IER 501: Pulsed Neutron Die-Away Experiments at LLNL

NSCP Technical Program Review
February 21-23, 2023

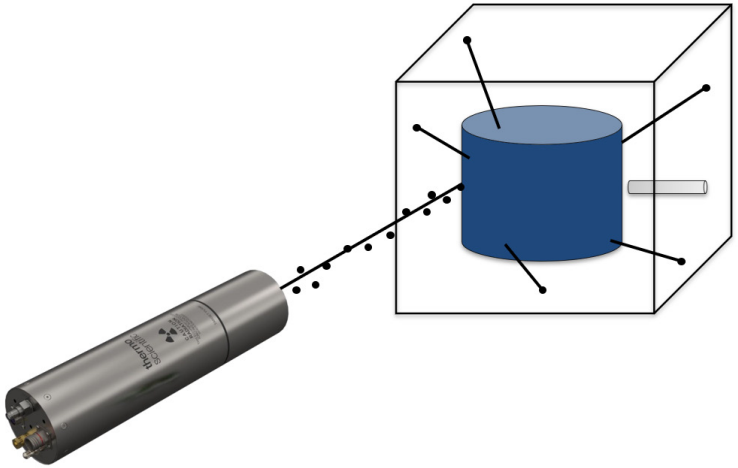
Daniel Siefman, R. Araj, W. Zywiec, D. Heinrichs, C. Percher
Nuclear Criticality Safety Division
siefman1@llnl.gov

LLNL-PRES-845313
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Lawrence Livermore National Laboratory

Why PNDA for TSL Validation?

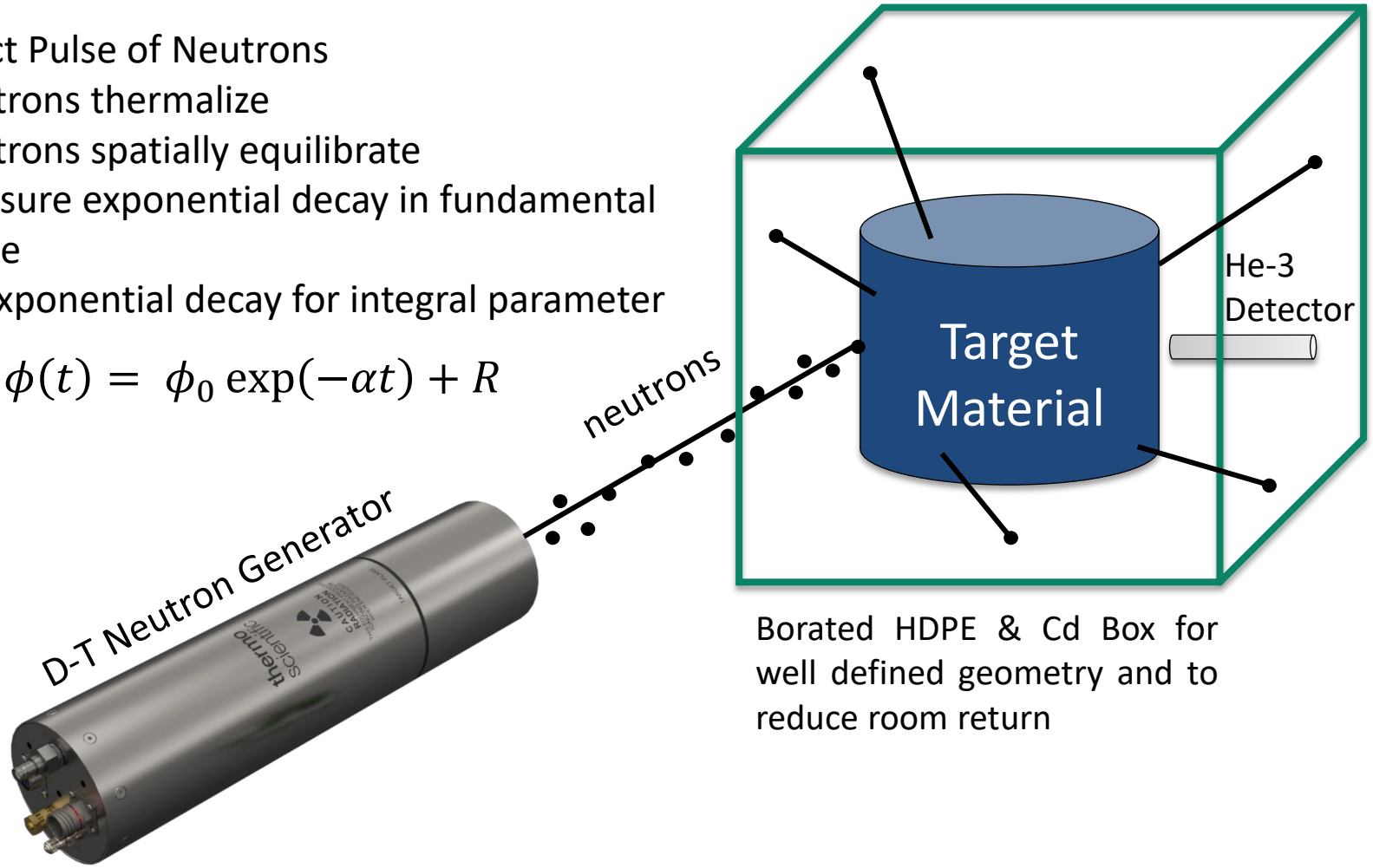
- Does not require fissile material
  - Non-nuclear facilities, reduced costs, fewer regulations, safer
- Very simple target shapes and compositions
  - Reduced uncertainties in benchmarks
  - Reduced material costs
  - Easy to change temperature
- Only sensitive to absorption and scattering of target medium
  - Reduces uncertainties from other nuclear data and compensating effects
  - Tune target size to vary effect of absorption vs. scattering
- Well conducted experiments have uncertainties of 0.1% - 0.5%



