WONDER 2026

^{50}Cr and ^{53}Cr (n,γ) cross section measurements at n_TOF and HiSPANoS

P. PÉREZ-MAROTO, C. GUERRERO, A. CASANOVAS,

B. FERNÁNDEZ & THE N_TOF COLLABORATION.

WONDER 2026, AIX-EN-PROVENCE. 30/06/2026

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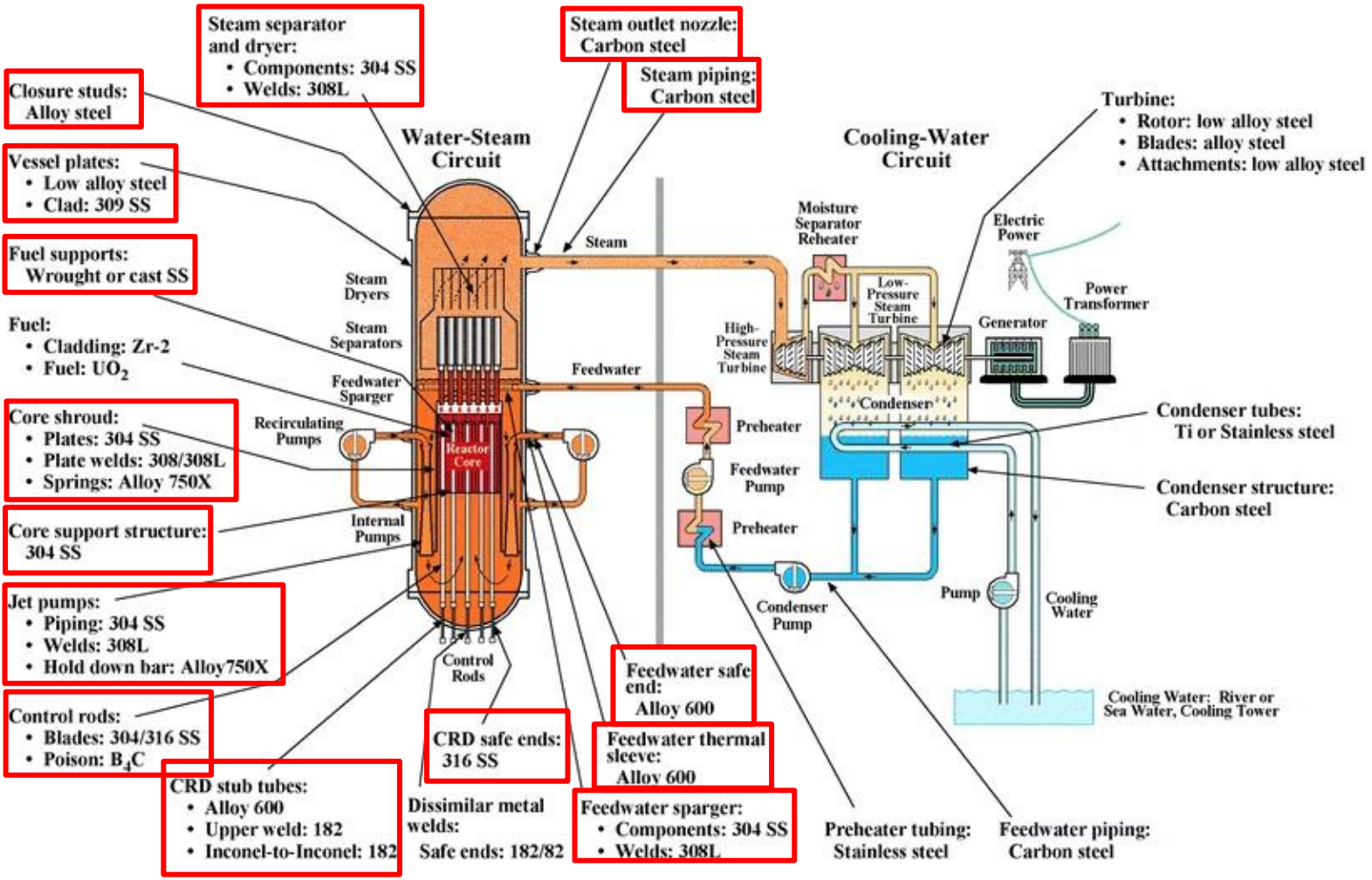
P. Pérez-Maroto PhD: "*Measurement of ^{50}Cr and ^{53}Cr neutron capture cross sections for nuclear technology at CERN n_TOF and HiSPANoS*"

I. Introduction

Why ^{50,53}Cr neutron capture?



- **Stainless Steel** → structural material in nuclear reactors.
- Contains 11-26% of chromium.
- Criticality benchmarks sensitive to chromium → dominated by

^{50,53}Cr (n,γ)

- ~30% discrepancies in ^{50}Cr and ^{53}Cr cross sections → 1% change in k_{eff} †.

†A. Trkov, "*On the Benchmarking of New Evaluated Nuclear Data Libraries*", INDC (NDS)-0751 (2018)

Why ^{50,53}Cr neutron capture?

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** → structural material in nuclear reactors.
- Contains 11-26% of chromium.
- Criticality benchmarks sensitive to chromium → dominated by

^{50,53}Cr (n,γ)

- ~30% discrepancies in ^{50}Cr and ^{53}Cr cross sections → 1% change in k_{eff} †.

↓

NEA High Priority Request List (HPRL):
^{50,53}Cr σ(n,γ) within 8-10% from 1 to 100 keV

†A. Trkov, "*On the Benchmarking of New Evaluated Nuclear Data Libraries*", INDC (NDS)-0751 (2018)

Previous measurements and evaluations

Several measurements have been performed during the 70s and 80s, and a more recent one in ORELA by Guber et al. (2011) †.

Experiment	Stieglitz (1971)	Beer (1975)	Kenny (1977)	Brusegan (1986)	Guber (2011)
Facility	RPI	FZK	ORELA	GELINA	ORELA
Detector	Scin.tank	Scin.tank	C_6F_6	C_6D_6	C_6D_6
Thickness ^{50}Cr (10^{-3} at/barns)	8	18	5/8	7	-
Thickness ^{53}Cr (10^{-3} at/barns)	14	14	8/12	12/60	14

- Goal: as many resonances as possible, even at high energies.
- Very **thick samples** were used → large **neutron multiple-scattering** effects.

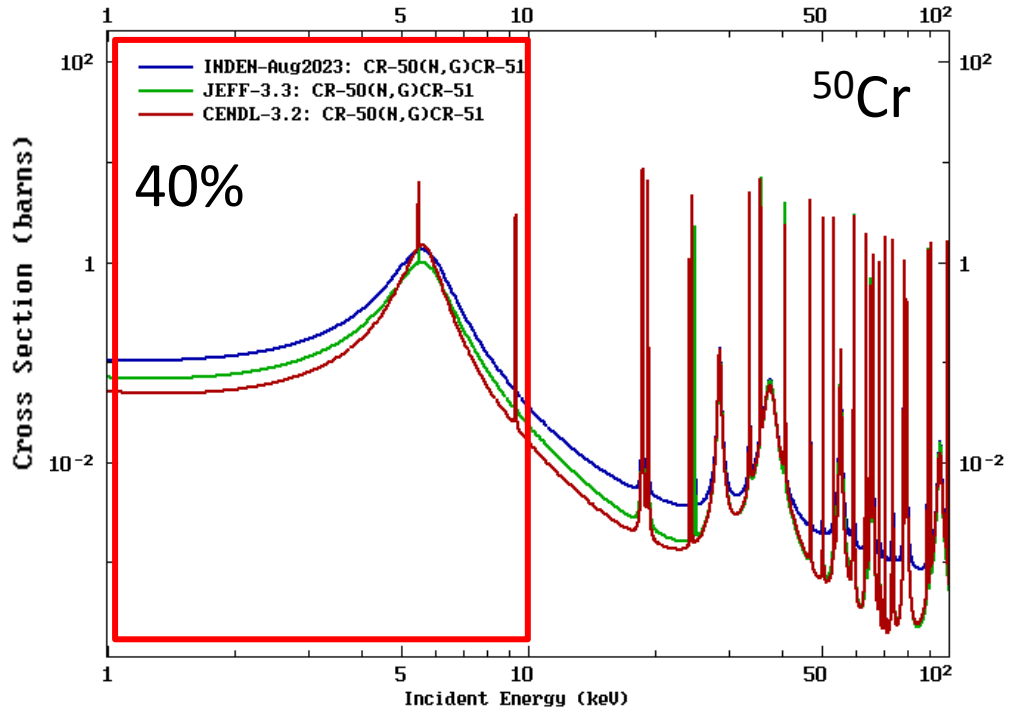
Guber improves the neutron sensitivity → Issues with sample characterization.

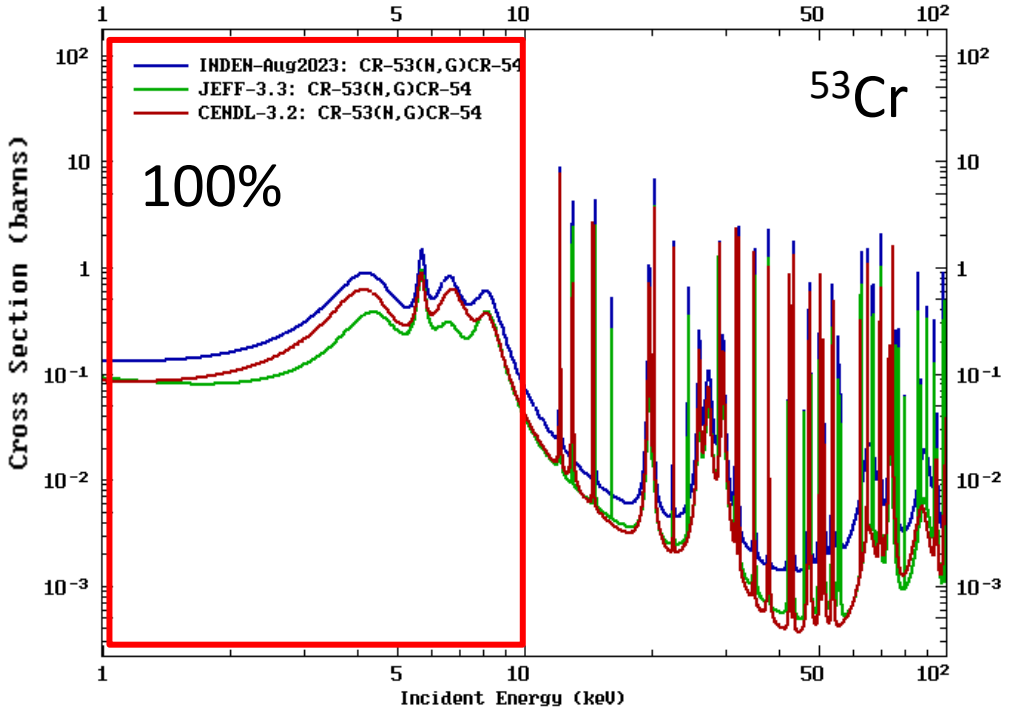
†K. H. Guber et al., "*Neutron cross-section measurements on structural materials at ORELA*", J. Korean Phys. 59, nº 2(3) (2011)

Previous measurements and evaluations

Evaluated data

- JEFF-3.3, ENDF/B-VIII.0 & JENDL-5 → Same XS, mainly based on Guber et al (2011).
- CENDL-3.2 → Uses data from the 70's and 80's.
- INDEN → Careful re-evaluation of multiple-scattering effects at Guber et al. data.
- ENDF/B-VIII.1, JEFF-4.0 → Has adopted INDEN.





II. ^{50}Cr activation measurement at HiSPANoS@CNA

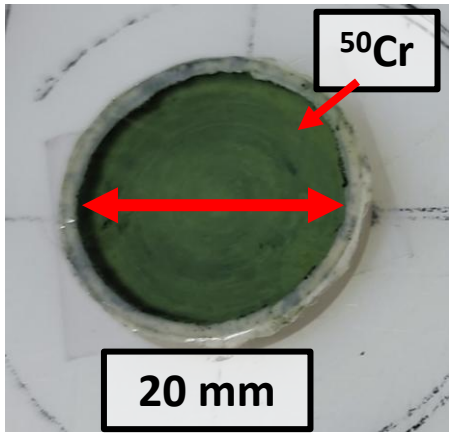
The HiSPANoS facility at CNA

HiSPANoS is the neutron facility of CNA †‡.

- Thermal (eV) → moderation
- Epithermal (keV) → Li(p,n)
- Fast (MeV) → ^{2}H(d,n) and Be/Li(p/d,n)
  - Continuous: activations/irradiations
  - Pulsed: ToF measurements

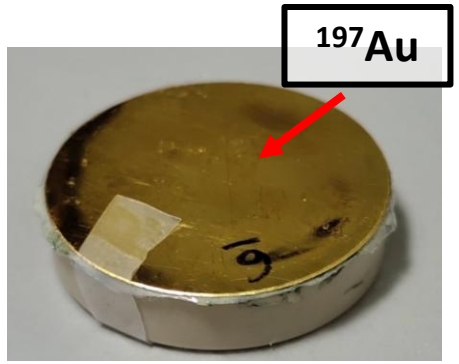
†M. Macías et al., "*The first neutron time-of-flight line in Spain: …*", Rad. Phys. and Chem. 168 (2020)
‡M. A. Millán-Callado et al., "*Continuous and pulsed fast neutron beams at the CNA HiSPANoS facility*", Rad. Phys. and Chem. 217 (2024)

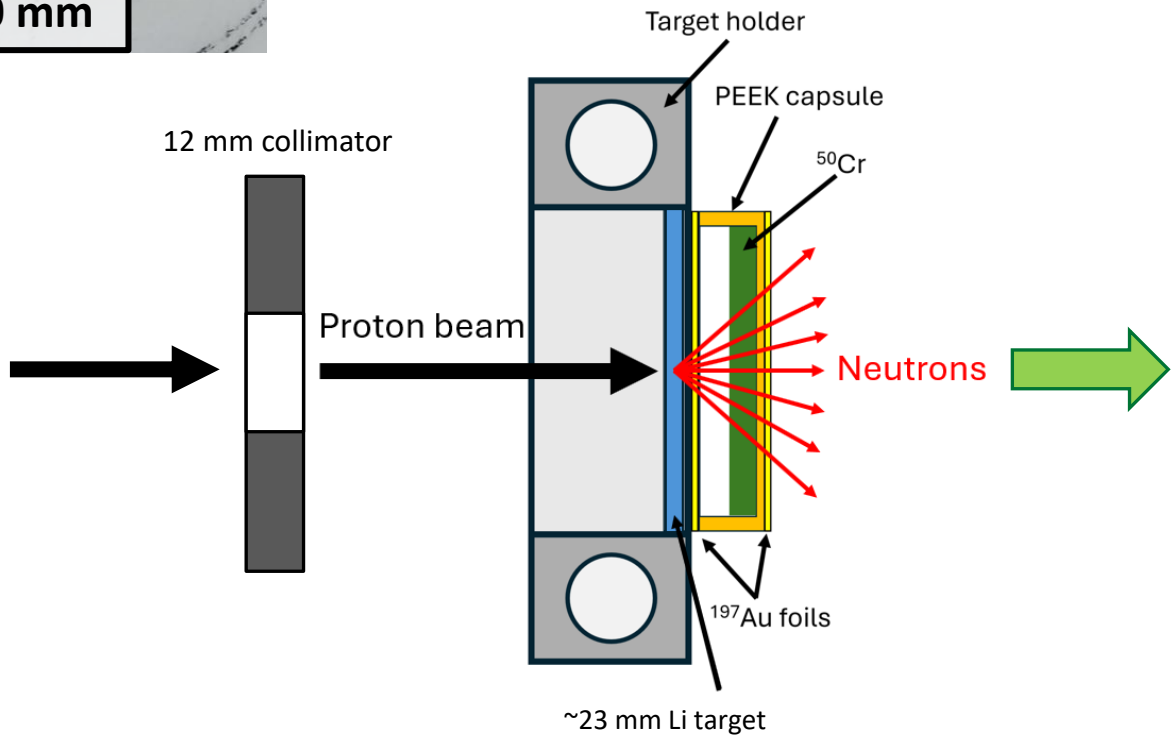
Experimental set-up. Activation sample

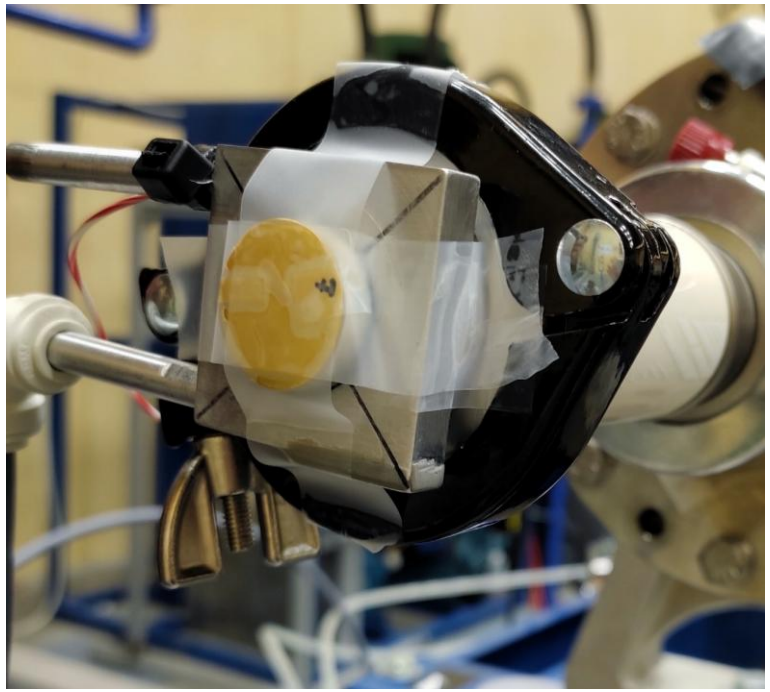


- 94.6(4)% enriched $^{50}Cr_2O_3$
- 723(3) mg of material
- Inside a PEEK capsule

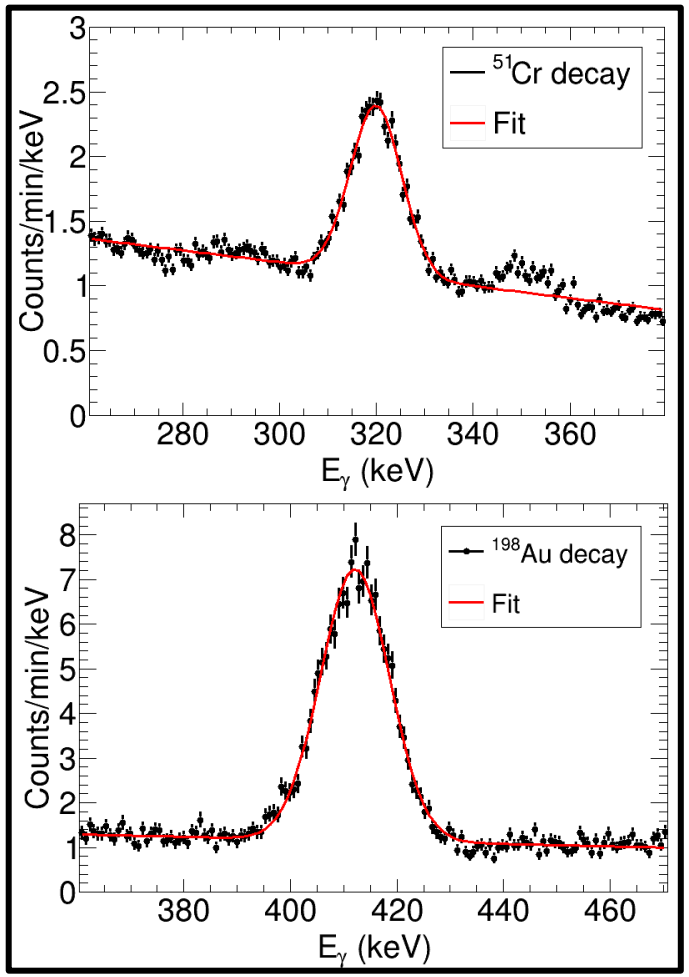
Measured relative to two ^{197}Au foils (standard cross section)







