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Institut de Tècniques Energètiques

$^{27}Al(\alpha,n)^{30}P$ cross-section from thick-target yield measurements at CMAM using the miniBELEN neutron counter

By Nil Mont Geli

On behalf of the MANY collaboration

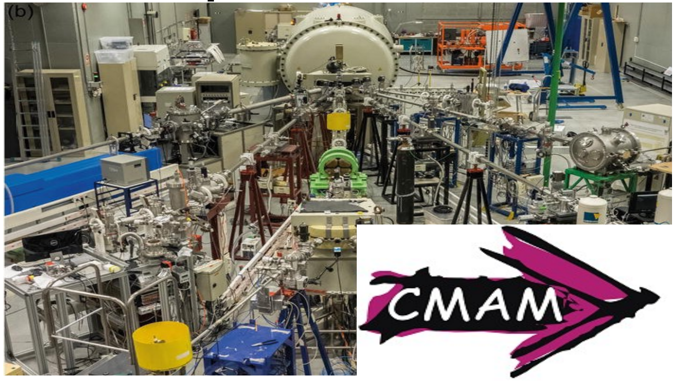
Institut de Tècniques Energètiques – Universitat Politècnica de Catalunya (INTE - UPC))

Institute of Energy Technologies – Technical University of Catalonia

The MANY Collaboration

Two Spanish facilities

Infraestructuras Científicas y Técnicas Singulares



UPC

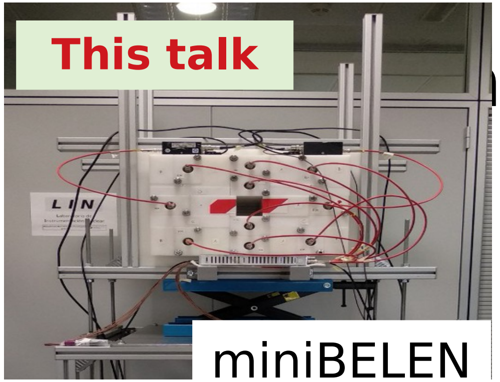
Universidad de Sevilla

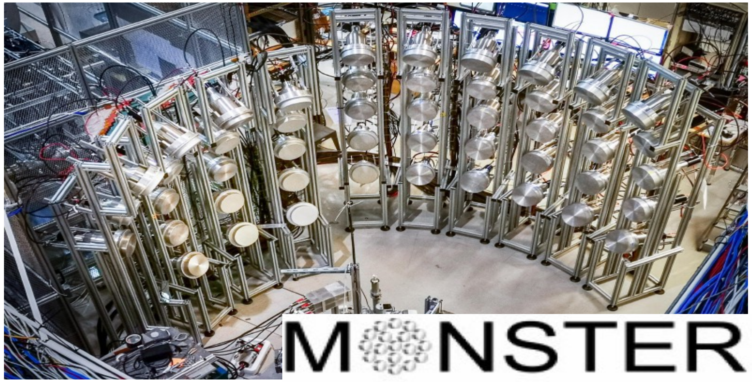
IFIC
INSTITUT DE FÍSICA CORPUSCULAR

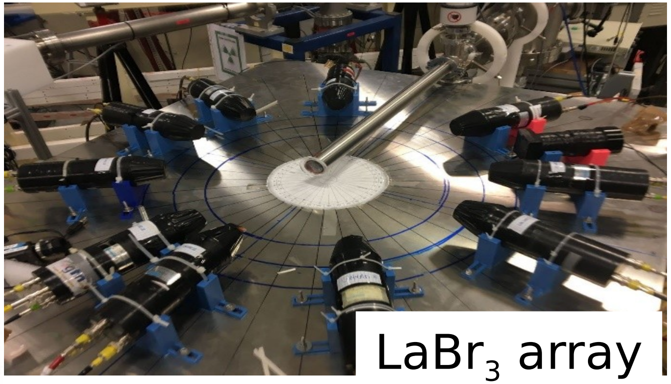
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

UNIVERSIDAD COMPLUTENSE MADRID

IEM
Instituto de Estructura de la Materia







MANY

The **MANY (Measurement of Alpha Neuntron Yields)** collaboration: recently formed, it is a collaboration between several institutions in Spain aiming to carried out measurements of (α,n) reaction cross-sections, production yields and neutron energy spectra.

"*most of the available experimental data was measured decades ago, is incomplete and/or the uncertainties in the cross sections and neutron emission spectra are rather large. Furthermore, the evaluated libraries are incomplete or based on evaluations that are now outdated*" INDC(NDS)-0836 tehcnical meeting report (November 2021)

Physical motivation:

- Nuclear astrophysics: source of neutrons for the s-process, "ligth" r-process.
- Rare-event experiments (dark matter, neutrinos, etc.): neutron-induced background in underground laboratories.
- Non-destrutice assays for spent fuel management and nonproliferation.
- Nuclear technologies: fission and fusion reactors, neutron-induced background in particle accelerators.

miniBELEN

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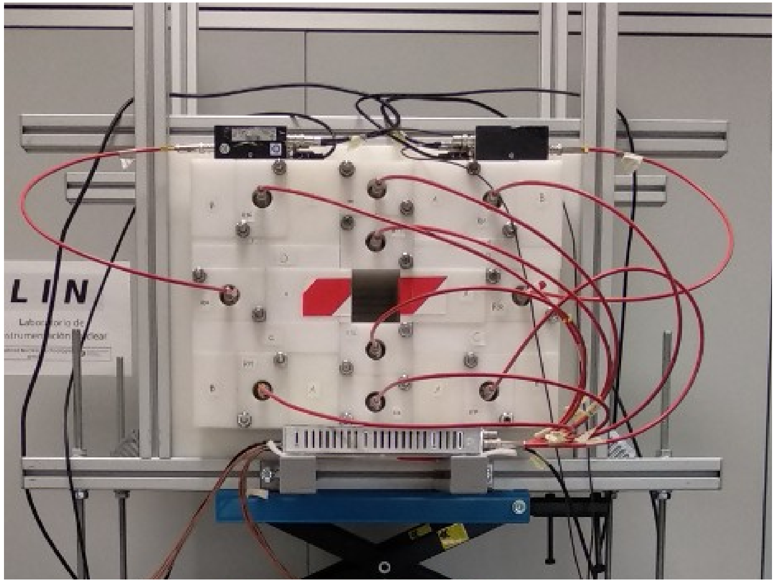
Main characteristics

- Long counter tehcnique: thermal neutrons counters (^{3}He) + moderator (hihg density polyethylene).
- Detection efficiency nearly independent from the neutron energy (**<u>flat response</u>**) up to 8/10 MeV.
- Modular moderator.



N. Mont-Geli *et al.*, EPJ Web of Conferences (2023)

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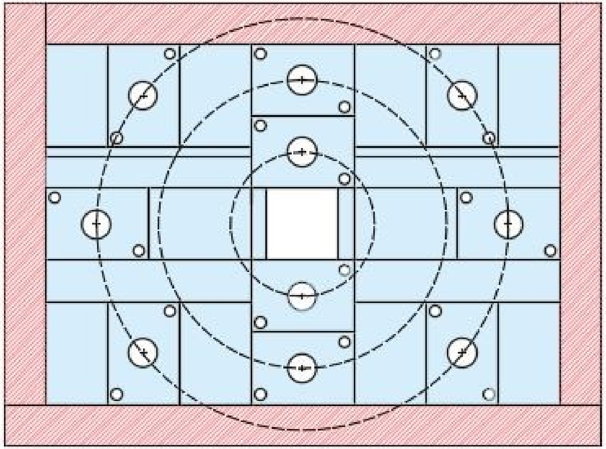
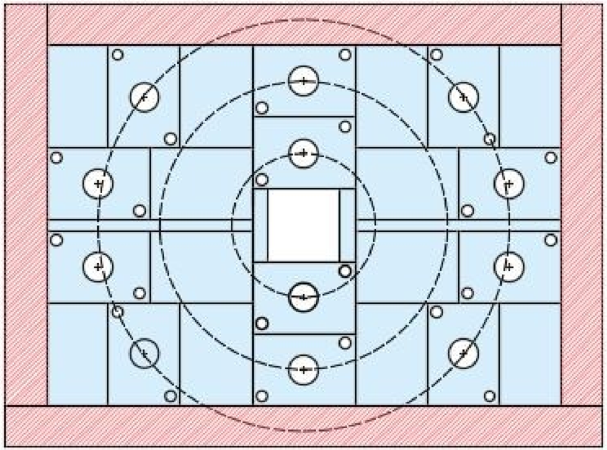
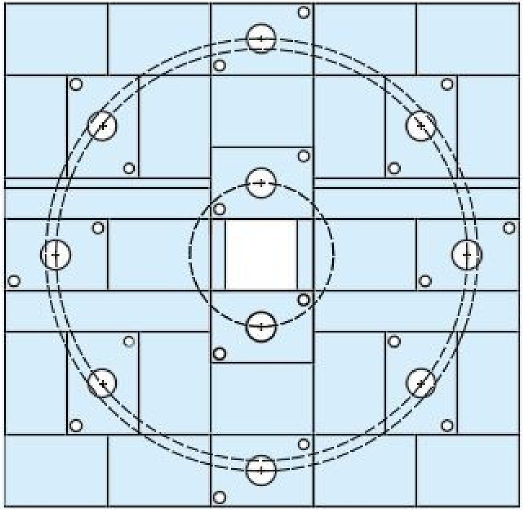
Three configurations:







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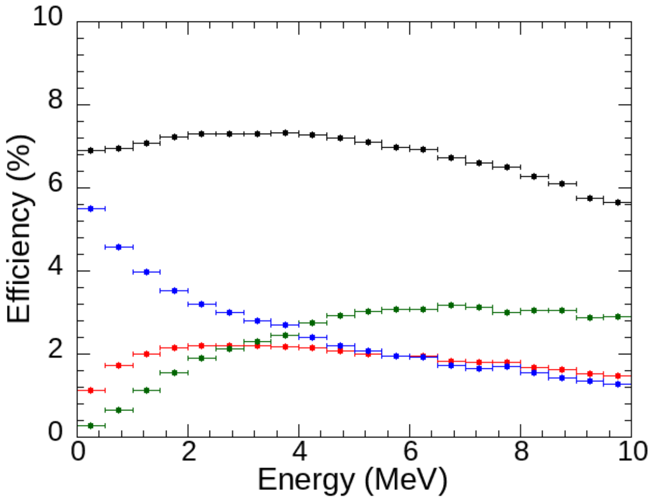
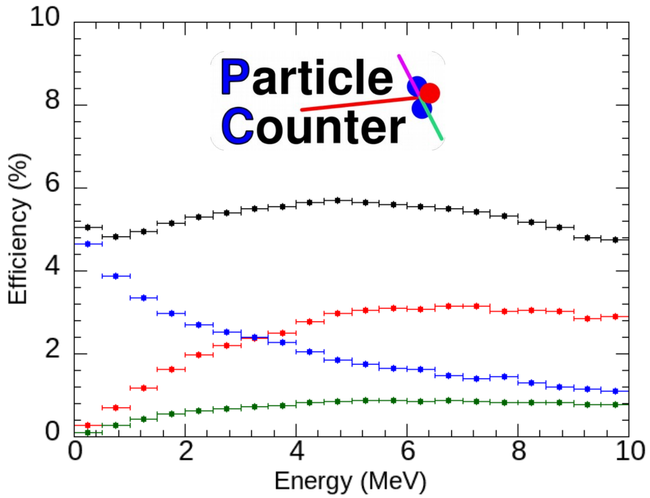
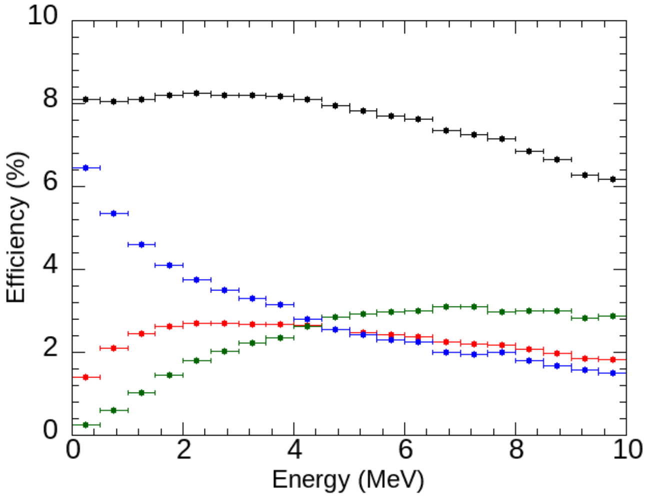
Three configurations:

www.particlecounter.net







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miniBELEN-10A

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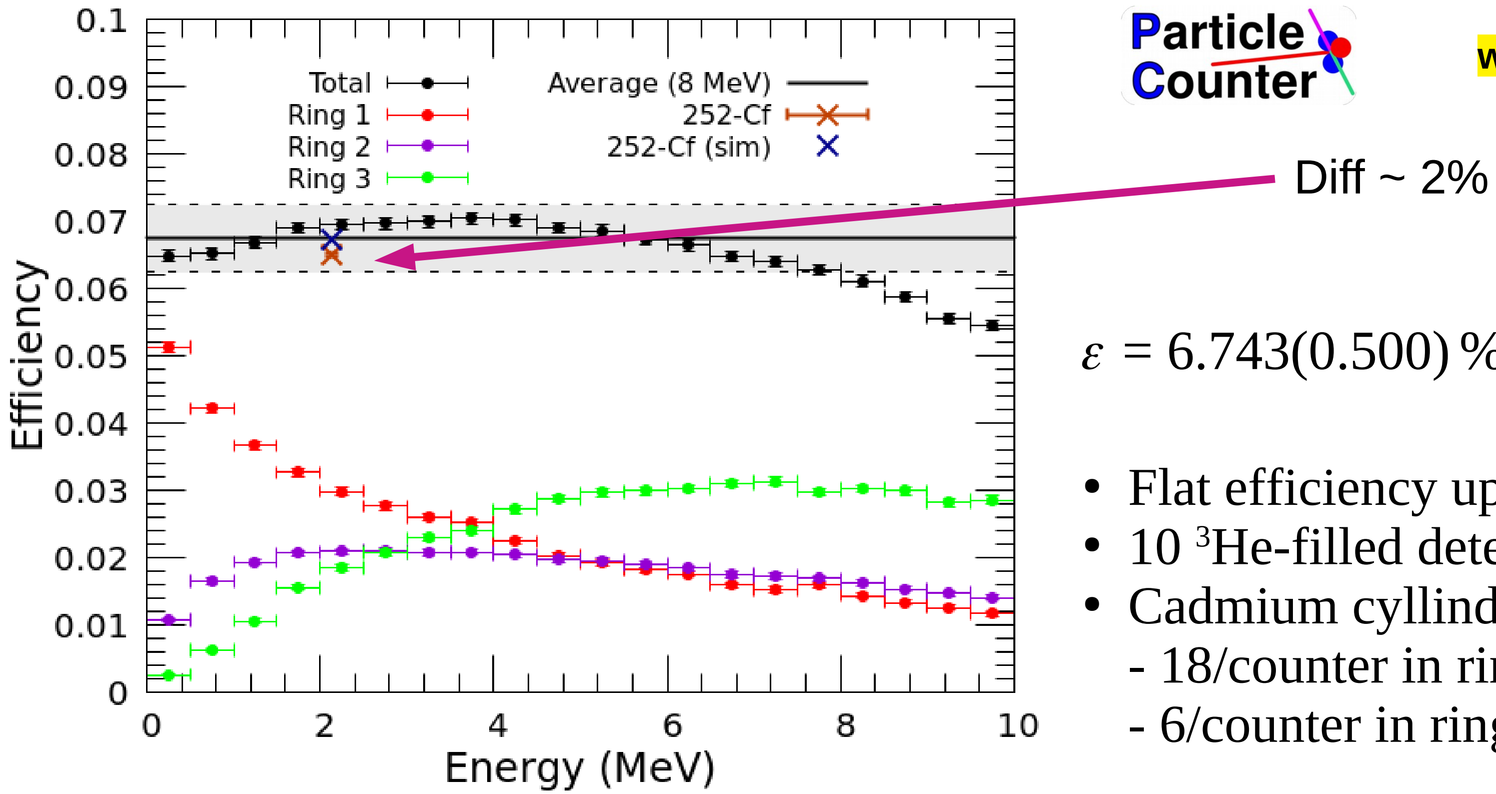

www.particlecounter.net

$$\varepsilon = 6.743(0.500)\,\% \quad \delta\varepsilon = \frac{\varepsilon_{max} - \varepsilon_{min}}{2}$$

- Flat efficiency up to 8 MeV.
- 10 ^{3}He-filled detectors.
- Cadmium cyllinders:
  - 18/counter in ring 1 (60% coverage).
  - 6/counter in ring 2 (20% coverage).

$^{27}Al(\alpha,n)^{30}P$

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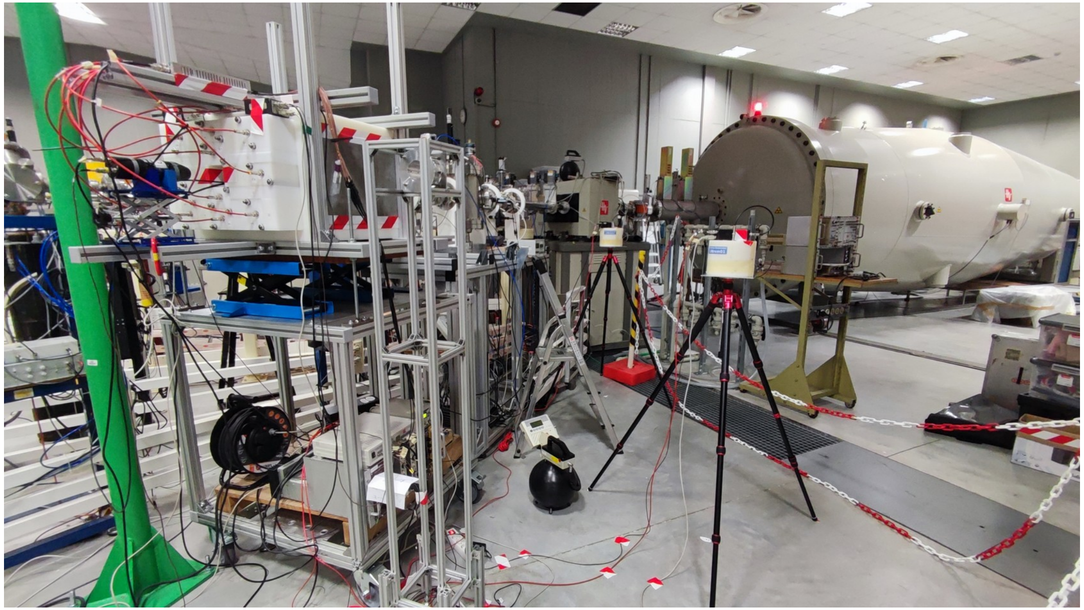
Centro de Micro-Análisis de Materiales (CMAM, Madrid)

- 5 MV Tandem accelerator. Beam particles: ^{4}He (q = +2).



Physical interests:

- Comissioning
- Nuclear astrophysics
- Nuclear reactors
- Underground laboratories.
- Management of spent fuel.

