^{7}Li elastic scattering cross section measurement using slowing-down spectrometer

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motivations

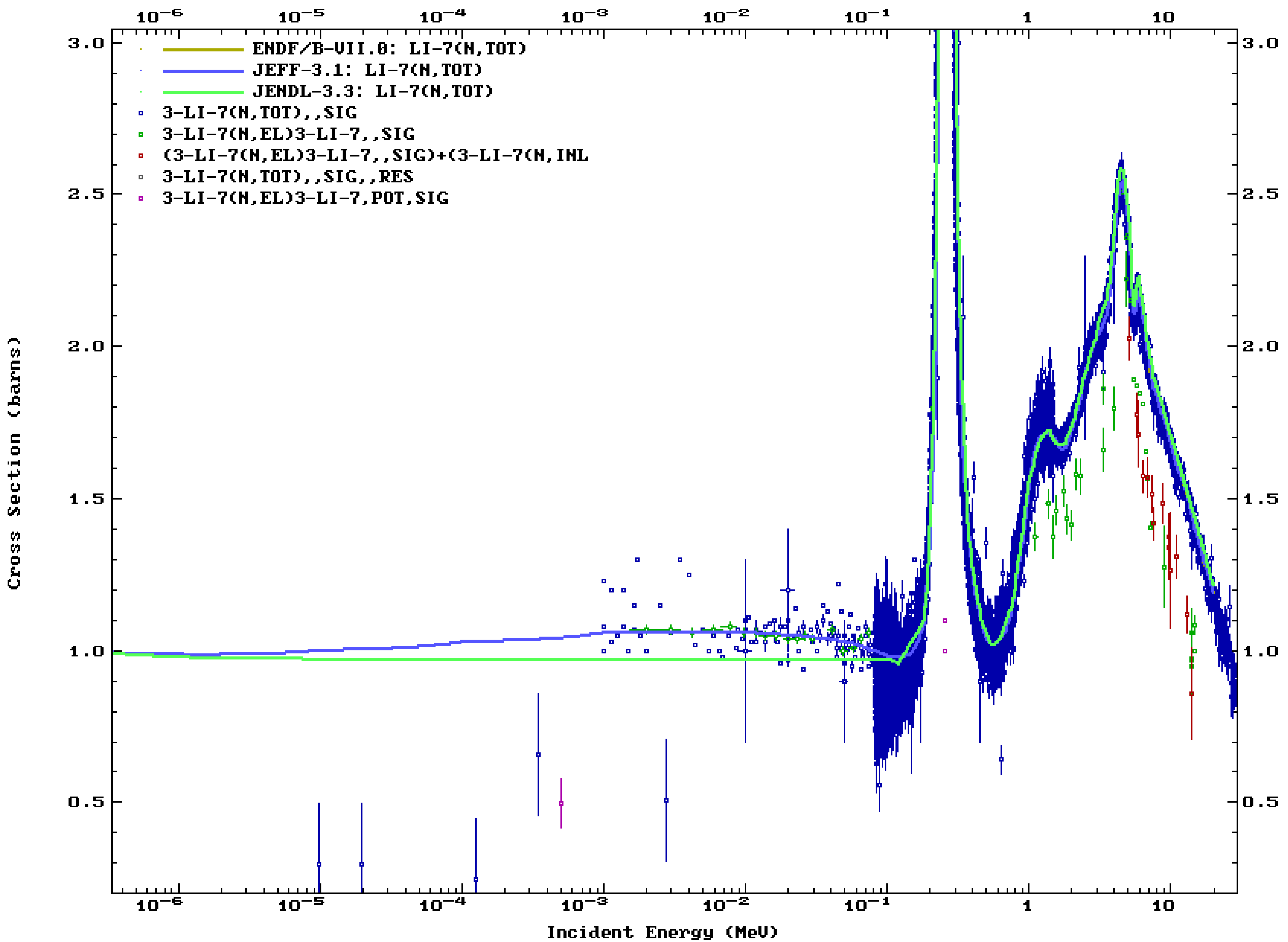
• Molten Salt Reactor is one of the six concepts of GEN-IV reactor and it is based on liquid mixed fuel-coolant :

Ex : the Thorium Molten Salt Reactor use ($^{7}LiF+ThF_4+UF_4$) as fuel and coolant

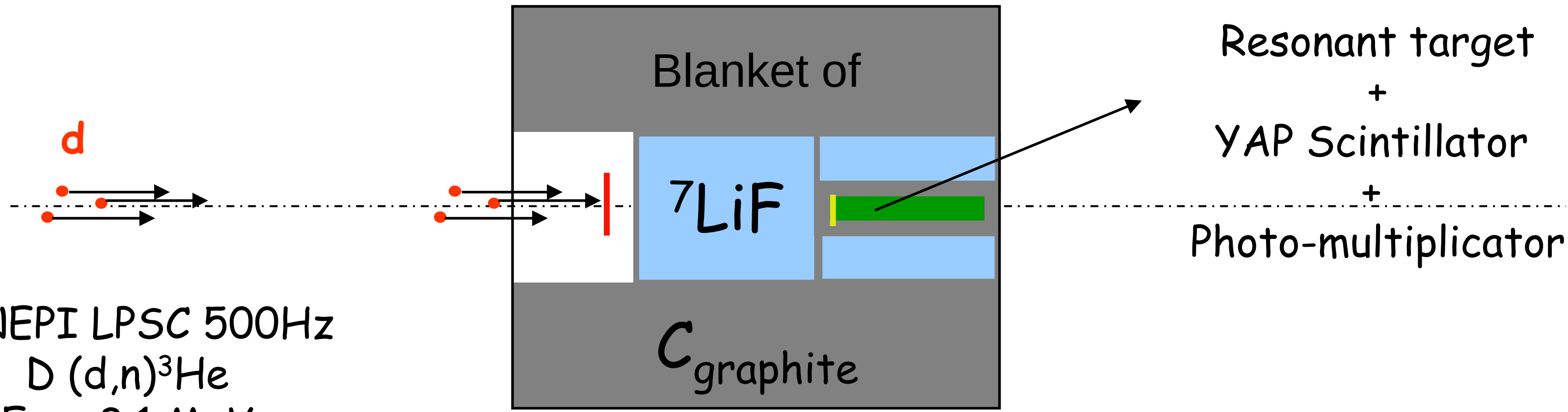
• To obtain the characteristics of breeder reactor, only ^{7}Li have to be consider in the core to avoid ^{6}Li(n,t) reaction which decreases the number of neutron useful for the regeneration of fissile nuclei.

• The only coolant properties of LiF salt are interesting in reactor studies; then neutron reactions on these nuclei are needed for reactor physics

^{7}Li total and elastic scattering cross section



Experimental set-up (1): Graphite LiF slowing down spectrometer



GENEPI LPSC 500Hz
D (d,n)^{3}He
En ~ 3.1 MeV

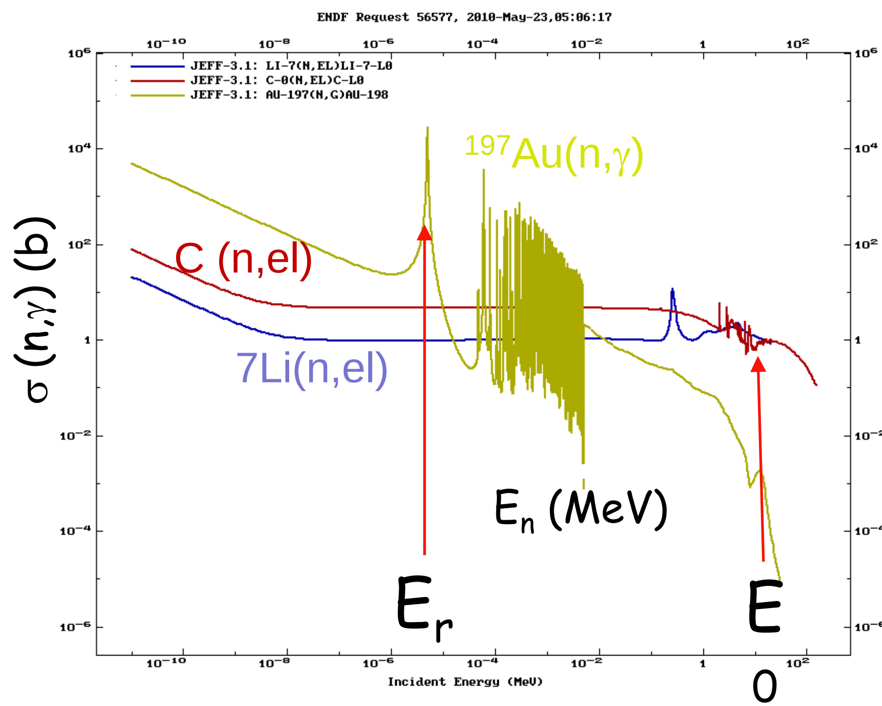
- Measurement of slowing down time :
  - Start : γ flash of GENEPI
  - Stop : ^{197}Au(n,γ) at (E_r, t_r)

- Time-Energy correlation :

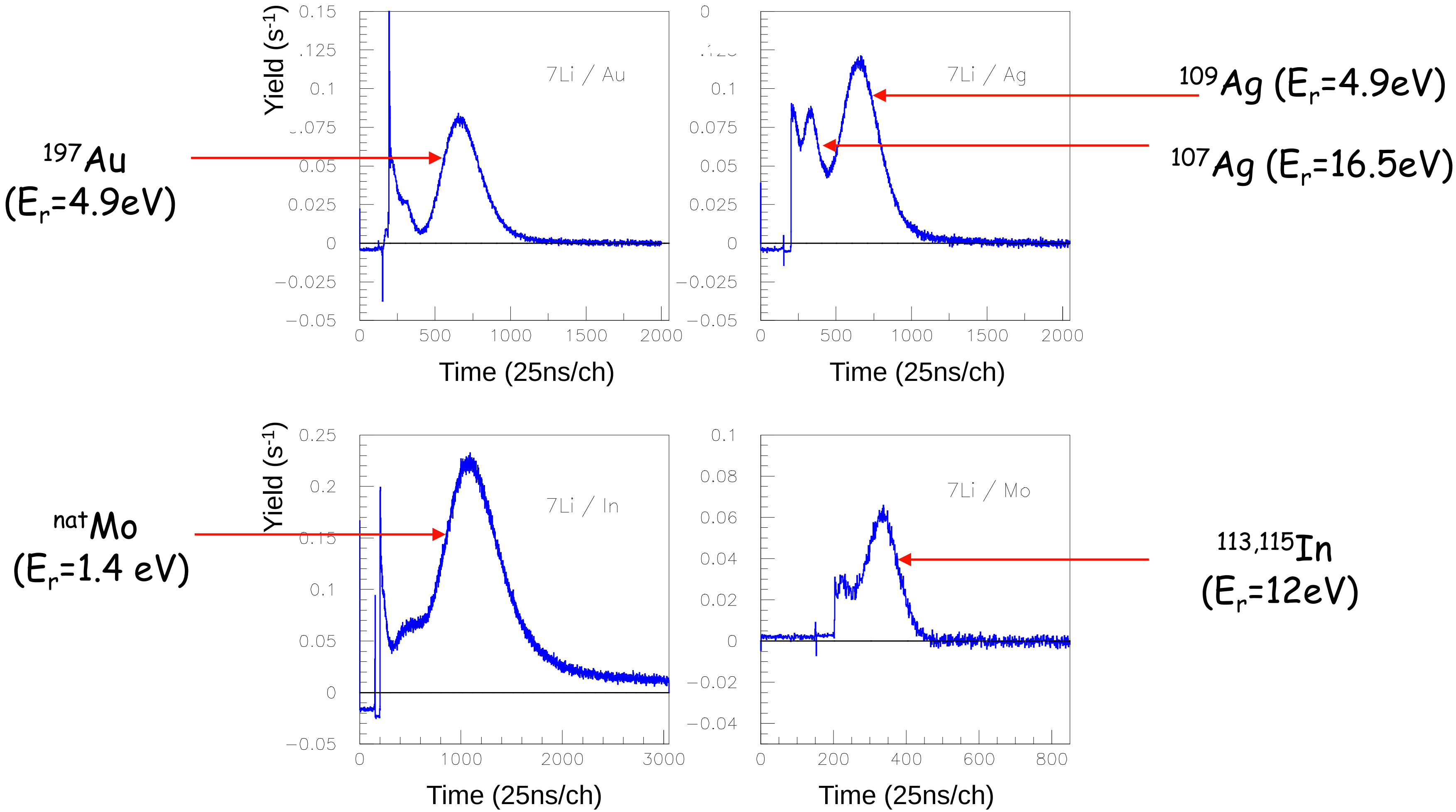
$$E_r = \frac{E_0 \cdot T_o}{(T_r + To)^2}$$

