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Fusion technologies data needs: the missing links

Jean-Christophe Sublet

United Kingdom Atomic Energy Authority,

Culham Campus, Abingdon, OX14 3DB, UK

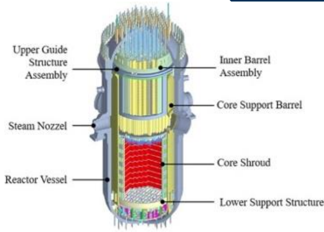
Exploring the fusion fuel landscape –

Nuclear data for materials science, component engineering

Transport theory and applications

The nuclear **landscapes are diverse**, and **applications driven**

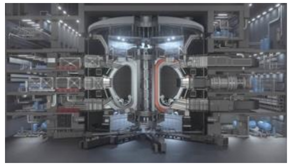
Nuclear **power** technologies, data requirements are also application driven



Nuclear Fusion requirement **significantly differs** from nuclear Fission

Fission power technologies relates to a **careful interpretation of the neutron balance/map (criticality Keff) in regular (2D) “cylindrical” lattice geometry** with neutron slowing down **from 2 MeV in moderator/coolant channels** from many **regularly spaced source terms** (fuel rod)

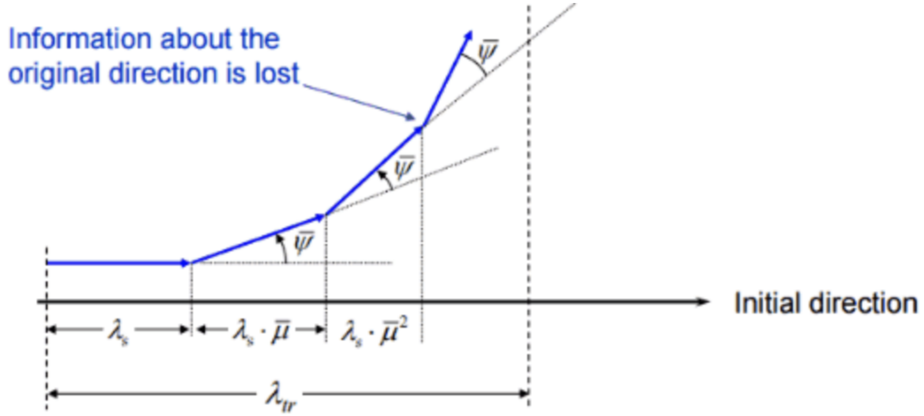
Fusion technologies relates to the **moderation, shielding in donut (3D) “spherical in the making” geometry** with neutron slowing down **from 14 MeV** from **a single large source term** (plasma)



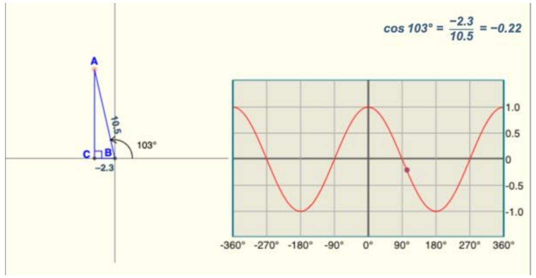
Which nuclear data types are important? e.g. **mubar and gamma production/heating**

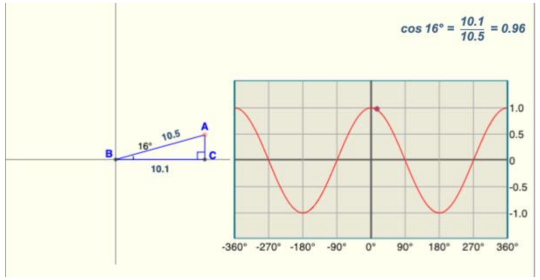
What is “mubar”

- In terms of cosine **(-1 < mubar < 1),** it is the **average lab frame scattering angle** for the neutron in elastic scattering **mf=4 mt=2**
- In terms of evaluated data $\boldsymbol{\mu_L}$, it is part of the continuous-slowing-down parameters as an auxiliary MT number **MT=251**
- It is processed by NJOY2016 card ***3 251 'mubar'/*, ** given by incoming group and exists in derived file only, **not in the original evaluation**
- The mubar is given **as mean, or average per group**
- It includes up-scatter (if present), self-scatter and down scatter
- NJOY2016 only calculates **the P1 contribution for mubar**
- **mubar** interact with the P1 fluxes ➔ **leakage rates**



What is “mubar”

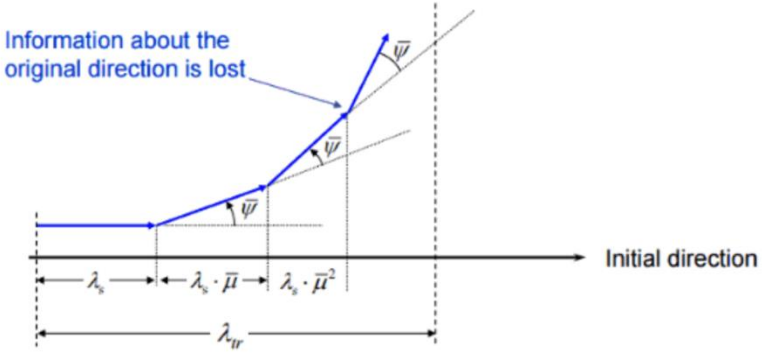


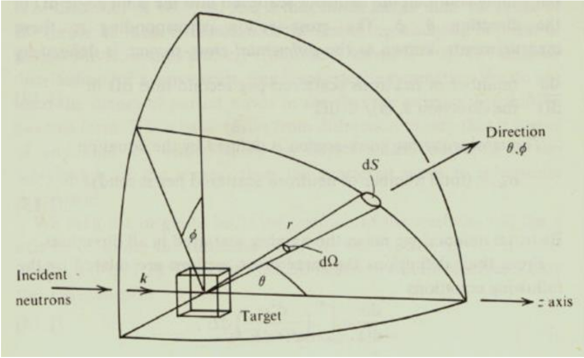


- When **mubar is positive**, the scattering event **move forward**, the mean free path **mfp is maximum**, longer, the **neutron escape**, the overall leakage is directed, increased in the cosine direction

- When **mubar is negative**, the scattering event **move backward**, the mean free path **mfp is reduced**, shorter, the overall leakage **is decreased**, the neutron population **stay stable**, is spatially maintained

- Uncertainty for mubar **exists - variance or standard deviation** – diagonal elements of the covariance – off-diagonal elements **represent the cross terms for the different groups**





Mubar mf=4 & mubar covariances mf=34

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ξ average logarithmic energy loss per collision

