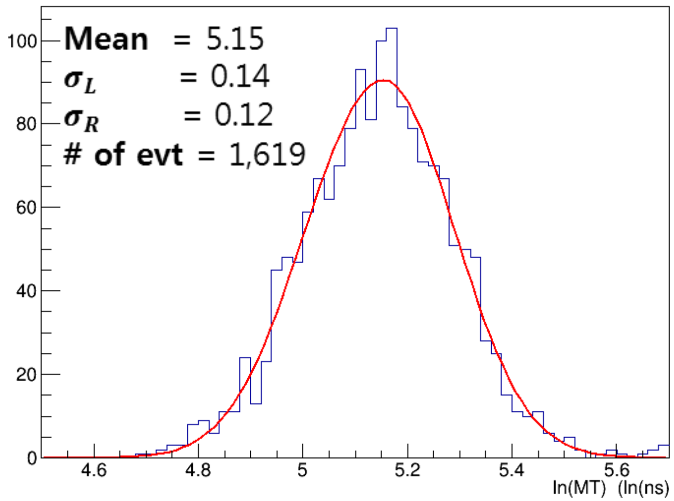
$$MT = \frac{1}{2} * \left(\frac{\sum clust00[n]*(time00[n]-det0.t0)}{\sum clust00[n]} + \frac{\sum clust01[n]*(time01[n]-det0.t0)}{\sum clust01[n]} \right)$$

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

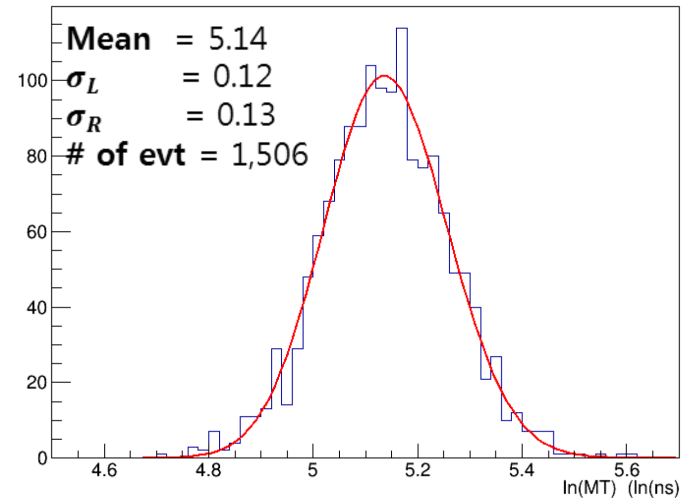
clust0x[n] : charge sum of n th cluster of PMT x
time0x[n] : mean time of n th cluster of PMT x
det0.t0 : mean time of 1st cluster of NaI signal

ln(MT) – Neutron generator - KRISS (Fit with Bi-Gaussian)

