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Recent experimental efforts for the astrophysical p-process

D. Galaviz

EuNPC2025

Caen, September 25th 2025

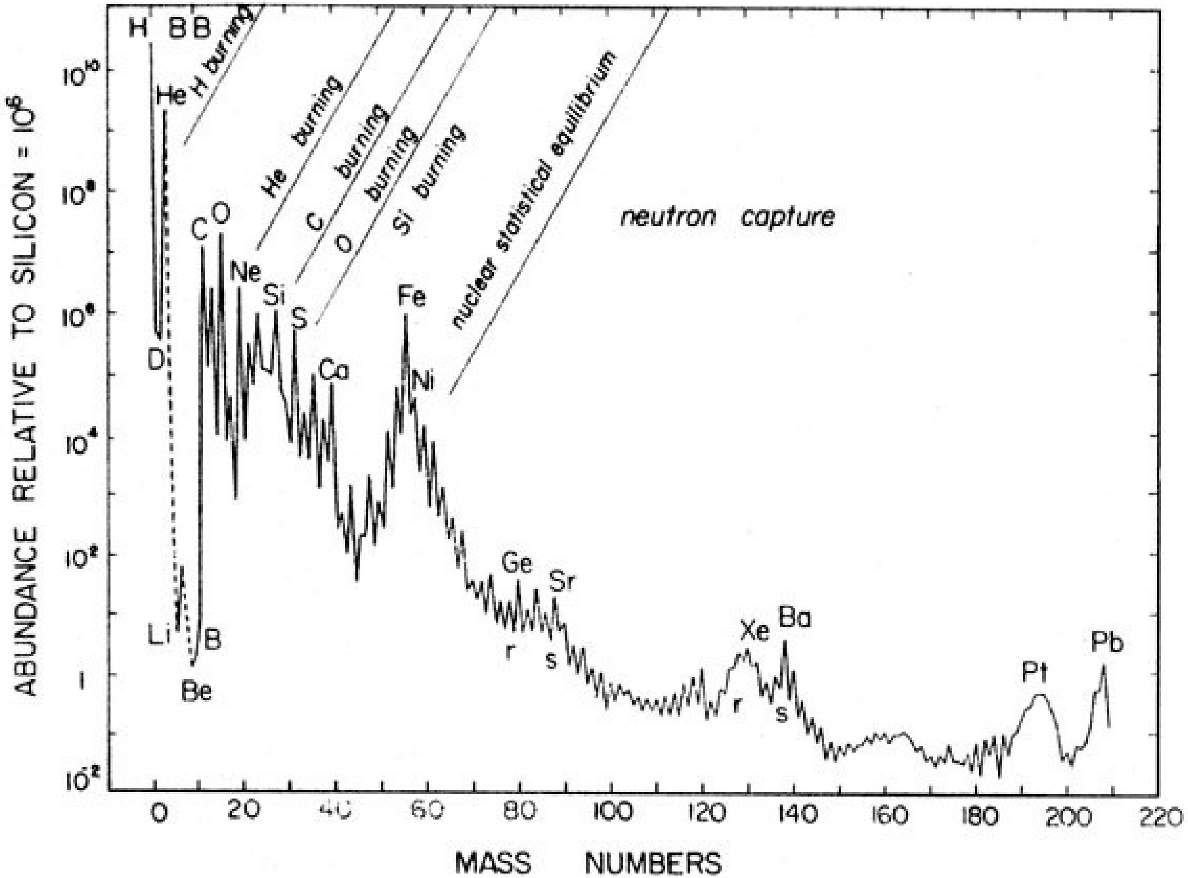
Overview

- Motivation: Explosive nucleosynthesis ; **p-process**
- Experimental efforts for
  - **α-nuclear potential** studies
  - **Proton capture** reaction studies
- Ongoing **analysis** and preliminary **results**
- Summary

