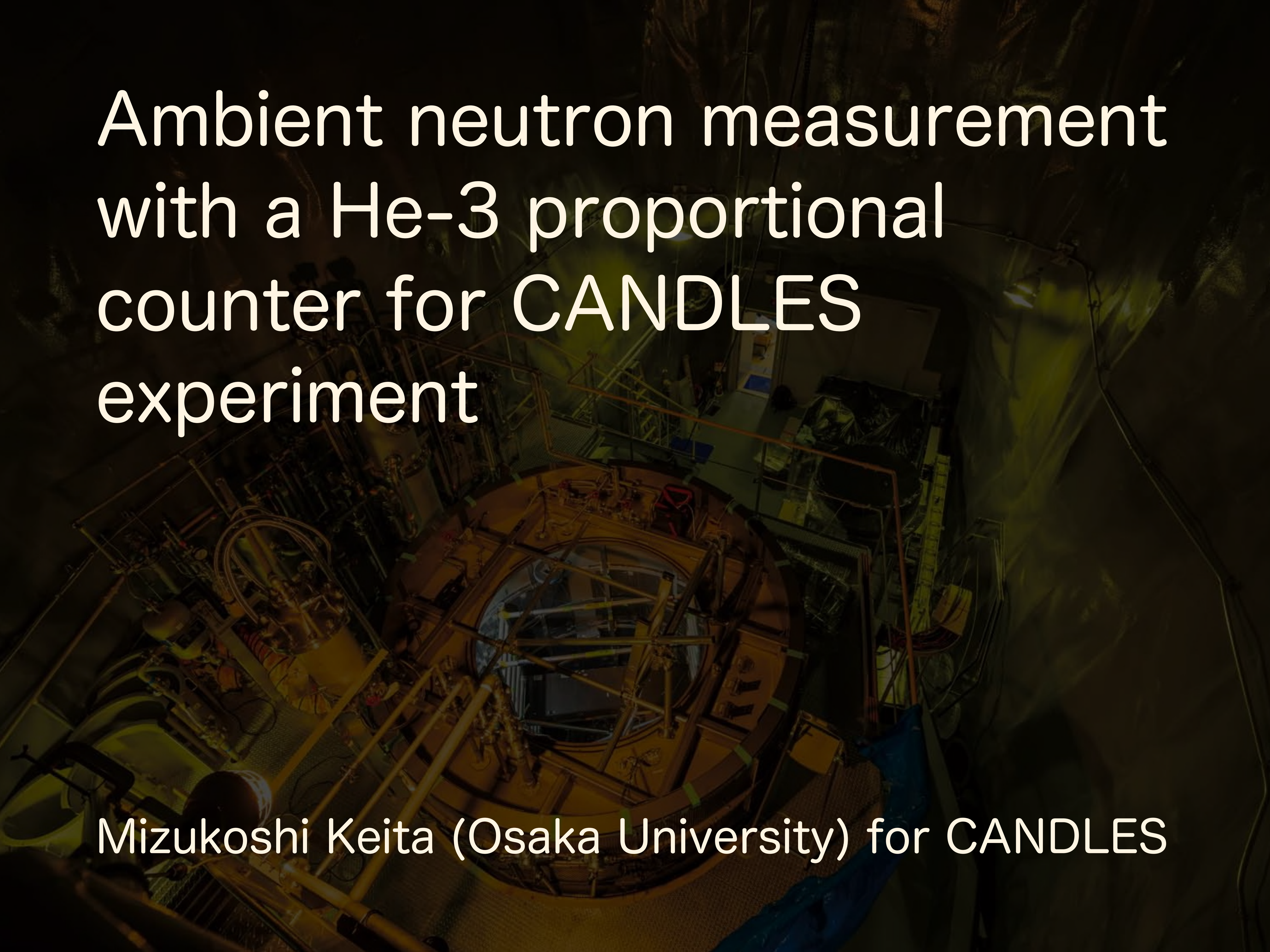


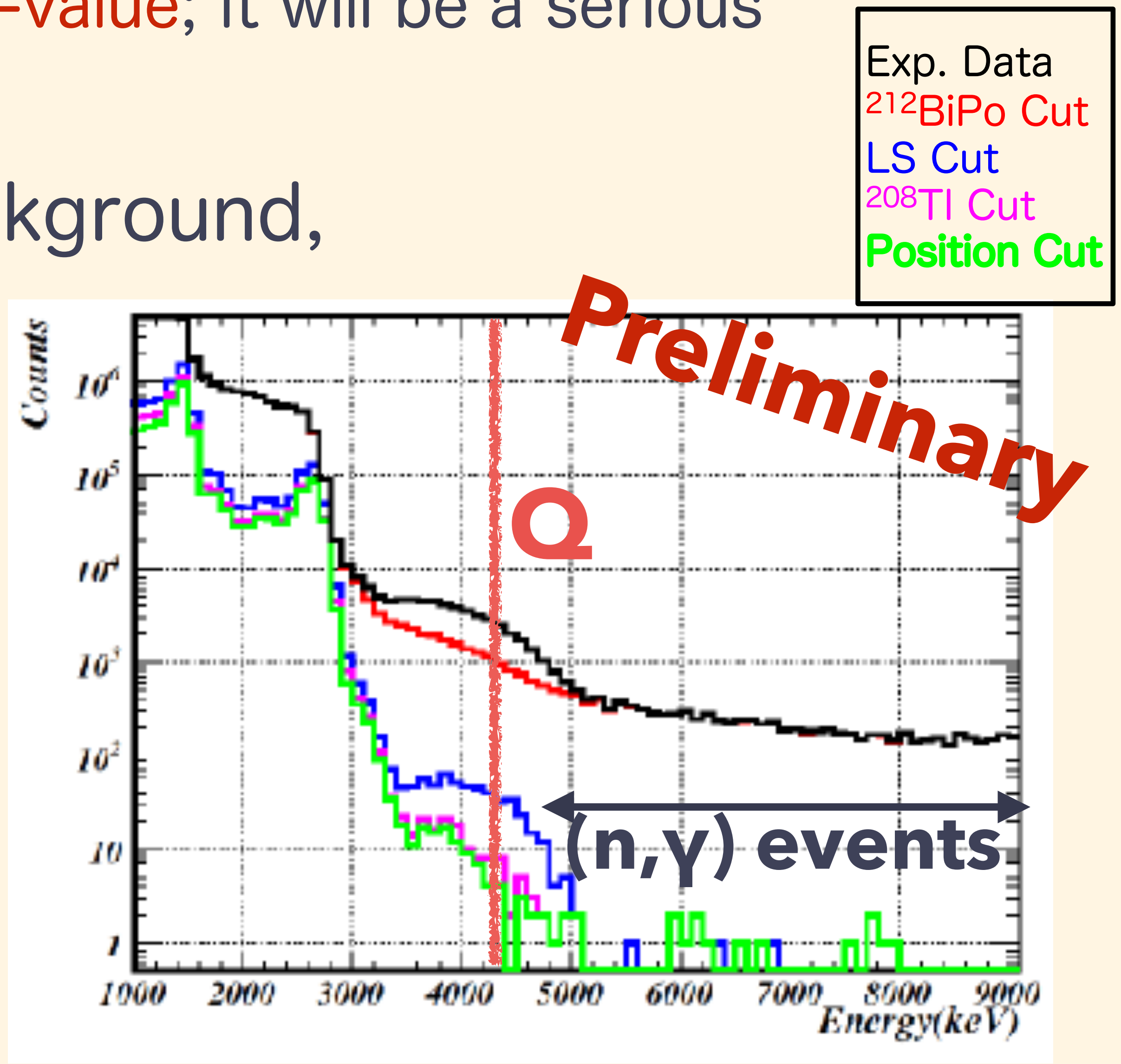
Ambient neutron measurement with a He-3 proportional counter for CANDLES experiment

Mizukoshi Keita (Osaka University) for CANDLES

Motivation

- Ambient neutron is a serious background for underground experiments searching rare events.
  - For neutrinoless double beta decay search, (n, γ) reaction can make high energy γ-ray around Q-value; it will be a serious background.
- To estimate and shield this background, it is important to evaluate the neutron flux.

