Fast neutron background measurement in CJPL

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Contents

Detector introduction

Neutron background measurement in CJPL

Intrinsic U/Th/Ac contamination calculation

Quenching factor of EJ-335 calculation

Neutron spectrum unfolding

Contents

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Intrinsic U/Th/Ac contamination calculation

Quenching factor of EJ-335 calculation

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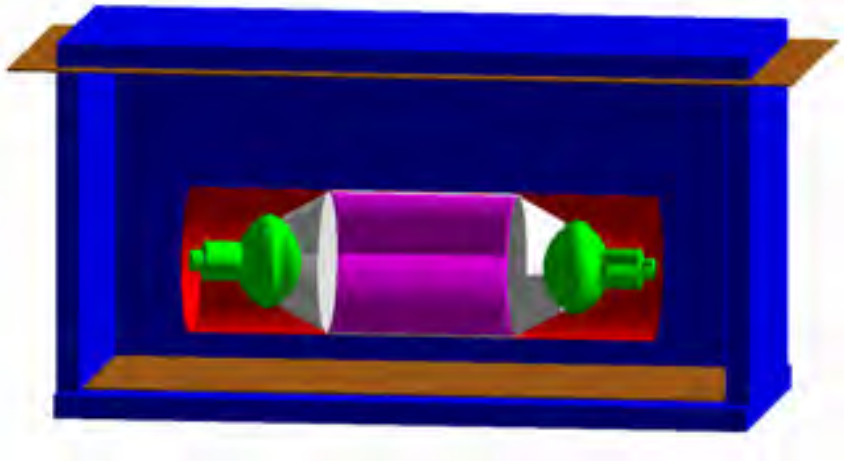
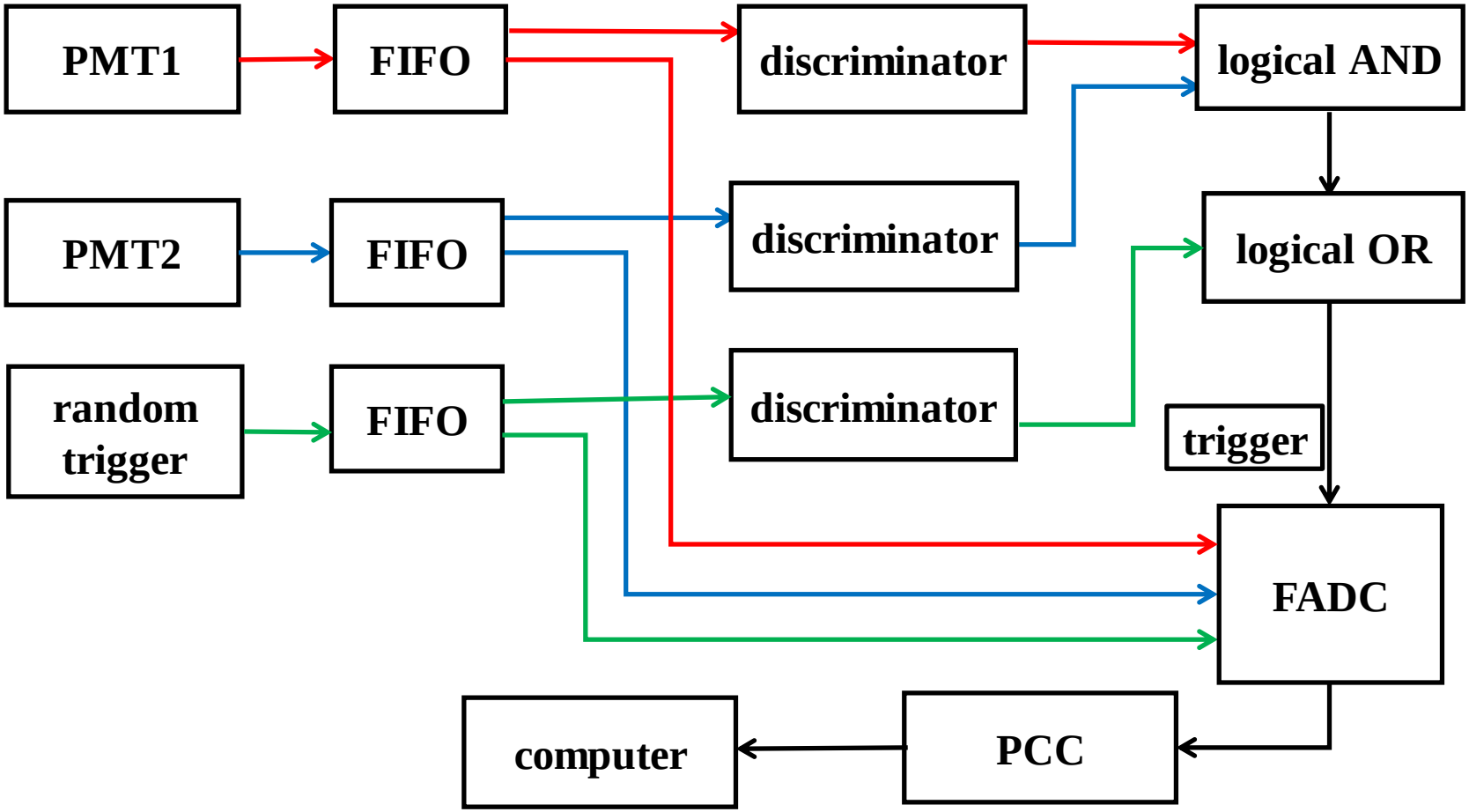
The structure of the detector

