Photonuclear Physics Models, Simulations, and Experiments for Nuclear Nonproliferation

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Overview

- Motivation and Objectives
- Background
- MCNP-PoliMi Code System
- MCNP–PoliMi Model Description
- Results and Comparison
- Continuing Work
- Summary and Conclusions

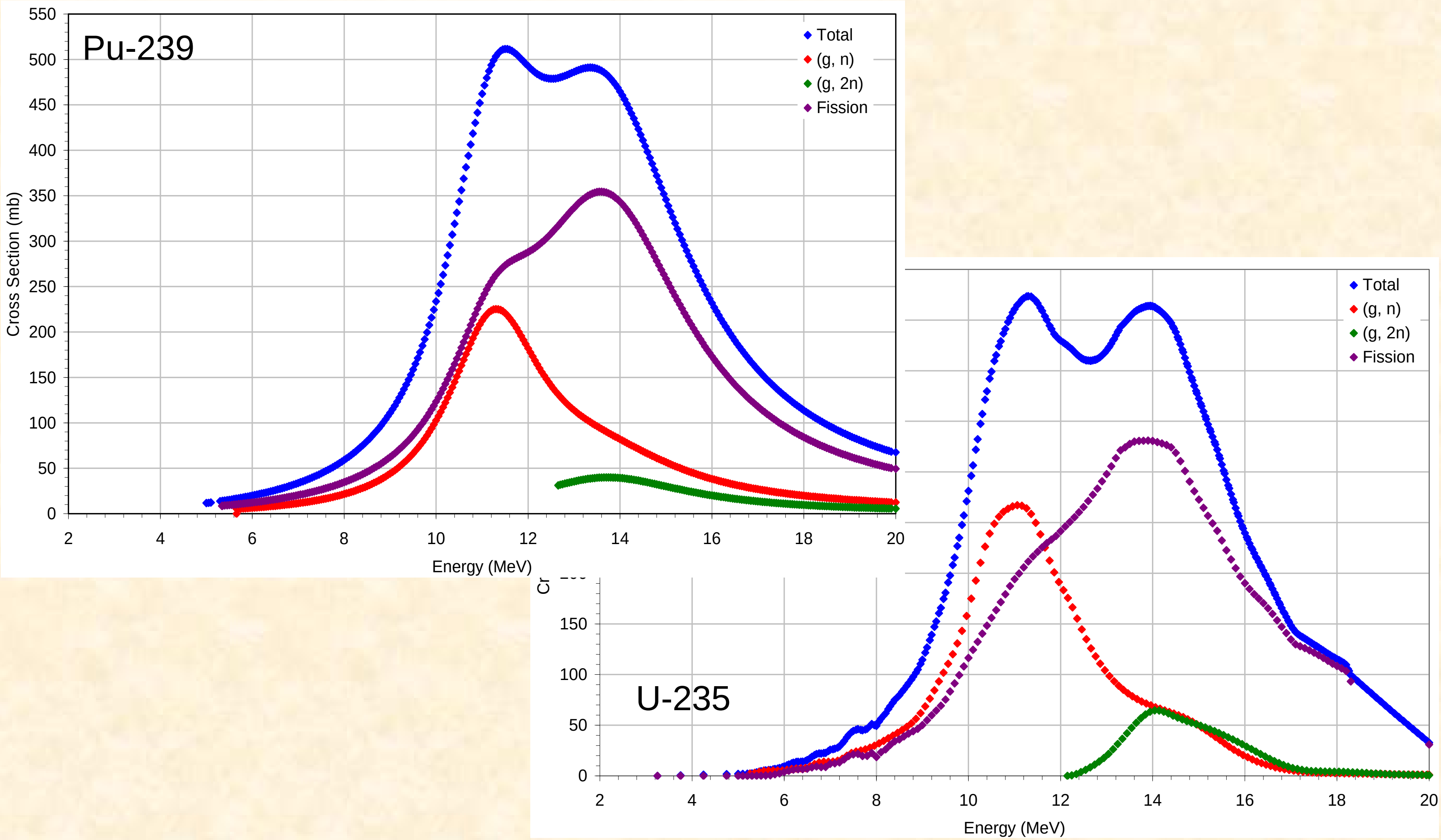
Motivation and Objectives

- Detection of diverted nuclear material is of increasing concern to the United States and other nations
- The most difficult problem is the detection of concealed uranium
  - The low spontaneous fission rate of uranium makes passive detection extremely difficult
- Objective:
  - Develop a system based on active interrogation to aid in the identification and attribution of diverted fissile material
  - This conceptual system is modeled and analyzed with new Monte Carlo codes to determine feasibility and limitations
- The comparisons here are validation of the MCNP-PoliMi code system for modeling such systems

Background
Active Interrogation

- Active interrogation sources are typically high-energy neutrons or photons
- There exist obvious trade-offs between these two particle types as interrogation sources
  - Neutrons have greater penetrability in high-Z materials
  - Photons have greater penetrability in low-Z materials
- Low-Z materials are commonly used in industrial packing applications
  - High-energy photons were chosen for this application

