# Real-Time Analysis of Organic Scintillator Neutron Noise Measurements

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## Introduction and Motivation

- Fissionable assembly's reactivity and k-effective multiplication factor have several applications in nuclear nonproliferation and safeguards, criticality safety, and emergency response
- The prompt neutron decay constant ∝ can be estimated using Rossi-alpha measurements/Feynman-Y analysis
- The Rossi-alpha method and other neutron noise measurement techniques require a list of neutron detection times
- Typically, neutron noise measurement techniques are performed only **after** the entire measurement time, which can take 20-120$^{+}$ min
- Instead, by performing neutron noise measurement techniques **during** the measurement process, potential errors during data collection can be identified immediately
- Errors include
  - Misclassification of neutron and photon particles
  - Abrupt increases in the uncertainty of the prompt neutron decay constant
  - Unexpected distribution of neutrons encountered across different detectors
- Real-time analysis determines when desired precision for the measurement is achieved

## Rossi-alpha Method

- Given a list of neutron times, we find the time differences between 1 neutron and subsequent neutrons such that the time difference ≤ reset time = 1000 ns
- Histogram of time differences is generated using bin width of 1ns
- $\alpha$ is a combination of the fit parameters of the two-exponential fit

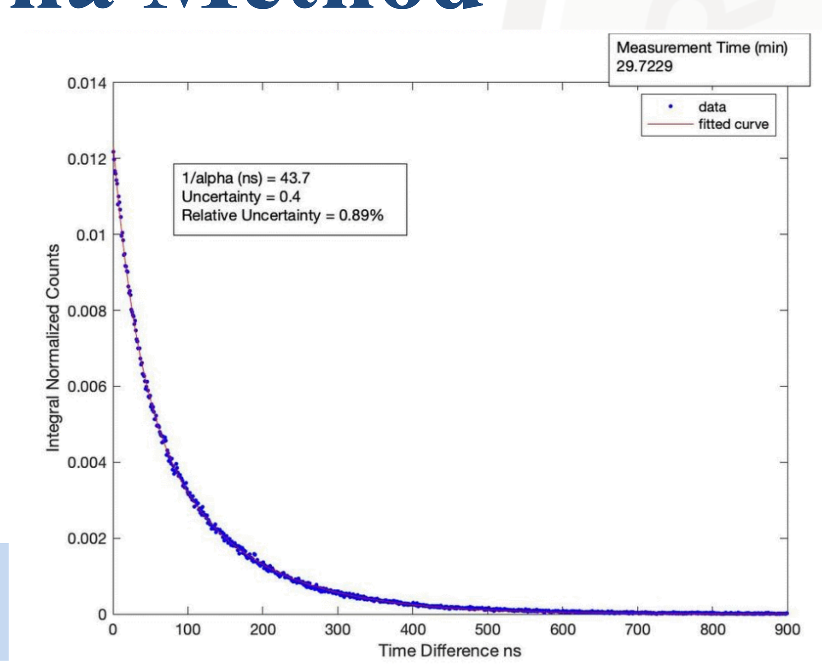


Fig. 1. Rossi-alpha histogram and associated uncertainty

## Feynman-Y Method

- Measures excess variance due to correlated counts from fission chains

$$Y = \frac{\sigma^2}{\mu} - 1$$

- If there is no correlation, fluctuations in counts per time from completely random source should follow Poisson distribution, Y = 0
- For a given gate width
  - Measurement time is divided nonoverlapping intervals of size gate width
  - Number of neutrons in each interval are counted
  - Finds variance and mean of these counts

