

Reporting Time-Of-Flight cross section data in EXFOR

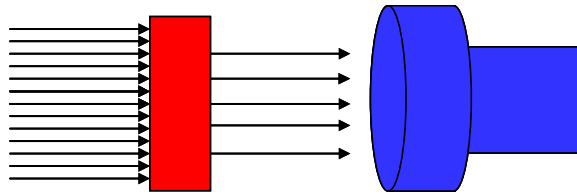
WPEC SG – 50

14 – 15 September 2020

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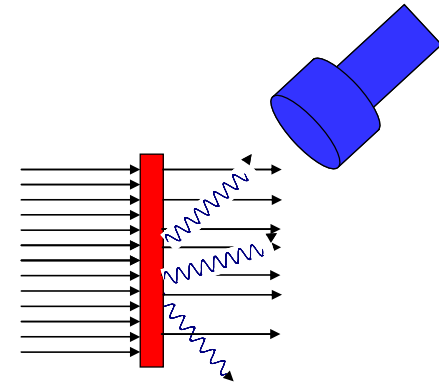
Cross section measurements: T_{exp} and Y_{exp}

Transmission



$$T_{\text{exp}} = N \frac{C'_{\text{in}} - B'_{\text{in}}}{C'_{\text{out}} - B'_{\text{out}}}$$

Reaction cross section



$$Y_{\text{exp}} = N \frac{\sigma_{\varphi}}{\varepsilon_r} \frac{C'_r - B'_r}{C'_{\varphi} - B'_{\varphi}}$$

Data reduction and analysis

Transmission

$$T_{\text{exp}} = \frac{C'_{\text{in}} - B'_{\text{in}}}{C'_{\text{out}} - B'_{\text{out}}}$$

C' dead time corrected counts
 B' background contribution
 N normalisation factor
 ε Detection efficiency

Reaction yield

$$Y_{\text{exp}} = N \frac{1}{\varepsilon} \frac{C'_r - B'_r}{\varphi}$$

Histogram operations + Covariance information

Y_{exp} + covariance
 T_{exp} + covariance

input

Models

Cross section measurements

Transmission

$$T = e^{-n \sigma_{\text{tot}}}$$

$$T_{\text{exp}} = \frac{C_{\text{in}}}{C_{\text{out}}}$$

- **Absolute** measurement
- **No additional** measurements

σ_{tot} : **most accurate cross section**

$^{197}\text{Au}(n,\gamma)$ from **transmission**

$$\sigma(n_{\text{th}}, \gamma) = 98.7 (1) \text{ b}$$

Reaction

$$Y_r \cong (1 - e^{-n\sigma_{\text{tot}}}) \frac{\sigma_r}{\sigma_{\text{tot}}}$$

$$Y_{\text{exp}} = N \frac{C_r}{\phi}$$

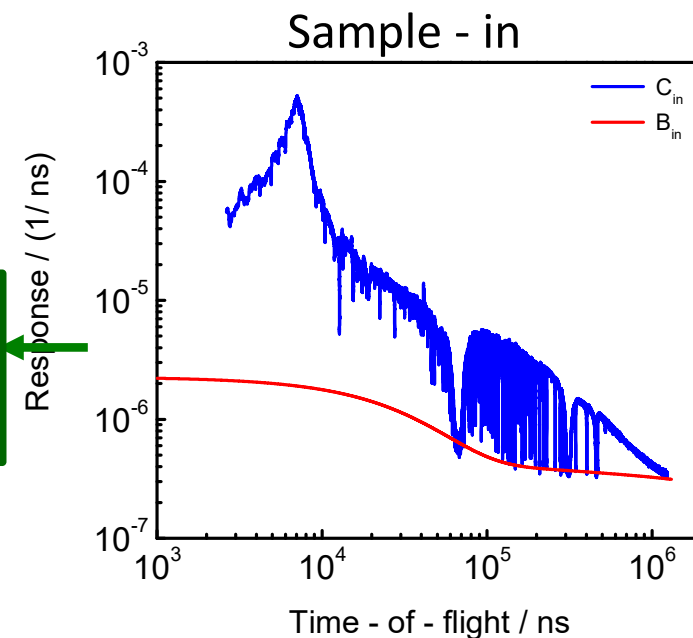
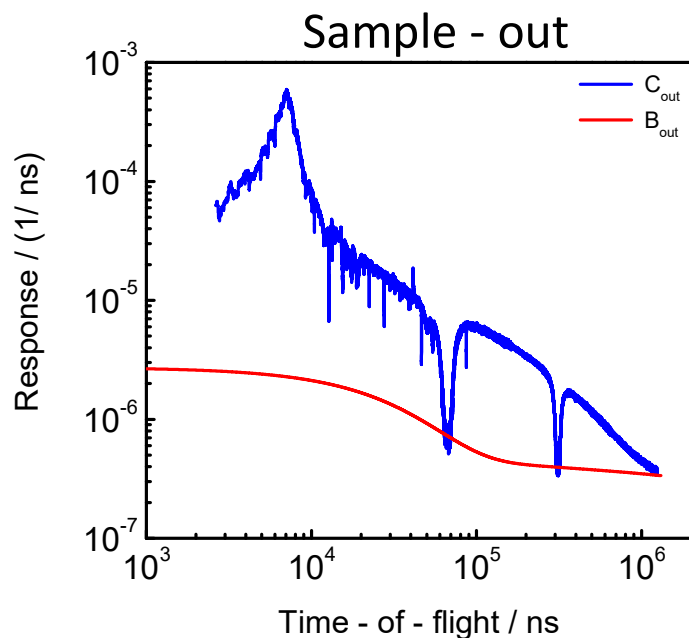
- **Normalisation** required +
- **Additional fluence rate** measurement

+ **complex relation** : $Y_r \Leftrightarrow \sigma_r$

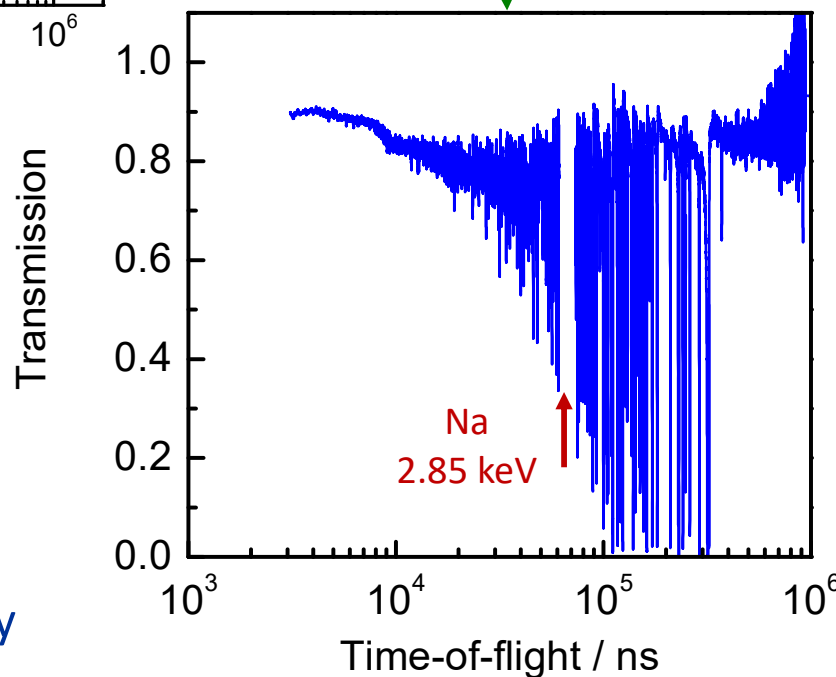
only for $n\sigma_{\text{tot}} \ll 1$: $Y_r \cong n \sigma_r$

$$(1 - e^{-n\sigma_{\text{tot}}}) \approx n\sigma_{\text{tot}} \quad e^{-n\sigma_{\text{tot}}} \approx 1 - n\sigma_{\text{tot}}$$

TOF-spectra $\Rightarrow T_{\text{exp}}$



$$T_{\text{exp}} = N \frac{C'_{\text{in}} - K B'_{\text{in}}}{C'_{\text{out}} - K B'_{\text{out}}}$$



N and **K** introduce correlated uncertainty components

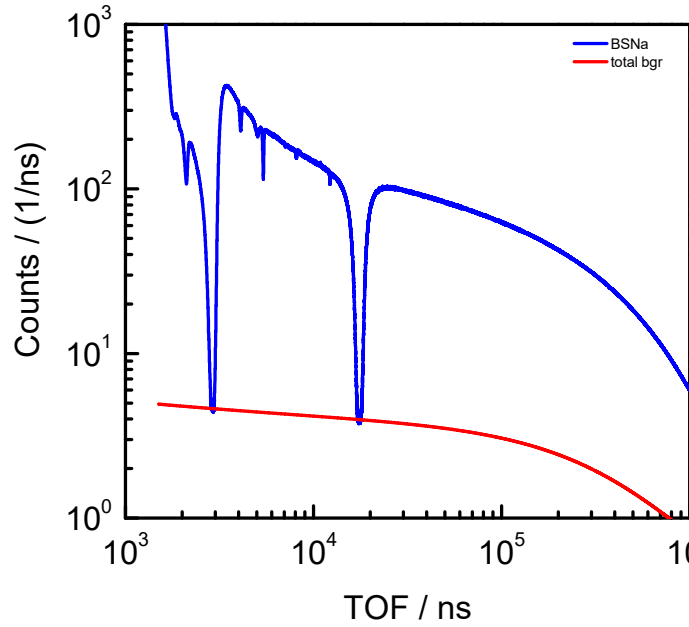
- Repeated measurements of sample-in and sample-out cycles to avoid impact of:
- Electronic drifts
 - Variations in beam intensity

