Description and usage of experimental data for evaluation in the resolved resonance region

Subgroup - 36

EC – JRC – IRMM

Standards for Nuclear Safety, Security and Safeguards (SN3S)

Agenda

1) **Status**

2) **EXFOR reporting, Meeting 8 – 10 October 2013, IAEA**

3) **Activities at IRMM in 2013 – 2014, B. Becker**

   - **AGS, Manual + distribution (OECD/NEA)**
   - **Full Bayesian analysis**

4) **Preparation Final report**

Objective

Produce accurate cross section data together with reliable covariance information in the resonance region

$\Rightarrow$ **Reduce bias effects**

$\Rightarrow$ **Produce reliable and realistic covariance data**

Activities

The main task:

identify and quantify the metrological parameters involved in each step of the evaluation process, starting from the production of experimental data.

Activities:

(1) Identify the uncertainty components

(2) Identify methods for evaluating uncertainties in the resonance region using experimental covariance information

(3) Define and analyse case studies

(4) Provide recommendations for reporting and usage of experimental details and uncertainty components

Status: finalised

(1-3) Nuclear data sheets, 113 (2012) 3054 – 3100

ND2013, Becker et al.

(2-3) Additional studies at IRMM: contribution to CW2014, Santa Fe

(4) Consultants meeting at IAEA

AGS, will be distributed by OECD/NEA

EXFOR, Reporting

- **Consultants' Meeting, 8 to 10 October 2013, IAEA Headquarters, Vienna, Austria**

  "EXFOR Data in Resonance Region and Spectrometers' Response Function"

  https://www-nds.iaea.org/index-meeting-crp/CM-RF-2013/

- **Summary**
  - **Report TOF- response function**
  - **Report full experimental details**
  - **Recommendation to report data in TOF**
  - **AGS concept recommended to process TOF-data**
  - **Templates to report TOF-data**

- **Examples**
  - **RPI**
  - **GELINA**

  https://www-nds.iaea.org/publications/indc/indc-eur-0032.pdf

(2-3) Evaluation methods

Methods to account for all uncertainty components

- **Conventional uncertainty propagation (CUP)** Fröhner, NSE 126 (1997) 1 – 18
- **Monte Carlo (MC)** De Saint Jean et al., NSE 161 (2009) 363 - 370
- **Marginalization (MA)** Habert et al., NSE 166 (2010) 276 - 287

Differ in the way the uncertainty of experimental parameters are taken into account

⇒ **Application: NDS 113 (2012) 3054 – 3100 + Becker et al. (ND2013)**

⇒ **Problems in understanding results: more studies required**

results reported at CW2014, Santa Fe

Unresolved resonance region

$$\chi^2(\vec{\theta}) = (Z_{exp} - Z_M(t,\vec{\theta}))^T \, V_{Z_{exp}}^{-1} \, (Z_{exp} - Z_M(t,\vec{\theta}))$$

$$\vec{\theta} = (\vec{\eta}, \vec{\kappa}) \begin{cases} \vec{\eta} : \text{resonance parameters} \\ \vec{\kappa} : \text{experimental parameters} \end{cases}$$

$$\vec{\theta} = (G_{\vec{\theta}}^T \, V_{Z_{exp}}^{-1} \, G_{\vec{\theta}})^{-1} (G_{\vec{\theta}}^T \, V_{Z_{exp}}^{-1} \, Z_{exp})$$

$$V_{\vec{\theta}} = (G_{\vec{\theta}}^T \, V_{Z_{exp}}^{-1} \, G_{\vec{\theta}})^{-1}$$

Conventional uncertainty propagation (CUP)

$$Z_{exp} = \begin{cases} < \sigma_{tot,exp} > \\ < \sigma_{\gamma,exp} > \\ . \\ . \\ \vec{\eta} \\ \vec{\kappa} \end{cases}$$

$$< \sigma_{tot,M} > = \frac{1}{N_{\sigma_{tot}}} f(R_\ell, S_\ell, T_{\gamma,\ell}) \qquad < \sigma_{\gamma,M} > = \frac{1}{N_{\sigma_\gamma}} g(R_\ell, S_\ell, T_{\gamma,\ell})$$

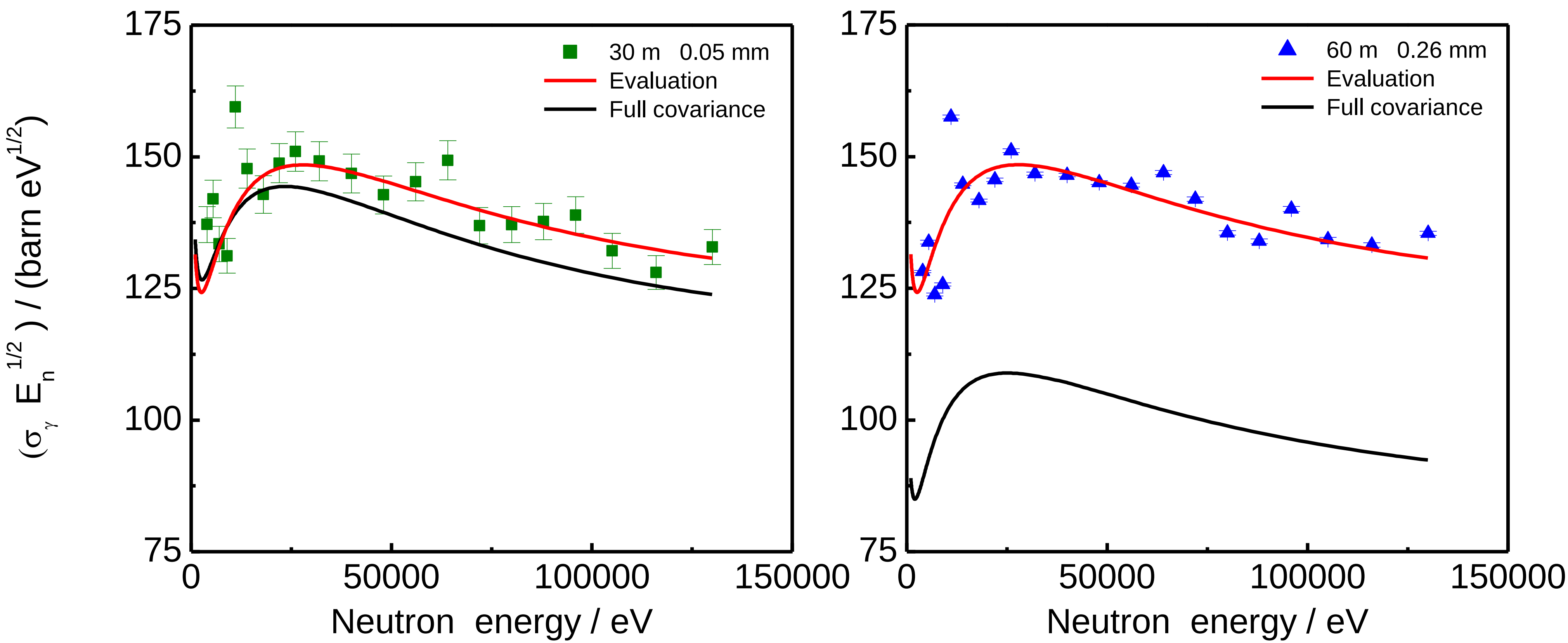
- **Include normalization as fit parameter**

  ⇒ avoids PPP

  in URR due to limitations of the model !