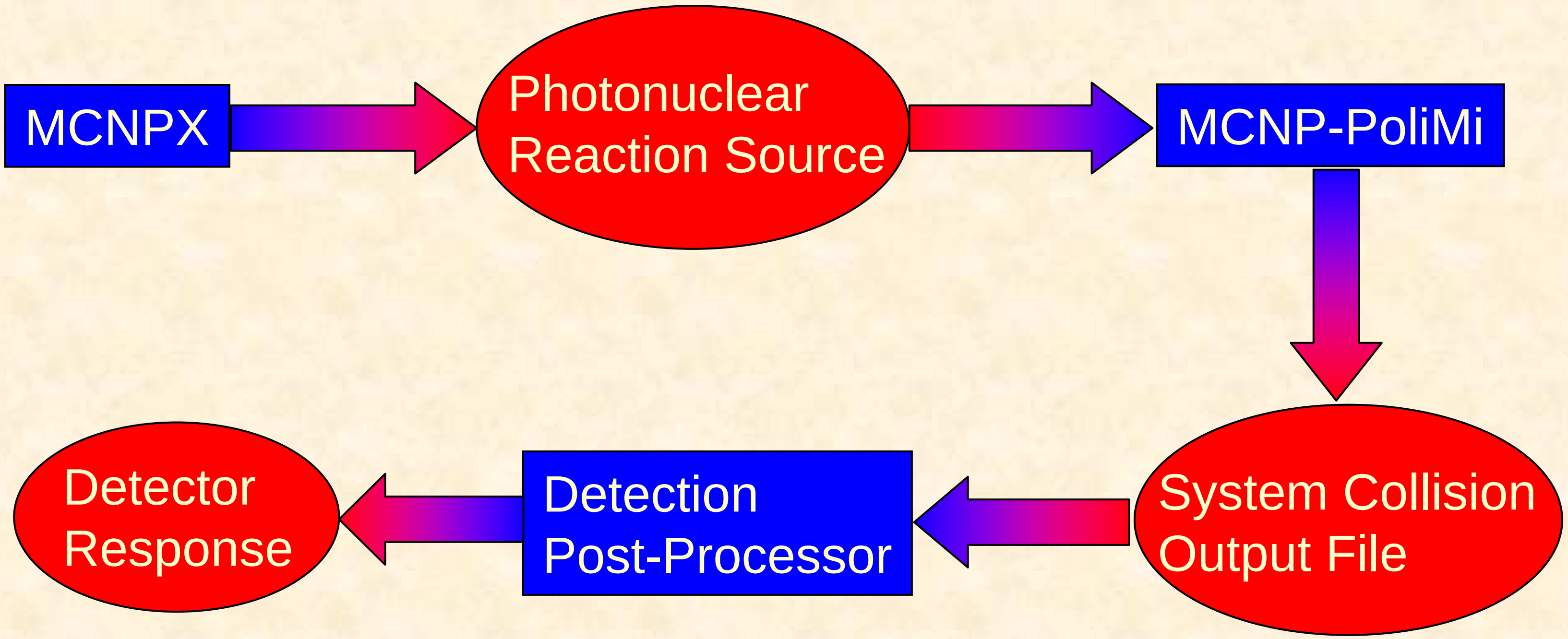
Background
Photonuclear Cross Sections



MCNP-PoliMi Code System
General Description

- Simulates photonuclear events and their progeny in fissile and other materials: (γ, n), (γ, $2n$), and (γ, fission)
  - Prompt neutrons and gamma rays associated with each event are also modeled explicitly
  - These models include some assumptions due to lack of basic photonuclear interaction data
- Simulates detector response to fast neutrons and photons
  - Computes the resulting correlation and multiplicity measurements among detectors

MCNP-PoliMi Code System
Calculation Flow



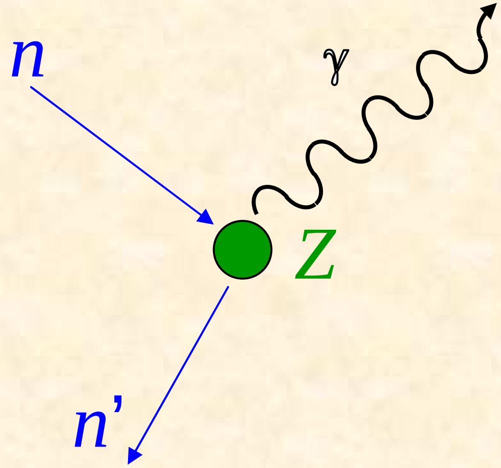
MCNP-PoliMi Code System
Physics of Particle Transport

1. Neutron interactions along with secondary neutron and gamma-ray production are correctly linked
2. Photon interactions along with secondary neutron and gamma-ray production are correctly linked
3. Neutron and photon-induced fission multiplicity distributions have been implemented

Correct simulation of the neutron and photon field in a multiplying (or non multiplying) medium on an event-by-event basis: this is a unique capability of our code system

MCNP-PoliMi Code System
Physics of Particle Transport

Standard MCNP

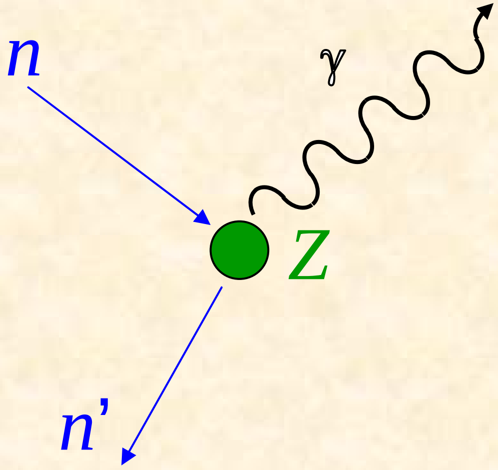


? Elastic scatter neutron

? Inelastic scatter neutron

? Fission …

MCNP-PoliMi



? Elastic scatter neutron

? Inelastic scatter neutron

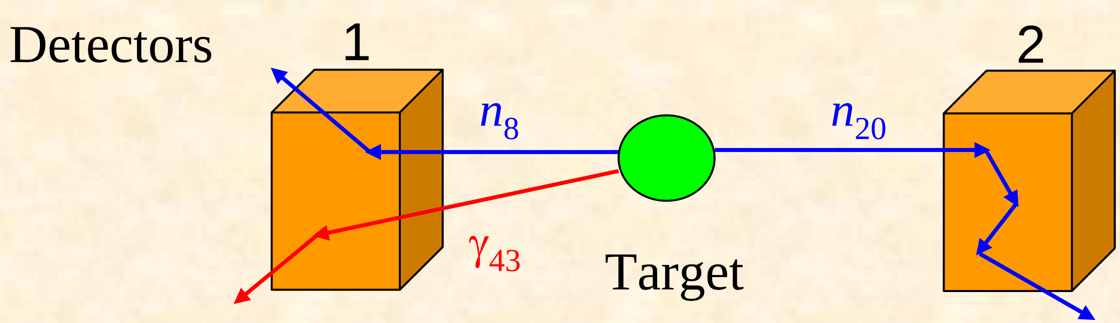
? Fission …

MCNP-PoliMi Code System
Physics of Detection

MCNP-PoliMi collision output file excerpt:

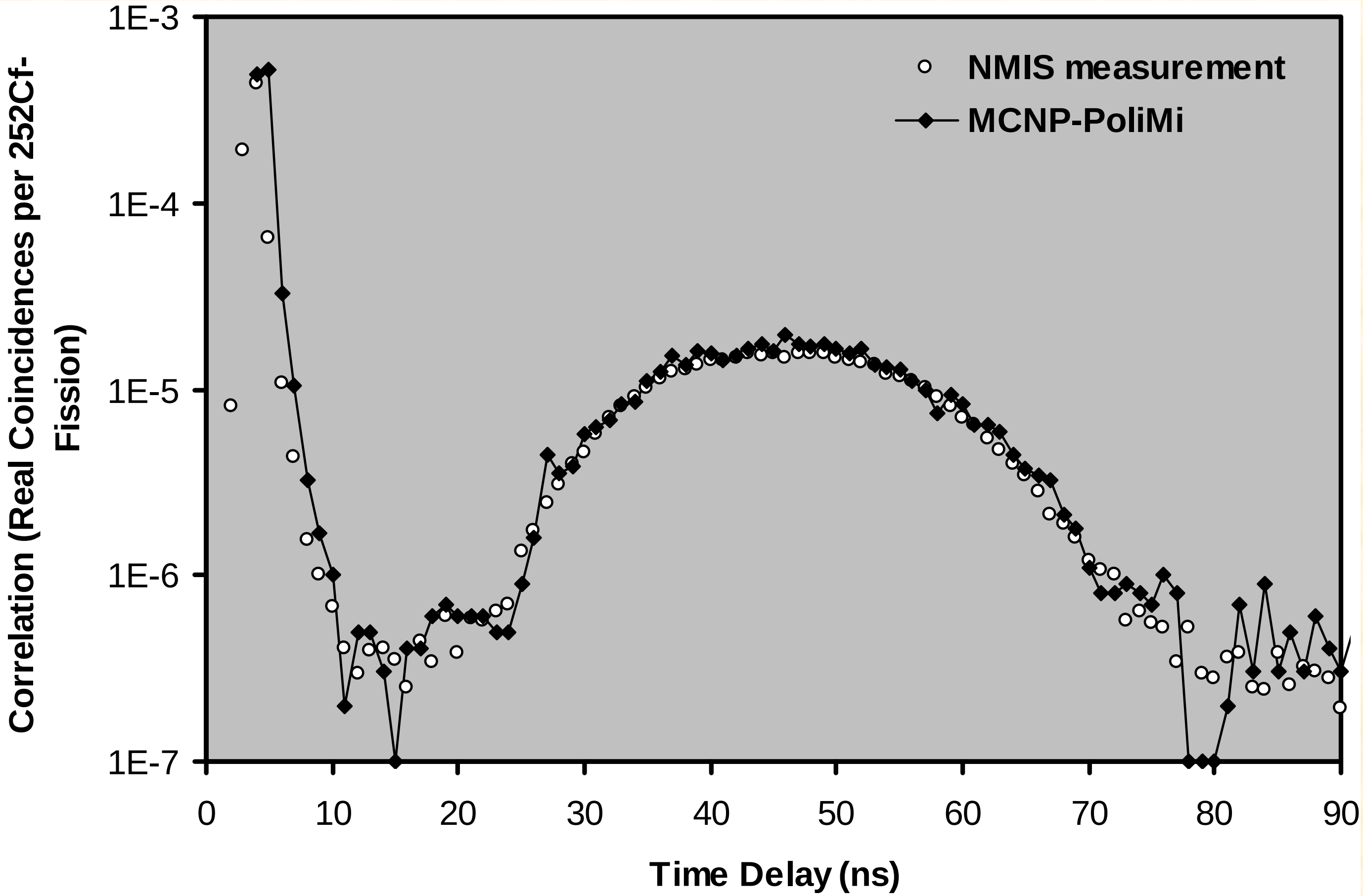
History number	Particle number	Projectile type*	Interaction type^Δ	Target nucleus•	Cell number of collision event	Energy deposited in collision (MeV)	Time (shakes)	Collision position (X)	(Y)	(Z)	Particle weight	Generation number	Number scatterings
...													
29	20	1	-99	1001	2	0.3105	2.743	-25.64	14.37	8.7	1	2	2
29	20	1	-99	1001	2	0.1894	2.846	-26.01	-14.8	9.48	1	2	3
29	20	1	-99	1001	2	0.1617	3.045	-27.27	15.07	10.1	1	2	4
29	43	2	1	6	1	0.7734	6.514	31.83	7.07	11.2	1	2	1
29	8	1	-99	1001	1	0.3731	3.965	27.84	18.82	-0.6	1	0	1
...													

* 1 = neutron; 2 = photon
Δ -99 = elastic scattering; 1 = Compton scattering
• 1001 = hydrogen; 6 = carbon



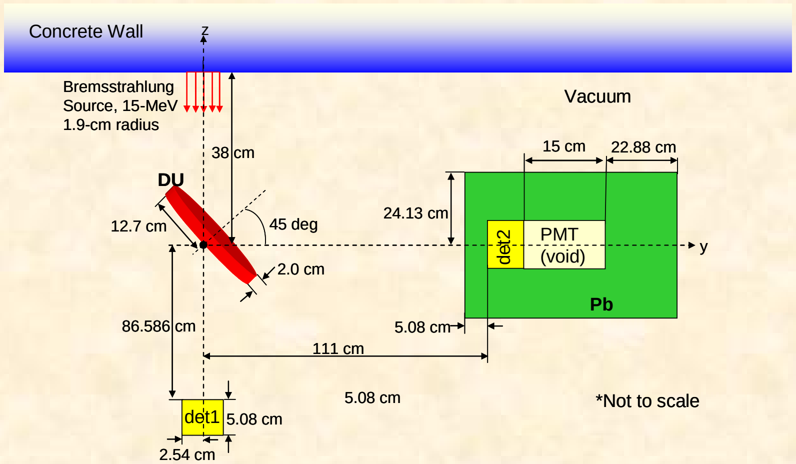
MCNP-PoliMi Code System
Detection Physics Validation