Neutron activation analysis



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

	$N_{act}(10^6)$
^{50}Cr	79(3)
^{197}Au$_{front}$	434(11)
^{197}Au$_{back}$	425(10)

<u>Efficiency</u> is the main source of uncertainty

	^{50}Cr (%)	^{197}Au$_{front}$(%)	^{197}Au$_{back}$(%)
I_γ	0.1	0.6	
ε	3.3	1.8	
C	1.3	1.7	1.5
$e^{\lambda t_w}$	0.01	0.08	0.07
$e^{-\lambda t_m}$	0.01	0.01	
f_{irr}	0.2	0.2	
Overall	**3.6**	**2.6**	**2.4**

$MACS_{30}(^{50}Cr)$ determination

$$\langle\sigma\rangle = \frac{\int \sigma_\gamma(E_n)\Phi(E_n)dE_n}{\int \Phi(E_n)\,dE_n} \rightarrow$$

If Φ is a Maxwellian distribution at a temperature of kT (keV)

$$\rightarrow \quad \boxed{\mathrm{MACS}_{kT} = \frac{2}{\sqrt{\pi}}\langle\sigma\rangle_{kT}}$$

$MACS_{30}(^{50}Cr)$ determination

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If Φ is a Maxwellian distribution at a temperature of kT (keV)

$$\rightarrow \quad \mathrm{MACS}_{kT} = \frac{2}{\sqrt{\pi}}\langle\sigma\rangle_{kT}$$

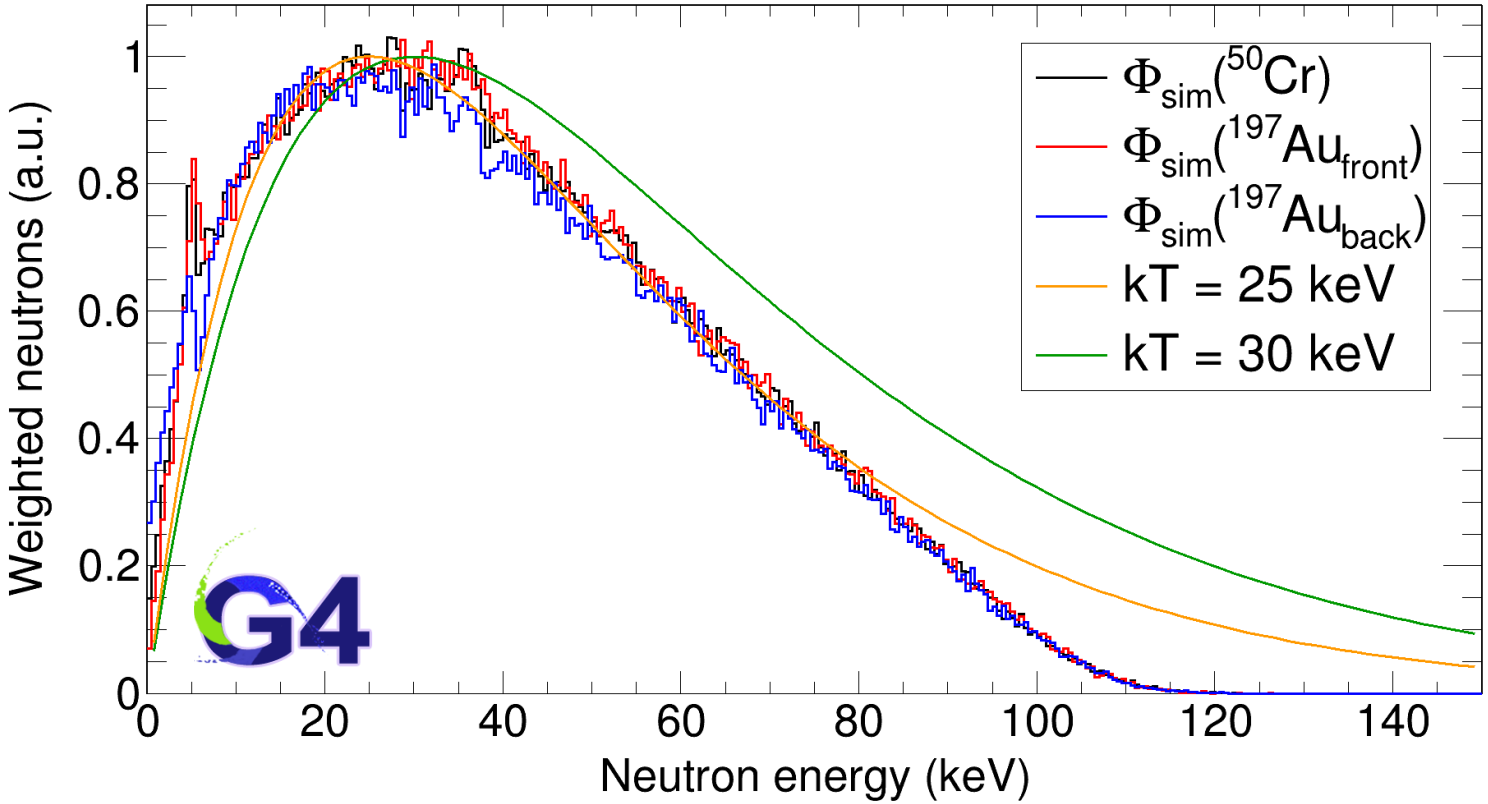
$MACS_{30}(^{50}Cr)$ relative to $MACS_{30}(^{197}Au)$:

$$\frac{\langle\sigma\rangle_{sim,\mathrm{Cr}}}{\langle\sigma\rangle_{sim,\mathrm{Au}}} = \frac{N_{act,\mathrm{Cr}}}{n_{\mathrm{at,Cr}}}\frac{n_{\mathrm{at,Au}}}{N_{act,\mathrm{Au}}}f_\Phi$$

↓

SimLiT + GEANT4

$$\mathbf{MACS_{30}(^{50}Cr) = \frac{2}{\sqrt{\pi}}\, f_{S\rightarrow M}\langle\sigma\rangle_{sim,^{50}Cr}}$$

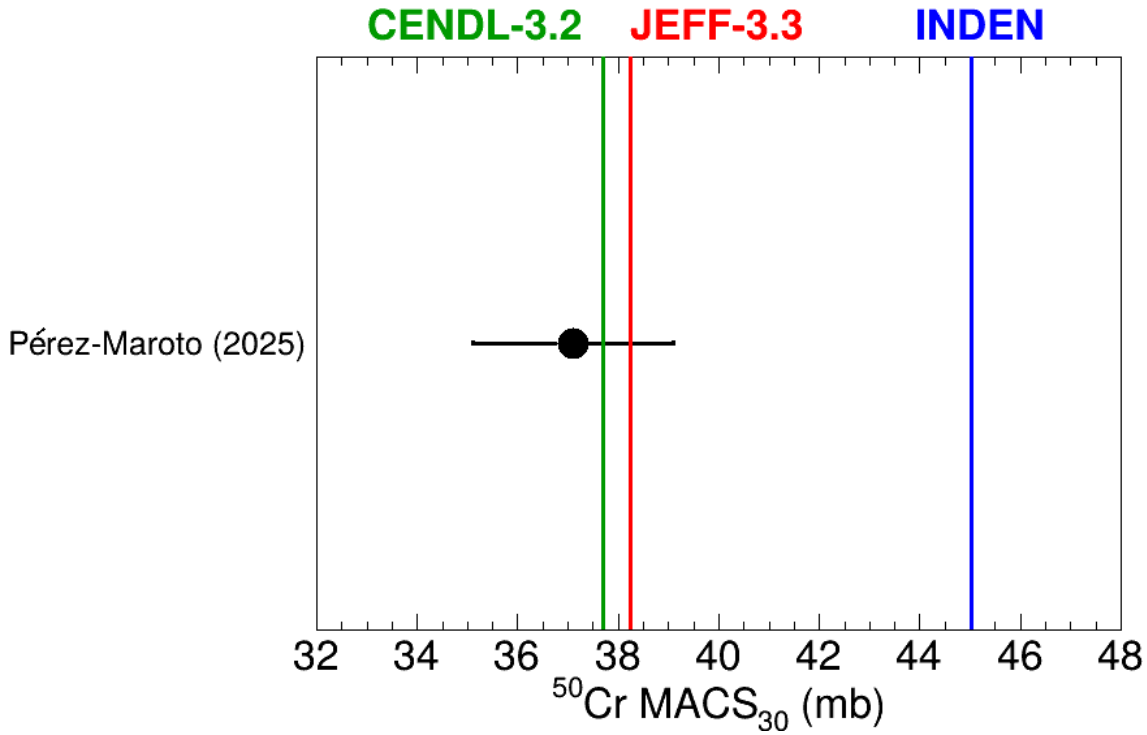


$MACS_{30}(^{50}Cr)$. Comparison with previous data

- First ^{50}Cr neutron activation measurement.
- Agreement with CENDL-3.2 and JEFF-3.3 (and therefore, ENDF/B-VIII.0 and JENDL-5).
- 20% lower than INDEN.

$MACS_{30}(^{50}Cr)$	$^{197}Au_{front}$	$^{197}Au_{back}$
JEFF-3.3	37.9 mb	38.5 mb
INDEN	35.7 mb	36.4 mb

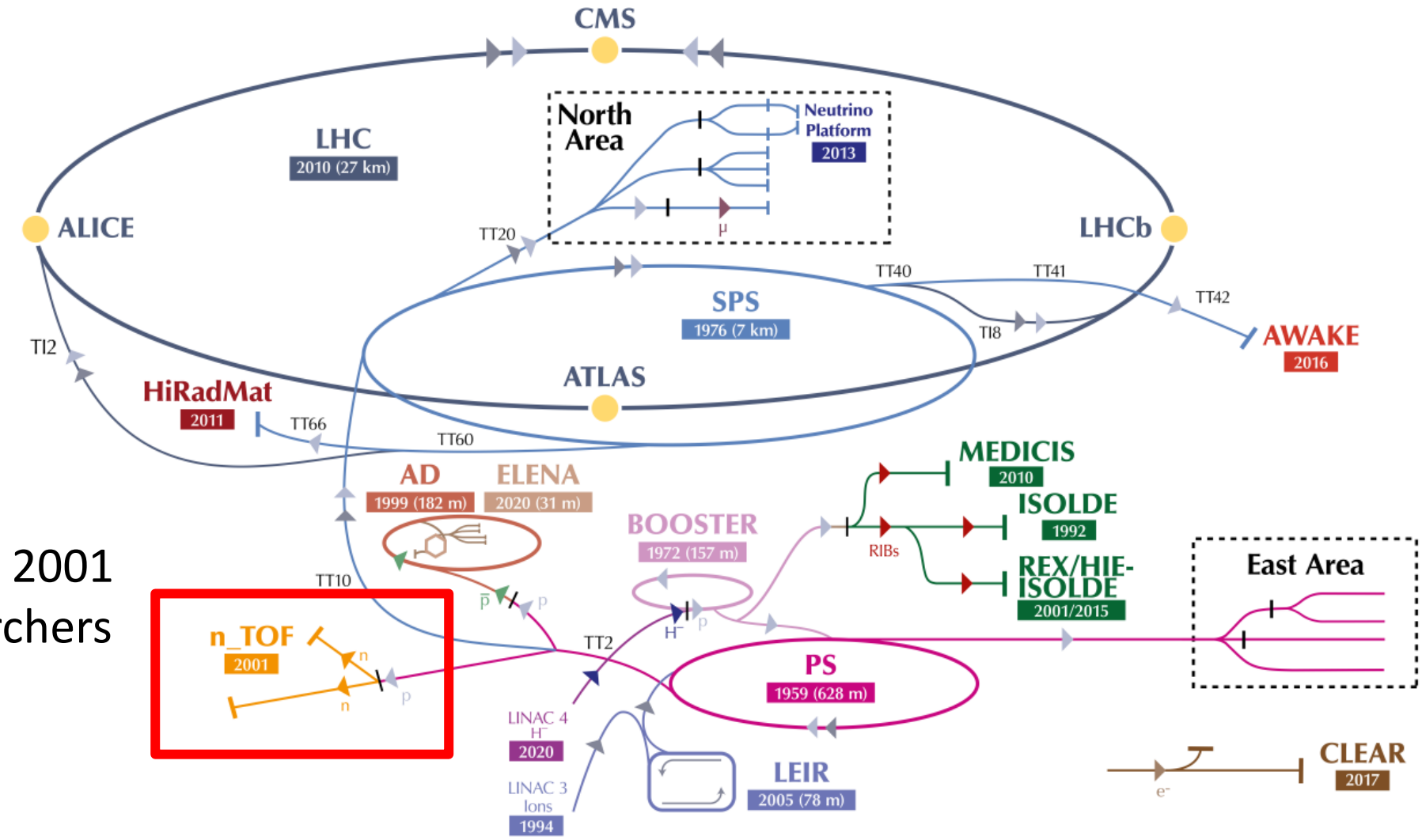
$MACS_{30}$ (^{50}Cr) = 37.1(20) mb → <6% unc.



P. Pérez-Maroto et al., "**Neutron activation as benchmark for cross section evaluations: Demonstration through the MACS of ^{50}Cr for nuclear technology applications**", *Physics Letters B*, 2025, vol. 862, p. 139360