Integral cross section measurement

<σ (^{7}Li, ^{19}F, ^{nat}C)>
on
[E_r; 3.1] MeV

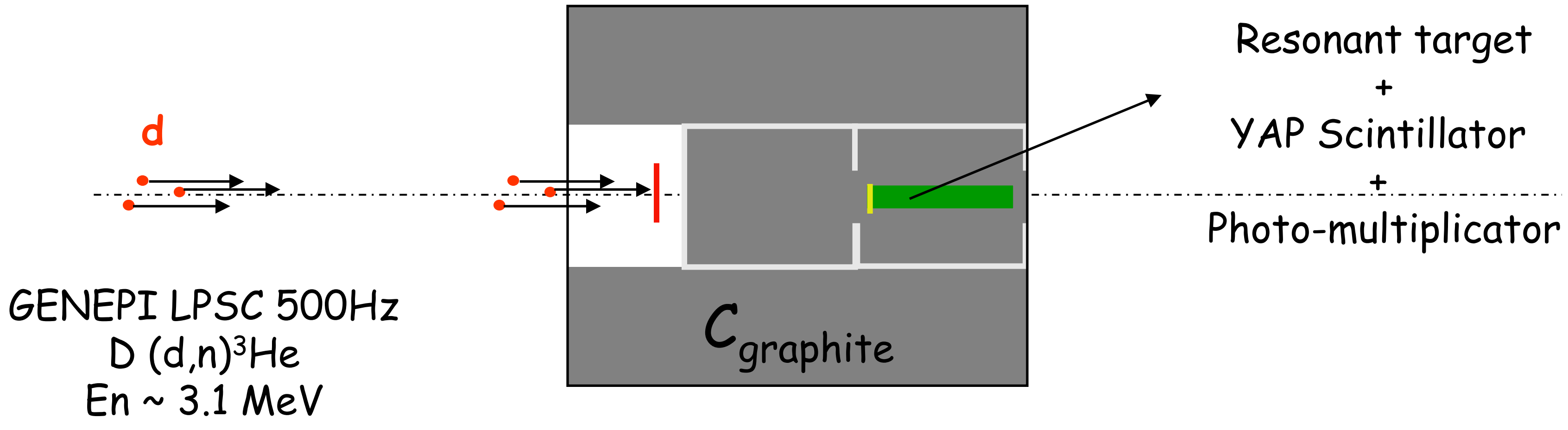


Neutron slowing down time measurement in the Graphite- LiF spectrometer



- The slowing down time $\mathbf{T_r}$ is function $<\sigma_{^7Li(n,el)}>$; $<\sigma_{^{19}F(n,el)}>$; $<\sigma_{^{nat}C(n,el)}>$, ρ_C ; ρ_{LiF}
- To determine $<\sigma_{^7Li(n,el)}>$, we use Monte Carlo simulations to extract the contribution of Li in the mean slowing down time $\rightarrow$ We need a *reference measurement on graphite* with the same set-up

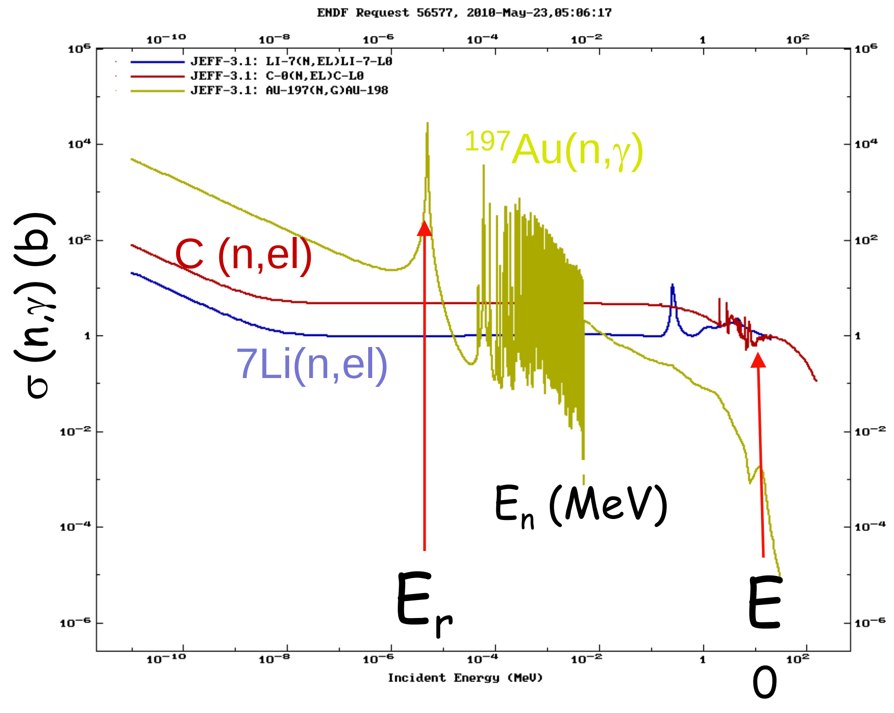
Experimental set-up (2): Graphite spectrometer



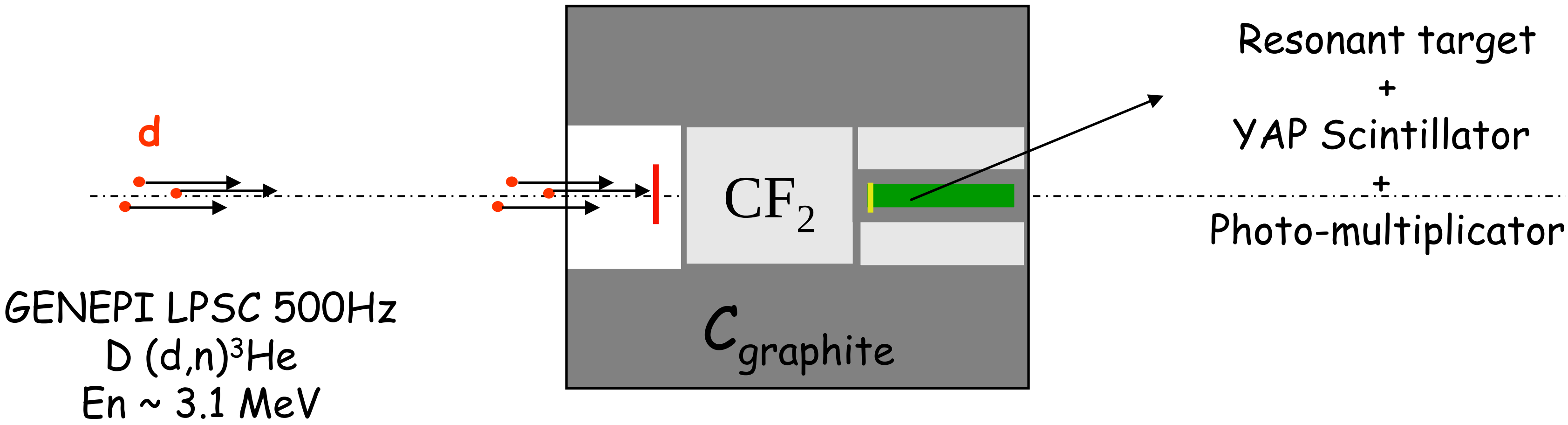
- reference slowing down time measurement : Graphite

Integral cross section
Measurement of $^{nat}C(n,el)$

$T_r = f(^{nat}C(n,el)\ ;\ \rho_C)$



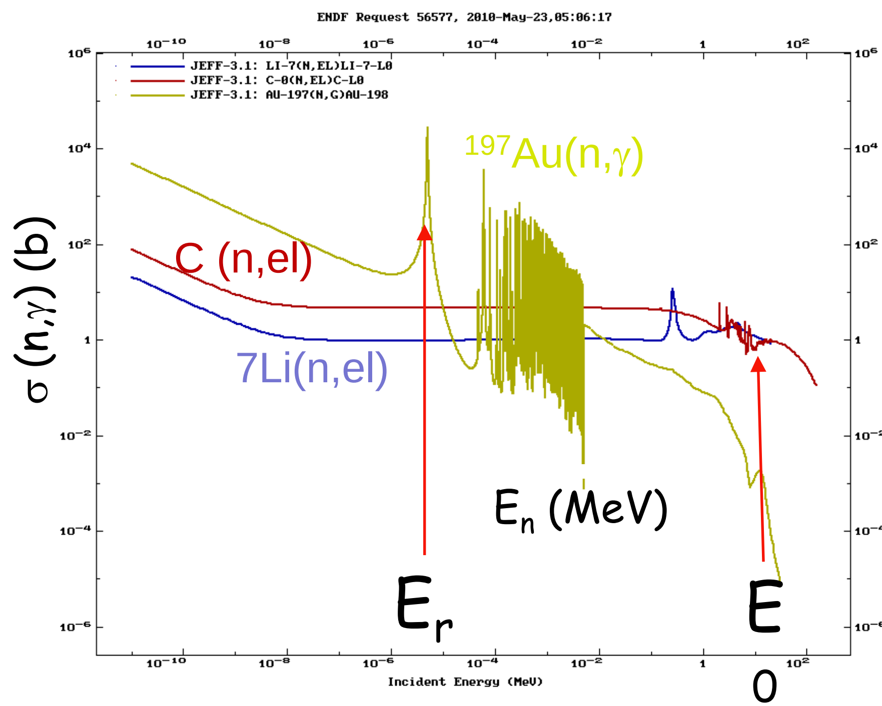
Experimental set-up (3): Graphite-Teflon spectrometer



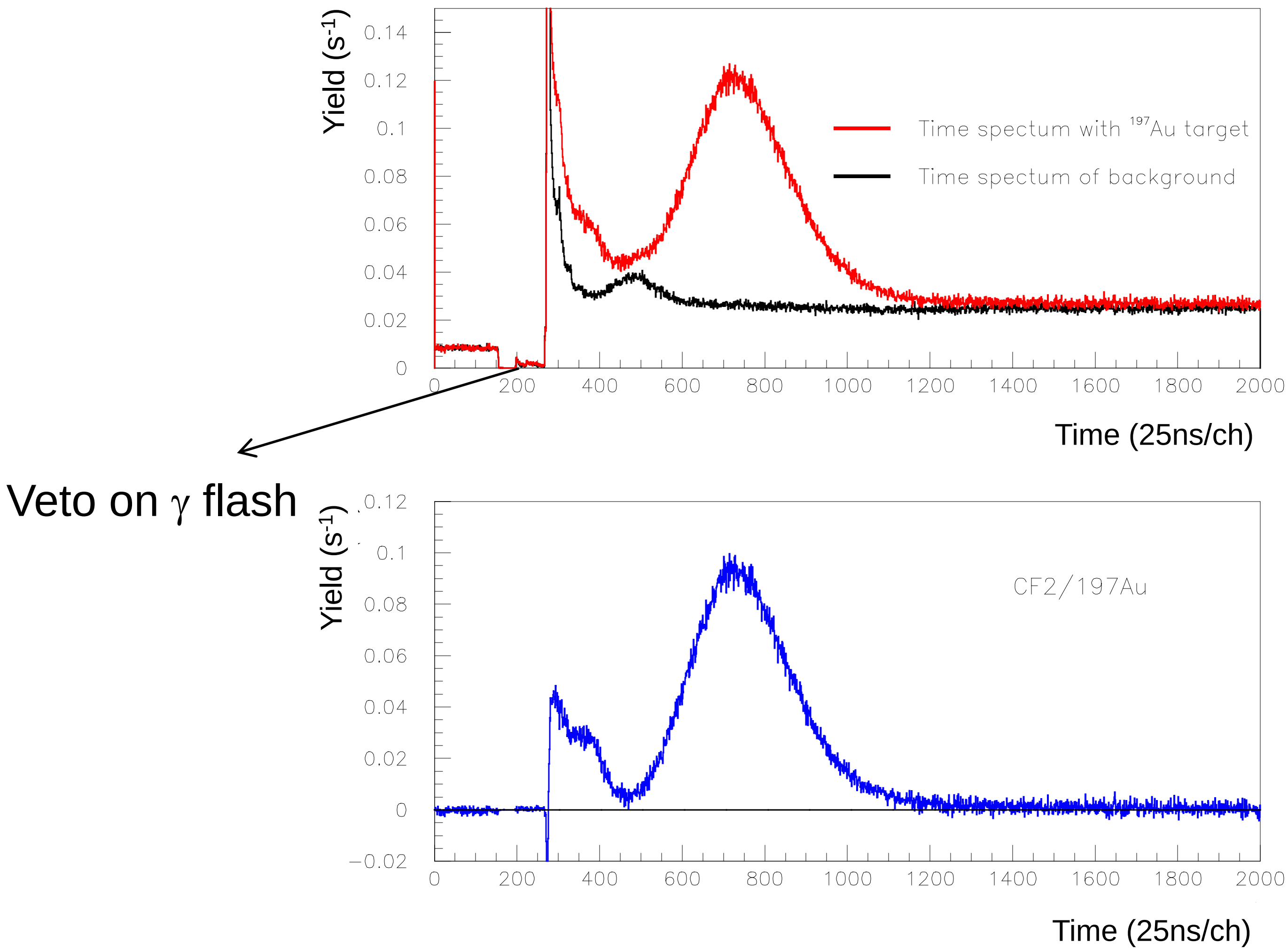
- slowing down time measurement of Teflon $(CF_2)_n$