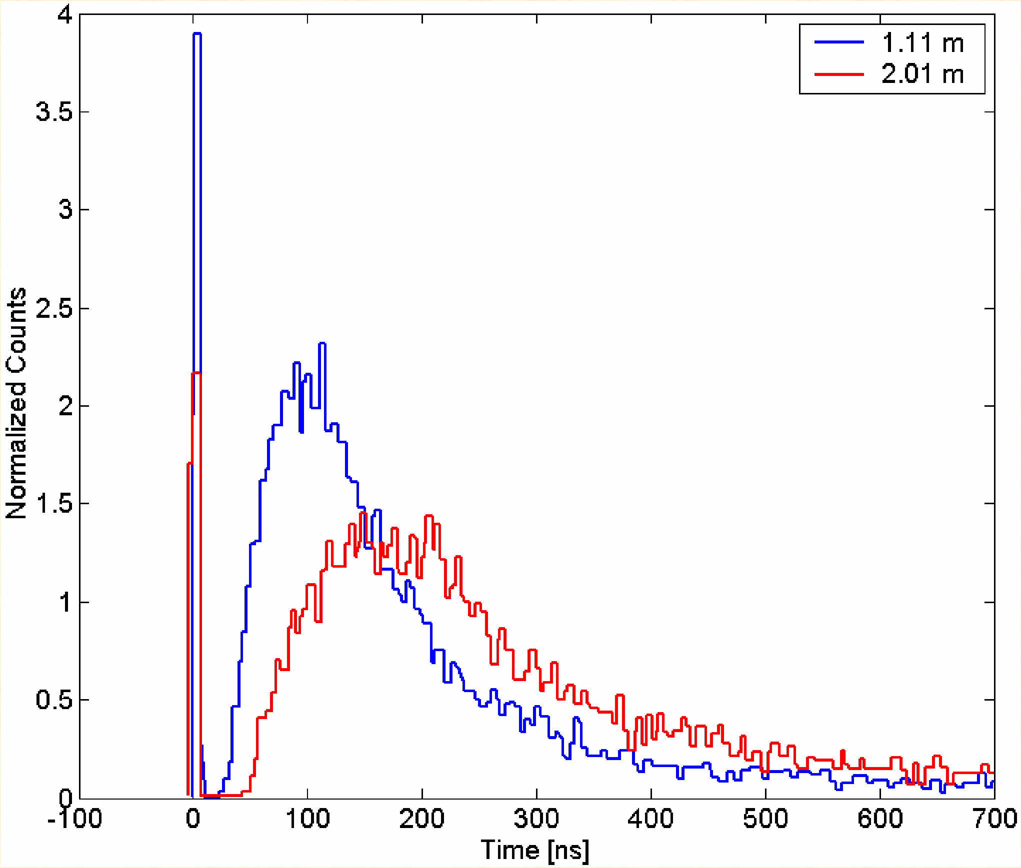
Plastic scintillator: 10.1 × 10.1 × 10.1 cm



MCNP-PoliMi Model
Idaho Accelerator Center (IAC) Setup

- Data was taken by IAC at two different stop detector separation distances

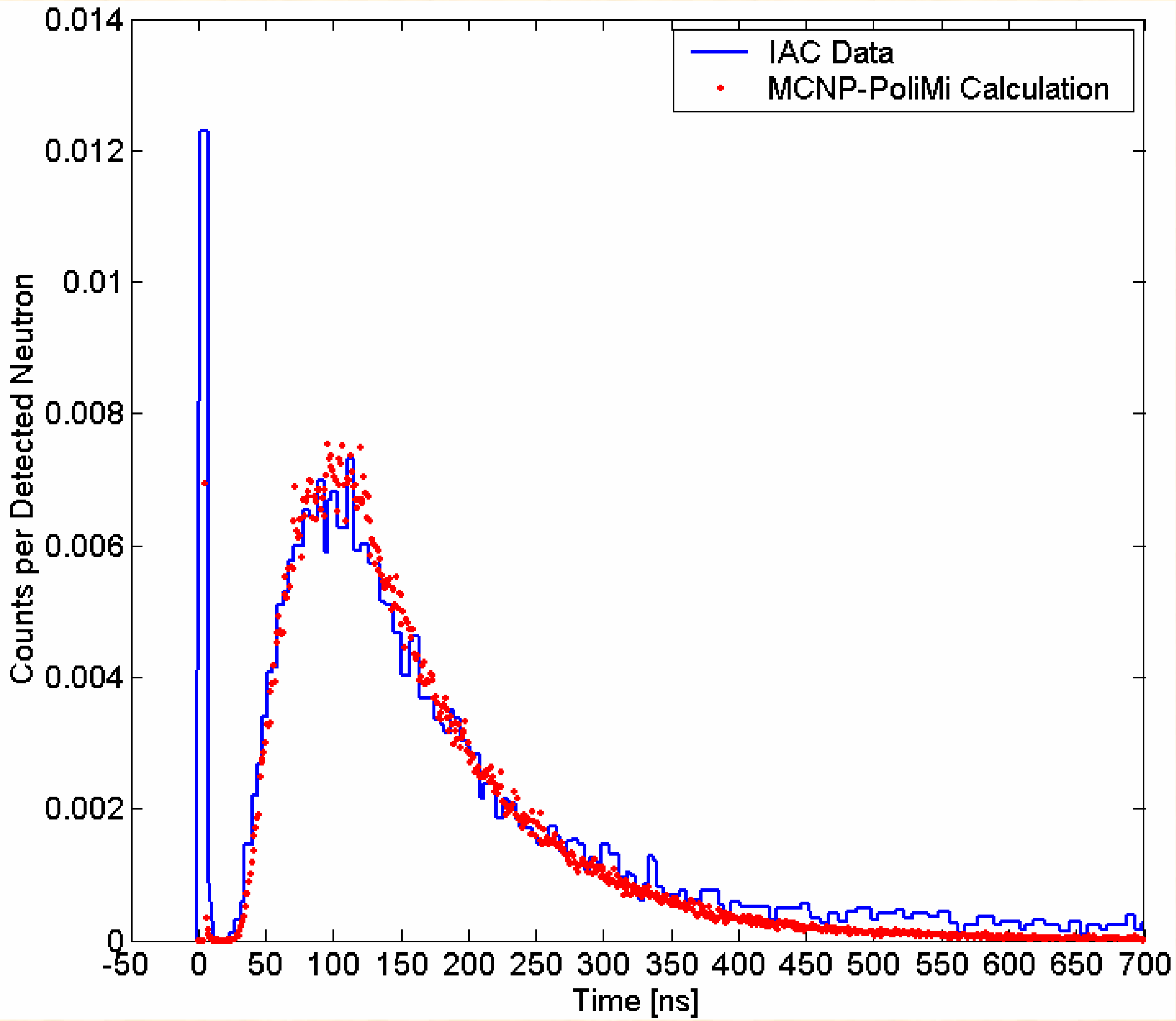




MCNP-PoliMi Model
Considerations and Assumptions

- Collimator and tungsten converter were modeled separately to expedite the calculations
  - A bremsstrahlung spectrum beam with diameter equal to that of the collimator was then implemented
- Detection threshold is a characteristic of the particular detectors
  - A value of 0.001 MeVee was assumed
- MCNP-PoliMi results as well as the experimental data were normalized for comparison
  - Each data set was normalized to the integral of the neutron region

