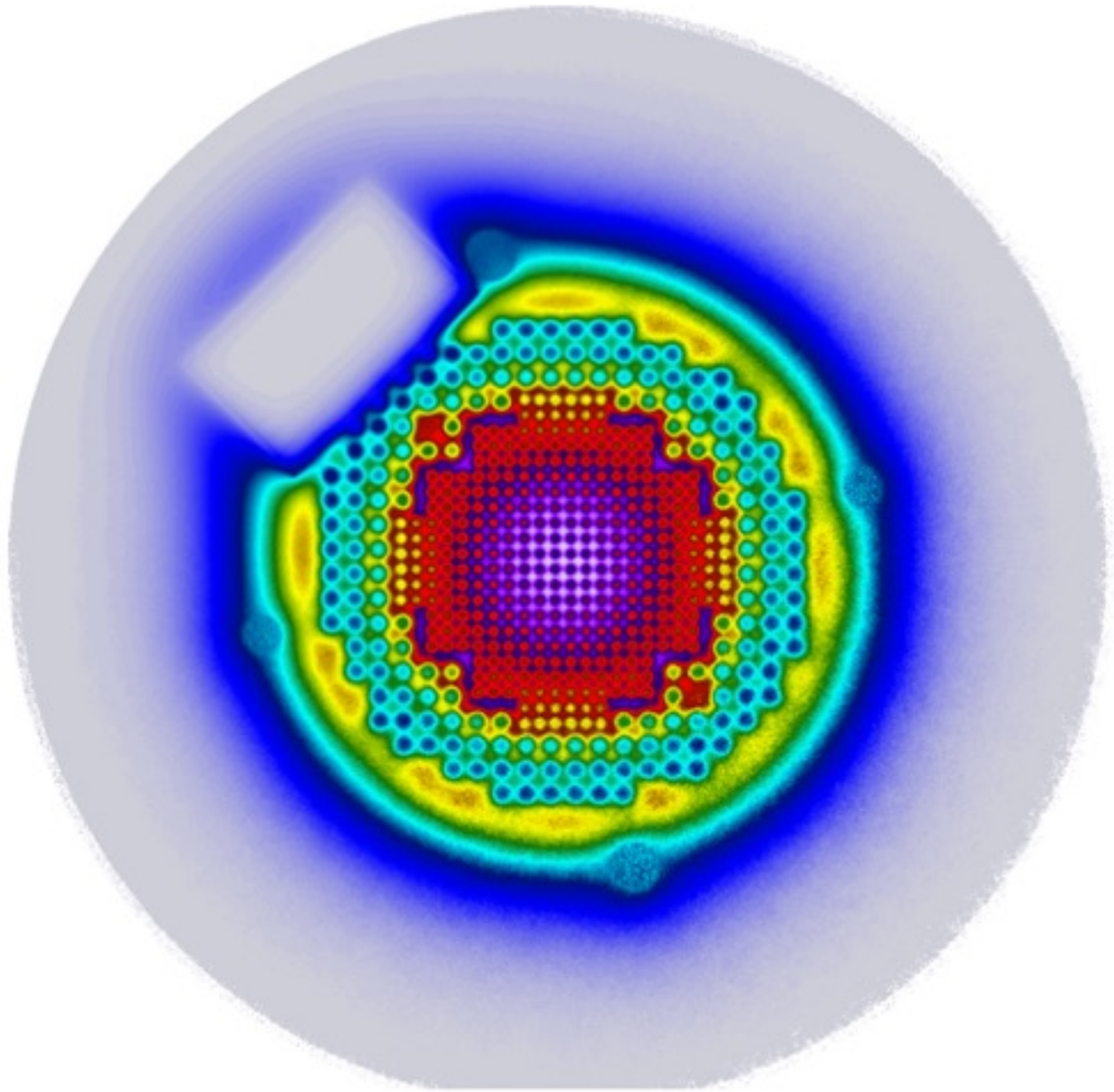
5TH INTERNATIONAL WORKSHOP ON NUCLEAR DATA EVALUATION FOR REACTOR APPLICATIONS

TOTAL MONTE CARLO ACCELERATION FOR THE PETALE EXPERIMENTAL PROGRAMME IN THE CROCUS REACTOR



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1: LRS/EPFL
2: LRT/PSI
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WONDER Conference - Aix en Provence - October 8th 2018

Summary

I - Introduction

- Context: BMC for integral experiment
- PETALE exp & specific requirements

II - TMC-CS

- Correlated Sampling principle
- Correlated Sampling on Nuclear Data

III - Validation

- Reference and comparison
- k_{eff} uncertainty propagation
- Flux / dosimetry application
- Inter-dosimeter correlation

Nuclear data assimilation using Bayesian Monte Carlo

Principle

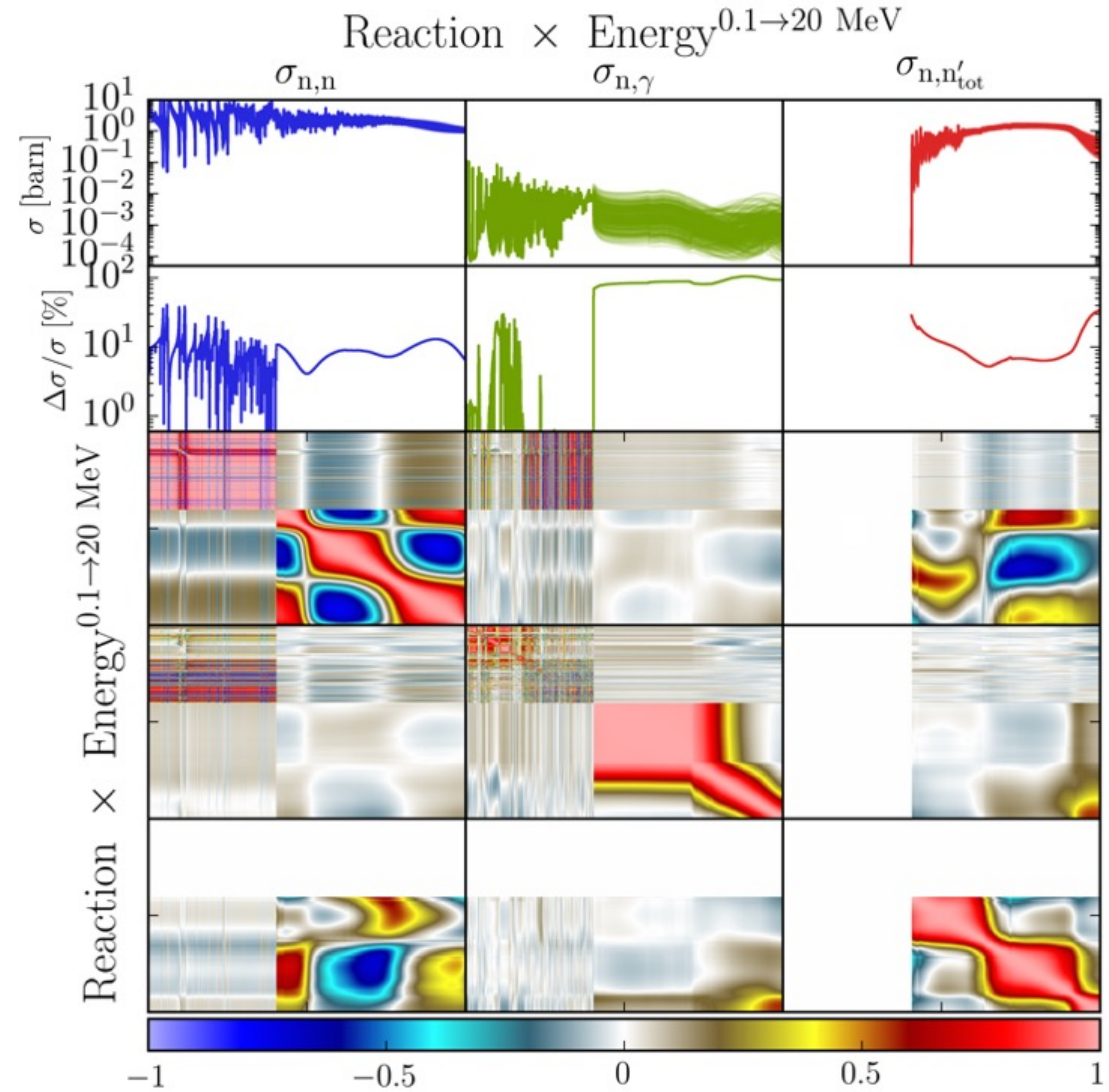
- Step 1: generation of random cross sections (XS) in agreement with the experimental knowledge
  ➙ *sampling on nuclear model parameters - TENDL*
  ➙ *sampling from covariance matrices*
- Step 2: Total Monte Carlo (TMC) uncertainty propagation
  ➙ *prior "C" value for each set of cross sections*
- Step 3: Comparison to experimental "*E*" results and XS-weighting in the BMC process
  ➙ *reduced posterior uncertainty using* $w_x = \exp\left(-\frac{\chi^2}{2}\right)$

(some of the) Advantages

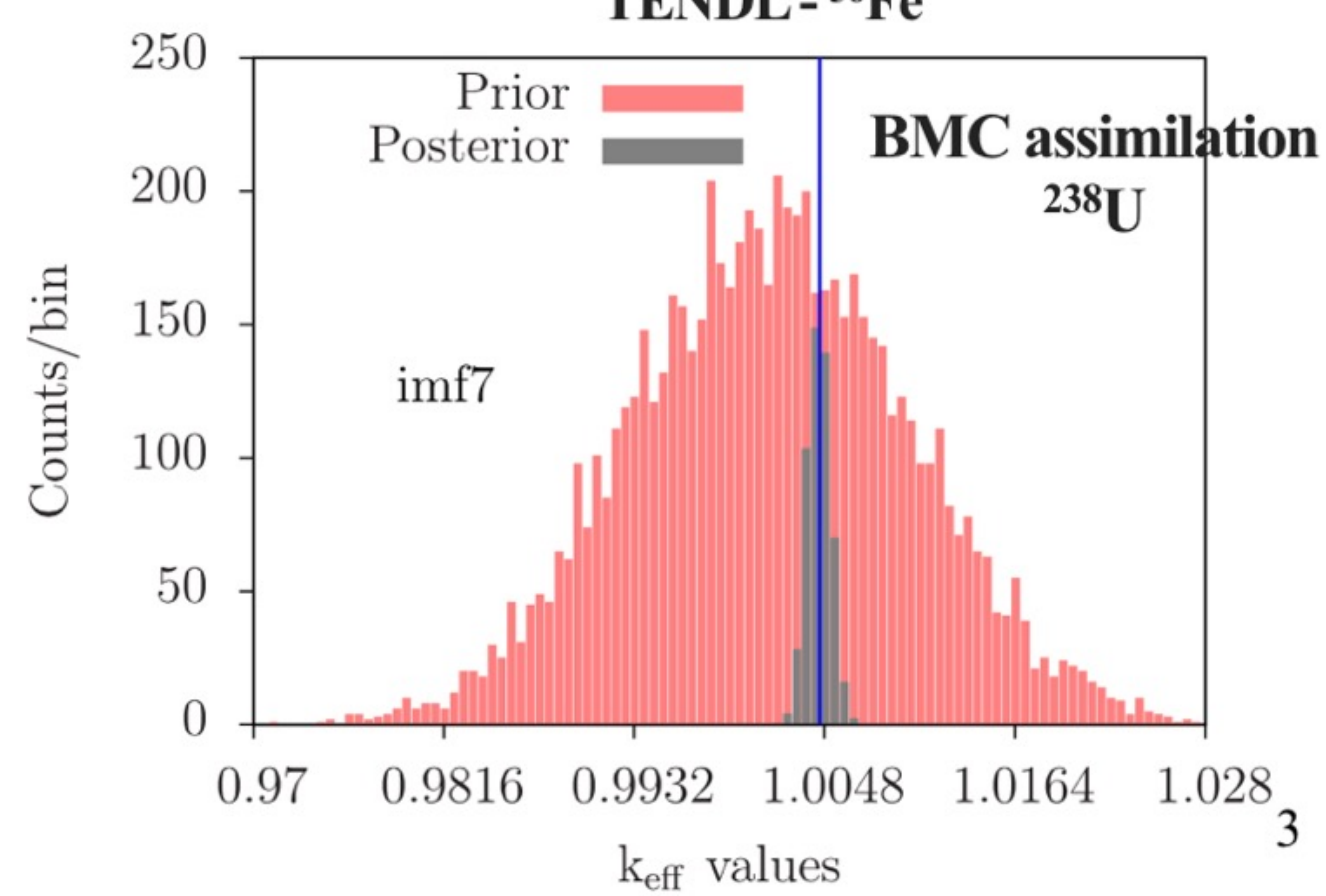
- No first order approximation
- Applicable on many kind of observables…

(some of the) Drawbacks

- Requires one calculation per set of cross sections
- … requires observables with a large dispersion



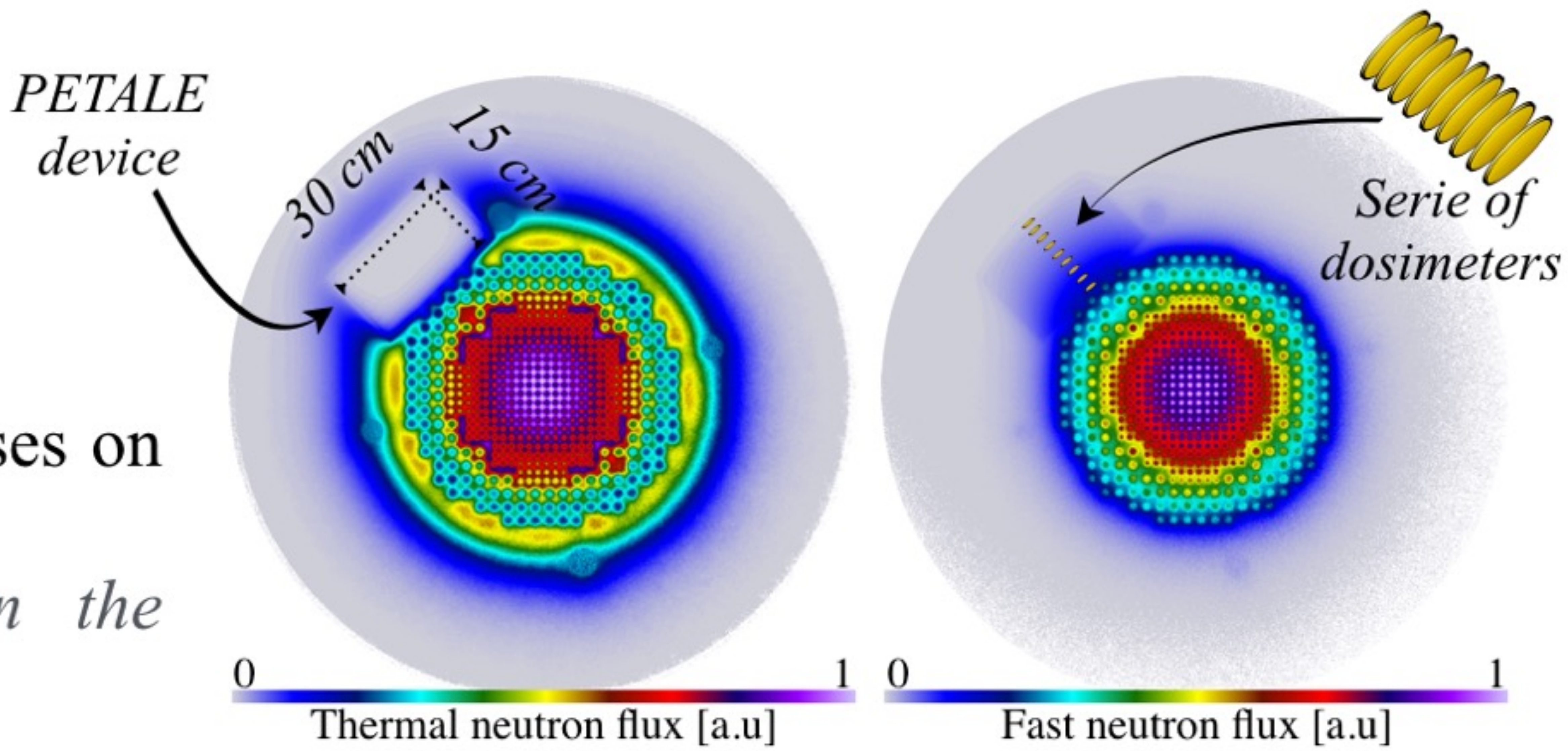
TENDL - ^{56}Fe



[Rochman, D. A., Bauge, E., Vasiliev, A., Ferroukhi, H., & Perret, G. (2018). Nuclear data correlation between different isotopes via integral information. *EPJ Nuclear Sciences & Technologies*, *4*, 7.]