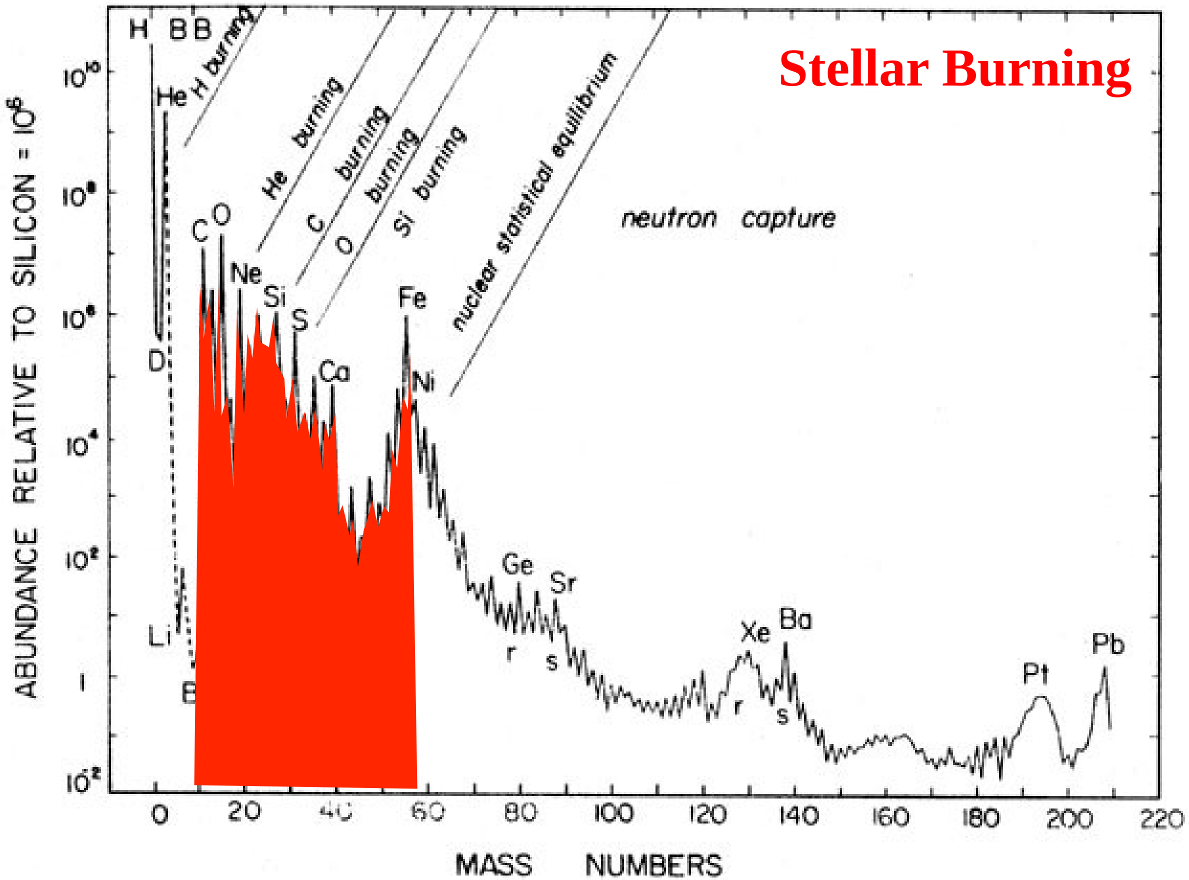
Motivation

p-nuclei nucleosynthesis

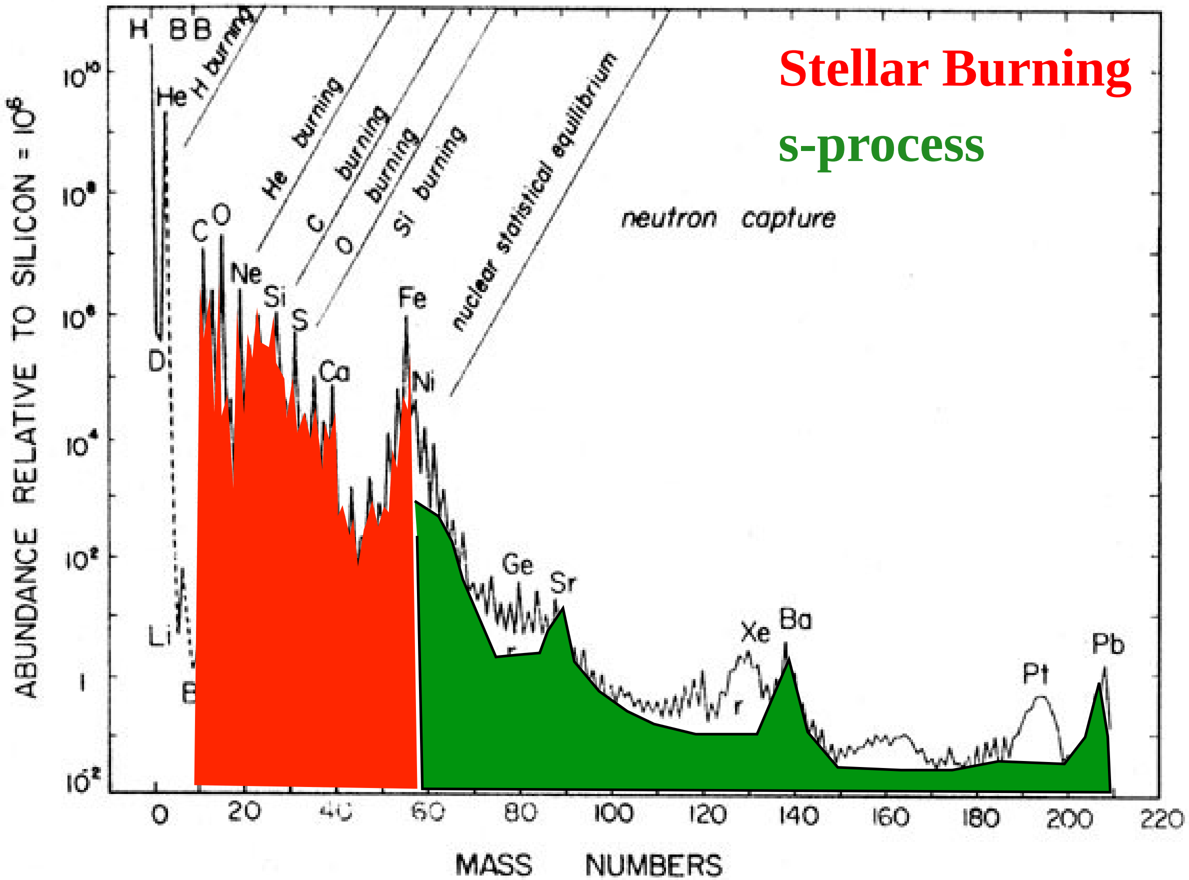
Stellar Nucleosynthesis



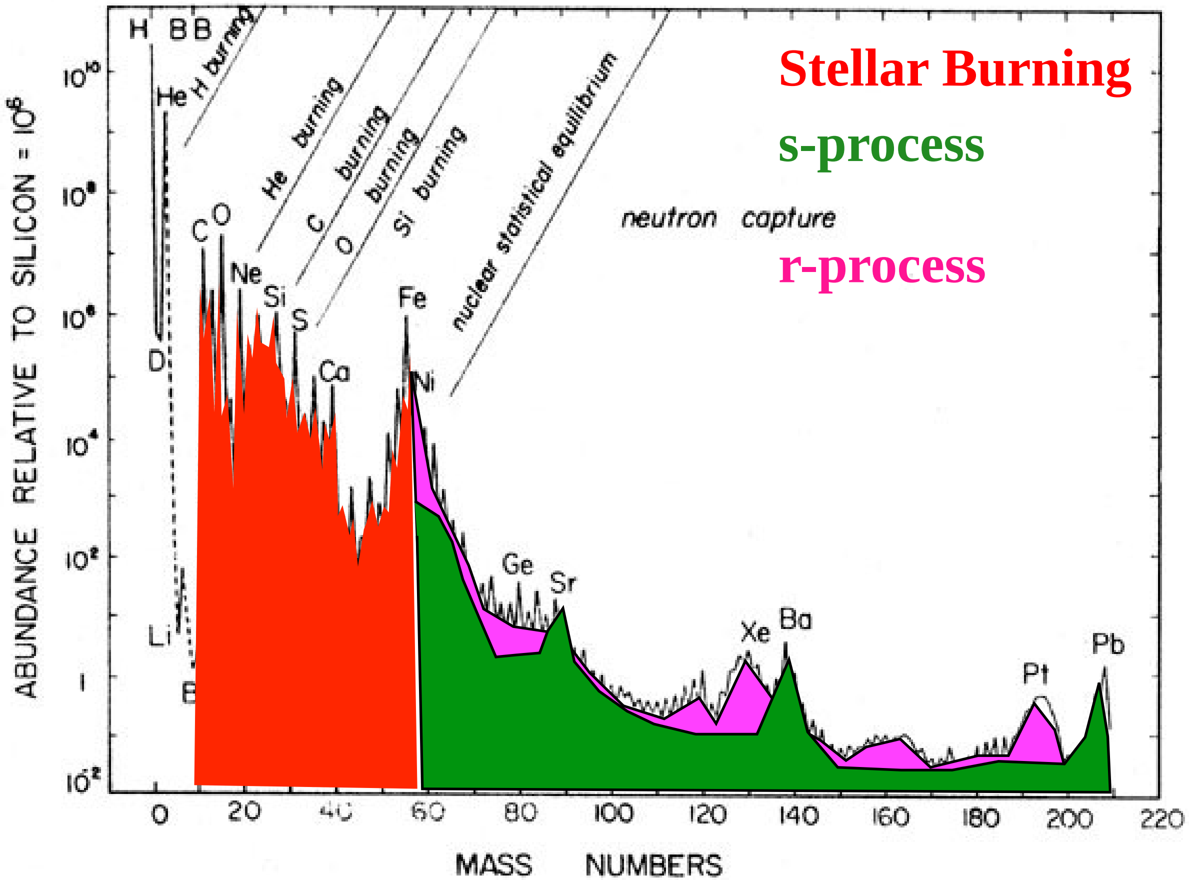
Stellar Nucleosynthesis



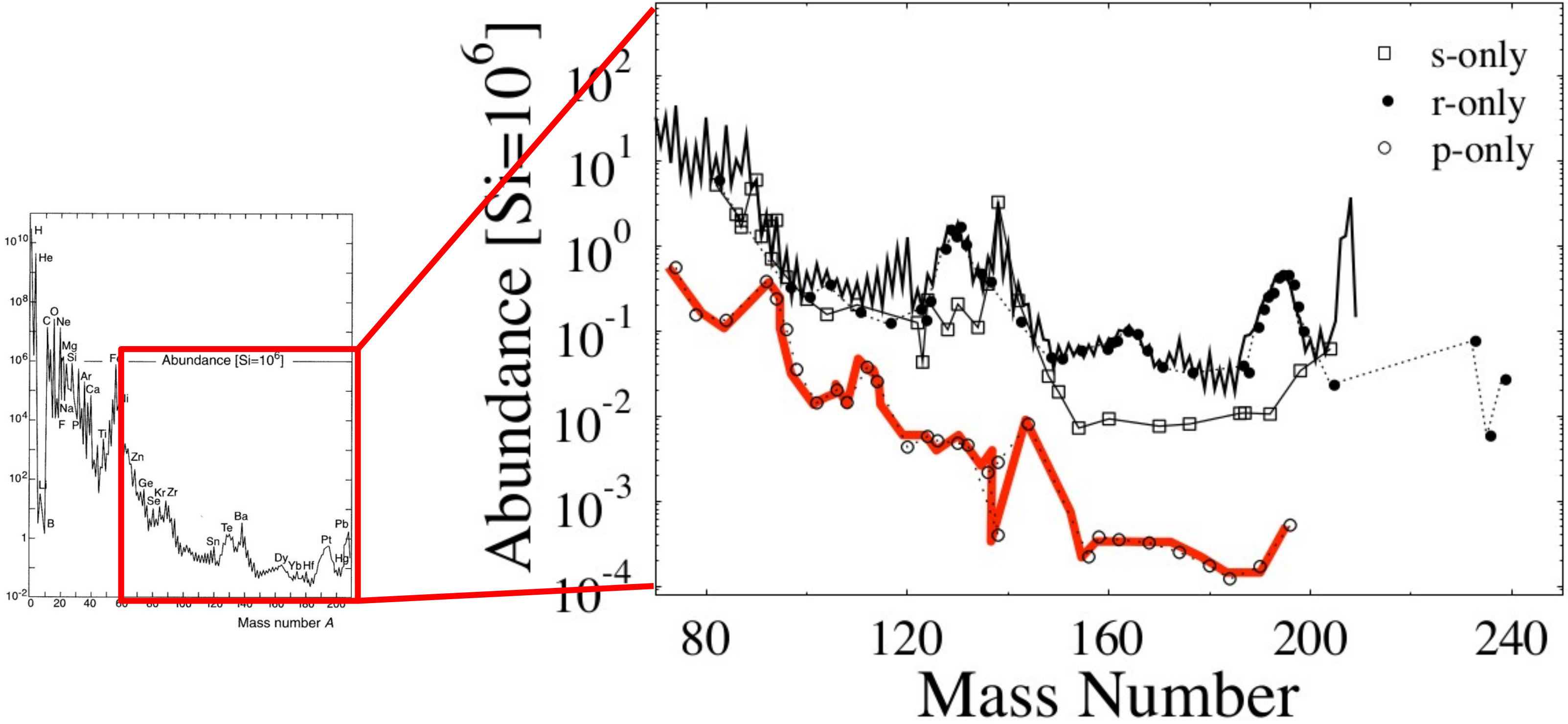
Stellar Nucleosynthesis



Stellar Nucleosynthesis



p-nuclei



Abundance [Si=10^6]
Mass number A
H
He
Li
B
C
O
Ne
Mg
Si
Na
F
P
Ar
Ca
Ti
Fe
Ni
Zn
Ge
Se
Kr
Zr
Sn
Te
Ba
Dy
Yb
Hf
Pt
Pb
Hg
Abundance [Si=10^6]
Mass Number
s-only
r-only
p-only