Pulsed Neutron Die Away Experiments

1. Inject Pulse of Neutrons
2. Neutrons thermalize
3. Neutrons spatially equilibrate
4. Measure exponential decay in fundamental mode
5. Fit exponential decay for integral parameter

$$\phi(t) = \phi_0 \exp(-\alpha t) + R$$



Borated HDPE & Cd Box for well defined geometry and to reduce room return

Sensitivity to TSLs

- Example: Historical water experiment in cylindrical geometry
  - A. Bracci & C. Coceva, "The diffusion parameters of thermal neutrons in water." *Il Nuovo Cimento*, **4** (1956)

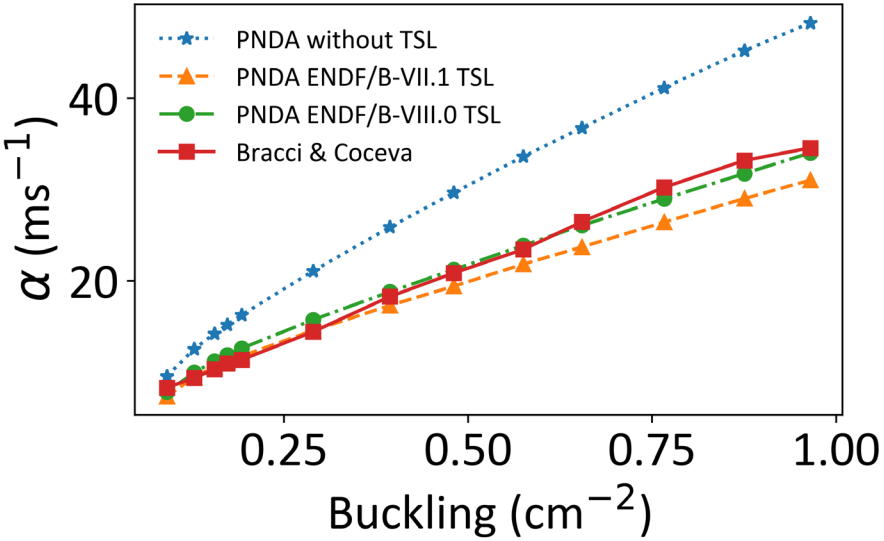


Figure: α vs. Buckling curve for experimental and simulated data

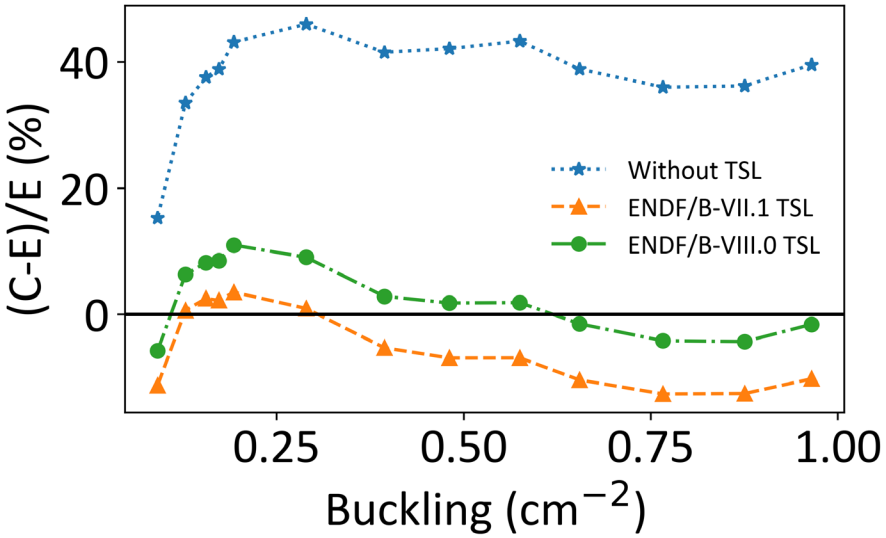
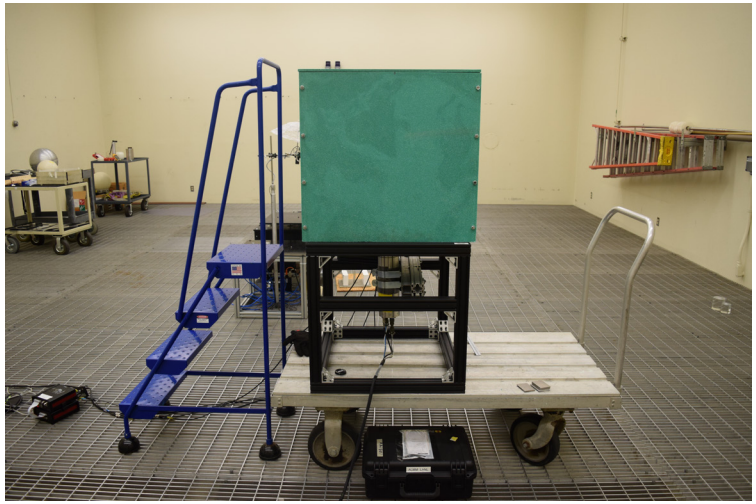
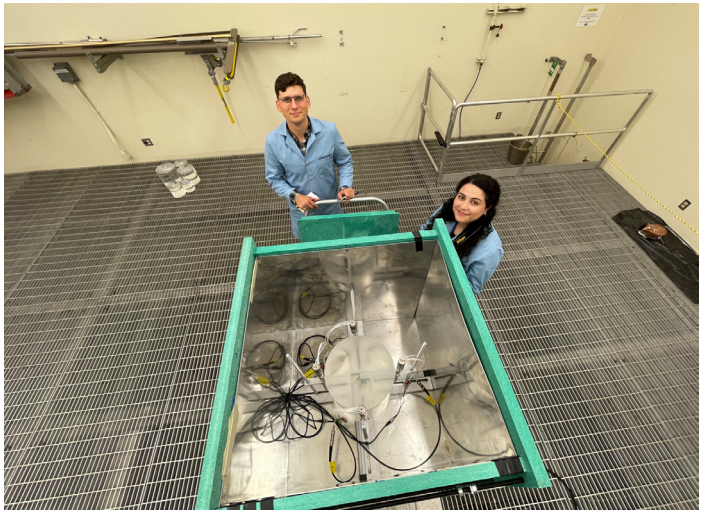