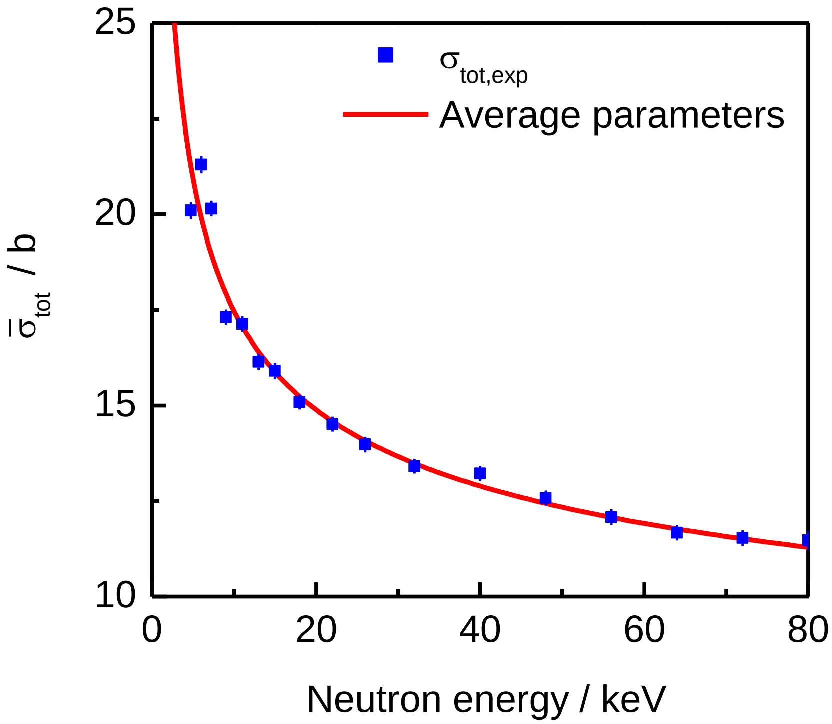
Nuclear Data Sheets 113 (2012) 3054 - 3100

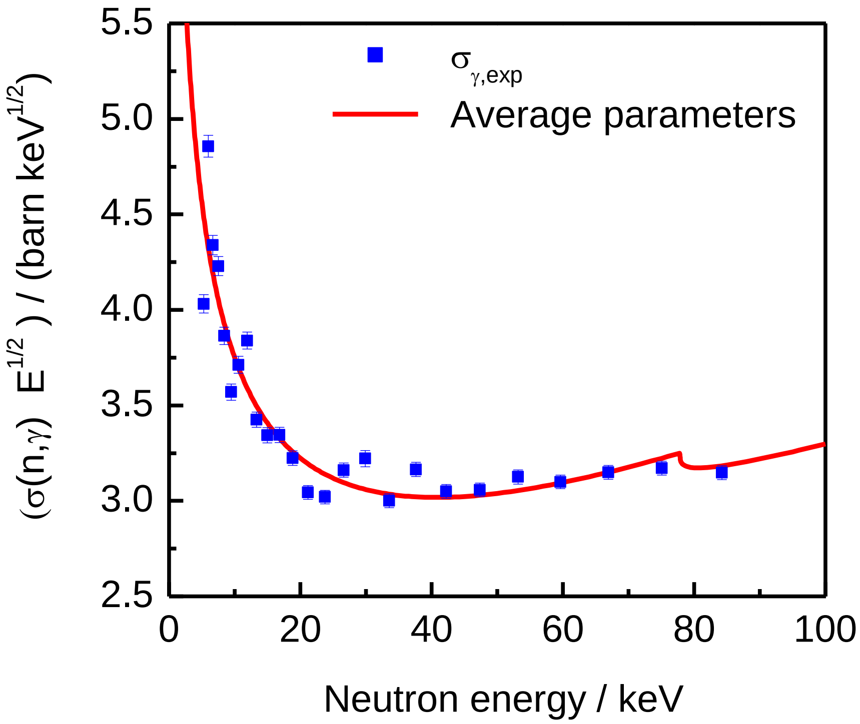
PPP in URR for $^{103}Rh(n,\gamma)$



Example URR : $\sigma(n,tot)$ and $\sigma(n,\gamma)$ for ^{197}Au

- **Transmission at 50 m (GELINA) : T_{exp} with $u_{N_{\sigma tot}} / N_{\sigma tot}$ = 2.0 % (normalization)**
  Sirakov et al., Eur. J. Phys. A 49 (2013) 1 - 10
- **Capture at 12.5 m (GELINA) : Y_{exp} with $u_{N_{\sigma\gamma}} / N_{\sigma\gamma}$ = 1.5 % (normalization)**
  Massimi et al., submitted to Eur. J. Phys. A
- **Hauser – Feshbach + WF : $(R_{\ell}, S_{\ell}, T_{\gamma,\ell})$**

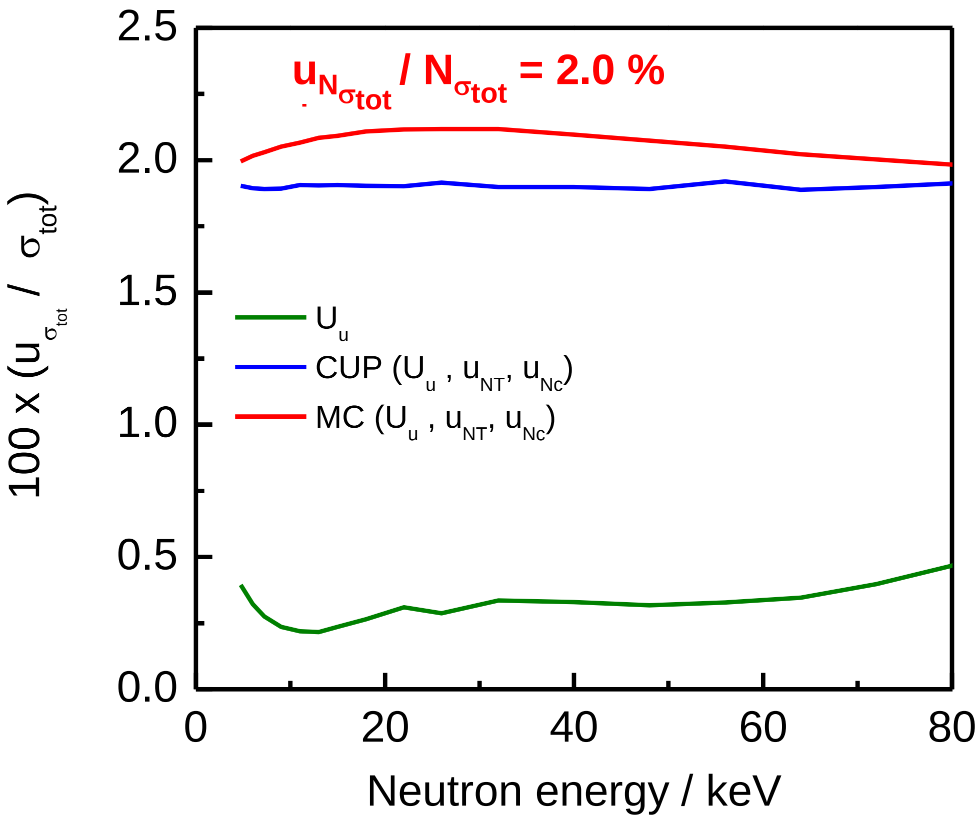


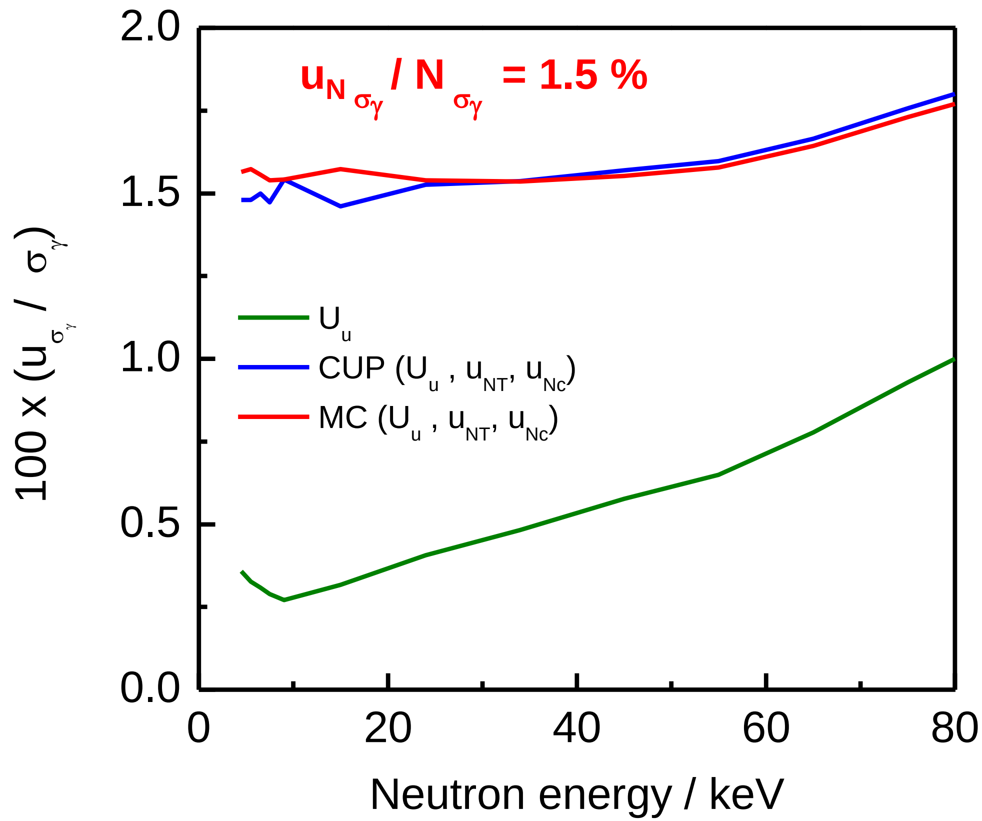


Parameter covariance matrix (GLSQ + CUP)

