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On the effect of coarse mesh versus fine mesh discretization for power reactor noise

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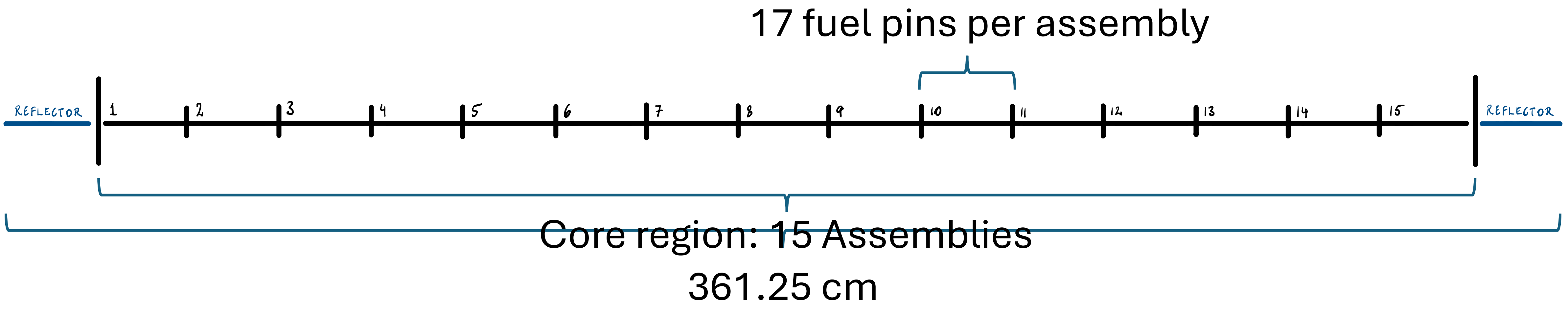
Outline

- Background
- A concrete example of a discrepancy between a coarse-mesh and a fine-mesh noise solution
- Previous work done to remedy this discrepancy
- How PhD project is meant to take this work further

Background

- Neutron noise is useful for reactor core diagnostics
- To study neutron noise, we need accurate & reliable mathematical models to run our simulations
- All simulations benefit from reducing the computational complexity of the model
- Diffusion approximation, Coarse spatial resolution and few energy groups are therefore attractive, especially for full-core simulations
- Of particular interest for neutron noise are calculations in linear theory in the frequency domain
    - Can be significantly more efficient than time-depedent calculations in certain circumstances
- ... But how accurate are such models?

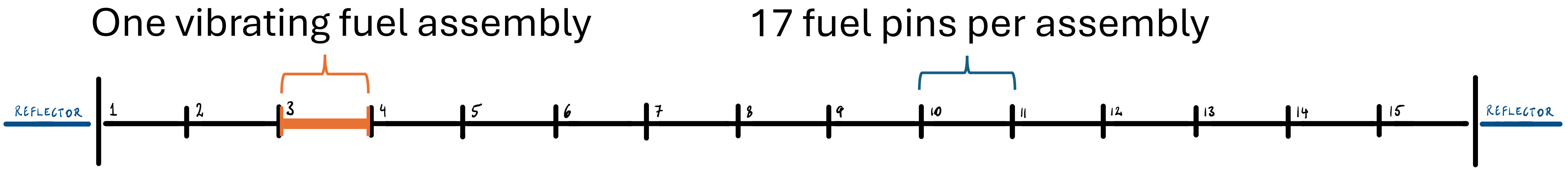
Example – 1D PWR Reactor



<u>System Specificatons:</u>

- 1D system of length of 361.25 cm
- Nuclear data from a PWR
- Core surrounded by reflector
- 15 fuel assemblies
- 17 fuel pins per fuel assembly

Example – 1D PWR Reactor



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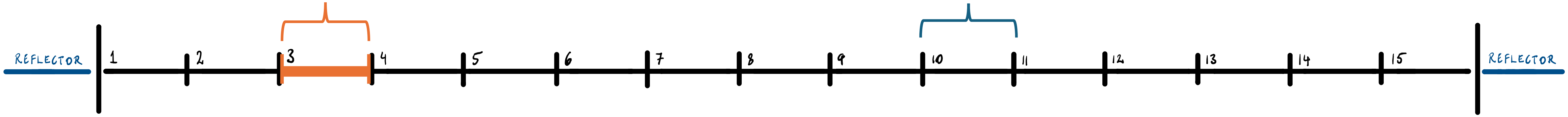
- One vibrating fuel assembly

Example – 1D PWR Reactor

One vibrating fuel assembly

17 fuel pins per assembly



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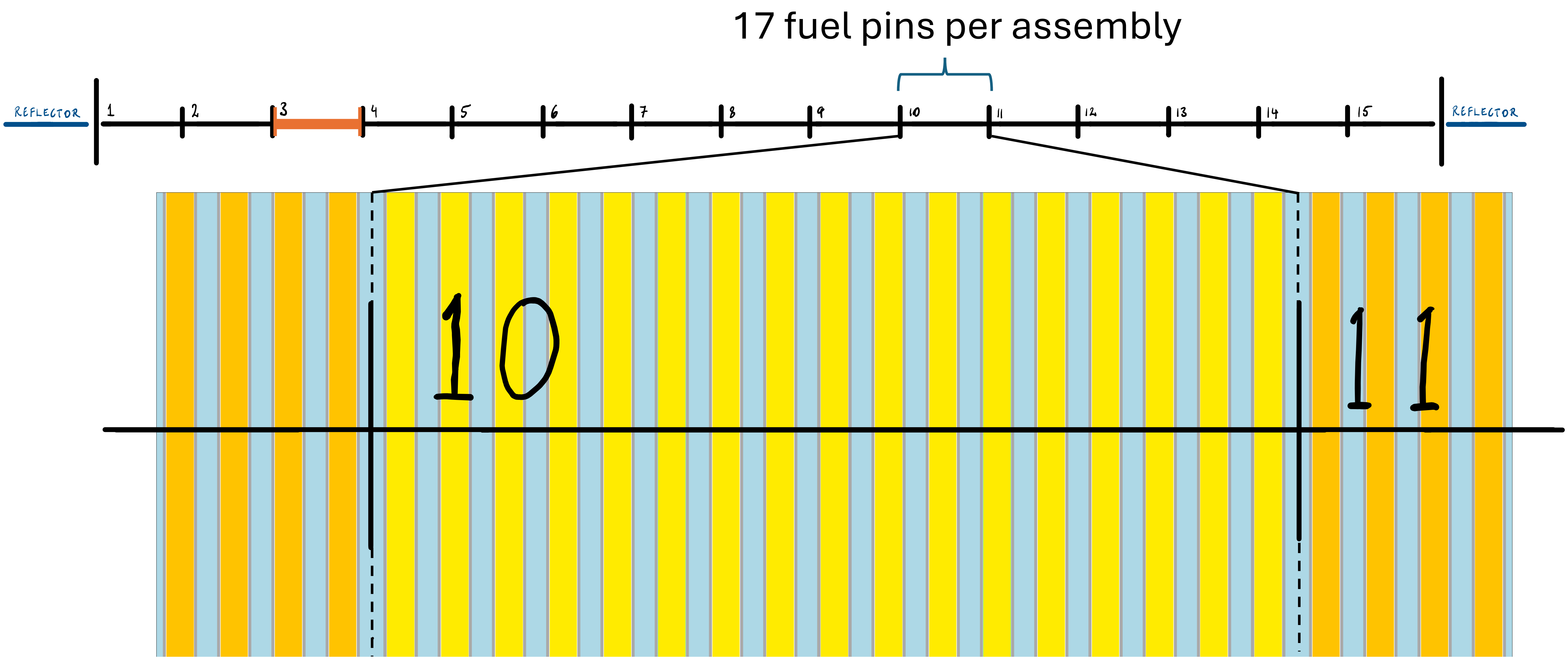
Simulations of induced neutron noise using model based on:

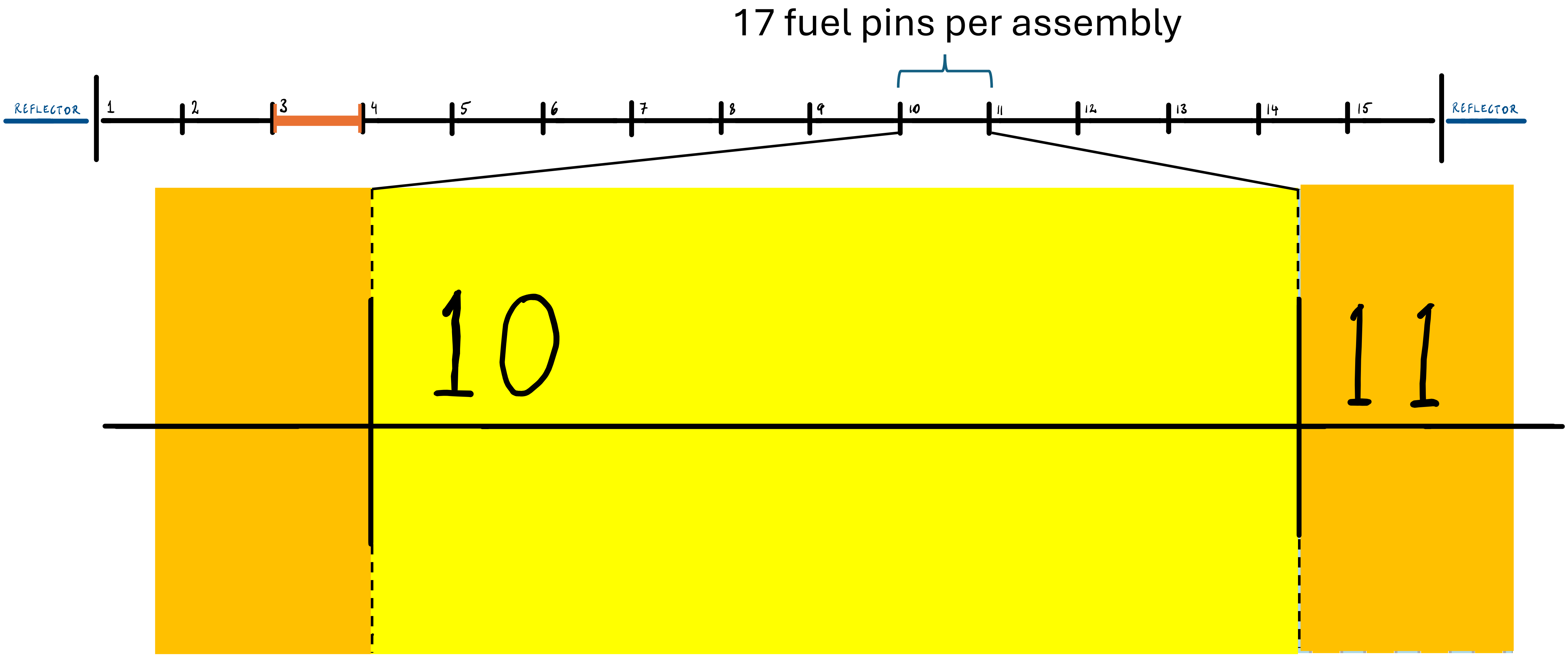
- Diffusion approximation
- Two energy groups
- Linear Theory in Frequency domain
- No thermal-hydraulic feedback
- ϵ/d –model for vibration noise source

Example – Two different homogenizations



Model 1 (Fine-mesh):
Homogenized cross-sections for individual fuel pins

Example – Two different homogenizations

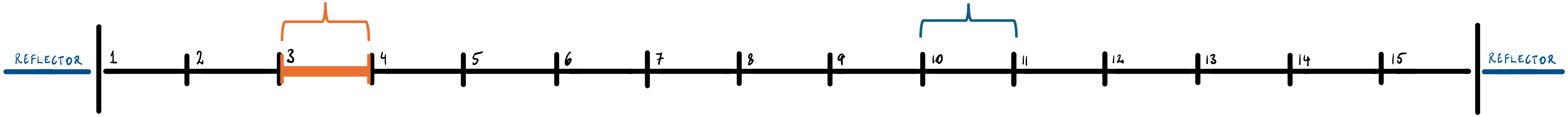


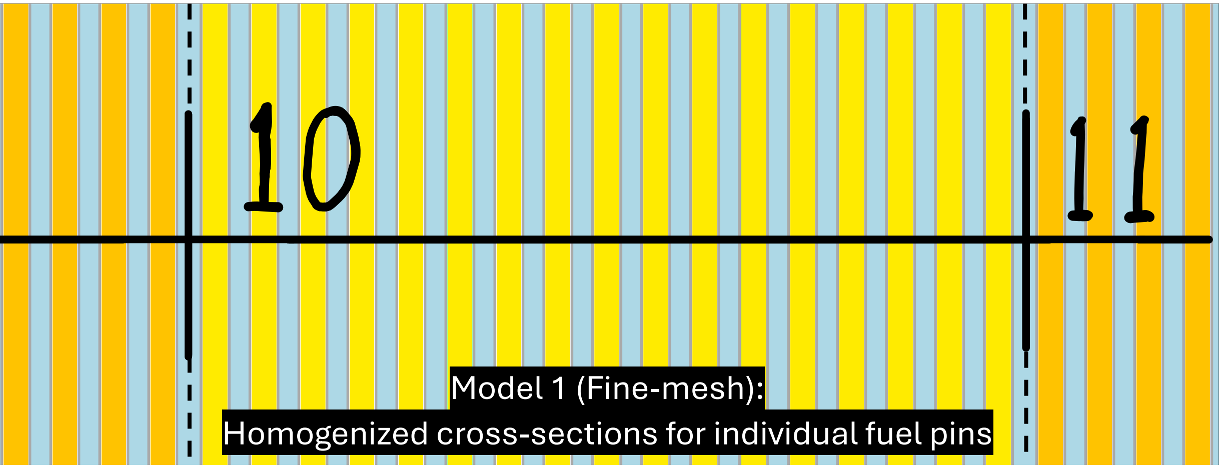
Model 2 (Coarse-mesh):
Homogenized cross-sections per assembly only

