Recent updates of the NeuCBOT program for evaluation of neutron yields and spectra from (α, n) reactions

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The importance of studying (α, n) reactions

- Neutrons from (α, n) reactions is one of the components of background in underground studies of rare events, such as WIMPs or neutrinos
- Neutrons from (α, n) reactoins on light nuclides can be used for passive non-destructive assays in nuclear waste management
- $^{13}C(\alpha, n)^{16}O$ is a source of neutrons for s- and weak r-processes in nucleosynthesis
- $^{13}C(\alpha, n)^{16}O$ can be studied as inverse reaction for better understanding neutron interactions with Oxygen in some nuclear fission reactors

Neutron Calculator Based On TALYS

GitHub

- Goal: Create a tool that low-background experiments can use for estimating neutron background induced by (α, n) reactions
- Design principles
  - Easy to use: usable by non-experts out-of-the-box
  - Flexible: usable by experiments with different materials, contaminants and secular equilibrium breaks
  - Easy to modify (written in Python!): adaptable to different needs
  - Fast calculation: using code optimisation and preset libraries to achieve ~5 second yield & spectrum calculation time

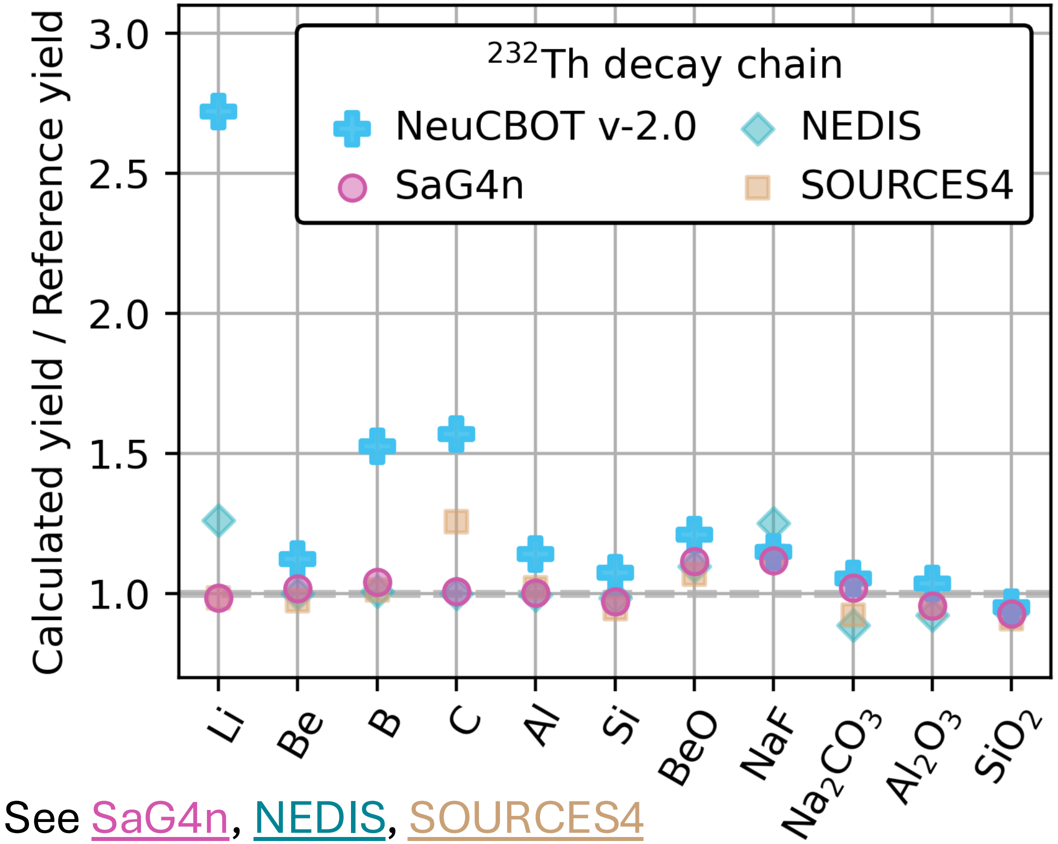
NeuCBOT updates

Version	Year	Added functional
v-1.0	2016 — 2020	Python2, neutron yields & spectra based on TENDL-2015 (TALYS-1.6)
v-2.0	2020 — 2023	Neutron yields & spectra based on TENDL-2019 (TALYS-1.95)
v-3.0	Current official version	Python3, neutron yields based on JENDL/AN-2005 for nuclides from Li to Si, gamma yields and spectra from $(\alpha, n\gamma)$ reactions based on TENDL-2019
v-3.5	Release in 2025	✓ Yields and spectra (+ partial reactions) based on JENDL-5 ✓ Yield from $^{13}C(\alpha, n)^{16}O$ (+ partial reactions) based on S. Harissopulos's experiment & P. Mohr's corrections ✓ α particle energy loss calculation • (avaliable soon) NeuCBOT Web Graphic User Interface

