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Monte Carlo Simulations of Multiplicity Measurements of the Plutonium BeRP Ball

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Detection for Nuclear Nonproliferation Group

Outline

- Motivation and Objective
- Background
- Multiplicity Counting
- Experimental Setup
- MCNP-PoliMi code system
- Results and Comparison
- Future Work

Motivation and Objective

- Motivation: To improve nuclear material accountability through improved characterization methods
- Objective: To benchmark the use of MCNP-PoliMi for the simulation of neutron multiplicity distributions from a plutonium sphere with various levels of moderation

Background

Neutron Multiplicity Counting

- Neutron multiplicity counting is useful in assessing materials without prior knowledge of the sample
  - Developed to assay impure plutonium bearing samples
  - Typically used to measure the entire volume of an item
- Neutrons were chosen because of their high penetrability
  - Thermal neutron detectors, such as ^{3}He detectors, are typically used
- Commonly applied in accountability measurements and weapons inspections

N. Ensslin, et al. *Application Guide to Neutron Multiplicity Counting*. LA-13422-M, 1998

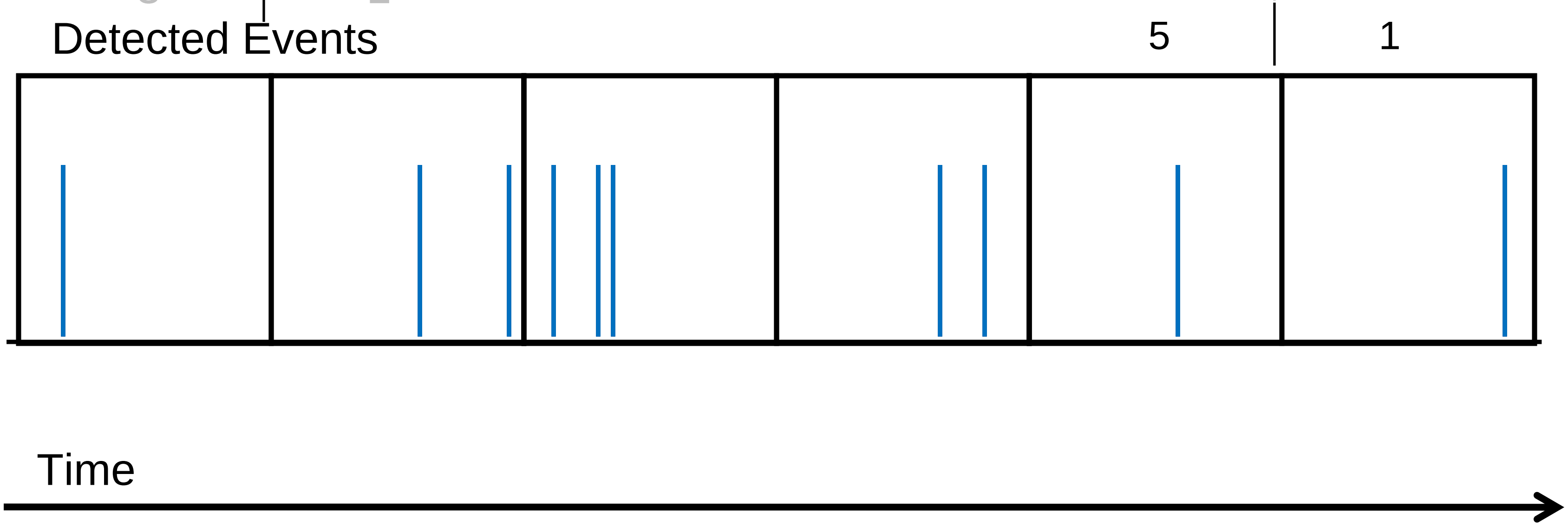
Multiplicity Counting
Neutron Distributions

