# Measurements of Response of $LaBr_{2.85}Cl_{0.15}$:Ce, $LaBr_3$:Ce and NaI(Tl) Crystals to Fast and Thermal Neutrons

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## Introduction

- Lanthanum Halides are the most sought after scintillators because of their excellent energy resolution and high γ-ray detection efficiency [1].
- Researchers are trying to further improve the performance of the Lanthanum Halide scintillators by growing crystals of similar structure, co-doping with various elements, etc. [2]. $LaBr_{2.85}Cl_{0.15}$:Ce (LBC) is an outcome of a similar quest.
- LBC has been grown by Scionix Holland BV, and it contains Chlorine in addition to Lanthanum and Bromine [3].
- LBC contains $^{35}$Cl having a large cross-section for reaction with fast neutrons, which makes LBC a possible scintillator for neutron detection.
- We have measured the response of LBC for fast and thermal neutrons.
- The response of $LaBr_3$:Ce and NaI:Tl was also measured for fast and thermal neutrons for comparison
- The fast neutrons from Am-Be were thermalized using paraffin bricks.
- Am-Be emits 4.4 MeV gamma γ-rays in addition to neutrons. In order to subtract the response of γ–rays, realistic Monte-Carlo simulations were carried out using GEANT4.
- The simulated response was subtracted from the mixed neutron-γ response of the crystals.
- The total detection efficiencies of the fast neutrons was calculated using the known activity of the Am-Be source.

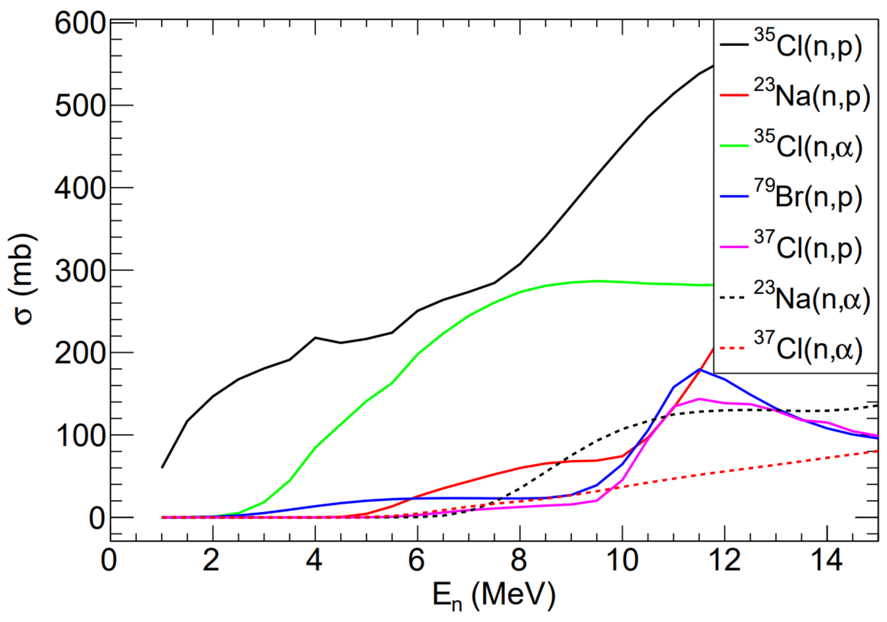


*Fig. 1 Cross-sections of major reactions of neutrons with various elements in the crystal.*

