CPAN Ingenio 2010

^{50}Cr(n,γ) cross section measurement at HiSPANoS@CNA

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UNIVERSIDAD DE SEVILLA

CNA Centro Nacional de Aceleradores

HiSPANoS

UPC

Πανεπιστήμιο Ιωαννίνων

nTOF

CERN

Motivation: nuclear data for criticality safety

NEA Nuclear Data High Priority Request List, HPRL

HPRL Main	High Priority Requests (HPR)	General Requests (GR)	Special Purpose Quantities (SPQ)		New Request	EG-HPRL (SG-C)
			Standard	Dosimetry		

Request ID	98		Type of the request	High Priority request	
Target	**Reaction and process**	**Incident Energy**	**Secondary energy or angle**	**Target uncertainty**	**Covariance**
24-CR-53	(n,g) SIG	1 keV-100 keV		8-10	Y
Field	**Subfield**	**Created date**	**Accepted date**	**Ongoing action**	**Archived Date**
Fission		20-JAN-18	05-FEB-18	Y	

Send a comment on this request to NEA.

Requester: Dr Roberto CAPOTE NOY at IAEA, AUT
Email: roberto.capotenoy@iaea.org

Project (context):

Impact:

Neutron absorption in the Cr isotopes of structural materials affects the criticality of fast reactor assemblies [Koscheev2017]. These cross sections are also of interest for stellar nucleosynthesis [Kadonis10].

Accuracy:

8-10% in average cross-sections and calculated MACS at 10, 30, 100 keV.

Selected criticality benchmarks with large amounts of Cr (e.g., PU-MET-INTER-002, and HEU-COMP-INTER-005/4=KBR-15/Cr) show large criticality changes of the order of 1000 pcm due to 30% change in Cr-53 capture in the region from 1 keV up to 100 keV [Trkov2018]. On the other side different evaluations (e.g., BROND-3.1, ENDF/B-VII.1, ENDF/B-VIII.0 and JEFF-3.3) for Cr-53(n,g) are discrepant by 30% in the same energy region. For Cr-50, evaluated files show better agreement at those energies but they are lower than Mughabghab evaluation of the resonance integral by 35%. These discrepancies are not reflected in estimated uncertainty of the evaluated files (e.g., JEFF-3.3 uncertainty is around 10% which is inconsistent with the observed spread in evaluations). Due to these differences we request new capture data with 8-10% uncertainty to discriminate between different evaluations and improve the C/E for benchmarks containing Chromium and/or SS.

Justification document:

Criticality benchmarks can test different components of stainless steel (SS), including Cr which is a large component of some SS. Currently, a large part of the uncertainty in SS capture seems to be driven by uncertainty in Cr capture [Koscheev2017]. Indeed, some benchmarks highly sensitive to Cr (as a component of SS) indicate a need for much higher capture in Cr for both Pu and U fueled critical assemblies (e.g., HEU-COMP-INTER-005/4=KBR-15/Cr and PU-MET-INTER-002=ZPR-6/10).

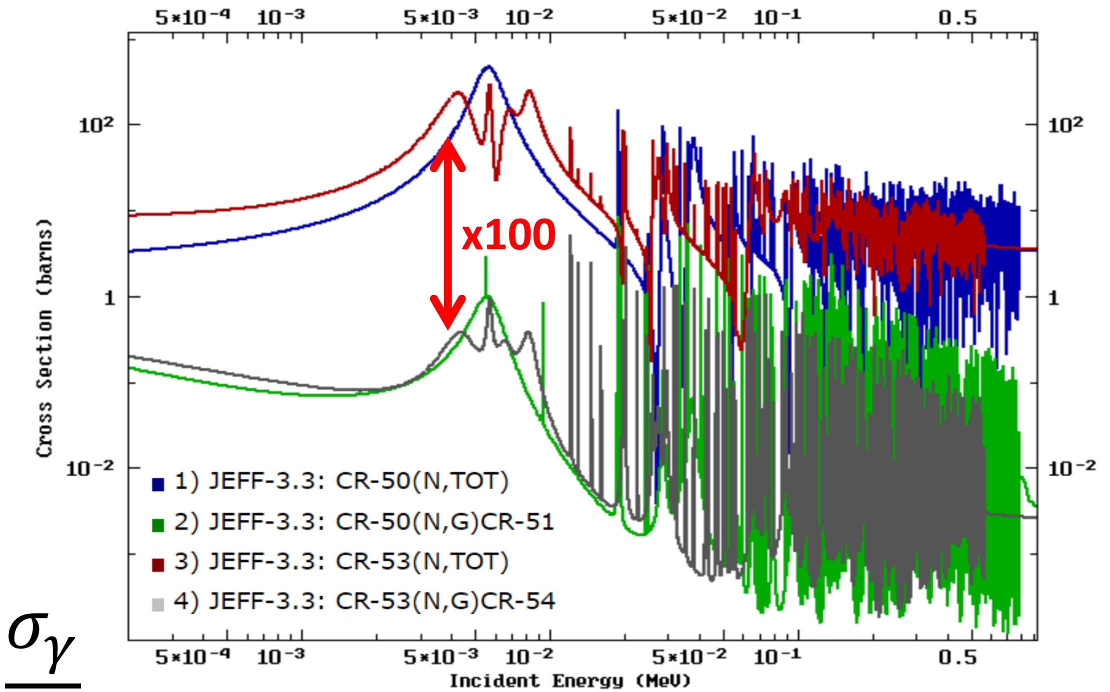
- Stainless Steel is often used as a **structural material in nuclear reactors** and contains between **11-26% of chromium**.

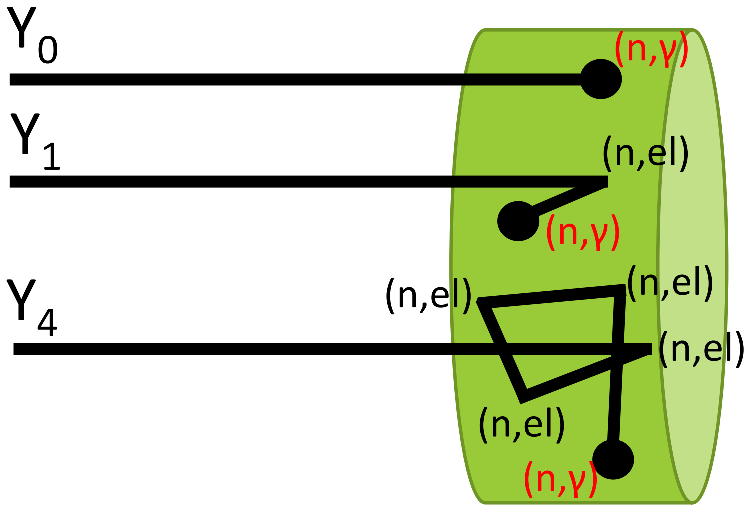
- There are **serious discrepancies** (~30%) between the different evaluated data of **^{50}Cr and ^{53}Cr capture cross section**, which is not present in the corresponding estimated uncertainties.