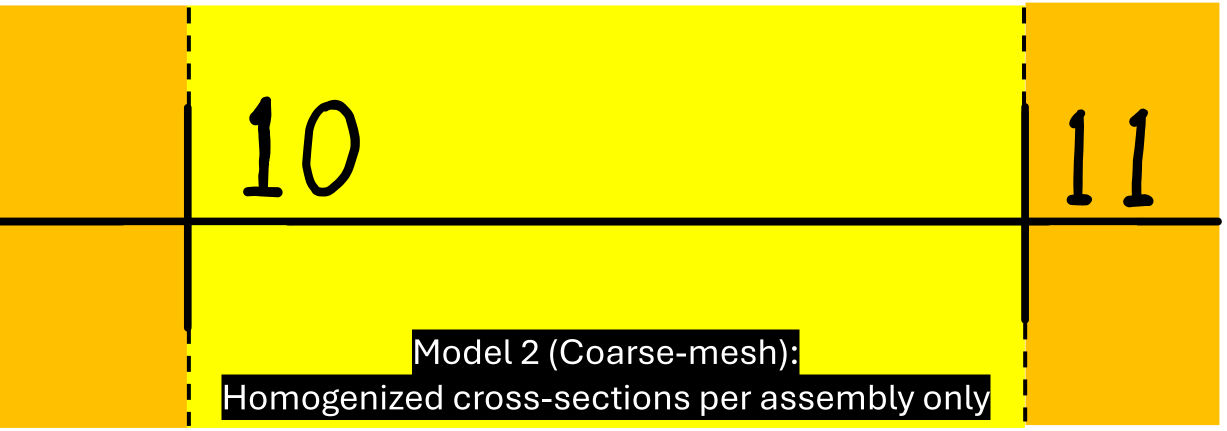
Example – Two different homogenizations

One vibrating fuel assembly

17 fuel pins per assembly



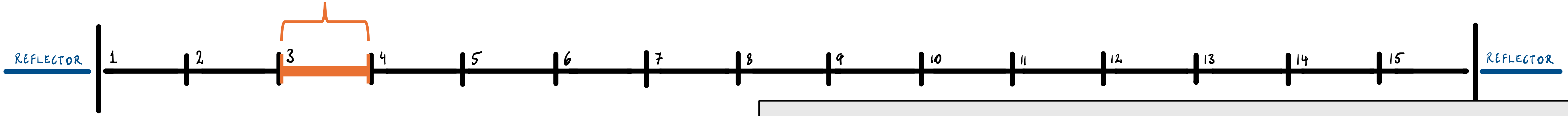


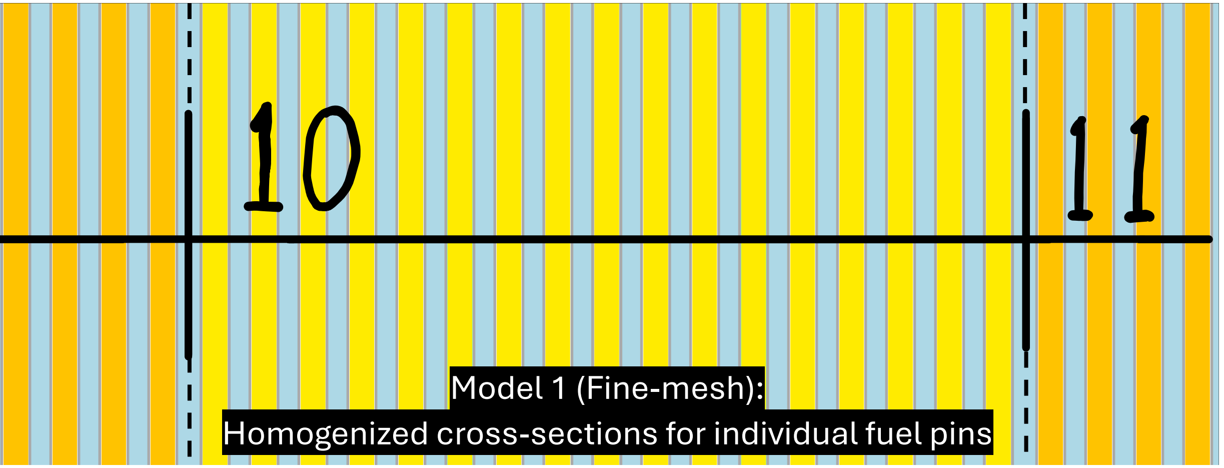


- Model 1 and Model 2 differ only in homogenization scheme
- However, ϵ/d –model leads to significantly different noise sources in the two models.
- This is because ϵ/d –noise sources are only non-zero at interfaces where cross-sections are discontinuous.
- (True for alternatives to ϵ/d –model also)

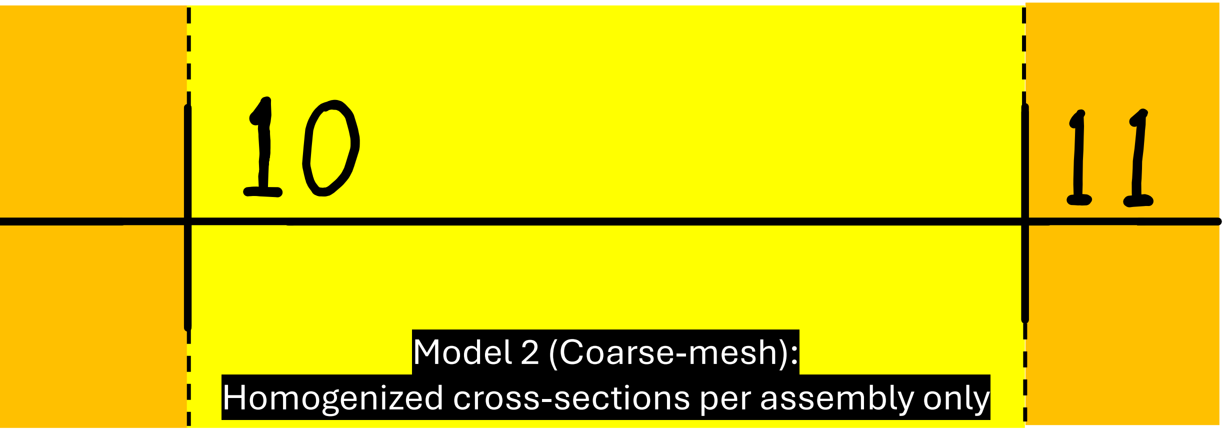
Example – Two different homogenizations

One vibrating fuel assembly



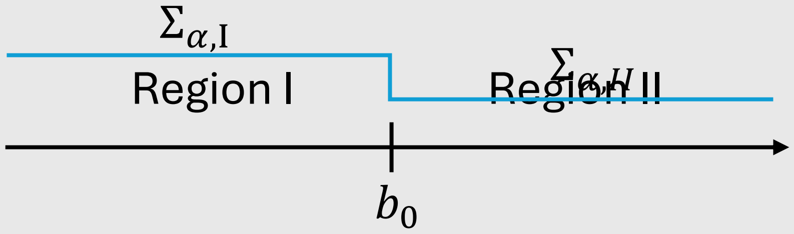


Model 1 (Fine-mesh):
Homogenized cross-sections for individual fuel pins



Model 2 (Coarse-mesh):
Homogenized cross-sections per assembly only

ϵ/d –model:



Static cross-sections spatial dependence:

$$\Sigma_{\alpha,0}(x) = [1 - \theta(x - b_0)]\Sigma_{\alpha,I} + \theta(x - b_0)\Sigma_{\alpha,\mathrm{II}}$$

Dynamic cross-sections spatial dependence:

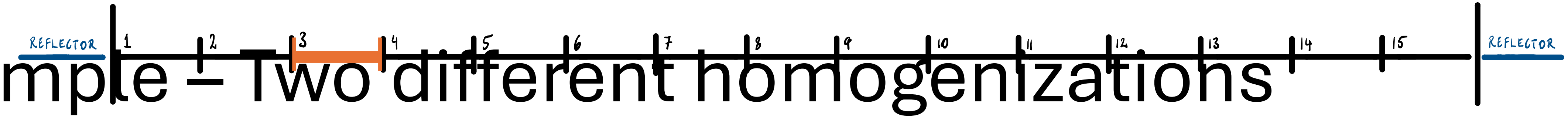
$$\delta\Sigma_\alpha(x,t) = [\theta(x - b_0 - \epsilon(t)) - \theta(x - b_0)]\Delta\Sigma_\alpha, \text{ where}$$

$$\Delta\Sigma_\alpha = \Sigma_{\alpha,\mathrm{II}} - \Sigma_{\alpha,I}$$

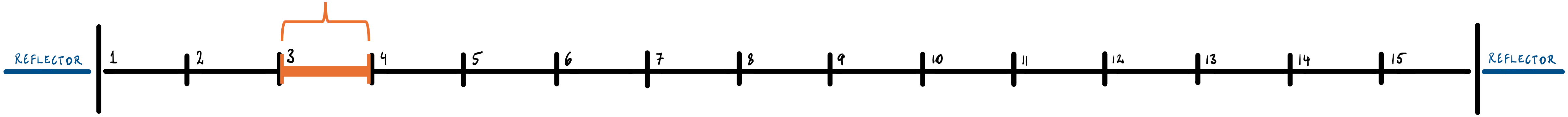
The ϵ/d –model gives $\delta\Sigma_\alpha(x,\omega)$ in ω –domain as:

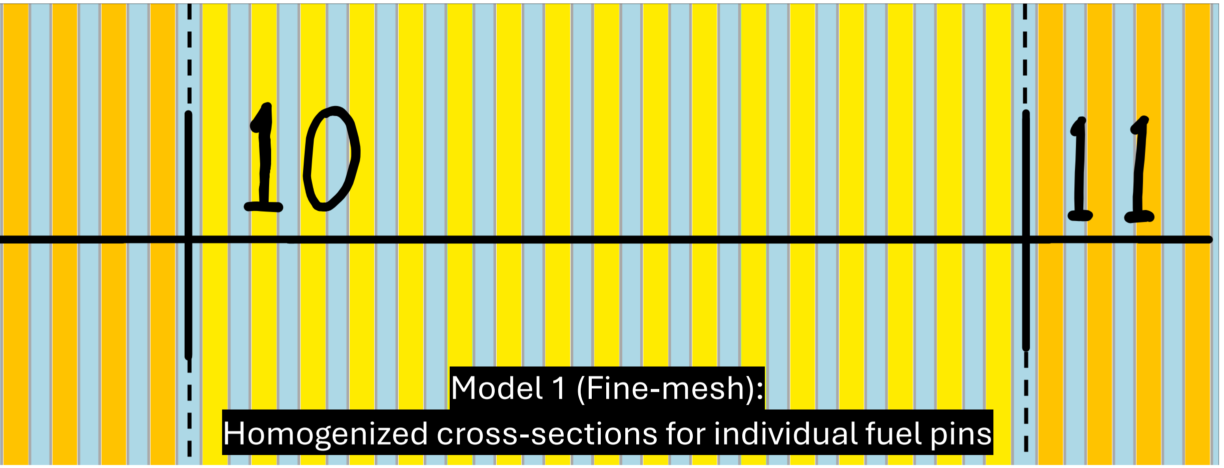
$$\delta\Sigma_\alpha(x,\omega) = \mathrm{F}\{\epsilon(t)\}(\omega)\,\delta(x - b_0)\Delta\Sigma_\alpha$$

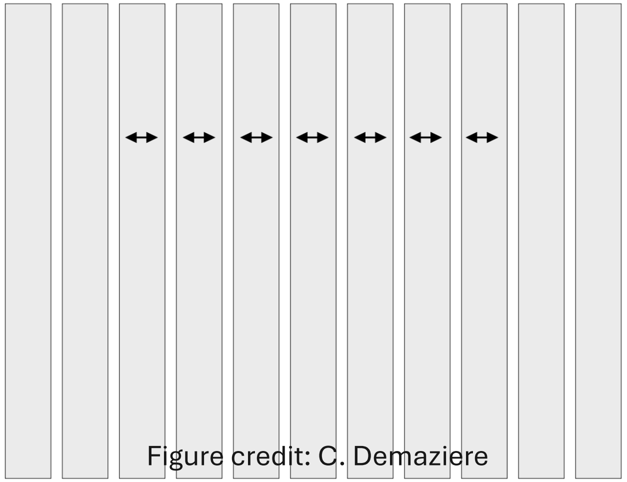
Example – Two different homogenizations



One vibrating fuel assembly

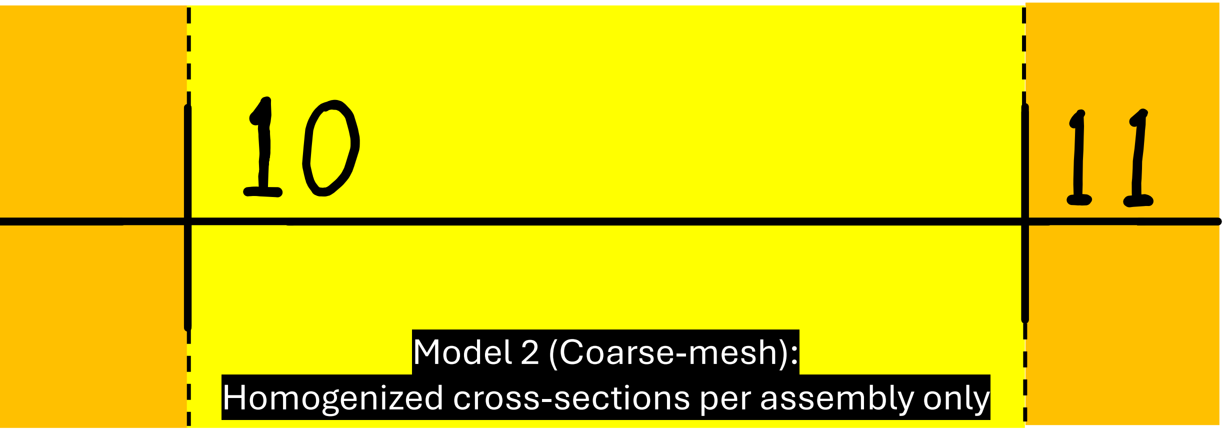


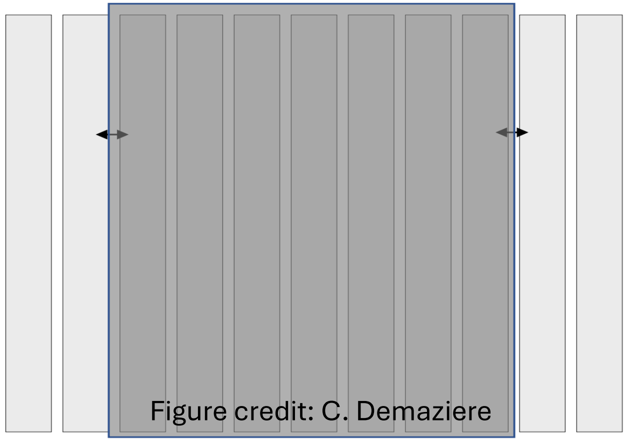




Model 1 (Fine-mesh):

- Cross-sections discontinuous at both boundaries of fuel pins (2x17)
- → 34 cross-section discontinuities per assembly
- Two energy groups (x2)
- → 68 noise sources per assembly





Model 2 (Coarse-mesh):

- Cross-sections discontinuous at fuel assembly interfaces only (2x1)
- Two energy groups (x2)
- → 4 noise sources per assembly