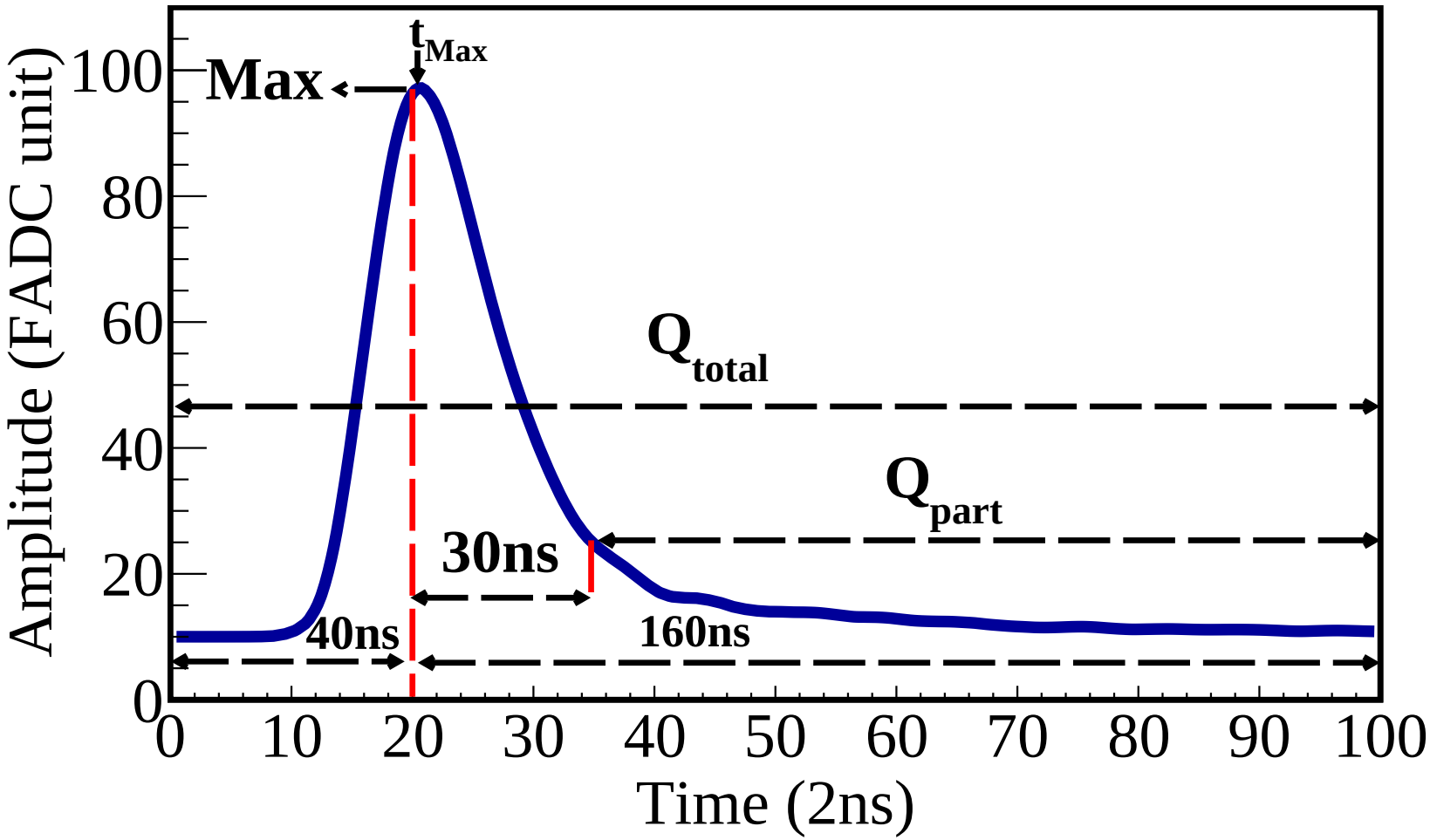


- liquid scintillator: 28.27 L EJ-335 doping with 0.5% gadolinium
- container: quartz glass with size of $\Phi 30 \times 40$ cm
- copper shell: 3 mm thickness cylinder
- lead shielding: 5 cm thickness

DAQ system

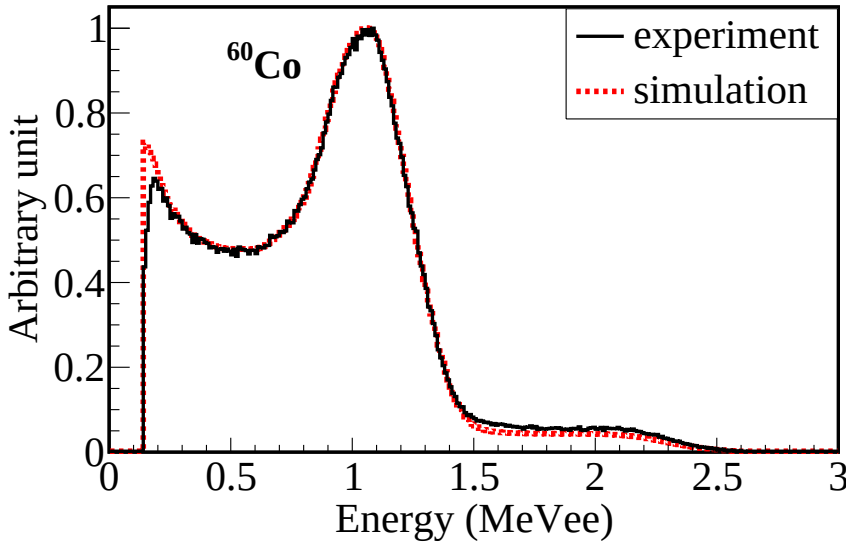

PMT1
FIFO
discriminator
logical AND
PMT2
FIFO
discriminator
logical OR
random trigger
FIFO
discriminator
trigger
FADC
computer
PCC

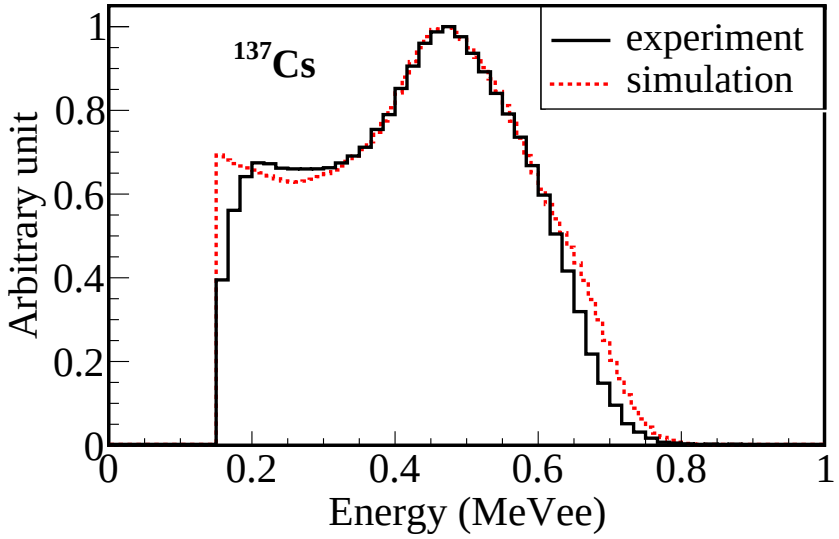
Parameters definition

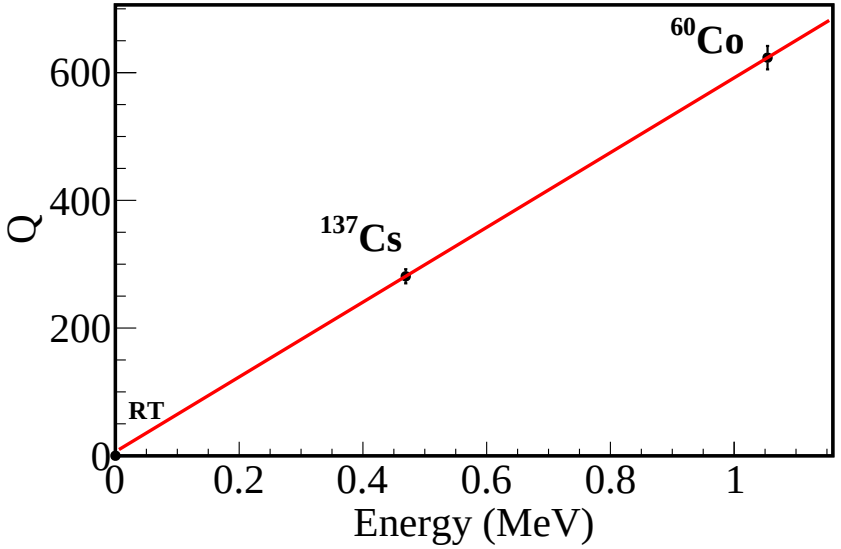


$$Q = \sqrt{Q_{total_{left}} \cdot Q_{total_{right}}} \qquad Dis = \frac{Q_{part_{left}} + Q_{part_{right}}}{Q_{total_{left}} + Q_{total_{right}}}$$