A >2 - $\xi \approx 2/(A+0.67)$

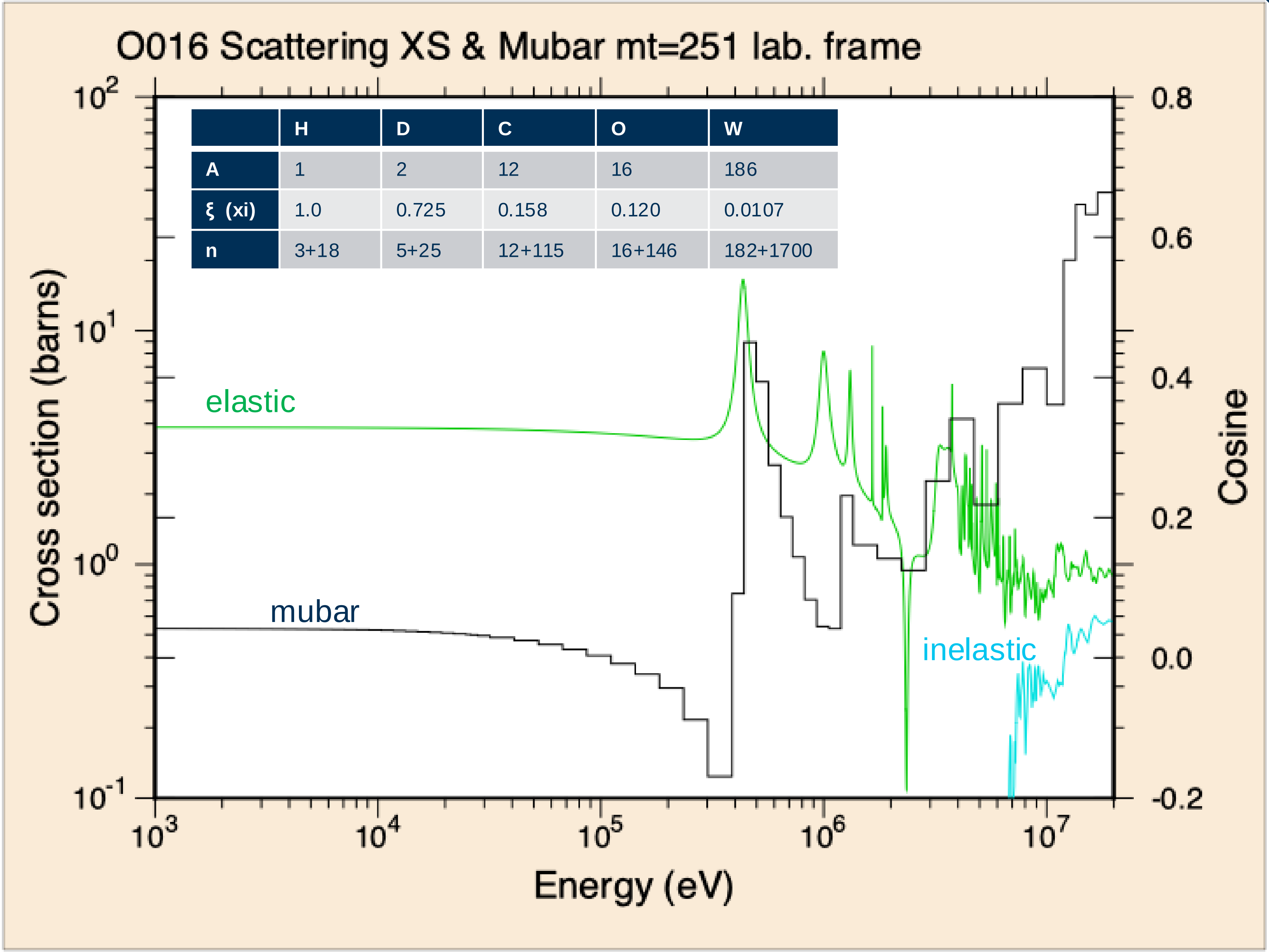
Collisions to moderate

$$n\xi \approx \ln\frac{E_i}{E_f}$$

H n ≈ 18 + 3 (14-7-3 MeV)

