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Characterization of Special Nuclear Material using a Time-Correlated Pulse-Height Analysis

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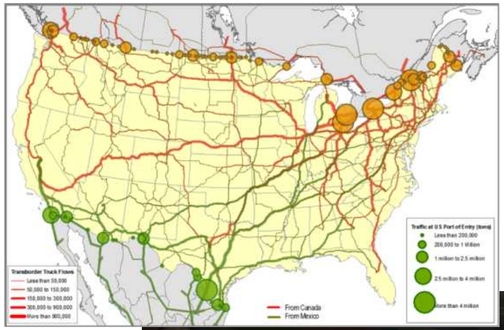
Detection for Nuclear Nonproliferation Group

Introduction

- Controlling fissile material is essential for global security and the future development of nuclear power
- This is complicated by several factors:
  - The identifying signal is difficult to distinguish from background
  - Signal is easy to shield
  - Only small quantities are needed for weapons
  - Many points of entry
- Advanced detection systems are needed to identify and characterize these materials



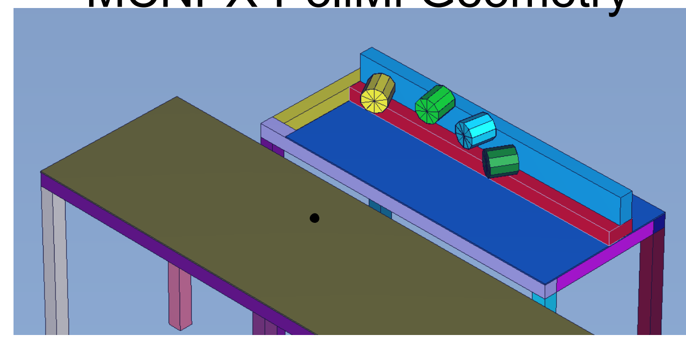
Background
Correlated-Particle Detection

- Fission chain-reactions produce neutrons and gamma rays that are *temporally* correlated
- The time-distribution of neutrons and gamma detection events permits characterization of the source
  - In particular, detection of time-correlated neutrons is a positive indication of induced fission chain-reactions, i.e., fissile material
  - The time-distribution of correlated neutrons is characteristic of neutron multiplication and lifetime
- Several detector options are available for this type of measurement
  - ^{3}He detectors: primarily thermal neutrons
  - Liquid scintillators: gamma rays and fast neutrons

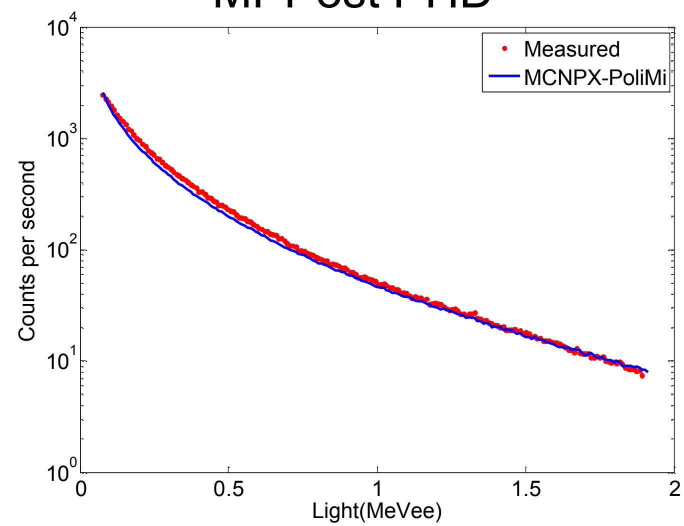
Simulation of Detector Response

- MCNPX-PoliMi
  - Developed to simulate neutron and gamma-ray correlation measurements
  - Provides a detailed list of particle collisions in a detector volume
- MPPost
  - Uses the list of particle collisions to create a detector response
  - Accounts for organic scintillation mechanics
    - Non-linearity
    - Different light production off of H and C
- Released through Radiation Safety Information Computational Center RSICC in April 2012