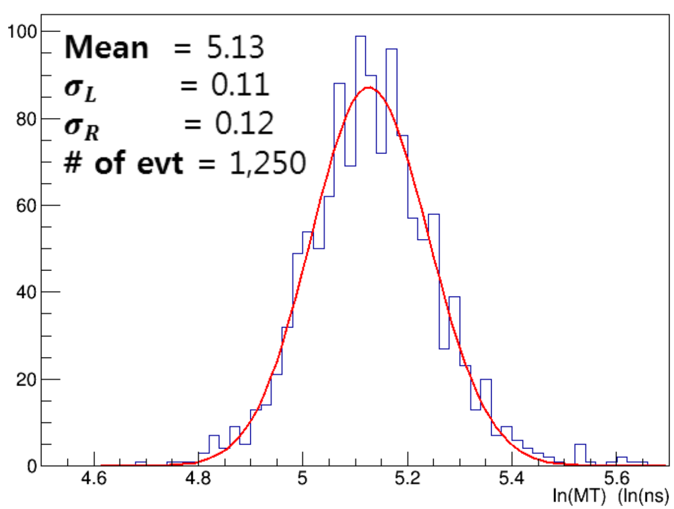
5~6 keV



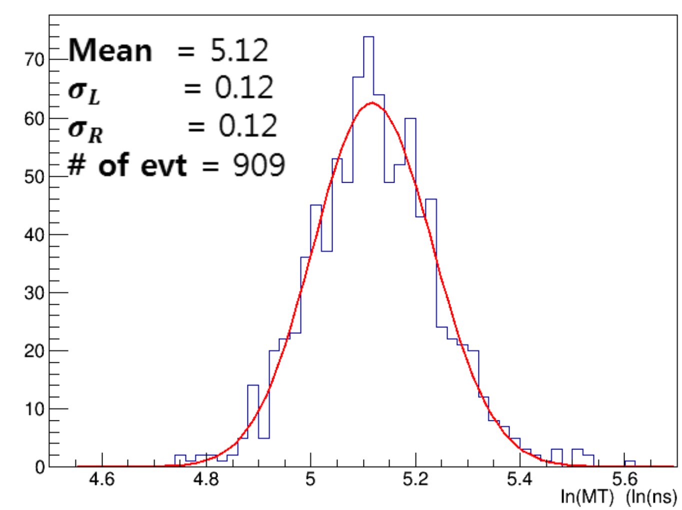
6~7 keV



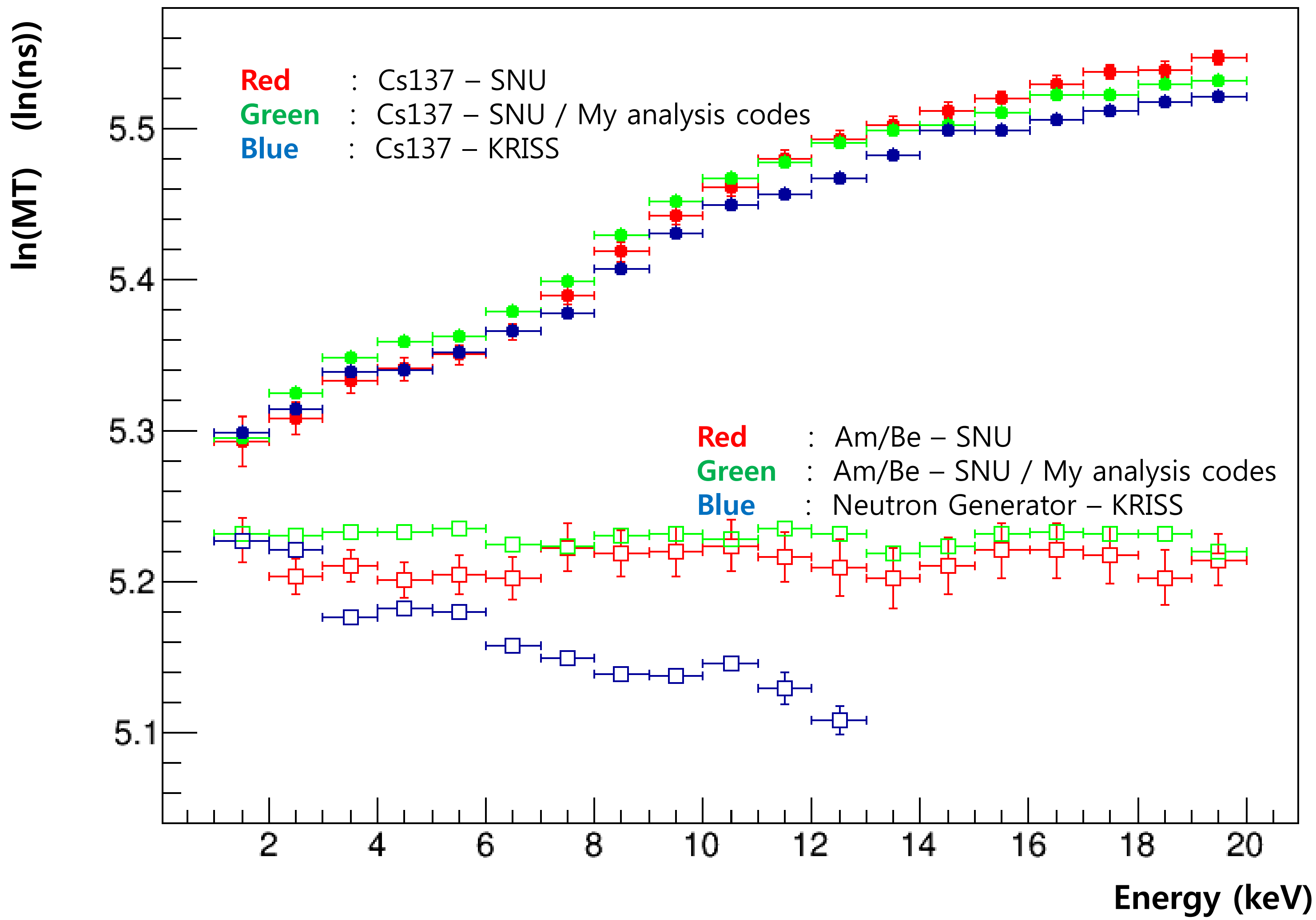
7~8 keV



8~9 keV

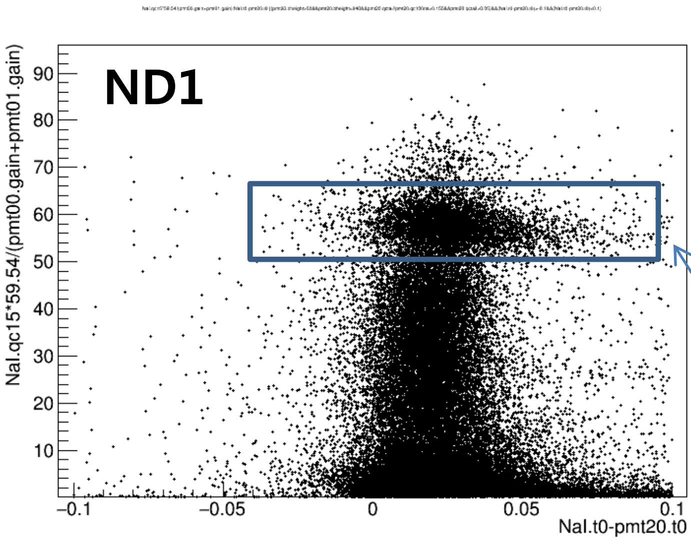


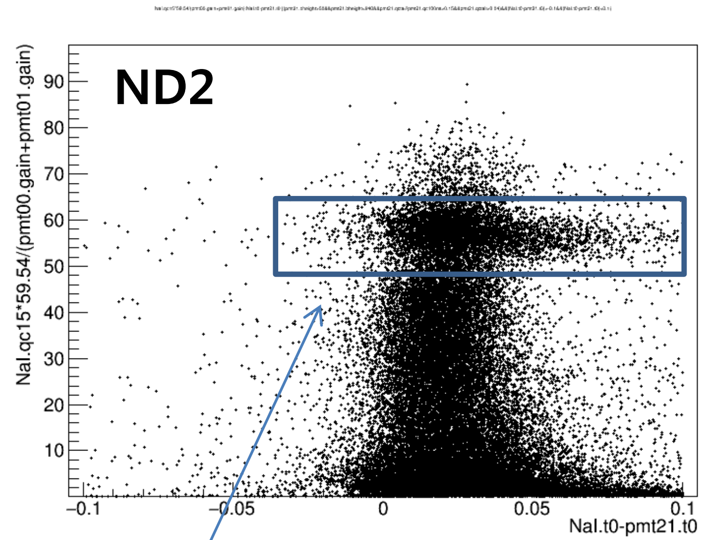
ln(MT) summary (temp)

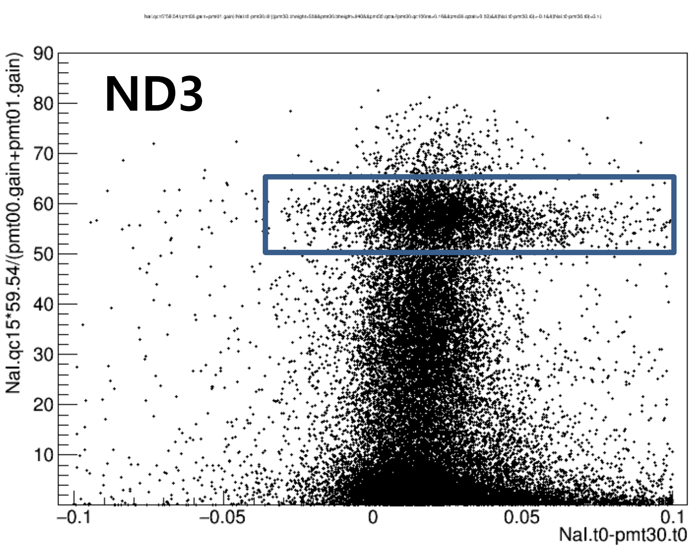


*For neutron generator data, generator was operated about 45 hours.
-> ~ 1,000 events/keV in 1~9 keV region

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

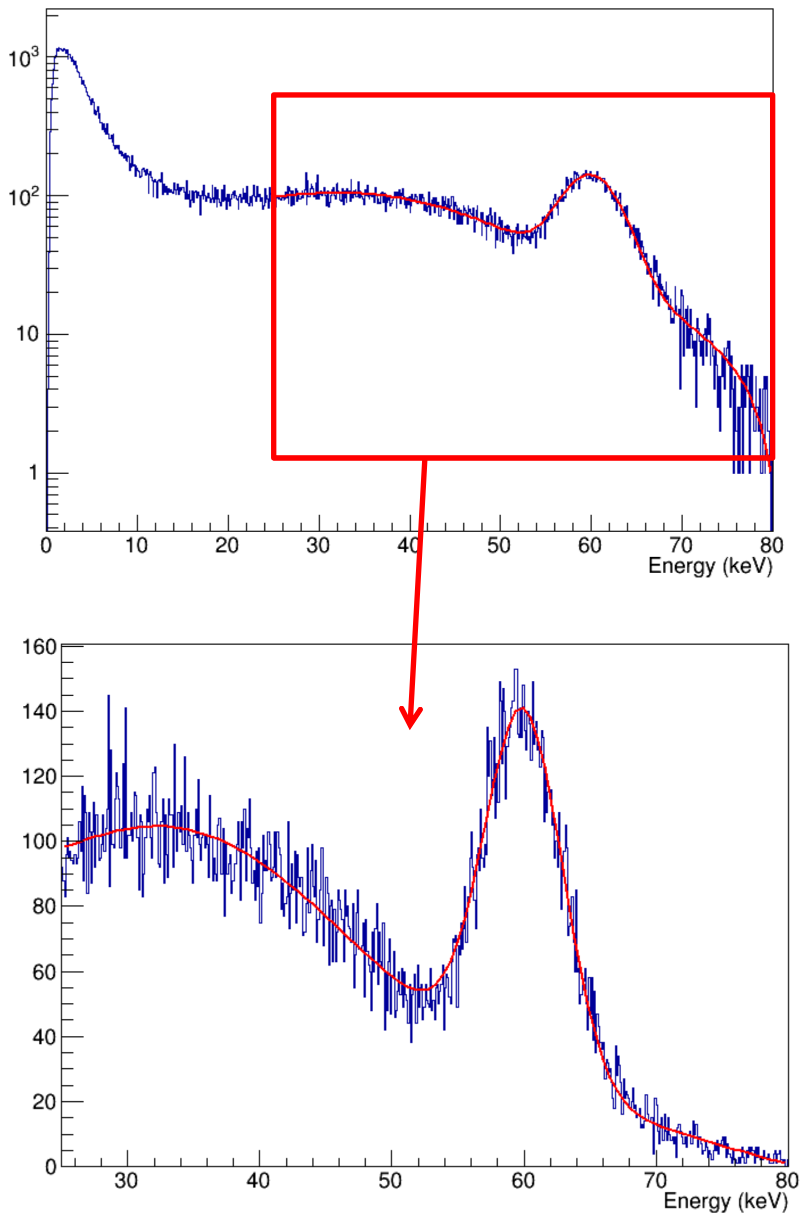






60 keV gamma ray events from Am source are remains after all cuts are applied.

