SAND2011-2315C

# Digital Fast Neutron Detection System for Simultaneous Time-Correlation and Spectrometry

**SNL11-R&D-015**

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**Sandia National Laboratories**

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# Project Summary

## Objective

- Develop a simple method to detect fissile materials based on the distribution of fast neutrons over time and energy

## Operating Principle

- Neutrons from induced fission chain reactions tend to emerge later than neutrons from spontaneous fission sources and other non-fissile sources

## Proposed Implementation

- Use a liquid organic scintillator to accumulate the distribution of fast neutrons over time and energy
- Develop metrics to discriminate between non-fissile and fissile sources based on the energy vs. time distribution

## Primary Deliverables

- Year 1: Conduct a computational study using MCNPX-PoliMi to evaluate the effectiveness of the proposed approach
- Years 2 & 3: Design and experimentally evaluate a fast neutron detection system to implement our proposed approach; contingent on success of Year 1 study

# Organizations and Personnel

**Sandia National Laboratories**

- John Mattingly, PI
- Peter Marleau, co-PI

**University of Michigan Nuclear Engineering**

- Sara Pozzi, PI
- Shaun Clarke
- Eric Miller

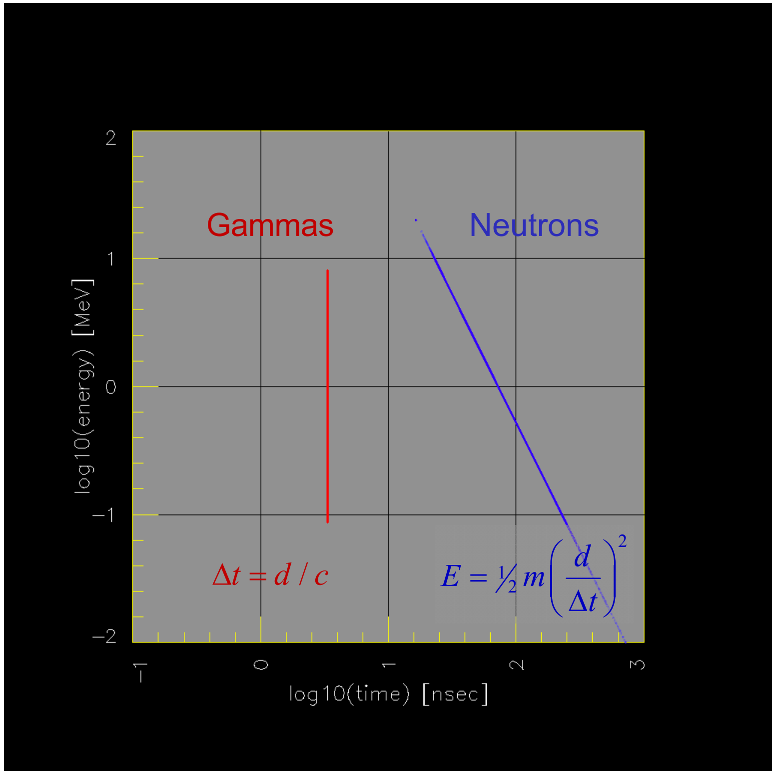
# Technical Approach

- Neutrons and gammas from different generations in an induced fission chain reaction are cross-correlated over time – they are temporally distributed according to the neutron lifetime
- Neutrons and gammas from later generations in a chain reaction exhibit arrival times that are later than their direct time of flight
- In particular, neutrons from induced fission arrive later than the direct time of flight corresponding to their energy
- Liquid organic scintillators are capable of measuring neutron and gamma arrival time (on the nanosecond scale) and, less precisely, their energy
- Consequently, it should be possible to detect chain reactions by detecting late-arriving neutrons (and gammas) using a liquid organic scintillator