Principle

- Heavy reflector near to the CROCUS reactor
  → *all details in V. Lamirand's presentation!*
- Regular spacing of dosimeters in the reflector
  → *~ cm radius and ~ 0.1 mm thickness*
- Apply a BMC (and other) nuclear data assimilation processes on the dosimeter activation
  → *progressive evolution of the reaction rate between the dosimeters*



Neutron flux in the CROCUS reactor estimated with Serpent2

Challenges

- Monte Carlo modeling
  Low flux (statistics) / streaming effect / dosimeter self-shielding
- Difficult TMC uncertainty propagation on reaction rates: $\sigma_{\text{Nuclear Data}} \sim \sigma_{\text{MC statistics}}$
  and σ_{ND} estimated via Δ Monte Carlo with independente neutron histories…
- Classic CROCUS calculation: days
  → *one caculation required per random cross section!*

Additional objective of this work

- Use the TMC with the Correlated Sampling technics to optimise the experimental setup / Run the experimental programme
  → *several configurations have to be studied*

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Correlated Sampling principle

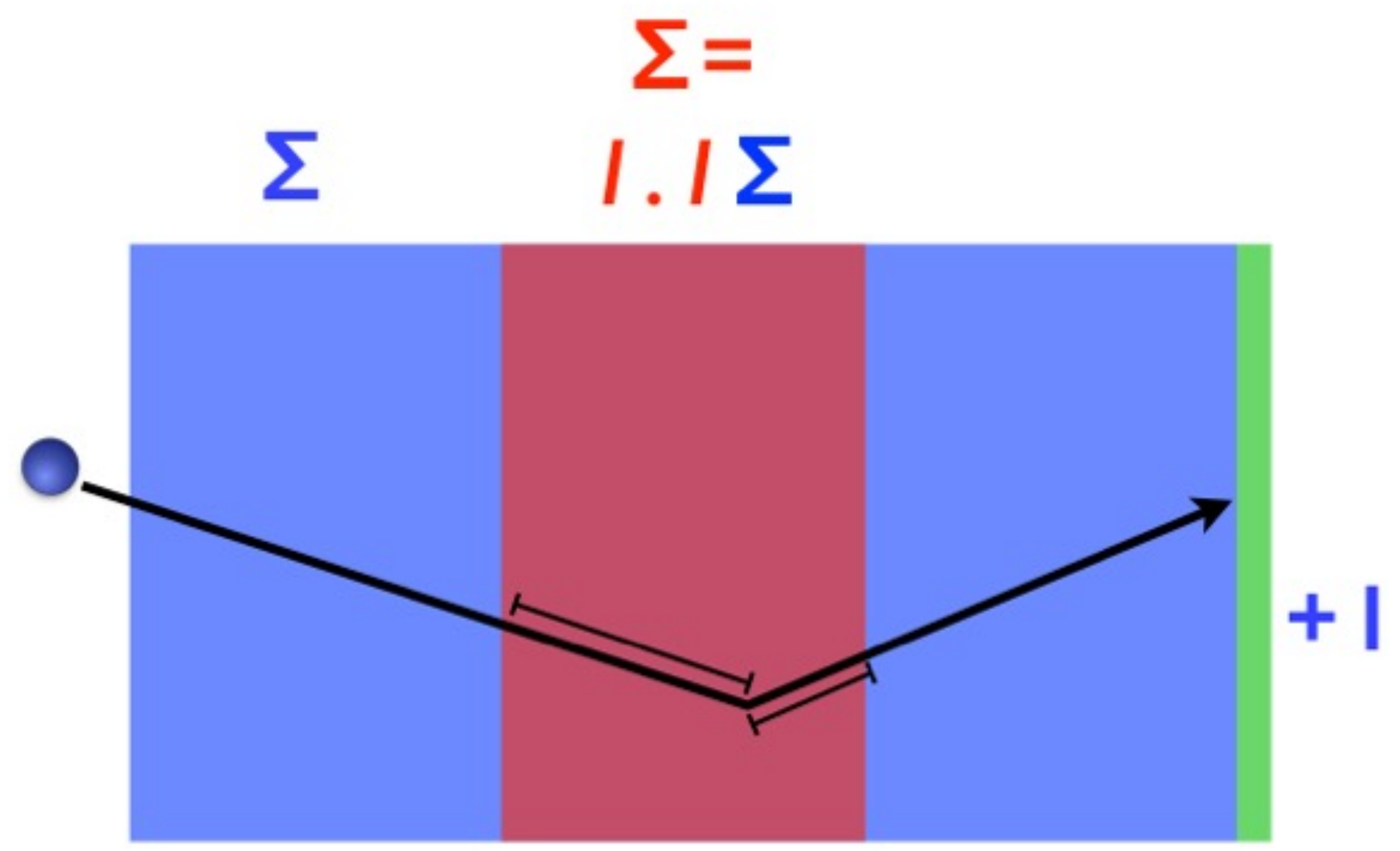
Correlated Sampling technics?

Principle

- Objective: replace 2 “close” calculations by a single one
  - → *calculation speed-up - only 1 run*
  - → *variance reduction - same neutron path*
  - → *no first order assumption*
- Neutron weight modification
  - → *ratio of probabilities between the two systems*
- Different application fields
  - → *surface displacement*
  - → *element concentration / density modification*
  - → *Doppler effect*
  - → *... nuclear data uncertainty*

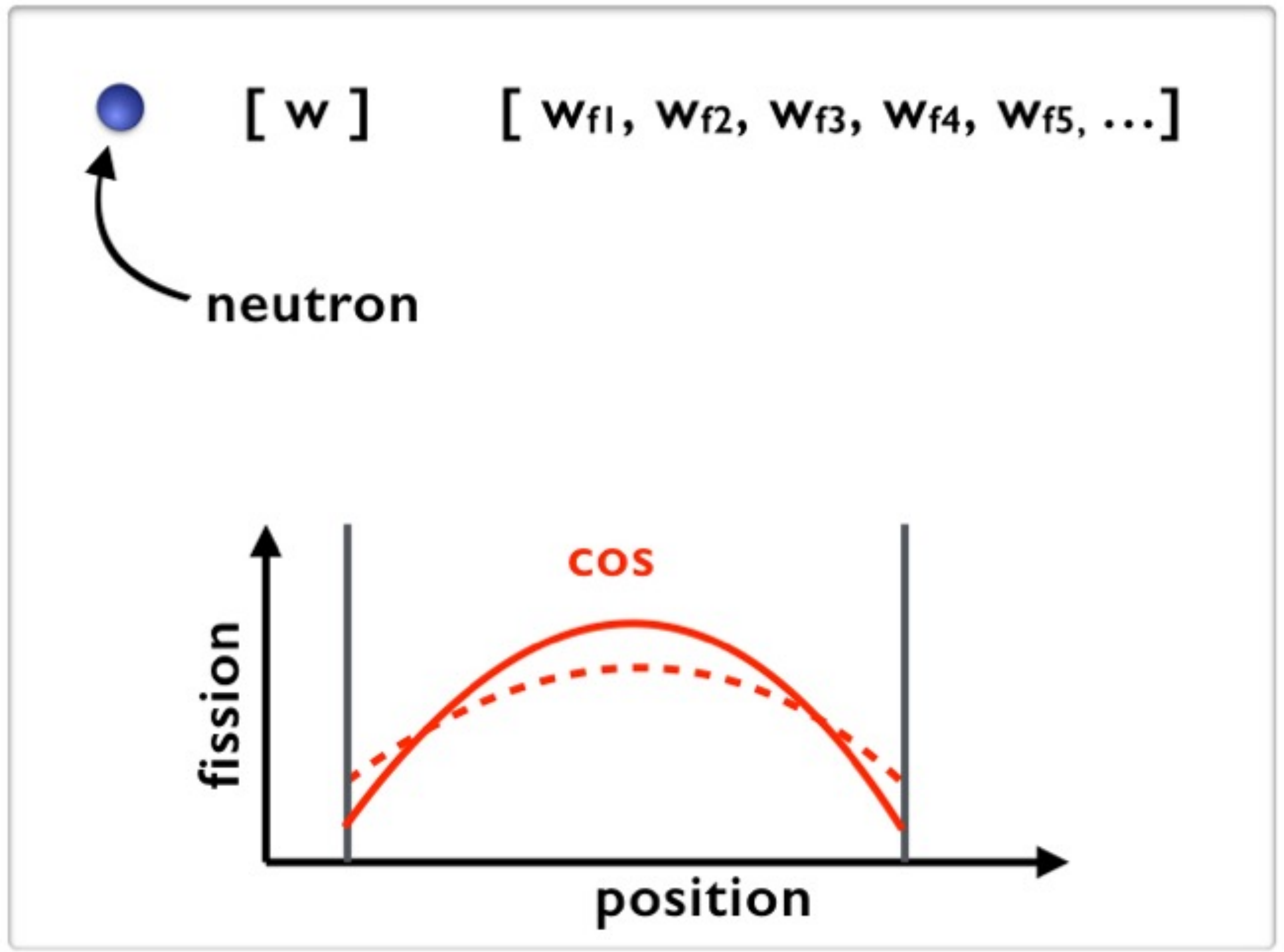
Drawbacks

- Needs probabilities different from zero and infinity
  - → *can not make isotope appears from scratch*
- If the systems are too different the neutron weight is too different
  - → *bad convergence*



Ratio of probability for a distance *d* sampling: $\dfrac{\Sigma_{\text{tot}}^{\text{pert}} \exp(-d \cdot \Sigma_{\text{tot}}^{\text{pert}})}{\Sigma_{\text{tot}} \exp(-d \cdot \Sigma_{\text{tot}})}$

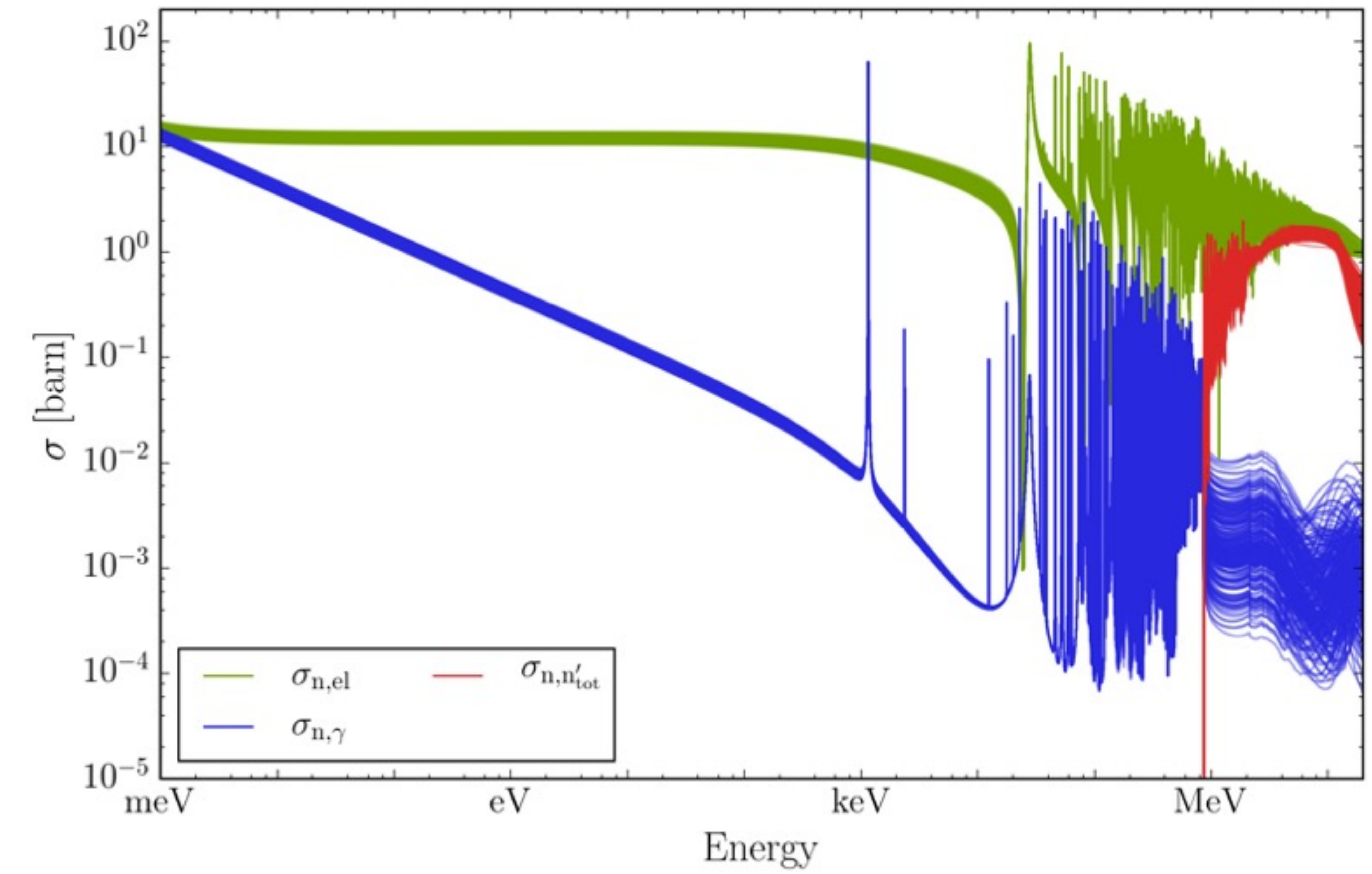
Ratio of probability for the reaction sampling: $\dfrac{\Sigma_{\text{n,r}} \cdot \Sigma_{\text{tot}}^{\text{pert}}}{\Sigma_{\text{tot}} \cdot \Sigma_{\text{n,r}}^{\text{pert}}}$



