Studies of primary and secondary scintillation yield in krypton

<u>R.D.P. Mano</u>[1], J.M.R. Teixeira[1], C.A.O. Henriques[1], C.M.B. Monteiro[1]

[1] LIBPhys, Department of Physics, University of Coimbra, 3004-516, Coimbra, Portugal

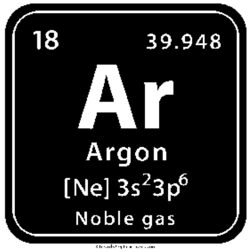
E-mail: rdpmano@uc.pt

XeSAT 2022
International Workshop on Applications of Noble Gas Xenon to Science and Technology

Motivation

Noble Gases have high photoionization cross sections and high secondary scintillation yields

- ❑ Higher density and atomic number
- ❑ Lower ionization and excitation energies



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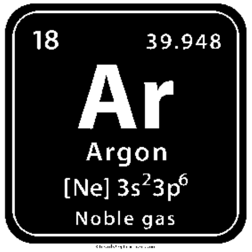

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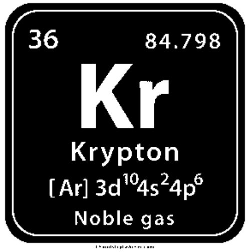

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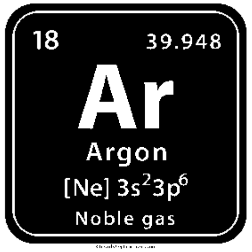

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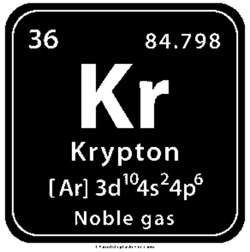

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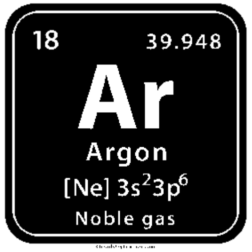

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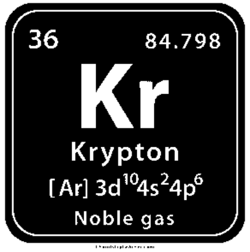

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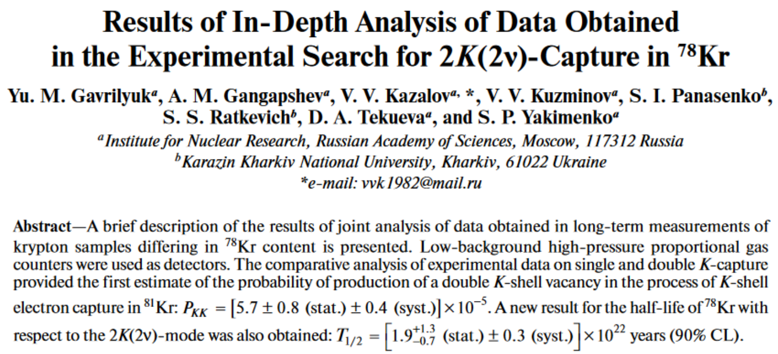

Results of In-Depth Analysis of Data Obtained in the Experimental Search for 2*K*(2ν)-Capture in ^{78}Kr

Yu. M. Gavrilyuk[a], A. M. Gangapshev[a], V. V. Kazalov[a, *], V. V. Kuzminov[a], S. I. Panasenko[b], S. S. Ratkevich[b], D. A. Tekueva[a], and S. P. Yakimenko[a]

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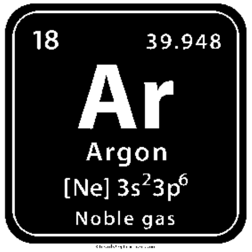

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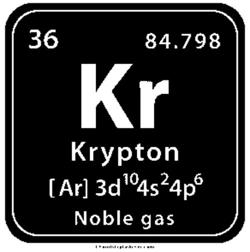

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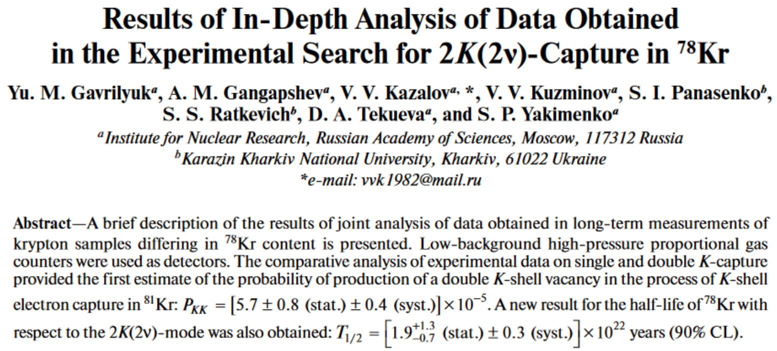

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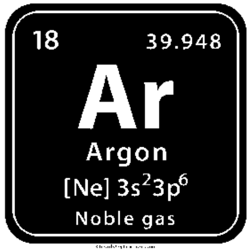

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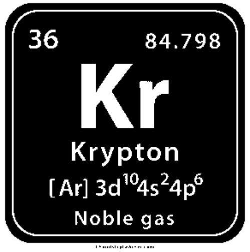