$^{27}Al(\alpha,n)^{30}P$

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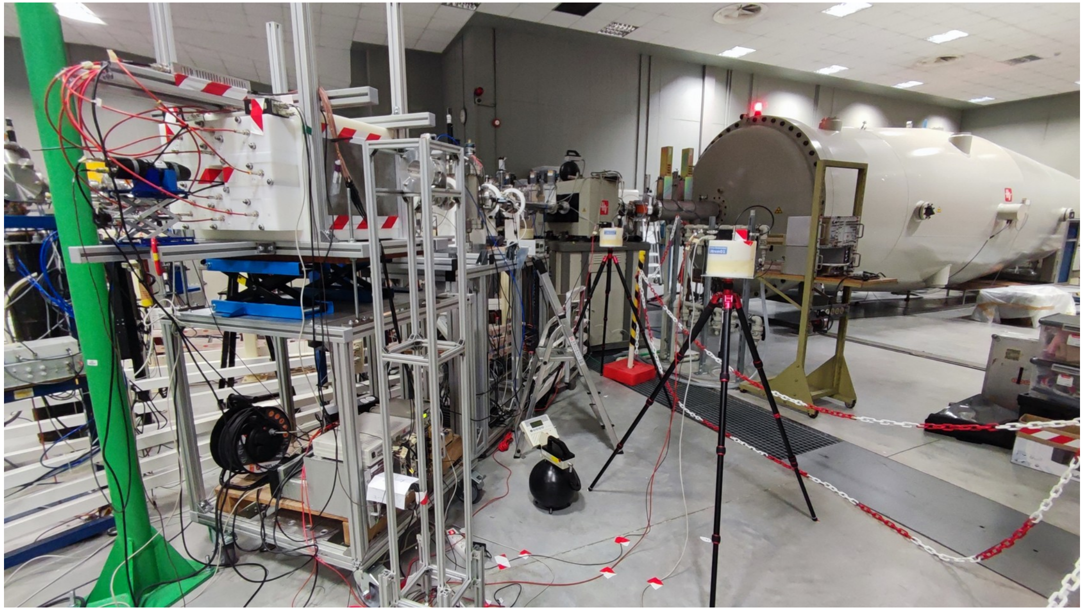
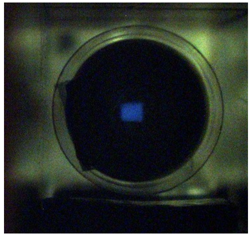

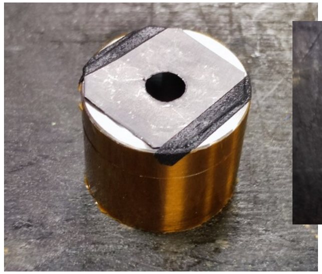
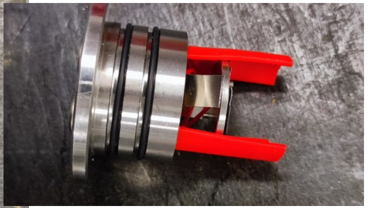
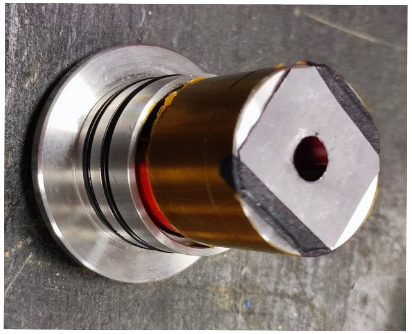

Neutron yields (thick target)

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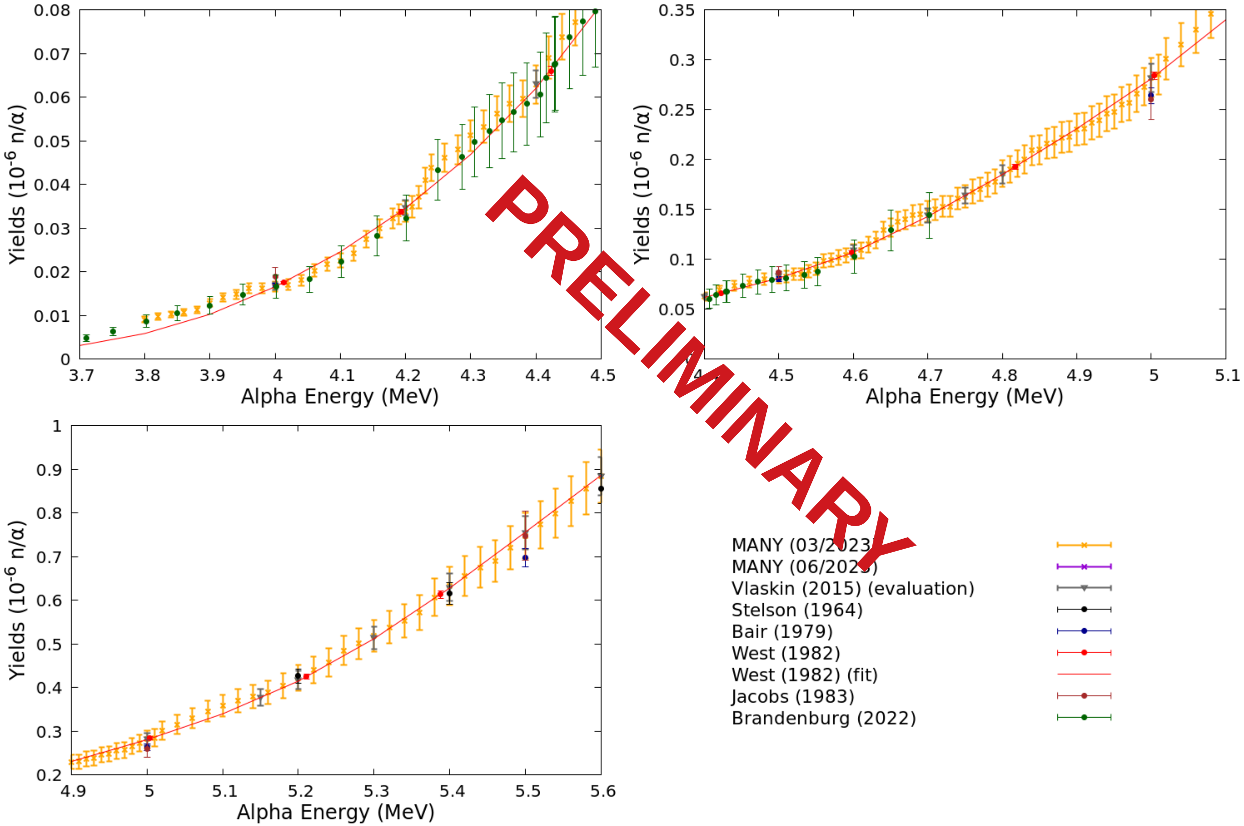
Neutron yields

$$Y = \frac{R}{I \cdot \varepsilon}$$

- Y = neutron yield
- R = miniBELEN neutron rate
- I = beam current (particles/s)
- ε = miniBELEN neutron efficiency

Background estimations using a dummy natural tantalum target (threshold ~ 10 MeV)

Uncertainty: systematic from the efficiency flatness hypothesis



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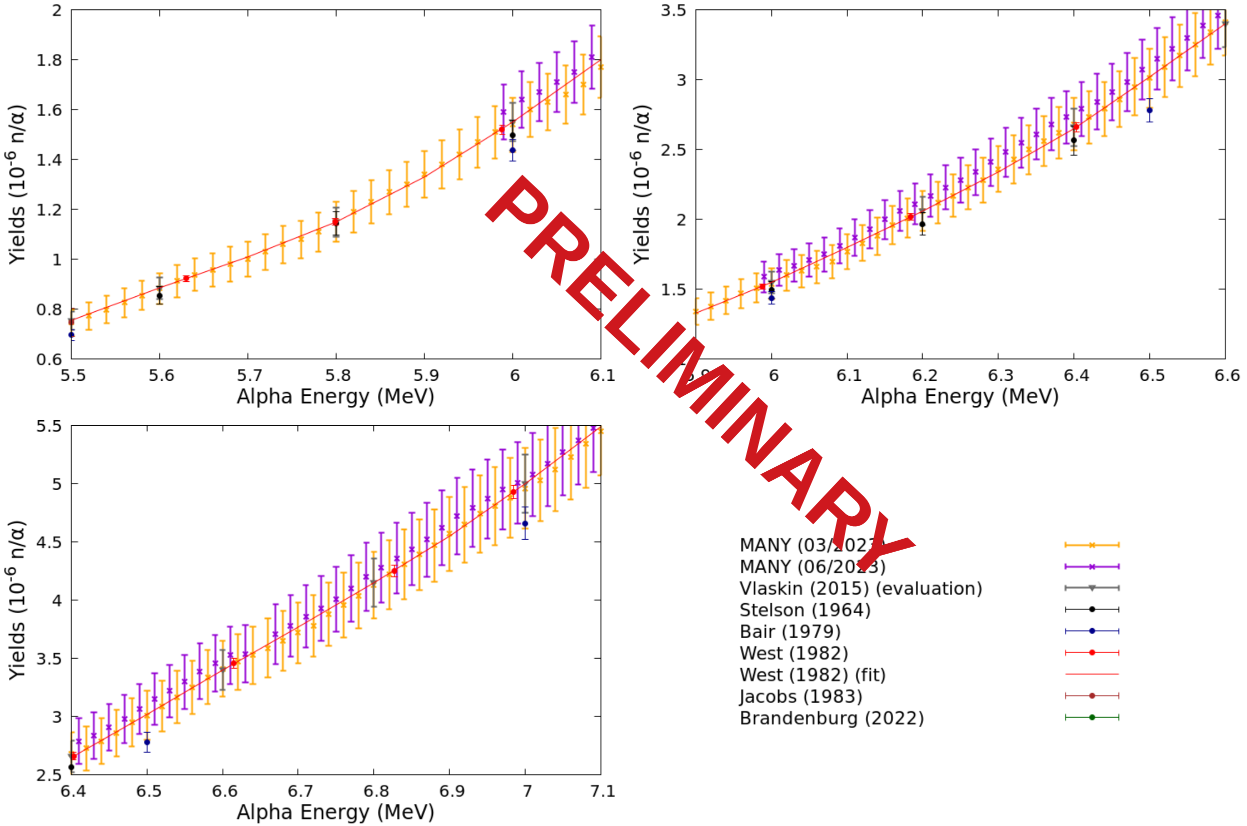