p-process nucleosynthesis

- Various sites as candidates for p-nuclei production

  - Ne/O layers of Type II SuperNovae (γ-process)
  - Type Ia SuperNovae

  } **s-process** seeds

  - νp-process
  - rp-process

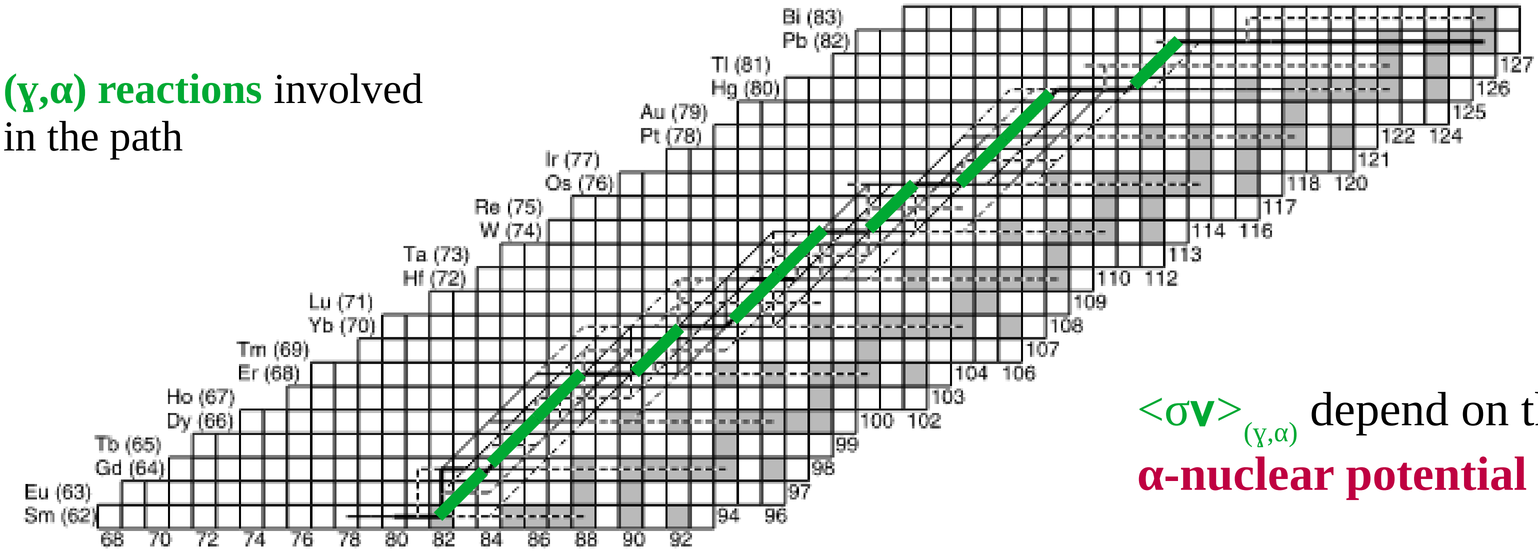
p-process nucleosynthesis

<u>Sensitivity studies</u> of **p-process** nucleosynthesis point out the strong dependence of the **α-nuclear potential** in the production of **heavy p-nuclei**

W. J. Rapp et al., Astrophys. J 653, 474 (2006)

Z

(ɣ,α) reactions involved in the path



$\langle\sigma v\rangle_{(\gamma,\alpha)}$ depend on the **α-nuclear potential**

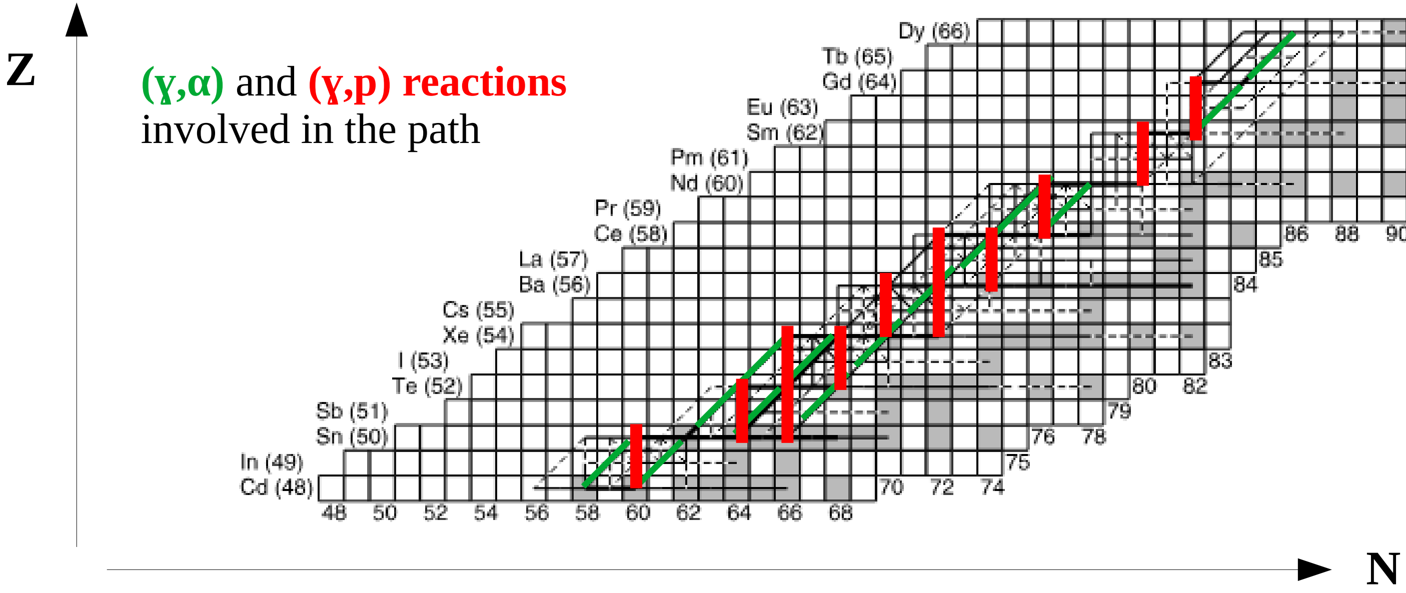
N

p-process nucleosynthesis

<u>Sensitivity studies</u> of **p-process** nucleosynthesis point out the importance of (γ,p) reactions in the production of **medium mass p-nuclei**

W. J. Rapp et al., Astrophys. J 653, 474 (2006)

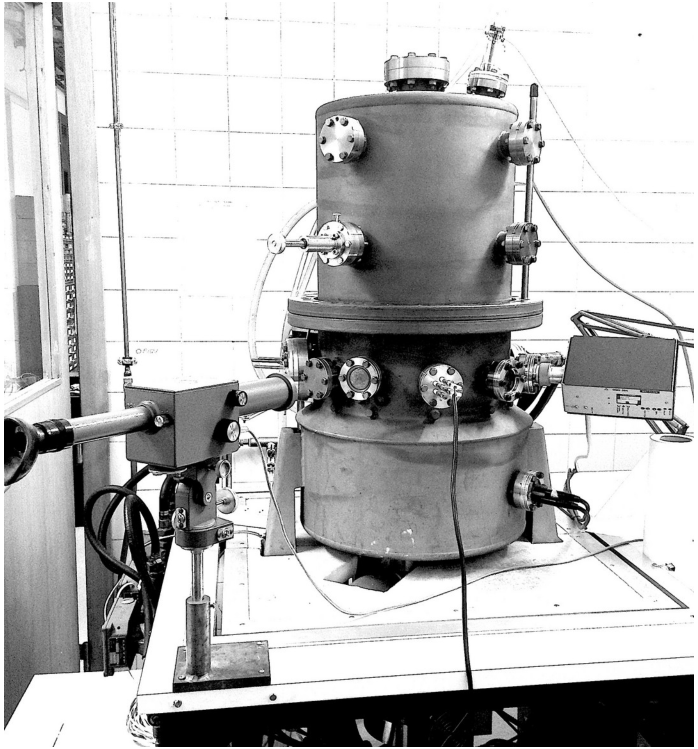
(γ,α) and **(γ,p) reactions** involved in the path



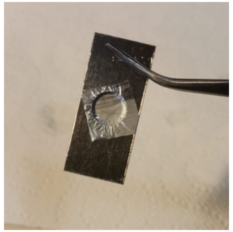
Where does an experiment begin?

And why could an isotopic chain be so interesting

Targets



Target Design Laboratory (**TDL**)

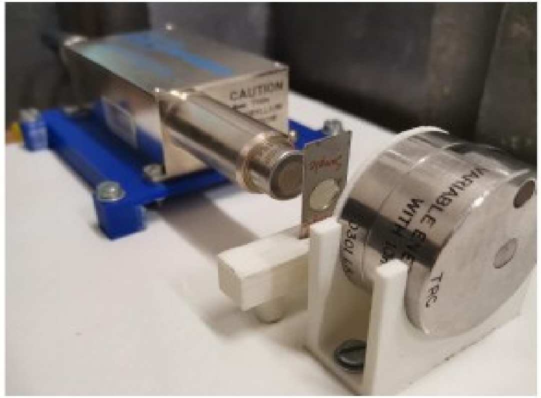


- Hydraulic bell-shaped steel evaporator
- Two pairs of electrodes
- Natural and highly enriched **self supporting targets**:
  - ^{197}Au (0.3 mg/cm^2)
  - ^{208}Pb (1-2 mg/cm^2)
  - **^{116,118}Sn** (0.3-0.5 mg/cm^2)

Target analysis methods

Alpha Energy Loss (AEL)

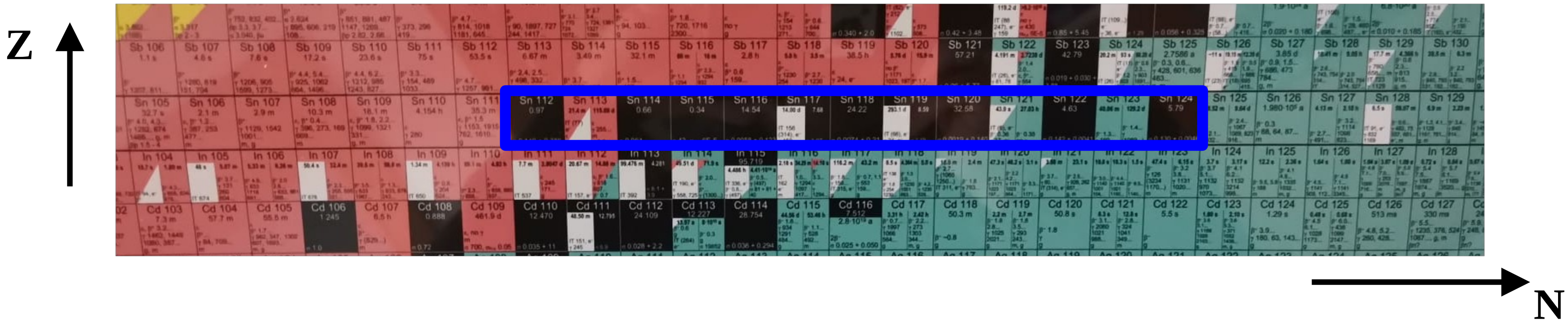
Rutherford Backscattering Spectrometry (RBS)



X-ray Attenuation

Why Sn-isotopes?

