# Measurement of fast neutron spectrum and flux in CJPL

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**Application of Germanium Detector in fundamental research**

**2011.3.23-29 Beijing**

# Outline

- Neutron background in underground lab
- Neutron detector design for CJPL
- Monte Carlo simulation
- Summary

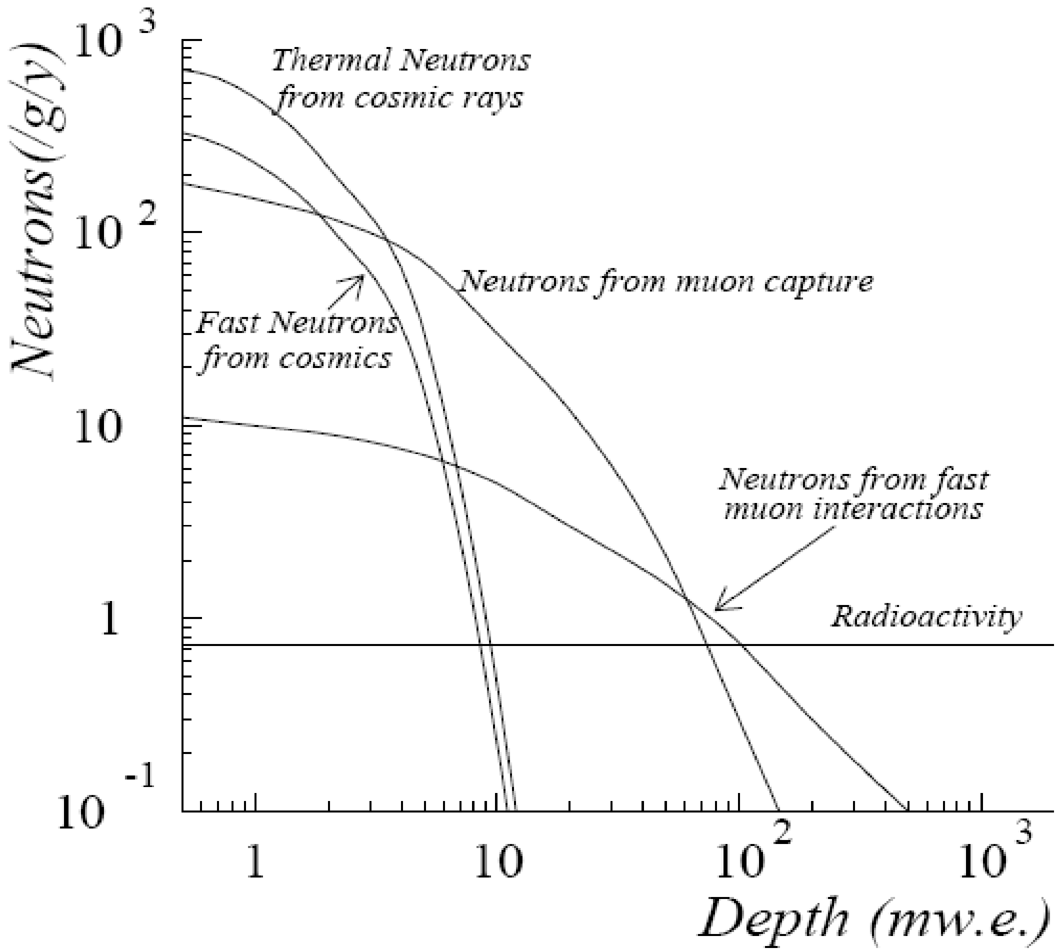
# Overview

- Neutrons are the most important background in the underground experiment.
- Characterization of the neutron flux and energy spectrum in the underground laboratory are important to evaluate the neutron induced background in such experiments.
- Low neutron flux ~$10^{-6}$ n/cm$^2$/s.
- Energy range from thermal to some tens of MeV.

# Sources of neutron background at underground laboratory

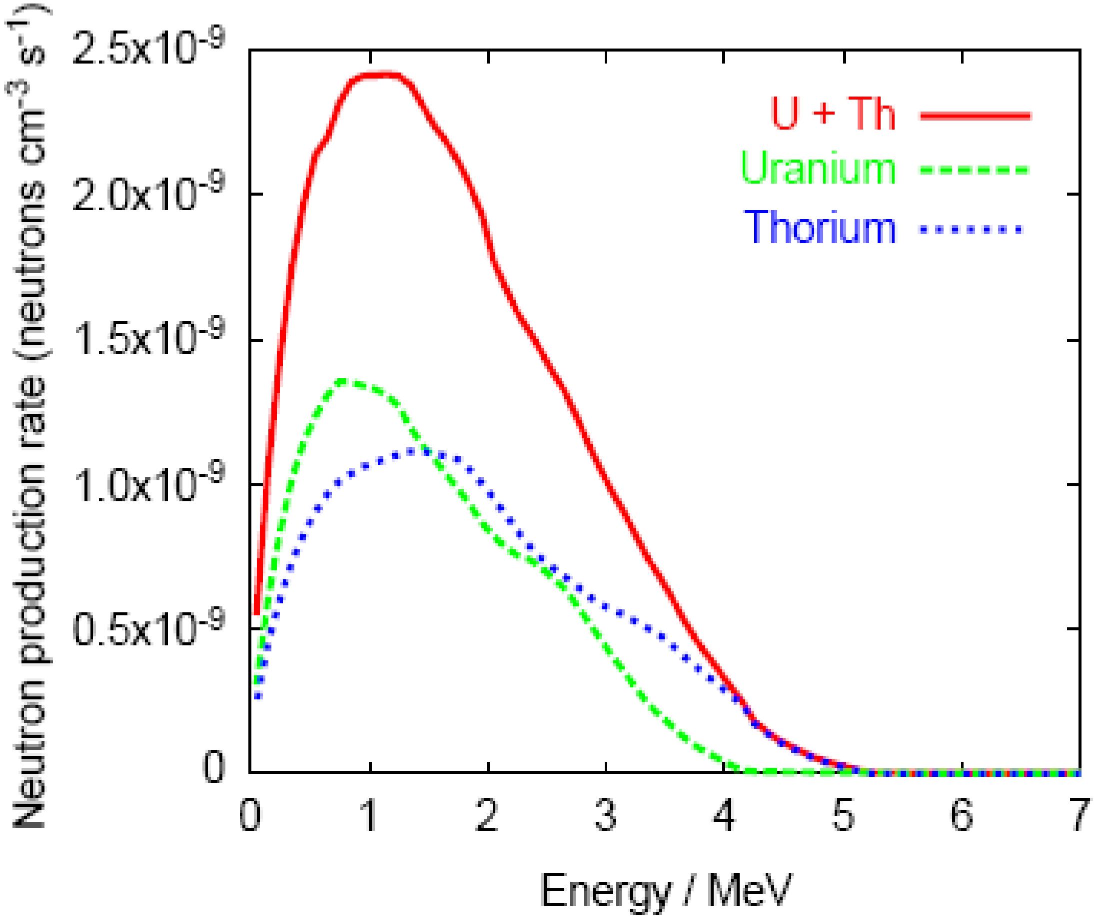
- $\mu$ induced neutrons
- Spontaneous fission of U238
- (a,n) reactions from U, Th series

