



# Evaluation of stable W isotopes in the resolved resonance region



## Joint Research Centre

Institute for Reference Materials  
and Measurements (IRMM)

<http://irmm.jrc.ec.europa.eu>

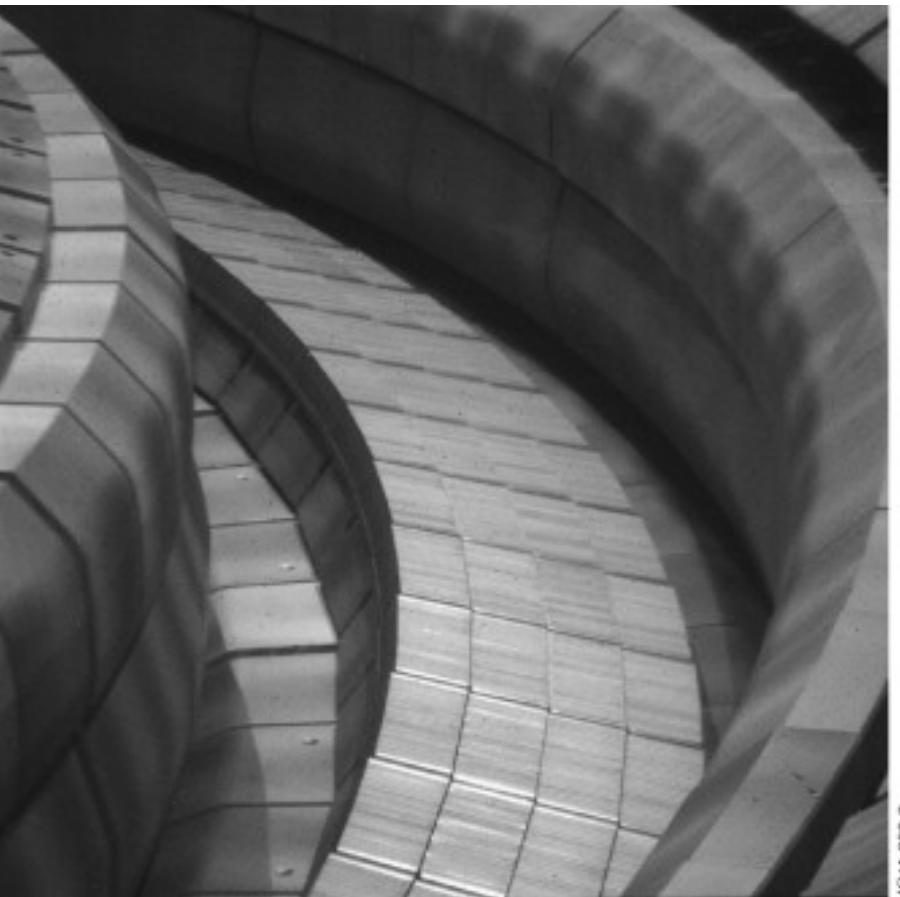


# Outline



- Motivation of the re-evaluation
- Description of the GELINA facility
- Transmission and capture experiments
- Samples
- Data reduction and background treatment
- Starting values of Resonance Parameters and other input data
- Results and conclusions