- **OECD NEA-HPRL** (High Priority Request List) → **^{50,53}Cr(n,γ) within 8-10% at 1 to 100 keV.**

Why the discrepancies?

- The main challenge for measuring Cr(n,γ) is the large **neutron multiple-scattering effects**
- In the previous measurements very thick samples were used, aiming for good statistics in a very wide energy range





$$Y_0 = (1 - e^{n\sigma_t})\frac{\sigma_\gamma}{\sigma_t}$$

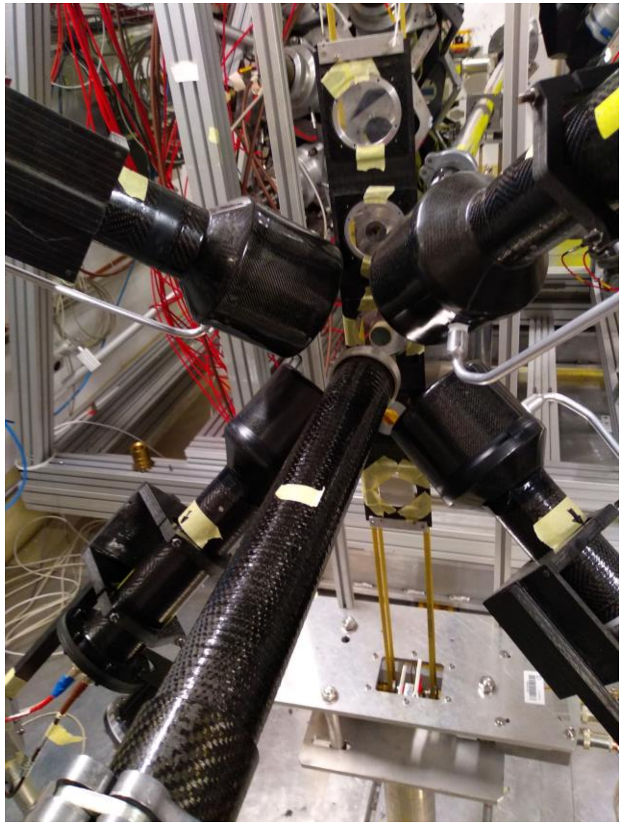
Capture yield (captures/neutron) $\rightarrow Y = Y_0 + Y_1 + \mathrm{Y}_2 + \mathrm{Y}_3 \ldots$

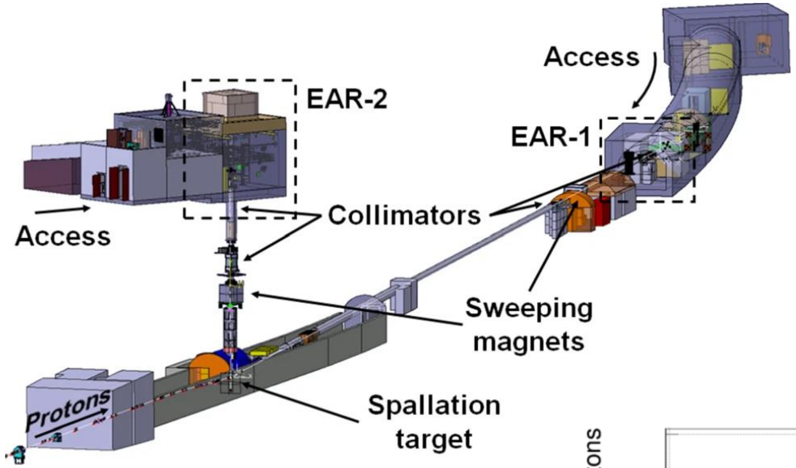
Analytical (accurate) — $Y_0 + Y_1$

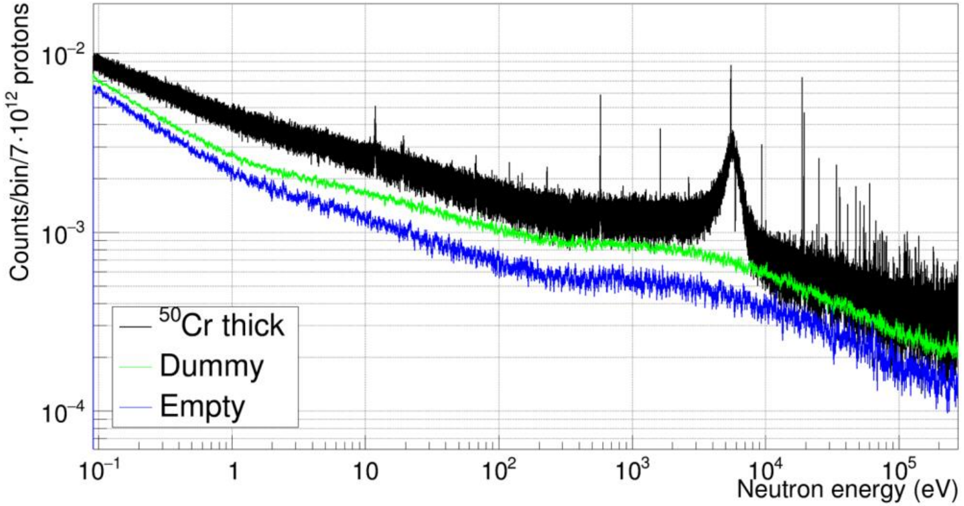
Numerical (aproximate) — $\mathrm{Y}_2 + \mathrm{Y}_3 \ldots$

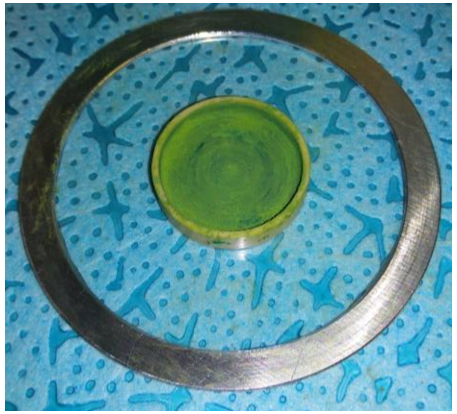
How to improve σ(n,γ) down to a few %?

