Electroluminescence Yield in Noble Gases in Uniform Electric Fields

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Introduction

Dual phase and high-pressure gaseous optical-TPCs are used in many modern day experiments to detect rare events, e.g., in experiments that search for the neutrinoless double beta decay and WIMP dark matter. These experiments use the electroluminescence processes in the gas to amplify the primary ionization signals produced by radiation interaction inside the detector active volume. Pure noble gases are an obvious choice for this kind of experiments. In order to decide what gas to use in a certain experiment, it is of utmost importance to determine the electroluminescence yield for each candidate. Using a gas proportional scintillation counter, coupled to a large area avalanche photodiode (LAAPD), we have done experimental studies on the electroluminescence yield for argon, krypton and xenon. With our setup it is possible to compare the pulse amplitudes generated by the VUV photons and the 5.9-keV X-rays interacting directly in the LAAPD. Thus, one can calculate the number of charge carriers produced by the scintillation pulse and, hence, the number of photons impinging the LAAPD. The obtained experimental results are compared with simulation results.

Method

The **Electroluminescence Yield**, **Y**, is the number of secondary scintillation photons (N_{VUV}) emitted per primary electron per unit of path length, and is given by the following equation:

$$Y = \frac{N_{VUV}}{N_e \times d}$$

where $N_e = E_{XR}/W_{Kr}$ is the average number of electrons produced by the absorption of the 5.9 keV x-rays in the gas and **d = 0.9 cm** is the GPSC scintillation gap.

The number of secondary scintillation photons (N_{VUV}) emitted is given by:

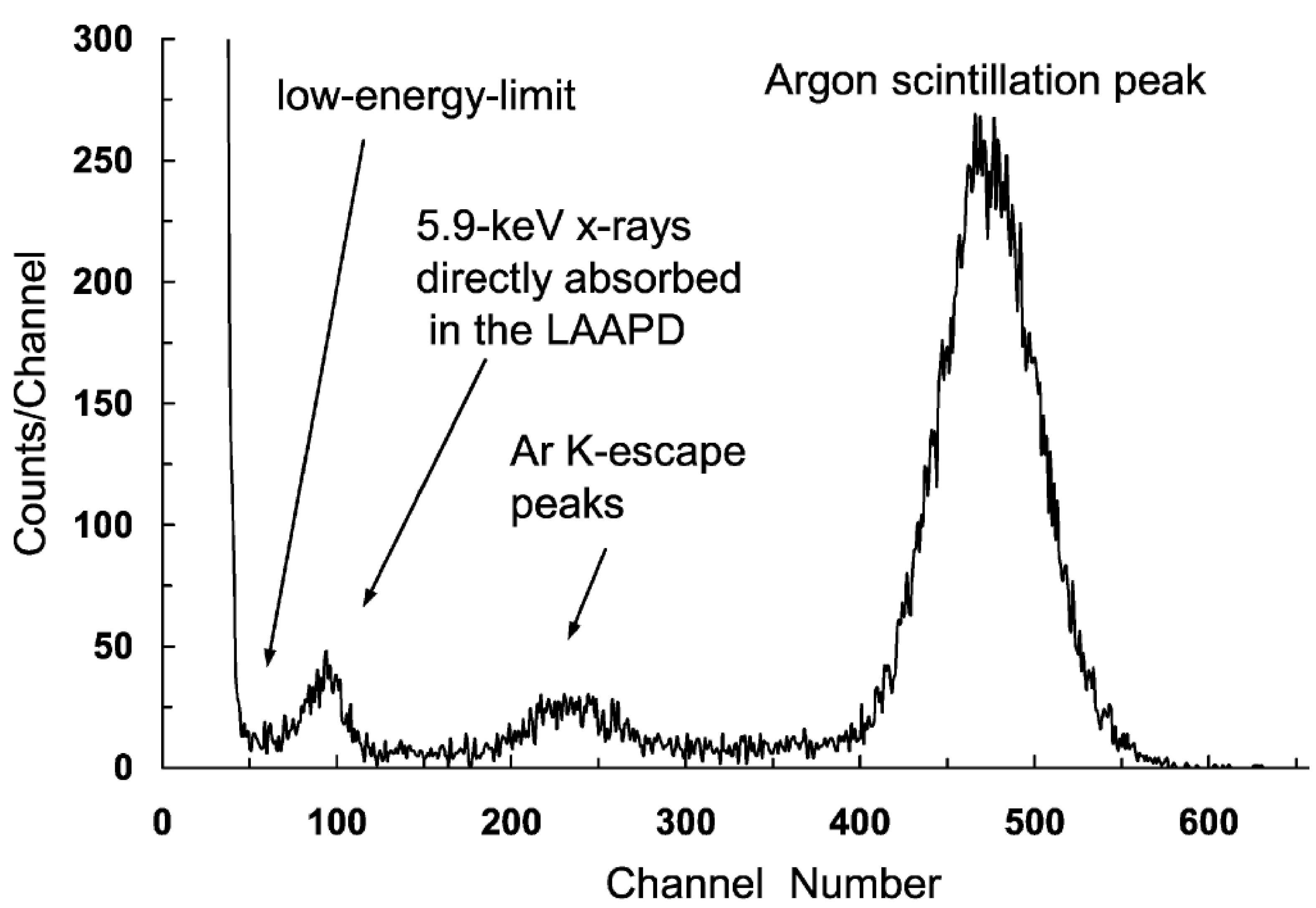
$$N_{VUV} = \frac{N_{VUV(LAAPD)}}{\Omega_r \times T}$$