Energy calibration







Contents

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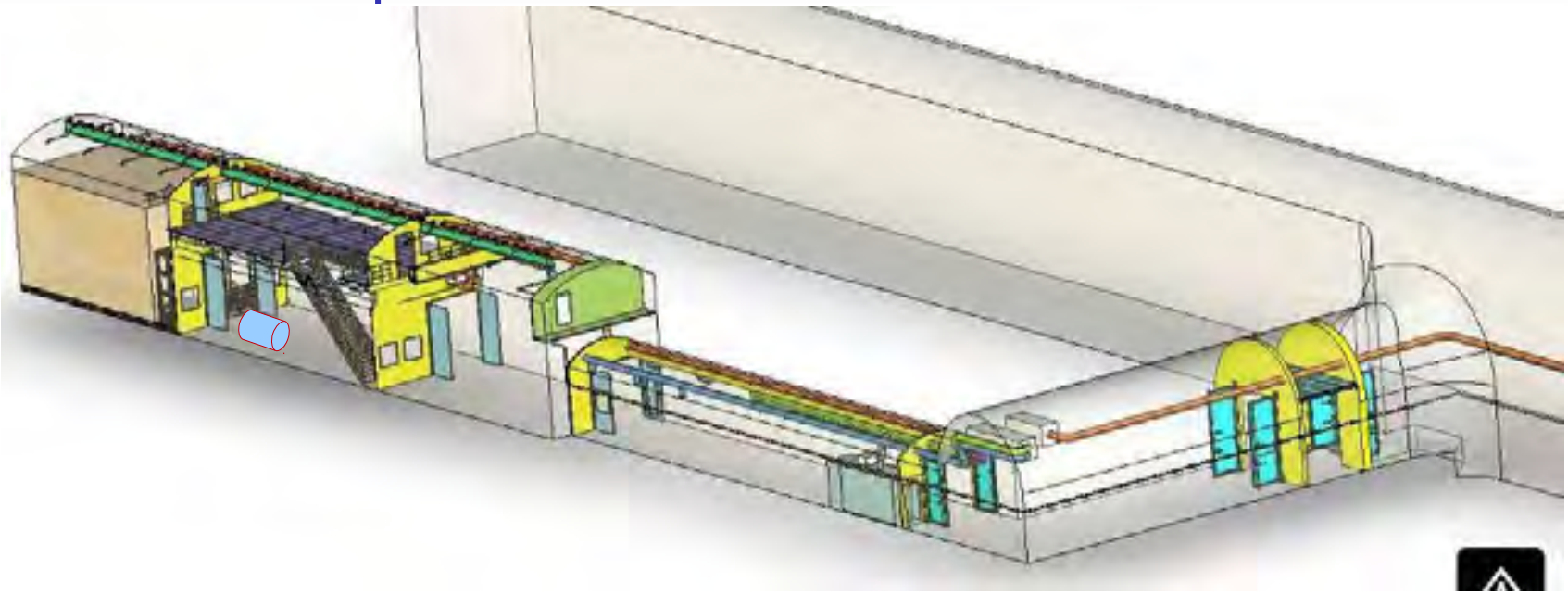
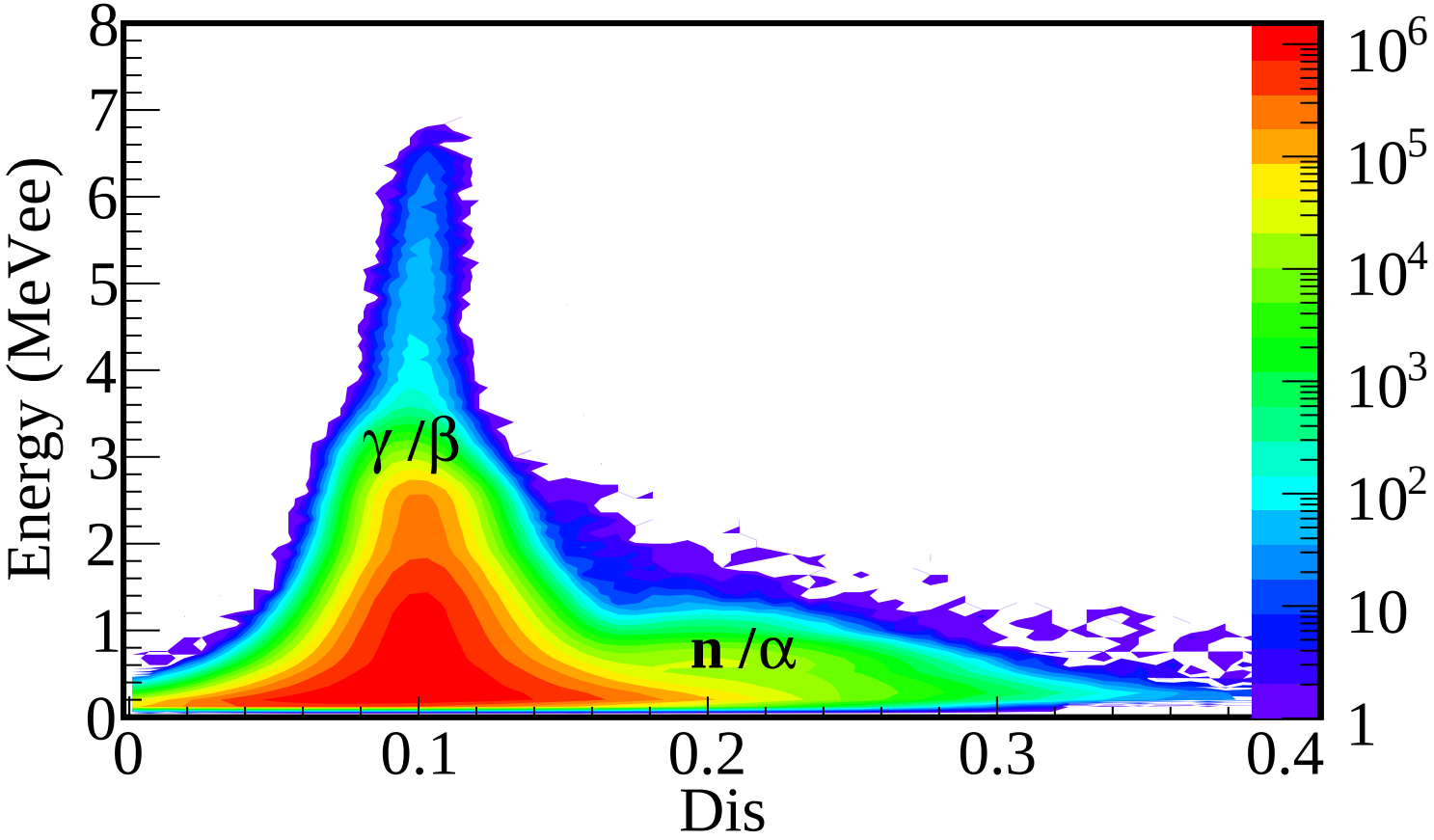
The position of the detector in CJPL