III. ^{50,53}Cr time-of-flight measurement at EAR1-n_TOF@CERN

The neutron Time-Of-Flight facility at CERN



n_TOF@CERN

In operation since 2001

2026: ~150 researchers from 42 institutes

The neutron Time-Of-Flight facility at CERN

↑ Flux
↓E_n resolution

EAR-2
19 m

Access

Collimators

Access

EAR-1

185 m
↓Flux
↑E_n resolution

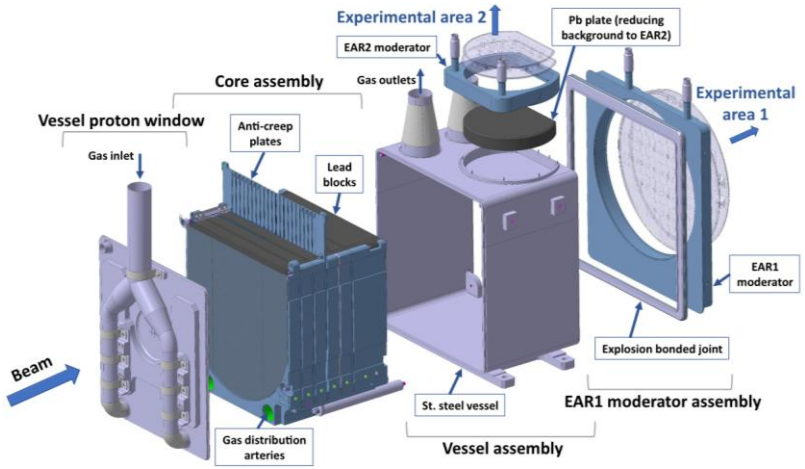
Sweeping magnets

Spallation target

Protons

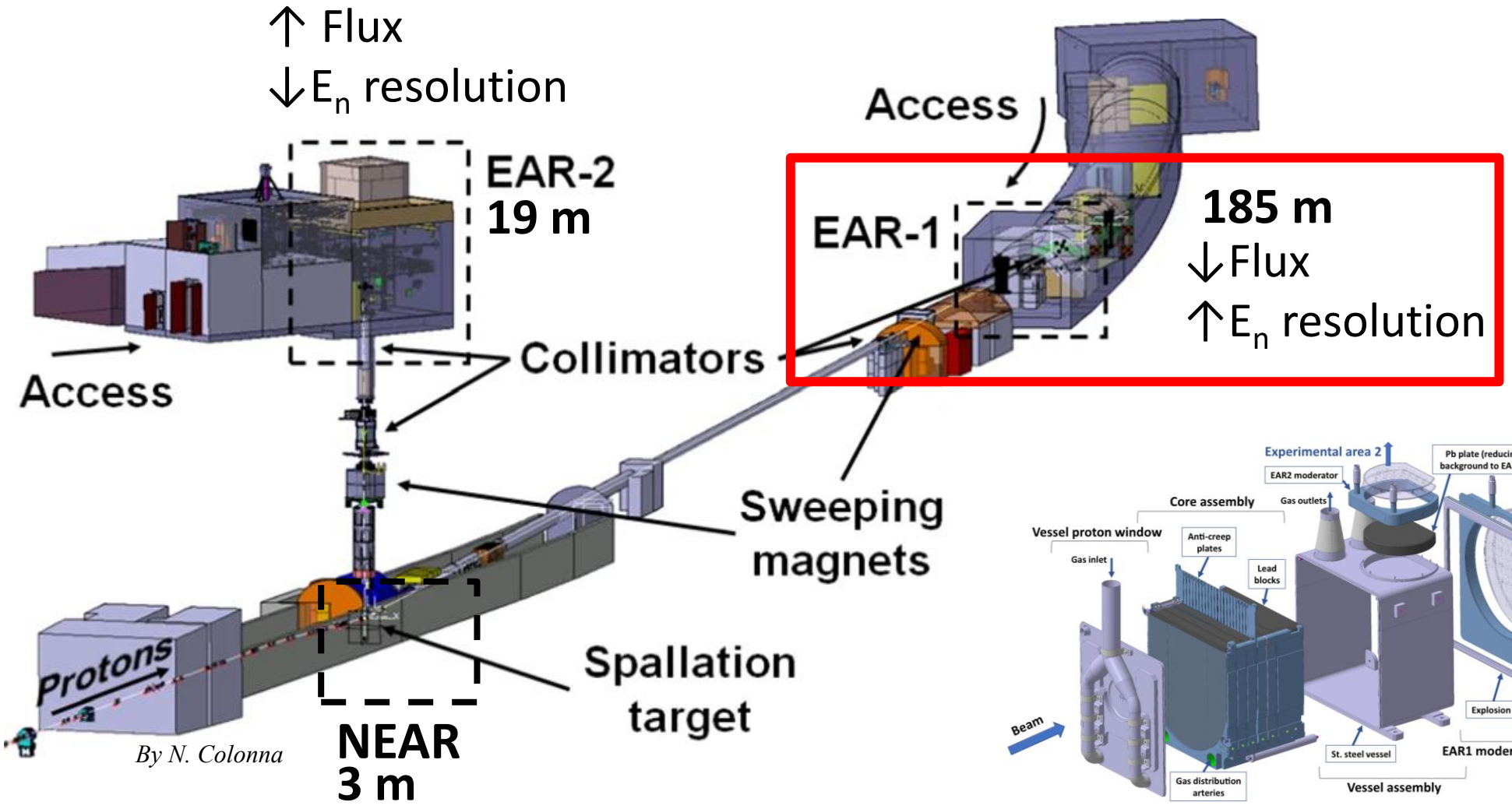
NEAR
3 m

By N. Colonna



https://ntof-exp.web.cern.ch

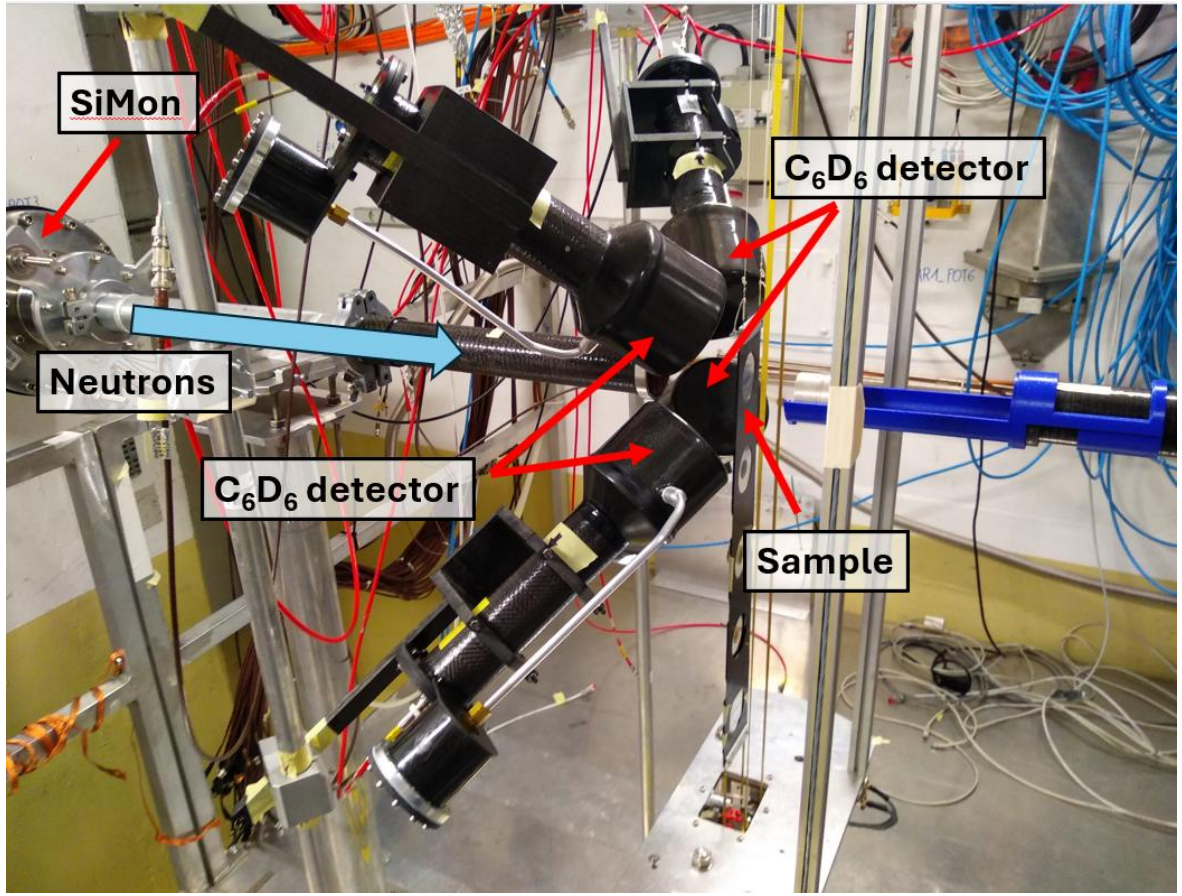
The neutron Time-Of-Flight facility at CERN



https://ntof-exp.web.cern.ch

Experimental set-up. C6D6 TED detectors

- 4 C_6D_6 TED detectors† at 8 cm and 125° from the sample.
- Developed specifically for n_TOF.
- Made of carbon fiber.
- Main advantages:
  - Very low neutron sensitivity
  - Very fast response and time resolution
- TED → Pulse Height Weighting Technique.

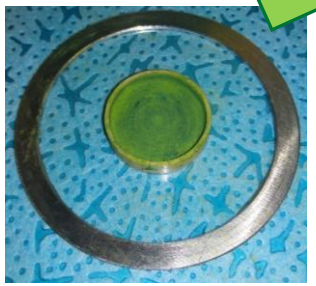


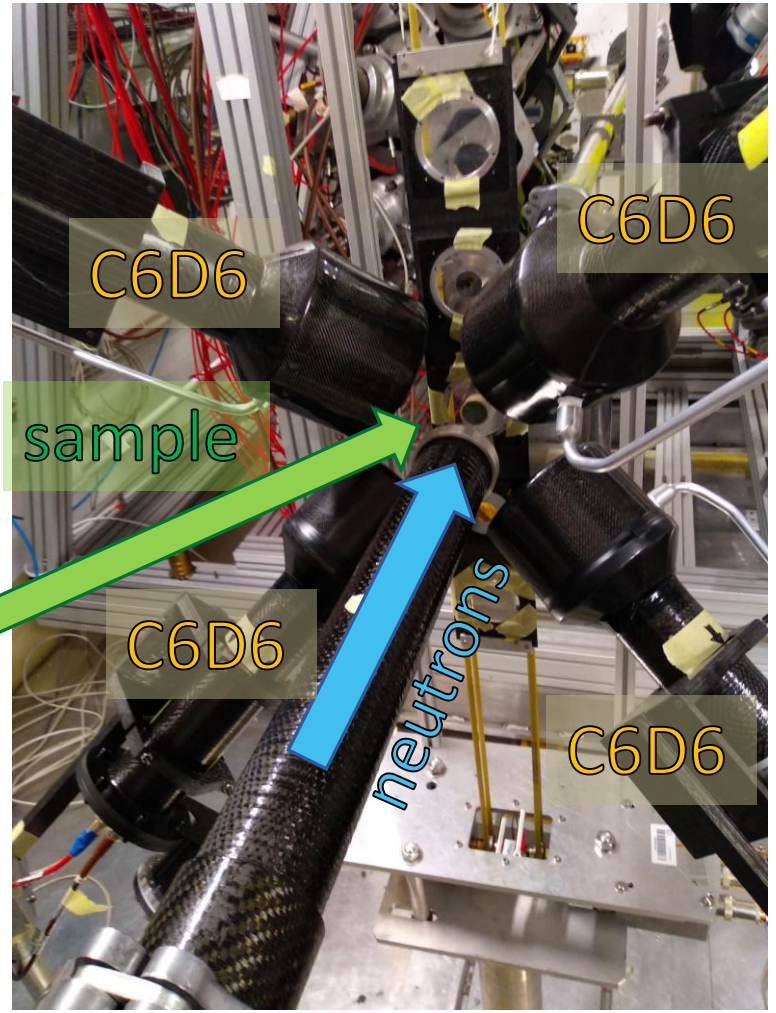
†R. Plag et al.,"*An optimized C_6D_6 detector for studies of resonance-dominated (n,γ) cross-sections*", Nucl. Inst. & Meth. in Phys. Res. A 496 (2003)

Experimental set-up. Samples

- The strategy is to use **two samples** for each isotope.
- 94.6(4)% of ^{50}Cr and 97.7(2)% of ^{53}Cr.

Experiment	Stieglitz (1971)	Beer (1975)	Kenny (1977)	Brusegan (1986)	Guber (2011)	**This work (2024)**
Thickness ^{50}Cr (10^{-3} at/barns)	8	18	5/8	7	-	**0.6/1.9** → x0.1
Thickness ^{53}Cr (10^{-3} at/barns)	14	14	8/12	12/60	14	**1.2/5.9** → x0.1





- Thin samples (1-10 keV) → MS effects under control
- Thick samples (10-100 keV) → Better statistics

Thinnest samples ever measured

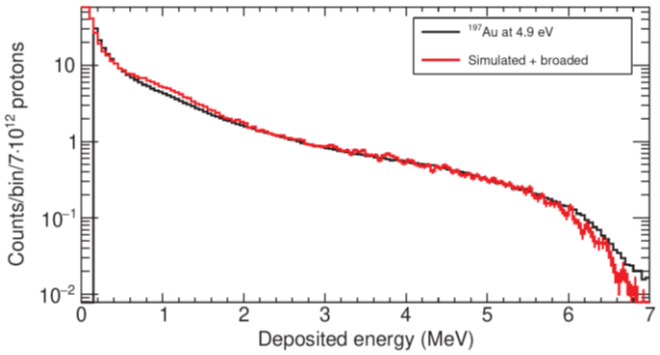
Plus ancillary samples… →

42 days long campaign
$750 \cdot 10^3$ protons pulses

Capture yield determination

$$Y(E_n) = F_{corr}\frac{C_w(E_n) - B_w(E_n)}{F_{BIF}\cdot\varepsilon_c\cdot\Phi(E_n)}$$

Capture yield determination

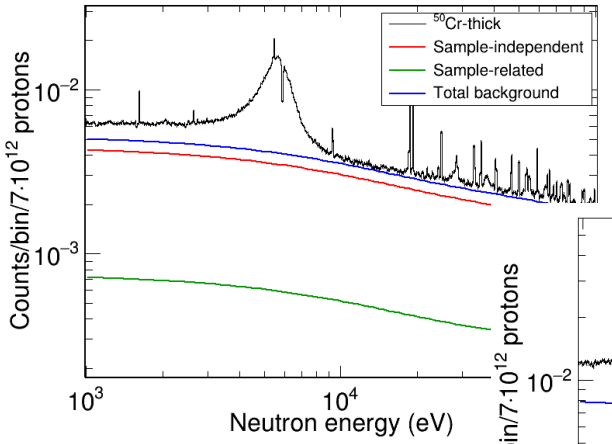


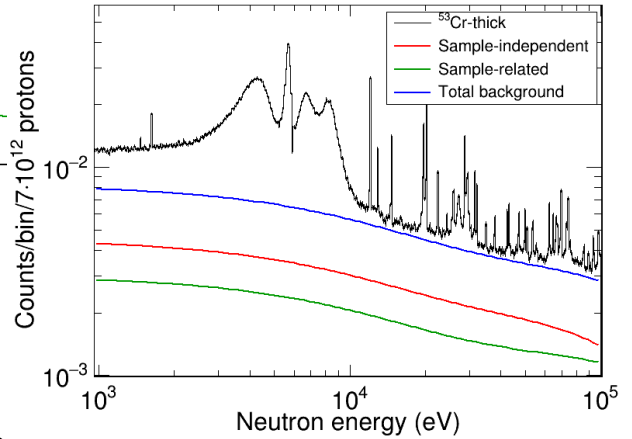
E_{thr} = 150 keV

Total weighted counts

Threshold correction factor

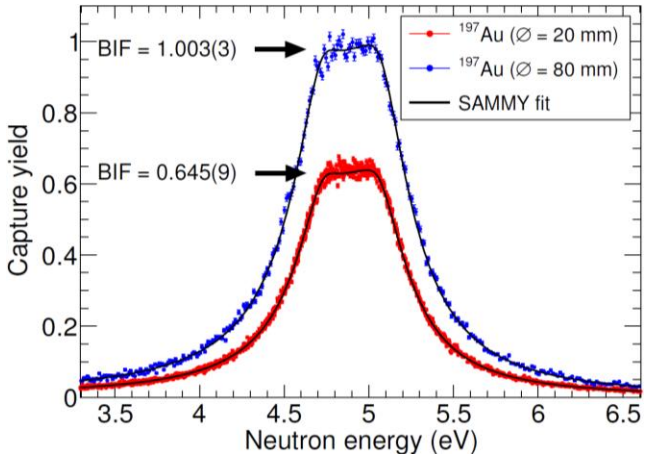
$$Y(E_n) = F_{corr} \frac{C_w(E_n) - B_w(E_n)}{F_{BIF} \cdot \varepsilon_c \cdot \Phi(E_n)}$$



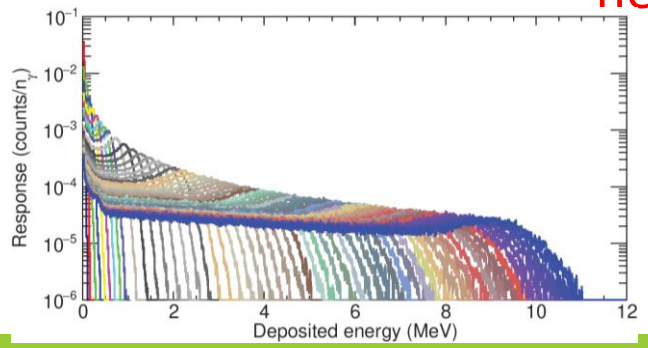


Background weighted counts

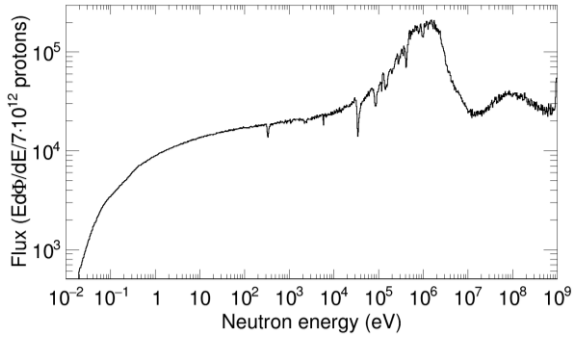
Beam Interception Factor (SRM)



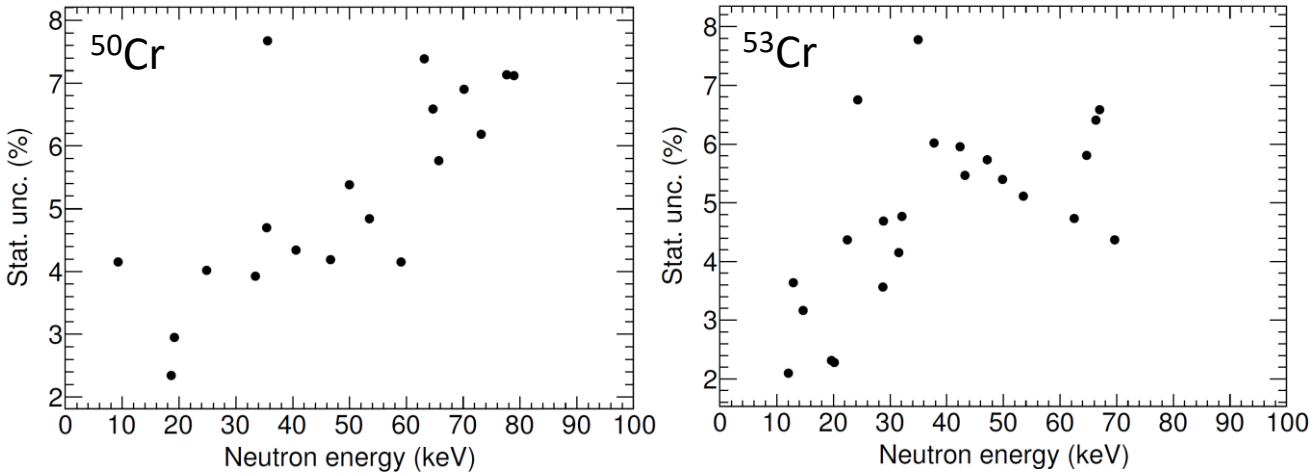
Efficiency (PHWT)



Evaluated neutron flux



Capture yield systematic uncertainties

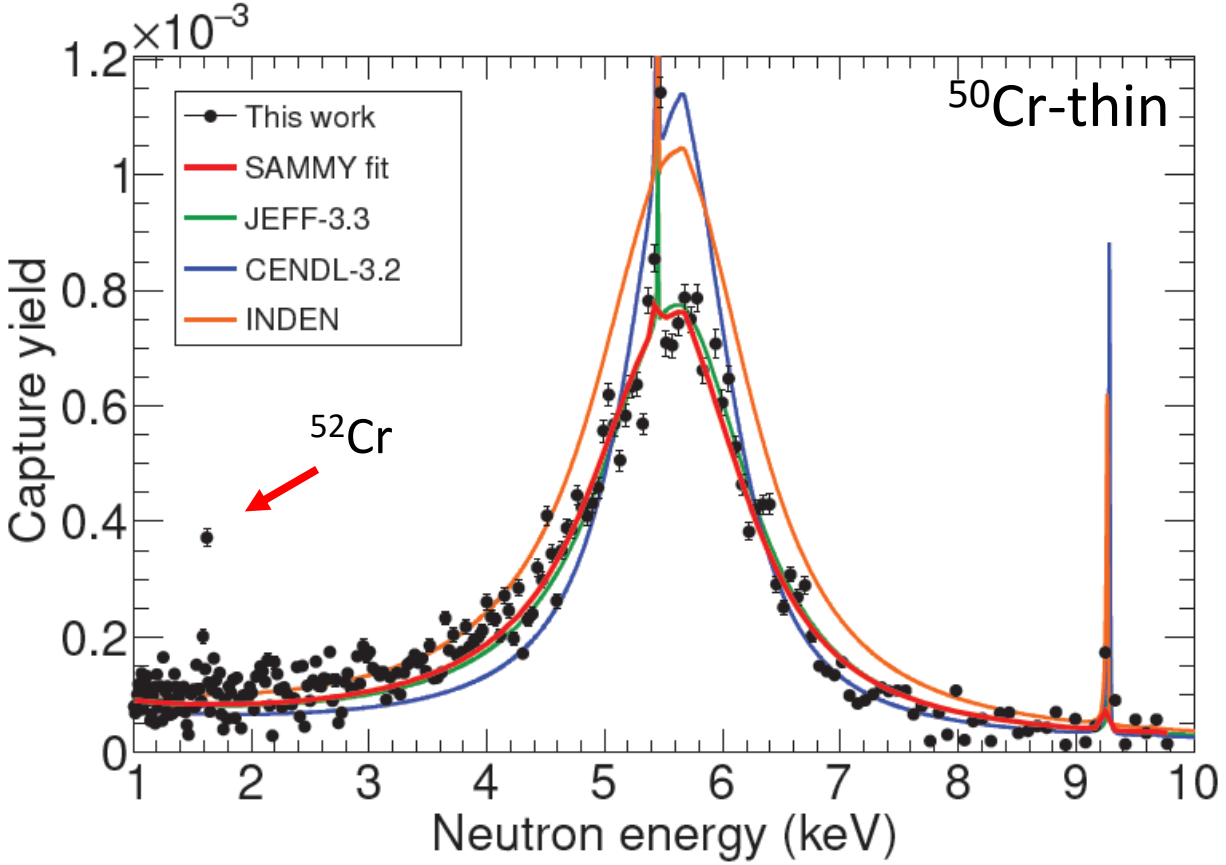


- A new methodology to apply the PHWT was implemented, which adds a source of uncertainty associated to the resonance total counts.
- In overall, the uncertainty remains below 9%, thus **fulfilling the NEA requirements**.

