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

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Ciências ULisboa

LIP

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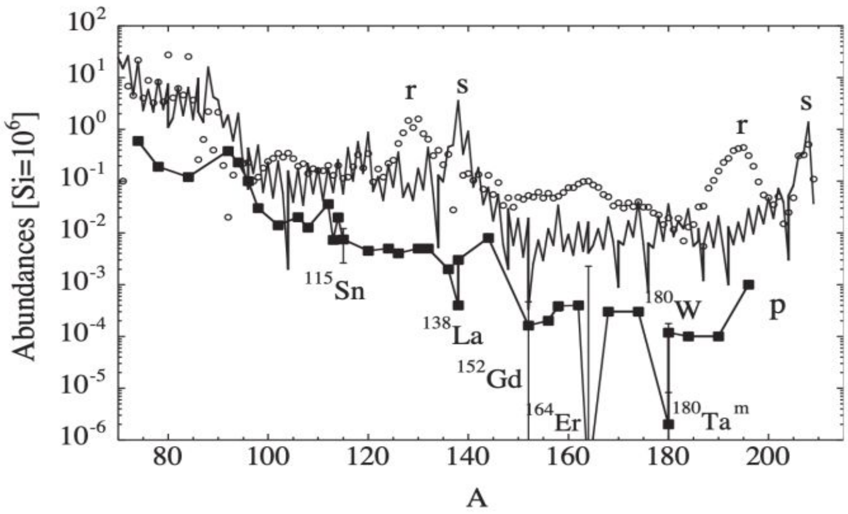
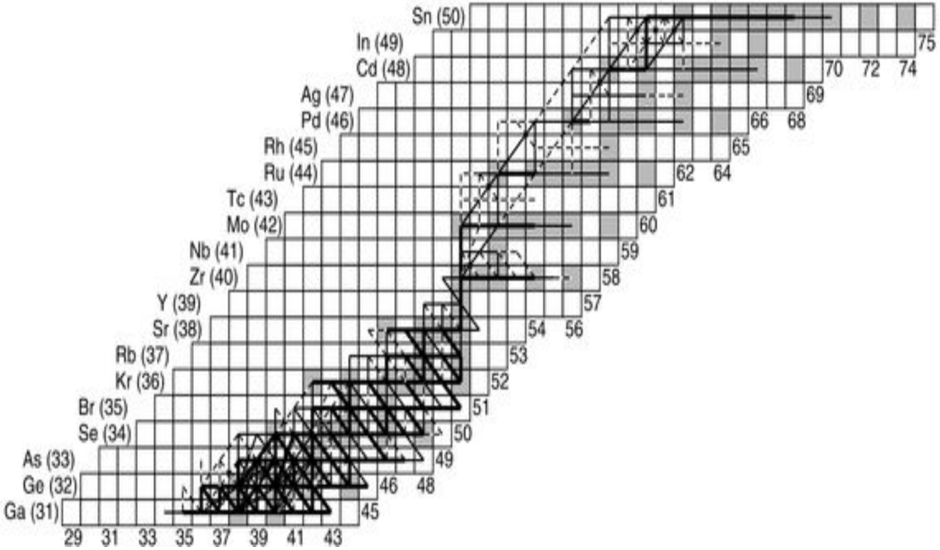
  - Motivation for studying $^{118}Sn(p,\gamma)^{119}Sb$ reaction
  - Activation method (using X-ray yields)
- Experimental methodology
- Study with natural Sn-targets
- Conclusions and Future Work

Abundance of elements in the universe



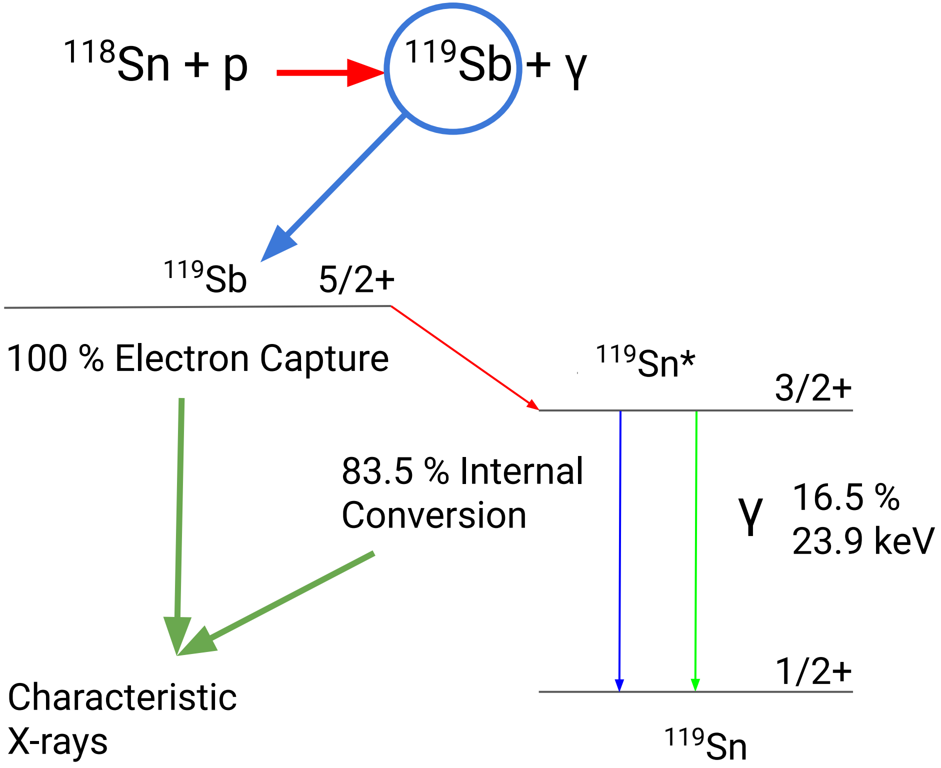
Src: M. Arnould and S. Goriely Physics Reports, vol. 384, no. 1-2, pp. 1–84, 2003.

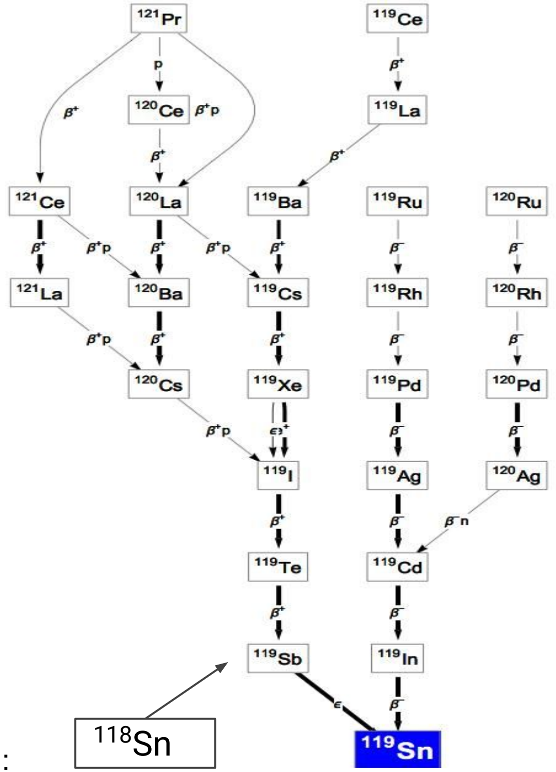
Reaction flux generated by Type II supernovae



Src: W. Rapp et al. The AstroPhys. J., vol. 653, no. 1, p. 474, 2006.

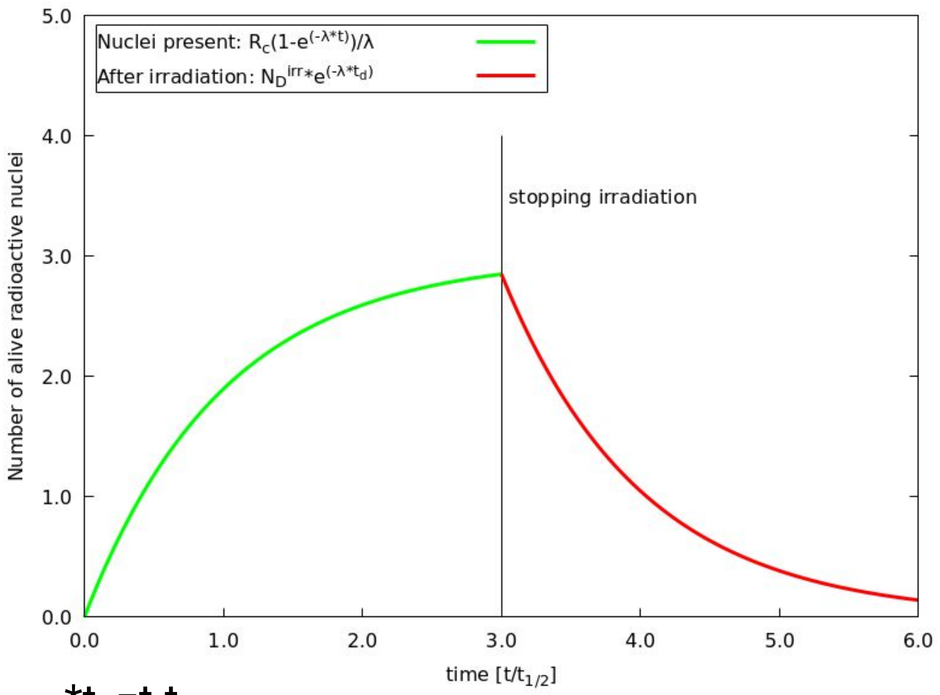
Motivation for Studying ^{118}Sn(p,γ)^{119}Sb



