IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Report on INDEN-LE meeting (29 Aug – 1 Sep 2023)

Vivian Dimitriou
Nuclear Data Section
International Atomic Energy Agency

International Nuclear Data Evaluation for Light Elements

- Neutron-induced reactions on ^{9}Be, ^{16}O, ^{14,15}N, ^{23}Na, for fission reactor applications
- Charged-particle induced reactions for nonproliferation, nuclear astrophysics, low-background measurements, and ion-beam analytical applications
- Zhenpeng Chen (Tsinghua U), James deBoer (Notre Dame), Vivian Dimitriou (IAEA), Gerry Hale (LANL), Helmut Leeb (TUW), Satoshi Kunieda (JAEA), Mark Paris (LANL), Marco Pigni (ORNL), Pierre Tamagno (CEA Cadarache), Ian Thompson (LLNL), Thomas Srdinko (TUW), Goran Arbanas (ORNL), Carl Brune (Ohio U), Stefan Kopecky (JRC-Geel)

Meeting 29 Aug – 1 Sep 2023

- n+^{16}O : improved evaluation, new (n,alpha) measurements (Chen, Cong)
- n+^{14}N: status of evaluation, new measurements (Hale, deBoer, Chen, Cong)
- n+^{9}Be: status of evaluation (Leeb, Srdinko)
- ^{7}Be: status of evaluations (^{3}He+^{4}He; p+^{6}Li) (Thompson, Paris, Pigni, deBoer)
- ^{13}C(alpha,n): experimental data (deBoer)
- ^{19}F(alpha,n): status of evaluation (Dimitriou)
- p+^{9}Be for compact neutron sources (Yoshie Otake)

Meeting website: https://conferences.iaea.org/event/364

(n,alpha) measurements

- New measurements of

$^{14}N(n, \alpha_{0,1})^{11}B$ and $^{16}O(n, \alpha_0)^{13}C$

Gas targets:

$^{14}N(n, \alpha_{0,1})^{11}B$: 4.53 - 5.51 MeV and 7.09 - 11.48 MeV

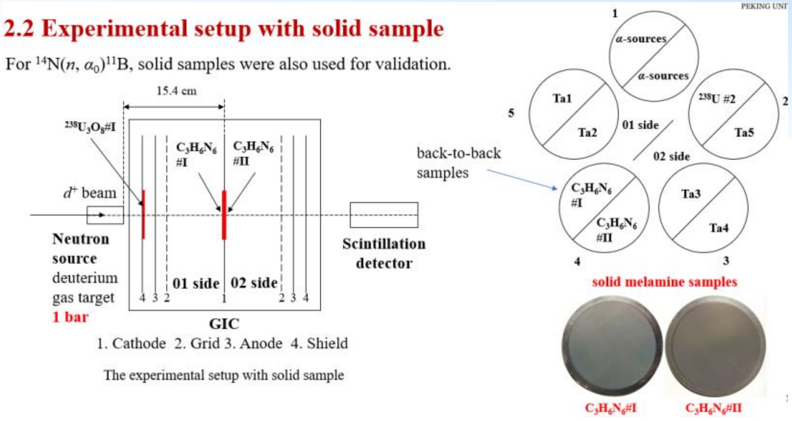
$^{16}O(n, \alpha_0)^{13}C$: 6.89 - 11.67 MeV

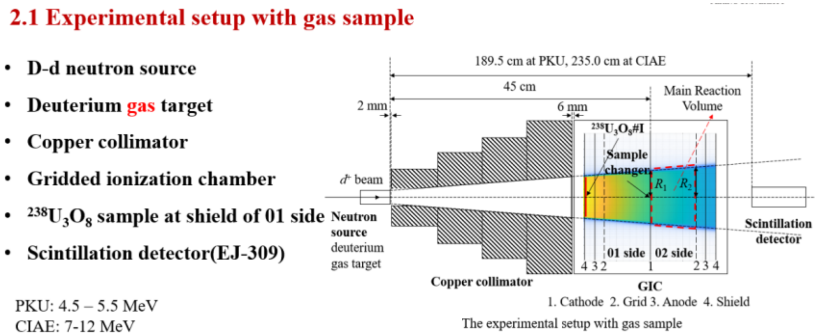
Solid targets: solid melamine ($C_3H_6N_6$)

$^{14}N(n, \alpha_0)^{11}B$: 4.59, 4.89 and 5.06 MeV

Peiking Univ: 4.5 – 5.5 MeV
CIAE: 7-12 MeV

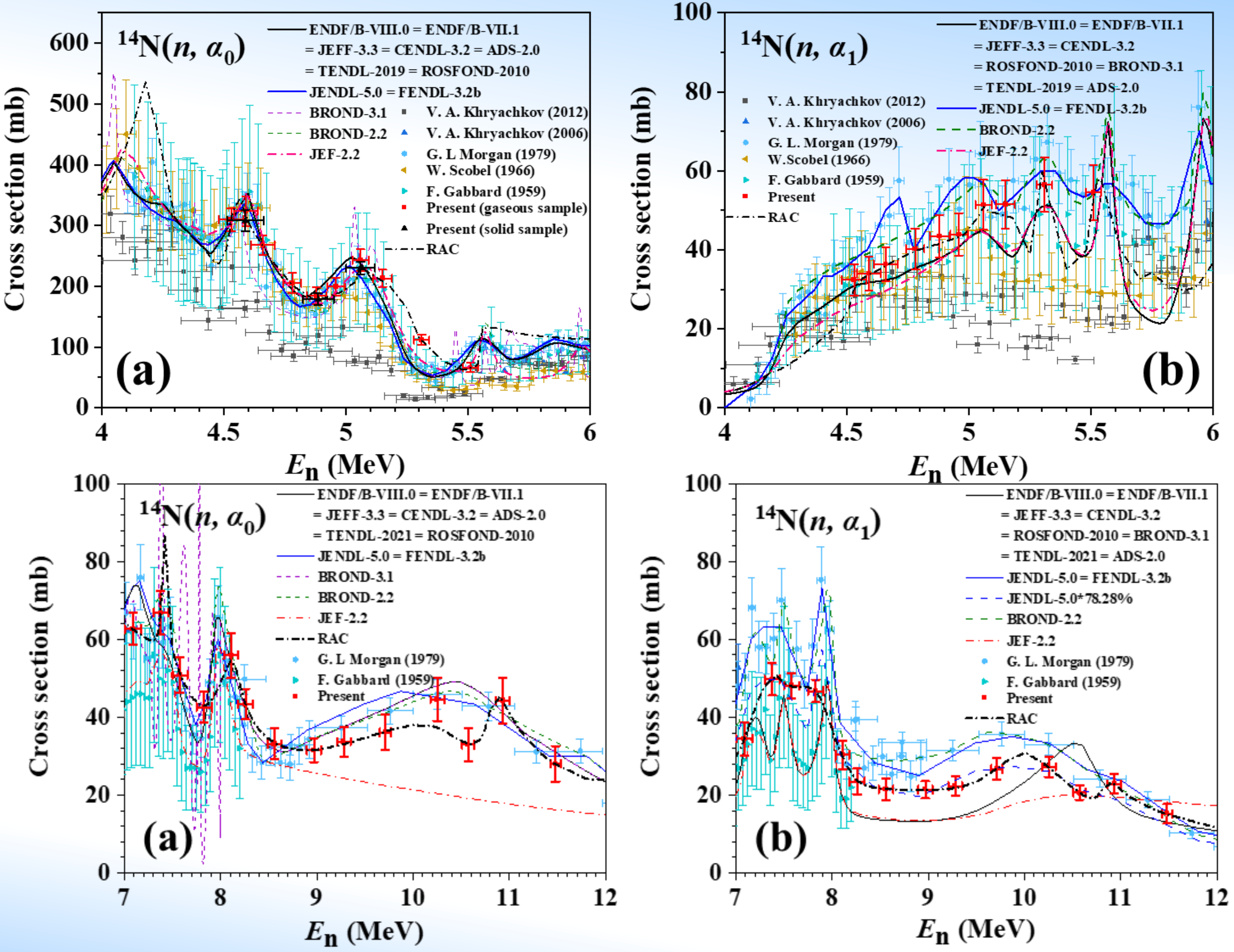
Y. W. Hu, Y. M. Gledenov, Z. Q. Cui, et al., to be submitted.