CANDLES all crystal (including low purity)
Live time 131 days

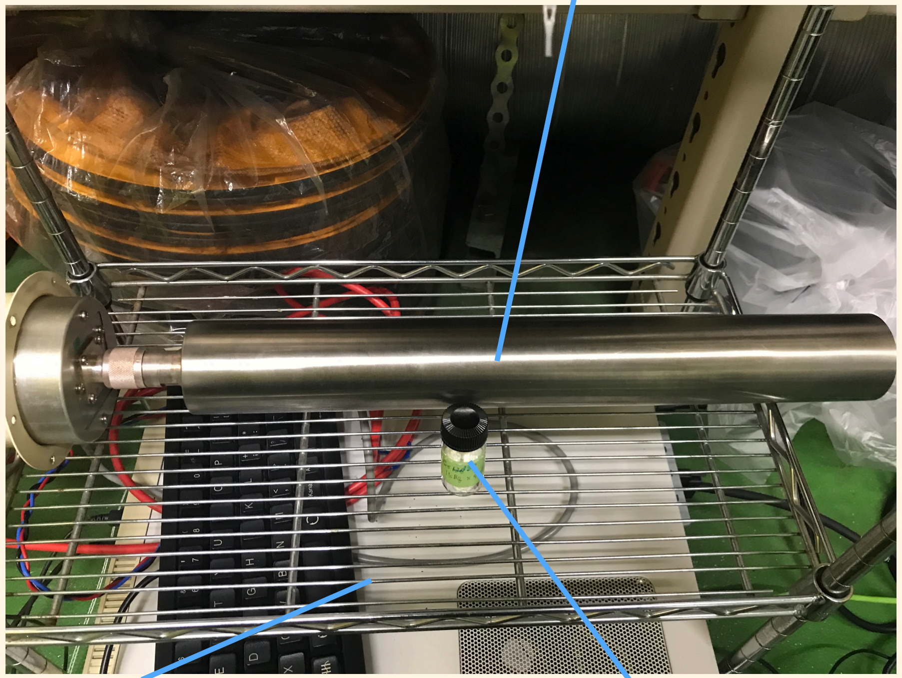


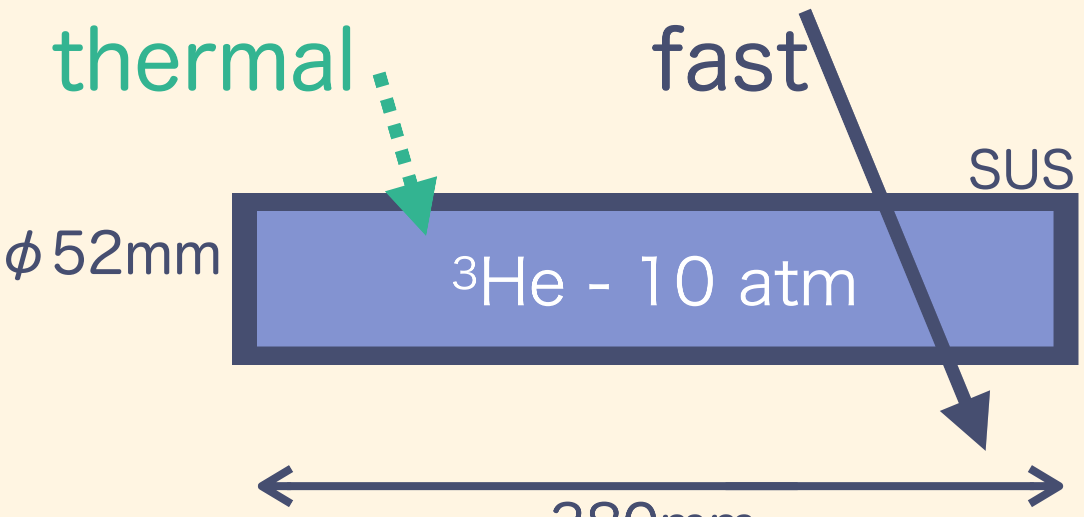
Detector and its principle

- We used a ^{3}He proportional counter.

$$^{3}\mathrm{He} + \mathrm{n} \rightarrow {}^{3}\mathrm{H} + \mathrm{p} + 0.76\ \mathrm{MeV}$$

  - The energy of the exothermal reaction in the neutron capture can be obtained.
  - This detector is sensitive to thermal neutrons (~0.025 eV), and <u>cannot</u> measure an initial neutron energy.

