

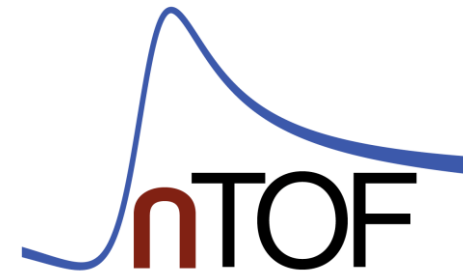
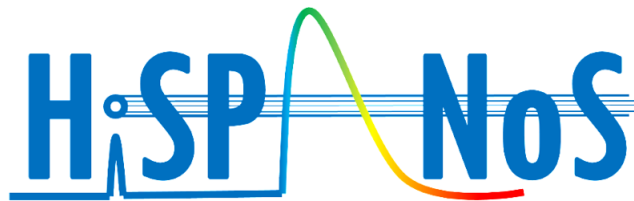
# $^{50,53}\text{Cr}$ (n, $\gamma$ ) cross section measurement at n\_TOF@CERN

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

AND THE N\_TOF COLLABORATION

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H2020-ARIEL 2<sup>ND</sup> SCIENTIFIC WORKSHOP & PROGRESS MEETING. 15/03/2023



# 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:**

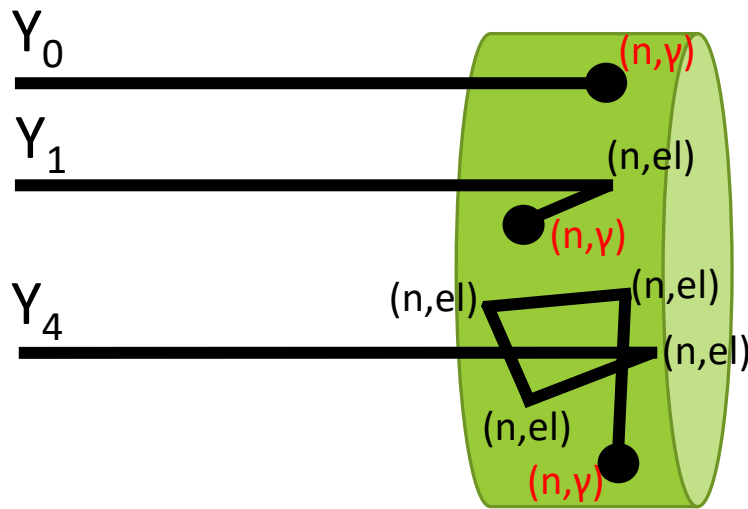
Criticality benchmarks can test different components of stainless steel (SS), including Cr which is a large component of some SS. Currently, a large part of the uncertainty in SS capture seems to be driven by uncertainty in Cr capture [Koscheev2017]. Indeed, some benchmarks highly sensitive to Cr (as 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 **<sup>50</sup>Cr and <sup>53</sup>Cr capture cross section**, which are not present in the corresponding estimated uncertainties.
- OECD NEA-HPRL (High Priority Request List)**  
 → **<sup>50,53</sup>Cr(n,γ) within 8-10% at 1 to 100 keV**

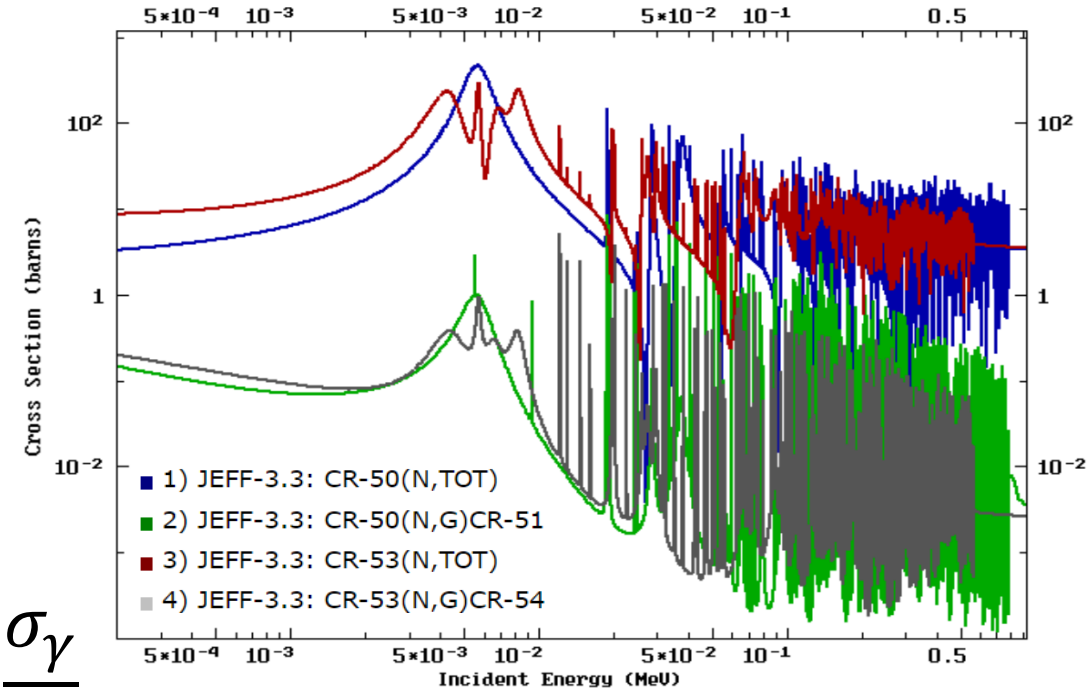
# Why the discrepancies?

- The main problem for measuring  $\text{Cr}(n,\gamma)$  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.



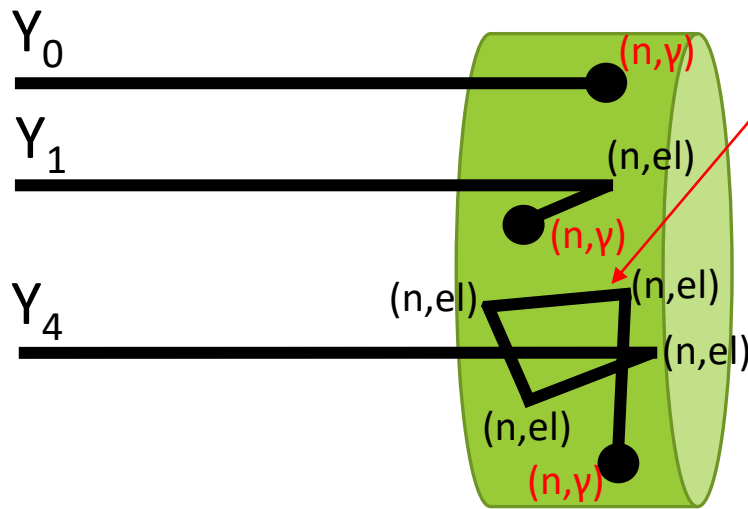
$$Y_0 = (1 - e^{-n\sigma_t}) \frac{\sigma_\gamma}{\sigma_t}$$

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



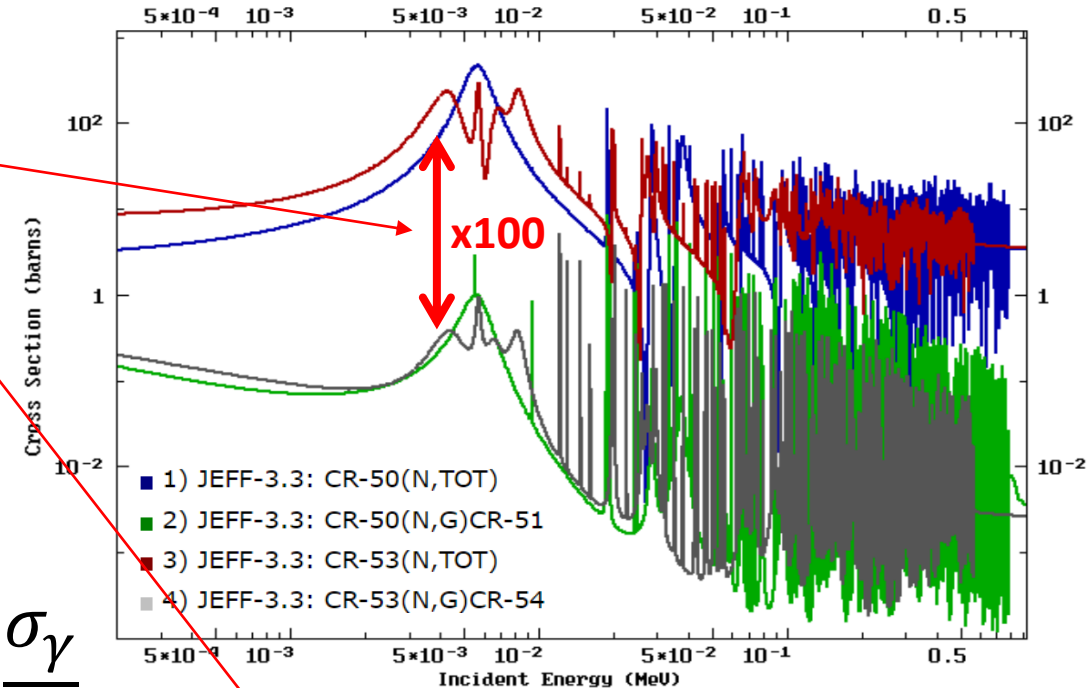
# Why the discrepancies?

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Capture yield  
(captures/neutron)



$$Y = Y_0 + \underbrace{Y_1}_{\text{Analytical (accurate)}} + \underbrace{Y_2 + Y_3 \dots}_{\text{Numerical (aproximate)}}$$

# How to improve $\sigma(n,\gamma)$ down to a few %?

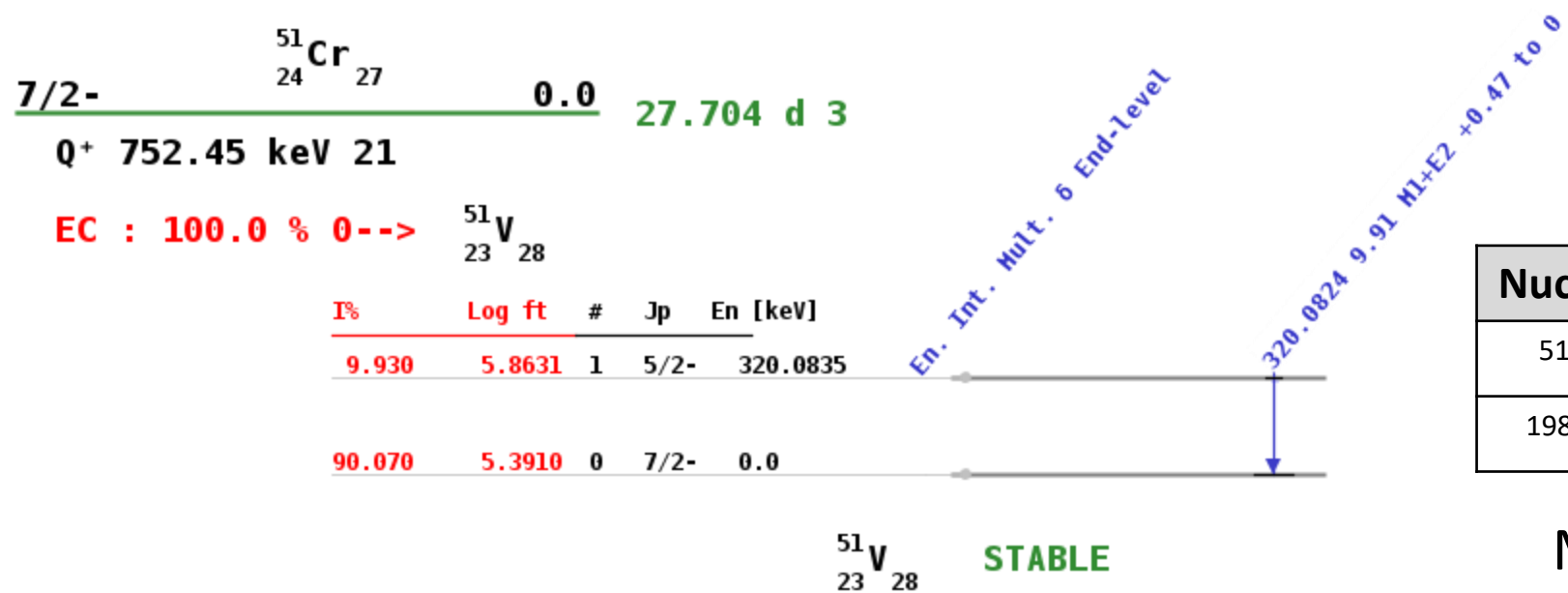
- Enriched (expensive and scarce) material with high purity  $\rightarrow$  94,6%  $^{50}\text{Cr}$  & 97,7%  $^{53}\text{Cr}$
- Controlling multiple-scattering effects:
  - Very thin/thin sample approach
  - $\text{C}_6\text{D}_6$  detectors (low sensitivity to scattered neutrons)

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 $^{50}\text{Cr}$ ( $10^{-3}$ at/barns)	18	8	7	5/8	-	0,6/1,9
Density $^{53}\text{Cr}$ ( $10^{-3}$ at/barns)	14	14	12/60	8/12	14	1,2/6

Our “thicks” are thinner than all previous  
 $\rightarrow$  lower multiple scattering corrections

