Los Alamos
NATIONAL LABORATORY

# Update of R-matrix evaluations with EDAf90

Consultancy Meeting on International Nuclear Data Evaluation Network-Light Elements

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LA-UR-22-25773

# Outline

- Review of R-matrix theory
  - Theoretical overview
    - R-matrix theory; resonance parameters
  - Evaluation pipeline
- New code implementation:
  - resonance parameters
    - `par2ENDFtk.py`
- $^{17}O$ evaluation

# Light-element R-matrix evaluation

## *R-matrix formalism*

Exterior region

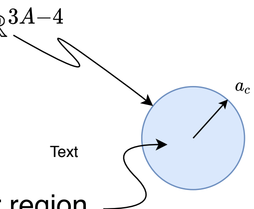
$$|\Psi_c^{(+)}\rangle = |\mathscr{I}_c\rangle - \sum_{c'} |\mathscr{O}_{c'}\rangle S_{c'c}$$

$$S_{cc'} = \delta_{cc'} + 2i\, T_{cc'}$$

$r \to \infty$

Channel surface

$\mathscr{S}_c \in \mathbb{R}^{3A-4}$




Interior region

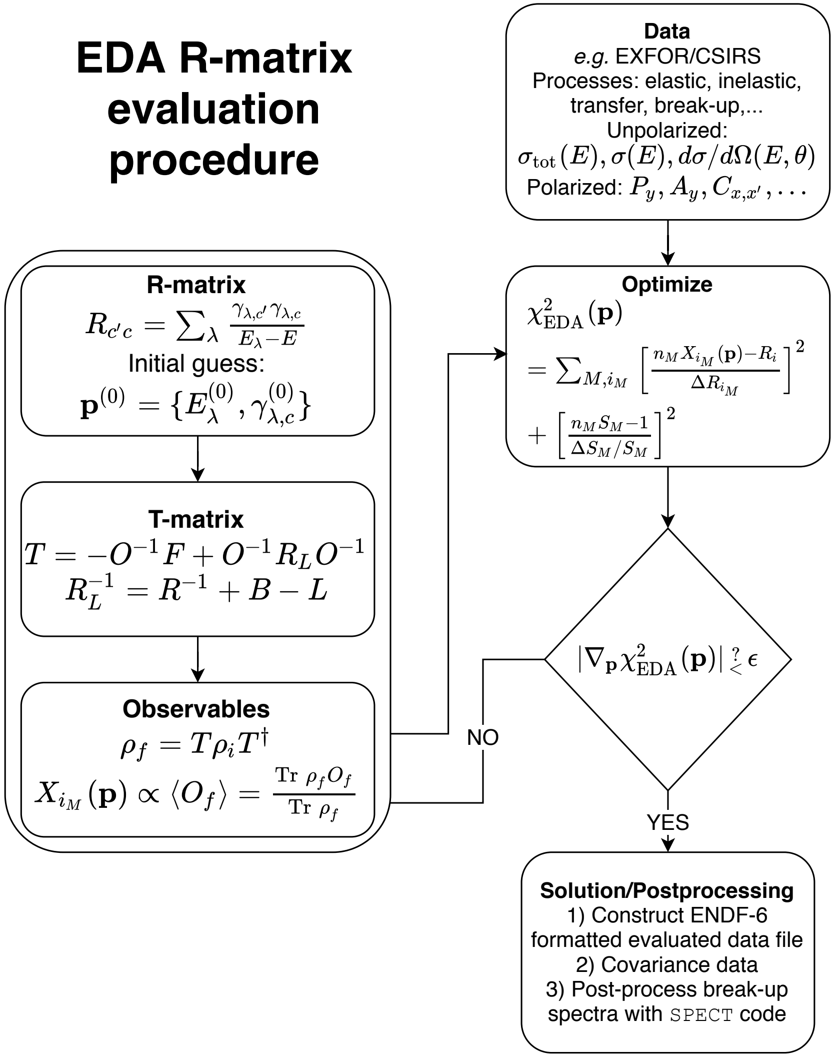
$$[H + \mathscr{L}_B]\,|\lambda\rangle = E_\lambda |\lambda\rangle$$

$$|\Psi^{(+)}\rangle = [H + \mathscr{L}_B - E]^{-1} \mathscr{L}_B |\Psi^{(+)}\rangle$$

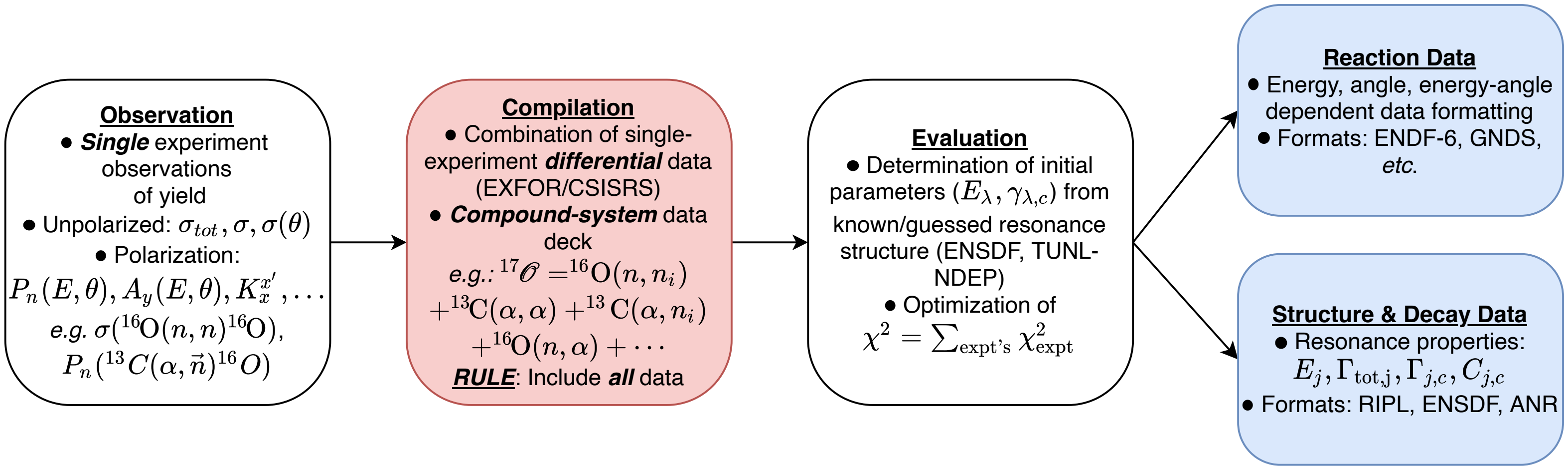
$$\mathscr{L}_B = \sum_c \frac{i a_c}{2 m_c} |a_c\rangle\langle a_c| (\hat{p}_r + i B_c)$$

$$R_{B,c'c} = \langle c' | [H + \mathscr{L}_B - E]^{-1} | c\rangle = \sum_\lambda \frac{\langle c'|\lambda\rangle\langle\lambda|c\rangle}{E_\lambda - E}$$

## EDA R-matrix evaluation procedure



# Evaluation pipeline




1. `EDAf90` code handles all types of data [*EXFOR/CSISRS; publications; priv. comm.*]
   - total, integrated, diff'l, polarized, unpolarized; neutron- and CP-induced: (n,X), (p,X), (d,X), (t,X),...
2. `EDAf90` handles all the compound system (here: $^{17}$**O**) data ***simultaneously***
3. Optimization over parameters simultaneously fits all the data with the same parameters
4. `EDAf90` → ENDF-6 formatted ENDF/B libraries for processing to CE & MG libraries
5. Testing & evaluation by hand; future: automate

# Resonance parameters

- Wigner-Eisenbud parameters
- Resolvents
  - S-matrix/T-matrix/$R_L$-matrix poles

$$R_L = \frac{1}{\mathscr{R}_L(E) - E}$$

$$\mathscr{R}_L(E) \equiv \mathscr{E} - \gamma\big(L(E) - B\big)\gamma^T$$

$$\mathscr{R}_L\big(E_i^{(L)}\big)|E_i^{(L)}\rangle = E_i^{(L)}|E_i^{(L)}\rangle$$

  - $R_S$-matrix (AKA “Brune alternative”) poles

$$R_S = \frac{1}{\mathscr{R}_S(E) - E}$$

$$\mathscr{R}_S(E) \equiv \mathscr{E} - \gamma\big(S(E) - B\big)\gamma^T$$

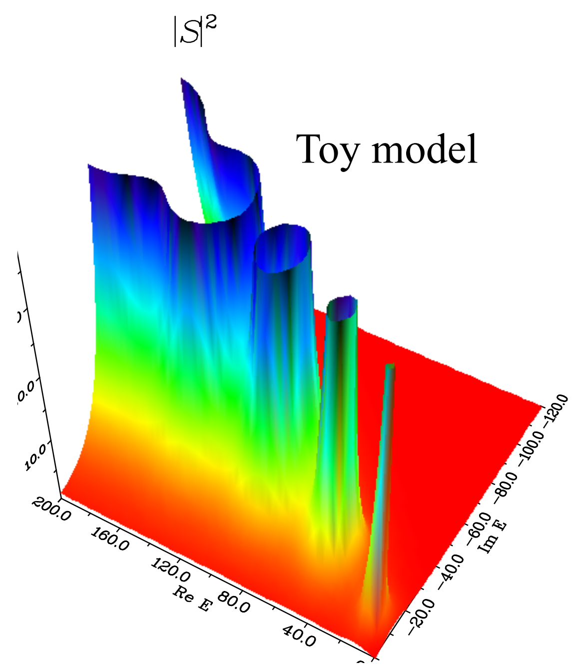
$$\mathscr{R}_S\big(E_i^{(S)}\big)|E_i^{(S)}\rangle = E_i^{(S)}|E_i^{(S)}\rangle$$

$$S = O^{-1}I + 2iO^{-1}R_L O^{-1}$$

$$R_L^{-1} = R^{-1} + B - L$$

$$R = \sum_\lambda \frac{|\lambda\rangle\langle\lambda|}{E_\lambda - E}$$

$$L = \frac{\rho}{O}\frac{\partial O}{\partial \rho} = S + iP$$



# New ENDF/B MF=2 formatting

## LRF=7 (R-matrix [un]Limited)

- CSEWG formats proposal
  - provisionally approved
  - R-Matrix Limited section
    - MF=2, MT=151, LRU=1, LRF=7, KRM=4, KRL=1
- `par2ENDFtk.py`
  - working with M. Lazaric (UNM, Perfetti group)
  - enabled by Ian Thompson's `eda_parfile.py`
  - `ENDFtk` by LANL dev's