Number of 60 keV gamma events in AmBe data



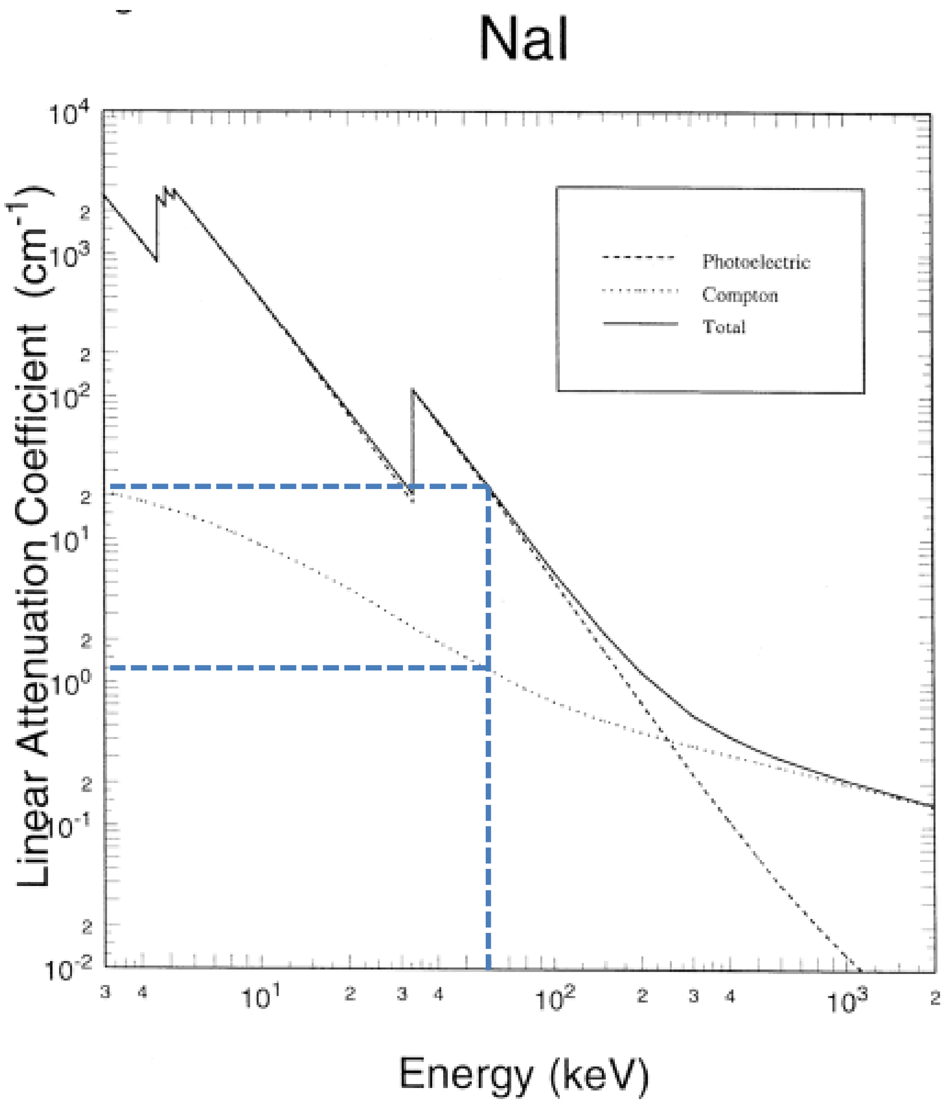
Fitting Function (Linear + two gaussian)

: **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

Gamma ray absorption in NaI



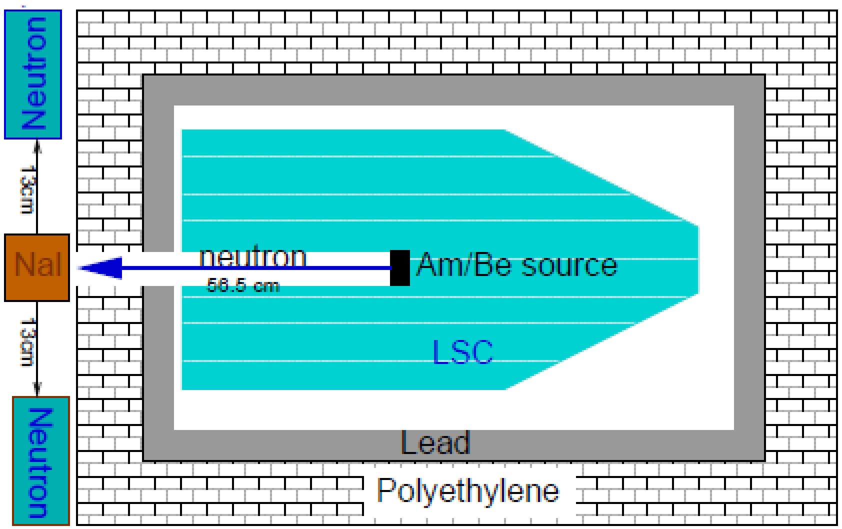
Compton : ~5% of Photoelectric

& 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)

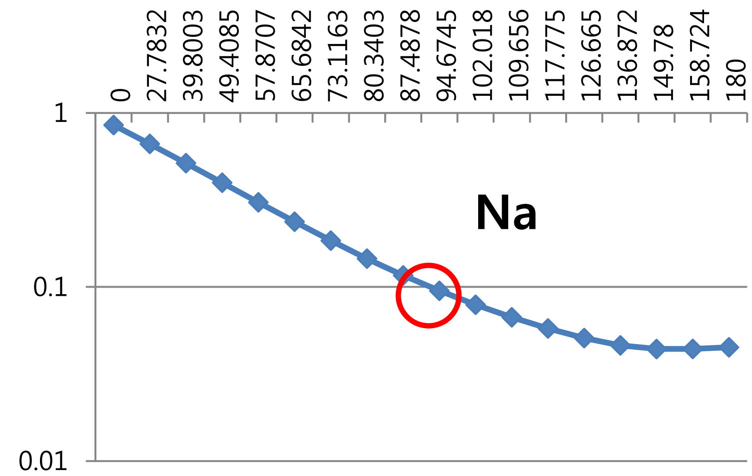
Not sufficient to explain difference in SNU and KRISS result

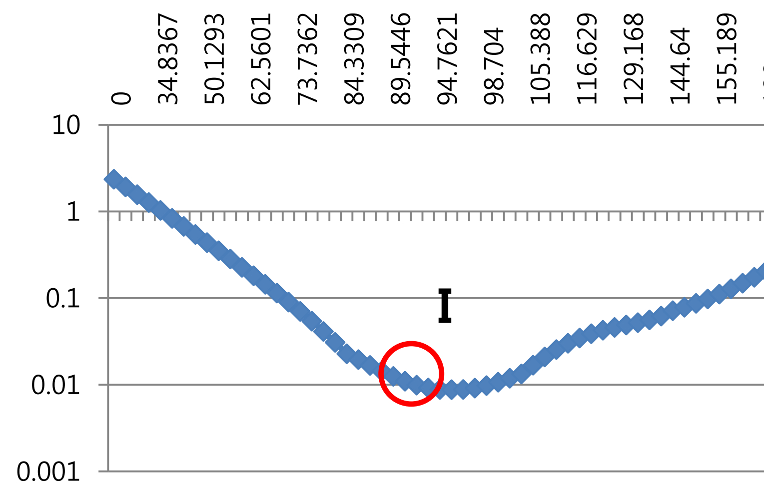
Am/Be experimental setup and cross section of Na and I



