Real-time fast neutron plutonium assay for plutonium storage and ageing applications

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The project

- **Objective:**
  1. Can plutonium (^{240}Pu) be discerned from Curium (^{244}Cm) in the field on the basis of differences in their fast neutron fission multiplicity distributions?
  2. Can the relative difference between uncorrelated, 'singles' neutrons derived from Americium (^{241}Am) and correlated neutron emissions from Plutonium (^{240}Pu) be exploited to infer plutonium ageing?
- **Sponsors:**
  1. EPSRC DISTINCTIVE
  2. The UK National Nuclear Laboratory
  3. Lancaster University

Motivation

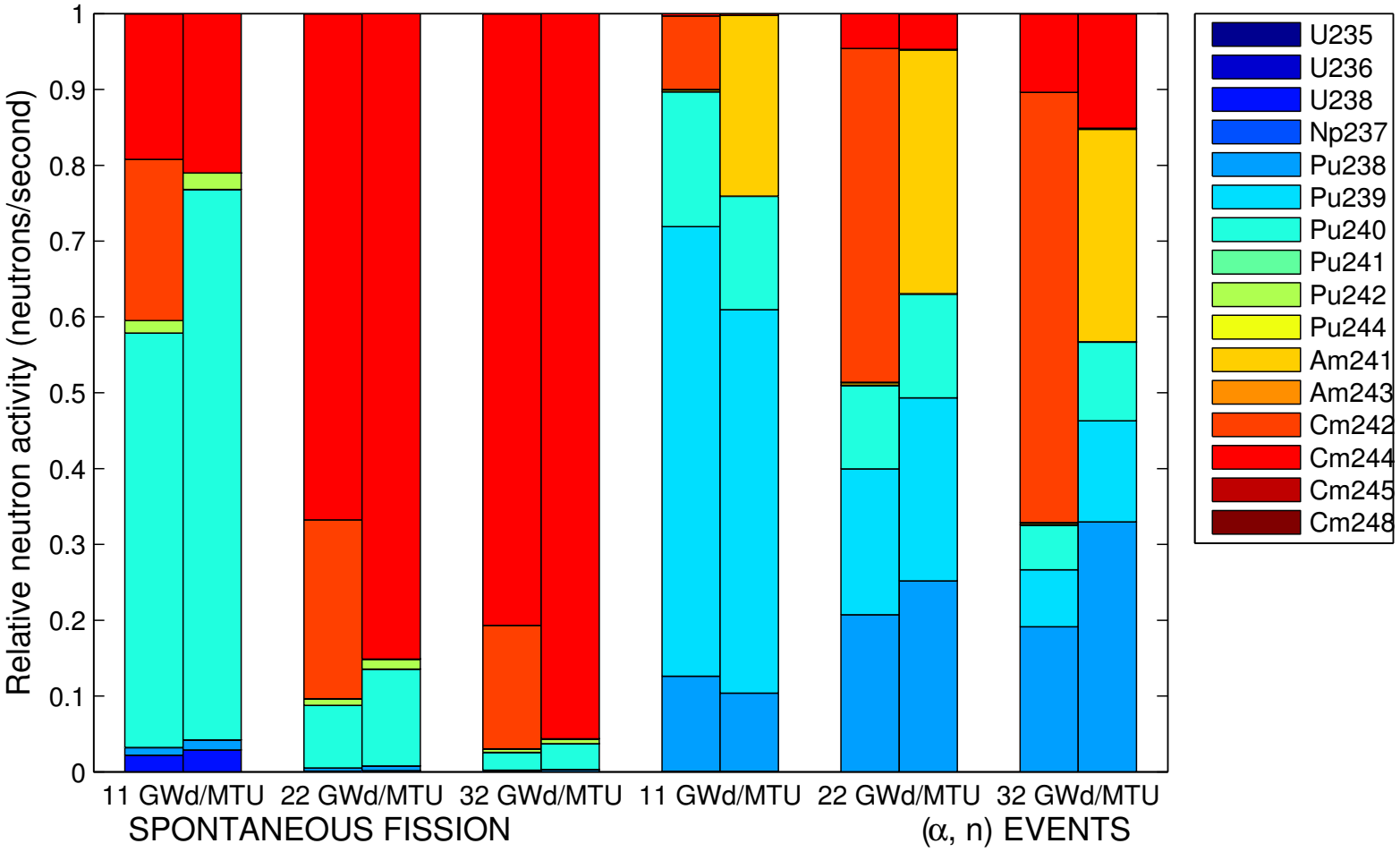
Impact of Curium in waste assay

- Small quantity of Curium in waste assay can result in severe over-estimation of plutonium and under-estimation of uranium content
- Lack of accurate characterisation of Curium can lead to a large uncertainty
- Cm-242/244 can act as intense neutron source, masking signal from Pu-240

Impact of (α,n) in waste assay

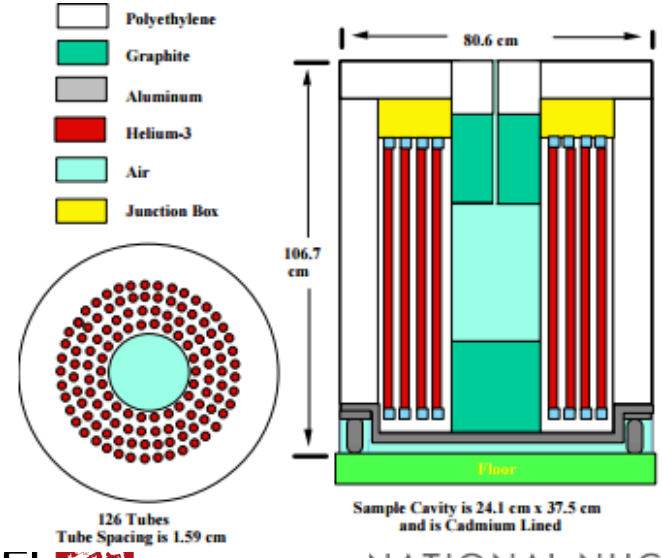
- Potentially high and unknown ratio of (α,n) to spontaneous fission neutron production rate together with the associated variability in the emitted neutron energy spectra may compromise traditional passive neutron correlation methods