# Neutron background sources



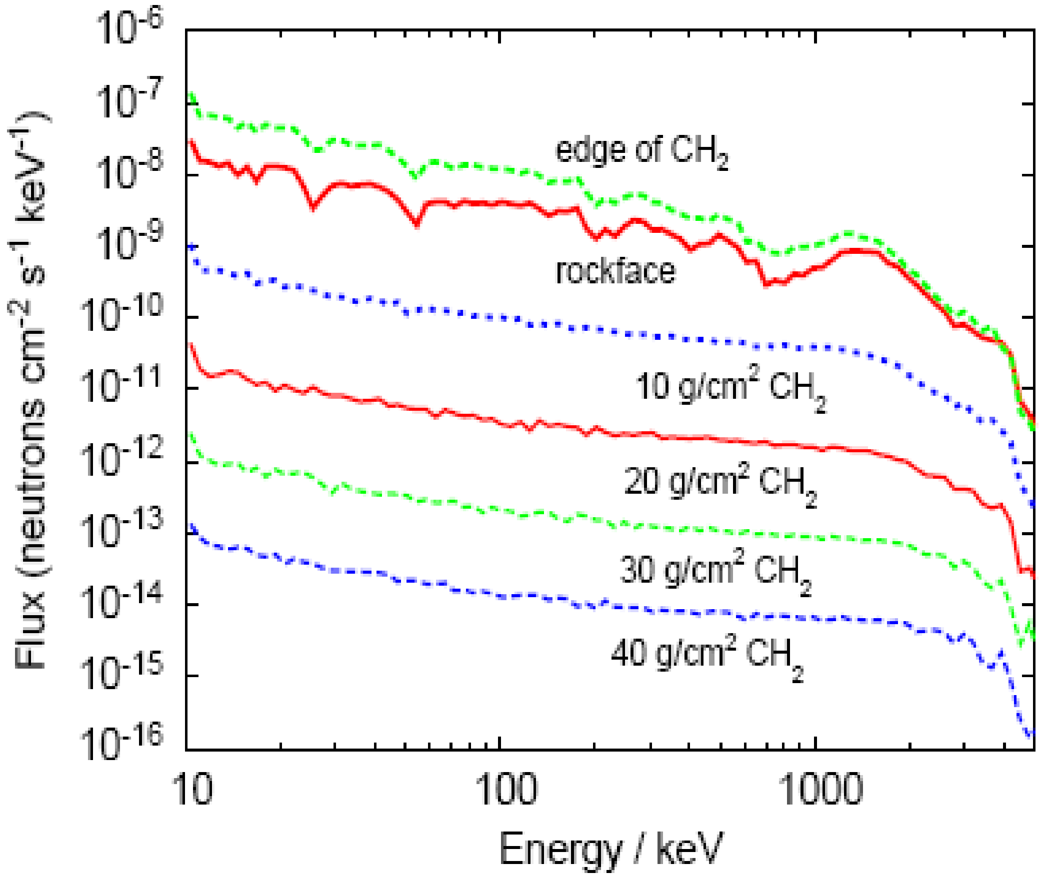

Neutron production as a function of depth underground

# Neutron spectrum from the decay chain of U and Th




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

# Neutron flux after PE shielding




Neutron energy spectra ,due to U,Th and travelling through different layers of CH2

# 2. Neutron detection of CJPL

- Therefore, to measure the neutron flux and energy spectra, we need:
  - A high sensitivity neutron detector.
  - Effective way to eliminate the gamma background since most of the neutron detectors are also sensitive to gammas.

# Neutron detection method

- Spectrometry of recoil nuclei
- Methods using nuclear reaction products

$^{3}He(n,p)^{3}H$, $^{6}Li(n,\alpha)^{3}H$,

$^{10}B(n,\alpha)^{7}Li$, $^{12}C(n,\alpha)^{9}Be$ and $^{28}Si(n,\alpha)^{25}Mg$

- Neutron time-of-flight method
- Threshold methods
- Methods using multisphere systems