Parameter		100 x (u_θ/θ)	$\rho(\theta,\theta')$ x 100						
			N_T	N_c	R^∞	S_0	S_1	T_γ^{2+}	T_γ^{2-}
$N_{\sigma tot}$	1.00	2.0 → 1.9	100	0	94	-68	-12	22	-2
$N_{\sigma\gamma}$	1.00	1.5 → 1.5		100	1	2	8	-84	-5
R^∞ / fm	-0.163	10.1			100	-44	5	8	-14
S_0 / 10^{-4}	1.89	1.8				100	35	-40	-12
S_1 / 10^{-5}	2.84	10.8					100	-52	-82
T_γ^{2+}/ 10^{-2}	3.44	2.8						100	65
T_γ^{2-}/ 10^{-2}	1.62	7.8							100

Cross Section Uncertainty





CUP : normalization uncertainties u_{N_T} and u_{N_c} propagate to

- **reaction model parameters and**
- **evaluated cross sections**

Monte Carlo + LSQ : De Saint Jean et al., NSE 161 (2009) 363 – 370

GLSQ : Resolved resonance region

$$\chi^2(\vec{\theta}) = (Z_{exp} - Z_M(t,\vec{\theta}))^T \, V_{Z_{exp}}^{-1} \, (Z_{exp} - Z_M(t,\vec{\theta}))$$

$$\vec{\theta} = (G_{\vec{\theta}}^T \, V_{Z_{exp}}^{-1} \, G_{\vec{\theta}})^{-1} \, (G_{\vec{\theta}}^T \, V_{Z_{exp}}^{-1} \, Z_{exp})$$

$$V_{\vec{\theta}} = (G_{\vec{\theta}}^T \, V_{Z_{exp}}^{-1} \, G_{\vec{\theta}})^{-1}$$

Conventional uncertainty propagation (CUP)

$$Z_{exp} = \begin{cases} T_{exp} \\ Y_{exp} \\ . \\ . \\ \vec{\eta} \\ \vec{\kappa} \end{cases}$$

$$T_M(t,\vec{\theta}) = \frac{1}{N_T} \frac{\int R(t,E)\, T'(E) dE}{\int R(t,E) dE} \qquad T'(E) = e^{-\sum_k n_k \bar{\sigma}_{tot,k}}$$

$$Y_M(t,\vec{\theta}) = \frac{1}{N_c} \frac{\int R(t,E)\, Y'(E) dE}{\int R(t,E) dE} \qquad Y'(E) = (1 - e^{-\sum_k n_k \bar{\sigma}_{tot,k}}) \frac{\bar{\sigma}_{\gamma,k}}{\bar{\sigma}_{tot,k}} + \ldots$$

GLSQ : include κ as adjustable parameter

$$\chi^2(\vec{\theta}) = (Z_{exp} - Z_M(t,\vec{\theta}))^T \, V_{Z_{exp}}^{-1} \, (Z_{exp} - Z_M(t,\vec{\theta}))$$

Fröhner, Nucl. Sci. Eng. 126 (1997) 1 – 18

JEFF Report 18

$$\vec{\theta} = (\vec{\eta}, \vec{\kappa}) \begin{cases} \vec{\eta} : \text{resonance parameters} \\ \vec{\kappa} : \text{experimental parameters} \end{cases}$$

$$\vec{\theta} = (G_{\vec{\theta}}^T \, V_{Z_{exp}}^{-1} \, G_{\vec{\theta}})^{-1} (G_{\vec{\theta}}^T \, V_{Z_{exp}}^{-1} \, Z_{exp})$$

$$V_{\vec{\theta}} = (G_{\vec{\theta}}^T \, V_{Z_{exp}}^{-1} \, G_{\vec{\theta}})^{-1}$$

Conventional uncertainty propagation (CUP)

$$Z_{exp} = \begin{cases} T_{exp} \\ Y_{exp} \\ . \\ . \\ \vec{\eta} \\ \vec{\kappa} \end{cases}$$

$$T_M(t,\vec{\theta}) = \frac{1}{N_T} \frac{\int R(t,E)\, T'(E) dE}{\int R(t,E) dE} \qquad T'(E) = e^{-\sum_k n_k \bar{\sigma}_{tot,k}}$$

- **Consider prior as experimental data ($\theta \in Z_{exp}$)**
  - $\Rightarrow$ allows correlation between prior and new (updating) data
    (not possible in Bayesian updating fitting approach)
- **Include experimental parameters as fit parameter ($\equiv$ including u_N in $V_{Z_{exp}}$)**
  - $\Rightarrow$ avoids PPP
  - $\Rightarrow$ allows full correlation between updating experimental data
  - $\Rightarrow$ verify the influence of u_κ on nuclear model parameters

Normalization uncertainty : RP from $Y_{exp,\gamma}$

Normalization capture data (external)

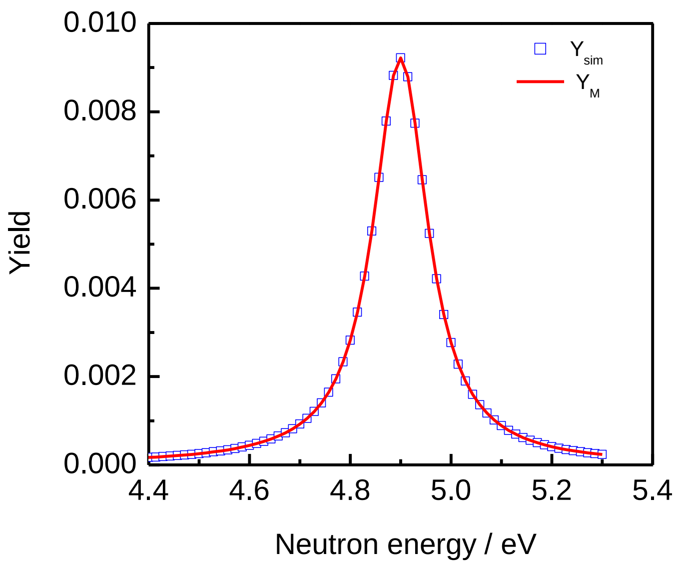
Y_{exp} with u_N / N ≈ 2%

$^{197}Au + n$

E_r = 4.9 eV

Γ_n = 0.015 eV

Γ_γ = 0.122 eV



	$Y \approx n\sigma_\gamma$		
	CUP		
Peak uncertainty (counts)	10 %	1%	0.1 %
u_N/N	0.019	0.019	0.019
$u_{\Gamma n}/\Gamma_n$	0.025	0.022	0.022
$u_{\Gamma\gamma}/\Gamma_\gamma$	0.018	0.003	0.003
$\rho(N,\Gamma_n)$	-0.90	-1.00	-1.00
$\rho(N,\Gamma_\gamma)$	0.15	0.84	1.00
$\rho(\Gamma_n,\Gamma_\gamma)$	-0.23	-0.85	-1.00

$$Y_M \approx n\,\sigma_\gamma$$

⇒ normalization uncertainty u_N / N ≈ 2% remains independent of counting statistics

⇒ u_N propagates fully to the uncertainty of Γ_n

Normalization uncertainty : RP from $Y_{exp,\gamma}$

Normalization capture data (external)

