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# Characterization of the Mini-X2 X-ray Tube and sensitivity measurements of a Triple-GEM

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**Summary.** — The study involves the detailed characterization of an X-ray source (Mini-X2 X-ray Tube) and the photon sensitivity measurements of a Triple Gas Electron Multiplier detector (GEM). In parallel to the experimental measurements, simulations were carried out with the GEANT4 Monte Carlo package (`https://geant4.web.com.ch/`) both to create a shielding that would allow safe operation and for a theoretical comparison of the sensitivity measurements.

## 1. – Introduction

A gas detector is generally used in particle physics experiments to detect charged particles. On the other hand, within an experimental apparatus composed of several detectors, there can be fluxes of neutral particles (photons or neutrons) which may constitute an important background. For this reason, it may be essential to estimate the sensitivity of a gas detector even to neutral particles. For the sensitivity measurements, two photon sources were used: the Mini-X2 X-ray Tube [1] and a $^{55}$Fe source, while a Triple Gas Electron Multiplier [2] (GEM) was used as a gas detector. At first, the Mini-X2 was characterized also aiming to create an efficient shield for the safe operation of the Mini-X2. Finally, photon sensitivity measurements were carried out after characterizing the Triple-GEM detector and compared with simulation results.

## 2. – Mini-X2 characterization and shielding construction

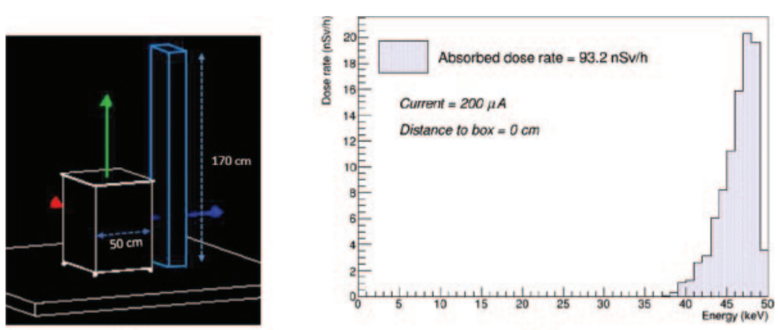
The Mini-X2 X-ray Tube consists of a cathode that, when heated by a current of a few microamperes, emits electrons by thermionic effect. These, due to the application of a positive voltage, move toward the Ag anode. When the electrons collide with it, X-photons are emitted by both Bremsstrahlung and characteristic radiation according to an energy spectrum ranging from 0 keV to 50 keV. For the characterization, the number of photons emitted per second by the Mini-X2 has to be quantified. The manual provides the data regarding the absorbed dose rate in air under certain conditions of distance, current, and voltage. The relationship between the absorbed dose rate in air and the number of photons emitted per second is given by the formula

$$\dot{D}_{air} = 5.76 \cdot 10^{-4} \int_{E_i}^{E_f} \frac{\phi k_E}{\Omega r^2} E_\gamma \left(\frac{\mu_{en}}{\rho}\right)_E \mathrm{d}E, \tag{1}$$

where the number of photons emitted in a second $\phi$ is the quantity searched, $r$ is the distance from the source, $E_\gamma$ is the photon energy in MeV, $\Omega$ is the emission angle, $k_E$ is the energy channel weight of the spectrum, and $\mu_{en}/\rho$ is the massive attenuation coefficient. The integral was replaced with a summation from 0 keV to 50 keV since the precise functional form of the energy was not known. Substituting within it the data given for the Mini-X2, the number of photons emitted per second in the 80 $\mu$A current case was found; from this, the number of photons in the 200 $\mu$A maximum applied current case is derived assuming a linear behavior, equal to

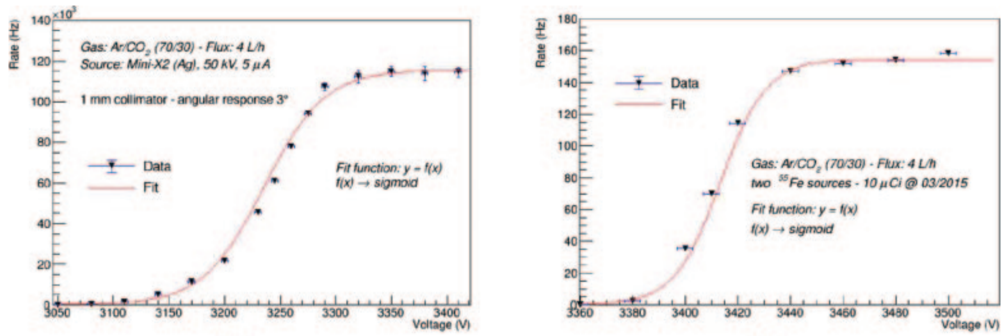
$$\phi_{200\mu A} = (4.53 \pm 0.29) \cdot 10^{11} \gamma/s. \tag{2}$$

The simulation software wrote for these studies is based on Geant4 and it reproduces a source simulating the Mini-X2 with all the above mentioned characteristics. It was evaluated the shielding effect of different materials to build a shield around the X-ray tube in order to perform measurements safely. A box was simulated around the source with dimensions 50 cm $\times$ 60 cm for the base and 70 cm for the height and it is shown in fig. 1(a). It consists of a double layer of copper (1.5 mm) and aluminum (3 mm) on the side faces, aluminum (3 mm) and lead (2 mm) on the bottom face and only aluminum (1 cm) on the top face. To verify the efficiency of the shielding, a volume of water near the box approximating a person was simulated. The dose rate absorbed by this volume in the case where the source emitted the maximum number of photons was evaluated. Under this higher risk condition, the simulation shown in fig. 1(b) returned an absorbed dose rate of 93.2 nSv/h, a negligible value compared to that of the ambient radiation, which is about 230 nSv/h.