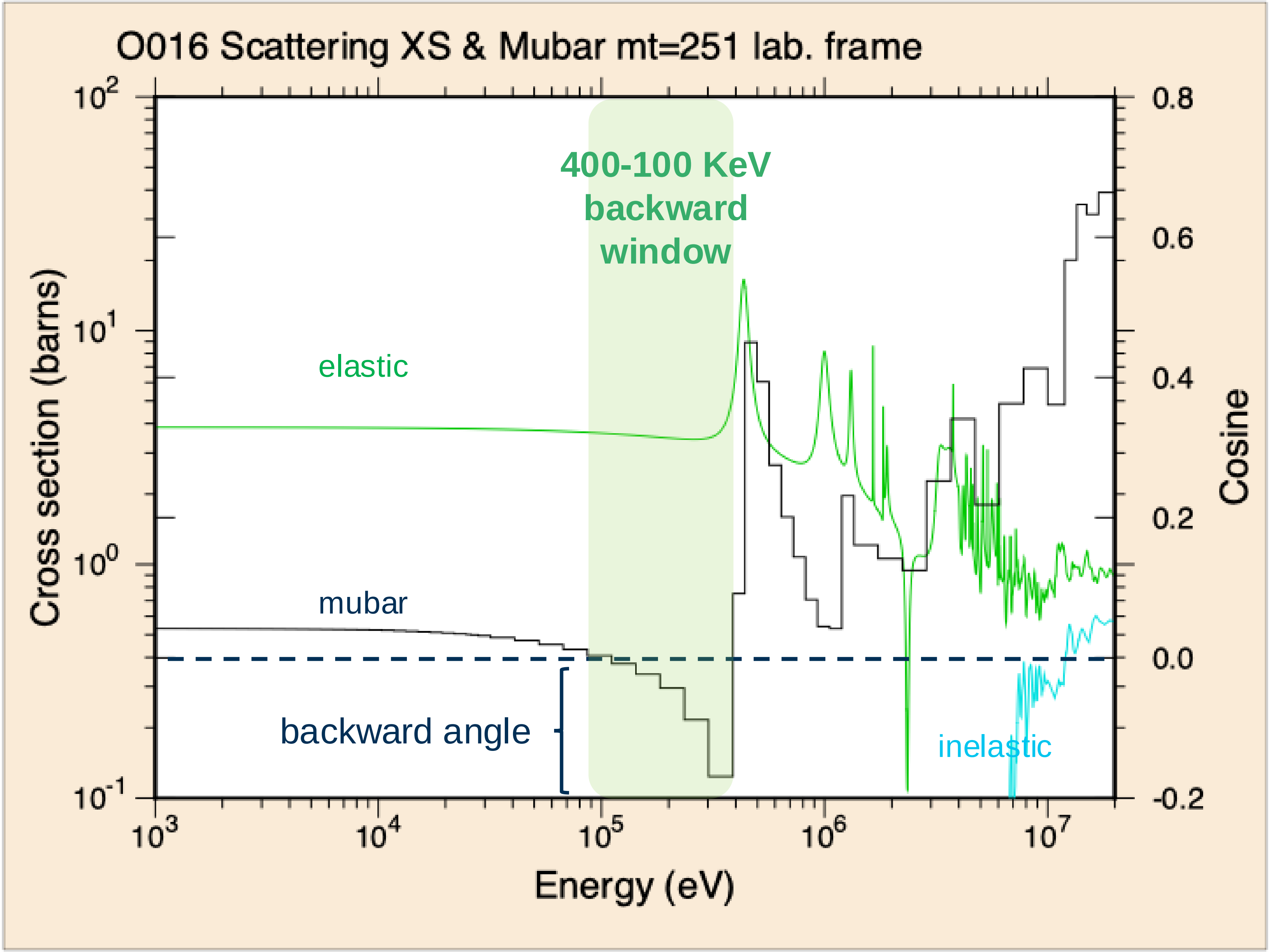
14 MeV => 2 MeV 3

2 MeV => 0.025 eV 18



	H	D	C	O	W
A	1	2	12	16	186
ξ (xi)	1.0	0.725	0.158	0.120	0.0107
n	3+18	5+25	12+115	16+146	182+1700