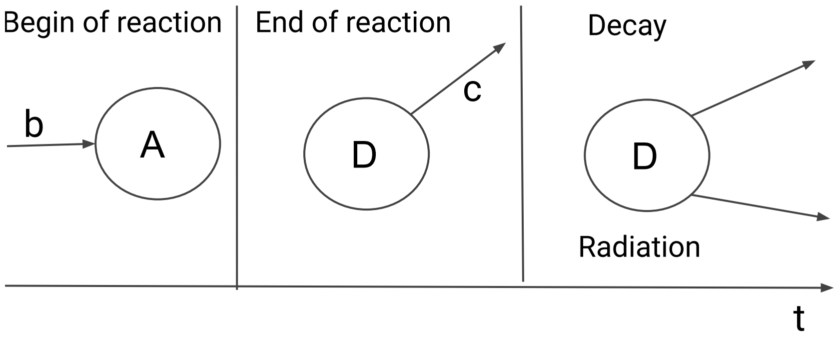


adapted from:
https://periodictable.com/Isotopes/050.119/index.full.html

Activation Method



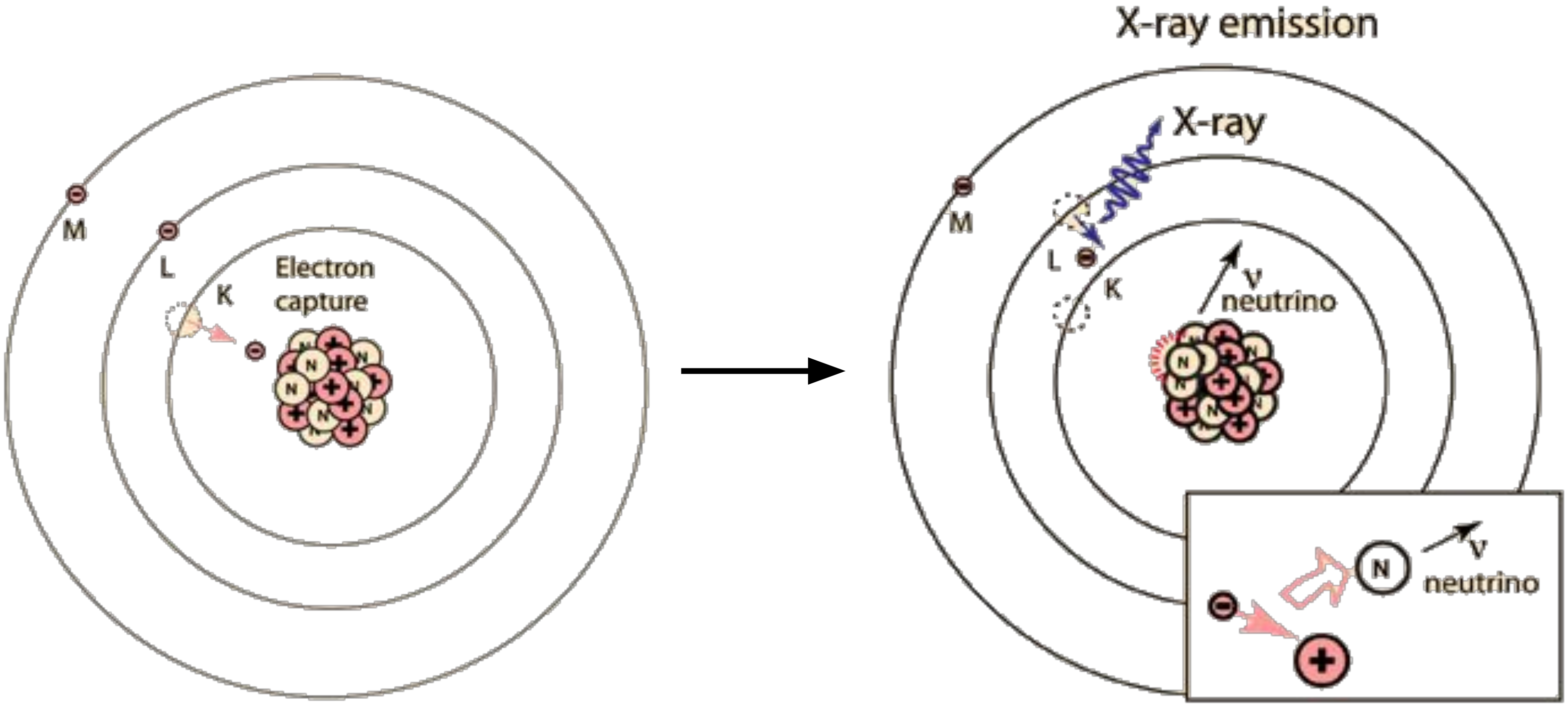
$*t_d=t-t_{irr}$



Limitations:

- $t_{irradiation}$ **e** $t_{acquisition}$ are proportional to $t_{1/2}$
- The created isotope must be radioactive
- Decay branching to excited states must be significant

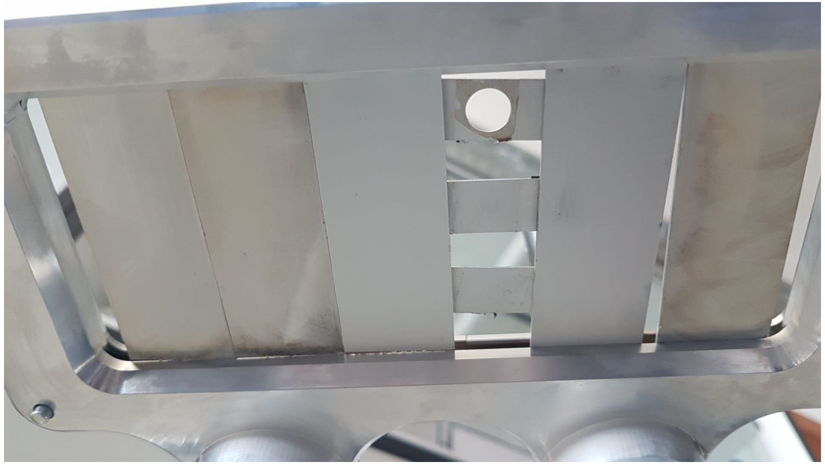
Electron Capture Decay

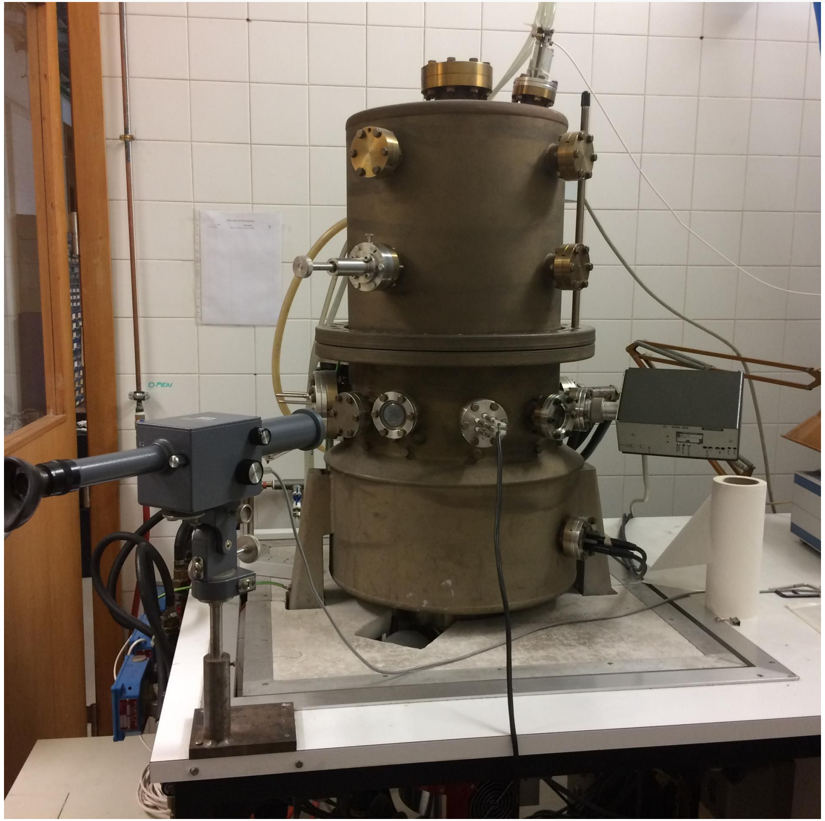


adapted from:
http://hyperphysics.phy-astr.gsu.edu/hbase/Nuclear/radact2.html

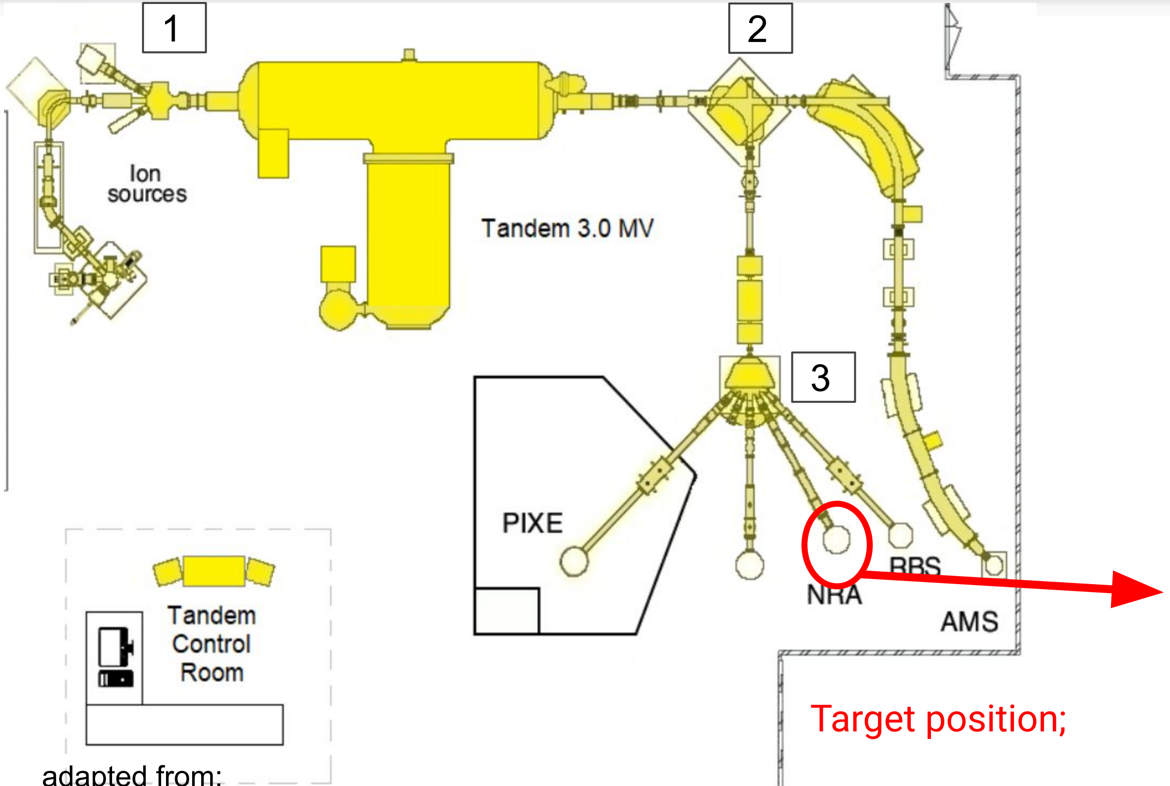
Target Production

- Target produced at LIP's NUC-RIA laboratory in FCUL, using the evaporation method
- Targets were evaporated over two different backings:
  - aluminium
  - copper