α-nuclear potential mass dependence in stable **Sn** isotopes



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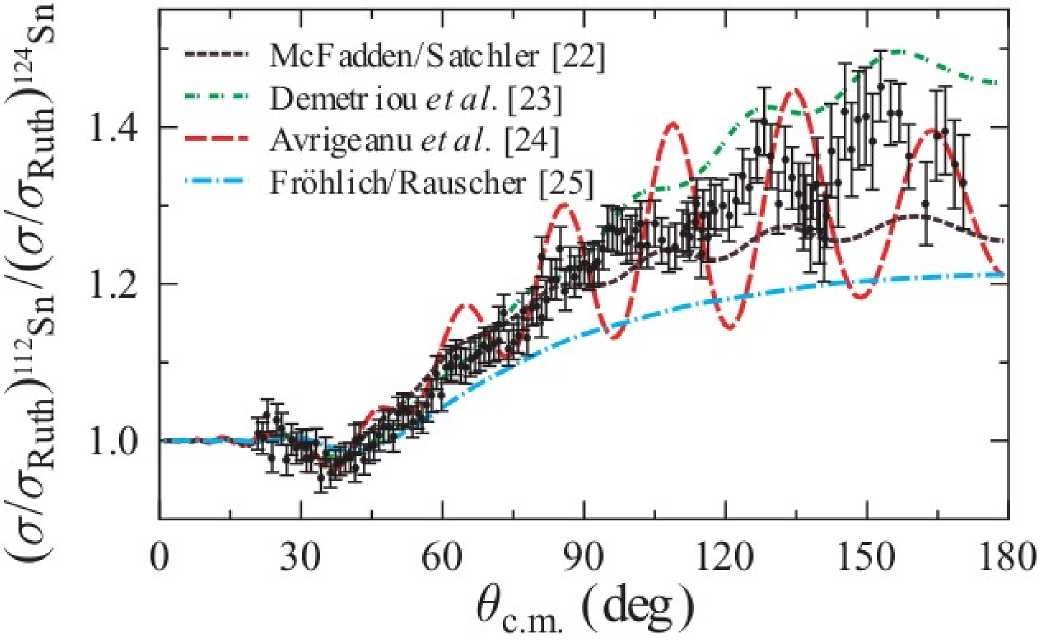

D. Galaviz et al, Phys. Rev. C 71, 065802 (2005)

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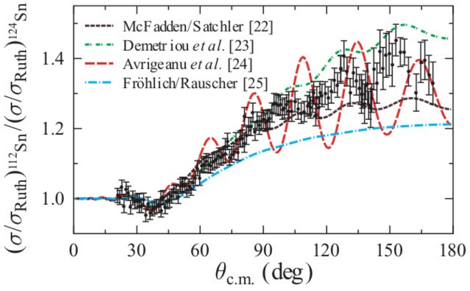

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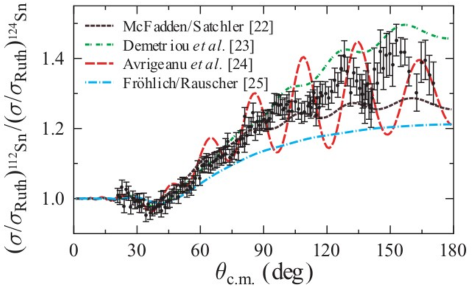

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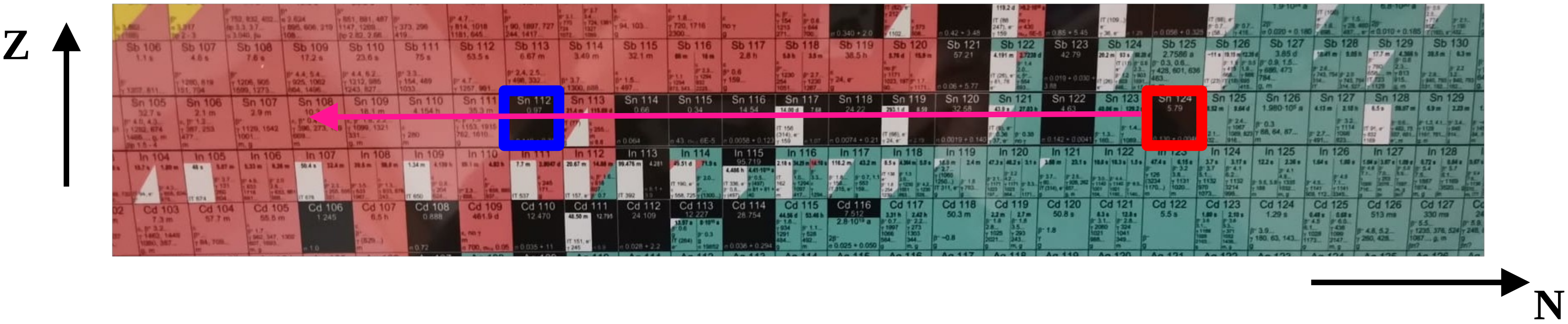

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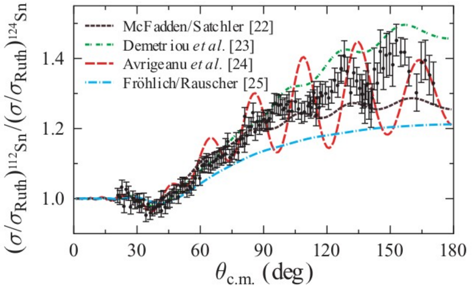

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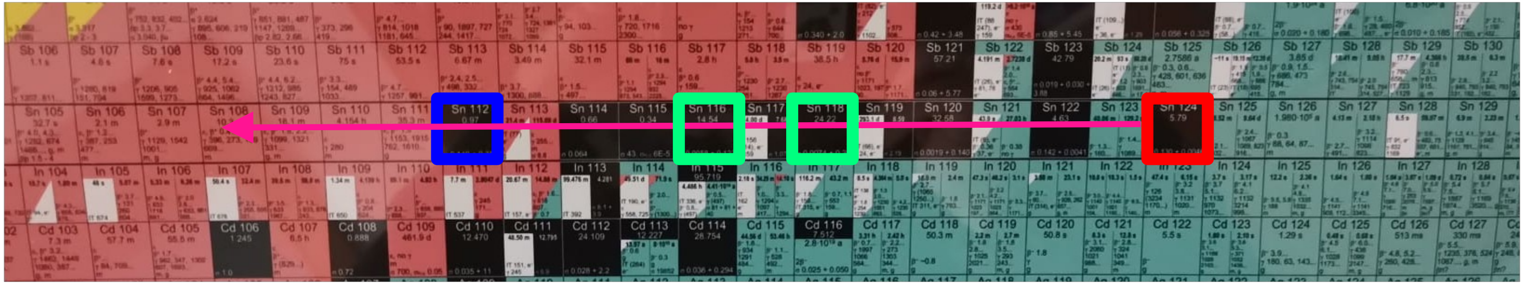

N

^{116}**Sn** and ^{118}**Sn** could greatly help tune extrapolations

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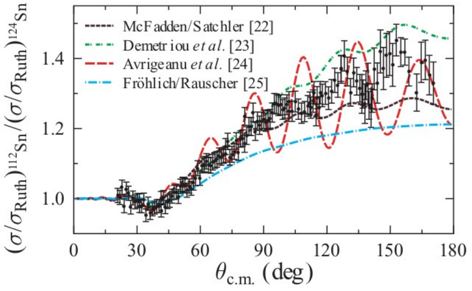
α-nuclear potential mass dependence in stable **Sn** isotopes



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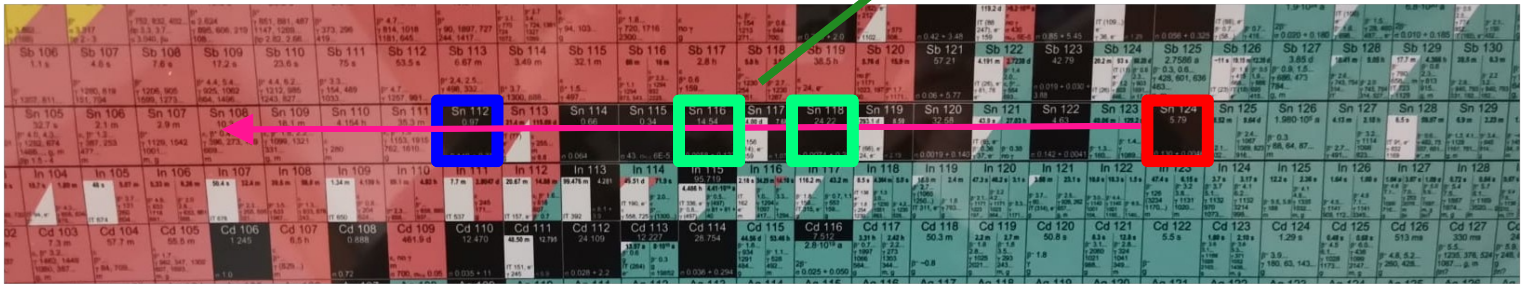


N

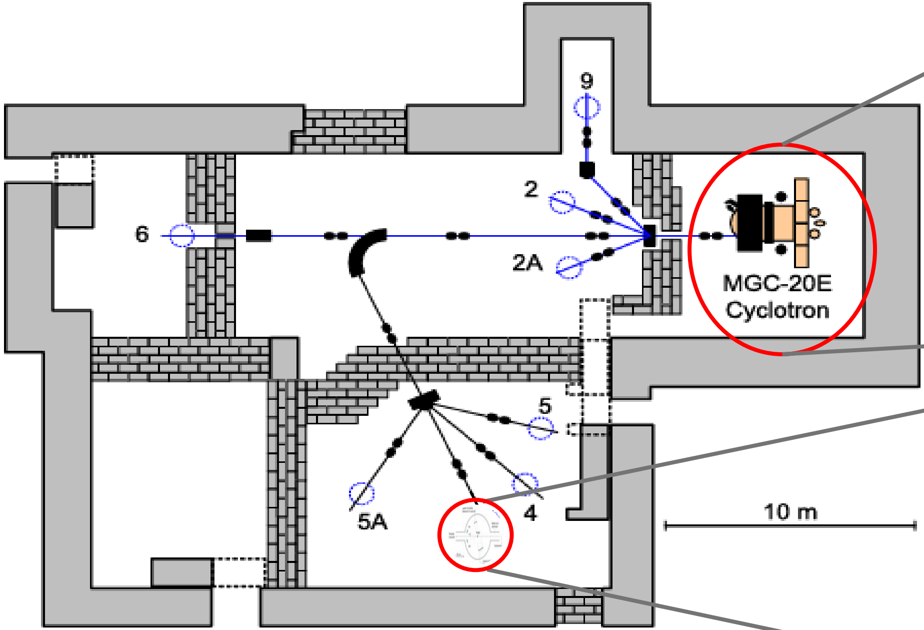
^{116}**Sn** and ^{118}**Sn** could greatly help tune extrapolations