Figure: Bias of simulations without TSLs, with ENDF/B-VII.1, and with ENDF/B-VIII.0 TSLs

FY22 PNDA Experiments

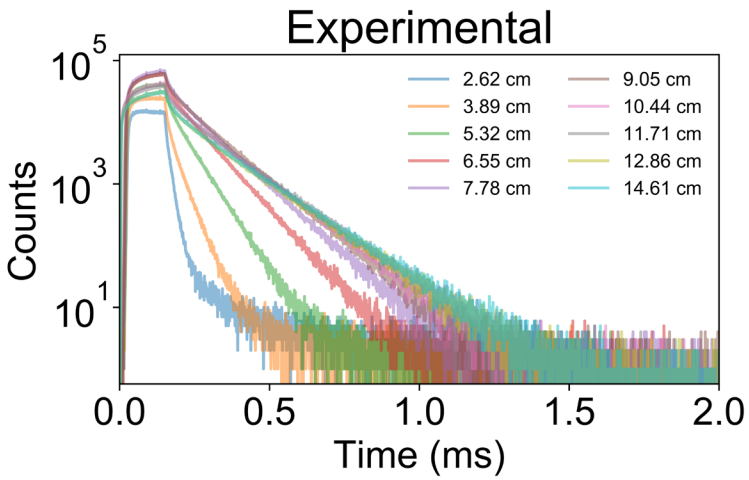
- CED-2, CED-3a, CED-3b written in FY22
- Benchmark experiments with high density polyethylene (HDPE) and Lucite
- 22 individual experiments with varying target sizes
- Conducted over one week in low-scatter facility at LLNL

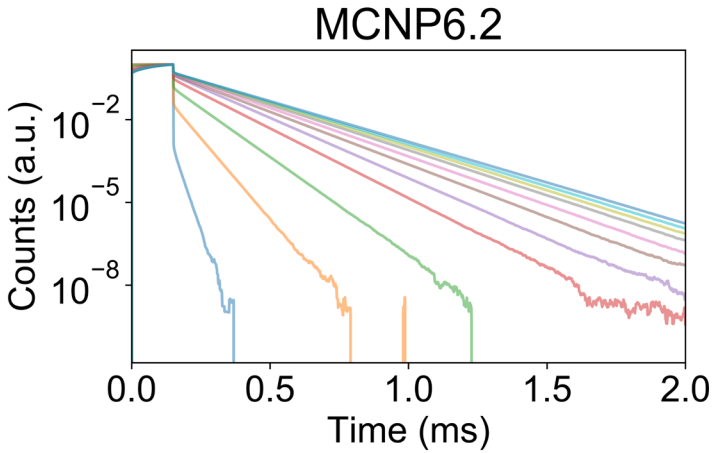




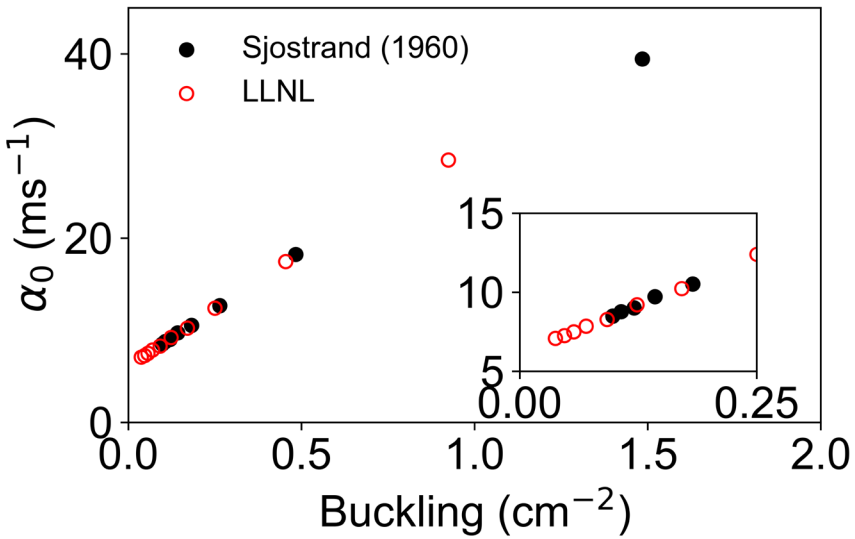
HDPE Die-Away Curves

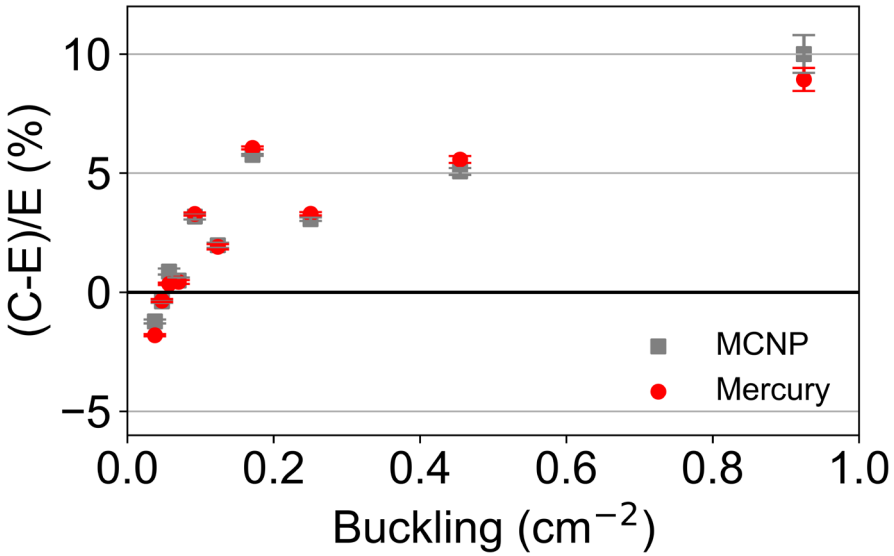
Figure: HDPE cylinders used in PNDA experiment