# importance of neutron cross section libraries for W



**Astrophysics**

**Dosimetry** →  $^{186}\text{W}$  (n, γ)

**Fission technology**

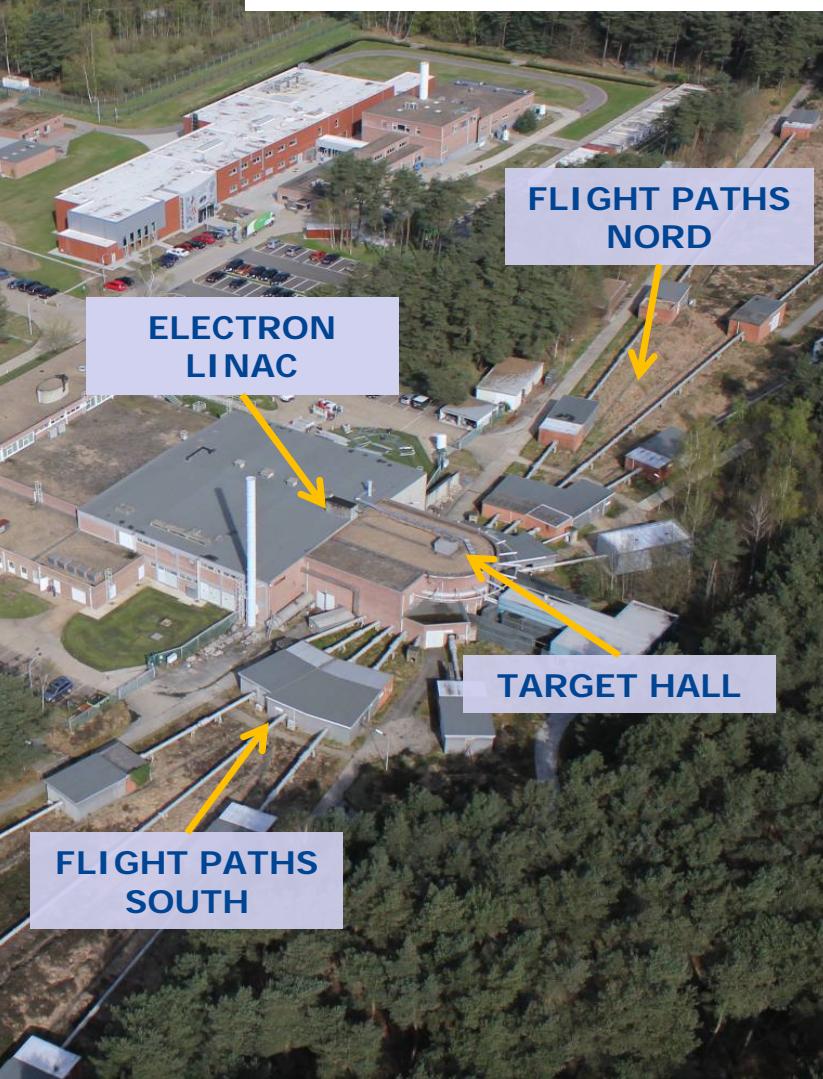
**Fusion technology:**

structural material for **PFCs**

**Plasma Facing Components :**

- divertor
- limiter
- first wall

# Geel Electron LINear Accelerator



- Electrons accelerated up to 150 MeV
- Repetition rate: 50 – 800 Hz
- **Pulsed neutron source** optimized for high resolution time of flight measurements
- Multi-user facility with 10 flight paths
- Flight path lengths: 10 m - 400 m
- The measurement stations with special equipment for:
  - Total cross section measurements
  - Partial cross section measurements

# Neutron production



## U-target

Rotating U-target (10% Mo alloy)

Cooled with liquid Hg

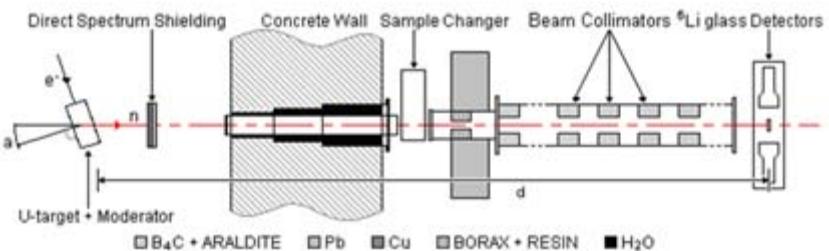
## Neutron production as a 2-steps process:

- Electrons produce Bremsstrahlung inside the U-target
- $(\gamma, n)$  and  $(\gamma, f)$  reactions in the U-target

## Neutron beam characteristics:

- Pulsed neutron beam with a white spectrum ( $10 \text{ meV} < E_n < 20 \text{ MeV}$ )
- Fast (not moderated) and slow components
- Low energy part of the neutron spectrum enhanced by a water moderator canned in Be
- Neutron intensity:  $1.6 \times 10^{12} \text{ n/s} - 2.5 \times 10^{13} \text{ n/s}$

# Transmission measurements

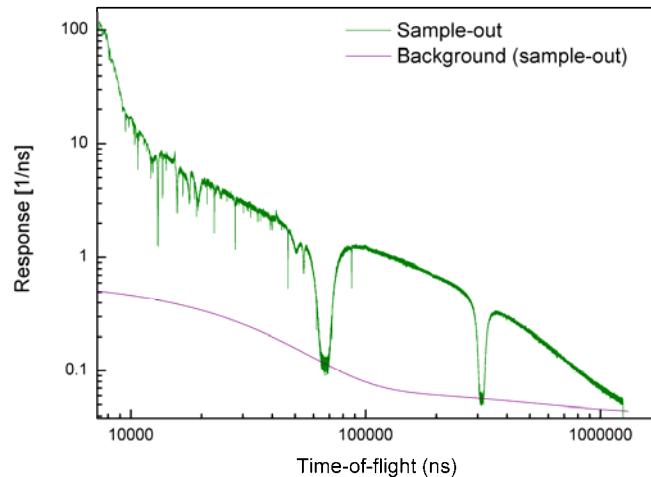
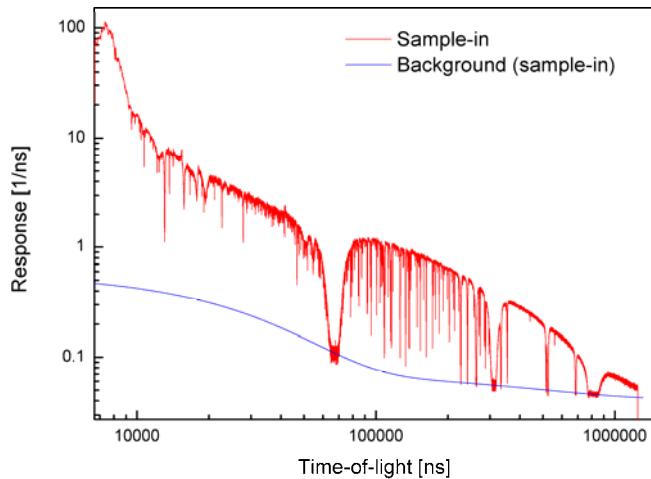


- Detector stations at FPL = 25 m, 50 m
- Moderated neutron component
- Machine frequency: 50 and 800 Hz
- 6.35 cm thick  $^{6}\text{Li}$ -loaded glass scintillators (95% enriched to  $^{6}\text{Li}$ )  $^{6}\text{Li}(\text{n},\text{t})\alpha$

- Sample changer remotely controlled
- Alternated sample-in and sample-out cycles

$$T_{\text{exp}}(t) = N_T \frac{C_{\text{in}}(t) - B_{\text{in}}(t)}{C_{\text{out}}(t) - B_{\text{out}}(t)} \leftrightarrow T_{\text{theor}}(t) = e^{-n\sigma_{\text{tot}}} \Rightarrow (E_r, g\Gamma_n)$$

# Background in transmission



## Condition of good transmission geometry:

- all detected neutrons have passed through the sample
- scattered neutrons are not detected

