

^{243}Am fission cross section measurements for transmutation

-

Variance-covariance analysis

Centre d'Etudes Nucléaires de Bordeaux-Gradignan

*G. Kessedjian**

* Postdoc. (ATER) LPSC Grenoble kessedjian@lpsc.in2p3.fr

*G.Kessedjian*¹⁾, *G.Barreau*¹⁾, *M.Aiche*¹⁾, *B.Jurado*¹⁾, *S.Czajkowski*¹⁾,
*D.Dassié*¹⁾, *B.Haas*¹⁾, *L.Mathieu*¹⁾⁻¹²⁾, *A.Bidaud*⁷⁾, *I.AIMahamid*⁴⁾, *J.Floyd*⁵⁾,
*W.Lukens*⁶⁾, *F.J.Hamsch*³⁾, *S.Oberstedt*³⁾, *J.Wilson*²⁾, *L.Audouin*²⁾,
*N.Capellan*²⁾, *L.Tassan-Got*²⁾, *B.Osmanov*¹⁾, *E.Berthoumieux*⁸⁾, *F.Gunsing*⁸⁾,
*Ch.Theisen*⁸⁾, *O.Serot*⁹⁾, *E. Bauge*¹⁰⁾, *I. Ahmad*¹¹⁾, *J.P.Green*¹¹⁾,
*R.V.F.Janssens*¹¹⁾

1)Centre d'Etudes Nucléaires de Bordeaux-Gradignan

2)Institut de Physique Nucléaire Orsay

3)EC-JRC-IRMM , Belgium

4)Wadsworth Center, Laboratory of Inorganic and Nuclear Chemistry

5)Environmental Health and Safety Division, LBNL, Berkeley

6)Chemical Science Division, LBNL, Berkeley,

7) LPSC Grenoble, France

8) CEA Saclay, France

9) CEA Cadarache, France

10) CEA, Bruyères-le-Châtel, France

11) Argonne National Lab., U.S.A.

12) CEA Cadarache

Acknowledgements : - CNRS programme PACE/GEDEPEON
- Euratom Transnational Access Programme NUDAME (Geel).

Transmutation studies

transmutation system studies



Evaluated cross sections



Necessity of nuclear data on Am and Cm



Activities of targets :

$$1\mu\text{g } (^{243}\text{Am}, 7380 \text{ ans}) = 10 \text{ kBq}$$

$$1\mu\text{g } (^{242}\text{Cm}, 162 \text{ jours}) = 100 \text{ MBq}$$



$^{243}\text{Am}(n,f)$
neutrons induced measurements
(direct method)



$^{242,243,244}\text{Cm}(n,f)$
surrogate measurements
(indirect method)

Transmutation studies

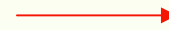
To study systems of transmutation



Sensitivity studies



Evaluated cross sections



Variances-covariances
of assessments



Necessity of nuclear data on Am and Cm



Activities of targets :

$1\mu\text{g } (^{243}\text{Am}, 7380 \text{ ans}) = 10 \text{ kBq}$

$1\mu\text{g } (^{242}\text{Cm}, 162 \text{ jours}) = 100 \text{ MBq}$



$^{243}\text{Am}(n,f)$
neutrons induced measurements
(direct method)



$^{242,243,244}\text{Cm}(n,f)$
surrogate measurements
(indirect method)

Independent measurements ?

Transmutation studies

To study systems of transmutation



Evaluated cross sections



Necessity of nuclear data on Am and Cm



Activities of targets :

$1\mu\text{g } (^{243}\text{Am}, 7380 \text{ ans}) = 10 \text{ kBq}$

$1\mu\text{g } (^{242}\text{Cm}, 162 \text{ jours}) = 100 \text{ MBq}$



$^{243}\text{Am}(n,f)$
neutrons induced measurements
(direct method)



$^{242,243,244}\text{Cm}(n,f)$
surrogate measurements
(indirect method)

Sensitivity studies

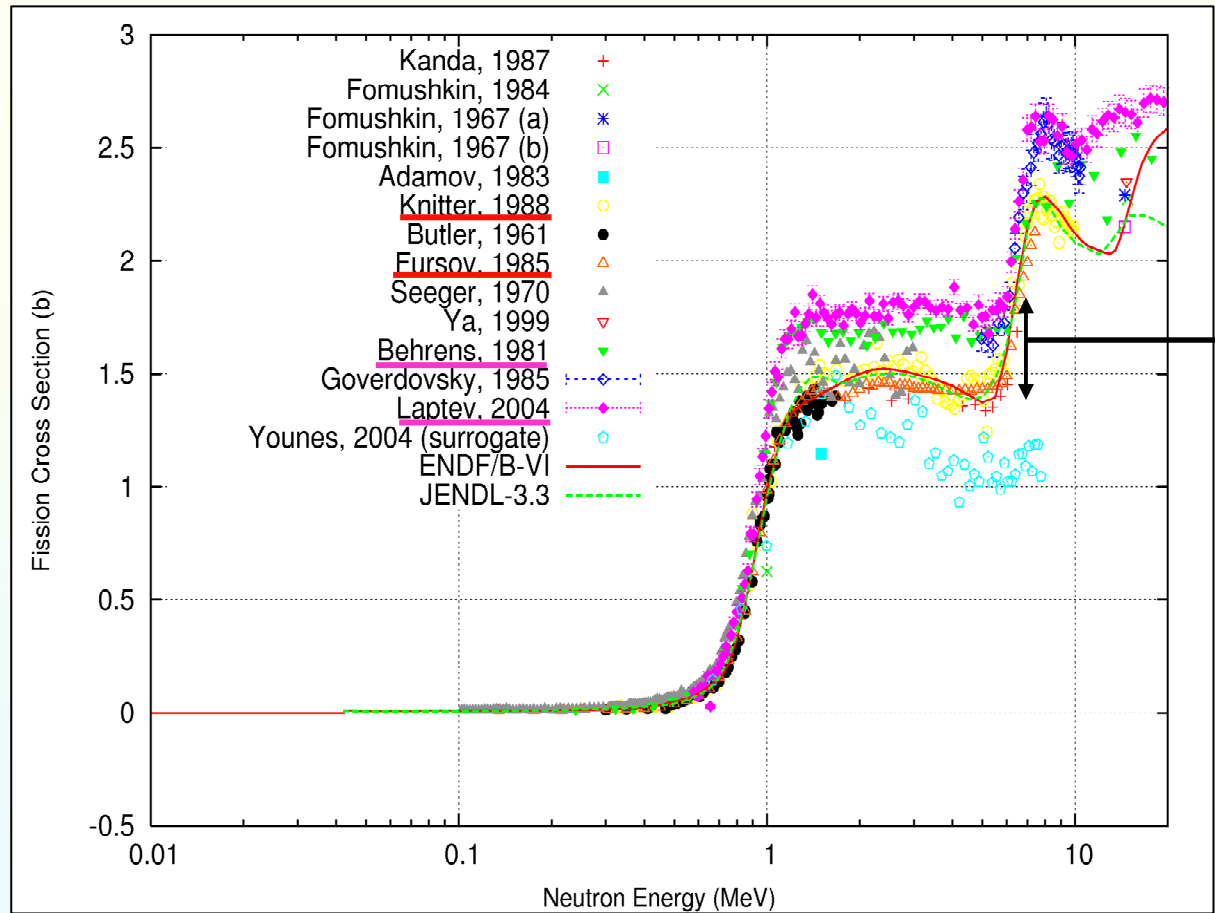


Variations-covariations
of assessments

Variations-covariations
of measurements

Independent measurements ?

Fission cross section data of ^{243}Am




discrepancies
of 15%


$$\sigma_{n,f}(E_n) = \frac{\tau_f}{\Phi_n(E_n)}$$

- separation of the ^{243}Am fission cross section into two distinct groups on the first and second chance
- our **goal** is to perform a **new independent measurement** of this fission cross section in fast neutron range (5% accuracy asked)


Measurement of fast neutron flux

 $\phi_n(E_n)$: measure of incident fast neutron flux in reference to a standard nuclear reaction : $^{235}\text{U}(n,f)$, $^{238}\text{U}(n,f)$, $^{239}\text{Pu}(n,f)$, (n,p)...

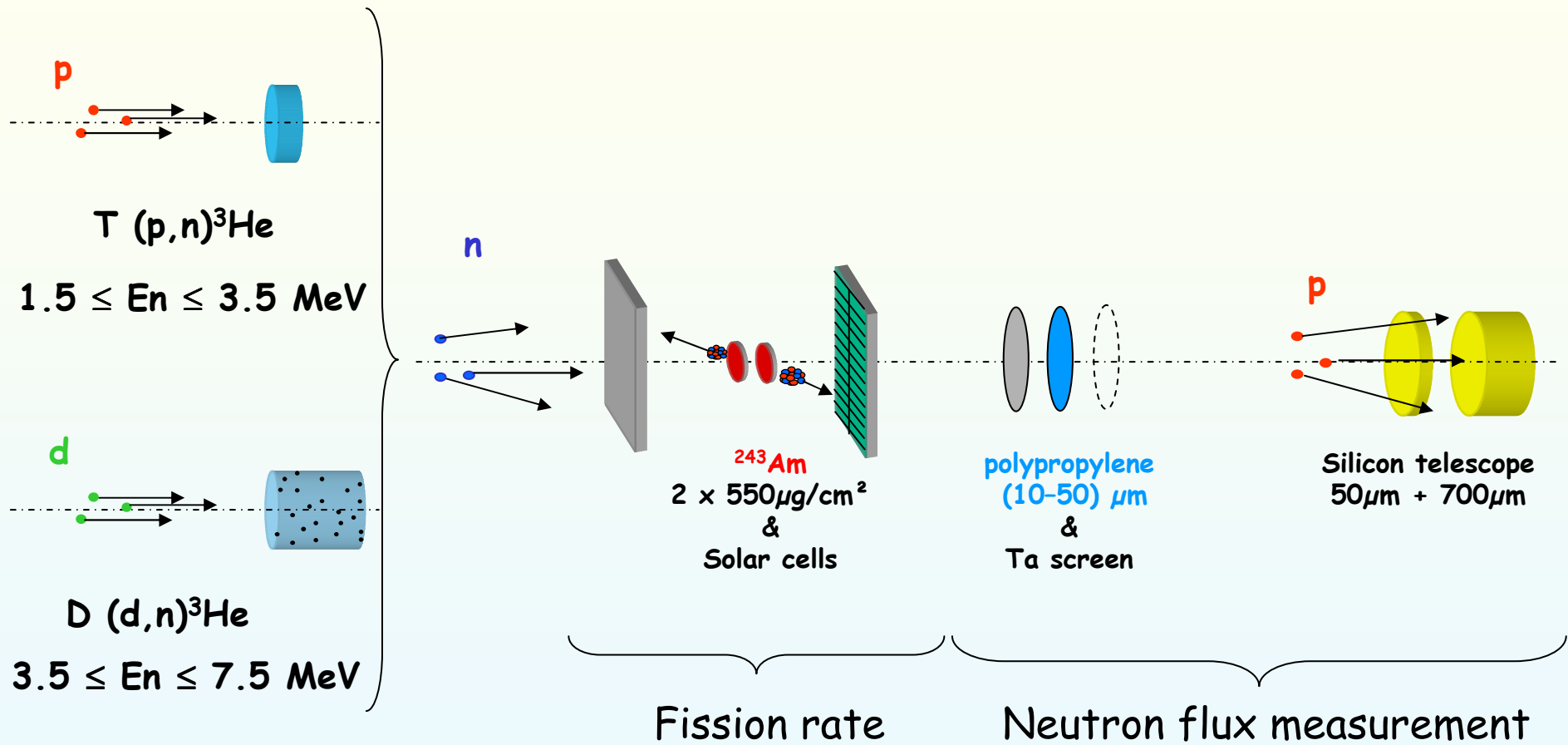
error of evaluations : $^{235}\text{U}(n,f) \sim (2-3) \%$
 $^{238}\text{U}(n,f) \sim (1-2) \%$

 First study of ^{243}Am fission cross section in reference to (n,p) elastic scattering (n, p) which is known with 0.5% accuracy in this energy range (1 - 10 MeV)

→ quasi-absolute measurement
→ new data are independent

 New study of ^{243}Am first chance fission cross section in reference to $^{238}\text{U}(n,f)$
→ new independent data

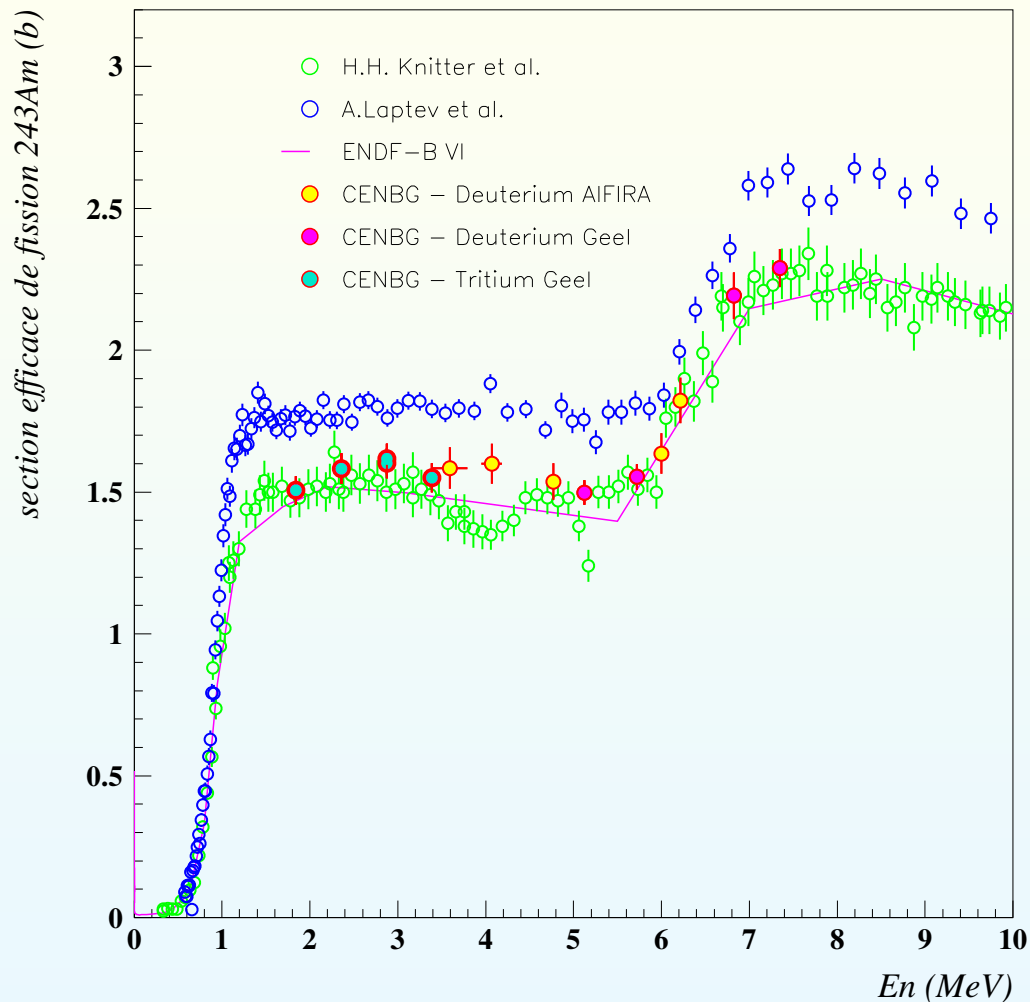
Experimental set-up for measurements in reference to (n,p) IRMM (Geel) & AIFIRA (CENBG)



$$\sigma_{n,f}(E_n) = \frac{\tau_f}{\phi_n(E_n)}$$

$$\phi_n(E_n) = \frac{N_p}{\sigma_{n,p}(E_n) \cdot \mathcal{E}_{telescope} \cdot N_H \cdot \Delta t}$$

^{243}Am fission cross section in reference to (n,p)



One measurement l at E_i

$$(\sigma_i)_l = \frac{(F_i/\Omega_l)_l}{(\Phi_n/\Omega_n)_i}$$

Few measurements at E_i

$$\langle \sigma \rangle_i = \frac{\langle F/\Omega \rangle_i}{(\Phi_n/\Omega_n)_i}$$

These new measurements are they **independent**?