Target Activation

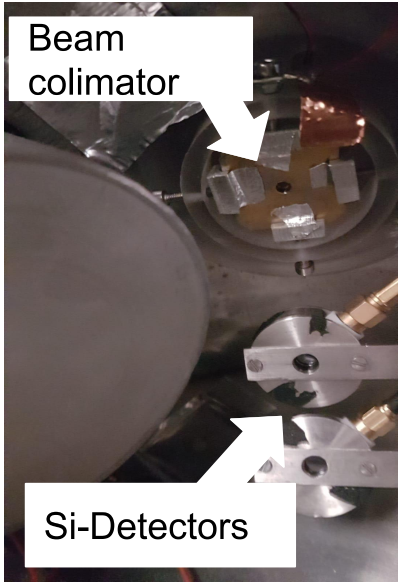


Target position;

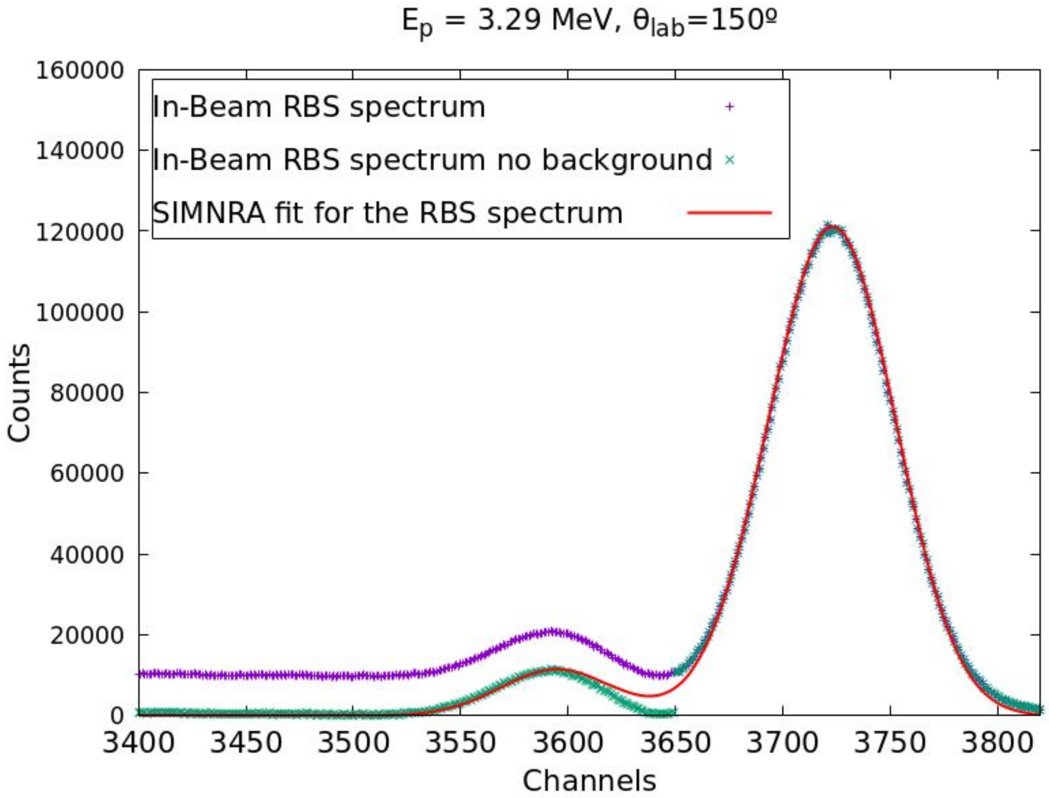
adapted from:
http://www.ctn.tecnico.ulisboa.pt/facilities/uk_lab_ion_beam.htm

Activation energy:

- 3.66 ± 0.01 MeV
- 3.29 ± 0.02 MeV
- 2.80 ± 0.01 MeV



In-Beam RBS



Relative Method:

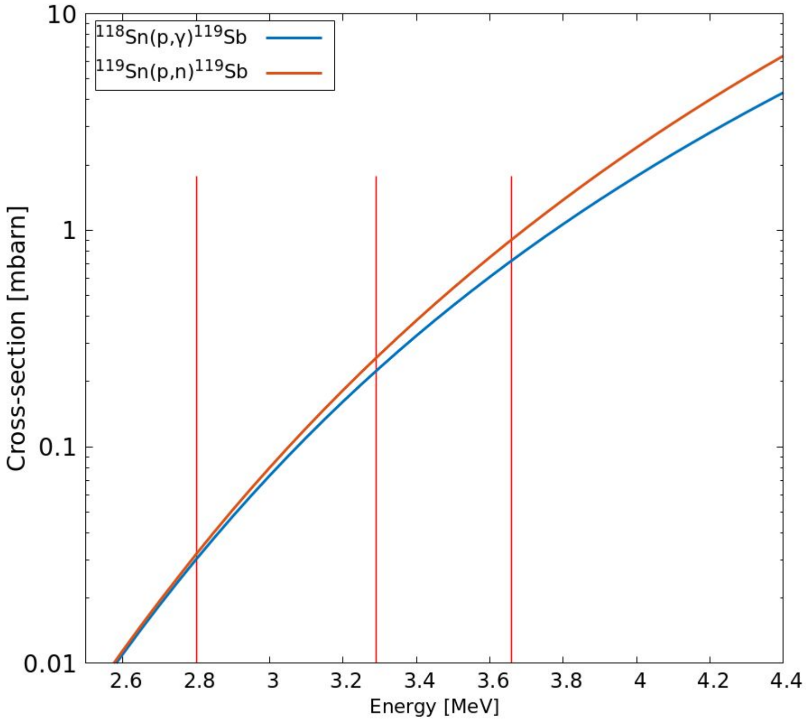
- Decay measurement
- In-line RBS measurement

Reduces systematic uncertainties from target thickness and flux measurements!

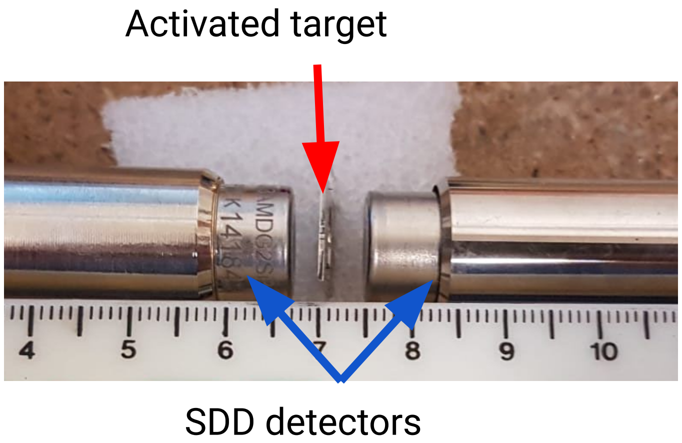
Study with natural Sn

Isotope	Abundance [%]	Reaction product	$t_{1/2}$
^{116}Sn	14.54 ± 0.09	^{117}Sb	2.80 ± 0.01 (h)
^{117}Sn	7.68 ± 0.09	^{118}Sb	3.6 ± 0.1 (min)
^{118}Sn	24.22 ± 0.09	^{119}Sb	38.2 ± 0.2 (h)
^{119}Sn	8.59 ± 0.09	^{120}Sb	15.89 ± 0.04 (min)
^{120}Sn	32.58 ± 0.09	^{121}Sb	stable

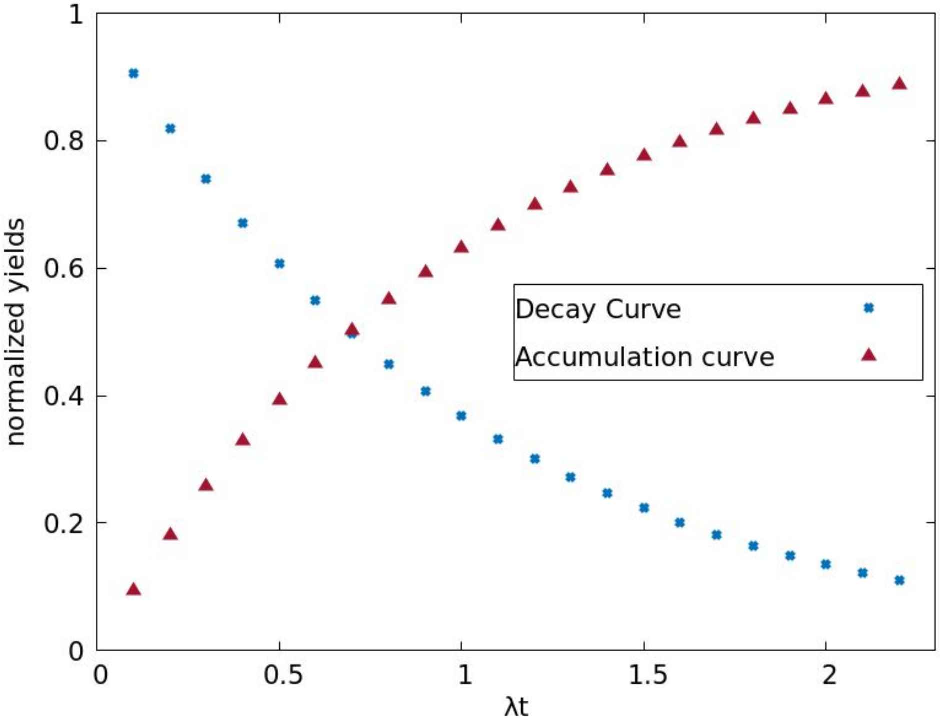
- Contribution from ^{117}Sn, ^{119}Sn and ^{120}Sn were considered negligible
- The contributions from the decay of ^{117}Sb need to be considered
- From this we were able to extract the cross-section for the ^{116}Sn(p,γ)^{117}Sb reaction



