



# Spectrum unfolding of $^{12}\text{C}(\text{d},\text{n})$ using the CATRiNA detectors

Ashton B. Morelock, Jesus F. Perello, Sergio Almaraz-Calderon, Ben Asher, Kristyn Brandenburg, Joseph Derkin, Gula Hamad, Yenuel Jones-Alberty, Eilens Lopez Saavedra, Zach Meisel, Thomas Massey, et al.

Department of Physics, Florida State University, Tallahassee, FL, 32306  
Email: amorelock@my.fsu.edu



## Introduction

The CATRiNA [1] deuterated neutron detector array at FSU is composed of 32 EJ315 detectors, making it a powerful and sensitive neutron detector array. Neutron energies can be extracted using their pulse-height spectrum through a method known as spectrum unfolding. An experiment analyzing  $^{12}\text{C}(\text{d},\text{n})$  was performed at the Edwards Accelerator Laboratory at Ohio University. Results from the spectrum unfolding of the  $^{12}\text{C}(\text{d},\text{n})$  reaction are presented in this work. Uncertainties generated through spectrum unfolding are also discussed.



Fig. 1: CATRiNA neutron detector array in neutron tunnel at Edwards Accelerator Laboratory.

## Iterative Bayesian Model

$$\phi(L) = \int \psi(E)R(L,E)dE \rightarrow \phi_i = \sum_{j=1}^J R_{ij}\psi_j, \quad i = 1, 2, \dots, I$$

$$Q(E|L) = \frac{\psi(E)R(L|E)}{\phi(L)} \rightarrow \psi(E) = \int \phi(L)Q(E|L)dL$$

$$\psi_j^{k+1} = \psi_j^k \sum_{i=1}^I \frac{R_{ij}\phi_i'}{\sum_{l=1}^J R_{il}\psi_l^k}, \quad j = 1, 2, \dots, J$$

The light output spectrum  $\phi(L)$  of a detector is described by a convolution of the detector's response function, denoted  $R(L,E)$ , and the incident neutron energy spectrum  $\psi(E)$ . The neutron energy spectrum can be unfolded, or extracted, from the light output spectrum by employing Bayesian statistics. The spectrum  $\psi(E)$  can be estimated using an iterative approach [2,3].

## Results: Unfolding

To extract the pulse-height spectra, neutrons from the PSD plot are projected along the x-axis.