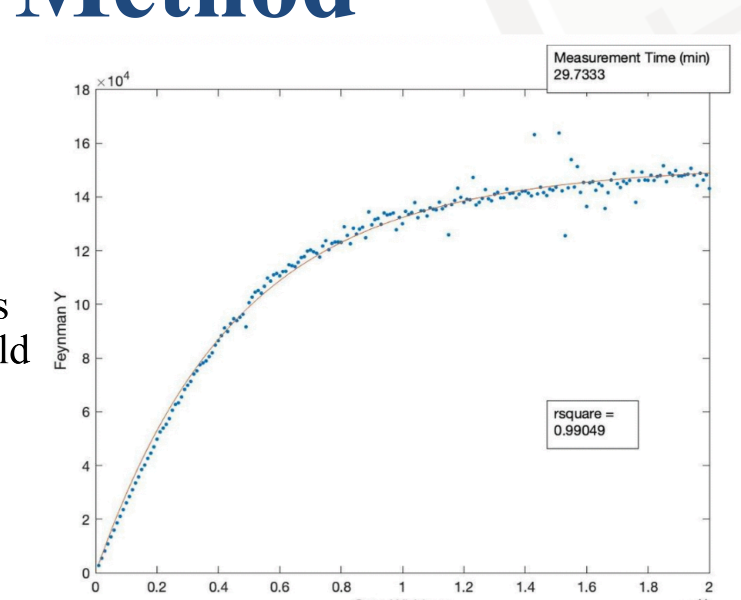


Fig. 2. Feynman-Y graph with 1-exponential fit

## Experimental Setup

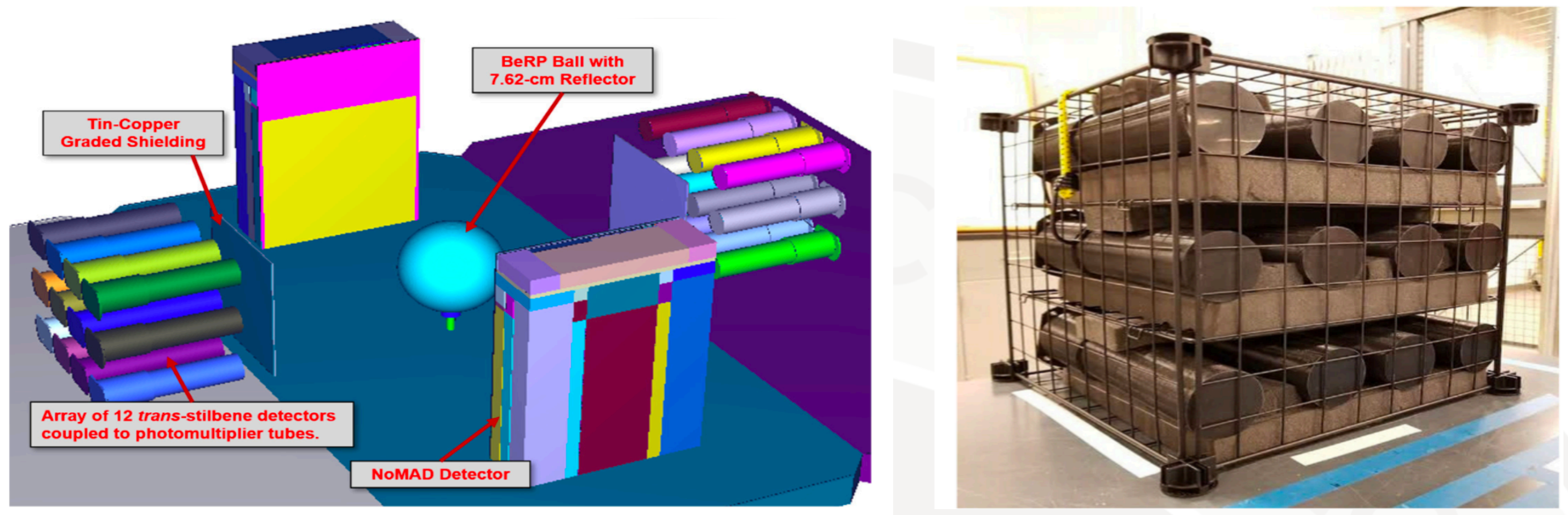


Fig. 3. (Left) Model of experimental setup and detection system measuring the BeRP ball and (Right) 3x4 array of trans-stilbene detectors

## Measurement and Analysis

- Neutron detection times are obtained using organic scintillators, which are sensitive to neutrons and photons
- Particles are classified as neutrons or photons using pulse shape discrimination (PSD), which classifies particles based on the fraction of the pulse that falls in the tail region (tail-to-total integral ratio)
- The figure of merit (FoM) calculation evaluates the effectiveness of this PSD technique by calculating the ratio of the distance between the peaks of the photon and neutron distributions to the sum of the widths of the photon and neutron distributions at half of their peak height
- We generate a count distribution of the types of particle multiplets is generated, where particles are considered to be correlated if they are detected within a 200 ns time window of each other
- Using Rossi-alpha method and Feynman-Y analyses, the prompt neutron period is calculated at regular intervals throughout the measurement, and the uncertainty of the measurement generally decreases