Correlated Sampling with multiple Cross Sections: TMC-CS

Principle

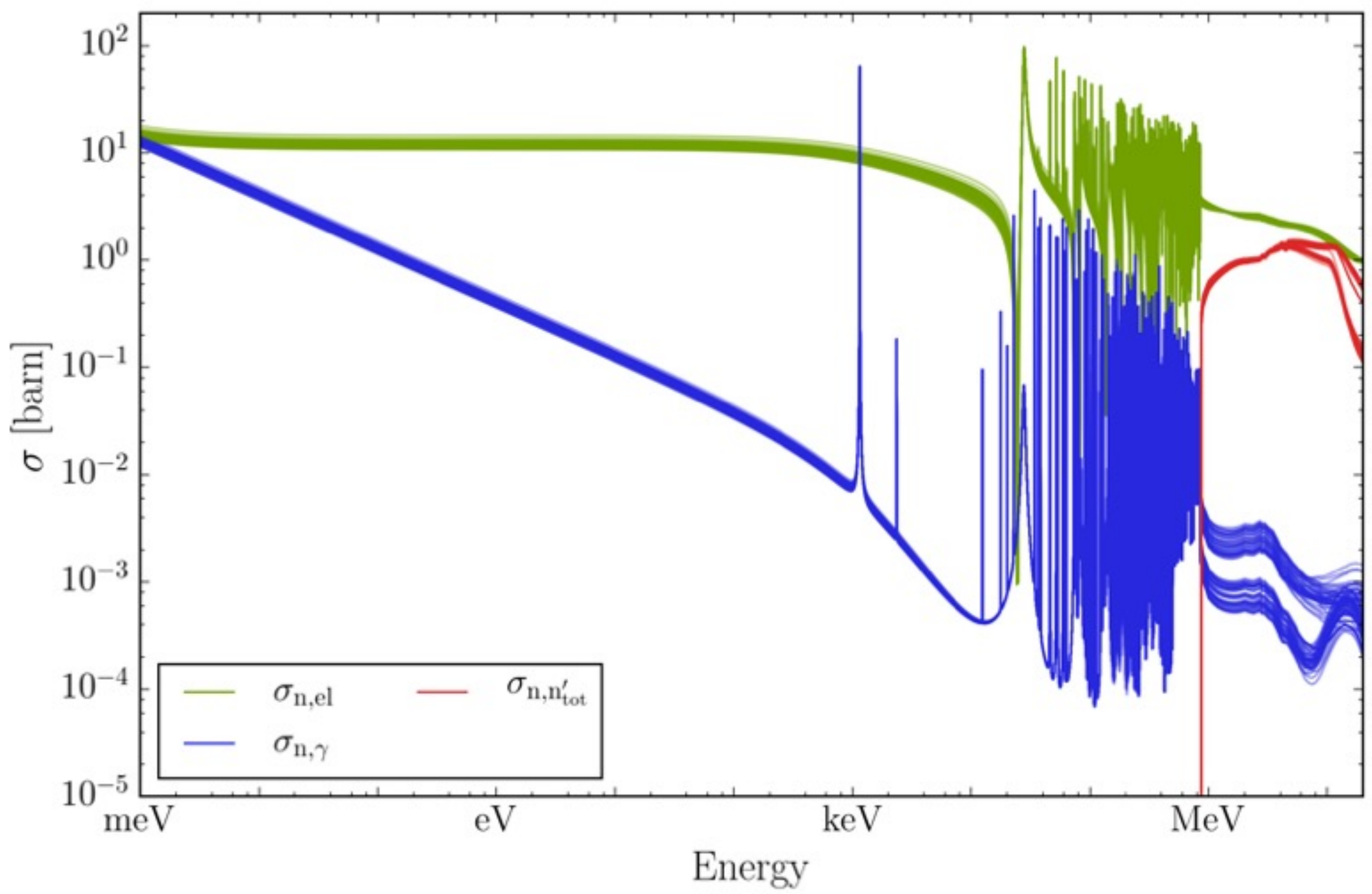
- Each set of cross sections corresponds to a different system
  ➙ *different probabilities during the transport*
- Neutron weight modification for each XS set
- Multiple "isotopes" and "mt" all together
  ➙ *ratio of probabilities between the two systems*



256 random TENDL ^{56}Fe cross sections

Nuclear Data cross sections

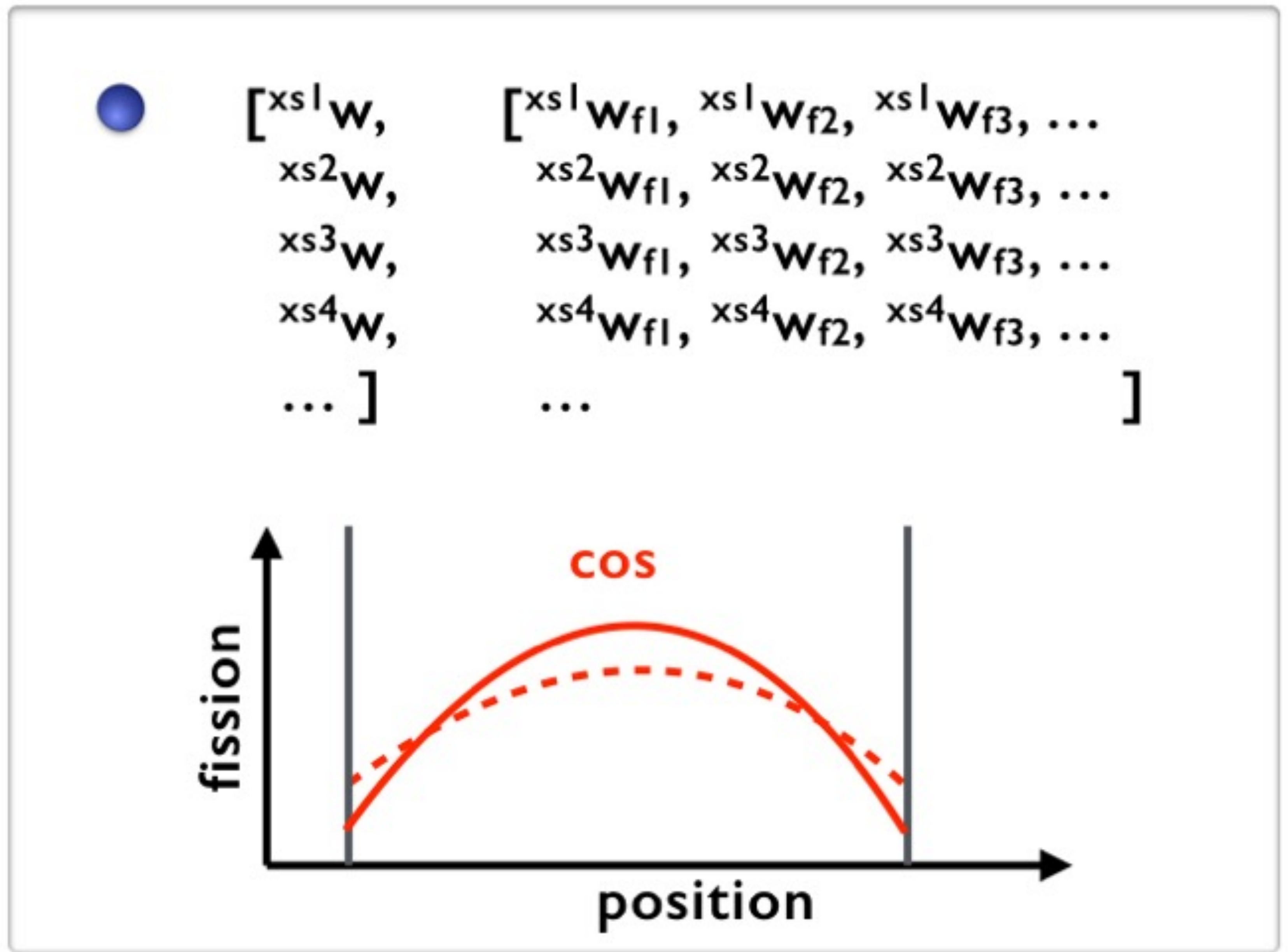
- "Classic" TENDL cross section
  ➙ *sampling on the nuclear data parameters*
- "Extended" TENDL - EUROfusion ("to fill the gap")
  ➙ *sampling on the nuclear models themselves (more challenging)*



2 models x 40 random ^{56}Fe cross sections

➙ *discontinuities*

➙ *non linearity?*



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TMC-Ref

- Classic Total Monte Carlo uncertainty propagation (reference)
- N calculations for N cross section sets

TMC-CS

- Uncertainty propagation using the correlated sampling technics
- N / (~64) calculations for N cross section sets
  memory limitation

TMC-sensi

- Uncertainty propagation using the sensitivities (Serpent code)
- XS % variation between ACE files #*x* and #0
  → *uncertainty propagation for each XS file*