## Black resonance filter technique

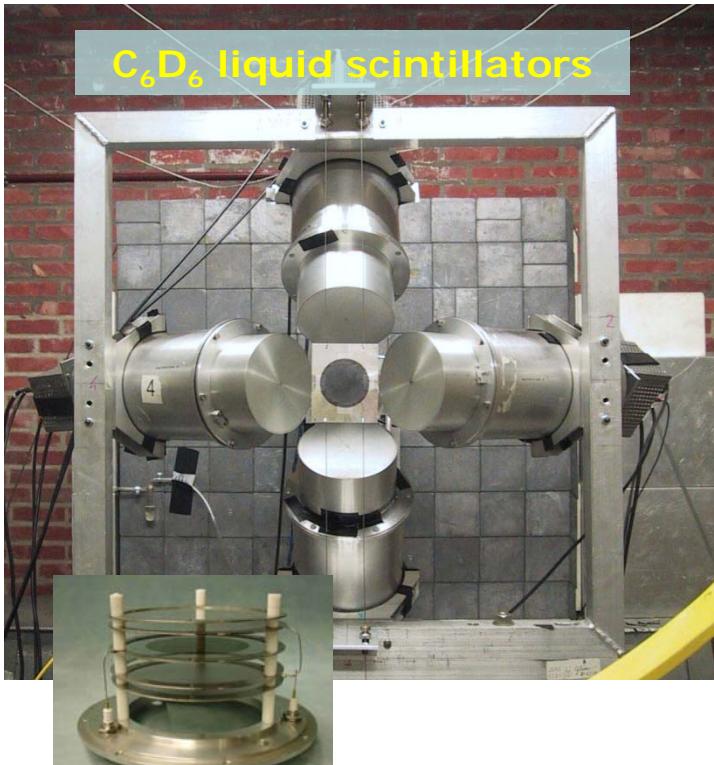
$$B(t) = B_0 + B_\gamma(t) + B_n(t)$$

Ambient component

2.2 MeV  $\gamma$ -rays emitted in the moderator after neutron capture

Scattered neutrons in the detector station

# Capture cross section measurements



$^{10}\text{B}$  Frisch gridded ionization chamber

- Detector stations at FPL = 12 m, 60 m
- Moderated neutron component
- Machine frequency: 50 and 800 Hz
- $\text{C}_6\text{D}_6$  liquid scintillators

- Total energy detection principle
- Pulse height weighting technique

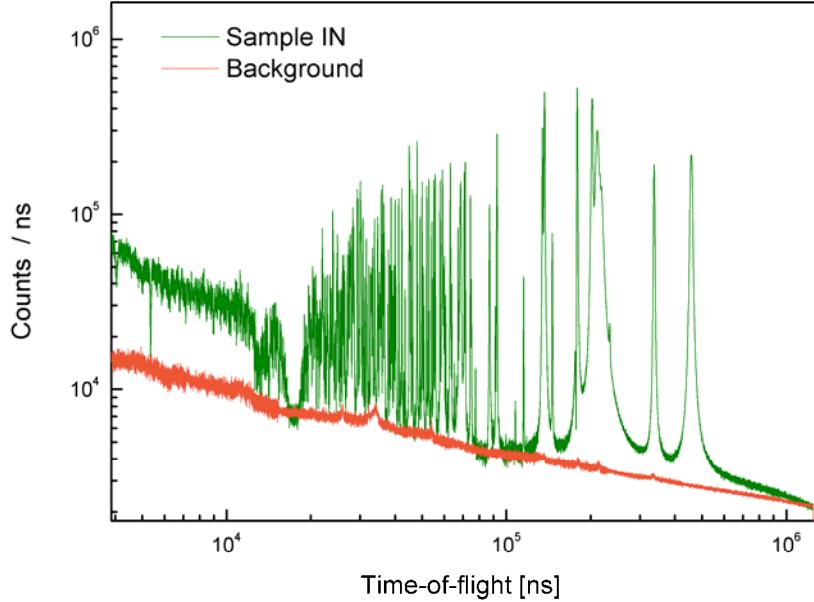
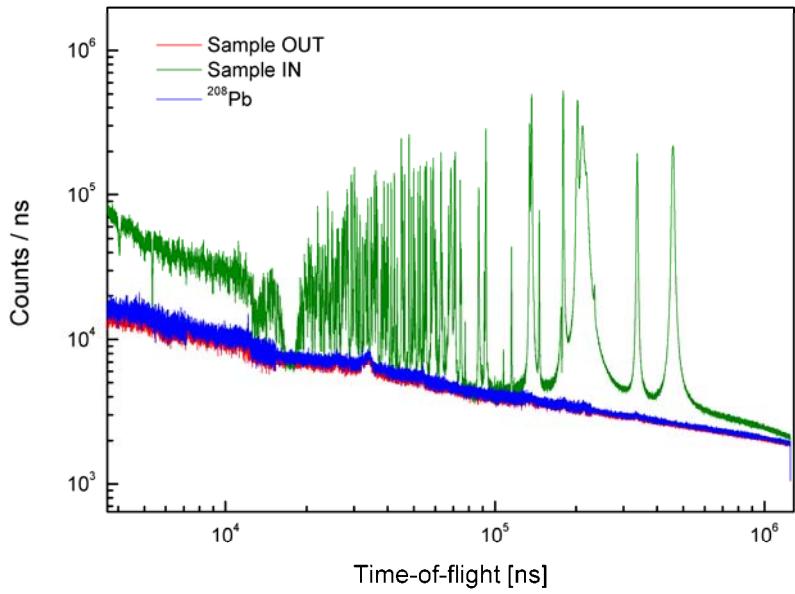
$$\int R(E_d, E_\gamma) W_F(E_d) dE_d = kE_\gamma$$

$$C_w(T_n) = \int C_c(T_n, E_d) W_F(E_d) dE_d$$

- $^{10}\text{B}$  Frisch gridded ionization chamber for neutron flux (80 cm before the sample)

$$Y_{\text{exp}} = \frac{N_C}{\varepsilon} \frac{C_w - B_w}{C_\varphi - B_\varphi} F_\varphi Y_\varphi \leftrightarrow \left(1 - e^{-n\sigma_{\text{tot}}} \right) \frac{\sigma_\gamma}{\sigma_{\text{tot}}} + \dots \Rightarrow (E_r, \frac{g\Gamma_n \Gamma_\gamma}{\Gamma}, \Gamma)$$

