LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

[MEASURING THE NEUTRON CAPTURE CROSS SECTION OF ARGON]

– *A Feasibility Study*

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MOTIVATION

- LAr is currently used as a detector material for several low energy and rare event searches which neutrons might interfere with and its' cross section is poorly known.

OBJECTIVES

- Identifying the best describing theorical models for the experimental data and the energy ranges that show the largest discrepancies between data and theorical models and that require further studies.

CROSS SECTION, σ

Measure of the probability that a specific process will take place when some kind of radiant excitation intersects a localized phenomenon.

ELASTIC CROSS SECTION, σ_E

Probability of a scattering process occurring when two particles elastically collide only changing its directions, where the kinetic energy and momenta are conserved.

NON-ELASTIC CROSS SECTION, σ_{NE}

= Total Cross-Section – Elastic Cross-Section

Probability of a scattering process occurring when two particles collide changing the target nucleous, and creating new particles, easily detectable.

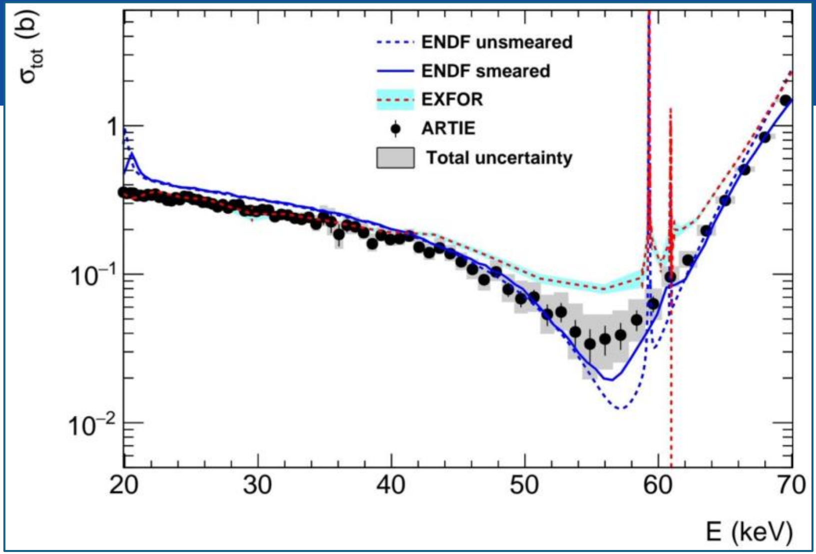
MEAN FREE PATH

$$\lambda[cm] = \frac{1}{\sigma[cm^2]n[cm^{-3}]}$$

n represents the density of particles in the medium.

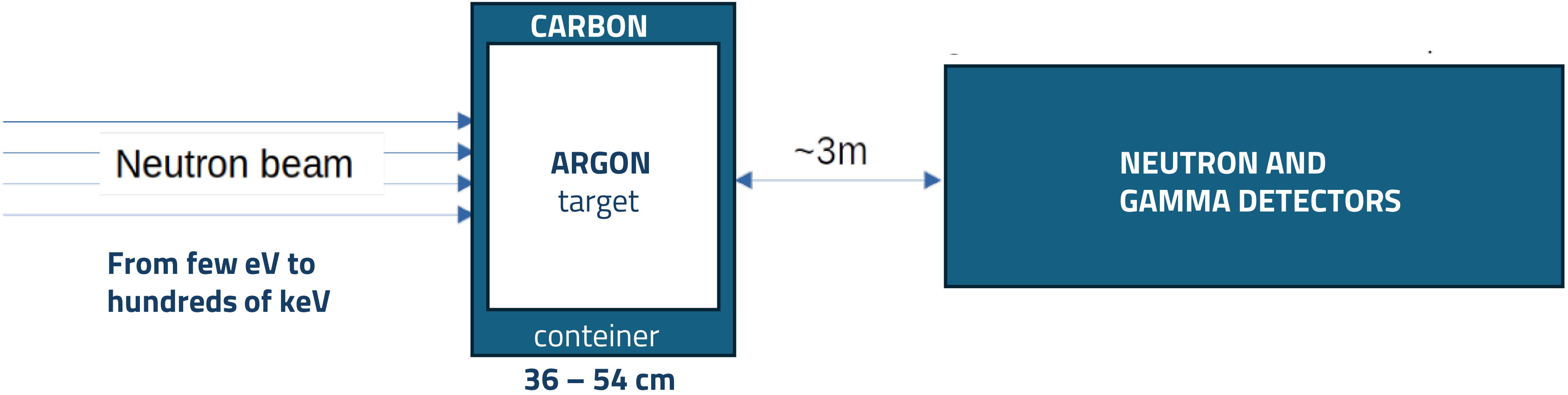
Particles' Path before an interaction.

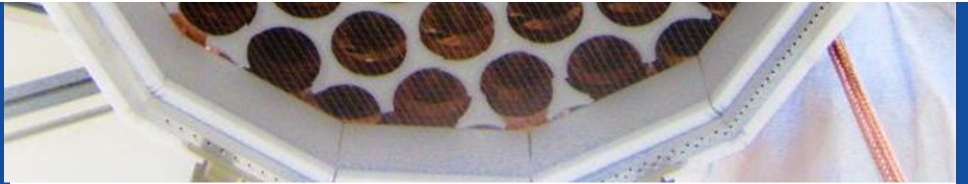
It was recently verified that the neutron's free path is approximately 10 times bigger that it was known before, due to the Neutron-Argon Cross Section being 10 times smaller. These new measurements are more in agreement with the theoretical models.



Neutron-Argon total cross section as a funcion of energy

MArEx at CERN Experimental Setup





Carbon and Argon
Natural Abundances

Argon 40

99,6%
18 protons
22 neutrons

Argon 36

0,336%
18 protons
18 neutrons

Argon 38

0,063%
18 protons
20 neutrons

Carbon 12

98,89%
6 protons
6 neutrons

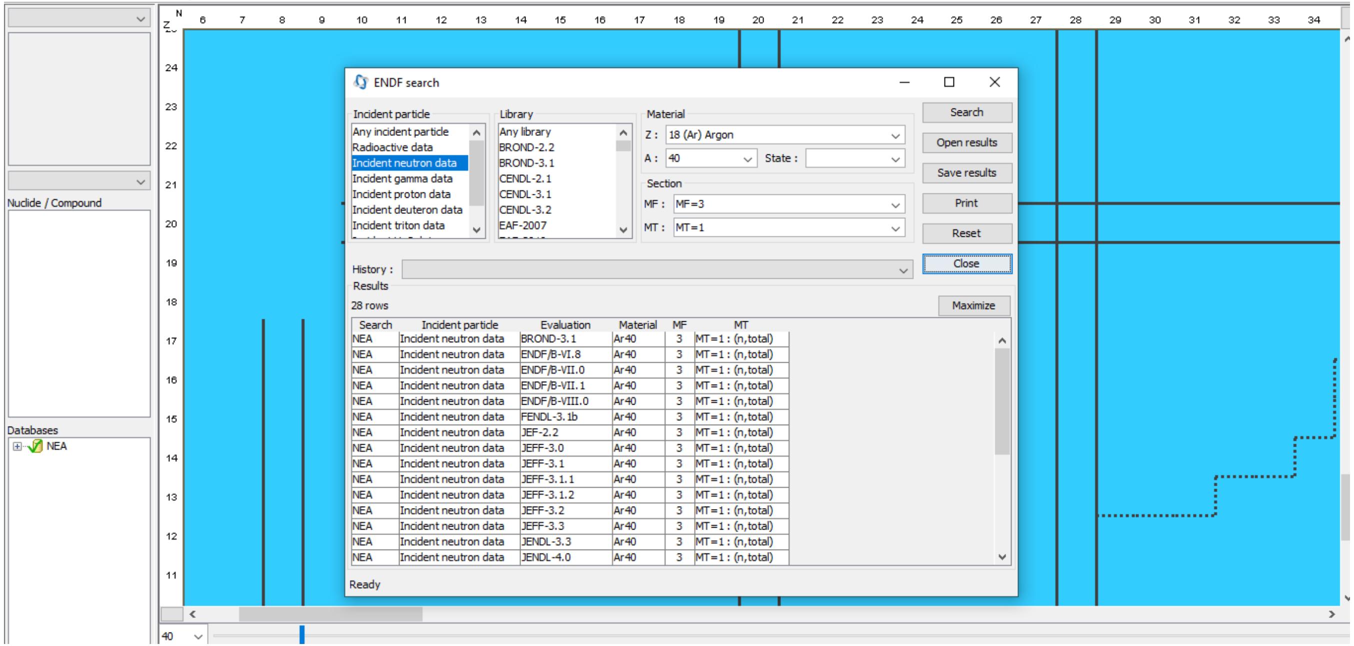
Carbon 13

1,11%
6 protons
7 neutrons

Janis Web 4.1

https://www.oecd-nea.org/janisweb/

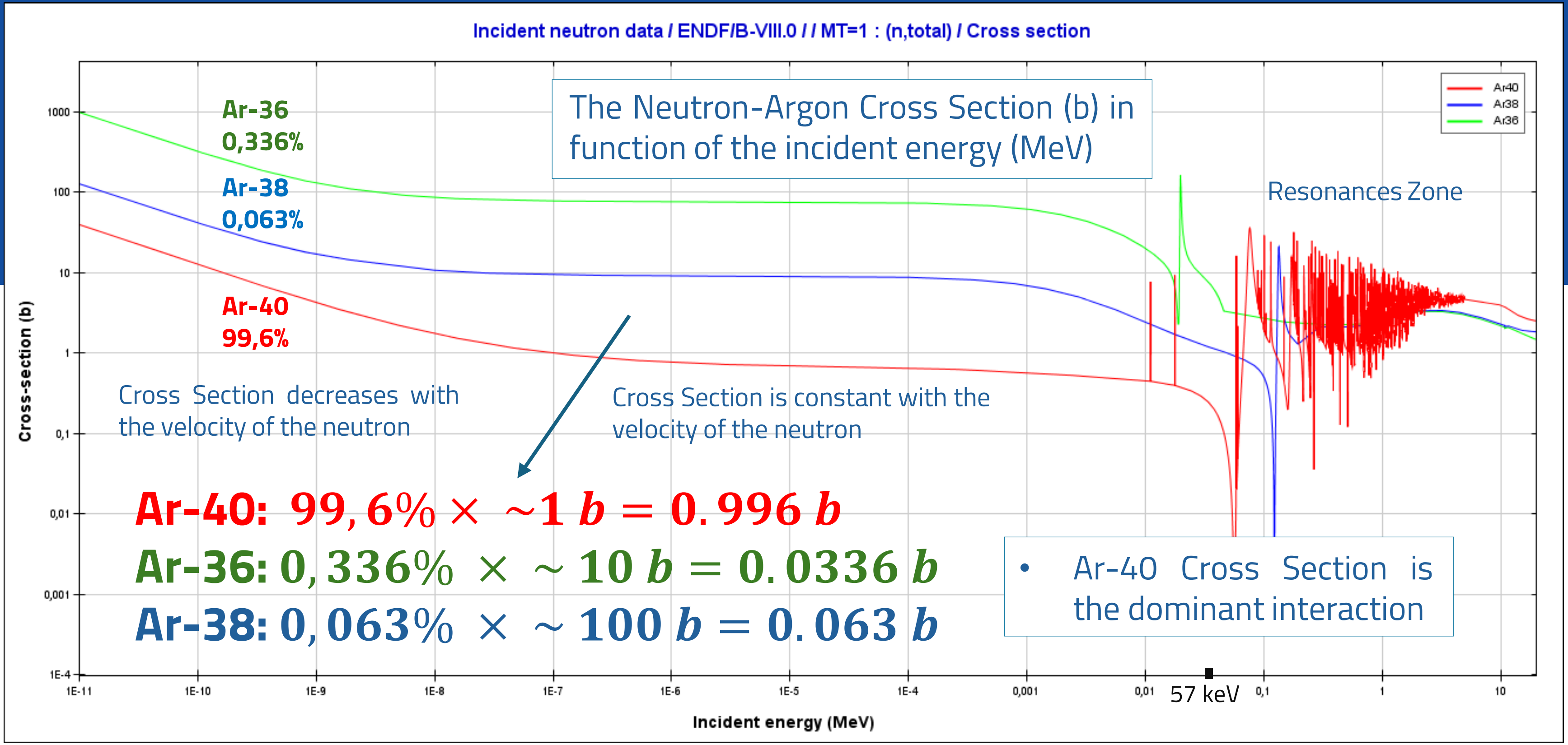
ENDF Theorical Models: Evaluated Nuclear Data Files
EXFOR Experimental Data: Experimental Nuclear Reaction Data



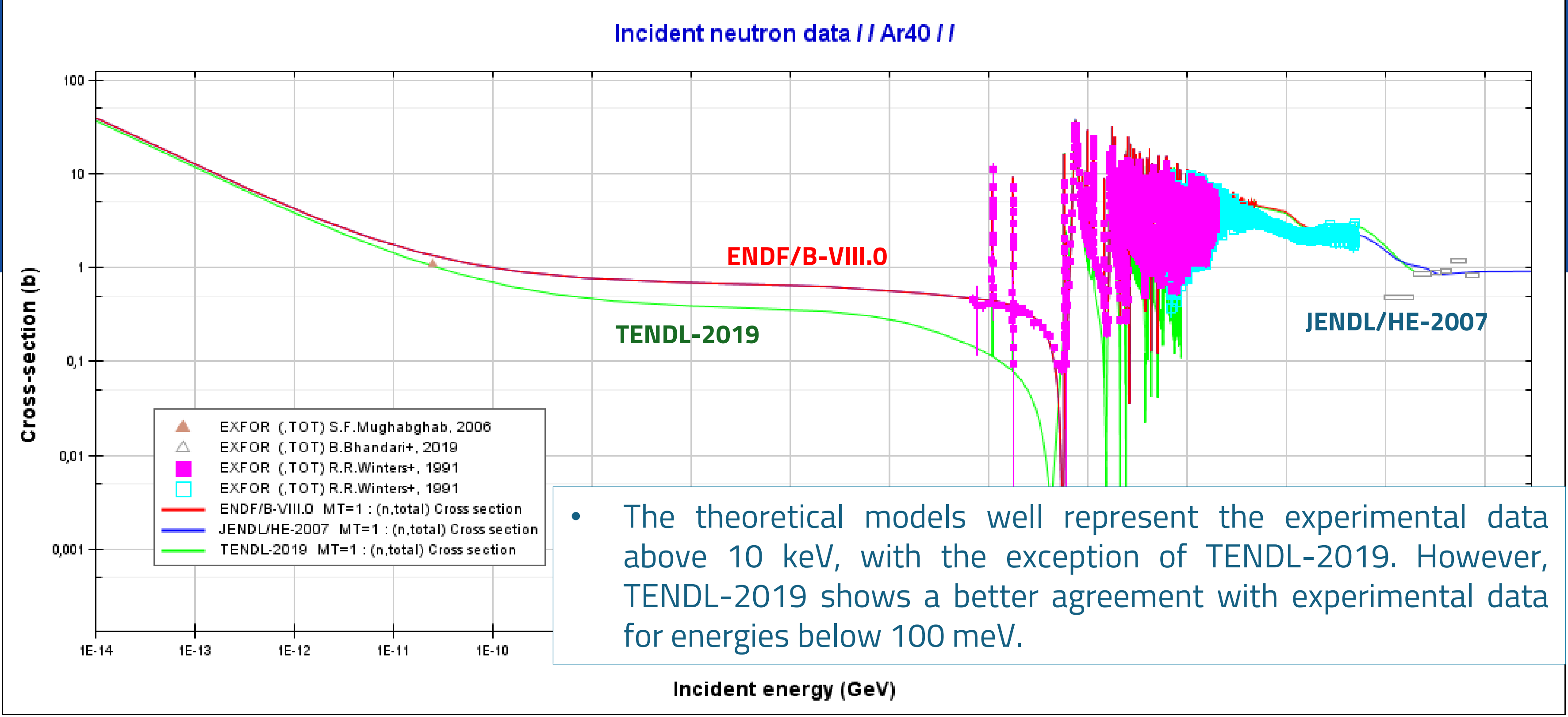
Janis Web 4.1 allows to stablish a comparisson between Neutron-Argon and Neutron-Carbon Cross Sections