Window = 16 µs

Multiplet	Count
1	3
2	2
3	1

Window = 32 µs

Multiplet	Count
1	0
2	1
3	1
4	0
5	1



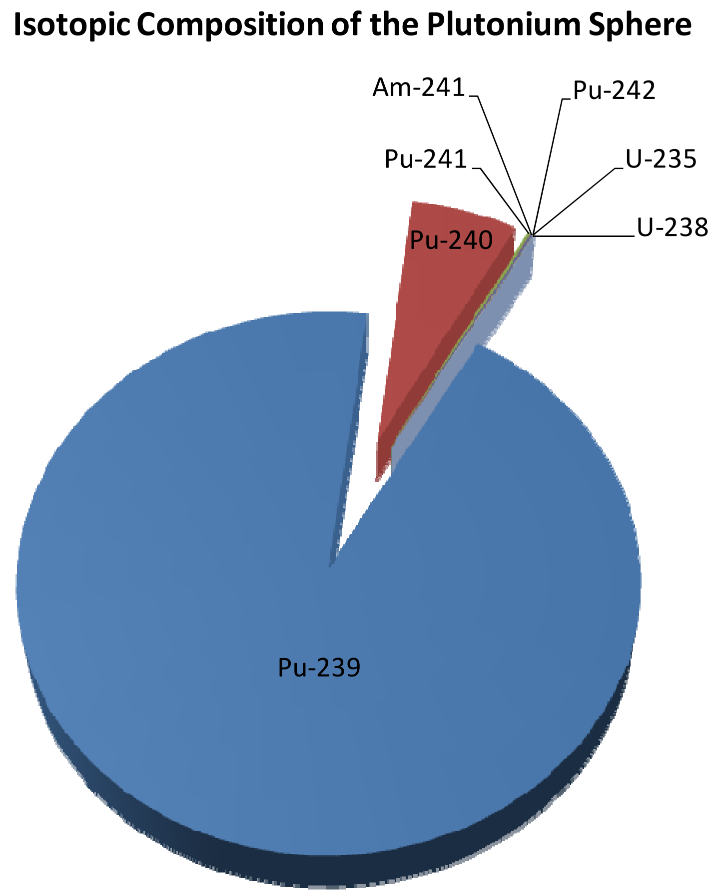
Experimental Setup

General Description

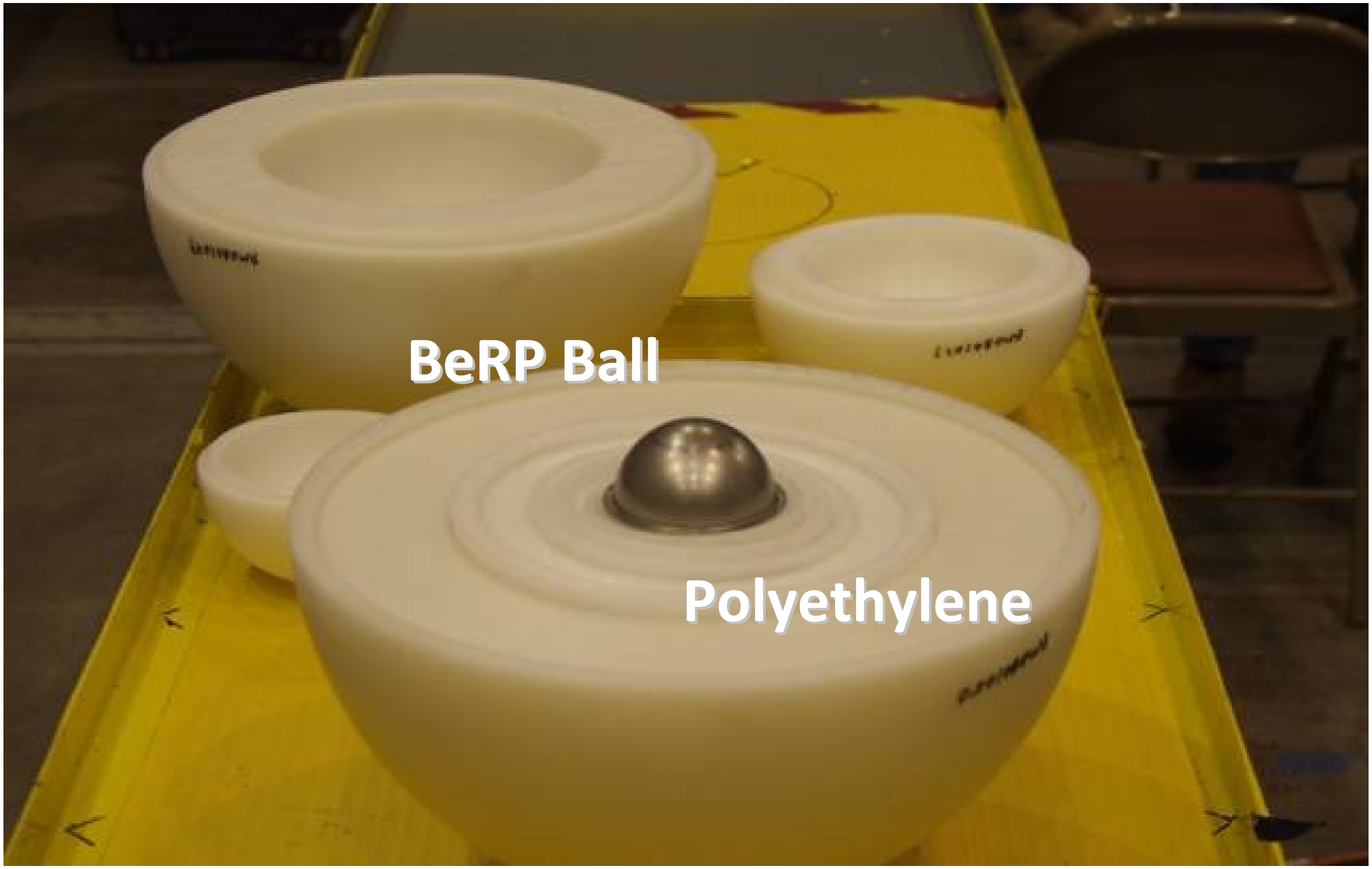
- A polyethylene bank of 15 ^{3}He detectors was located 50 cm from the source
- Polyethylene shells were added around the sphere in varying increments up to 6 inches
- Stands were used to keep the center of the plutonium sphere at the same point for all measurements
- These measurement were performed at the Nevada Test Site by Sandia National Laboratories personnel