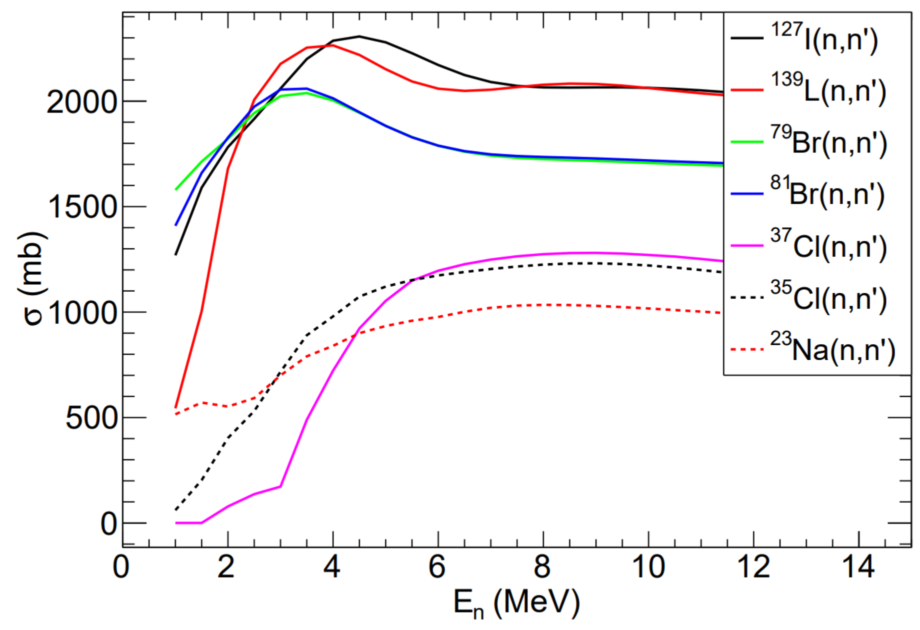


*Fig. 2 Cross-sections of in-elastic scattering of the neutrons from various elements in the crystal.*

- The inelastic scattering cross-sections are quite high as compared to different reaction cross-sections.

## Fast neutron response of $LaBr_{2.85}Cl_{0.15}$:Ce, $LaBr_3$:Ce and NaI(Tl)

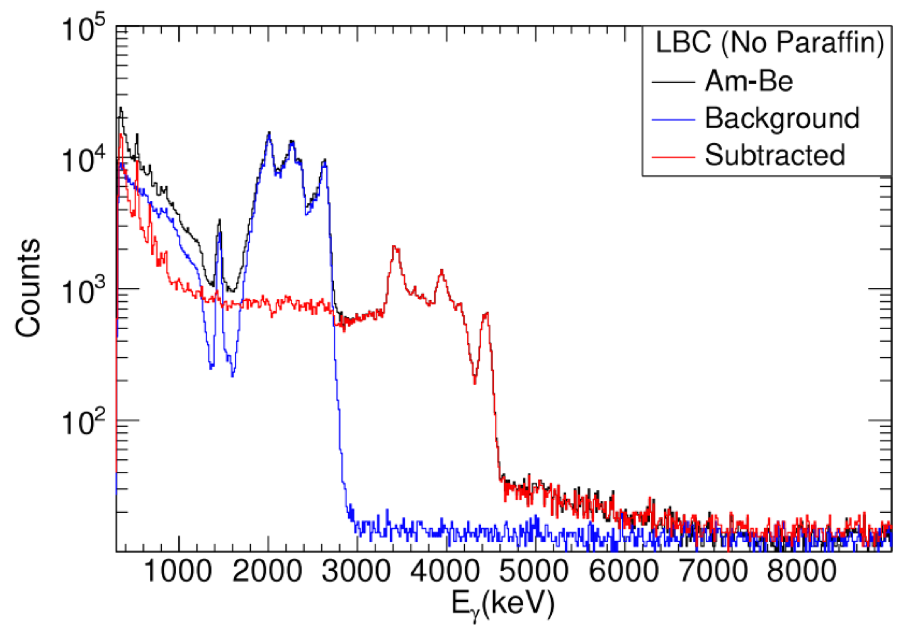


*Fig. 3 Energy spectrum of LBC for fast neutrons, background spectrum for the same time and background subtracted spectrum.*