Spontaneous Fission and (Alpha, n) reactions

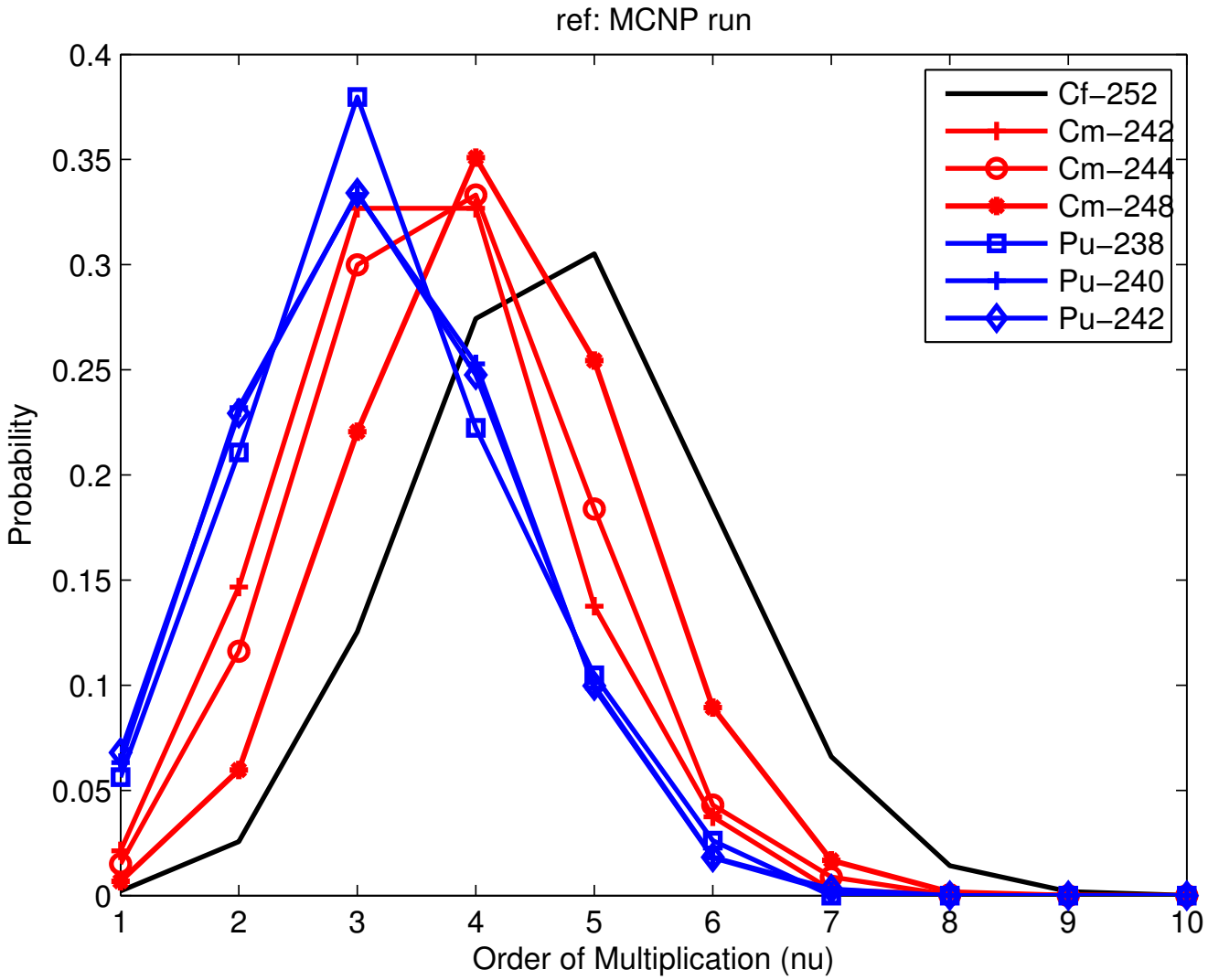


Possible Solutions

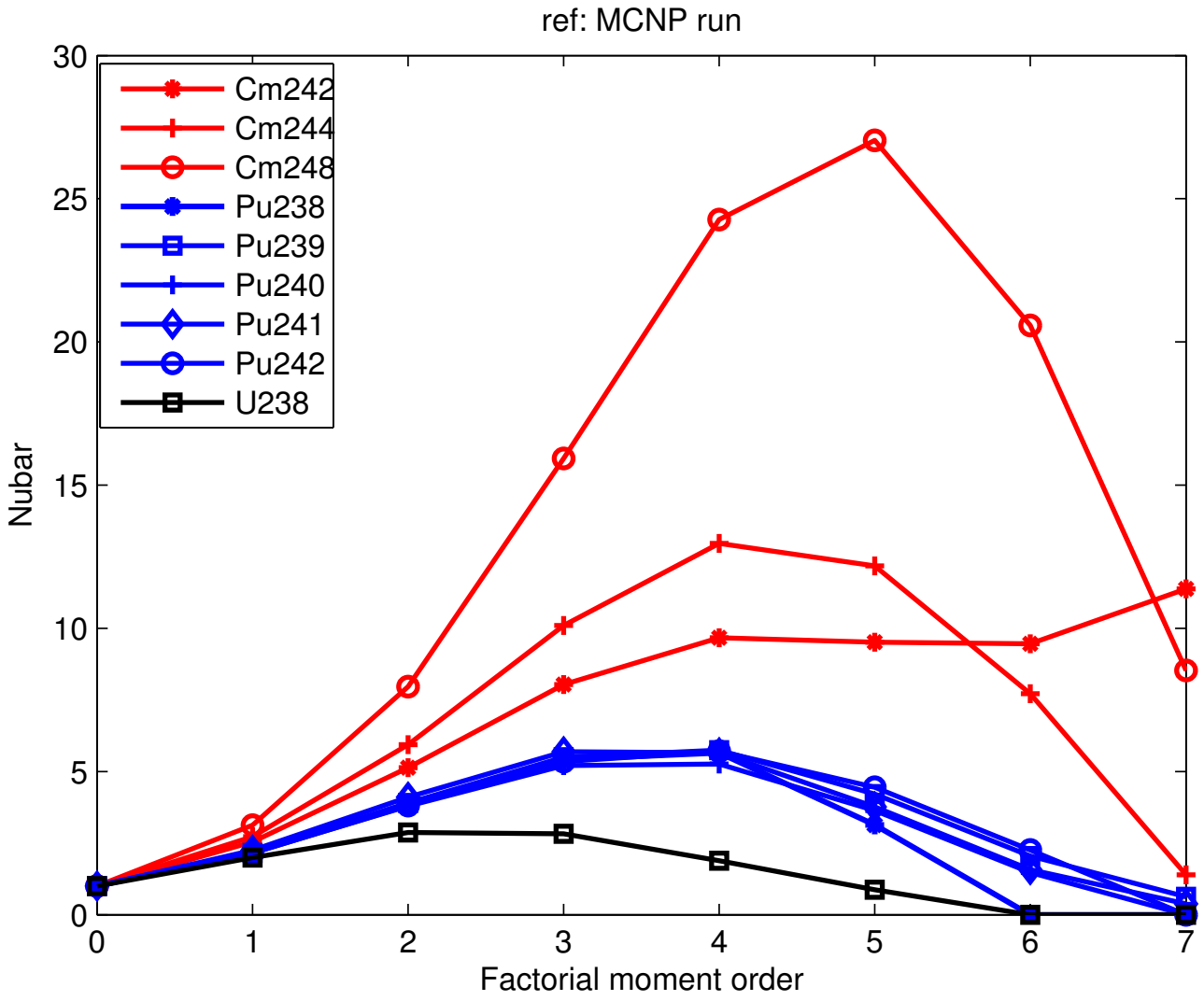
- Gamma Spectroscopy
- Simulations and laboratory analysis
- Multiplicity Analysis



Multiplicity



Multiplicity: Factorial Moments



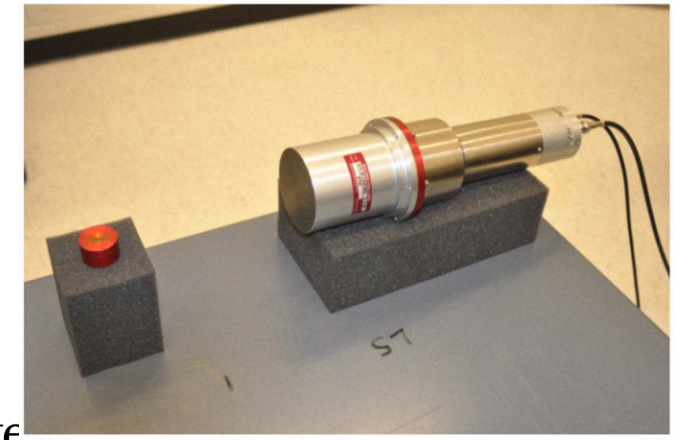
Multiplicity: Neutron Detectors