X-ray acquisition

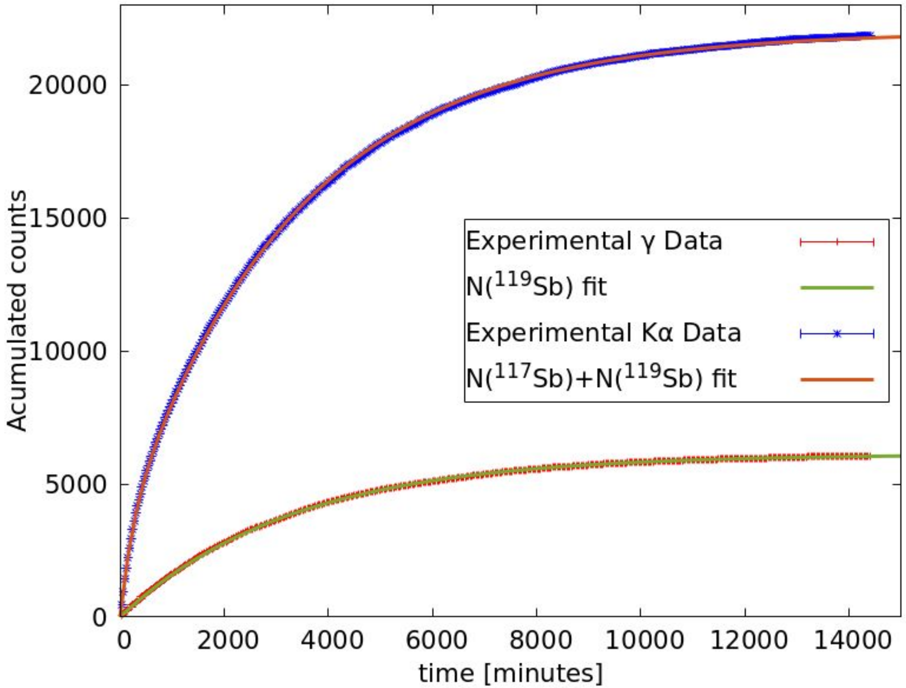


- Time properties of the decay were studied
- The total number of decays were deducted by fitting a function
- The contribution of the decay of interest was disentangled from others