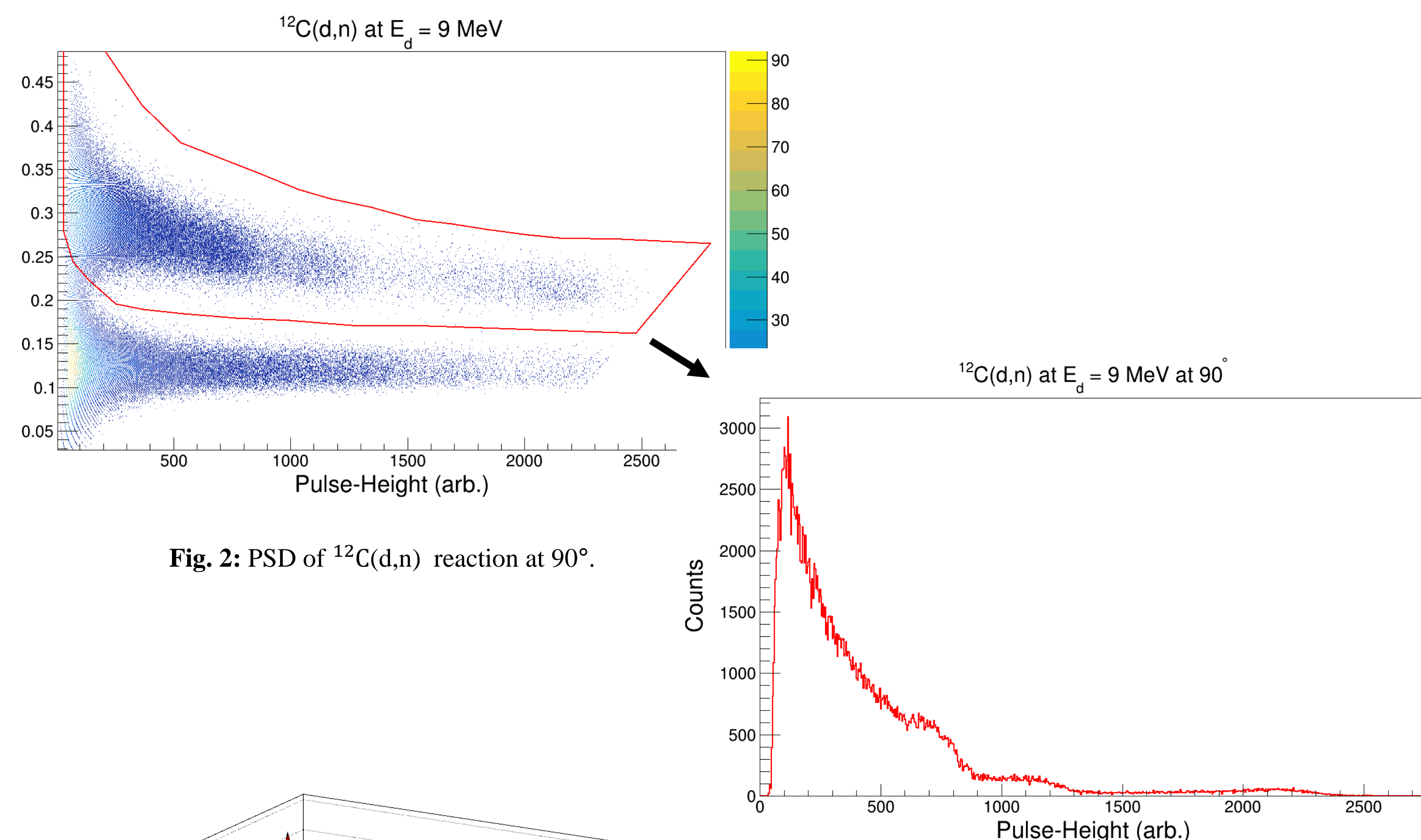


Fig. 2: PSD of  $^{12}\text{C}(\text{d},\text{n})$  reaction at  $90^\circ$ .

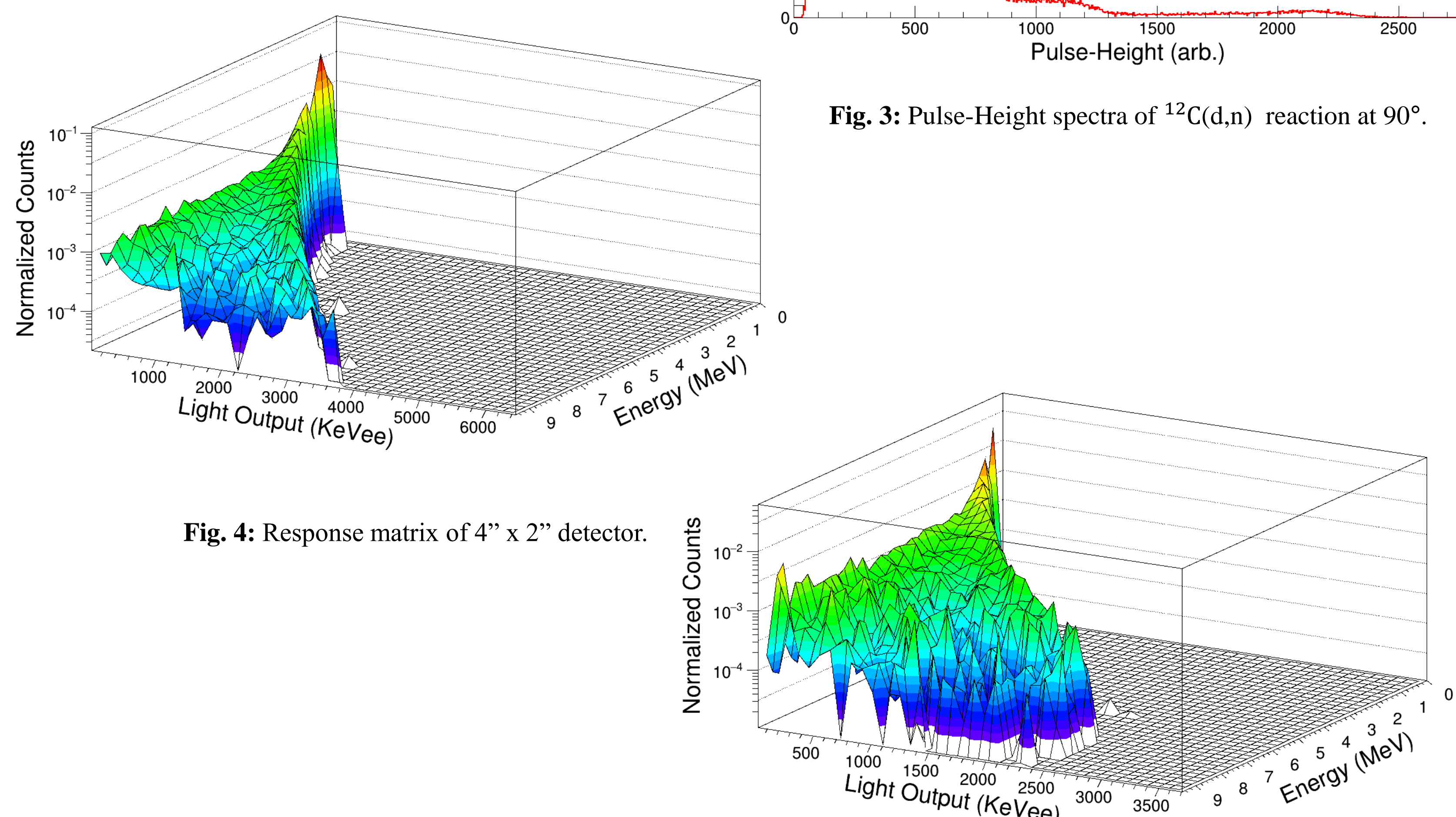


Fig. 4: Response matrix of  $4'' \times 2''$  detector.