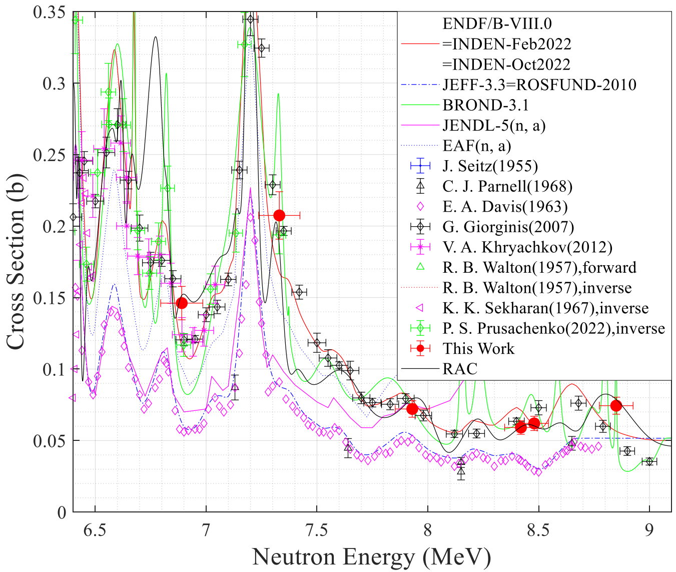


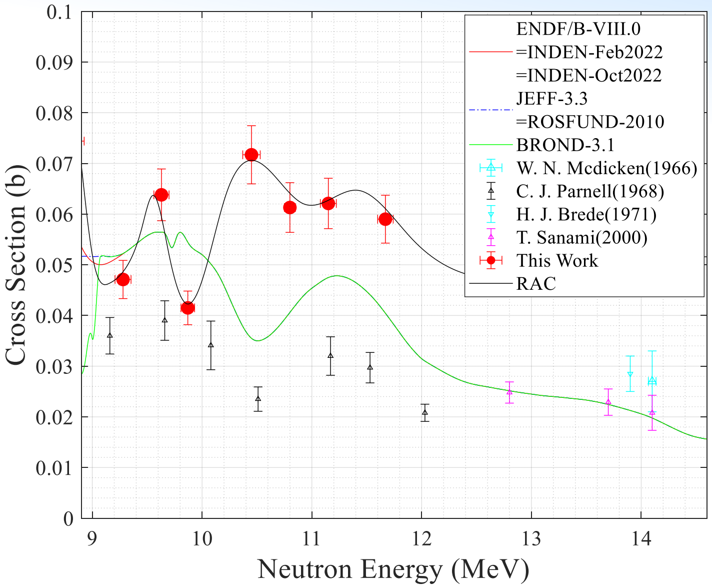
^{14}N(n,alpha)

New data
+
RAC
evaluation



$^{16}O(n,alpha)$

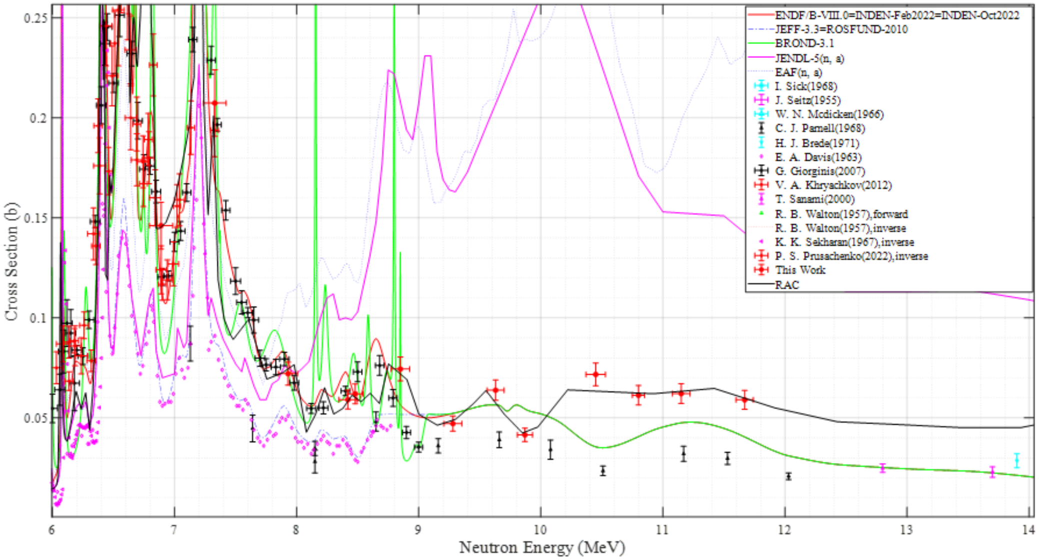




New data + RAC evaluation

More experiments on other target nuclides to follow

^{17}O evaluation by Chen et al. using RAC



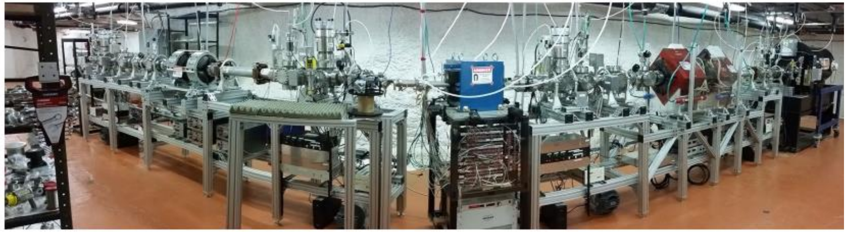
^{16}O(n,alpha) with new data

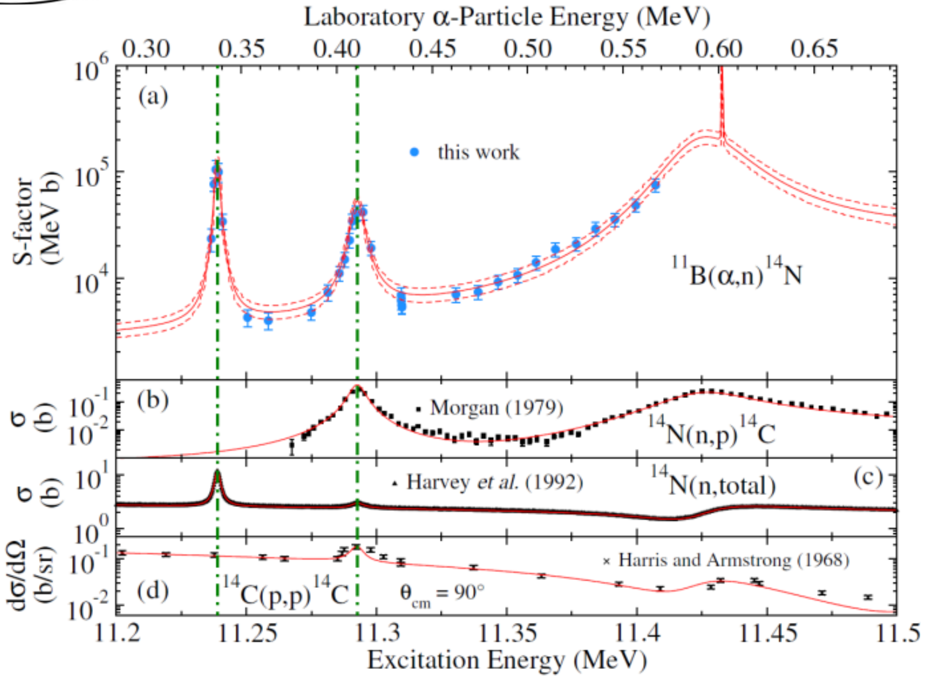
$^{11}B(\alpha,n)^{14}N$ at CASPAR (caspar.nd.edu)

Compact Accelerator System for Performing Astrophysical Research

- Michael Wiescher (ND)
- Dan Robertson (ND)
- Frank Strieder (SDSM)
- Tyler Borgwardt (SDSM, now at LANL)

4850 ft level of the Homestake mine in South Dakota





New measurements at Notre Dame

Talk by deBoer

New measurement at the ELBE facility at HZDR

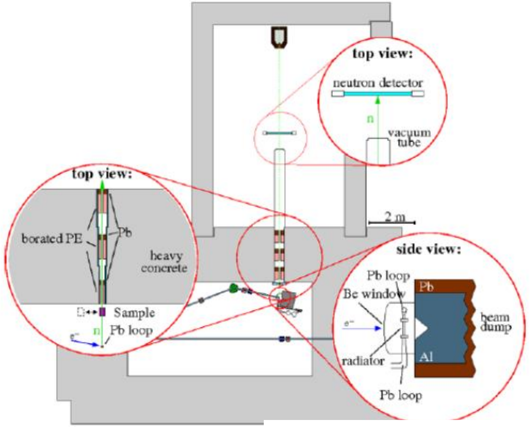
Arnd Junghans and Roland Beyer et al. (2020)

Pulsed electron beam for time of flight

Impinged on a thick liquid lead production target where they produce bremsstrahlung radiation

Neutrons produced by Pb(γ,n), creating a "white" neutron source

Built for fast neutron induced measurements in the keV to MeV range



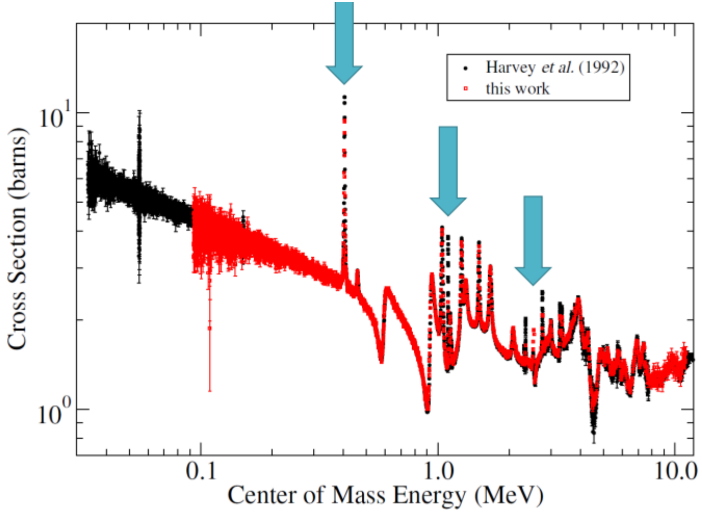
New measurements of $^{14}N(n,tot)$

Talk by deBoer

ELBE measurement is from 0.1 to 12 MeV

Generally good agreement

Our data still have some issues to be sorted out (which I just realized when preparing this talk)