# How to improve $\sigma(n,\gamma)$ down to a few %?

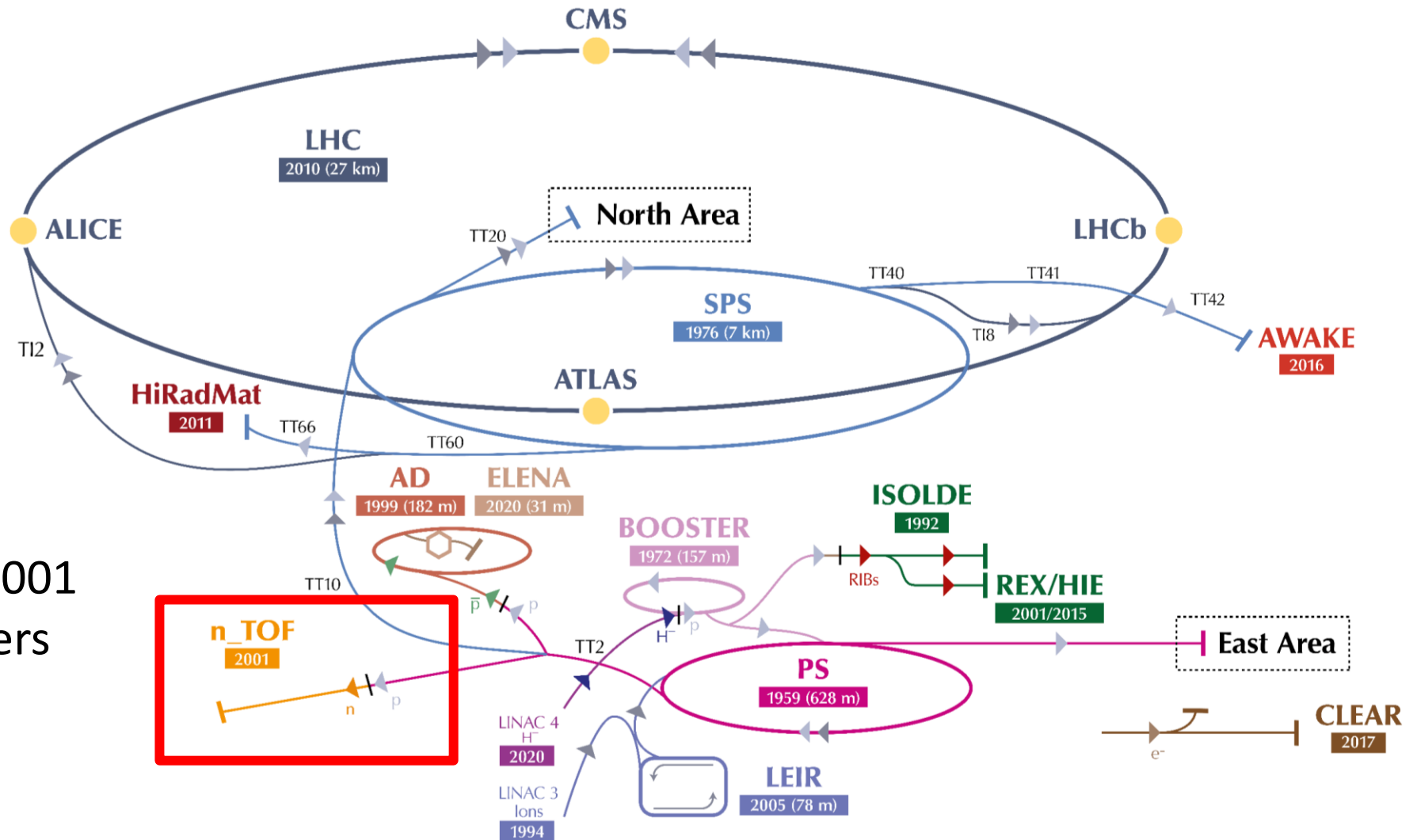
- Enriched (expensive and scarce) material with high purity  $\rightarrow$  94,6%  $^{50}\text{Cr}$  & 97,7%  $^{53}\text{Cr}$
- Controlling multiple-scattering effects:
  - Very thin/thin sample approach
  - $\text{C}_6\text{D}_6$  detectors (low sensitivity to scattered neutrons)
- Complementing with  $^{50}\text{Cr}$  activation measurement  $\rightarrow$  HiSPANoS@CNA



Nucleus	T <sub>1/2</sub> (days)	E <sub>γ</sub> (keV)	I <sub>γ</sub> (%)
<sup>51</sup> Cr	27,7	320,1	9,9
<sup>198</sup> Au	2,69	411,8	95,5

More info on the last slide...

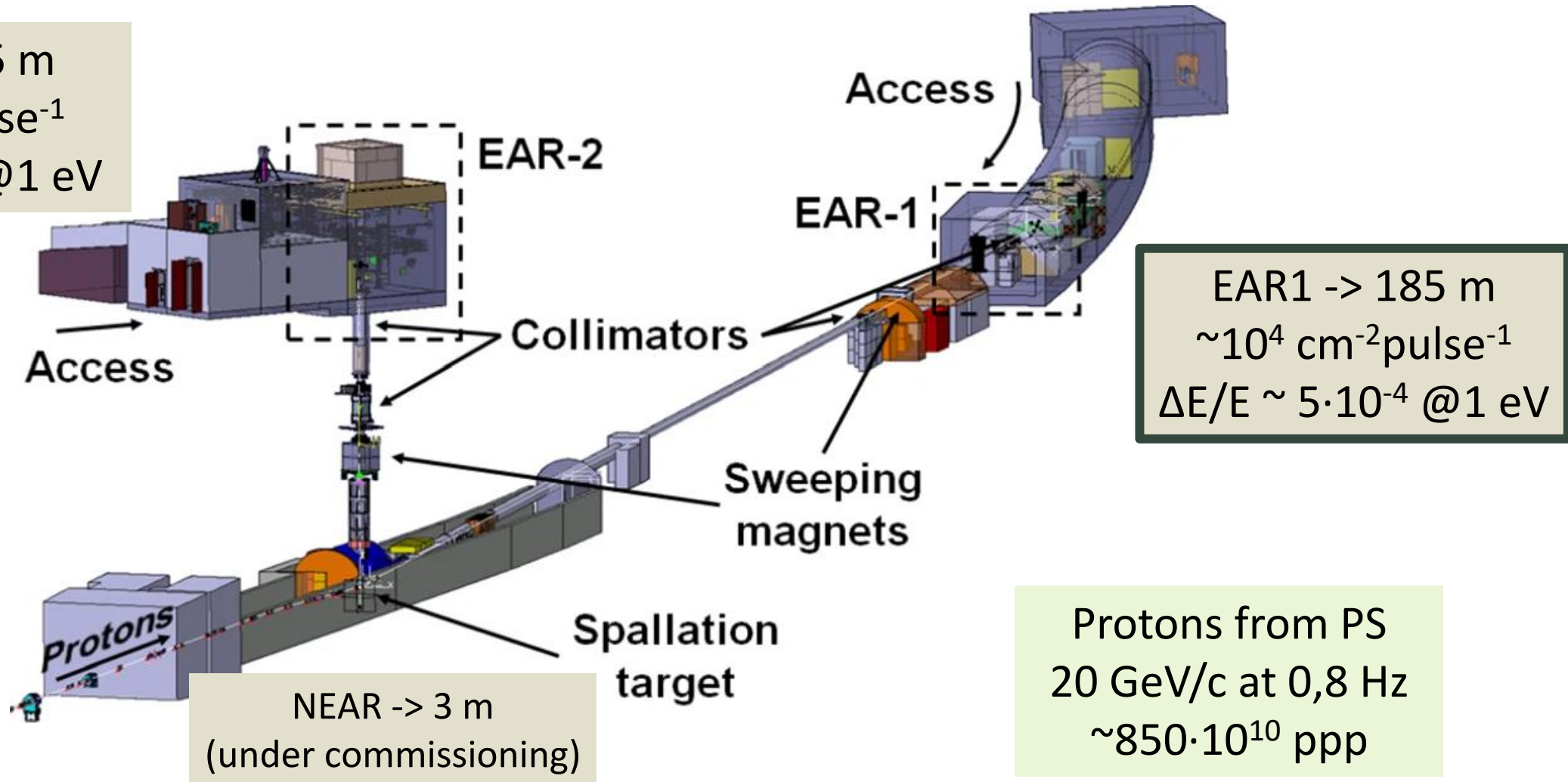
# The neutron Time-Of-Flight facility at CERN



## n\_TOF@CERN

In operation since 2001  
2022: 131 researchers  
from 37 institutes

# The neutron Time-Of-Flight facility at CERN

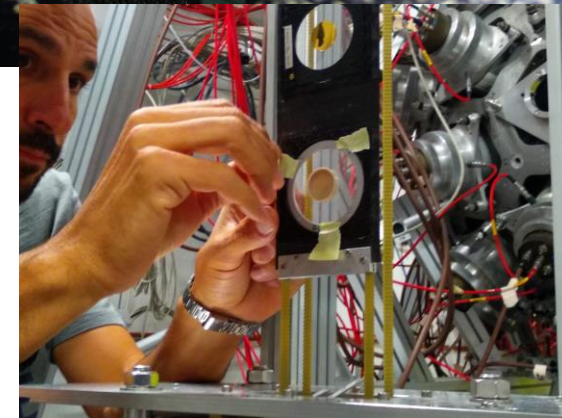
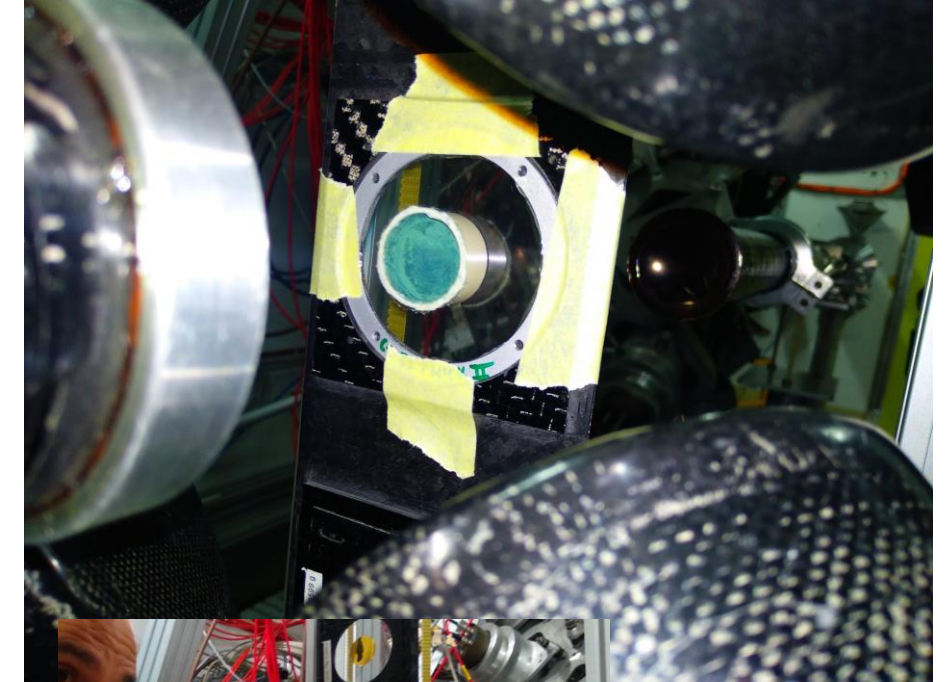
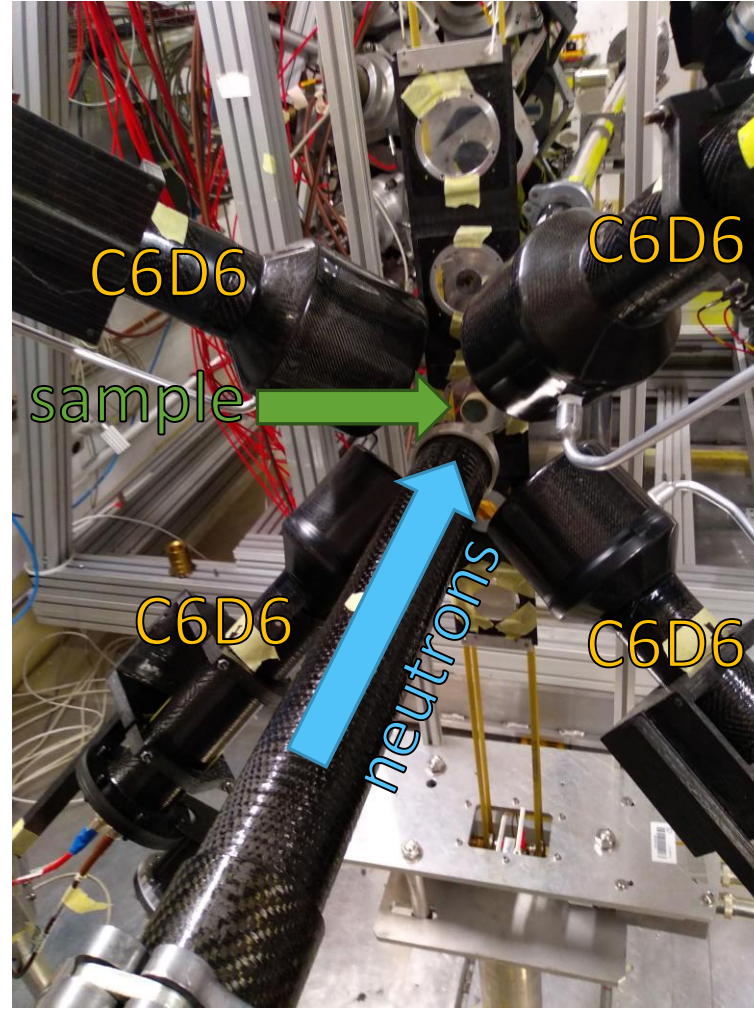


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# Samples and detector set-up (EAR1)



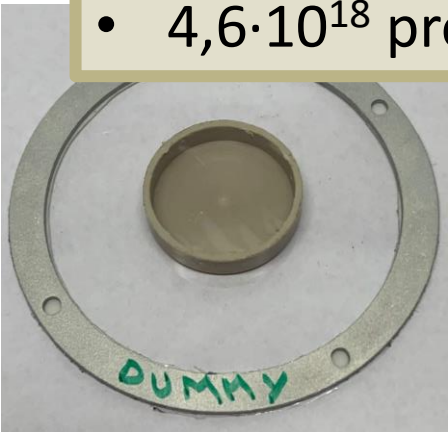
$\text{Cr}_2\text{O}_3$  powder pressed in a PEEK capsule & Al holder



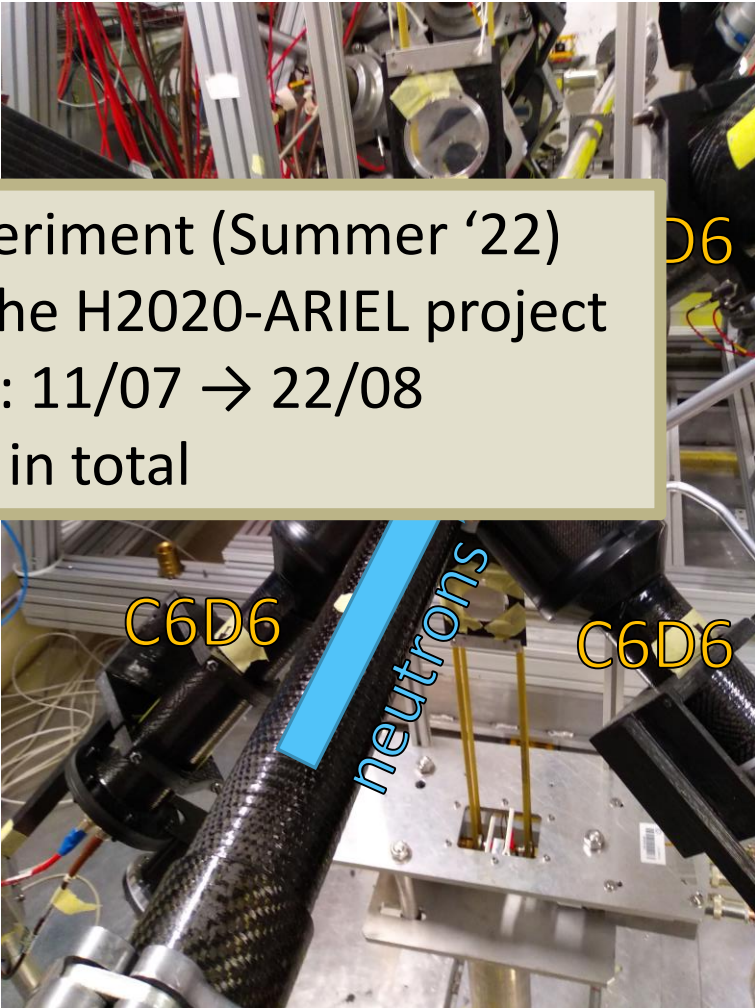
# Samples and detector set-up (EAR1)