Elastic scattering

In direct kinematics

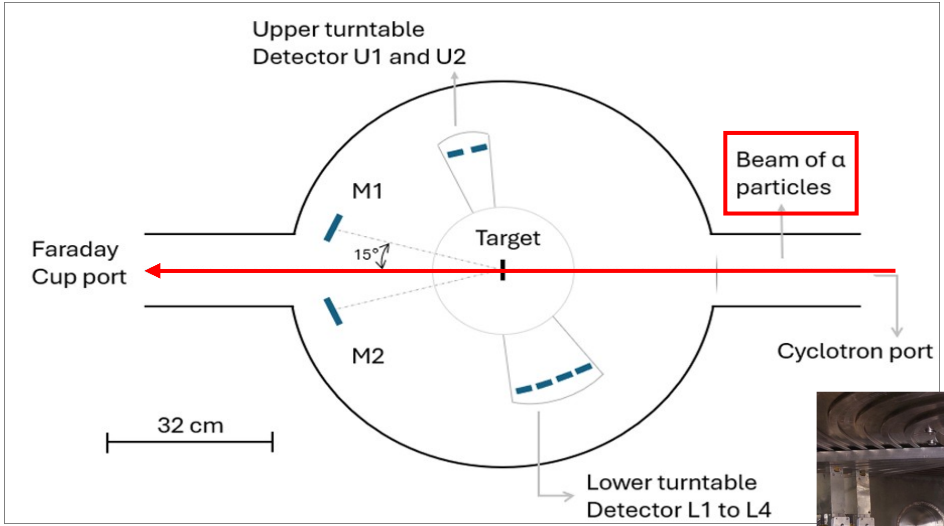
ATOMKI

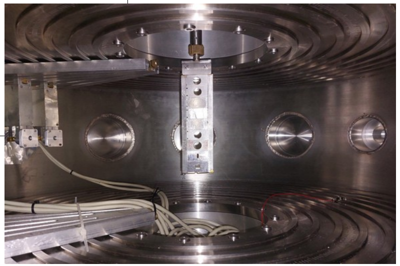
Cyclotron provides **α-particle** beams up to **20 MeV**