$$\frac{u_N}{N} \approx 0.25\% \Rightarrow N = 1.0000 (25)$$

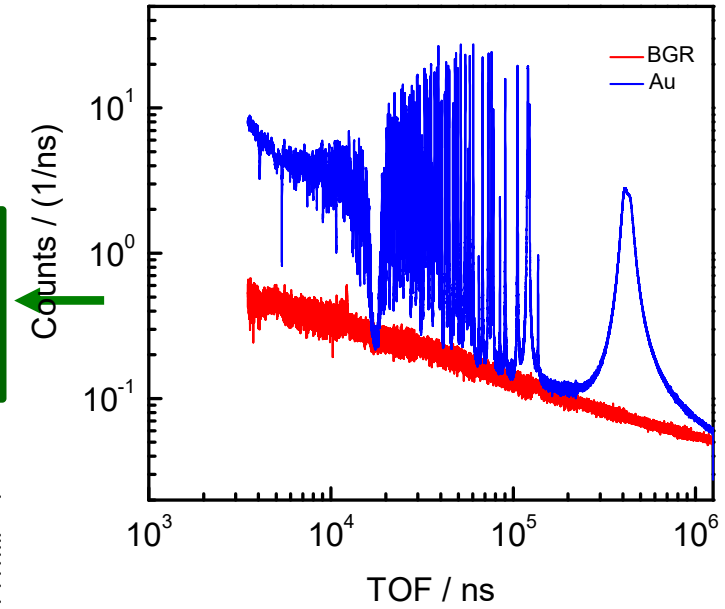
$$\frac{u_K}{K} \approx 3\% \Rightarrow K = 1.00 (3)$$

Only with fixed BGR filters

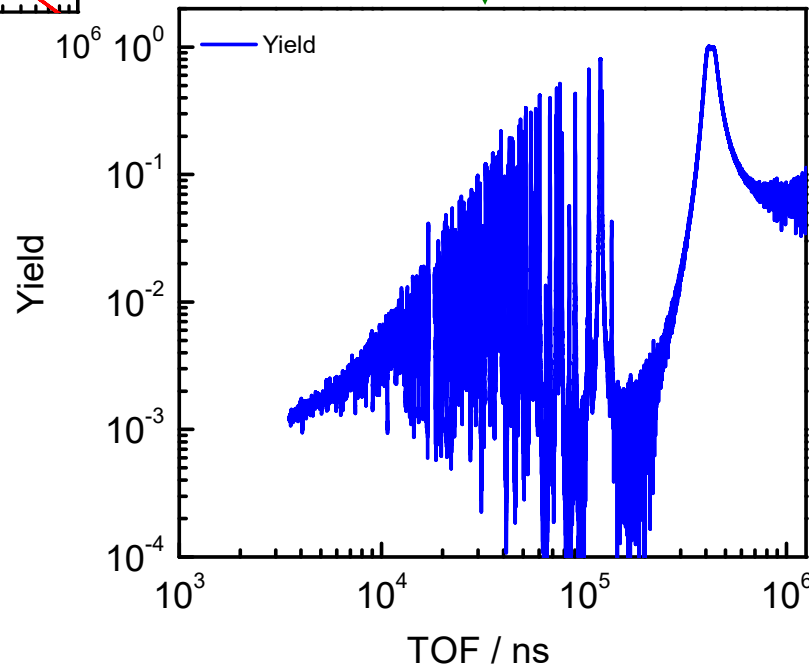
Y_{exp} for $^{197}\text{Au}(n,\gamma)$



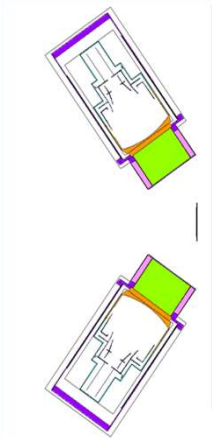
$$Y_{\text{exp}} = N \frac{C_r' - K_\gamma B_r'}{C_\phi - K_\phi B_\phi'} Y_\phi$$



N , K_γ and K_ϕ introduce correlated uncertainty components

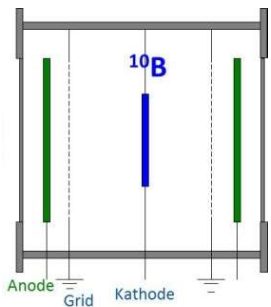


General: $\sigma(n,r)$ measurements



$$C_r = \varepsilon_r \Omega_r P_r Y_r A_r \varphi$$

- φ Neutron fluence rate
- ε Detection efficiency
- Ω solid angle (sample-detector)
- P Escape probability
- A Effective area



$$C_\varphi = \varepsilon_\varphi \Omega_\varphi P_\varphi Y_\varphi A_\varphi \varphi$$

$$Y_{r,exp} = \frac{\varepsilon_\varphi}{\varepsilon_r} \frac{\Omega_\varphi}{\Omega_r} \frac{P_\varphi}{P_r} \frac{A_\varphi}{A_r} \frac{C_\gamma}{C_\varphi} Y_\varphi$$

$\Rightarrow Y_{r,exp}$: ratio of results of 2 complicated measurements

Neutron fluence rate measurements: standard reactions

Reaction	2200 m/s	Energy region	
		E_{low}	E_{high}
$^1\text{H}(n,n)$		1 keV	20 MeV
$^3\text{He}(n,p)$	X	25.3 meV	50 keV
$^6\text{Li}(n,t)$	X	25.3 meV	1 MeV
$^{10}\text{B}(n,\alpha)$	X	25.3 meV	1 MeV
$^{10}\text{B}(n,\alpha_1\gamma)$	X	25.3 meV	1 MeV
$^{\text{nat}}\text{C}(n,n)$		25.3 meV	1.8 MeV
$^{197}\text{Au}(n,\gamma)$	X	0.2 MeV	2.5 MeV
$^{235}\text{U}(n,f)$	X	0.15 MeV	200 MeV (1 GeV)
$^{238}\text{U}(n,f)$	X	2 MeV	200 MeV (1 GeV)
$^{239}\text{Pu}(n,f)$	X	0.15 MeV	300 MeV
$^{209}\text{Bi}(n,f)$		34 MeV	1 GeV
$^{\text{nat}}\text{Pb}(n,f)$		34 MeV	1 GeV

For neutron fluence rate measurements

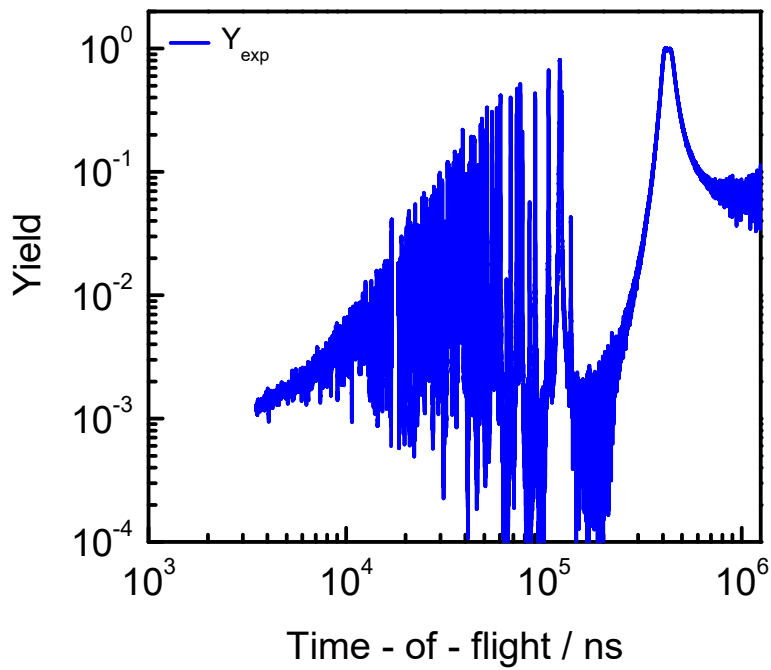
a transfer reaction with a well-known cross section is required:

Standard and **reference** reactions

<https://www-nds.iaea.org/standards/>

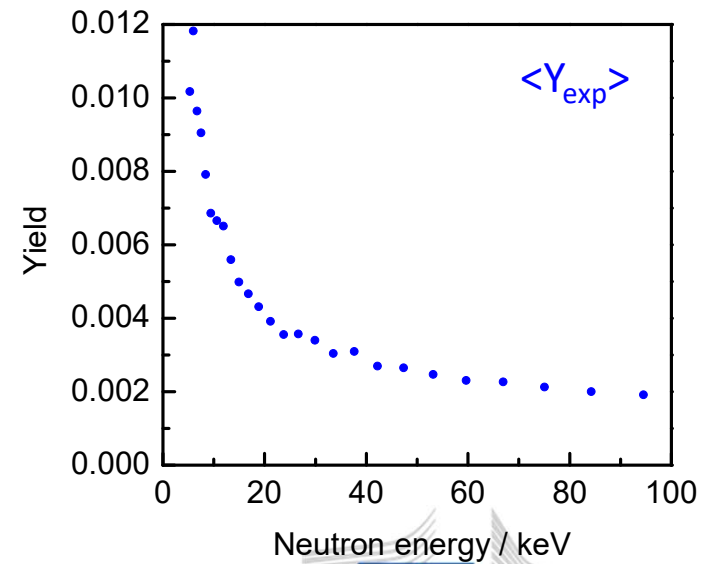
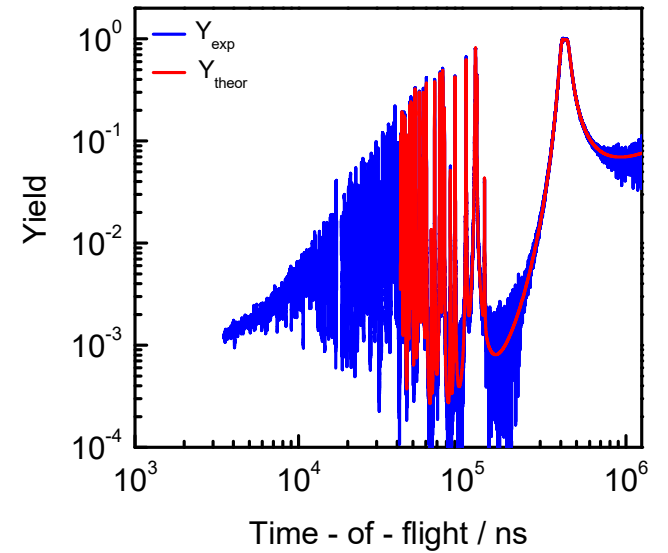
To create **traceable data** the **reference** or **standard cross section** used to determine the energy distribution of the incident neutron beam should be **specified**.

