Absolute primary scintillation yield in Xe for electrons and alpha particles

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Introduction

Xenon scintillation has been widely used in recent particle physics experiments [1-3]. However, information on primary scintillation yield in the absence of recombination is still scarce and dispersed. The mean energy required to produce a vacuum ultraviolet (VUV) scintillation photon (w_{sc}-value) in gaseous Xe has been measured in the range of 30-120 eV, e.g., [4] and references therein. Lower w_{sc}-values are often reported for alpha particles compared to electrons produced by gamma or x-rays, being this difference not understood.

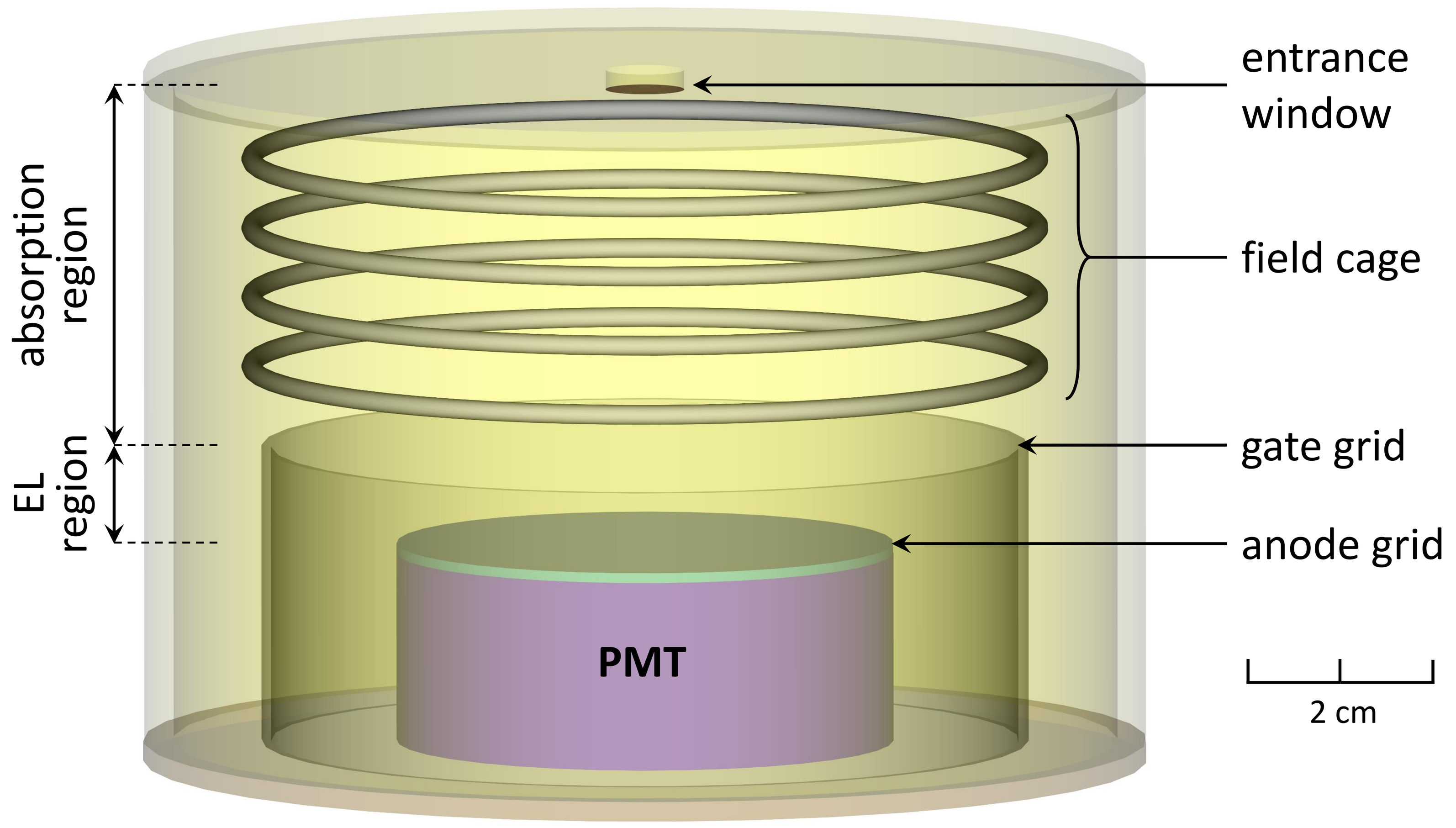
Seeking for a better understanding of literature values, we carried out a systematic study of the absolute primary scintillation yield in Xe, using a Gas Proportional Scintillation Counter (GPSC).

