Lawrence Livermore National Laboratory

Fast Neutron and Gamma Ray Detection and Multiplicity Counting with LLNL Scintillator Array

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LLNL Group Effort

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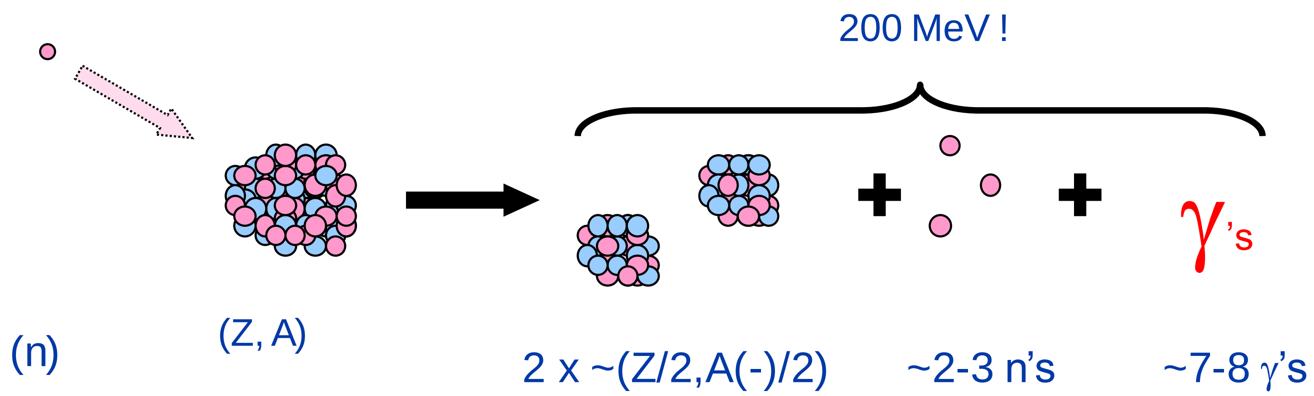
Why is Special Nuclear Material Special?

- Special Nuclear Material Can Support Fission Chains
- SNM Materials are Plutonium, Uranium, Neptunium, (DU, Natural Uranium)

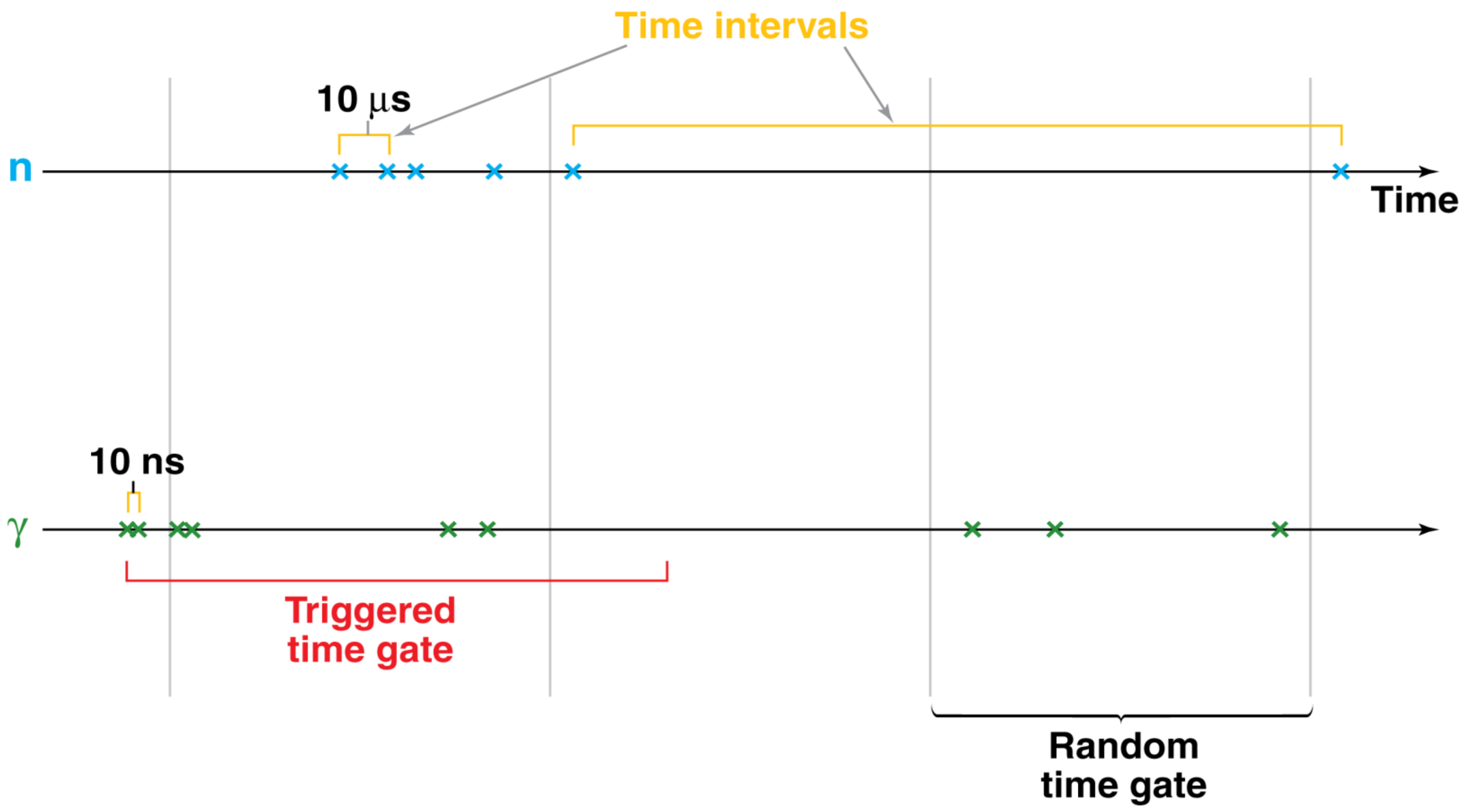


Neutrons can induce fission in SNM

LLNL Neutron Detection and Assessment

- Understand Theory of Fission Chains From First Principles
- Compare Expected Theoretical Predictions to measured distributions as a function of time (source strength, multiplication, efficiency and alpha ratio)
- Fit the distributions (as a function of time) for best solutions
- Started by treating thermal detection with thermal (μs) time scales
- Been developing use of Fast Scintillators (LS/plastic/stilbene w/PSD)
- Taking advantage of fast (ns time scales) and momentum information
- Working on PSD