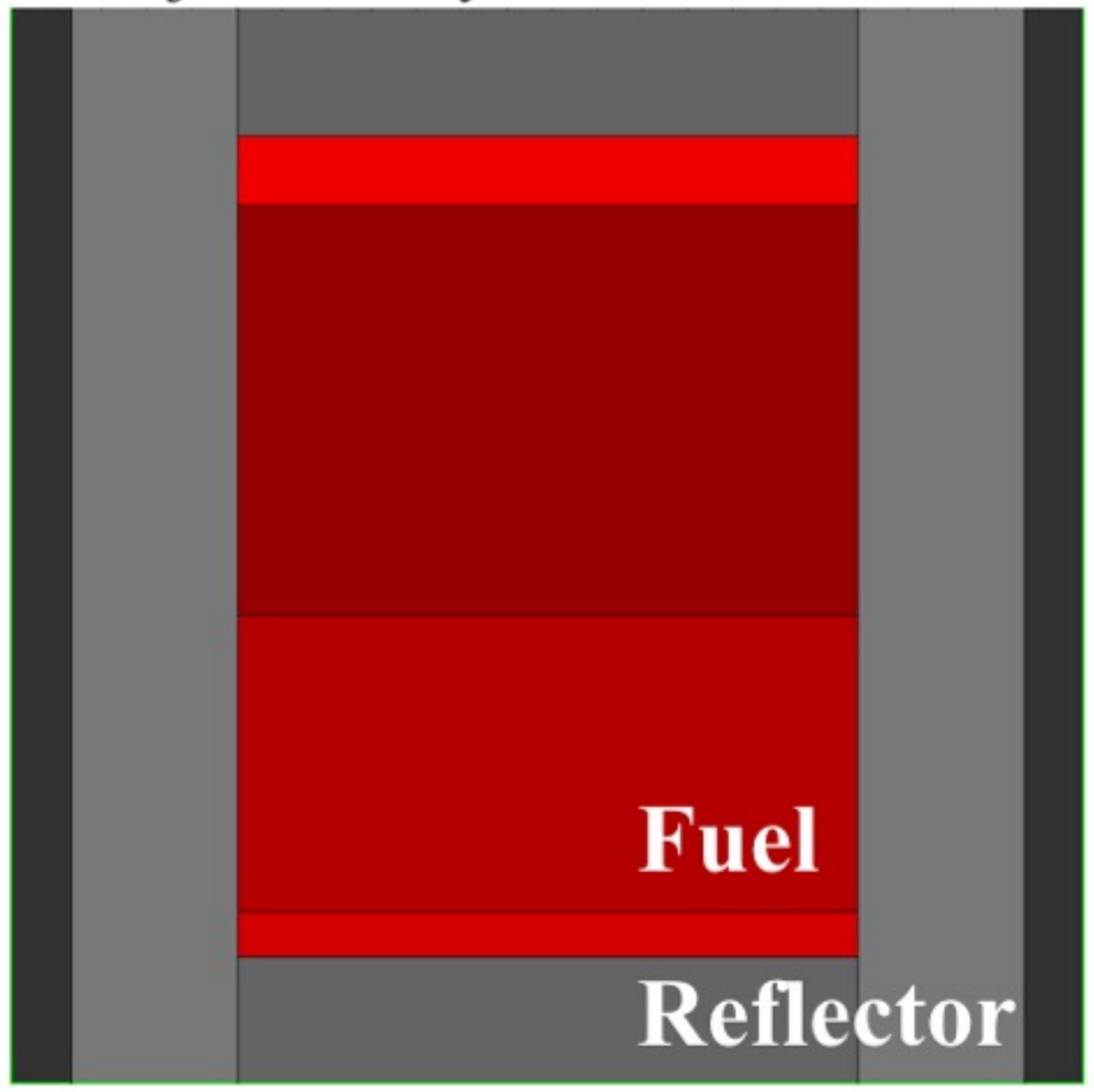
Sensi

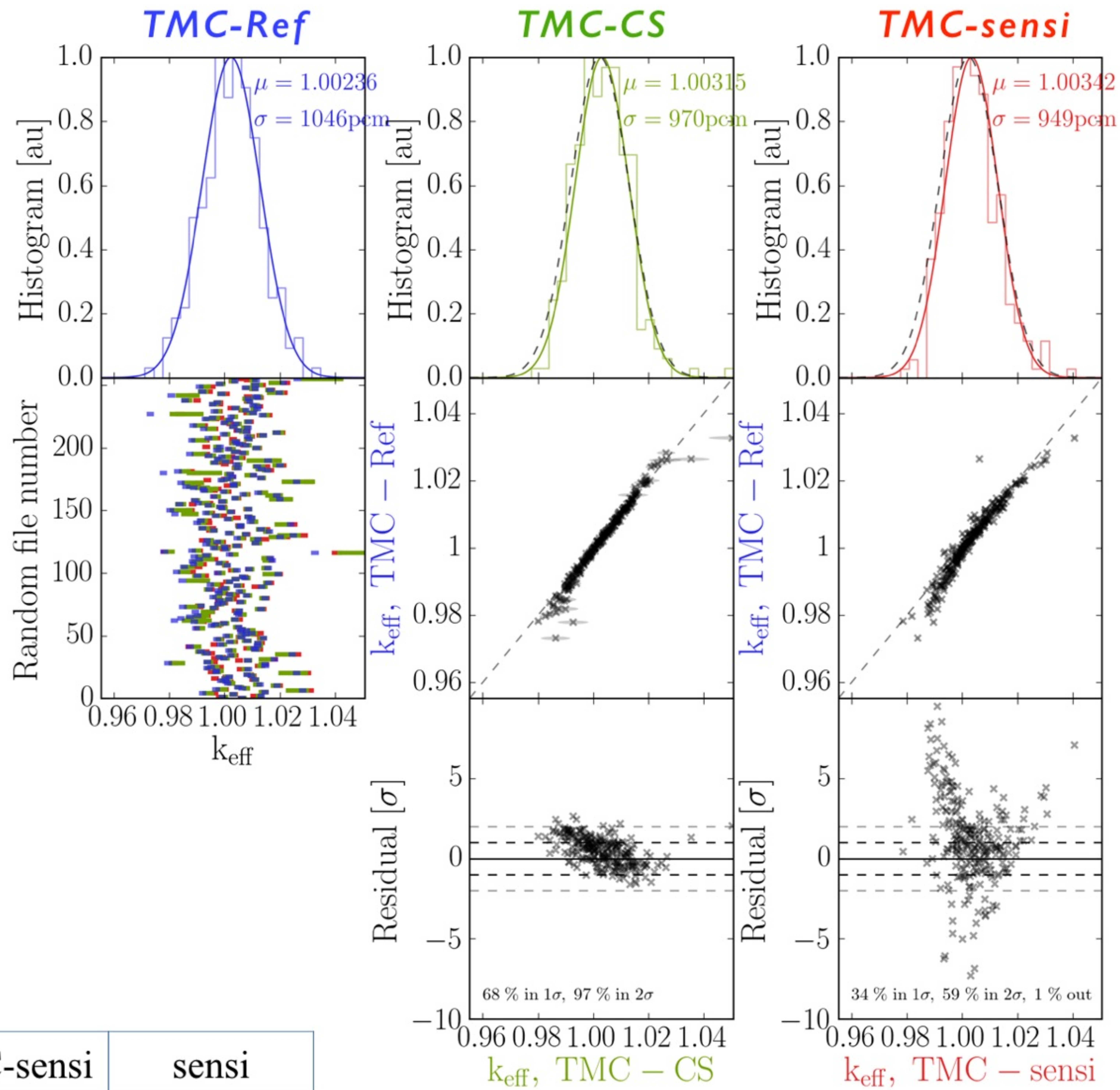
- Uncertainty propagation using the sensitivities (Serpent code)
- Covariance matrix from all the random XS files
  → *one uncertainty propagation value*

HMI-001: ^{56}Fe

- Large uncertainty ~1000 pcm
- Same global distributions
- Good file to file agreement
- TMC-CS: difference appears after 2000 pcm
- TMC-sensi: good linearity with a comma trend

^{235}U(93%) / Iron cylinder reflected by stainless steel

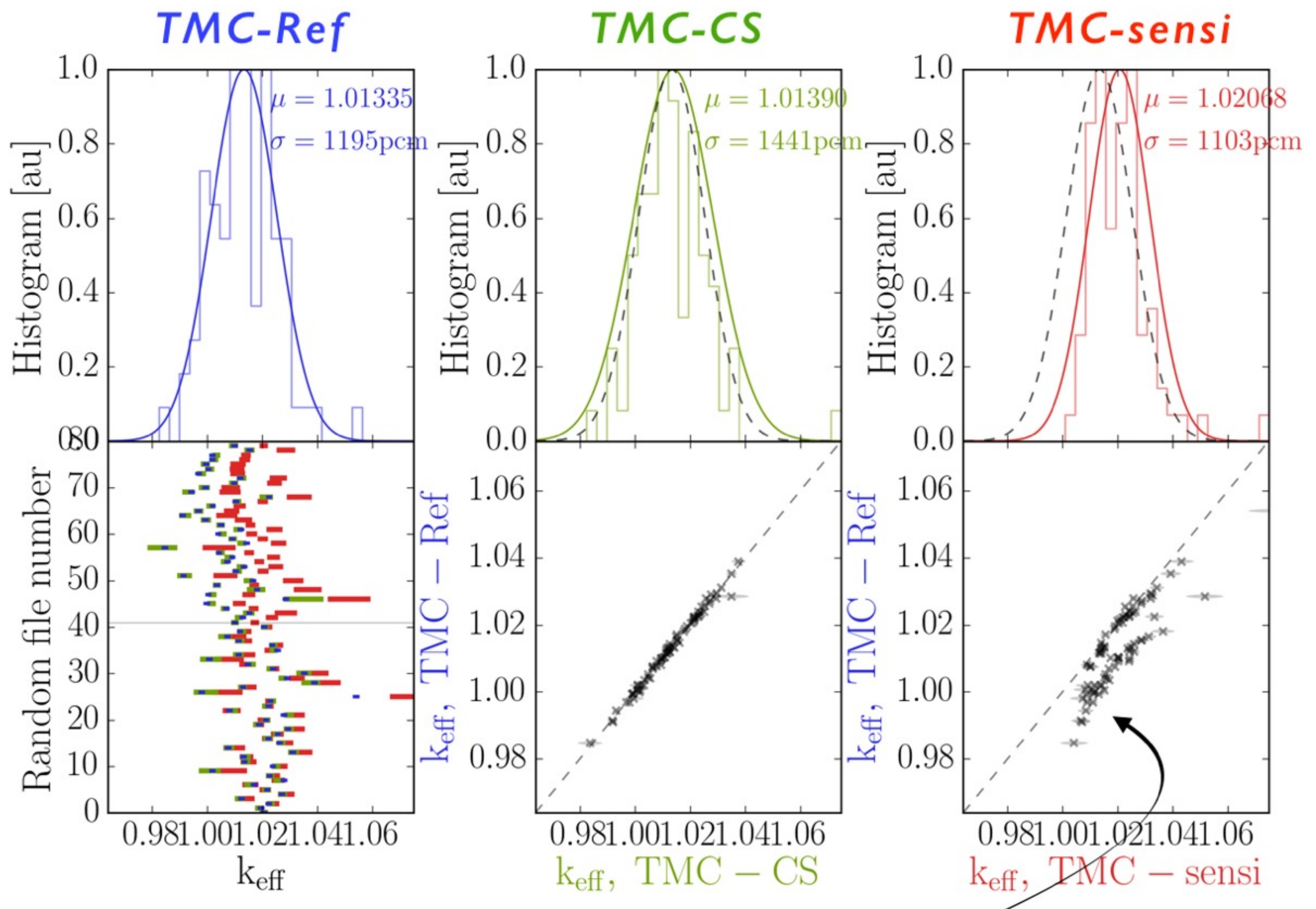


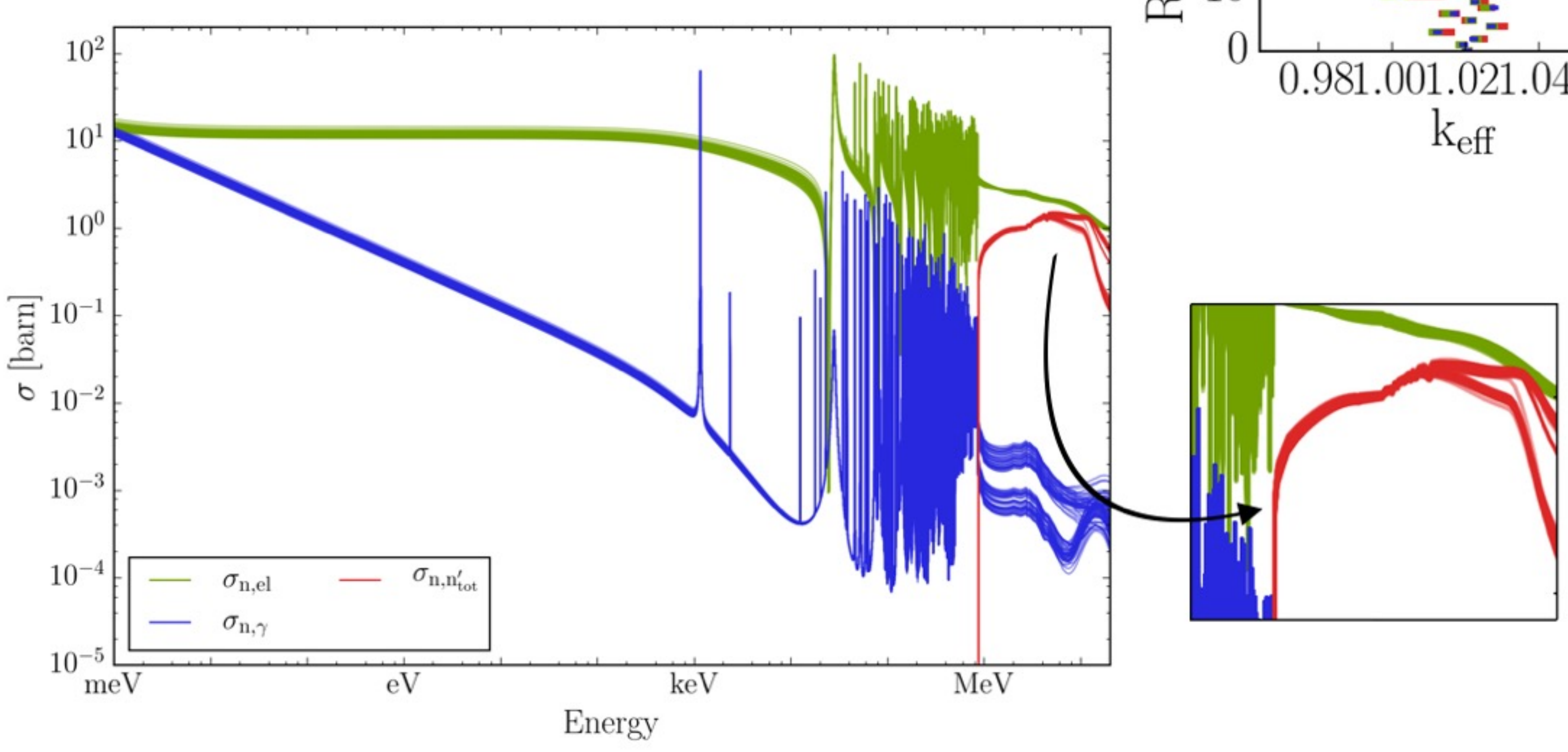


	TMC-Ref	TMC-CS	TMC-sensi	sensi
σ_{keff} [pcm]	1046	970	949	1086

HMI-001: [56]Fe & extended TENDL

- Large uncertainty ~1000 pcm
- Same global distribution
- Good file to file agreement
- Non linearity appears on the sensitivity approach



