Uncertainties for the Ringhals fuel storage, due to nuclear data

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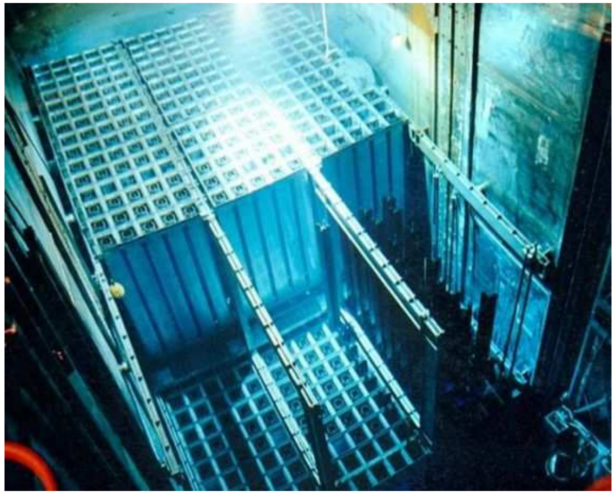
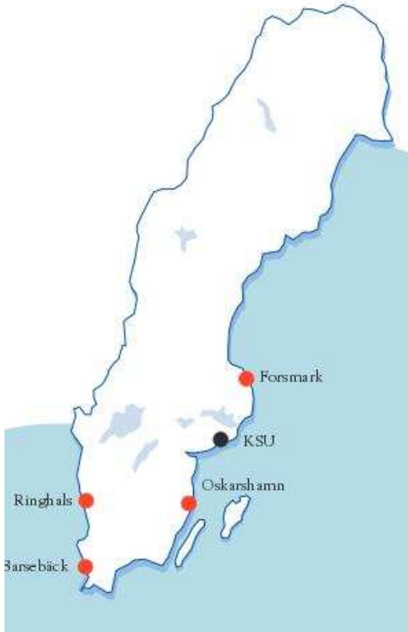
Contents





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Available: hundreds of random $^{235,238}U$ nuclear data, hundreds of benchmarks.

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Goal: Calculate uncertainties with available random files (and with/without benchmarks) for the Ringhals fuel storages. We do not focus on the central values (can be adjusted in a later exercise).

Considered systems: the Ringhals fuel storage

- Ringhals 3: PWR Westinghouse, 3 GWt, 157 17x17 fuel elements (523 kg of UO_2/elements), 48 control rods
- Fuel storage: 2 cases of wet pool storage of Ringhals 3,
- MCNP simulations were performed with only fresh fuel assemblies
- AREVA HTP 17x17-24-1 fuel assembly with 264 fuel rods, 24 guide thimbles and one instrumentation tube.

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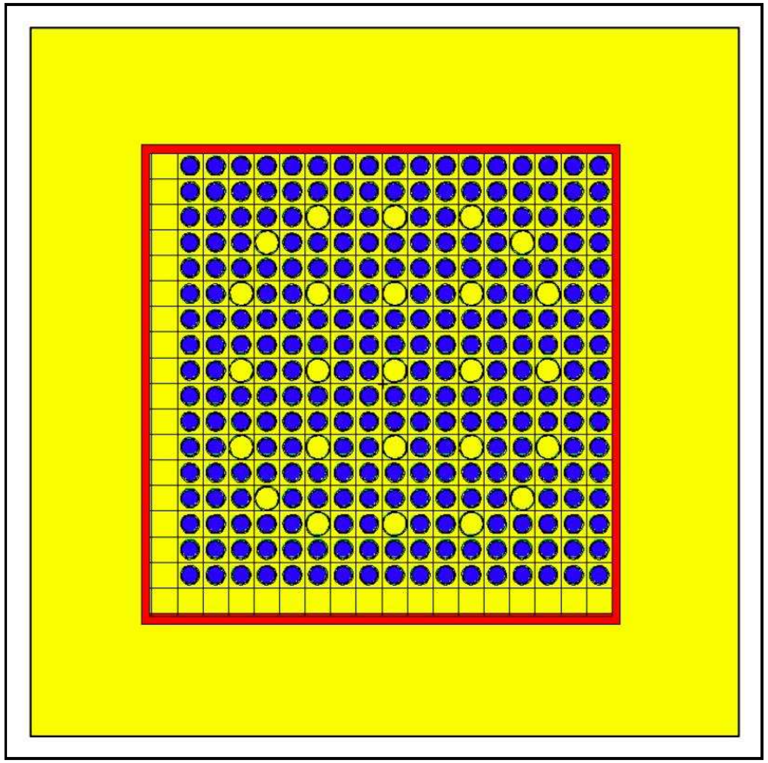


The position of the fuel assembly is not entirely certain, it is placed in that configuration which obtains the highest k_{eff}. Yellow represents water, red is stainless steel and blue is UO_2.

