Validating Organic Scintillator Rossi-alpha Measurements of Fast Metal Assemblies using Simulations

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Introduction and Motivation

- Measurements of reactivity, ρ, or the k-effective multiplication factor, k_{eff}, of SNM assemblies are crucial to nuclear nonproliferation, safeguards, and criticality safety.
- k_{eff} describes the neutron multiplication within a system; inter-generational ratio.
- Rossi-alpha measurements estimate the prompt neutron decay constant, α, to infer k_{eff}, which cannot be measured directly.
- Previous work has shown that ^{3}He-gas proportional counter-based detection systems (tens of microseconds) are insensitive to α^{-1} of fast assemblies (tens of nanoseconds).
- Faster detection systems are of interest, such as those based on organic scintillation detectors, to augment the current Rossi-alpha toolbox.

We validate organic scintillator-based Rossi-alpha measurements of fast assemblies by comparing measurement to two different, independent simulations.

Rossi-alpha

- Obtain time differences between all neutron detections. Create a histogram of time differences.
- Prompt neutron decay constant, α, determined from fit of time-difference histogram.

$$\rho = \frac{k_{\text{eff}} - 1}{k_{\text{eff}}} = \beta_{\text{eff}} - \alpha\Lambda$$

- Determine β_{eff} and Λ, typically through with simulation.

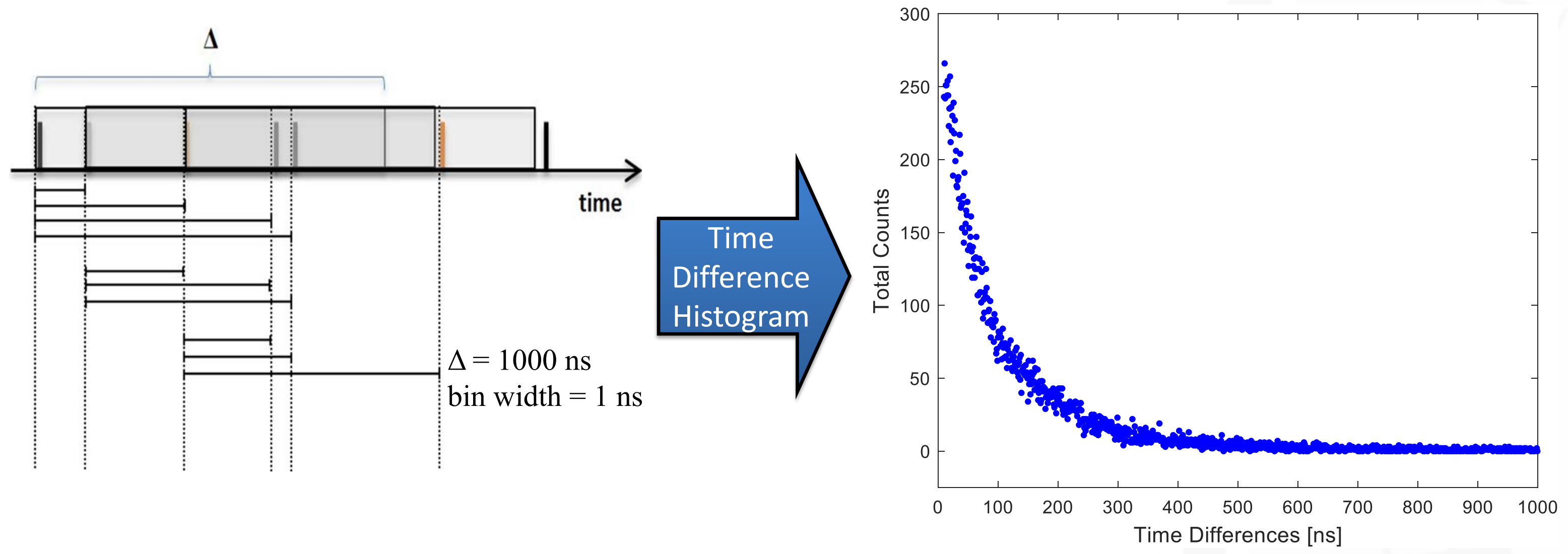

Fig. 1. (Left) Type-I binning time difference become (right) a Rossi-alpha histogram