MCNP-PoliMi Results
Comparison to IAC Data, 1.11-m Separation



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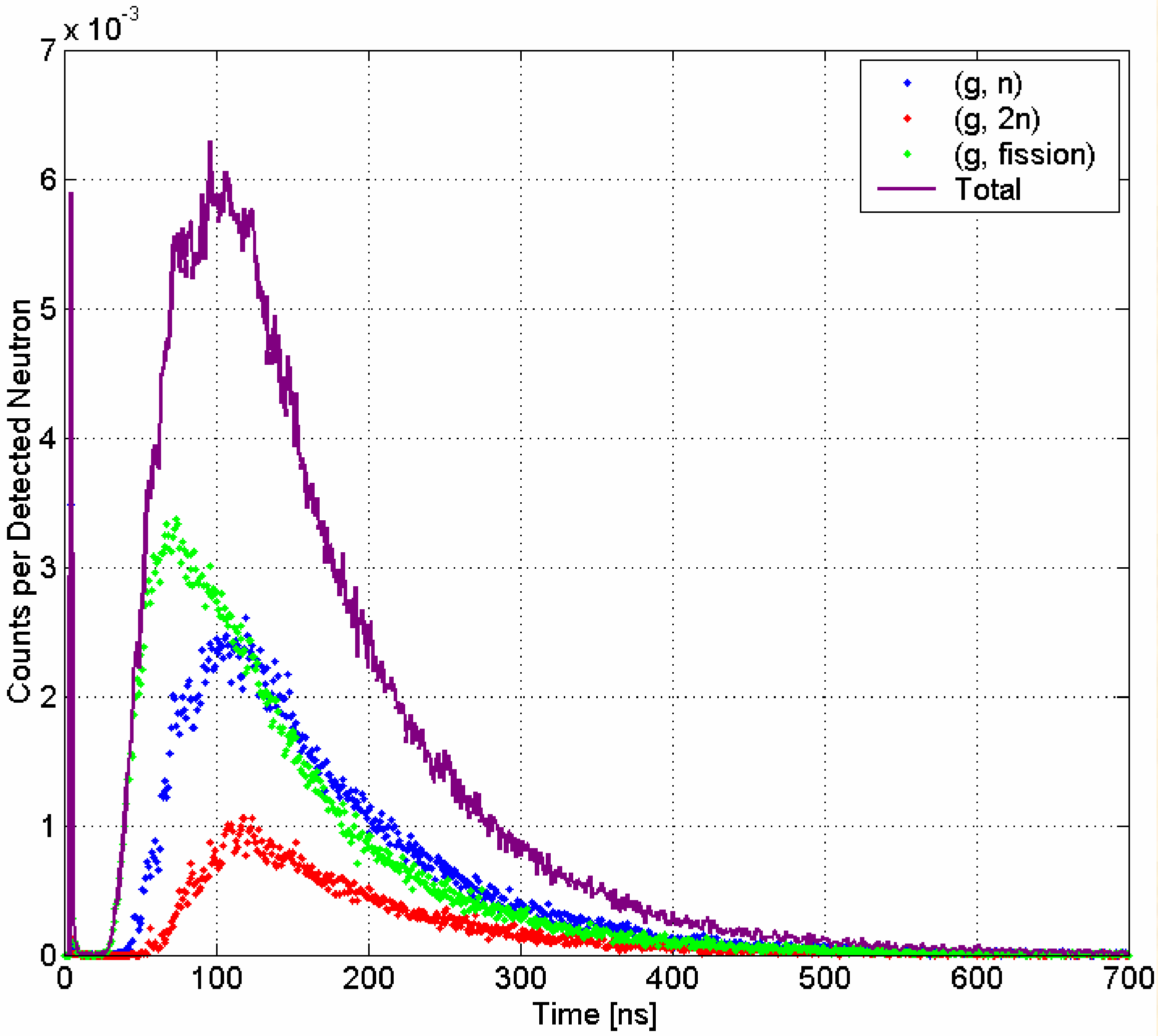
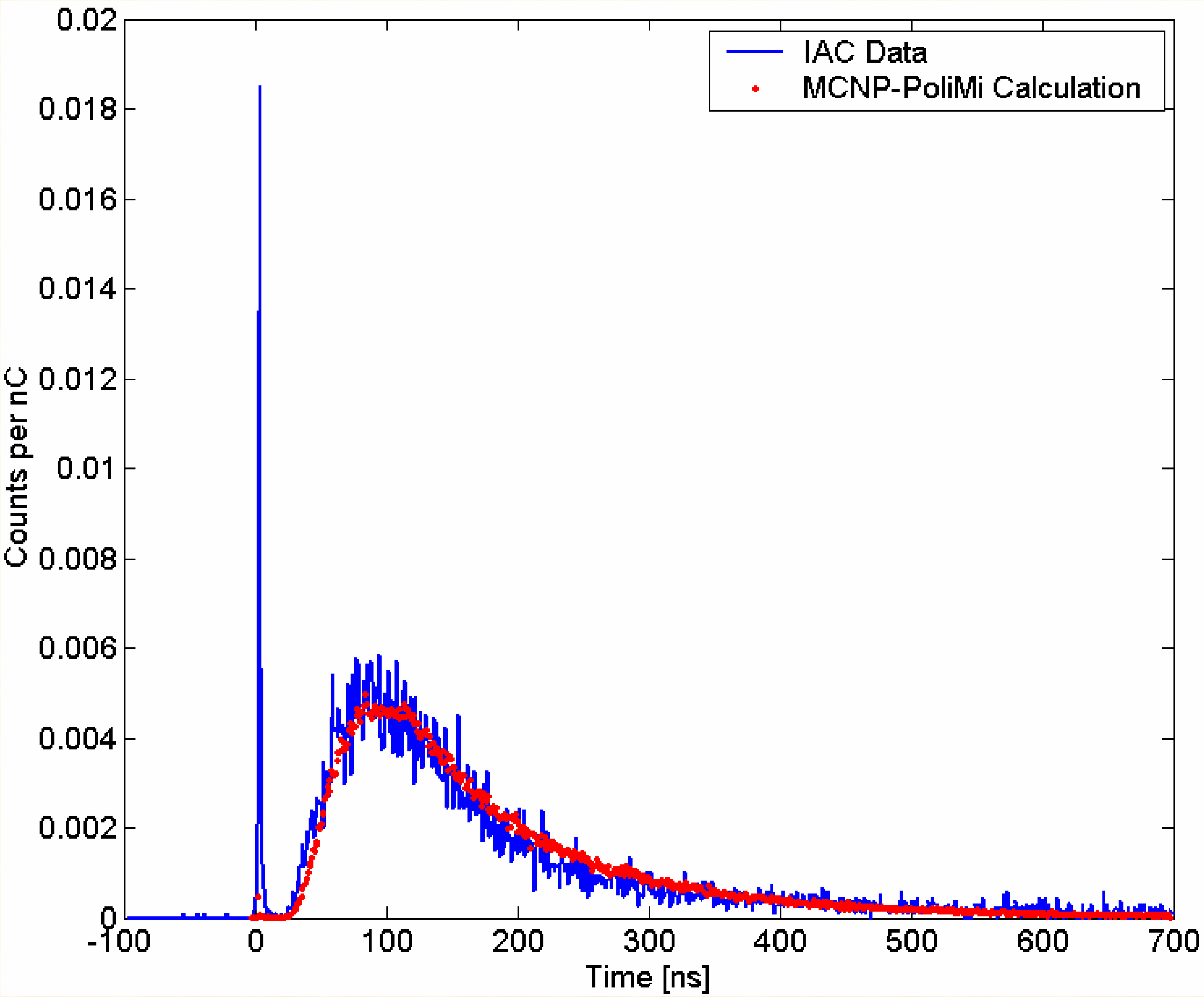
MCNP-PoliMi Results
Reaction-Specific Contributions