First HDPE Validation



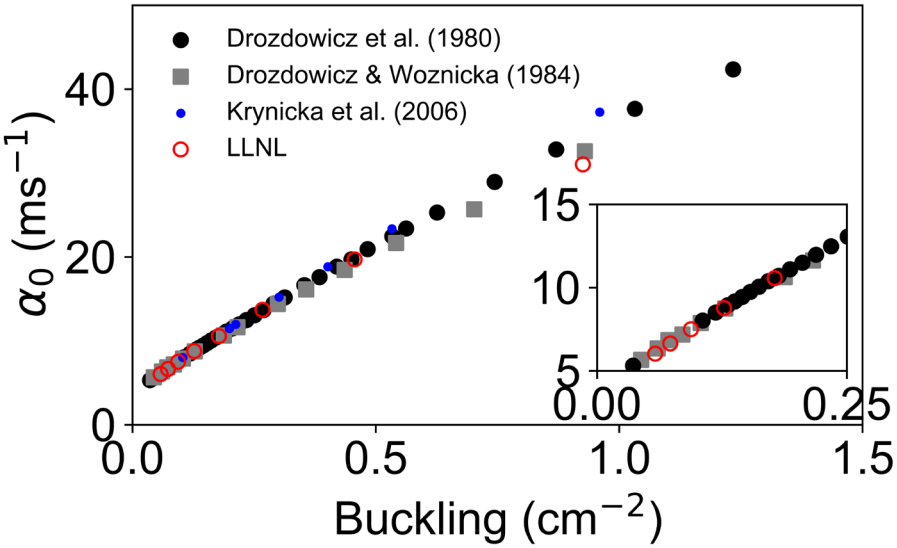


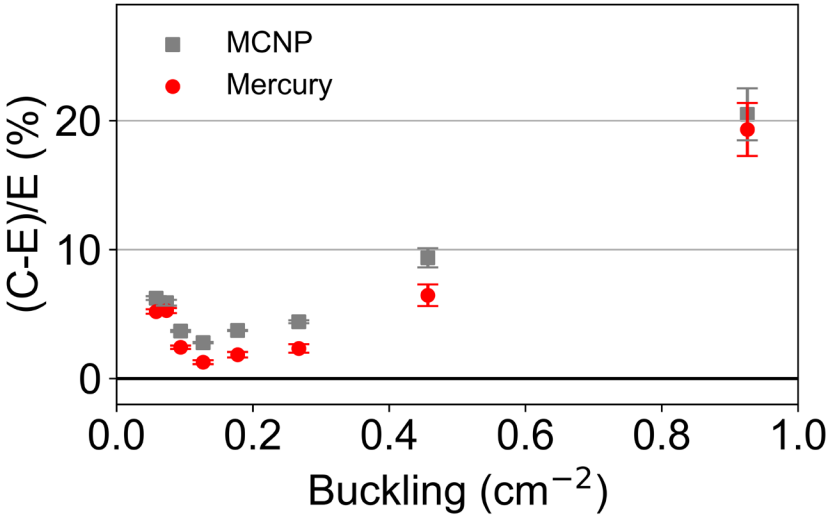
- General trend of increasing bias with smaller sampler size (larger buckling)

Lucite Results

Polymethyl Methacrylate

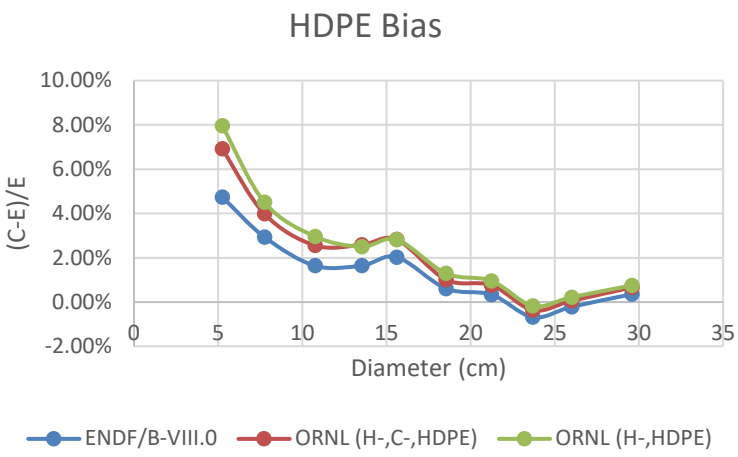
Figure: Lucite cylinders used in PNDA experiment

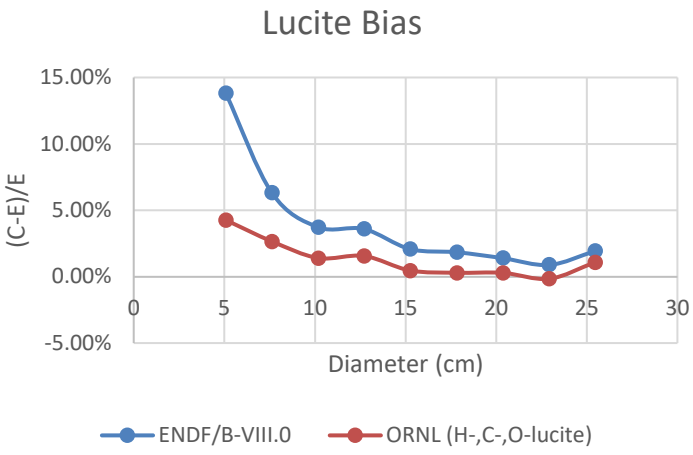




Support to ORNL TSL Validation

- Kemal Ramic at ORNL currently evaluating Lucite and HDPE TSLs for NCSP
- Preliminary PNDA results providing validation information
- New Lucite evaluation shows improvement vis. ENDF/B-VIII.0
- HDPE shows slight poorer performance





