Study of plastic scintillators for fast neutron measurements

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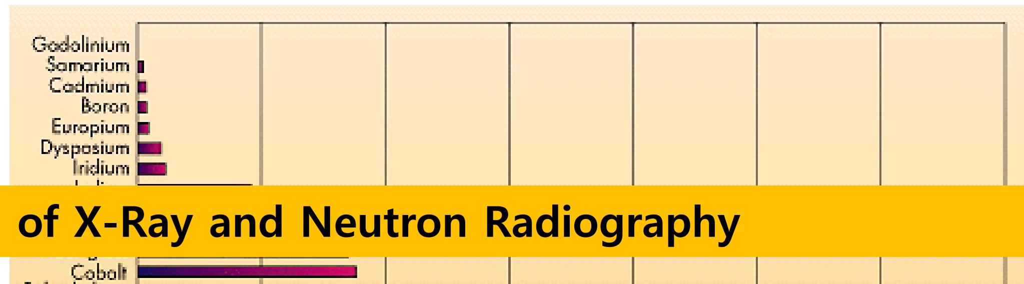
Contents

Introduction & motivation

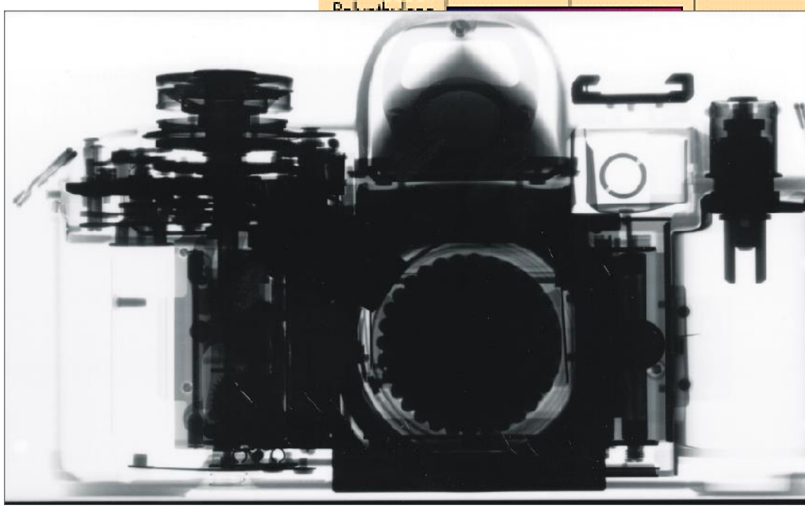
- Fast neutrons are applied for the treatment of the human cancers, material science and biology.
  - Neutrons have a higher biological effectiveness than both photons and protons.
  - Neutrons are especially effective against advanced tumors like head, neck and prostate cancer.

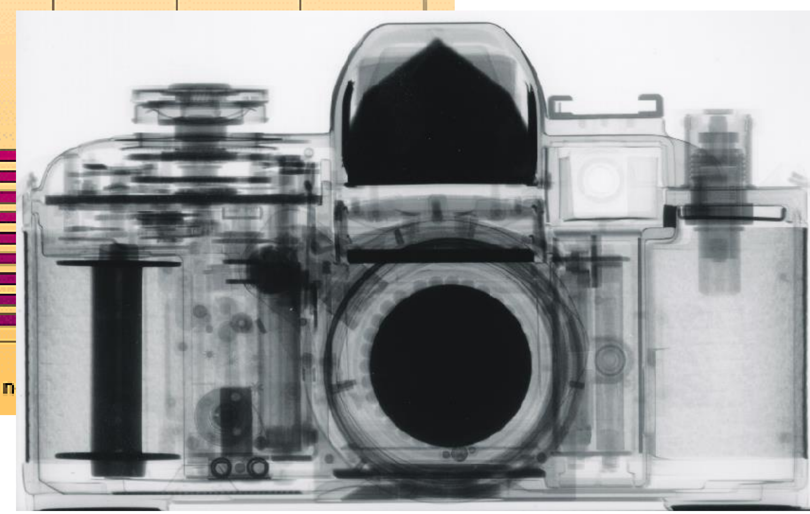
Introduction & motivation

– Neutron radiography is used to find out slight defect in materials.