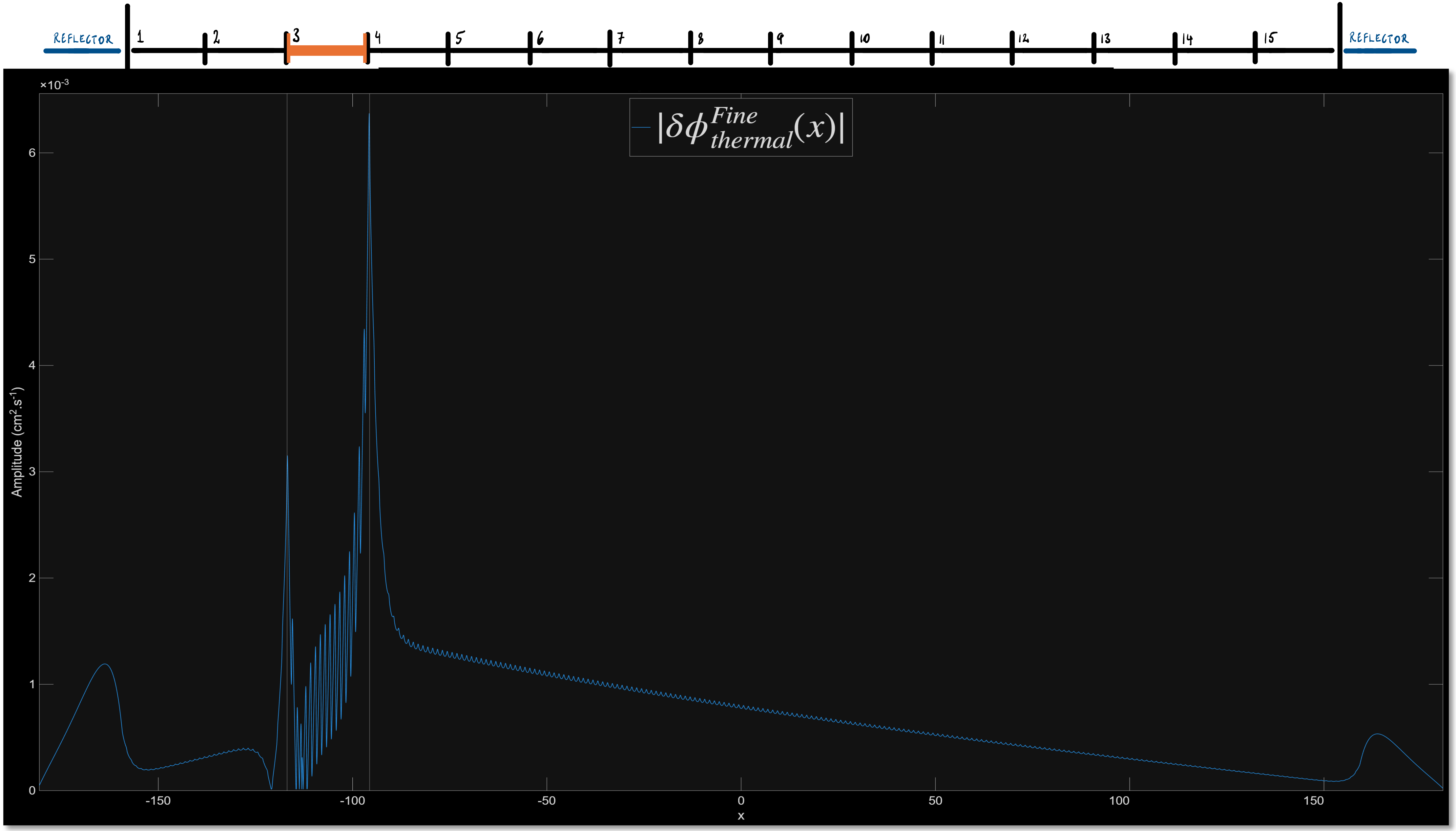
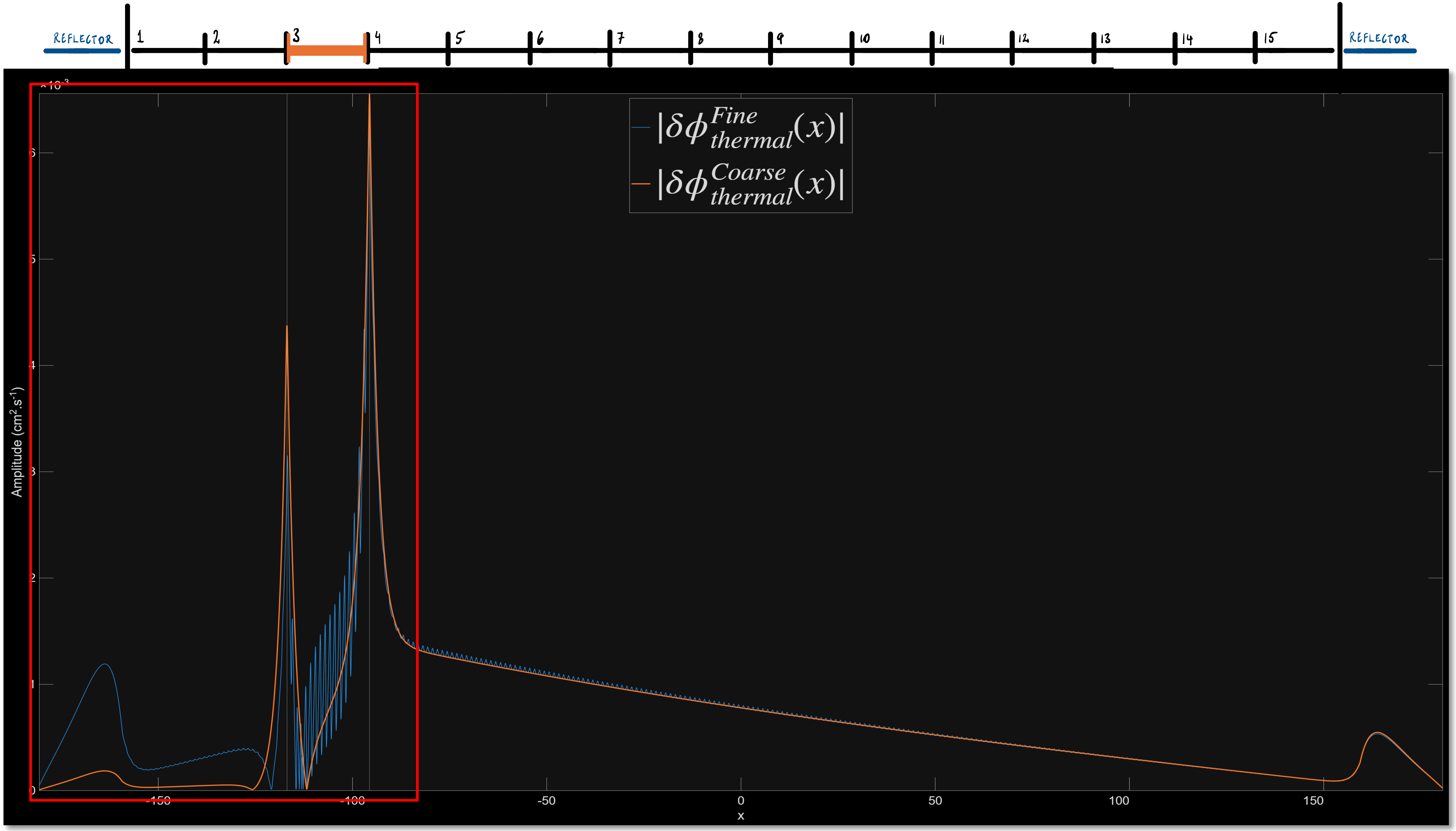


Figure credit: C. Demaziere

Amplitude of Fine-mesh thermal neutron noise



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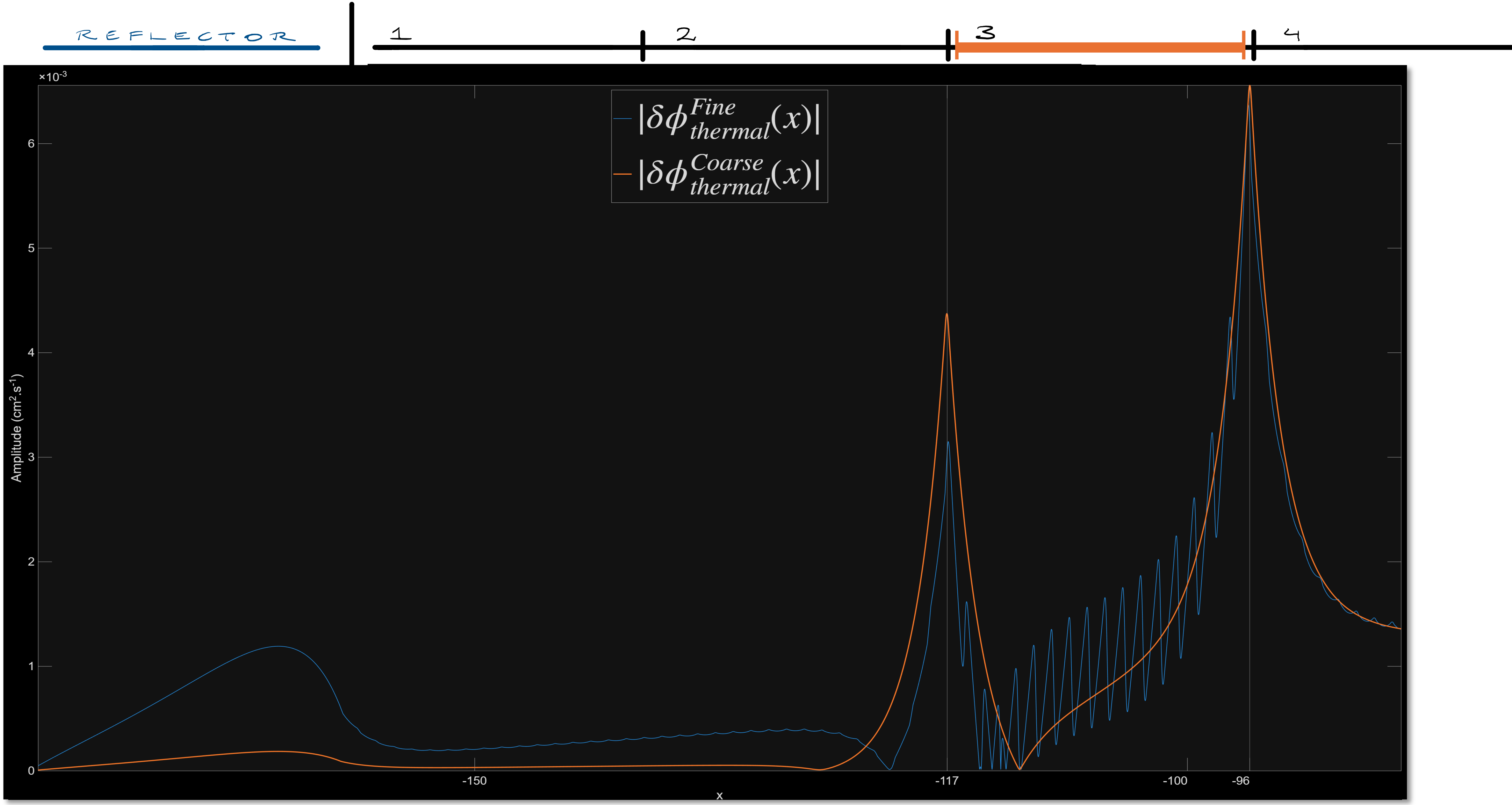
Comparison { Amplitude of Fine-mesh thermal neutron noise
Amplitude of Coarse-mesh thermal neutron noise