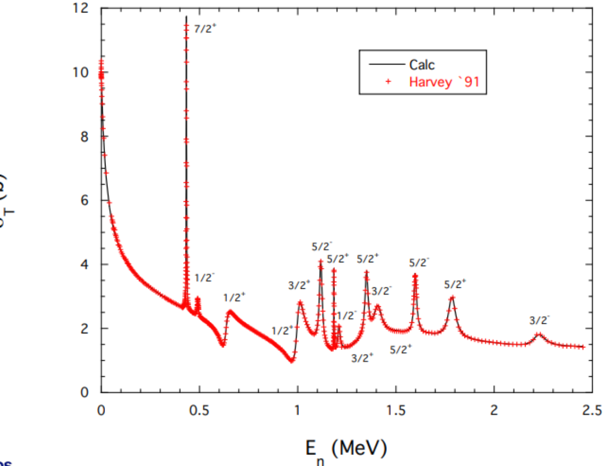


^{15}N evaluation by G. Hale and M. Paris

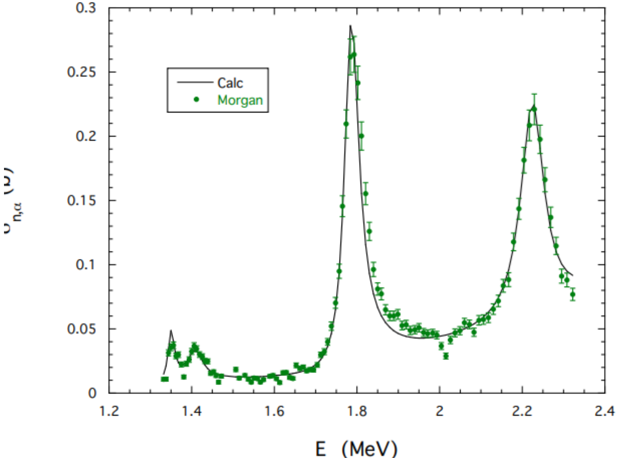
channel	a_c (fm)	l_{max}
n+^{14}N	2.5	2
p+^{14}C	4.3	3
α+^{11}B	5.1	3

Reaction	Energies (MeV)	# data points	Types of data	χ^2
^{14}N(n,n)^{14}N	$E_n = 0 - 2.5$	931	σ_T, $\sigma(\theta)$	889
^{14}N(n,p)^{14}C	$E_n = 0 - 3.0$	362	σ_{int}	766
^{14}N(n,α)^{11}B	E_n=1.33 – 2.32	104	σ_{int}	304
^{14}C(p,n)^{14}N	E_p=1.17 – 3.1	407	σ_{int}, $\sigma(\theta)$, $A_y(\theta)$	1163
^{11}B(α,n)^{14}N	E_α=0.33 - 2.39	190	σ_{int}	626
^{11}B(α,p)^{14}C	E_α=1.45 - 2.94	145	σ_{int},$\sigma(\theta)$	564
	Total	2139		4312

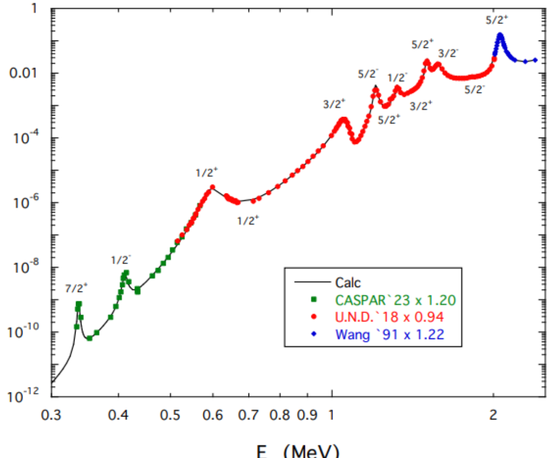
n+^{14}N Total Cross Section



^{14}N(n,α)^{11}B Integrated Cross Section



^{11}B(α,n)^{14}C Integrated Cross Section

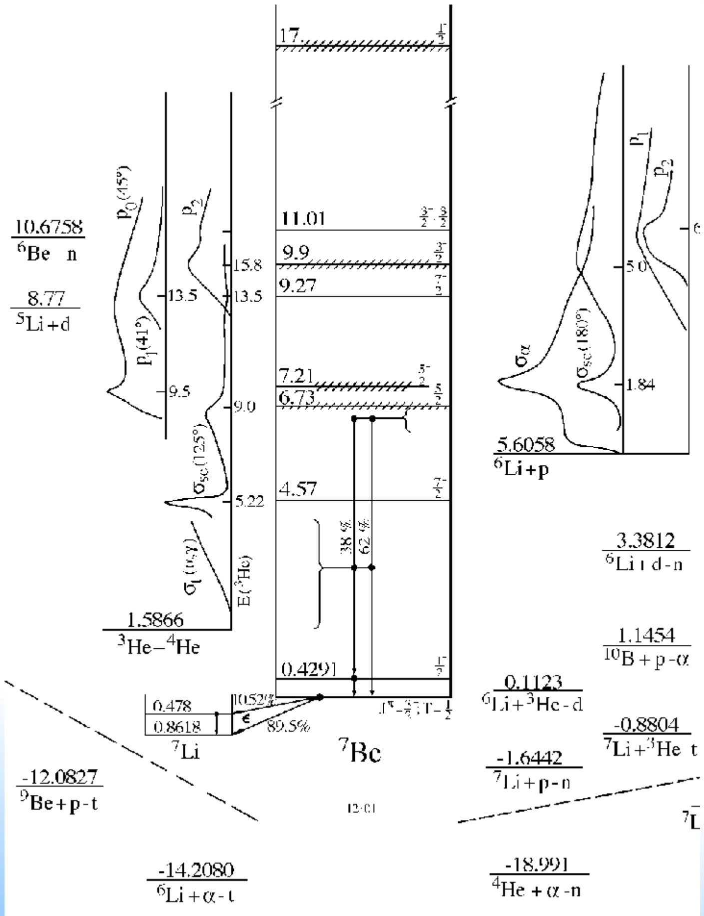


^{7}Be compound system

- Subject of several group exercises done by INDEN-LE groupd
  - Systematic inter-comparison of R-matrix codes
  - Inter-comparison of statistical methods (fit convergence and covariances)
  - Comparison of evaluations with certain common conditions (all exercises and comparisons of results are described in INDEN-LE reports

^{7}Be cont'd

Levels and resonance parameters (TUNL)



J^π	T	E_x	E_α	$E_{^3\mathrm{He}}$	E_p
$\frac{3}{2}^-$	$\frac{1}{2}$	0.0	−3.6905	−2.7806	−6.5418
$\frac{1}{2}^-$	–	0.4291	−2.6921	−2.0284	−6.0413
$h+\alpha$	–	1.5866	0.0	0.0	−4.6908
$\frac{7}{2}^-$	–	4.57	−6.94	5.2335	−1.2090
$p+{}^6\mathrm{Li}$	–	5.6058	9.3579	7.0507	0.0
$\frac{5}{2}^-$	–	6.73	11.9760	9.0233	1.3128
$\frac{5}{2}^-$	–	7.21	13.0940	9.8657	1.8733
$\frac{7}{2}^-$	–	9.27	13.4815	17.8930	4.2793
$\frac{3}{2}^-$	–	9.9	14.5875	19.3609	5.0153
$\frac{3}{2}^-$	$\frac{3}{2}$	11.01	16.5364	21.9477	6.3122

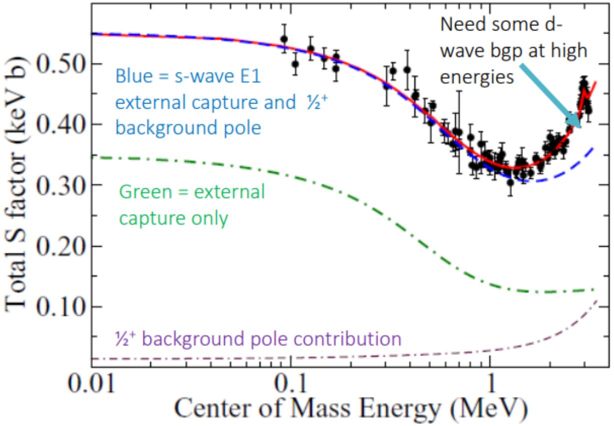
Channels: p+^{6}Li; ^{3}He+^{4}He; γ+^{7}Be is a new addition

Excitation energies: up to 20 MeV

^{7}Be: capture channel

- Review of capture data: ^{3}He(α,γ) and ^{6}Li(p,γ) data (1960s – 2022) – James deBoer
  - No angular distributions for ^{3}He(α,γ); ongoing efforts at Felsenkeller underground lab at HZDR

Low-energy LUNA data



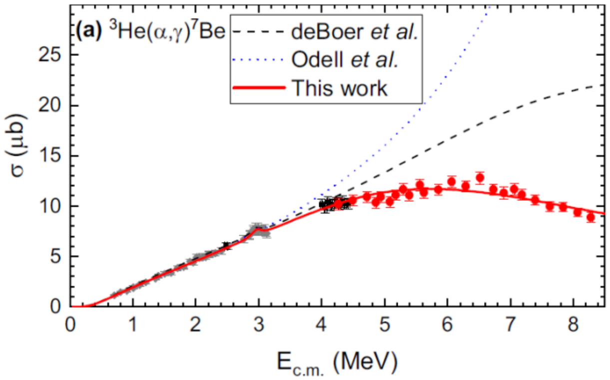
The high energy Toth data

The data seem to indicate a resonance at these higher energies, but none of the known levels in ^{7}Be seem to be able to reproduce the shape

Background levels from R-matrix fits overshoot the data, but maybe not surprising

Toth introduces a very broad ½+ level at E_x= 7.5 MeV with a width of 8 MeV!!!