Y_{exp} with u_N / N ≈ 2%

^{197}Au + n

E_r = 4.9 eV

Γ_n = 0.015 eV

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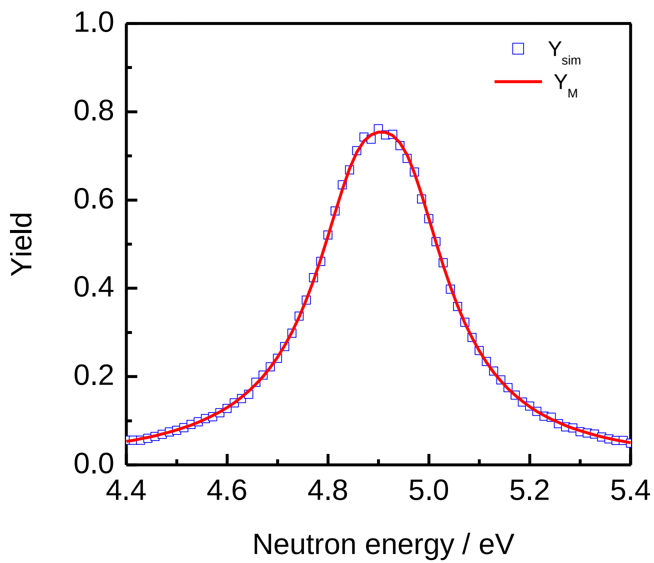

	Sample thickness : 0.01 mm		
	CUP		
Peak uncertainty (counts)	10 %	1%	0.1 %
u_N/N	0.019	0.009	0.001
$u_{\Gamma n}/\Gamma_n$	0.030	0.013	0.001
$u_{\Gamma\gamma}/\Gamma_\gamma$	0.022	0.006	0.001
$\rho(N,\Gamma_n)$	-0.91	-1.00	-1.00
$\rho(N,\Gamma_\gamma)$	0.50	0.94	0.96
$\rho(\Gamma_n,\Gamma_\gamma)$	-0.67	-0.96	-0.97

$$Y_M \approx (1 - e^{n\sigma_{tot}}) \frac{\sigma_\gamma}{\sigma_{tot}}$$

⇒ normalization uncertainty u_N decreases with increasing counting statistics

⇒ u_N has no impact on Γ_n in case of high precision data

Normalization uncertainty : RP from $Y_{exp,\gamma}$

European Commission

Normalization capture data (external)
Y_{exp} with u_N / N = 2%

CUP + GLSQ

Final normalization uncertainty and its impact on nuclear model parameters depend on:

- on the precision of the data
- target thickness

$Y \approx n\sigma_\gamma$

Peak uncertainty (counts)	CUP 10%	CUP 1%	CUP 0.1%
u_N/N	0.019	0.019	0.019
$u_{\Gamma n}/\Gamma_n$	0.025	0.022	0.022
$u_{\Gamma\gamma}/\Gamma_\gamma$	0.018	0.003	0.003
$\rho(N,\Gamma_n)$	-0.90	-1.00	-1.00
$\rho(N,\Gamma_\gamma)$	0.15	0.84	1.00
$\rho(\Gamma_n,\Gamma_\gamma)$	-0.23	-0.85	-0.97

Sample thickness : 0.010 mm

Peak uncertainty (counts)	CUP 10%	CUP 1%	CUP 0.1%
u_N/N	*0.019*	*0.009*	*0.001*
$u_{\Gamma n}/\Gamma_n$	*0.030*	*0.013*	*0.001*
$u_{\Gamma\gamma}/\Gamma_\gamma$	0.022	0.006	0.001
$\rho(N,\Gamma_n)$	-0.91	-1.00	-1.00
$\rho(N,\Gamma_\gamma)$	0.50	0.94	0.96
$\rho(\Gamma_n,\Gamma_\gamma)$	-0.67	-0.96	-0.97

Normalization uncertainty : RP from $Y_{exp,\gamma}$

Normalization capture data (external)
Y_{exp} with $u_N / N = 2\%$

CUP + GLSQ
Final normalization uncertainty and its impact on nuclear model parameters depend on:
- on the precision of the data
- target thickness

Monte Carlo + GLSQ
De Saint Jean et al., NSE 161 (2009) 363 – 370

Normalization
- Is not updated (by constraint)
- Has a direct impact on $u_{\Gamma n}$ and $u_{\Gamma\gamma}$ also in case of high precision data

	$Y \approx n\sigma_\gamma$					
	CUP			MC		
Peak uncertainty (counts)	10%	1%	0.1%	10%	1%	0.1%
u_N/N	0.019	0.019	0.019			
$u_{\Gamma n}/\Gamma_n$	0.025	0.022	0.022	0.025	0.022	0.021
$u_{\Gamma\gamma}/\Gamma_\gamma$	0.018	0.003	0.003	0.018	0.003	0.002
$\rho(N,\Gamma_n)$	-0.90	-1.00	-1.00			
$\rho(N,\Gamma_\gamma)$	0.15	0.84	1.00			
$\rho(\Gamma_n,\Gamma_\gamma)$	-0.23	-0.85	-0.97	-0.14	-0.84	-1.00

	Sample thickness : 0.010 mm					
	CUP			MC		
Peak uncertainty (counts)	10%	1%	0.1%	10%	1%	0.1%
u_N/N	*0.019*	*0.009*	*0.001*			
$u_{\Gamma n}/\Gamma_n$	*0.030*	*0.013*	*0.001*	0.042	0.037	0.039
$u_{\Gamma\gamma}/\Gamma_\gamma$	0.022	0.006	0.001	0.031	0.020	0.021
$\rho(N,\Gamma_n)$	-0.91	-1.00	-1.00			
$\rho(N,\Gamma_\gamma)$	0.50	0.94	0.96			
$\rho(\Gamma_n,\Gamma_\gamma)$	-0.67	-0.96	-0.97	-0.35	-0.99	-1.00

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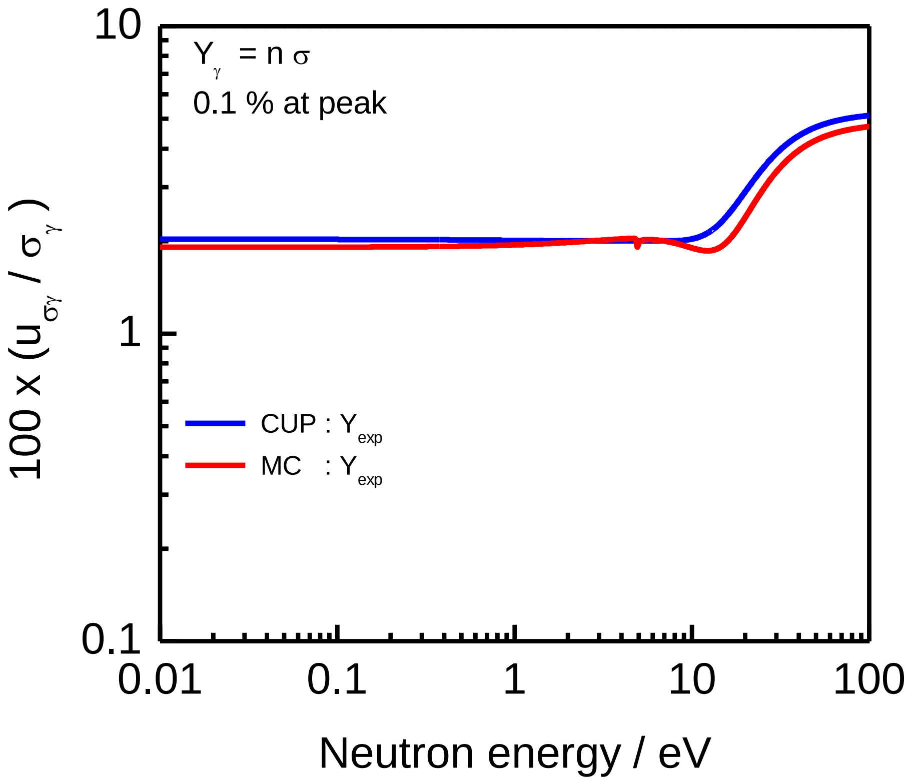
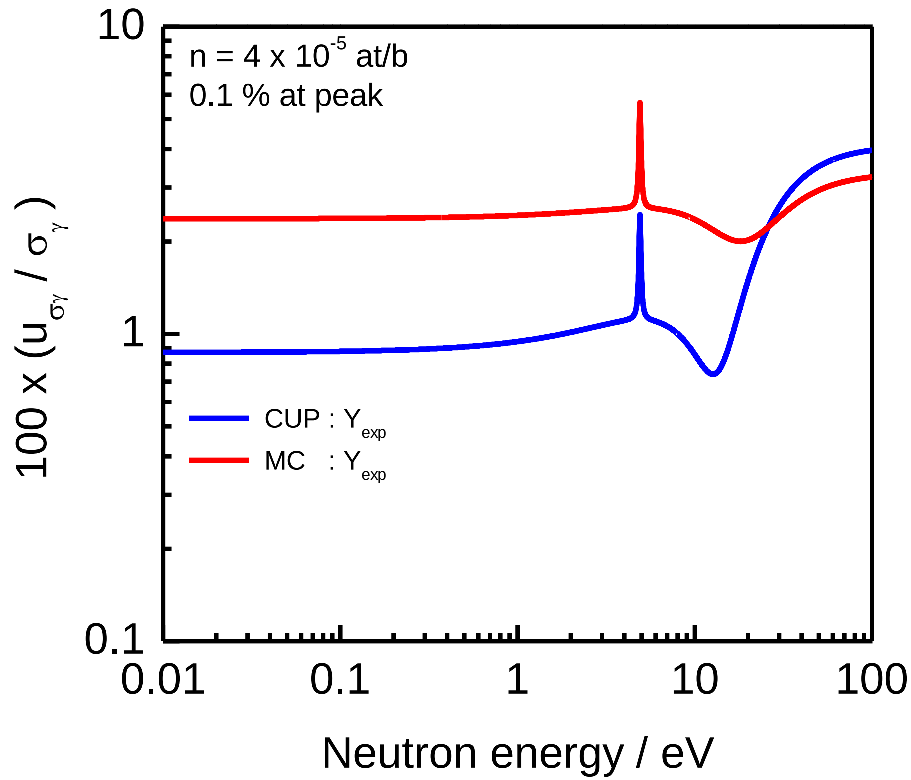
Uncertainty on σ(n, γ): Y_{exp}