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Comparison { Amplitude of Fine-mesh thermal neutron noise
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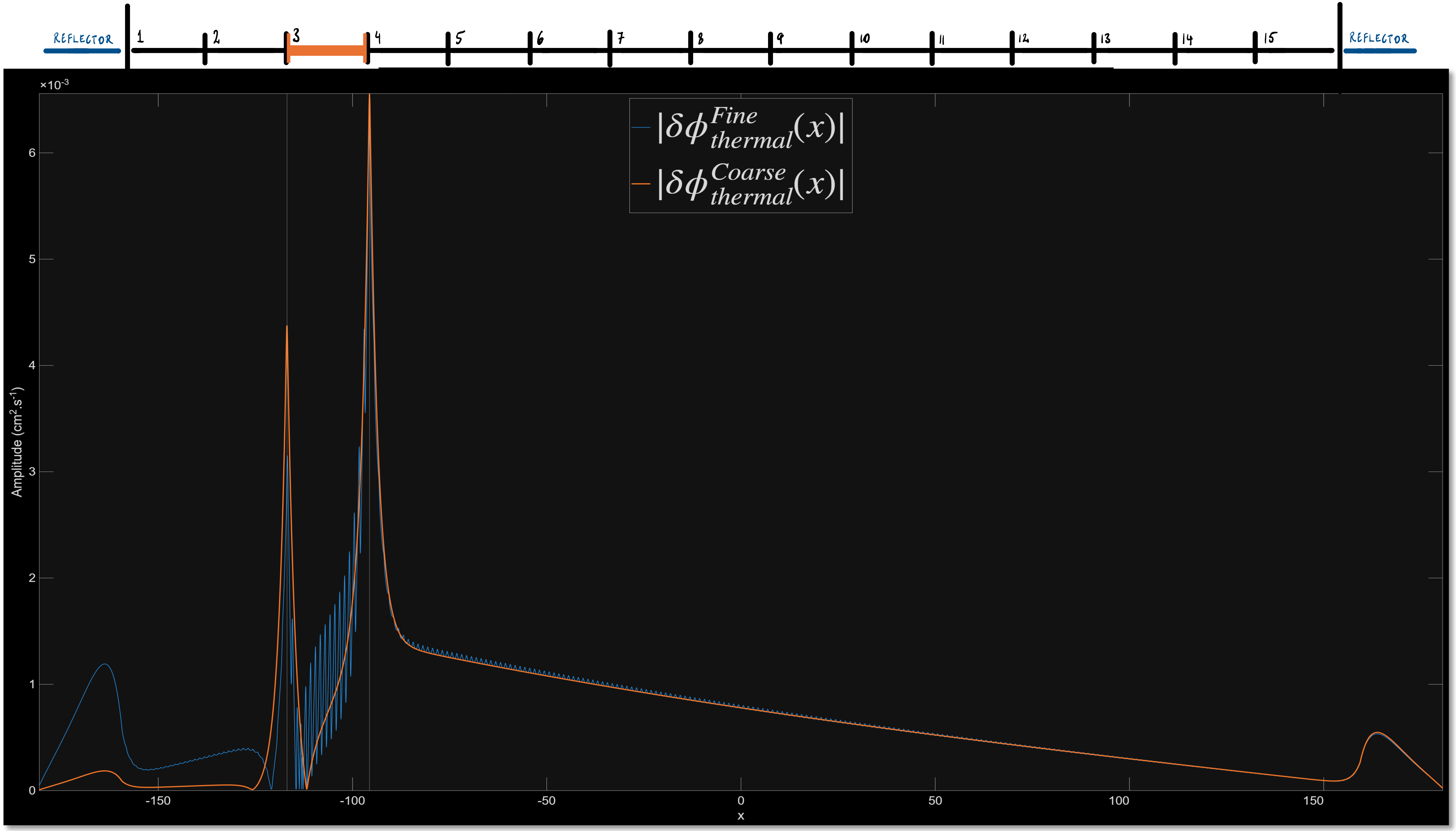

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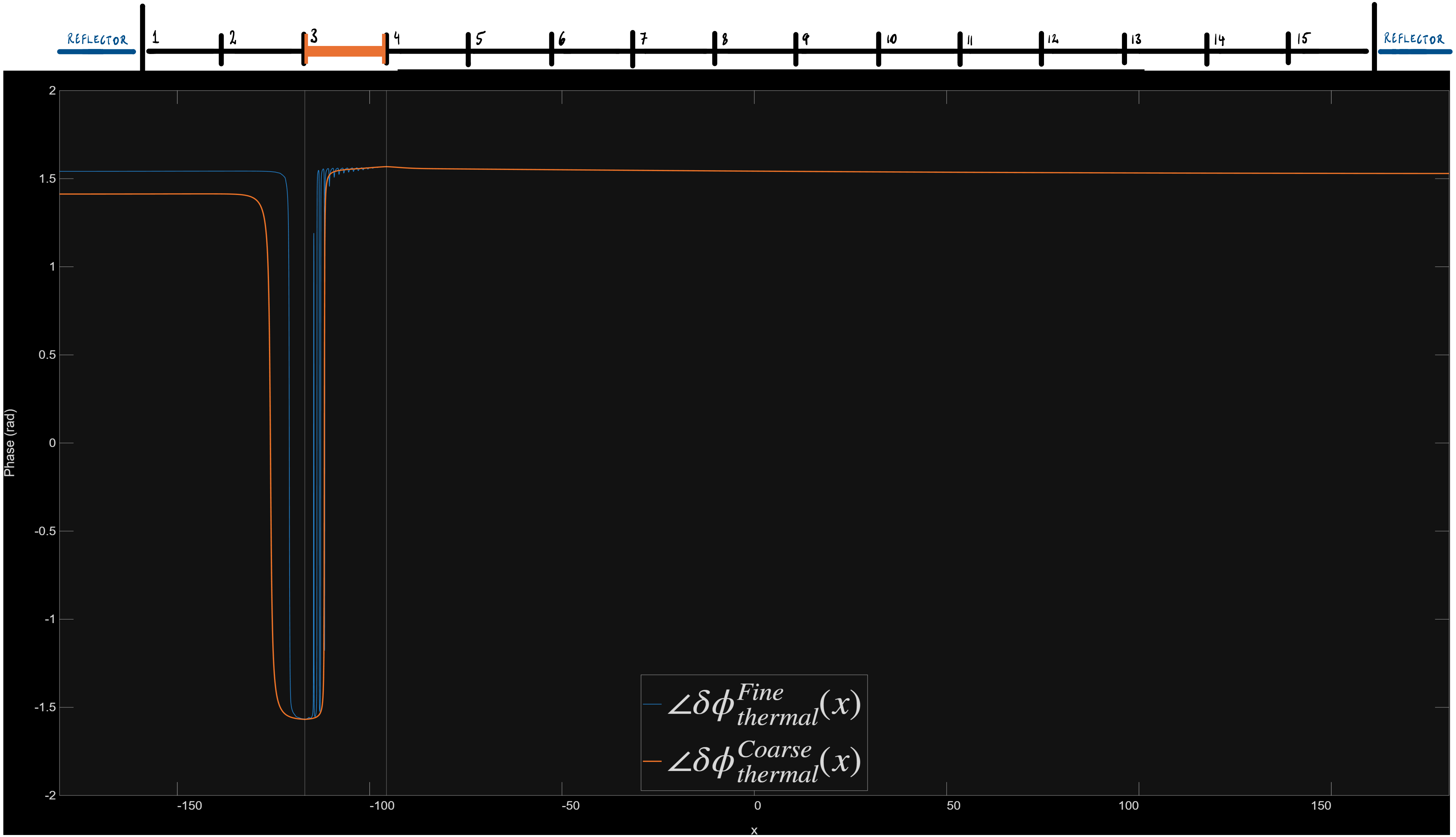

