Monte Carlo Analysis of the Statistics of Neutron Detection by Organic Scintillators

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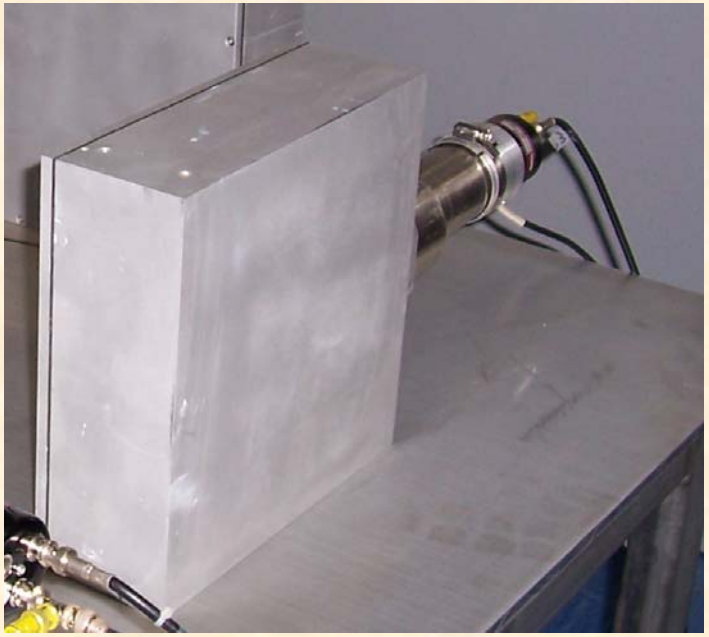
Objective

- Monte Carlo analysis of event-by-event neutron detection in organic scintillators
- Comparison of simulations with experimental data
- Analytical formulation of neutron detection

Organic Liquid and Plastic Scintillators



- Sensitive to fast neutrons and gamma rays
- Scintillation pulse generated in the material by
  - H elastic scattering
  - C elastic and inelastic scattering

Main Features of MCNP-PoliMi

The modifications performed to MCNP-4C can be grouped into two subsets:

- Physics of particle transport
- Physics of detection

Main Features of MCNP-PoliMi Physics of Particle Transport

1. Neutron interaction and secondary gamma production are correctly linked
2. Neutron and gamma fission multiplicity distributions have been implemented

- Simulation of the full statistics of neutron and gamma rays in multiplying (and non-multiplying) media
- Analog simulation

Physics of Particle Transport Program Flow

MCNP

Secondary Gamma Generation → Neutron Collision Type

MCNP-PoliMi

Neutron Collision Type → Secondary Gamma Generation

Physics of Particle Transport Secondary Gamma Generation

MCNP-PoliMi: Secondary gamma generation is based on the principle of conservation of energy at each neutron interaction and relies on the data present in the ENDF-Based MCNP libraries. Approximations were made as necessary.

Main Features of MCNP-PoliMi Physics of Detection

Detailed information on the interactions of neutrons and gamma rays in user-defined cells (typically detectors) is printed to file, to be analyzed with a post-processing code

