

# Tuning Gaseous Detector Sensitivity for Monitoring Applications in Fusion Reactors

Orientador: Prof. Dr. Tiago Fiorini da Silva

Coorientador: Prof. Dr. Zwinglio de Oliveira Guimarães Filho

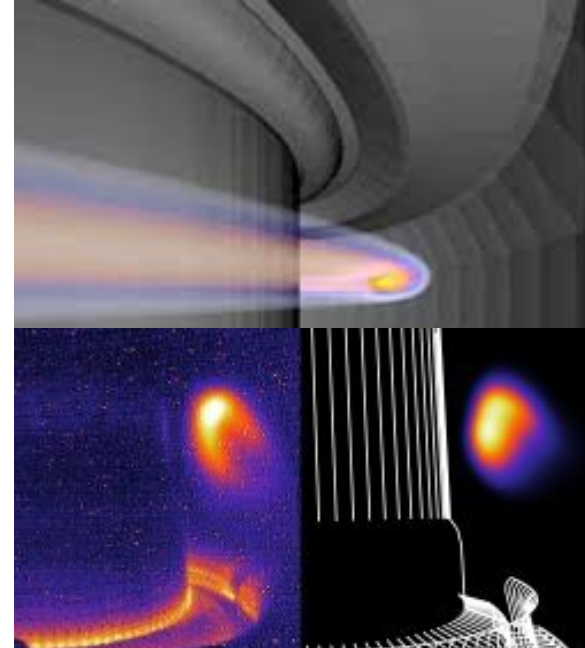
Juliano Henrique Leite dos Santos - bolsista PUB



Runaway electrons (RE) are electrons in a plasma that are continuously accelerated by an electric field to relativistic energies. In tokamaks, this phenomenon occurs when the accelerating force produced by the toroidal electric field exceeds the collisional drag force experienced by the electrons in the plasma.

Under normal conditions, electrons lose energy through collisions with other plasma particles. However, as the electron velocity increases, the collisional friction decreases. Above a critical energy, the electric field becomes dominant, causing some electrons to undergo continuous acceleration instead of thermalizing with the plasma. These electrons are referred to as runaway electrons.

When runaway electrons interact with matter they generate Bremsstrahlung radiation, producing a broad spectrum of hard X-rays and gamma rays that can be used for runaway-electron diagnostics.



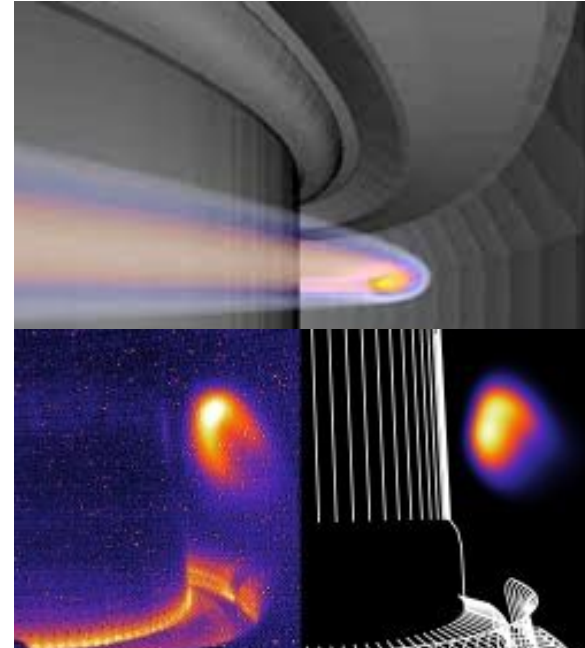
Upper image: A computer-generated 3-D view shows runaway electrons in DIII-D based on high speed 2-D images of synchrotron emission Credit: N.W. Eidietis and M.R. Wade, General Atomics

Synchrotron radiation emitted by runaway electrons in Alcator C-Mod. Left: experimental image (Robert Granetz and Alex Tinguely, MIT), right: emission calculated by the SOFT model (Mathias Hoppe, Chalmers University).

Scintillator-based detectors are currently used for the study of runaway electrons, which consists in unwanted relativistic electrons that can damage the integrity of tokamaks and should be mitigated.

In the case of TCABR, they can also be studied in order to access information about the initial conditions of the discharge.