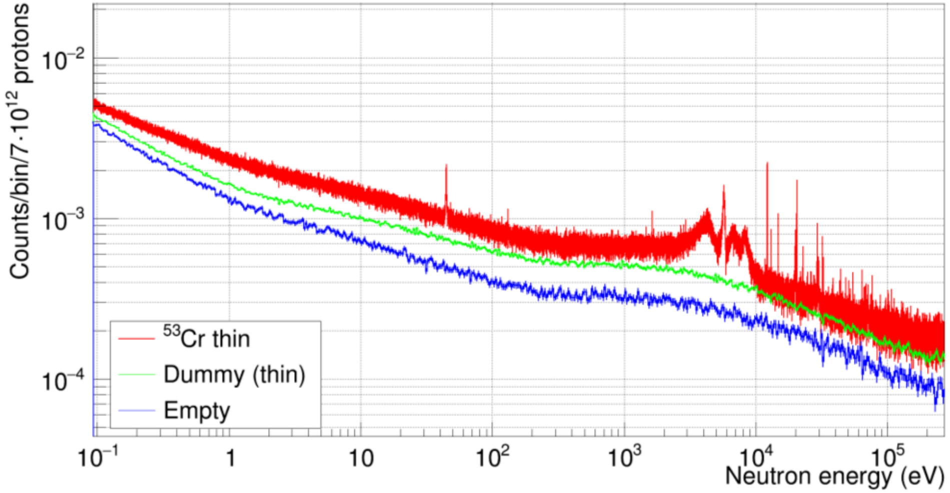
- Time-of-flight measurement → n_TOF@CERN (Geneva, Switzerland) with very thin samples to minimize multiple-scattering effects





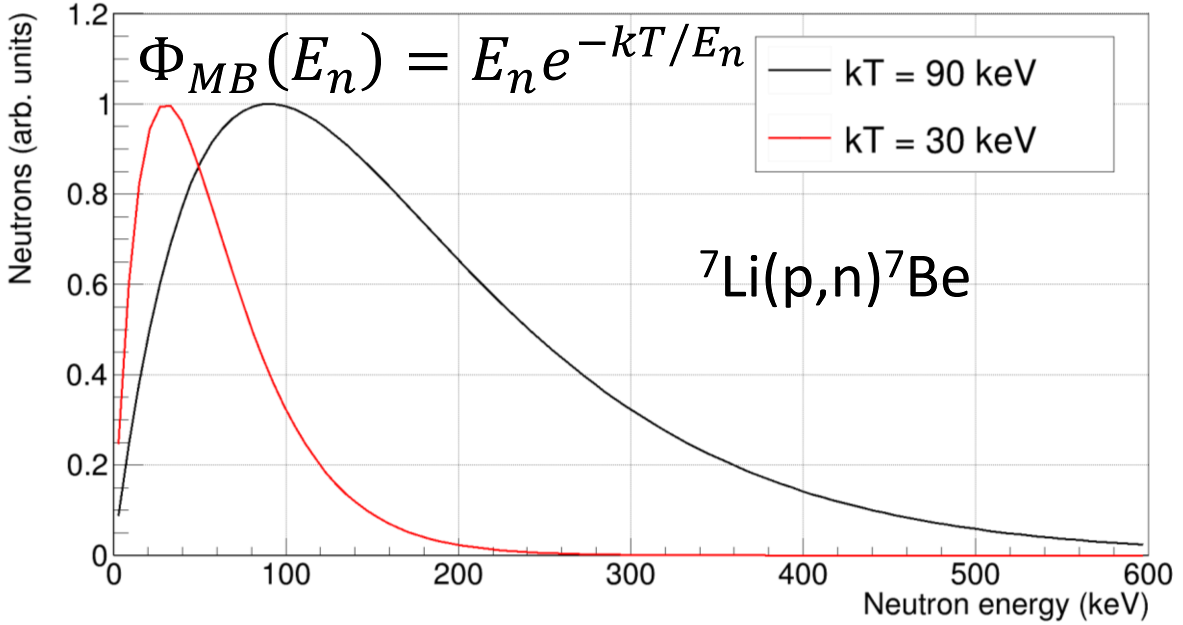


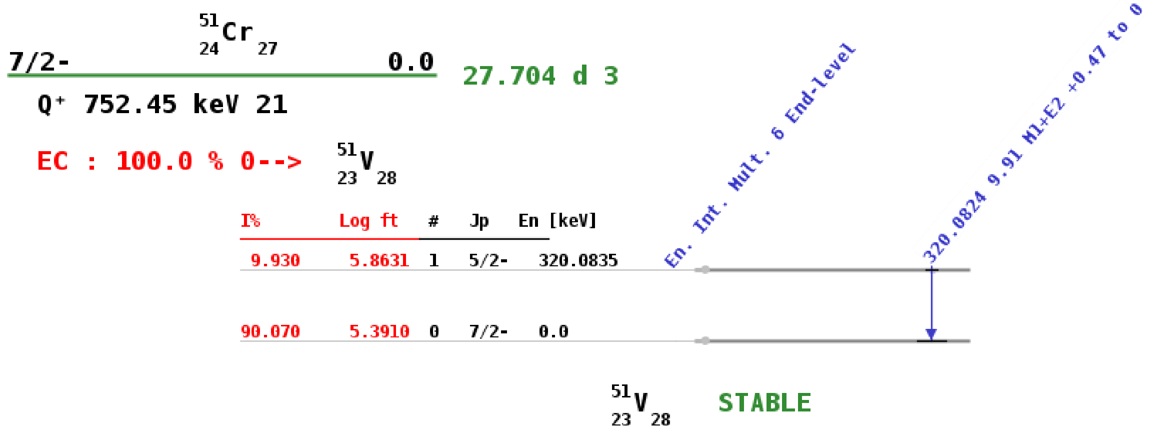




How to improve σ(n,γ) down to a few %?

- Time-of-flight measurement → n_TOF@CERN (Geneva, Switzerland) with very thin samples to minimize multiple-scattering effects
- **^{50}Cr activation measurement** → HiSPANoS@CNA (Seville, Spain). MACS at 30 and 90 keV