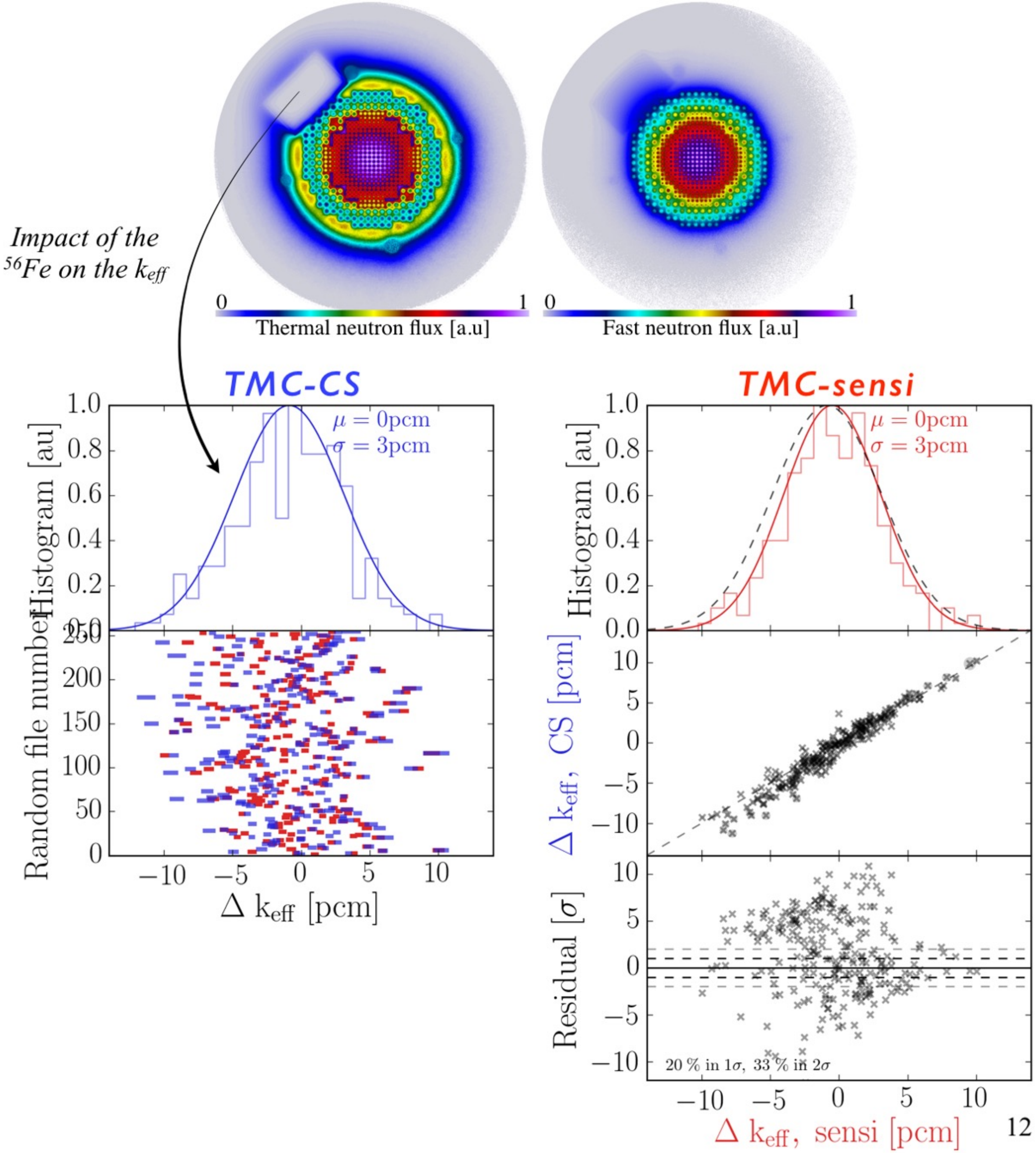


Validation

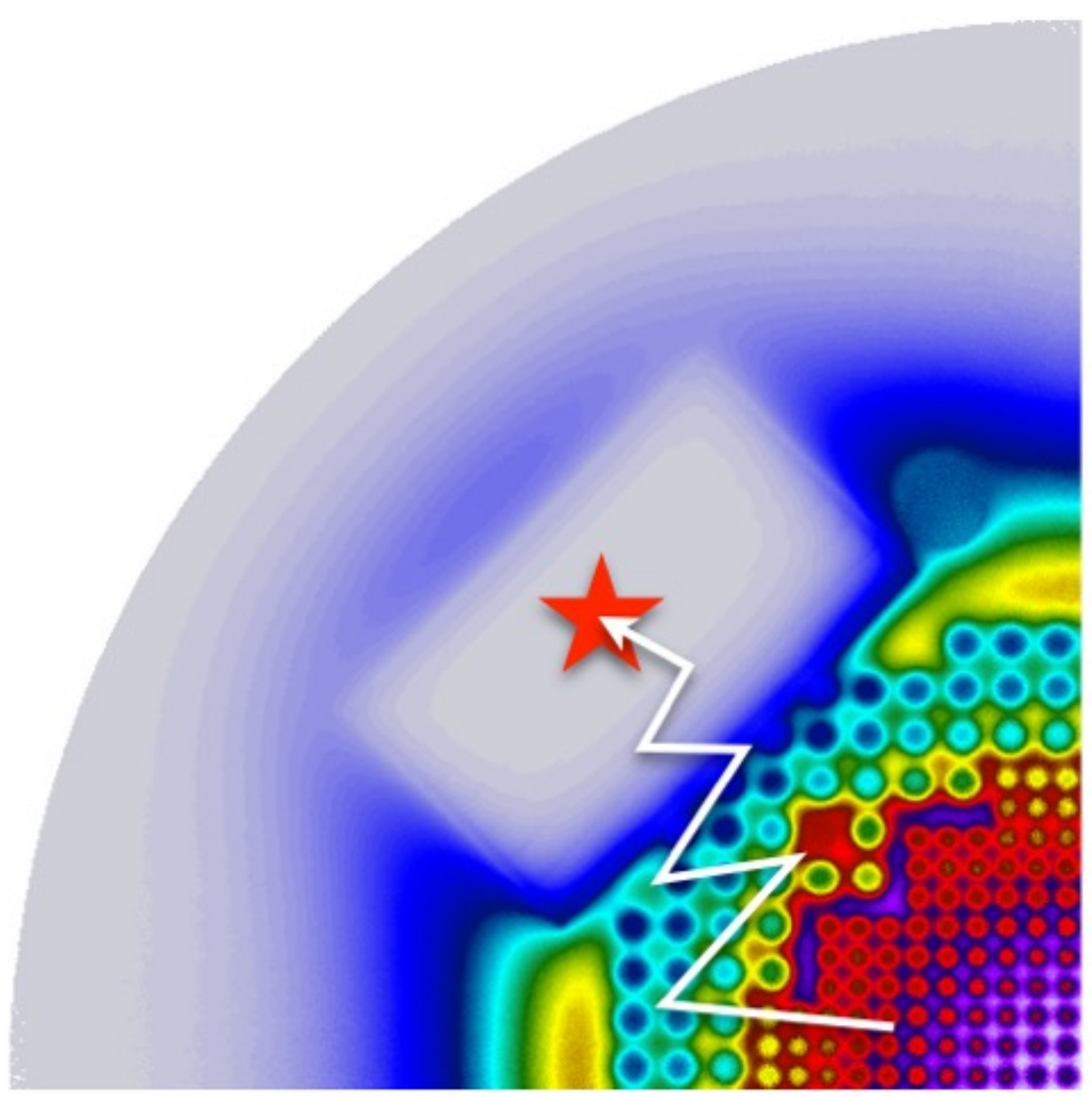
k_{eff} uncertainty propagation

CROCUS: ^{56}Fe

- Small uncertainty ~3pcm
- TMC-CS / TMC-sensi: good agreement! …
- … no TMC-Ref
  $\sigma_{MC\ stat} \sim \sigma_{ND}$



- Neutron flux / reaction rate in the dosimeters can be compared to TMC-Ref!
- But requires neutron biasing



Introduction

PETALE exp & specific requirements

Thermal neutron with a weight of 1

Thermal neutron with a weight of 0.5

Principle

- On the fly learning of the “minimal number of displacements” required to reach the target
  → *Neutron splitting*
- Geometric X Energy grid (no angular grid yet)

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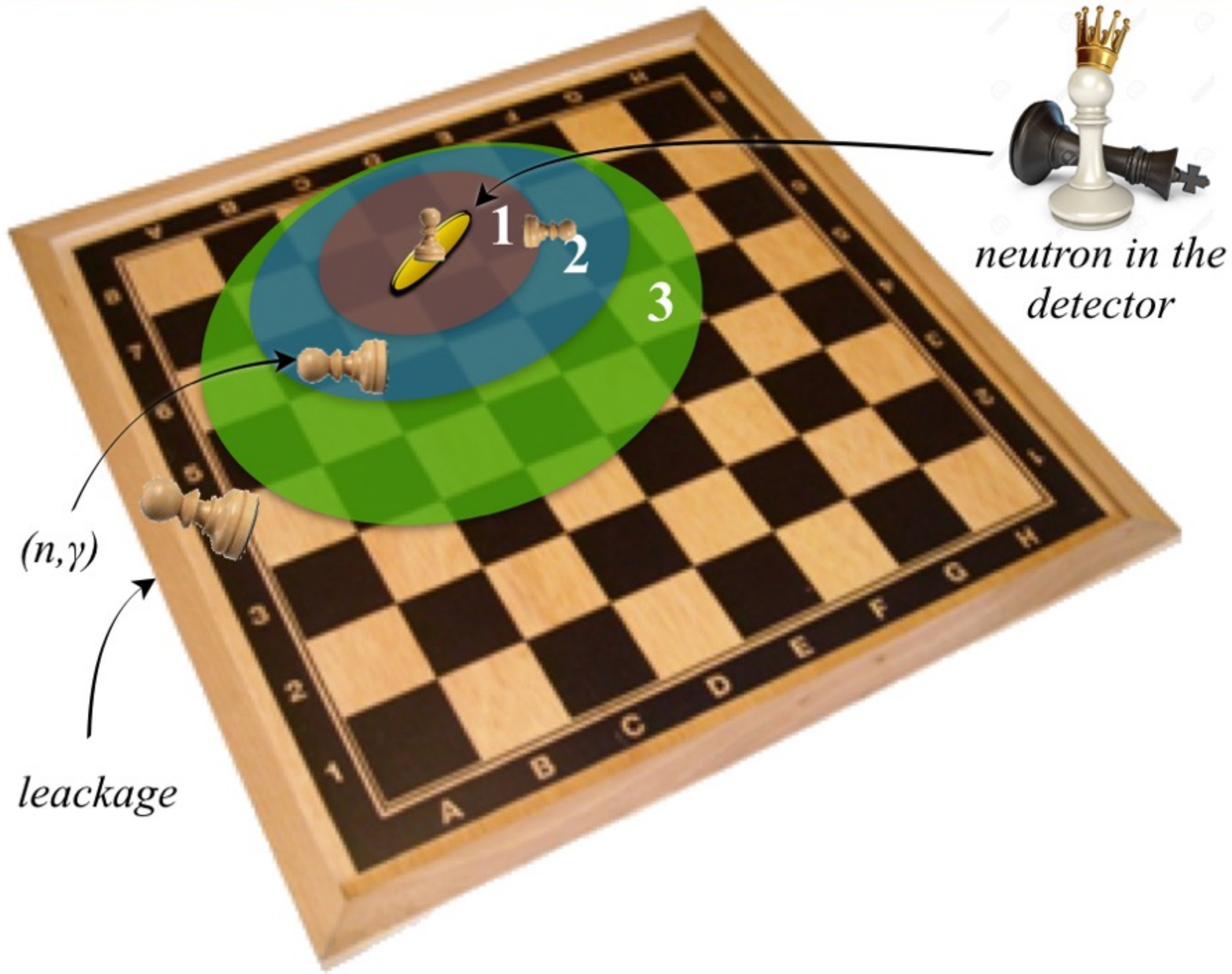


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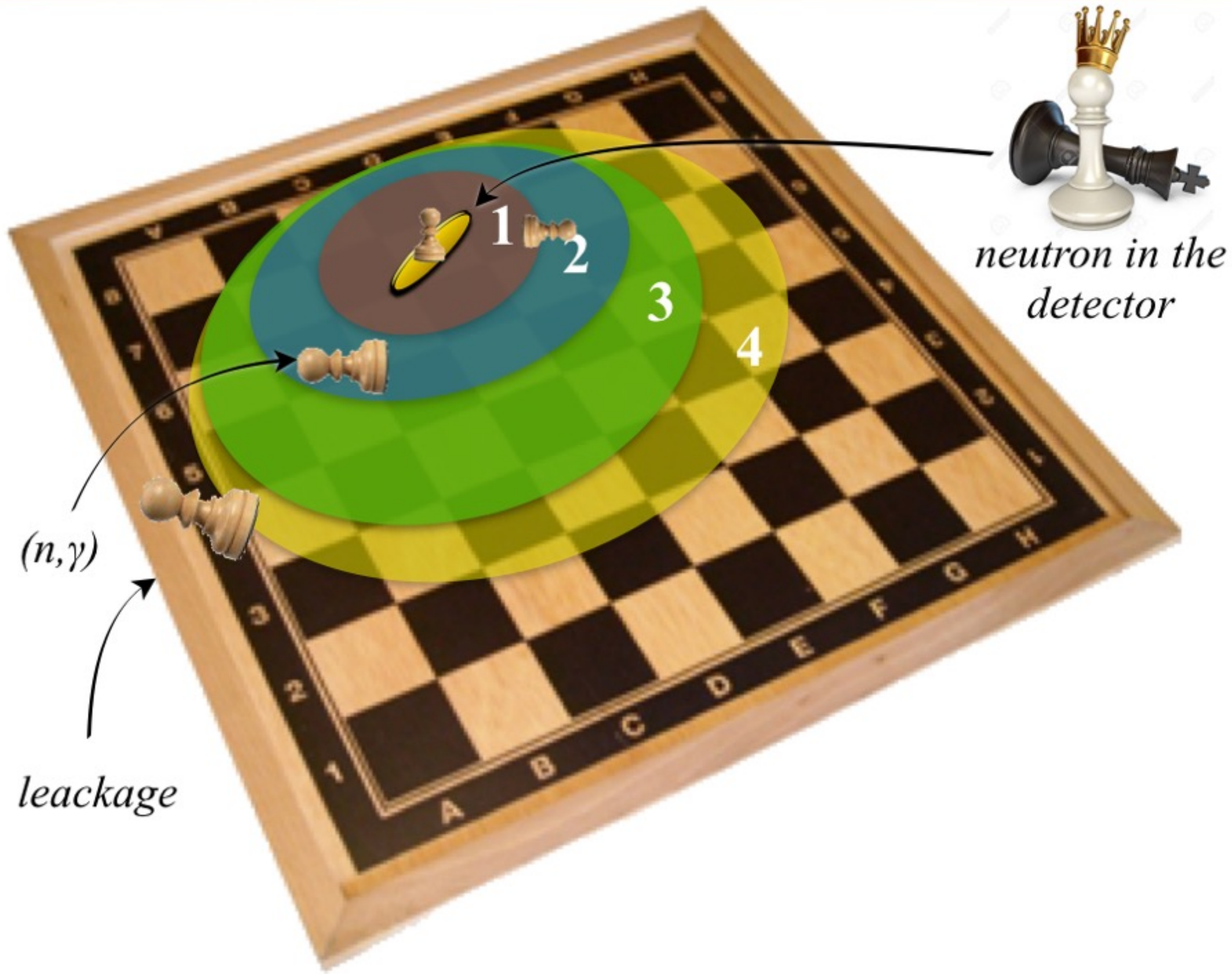
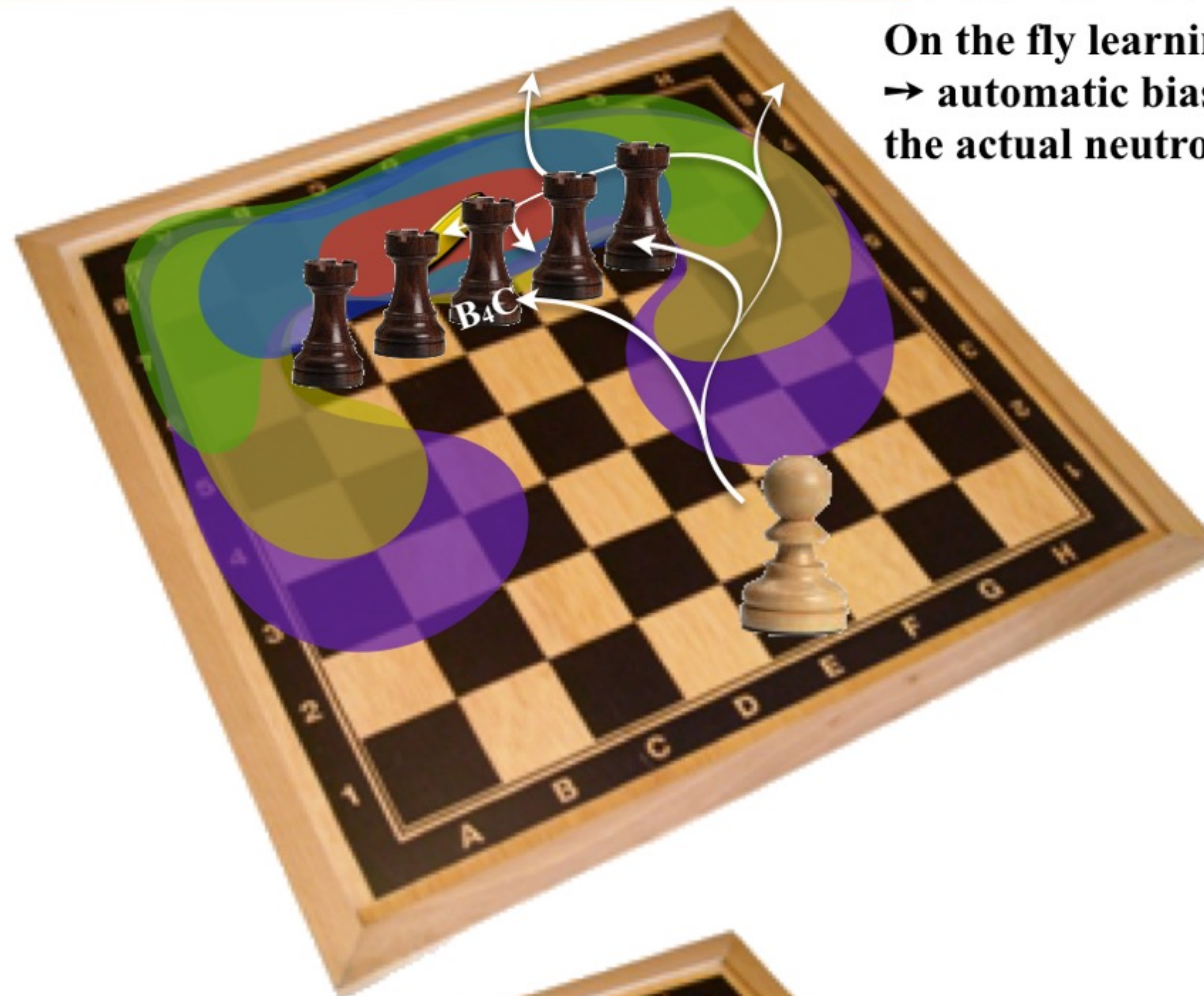
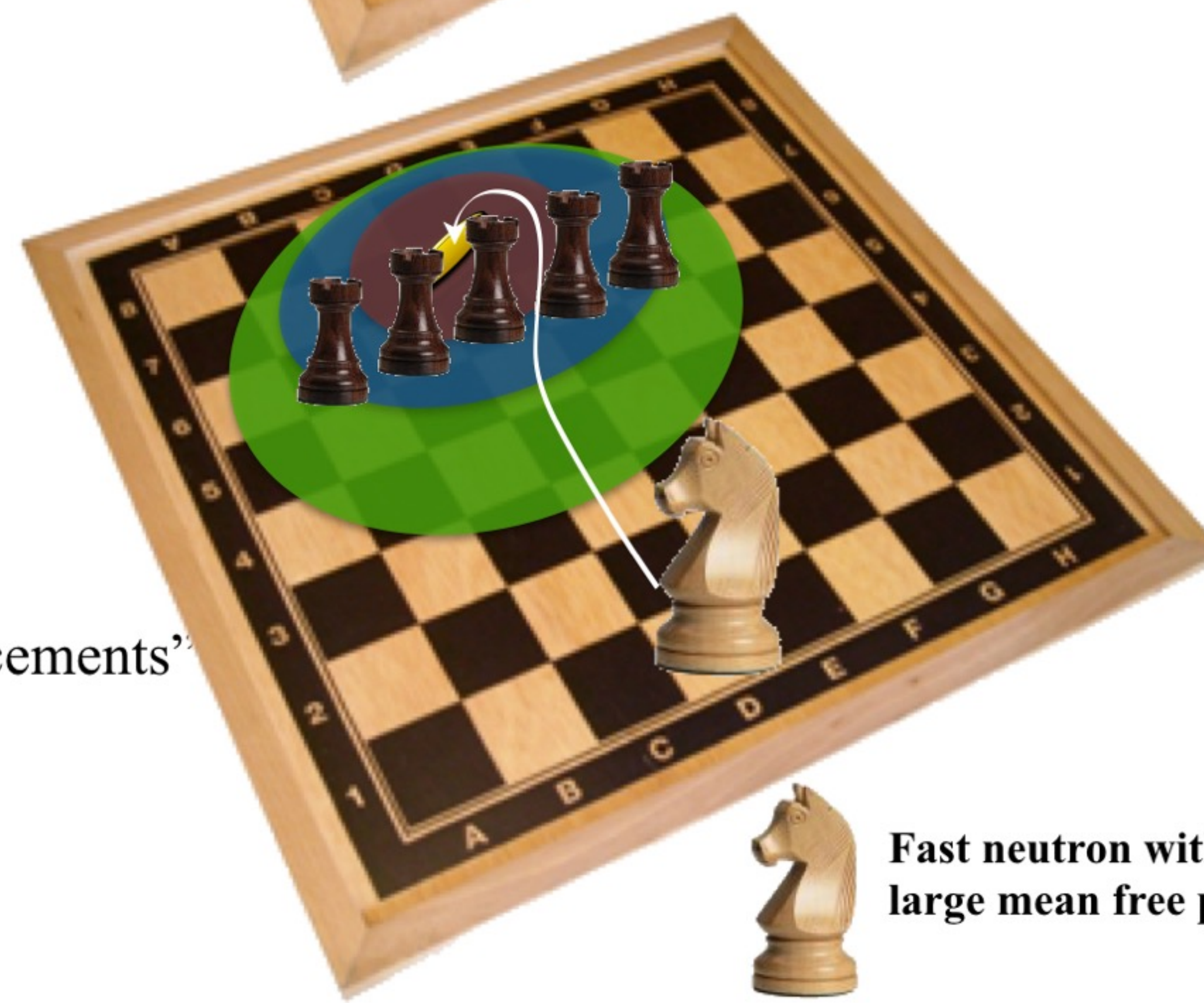