This looks like an interesting challenge for this group



^{7}Be: LANL (Hale and Paris)

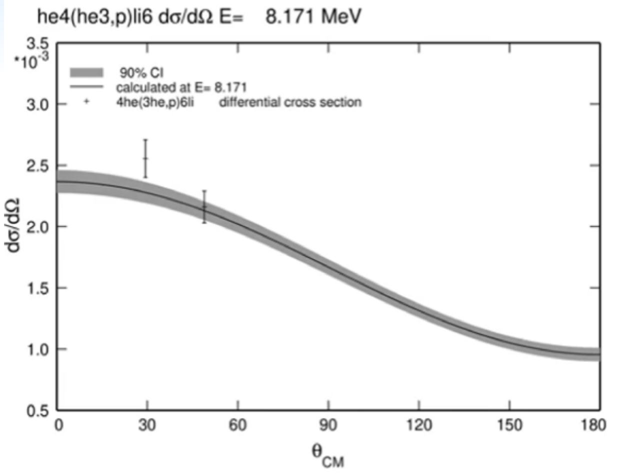
IAEA

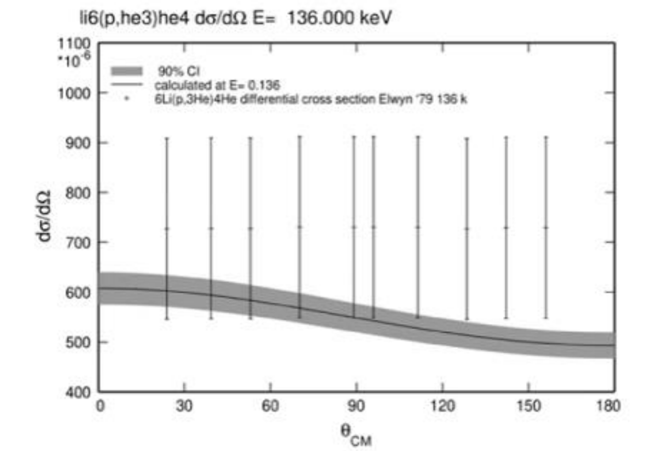
Channel	a_c(fm)	ℓ_{max}
h+^{4}He (0^-)	4.43	4
p+^{6}Li(1^+)	3.13	1
γ+^{7}Be ($\frac{3}{2}^-$)	50.0	1

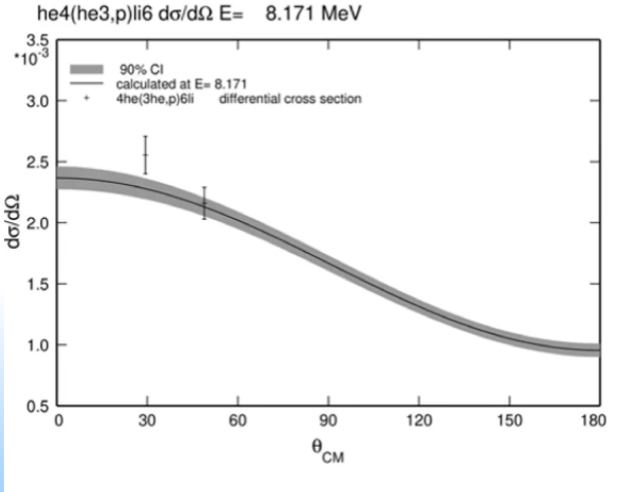
Process	Energy range (MeV)	N_{dat}	χ^2/N_{dat}	Observables
^{4}He(h, h)^{4}He	(1.2, 10.8)	1575	1.96	$\sigma(\theta)$, $A_y(\theta)$
^{4}He(h, p)^{6}Li	(7.8, 10.8)	130	1.25	$\sigma(\theta)$
^{4}He(h, γ)^{7}Be	(0.287, 2.18)	40	1.32	σ
^{6}Li(p, h)^{4}He	(0.025, 2.97)	875	5.10	$\sigma, \sigma(\theta), A_y(\theta)$
^{6}Li(p, p)^{6}Li	(0.495, 2.6)	200	3.23	$\sigma(\theta)$
^{6}Li(p, γ)^{7}Be	(0.157, 1.17)	28	3.04	σ

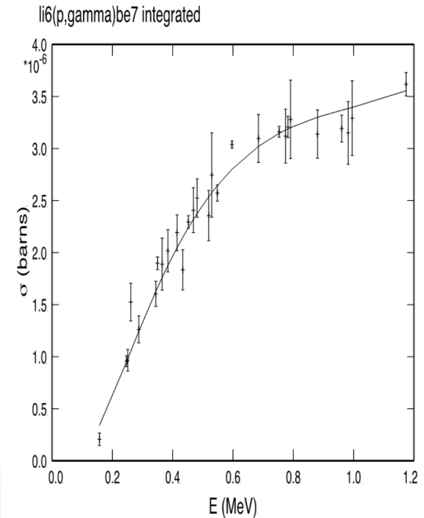
Results for LANL

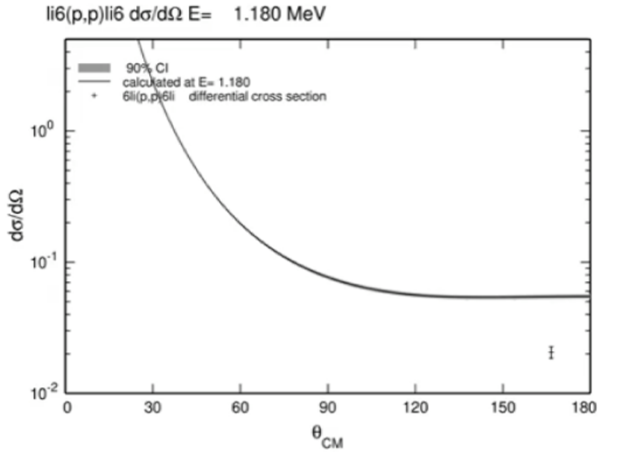
In progress: more exp. data to be added











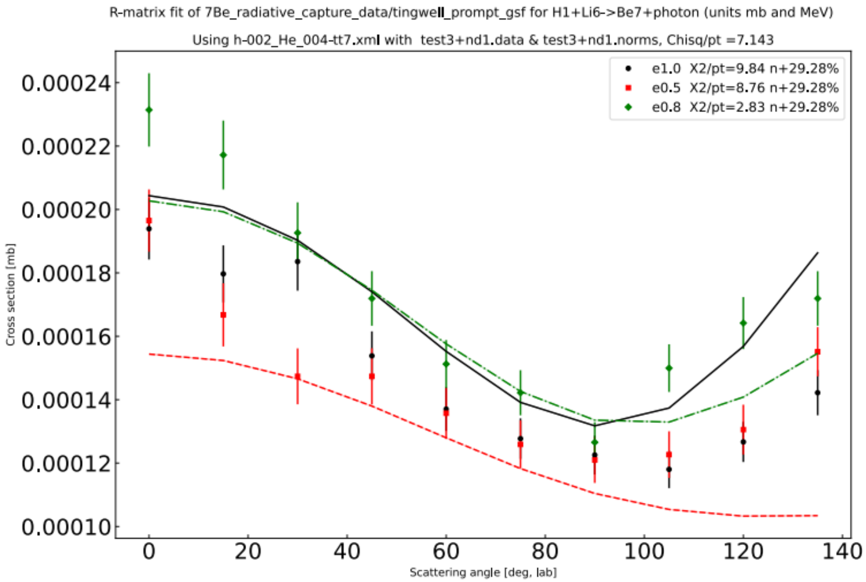
^{7}Be: LLNL (Thompson)

Extend evaluation to include ^{6}Li excited states and capture to ^{7}Be excited states

