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Characterization and Calibration of a Triple-GEM Detector for Medical Dosimetry

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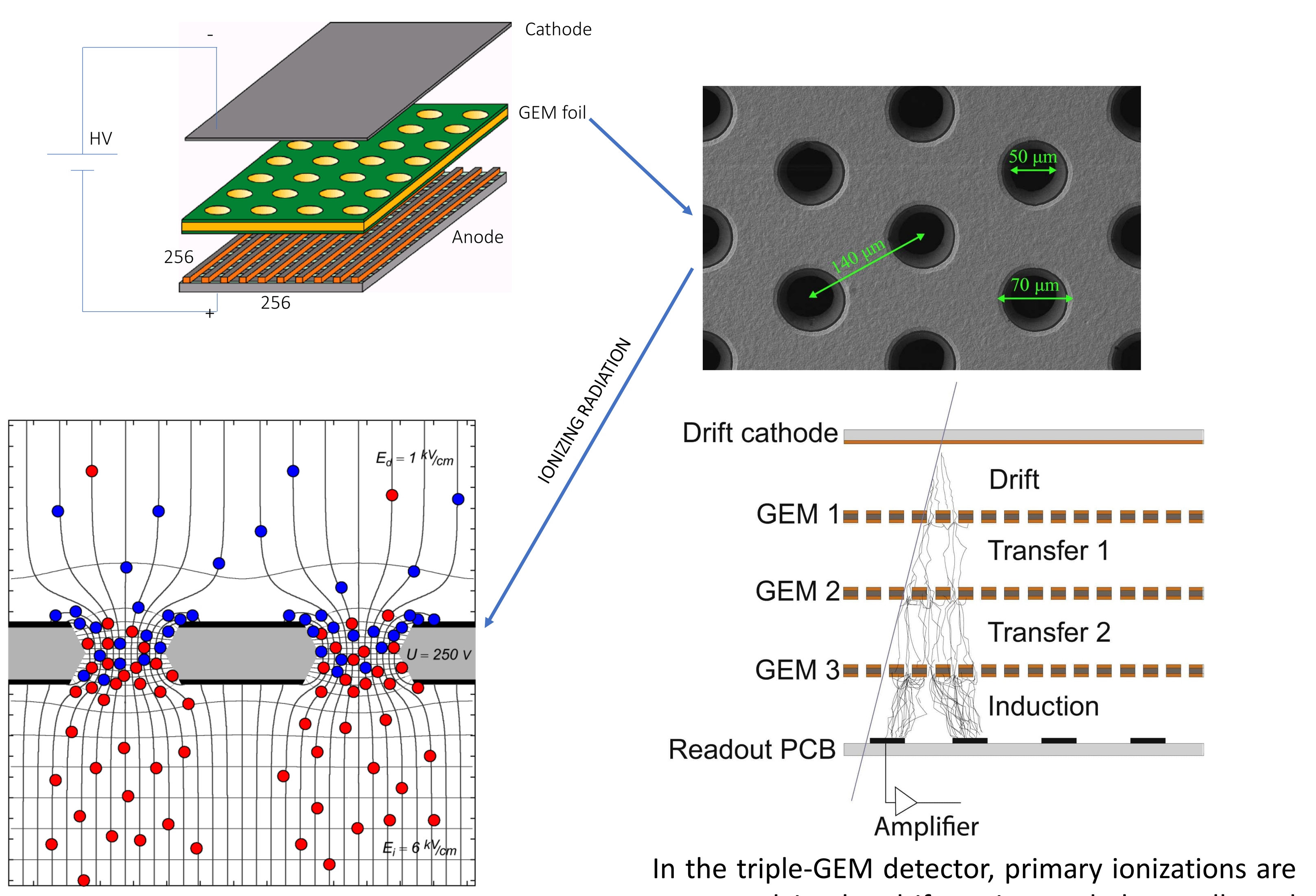
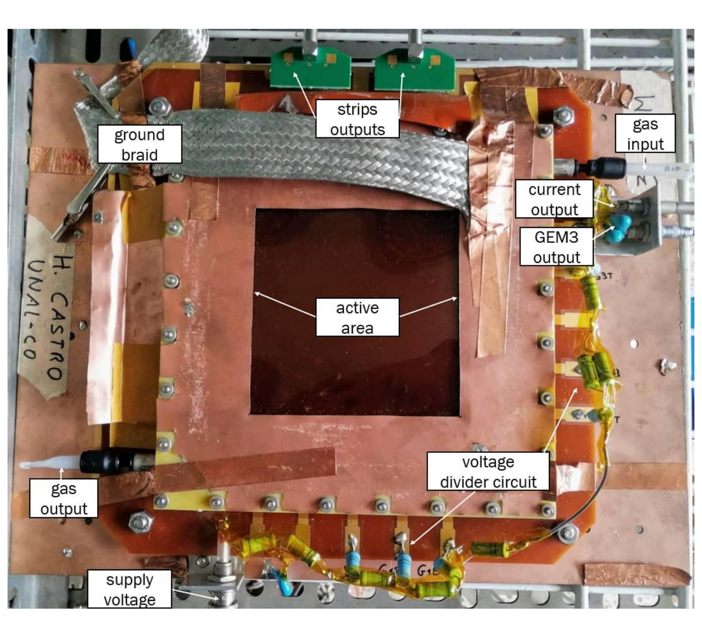
ABSTRACT