Integral cross section Measurement of $^{19}F(n,el)$

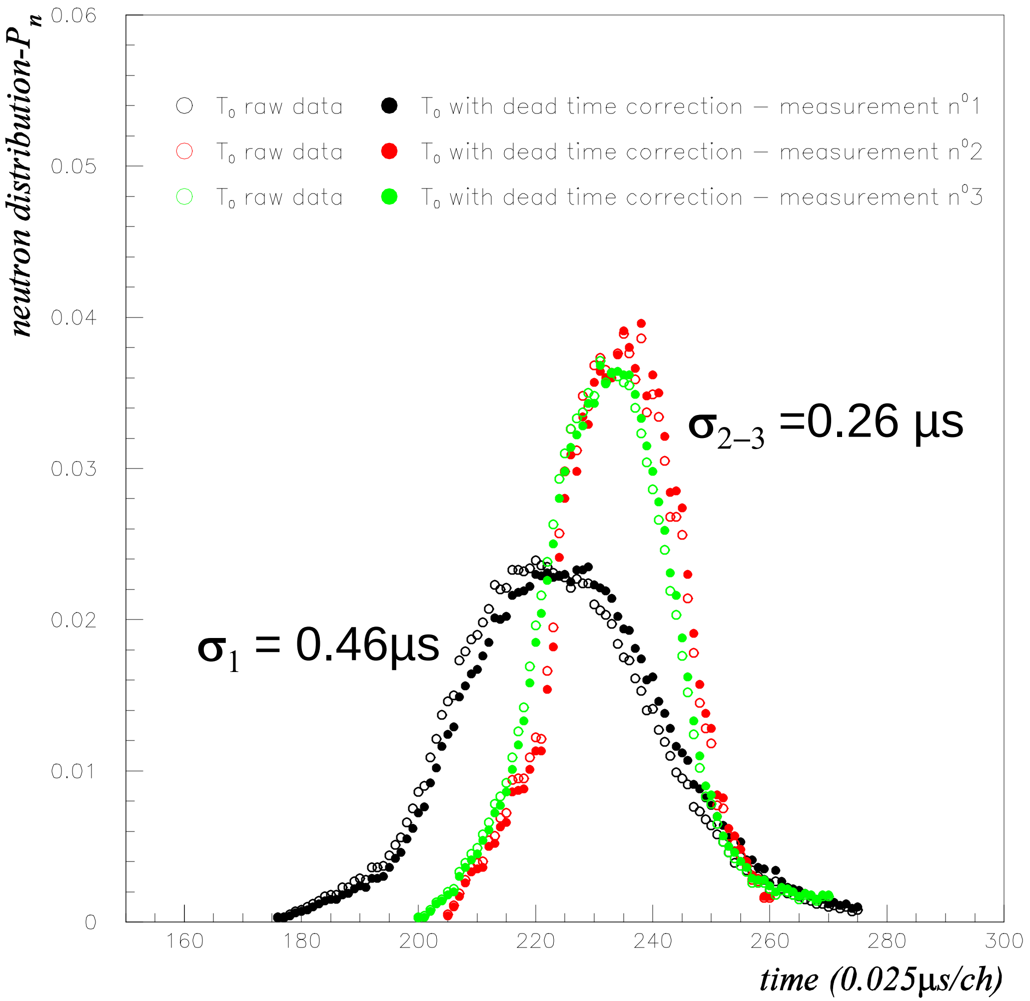
$$T_r = f(\,^{nat}C(n,el)\ ;\ \rho_C\ ;\ ^{19}F(n,el)\ ;\ m_{Teflon}\ ;\ V_{Teflon})$$



Data analysis : slowing down time measurement



Data analysis : γ flash



γ flash gives : - the reference time

- the time resolution of neutron pulse

Data analysis : 1) Integral cross section measurement of ^{nat}C (n,el)

We measure the resonant time : $\mathbf{T_r = f(\sigma(^{nat}C(n,el)) ; \rho_C)}$

And we search $\mathbf{\sigma(^{nat}C(n,el)) = g(T_r ; \rho_C)}$ and the uncertainty on this measurement

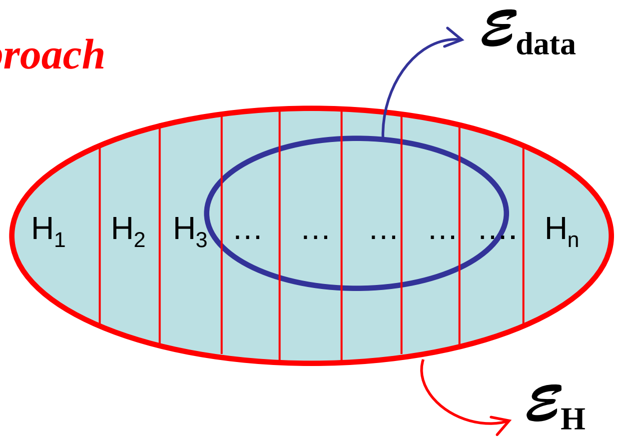
For the low probability events, one method useful is the ***Bayesian approach***

$$\mathbf{P(data \mid H) . P(H) = P(H \mid data) . P(data)}$$

$$\mathbf{P(H_i \mid data) = \frac{P(data \mid H_i) . P(H_i)}{P(data)}}$$

prior

Posterior



If $\mathcal{E}_{data}$ C $\mathcal{E}_H$ then $\mathbf{P(data) = \sum_i P(data \mid H_i) . P(H_i) = \int_{\mathcal{E}_H} P(data \mid H) . P(H)\ dH}$

Then, the probability of "data given H_i" is determined by the likelihood function :

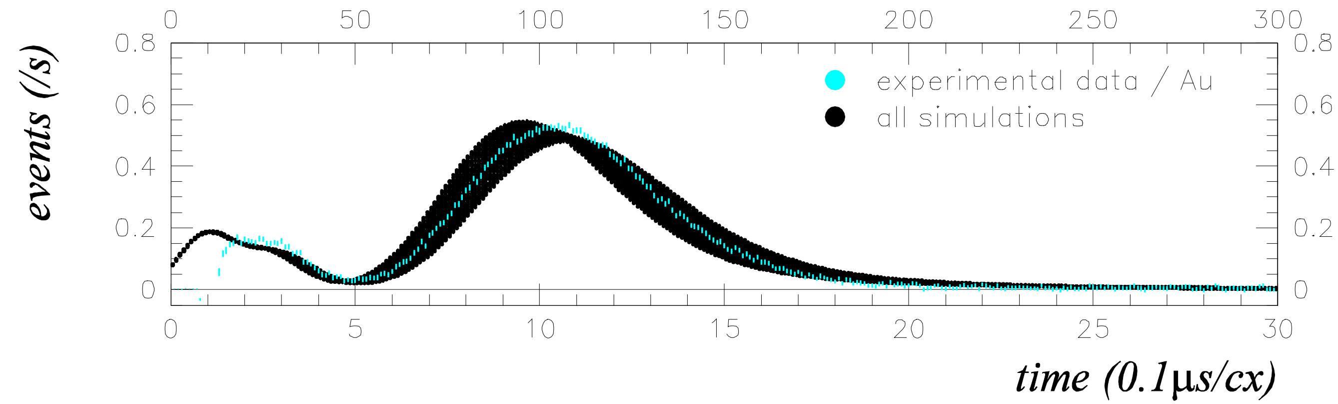
$$\mathbf{P(data \mid H_i)} \propto \mathcal{L}\mathbf{(H_i ; data)} \propto \mathbf{exp(-\frac{\chi^2}{2})}$$ if the uncertainties follow a Gaussian distribution

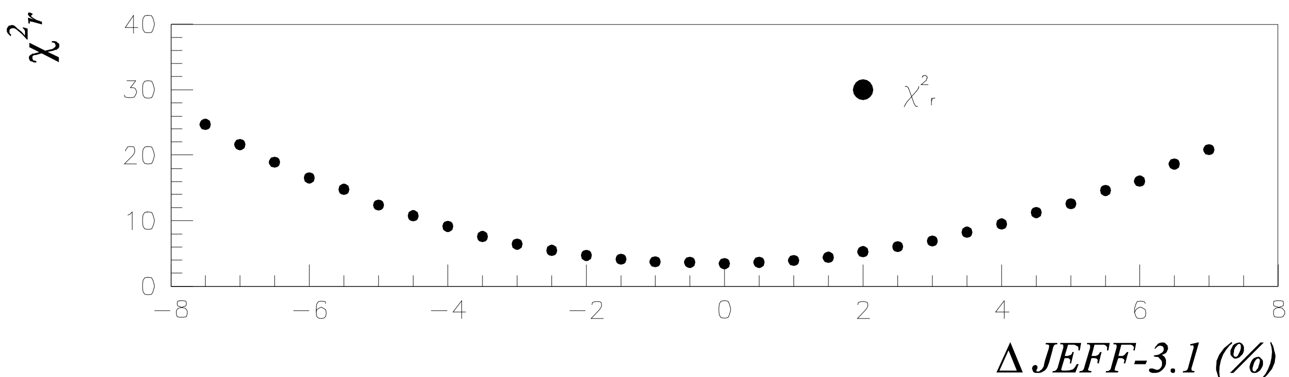
$$\chi^2 = \sum \frac{\left(N_{cal}(t) - N_{exp}(t) \right)^2}{\sigma^2(N_{cal}) + \sigma^2(N_{exp})}$$

and $\mathbf{(Tr)_{cal}}$ **= MCNP Calculation** $\mathbf{(H_i)}$

Statistical uncertainties $\sigma(N_{cal})$

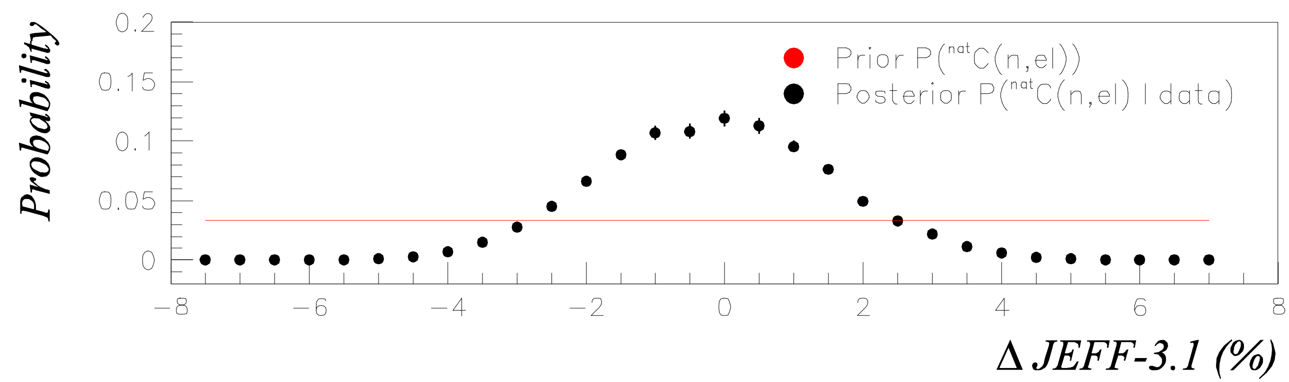
Data analysis : 1) Integral cross section measurement of ^{nat}C (n,el)





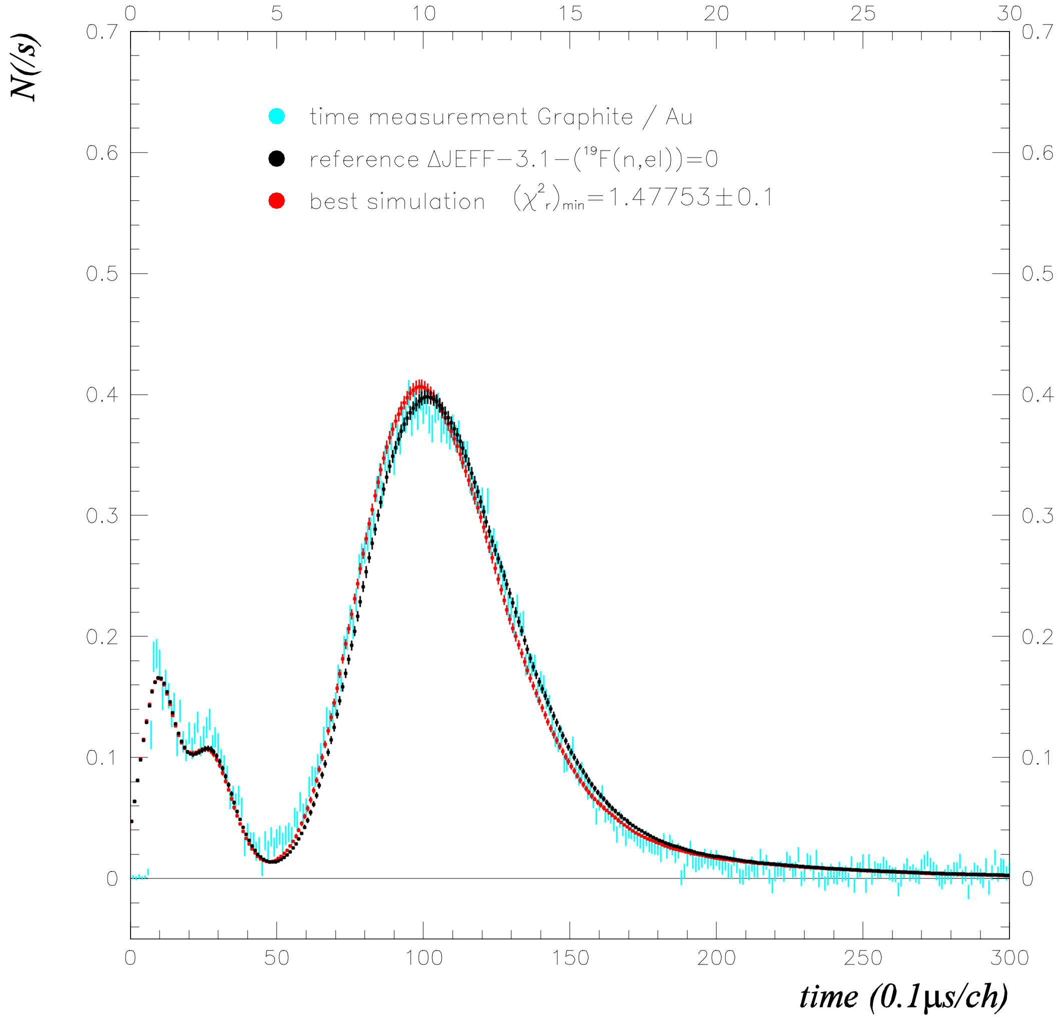
Each point correspond to a MCNP calculation which needs 24h on 20 CPU

