CDEX Collaboration

Gd-doped Liquid Scintillator Fast Neutron Detector Calibration

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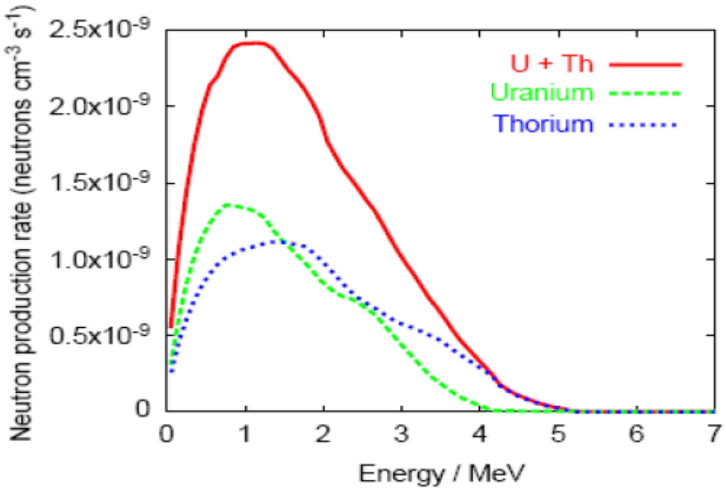
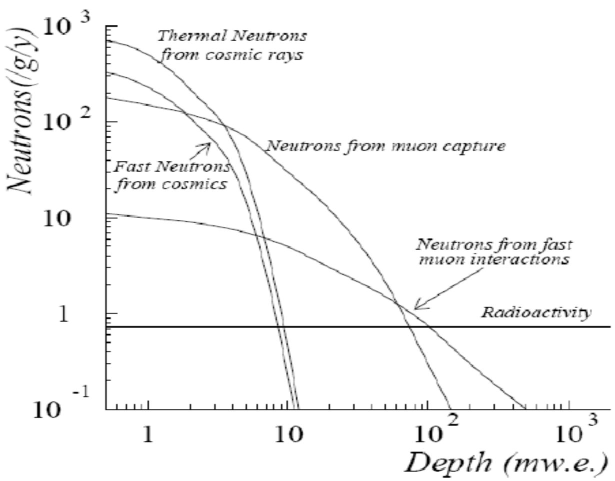
Outline

- Neutron Background in Underground Laboratory
- Fast Neutron Detector Design
- Gamma Calibration
- Neutron Calibration
- Summary and Further Work

Neutron Background in Underground Laboratory



Simulated energy spectrum of neutron produced in rock salt
NIM A 546(2005) 509-522



Neutron production as a function of depth

Features of neutron background in underground laboratory:

- **Source**

  1. (α,*n*) reactions from U, Th series in the rock and other materials

  2. muon induced neutrons

  3. Spontaneous fission of ^{238}U

- **Low neutron flux**

  estimated fast neutron flux in CJPL:

  ~ 10^{-6}/cm^2/s^{-1}

- **Energy range**

  from thermal to tens of MeV.

Fast Neutron Detector Design

➢ Requirement

- ✓ A high sensitivity neutron detector.
- ✓ Effective way to eliminate the gamma background since most of the neutron detectors are also sensitive to gammas.

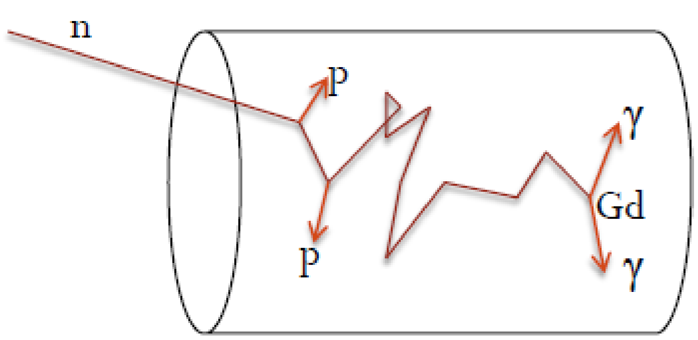
⇨

Ideal Neutron Detector:

- ✓ big sensitive mass;
- ✓ high neutron detection efficiency;
- ✓ good energy resolution;
- ✓ low sensitivity to gamma;

➢ Schematic diagram

Organic scintillator has a higher detection efficiency and a certain ability of pulse shape discrimination.