Normal and worst cases

Normal case

- 1st conservative assumption: no boron in water (even if in reality water contains boron),
- 2nd conservative assumption: the pool was assumed to be filled with fresh fuel (4.65 wt. % ^{235}U).

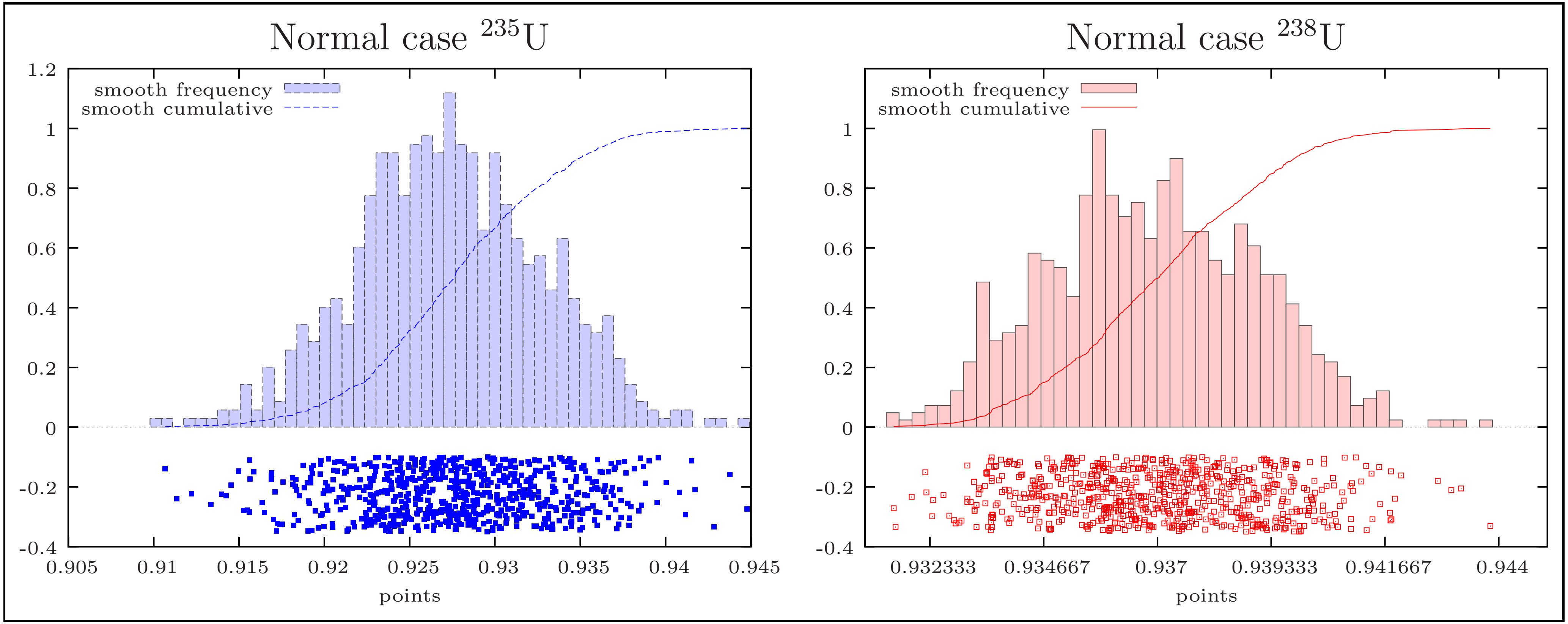
Worst case

- coolant water becomes steam which contains boron in order to prevent criticality
- (The enrichment is smaller in order to pass the safety requirements.)

	normal case	worst case
Number of rods	264	264
Distance between clusters [cm]	14.06	14.06
Enrichment [wt % ^{235}U]	4.65	4.55
Temperature [C]	20	20
Pitch [cm]	1.26	1.26
Boron in moderator [ppm]	0	2500
Water density [g/cm]	0.9981	0.08

fast TMC applied to both cases on k_{eff}

	random ^{235}U	random ^{238}U	Total uncertainties
Normal	0.92767 ± 550 pcm	0.93703 ± 215 pcm	590 pcm
Worst	0.98659 ± 650 pcm	0.99325 ± 680 pcm	940 pcm