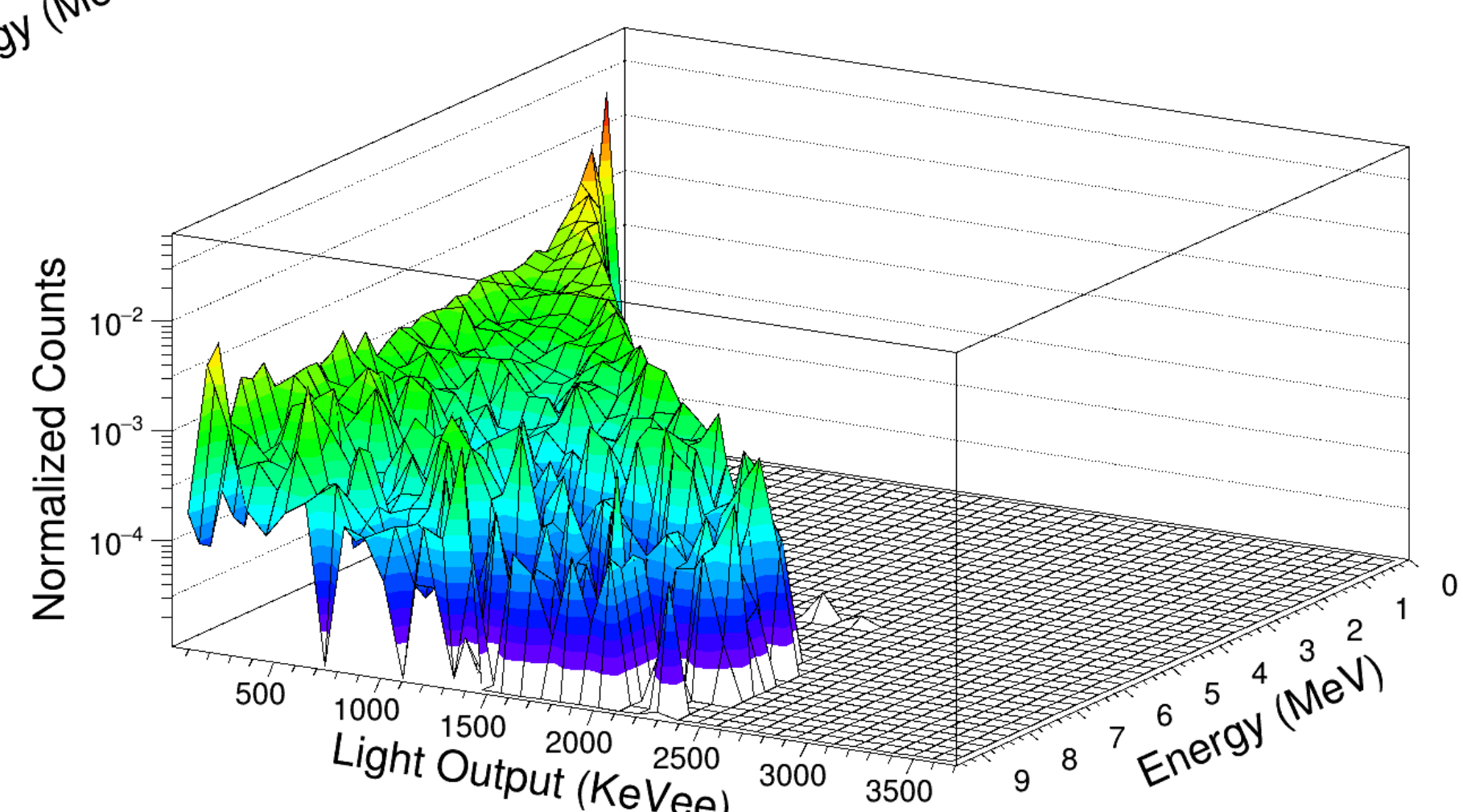


Fig. 5: Response matrix of  $2'' \times 2''$  detector.