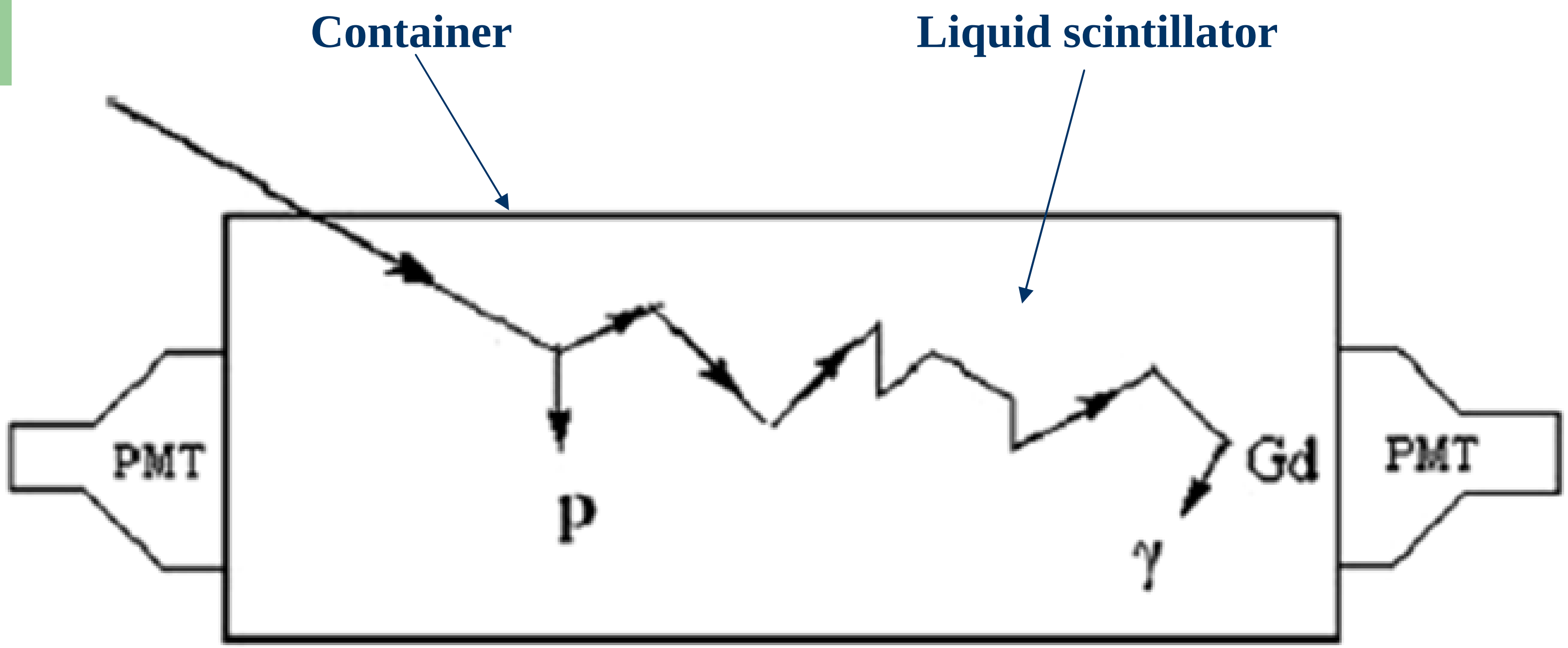
# Neutron spectrometer characteristics

Table 1
Neutron spectrometer characteristics

| Spectrometer | | | | Typical characteristics for | | |
|---|---|---|---|---|---|---|
| No. | Type | Ref. | Energy range (MeV) | Energy (MeV) | Resolution (FWHM) | Detection efficiency |
| 1 | Recoil proportional counter | [27] | 0.05–5 | 1 | 10%[a] | 3% |
| 2 | Organic scintillator | [31] | 2–150 | 8 | 4%[a] | 20% |
| 3 | Recoil proton telescope | [45] | 1–250 | 60 | 4%[a] | <0.05% |
| 4 | Capture-gated | [49] | 1–20 | 5 | 50%[a] | 1% |
| 5 | $^{3}$He gridded ionization chamber | [61] | 0.05–10 | 1 | 2%[a] | 0.3% |
| 6 | $^{3}$He-semiconductor sandwich | [64] | 0.1–20 | 1 | 50 keV[a] | 0.1% |
| 7 | Diamond semiconductor | [68] | 8–20 | 14 | 1%[b] | 1% |
| 8 | Time-of-flight | [74] | 1–15 | 2.5 | 5%[c] | 0.05 $cm^{-2}$ |
| 9 | Foil radioactivation | [79] | 0.2–20 | — | — | — |
| 10 | Superheated drop (bubble) | [82] | 0.1–20 | — | — | — |
| 11 | Multisphere | [91] | $10^{-8}$–200 | — | — | — |

[a]Pulse height resolution.
[b]Energy resolution.
[c]Time-of-flight resolution.

# Neutron detector scheme of CJPL

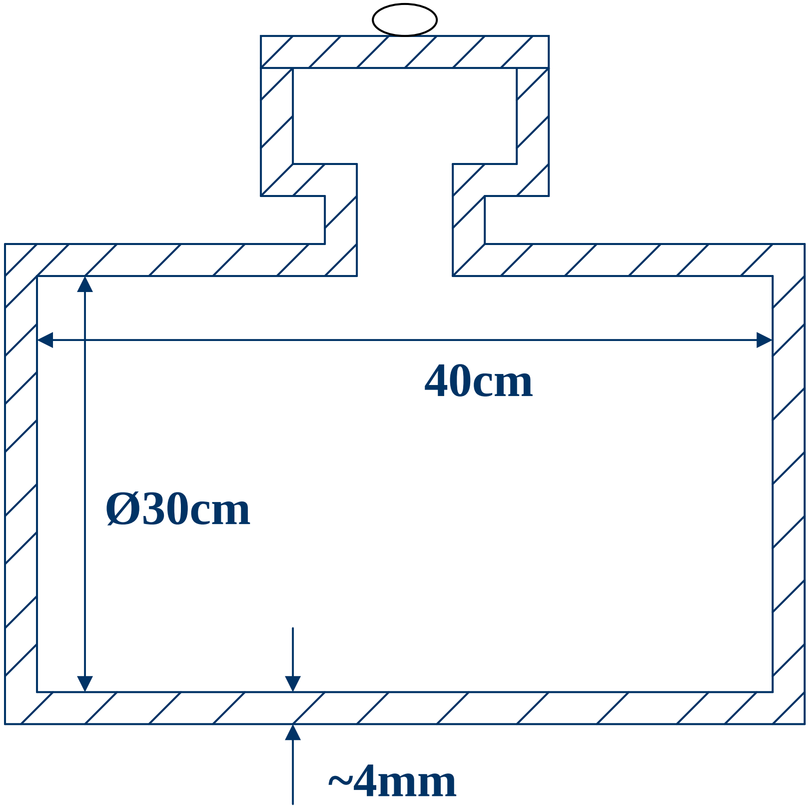



- Simple, low cost
- Fast and slow signal coincidence measurement
- PSD could be applied

  Fast: n, Slow: gamma or gamma + charged particles

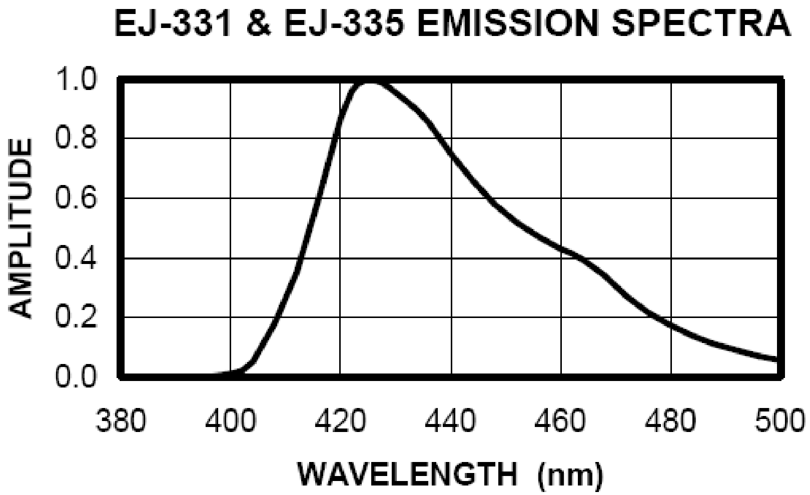
# Container (under construction)