Helium-3 Detectors

- increasingly rare commodity
- requires thermalization
- long detection gate
- cannot discriminate between neutrons from different isotopes

Liquid Scintillation Detectors

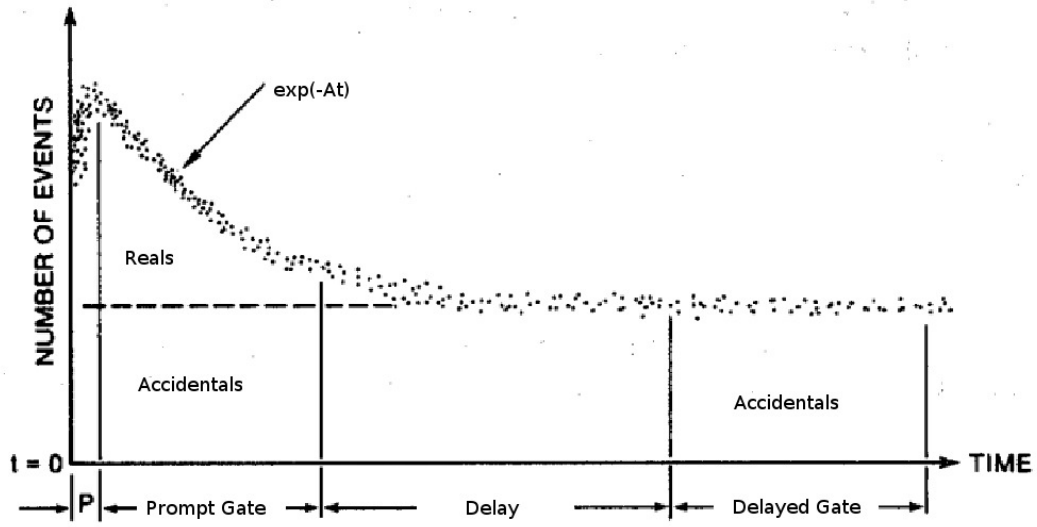
- does not require thermalization
- very short detection gate
- sensitive to gamma radiation



