DE LA RECHERCHE À L'INDUSTRIE

EVALUATION OF NUCLEAR DATA AND THEIR UNCERTAINTIES

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OUTLINES

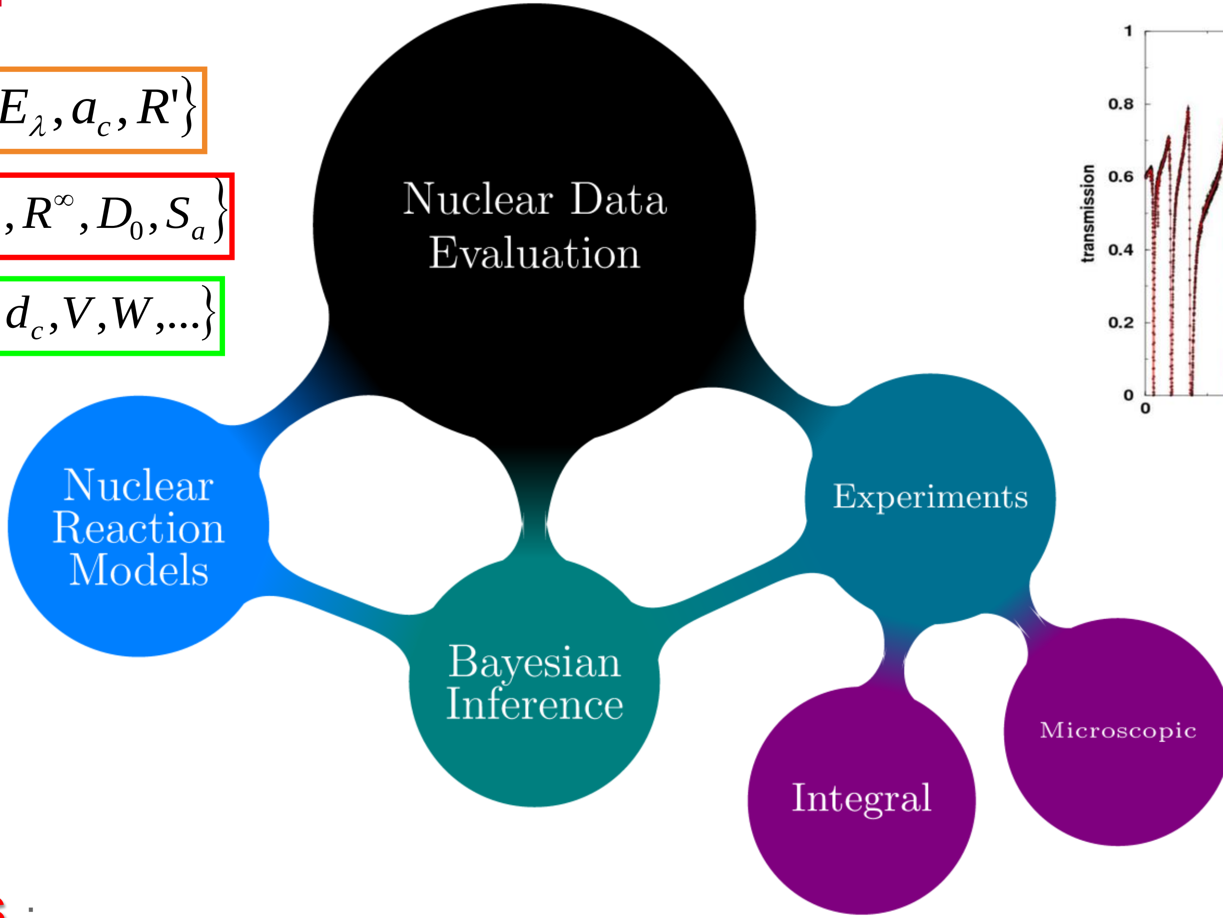
1. Reminders, context and objectives
2. Bayesian inference (Generalize least square and Monte-Carlo)
3. Summary of recent CEA-Cadarache activities A few examples:
4. Conclusions and Perspectives