- 12 weeks of experiment (Summer '22)
- Stay funded by the H2020-ARIEL project
- 42 days of beam: 11/07 → 22/08
- $4,6 \cdot 10^{18}$  protons in total

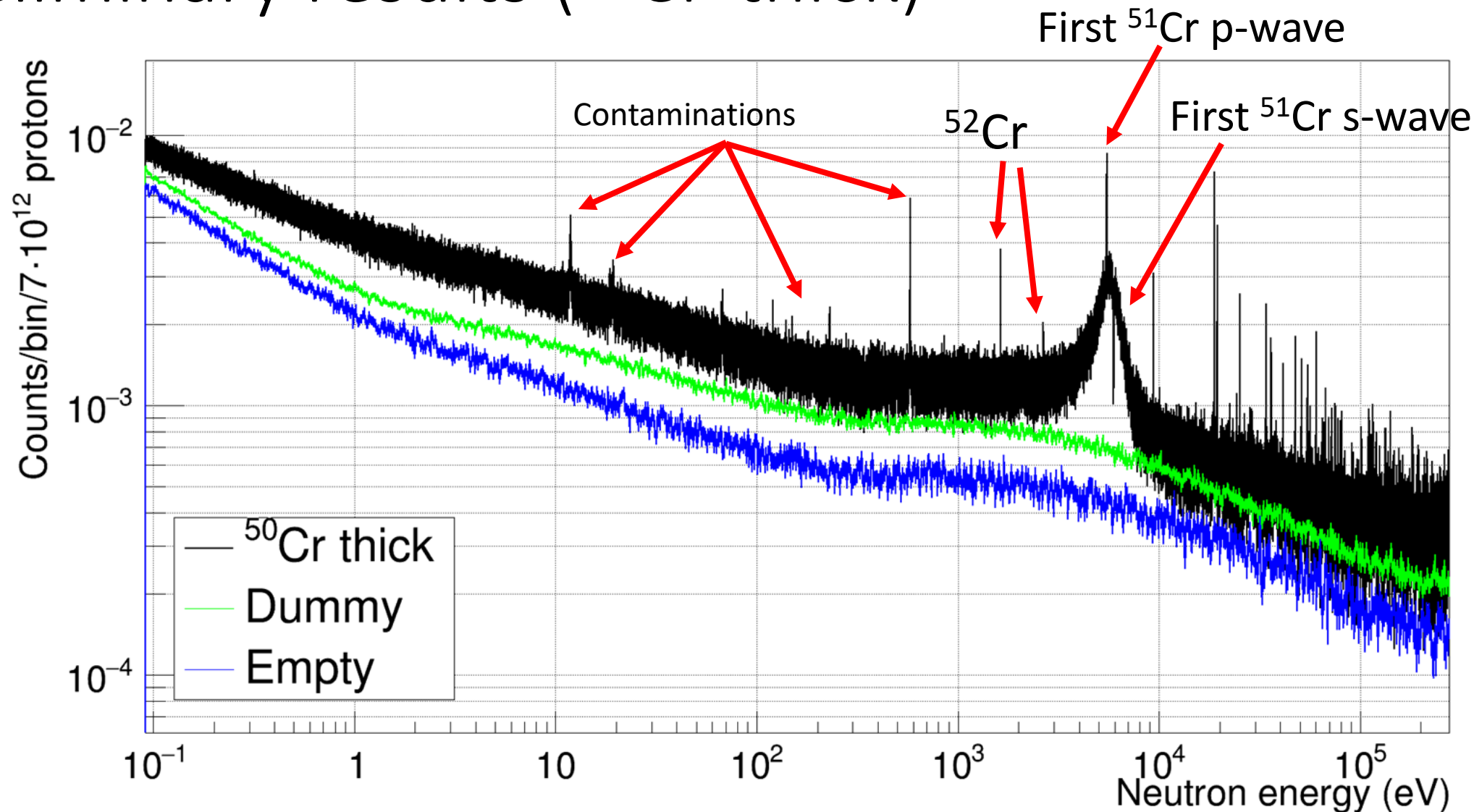


Cr<sub>2</sub>O<sub>3</sub> poder pressed in a PEEK capsule & Al holder

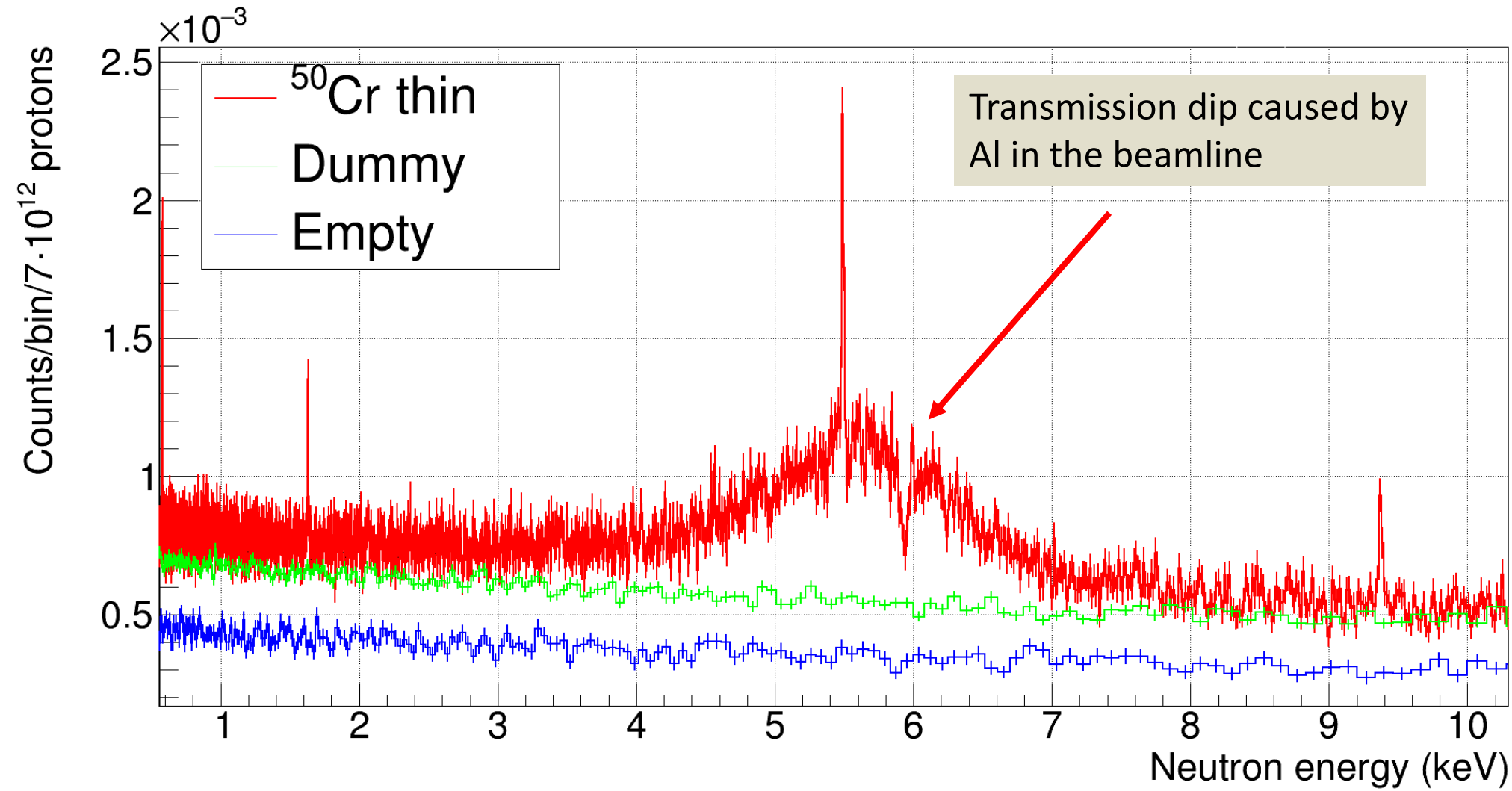


Complementary measurements	
natCr	Resonance identification
<sup>197</sup> Au	Normalization
<sup>27</sup> Al	Calibration
Empty	Background
Dummy	Background
<sup>50,53</sup> Cr & Dummy with filters	<sup>206</sup> Bi and <sup>27</sup> Al filters Background

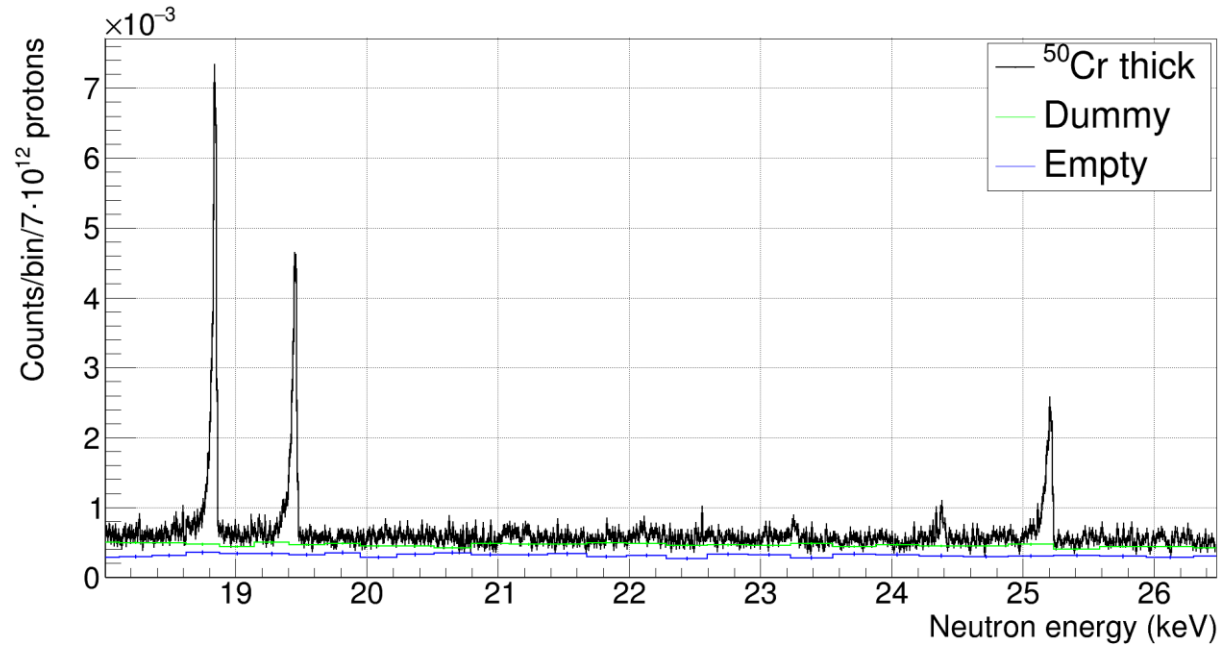
# Preliminary results ( $^{50}\text{Cr}$ -thick)



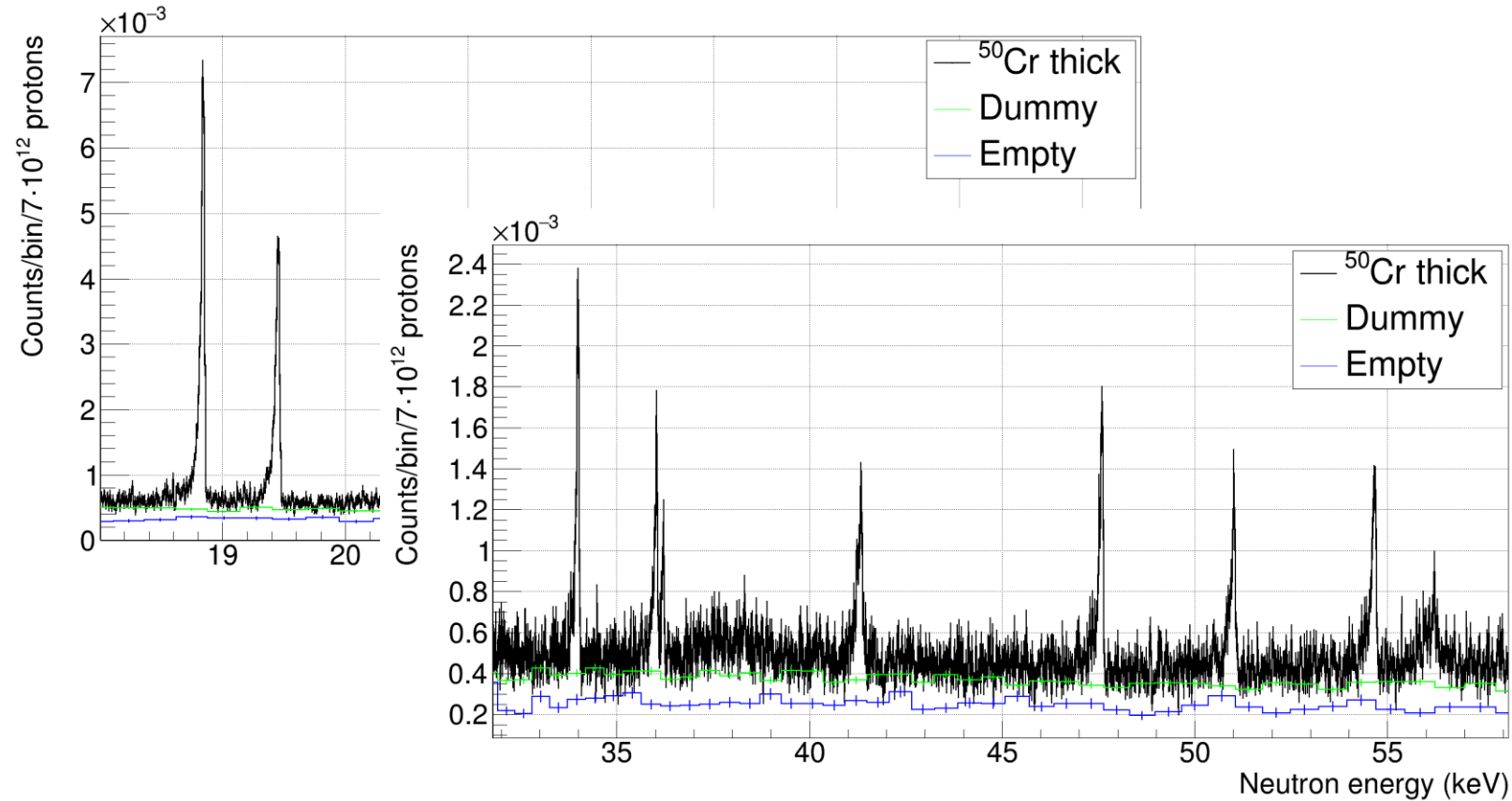
# Preliminary results ( $^{50}\text{Cr}$ -thin)