Data analysis



RRR
Resonance shape analysis

URR
Average parameters



Resonance shape analysis

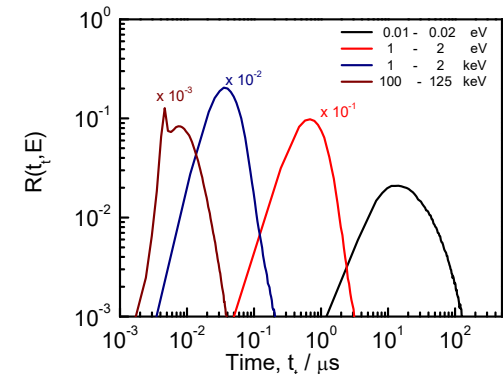
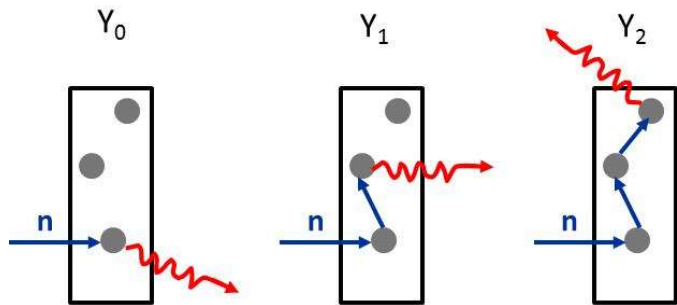
$$\chi^2(\mathbf{RP}) = (\mathbf{Y}_{\text{exp}} - \mathbf{Y}_M)^T \mathbf{V}_{\mathbf{Y}_{\text{exp}}}^{-1} (\mathbf{Y}_{\text{exp}} - \mathbf{Y}_M)$$

$$Y_{\text{exp}} = N \frac{C'_r - K_\gamma B'_r}{C_\phi - K_\phi B'_\phi} Y_\phi$$

$$Y_M(t_m) = \int \mathbf{R}(t_m, \mathbf{E}) Y_r(\mathbf{E}) dE_n$$

$$Y_r(\mathbf{E})(E) \cong (1 - e^{-n \bar{\sigma}_{\text{tot}}}) \frac{\bar{\sigma}_r}{\bar{\sigma}_{\text{tot}}} + \dots$$

$\mathbf{R}(t_m, \mathbf{E})$: response of TOF-spectrometer




$$Y_r = F(n, \sigma_r, \sigma_n, \sigma_{\text{tot}}, T)$$

- | | | |
|-----------------------|---|---------------------|
| n | : | areal density |
| σ_{tot} | : | total cross section |
| σ_r | : | (n,r) cross section |
| σ_n | : | (n,n) cross section |
| T | : | sample temperature |

$\Rightarrow Y_M$ depends on

- $Y_M = F(n, \sigma_r, \sigma_n, \sigma_{\text{tot}}, T)$
- Sample properties
- Response function

Reporting of data in EXFOR

 **IAEA**
International Atomic Energy Agency

INDC(NDS)-0647
Distr. AC/GJ/NC/ST

INDC International Nuclear Data Committee

Summary Report of the Consultants' Meeting on

**EXFOR Data in Resonance Region and
Spectrometer Response Function**

IAEA Headquarters, Vienna, Austria
8 – 10 October 2013


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December 2013



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Vienna International Centre, P.O. Box 100, 1400 Vienna, Austria


Data Bank
NEA/DB/DOC(2014)4
www.oecd-nea.org



**Analysis of Geel
Spectra – AGS**

Users' manual

 **IAEA**
International Atomic Energy Agency

INDC(EUR)-0037
Distr. G+J

INDC International Nuclear Data Committee

Results of time-of-flight transmission measurements
for $^{155,157}\text{Gd}$ at a 10 m station at GELINA

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September 2020

IAEA Nuclear Data Section, Vienna International Centre, A-1400 Vienna, Austria

Reporting according to NDS/IAEA recommendations based on **AGS concept**
⇒ fully **traceable** and **transparent data**

Reporting TOF-data in RRR

A) Experimental conditions

- Facility
- Neutron production
- Detection system
- Sample characteristics

B) Experimental data (data reduction)

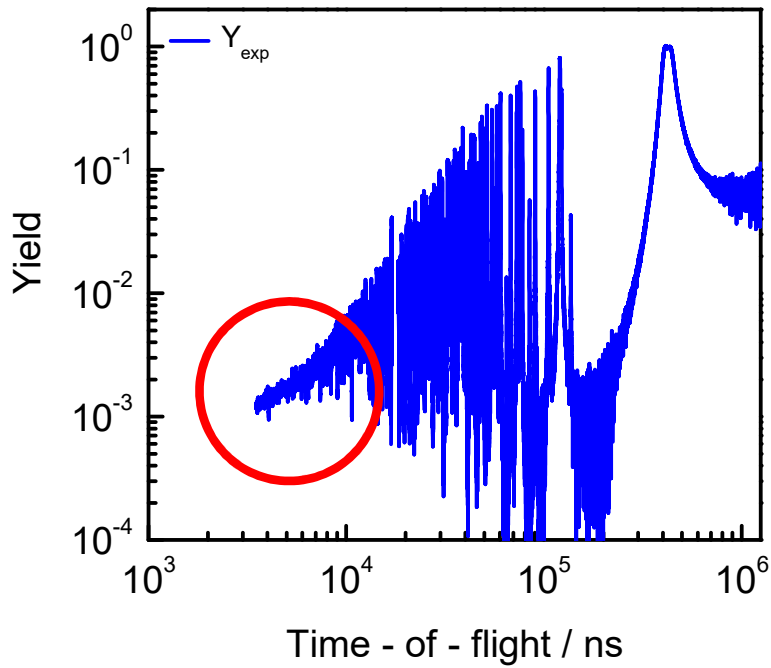
- Background subtraction
- Dead time correction
- Neutron fluence (*reaction cross section data*)
- Normalisation (*reaction cross section data*)
- Correction factors
- Covariance information (**AGS-concept**)

Reporting TOF-data in RRR

1. Main Reference		[a]
2. Facility	GELINA	[b][c]
3. Neutron production		
Neutron production beam	Electron	
Nominal average beam energy	100 MeV	
Nominal average current	30 μ A	
Repetition rate (pulses per second)	400 Hz	
Pulse width	2 ns	
Primary neutron production target	Mercury cooled depleted uranium	
Target nominal neutron production intensity	$3.4 \times 10^{13} \text{ s}^{-1}$	
4. Moderator		
Primary neutron source position in moderator	Above and below uranium target	
Moderator material	2 water filled Be-containers around U-target	
Moderator dimensions (internal)	$2 \times (14.6 \text{ cm} \times 21 \text{ cm} \times 3.9 \text{ cm})$	
Density (moderator material)	1 g/cm ³	
Temperature (K)	Room temperature	
Moderator-room decoupler (Cd, B, ...)	None	
5. Other experimental details		[d]
Measurement type	Transmission	
Method (total energy, total absorption, ...)	Good transmission geometry	
Flight Path length (m) (moderator center-detector front face)	$L = 10.861 (1) \text{ m}$	
Flight path direction	18° with respect to normal of the moderator face viewing the flight path	
Neutron beam dimensions at sample position	10 mm in diameter	
Neutron beam profile	-	
Overlap suppression	4 mm Cd overlap filter	
Other fixed beam filters	Na, Co, Pb	
6. Detector		
Type	Scintillator	
Material	Li-glass	
Surface Dimensions	76 mm \times 76 mm square	
Thickness (cm)	6.35 mm	
Detector(s) position relative to neutron beam	In the beam	
Detector(s) solid angle	-	
7. Sample		
Type (metal, powder, liquid, crystal)	Metal	
Chemical composition	Gd (100 %)	
Isotopic composition (wt%)	¹⁵² Gd (0.03 %), ¹⁵⁴ Gd (0.63 %), ¹⁵⁵ Gd (91.74 %), ¹⁵⁶ Gd (5.12 %), ¹⁵⁷ Gd (1.14 %), ¹⁵⁸ Gd (0.94 %), ¹⁶⁰ Gd (0.4 %)	
Sample composition (at/b)	$12.353 (12) \times 10^{-9} \text{ at/b of } ^{155}\text{Gd}$	
Temperature	20 °C	
Sample mass (g)	100.6 (1) mg	
Geometrical shape (cylinder, sphere, ...)	Disk	
Surface dimension	316.4 (1) mm ²	