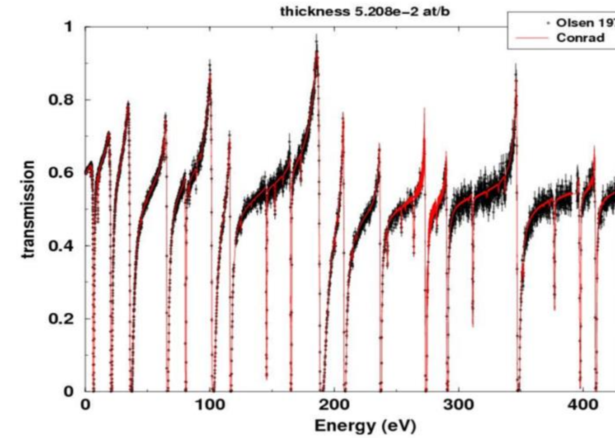
CROSS SECTIONS "KNOWLEDGE"
EVALUATION IN THE RESONANCE RANGE AND HIGHER

$$\vec{x} = \{\gamma_{a\lambda}, E_\lambda, a_c, R'\}$$

$$\vec{x} = \{\langle\Gamma_a\rangle, a_c, R^\infty, D_0, S_a\}$$

$$\vec{x} = \{\beta_2, a_c, d_c, V, W, \ldots\}$$

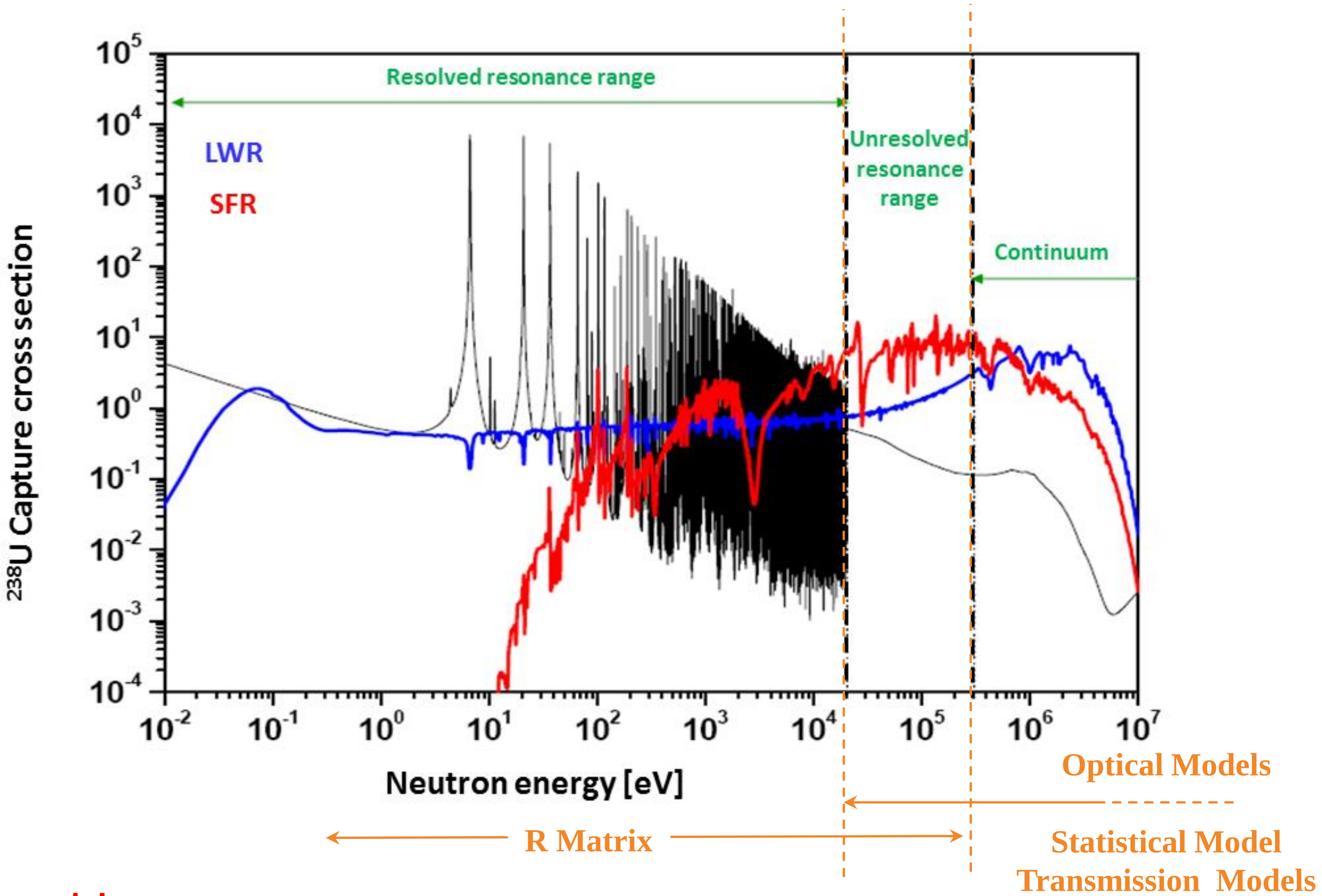




Issues :

- Systematic experimental uncertainties
- Phenomenological Nuclear reaction model theories + Parameters
- Model defects (Epistemic Uncertainties)
- Integral experiment assimilation
- Common Physics from RRR to Continuum

CROSS SECTIONS "KNOWLEDGE"
EVALUATION IN THE RESONANCE RANGE AND HIGHER



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Nuclear reaction models

Experiments (microscopic/integral)

Bayesian inference technique

Evaluation of uncertainties (variances and correlations)

