Project in the framework of EFNUDAT

Resonance parameters for ^{197}Au +n from transmission, capture and self-indication measurements at GELINA

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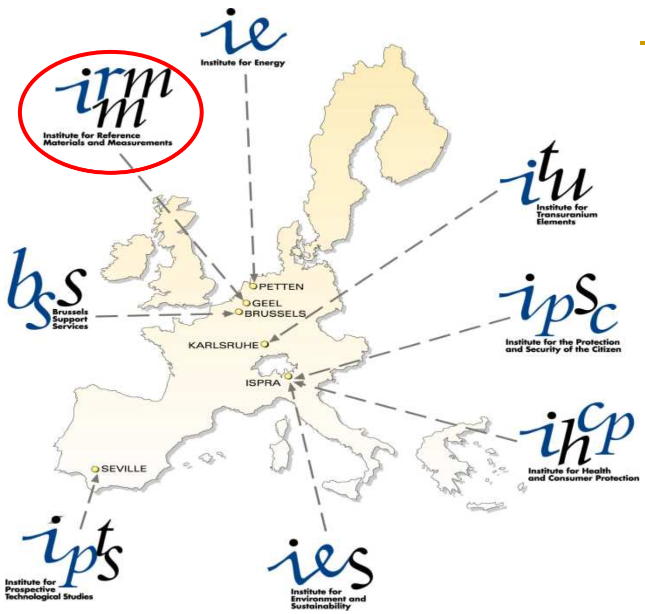

EC - JRC – IRMM

Mission:

to promote a common European measurement system in support of EU policies

JRC
EUROPEAN COMMISSION

Resonance parameters for ^{197}Au + n from transmission, capture and self-indication measurements at GELINA

- The importance of $^{197}Au(n,\gamma)^{198}Au$ reaction cross section
- Time-of-flight measurements
- Measurements techniques and detectors
- Measurements at IRMM - GELINA
- Results and conclusions

The importance of $^{197}Au(n,\gamma)^{198}Au$ "Reference cross-section"

- The $^{197}Au(n,\gamma)$ cross section is considered as a standard:
  - at thermal energy (0.025 eV) where the cross section is known with an uncertainty of 0.1%
  - between 0.2 and 2.5 MeV of 1%
- Thanks to its high cross section the resonance at 4.9 eV is used to appy the "saturated resonance technique"

- In both cases it allows to normalize capture data (used as reference in neutron facilities)
- Widely used in nuclear reactor and other applications for neutron flux determination

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The importance of $^{197}Au(n,\gamma)^{198}Au$ "Reference cross-section"

The normalization factor (N) is the link between the measured capture yield and the cross-section.

N is a factor that groups together:

- the detector efficiency
  - the capture measurement
  - the flux measurement
- the fraction of neutron flux impinging on the sample
- (…other experimental effects, if present)

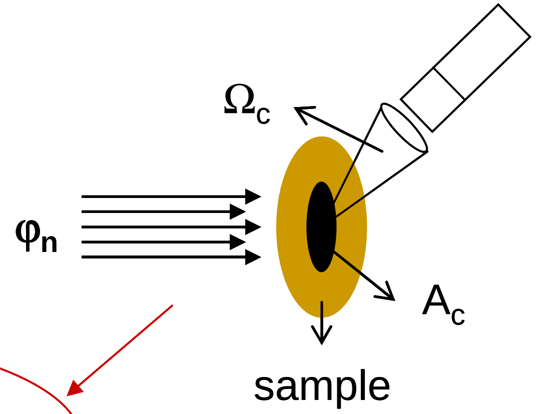
Ideally the normalization factor is a time-independent factor, which can be deduced **from a known yield:**

$$\rightarrow N = Y_{calculated}/Y_{measured}$$

The importance of $^{197}Au(n,\gamma)^{198}Au$ "Reference cross-section"

Capture detector

$$Y_{exp}(E_n) = \frac{C_c(E_n)}{\Omega_c A_c \varphi_n(E_n)}$$

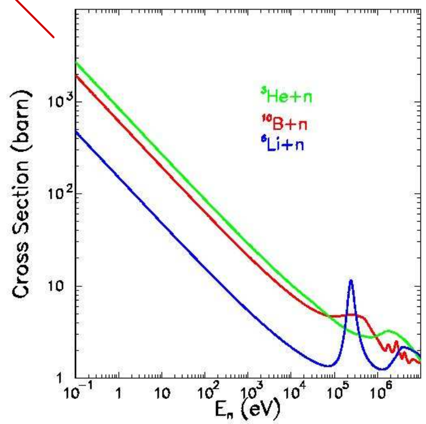


$$Y_{exp}(E_n) = N \frac{C_c(E_n)}{C_\varphi(E_n)} Y_\varphi(E_n)$$

"Flux" detector

$$Y_\varphi(E_n) = \frac{C_\varphi(E_n)}{\Omega_\varphi A_\varphi \varphi_n(E_n)}$$

$$Y_\varphi(E_n) \approx n\sigma_{st}$$



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The importance of $^{197}Au(n,\gamma)^{198}Au$ "The saturated resonance techniques"

A resonance is saturated when all incoming neutrons are absorbed in the sample

This technique requires:

- $n\sigma_{tot} >> 1$
- $\Gamma_\gamma >> \Gamma_n$

^{197}Au resonance at 4.9 eV:

- $\sigma_{tot}(4.9\ eV) \sim 3\times10^4$ barns
  Minimum thickness ≈ 30 μm
- $\Gamma_\gamma = 124$ meV; $\Gamma_n = 15.2$ meV

Remark: correction for gamma-ray attenuation in sample[2]

Normalization does **not** depend on the resonance parameters[2], i.e. independent of cross section value

→ Absolute Measurement

[2] A. Borella et al., NIM A **577** (3) (2007) 626

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Time-Of-Flight measurements

See lecture of
Dr. Peter Siegler, EC-JRC-IRMM
Neutron cross section measurements in the resonance region at GELINA