Y_{exp} with u_N / N = 2%





Full Bayesian statistical analysis

European Commission

- **Bayes' theorem:**

$$P(\theta|Z) = \frac{P(Z|\theta)\,P(\theta)}{P(Z)}$$

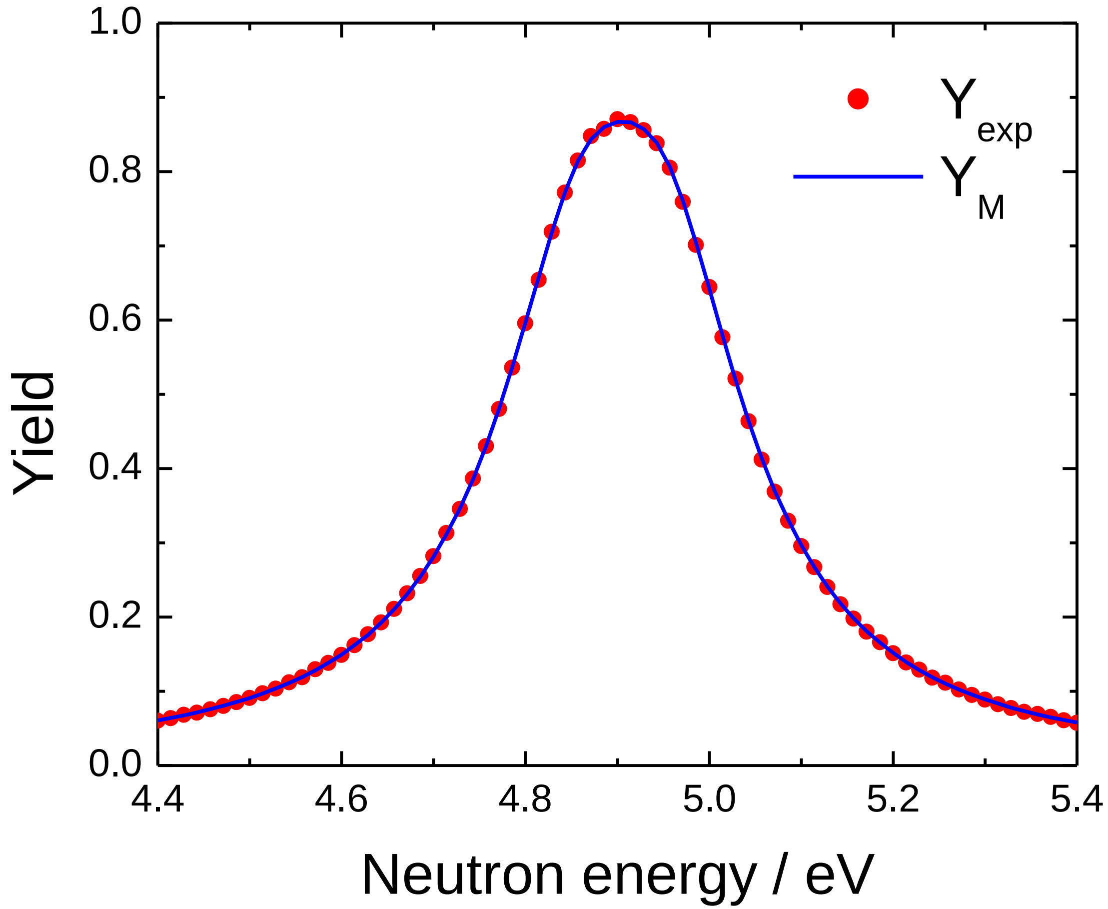
- $P(\theta)$: Prior probability distribution gets updated
- $P(Z|\theta)$: Likelihood of acquired additional data Z (transmission, yield, …)
- $P(\theta|Z)$: Updated posterior probability distribution

$P(\theta)$ and $P(Z|\theta)$ based on maximum entropy

- **Example: RP derived from Y_{exp} for E_r = 4.9 eV of ^{197}Au, (0.02 mm thick sample)**
  - $P(\theta)$ prior for $\theta = (\eta, \kappa)$
    - $N_c = 1.00 \pm 0.02$: normal distribution
    - $(\Gamma_n , \Gamma_\gamma)$: non-informative prior (Γ_n & Γ_γ > 0), Jeffrey's prior
  - $P(Y_M|\theta)$ likelihood of yield
    - $(Y_{exp}, V_{y_{exp}})$: normal distribution

$$P(Y_M|\theta) = \frac{1}{\sqrt{\det(2\pi V_Y)}}\, e^{-\frac{1}{2}(Y_{exp}-Y_M(\theta))^T V_Y^{-1}(Y_{exp}-Y_M(\theta))}$$