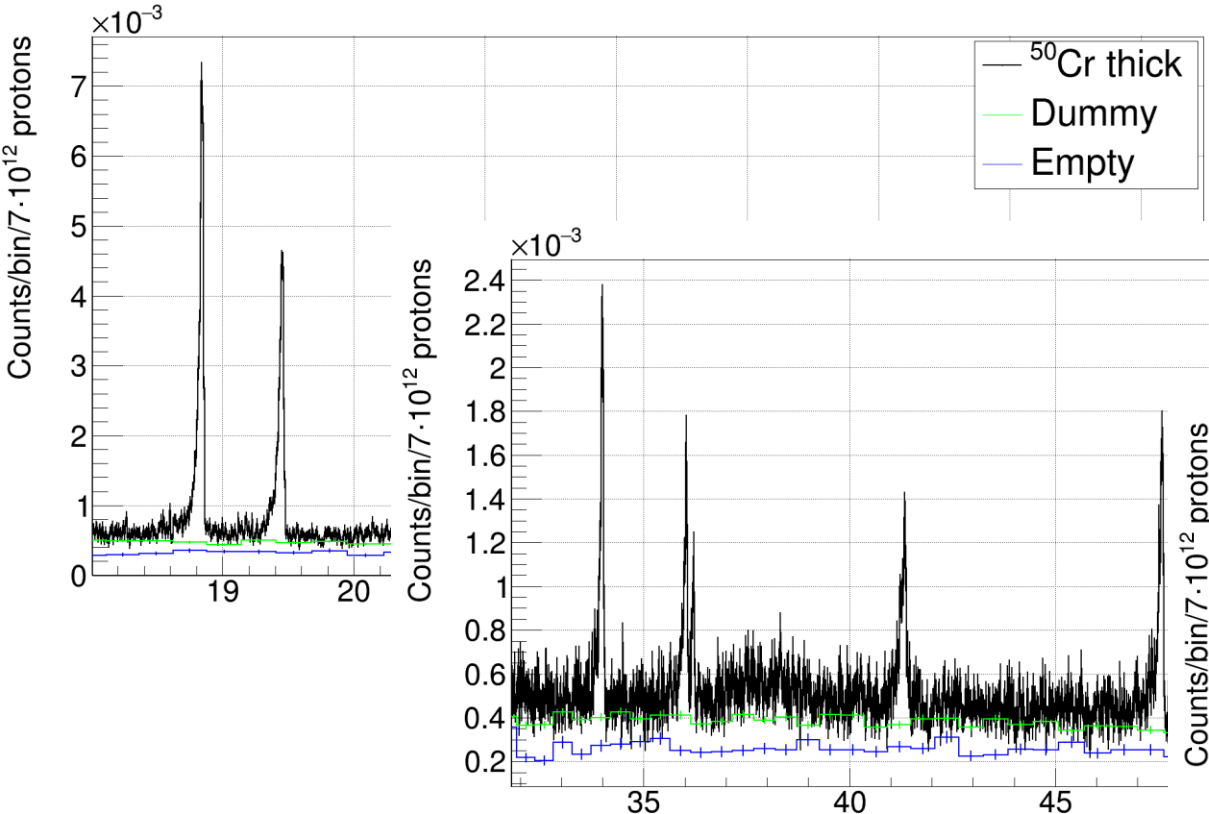
# Preliminary results ( $^{50}\text{Cr}$ -thick)



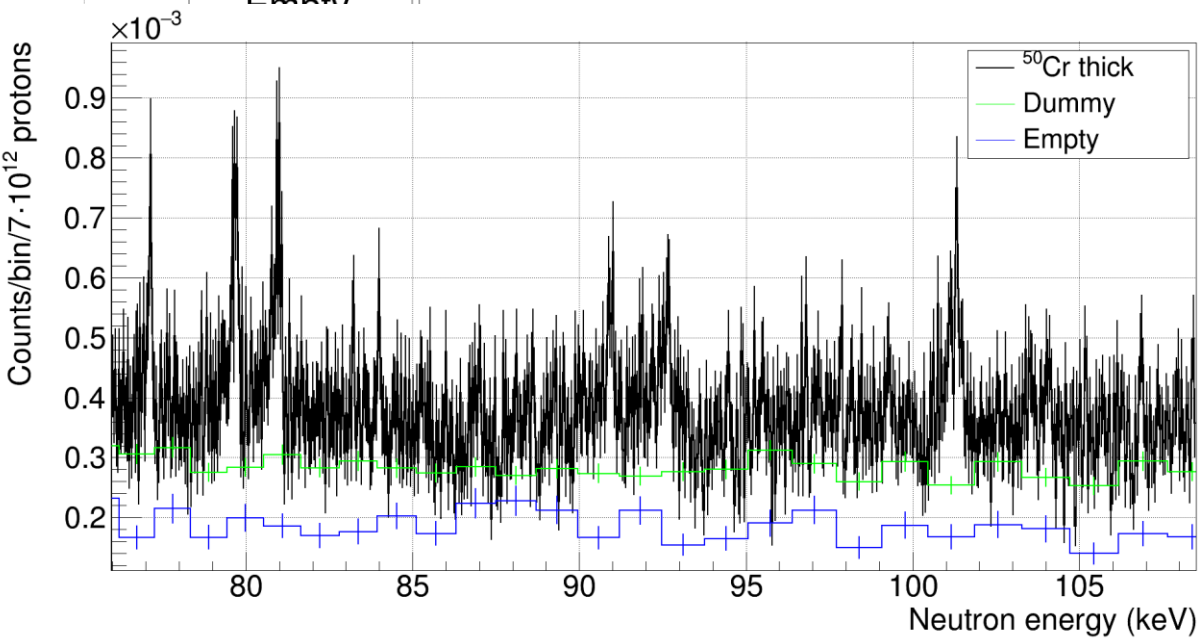
# Preliminary results ( $^{50}\text{Cr}$ -thick)



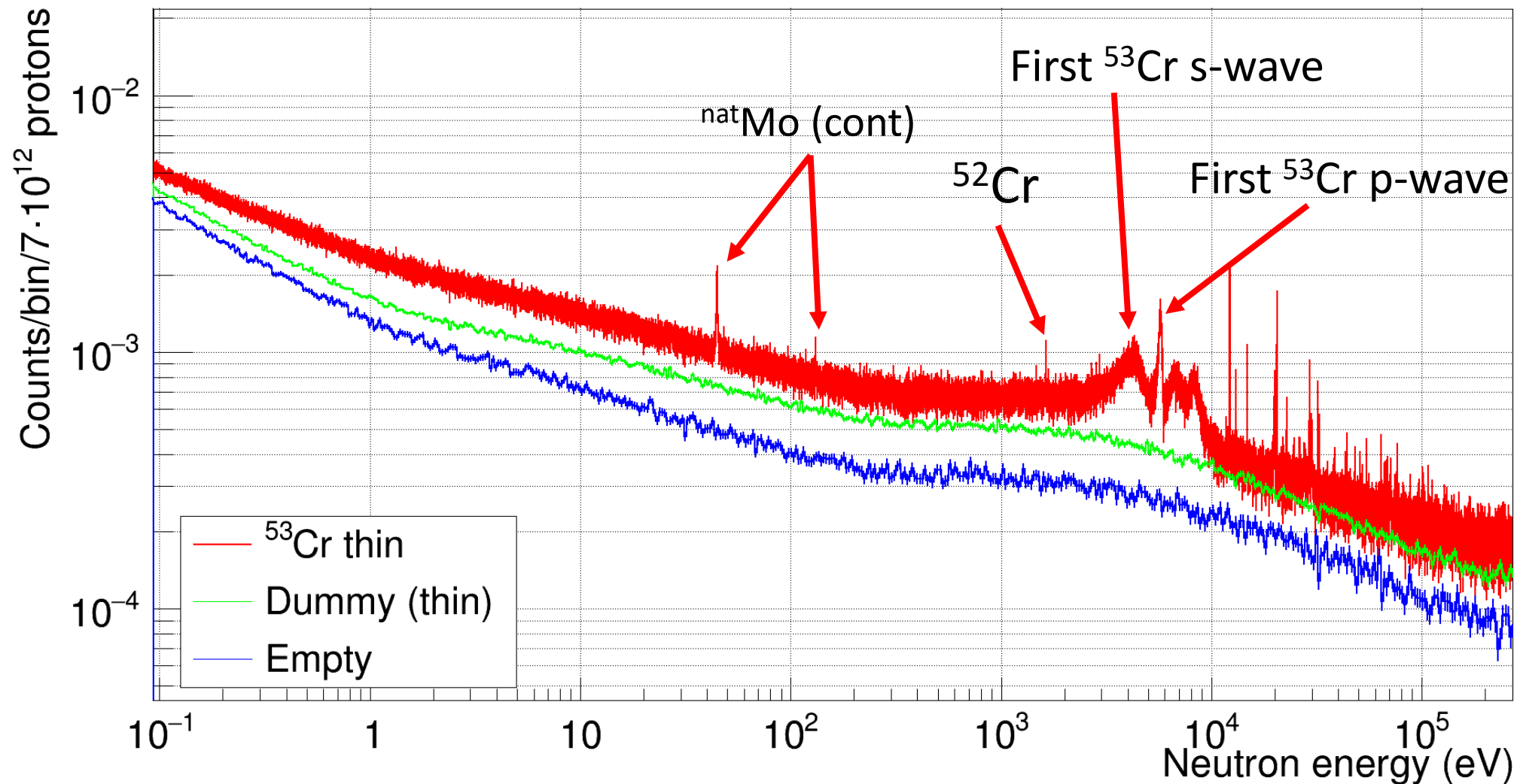
# Preliminary results ( $^{50}\text{Cr}$ -thick)



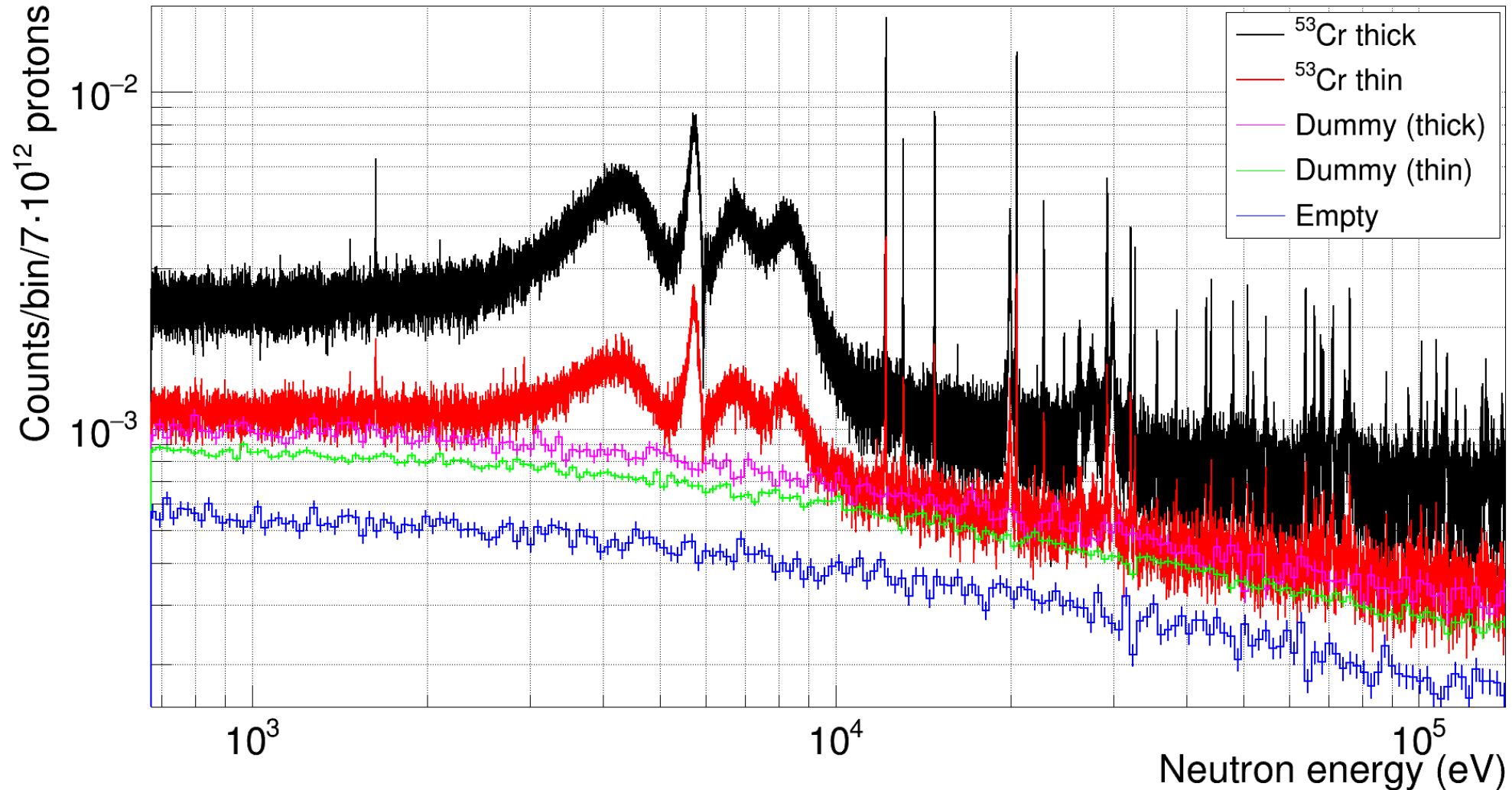
Aimed **100 keV limit reached**, with limited statistics  
(mass limited by **2,7** times )