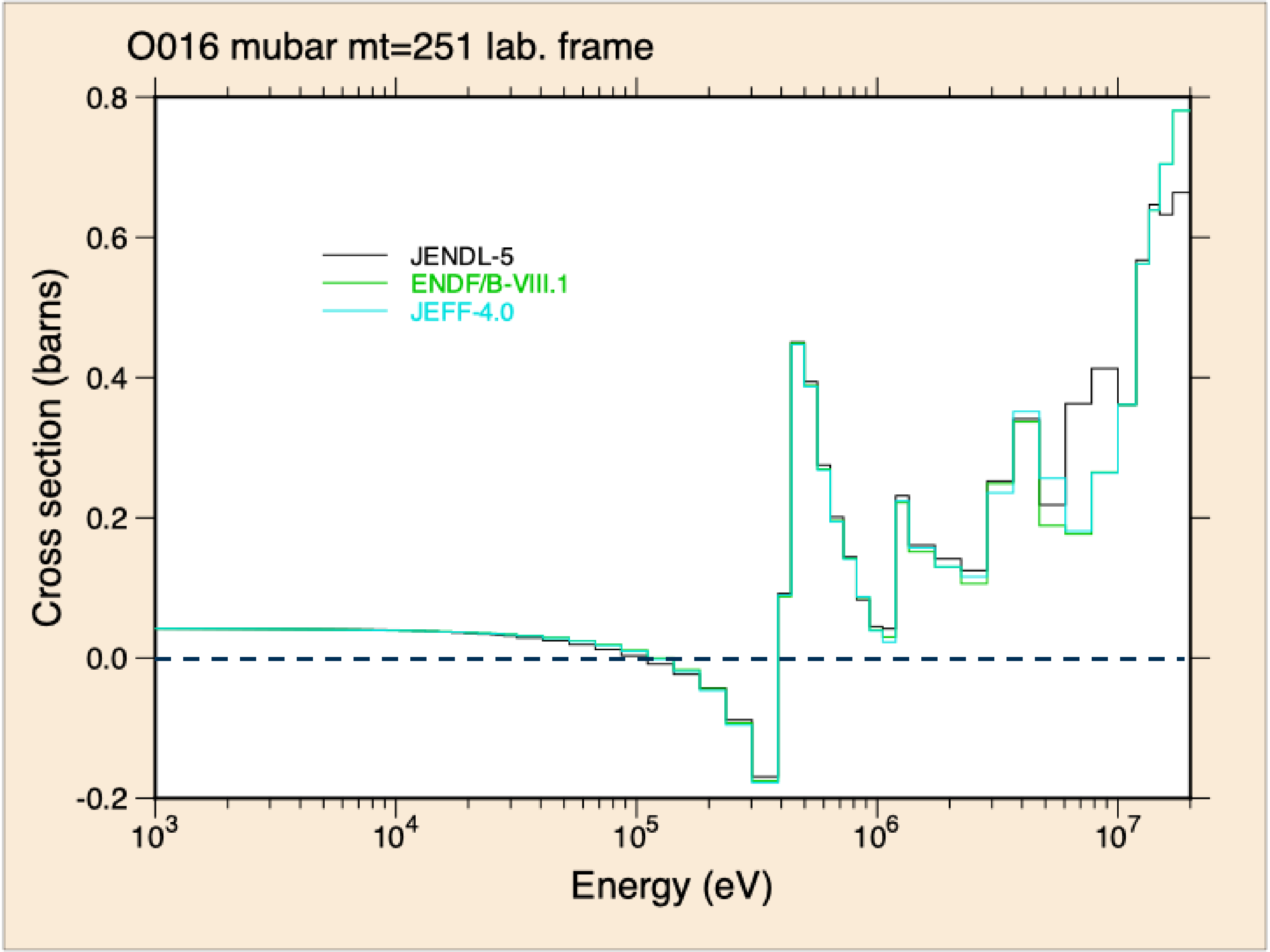
Mubar mf=4 & mubar covariances mf=34



+ cosines

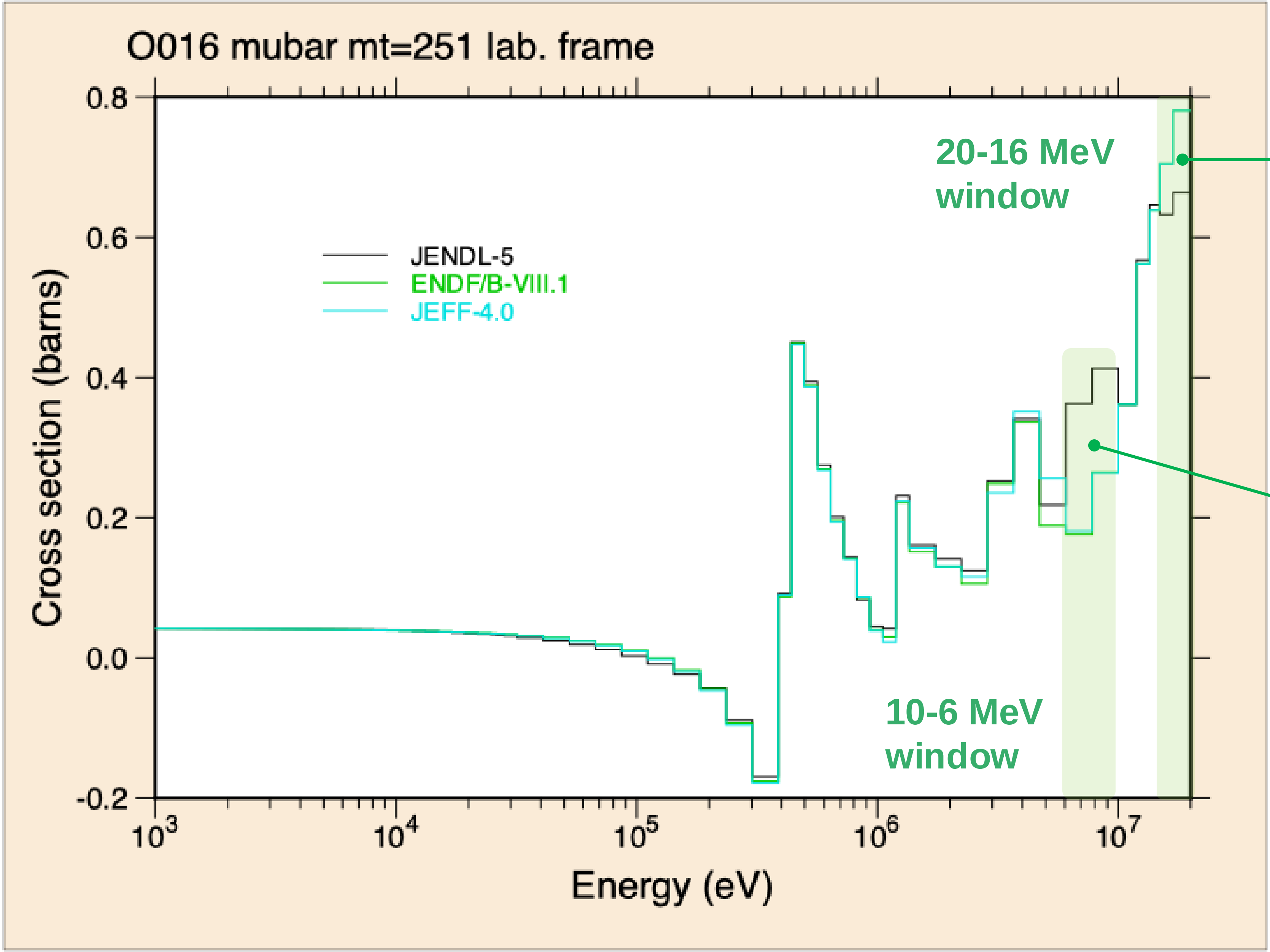
- cosines

Mubar & library differences



ENDF/B-VIII.1 and JEFF-4.0 mubar are similar but **not** with **JENDL-5**

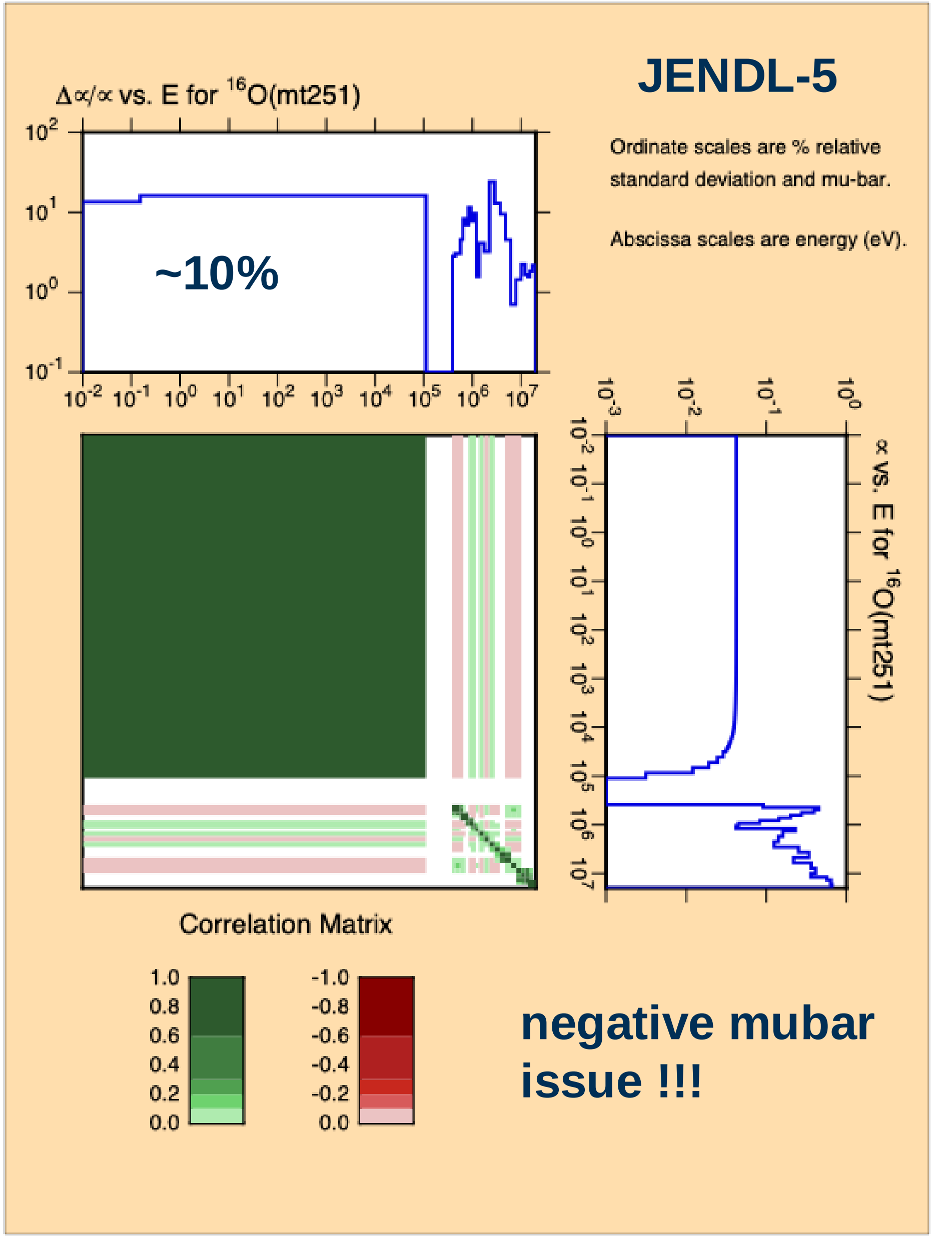
Mubar & library differences

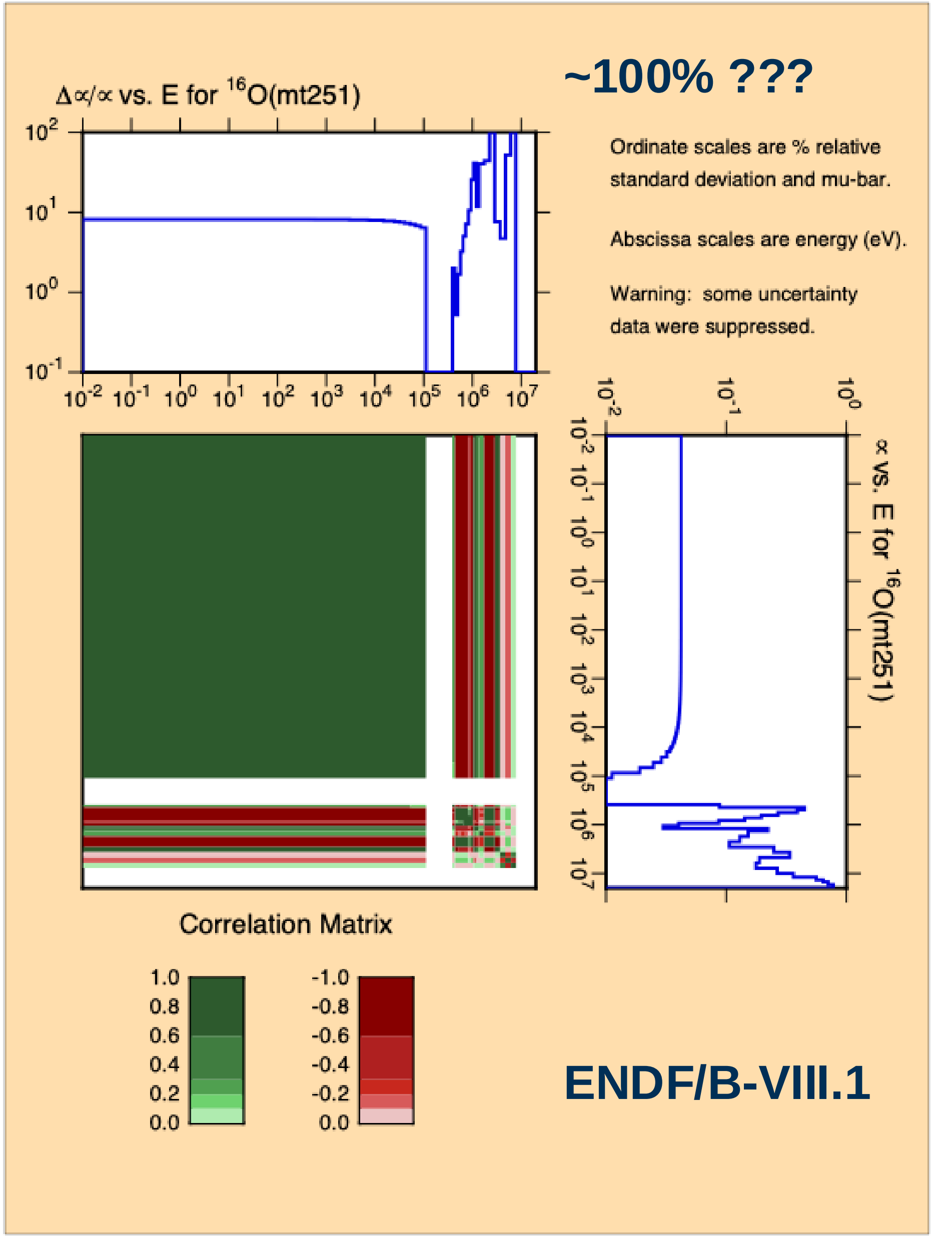


20-16 MeV ~25% differences in cosine - too high