We characterized and calibrated a triple Gas Electron Multiplier (triple-GEM) detector, and studied its possible applications in medical dosimetry. The response to various sources of radiation was analyzed, and its gain, energy resolution, and time resolution were calculated. Then, radiation doses from an Iron-55 source and a medical portable X-ray machine were measured, obtaining the calibration factor for the GEM detector by comparison with reference values. We found an energy resolution of 19.5%, a time resolution of 40 ns, and a maximum gain of 5x10^6. The detector's response to dose measurements was linear, with a calibration coefficient of 1.13x10^4 for different sources of radiation. It was concluded that GEM detectors can be reliably used as dosimeters in nuclear medicine and radiology.

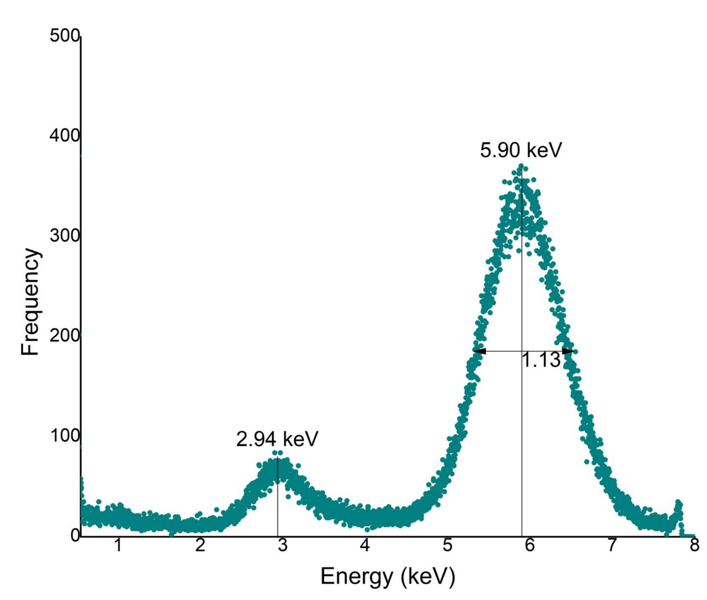
THE TRIPLE-GEM DETECTOR



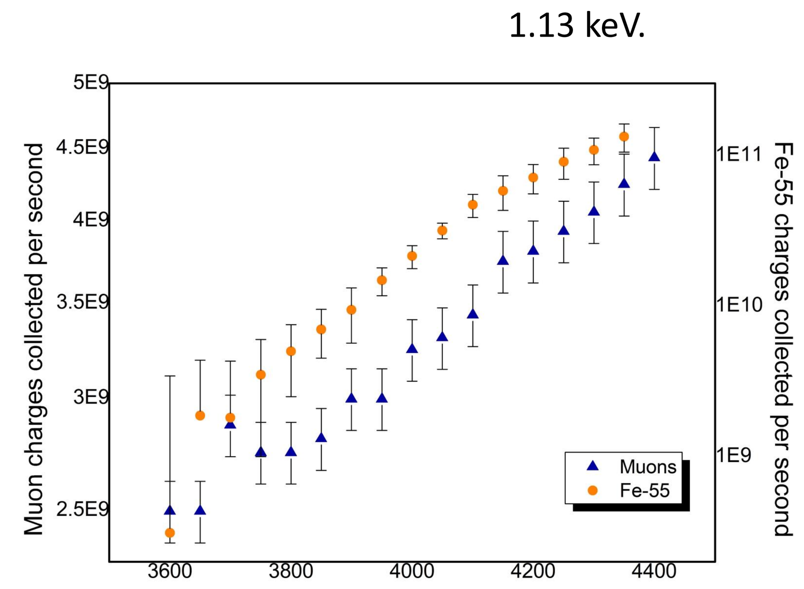
In the triple-GEM detector, primary ionizations are generated in the drift region and then collected and multiplied successively in each GEM foil.