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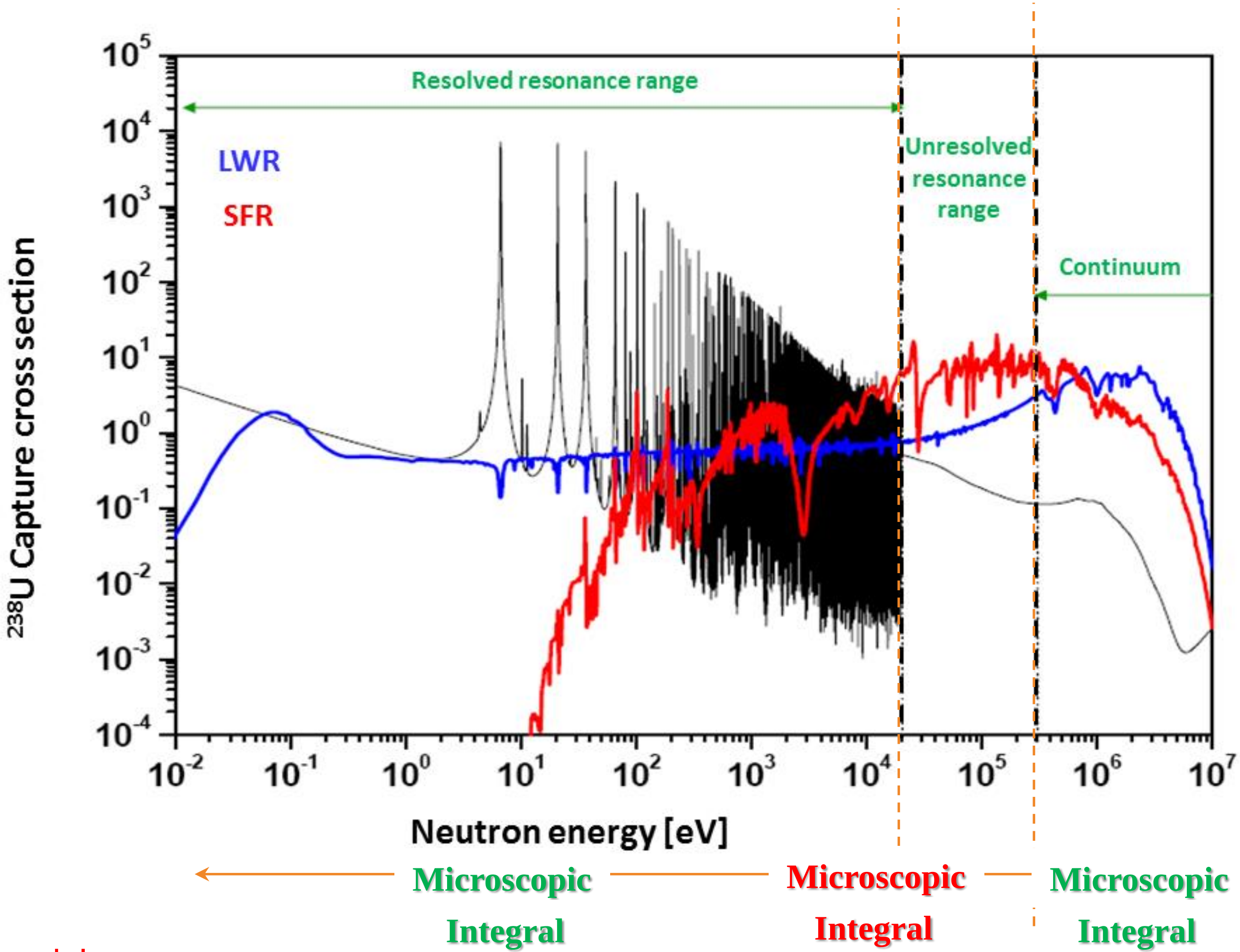

