C.4 VALIDATION OF DATA ANALYSIS PROCEDURES

We present here the main steps of the simulation, the information saved in the output file, the principle for the efficiency and pile-up analysis methods and validation with experimental data and MCNP simulations.

Main steps of the simulation process

1. A primary photon is emitted by the γ-ray source placed in the laser photon – electron interaction point. This is considered to be the start of the event indexed *k*;
2. The primary photon is propagated through the experimental hall. Some of the photons pass through the collimator and hit the target;
3. Secondary particles may be emitted from the target, depending whether and how the primary photon interacted in the target;
4. Secondary particles are propagated from the target through the experimental hall. As the target is placed in the center of the analyzed detection array, some particles may hit one of the detectors and, out of these, some may deposit energy in it. When all the secondary particles have deposited their entire energy or have left the experimental hall the *k* event is finished and event *k+1* is started: another primary photon is emitted from the source.

Information saved in the output file

For each of these events the following information is stored in list mode for selected sensitive volumes (target and detectors):

a) the incident energy of primary γ-ray and the total energy deposition in the target
b) the multiplicity of hit detectors and the multiplicity of detectors with energy deposition;
c) the energy deposition time stamp relative to the beginning of the event, defined as the average between the time stamps of the first and the last interactions in a certain sensitive volume, regardless of which particle interacted in the volume.
d) the incident energy and type of each secondary particle which hits a detector and which detector was hit;
e) the total deposited energy for each detector.

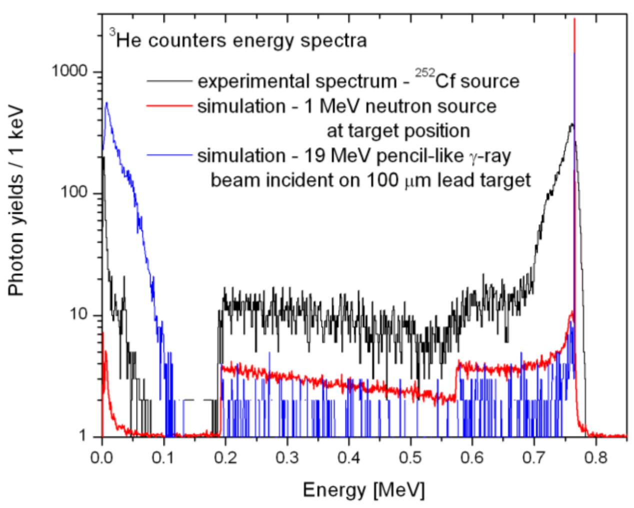

Figure C.36 Comparison between:

(black line) ^{252}Cf experimental spectrum.

(red line) Simulation of energy spectrum of a 1 MeV monochromatic neutron source.

(blue line) Simulation of energy spectrum taken for 19 MeV pencil-like γ-ray beam hitting a 100 μm lead target.

Both sources and the target are placed inside the polyethylene moderator described in Section 3.2.1. Spectra taken with ^{3}He counter.

Comparison of simulated energy spectra with experimental ones

An experimental energy spectrum of a ^{252}Cf source recorded with a ^{3}He counter placed in the outer ring of the 4π neutron detector described in Section 3.2.1 is compared with two simulated spectra in Figure C.36. The red line represents the simulation of the energy spectrum of a 1 MeV monochromatic neutron source placed in the center of the moderator at the target position. The blue line represents the energy spectrum taken with an identical counter placed in the same position, when a 0.1 mm lead target placed in the center of the moderator is irradiated with a pencil-like monochromatic 19 MeV γ-ray beam.

The energy spectrum recorded for a monochromatic neutron source placed at target position in the moderator has sufficiently good statistics to observe the step structure given by wall effects, which is characteristic to both ^{3}He and BF_3 counters.

The energy spectrum taken for an irradiated lead target has a considerable low energy component below 100 keV given by γ-ray, electron and positron interactions in the counter. The low energy component can be easily discriminated from the neutron events applying an amplitude threshold.