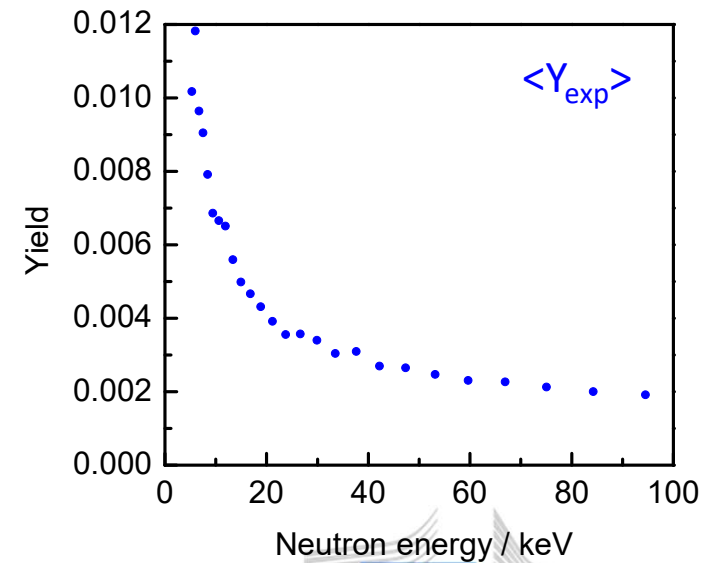
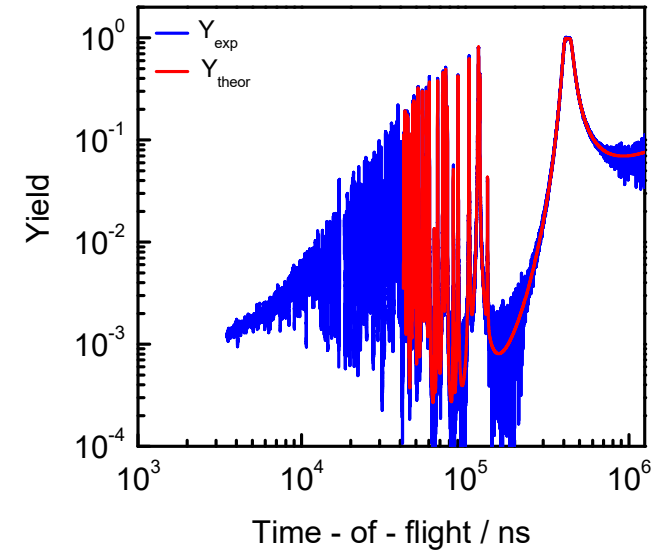
8. Data Reduction Procedure		[d][e]
Dead time correction	Done (< factor 1.2)	
Background subtraction	Black resonance technique	
Flux determination (reference reaction, ...)	-	
Normalization	1.0000 (25)	
Detector efficiency	-	
Self-shielding	-	
Time-of-flight binning	Zone length bin width	
	4096 2 ns	
	5120 4 ns	
	5120 8 ns	
	4096 16 ns	
	4096 32 ns	
	4096 64 ns	
	12288 128 ns	
	4096 512 ns	
	1024 2048 ns	
	1024 4096 ns	
	20480 8192 ns	
9. Response function		[f][g]
Initial pulse	Normal distribution, FWHM = 2 ns	
Target / moderator assembly	Numerical distribution from MC simulations	[h]
Detector	Analytical function defined in REFIT manual	[h]

Data analysis in URR

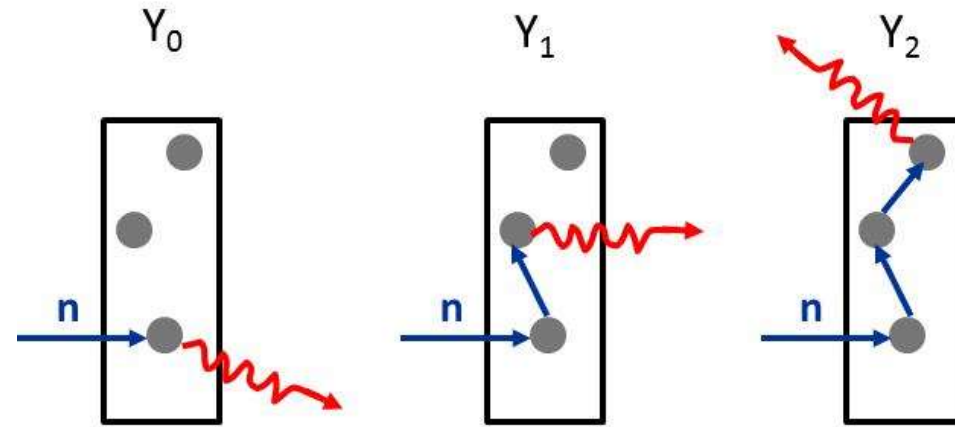
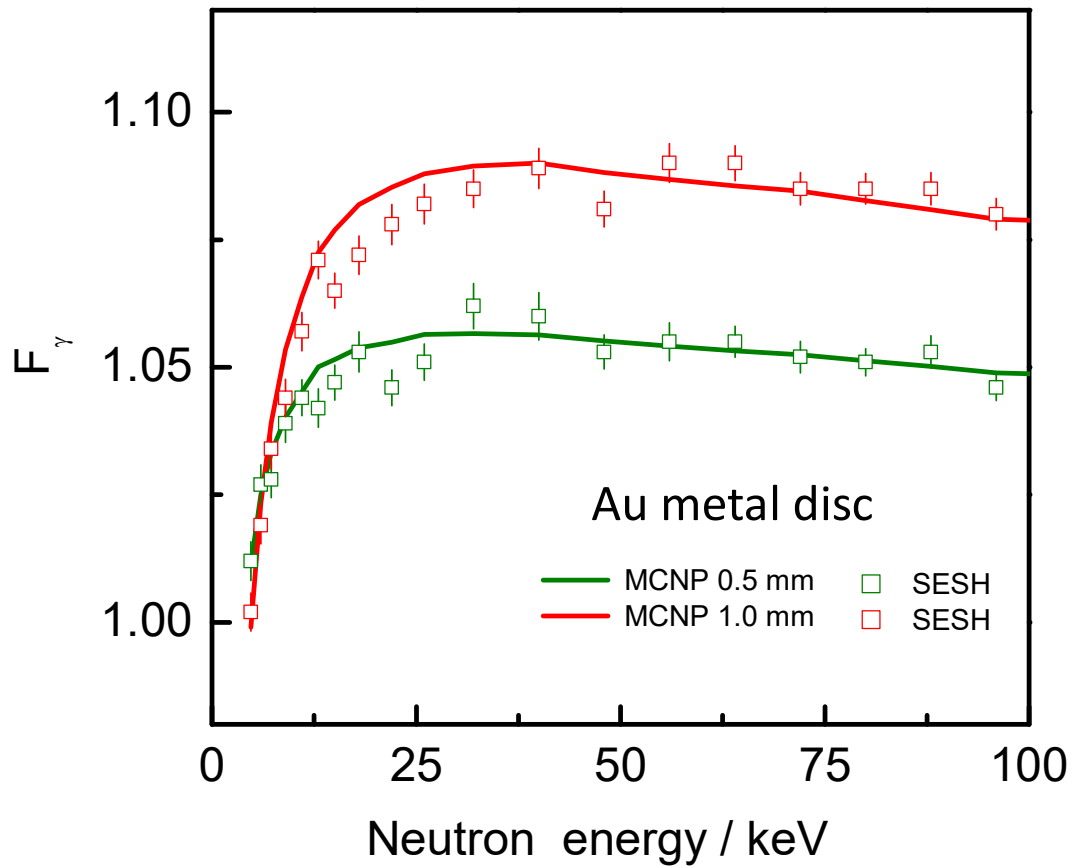


RRR
Resonance shape analysis

URR
Average parameters



From average Y_{exp} to average σ_{γ}



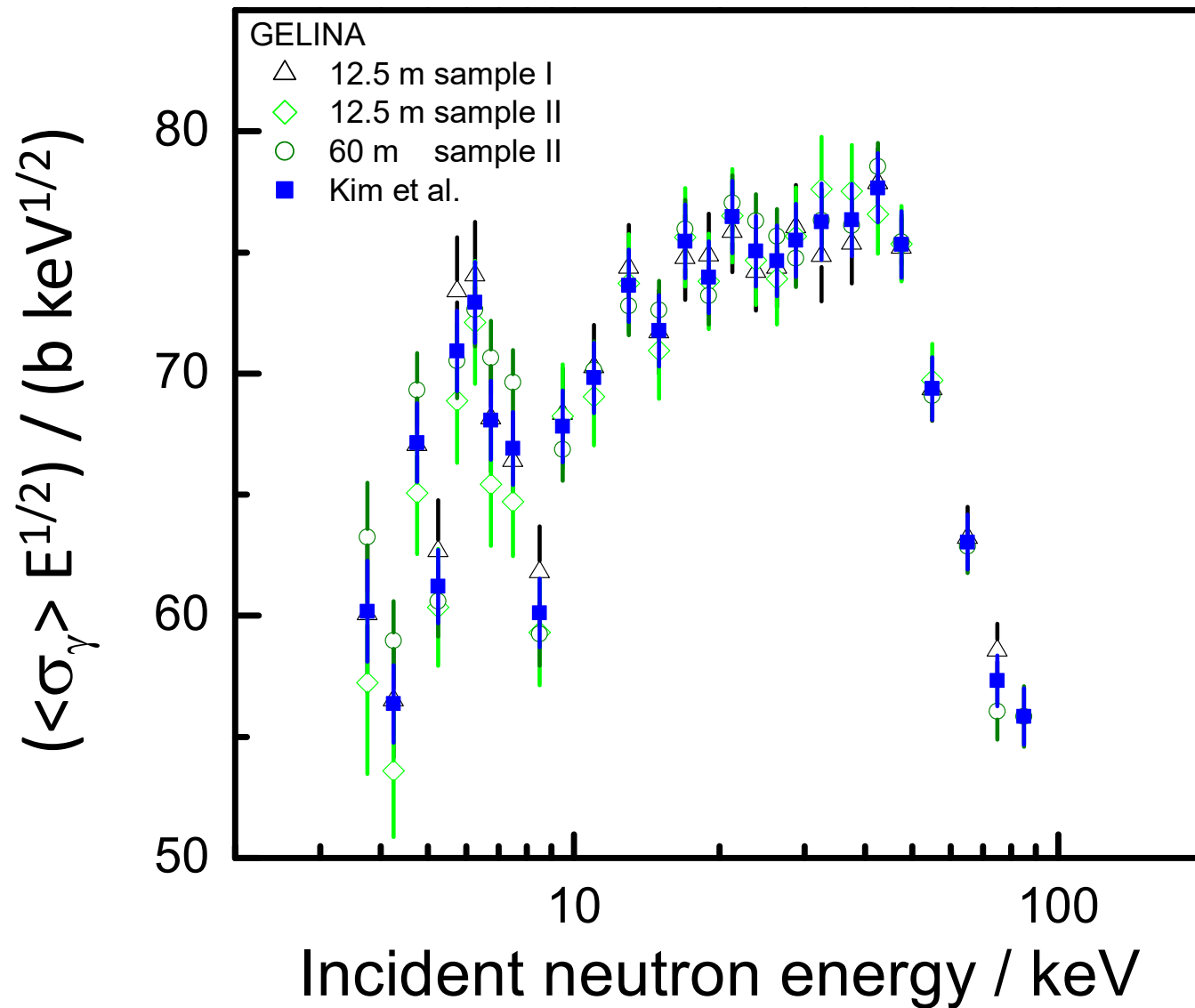
$$\langle Y_{\gamma, \text{exp}} \rangle = \langle Y_0 + Y_1 + Y_2 + \dots \rangle$$