$P(\Delta C \mid data) \propto \mathcal{L}(data\,;\Delta C)\ .\ Prior(\Delta C)$



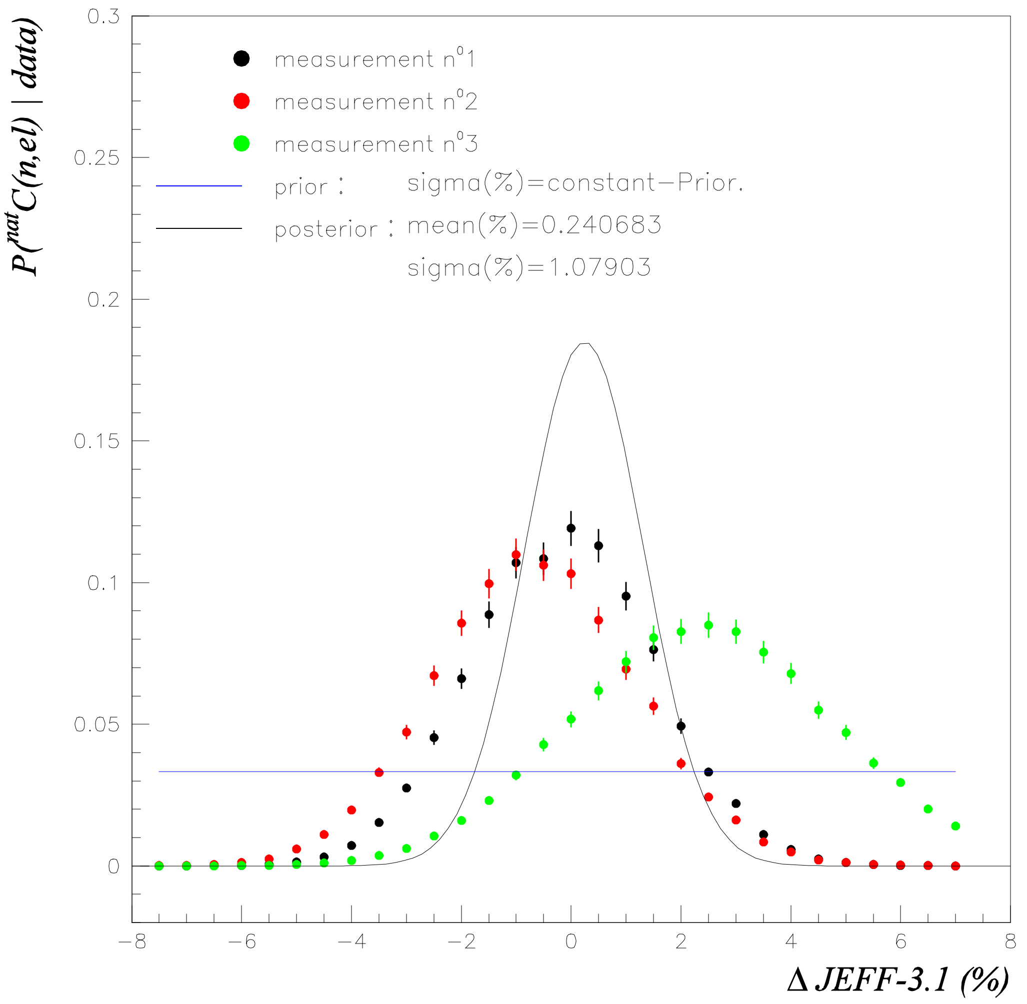
Data analysis : 1) Integral cross section measurement of ^{nat}C (n,el)

Comparison between experimental measurement and MCNP calculations



1) Integral cross section measurement of ^{nat}C (n,el)

Prior Δ(JEFF-3.1) = constant
→ integral measurement with slowing down Graphite spectrometer of **σ**(^{nat}C(n,el))
without « a priori » : Prior = constant
→ experimental resolution of spectrometer : systematic error s_c=1.7%



m_1 = -0.13%
σ_{m1} = 1.66%

m2 = -0.65%
σ_{m2} = 1.82%

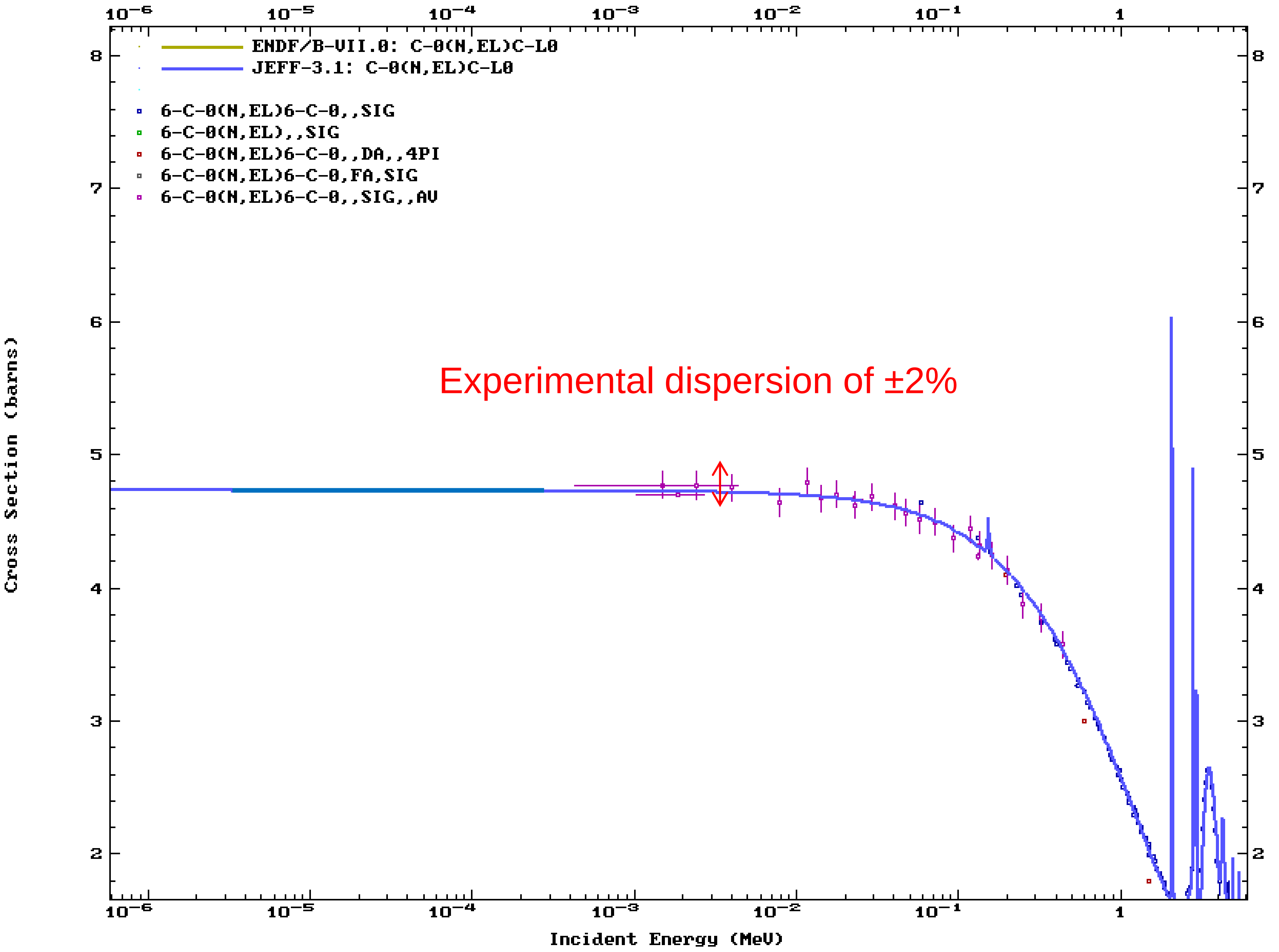
m_3 = 2.28%
σ_{m3} = 2.25%

****

<mean> = 0.24%
$\sigma_{<mean>}$ = 1.08%

****

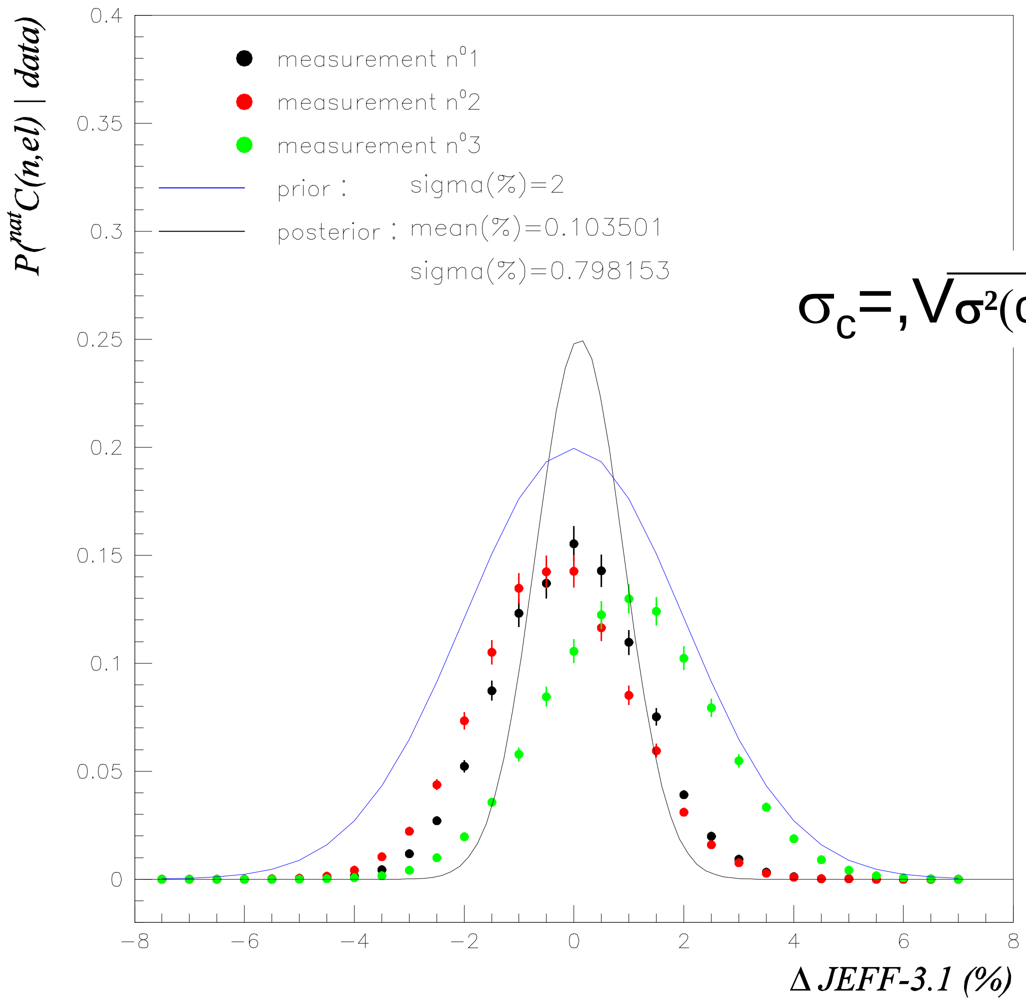
1) Integral cross section measurement of ^{nat}C (n,el)



1) Integral cross section measurement of ^{nat}C (n,el)

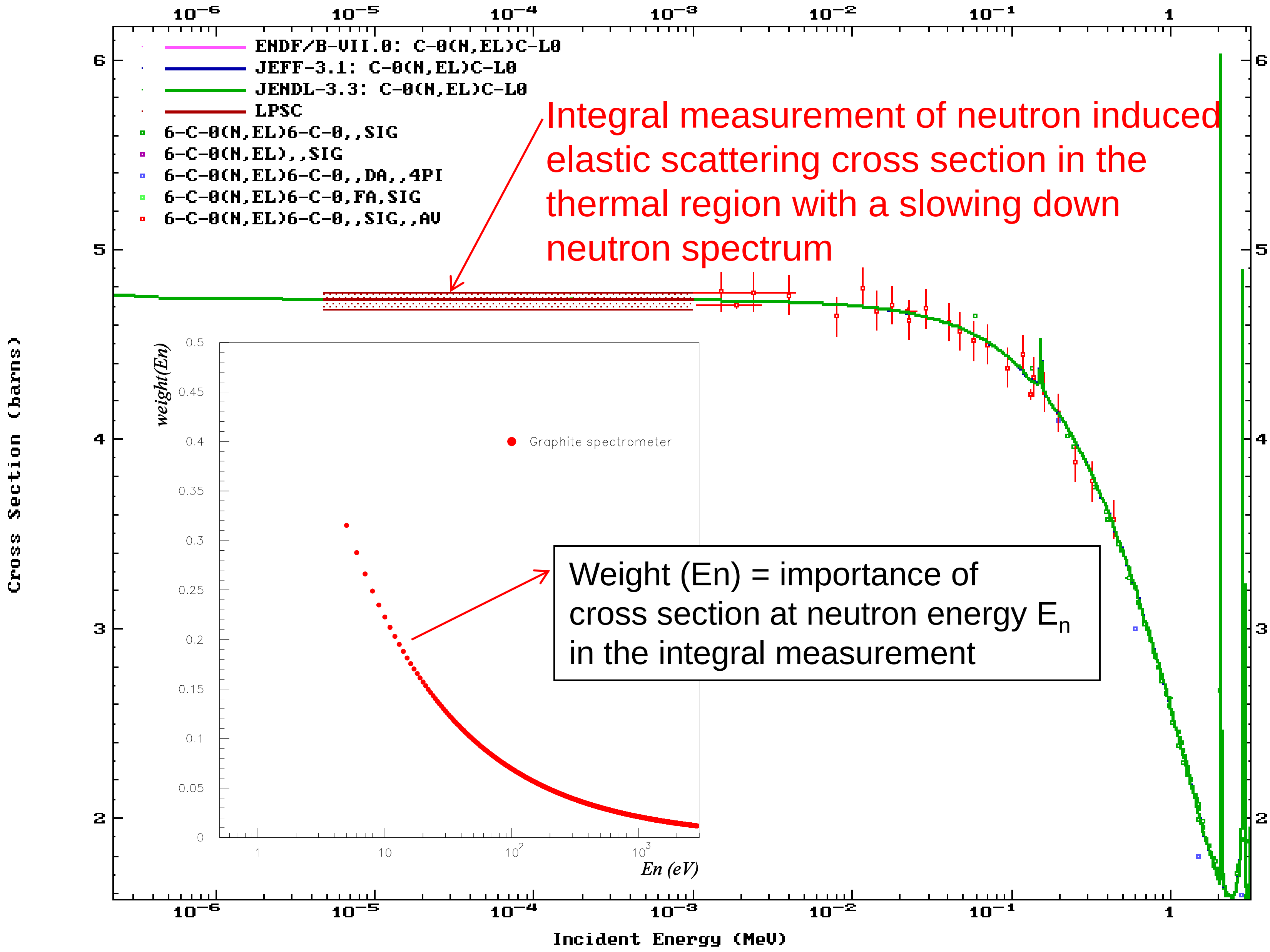
Prior ΔJEFF-3.1 = G(m=0; **σ** = 2%)