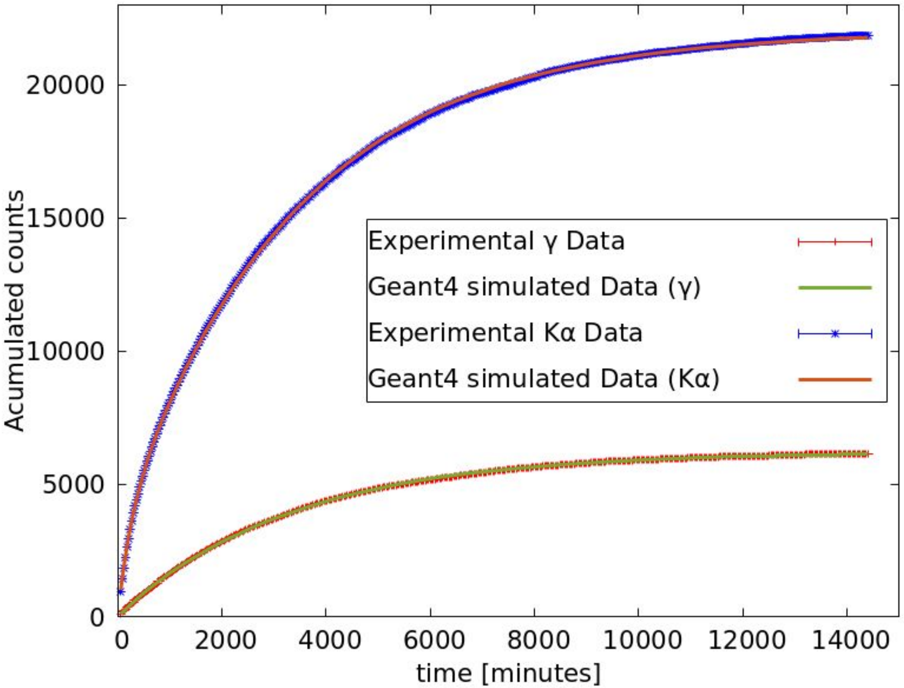


Accumulation curve - Study

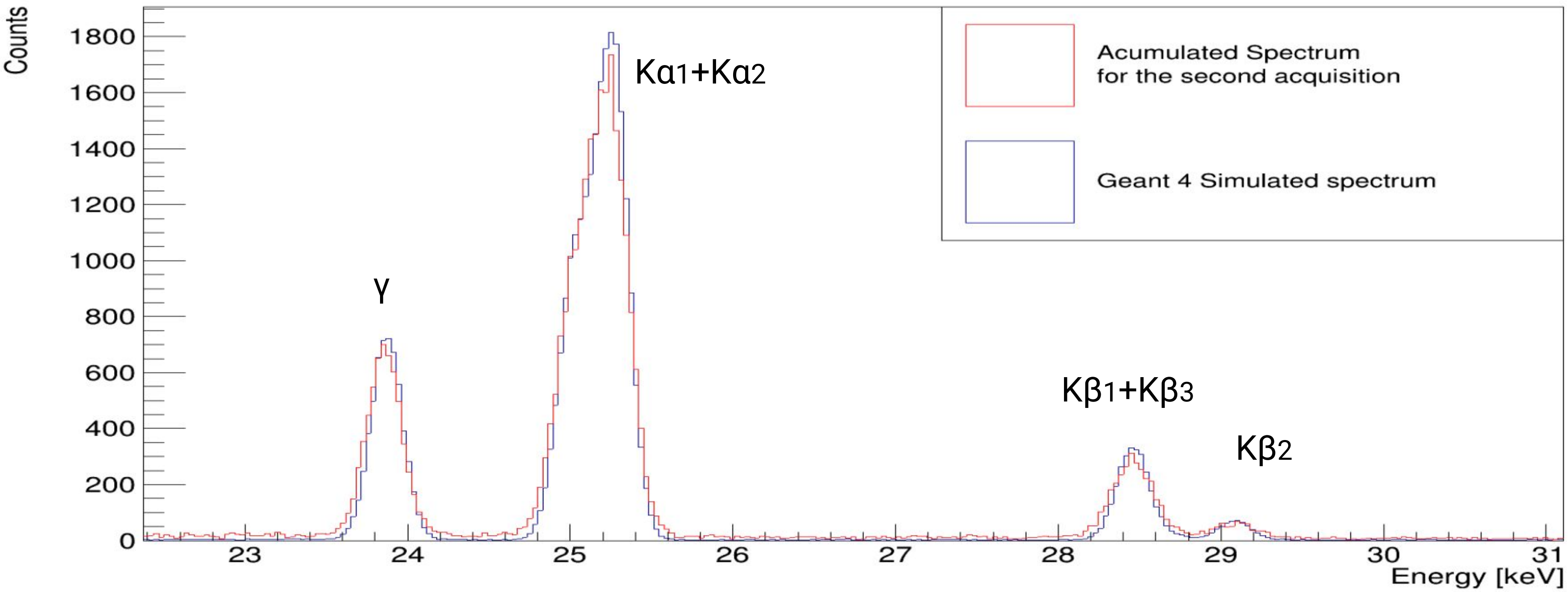
Gnuplot fit



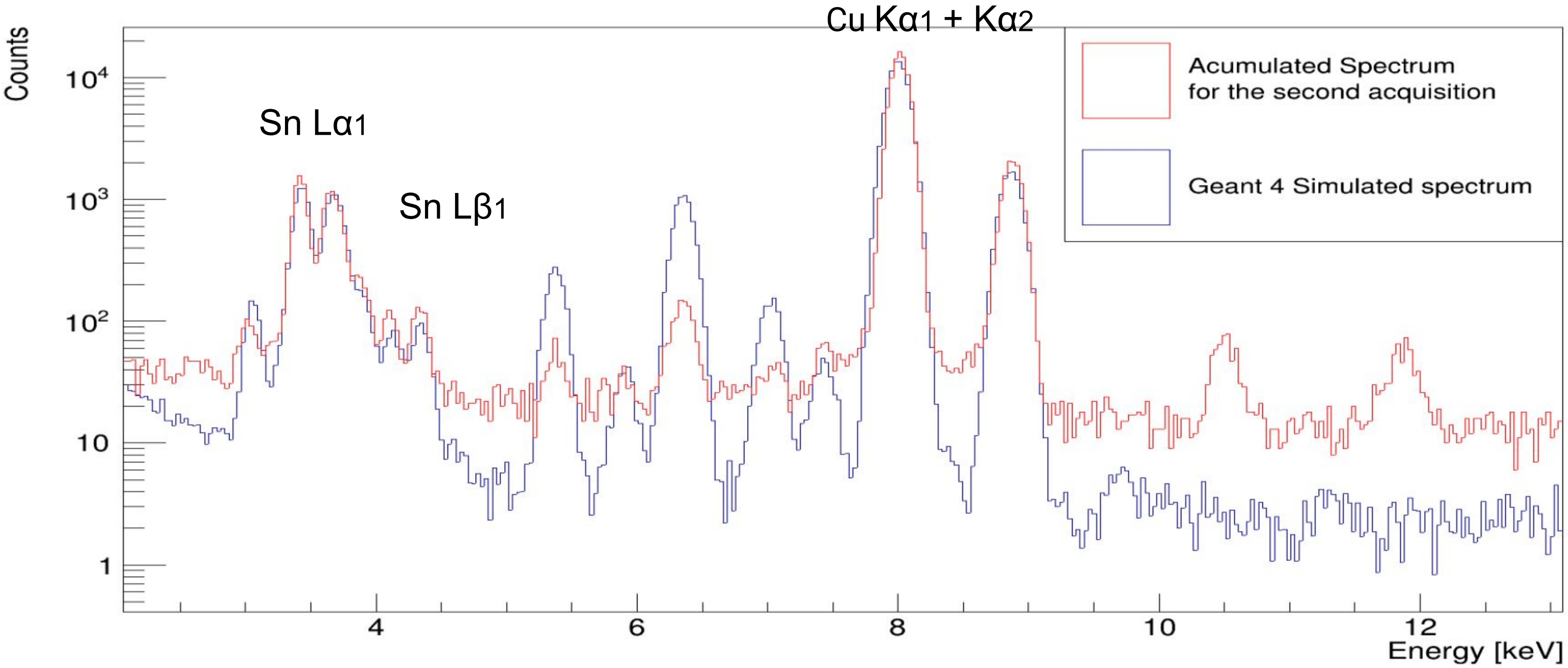
Geant4 Simulation



Accumulated spectrum



Accumulation spectrum - Low energy

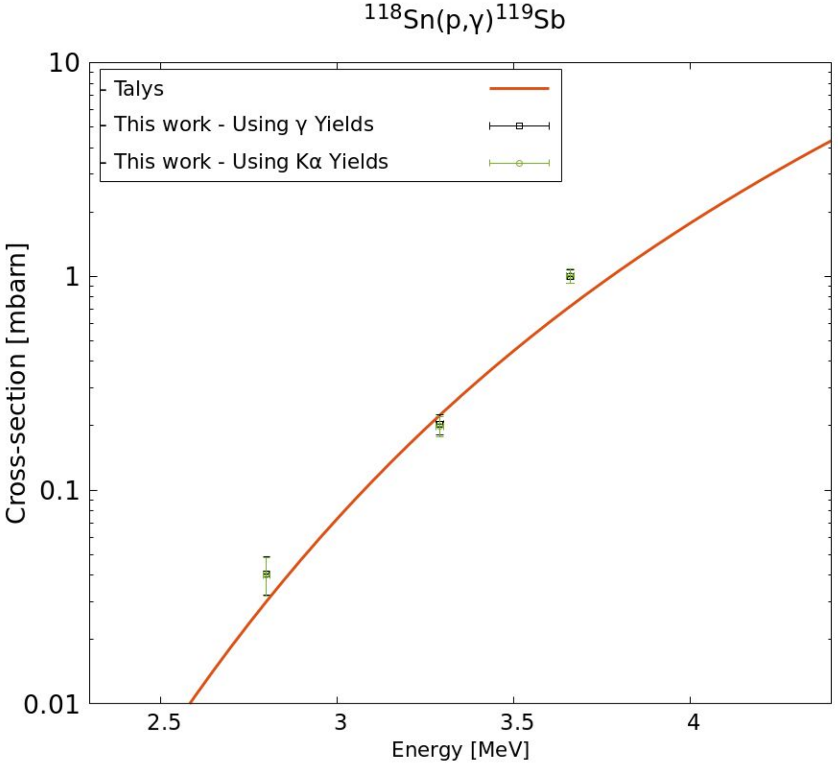


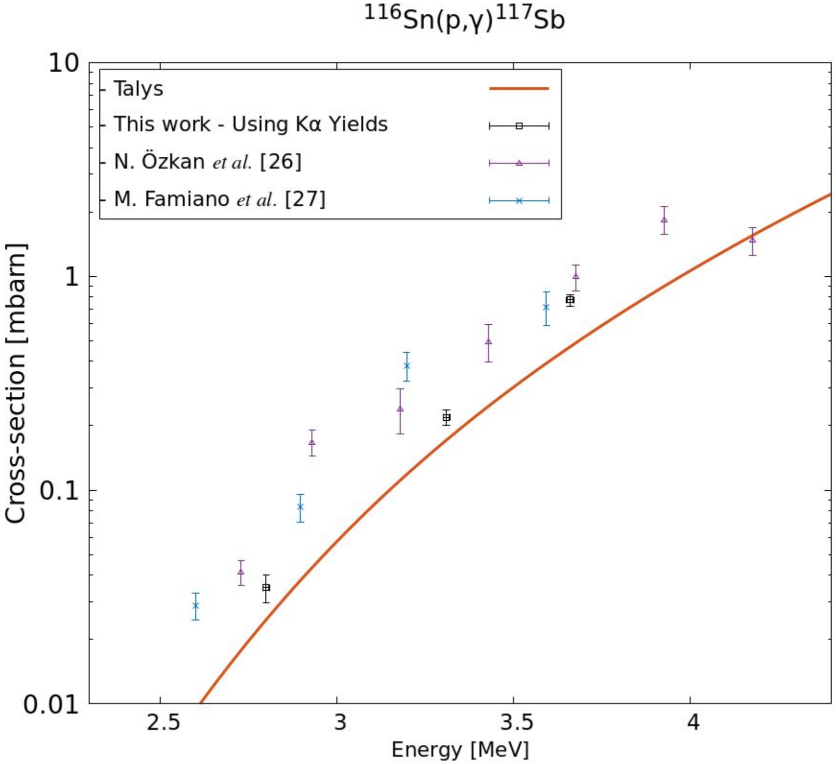
Cross-section Calculation

		σ [mbarn]		
	E_p [MeV]	2.80	3.29	3.66
^{116}Sn$(p,\gamma)^{117}$Sb	Kα	0.035 ± 0.005	0.22 ± 0.01	0.77 ± 0.05
^{118}Sn$(p,\gamma)^{119}$Sb	Kα	0.034 ± 0.005	0.17 ± 0.02	0.86 ± 0.05
	γ	0.035 ± 0.005	0.17 ± 0.02	0.86 ± 0.05

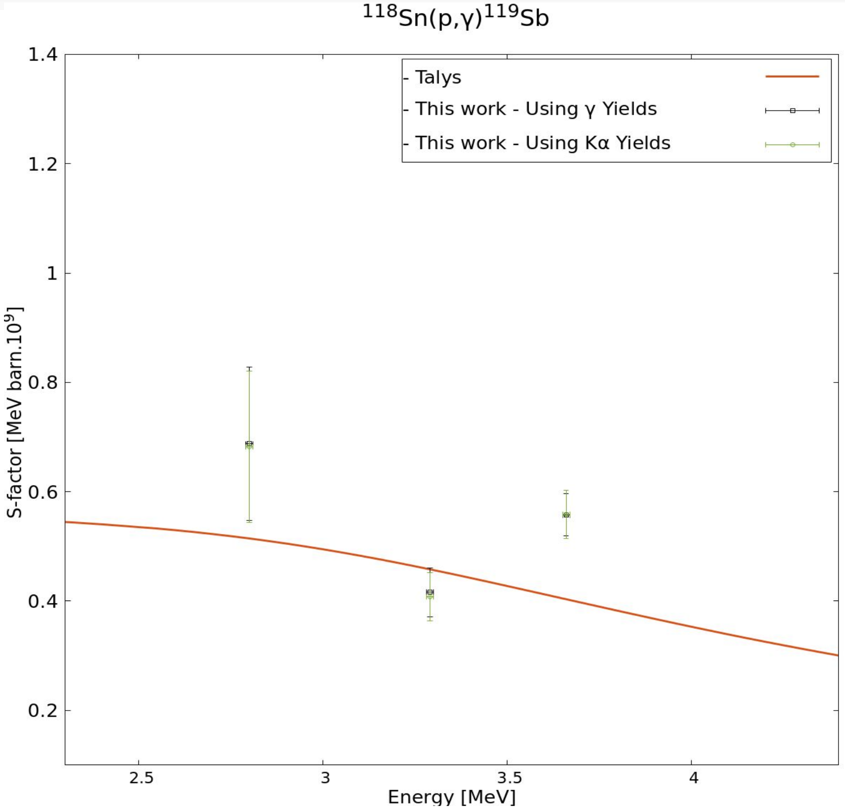
Cross-section calculated using **Kα** yields and **γ** yields are the same: **validating the method**

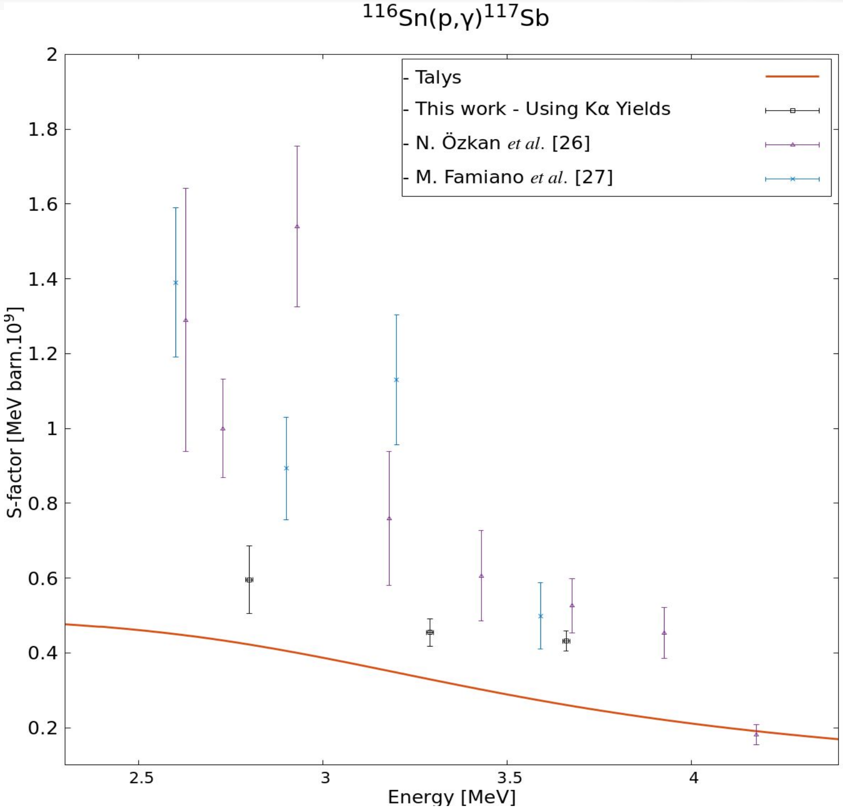
Cross-section evaluation





S-factor evaluation





Conclusions

- Activation method was successful
- Simulations showed promising results
- $^{118}Sn(p,\gamma)^{119}Sb$ reaction cross-sections are compatible with theory
- $^{116}Sn(p,\gamma)^{117}Sb$ reaction cross-sections in agreement with literature
- **Validation that X-ray yields can be complementary or a substitute to γ-ray yields**

Future work

- Calculate the cross-section using low energy X-ray
- Produce and characterize a highly enriched target of ^{118}Sn
- Activate at several energies in order to extract the energy dependence of the cross-section and of the corresponding astrophysical S-factor

Thank you very much!

