

# Determination of $^{118}\text{Sn}(p,\gamma)^{119}\text{Sb}$ cross-section at astrophysical energies from X-ray emission yields

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## Introduction

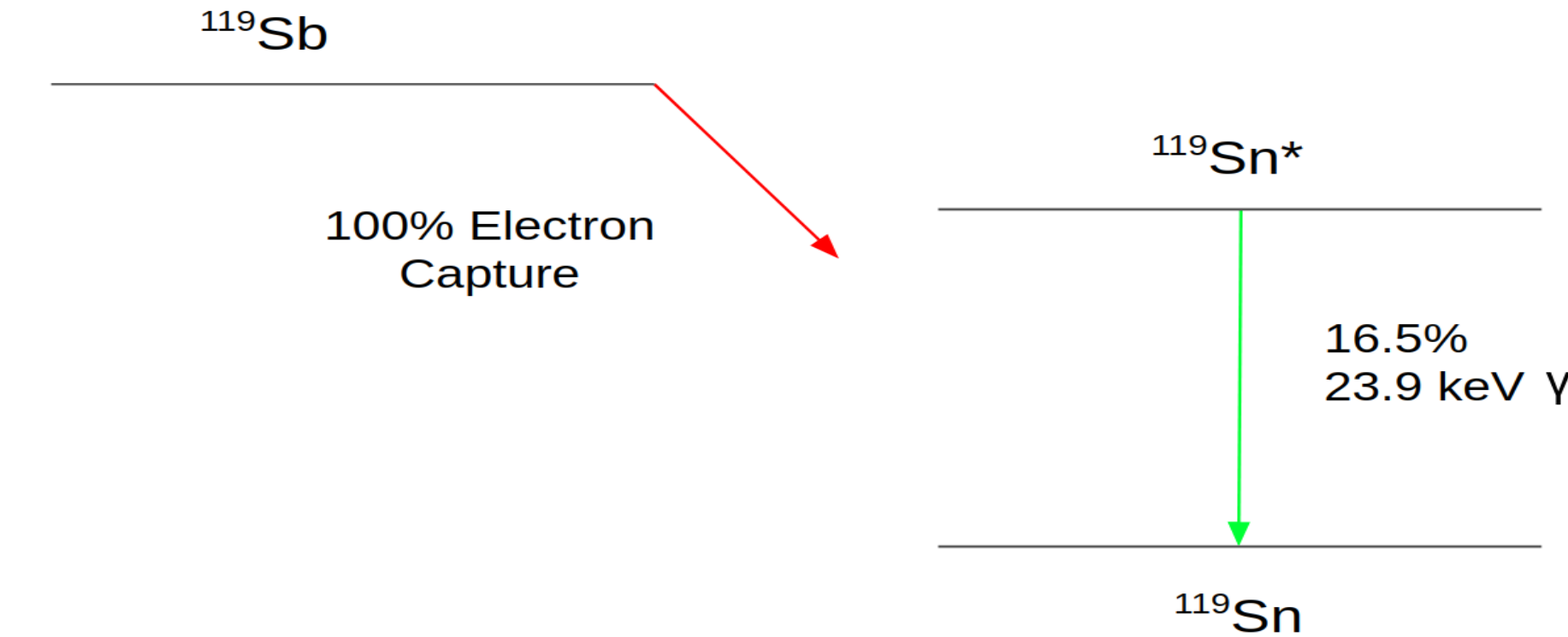
The stellar synthesis of elements heavier than Fe is explained by slow (s) and rapid (r) neutron capture processes, involving explosive events (e.g. supernovae and kilonovae). However, about 35 proton-rich naturally occurring isotopes between Se and Hg cannot be produced by neutron capture processes. The reaction network for the production of the so-called p-nuclei combines  $(\gamma, n)$  and  $(p, \gamma)$  reactions on preexisting s- and r-process seed nuclei [1].

