Comparing CENNS detector simulations of Geant4 and MCNP

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Abstract

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory is also a neutrino source. The Duke Neutrino Group has built a detector prototype to observe coherent elastic neutrino-nucleus scattering (CENNS), a process that has been predicted but never observed so far. Beforehand, the detector was simulated with the MCNP-Polimi framework and the goal of this paper is to reproduce the results with Geant4.

1 Simulation setup

The Geant4 simulation toolkit was used to reproduce the results of #paper#. The detector setup can be seen in figure 1. The detector's core consists of a lead cube (50 cm edge-length) with 4 holes that hold one EJ-301 scintillator, each. These are frustums of a cone and are made of pure liquid EJ-301 (C_8H_{10}). The sides and the bottom of the lead cube are covered with a 1 cm thick layer of EJ-200 a solid plastic scintillator ($C_{10}H_{11}$]). Above the lead cube is a gap of 21 cm followed by an Al-7075 plate with a thickness of 2 cm. This plate shall reduce signals of cosmic neutrinos in the real detector. The whole setup is enclosed by a $1\,m^3$ water cube.
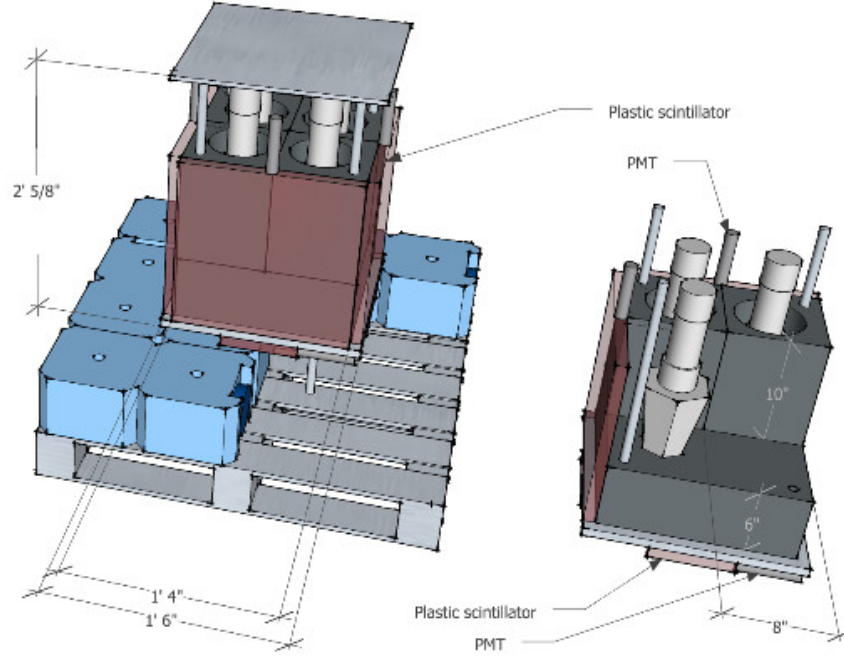

Figure 1: Layout of the detector. PMTs on top of the scintillators and rods to stabilize the setup were not simulated. The water bricks were replaced by a wall of pure water (no gaps or plastic inside) to speed up the simulation.

Neutrons are being generated only inside the lead at a random position with a random direction.

If a particle enters one of the scintillators and deposits energy, that amount will be converted into electron-equivalent energy by using the graph in figure 2.

In addition to the four particles mentioned in this graph there is also a number of γ, e^+ and deuterons that enter the scintillator. Since e^+ have the same mass and charge as e^- and γ will decay into $e^- + e^+$, both are treated as electrons. Deuterons will approximately emit a number of photons that lies in the middle between p and α.
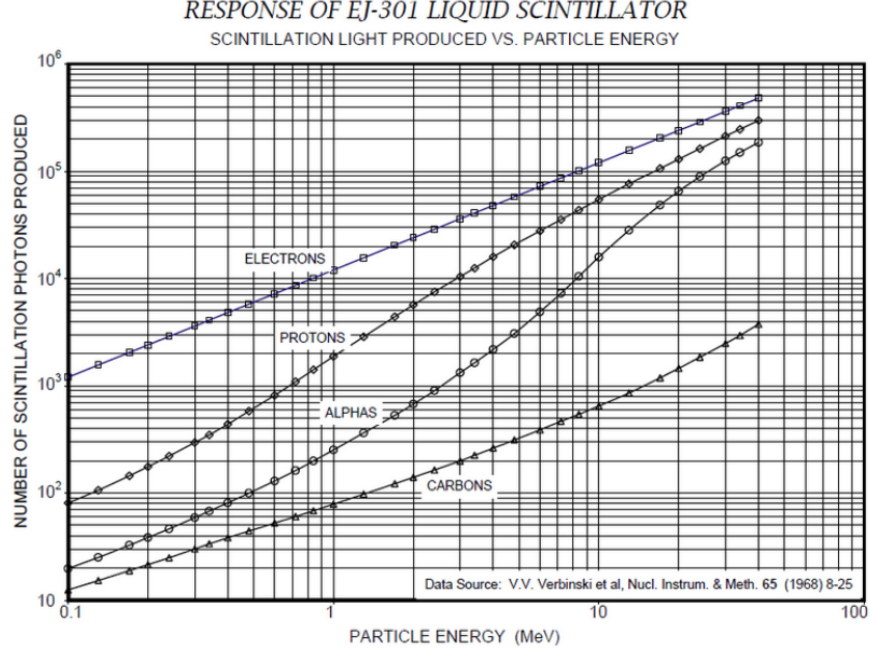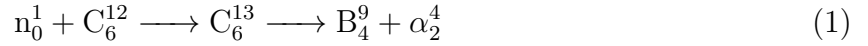
Figure 2: Photon response of the EJ-301 scintillator.

