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SIMULATION OF THE ELECTROMAGNETIC BACKGROUND RADIATION FOR THE RISING EXPERIMENTAL SET-UP*

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High level of electromagnetic radiation is produced in the interaction of relativistic ions with matter. A model to simulate it within GEANT4 has been developed in order to evaluate these sources of background and their influence on the experimental spectra. New classes have been added to the standard GEANT4 program libraries, describing the radiative electron capture, primary bremsstrahlung and secondary bremsstrahlung processes. Simulations of experiments within the RISING stopped beam campaign and comparison with the experimental results are presented.

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1. Introduction

Utilization of secondary beams for spectroscopic experiments at relativistic energies is a major tool in studying exotic nuclei. Experiments with this technique are carried out at GSI, Darmstadt within the RISING (Rare

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ISotope INvestigations at GSI) project [1]. Here we report on a study of the background bremsstrahlung radiation in such experiments. The importance of the problem is related to the high production cross sections, high multiplicity and high end–point energy of the bremsstrahlung photons due to interaction of the relativistic ions with matter. As a result, the detector response is influenced to a large extent by the emitted bremsstrahlung. Detailed knowledge of the origin of the background and the way it influences the detection system is needed in order to be able reliably to determine reaction γ-rays of interest. Thus, the main motivation of this work is to create a reliable simulation tool for the background radiation processes in spectroscopic experiments with relativistic ions.

The model uses the GEANT4 [2] Monte Carlo simulation tool. In its standard distribution (up to version GEANT4.8.1) electron capture and bremsstrahlung processes for relativistic ions are not implemented. In order to introduce the bremsstrahlung emission in cases like this, two approaches are possible: *(i)* to consider the dynamics of the individual electrons involved in the stopping process of the ions and consequently track them, or *(ii)* create directly photons using theoretical cross sections for bremsstrahlung emission. The advantage of the first approach is that all particles involved in the bremsstrahlung process are tracked down one by one and proper picture of the angular distributions could be obtained. Disadvantage in this case is that the model is very time and resource consuming. The second approach takes advantage of the well defined relations describing the processes, which can be compared to experiment. A major disadvantage is the assumption that the born electrons never leave the target, reducing the applicability of this processes to thick targets. In the present study the second approach is used.

2. Bremsstrahlung of relativistic ions

The most important processes resulting in emission of electromagnetic radiation in heavy-ion atom collisions are: the K and L X-ray radiation from ionized target (or projectile) atoms, radiative electron capture (REC) — a process of capture of target electrons in a bound atomic state of the projectile, primary bremsstrahlung (PB) — a process of capturing a target electron into an atomic continuum state of the projectile, and secondary bremsstrahlung (SEB) which is emitted during the slowing down of the fast moving electrons produced in a collision with the projectile [3]. Although the X-rays originating from ionized target atoms have the highest intensity, they have very low energies in the case of light materials. In the experiments considered here they do not reach the detectors, and therefore, are not considered. REC and PB are one–step processes. REC results in discrete lines, because the electron is captured in a well defined atomic state of the projectile. In the second case, due to the interaction with the continuum, the spectrum is continuous. The SEB process is a two–step process and the bremsstrahlung results from the interaction between the emitted electrons and matter, and involves the following steps: *(i)* interaction of the heavy ion with a target atom and emission of a relativistic electron and *(ii)* interaction of this electron with matter and emission of photons. In the accepted approach the electrons do not appear in the simulation process. We also assume that scattered electrons do not leave the target. The latter assumption is justified for thick targets. The properties of the three processes (energy spectra, cross sections and angular distributions) are described in details in Refs. [3, 4]. The theoretical cross sections are implemented in the simulations.

The GEANT4 cross sections for the REC process calculated within this model are compared in Fig. 1(a) with numerical calculations using different approximate models [3]. The simulations yield the proper order of magnitude of the cross section. In Fig. 1(b) the experimental data for 60 keV bremsstrahlung photons emitted in the stopping of 197 AMeV in different target materials [3] are compared with calculated PB and SEB cross sections integrated over the angle. In the low Z region the PB process has a larger contribution than SEB process, while for higher Z targets the situation is reverse. In the model the different processes are implemented in GEANT4 as separate classes (K and L REC are considered separately).

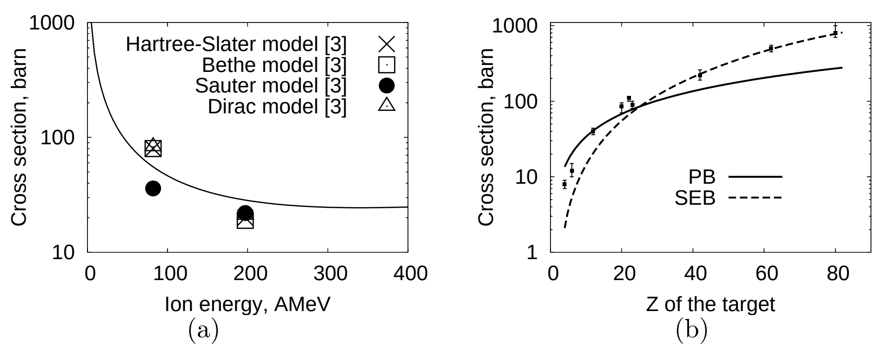

Fig. 1. (a) Comparison of GEANT4 calculations (solid line) with analytical model calculations for the REC cross section. (b) Experimental cross section for 60 keV bremsstrahlung photons as a function of the atomic number Z (dots) [3] *vs* calculations for the PB and SEB cross sections.