On the fly learning
→ automatic bias on the actual neutron path



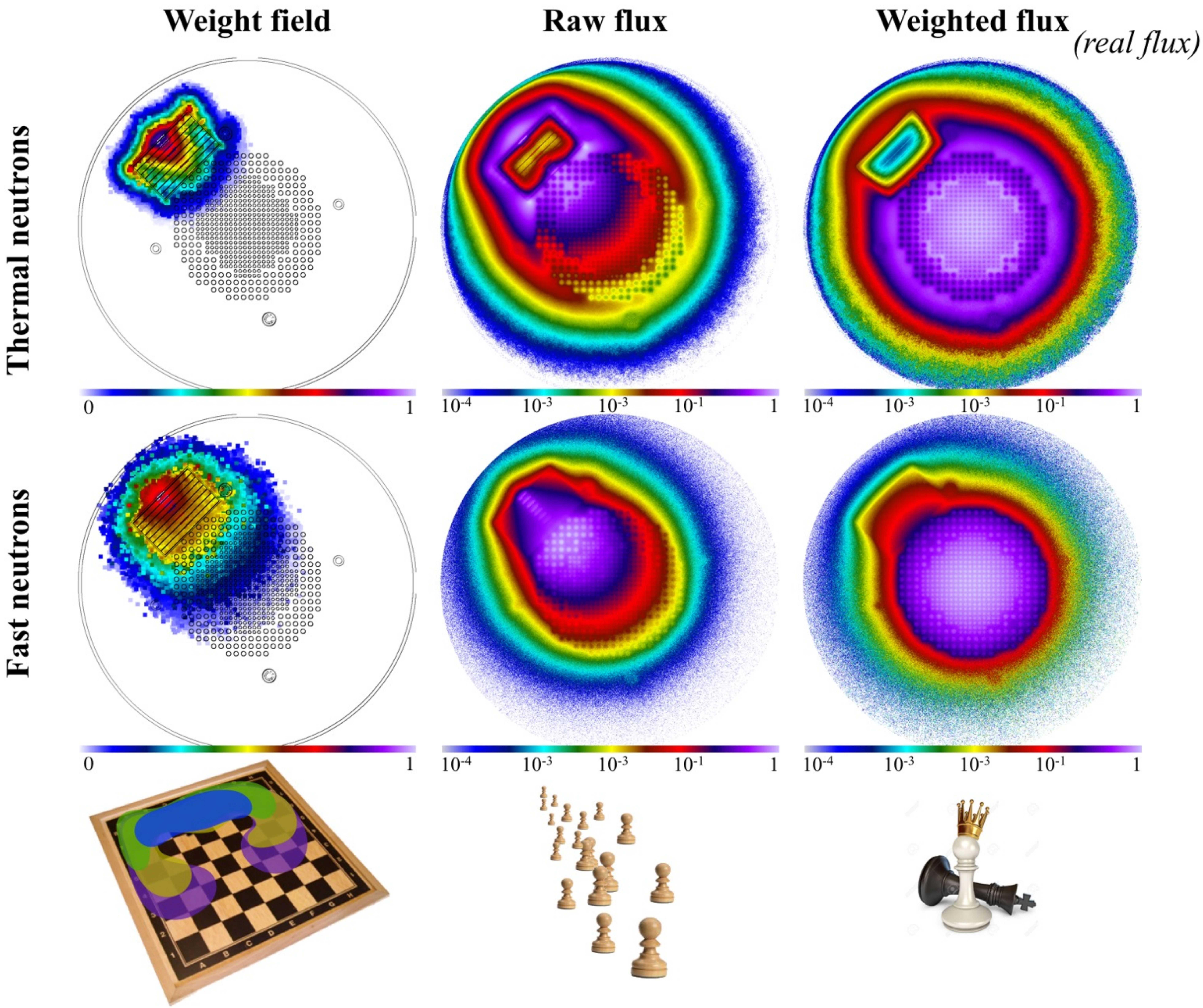
Thermal neutron with a weight of 1

Thermal neutron with a weight of 0.5

Fast neutron with a large mean free path

Principle

- On the fly learning of the "minimal number of displacements" required to reach the target
  → *Neutron splitting*
- Geometric X Energy grid (no angular grid yet)

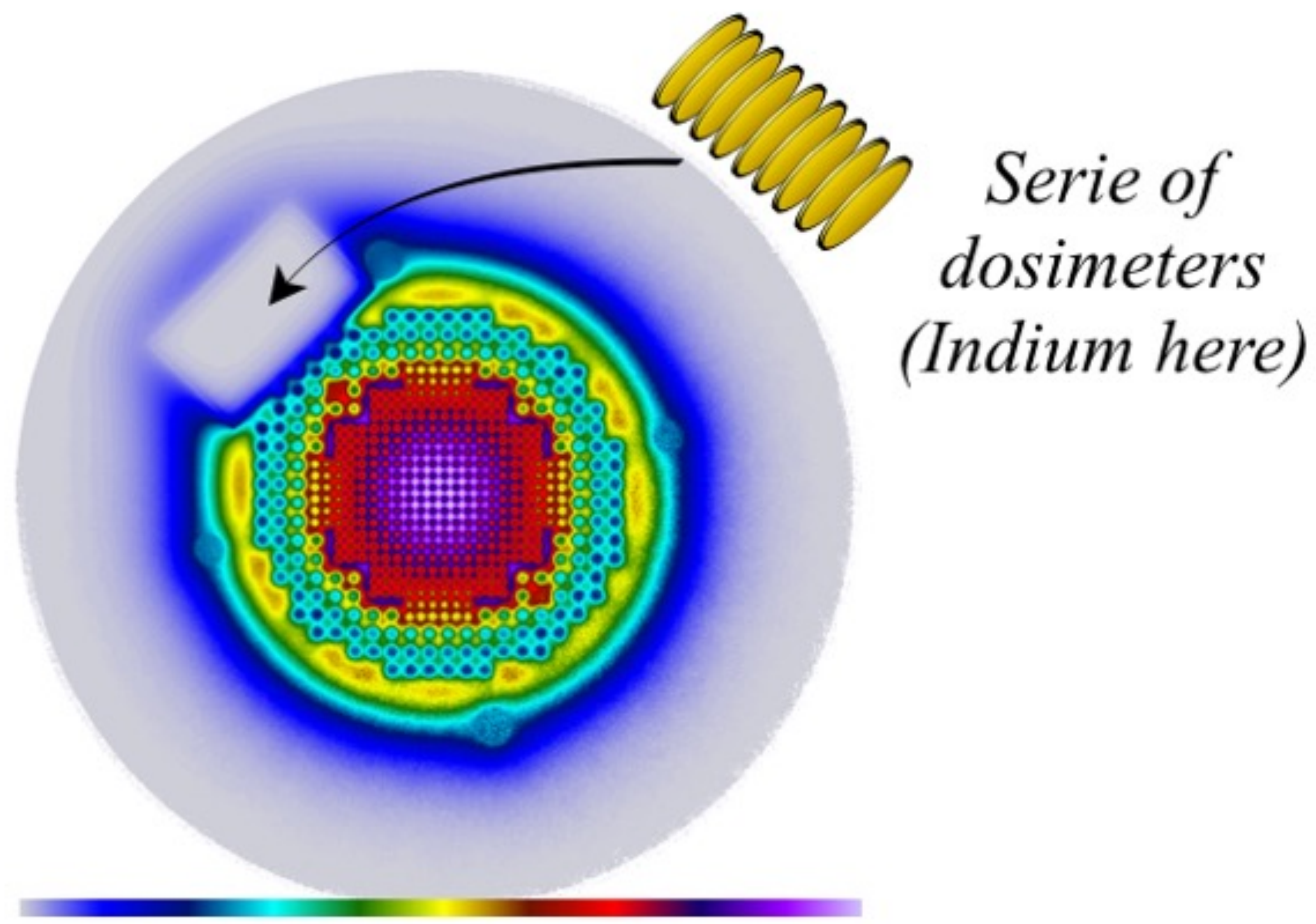


Acceleration factor (FOM)

- ~10 in the fast range
- ~50 in the thermal range

CROCUS dosimetry: neutron flux

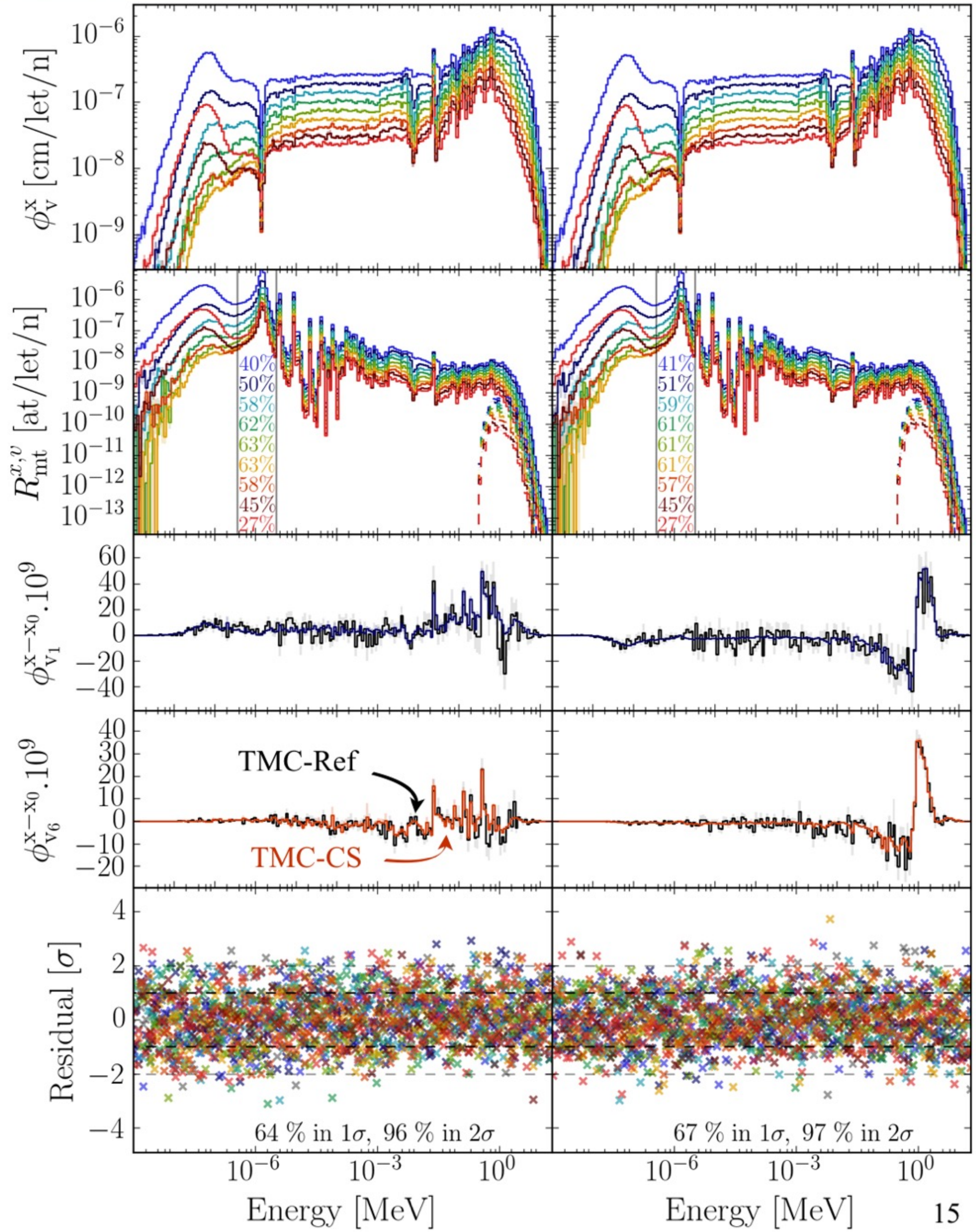
- Flux calculated in all the dosimeters



- Each flux is declined according to each TENDL cross section
  → *all Fe isotopes, all mt reactions*
- Spectrum distribution different according to the XS