Also, in approx. 0.5% of the events the reaction

$$n_0^1 + C_6^{12} \longrightarrow C_6^{13} \longrightarrow B_4^9 + \alpha_2^4 \tag{1}$$

can occur. The electron-equivalent energy of the beryllium nucleus will not be calculated because this effect should be negligible.

2   Results and Discussion

2.1   Correct set up

First of all, it was necessary to verify that the neutrons were generated in the correct volume. Figure ?? and ?? show that the particles were generated only inside the lead and not inside the holes which contain the scintillators. Figure ?? and ?? show that the direction of the neutrons is equally distributed.

2.2   Efficiency

An event will be marked as "valid" once the energy deposition in a single scintillator exceeds a given threshold in keVee. Figure 3 and ?? show the percentage of how many events were marked as "valid" at a given energy of the primary particle. Two different thresholds 30 keVee and 100 keVee were used.
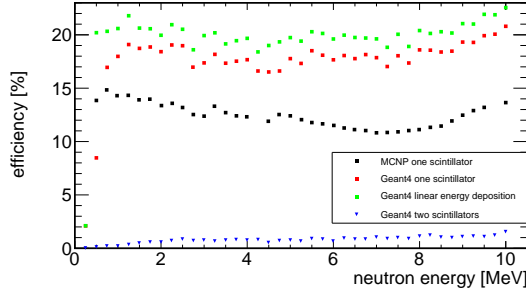
(a) 30 keVee threshold
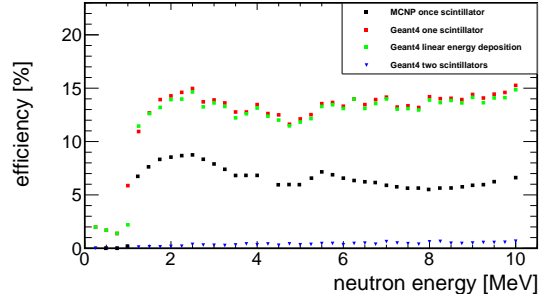
(b) 100 keVee threshold

Figure 3: Percentage of "valid" events for given monochromatic primary particles with a given threshold. MCNP results of "two scintillators" were not included, they varied between 0-1%.

It has to be noted that the MCNP code did not use figure 2 to convert the deposited energy to keVee. Instead it was assumed that the scintillator response of a proton is about $1/10$ th and of a carbon $1/100$ th that of an electron. This approximation is valid for low energies but at ~ 0.7 MeV the proton response of protons rises. Figures 4a/b show that most neutrons have energies > 1 MeV. Therefore the non-linear part might not be negligible.
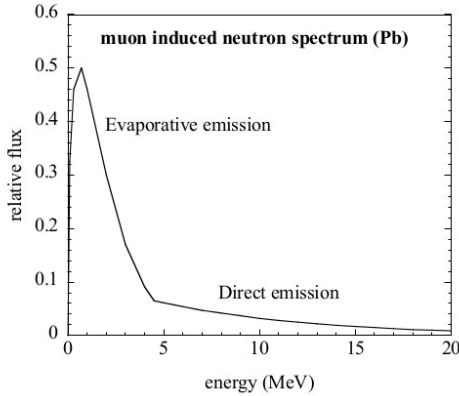
(a) MCNP
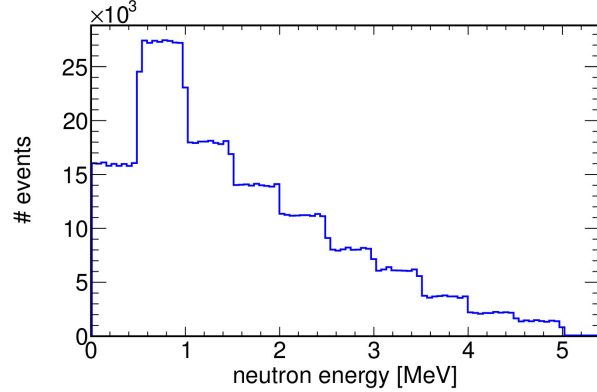
(b) Geant4

Figure 4: Energy distribution of the primary neutrons. A 5 MeV cutoff was used in both programs. To emulate a distribution like 4a, 10 data points were read by a digitizer. This results in the sharp edges in 4b.