Comparison of X-Ray and Neutron Radiography





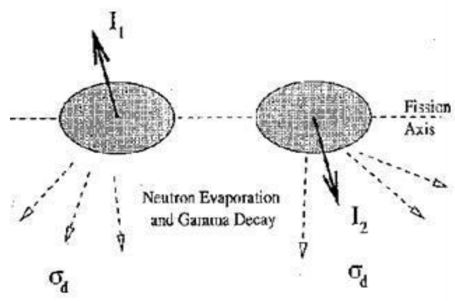
Introduction & motivation

- Fast neutron – proton elastic scattering can be applied to reconstruction of the neutron tracks emitted from sources.

- Elastic scattering produces an energetic proton, which can be measured by proton-rich organic scintillators.

- It will be important to diagnose the characteristics of the plastic scintillators for the measurement of fast neutrons.

Experimental setup



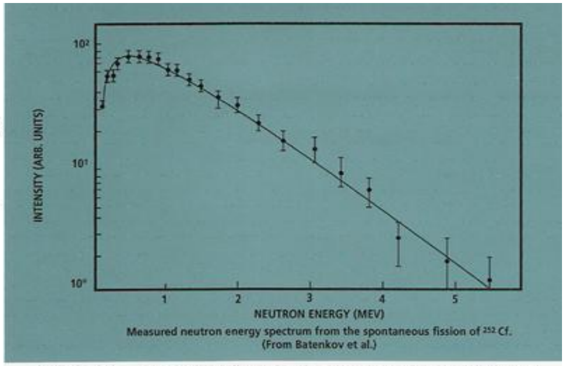
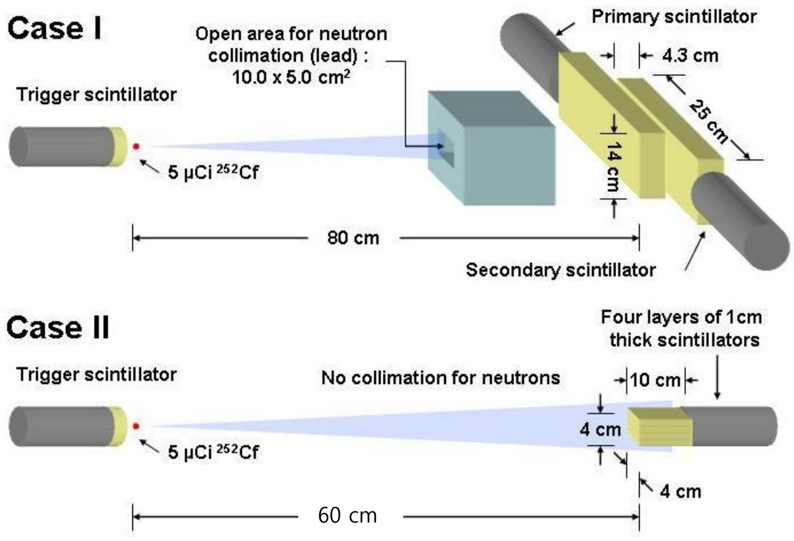


Figure 52-B — Cf-252 Neutron Energy Spectrum From O.I. Batenkov et al., INDC(NDS)-146, (1983)

- A 5μCi ^{252}Cf was used for the energy measurements.
  - Branching ratio for fission = 0.0309
  - Branching ratio for α-decays = 0.969
- The fission decay was triggered by either neutron or γ-ray emitted from the fission fragments.