MCNPX-PoliMi Geometry

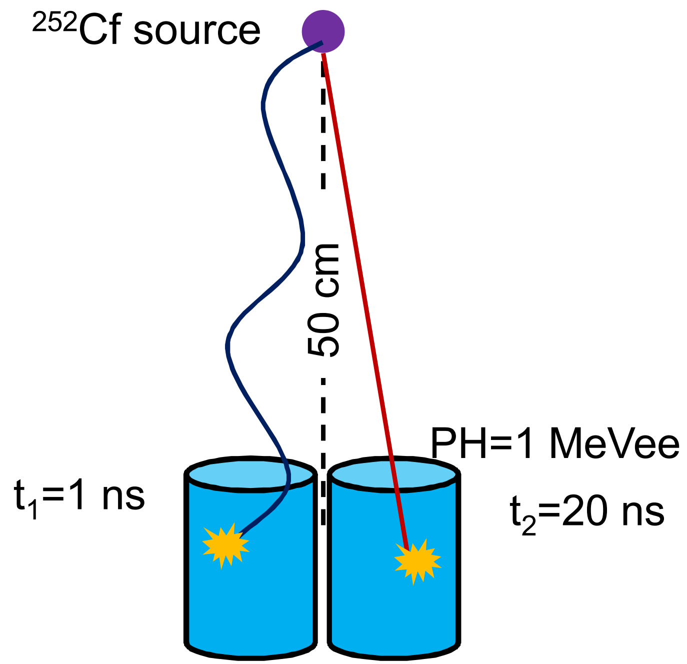


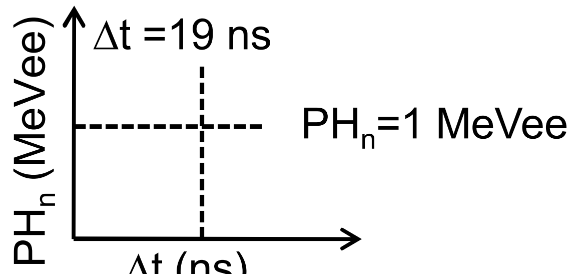
MPPost PHD



Time-Correlated Pulse-Height *Concept*

- Use correlated P-N events
  - Trigger on the gamma ray
  - Pulse height information of the neutron
- Pulse-height information can be extracted for each correlated pair
  - Time-correlated pulse-height (TCPH)
- Create a surface plot of Δt and pulse height
- This surface plot will be sued to make an estimation of the source multiplication





Time-Correlated Pulse-Height

Physics

- For a given time the max pulse height for the neutron can be determined:

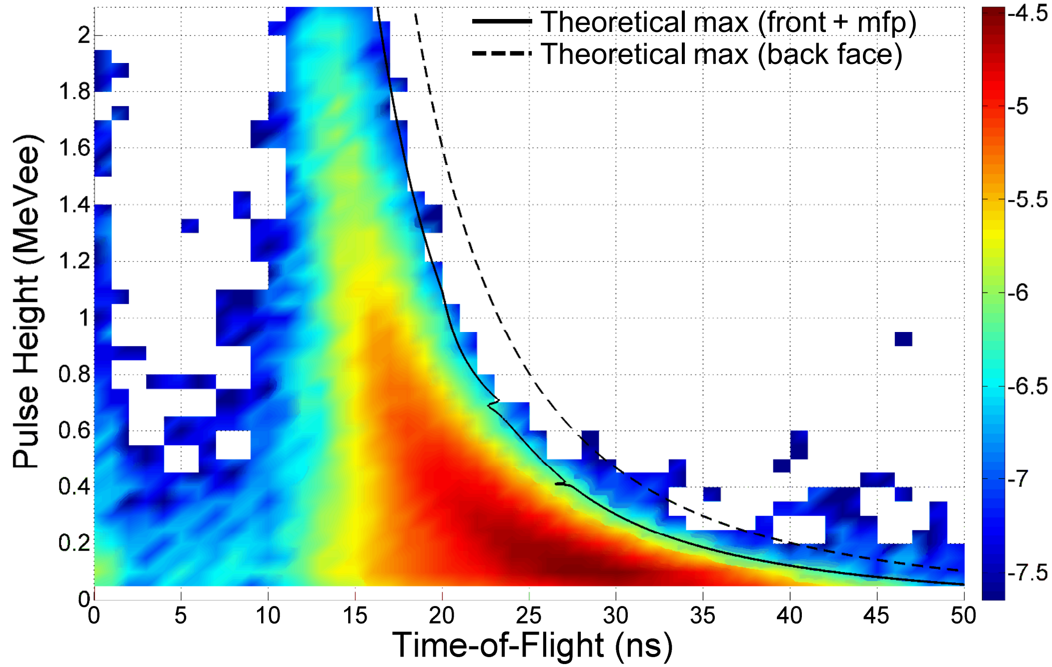
$$E_n = \frac{1}{2} m_n \left(\frac{d}{t}\right)^2$$