# Background in capture



$$B_\gamma(t) = b_0 + k_1(C_{SO}(t)) + k_2(C_{Pb}(t) - C_{SO}(t))$$

# Samples



Metallic disk	Enrichment (%)	Thickness (mm)	Area (mm <sup>2</sup> )	Weight (g)	Areal density (at/b)
<sup>nat</sup> W	--	15	2828	821	0.095
<sup>nat</sup> W	--	0.4	6060	118	0.0064
<sup>nat</sup> W	--	0.22	5030	21	0.0013
<sup>182</sup> W	94.50%	1.29	3421	48	0.0047
<sup>182</sup> W	94.50%	3.87	3421	140	0.0136
<sup>183</sup> W	83.75%	1.30	3959	46	0.0038
<sup>183</sup> W	83.75%	2.85	3964	94	0.0078
<sup>184</sup> W	94.50%	1.15	3920	45	0.0038
<sup>184</sup> W	94.50%	2.25	3615	90	0.0081
<sup>186</sup> W	94.50%	1.09	3802	45	0.0038
<sup>186</sup> W	94.50%	2.18	3761	90	0.0078



# Starting values: resonance parameters

Camarda et al., *Phys. Rev. C*, Vol. 8 num. 5, 1813-1826 (1973)

- Columbia Univ. Nevis synchrocyclotron
- Measurements on  $^{182}\text{W}$ ,  $^{184}\text{W}$ ,  $^{186}\text{W}$  enriched samples and  $^{\text{nat}}\text{W}$
- Transmission measurements (200 m and 40 m)
- Self-indication measurements (40 m)

$$\rightarrow g\Gamma_n$$

Macklin et al., *Nucl. Sc. Eng.*, Vol. 84, 98-119 (1983)

- Oak Ridge Electron Linear Accelerator
- Measurements on  $^{182}\text{W}$ ,  $^{183}\text{W}$ ,  $^{184}\text{W}$ ,  $^{186}\text{W}$  enriched samples
- Capture measurements (40 m)

$\langle \Gamma_\gamma \rangle$	
$^{182}\text{W}$	$(53 \pm 2) \text{ meV}$
$^{183}\text{W}$	$(55 \pm 1) \text{ meV}$
$^{184}\text{W}$	$(57 \pm 4) \text{ meV}$
$^{186}\text{W}$	$(60 \pm 3) \text{ meV}$

# Starting values: scattering radius and negative resonances

Coherent scattering lengths, thermal capture cross sections and negative resonance parameters for tungsten isotopes

Isotope	$b_{coh}$ [fm]	$\sigma_\gamma^0$ [b]	Negative Resonance Parameters		
			$E_r$ [eV]	$\Gamma_n$ [eV]	$\Gamma_\gamma$ [eV]
$^{182}\text{W}$	$7.04 \pm 0.04$	$19.9 \pm 0.3$	- 4.16	$0.12 \times 10^{-2}$	$0.53 \times 10^{-1}$
$^{183}\text{W}$	$6.59 \pm 0.04$	$10.4 \pm 0.2$	- 46.0	0.13	$0.55 \times 10^{-1}$
$^{184}\text{W}$	$7.55 \pm 0.06$	$1.7 \pm 0.1$	- 200.0	$0.12 \times 10^{-2}$	$0.57 \times 10^{-1}$
$^{186}\text{W}$	$-0.73 \pm 0.04$	$38.1 \pm 0.5$	- 217.5	$0.47 \times 10^{-2}$	$0.60 \times 10^{-1}$

Knopf and  
Waschkowski  
1987

Mughabghab  
2006

average value  
Mackling et al.  
1983

$$a = R' - 2.277 \times 10^{-3} \left( \frac{A+1}{A} \right) \sum_j \frac{\Gamma_{nj}^0}{E_{0j}}$$

$$b = \left( \frac{A+1}{A} \right) a + Z \times b_{ne}$$

$$b_{ne} = -(1.38 \pm 0.03) \times 10^{-3} \text{ fm}$$

$$R' = 9.4 \text{ fm}$$



# Data reduction and data analysis

Data reduction performed with **AGS** package:

- Normalization of spectra
- Dead time correction
- Background subtraction
- Full uncertainty propagation
- Experimental Covariance Matrix