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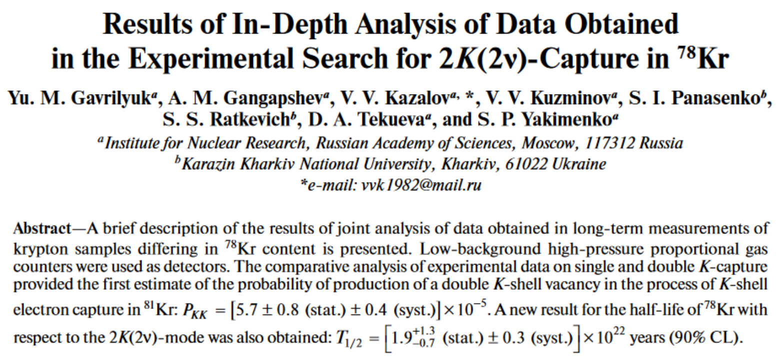

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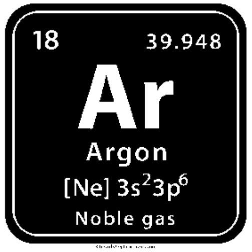

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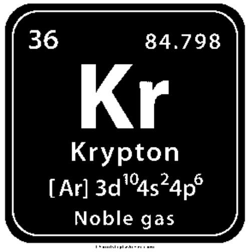

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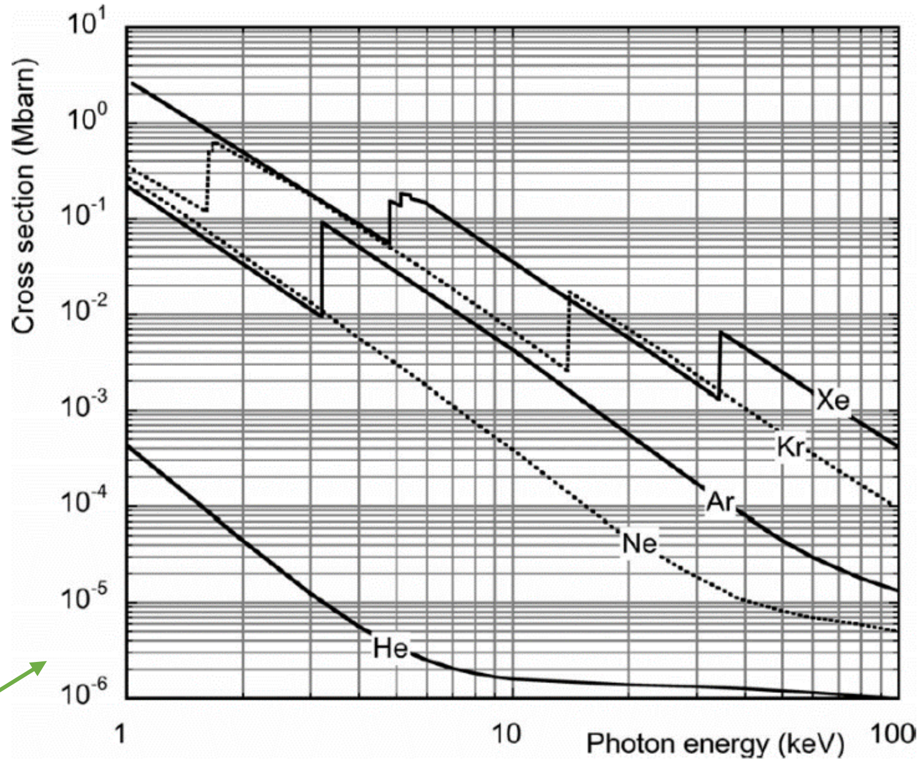

[F. Sauli. Gaseous Radiation Detectors: Fundamentals and Applications. Cambridge: Cambridge University Press, 2014.]

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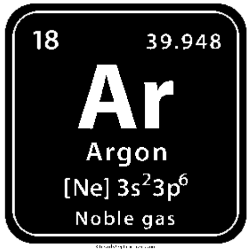

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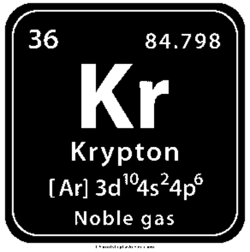