Capture measurements for ^{197}Au



$^{197}Au + n$

E_r = 4.9 eV

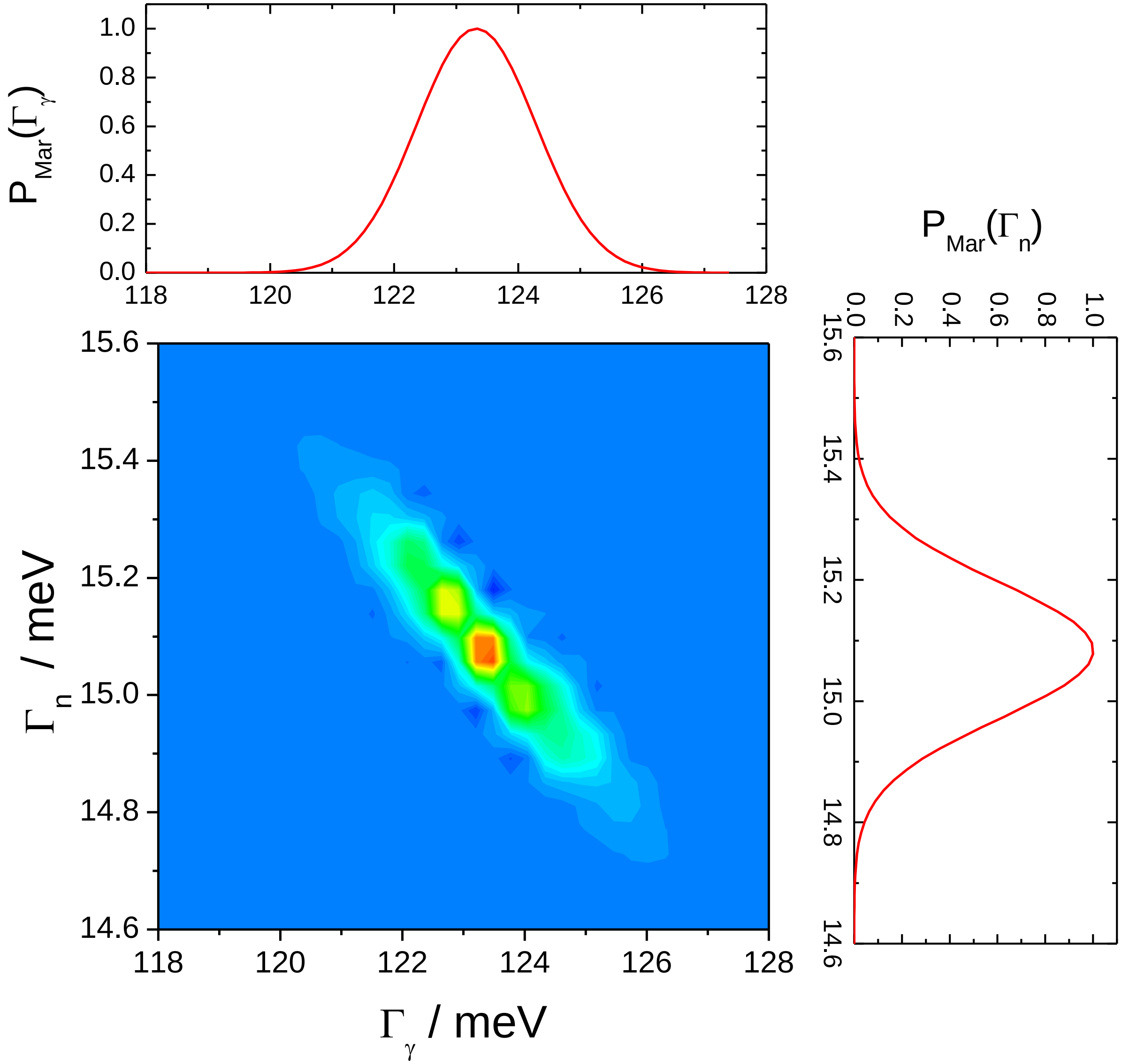
Γ_n = 0.015 eV

Γ_γ = 0.122 eV

Generated test case:

- **Large yield with extreme small counting statistics uncertainties (0.2% in the peak)**
- **Randomized data points**

Posterior distributions P(N, Γ_n, Γ_γ)



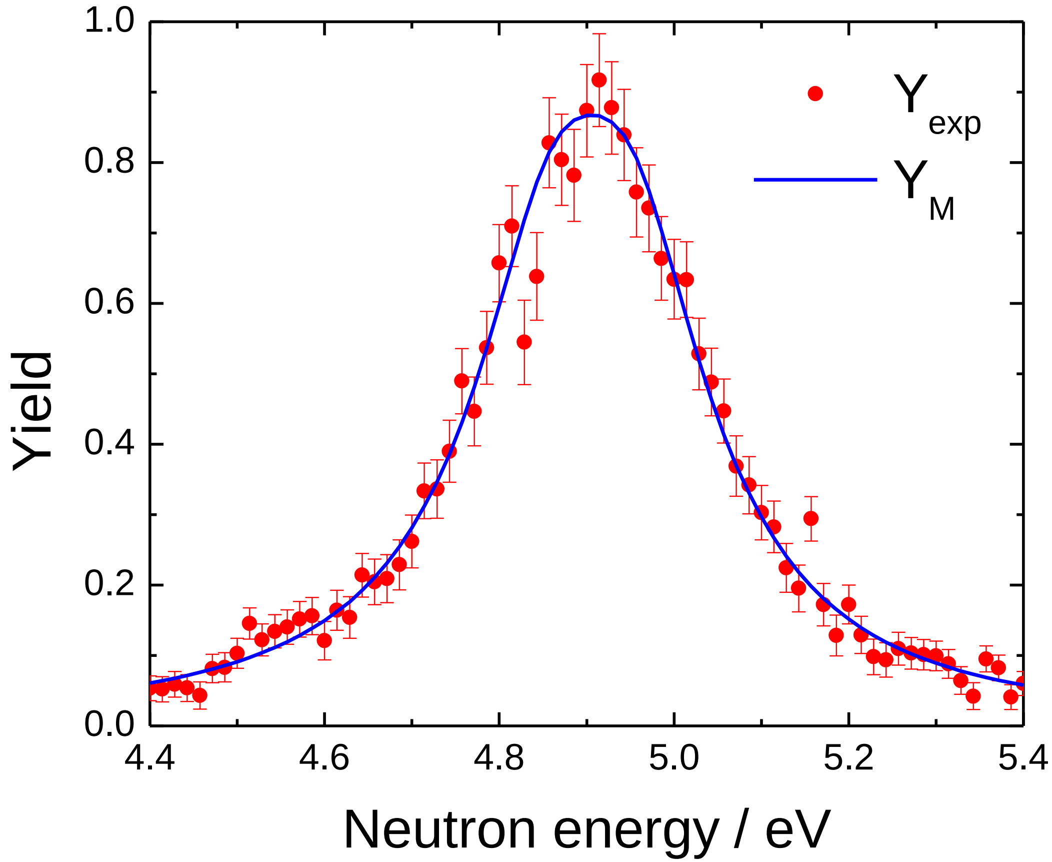
^{197}Au + n
E_r = 4.9 eV
Γ_n = 0.015 eV
Γ_γ = 0.122 eV

1st and 2nd moment of marginalized distribution:
N = 1.0001 ± 0.0009
Γ_n = 0.0151 ± 0.0001 eV
Γ_γ = 0.1233 ± 0.0010 eV

