The BLOOM program on stainless-steel at CROCUS

Thomas Ligonnet,
V. Lamirand

INDEN Consultancy Meeting 2025

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EPFL
- Laboratory for Reactor Physics and Systems Behaviour

The HARVEST-X project

*Heuristic Assimilation, Reproduction, and Validation of Experiments for stainless **STeel** Cross sections*

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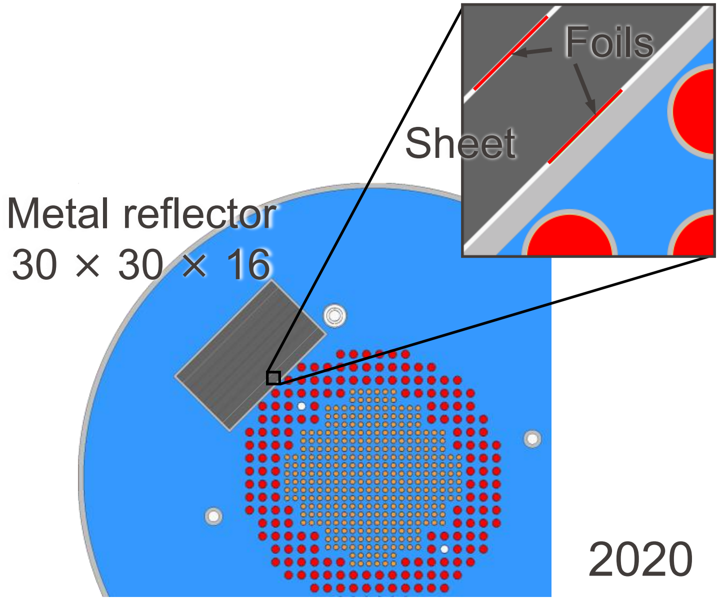
Analysis and assimilation of existing experimental data

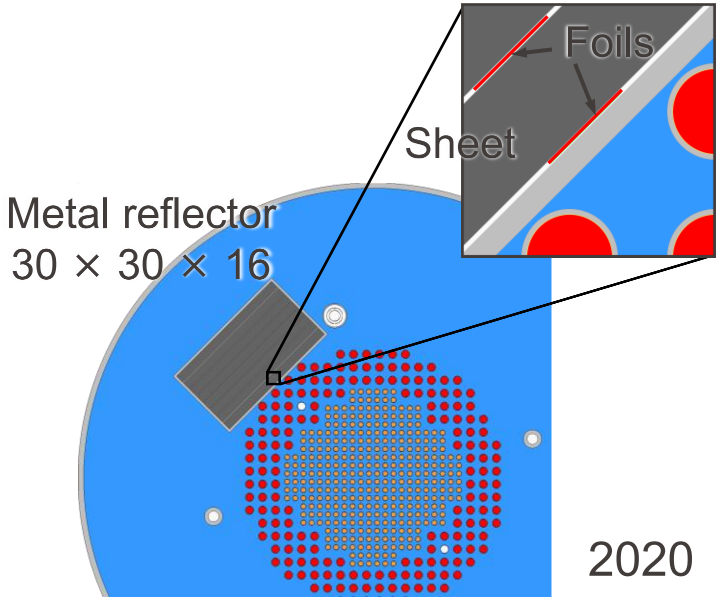
- Results and benchmarking of the **PETALE** program
    - Ongoing for submission to ICSBEP (UC Berkeley+EPFL+LLNL)



Ligonnet, Thomas, et al. "High-Resolution Modeling Without Computation Slowdown for PETALE in CROCUS." *Nuclear Science and Engineering* 199.(2025)
V. Lamirand et al., “Design of separated element reflector experiments in CROCUS: PETALE,” React. Dosim. 16th Int. Symp. ASTM STP1608, p. 7, 2018.
V. Lamirand, T. Ligonnet, A. Laureau, A. Vasiliev, A. Pautz, “HARVEST-X – Heuristic Assimilation…” SNSF proposal, 2022.

The HARVEST-X project

Heuristic Assimilation, Reproduction, and Validation of Experiments for stainless ***STeel*** *Cross sections*



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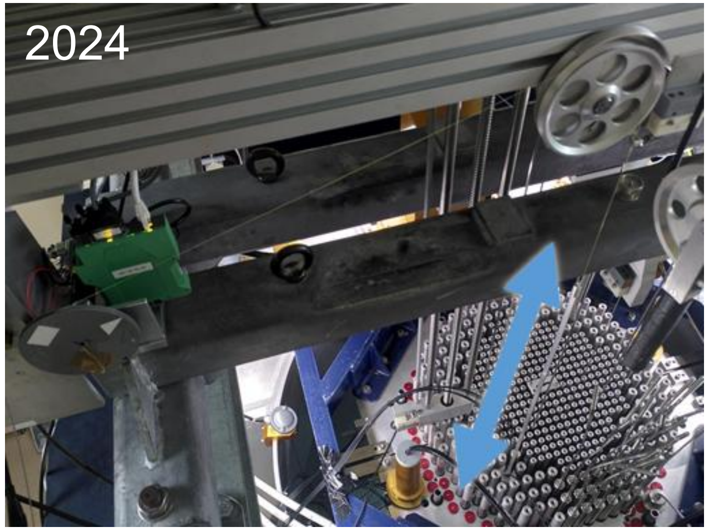


Production and analysis of new complementary experimental results, allowing to tackle biases

- Reproduction with **other systems**
- Reproduction with **other methods**
  - **Pile-oscillation experiments in CROCUS: BLOOM**

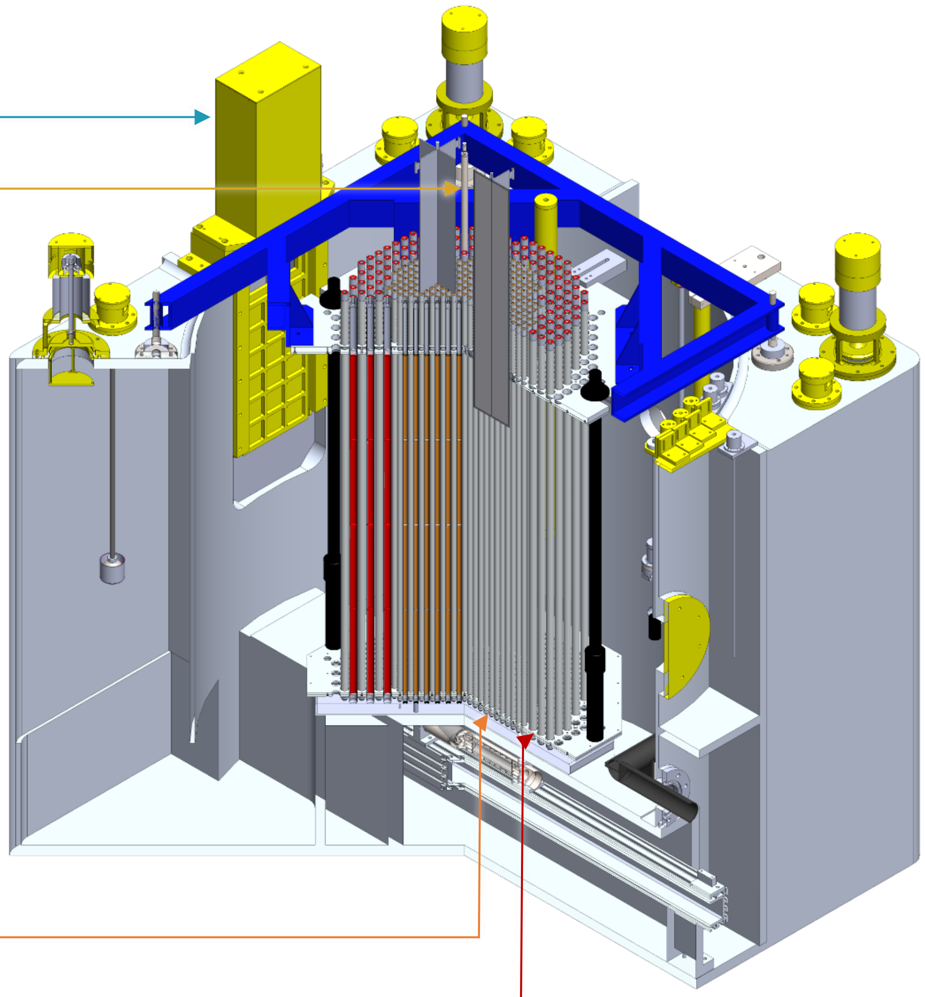
Ligonnet, Thomas, et al. "Pile-oscillation results for stainless steel with local and 3D global measurements." *EPJ Web of Conferences*. Vol. 338. EDP Sciences, 2025.
Ligonnet, Thomas, et al. "Design of an Open-Loop Pile-Oscillation Program in the CROCUS Reactor." *IEEE Transactions on Nuclear Science* 71.5 (2024): 1001-1009.
Ligonnet, Thomas, et al. "POLLEN: A pile-oscillator for the Bloom experimental program." *EPJ Web of Conferences*. Vol. 288. EDP Sciences, 2023.

The CROCUS reactor

Reactor type
- LWR with partially submerged core
- Room T (controlled) and atmospheric P
- Forced water flow (160 $l.min^{-1}$)

Operation
- 100 W (zero-power reactor)
- i.e. maximum 2.5×10^9 $cm^{-2}.s^{-1}$
- Control: B_4C rods and spillway

Core
- ⌀60 cm/100 cm, 2-zone
- Inner: 336 UO_2 1.806 wt% 1.837 cm
- Outer: 176 U_{met} 0.947 wt% 2.917 cm



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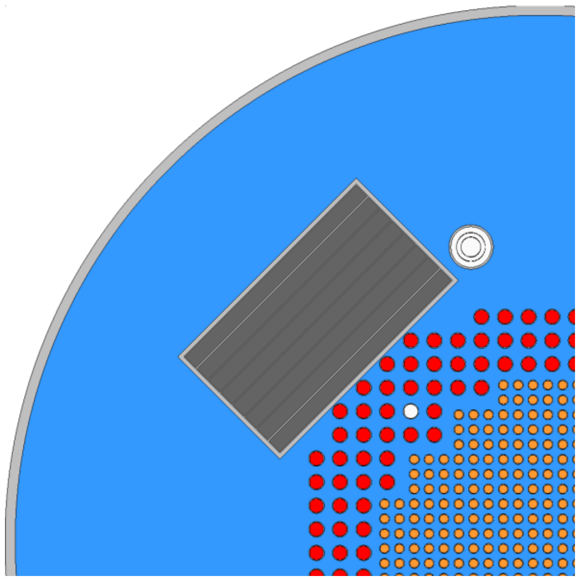
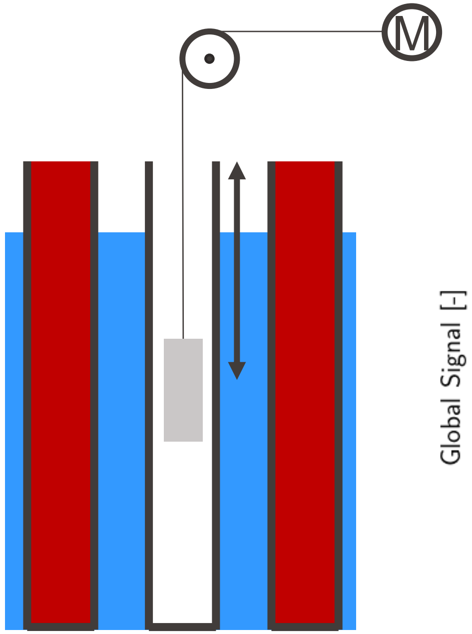
U. Kasemeyer *et al.*, “Benchmark on Kinetic Parameters in the CROCUS Reactor,” in IRPhE, no. 4440, OECD, Ed. 2007, p. 94
J. M. Paratte *et al.*, “A benchmark on the calculation of kinetic parameters based on reactivity…,” Ann. Nucl. Energy, vol. 33, no. 8, pp. 739–748, May 2006

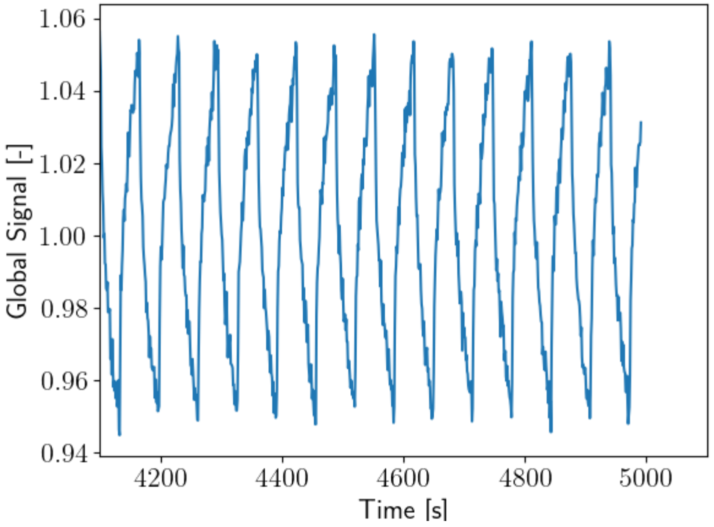
The BLOOM program in CROCUS

Reproduction of PETALE critical experiments

- Same materials/system/QoI **but** different method: pile oscillation (open loop)
- **Quantities of interest:**
  - Reactivity worth







Global

The BLOOM program in CROCUS

Reproduction of PETALE critical experiments

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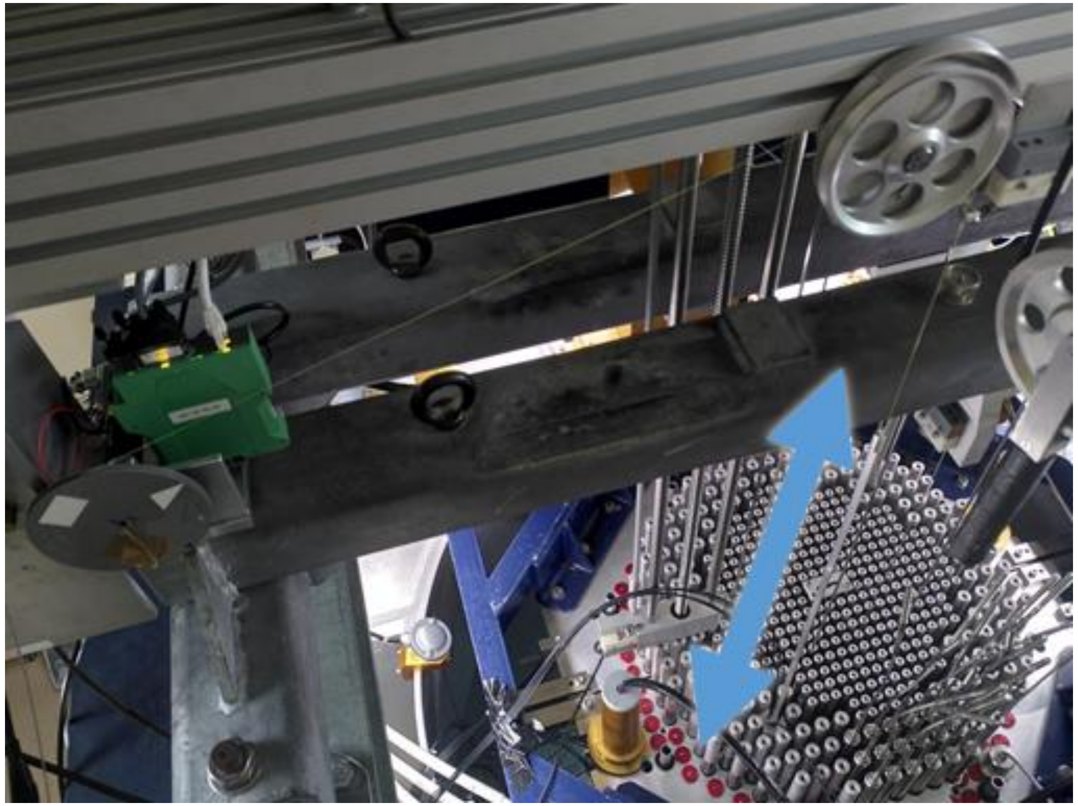
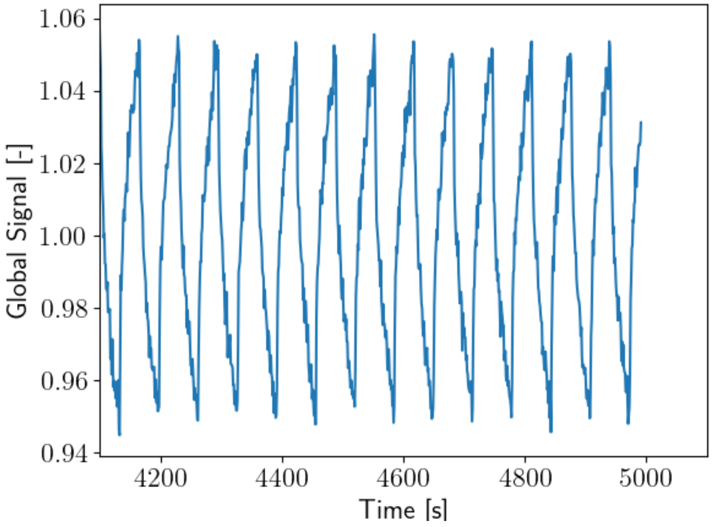




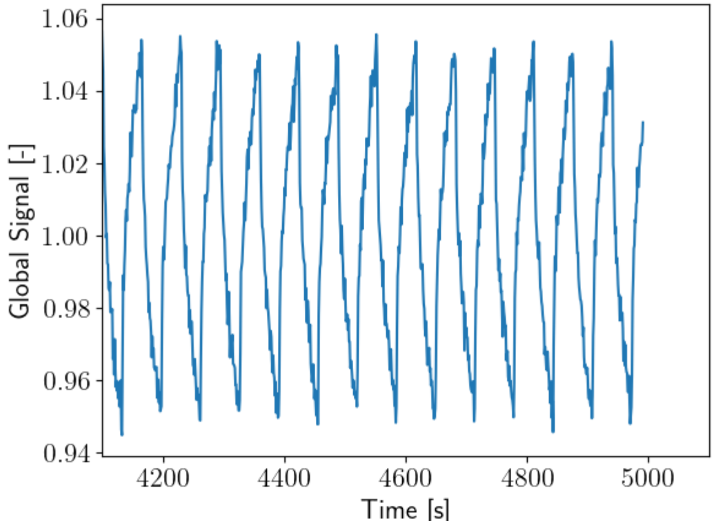
Global → Reactivity

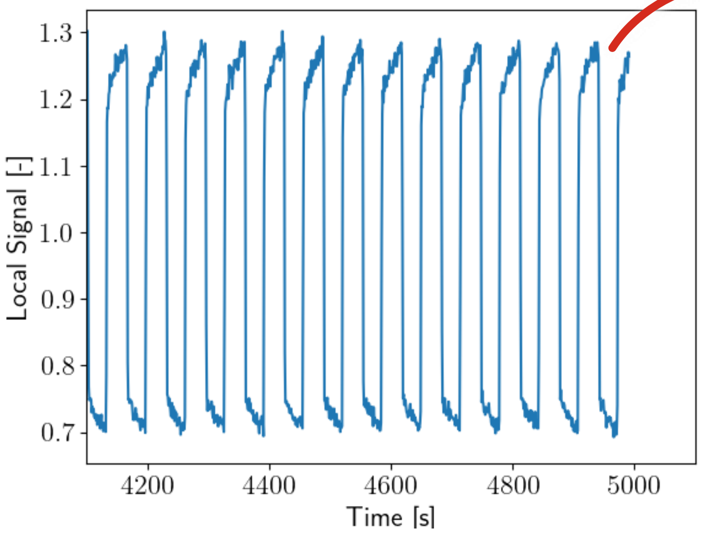
The BLOOM program in CROCUS

BLOOM

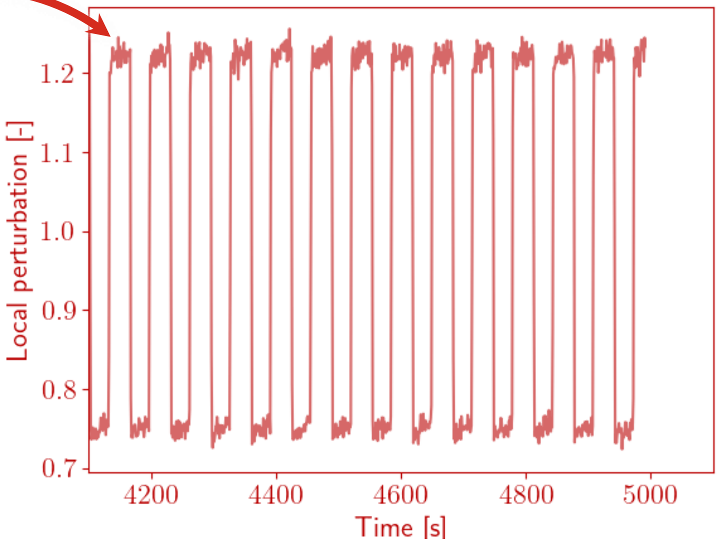
Reproduction of PETALE critical experiments

- Same materials/system/QoI **but** different method: pile oscillation (open loop)
- **Quantities of interest:**
  - Reactivity worth
  - Local flux perturbation





- Global



Global → Reactivity

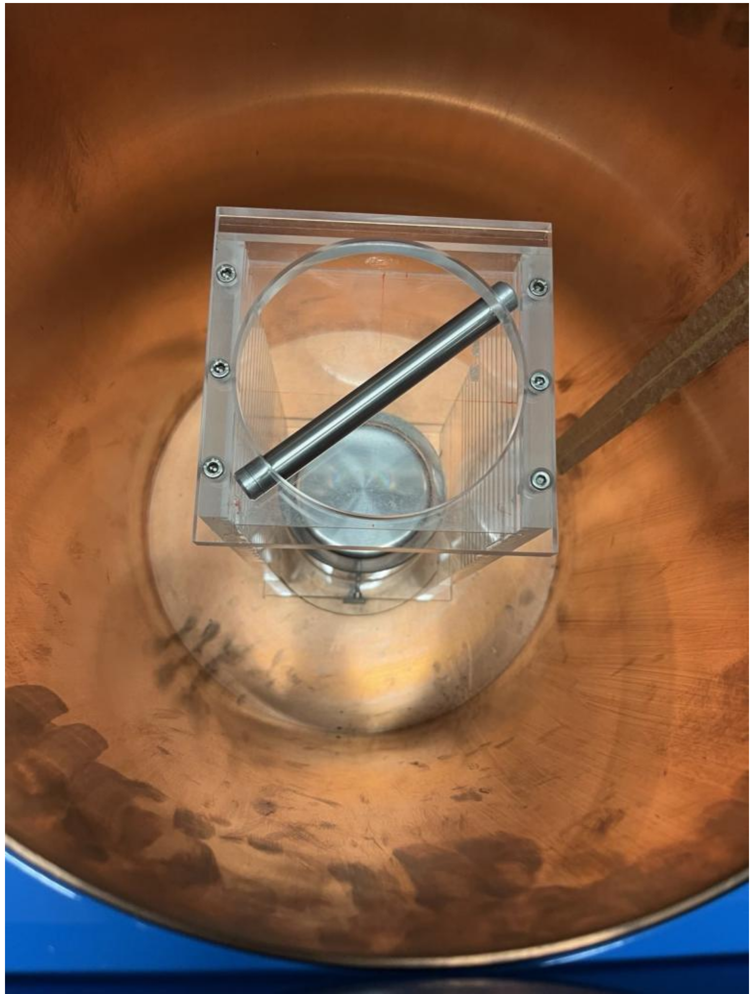
Local signal → Local perturbation

The BLOOM program in CROCUS

BLOOM

Reproduction of PETALE critical experiments

- Same materials/system/QoI **but** different method: pile oscillation (open loop)
- **Quantities of interest:**
  - Reactivity worth
  - Local flux perturbation
  - Sample activation



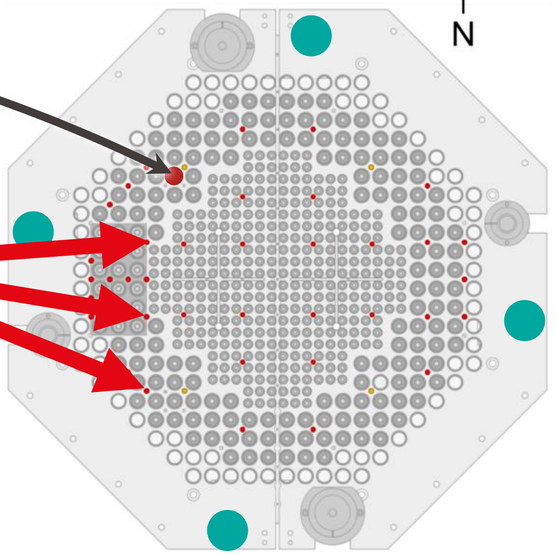
Global and distributed flux: SAFFRON array

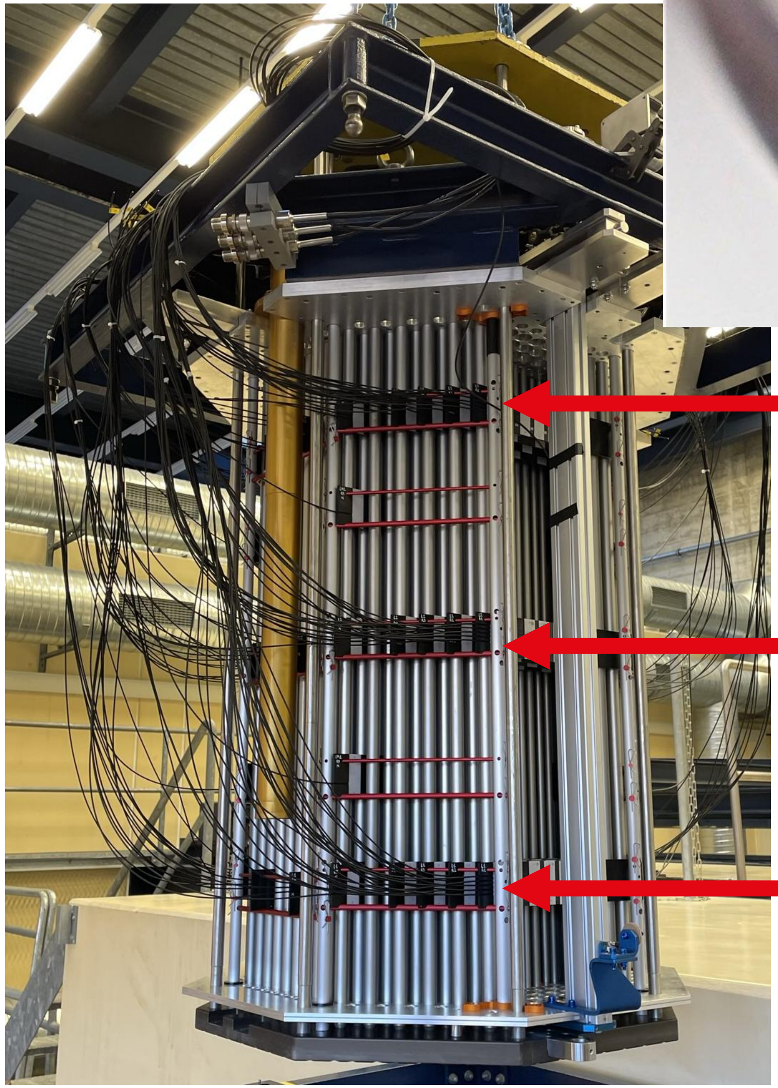
3D array of MiMi detectors in CROCUS

- Developed by Fanny Vitullo during her PhD
- Array of 160 MiMi neutrons detectors
- Mapping of the core: 3 main axial layers
- **~240 kcps/W** over many detectors
  - Perfect for global signal measurement
  - Allows **testing the validity of PK assumption**

Oscillation channel

~50 per level





Axial levels

Vitullo, Fanny. *Miniature and Minimalistic Neutron Detectors for Online High-Resolution Experiments in the Zero-Power Reactor CROCUS*. No. THESIS. EPFL, 2022.

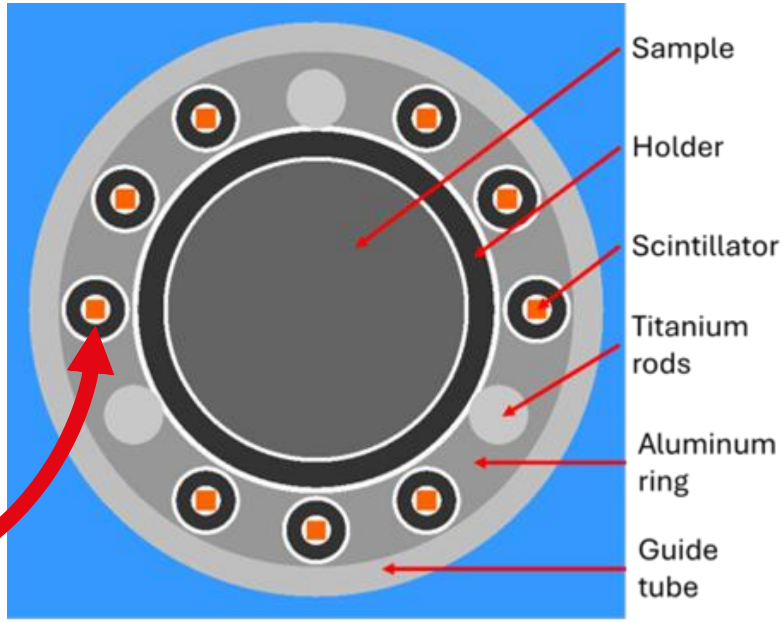
EPFL

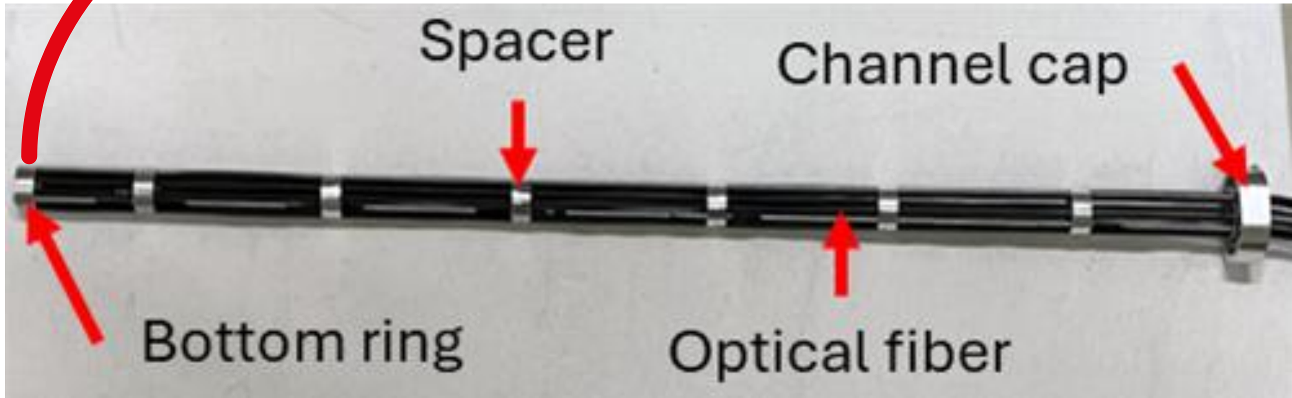
Local flux: instrumented channel

SAFFRON BLOOM

Global & **local** measurements

- Set in the control rod guide tube
  - Air filled
- Aluminum for rings and holder
  - With titanium rods for mechanical stability
- Instrumented with a ring of 9 MiMis
  - **~25 kcps/W for the local signal**
  - At 2.1 mm from sample surface
  - Placed at core mid-height
- Sample diameter up to 10.25 mm
  - Possibly up to 12 mm without a holder





Studied materials: stainless steel & more

Focus on stainless-steel related samples

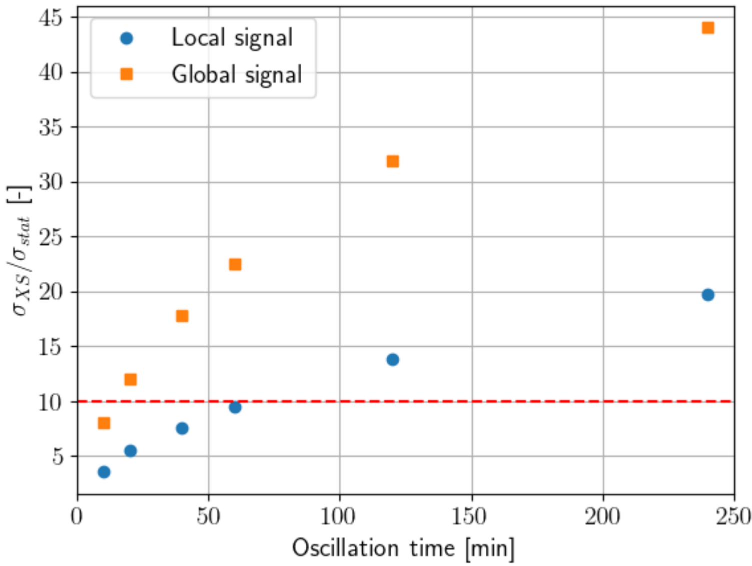
- Reuse of **PETALE spares** for main components
  - Fe, Ni, Cr, 304L
- Additional minor alloying elements
  - C, Mn, Mo, Nb, Si, V, Zn
- Exotic alloying elements and other materials of interest
  - Al, Cu, Ta, Ti, W, Y
  - 304, 316, Incoloy-800, Incoloy-718
- Reference materials
  - **Au**, D_2O, H_2O, ^6Li (solution), ^{10}B (solution)

Totaling 25 materials and 40 samples

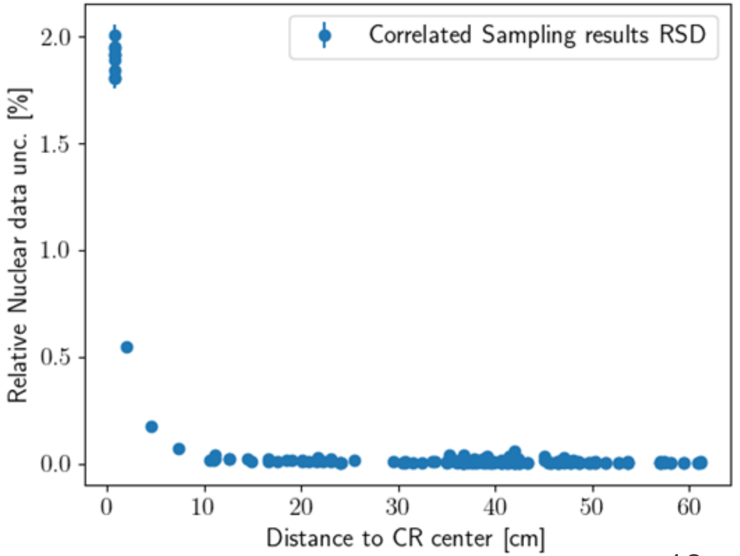
Design by uncertainty propagation

- Objective: factor 10 between Exp. and ND uncertainties
  - Iron sample
- Main limitations
  - Strict max power: 1.1 W
  - Sample diameter: ⌀16 mm/⌀10 mm with detector ring

3 W / ⌀16 mm

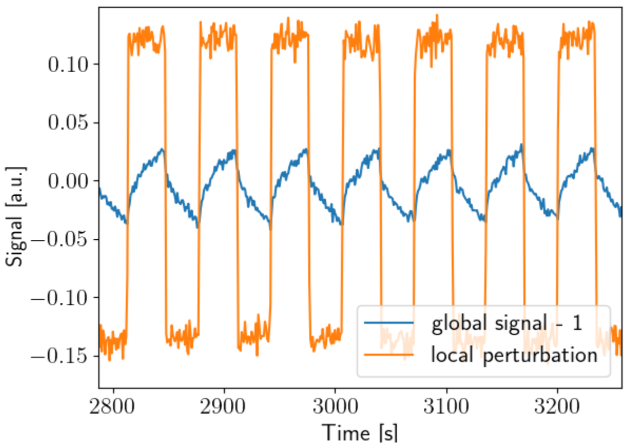


- Design results
  - Averaged operation power: 0.9 W
  - Oscillation period: 64.8 s
  - Duration: 1h30
  - Minimum achievable uncertainty: 0.02 pcm
- Uncertainty estimates for iron (JEFF-3.3)
  - Local: $\sigma_{ND} = 1.9\% \leftrightarrow \sigma_{Exp} = 0.04\%$ **×50**
  - Global: $\sigma_{ND} = 2.8\% \leftrightarrow \sigma_{Exp} = 0.25\%$ **×10**