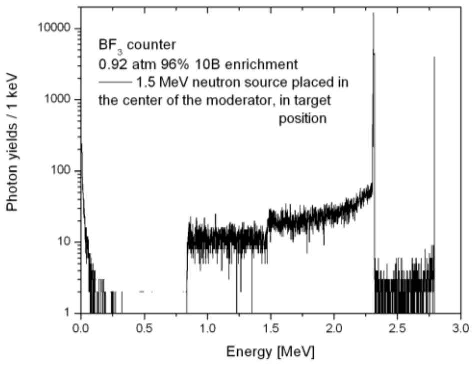

Figure C.37 Energy spectrum of a 1.5 MeV monochromatic neutron source placed inside the high efficiency 4π neutron detector recorded with a BF_3 detector.

Figure C.37 shows the energy deposition in a BF3 counter when a monochromatic 1.5 MeV neutron is placed in the center of the 4π neutron detector.

Detection efficiency studies

The detection efficiency of the 4π neutron detector in Section 3.2.1 has been measured experimentally using a ^{252}Cf source and estimated using MCNP simulations. We have calculated the detection efficiency using the Geant4 simulation code and we obtained very good agreement between our results and the MCNP one, as can be seen in Figure C.38.

The detection efficiency values are obtained as the ratio between the registered neutron events and the total number of emitted neutrons. The detection efficiency for counters from the same ring is summed up to obtain the detection efficiency of the ring. The total detection efficiency represents the sum of the detection efficiencies of the three neutron counters rings.

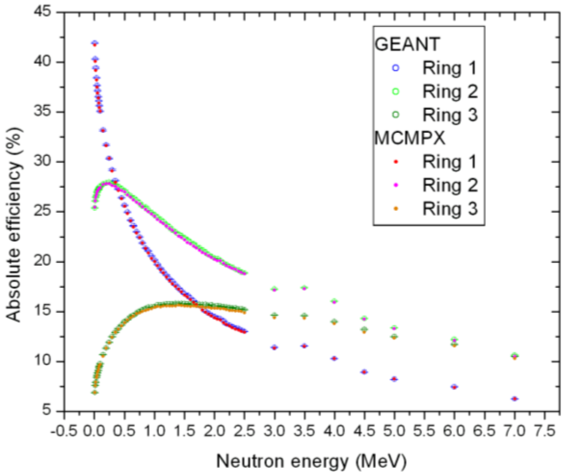

Figure C.38 Neutron detection efficiency values for the 4π neutron detector described in Section 3.2.1 versus energy. Both MCNP and Geant4 simulations are represented.

Pile-up studies

Pile-up studies are necessary for developing the experimental setups at ELI-NP because of the time structure of the γ-ray beam. Each micro-bunch will deliver 10^5 γ-rays during 1 – 2 ps, therefore the detectors will detect simultaneously the secondary radiation produced in the target. Simulated pile-up energy spectra are obtained by summing for each detector the energy deposition from N consecutive events, where N = 10^5 for the case of a micro-bunch.

The ability of our code to reproduce real pile-up spectra was tested against experimental data taken at NewSUBARU during the photoneutron cross section measurements on Sm and Nd isotopes in 2013.

The γ-ray beam was monitored during irradiation and measurement with a 6"×5" NaI(Tl) detector placed in beam, downstream of the neutron detector. The Nd:YVO_4 (λ = 1.064μm) laser operated at 20 kHz frequency produced pulses of light of 60 ns duration. The LCS γ-rays were generated in bunches corresponding to each laser light pulse. The number of LCS γ-rays per bunch is given by a Poisson distribution [Kon11]. The LCS γ-rays generated during the same laser pulse were detected simultaneously by the NaI(Tl) detector, thus obtaining multi-photon pile-up spectra. Before and after each irradiation, we recorded the incident LCS γ-ray beam produced at a reduced laser power, obtaining single-photon NaI(Tl) energy spectra. Typical examples of experimental single-photon and pile-up energy spectra are displayed in Figure C.39 and C.40, respectively.

The number of recorded γ photons was obtained using the "pile-up" method described in [Kon11]. Using this method, the average number of photons per bunch is determined by the ratio between the average channels of the pile-up and the single-photon spectra. We performed GEANT4 Monte Carlo simulations in order to analyze and test the "pile-up" method.