Calculated visible energy of I recoil events < 10 keV

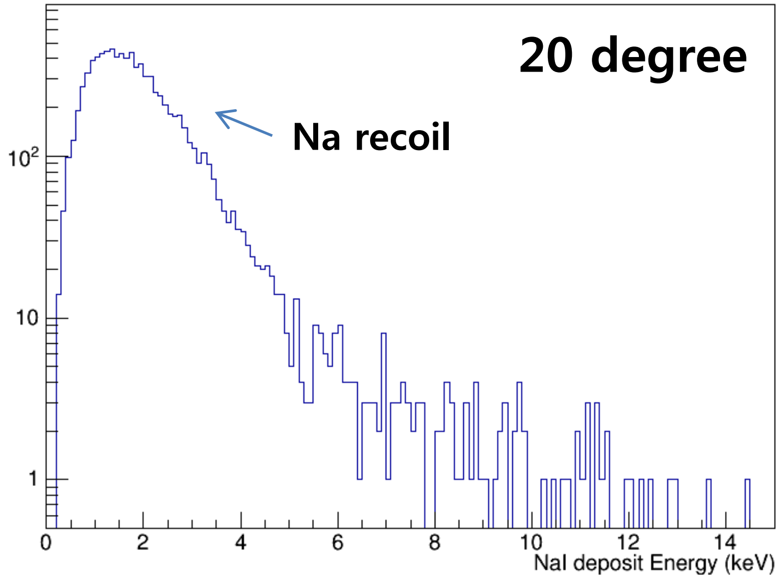
(energy of neutron < 8 MeV)

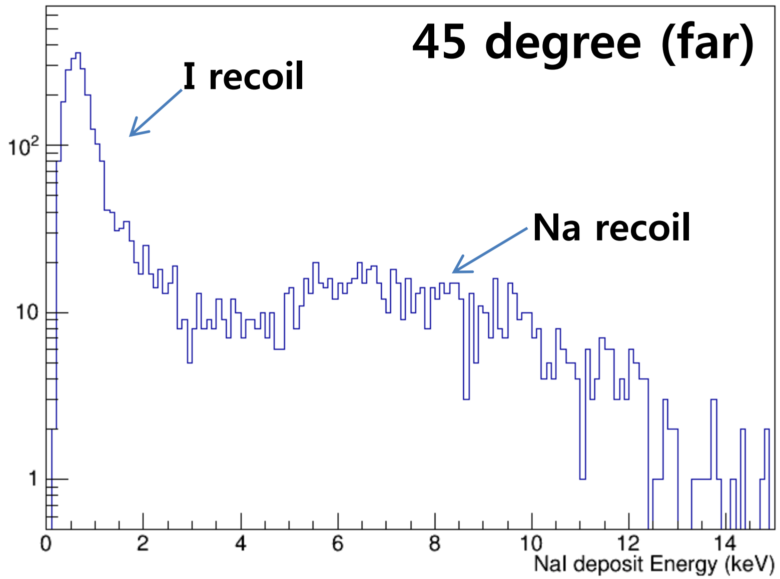


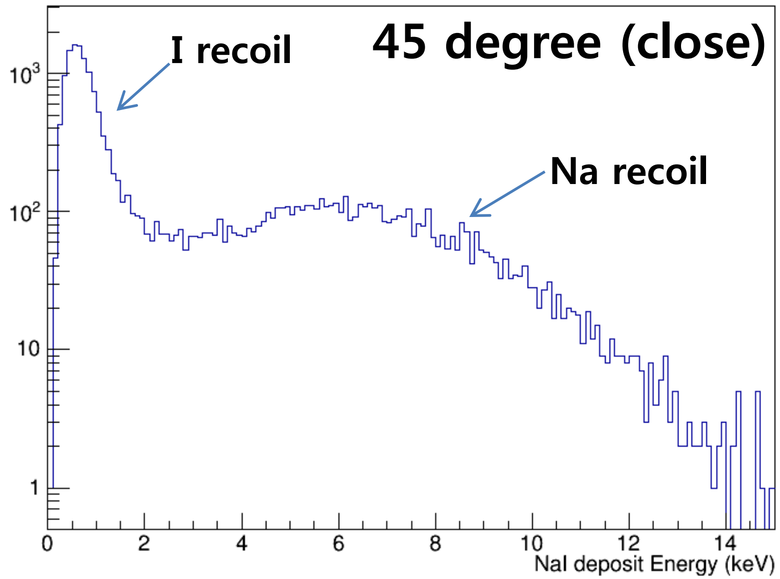


X axis : Neutron scattering angle
Y axis : Cross secion
(data from ENDF)