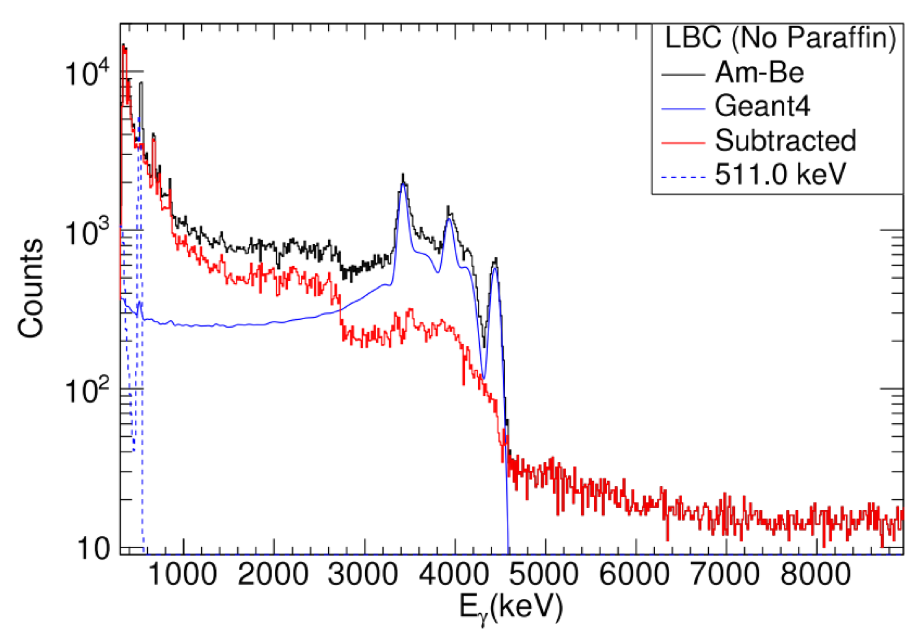


*Fig. 4 Background subtracted energy spectrum of LBC for fast neutrons, Geant4 simulated spectrum for 4.4 and 0.511 MeV γ–rays and Geant4 subtracted spectrum.*

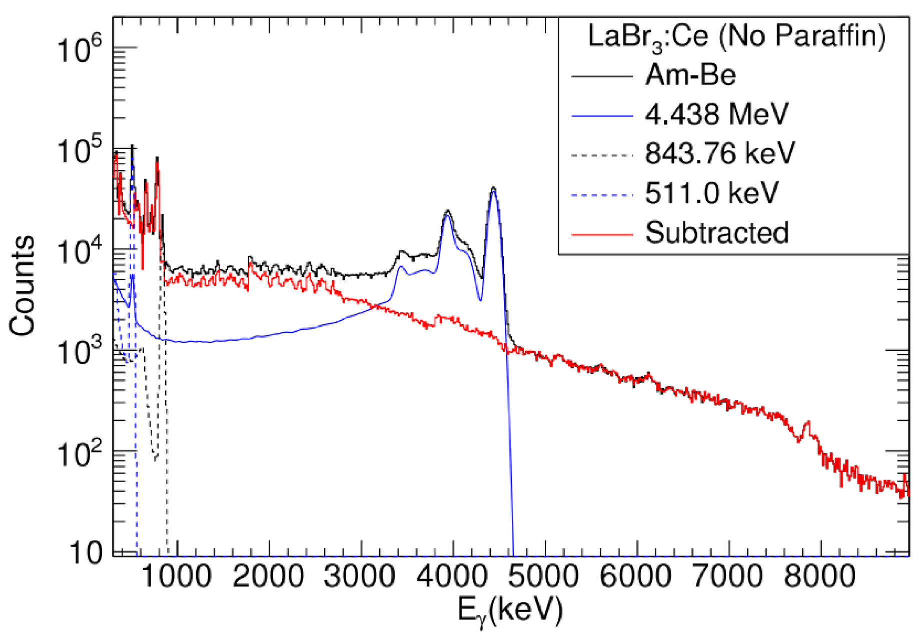


*Fig. 5 The background subtracted spectrum of LaBr3:Ce along with GEANT4 simulated response of LaBr3:Ce for 4.438, 0.844, 0.511 MeV γ-rays and their subtracted spectrum.*