*correlations of errors on measurements:
 $^{243}\text{Am}(n, f) / (n, p)$*

Variance (σ_i) =

Statistical
Variances

+

Systematic
Variances

(N_f, N_p)

Quantities of ^{243}Am or polypropylene
Efficiencies of detection (fission et protons)
Solid angle of target

*correlations of errors on measurements:
 $^{243}\text{Am}(n, f) / (n, p)$*

Variance (σ_i) =

Statistical
Variances

+

Systematic
Variances

$(N_f; N_p)$



Minimization



Quantities of ^{243}Am or polypropylene
 Efficiencies of detection (fission et protons)
 Solid angle of target



Systematic is majored
in errors of measurements



Measurements ($\sigma_i; \sigma_j$)
non-independent

*correlations of errors on measurements:
²⁴³Am(n, f) / (n, p)*

Variance (σ_i) =

Statistical
Variances

+

Systematic
Variances

($N_f; N_p$)



Minimization



Quantities of ²⁴³Am or polypropylene
 Efficiencies of detection (fission et protons)
 Solid angle of target



Systematic is majored
in errors of measurements



Measurements ($\sigma_i; \sigma_j$)
non-independent

Covariance ($\sigma_i; \sigma_j$) =



correlations of errors on measurements:
 $^{243}\text{Am}(n, f) / (n, p)$

Variance (σ_i) = S_i^2 Statistical variances + S_i^2 Systematic variances + S_i^2 Covariances of parameters

↓
 Not necessary independents
 eg : solid angle of targets ↗

Covariance ($\sigma_i; \sigma_j$) = $S_i S_j$ Systematic variances + $S_i S_j$ Covariances of parameters

$$S_i = \frac{\partial \sigma_i / \partial a}{\sigma_i} = \frac{\text{Variation of measurement } \sigma_i}{\text{Variation of parameter } a} \quad \text{without unity (\%/%)}$$

$$\langle \sigma \rangle_i = \frac{\langle F/\Omega \rangle_i}{(\Phi_n/\Omega_n)_i} \left\{ \begin{array}{l} S_i(\langle F/\Omega \rangle_i) = 1 ; S_i(\Phi_n) = -1 \text{ et } S_i(\Omega_n) = 1 \\ S_i(F_\ell) = S_i(\Omega_\ell) = \frac{\text{Var}(\langle F/\Omega \rangle_i)}{\langle F/\Omega \rangle} / \frac{\text{Var}(F_\ell/\Omega_\ell)}{F_\ell / \Omega_\ell} \end{array} \right.$$

correlations of errors on measurements:
 $^{243}\text{Am}(n, f) / (n, p)$

$$\text{Variance } (\sigma_i) = S_i^2 \text{ Statistical variances} + S_i^2 \text{ Systematic variances} + S_i^2 \text{ Covariances of parameters}$$

↓
 Not necessary independents
 eg : solid angle of targets

$$\text{Covariance } (\sigma_i; \sigma_j) = S_i S_j \text{ Systematic variances} + S_i S_j \text{ Covariances of parameters}$$

$$\text{Correlation } (\sigma_i; \sigma_j) = \frac{\text{Cov } (\sigma_i; \sigma_j)}{\sqrt{\text{Var}(\sigma_i) \cdot \text{Var}(\sigma_j)}} \longrightarrow \text{without unity limited between -1 and +1}$$

correlations of errors on measurements:
 $^{243}\text{Am}(n, f) / (n, p)$

$$\text{Variance } (\sigma_i) = S_i^2 \text{ Statistical variances} + S_i^2 \text{ Systematic variances} + \lambda S_i^2 \text{ Covariances of parameters}$$

\downarrow
 Not necessary independents
 eg : solid angle of targets

$$\text{Covariance } (\sigma_i; \sigma_j) = S_i S_j \text{ Systematic variances} + \lambda S_i S_j \text{ Covariances of parameters}$$

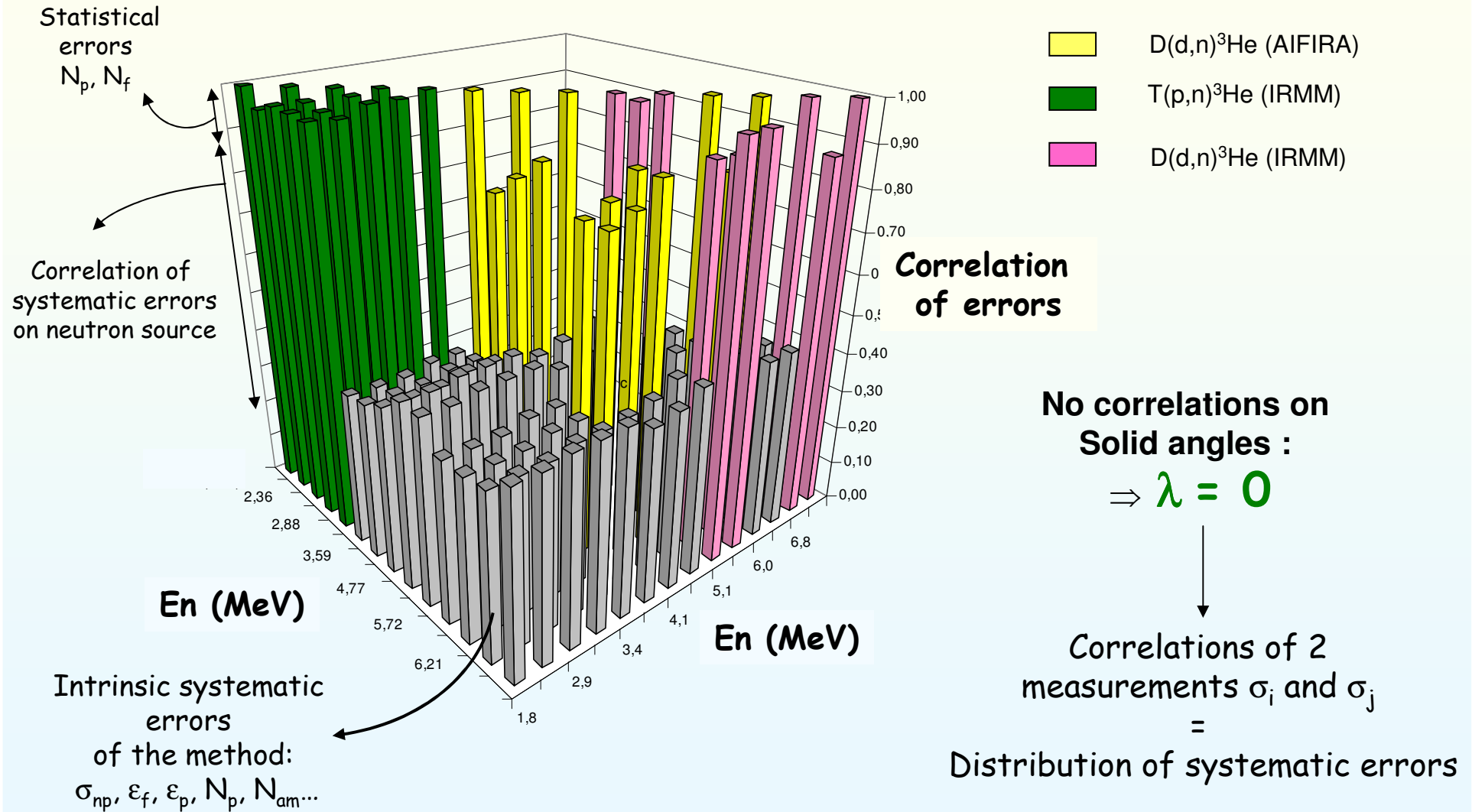
$$\text{Correlation } (\sigma_i; \sigma_j) = \frac{\text{Cov } (\sigma_i; \sigma_j)}{\sqrt{\text{Var}(\sigma_i) \cdot \text{Var}(\sigma_j)}} \longrightarrow \begin{array}{l} \text{without unity} \\ \text{limited between -1 and +1} \end{array}$$

↪

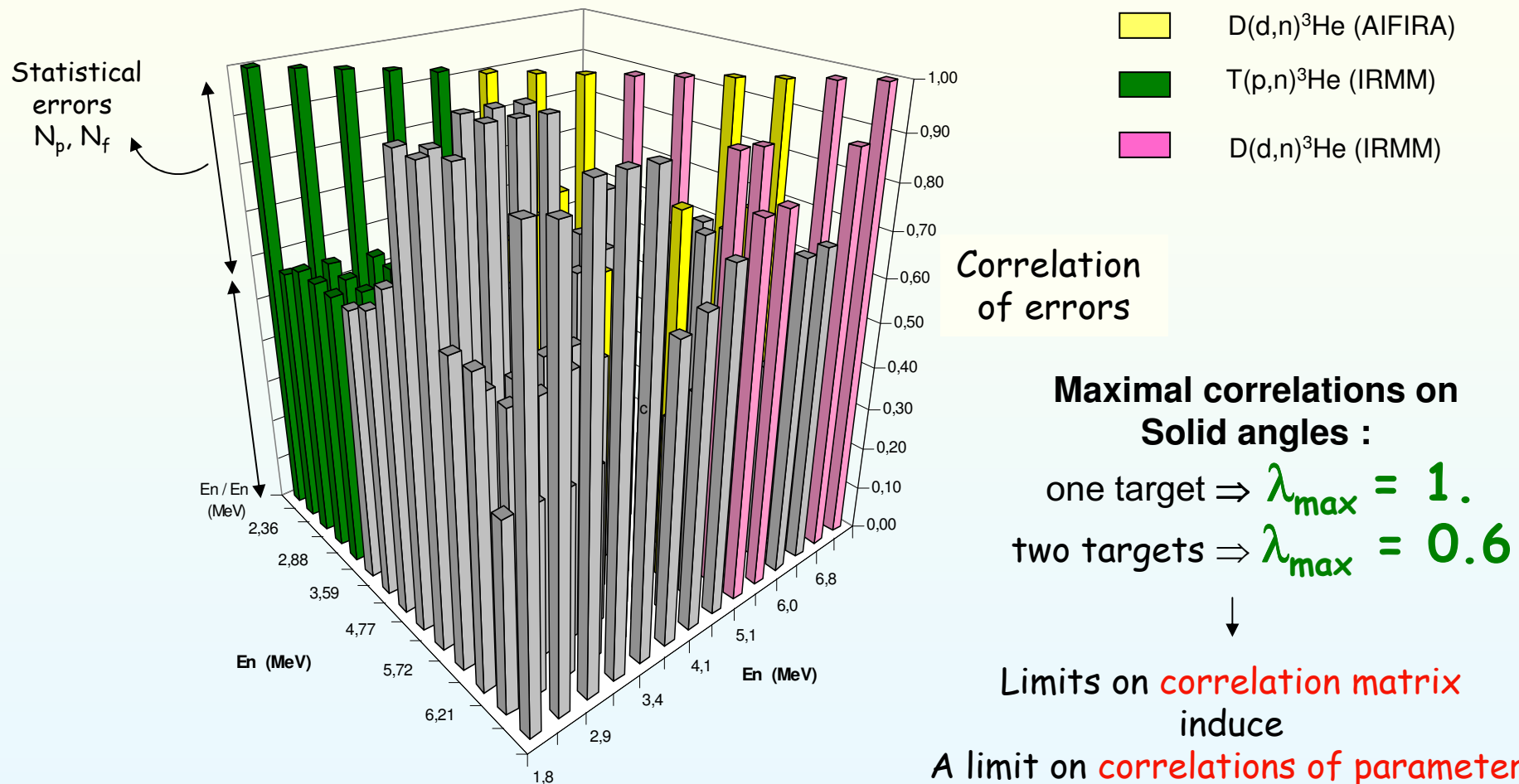
$$\left| \begin{array}{l} \text{Covariances} \\ \text{of solid angles } (\Omega_i; \Omega_j) \end{array} \right| \leq \text{Var}(\Omega_i) \times \text{Var}(\Omega_j)$$

$$0 \leq \lambda \leq 1$$

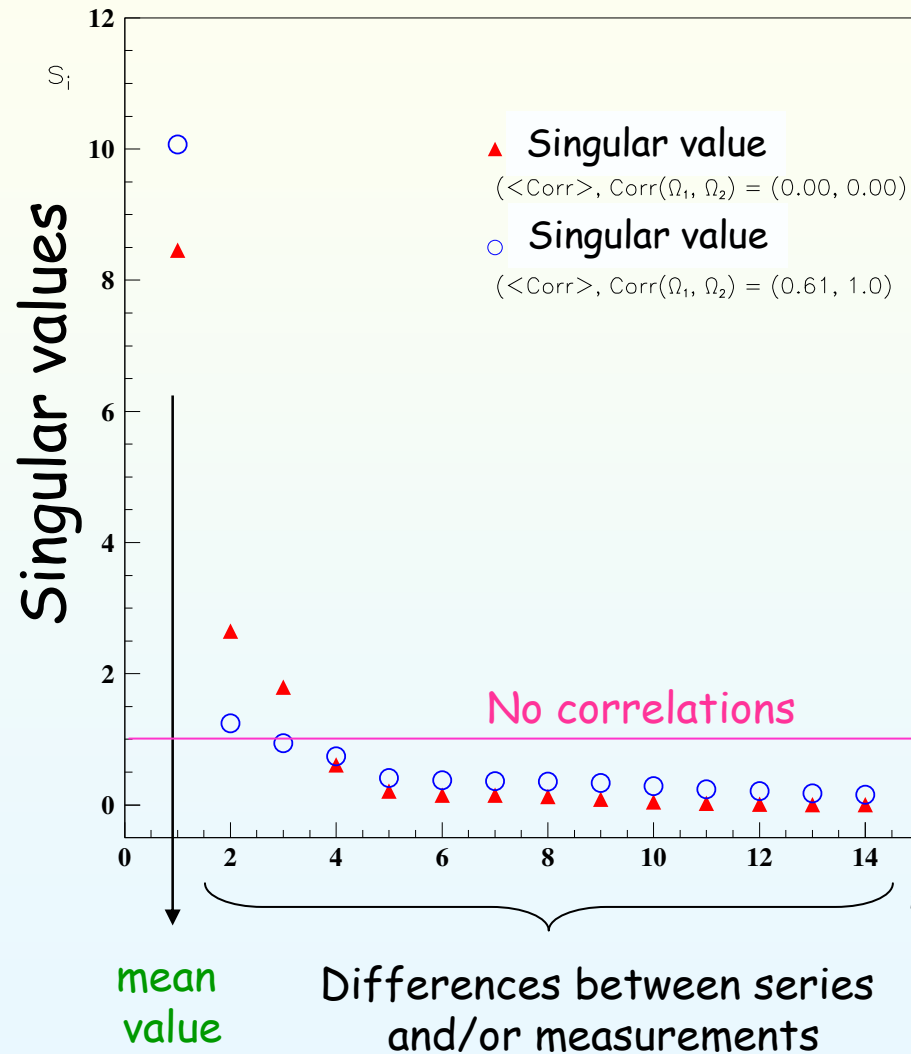
correlations of errors on measurements: $^{243}\text{Am}(n, f) / (n, p)$



correlations of errors on measurements: $^{243}\text{Am}(n, f) / (n, p)$



correlations of errors on measurements: $^{243}\text{Am}(n, f) / (n, p)$



Singular values are **similar**
for the two limit matrices

Measurements, errors
and their correlations of errors
provide the **same information**