- ➢ Large Volume
- ➢ Pulse Shape Discrimination
- ➢ Fast and slow signal coincidence measurement

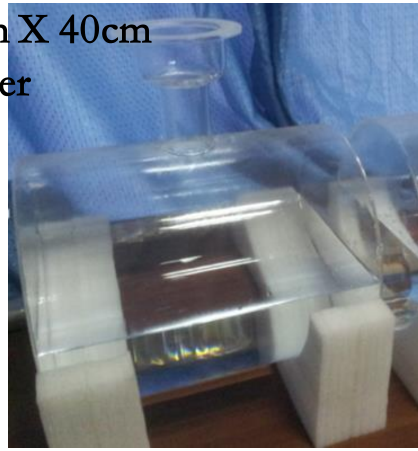
We choose Gd-doped liquid scintillator as our detector material

Fast Neutron Detector Design

Quartz Glass Cylinder

Φ30cm X 40cm

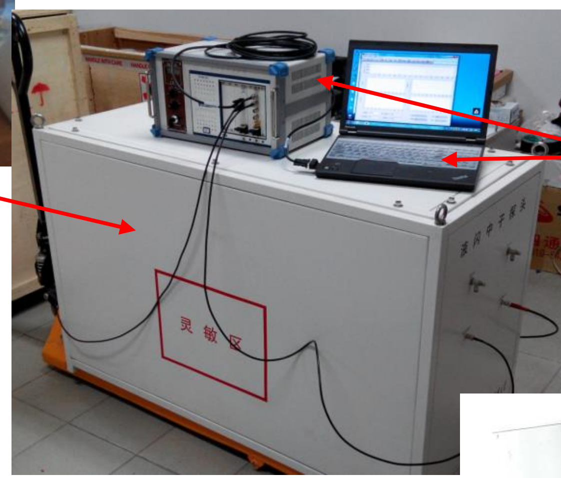
~28 Liter



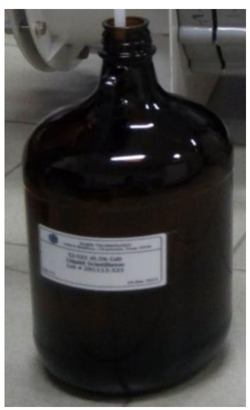
PMT

Hamamatsu， 8 inch， R5912-20

Neutron Detector



DAQ system



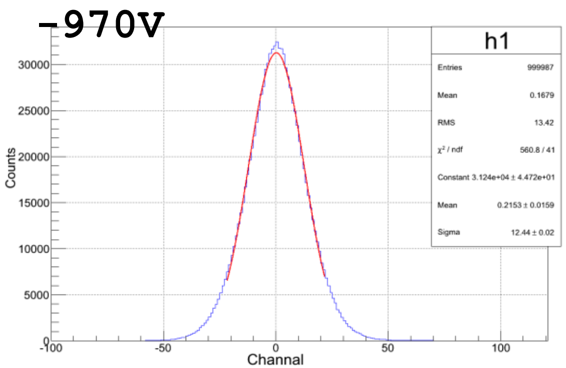
EJ-335

0.5% Gd doped Liquid Scintillator

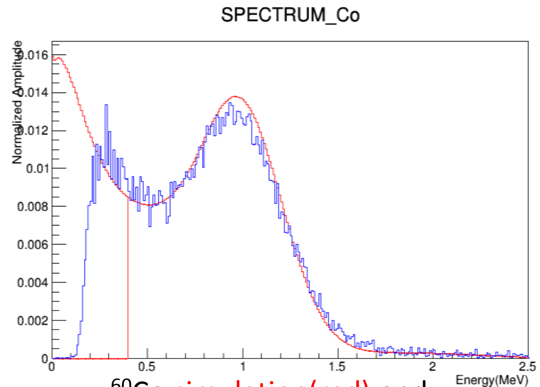
DAQ

NI-5160, 10bit, 1.25GHz Sampling Rate ADC

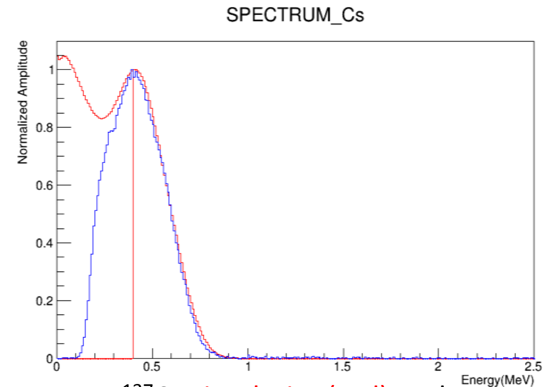