- **Material: quartz (>99.99%)**
  - **Low radioactive impurity**
- **Volume: ~28L**

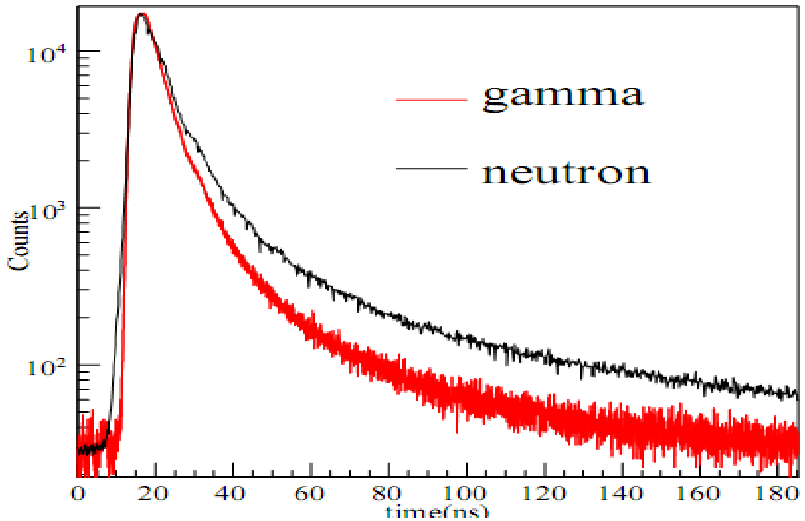


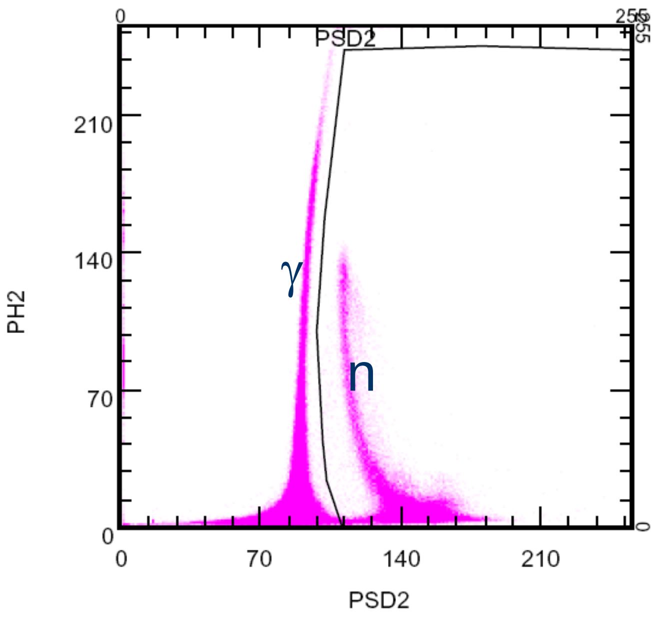
# Liquid scintillator: EJ-335

- PROPERTIES
  - Gadolinium content: 0.25% w/w
  - Specific Gravity: 0.89
  - Light Output (% of Anthracene): 55%
  - Bulk Light Attenuation Length: >4.5 meters
  - Refractive Index: 1.49
  - Flash Point: 64°C (147°F)
- ATOMIC COMPOSITION
  - No. of H Atoms per $cm^3$ : $6.16 \times 10^{22}$
  - No. of C Atoms per $cm^3$ : $3.93 \times 10^{22}$
  - H/C Ratio: 1.57
  - No. of Electrons per $cm^3$ : $30.6 \times 10^{22}$