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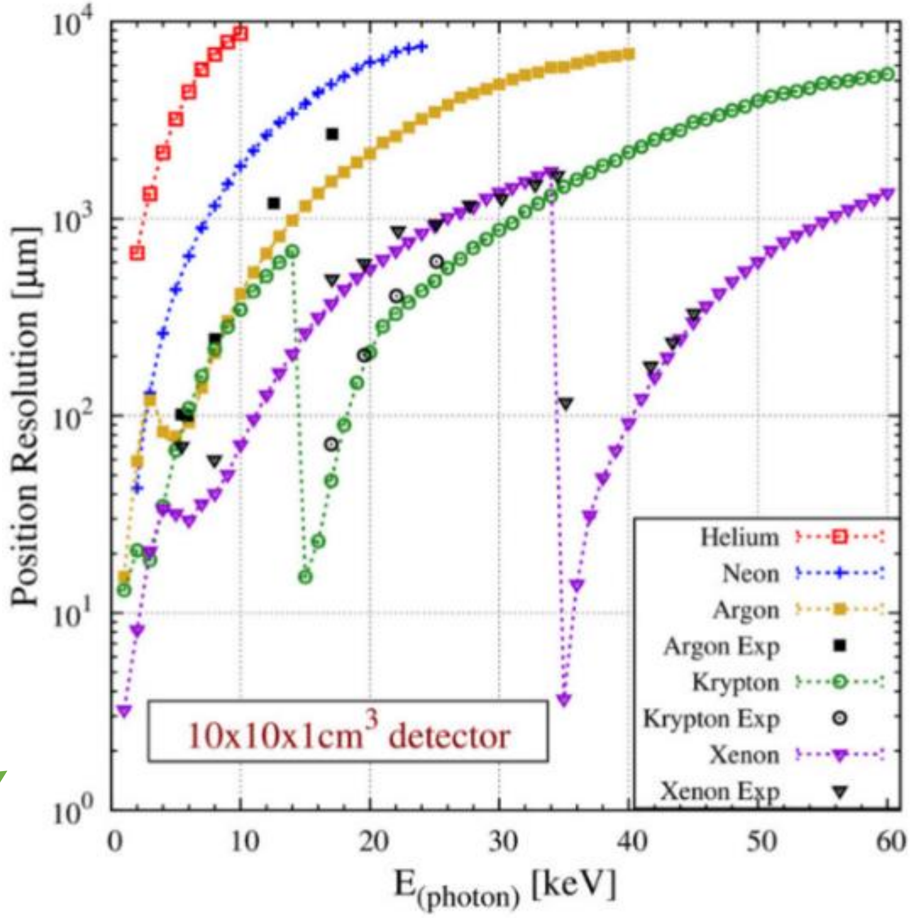
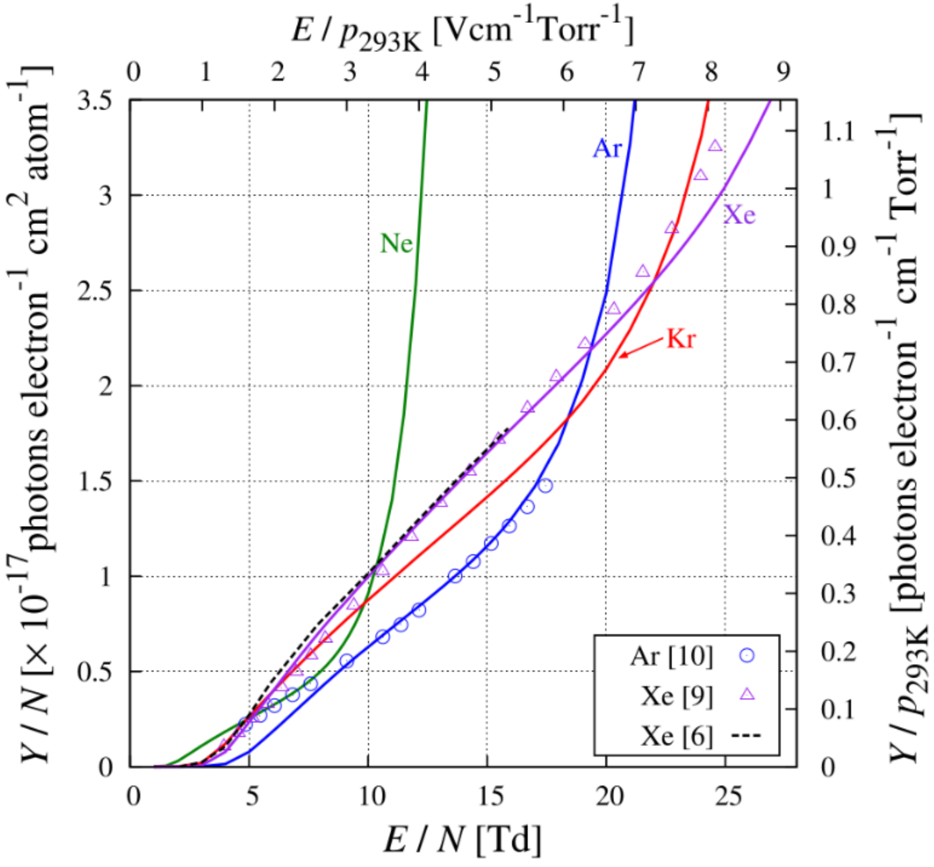


[C. D. R. Azevedo et al., Physics Letters B, 741:272–275, 2015.]

Motivation

'A simulation toolkit for electroluminescence assessment in rare event experiments'

[C.A.B. Oliveira et al., 2011]



- For Xe and Ar the secondary scintillation yield is already well established;
- Xenon is the gas that has the highest secondary scintillation gains in the linear region, followed by krypton, argon and neon;
- **No experimental data to backup the secondary scintillation yield results obtained for krypton.**

[6] F.P. Santos, et al., J. Phys. D. Appl. Phys. 27 (1994) 42.
[9] C.M.B. Monteiro, et al., J. Instrum. 2 (2007) P05001.
[10] C.M.B. Monteiro, et al., Phys. Lett. B 668 (2008) 167.