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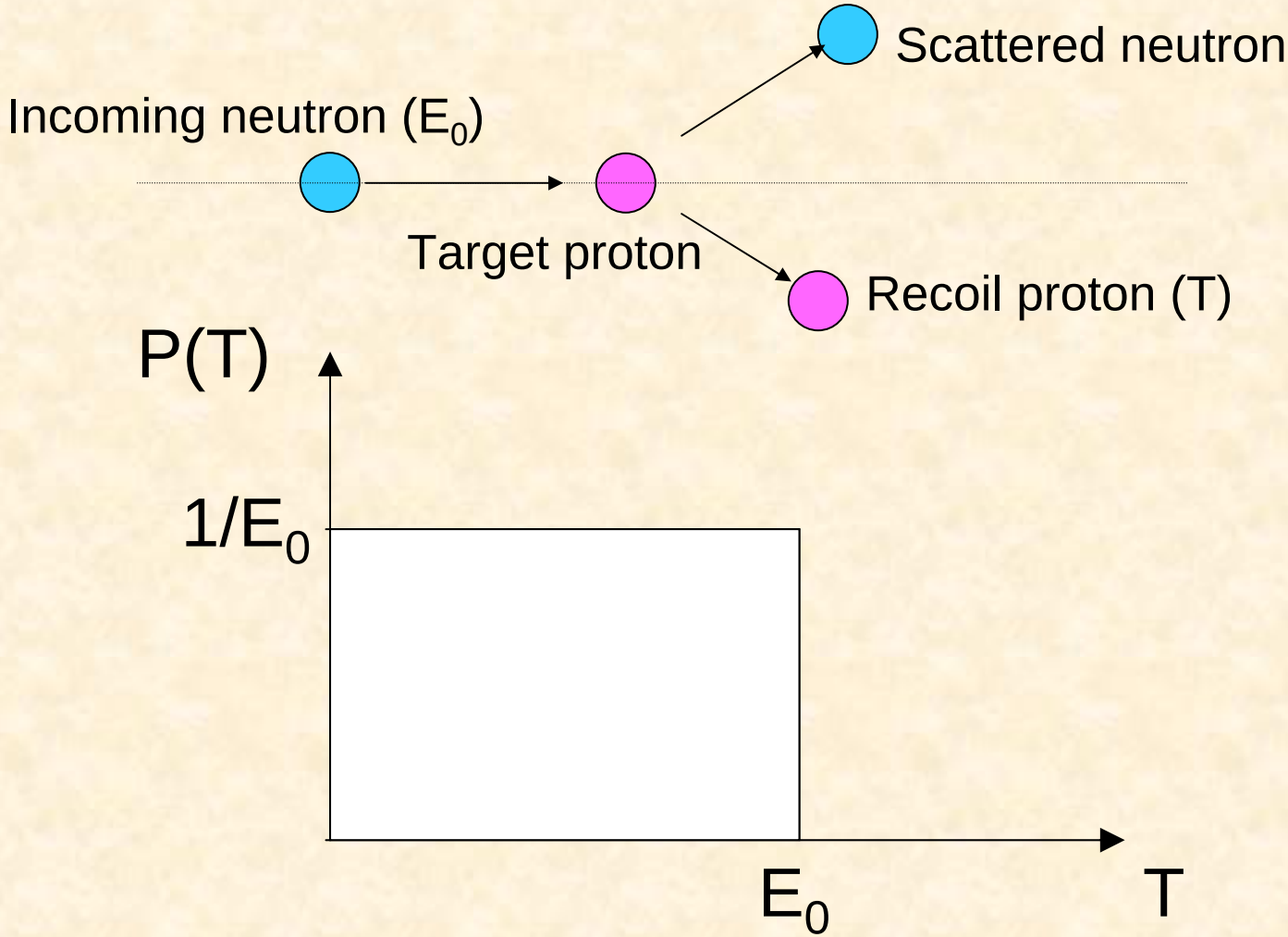
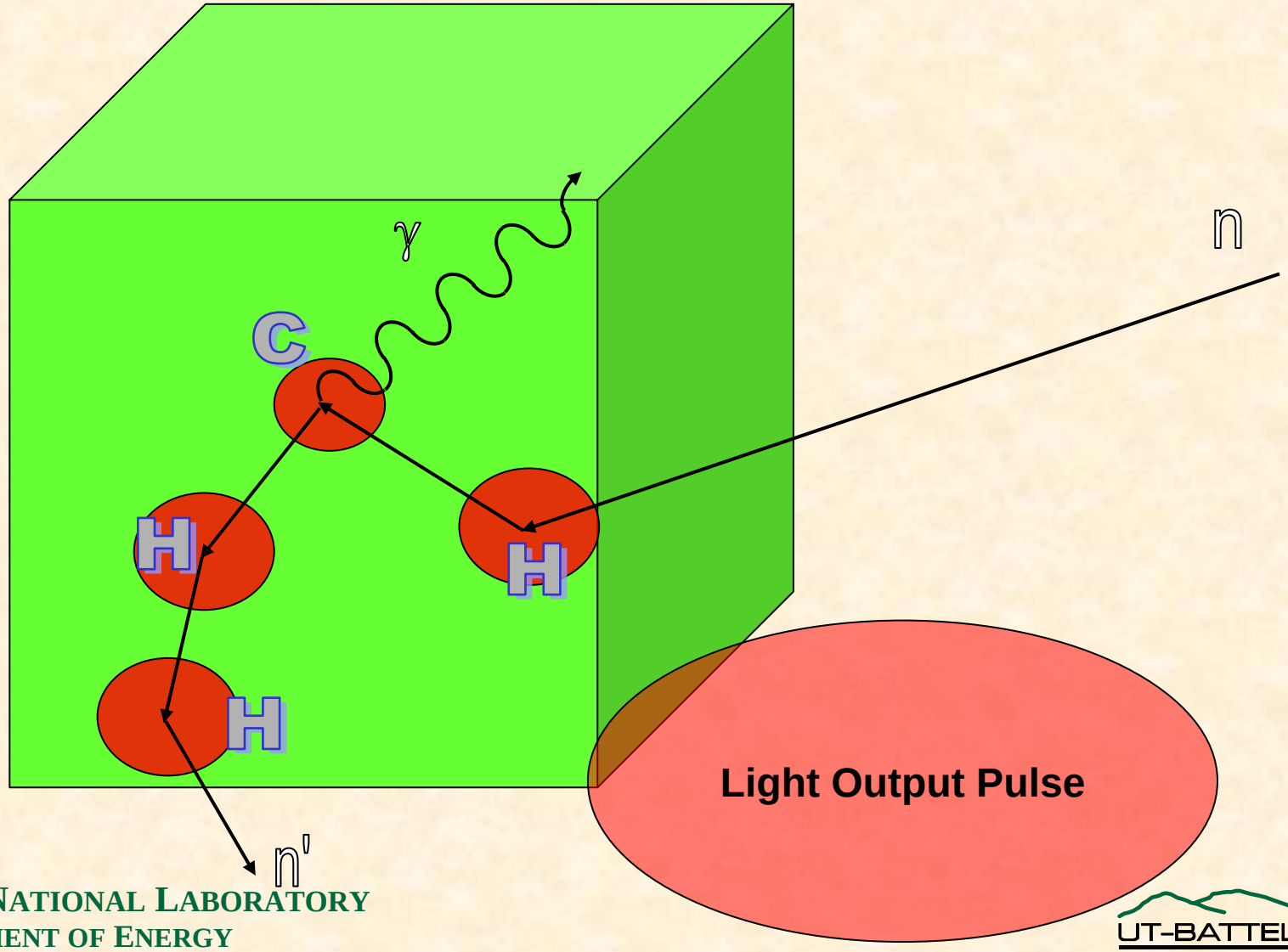
Improved simulation of detector response