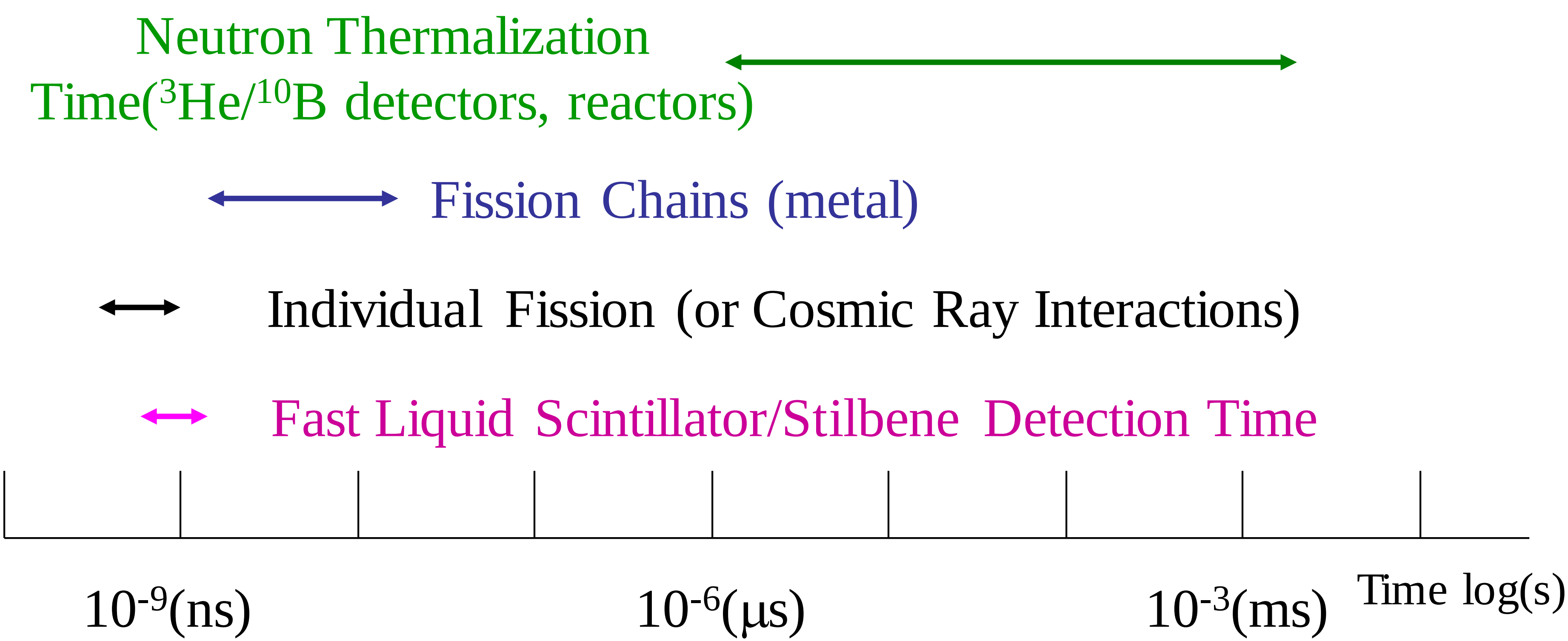
Three Ways to Count Time Series



We Have Developed the Theory for all Three Ways

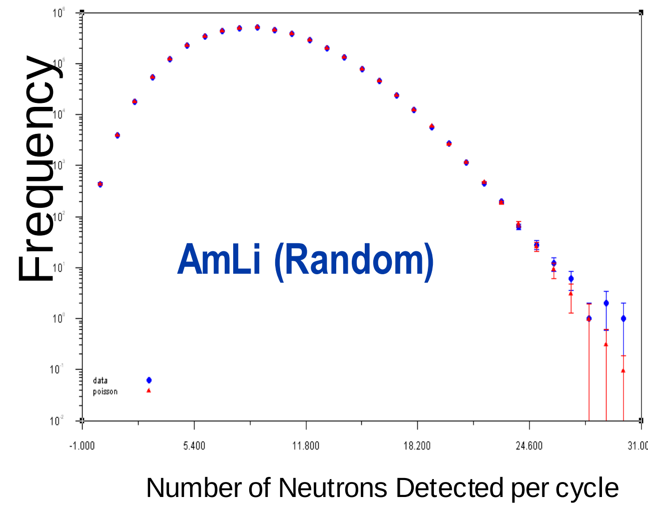
Time Scales – What Does Fast Timing Buy?

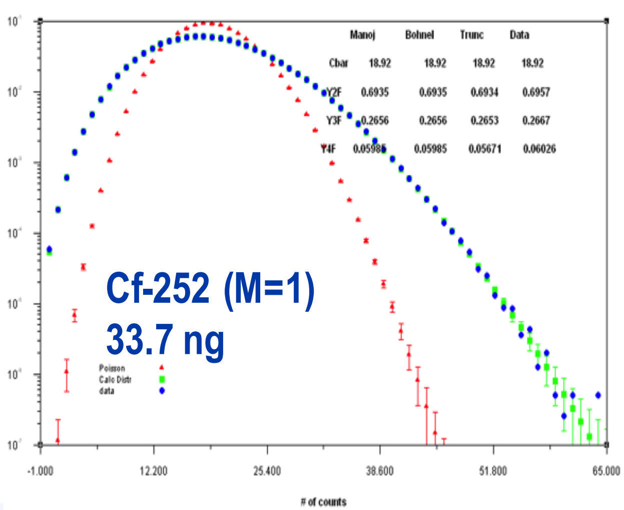
Liquid Scintillator is fast (nanoseconds) can detect *individual fissions* even in high count rate environments



Visualizing Fission – Count Distribution High Efficiency Data

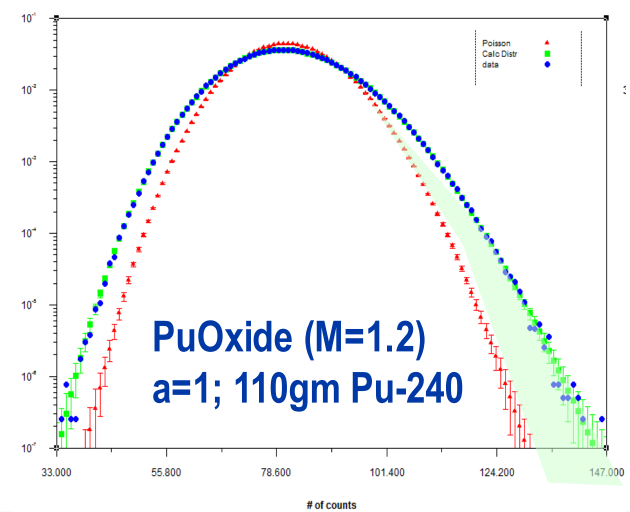
High Efficiency – NMC (ε~ 50%)