Energy Calibration with Gamma Source



Energy Spectrum of Random Trigger



^{60}Co simulation(red) and experiment(blue) spectrum



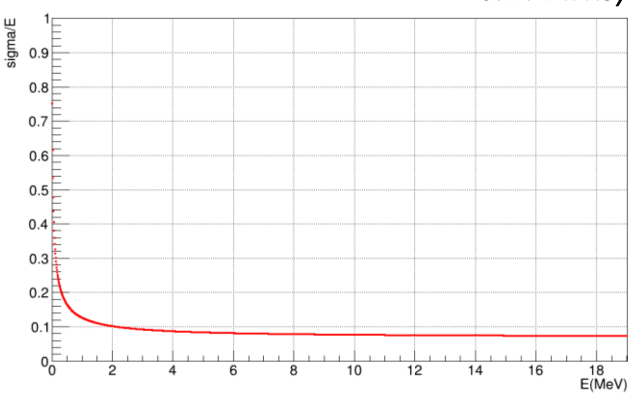
^{137}Cs simulation(red) and experiment(blue) spectrum

Simulated energy deposition spectrum was convolved with the energy resolution of the detector

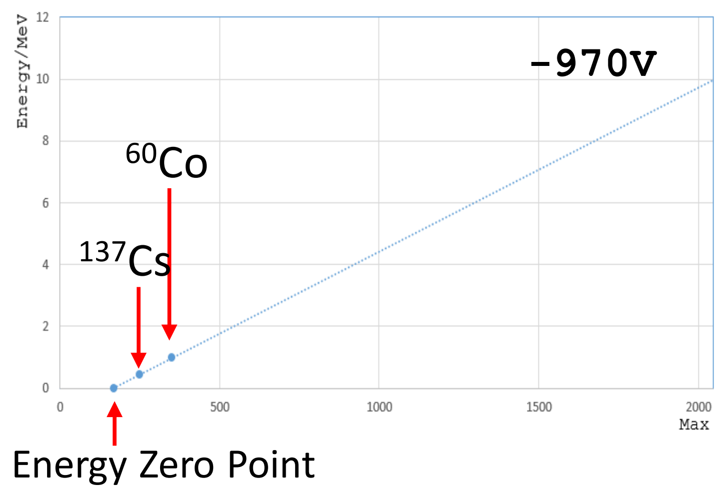
$$\sigma = \sqrt{\alpha \cdot E^2 + \beta E} \quad ;$$

(Theory And Practice of Scintillation Counting, J.B. Birks)

$\alpha_{970V} = 0.0048$, $\beta = 1.12$



Relationship of sigma/E and Energy



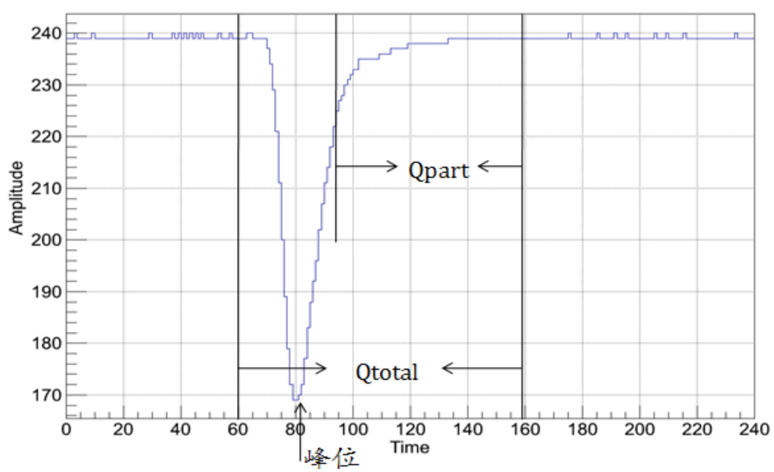
Performance of The Fast Neutron Detector