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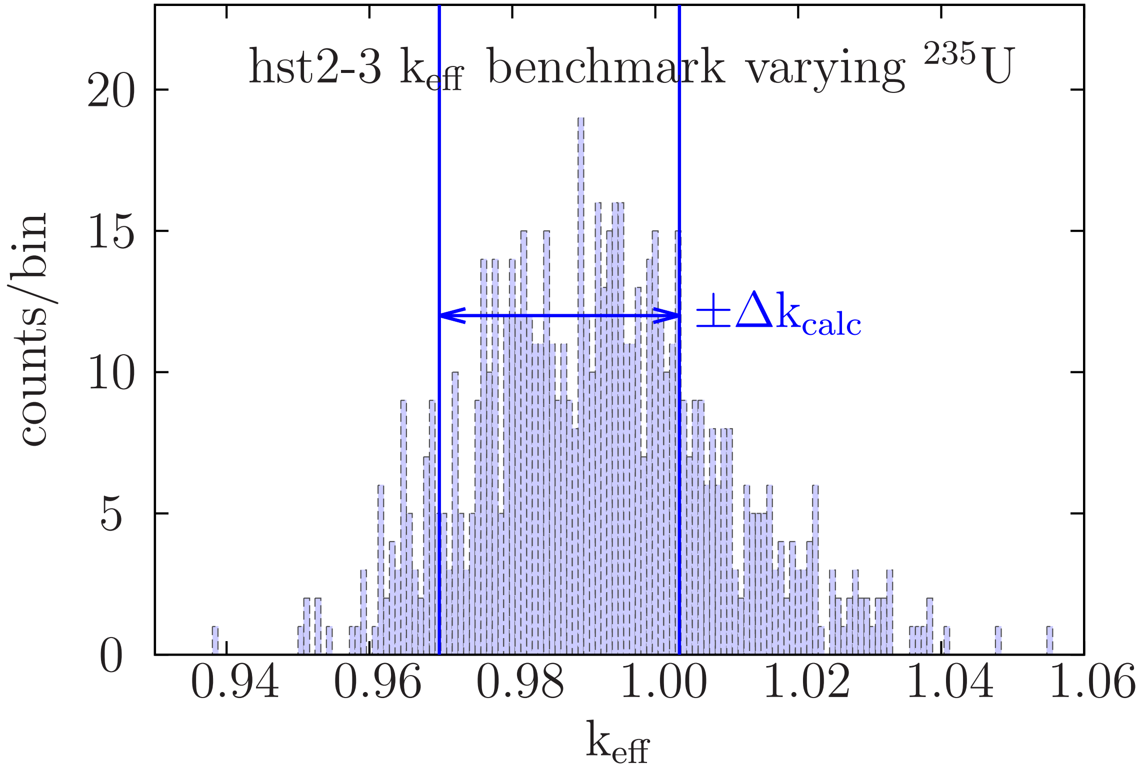
How can we reduce these uncertainties ?
By selecting random nuclear data files based on criticality experimental uncertainties:

1. with a large selection of criticality benchmarks,
   - ☞ (hundreds of leu, heu, ieu and mix benchmarks)
2. taking into account how relevant they are (correlation),
3. and combining their importance (not a trivial work).
   - ☞ many theories (maximum likelihood, empirical likelihood method, Generalized Regression estimation...)

reducing uncertainties using weights: Example with 1 benchmark



- ☛ 700 random ^{235}U files: $\Delta k_{eff} = 1680$ pcm

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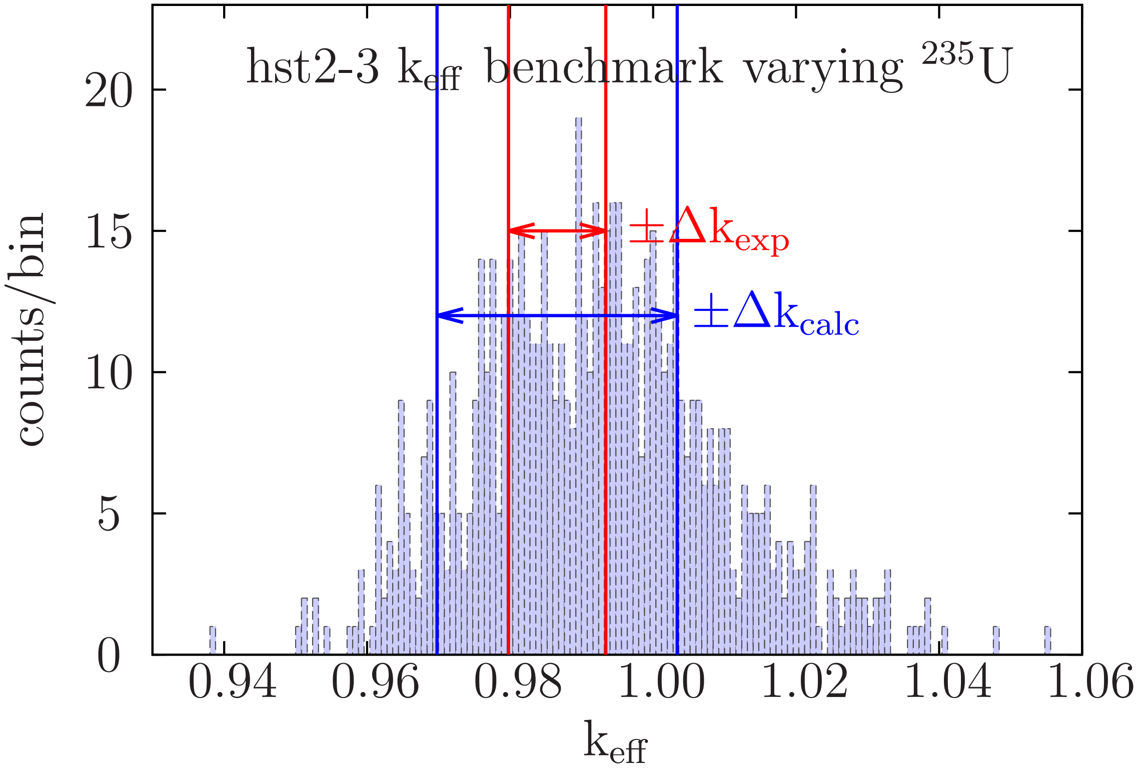

