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Optical analysis of the reaction chamber for the ELIADE array

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Abstract

The ELI-NP Array of DEtectors (ELIADE) is one of the experimental setups being built at ELI-NP. The reaction chamber for the ELIADE array is, together with the CCD camera the goal of our research team. The precision of the experiment make important the small deformation and the vibration of the equipment. In the same time the optical system must be exactly enough to not introduce more inaccuracies. To study this, a model using Finite Element Method is used. In the experiment that will be conduct in the laboratory with ELIADE, precision is so important that it require extremely small deformation of the device. For this a model that takes into account the elasticity and the dynamic of the system must be used in order to study the motion of the ELIADE array.

Keywords: Reaction chamber,gamma beam,control, optical system

1. Introduction

The Gamma Beam System (GBS) is based on the creation of high energy photons after the collision between a visible light laser (2.3eV, 515 nm) and a high energy electron beam. The collision between the free electrons (not bound "inside" an atom) and photons is described by a process named "Compton scattering". In nature, this kind of

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collisions usually takes place between an electron at rest and a high energy photon, and results in the electron gaining energy at the expense of the photon which loses some of its energy. Because in the GBS, the roles are reversed (the electron has much more energy than the photon), the photon is the one gaining energy, and as a result, we say that we are dealing with "an inverse Compton scattering", [1]

The ELI-NP Array of DEtectors (ELIADE) is one of the experimental setups being built at ELI-NP which could benefit from the present project. From the physics point of view the array is made of 8 (up to 12) HyperPure Germanium (HPGe) segmented clover detectors. The experiments envisaged for ELI-NP require this detector to be placed on two rings, relative to the forward direction of the gamma beam. The detector's axis are all converging to a "theoretical" point which we call "the center of the array". Ideally, this is point where the photon beam intersects the target inside the reaction chamber (Fig.1).

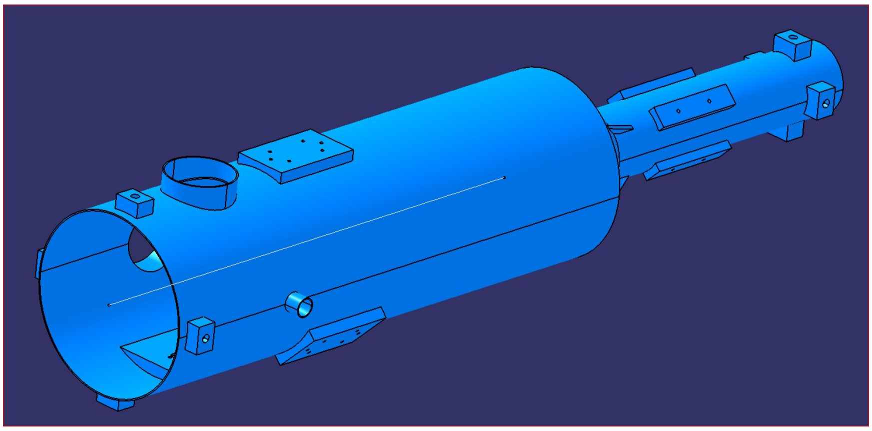


Figure 1. The sketch of the interaction chamber

An important distinction that needs to be done is the difference between the "center of array" (described above) and the "desired center of the target". The surface of the gamma beam spot size on the target depends on a number of factors, but will typically range between 0.5 and 2 mm in diameter. Ideally, the two are identical, but deviations from the ideal case have very different impacts on the experiments. The problem becomes the precision obtains in the experiment. To achieve this is necessary to make an suitable model in order to obtain a dynamical response of the system.

2. Current state and research context in the dynamic analysis

The interaction chamber for the ELIADE array must have a good rigidity in order the minimize the elastic deformations of this device. The hypothesis of rigid body, frequent used in the dynamical analysis of multibody systems, may be satisfactory in most applications but not here. The different parts of the device consists of elastic elements to a smaller or greater extent. In our case the elasticity becomes a significant element. The deformations and the possible vibration may have, generally, an unfavorable influence on the operation of the device.