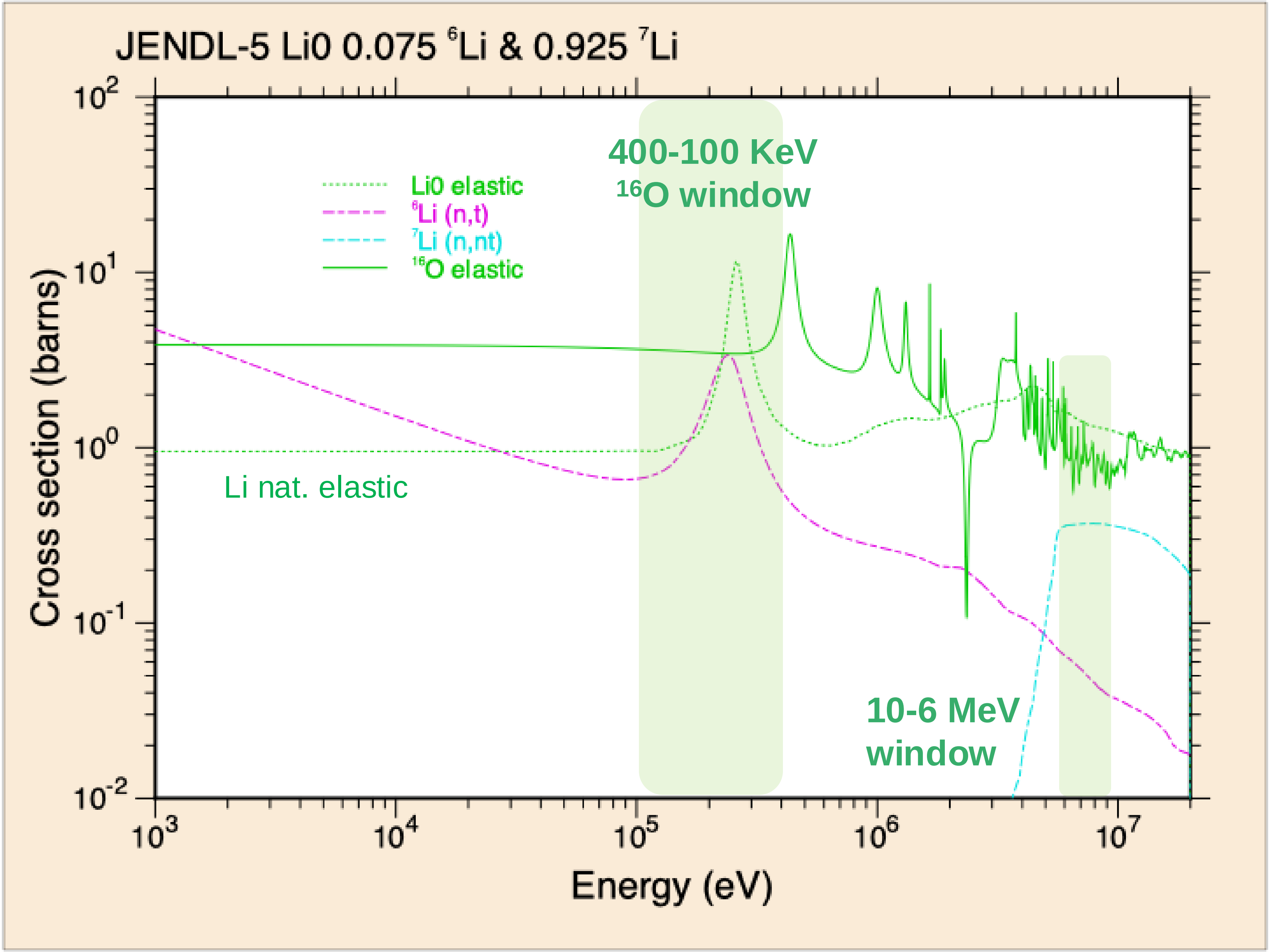
10-6 MeV ~50% difference in cosine

Mubar covariances JENDL-5 & ENDF/B-VIII.1





Mubar & tritium production in Lithium



^{16}O 400-100 KeV negative mubar **enhances** tritium production in the Li^6 240 KeV resonance region

10-6 MeV ~50% difference in cosine **impact** the Li^7(n,n't) plateau

Gamma rays from 14 MeV neutron interactions