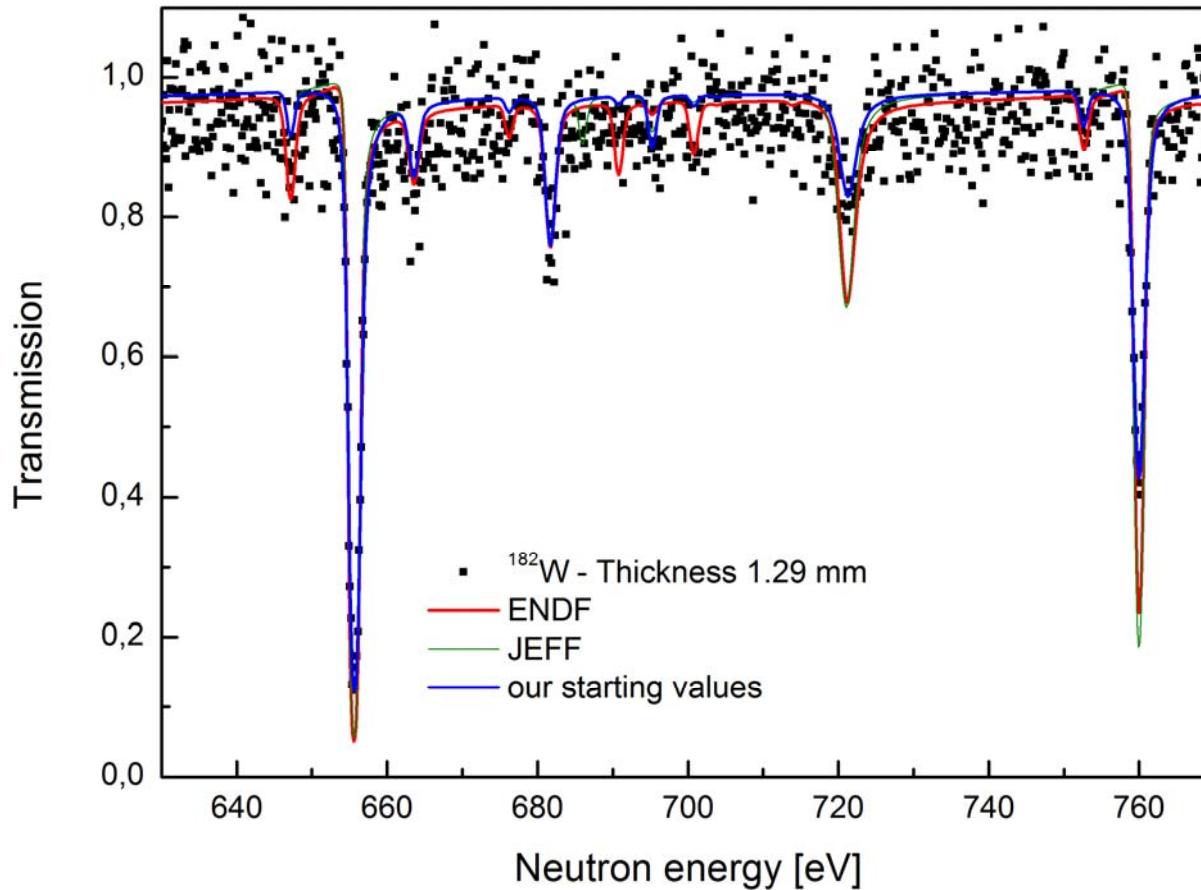
Resonance parameters extracted with **REFIT2**

- least-square fitting program
- Reich-Moore approximation of R matrix theory
- Takes into account various experimental effect:
  - Response of the TOF spectrometer
  - Sample in-homogeneities
  - Self shielding
  - Multiple scattering
  - Doppler broadening
  - Neutron sensitivity for capture detector
  - Gamma ray attenuation in the sample