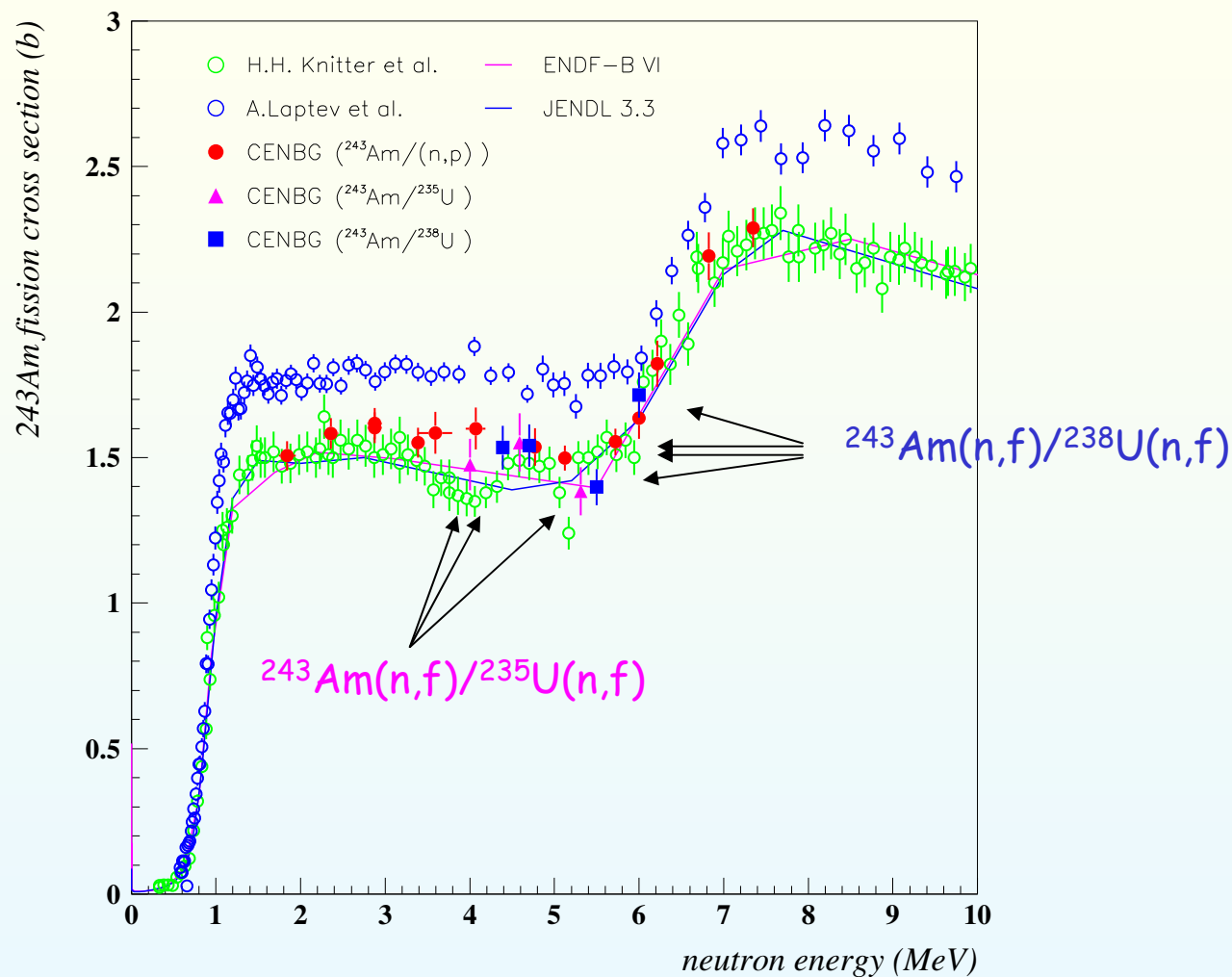
Correlation of solid angles increase
the weight of first singular values

In this case
correlations of parameters
induce
a new distribution of syst. errors

Conclusion on the interest of variance-covariance analysis

- to compare measurements and understand the distribution of systematic errors for a **same set-up, correlations are not equal**
- this matrix define the importance of data :
 - in a set of measurements
strong **correlations** → define the ratio $^{243}\text{Am}(n,f) / (n,p)$ with a good accuracy
 - between 2 sets of measurements
low **correlation** → provide statistical weight of our data in reference to the existing data
- Limits on correlation matrix :
 - give a limit on the correlations of parameters
 - **give the limits on errors of measurements**
→ errors are content between **2.1 à 3.4% (Geel)**
&
3.2 à 4.6% (AIFIRA)

^{243}Am fission cross section in reference to $^{238,235}\text{U}(n,f)$



$$\text{Corr}(^{243}\text{Am}(n,f)/(n,p); ^{243}\text{Am}(n,f)/^{238}\text{U}(n,f)) \leq 0.17$$

$$\text{Corr}(^{243}\text{Am}(n,f)/(n,p); ^{243}\text{Am}(n,f)/^{235}\text{U}(n,f)) = 0$$

conclusions

- Neutron-proton elastic scattering allows to measure fission cross sections with a good accuracy (< 4%)

- * error on (n,p) scattering very low in reference to the other systematic errors

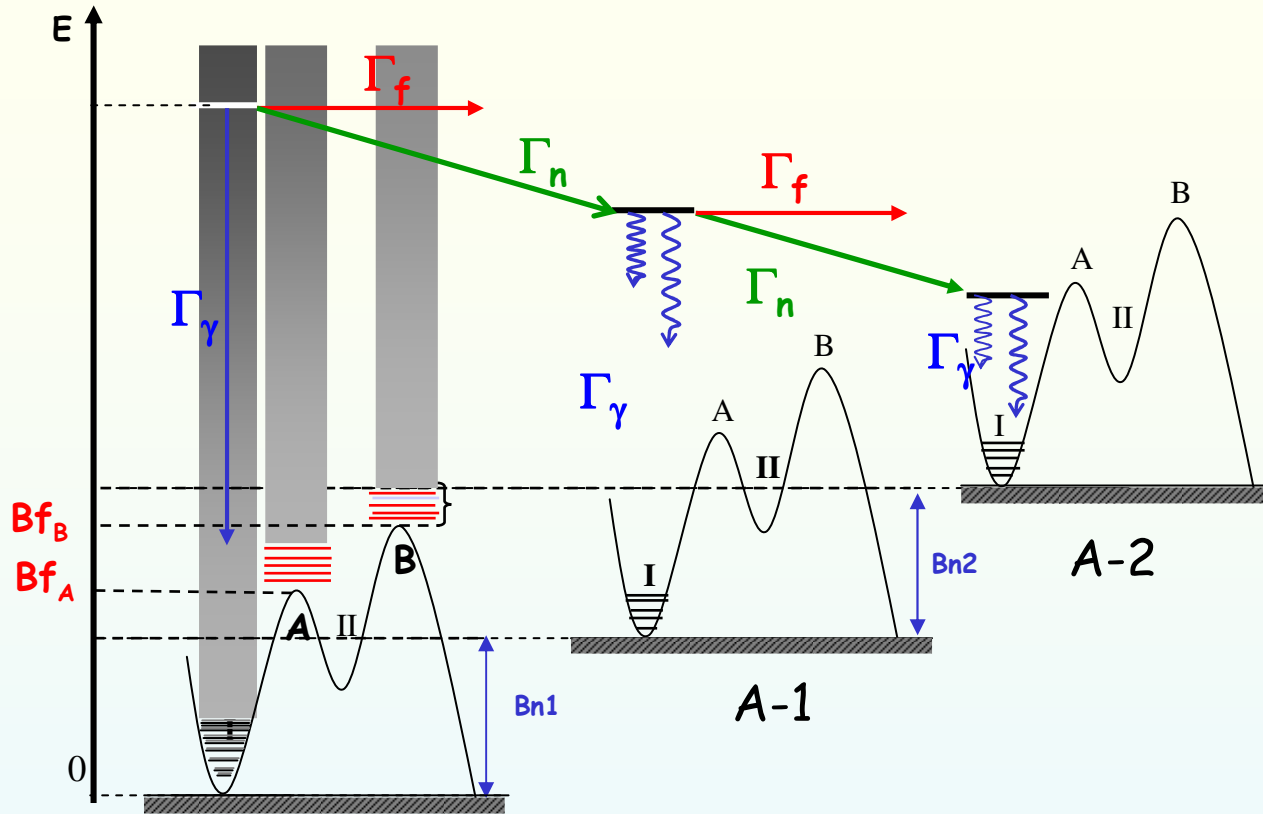
- quasi-absolute measurements
independent of existing data

- Covariance matrices allow to :

- compare measurements
 - understand the distribution of systematic errors
 - define the importance of data

- Covariance analysis have to be completed for all database to obtain a better evaluation of cross sections and their associated errors.

Statistical analysis of ^{243}Am fission cross section



$$\bar{\Gamma}_T = \bar{\Gamma}_f + \bar{\Gamma}_n + \bar{\Gamma}_\gamma$$

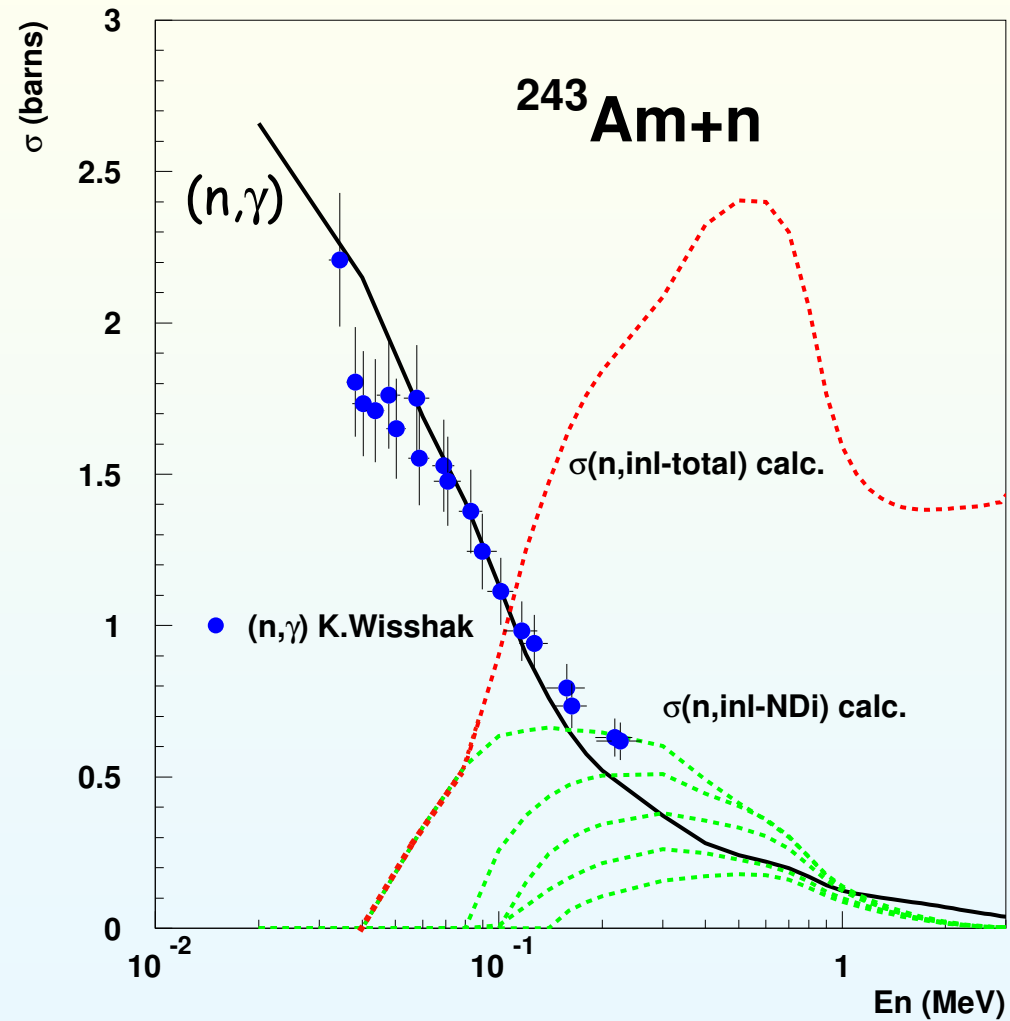
$$P_i = \frac{\bar{\Gamma}_i}{\bar{\Gamma}_T}$$

Adjusted parameters:

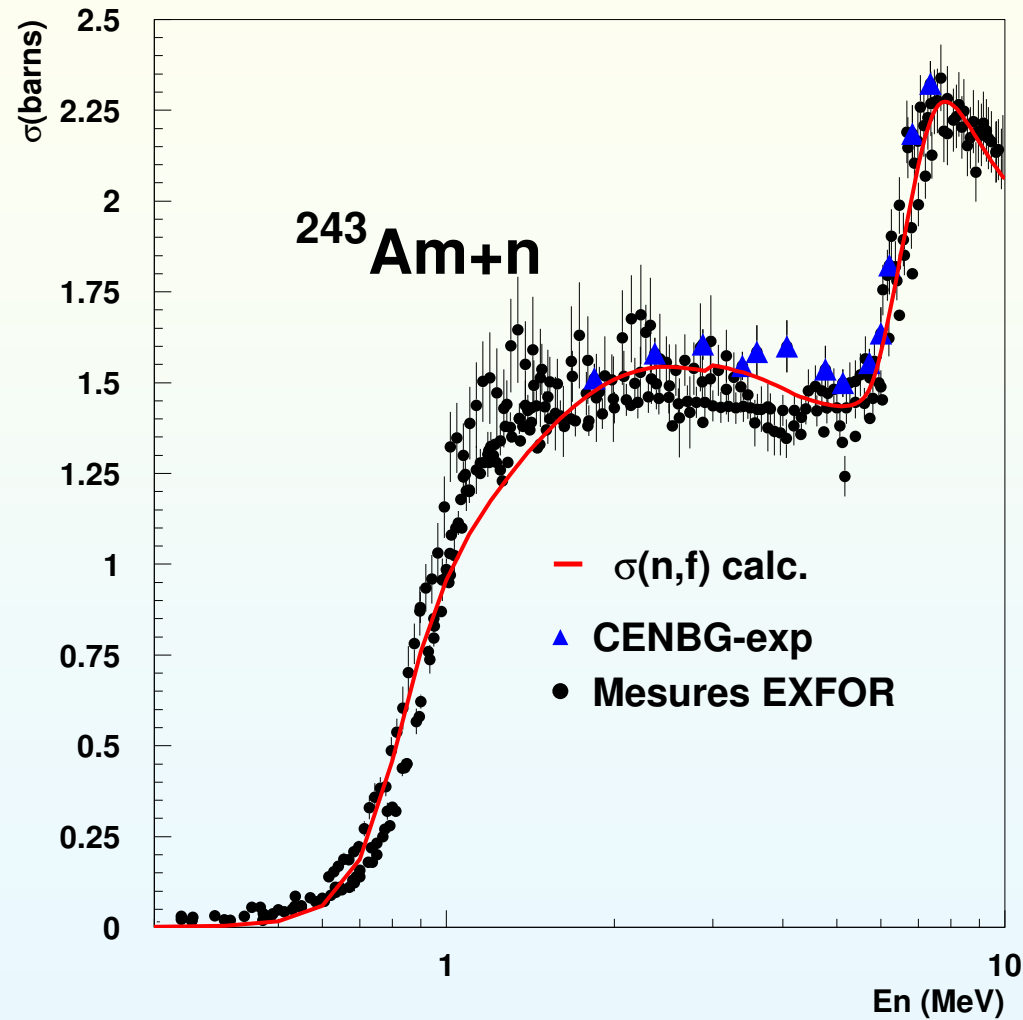
- Barriers : - height
- width
- level densities
 - pairing Δ_I
 - structure parameters ...

$$\sigma_F(E_n) = \sigma_{NC}(E_n) \underbrace{\left[\left(\frac{\bar{\Gamma}_f}{\bar{\Gamma}_T} \right)_{A=244} + \left(\frac{\bar{\Gamma}_n}{\bar{\Gamma}_T} \right)_{A=244} \times \left(\frac{\bar{\Gamma}_f}{\bar{\Gamma}_T} \right)_{A-1=243} \right]}_{P(E_n)}$$