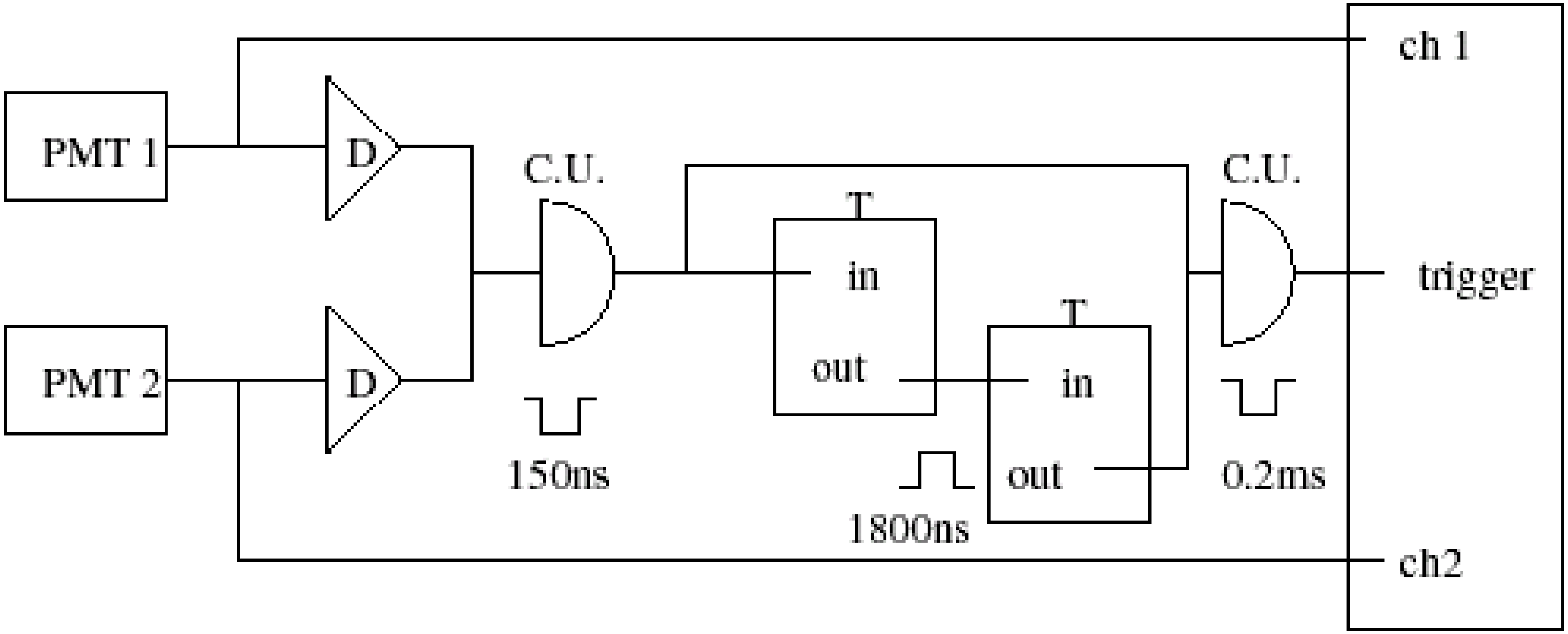


# PSD of liquid scintillator



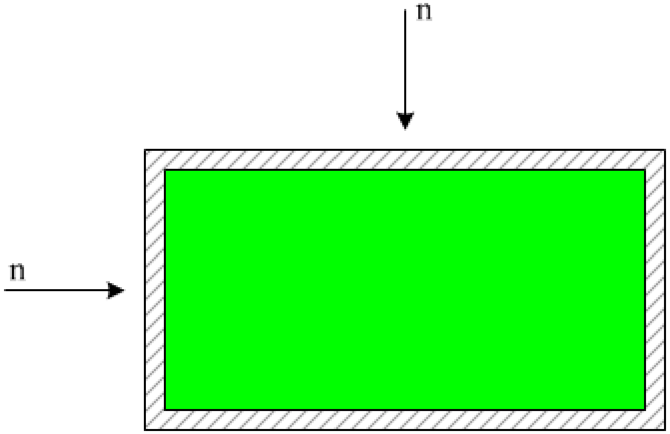



# Trigger electronics



# 3. Monte Carlo simulation

- Geant 4
- Geometry

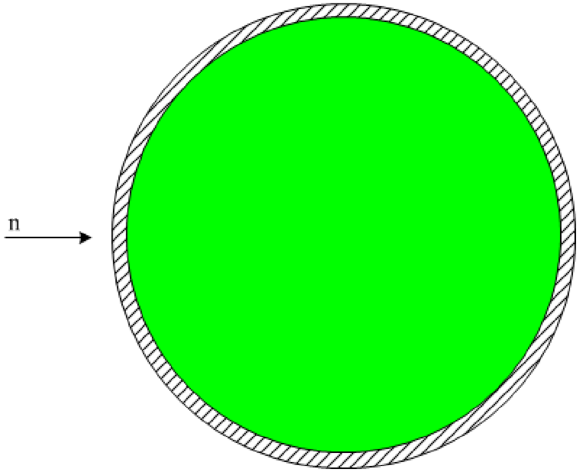



$\phi 20 \times 40$ cm

$\phi 25 \times 40$ cm

$\phi 30 \times 40$ cm

$\phi 40 \times 40$ cm




D = 40 cm

# Liquid scintillator

- Gd-LS EJ-331
  - Density: 0.9 g/cm$^3$
  - Gd concentration: 0.5% (by weight)
  - H:C = 1.32:1
- B-LS EJ-399
  - Density: 0.92 g/cm$^3$
  - $^{10}$B concentration: ~1%
  - C:H:O:$^{10}$B = 2.9 : 5.03 : 0.814 : 0.053

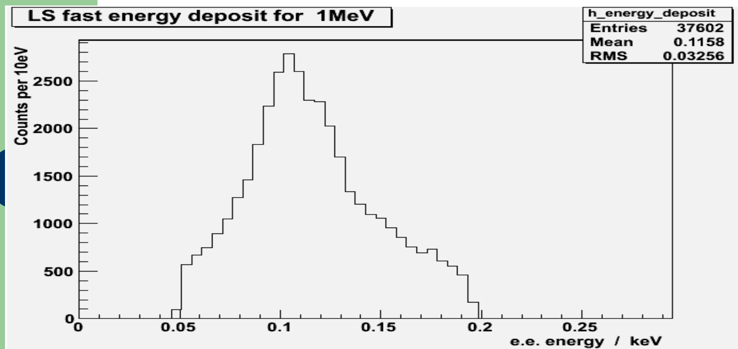
# Parameters to simulate

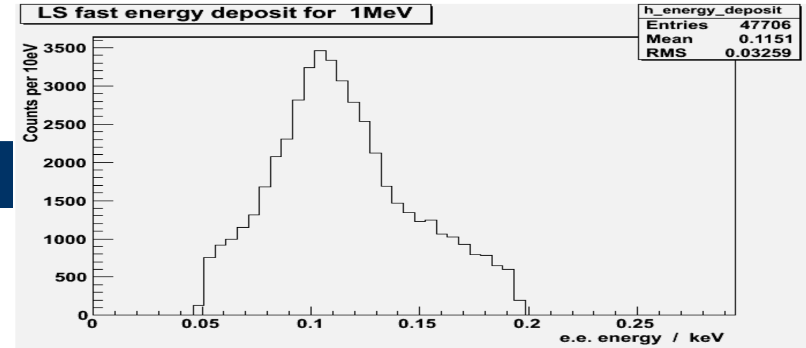
- Fast signal: recoil nuclei
- Slow signal:
  - Gd-LS gamma
  - B-LS gamma + 7Li + alpha
- Neutron detection efficiency