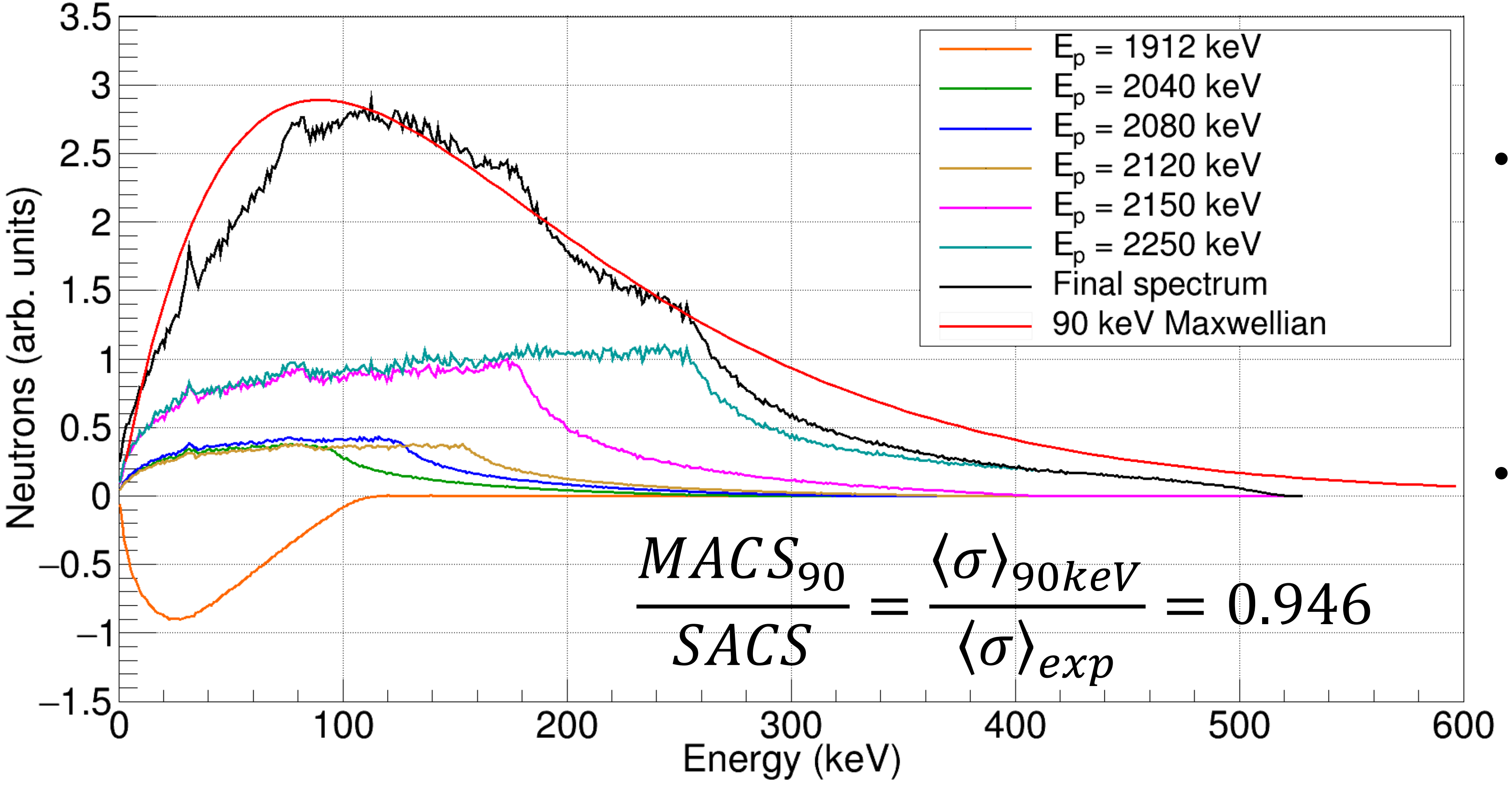




$$MACS \propto \langle\sigma_{MB}\rangle_{kT} = \frac{2}{\sqrt{\pi}} \frac{\int \sigma(E_n)\Phi_{MB}(E_n)dE_n}{\int \Phi_{MB}(E_n)\,dE_n}$$

- A 30 keV quasi-Maxwellian spectrum can be "easily" produced by Li(p,n) with E_p=1912 keV.
- How to produce a 90 keV MB spectrum → **new technique** being tested at CNA.

^{50}Cr activation: how to make a 90 keV MB?



$$\frac{MACS_{90}}{SACS} = \frac{\langle\sigma\rangle_{90keV}}{\langle\sigma\rangle_{exp}} = 0.946$$

- 90 keV spectrum → linear combination of fluxed obtained from different proton energies.
- Idea proposed by Reifarth et al., but never implemented.

Reifarth, R. et al, "*Neutron-induced cross sections-from raw data to astrophysical rates*". The European Physical Journal Plus, 133(10), 424 (2018)

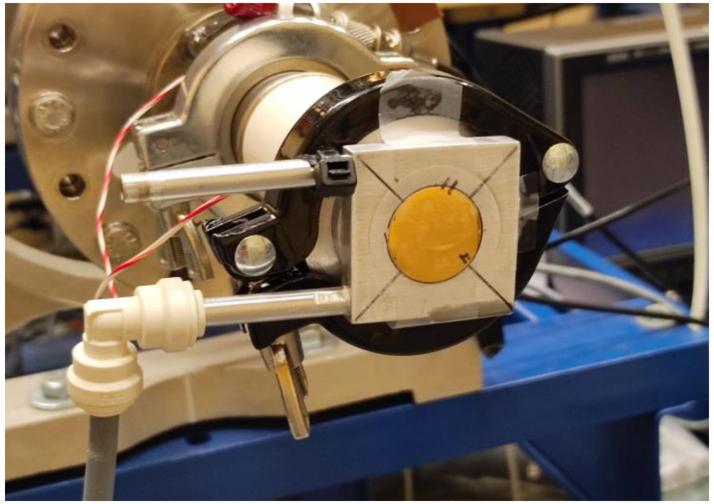
The HiSPANoS@CNA Facility

- HiSPANoS is the neutron facility of CNA.
- Using the 3MV Tandem accelerator we can produce thermal, epithermal and monoenergetic-fast neutrons with the reactions Li(p,n), ^{2}H(d,n) and Be(d,n), mostly.
  - Continuous beam for activations.
  - Pulsed beam for TOF measurements.

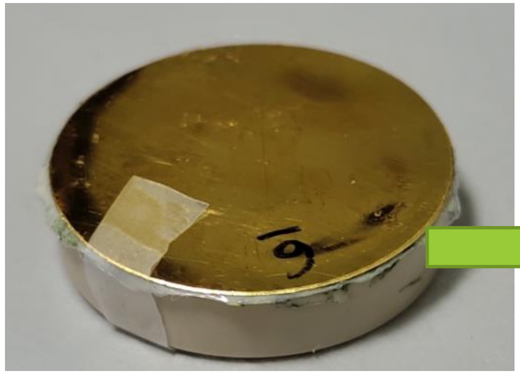
M. Macías et al, "*The first neutron time-of-flight line in Spain: …*", Rad. Phys. and Chem. 168 (2020)
M. A. Millán-Callado et al., "*Continuous and pulsed fast neutron beams at the CNA HiSPANoS facility*", Rad. Phys. and Chem. (accepted)

^{50}Cr activation: set-up

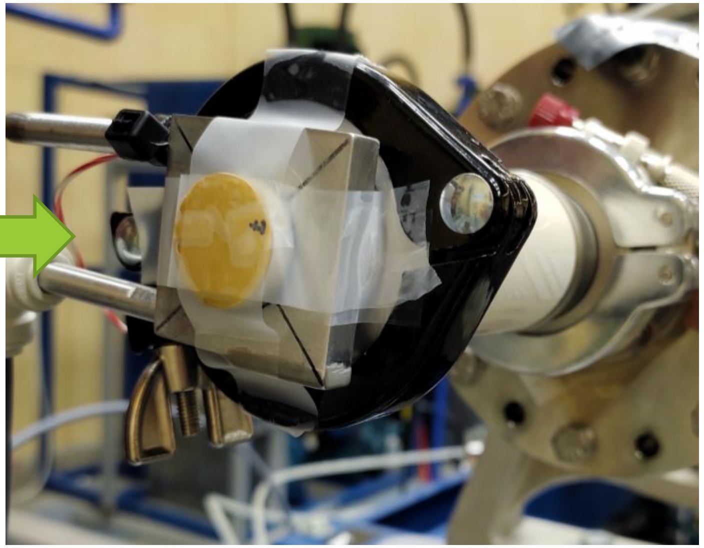
Metallic Li for higher production → cooled target