Experiment Setup
Source Modeling

- The fissile material was a 4.483-kg sphere of weapons-grade plutonium metal
- The measurement was also repeated using a ^{252}Cf source as a calibration



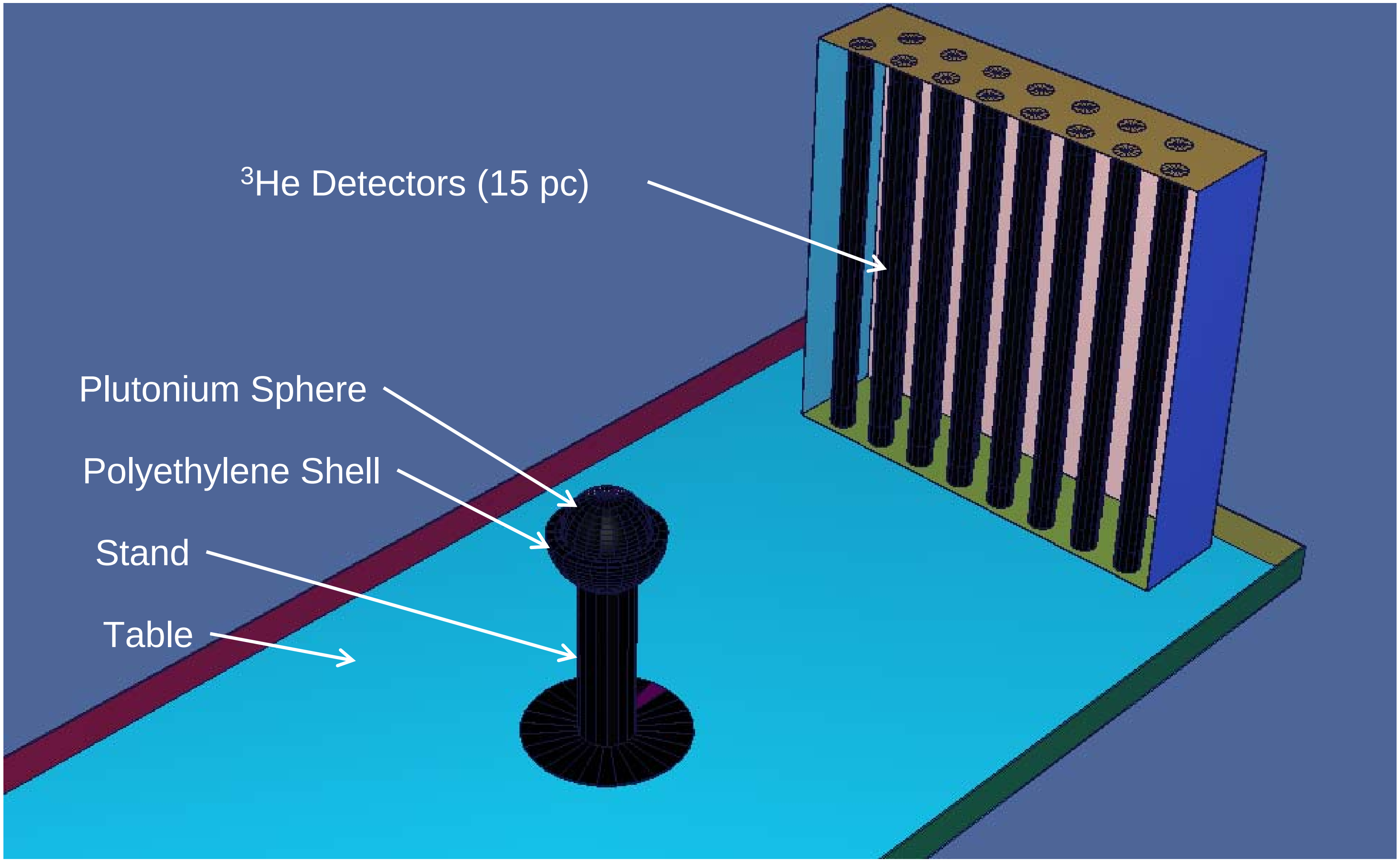
Experiment Setup
Plutonium Sphere and Polyethylene Shells