$$\langle Y_{\gamma, \text{exp}} \rangle \neq n \langle \sigma_{\gamma} \rangle$$

$$\langle Y_{\gamma, \text{exp}} \rangle = F_{\gamma} n \langle \sigma_{\gamma} \rangle$$

$$F_{\gamma} = \frac{\langle Y_{\gamma}(n) \rangle / n}{\langle Y_{\gamma}(n_{\text{thin}}) \rangle / n_{\text{thin}}}$$

GELINA: from $\langle Y_{\text{exp}} \rangle$ to $\langle \sigma_{\gamma} \rangle$



Reporting $\langle \sigma_\gamma \rangle$

E_l / eV	E_h / eV	σ_γ / b
3500	4000	0.9828
4000	4500	0.8645
4500	5000	0.9743
5000	5500	0.8448
5500	6000	0.9355
6000	6500	0.9226
6500	7000	0.8286
7000	8000	0.7726
8000	9000	0.6521
9000	10000	0.6958
10000	12000	0.6657
12000	14000	0.6458
14000	16000	0.5860
16000	18000	0.5787
18000	20000	0.5366
20000	22500	0.5246
22500	25000	0.4871
25000	27500	0.4608
27500	30000	0.4453
30000	35000	0.4230
35000	40000	0.3942
40000	45000	0.3767
45000	50000	0.3457
50000	60000	0.2959
60000	70000	0.9828
70000	80000	0.8645
80000	90000	0.9743

$(C_w, C_{w,0}, C_{w,Pb}, C_\phi)$

$$B_w(t) = b_0 + C_{w,0}(t) + R_n(C_{w,Pb} - C_{w,0})(t)$$

$$Y_{\text{exp}} = N \frac{C_w - k_\gamma B_w}{C_\phi - B_\phi} Y_\phi$$

$\langle \sigma_\gamma \rangle$

Reporting: $\langle \sigma_\gamma \rangle$ + covariance data (AGS-formalism)

E_l / eV	E_h / eV	σ_γ / b	u_{σ_γ}	AGS		
				u_u	S_{k_γ}	S_N
3500	4000	0.9828	0.034	0.0138	-0.0145	0.0147
4000	4500	0.8645	0.0246	0.0092	-0.0135	0.0130
4500	5000	0.9743	0.0234	0.0085	-0.0129	0.0146
5000	5500	0.8448	0.0209	0.0080	-0.0116	0.0127
5500	6000	0.9355	0.0220	0.0088	-0.0104	0.0140
6000	6500	0.9226	0.0212	0.0087	-0.0096	0.0138
6500	7000	0.8286	0.0198	0.0085	-0.0087	0.0124
7000	8000	0.7726	0.0174	0.0058	-0.0079	0.0116
8000	9000	0.6521	0.0153	0.0056	-0.0071	0.0098
9000	10000	0.6958	0.0152	0.0054	-0.0067	0.0104
10000	12000	0.6657	0.0138	0.0039	-0.0060	0.0100
12000	14000	0.6458	0.0132	0.0040	-0.0056	0.0097
14000	16000	0.5860	0.0120	0.0040	-0.0050	0.0088
16000	18000	0.5787	0.0117	0.0040	-0.0048	0.0087
18000	20000	0.5366	0.0108	0.0039	-0.0047	0.0081
20000	22500	0.5246	0.0103	0.0035	-0.0052	0.0079
22500	25000	0.4871	0.0095	0.0033	-0.0042	0.0073
25000	27500	0.4608	0.0090	0.0033	-0.0033	0.0069
27500	30000	0.4453	0.0089	0.0035	-0.0029	0.0067
30000	35000	0.4230	0.0088	0.0031	-0.0028	0.0064
35000	40000	0.3942	0.0077	0.0026	-0.0021	0.0059
40000	45000	0.3767	0.0069	0.0022	-0.0018	0.0057
45000	50000	0.3457	0.0063	0.0021	-0.0022	0.0052
50000	60000	0.2959	0.0055	0.0016	-0.0145	0.0044
60000	70000	0.9828	0.0044	0.0013	-0.0135	0.0037
70000	80000	0.8645	0.0038	0.0012	-0.0129	0.0031
80000	90000	0.9743	0.0040	0.0017	-0.0116	0.0029

$(C_w, C_{w,0}, C_{w,Pb}, C_\phi)$

$$B_w(t) = b_0 + C_{w,0}(t) + R_n(C_{w,Pb} - C_{w,0})(t)$$

$$Y_{\text{exp}} = N \frac{C_w - k_\gamma B_w}{C_\phi - B_\phi} Y_\phi$$

$$\langle \sigma_\gamma \rangle \quad \text{and} \quad V_Z = D_Z + S_Z S_Z^T$$

u_u and $S_{(k_\gamma, N)}$

Reporting: $\langle \sigma_\gamma \rangle$ + covariance data (AGS-formalism)

E_l / eV	E_h / eV	σ_γ / b	u_{σ_γ}	AGS		
				u_u	S_{k_γ}	S_N
3500	4000	0.9828	0.034	0.0138	-0.0145	0.0147
4000	4500	0.8645	0.0246	0.0092	-0.0135	0.0130
4500	5000	0.9743	0.0234	0.0085	-0.0129	0.0146
5000	5500	0.8448	0.0209	0.0080	-0.0116	0.0127
5500	6000	0.9355	0.0220	0.0088	-0.0104	0.0140
6000	6500	0.9226	0.0212	0.0087	-0.0096	0.0138
6500	7000	0.8286	0.0198	0.0085	-0.0087	0.0124
				0.0058	-0.0079	0.0116
				0.0056	-0.0071	0.0098
				0.0054	-0.0067	0.0104
				0.0039	-0.0060	0.0100
				0.0040	-0.0056	0.0097
14000	16000	0.5860	0.0120	0.0040	-0.0050	0.0088
16000	18000	0.5787	0.0117	0.0040	-0.0048	0.0087
18000	20000	0.5366	0.0108	0.0039	-0.0047	0.0081
20000	22500	0.5246	0.0103	0.0035	-0.0052	0.0079
22500	25000	0.4871	0.0095	0.0033	-0.0042	0.0073
25000	27500	0.4608	0.0090	0.0033	-0.0033	0.0069
27500	30000	0.4453	0.0089	0.0035	-0.0029	0.0067
30000	35000	0.4230	0.0088	0.0031	-0.0028	0.0064
35000	40000	0.3942	0.0077	0.0026	-0.0021	0.0059
40000	45000	0.3767	0.0069	0.0022	-0.0018	0.0057
45000	50000	0.3457	0.0063	0.0021	-0.0022	0.0052
50000	60000	0.2959	0.0055	0.0016	-0.0145	0.0044
60000	70000	0.9828	0.0044	0.0013	-0.0135	0.0037
70000	80000	0.8645	0.0038	0.0012	-0.0129	0.0031
80000	90000	0.9743	0.0040	0.0017	-0.0116	0.0029

Propagation of uncorrelated uncertainties due to counting statistics

$$(C_w, C_{w,0}, C_{w,Pb}, C_\phi)$$

$$B_w(t) = b_0 + C_{w,0}(t) + R_n(C_{w,Pb} - C_{w,0})(t)$$

$$Y_{\text{exp}} = N \frac{C_w - k_\gamma B_w}{C_\phi - B_\phi} Y_\phi$$

$$\langle \sigma_\gamma \rangle \quad \text{and} \quad V_Z = D_Z + S_Z S_Z^T$$

u_u and $S_{(k_\gamma, N)}$

Reporting: $\langle \sigma_\gamma \rangle$ + covariance data (AGS-formalism)