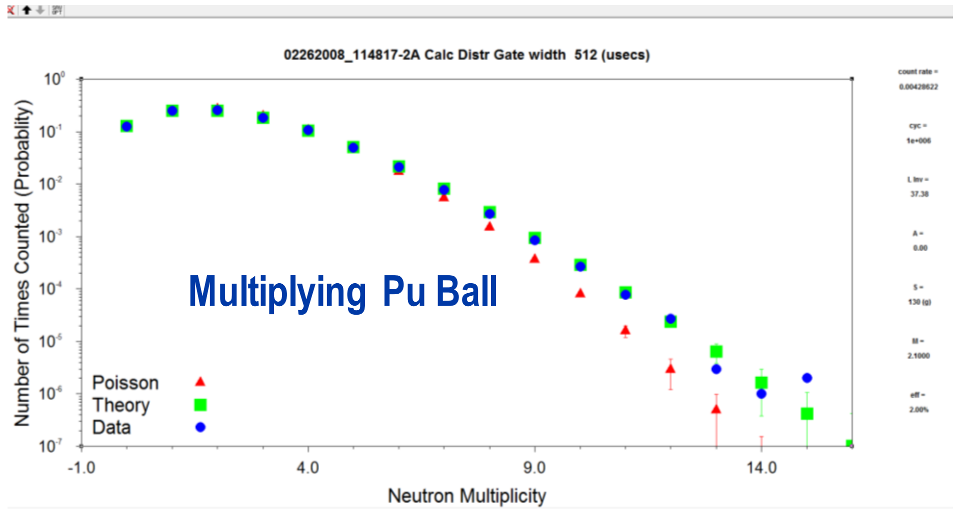


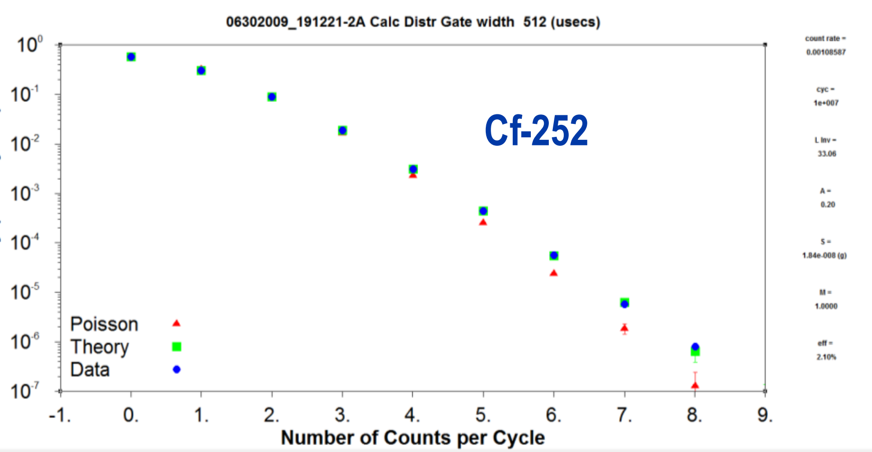
	Manoj	Bohnel	Trunc	Data
Cbar	18.92	18.92	18.92	18.92
Y2F	0.6935	0.6935	0.6934	0.6957
Y3F	0.2656	0.2656	0.2653	0.2667
Y4F	0.05985	0.05985	0.05671	0.06026

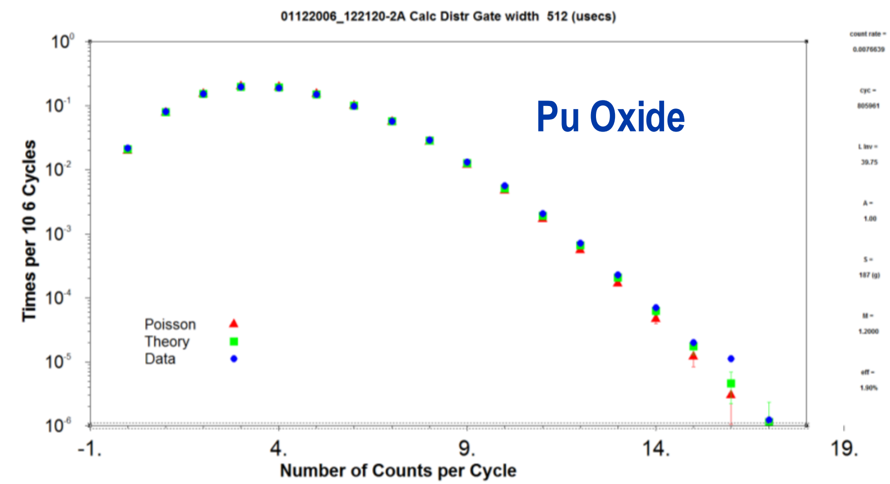
Poisson
Data
Theory



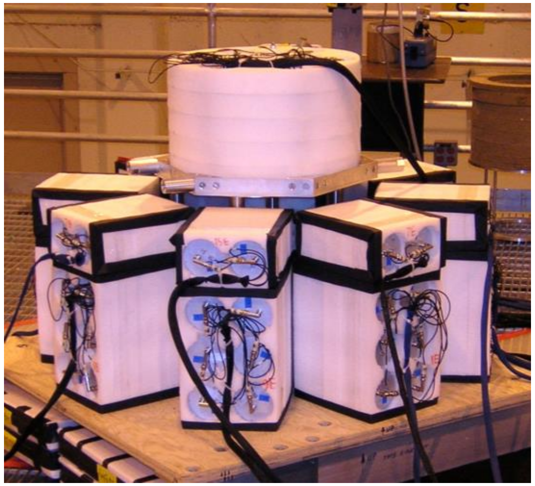
Visualizing Fission – Count Distribution
Low Efficiency Data