→ integral measurement with slowing down spectrometer of **σ**(^{nat}C(n,el)) using the knowledge of existing data



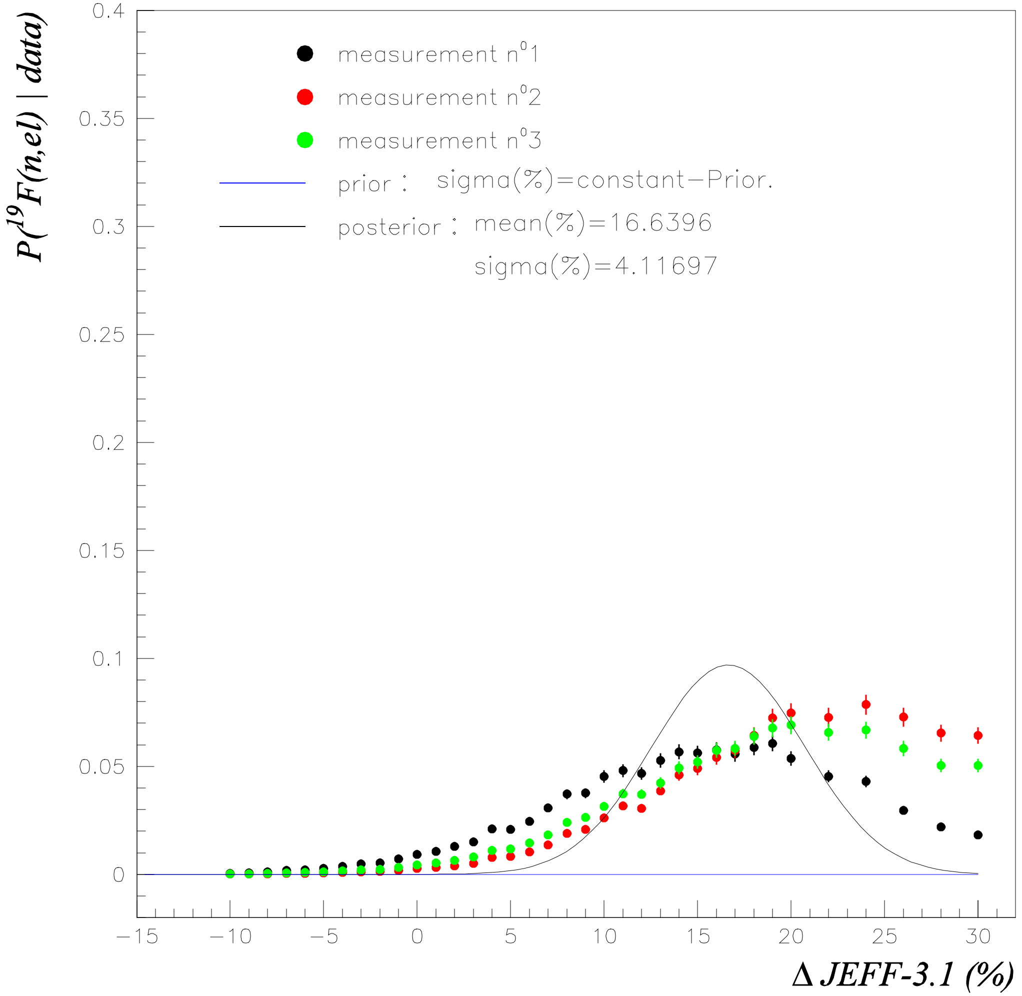
$$\sigma_c = \sqrt{\sigma^2(c(n,el)) + \sigma^2(\rho)} = 1\%$$

1) Integral cross section measurement of ^{nat}C (n,el)

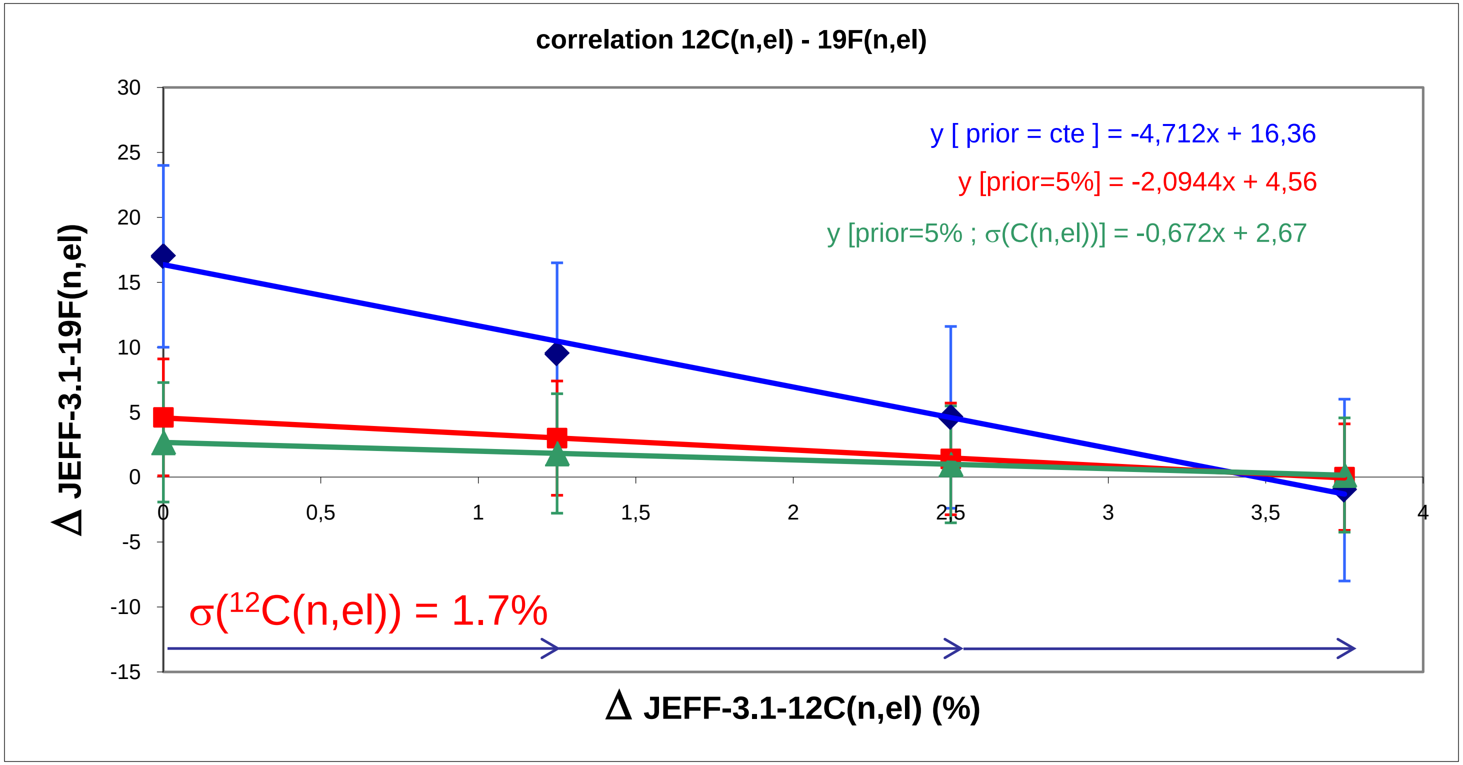


2) Integral cross section measurement of ^{19}F (n,el)

Prior ΔJEFF-3.1 sigma = constant



Correlation between $^{nat}C(n,el)$ and $^{19}F(n,el)$ (for only one measurement)

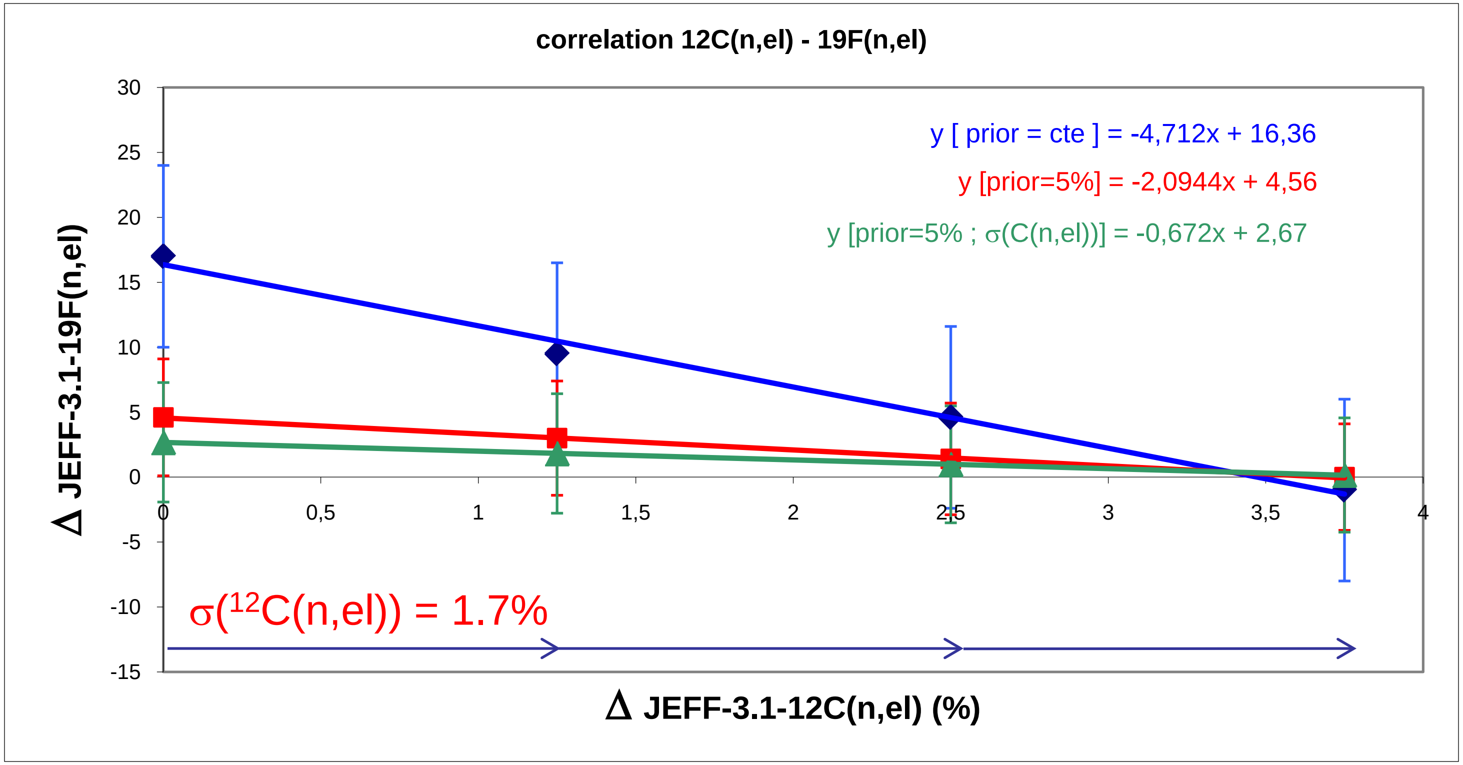


systematic dispersion on graphite explain the deviation of $^{19}F(n,el)$ measurement

$P(^{19}F(n,el)|\ data;\ C(n,el))$

Nuisance parameter

Correlation between $^{nat}C(n,el)$ and $^{19}F(n,el)$ (for only one measurement)



systematic dispersion on graphite explain the deviation of $^{19}F(n,el)$ measurement

$P(^{19}F(n,el)|\ data;\ C(n,el))$ → Nuisance parameter

$$\chi^2 = \sum_t \frac{\left((\mathbf{N}_{cal}(\mathbf{t}) - \mathrm{N}_{exp}(\mathbf{t}) \right)^2}{\boldsymbol{\sigma}^2(\mathbf{N}_{cal}) + \boldsymbol{\sigma}^2(\mathrm{N}_{exp}) + \left(\frac{\partial \mathrm{N}_{cal}(t)}{\partial t}\right)^2 . \boldsymbol{\sigma}^2(<Tr>)}$$