Contribution	Syst. Unc. (%)	
	^{50}Cr	^{53}Cr
Sample thickness	0.4	0.2
Monitor norm.	2.5	2.5
Neutron flux shape	2	2
Saturated res. norm.	1.5	1.5
Sample alignment	2	2
PHWT implementation	1.7	1.7
Cr cascades ⊗ f_{thr}	1	1
RWF ⊗ statistics	2.3 - 7.7	2.1 - 7.8
Overall (1-10 keV)	**4.5**	**4.5**
Overall (10-100 keV)	**5.1 - 9.0**	**5.0 - 9.0**

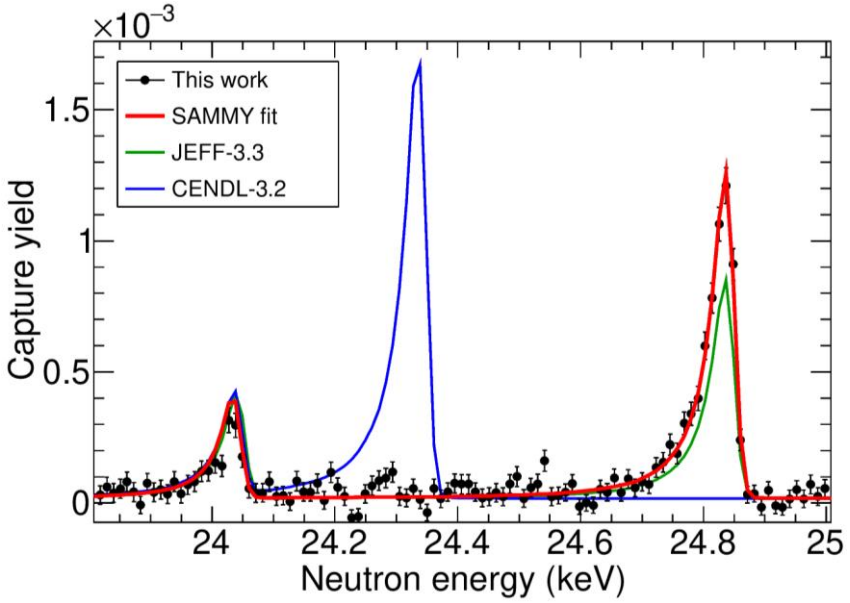
Resonance analysis with SAMMY (^{50}Cr)

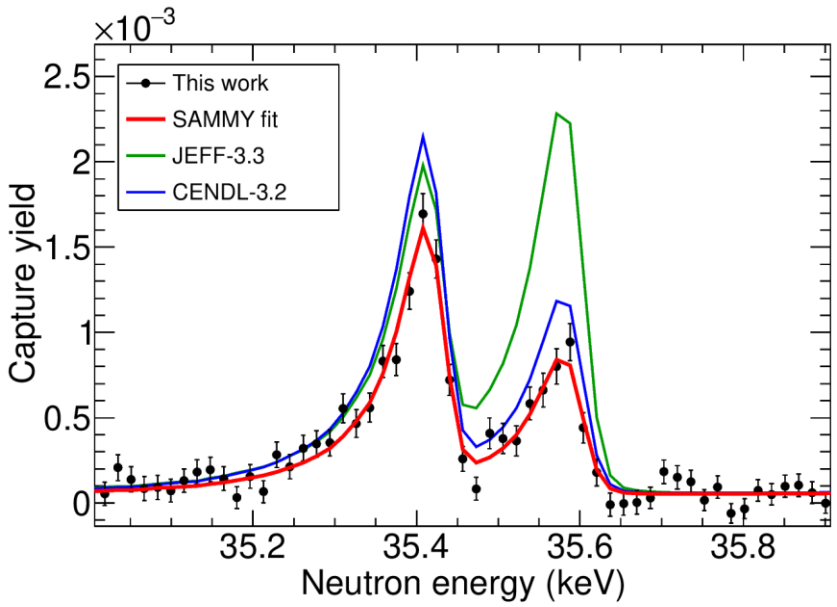
- Main resonance → in agreement with JEFF-3.3 (even K_γ also similar to CENDL-3.2).
- Overestimation by INDEN.
- Previous energy shifted: from $E_n = 5.621$ keV to $E_n = 5.581(6)$ keV → Multiple-scattering effects

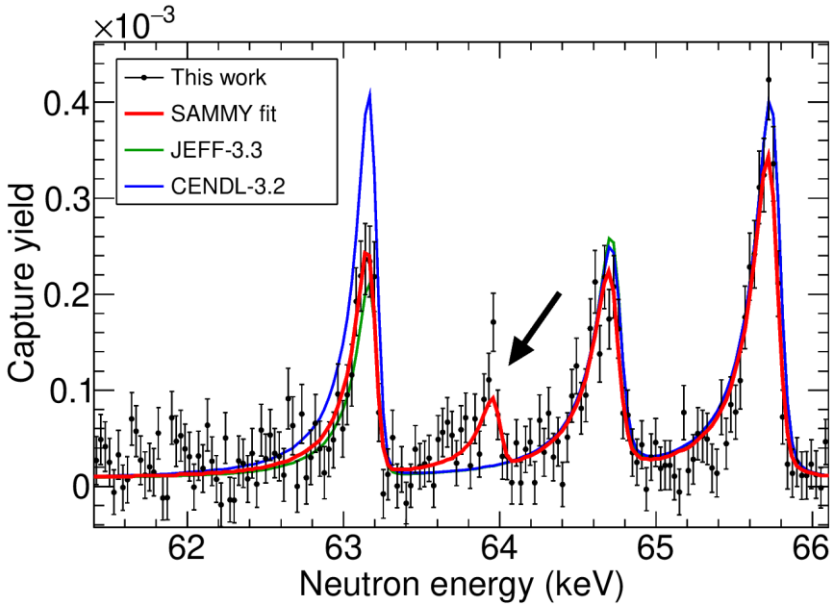


Resonance analysis with SAMMY (^{50}Cr)

- For $E_n > 10$ keV, INDEN adopts the same parameters than JEFF-3.3
- 33 resonances described.
- 3 of them removed from JEFF-3.2, but visible in our data (for example at 64 keV).

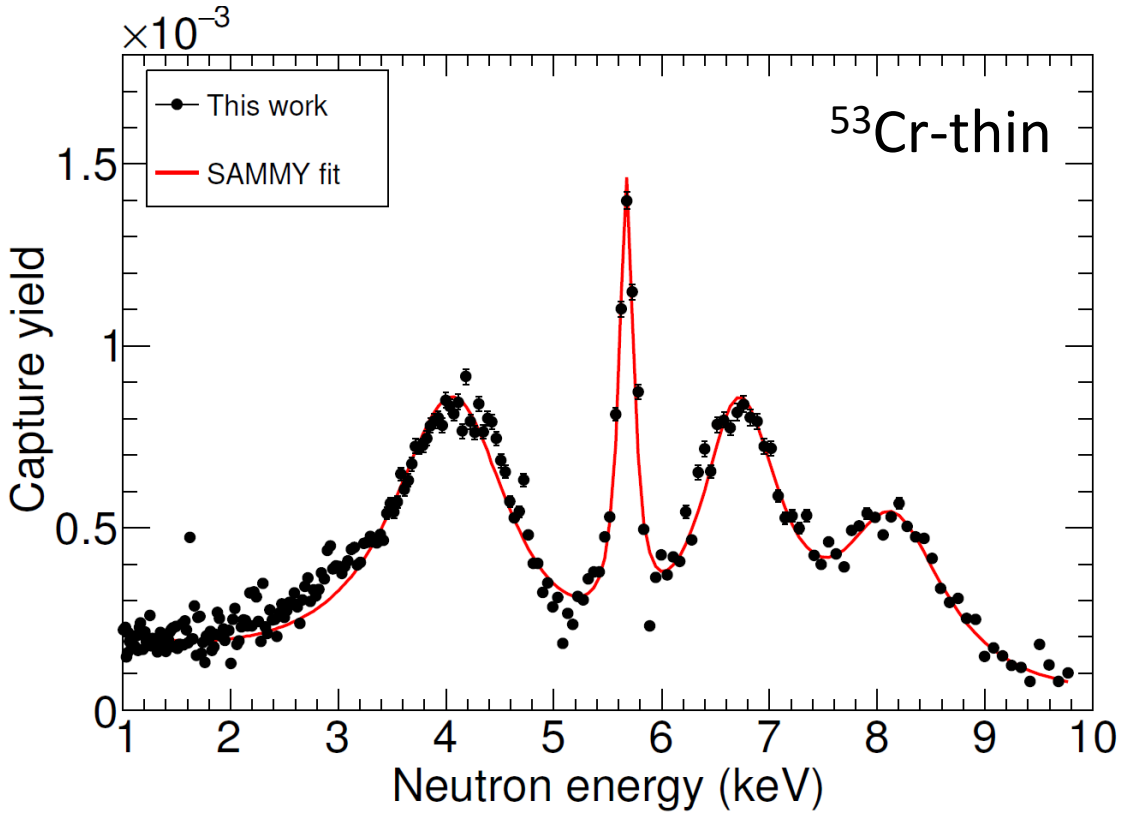


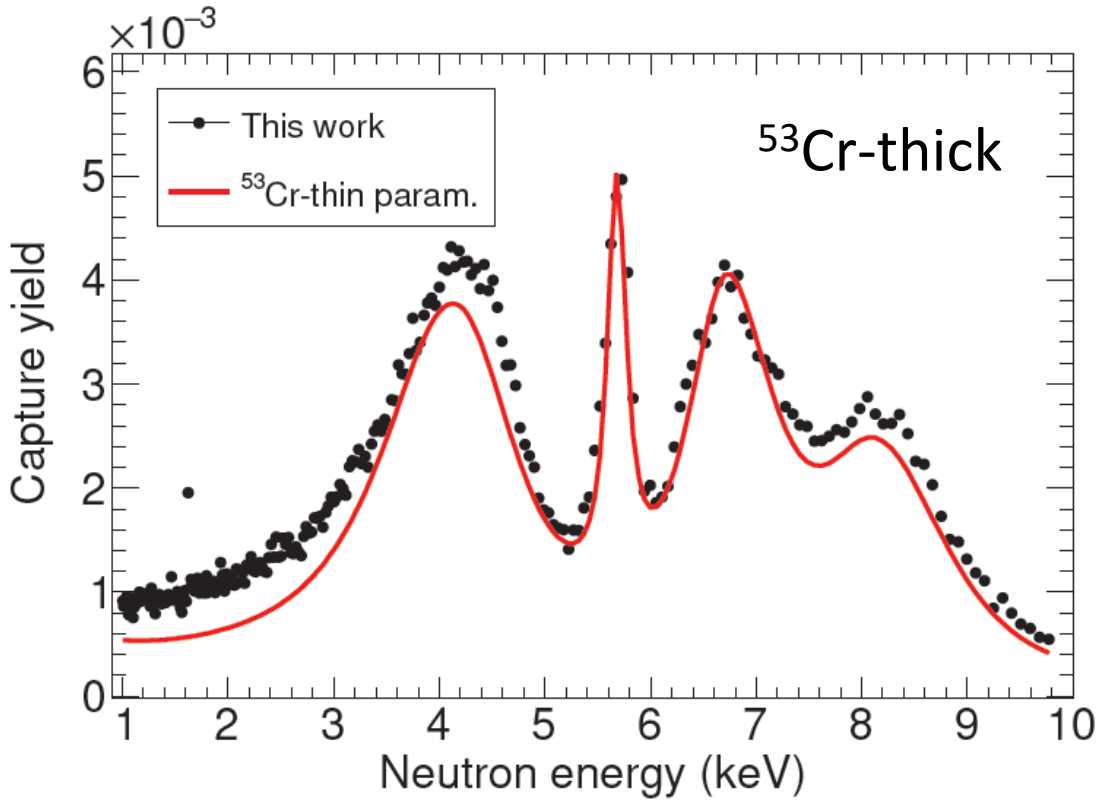




Resonance analysis with SAMMY (^{53}Cr)

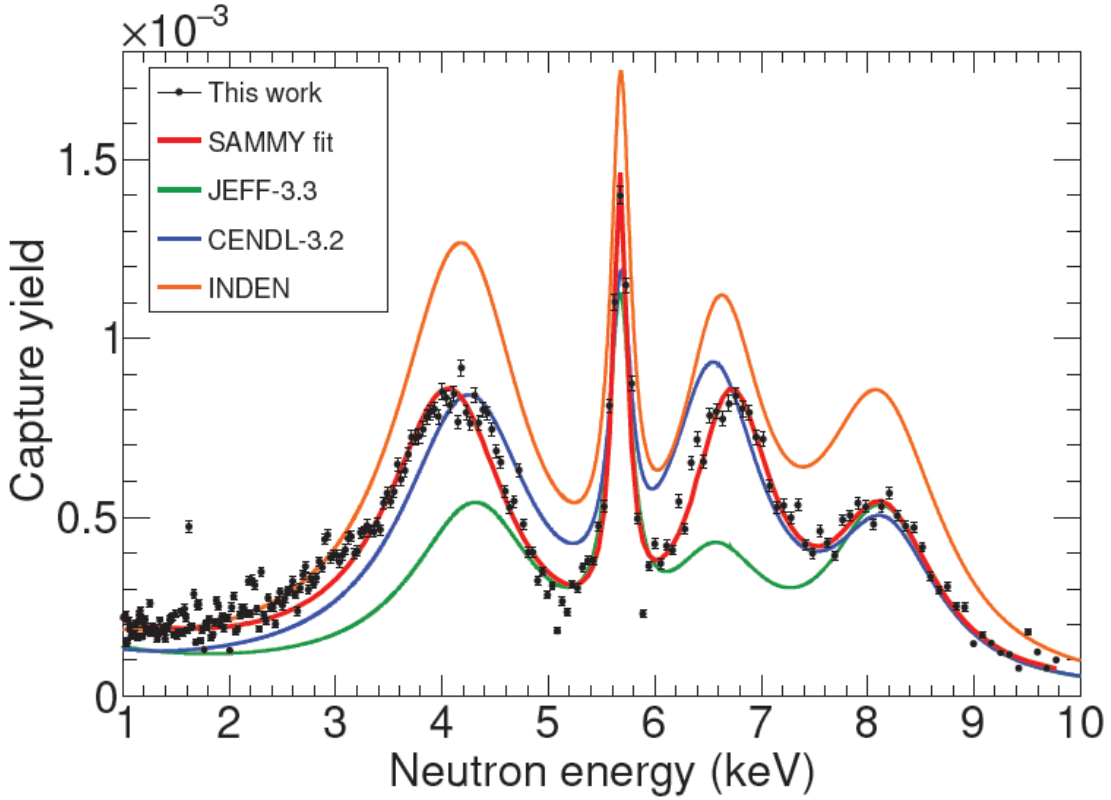
- The MS effects are very large → ~7mm thickness.
- SAMMY fails to accurate evaluate the very strong MS effects.





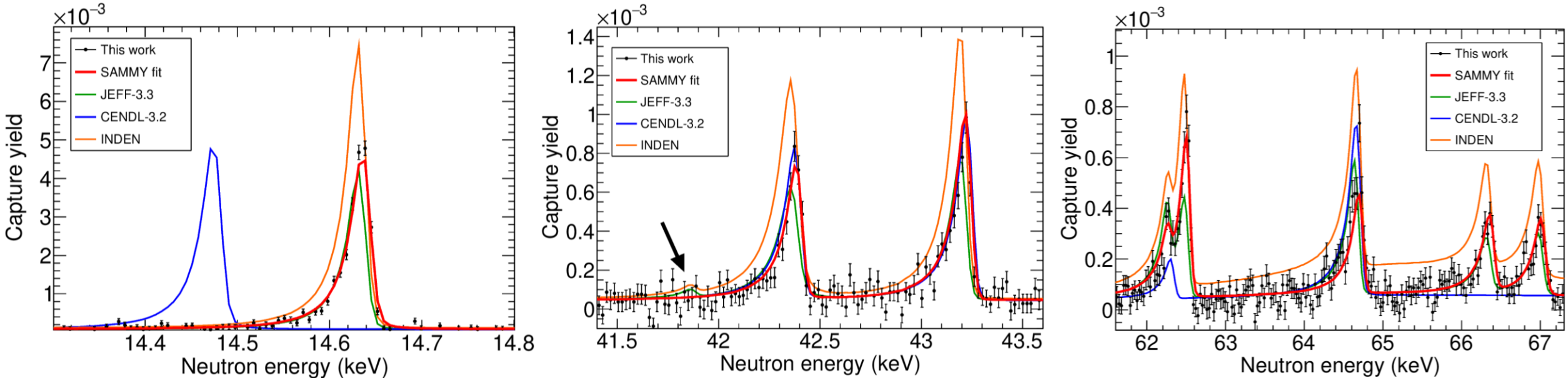
Resonance analysis with SAMMY (^{53}Cr)

- The MS effects are very large → ~7mm thickness.
- SAMMY fails to accurate evaluate the very strong MS effects.
- Our data is much closer to CENDL-3.2 (still with differences).



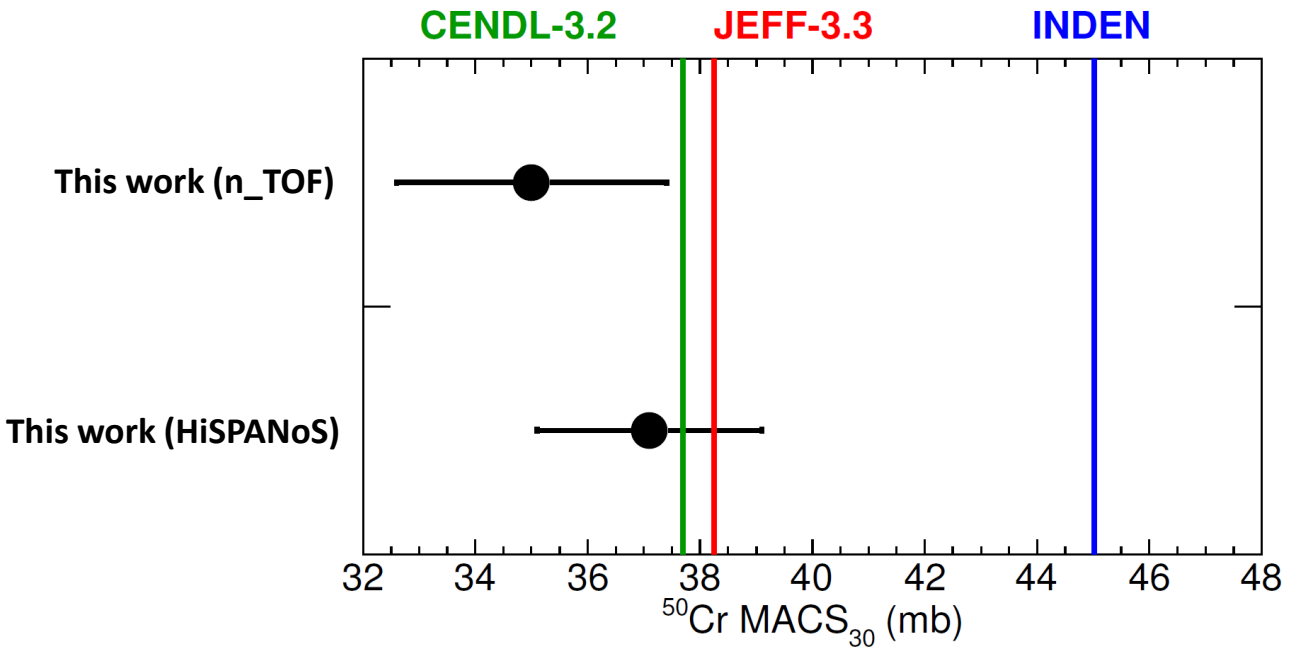
Resonance analysis with SAMMY (^{53}Cr)

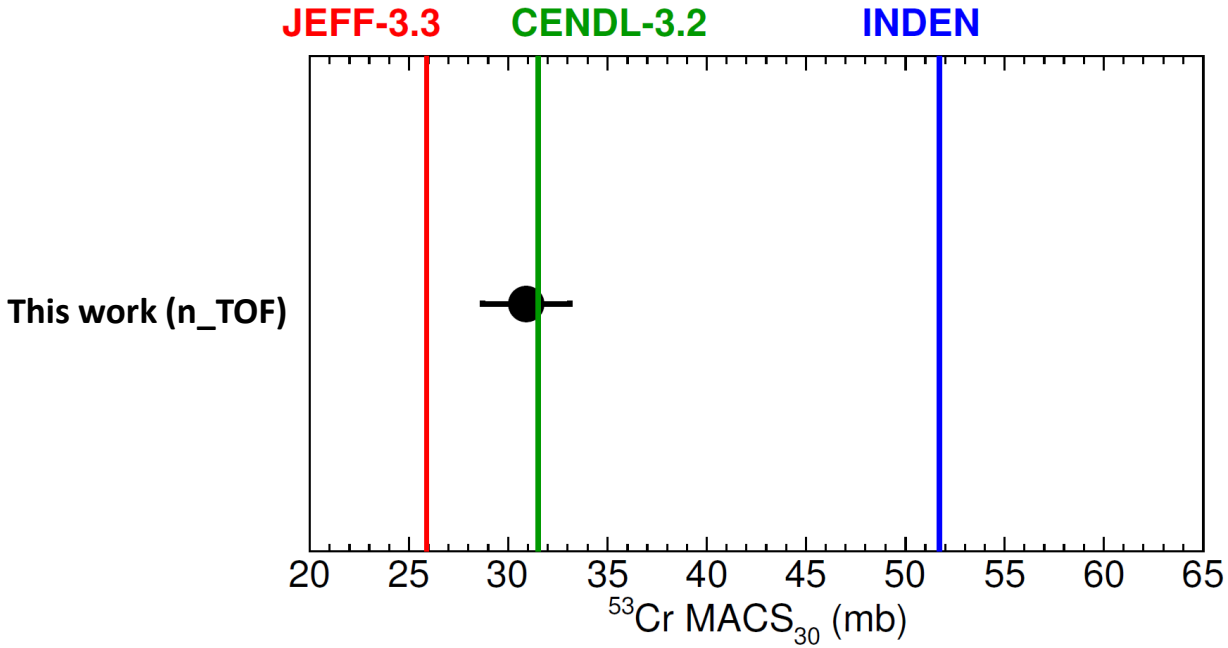
- More differences between evaluations than in ^{50}Cr.
- A total of 51 resonances have been described.
- Some of them (included in JEFF-3.3 and INDEN) are not visible in our data.
- In general, INDEN seems to overestimate the capture cross section.