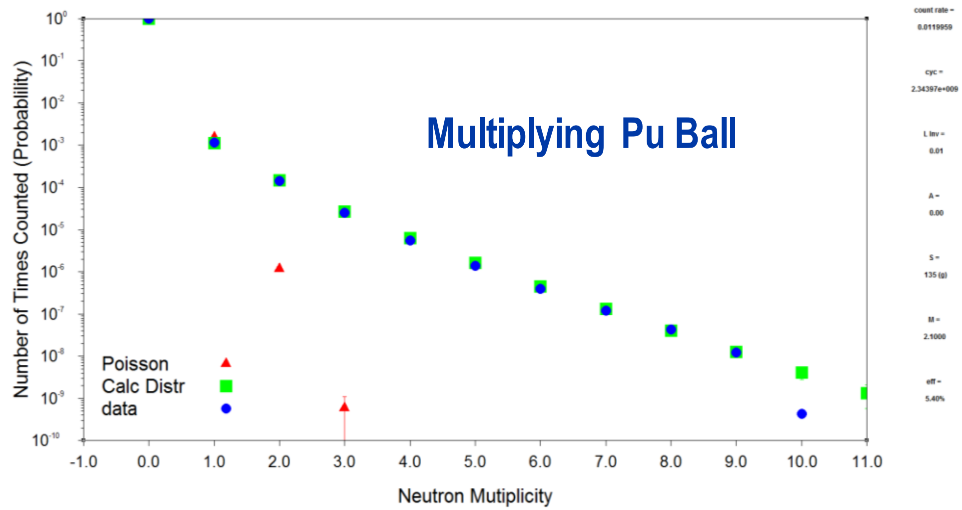


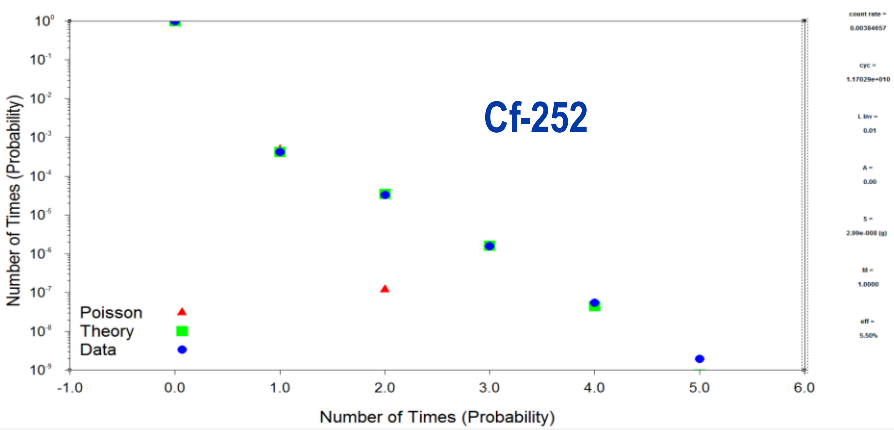


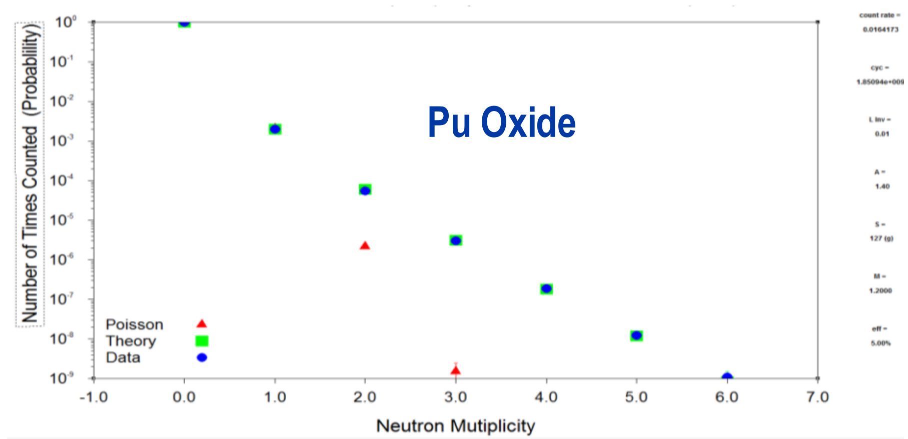


Count Distributions – Fast Detection
LLNL Liquid Scintillator Array – (ε~ 5-7%)

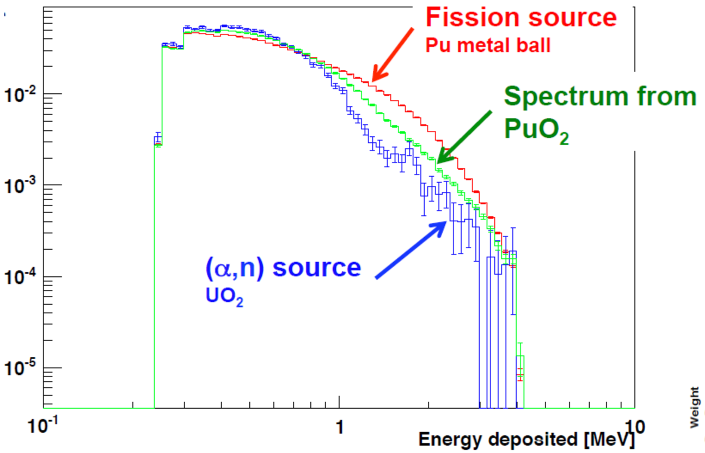


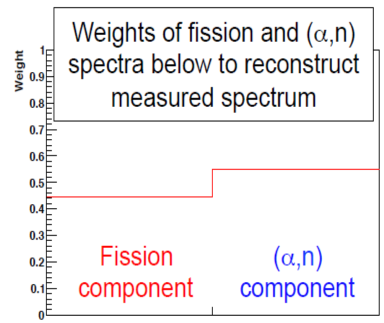




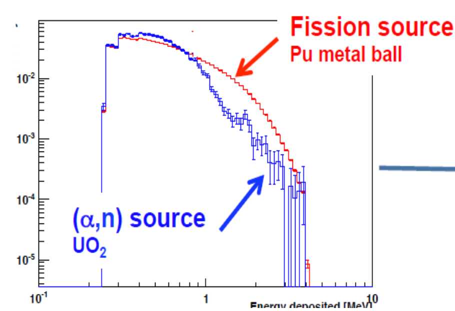


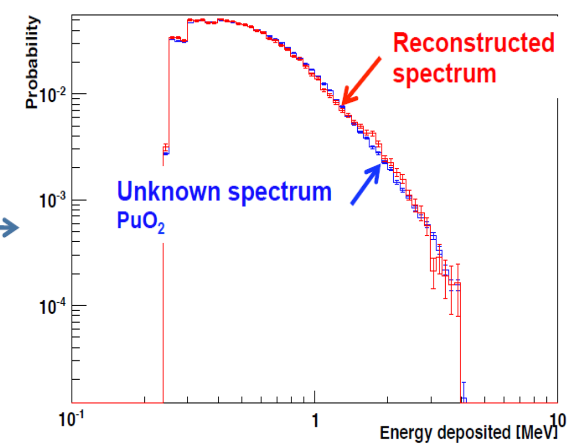
Neutron Momentum Spectrum from Fission and Oxygen -18 (alpha –n) Differ



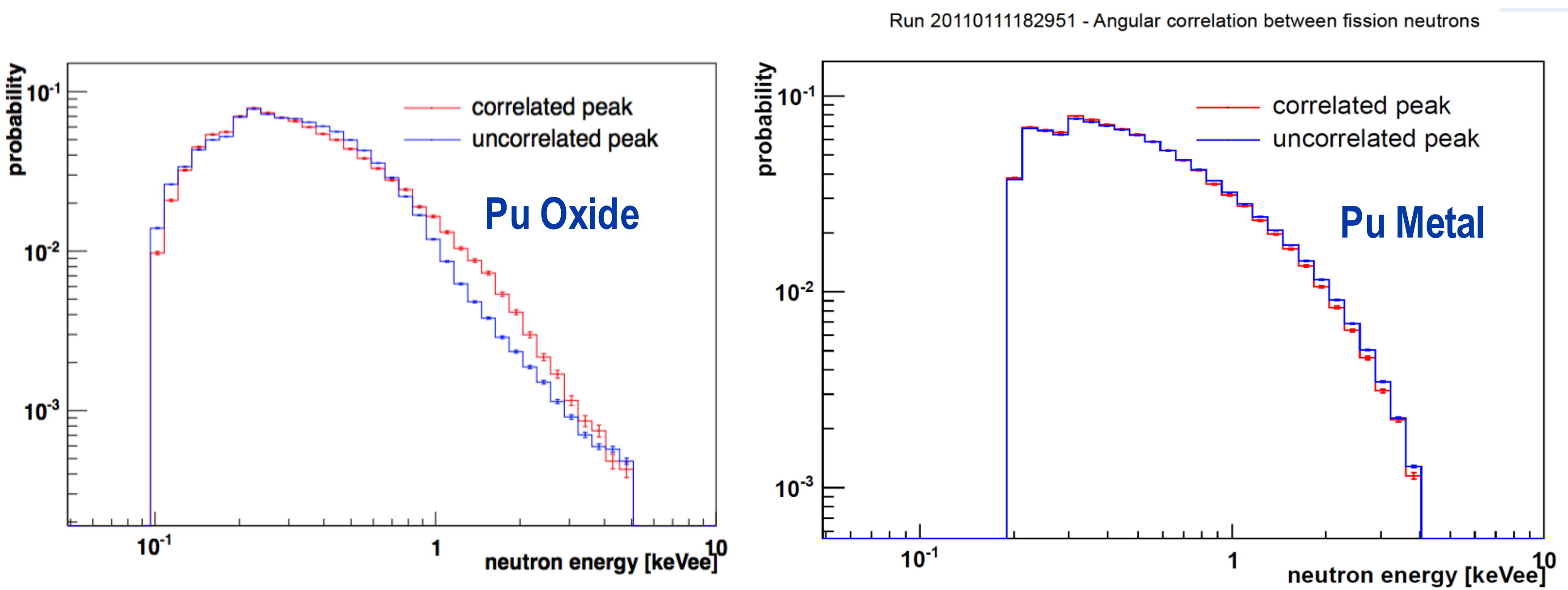


- A spectrum from an unknown source can be decomposed into its fission and (α,n) components