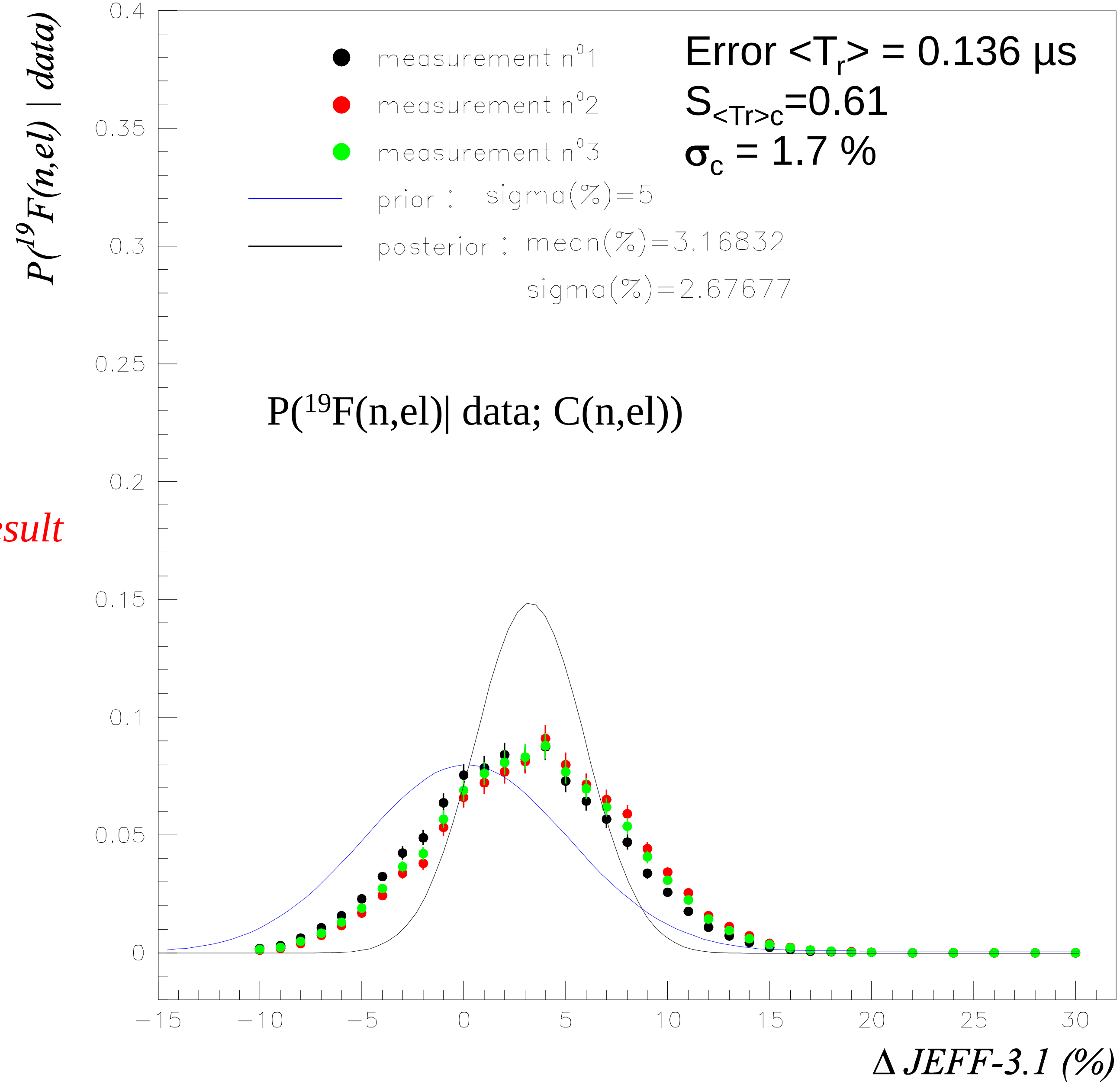
Statistical errors — systematic error on mean time

with $\frac{\boldsymbol{\sigma}(<T_r>)}{<T_r>} = \mathbf{S}_{<Tr>C} \cdot \boldsymbol{\sigma}_c\ (\%)$

Systematic error

2) Integral cross section measurement of ^{19}F (n,el)

Preliminary result

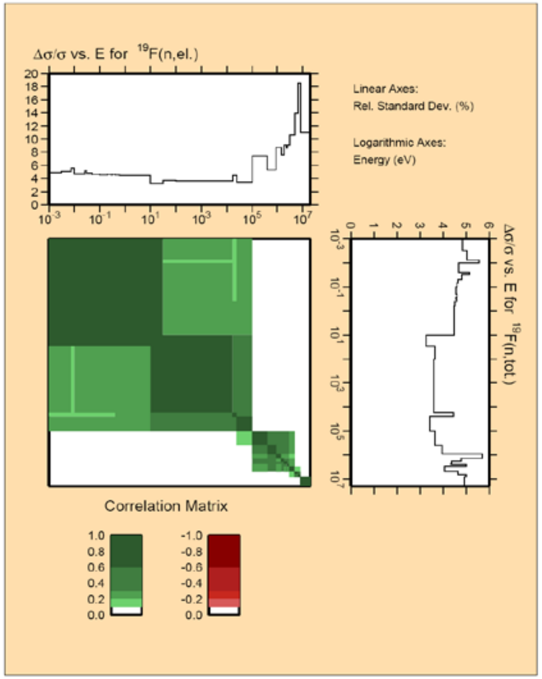


2) Integral cross section measurement of ^{19}F (n,el)

Mean value of ^{12}C(n,el) elastic scattering Plateau ΔJEFF-3.1 = 0.1 (1) %

^{19}F(n,el) elastic scattering Plateau ΔJEFF-3.1 = 3.1 (2.7) % / **σ**Jeff-3.1 = ~ 4%

$$\frac{\partial\, ^{19}\mathrm{F(n,el)}}{\partial\, ^{nat}\mathrm{C(n,el)}} = \rho_{C;F}\,\frac{\boldsymbol{\sigma}_F}{\boldsymbol{\sigma}_C}$$



Correlation matrix of mean measurements on C and F

ρ	^{nat}C(n,el)	^{19}F(n,el)	^{7}Li(n,el)
^{nat}C(n,el)	1	-0.25	?
^{19}F(n,el)	-0.25	1	?
^{7}Li(n,el)	?	?	1

Preliminary results

Perspective 3) absolute Integral cross section measurement of ^{7}Li (n,el)

$$P(^{7}Li(n,el)|\ data;\ C(n,el)\ ;\ ^{19}F(n,el);\ ;\ \rho_{C}\ ;\ m_{LiF};\ V_{LiF}) = ?$$

Nuisance parameterS

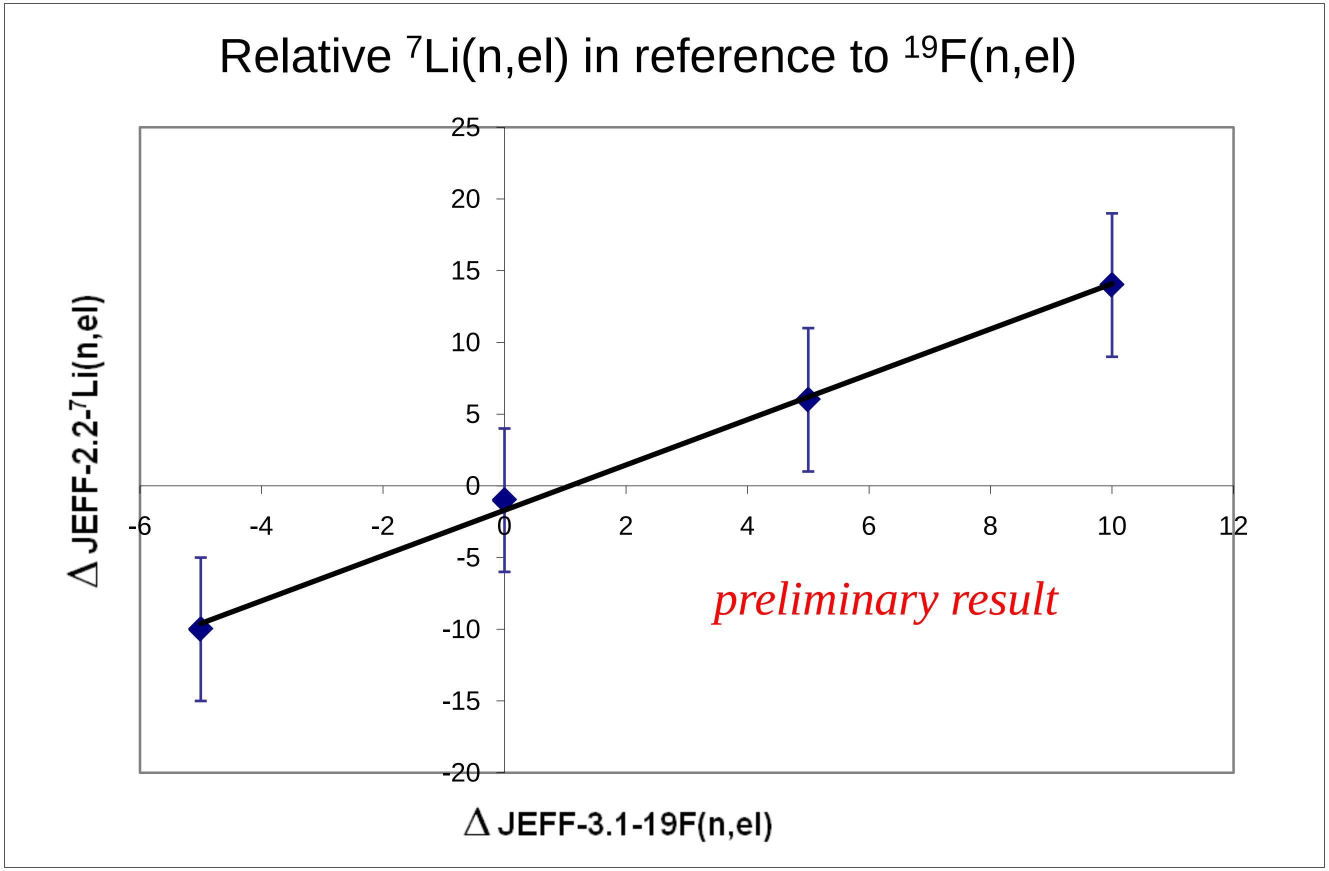
$\rho_{7Li;\ F}$ = ? Because many cracks on LiF cristal

Perspective 3) absolute Integral cross section measurement of ^{7}Li (n,el)

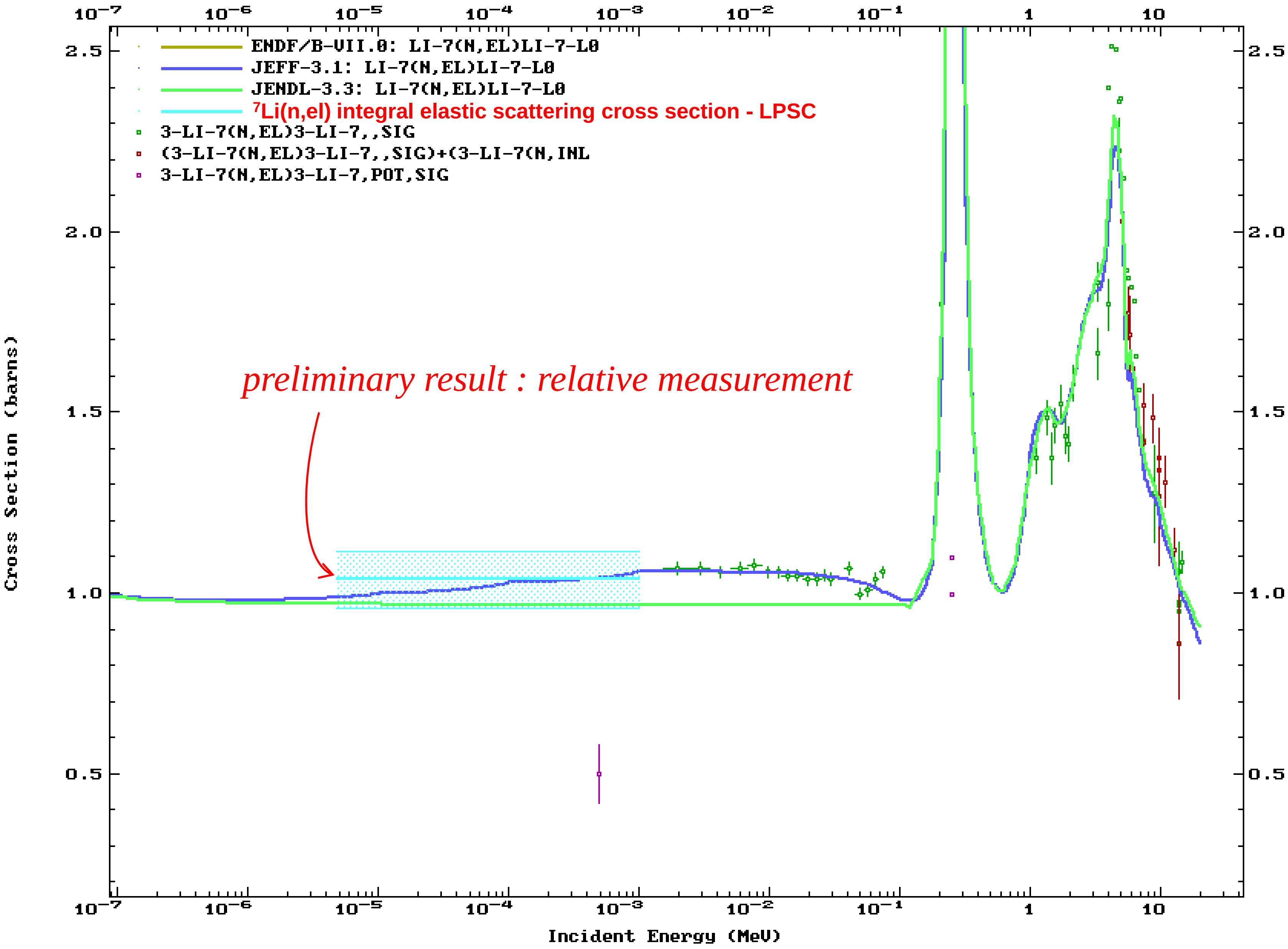
$P(^7Li(n,el)|\ data;\ C(n,el)\ ;\ ^{19}F(n,el);\ ;\ \rho_{C\ ;}\ m_{LiF};\ V_{LiF}) = ?$