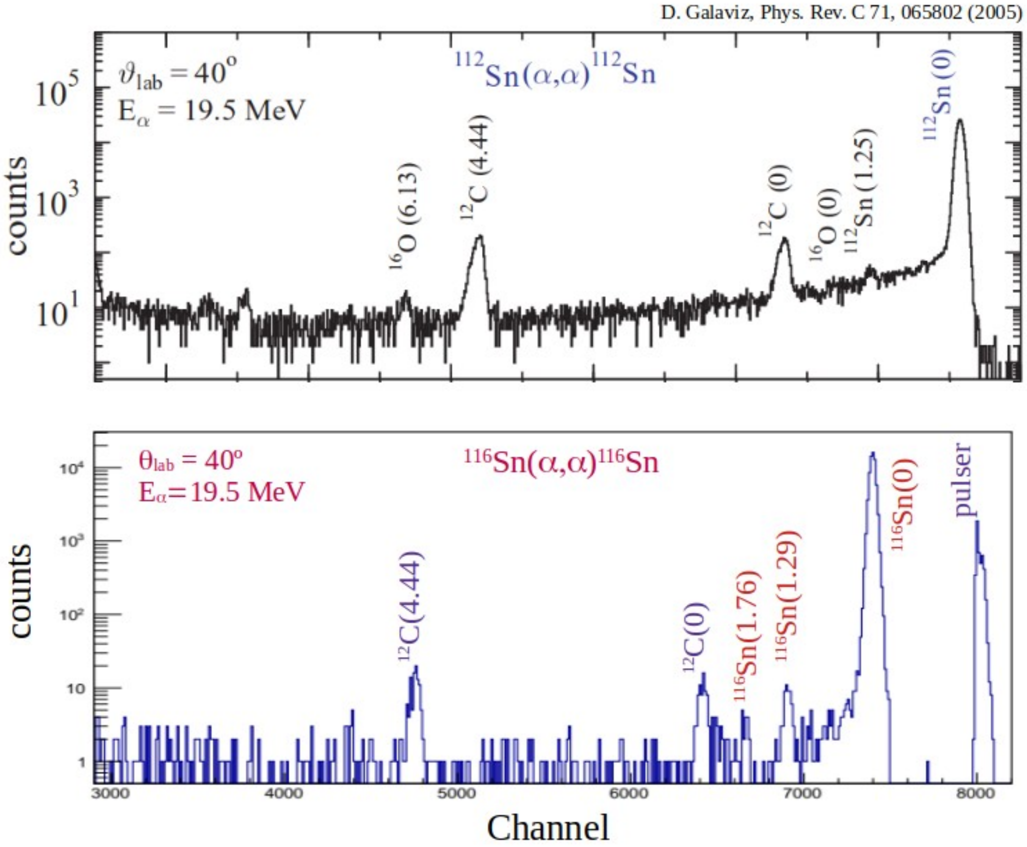
ATOMKI

New detectors and **upgraded data acquisition**





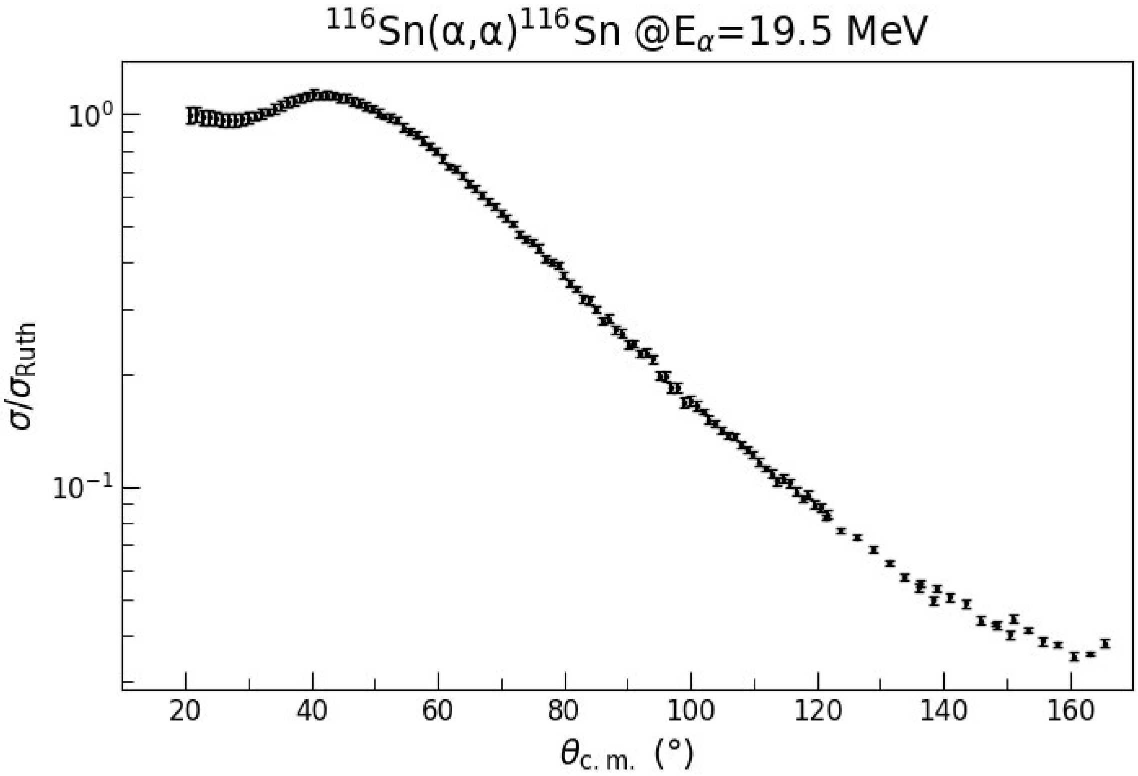
Online spectra



2005

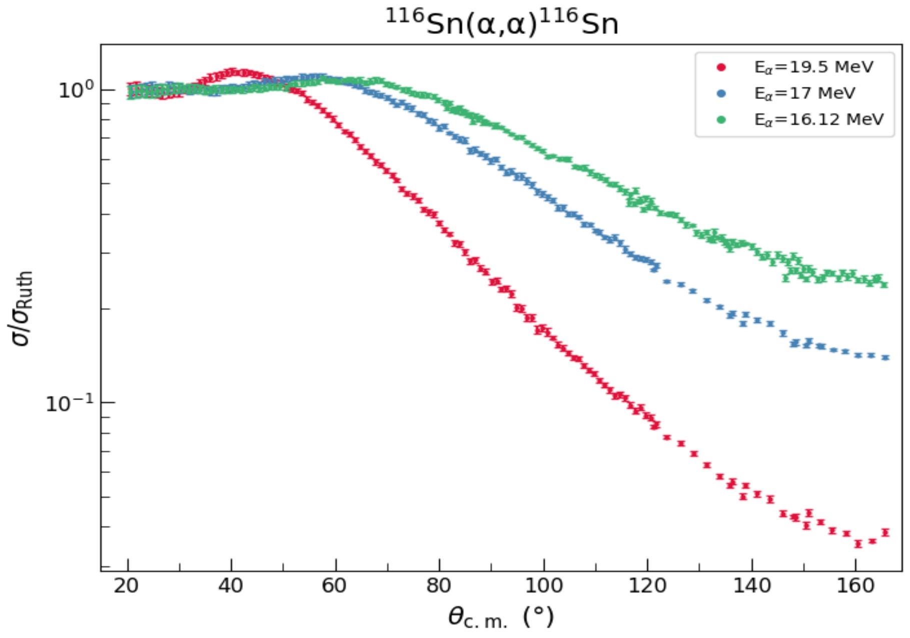
2024

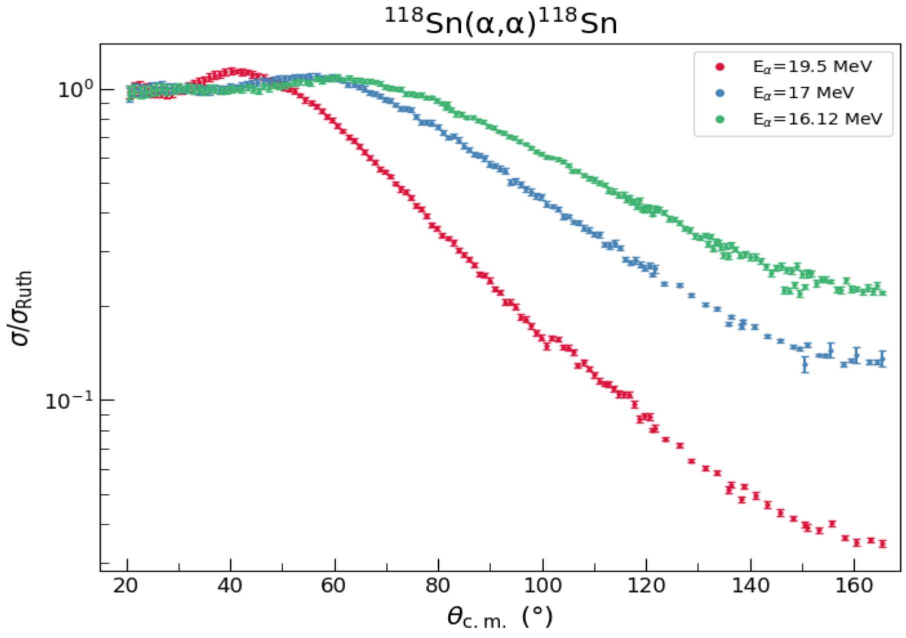
Elastic scattering angular distributions



Elastic scattering angular distributions

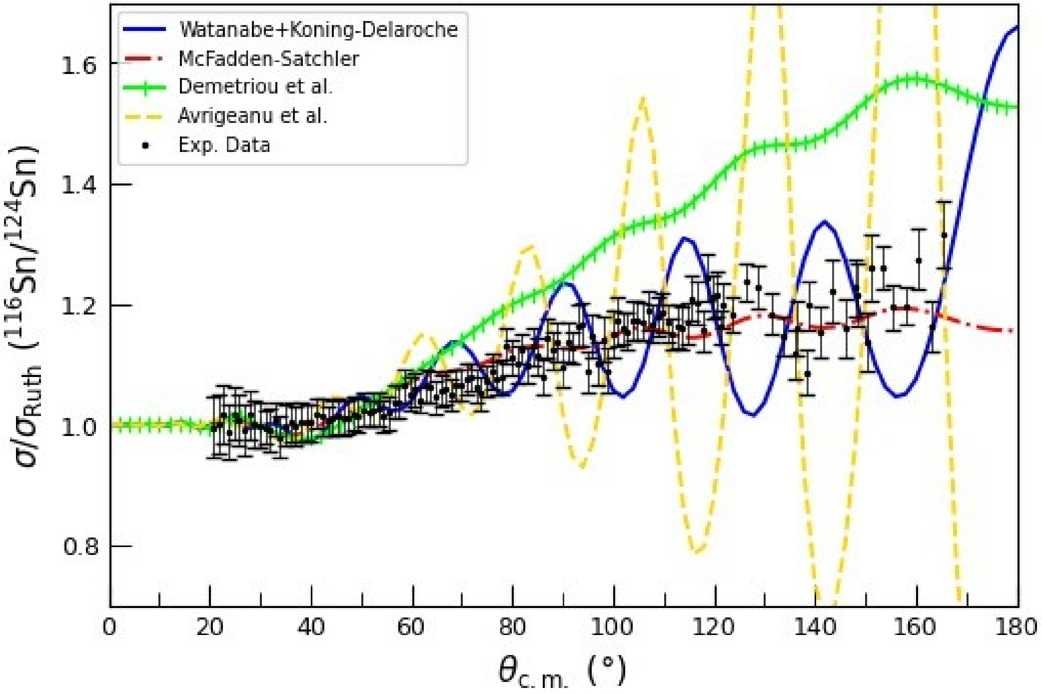
Six angular distributions → Three energies: **16.1, 17 and 19.5 MeV** X Two isotopes: **^{116}Sn** and **^{118}Sn**

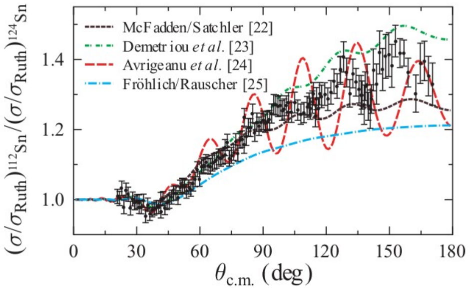




Elastic scattering angular distributions

Cross section ratios
(various possibilities)



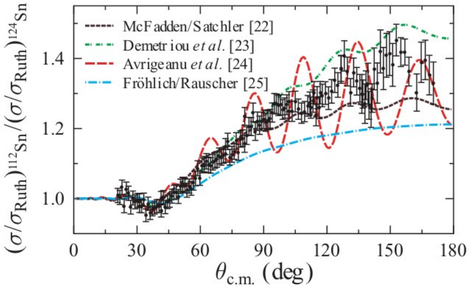


Analysis in progress

R. Nunes

Why Sn-isotopes?

α-nuclear potential mass dependence in stable **Sn** isotopes



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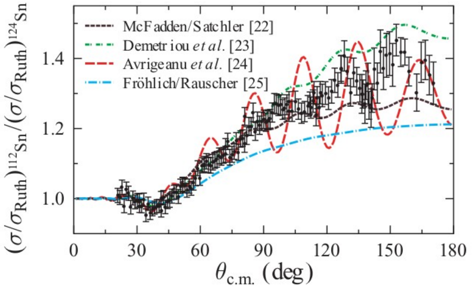

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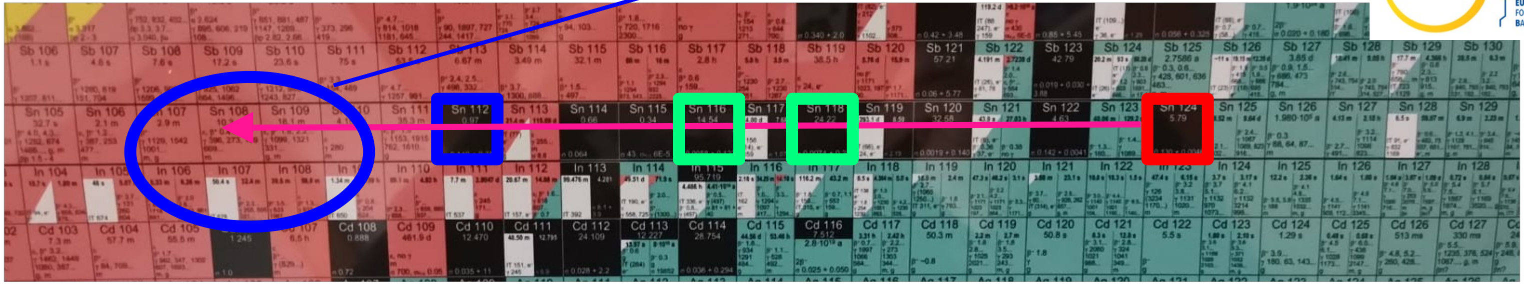
IS698: **α** elastic **scattering** in **inverse kinematics** on **^{108,109,110}Sn**