Organic Scintillators

- Organic scintillators capable of detecting both fast neutron and gamma rays have become popularized.
- They are scatter-based recoil detectors sensitive to fast neutrons **without moderation** and have:
  - Observable neutron energy range from 0.5 MeV to 5.5 MeV
  - Nanosecond timing capabilities
  - Pulse-shape discrimination (PSD) implemented to separate neutron events

Fig. 2. Trans-stilbene crystal and ET 9214B PMT couple.

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Experimental and Simulation Setups

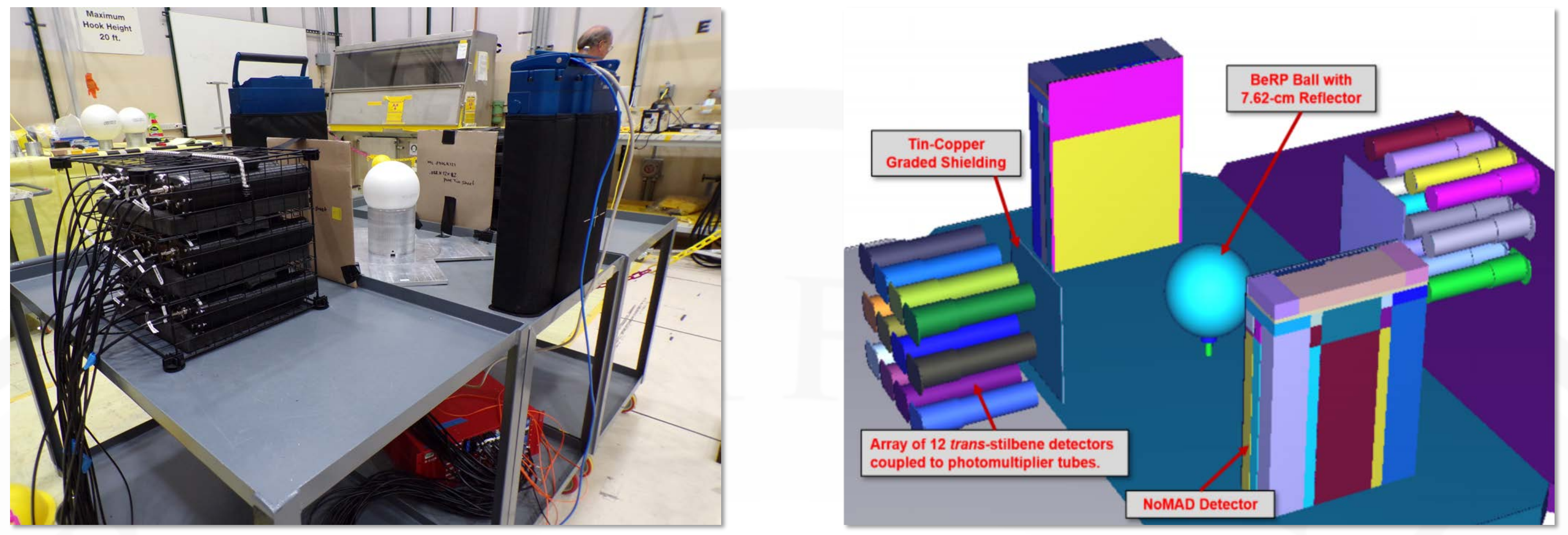
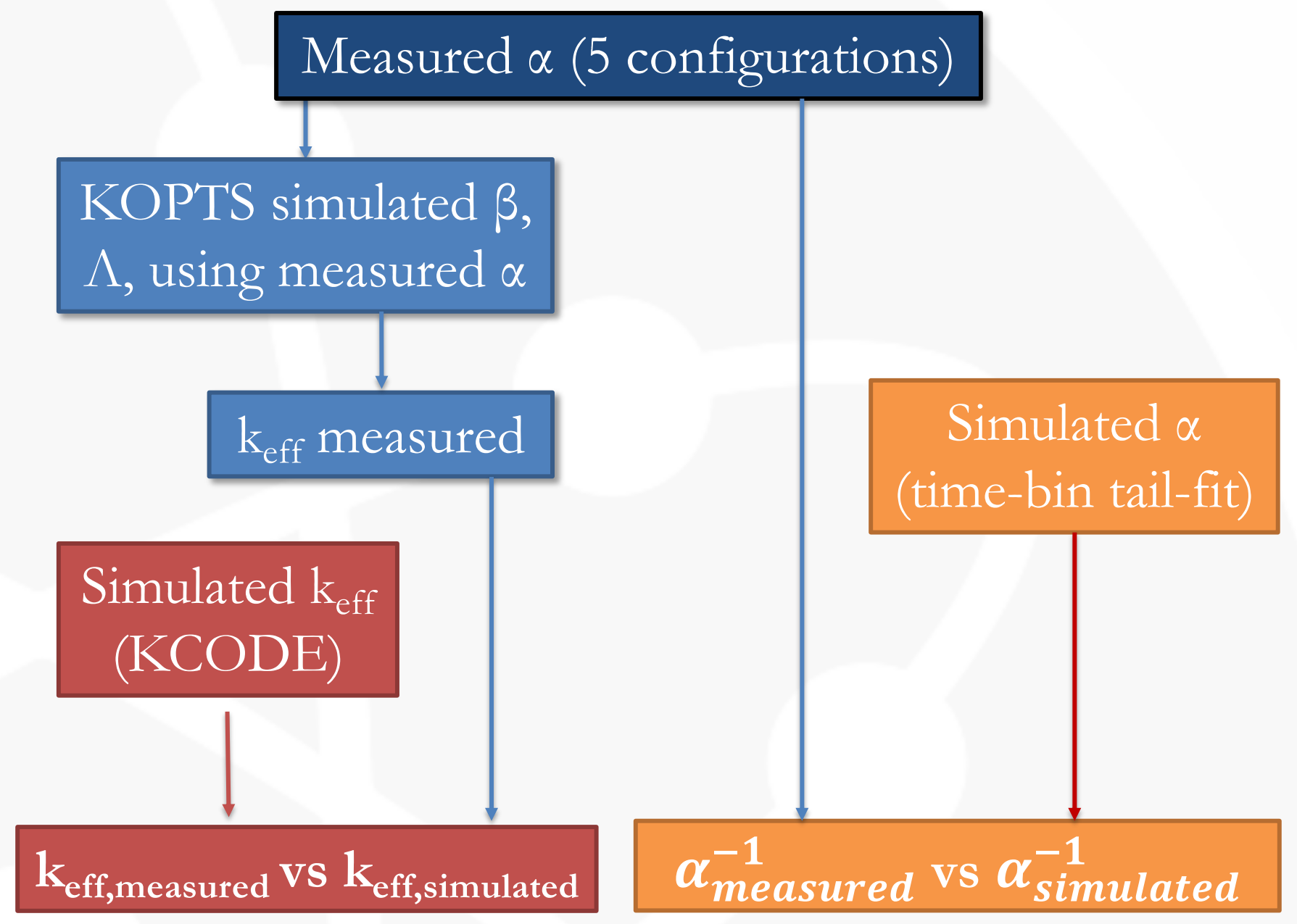


Fig. 4. (Left) Experimental setup of 12 *trans*-stilbene detectors measuring the BeRP ball in five different reflectors for 30 minutes and (Right) MCNP model representative of all scenarios for both simulations