# Energy vs. Time-of-Arrival Distribution

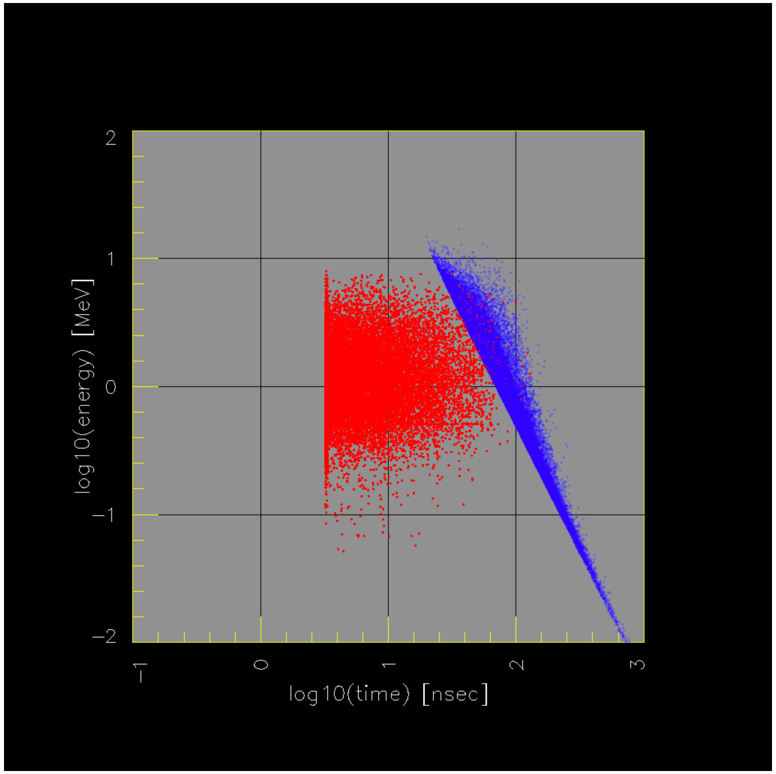
## Cf-252

**Non-Fissile**




## 4.5 kg Plutonium (BeRP Ball)

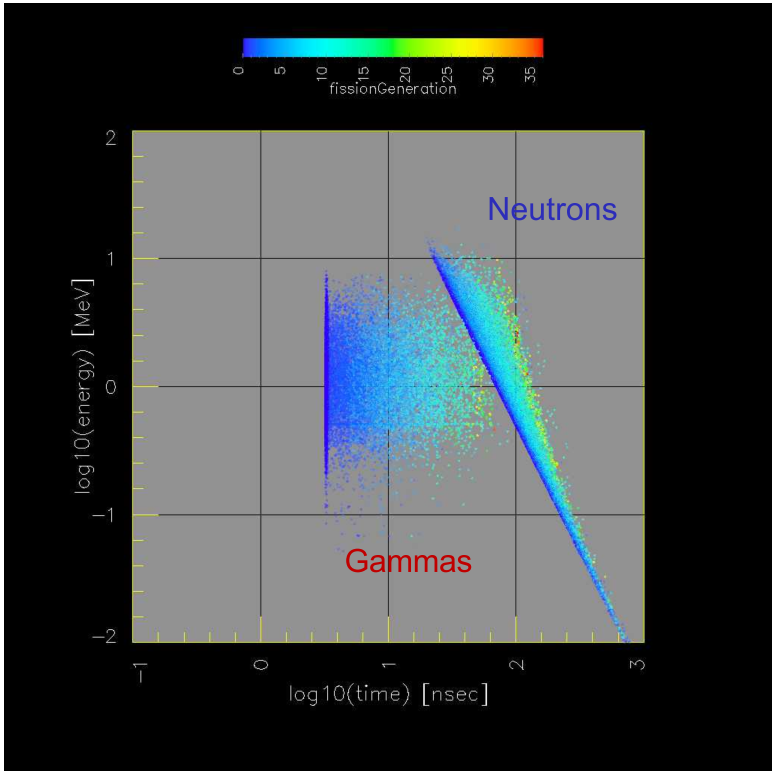
**Neutron Multiplication = 4.4**



# Induced Fission Chain Reaction Dynamics

- Neutrons and gammas from later generations in induced fission chain reactions tend to arrive long after those from earlier generations
- When they emerge from the "tail end" of a chain reaction, neutrons and gammas arrive much later than their corresponding direct time-of-flight
- In particular, neutrons from induced fission exhibit a "bulge" at later time-of-arrival and energy