E_l / eV	E_h / eV	σ_γ / b	u_{σ_γ}	AGS		
				u_u	S_{k_γ}	S_N
3500	4000	0.9828	0.034	0.0138	-0.0145	0.0147
4000	4500	0.8645	0.0246	0.0092	-0.0135	0.0130
4500	5000	0.9743	0.0234	0.0085	-0.0129	0.0146
5000	5500	0.8448	0.0209	0.0080	-0.0116	0.0127
5500	6000	0.9355	0.0220	0.0088	-0.0104	0.0140
6000	6500	0.9226	0.0212	0.0087	-0.0096	0.0138
6500	7000	0.8286	0.0198	0.0085	-0.0087	0.0124
7000	7500	0.8286	0.0198	0.0085	-0.0079	0.0116
8000	8500	0.8286	0.0198	0.0085	-0.0071	0.0098
9000	9500	0.8286	0.0198	0.0085	-0.0067	0.0104
10000	10500	0.8286	0.0198	0.0085	-0.0060	0.0100
12000	13000	0.8286	0.0198	0.0085	-0.0056	0.0097
14000	16000	0.5860	0.0120	0.0040	-0.0050	0.0088
16000	18000	0.5787	0.0117	0.0040	-0.0048	0.0087
18000	20000	0.5366	0.0108	0.0039	-0.0047	0.0081
20000	22500	0.5246	0.0103	0.0035	-0.0052	0.0079
22500	25000	0.4871	0.0095	0.0033	-0.0042	0.0073
25000	27500	0.4608	0.0090	0.0033	-0.0033	0.0069
27500	30000	0.4453	0.0089	0.0035	-0.0029	0.0067
30000	35000	0.4230	0.0088	0.0031	-0.0028	0.0064
35000	40000	0.3942	0.0077	0.0026	-0.0021	0.0059
40000	45000	0.3767	0.0069	0.0022	-0.0018	0.0057
45000	50000	0.3457	0.0063	0.0021	-0.0022	0.0052
50000	60000	0.2959	0.0055	0.0016	-0.0145	0.0044
60000	70000	0.9828	0.0044	0.0013	-0.0135	0.0037
70000	80000	0.8645	0.0038	0.0012	-0.0129	0.0031
80000	90000	0.9743	0.0040	0.0017	-0.0116	0.0029

$$S_{k_\gamma} = \frac{\partial \langle \sigma_\gamma \rangle}{\partial k_\gamma} u_{k_\gamma}$$

$(C_w, C_{w,0}, C_{w,Pb}, C_\phi)$

$$B_w(t) = b_0 + C_{w,0}(t) + R_n(C_{w,Pb} - C_{w,0})(t)$$

$$Y_{\text{exp}} = N \frac{C_w - k_\gamma B_w}{C_\phi - B_\phi} Y_\phi$$

$$\langle \sigma_\gamma \rangle \quad \text{and} \quad V_Z = D_Z + S_Z S_Z^T$$

u_u and $S_{(k_\gamma, N)}$

Reporting: $\langle \sigma_\gamma \rangle$ + covariance data (AGS-formalism)

E_l / eV	E_h / eV	σ_γ / b	u_{σ_γ}	AGS		
				u_u	S_{k_γ}	S_N
3500	4000	0.9828	0.034	0.0138	-0.0145	0.0147
4000	4500	0.8645	0.0246	0.0092	-0.0135	0.0130
4500	5000	0.9743	0.0234	0.0085	-0.0129	0.0146
5000	5500	0.8448	0.0209	0.0080	-0.0116	0.0127
5500	6000	0.9355	0.0220	0.0088	-0.0104	0.0140
6000	6500	0.9226	0.0212	0.0087	-0.0096	0.0138
6500	7000	0.8286	0.0198	0.0085	-0.0087	0.0124
7000				0.0058	-0.0079	0.0116
8000				0.0056	-0.0071	0.0098
9000				0.0054	-0.0067	0.0104
10000				0.0039	-0.0060	0.0100
12000				0.0040	-0.0056	0.0097
14000	16000	0.5860	0.0120	0.0040	-0.0050	0.0088
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18000	20000	0.5366	0.0108	0.0039	-0.0047	0.0081
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80000	90000	0.9743	0.0040	0.0017	-0.0116	0.0029

$$S_N = \frac{\partial \langle \sigma_\gamma \rangle}{\partial N} u_N$$

$(C_w, C_{w,0}, C_{w,Pb}, C_\phi)$

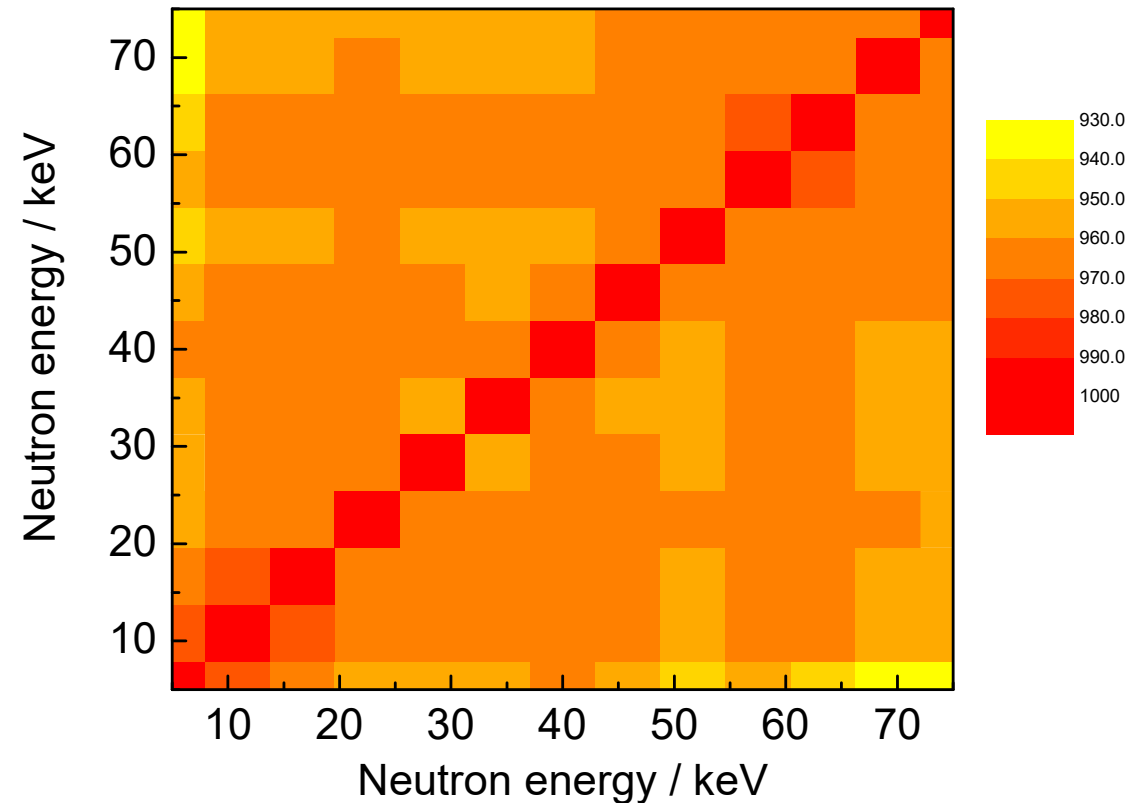
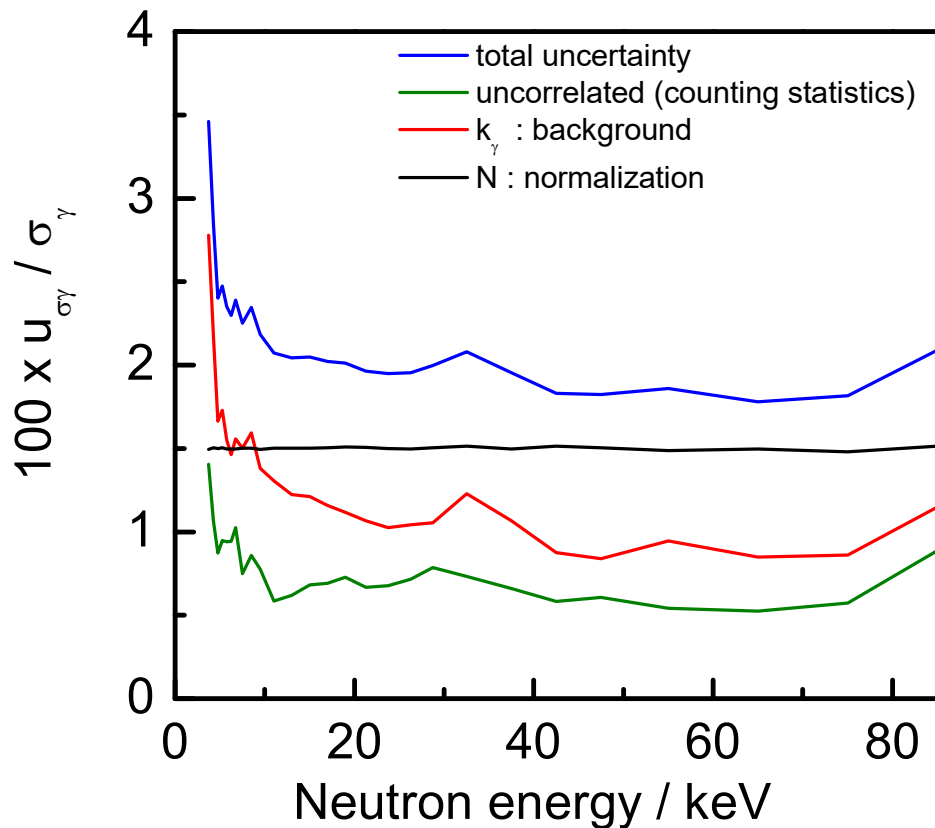
$$B_w(t) = b_0 + C_{w,0}(t) + R_n(C_{w,Pb} - C_{w,0})(t)$$

$$Y_{exp} = N \frac{C_w - k_\gamma B_w}{C_\phi - B_\phi} Y_\phi$$

$$\langle \sigma_\gamma \rangle \text{ and } V_Z = D_Z + S_Z S_Z^T$$

u_u and $S_{(k_\gamma, N)}$

Reporting: $\langle \sigma_\gamma \rangle$ + covariance data (AGS-formalism)



Covariance matrix

Total uncertainty dominated by correlated components due to normalisation and background