Continuous mathematical models can be applied, from theoretical point of view, but are not useful in practical applications. The best way of approaching the problem is to apply the finite element method. The advantages of this approach result from [2]-[6].

The papers approaching this field have performed an analysis of a single deformable element, having a plane motion and then the study extended to the mechanisms with plane-parallel motion [7],[8] with all the deformable elements. In [9] the results obtained in this field are being synthesized and some theoretical assumption are presented in [10]-[11]. A study of the composite materials that can be used in the device can be found in [12]-[16]. Dynamic analysis of the multibody systems with elastic element can be found in [17]-[19].

3. Optical system

In order to create a convenient optical system (SO) for capturing the radiation beam profile, an initial set of conditions must be established during development. The calkculus is made using the references [20]-[30].
1) **Magnification of the optical system** (S.O.) is an important size to ensure that the CCD sensor of the camcorder can be fully captured by the beam. The action of an SO is synthesized through the following relationship:

[IMAGINE]=[S.O.] [OBIECT]

which turns into the following relationship:

$$\begin{bmatrix} \alpha' \\ x' \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} \alpha \\ x \end{bmatrix}$$

where x and α, respectively x 'and α' are the position parameters of the object respetively the image. The matrix formed by the terms a, b, c, d represents the S.O.

The values of the S.O. are restricted by the condition that the value of the determinant associated with the matrix has the value equal to 1, ie ad-bc = 1.

In this respect, for a lens with the radii of curvature R_1 and R_2, the thickness *t* and the refractive index *n* the matrix is:

$$[LENS] = \begin{bmatrix} 1 & (n'-n)\frac{1}{R_2} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \frac{t}{n'} & 1 \end{bmatrix} \begin{bmatrix} 1 & (n'-n)\frac{1}{R_1} \\ 0 & 1 \end{bmatrix}$$

where n=1.

Inside each of the lenses, the translation matrix must also be written:

$$[SO] = [LEN\_S3][TRAN\_S2][LEN\_S2][TRAN\_S1][LEN\_S1]$$

This relationship can be used to dimension S.O.

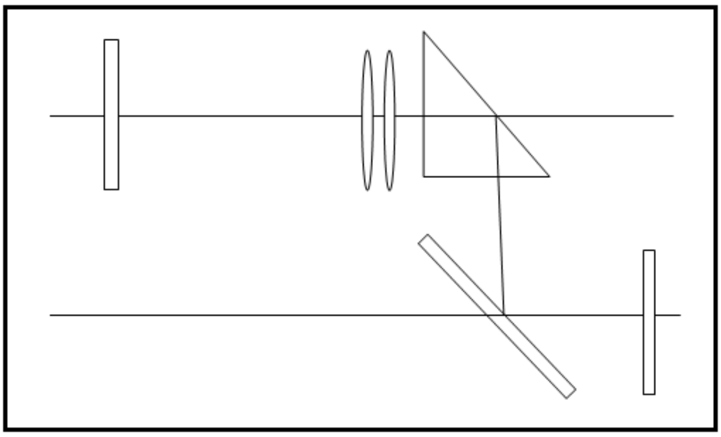


Figure 2. The sketch of the optical system

2) For **scintillators** where the radiation level is very low, it is necessary to determine the area of **optical radiation collection** by S.O. (aperture S.O.). Using this model we determine if the intensity of light created by the gamma-ray

scintillation interaction is sufficient to measure with the camera's sensor. It includes a power transmission calculation, an analysis of the sensitivity of the sensor and of the system. Therefore, the power transmitted through the system (the power at the output of the light radiation) can be determined as the amount of energy deposited / second by the absolute efficiency of the scintillator.

Thus, assuming that the power emitted by the scintillator is transmitted uniformly, then the amount of power transferred to the CCD sensor can be calculated using the input pupil aperture and the lens transmission coefficients of the S.O.