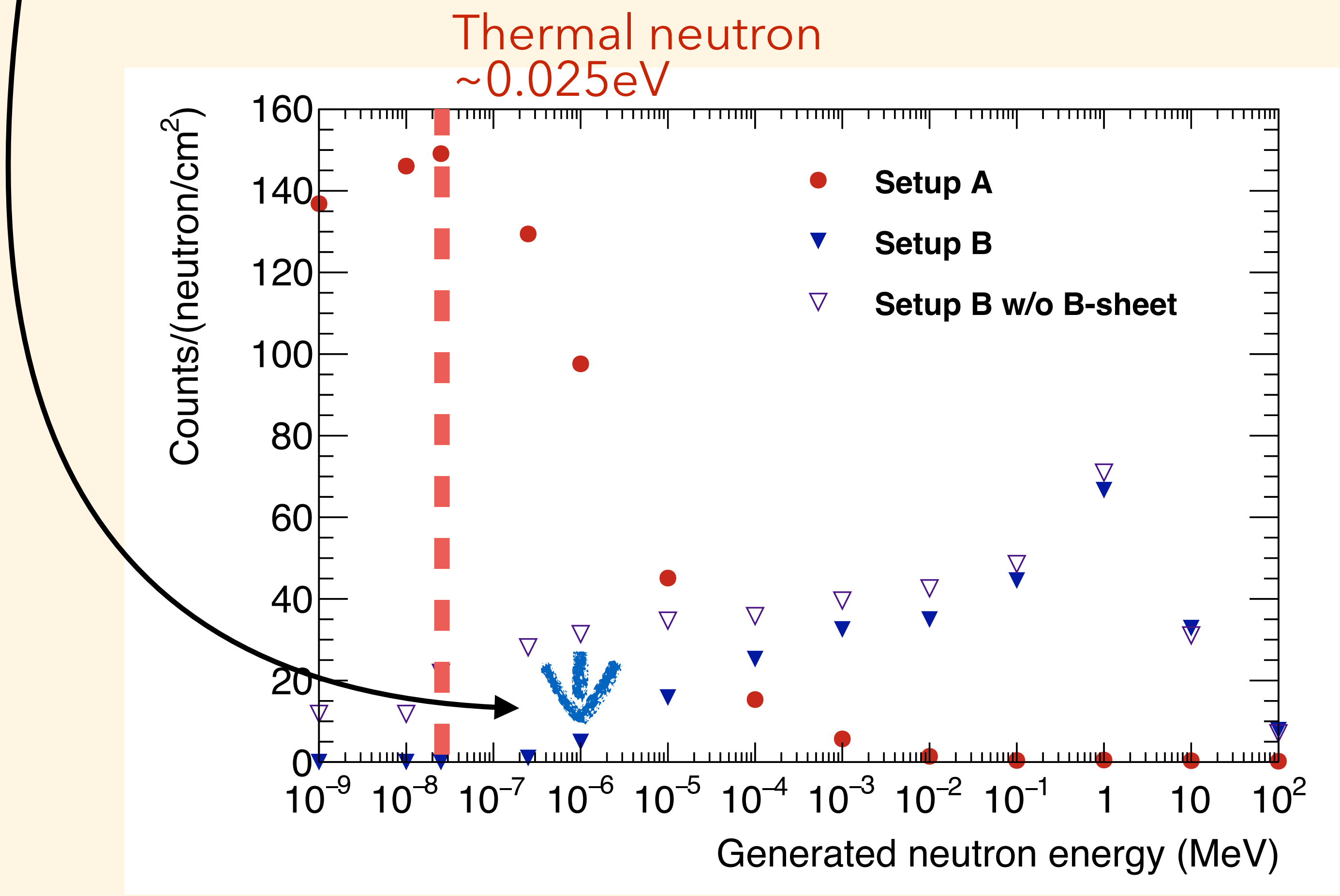




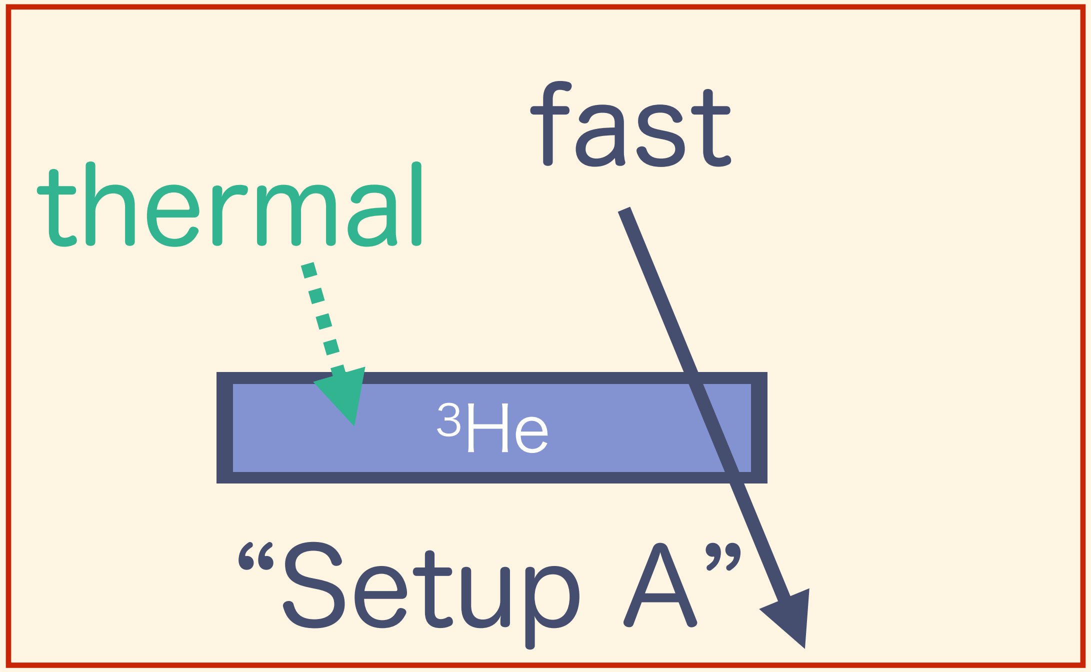
"Setup A"

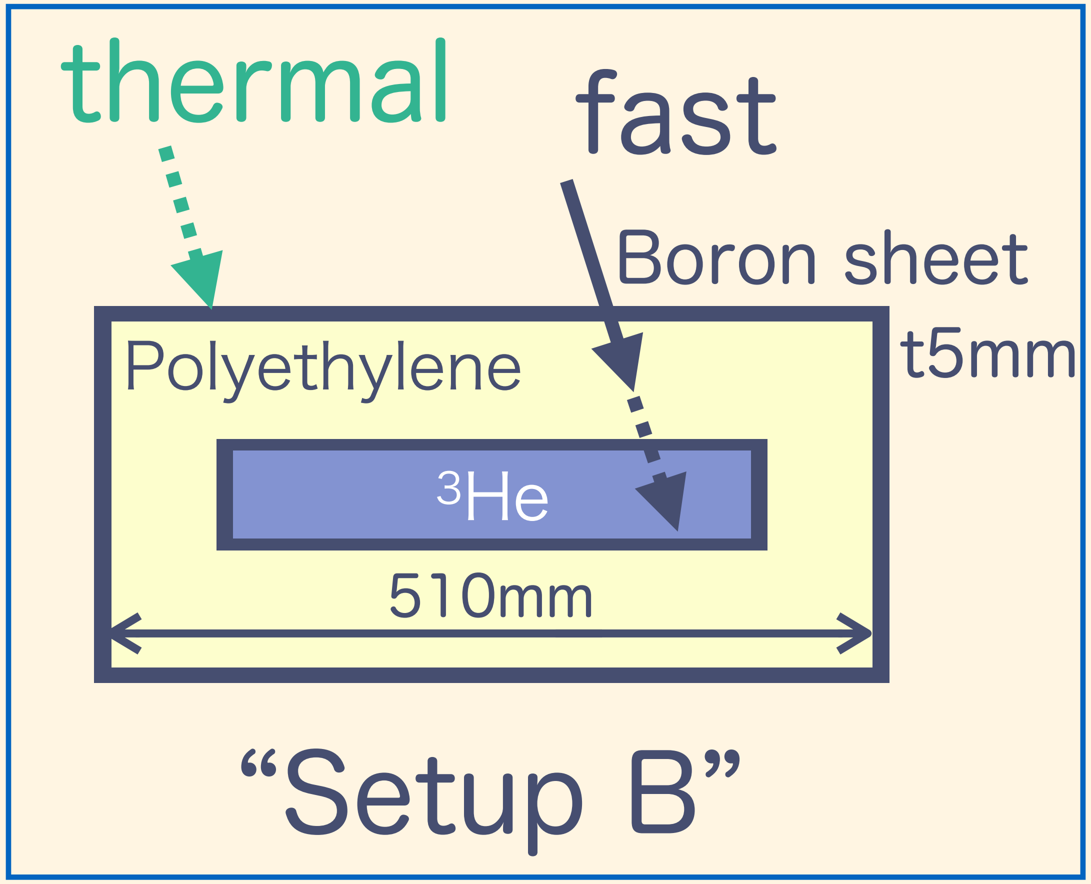
Setups for high energy neutron

- To measure high energy neutron, we used a moderator (polyethylene).
- Boron sheet captured thermal neutrons and reduce its effect.