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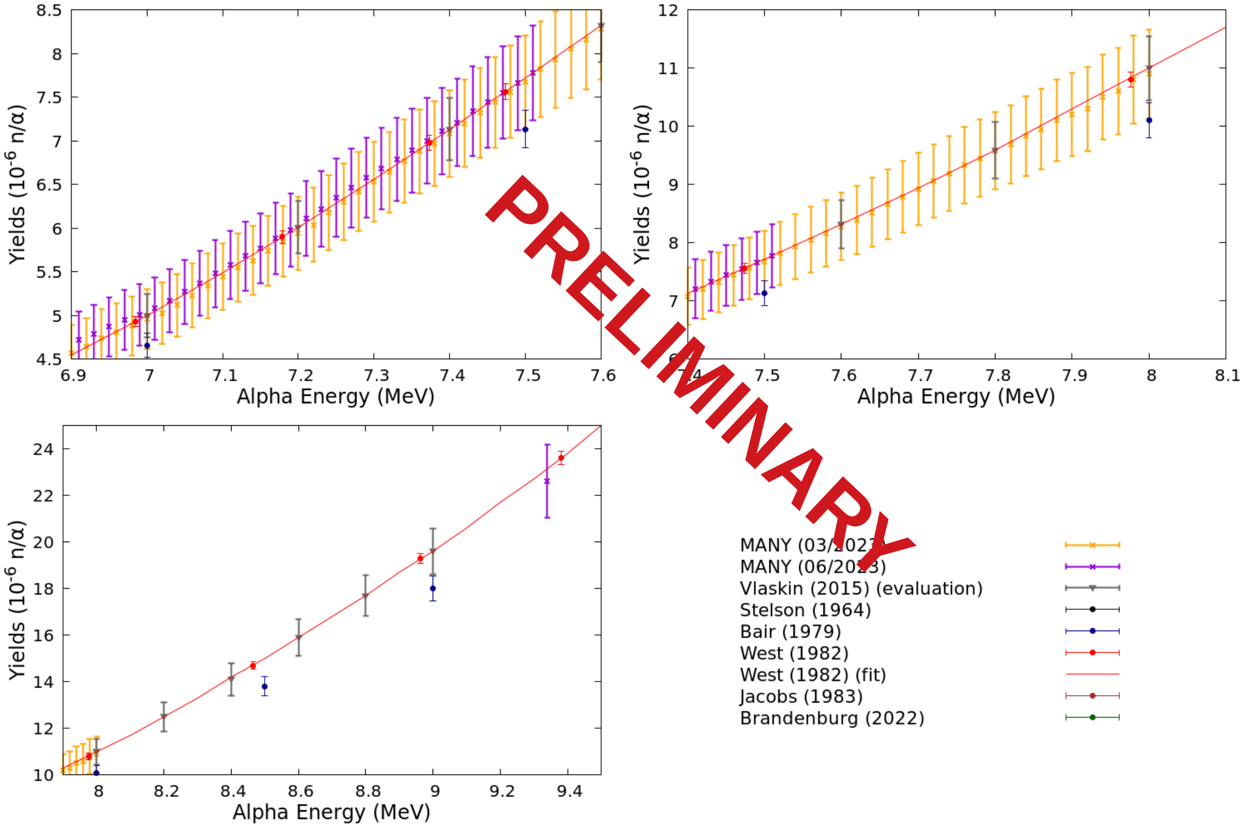

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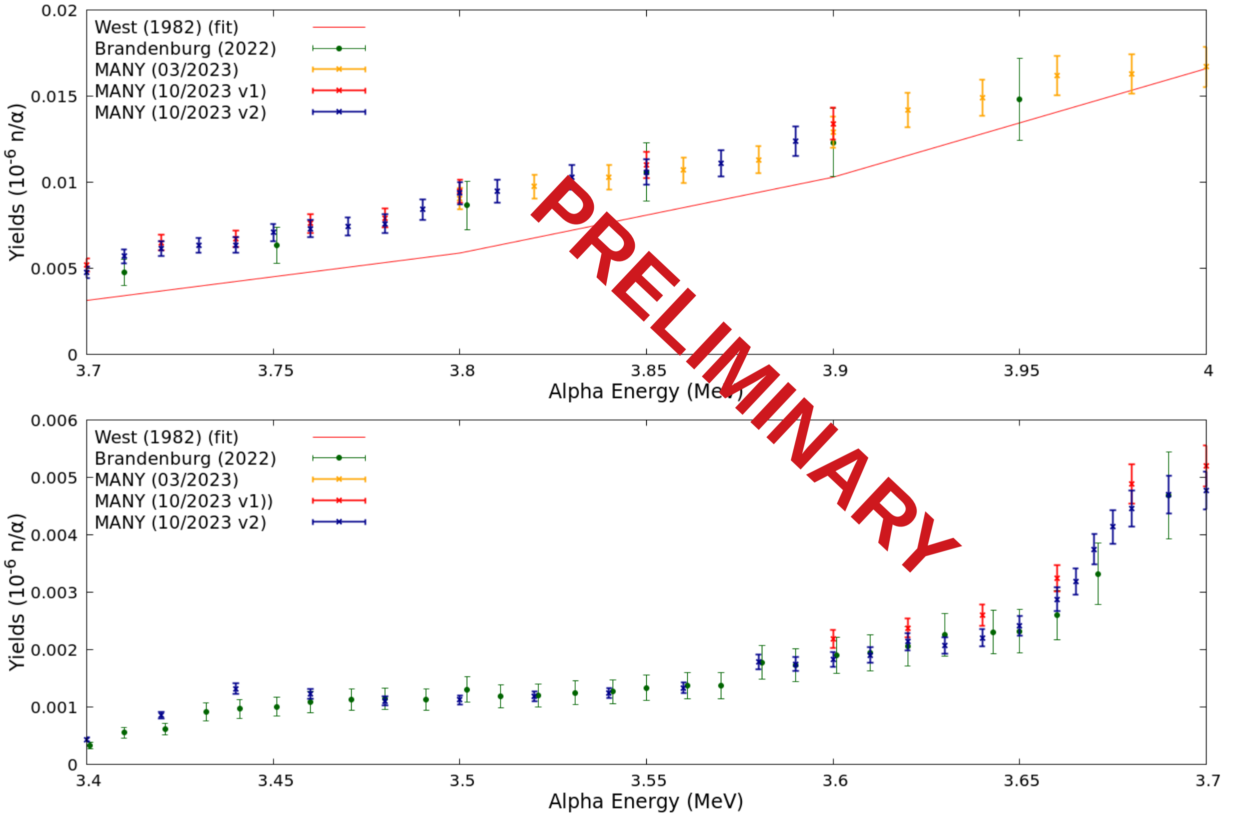

Neutron yields (thick target)

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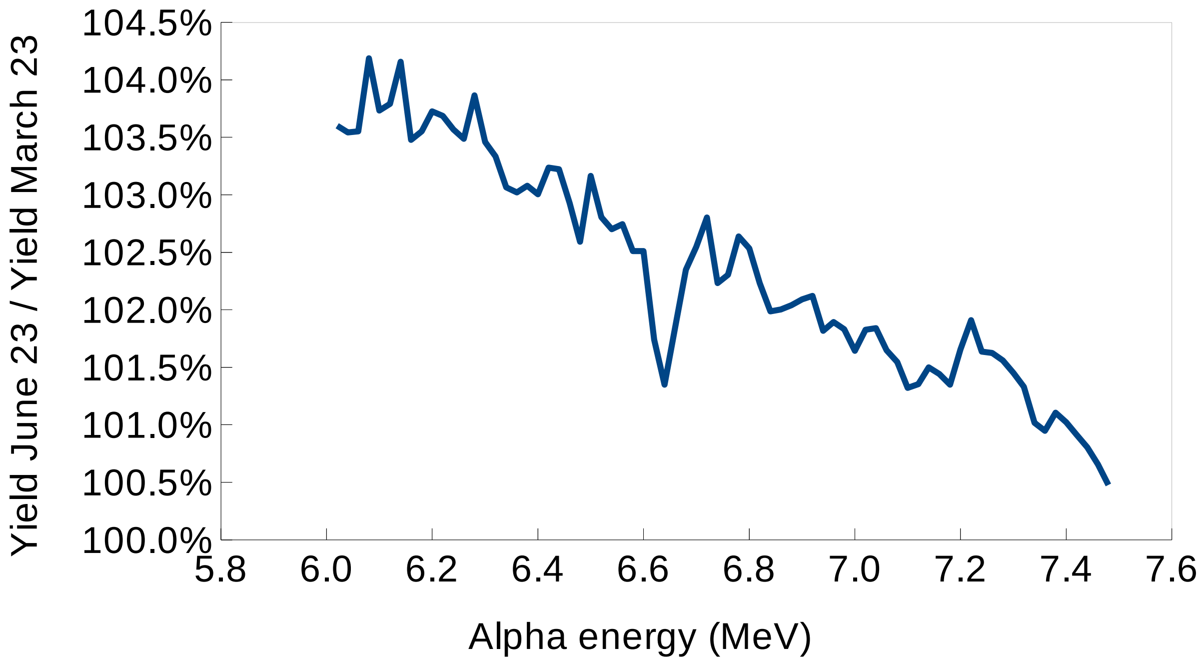
Neutron yields (june vs march 2023)

Background estimation:

March 2023: YES
June 2023: NO

Larger Background in June 23???



$^{27}Al(\alpha,n)^{30}P$ cross-sections

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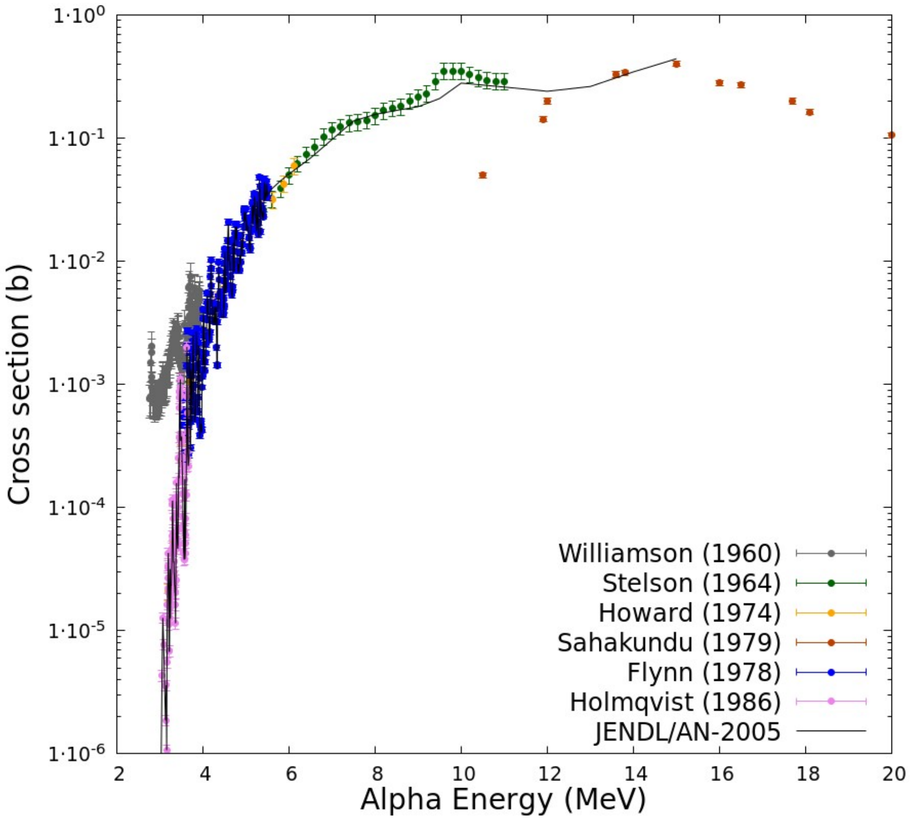