1.
Argon (target)

Total 40Ar, 36Ar and 38Ar Cross Section

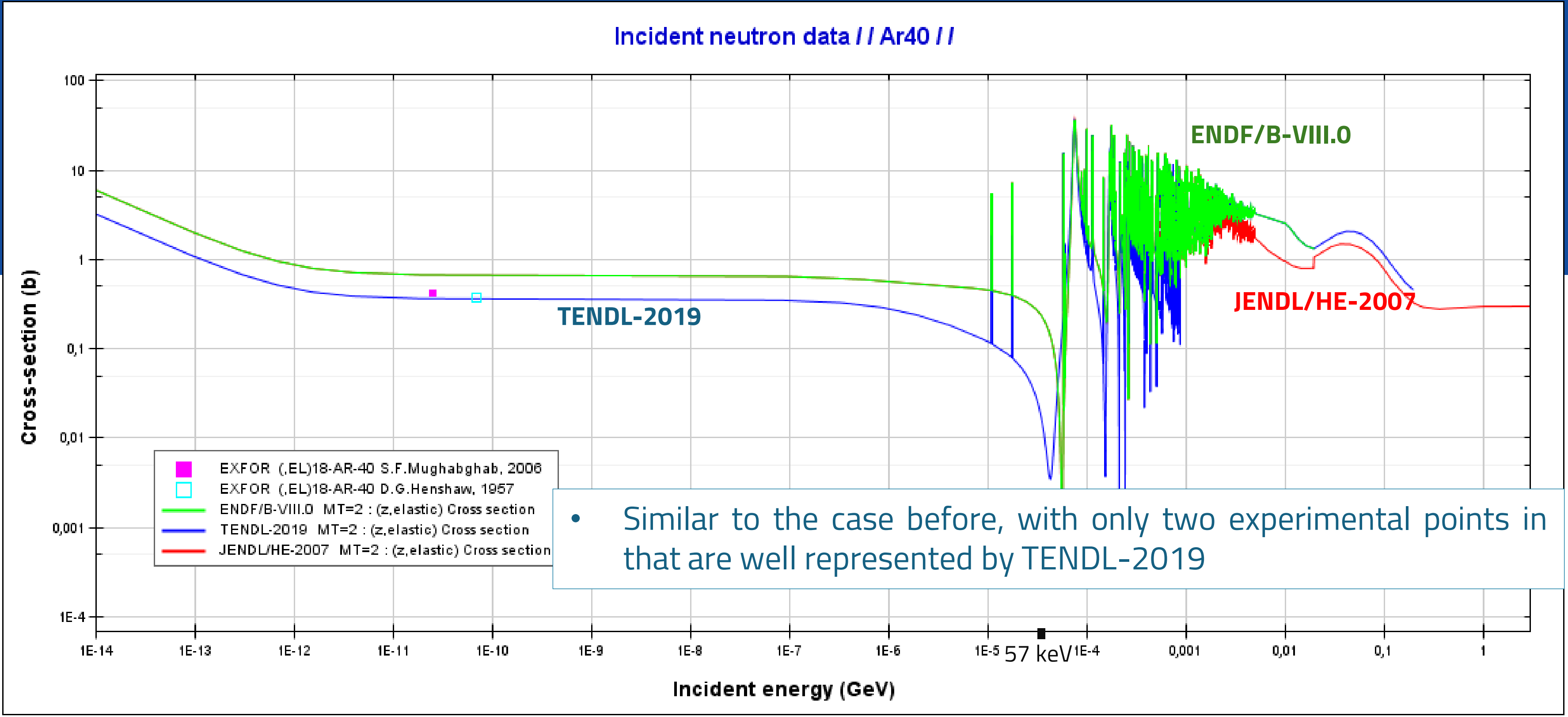


Total 40Ar Cross Section



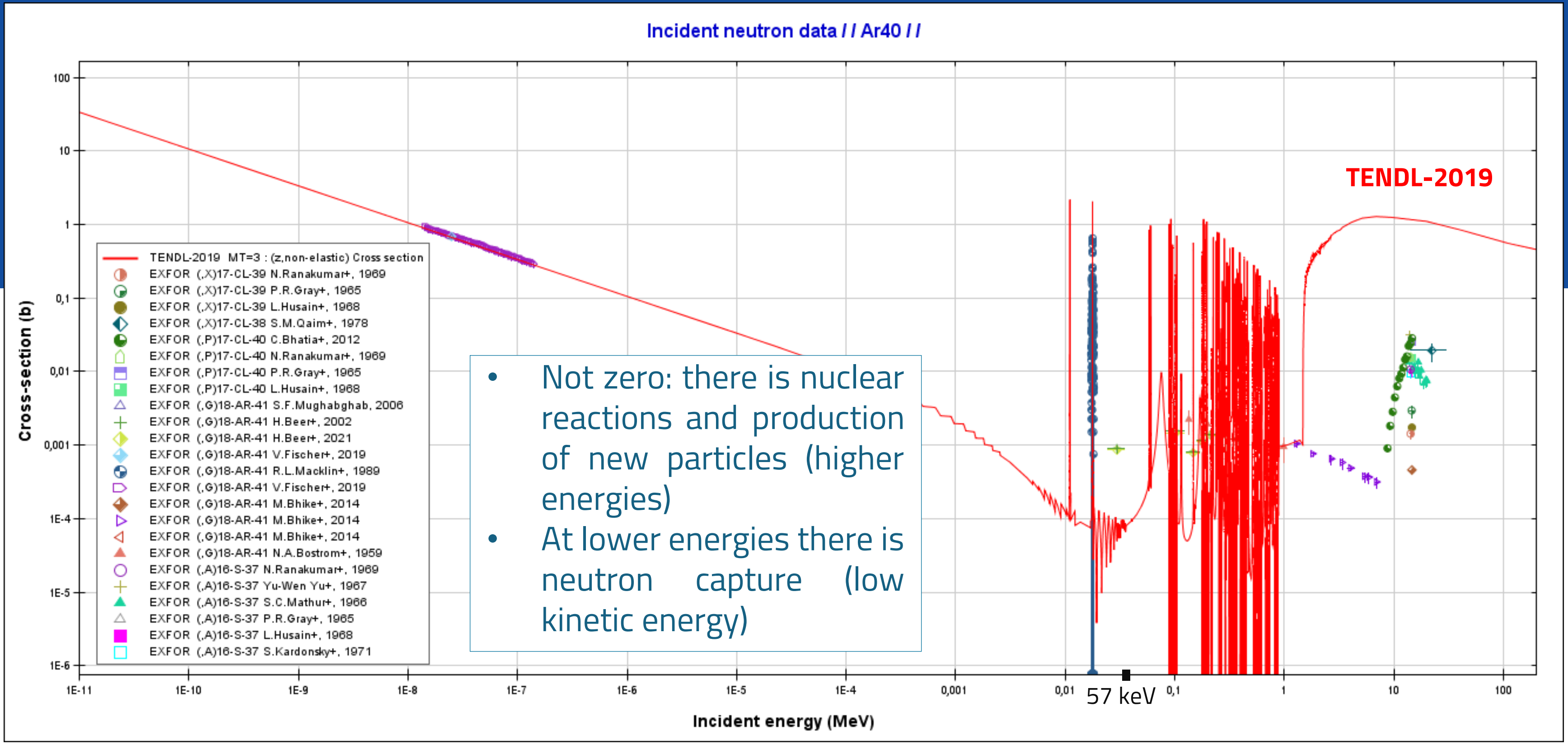
- The theoretical models well represent the experimental data above 10 keV, with the exception of TENDL-2019. However, TENDL-2019 shows a better agreement with experimental data for energies below 100 meV.

Elastic 40Ar Cross Section



- Similar to the case before, with only two experimental points in that are well represented by TENDL-2019

Non-Elastic 40Ar Cross Section



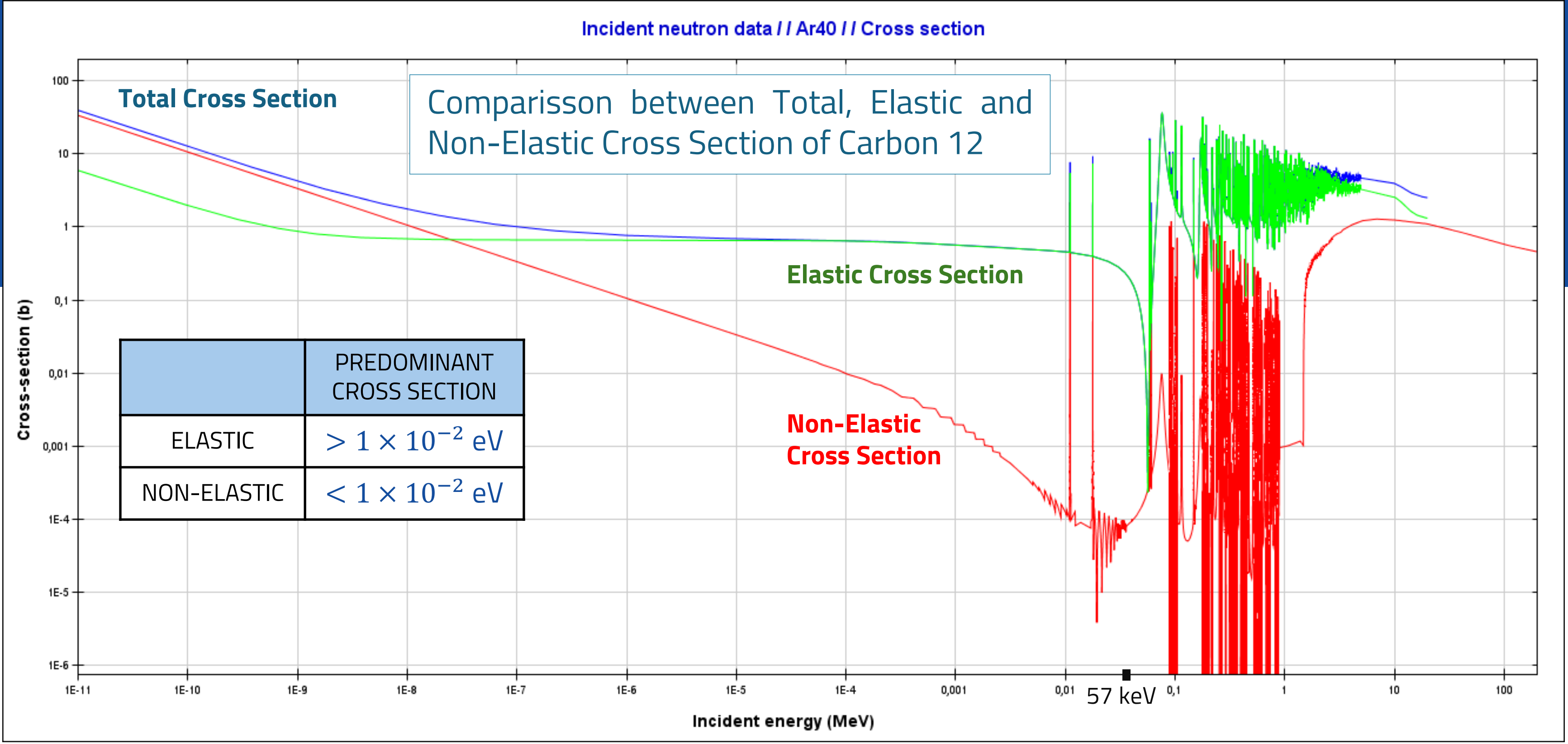
- Not zero: there is nuclear reactions and production of new particles (higher energies)
- At lower energies there is neutron capture (low kinetic energy)

DETECTED NUCLEAR REACTIONS

ENERGY	EMISSION
[10; 100] MeV	n + Ar-40 → α + S-37
[0.01; 0.1] eV / [1; 10] MeV	n + Ar-40 → γ + Ar-41 (n-capture)
[8; 20] MeV	n + Ar-40 → p + Cl-40
[0.01; 0.05] MeV	n + Ar-40 → X(2n+p) + Cl-38 n + Ar-40 → X(n+p) + Cl-39

TERMAL NEUTRONS: Specific energy state of neutrons are characterized by their kinetic energy, which is roughly equivalent to the thermal energy of their surrounding environment, typically at room temperature and are more likely to interact with atomic nuclei due to their lower kinetic energy.

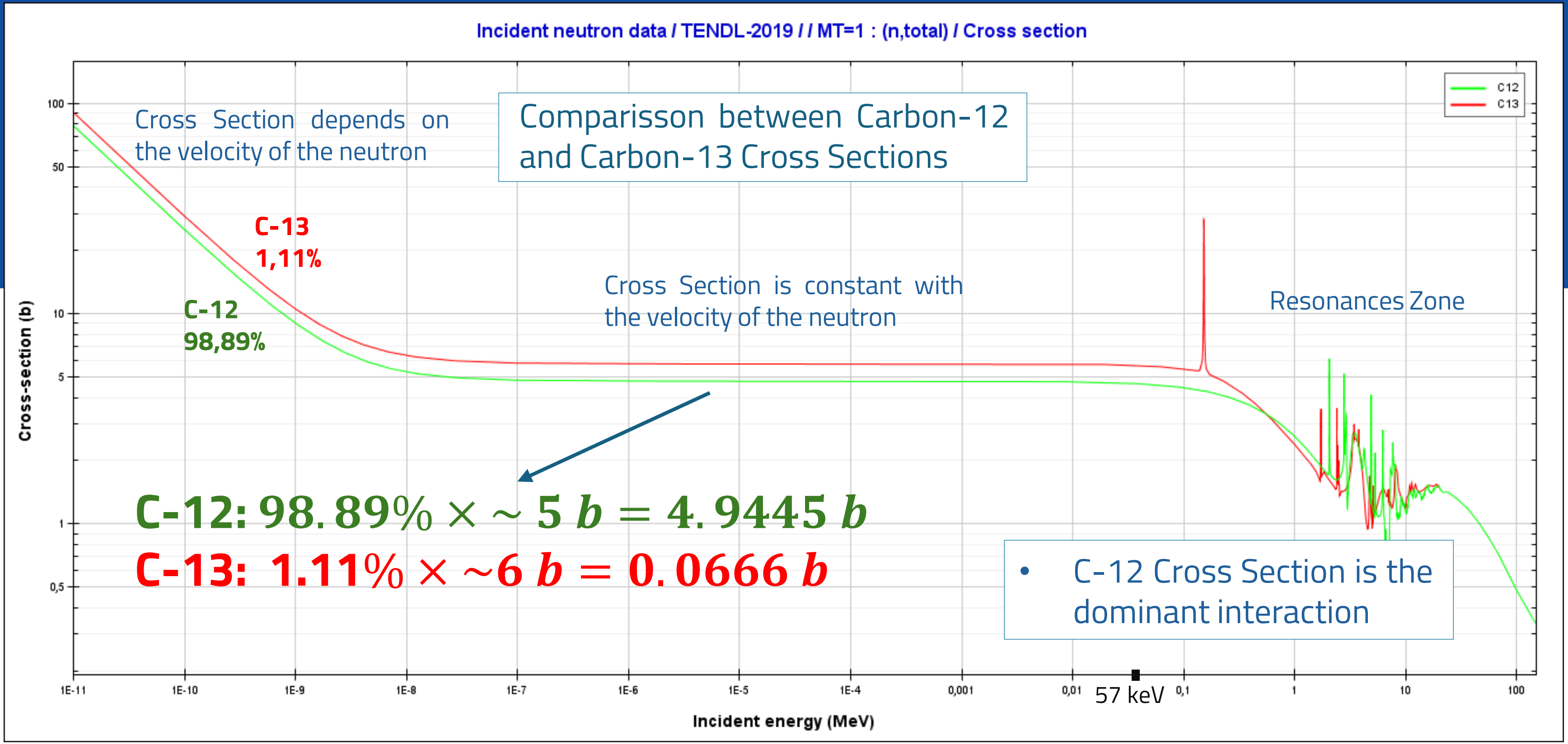
Total, Elastic and Non-Elastic 40Ar Cross Section



	PREDOMINANT CROSS SECTION
ELASTIC	$> 1 \times 10^{-2}$ eV
NON-ELASTIC	$< 1 \times 10^{-2}$ eV