**Proposal to CSEWG**
**Clarification of R-Matrix Limited format**
**Relativistic flag KRL for LRF=7 formatting***

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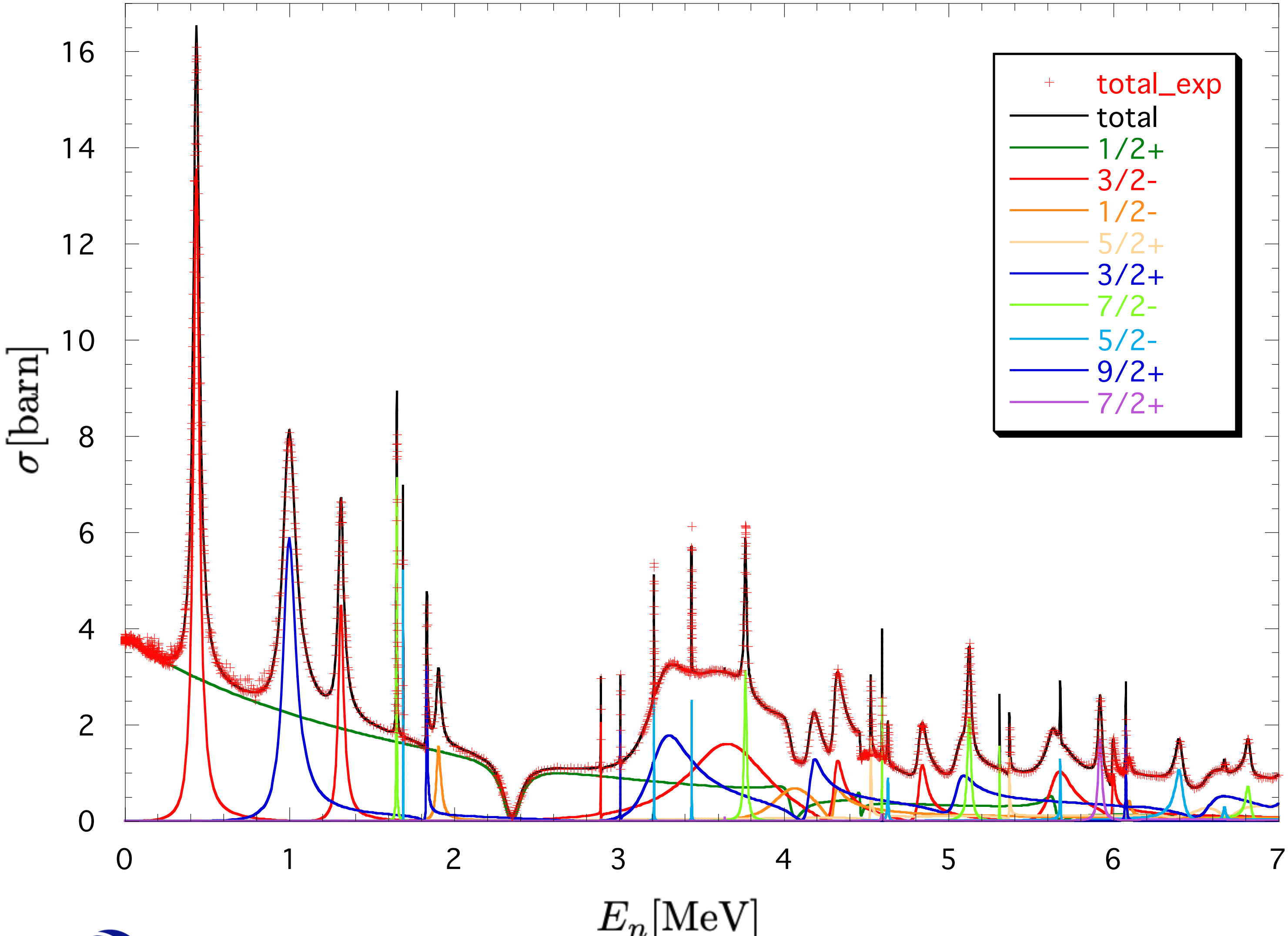
*Lawrence Livermore National Laboratory*

```
                           ENDF/B-TEST FILE                                   825 1451
                    G.M. Hale, M.W Paris, M. Lazaric                          825 1451
                              June 2022                                       825 1451
                                                                              825 1451
                                 1        451         20          3 825 1451
                                 2        151        112          3 825 1451
                                 3          1          4          3 825 1451
                                 3          2          4          3 825 1451
                                                                    825 1  0
                                                                    825 0  0
 8.016000+3 1.585751+1          0          0          1          0 825 2151
 8.016000+3 1.000000+0          0          0          1          0 825 2151
 1.000000-5 7.000000+6          1          7          0          1 825 2151
 0.000000+0 0.000000+0          1          4         11          0 825 2151
 0.000000+0 0.000000+0          2          0         24          4 825 2151
 1.000000+0 1.585751+1 0.000000+0 8.000000+0 5.000000-1 0.000000+0 825 2151
 0.000000+0 1.000000+0 1.000000+0 2.000000+0 1.000000+0 1.000000+0 825 2151
 3.967131+0 1.288839+1 2.000000+0 6.000000+0 0.000000+0-5.000000-1 825 2151
-2.214637+6 1.000000+0 1.000000+0 8.000000+2 1.000000+0-1.000000+0 825 2151
 5.000000-1 1.000000+0          0          0         12          2 825 2151
 1.000000+0 0.000000+0 5.000000-1 0.000000+0 0.000000+0 4.400000-3 825 2151
 2.000000+0 0.000000+0 5.000000-1-4.000000+0 0.000000+0 5.400000-3 825 2151
 0.000000+0 0.000000+0          0          6         36          6 825 2151
 2.277257+6 2.573269+2 7.718658+2 0.000000+0 0.000000+0 0.000000+0 825 2151
 3.723113+6 7.711451+1-3.480746+2 0.000000+0 0.000000+0 0.000000+0 825 2151
 4.005654+6 5.265391+1-2.742649+2 0.000000+0 0.000000+0 0.000000+0 825 2151
 4.658715+6 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 825 2151
 5.006154+6-1.149261+2 4.213175+1 0.000000+0 0.000000+0 0.000000+0 825 2151
-2.916058+6 9.019007+2 0.000000+0 0.000000+0 0.000000+0 0.000000+0 825 2151
```

# Total cross section

***Partial cross section decomposition: highlight ½⁺ background wave***




- ✓ $\frac{1}{2}^+$ "hardly" resonant
- ✓ "Windows"
  - Destructive interference b/w hard-sphere and pole terms
- ✓ R-matrix pole is sensitive to channel radius
- ✓ But phase shift/Xsec is not

# $R_L$ resonance parameters

| | $E_n$ (MeV) | $E_\alpha$ (MeV) | $E_x$ (MeV) | $J^\pi$ | $\Gamma$ (keV) | $E_x$ (MeV) | $J^\pi$ | $\Gamma$ (keV) |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.4344 | -2.3618 | 4.5522 | $3/2^-$ | 41.12 | $4.5538 \pm 1.6$ | $3/2^-$ | $40 \pm 5$ |
| 2 | 0.9960 | -1.6710 | 5.0805 | $3/2^+$ | 89.64 | $5.0848 \pm 0.9$ | $3/2^+$ | $96 \pm 5$ |
| 3 | | | | | | $5.21577 \pm 0.45$ | $9/2^-$ | $< 0.1$ |
| 4 | 1.3122 | -1.2821 | 5.3779 | $3/2^-$ | 39.28 | $5.3792 \pm 1.4$ | $3/2^-$ | $28 \pm 7$ |
| 5 | 1.6514 | -0.8649 | 5.6969 | $7/2^-$ | 3.77 | $5.69726 \pm 0.33$ | $7/2^-$ | $3.4 \pm 0.3$ |
| 6 | 1.6902 | -0.8172 | 5.7334 | $5/2^-$ | 0.160 | $5.73279 \pm 0.52$ | $(5/2^-)$ | $< 1$ |
| 7 | 1.8335 | -0.6409 | 5.8682 | $3/2^+$ | 6.730 | $5.86907 \pm 0.55$ | $3/2^+$ | $6.6 \pm 0.7$ |
| 8 | 1.9050 | -0.5529 | 5.9355 | $1/2^-$ | 29.74 | $5.939 \pm 4$ | $1/2^-$ | $32 \pm 3$ |
| 9 | 2.3486 | -0.0072 | 6.3527 | $1/2^+$ | 125.88 | $6.356 \pm 8$ | $1/2^+$ | $124 \pm 12$ |
| 10 | 2.8902 | 0.6590 | 6.8621 | $3/2^-$ | 0.36 | $6.862 \pm 2$ | $(5/2^+)$ | $< 1$ |
| 11 | 3.0082 | 0.8041 | 6.9731 | $3/2^+$ | 0.33 | $6.972 \pm 2$ | $(7/2^-)$ | $< 1$ |
| 12 | 3.2128 | 1.0558 | 7.1655 | $5/2^-$ | 1.67 | $7.1657 \pm 0.8$ | $5/2^-$ | $1.38 \pm 0.05$ |
| 13 | 3.2515 | 1.1034 | 7.2019 | $3/2^+$ | 289.00 | $7.202 \pm 10$ | $3/2^+$ | $280 \pm 30$ |
| 14 | 3.4400 | 1.3353 | 7.3792 | $5/2^+$ | 0.56 | $7.3792 \pm 1.0$ | $5/2^+$ | $0.64 \pm 0.23$ |
| 15 | 3.4427 | 1.3385 | 7.3817 | $5/2^-$ | 1.29 | $7.3822 \pm 1.0$ | $5/2^-$ | $0.96 \pm 0.20$ |
| 16 | 3.6434 | 1.5853 | 7.5704 | $7/2^+$ | 0.260 | | | |
| 17 | 3.6604 | 1.6063 | 7.5864 | $3/2^-$ | 575.16 | $7.559 \pm 20$ | $3/2^-$ | $500 \pm 50$ |
| 18 | | | | | | $7.576 \pm 2$ | $(7/2^+)$ | $< 0.1$ |
| 19 | 3.7685 | 1.7393 | 7.6881 | $7/2^-$ | 17.150 | $7.6882 \pm 0.9$ | $7/2^-$ | $14.4 \pm 0.3$ |
| 20 | 4.0419 | 2.0755 | 7.9452 | $1/2^-$ | 320.35 | $7.956 \pm 6$ | $1/2^+$ | $90 \pm 9$ |
| 21 | 4.0476 | 2.0826 | 7.9506 | $1/2^+$ | 76.370 | $7.99 \pm 50$ | $1/2^-$ | $270 \pm 30$ |
| 22 | 4.1619 | 2.2232 | 8.0581 | $3/2^+$ | 74.750 | $8.070 \pm 10$ | $3/2^+$ | $85 \pm 9$ |
| 23 | 4.3031 | 2.3969 | 8.1909 | $1/2^-$ | 45.850 | | | |
| 24 | 4.3125 | 2.4084 | 8.1997 | $3/2^-$ | 63.010 | $8.200 \pm 7$ | $3/2^-$ | 60 |