Two working voltage: -970V、-1065V

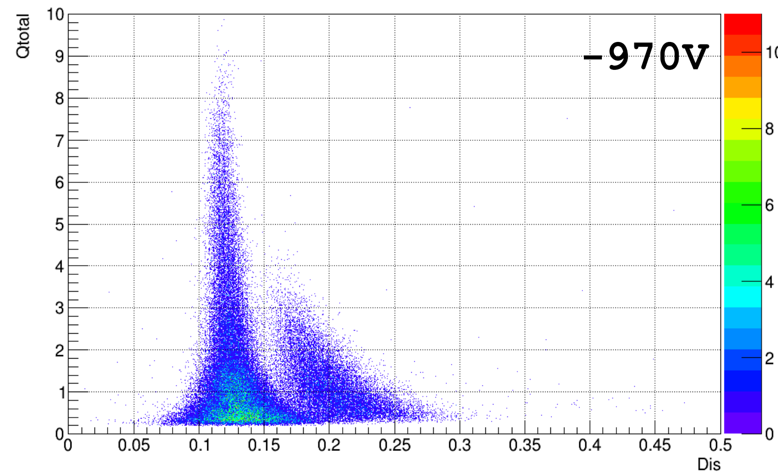
Votage	Energy measurement range (MeVee, equivalent electron energy)	Energy measurement range (MeV)
-970V	0.25~10	1.2~16
-1065V	0.05~3.4	0.4~ 6.8

-970V for high energy fast neutron measurement, -1065V for low energy neutron measurement.

n-γ discrimination



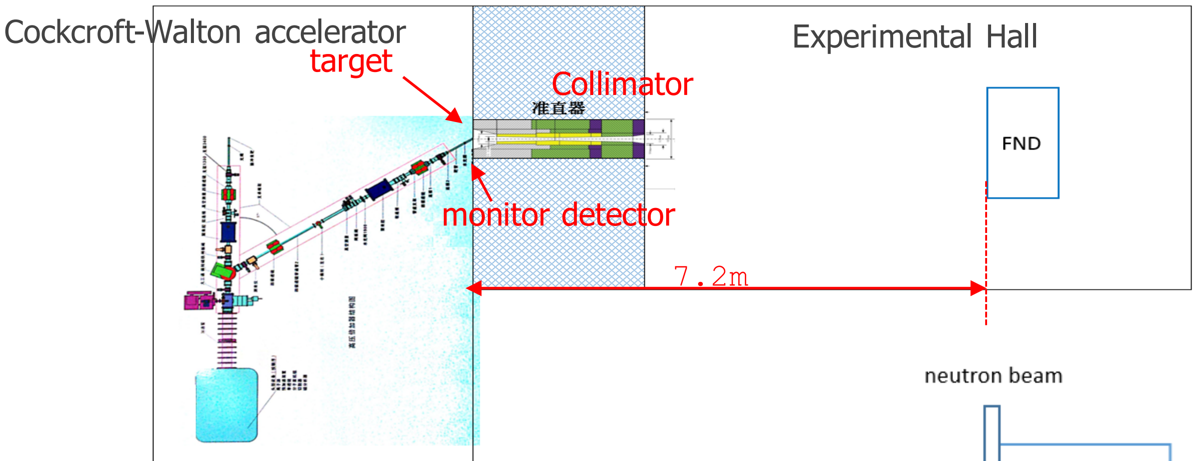
Charge comparison method was used to perform the n-gamma discrimination