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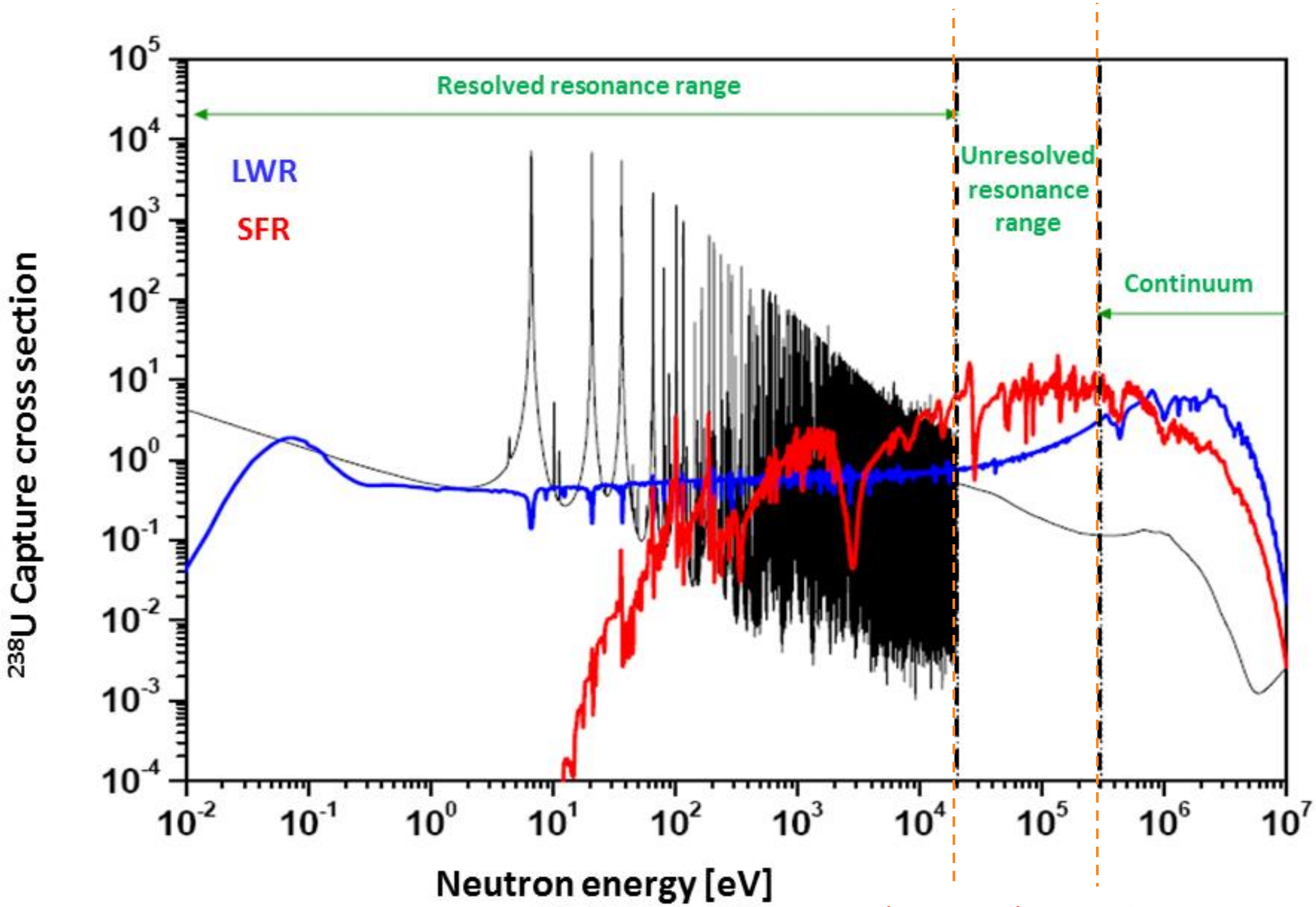

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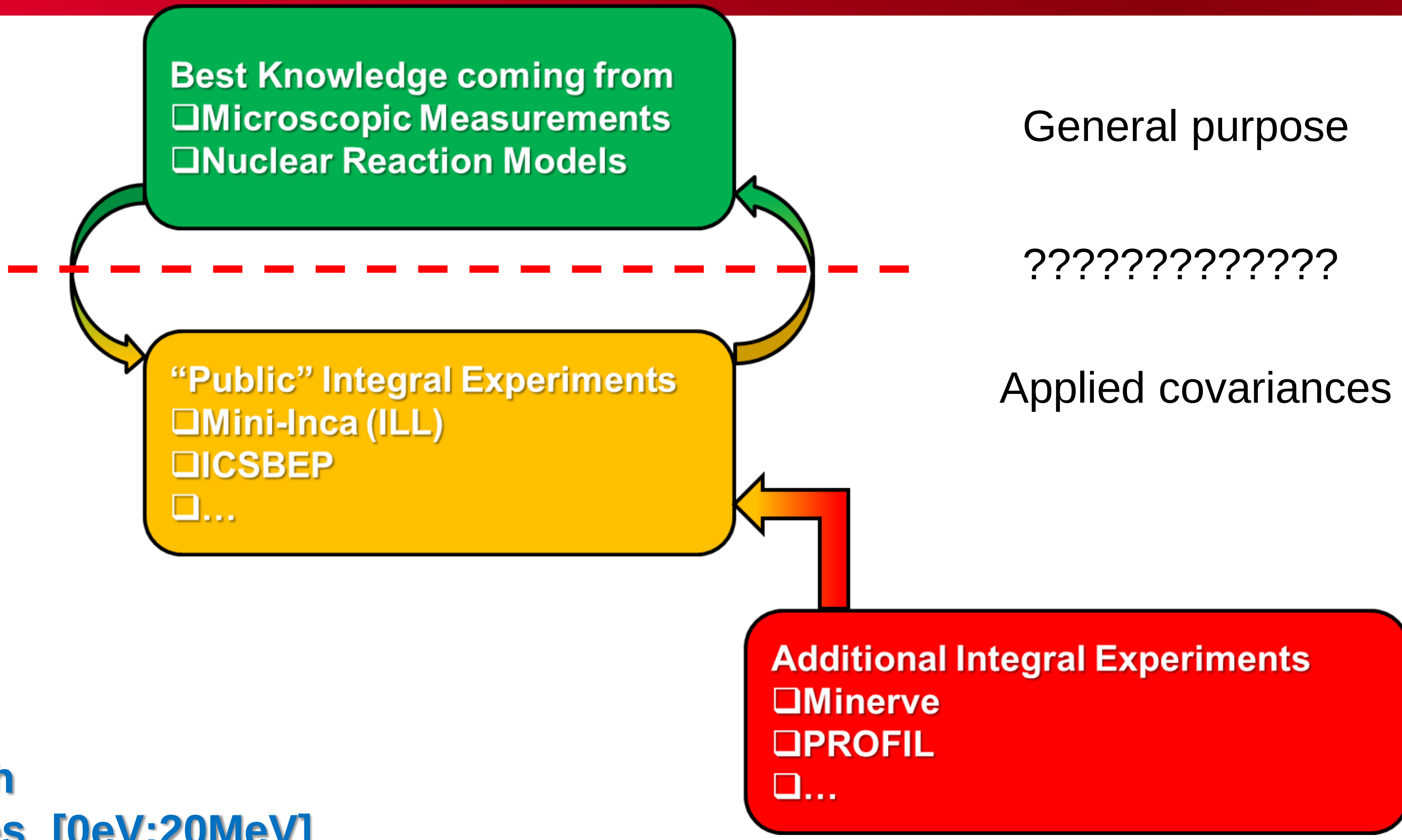
GLS — Microscopic — GLS UMC BMC