Organic Scintillators



Mechanisms of Detection in Organic Scintillators



Simulation of Light Output in Scintillators: Gamma Ray

Gamma rays interact by Compton scattering on electrons.
The light output (*L* in MeVee) is related to the energy deposited
(*T* in MeV)

$$L(T) = A \cdot T$$

with *A* = 1 MeVee/MeV

Simulation of Light Output in Scintillators: Neutrons

For H scattering, the relationship between energy deposited (*T* in MeV) and light output (*L* in MeVee) is

$$L(T) = aT^2 + bT$$

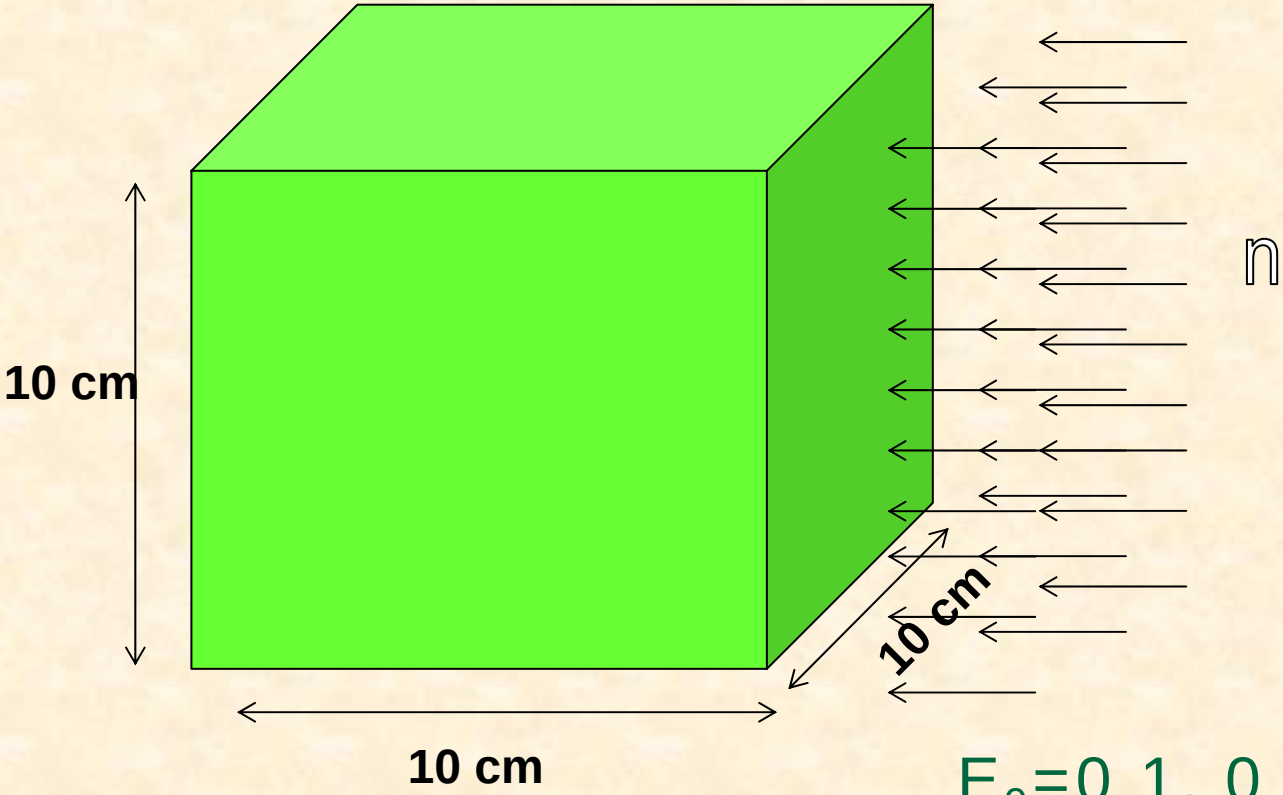
with *a* = 0.035 MeVee/MeV^2 and *b* = 0.141 MeVee/MeV for liquid scintillators.

For C scattering, the light output is very small,

$$L(T) = cT$$

with *c* = 0.02 MeVee/MeV.