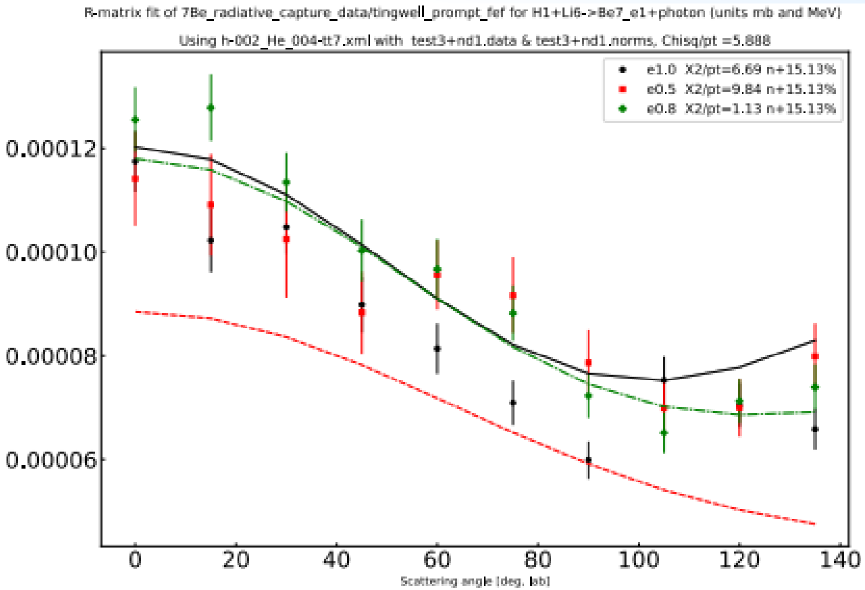
- Include 1st excited state (3+ resonance)
- Capture channels will be treated either as (i) primary channels or (ii) with Reich-Moore
  - two approaches require different ENDF MT assignment:
  - with R-M cannot distinguish btw ground state and 1st excited state (manually)
- Add more experimental data up to 20 MeV – assess quality of data (already done for Tombrello alpha elastic, Spiger alpha elastic, Elwyn palpha
- Use Ferdinand and Rflow (uses tensorflow with cpus ad gpus)

Fitting primary gammas: (p,γ)

ENDF MT=900 and 901 for ground state, 1st excited state



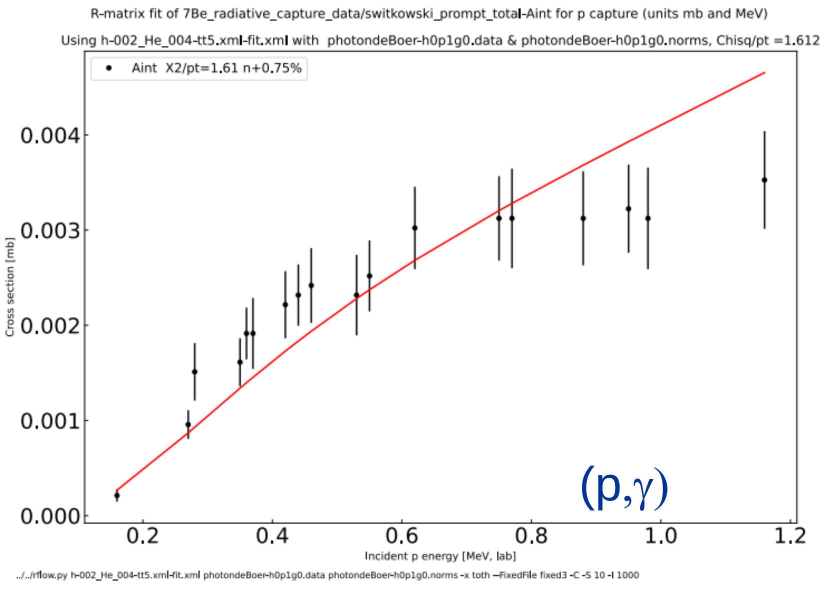
Ground state

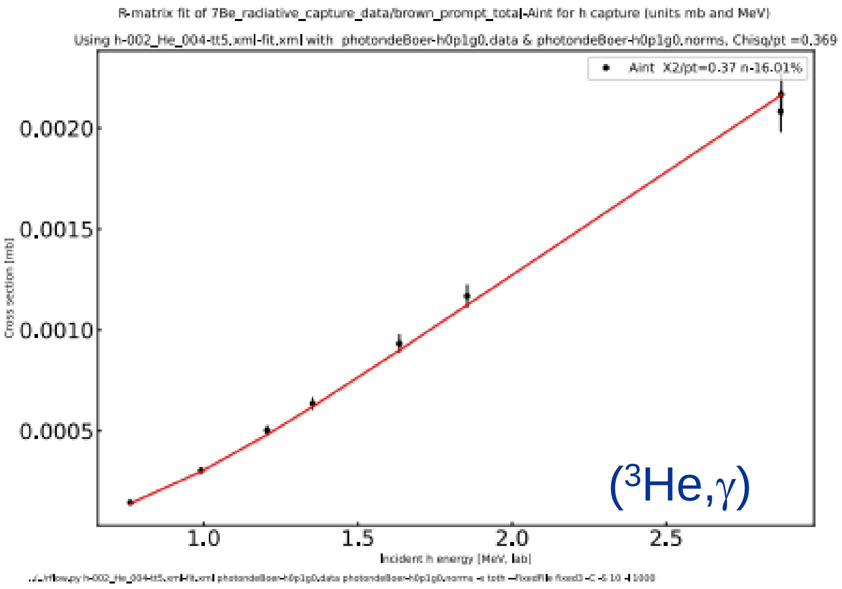


1st excited state

Fitting inclusive gammas using Reich-Moore

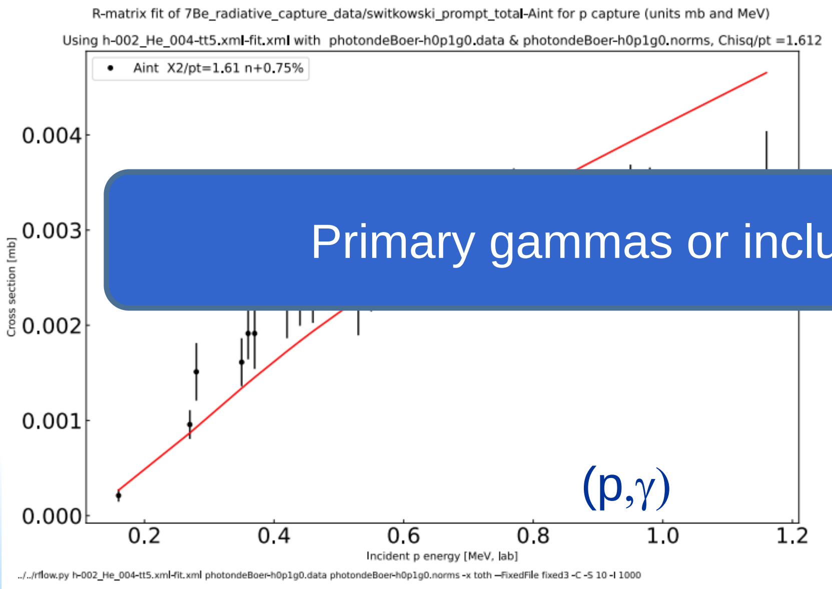
- Fit damping width for each R-matrix pole above threshold
- ENDF MT=102