There are a few ways to produce weights:

- ☞ using accept/reject,
- ☞ using cumulative distributions,
- ☞ using normal/modified χ^2.

- ☛ 700 random ^{235}U files: $\Delta k_{eff} = 1680$ pcm
- ☛ Experimental benchmark uncertainty: 680 pcm
- ☛ Use weights to reduce the calculated uncertainties

reducing uncertainties using weights: Example with 1 benchmark

1. accept/reject works, but a few files remain in case of many benchmarks,
2. cumulative distributions works, but give very peaked distributions,
3. normal χ^2 doesn't work because of very different k_{eff} between benchmarks,
4. modified χ^2 works:

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For a given benchmark, random file i will have the weight ω_i (α: adjustment factor):

$$\omega_i = e^{-\chi_i^2/2} \text{ from the maximum likelihood function, with} \quad (1)$$

$$\chi_i^2 = \left(\frac{k_{\mathrm{eff,i}} - \overline{k_{\mathrm{eff}}}}{\alpha \cdot \Delta \mathrm{k_{exp}}}\right)^2 \quad (2)$$

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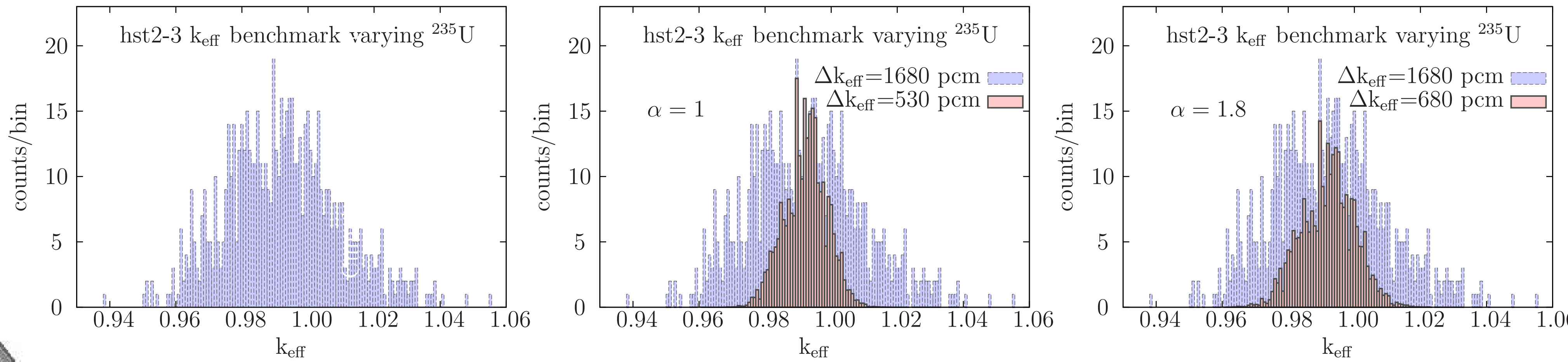

$\mathbf{k_{eff}}$ correlation

The first important quantity when using other benchmarks is *their relevance for the considered system*. We use the Pearson correlation coefficient:

$$\rho_{xy} = \frac{\sum_{i=1}^{n} (x_i - \overline{x})(y_i - \overline{y})}{(n-1) s_x s_y} \qquad (3)$$

with x_i, y_i the random k_{eff} for two systems, $\overline{x}, \overline{y}$ the average k_{eff} for both systems, and s_x and s_y their standard deviations.