Microscopic Integral | Microscopic Integral | Integral Microscopic

Nuclear reaction models
Experiments (microscopic/integral)
Bayesian inference technique
Evaluation of uncertainties (variances and correlations)

COVARIANCE MATRICES METHODOLOGIES



Breakthrough

- Covariances [0eV;20MeV]
- Evaluation methodologies
- Understanding of discrepancies
- Covariance methodologies
- Reduction of Uncertainties

Bayesian inference (probability density):

Model

$$p(\vec{x}\,|\,M,\vec{y},U)=\frac{p(\vec{x}\,|\,M,U)\cdot p(\vec{y}\,|\,M,\vec{x},U)}{\int d\vec{x}\cdot p(\vec{x}\,|\,M,U)\cdot p(\vec{y}\,|\,M,\vec{x},U)}$$

Model parameters — New measurements — *a priori* information

Formulation:

$$posterior[p(\vec{x}|\vec{y},U)] \propto prior[p(\vec{x}|U)]\cdot likelihood[p(\vec{y}|\vec{x},U)]$$

Estimation of the first two moments

of the *a posteriori* distribution

GENERAL MATHEMATICAL FRAMEWORK

Bayesian inference (probability density):

Maximum Entropy Principle

Laplace approximation
(Sammy,Refit,Conrad, SOK…)

Monte-Carlo
(UMC*, Forward-Backward, BMC**…)

Estimation of a cost function
(Generalized Chi-square)

$$\chi^2_{GSL} = \left(\vec{x}-\vec{x}_m\right)^T M_x^{-1}\left(\vec{x}-\vec{x}_m\right) + \left(\vec{y}-\vec{t}(\vec{x})\right)^T M_y^{-1}\left(\vec{y}-\vec{t}(\vec{x})\right)$$

- Estimate 1st two moments of $p(\vec{x}|M,\vec{y},U)$ with Monte-Carlo
- Sample of $p(\vec{x}\,|\,M,U) \rightarrow \vec{x}_k$
- For each $\vec{x}_k$ → associate a weight

For ex. →Likelihood $\ell_k[p(\vec{y}|M,\vec{x}_k,U)]$

*R. Capote and D. Smith, Nucl. Data Sheets **109**, 2768 (**2008**)
C. De Saint Jean et al., ND2016, EPJ-Web to be puplished (2017**)

Summary of recent CEA –Cadarache activities

- Solutions proposed and tested for the proper treatment of Syst. Exp. Uncertainties
  - Various marginalization methods

B. Habert et al., Nuc. Sci. Eng., **166**, 276 (**2010**) + PhD Thesis
C. De Saint Jean et al., Nuc. Sci. Eng., **161**, 363 (**2009**).
G. Noguere et al., Nuclear Data Sheets, **118** (**2014**) 349-352
E. Privas PhD thesis
C. De Saint Jean et al., EPJ Web (ND2016) to be published

- Bayesian Monte-Carlo as reference for evaluation

→ cross validation purposes for Conrad code : all algorithms implemented

C. De Saint Jean et al., ND2016, EPJ-Web to be puplished (**2017**)

- Monte-Carlo in RRR/URR/Fast range:
  - Sampling prior is not a problem (LHS)→getting posterior **distributions** is the issue
- Full energy domain covariances