## Results

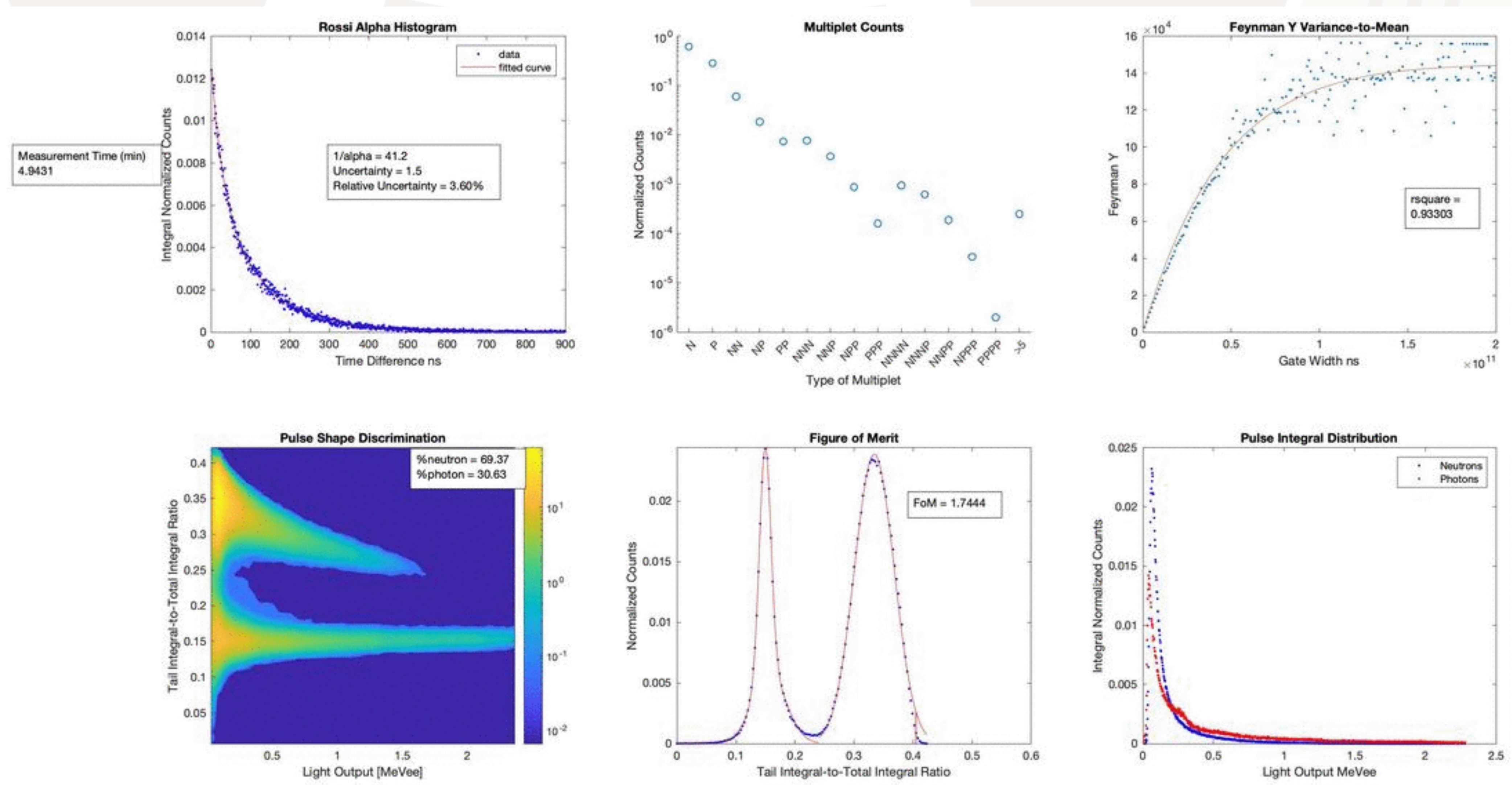


Fig. 4. Real-time analysis generates the above 6 graphs at frequent intervals during the measurement process