Evaluated $^{243}\text{Am}(n,\gamma)$ and $^{243}\text{Am}(n,n')$

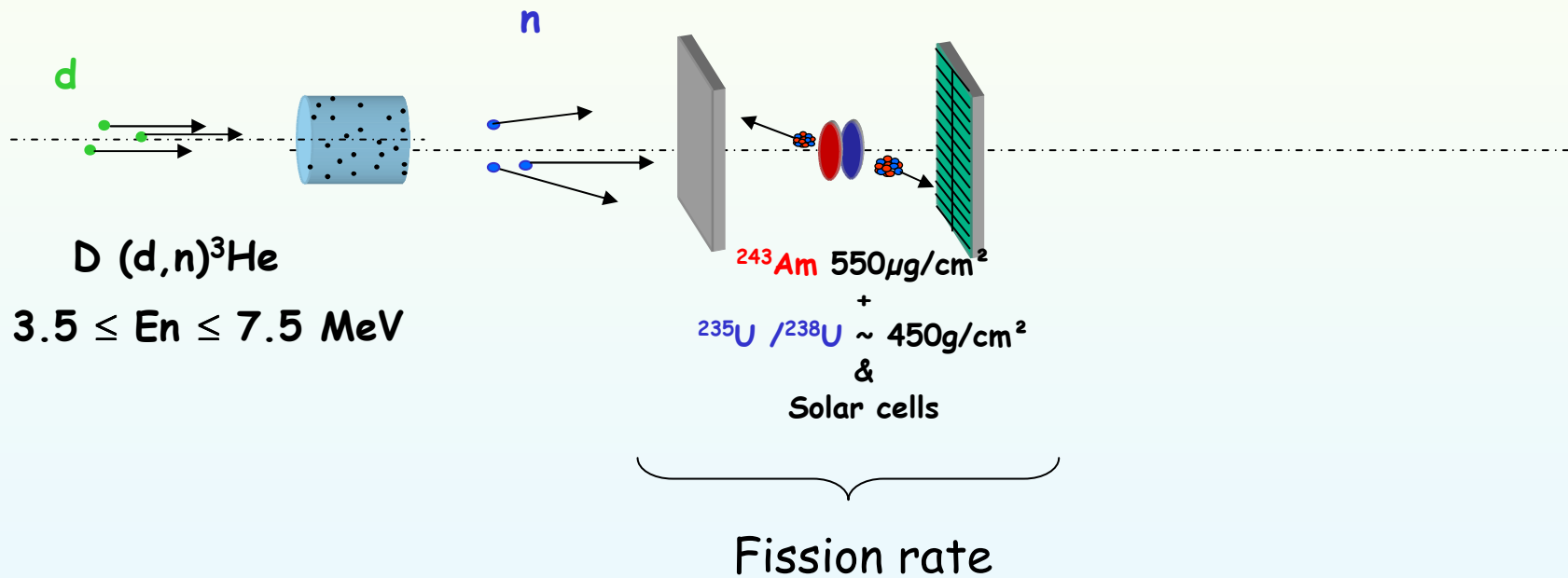


$^{243}\text{Am}(n,f)$ evaluation



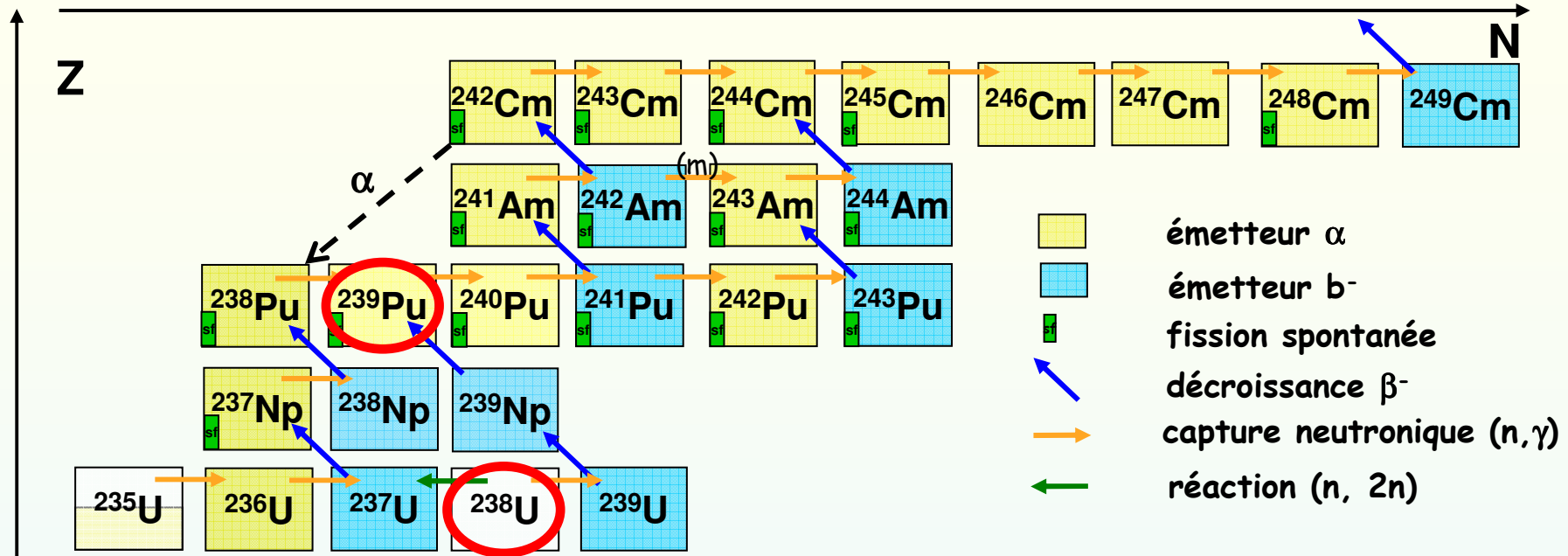
Evaluation with
~700 points in fast neutron
energy range up to 10 MeV

Experimental set-up for measurements in reference to $^{235,238}\text{U}(n,f)$: AIFIRA (CENBG)



$$\sigma_{n,f}(E_n) = \frac{\tau_f}{\phi_n(E_n)}$$

context of minor actinides

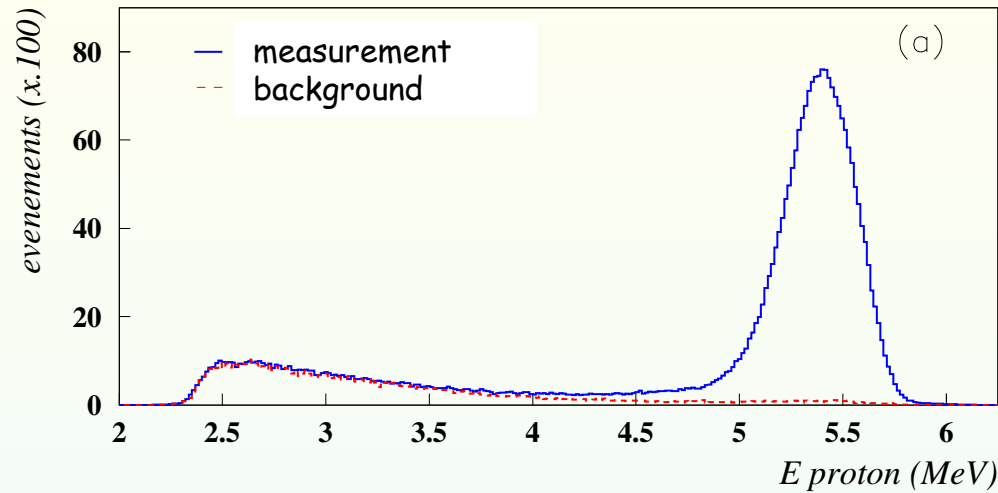


- Uranium et plutonium : major actinides
- **minor Actinides (MA)** : Np, Am, Cm
- P.f. et MA represent **0.2%** of volume
96% activity
- to decrease the radio-toxicity : **transmutation** des MA
→ ie neutron induced fission
in a fast neutron energy range

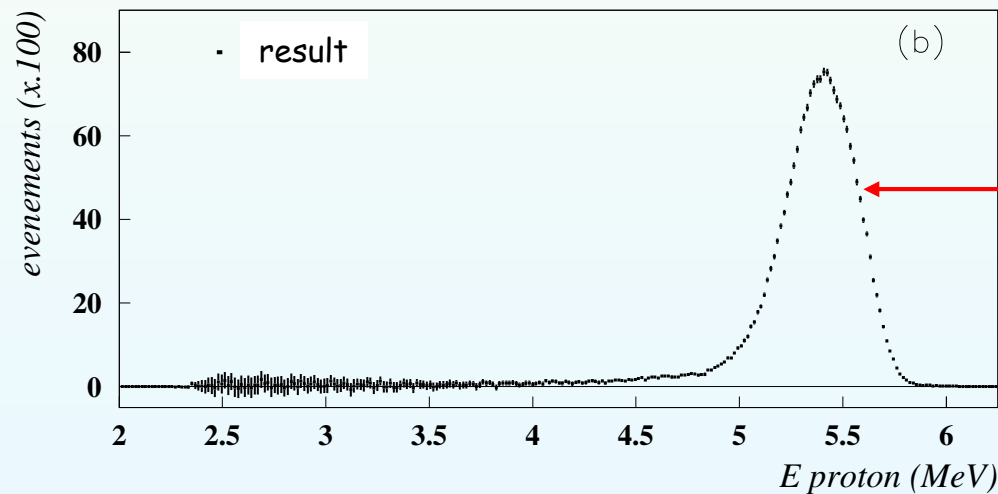
Life-time MA

^{237}Np	$\rightarrow 1,14 \cdot 10^6 \text{ y}$
^{241}Am	$\rightarrow 432 \text{ y}$
^{243}Am	$\rightarrow 7380 \text{ y}$
^{242}Cm	$\rightarrow 162 \text{ d}$
^{244}Cm	$\rightarrow 18 \text{ y}$

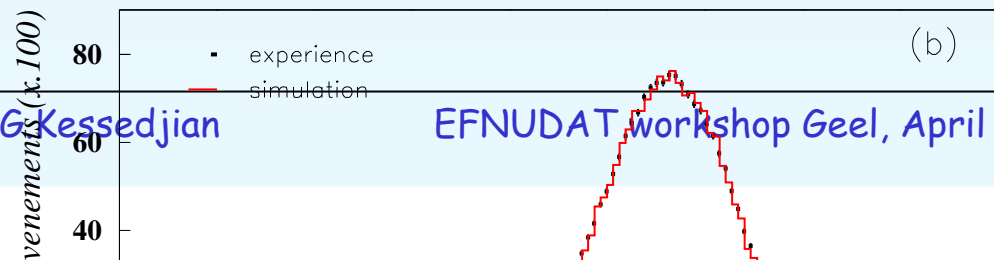
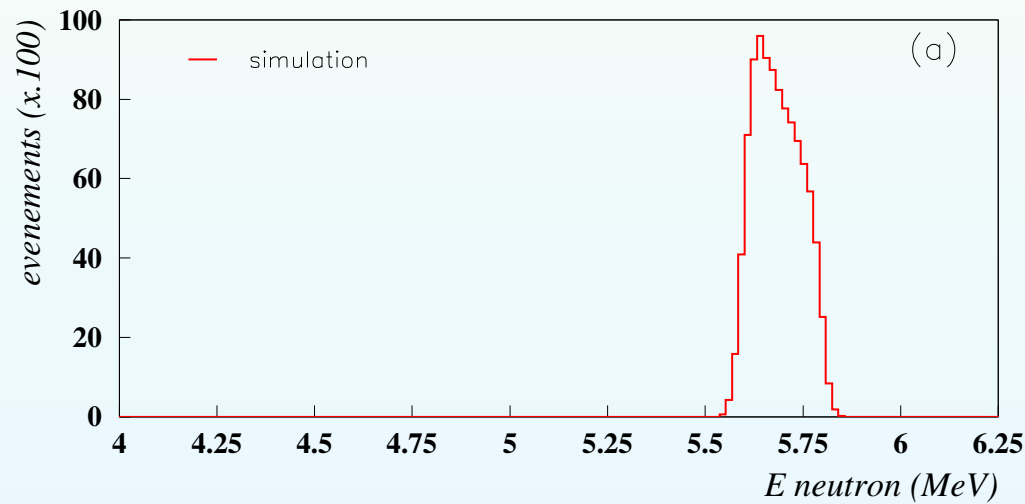
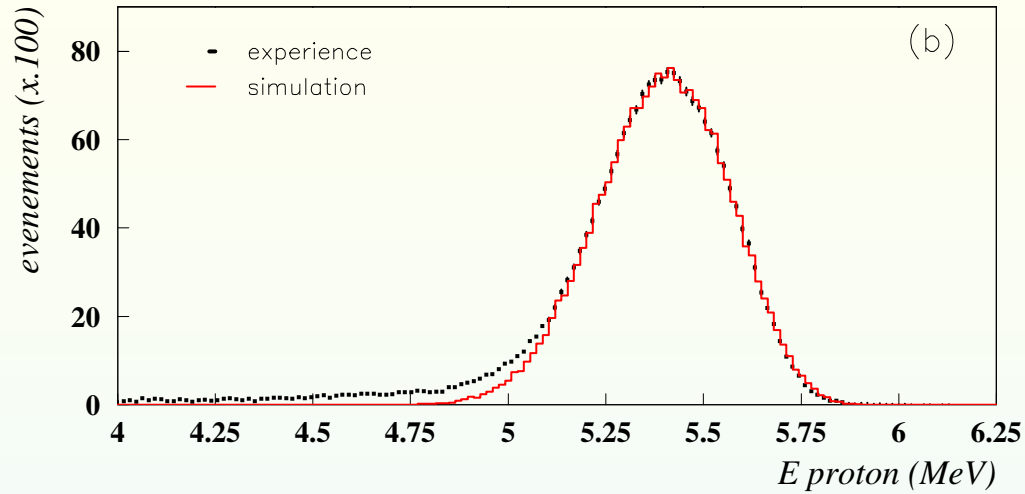
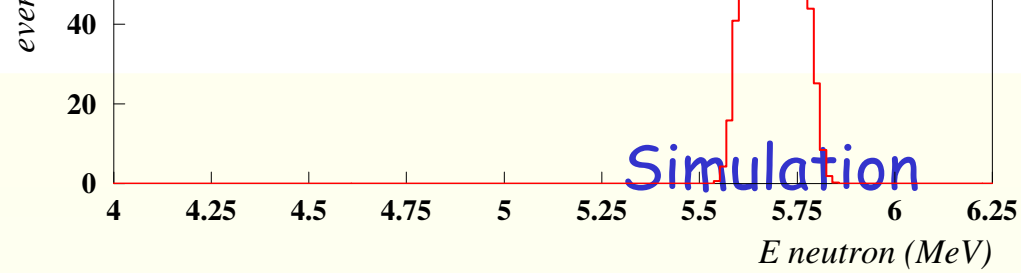
Recoil proton spectrum



Ed=3 MeV
Polypropylene=50μm

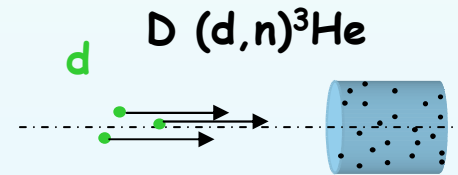


$$N_p^{\text{exp}} \left\{ \begin{array}{l} E_n \pm \Delta E_n \quad ? \\ \sigma_{n,p}(E_n) \quad ?? \\ \varepsilon_{\text{telescope}} \quad ??? \end{array} \right.$$