Efficiency estimated by Geant4





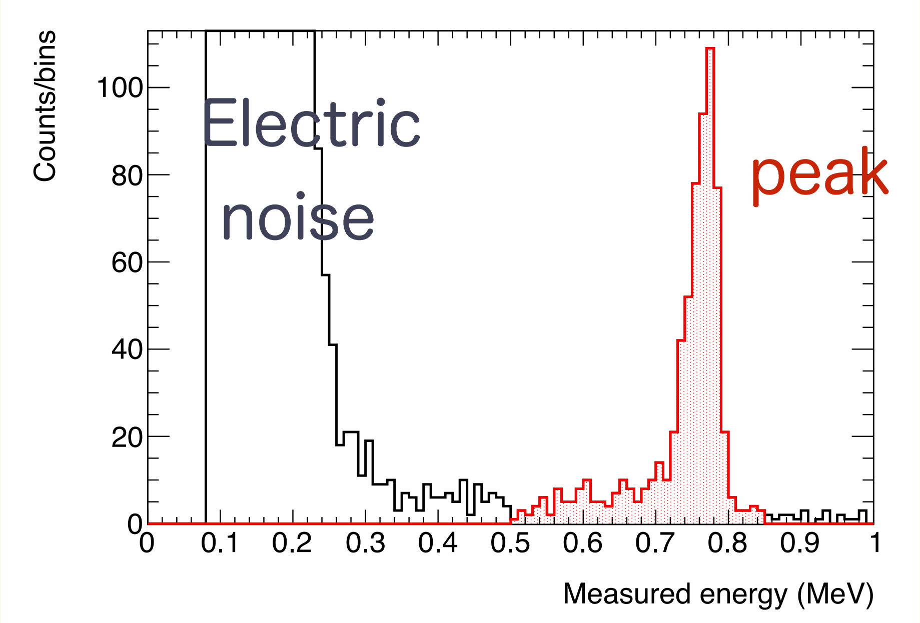
Results

$$^{3}\mathrm{He} + \mathrm{n} \rightarrow {}^{3}\mathrm{H} + \mathrm{p} + 0.76\ \mathrm{MeV}$$

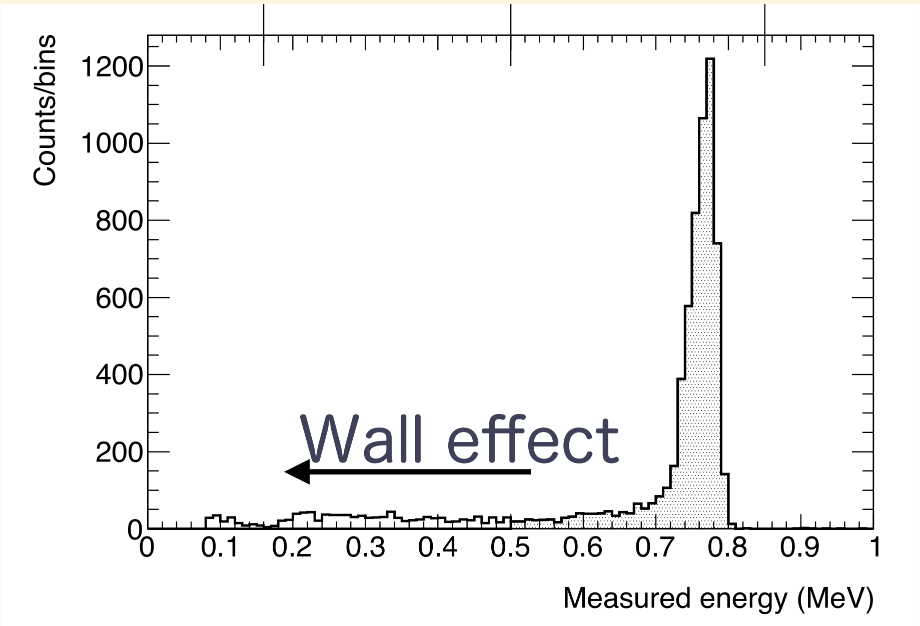
- Full energy peak is 0.76 MeV.
  If ^{3}H or p escapes, continuum region will be made in a low energy (Wall effect).
- Low energy region below 0.3 MeV is dominated by electric noise for ambient neutron measurement.
- We counted events up to 0.85 MeV and down to 0.5 MeV, then the number of total events was estimated by a clear spectrum observed using ^{252}Cf.

Count rate in each setup

Setup	A	B
Count rate ($\times 10^{-3}$cps)	1.295 ± 0.034	0.446 ± 0.018
Live time (day)	14.03	19.27



Measured spectrum in setup B



Spectrum of Source (^{252}Cf)

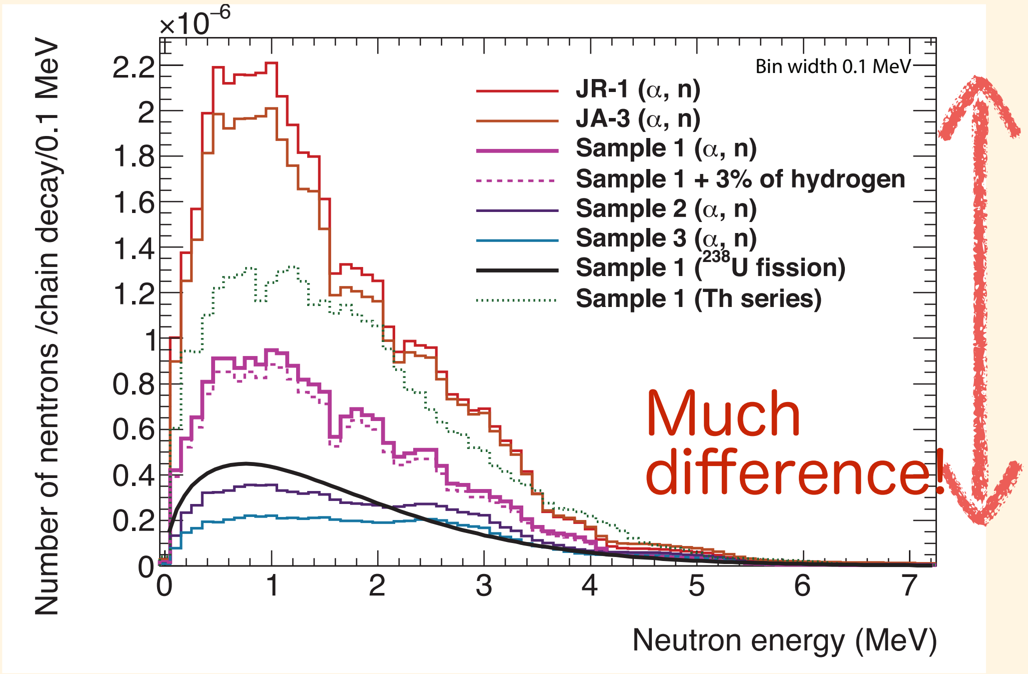
- The count rate of Setup A (R_A) and B (R_B) involves a detection of thermal and fast neutron, respectively.

Simulation

- To convert from the count rates (R_A, R_B) to ambient neutron flux, the shape of the spectrum was required. The shape cannot measured by ^{3}He detector thus estimated by simulation.
- We considered the source of the neutrons made from (α,n) reaction of U/Th series decay.
    - Neutron induced by cosmic muon is negligible.
- We picked three types of rocks as samples, they had much different abundance of chemical compositions.
    - <u>The difference affects much the yield of neutrons.</u>

Main components in each samples

(wt. %)	sample1	sample2	sample3
O	40.5	37.9	35.6
Ca	28.0	24.3	29.7
Si	16.6	15.6	12.0
Fe	7.6	16.6	13.5
Al	5.2	0.3	0.1
Mn	0.8	3.5	2.9