Modeling with MCNP-PoliMi

- A post-processor was developed to apply the sliding window and 4 μs of dead time to each of the 15 ^{3}He detectors
- The ^{252}Cf source was modeled as a point source
- The plutonium sphere was modeled using the built-in MCNP-PoliMi ^{240}Pu spontaneous fission source
- The standard MCNP treatment was used for induced neutron emission

Experiment Setup
MCNP-PoliMi Geometry



Feynman-Y

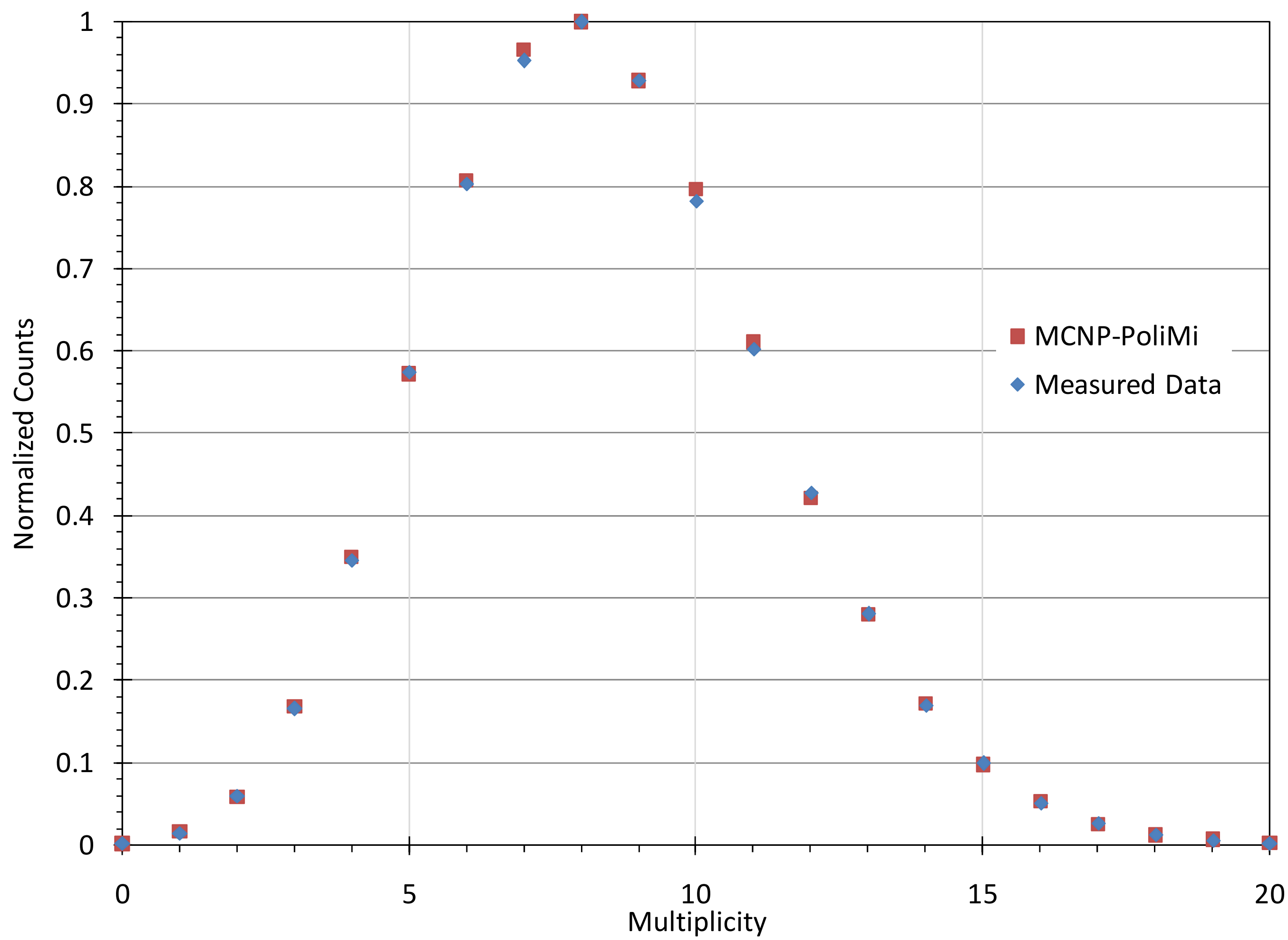
- The Feynman-Y is a commonly used metric that measures the variance of counting distribution in excess of the variance of a Poisson distribution
- The Feynman-Y is used to compare the measured data to the simulated results

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

- If the distribution matched the Poisson distribution exactly the Feynman-Y would have a value of 0