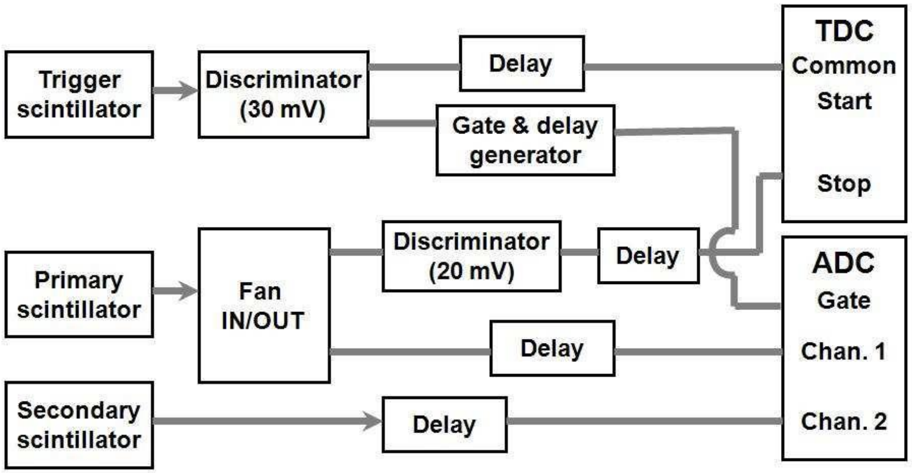
Experimental setup

- Case Ⅰ
  - 2 scintillators were used for full absorption.
  - Neutron events were triggered by trigger scintillator & primary scintillator.



- Case Ⅱ
  - 4 layered scintillator with 1-cm-thick plate were used for high efficiency and resolution.
  - Because of small detectable range, no collimator in front of the 4 layered scintillators.

Experimental setup



- Neutron energy measured by the TOF

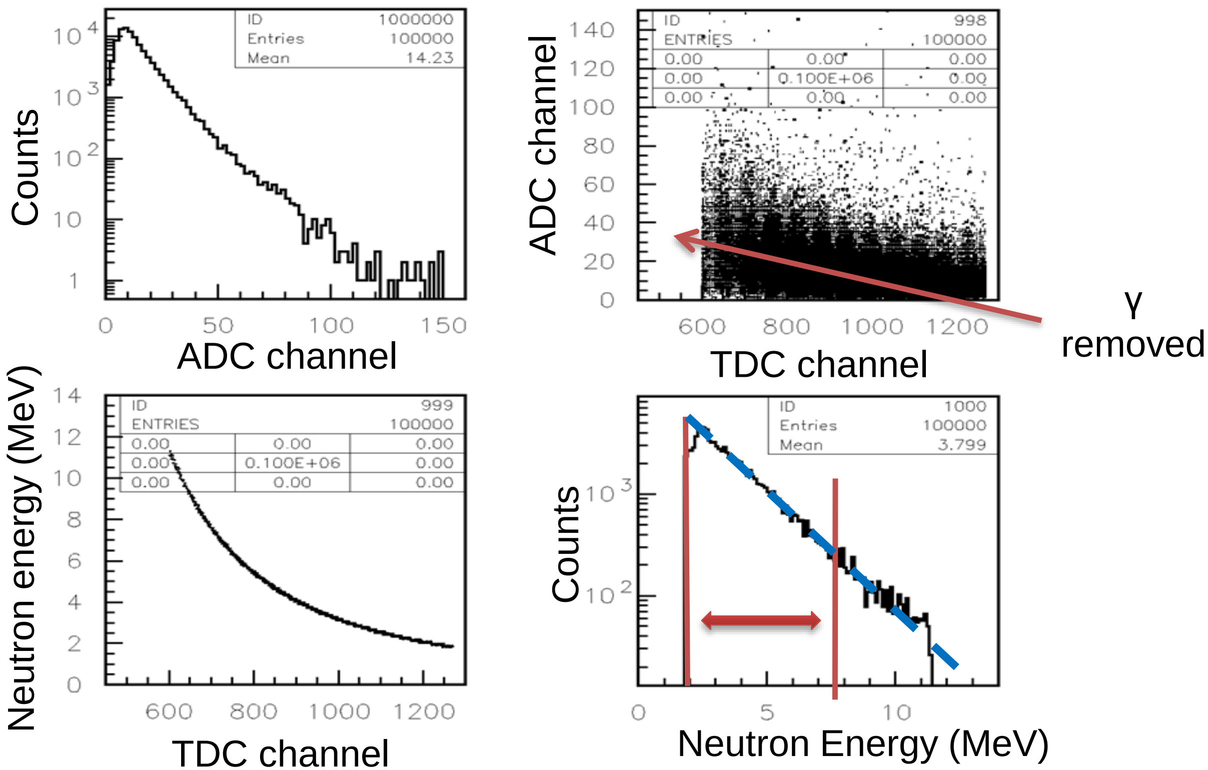
$$E = A\left(\frac{L}{T_s(T - T_0)}\right)^2$$

– T=Arrival time of neutron
– L=Distance between the source and the neutron detector
– T_s=Conversion factor of TDC (0.2651 ns/ch)
– T_0=Time offset

- Uncertainties for the neutron energy measurement
  1. Uncertainty of the flight distance caused by the finite thickness of the detectors.
  2. Uncertainty of the flight-time caused by finite time resolution of the test system.