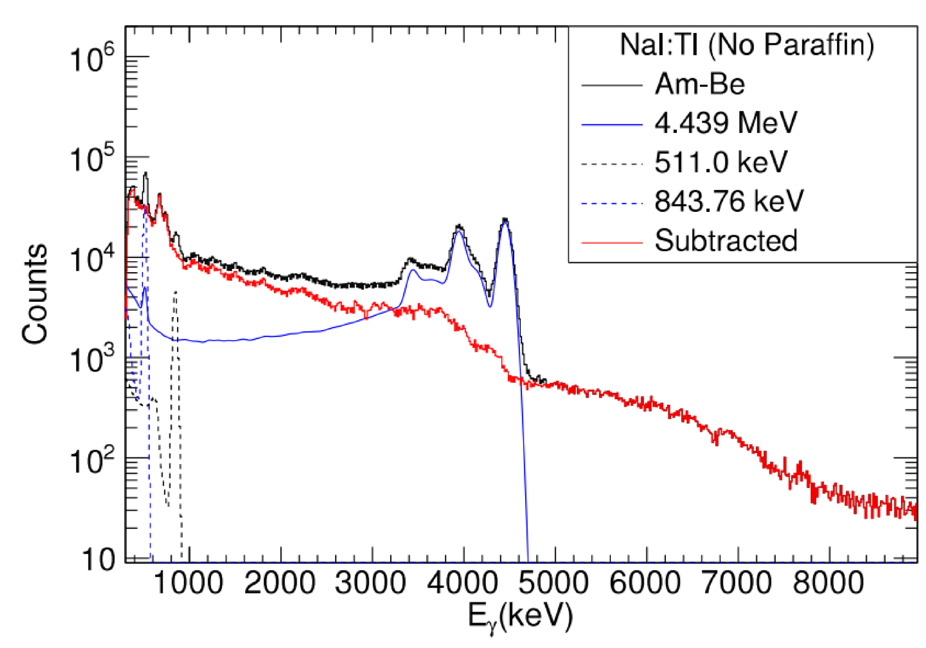


*Fig. 6 The background subtracted spectrum of NaI:Tl along with GEANT4 simulated response for 4.438, 0.844 and 0.511 MeV γ-rays and their subtracted spectrum.*

## Thermal neutron response of $LaBr_{2.85}Cl_{0.15}$:Ce, $LaBr_3$:Ce and NaI(Tl)

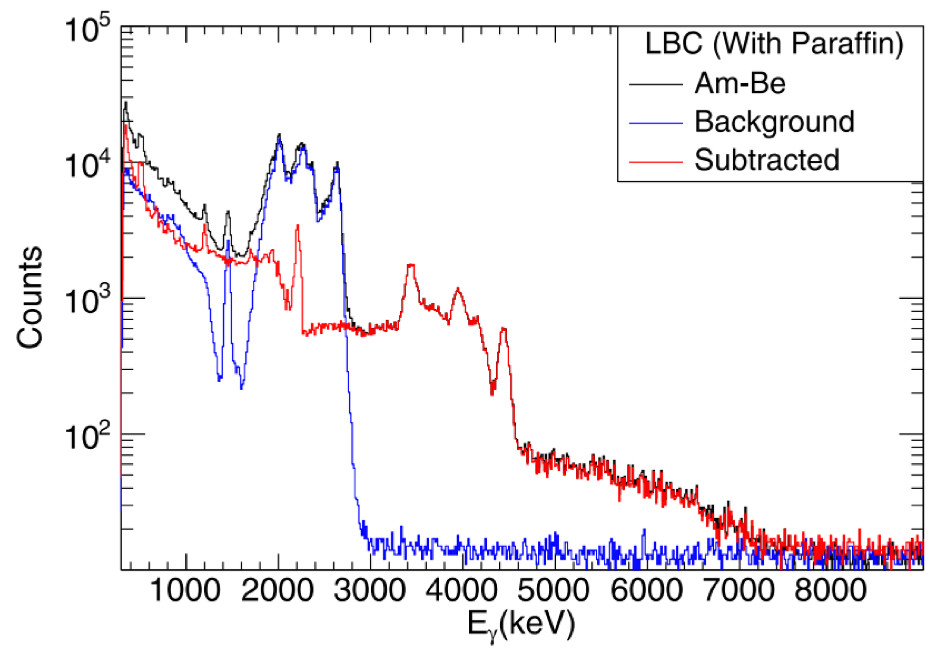


*Fig. 7 Energy spectrum of LBC for thermal neutrons, background spectrum for the same time and background subtracted spectrum.*