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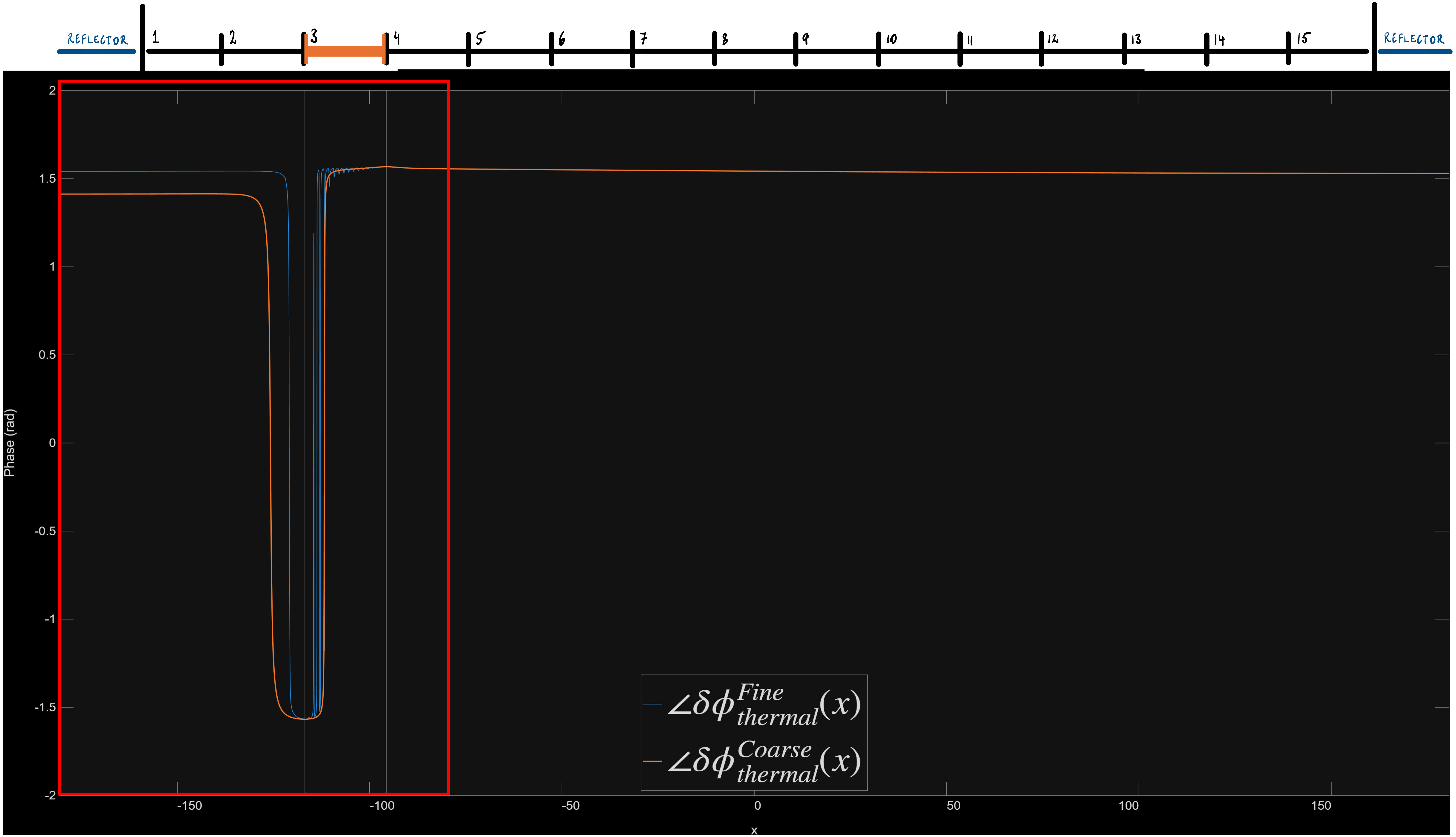
Comparison {
Phase of Fine-mesh thermal neutron noise
Phase of Coarse-mesh thermal neutron noise



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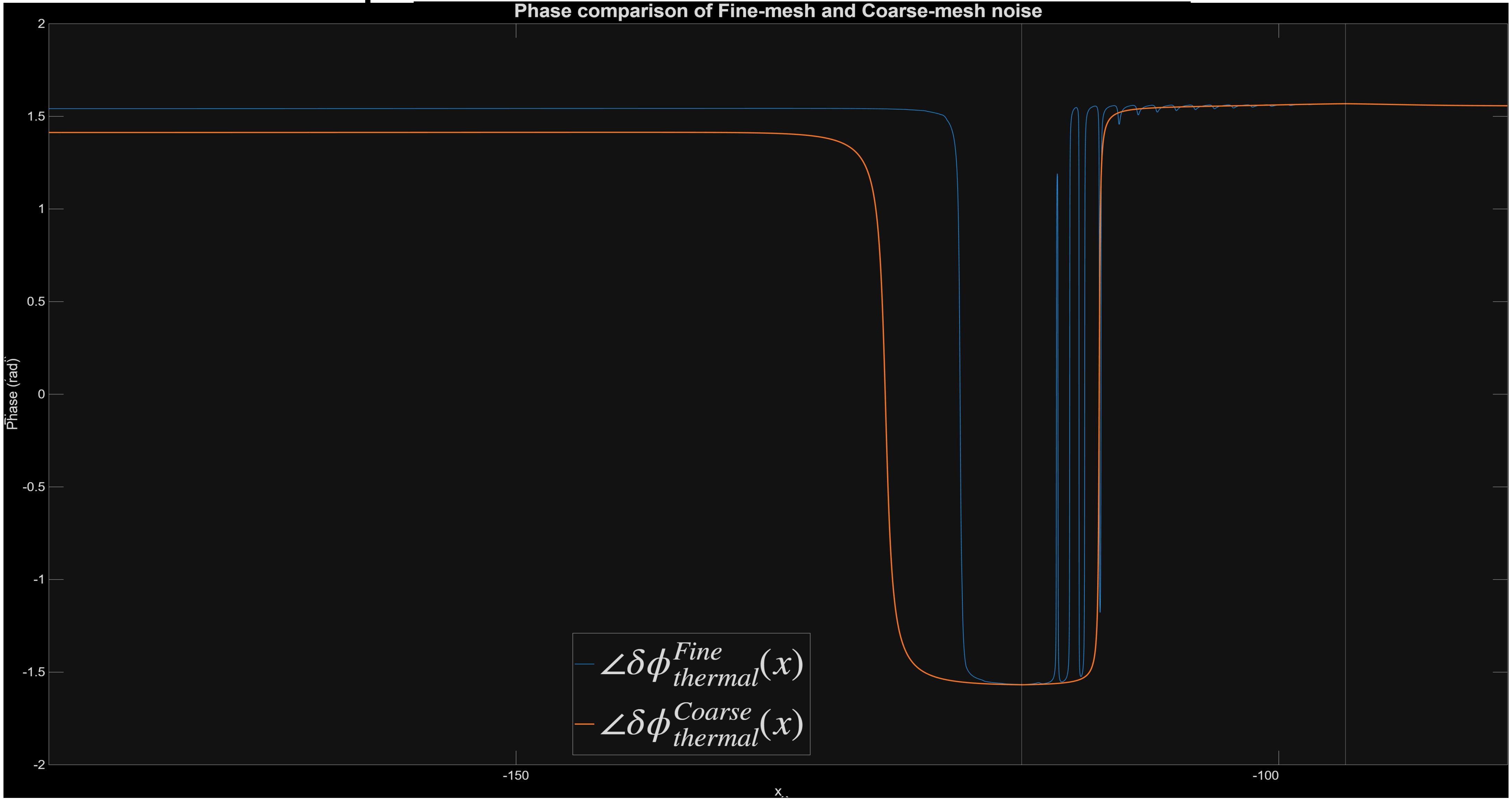
Comparison { Phase of Fine-mesh thermal neutron noise
Phase of Coarse-mesh thermal neutron noise