Multiplicity: Data Analysis Methods

- Rossi-alpha Method
- Feynman-alpha Method
- Variable Deadtime Method

Multiplicity: Rossi-alpha Method

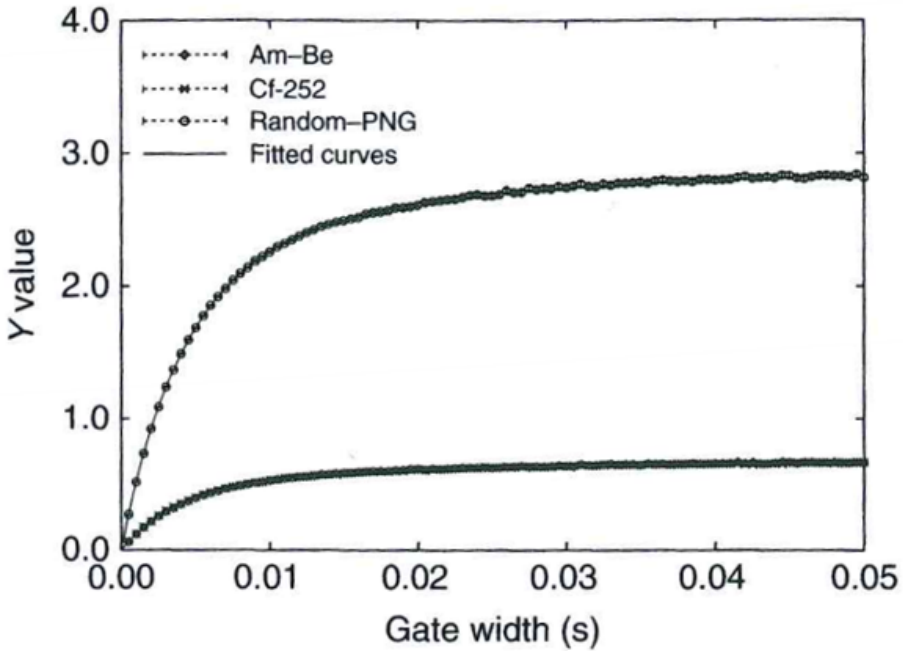


$$P(t) = Aexp^{-\alpha t} + F\epsilon$$

$$S = F\epsilon M\bar{\nu}_{sf1}(1+\alpha)$$

$$D = \frac{F\epsilon^2 f_d M^2}{2}\left[\bar{\nu}_{sf2} + \left(\frac{M-1}{\bar{\nu}_{i1}-1}\right)\bar{\nu}_{sf1}(1+\alpha)\bar{\nu}_{i2}\right]$$

Multiplicity: Feynman-alpha Method



Statistical method: Neutron counts with respect to various counting gate widths are measured to obtain the gate width dependence of the variance-to-mean ratio of neutron counts minus unity.

$Y_{\text{var}}(iT) = \frac{\nu(iT) - \mu(iT)}{\mu(iT)}$

Workspace

- Number density analysis
- Simulating multiplicity responses from liquid scintillator
- Simulating neutron cross talks
- FPGA-based real time system capable of carrying out online data processing

Simulation: MCNP6 Multiplicity Toolkit

- C++ toolkit to parse through MCNP6/MCNPX-PoliMi output files
- Reproduce **multiplicity distribution** and **cross-talk corrections**
  - Tracks neutron interaction during a detection window(s)
  - Energy was deposited by the neutron during a detection window(s)
  - Number of detectors were triggered during a detection window(s)
  - Variable gate-width and energy threshold

Multiplicity outputs

- Rossi-alpha based neutrons and photon multiplicity distribution (Real & Accidental)
- Rossi-alpha distribution
- Rossi-alpha based neutron and photon cross-talk
- Feynman-alpha distribution