NeuCBOT-JENDL update motivation

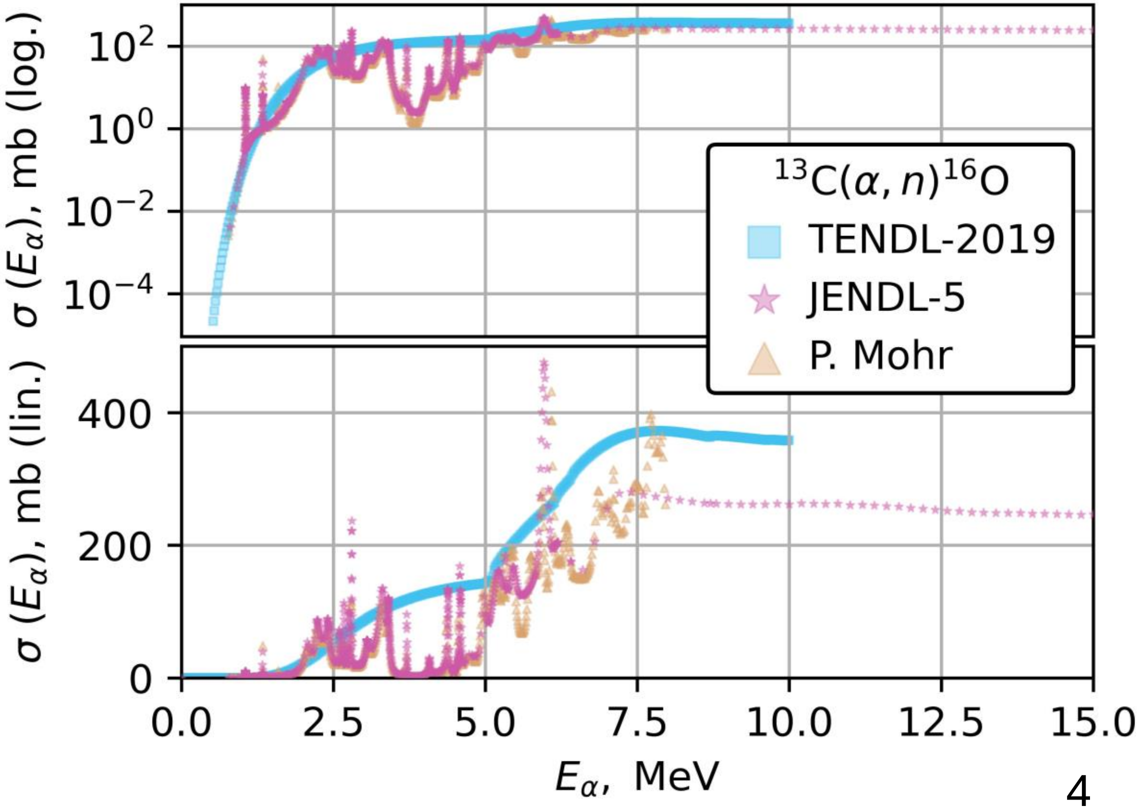
See ref. data

NeuCBOT v-2.0 sometimes predicts higher yields than have been measured

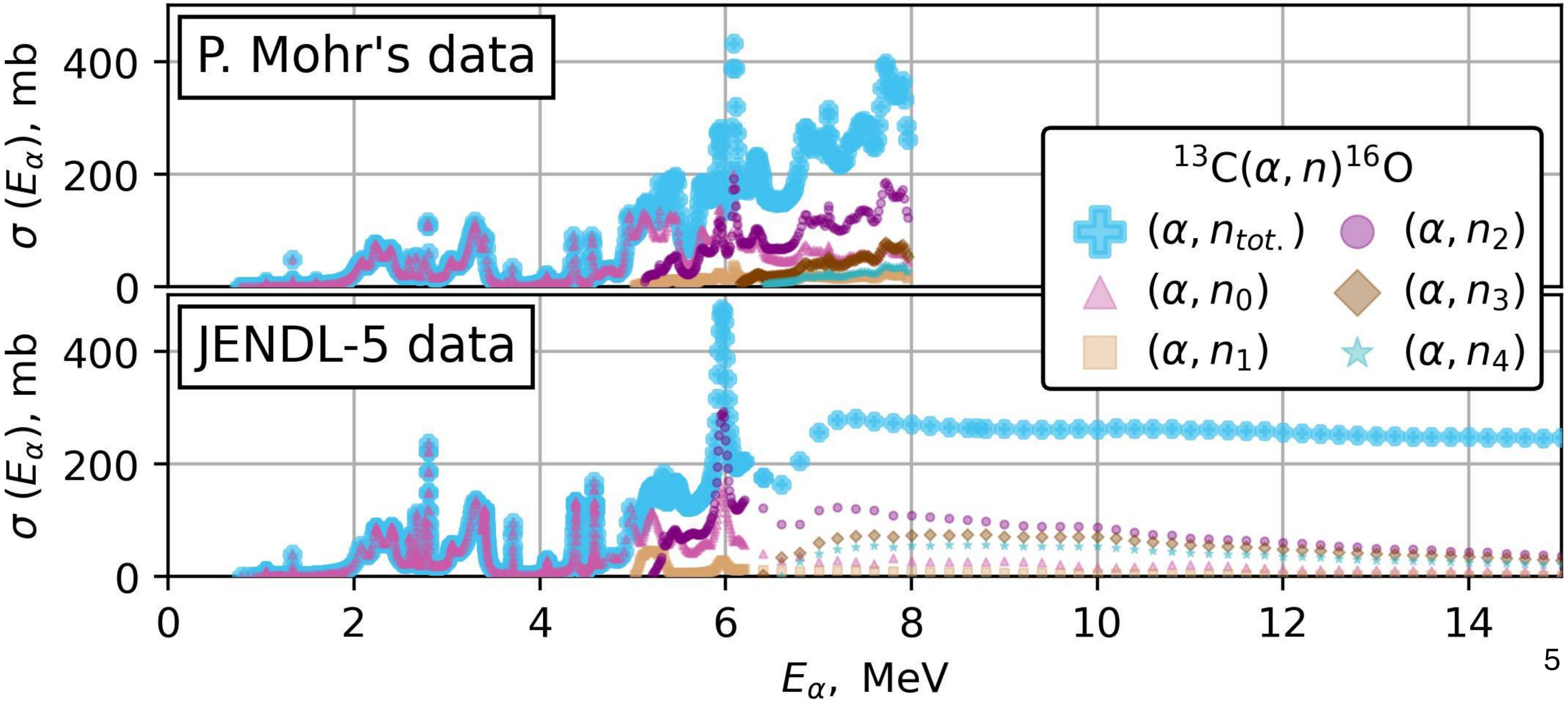


See SaG4n, NEDIS, SOURCES4

TENDL uses a statistical nuclear model which is inaccurate for light nuclei

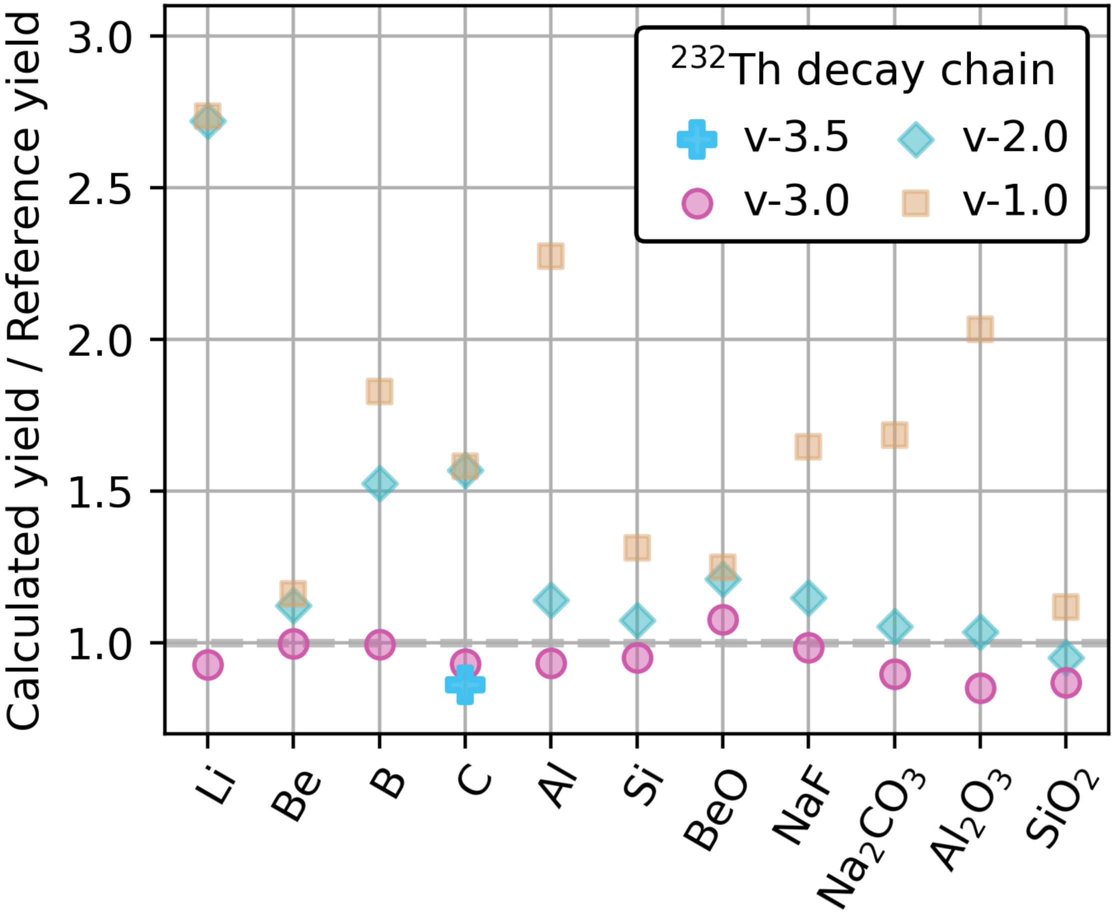


JENDL & Mohr's $^{13}C(\alpha, n)^{16}O$ reaction x-sections



Neutron yield calculation results

See ref. data



For natural Carbon target per decay of ^{232}Th:

Program	Yield $\times 10^{-7}$	Rel. to ref. %
NeuCBOT v-2.0 (TENDL-2019)	3.61	157
NeuCBOT v-3.0 (JENDL-5)	2.14	93
NeuCBOT v-3.5 (JENDL-5 + Mohr)	1.98	86
SaG4n (JENDL-5)	2.32	101

From yields to spectra

Yield calculation

$$Y_i = \sum_{\alpha} P_\alpha \sum_m \frac{N_A C_m}{A_m} \int_0^{E_\alpha} \frac{\boxed{\sigma_m\left(\tilde{E}_\alpha\right)}}{\xi\left(\tilde{E}_\alpha\right)} \mathrm{d}\tilde{E}_\alpha$$

- X-section $\sigma_m(E_\alpha)$ may be obtained from [JENDL-5 Alpha-particle sublibrary] and from [Peter Mohrs corrections] of the [Sotirios Harissopuloss experiment]

Spectrum calculation

$$Y_i\left(E_n\right) = \sum_{\alpha} P_\alpha \sum_m \frac{N_A C_m}{A_m} \int_0^{E_\alpha} \frac{\boxed{\sigma_m\left(\tilde{E}_\alpha, E_n\right)}}{\xi\left(\tilde{E}_\alpha\right)} \mathrm{d}\tilde{E}_\alpha$$

- Differential x-section $\sigma_m(E_\alpha, E_n)$ may be obtained from [JENDL-5 Alpha-particle sublibrary] via some preliminary calculations