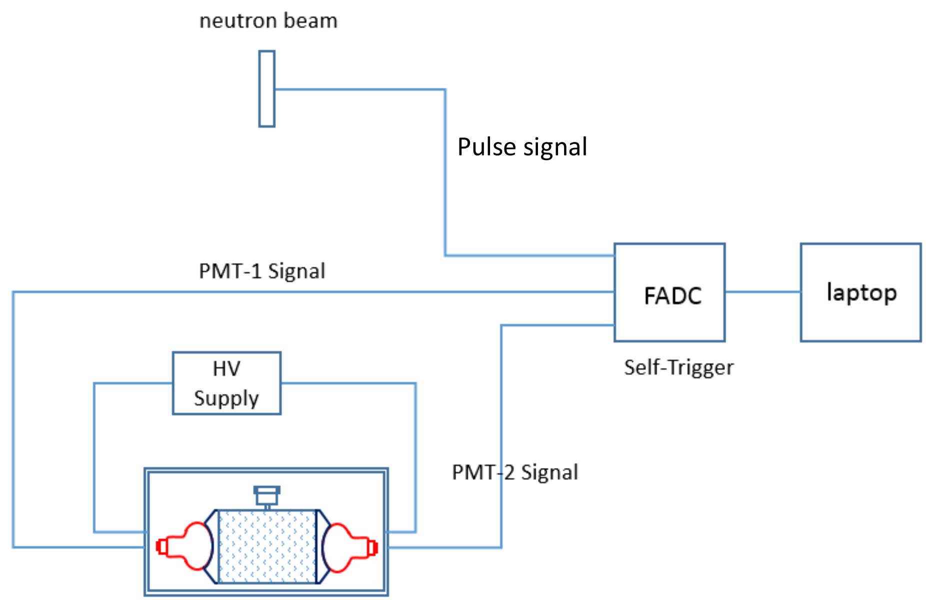
n-γ discrimination of PuC source

Neutron Calibration

Monoenergetic Neutron Calibration Schematic Diagram



Nanosecond pulsed beam:
angle of emergence: 32.6°
Two kinds of monoenergetic neutrons:
① D-D: 2H(d,n)3He, ~2.5MeV
② D-T: 3H(d,n)4He, ~14.8MeV

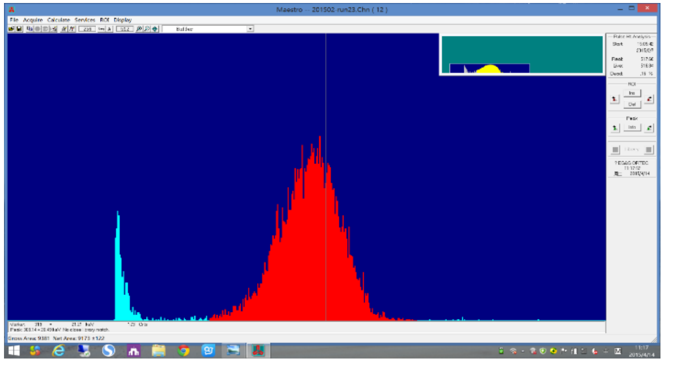


DAQ System of Neutron Calibraiton

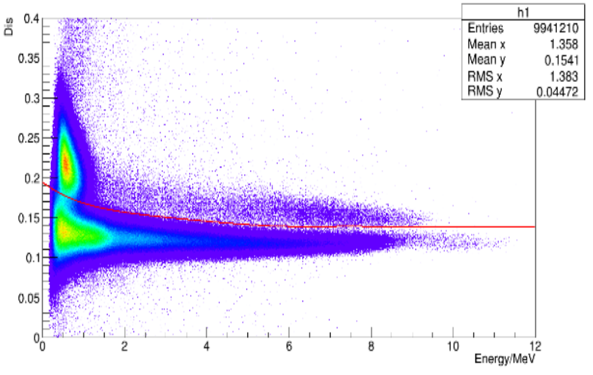
Neutron Calibration(DD,2.5MeV)

$$\frac{\sigma(32.6^{\circ})}{\sigma_T} \cdot \Omega$$

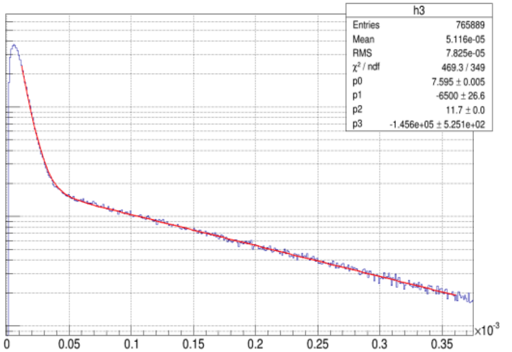
Monitor Detector
peak area: 9173
Total Neutron Number: 9173*1.44e6*1.767e-4
=2334051



spectrum measured by monitor detector



n-γ discrimination curve



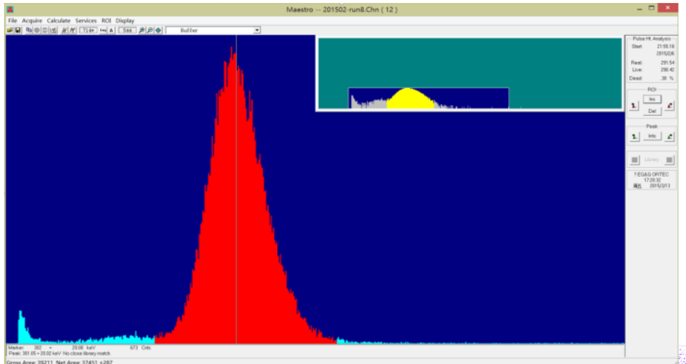
Time interval distribution

Example of a neutron event

Detected neutron: 557455
Detection Efficiency(DD,2.5MeV neutron):
557455/2334051=23.9%