MCNP-PoliMi Simulation Geometry

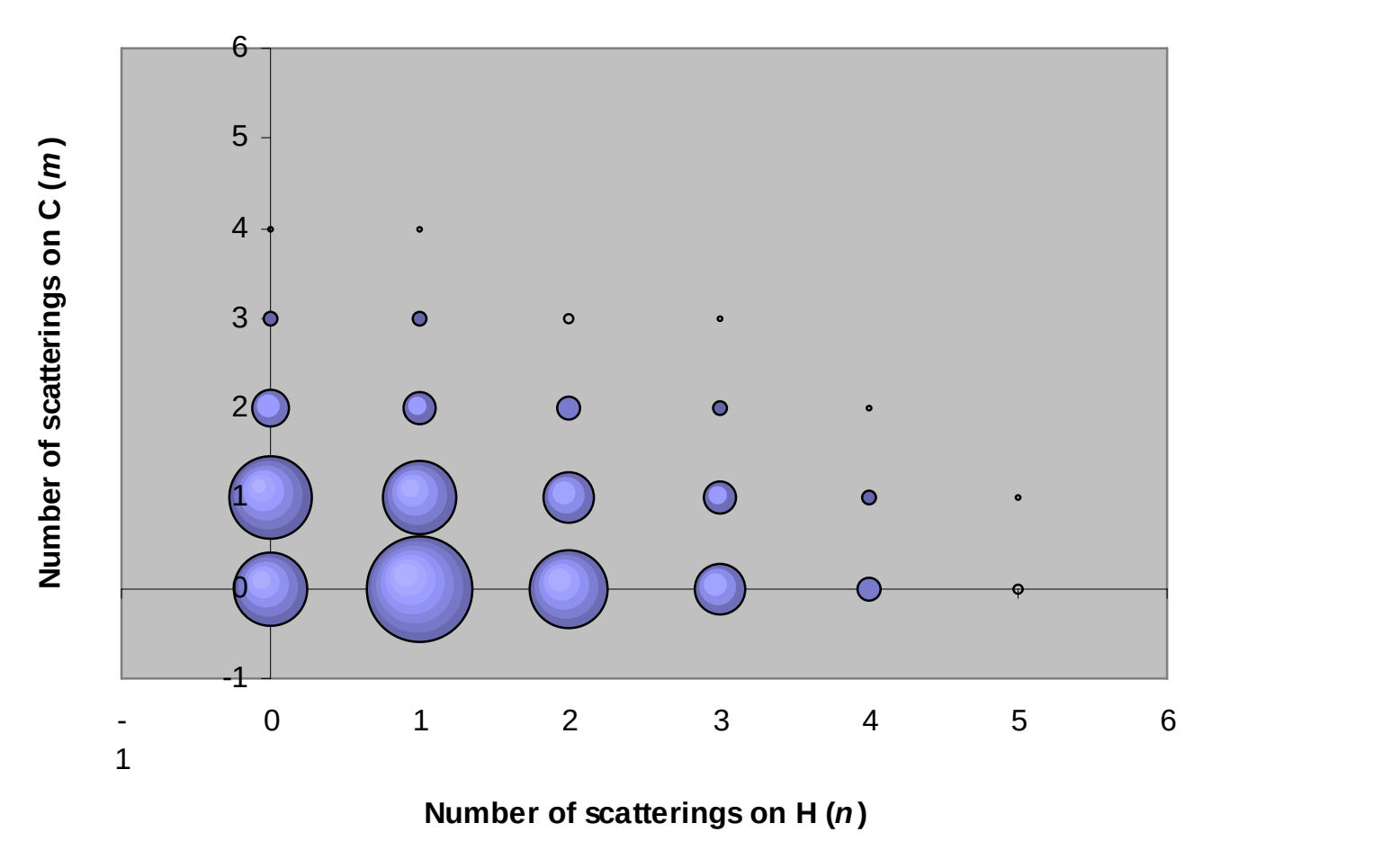


H:C ratio 0.548:0.452

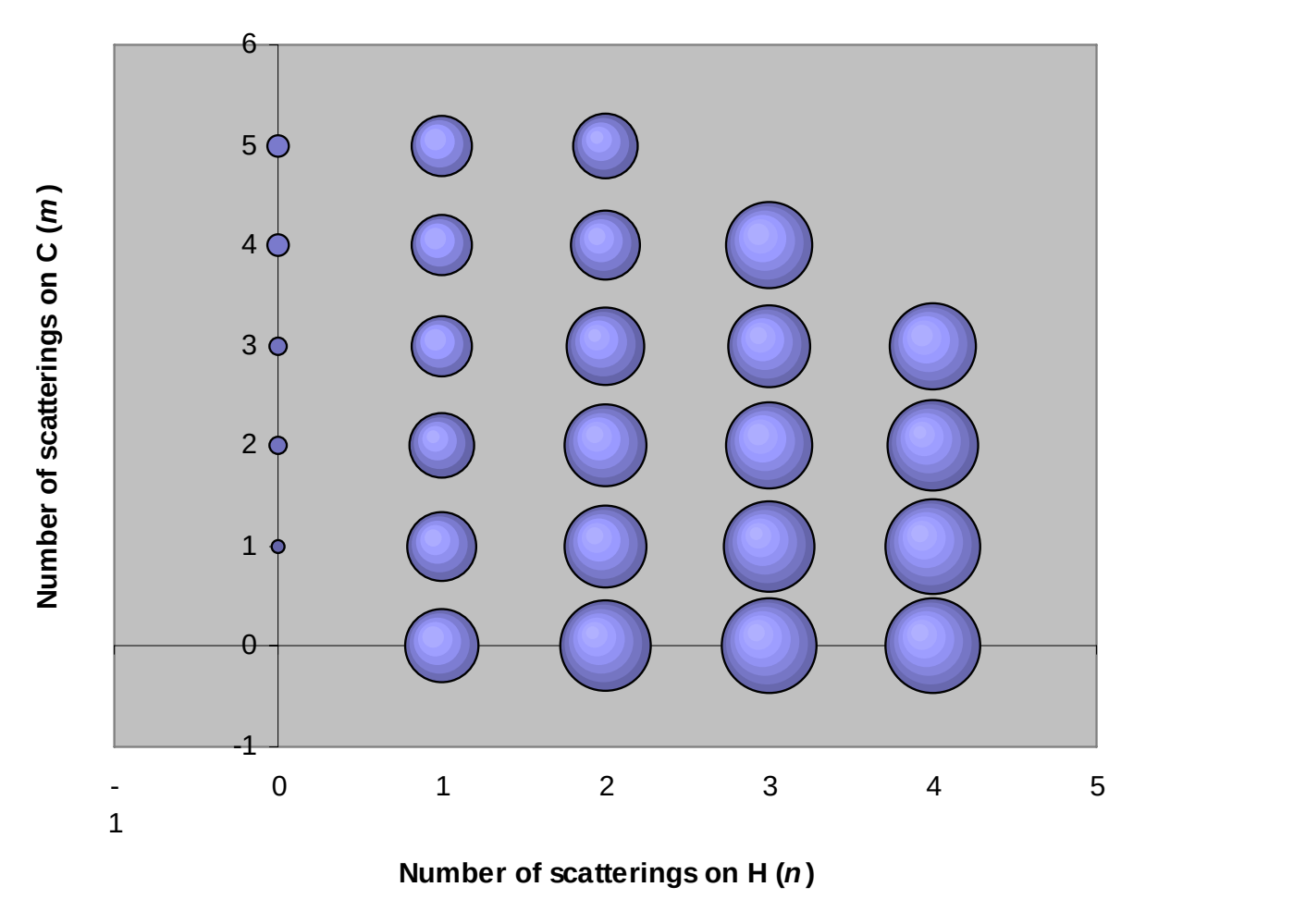
Density 0.96 g/cm^3

E_0=0.1, 0.2, ...