The triple-GEM detector used in this study. It was acquired and assembled at CERN under the RD-51 collaboration.



Spectrum of Fe-55 taken with the triple-GEM detector. The small peak on the left is the argon escape peak at 2.94 keV, and the peak on the right is the Fe-55 characteristic peak at 5.9 keV. The latter has an FWHM of 1.13 keV.



Number of charges collected per second with cosmic muons and the Fe-55 source vs Applied voltage. This plot shows that the detector is operating in the proportional counter region, where counts are proportional to the energy deposited by incoming particles. A gain vs voltage curve was also plotted but is omitted because it looks identical to these curves except for a scale factor. The gain ranges between 3 × 10^4 and 4.7 × 10^6.

MEDICAL DOSIMETRY

The absorbed dose in a medium D_{med} is the total energy per unit mass deposited by ionizing radiation. It is given by $D_{med} = \frac{dE}{dm}$, where dE is the energy absorbed by a volume of mass dm.

Each time a photon interacts with the gas in the drift region of the GEM it deposits some energy. The total energy can be expressed in terms of the primary charge produced through gas ionizations Q_{prim}, the average energy required to cause one ionization W_{gas}, and the mass of gas in the drift region m_{gas}. The dose deposited in the gas D_{gas} is given by

$$D_{gas} = \frac{Q_{prim}}{m_{gas}} \frac{W_{gas}}{e}$$

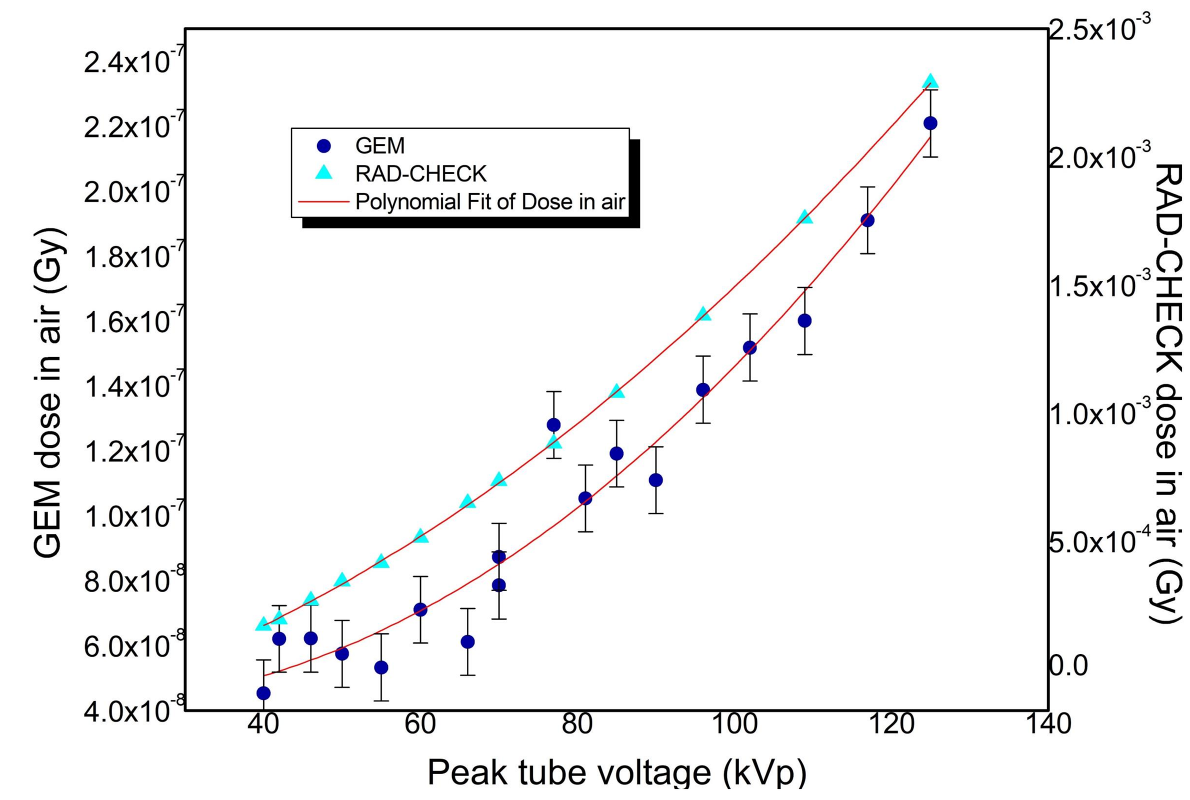
The dose absorbed by the detector can be converted into dose absorbed by any other medium using Big Cavity theory, which provides the following equation for particles of energies lower than 1 MeV:

$$\frac{D_{med_1}}{D_{med_2}} = \frac{(\mu_{en}/\rho)_{med_1}}{(\mu_{en}/\rho)_{med_2}}$$