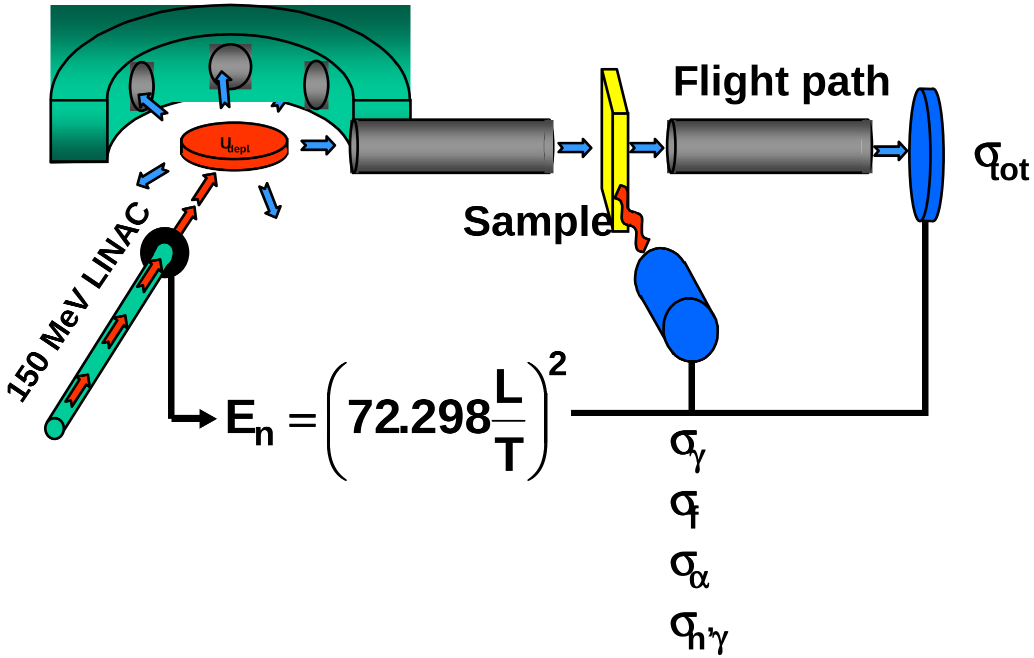
The Time-Of-Flight (TOF) technique requires a pulsed neutron source:

- **charged particles on a target (electron Bremsstrahlung isotropic emission: $\Phi_n(L) \propto 1/L^2$)**

Related Problems

- **Neutrons overlap**
- **Dead time**
- **Resolution**

$$\frac{\Delta E_n}{E_n} = 2 \times \sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$



Time-Of-Flight measurements
Limitations due to the resolution

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Area ≈ Independent of resolution

	Area	Resonant Part	
	$E_0, \Gamma_n, \Gamma_\gamma, g$	$\Gamma_n \gg \Gamma_\gamma$	$\Gamma_\gamma \gg \Gamma_n$
A_{tot}(thin)	$ng\Gamma_n$	$\approx ng\Gamma_n$	$\approx ng\Gamma_n$
A_{tot}(thick)	$\sqrt{ng\Gamma_n\Gamma}$	$\approx \sqrt{ng}\Gamma_n$	$\approx \sqrt{ng\Gamma_n\Gamma}$
A_γ(thin)	$ng\frac{\Gamma_n\Gamma_\gamma}{\Gamma}$	$\approx ng\Gamma_\gamma$	$\approx ng\Gamma_n$
A_n(thin)	$ng\frac{\Gamma_n\Gamma_\gamma}{\Gamma}$	$\approx ng\Gamma_n$	$\approx ng\frac{\Gamma_n\Gamma_n}{\Gamma}$
R_γ	$\sqrt{\frac{\Gamma}{n_t g\Gamma_n}}$	$\approx \frac{1}{n_t g}$	$\approx \sqrt{\frac{\Gamma}{n_t g\Gamma_n}}$

$$
\begin{aligned}
f_{obs}^{Cap} &= f(E_0, \Gamma_\gamma, \Gamma_n, J, \ell) \\
f_{obs}^{Tra} &= f(E_0, \Gamma_\gamma, \Gamma_n, J, \ell) \\
f_{obs}^{S-I} &= f(E_0, \Gamma_\gamma, \Gamma_n, J, \ell)
\end{aligned}
$$

Combination of experimental data required

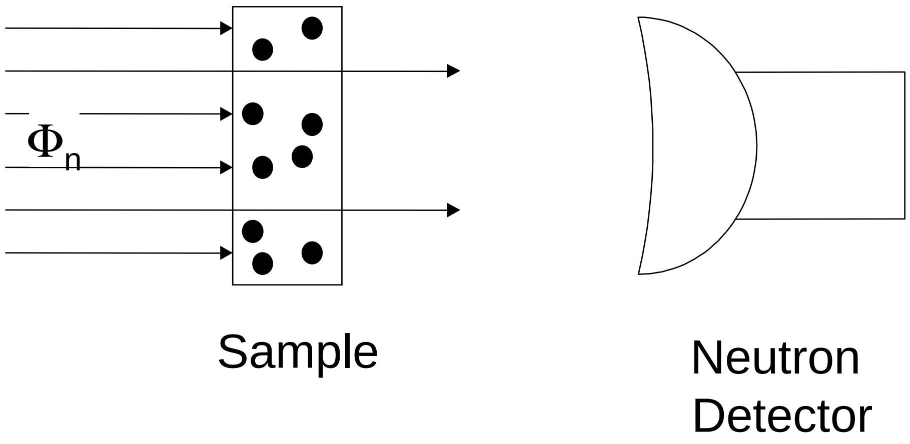
Self-indication always complementary

Measurement techniques and detectors

Transmission experiment

$$T = \frac{C_{in}}{C_{out}} \cong e^{-n\sigma_{tot}}$$

- Incoming neutron flux cancels
- Detection efficiency calcels



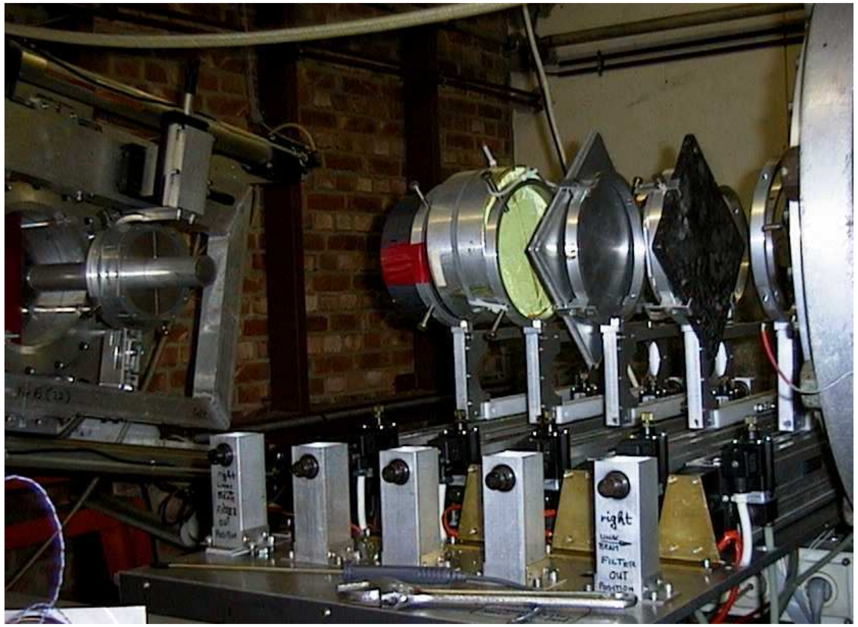
Good Geometry (collimation)