Z



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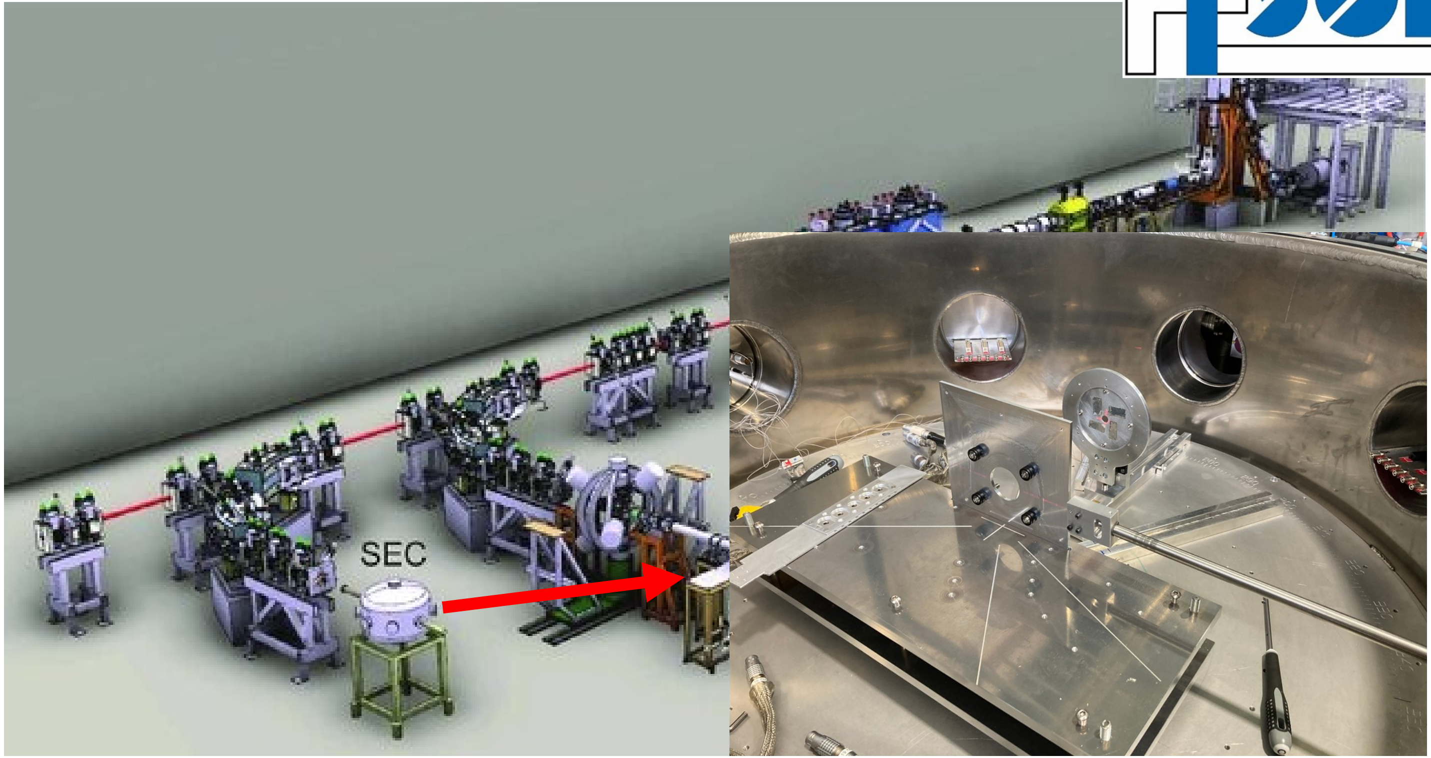
Elastic scattering

In inverse kinematics

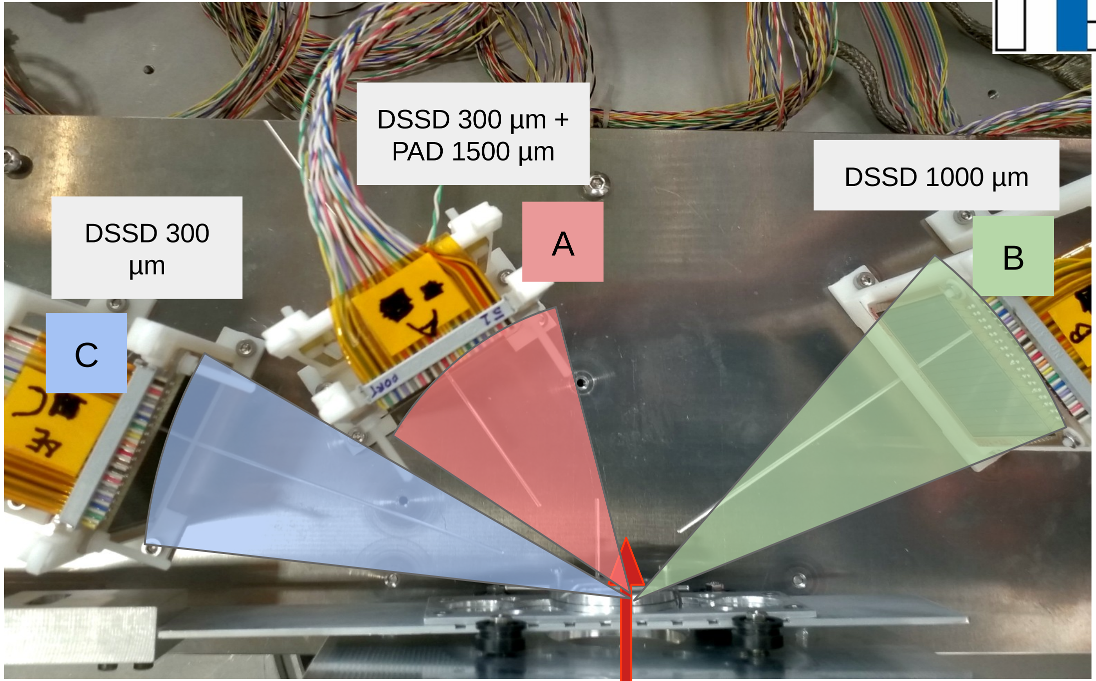
Inverse kinematics experiment: IS698



Inverse kinematics experiment: IS698

Telescope A
22° to 51°

Detector C
60° to 80°



Detector B
44° to 66°

^{A}Sn Beam

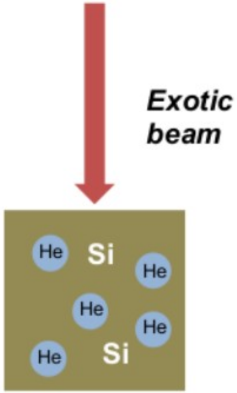
Inverse kinematics experiment: IS698

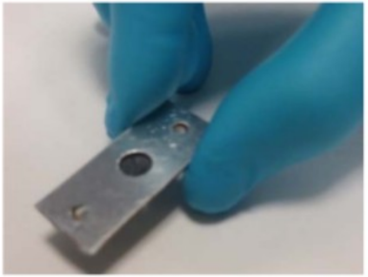
Element	Si	He	C	N	O	H
atoms/cm^2 (x10^{15})	2820	1280	100	390	380	475

Magnetron sputtering
Si/He films

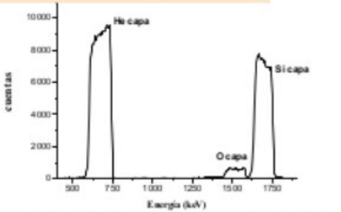
↓

Elastic Scattering in
Inverse Kinematics

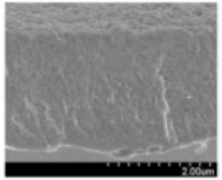




Self-supported Si:He target



RBS spectrum of Si:He target using 2,0 MeV protons and 165° scattering angle

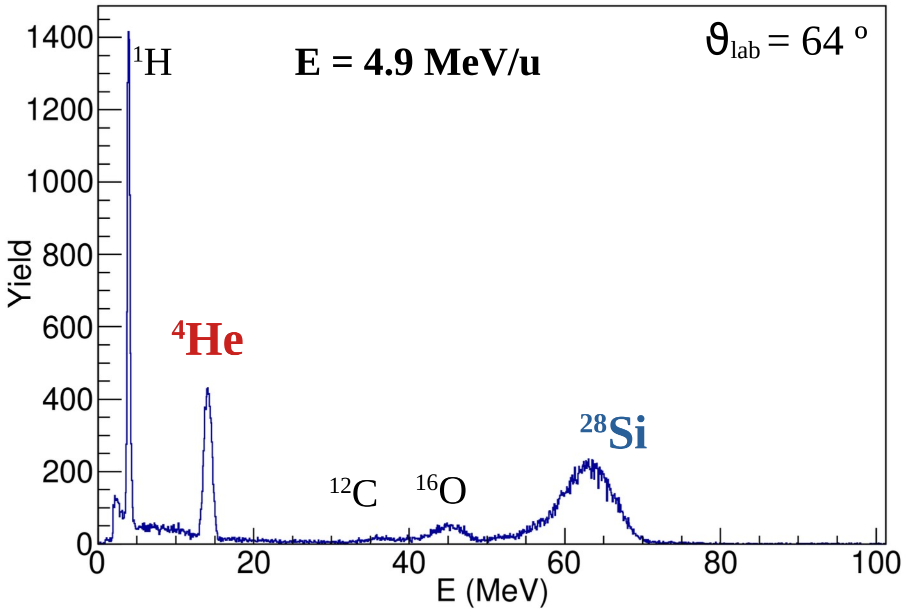


SEM corss section of the Si:He target

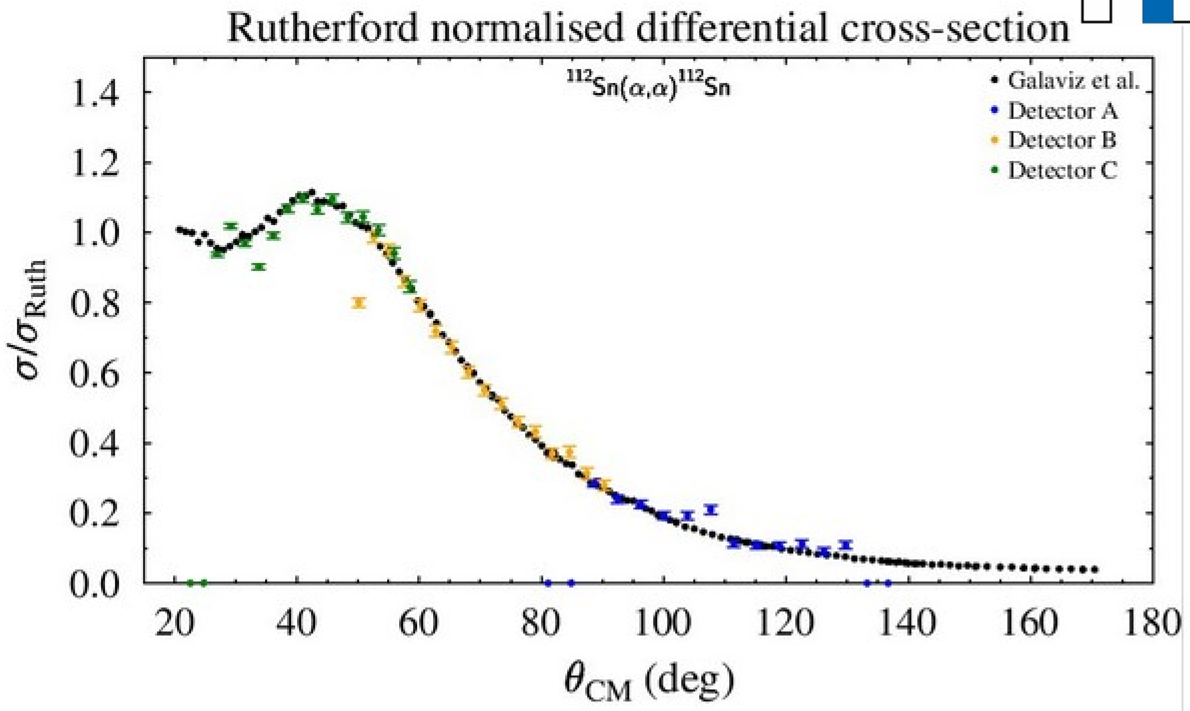
V. Godinho *et al.*, ACS Omega 2016, 1 (6), 1229 (2016)