# $R_L$ resonance parameters

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 24 | 4.3125 | 2.4084 | 8.1997 | $3/2^-$ | 63.010 | $8.200 \pm 7$ | $3/2^-$ | 60 |
| 25 | 4.4648 | 2.5957 | 8.3429 | $1/2^+$ | 13.280 | $8.3424 \pm 0.9$ | $1/2^+$ | $11.4 \pm 0.5$ |
| 26 | 4.5284 | 2.6739 | 8.4027 | $5/2^+$ | 5.3800 | $8.4023 \pm 0.8$ | $5/2^+$ | $6.17 \pm 0.13$ |
| 27 | 4.5963 | 2.7575 | 8.4666 | $7/2^-$ | 1.2200 | $8.4660 \pm 0.8$ | $(9/2^+)$ | $2.13 \pm 0.11$ |
| 28 | 4.5967 | 2.7580 | 8.4670 | $7/2^+$ | 7.9200 | | | |
| 29 | 4.6331 | 2.8028 | 8.5012 | $5/2^-$ | 6.8300 | $8.5007 \pm 0.8$ | $5/2^-$ | $6.89 \pm 0.22$ |
| 30 | 4.8313 | 3.0466 | 8.6876 | $3/2^-$ | 53.540 | $8.6870 \pm 1.0$ | $3/2^-$ | $55.3 \pm 0.6$ |
| 31 | 5.0564 | 3.3235 | 8.8993 | $3/2^+$ | 107.10 | $8.897 \pm 8$ | $3/2^+$ | $101 \pm 3$ |
| 32 | 5.1264 | 3.4096 | 8.9651 | $7/2^-$ | 23.640 | $8.9672 \pm 1.7$ | $7/2^-$ | $26 \pm 2$ |
| 33 | 5.1468 | 3.4347 | 8.9843 | $1/2^-$ | 162.56 | $9.147 \pm 4$ | $1/2^-$ | $4 \pm 3$ |
| 34 | 5.3094 | 3.6347 | 9.1372 | $7/2^-$ | 1.0400 | 9.18 | $7/2^-$ | 3 |
| 35 | 5.3699 | 3.7091 | 9.1941 | $5/2^+$ | 3.6900 | $9.1939 \pm 0.8$ | $5/2^+$ | $3.53 \pm 0.13$ |
| 36 | 5.6477 | 4.0508 | 9.4553 | $1/2^+$ | 59.190 | | | |
| 37 | 5.6505 | 4.0542 | 9.4579 | $3/2^-$ | 158.70 | 9.42 | $3/2^-$ | 120 |
| 38 | 5.6789 | 4.0891 | 9.4846 | $5/2^-$ | 3.8400 | $9.492 \pm 4$ | $5/2^-$ | $15 \pm 1$ |
| 39 | 5.9203 | 4.3860 | 9.7116 | $7/2^+$ | 24.320 | $9.7119 \pm 0.9$ | $7/2^+$ | $23.1 \pm 0.3$ |
| 40 | 5.9241 | 4.3907 | 9.7152 | $3/2^+$ | 306.44 | | | |
| 41 | 5.9966 | 4.4799 | 9.7834 | $3/2^-$ | 13.780 | $9.7833 \pm 0.9$ | $3/2^+$ | $11.7 \pm 0.3$ |
| 42 | 6.0772 | 4.5791 | 9.8592 | $9/2^+$ | 4.6100 | $9.8589 \pm 0.9$ | $(5/2^-)$ | $4.01 \pm 0.2$ |
| 43 | 6.0931 | 4.5986 | 9.8741 | $1/2^-$ | 18.810 | $9.8765 \pm 1.3$ | $(1/2^-)$ | $16.7 \pm 1.7$ |
| 44 | 6.1608 | 4.6819 | 9.9378 | $7/2^+$ | 96.220 | $9.976 \pm 20$ | $5/2^+$ | 80 |
| 45 | | | | | | $10.045 \pm 20$ | | 100 |
| 46 | 6.4046 | 4.9817 | 10.167 | $5/2^-$ | 56.720 | $10.1678 \pm 1.0$ | $7/2^-$ | $49.1 \pm 0.8$ |
| 47 | 6.5460 | 5.1557 | 10.300 | $5/2^+$ | 273.02 | $10.336 \pm 15$ | $5/2^+$,$7/2^-$ | 150.00 |
| 48 | 6.5811 | 5.1989 | 10.333 | $7/2^+$ | 559.73 | | | |
| 49 | 6.6747 | 5.3140 | 10.421 | $5/2^-$ | 17.000 | $10.423 \pm 3$ | | $14 \pm 3$ |
| 50 | | | | | | 10.49 | $5/2^+$,$7/2^-$ | $75 \pm 30$ |
| 51 | 6.8236 | 5.4971 | 10.561 | $7/2^-$ | 33.730 | $10.5591 \pm 1.$ | $(7/2^-)$ | $42.5 \pm 1.1$ |
| 52 | 7.0427 | 5.7666 | 10.767 | $3/2^+$ | 152.06 | $10.777 \pm 3$ | $1/2^+$,$7/2^-$ | $74 \pm 3$ |

# ENDF/B history

## *6.8, 7.1, 8.0*

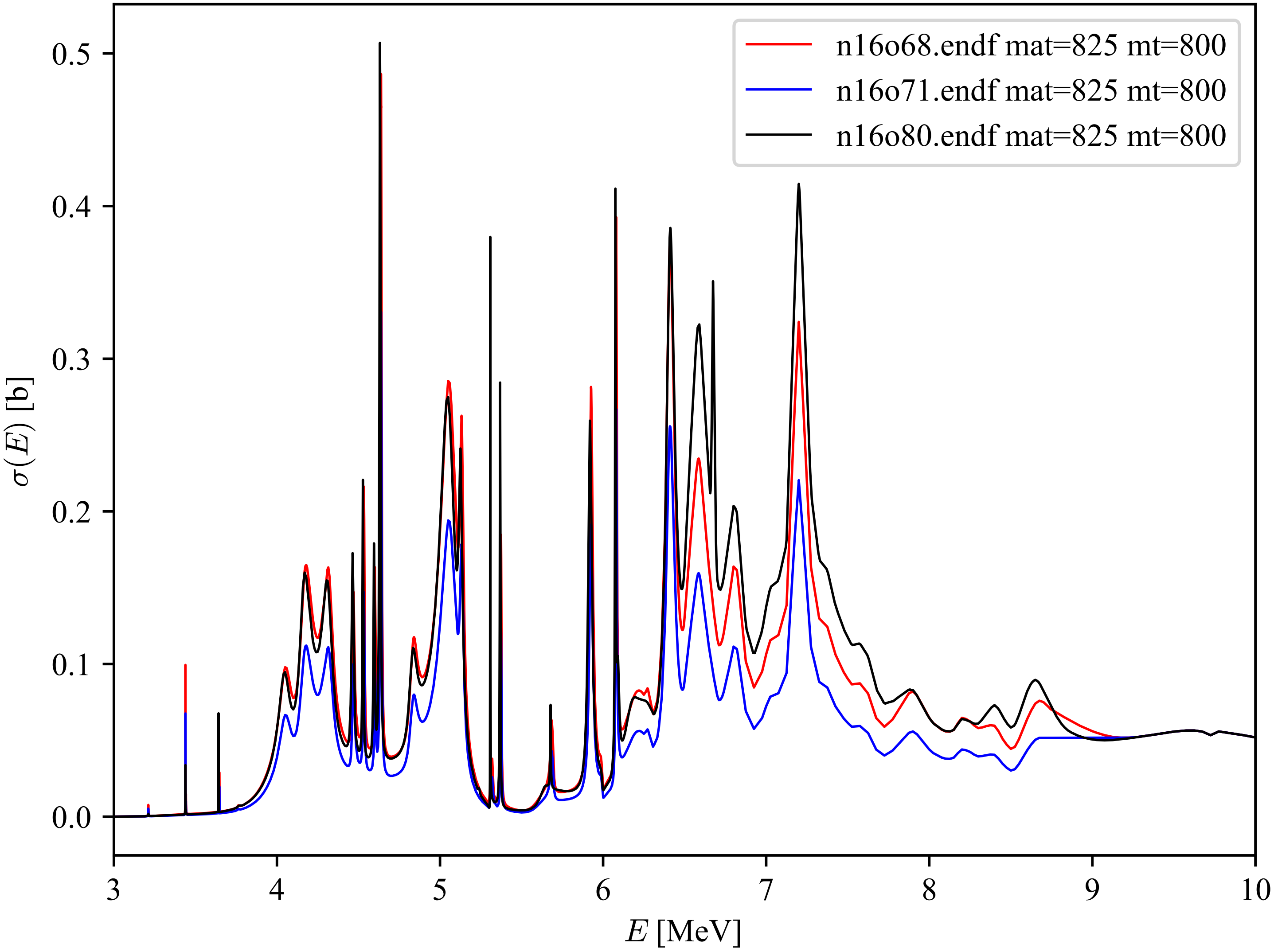
- ENDF/B-VI.8 (2001 April): LANL(Chadwick, Hale, Young), KAPL(Caro, Lubitz)
  - Below 3.4 MeV*: R-*function* + optical model (OPTIC code; Caro)
  - $3.4 < E_n < 6.25$ MeV: LANL R-matrix (multichannel; EDA)
    - Data: n+$^{16}$O (total) [Johnson75, Larson80], $^{16}$O(n,el) ang.[Lane60,…], $^{16}$O(n,$\alpha_0$) [inverse Walton et al.], $^{13}$C($\alpha$,n), $^{13}$C($\alpha$,el) excit. fn
  - $E_n > 6.25$
    - 6.25 → 20: subtraction of non-elastic (MT=3) from total
    - Inelastic (MT51, …, 57)
      - $^{16}$O(n,x$\gamma$) Nelson, Chadwick, Michaudon & Young NSE99
  - MT800: Bair&Haas73 without renormalization
    - 6.2→20: factor of 1.5 "bring into rough agreement" (n,$\alpha_0$) of Davis '63
  - MT801-803: inferred from (n,$\alpha\gamma$) [Nelson99]
- ENDF/B-VII.1 (2005 Dec.): VI.8+Page+Kawano+Young
  - MT=800: 32% reduction (n,$\alpha_0$) 2.4→8.9 MeV
    - "assuming Harissopulos05 are definitive"; "Ha05 is 100% correct, BH73 100% wrong norm"
- ENDF/B-VIII.0 (2016 Dec.): VII.1+Hale+Kawano+MWP
  - Re-evaluation of Ha05 by Giorginis et al. (CIELO)
- JENDL-4.0 (2010)
  - $^{16}$O(n,$\alpha_{tot}$) < 6.5 MeV ~ ENDF/B-VII.0

*all incident neutron lab energies [MeV]

# ENDF/B comparisons $^{16}O(n,\alpha_0)^{13}C$ [MT=800]

***6.8, 7.1, 8.0***

- Three regions
  - I. < 5.2 MeV
  - II. 5.2 → 6 MeV
  - III. > 6 MeV
- Trends
  - I. 7.1 < 6.8/8.0
  - II.~Equivalent
  - III.7.1 < 6.8 < 8.0



# $^{17}$O Preliminary evaluation

## *Preliminary results*

- Configuration: channels, R-matrix parameters
- Observed data in `data` deck
  - Channels: $(n,n_0)$, $(n,n_2)$, $(\alpha,n_0)$, $(\alpha,n_1)$, $(\alpha,n)$
  - Types: total, integrated, differential, *polarization* $[A_y, P_n]$

| Channel | $a_c$(fm) | $\ell_{\max}$ |
|---|---|---|
| $n+^{16}$O($0^+$;gs) | 4.40 | 4 |
| $\alpha+^{13}$C($\frac{1}{2}^-$; gs) | 5.40 | 5 |
| $n_1+^{16}$O($0^+$; 6.05 MeV) | 5.00 | 3 |
| $n_2+^{16}$O($3^-$; 6.13 MeV) | 5.00 | 2 |

| Reaction | Range $E_n$, $E_\alpha$ (MeV) | $N_{\text{dat}}$ | Observables |
|---|---|---|---|
| $^{16}$O$(n,n)^{16}$O | (0.0, 7.0) | 2,909 | $\sigma_{\text{tot}}, \sigma, \sigma(\theta), A_y(\theta)$ |
| $^{16}$O$(n,n_2)^{16}$O($3^-$; 6.13 MeV) | (6.6, 8.8) | 45 | $\sigma(\theta)$ |
| $^{13}$C$(\alpha,\alpha)^{13}$C | (2.0, 5.7) | 1,397 | $\sigma(\theta)$ |
| $^{13}$C$(\alpha,n)^{16}$O | (.23, 8.0) | 1,054 | $\sigma_r$ |
| $^{13}$C$(\alpha,n_0)^{16}$O($0^+$; gs ) | (1.0, 6.5) | 3,116 | $\sigma, \sigma(\theta)$ |
| $^{13}$C$(\alpha,n_1)^{16}$O($0^+$; 6.05 MeV) | (5.1, 5.6) | 113 | $\sigma, \sigma(\theta)$ |
| Total | | 8,634 | 5 types |

**17O system channel/pars**

- # channels: 45
  - $J^\pi=1/2^\pm, \ldots, 11/2^\pm$
- # parameters
  - $E_\lambda$: 81 level energies
  - $\gamma_{\lambda,c}$: 322 reduced widths
- # Normalizations
  - $n_M$: 95 norm scales
  - $\Delta E_M$: 4 shift factors