(a) (b)

Fig. 1. – (a) Simulation setup with box and water volume. (b) Dose rate absorbed by a person at a distance of 0 m from the box. Each channel of the histogram corresponds to the contribution to the absorbed dose rate due to each channel of the energy spectrum of photons exiting the Mini-X2.




(a) (b)

Fig. 2. – Rate as a function of the voltage for Mini-X2 (a) and Fe55 (b).

## 3. – Triple-GEM characterization

The source characterized before was used on a Triple-GEM detector for photon sensitivity measurements. The detector consisted of 10 cm x 10 cm GEM sheets arranged between two electrodes and with gap sizes of 3/1/2/1 mm within which was a gas mixture. A Triple-GEM detector is a charged particle detector; however, photons can also produce a signal. These can interact with the internal components of the detector (Cu) and produce electrons that can ionize the gas, producing the electronic cascade returning the anode signal. To characterize the detector, rate and gain measurements as the voltage applied to the electrodes were carried out. The first ones for the Mini-X2 and $^{55}$Fe are shown in fig. 2(a) and (b). The voltage at which the rate reaches the plateau, in fig. 2(a) and (b), allows us to identify when the detector is efficient.

## 4. – Sensitivity measurement

Photon sensitivity was estimated both experimentally and through simulations with Geant4. Experimentally, it was calculated as the ratio of the rate at the plateau to the incident photon flux. With Geant4, after reproducing the detector in detail, the sensitivity was calculated as the ratio of the number of photons producing an electron in the first two gaps to the incident flux. This approximation is because Geant4 does not reproduce the charge multiplication that occurs. Therefore, only the electrons produced in the first two gaps are assumed to produce a visible signal. A comparison of the experimental and simulated results is shown in table I.

The quoted errors are statistical; possible systematic errors related to the LBE physics list [3] used in Geant4 or due to not completely correct reproduction in all details of the box were not quantified.

TABLE I. – *Comparison of simulated and experimental sensitivity for both sources.*

| Source | Simulated sensitivity | Experimental sensitivity |
|---|---|---|
| $^{55}$Fe | $(1.969 \pm 0.036) \cdot 10^{-3}$ | $(3.32 \pm 0.18) \cdot 10^{-3}$ |
| Mini-X2 | $(1.225 \pm 0.005) \cdot 10^{-2}$ | $(6.80 \pm 0.07) \cdot 10^{-2}$ |

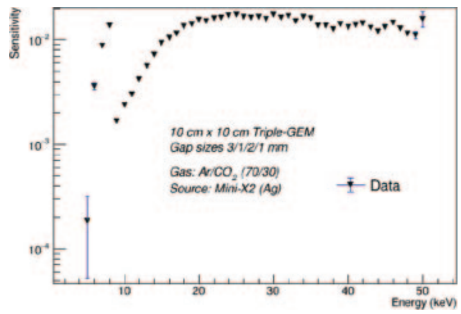



Fig. 3. – Sensitivity as a function of the energy.

In fig. 3 the sensitivity as a function of energy is shown. Up to 8 keV, the photons interact with the Ar inside the detector by emitting a large number of electrons of energy lower than 8 keV. Because they are formed internally the active gas, almost all of these electrons, are detected. Instead, at higher energies, the photons make a photoelectric effect in the inner copper present in the detector. In this case, because the interaction takes place in the copper, the amount of electrons reaching the gas is significantly less than the number of those produced. Therefore, for the same number of incident photons, the number of electrons detected, and thus the sensitivity, will be greater at energies below 8 keV.

The decreasing trend as energy increases is matched with simulations performed in a previous study at CMS [4] in which the analysis of photon sensitivity starts from 100 keV and returns a value of about $3 \cdot 10^{-3}$.

## 5. – Conclusion

The main results obtained during the work are summarised. The Mini-X2 X-ray Tube was characterized by estimating its emissive power. Thanks to these analyses, the absorbed dose rate was theoretically evaluated as the distance varies, and this was used to design (through Geant4 based simulation) a shielding for the Mini-X2 safe operation. The Triple-GEM characterization has then been carried out with the Mini-X2 and the $^{55}$Fe sources, obtaining rate, gain, and sensitivity measurements in two cases. In the last part, the experimental sensitivity and the sensitivity obtained from the simulation were compared and a good agreement in terms of one order of magnitude was obtained.

REFERENCES

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