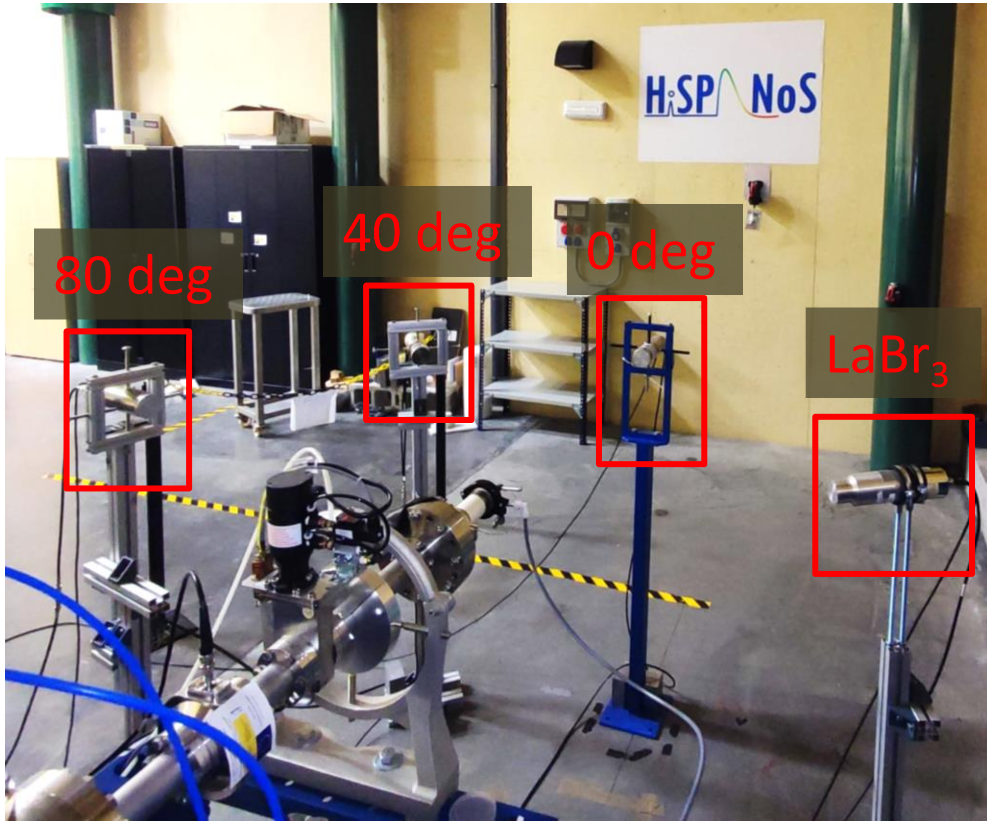


^{197}Au irradiation for activation checks



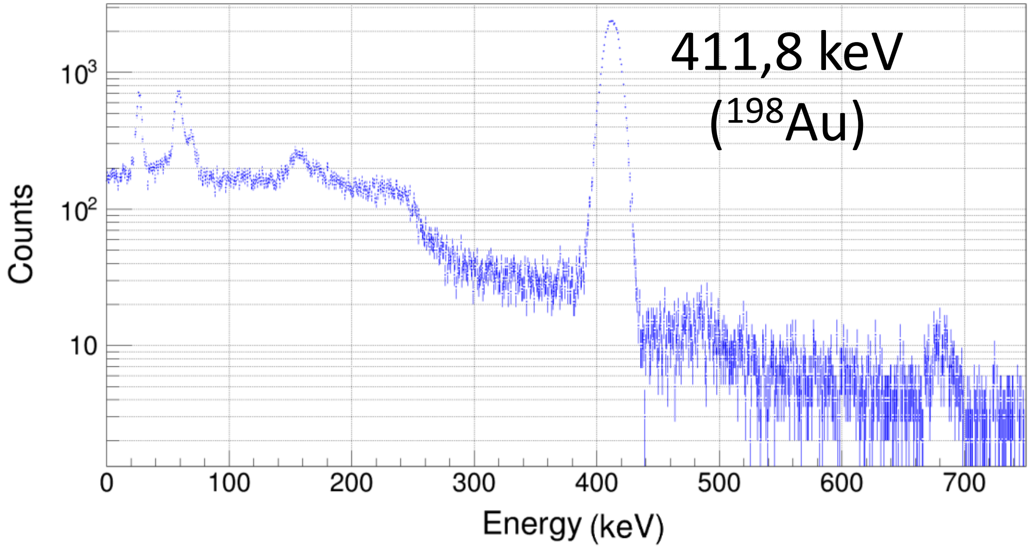
^{197}Au + ^{50}Cr + ^{197}Au sample

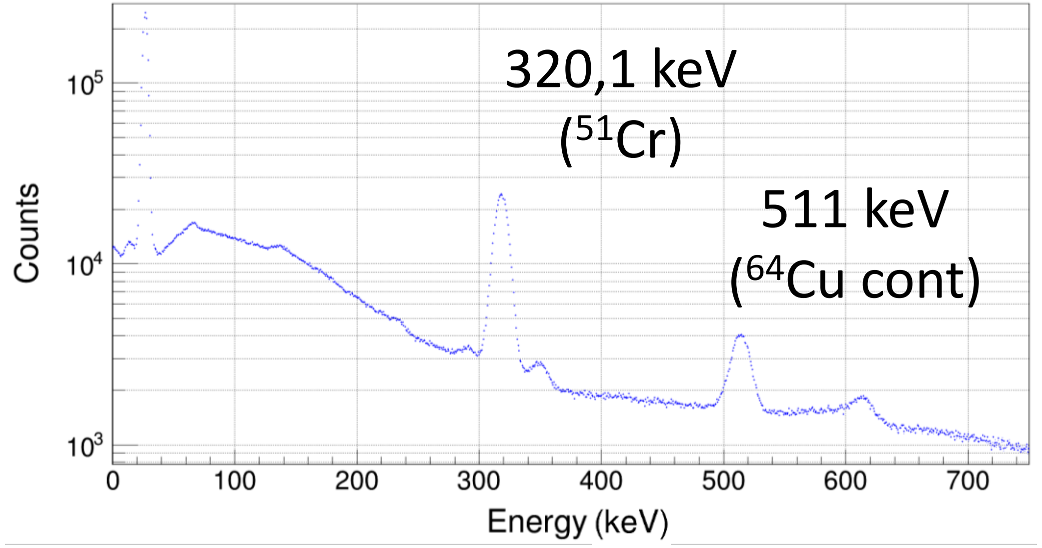


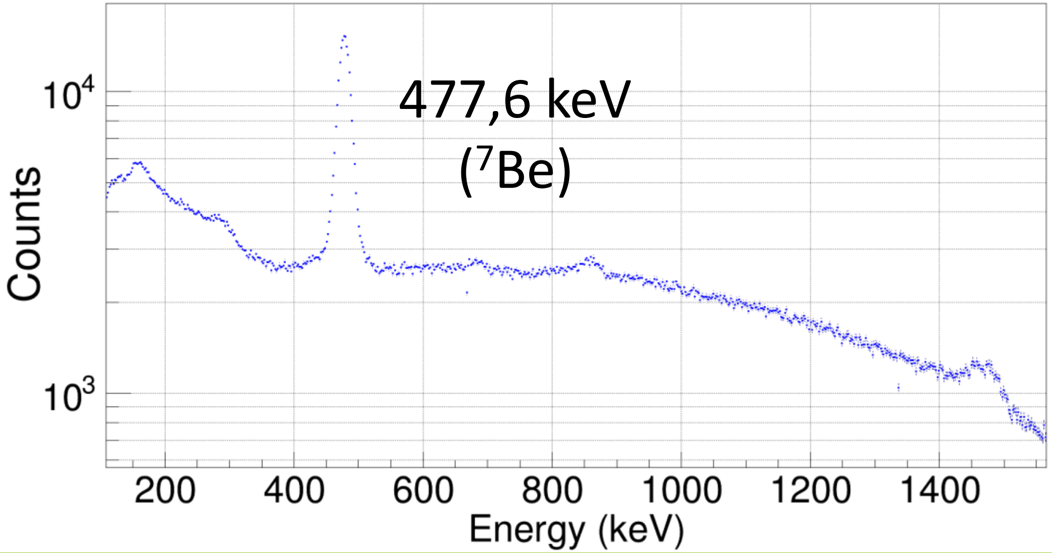


- 3 Lithium-glass neutron monitors
- 1 $LaBr_3$ for ^{7}Be decay