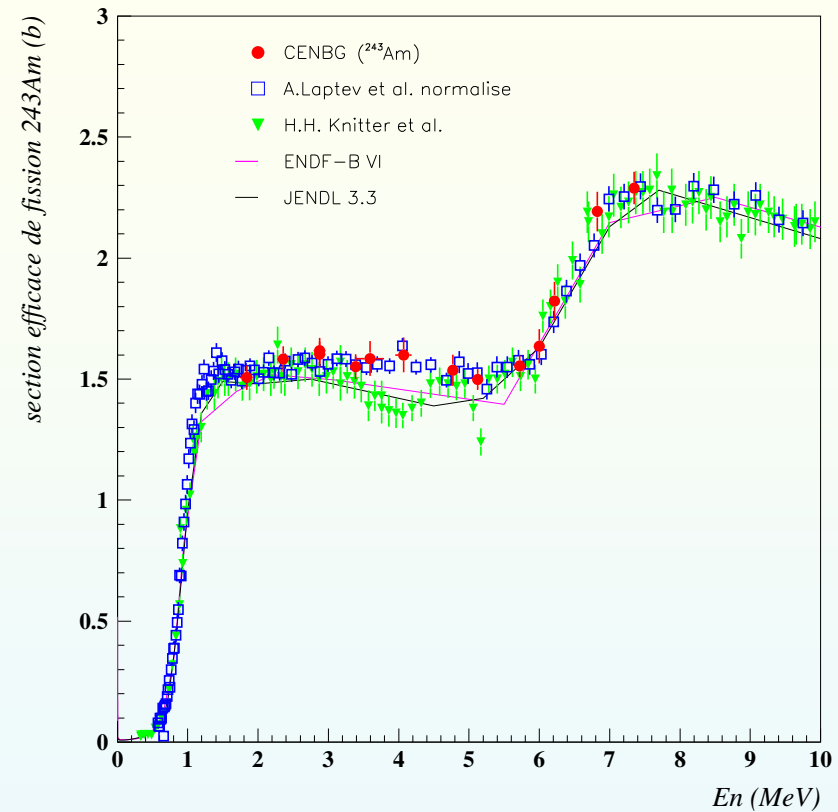
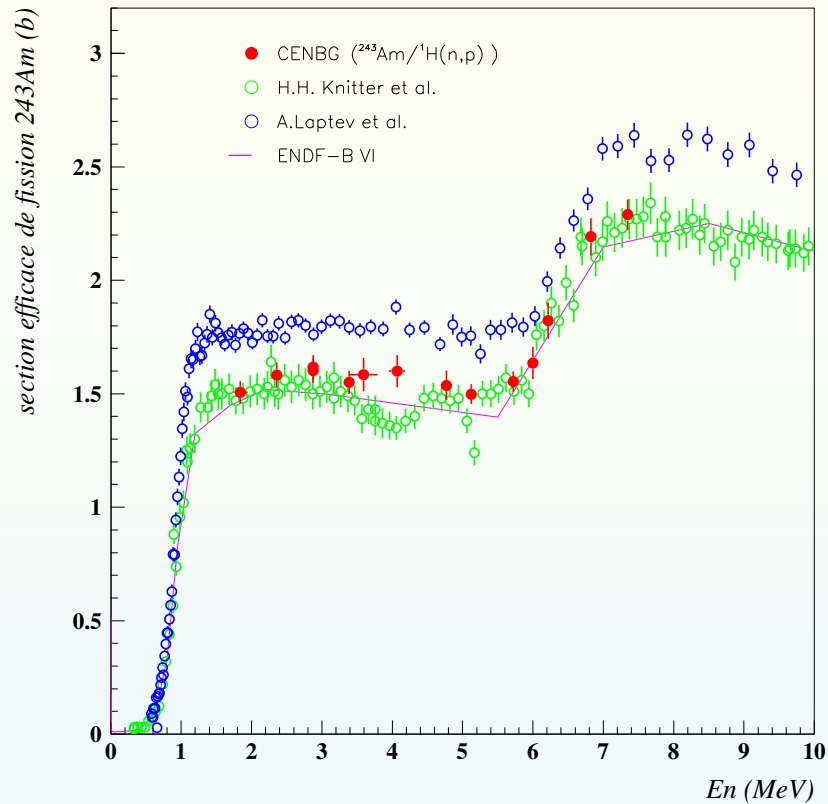


Ed=3 MeV
Polypropylene=50μm

$$\left\{ \begin{array}{l} E_n \pm \Delta E_n \rightarrow \bar{\sigma}_{n,p}(E_n) \\ \epsilon_{\text{télescope}} \end{array} \right\}$$



^{243}Am fission cross section



- Systematic deviation A.Laptev/CENBG : 12.8 % ($\chi^2 = 0.98$)
- discrepancies from 3 to 5 MeV between these different sets of data

Corrélations des angles solides : $\langle \text{corr} \rangle = 0$

$\text{Corr}(\Omega_n; \Omega_2) = 0$

En / En (MeV)	1,84	2,36	2,88	2,88	3,39	3,59	4,07	4,77	5,12	5,72	6,00	6,21	6,82	7,35
1,84	1	0,96	0,98	0,98	0,98	0,39	0,40	0,42	0,47	0,47	0,41	0,41	0,42	0,47
2,36		1	0,98	0,97	0,97	0,38	0,40	0,42	0,47	0,47	0,40	0,40	0,41	0,46
2,88			1	0,99	0,99	0,38	0,39	0,42	0,48	0,48	0,40	0,40	0,41	0,47
2,88				1	0,99	0,40	0,41	0,43	0,48	0,48	0,41	0,42	0,43	0,47
3,39					1	0,39	0,40	0,43	0,48	0,47	0,41	0,41	0,42	0,47
3,59						1	0,79	0,84	0,45	0,45	0,81	0,81	0,43	0,44
4,07							1	0,86	0,46	0,46	0,83	0,83	0,44	0,45
4,77								1	0,49	0,49	0,88	0,88	0,47	0,48
5,12									1	1,00	0,47	0,47	0,92	0,99
5,72										1	0,47	0,47	0,91	0,99
6,00											1	0,85	0,45	0,46
6,21												1	0,45	0,46
6,82													1	0,89
7,35														1

Série n°1 - geel T(p,n) - / (n,p)

Série n°2 - geel D(d,n) - / (n,p)

Série n°3 - AIFIRA D(d,n) - / (n,p)

Corrélations des angles solides : $\langle \text{corr} \rangle = 0,61$
 $\text{Corr}(\Omega_n; \Omega_2) = 1.0$

En / En (MeV)	1,84	2,36	2,88	2,88	3,39	3,59	4,07	4,77	5,12	5,72	6,00	6,21	6,82	7,35
1,84	1	0,59	0,62	0,62	0,61	0,61	0,64	0,70	0,97	0,97	0,66	0,66	0,42	0,95
2,36		1	0,62	0,61	0,60	0,52	0,55	0,60	0,95	0,95	0,57	0,57	0,41	0,93
2,88			1	0,64	0,63	0,52	0,55	0,60	1,00	1,00	0,56	0,56	0,41	0,98
2,88				1	0,63	0,54	0,57	0,62	1,00	1,00	0,59	0,59	0,43	0,98
3,39					1	0,54	0,56	0,62	0,99	0,99	0,58	0,58	0,42	0,97
3,59						1	0,68	0,75	0,69	0,68	0,70	0,70	0,43	0,66
4,07							1	0,78	0,72	0,71	0,73	0,74	0,44	0,68
4,77								1	0,79	0,78	0,81	0,81	0,47	0,75
5,12									1	0,83	0,74	0,74	0,92	0,82
5,72										1	0,73	0,74	0,91	0,82
6,00											1	0,76	0,45	0,71
6,21												1	0,45	0,71
6,82													1	0,89
7,35														1

Série n°1 - geel T(p,n) - / (n,p)

Série n°2 - geel D(d,n) - / (n,p)

Série n°3 - AIFIRA D(d,n) - / (n,p)

Dans quel spectre de neutrons incinérer les actinides mineurs ?

$\alpha = \frac{\text{Taux de capture}}{\text{Taux de fission}}$			
Spectre noyaux	Thermique	Épithermique	Rapide
^{237}Np	63	30	5.3
^{241}Am	100	44.5	7.4
^{243}Am	111	63.4	8.6
^{242}Cm	3.9	3.6	1.7
^{243}Cm	0.16	0.2	0.14
^{244}Cm	16	13.1	1.4

Dispositif expérimental IRMM (Geel) & AIFIRA (CENBG)

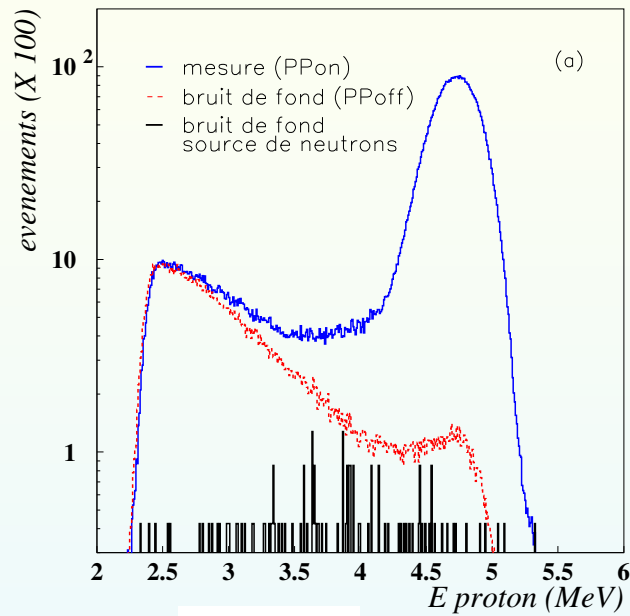
$$\sigma_{n,f}(E_n) = \frac{\tau_f}{\phi_n(E_n)} \qquad \phi_n(E_n) = \frac{N_p}{\sigma_{n,p}(E_n) \cdot \epsilon_{telescope} \cdot N_H \cdot \Delta t}$$

• mesures expérimentales \Rightarrow $\left\{ \begin{array}{l} \text{spectre de fragments de fission} \\ \text{spectre de protons} \end{array} \right.$

• Simulation $\left\{ \begin{array}{l} \text{Spectre de neutrons} \quad E_n \pm \Delta E_n \rightarrow \overline{\sigma_{n,p}(E_n)} \\ \text{efficacité de détection des protons } \epsilon_{\text{télescope}} \sim 10^{-2} \\ \text{efficacité de détection des neutrons } \epsilon_{\text{détecteur n}} \sim (2-8) \cdot 10^{-6} \end{array} \right.$

Protons de basse énergie

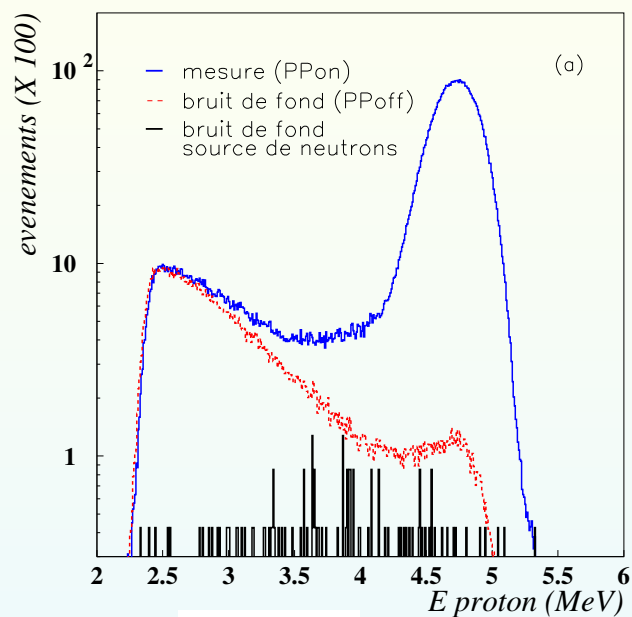
1) Mesure de bruit de fond de la source de neutrons



< 0.6%

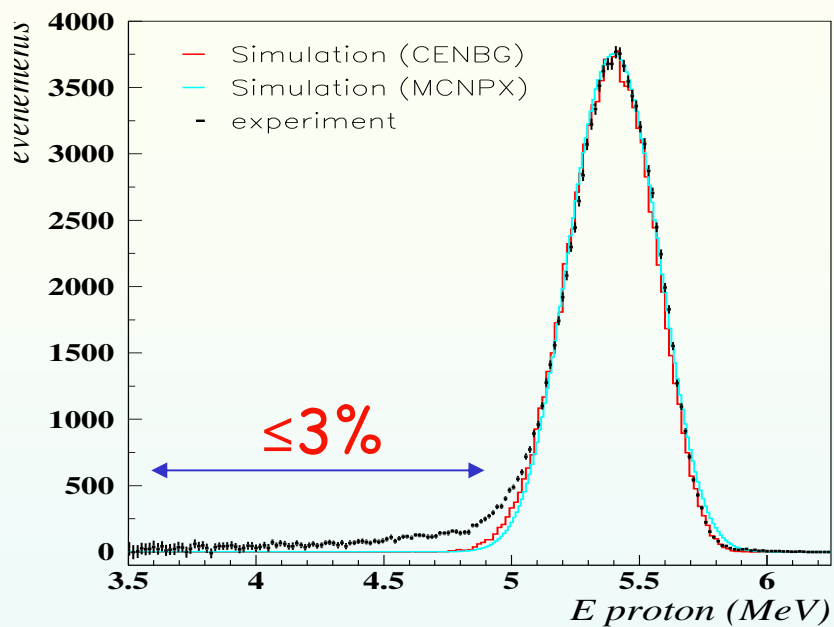
Protons de basse énergie

1) Mesure de bruit de fond de la source de neutrons



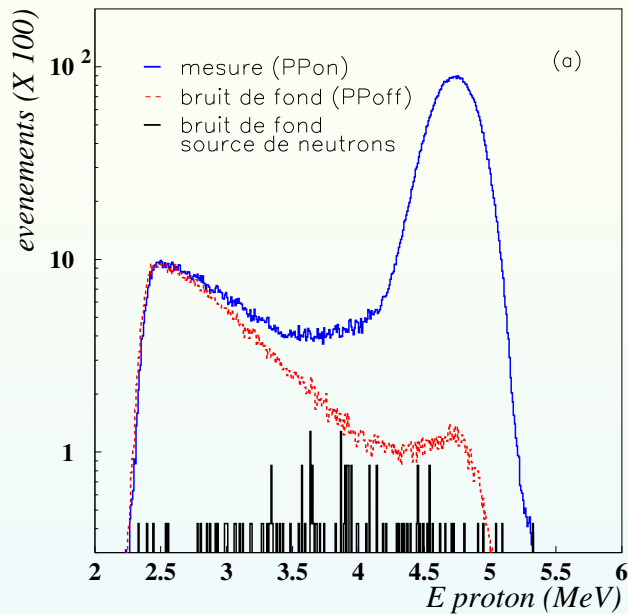
< 0.6%

2) Simulation du spectre de protons de recul avec MCNPX



Protons de basse énergie

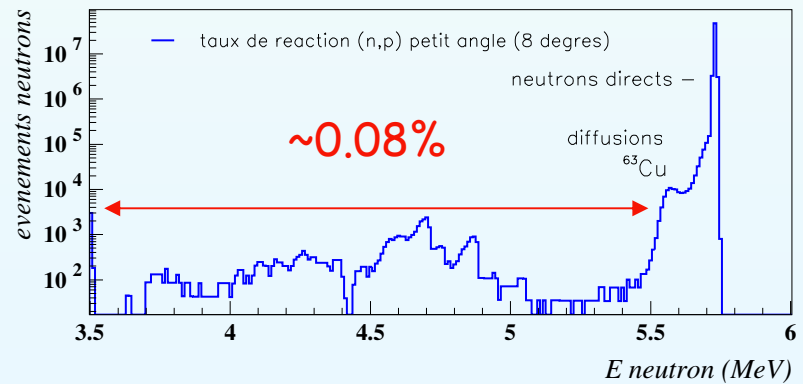
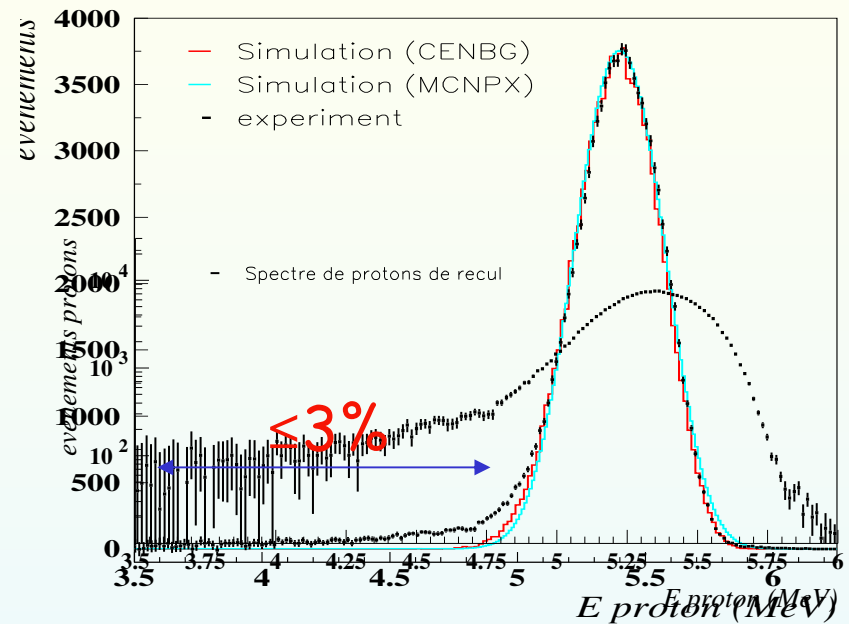
1) Mesure de bruit de fond de la source de neutrons