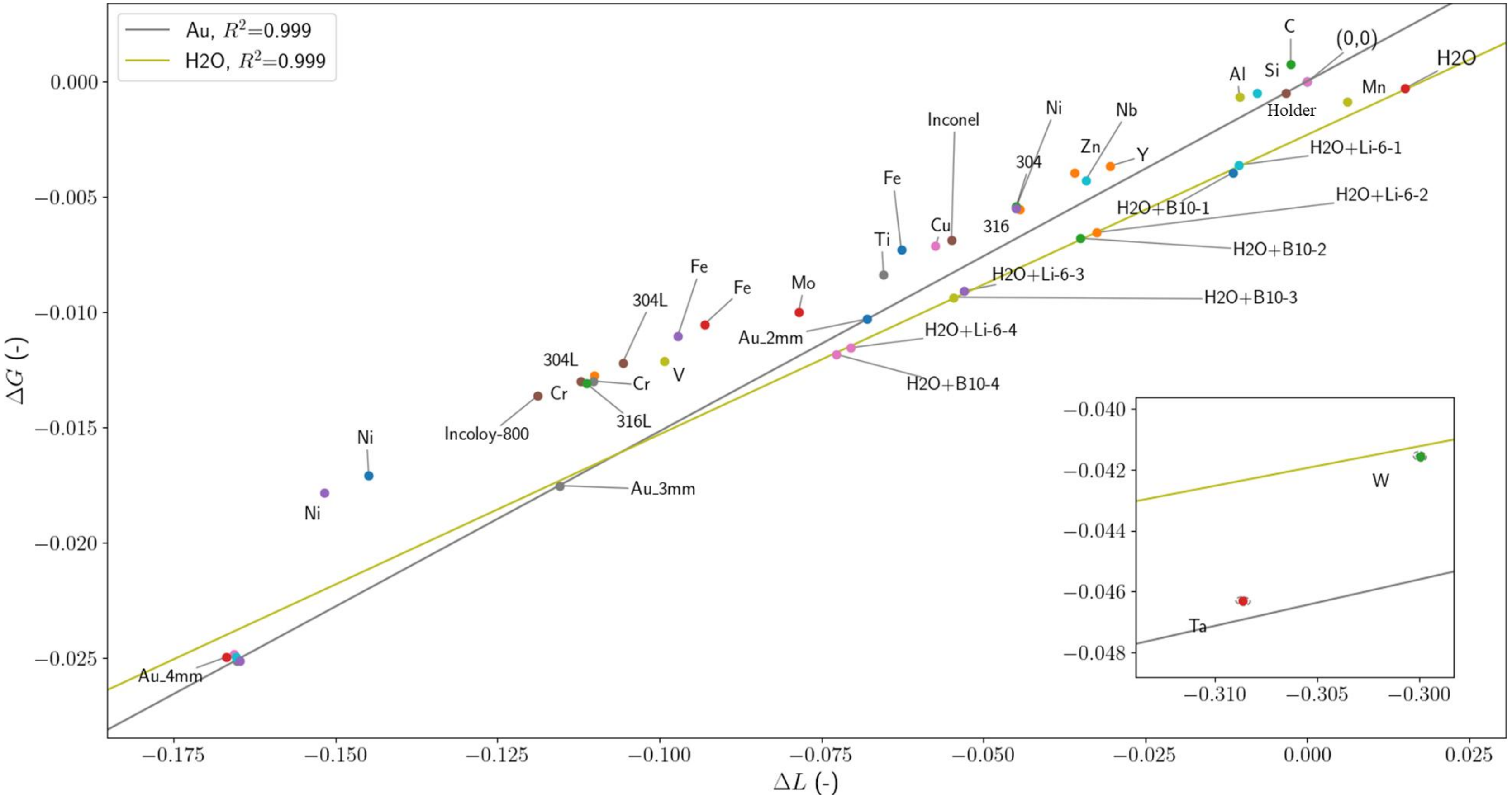


Global vs. Local

- 45 experiments
  - 1h30 of oscillation at ~0.9 W each
  - Mostly absorbers
- Global perturbation amplitude ΔG vs. local one ΔL[1]



25 materials
40 samples

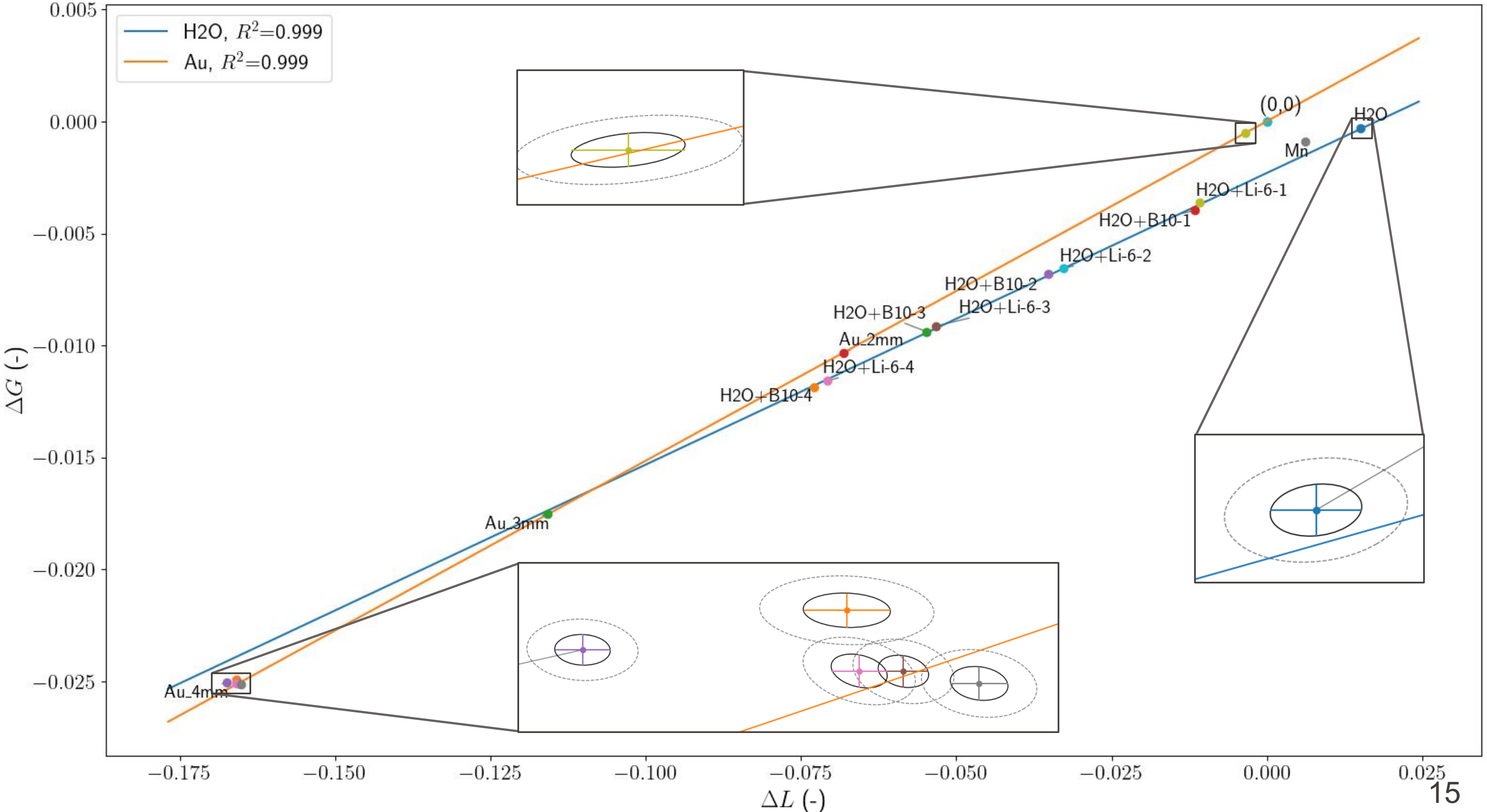


1. Geslot, Benoit, Adrien Gruel, Stéphane Bréaud, Pierre Leconte, and Patrick Blaise. "Innovative Hybrid Pile Oscillator Technique in the Minerve Reactor: Open Loop Versus Closed Loop." *IEEE Transactions on Nuclear Science* 65, no. 11 (November 2018): 2767–75. https://doi.org/10.1109/TNS.2018.2874690.

Proportionality for H_2O and Au references

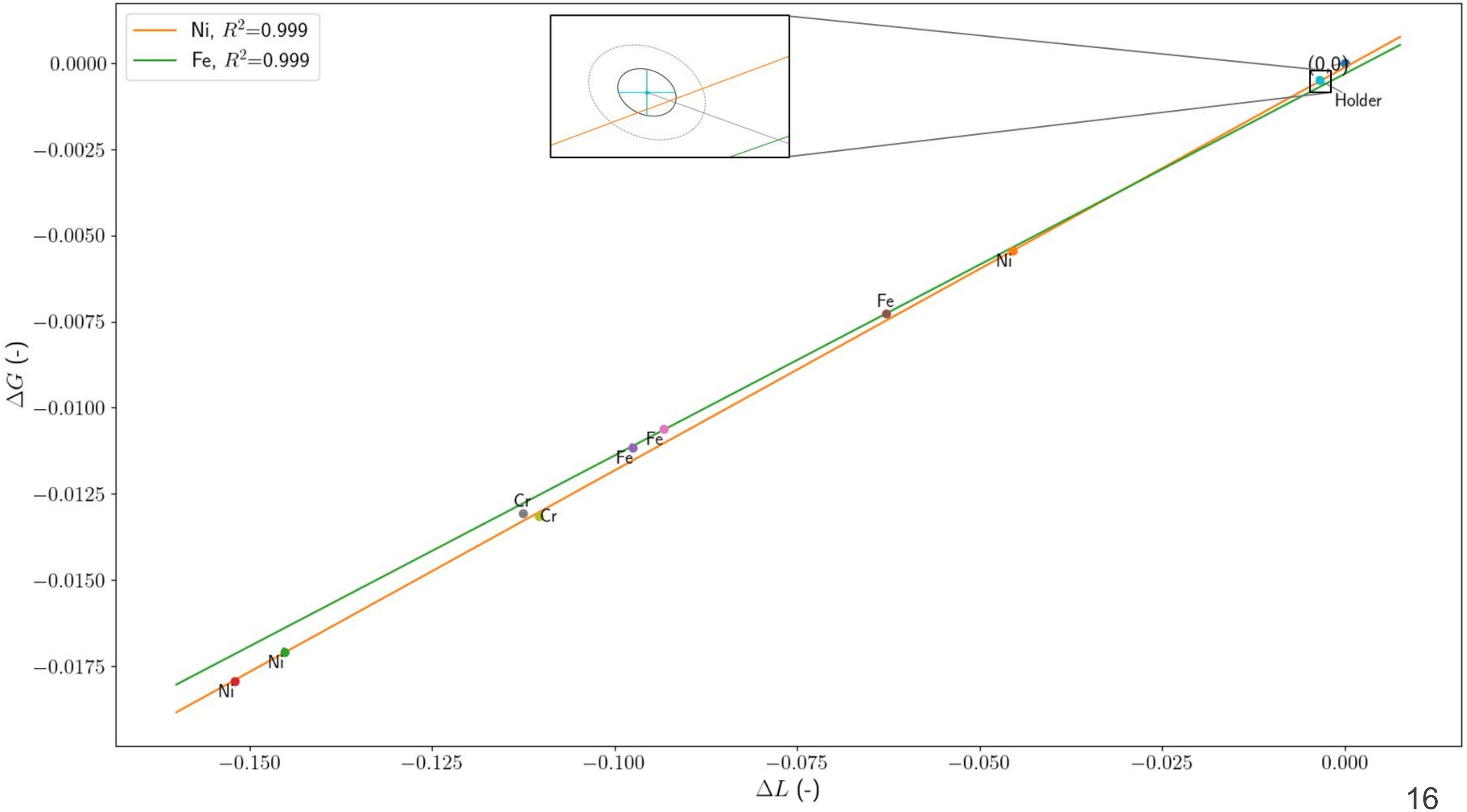
- Reproduction of past reference experiments
- A Linear relationship is observed between the perturbation
  - 8 samples with different concentrations of ^{10}B or ^{6}Li
  - 3 gold samples with different diameters

METHOD VALIDATED



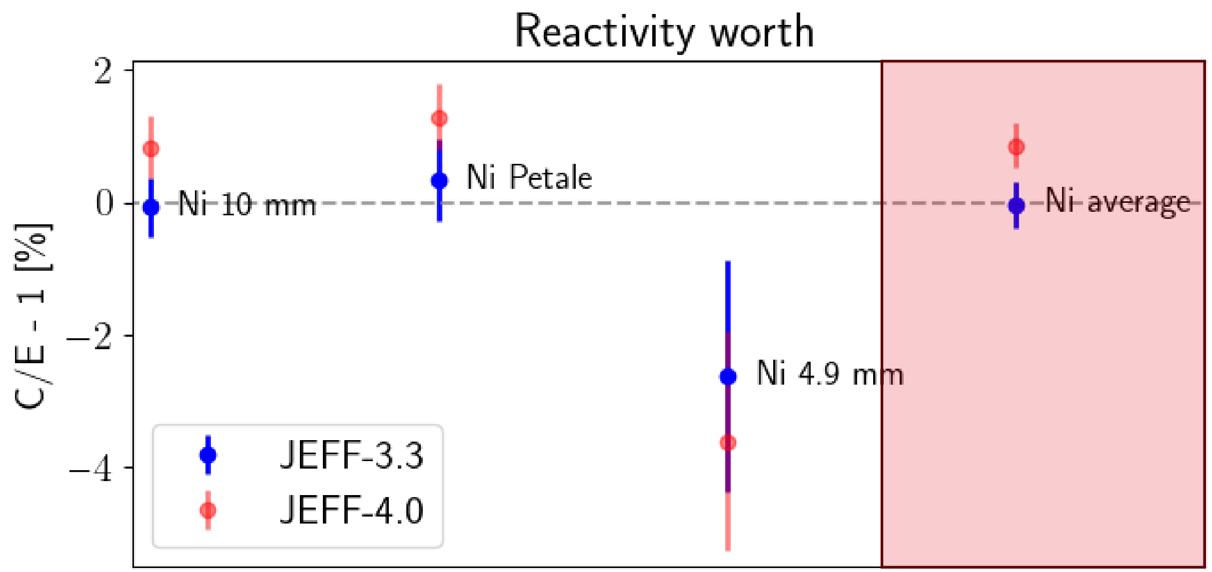
Proportionality for Fe and Ni samples

- Linear behaviour also observed for other elements
  - Nickel sample in agreement with the empty sample
  - Iron sample at four experimental standard deviation
    - Fitting uncertainty increased by the closeness in space



How-to: results presentation

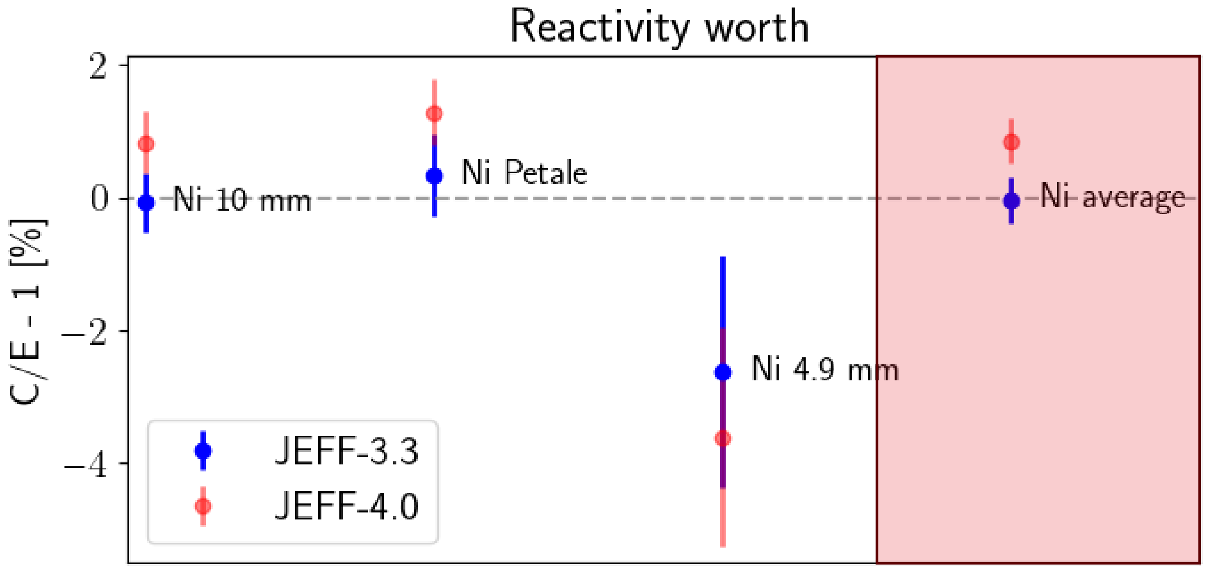
- Full model XS changed
  - Blue: JEFF-3.3
  - Red: JEFF-4.0
- Measurement uncertainties:
  - ~0.02 pcm
- Black Body Exact Perturbation sim.
  - Uncertainty 0.04 pcm
    - ~30h on a large workstation
- Inverse Variance weighted average



From JEFF-3.3 to JEFF-4.0: Ni

C/E for nickel pile-oscillation experiments

- Nickel C/E seems to degrade
  - C/E Increase of +1 %
  - From agreement to disagreements
  - Degradation of Ni was also observed with PETALE non-threshold

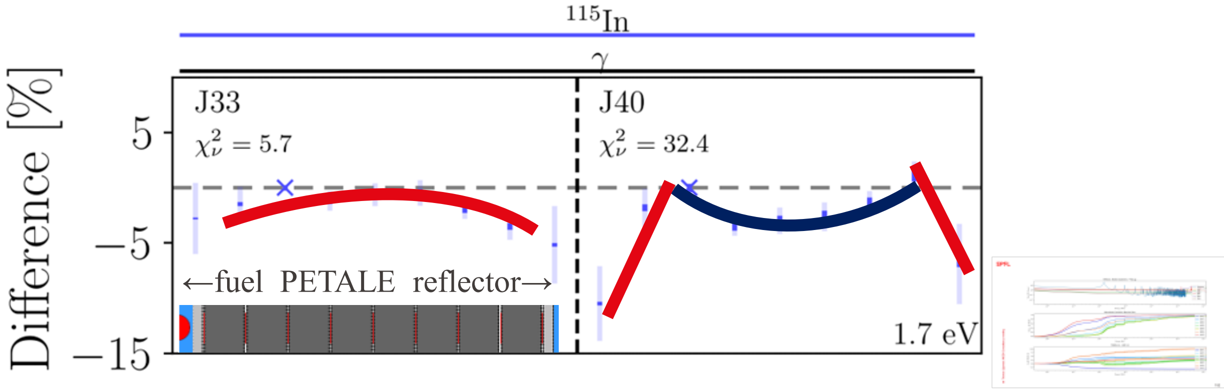


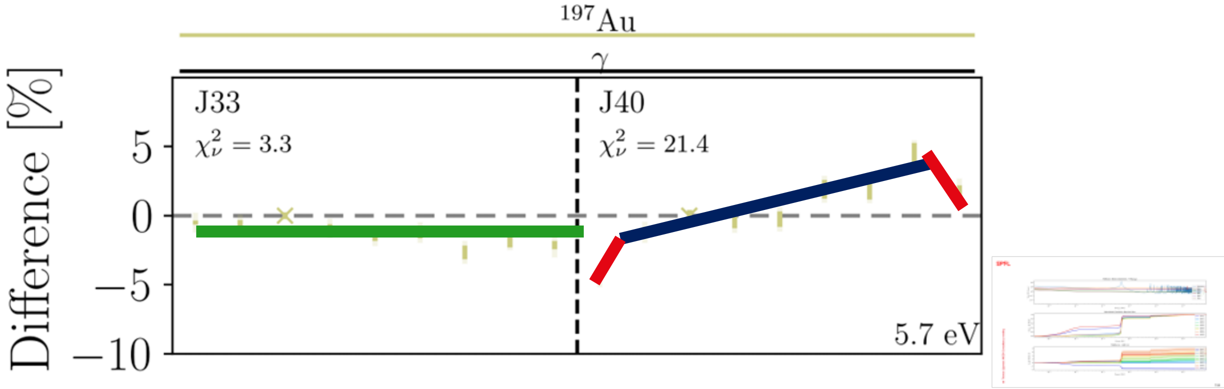
Ni

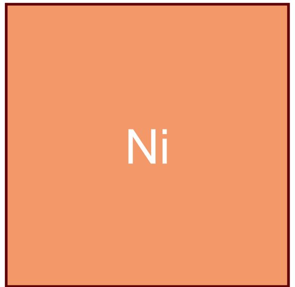
From JEFF-3.3 to JEFF-4.0: Ni

C/E for nickel transmission experiments

- Magnified drops at the reflector edges
- Gradual increase with depth







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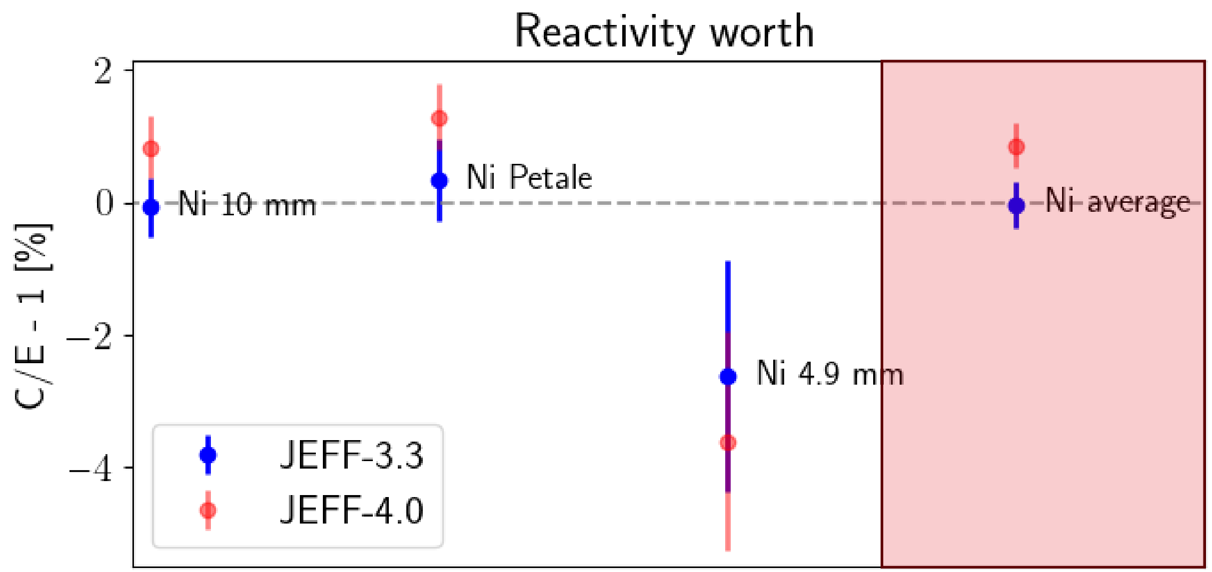


Ni

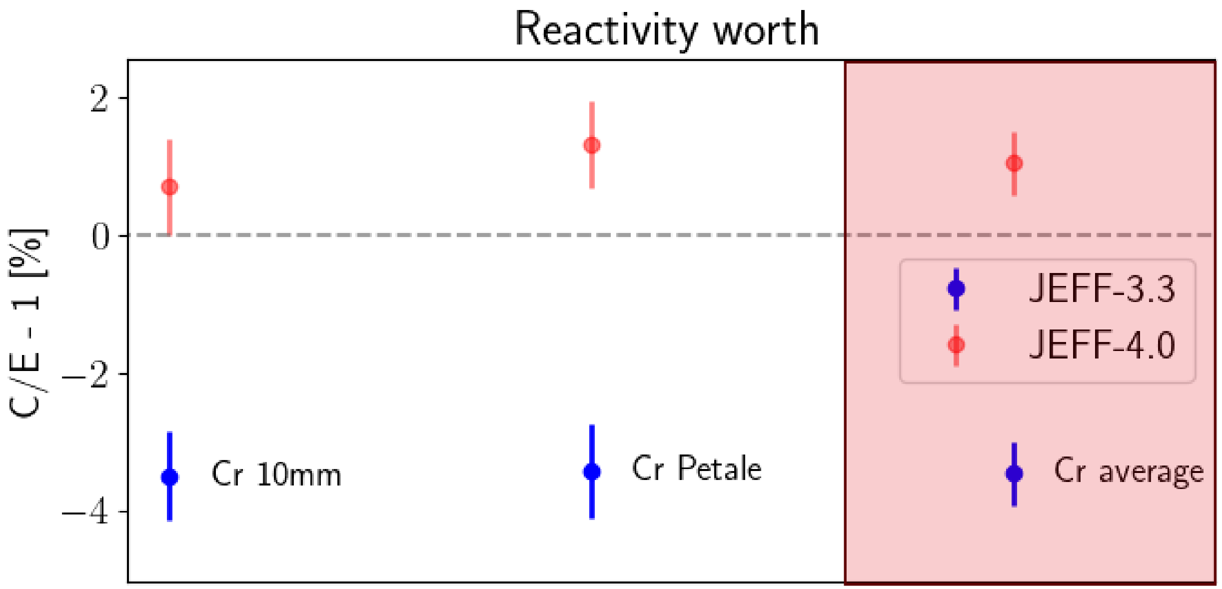
PETALE: degradation in thermal, same with fast

→ BLOOM: slight degradation

From JEFF-3.3 to JEFF-4.0: Cr

C/E for chromium pile-oscillation experiments

- Clear improvement of the C/Es
  - From -3.5 % to +1 %
  - ~ 2 sigma distance from experiments with JEFF-4.0
  - Unlike PETALE results
    - Degradation of non-threshold dosimeters

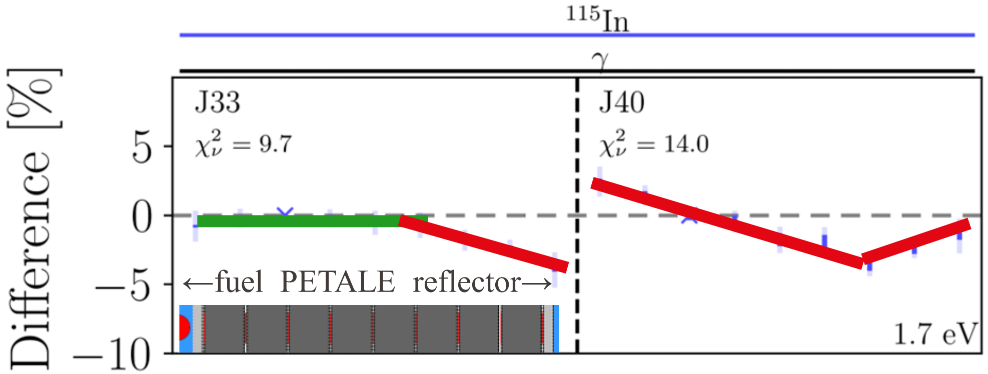


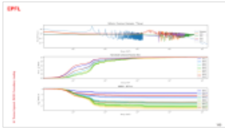
Ni | Cr

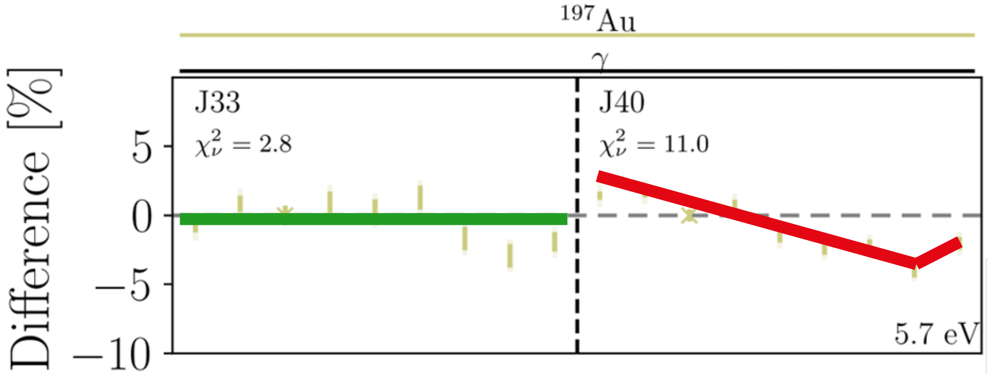
From JEFF-3.3 to JEFF-4.0: Cr

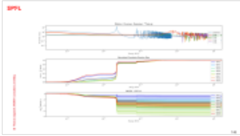
C/E for chromium transmission experiments

- A trend appeared in the near thermal range for chromium
  - Visible with both experiments
  - Degraded χ^2_ν









Ni	Cr

From JEFF-3.3 to JEFF-4.0: Cr

C/E for chromium pile-oscillation experiments

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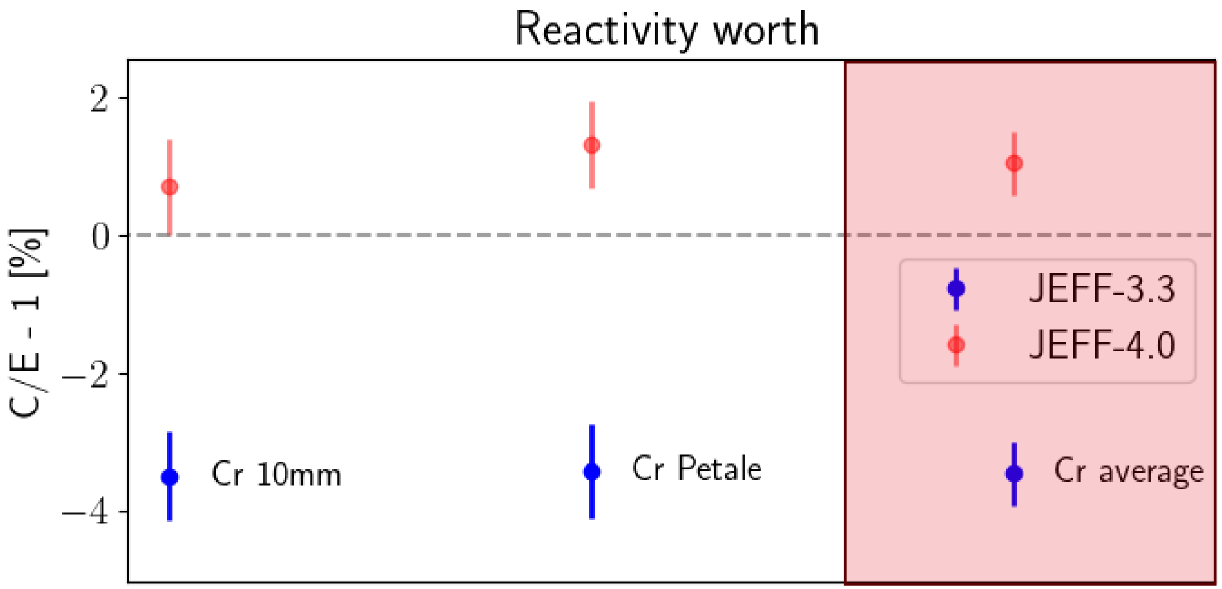


Ni	Cr

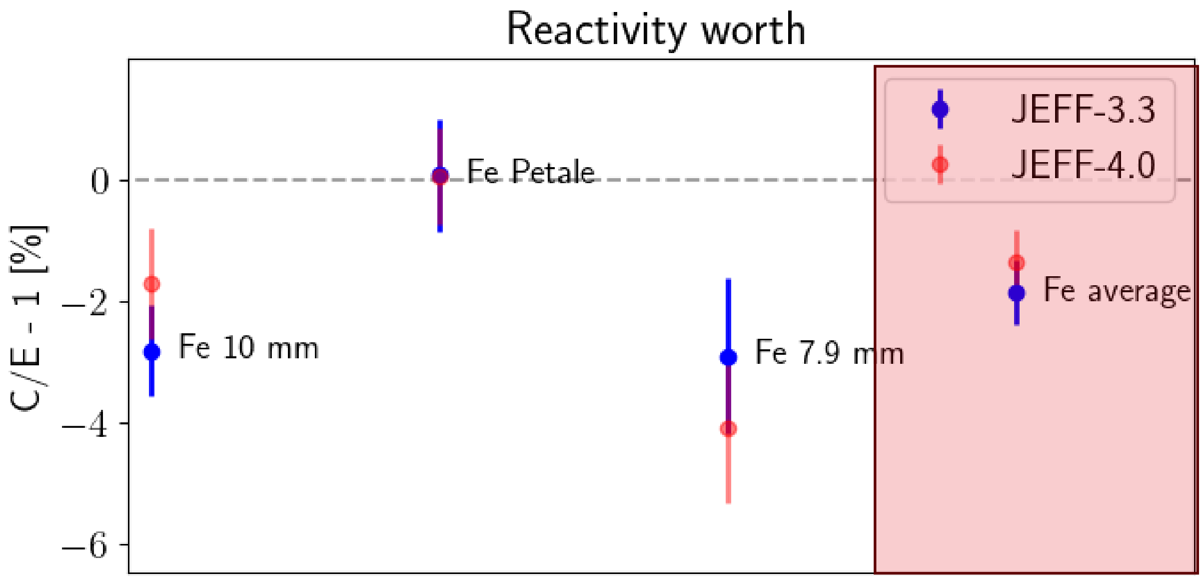
PETALE: slightly better @2 MeV, worse for non-threshold

→ BLOOM: Clear improvement

From JEFF-3.3 to JEFF-4.0: Fe

C/E for iron pile-oscillation experiments

- No statistically significant differences
  - Similar to PETALE non-threshold
  - Averaged results at >2σ from 0
  - Close to JEFF-3.1.1 in MAESTRO
    - 0.3 ± 1.2 %*
  - Smaller uncertainties needed (sim.)