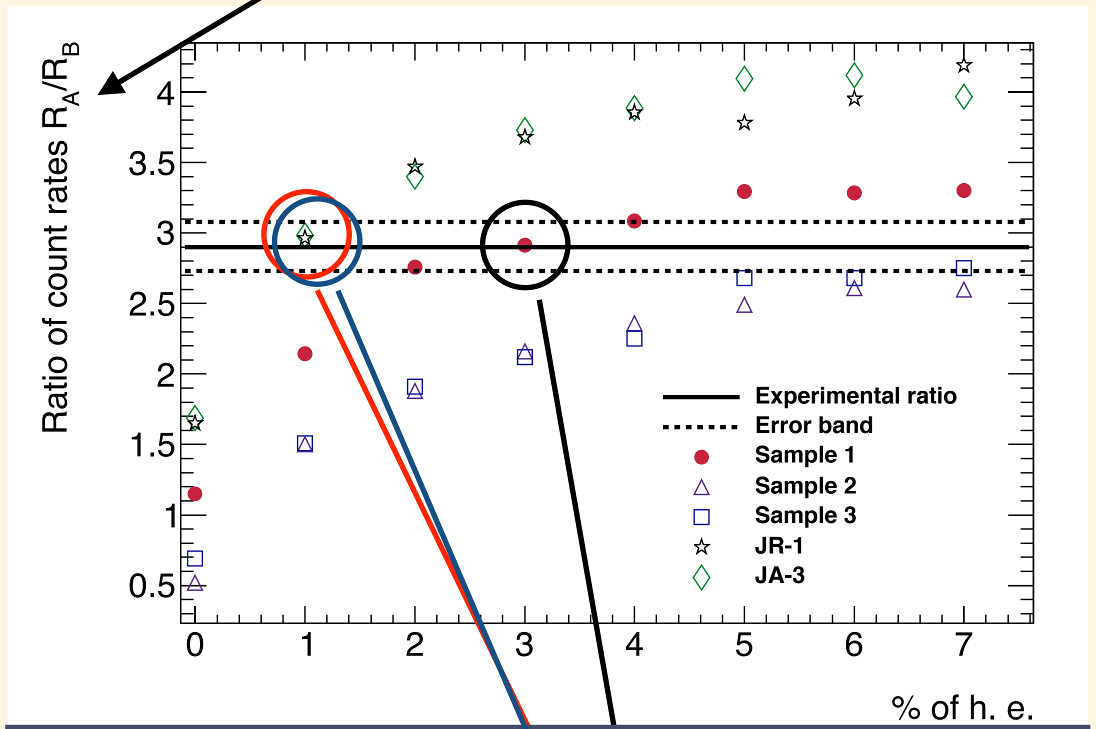
Generated neutron in vary rocks

JR-1 and JA-3 are geometrical reference database

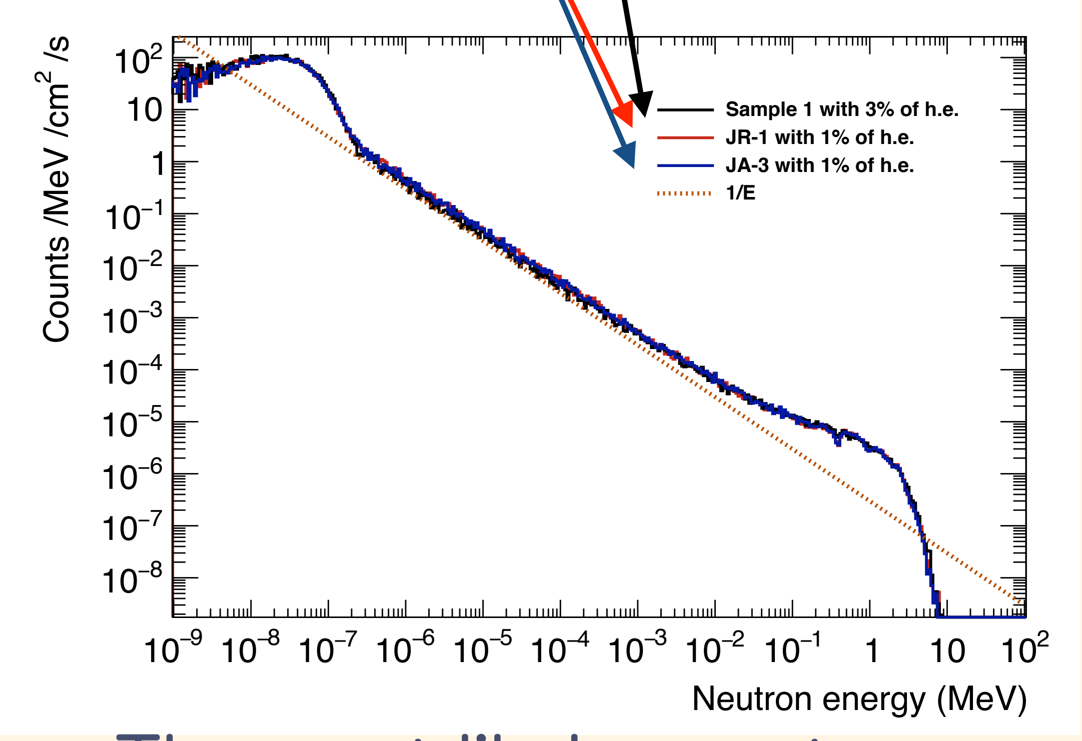
Data-driven Analysis

- We <u>cannot investigate</u> the all wall rock components in details.
  - Especially amount of water contents in the rock and chemical composition including Hydrogen will much affect thermalization of fast neutrons.
  - Thus, thermalization in the rock was <u>unknown</u>.
- We regarded the percentage of hydrogen (%of h. e.) in simulation as a thermalization parameter.
  - %of h.e. was derived by the experimental result (the ratio between setups A and B) in each rock component.
- The most likely spectra (made from experimental data) in each sample <u>are almost same</u>.

Thermalization parameter obtained by measurement



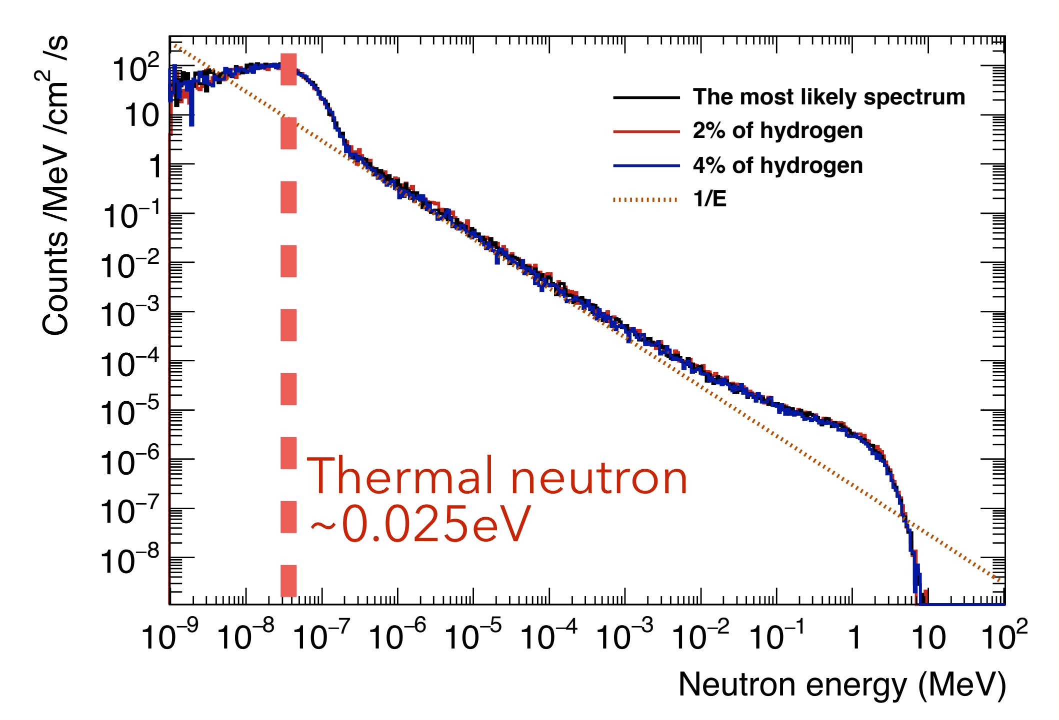
Experimental ratio v.s. parameter



The most likely spectrum

Obtained spectrum

- We obtained the most likely spectrum of the ambient neutron.
- We compared the fluxes (the previous study fluxes in other underground laboratories).
  - They are the same order of magnitude.
  - It is difficult to compare the result simply because there are many difference in these measurement (e.g., detector, assumption of spectrum shape, and definition of flux)