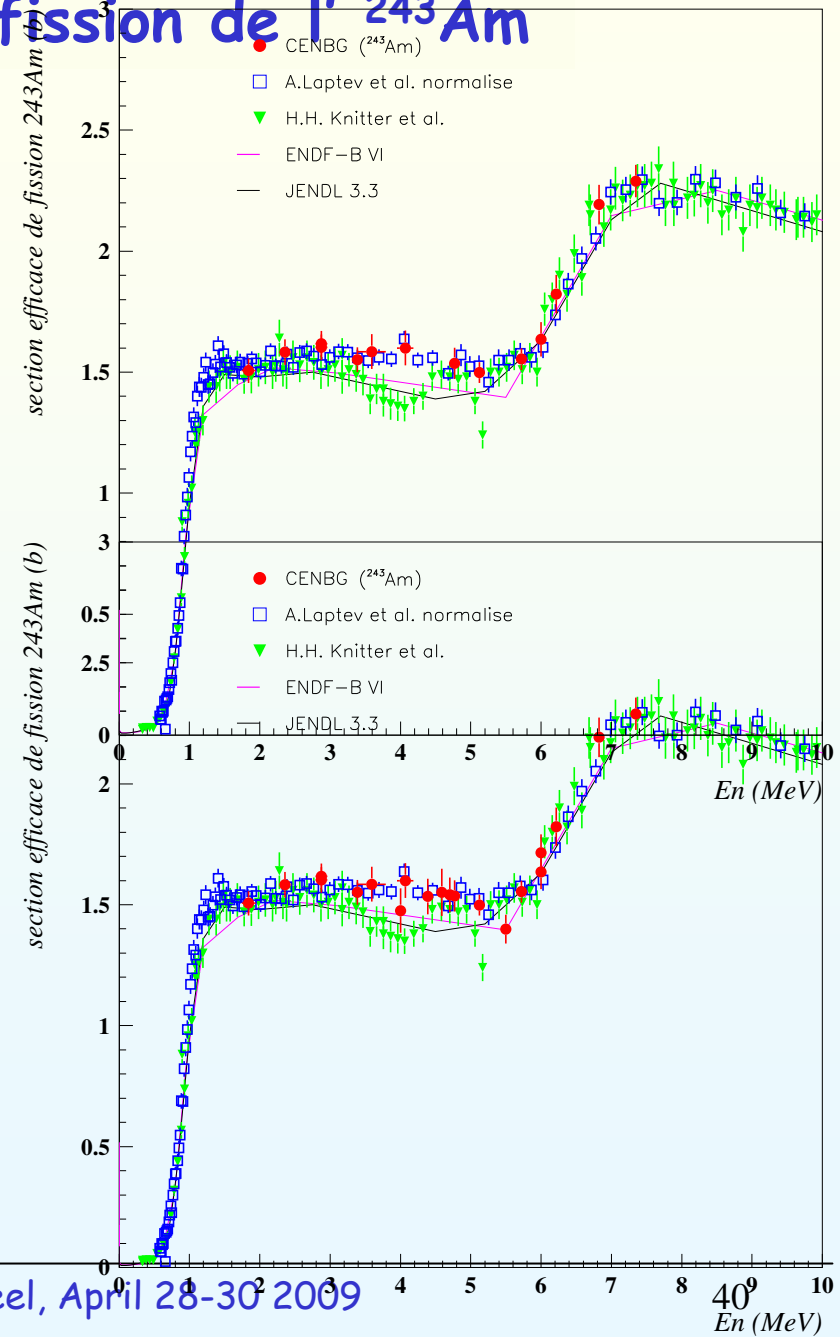
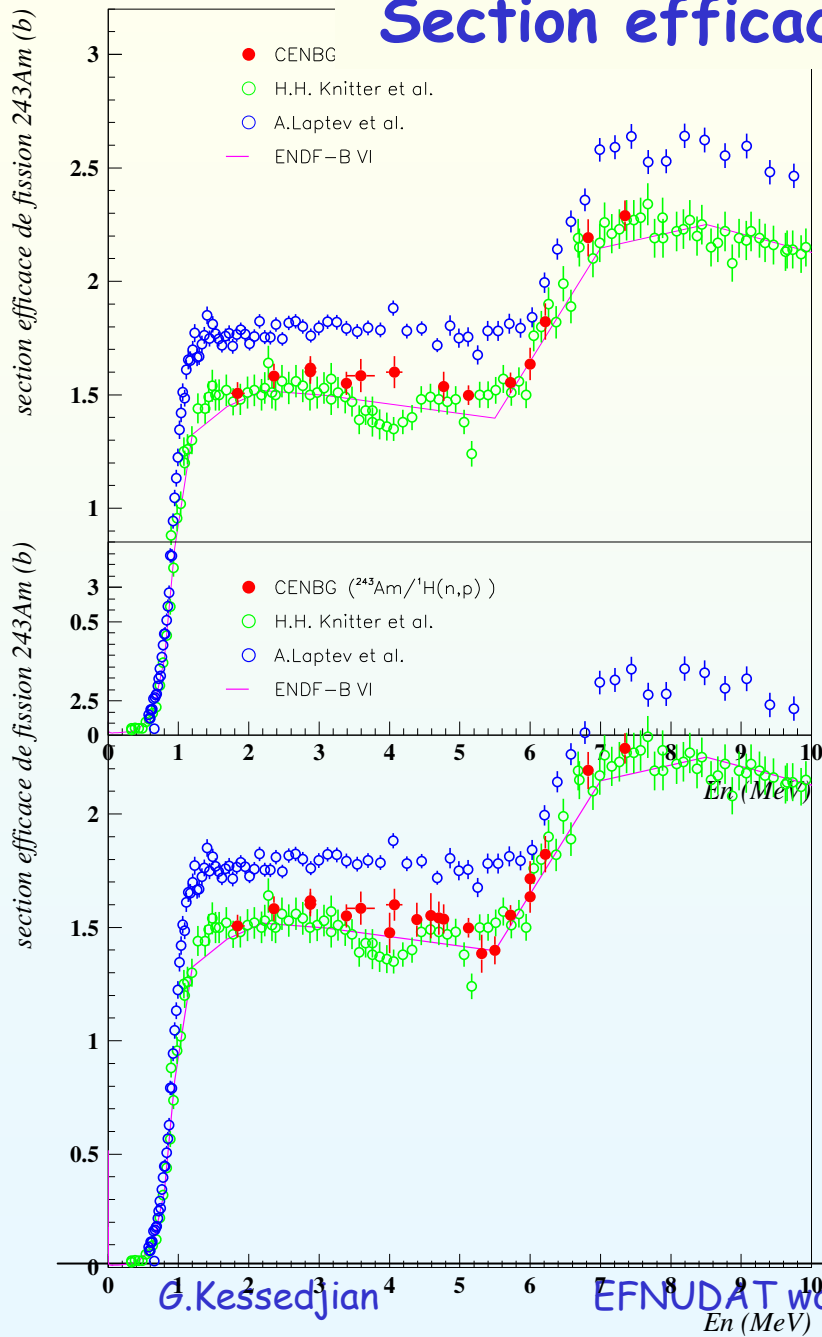
< 0.6%

3) Simulation de l'environnement neutrons au niveau du polypropylène

2) Simulation du spectre de protons de recul avec MCNPX



Section efficace de fission de l' ^{243}Am

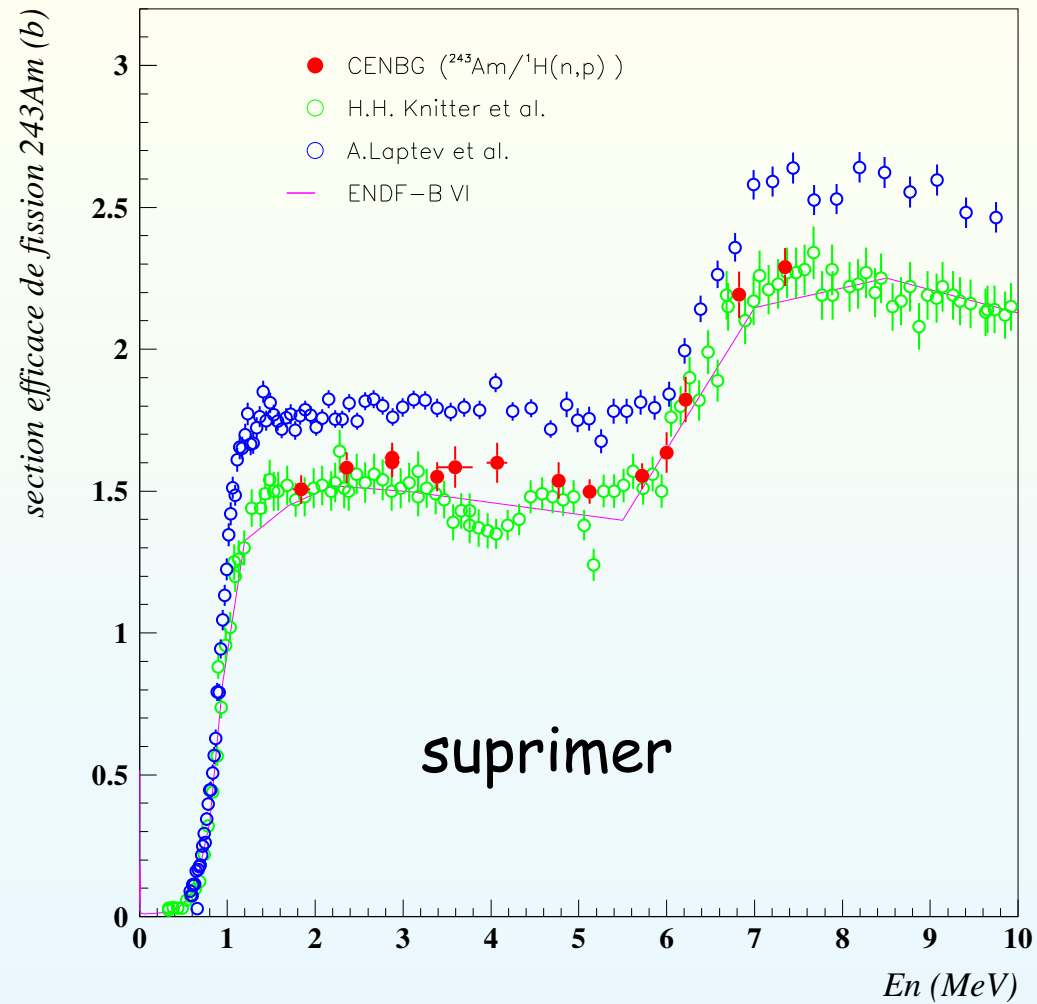


G.Kessedjian

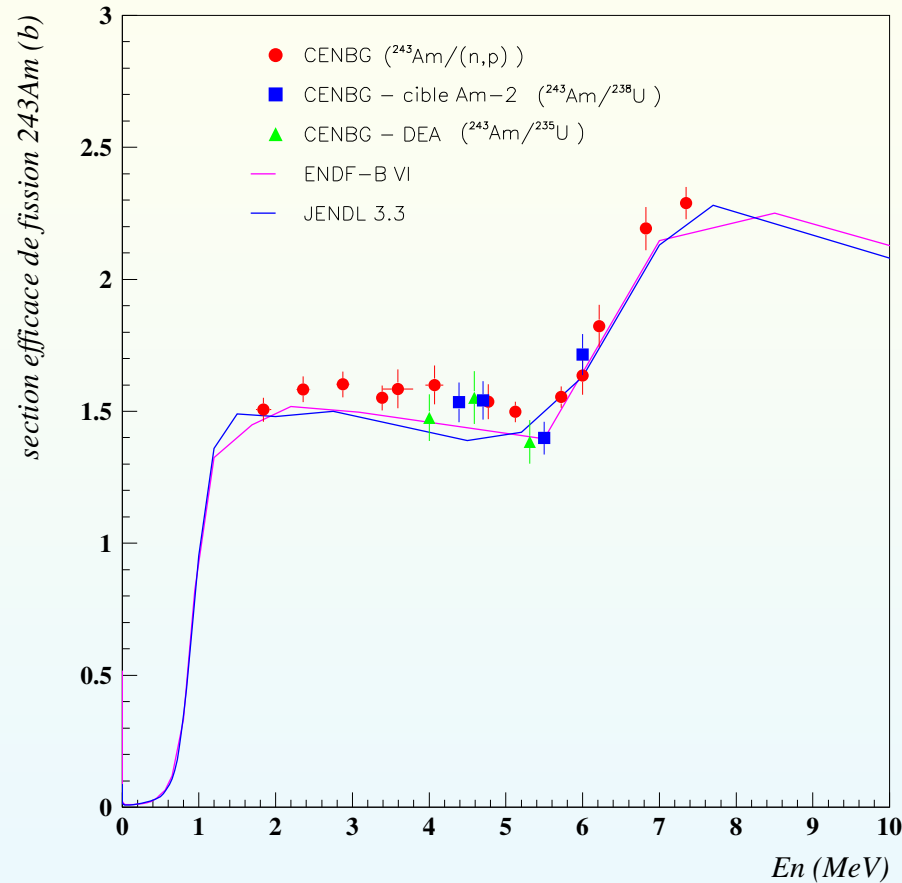
EFNUDAT workshop Geel, April 28-30 2009

40^9
 E_n (MeV)

Section efficace de fission de l' ^{243}Am / (n,p)



Mesures complémentaires : section efficace $^{243}\text{Am}(n,f) / ^{235,238}\text{U}(n,f)$

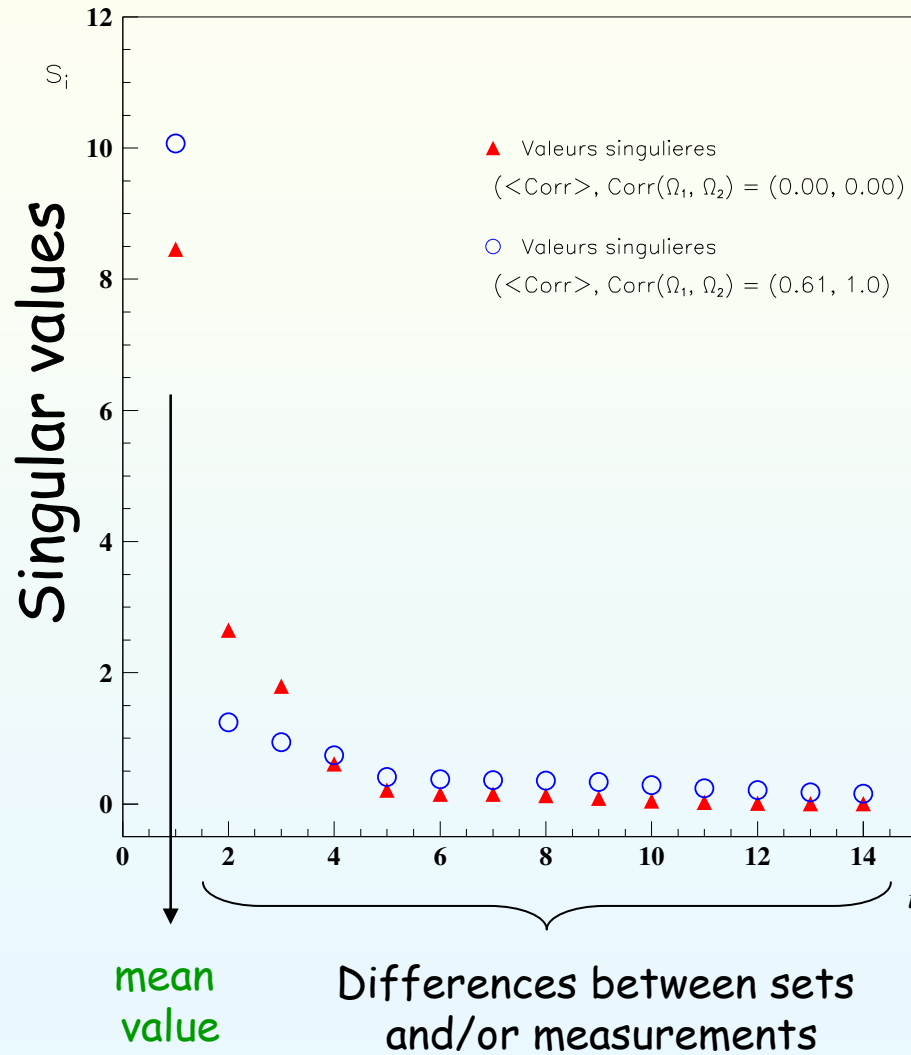


Nouvelles mesures :