Experimental setup

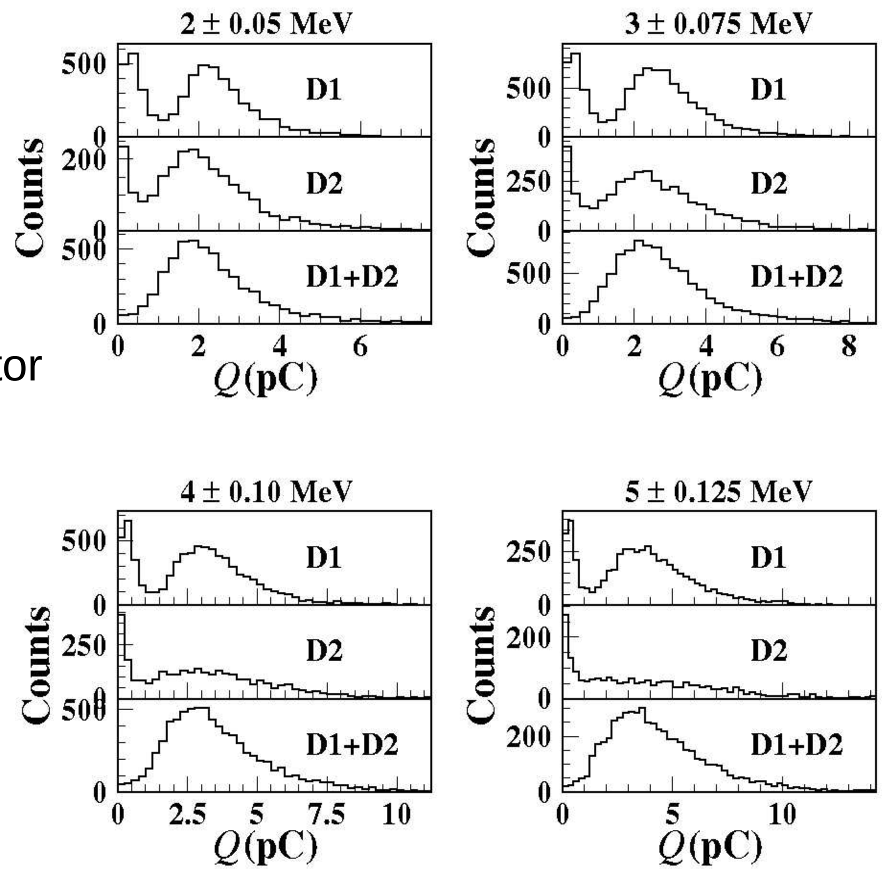
- Selection of the neutron energy : $2 < E_n < 7.5$ MeV
  - $E_n > 7.5$ MeV : the contamination of the gamma rays emitted from α and fission decays.
  - $E_n < 2$ MeV : excluded to minimize the perversion in the neutron-energy spectra due to the threshold on the pulse height (30 mV).



Pulse analysis

Pulse spectra of the fast neutrons (Case Ⅰ)

- Energy distribution of primary detector
  - Energy is deposited partially.
- Energy distribution of secondary detector
  - The rest energy is fully absorbed.
- Total energy distribution
  - At higher neutron energies, energy resolution is worse, and distribution is broader.