1. All detected neutrons have traversed the sample
2. Neutron scattered in the sample do not reach the detector

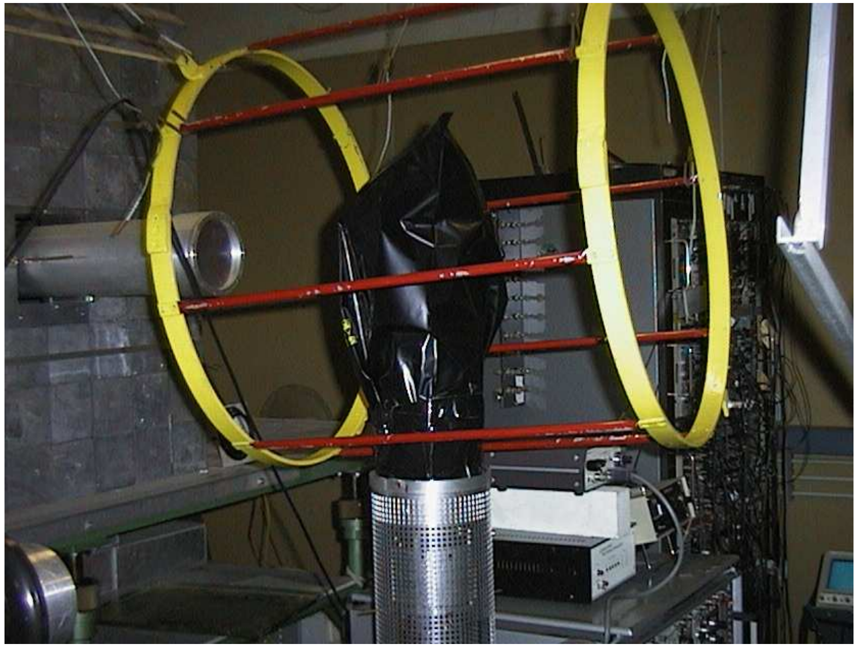
→ Direct relation between T and σ_{tot}

Measurement techniques and detectors

Transmission experiment
Set up



Sample



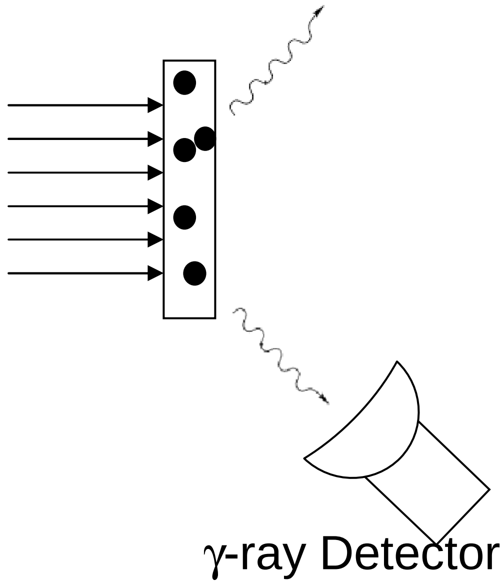
Detector

Measurement techniques and detectors

Capture experiment

$$C_r = \varepsilon_r Y_r A_r \varphi_r$$

- φ_r Neutron Fluence Rate
- ε_r Detection efficiency (for a reaction event)
- A_r effective area
- Y_r reaction yield (beam fraction undergoing the partial Reaction)



Complex relation between C_r and Y_r

Y_r related to σ_r

$$Y_r = (1 - e^{-n_r \sigma_t}) \frac{\sigma_r}{\sigma_t}$$

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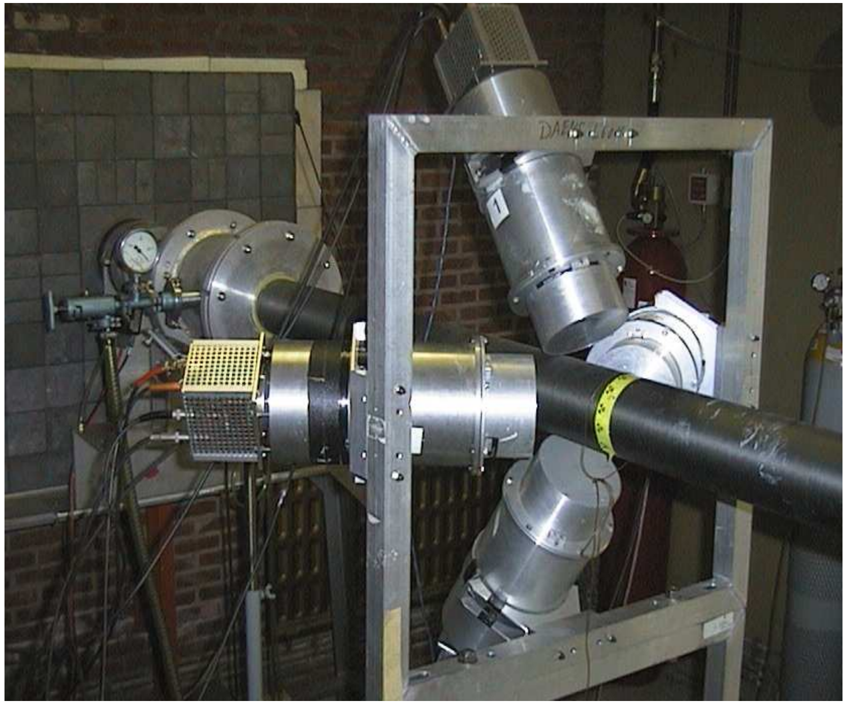
Measurement techniques and detectors

Capture experiment
Set up

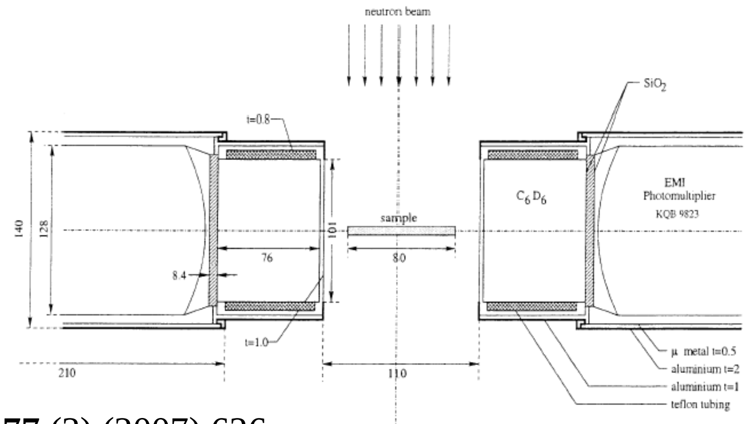


Detector

Technique: Total Energy Detector

Type: C_6D_6 and Weighting Function

- \+ Correction for the resonance strength
- \+ Correction for the neutron sensitivity