**4.5 kg Plutonium (BeRP Ball)**

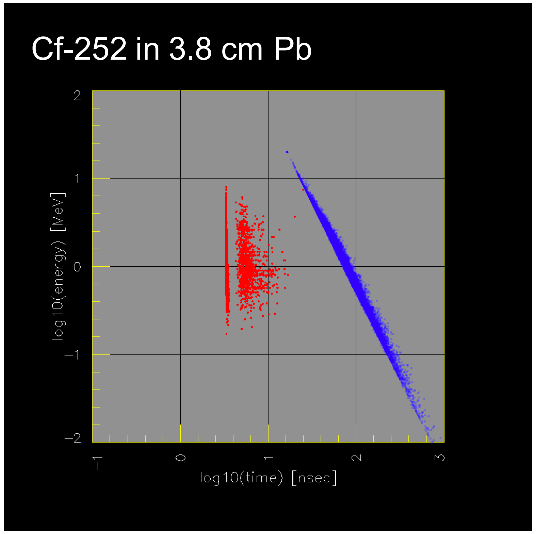


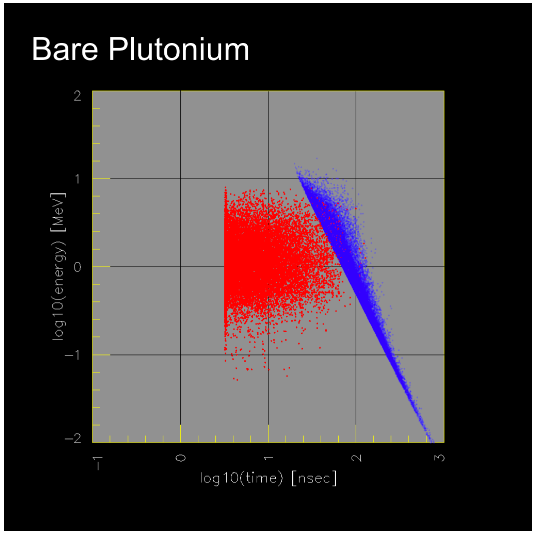
# Scattering Effects

- Scattering also delays the time-of-arrival by lengthening the flight path from the direct “line-of-sight” path

- In low-Z scattering materials, the neutron energy is substantially reduced by each collision
- Consequently, the energy vs. time distribution is “shifted” towards lower energy

- In high-Z materials, very little energy is lost in each neutron collision
- However, the delay in time-of-arrival induced by scattering in high-Z materials is not as substantial as the delay resulting from induced fission



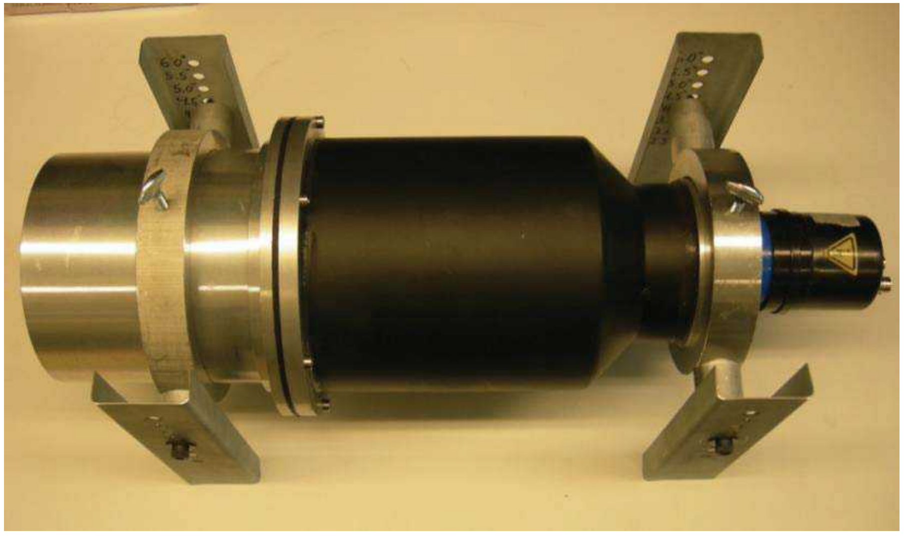
# Implementation

- Use a fast organic scintillator to accumulate the energy vs. time distribution of neutrons and gammas
- Specifically, use a *liquid organic scintillator*, because it enables neutron/gamma discrimination based on pulse shape

- Liquid organic scintillators can measure time of arrival on a nanosecond scale
- Their energy resolution is relatively poor, because they measure partial energy deposition via scatter