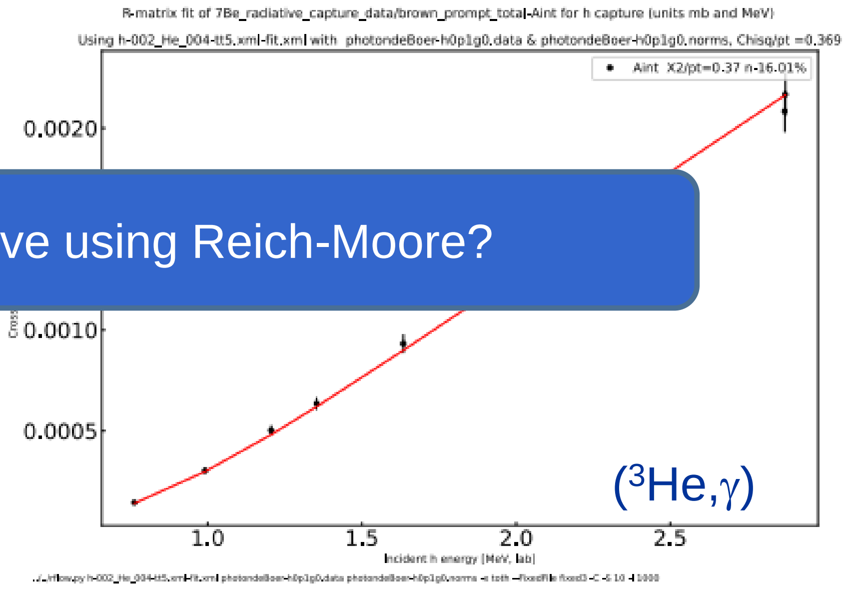




Fitting inclusive gammas using Reich-Moore

- Fit damping width for each R-matrix pole above threshold
- ENDF MT=102

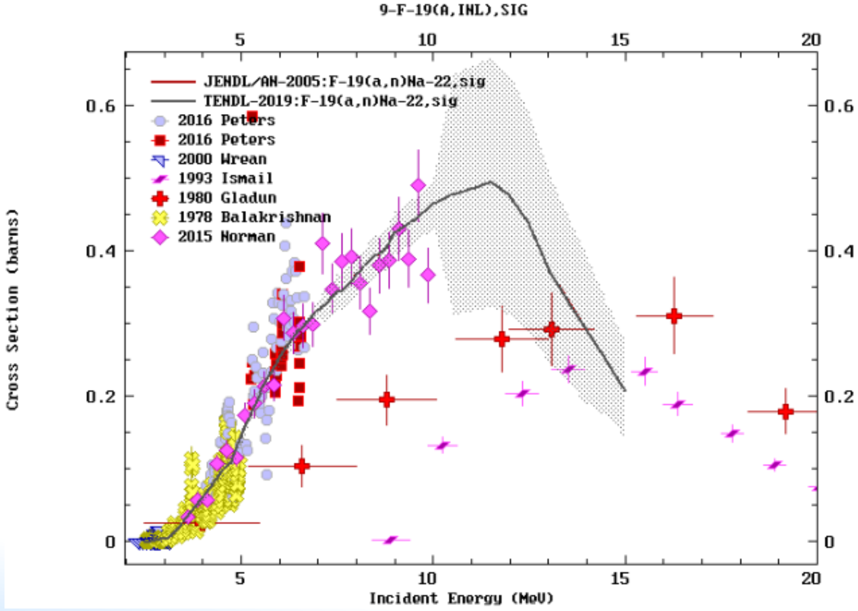




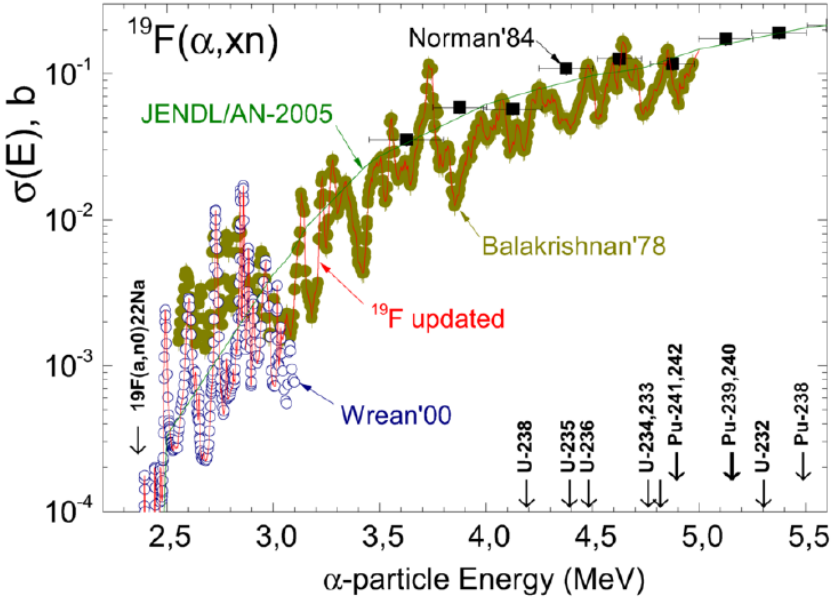
Primary gammas or inclusive using Reich-Moore?

^{19}F(alpha,n) evaluation (Dimitriou and Vagena)

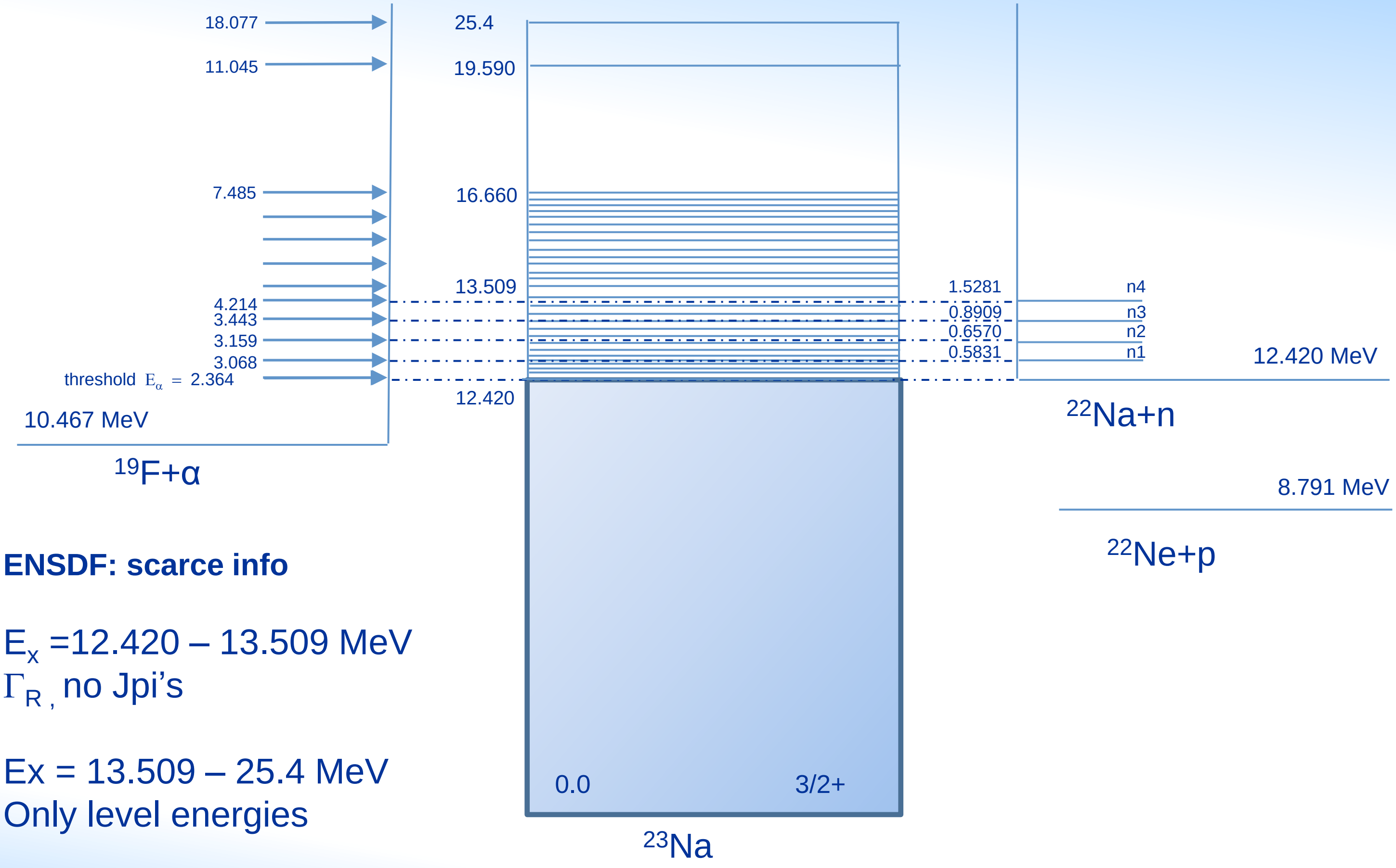
Data libraries



Recent no-model evaluation



Simakov et al., NDS 137 (2017) 190



ENSDF: scarce info

E_x =12.420 – 13.509 MeV
Γ_R , no Jpi's

Ex = 13.509 – 25.4 MeV
Only level energies

Level scheme

ENSDF 2022: ^{23}Na

E_α(MeV)	E_x (MeV)	Jpi	Γ_α (eV)
2.363	12.419	(7/2+,5/2+)	116(20)
2.446	12.488	(13/2+)	5000(2000)
2.612	12.625		25000
2.630	12.64		10000(5000)
2.738	12.729		130000(2000)
2.824	12.8		6000(3000)
2.846	12.818		5000(2000)
2.882	12.848		11000(5000)
2.887	12.852		9000(4000)
2.978	12.927		6000(3000)
3.156	13.074		12000(4000)
3.289	13.184		9000(4000)
3.304	13.196		9000(4000)
3.366	13.248		10000(5000)
3.404	13.279		14000(7000)
3.474	13.337		8000(4000)
3.549	13.399		13000(6000)
3.623	13.46		23000(11000)
3.682	13.509		10000(5000)

(α,p_0) measurements Schier et al, 1976

E_α	E_x	Jpi
1.318	11.556	1/2+
1.492	11.700	1/2 +-
1.507	11.712	3/2-
1.879	12.019	1/2+,5/2+
1.954	12.081	1/2+-
2.002	12.121	1/2-
2.081	12.186	5/2+
2.102	12.203	5/2+
2.199	12.284	1./2+,1/2-
2.319	12.383	3/2-
2.402	12.451	7/2-
2.45	12.491	3/2+
2.538	12.564	3/2+,3/2-
2.639	12.647	3/2-
2.742	12.732	5/2+,7/2-
3.036	12.975	1/2+,7/2-
3.165	13.082	1/2+,7/2-
3.266	13.165	5/2+,7/2-
3.308	13.200	7/2-,9/2+
3.361	13.243	5/2+,5/2-
3.548	13.398	3/2-,7/2-
3.735	13.552	1/2-,5/2+
3.87	13.664	5/2+,7/2-
4.115	13.866	1/2-,7/2-
4.186	13.925	3/2-,5/2+
4.344	14.056	3/2-,7/2-
4.5	14.184	3/2-,3/2+
4.616	14.280	3/2-,3/2+
4.704	14.353	1/2+,7/2-
4.825	14.453	1/2+,7/2-