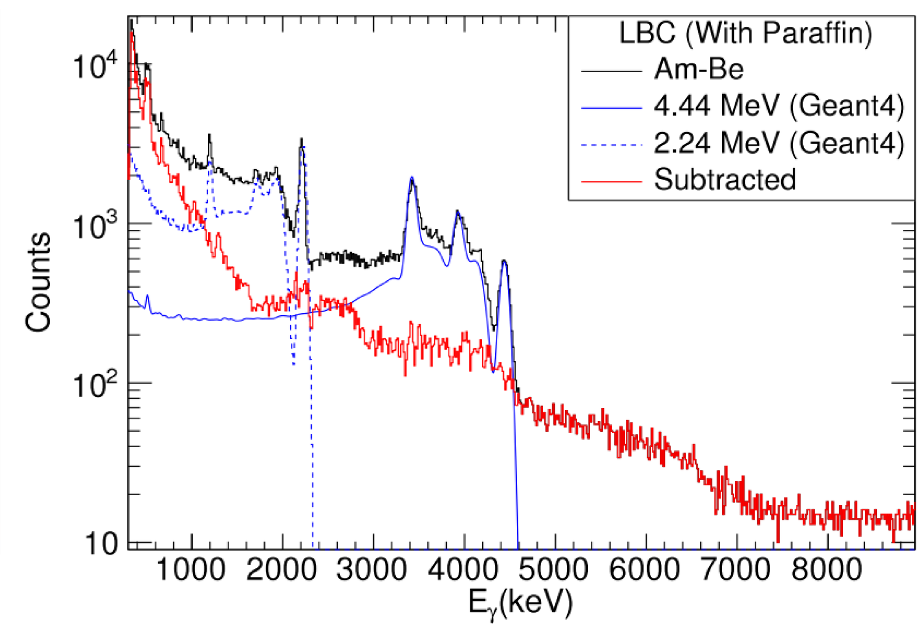


*Fig. 8 Background subtracted energy spectrum of LBC for thermal neutrons, Geant4 simulated spectrum for 4.4 and 2.2 MeV γ–rays and Geant4 subtracted spectrum.*

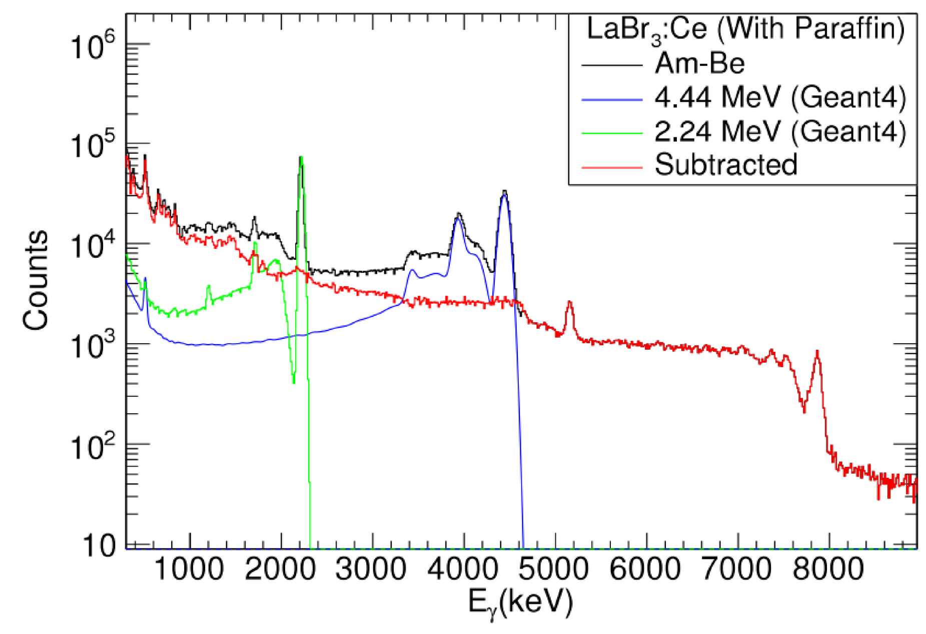


*Fig. 9 Background subtracted energy spectrum of LBC for thermal neutrons, Geant4 simulated spectrum for 4.4 and 2.2 MeV γ-rays and Geant4 subtracted spectrum.*