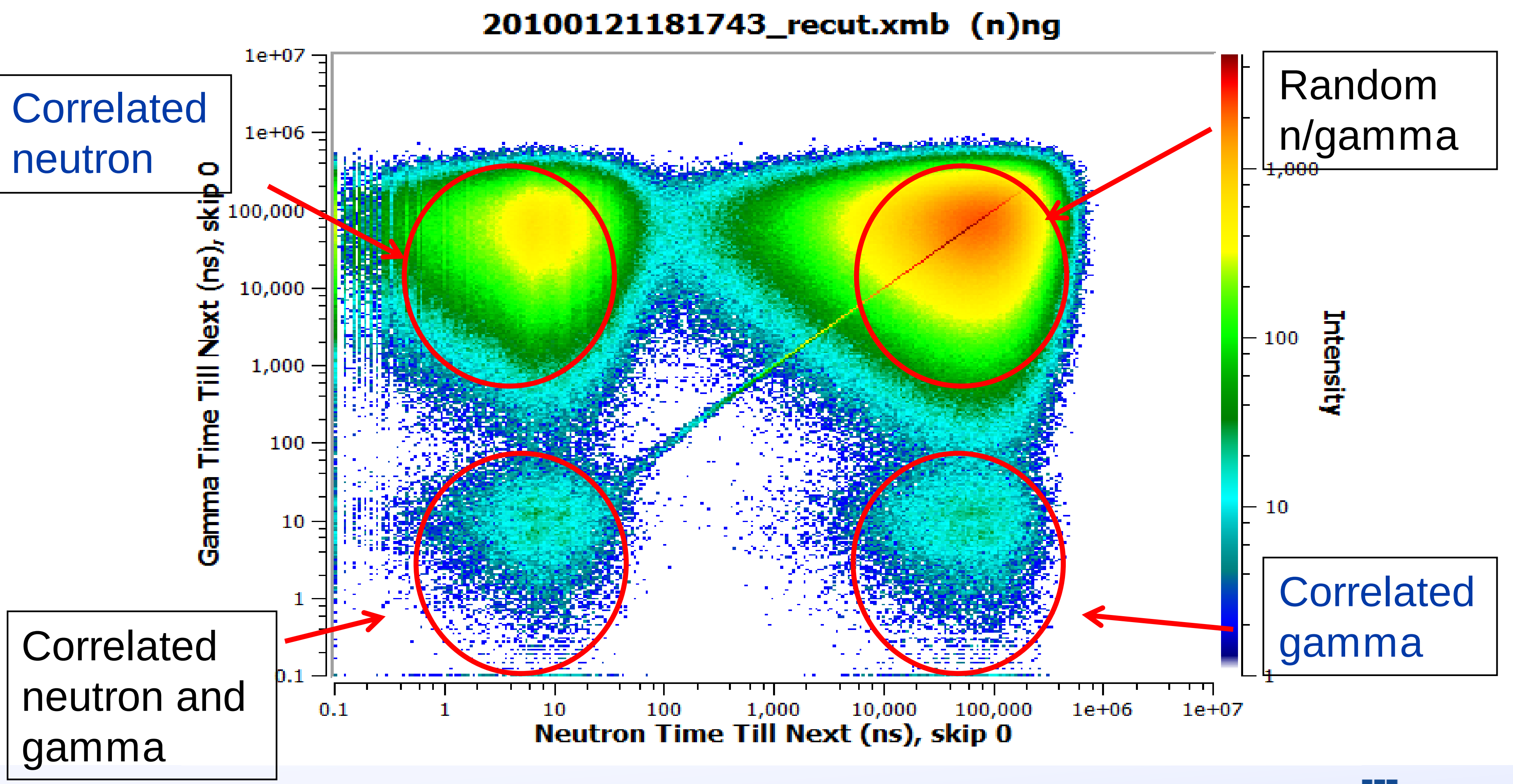


Neutron Momentum Spectrum Correlated Vs. Uncorrelated neutrons



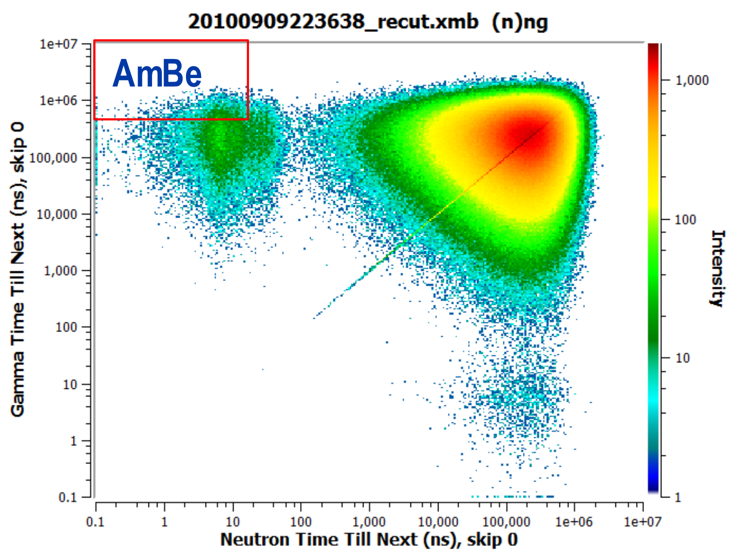
Plutonium Oxide; Pu metal
Correlated Neutrons are from fission,
uncorrelated from fission and alpha-n neutrons

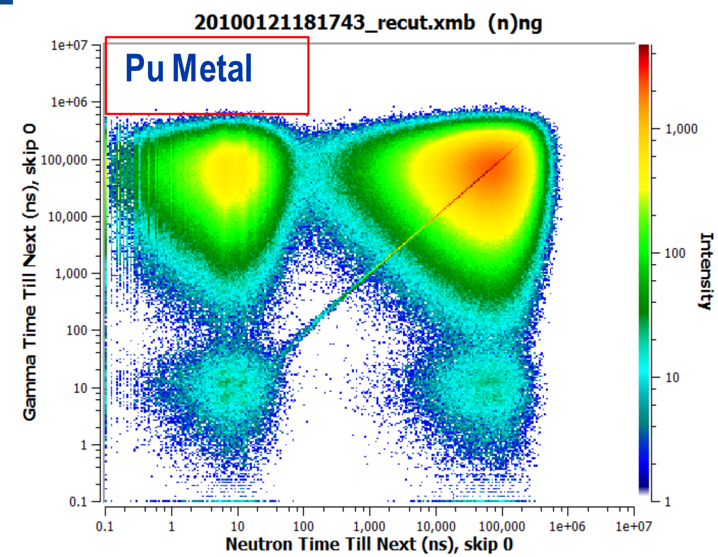
2-Dimensional (Log)Time Interval plots*Neutron-Neutron Vs *Neutron-Gamma