Ni | Cr | Fe

*Gilles NOGUERE, private communication

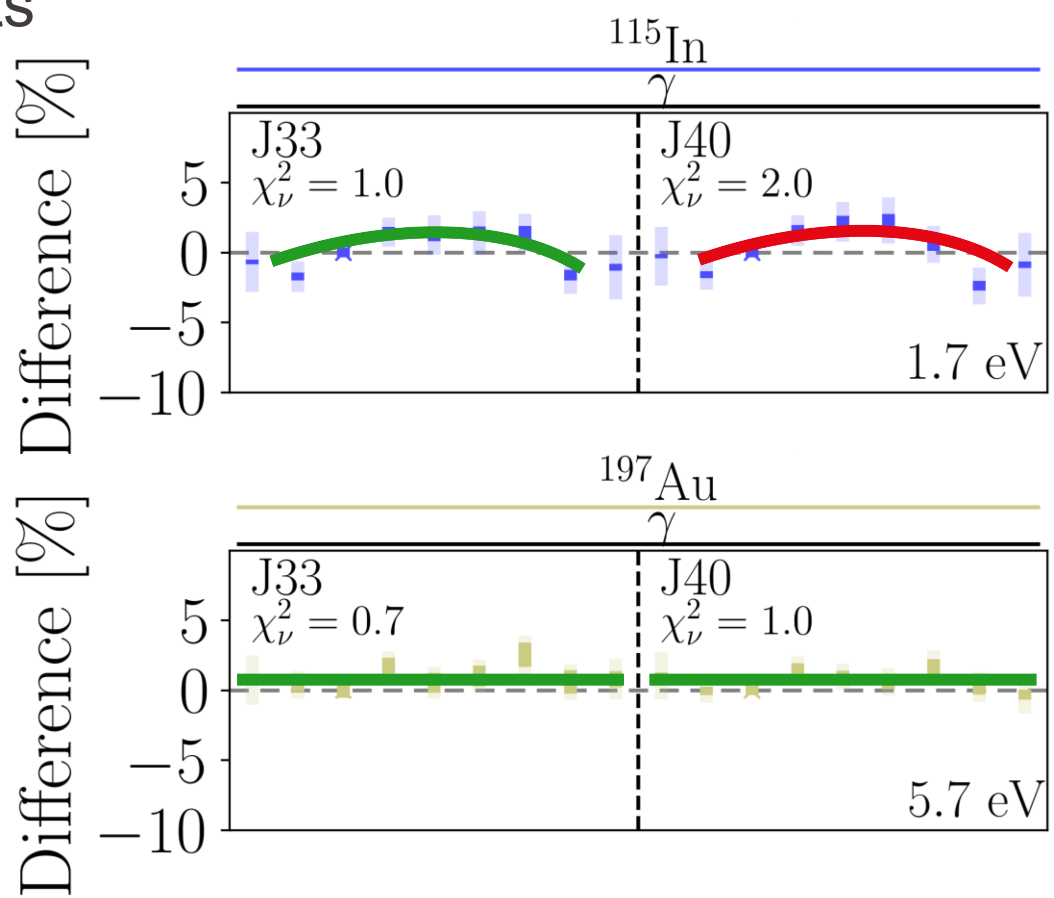
EPFL

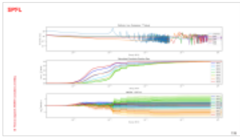
From JEFF-3.3 to JEFF-4.0: Fe Reflectors

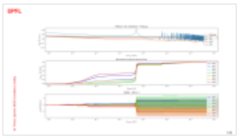
PETALE

C/E for iron transmission experiments

- ^{115}In(n,g) is slightly less consistent
  - χ^2_ν from 1.0 to 2.0
- ^{197}Au(n,g) in agreement with the experimental data
  - Flat C/E







Fe

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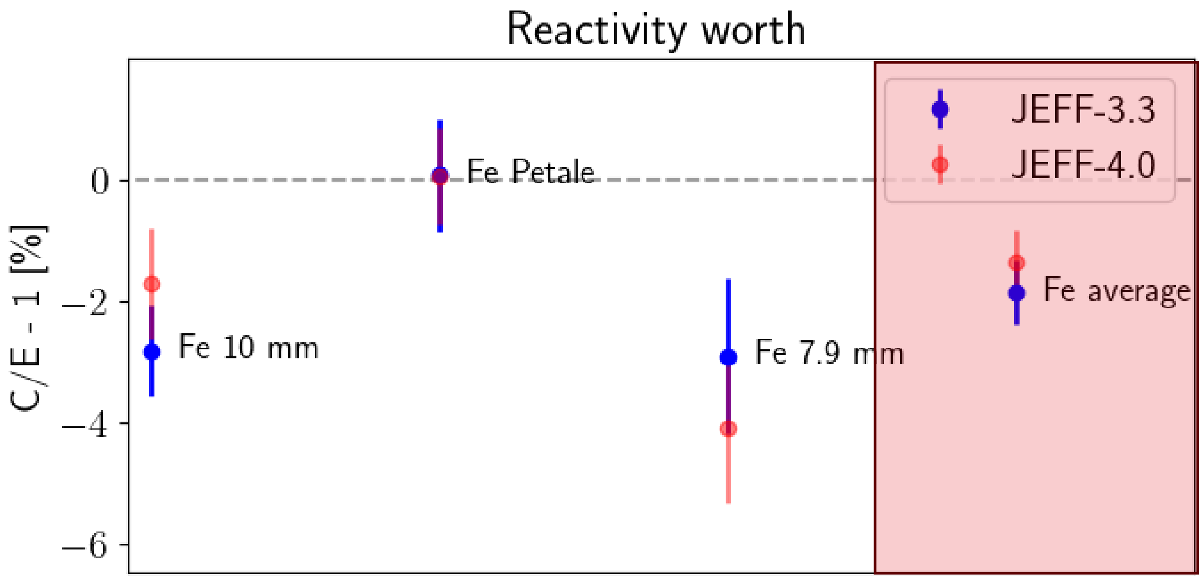
From JEFF-3.3 to JEFF-4.0: Fe

C/E for iron pile-oscillation experiments

- **No statistically significant differences**
  - Similar to PETALE non-threshold
  - Averaged results at >2σ from 0
  - Close to JEFF-3.1.1 in MAESTRO
    - 0.3 ± 1.2 %*
  - Smaller uncertainties needed (sim.)



Ni	Cr	Fe

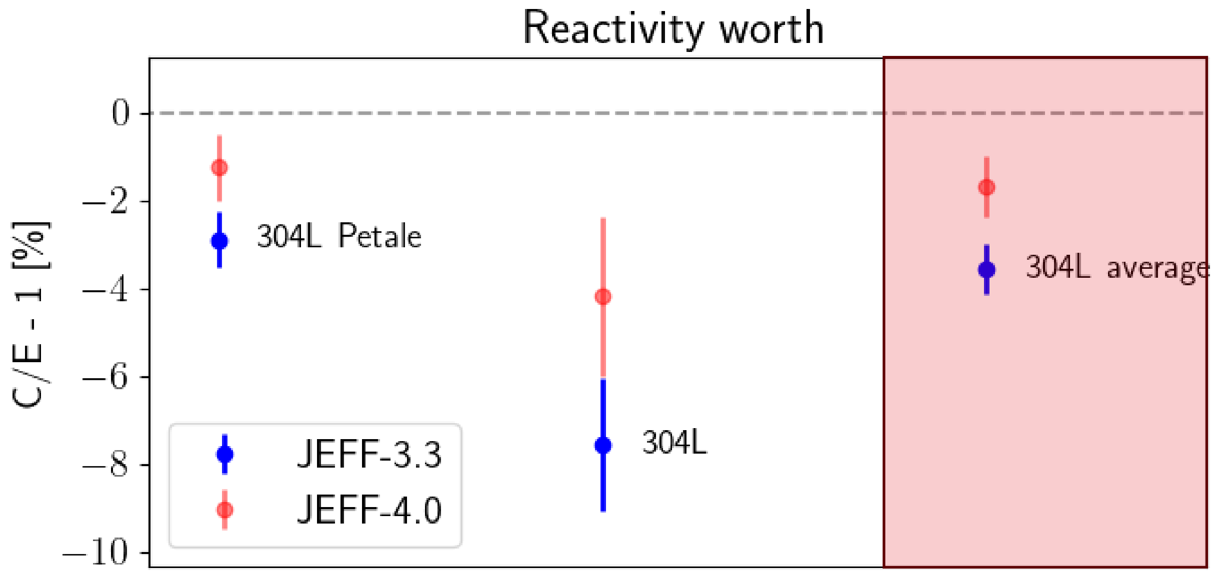
PETALE: clear improvement @2 & 3.6 MeV, slight degradation above, status quo below

→ BLOOM: Status quo

From JEFF-3.3 to JEFF-4.0: 304L

C/E for 304L pile-oscillation experiments

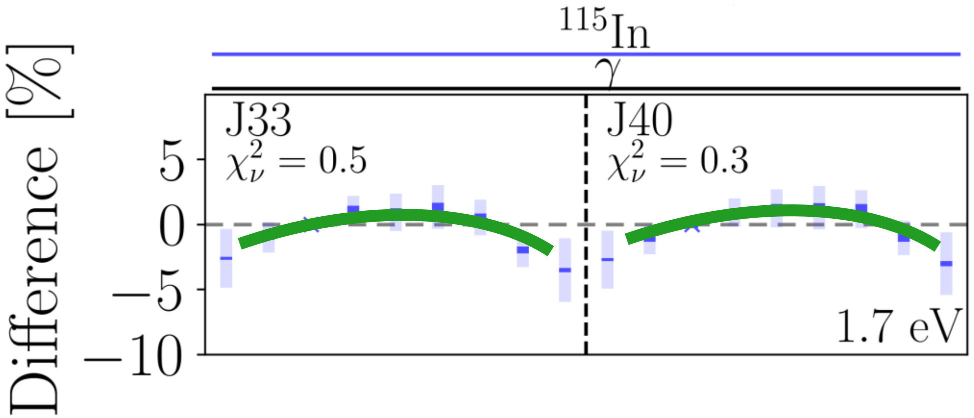
- Clear improvement of C/Es
  - Rightfully driven by Cr…
  - …and wrongfully by the Ni
  - JEFF-4.0 close to the iron results

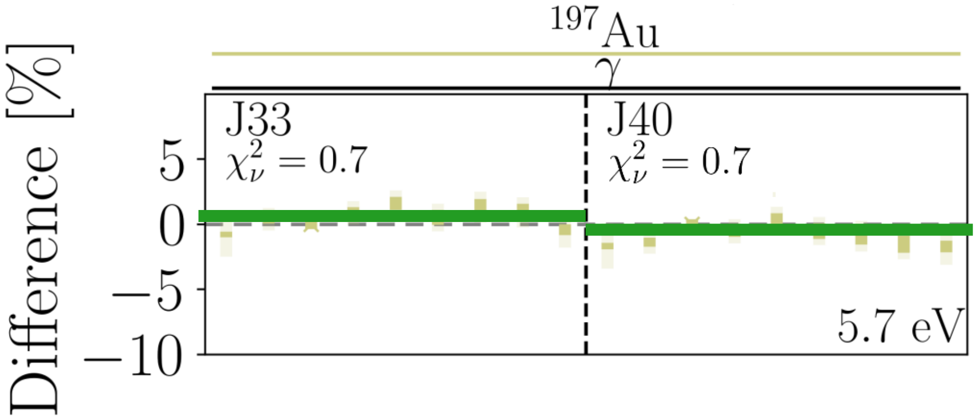


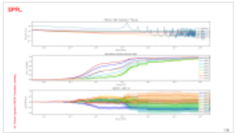
Ni	Cr	Fe	304L

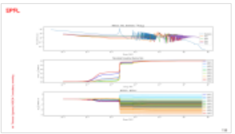
From JEFF-3.3 to JEFF-4.0: 304L Reflectors

C/E for 304L transmission experiments







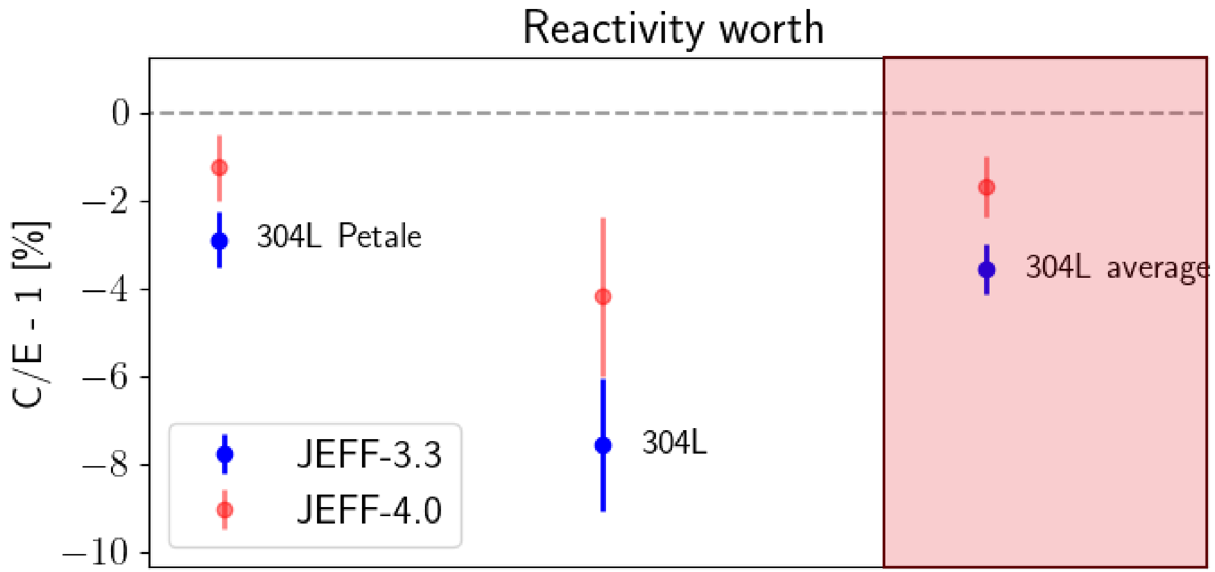


- Both evaluations are in agreement with the experiments
  - Flat C/E
  - χ^2_ν also in agreement

From JEFF-3.3 to JEFF-4.0: 304L

C/E for 304L pile-oscillation experiments

- Clear improvement of C/Es
  - Rightfully driven by Cr…
  - …and wrongfully by the Ni
  - JEFF-4.0 close to the iron results



Ni	Cr	Fe	304L

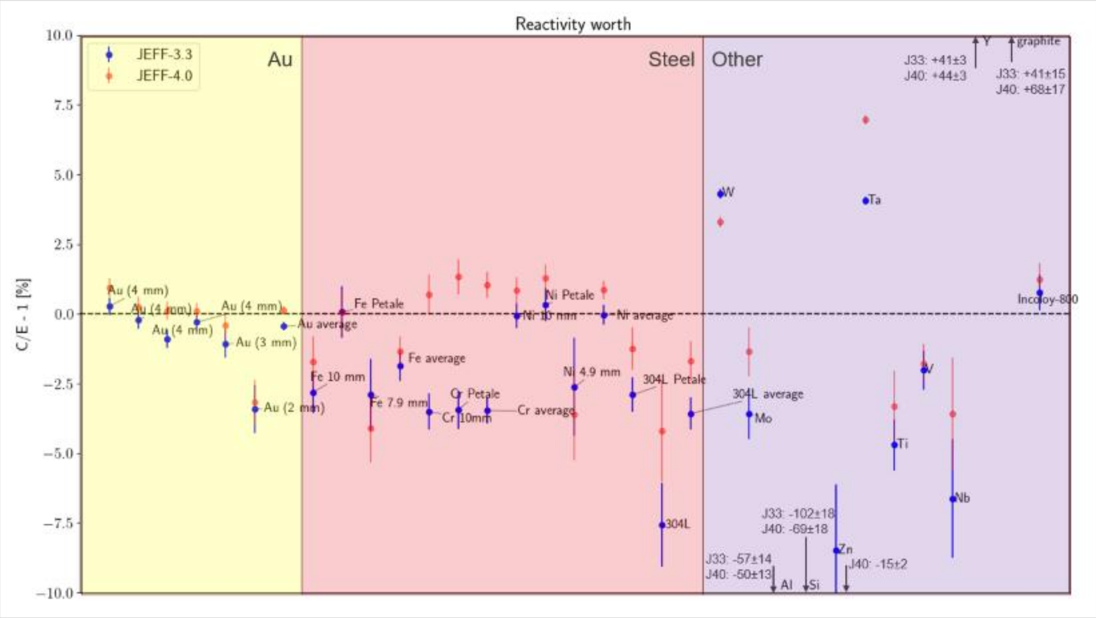
PETALE: Clear improvement @2 & 3.6 MeV, slight improvement above, status quo below

→ BLOOM: Improvement

BLOOM Library Comparison Results

- Δρ: 0.2 to 24 pcm
- Constant uncertainties
  - Regardless of the sample

- Clear Improvements:
  - W
  - Mo
- Small improvement:
  - Si
- Clear degradation:
  - Ta
  - Zn



Conclusion

- The BLOOM program was performed at the end of 2024
  - 40 experiments
  - Focusing on stainless steel
  - measurement uncertainties ~0.02 pcm

- Analysis status
  - First analysis performed as part of my thesis
  - Modelling and simulation with Black Body Exact Perturbation
    - Current uncertainties: ~0.04 pcm

- Stainless steel results
  - Chromium shows a clear improvement
  - Nickel degrades slightly
  - Iron is untouched
  - 304L Improves

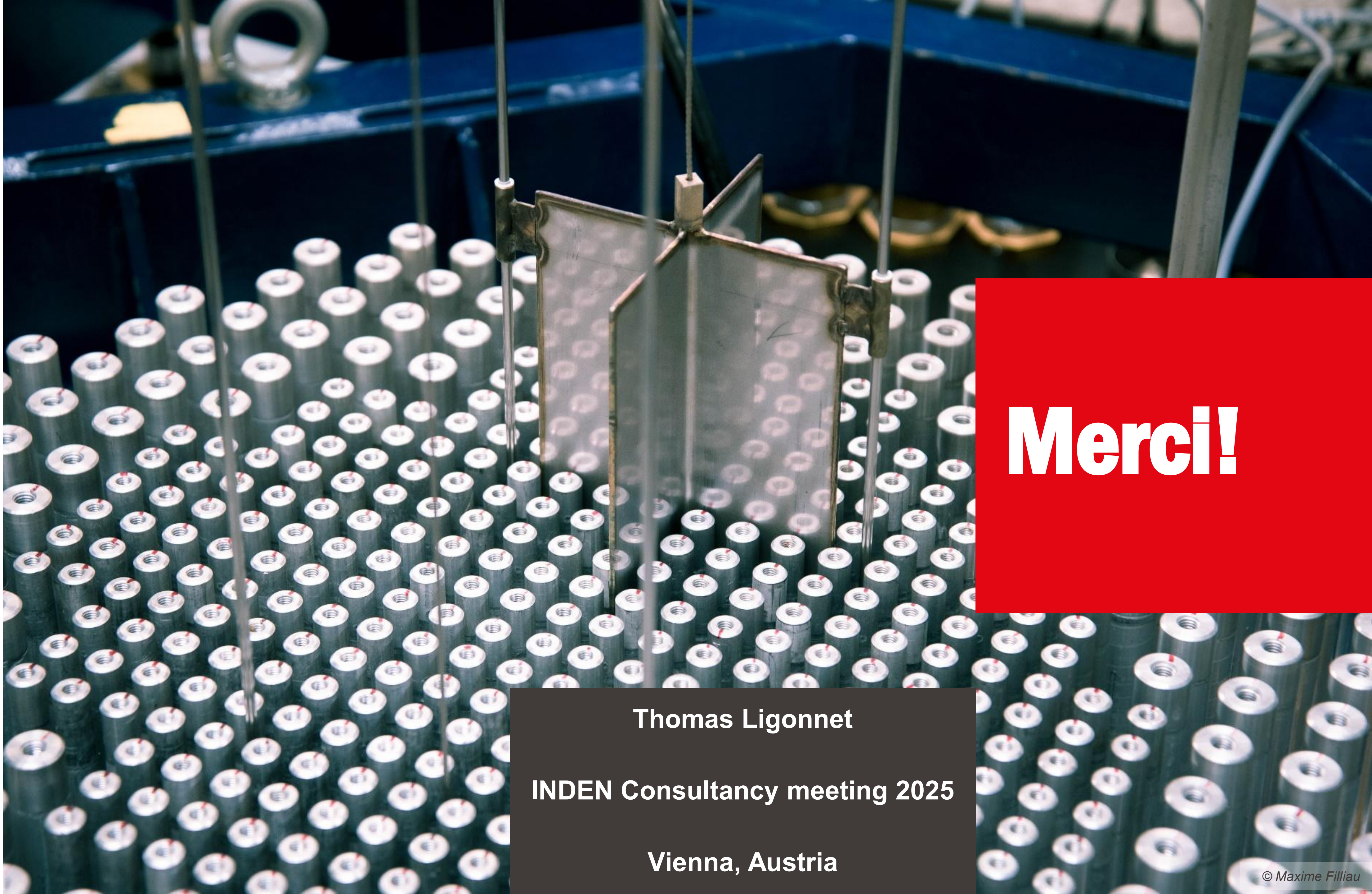
Outlook

HARVEST-X

- PETALE ICSBEP benchmarking
  - targeting acceptance in April 2028
- New transmission experiments
  - GRAPE: accelerator-based source
  - GODIVA-IV

BLOOM

- Finalization of analysis and benchmarking
  - Developments for the interpretation of local signals
  - Proposal submitted
- Expansion of the program to non-structural material, e.g., fissile samples
  - Higher power irradiations for higher precision
  - Feedback on isotopes of the high-priority list
  - Test data for highly needed materials, e.g., **HALEU**, using only small quantities!



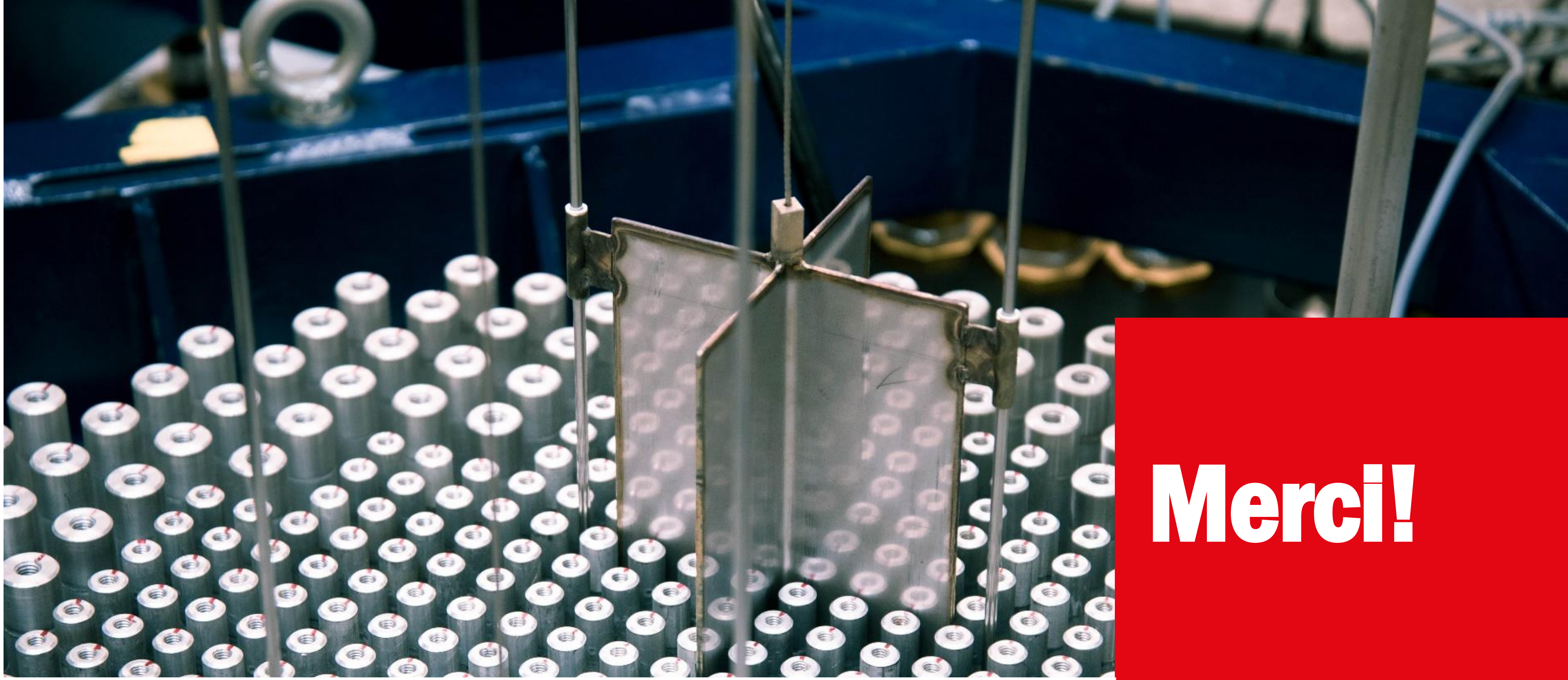
Merci!

Thomas Ligonnet

INDEN Consultancy meeting 2025

Vienna, Austria

EPFL



Merci!

Public PhD Defense

Analysis and Reproduction of Stainless-steel Integral Experiments Towards Nuclear Data Assimilation

19.12.2025 at 13:30 GMT+1

Zoom: 625 1741 8008

Point kinetics testing

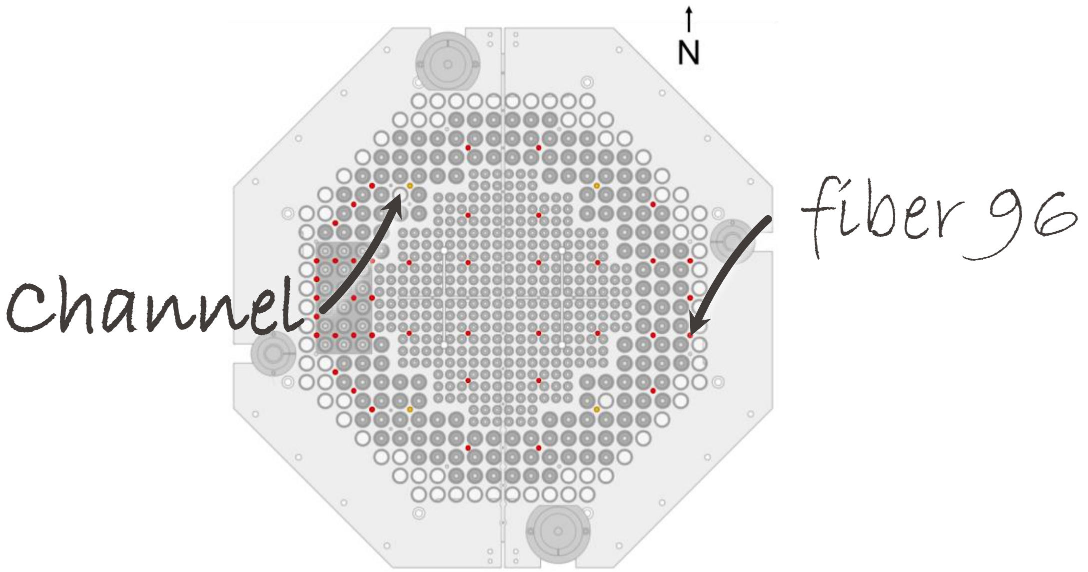
Flux redistribution verification:

- Would imply a correction factor for global
- Computation of the spectral power ratio[1]
  - Using 1st harmonic of CPSD
  - Comparison with core center fiber nº 96

$$SPR_{i,77} \equiv \frac{\sqrt{P_{i,i}}}{\sqrt{P_{77,77}}} = \frac{1}{M}\Sigma_j^M \frac{P_{i,j}}{P_{j,77}}$$

- Local amplitude effect clearly visible
  - Dissipate at 15 cm
- No significant flux redistribution

No correction required!



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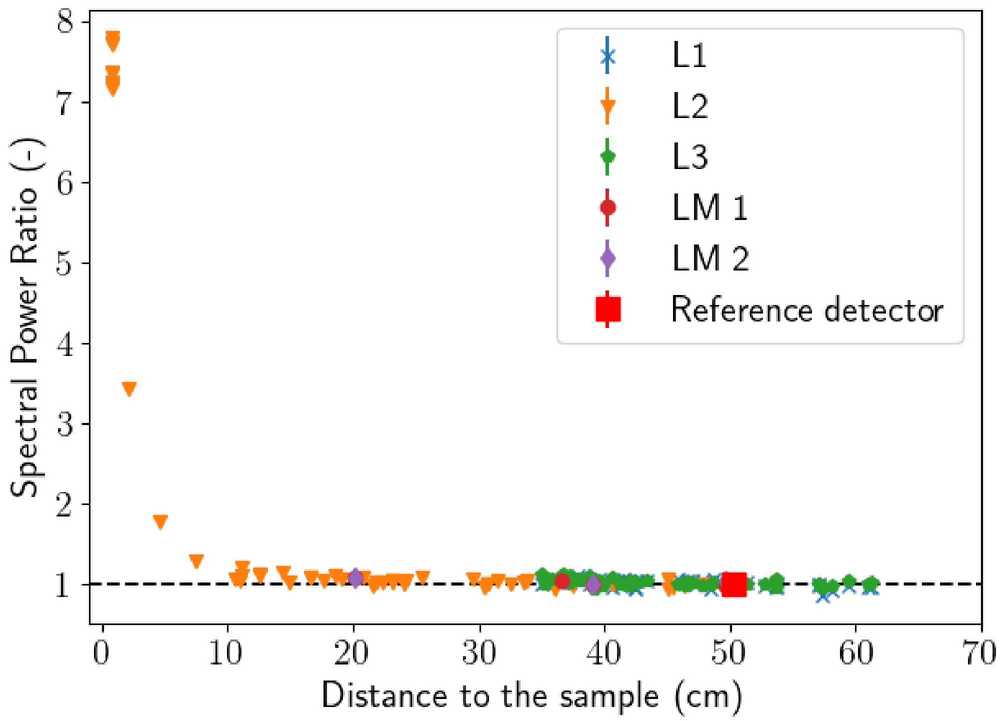
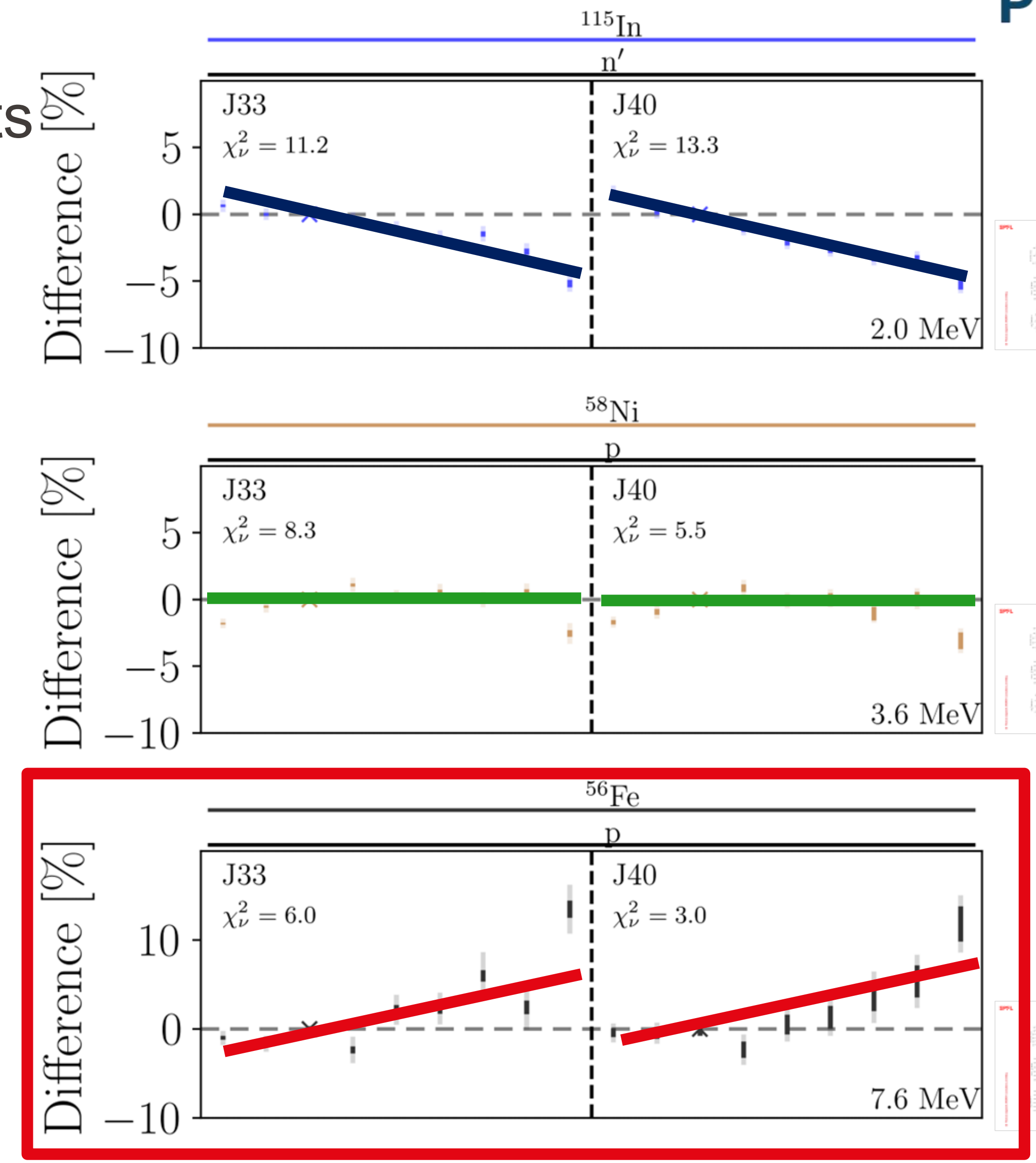
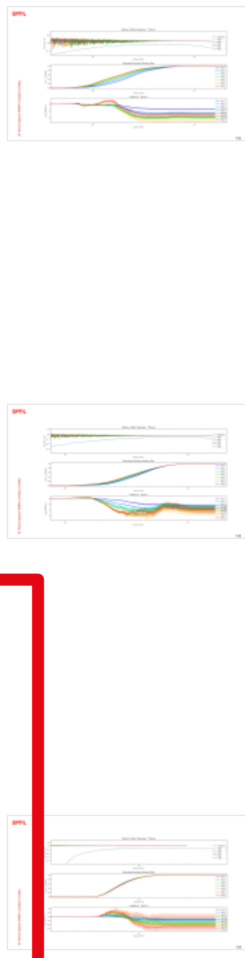


1, Ambrožič, Klemen, et al. "CORTEX experiments, Part II: Postprocessing of neutron noise time series to determine reliable mean and uncertainties." Annals of Nuclear Energy 208 (2024): 110704.