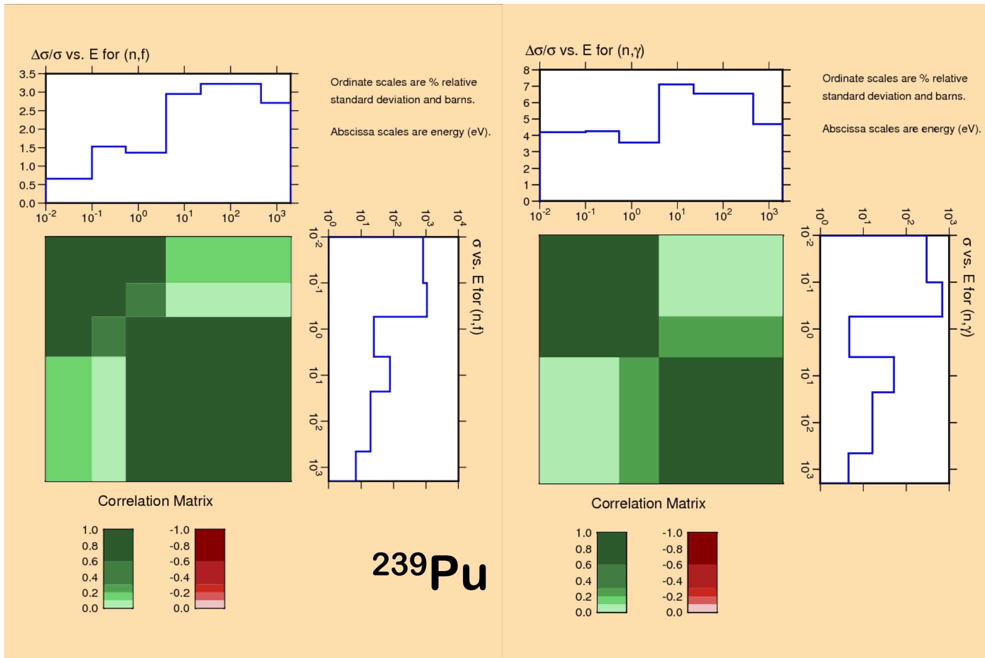
C. De Saint Jean, E. Privas et al., Nuclear Data Sheets, **118** (2014).
P. Archier et al, Nuc. Data Sheets, **115** (2014).

- Integral data assimilation :
  - GLS/BMC
  - Models parameters as well as multigroup cross sections

C. De Saint Jean et al, Nuclear Data Sheet **123** (**2015**), 178-184
E. Privas et al., ISRD15 proceedings EPJ-Web (**2016**)
C. De Saint Jean et al., ND2016, EPJ-Web to be puplished (**2017**)

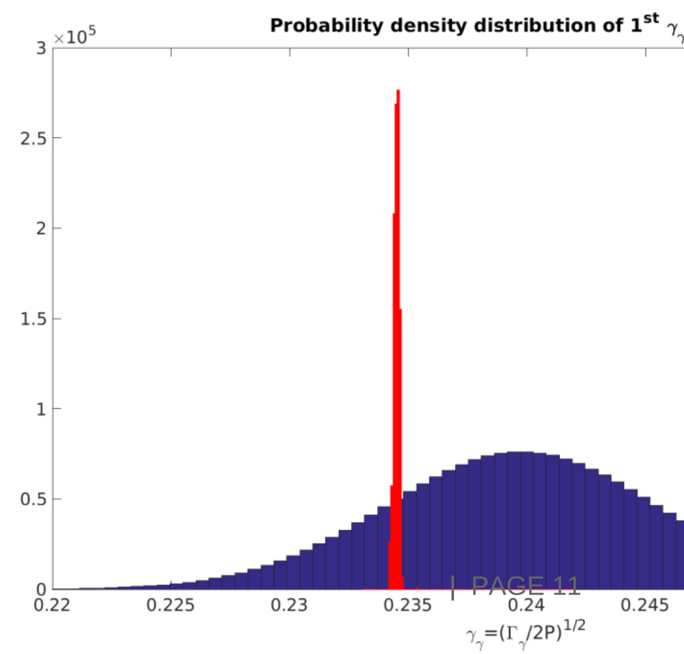
Various results (COMAC/JEFF/BMC)

- **Results of Marginalization fo Exp. Syst. uncertainties algorithm in Conrad**



- **Covariances in JEFF3.2 and JEFF3.3**
- **^{239,240}Pu, ^{235,238}U, ^{23}Na, ^{241}Am …etc**
- **CEA internal data base : COMAC**

- **BMC : Very Challenging example on ^{155}Gd* :**
  - **Bayesian Monte-Carlo inference ok**
  - **Equivalent to Generalize Least Square**
  - **But : time consuming / convergence issues**