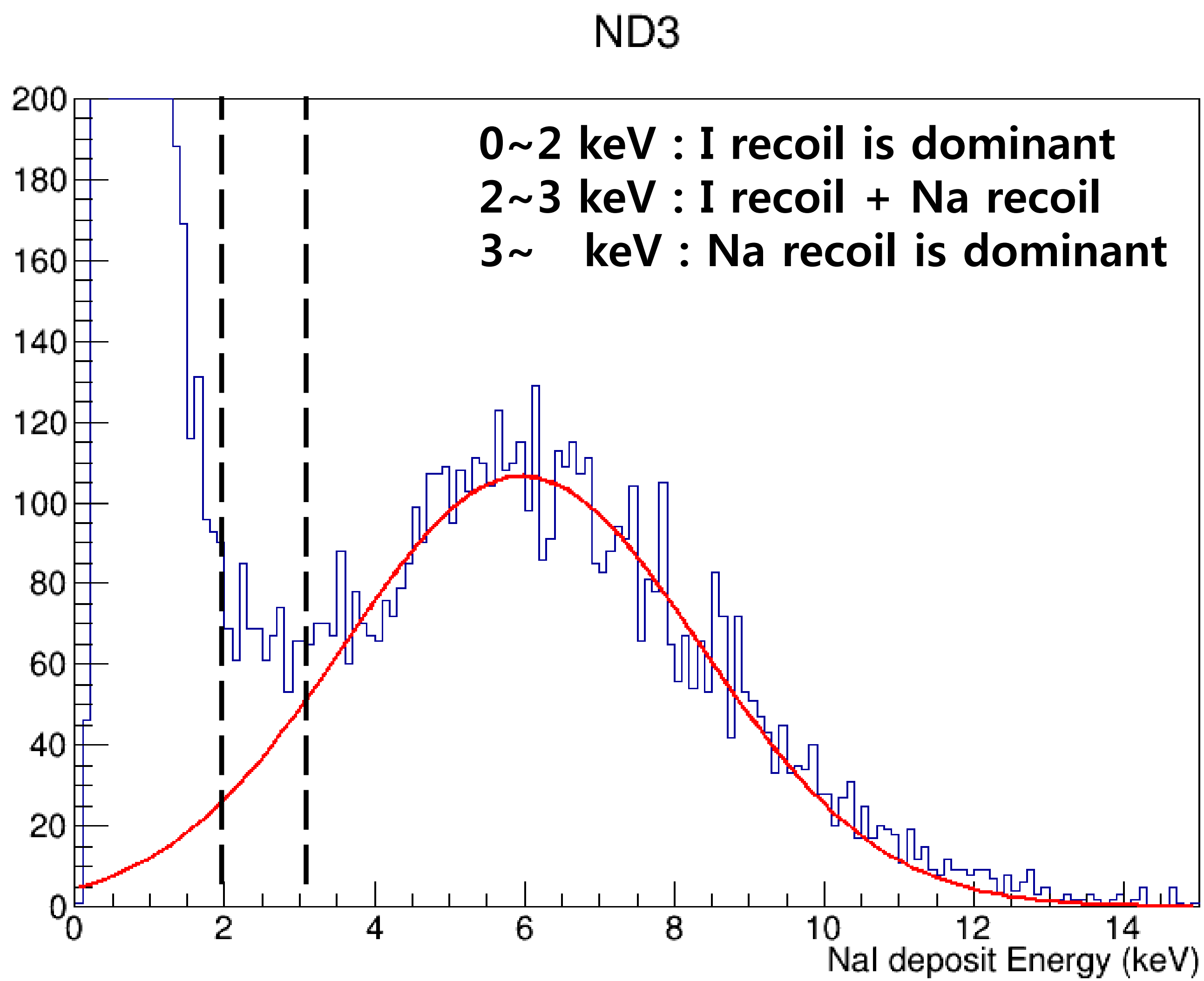
Deposit energy on NaI



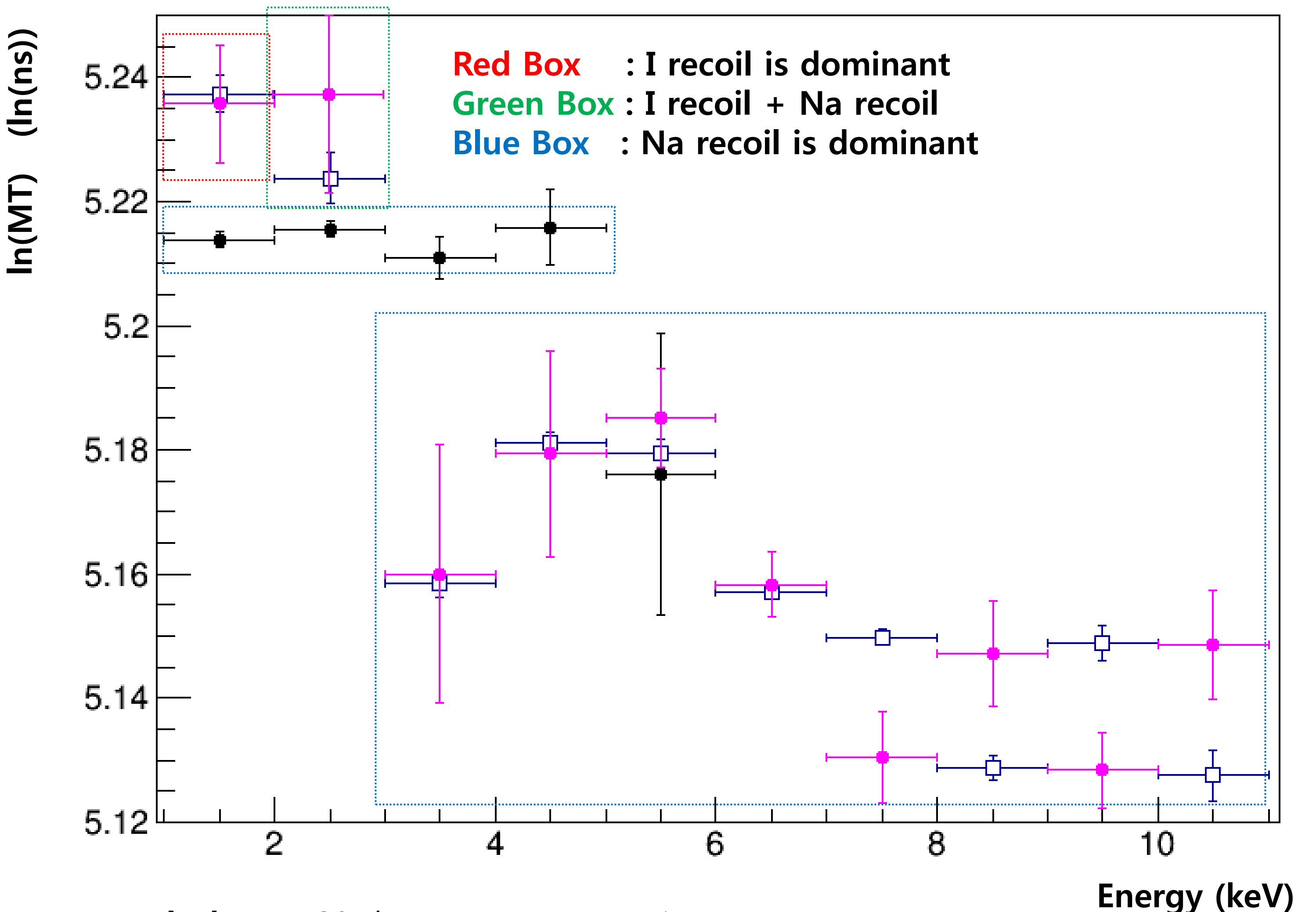




Deposit energy on NaI



ln(MT)



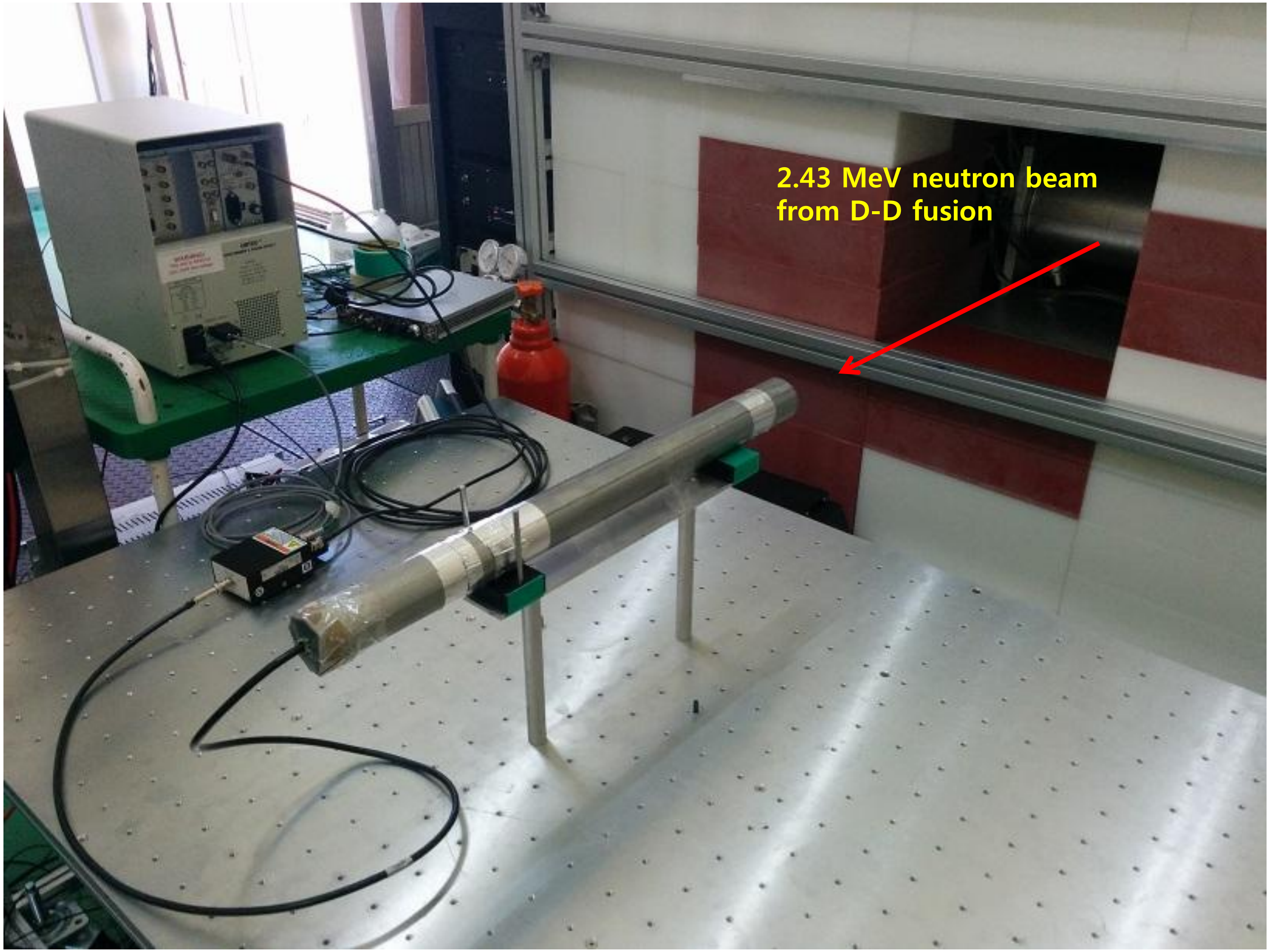
Black : 20 degree (set 1)
Purple : 45 degree - far (set 1)
Blue : 45 degree - close (set 2)