Experimental setup

The GPSC comprises a 3.6-cm thick absorption region and a 1-cm thick electroluminescence region. The former is delimited by the detector entrance window and the gate wire grid, while the later is stablished between the gate and anode grid, placed just above the photosensor, a 2'' Photomultiplier Tube (PMT). A field cage maintains the electric field uniformity along the absorption region.

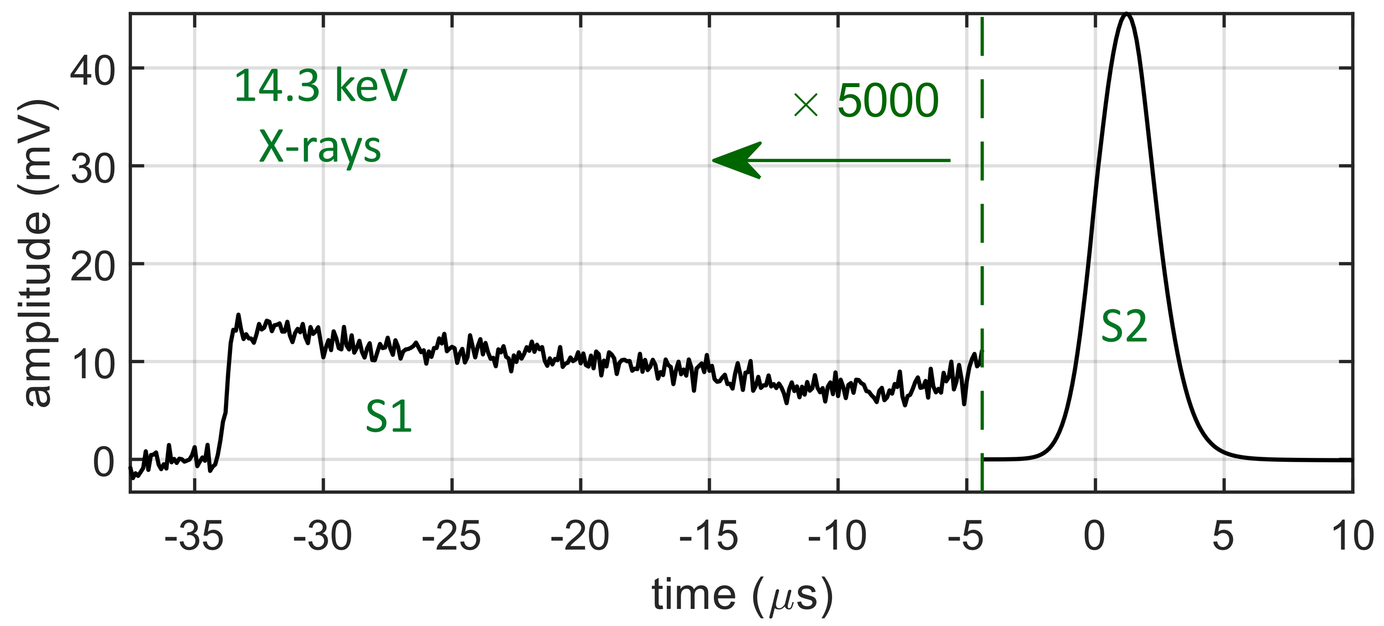
The Xe primary scintillation was measured for x-rays (5.9-25 keV) and alpha particles (2.3 MeV), produced by ^{244}Cm, ^{55}Fe, ^{109}Cd and ^{141}Am collimated radioactive sources. Waveforms produced at the PMT output are directly digitized using a high sampling rate oscilloscope, triggered on the secondary scintillation peak.

A simplified 3D view of the GPSC:



Analysis method

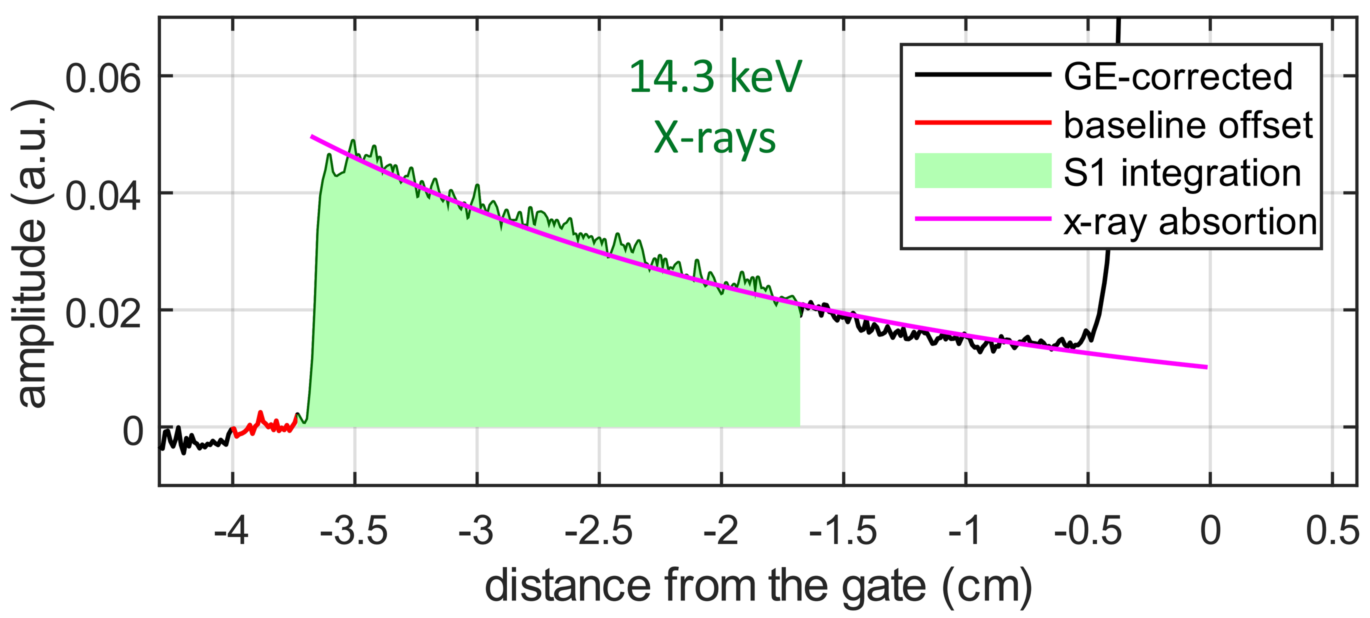
The primary scintillation signal (S1) is about 3 orders of magnitude lower than the secondary scintillation signal (S2), being hardly distinguishable from the electronic noise for low energy x-rays. Therefore, we rely on the average waveform computed from several x-ray events to cancel out the baseline fluctuations, e.g., the average waveform obtained from 1 million 14.3-keV x-ray detections:



The analysis methodology can be summarized as follows:

1. X-ray energies are selected using the S2-integral distribution.
2. The electron drift velocity is computed from the time elapsed between S1 and S2, allowing to represent the average waveform as a function of distance.
3. The waveform is corrected for the detector geometrical efficiency (GE), obtained from a GEANT4 simulation.
4. The S1 emission is integrated along the first 2-cm depth.
5. Finally, this value is corrected for the baseline offset, and for the ratio of interactions occurring within the integration region, which is estimated from the theoretical x-ray absorption law.

As an example, the S1 integration of the GE-corrected waveform:



For alpha particles, S1 is large enough to measure w_{sc} in a per-event basis, allowing to crosscheck the average waveform method.

Results (preliminary)

The w_{sc}-values obtained experimentally for several x-ray energies and alpha particles are listed below:

Energy (keV)	w_{sc}-value (eV)
5.9 (Mn K-s)	50.1 ± 10% (sta.) ± 25% (sys.)
9.4 (Pt L-α)	40.2 ± 15% (sta.) ± 25% (sys.)
14.3 (Pu L-α)	43.1 ± 10% (sta.) ± 25% (sys.)
18.1 (Pu L-β1,β2)	43.8 ± 12% (sta.) ± 25% (sys.)
21.5 (Pu L-Υ)	45.9 ± 15% (sta.) ± 25% (sys.)
22.0 (Ag k-α)	44.5 ± 10% (sta.) ± 25% (sys.)
25.0 (Ag k-β1,β2)	50.0 ± 15% (sta.) ± 25% (sys.)
2300 (α, average method)	46.6 ± 5% (sta.) ± 25% (sys.)
2300 (α, per-event method)	46.5 ± 5% (sta.) ± 25% (sys.)

The w_{sc}-values obtained for electrons produced by x-rays are considerably lower than the values reported on literature (120-60 keV [4]), being similar to the values obtained for alpha particles. The electroluminescence yield (not shown here) estimated using the same methodology agree with simulations [4], within a 10%-difference. This result, together with the good agreement observed for alpha particles between the average waveform and per-event method, demonstrate the reliability of our analysis and the GE simulation model.

Conclusion

Despite the large uncertainties (to be improved in final results), we may conclude that the **w_{sc}-value does not depend significantly neither on the nature of the interacting particle, nor on its energy**. Moreover, w_{sc}-values were found to be independent on the electric field in both the EL and absorption regions.

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References

[1] E. Aprile, *et al.* (XENON), Eur. Phys. J. C 77 (2017), 881.
[2] D. S. Akerib, *et al.* (LUX-ZEPLIN), Phys. Rev. D 101 (2020), 052002.
[3] P. Ferrario, *et al.* (NEXT), JHEP 10 (2019), 052.
[4] C. D. R. Azevedo, *et al.*, JINST 11 (2016), C02007.