The most likely spectrum

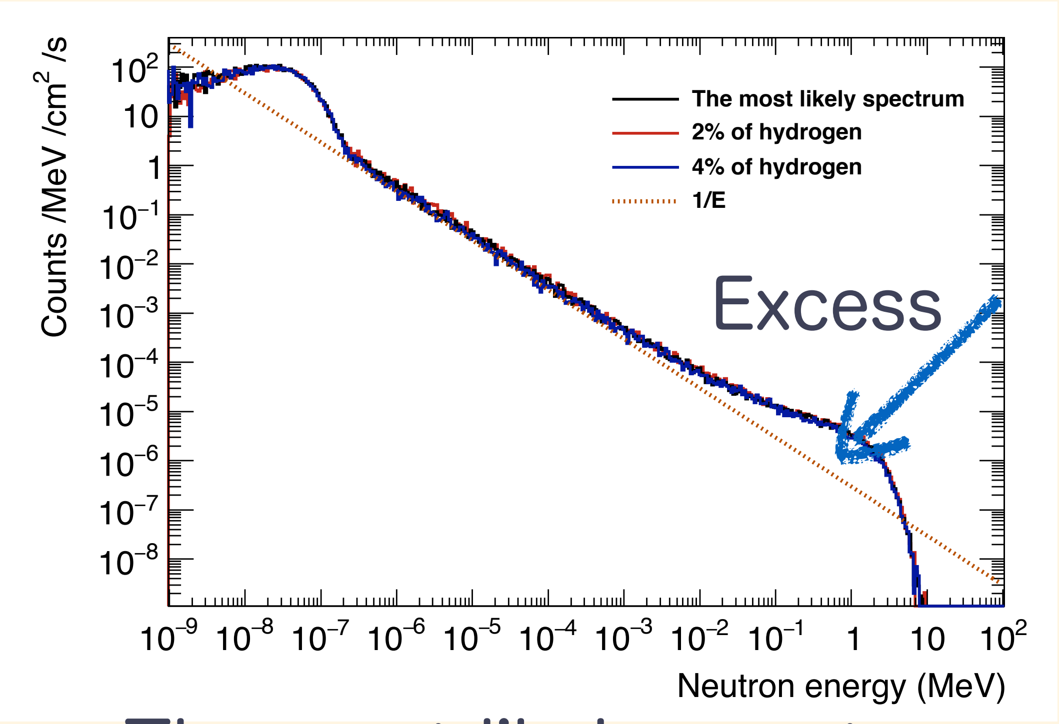
Neutron fluxes in previous researches

Flux ($\times 10^{-6}$ cm^{-2} s^{-1})	Thermal	Non-thermal
Kamioka (This result, Mizukoshi)	$7.9 \pm 0.23 {}^{+0.7}_{-0.7}$	$15.6 \pm 0.5 {}^{+1.2}_{-1.4}$
Kamioka (Minamino 2004)	8.26 ± 0.58	11.5 ± 1.2
Gran Sasso (A. Lindi 1988)※	13.3 ± 1.5	10.2 ± 1.1
LSM (K. Eitel 2012)※	14.3 ± 1.3	4.2 ± 2.8

※They used the different definition of flux. We adjusted the same definition of us.

Discussions

- In the previous research, rough spectral shape was assumed (e.g., Boltzmann distribution and 1/E).
- The most likely spectrum suggests the excess in a few MeV.
  - The excess is interesting for direct dark matter search.
  - The excess should be confirmed by a liquid scintillator which has a sensitivity for the neutron.



The most likely spectrum

- Since the cross section of high energy neutrons is small, it continues to be a high energy neutron.
- Once it lose energy, the cross section increases. it continues to lose energy.
- Therefore, the excess will remain at several MeV.

Summary

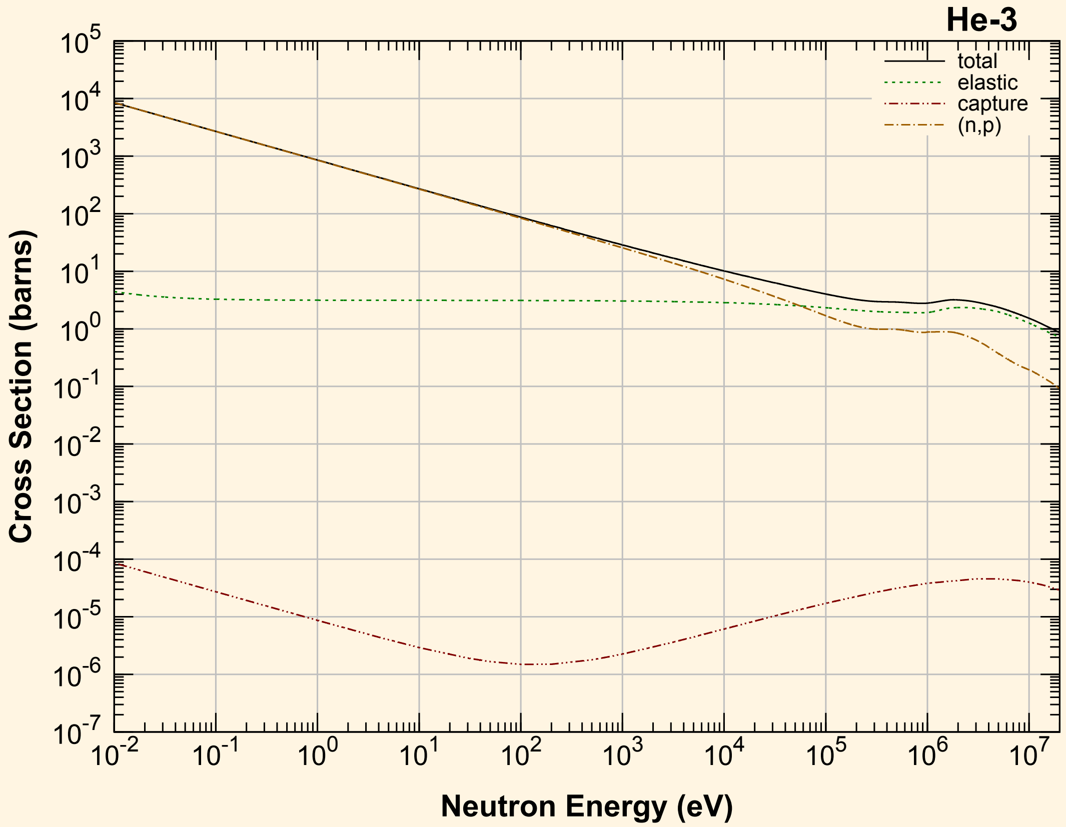
- We evaluated an ambient neutron spectrum and obtained the flux at the Kamioka Observatory.
  - using ^{3}He proportional counter and moderator effectively
  - with data-driven analysis and simulation
  - considering systematic errors
- Spectral excess around a few MeV was suggested. It should be confirmed by a sensitive detector for non-thermal neutron.
  - We are preparing a low BG liquid scintillator.
- We published the manuscript to the preprint server (arXiv: 1803.09757)

Thank you for your attention.