Summary & Plans

- **Measured PSD power of NaI crystal**
- **Different result with SNU result (same crystal)**
- **Found problem in DAQ trigger condition**
  -> DAQ is ongoing with fixed trigger condition
  (Still different with SNU data)

Backup Slides

Measured neutron beam energy with 50cm (5cm diameter) He3 detector



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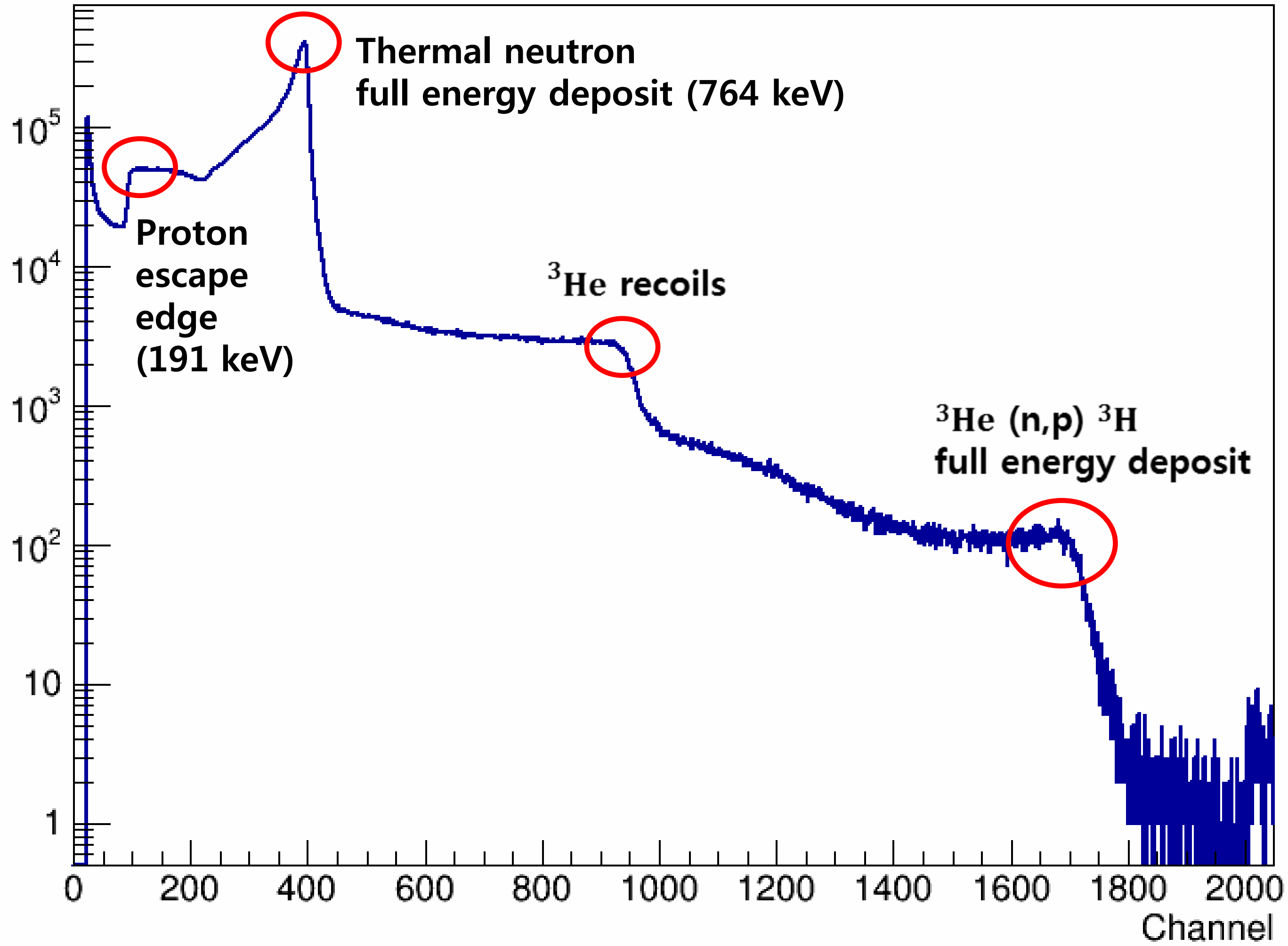
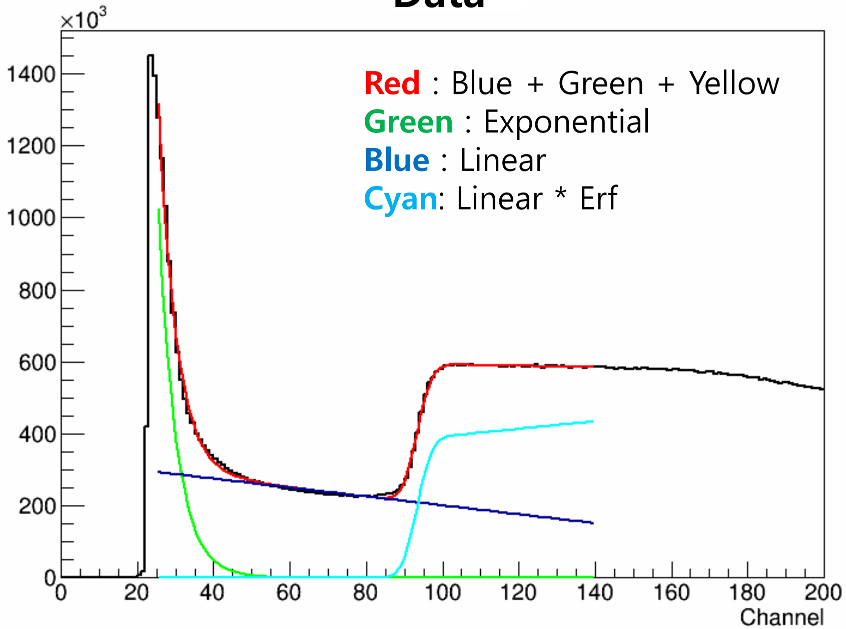
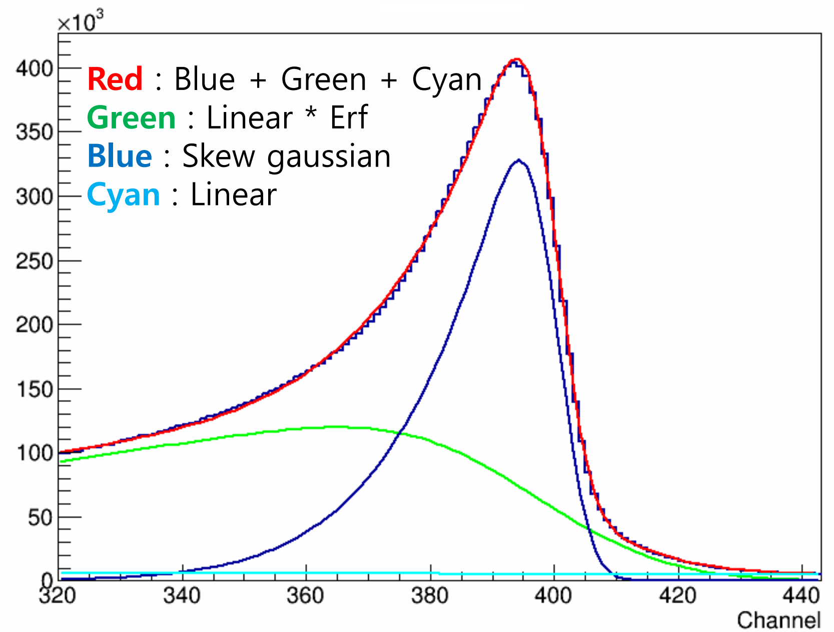