JEFF33=JEFF3.2 EVALUATION IN RRR AND CONTINUUM → ^{23}NA

- **Full genuine evaluation for JEFF3.2**

New Microscopic experiment *

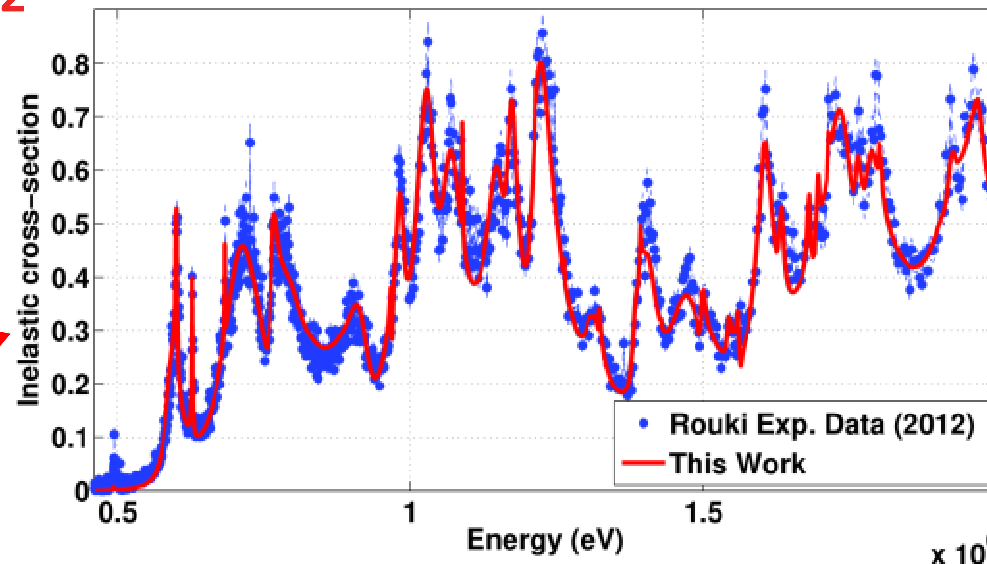
Rouki et al. new (n,n') at IRMM

New evaluation**

New RRR increased up to 2 MeV

Resonance analysis of (n,n')

New Optical Model calculations



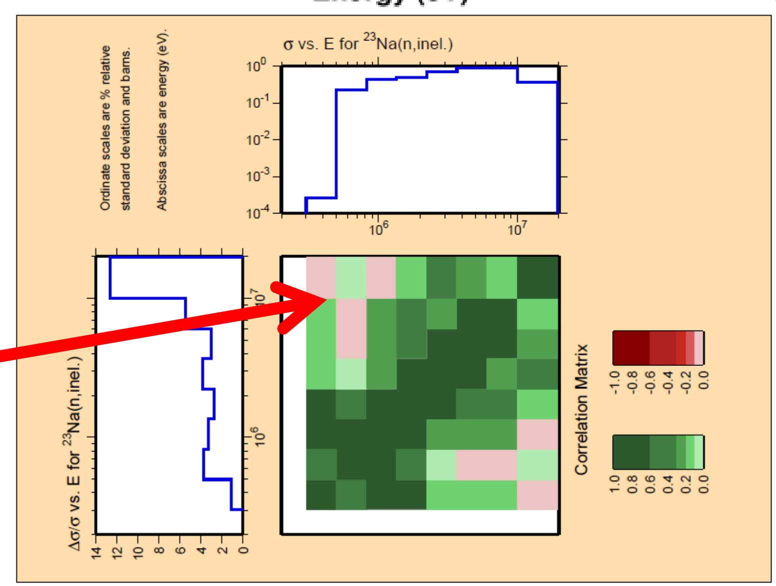
Full energy range covered for uncertainties

Syst. Exp. Uncertainties

(2.6 % normalisation Rouki)