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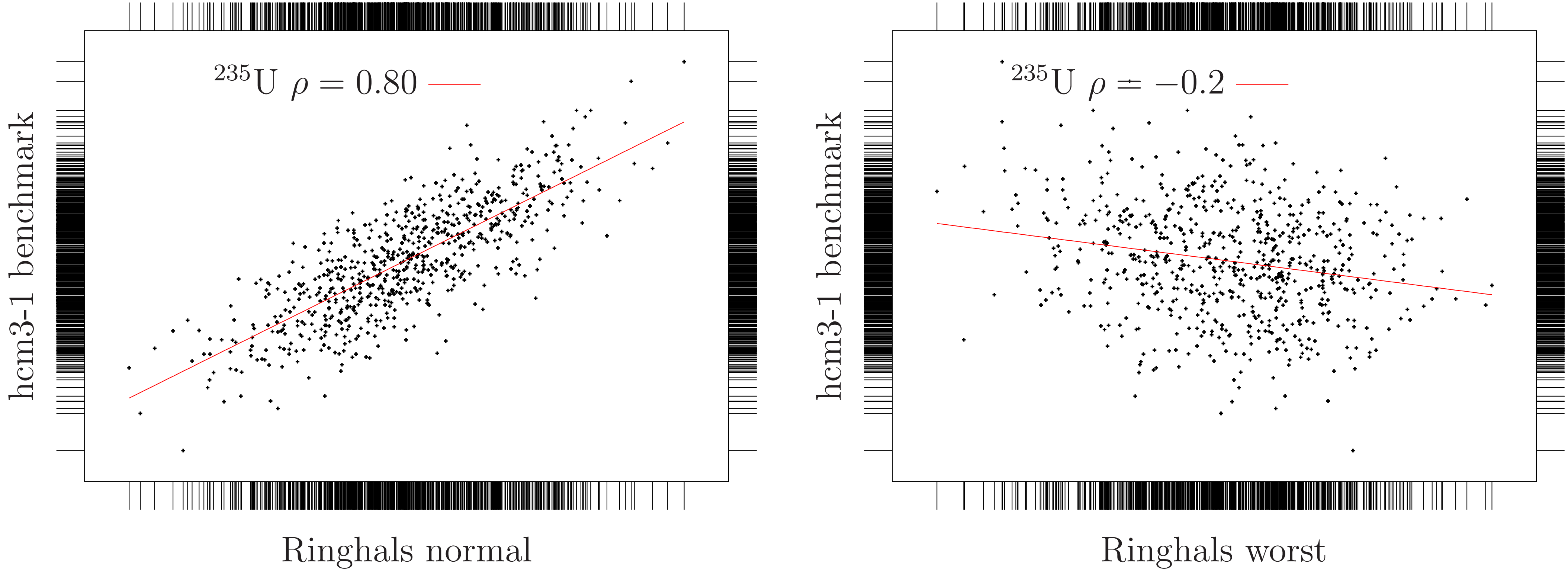
ρ between Ringhals Normal (and Worst) and hst, hmt, hct, hci, lct, lst, ici, mst, imf,..., changing ^{235}U and ^{238}U

- If ρ is high: relevant benchmark,
- If ρ is low: unsuitable benchmark.

k_{eff} correlation ρ



Combining weights for many benchmarks

How to combine different weights from different benchmarks and apply them to Ringhals ?

The selected solution is the maximum likelihood function (for file *i*):

$$\boxed{\omega_i = \sum_{benchmark\ j} \rho^{(j)} \exp^{-\frac{\left(\chi_i^2\right)^{(j)}}{2}}} \tag{4}$$

$$\left(\chi_i^2\right)^{(j)} = \left(\frac{k_{\mathrm{eff,i}}^{(j)} - \overline{k_{\mathrm{eff}}^{(j)}}}{\alpha^{(j)} \cdot \Delta \mathrm{k}_{\mathrm{exp}}^{(j)}}\right)^2 \tag{5}$$

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- ^{235}U Ringhals normal: 120 benchmarks and ^{235}U Ringhals Worst: 140 benchmarks,
- ^{238}U Ringhals normal: 35 benchmarks and ^{238}U Ringhals Worst: 30 benchmarks.