Judgment Condition of neutron event:
1、current signal: gamma
2、 previous signal: neutron
3、Time interval: < 60μs

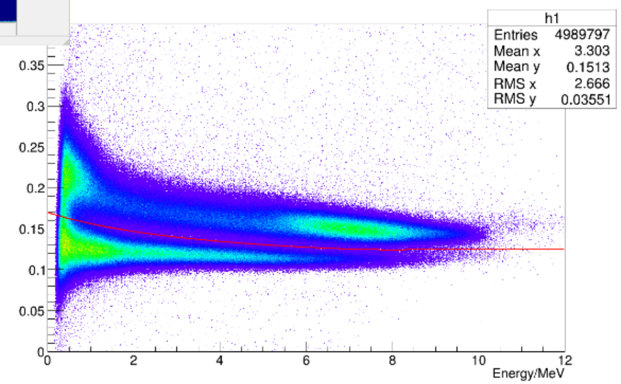
Neutron Calibration(DT,14.8MeV)



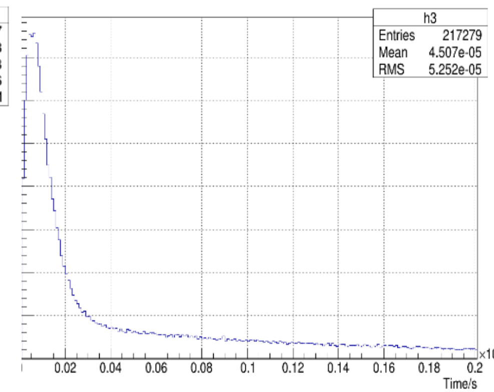
peak measured by monitor detector

Monitor Detector
peak area: 37451
Total Neutron Number: 37451*1.5e6*1.263e-4
=7,093,463

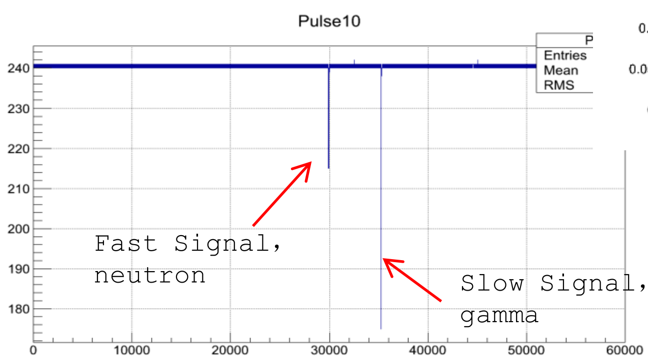
$$\frac{\sigma(32.6°)}{\sigma_T}\cdot\Omega$$



n-γ discrimination curve



Time interval distribution



Example of a neutron event

Judgment Condition

1、current signal: gamma

2、 previous signal: neutron

3、Time interval: < 60μs

Detected neutron: 1425152

Efficiency(14.8MeV): 1425152/7093463 =20.1%

Energy Spectrum Unfolding

Principle:

Measurement recoil proton Spectrum

The incident neutron energy spectrum

$$\frac{dN}{dH} = \int R(H,E)\Phi(E)dE$$

Discretized form

$$N_i = \sum_j R_{ij}\Phi_j$$

matrix form

$$N = R\Phi$$

The detector response matrix

Input: ① Measurement recoil proton spectrum

②The detector response matrix

③ The initial spectrum

Output:

The incident neutron energy spectrum

iteration :