For a scintillator placed at a distance from the first lens surface of the S.O., the power at the CCD sensor level will be:

$$P_{CCD} = \frac{\pi\left(\frac{D_A}{2}\right)^2}{4\pi d^2} T_{lentila}\ \eta\ P_{absorbita} = \frac{1}{16}\left(\frac{D_A}{d}\right)^2 T_{lentila}\ \eta\ P_{absorbita}$$

The principle sketch is the following:

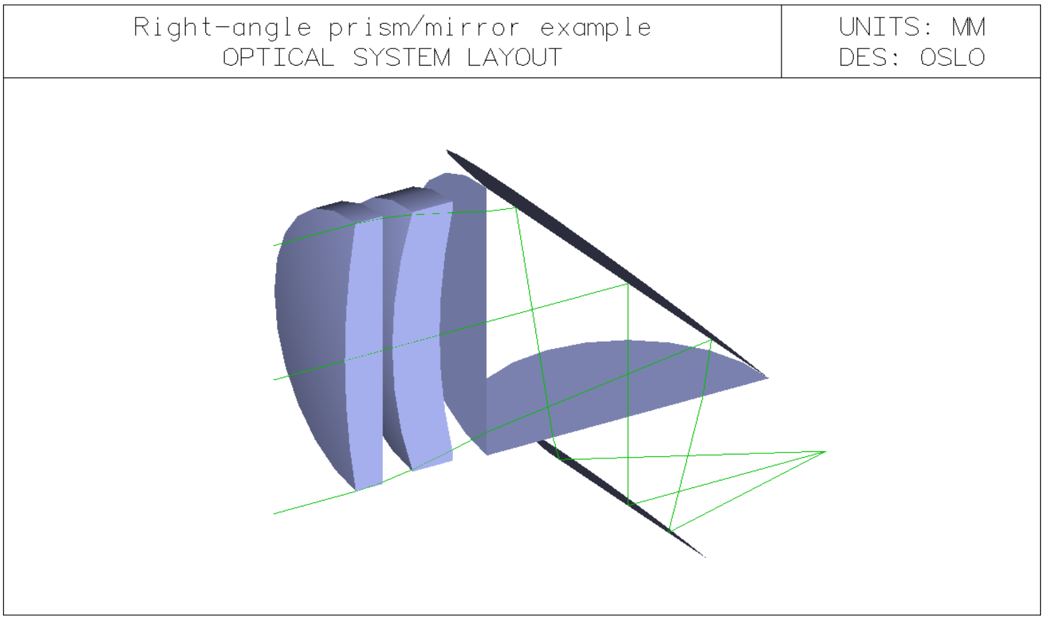


Figure 3. Physical model of the optical system

In our case, replacing the calculation relation of PCCD in the NC relation we will obtain:

$$[S.O.] = \begin{bmatrix} 6{,}63 & \left(arctg\frac{R_{iesire} - 7{,}93}{l'} - 6{,}63 \cdot arctg\frac{\frac{D_A}{2} - 50}{l} \right) \\ 0 & 0{,}158 \end{bmatrix}$$