$^{27}Al(\alpha,n)^{30}P$ cross-sections

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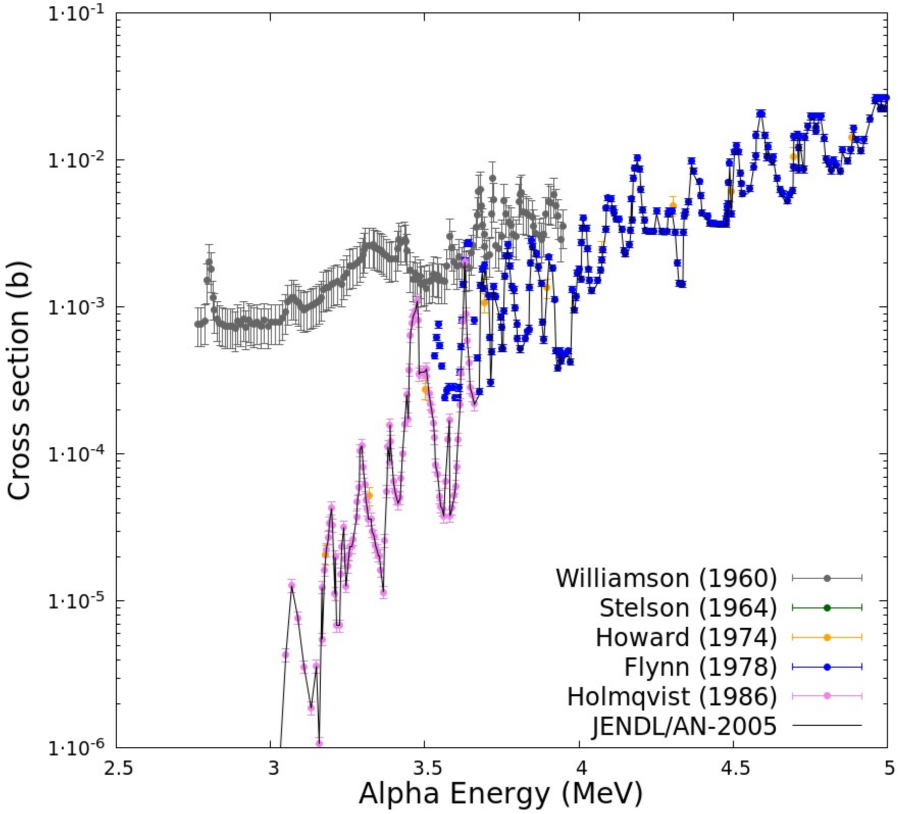

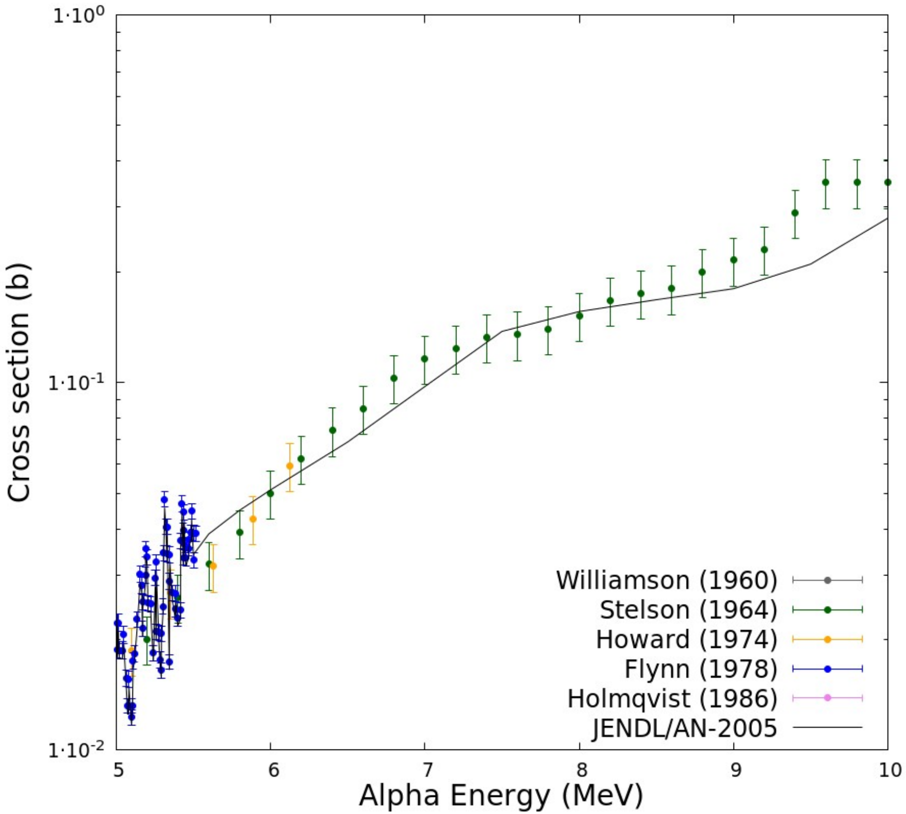

Cross section

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$$\sigma(E_\alpha) = \frac{N_A}{A_t} \frac{dY(E_\alpha)}{dE} \cdot \frac{dS}{dx}$$

σ = cross-section
N_A = Avogadro number
A_t = target atomic mass
dS/dX = stopping power
dY/dE = derivative of the neutron yield
E_α = beam energy

In this talk I will evalaute the effect of:

- Determination of the neutron yields (June vs March 2023 campaigns).
- Methodologies to estimate the yields derivative.
- Stopping powers.

Estimate the derivative

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Method 1: difference quotient

$$f'(x) = \frac{f(x+h) - f(x)}{h}$$

Method 2: symmetric derivative

$$f'(x) = \frac{f(x+h) - f(x-h)}{2h}$$

Cross sections

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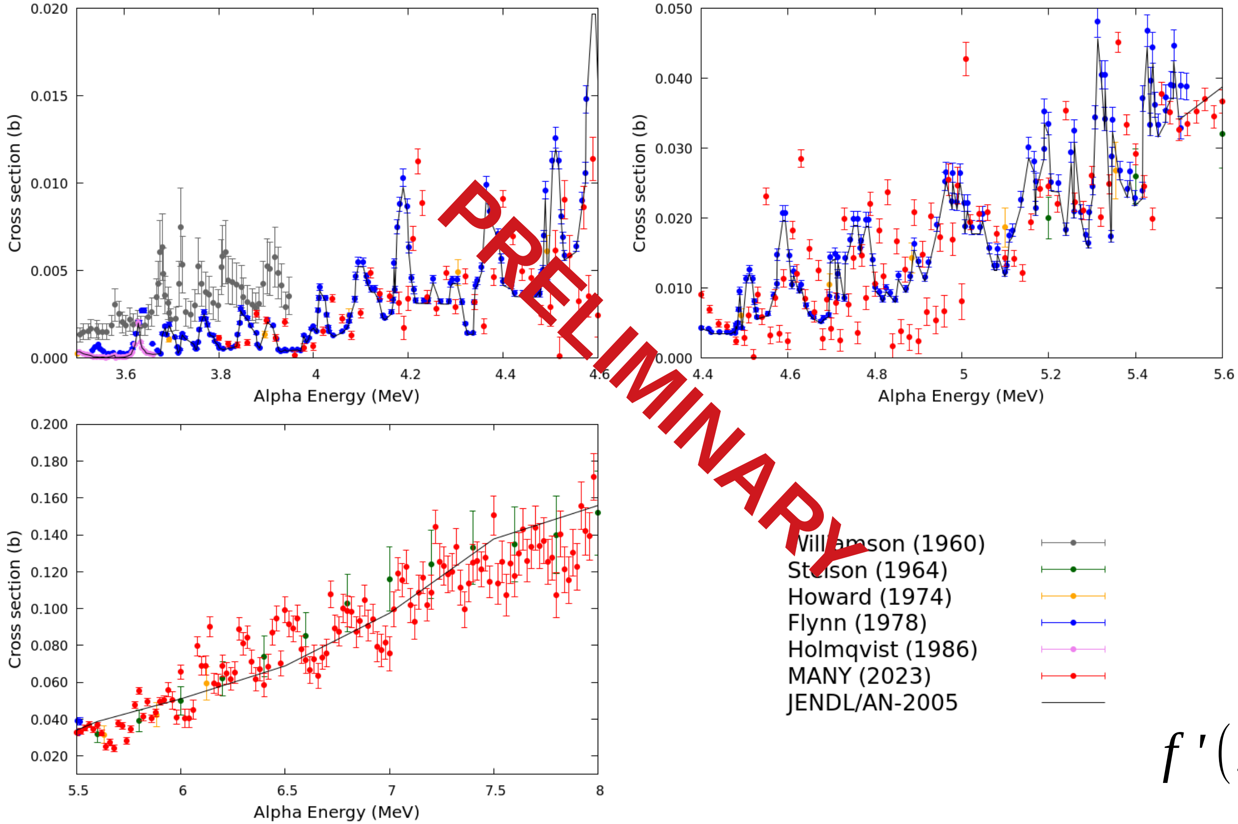