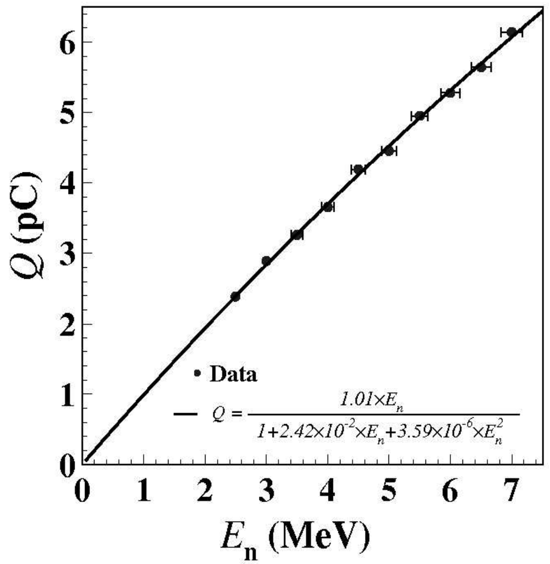
Pulse analysis

Neutron energy dependence of total light output (Case Ⅰ)

- Birk's formula

$$\frac{dL}{dx} = \frac{A\frac{dE}{dx}}{1 + kB\frac{dE}{dx}} = \frac{A\frac{dE}{dx}}{1 + B\frac{dE}{dx} + C\left(\frac{dE}{dx}\right)^2}$$

  - dL/dx : (light output) / (unit length)
  - A : absolute scintillation efficiency
  - kB, B : parameter relating the density of ionization centers to dE/dx



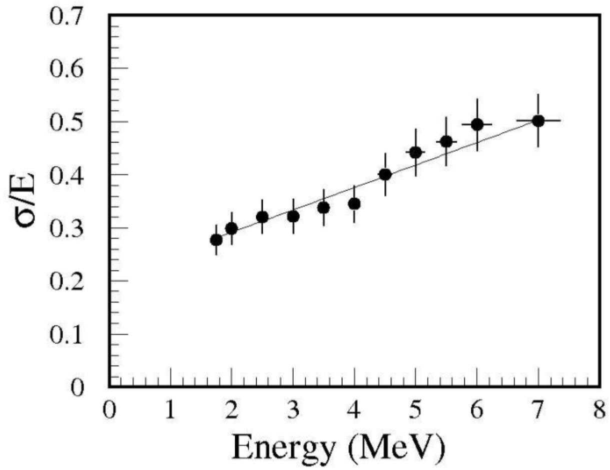
$$Q = \frac{1.01 \times E_n}{1 + 2.42 \times 10^{-2} \times E_n + 3.59 \times 10^{-6} \times E_n^2}$$

- Approximately linear, but small amount of non-linearity exist.

Pulse analysis

Energy resolution of the D1 (Case Ⅰ)

- At higher neutron energies, poorer resolutions occur.
  - The number of fully absorbed neutron decreases.
  - Light collection efficiency decreases as multiple scattering increases.
  - Any other reasons?

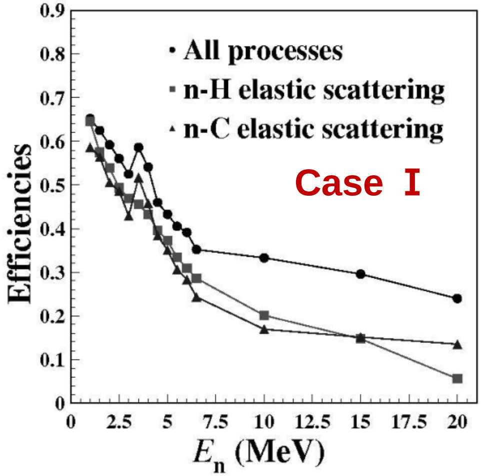


- Probably, other scattering processes affect the light yield.

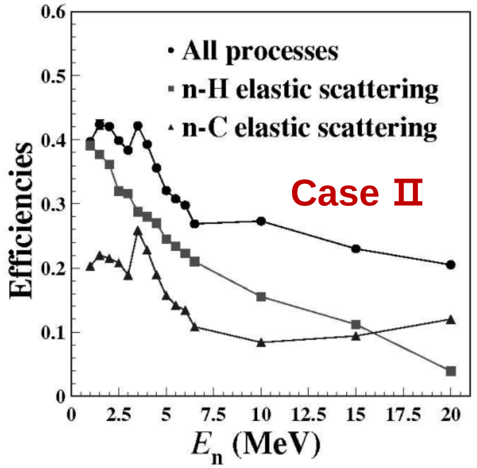
GEANT4 simulation

Sensitivities was predicted as a function of the neutron energy

- At higher neutron energies, n-^{12}C scattering occurs more frequently.