Hauser-Feshbach + width fluctuations

$$\langle \sigma_{\text{tot}} \rangle = f(R, S_{\ell=0,1,2})$$

$$\langle \sigma_{\gamma} \rangle = h(T_{\gamma,0}^+, T_{\gamma,0}^-, S_{\ell=0,1,2})$$

$$\langle \sigma_{\text{tot}} \rangle = \frac{4\pi}{k_n^2} g \sin^2 \varphi \left[1 - \frac{T_n}{2} \right] + \frac{\pi}{k_n^2} g T_n$$

$$\langle \sigma_{\gamma} \rangle = \frac{\pi}{k_n^2} g \frac{T_n T_{\gamma}}{T} F_{n\gamma}$$

$$\alpha = kR$$

$$T_n^{\ell}(E_n) \cong 2\pi \sqrt{\frac{E_n}{1\text{eV}}} v_{\ell}(E_n) S_{\ell}$$

$$T_{\gamma}(E) \approx 2\pi \frac{\langle \Gamma_{\gamma} \rangle}{D}$$

ℓ	φ_{ℓ}
0	α
1	$\alpha - \arctan \alpha$
2	$\alpha - \arctan(3\alpha/3-\alpha^2)$

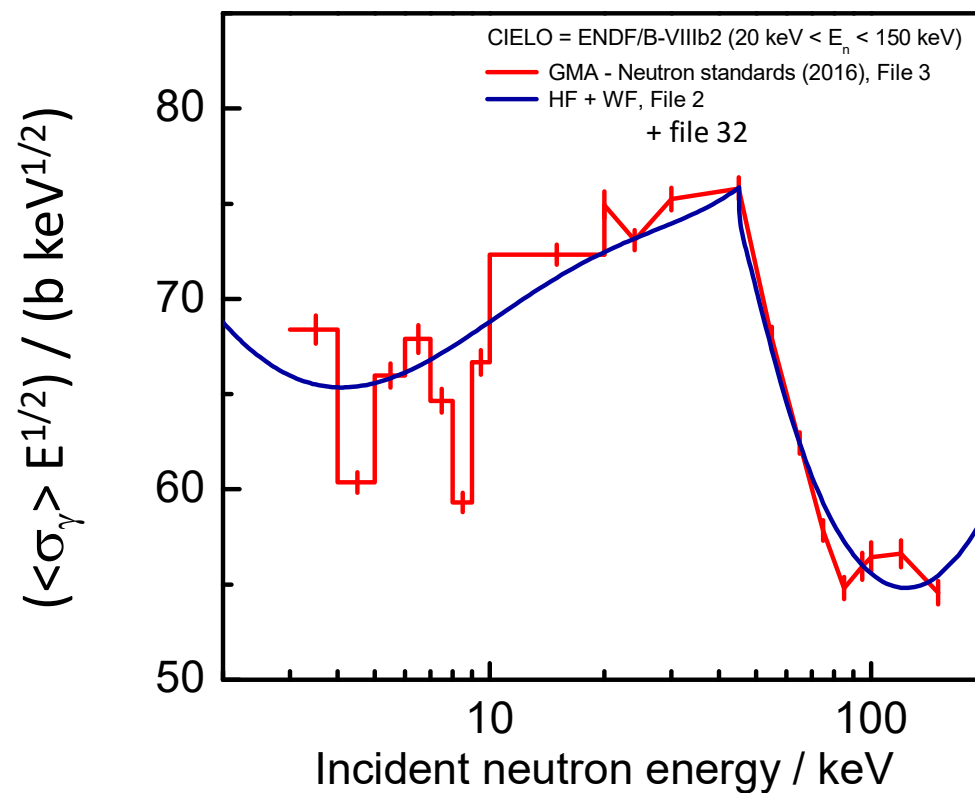
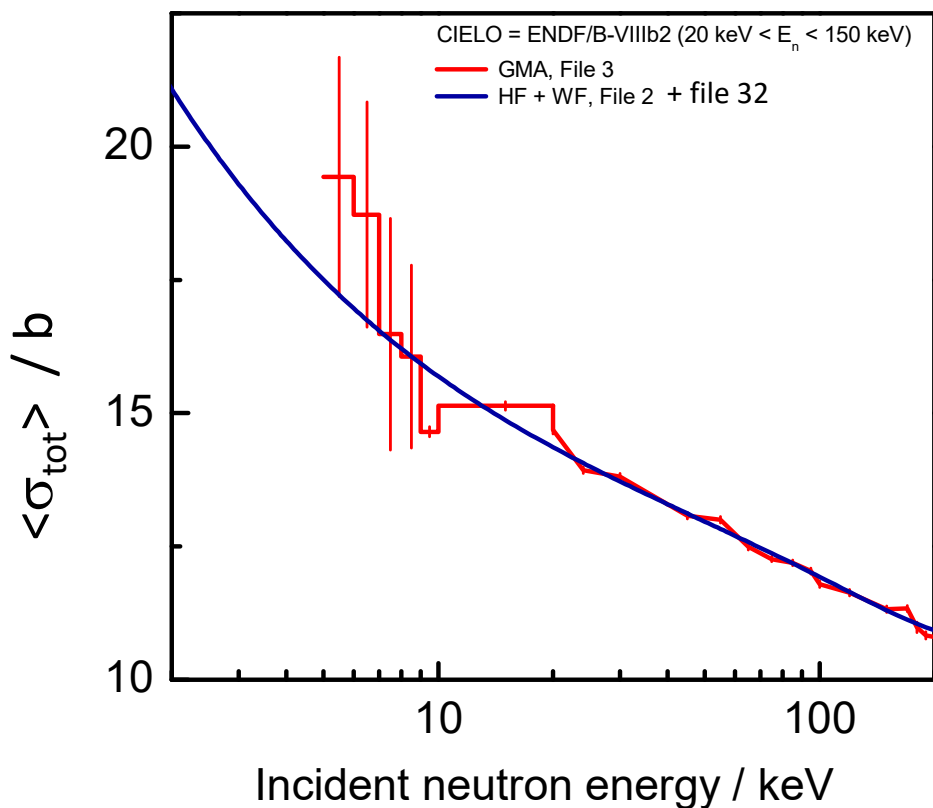
ℓ	P_{ℓ}	v_{ℓ}
0	α	1
1	$\alpha^3/(1+\alpha^2)$	$\alpha^2/(1+\alpha^2)$

$$\rho(E, J) \approx \frac{2J+1}{T} e^{\frac{E-E_0}{T}}$$

Sirakov et al., ANE 35 (2008) 1223

Sirakov et al., EPJA 53 (2017) 199

Evaluation for $n + {}^{238}\text{U}$ in URR : 20 keV - 150 keV



Parameter	Correlation matrix					
R / fm	9.483 (20)	1	-0.70	-0.86	0.75	-0.37
$S_0 / 10^{-4}$	1.064 (15)		1	0.46	-0.49	0.30
$S_1 / 10^{-4}$	1.641 (33)			1	-0.82	0.37
$T_\gamma^+ / 10^{-3}$	6.60 (14)				1	-0.31
$T_\gamma^- / 10^{-3}$	6.37 (7)					1

Importance of a correct evaluation of $V_{\sigma_{\text{exp}}}$: e.g. $^{103}\text{Rh}(n,\gamma)$

$$Y_{\text{exp},\gamma} = k \frac{C_w - b_w}{C_\phi - b_\phi} Y_\phi$$

$$V_Y = D_u + V_k + V_b$$

$$u_k/k = 2\%$$



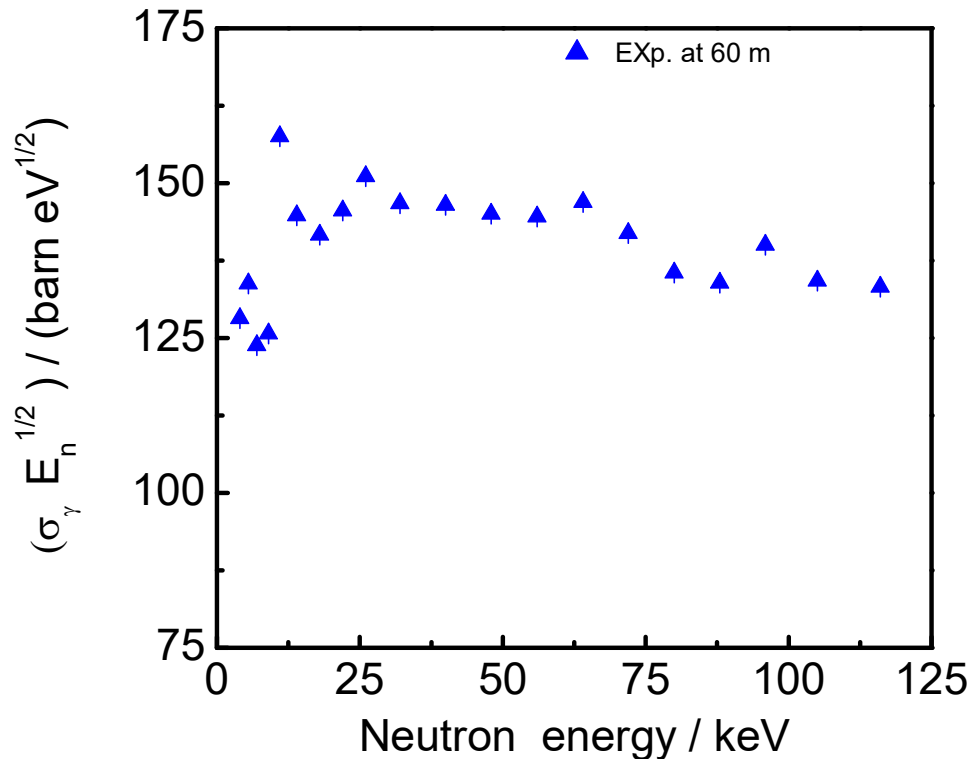
$$(Y_{\text{exp},\gamma}, V_Y)$$



$$(\sigma_{\text{exp},\gamma}, V_{\sigma_{\text{exp}}})$$

$$\sigma_{\text{exp},\gamma} \approx \frac{Y_{\text{exp},\gamma}}{n} \quad n: \text{areal density}$$