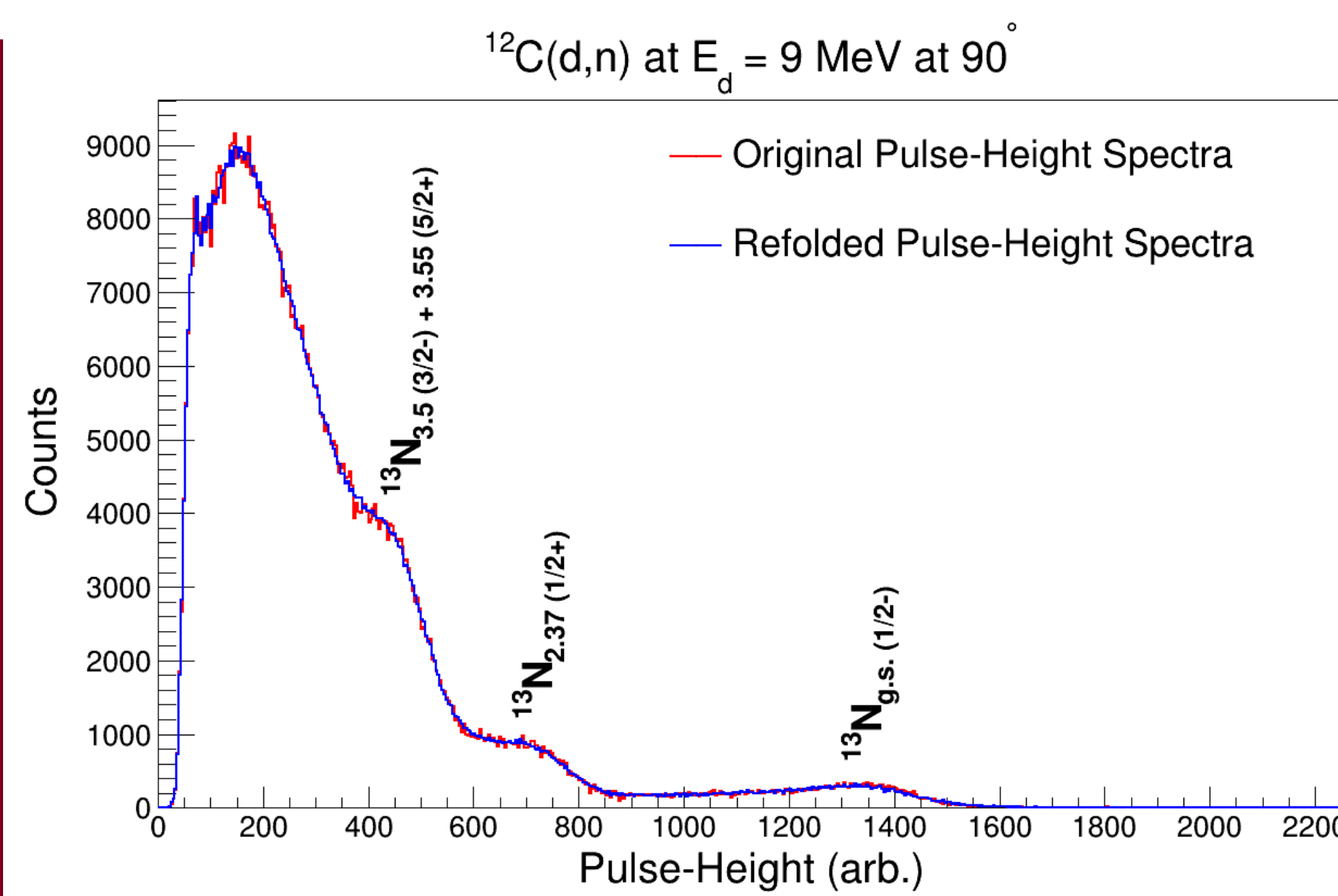


Fig. 6: Light output spectra of  $^{12}\text{C}(\text{d},\text{n})$  for beam energy of 9 MeV for  $4'' \times 2''$  detector.