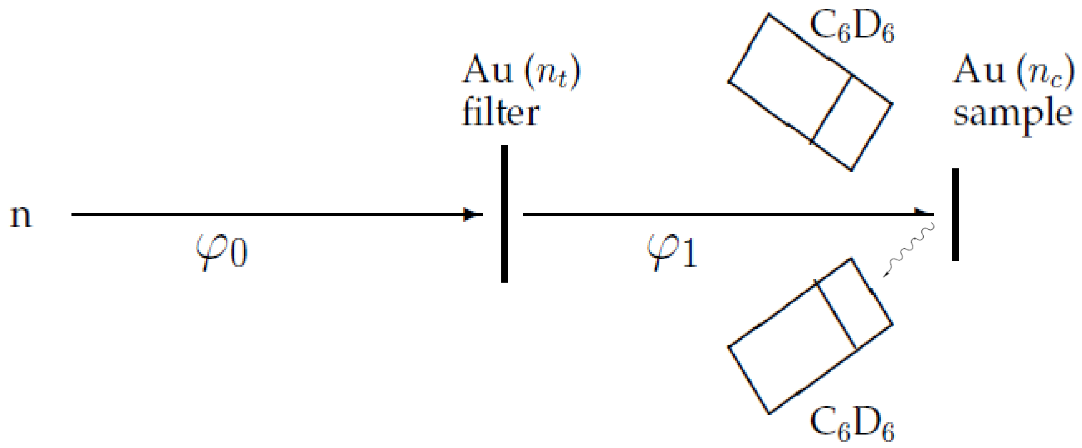


A. Borella et al., NIM A **577** (3) (2007) 626

Self-Indication Measurement

- Combination of capture and transmission principle
- Au sample as a capture and transmission sample

$$C_{SI} = \varepsilon_c Y_c(E_n) e^{-n_t \sigma_{tot}} \varphi_0(E_n)$$



Measurement at IRMM – GELINA

Au transmission { **Resonance energy** / **$g\Gamma_n$**

Flight path	Frequency	Sample	Overlap filters	Background filters
49.34	50Hz	10.0 μm	Cd	Na,Co
49.34	50Hz	20.0 μm	Cd	Na,Co
49.34	50Hz	50.0 μm	Cd	Na,Co
49.34	800Hz	3.0 mm	^{10}B	Na,Co
26.45	50Hz	3.0 mm		Pb, Na, Co, Rh
26.45	400Hz	3.0 mm	^{10}B	Pb, Na, Co, Rh
26.45	800Hz	3.0 mm	^{10}B	Pb, Na, Co, Rh

- **Different flight path and repetition rate (50 and 800 Hz)**
- **Several Au sample of different thickness (10 μm up to 3 mm thick samples)**

Data reduction packages AGL and AGS (Analysis of Generic TOF Spectra) with full propagation of uncertainties and complete covariance matrix

Maximum dead time correction 2%

Measurement at IRMM – GELINA

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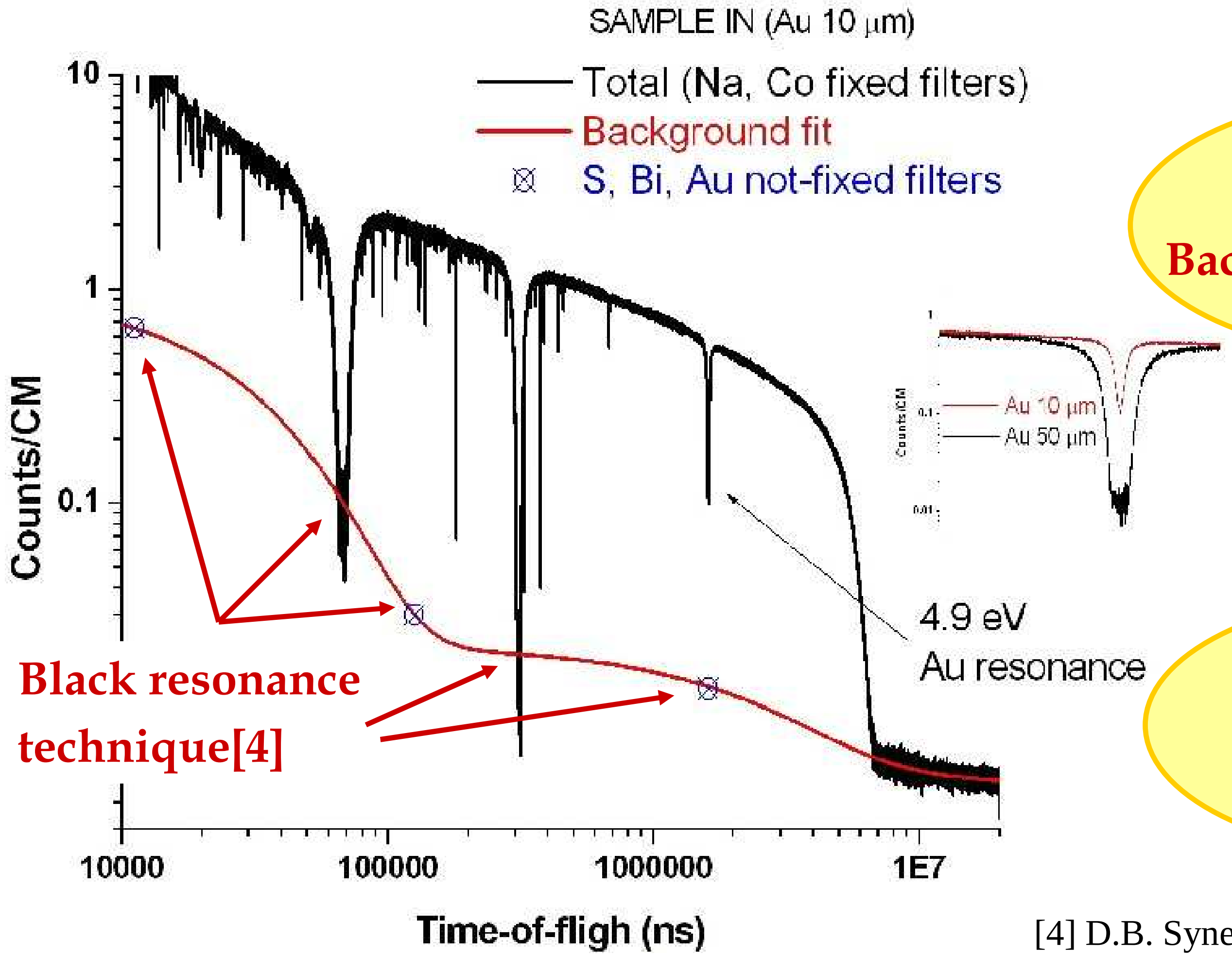
Au transmission → Sample in