$V_{\sigma_{\text{exp}}}$ includes 2% due k based on σ_{exp}



Importance of a correct evaluation of $V_{\sigma_{\text{exp}}}$: e.g. $^{103}\text{Rh}(n,\gamma)$

$$Y_{\text{exp},\gamma} = k \frac{C_w - b_w}{C_\phi - b_\phi} Y_\phi$$

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$$(Y_{\text{exp},\gamma}, V_Y)$$



$$(\sigma_{\text{exp},\gamma}, V_{\sigma_{\text{exp}}})$$

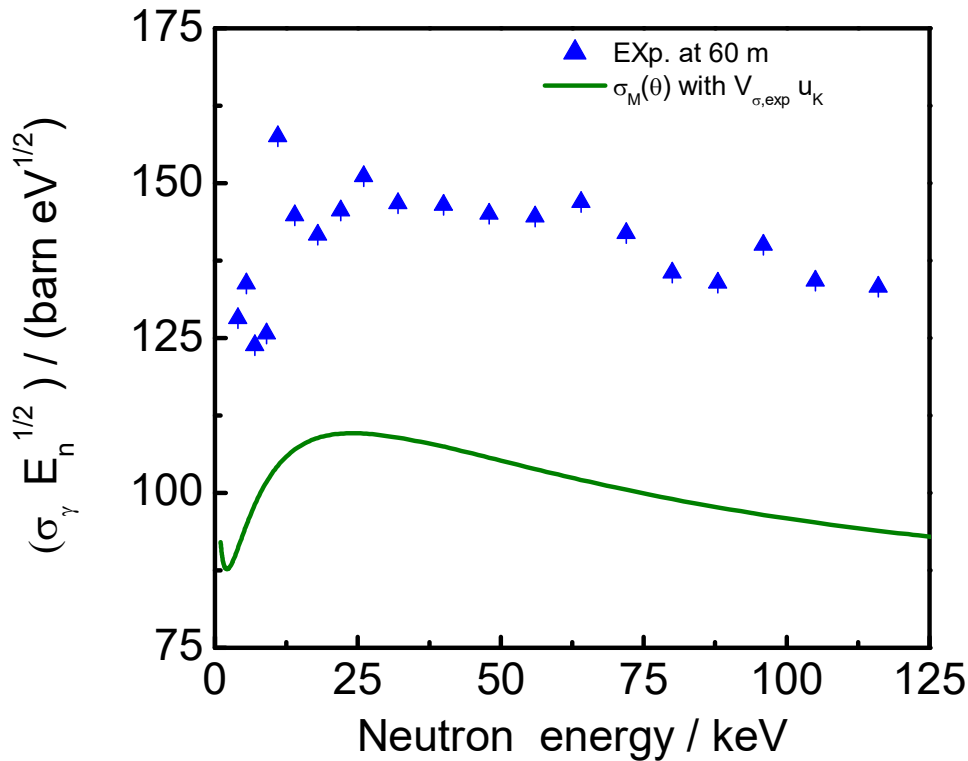
$$\sigma_{\text{exp},\gamma} \approx \frac{Y_{\text{exp},\gamma}}{n} \quad n: \text{areal density}$$

$V_{\sigma_{\text{exp}}}$ includes 2% due k based on σ_{exp}



$$\chi^2(\theta) = (\sigma_{\text{exp}} - \sigma_M(\theta))^T V_{\sigma_{\text{exp}}}^{-1} (\sigma_{\text{exp}} - \sigma_M(\theta))$$

$\sigma_M(\theta)$: HF + WF



Solution : include (k_{exp}, u_k) as input experimental data

$$Y'_{\text{exp},\gamma} = \frac{C_w - b_w}{C_\phi - b_\phi} Y_\phi$$

$$V_{Y'} = D_u + V_b$$

$$(k'_{\text{exp}}, u_{k'})$$

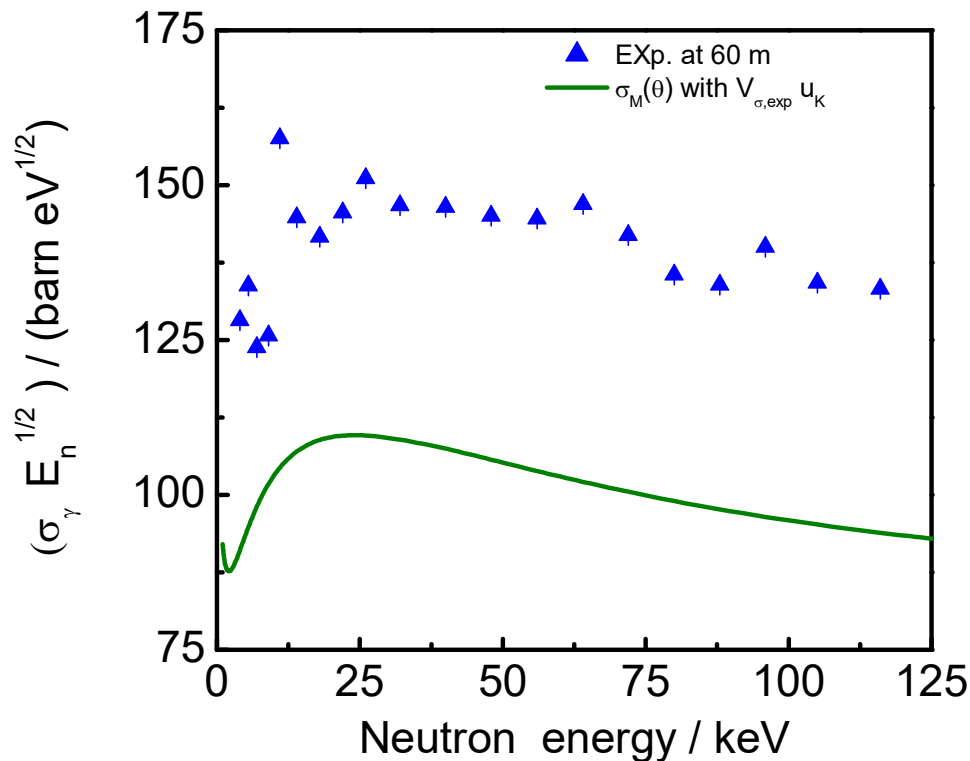
$V_{Y'}$: does not include u_k



$$(Z_{\text{exp}}, V_Z) = \begin{cases} (\sigma'_{\text{exp},\gamma}, V_{\sigma'}) \\ (k'_{\text{exp}}, u_{k'}) \end{cases}$$

$$\sigma'_{\text{exp},\gamma} \approx k' \frac{Y'_{\text{exp},\gamma}}{n}$$

n : areal density



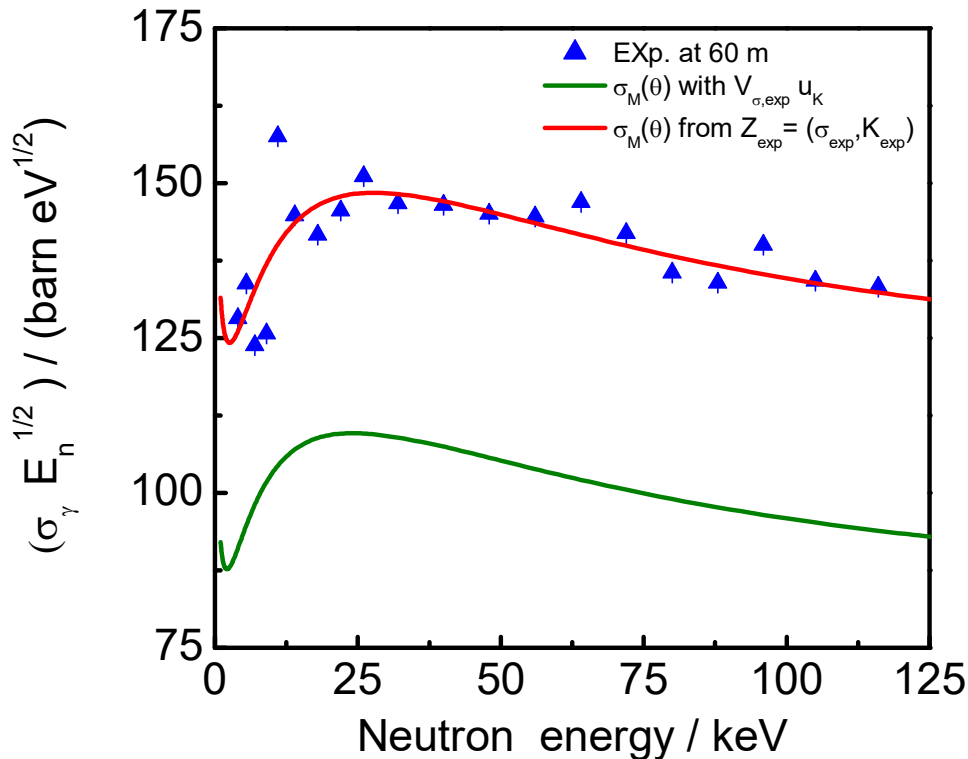
Solution : include (k_{exp}, u_k) as input experimental data

$$Y'_{\text{exp},\gamma} = \frac{C_w - b_w}{C_\phi - b_\phi} Y_\phi$$

$$V_{Y'} = D_u + V_b$$

$$(k'_{\text{exp}}, u_{k'})$$

$V_{Y'}$: does not include u_k



$$(Z_{\text{exp}}, V_Z) = \begin{cases} (\sigma'_{\text{exp},\gamma}, V_{\sigma'}) \\ (k'_{\text{exp}}, u_{k'}) \end{cases}$$

$$\sigma'_{\text{exp},\gamma} \approx k' \frac{Y'_{\text{exp},\gamma}}{n}$$

n : areal density

$$\chi^2(\theta) = (Z_{\text{exp}} - Z_M(\theta))^T V_Z^{-1} (Z_{\text{exp}} - Z_M(\theta))$$

$$Z_M = \begin{cases} k' = k' \\ \sigma_M(\theta) : \text{HF} + \text{WF} \end{cases}$$