Knowledge of neutrons interactions and particle production in **thick** component is required to have confidence in the simulation of **Tritium Production Rate TPR** & **heating**

Open γ-producing channels

In ^{186}W, at E_n = 25.3 meV; $\sigma_R(n+^{186}W\ @\ E_n)=\sigma(n,\gamma)$ **Fission range < 2 MeV**

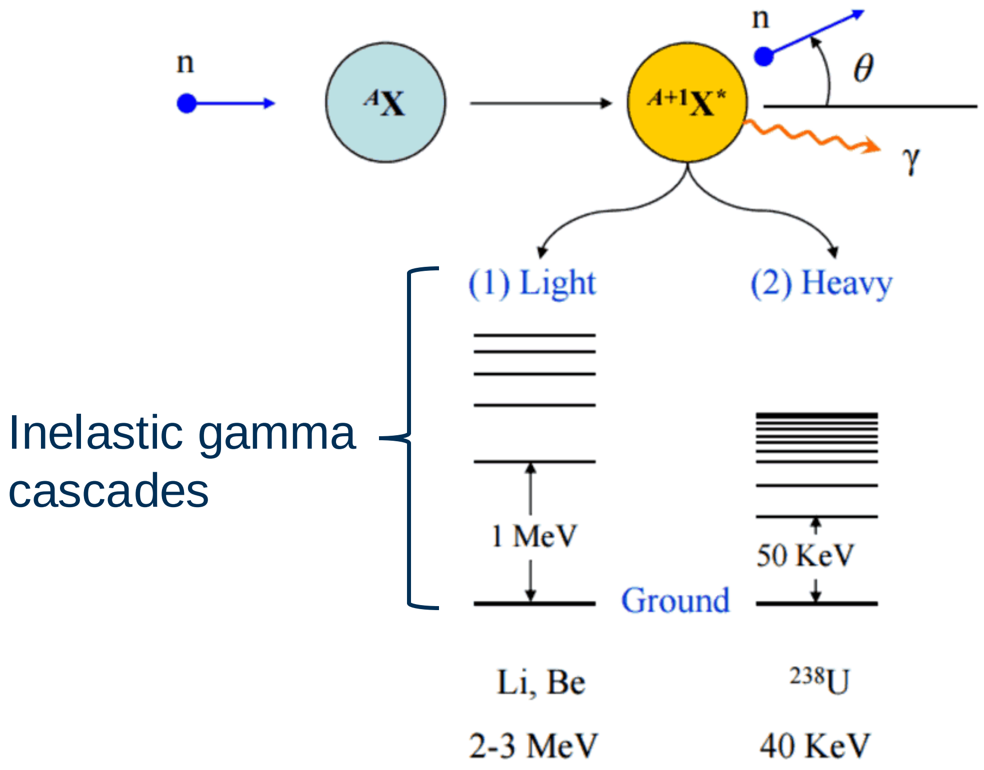
In ^{186}W, at E_n = 14 MeV; $\sigma_R(n+^{186}W\ @\ E_n) = \sigma(n,\gamma)$ **+ σ(n,n′) + σ(n,np) + σ(n,2n) +.. Fusion range < 14 MeV**