From JEFF-3.3 to JEFF-4.0: Ni

C/E for nickel transmission experiments





- Globally: change in trend
- JEFF-4.0 similar to JEFF-3.3

Ni

From JEFF-3.3 to JEFF-4.0: Ni

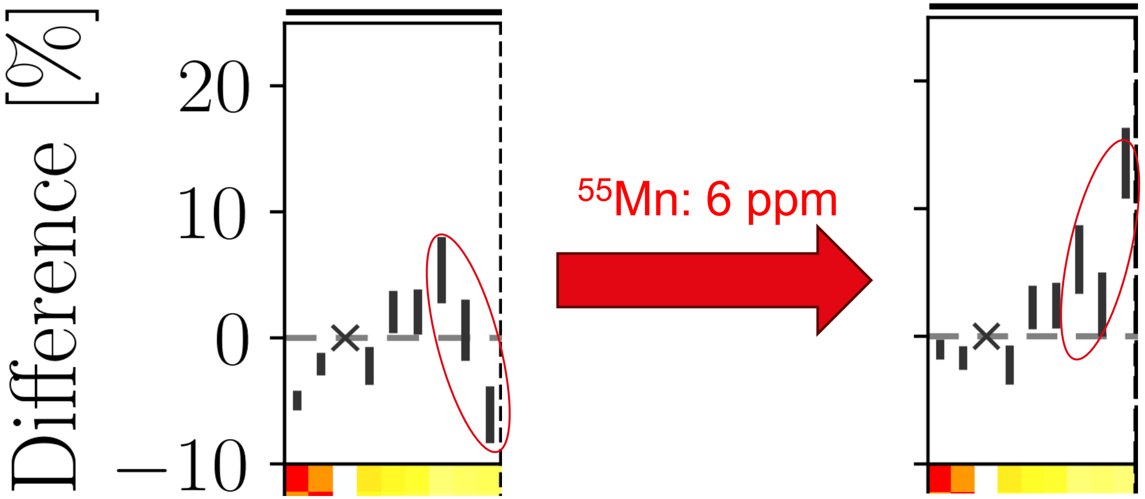
C/E for nickel transmission experiments

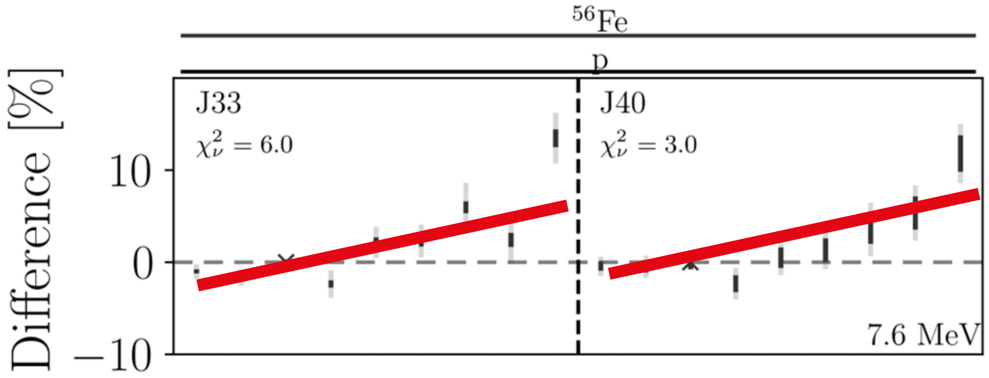
- ^{55}Mn impurities in iron dosimeters

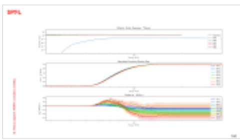
^{56}Fe(n,p) $\xrightarrow{\text{Fast}}$ ^{56}Mn

^{55}Mn(n,γ) $\xrightarrow{\text{Thermal}}$ ^{56}Mn

- ~6 ppm, but up to 20 % of the activity





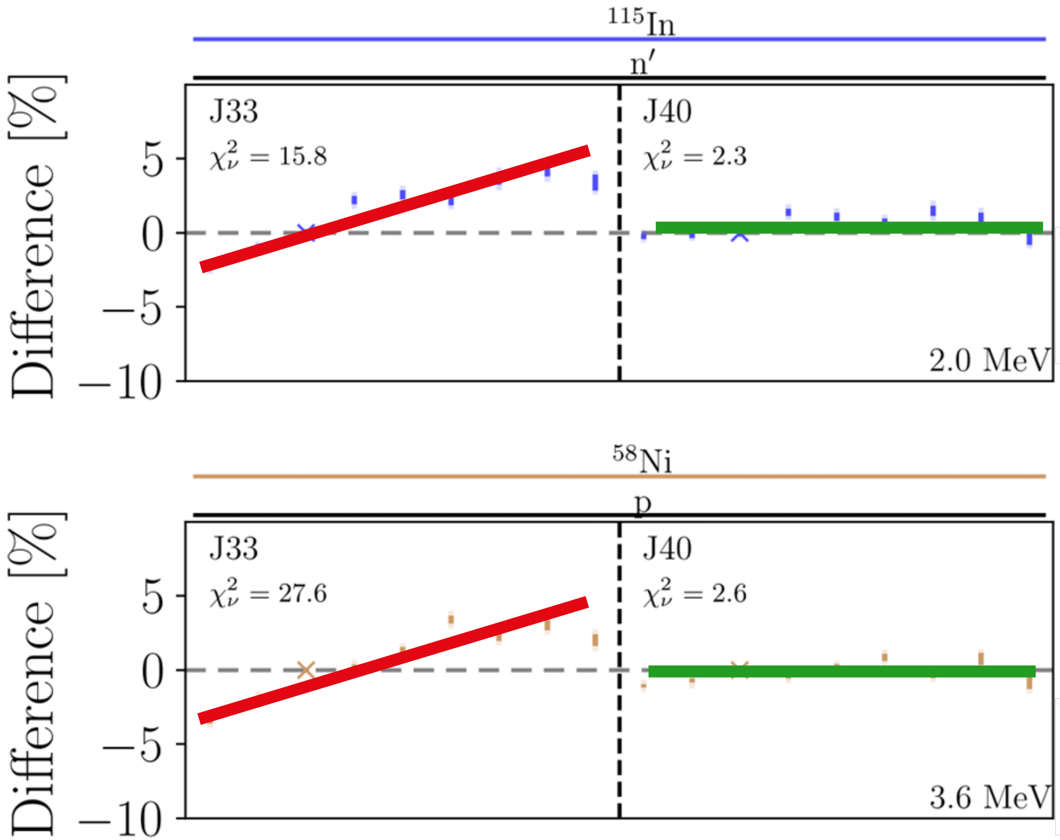


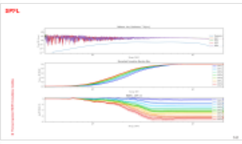
Ni

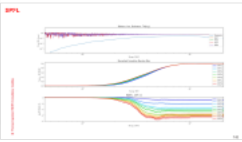
From JEFF-3.3 to JEFF-4.0: Fe

C/E for iron transmission experiments

- Improvement of the results
  - Both around 2 MeV and 3.6 MeV
  - The previous trend is flattened





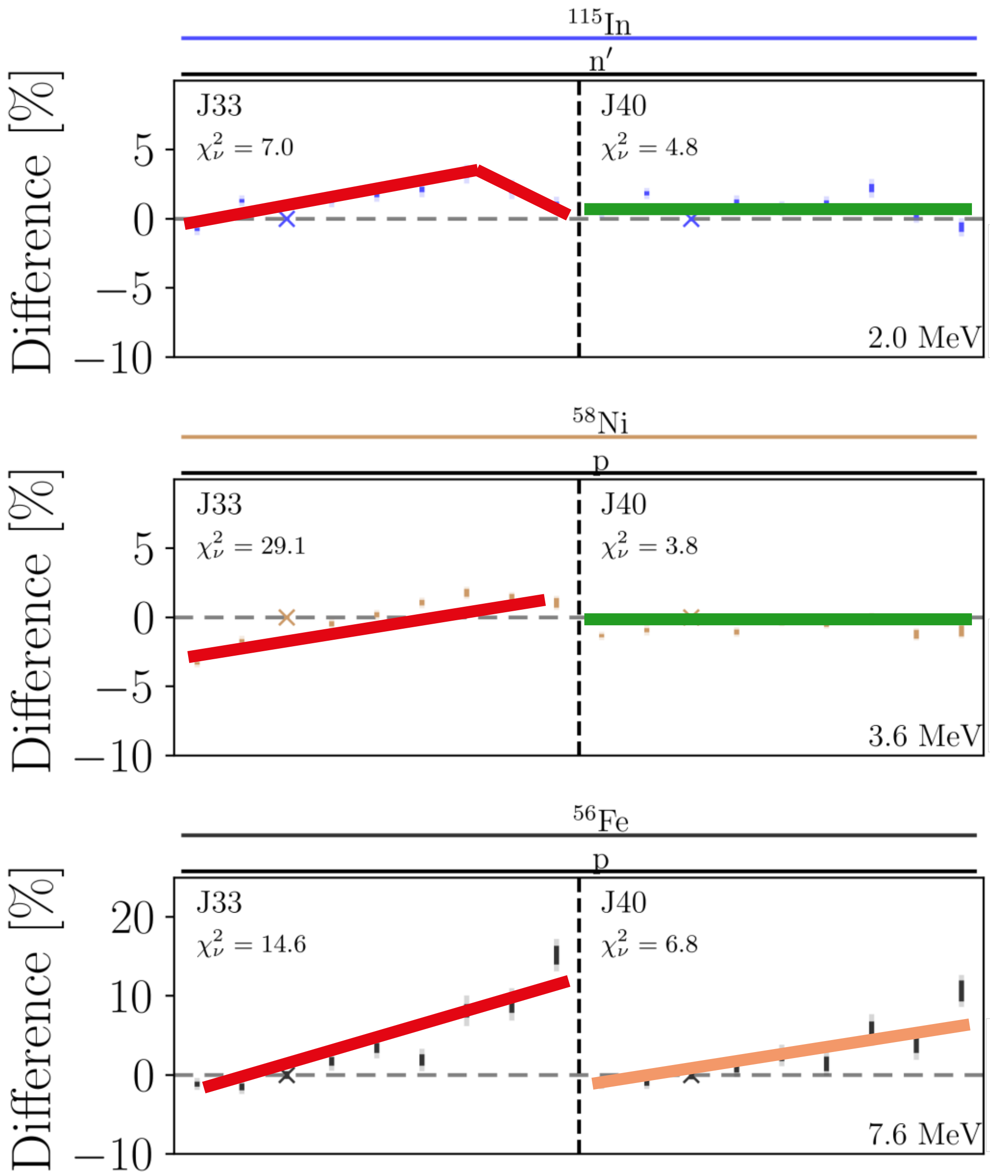


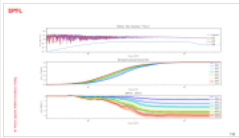
Ni	Cr	Fe

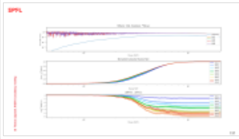
From JEFF-3.3 to JEFF-4.0: 304L

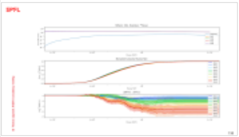
C/E for 304L transmission experiments

- Previous trends flattened
  - Especially for ^{115}In(n,n’) and ^{58}Ni(n,p)
  - Slightly better at higher energy
    - ^{56}Fe(n,p): Suspected compensation from Cr







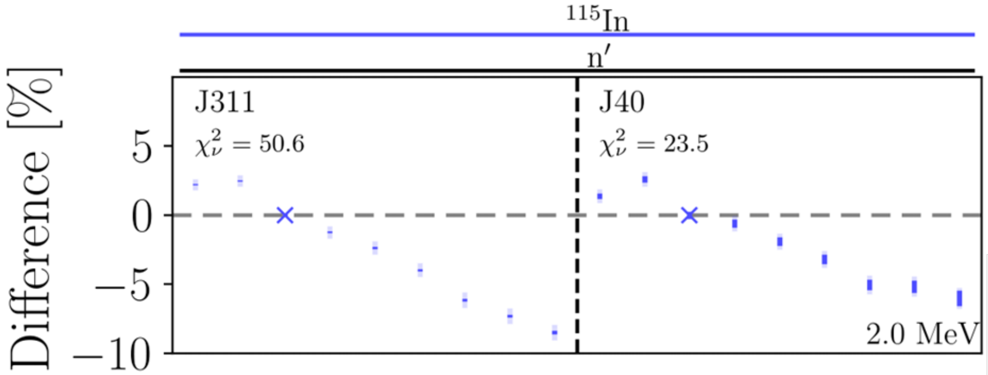


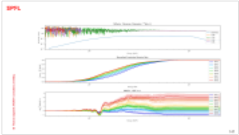
Ni	Cr	Fe	304L

From JEFF-3.3 to JEFF-4.0: Cr Reflectors

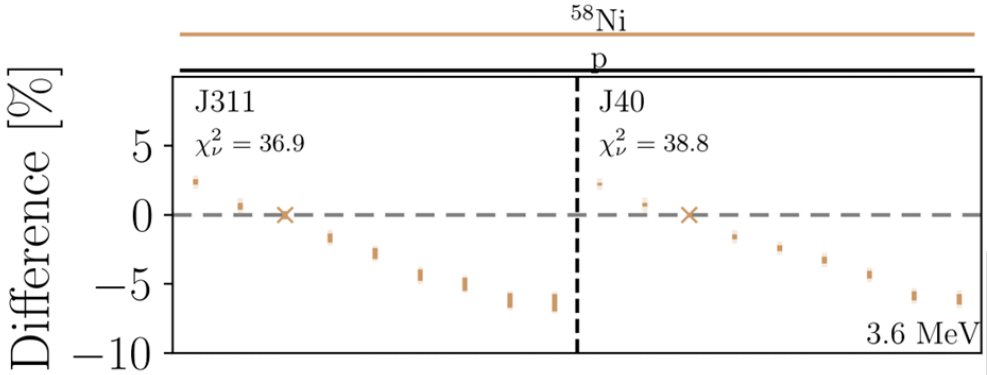
C/E for chromium transmission experiments

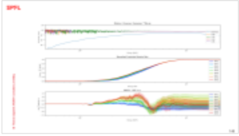
- The discrepancies around 2 MeV are reduced with JEFF-4.0
  - A clear trend is still visible





- The Ni dosimeter trend is preserved
  - But the activation spectrum is different



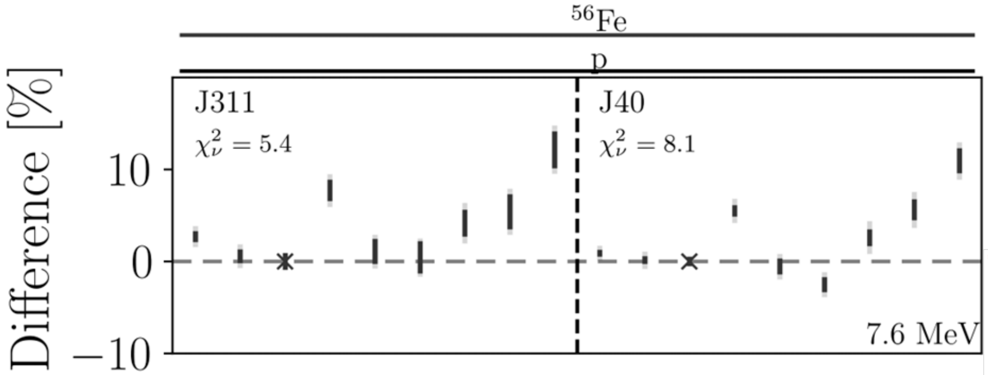


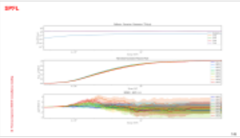
Cr

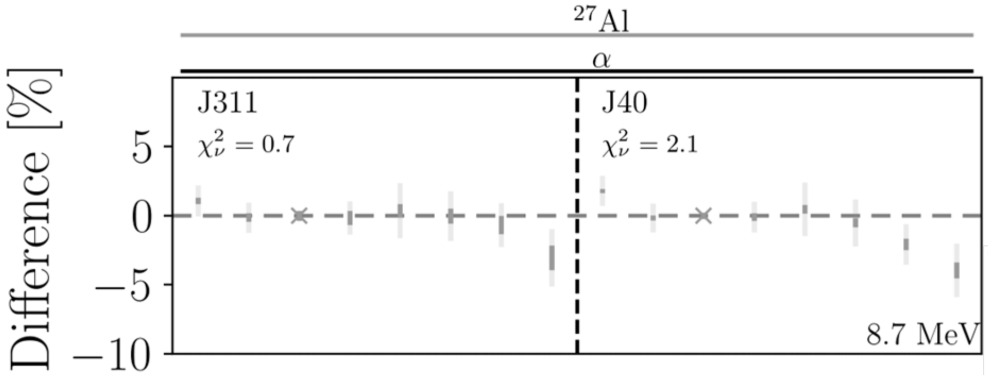
From JEFF-3.3 to JEFF-4.0: Cr Reflectors

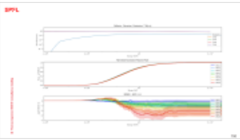
C/E for chromium transmission experiments

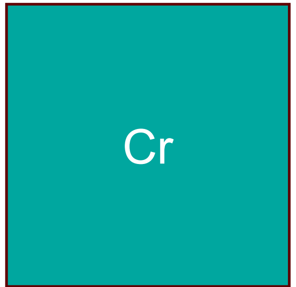
- The trends at higher energy
  - No significant differences are between evaluations
  - Small differences could be from the calculation statistics









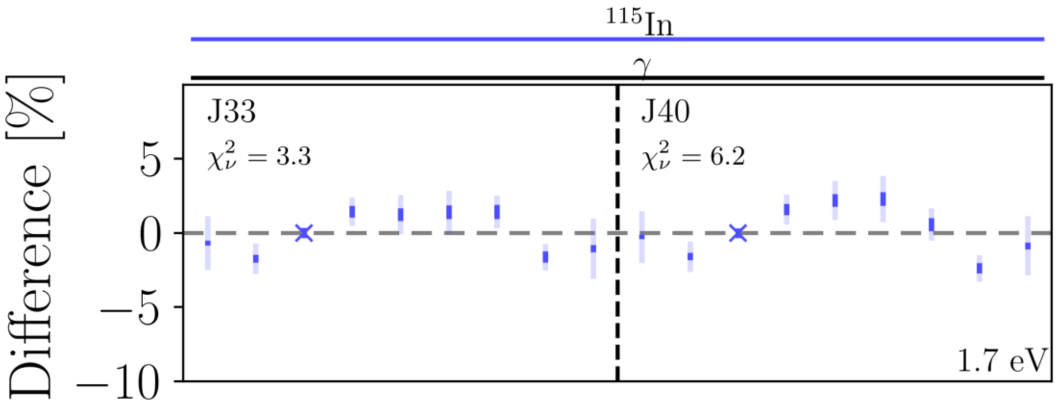


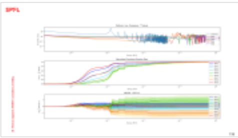
From JEFF-3.3 to JEFF-4.0: Fe Reflectors

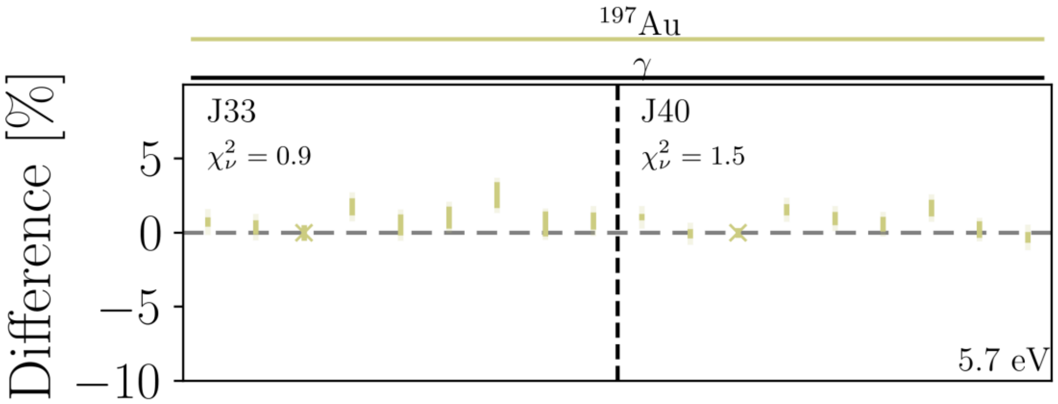
C/E for iron transmission experiments

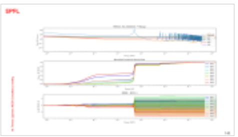
- ^{115}In(n,g) is slightly less consistent
  - χ^2_ν from 3.3 to 6.1
- ^{197}Au(n,g) in agreement with the experimental data
  - Flat C/E

Fe



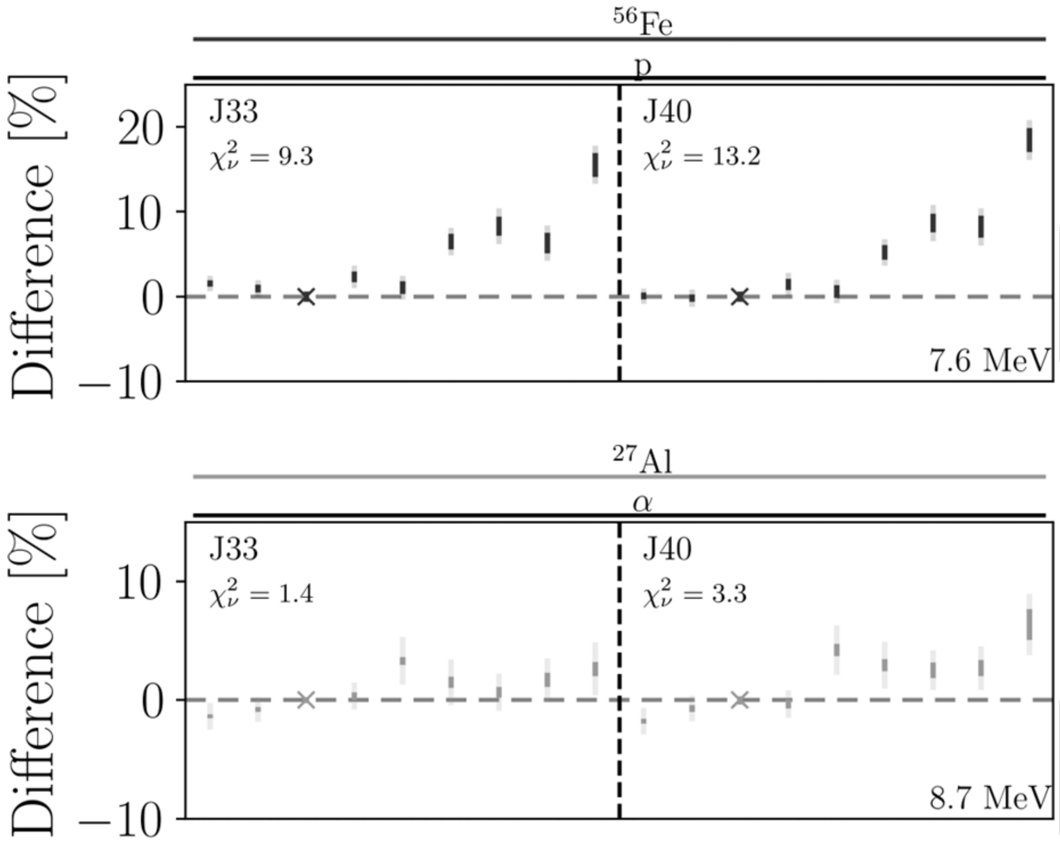


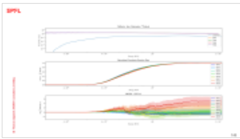


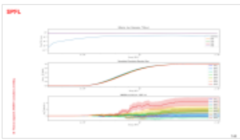


From JEFF-3.3 to JEFF-4.0: Fe Reflectors

C/E for iron transmission experiments







- Degradation at higher energy
  - Slight increase in trend
  - Statistically significant

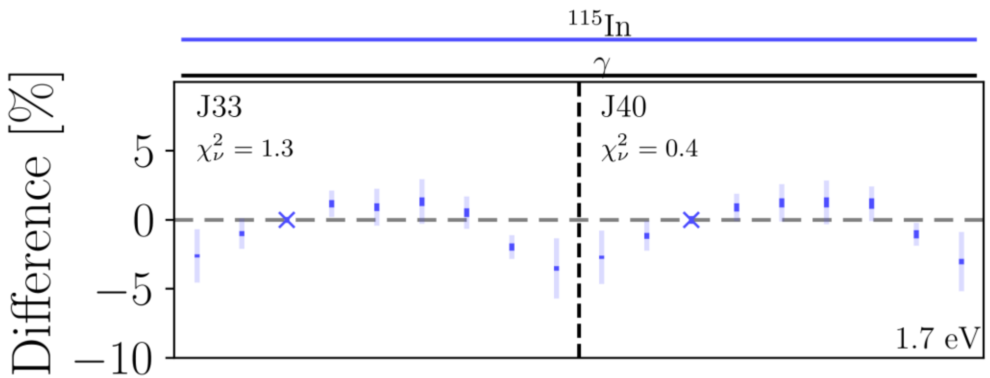
Fe

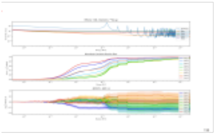
From JEFF-3.3 to JEFF-4.0: 304L Reflectors

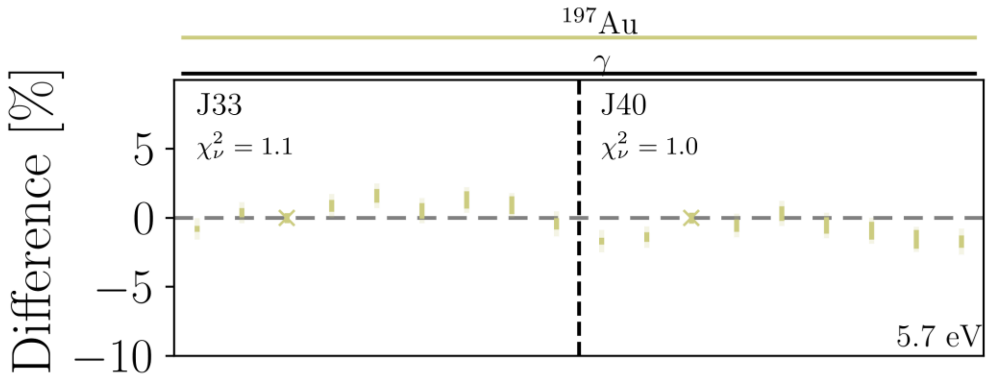
EPFL

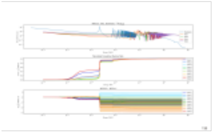
C/E for 304L transmission experiments

- Both evaluations are in agreement with the experiments
  - Flat C/E
  - χ^2_ν also in agreement









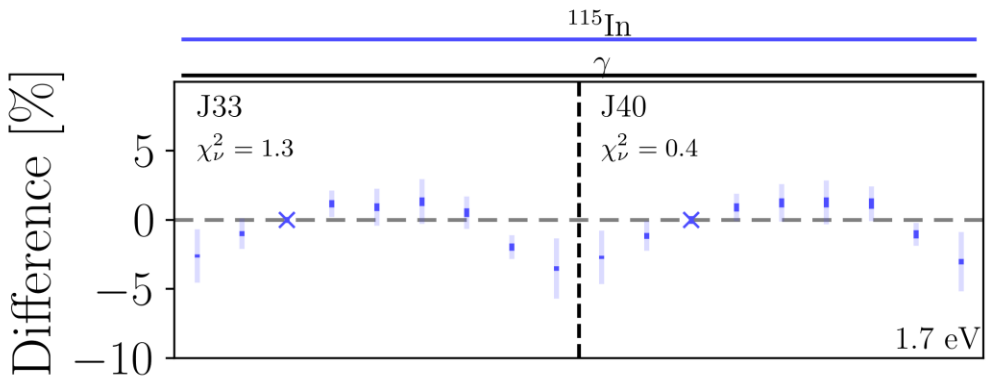
304L

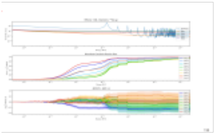
From JEFF-3.3 to JEFF-4.0: 304L Reflectors

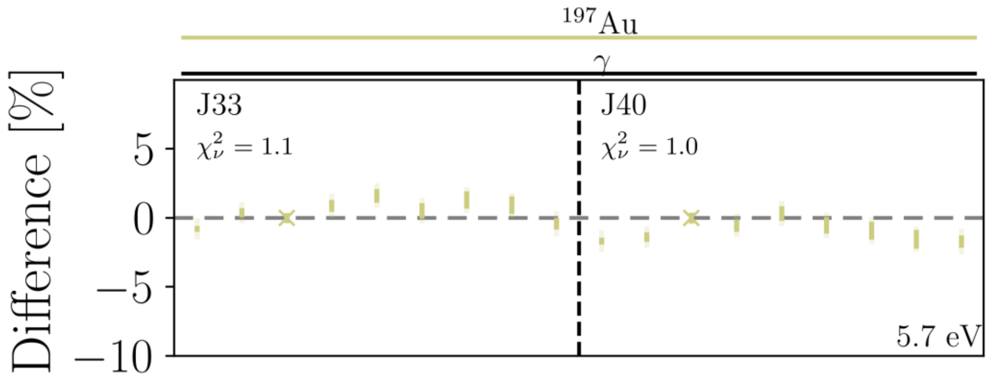
C/E for 304L transmission experiments

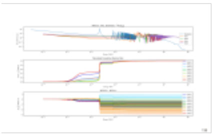
- **Both evaluations are in agreement with the experiments**
  - Flat C/E
  - χ^2_ν also in agreement

304L







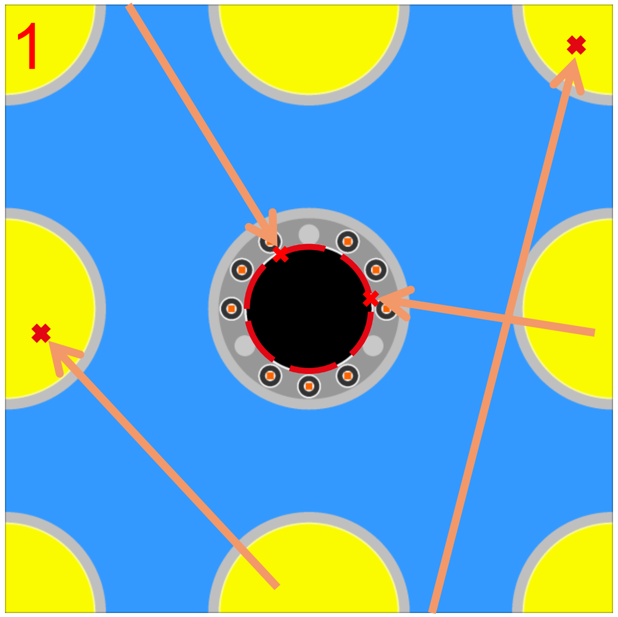


Black body exact perturbation

- Derived from the exact perturbation theory[1]
- Reactivity worth of a sample against a perfect absorber (black body)

Calculation with Serpent in 2 parts

1. Generation of sources with a black body
   - Only done once
   - Material set as “outside”
   - Surface Tracking **only!**
   - Outputs:
     - Fission source
     - All neutrons entering the black body (>1M)
     - *W* The sum of their weight
     - k_{BB} the simulation k-effective
     - N the total number of histories



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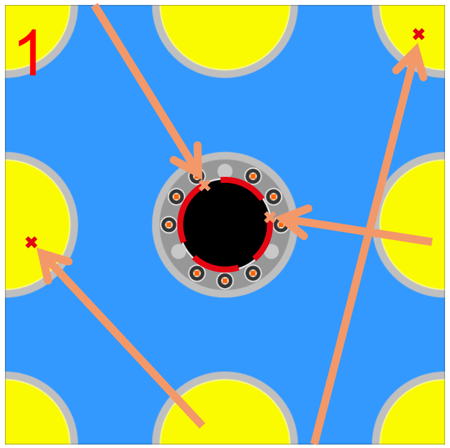
1. G. Truchet, P. Leconte. Small sample reactivity worths calculation exact perturbation theory and Monte Carlo transport. M&C2019, Aug 2019, Portland, United States.

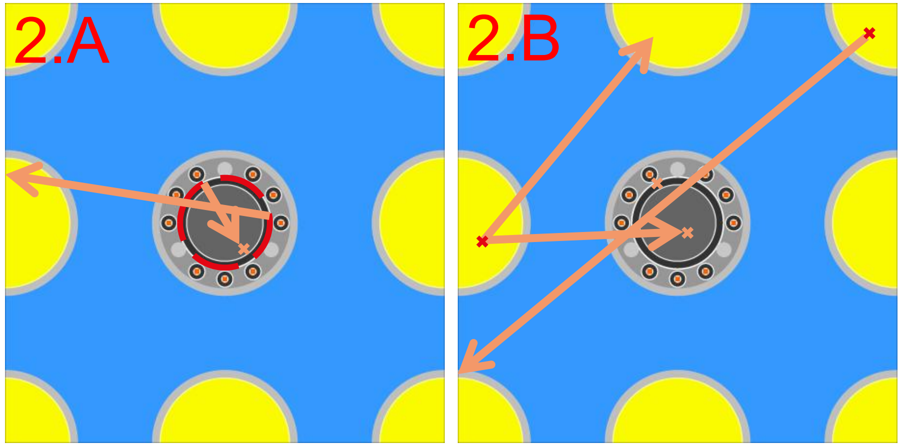
Black body exact perturbation

- Derived from the exact perturbation theory
- Reactivity worth of a sample against a perfect absorber (black body)

Calculation with Serpent in 2 parts

1. Generation of sources with a black body
   - Common to all samples
2. K-eigenvalue simulations with the sample
   - One simulation *A* with the black body record as the initial source
   - One simulation *B* with the black body fission source as the initial source
   - Record the cycle-wise k_{eff} of **all** cycles
   - 30 cycles
   - > 5M neutrons per cycle (5 times the source)





Black body exact perturbation

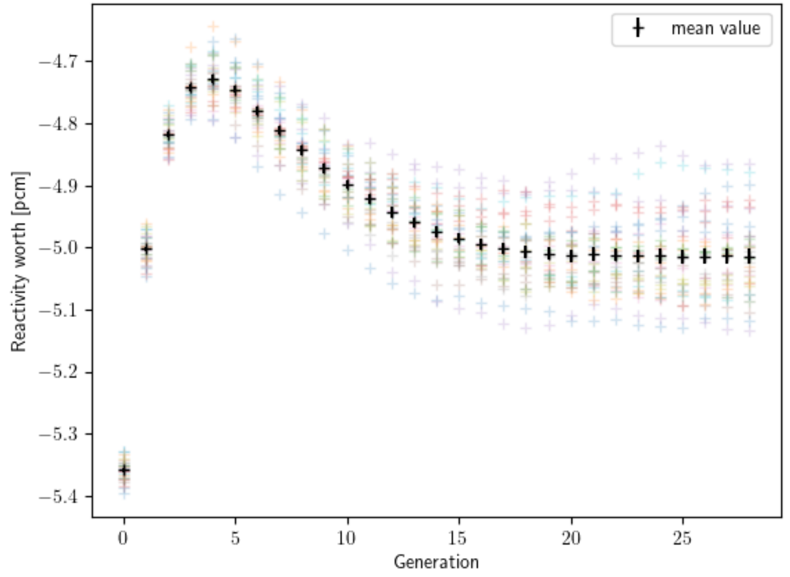
- Derived from the exact perturbation theory
- Reactivity worth of a sample against a perfect absorber (black body)

$$\Delta\rho_{S-BB} = \frac{W \prod_{i=1}^{30} k_{eff,i}^{A}}{N k_{BB} \prod_{i=1}^{30} k_{eff,i}^{B}}$$

- Sample reactivity worth:
  - Difference with a sample of air
    - Common to all cases

$$\Delta\rho_{S-Air} = \Delta\rho_{S-BB} - \Delta\rho_{Air-BB}$$

- Uncertainties by repetition with different seeds
  - 64 instances
  - ~0.05 pcm on the reactivity worth