FY23 Benchmarking Efforts

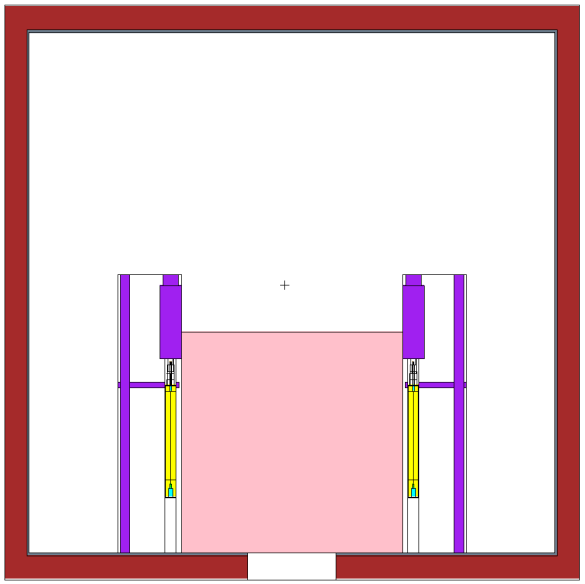


Figure: Detailed modeling of detector effects

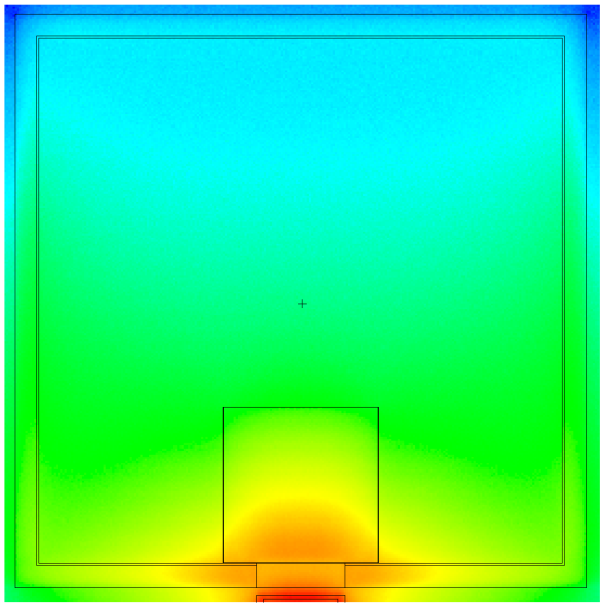
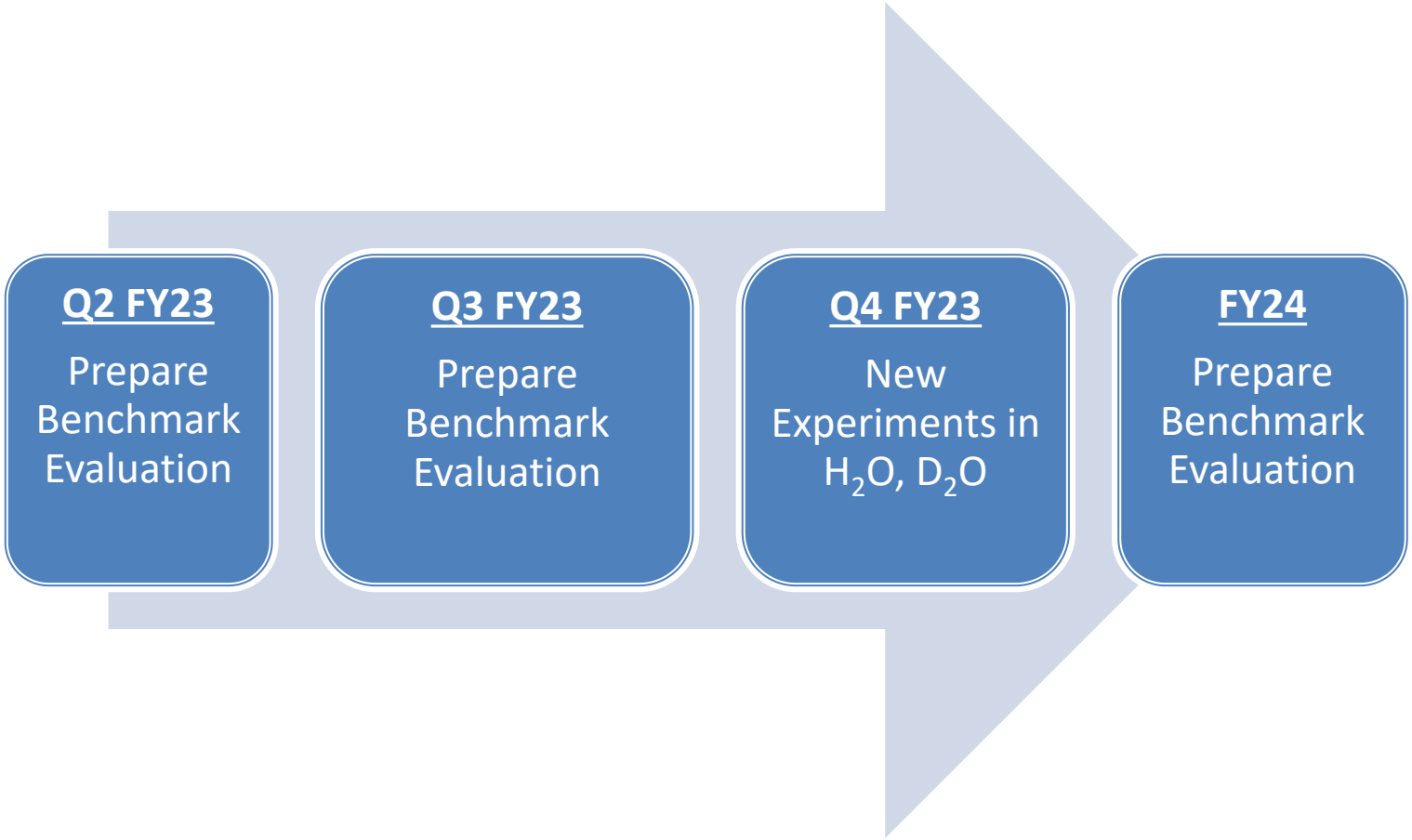