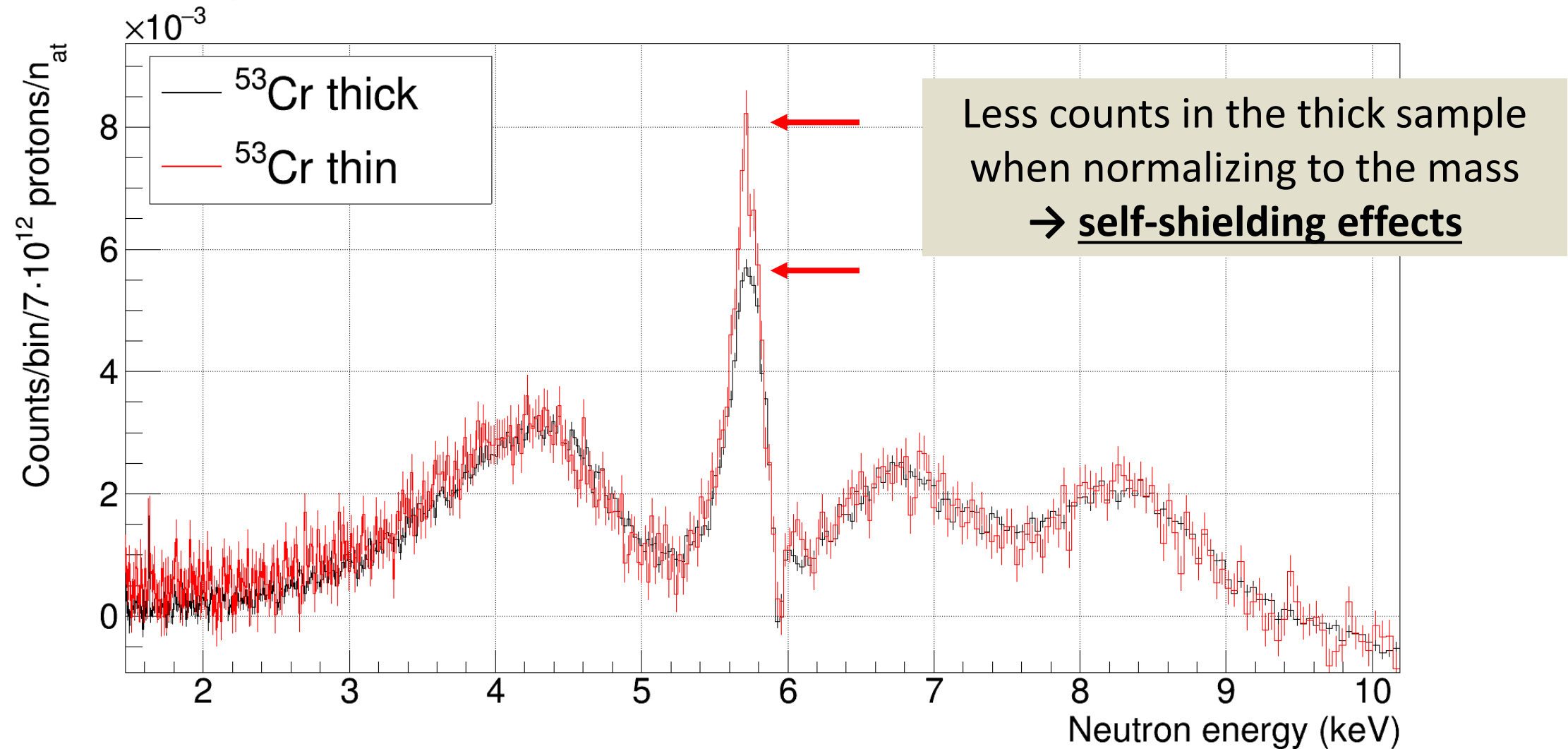
# Preliminary results ( $^{53}\text{Cr}$ -thin)



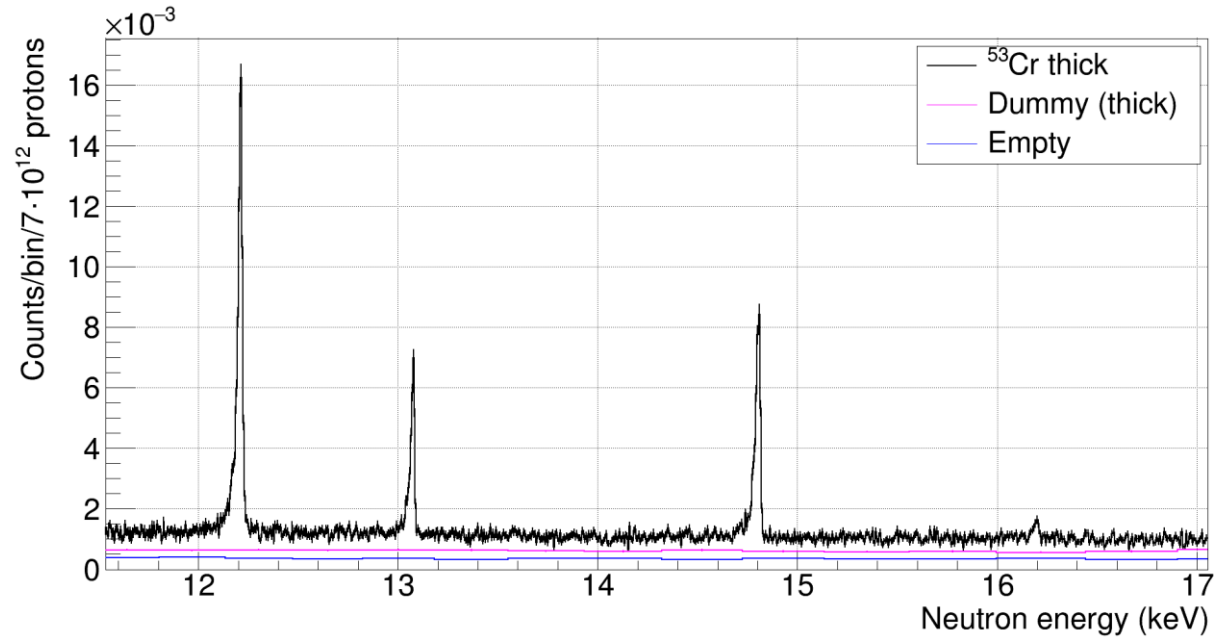
# Preliminary results ( $^{53}\text{Cr}$ : thin vs. thick)



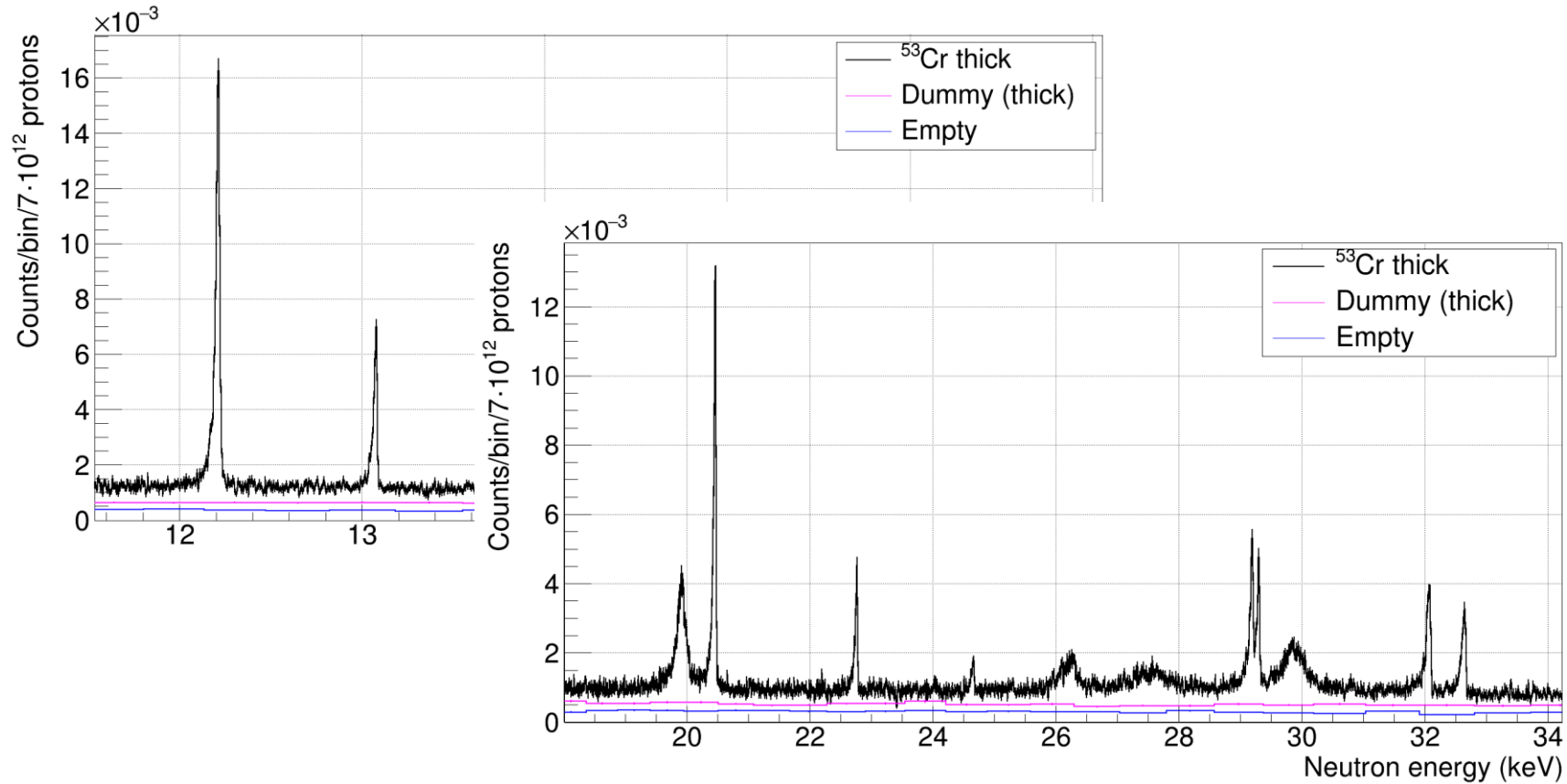
# Preliminary results ( $^{53}\text{Cr}$ : thin vs. thick)



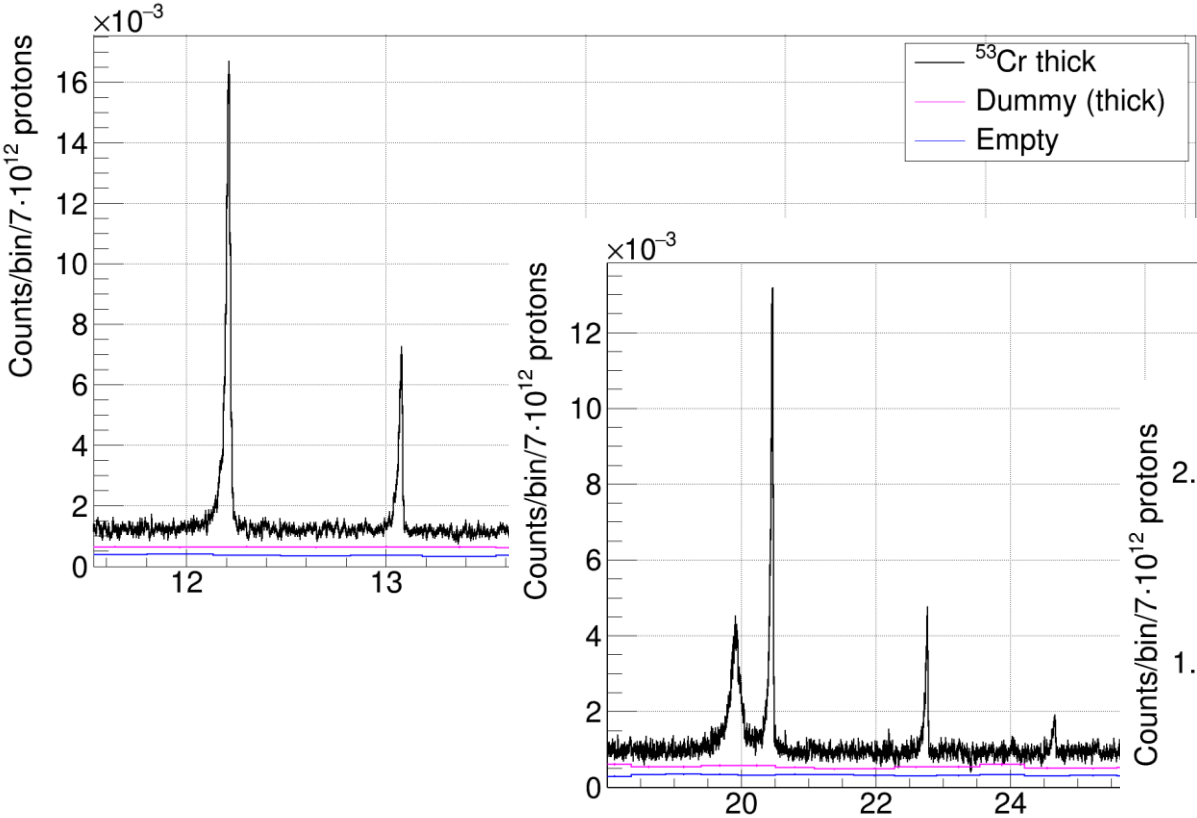
# Preliminary results ( $^{53}\text{Cr}$ -thick)



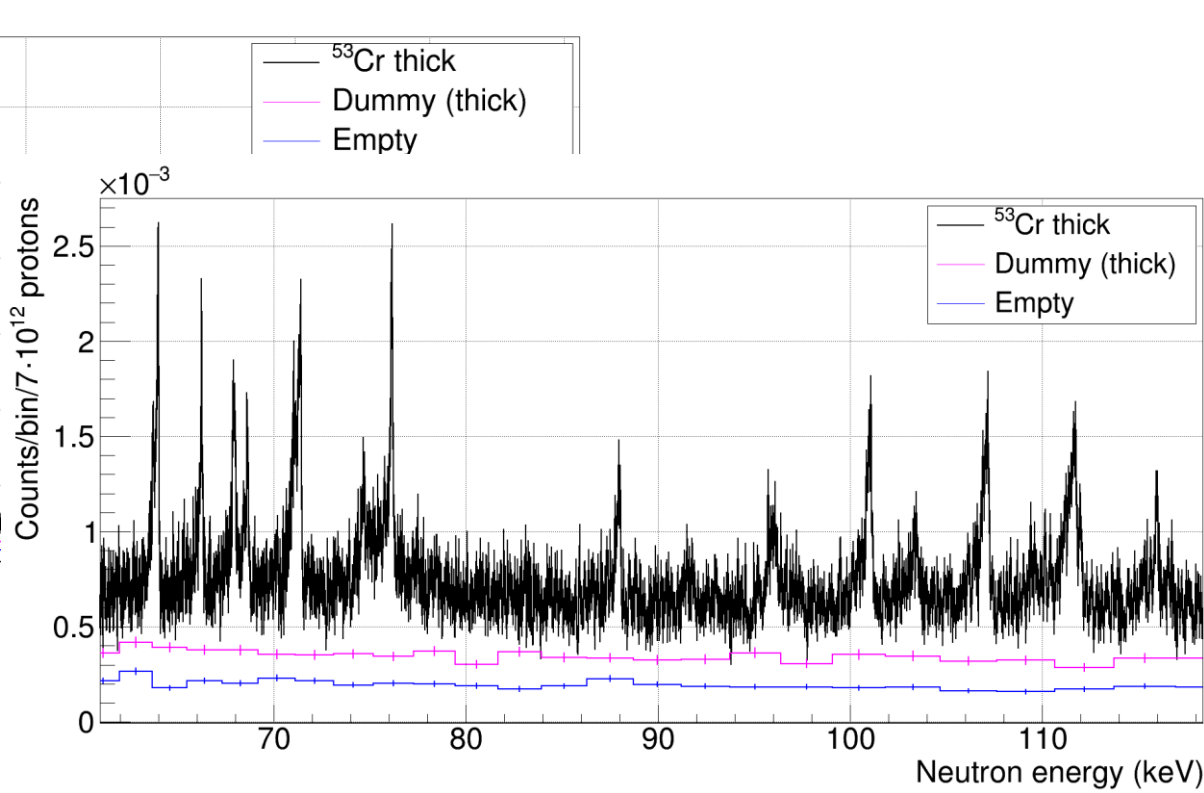
# Preliminary results ( $^{53}\text{Cr}$ -thick)