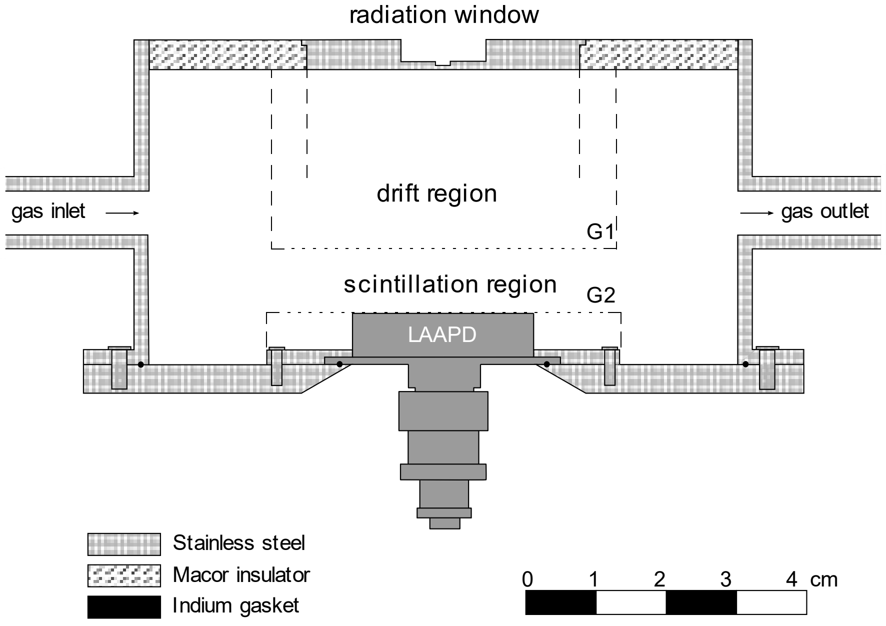
Secondary Scintillation Yield

Experimental Setup

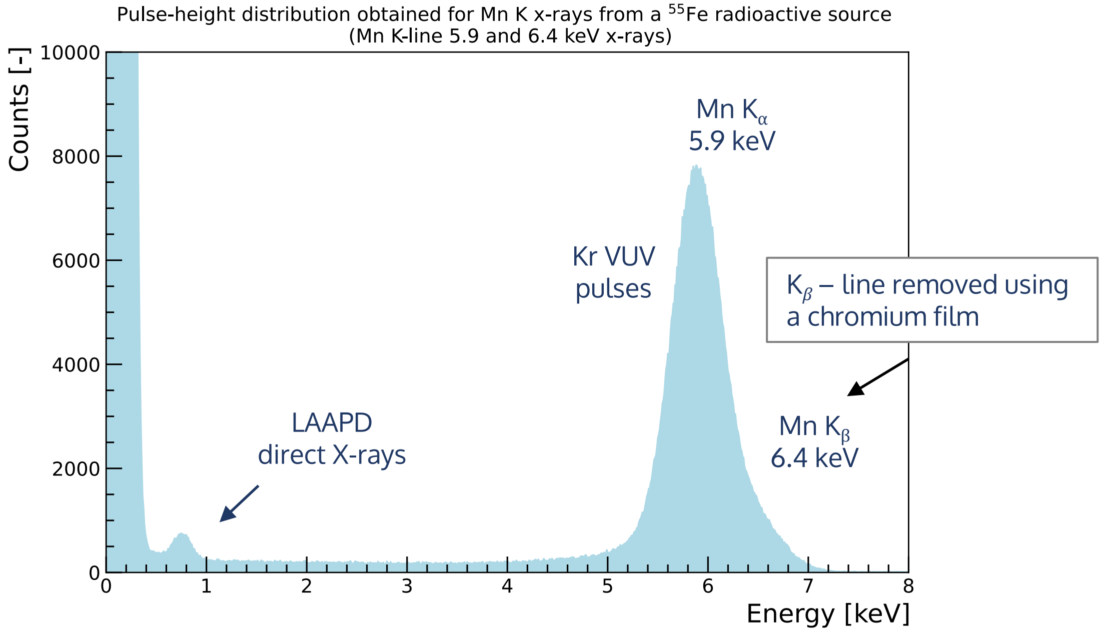
Method

Results

Experimental Setup



- Absorption region: 2.5 cm
- Scintillation region: 0.9 cm
- The Large Area Avalanche Photodiode (LAAPD) is a deep-UV enhanced series from Advanced Photonix Inc., with 16mm active diameter. It was biased at 1840V, corresponding to a gain of approximately 150.
- 1.1 bar of krypton, purified by St707 SAES getters, which were set to a stable temperature of about 150°C.
- Detector irradiated with X-rays from a ^{55}Fe radioactive source.



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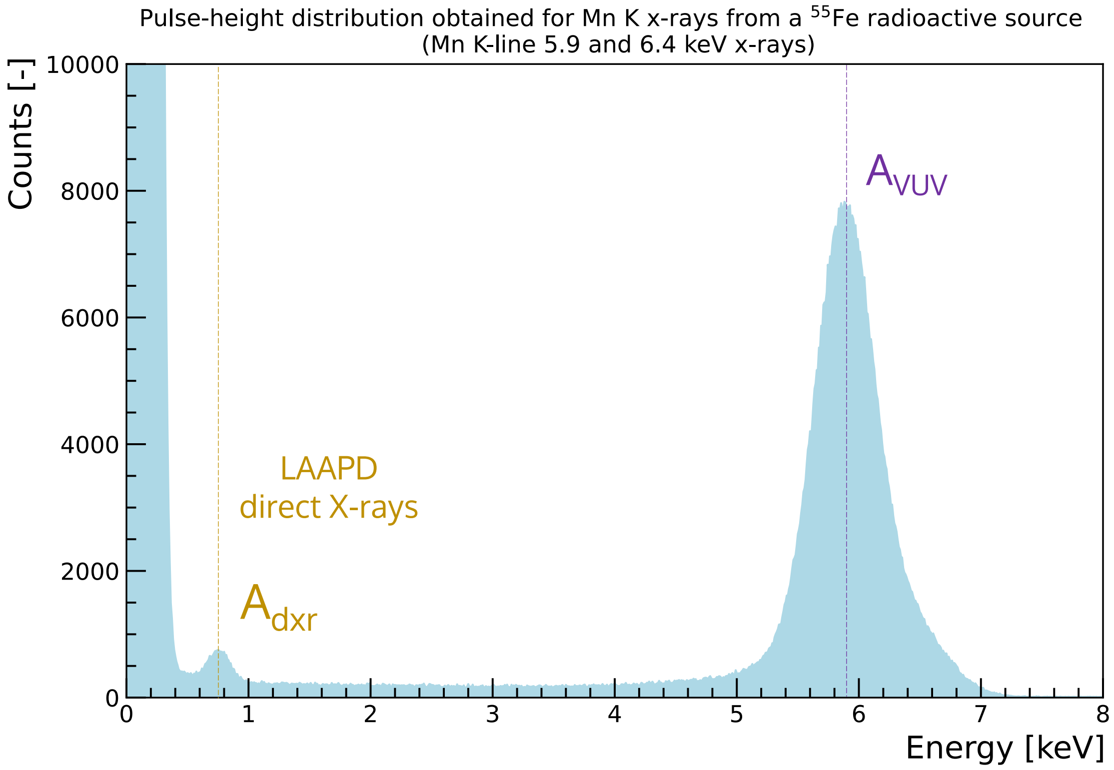