M. Xarepe[1,2,3], D Galaviz[1,2,3], E. Galiana[1,2,3], E. Alves[4], F. G. Barba[1,2,3], J. P. Marques[1,2,3],
J. M. Sampaio[1,2,3], J. Rocha[4], L. Peralta[1,2,3], P. Teubig[1,2,3], R. Pestana[1,2,3], R. Pires[1,2,3]

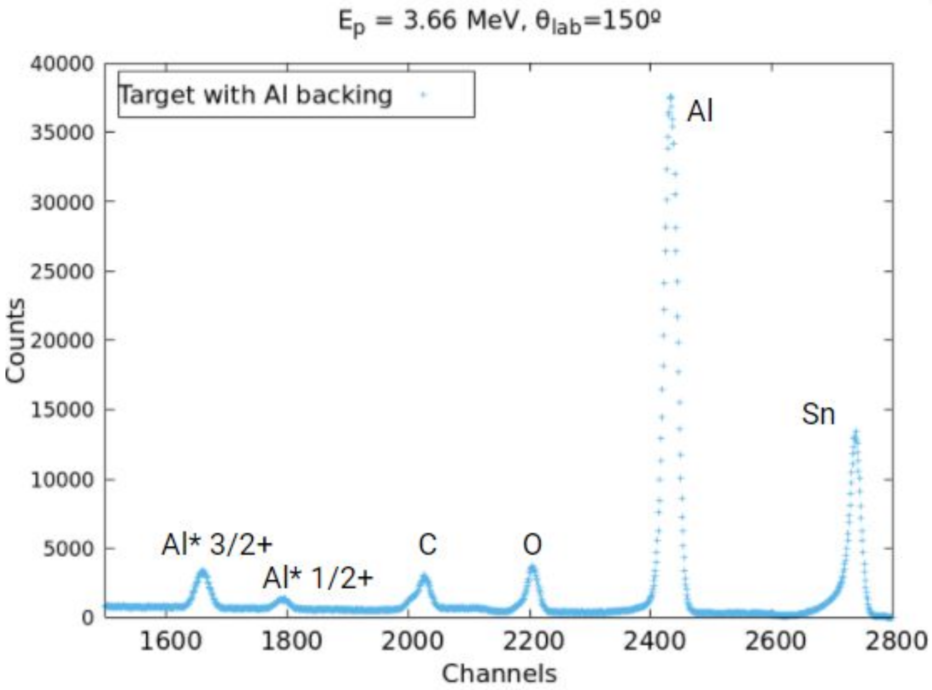
1 Ciências ULisboa

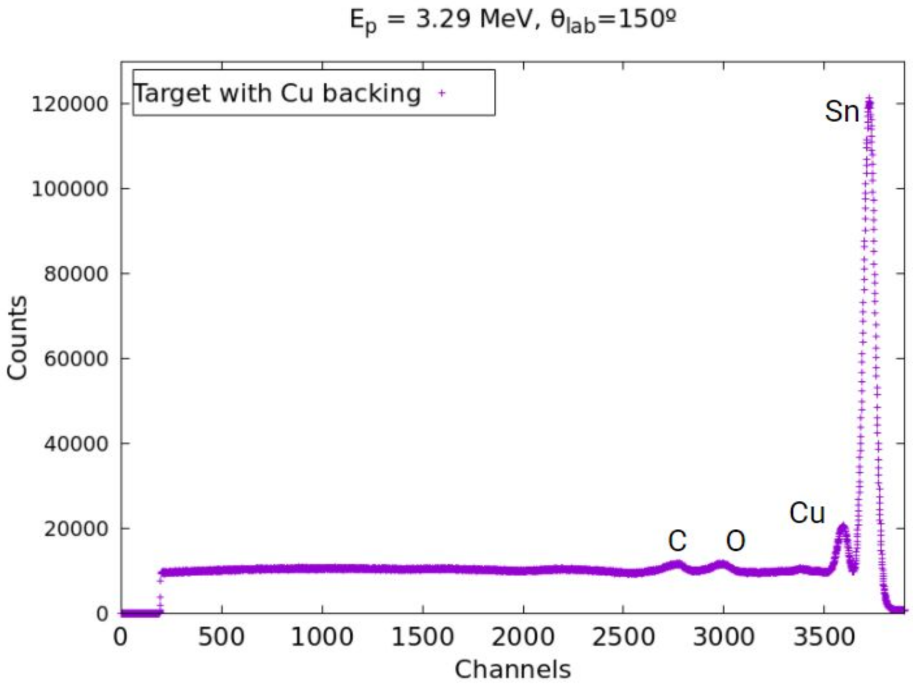
2 LIP

3 NUC-RIA Nuclear Reactions Instrumentation and Astrophisics

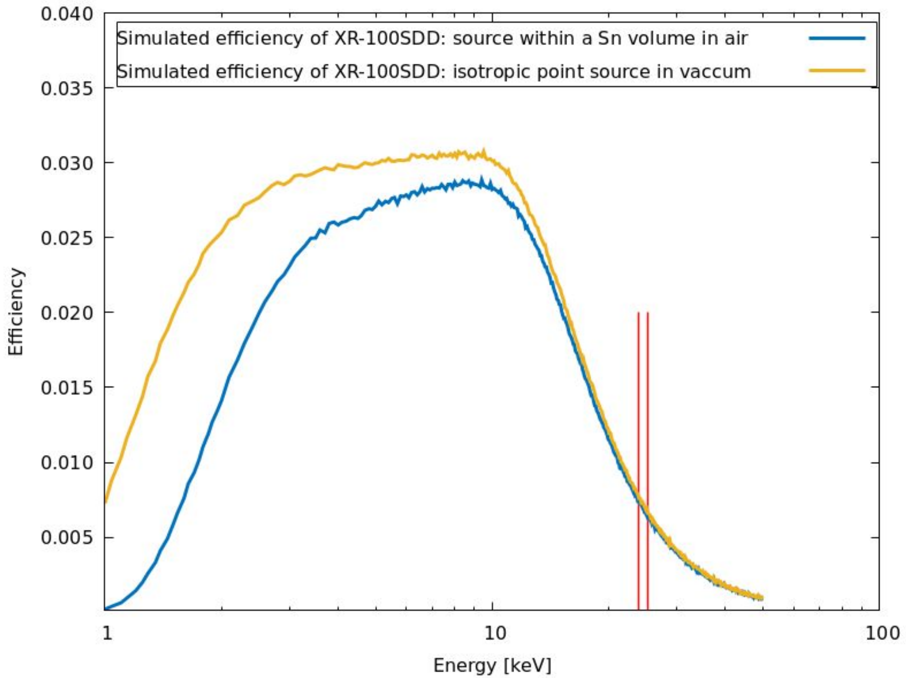
4 IST

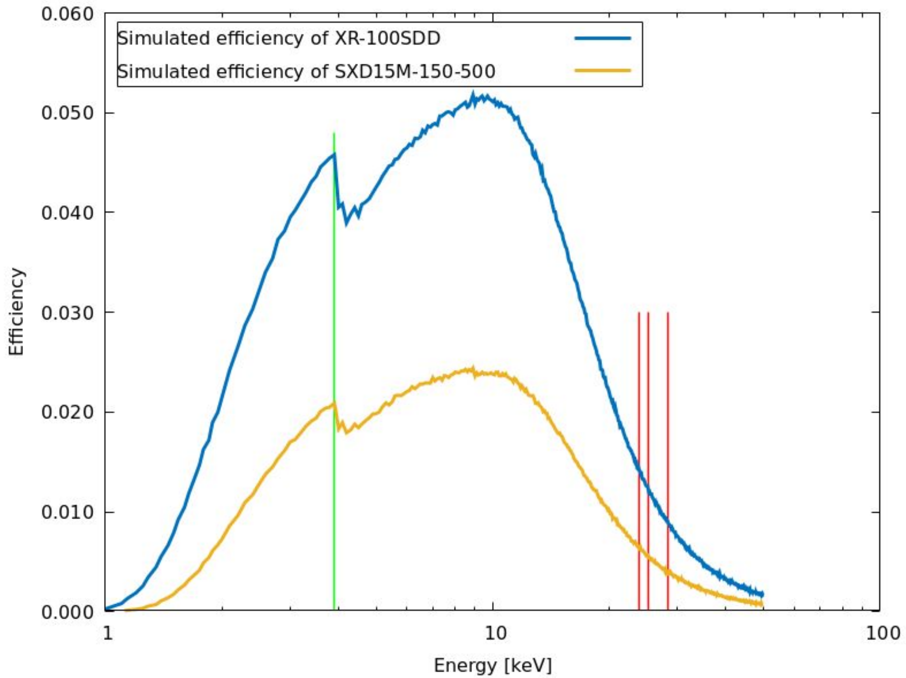
high energy p-RBS



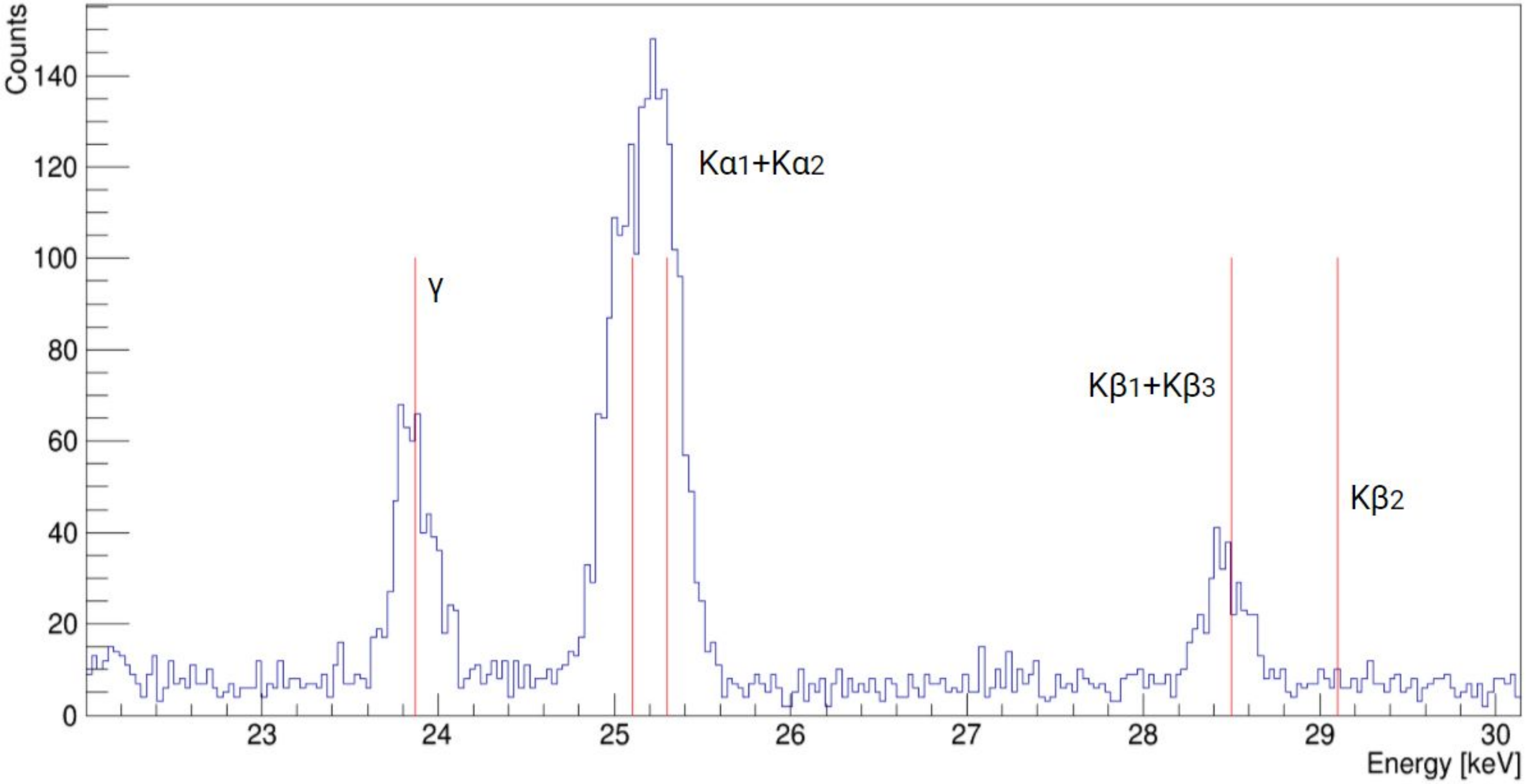


Simulation - Detector efficiency

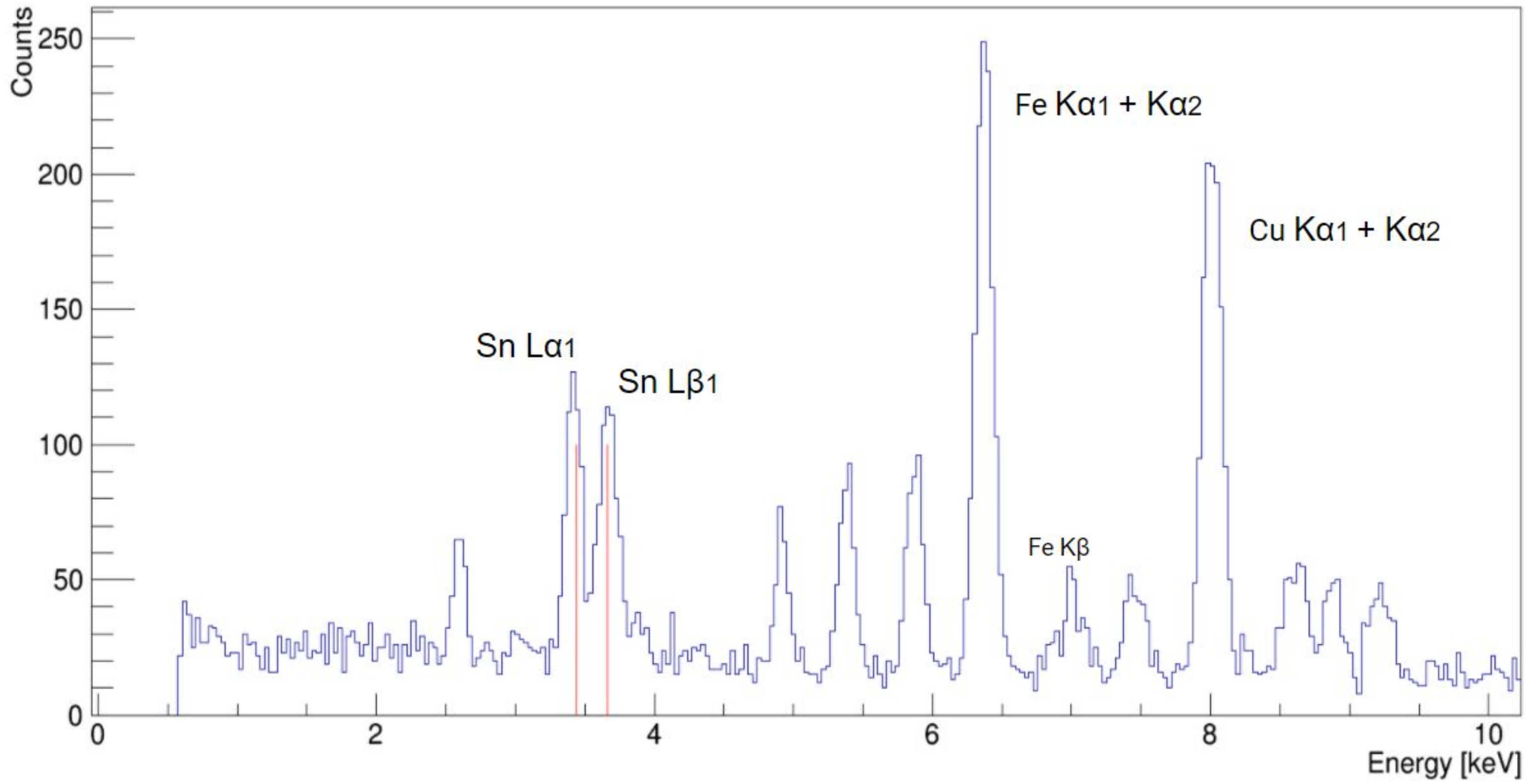




Accumulation spectrum - Ep=3.66 MeV



Accumulation spectrum - Ep=3.66 MeV



Cross-section Calculation - Absolute method

$$N_{decay} = \frac{N^{part}_{peak}}{\eta \cdot \epsilon_D}$$

$$N_{decay} = N_D^{irr} \cdot e^{-\lambda \cdot t_{trans}} \cdot \left(1 - e^{-\lambda \cdot t_{acqui}}\right)$$