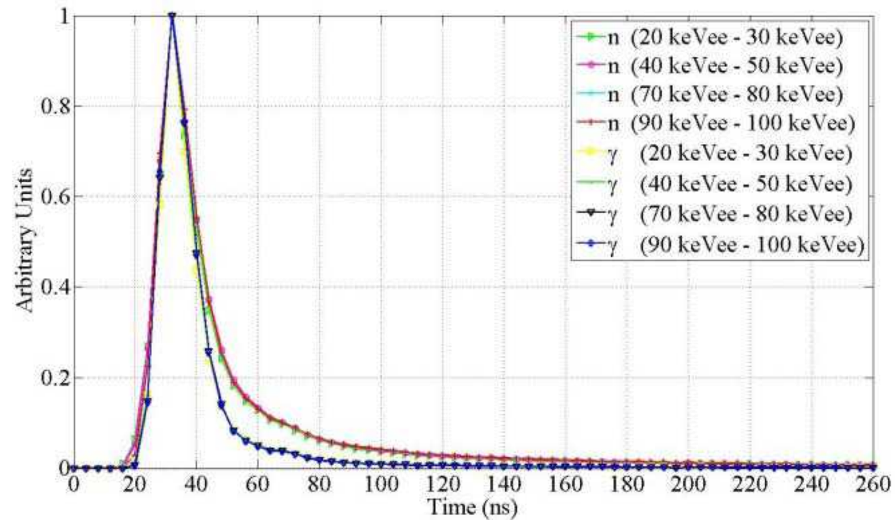
- Develop metrics that detect late-arriving neutrons and gammas

EJ-309 Liquid Organic Scintillator



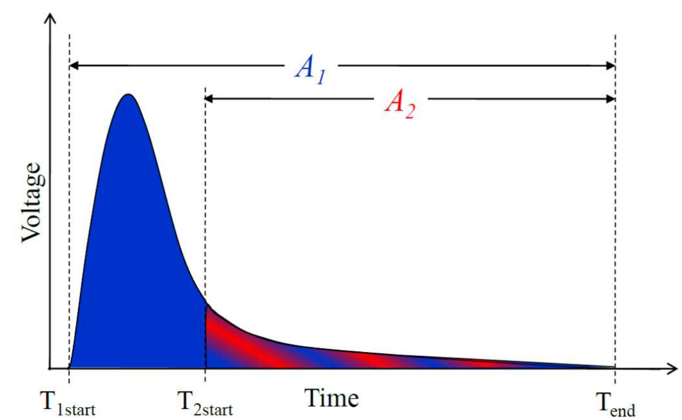
# Pulse Shape Discrimination (PSD)

- Light pulses in organic scintillators exhibit two decay constants
  - Short decay constant due to *prompt fluorescence*: independent of incident radiation type
  - Long decay constant due to *delayed fluorescence*: characteristic of incident radiation type




- The fraction of the area under the tail of a pulse can be used to discriminate between gammas and neutrons

- High-speed ADCs can be used to implement PSD



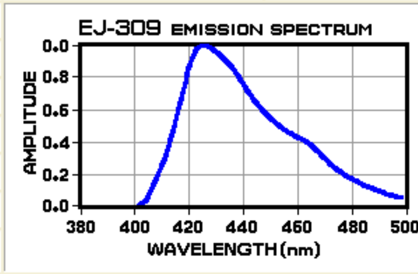

$$R \equiv \frac{\text{Tail Integral}}{\text{Total Integral}} = \frac{A_2}{A_1}$$

# EJ-309 Liquid Organic Scintillator

- EJ-309 (from Eljen Technology) is a relatively new liquid organic scintillation material
- EJ-309 has PSD characteristics nearly as good as the de facto standard, NE-213 (a.k.a. EJ-301 or BC-501A)
- Compared to NE-213, EJ-309 has low toxicity and a very high flash point (> 140 C)