Figure: Detailed modeling of generator and box scattering effects

Timeline


Q2 FY23
Prepare Benchmark Evaluation
Q3 FY23
Prepare Benchmark Evaluation
Q4 FY23
New Experiments in H_2O, D_2O
FY24
Prepare Benchmark Evaluation

Questions, Comments, Discussion

This work was supported by the United States Department of Energy (DOE) Nuclear Criticality Safety Program (NCSP), funded and managed by the National Nuclear Security Administration for the DOE. It was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Lawrence Livermore National Laboratory

Integral Parameter: α eigenvalue

$$\phi(t) = \phi_0 \exp(-\alpha t) + R$$

$$\alpha = \overline{v\Sigma_a} + \overline{vD_0}\, B_0^2 - CB_0^4 + \cdots$$

- α: flux decay-time eigenvalue [s^{-1}]
- D_0 [cm^2-s^{-1}] is the asymptotic diffusion coefficient
- C: "cooling coefficient" [cm^2]
- B_0^2: geometric Buckling [cm^{-2}]
- *v* thermal neutron velocity (2.2 x 10^5 cm/s)
- Σ_a macroscopic absorption cross section [cm^{-1}]

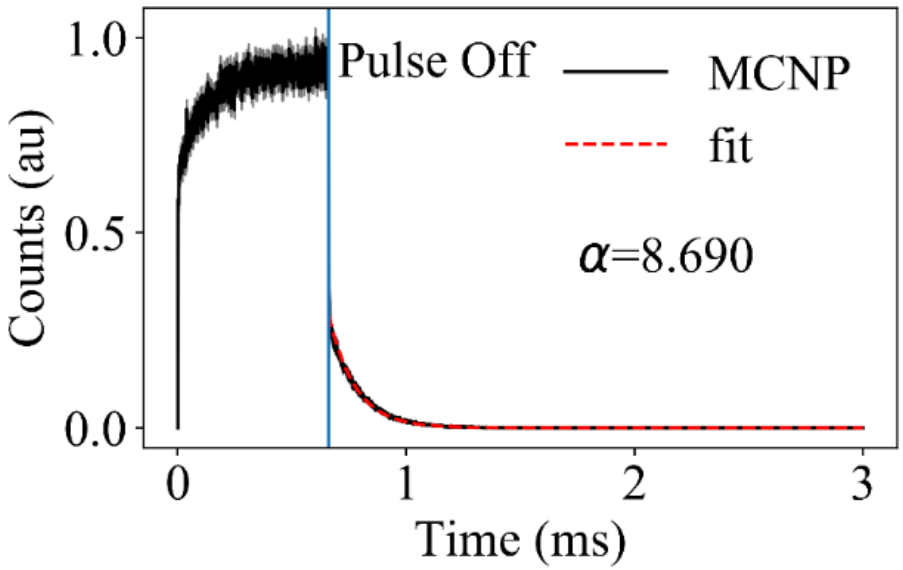
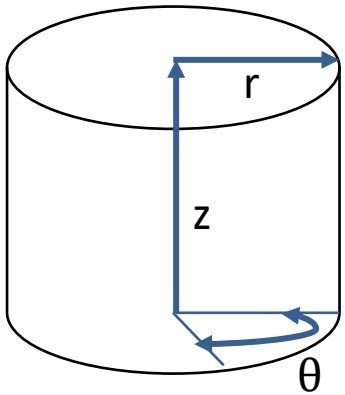