fast TMC + other benchmarks applied to both cases on k_{eff}

Only TMC

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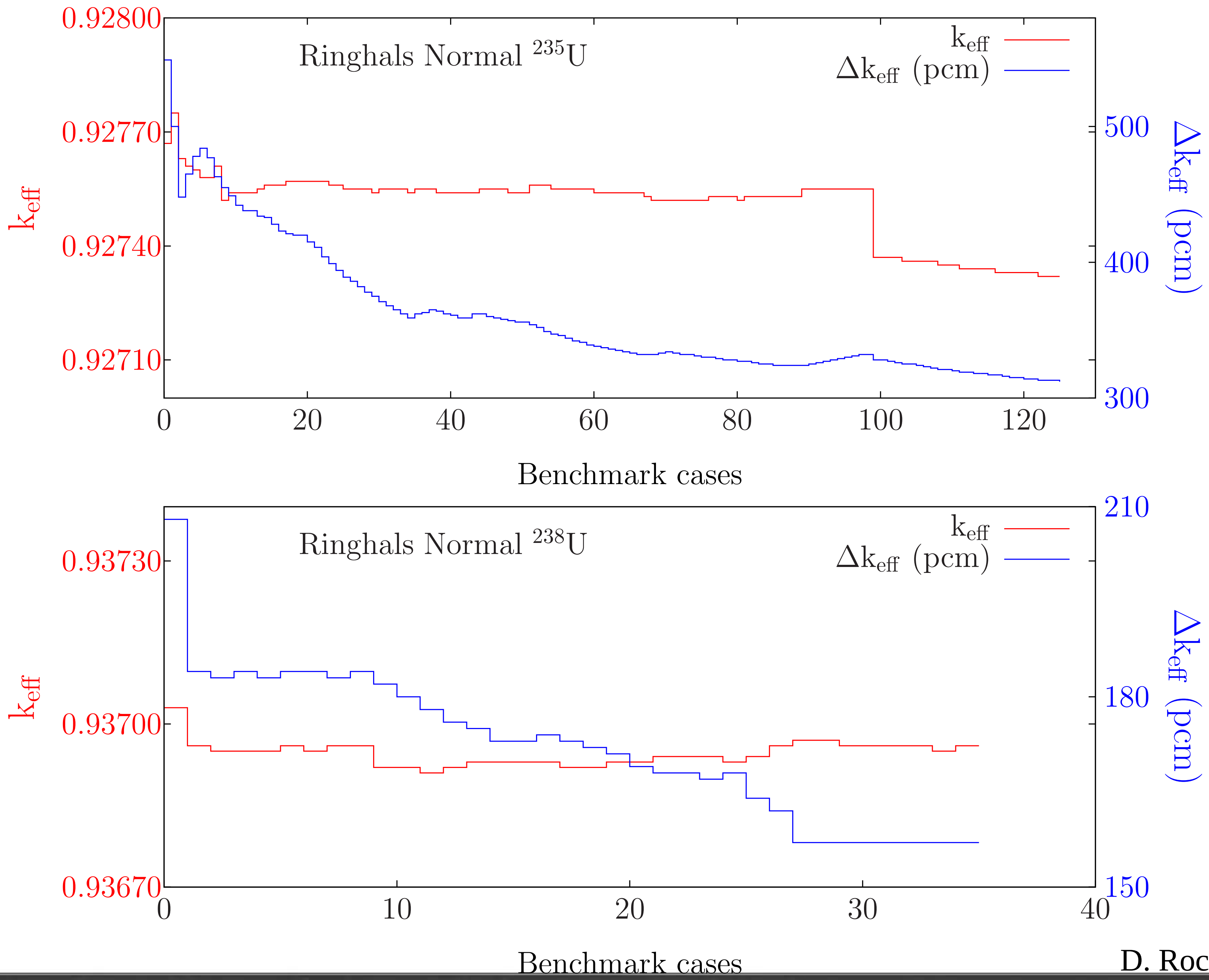
TMC + other benchmarks