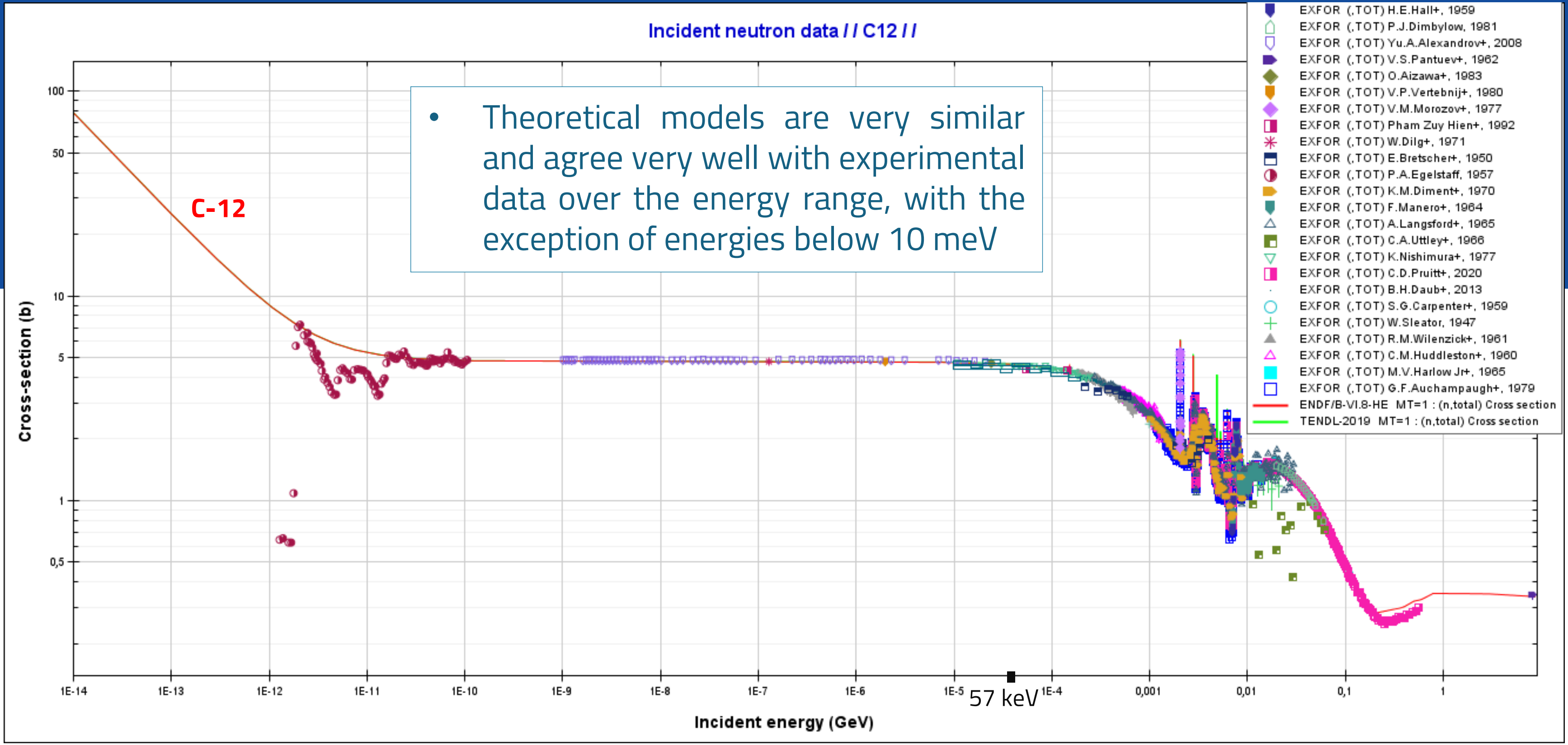
2.
Carbon (conteiner)

Total 12C and 13C Cross Section

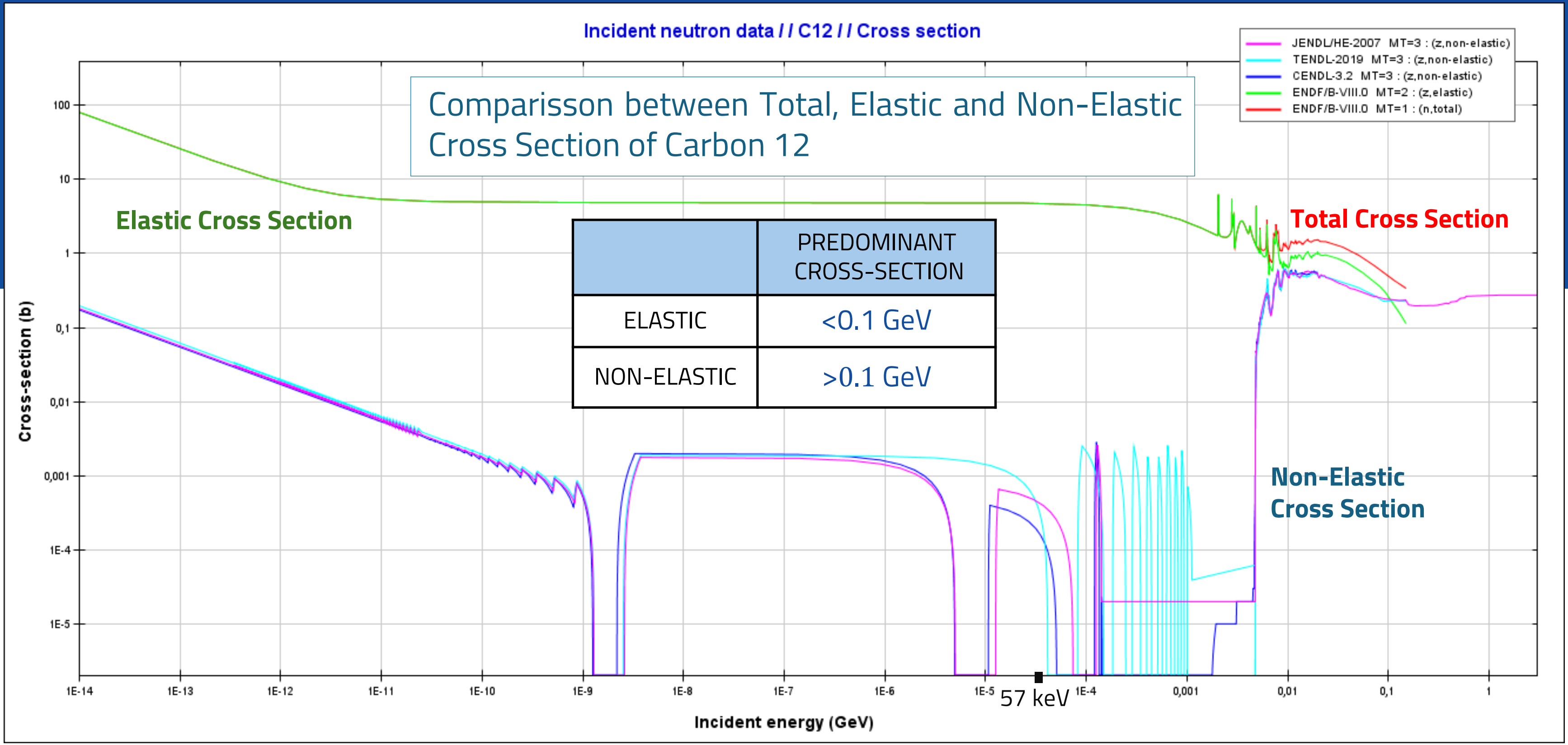


Total 12C Cross Section

- Theoretical models are very similar and agree very well with experimental data over the energy range, with the exception of energies below 10 meV



Total, Elastic and Non-Elastic 12C Cross Section

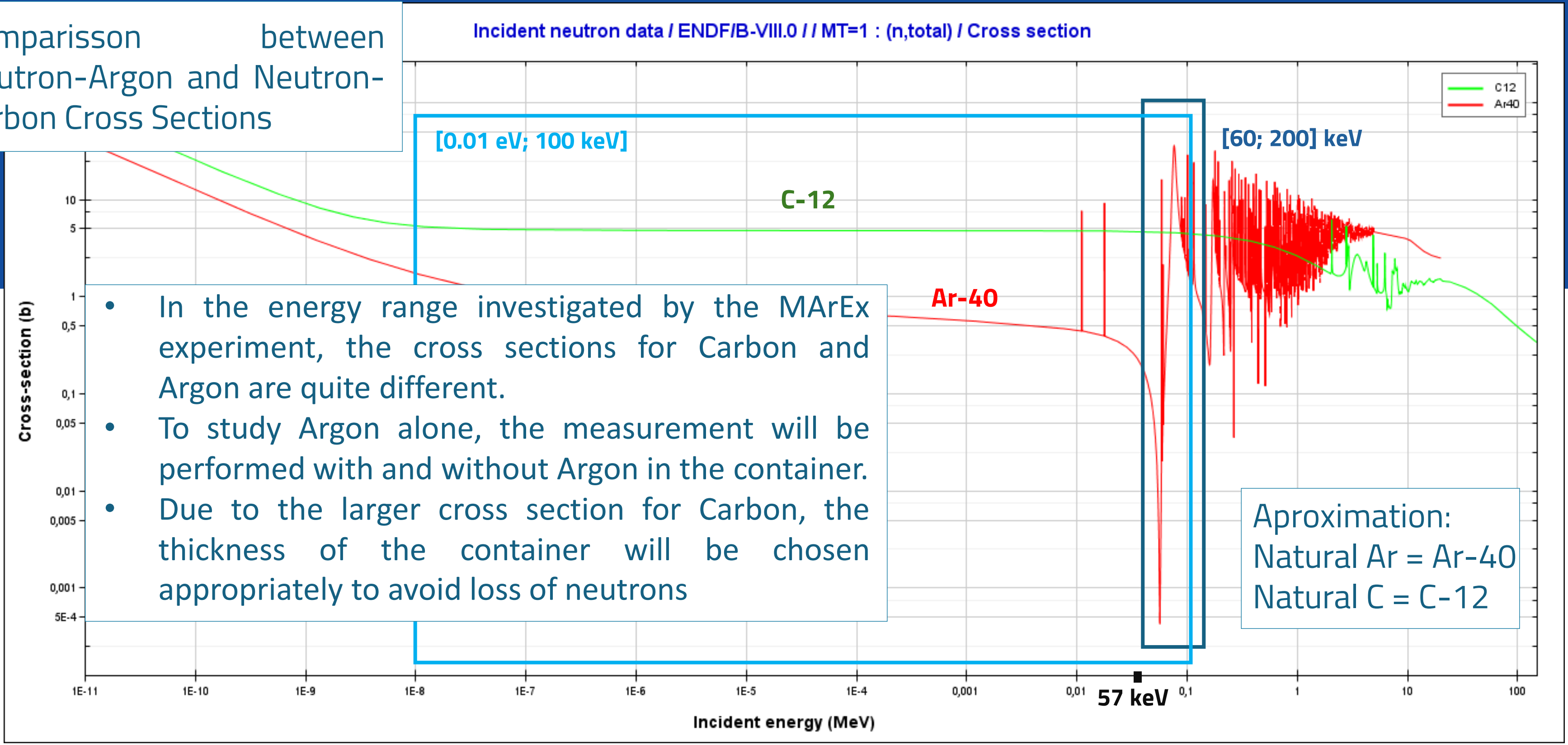


Comparisson between Total, Elastic and Non-Elastic Cross Section of Carbon 12

	PREDOMINANT CROSS-SECTION
ELASTIC	<0.1 GeV
NON-ELASTIC	>0.1 GeV

Total 40Ar Cross Section vs 12C Cross Section

Comparisson between Neutron-Argon and Neutron-Carbon Cross Sections



- In the energy range investigated by the MArEx experiment, the cross sections for Carbon and Argon are quite different.
- To study Argon alone, the measurement will be performed with and without Argon in the container.
- Due to the larger cross section for Carbon, the thickness of the container will be chosen appropriately to avoid loss of neutrons

Aproximation:
Natural Ar = Ar-40
Natural C = C-12

CONCLUSIONS

- I have shown that for natural abundance targets the dominant interactions are on the most abundant isotopes: 40Ar and 12C.

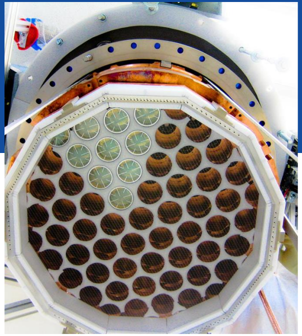
- For neutron's interactions on **Carbon** targets, theoretical models agree very well with experimental data over the energy range, with the exception of energies below 10 meV, which however are less relevant for the MArEx experiment.

- Due to this well known behaviour Carbon is a good material for building containers + neutron interactions on Carbon can be used as a reference.

CONCLUSIONS

- For neutron's interactions on **Argon** targets, the theoretical models well represent the experimental data above 10 keV, with the exception of TENDL-2019. However, TENDL-2019 shows a better agreement with experimental data for energies below 100 meV.

- It is important to investigate the energy range below 10 keV (lack of experimental data) and the resonance region (disagreement between old and new experimental data).

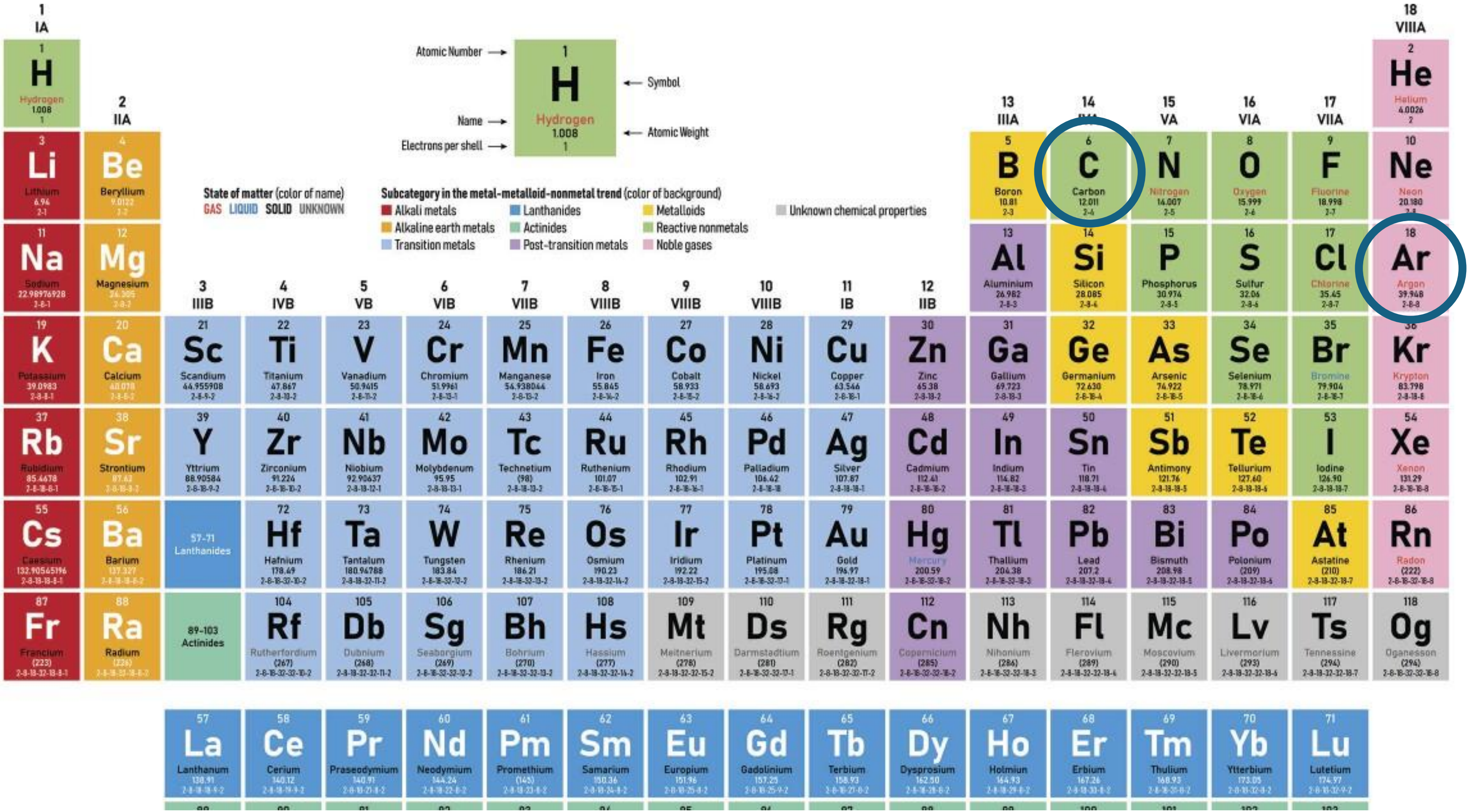


Thank you for the atention!

Any questions?