^{50,53}Cr(n,γ) at EAR1 results

MACS$_{30}$ extracted from n_TOF (E_n<100 keV) + evaluations above 100 keV.





- Results for ^{50}Cr and ^{53}Cr are 20% and 70% lower than INDEN, respectively.
- ^{50}Cr → MACS$_{30}$ from HiSPANoS and n_TOF are compatible within uncertainty.

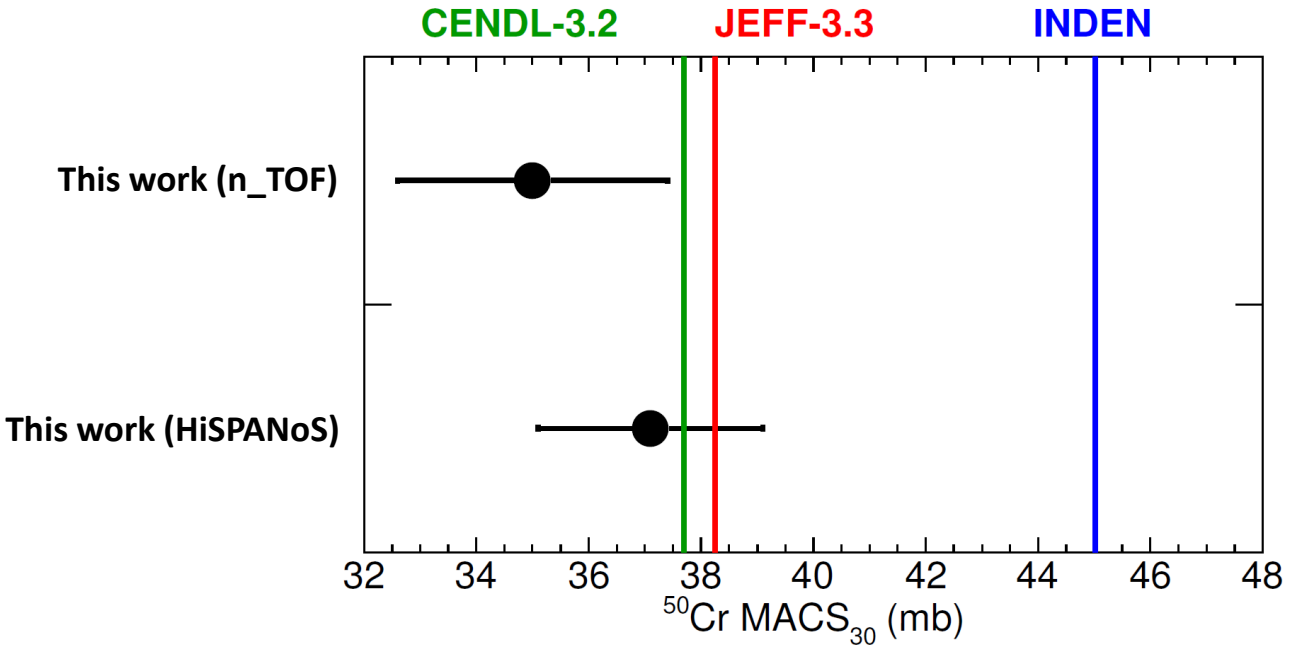
P. Pérez-Maroto et al., "**New measurement ^{50}Cr and ^{53}Cr (n,γ) cross sections at n_TOF: a call for chromium nuclear data revision** ", *The European Physical Journal A, 2026, vol. 62(1), p. 5*

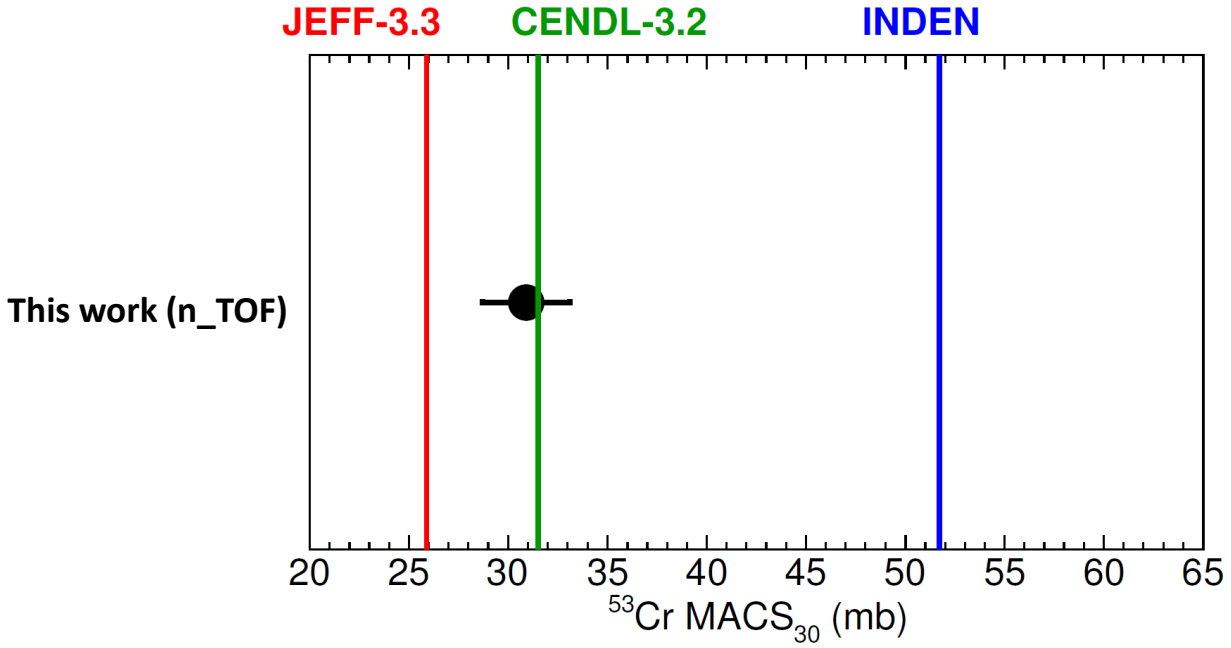
IV. Summary & Conclusions

Summary & Conclusions

- A clear goal: improving the ^{50,53}Cr(n,γ) cross section to 8-10% accuracy at 1-100 keV.
- Two experiments:
  - ^{50}Cr activation at HiSPANoS@CNA.
  - ^{50,53}Cr ToF at n_TOF@CERN.

- Uncertainties within the objective.
- Both cross sections clearly lower than INDEN.
- Both experiments are compatible.





WONDER 2026

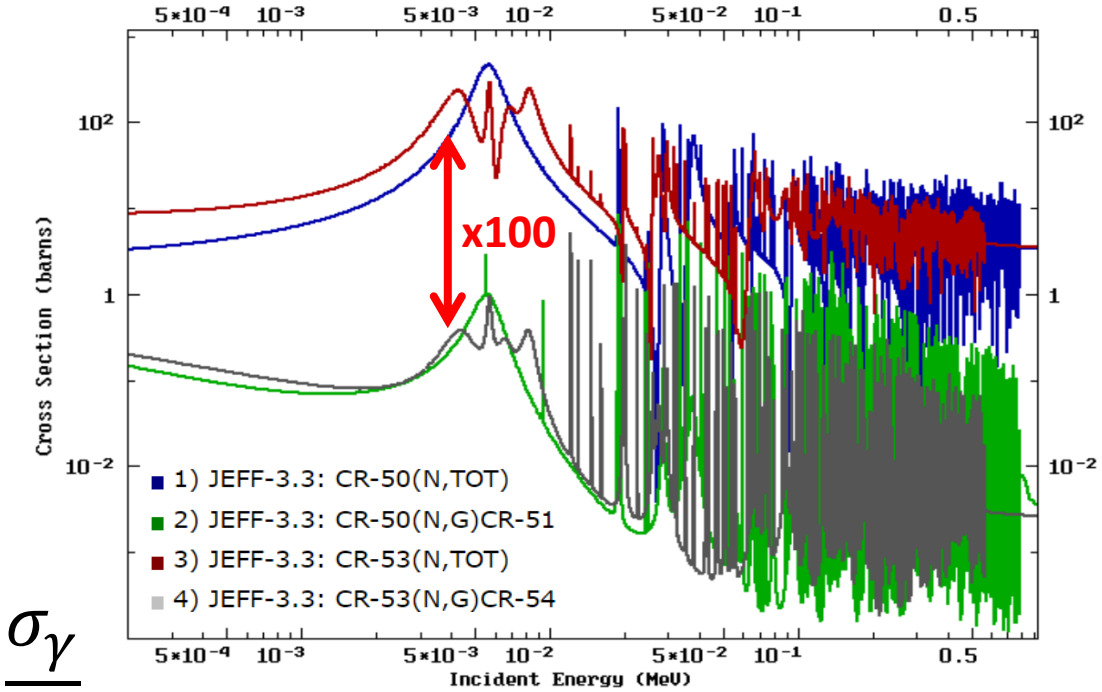
Thank you for your attention

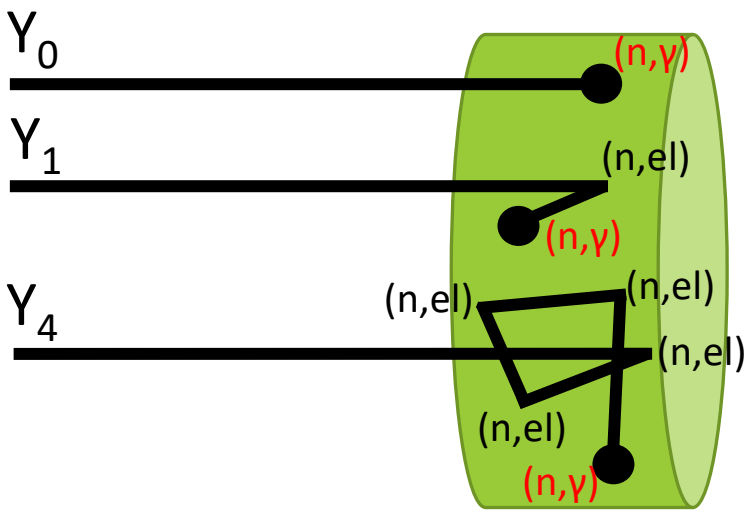
Pablo Pérez Maroto - pperezma@cern.ch

Acknowledgements: Euroatom research and training programme 2014-2018 under grant agreement No 847594 (ARIEL). Spanish national projects RTI2018-098117-B-C21, PID2019-104714GB-C22, PID2021-123879OB-C21 and PID2022-138297NB-C22 funded by MCIN/AEI/10.13039/501100011033 and by "ERDF A way of making Europe". FPI national Grant No PRE2019-089678. Recovery & Resilience Facility (Spain). The European Union – NextGenerationEU.

Backup. Why the discrepancies?

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



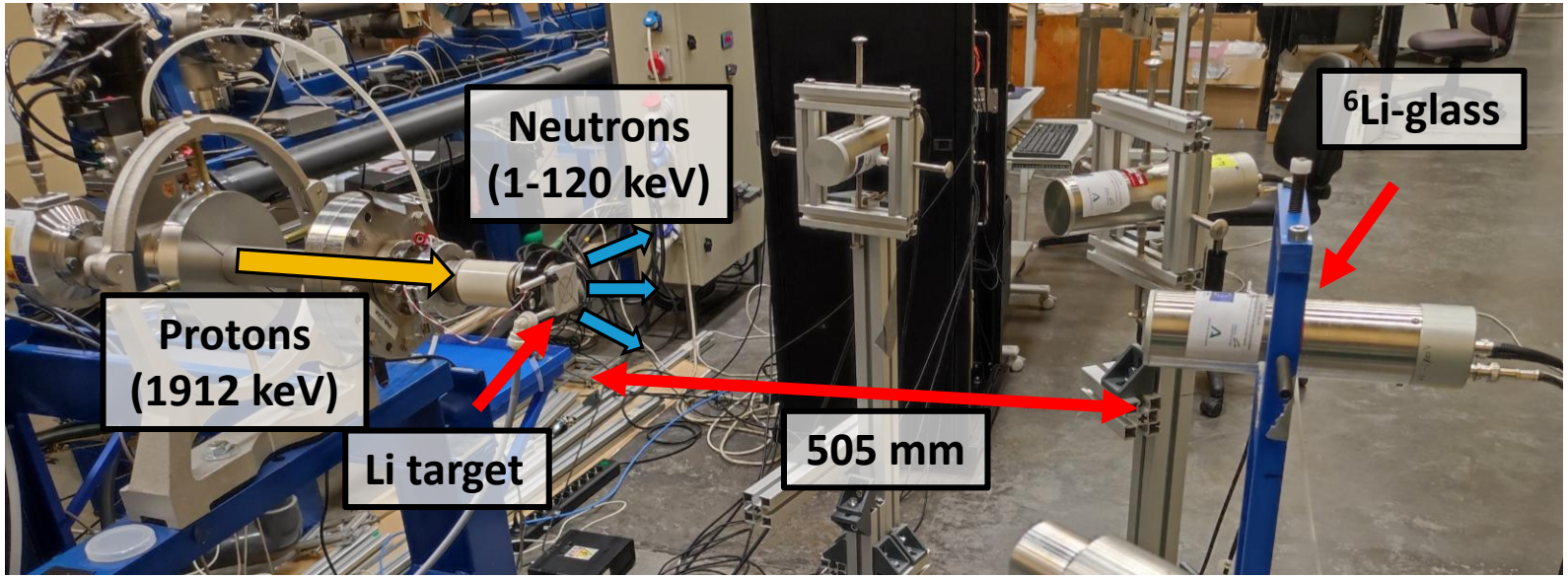


$$Y_0 = (1 - e^{n\sigma_t})\frac{\sigma_\gamma}{\sigma_t}$$

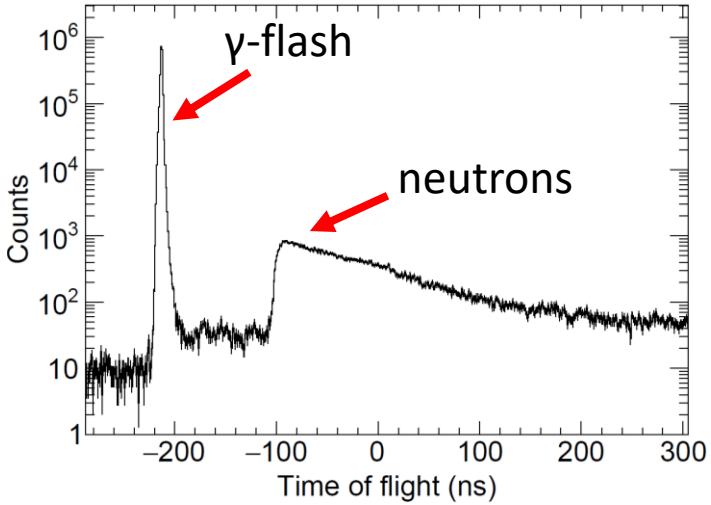
Capture yield (captures/neutron) $\rightarrow Y = \underbrace{Y_0 + Y_1}_{\text{Analytical (accurate)}} \underbrace{+ Y_2 + Y_3 \ldots}_{\text{Numerical (aproximate)}}$

Backup. MB spectrum: ToF characterization

A 30 keV quasi-Maxwellian spectrum can be produced by ^{7}Li(p,n) with E_p=1912 keV†.