The widening of the range of actuation of GEM's could also present many other applications involving imaging and high energy physics experiments.



Upper image: A computer-generated 3-D view shows runaway electrons in DIII-D based on high speed 2-D images of synchrotron emission Credit: N.W. Eidietis and M.R. Wade, General Atomics

Synchrotron radiation emitted by runaway electrons in Alcator C-Mod. Left: experimental image (Robert Granetz and Alex Tinguely, MIT), right: emission calculated by the SOFT model (Mathias Hoppe, Chalmers University).

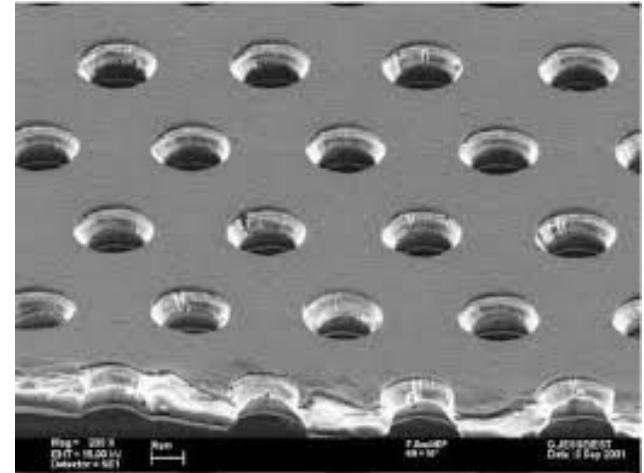
Specifically for TCABR, the detector used presents the limitation of being an integrating scintillator, which prevents it from distinguishing between energy and intensity of the beam and further extracting information about its energy.

A GEM converted for high energies presents the possibility of providing more information about the energy that could be correlated with the information of the other detector.



GEM's are detectors that work within the range of low-energy X-rays, and so are not usually appropriate for high energy applications.

The conversion of the GEM's for gamma ray energy detection would be done by placing a plate from a specific material, which would in turn by means of gamma X-ray fluorescence generate a spectrum with characteristic lines from the plate's material in the detector.



For the simulation used to find an adequate plate for this conversion we can use a Beer-Lambert analogue law,

$$dI = -\mu I(x) dx$$

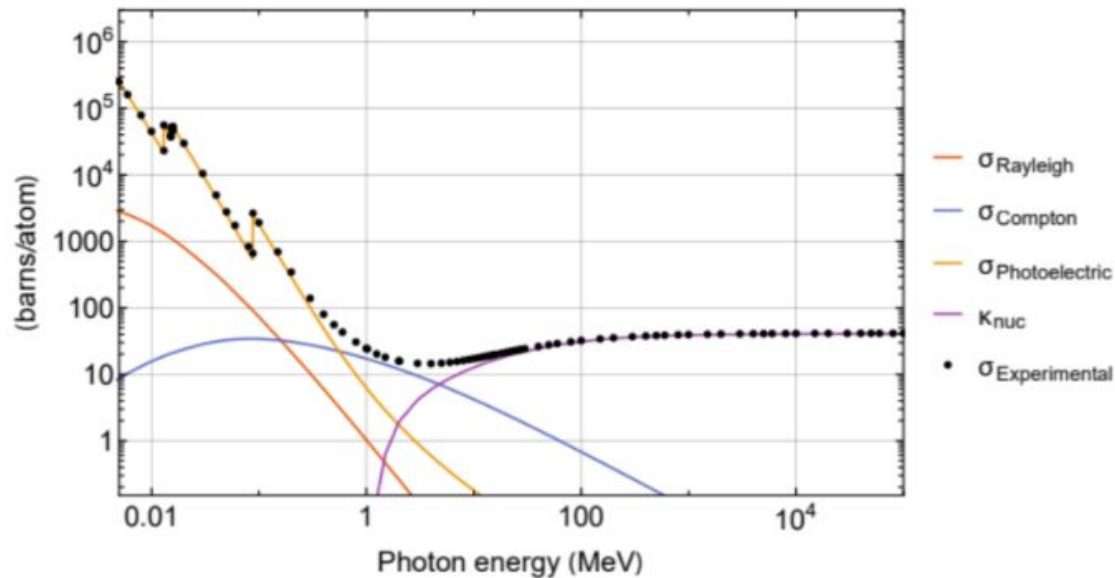
and admitting a constant profile of constant excitation through the material, and for the sake of simplification, no attenuation of the incident photons we arrive at the following expression:

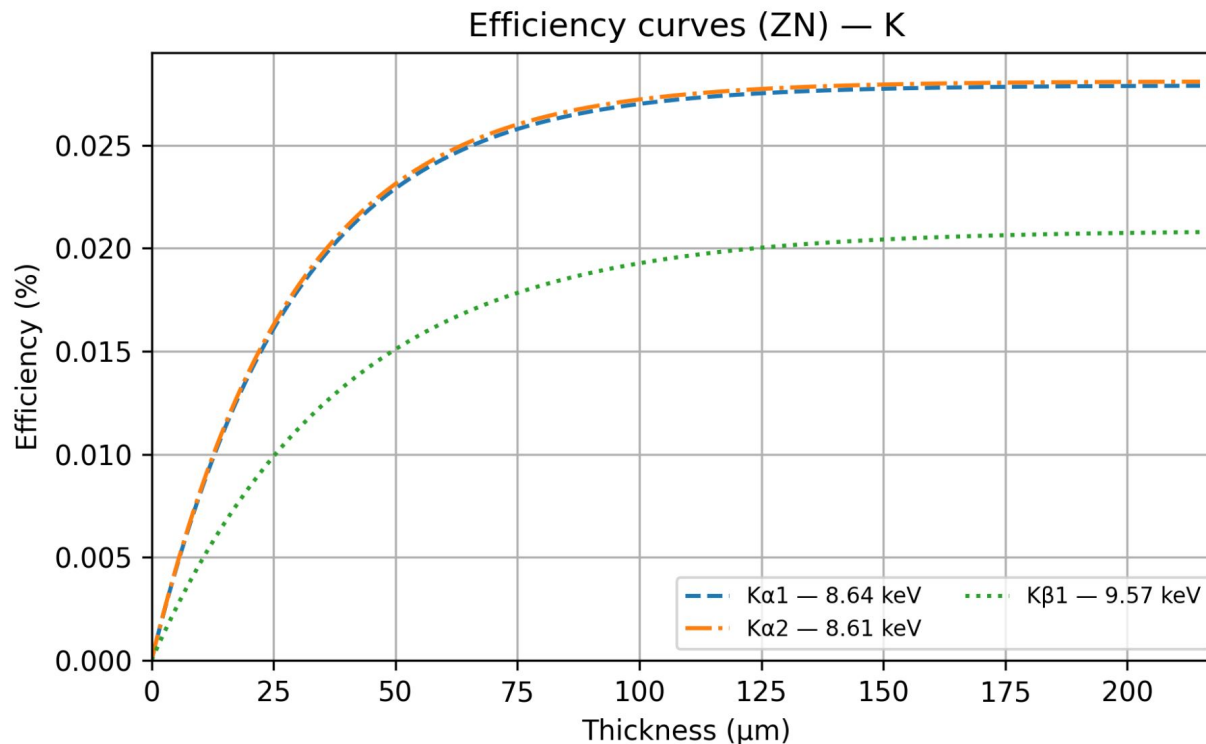
$$dS \propto \mu I(x) dx$$

after being integrated, this expression will provide saturation curves in which the parameters are the material, thickness and the transition being evaluated. Further on, we can also establish the quantum efficiency of detection:

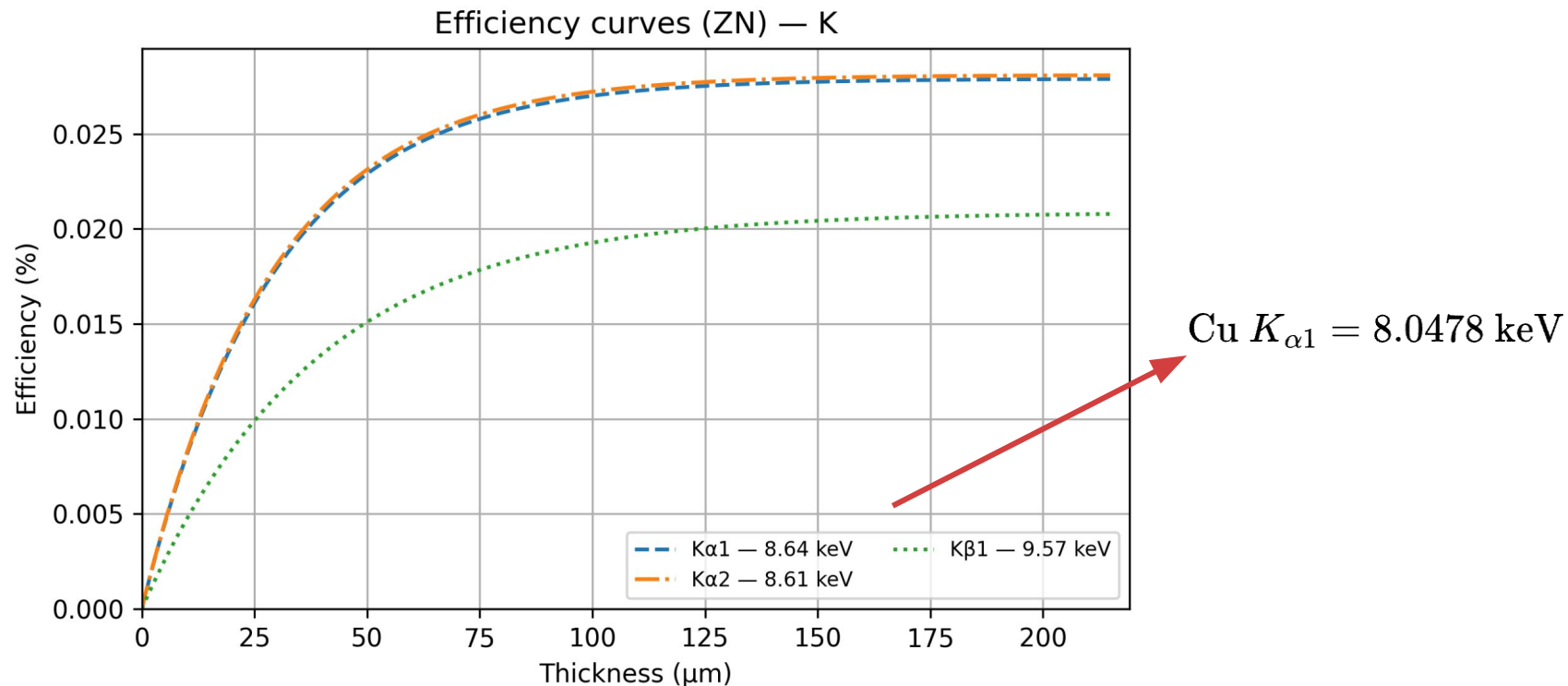
$$\varepsilon = 1 - e^{-\mu x}$$

In order to generate the saturation curves by this methodology, it was used empirical data obtained in the XCOM Photon Cross Sections Database from NIST, considering multiple types of photon-matter interactions.