where $\Omega_r = 0.2$ is the LAAPD relative solid angle, **T = 80%** is the grid transparency and $N_{VUV(LAAPD)}$ is the average number of VUV photons that reach the LAAPD:

$$N_{VUV(LAAPD)} = \frac{A_{VUV}}{A_{dxr}} \times \frac{N_{e(LAAPD)}}{QE}$$

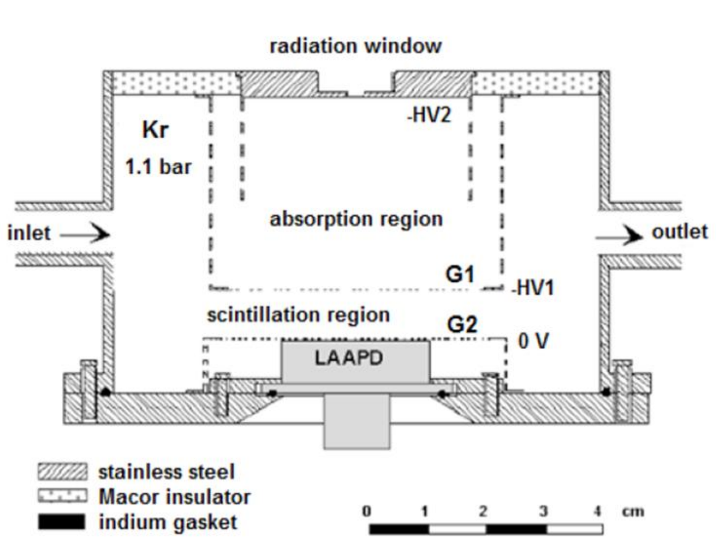
In the equation above, A_{VUV} represents the amplitude of the VUV pulses from the gas electroluminescence induced by x-rays absorbed in the gas; A_{dxr} is the amplitude of the x-ray pulses directly absorbed in the LAAPD, crossing the gas without interacting and **QE** is the LAAPD quantum efficiency for the gas second continuum wavelength;

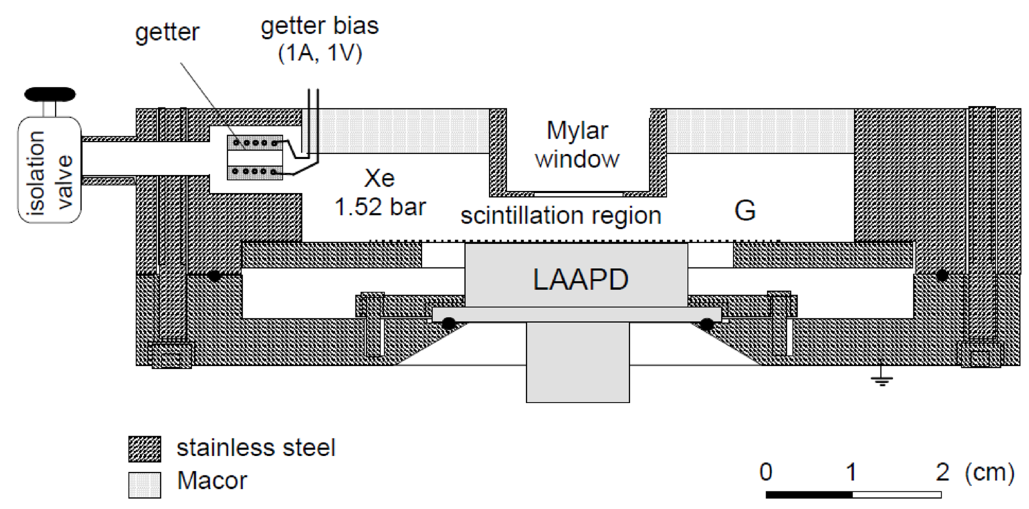
$N_{e(LAAPD)} = E_{XR}/W_{Si} = 1628$ is the average number of electron–hole pairs produced through direct absorption of the 5.9-keV x-rays in the LAAPD (silicon W-Value = 3.62 eV).



Experimental Setup

For Ar and Kr, a standard uniform field type GPSC was used with a 2.5 cm thick absorption region and a 0.9 cm thick scintillation region. The detector is depicted schematically in the figure below on the left. The GPSC enclosure is a stainless steel cylinder with 10 cm in diameter and 5 cm in height.