- en bon accord avec les mesures (n/p)
- (quasi-/totalement) indépendantes
des mesures en (n,p)

Effets systématiques
correctement traités

correlations of errors on measurements: $^{243}\text{Am}(n, f) / (n, p)$



Singular values are **similar**
for the two limit matrices

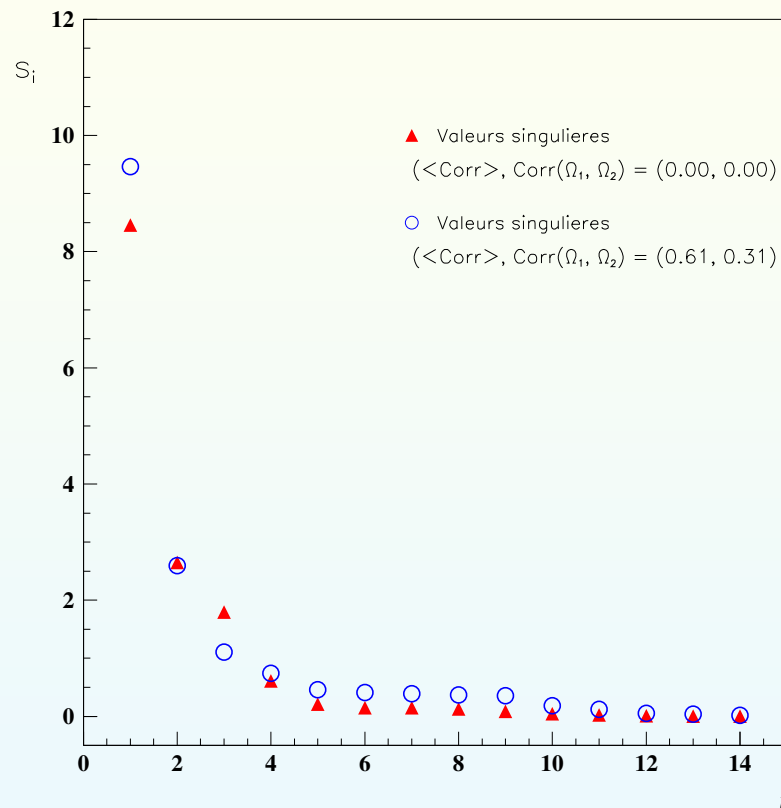


Measurements, errors
and theirs correlations of errors
provide the **same information**



Correlation of solid angles
increase the first singular value

Valeurs singulières des n mesures : $^{243}\text{Am}(n, f) / (n, p)$



Similarité des spectres des valeurs singulières des deux matrices

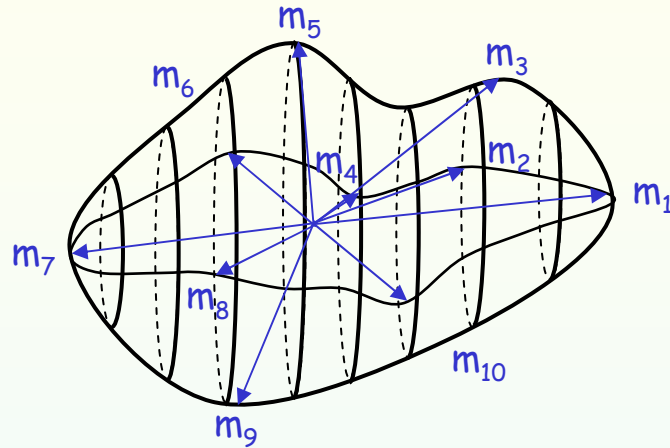


Les mesures, leur(s) erreur(s)
et leur(s) matrice(s)
de corrélation des erreurs
traduisent la même information

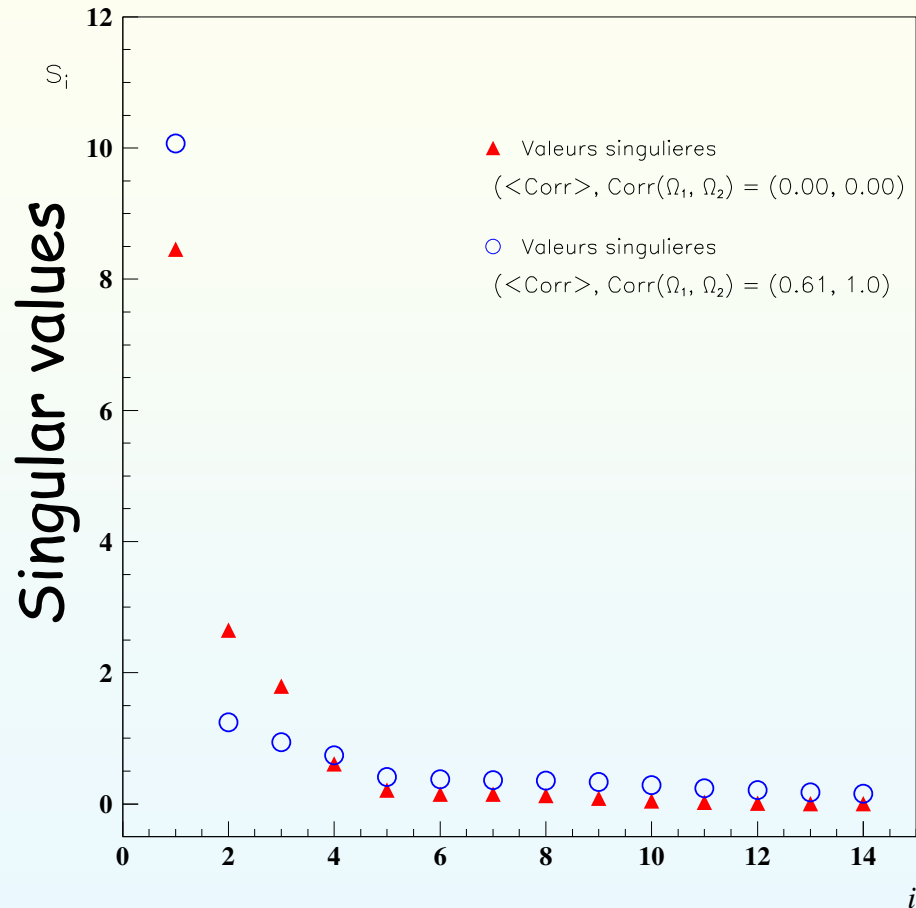


La forte corrélation des
paramètres (angles solides)
renforce la première valeur singulière

Interprétation géométrique de la covariance des n mesures

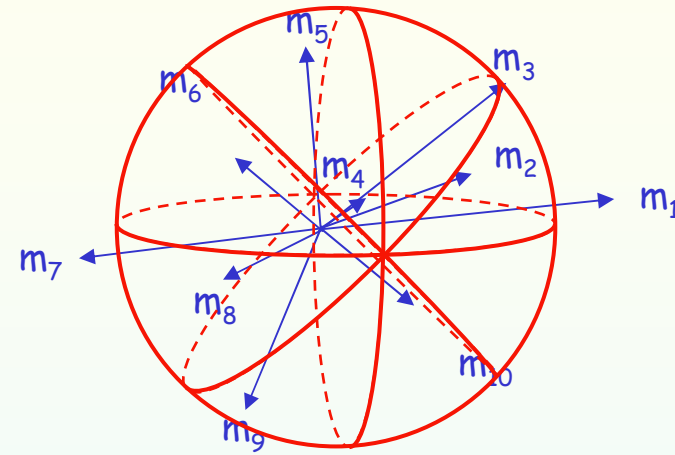
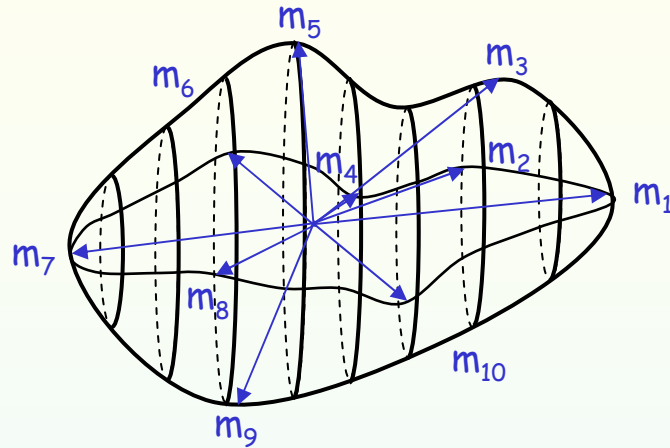


correlations of errors on measurements: $^{243}\text{Am}(n, f) / (n, p)$



Sing.Values (without unity)	Statistical weight (%)	cumulative weight (%)
8,4554	59,0	59,0
2,6491	18,5	77,5
1,7932	12,5	90,0
0,6119	4,3	94,3
0,2132	1,5	95,8
0,1503	1,0	96,8
0,1494	1,0	97,9
0,1302	0,9	98,8
0,0875	0,6	99,4
0,0427	0,3	99,7
0,0227	0,2	99,8
0,014	0,1	99,9
0,0072	0,1	100,0
0,0025	0,0	100,0
Sing.Values (without unity)	Statistical weight (%)	cumulative weight (%)
10,0709	63,3	63,3
1,2477	7,8	71,2
0,9393	5,9	77,1
0,7382	4,6	81,7
0,4087	2,6	84,3
0,3781	2,4	86,7
0,3645	2,3	89,0
0,3534	2,2	91,2
0,3319	2,1	93,3
0,2864	1,8	95,1
0,2402	1,5	96,6
0,2098	1,3	97,9
0,178	1,1	99,0
0,1543	1,0	100,0

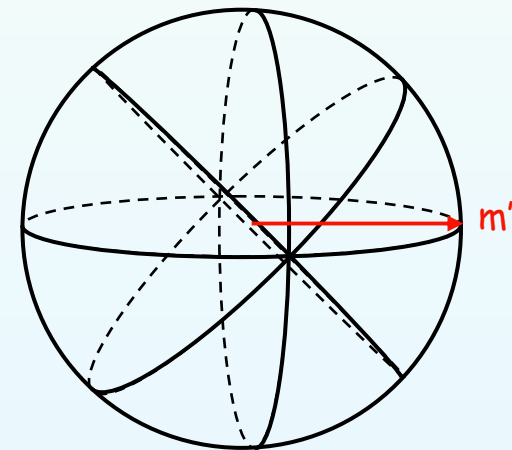
Interprétation géométrique de la covariance des n mesures



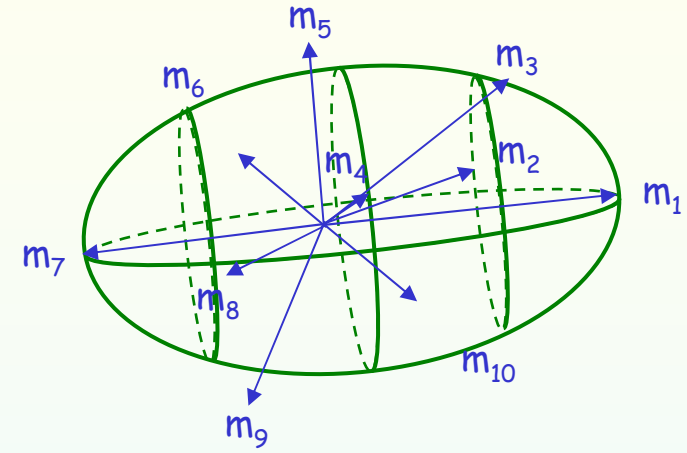
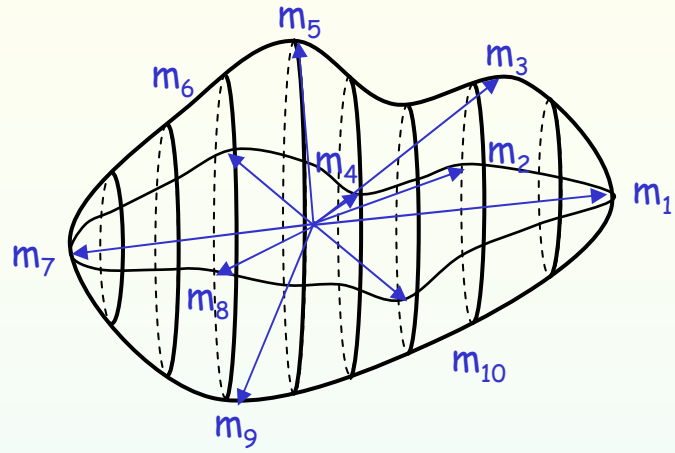
Valeur singulière S_1



Valeur moyenne
des n mesures



Interprétation géométrique de la covariance des n mesures

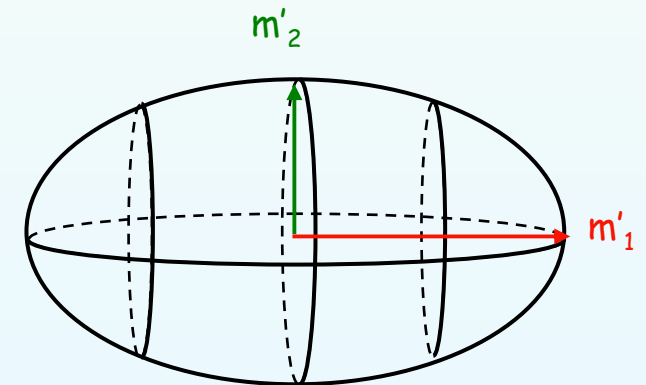
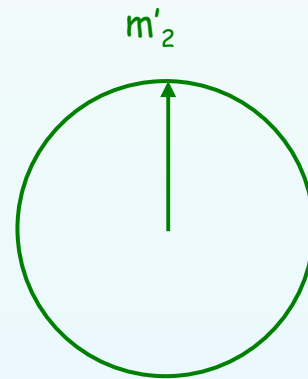


Valeur singulière S_2

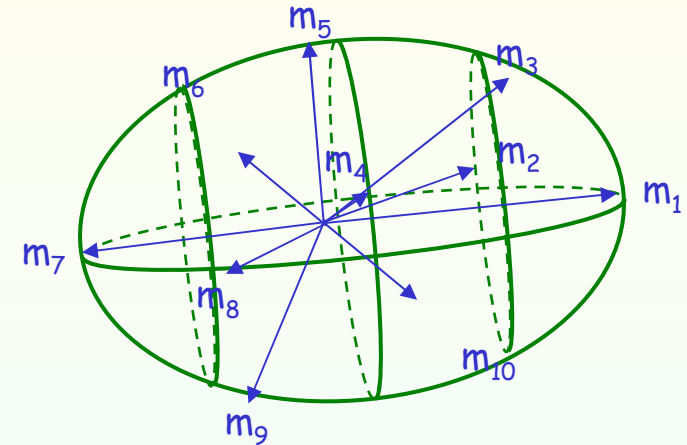
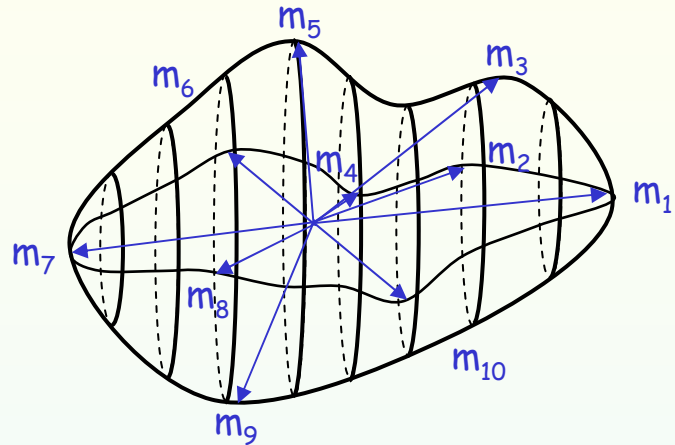