- The full absorption of the 5.9 keV X-ray in the **LAAPD** will produce an a **average number of free electrons, N_{XR},** given by:

$$N_{XR} = \frac{E_{XR}}{W_{Si}}$$

- The **average number of VUV photons impinging the LAAPD** for the scintillation pulses due to the 5.9-keV X-ray full-absorption in the gas is:

$$N_{VUV,LAAPD} = \frac{A_{VUV}}{A_{dXR}} \times \frac{N_{XR}}{Q_E}$$

- The **total number of VUV photons** produced by the full absorption of the 5.9 keV X-ray in the detector is:

$$N_{VUV,total} = \frac{N_{VUV,LAAPD}}{T \times \Omega_{rel}}$$

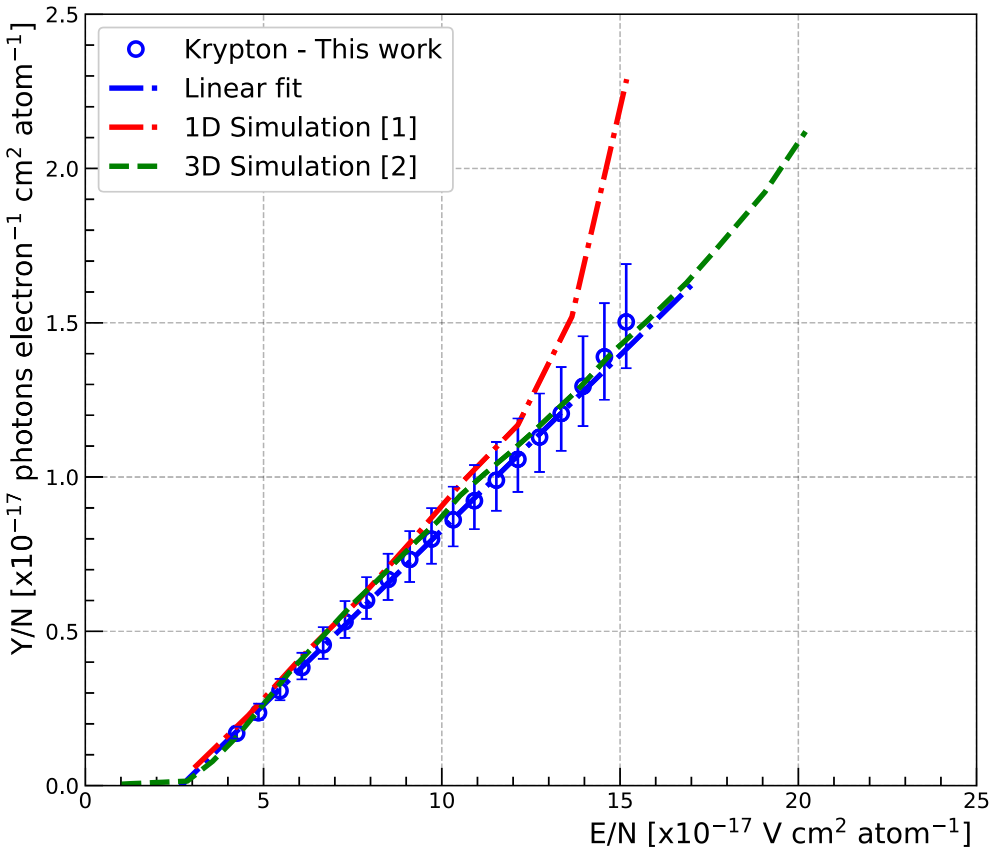
- The **average number of primary electrons** produced in krypton by full absorption of the 5.9 keV X-ray is:

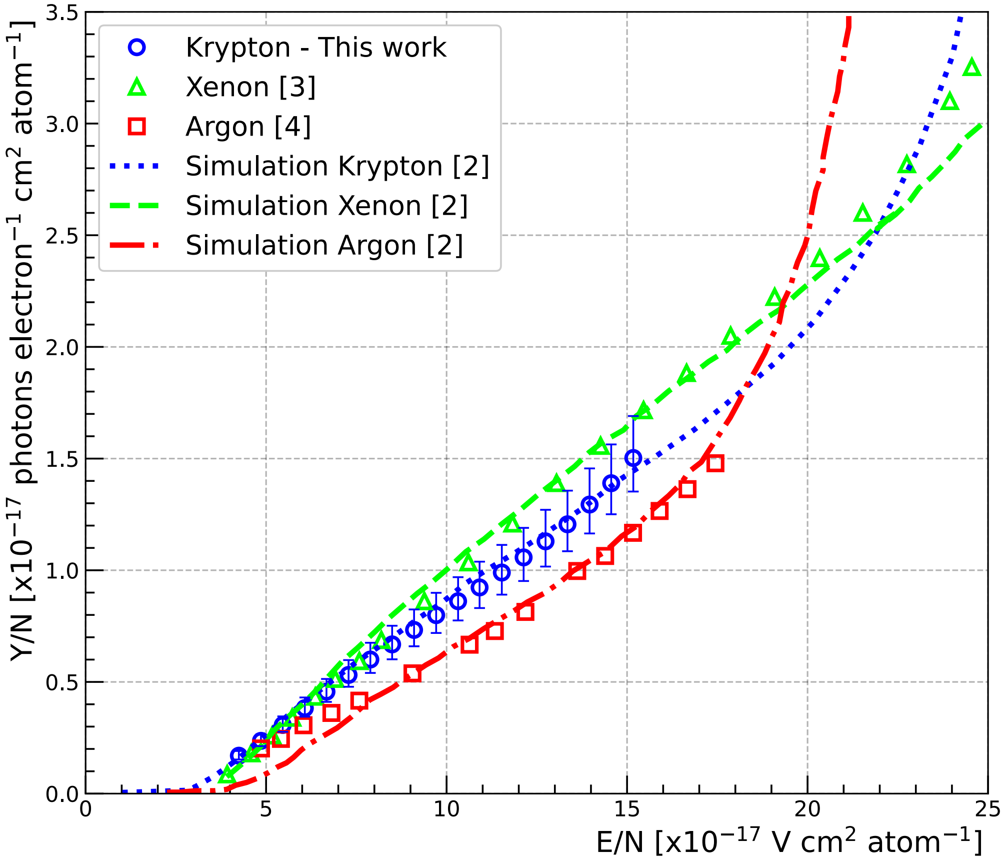
$$N_e = \frac{E_{XR}}{W_{Kr}}$$

- Therefore, the **reduced secondary scintillation yield** is given by:

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

Results





- The slope of the linear dependence corresponds to the **scintillation amplification parameter**, i.e., the number of photons produced per drifting electron and per volt.
- A value of about **113 ± 14 photons/kV** was measured for reduced electric fields between 1.0 and 3.3 kV cm^{-1} bar^{-1}.

[1] T.H.V.T. Dias et al., A unidimensional Monte-Carlo simulation of electron drift velocities and electroluminescence in argon, krypton and xenon, J. Phys. D, Appl. Phys. 19 (1986) 527.
[2] C.A.B. Oliveira et al., A simulation toolkit for electroluminescence assessment in rare event experiments, Phys. Lett. B 703 (2011) 217.
[3] C.M.B. Monteiro, et al., Secondary Scintillation Yield in Pure Xenon, J. Instrum. 2 (2007) P05001.
[4] C.M.B. Monteiro et al., Secondary scintillation yield in pure argon, Physics Letters B, Volume 668, Issue 3, 2008, Pages 167-170.