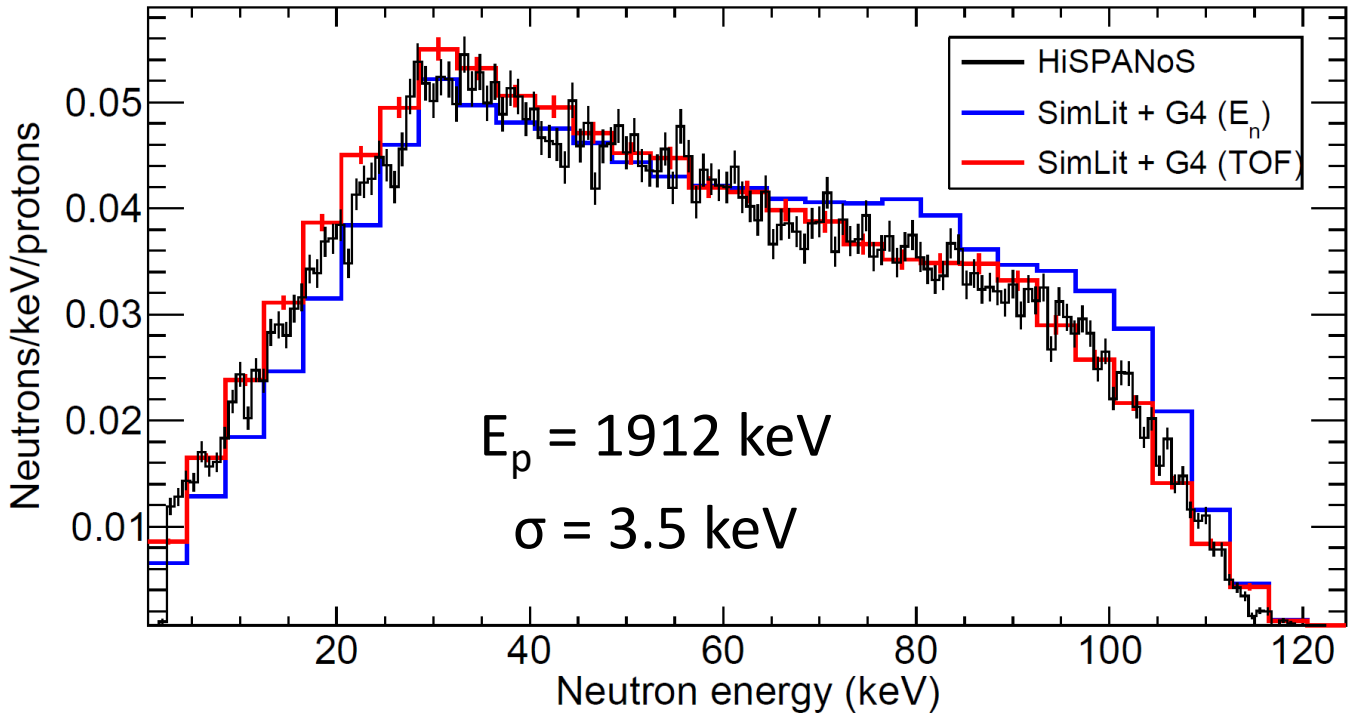
Li-glass detectors → based on the ^{6}Li(n,α)^{3}H reaction



†W. Ratynski & F. Käppeler, "*Neutron capture cross section of ^{197}Au: A standard for stellar nucleosynthesis*", Physical Review C 37(2) (1988)

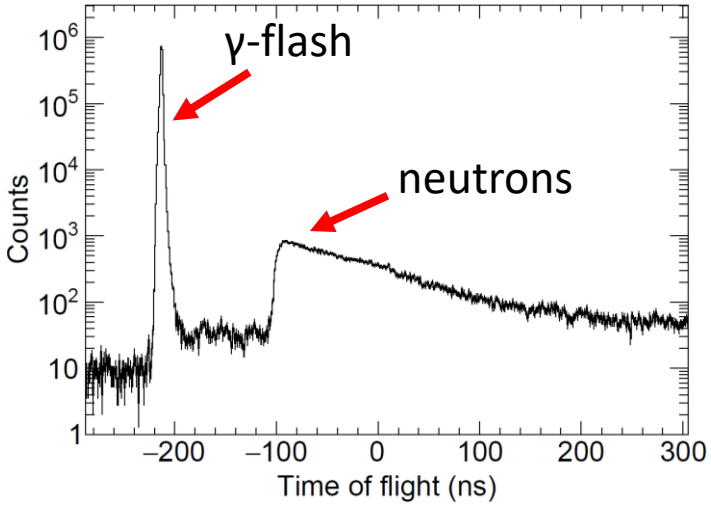
Backup. MB spectrum: ToF characterization

The neutron field was characterized by time-of-flight + simulations.



$$E_n = \frac{K^2 L^2}{t^2}$$

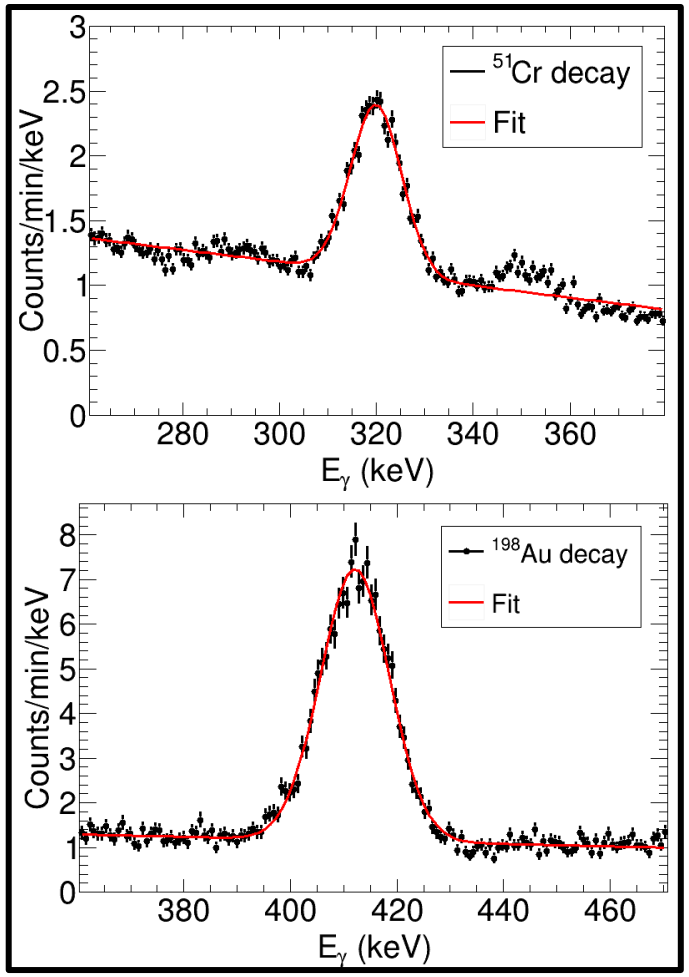
Li-glass detectors → based on the $^6Li(n,\alpha)^3H$ reaction



- SimLiT → Neutron production
- GEANT4 → Neutron transport

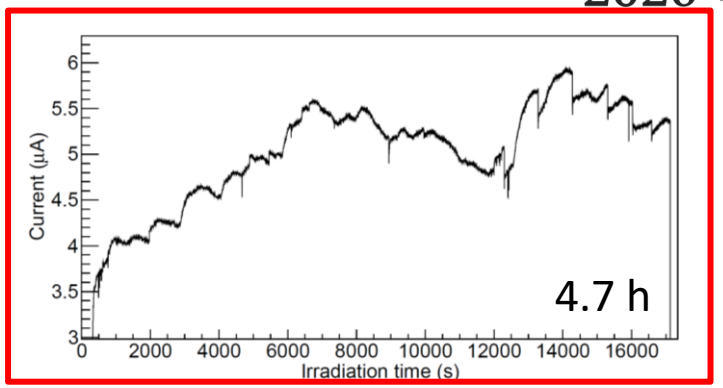
} The neutron field was characterized by time-of-flight + simulations.

Backup. Neutron activation analysis



Counts → Gaussian + linear fit

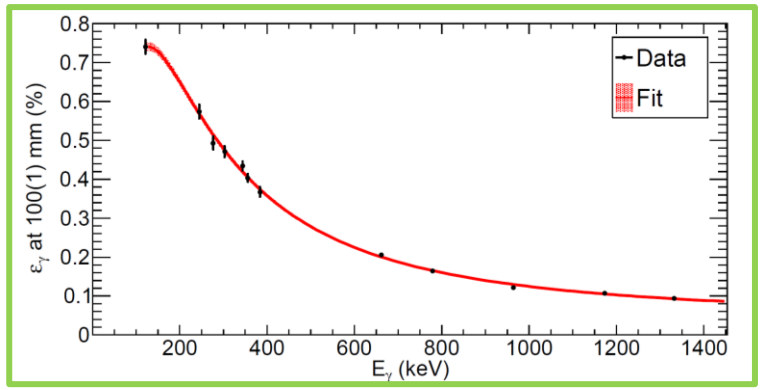
$$N_{act} = \frac{A_{EOI}}{\lambda} = \frac{C \cdot e^{\lambda t_{wait}} \cdot f_{irr}}{I_\gamma \cdot \varepsilon \cdot (1 - e^{-\lambda t_{meas}})}$$

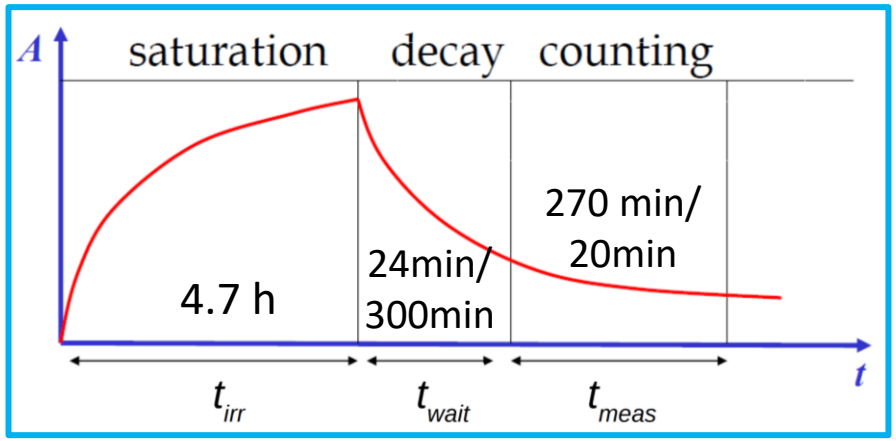


Decay during irradiation → current measurement

Decay during transport and measurement

Efficiency





Backup. Ancillary samples

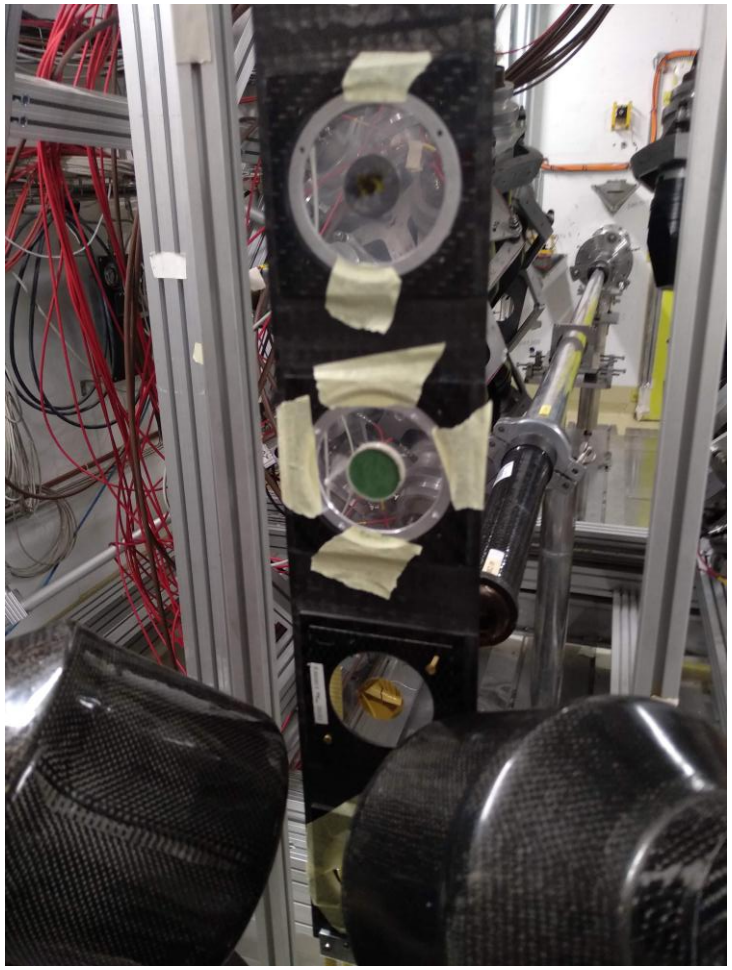
Some ancillary measurements were performed during the experimental campaign

- Dummy (empty PEEK capsule)
- Empty (empty aluminum ring)
- 1 mm ^{nat}C (neutron-scattering)

→ Background

- 100 µm ^{197}Au (two diameters) → Normalization

Sample	Diameter (mm)	n_{at} (10^{-3}at/b)
Dummy (2)	22	-
^{197}Au	20	0.583
^{197}Au	80	0.644
^{nat}C	20	8.702

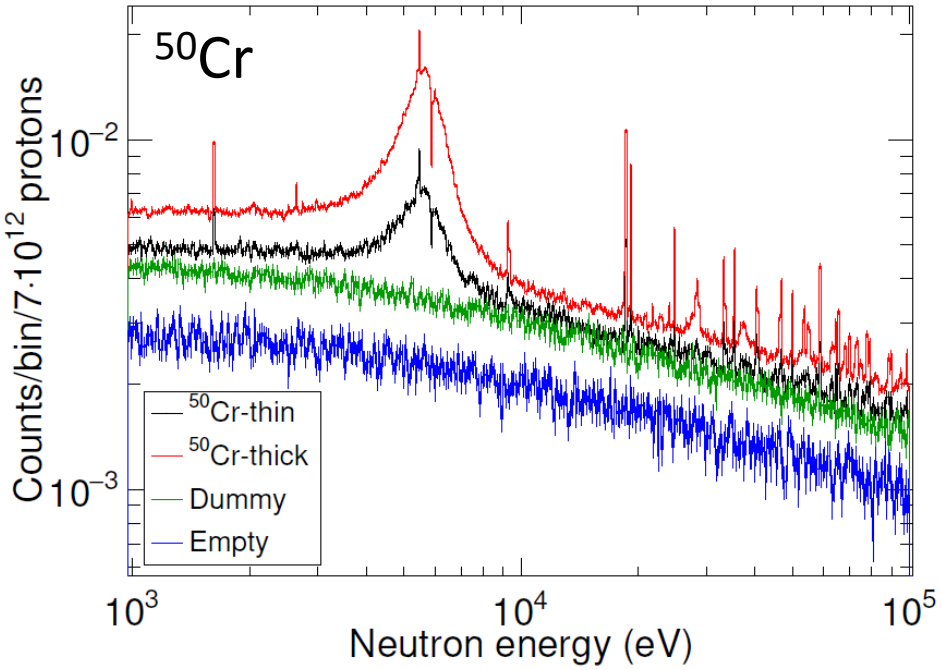


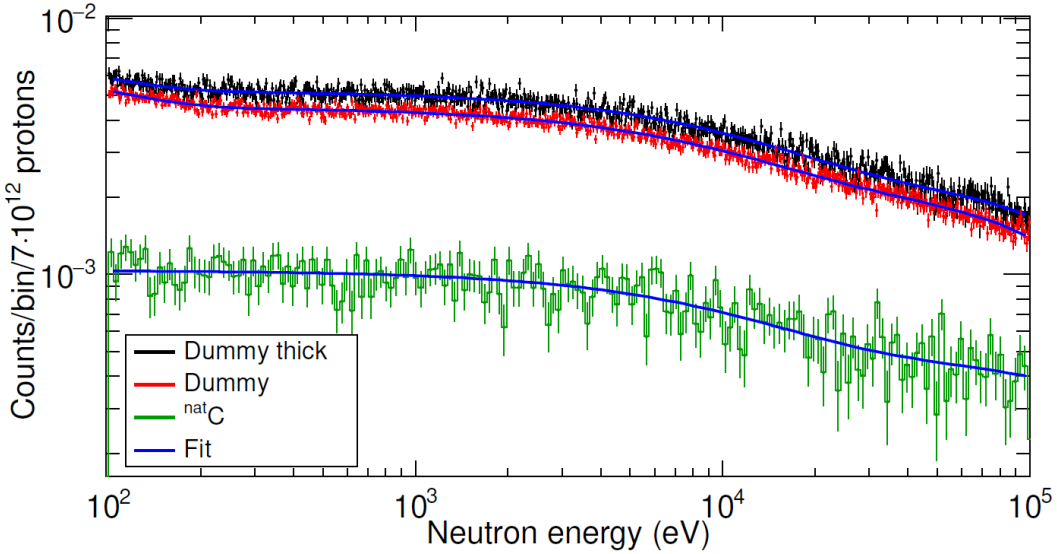
Backup. Background determination

The background affecting the measurement can be divided in:

- Sample independent → Neutron-scattering and capture outside the sample: Dummy & Empty
- Sample related → Neutron-scattering **inside the sample**: ^{nat}C

$$F_n = \left\langle \frac{\sigma_{\mathrm{el},Cr}}{\sigma_{\mathrm{el},C}} \right\rangle \frac{n_{\mathrm{at},Cr}}{n_{\mathrm{at},C}}$$

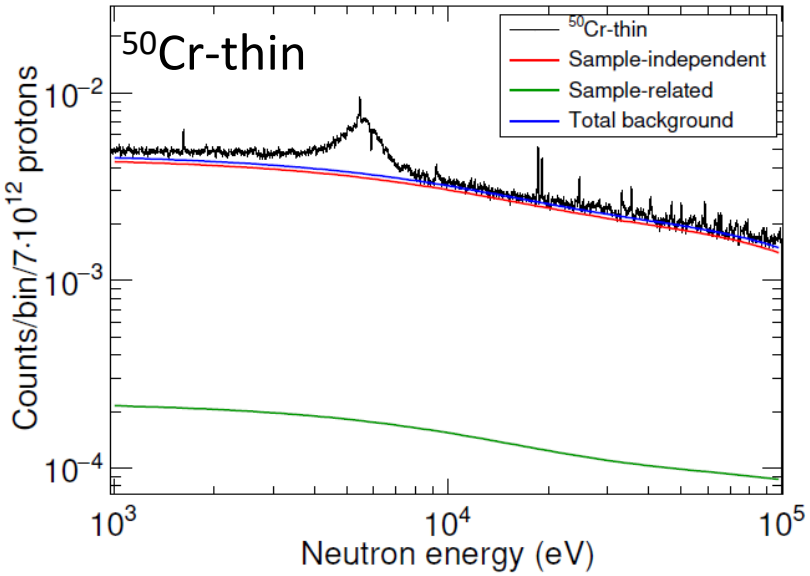


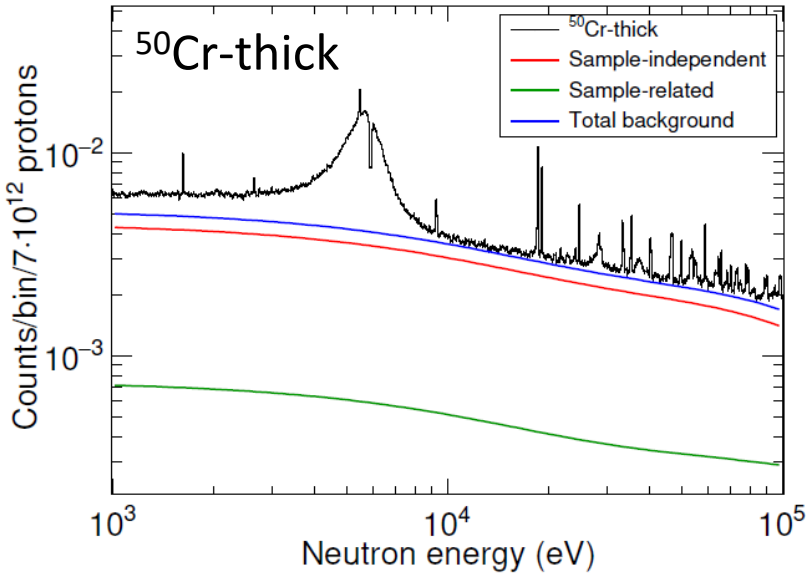


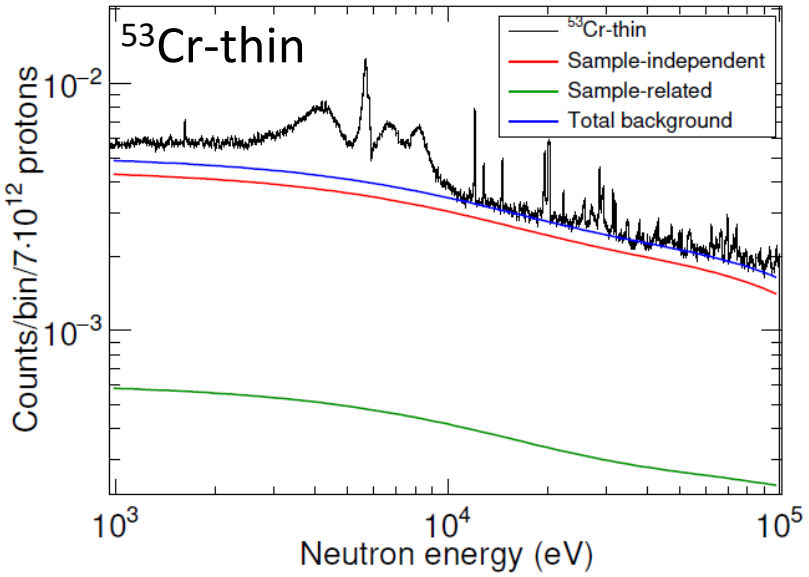
Sample	F_n
^{50}Cr-thin	0.25
^{50}Cr-thick	0.72
^{53}Cr-thin	0.59
^{53}Cr-thick	2.91

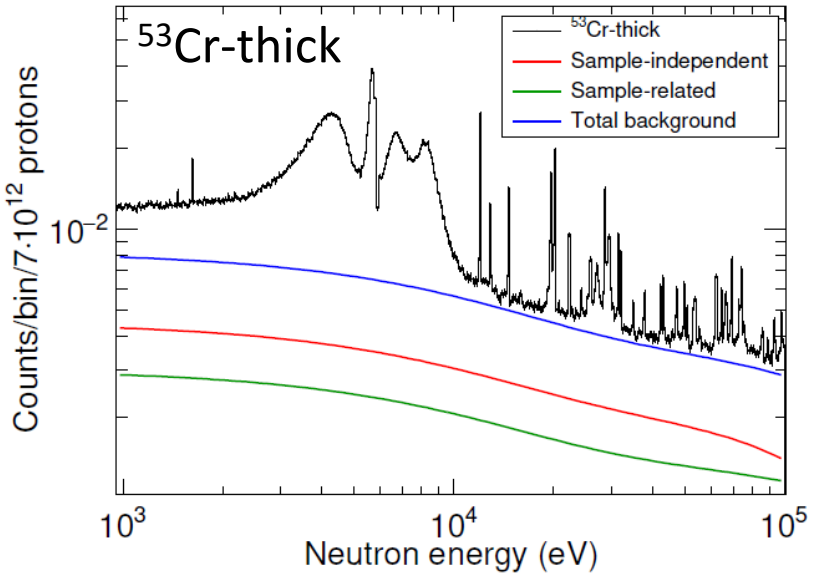
$$B(E_n) = a_0 + \sum_{i=1}^{k} b_i \left(1 - e^{-c_i E_n}\right) e^{-d_i E_n}$$

Backup. Background determination









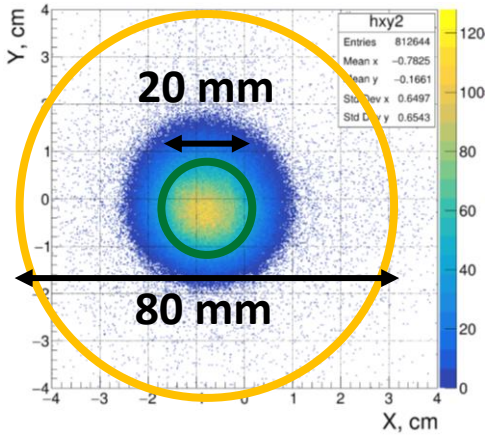
- Some background is still visible below the main resonance in the thick samples → Region not used.
- The residual background is included in the yield analysis.