Observation:

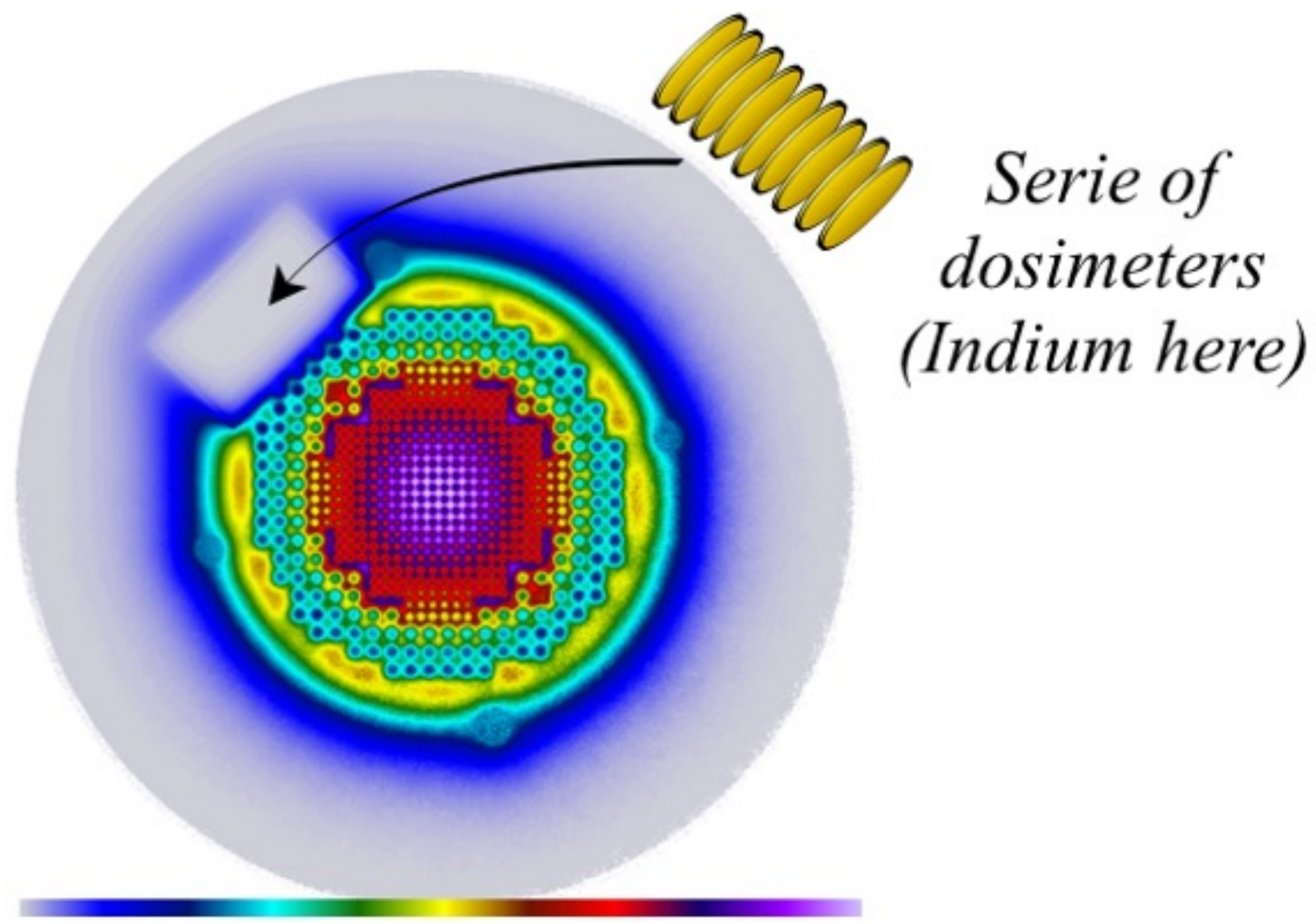
- Impact of ND uncertainty directly visible on the flux in the dosimeters
- Very close trend line between TMC-Ref and TMC-CS
- Reduced statistical uncertainty



Flux / dosimetry application

CROCUS dosimetry: reaction rate

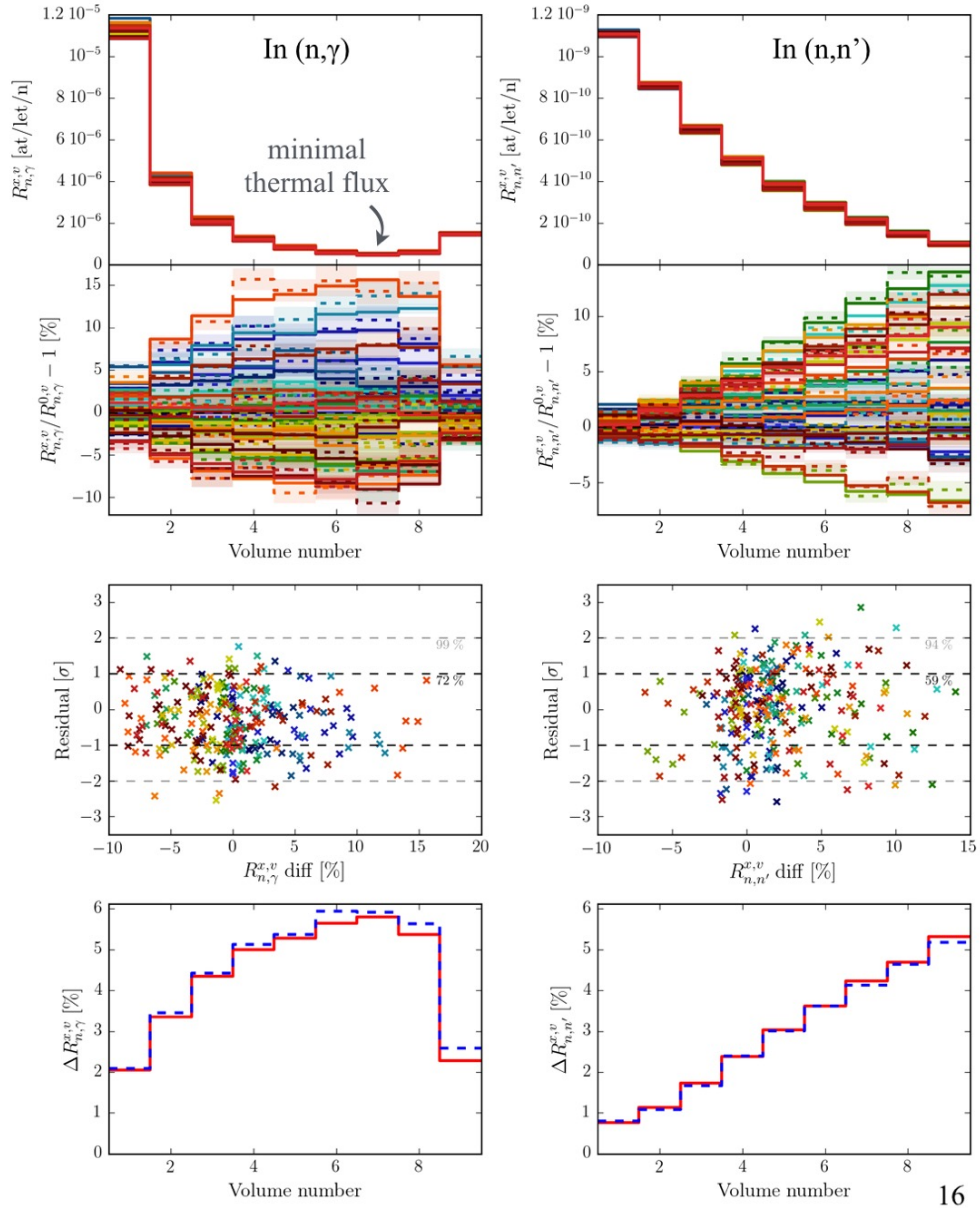
- Flux calculated in all the dosimeters



- Each reaction rate is declined according to each TENDL cross section
  → *all Fe isotopes, all mt reactions*

Observation:

- Very good prediction of the reaction rates difference between the TENDL cross sections (useful for BMC)