More open channels @ 14 MeV

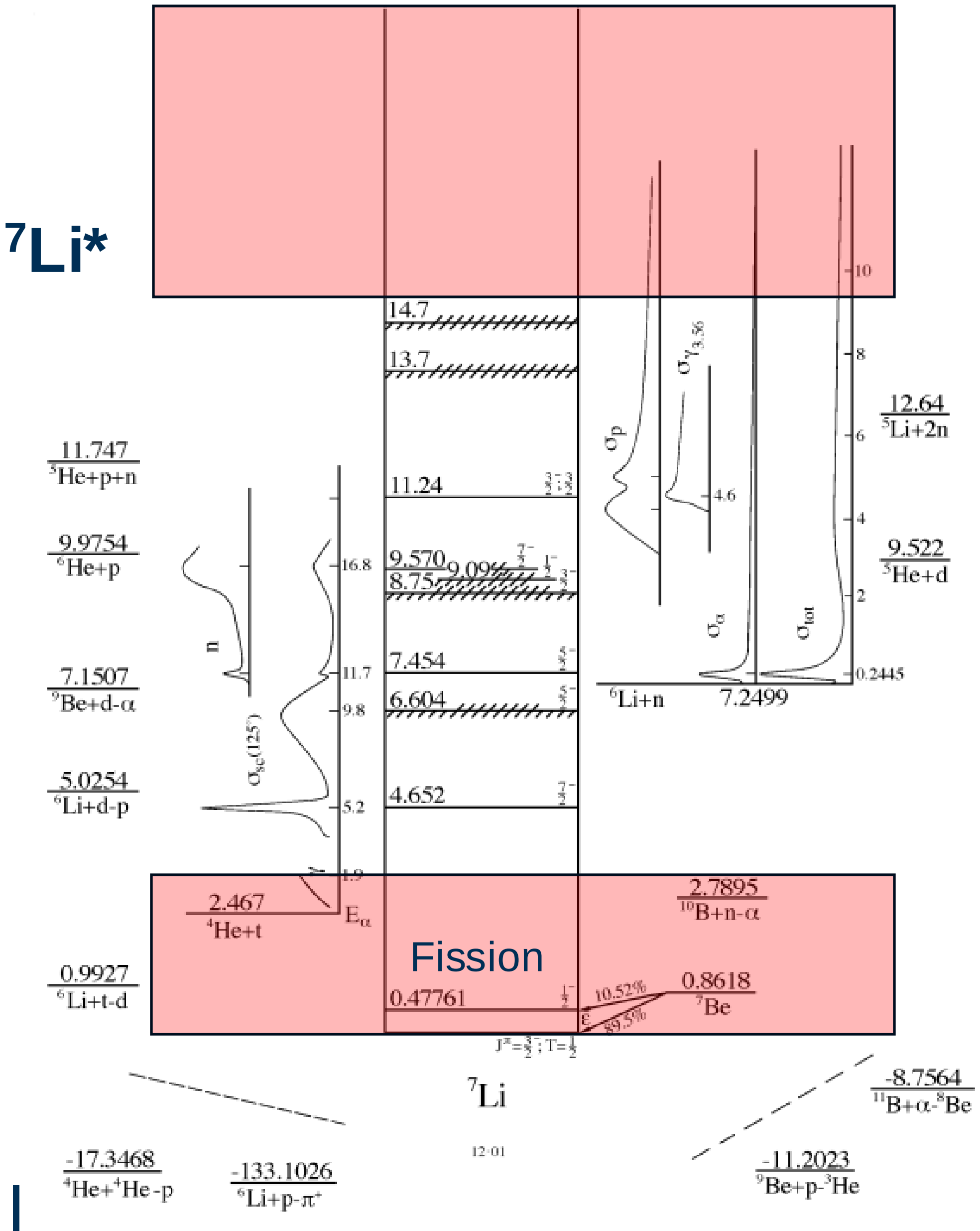
Prompt (A*, A+1,..) and delayed γ-rays

Bagdad atlas & EGAF & ENSDF

- missing excited states (A*)
- missing prompt – primary & secondary
- incomplete de-excitation scheme
- **➔incomplete evaluated file**



A=7 energy levels



^{7}Li+n E_{lab}=18 MeV

Products	Q-value (MeV)	Threshold
^{8}Li + γ	2.032	0
^{7}Li + n	0	0
α + **n** + **<u>t</u>** (n,n't)	**-2.467**	**2.822**
^{5}He + **<u>t</u>**	**-3.203**	**3.664**
^{4}H + α	-4.070	4.650
^{6}Li + **2n**	-7.251	**8.294**
^{6}He + d	-7.749	8.864
α + **2n** + d	-8.724	**9.980**
^{5}He + **n** + d	-9.460	**10.821**
^{6}He + **n** + p	-9.973	**11.409**
^{7}He + p	-10.384	11.878
α + **3n** + p	-10.949	**12.525**
^{5}He + **2n** + p	-11.684	**13.366**
^{5}Li + **3n**	-12.910	**14.770**

<u>t</u>
t out

bold
n out

fusion
only

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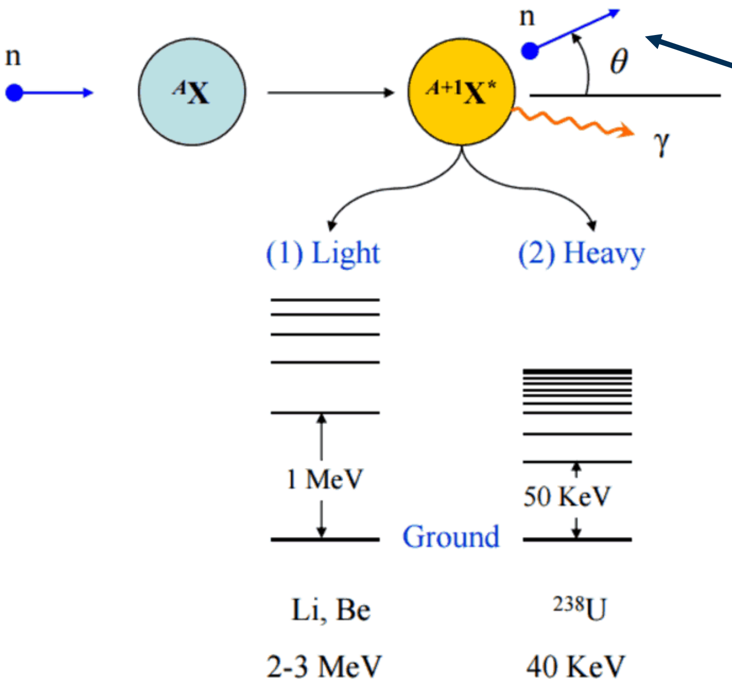
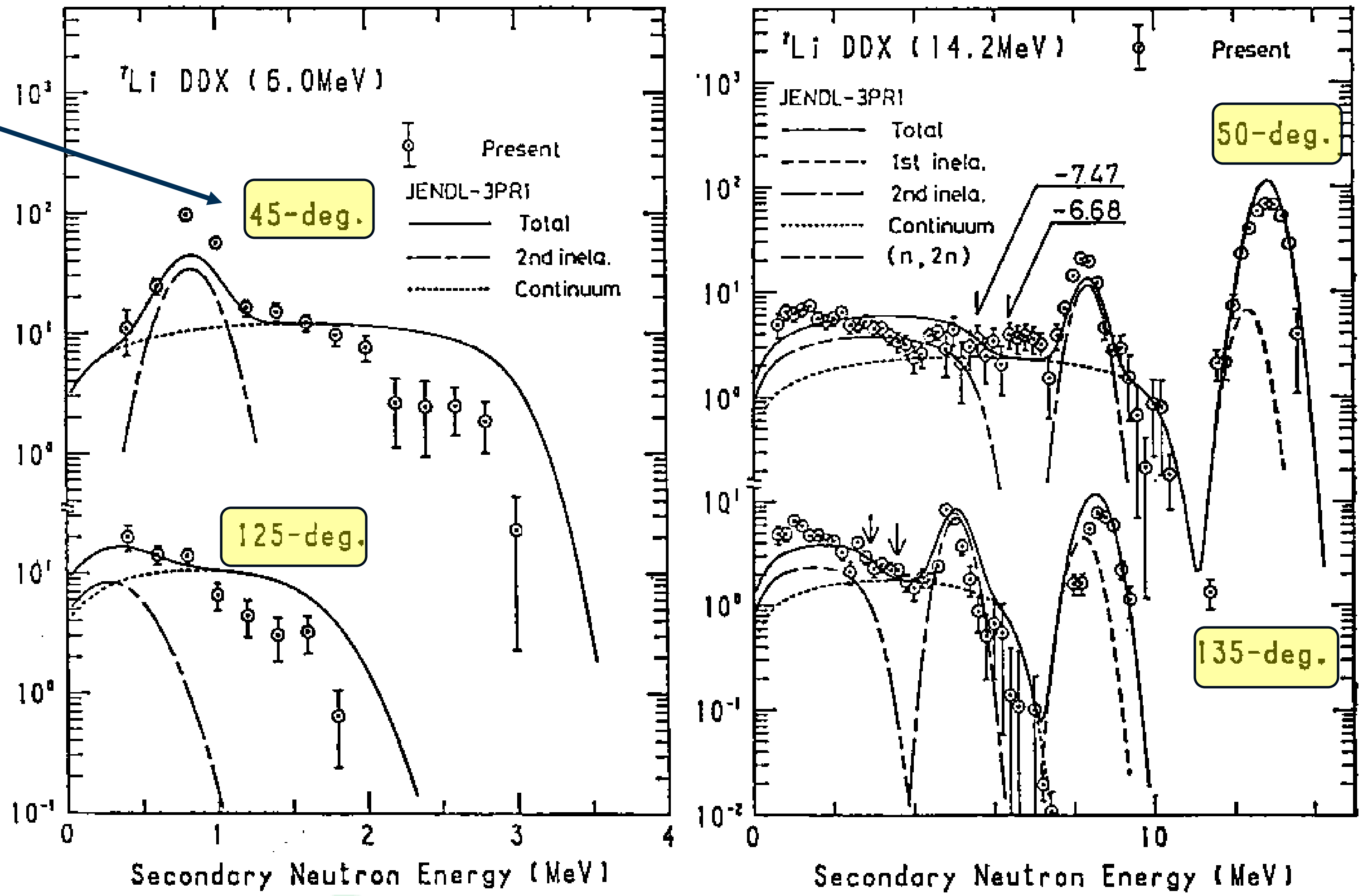
- Li evaluation uncertainty, integral experiments are needed to **V&V fusion metrics**
- ENDF/B-VIII, JENDL-5 Li evaluations rely on pseudo levels !!
- DDXs on ^{7}Li (b) 6 MeV and (c) 14.2 MeV, exhibit C/E disagreements -log-lin@deg.