# Preliminary results ( $^{53}\text{Cr}$ -thick)



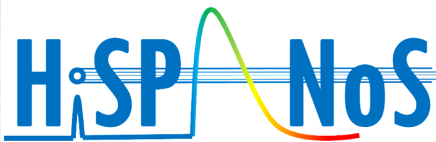
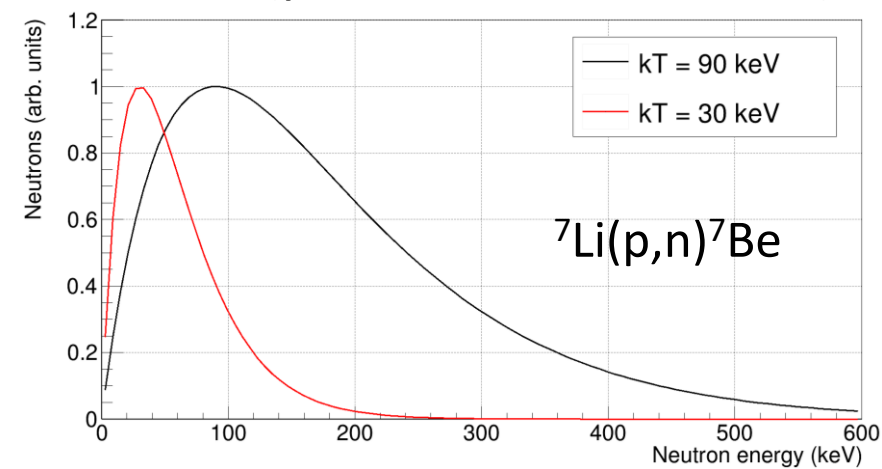
Aimed **100 keV limit reached**, with limited statistics  
(mass limited by **1,3** times )



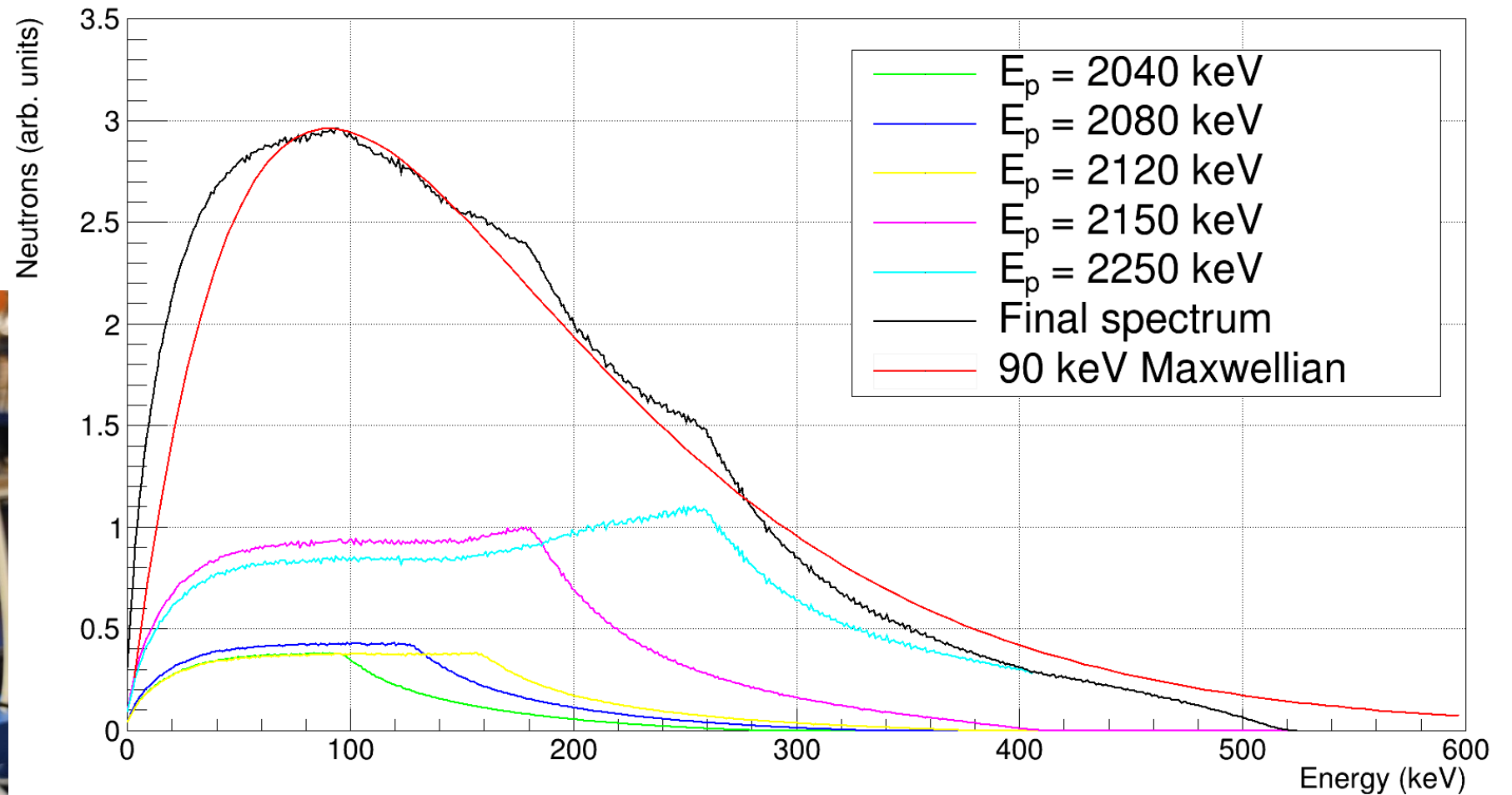
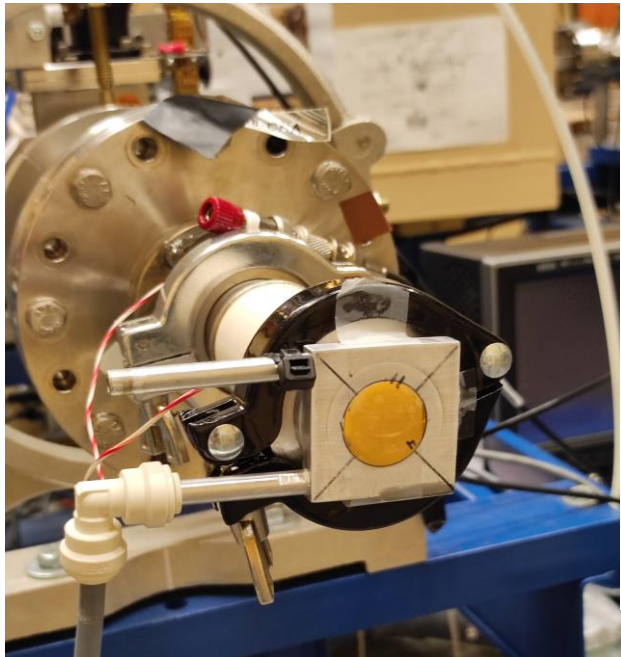
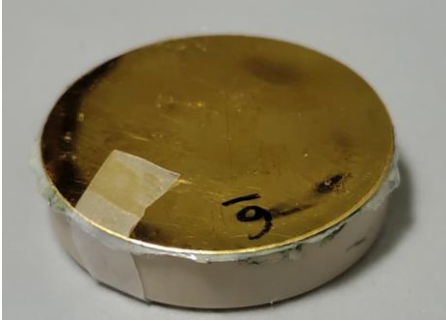
# $^{50}\text{Cr}$ MACS measurement at HiSPANoS@CNA

	Time of flight technique	Neutron activation
Energy and resonance shape	Very well defined	Limited “resolution” (MB distribution)
Absolute value	Susceptible to systematic effects	Very accurate

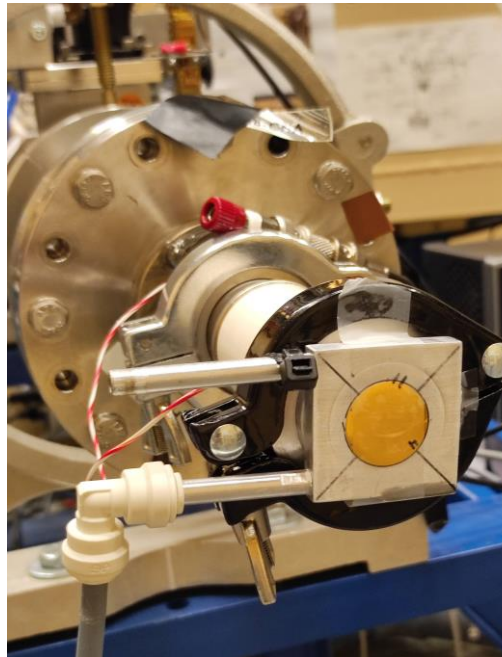
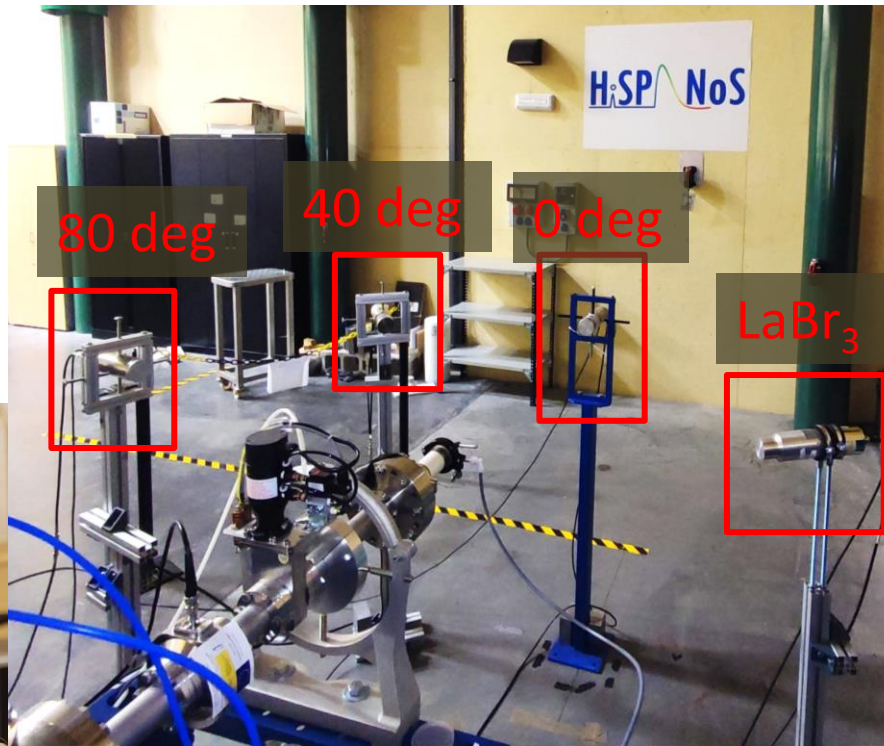
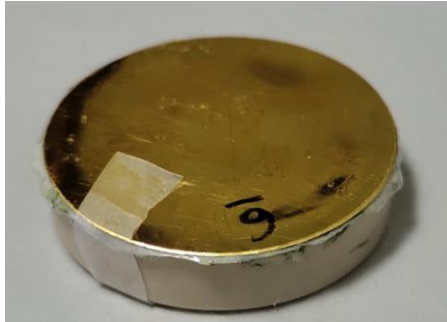
- An integral measurement can be very helpful with the analysis.
- ***“Development of a 90 keV Maxwellian neutron spectrum and measurement of the 30 & 90 keV  $^{50}\text{Cr}$  MACS for criticality safety”*** accepted within H2020-ARIEL Transnational Access (performed last week).



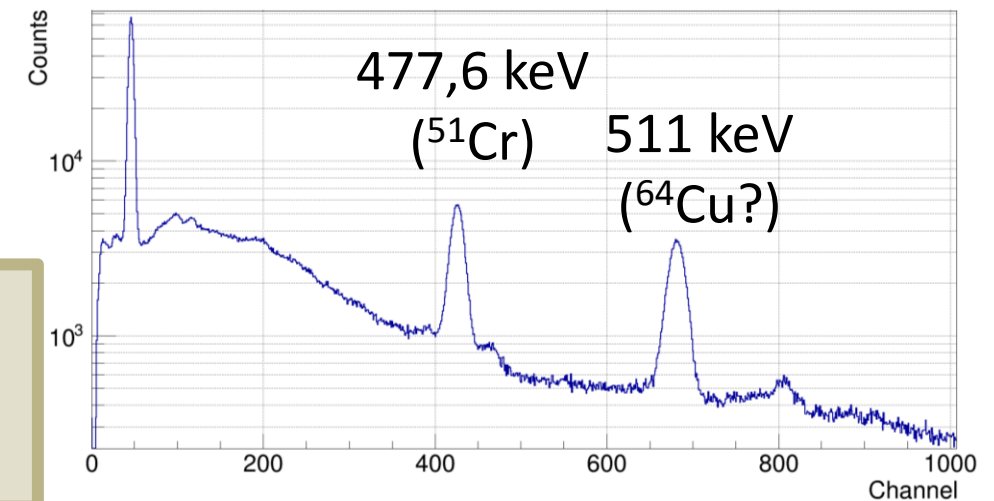
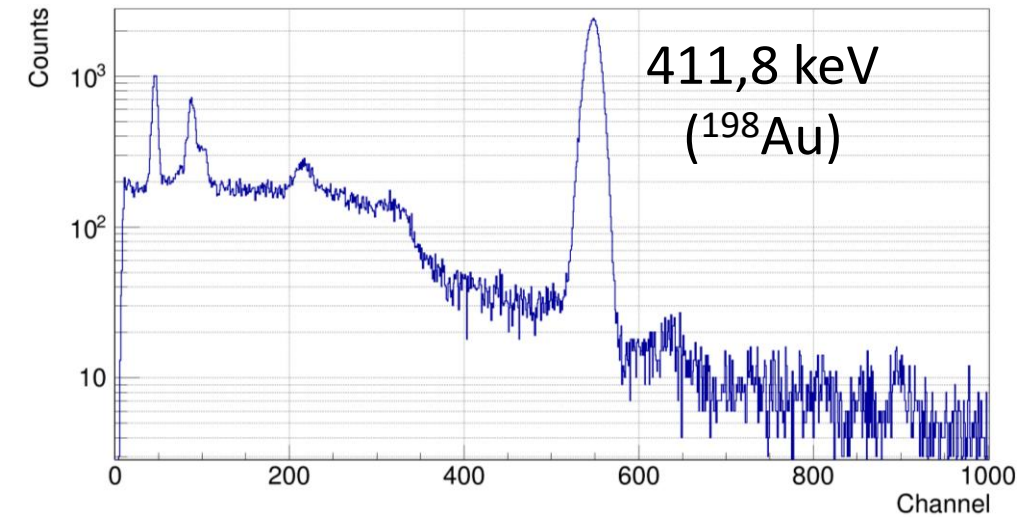
# $^{50}\text{Cr}$ MACS measurement at HiSPANoS@CNA