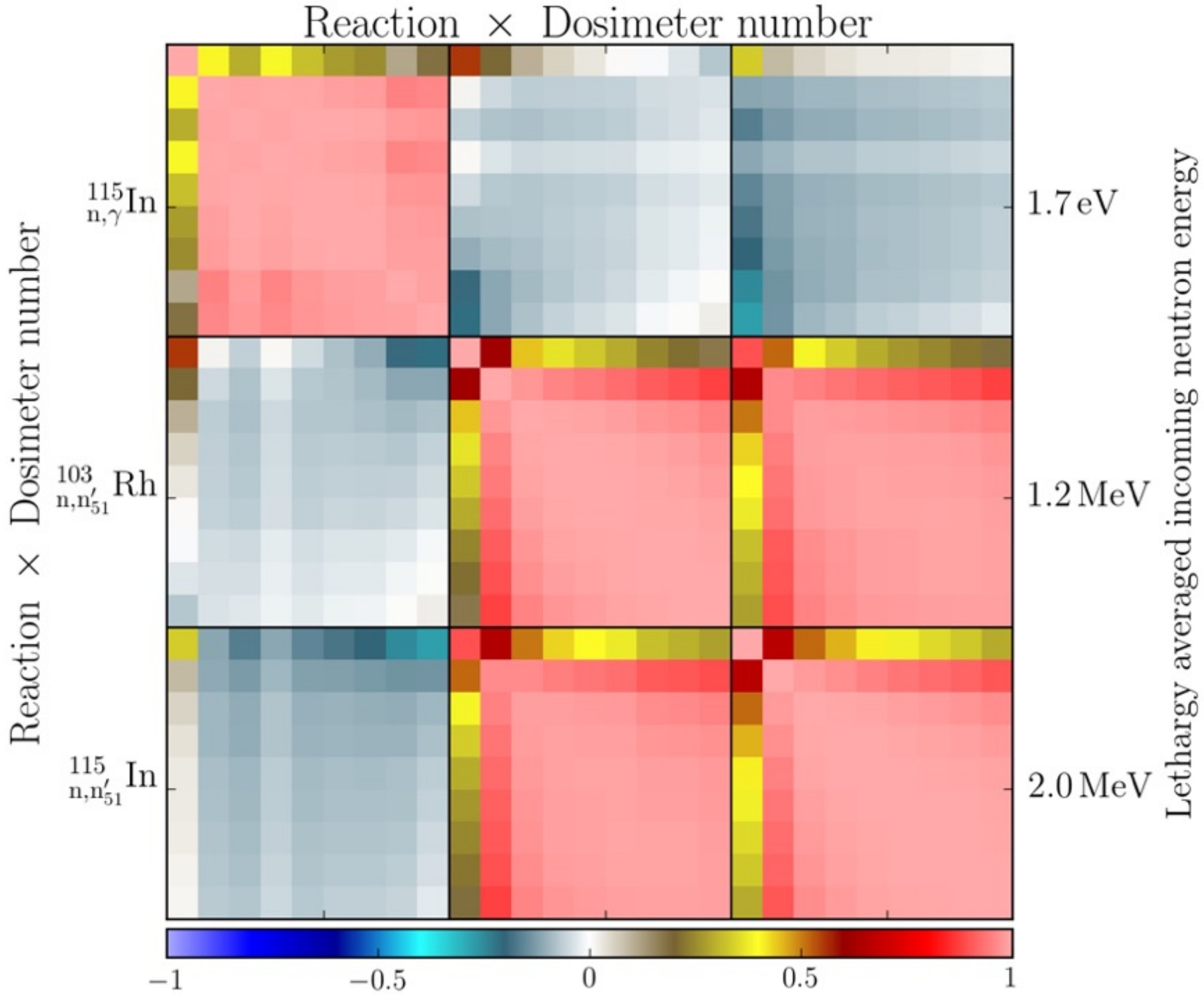


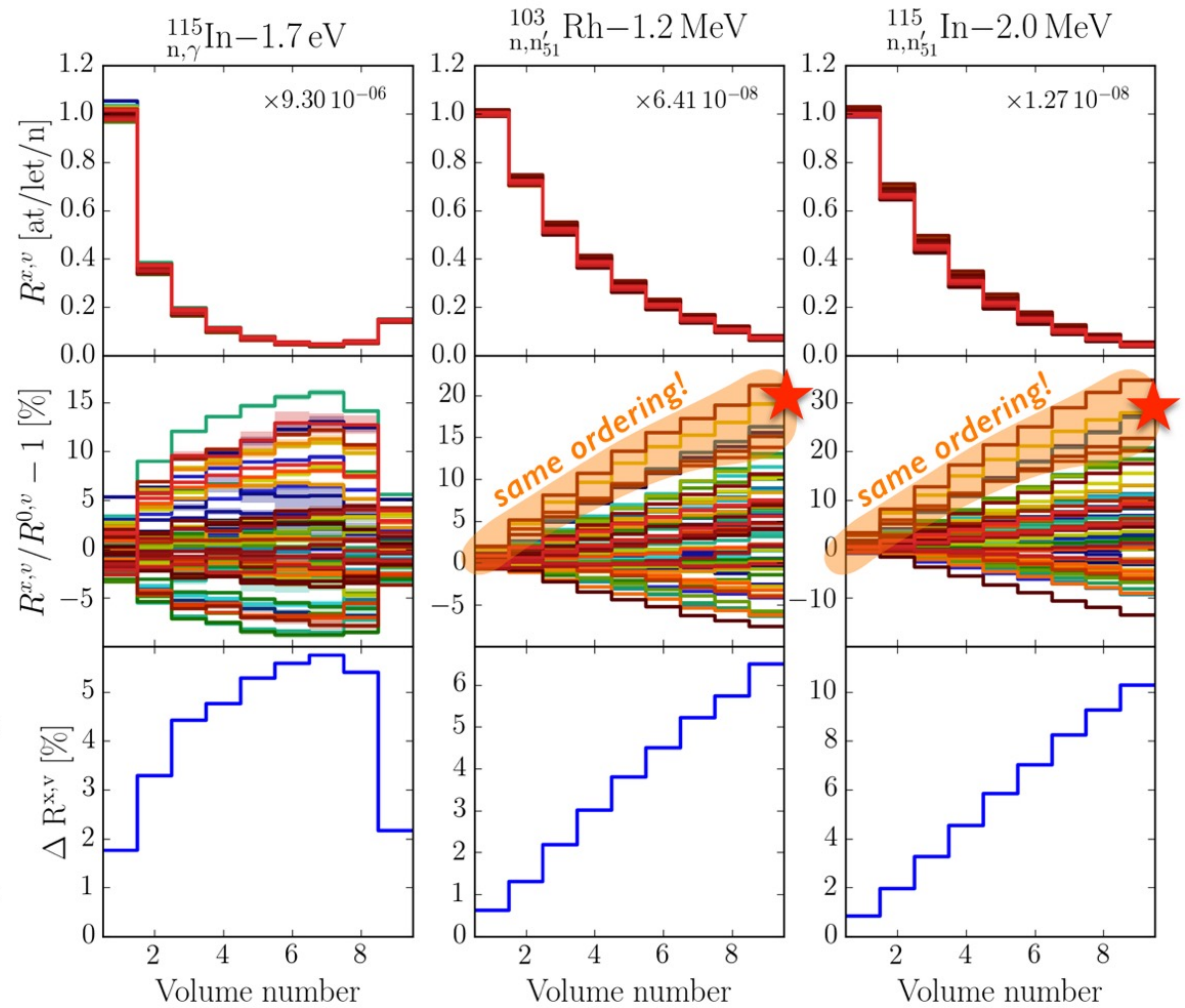
Inter-dosimeter correlation

Separation power

- Multiple dosimeters… all independant ?
- Rhodium-Indium inelastic threshold reactions: similar ordering

Dosimeter correlation matrix





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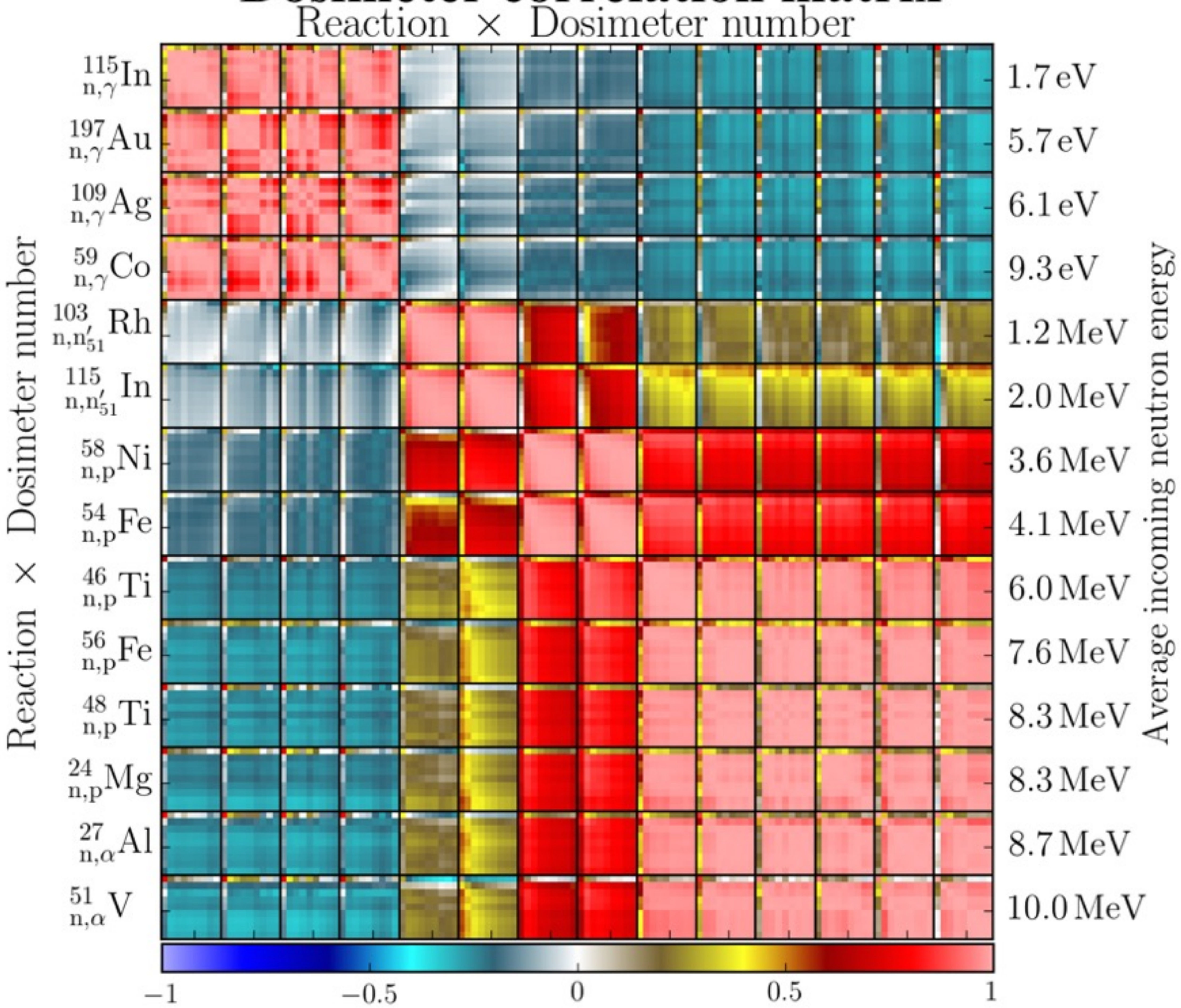
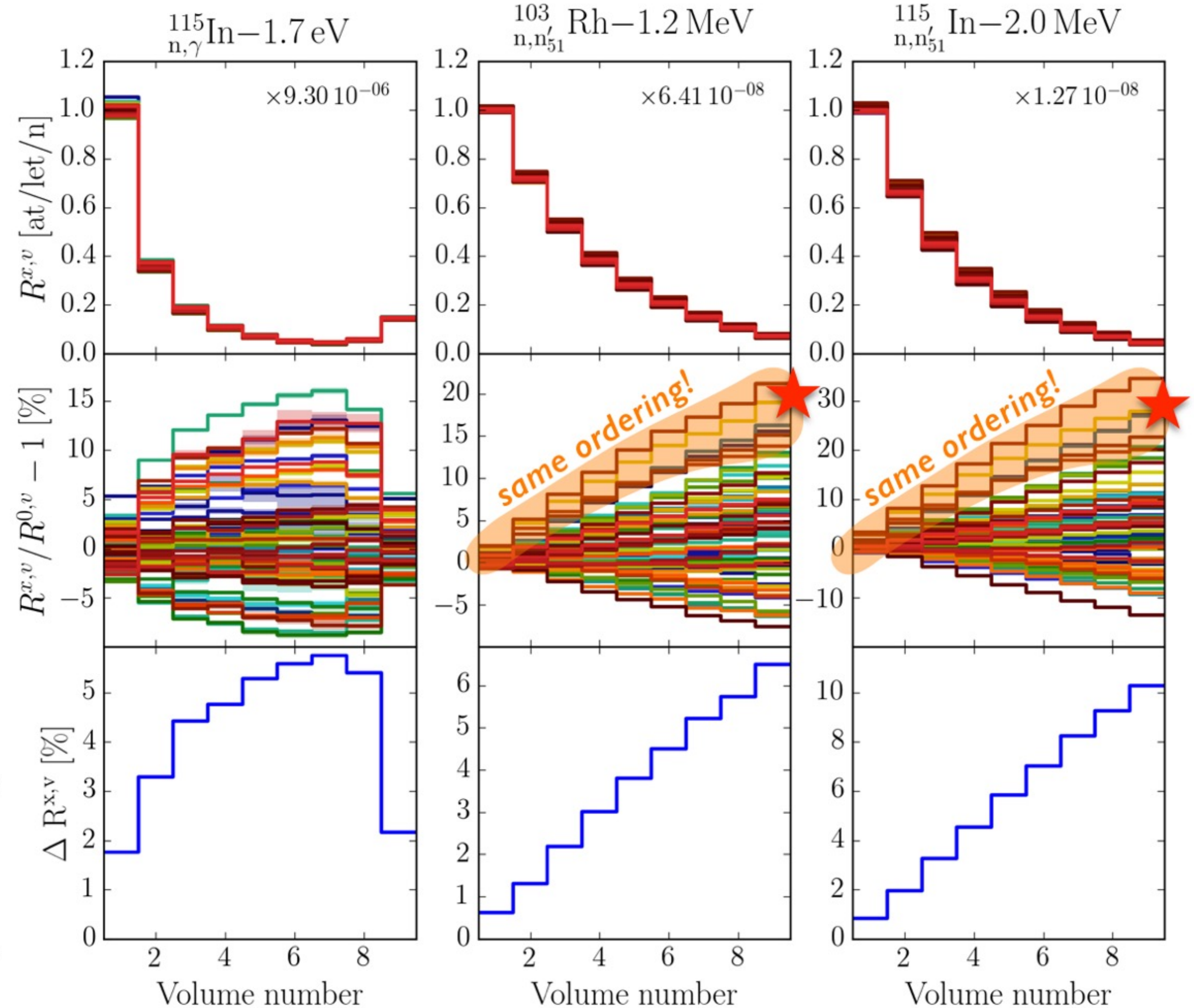
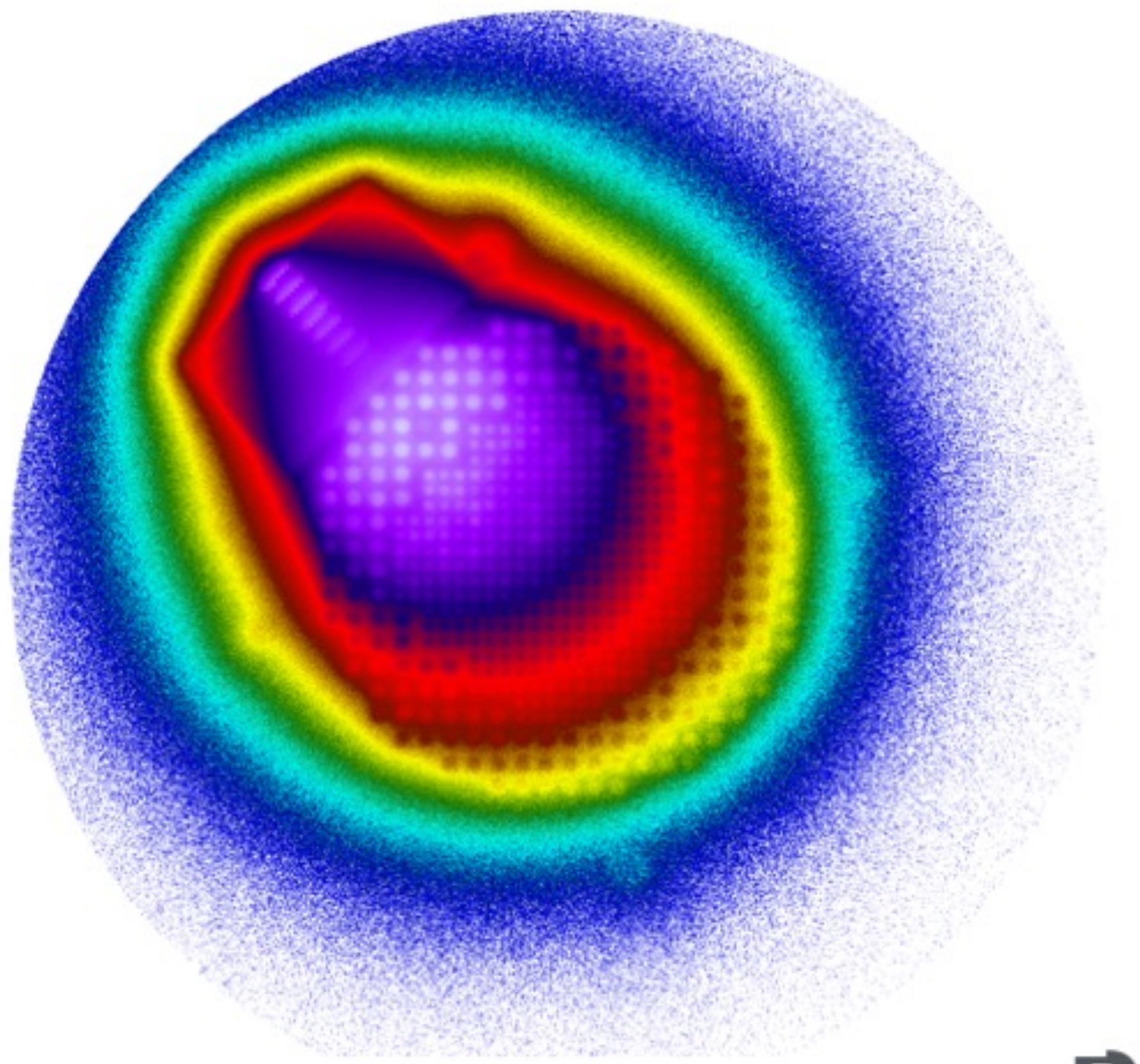




- Method generic for many dosimeters
- Important for dosimeter choice! ➞ see V. Lamirand presentation

Conclusion



Methodology

- The correlated sampling is nuclear data uncertainty propagation friendly

Results

- Approach usable for different systems HMI-001, CROCUS, …
- Helpful for observables with a small dispersion

Perspectives

- Apply BMC assimilation using TMC-CS
- Add ν, χ in the CS for fissionable isotopes & angular sampling
- Consider the angular dependance for the automatic biasing

Thank you for your attention!

Do you have some questions?

EUROfusion

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