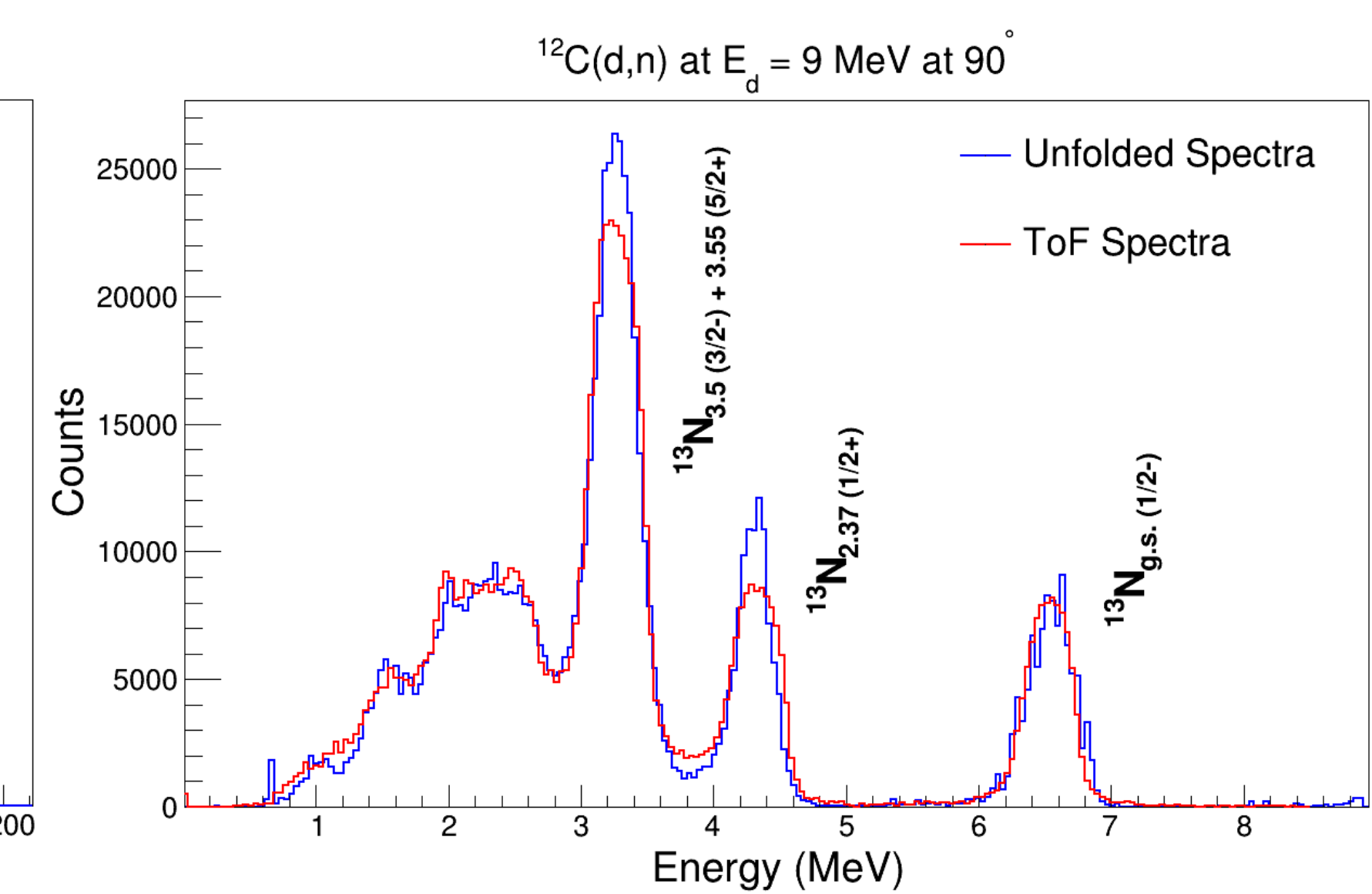


Fig. 7: Unfolded neutron energy spectra of  $^{12}\text{C}(\text{d},\text{n})$  for beam energy of 9 MeV for  $4'' \times 2''$  detector.