Différences

$$m_{\text{tritium}} - m_{\text{deutérium}}$$



Interprétation géométrique de la covariance des n mesures

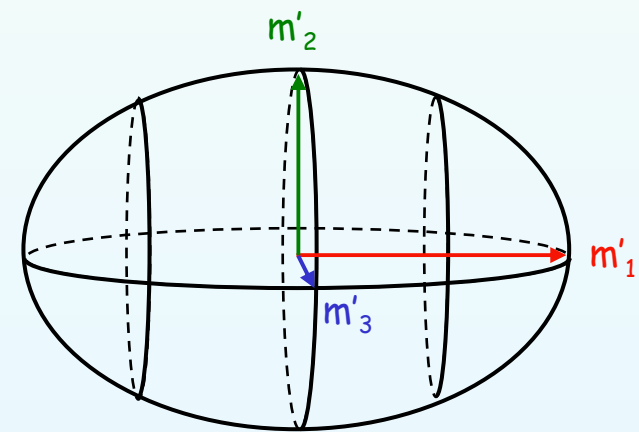
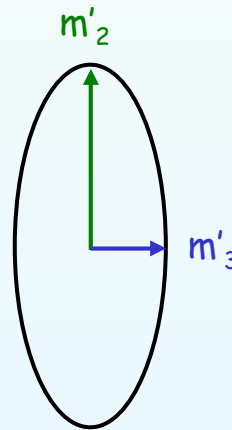


Valeur singulière S_3

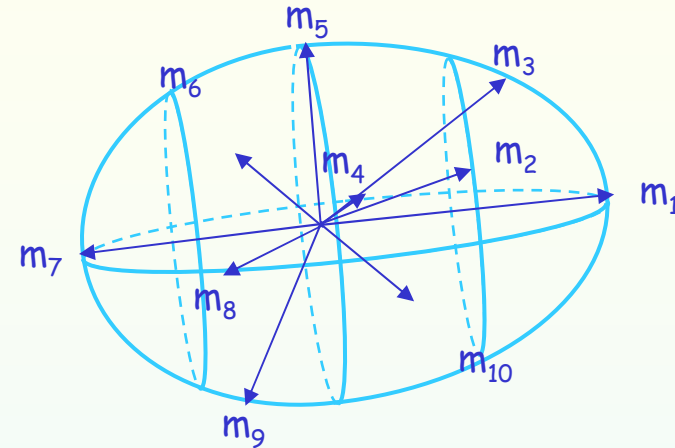
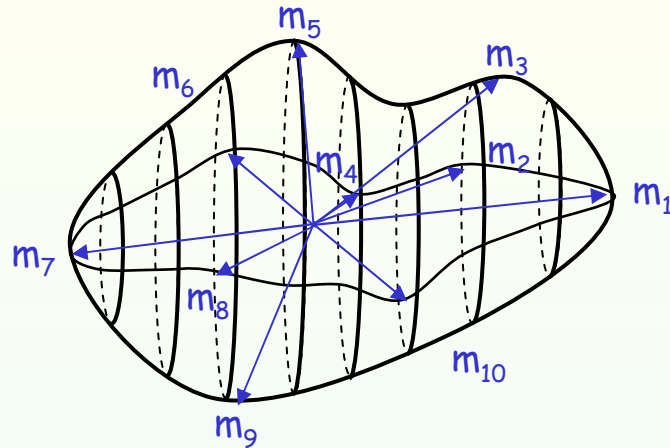


différences

$$m_{\text{tritium}} - m_{\text{d-Geel}}$$



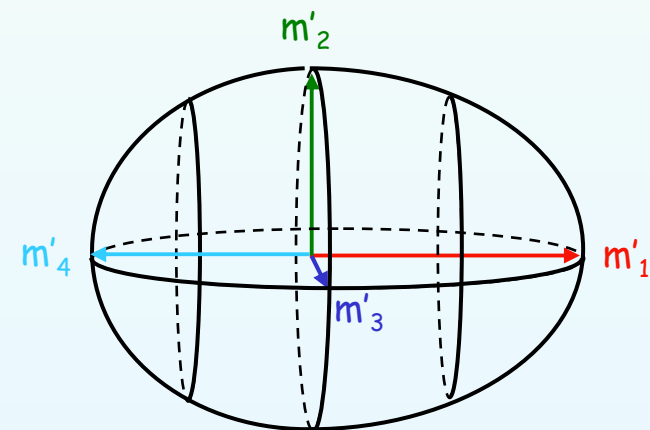
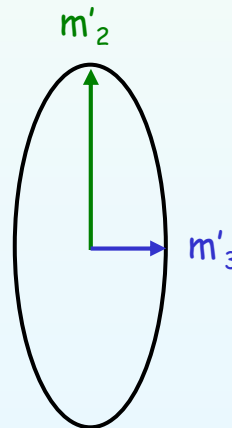
Interprétation géométrique de la covariance des n mesures



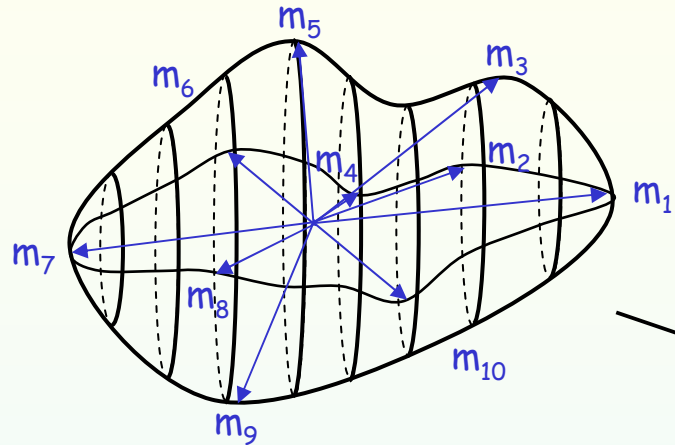
Valeur singulière S_4



Représentative
des autres V.S. :
différence locale
entre les mesures

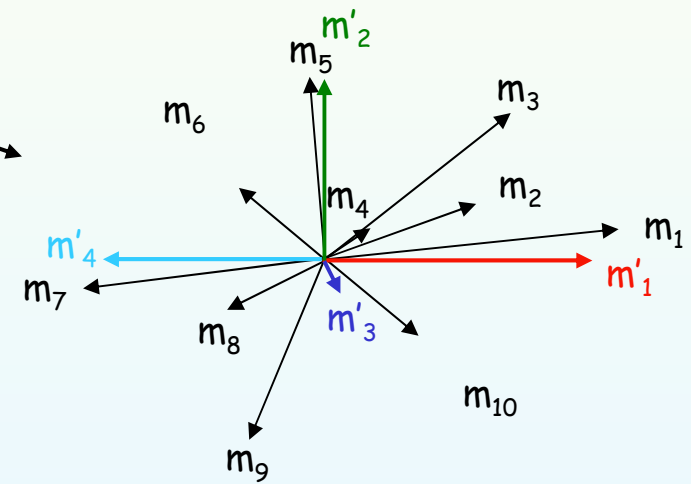


Interprétation géométrique de la covariance des n mesures

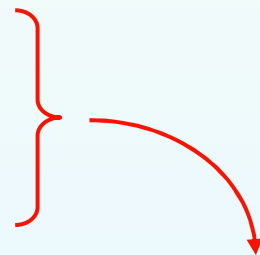


Mesures liées m_i

Mesures m'_i quasi-indépendantes



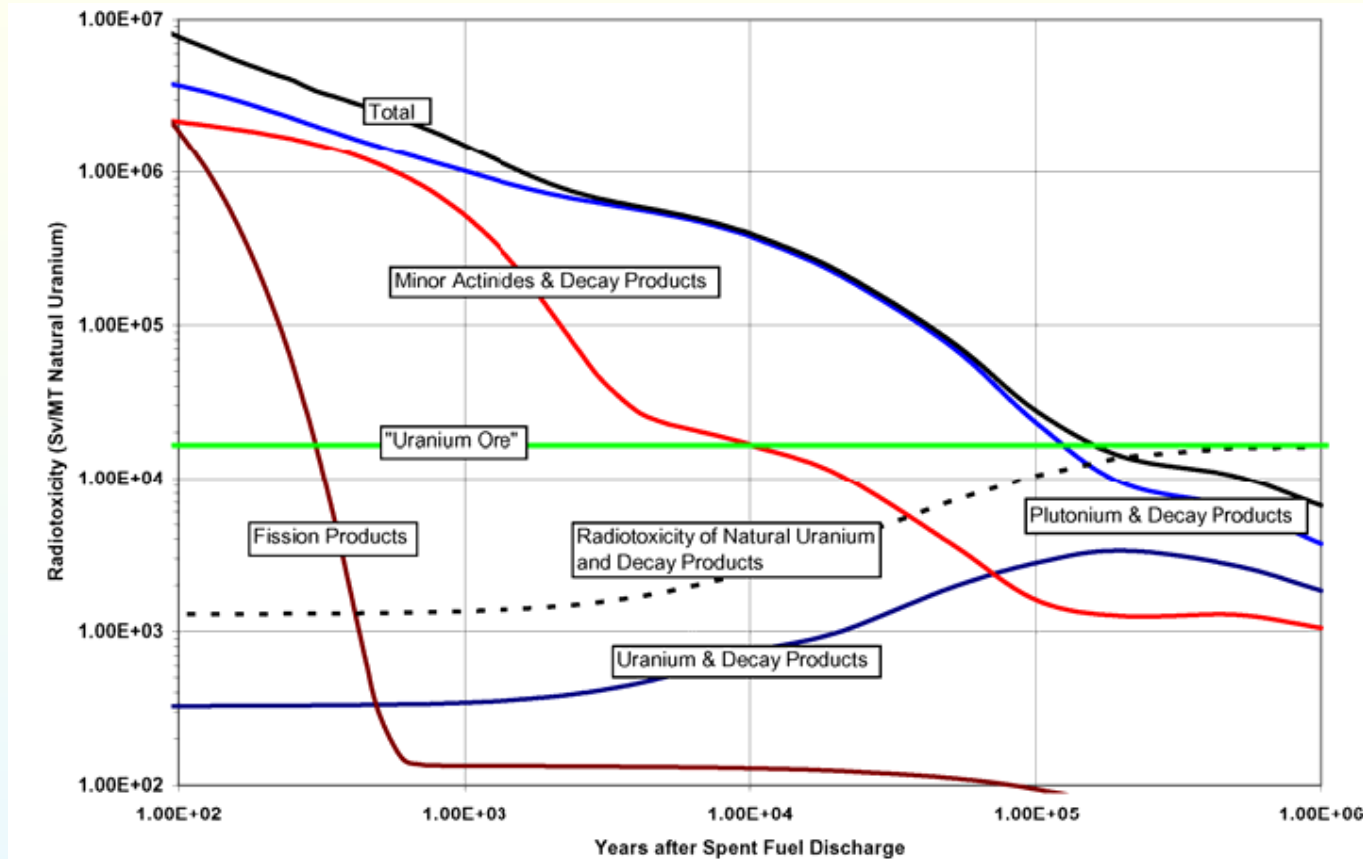
Si (sans unité)	Poids stat. (%)	Poids cumulé (%)
8,46	59,0	59,0
2,65	18,5	77,5
1,79	12,5	90,0
0,612	4,3	94,3
0,213	1,5	95,8
0,150	1,0	96,8
0,149	1,0	97,9
0,130	0,9	98,8
0,088	0,6	99,4
0,043	0,3	99,7
0,023	0,2	99,8
0,014	0,1	99,9
0,007	0,1	100,0
0,003	0,0	100,0



Information principalement apportée par les premières valeurs singulières

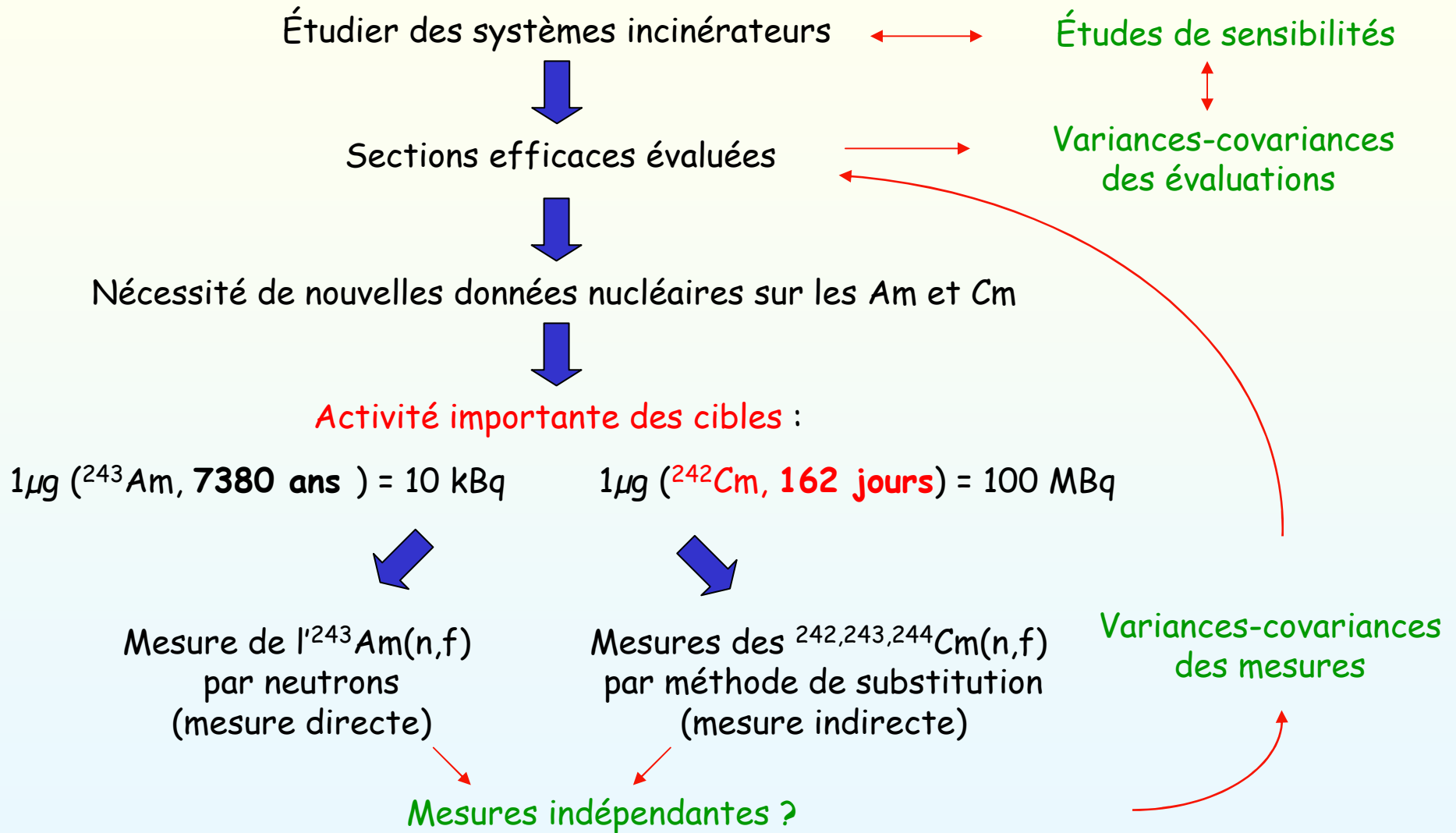
Évolution de la radio-toxicité du combustible utilisé

NEA Physics and Safety of Transmutation Systems



Uranium et plutonium valorisable
Transmutation des A.M.: réaction de fission induite par neutrons

Les méthodes



conclusions

- Neutron-proton elastic scattering allows to measure fission cross sections with a good accuracy (< 4%)

- * error on (n,p) scattering very low in reference to the other systematic errors

quasi-absolute measurements
independent of existing data

- covariance analysis have to be complete for all database to obtain an a better evaluation of fission cross section and associated errors