GLSQ + CUP
N = 1.0000 ± 0.0008
Γ_n = 0.0151 ± 0.0001 eV
Γ_γ = 0.1233 ± 0.0010 eV

≠ MC

Capture measurements for ^{197}Au



$^{197}Au + n$

$E_r = 4.9$ eV

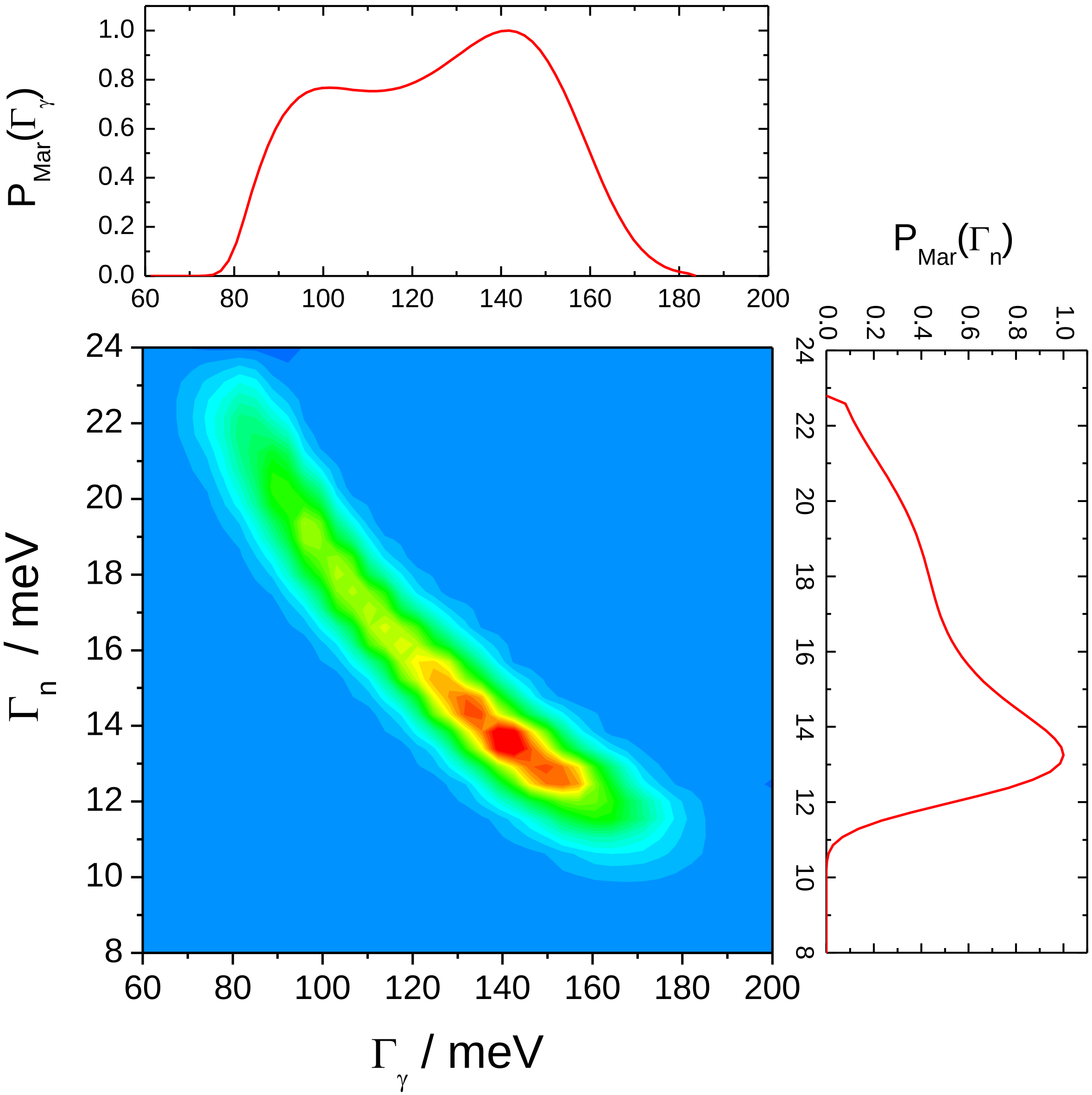
$\Gamma_n = 0.015$ eV

$\Gamma_\gamma = 0.122$ eV

Generated test case:

- **Large yield with relatively large counting statistics uncertainties**
- **Randomized data points**

Posterior distributions P(N, Γ_n, Γ_γ)



^{197}Au + n

E_r = 4.9 eV

Γ_n = 0.015 eV

Γ_γ = 0.122 eV

1st and 2nd moment of marginalized distribution:

N = 1.00 ± 0.018

Γ_n = 0.016 ± 0.003 eV

Γ_γ = 0.126 ± 0.022 eV

GLSQ + CUP

N = 1.00 ± 0.019

Γ_n = 0.013 ± 0.002 eV

Γ_γ = 0.143 ± 0.017 eV

Max. likelihood

Resonance parameters + covariances in RRR

$$\chi^2(\vec{\theta}) = (Z_{exp} - Z_M(t,\vec{\theta}))^T V_{Z_{exp}}^{-1} (Z_{exp} - Z_M(t,\vec{\theta}))$$

$$\vec{\theta} = (\vec{\eta}, \vec{\kappa}) \begin{cases} \vec{\eta} : \text{resonance parameters} \\ \vec{\kappa} : \text{exp erimental parameters} \end{cases}$$

$$\vec{\theta} = (G_{\vec{\theta}}^T V_{Z_{exp}}^{-1} G_{\vec{\theta}})^{-1} (G_{\vec{\theta}}^T V_{Z_{exp}}^{-1} Z_{exp}) \quad \text{(LSQ)}$$

$$V_{\vec{\theta}} = (G_{\vec{\theta}}^T V_{Z_{exp}}^{-1} G_{\vec{\theta}})^{-1} \quad \text{(CUP)}$$

$$Z_{exp} = \begin{cases} T_{exp} \\ Y_{exp} \\ . \\ . \\ . \\ \vec{\eta} \end{cases}$$

$$Y_M(t,\vec{\theta}) = \frac{1}{N_c} \frac{\int R(t,E)\, Y'(E) dE}{\int R(t,E) dE} \qquad Y'(E) = (1 - e^{-\sum_k n_k \bar{\sigma}_{tot,k}}) \frac{\bar{\sigma}_{\gamma,k}}{\bar{\sigma}_{tot,k}} + \dots$$

- No direct measurement of the cross section
- Interpretation model depends on RP and experimental parameters
- **GLSQ + CUP relies on a perfect model (reaction + experiment)**

$$P(\theta|Z,M) \propto P(Z|\theta,M)\, P(\theta)$$

Validation of resonance parameters by NRTA

- **Covariances for W isotopes** **(NDS, various publications)**

- **Validation experiment: determine areal density by NRTA**
  - **Sample: metallic disc of ^{nat}W**
    - Homogeneous sample
    - Areal density n : from weight and area

    $\Rightarrow u_n/n < 0.1\ \%$

  - **Transmission : absolute measurement**
    - Absolute measurement
    - Methodology well understood (background, dead time correction,…)

      Nuclear Data Sheets 113 (2012) 3054 – 3100

    $\Rightarrow u_{T_{exp}}/T_{exp} < 0.3\ \%$

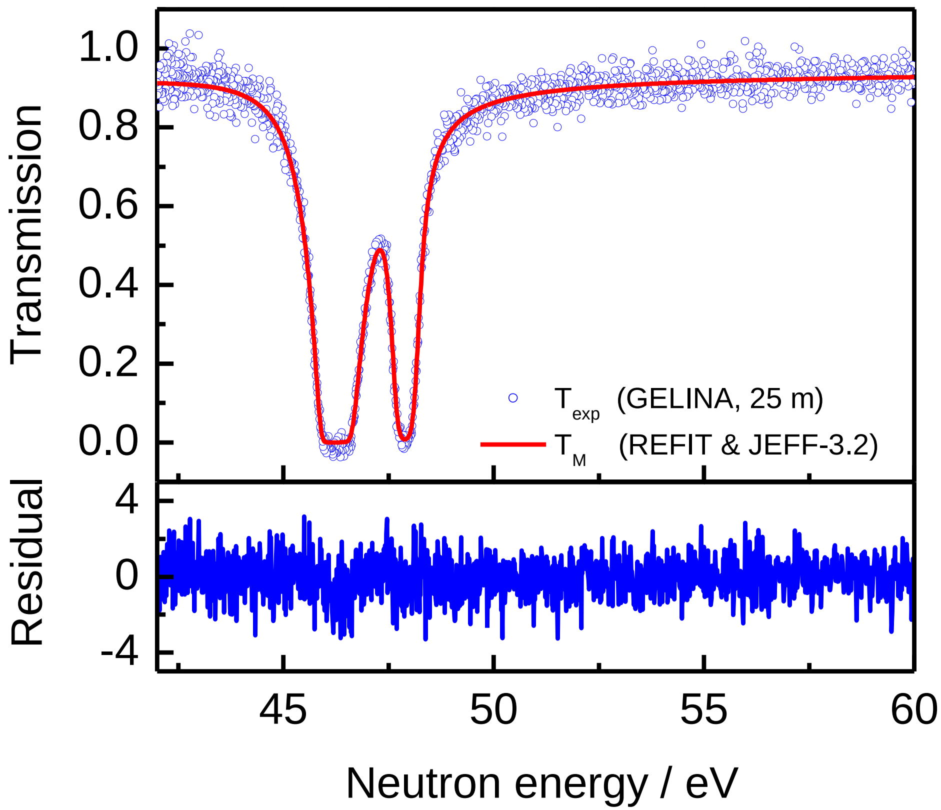
    $\Rightarrow$ **One of the most accurate integral experiment to validate resonance parameters**

Validation of resonance parameters by NRTA

Transmission measurements

- a 25 m station of GELINA
- ^{6}Li detector

Y_M : REFIT



Least squares adjustment (REFIT)

$$T_M(t,\vec{\theta}) = \frac{\int R(t,E)\, e^{-\sum_k n_k \bar{\sigma}_{tot,k}}\, dE}{\int R(t,E)\, dE}$$

$$\vec{\theta} = (\vec{\eta}, \vec{\kappa}) \begin{cases} \vec{\eta} : \text{resonance parameters} \\ \vec{\kappa} : \text{experimental parameters} \end{cases}$$

$$\vec{\theta} = (G_{\vec{\theta}}^{T}\, V_{T_{exp}}^{-1}\, G_{\vec{\theta}})^{-1}\, (G_{\vec{\theta}}^{T}\, V_{T_{exp}}^{-1}\, T_{exp})$$

$$V_{\vec{\theta}} = (G_{\vec{\theta}}^{T}\, V_{T_{exp}}^{-1}\, G_{\vec{\theta}})^{-1}$$