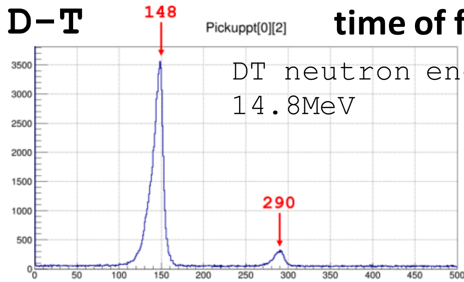
$$\Phi_i^{j+1} = \Phi_i^j \exp\left(\frac{\sum_{k=1}^{K} W_{ik}^j \ln\left(\frac{N_k}{\sum_{i=1}^{I} R_{ki}\Phi_i^j \Delta E_i} \right)}{\sum_{k=1}^{K} W_{ik}^j} \right)$$

$$j = 1,2......J$$

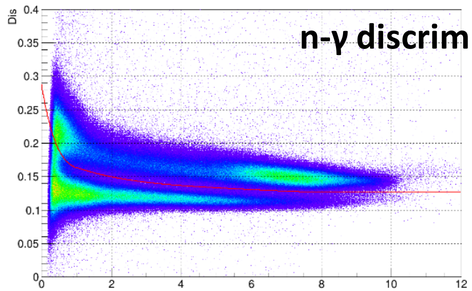
$$W_{ik}^j = \frac{R_{ki}\Phi_i^j}{\sum_{i=1}^{I} R_{ki}\Phi_i^j} \frac{N_k^2}{\sigma_k^2}$$