$$f'(x) = \frac{f(x+h) - f(x)}{h}$$

Cross sections

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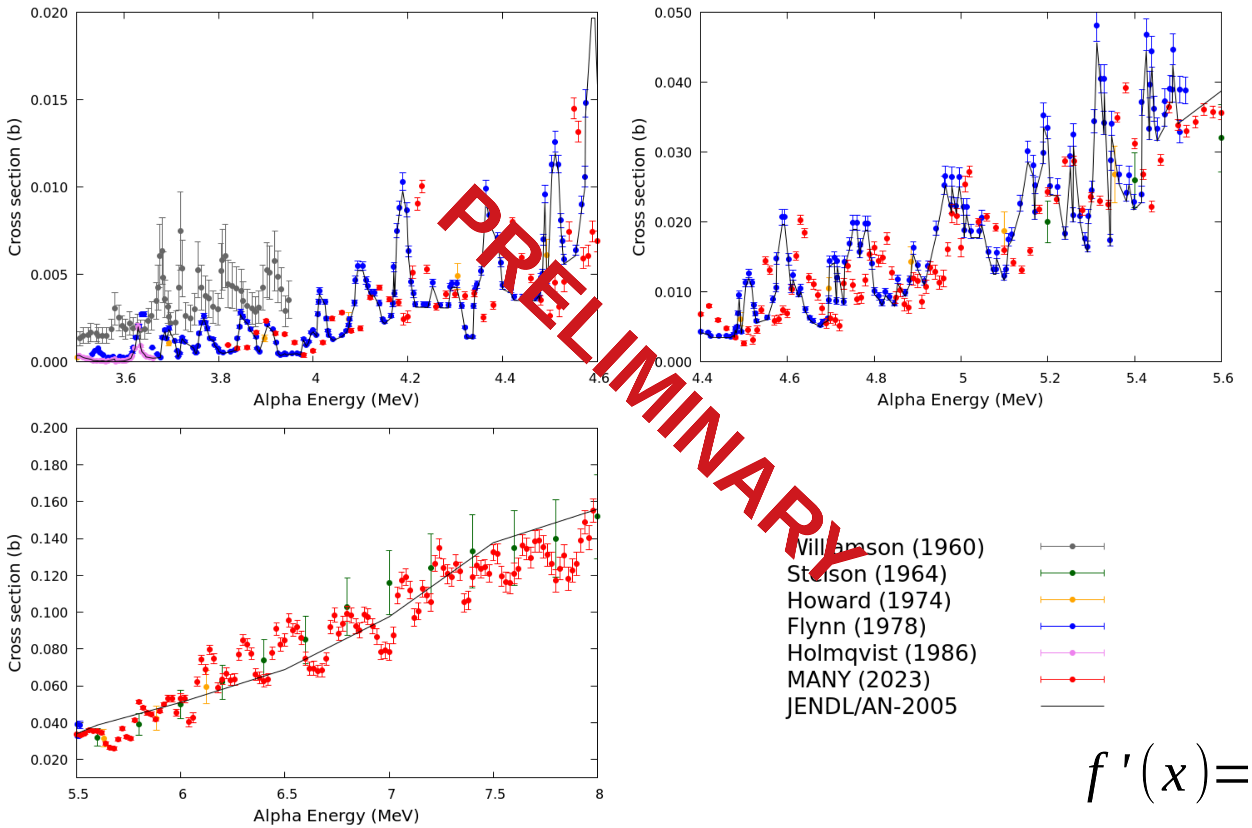

$$f'(x)=\frac{f(x+h)-f(x-h)}{2h}$$

Cross sections

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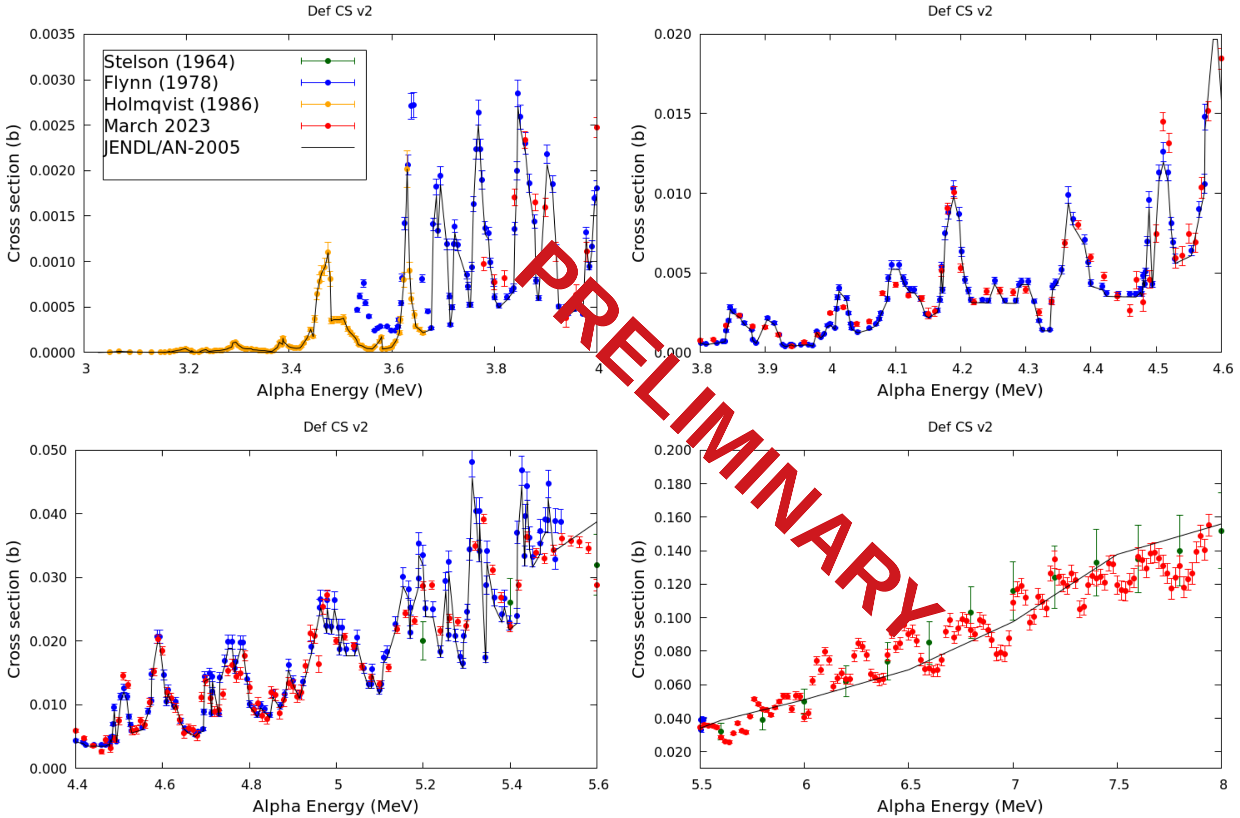
Applying a -40 keV correction on the beam energy in the MANY data



Conclusion:
40 keV shift between our data and the Flynn data

Data consistency

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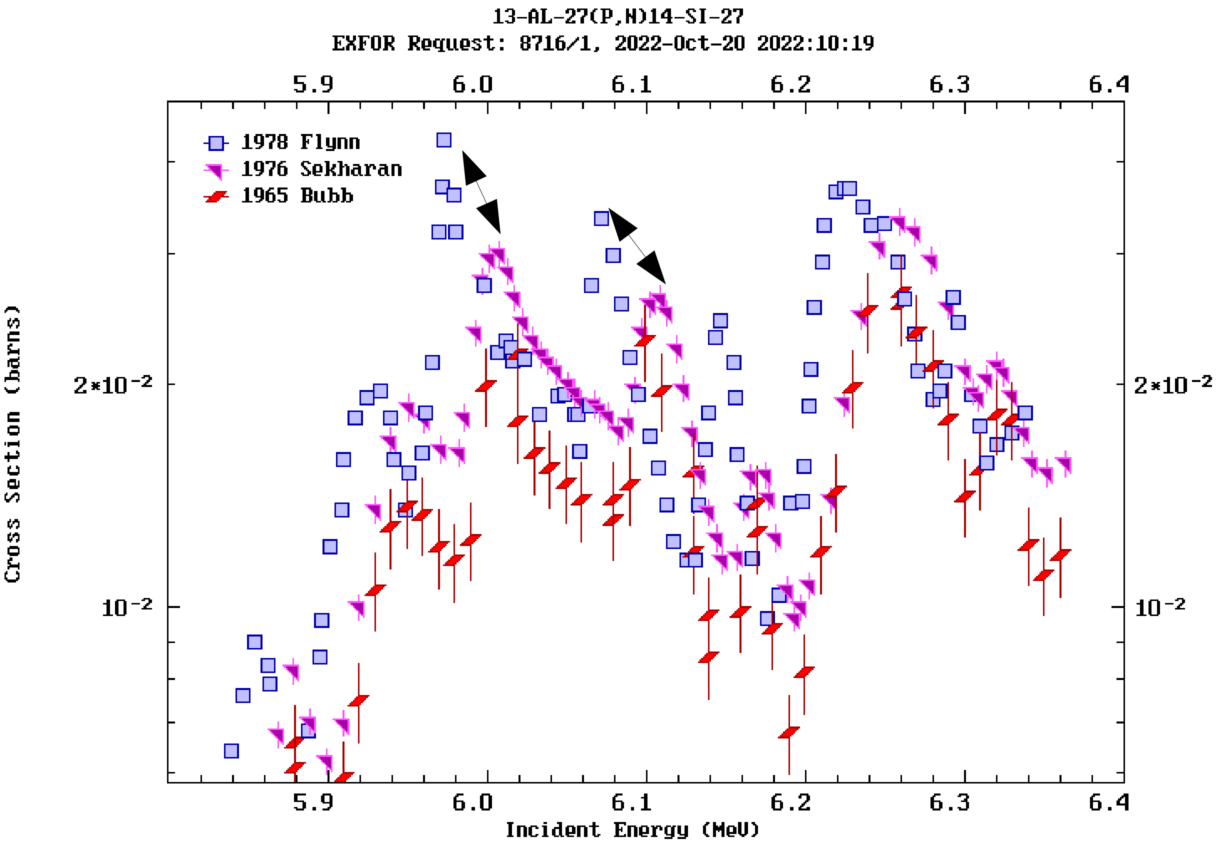
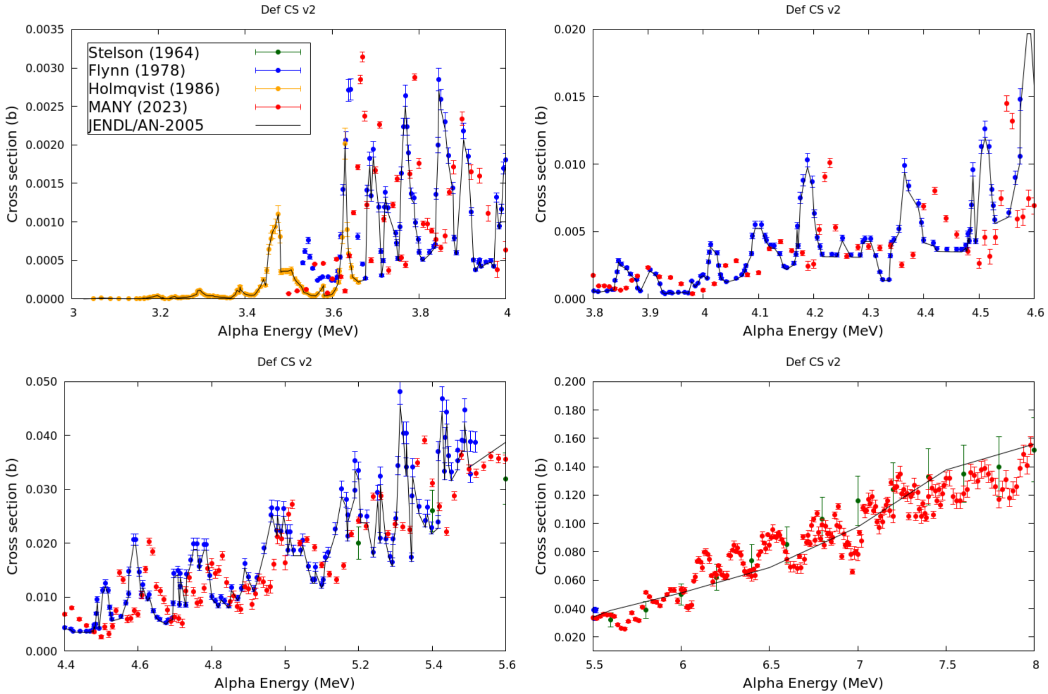
Cross-sections (p,n)