# Simulated spectrum of fast and slow signal (1 MeV,ϕ20×40 cm)

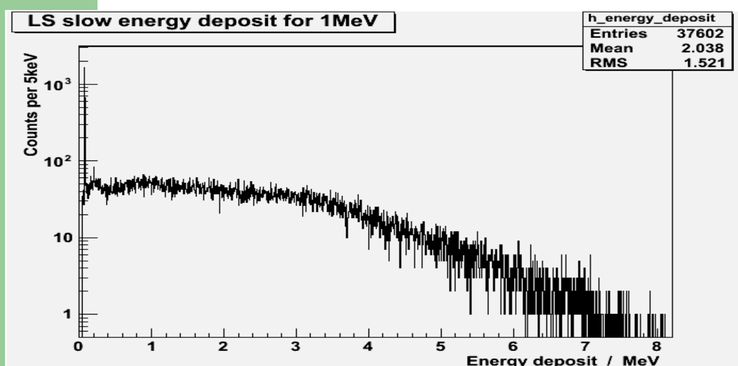
Gd-LS

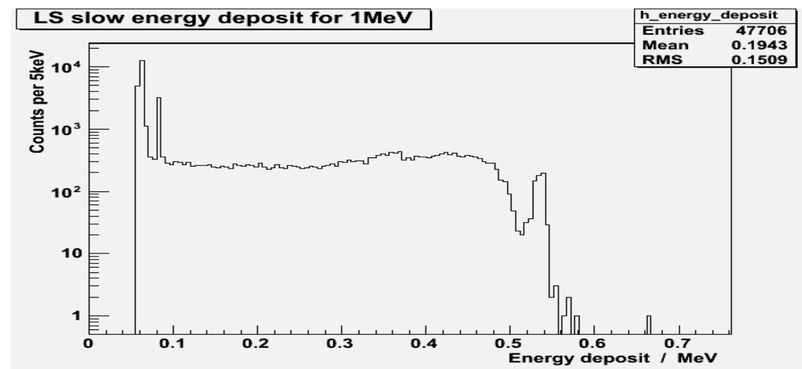
B-LS



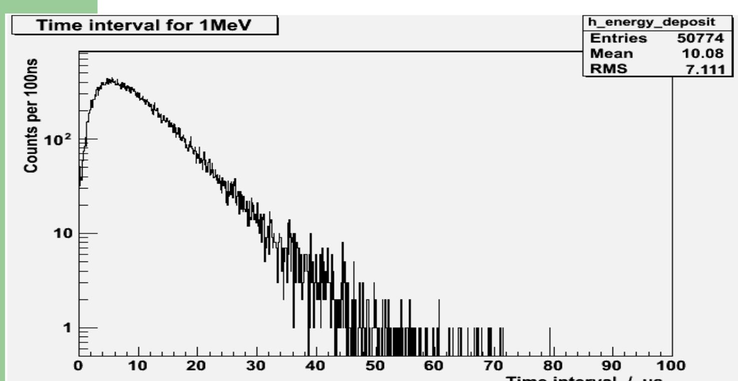



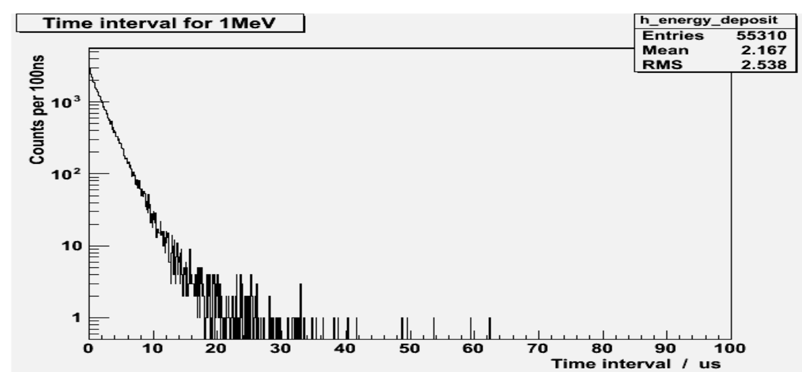

fast




slow



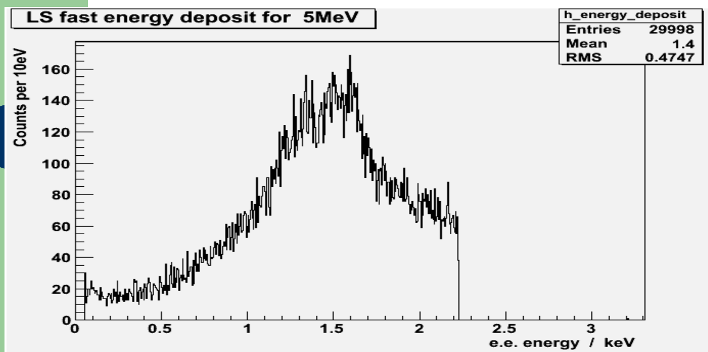



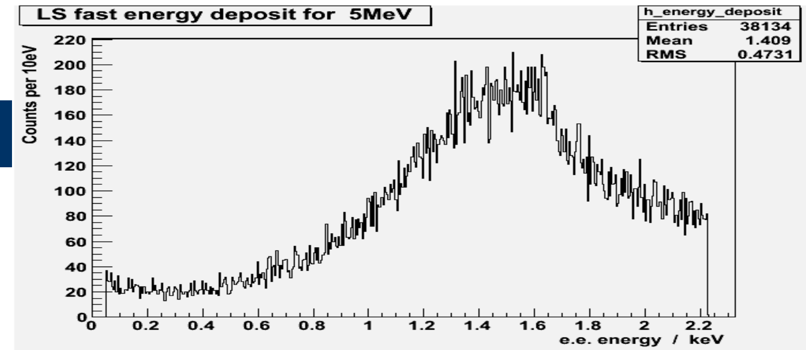

capture time

# Simulated spectrum of fast and slow signal (5 MeV,ϕ20×40 cm)

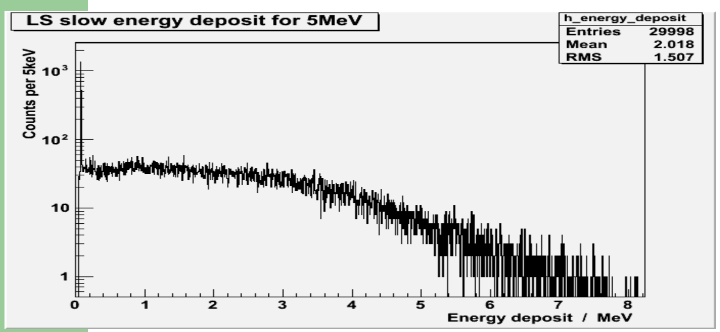
Gd-LS

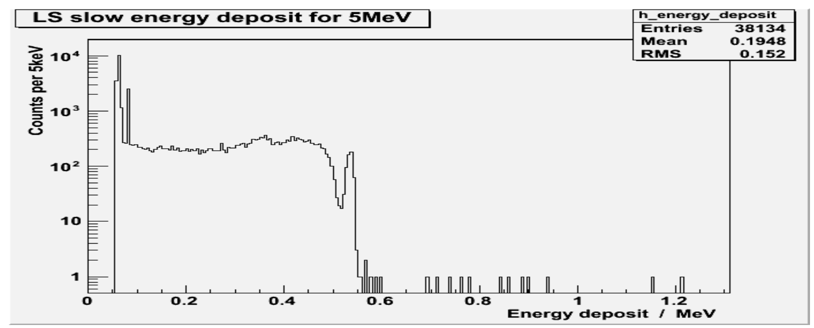
B-LS