# $^{50}\text{Cr}$ MACS measurement at HiSPANoS@CNA



- 3 Lithium-glass neutron monitors
- 1  $\text{LaBr}_3$  for  $^7\text{Be}$  decay
- 1  $\text{LaBr}_3$  for  $^{198}\text{Au}$  and  $^{51}\text{Cr}$  decay



# Summary & Outlook

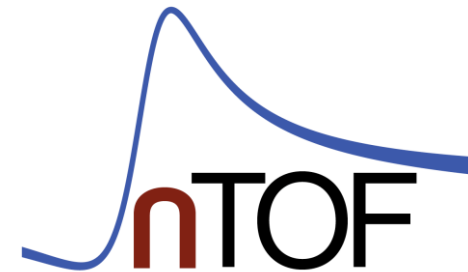
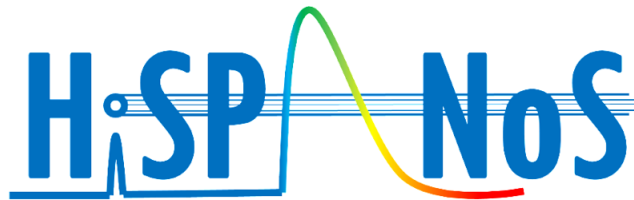
- The goal is to improve the  $^{50,53}\text{Cr}(n,\gamma)$  cross section to 8-10% accuracy at 1-100 keV.
- Two experiments:
  - n\_TOF@CERN (Summer'22)
  - HiSPANoS@CNA (March'23)
- Preliminary results show high quality data.
- Next steps:
  - Counts/pulse  $\xrightarrow{\text{PHWT}}$  Yield (capture/neutrons)
  - Identify (and correct?) systematic effects
  - Resonance analysis
- $^{50}\text{Cr}$  activation @CNA data analysis



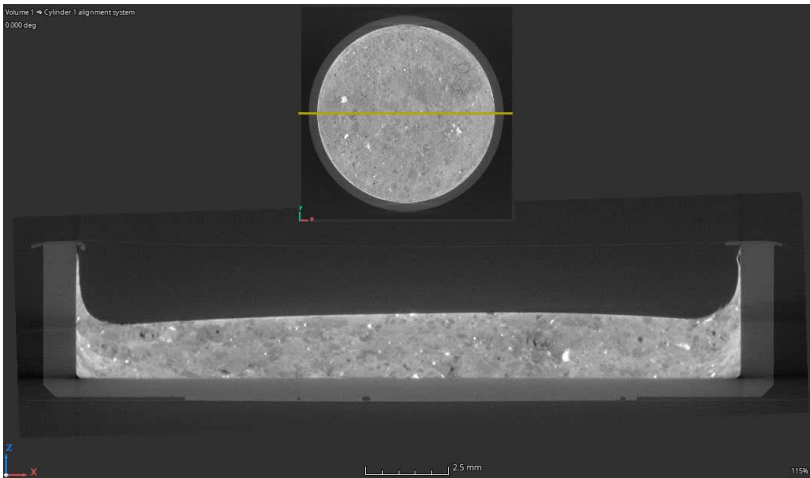
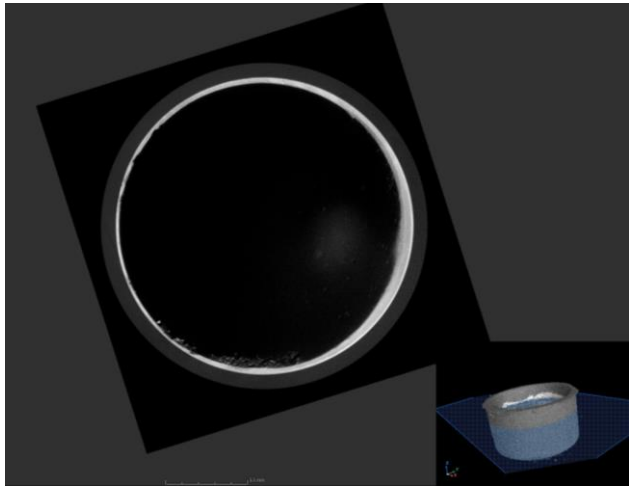
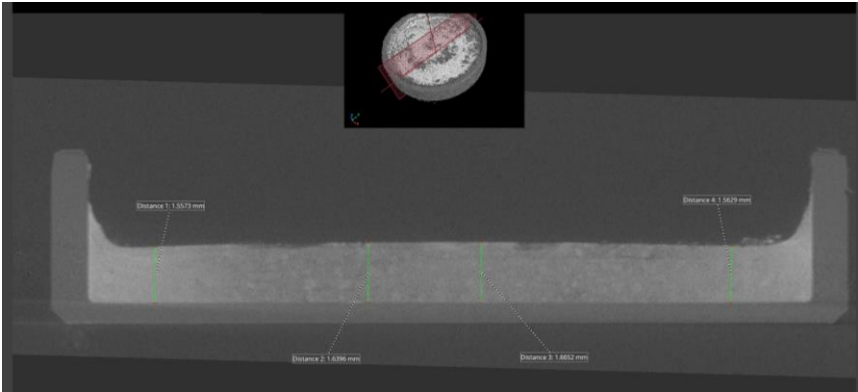
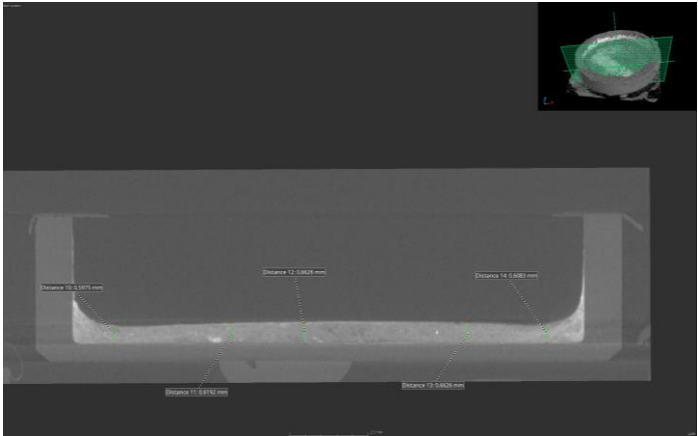
n\_TOF experiment  
data analysis (2023)

# Thank you!

Pablo Pérez Maroto  
ppmaroto@us.es

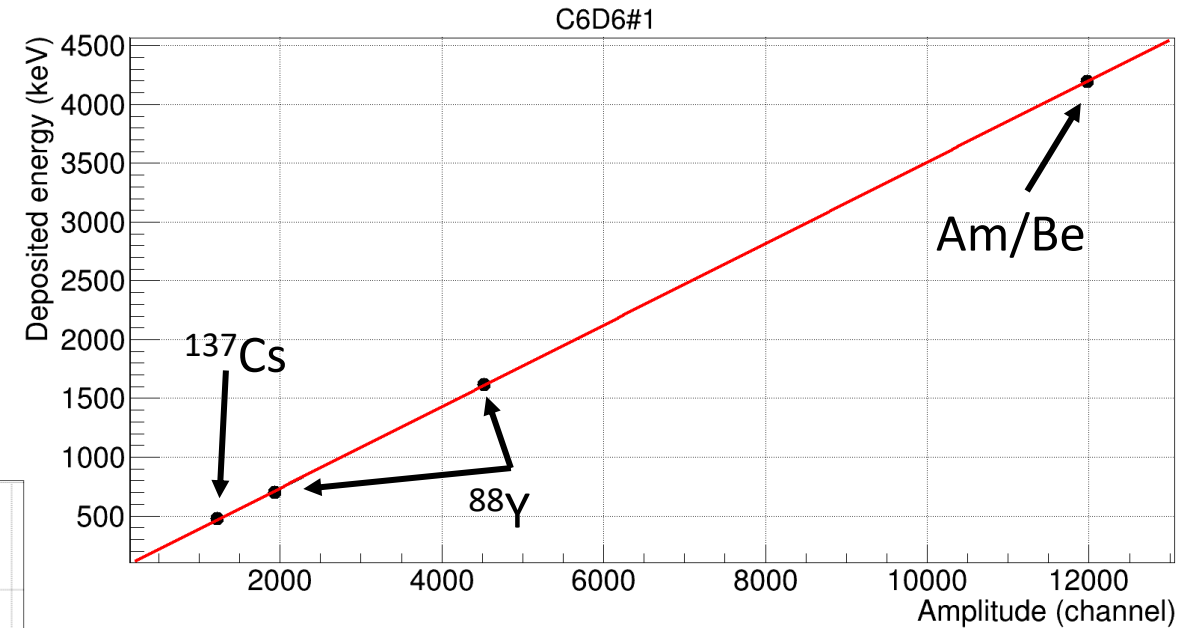
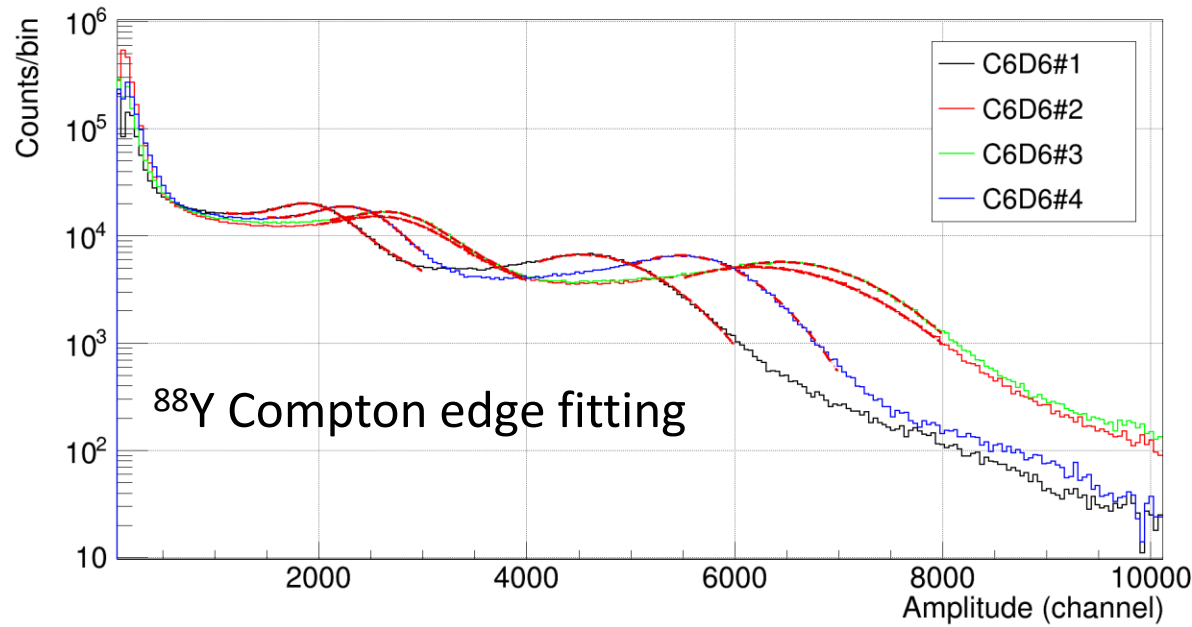