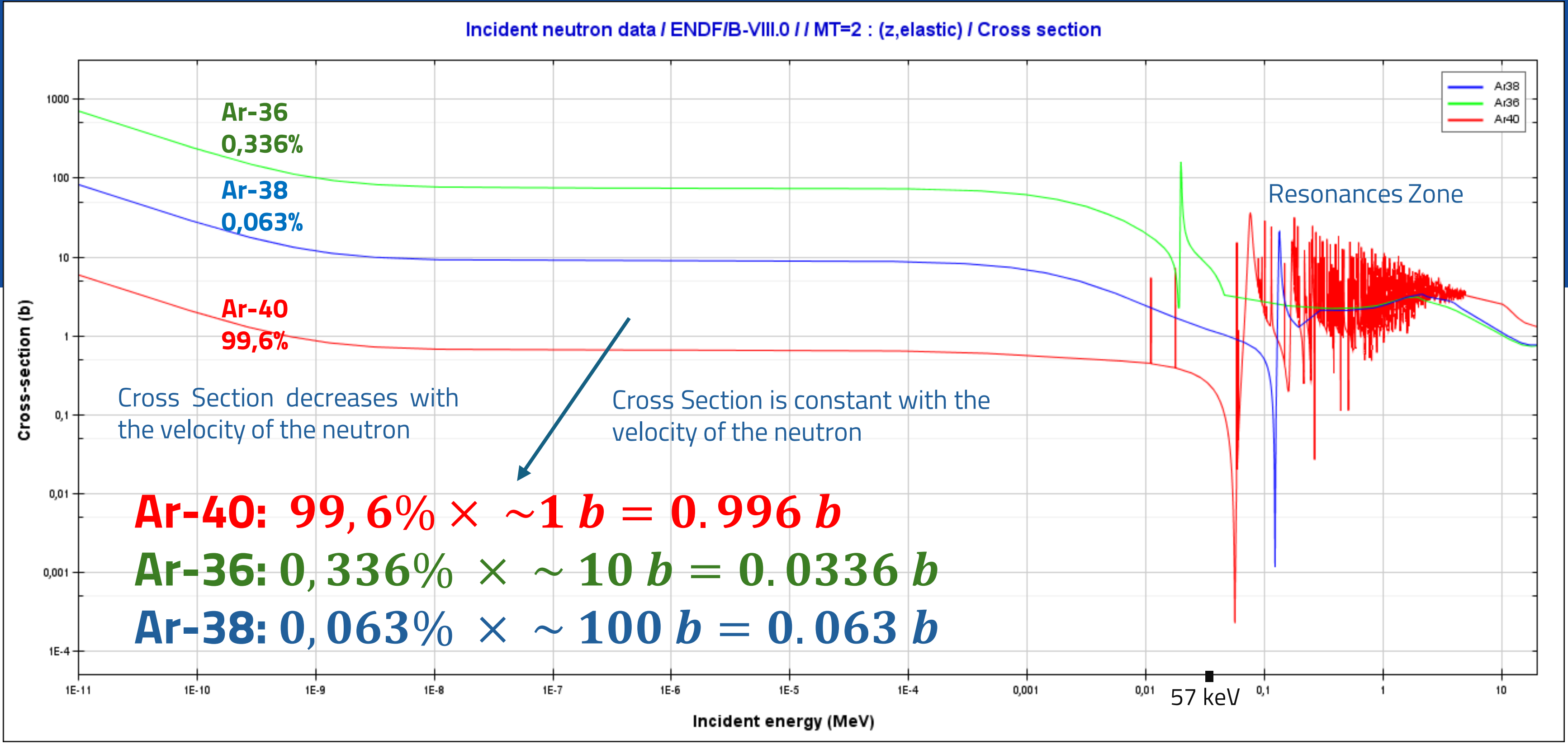
You can find me at fc58292@alunos.fc.ul.pt

5.
Backup



1 IA
2 IIA
3 IIIB
4 IVB
5 VB
6 VIB
7 VIIB
8 VIIIB
9 VIIIB
10 VIIIB
11 IB
12 IIB
13 IIIA
14 IVA
15 VA
16 VIA
17 VIIA
18 VIIIA
Atomic Number
Symbol
Name
Atomic Weight
Electrons per shell
1 H Hydrogen 1.008 1
State of matter (color of name)
GAS LIQUID SOLID UNKNOWN
Subcategory in the metal-metalloid-nonmetal trend (color of background)
Alkali metals
Alkaline earth metals
Transition metals
Lanthanides
Actinides
Post-transition metals
Metalloids
Reactive nonmetals
Noble gases
Unknown chemical properties
1 H Hydrogen
2 He Helium
3 Li Lithium
4 Be Beryllium
5 B Boron
6 C Carbon
7 N Nitrogen
8 O Oxygen
9 F Fluorine
10 Ne Neon
11 Na Sodium
12 Mg Magnesium
13 Al Aluminium
14 Si Silicon
15 P Phosphorus
16 S Sulfur
17 Cl Chlorine
18 Ar Argon
19 K Potassium
20 Ca Calcium
21 Sc Scandium
22 Ti Titanium
23 V Vanadium
24 Cr Chromium
25 Mn Manganese
26 Fe Iron
27 Co Cobalt
28 Ni Nickel
29 Cu Copper
30 Zn Zinc
31 Ga Gallium
32 Ge Germanium
33 As Arsenic
34 Se Selenium
35 Br Bromine
36 Kr Krypton
37 Rb Rubidium
38 Sr Strontium
39 Y Yttrium
40 Zr Zirconium
41 Nb Niobium
42 Mo Molybdenum
43 Tc Technetium
44 Ru Ruthenium
45 Rh Rhodium
46 Pd Palladium
47 Ag Silver
48 Cd Cadmium
49 In Indium
50 Sn Tin
51 Sb Antimony
52 Te Tellurium
53 I Iodine
54 Xe Xenon
55 Cs Caesium
56 Ba Barium
57-71 Lanthanides
72 Hf Hafnium
73 Ta Tantalum
74 W Tungsten
75 Re Rhenium
76 Os Osmium
77 Ir Iridium
78 Pt Platinum
79 Au Gold
80 Hg Mercury
81 Tl Thallium
82 Pb Lead
83 Bi Bismuth
84 Po Polonium
85 At Astatine
86 Rn Radon
87 Fr Francium
88 Ra Radium
89-103 Actinides
104 Rf Rutherfordium
105 Db Dubnium
106 Sg Seaborgium
107 Bh Bohrium
108 Hs Hassium
109 Mt Meitnerium
110 Ds Darmstadtium
111 Rg Roentgenium
112 Cn Copernicium
113 Nh Nihonium
114 Fl Flerovium
115 Mc Moscovium
116 Lv Livermorium
117 Ts Tennessine
118 Og Oganesson
57 La Lanthanum
58 Ce Cerium
59 Pr Praseodymium
60 Nd Neodymium
61 Pm Promethium
62 Sm Samarium
63 Eu Europium
64 Gd Gadolinium
65 Tb Terbium
66 Dy Dysprosium
67 Ho Holmium
68 Er Erbium
69 Tm Thulium
70 Yb Ytterbium
71 Lu Lutetium

Elastic 40Ar, 36Ar and 38Ar Cross Section (backup)

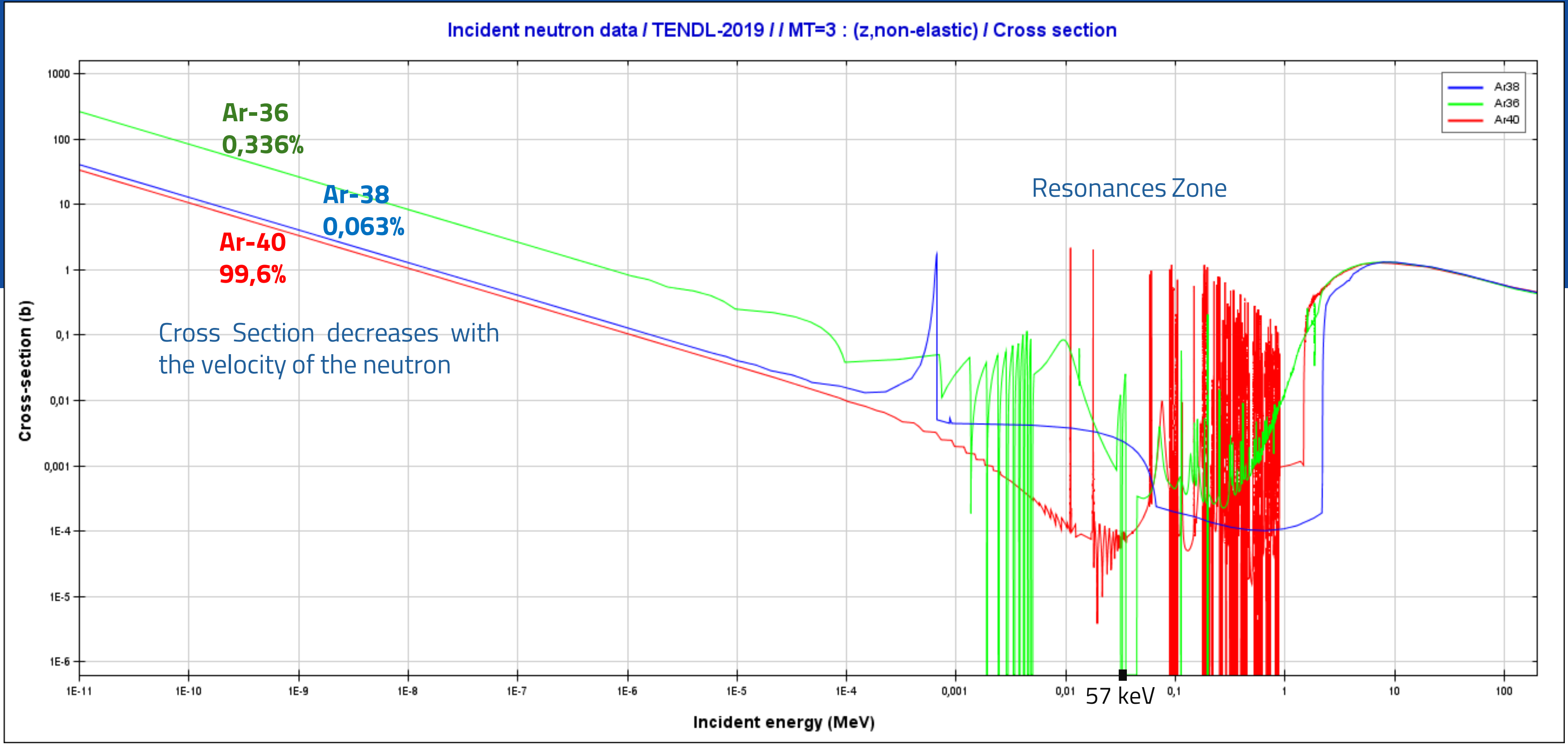


Ar-40: $99,6\% \times \sim 1\ b = 0.996\ b$

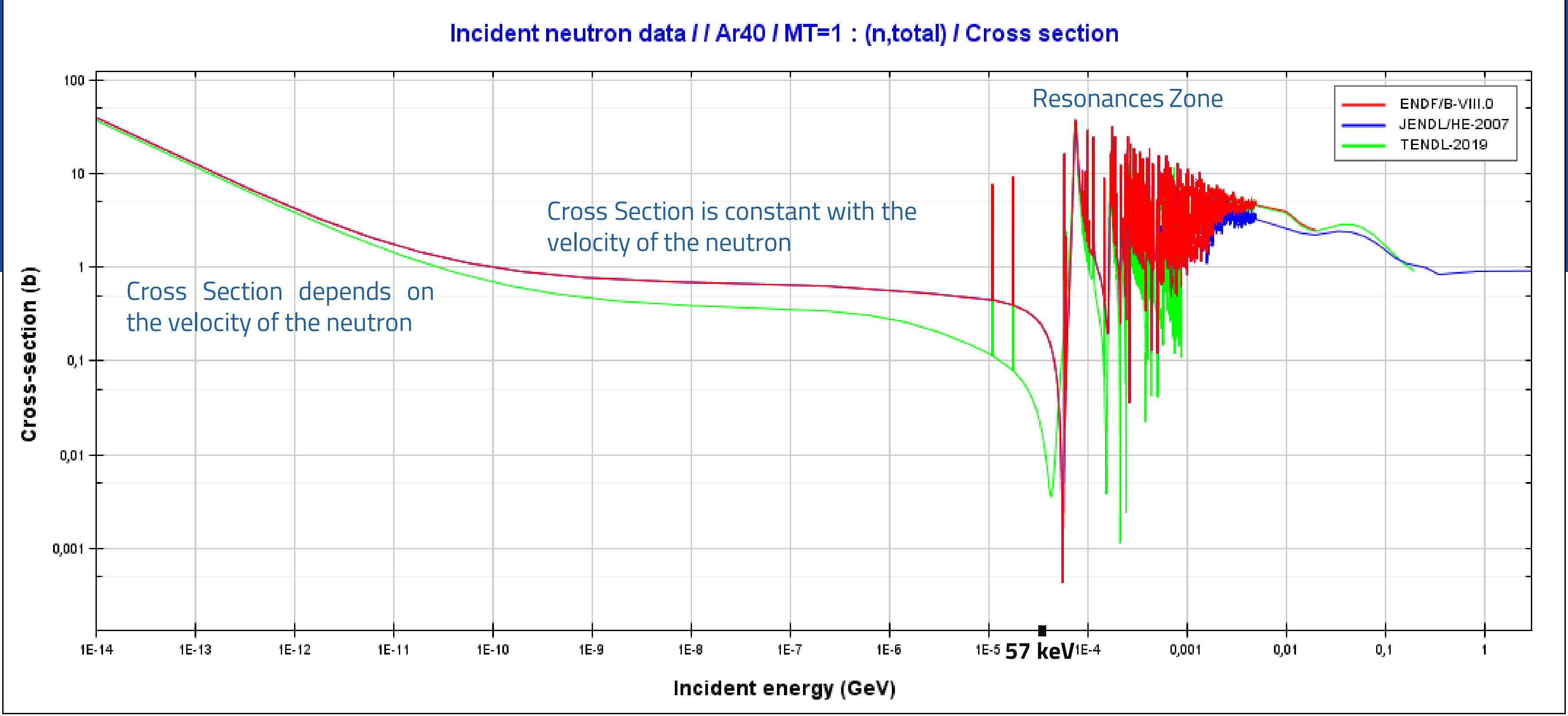
Ar-36: $0,336\% \times \sim 10\ b = 0.0336\ b$

Ar-38: $0,063\% \times \sim 100\ b = 0.063\ b$

Non-Elastic 40Ar, 36Ar and 38Ar Cross Section (backup)