$$PH = aE_n - b\left(e^{cE_n{}^1}\right)$$

E_n = neutron energy
E_d = neutron energy deposited
d = source-detector distance
m_n = neutron mass
t = neutron arrival time
PH = light output

d1 =Source to detector +mfp ~ 52.5 cm

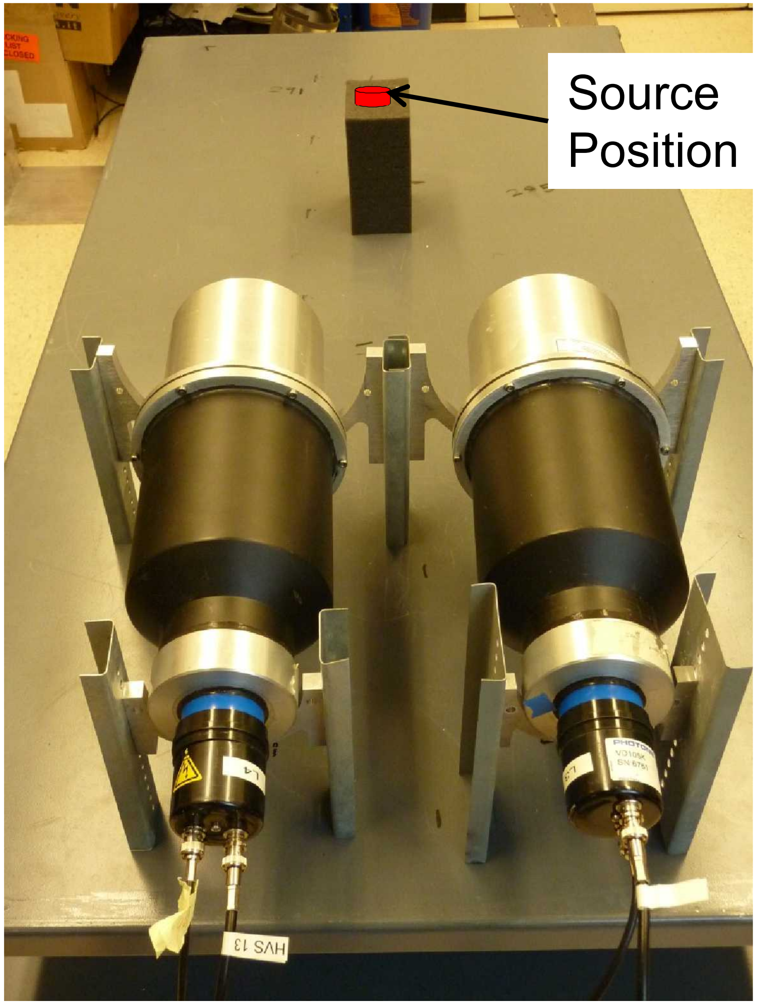
d2 =Source to back face = 62.5 cm



Simulated TCPH for ^{252}Cf

Validation Measurement
Setup

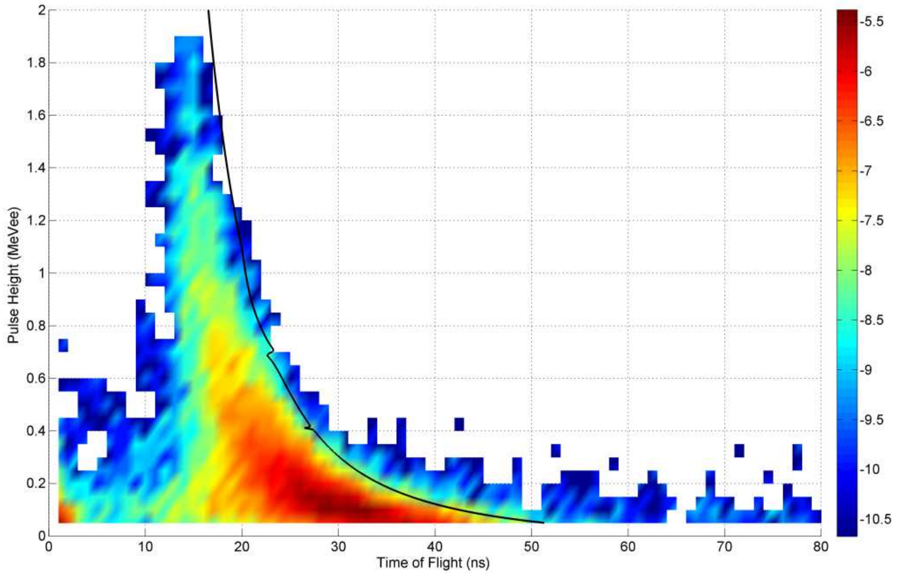
- Two gain-matched 12.5×12.5-cm EJ-309 detectors placed side-by-side
  - Source: 41683 n/s ^{252}Cf
  - Threshold: 0.070 MeVee
  - Source-detector distance: 50 cm
  - Data was collected with a 250-MHz, 12-bit waveform digitizer
  - PSD was performed using an offline charge-integration technique
- The experiment was performed in three configurations: bare, lead-shielded, and polyethylene-shielded
  - Shielding blocks were place in front of the source