RRR/Continum covered

with cross correlations

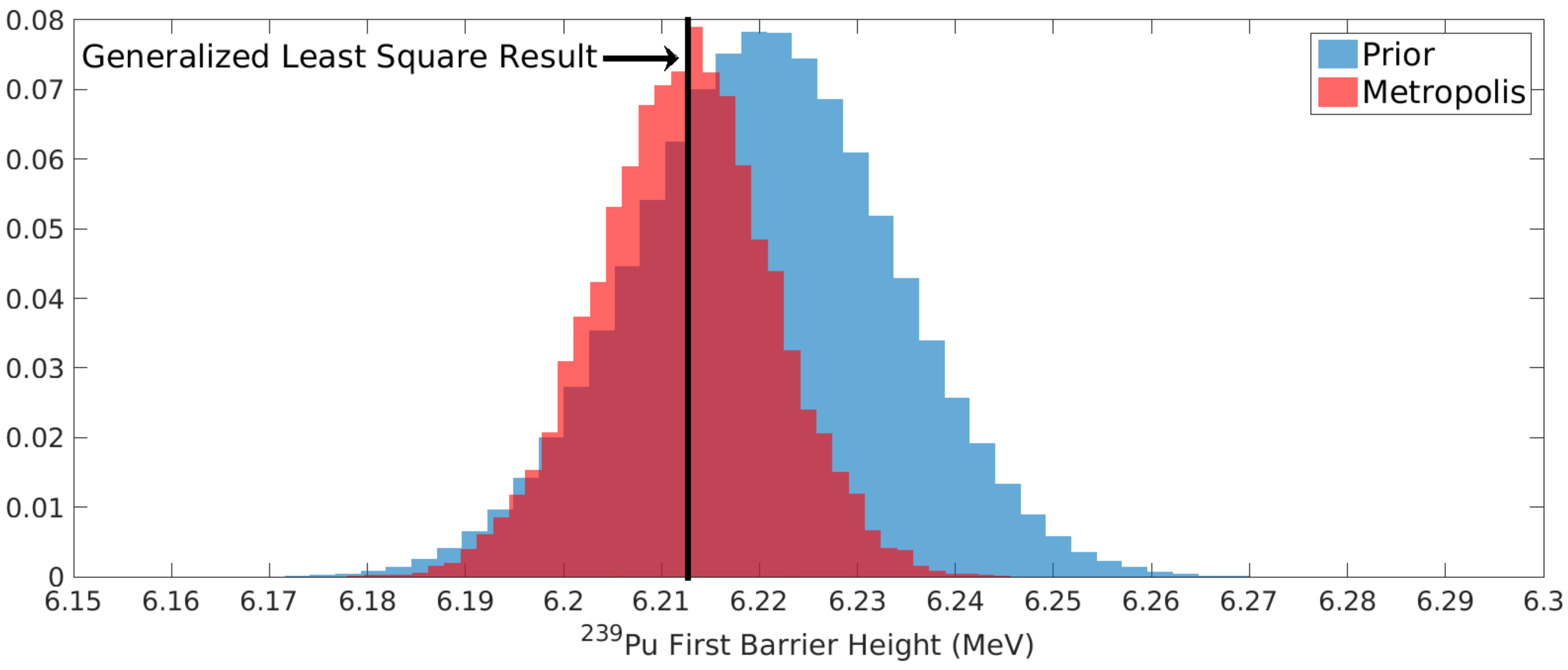


*Rouki et al., NIM in Physics Research Section A, **672** (2012)
Archier et al, Nuc. Data Sheets, **115 (2014).

Bayesian inference with Monte-Carlo IDA and Fast energy range : ^{239}Pu

Data assimilation of JEZEBEL*

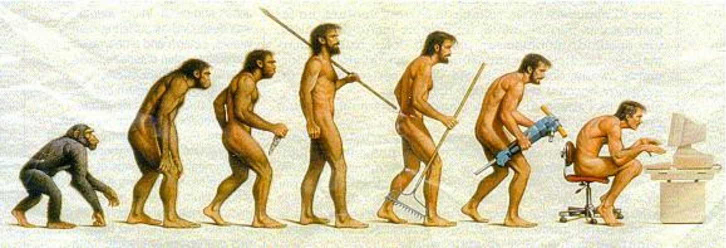
Nuclear model parameter adjustement



Metropolis find the same result as GLS even though change is very low (less than 0.5%)

CONCLUSIONS

- Several kind of Nuclear Data
- Several kind of Nuclear Reaction Models
- Several kind of Experiments
- Several kind of Covariance Matrices



- Progress on Methodologies needed:
  - Data assimilation techniques
  - Adding physical constraints (On several models)

- Progress on Experiments needed:
  - Reduction of systematic uncertainties for microscopic measurements
  - Integral experiments to target limited energy domain / reactions / isotopes

- Progress on Nuclear models needed:
  - Microscopic models and/or a priori model uncertainties + model defects
  - URR, the accumulation of all pbs (processing, models, experiments)
  - Avoid compensations

- Needs to define Covariance estimation benchmarks:
  - Fixed experiments
  - Fixed a priori (on parameters and/or cross section & uncertainties)
  - Incremental complexity
  - Compare covariance evaluation methodologies

Perspectives /open questions with Bayesian Monte Carlo

- Open a range of scientific activities → Beyond covariance matrices
- On going :
  - Full covariance of U,Pu in JEFF: simplify connection RRR/HE
  - Nuisance parameters (normalization, background, detectors efficiency, …)
  - Towards the Full Bayesian approach (experiment and theory)
  - Integral Data Assimilation and/or Transpositions to reactors neutronic uncertainties
  - Model deficiencies
  - Full Monte-Carlo (FMC) : from nuclear reaction models to Reactors

    (please …. without format/files/processing !!!!!)
- Is it worthwhile for evaluation? Yes ! But … more to come
  - Local minima's ? →Elaborated Markov chains ?
  - Actual weak point : Gaussian likelihood is always chosen

    →change of paradigm needed for representing experiments ?
  - Non linearities ? ; Non-gaussian posterior pdf's?