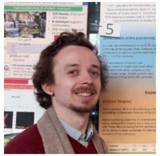
Inverse kinematics experiment: IS698

Elastic scattering $^{4}He(^{112}Sn,\alpha)^{112}Sn$



Inverse kinematics experiment: IS698





F. G. Barba
(ID 180)

Proton capture reactions

Using X-rays

Activation method for (p,γ)

- Suitable method to measure **radiative capture** cross sections

- Focus on **s-process nuclei** (seeds for γ-process):

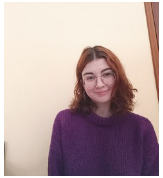
  nuclear products **decay** via ε/β^{+}

- Many cases suffer from **low branching ratios** or **no γ emission**

Determine **(p,γ) cross sections** based on **X-ray yields**

(following the work of G. G. Kiss, et al. Phys. Lett. B 735 (2014))

Activation method for (p,γ)



M. Paulino
(ID 146)

Comming up in this session...

NOVA SCHOOL OF SCIENCE & TECHNOLOGY

Measurement of the $^{118}Sn(p,\gamma)^{119}Sb$ cross-sections with low energy protons using the activation technique

M. Paulino[1,2], L. Alves[3], V. Corregidor[3], J. Cruz[2], D. Galaviz[1,4], R. Nunes[1,4], R. Pires[1,4], R. Silva[3], P. Teubig[1,5], A. Vicente[1,4]

[1] LIP, [2] NOVA-FCT, [3]CTN-IST, [4]FCUL,[5]IADE

European Nuclear Physics Conference 2025 (EuNPC2025)

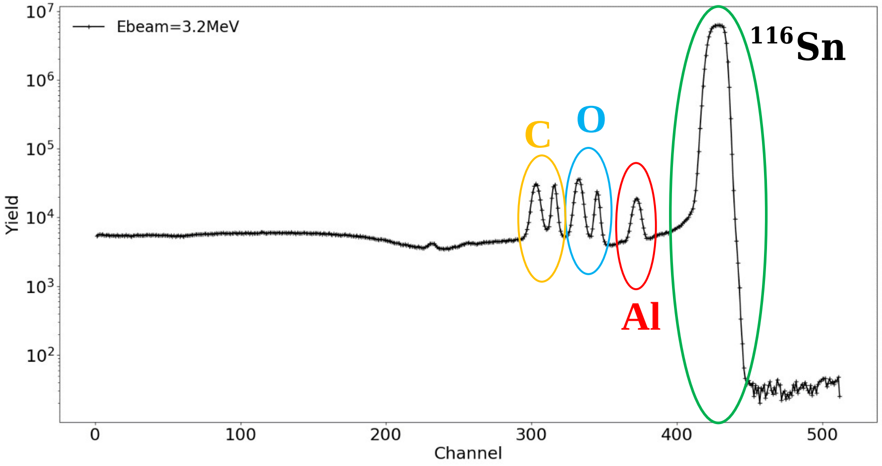
Activation method for (p,γ)

$^{116}Sn(p,\gamma)^{117}Sb$

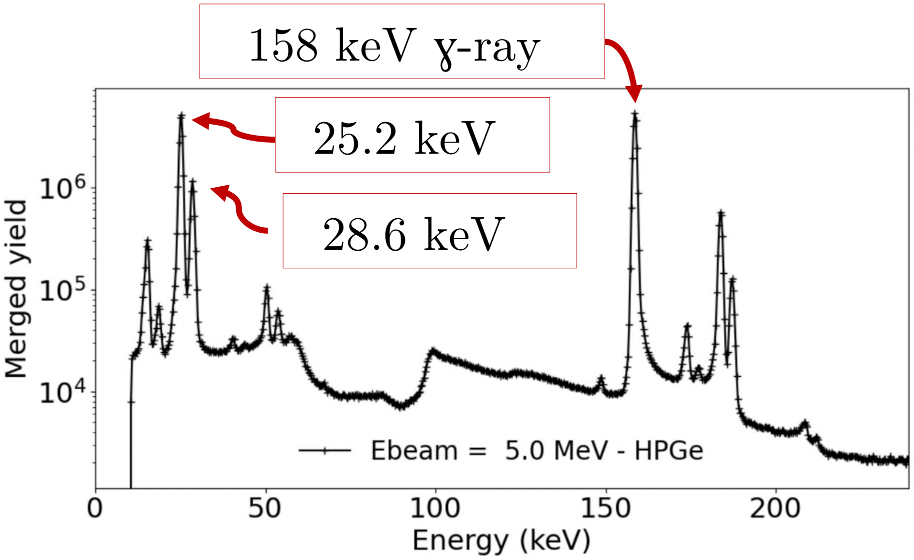
Activation method for (p,γ)

$^{116}Sn(p,\gamma)^{117}Sb$

Online RBS



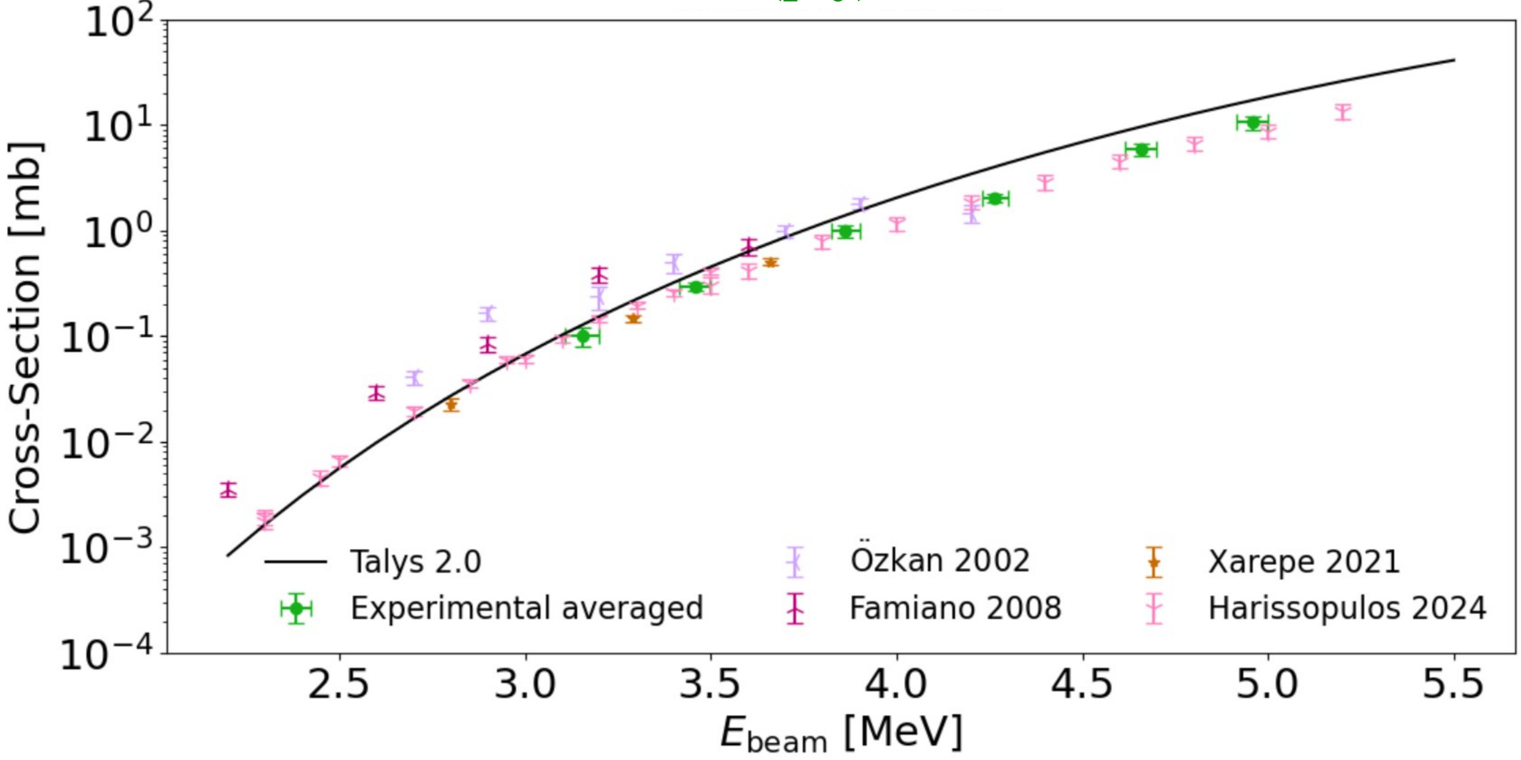
Decay



Activation method for (p,γ)

R. Pires

$^{116}Sn(p,\gamma)^{117}Sb$



Summary

Summary

- p-process motivated experiments: → **α-nuclear potential** studies; **Proton capture** reaction studies
- Complementarity relevance: → **RIBs**; Small scale facilities