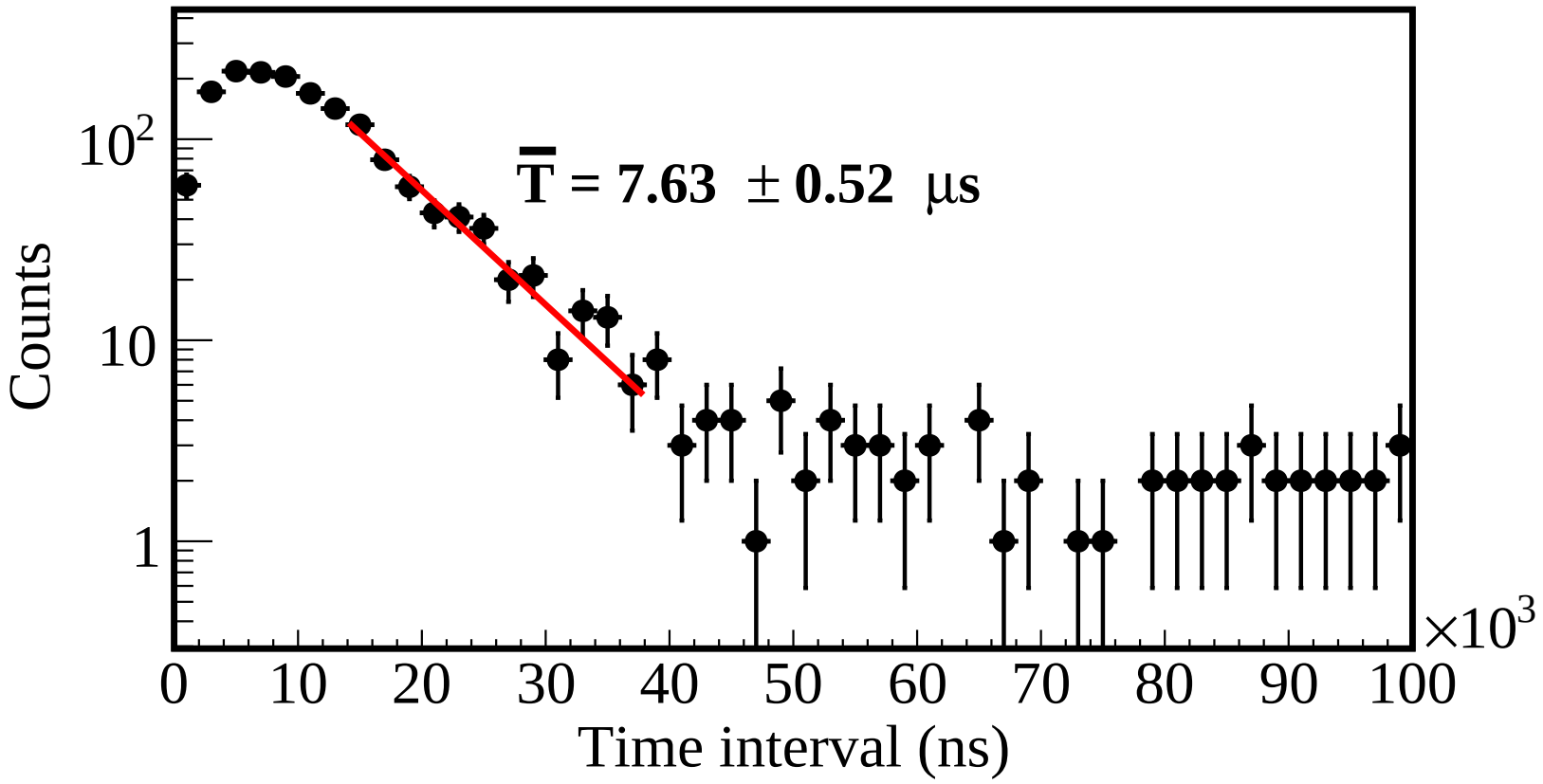
- The detector was running in CJPL hall from October, 2013 to February, 2015 with 8971 $kg \cdot day$ lively data.
- The detector have been located in CJPL polythene(PE) room since February, 2015.

Data in CJPL hall



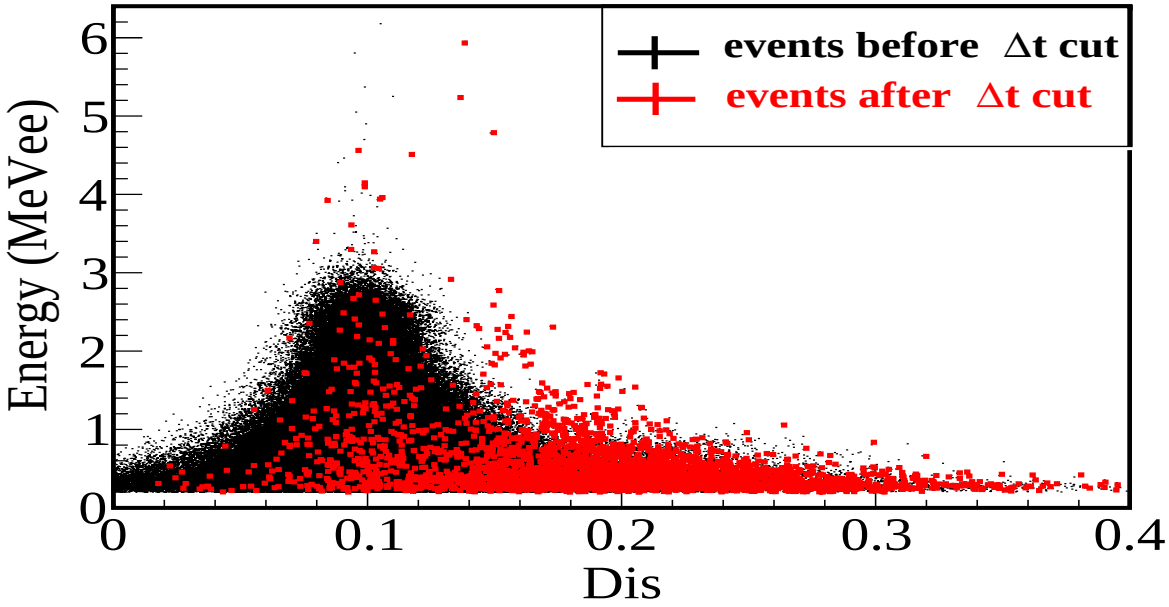
- Fast-slow coincident method has been used to select the neutron events.
- The γ events which energy higher than 3.0 MeV has been selected as the slow signal.

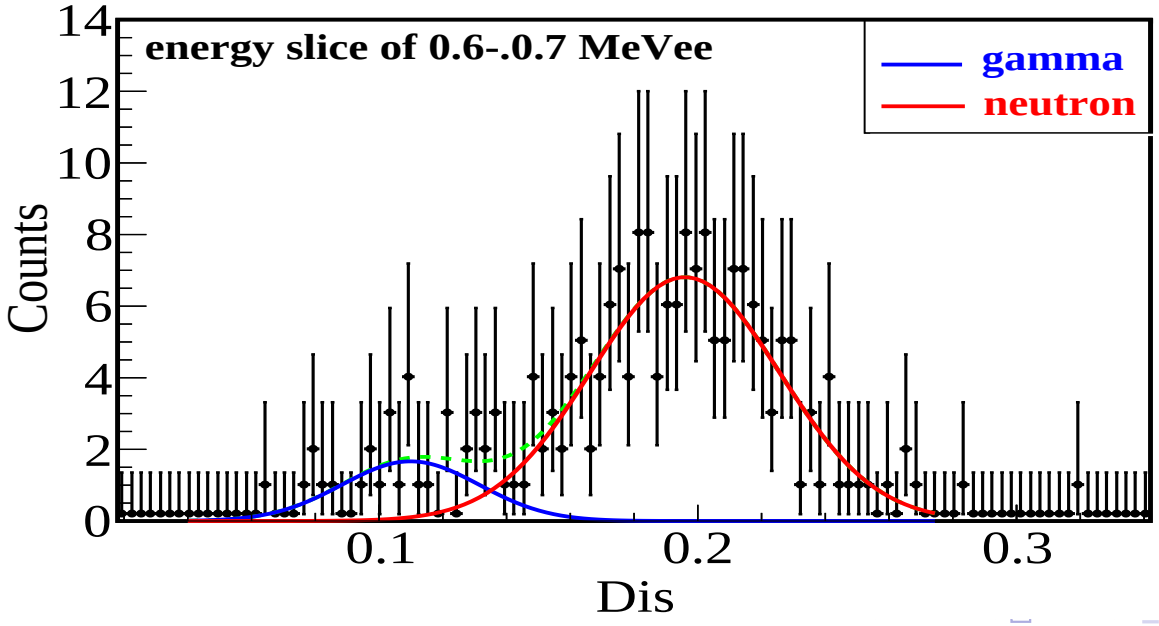
Time interval distribution between fast and slow signals



- Only the events that satisfy $2\mu s < \Delta t < 30\mu s$ has been selected.