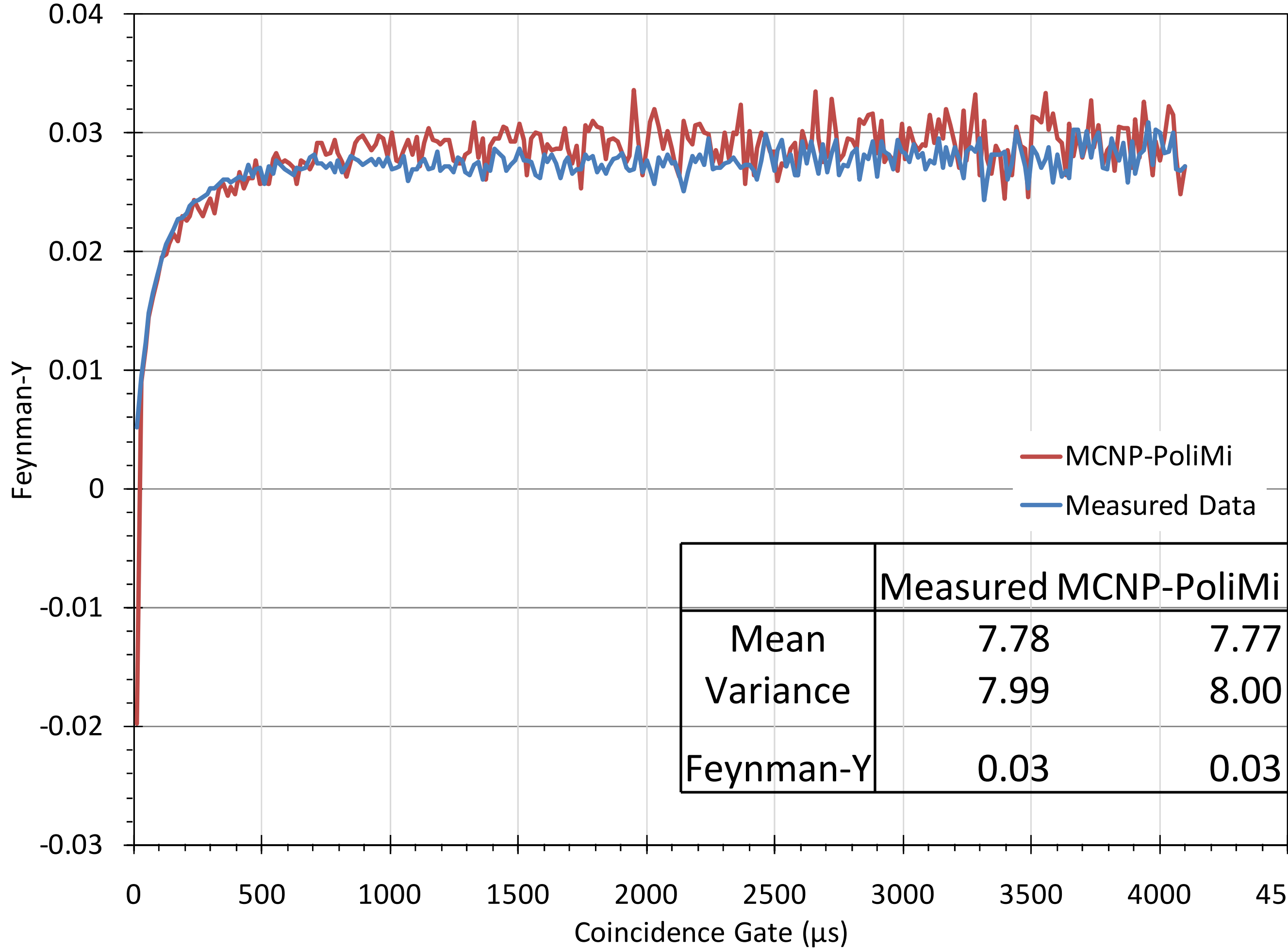
^{252}*Cf:* Neutron Multiplicity Distribution

0 inches of Polyethylene



^{252}Cf: Feynman-Y

0 inches of Polyethylene



	Measured	MCNP-PoliMi	% Difference
Mean	7.78	7.77	-0.02
Variance	7.99	8.00	0.09
Feynman-Y	0.03	0.03	4.19