## Additional Results

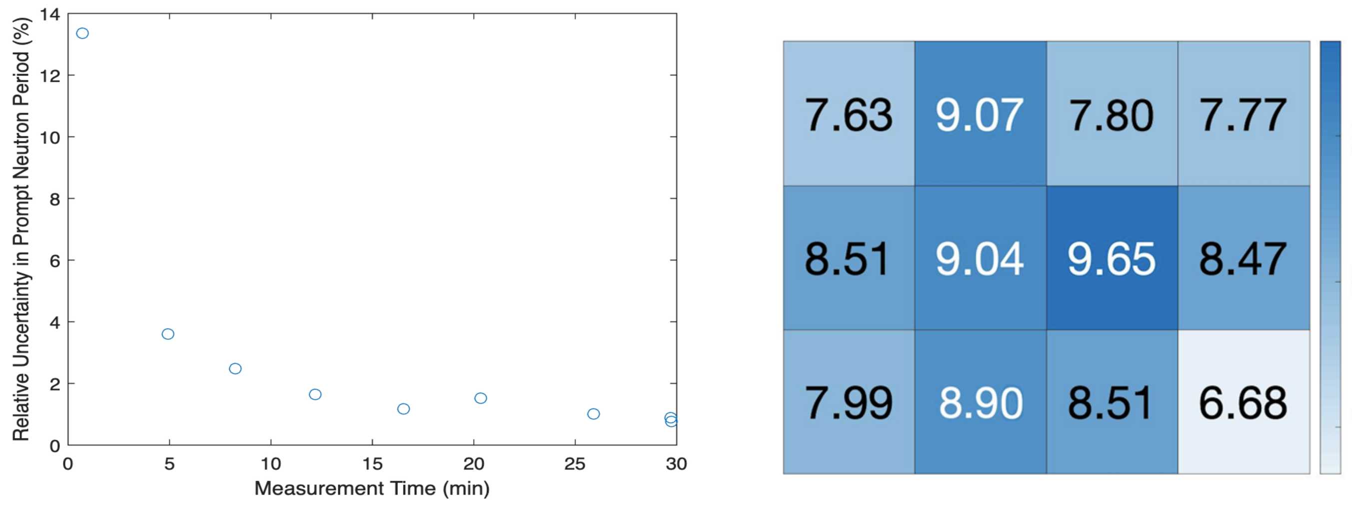


Fig. 5. (Left) Relative uncertainty in the prompt neutron period as a function of measurement time and (Right) Percentage of all neutrons detected by each detector in the 3x4 array

- Real-time analysis can assist researchers in obtaining measurements with the targeted precision while minimizing the duration of the measurement process
- For example, if researchers are targeting a relative uncertainty of less than 2% in the estimation of the prompt neutron decay constant, real-time analysis may indicate that a relative uncertainty of 2% has been achieved after just 12.17 minutes of experimentation, which is significantly shorter than the planned 20-30 minute measurement time.
- Detectors in the corners of the 3x4 array tend to detect fewer particles
- In theory, the number of neutrons recorded by detector is inverse squared proportional to the detector's distance from the source
- Based on known positioning of detectors, 3 detectors can be used to estimate the distances to the source
- Estimation is most accurate between diagonal detectors

## Conclusions

- Real-time analysis is computationally cheap and should be used during measurements so as to not waste measurement time/money
- Real-time analysis ensures that sufficient data is collected to achieve the desired measurement precision
- Real-time analysis verifies whether individual detectors have consistent responses, identifying detectors that are providing less accurate results

## Future Work

- Estimating ∝ from Feynman-Y in real-time and comparing this value to Rossi-Alpha's estimate
- Determining uncertainty of the detector distance calculation
- Using photons instead of neutrons for finding these distances to mitigate effects of neutron crosstalk

## Impact

- Expected Impact: Future measurements will be more efficient and accurate, requiring less measurement time and money
- MTV Impact: Gained experience in developing code to analyze complex trends in data
- These skills are valuable to future internships and research projects in a variety of fields from nuclear engineering to software development

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