Nuisance parameterS

$\rho_{7Li;\ F}$ = ? Because many cracks on LiF cristal

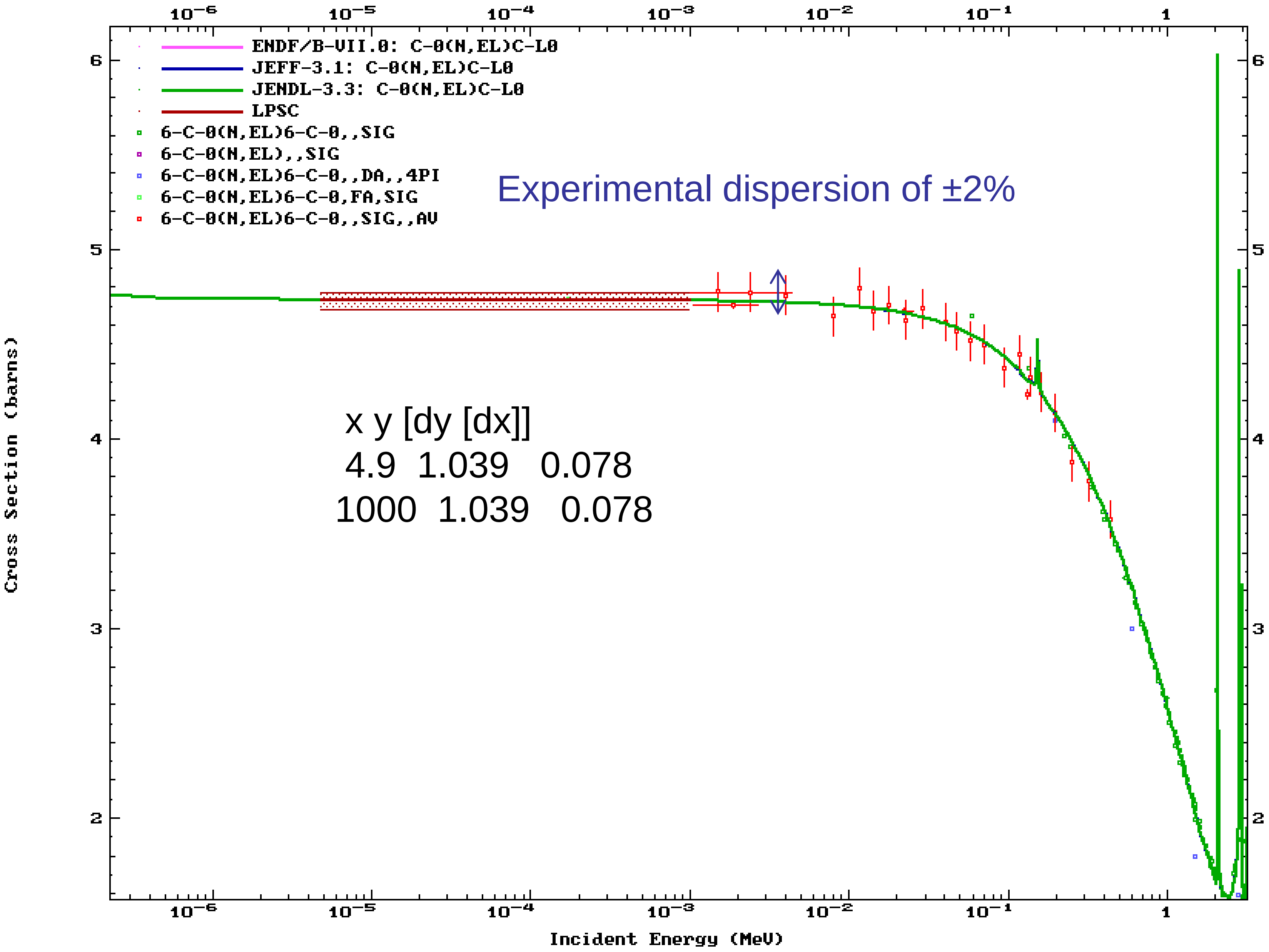


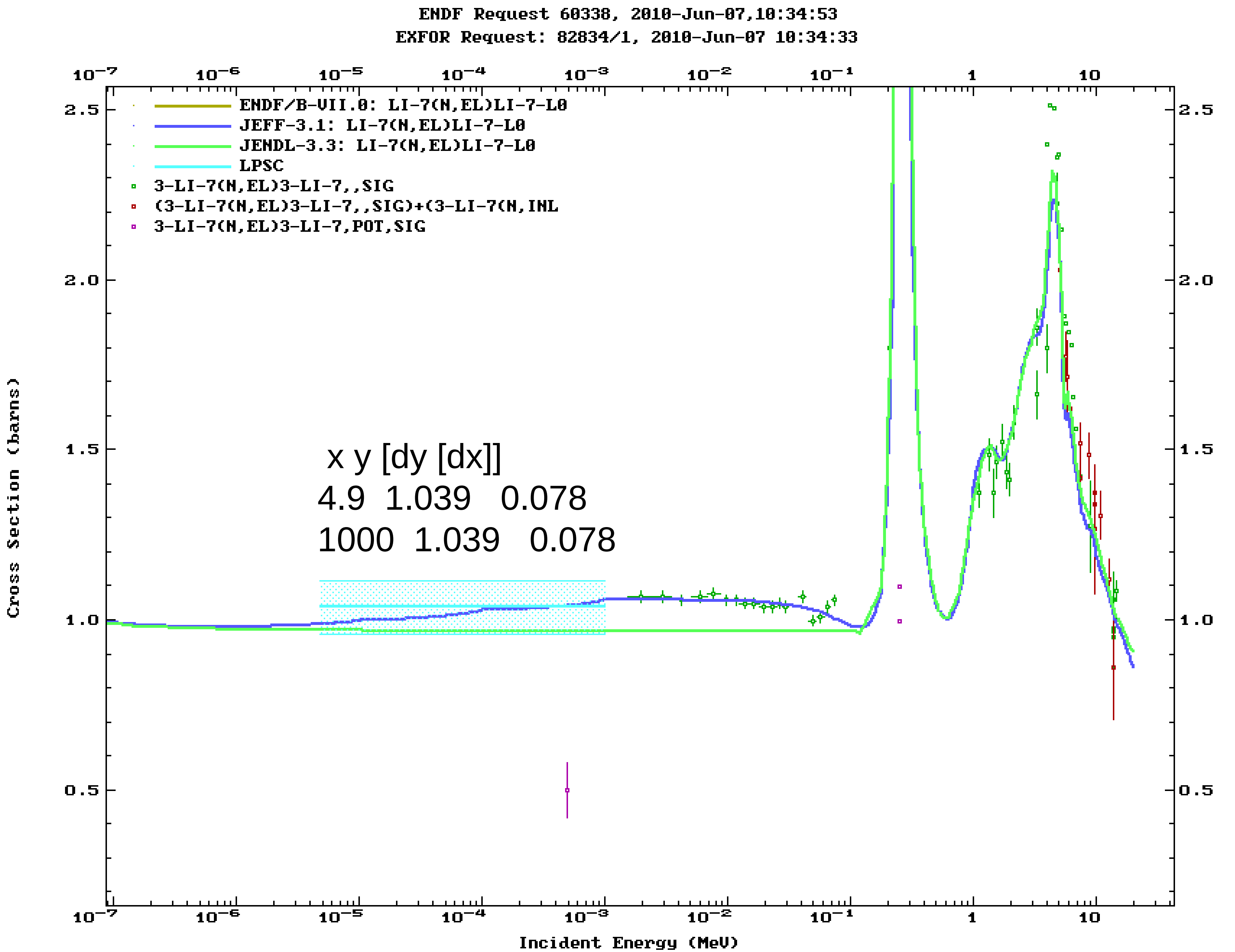
Perspective 3) absolute Integral cross section measurement of ^{7}Li (n,el)



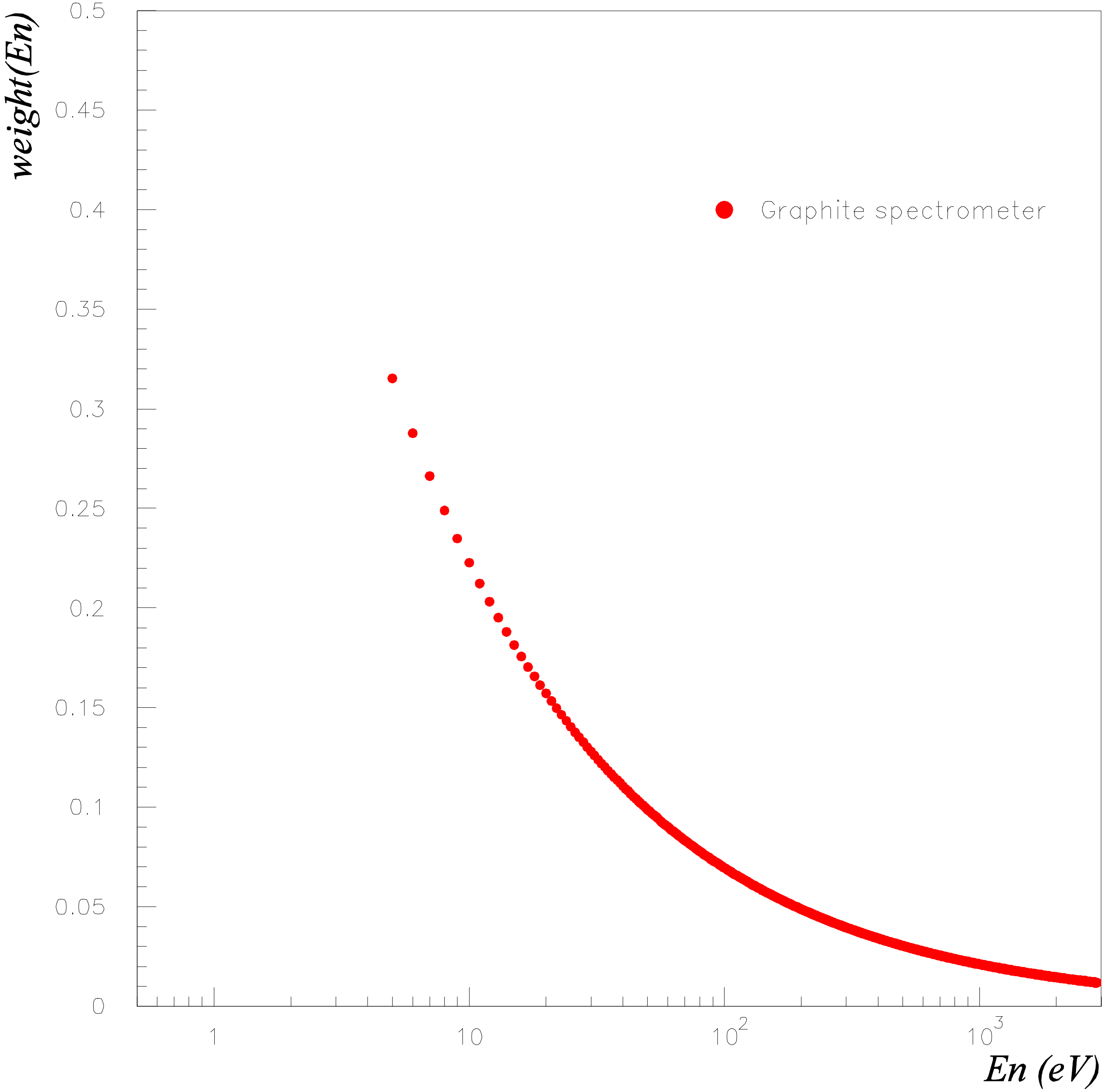
Backup

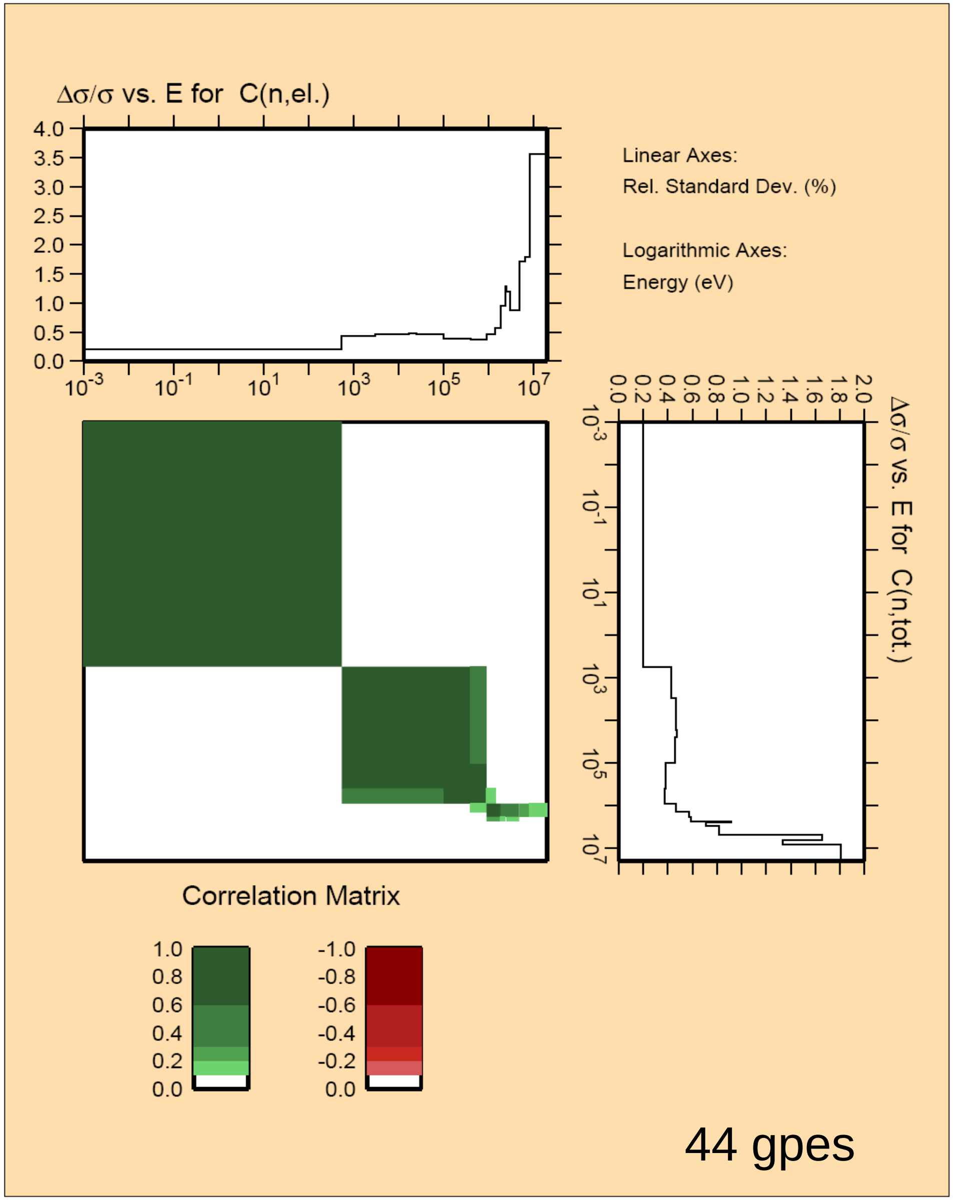
1) Integral cross section measurement of ^{nat}C (n,el)

