Monte-Carlo study of the influence of backscattered electrons on the transmission of a mini-orange β spectrometer

Pavel Detistov 1, Dimitar L. Balabanski 2

1INRNE–BAS, 72 Tz. Shousee Blvd, 1784 Sofia, Bulgaria
2ELI-NP, IFIN-HH, Reactorului Str 30, 077125 Magurele, Ilfov, Romania
E-mail: detistov@inrne.bas.bg

Abstract. This work is a part of the performance investigation of the recently constructed Mini-Orange beta spectrometer. The spectrometer has eight different configurations using three different magnet shapes and combination of three, four, and six magnet pieces allowing detection of electrons in wide kinetic energy range. The performance of the device is studied using the GEANT4 simulation tool. Evaluation of the device’s basic parameters has been made, paying special attention to the backscattering, for which a study of the dependence of this process on the energy and the angle is made.

1. Introduction
Mini-orange type β spectrometers (MOBS) are a compact instruments for experimental study of conversion electrons in the in-beam measurements. We constructed a MOBS whose magnetic configurations follow the original design suggested at Groeningen [1][2]. The expected improvement is related to the electron detector part. The selected detector was chosen after preliminary investigation reported in [3]. In the present work more detailed study is made with the selected Si particle detector.

The performance of the MOBS depends on the number of detected electrons in the particle detector. Due to the backscattering some part of the electrons are lost. In this work we evaluate them using the GEANT4 simulation tool [4].

2. Mini–orange spectrometer description
MOBS is a system consisting of a set of several orange shaped wedges of SmCo5 permanent magnets which are placed around a solid core made of heavy elements, and a particle detector behind. The magnets have been produced in three different shapes, designated as “A”, “B” and “C” types. Eight different configurations have been produced in order to cover wide electron energy range. Designation of each configuration was made by the letter for the shape type and the number of magnets. Thus, configuration “A4” has 4 magnets of “A”–type shape. The full set is shown in picture in Figure 1.

Based on a preliminary study [3] a MSQ25-1000 was selected as an electron detector. The active area of the detector is 2500 mm², it consists of 4 segments with dimensions 24.95 mm
× 24.95 mm, and active detector thickness of 1.0 mm. According to [5] the thickness of the detector corresponds to a electron range of about 0.55 MeV.

A MOBS is defined by the following parameters: the magnet shape, the number of magnets, the magnetic field strength, the distances between the center line of the magnet set and the detector face (g) or the target face (f), the geometrical shadowing factor (b) defined as the ratio of the angles occupied by the magnets and between the magnet faces, and the transmission (T), which is defined as the ratio of the number of counts in the energy spectra peak to the total number of events.

Using the measured magnetic field map, simulations of the transmission have been calculated and transmission curves have been obtained. Example transmission curves for one of the configurations is shown in Figure 2. From the transmission curves could be seen that the system is not very sensitive to the position of the detector, but is very sensitive to the position of the source.

The evaluated parameters of the MOBS are listed in the Table 1.

![Figure 1. The complete set magnet configurations with their protective containers.](image1)

![Figure 2. Transmission curves for A3, for various distances g and f.](image2)

| Parameter                      | A3  | A4  | A6  | B3  | B4  | B6  | C3  | C4  |
|-------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Shadowing factor — b          | 0.2 | 0.286 | 0.5 | 0.1 | 0.143 | 0.2 | 0.2 | 0.286 |
| Transmission $T_{max}$, %     | 7.3 | 4.2 | 1.15 | 8.4 | 9.8 | 10.8 | 3.4 | 1.36 |
| Optimal energy range, $E_{min}$ MeV | 0.25 | 0.5 | 1.2 | 0.1 | 0.25 | 0.5 | 0.25 | 0.5 |
| Optimal energy range, $E_{max}$ MeV | 1.25 | 1.5 | 2.0 | 1.0 | 1.25 | 1.25 | 1.5 | 1.25 |

For estimation of the detector performance alone a simulation of its efficiency for electrons has been made. The resulting efficiency curves are given in Figure 2. They indicate that there is a gradual drop of the efficiency after around 0.5 MeV. This is a limitation resulting from the detector thickness. In contrast to $\gamma$ –rays, electrons does not travel in the straight lines inside
the solid, and their calculated range is a sum of all path they pass inside the material. This is the reason why electrons with higher energies could be detected into a thinner detector.

Figure 3. Simulated detector efficiency at various f and g distances.

Figure 4. Dependence of the number of backscattered electrons on the incident energy and angle.

3. Backscattering of electrons from the detector

When electrons bombard a surface part of them scatter back as a result from their interaction with atoms in the solid. These are the backscattered electrons. They scatter either elastically or inelastically. Those who scatter inelastically contribute to the background in the energy spectra of the detector. In both cases, such electrons, though transmitted by the magnetic filter of the MOBS to the detector, are lost and does not contribute to the measurement results, reducing the overall transmission of the system.

Electrons bombard the detector surface at various angles depending on their energy. In Figure 5 is shown the area of the detector where electrons hit the detector surface for various electron energies. At the maximum of the transmission value for a given MOBS configuration there is a single spot at the center of the detector. In such a case the angle of the incident electrons is between 40 and 50 degrees. In case when electrons are scattered back towards the system of magnets they are diverted in the direction out of the system, due to the Lorenz force, produced by the magnetic field.

In order to evaluate the amount of backscattered electrons at various incident angles, we made a simulation using monoenergetic electrons which bombard the detector surface at various angles. The results are shown in Figure 4. It could be seen that number of backscattered electrons depends strongly on the angle of incidence, and are not very sensitive to the energy.

Based on this values we could conclude that between 20 and 30 % of electrons backscatter from the surface. This should be valid for all configurations due to the low sensitivity with respect to the energy.

In Figure 6 four energy spectra are shown for different electron energies. From the spectra it could be seen that at lower energies the main contribution is from the backscattered electrons. At higher energies there are other contributions from secondary processes, which are not considered here.

4. Conclusions

Using the GEANT4 simulation toolkit an investigation of the MOBS have been made. Transmission curves for all configurations have been obtained for the particular type of particle
Figure 5. Map of the electron hits on the detector surface for magnet configuration A3 at electron energies a) 0.7 MeV, b) 1.5 MeV and c) 2.0 MeV.

Figure 6. Detector spectra for monoenergetic electrons at different incident energies. Red line corresponds to the spectra in the detector and the blue line is the energy deposited by the back scattered electrons.

detector and the recommended energy range for each magnet configuration have been estimated.

Also, backscattering of electrons from the detector surface has been studied. These electrons contribute to the long energy tail in the energy spectra and in this way they reduce the overall transmission of the system.

The work is supported by the DID02/16 contract with the Bulgarian National Science Fund.

References
[1] Van Klinken J, Feenstra S J, Wisshak K, Faust H 1975 Nucl. Instr. and Meth., 130 (2) 427
[2] Van Klinken J, Wisshak K, 1972 Nucl. Instr. and Meth., 98 (1) 1
[3] Detistov P, Balabanski D L 2013 Proc. of the 32-nd Intern. Workshop on Nucl. Theory, Rila Mount. 32 164
[4] Agostinelli S et al., 2003 Nucl. Instr. and Meth. A 506(3) 250
[5] NIST web site: http://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html [last visited 7.10.2014]
[6] Guerro L, Blasi N, Saltarelli A 2014 Nucl. Instr. and Meth. A 739 32