$$N_D^{irr} = \sigma \cdot N_A \cdot \phi_b \cdot \frac{1 - e^{-\lambda t}}{\lambda}$$

N^{part}_{peak} = Area under the peak;

N^{irr}_{D} = Number of existing ^{119}Sb at the end of the irradiation;

N_{decay} = Total number of decays during acquisition;

σ = Cross-section;

Φ_b = Proton flux;

N_A = Surface density of the target;

Cross-section Calculation - relative method

$$\sigma = \frac{R_c}{N_{A_1} \cdot \phi_b}$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{scat} = \frac{r(\theta, \phi)}{4\pi \cdot N_{A_2} \cdot \phi_b}$$

$$\sigma = \left(\frac{d\sigma}{d\Omega}\right)_{scat} \left[\frac{4\pi R_c}{r(\theta, \phi)}\right]$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{Ruth} = \left(\frac{zZ_A e^2}{4\pi\epsilon_0}\right)^2 \left(\frac{1}{4E}\right)^2 \left[\frac{1}{\sin^4(\frac{\theta}{2})}\right]$$

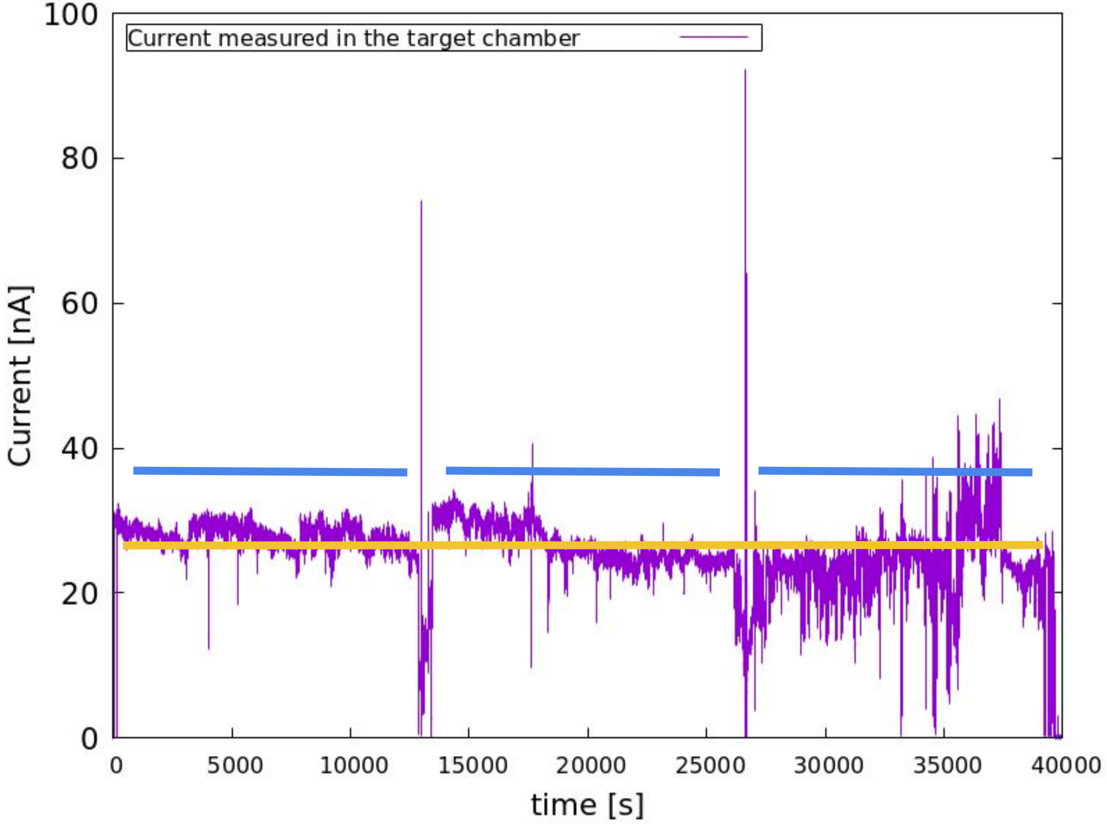
Rc = Reaction Rate;
r(Θ,Φ)=Angular distribution of the rate of scattered particles.