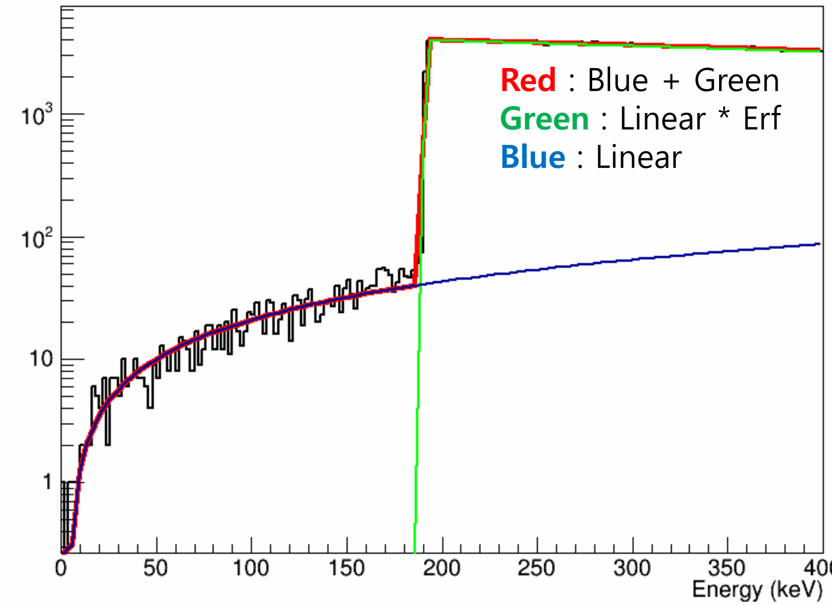
Thermal neutrons (191 keV proton escape edge / 763 keV full energy peak)