- 1 $LaBr_3$ for ^{198}Au and ^{51}Cr decay

Preliminary results

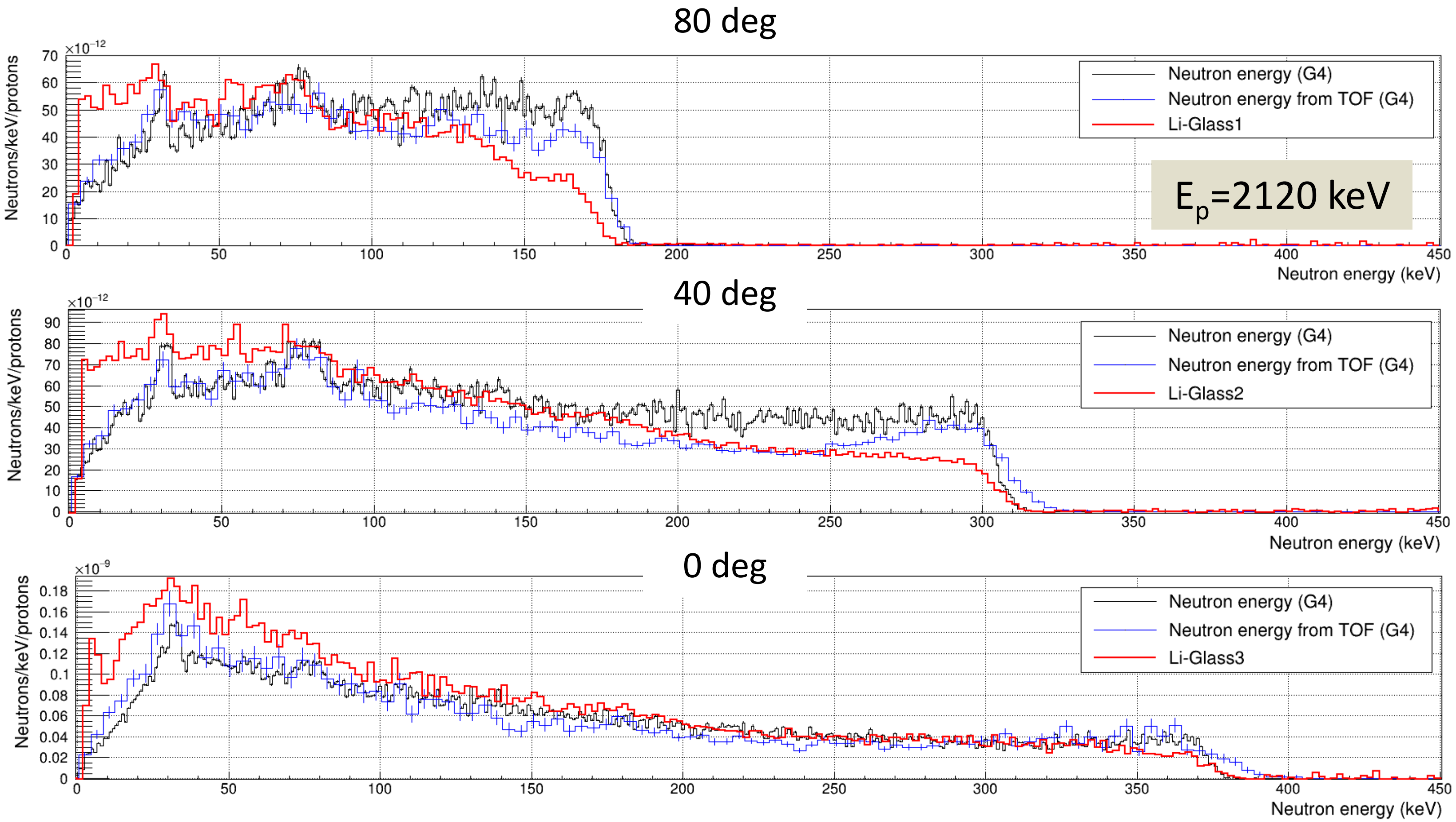






- 28 samples activated with 6 different neutron fluxes (plus the Li target).
- Validation with simulations (SimLit + GEANT4).
- Spectra characterization is not strictly necessary (and is usually not performed).