We simulated the response function of a 6"×5" NaI(Tl) detector to an incident γ-ray beam emitted along its symmetry axis. One can see in Figure c.39 that the experimental single-photon spectrum spectrum is well reproduced by the simulation. The experimental photons with energies above the maximum energy limit correspond to coincidence detection events in the NaI(Tl) crystal.

We compared an experimental pile-up spectra corresponding to a 9.51 MeV maximum energy incident LCS beam with a simulated one, as shown in Figure C.40. The simulated pile-up spectra was created as described above, by summing energies deposited by individual photons corresponding to the single-photon spectra from Figure C.39. The numbers of photons per bunch were randomly generated from a Poisson distribution with mean 1.35.

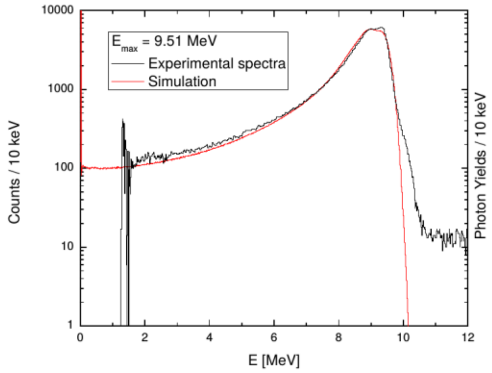

Figure C.39 Experimental (black) and simulated (red) single- photon energy spectra obtained with a 6”x5” NaI(Tl) detector. Maximum energy of the LCS beam is 9.51 MeV (734.7 MeV electron energy).

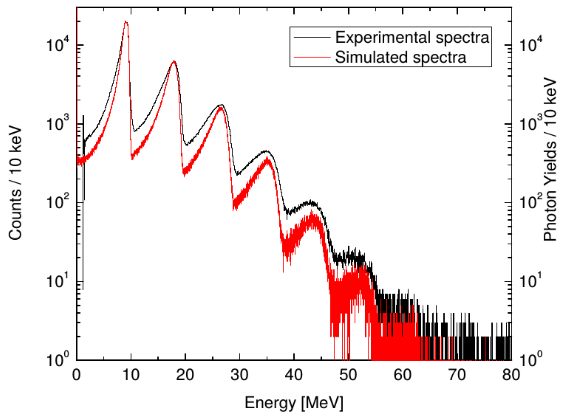

Figure C.40 Experimental pile-up spectra of a 9.51 MeV maximum energy LCS γ-ray beam measured with the 6” × 5” NaI(Tl) detector (black) and the simulated pile-up spectra obtained by summing randomly generated numbers of photons from the single-photon spectra presented in Figure C.39 (red).

The energy deposition in the detectors can be correlated with the incident particle type and one can obtain the contribution given by a certain type of incident radiation to the total detector response. In such a way, the γ-ray beam induced background is studied by applying conditions on the type of incident particles.

C.5 CONCLUSIONS

We have developed a realistic and complex code for the simulation of the Compton scattering of a laser photon on a relativistic electron. The code provides:

- γ-ray beam energy spectra incident on a monitor detector;
- transverse energy and intensity beam profile;
- type and degree of polarization,

by placing a monitor target anywhere along the beam axis.

The geometry of the collimation system, experimental hall, experimental setups proposed by the GANT workgroup and the gamma beam dump was implemented in the code.

The simulation code treats electromagnetic processes (Livermore or Penelope) and hadronic processes, for which are used high precision models based on ENDF data bases, in particular for neutrons a special treatment is applied at energies below 4 eV, crucial for description of thermalization processes. Additionally, photonuclear, electronuclear and detailed atomic processes are considered. For NE213 liquid scintillator, the total light production was simulated taking into account the particle that deposited energy into the scintillator.

The simulation code was validated against experimental data taken at NewSUBARU, concerning:

- Energy spectra of LCS γ-ray beam
- Intensity of LCS γ-ray beam
- Energy deposition spectra in ^{3}He
- Detection efficiency of 4π neutron detector consisting in 20 ^{3}He counters embedded in polyethylene moderator. Our values reproduce both the experimental measurement and the MCNP simulations.
- Data analysis method of pile-up spectra