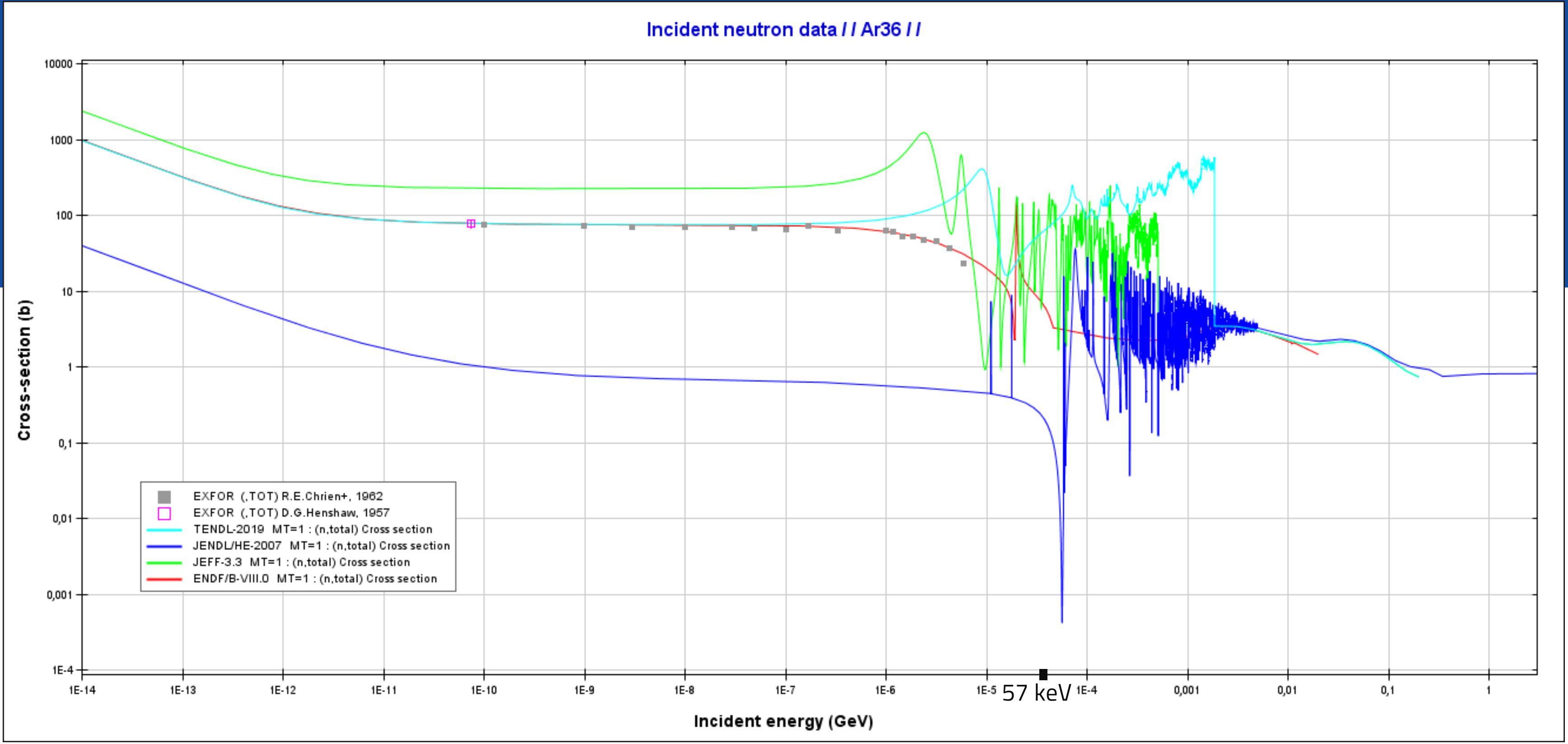


Total 40Ar Cross Section

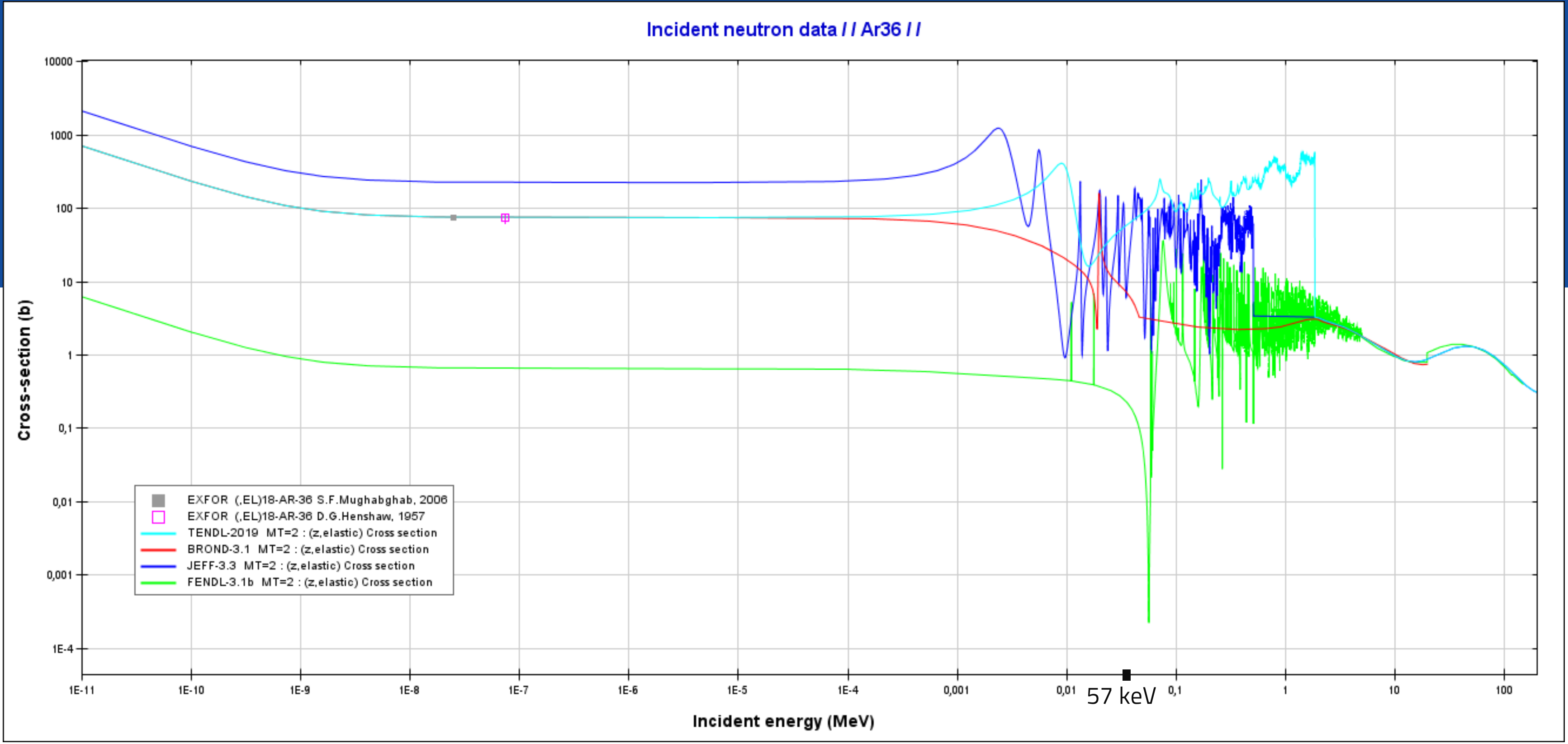


3.1.2
Argon 36 (backup)

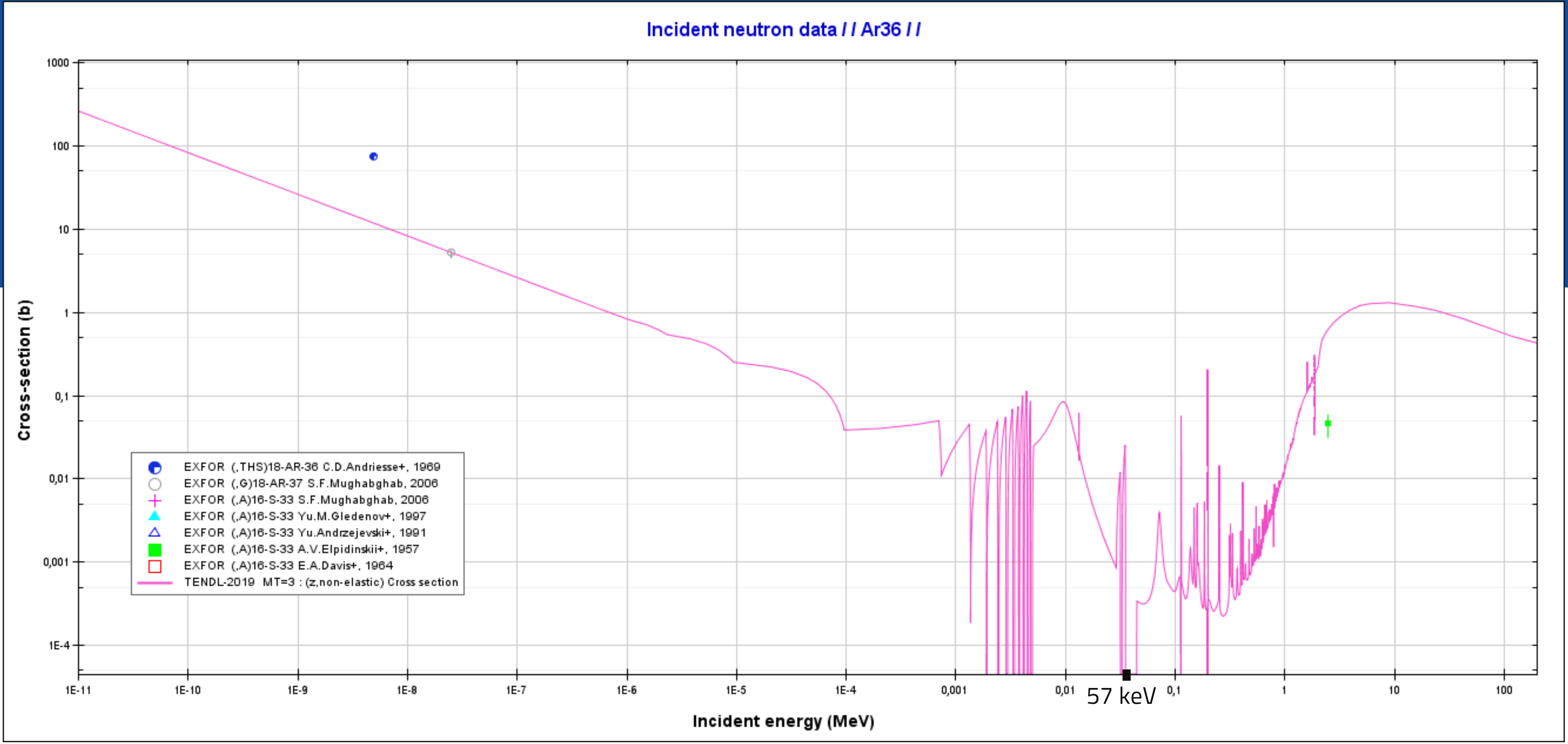
Total 36Ar Cross Section



Elastic 36Ar Cross Section

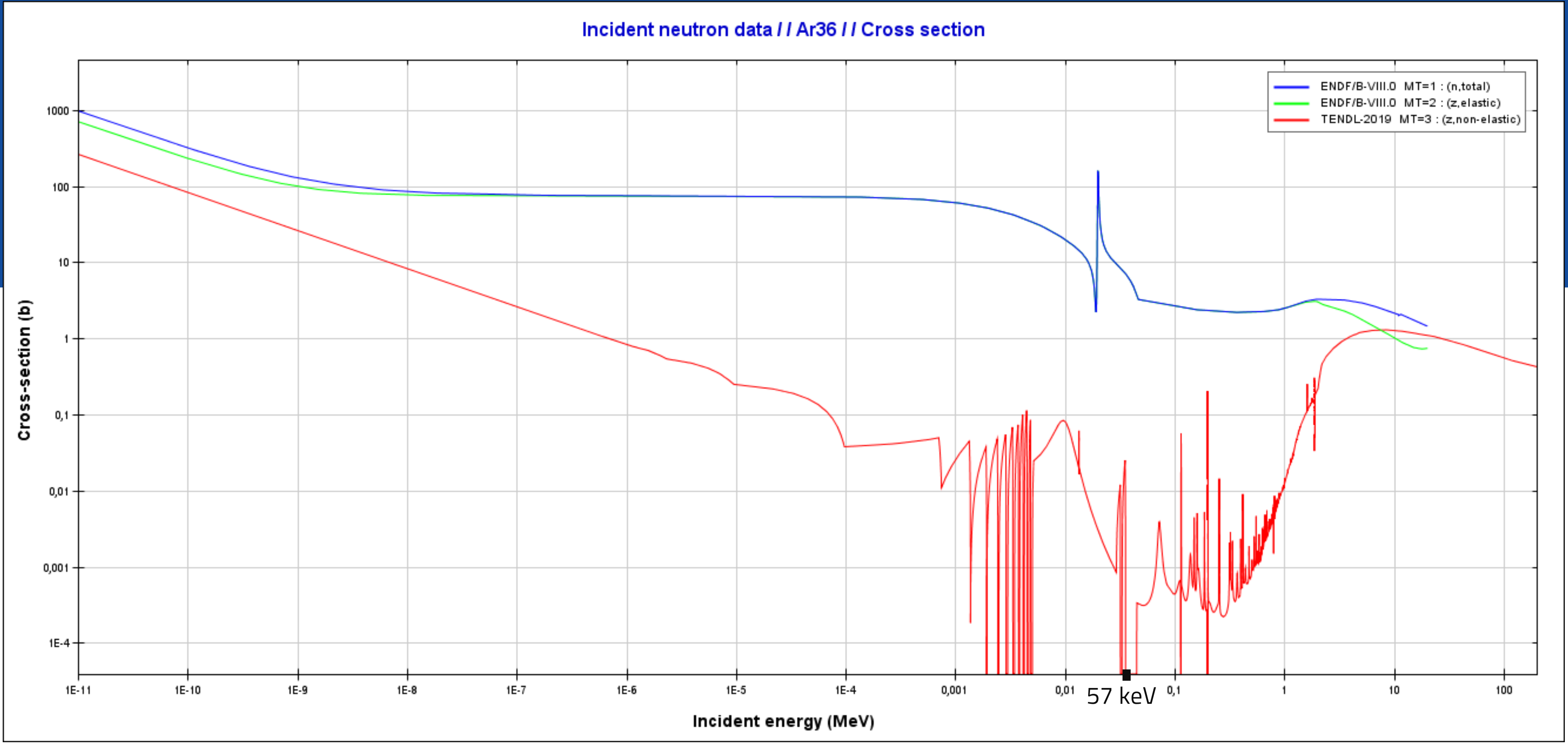


Non-Elastic 36Ar Cross Section



ENERGY	EMISSION
[0.01; 0.1] eV	**n + Ar-36 → α + S-16**
[0.01; 0.1] eV	**n + Ar-36 → γ + Ar-37**
[0.001; 0.01] eV	**n + Ar-36 → Cl-40** THS...

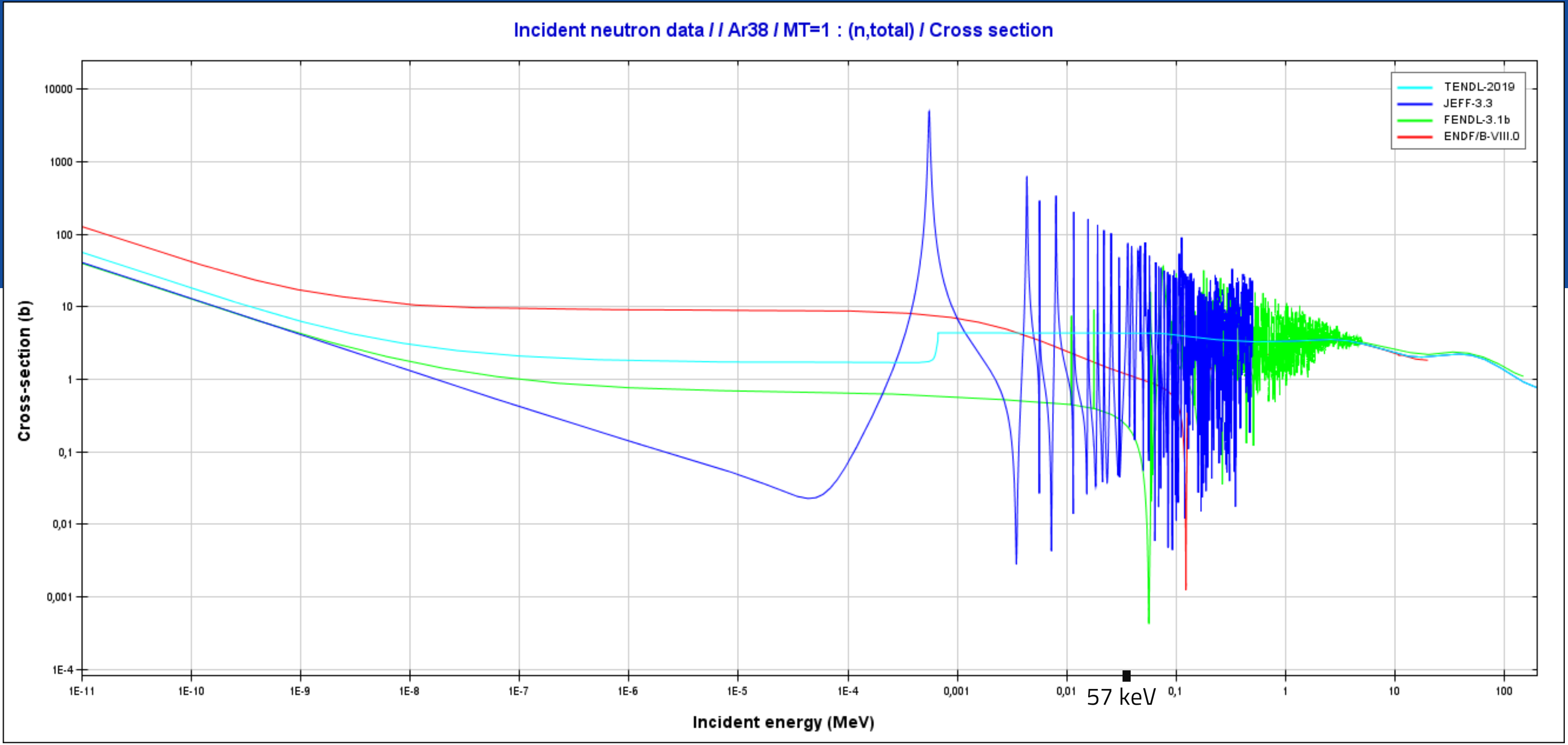
Total, Elastic and Non-Elastic 36Ar Cross Section