Backup. Capture yield normalization: SRM

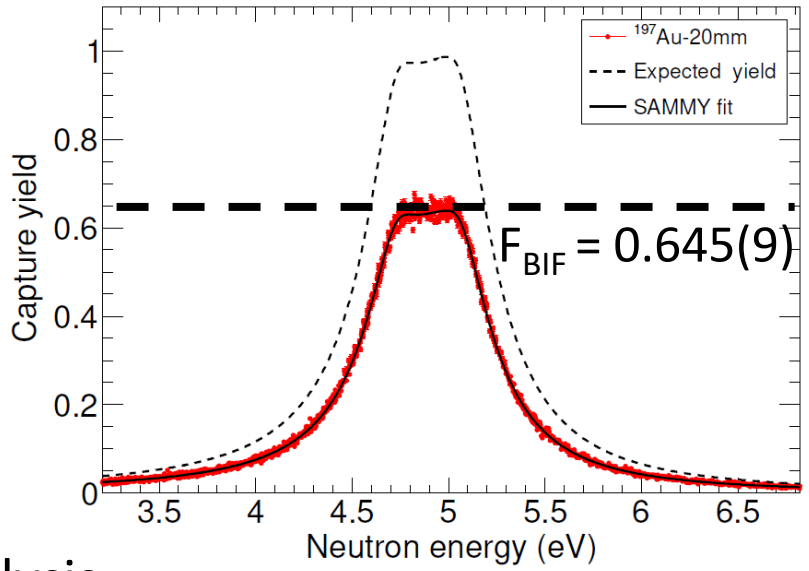
The final step to obtain the capture yield is the normalization factor F_{BIF} → ^{197}Au sample

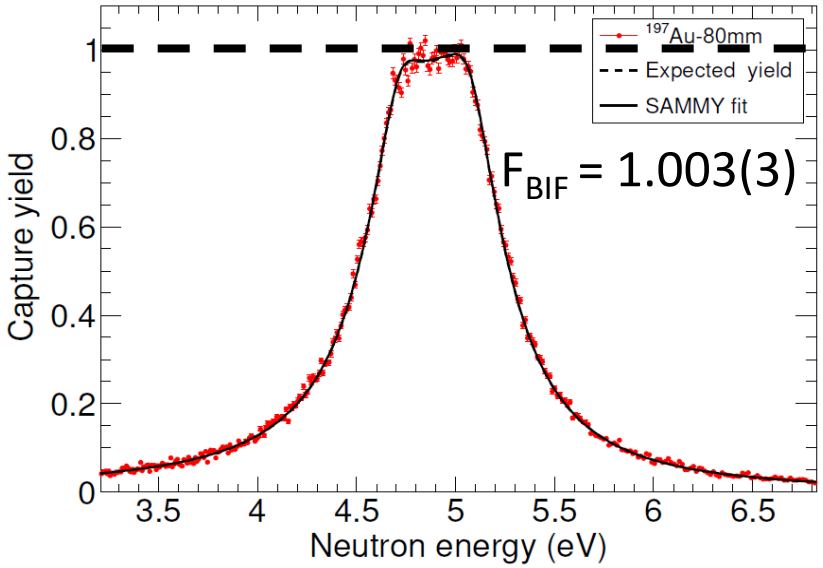
$$Y(E_n) = (1 - e^{-n\sigma_t})\frac{\sigma_\gamma}{\sigma_t} \begin{cases} n_{at}\sigma_t \gg 1 \\ \sigma_t \approx \sigma_\gamma \end{cases} \rightarrow Y(E_n) \cong 1$$

→ **Saturated Resonance Method (SRM)** †



- 100 µm thick ^{197}Au sample → the 4.9 eV resonance **saturates**.
- 80 mm sample to validate the analysis methodology.

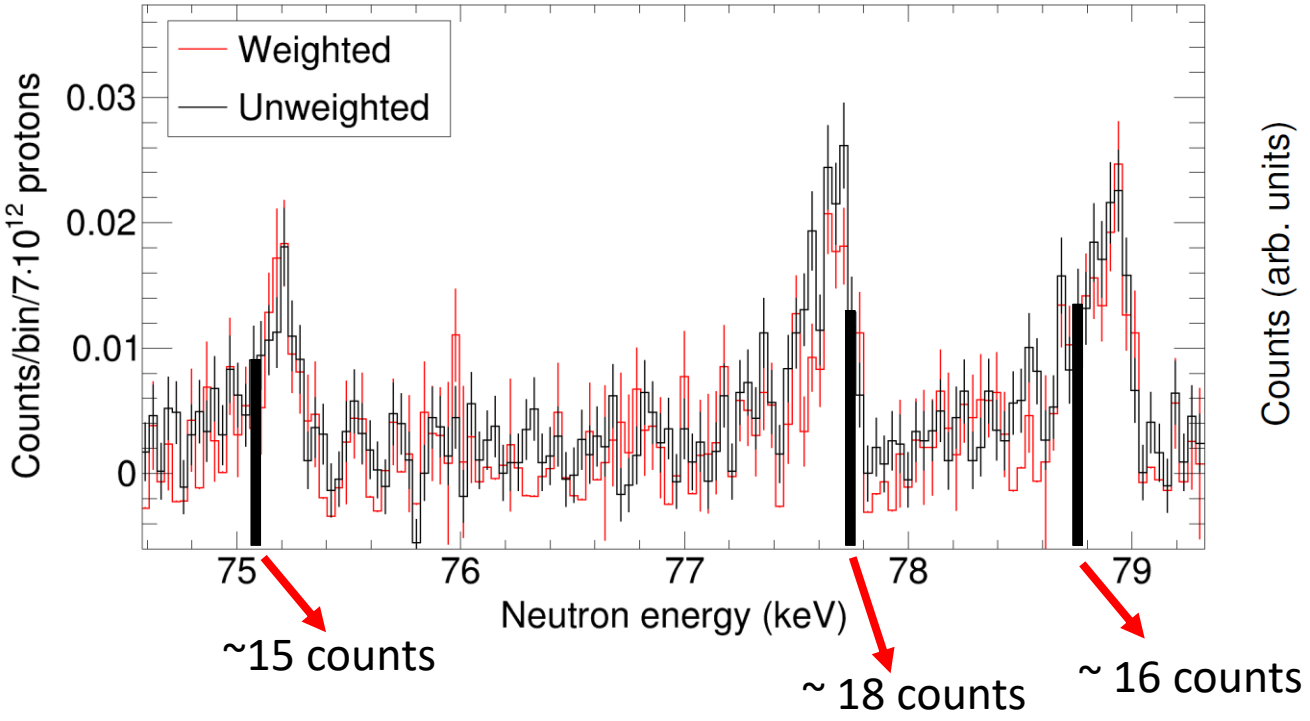


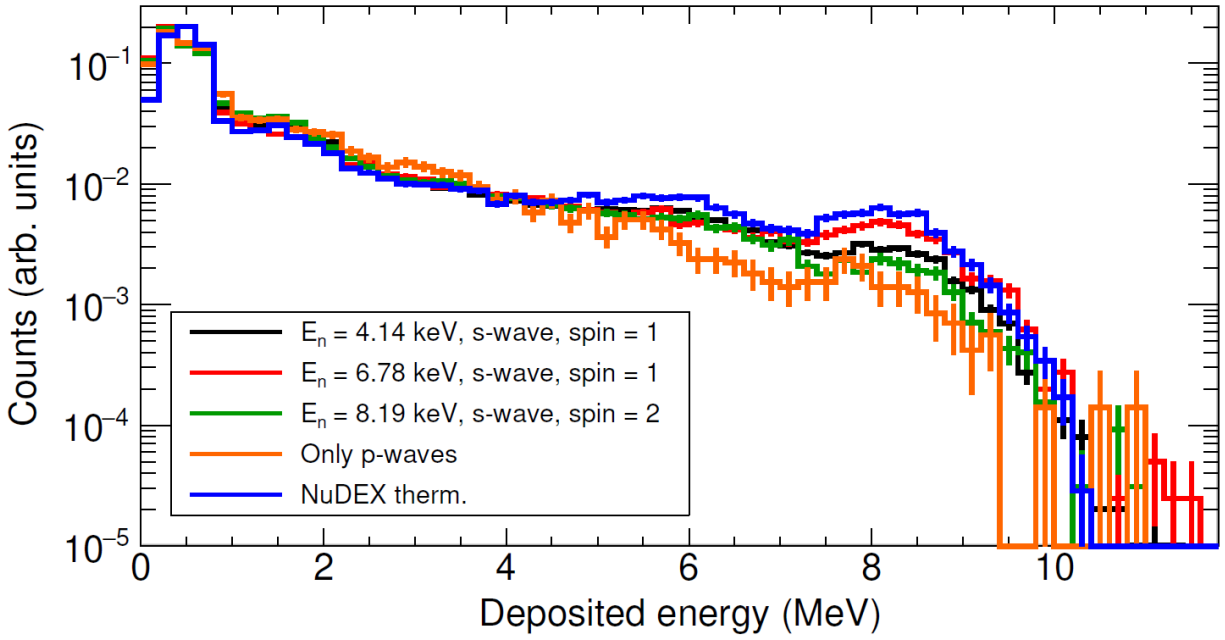


†R. L. Macklin, "*Absolute neutron capture yield normalization*", Nuclear Instruments and Methods 164(1) (1979)

Backup. Capture yield analysis

The WF enhance the natural statistical fluctuations → Limited statistics bin-by-bin.





Backup. Capture yield analysis

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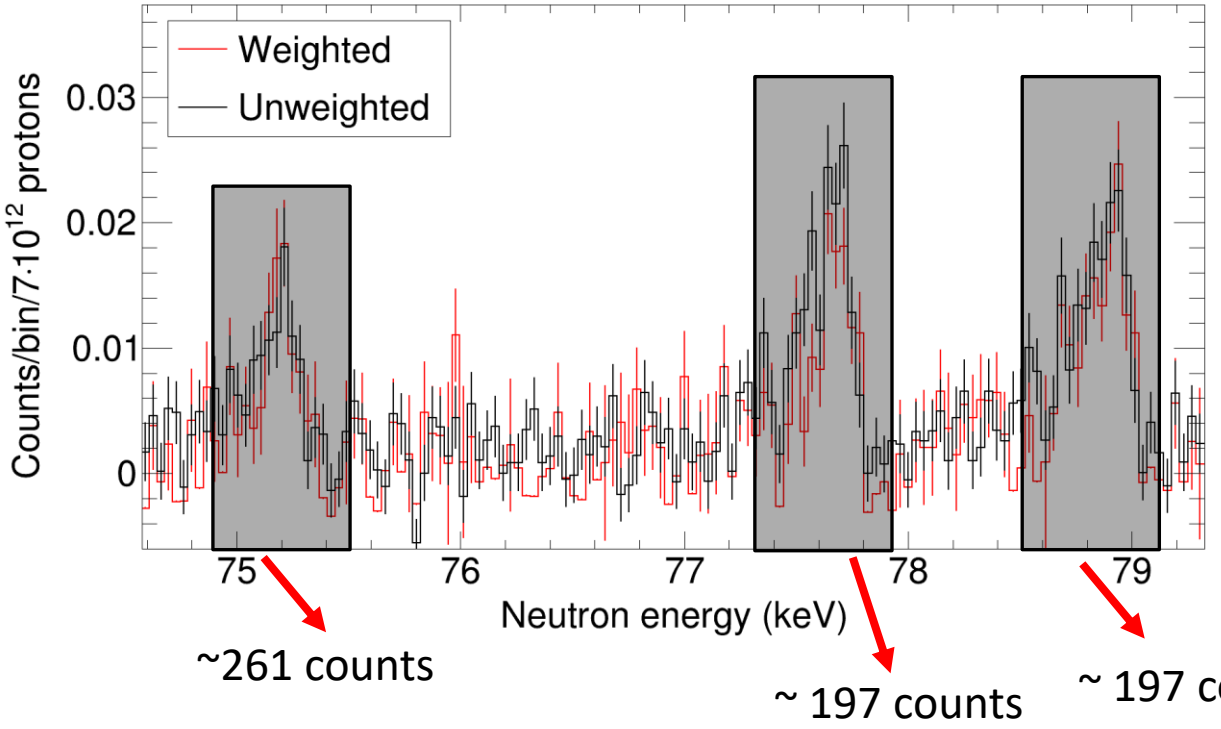


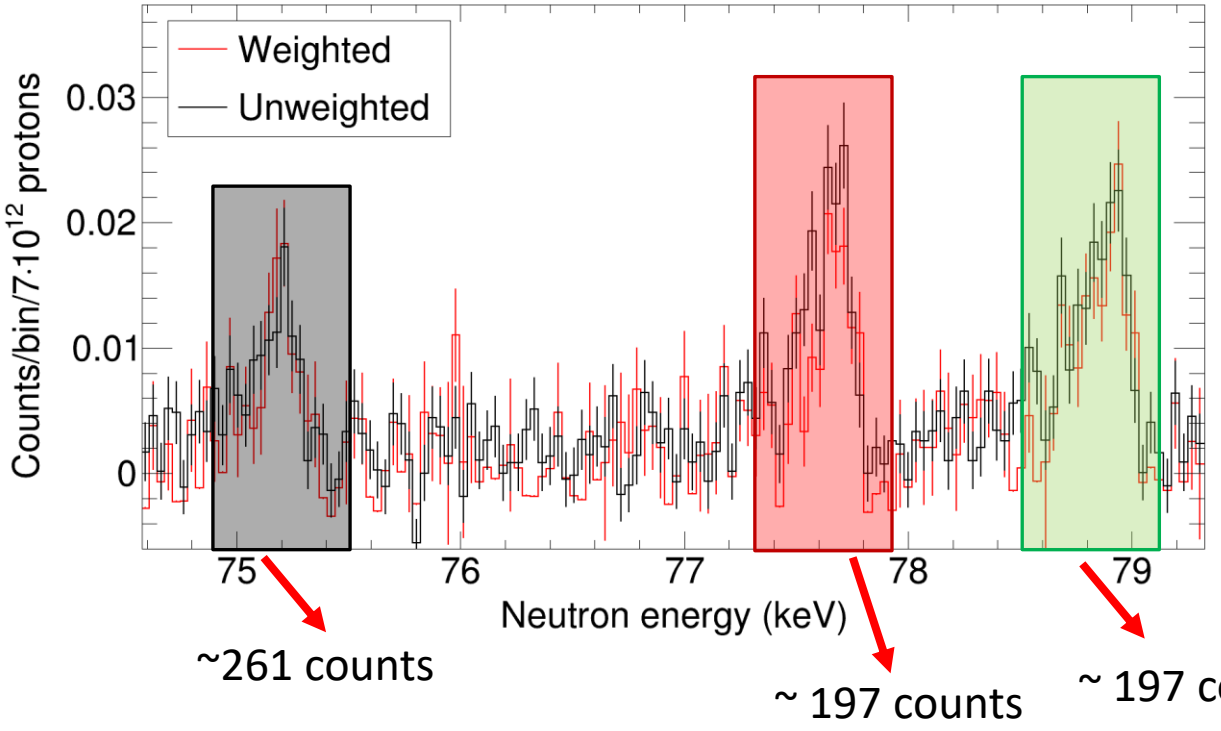
- Solution: **Average Weighting Factor (AWF)**.
- Used at n_TOF to extend the energy range.
  - $J = 0^+$
  - Heavy nuclei

Same de-excitation pattern for every resonance

$$WF_{res} = \frac{A_r^{\text{weighted}}}{A_r^{\text{unweighted}}} \rightarrow \langle WF_{res} \rangle$$

Backup. Capture yield analysis

The WF enhance the natural statistical fluctuations → Limited statistics bin-by-bin.



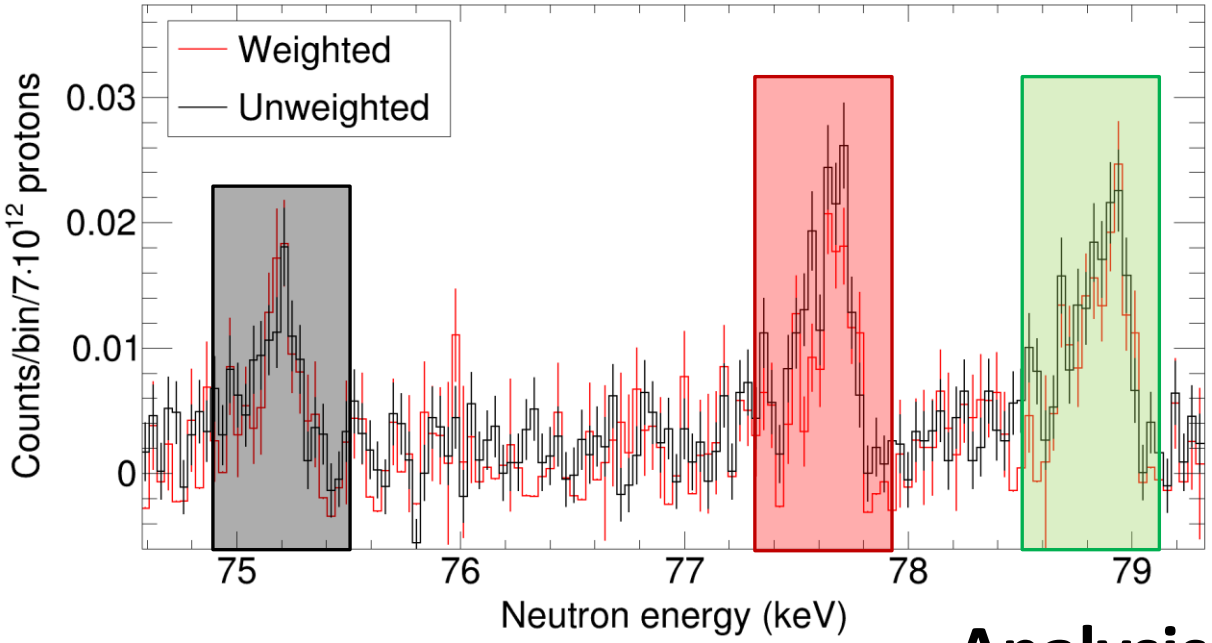
- Solution: **Average Weighting Factor (AWF)**.
- Used at n_TOF to extend the energy range.
  - $J = 0^+$
  - Heavy nuclei

  } Same de-excitation pattern for every resonance
- New technique proposed:
  Resonance Weighting Factor (RWF)

$$WF_{res} = \frac{A_r^{\text{weighted}}}{A_r^{\text{unweighted}}} \rightarrow \langle WF_{res} \rangle$$

Backup. Capture yield analysis

The WF enhance the natural statistical fluctuations → Limited statistics bin-by-bin.