Backup slides

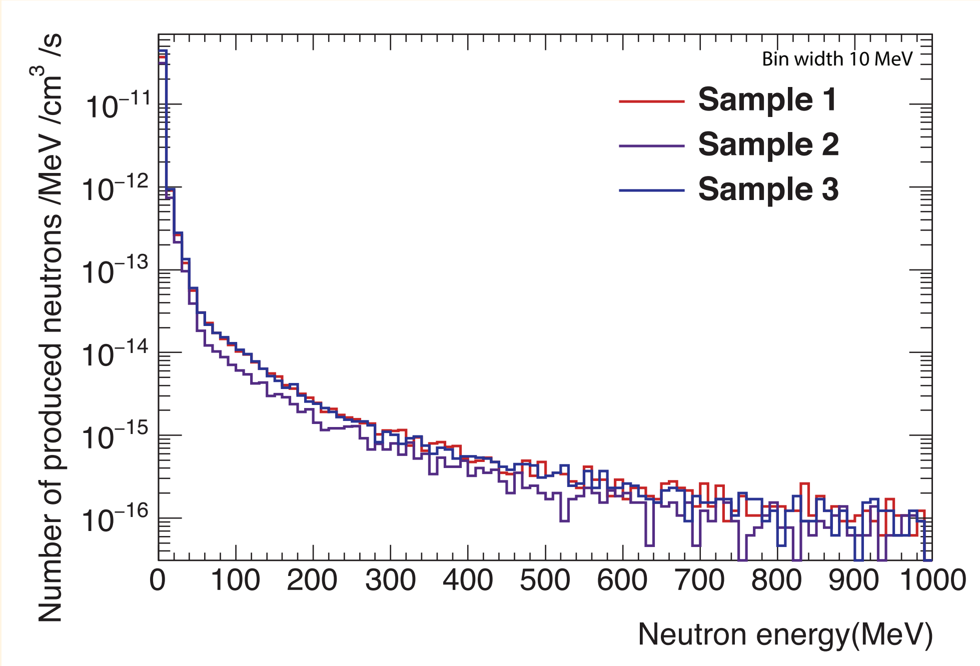
He-3 Cross section for neutron

- He cross section is much large for thermal neutrons.
- Cross sections of the rock components have the same trend.
  - Since the cross section of high energy neutrons is small, it continues to be a high energy neutron.
  - Once it lose energy, the cross section increases. it continues to lose energy.
  - Therefore, the dip will remain at several MeV.

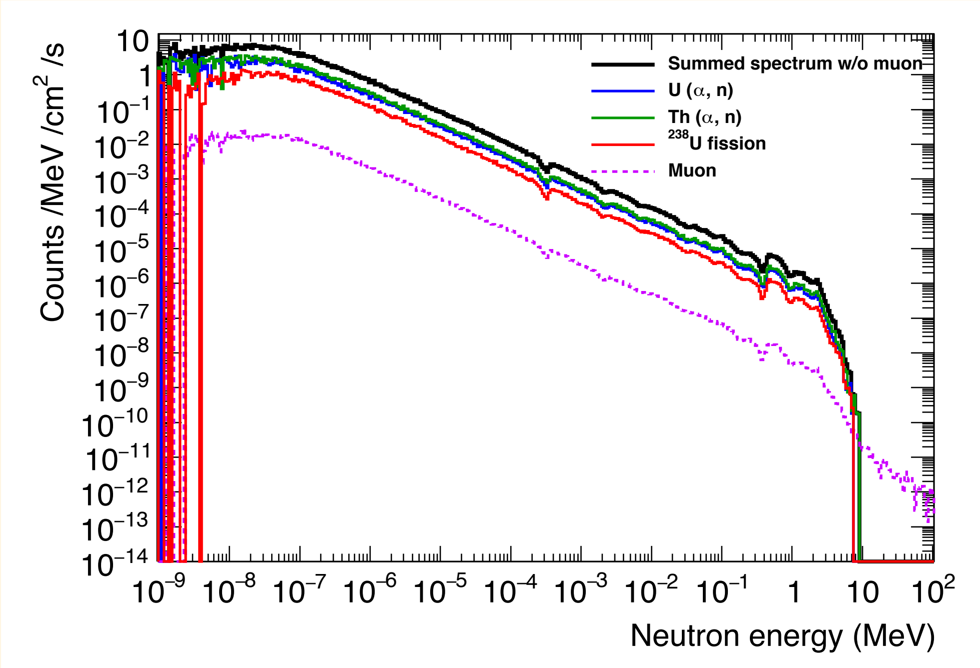


Neutron source (Not U/Th)

- We can consider the ambient neutron made from cosmic muon.
  - It can make high energy neutron (>10 MeV), the number of neutrons by muon is 100 times less than the ones by U/Th series.
- In this research, we ignored the contribution of muon.