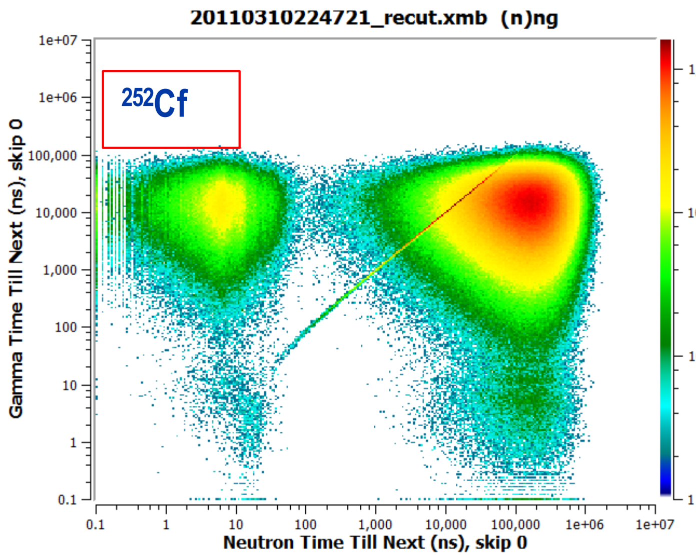


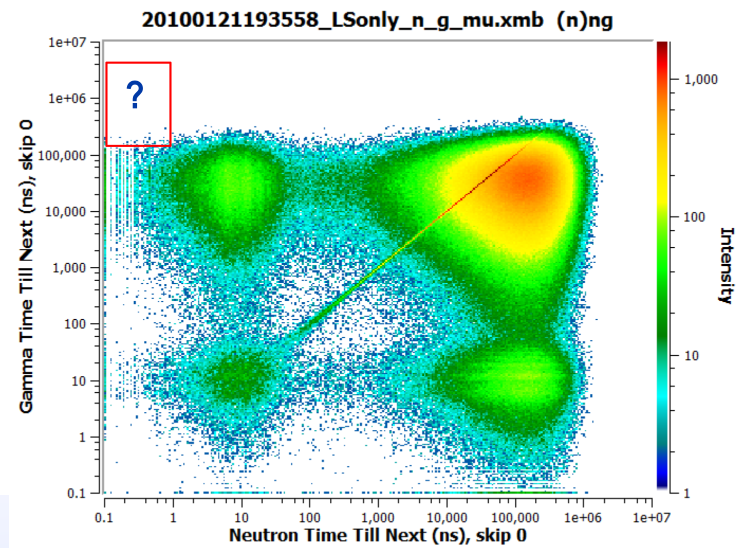
2-Dimensional Time Interval Plots

*Neutron-Neutron Vs *Neutron-Gamma



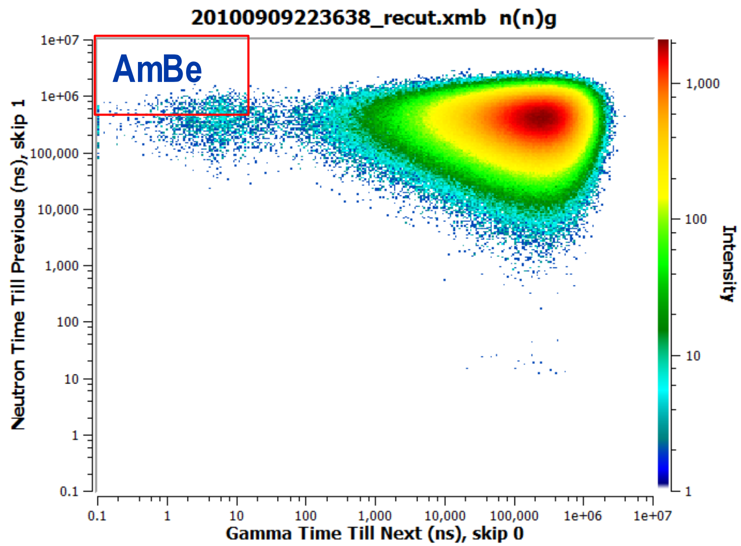


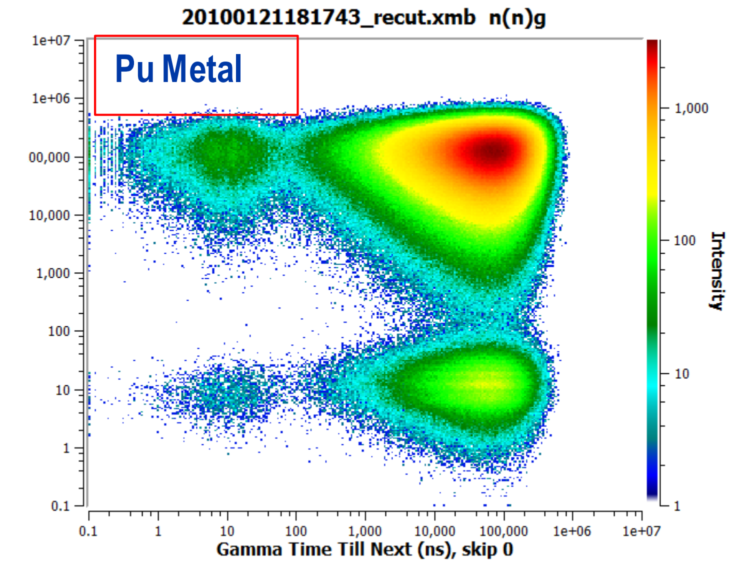


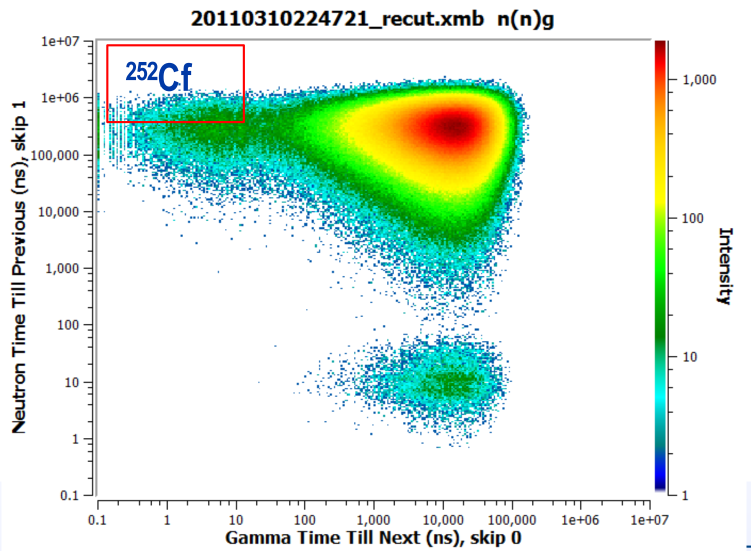


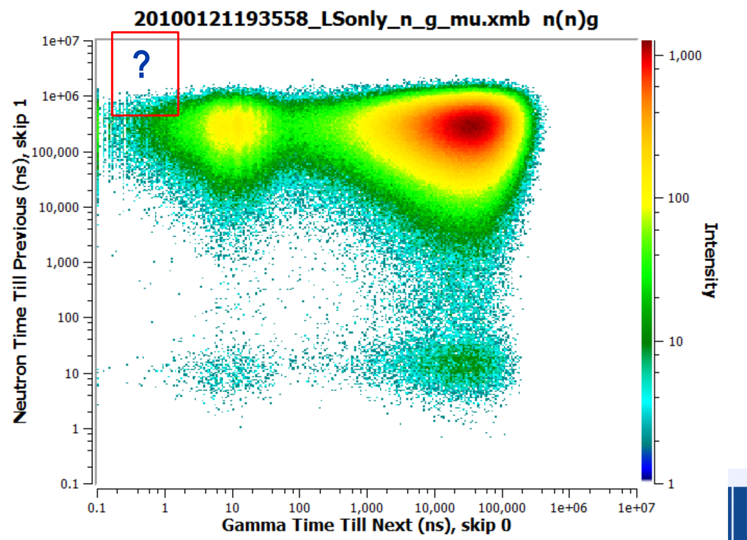
2-Dimensional Time Interval Plots

X-Next Gamma; Y- Previous skip 1 Neutron

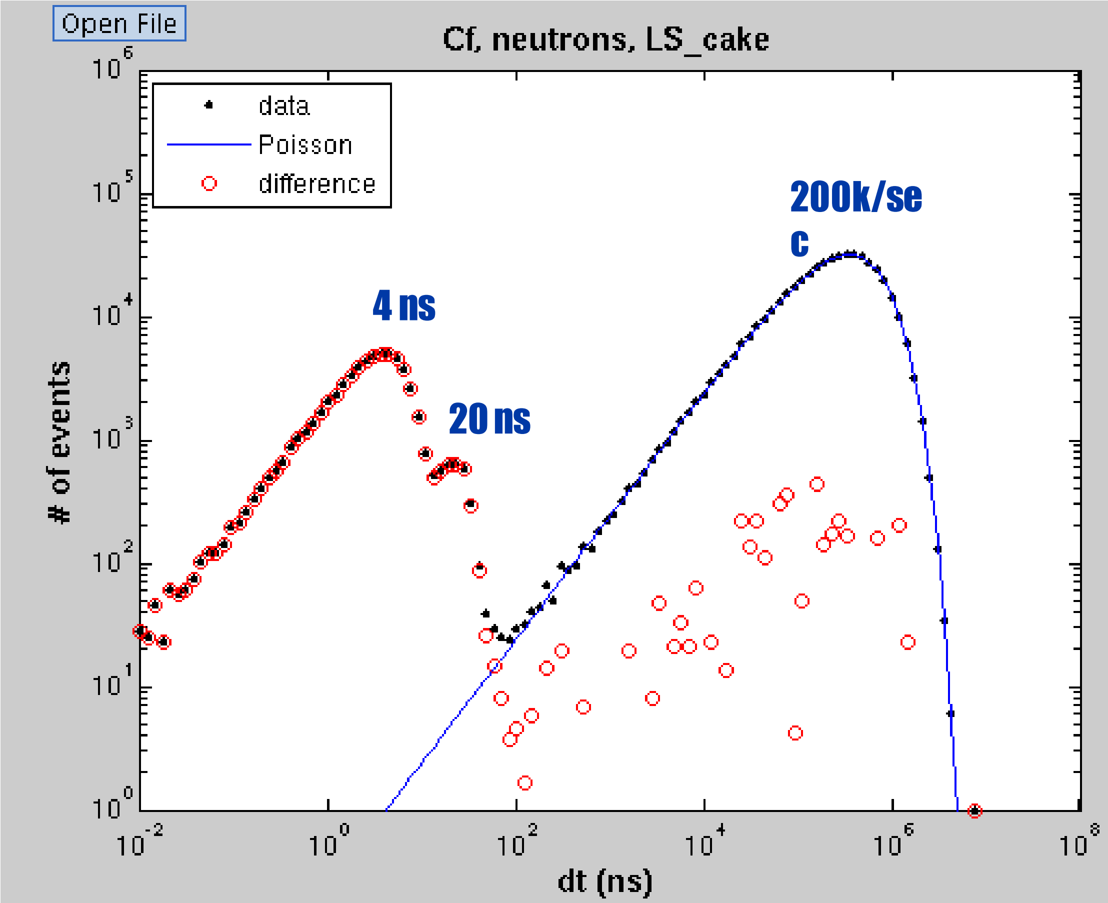