3. Bremsstrahlung in RISING stopped beam experiments

The RISING stopped beam set–up [7] consists of 15 Euroball Cluster detectors in 4π geometry, divided in 3 rings — at 55°, 90° and 125°. The secondary beam, which is selected by the Fragment Separator (FRS) passes in its last section through two multi-wire chambers, an ionization chamber and a time-of-flight scintillator, then it is slowed down with an Al degrader and stops in a target catcher, a 7 mm plastic in this case [8]. In the simulation the RISING detector array, the plastic target and the Al degrader, as the major source of bremsstrahlung, are considered.

An example is provided for the decay of the (7^-), $T_{1/2} = 280$ μs isomer in ^{202}Pt [5]. It decays by a cascade of three γ-rays, a doublet of 535 keV and a 719 keV γ-ray. The first 535 keV transition populates the 4_1^+ state, which decays via two consequential E2 transitions. The measured isomeric ratio is $\sim 15\%$. An event simulator for isomeric decays has been implemented which takes into consideration the orientation of the emitted γ-rays. The energy of the ions before the Al degrader is 422 AMeV, according to the MOCADI [6] (simulation program to calculate the transport of primary beams) calculations. As a result of the slow extraction of the ions from the primary target they are considered to arrive in an average interval of about 1 ms. In this way the detector response to the arrival of a single ion can be studied. The event simulator takes into consideration whether the impinging ion is an isomer and sets the time of emission of the γ-rays.

In Fig. 2 the experimental data are compared to simulated spectra for the forward and backward detectors. The simulated spectra are shifted downwards by an order of magnitude. The ratio of the experimental to the simulated spectra is shown in the lower part of the figure. There is a good agreement with the data at lower energies for forward angles. At back-

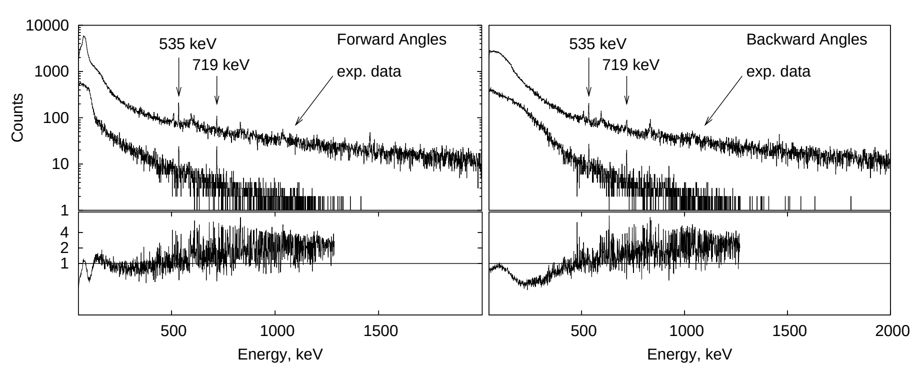

Fig. 2. Simulated *vs* experimental spectra of the ^{202}Pt isomeric decay for the forward (left) and backward (right) detectors (see details in the text).

ward angles at lower energies the agreement is worse and the simulation overestimates the bremsstrahlung flash. These photons originated from the Al degrader. At present, the simulations do not consider all construction materials, *e.g.* the supporting frame, which results in a larger number of low energy photons reaching these detectors. The model fails to reproduce also the high energy tail that is observed in the experiment. Note that this tail is much more pronounced at backward angles, while the bremsstrahlung flash is localized at forward angles. The reason for the high energy tail are relativistic electrons or light particles which come with the beam and hit directly the detectors. Such processes are not considered in the simulations. The spectra of the forward detectors are reproduced reasonably well because, due to the geometry of the experiment, these detectors see predominantly the bremsstrahlung flash. The decay γ–rays of ^{202}Pt are presented in Fig. 3. The intensities of 535 and 719 keV transitions, although overestimated, are reproduced reasonably well. For the 535 keV γ-rays the difference is about 30% and increases towards higher energies because, as mentioned, high energetic particles and other processes, resulting in low energy γ-rays radiation, are not taken into account.

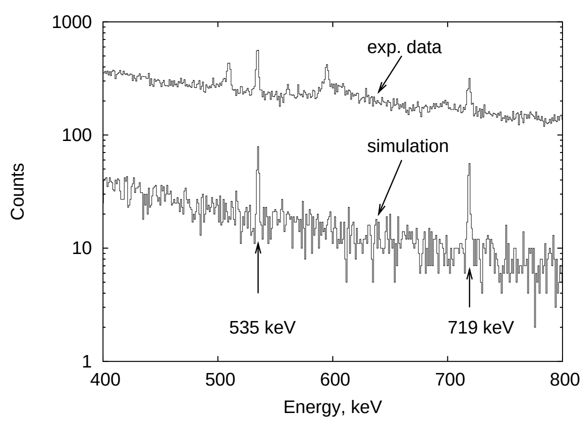

Fig. 3. The ^{202} Pt isomeric decay spectra. The upper line is experimental spectrum and the lower — the simulated spectrum which is shifted downwards by an order of magnitude.

In conclusion, the developed tool allows the bremsstrahlung emitted in stopping of relativistic heavy ions to be simulated with GEANT4. The provided example for the isomeric decay of ^{202}Pt, which was measured within the stopped beam RISING campaign [8], demonstrates the applicability of the simulation tool. In the future the developed model will be used in simulations of different experiments utilizing relativistic ions beams.

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