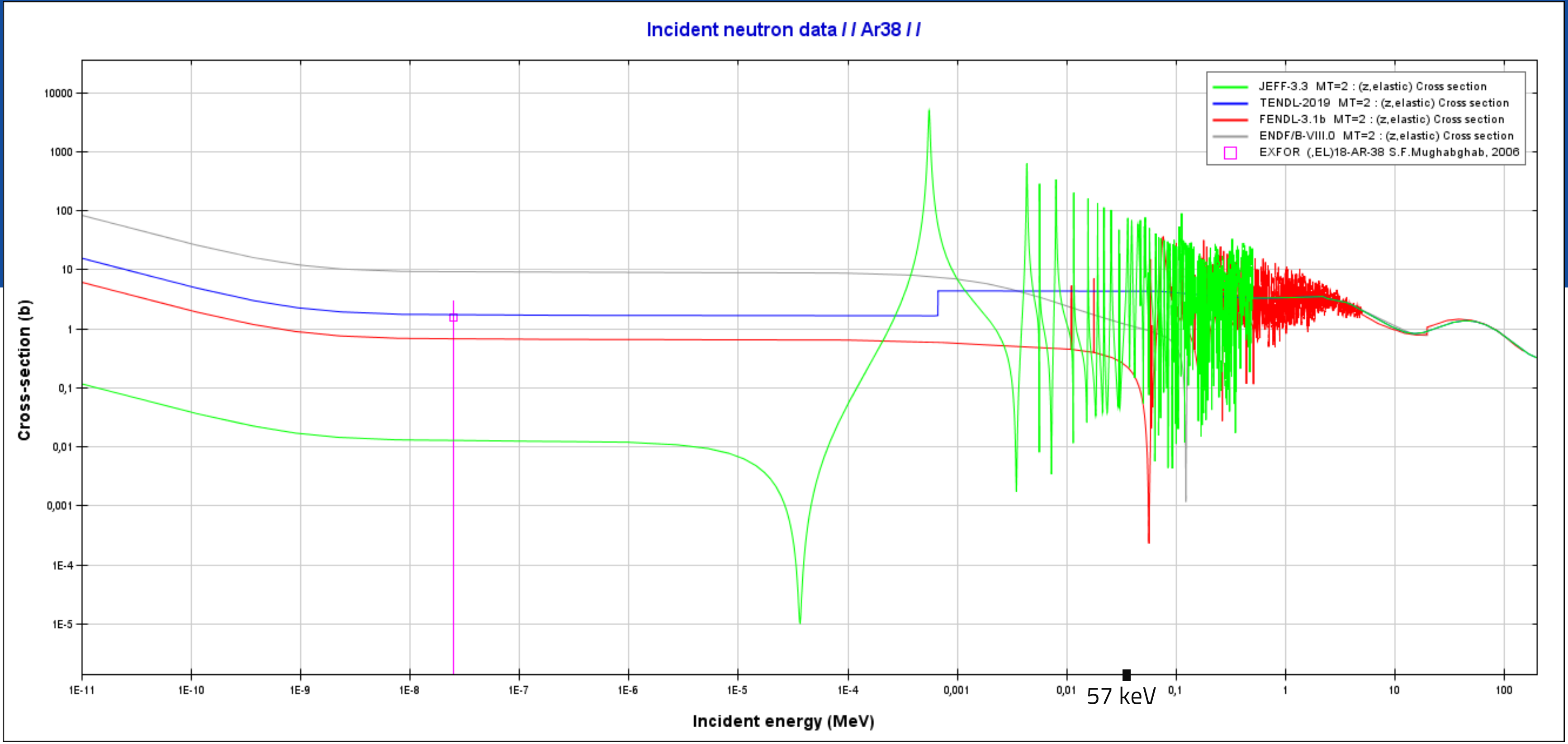
	PREDOMINANT CROSS-SECTION
ELASTIC	$[1 \times 10^{-11}; \pm 9]$ MeV
NON-ELASTIC	[± 9; 100] MeV

3.1.3
Argon 38 (backup)

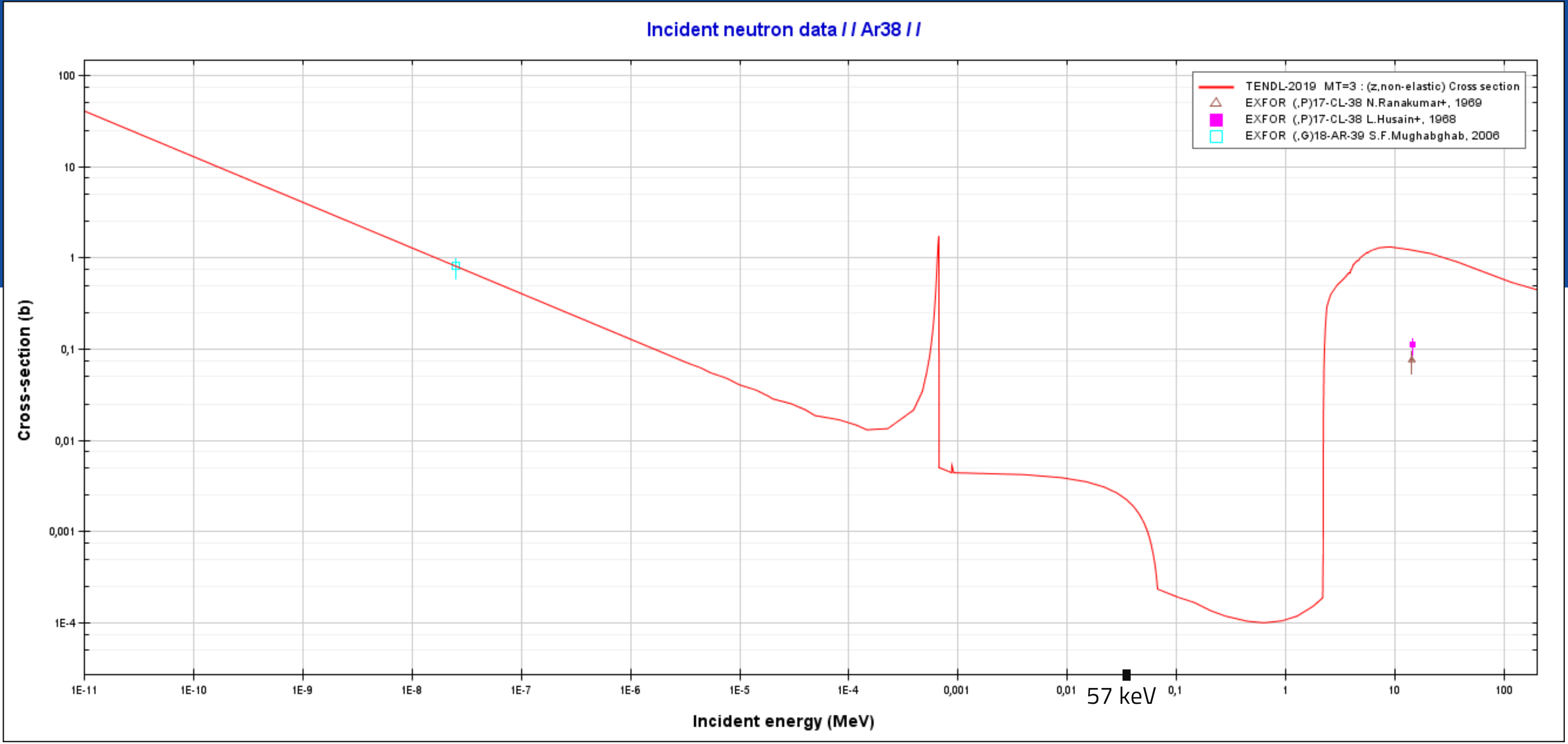
Total 38Ar Cross Section



Elastic 38 Cross Section

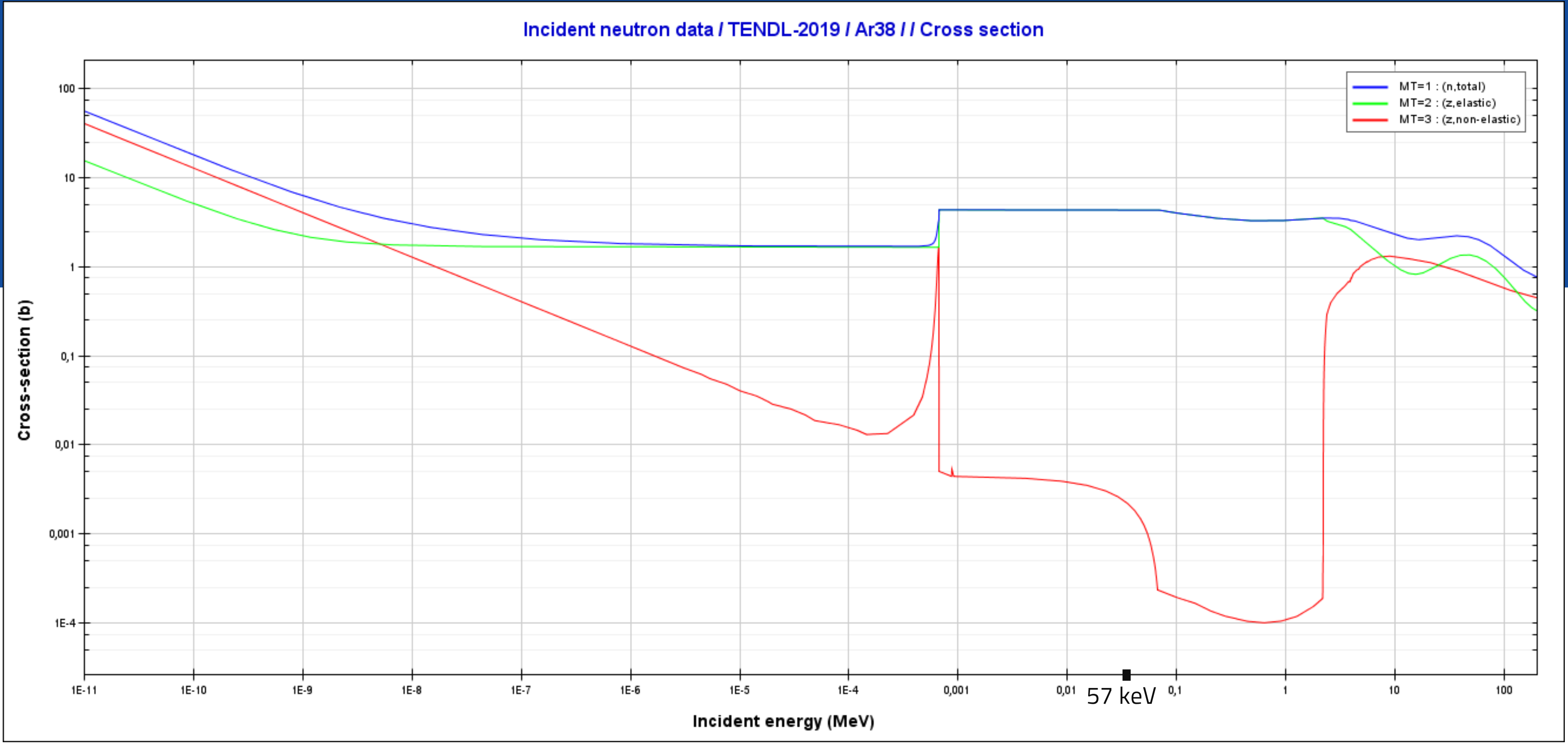


Non-Elastic 38Ar Cross Section



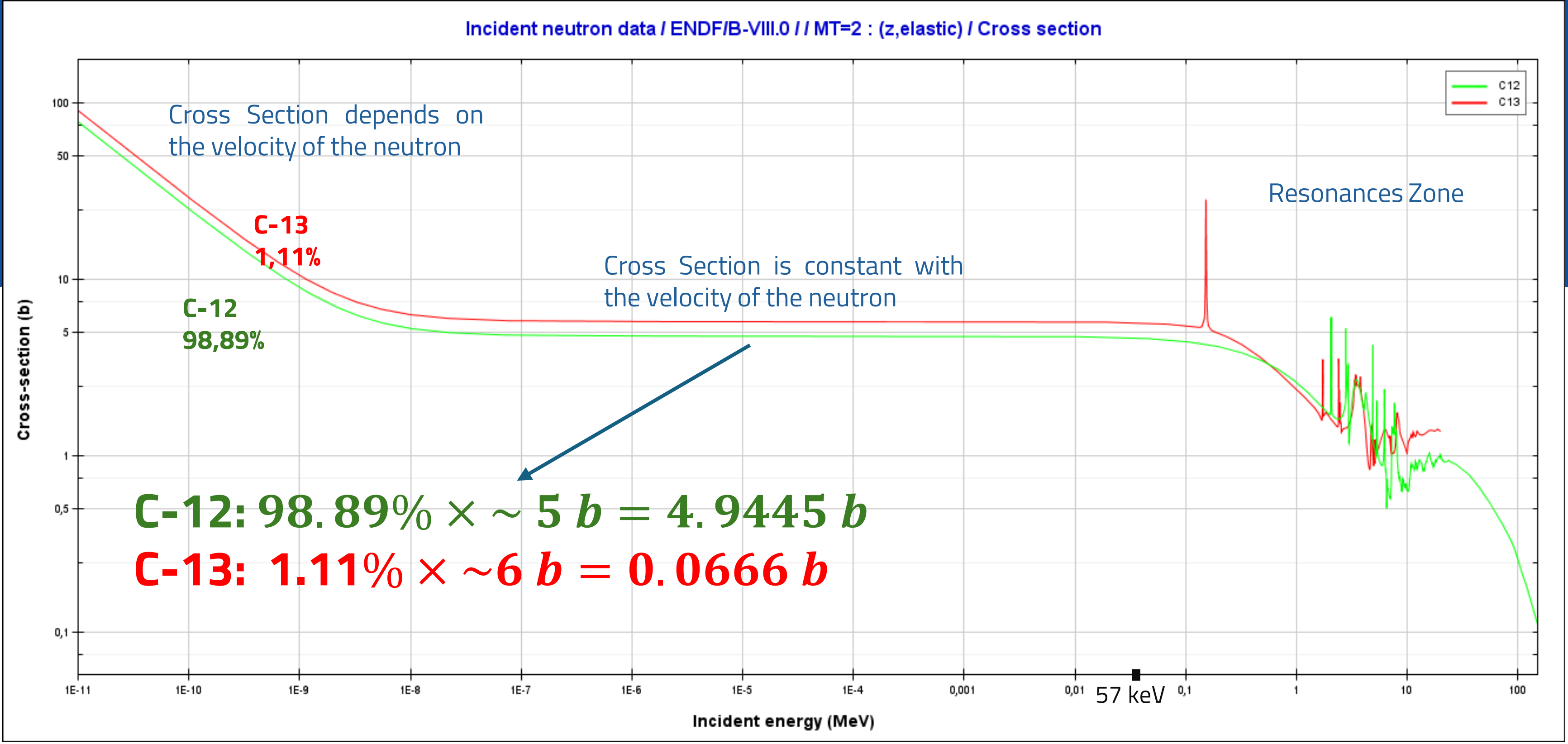
ENERGY	EMISSION
[0.01; 0.1] eV	**n + Ar-38 → γ + Ar-39**
[10; 100] MeV	**n + Ar-38 → p + Cl-38**

Total, Elastic and Non-Elastic 38Ar Cross Section



	PREDOMINANT CROSS-SECTION	
ELASTIC	$[\pm 7 \times 10^{-9}; \pm 9]$ MeV	$[\pm 40; \pm 100]$ MeV
NON-ELASTIC	$[1 \times 10^{-11};\pm 7 \times 10^{-9}]$ MeV	$[\pm 9; \pm 40]$ MeV