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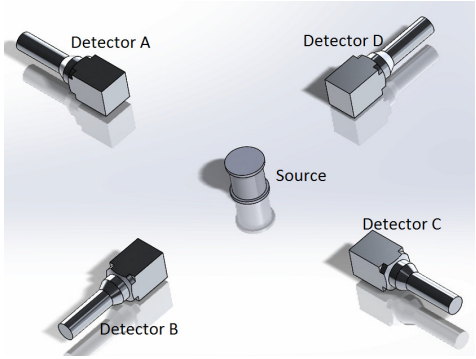
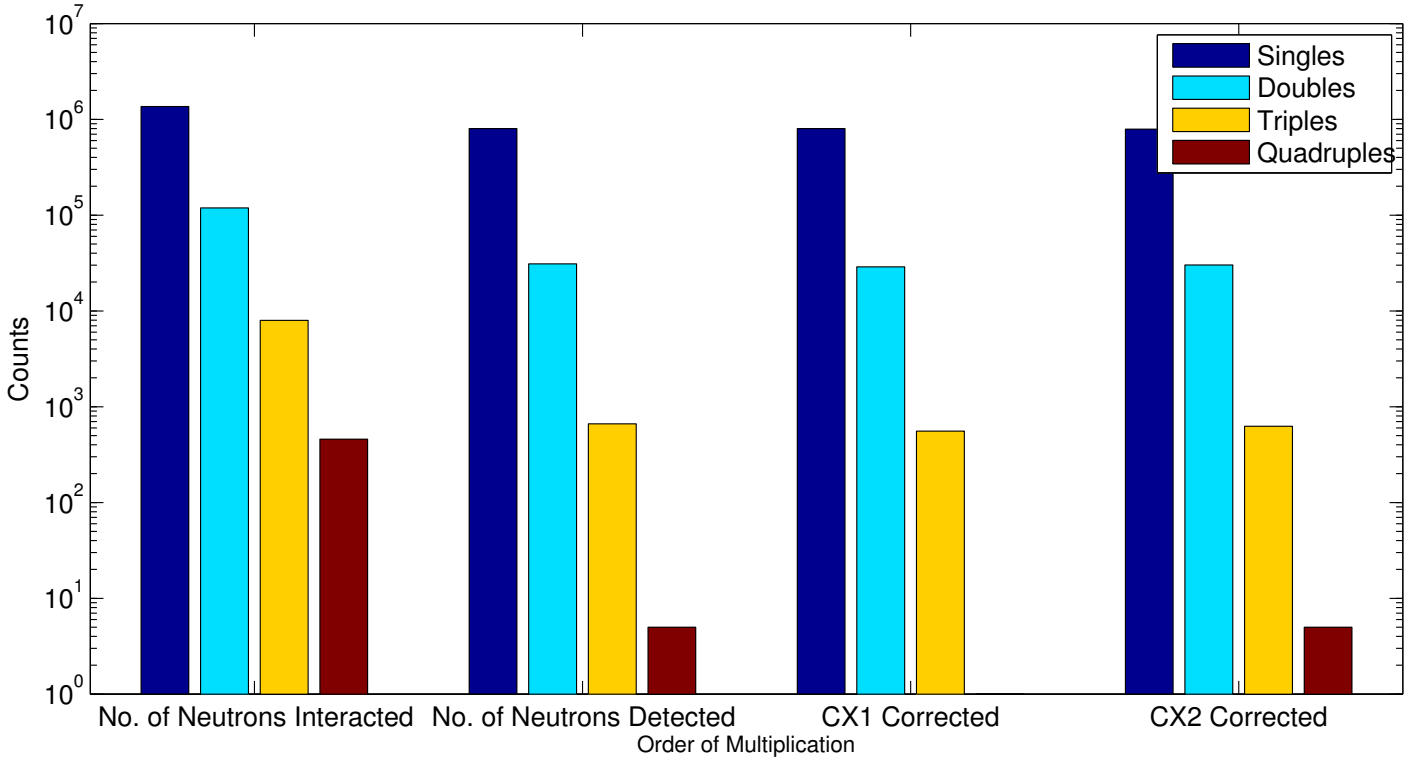
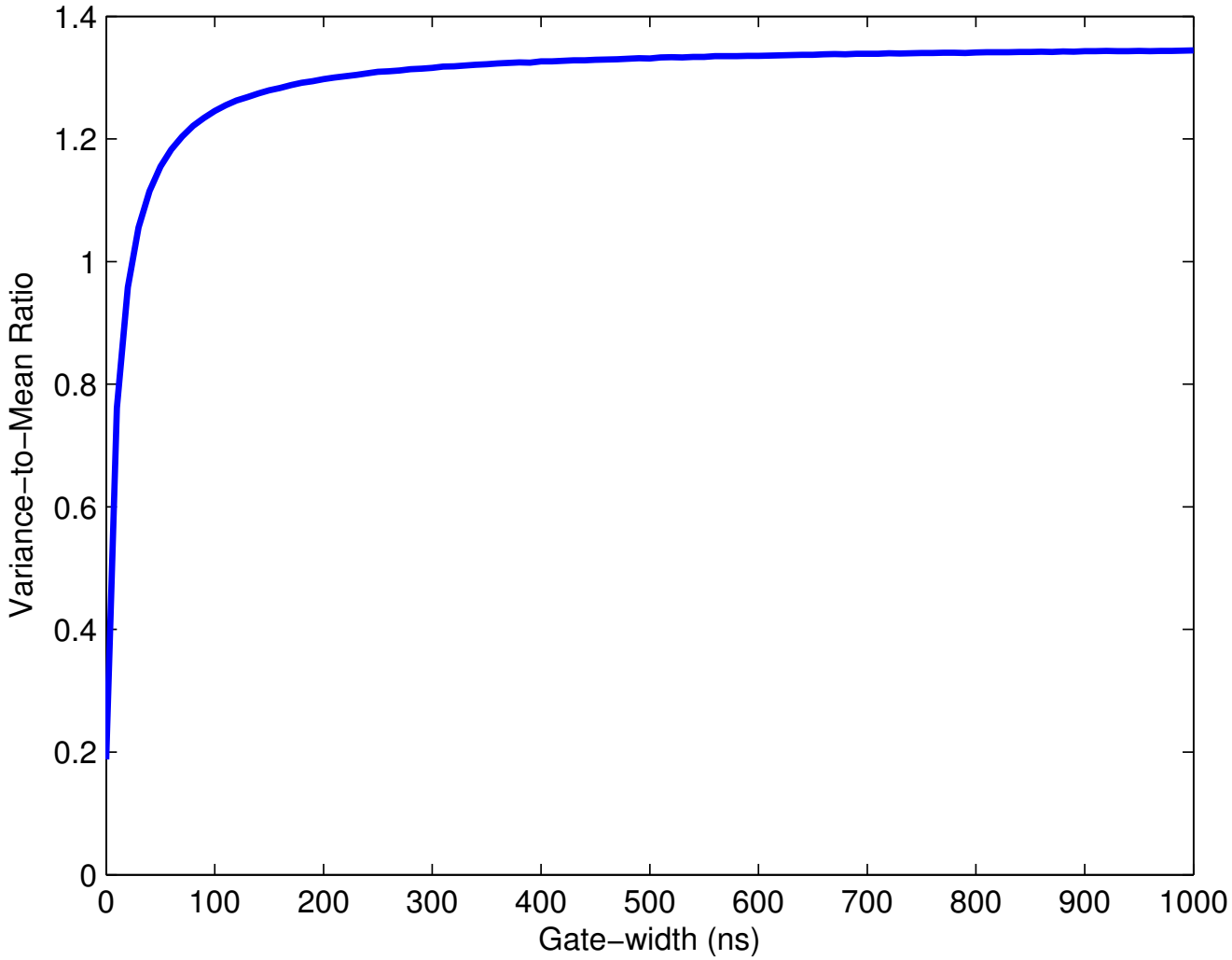
Simulation Results: Rossi-α