k_{eff} of the Plutonium Sphere

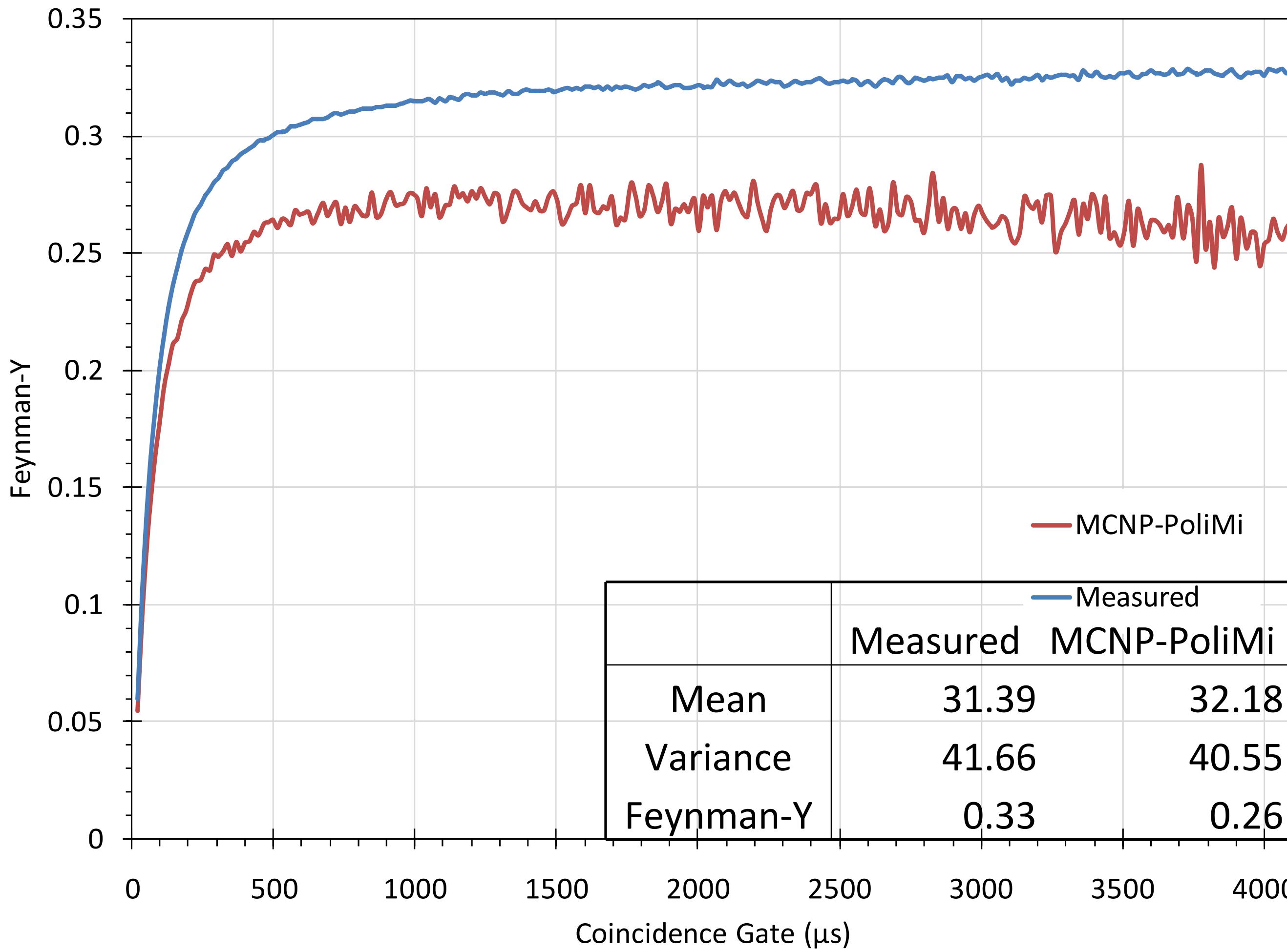
Polyethylene Thickness	Benchmark	MCNP-PoliMi	% Difference
0.0	0.7805	0.7740	-0.835
0.5	0.8253	0.8237	-0.194
1.0	0.8665	0.8668	0.037
1.5	0.8999	0.8991	-0.089
3.0	0.9364	0.9348	-0.176
6.0	---	0.9381	---

- To evaluate the accuracy of the constructed MCNP-PoliMi model the k_{eff} was calculated and compared to a benchmark for this plutonium sphere

Timothy E. Valentine, "Polyethylene-Reflected Plutonium Metal Sphere Subcritical Noise Measurement,", SUB-PU-MIXED-00.