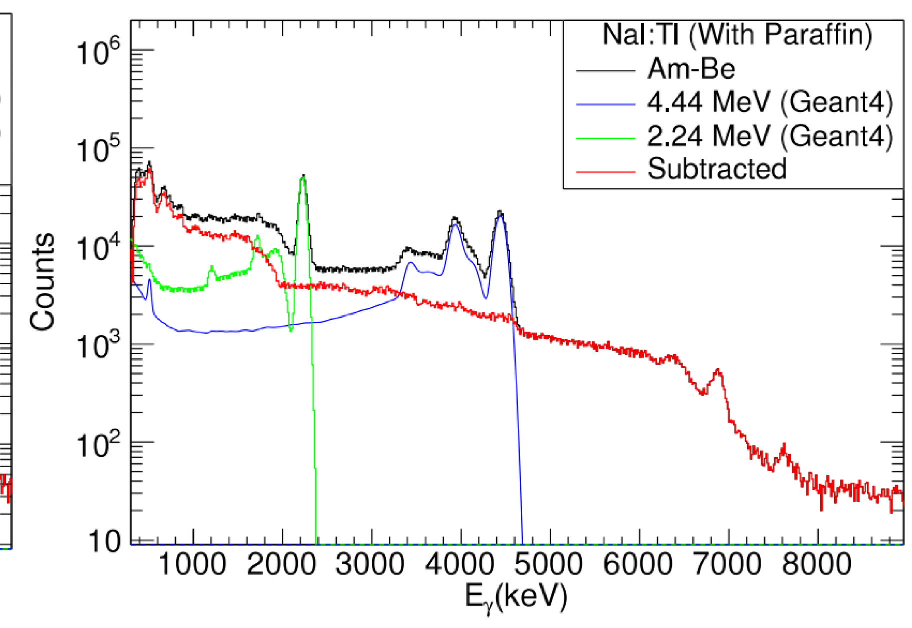


*Fig. 10 The background subtracted spectrum of NaI:Tl with paraffin bricks along with GEANT4 simulated response for 4.44 & 2.22 MeV γ-rays and their subtracted spectrum.*

## GEANT4 simulations for fast neutrons

- Figure 11 presents the energy distribution of neutrons from Am-Be.
- Figure 12 shows the final response of LBC to fast neutrons. It also presents the corresponding GEANT4 simulated spectrum.
- Figure 13 and 14 presents the fast neutron response of $LaBr_3$:Ce and NaI:Tl, respectively.
- GEANT4 simulated spectrum agrees well above 1 MeV with the experimentally obtained response in the case of $LaBr_3$:Ce.
- In the case of LBC and NaI:Tl, the agreement with the simulations is not so good. There seems to be some leftover contribution from the 4.44 MeV γ-rays in the experimental spectrum.
- Also, for all the three detectors the simulations don't agree in the low energy region of less than 1 MeV which has many discrete γ-rays.
- Work is in progress to improve the GEANT4 simulations.

*Table 1. The total detection efficiencies of LBC, NaI:Tl and $LaBr_3$:Ce detectors for fast neutrons.*

| Detector | Size | Volume($cm^3$) | Efficiency |
|---|---|---|---|
| LBC | 1″×1″ | 12.87 | 50.6% ± 15.3% |
| NaI:Tl | 4″×4″ | 823.70 | 79.9% ± 11.5% |
| $LaBr_3$:Ce | 3.5″×6″ | 945.97 | 89.3% ±14.6% |

- Table 1 presents the total detection efficiencies of the LBC, NaI:Tl and $LaBr_3$:Ce detectors for fast neutrons.
- The efficiencies clearly shows a volume dependence. $LaBr_3$:Ce having the highest volume is the most efficient in fast neutron detection and LBC has the least efficiency.