Flynn data on (p,n) reactions also present a negative ~ 50 keV shift with other data in the literature



Complete data -set

Cross-sections from 3.5 up to 8 MeV (reaction trheshold is 3.1 MeV)



Complete data -set

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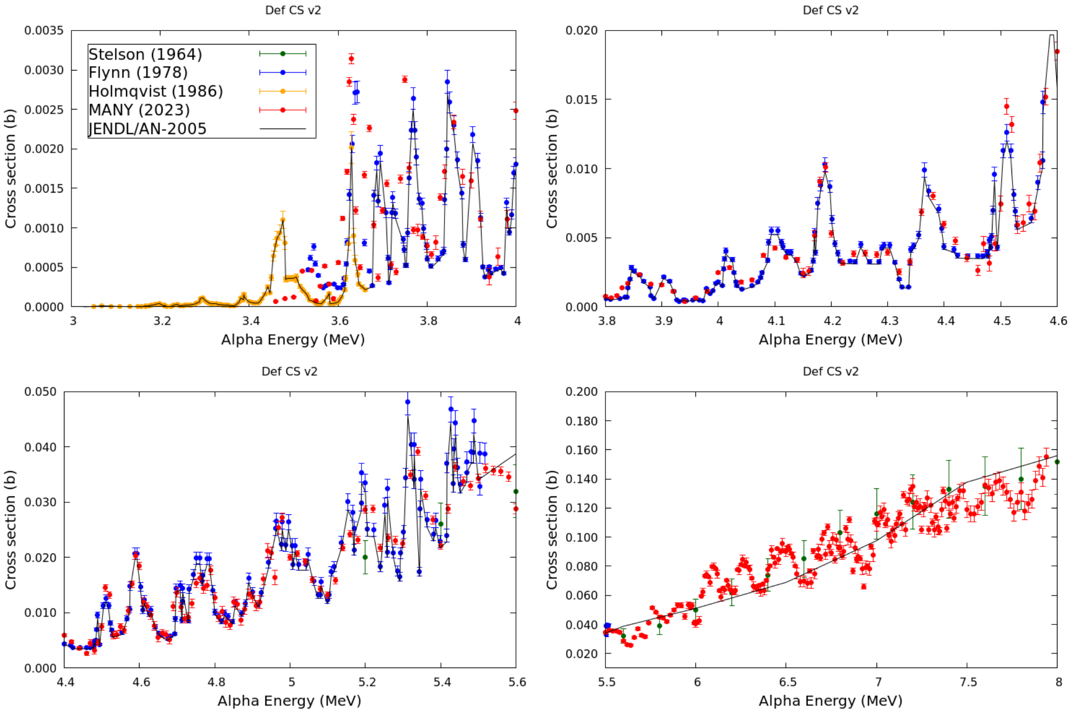
Cross-sections from 3.5 up to 8 MeV (reaction trheshold is 3.1 MeV)

Applying a -40 keV



Stopping powers

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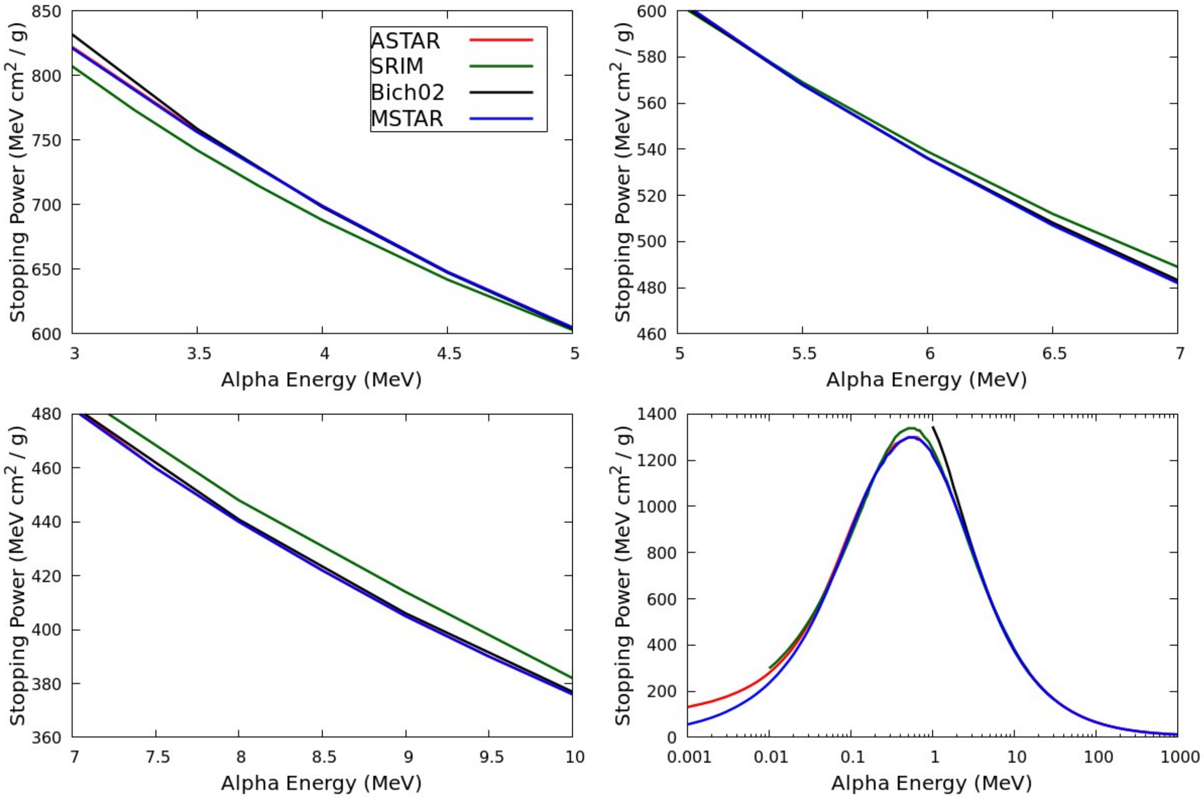

Stopping powers

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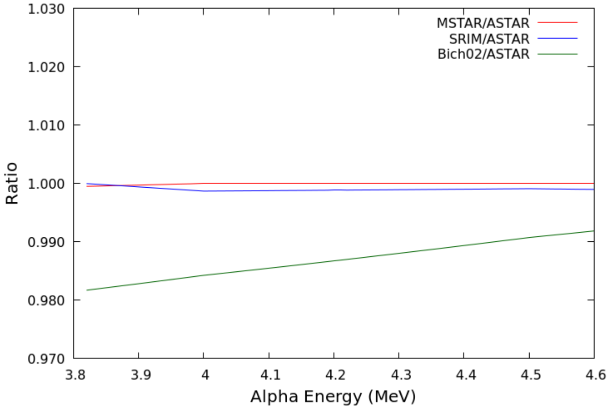

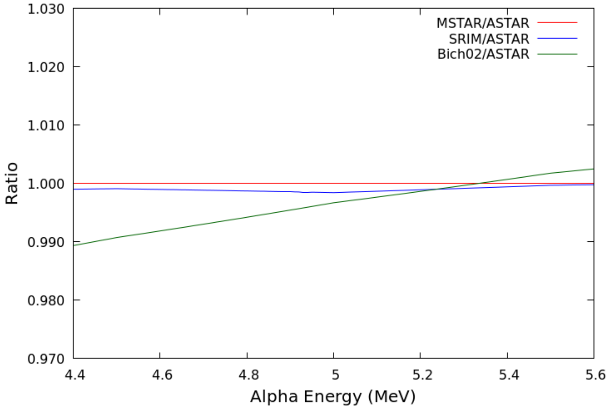

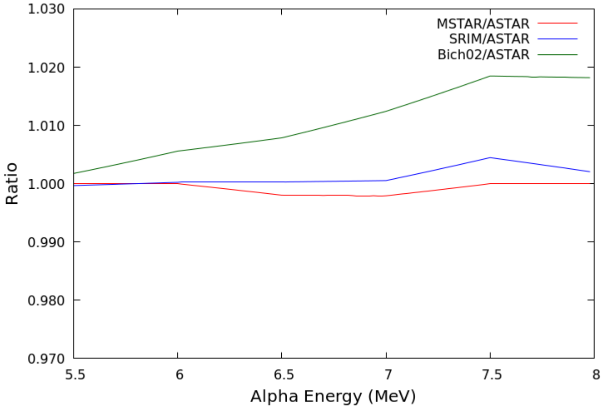

Precicison on the CS measuremetns is of about 4 – 5%

Larger differences of about 1 – 2%

Summary

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- Measurement of the $^{27}Al(\alpha,n)^{30}P$ reaction cross section from 4 up to 8 MeV from thick-target yields using a moderated neutron counter.

- Assessment of the effect of using different methodologies to compute the derivative of the yield and of using different models for the Stopping Power.