- Total light yield can be reduced because the kB value for n-^{12}C scattering is lager than n-p scattering.
  → Poorer resolutions!

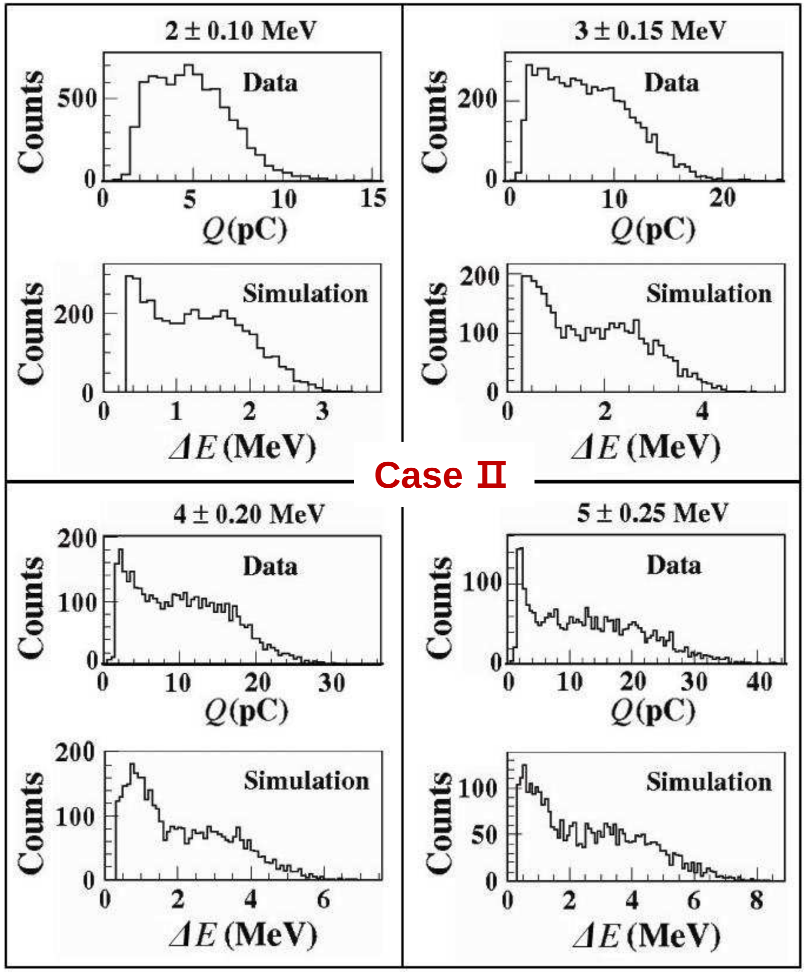


GEANT4 simulation

Deposit energies of the fast neutrons and the comparisons to the pulse spectra

- Simulation's peak becomes narrower in data

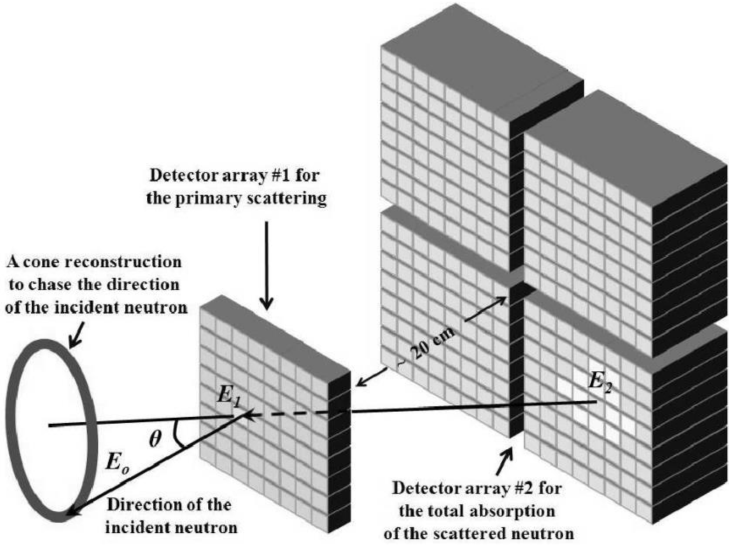
- Origin of discrepancies between the data and the simulations
  - Difference in the light yields between p and ^{12}C.
  - The difference becomes larger at the lower neutron energies, because of the threshold effect.