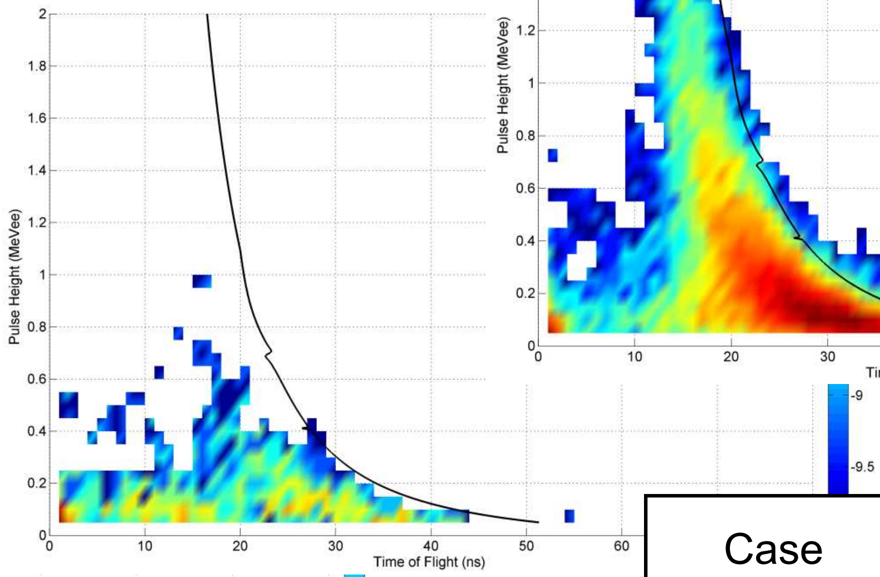
Validation Measurement

TCPH Results

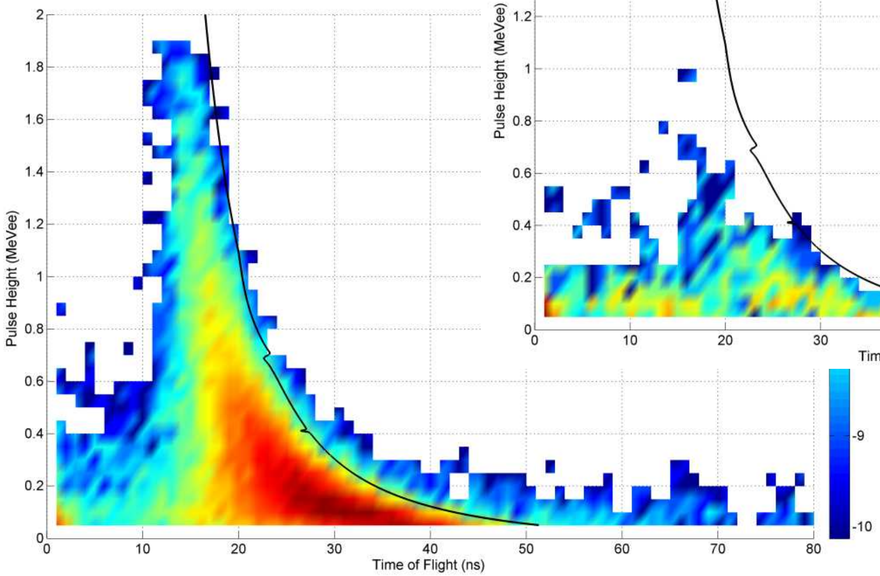
Polyethylene



Lead



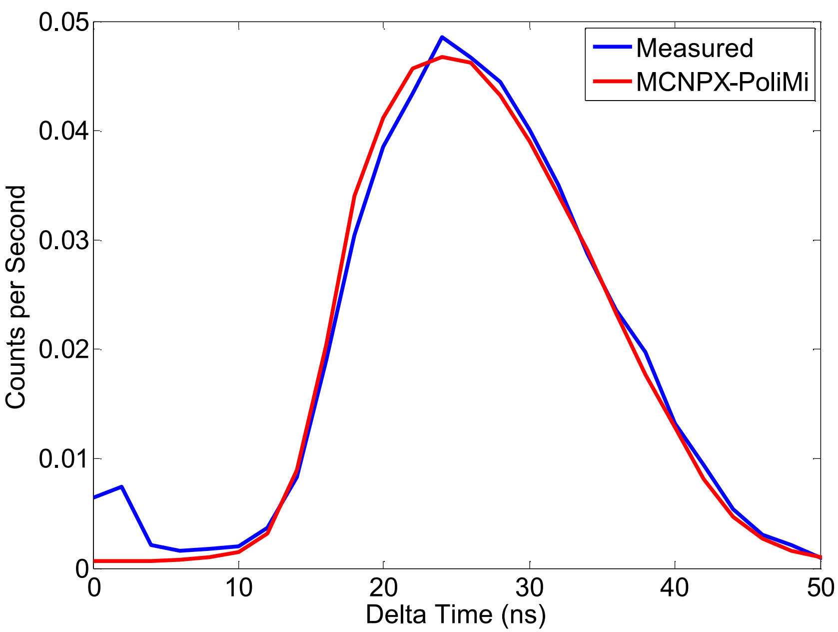
Bare



Case	Shield (cm)	Measurement Time (hr)
Bare	---	6.98
Lead	5.08	6.00
Polyethylene	5.08	12.00