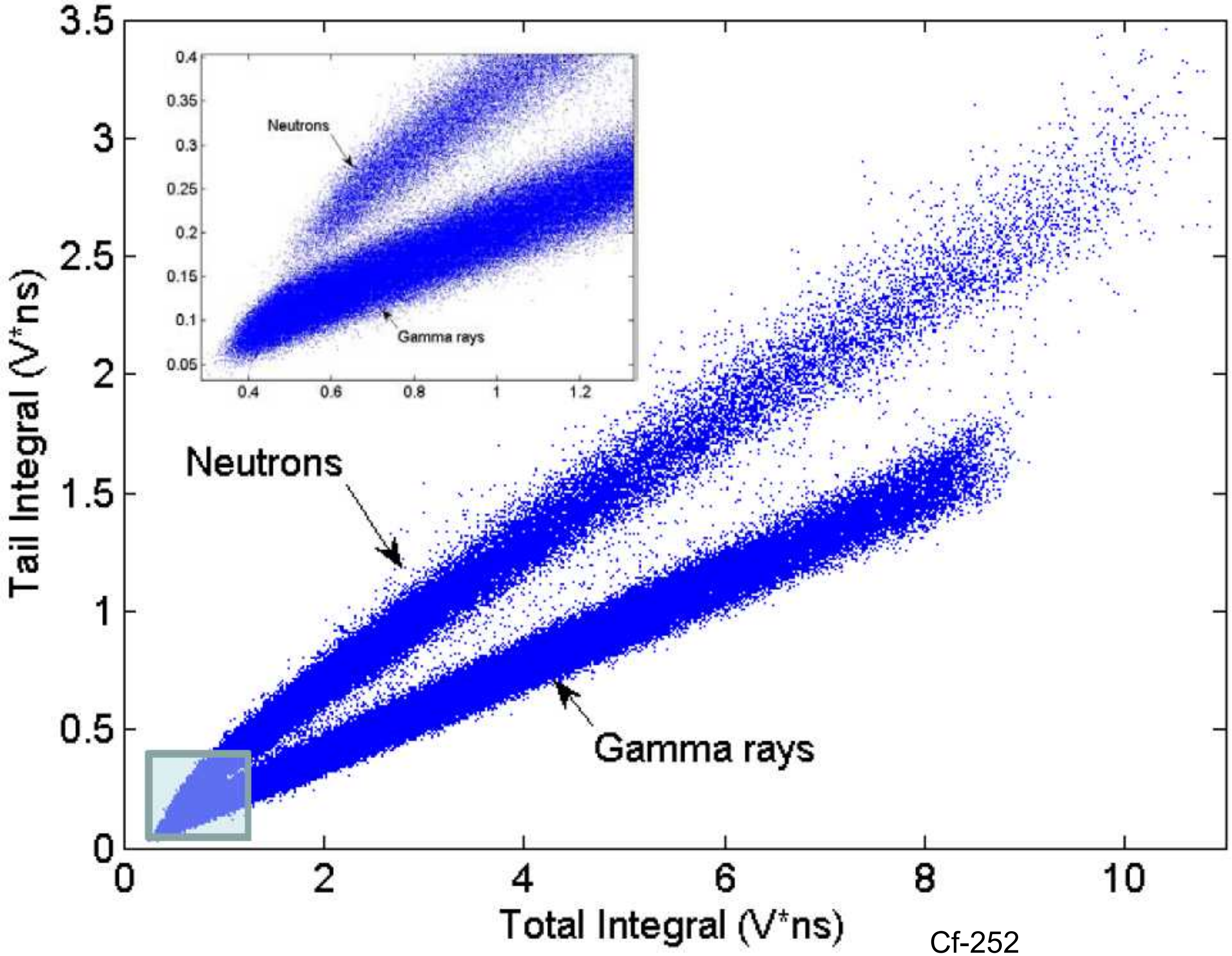
| PROPERTIES | |
|---|---|
| Light output (% of anthracene) | 75% |
| photons produced by 1MeV $e^-$ | 11,500 |
| wavelength of max. emission | 424 nm |
| Decay time (short component) | 3. 5 ns |
| Bulk light attenuation length | > 1 meter |
| specific gravity | 1. 964 |
| Refractive Index | 1. 57 |
| Flash Point | 144°C (291°F) |
| Boiling Range | 290°C ~ 300°C |
| Vapor Pressure @20°C | > 0. 002 mmHg |

| ATOMIC COMPOSITION | |
|---|---|
| No. of H atoms / $cm^3$ | 5. 46 x $10^{22}$ |
| No. of C atoms / $cm^3$ | 4. 37 x $10^{22}$ |
| H: C Ratio | 1. 25 |