- New data
  - Ciani *et al.* (2021) $(\alpha,n_0)$
  - Brandenburg & Meisel (2021) $(\alpha,n)$
  - Febbraro, DeBoer *et al.* (2020) $(\alpha,n_0)$, $(\alpha,n_1)$

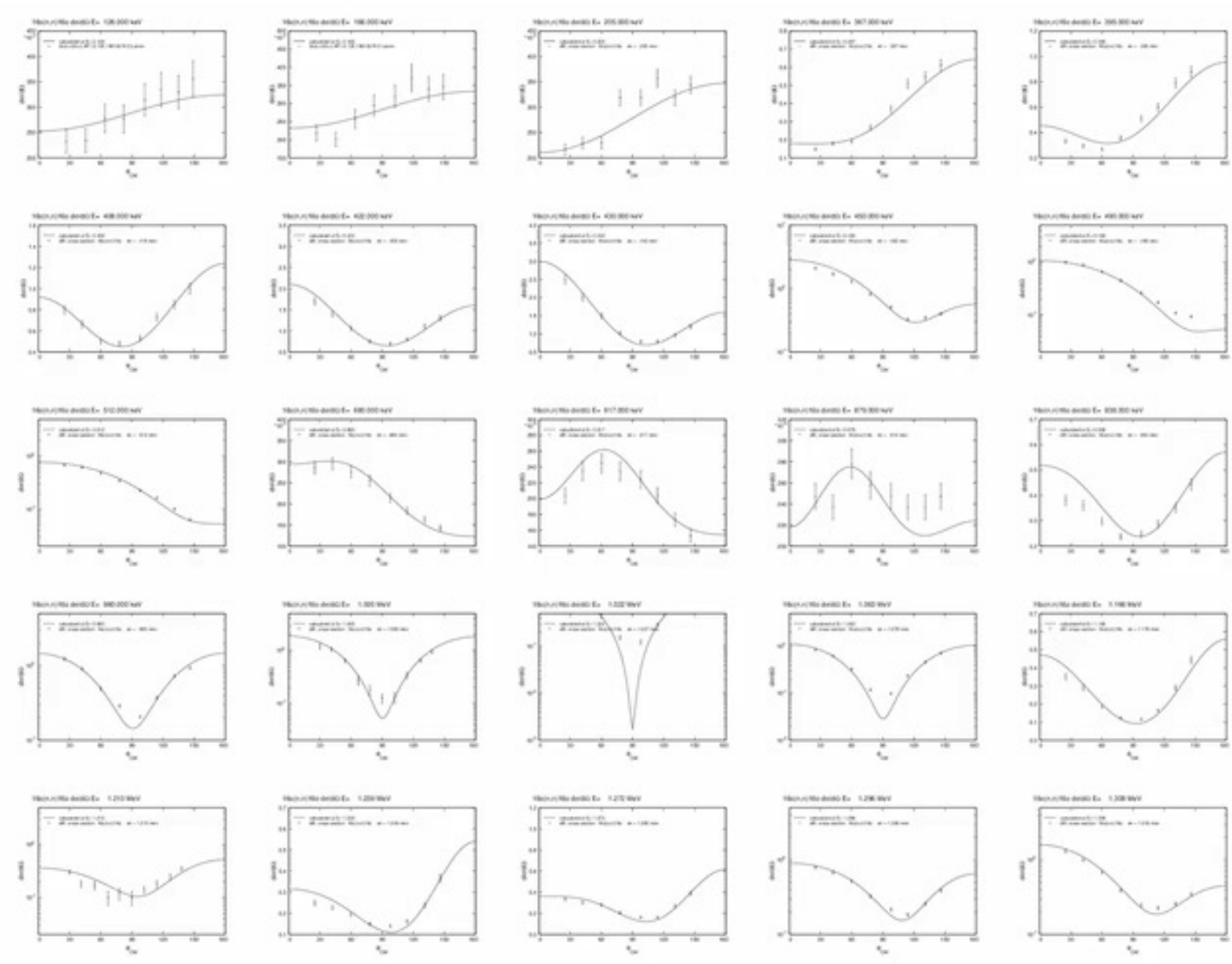
# $^{17}O$ Preliminary evaluation

## *Normalizations*

| index | epower | ident | weight | exp norm | normalization | | chi-square |
|---|---|---|---|---|---|---|---|
| 480 | 0.0 | | 0.0000E+00 | 1.000 | 0.10000000E+01f | fx | 0.00000000 |
| 481 | 0.0 | droteng | 0.0000E+00 | 1.000 | 0.99713533E+00f | fx | 0.00000000 |
| 482 | 0.0 | Walt57en | 0.0000E+00 | 1.000 | 0.99071799E+00f | fx | 0.00000000 |
| 483 | 0.5 | B&Heng | 0.0000E+00 | 1.000 | 0.99523830E+00f | fx | 0.00000000 |
| 484 | | | 0.0000E+00 | 1.000 | 0.10000000E+01f | fx | 0.00000000 |
| 485 | | txs0 | 0.0000E+00 | 1.000 | 0.97076952E+00f | fx | 0.00000000 |
| 486 | | RDA1.260 | 0.0000E+00 | 1.000 | 0.11668606E+01f | fx | 0.00000000 |
| 487 | | RDA1.660 | 0.0000E+00 | 1.000 | 0.84211924E+00f | fx | 0.00000000 |
| 488 | | n1xs | 1.1111E+01 | 1.000 | 0.78497423E+00f | fx | 0.51373424 |
| 489 | | n2xs | 0.0000E+00 | 1.000 | 0.98117188E+00f | fx | 0.00000000 |
| 490 | | n3xs | 0.0000E+00 | 1.000 | 0.97082431E+00f | fx | 0.00000000 |
| 491 | | n4xs | 0.0000E+00 | 1.000 | 0.92638971E+00f | fx | 0.00000000 |
| 492 | | txs1 | 0.0000E+00 | 1.000 | 0.10723449E+01f | fx | 0.00000000 |
| 493 | | hun2.34 | 0.0000E+00 | 1.000 | 0.12868156E+01f | fx | 0.00000000 |
| 494 | | drigxs | 0.0000E+00 | 1.000 | 0.10115165E+01f | fx | 0.00000000 |
| 495 | | phi6.0 | 0.0000E+00 | 1.000 | 0.10707884E+01f | fx | 0.00000000 |
| 496 | | kin6.0 | 0.0000E+00 | 1.000 | 0.10487797E+01f | fx | 0.00000000 |
| 497 | | cha6.0 | 0.0000E+00 | 1.000 | 0.11072945E+01f | fx | 0.00000000 |
| 498 | | boerker | 0.0000E+00 | 1.000 | 0.72644225E+00f | fx | 0.00000000 |
| 499 | | kin6.4 | 0.0000E+00 | 1.000 | 0.11005954E+01f | fx | 0.00000000 |
| 500 | | cha6.5 | 0.0000E+00 | 1.000 | 0.11632047E+01f | fx | 0.00000000 |
| 501 | | phi7.0 | 0.0000E+00 | 1.000 | 0.13307655E+01f | fx | 0.00000000 |
| 502 | | kin7.0 | 0.0000E+00 | 1.000 | 0.12513925E+01f | fx | 0.00000000 |
| 503 | | ohkubo | 0.0000E+00 | 1.000 | 0.97473205E+00f | fx | 0.00000000 |
| 504 | | johnson | 0.0000E+00 | 1.000 | 0.99929878E+00f | fx | 0.00000000 |
| 505 | | txs2 | 0.0000E+00 | 1.000 | 0.10151521E+01f | fx | 0.00000000 |
| 506 | | cierjack | 2.5000E+03 | 1.000 | 0.97067022E+00f | fx | 2.15058999 |
| 507 | | nel99n2x | 0.0000E+00 | 1.000 | 0.17721340E+00f | fx | 0.00000000 |
| 508 | | luna2021 | 0.0000E+00 | 1.000 | 0.80145634E+02f | fx | 0.00000000 |
| 509 | | drotleff | 1.0000E+02 | 1.000 | 0.84350979E+00f | fx | 2.44891858 |
| 510 | | heilan | 0.0000E+00 | 1.000 | 0.77664452E+00f | fx | 0.00000000 |
| 511 | | kellogg | 1.0000E+01 | 0.855 | 0.52194563E+00f | fx | 1.10925213 |