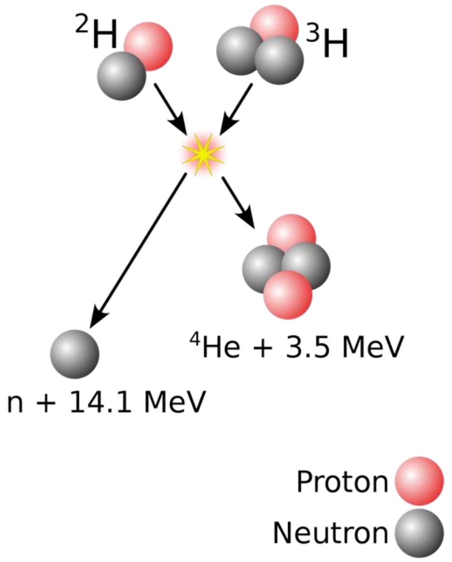
n' DE/DA secondary distribution are important data



(b) (c)

Courtesy: S. Chiba

Neutron & fusion technology



^{2}H + ^{3}H =(^{5}He)=> ^{4}He + n + **17.6 MeV** @~1.00

D + T =(^{5}He)=> ^{5}He + γ_0 (**16.75 MeV**) @~4 10^{-5}

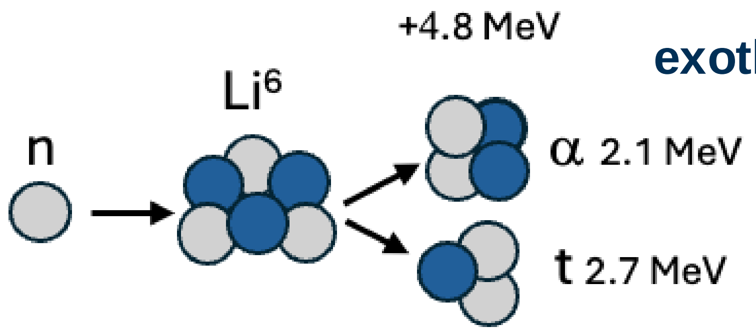
^{5}He*+ γ_1 (~**13.5 MeV**) $\gamma_1 : \gamma_0$ ~2.1 in ICF

~# in MCF

Tritium need to be breed, Deuterium 0.015% (150 ppm)

n + ^{6}Li ===> ^{4}He + ^{3}H (tritium) + **4.8 MeV - gas emission - breakup**

n + ^{7}Li ===> ^{4}He + ^{3}H + n **- still gas emission - breakup**

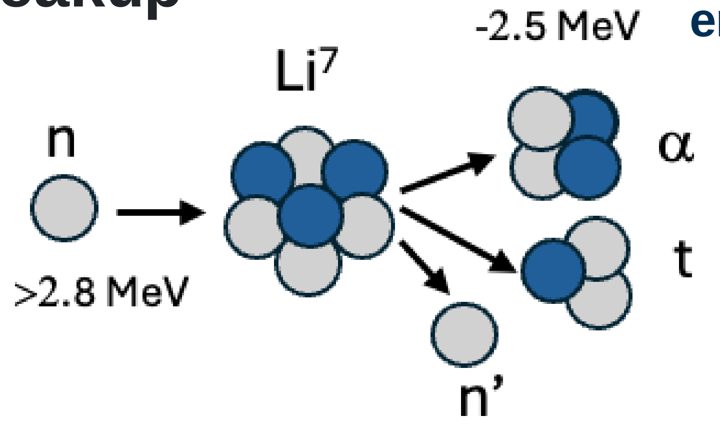


exothermic +

Born fast & in-flight

***β*- ^{3}He**

endothermic -



In both cases, the target **Li^6, Li^7 disappear, is burned, depleted**