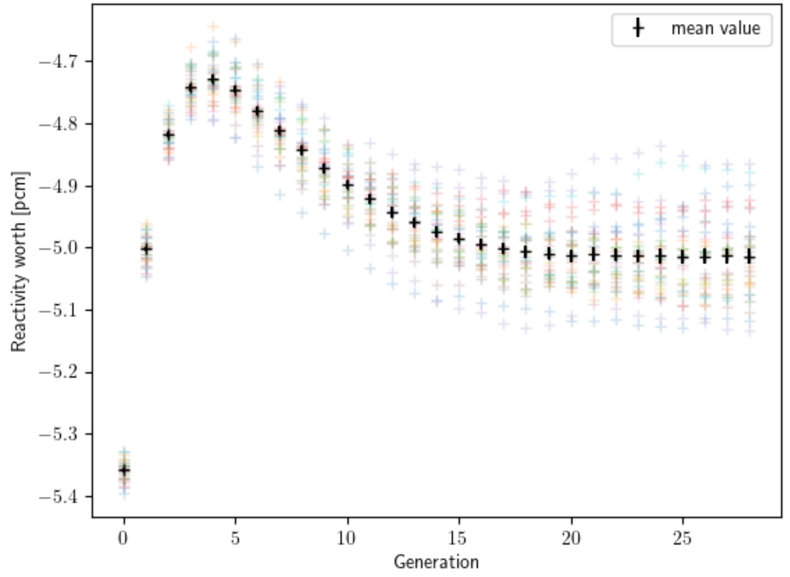


Verification against the standard method

- Reactivity worth iron sample JEFF-3.3
  - k-eigenvalue: 5.6±0.5 ppm
    - Week-long simulations
  - BBEP: 5.45±0.05 ppm
    - ~25 h each reactor configuration

$$\Delta\rho_{S-BB} = \frac{W \prod_{i=1}^{30} k_{eff,i}^{A}}{N k_{BB} \prod_{i=1}^{30} k_{eff,i}^{B}}$$

$$\Delta\rho_{S-Air} = \Delta\rho_{S-BB} - \Delta\rho_{Air-BB}$$



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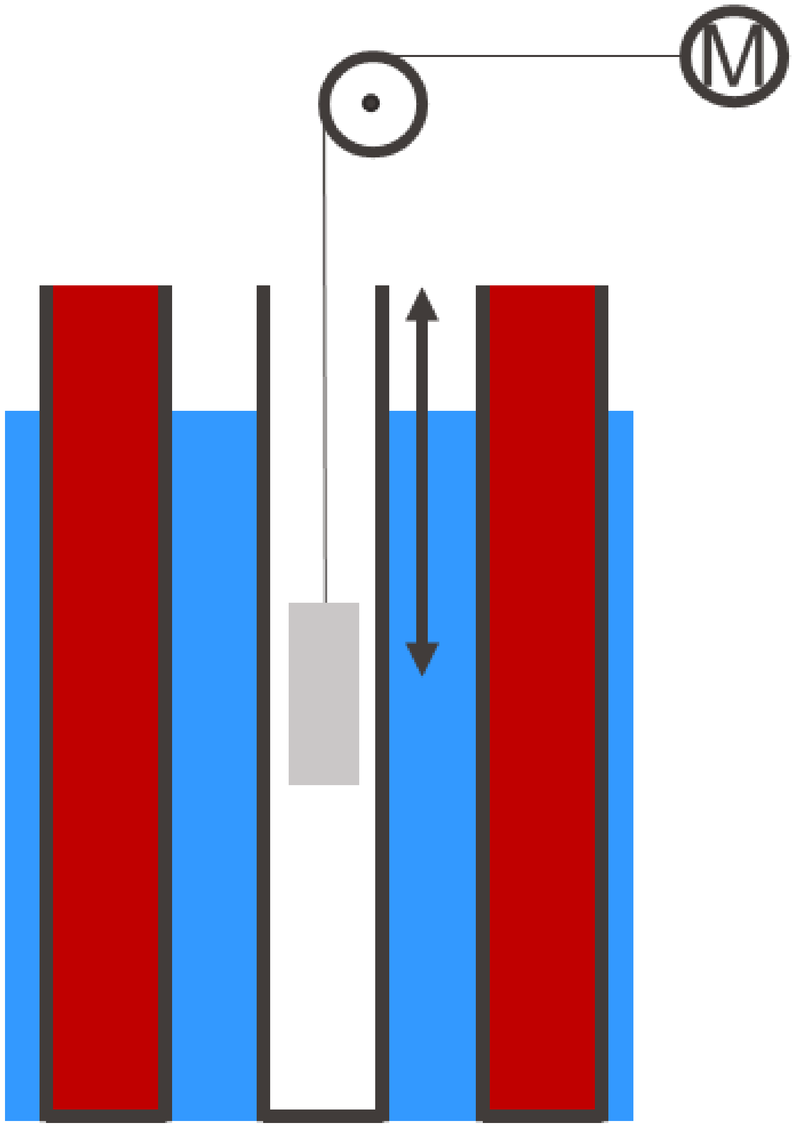
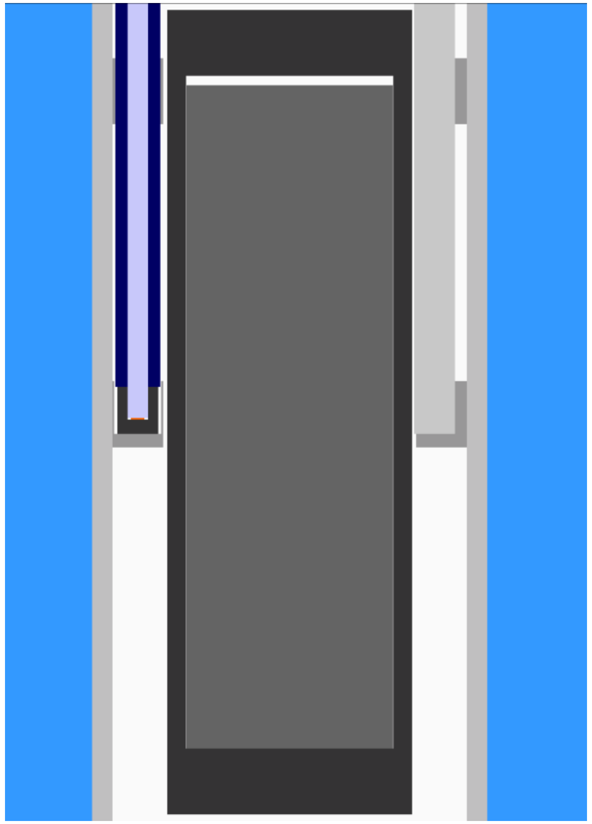
Model profile BLOOM





Point kinetics testing

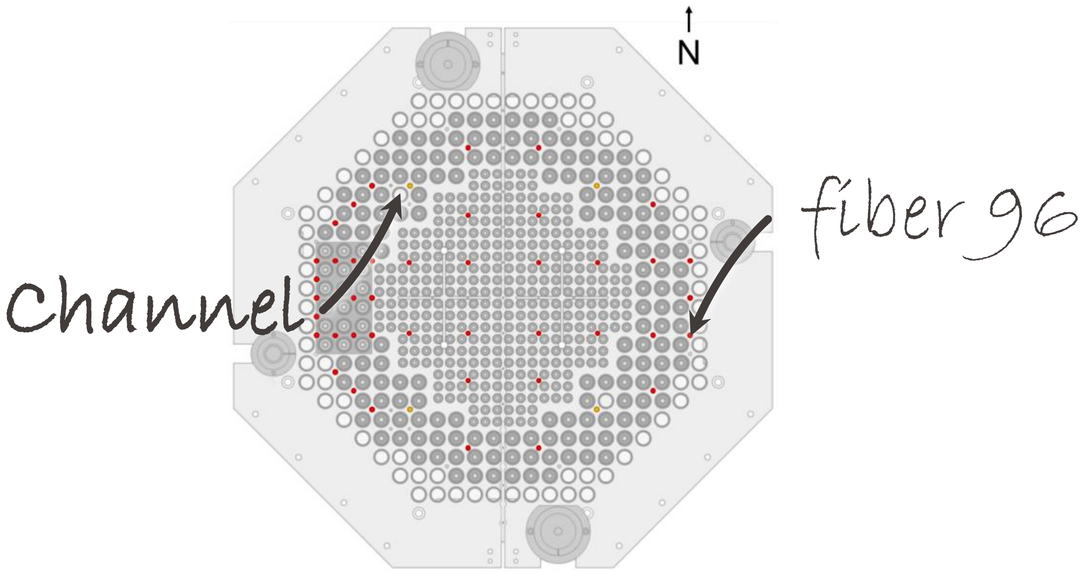
Flux redistribution verification:

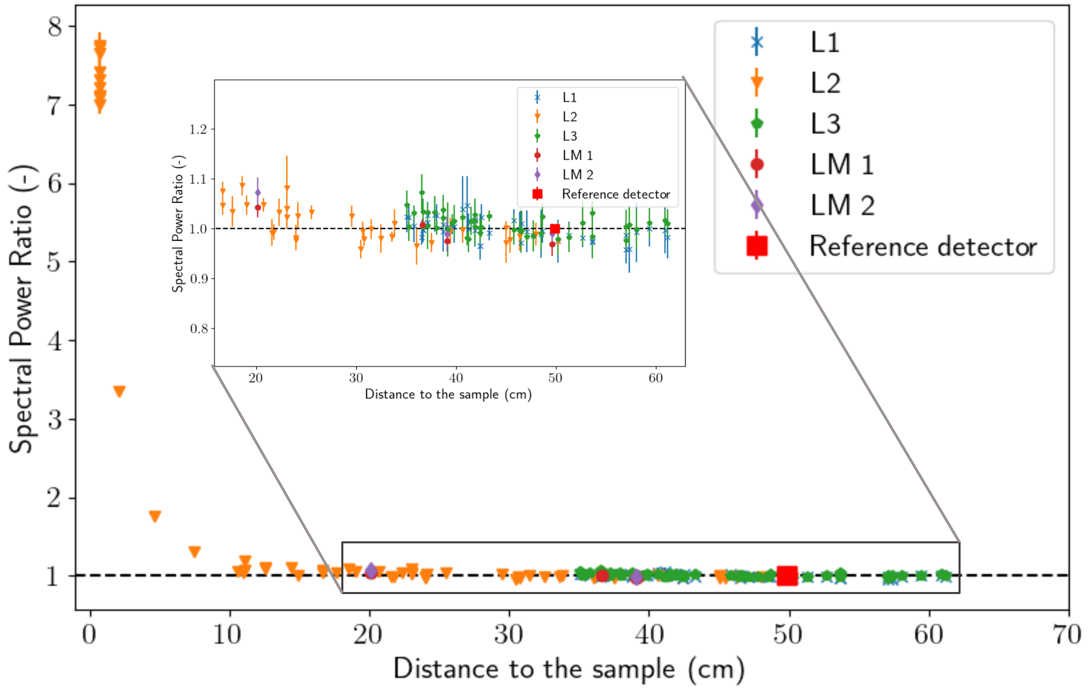
- Would imply a correction factor for global
- Computation of the spectral power ratio[1]
  - Using 1st harmonic of CPSD
  - Comparison with core center fiber nº 96

$$SPR_{i,77} \equiv \frac{\sqrt{P_{i,i}}}{\sqrt{P_{77,77}}} = \frac{1}{M}\Sigma_j^M \frac{P_{i,j}}{P_{j,77}}$$

- Local amplitude effect clearly visible
  - Dissipate at 15 cm
- No significant flux redistribution

➡ **No correction required!**





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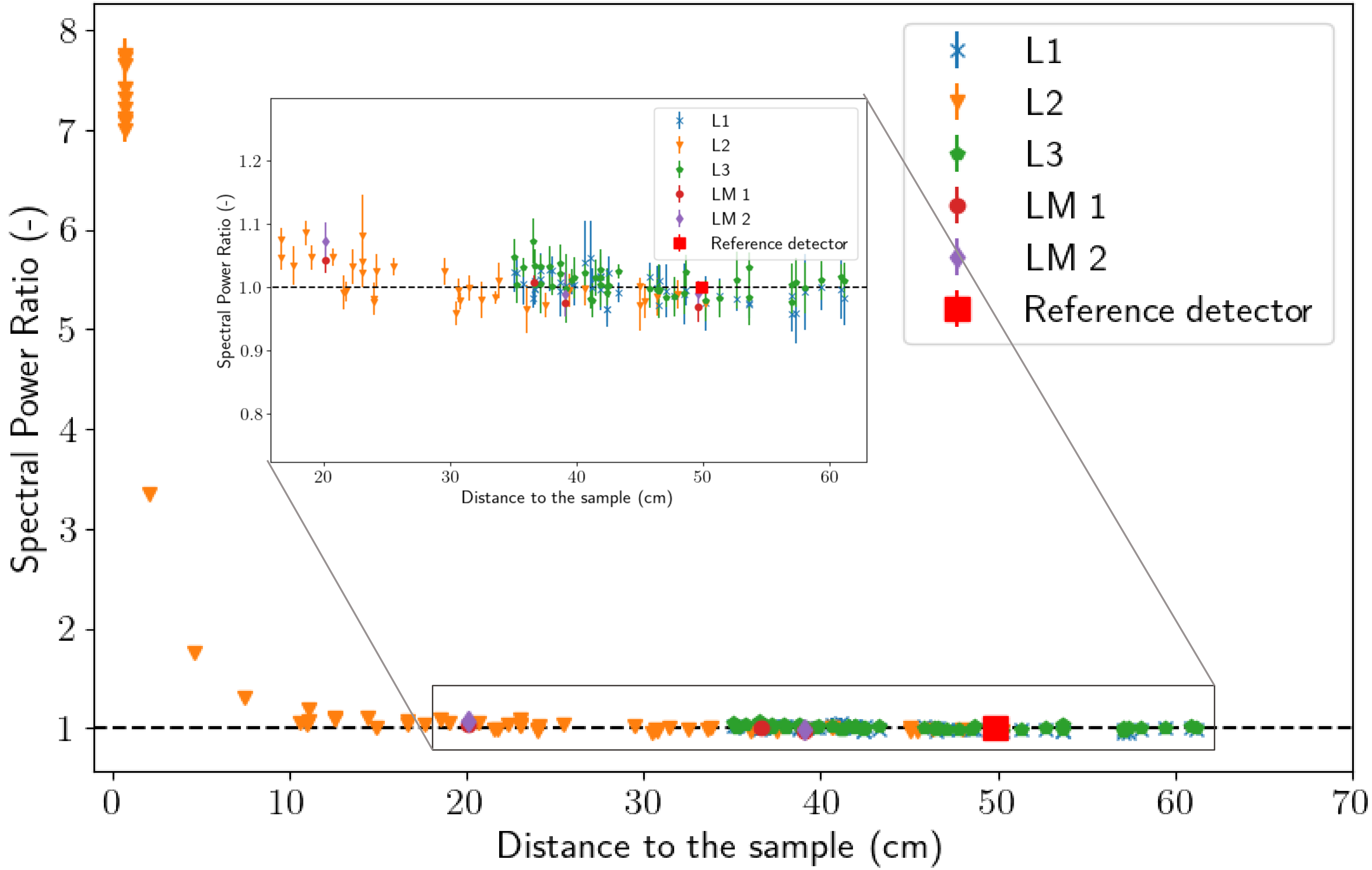
1, Ambrožič, Klemen, et al. "CORTEX experiments, Part II: Postprocessing of neutron noise time series to determine reliable mean and uncertainties." Annals of Nuclear Energy 208 (2024): 110704.

EPFL

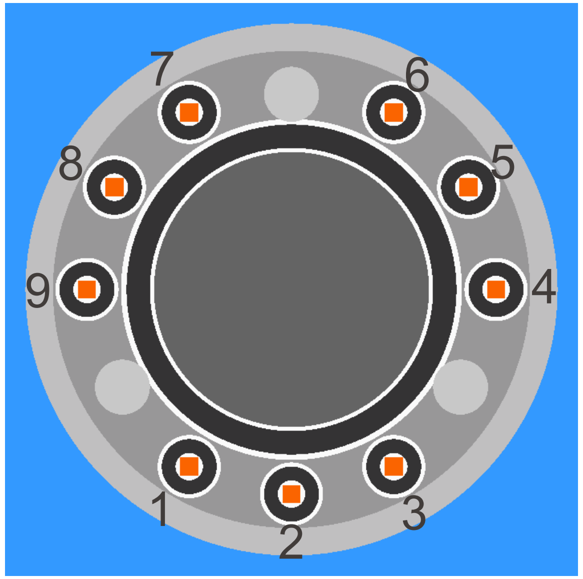


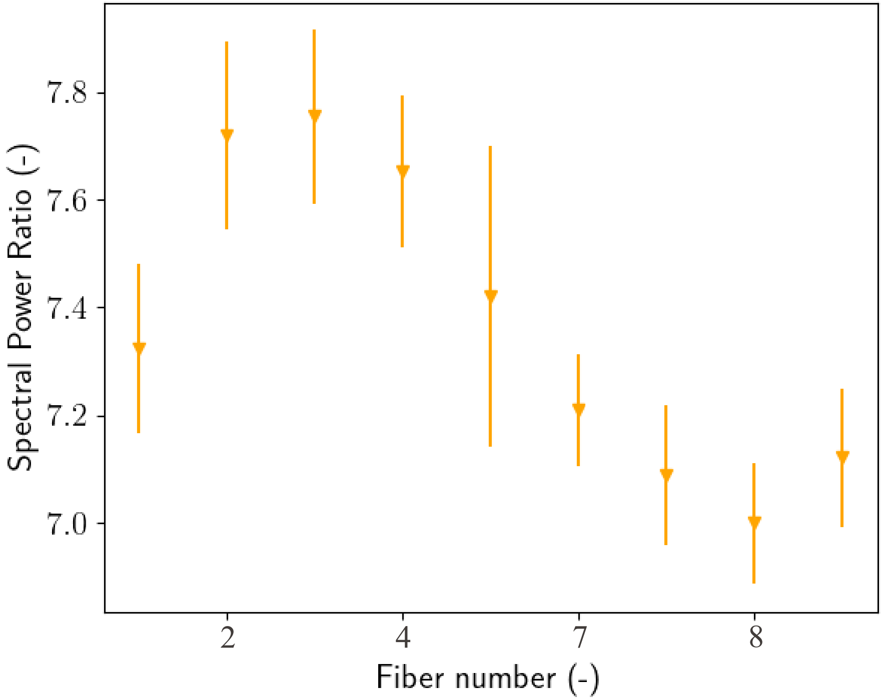
Spectral Power Ratio (-)
8
7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
Distance to the sample (cm)
L1
L2
L3
LM 1
LM 2
Reference detector
1.2
1.1
1.0
0.9
0.8
20
30
40
50
60

Angular distribution the ΔL

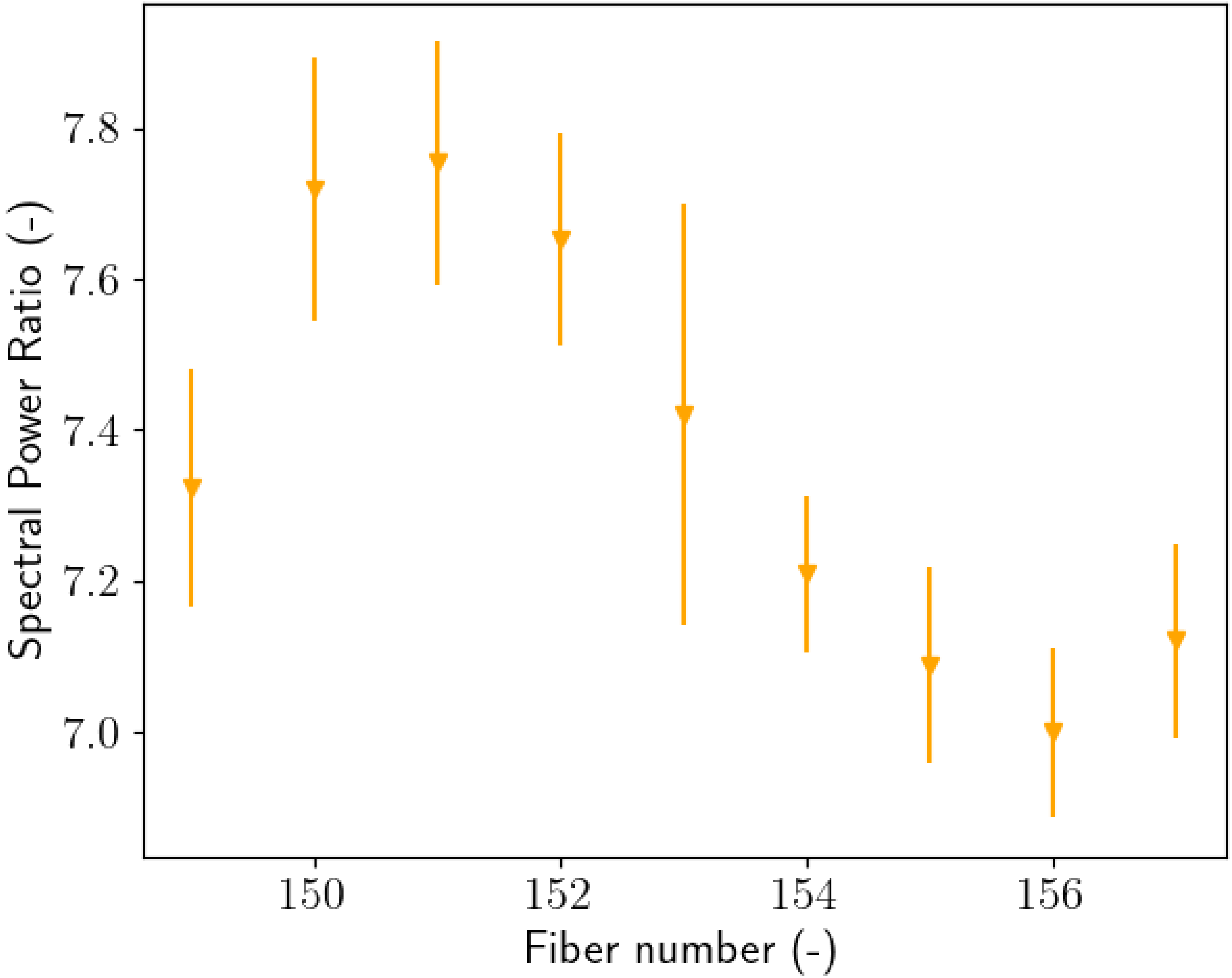
Angular distribution of the local detectors observed

- SPRs significantly different
- Measured with the gold sample
- Highly correlated uncertainties
  - ~ 95%
- Flux gradient in the channel was already measured
- Further investigation would be interesting while treating local signals in more details





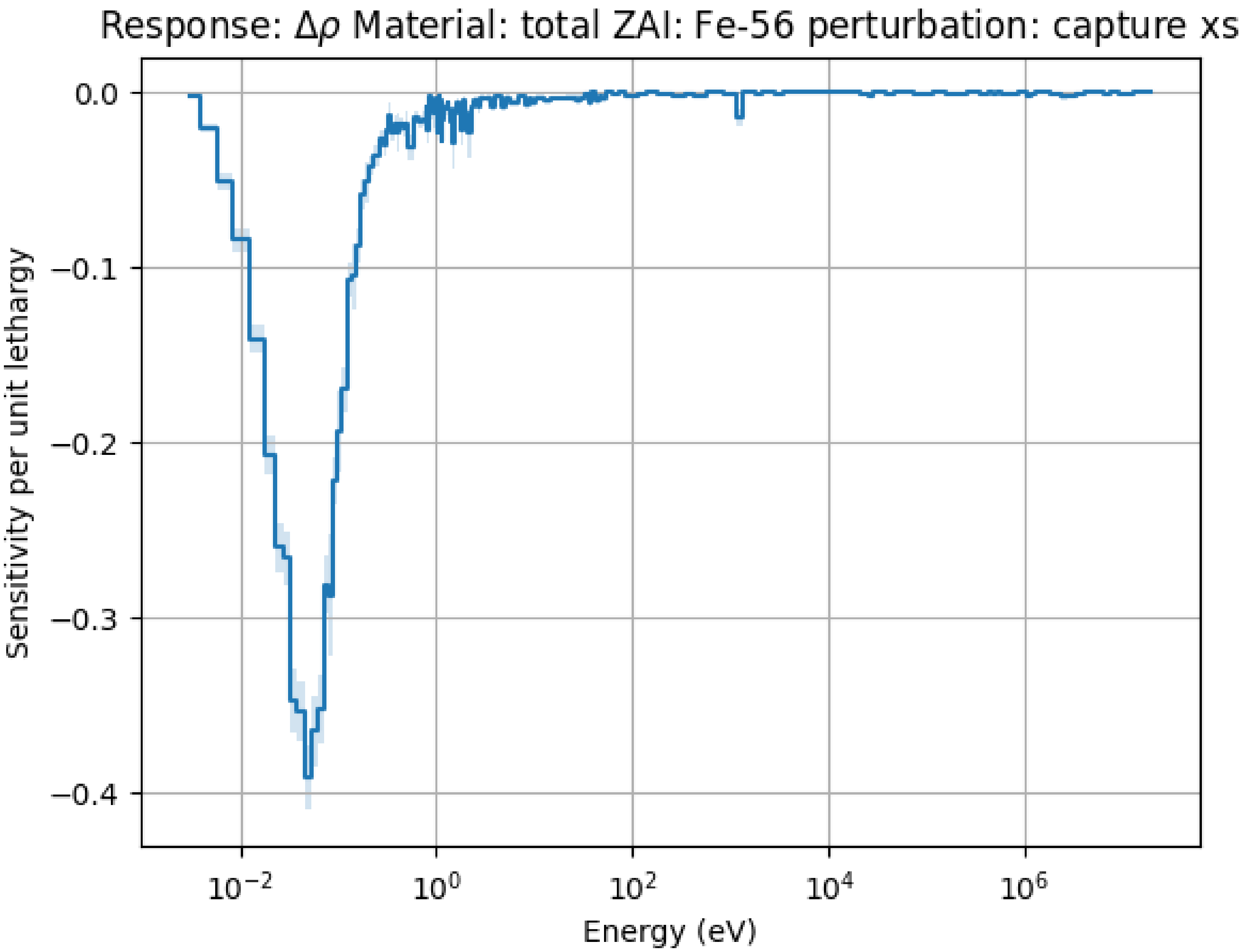
EPFL



7.8
7.6
7.4
7.2
7.0
Spectral Power Ratio (-)
150
152
154
156
Fiber number (-)

EPFL

Sensitivity iron



Reference MAESTRO

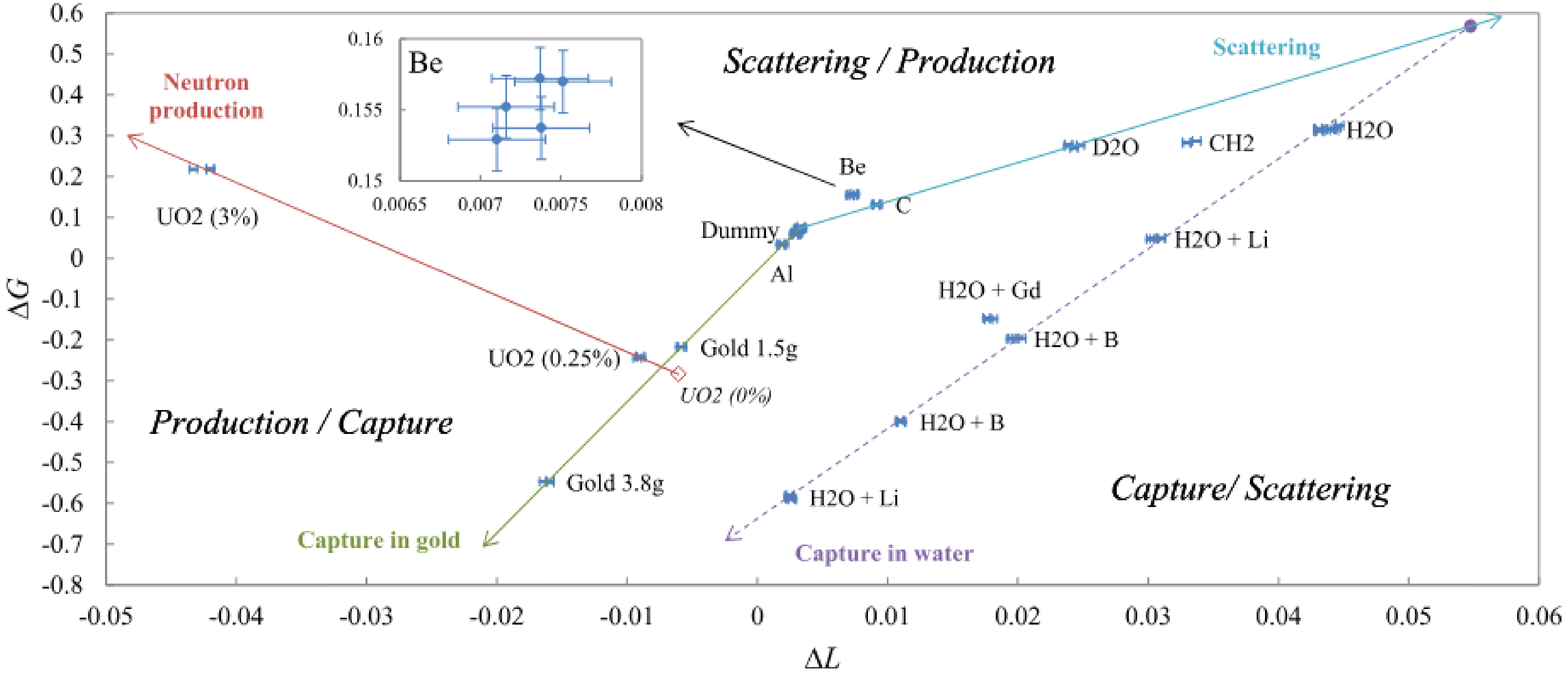
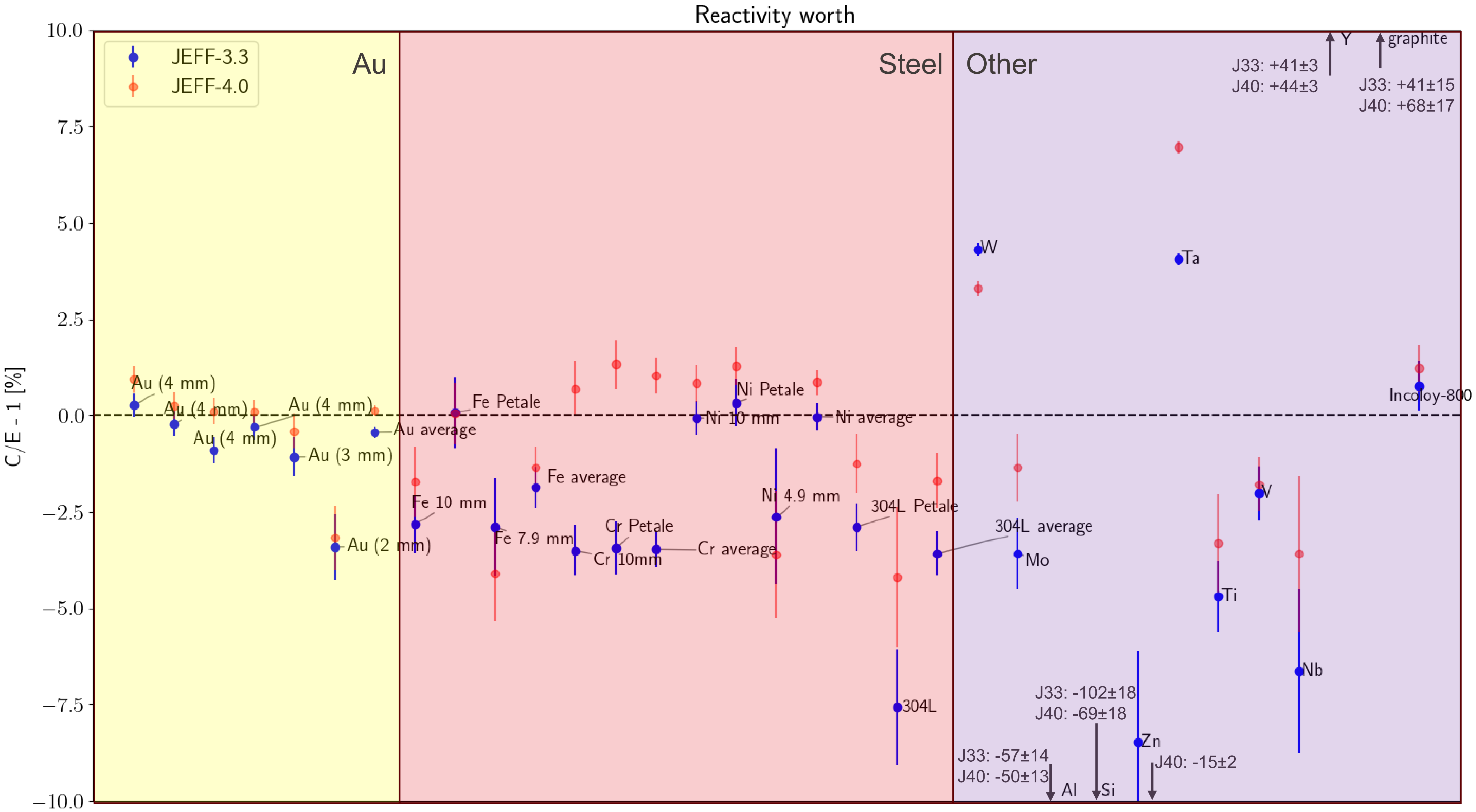
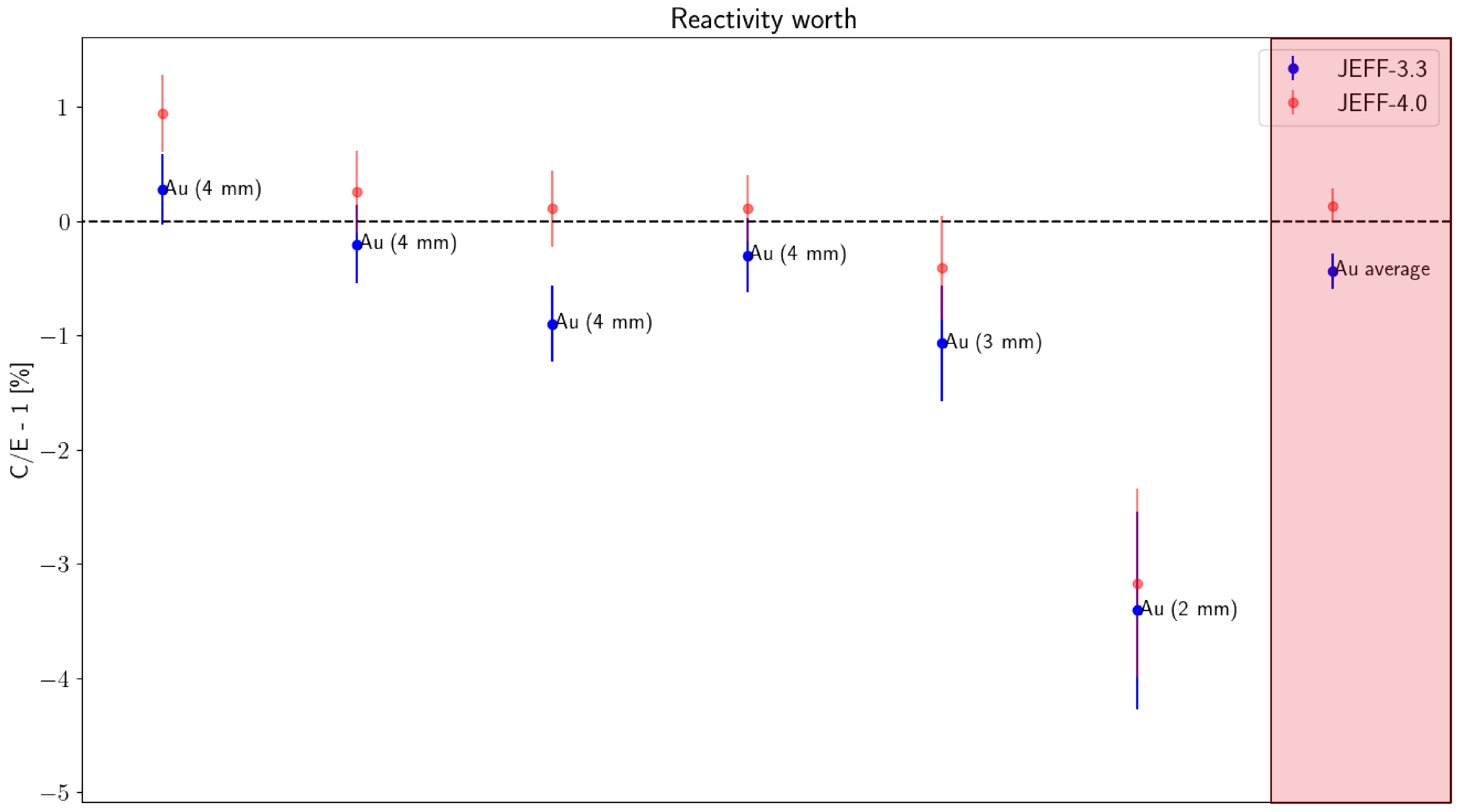


Fig. 5. CLO results in the (ΔG and ΔL) plane. Points include associated uncertainties. A closer view of Beryllium sample shows the error bars more clearly.