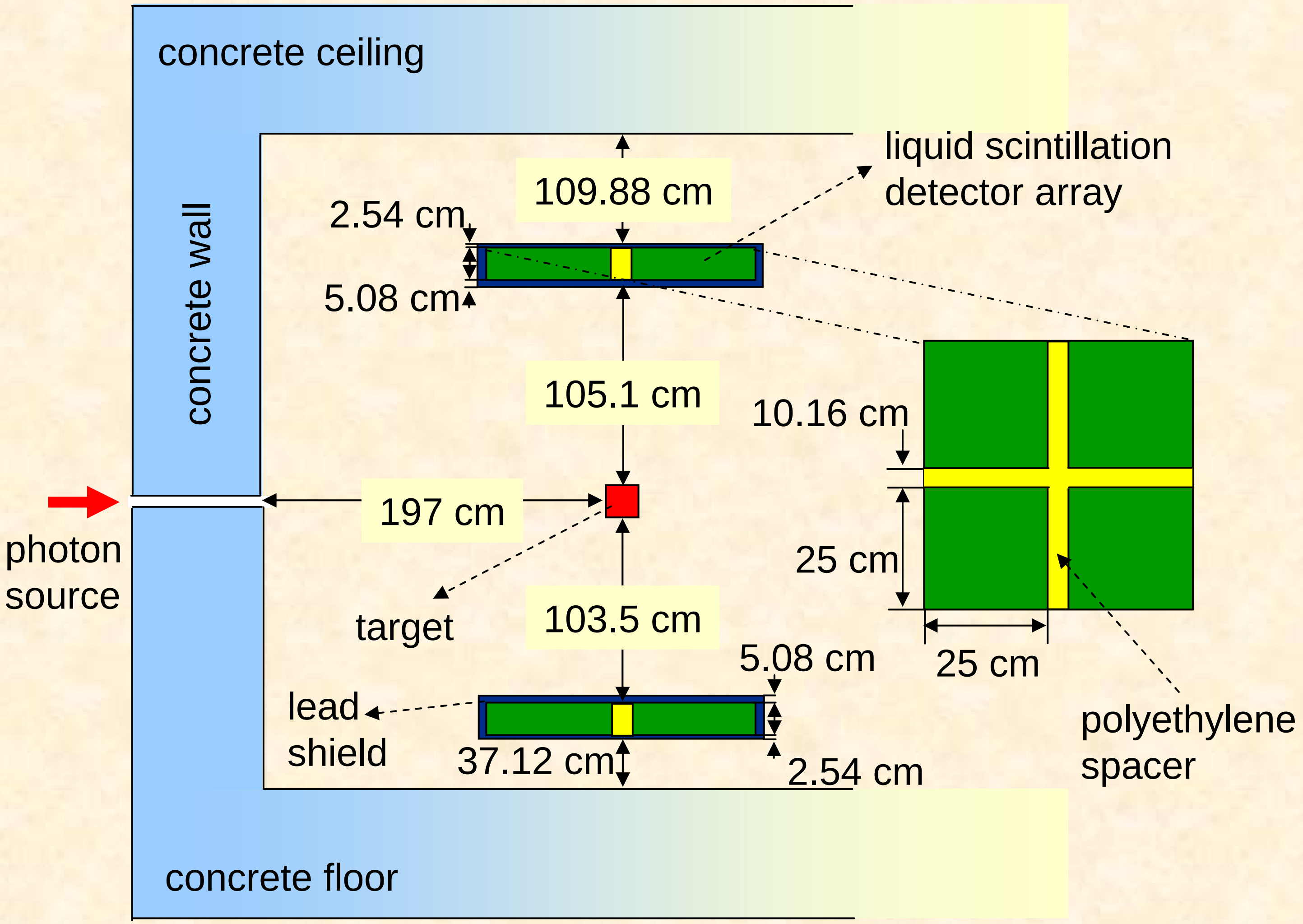
Continuing Work
Absolute Data Comparison

- Efforts are currently under way to compare MCNP-PoliMi calculations to experimental data in an absolute manner
- Previously shown results were normalized and attest only to our ability to compare the shape of the data, not the magnitude, for small plastic detectors
- Future results will be expressed in absolute units such as counts per nanoCoulomb of accelerator charge
  – The first tests of this capability use data taken from the same system as shown earlier with 21-MeV photons
  – The second tests use larger, 25 by 25-cm, liquid detectors