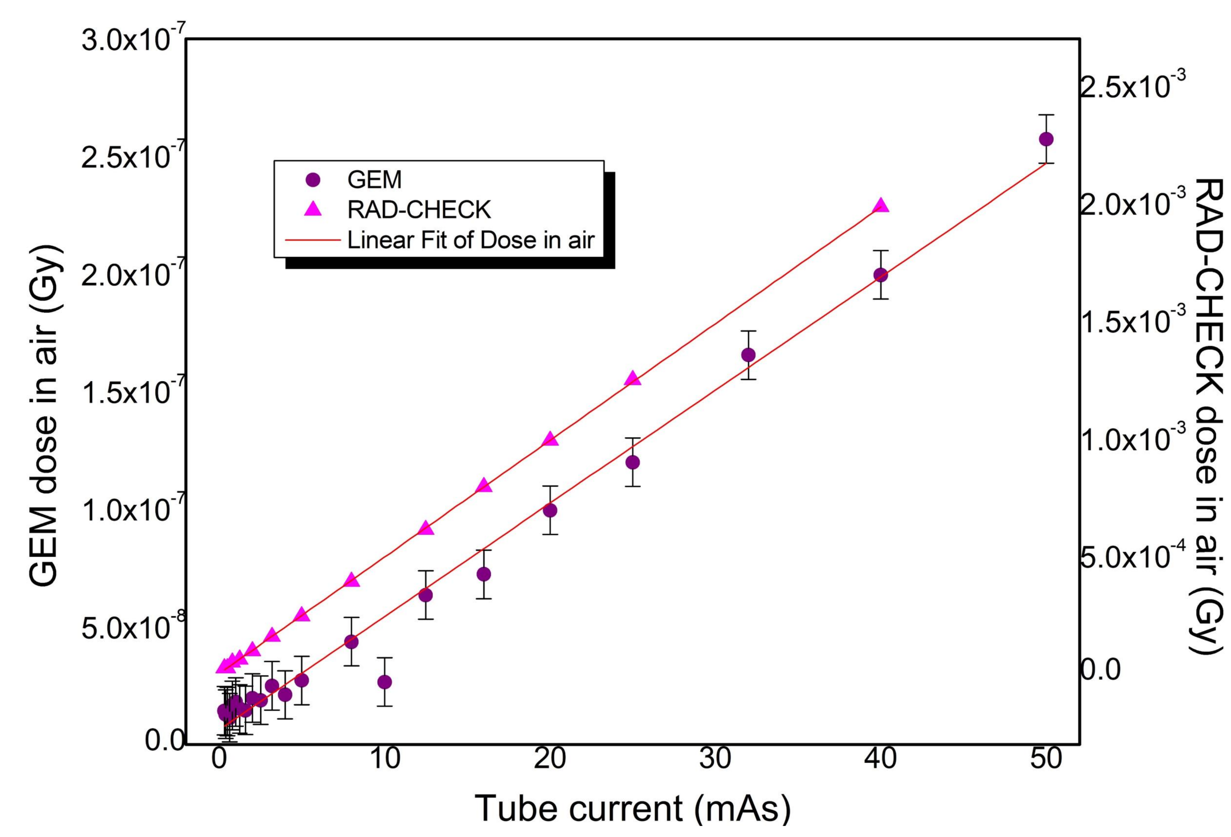
where D_{med_1} is the dose deposited in the required medium, D_{med_2} is the dose deposited in the detector, and (μ_{en}/ρ) is the mass linear attenuation coefficient of each medium.

Converting the dose absorbed in the detector D_{med_2} to the dose absorbed in air D_{air} is especially useful because most dosimeters are calibrated in terms of the energy that would be absorbed in air.