- Solution: **Average Weighting Factor (AWF)**.
- Used at n_TOF to extend the energy range.
  - $J = 0^+$
  - Heavy nuclei

  } Same de-excitation pattern for every resonance
- New technique proposed:
  Resonance Weighting Factor (RWF)

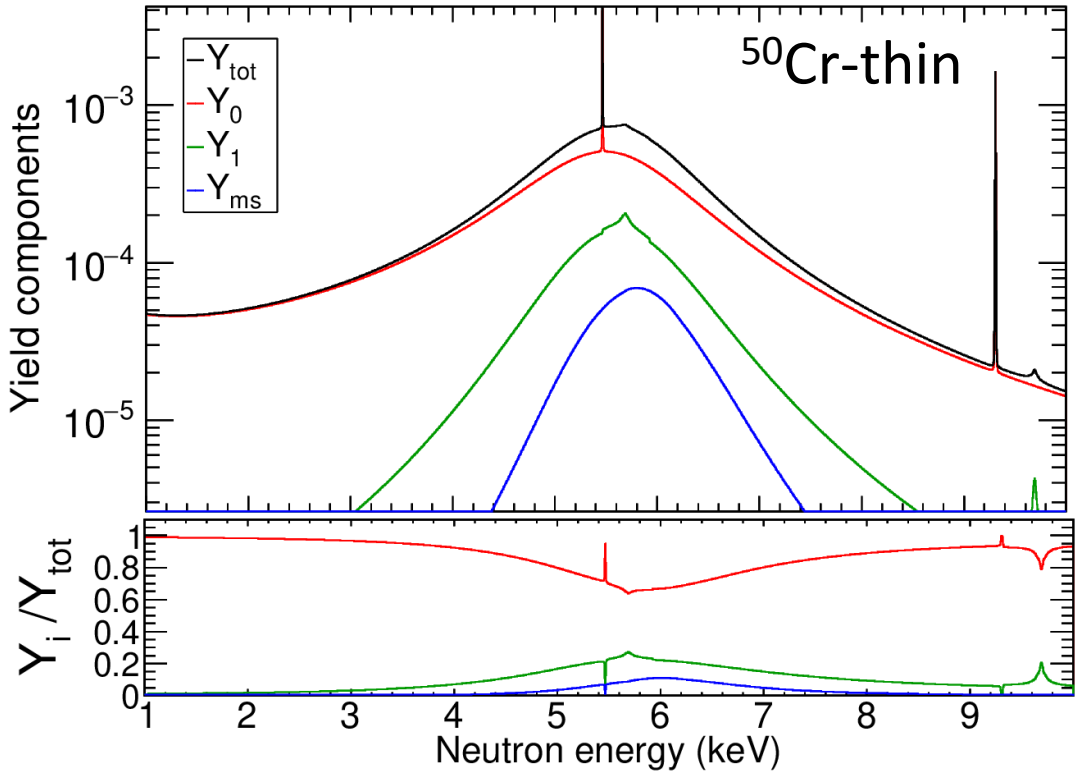
Analysis strategy

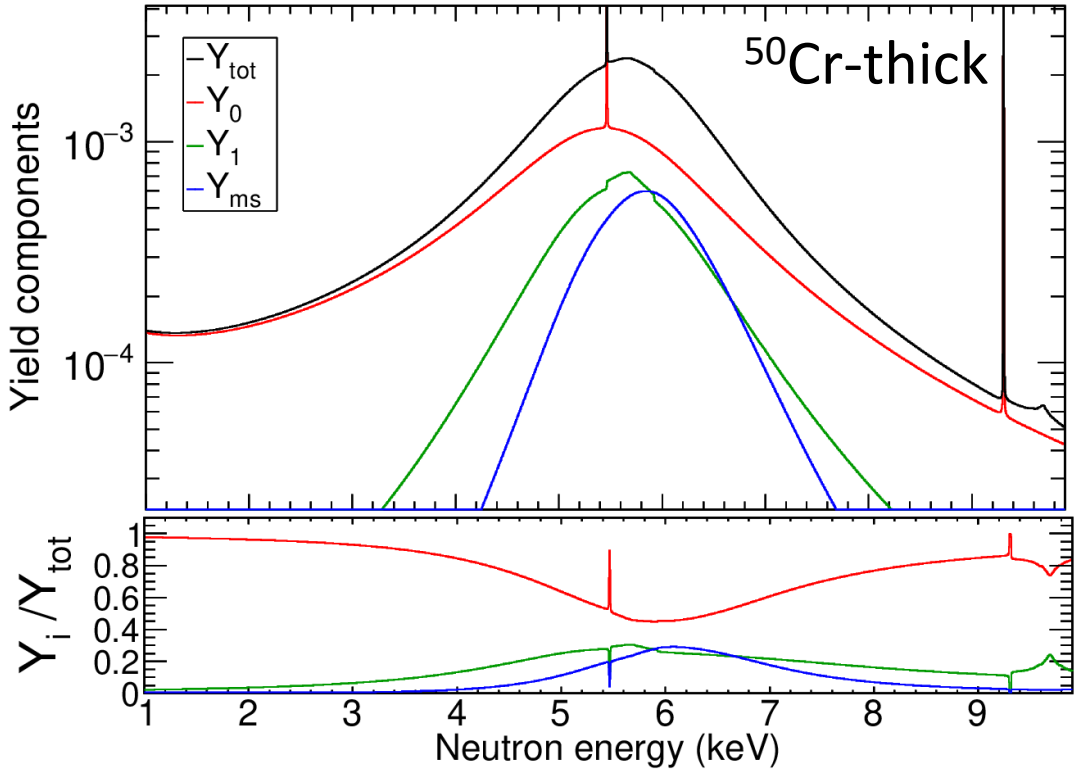
- Very good statistics (6) → PHWT → Thin samples (1-10 keV)
- Good statistics (42) → RWF → Thick samples (10-100 keV)
- Bad statistics (24) → AWF → Thick samples (10-100 keV)

Backup. Resonance analysis with SAMMY (^{50}Cr)

- Main resonance → in agreement with JEFF-3.3 (even K_γ also similar to CENDL-3.2).
- Overestimation by INDEN.
- Previous energy shifted: from $E_n = 5.621$ keV to $E_n = 5.581(6)$ keV.
- Resonance deformed in the thick sample.

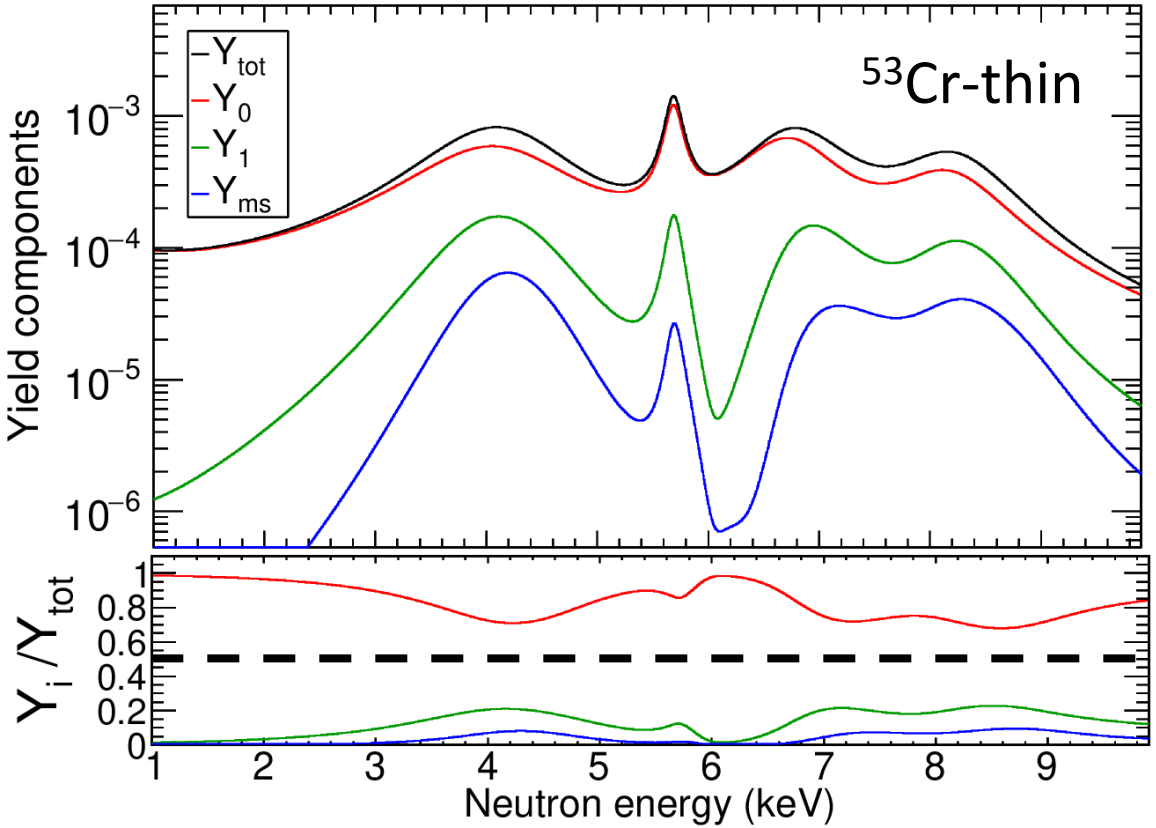
} Multiple-scattering effects

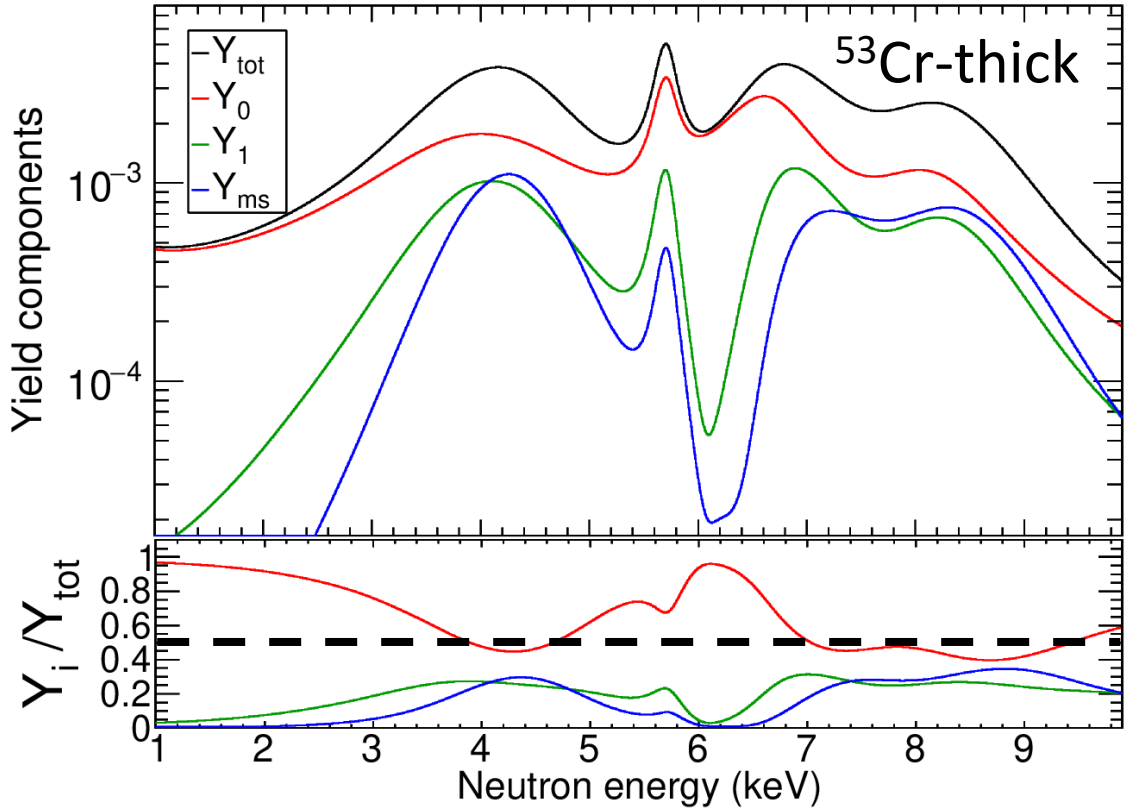




Backup. Resonance analysis with SAMMY (^{53}Cr)

- The MS effects are very large → ~7mm thickness.
- SAMMY fails to accurate evaluate the MS effects.

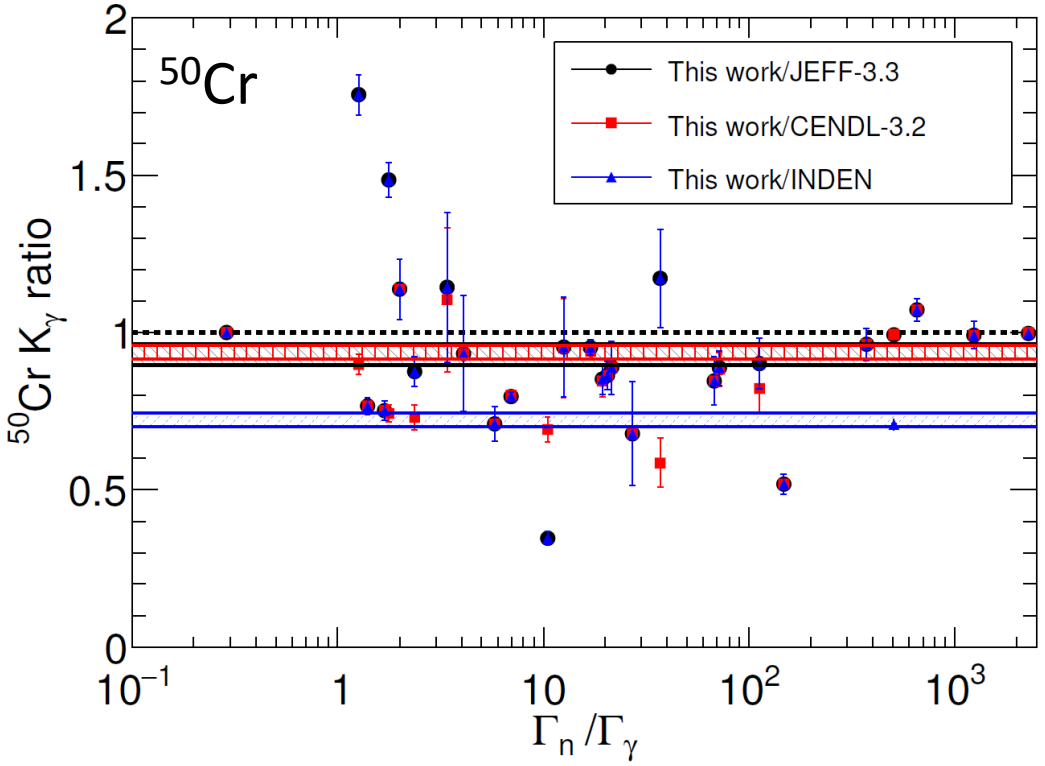


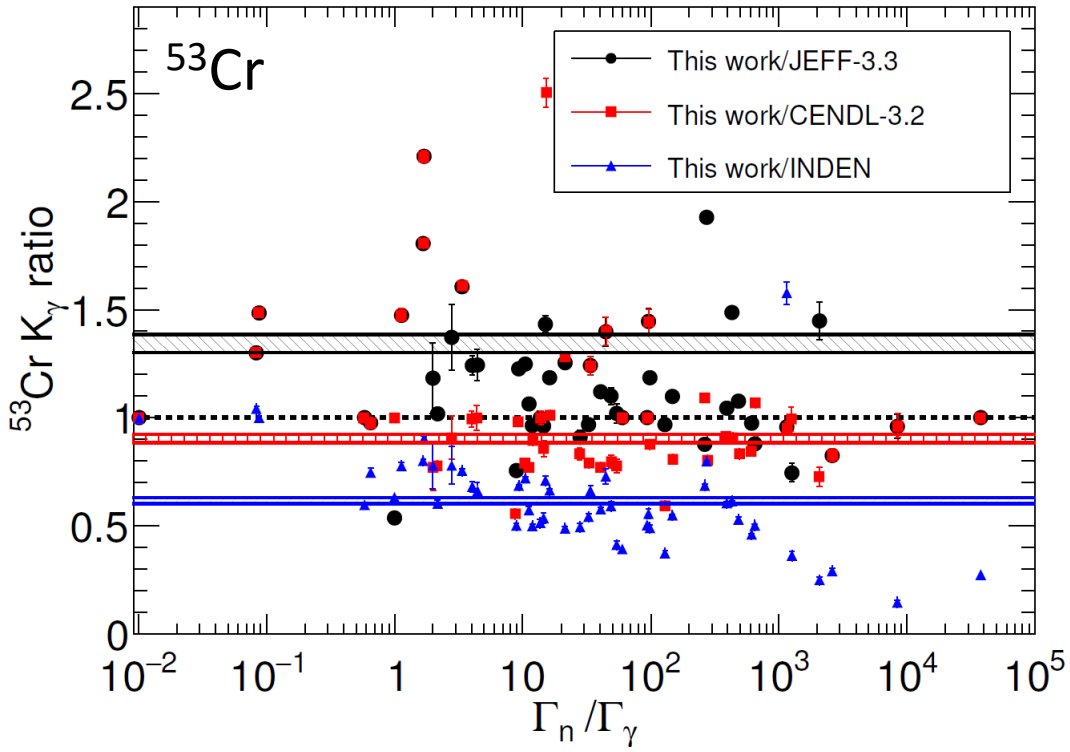


Backup. ^{50,53}Cr(n,γ) at EAR1 results

$$K_\gamma = g_J \frac{\Gamma_\gamma \Gamma_n}{\Gamma_\gamma + \Gamma_n}$$

- The radiative kernel K_γ gives information resonance by resonance.
- ^{50}Cr → 7% lower than JEFF-3.3 and CENDL-3.2, 40% lower than INDEN.
- ^{53}Cr → 35% higher than JEFF-3.3, 10% and 60% lower than CENDL-3.2 and INDEN, respectively.





Backup. ^{50,53}Cr (n,γ) at EAR1 results

	^{50}Cr MACS (mb)	^{53}Cr MACS (mb)
JEFF-3.3 (2017)	38.2	25.9
CENDL-3,2 (2020)	37.7	31.5
INDEN (2023)	45.0	51.7
HiSPANoS(2025)	**37.1(20)**	-
n_TOF (2025)	**35.0(24)**	**30.9(22)**