http://www.eljentechnology.com

# Digital PSD with EJ-309

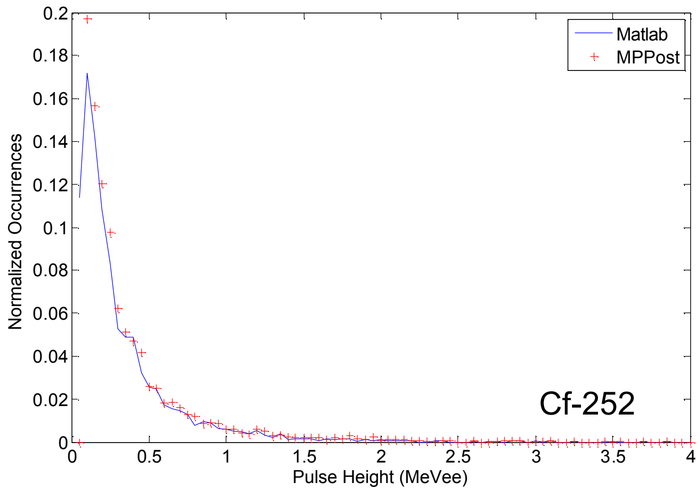


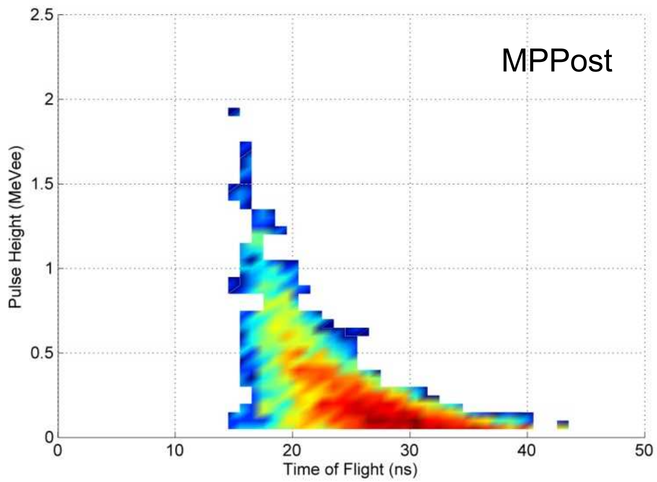

Cf-252
70 keVee threshold
Equivalent to 450 keV neutron threshold

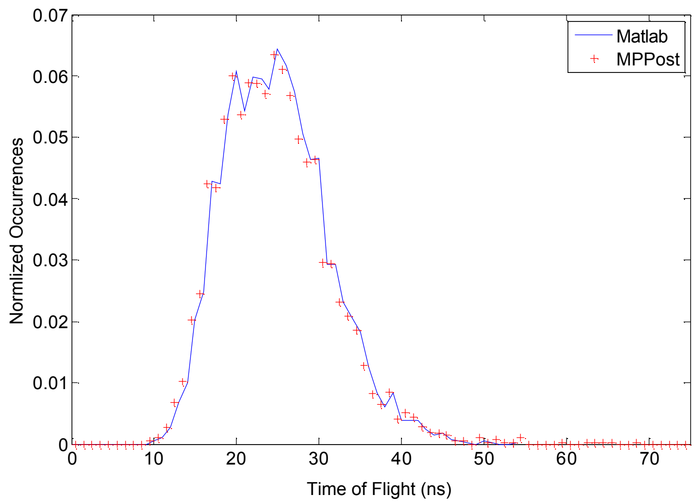
# Progress

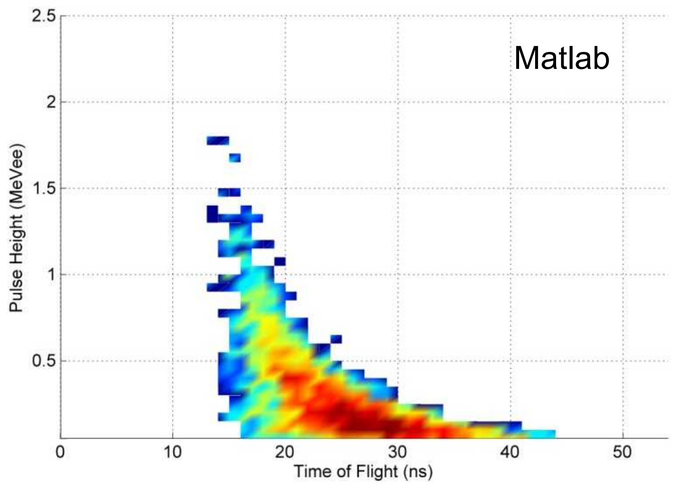
- Developed a plan for a computational study to evaluate the effectiveness of our proposed implementation – the plan is designed to compare/contrast the energy vs. time distribution for non-fissile sources and fissile sources
- Developed the tools necessary to execute the computational study – these tools are mainly post-processors that accumulate different metrics of the energy vs. time distribution from MCNPX-PoliMi simulations
- Cross-validated two post-processor implementations against each other