Figure: Example of pulsed-die-away curve modeled in MCNP

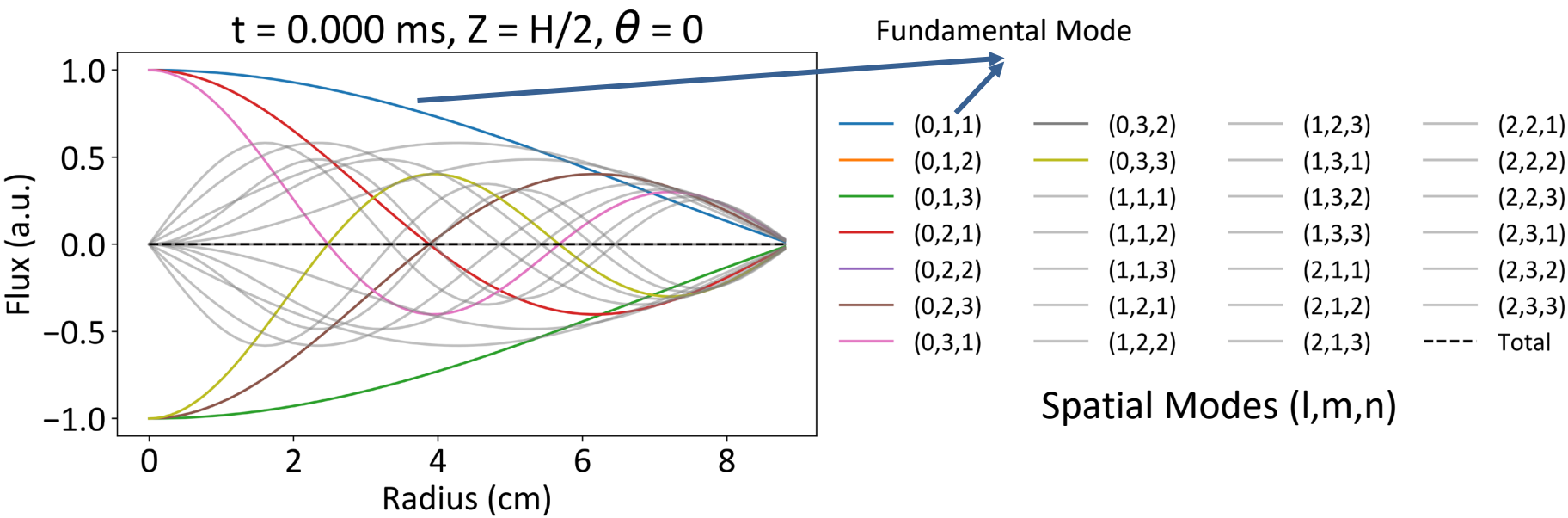
Decay to Fundamental Mode

Large Cylindrical Sample

$$\phi(r,\theta,z,t) = \sum_{l,m,n} C_{l,m,n} \sin\left(\frac{n\pi}{H} z\right) J_l(a_{l,n} r) \cos l\theta \exp\left[-\underbrace{\left(\overline{v\Sigma_a} + \overline{vD_0}\, B_{n,m,l}^2\right)}_{\alpha_{l,m,n}} t\right]$$



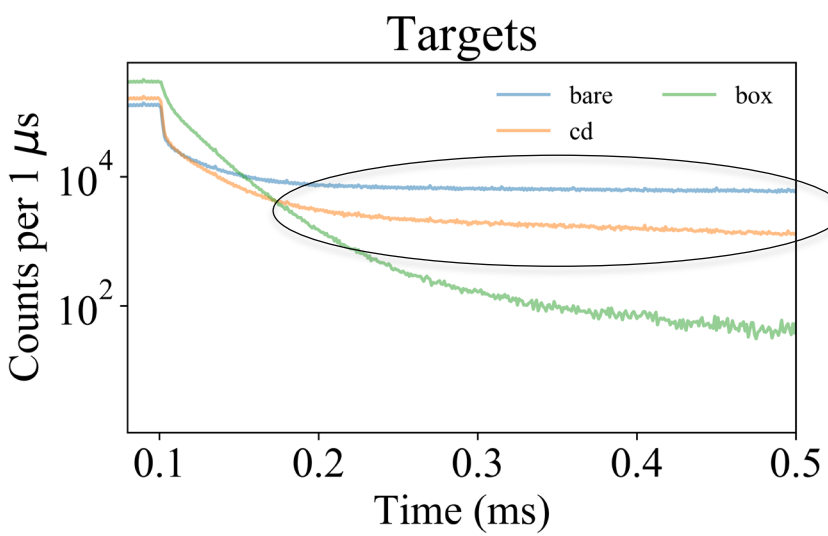
Focusing only on modes of Bessel function:

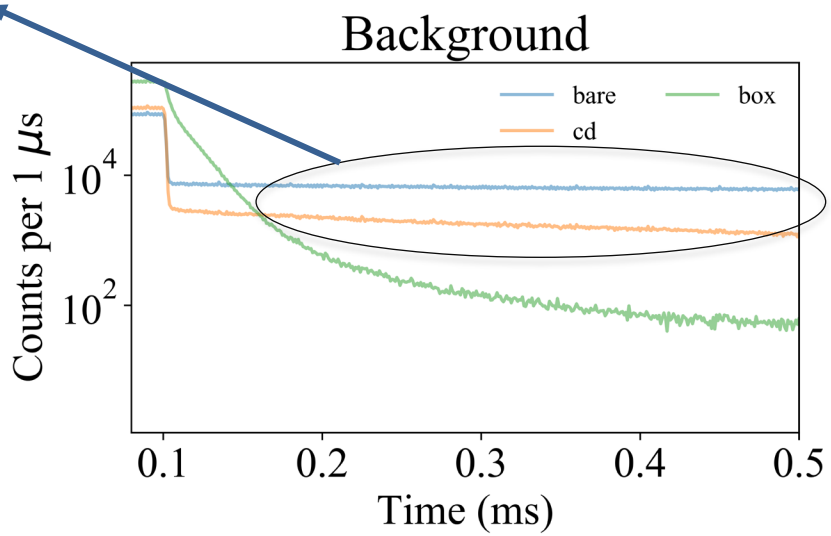


Effect of Shielding Box

Measurements in Low-Scatter Facility

Room Return





Sensitivity Depends on Target Size

- Small targets (large Bucklings) are more sensitive to scattering
- Large targets (small Bucklings) are more sensitive to absorption

$$B_0^2 = \left(\frac{\pi}{H + 2\delta}\right)^2 + \left(\frac{2.405}{R + \delta}\right)^2$$

$$\alpha = \underbrace{\overline{v\Sigma_a}}_{\text{Absorption}} + \underbrace{\overline{vD_0}\, B_0^2 - CB_0^4}_{\text{Scattering}}$$