The efficiency of the Geant4 simulation is about 5% higher. This might be a result of the superior tracking algorithms of Geant which will also track secondaries, whereas the MCNP simulation was run in neutron and photon mode only ??.

Also, the scintillators were simulated as frustums of a cone instead as frustums of a hexagonal pyramid. This increases the cross-sectional area of each scintillator slightly and might result in more valid events.

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2.3 Timing

Figure 5 and **??** show a distribution of the arrival time of a signal. The neutron is being generated at $t = 0\,\text{ns}$ and a signal arrives once the energy deposition one scintillator exceeds a given threshold ($30\,\text{keVee}$ or $100\,\text{keVee}$) for the first time.
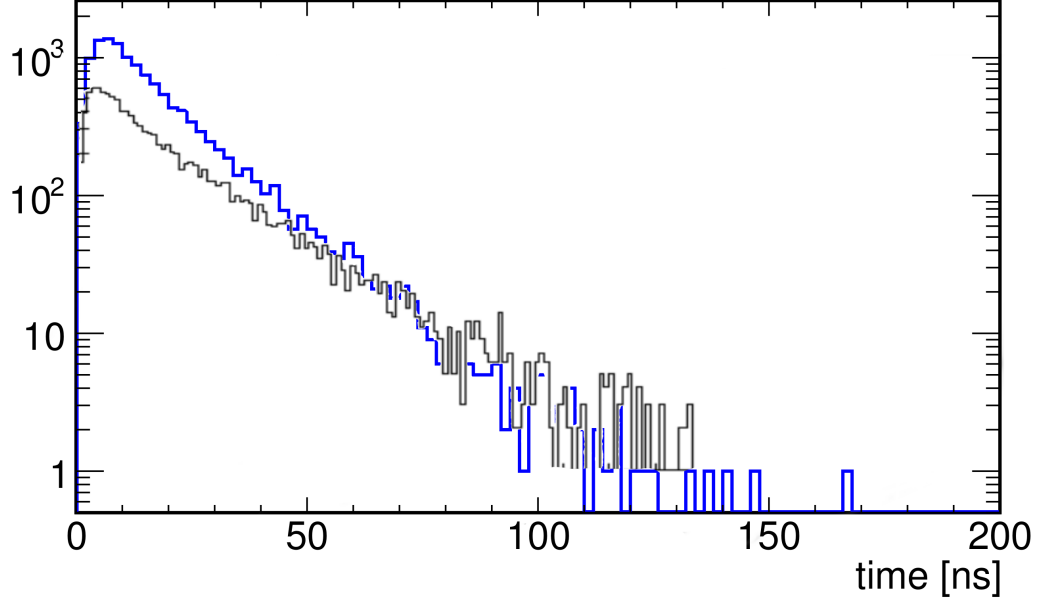

Figure 5: Black: MCNP, blue: Geant4. Threshold is $30\,\text{keVee}$. Both histograms are not normalized.

The timing graphs of both, Geant4 and MCNP simulation, show a dropoff at $0\,\text{ns}$ due to the threshold and end somewhere between $100\,\text{ns}$ and $140\,\text{ns}$.

2.4 Energy deposition

Finally, the energy deposition of both simulations are being compared. Figure 2 provided the necessary data to convert the energy to keV electron equivalent (keVee). As mentioned before, γ and e^+ are treated as e^- and deuterons lie in the middle between p and α. Seldom particles like beryllium will be ignored.
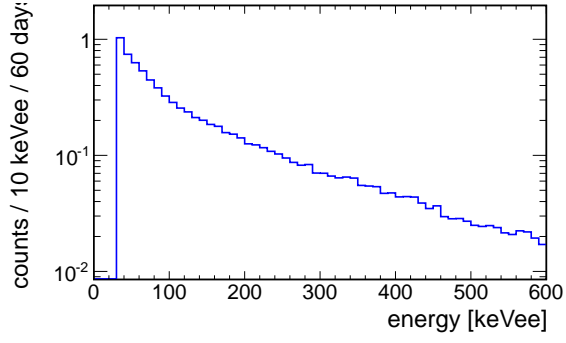
(a) Timing of Geant4 simulation.
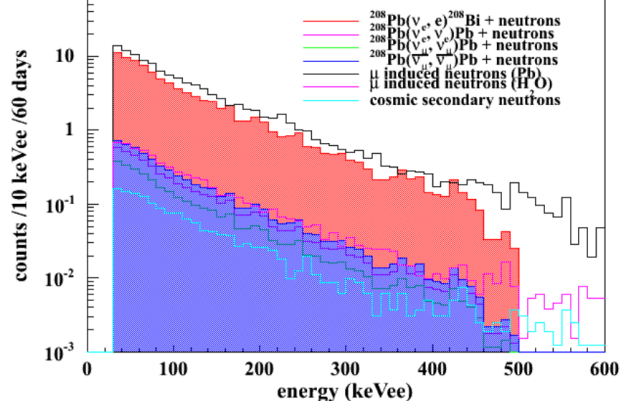
(b) Timing of MCNP simulation.

Figure 6: Threshold 30 keVee

3 Conclusion

Acknowledgments

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References