Random coincident events





Preliminary results of fast neutron flux in CJPL

data set	^{252}Cf	CJPL hall	CJPL PE room
raw counts	4.09×10^6	8.59×10^8	
exclude noise			
$\lambda[\Pi\lambda](\%), \epsilon(\%)$	98.79[98.79],100	99.85[99.85],100	99.98[99.98],100
γ >3.0MeV			
$\lambda[\Pi\lambda](\%), \epsilon$ (%)	14.60[14.42], —	0.0447[0.0446], —	0.097[0.097], —
PSD selection for γ (slow signal)			
$\lambda[\Pi\lambda](\%), \epsilon$ (%)	96.86[13.97],97.72	100[0.0446],100	100[0.097],100
neutron threshold 0.23MeVee			
(equivalent 1 MeV neutron energy)			
$\lambda[\Pi\lambda](\%), \epsilon$ (%)	84.50[11.80], —	85.41[0.038], —	72.17[0.070], —
Δt selection (2-30μs)			
$\lambda[\Pi\lambda](\%), \epsilon$ (%)	47.86[5.65], —	0.938[0.00036], —	0.132[0.000092], —
exclude random coincidence			
$\lambda[\Pi\lambda](\%), \epsilon(\%)$	77.50[4.38],100	86.78[0.00031],100	71.74[0.000066],100
efficiency correction of PSD	$183,334 \pm 456$	2666 ± 78	66 ± 8
neutron passed the detector	$(6.10 \pm 0.61) \times 10^6$	$(8.89 \pm 0.93) \times 10^4$	$(2.20 \pm 0.35) \times 10^3$
lively time	$8.2144 \times 10^4 s$	356.37d	130.47d
detection efficiency(%)		3.00 ± 0.30	
detector cross section(cm^2)		5183.63	
neutron flux at detector($n\ cm^{-2}s^{-1}$)		$\mathbf{(0.56 \pm 0.06) \times 10^{-6}}$	$\mathbf{(0.38 \pm 0.06) \times 10^{-7}}$

$\lambda(\%)$ and $\Pi\lambda(\%)$ are the individual and cumulative background survival fraction respectively, and $\epsilon\%$ is the candidate signal efficiency.

Fast neutron flux compare with other underground lab.

- CJPL hall: $(0.56 \pm 0.06) \times 10^{-6}\ n\ cm^{-2}s^{-1}$ from 1MeV to 10 MeV
- Canfranc: $(0.65 \pm 0.02) \times 10^{-6}\ n\ cm^{-2}s^{-1}$ from 1MeV to 10 MeV
- Gran Sasso: $(0.60 \pm 0.07) \times 10^{-6}$ n $cm^{-2}s^{-1}$ from 1MeV to 10 MeV
- Boulby: $(1.72 \pm 0.61(stat.) \pm 0.38(syst.)) \times 10^{-6}\ n\ cm^{-2}s^{-1}$ above 0.5 MeV

Contents

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Decay sequences selection

- **Thorium series**

$$^{212}Bi \xrightarrow[Q=2.25MeV]{\beta^-} {}^{212}Po \xrightarrow[Q=8.96MeV]{\alpha(299ns)} {}^{208}Pb$$

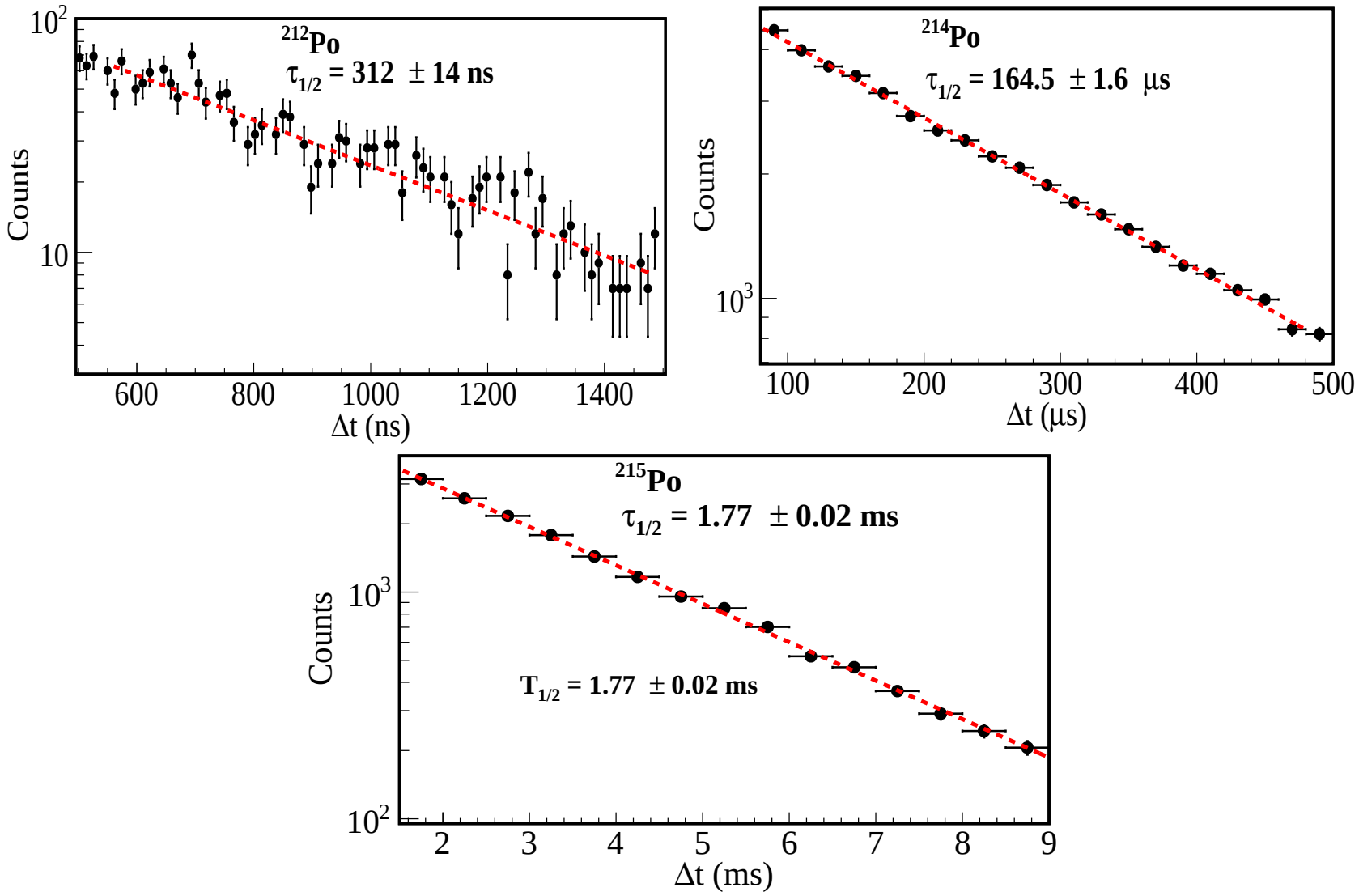
- **Uranium series**

$$^{214}Bi \xrightarrow[Q=3.27MeV]{\beta^-} {}^{214}Po \xrightarrow[Q=7.83MeV]{\alpha(164.3\mu s)} {}^{210}Pb$$