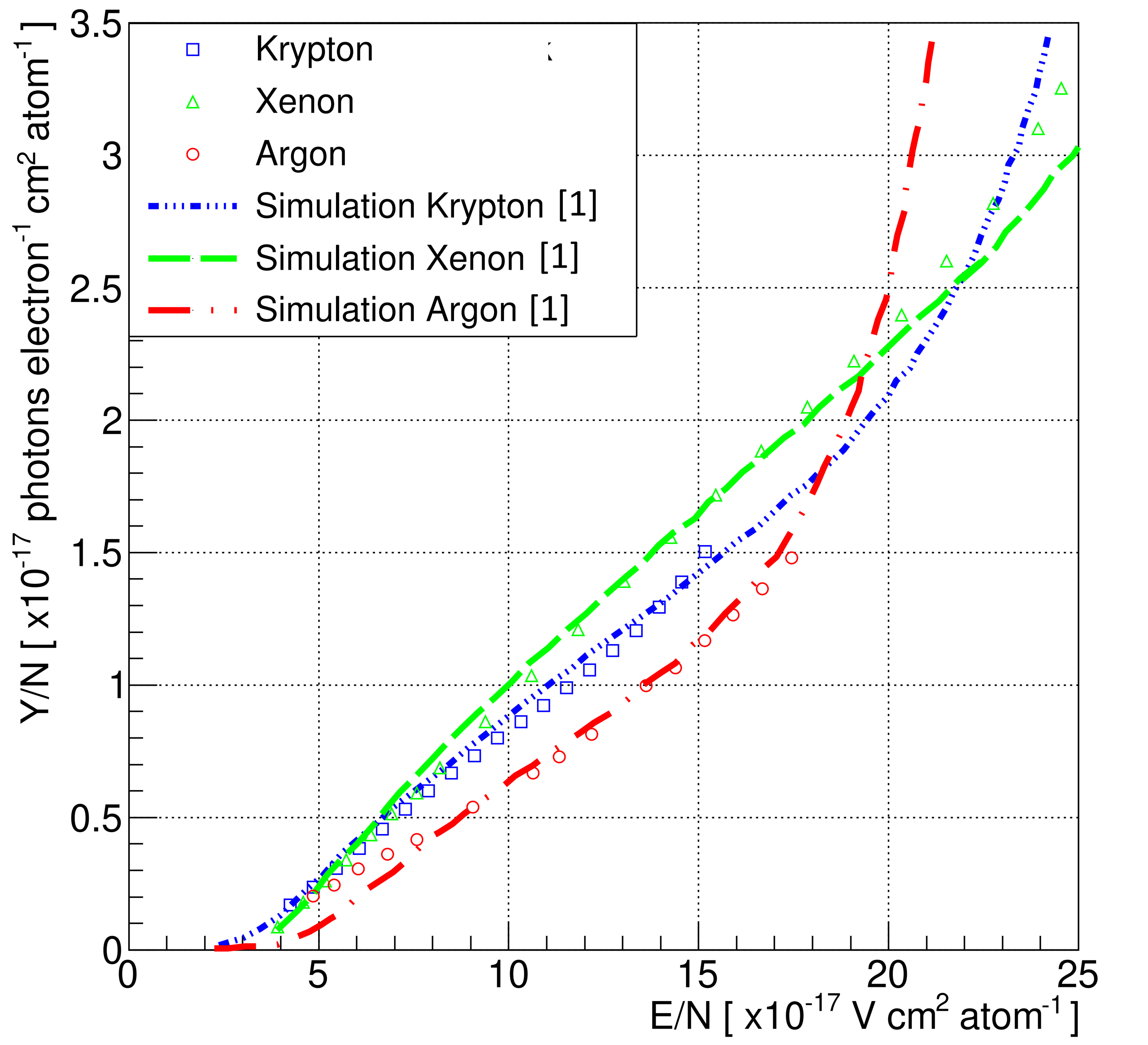




For Xe, a driftless GPSC was used, with a 1.1 cm thick absorption region. The detector is depicted schematically in the figure above on the right.
Both detectors integrate a large area avalanche photodiode (LAAPD) from Advanced Photonics, Inc. (16 mm in diameter) as the VUV photosensor.

Electroluminescence Yield

In the figure below is depicted the reduced electroluminescence yield, Y/N, as a function of the reduced electric field, E/N, in the scintillation region, for Ar, Kr and Xe. Simulation results obtained in [1] are also presented.



Conclusions

- Absolute measurements of the electroluminescence yields obtained in an Ar, Kr and Xe GPSC at room temperature are reported.
- The obtained experimental results are compatible with results from simulation available in the literature.
- The value of the scintillation amplification parameter obtained, defined as the number of photons produced per drifting electron per kilovolt, was 81 photons/kV for argon, 113 photons/kV for krypton and 140 photons/kV for xenon.
- The energy resolution and the scintillation and ionization thresholds were also studied. Best energy resolution values for 5.9 keV x-rays of 12.5%, 9.5% and 7.8% were obtained for argon, krypton and xenon, respectively.
- The scintillation and ionization thresholds obtained were 0.55 and 3.0 kV cm^{-1} bar^{-1} for argon, 0.7 and 3.3 kV cm^{-1} bar^{-1} for krypton and 0.8 and 4.5 kV cm^{-1} bar^{-1} for xenon.

Acknowledgements

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References

[1] C.A.B. Oliveira et al., A simulation toolkit for electroluminescence assessment in rare event experiments, Phys. Lett. B 703 (2011) 217.