Sample out
Background level ≈ 1%

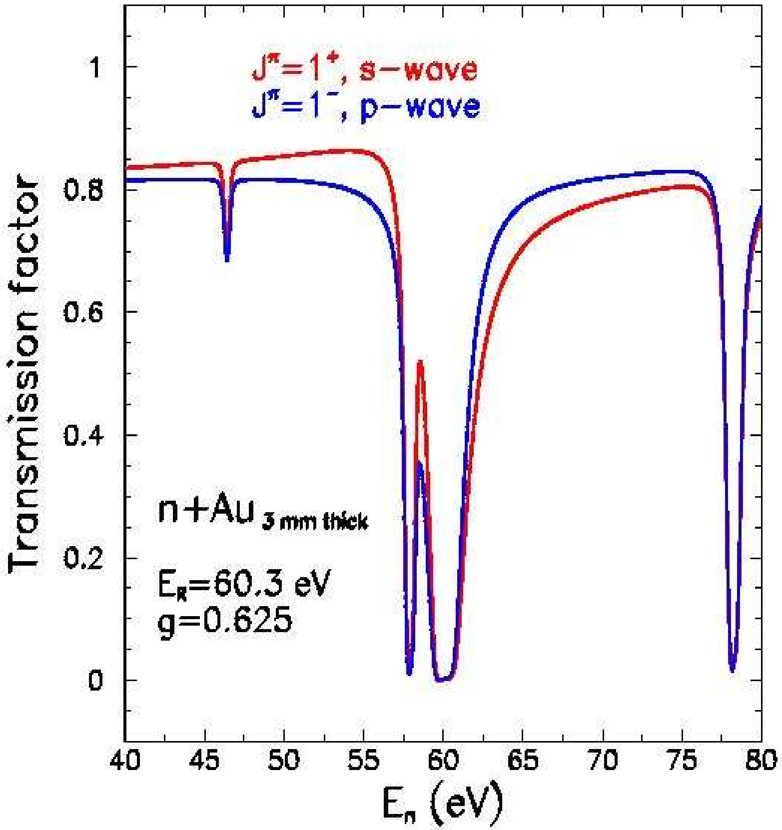
Background level at 4.9 eV ≈ 10%

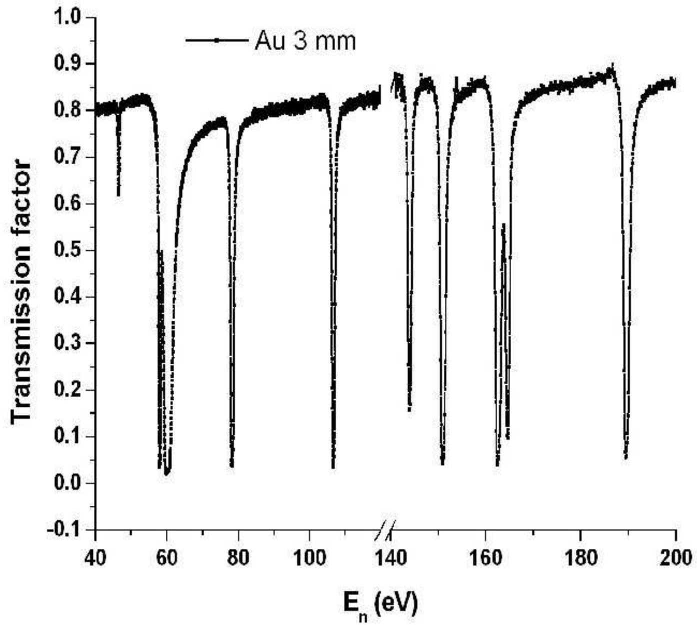
[4] D.B. Syne., NIM **198** (1982) 357-364

Measurement at IRMM – GELINA

Au transmission on a thick sample:

- identification of s-wave resonances





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Au capture measurements

	Sample	Overlap	filters Background
FP5-12m 50 Hz 4 C_6D_6 "pyramid"	T2 - 1.0 mm		Co, Bi, Na
	C2 - 0.5 mm		Co, Bi, Na
	C2 - 0.5 mm		W, Co, Bi, Na
	C2 - 0.5 mm		Ag, W, Co, Bi, Na
	C2 - 0.5 mm	Cd	Co, Bi, Na
	C1 - 0.1 mm		Co, Bi, Na
	S1 - 0.05 mm		Co, Bi, Na
	N2 - 0.01 mm		Co, Bi, Na
	N3 - 0.005 mm		Co, Bi, Na
FP5-12m 50 Hz 2 C_6D_6 "cylinder"	C2-0.5mm		Co, Bi, Na
	C2-0.5mm	Cd	Co, Bi, Na
FP15-30m 50 Hz 2 C_6D_6 "cylinder"	T2 - 1.0 mm	Cd	Na,Pb
	C2 - 0.5 mm	Cd	Na,Pb
	C2 - 0.5 mm	Cd	W, Co, Na, Pb
	C1 - 0.1 mm	Cd	Na,Pb
	N17 - 0.1 mm	Cd	Na,Pb
	S1 - 0.05 mm	Cd	Na,Pb
	N2 - 0.01 mm	Cd	Na,Pb
	N3 - 0.005 mm	Cd	Na,Pb
FP15-30m 800 Hz 2 C_6D_6 "cylinder"	T2 - 1.0 mm	^{10}B	Pb, Al
	C2 - 0.5 mm	^{10}B	Pb, Al
	T1 - 0.1 mm	^{10}B	Pb, Al
	T1 - 0.1 mm	^{10}B	Pb, Al, S
	T1 - 0.1 mm	^{10}B	Pb, Al, Na
FP14-60m 800 Hz 4 C_6D_6 "cylinder"	C1 - 0.1 mm	Cd	Co, Na

- Different flight path, repetition rate (50 and 800 Hz) and C_6D_6 detectors
- Several Au sample of different thickness (10 mm up to 1 mm thick samples)
- Data reduction packages AGL and AGS (*) (Analysis of Generic TOF Spectra) with full propagation of uncertainties and complete covariance matrix
- Maximum dead time correction 20%