Measurement and Analysis

- The configuration in figure 4 is based on previous Device Assembly Facility measurements and simulations.
- Two 12 trans-stilbene scintillator arrays and two NoMAD detectors.
- 4.5 kg of alpha-phase, beryllium reflected weapons-grade plutonium (BeRP ball) in five different reflector configurations:
  - Bare
  - 7.62 cm Iron
  - 7.62 cm Copper
  - 7.62 cm Tungsten
  - 7.62 cm Nickel



Measured α (5 configurations)

KOPTS simulated β, Λ, using measured α

k_{eff} measured

Simulated α (time-bin tail-fit)

Simulated k_{eff} (KCODE)

$k_{eff,measured}$ vs $k_{eff,simulated}$

$\alpha^{-1}_{measured}$ vs $\alpha^{-1}_{simulated}$

Fig. 5. Process of independently simulating and comparing time-bin tail-fit and KCODE

Results

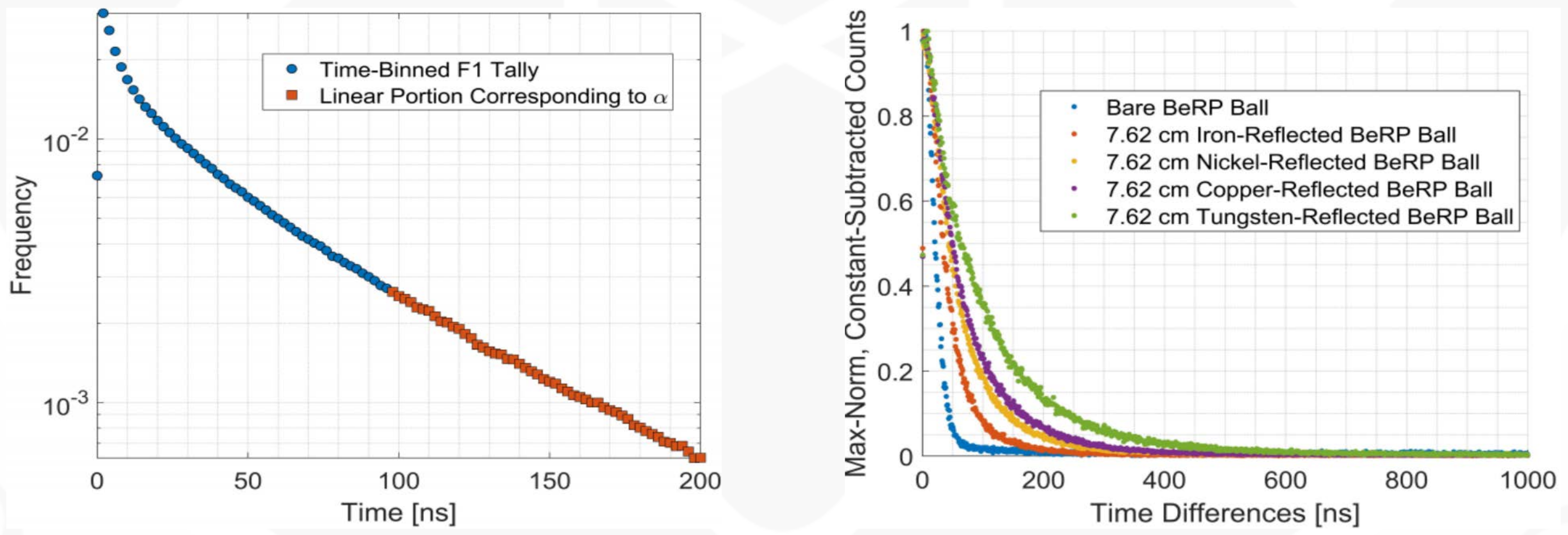


Fig. 6. (Left) Sample time-bin tail-fit distribution used to directly estimate α from simulation with a 2-exp fit, which is applied to (Right) peak normalized Rossi-alpha histograms for each reflector.