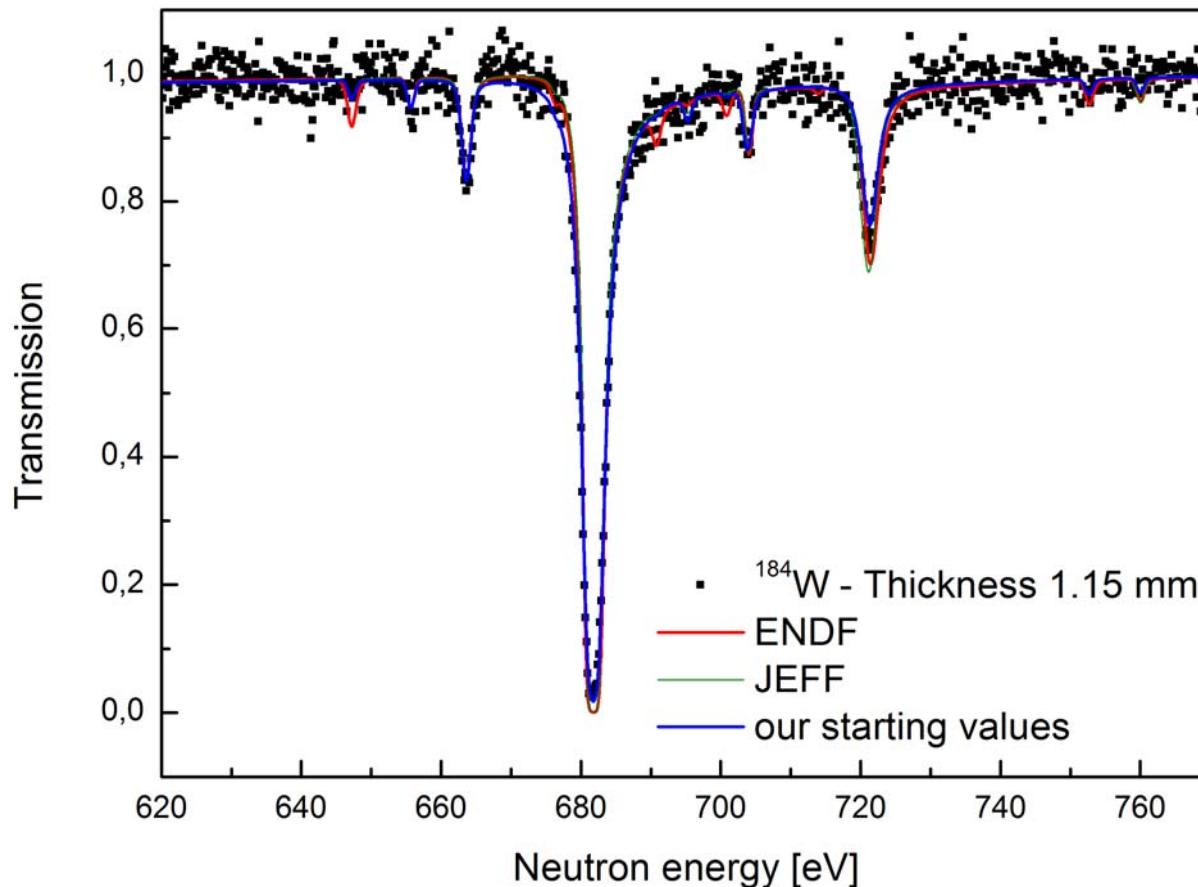
# Results



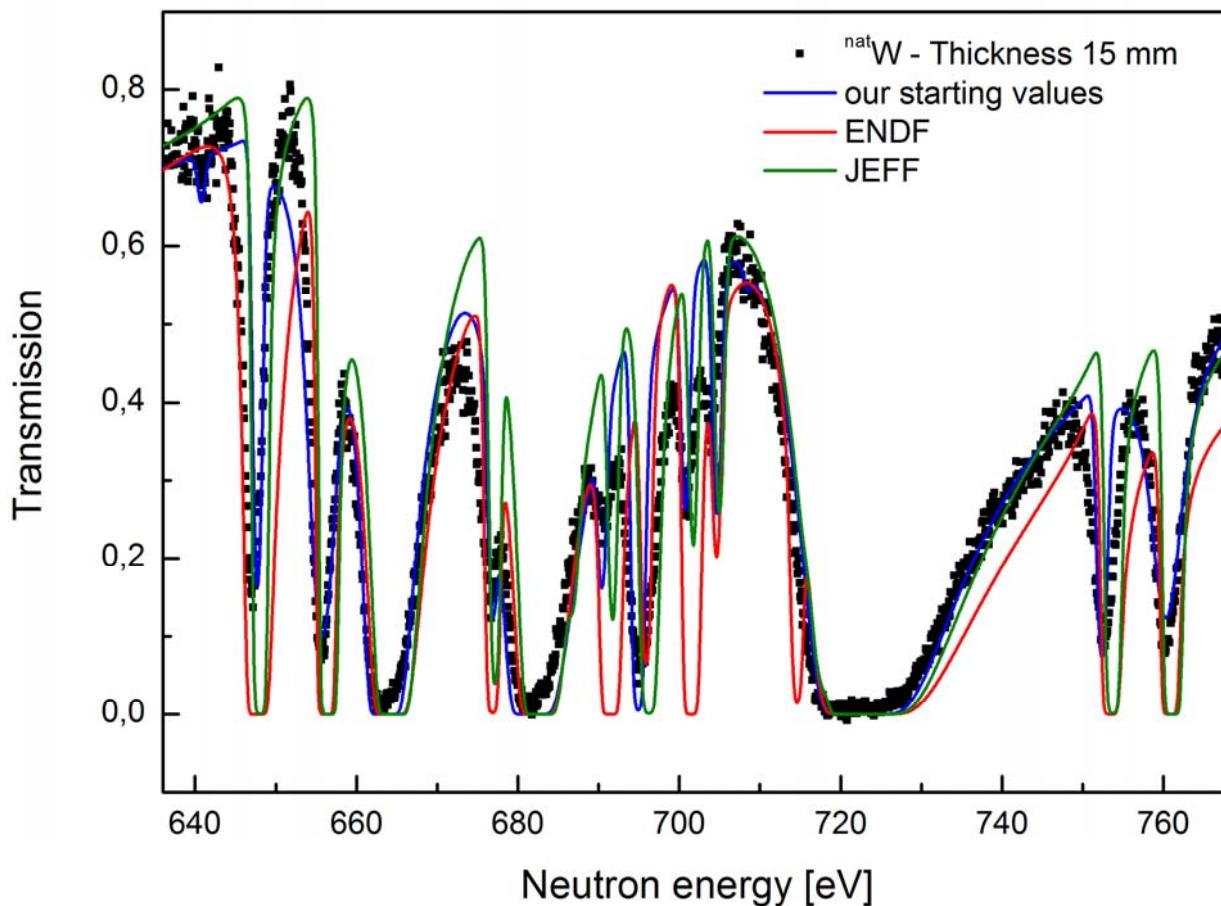
FPL 50 m - Machine freq. 800 Hz



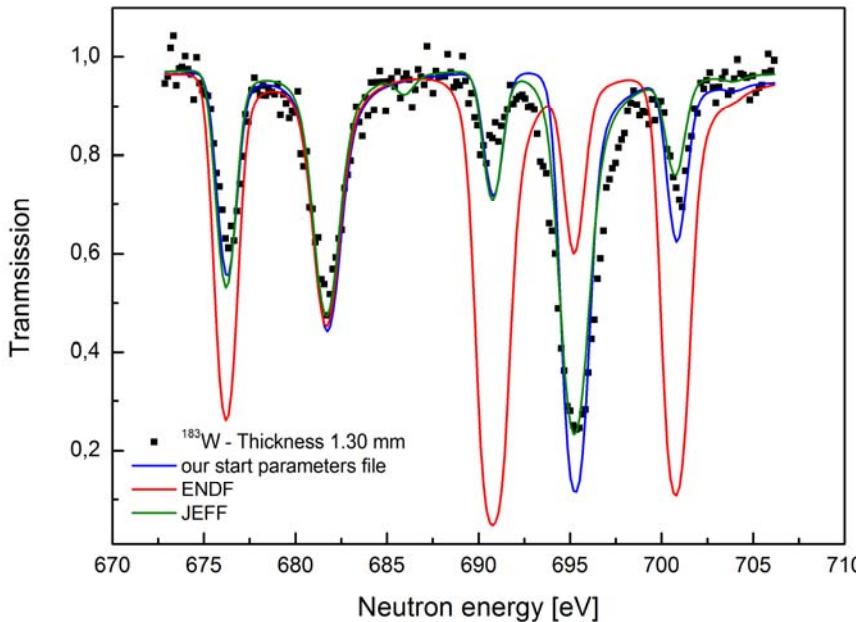
FPL 50 m - Machine freq. 800 Hz



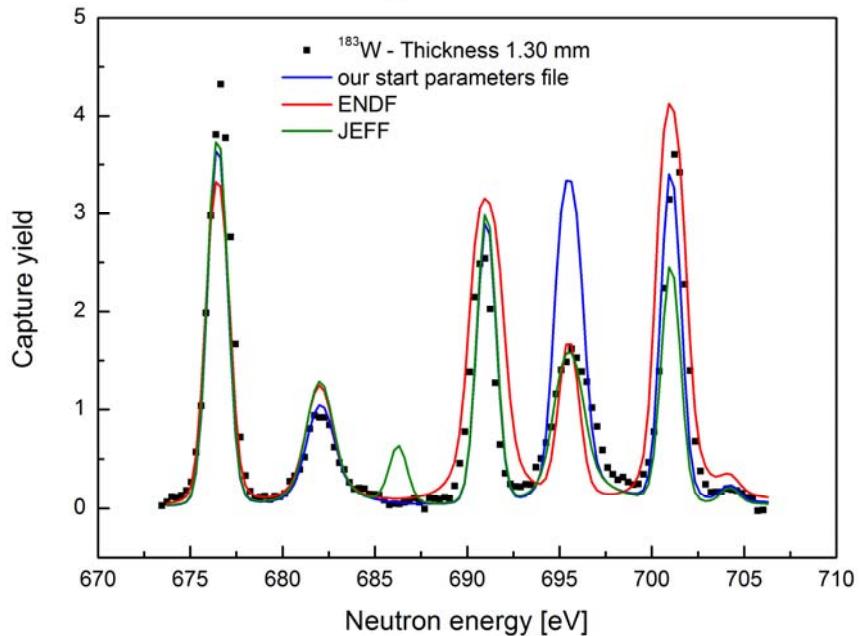
FPL 25 m - Machine freq. 800 Hz



FPL 50 m - Machine freq. 800 Hz

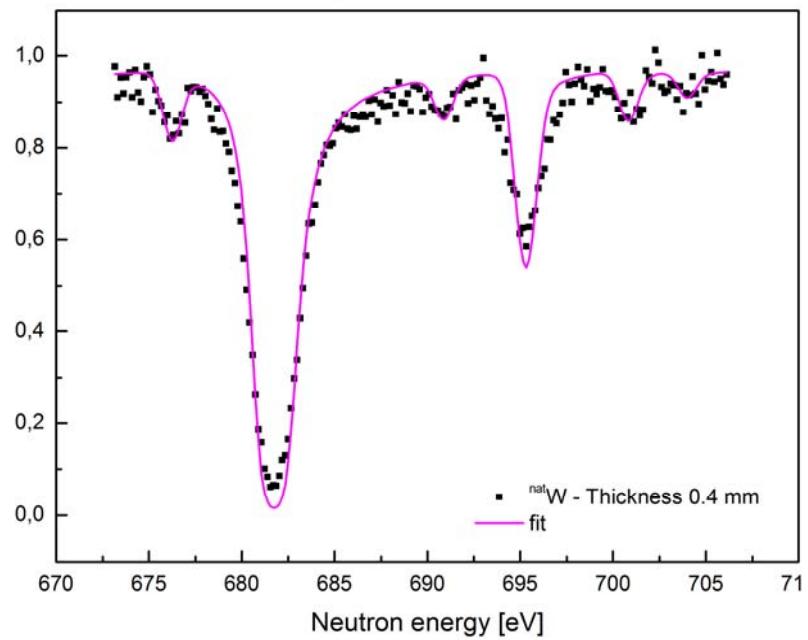


FPL 60 m - Machine freq. 800 Hz



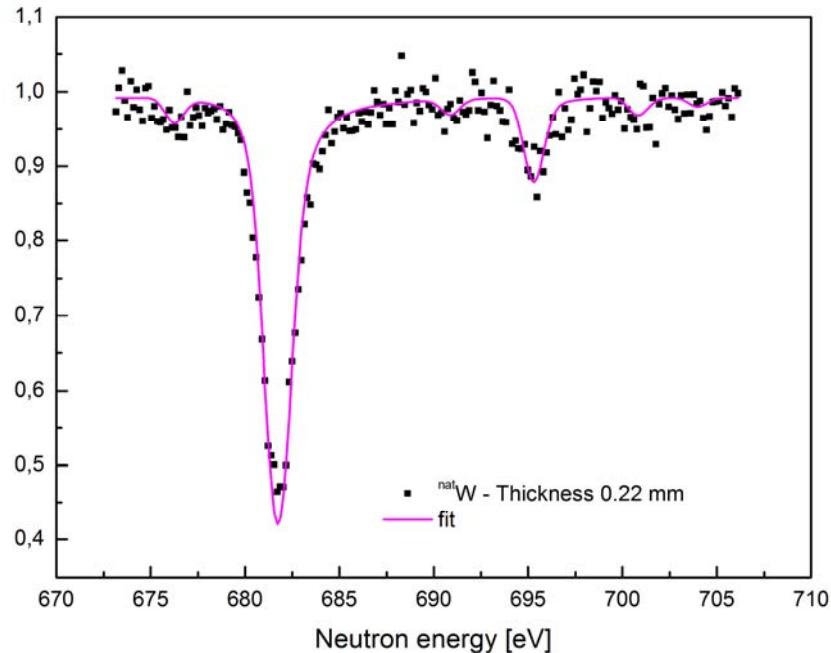