# $^{17}$O Preliminary evaluation scope

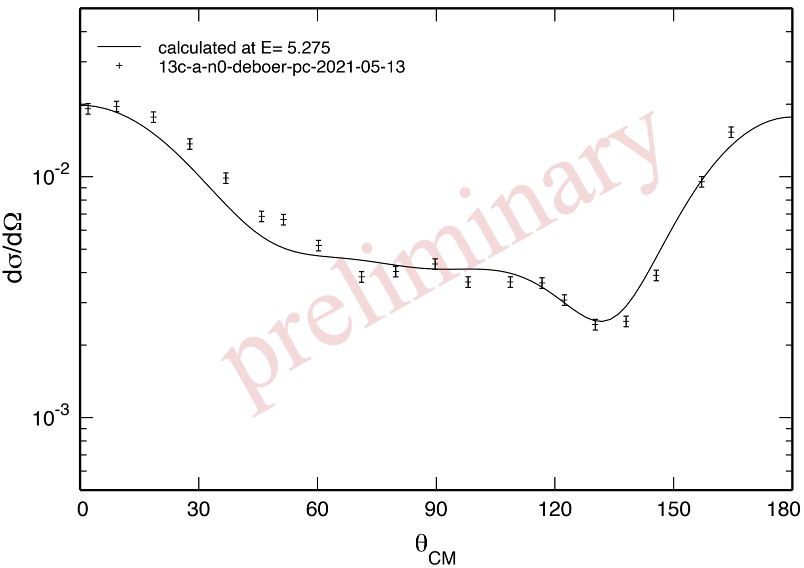
## *Preliminary results*



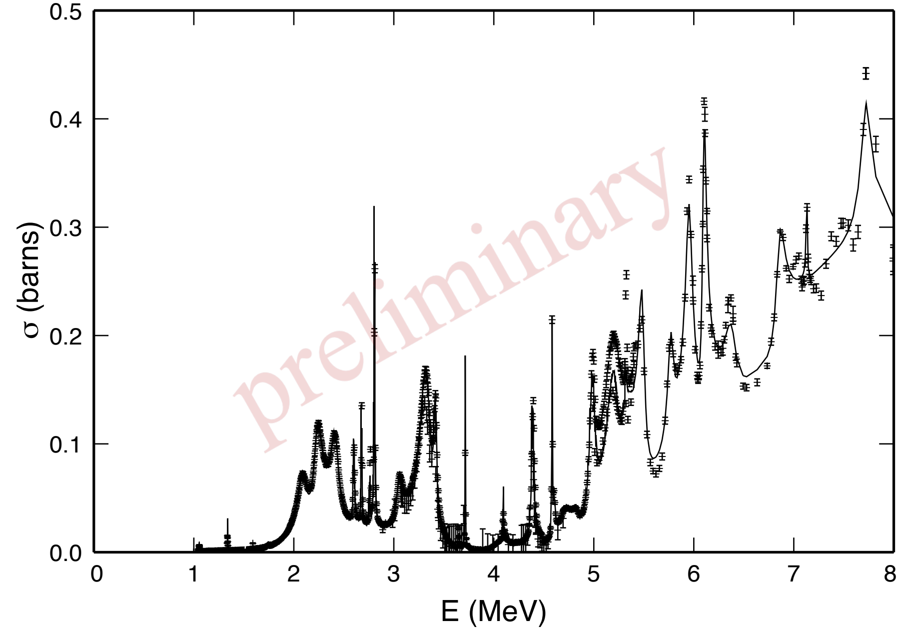
# $^{17}$O Preliminary evaluation

## *Preliminary results: ($\alpha$,$n_0$)*

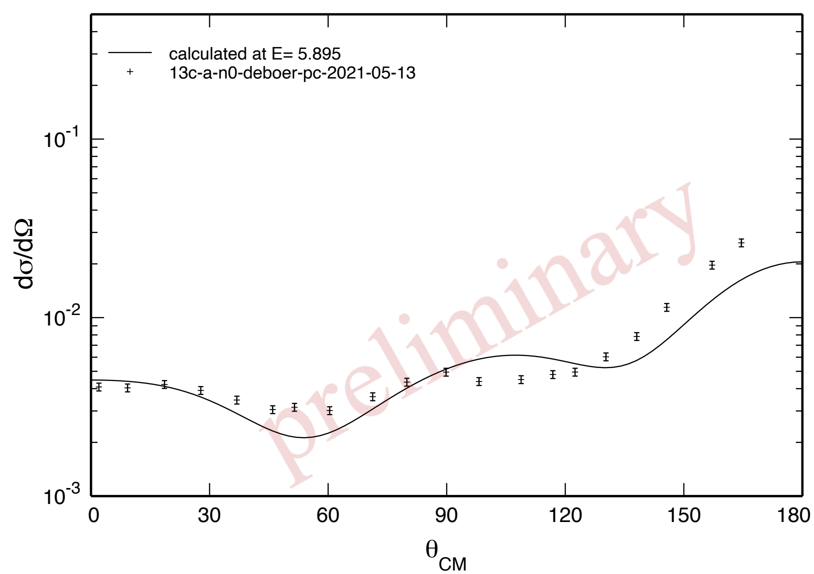
13c(4he,n)16o dσ/dΩ E= 5.275 MeV



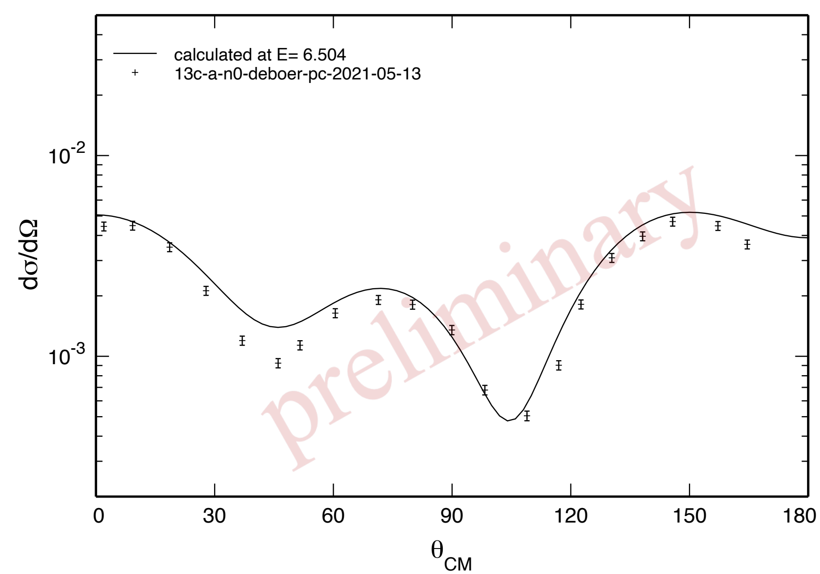

13c + 4he reaction




13c(4he,n)16o dσ/dΩ E= 5.895 MeV

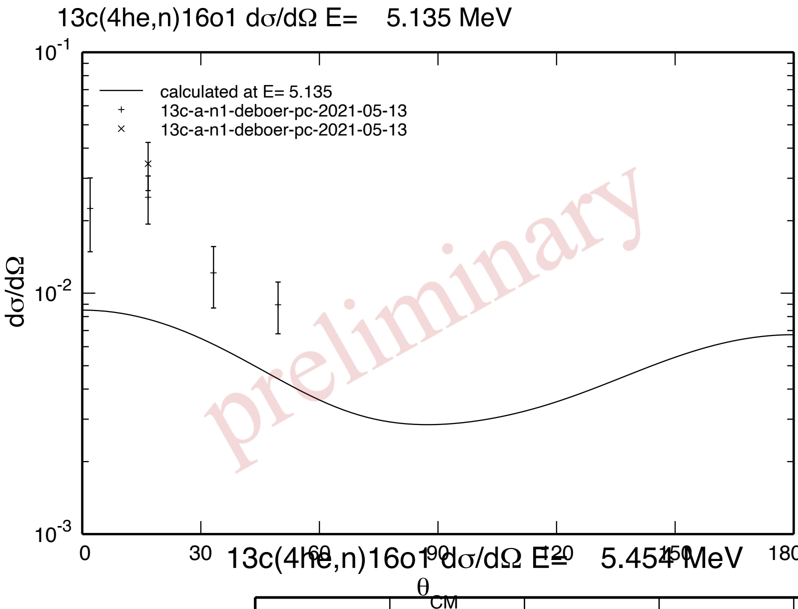


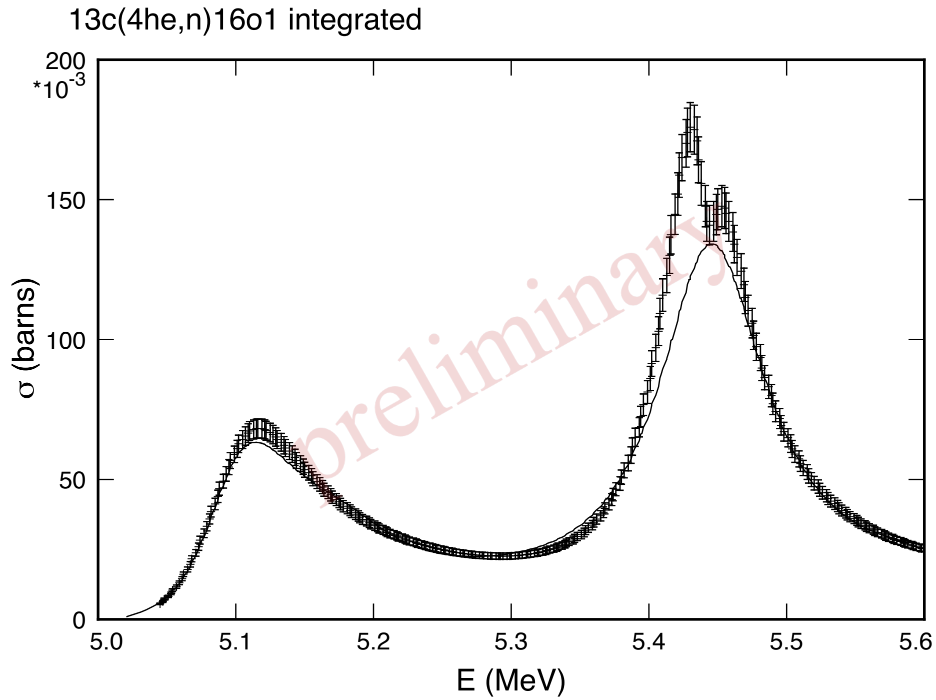

13c(4he,n)16o dσ/dΩ E= 6.504 MeV

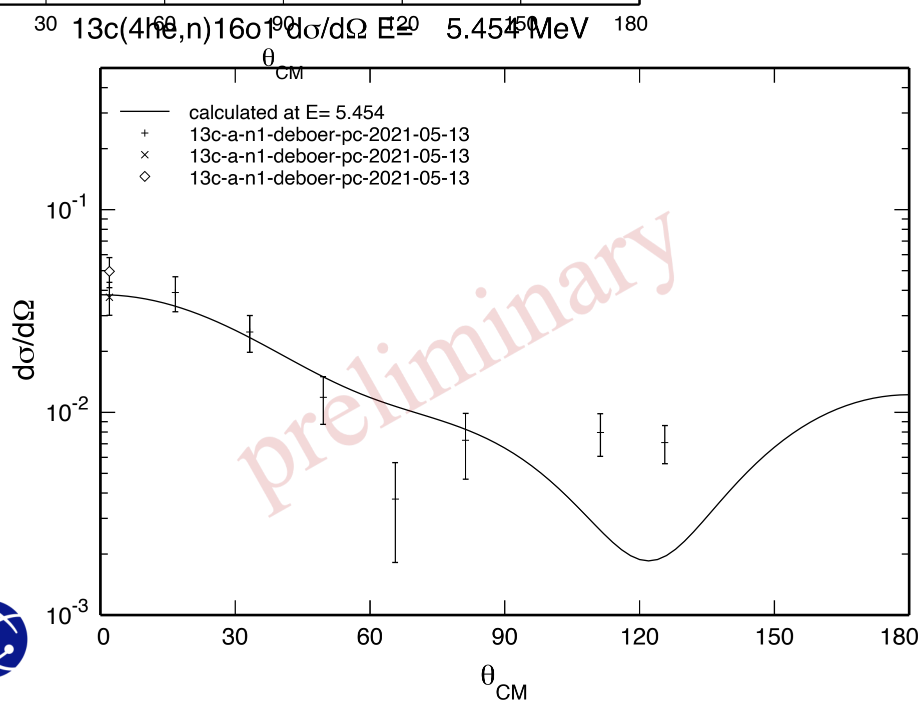


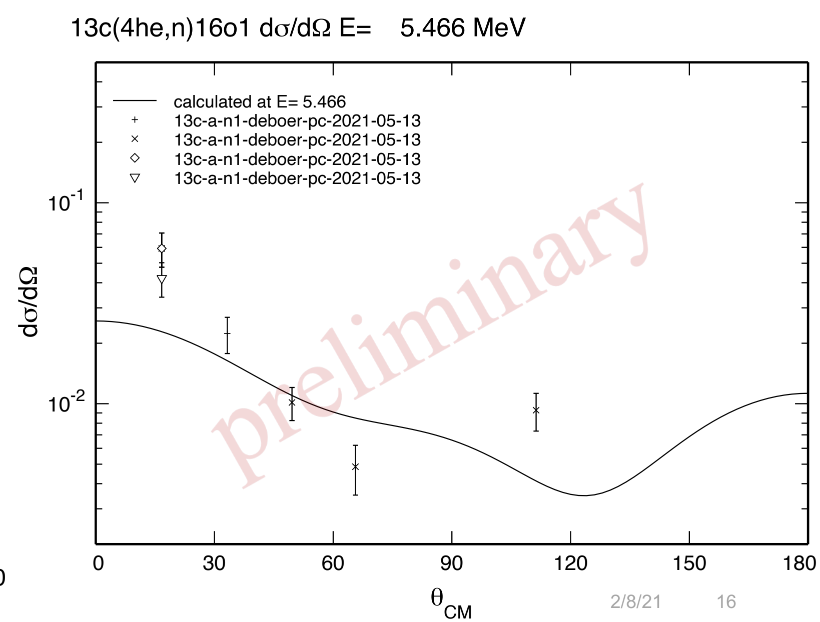
# $^{17}O$ Preliminary evaluation

## *Preliminary results: (α,$n_1$)*



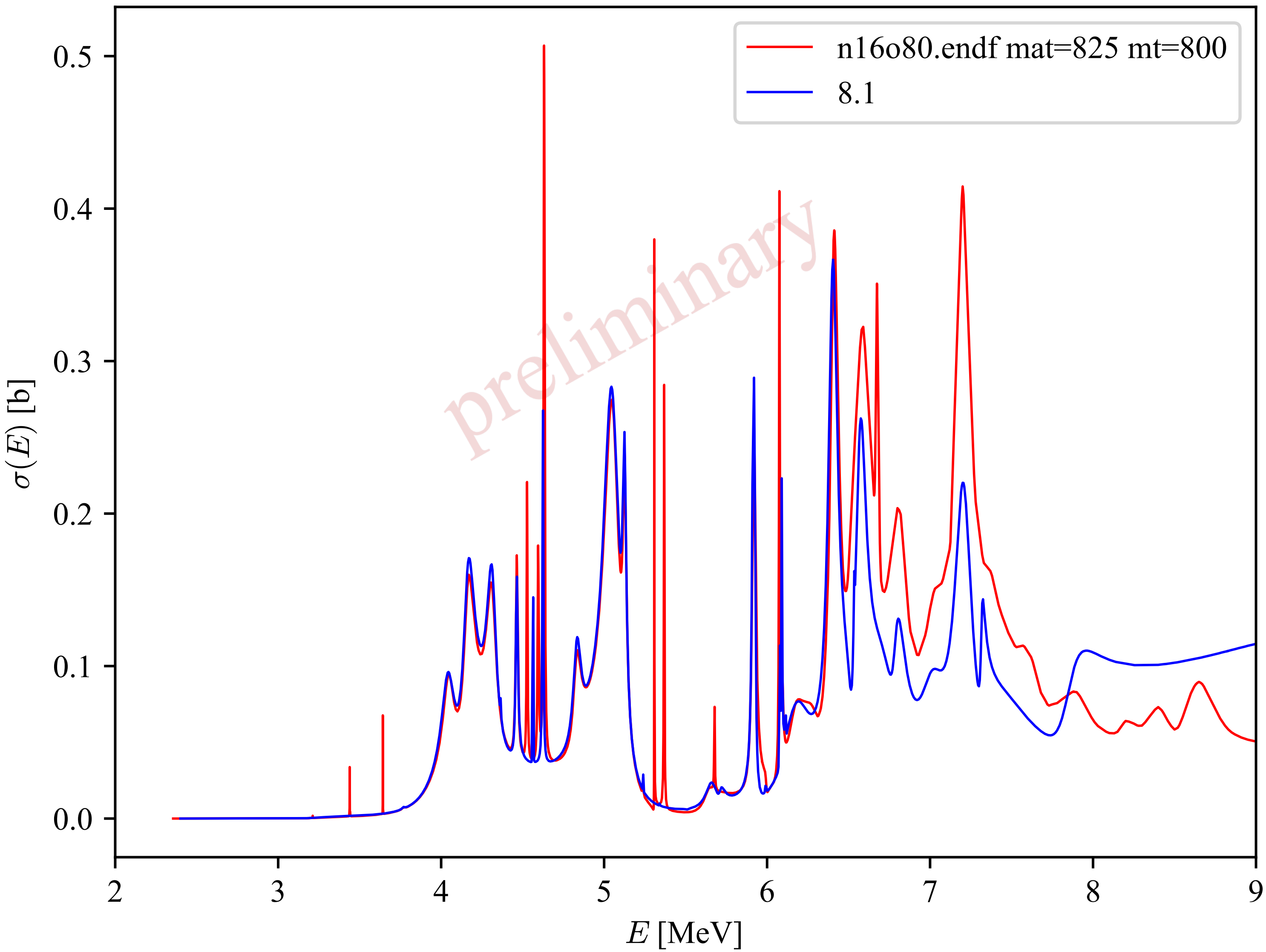



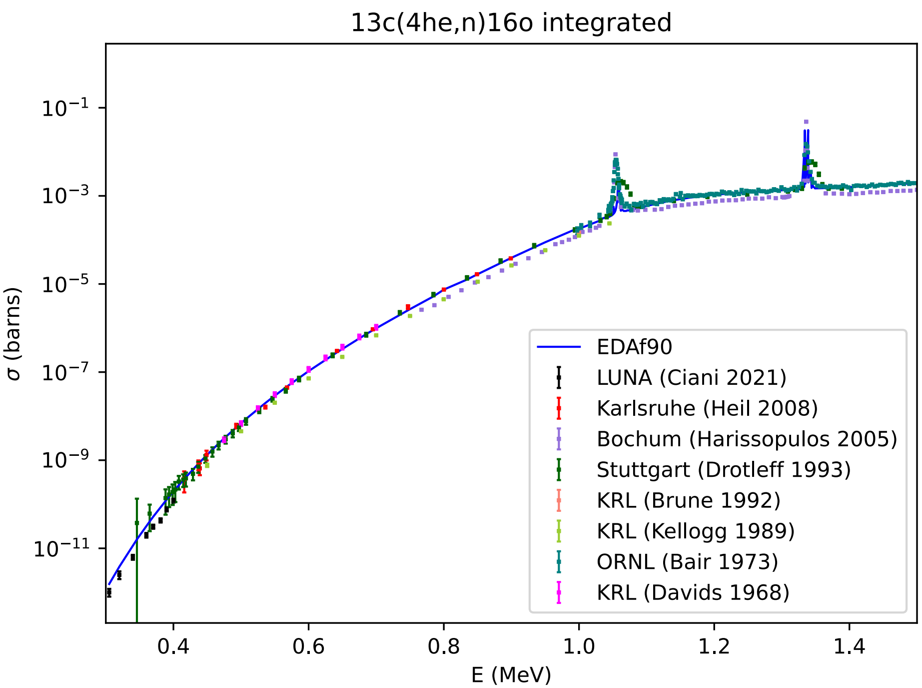
# ENDF/B-VIII.0 $^{16}O(n,\alpha_0)^{13}C$ [MT=800]

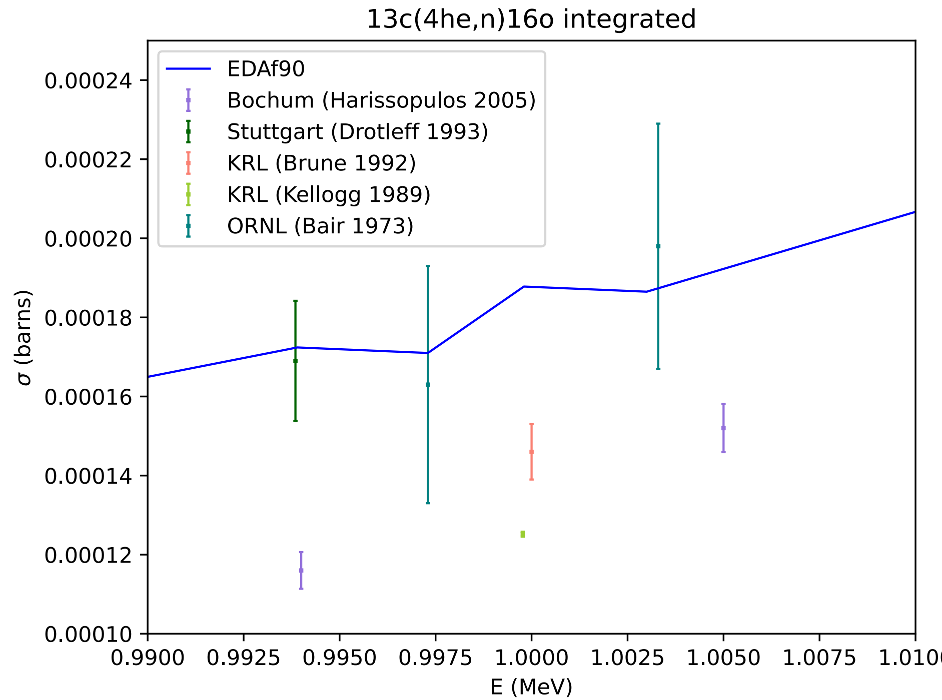
***Comparison with New Evaluation "8.1"***



# $^{17}$O Preliminary evaluation

## *Preliminary results: low energy*



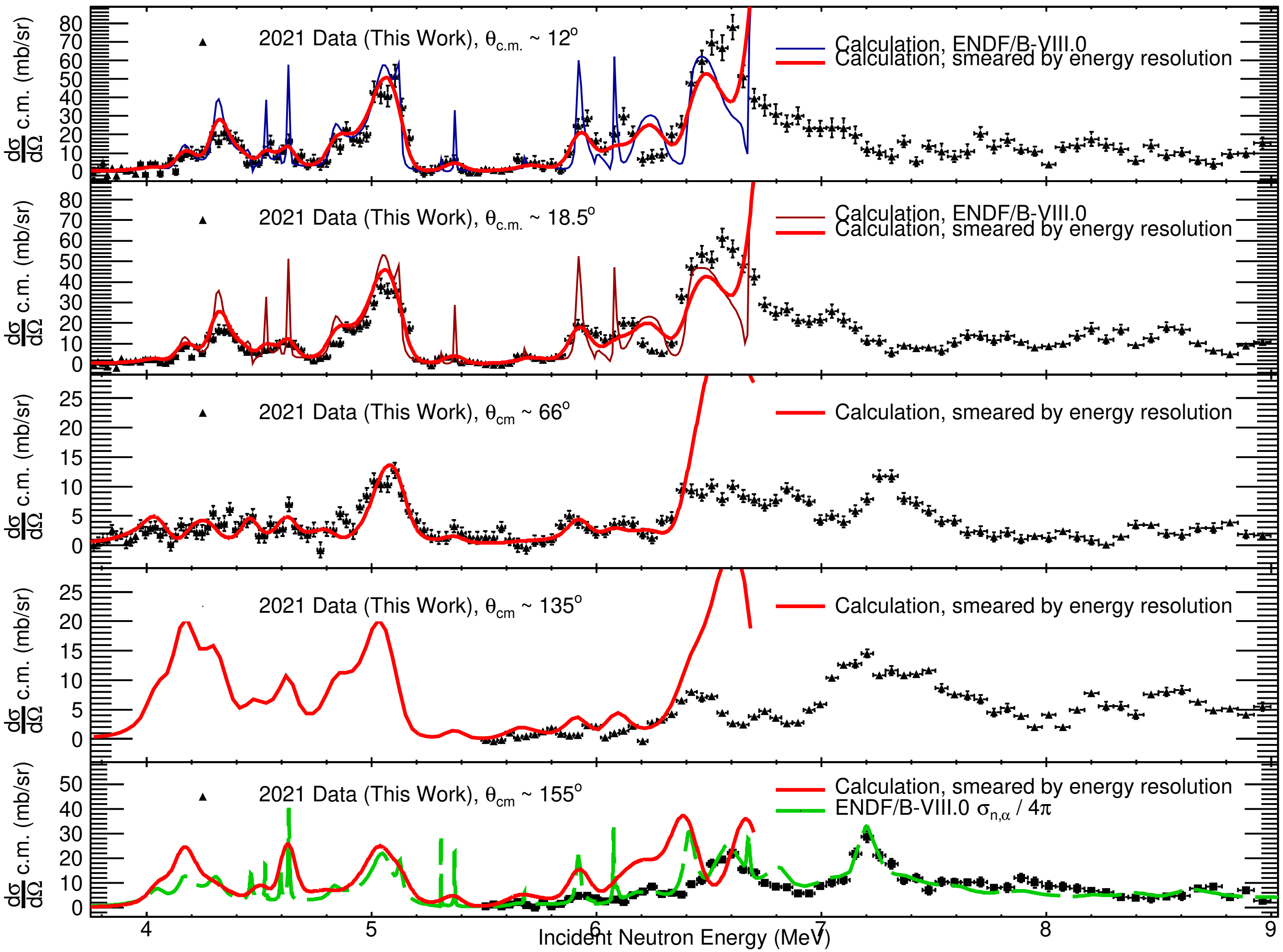

| Experiment | $E_\alpha$ [MeV] | $\sigma_{(\alpha,n)}$ [$\mu$b] | 1.000 MeV |
|---|---|---|---|
| KRL (Brune 1992) | 1.0000 | 146(7) | 146(7) |
| ORNL (Bair 1973) | 1.0033 | 198(3) | 179(4) |
| Stuttgart (Drotleff 1993) | 0.9939 | 169(2) | 187(3) |
| Bochum (Harissopulos 2005) | 0.994 | 116(5) | 136(7) |
| Bochum (Harissopulos 2005) | 1.005 | 152(6) | – |
| KRL (Kellogg 1989) | 0.9998 | 125(6) | 126(8) |

Measurements of $\sigma_{(\alpha,n)}(E_\alpha = 1.0$ MeV$)$ for laboratory incident energies given in the first column, the value quoted in the second column, and the values linearly interpolated from the tabular data in the experiment's publication in the right-most column. No re-normalization factors have been applied to these values. In particular, the ORNL value of Bair & Haas[37]is quoted as originally presented without the 0.8 factor mentioned in their *Note added in proof*.