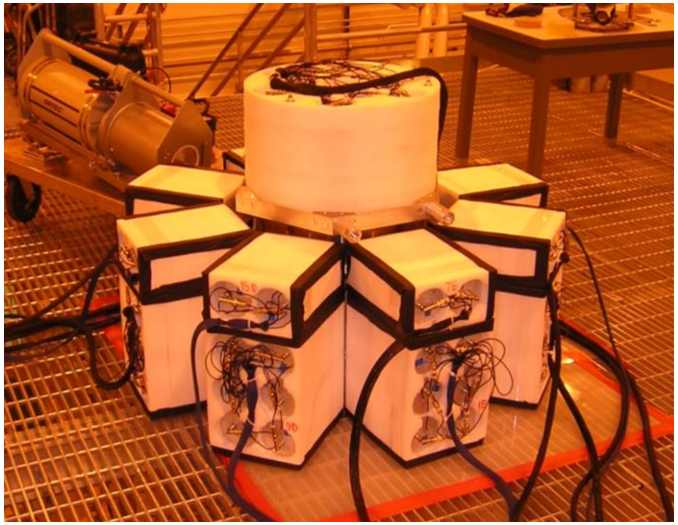






Time intervals between particles: fast neutron counting

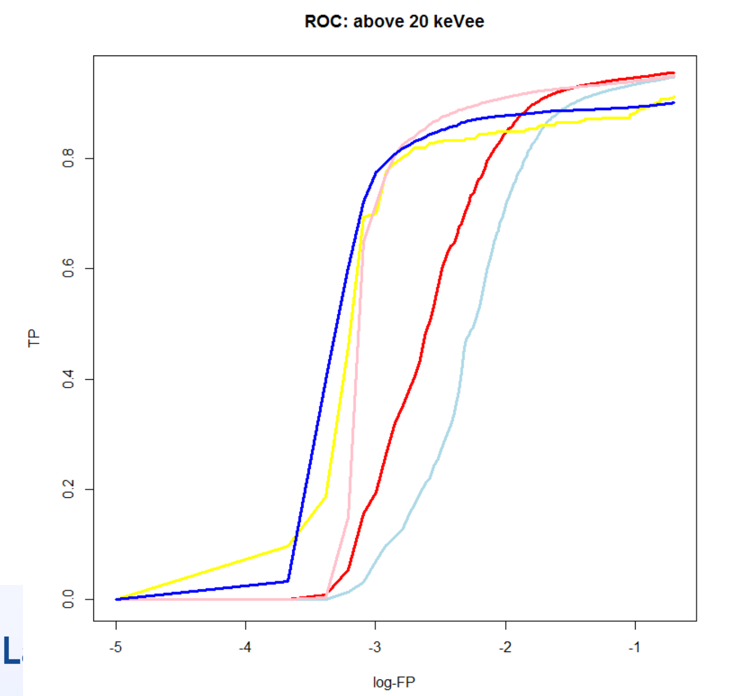


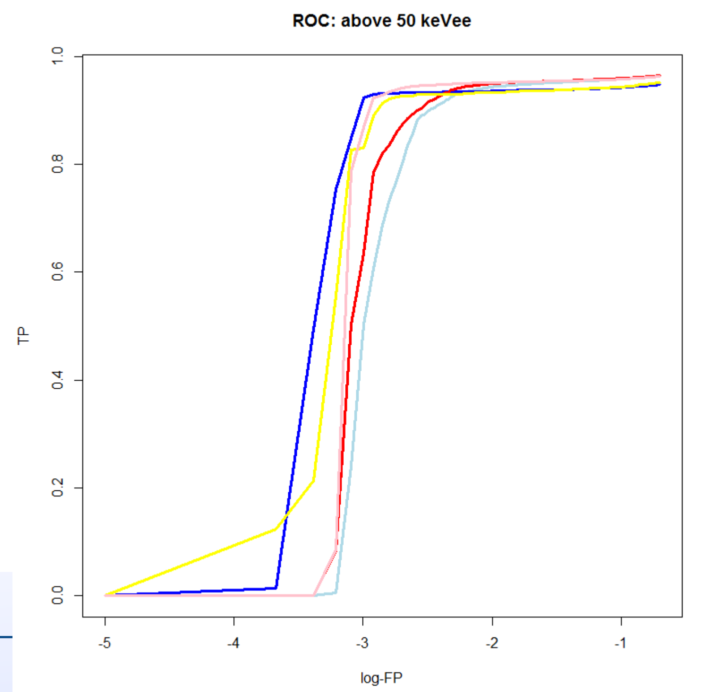


Cf implies no chains, so these should all be neutrons with systematic spread like ~4ns. But *there is a peak at 20 nsec apart*. For those, the leading event is a gamma ***misidentified*** as a neutron followed by a neutron from the same fission, at its fission time of flight.