^{240}Pu Results

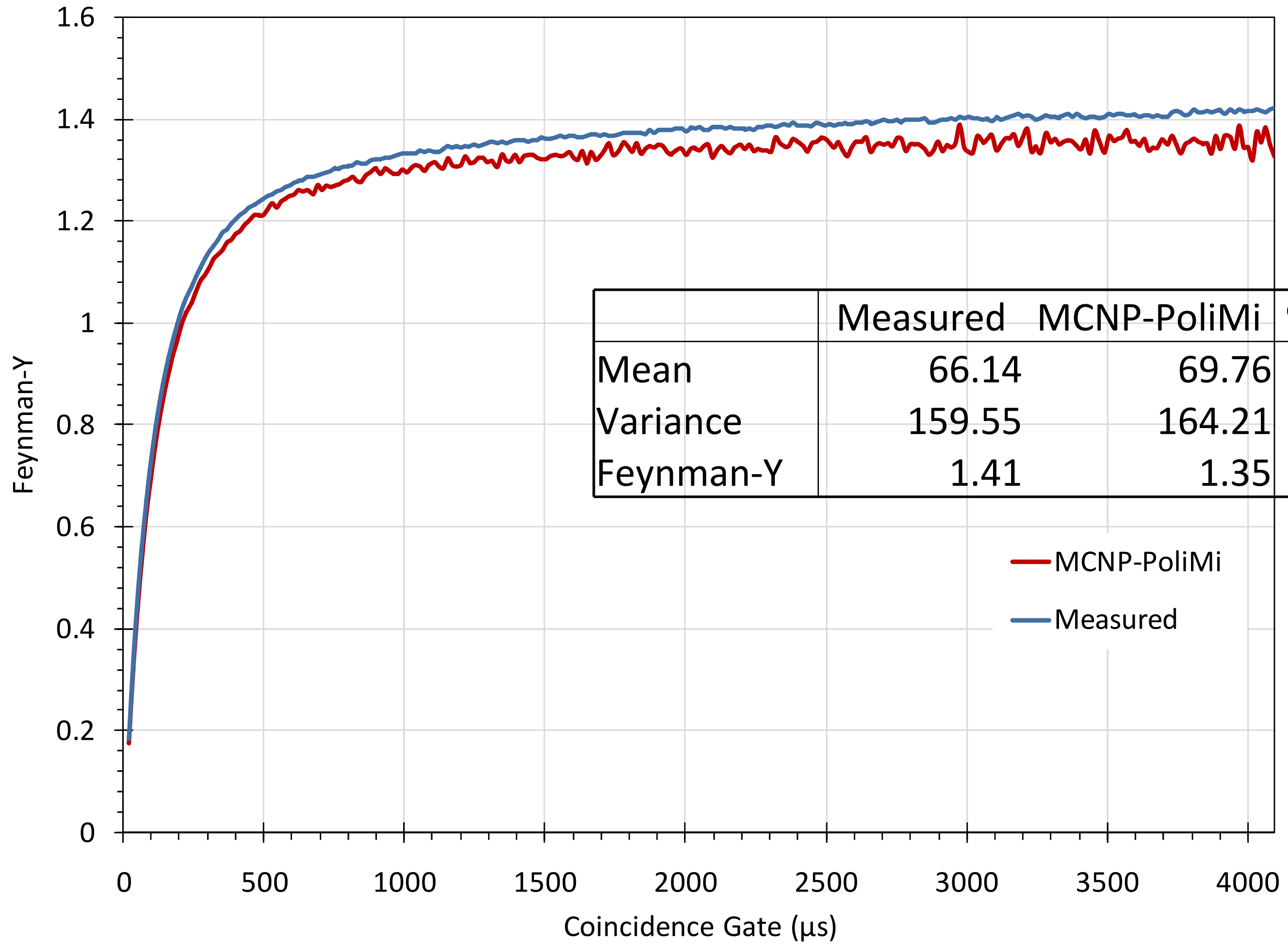
0 inches of Polyethylene



	Measured	MCNP-PoliMi	% Difference
Mean	31.39	32.18	2.52
Variance	41.66	40.55	-2.66
Feynman-Y	0.33	0.26	-21.21