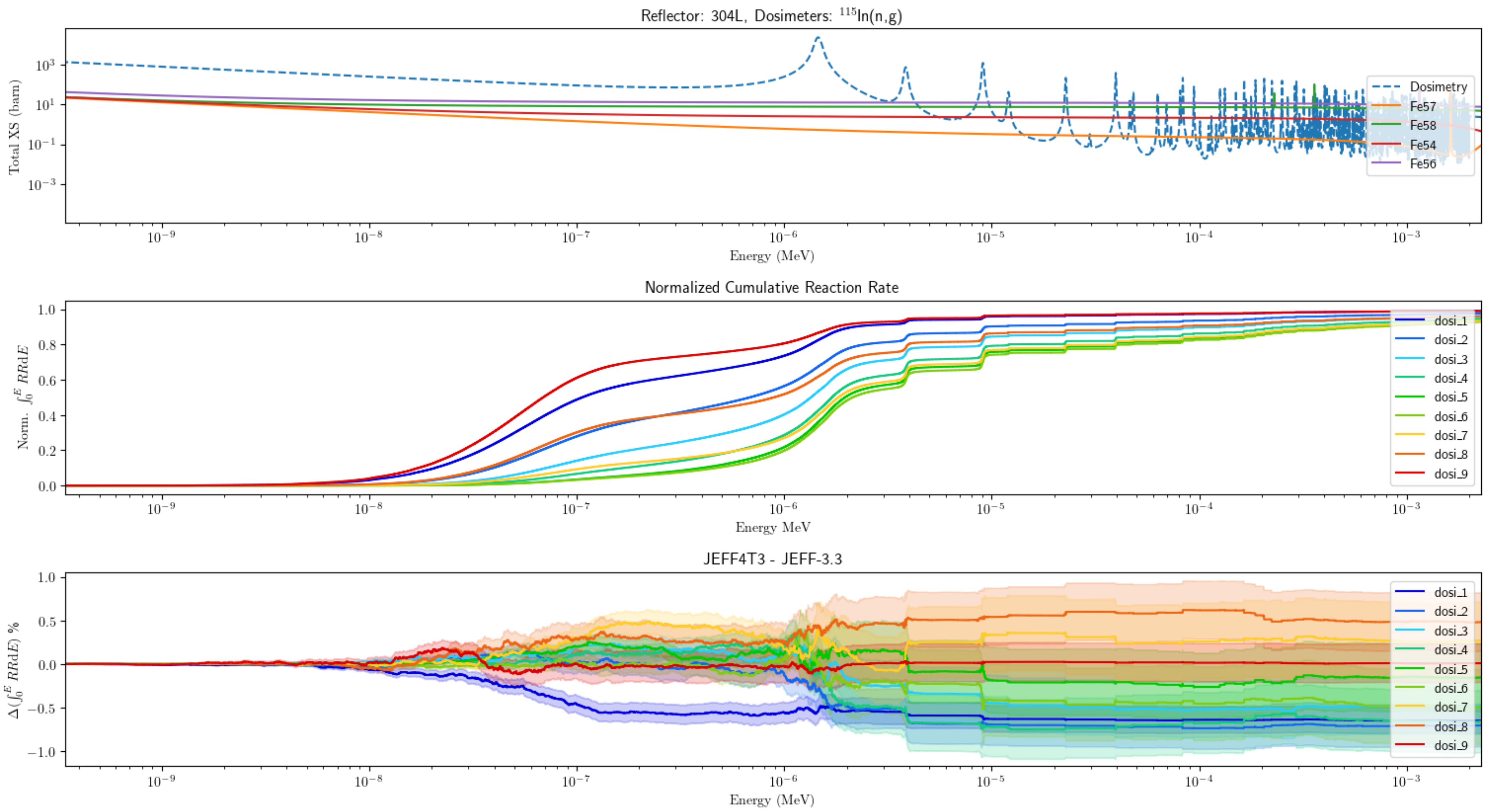
B. Geslot, et al. "Innovative Hybrid Pile Oscillator Technique in the Minerve Reactor: Open Loop Versus Closed Loop," in *IEEE Transactions on Nuclear Science*, doi: 10.1109/TNS.2018.2874690.



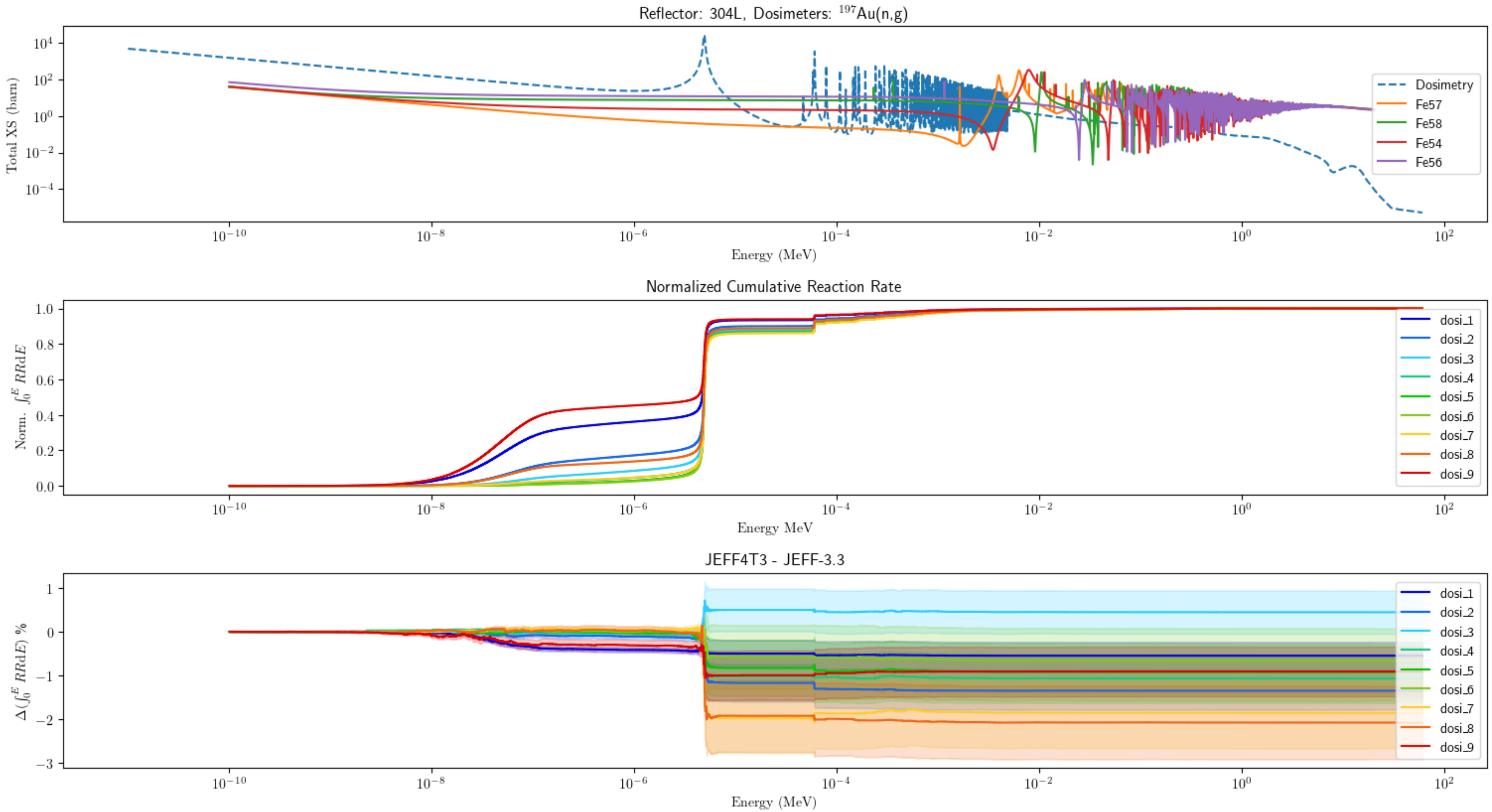
Reactivity worth
JEFF-3.3
JEFF-4.0
Au
Steel
Other
C/E - 1 [%]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
Au (4 mm)
Au (4 mm)
Au (4 mm)
Au (4 mm)
Au (3 mm)
Au (2 mm)
Au average
Fe Petale
Fe 10 mm
Fe 7.9 mm
Fe average
Cr Petale
Cr 10mm
Cr average
Ni Petale
Ni 10 mm
Ni average
Ni 4.9 mm
304L Petale
304L
304L average
W
Ta
Mo
Ti
V
Nb
Zn
Incoloy-800
Y
graphite
J33: +41±3
J40: +44±3
J33: +41±15
J40: +68±17
J33: -102±18
J40: -69±18
J33: -57±14
J40: -50±13
J40: -15±2
Al
Si



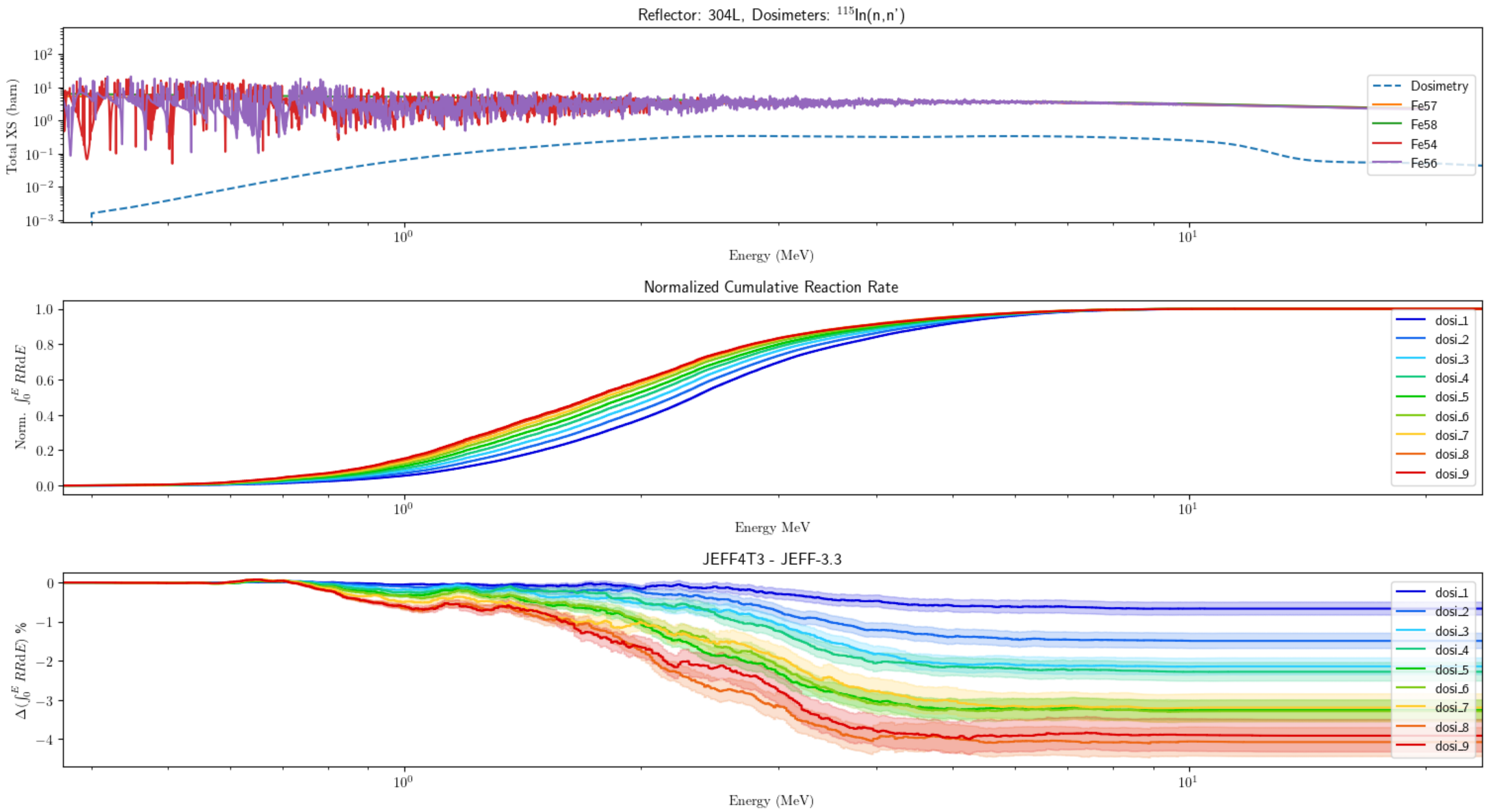
Reactivity worth
C/E - 1 [%]
1
0
−1
−2
−3
−4
−5
JEFF-3.3
JEFF-4.0
Au (4 mm)
Au (4 mm)
Au (4 mm)
Au (4 mm)
Au (3 mm)
Au (2 mm)
Au average



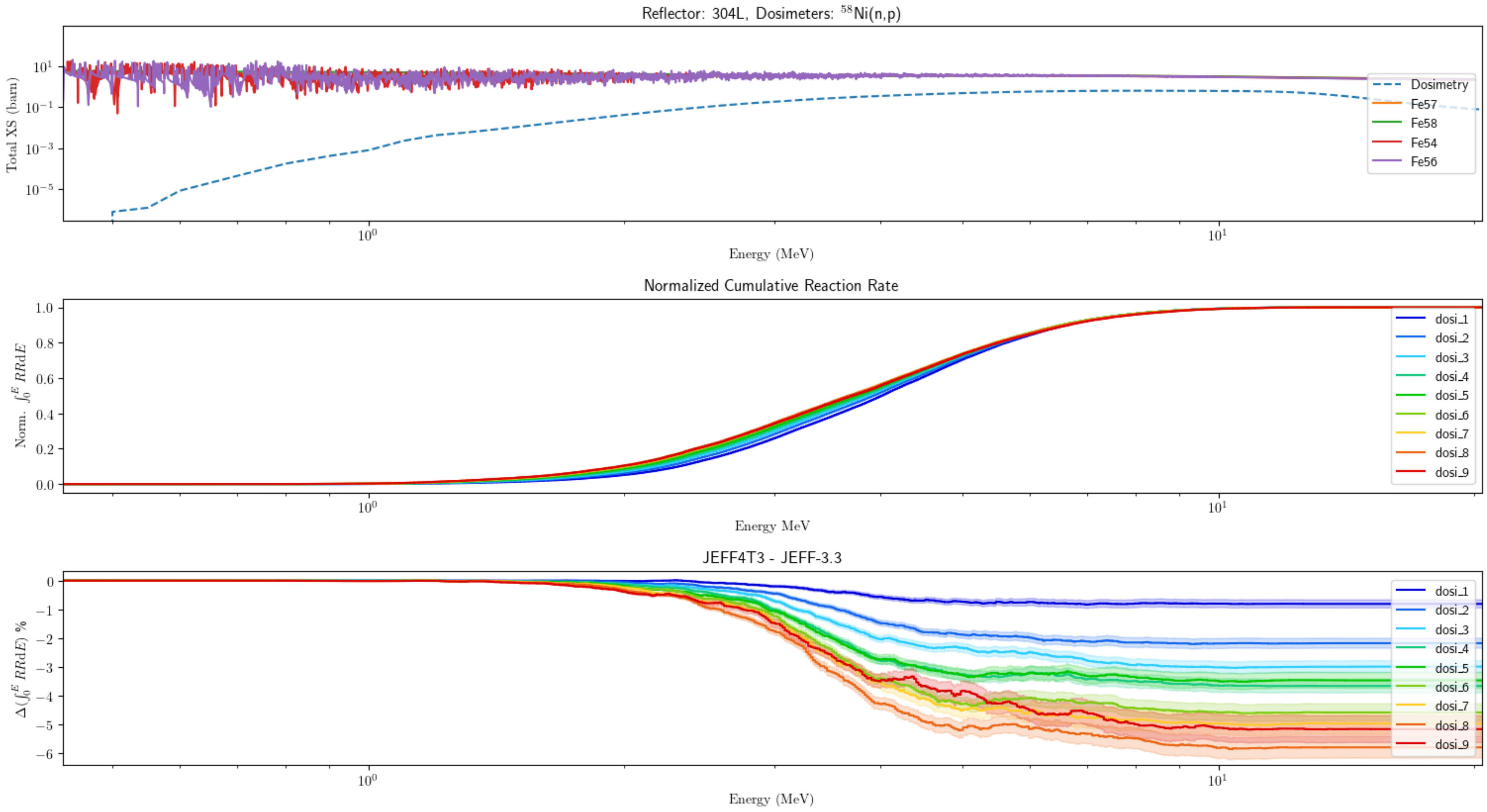
Thomas Ligonnet, INDEN Consultancy meeting



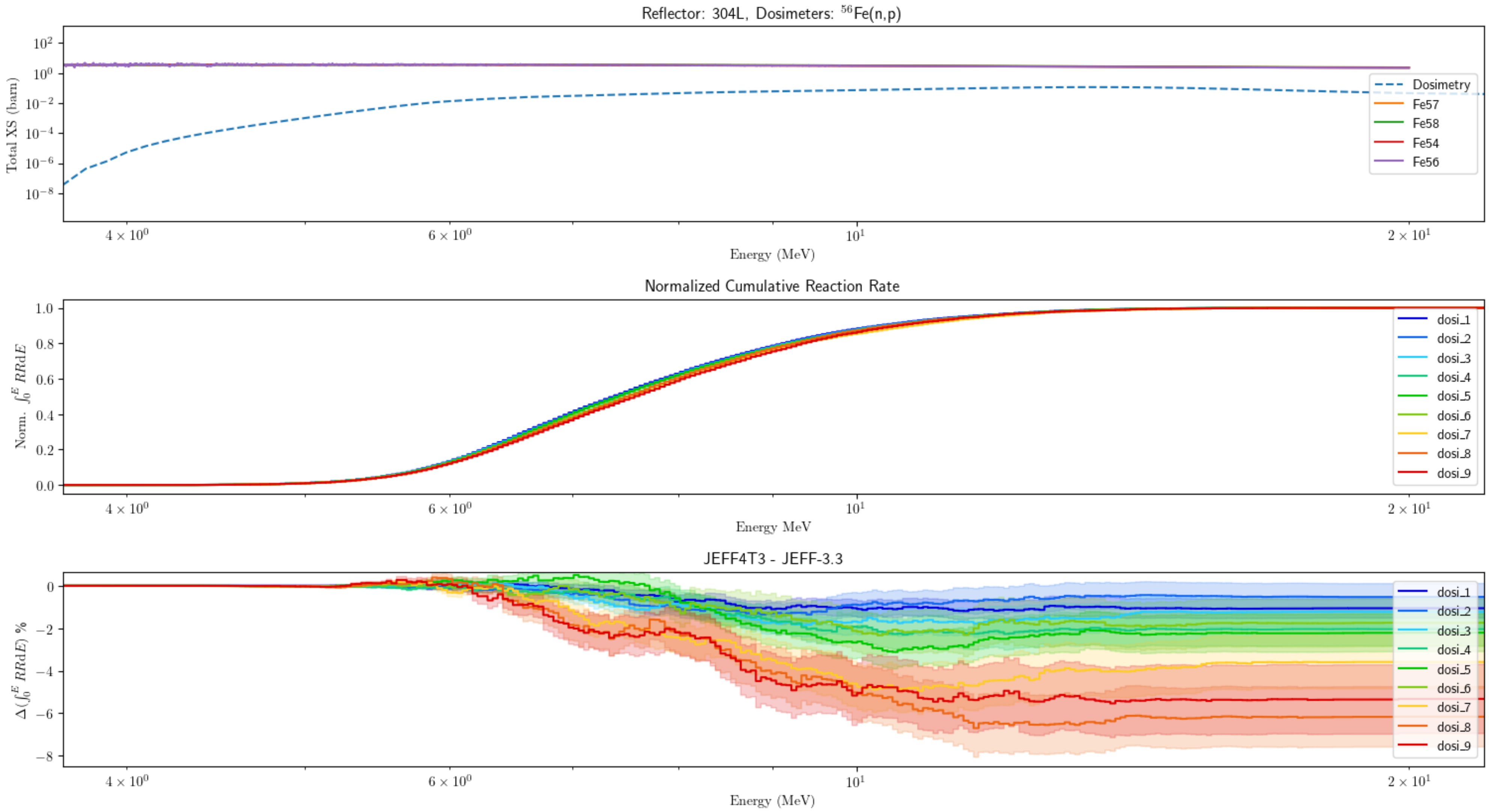
Reflector: 304L, Dosimeters: ^{197}Au(n,g)
Total XS (barn)
Energy (MeV)
Dosimetry
Fe57
Fe58
Fe54
Fe56
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
JEFF4T3 - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)



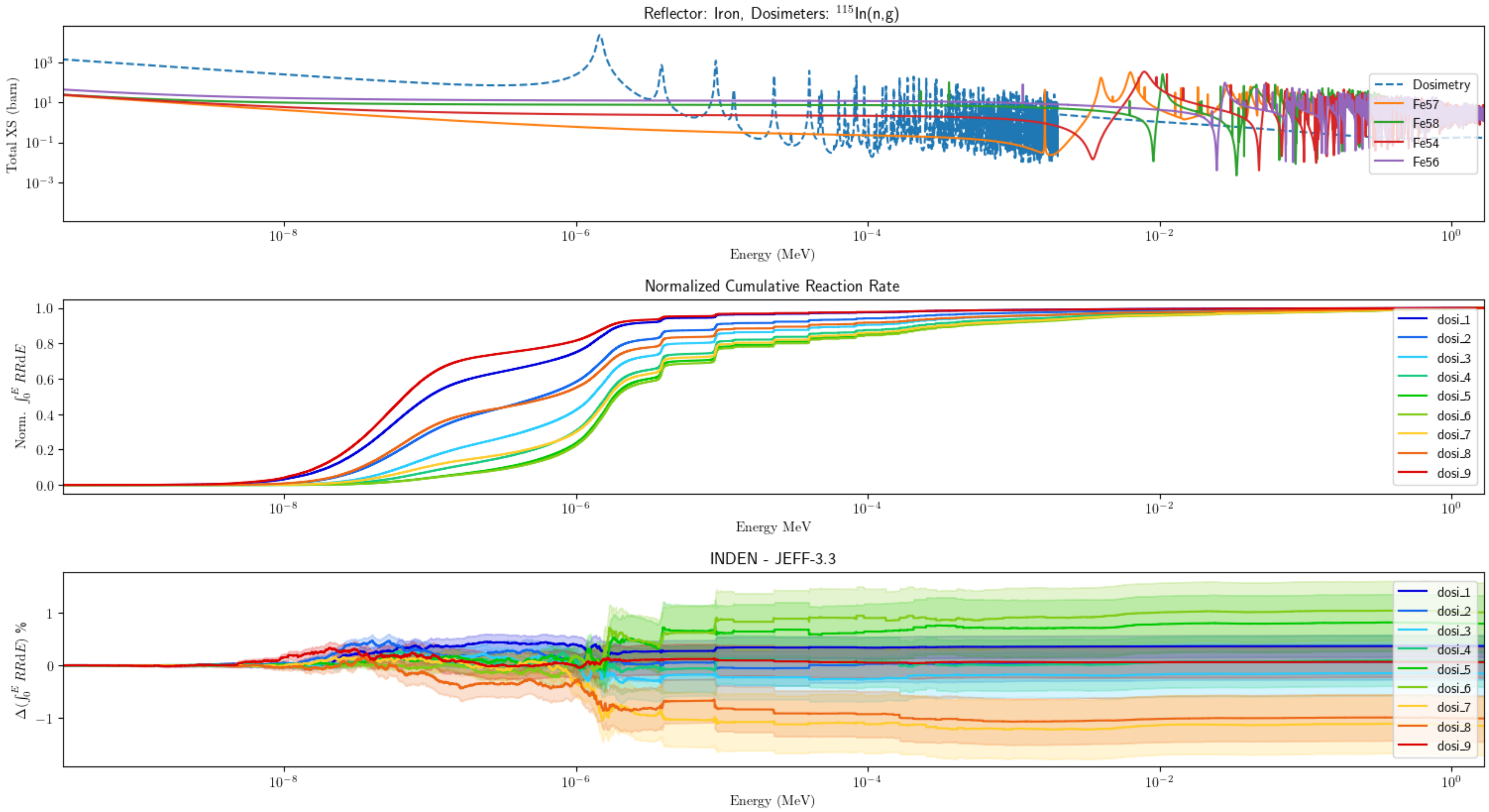
Reflector: 304L, Dosimeters: ^{115}In(n,n')
Total XS (barn)
Energy (MeV)
Dosimetry
Fe57
Fe58
Fe54
Fe56
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
JEFF4T3 - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)

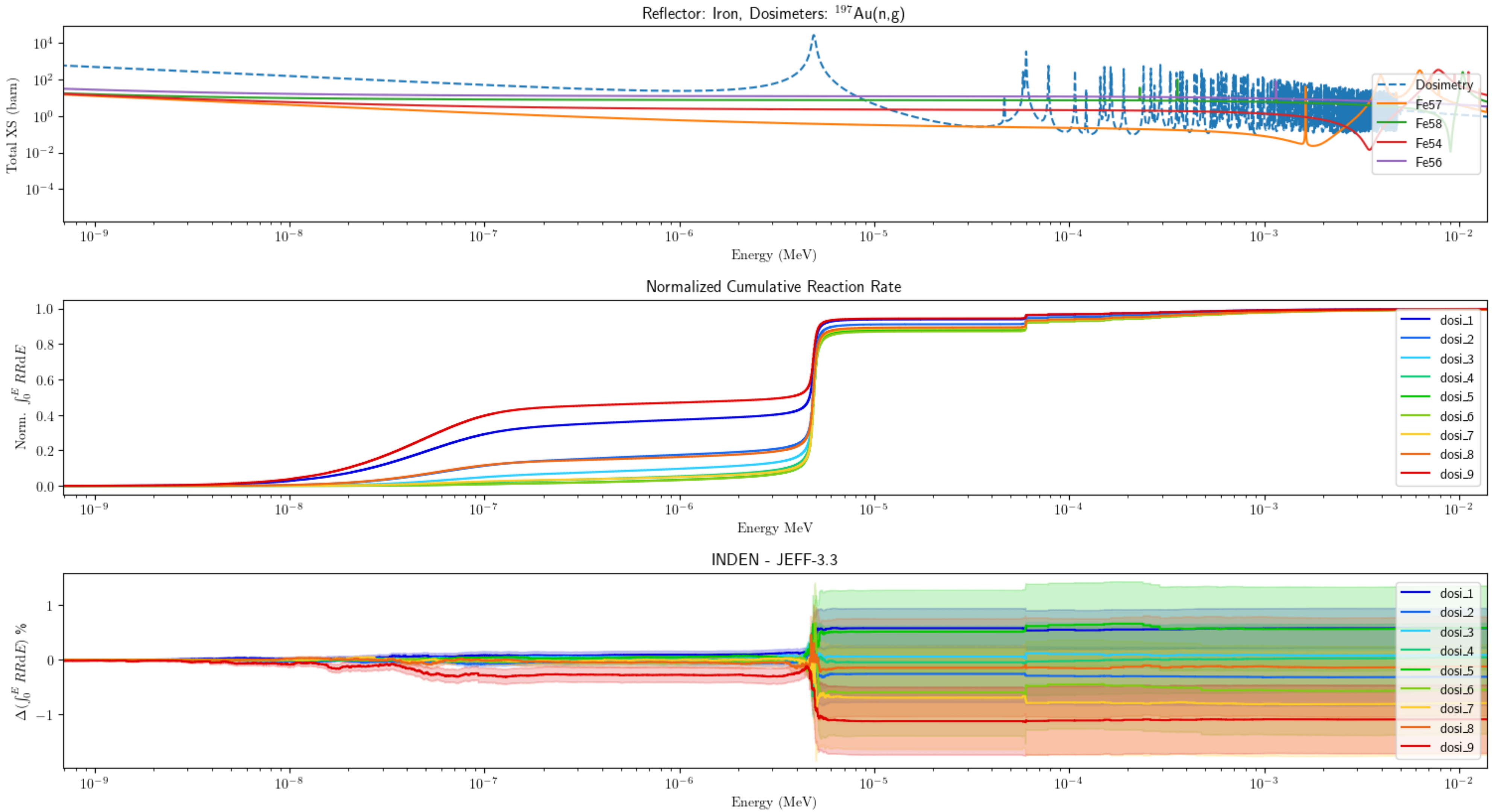


Reflector: 304L, Dosimeters: ^{58}Ni(n,p)
Total XS (barn)
Energy (MeV)
Dosimetry
Fe57
Fe58
Fe54
Fe56
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
JEFF4T3 - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)

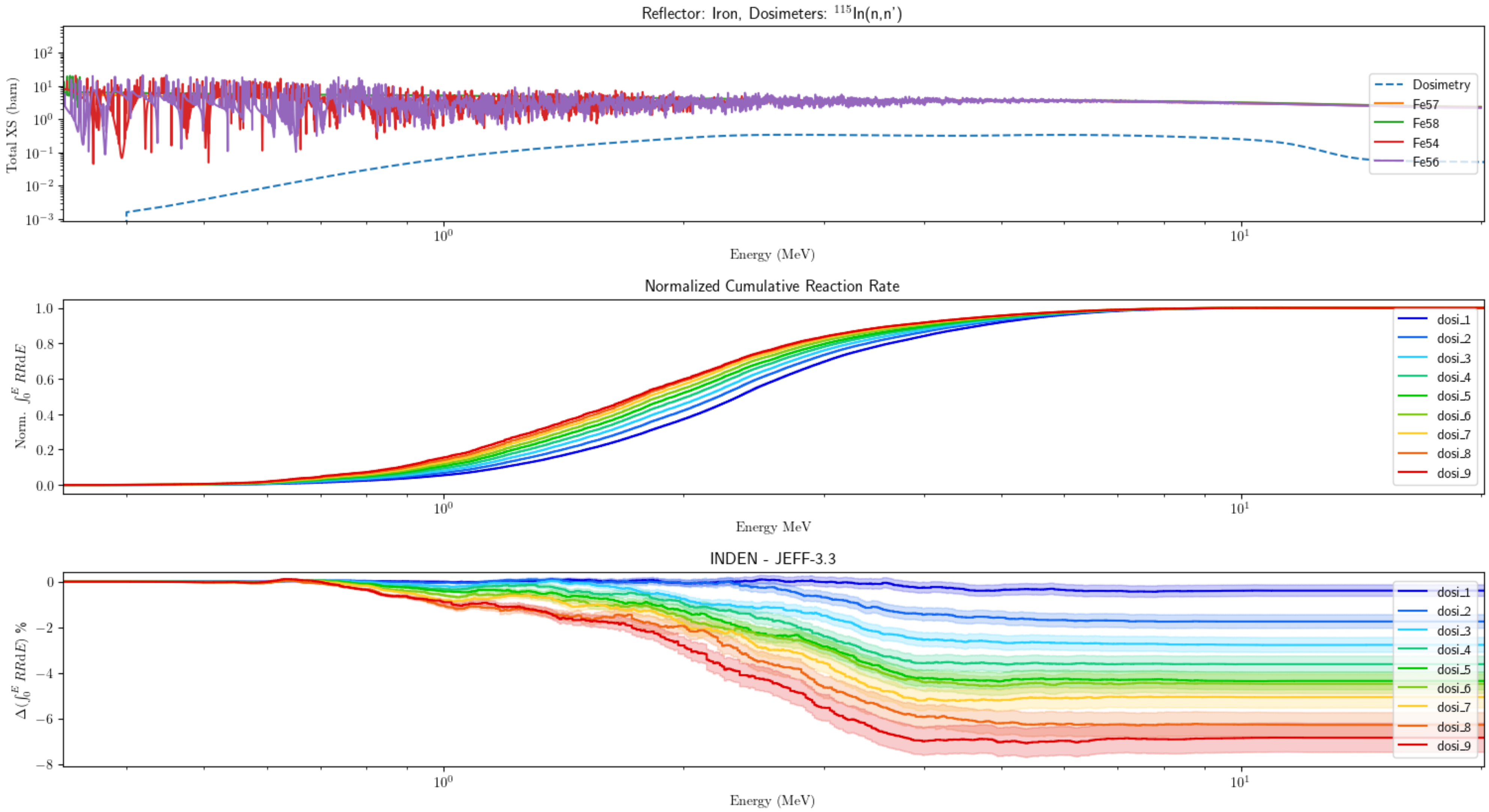


Thomas Ligonnet, INDEN Consultancy meeting

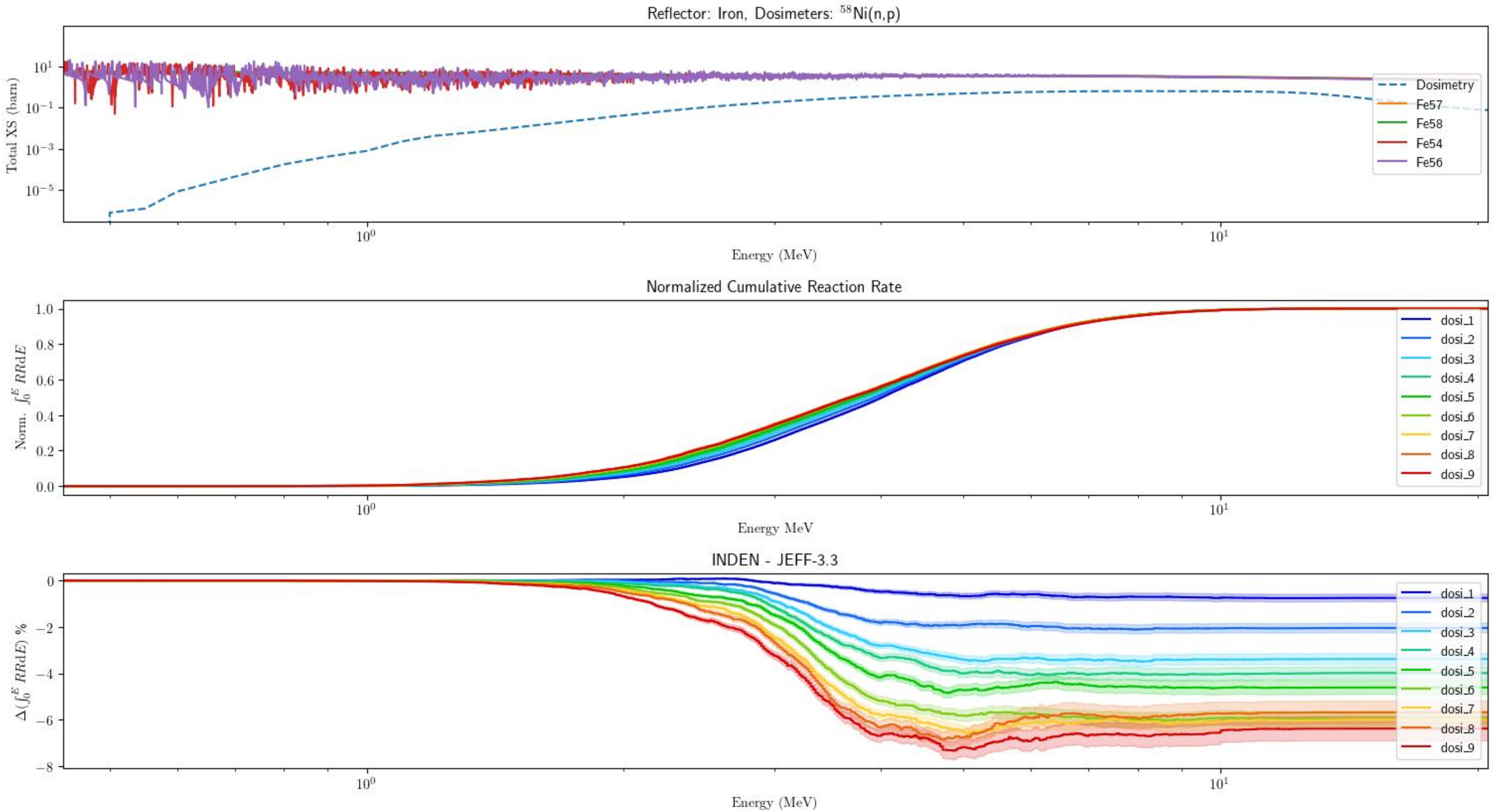

Reflector: Iron, Dosimeters: 115In(n,g)
Total XS (barn)
Energy (MeV)
Dosimetry
Fe57
Fe58
Fe54
Fe56
Normalized Cumulative Reaction Rate
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
INDEN - JEFF-3.3
Energy (MeV)


Reflector: Iron, Dosimeters: ^{197}Au(n,g)
Total XS (barn)
Energy (MeV)
Dosimetry
Fe57
Fe58
Fe54
Fe56
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
INDEN - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)