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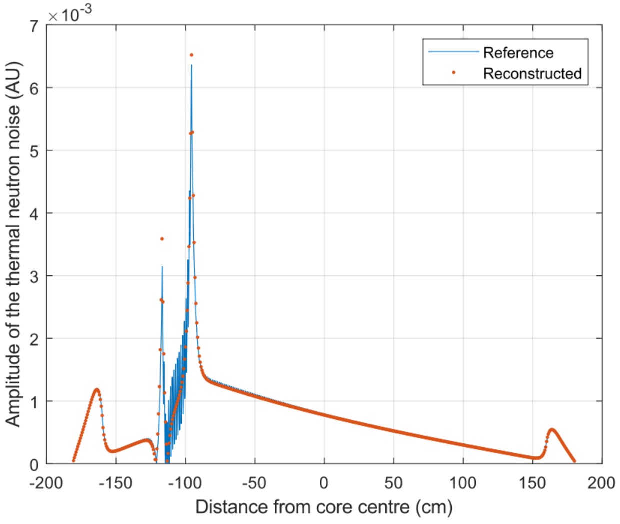
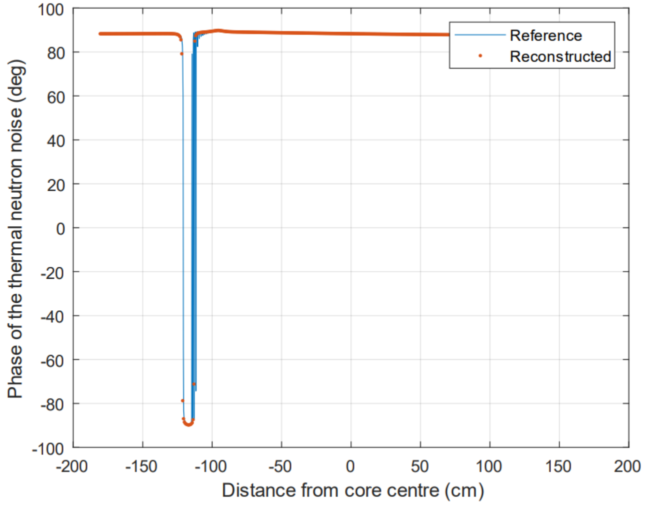
Comparison $\left\{ \begin{array}{l} \text{Phase of Fine-mesh thermal neutron noise} \\ \text{Phase of Coarse-mesh thermal neutron noise} \end{array} \right.$

Work done to match the fine-mesh solution

- Some work has been done to explore solutions to this problem*





*Demaziere, C. (2022). On the modeling of fuel assembly vibrations using coarse mesh approaches, PHYSOR 2022

- Paper investigated if Model 2 (Coarse-mesh) can be:
  - Adjusted such that the Model 2 neutron noise reproduces the Model 1 neutron noise global behavior,
  - by only adjusting the existing 4 noise sources in Model 2.

- Paper demonstrated that this is possible
  - The 4 noise sources of Model 2 adjusted to the total reactivity of the 68 noise sources of Model 1
  - This methodology is one among several that will be pursued in PhD project.

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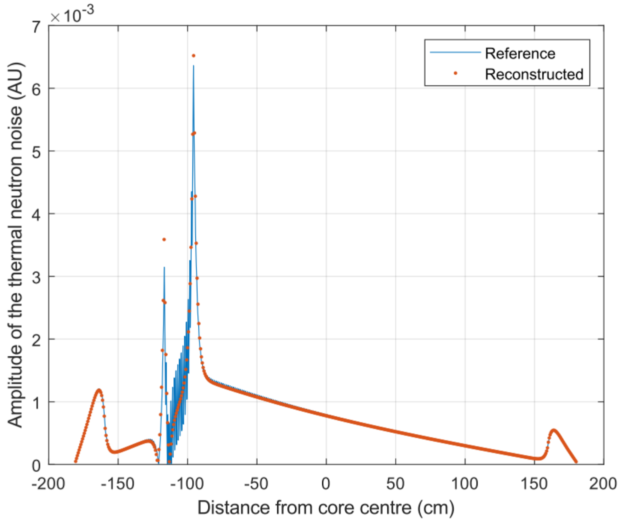
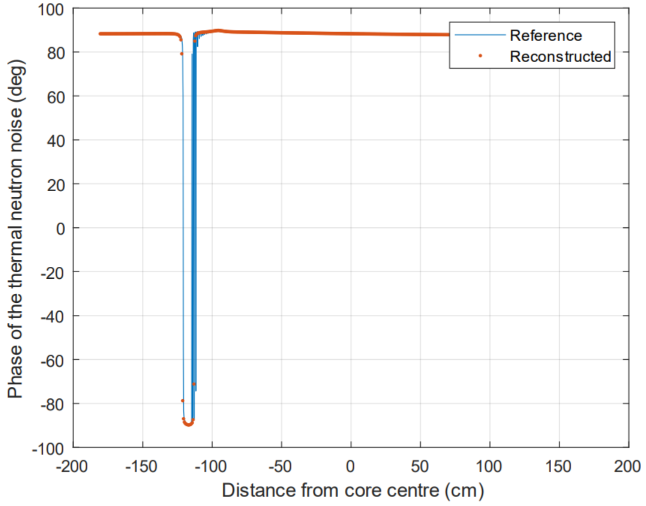
PhD Aim

- Some work has been done to explore solutions to this problem*





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- PhD aims at
  - An organic investigation on possible approaches to reconcile coarse low-order solutions with high-order solutions in a generalized framework
  - Develop a formal “Noise Equivalence” methodology.

- Such methods are analogous to equivalence methods in homogenization for static calculations
  - Discontinuity factors, Super homogenization, etc.
  - Noise equivalence methodology should extend analogous methods to dynamic calculations.

PhD Plan – Study neutron noise equivalence

- Need for solvers designed to have control of the neutron phase space resolution, i.e.
  - The spatial, energy, angular resolution
- A new, flexible library of solvers tailored for 1-D problems is under development:
  - Diffusion/SP1/SP3/…/SPN solvers
  - Allows separating effects of discretization resolution from each other
- Demonstration using in-house solvers already developed
  - Diffusion solvers: CORE SIM / CORE SIM+
  - Sn transport solver: NOISE-SN

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