Kuperus 1965

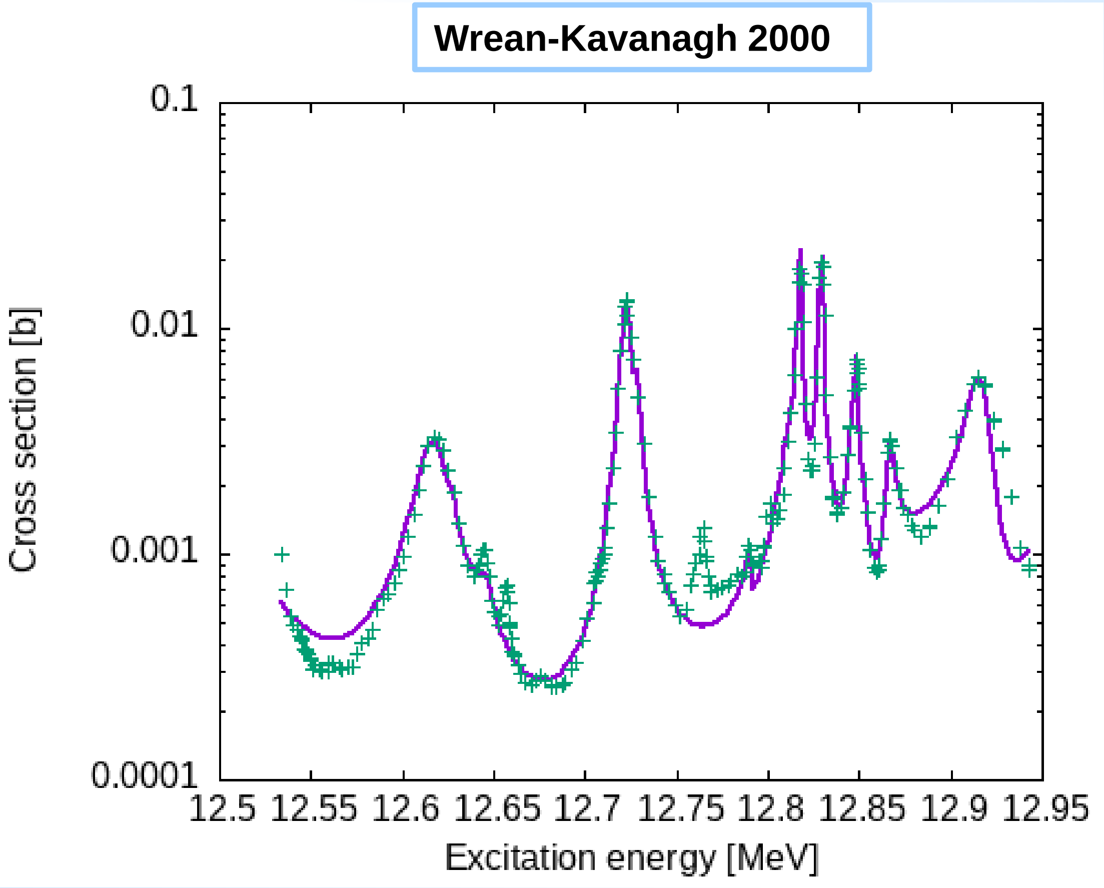
Schier 1976

$^{19}F(\alpha,\alpha_0)^{19}F$ resonance parameters

Cseh et al, 1984

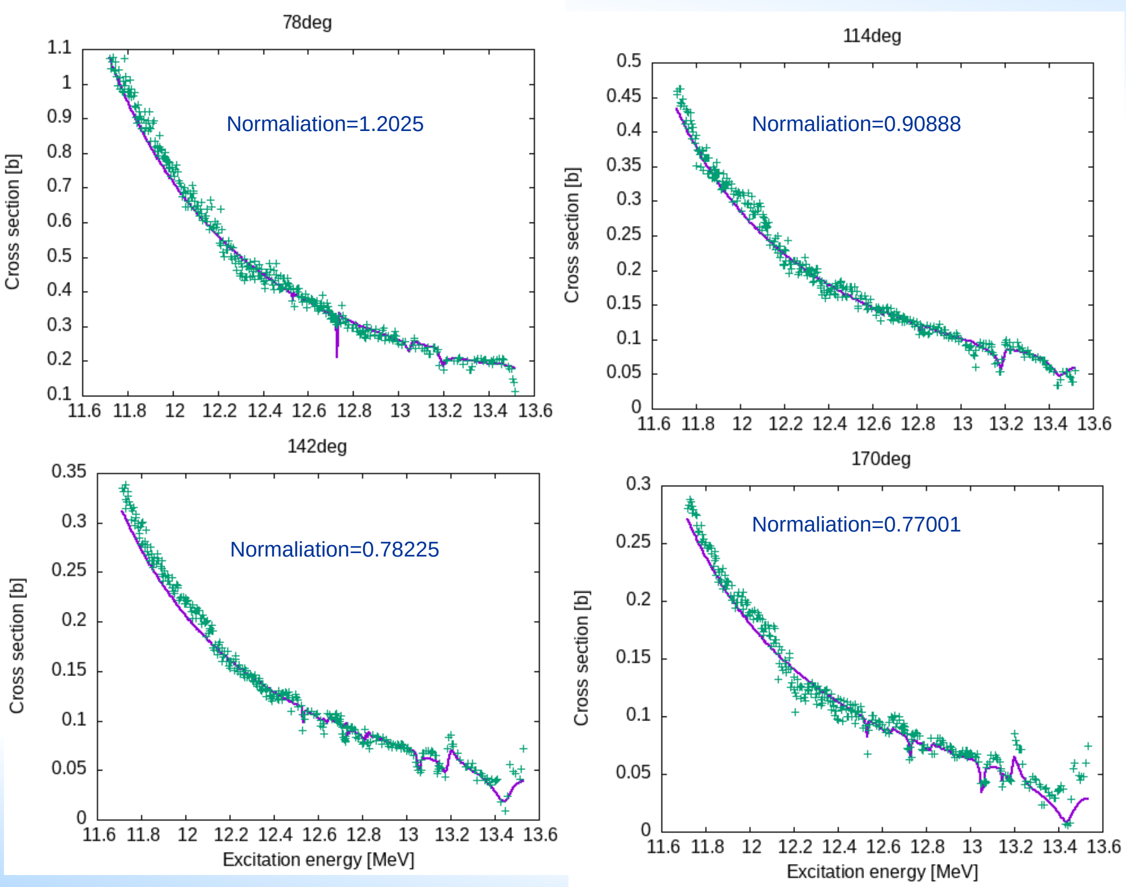
E_α a) (MeV)	E_x b) (MeV)	l_α	J^π	Γ_α/Γ c)	Γ c) (keV)	γ_α^2 (keV)
2.513	12.544	2	$\frac{3}{2}^+, \frac{5}{2}^+$	0.23, 0.16	6.6	76, 52
2.632	12.642	0	$\frac{1}{2}^+$	0.17	11	15
		1	$\frac{1}{2}^-, \frac{3}{2}^-$	0.21, 0.11	13	34, 18
2.737	12.729	2	$\frac{3}{2}^+, \frac{5}{2}^+$	0.17, 0.12	12	44, 31
2.813	12.791	2	$\frac{3}{2}^+, \frac{5}{2}^+$	0.065, 0.045	11	12, 9
2.846	12.819	1	$\frac{1}{2}^-, \frac{3}{2}^-$	0.37, 0.20	3.4	8.4, 4.5
2.873	12.841	2	$\frac{3}{2}^+, \frac{5}{2}^+$	0.11, 0.074	17	27, 19
2.887	12.852	0	$\frac{1}{2}^+$	0.11	5.5	2.3
		1	$\frac{1}{2}^-, \frac{3}{2}^-$	0.12, 0.064	12	8.4, 4.5
3.126	13.050	2	$\frac{3}{2}^+, \frac{5}{2}^+$	0.14, 0.097	9	9, 6.2
3.151	13.071	1	$\frac{1}{2}^-, \frac{3}{2}^-$	0.39, 0.21	6.8	8.5, 4.6
3.156	13.075	2	$\frac{3}{2}^+, \frac{5}{2}^+$	0.21, 0.15	12	18, 12
3.250	13.153	2	$\frac{3}{2}^+, \frac{5}{2}^+$	0.18, 0.12	11	11, 7.5
3.302	13.195	0	$\frac{1}{2}^+$	0.90	6.3	9
3.359	13.243	3	$\frac{5}{2}^-, \frac{7}{2}^-$	0.15, 0.11	12	24, 18
3.467	13.332	2	$\frac{3}{2}^+, \frac{5}{2}^+$	0.24, 0.17	23	18, 12
3.567	13.422	3	$\frac{5}{2}^-, \frac{7}{2}^-$	0.07, 0.053	15	8.3, 6.3
3.621	13.459	1	$\frac{3}{2}^-$	0.69	22	20