In view of the huge number of reactions involved, stellar networks usually rely on theoretical cross-sections. It is of utmost importance to validate these models on a grid of experimental cross-sections spread over the entire nuclear chart, since the predictions may exhibit large uncertainties even for stable isotopes.

In this work, the **Activation Method** is used to measure for the first time the cross-section of the **radiative proton capture reaction**  $^{118}\text{Sn}(p,\gamma)^{119}\text{Sb}$ . The  $\gamma$ -emission associated to the electron capture to the excited state of  $^{119}\text{Sb}$  will be used to validate the method.

## $^{119}\text{Sb}$ decay scheme

### Electron capture and $\gamma$ -emission decay



### K-line X-ray emissions

X-ray	Energy [keV]	Relative X-ray intensity per decay [%]
$\text{K}\alpha_2$	25.044	$21.0 \pm 0.5$
$\text{K}\alpha_1$	25.271	$38.9 \pm 0.9$
$\text{K}\beta_3$	28.444	$3.5 \pm 0.8$
$\text{K}\beta_1$	28.486	$6.80 \pm 0.15$
$\text{K}\beta_2$	29.111	$1.86 \pm 0.40$

## Activation Method

The standard method used for cross-section measurements is the **Activation Method** [2]. By irradiating the target, in most cases, radioactive nuclei are created, and even though they are trapped in the target, their decay radiation has enough kinetic energy to escape. By measuring these particles it is possible to calculate the number of produced nuclei,  $N_D$ , at the end of the irradiation, see Eq. (1)

$$N_{decay} = N_D \cdot e^{-\lambda t_w} \cdot (1 - e^{-\lambda t_e}), \quad (1)$$

which combined with Eq. (2), can be used to calculate the cross-section.

$$N_D = \sigma \cdot N_A \cdot \phi_b \cdot \frac{1 - e^{-\lambda t_{irrad}}}{\lambda}, \quad (2)$$