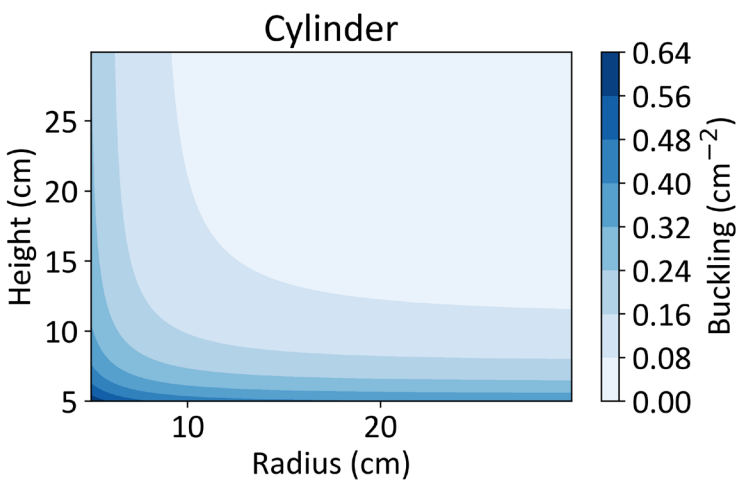


Figure: Buckling vs. cylinder dimensions

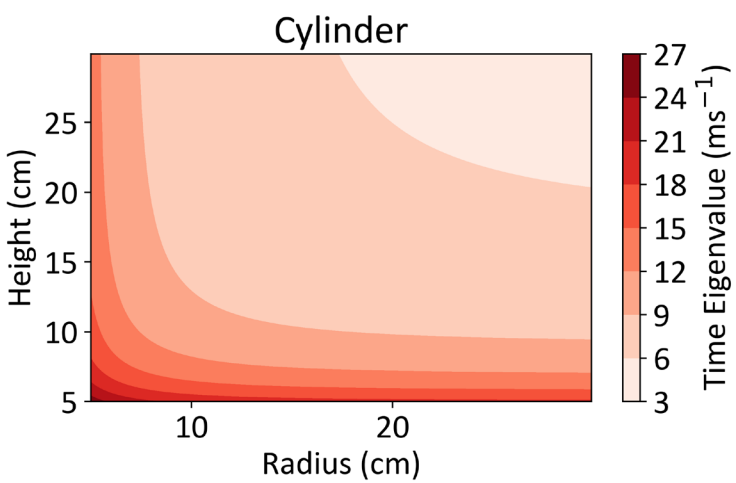


Figure: α vs. cylinder dimensions

Interpretation of Results

- Need to select data to include in the fit
- Too early data:
  - Flux is not fully thermalized or in fundamental spatial mode
- Too late data:
  - Noisy (room return) and larger uncertainty in α

$$\phi_{fit}(t) = \phi_0 \exp(-\alpha t) + R$$

$$\chi^2 = \sum_i \left(\phi_{data}^{(i)} - \phi_{fit}^{(i)}\right)^2$$

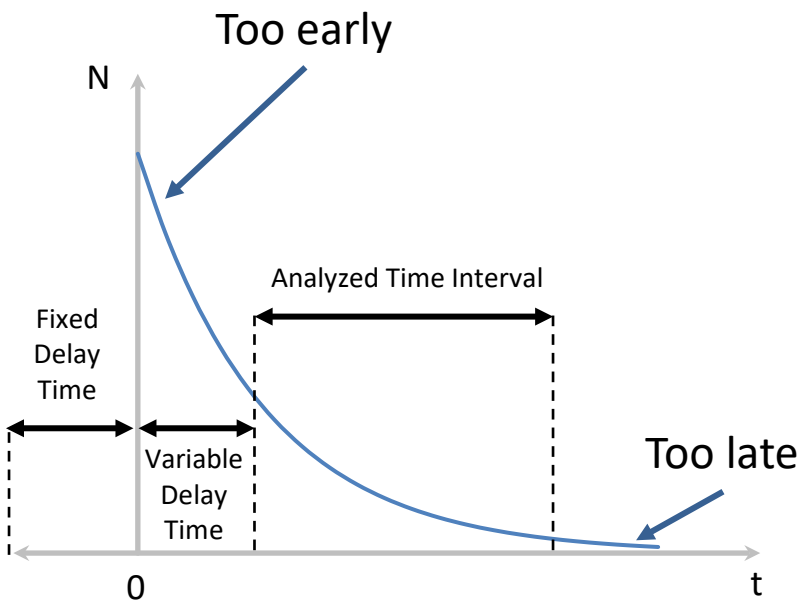
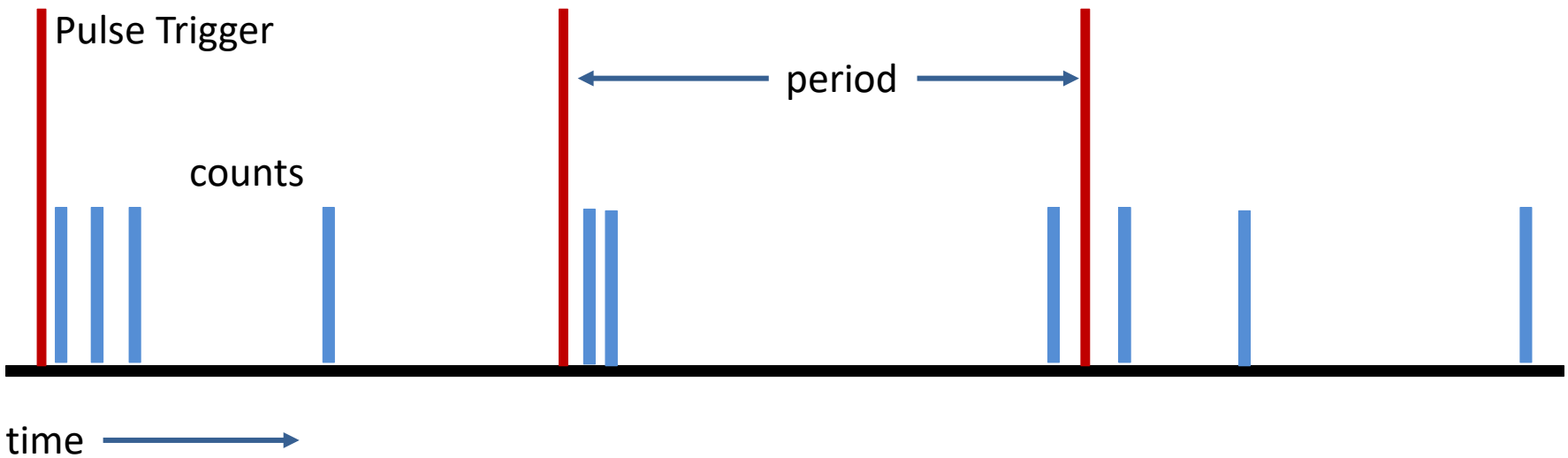


Figure: Position of the analyzed time interval

Algorithm

- Neutron counts and generator trigger recorded as list mode data
- Few counts per pulse, but many pulses allows to reconstruct die away curve
- Trigger is initiating event, $t_{trigger}$
- Sum counts in bins on die away curve as $t_{tag} - t_{trigger}$ in histogram



Algorithm: Sum pulse counts to construct curve