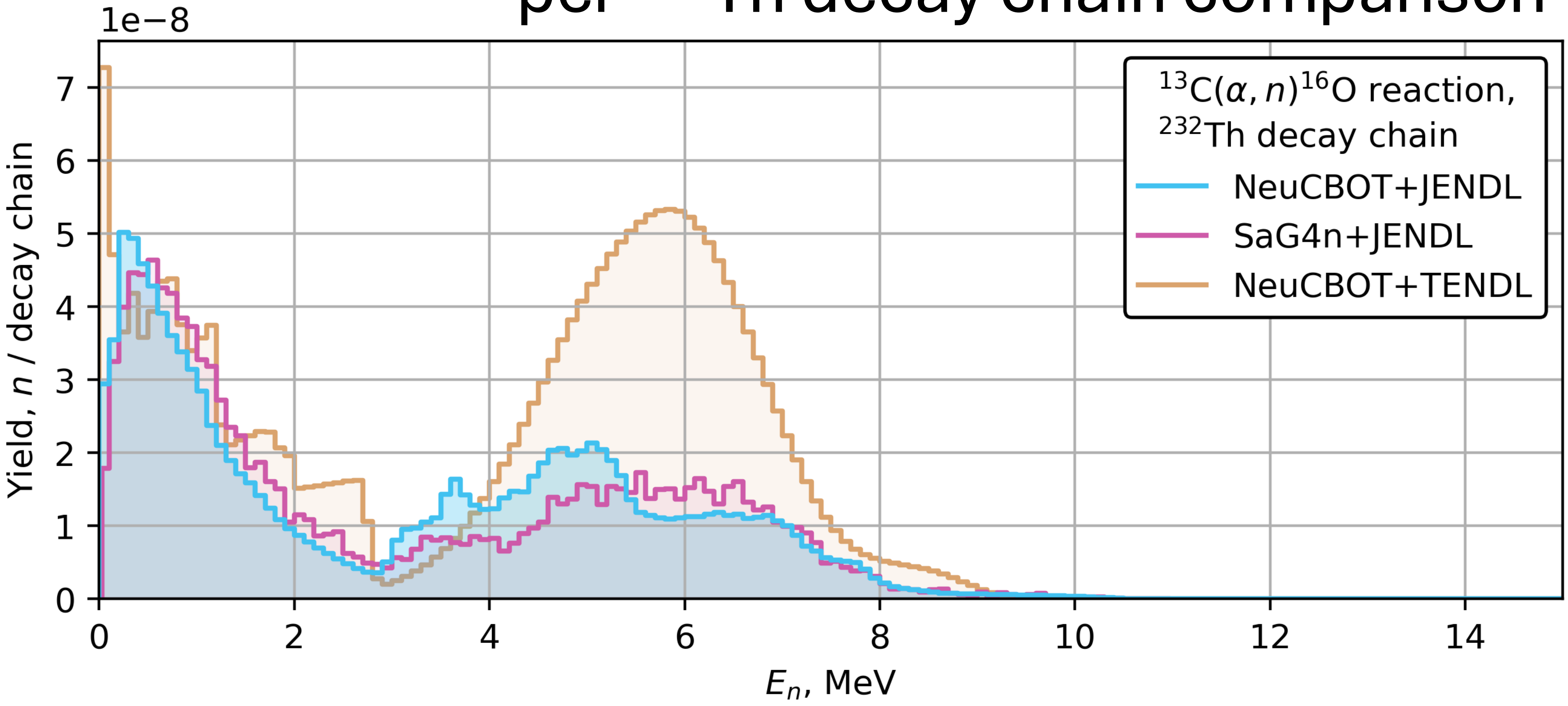
Differential x-section calculation

- JENDL-5 contains energy-angle distributions as a differential parameter
- It can be converted to differential x-section via formula

$$\sigma_m\left(E_\alpha, E_n\right) = \sigma_m\left(E_\alpha\right)\frac{\partial\cos\theta}{\partial E_n}p\left(E_\alpha, \cos\theta\right)$$

- Where the dependence $E_n(\cos\theta)$ is derived from kinematics of compaund nucleus in classic approach

Neutron spectra from $^{13}C(\alpha, n)^{16}O$ reaction per ^{232}Th decay chain comparison



Conclusion

The **NeuCBOT** project is actively developing:

- Our team grew twice(!) since the v-3.0 update in 2023
- Features added in v-3.5 update:
  - Neutron spectra calculation via JENDL-5
  - Partial reactions yields and spectra calculation via JENDL-5
  - $^{13}C(\alpha, n)^{16}O$ reaction yield calculation via P. Mohr's data
  - α particle energy loss calculation

Conclusion

Further development:

- Web GUI
- Stopping power revision
- γ yields & spectra from de-excitation of the residual nucleus calculation
- Alternative x-section libraries implementation
- Error estimation

Thank you for your attention!

NeuCBOT v-3.0

GitHub

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Papers:

S. Westerdale and P. D. Meyers. NIM A 875, 11 (2017)

M.B. Gromov, S. Westerdale, I.A. Goncharenko, A.S. Chepurnov. Phys. At. Nucl. 86, 2 (2023)

Other papers:

JENDL-5 — O, Iwamoto, et al. JNST 60(1), 1–60 (2022)

Reference yields —
A.C. Fernandes, et al. EPJ 153,07021 (2017)

P. Mohr's correction to Harissopulos's x-sections —
P. Mohr, Phys. Rev. C 97, 064613 (2018)

S. Harissopulos's experimental $^{13}C(\alpha, n)^{16}O$ x-sections —
S. Harissopulos, Phys. Rev. C 72, 062801(R) (2005)