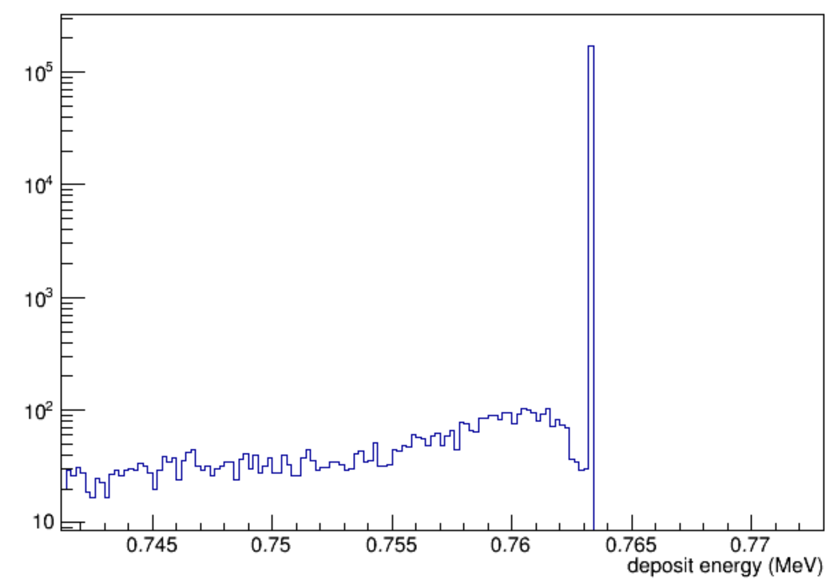
Data



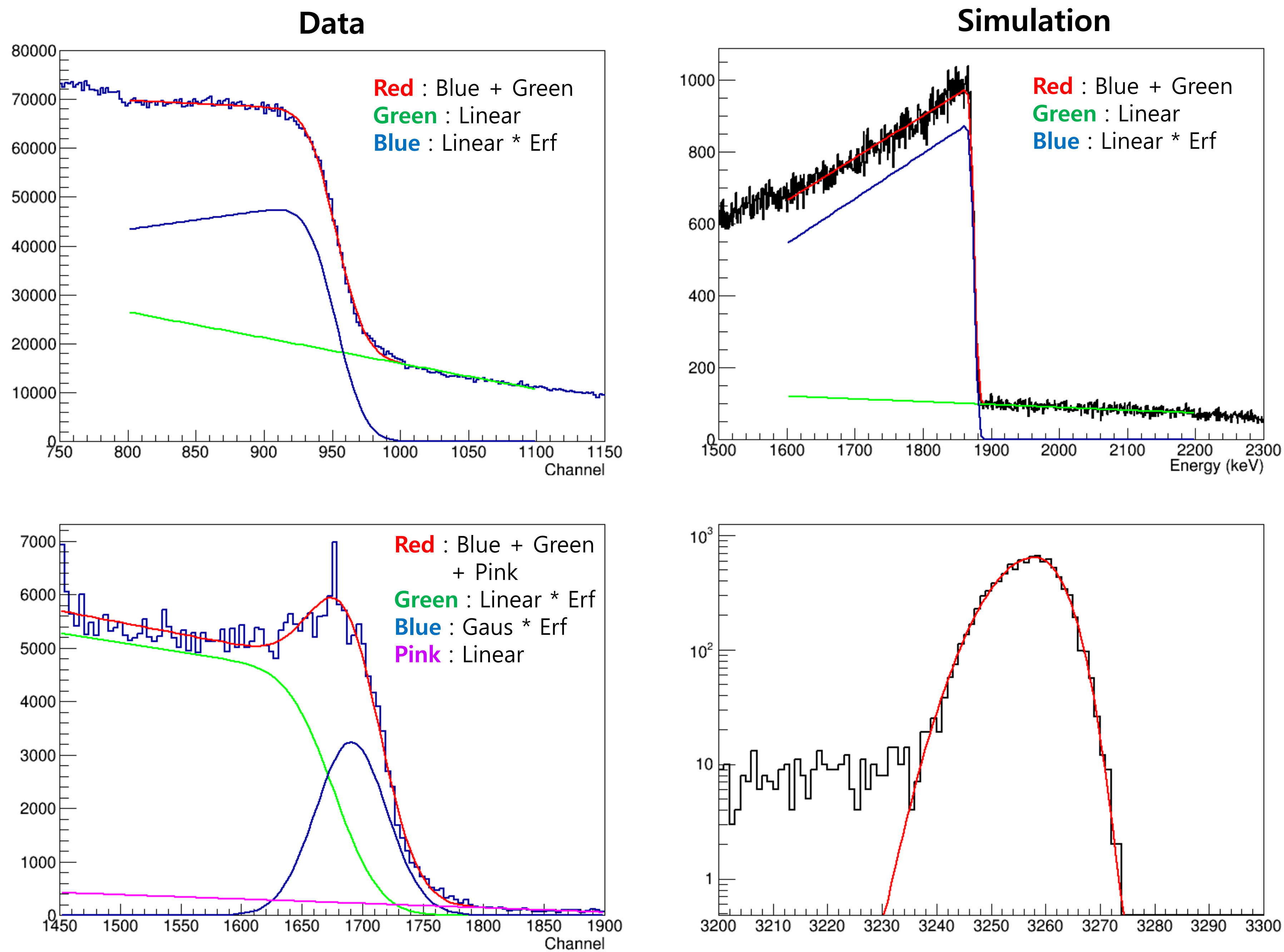


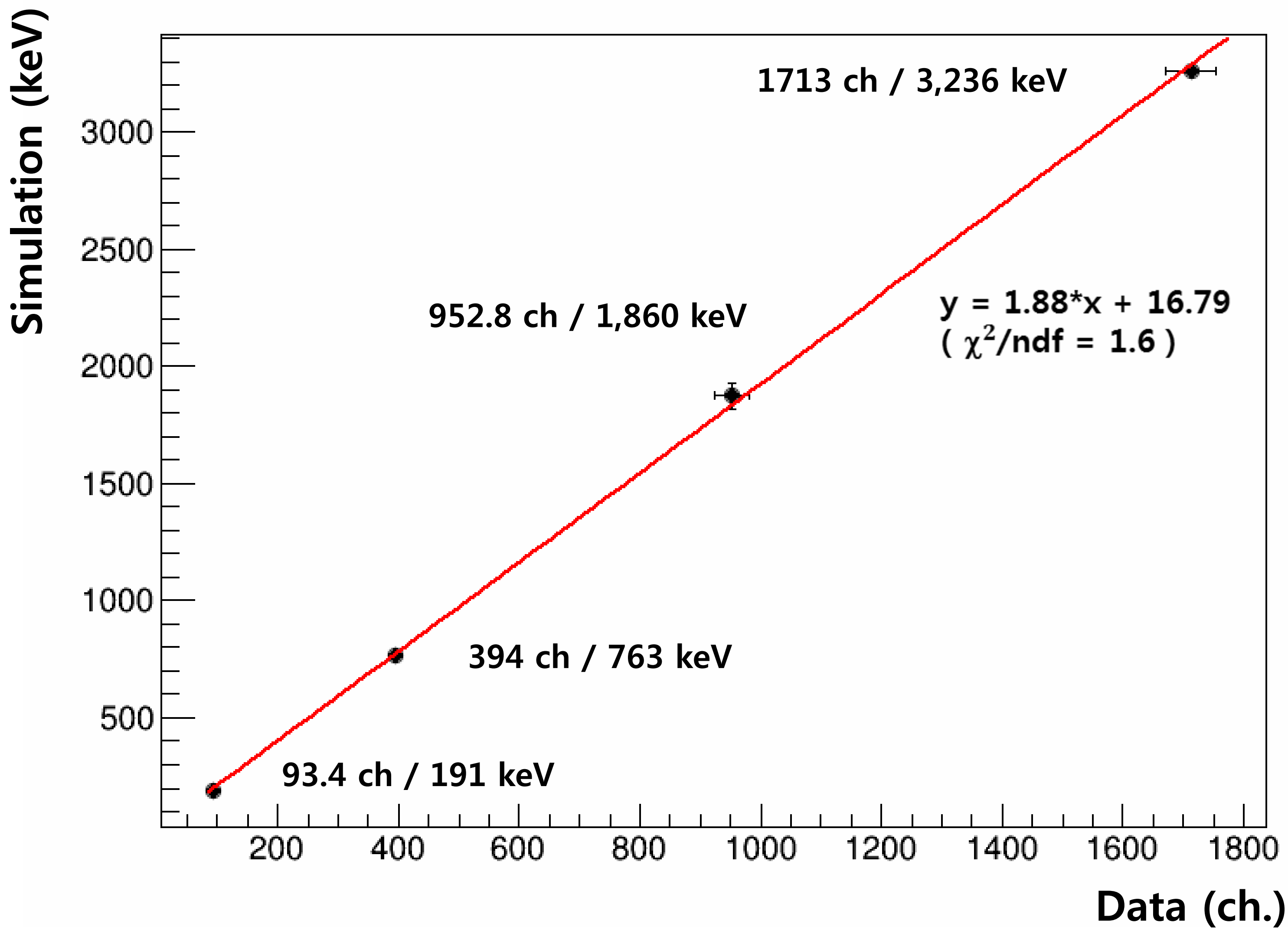
Simulation





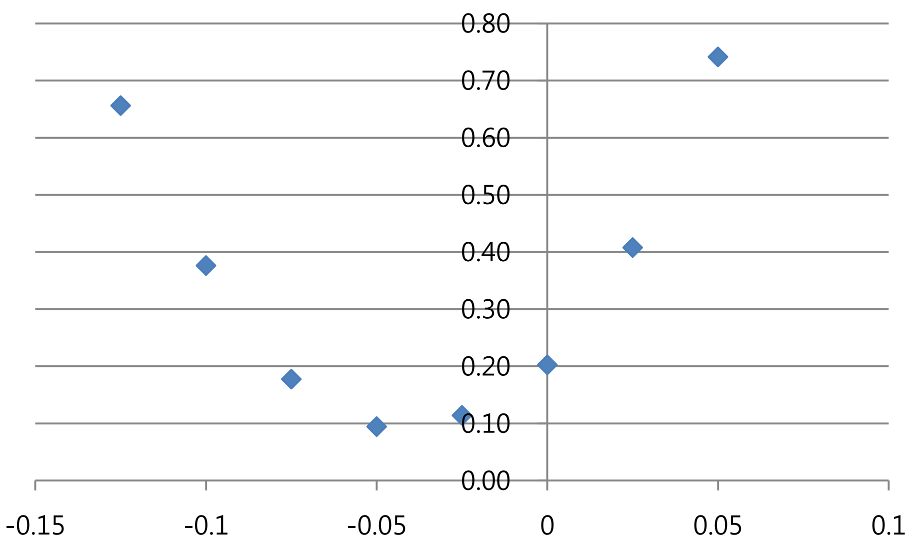
Neutrons from generator (^{3}He recoils / ^{3}He (n,p) ^{3}H)





Simulation (keV)
3000
2500
2000
1500
1000
500
200
400
600
800
1000
1200
1400
1600
1800
Data (ch.)
1713 ch / 3,236 keV
952.8 ch / 1,860 keV
394 ch / 763 keV
93.4 ch / 191 keV
y = 1.88*x + 16.79
(χ^2/ndf = 1.6)

Energy difference (MeV)	Proton escape		Thermal n full energy peak		3He recoil		p+t full energy peak		Const.	Slope	χ^2/ndf
	Data	Sim	Data	Sim	Data	Sim	Data	Sim			
- 0.1	93.4 ± 2.79	191 ± 5.73	393 ± 8.92	763 ± 22.89	952.8 ± 28.56	1785 ± 53.6	1713 ± 41	3,136 ± 94.1	17.46	1.86	**0.38**
- 0.05	″	″	″	″	″	1823 ± 54.7	″	3,186 ± 95.6	14.54	1.89	**0.09**
± 0	″	″	″	″	″	1860 ± 55.8	″	3,236 ± 97.1	11.67	1.92	**0.20**
+ 0.05	″	″	″	″	″	1898 ± 56.9	″	3,286 ± 98.6	8.78	1.94	**0.74**
+ 0.1	″	″	″	″	″	1936 ± 58.1	″	3,333 ± 100.0	5.99	1.97	**1.57**



Neutron Beam energy
= **2.43 ± 0.03** (MeV)

X axis : Neutron energy difference
Y axis : chi-sqr / ndf