Primary Scintillation

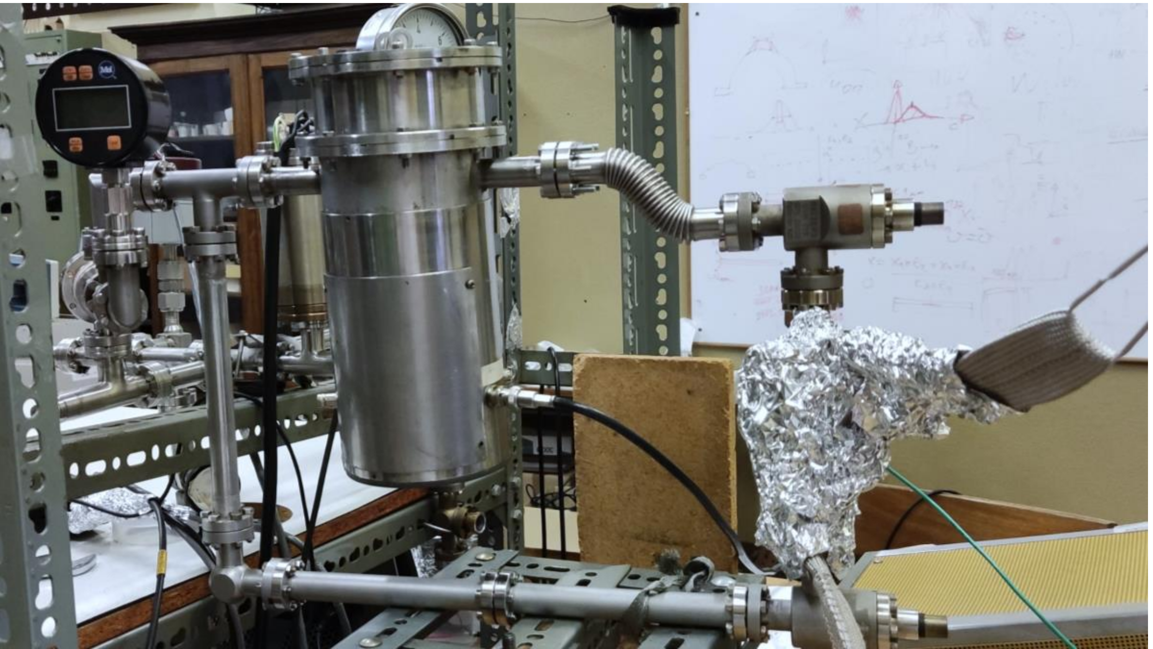
Experimental Setup

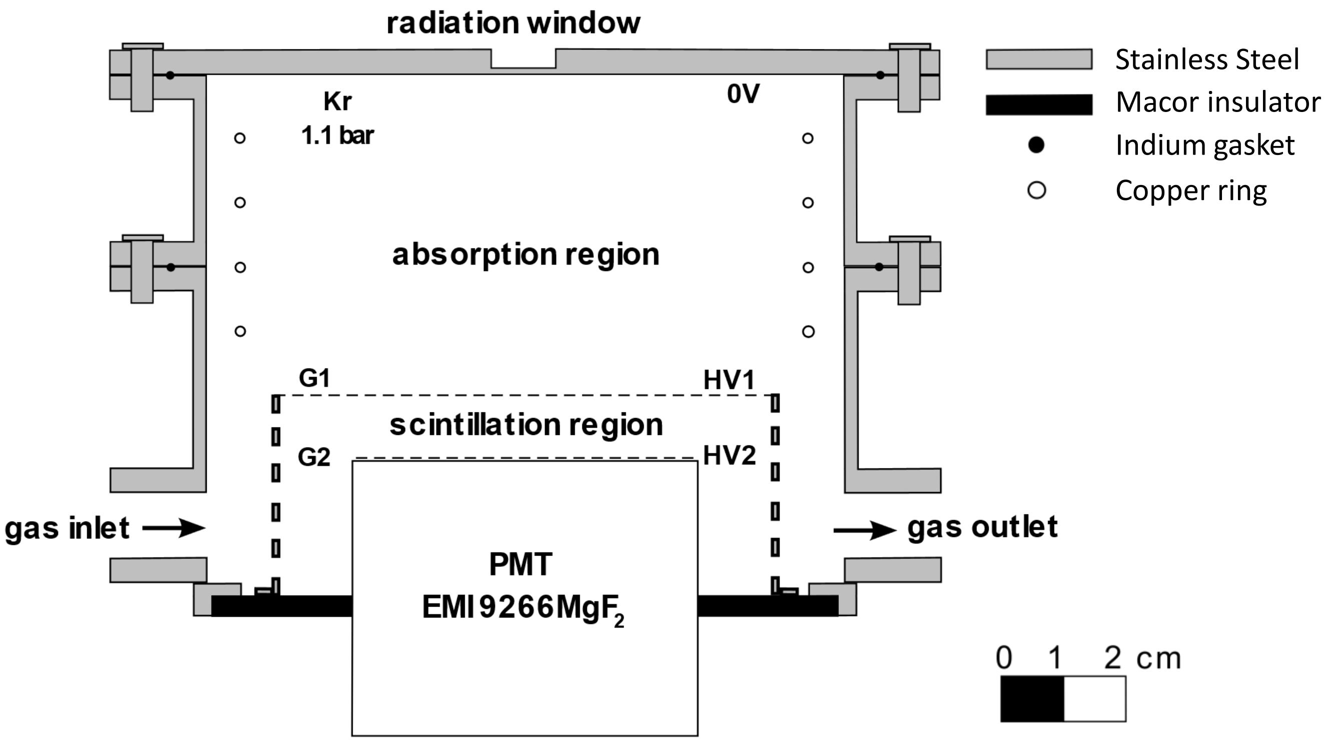
Method

Preliminary Results

Experimental Setup

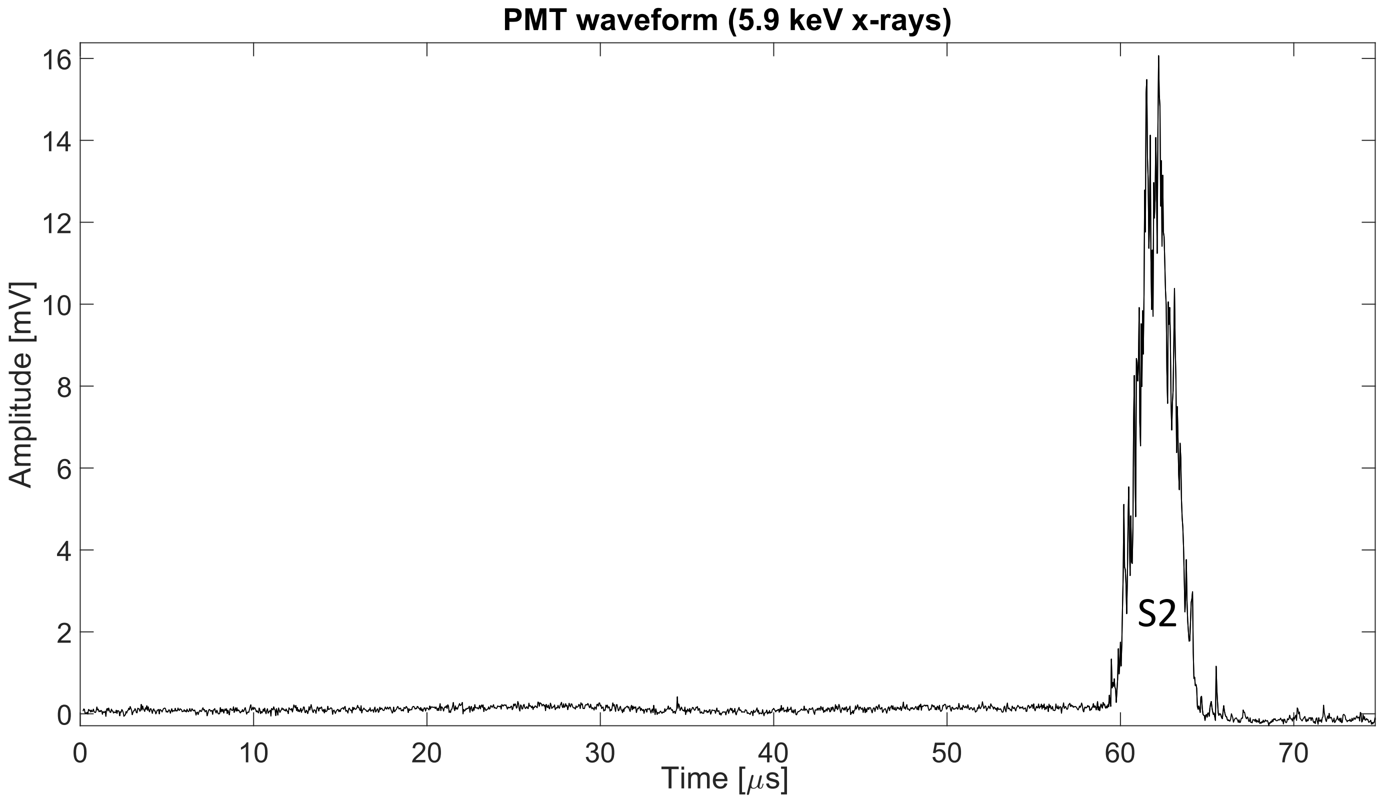
- Absorption region: 5.0 cm
- Scintillation region: 0.9 cm
- PMT with a MgF_2 window.
- 1.1 bar of krypton, purified by St707 SAES getters, which were set to a stable temperature of about 150°C.