Classifier performance curves

- Here are misidentification tradeoff curves (ROC curves) for five classifier methods. The user can adjust a (hidden) classifier parameter to choose an acceptable tradeoff.
- Horizontal axis is log of false neutron rate (measure of neutron purity). Vertical axis is true neutron rate (measure of neutron loss).
- Left graph is a cutoff in energy above 20 keVee, right is cutoff above 50 keVee.
- The worst method (pale blue) is tail-to-total. Even above 50 keVee, tail-to-total is 3 times worse false neutrons at constant true neutron than the best classifier.

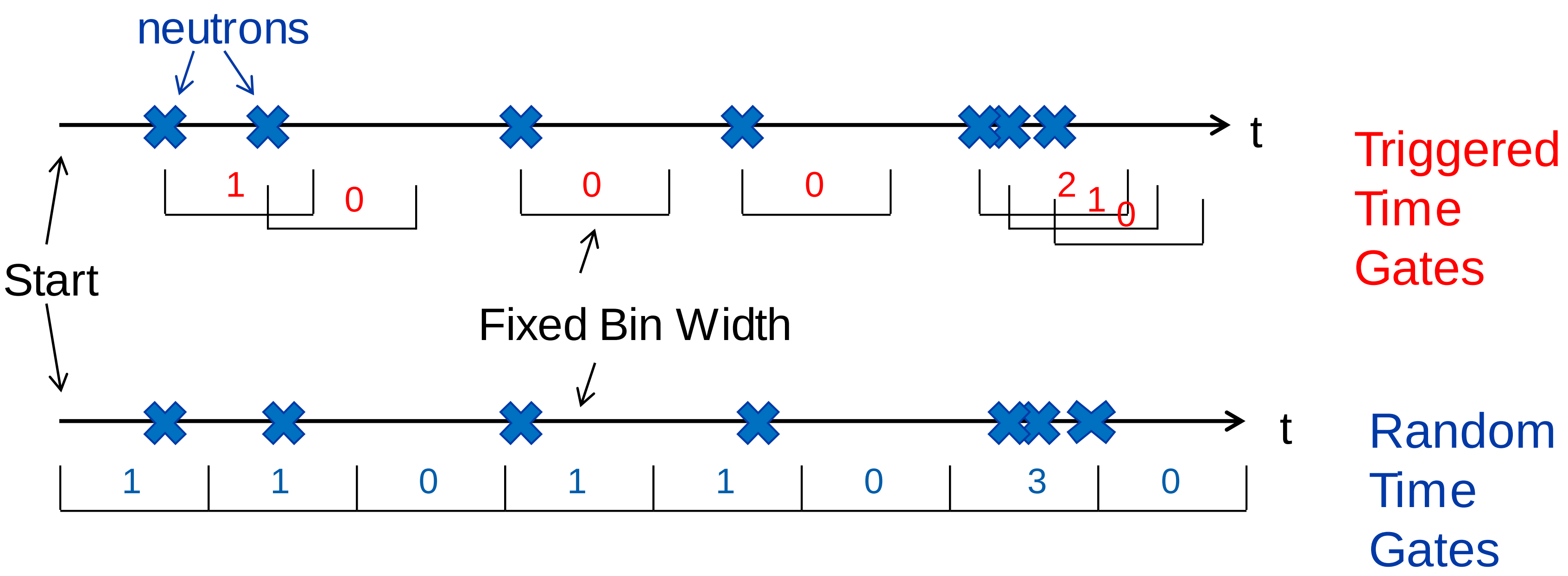




Conclusions

- It is clear that sensitivity to fission production time scale makes fast scintillation detection methods are worth the additional complexity.
- We (LLNL) are continuing to develop "robust" fast neutrons and gamma rays correlation algorithms for detection assay
- We are currently working on better detection methods, particularly better data collection and PSD algorithms suitable for field use.
- Fast Neutron (and Gamma ray) correlation measurements still have many unexplored applications and possibilities.
- We are working on fieldable systems and imaging methods (not reported on here).

Triggered Vs. Random Time Gates – Count Distributions Vs. Moments

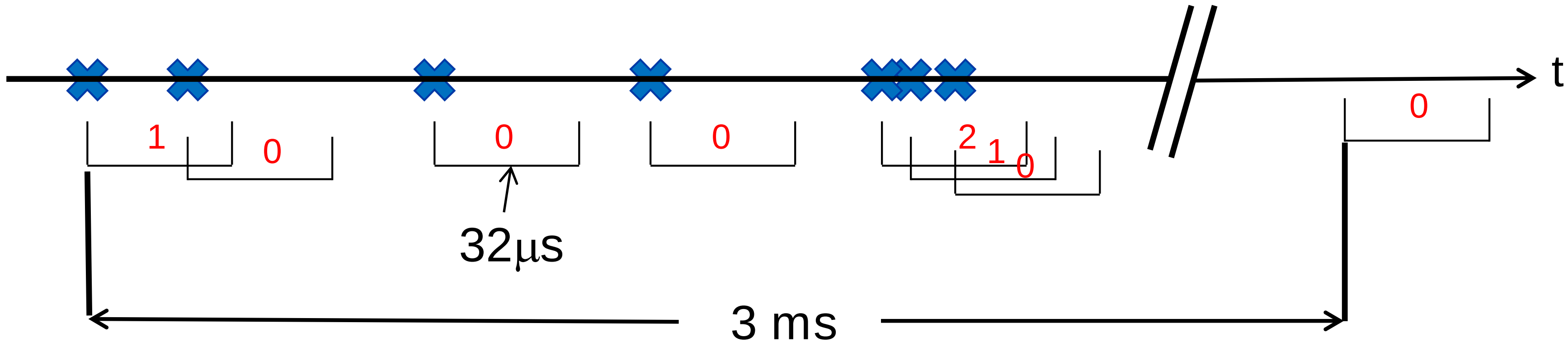


For Given Bin Width – Plot Count Distribution of neutron counts

Or -Turn Counts into Moments – (do combinatorics of count distributions)

1^{st} moment count rate
2^{nd} moment # pairs
3^{rd} moment # triples
...etc.

Shift Registers are Triggered Time Gates



A fixed time gate (e.g. 32μs) is started when a neutron detection is made and then a random gate of the same width is taken a long time later (e.g. 3ms) and the results (presumed to be the random rate) is subtracted.