(alpha,n) results up to ~3 MeV



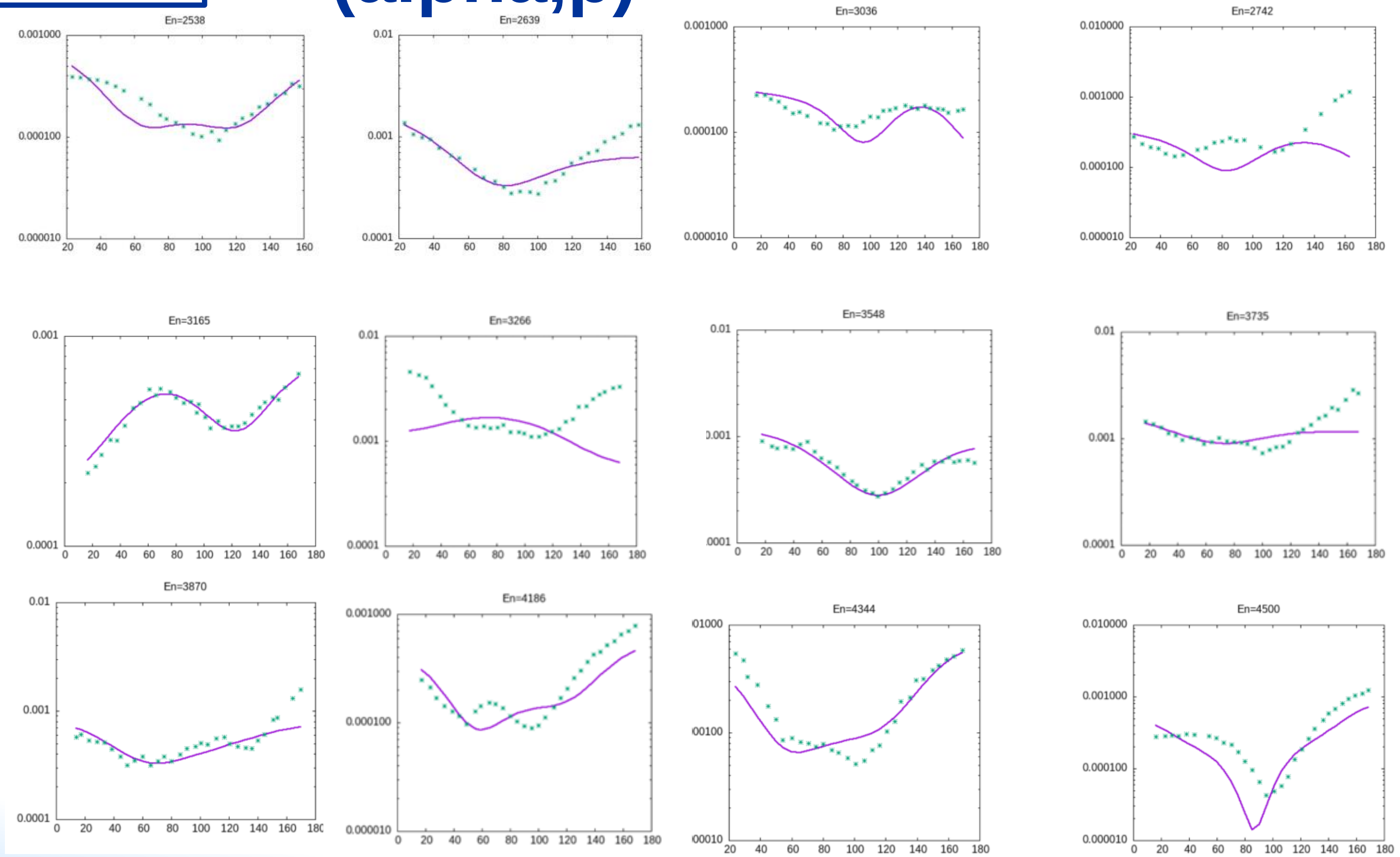
(alpha,el)

Cseh et al 1984



Schier et al 1976

(alpha,p)



Excitation energy(MeV)

Yoshie Otake
RIKEN

RIKEN RANS Development

Compact neutron systems for practical use！

neutrons, anytime, anywhere

Source and instrumentation are inseparable relationship

The development purpose

in order to respond to the needs! New needs

→Standard Model of non-destructive test as evaluation analyzer

Neutron Source development

RANS, RANS-II, RAS-III
(Accelerator-based)
RANS-μ (RI)
＋Moderator, reflector, shielding

R&D

Instruments design, analytical methods should be based on strong demand from the society

The most critical need is non-destructive diagnostic system for infrastructure:

To meet needs : preventive maintenance

IAEA

Salt damage->bridges collapse

USA I-70 Concrete bridge collapse

Dec. 2005 , 45 years after the construction Pennsylvania. Rebar corrosion because of **ant freezing agent**

From：Pittsburg Post-Gazette

Initial construction failure

Canada Collapse of a Portion of de la Concorde Overpass

Sept, 2006, 35 years after construction, Montreal

Initial construction failure

出典：落橋に関する委員会報告書

Message from Dr. Banthia to Japanese researchers:
The novel non-destructive test methods such as x-ray, electromagnetic induction method, elastic wave method.出典：六郷ら、カナダのデラコンコルド跨道橋の崩落事故に学ぶ、コンクリート工学,2008.12

From Mr. R.Ooishi (Institute Public Work)

Italy ·Moradi bridge collapse （14 Aug.2018. ） Salt damage

Vigili del Fuoco/AFP

Taiwan bridge collapse1 Oct. 2019）

写真：https://udn.com/news/story/7321/4078135

RAP

Neutron sources

IAEA

- For high efficiency of a small compact system that includes shielding:
  - ion beam energy < 12 MeV
  - Neutron flux at target position ~10^{12}/sec
  - Suitable sources: Li(p,n), Be(p,n), Li(d,n), Be(d,n)

- No suitable proton library for low-energy protons
- New analytical function was proposed to provide p-Be source neutron production spectrum
- Calculate total production cs, ang.distribution and double-differential cs for p<12 MeV
- Measurements using In foil to validate the function (^{115}In(n,n') reaction rate)

Li (p,n)
Be (p,n)
Li (d,n)
Be (d,n)

small system=> Proton or deuteron E> 2 MeV
few activation waste, proton Energy < 12MeV

Higher energy proton beam,

Target: W, Ta, etc.
Please refer **HBS report from JCNS**

Be (γ,n)
Pb (γ,n)
Ta (γ,n)

Electron > 30MeV is needed, too high energy for compact source
Easy to operate

- Nuclear fusion

DD neutron tube: too small amount
DT: neutron energy is too high, and Tritium is not favarable for compact source

Still 15% overestimation of ^{115}In(n,n') reaction rate but better than 65% underestimation with ENDF/B-VII.0

Wakabayashi et al, J. Nucl. Sci. Tech., DOI:10.1080/00223131.2018.1445566

Upcoming event in 2023-2024

- 2nd TM on (alpha,n) reaction nuclear data evaluation and data needs, 27 Nov - 1 Dec 2023, virtual
  - Purpose: to review status of (alpha,n) reaction data at low energies up to 10 MeV relevant for applications in
    - nuclear fuel cycle (with emphasis on ^{17}O compound system),
    - spent fuel management, nonproliferation
    - low background experiments
    - nuclear astrophysics
    - fusion applications.

We will also review the status of model and applications codes, as well as of evaluated libraries.

https://conferences.iaea.org/event/366/

Also in 2024

7th Workshop on Compound-Nuclear Reactions and Related Topics (CNR*24)

- Keynote talks
- Oral/poster presentations
- Proceedings

- No registration fees
- Registration: 1 Dec 2023
- Abstracts: 1 Dec 2023

Organisers:
Vivian Dimitriou
Roberto Capote
Georg Schnabel

Compound-Nuclear Reactions and Related Topics (CNR*24)

8–12 Jul 2024
Vienna International Centre
Europe/Vienna timezone

Enter your search term

- Overview
- Committees
- Important deadlines
- Registration and Participation
- Call for Abstracts
- Timetable
- Practical information
- Code of conduct (UN)

Contact
p.dimitriou@iaea.org
k.nathani@iaea.org

The 7th international workshop on Compound-Nuclear Reactions and Related Topics will be held from 8 to 12 July 2024 at the International Atomic Energy Agency, Vienna, Austria.

Following in the footsteps of previous workshops held in Yosemite National Park (2007), Bordeaux (2009), Prague (2011), Sao Paolo (2013), Tokyo (2015) and Berkeley (2018), the meeting will bring together scientists from the fields of nuclear theory, experiment, nuclear astrophysics, data evaluation, and other applications. The primary goal is to provide a forum for reviewing the status of experimental and theoretical efforts in compound-nuclear reactions and related areas, discussing recent developments, and exploring how these improvements can be integrated into practical applications.

The meeting will comprise a series of invited overview talks, oral contributions, and poster presentations, with emphasis on stimulating interactions and discussions among the participants.

Topics to be covered:

- Nuclear reaction mechanisms (direct, compound, pre-equilibrium, other)
- Nuclear fission
- Statistical Hauser-Feshbach theory
- Surrogate methods
- Optical model
- Level densities and photon strength functions
- R-matrix theory
- Nuclear structure for nuclear reactions
- Measurements relevant to compound-nuclear reactions (direct and indirect)
- Nuclear data evaluation and dissemination
- Applications in nuclear astrophysics, energy, waste management, nonproliferation, medical physics, etc.
- Experimental facilities

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Thank you!