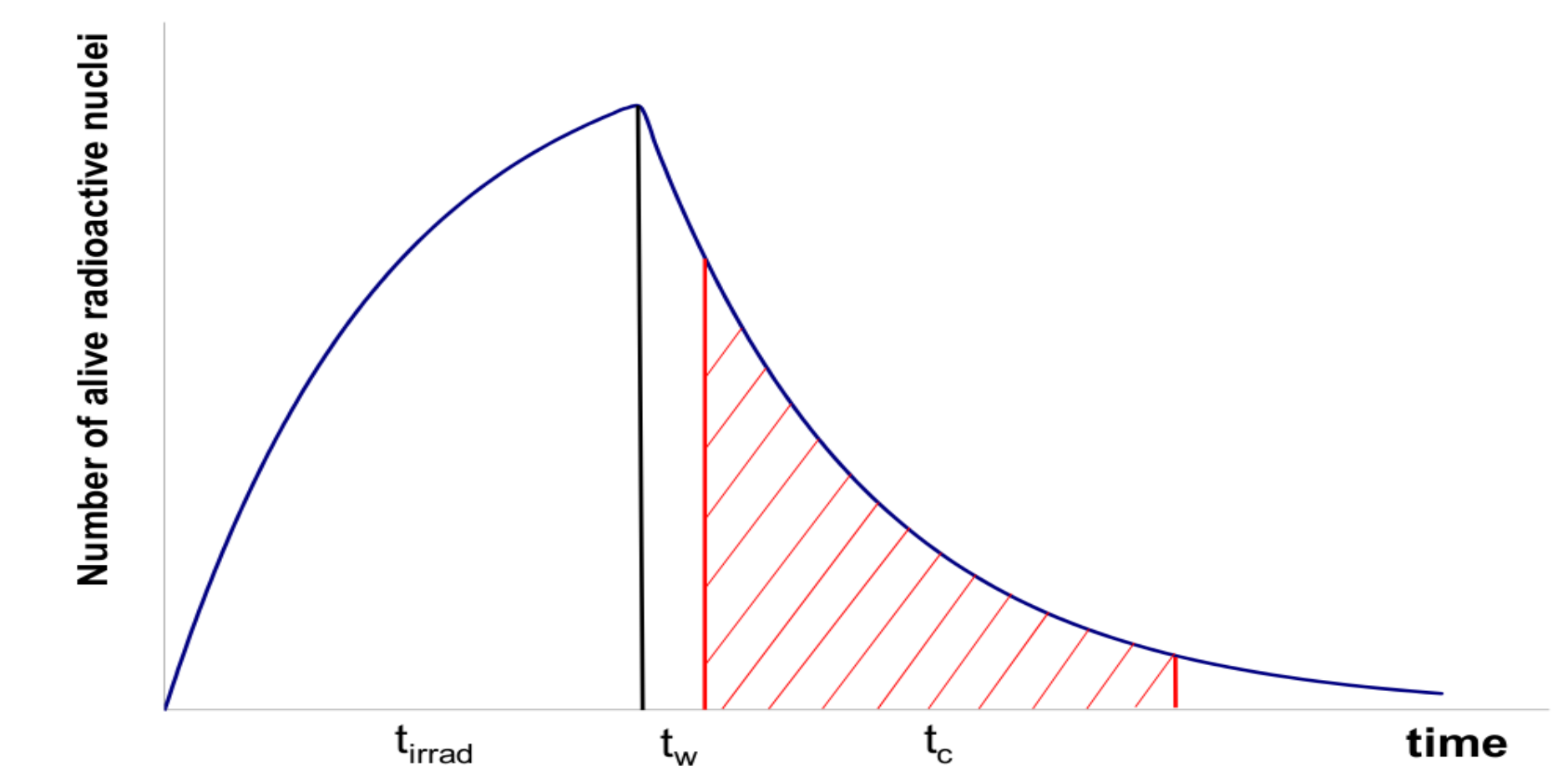


Image taken from [3]

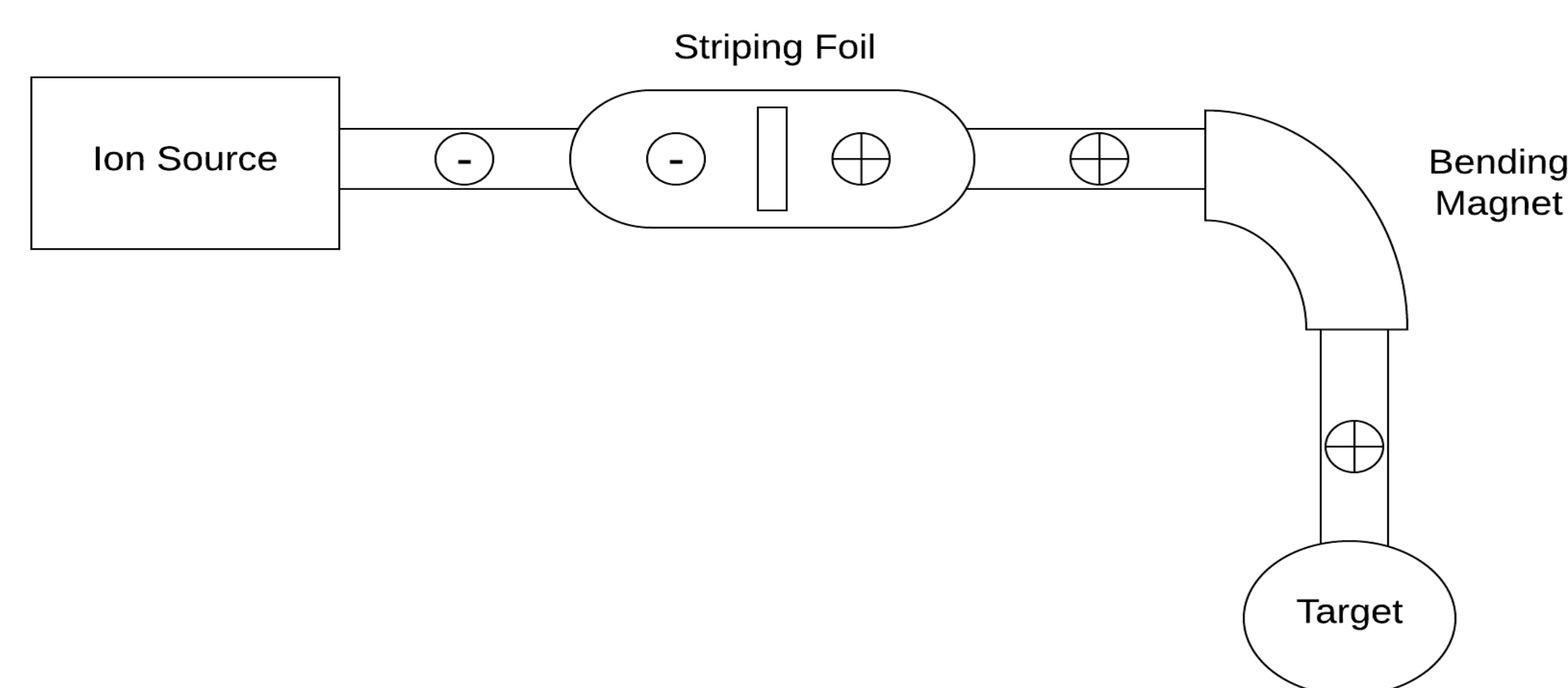
- Both the irradiation and acquisition time depend on the length is the half-life;
- It is impossible to use this method if the nucleus only decays by electron capture with no  $\gamma$ -emission associated;