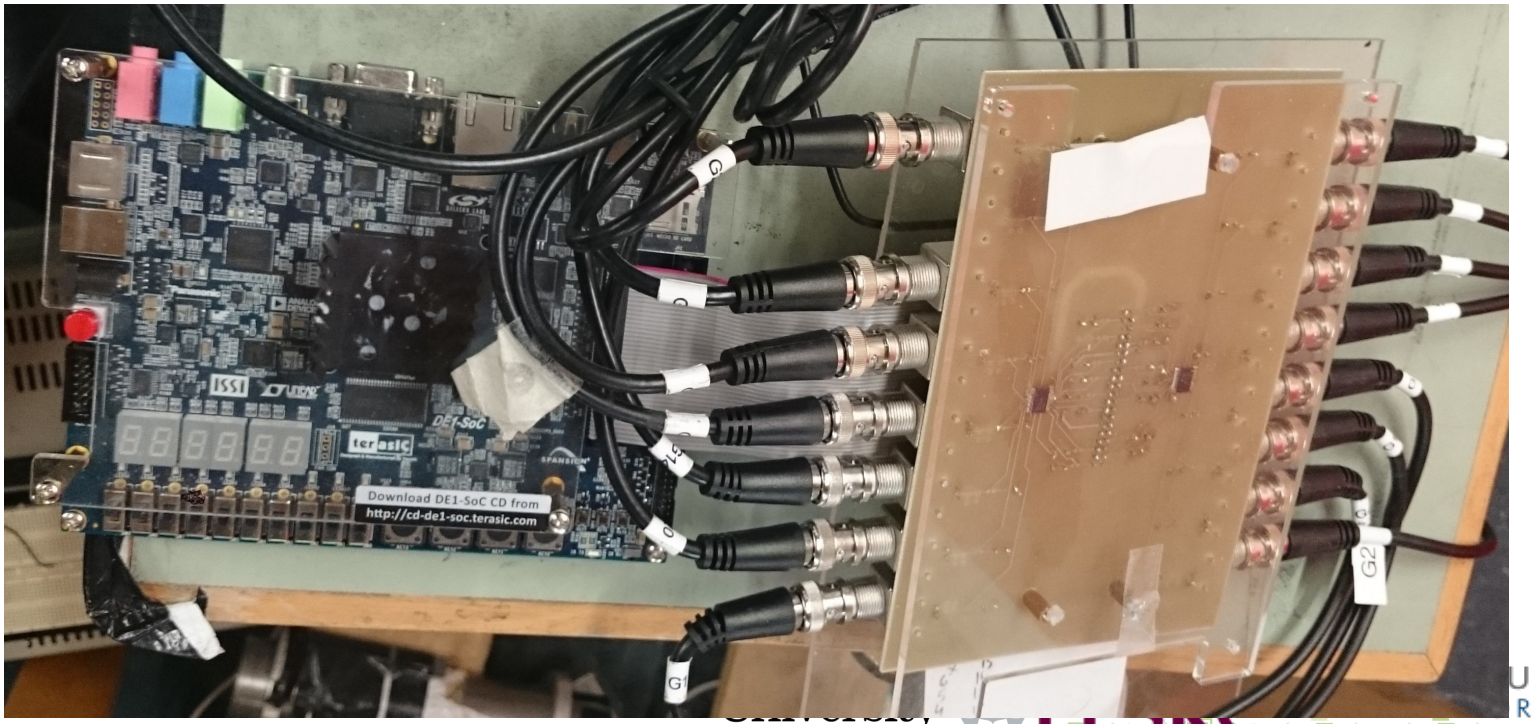
Simulation Results: Feynman-α



Hardware: Multiplicity register

Based on Altera DE1-SoC FPGAs

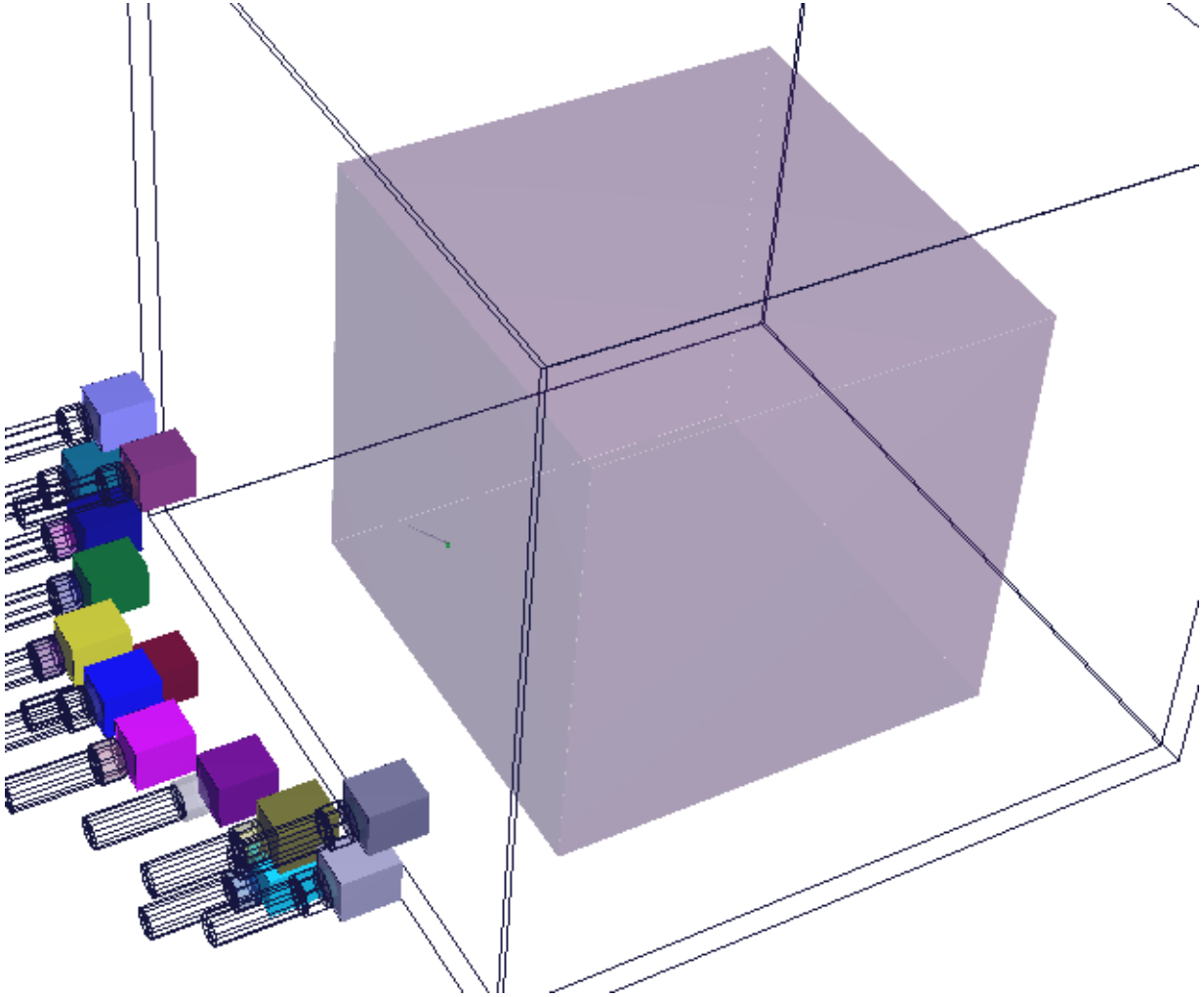
- Runs linux kernel, to allow user to connect monitor and keyboard to use device as a standalone system.
- Rossi-α & Feynman-α using shared circuit
- Time-of-flight analysis