# Comparison LENZ(2017) data vs. ENDF/B-VIII.0

## $^{16}O(n,\alpha_0)^{13}C$ excitation functions

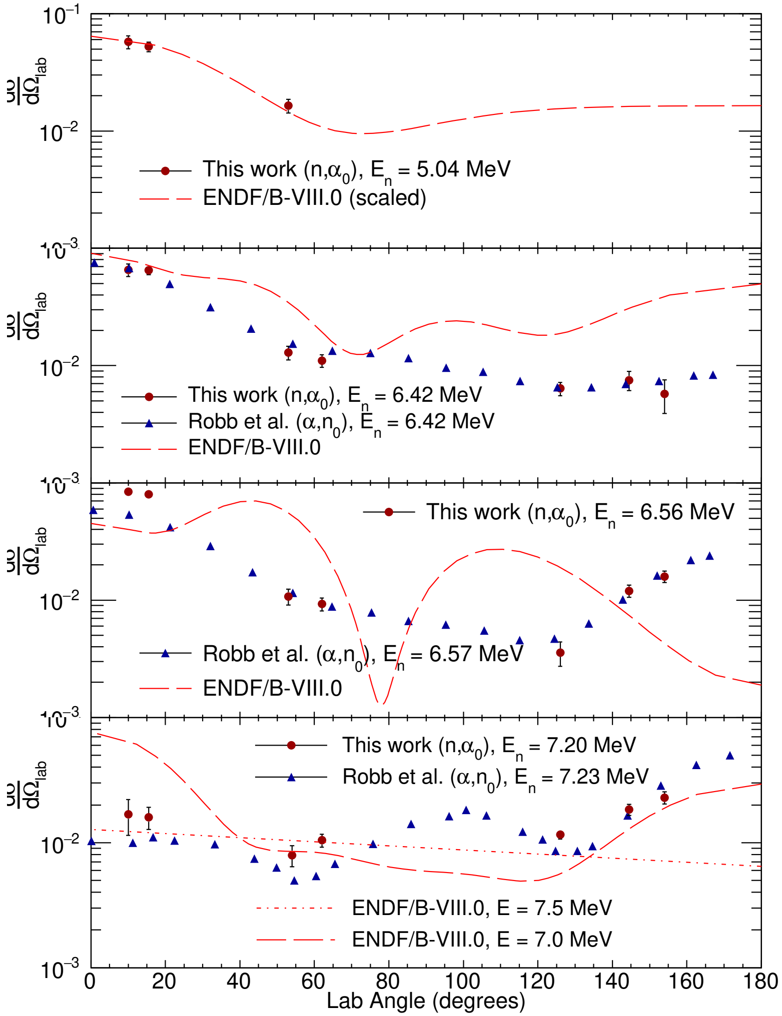
## *S. Kuvin & H.Y. Lee (LANL)*

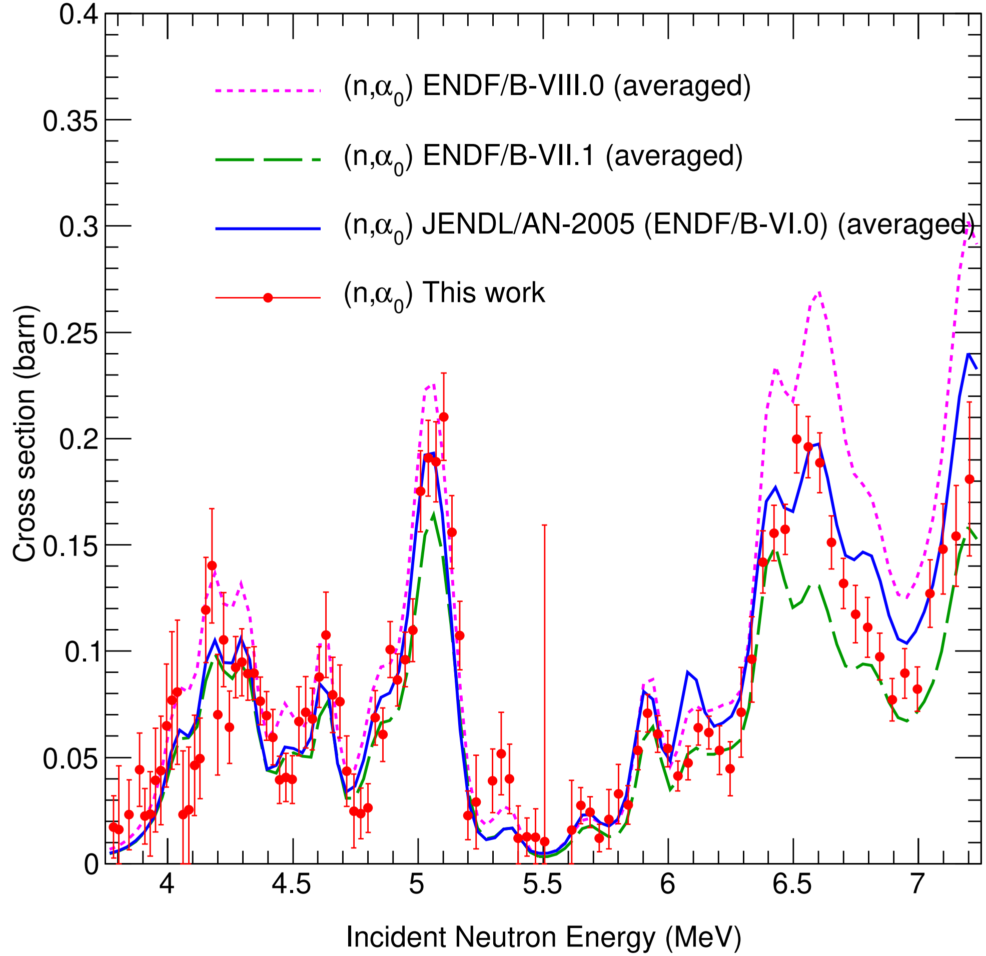


# Comparison LENZ(2017) data vs. ENDF/B-VIII.0

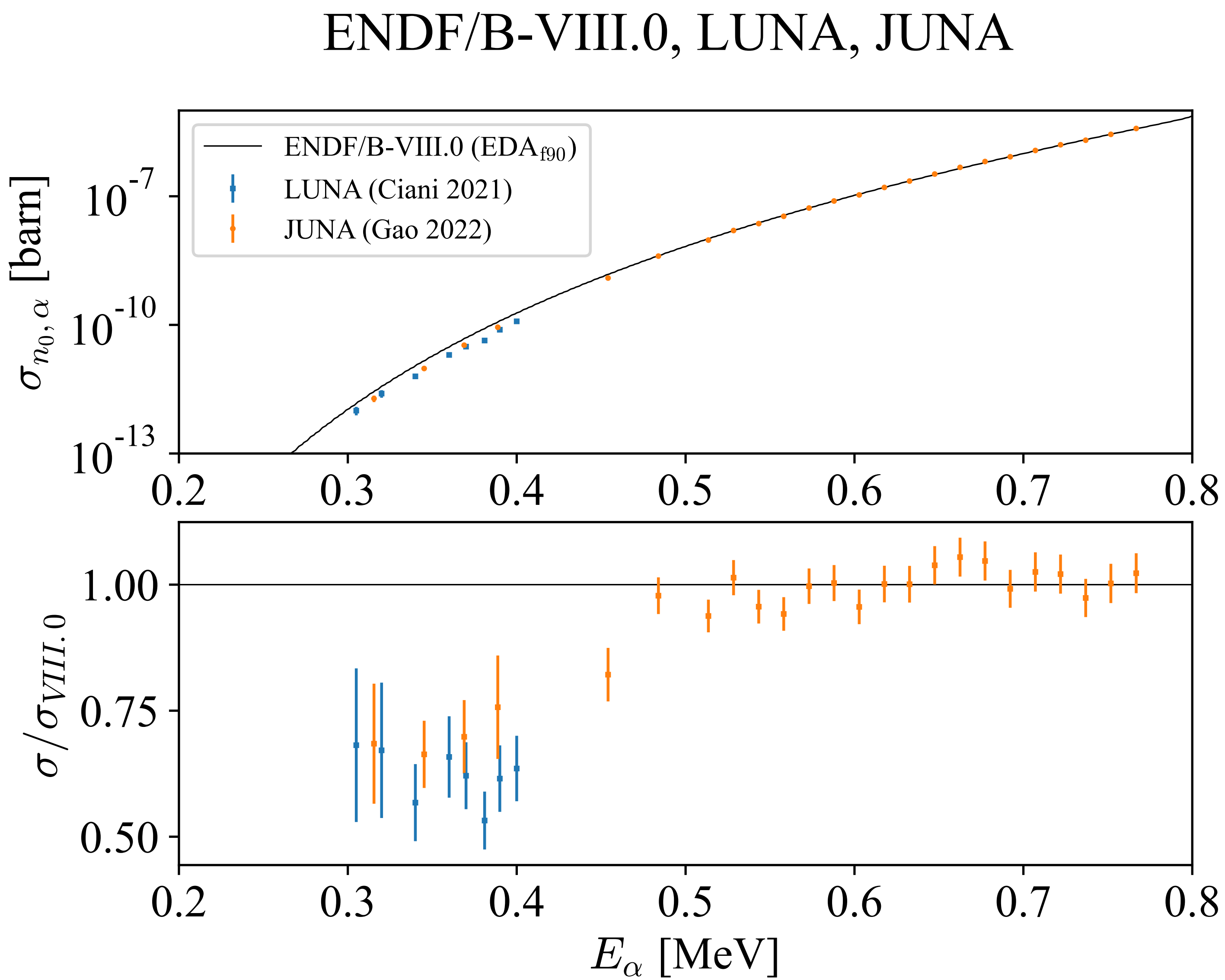
## $^{16}O(n,\alpha_0)^{13}C$ excitation functions