Cross-section Calculation

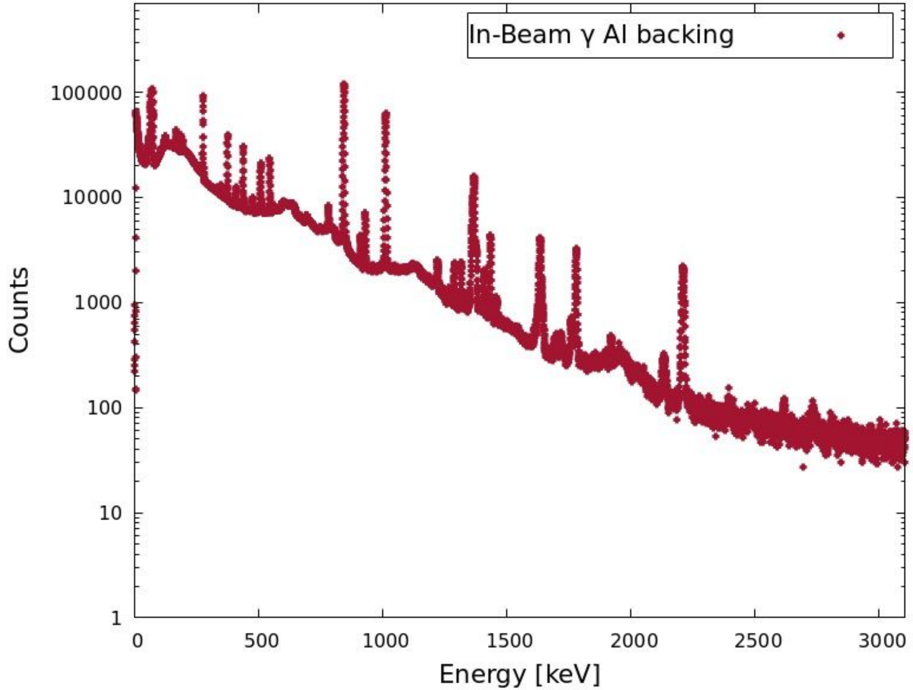
		^{118}Sn$(p,\gamma)^{119}$Sb		
	E_p	2.8	3.29	3.66
σ [mbarn] absolute	γ	0.08 ± 0.01	0.28 ± 0.01	1.6 ± 0.4
	Kα	0.08 ± 0.01	0.28 ± 0.01	1.6 ± 0.3
σ [mbarn] relative	γ	0.053 ± 0.008	0.27 ± 0.02	1.33 ± 0.07
	Kα	0.053 ± 0.008	0.27 ± 0.02	1.34 ± 0.08

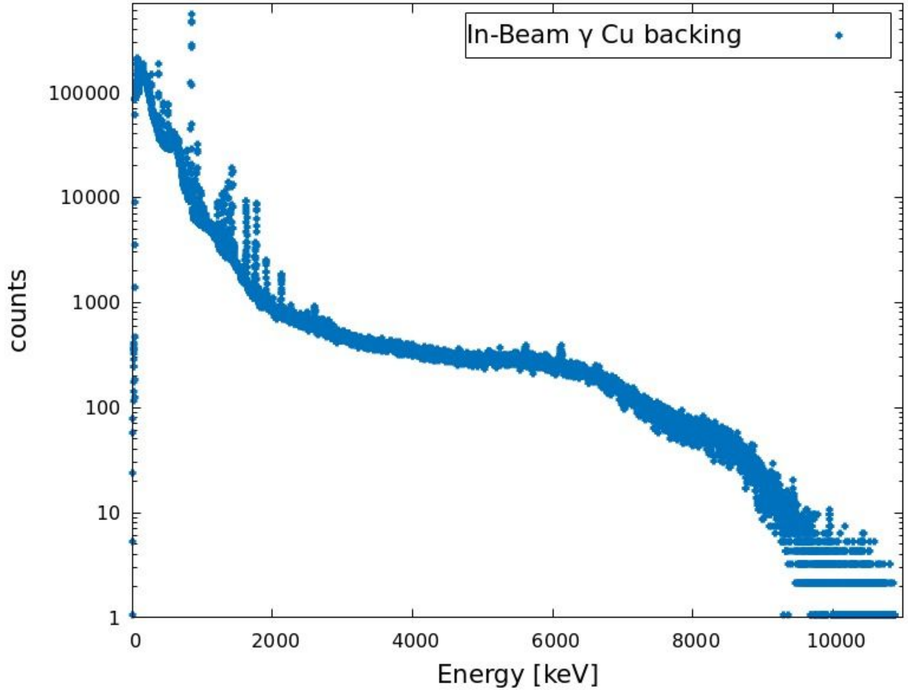
	^{116}Sn$(p,\gamma)^{117}$Sb		
E_p	2.8	3.29	3.66
σ [mbarn] absolute	0.048 ± 0.006	0.19 ± 0.02	0.9 ± 0.2
σ [mbarn] relative	0.035 ± 0.005	0.22 ± 0.01	0.077 ± 0.05

First irradiation - Current study



In-line γ acquisition

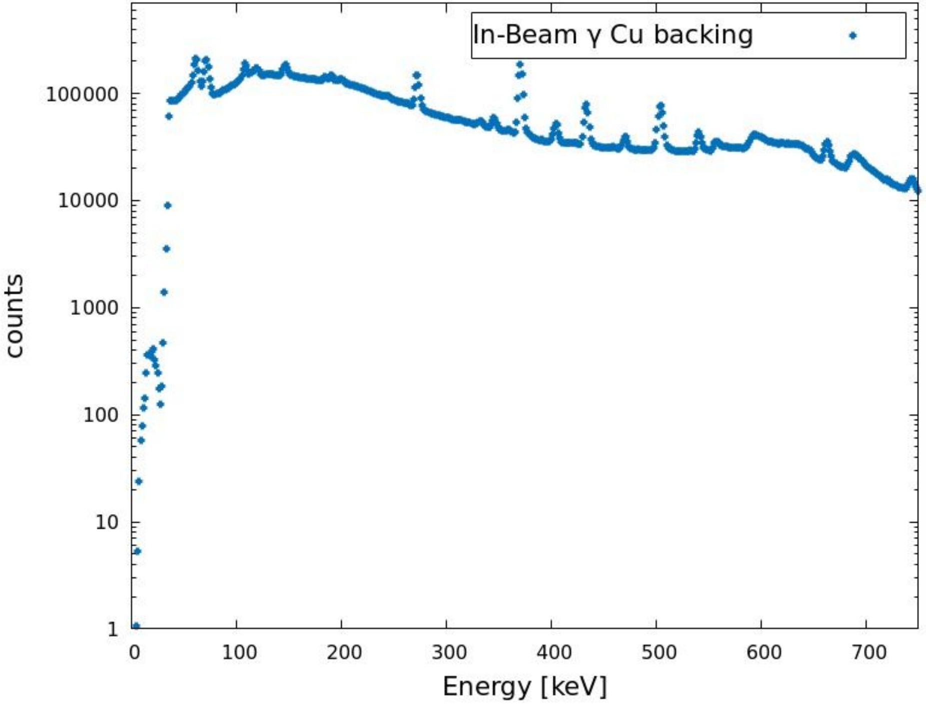




In-line γ acquisition

First excited states of ^{119}Sb(g.s $5/2^{+}$):

- 270.52 keV -> $J^{\pi} = 7/2^{+}$
- 644.03 keV -> $J^{\pi} = 1/2^{+}$
- 699.88 keV -> $J^{\pi} = 3/2^{+}, 5/2^{+}$



Cross-section Calculation - absolute method

Considering mean flux;

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

Considering discrete flux

$$\sigma = \frac{N_D^{irr}\lambda}{N_A}\left[\phi_b^n\left(1 - e^{-\lambda t_n}\right) + \sum_{i=1}^{n-1}\phi_b^i\left(1 - e^{-\lambda t_i}\right)\prod_{j=i+1}^{n} e^{-\lambda t_j}\right]^{-1}$$

	Reaction	$^{118}\mathrm{Sn}(p,\gamma)^{119}\mathrm{Sb}$		$^{116}\mathrm{Sn}(p,\gamma)^{117}\mathrm{Sb}$	
	E_p [MeV]	3.66 ± 0.01	3.29 ± 0.02	3.66 ± 0.01	3.29 ± 0.02
σ [mbarn] mean flux	γ	1.6 ± 0.4	0.28 ± 0.01		
	Kα	1.6 ± 0.4	0.28 ± 0.01	1.0 ± 0.2	0.23 ± 0.02
σ [mbarn] discrete flux	γ	1.6 ± 0.3	0.27 ± 0.01		
	Kα	1.6 ± 0.2	0.27 ± 0.01	1.0 ± 0.2	0.22 ± 0.02

Cross-section Calculation - relative method

Considering mean flux;

$$\sigma = \left(\frac{d\sigma}{d\Omega}\right)_{Ruth} \frac{4\pi N_D^{irr}\epsilon_p}{1-e^{-\lambda t}} \frac{\lambda t}{w_A N_p}$$

Considering discrete flux

$$\sigma = \frac{4\pi\epsilon_p N_D^{irr}}{w_A} \cdot \left(\frac{d\sigma}{d\Omega}\right)_{Ruth} \cdot \left[\frac{N_p^n}{\lambda t_n}\left(1-e^{-\lambda t_n}\right) + \sum_{i=1}^{n-1} \frac{N_p^i}{\lambda t_i}\left(1-e^{-\lambda t_i}\right) \prod_{j=i+1}^{n} e^{-\lambda t_j}\right]^{-1}$$

	Reaction	$^{118}\mathrm{Sn}(p,\gamma)^{119}\mathrm{Sb}$		$^{116}\mathrm{Sn}(p,\gamma)^{117}\mathrm{Sb}$	
	E_p [MeV]	3.66 ± 0.01	3.29 ± 0.02	3.66 ± 0.01	3.29 ± 0.02
Cross-section [mbarn] mean flux	γ	1.3 ± 0.1	0.27 ± 0.02		
	$K\alpha$	1.31 ± 0.06	0.27 ± 0.01	0.8 ± 0.1	0.24 ± 0.02
Cross-section [mbarn] discrete flux	γ	1.3 ± 0.1	0.27 ± 0.02		
	$K\alpha$	1.31 ± 0.08	0.27 ± 0.01	0.9 ± 0.2	0.23 ± 0.02