Potential application to the neutron camera

Neutron camera system with PSPMT

- The neutron camera is a useful detector to search for any hidden fast-neutron sources.



- The energy of recoil nucleus by neutron - nucleus elastic scattering

$$E = E_0 \frac{4A}{(1+A)^2} \sin^2\theta$$

- Proton takes a half of neutron's energy (A=1) $\rightarrow E_1 = E_0 \sin^2\theta$, $E_2 = E_0 \cos^2\theta$

- The angle of the neutron track is $\theta = \tan^{-1}\sqrt{\frac{E_1}{E_2}}$

- We are developing the practical neutron camera as an application of the neutron detector.

Conclusions

- We have measurement of the light yields and the pulse (energy) resolutions as a function of the neutron energy by the TOF method.

- The data have been compared with the GEANT4 simulations : The pulse resolution increased with the neutron energy.
  - The spatial range for the absorption via the multiple scatterings increases as the neutron energy.
  - The relative strength of n-^{12}C to n-p in the elastic scattering accounts for the worse resolutions at higher energies.

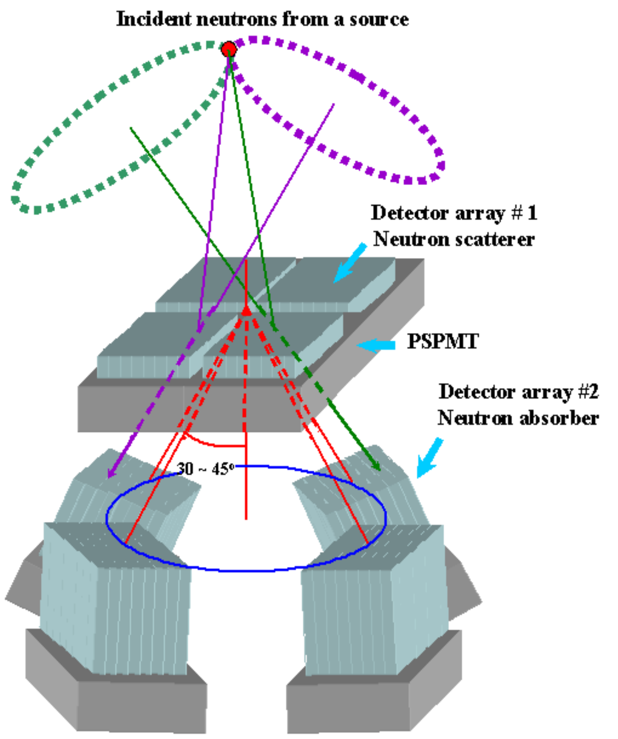
- We are developing the neutron camera as a potential application.

Back up

Potential application to the neutron camera

- The resolution for the scattering angle to determine the neutron direction

$$\delta\theta = \frac{\cos^3\theta}{2\sin\theta}\frac{E_1}{E_2}\left\{\left(\frac{\sigma_{E_1}}{E_1}\right)^2 + \left(\frac{\sigma_{E_2}}{E_2}\right)^2\right\}^{1/2}$$



- For example,
  - 2m from neutron source material
  - FWHM of scintillation fiber pixel is 0.35 → $\frac{\sigma_E}{E} = 0.15$
  - σ_θ^T is 60 mrad → the diameter of a cone is 24㎝
  - If area of neutron scatter is 200 ㎠, with 0.2 ㎐ detection, neutron source material weighs about 100 kg.

References

- Page 3 : www.symmetrymagazine.org/cms/?pid=1000102
- Page 4 : http://www.ati.ac.at/~neutropt/experiments/Radiography/radiography.html
- Original paper : JKPS 2009 54:586-591