Generated neutrons from cosmic muon



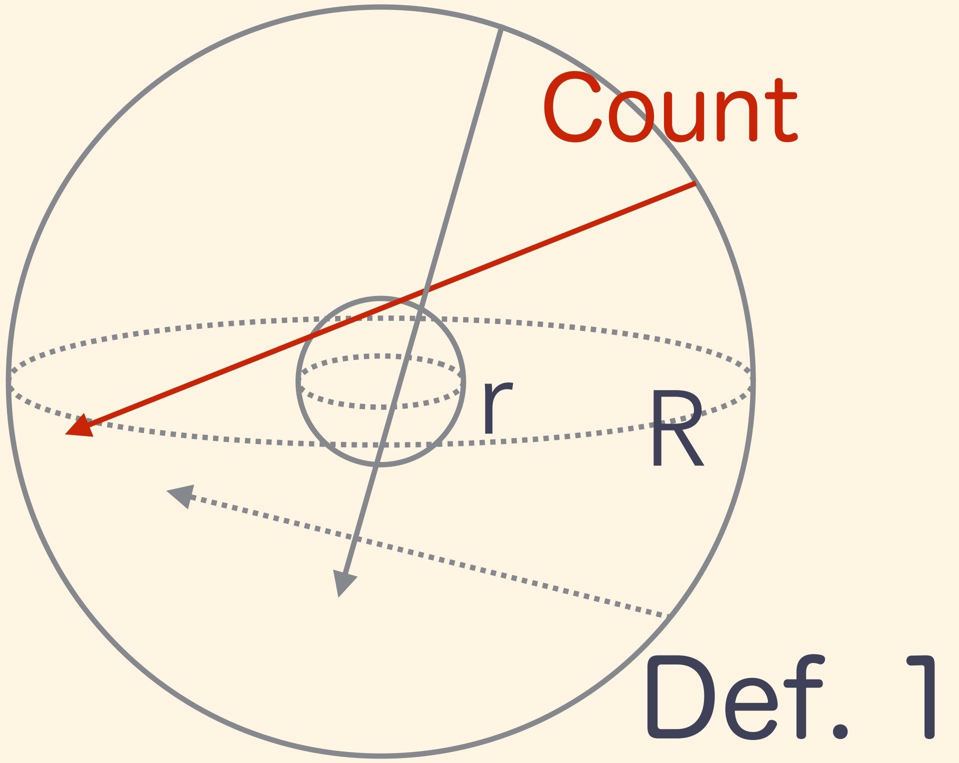
Spectrum of each source for sample1

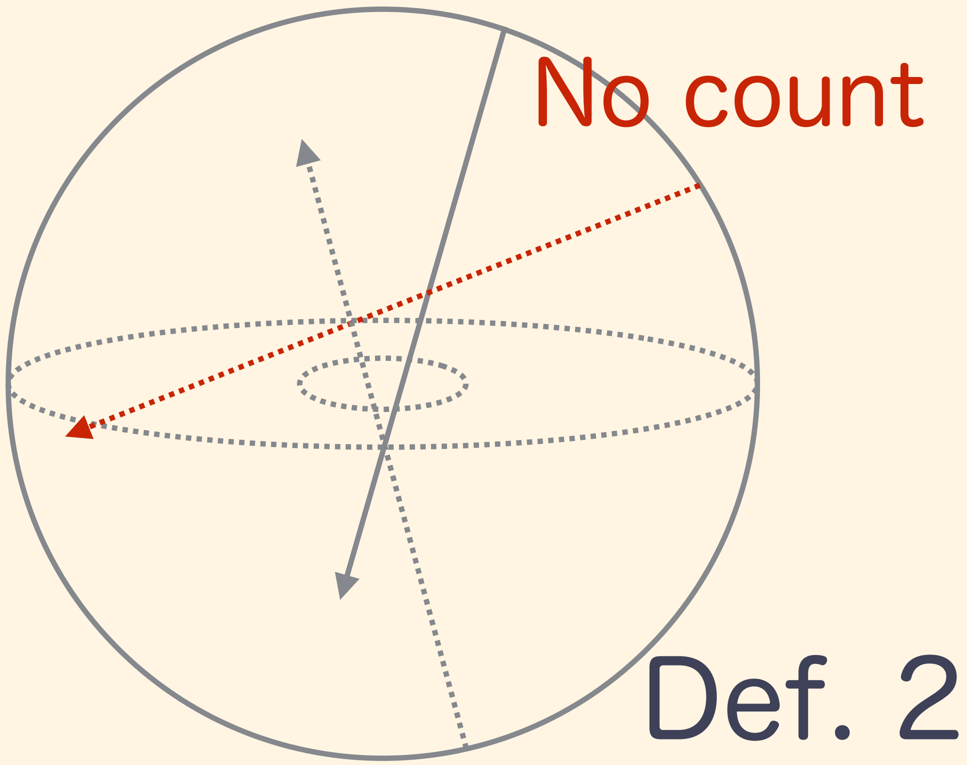
All components of the rocks

(wt. %)	sample1	sample2	sample3	sampleA	sampleC	KamRock
Si	16.6	15.6	12.0	29.1	27.8	18.5
Ti	0.2	0.0	0.0	0.5	0.5	0.1
Al	5.2	0.3	0.1	7.1	8.3	10.6
Fe	7.6	16.6	13.5	4.6	4.5	1
Mn	0.8	3.5	2.9	0.1	0.1	0
Mg	0.6	1.1	0.7	2.2	1.3	0.3
Ca	28.0	24.3	29.7	4.5	5.2	1.8
Na	0.0	0.2	0.0	2.4	2.6	3.9
K	0.0	0.1	0.0	1.2	1.5	2.1
P	0.2	0.0	0.0	0.1	0.1	0.1
S	0.0	0.1	1.2	0.0	0.0	0
Zn	0.0	0.1	4.3	0.0	0.0	0
Sr	0.1	0.0	0.0	0.0	0.0	0
Nb	0.0	0.0	0.0	0.0	0.0	0
Sn	0.1	0.0	0.0	0.0	0.0	0
Pb	0.0	0.0	0.0	0.0	0.0	0
O	40.5	37.9	35.6	48.3	48.1	60.7

Definition of Flux

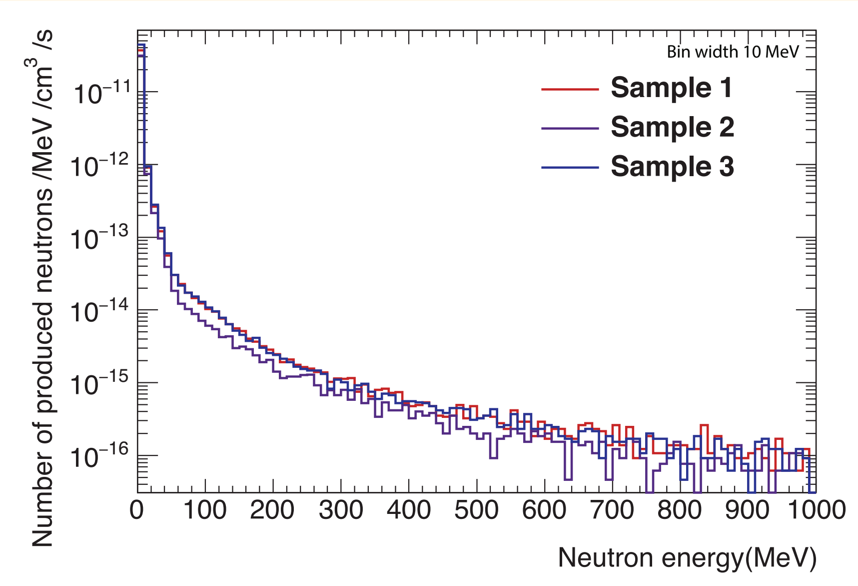
- Two types of definition are used.
- (1)Number of particle through the sphere (radius r)/
  the area of grate circle(πr^2)
  - Widely used in Nuclear physics
  - We use that.
- (2)Number of particle through the circle (radius r)/ the area (πr^2)
  - Widely used in Particle physics
  - LSM and Gran Sasso would use this definition.



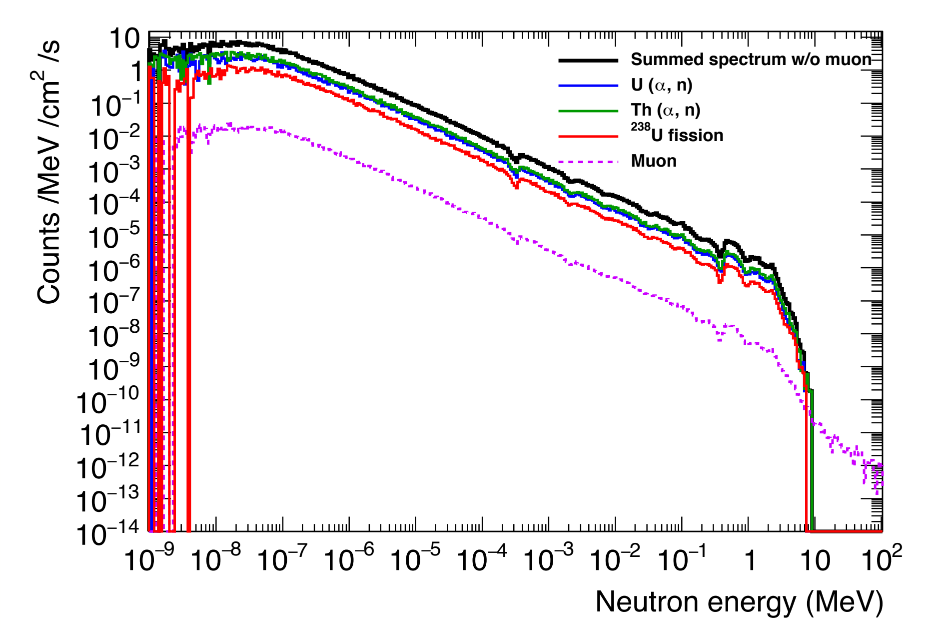


U/Th系列以外の寄与(Muon)

- U/Th系列核の寄与以外に宇宙線Muonの寄与が考えられる.
- 確かに,U/Th核より高エネルギー(>10MeV)の中性子を生成可能.
- ただし,U, Th系列の1/100の中性子しか生成できないので,本研究では無視した.



Muonにより岩石で生成される中性子



得られたスペクトル形の生成要因内訳