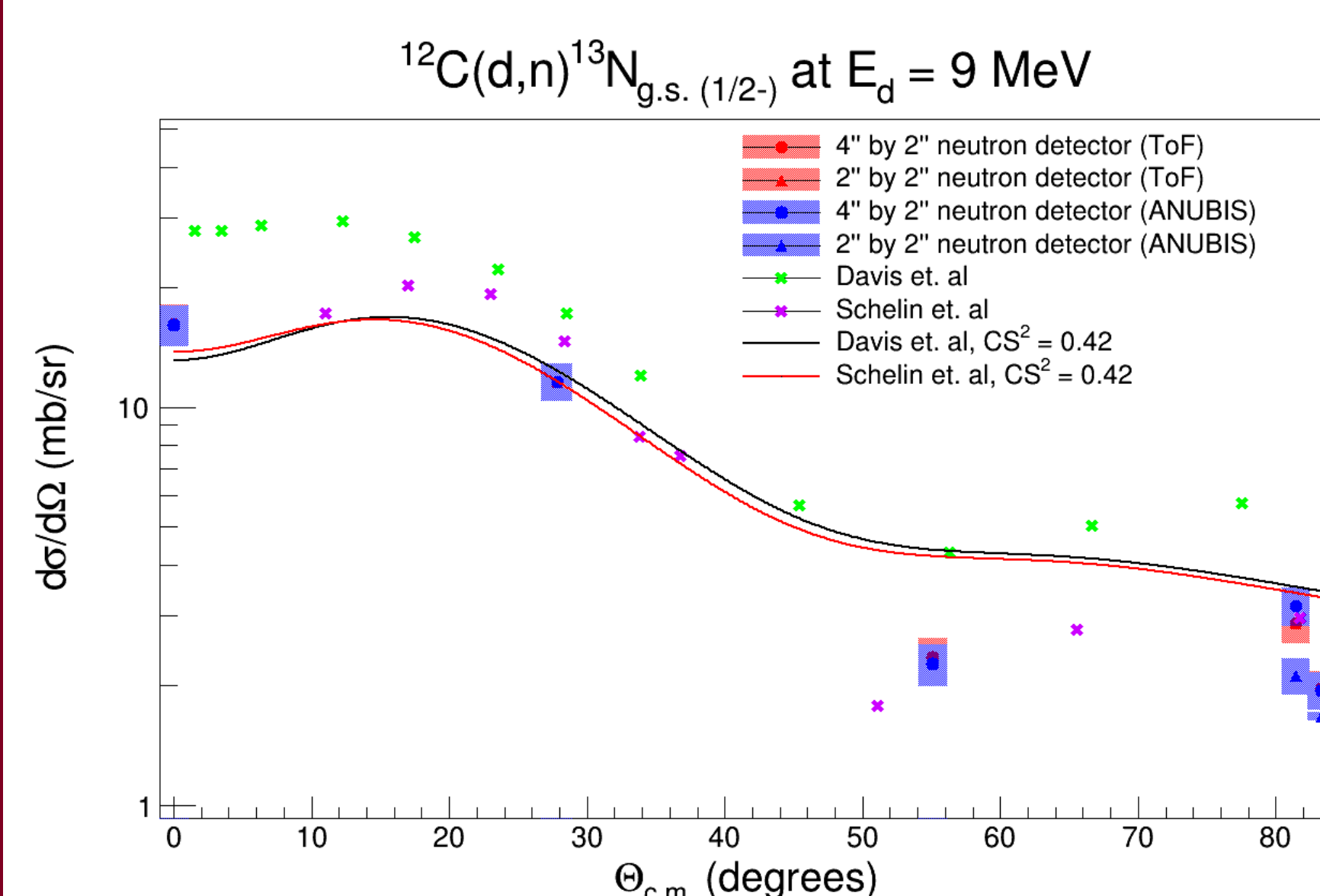


Fig. 8: Cross sections extracted from Fig. 7 for  $^{13}\text{N}_{3,5}(1/2^-)$ .

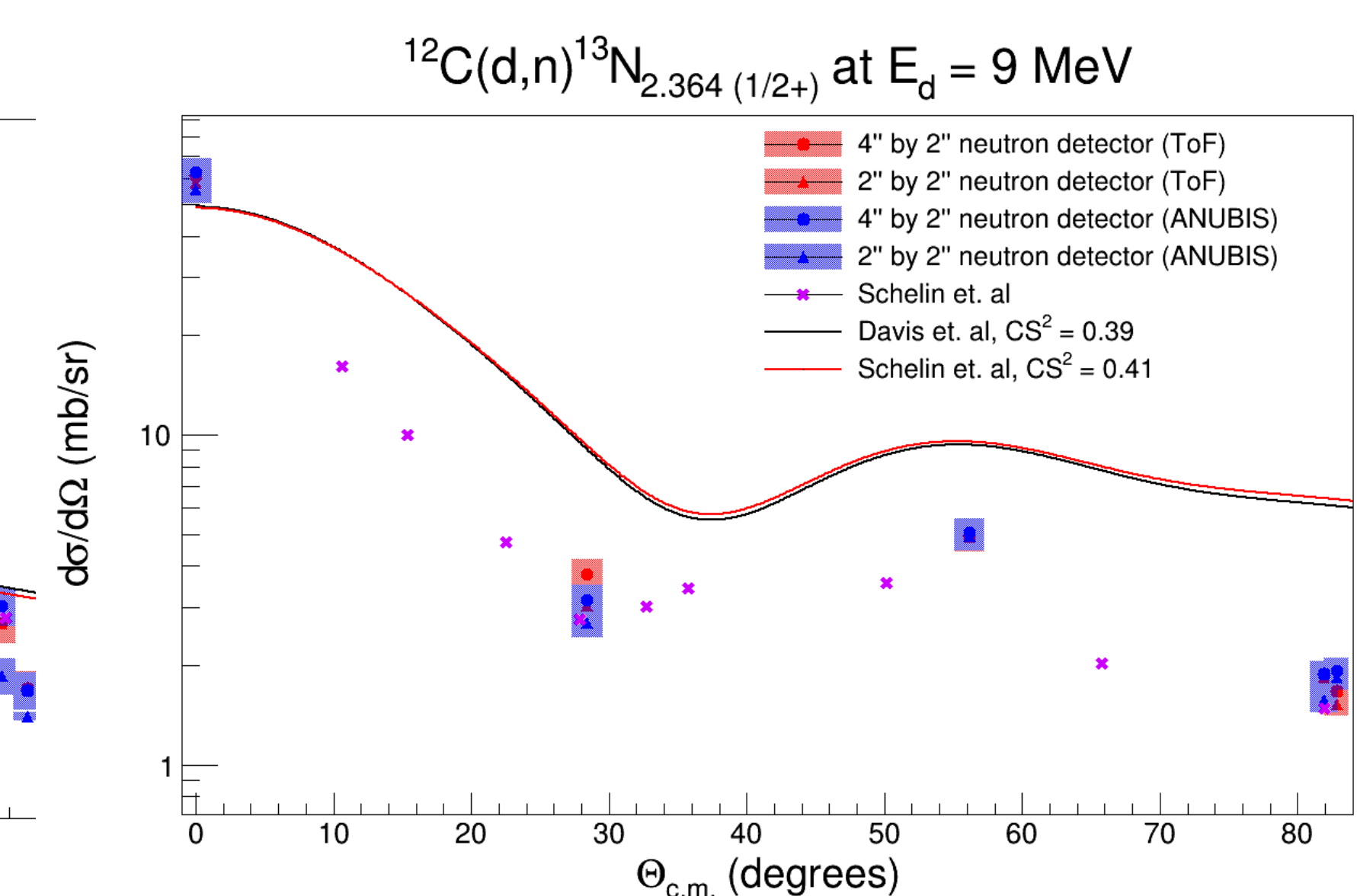


Fig. 9: Cross sections extracted from Fig. 7 for  $^{13}\text{N}_{2,364}(1/2^+)$ .