5 MeV, with energy distributed uniformly in 0.1 MeV intervals

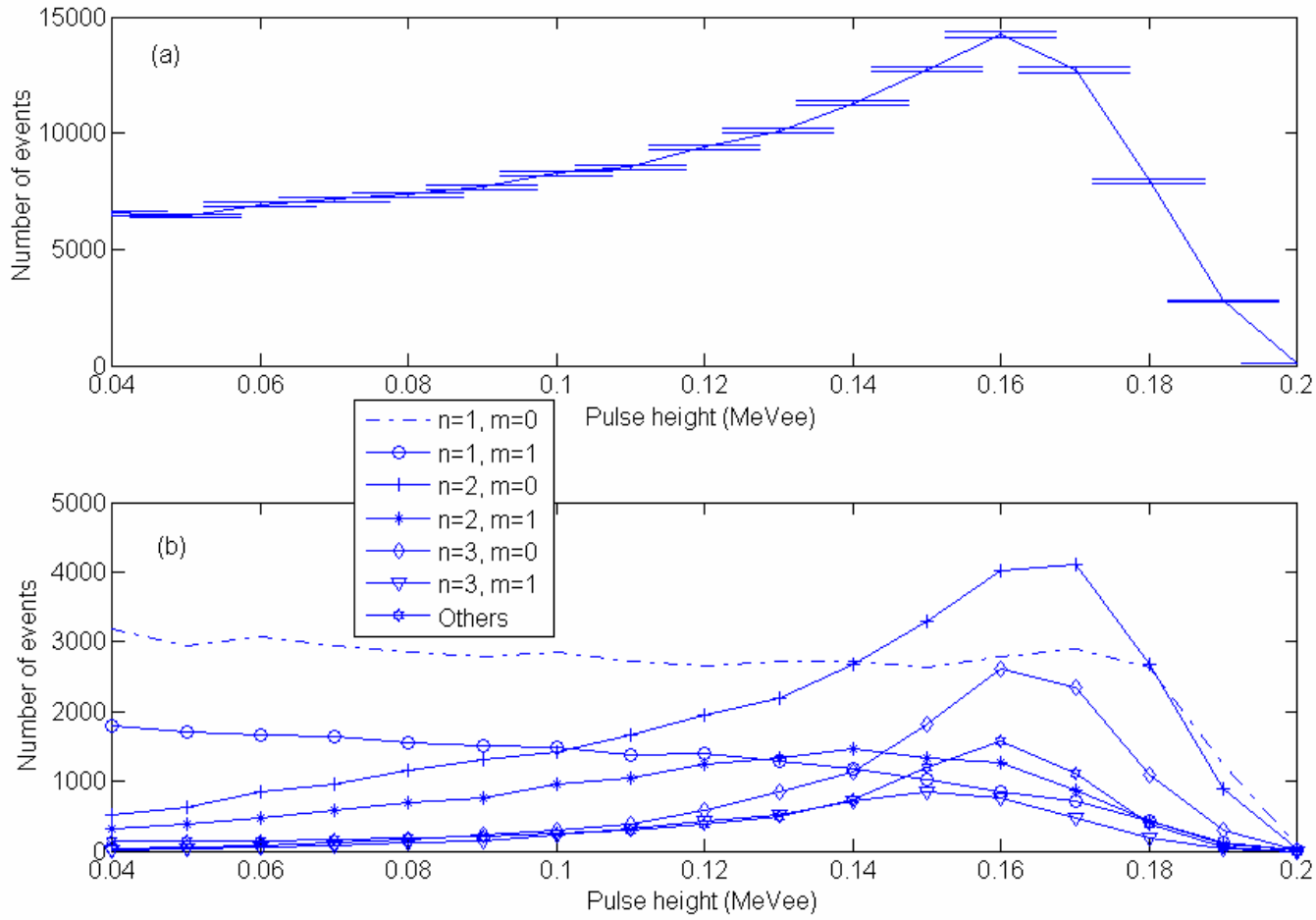
Probability of *n* scatterings on H and *m* on C in Liquid Organic Scintillator