- Reproducibility of the data: effect of the neutron background.

- Future: data near the reaction trheshold (october 2023)

List of collaborators

INTE-UPC: *N* Mont-Geli, *M* Pallàs, *G* Cortés, *F* Calviño, *A* De Blas and *R* Garcia.

IFIC – UV – CSIC: *A* Tarifeño-Saldivia, *E* Nácher, *J L* Tain, *A* Algora, *J* Balibrea-Correa, *C* Domingo-Pardo, *J* Lerendegui-Marco and *S E A* Orrigo.

GFN – UCM: *L M* Fraile, *O* Alonso-Sañudo, *J* Benito, *M* Llanos, *V* Martínez-Nouvilas, *J R* Murias, *J M* Udías and *V* Sánchez-Tembleque.

CMAM – UAM: *S* Viñals and *G* García.

IEM – CSIC: A Perea, *M J G* Borge, *J A* Briz and *O* Tengblad.

CIEMAT: *V* Alcayne, *D* Cano-Ott, *E M* González-Romero, *T* Martínez, *A* Pérez de Rada, *V* Pesudo, *J* Plaza, *A* Sánchez, *R* Santorelli, and *D* Villamarín.

CNA – US: *B* Fernández, *J* Gómez-Camacho, *C* Guerrero and *J M* Quesada

Acknowledgements

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CMAM – UAM: *S* Viñals and *G* García and *J* Sanchez.

IEM – CSIC: A Perea, *M J G* Borge, *J A* Briz and *O* Tengblad and *D* ???

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CNA – US: *B* Fernández, *J* Gómez-Camacho, *C* Guerrero and *G* Auñon

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Backup slides

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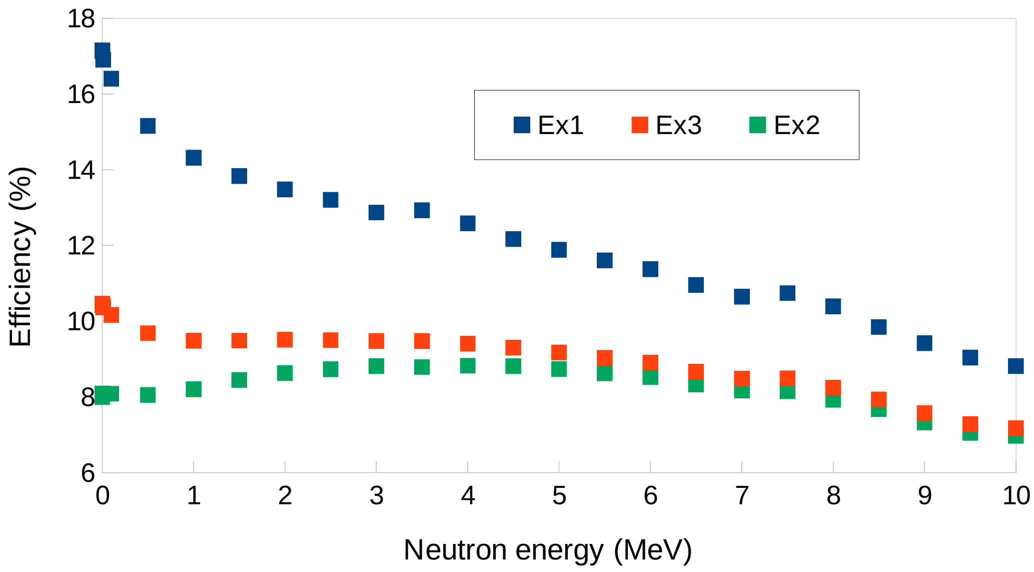
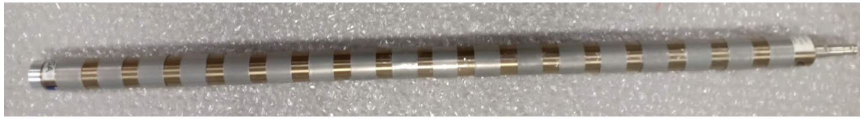
Composition method

- Use of cadmium to obtain a flat response.



Ex1: $f_1 = f_2 = f_3 = 1$
Ex2: $f_1 = 0.6,\ f_2 = 0.8,\ f_3 = 1$
Ex3: $f_1 = 0.45,\ f_2 = 0.95,\ f_3 = 1$

$$\varepsilon(E) = \sum_{i=1}^{3} \varepsilon_i(E) = \sum_{i=1}^{3} f_i(E)\cdot\varepsilon_i(E)$$



miniBELEN

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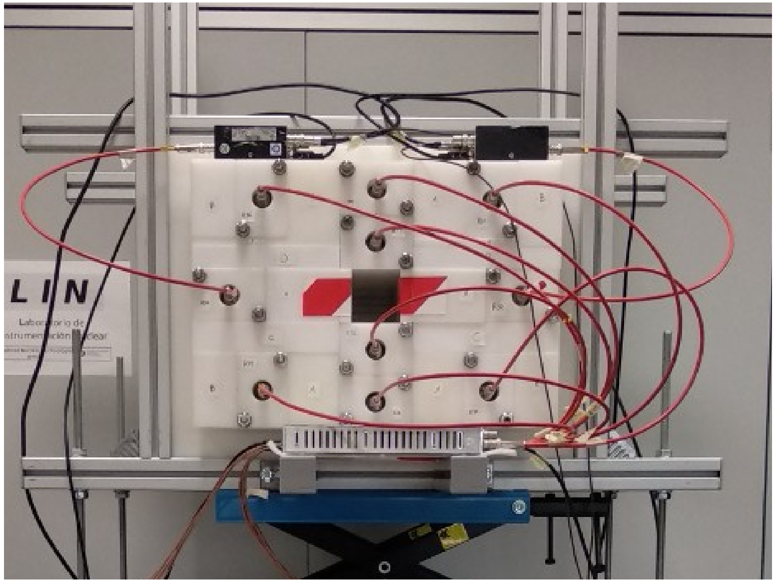
Design constraints

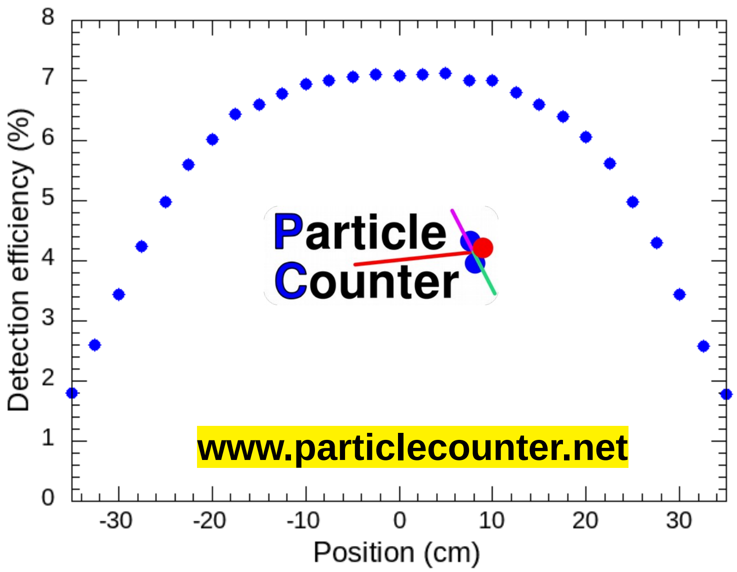
- Long counter tehcnique: thermal neutrons counters (^{3}He) + moderator (hihg density polyethylene).
- Detection efficiency nearly independent from the neutron energy (flat response) up to 8/10 MeV.
- Modular moderator.

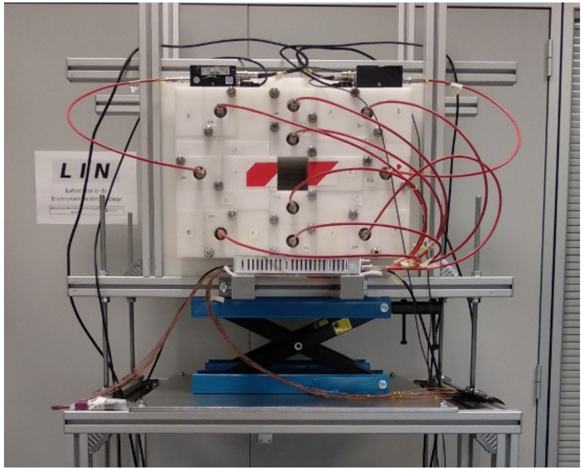


miniBELEN

miniBELEN-10A (modular neutron counter):

- ^{3}He-filled proportional counter + HDPE.
- Flat response up to 8/10 MeV.





$^{27}Al(\alpha,n)^{30}P$

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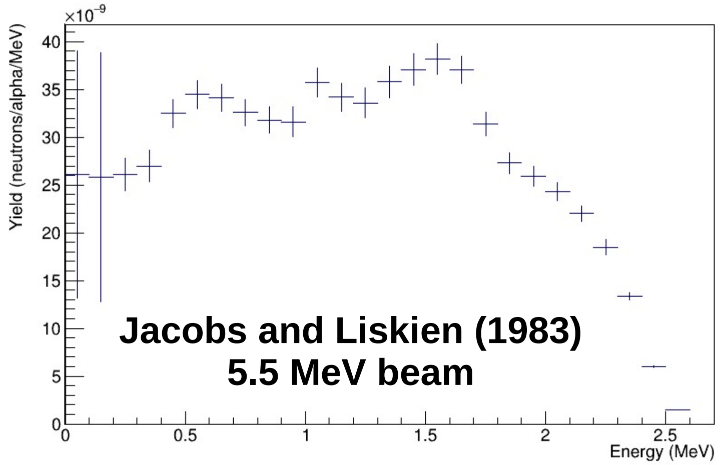
Bench-marking of the efficiency calculation using the $^{27}Al(\alpha,n)$ reactions

$$Eff_{Ri} = \int \varepsilon_i(E)S(E)\,dE$$

$$Q = \frac{Rate_i / Rate_j}{Eff_{Ri} / Eff_{Rj}}$$



Q (R1/R2)	Error	Q (R1/R3)	Error	Q (R2/R3)	Error
0.93	0.04	0.93	0.04	1.03	0.02

$^{27}Al(\alpha,n)^{30}P$ measurement

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Cross-sections (p,n)

Flynn data on (p,n) reactions also present a 50 keV with other data in the literature