1 Collimator simulations for development of a scanning system

The *Compex* project comprises the development and study of a novel HPGe detector set-up. In its' beauty it will consists of five *Compex*¡++¿ Clovers, i.e. five groups of four crystals brought together within a capsule. In nuclear spectroscopy experiments where very exotic structures are to be studied it is necessary to employ a high resolution HPGe detectors. In addition these detectors need to be compact. The compact and exotic together brings *Compex*. In order to confidently discover new physics and propose new nuclear structure properties it is of utmost importance to know the characteristics of the detectors. In this regard it is hence essential to characterise the *Compex* set-up in detail.

The characterisation of HPGe crystals is achieved with a scanning system. There exists some different scanning systems []. All systems utilise a collimator in some way. In the traditional scanning system a γ-beam is directed to one end of the crystal in a right angle. Surrounded on the sides of the crystal other γ-detectors, such as scintillators, are placed. With the help of slits 90° Compton scattered γ-rays with a specific energy can be gated on. The origin of such signals can be narrowed down to a small region in the crystal and therefore its properties here can be known. By doing this for many regions one scans a complete crystal and studies:

- Energy resolution
- Signal amplitude
- Rise time

Other scanning techniques are the pulse shape comparison scan and the mix of PSCS and γ-ray imaging. A first intention is to characterise the *Compex* crystals with the traditional technique. To be able to do this one needs a collimator. Important properties of the collimator are:

- Divergence of γ-rays
- Scattering efficiency (full energy efficiency)

The simplest collimator is a volume with a cylinder hole where the volume can absorb γ-rays which are emitted badly. By adjusting the diameter of the cylinder the beam divergence can easily be determined. The scattering efficiency is not trivial to know. The idea of integrating cones on top of the cylinder was told to be a preferable configuration concerning the scattering efficiency. In this small project the performance of different collimators have been studied to determine the suitable collimator in use within the *Compex* project.

2 Geometry definition

The base geometry:

World $1 \times 1 \times 1$ m^3, air

Cylinder Outer radius 10 cm, length 10 cm, lead. If needed an inner diameter of 1 or 1.5 mm. Placed towards the $+\hat{z}$ starting in $z = 0$.

Integrated cones N integrated cones were placed within the mother volume cylinder, with a set inner diameter to match that of the mother and an outer diameter which varied for optimised performance. The cones were placed in such a way that the complete cylinder in $+\hat{z}$ was filled and the direction of the cones was varied with a 180° rotation. The tip of the cones in the same direction of the beam was by far the best and if not otherwise mentioned (denoted flipped), it was employed.

Integrated cylinders N integrated cylinders were placed within the mother volume cylinder now with an inner diameter set to zero. Cylinders, first one with a diameter of 1 mm and then $N - 1$ with a varied increasing diameter for best performance, were placed such that the cylinder with the smallest diameter was at the exit of the collimator.

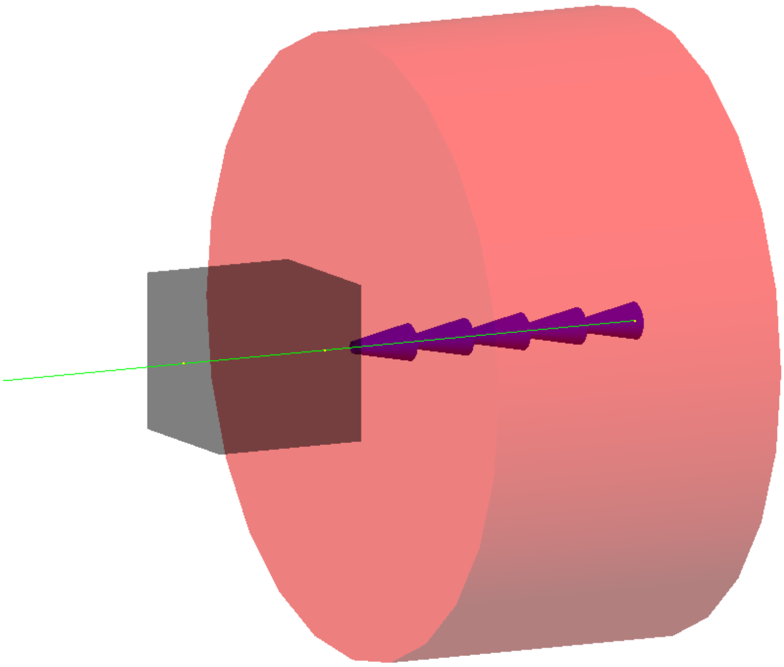

Figure 1: Geometry

3 Method

3.1 Primary generator and run

The primary generator in Geant4 was set as follows:

Particle Gamma-photons

Primary vertex $(0, 0, 0)$

Energy 661.7 keV to resemble a ^{137}Cs source

Direction $(u_x, u_y, 1)$ where:

$$u_x = r \cdot \cos\theta \tag{1}$$
$$u_x = r \cdot \sin\theta \tag{2}$$
$$\theta = \text{uniform random number} : [0, 2\pi] \tag{3}$$
$$r = 0.1 \cdot \sqrt{\text{uniform random number} : [0, 1]} \tag{4}$$

A run was comprised of $2 \cdot 10^6$ events. For the first run it was 100000.