## Results: Uncertainties

$$\psi_j^{k+1} = \psi_j^k \sum_{i=1}^I \frac{R_{ij}\phi_i'}{\sum_{l=1}^J R_{il}\psi_l^k} \rightarrow \psi_j^{k+1} = M_{ji}^k \times \phi_i' \quad \text{where} \quad M_{ji} = \frac{R_{ij}\psi_j^k}{\sum_{l=1}^J R_{il}\psi_l^k}$$

$$\mathbf{V}_\psi = \mathbf{V}(\phi')_\psi + \mathbf{V}(\mathbf{M})_\psi$$

$$\mathbf{V}(\phi')_\psi = \mathbf{M}\mathbf{V}_\phi\mathbf{M}^T, \quad \mathbf{V}_{kl}(\mathbf{M})_\psi = \sum_{i,j=1}^I \phi_i'\phi_j'\text{Cov}(M_{ki}, M_{lj})$$

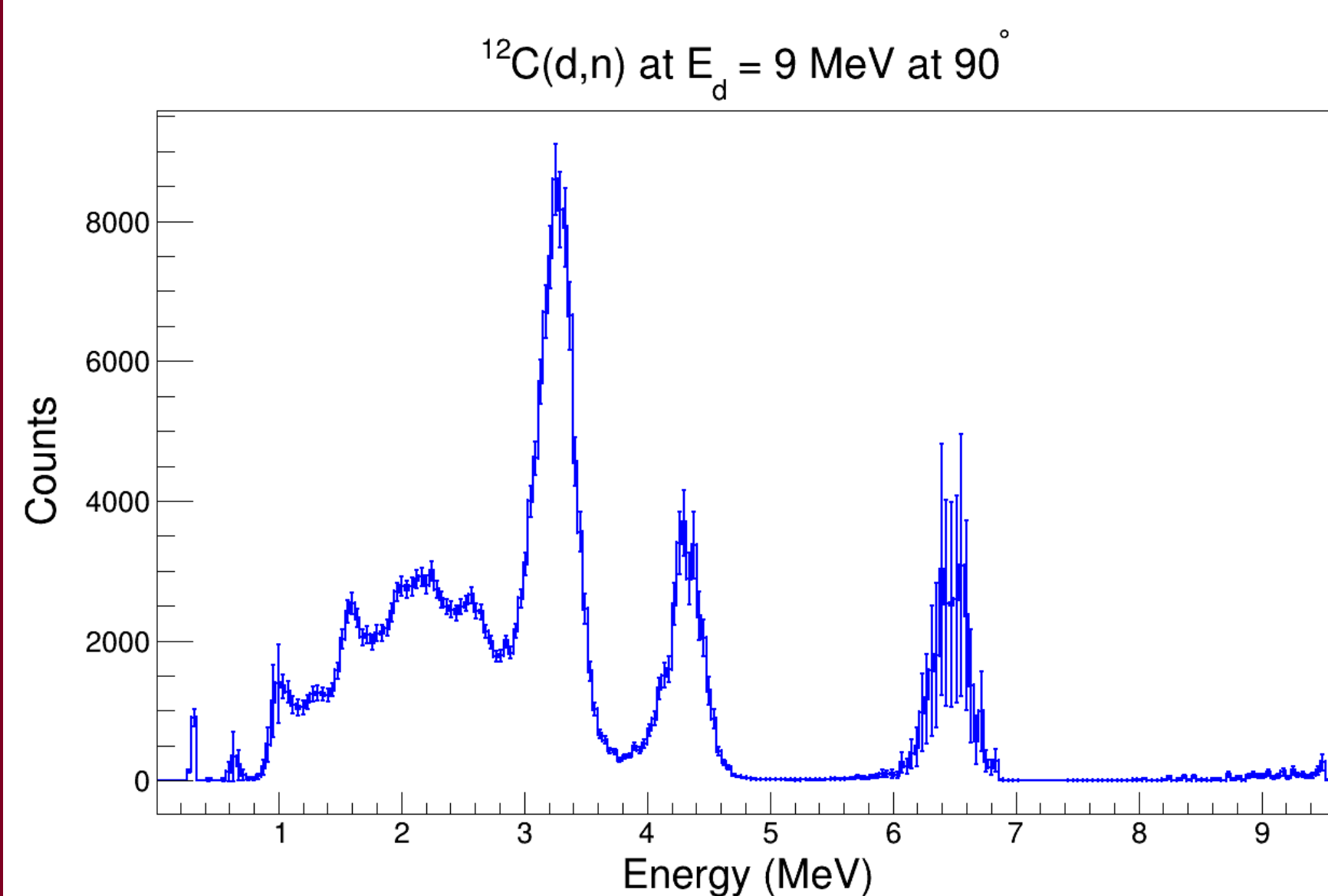


Fig. 10: Unfolded neutron energy spectra of the  $^{12}\text{C}(\text{d},\text{n})$  for beam energy of 9 MeV for  $2'' \times 2''$  detector with uncertainties.