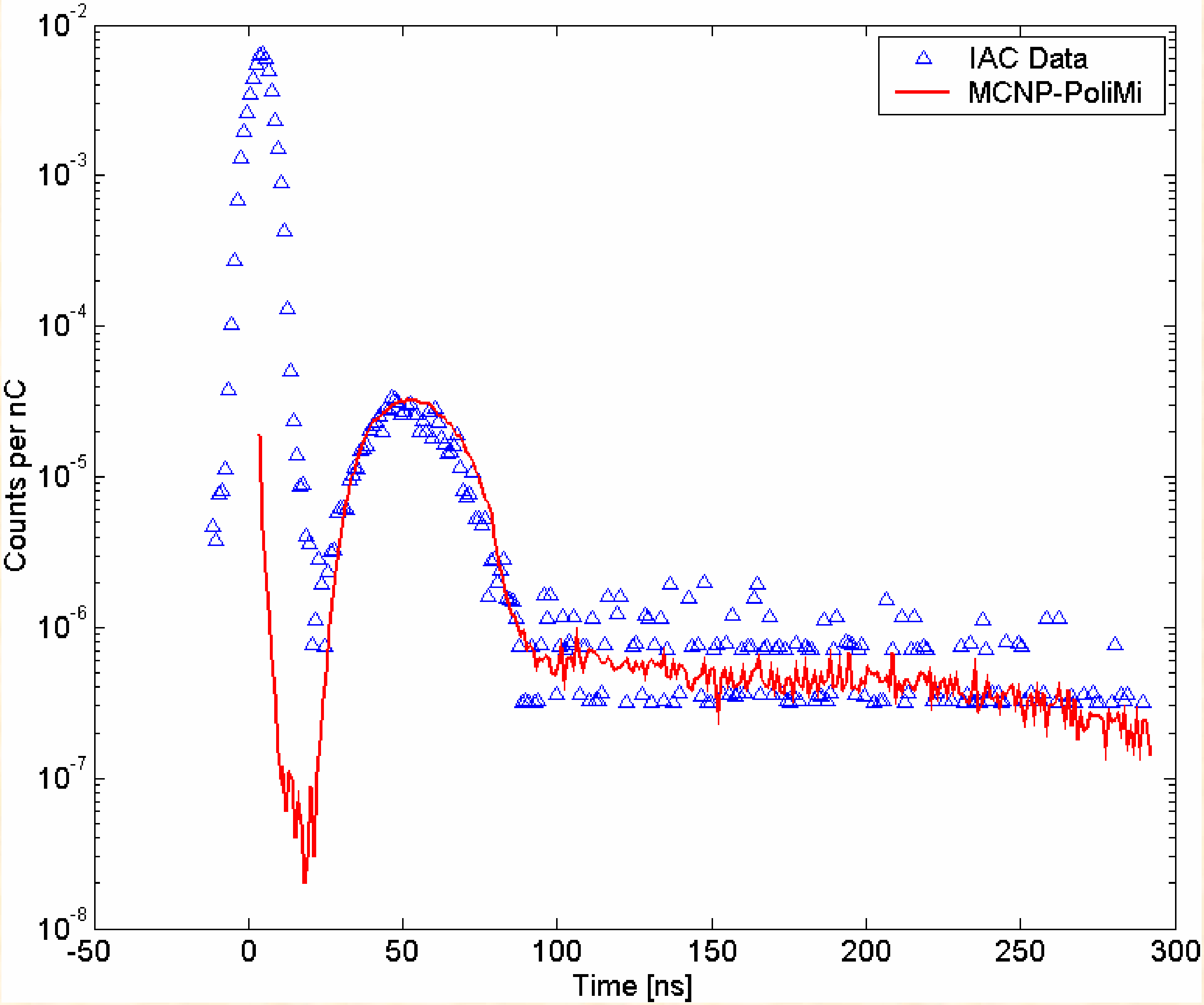
Continuing Work
Absolute Comparison, 21MeV, 2" detector



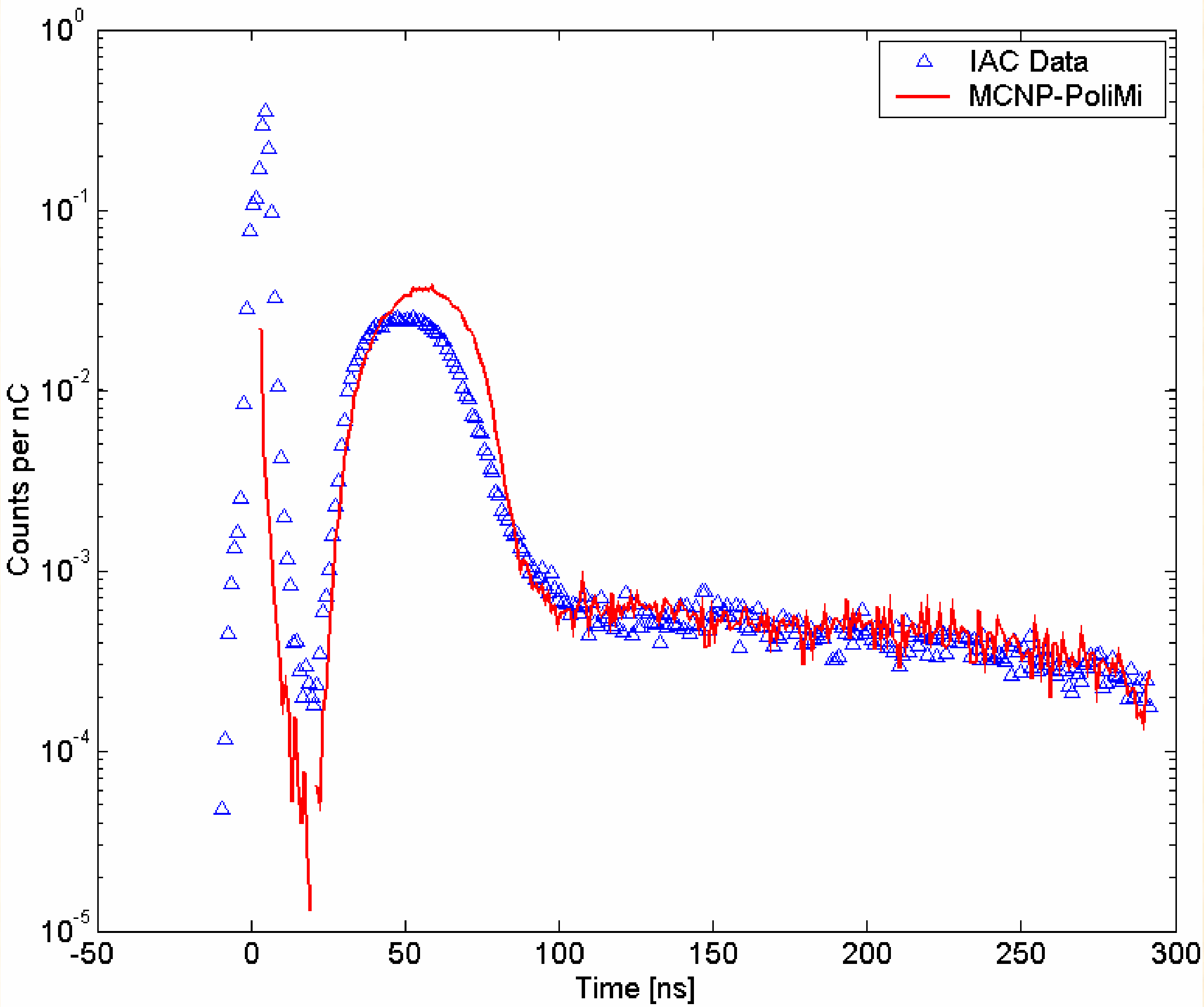
Continuing Work
Absolute Comparison Model



