NUCLEAR THEORY, Vol. 32 (2013)
eds. A.I. Georgieva, N. Minkov, Heron Press, Sofia

Simulations of the Mini-Orange β Spectrometer Transmission Curves in Different Magnets Configurations

P. Detistov[1], **D.L. Balabanski**[2]

[1]INRNE-BAS, 1784 Sofia, Bulgaria
[2]IFIN-HH/ELI-NP, PO Box MG-6 , Bucharest-Magurele, Romania

Abstract. A β-spectrometer of "mini-orange" type has been constructed. It consists of $SmCo_5$ magnets with three different shapes in eight configurations. The electrons are detected using Si detector behind the spectrometer at variable positions.

This work presents a study of the spectrometer performance and evaluation of the electron transmission curves using GEANT4 Monte-Carlo simulation tool taking into account the measured map of the spectrometer magnetic field. Optimization of the set-up is made for variable of electron energies.

1 Introduction

Mini-orange β spectrometer is a tool for studies of conversion electrons in in-beam experiments. Such spectrometer has been constructed as a replica of the device designed at Groeningen in late 70's of the last century [1].

In the present work results from simulation work using the GEANT4 Monte-Carlo simulation tool [3] are presented aiming to get preliminary information for the device performance.

2 Mini-Orange Type β Spectrometer

The mini-orange β spectrometer consists of two parts – a set of permanent magnets placed symmetrically around the central absorber and a particle detector behind the magnets. The permanent magnets produce magnetic field in direction transverse to the direction of the electron momentum. As a result the trajectories of the electrons change due to the Lorenz force. The direction of the magnetic field lines is chosen in a such way to focus electrons towards the center line of the spectrometer. The magnets are made of $SmCo_5$ and have three different wedge-type shapes denoted as A, B and C types [1]. For the different configurations sets of three, four, and six magnets of the same shape are used. Thus, the notations for the different configurations become 3A, 3B, 3C, 4A, 4B, 4C, 6A, and 6B. For example, a magnet set 4A contains four A-type magnets. The

Figure 1. The magnet sets.

magnet sets are designed to have same attachment to allow interchangeability among them. The picture of all produced magnet sets is shown in figure 2.

An absorber protects the particle detector from direct hit of electrons, γ-, and X-rays. The materials used are Sn and Pb.

The spectrometer is intended for in-beam in a close geometry to the target. For this reason a special reaction chamber to contain the target and the β-spectrometer was designed and manufactured. The holder for the magnet sets is welded within the vacuum chamber. It has special locking channels allowing positioning of the magnet sets at various distances with respect to the target in 5 mm steps.

Behind the magnets, in the vacuum chamber an electron detector should be placed. The position of the detector should be variable in order to allow fine tuning of the spectrometer for specific electron energies. The thickness of the detector should be capable to stop electrons with energies up to 3 MeV. In the case of Si the range of electron with such energy is less than 10 mm, according to the CSDA calculations [4]. Thus, the detector thickness should be in the range of 10 to 15 mm. The optimal detector diameter was selected based on the simulations.

The most important parameters for the mini-orange spectrometer are:

- The magnetic field strength. The values of the magnetic field have been measured after the fabrication of the magnets and their assembly. Typical values for the fields between each couple of magnets is in range 0.1 and 0.35 Teslas.
- The distances between the centreline of the magnet sets and the target (f) and between the centerline of the magnet sets an the particle detector (g).
- The detector geometrical shadowing factor. This factor is the relation be-

Table 1. Geometrical shadowing factors for the different geometries

Number / type	A	B	C
3	0.2	0.1	0.2
4	0.286	0.143	
6	0.5	0.2	

tween the angle occupied by the magnets and the angle between each couple of magnets (see Ref. [1]). Calculated values for the different configurations are given in Table 1.

- The transmission of the mini-orange spectrometer, defined as the ratio between the number of counts at the detector spectra corresponding to the energy of the electrons and the total number of emitted electrons with a constant energy in 4π space around a point electron source.

Transmission curves represent graphs of the transmission with respect to the electron energies for given configuration at a constant source/detector positions. They are of particular interest for the present study because they show the electron energy range at which a given mini-orange configuration has the most efficient regime.

3 Simulation Model

The simulation model was developed using the GEANT4 Monte-Carlo simulation tool. All geometries have been implemented in the model using the real dimensions and materials of the produced elements. The model includes the magnets, the core, the holder and the Si particle detector for each configuration. The measured values of the magnetic field for all configurations are hard-codded into the model. The variable parameters for each configuration are the position of the source, position of the detector, and the detector size. The event generator shoots one electron per event in a 4π geometry.

Using the model, simulations have been performed by changing all the parameters against each other. The parameters values used are summarized in Table 2.

Table 2. Parameters used for simulations

Parameter	Unit	value/range
Configuration	signature	3A, 4A, 6A, 3B, 4B, 6B, 3C, 4C
Number of events	number	60000
Distance from the source	mm	25, 30, 35, 40
Distance from the detector	mm	45, 60
Detector size	mm	10,20,30,40

A resulting transmission value is produced by division of the counts number in the pick on the number of events for one run at given electron energy.