Energy Spectrum Unfolding

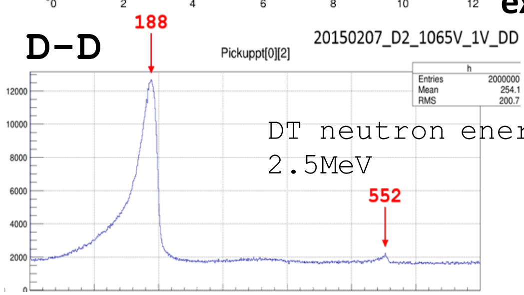
D-T **time of flight**

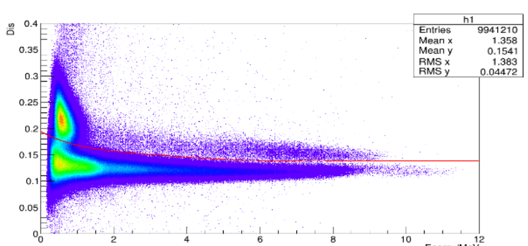


n-γ discrimination



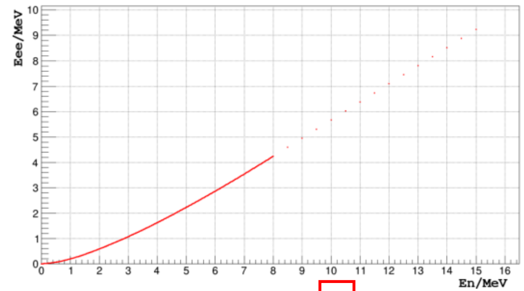
D-D





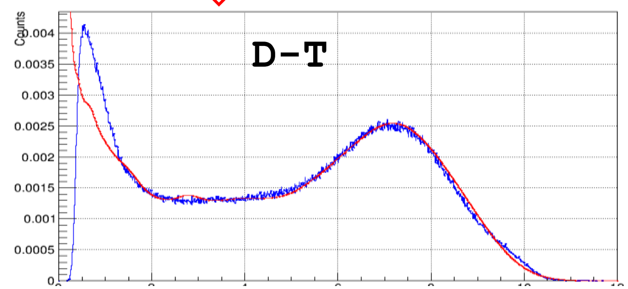
experiment

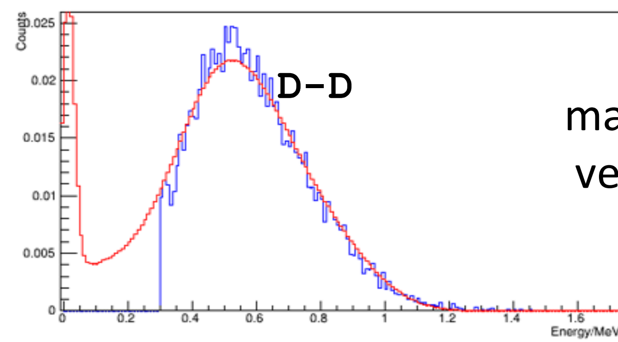
light response curve



simulation → **Response Matrix**

simulation



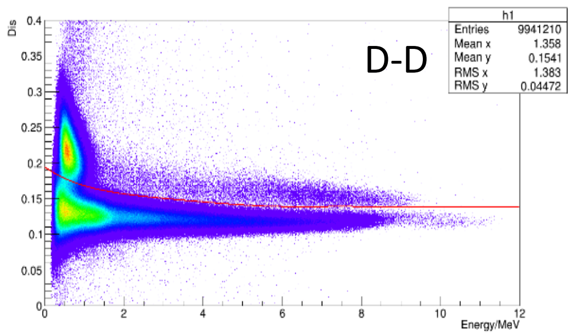


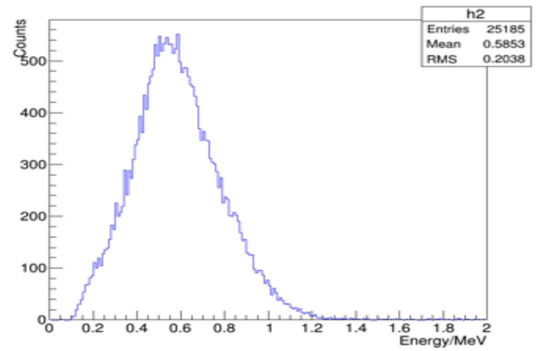
matched each other very well

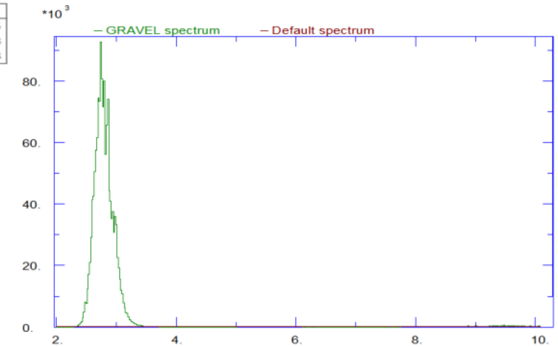
recoil proton spectrum (simulation(red), experiment(blue))

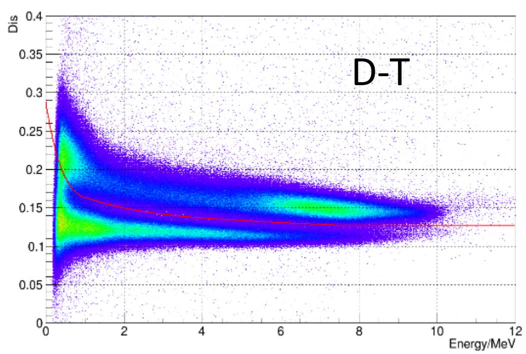
Energy Spectrum Unfolding

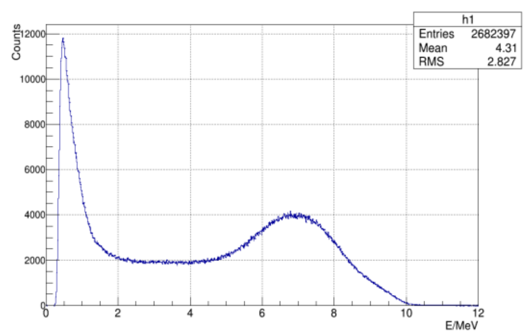
n-γ discrimination | recoil proton spectrum | Incident neutron energy spectrum

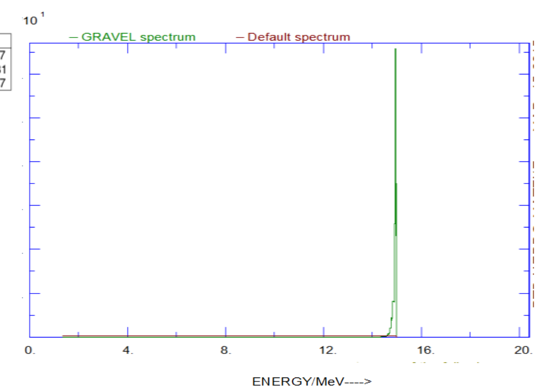












Summary and Further Work

Summary

- ✓ Gamma and Neutron calibration
- ✓ Broad Energy measurement range： 1.2MeV ~ 16MeV
- ✓ Relatively high detection efficiency
- ✓ Ability of n-γ discrimination
- ✓ Flux and incident energy spectrum measurement

Further Work

- ✓ Data analysis of Neutron Calibration Experiment (10-14 OCT, 2015)

  Energy Points: 1.2MeV, 1.8MeV, 2.5MeV, 4MeV, 5MeV, 6MeV, 14.8MeV

  more precise detection efficiency Curve of the FND.

Thank You!