(*)Accepted by IAEA for EXFOR

Measurement at IRMM – GELINA

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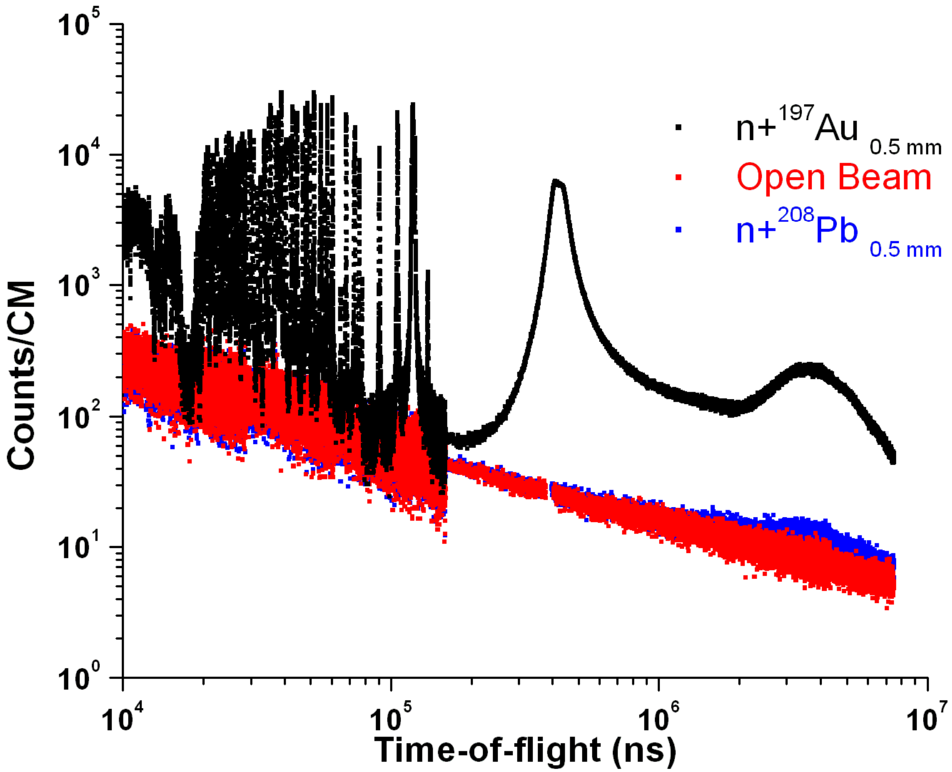
Au capture measurements (capture)

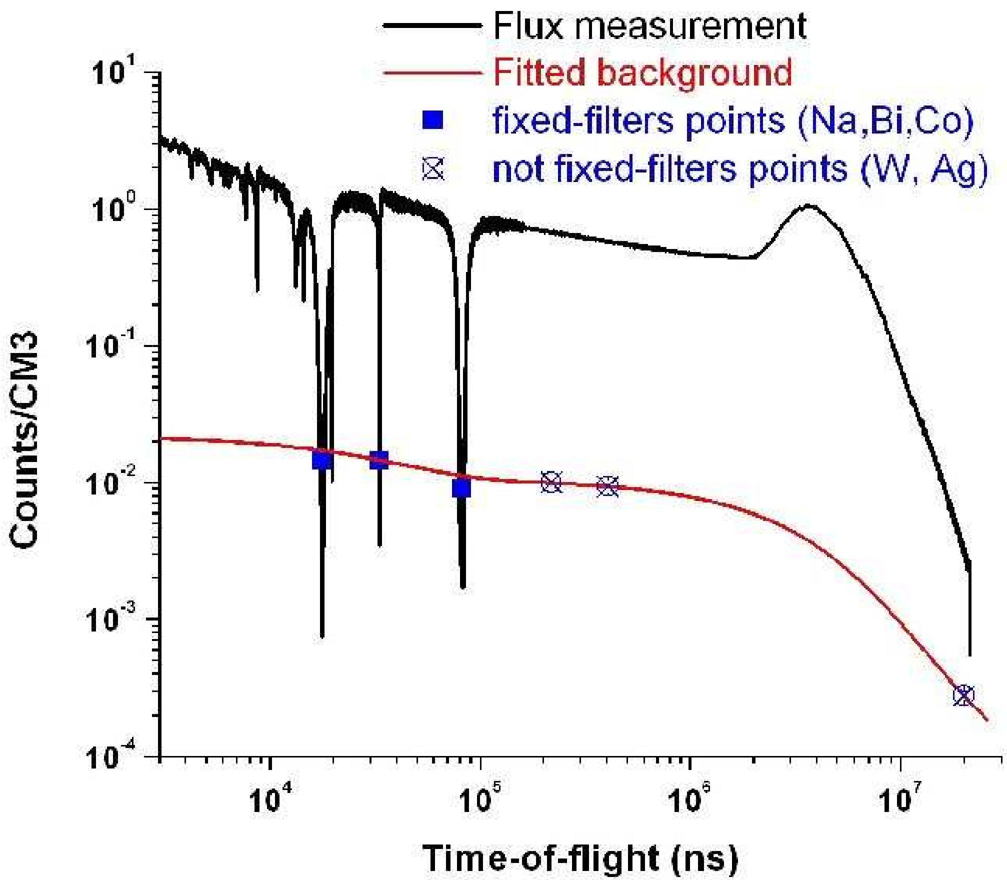


Neutron sensitivity very low

Good approximation for background

Measurement at IRMM – GELINA

Au capture measurements (flux)