### *S. Kuvin & H.Y. Lee (LANL)*



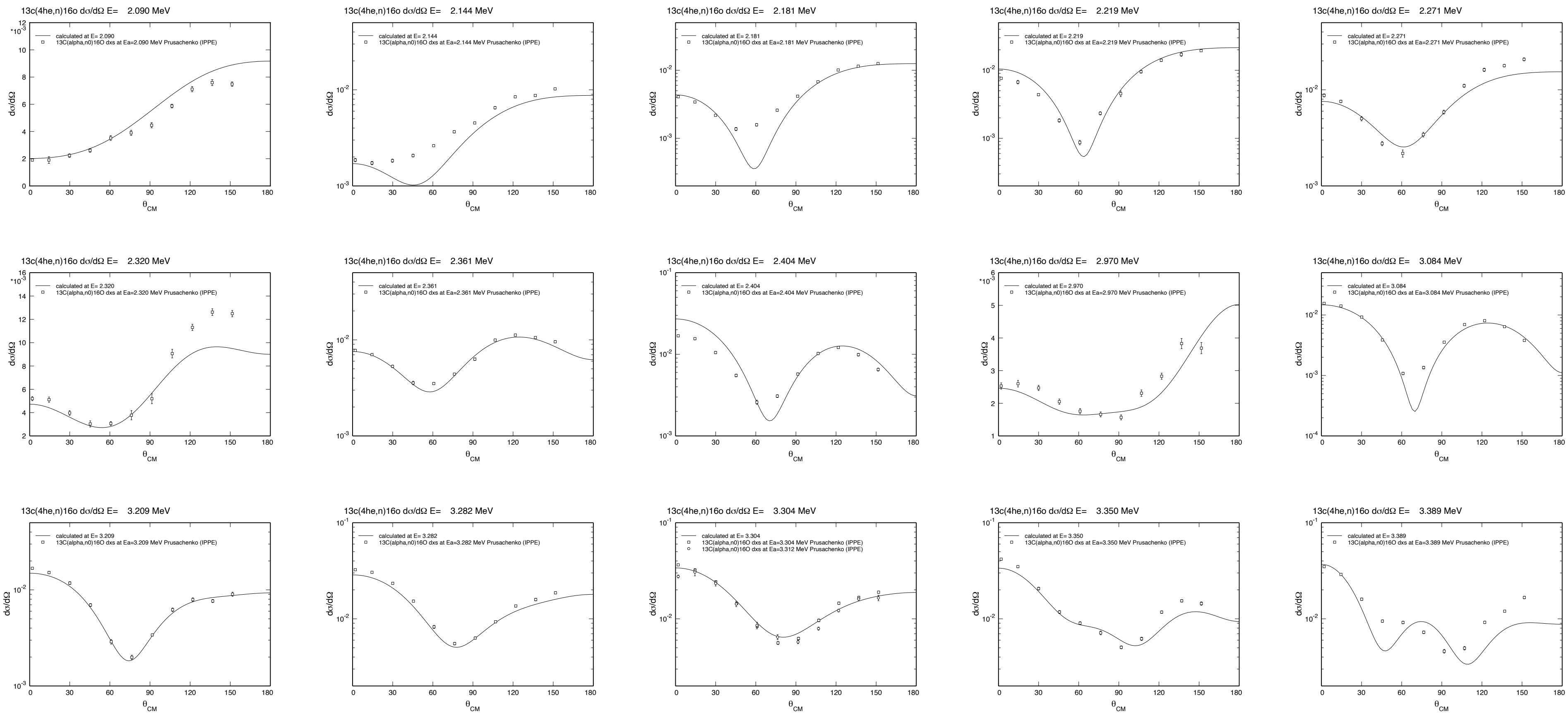
# ENDF/B-VIII.0
## *vs. new data*




- Data from JUNA collaboration, courtesy of James deBoer

# $^{13}C(\alpha,n_0)^{16}O$ Angular distributions

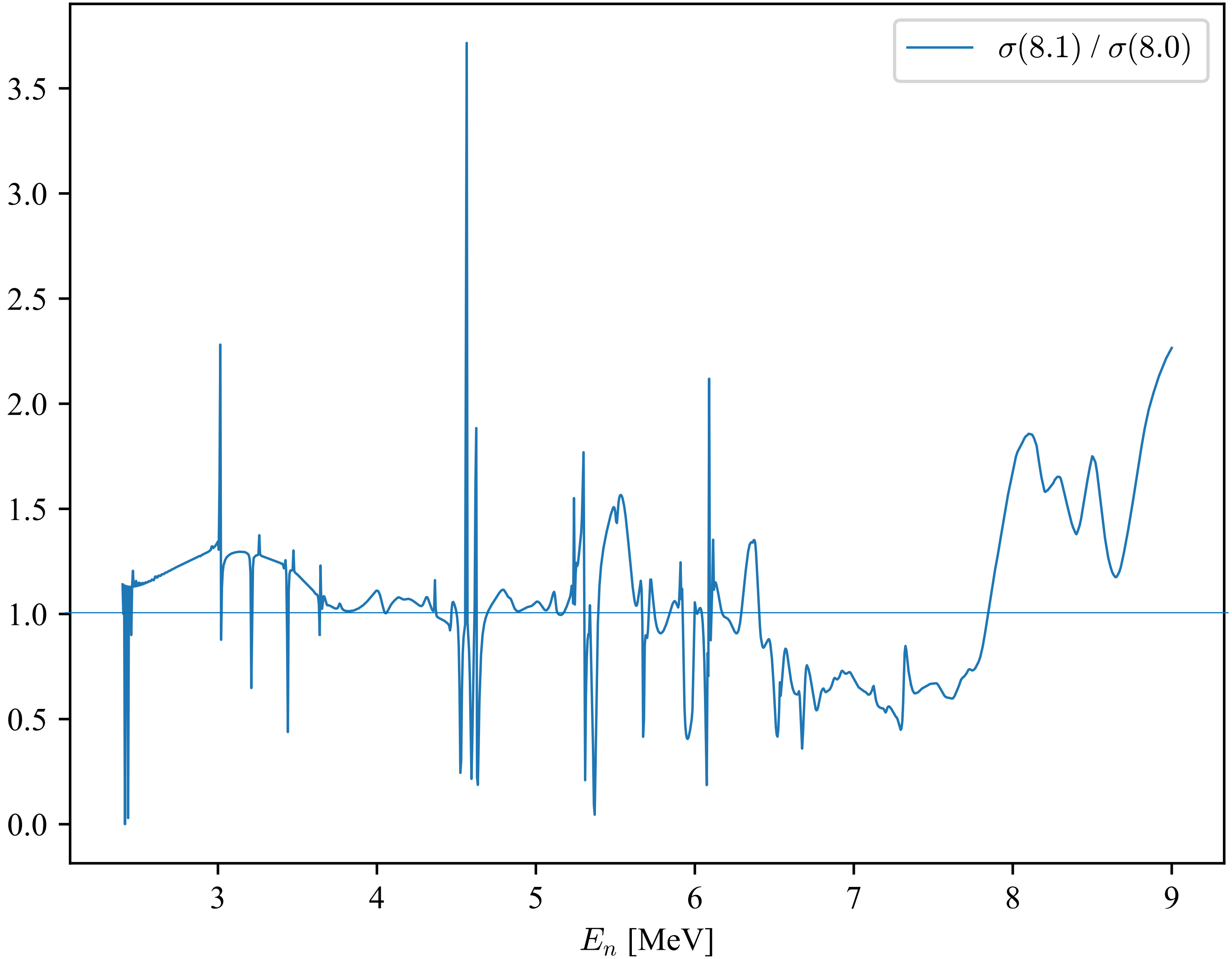
*IPPE Prusachenko et al. PRC105, 024612 (2022)*



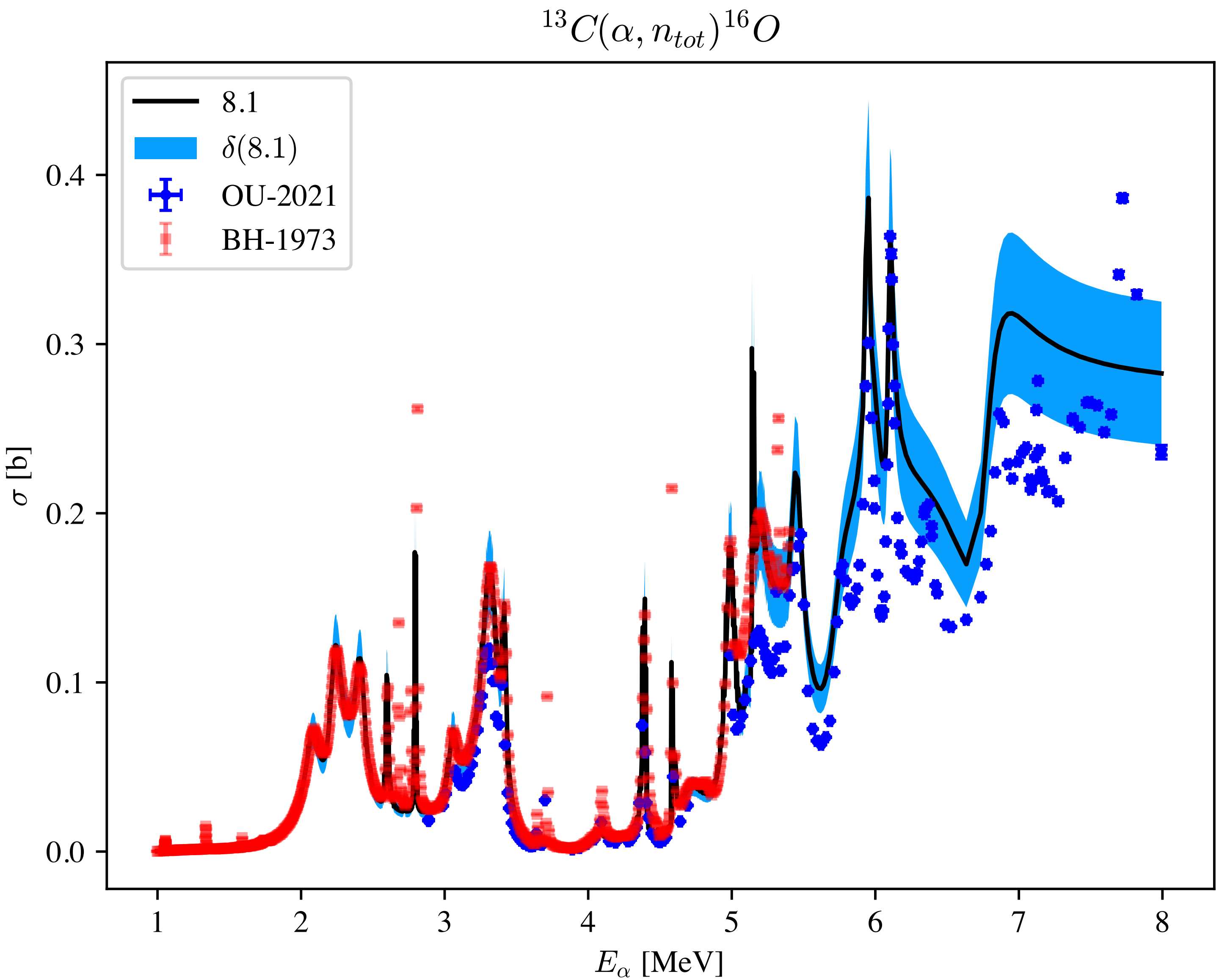

- Energies measured: 2.1 MeV < $E_\alpha$ < 6.2 MeV
- Energies shown here: 2.1 MeV < $E_\alpha$ < 3.4 MeV
- ENDF/B-VIII.0 was fit with data from Roddy Walton
  - reversed from $(\alpha,n_0)$ to $(n,\alpha_0)$ by Graham Foster

# ENDF/B-VIII.0 $^{16}$O(n,$\alpha_0$)$^{13}$C [MT=800]

***Ratio of New Evaluation to ENDF/B-VIII.0***



# Preliminary new evaluation with *fit errors* vs. OU(2021) & Bair & Haas(1973)



# Outlook

- n+$^{16}$O
  - Complete the evaluation to $E_n$ ~ 9 MeV (optimistically to 10 MeV)
    - add missing data
    - Investigate normalization of the $(n,n_{tot})$ Cierjacks' '68 & '83 datasets
  - $^{13}C(\alpha,n_0)^{16}O$ is currently too high everywhere
    - Note that $(n,n_{tot})$ and $(n,\alpha_x)$ are tightly correlated by unitarity
  - Perform a complete normalization/covariance study