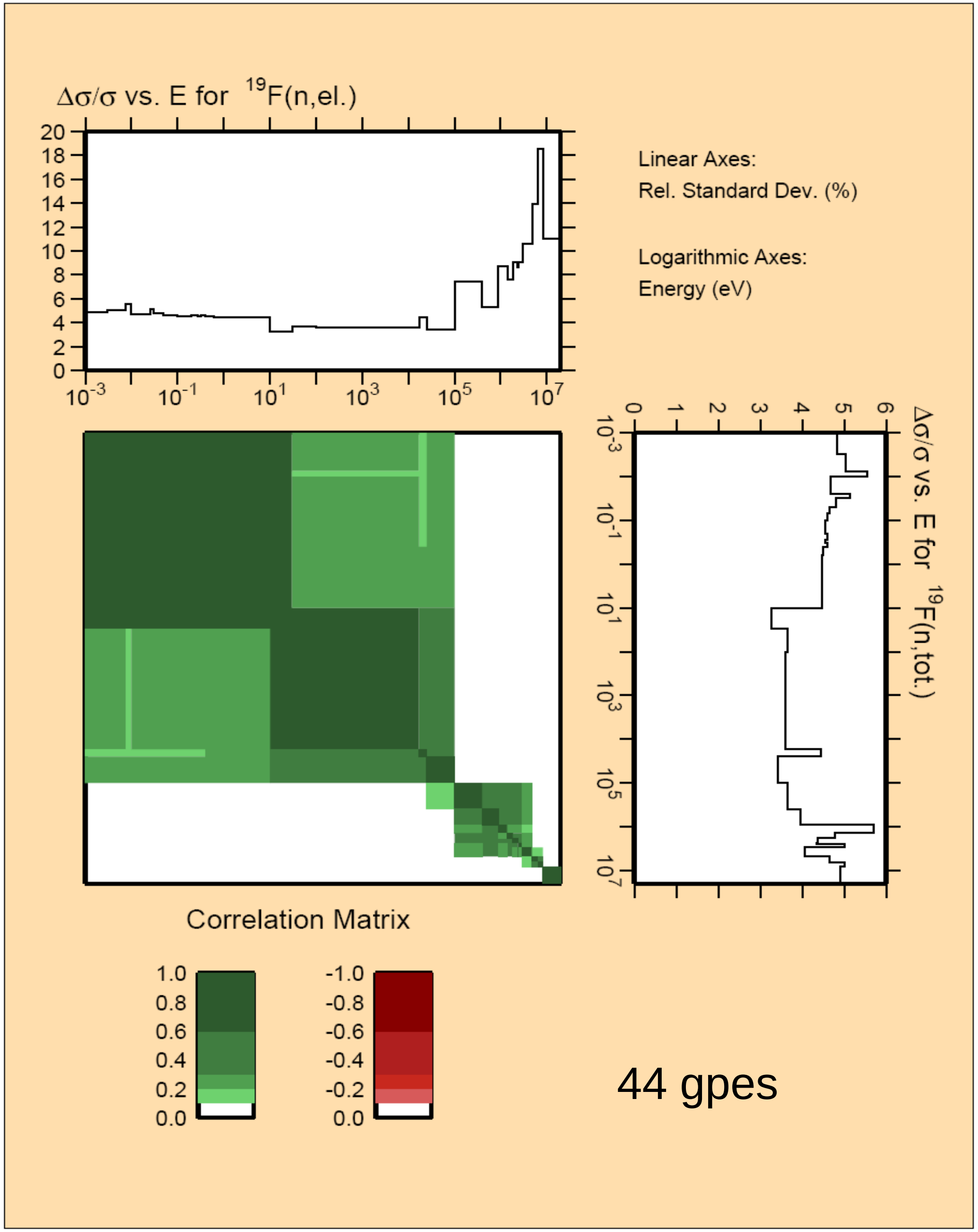


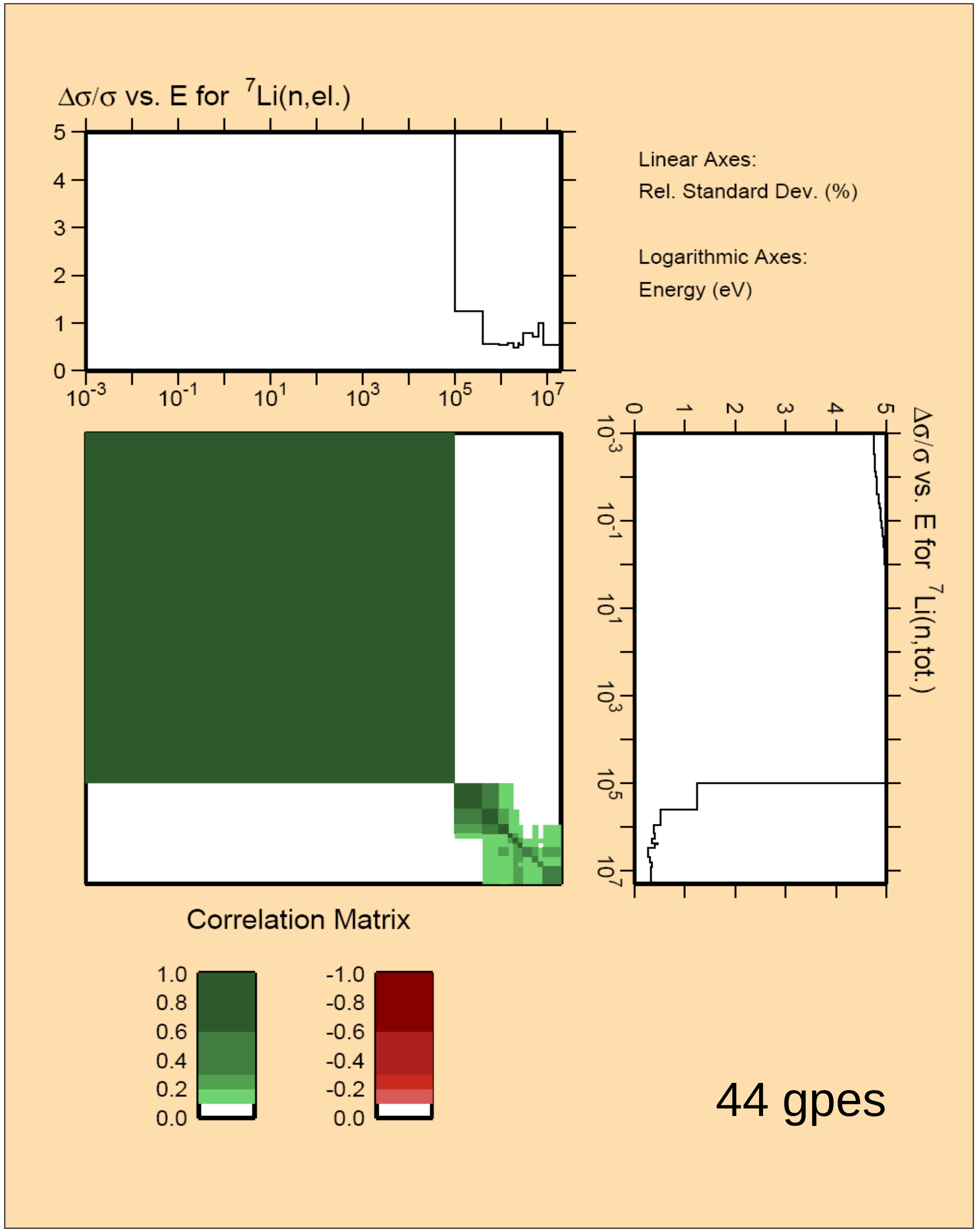


ENDF Request 60338, 2010-Jun-07,10:34:53
EXFOR Request: 82834/1, 2010-Jun-07 10:34:33
ENDF/B-VII.0: LI-7(N,EL)LI-7-L0
JEFF-3.1: LI-7(N,EL)LI-7-L0
JENDL-3.3: LI-7(N,EL)LI-7-L0
LPSC
3-LI-7(N,EL)3-LI-7,,SIG
(3-LI-7(N,EL)3-LI-7,,SIG)+(3-LI-7(N,INL
3-LI-7(N,EL)3-LI-7,POT,SIG
x y [dy [dx]]
4.9 1.039 0.078
1000 1.039 0.078
Cross Section (barns)
Incident Energy (MeV)

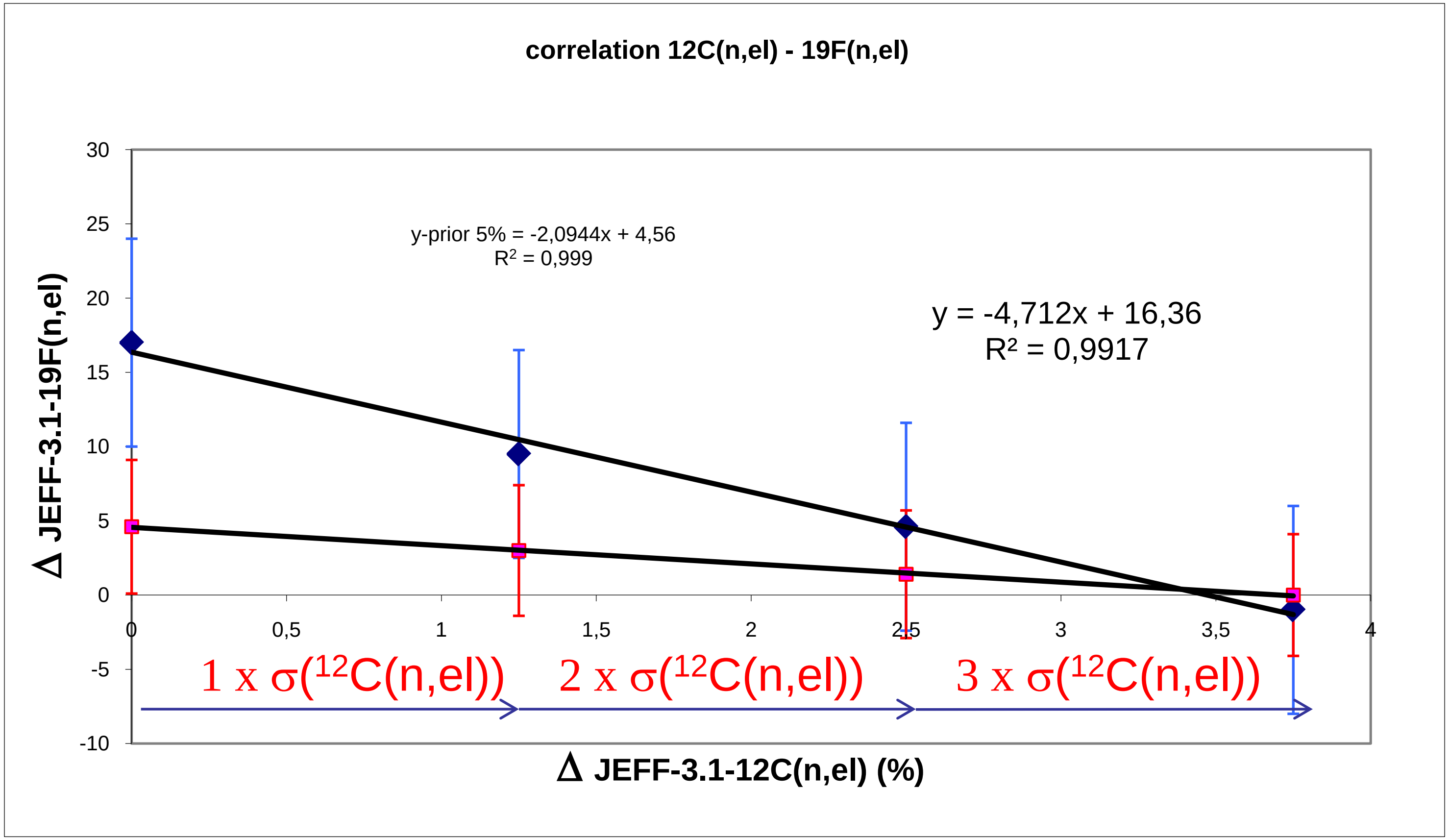

weight(En)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Graphite spectrometer
1
10
10^2
10^3
En (eV)


Δσ/σ vs. E for C(n,el.)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10-3
10-1
10 1
10 3
10 5
10 7
Linear Axes:
Rel. Standard Dev. (%)
Logarithmic Axes:
Energy (eV)
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0
Δσ/σ vs. E for C(n,tot.)
Correlation Matrix
1.0
0.8
0.6
0.4
0.2
0.0
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
44 gpes


Δσ/σ vs. E for 19F(n,el.)
Linear Axes:
Rel. Standard Dev. (%)
Logarithmic Axes:
Energy (eV)
Δσ/σ vs. E for 19F(n,tot.)
Correlation Matrix
1.0 0.8 0.6 0.4 0.2 0.0
-1.0 -0.8 -0.6 -0.4 -0.2 0.0
44 gpes



Δσ/σ vs. E for ⁷Li(n,el.)
Linear Axes:
Rel. Standard Dev. (%)
Logarithmic Axes:
Energy (eV)
Δσ/σ vs. E for ⁷Li(n,tot.)
Correlation Matrix
44 gpes



We have to introduce the resolution of graphite spectrometer to analyze the Fluor cross section

Interprétation géométrique : cas le plus simple