It was proposed by G.G.Kiss and his team [2] to **measure the decay of X-rays, that are emitted in cascades after the electron capture.**

## Experimental methodology

The highly enriched  $^{118}\text{Sn}$  (with a Cu backing) target will be irradiated at the 3 MV Tandem Accelerator at the CTN/IST facility. Rutherford backscattering spectrometry will be employed to confirm the homogeneity of the target. The target will be irradiated at astrophysical relevant energies (3-4 MeV) corresponding to 2.5 GK. Special care will be taken to keep a well known constant flux,  $\phi_b$ .

### Scheme of the Tandem accelerator at CTN/IST



The X-ray emission spectra will be acquired using a the XR-100SDD (Silicon Drift Detector) from Amptek, which has a 125 eV FWHM Resolution at 5.9 keV. The energy calibration and energy dependence of the resolution in the region of interest will be determined using known X-ray emission sources.

## Simulations of the emission spectra

Monte Carlo simulations of the experimental setup will be done to determine contributions of the geometry setup to the overall uncertainty and also to obtain the efficiency of the detector. These simulations will be done using Geant4 [4], which is considered the state-of-the-art code for simulation of particle transport and interaction with matter.

We will also simulate all the dipolar radiative transitions between one-hole K-shell configurations in Sn atoms and all final configurations in the relevant energy range (20–30 keV) with the MCDFGME code [5].

The results from atomic physics calculations will be used to feed the particle transport code, allowing for a direct comparison between experimental data and theoretical predictions.

## Data analysis

A Root-based algorithm is being developed to fit the experimental spectra and determine the peak areas. From the peak area  $A$ , the number of decays,  $N_{decay}$  can be calculated using, Eq. 1

$$N_{decay} = \frac{A - A_{background}}{\eta \cdot \epsilon}, \quad (3)$$

where  $\epsilon$  is the detector efficiency and  $\eta$  the relative intensity of the decay. Fitting Eq. (1) to the  $N_{decay}$  values as a function of time, the fit parameter  $N_D$  is obtained. The cross-section will be estimated using Eq. (2).

## References

- [1] E. M. Burbidge et al. vol. 29, no. 4, p. 547, 1957.
- [2] G.G. Kiss *et al.*, Physics Letters B 695(5):419–423 (2011)
- [3] Gy Gyürky The European Physical Journal A 55(3):41 2019
- [4] <http://geant4.cern.ch>
- [5] P. Indelicato, Phys. Rev. A 51:1132–1145 (1995)