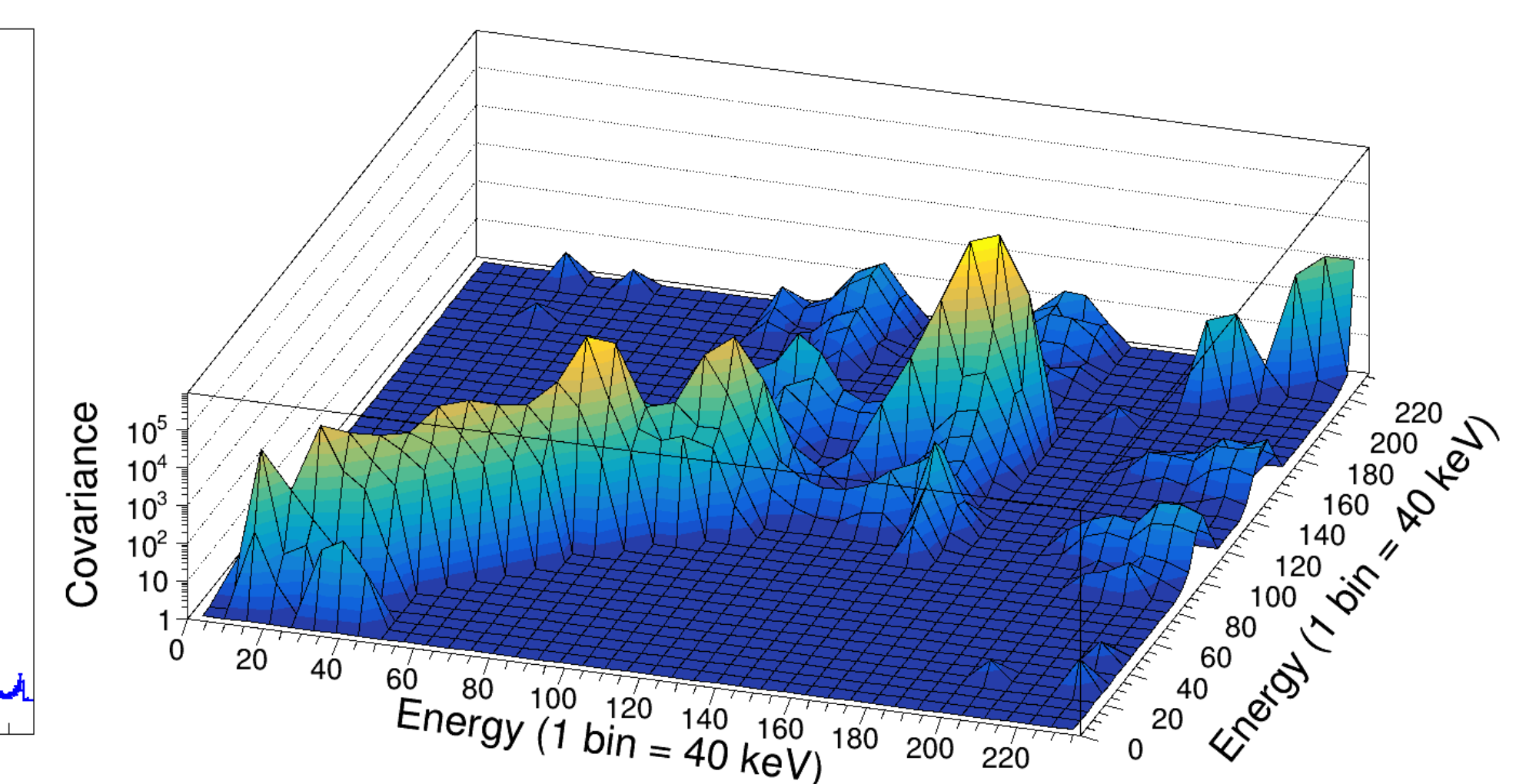


Fig. 11: Covariance matrix of unfolded neutron energy spectra of the  $^{12}\text{C}(\text{d},\text{n})$  for beam energy of 9 MeV for  $2'' \times 2''$  detector.

## References

- [1] J.F. Perello, S. Almaraz-Calderon, B.W. Asher, L.T. Baby, N. Gerken, K. Hanselman, *Characterization of the CATRiNA neutron detector system*, NIM A 930 (2019) 196
- [2] L. B. Lucy, *An iterative technique for the rectification of observed distributions*, AJ 79 (1974) 745
- [3] Tain, Cano-Ott, NIMA571,728(2007)37



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