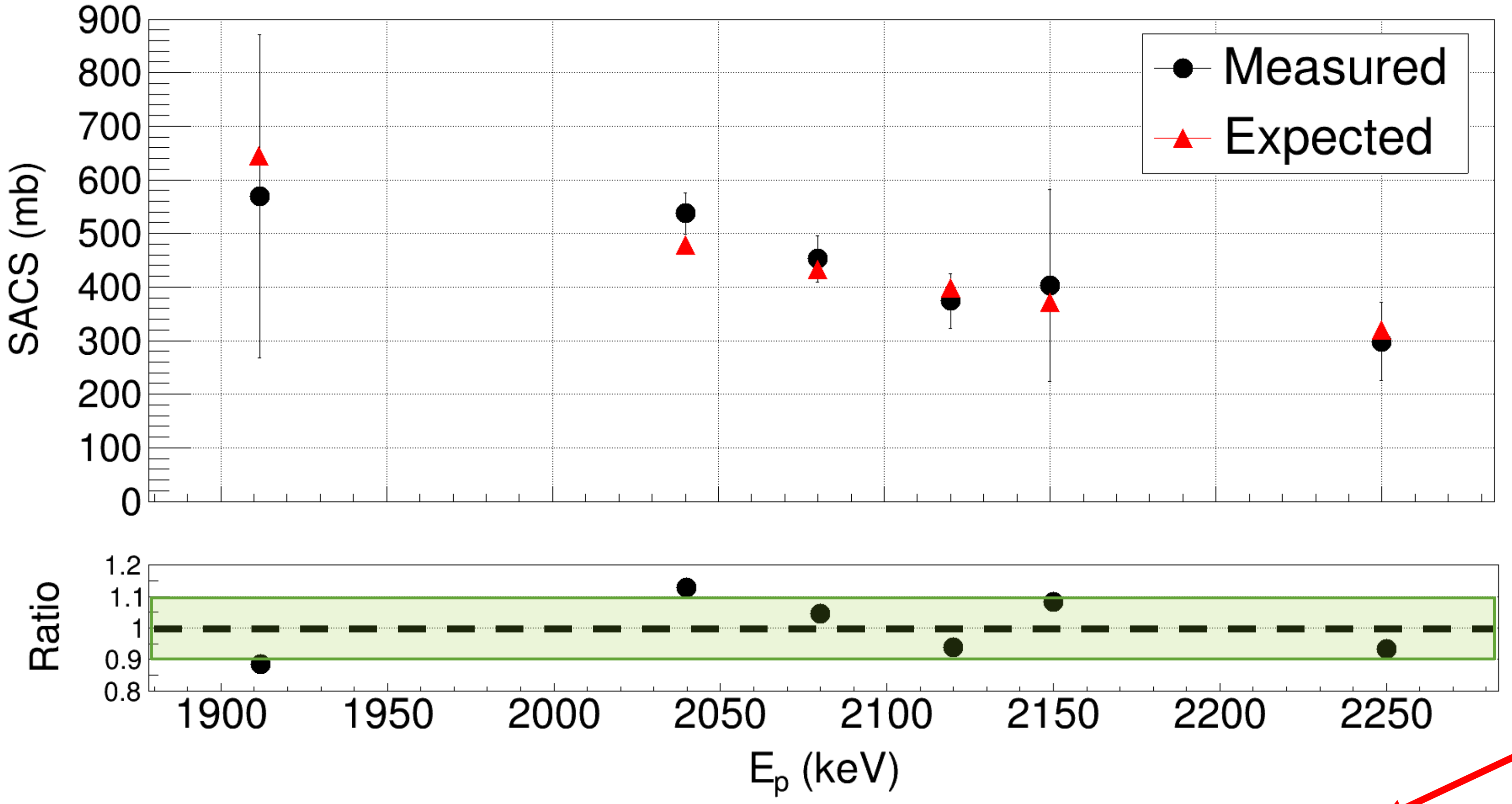
Preliminary results (TOF measurements)



- Some differences between the measured and the simulated spectra.
- With the simulations we will obtain the accurate E_p value of the irradiations.
- Differences maybe due to detector resolution function? Bad background subtraction?

Work ongoing…

Preliminary results (^{197}Au SACS)

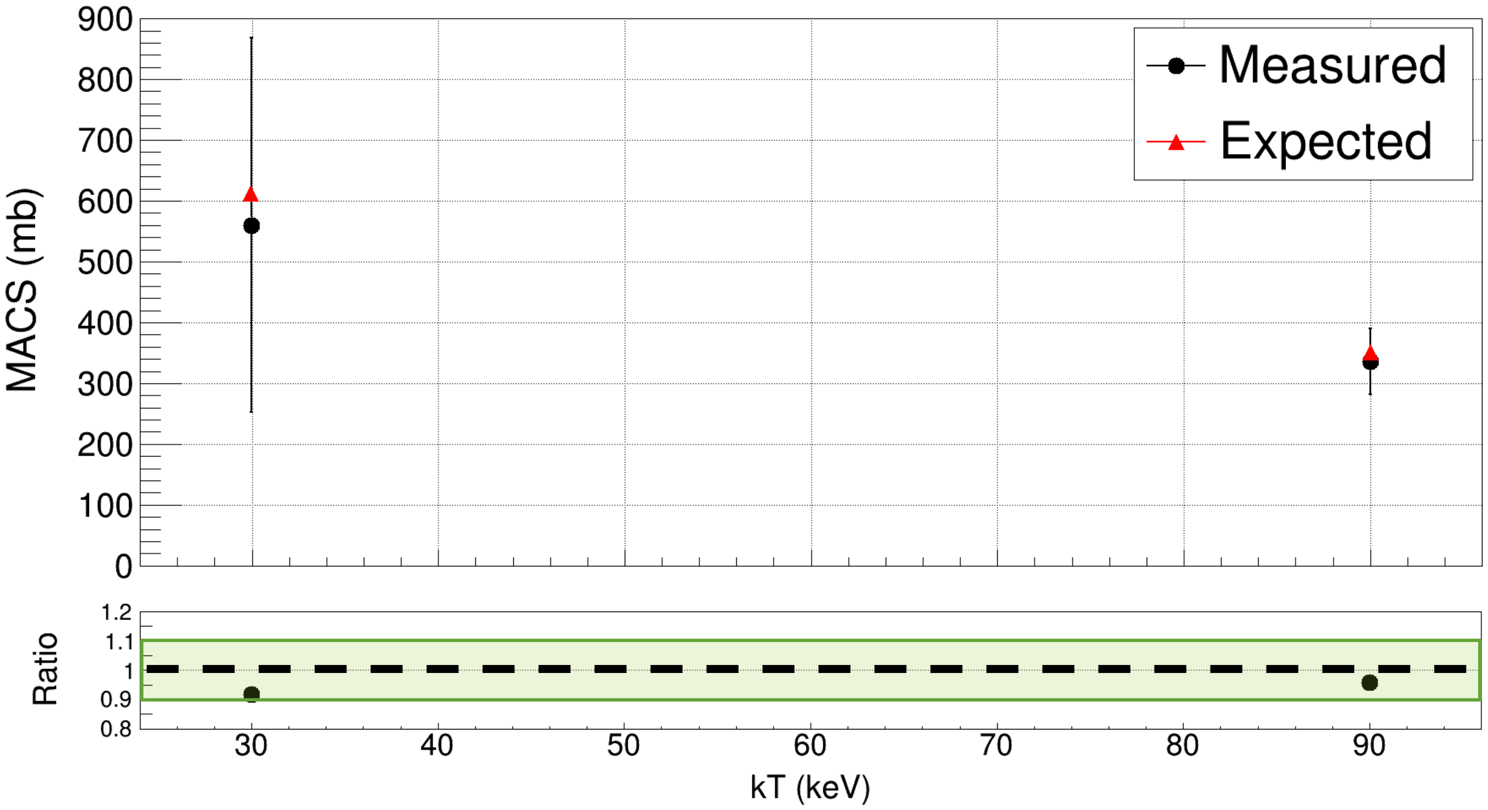


- Large statistical uncertainties due to ^{7}Be build-up: it can be reduced exchanging the Li target between irradiations (next time).
- The SACS are in agreement with the expected values within 12% in the worst case.