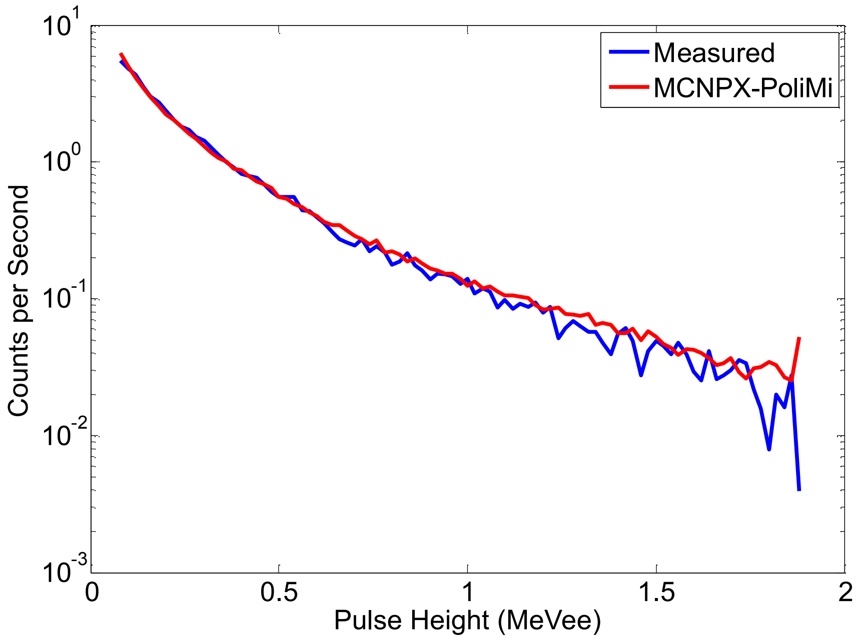
Validation Measurement

Comparison to Simulation – Bare ^{252}Cf



Integral time-of-flight distribution

Percent difference= -3.51%



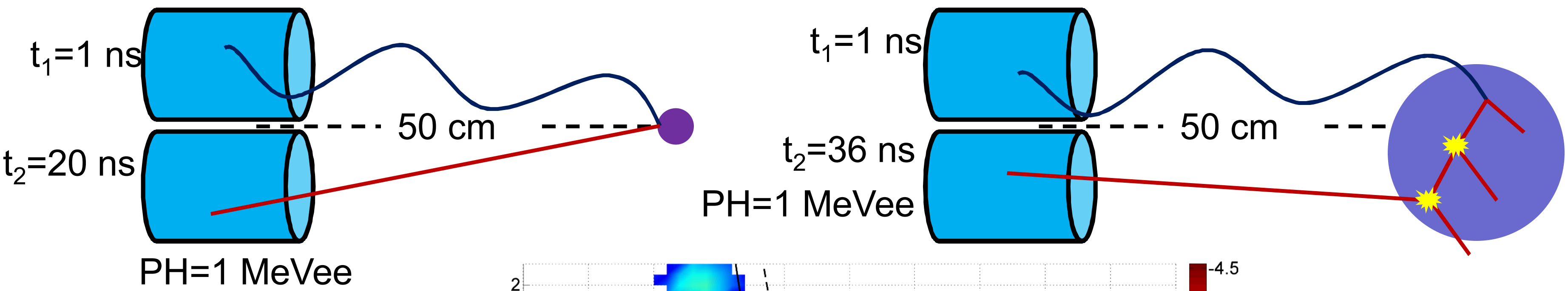
Integral pulse-height distribution

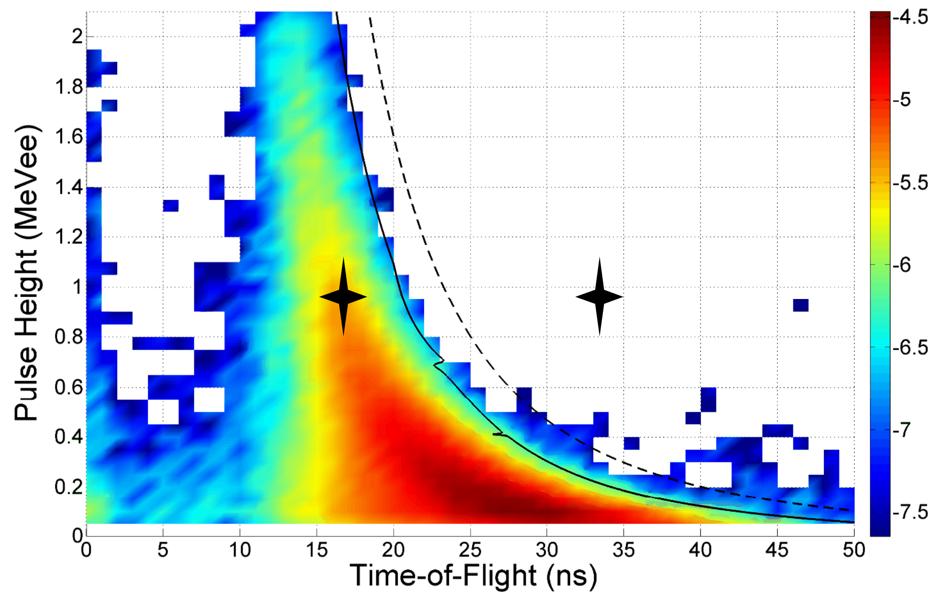
Percent difference= 11.44%

Identification of a Multiplying Source

Overview

Non-multiplying **Multiplying**





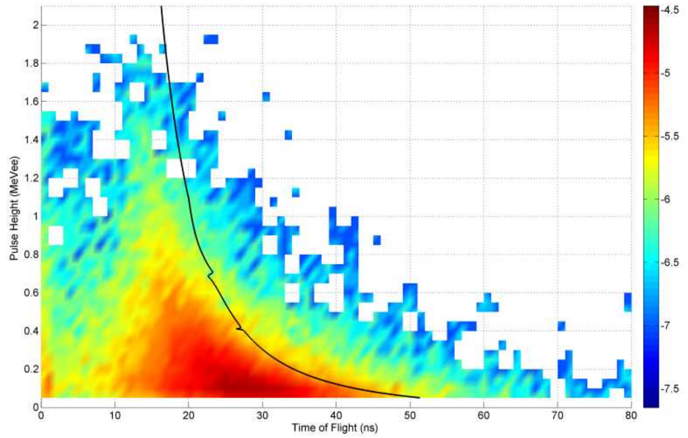
Identification of a Multiplying Source

Simulated Effect of Multiplication on TCPH

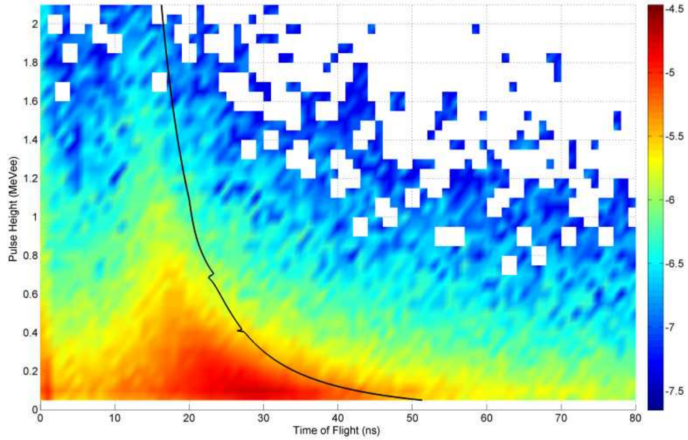
- Subcritical multiplication defined as:

$$M = \frac{1}{1 - k_{eff}}$$