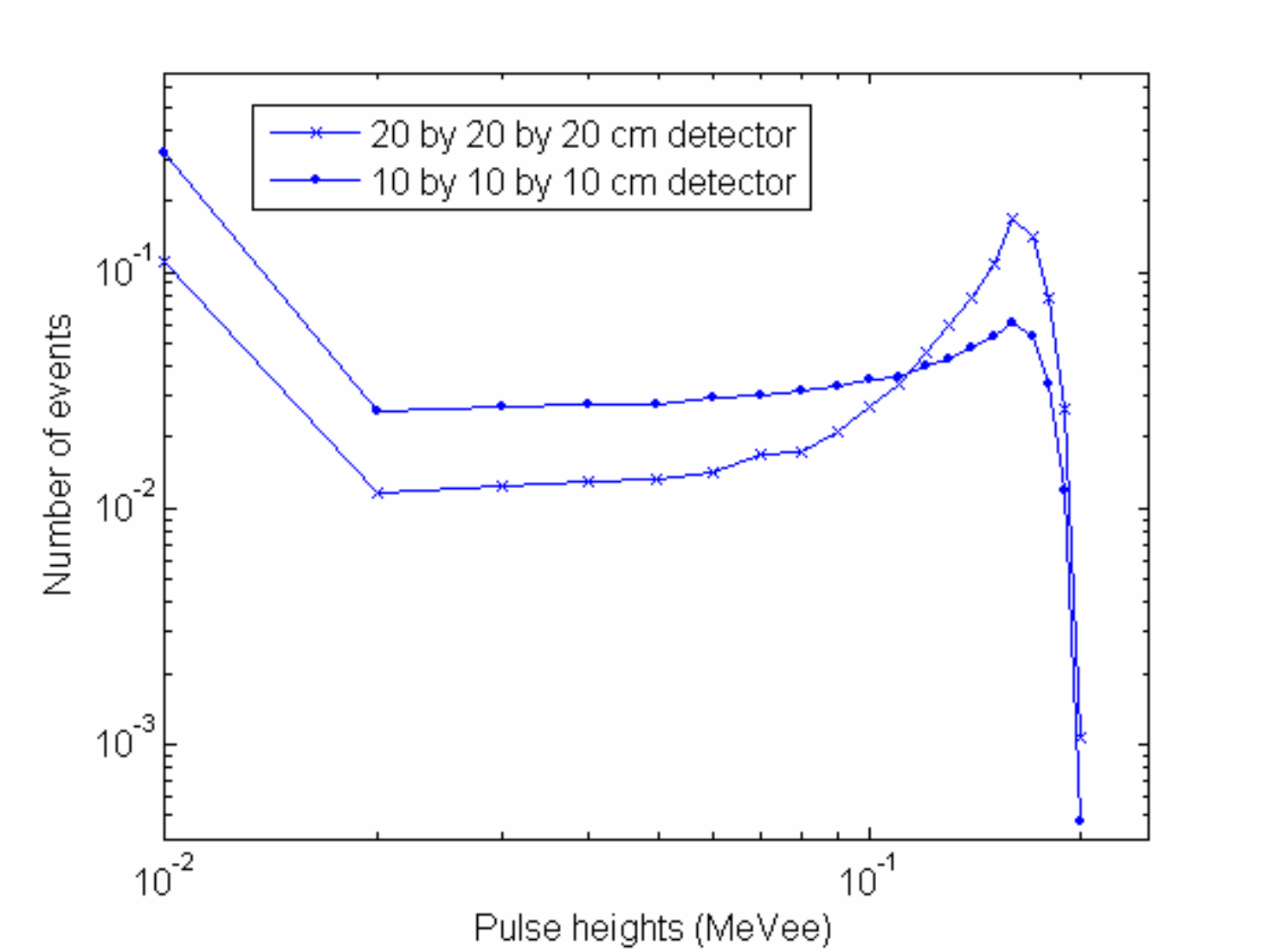
Pulse Height Distributions for Liquid Organic Scintillator



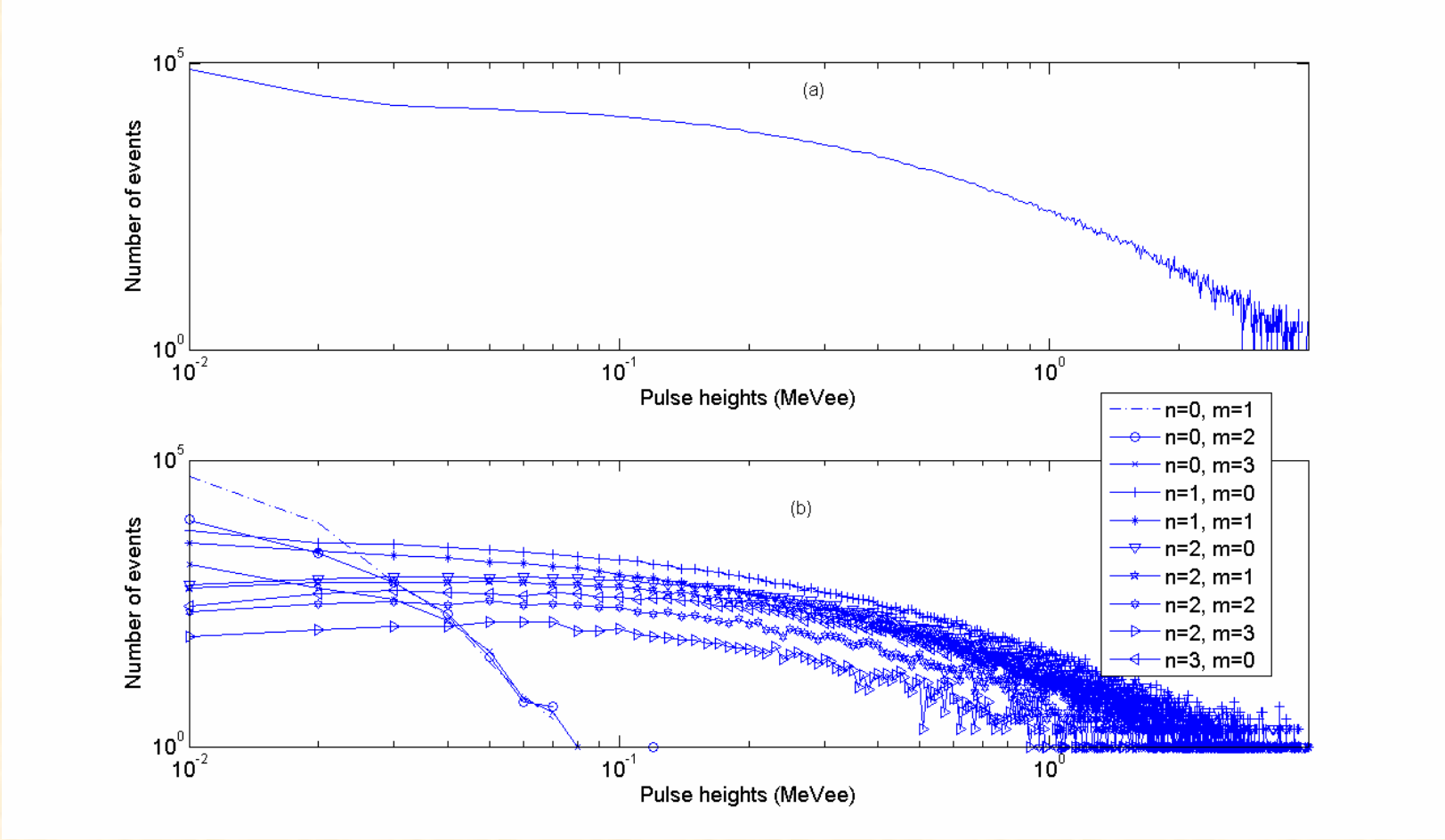
Pulse Height Distributions for 1 to 1.1-MeV Neutrons