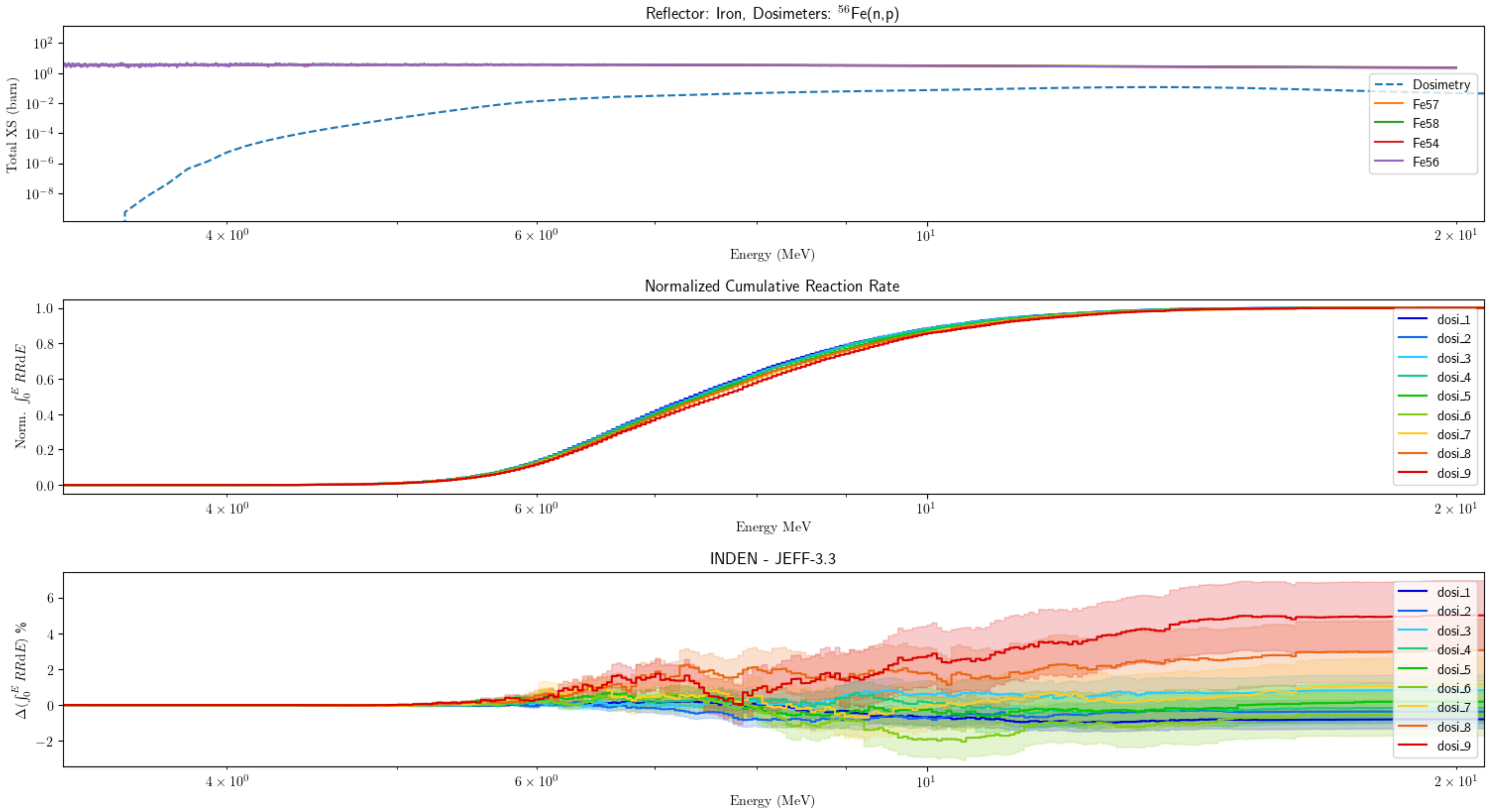
EPFL



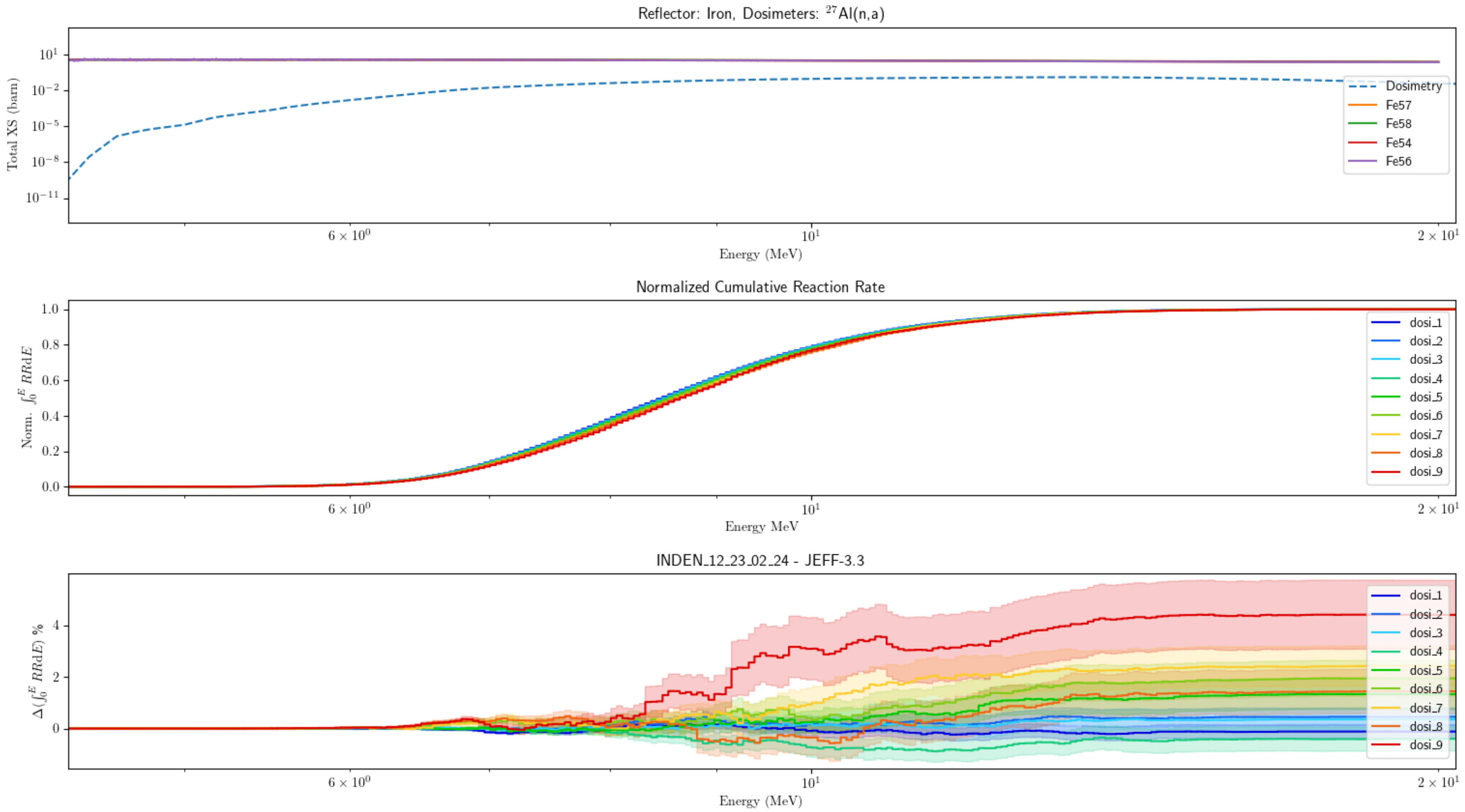
Reflector: Iron, Dosimeters: 115In(n,n')
Total XS (barn)
Energy (MeV)
Dosimetry
Fe57
Fe58
Fe54
Fe56
Normalized Cumulative Reaction Rate
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
INDEN - JEFF-3.3
Energy (MeV)



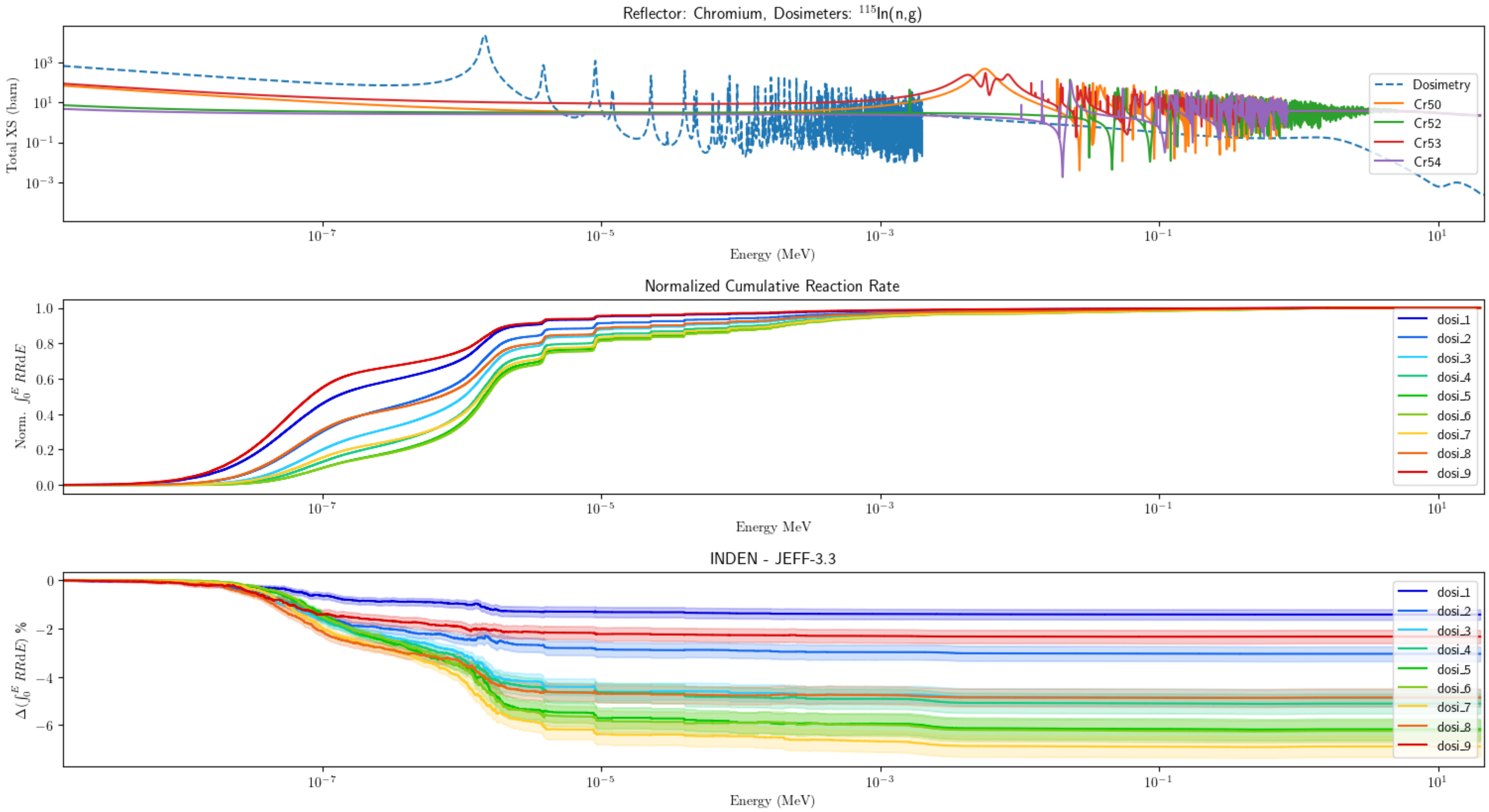
Reflector: Iron, Dosimeters: 58Ni(n,p)
Total XS (barn)
Dosimetry
Fe57
Fe58
Fe54
Fe56
Energy (MeV)
Normalized Cumulative Reaction Rate
Norm. ∫E0 RRdE
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
Energy MeV
INDEN - JEFF-3.3
Δ(∫E0 RRdE) %
Energy (MeV)



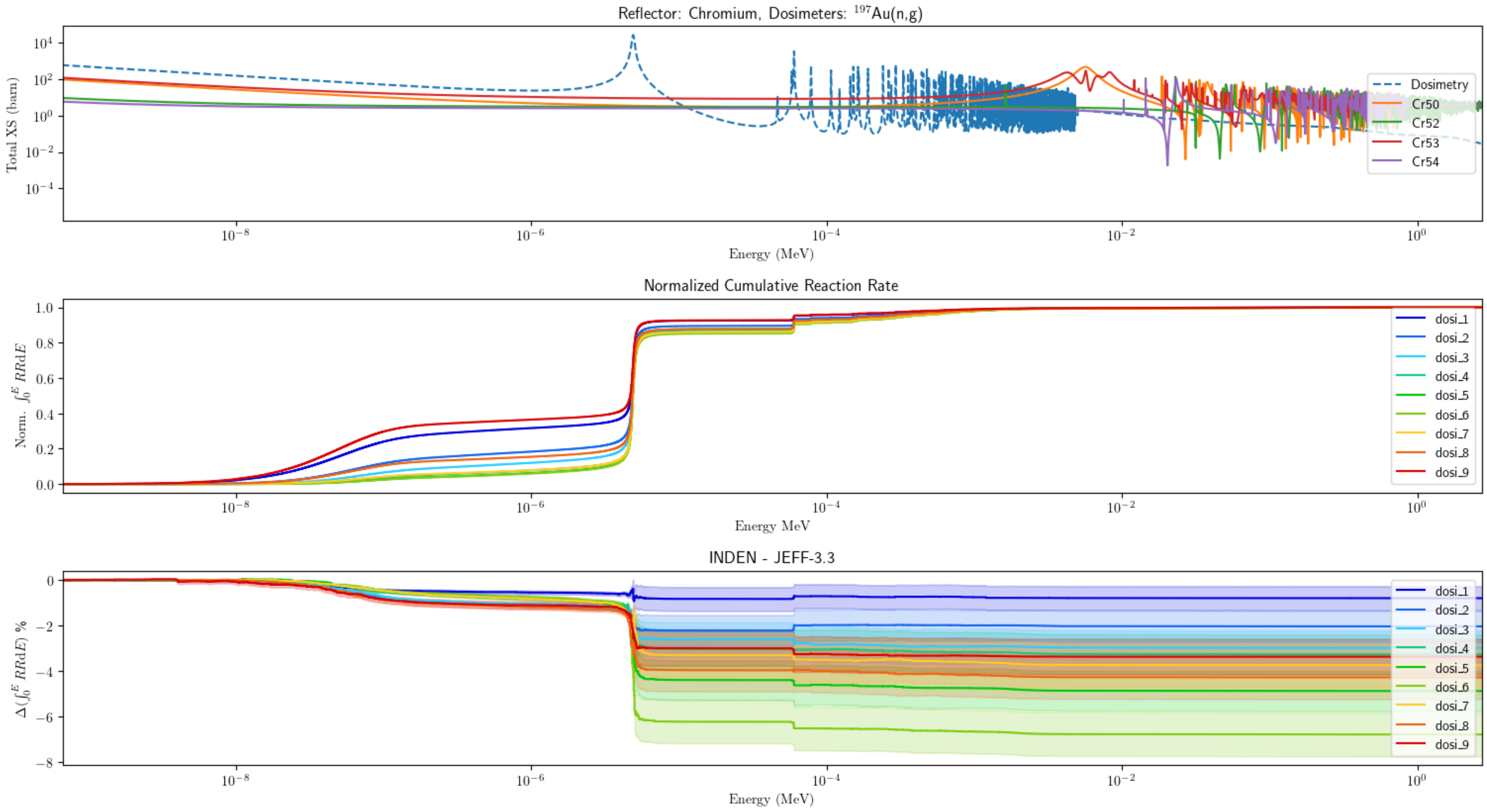
Reflector: Iron, Dosimeters: ^{56}Fe(n,p)
Total XS (barn)
Dosimetry
Fe57
Fe58
Fe54
Fe56
Energy (MeV)
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
Energy MeV
INDEN - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)



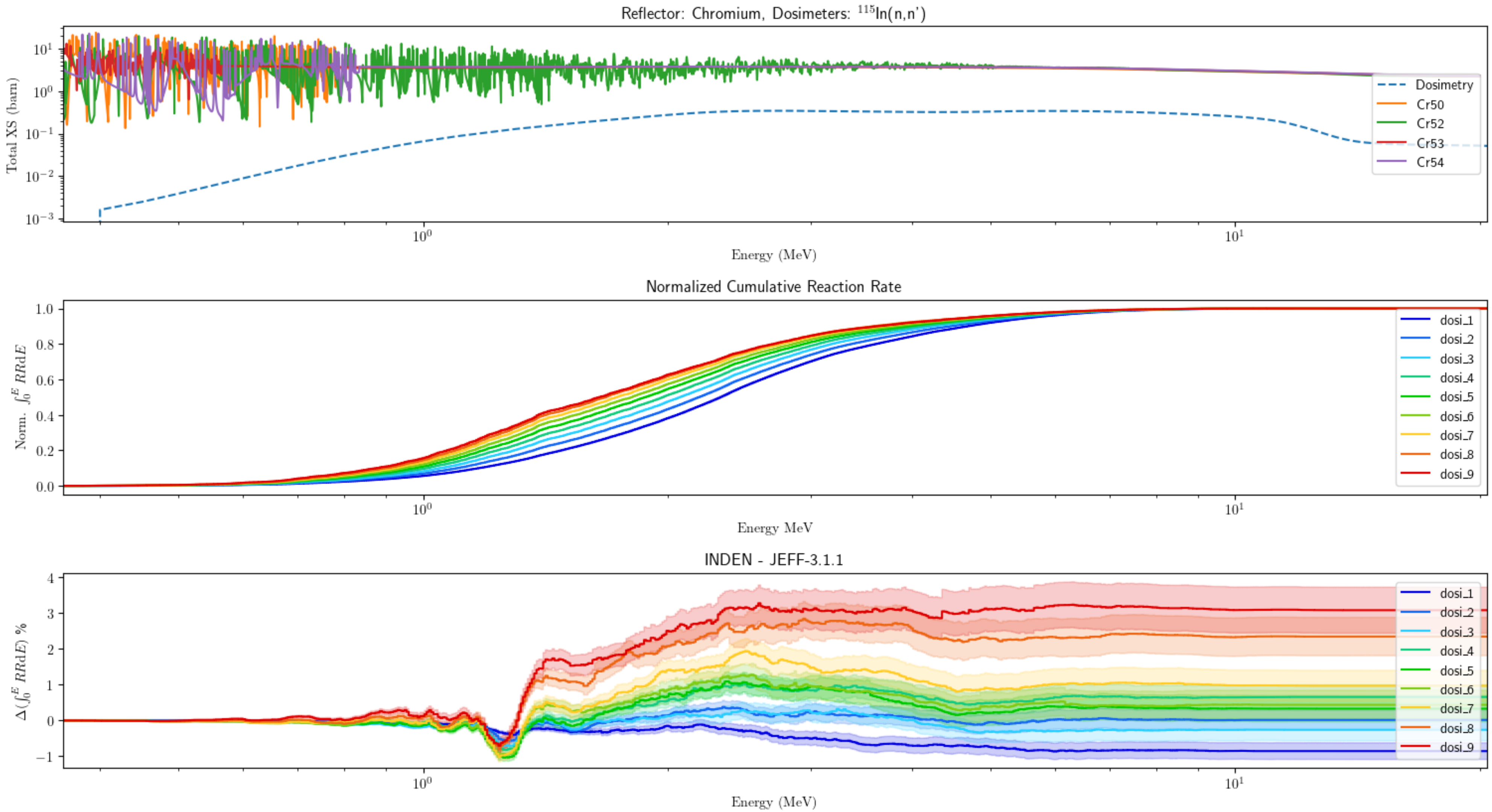
Reflector: Iron, Dosimeters: 27Al(n,a)
Total XS (barn)
Energy (MeV)
Dosimetry
Fe57
Fe58
Fe54
Fe56
Normalized Cumulative Reaction Rate
Energy MeV
INDEN_12_23_02_24 - JEFF-3.3
Energy (MeV)
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9



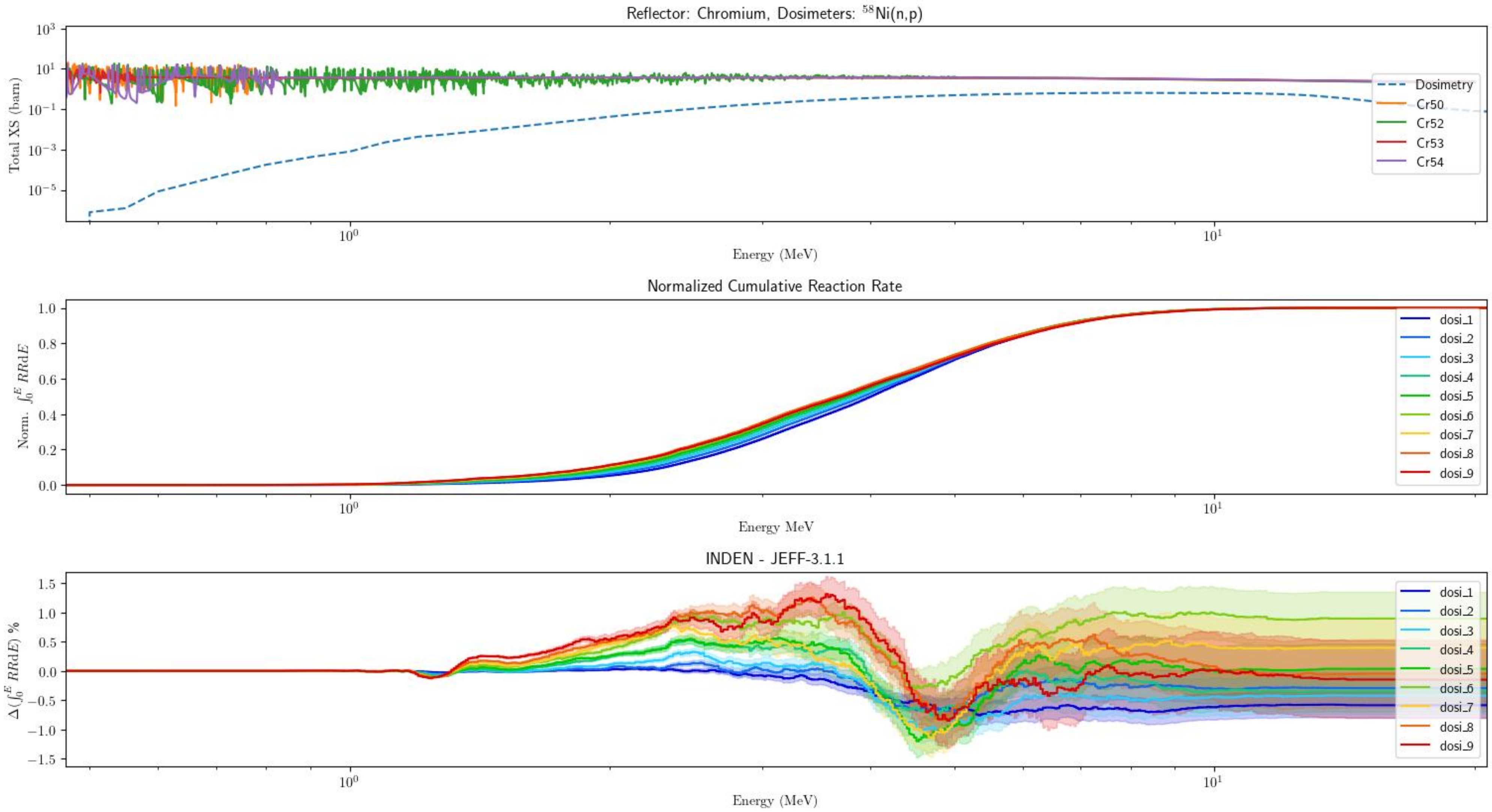
Reflector: Chromium, Dosimeters: ^{115}In(n,g)
Total XS (barn)
Energy (MeV)
Dosimetry
Cr50
Cr52
Cr53
Cr54
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
INDEN - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)



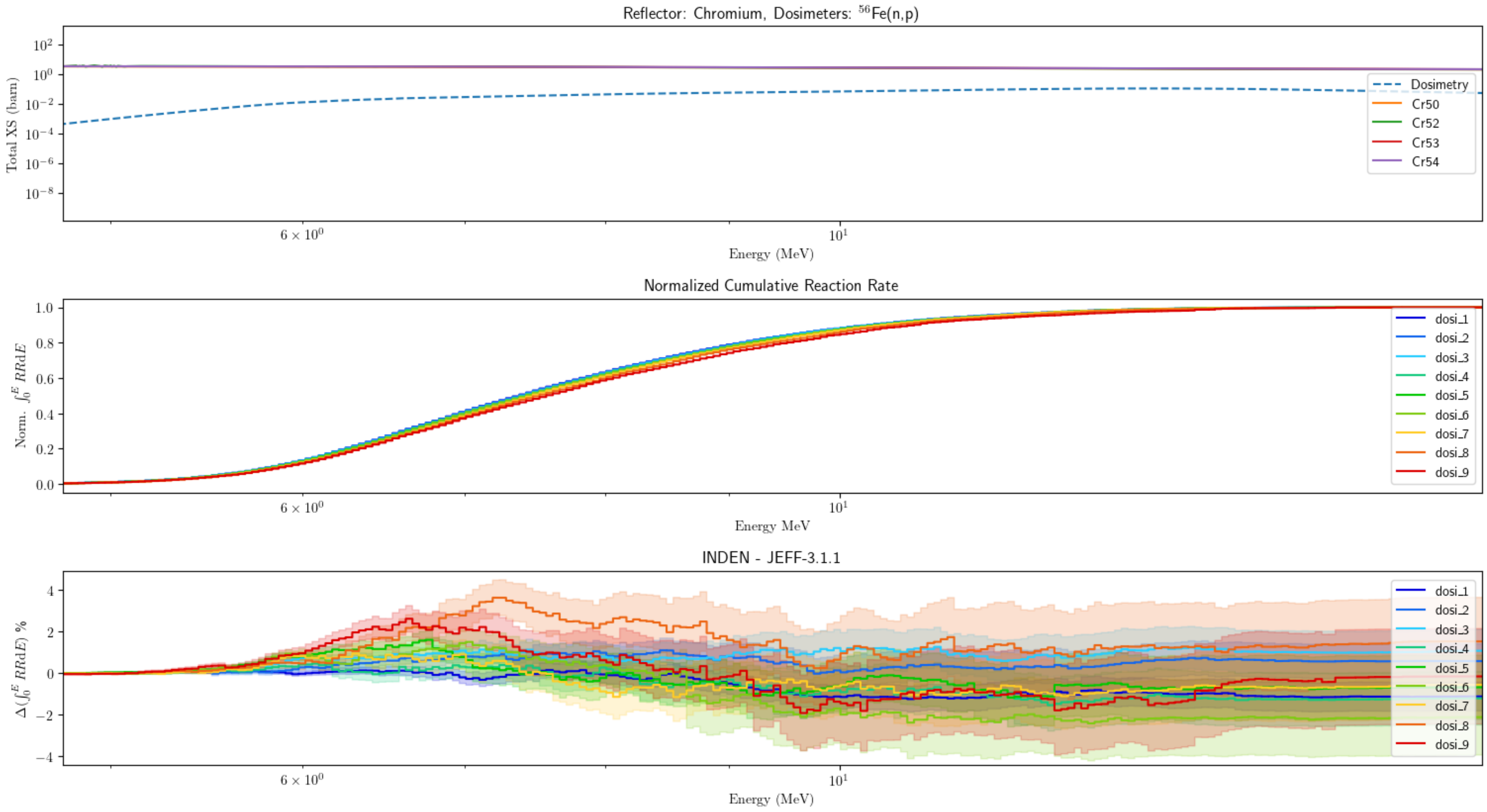
Reflector: Chromium, Dosimeters: ^{197}Au(n,g)
Total XS (barn)
Energy (MeV)
Dosimetry
Cr50
Cr52
Cr53
Cr54
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
INDEN - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)



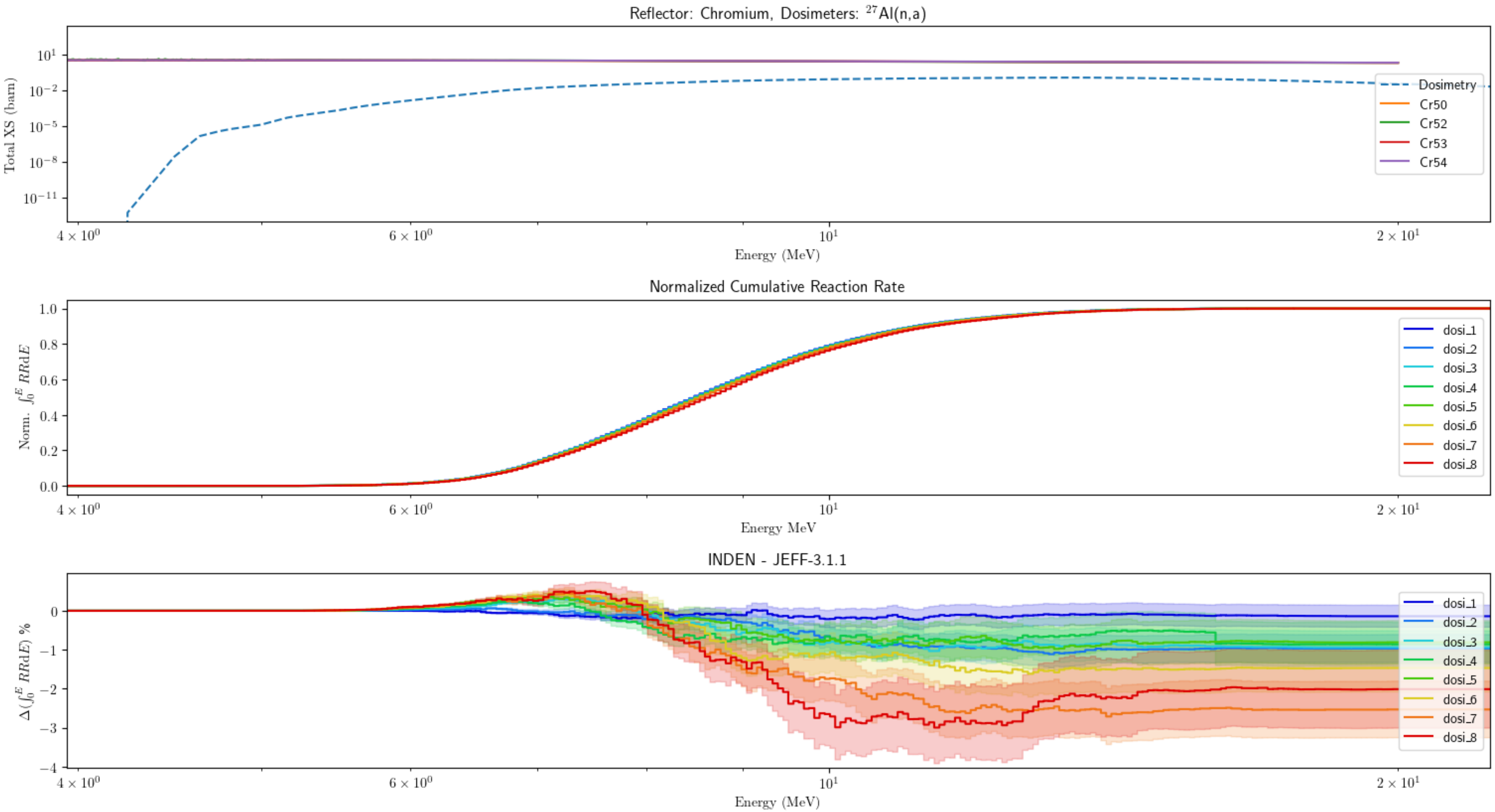
Reflector: Chromium, Dosimeters: ^{115}In(n,n')
Total XS (barn)
Energy (MeV)
Dosimetry
Cr50
Cr52
Cr53
Cr54
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
INDEN - JEFF-3.1.1
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)



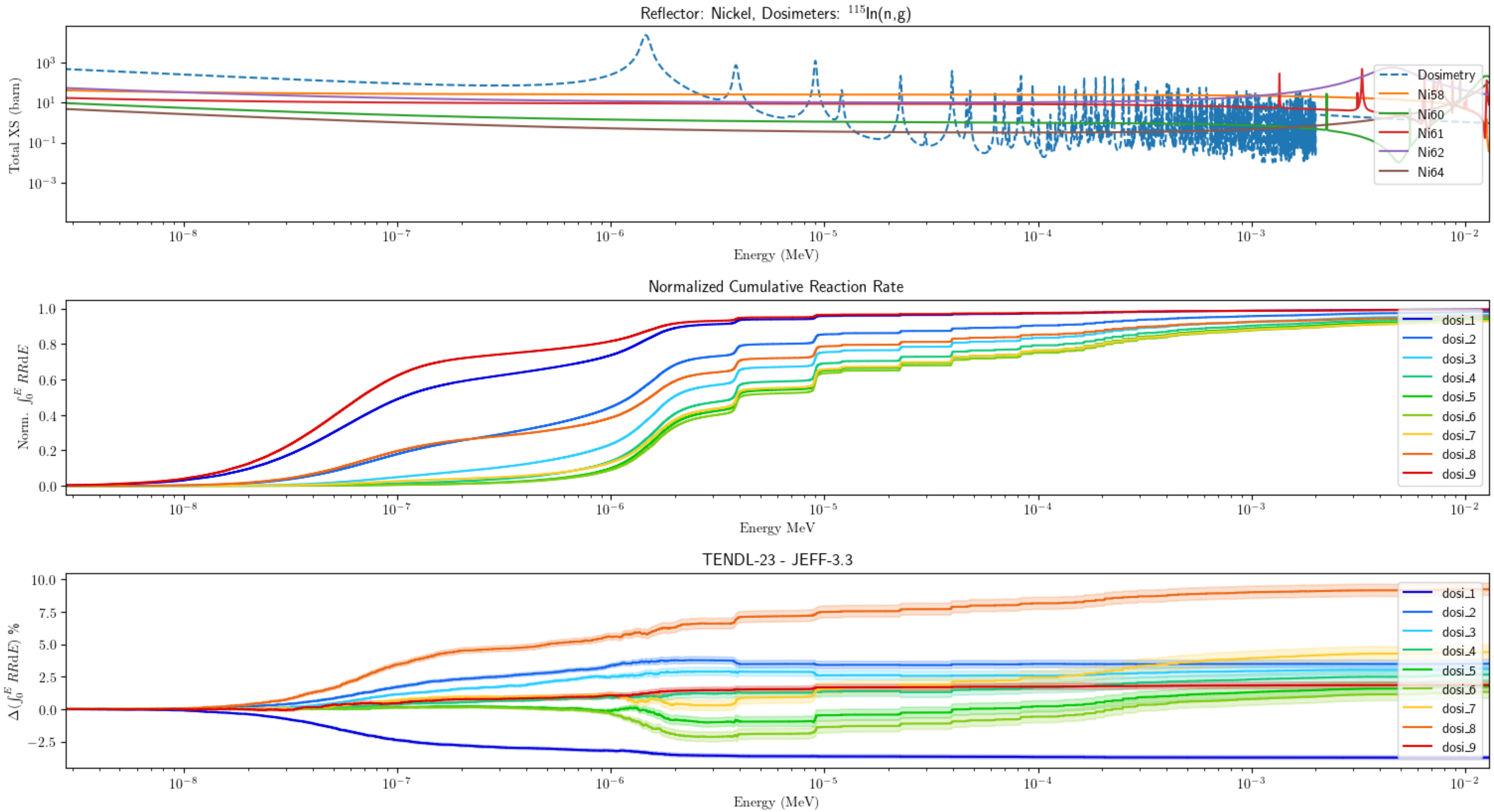
Reflector: Chromium, Dosimeters: 58Ni(n,p)
Total XS (barn)
Energy (MeV)
Dosimetry
Cr50
Cr52
Cr53
Cr54
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
INDEN - JEFF-3.1.1
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)


Reflector: Chromium, Dosimeters: ^{56}Fe(n,p)
Total XS (barn)
Dosimetry
Cr50
Cr52
Cr53
Cr54
Energy (MeV)
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
Energy MeV
INDEN - JEFF-3.1.1
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)