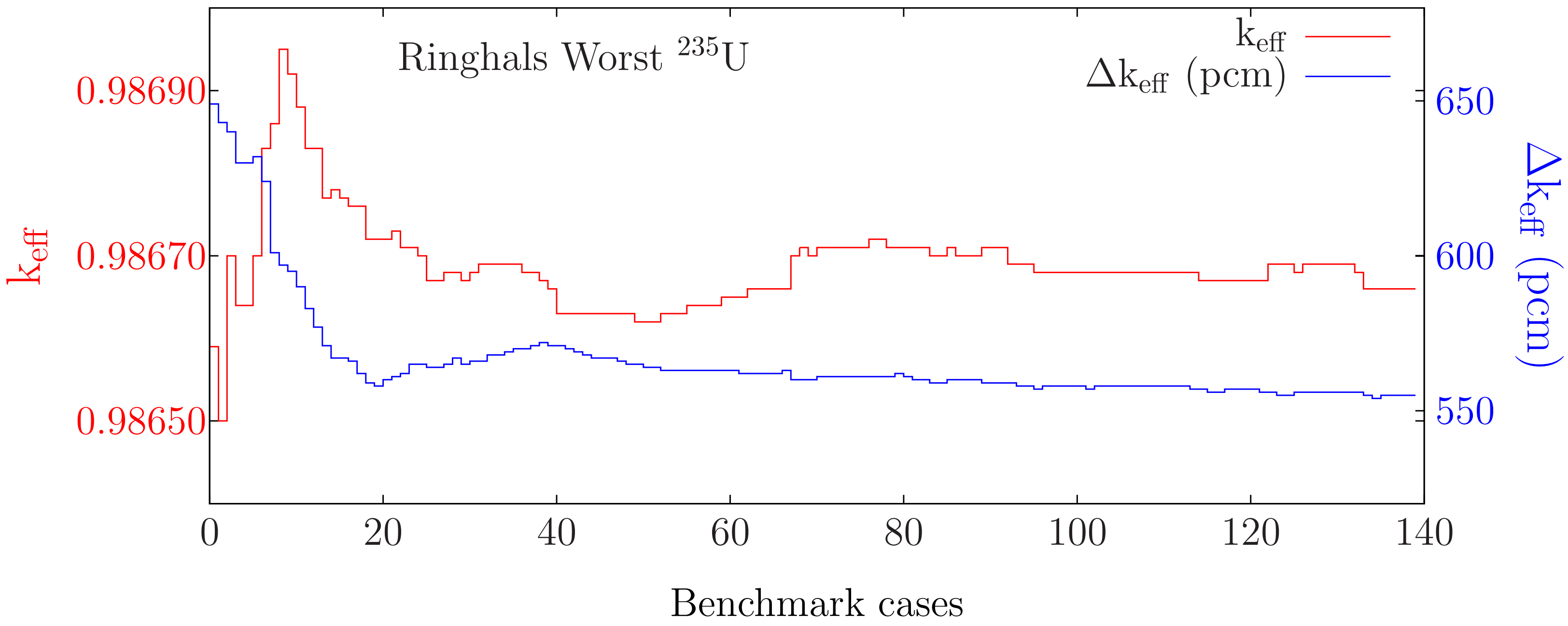
	random ^{235}U	random ^{238}U	Total uncertainties
Normal	0.92732 ± 310 pcm	0.93695 ± 155 pcm	345 pcm (-40%)
Worst	0.98666 ± 555 pcm	0.99321 ± 575 pcm	800 pcm (-15%)

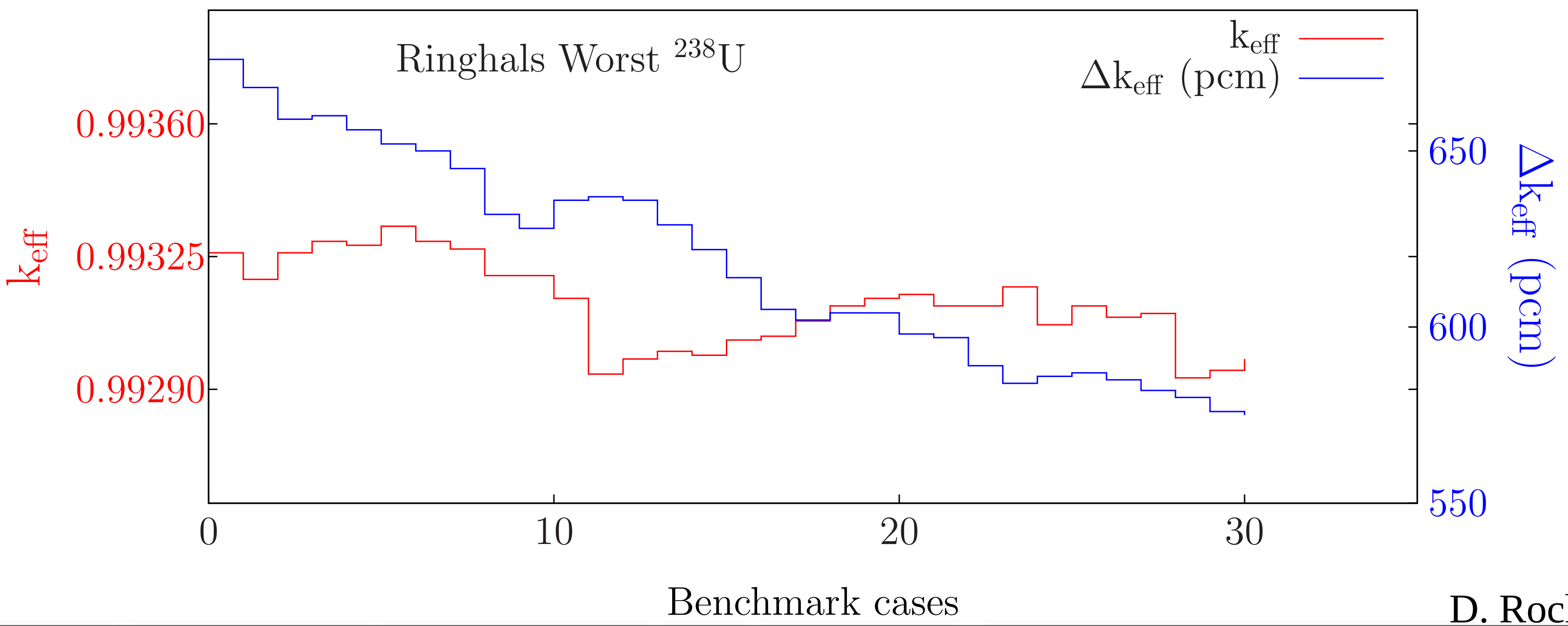
See (1) convergence of results and (2) final distributions