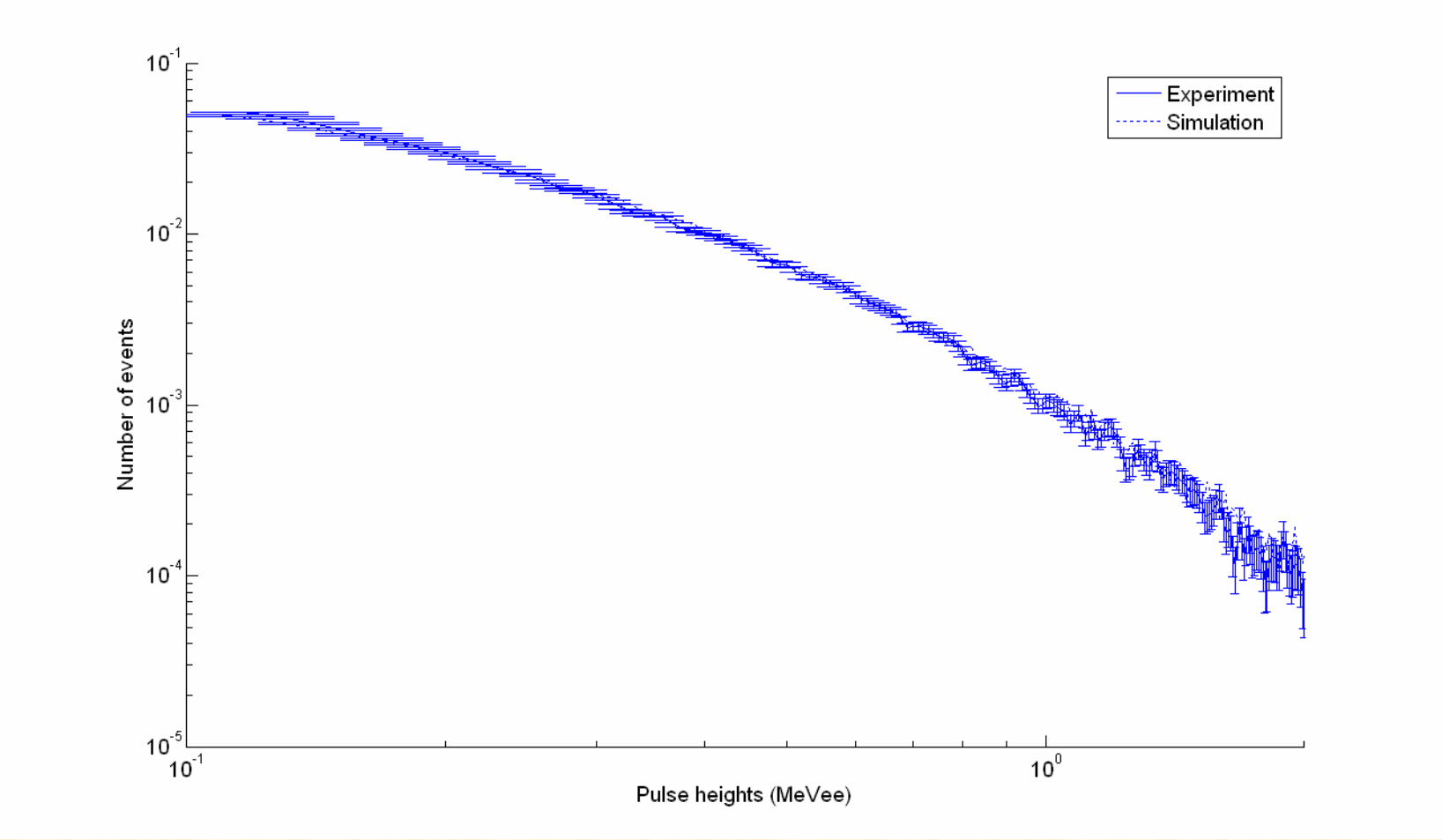
Effect of Detector Size



Pulse Height Distribution Cf-252



Measured and Simulated Pulse Height Distributions Cf-252



Analytical Derivation

Single scattering on H

$$f_1(L, E_0) = \frac{1}{E_0\sqrt{b^2 + 4aL}}$$

$$L(T) = aT^2 + bT$$

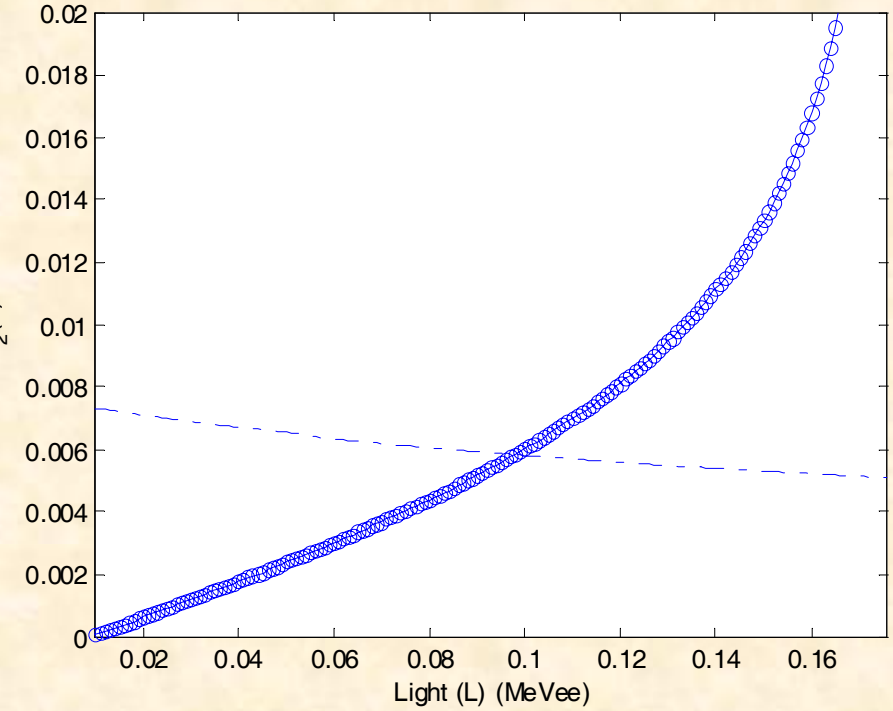
$$p(T, E_0)dT = \frac{dT}{E_0}$$

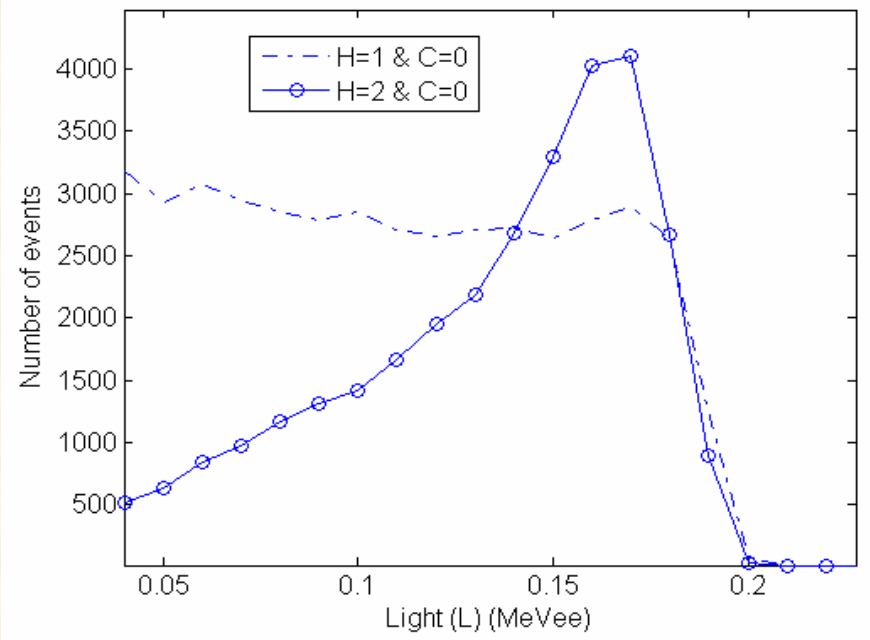
Double scattering on H

$$f_2(L, E_0) = \int_0^L f_1(L - l, E_0 - T(l))\, f_1(l, E_0)dl =$$

$$= \frac{1}{E_0}\int_0^L \frac{1}{\left(E_0 - T(l)\right)\sqrt{b^2 + 4a(L - l)}}\frac{1}{\sqrt{b^2 + 4al}}dl$$

Comparison of Analytical and Monte Carlo Simulation





Conclusions

We have developed a simulation tool to investigate neutron detection by organic scintillators

The tool is based on event-by-event simulation and allows us to calculate the light output for a given neutron history

The results from the simulation tool are in very good agreement with measurements

The statistics of the number of collisions is of interest to understand the process of neutron spectrum unfolding with this type of detector

Acknowledgments

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