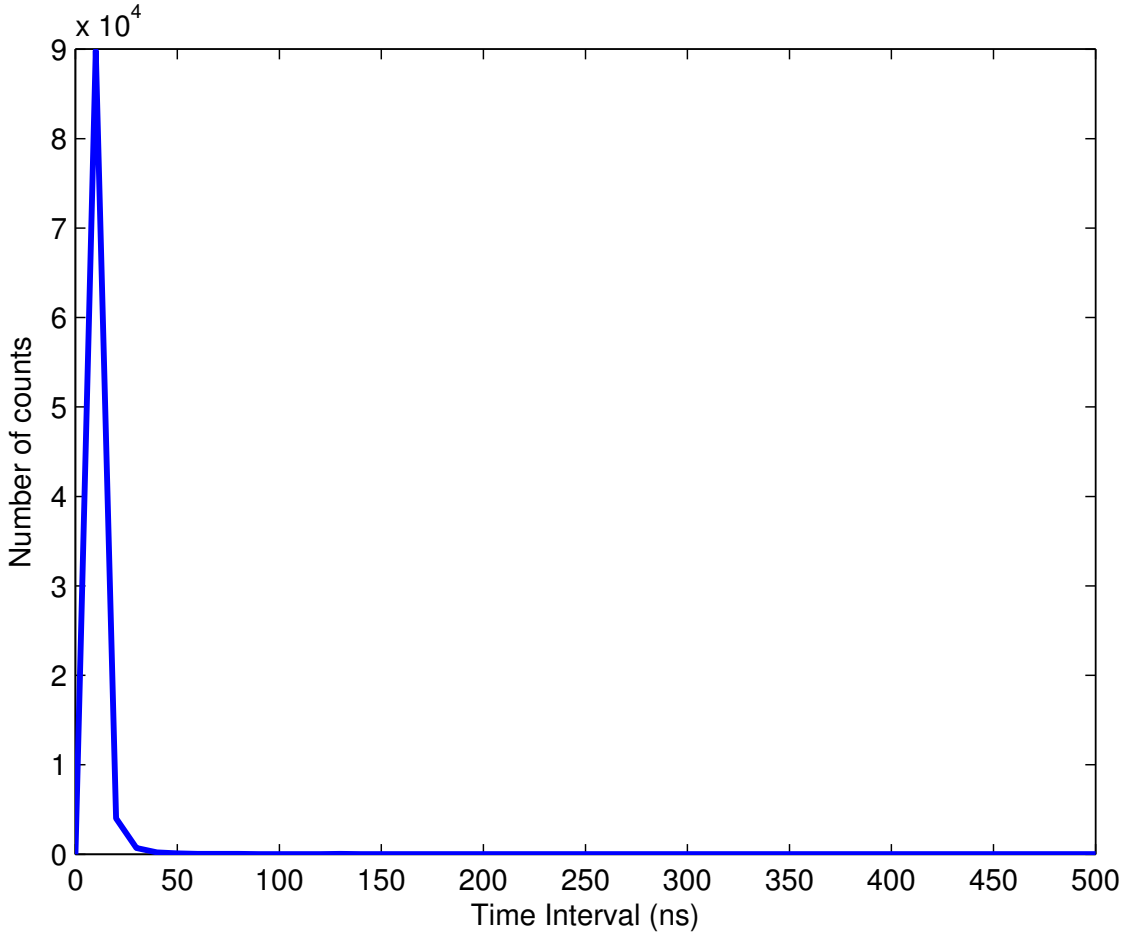
Hardware Results: Mixed field analyser

Hardware Results: Experimental setup

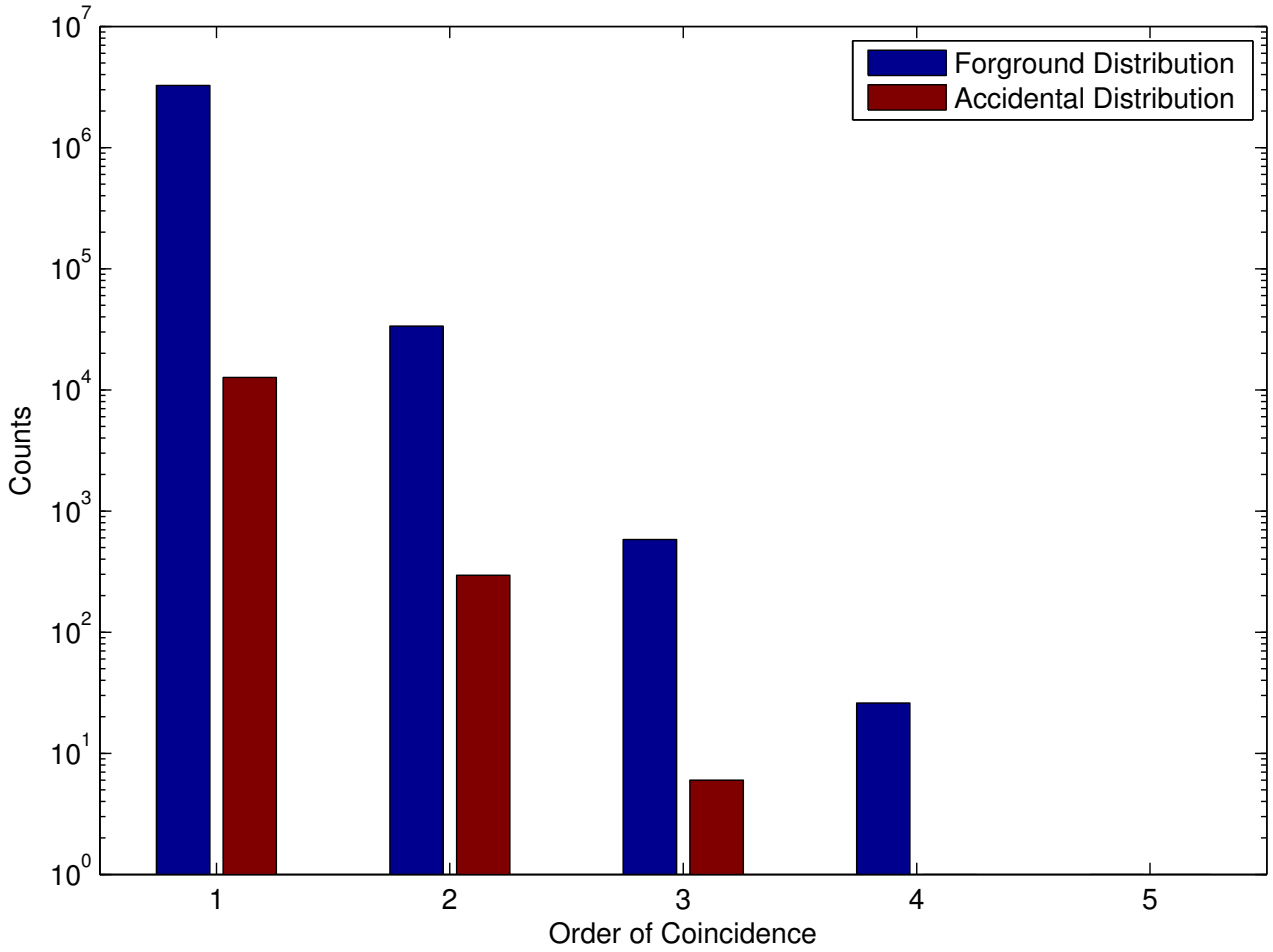
Hardware Results: Experimental setup



Hardware Results: Rossi-alpha distribution



Hardware Results: Coincidence distribution



Future work

Planned work

- Unfolding multiplicity distribution
- Controlled cross-talk based experiments
- Am-241Be/Cf-252/Cm-244/Pu-240 based multiplicity experiments
- Semi-empirical model for neutron cross-talk
- Designing of detection system
- Neutron multiplicity as a function of neutron energy
- Neutron-Gamma joint multiplicity.

Thank you!