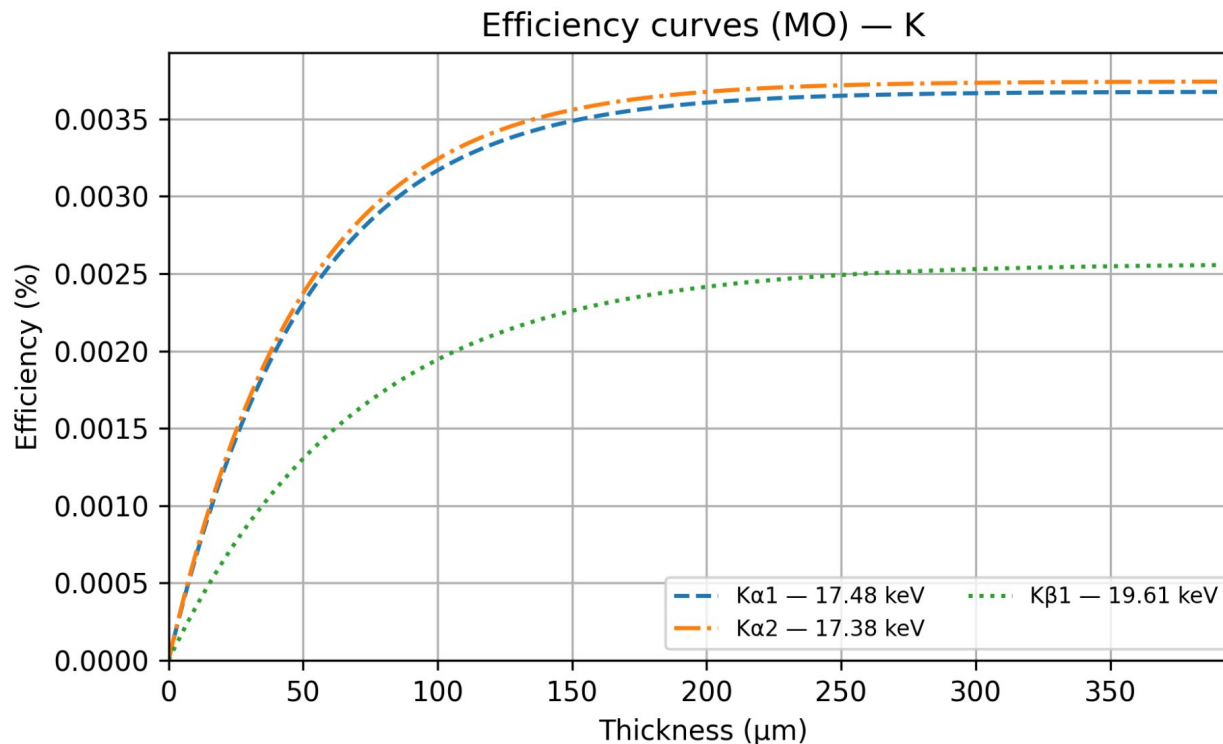




Considering 1 cm and 1 ATM of pressure for pure Ar in the gaseous detector.



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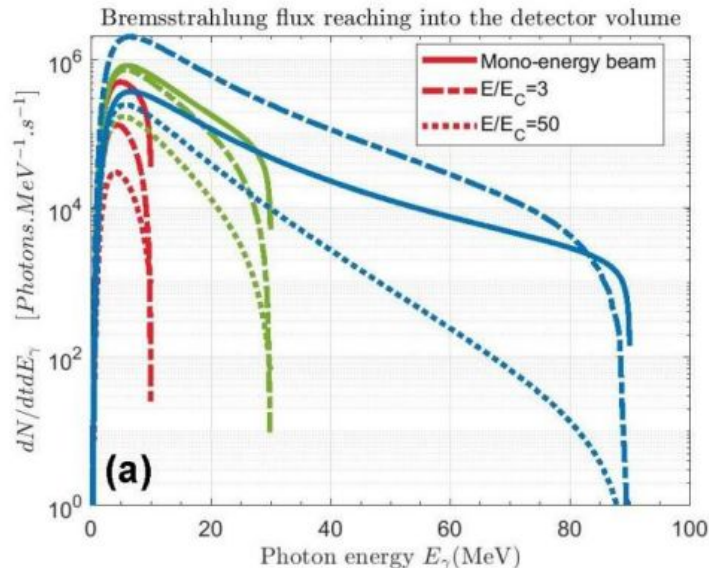
Considering 1 cm and 1 ATM of pressure for pure Ar in the gaseous detector.

Because a high flux in RE monitoring applications is expected, efficiencies as low as  $10^{-5}$  can still be reasonable, considering that the expected flux can be very high ( $\Phi \sim 10^7 - 10^8$  photons/s)

$$S_f = \eta \cdot \Phi_\gamma$$

$$S_b = 3.5 \times 10^{-5} \times 10^7 \approx 350 \text{ counts/s.}$$

$$\text{SNR} \approx \sqrt{N} \approx 19$$



S. P. Pandya *et al.*, "Modeling of bremsstrahlung emission from the confined runaway electrons and applications to the hard X-ray monitor of ITER," *Physica Scr.* **93**, 115601 (2018).

The results obtained by the simulation point to certain materials that can potentially be used for this conversion, like Molybdenum. The efficiency, although very low, is expected and, due to the application in high flux situations, it not only should provide enough SNR, it could be appropriate in order not to saturate the detector.

Consequently, the analysis points to a possible feasibility of this conversion, that will be further tested by simulations and experimentally.