- **Actinium series**

$$^{219}Rn \xrightarrow[Q=6.95MeV]{\alpha(3.96s)} {}^{215}Po \xrightarrow[Q=7.527MeV]{\alpha(1.78ms)} {}^{211}Pb$$

Time interval distribution of Cascade decays



Measurement activity of the intrinsic U/Th/Ac

half life and alpha particle energy

Decay sequence	Measured half life	Nominal half life	Measured alpha energy(MeVee)	Nominal alpha energy(MeVee
Thorium: ^{212}Bi $\rightarrow^{212}$ Po	$312 \pm 14ns$	$299ns$	^{212}Po: 1.07 ± 0.09	8.96
Uranium: ^{214}Bi $\rightarrow^{214}$ Po	$164.5 \pm 1.6\mu s$	$164.3\mu s$	^{214}Po: 0.87 ± 0.07	7.83
Actinium: ^{219}Rn $\rightarrow^{215}$ Po	$1.77 \pm 0.02ms$	$1.78ms$	^{215}Po: 0.76 ± 0.07 ^{219}Rn: 0.66 ± 0.06	7.53 6.95

activity of the intrinsic U/Th/Ac

Decay sequence	Measured activity (mBq kg^{-1})
Thorium: ^{212}Bi $\rightarrow^{212}$ Po	0.144 ± 0.004
Uranium: ^{214}Bi $\rightarrow^{214}$ Po	1.78 ± 0.01
Actinium: ^{219}Rn $\rightarrow^{215}$ Po	0.861 ± 0.009

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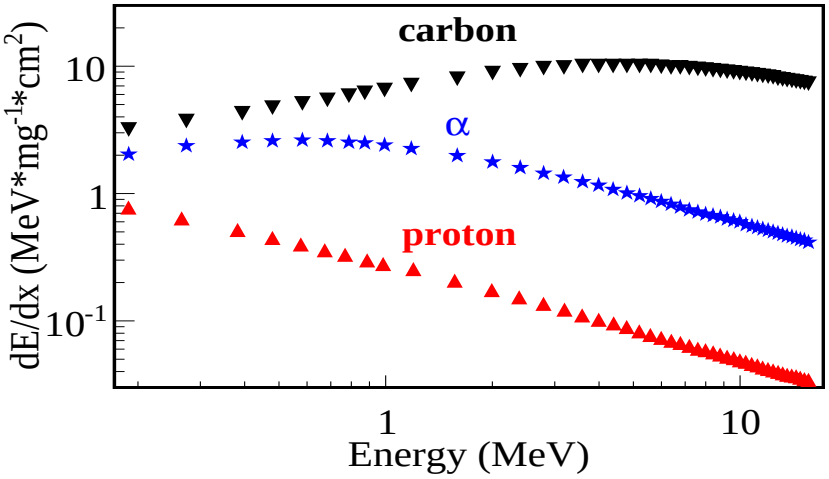
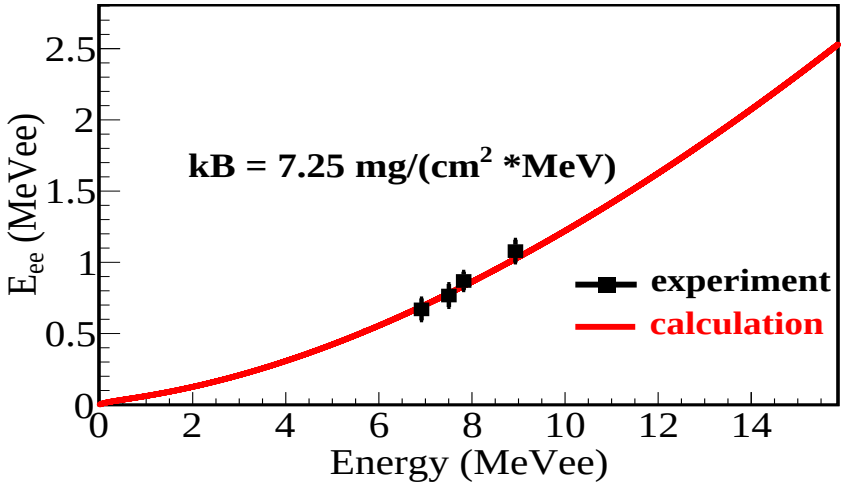
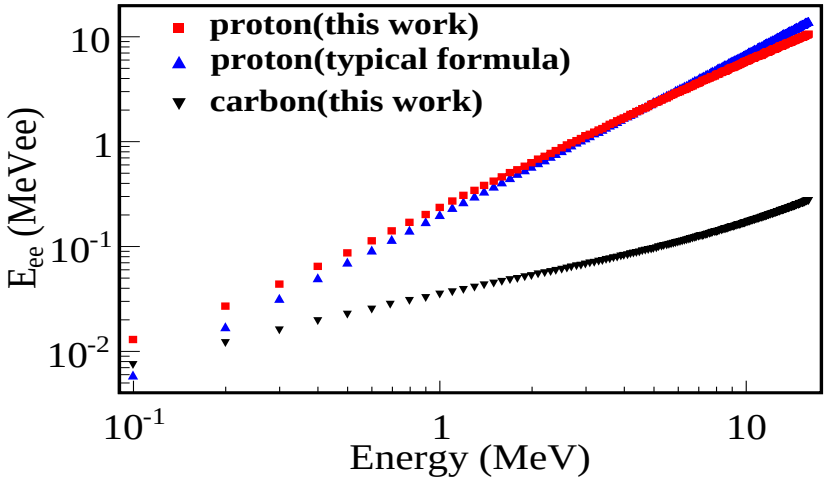


1. Stoping power calculated by TRIM



2. Alpha particle quenching factor in EJ-335



3. Proton and Carbon quenching factor in EJ-335.

Typical formula: $Eee = 0.2E^{1.53}$

Birks theory has been used for this calculation:

$$Eee = \int_0^E \frac{dE}{1 + kB(\frac{dE}{dX})}$$

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SAND-II method to unfold the spectrum