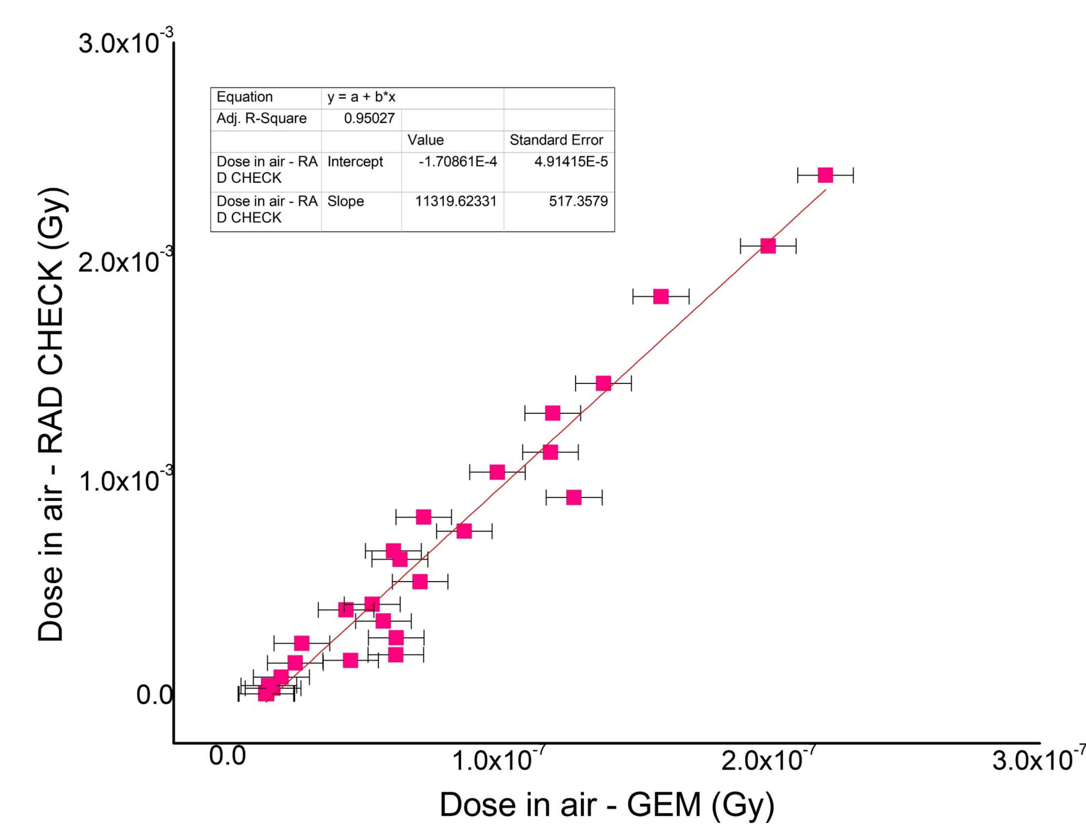
DOSIMETRY RESULTS



Dose in air vs Peak voltage measured with the triple-GEM detector compared to the reference dosimeter. Measurements were made at an SOD of 88 cm and tube current of 16mAs. The relationship is quadratic despite high dispersion at low voltages.



Dose in air vs Tube current measured with the triple-GEM detector and the reference detector. Measurements were made at an SOD of 88 cm and peak tube voltage of 73 kVp. Both sets of data are well fitted to a linear function as expected.



Dose in air measured with the triple-GEM detector compared to measurements with the reference detector. The linear fit provides the calibration function: Dose = 1.13 · 10^4 × Measured Dose — 1.71 · 10^{-4}, so the calibration factor is 1.13 · 10^4.

VIABILITY OF DOSIMETRY APPLICATIONS

The triple-GEM detector proved to be suitable for dose measurements of both radioactive sources and X-rays, at a wide range of tube currents and peak voltages. The calibration factor was constant regardless of energy, type of radiation or detection sensitivity. Because triple-GEM detectors have countless advantages such as flexible geometries, large detection areas, high spatial resolution, mass production, and low cost, using them as dosimeters presents great advantages. Therefore, it seems reasonable to conclude that the triple-GEM detector could become a very useful and advantageous dosimeter in nuclear medicine and radiology. The possibility that GEM detectors provide of using a pixelated readout board with high spatial resolution, would allow users to make 2D dose maps, which common dosimeters cannot do. This advantage could help reduce unwanted doses that patients receive in treatments, and verify the uniformity of radiation beams.

A final remark to be taken into account in further research is that, to reliably use the triple-GEM detector as a clinical dosimeter, the instrumentation must be adapted to make it portable, and effective noise shielding must be provided.

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