- Starting to validate post-processors against experiments previously conducted at SNL/CA
- Developed a simple trigger method to measure neutron and gamma time-of-arrival from the detector pulse train
- Starting to compare/contrast the energy vs. time distribution for non-fissile and fissile sources

# MCNPX-PoliMi Post-Processor Cross-Validation



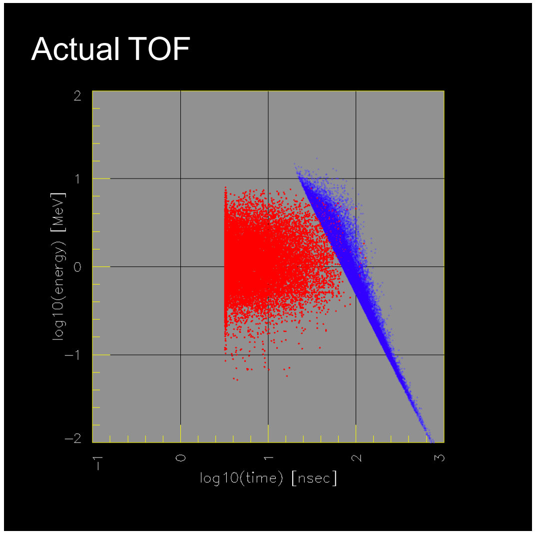



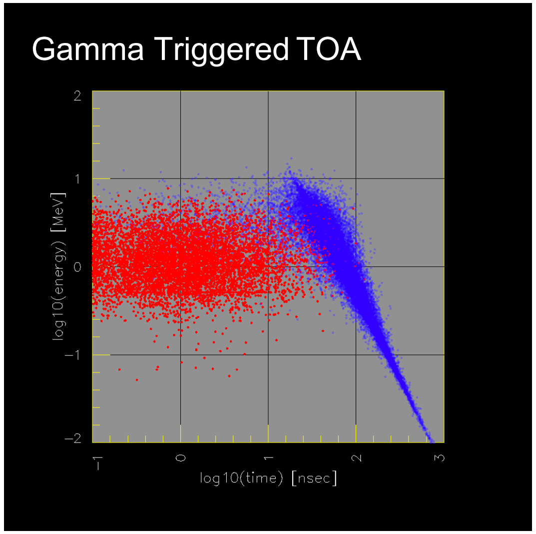
# Simple Trigger Method to Measure Time-of-Arrival

- Actual time-of-flight (TOF) isn't directly observable
- We can't actually measure when any particular chain reaction was initiated

- Neutrons and gammas from chain reactions tend to arrive in "bursts"
- In a particular burst, the gammas tend to arrive before the neutrons