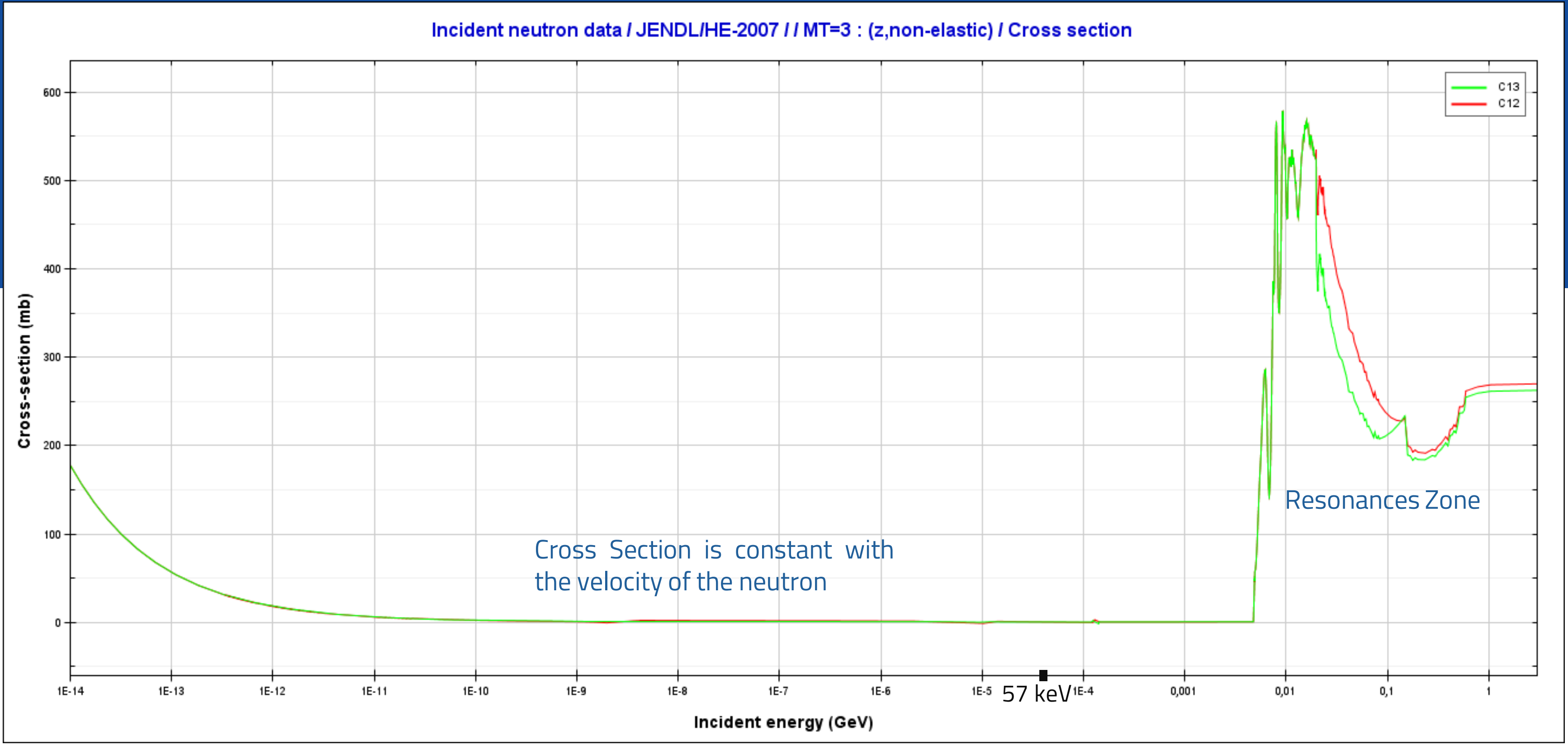
Elastic 12C and 13C Cross Section (backup)



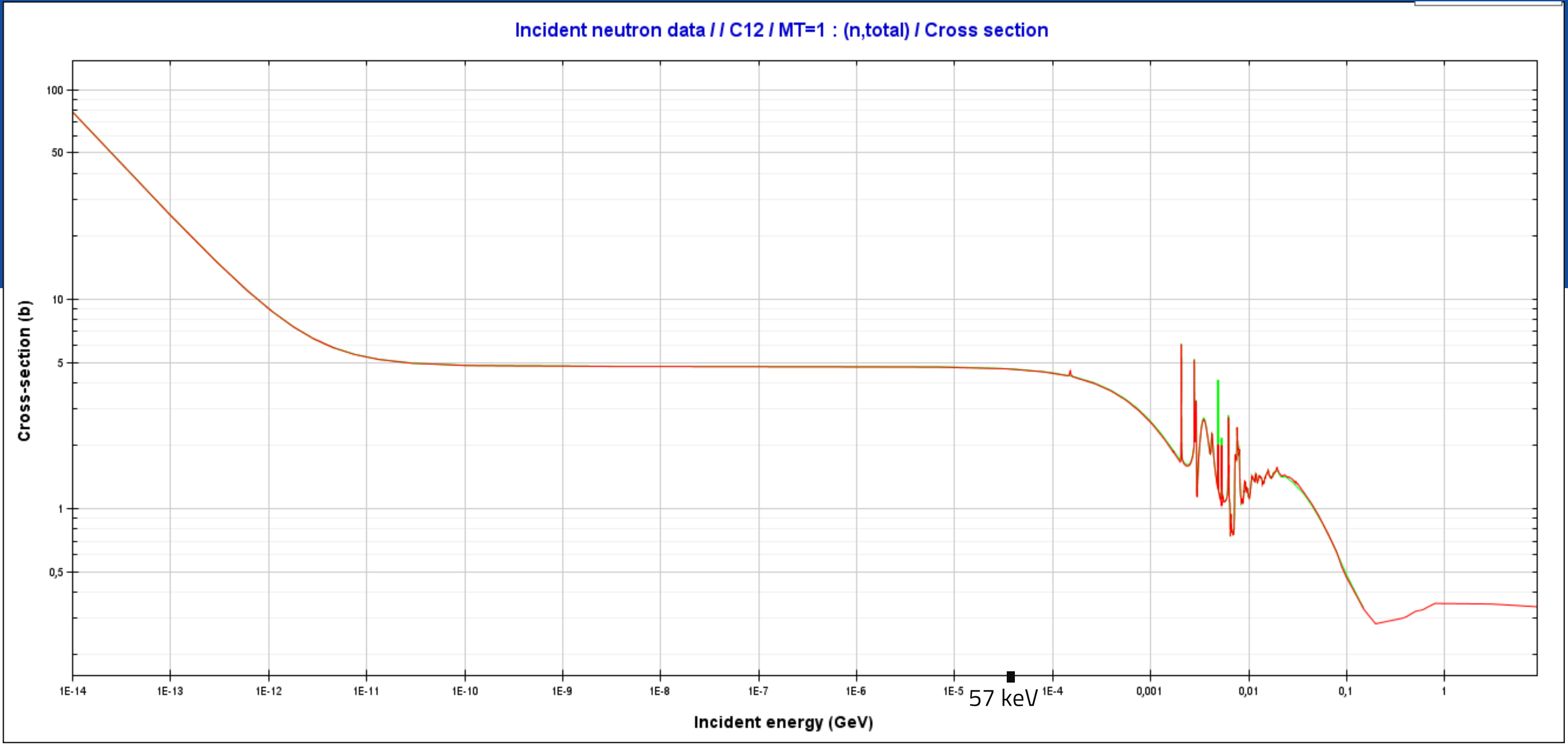
$$\text{C-12: } 98.89\% \times \sim 5\ b = 4.9445\ b$$

$$\text{C-13: } 1.11\% \times \sim 6\ b = 0.0666\ b$$

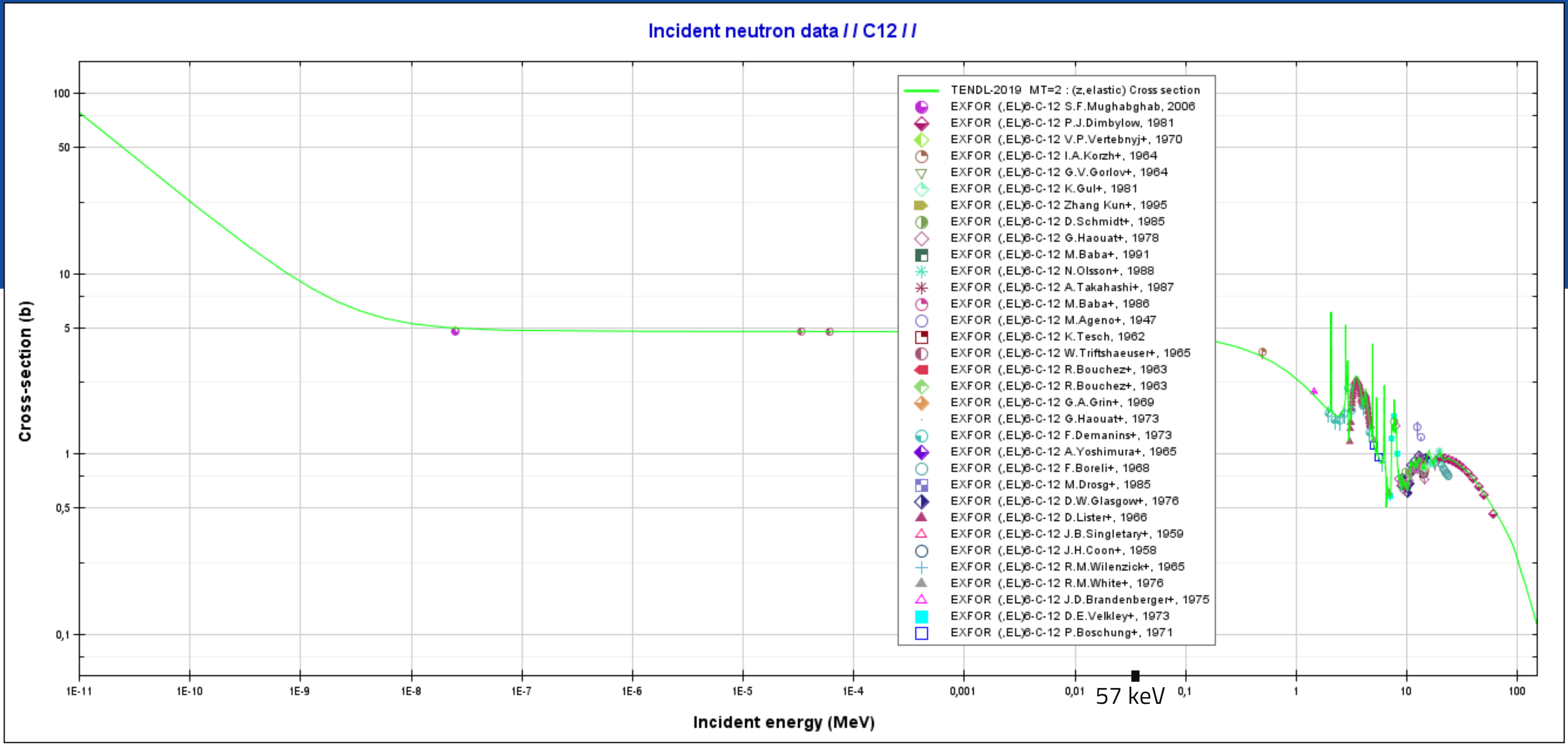
Non-Elastic 12C and 13C Cross Section (backup)



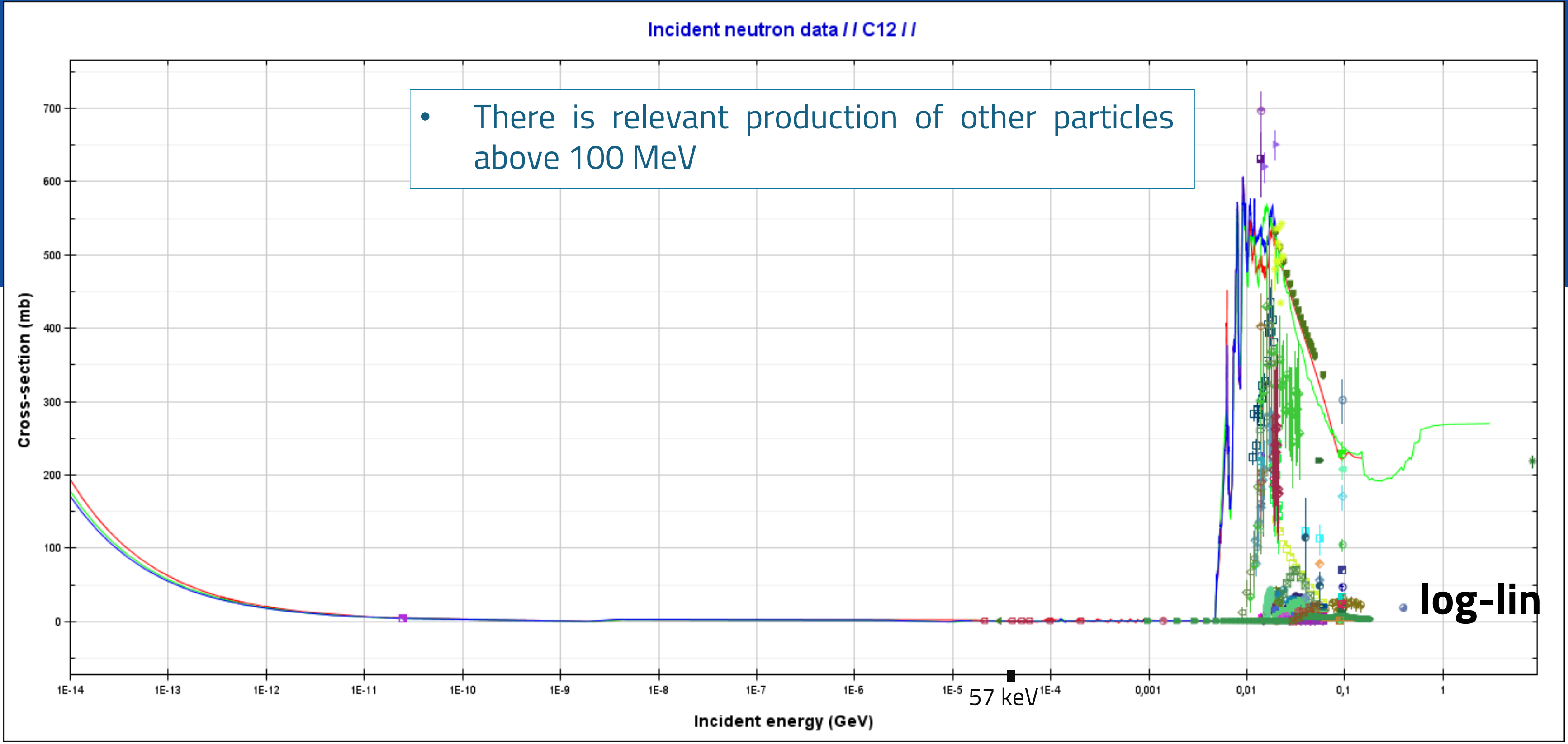
Total 12C Cross Section (backup)



Elastic 12C Cross Section (backup)



Non-Elastic 12C Cross Section (backup)



- There is relevant production of other particles above 100 MeV

EMISSION	PRODUCION
[0.01; 0.05] GeV	**n + C-12 → X + H-0**
[0.05; 0.1] GeV	**n + C-12 → X + H-1**
[0.05; 0.1] GeV	**n + C-12 → X + H-2**
[0.05; 0.1] GeV	**n + C-12 → X + H-3**
[0.05; 0.1] GeV	**n + C-12 → X + He-3**
[0.01; 0.1] GeV	**n + C-12 → X + He-4**
[0.005; 0.1] GeV	**n + C-12 → n + 2α + He-4**
[0.01; 0.1] GeV	**n + C-12 → α + n + p + H-3 + He-4**
[0.01; 0.1] GeV	**n + C-12 → 2α + He-5**
[0.05; 0.1] GeV	**n + C-12 → X + He-6**
[0.01; 0.1] GeV	**n + C-12 → n + p + n + α + Li-6**
[0.01; 0.1] GeV	**n + C-12 → α + H-2 + Li-7**
[0.01; 0.1] GeV	**n + C-12 → α + n + p + Li-7**

[0.01; 0.1] GeV	**n + C-12 → n + p + α + Li-7**
[0.001; 1] GeV	**n + C-12 → p + α + Li-8**
[0.05; 0.1] GeV	**n + C-12 → X + Li-8**
[0.05; 0.1] GeV	**n + C-12 → X + Li-9**
[0.01; 0.1] GeV	**n + C-12 → 2n + α + Be-7**
[0.01; 0.1] GeV	**n + C-12 → n + α + n + Be-7**
[0.001; 0.5] GeV	**n + C-12 → X + Be-7**