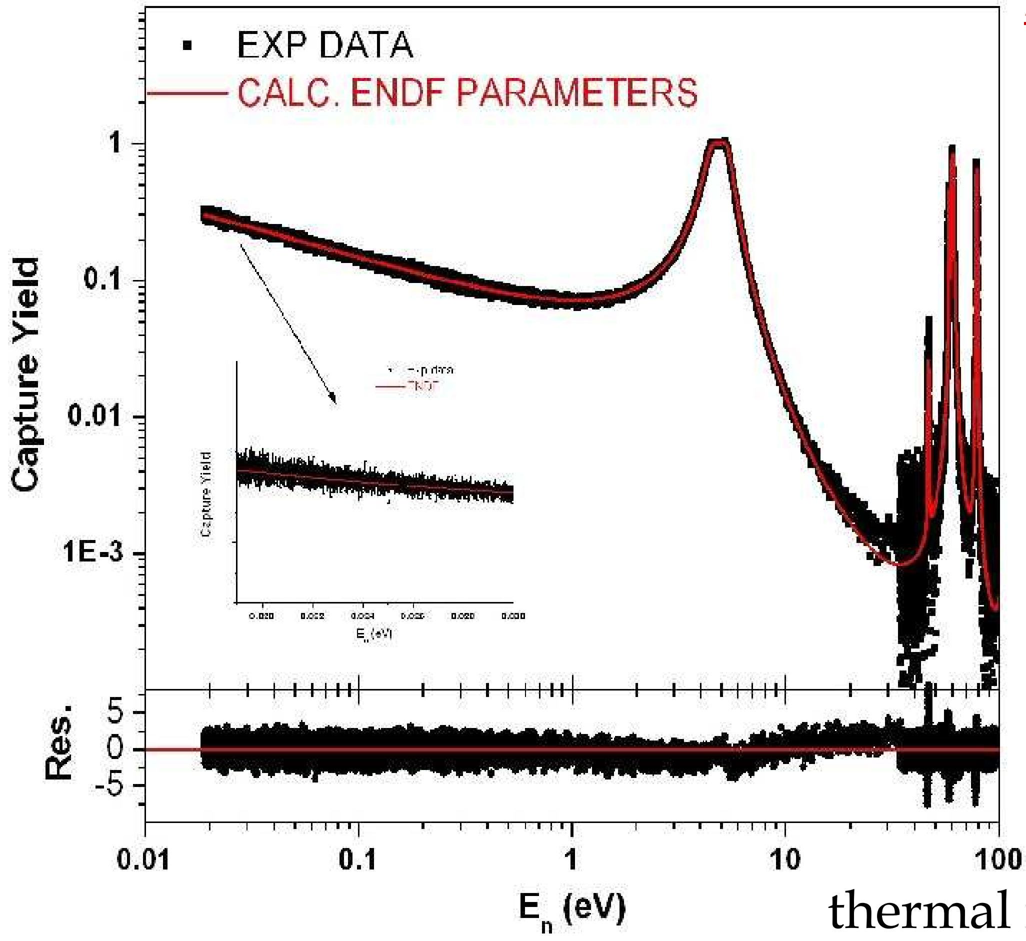


Background level ≈ 1%

Measurement down to the thermal energy

Measurement at IRMM – GELINA

Au capture measurements at 12 m flight path



Normalization: saturated resonance at 4.9 eV

Thermal cross section reproduced within 1%

thermal region → negative resonance(s)

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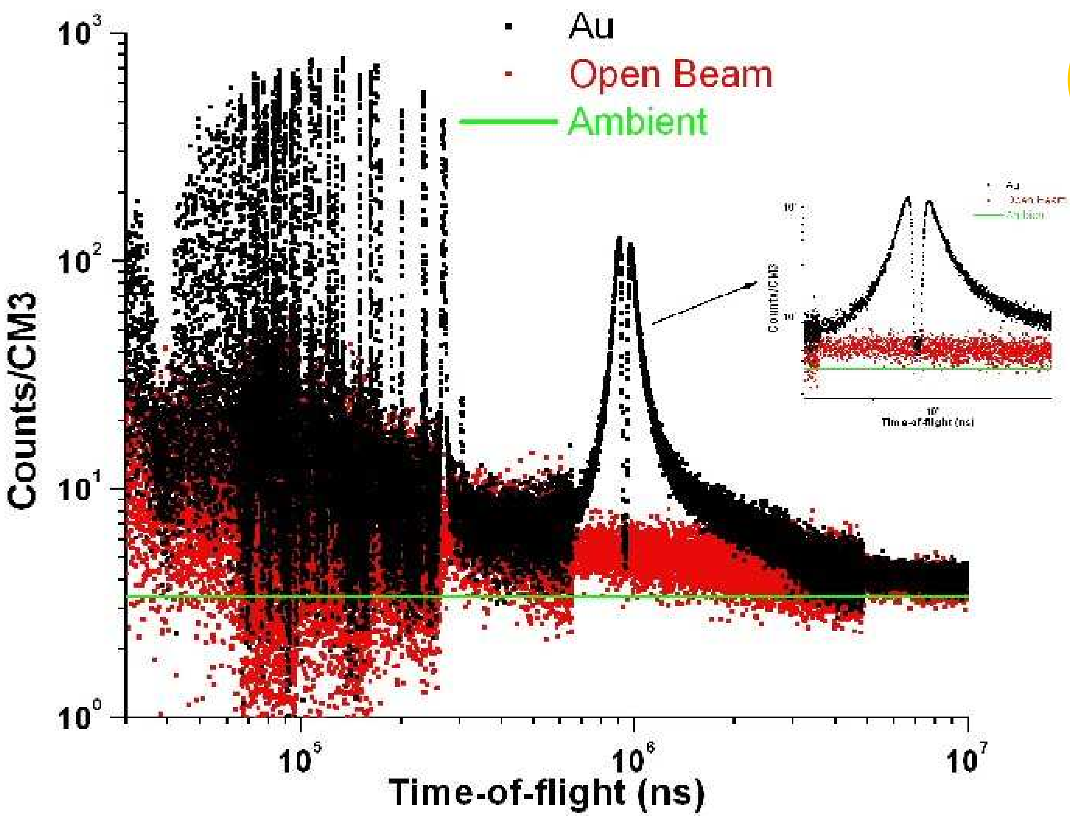
Measurement at IRMM – GELINA

Au self-indication measurement I



1° measurement at GELINA

- 28 m flight path
- Au samples 0.1 mm thick

Good determination of the background

(for saturated resonances)