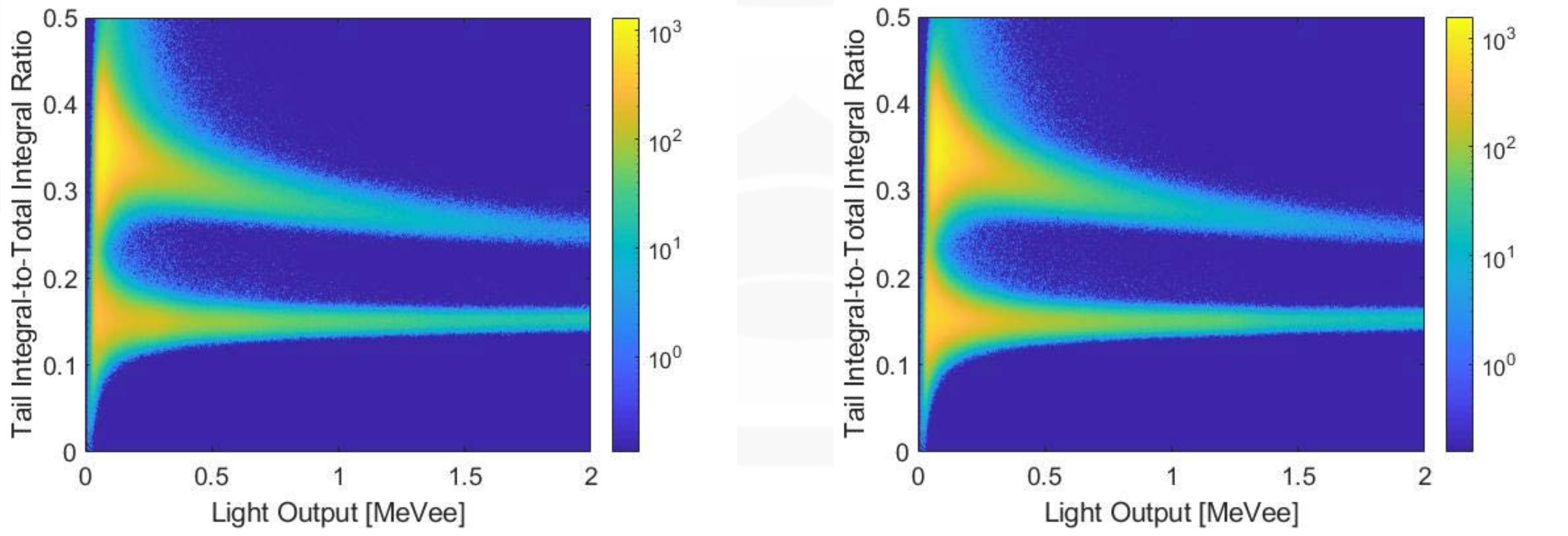


Fig. 7. PSD plots for (Left) tungsten and (Right) copper measured for 30 and 20 minutes respectively