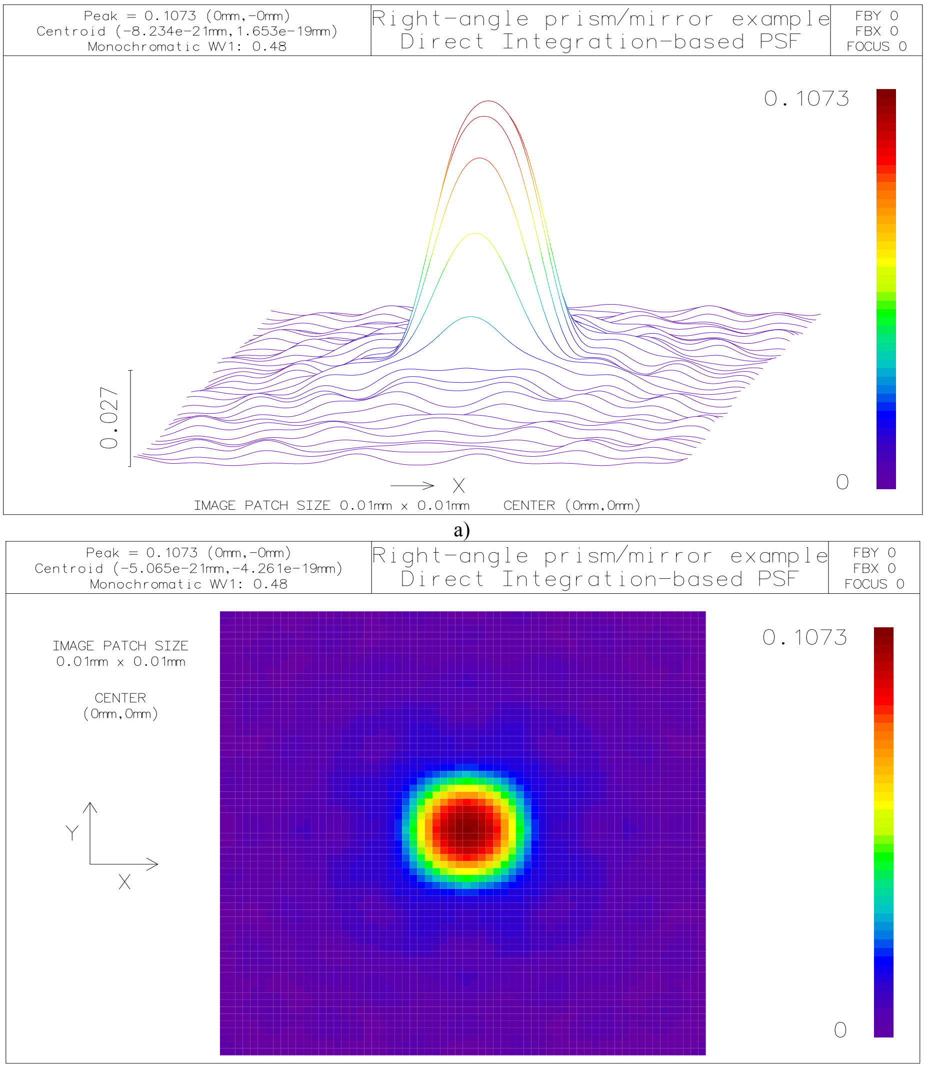
$$N_C = int\left[\frac{1}{16}\left(\frac{D_A}{d}\right)^2 R_{CCD} \cdot T_{lentila} \cdot \eta \cdot P_{absorbita} \cdot t_{int}\right]$$

A simplified form is:

$$N_C = int\left[R_{sist} \cdot P_{absorbita} \cdot t_{int}\right]$$

where $$R_{sist} = \frac{P_{CCD}}{P_{abs}} R_{CCD} = \frac{1}{16}\left(\frac{D_A}{d}\right)^2 \cdot R_{CCD} \cdot T_{lentila} \cdot \eta$$

This relationship describes the entire optical system having as design variables: the distance between the scintillator and the first lens, the distance between the last lens and the CCD sensor, the pupil diameter of the DA and the curvature radius of the last lens in the S.O.



a)

b)

Figure 4. Distribution of the light produced by scintillator arround the optical axis

4. Conclusions

The phenomenon of attenuation of the radiation intensity γ when passing through a layer of the substance is due to both phenomena of absorption of the quantum energy γ by the atoms of the substance, as well as some phenomena of diffusion of these quantums. For the energies that the quantum (photons) γ emitted by radioactive sources (eg 100 KeV ... 3 MeV) the main radiation interaction processes with the substance are the following: 1) - photoelectric effect; 2) - pair formation (phenomena leading mainly to energy absorption) ; 3) - the Compton effect (which is mainly a diffusion phenomenon, but only with the partial absorption of quantum energy).

Therefore, the entire 20.2 Mpixeli sensor (for a 20.2 MP camera) will obtain a total number of photons in one second: Ntotal = 2,3 10-5 20,2 106 = 464, 6 photons / second. Respectively each pixel will reach 0.0828 photon / pixel / h in one hour and 1.67 106 photons / h will be added to the entire sensor surface.

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