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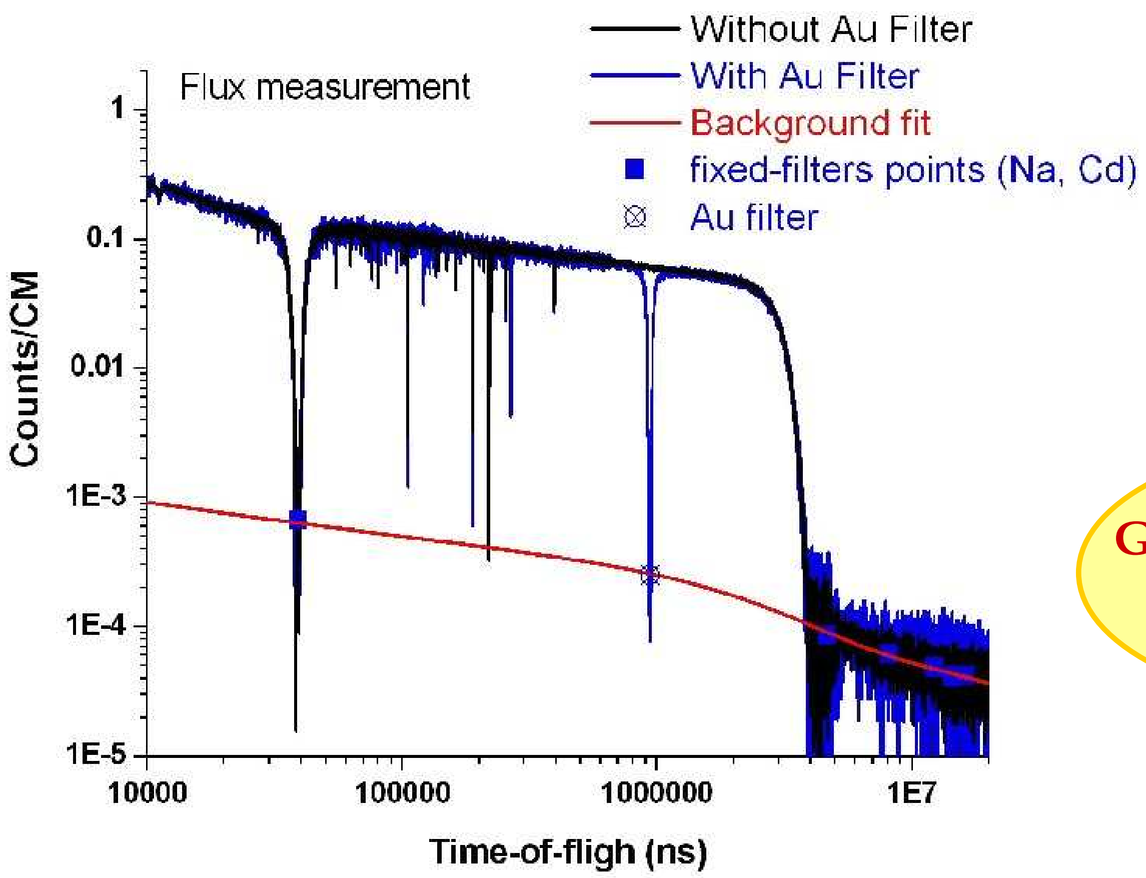
Measurement at IRMM – GELINA

Au self-indication measurement II



Good determination of the background

Measurement at IRMM – GELINA

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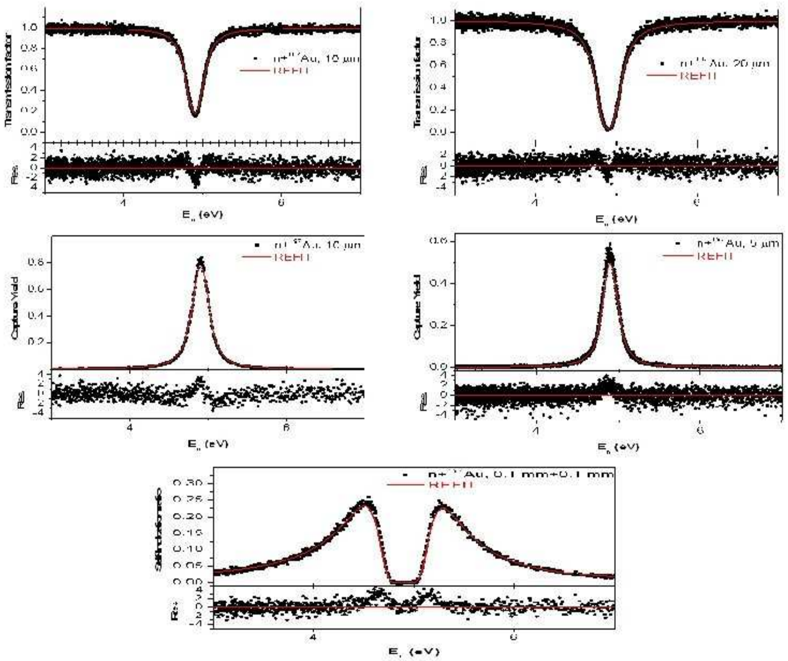
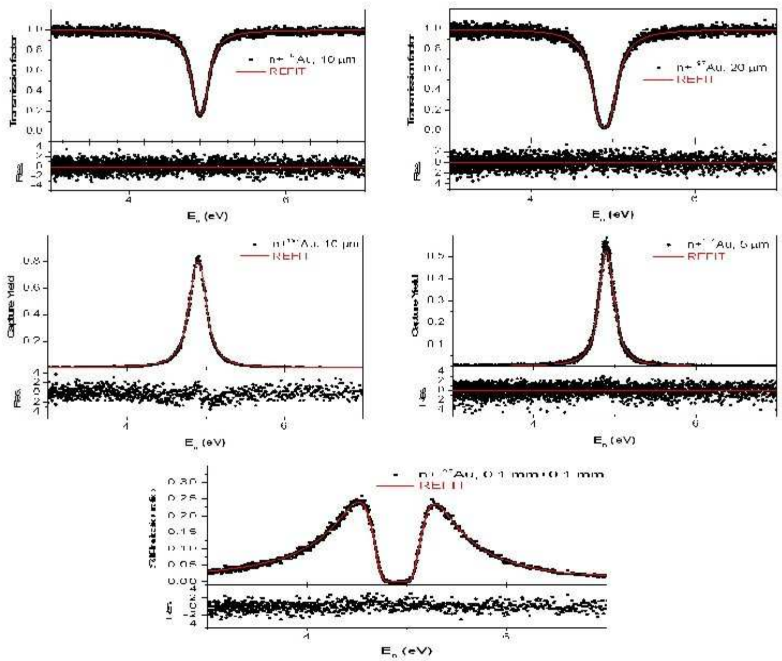
Resonance shape analysis (transmission, capture and Self-Indication)

1st Au resonance

J = 1



J = 2



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Measurement at IRMM – GELINA

Resonance shape analysis with χ^2 evaluation for the ˆ1st Au resonance

Measurement	sample thickness	χ^2 J=1	χ^2 J=2
Transmission	10 μm	1.11	0.97
Transmission	20 μm	1.09	0.98
Self-indication	0.1 mm	**1.66**	**1.04**
Capture	5 μm	1.28	1.16
Capture	10 μm	1.27	1.20
Global	-	1.28	1.07

The self-indication measurement presents the larger variation on $\chi 2$

→ **Self-indication** needed to determine the spin factor

Results

Determination of resonance parameters up to 200 eV:

- **Validation of the results with the measurement of the cross section at thermal energy**
- **Deterministic assignment of the total angular momentum of 9 resonances**
- **Determination of the parameter of 12 resonances, in particular for the 4.9 eV resonance with an accuracy better than 0.5%**

Summary and conclusions

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- This work is intended to provide an important contribution to an ongoing effort towards the extension of the energy region in which Au(n,γ) is considered as a standard. In particular in the resolved resonance region.

- In the framework of the EFNUDAT project we have performed a series of transmission, capture and self-indication measurements at the GELINA time-of-flight facility, in different conditions of neutron beam, background, flight path length, experimental set up, data acquisition, …;

- Present data valuable input for new evaluation.