^{240}Pu Results

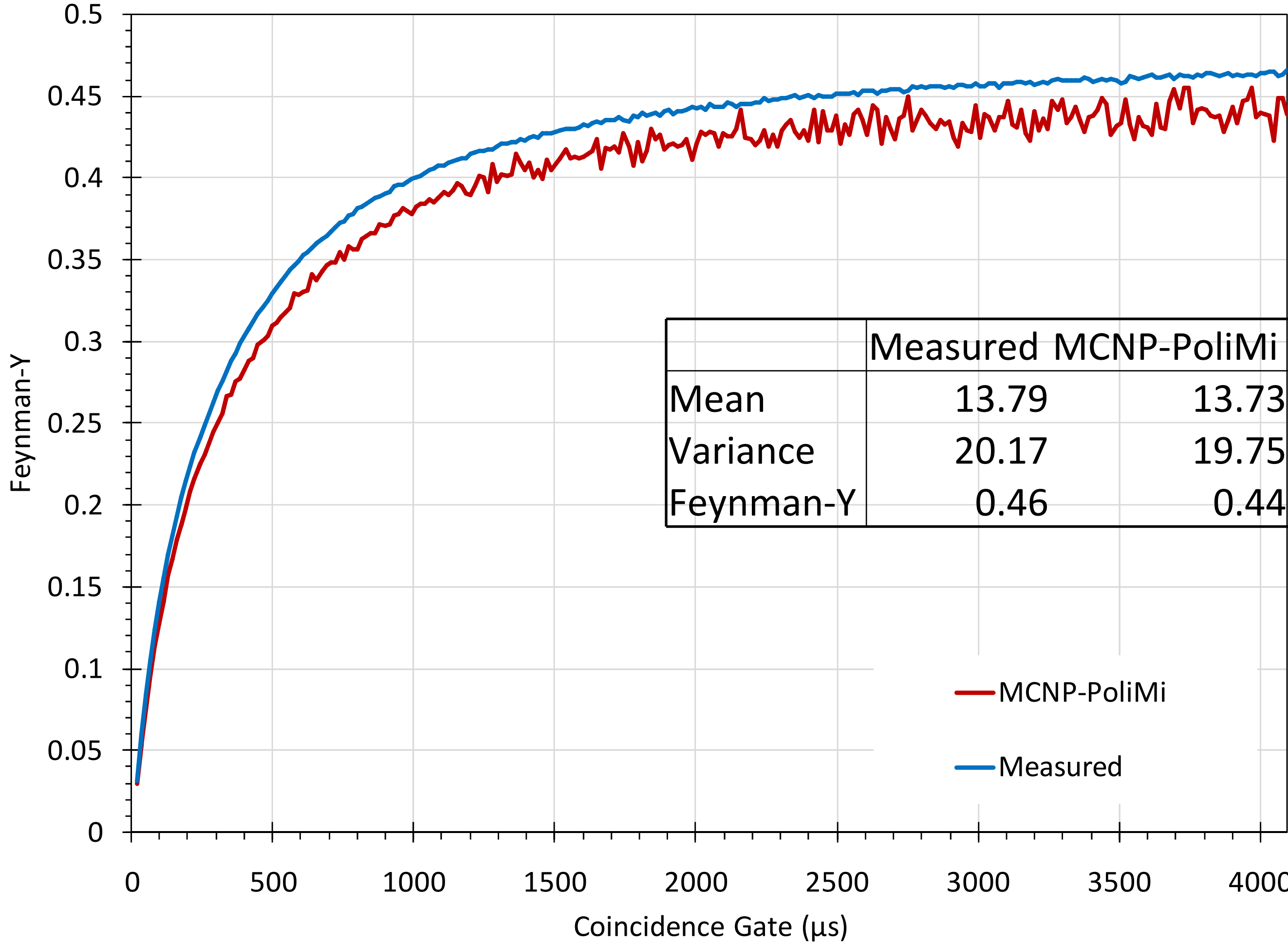
1.5 inches of Polyethylene



	Measured	MCNP-PoliMi	% Difference
Mean	66.14	69.76	5.47
Variance	159.55	164.21	2.92
Feynman-Y	1.41	1.35	-4.26

^{240}Pu Results

6.0 inches of Polyethylene



	Measured	MCNP-PoliMi	% Difference
Mean	13.79	13.73	-0.44
Variance	20.17	19.75	-2.08
Feynman-Y	0.46	0.44	-4.35

Deterministic Approach
Feynman-Y

Polyethylene Thickness (in)	Measured	MCNP-PoliMI	Kynea3	Alpha79h
0.0	0.33	0.26	0.29	0.29
0.5	0.55	0.52	0.54	0.55
1.0	0.91	0.90	0.95	1.01
1.5	1.42	1.35	1.50	1.65
3.0	1.74	1.73	1.86	2.06
6.0	0.47	0.44	0.44	0.48

- The calculation of the Feynman-Y for this experimental setup is also being performed at the University of Florida using the Kynea3 and Alpha79h cross-section libraries
- There is good agreement between all of the results of the moderated cases and the measured data

John Mattingly, Glenn Sjoden, Ce Yi. *Alpha79i Neutron Cross-Section Library Performance Testing*. Pending Publication

Summary and Conclusions

- Measurements were taken with a weapons-grade plutonium metal sphere
- A bank of 15 polyethylene moderated ^{3}He detectors were used to detect neutrons
- The Feynman-Y is extremely sensitive to small changes in the mean and variance of the distribution
- MCNP-PoliMi can accurately predict the Feynman-Y
  - Within 5% of the measured data for the moderated cases
  - Within 22% of the measured data for the bare sphere
- Future work will investigate the deviation in the bare plutonium sphere case

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^{252}Cf Results

Sensitivity of the Feynman-Y

Polyethylene Thickness (in)	% Difference		
	Mean	Variance	Feynman-Y
0.0	-0.02	0.09	4.19
0.5	0.30	0.10	-6.18
1.0	1.75	1.38	-12.80
1.5	-1.82	-2.27	-14.48
3.0	0.19	-0.19	-21.39
6.0	-0.40	-0.52	-32.90

- These results show the sensitivity of the Feynman-Y metric
- The mean and variance are predicted within 2.3% in every case yet the Feynman-Y can differ by as much as 33%