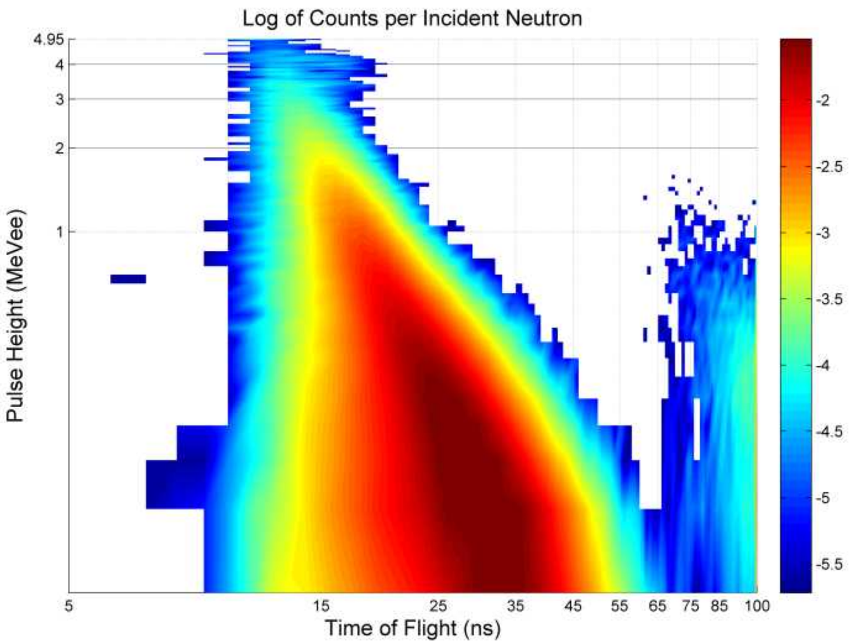
- We can trigger a time-of-arrival (TOA) "clock" for each particle using the time of the preceding gamma
- This trigger method preserves the overall structure of the energy vs. time distribution, though it does "smear" the distribution over time



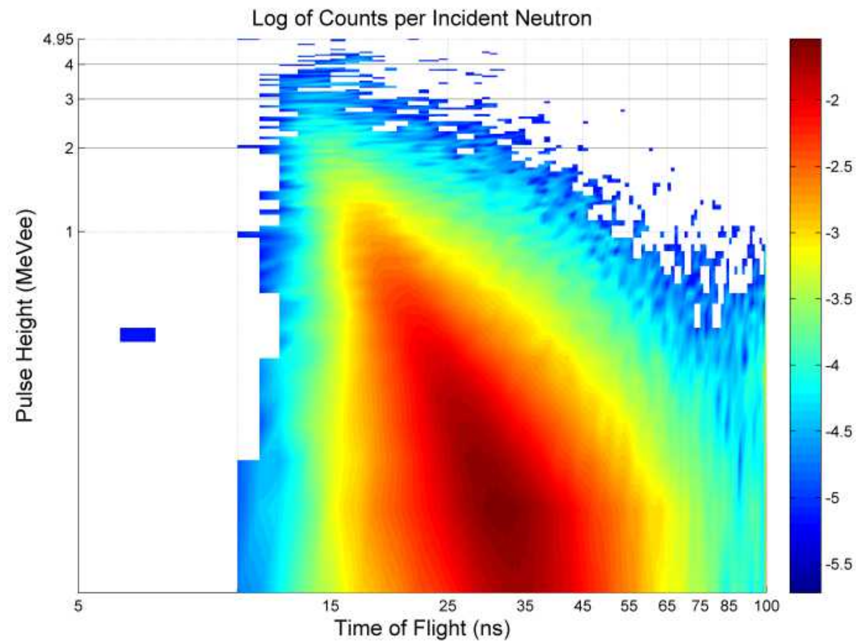



# Comparison of Energy vs. Time Distribution Including Detector Response and Floor Reflection

**Cf-252**




**Plutonium (BeRP Ball)**



# Summary

- Sandia and UM are developing a simple concept to detect fissile material
  - Based on the distribution of fast neutrons (and gammas) over time and energy
  - Detects late-arriving neutrons (and gammas) from induced fission chain-reactions
  - Employs a liquid organic scintillator to accumulate the energy vs. time distribution of fast neutrons and gammas

- We're executing a computational study to evaluate the effectiveness of our proposed approach

- If we're able to successfully demonstrate the effectiveness of our proposed approach (success will be judged by the customer), we'll proceed to design and experimentally evaluate a system that implements that approach

# Ongoing Work During Year 1

- Complete MCNPX-PoliMi simulations of non-fissile and fissile sources
- Develop alternative trigger methods to measure neutron and gamma time-correlation
- Develop metrics that discriminate between non-fissile and fissile sources based on energy vs. time distribution
- Evaluate effectiveness of using time vs. energy distribution of neutrons and gammas to detect induced fission chain reactions
  - Include effect of scattering by different shielding and reflecting materials
  - Address tradeoffs between detection threshold, sensitivity, detector size, signal-to-noise ratio, and acquisition time
- Report findings to customer by end of Year 1