Results Continued

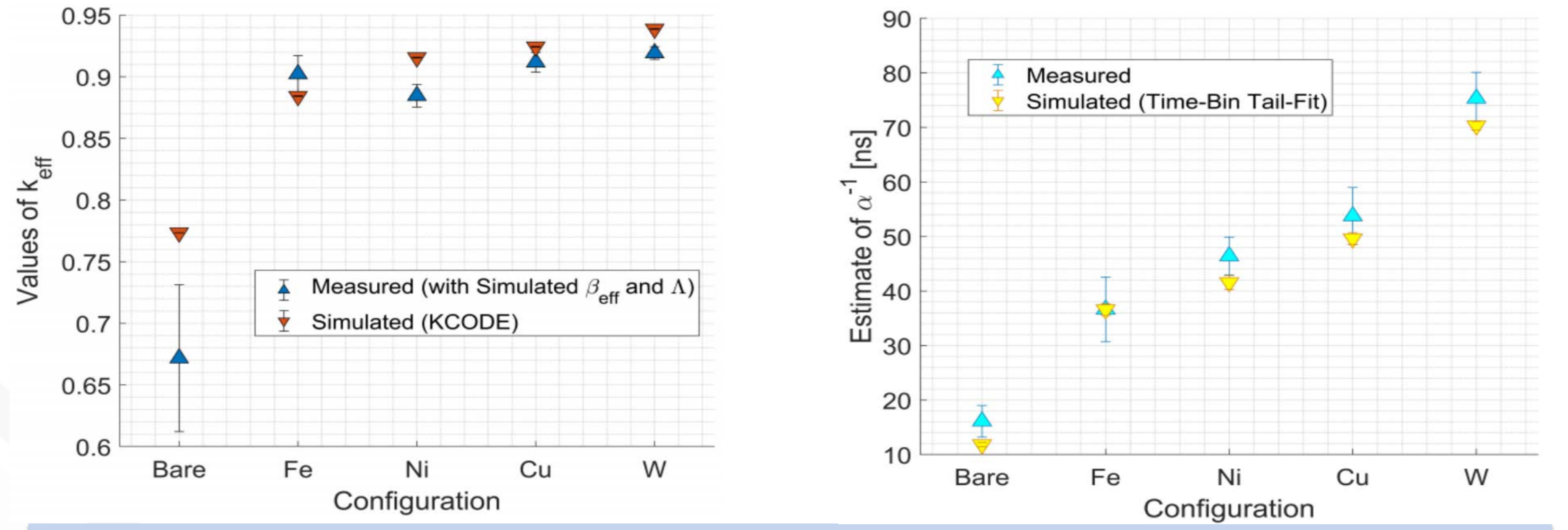


Fig. 8. (Left) Comparison of KCODE $k_{eff,simulated}$ and α with KOPTS $k_{eff,measured}$. (Right) Comparison of time-bin tail-fit of $\alpha^{-1}_{measured}$ and $\alpha^{-1}_{simulated}$.

- An array of organic scintillators was used to measure five subcritical assemblies: a bare sphere of approximately 4.5 kg of alpha-phase, weapons-grade plutonium and the same sphere reflected by 7.62 cm of iron, nickel, copper, or tungsten.
- We aimed to use simulations to validate the use of organic scintillators in Rossi-alpha measurements of the prompt neutron decay constant, α.
- Figure 7 (left) is given as inverse alpha, α^{-1}, to compare units of time and the measured and simulated confidence intervals overlap as:
  - 1-σ for iron, copper, and tungsten cases, 1.02 σ for nickel, and 1.31 σ for bare.
  - Overall, good agreement between $\alpha^{-1}_{measured}$ and $\alpha^{-1}_{simulated}$.
- Figure 7 (right) is the result of using measured α to KOPTS simulated values of β_{eff} and Λ, and calculate $k_{eff,measured}$ to then be compared to the $k_{eff,sim}$ from KCODE simulations.
  - Measured estimates of k_{eff} are less than simulation calculated k_{eff} except for iron.
  - Error and uncertainty in $k_{eff,measured}$ increases as $k_{eff,simulated}$ decreases as expected, since the point kinetics model assumes k_{eff} ≈1, thus performing worse for more subcritical systems.

Conclusion and Future Work

- This work shows that organic scintillator-based systems are sensitive to fast assemblies.
- Organic scintillators should replace ^{3}He in fast metal applications.
- The two-exponential model adequately describes physical phenomenon using two region point kinetics.
- Future: Validating the model for both ^{3}He-based and organic scintillator-based systems for general reflectors.
- Future: Comparison of ^{3}He-based and organic scintillator-based detection systems in time-correlated, microscopic neutron noise methods.

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