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

$$j = 1, 2, \cdots, J,$$

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

J: iterate times

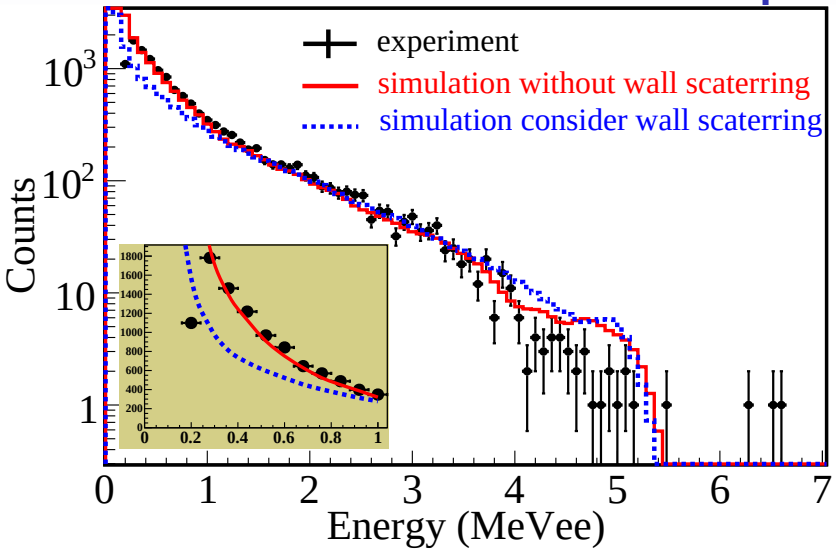
Φ_i^1 :initial spectrum

Φ_i^J :unfolding result

R_{ki} :response function

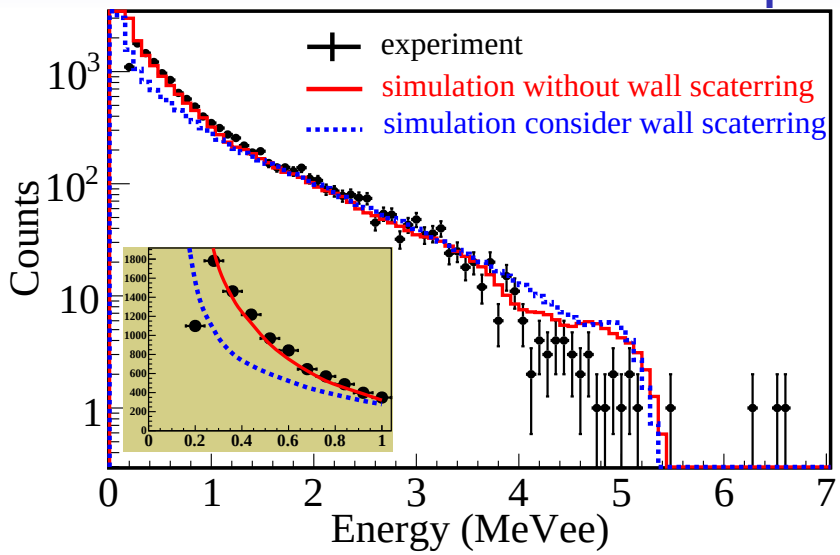
Geant4 has been used to simulate the response function