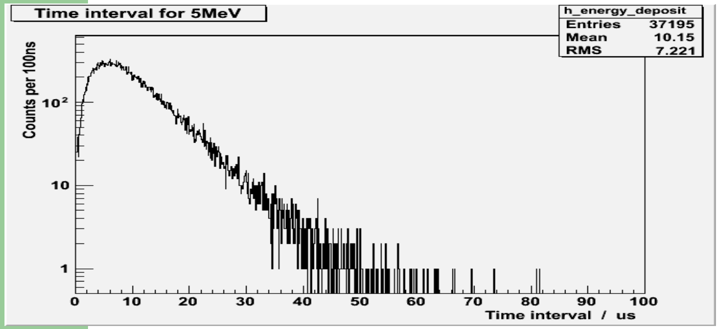



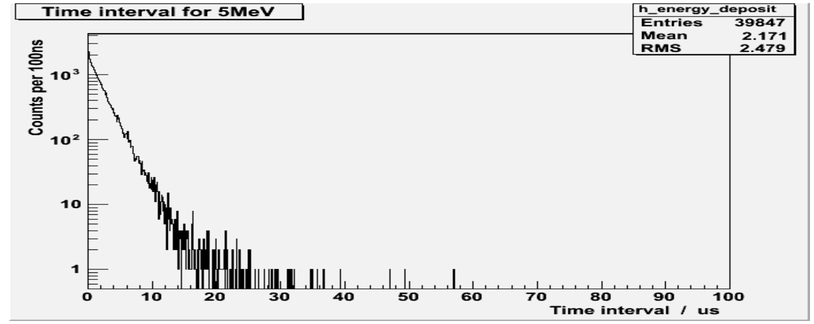

fast



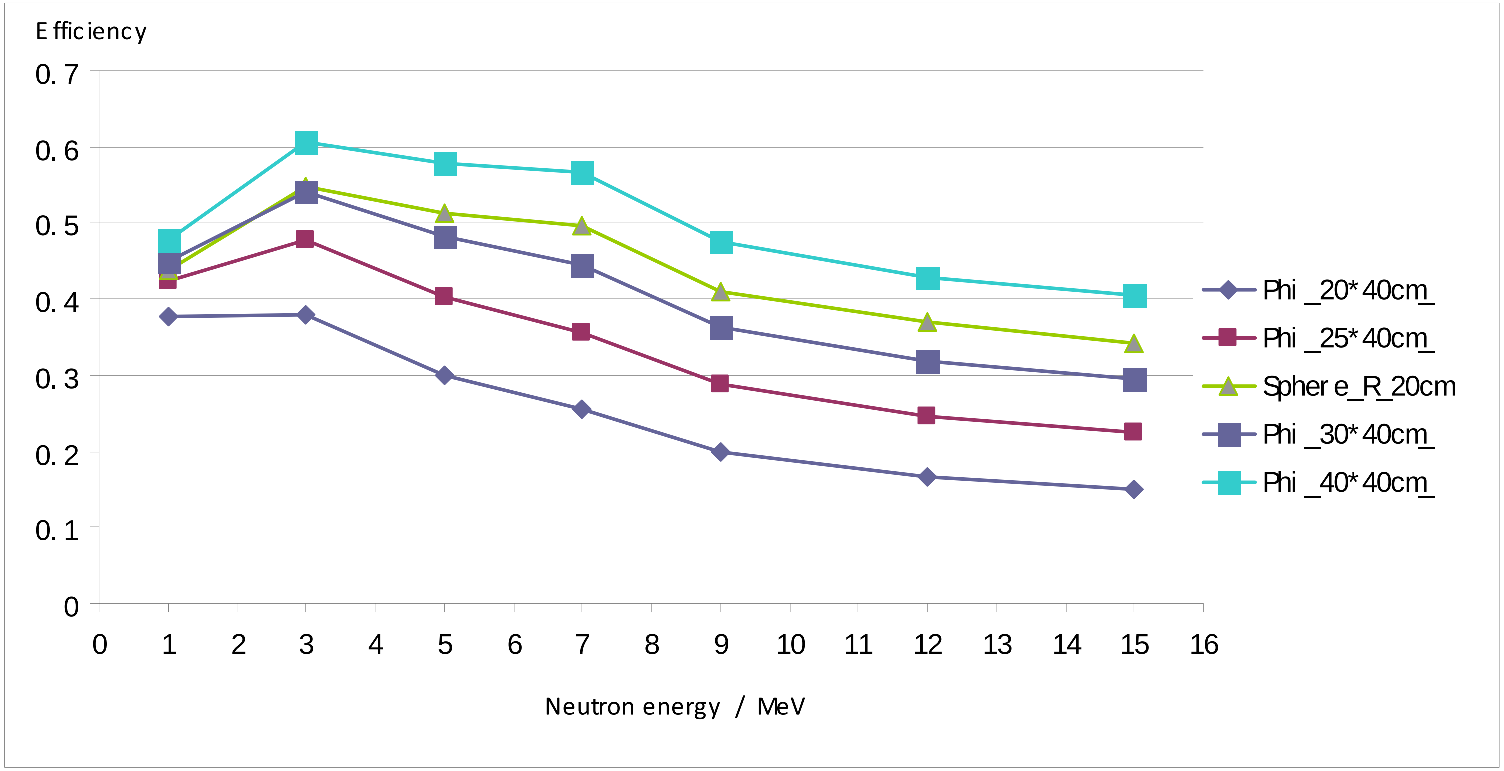

slow



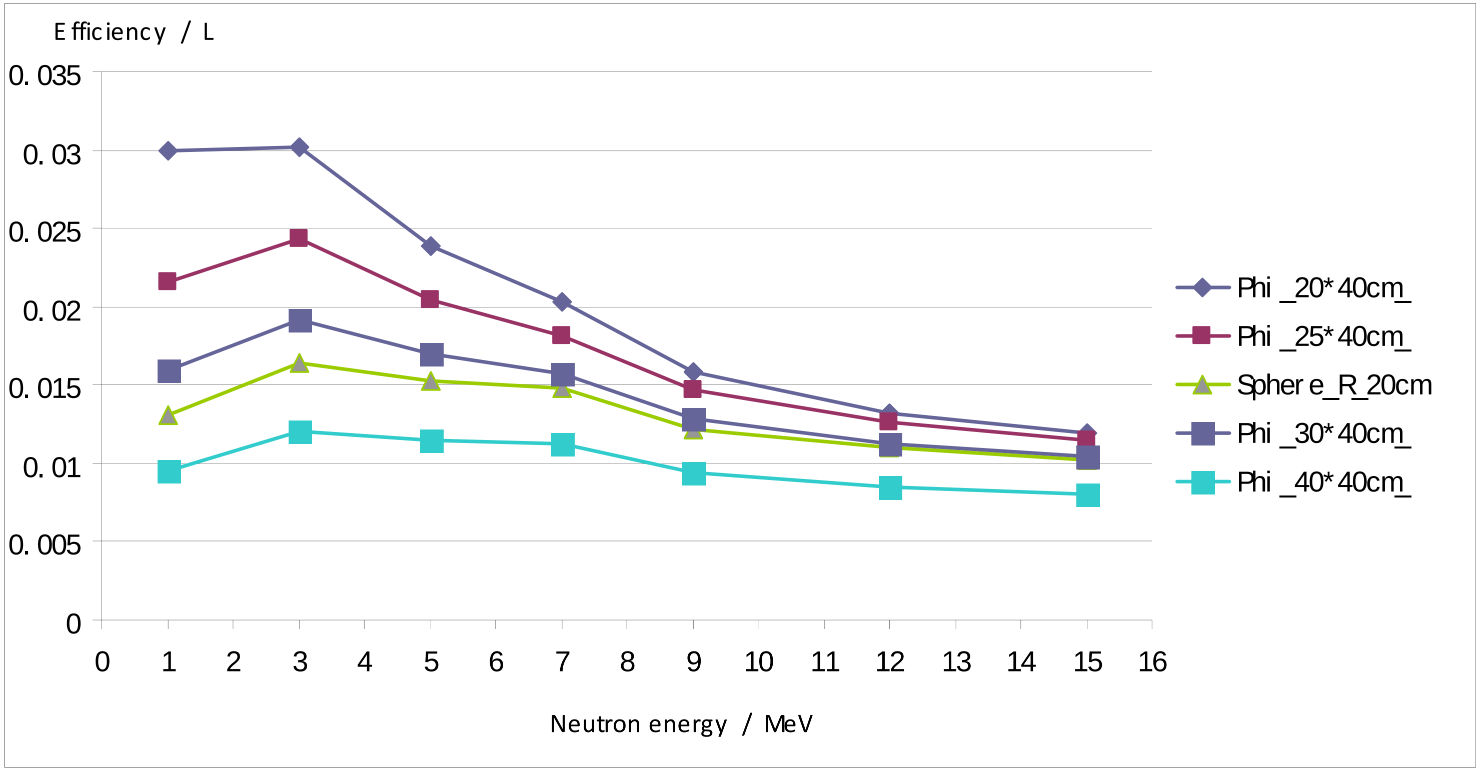




capture time

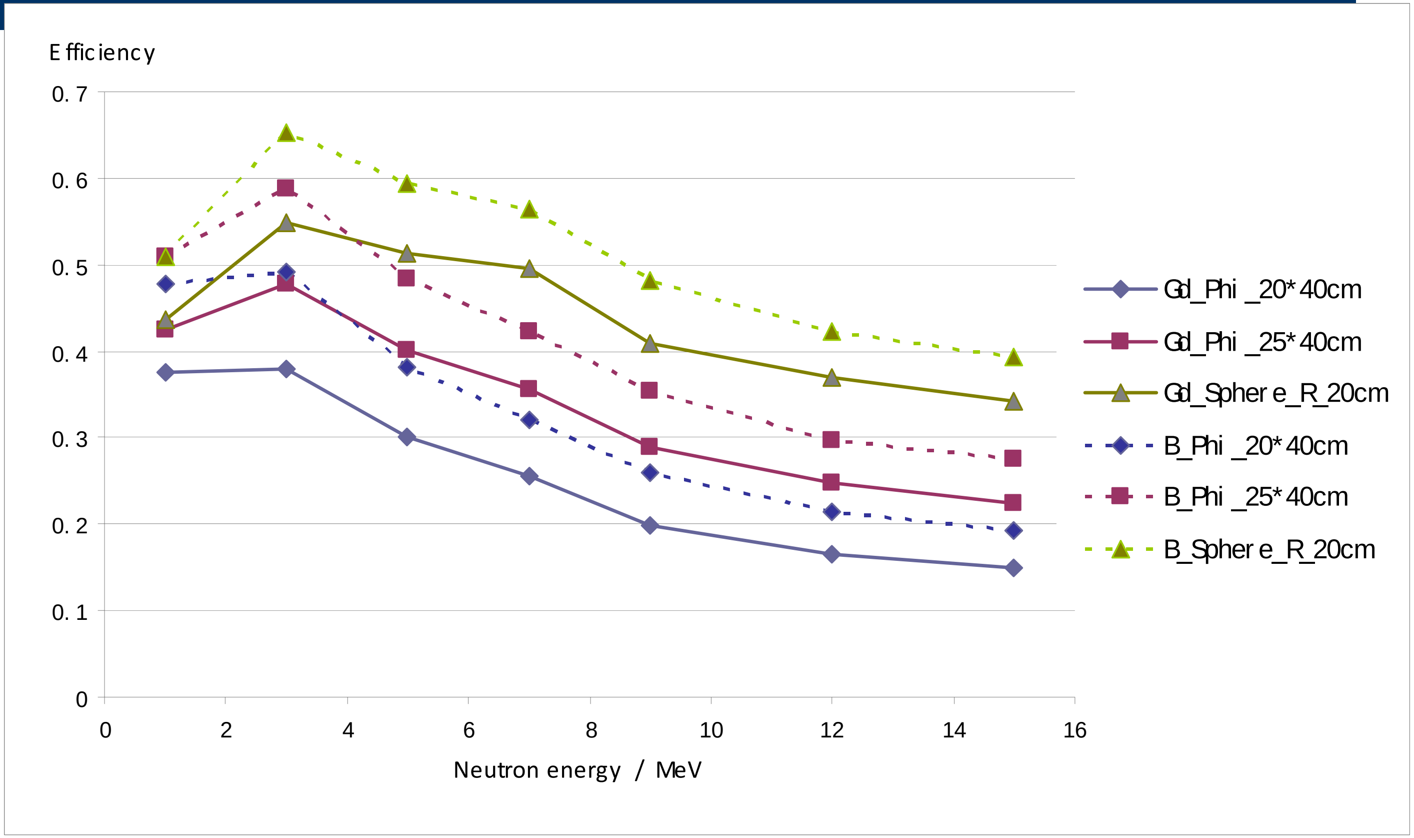
# Detection efficiency (Gd-LS)



# Detection efficiency per liter (Gd-LS)



# Comparison of Gd-LS and B-LS




**At same condition, the detection efficiency of B-LS is high that of Gd-LS**

# Why we choose Gd-LS ?

- Good PSD performance
- Slow signal is only from gamma, no charged particle
- Long term stability

# Summary

- Neutrons are the most important background in the underground experiment. The underground neutron flux is very low and the energy range is wide. So we need high sensitivity neutron detector and discriminate the neutron and gamma signal
- We have designed large volume liquid scintillator detector, the container will be made of quartz, and EJ-335 Gd loaded liquid scintillator will be used.
- Monte Carlo simulation has been performed for the design of neutron detector with Geant 4.

# Thanks !