Convergence of results: Ringhals normal

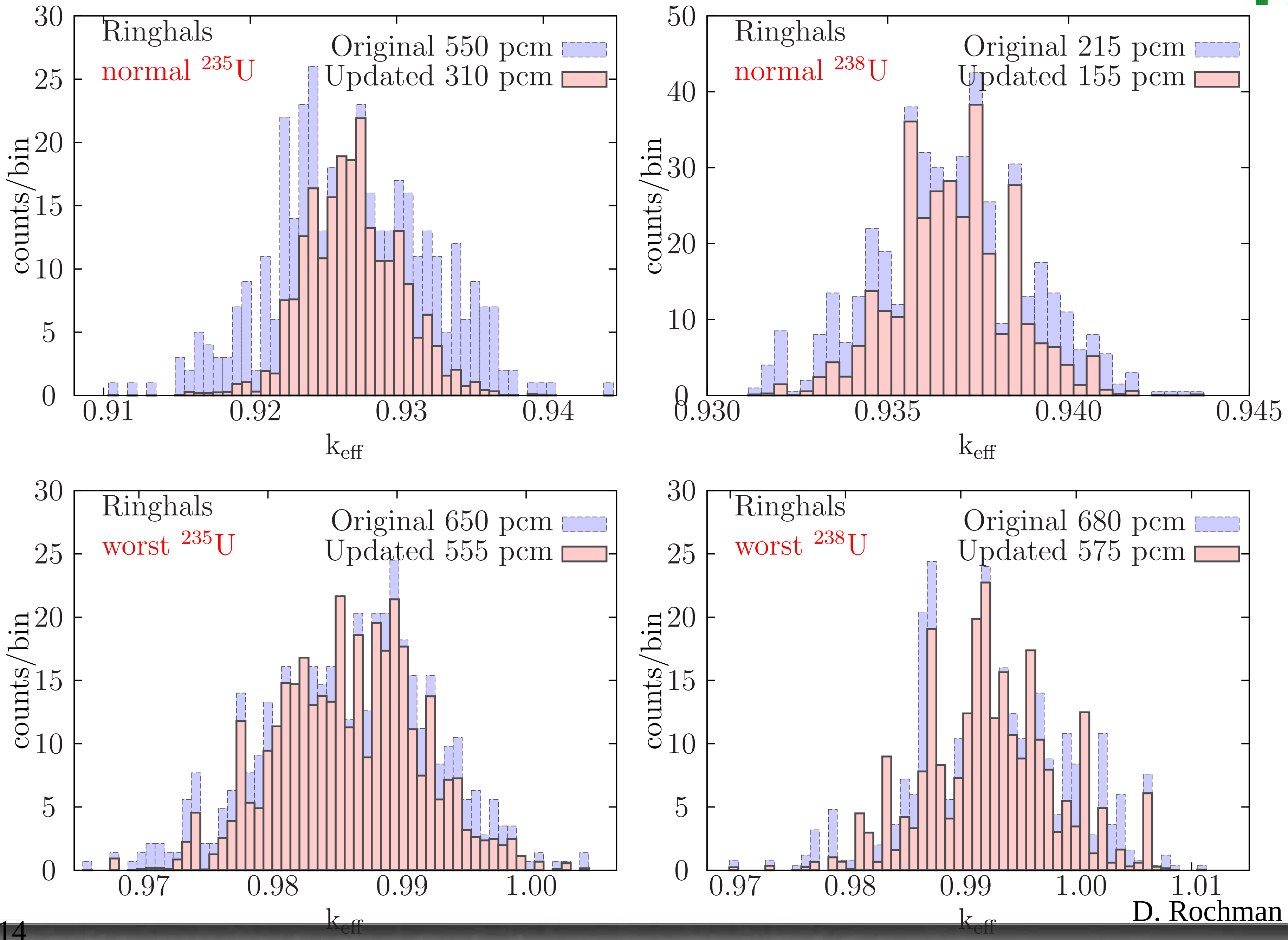


Convergence of results: Ringhals worst





Distributions of events



Conclusion and improvements

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- Calculated uncertainties can be reduced for fuel storage using criticality benchmarks (40 % normal case and 15 % worst case),

- to do: consider other nuclear data uncertainties (thermal scattering),
- to do: adjust central values,
- to do: compare with experimental data (if available),