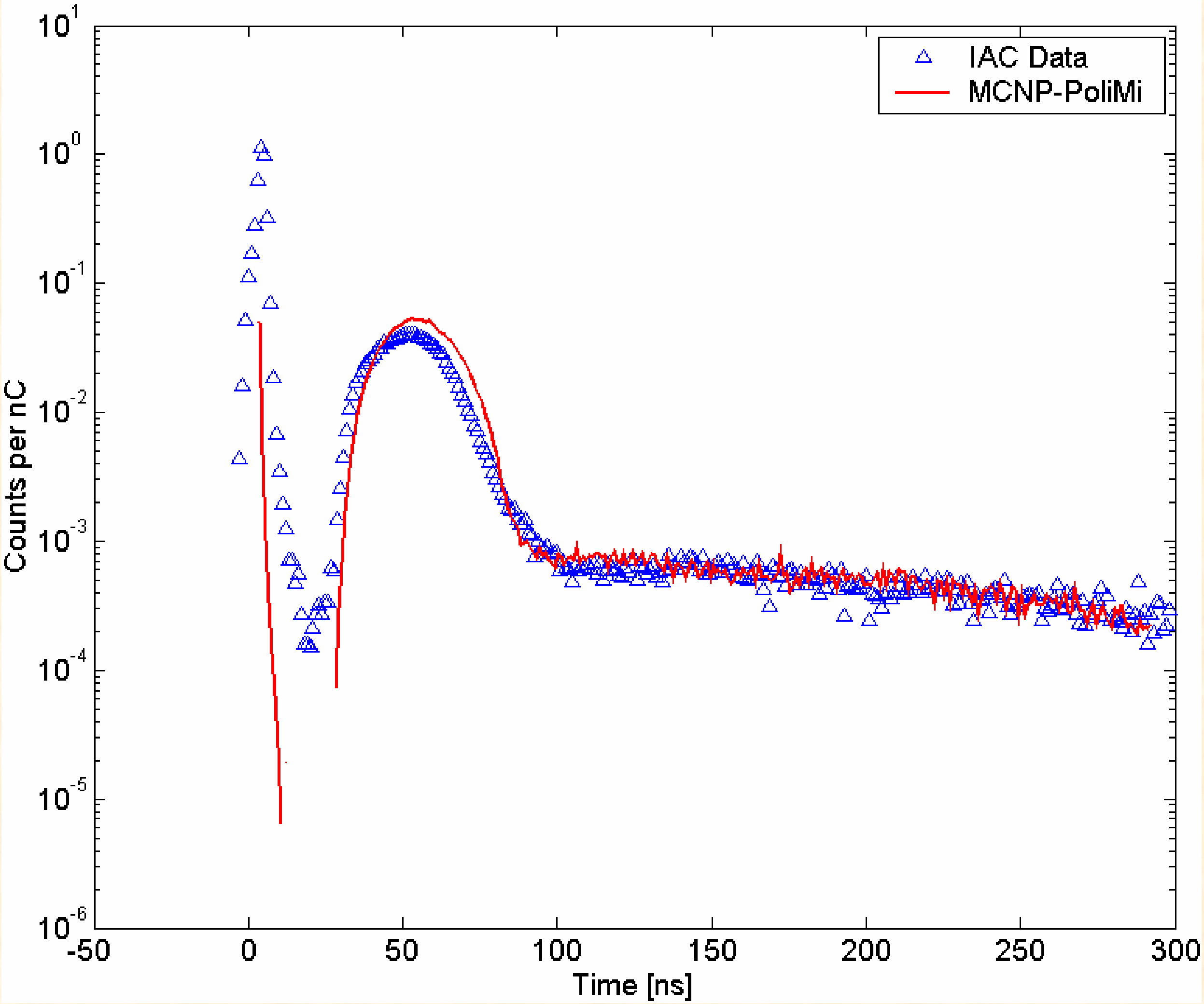
Continuing Work
Absolute Comparison, DU, 6.5 MeV Beam



Continuing Work
Absolute Comparison, DU, 15MeV Beam



Continuing Work
Absolute Comparison, Pb, 15MeV Beam



Summary and Conclusions

- Our MCNP-X/MCNP-PoliMi code system is a unique tool that is instrumental in simulating scenarios of interest in homeland security and nuclear nonproliferation
  - Can correctly simulate the neutron and photon field generated in active interrogation using neutrons and photons
  - A specialized post processing code has been developed to model accurately the response of plastic scintillation detectors
- Comparisons of experimental data and code results show excellent agreement for low energy and/or small detectors
  - Can simulate not only the shape of the photonuclear response, but also the amplitude
- Continuing work is focused on resolving the discrepancies for the larger detectors and high energy

Acknowledgement

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