$G_{\vec{\theta}}$: partial derivatives

(non - linear model : solved by iteration)

Validation of resonance parameters by NRTA

Reference	E_R = 46.26 eV				E_R = 47.80 eV				100 x n_{FIT}/n	
	Γ_n / meV		Γ_γ / meV		Γ_n / meV		Γ_γ / meV			
ENDF/B - VI.8	154		69		115		78		109.7	(0.5)
JENDL - 3.3	154		46		119		81		111.3	(0.5)
ENDF/B - VII.1	154	(0.8)	46	(2.1)	119	(1.2)	81	(5.1)	111.3	(1.1)
JEFF - 3.2	163.4		75.3		120.8		61.5		100.2	(0.5)

Overestimation of n compensates for underestimation of Γ_n

Impact of sample characteristics

Declared : $n_W = (1.084 \pm 0.014)\ 10^{-3}$ at/b

T_M (hom.) : $n_W = (0.939 \pm 0.003)\ 10^{-3}$ at/b

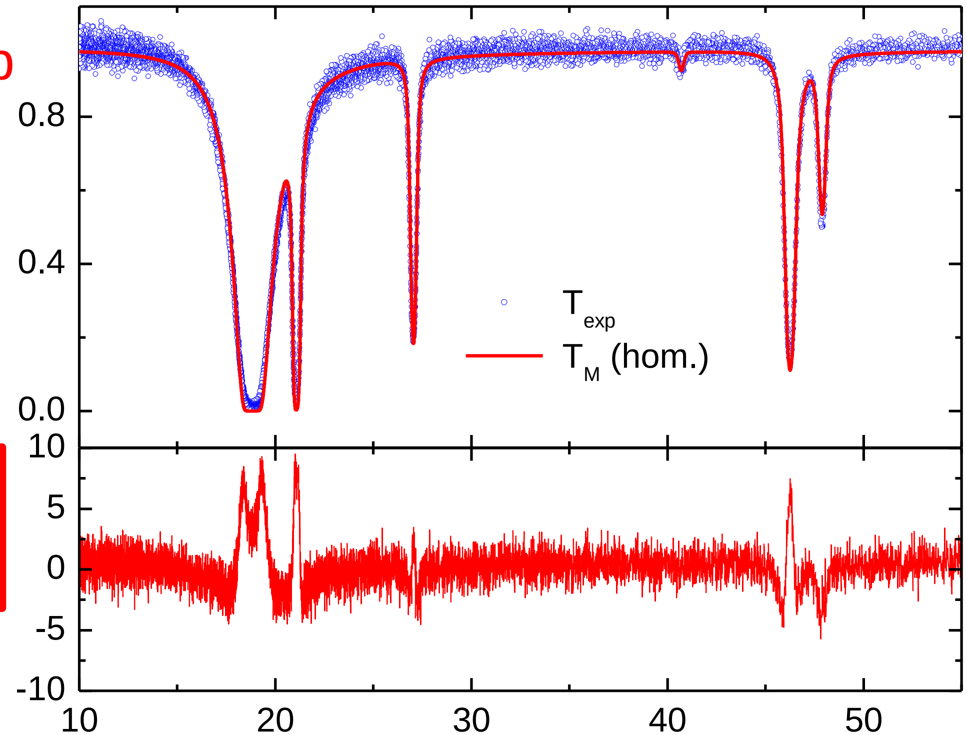
Heterogeneous sample:

$$\bar{T} = \int T(n')p(n')dn' = \int e^{-n'\sigma_{tot}} p(n')dn'$$

$$\neq$$

$$T(\bar{n}) = e^{-\bar{n}\sigma_{tot}}$$

^{nat}W-powder mixed with ^{nat}S-powder
(80 cm diameter, 14 g ^{nat}W, 3.5 g ^{nat}S)



Similar bias effects:

-when determining RP from such samples (Γ_n underestimated)

-integral reactor experiments with powder samples

Impact of sample characteristics

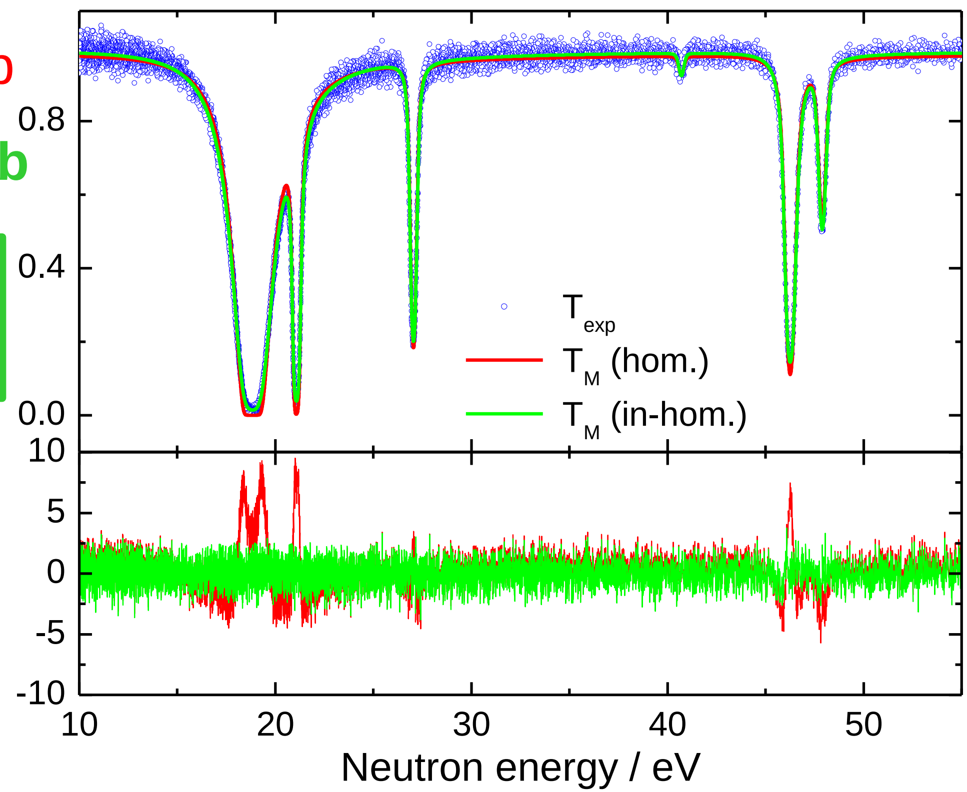
Declared : $n_W = (1.084 \pm 0.014)\ 10^{-3}$ at/b

T_M (hom.) : $n_W = (0.939 \pm 0.003)\ 10^{-3}$ at/b

T_M (inhom.) : $n_W = (1.096 \pm 0.003)\ 10^{-3}$ at/b

$$\bar{T} = \int T(n')p(n')dn' = \int e^{-n'\sigma_{tot}} p(n')dn'$$

^{nat}W-powder mixed with ^{nat}S-powder
(80 cm diameter, 14 g ^{nat}W, 3.5 g ^{nat}S)



T_M: REFIT + JEFF 3.2

LP Model

Levermore, Pomraning et al., J. Math. Phys. 27, 2526, 1986

Implemented in REFIT

Becker et al., Eur. Phys. J. Plus 129 (2014) 58 - 9

Summary & conclusions

- Methods to produce and report (Z_{exp}, $V_{Z_{exp}}$) well establsihed
- (RP ,V_{RP}) in URR: well understood
- (RP ,V_{RP}) in RRR:
  - Covariances (including correlations) depend on the experimental conditions!
  - Main problem: propagate the covariance of experimental parameters
  - GLSQ + CUP : relies on a perfect model (reaction and experiment)
    - Requires verification of the quality of the model
  - GLSQ + MC: conservative
    - Recommended when quality of the experimental model cannot be verified
- Transmission measurements on homogeneous well-characterized samples can be considered as one of the most accurate integral experiments to validate cross data in the RRR.
- Data obtained with powder samples might be strongly biased!