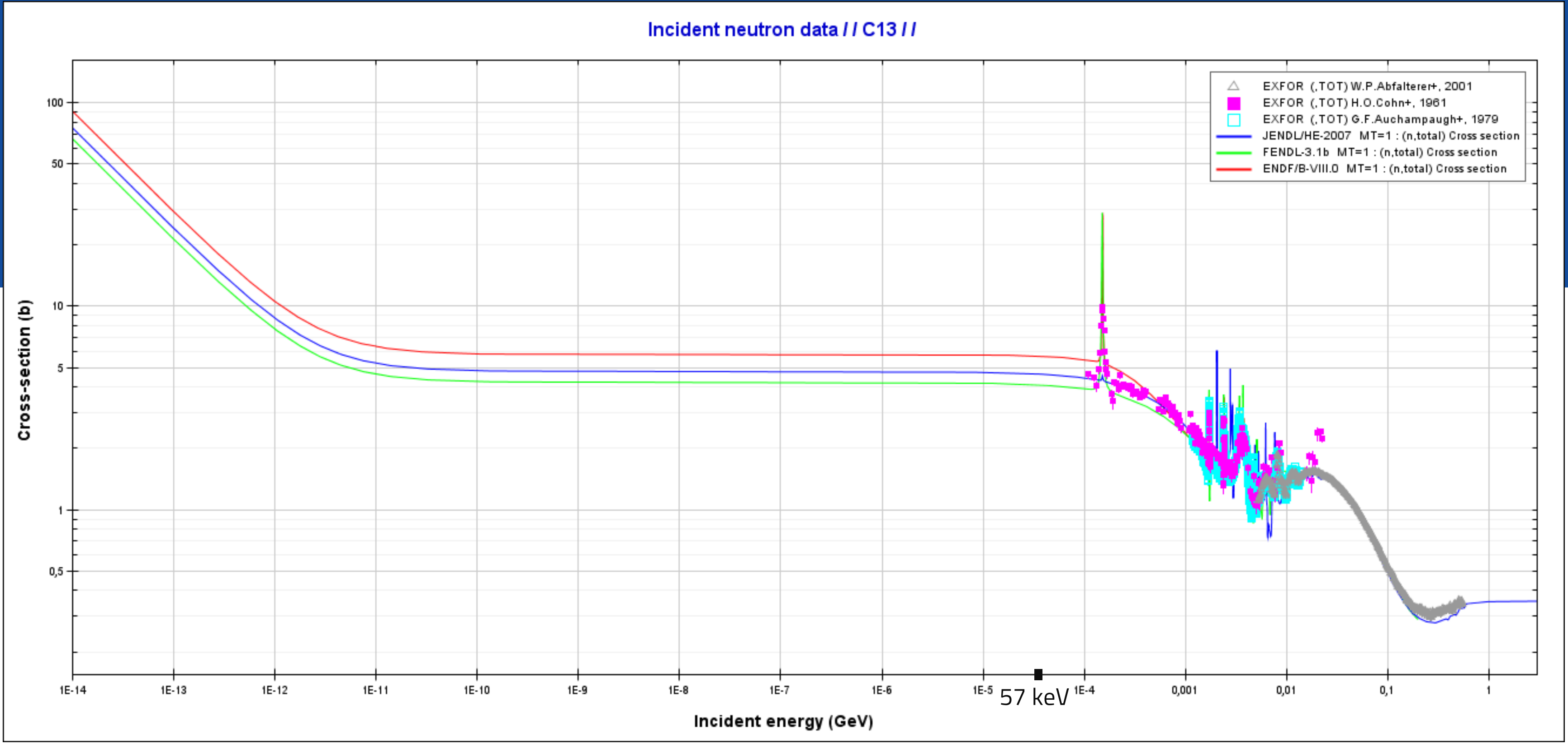
[0.01; 0.1] GeV	**n + C-12 → α + n + Be-8**
[0.01; 0.1] GeV	**n + C-12 → n + α + Be-8**
[0.01; 0.1] GeV	**n + C-12 → n + p + H-3 + Be-8**
[0.01; 0.1] GeV	**n + C-12 → α + Be-9**
[0.01; 0.1] GeV	**n + C-12 → n + H-3 + Be-9**
[0.01; 0.1] GeV	**n + C-12 → p + H-3 + Be-9**
[0.01; 0.1] GeV	**n + C-12 → p + H-2 + Be-10**

[0.05; 0.1] GeV	**n + C-12 $\rightarrow$ X + B-8**
[0.01; 0.1] GeV	**n + C-12 $\rightarrow$ 2n + H-2 + B-9**
[0.01; 0.1] GeV	**n + C-12 $\rightarrow$ 2n + p + B-10**
[0.01; 0.1] GeV	**n + C-12 $\rightarrow$ H-2 + n + B-10**
[0.01; 0.1] GeV	**n + C-12 $\rightarrow$ n + H-2 + B-10**
[0.01; 0.1] GeV	**n + C-12 $\rightarrow$ n + p + n + B-10**
[0.01; 0.1] GeV	**n + C-12 $\rightarrow$ H-3 + B-10**

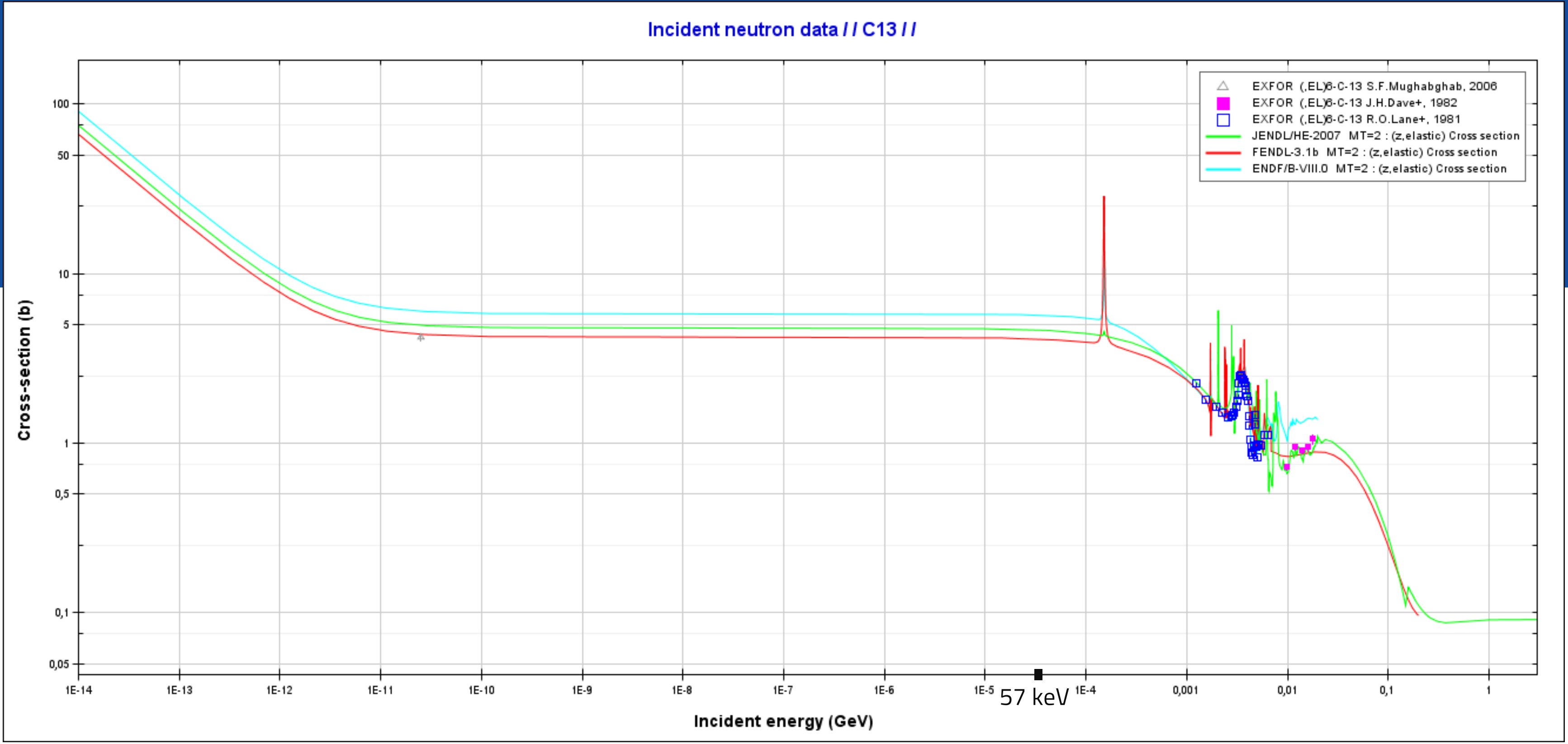
[0.01; 0.1] GeV	**n + C-12 $\rightarrow$ H-2 + B-11**
[0.01; 0.1] GeV	**n + C-12 $\rightarrow$ n + p + B-11**
[0.01; 0.1] GeV	**n + C-12 $\rightarrow$ p + B-12**
[0.01; 0.1] GeV	**n + C-12 $\rightarrow$ 3n + C-10**
[0.001;1] GeV	**n + C-12 $\rightarrow$ 2n + C-11**
[0.1; 10] meV	**n + C-12 $\rightarrow$ THS + C-12**
[0.01; 0.1] eV/ [0.01; 1] MeV	**n + C-12 $\rightarrow$ γ + C-13**

3.2.2
Carbon 13 (backup)

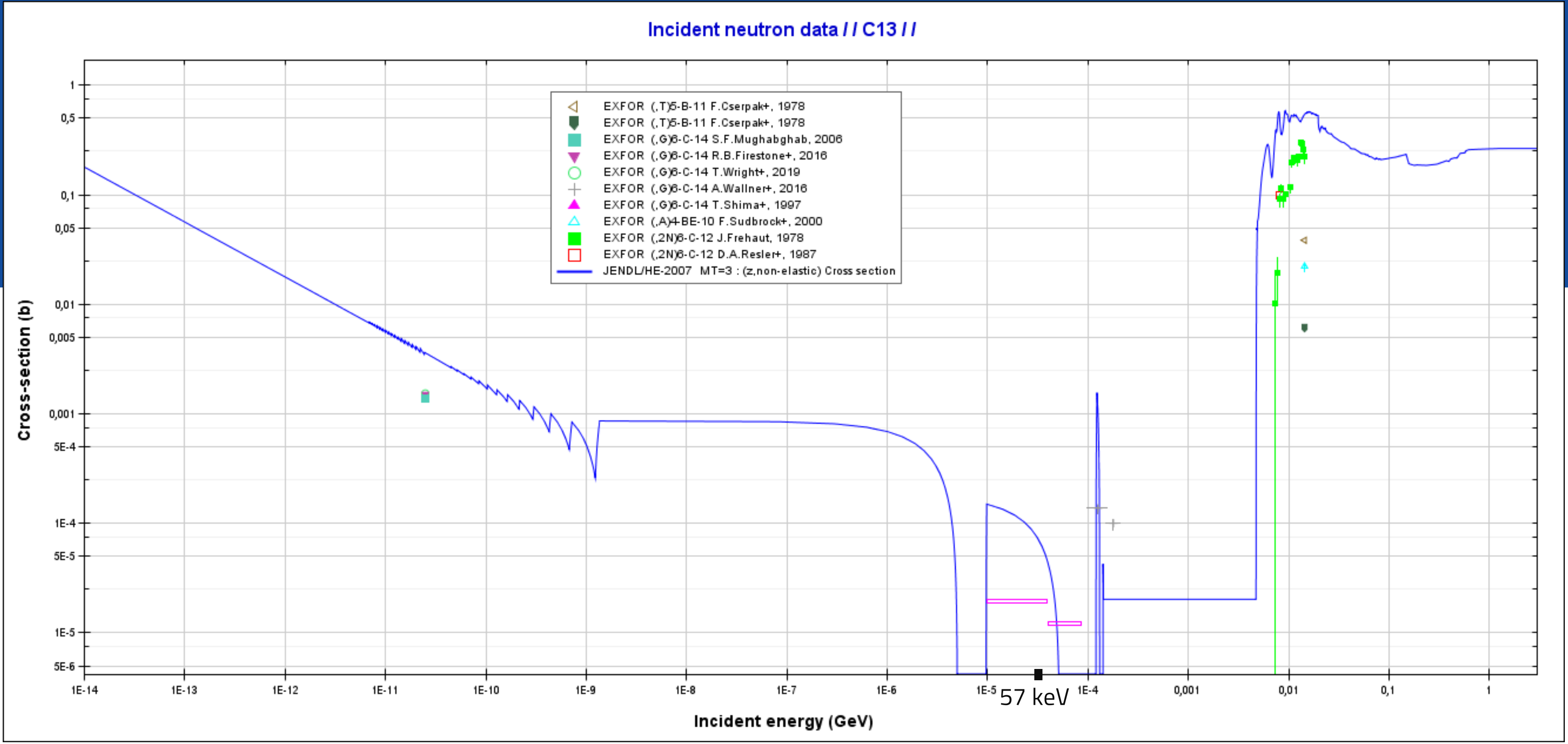
Total 13C Cross Section



Elastic 13C Cross Section

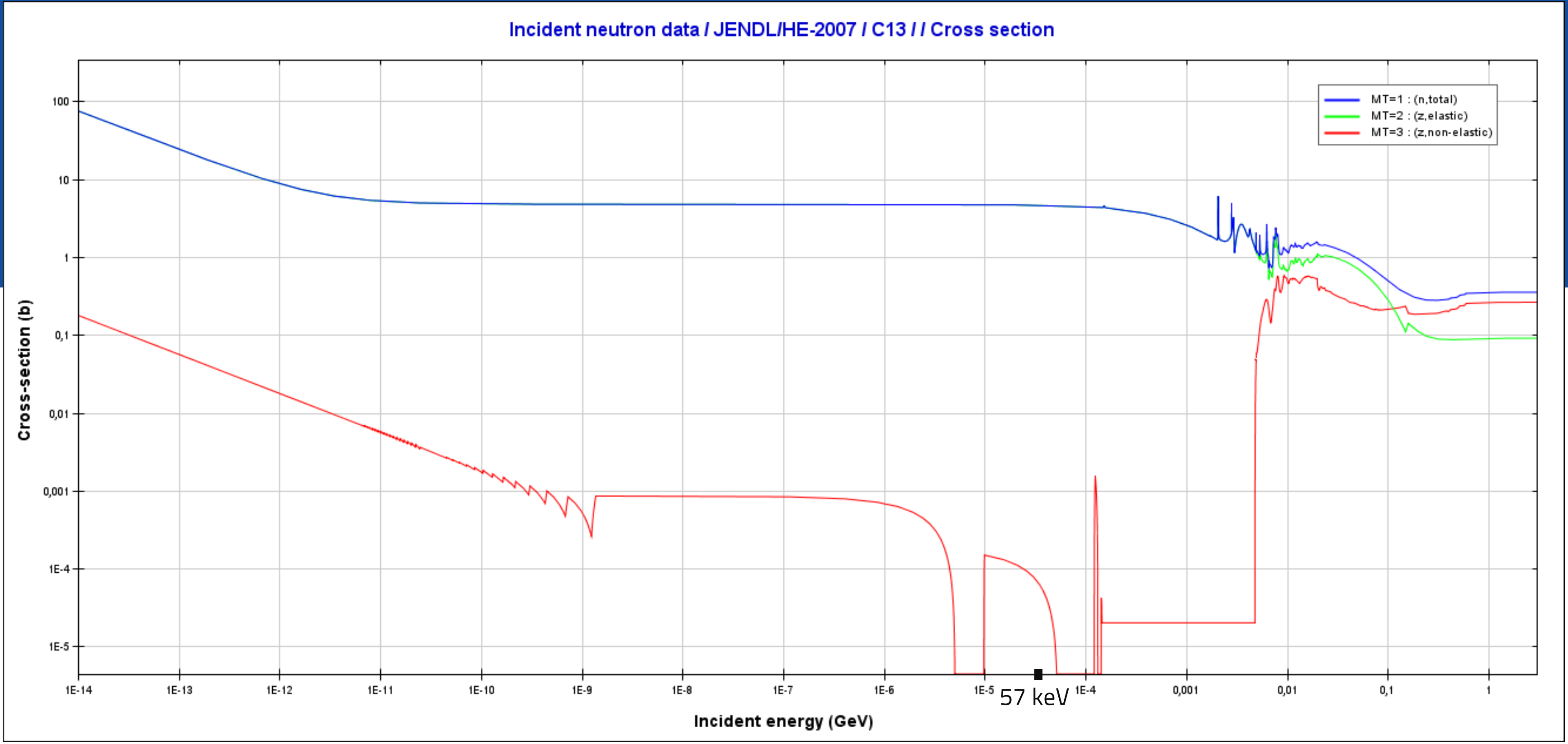


Non-Elastic 13C Cross Section



ENERGY	EMISSION
[0.005; 0.05] GeV	**n + C-13 → 2n + C-12**
[0.01; 0.05] GeV	**n + C-13 → α + Be-10**
[0.01; 0.1] eV + $[1 \times 10^{-5}; 5 \times 10^{-4}]$ GeV	**n + C-13 → γ + C-14**
[0.01; 0.1] GeV	**n + C-13 → H-3 + B-11**

Total, Elastic and Non-Elastic 13C Cross Section



	PREDOMINANT CROSS-SECTION
ELASTIC	$[1 \times 10^{-14}; 0.1]$ GeV
NON-ELASTIC	$[0.1 ; 1]$ GeV