FPL 50 m - Machine freq. 800 Hz

Transmission

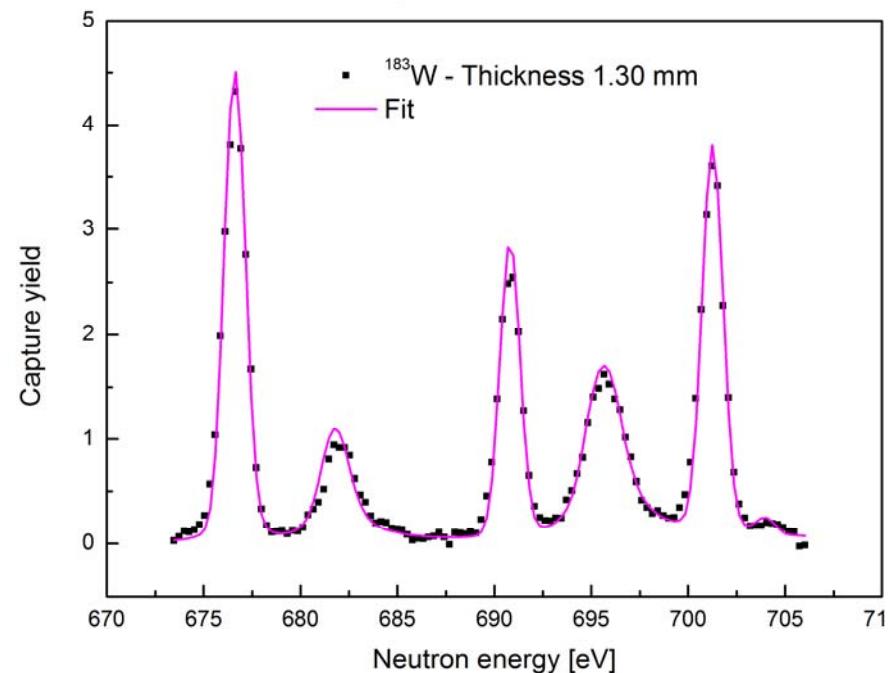


FPL 50 m - Machine freq. 800 Hz

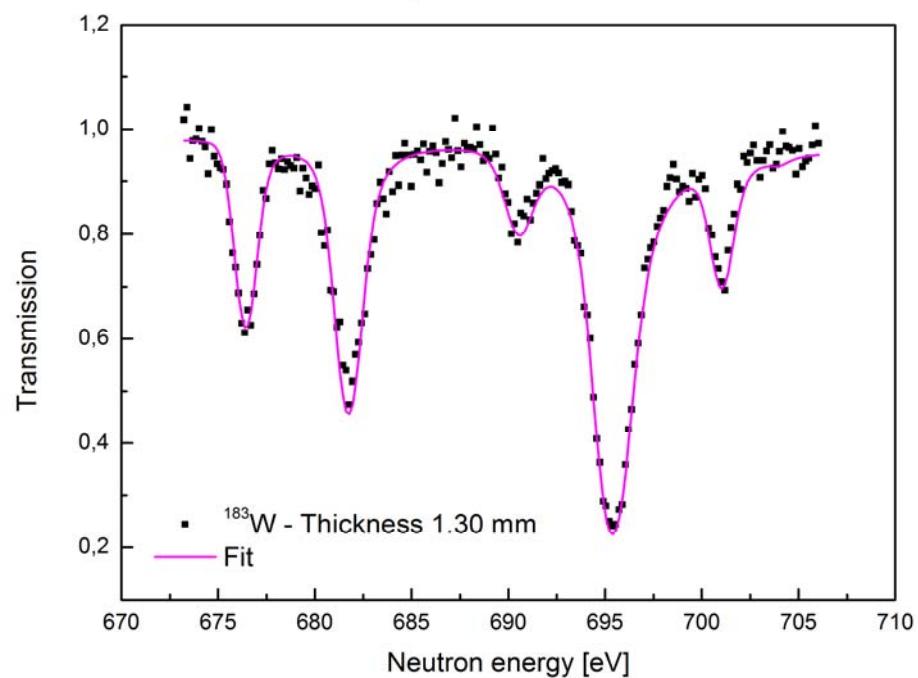
Transmission



FPL 60 m - Machine freq. 800 Hz



FPL 50 m - Machine freq. 800 Hz





# Conclusions and improvements

- Preliminary results
- Validity of the start parameters file based on literature
- Validity of the approach based on natural thick and thin samples
- Even isotopes need a minor adjustment
- $^{183}\text{W}$  shows the most severe problems
- A new evaluation of  $^{183}\text{W}$  is therefore claimed with priority
- Spin adjustment for  $^{183}\text{W}$
- Use of the scattering radius obtained with optical model calculation and suitable choice of negative resonances to match the coherent scattering length and thermal capture cross section.