- Polyethylene was added to change the multiplication of a 4.5-kg WGPu sphere
  - Bare Sphere: M=4.48
  - 3.81-cm polyethylene: M=10.52
- Events above the line are considered to be from multiplication



Bare WGPu sphere

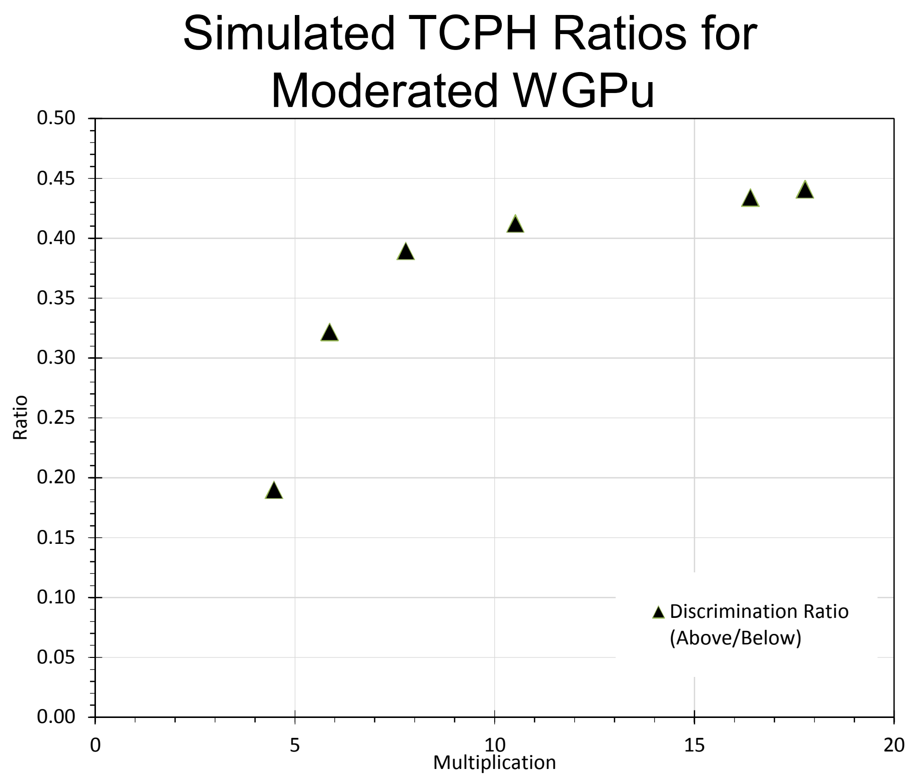


3.81-cm polyethylene

Identification of a Multiplying Source

Changing Multiplication with Polyethylene

Polyethylene Thickness (cm)	k_{eff}	Multiplication	Ratio
Bare	0.777	4.480	0.190
1.27	0.830	5.870	0.322
2.54	0.872	7.780	0.389
3.81	0.905	10.520	0.412
7.62	0.939	16.400	0.434
15.24	0.944	17.770	0.441



- The ratio of events above and below the line were used to characterize each case
- The polyethylene shells act as shielding complicating the measurement of multiplicity

Summary

- The presence of late-arriving high-energy neutrons is an indication of multiplication in a source
  - Measured ^{252}Cf data has shown that TCPH analysis is feasible
  - The simulated shape of the TCPH distribution agrees well with the measured results
  - Simulated discrimination ratio has trends well with increasing multiplication
- Future Work
  - Optimize and improve the multiplication determination technique
  - Perform a TCPH measurement with a multiplying source

Acknowledgements

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