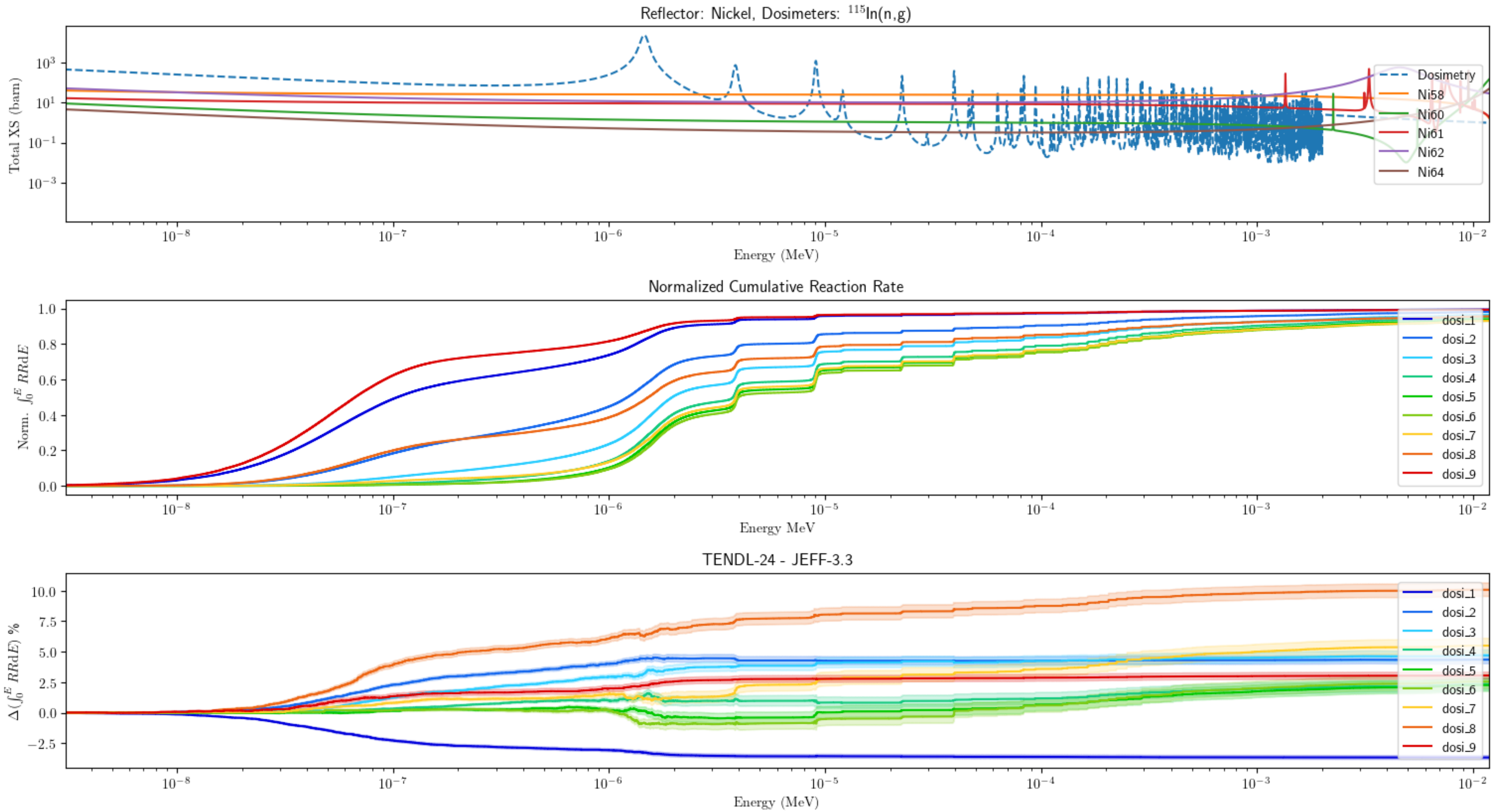
EPFL



Reflector: Chromium, Dosimeters: ^{27}Al(n,a)
Total XS (barn)
Energy (MeV)
Dosimetry
Cr50
Cr52
Cr53
Cr54
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
INDEN - JEFF-3.1.1
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)

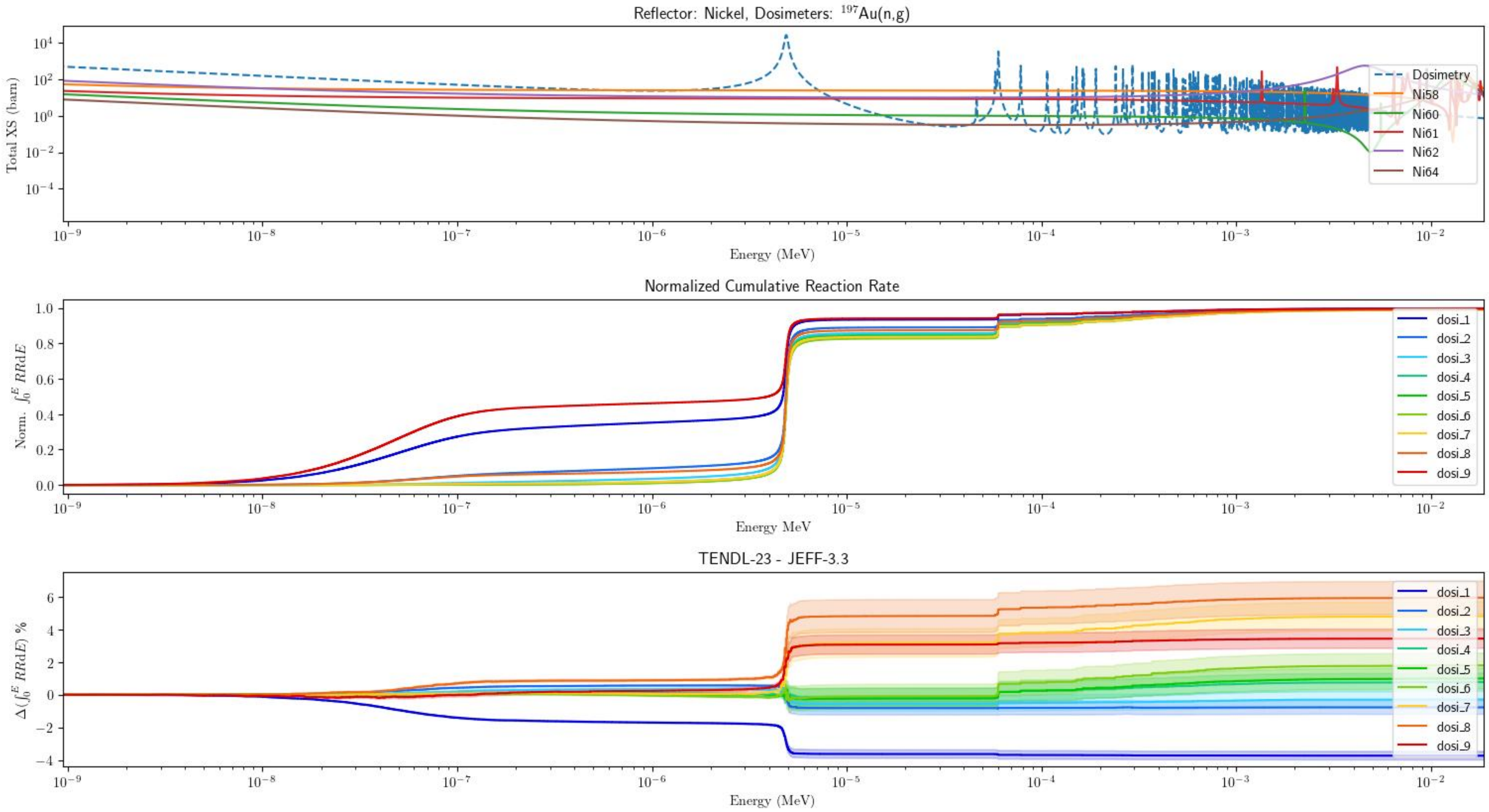


Reflector: Nickel, Dosimeters: ^{115}In(n,g)
Total XS (barn)
Energy (MeV)
Dosimetry
Ni58
Ni60
Ni61
Ni62
Ni64
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
TENDL-23 - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)



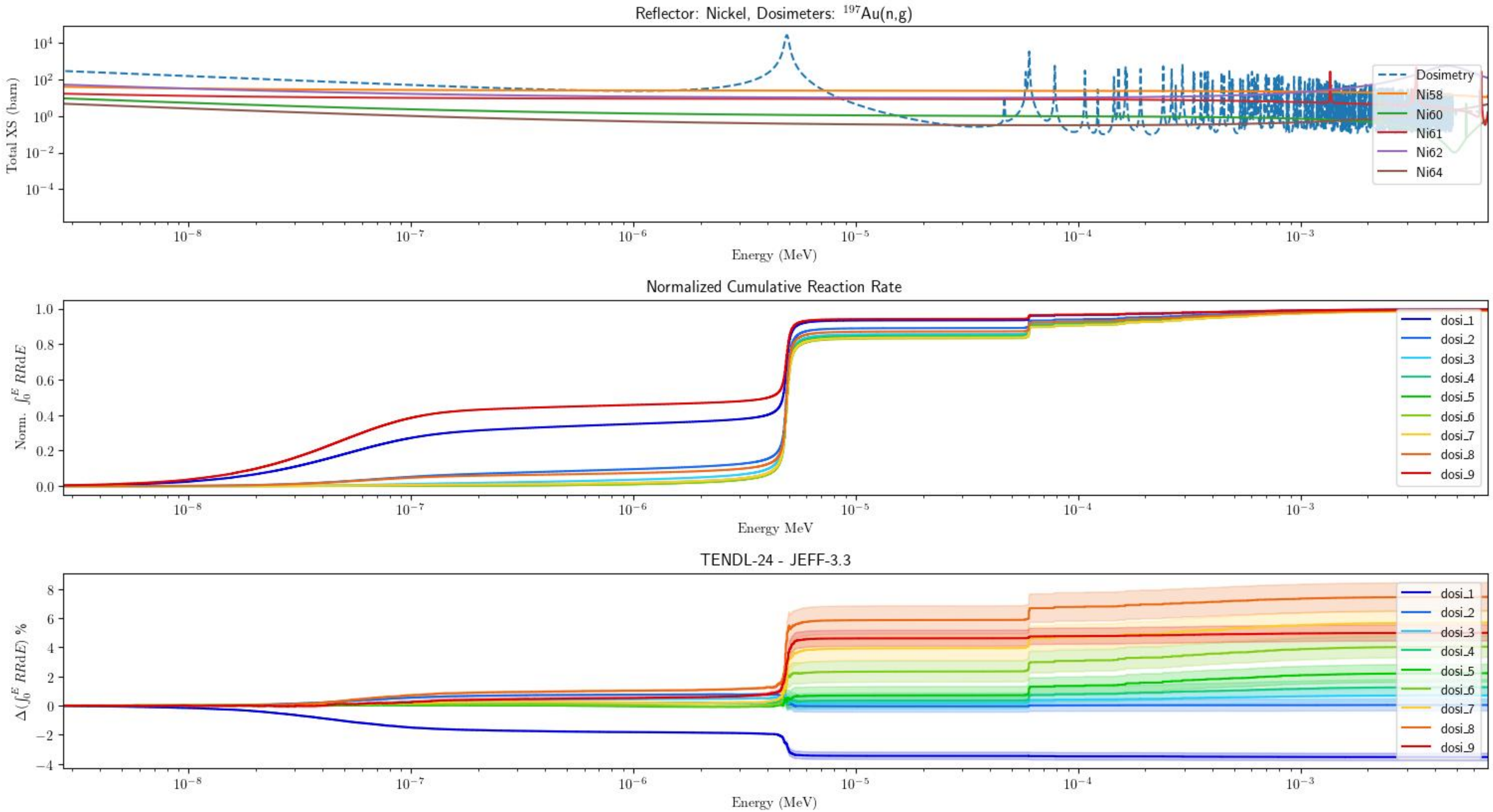
Reflector: Nickel, Dosimeters: ^{115}In(n,g)
Total XS (barn)
Energy (MeV)
Dosimetry
Ni58
Ni60
Ni61
Ni62
Ni64
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
TENDL-24 - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)

EPFL

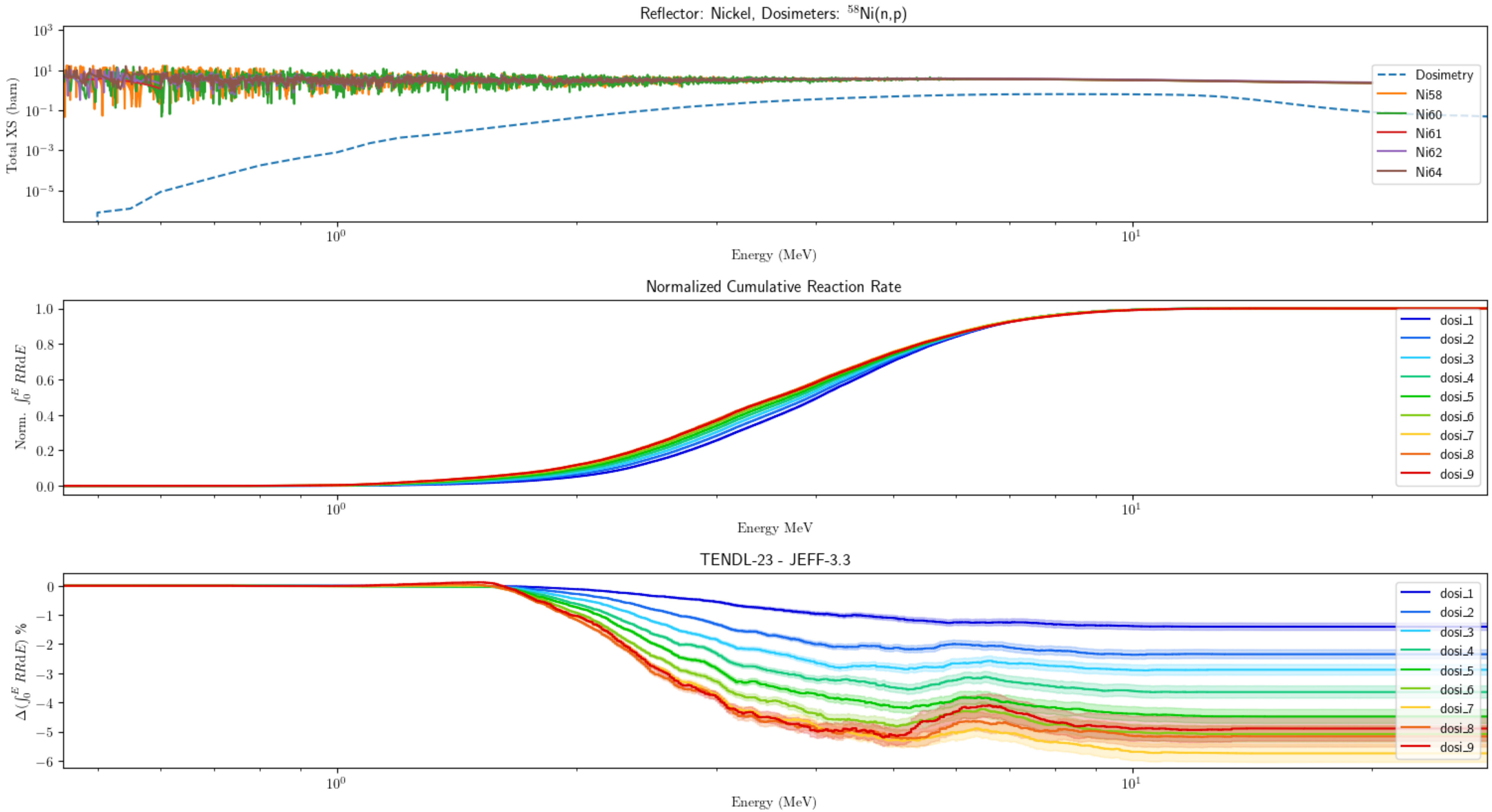


Reflector: Nickel, Dosimeters: ^{197}Au(n,g)
Total XS (barn)
Energy (MeV)
Dosimetry
Ni58
Ni60
Ni61
Ni62
Ni64
Normalized Cumulative Reaction Rate
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
TENDL-23 - JEFF-3.3
Energy (MeV)

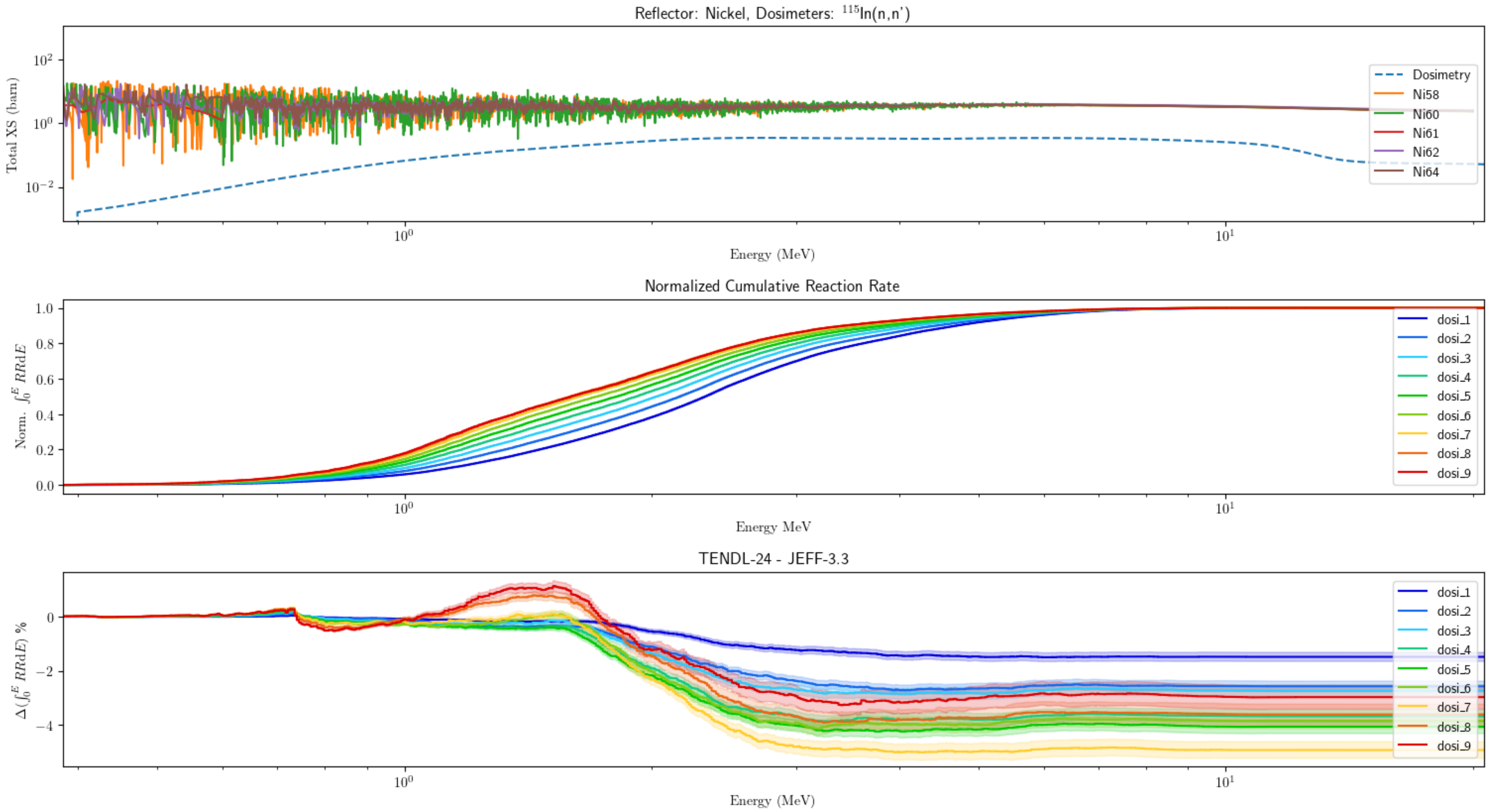
EPFL



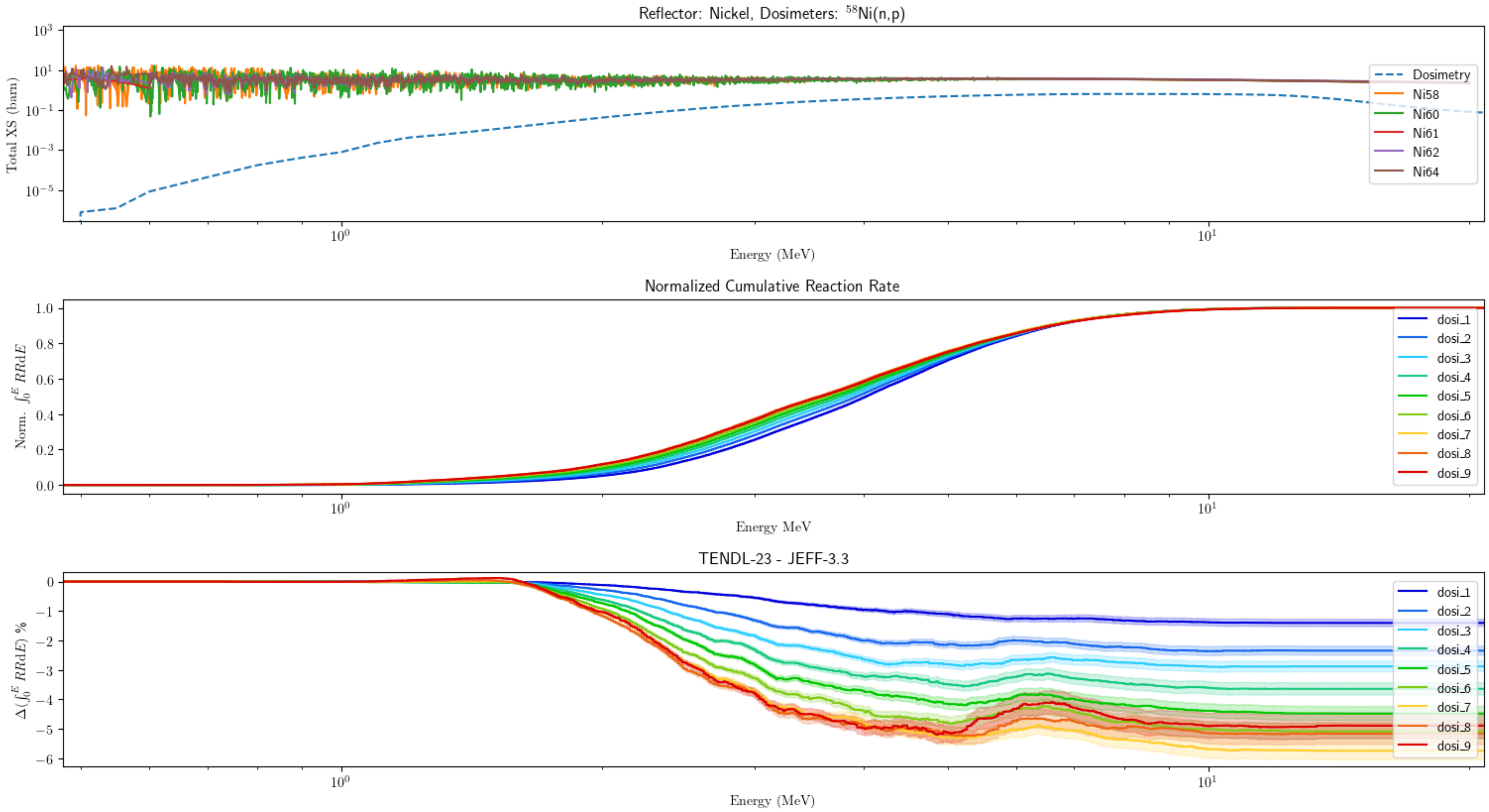
Reflector: Nickel, Dosimeters: ^{197}Au(n,g)
Total XS (barn)
Energy (MeV)
Dosimetry
Ni58
Ni60
Ni61
Ni62
Ni64
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
TENDL-24 - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)



Reflector: Nickel, Dosimeters: 58Ni(n,p)
Total XS (barn)
Energy (MeV)
Dosimetry
Ni58
Ni60
Ni61
Ni62
Ni64
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
TENDL-23 - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)

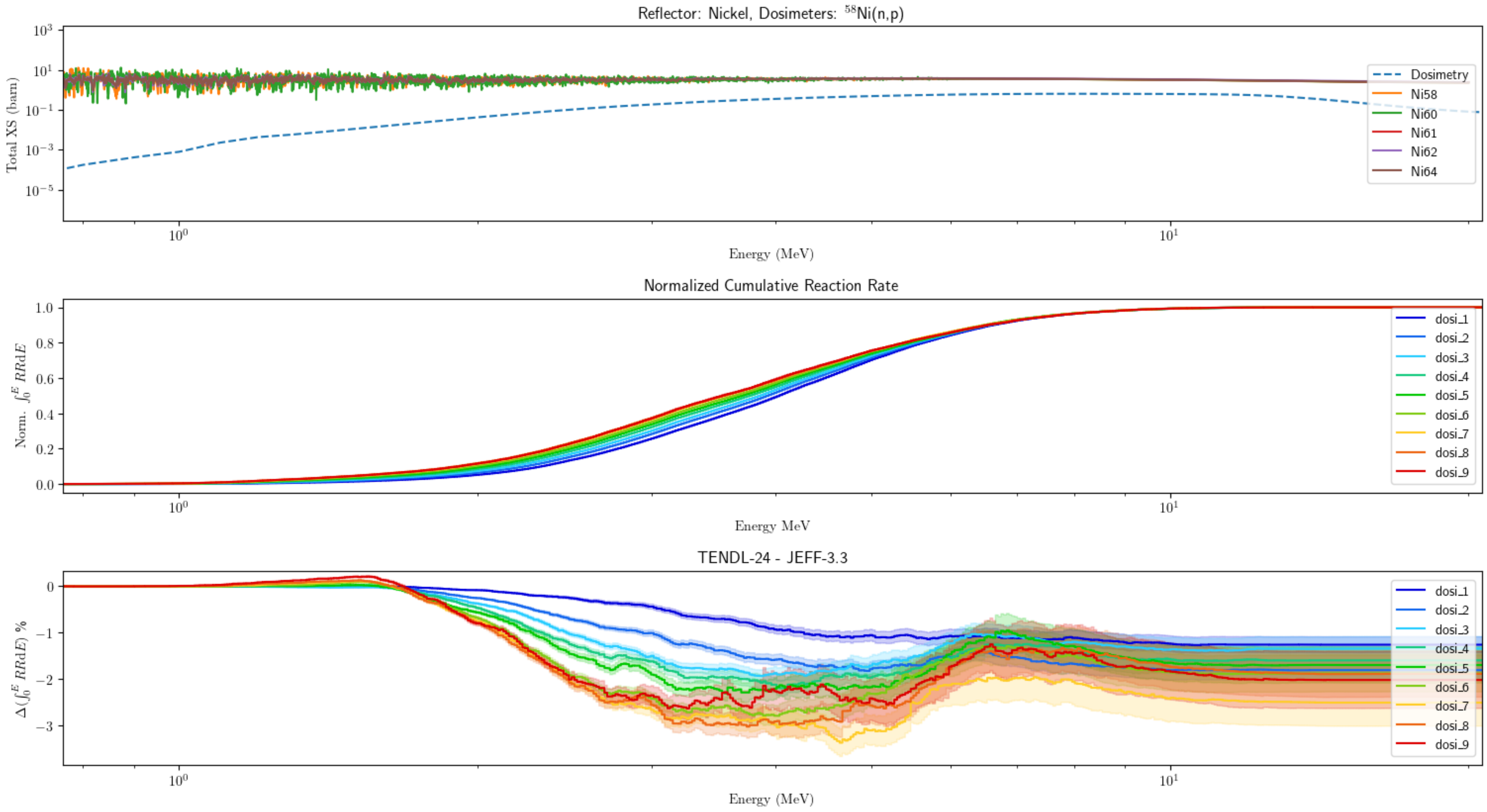


Reflector: Nickel, Dosimeters: ^{115}In(n,n')
Total XS (barn)
10^{2}
10^{0}
10^{-2}
Dosimetry
Ni58
Ni60
Ni61
Ni62
Ni64
Energy (MeV)
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
1.0
0.8
0.6
0.4
0.2
0.0
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
Energy MeV
TENDL-24 - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
0
−2
−4
Energy (MeV)

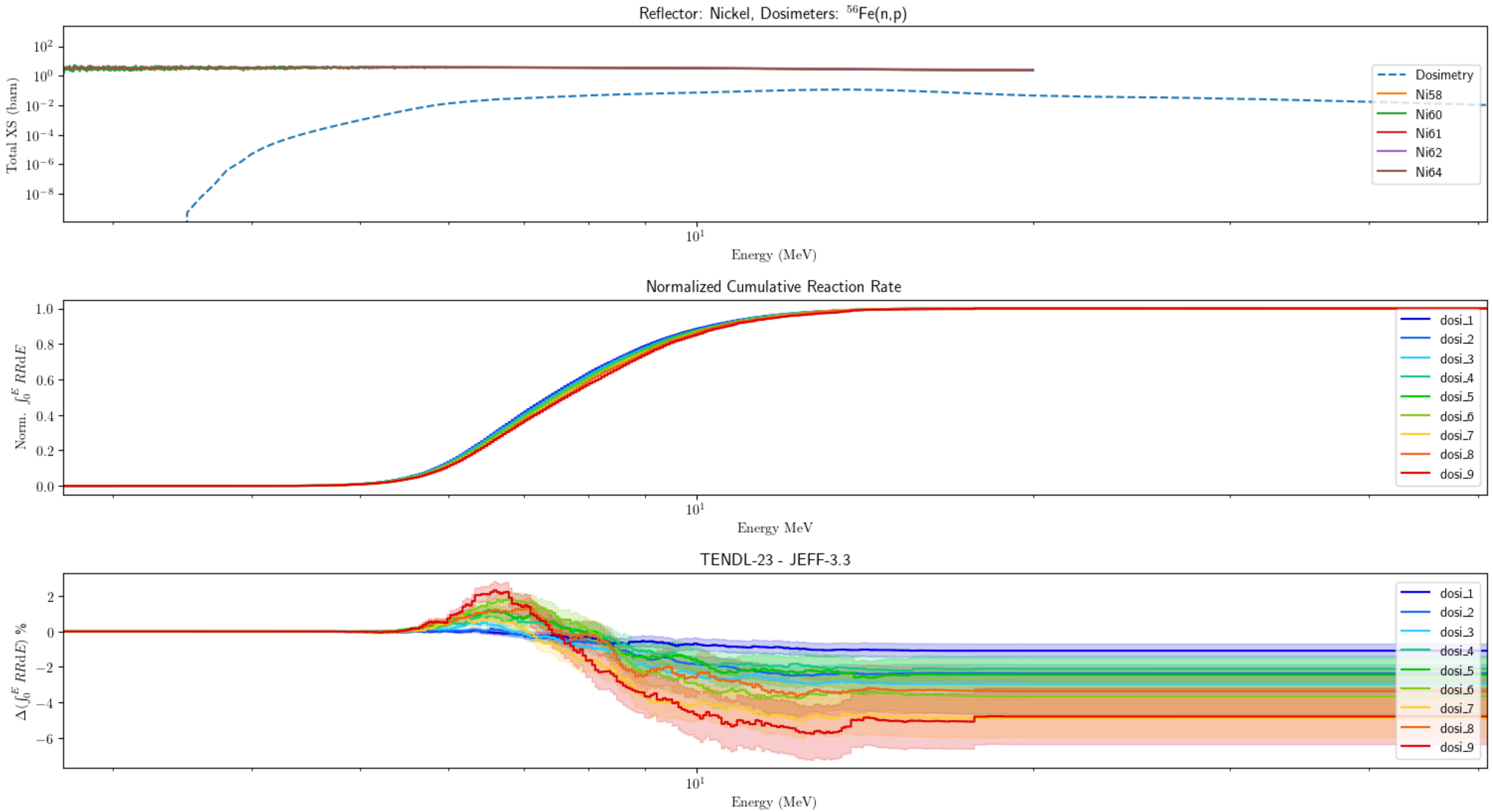


Reflector: Nickel, Dosimeters: ^{58}Ni(n,p)
Total XS (barn)
Energy (MeV)
Dosimetry
Ni58
Ni60
Ni61
Ni62
Ni64
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
TENDL-23 - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)

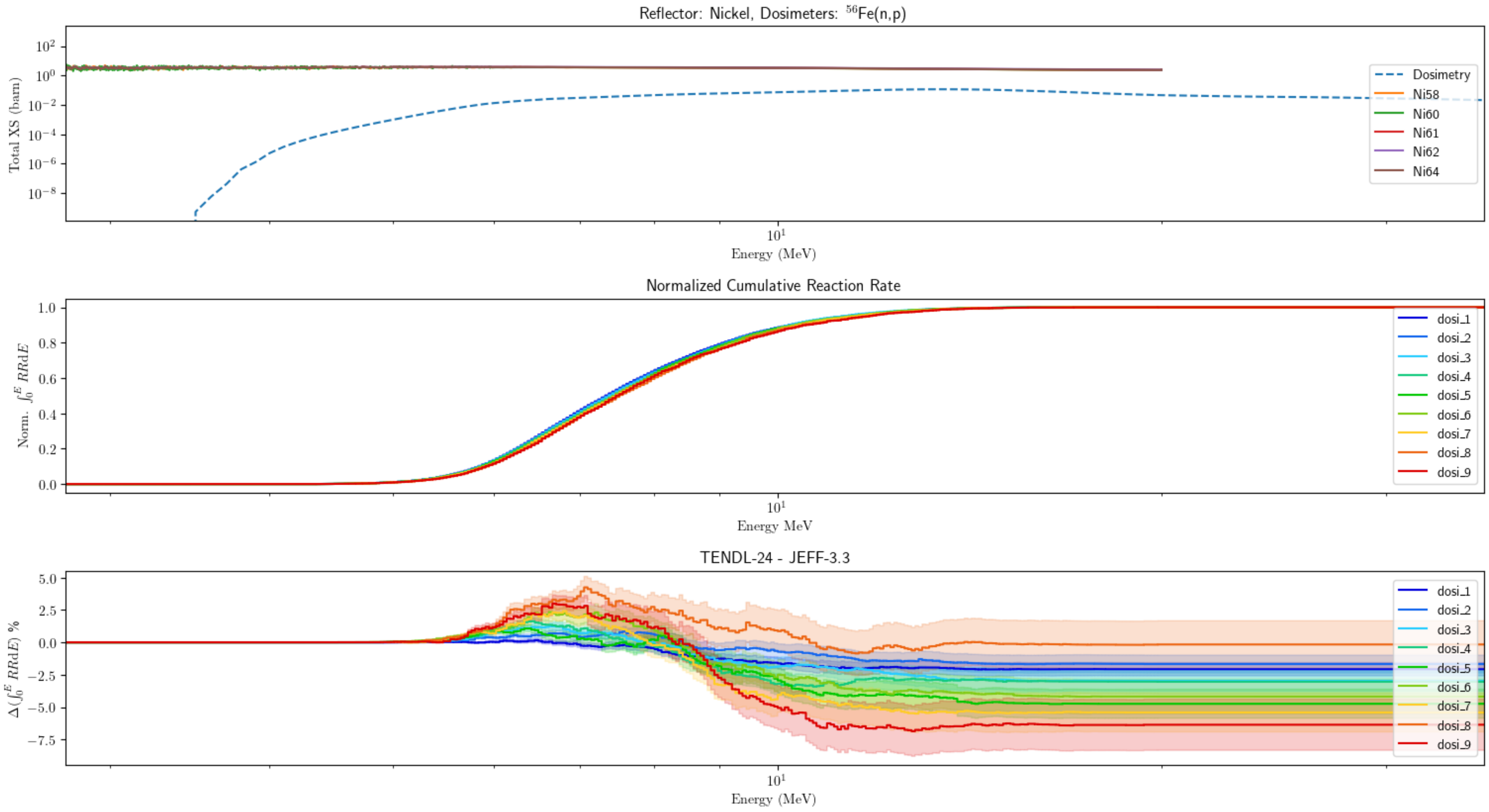
EPFL



Reflector: Nickel, Dosimeters: ^{58}Ni(n,p)
Total XS (barn)
Energy (MeV)
Dosimetry
Ni58
Ni60
Ni61
Ni62
Ni64
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
TENDL-24 - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)


Reflector: Nickel, Dosimeters: 56Fe(n,p)
Total XS (barn)
Energy (MeV)
Dosimetry
Ni58
Ni60
Ni61
Ni62
Ni64
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
TENDL-23 - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)

EPFL



Reflector: Nickel, Dosimeters: ^{56}Fe(n,p)
Total XS (barn)
Energy (MeV)
Dosimetry
Ni58
Ni60
Ni61
Ni62
Ni64
Normalized Cumulative Reaction Rate
Norm. $\int_0^E RRdE$
Energy MeV
dosi_1
dosi_2
dosi_3
dosi_4
dosi_5
dosi_6
dosi_7
dosi_8
dosi_9
TENDL-24 - JEFF-3.3
$\Delta(\int_0^E RRdE)$ %
Energy (MeV)