4 Results

The first step of the work was to determine the size of the particle detector for the spectrometer. To do that a simulations of four different detector sizes have been made and the transmission curves has been produced. As an example the transmission curves for the configuration 6A are shown in Figure 2. Each curve corresponds to a single detector size. From the figure could be seen that lower detector diameter produces lower transmission value which means less efficient device. But looking on the shape of the transmission curves the larger detector produces wider transmission curve. Thus, electrons within a wider energy range are detected by the spectrometer. Compromising between the bigger efficiency and the selectivity of the electron energy range a value for the Si detector diameter of 20 mm has been selected.

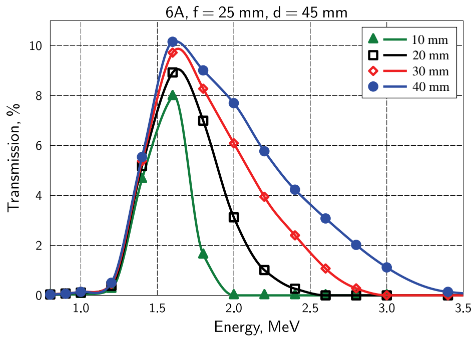

Figure 2. Transmission curves for different detector sizes for configuration A6 and fixed parameters f and g.

After setting the detector diameter, simulation of the mini-orange performance has been done. Typical transmission curves for two configurations produced by the simulation are shown in Figure 4.

From the results following conclusions could be made.

- Electrons with energies in the range between 0.2–2.5 MeV could be measured by changing the magnet sets of the β spectrometer.
- A change of the distance from the source could be used as a tuning factor if a shift towards lower or higher efficiency for given electron energy is needed. The change of one step (5 mm) for this distance would change the maximum transmission point value with about 10% at the higher energies to about 20% at lower energies.

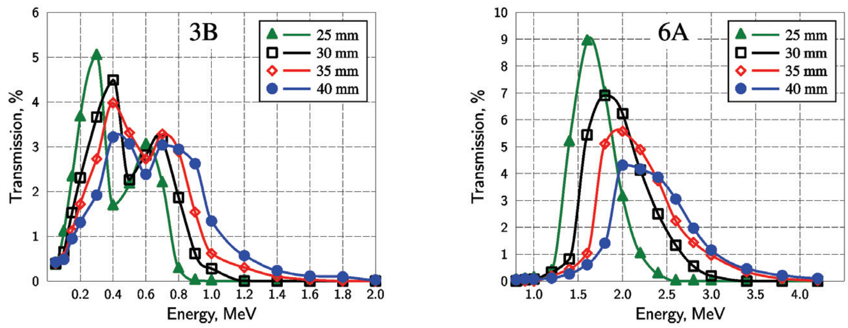

Figure 3. Simulation results of the transmission curves for all configurations at 45 mm distance of the detector from the center of magnets. Different curves represent different source positions with respect to the center of the magnet sets.

- The influence of the particle detector position is small. Significant difference begins to appear at higher electron energy values (above 1.5 MeV). Generally, putting away the particle detector from the magnets causes an increase of the transmission. This is a result from the fact that more electrons in wider energy range bent by the magnetic fields reach the detector. Note that this results in a reduction of the energy resolution of the system.

- Configuration 3B has the worst magnetic field homogeneity. The transmission curves for this configuration display two–picks structure. This is related to the non-homogeneity of the magnetic field between the neighboring magnets. As a result the spectrometer analyses two type of trajectories: one is determined by the magnetic field near the magnet walls, that is responsible for the higher energy peak, and the other by the part of the gap in the center between the magnets, responsible for the lower energy peak. Such behavior is visible also for some other configurations, but is not so pronounced.

- The 3A and 6B configurations have similar peak energy for the transmission at the closest point to the source, but the difference between the transmission values is about 1.5 times more in favor of the 6B configuration.

- Configurations with 6 magnets have best performance for selection of single energy, close to the maximum transmission point. This is due to the best homogeneity of the magnetic field.

5 Conclusions

The performance of the constructed mini-orange β-spectrometer has been made using the GEANT4 Monte-Carlo simulation tool. The optimal size of the electron detector has been calculated based on the simulations. The transmission curves of the device have been produced. They could be used as a reference for the experimental investigation of the device.

This work was supported by the DID02/16 contract with the Bulgarian National Science Fund.

References

[1] J. Van Klinken, S.J. Feenstra, K. Wisshak, H. Faust, *Nucl. Instrum. Methods* **130** (1975) 427-441.

[2] J. Van Klinken, K. Wisshak, *Nucl. Instrum. Methods* **98** (1972) 1-8.

[3] S. Agostinelli *et al.*, *Nucl. Instrum. Methods A* **506** (2003) 250-303.

[4] NIST web site: *http://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html*[last visited 24.10.2013]