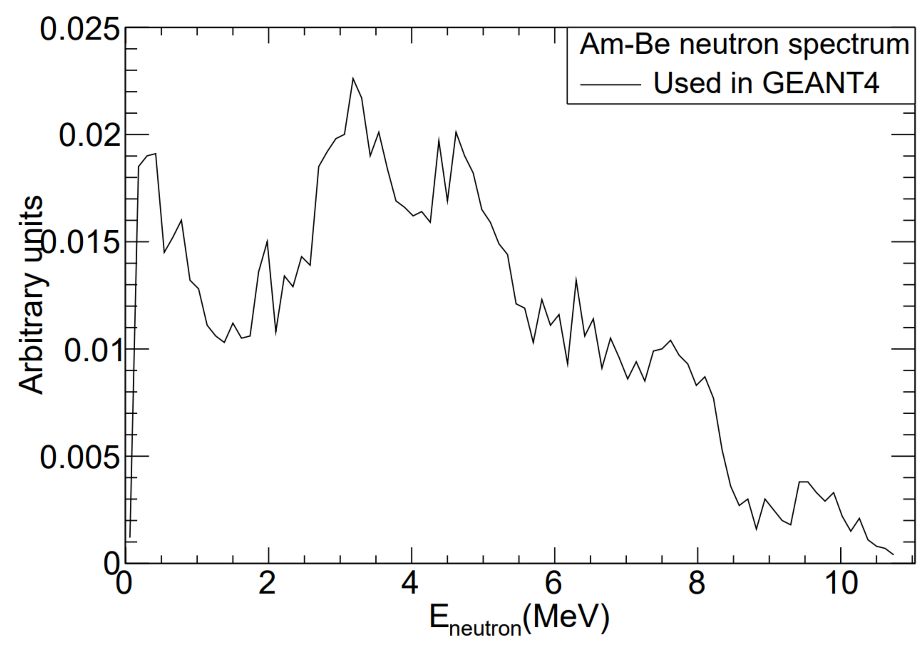


*Fig. 11 Spectrum of fast neutrons from Am-Be used in GEANT4 simulations.*

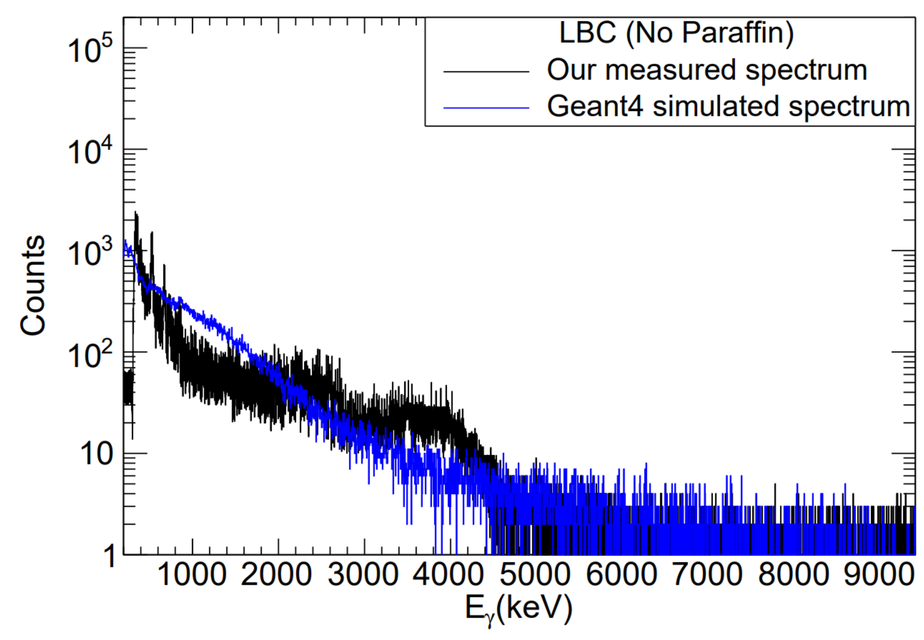


*Fig. 12 Final response of LBC to fast neutrons and GEANT4 simulated spectrum.*

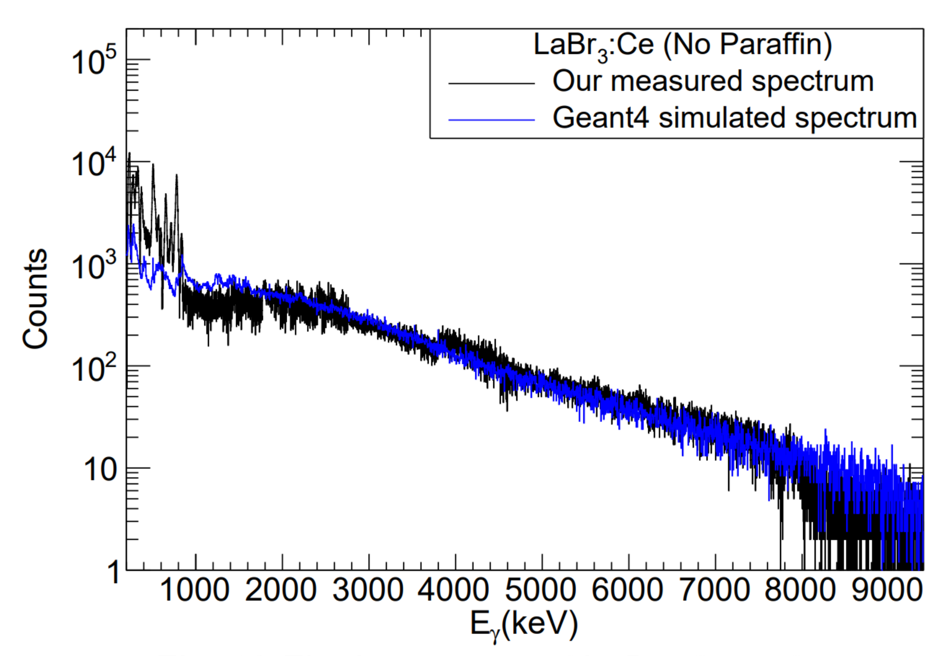


*Fig. 13 Final response of $LaBr_3$:Ce to fast neutrons and GEANT4 simulated spectrum.*

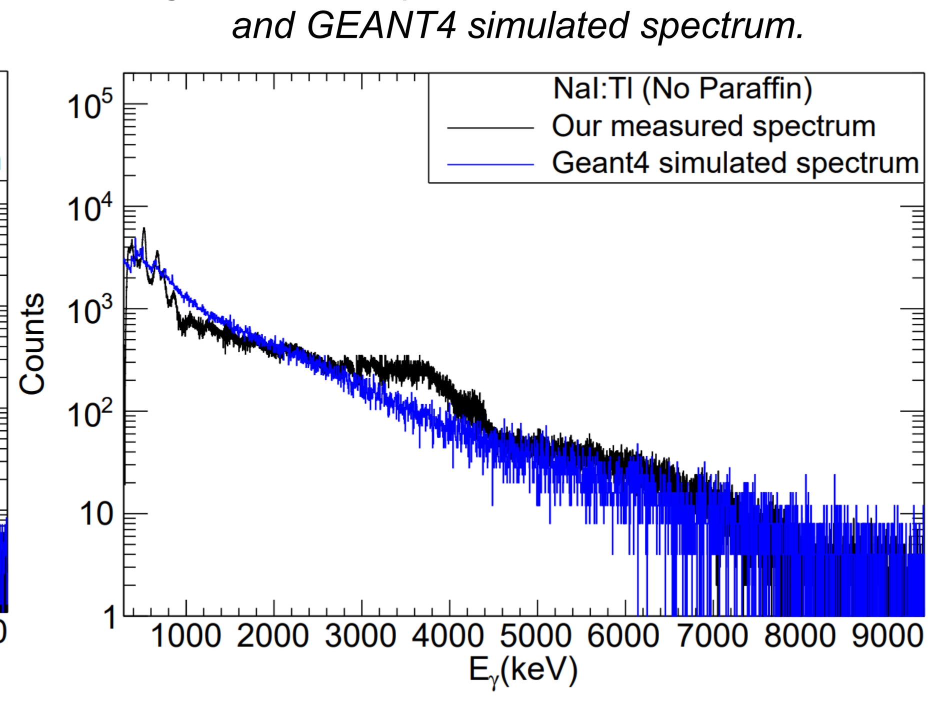


*Fig. 14 Final response of NaI:Tl to fast neutrons and GEANT4 simulated spectrum.*

**References**
[1] I. Mazumdar et al., Nucl. Instrum. Methods Phys. Res. A 705, 85 (2013)
[2] S. Panwar et al., Nucl. Instrum. Methods Phys. Res. A 982, 164567 (2020)
[3] V. Ranga et al., Nucl. Instrum. Methods Phys. Res. A 1041, 167369 (2022)

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