^{197}Au(n,γ) is indeed quite well known (it's a standard above 2,5 keV)

$$SACS = \frac{1}{n_{at}} \frac{N_{act\,^{198}Au}}{N_{act\,^{7}Be}}$$

Preliminary results (^{197}Au MACS)



- ^{197}Au MACS$_{30}$ has 50% stat. uncertainty, but only differs 9% from the KADONIS value.
- ^{197}Au MACS$_{90}$ agrees within only 6% with the expectation from the evaluation, which is excellent considering that ^{197}Au(n,γ) is standard in this region .
- **First $\langle\sigma\rangle_{90keV}$ measurement ever!**

- When the ^{197}Au activations and TOF spectra are perfectly understood, we will apply everything learned to the ^{50}Cr MACS$_{30,90}$
- A lot of work ahead!

Summary & Outlook

- A clear goal: improving the $^{50,53}Cr(n,\gamma)$ cross section to 8-10% accuracy at 1-100 keV
- Two experiments:
  - n_TOF@CERN, Summer'22 (H2020-Ariel Scientific Visit).
  - **^{50}Cr activation at HiSPANoS@CNA**, March'23 (H2020-Ariel Transnational Access).
- Preliminary results show high quality data.

- $MACS_{90}$ measurement using a new technique → preliminary ^{197}Au test.
- Some discrepancies at the TOF spectra → work ongoing.
- Preliminary ^{197}Au SACS and $MACS_{30,90}$ in agreement with the expected values.
- First time ever $MACS_{90}$ experimental measurement.
- Everything learned will be apply to the ^{50}Cr case (and more nuclei in the future…).

Thank you!

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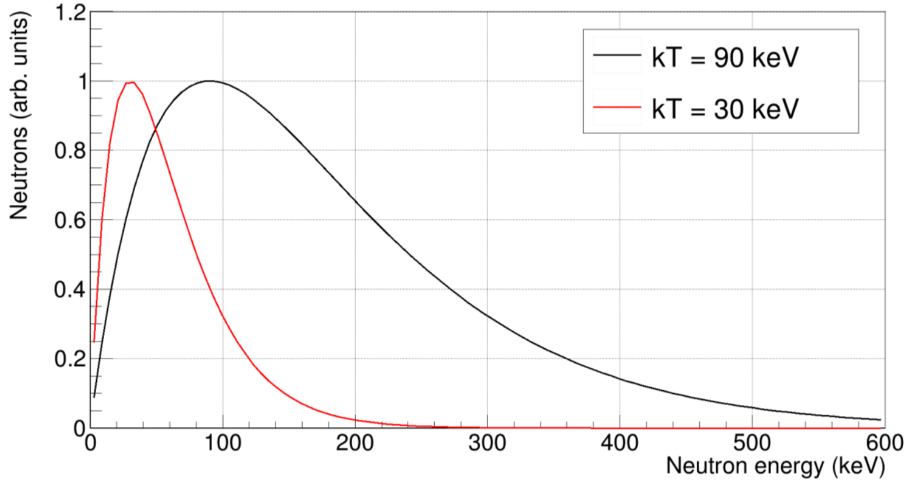
Backup. How to improve σ(n,γ) down to a few %?

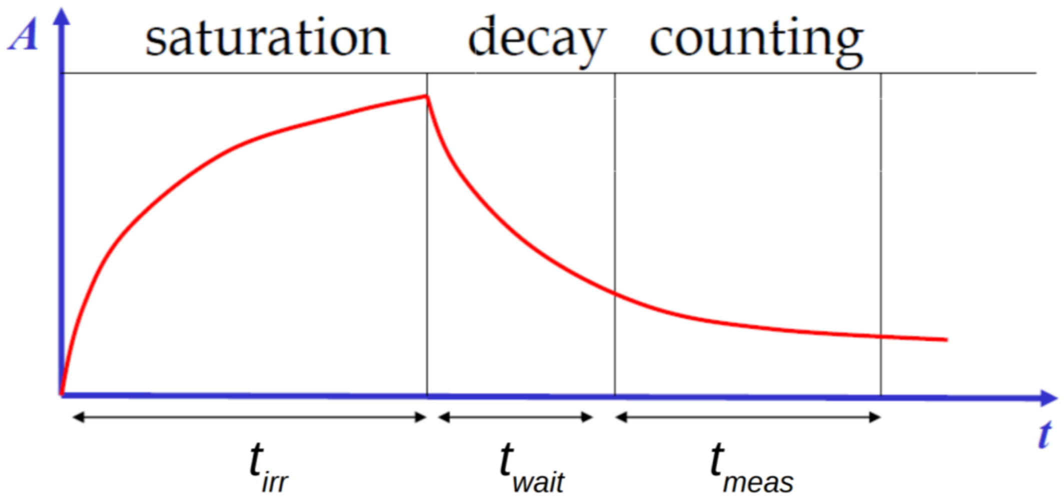
- Enriched (expensive and scarce) material with high purity → 94,6% ^{50}Cr & 97,7% ^{53}Cr
- Controlling multiple-scattering effects:
  - Very thin/thin sample approach
  - C_6D_6 detectors (low sensitivity to scattered neutrons)

Experiment	Beer (1975)	Stieglitz (1971)	Brusegan (1986)	Kenny (1977)	Guber (2011)	**This work (2022)**
Facility	FZK	RPI	GELINA	ORELA	ORELA	**n_TOF**
L (m)	0,7	27	60	40	40	**185**
Energy (keV)	1-300	1-200	1-200	1-200	0,01-600	**1-100**
Density ^{50}Cr (10^{-3} at/barns)	18	8	7	5/8	-	**0,6/1,9**
Density ^{53}Cr (10^{-3} at/barns)	14	14	12/60	8/12	14	**1,2/6**

Our "thicks" are thinner than all previous → lower multiple interaction corrections

Backup. Averaged cross section equations





$$N_{act} = \frac{A_{EOI}}{\lambda} = \frac{\dot{C} t_{meas} e^{\lambda t_{wait}}}{I_\gamma \varepsilon (1 - e^{-\lambda t_{meas}})}$$

$$\downarrow$$

$$\varepsilon = \varepsilon_\lambda K_\Omega K_\gamma$$

$$SACS = \frac{1}{n_{at}} \frac{N_{act}}{N_{neutrons}} = \frac{1}{n_{at}} \frac{N_{act}}{N_{act\ ^7Be}}$$

$$\langle \sigma \rangle = \frac{\int \sigma(E_n) \Phi(E_n) dE_n}{\int \Phi(E_n)\, dE_n} \rightarrow MACS = \frac{2}{\sqrt{\pi}} \frac{\langle \sigma \rangle_{kT}}{\langle \sigma_\Phi \rangle} SACS$$

Backup. ^{50}Cr activation: preliminary results