Neutron spectrum unfolding

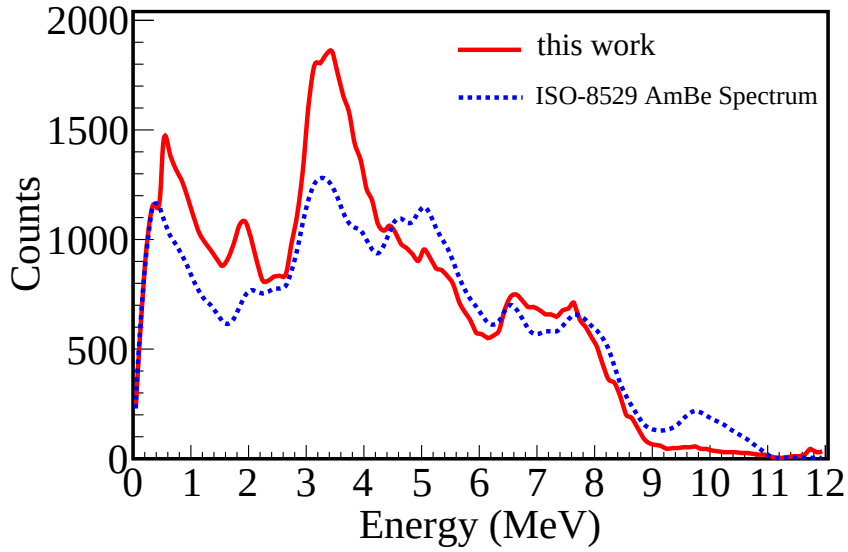


AmBe neutron source recoil spectrum

Neutron spectrum unfolding

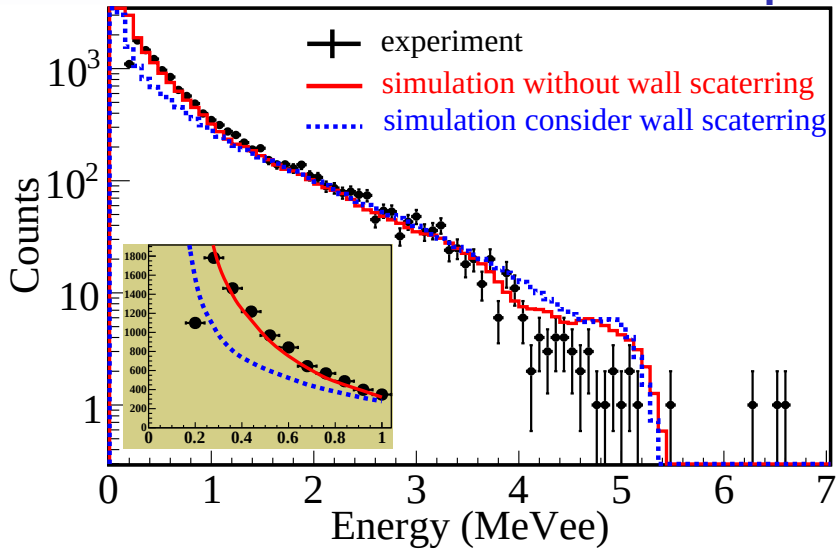


AmBe neutron source recoil spectrum

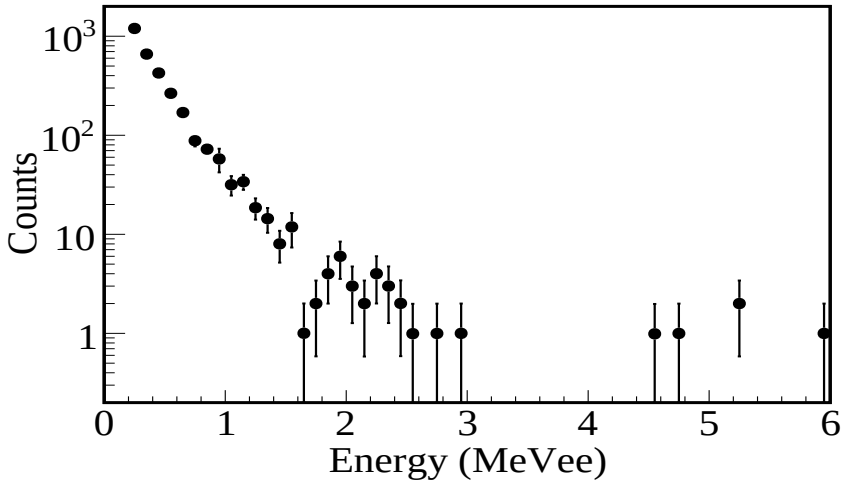


AmBe spectrum unfolding result

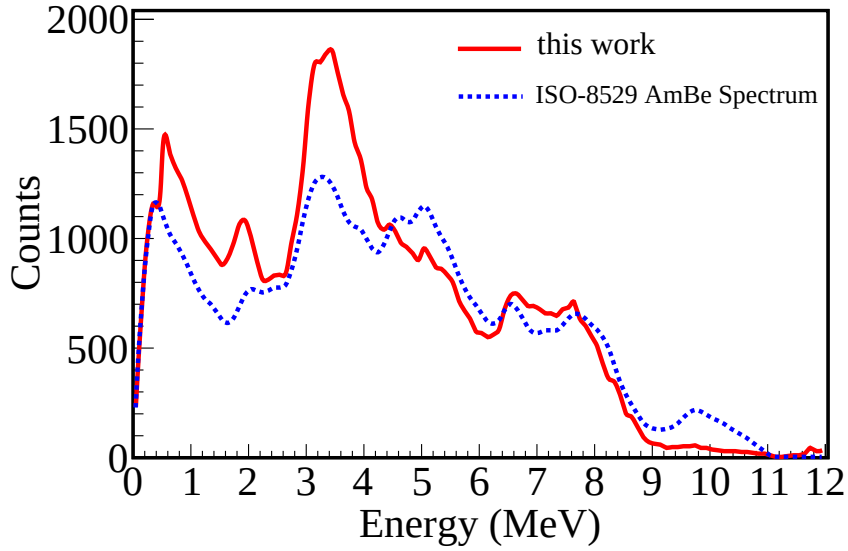
Neutron spectrum unfolding



AmBe neutron source recoil spectrum

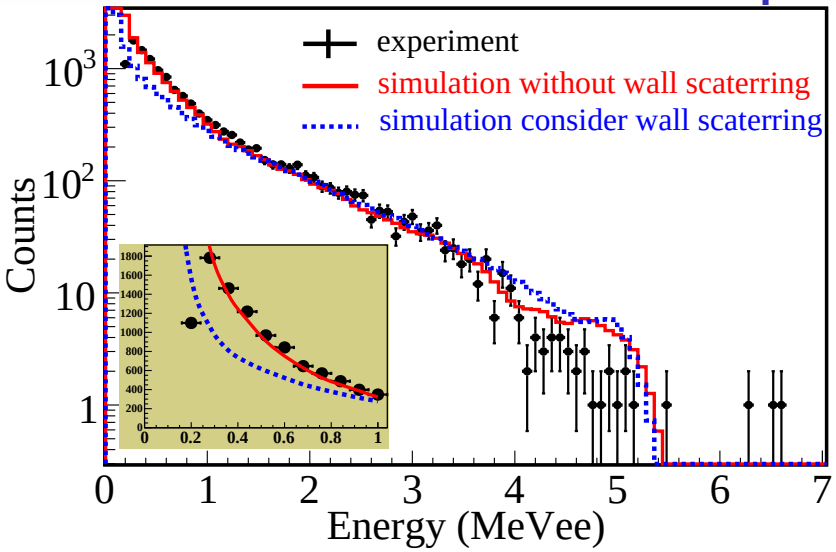


CJPL hall neutron recoil spectrum

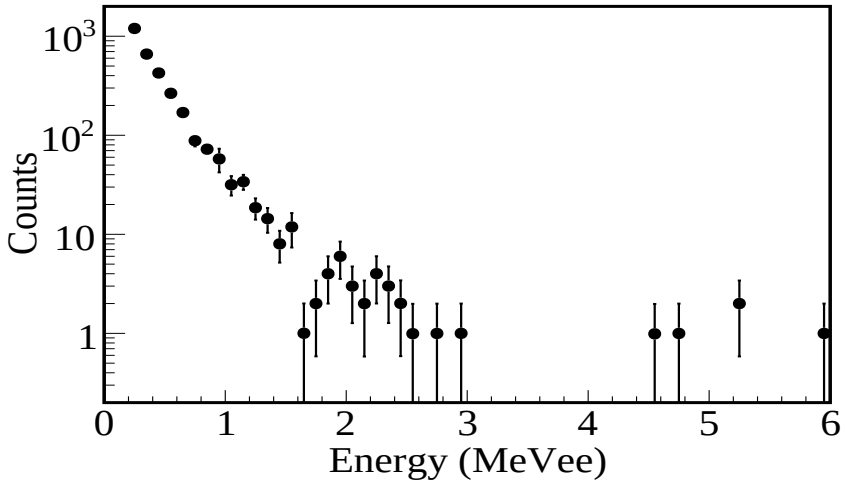


AmBe spectrum unfolding result

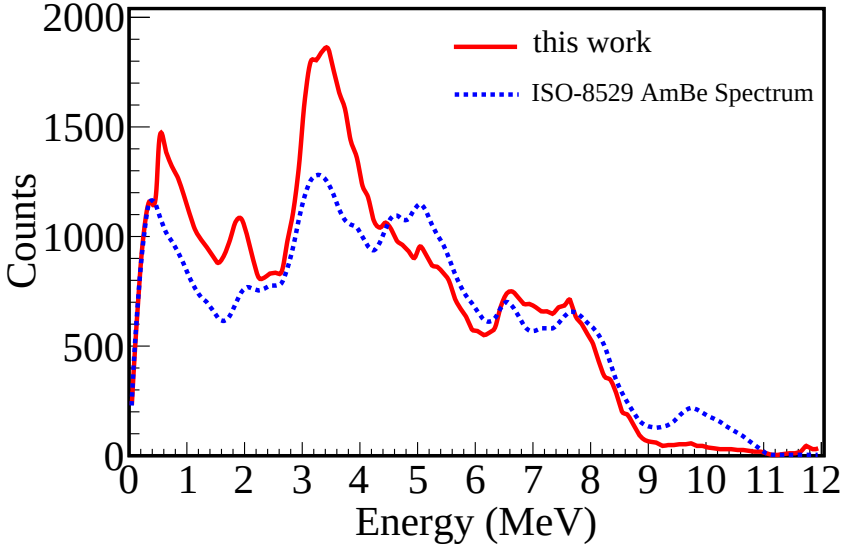
Neutron spectrum unfolding



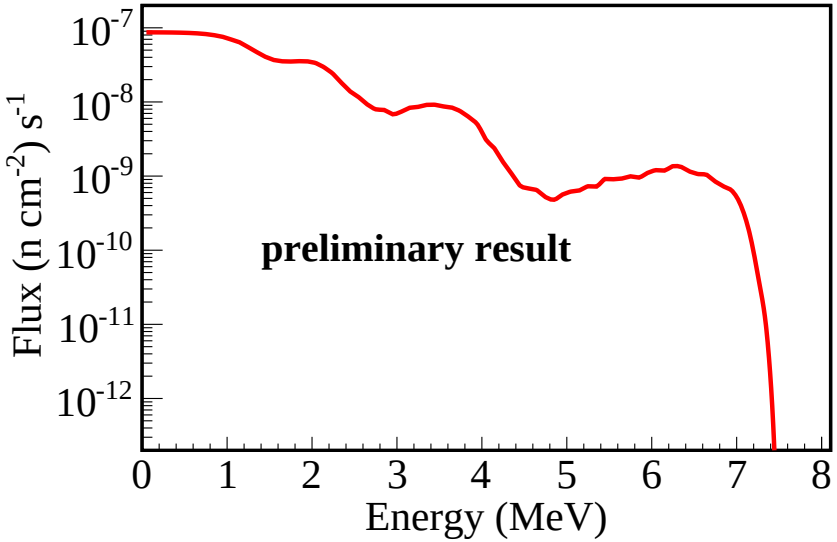
AmBe neutron source recoil spectrum



CJPL hall neutron recoil spectrum



AmBe spectrum unfolding result



CJPL neutron spectrum unfolding result

Summary

- The fast neutron flux(preliminary result) in CJPL had been measured to be $(0.56 \pm 0.06) \times 10^{-6}\ n\ cm^{-2}s^{-1}$ in the hall, and $(0.38 \pm 0.06) \times 10^{-7}\ n\ cm^{-2}s^{-1}$ in the polythene room.
- The intrinsic contamination of Thorium, Uranium and Actinium have been calculated.
- The kB constant had been determined to be $7.25\ mg/(cm^2 \cdot MeV)$, and then we calculated the quenching factor of EJ-335 liquid scintillator.
- The neutron spectrum in CJPL hall had been unfolded.