# Backup. Tomography of the samples



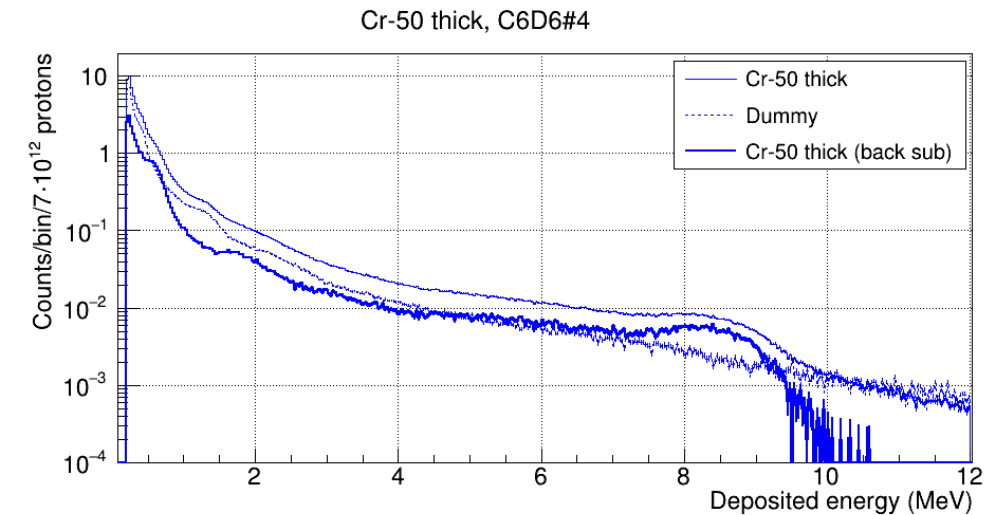
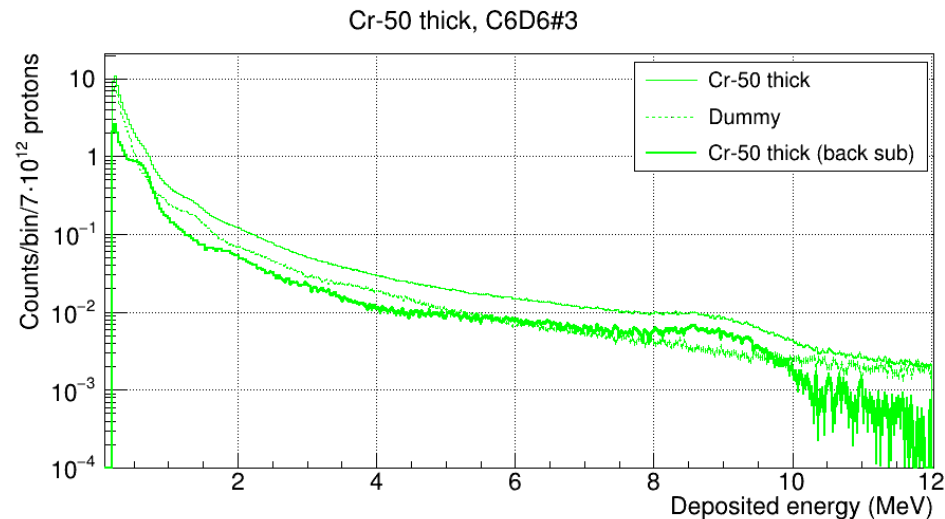
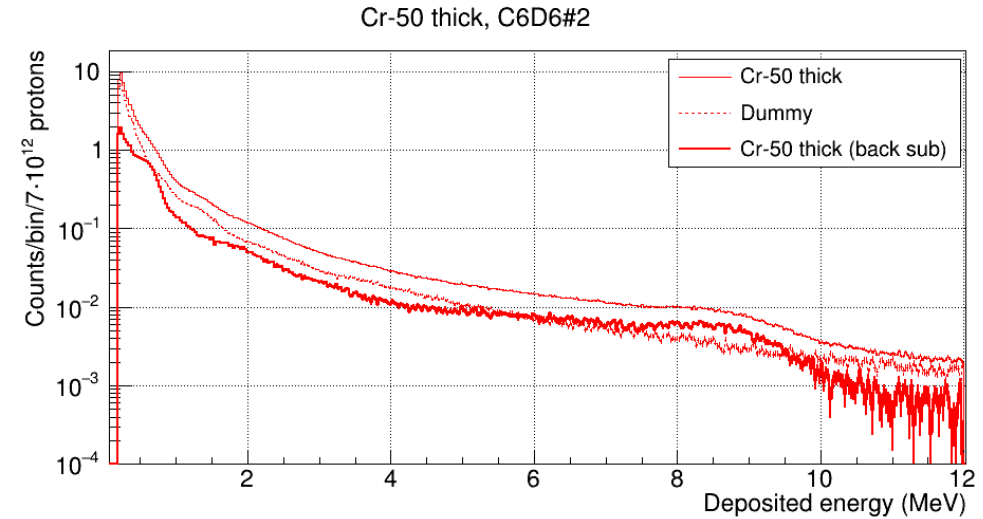
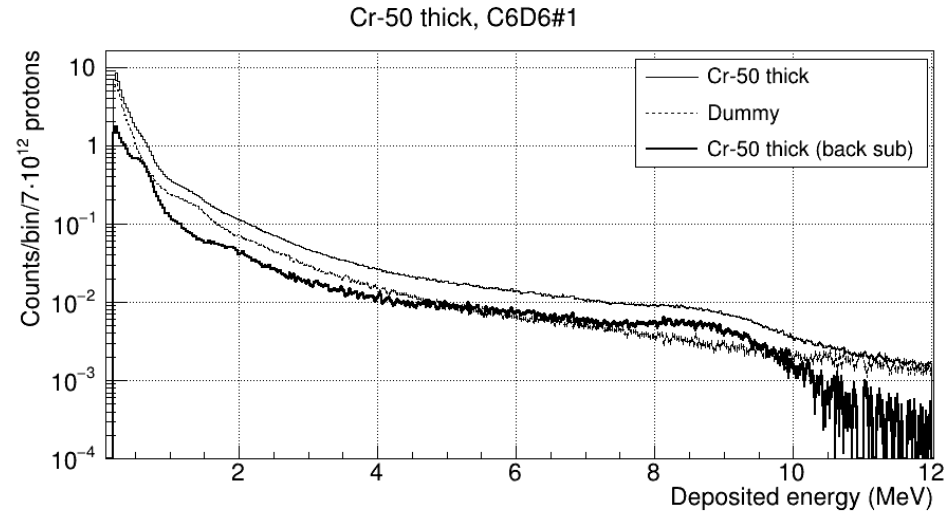
# Backup. Preliminary results: calibration

Source	Photopeak (keV)	Compton edge (keV)
$^{137}\text{Cs}$	661,7	477,3
$^{88}\text{Y}$	898,0	699,1
	1836,1	1611,8
Am-Be	4438,9	4197,3

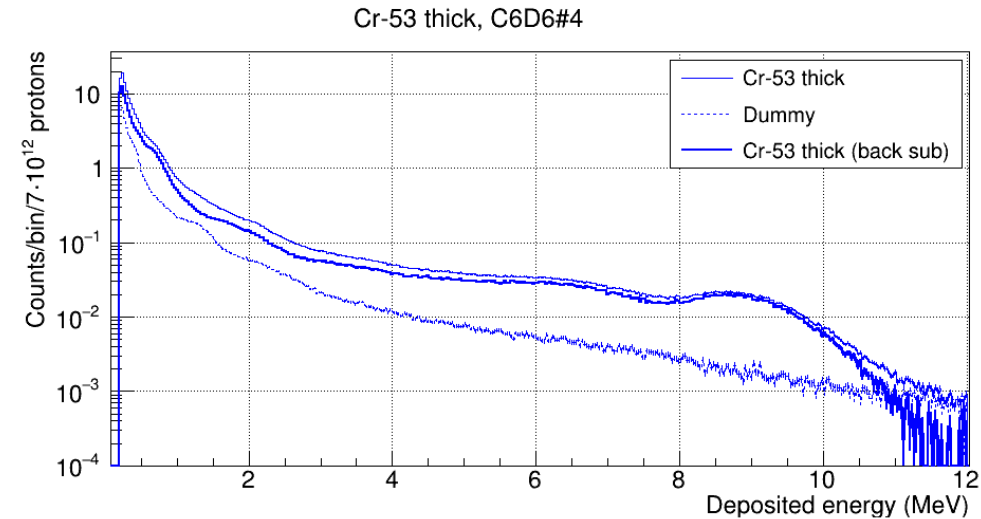
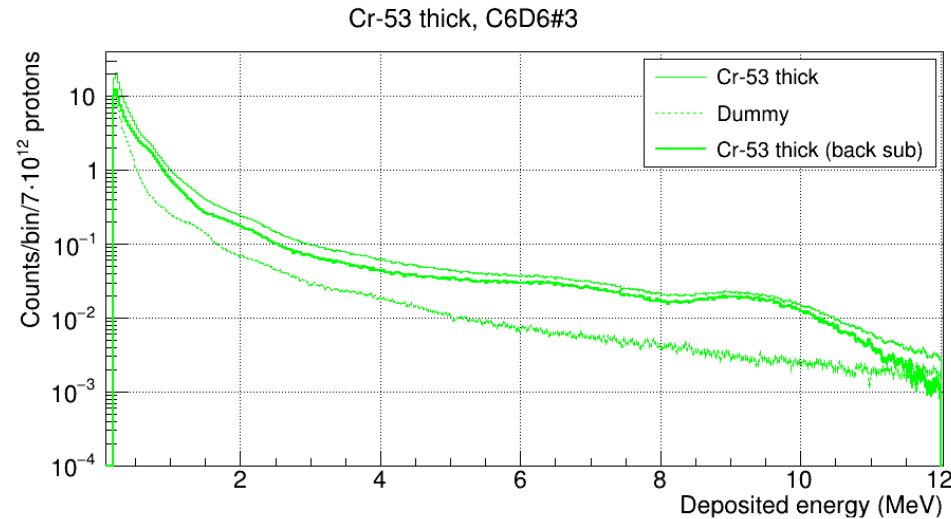
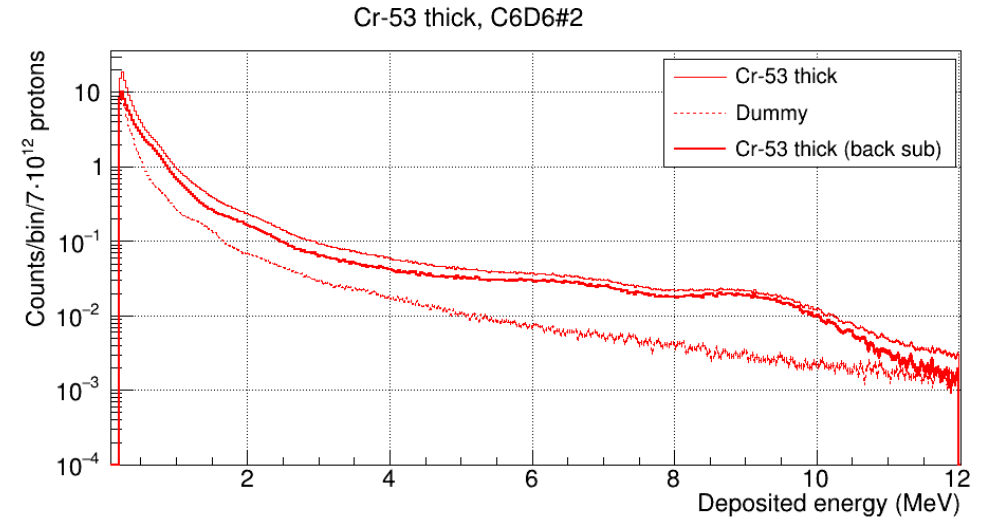
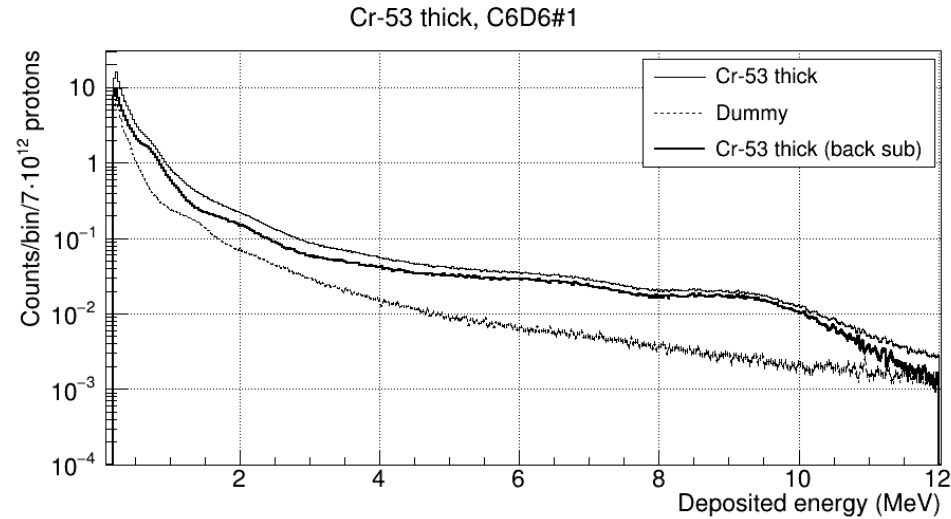


For calibration → gaussian fitting of the high-energy tail of the Compton edge

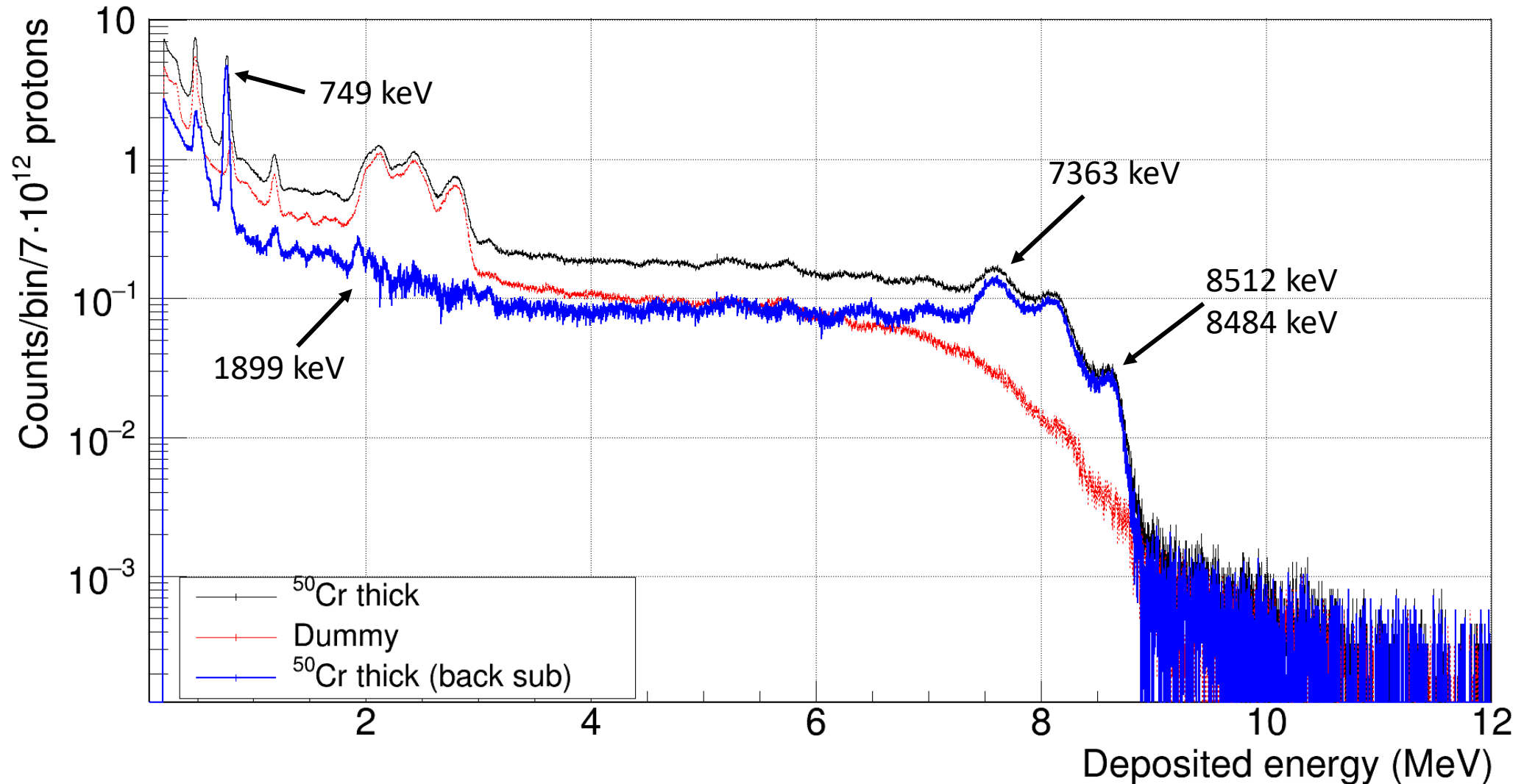
# Backup. Preliminary results: $^{50}\text{Cr}$ cascades



# Backup. Preliminary results: $^{53}\text{Cr}$ cascades



# Backup. $^{50}\text{Cr}(n,\gamma)$ cascades at EAR2



# Backup. $^{53}\text{Cr}$ (n, $\gamma$ ) cascades at EAR2