3.2 Detectors

For the final analysis a box scoring mesh with the following settings was created:

Size $5 \times 5 \times 0.01$ cm^3

Location $(0, 0, 150.0)$ mm

Binning 500×500

I.e. it was set 5 cm from the collimator exit to resemble a real *Compex* crystal scanning.

For the detailed examination with the too large inner diameter the following box scoring mesh was used:

Size $2 \times 2 \times 0.1$ cm^3

Location $(0, 0, 100.5)$ mm

Binning 200×200

I.e. it was set directly on top of the collimator exit.

A sensitive detector was set up to create an energy spectrum. It was placed 5 cm away from the collimator exit and only stored the full energy of the incoming photons.

3.3 Analysis

The flux (first time cm^{-2}) in number of γ-rays was scored with one of the built-in Geant4 scorers. Besides this, the sensitive detector scored the energy of the incoming photons and stored the energies in a histogram. The scattering efficiency was determined as the ratio of the number of full energy γ-rays and the total detected in the sensitive detector. The beam divergence was determined as 3σ of the 2D flux. Finally, the required activity was calculated on the basis of the number of full energy γ-rays detected and the solid angle coverage:

$$\Omega = \frac{5^2}{100^2} \tag{5}$$

4 Results

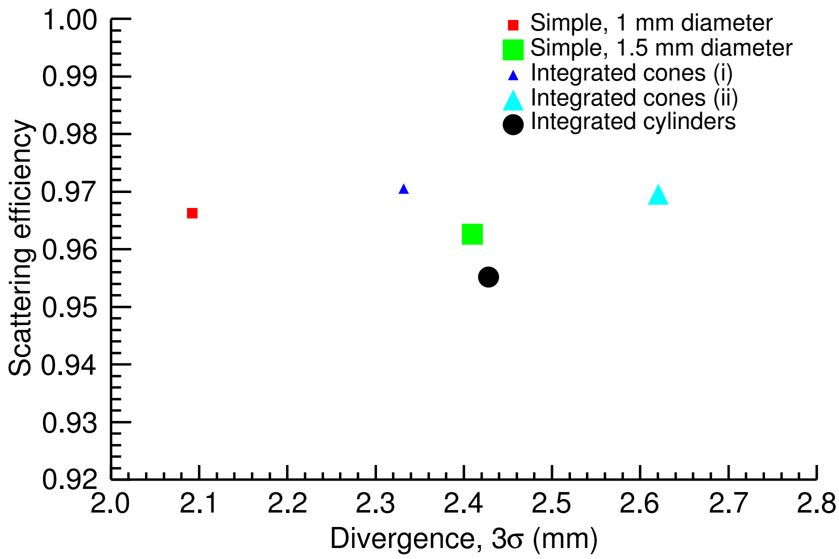

Figure 2: Results

Simple, 1 mm diameter A cylindrical collimator with diameter 1 mm.

Simple, 1.5 mm diameter A cylindrical collimator with diameter 1.5 mm.

Integrated cones (i) 5 cones (20 mm length) with an inner diameter of 1 mm and an outer of 1.4 mm.

Integrated cones (ii) 5 cones (20 mm length) with an inner diameter of 1.5 mm and an outer of 1.9 mm.

Integrated cylinders 5 cylinders (20 mm length) where the last one had a diameter of 1 mm and the rest an increasing diameter of 0.05 mm.

The required activity to achieve a count rate of 1 kHz for the first configuration is about 500 MBq.

5 Conclusion

It seems true that a collimator with integrated cones actually is able to increase the scattering efficiency, but it largely depends on the dimensions of the cones. However, many factors speak against such a configuration:

- The scattering efficiency is only increased marginally.
- The scattering efficiency is already close to maximum with the conventional collimator type.

- The beam divergence increases.
- It is unclear of whether it is possible to manufacture such a structure.

The beam divergence is rather not a measure of the spread of the beam but more a measure of leakage γ-rays making it through the lead block.

Several further configurations were investigated to see if they possibly could better optimise a collimator. These were:

- Integrated cones with the end coned removed.
- Integrated cones separated a set distance.
- Integrated cones flipped.
- Integrated cylinders separated a set distance.
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Several different dimensions were examined for the different configurations (see notes.txt in 2nd_analysis).