- Detector irradiated with X-rays from a ^{55}Fe and a ^{244}Cm radioactive sources.
- PMT waveforms were digitized using a high sampling-rate oscilloscope (10GS/s)

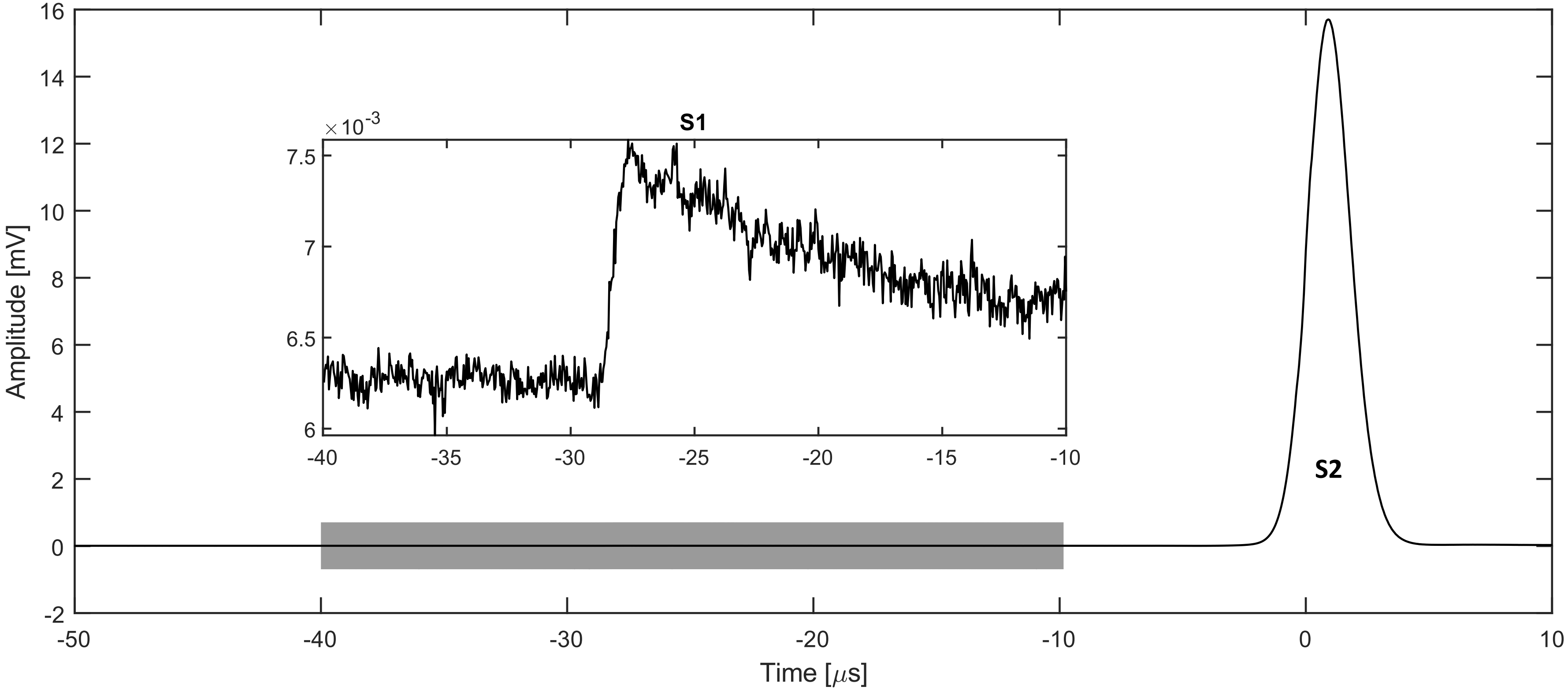
Method – Waveform sampling and averaging



- PMT waveforms are triggered on the rising edge of the **secondary scintillation signal (S2)**
- The **amplitude of the primary scintillation signal (S1) is very low** and may be indistinguishable from the electronic noise
- An **average over several waveforms** is performed to reduce the electronic noise to a low level
- **Background events are discriminated** to avoid additional contamination in the S1 region

Method – Waveform sampling and averaging

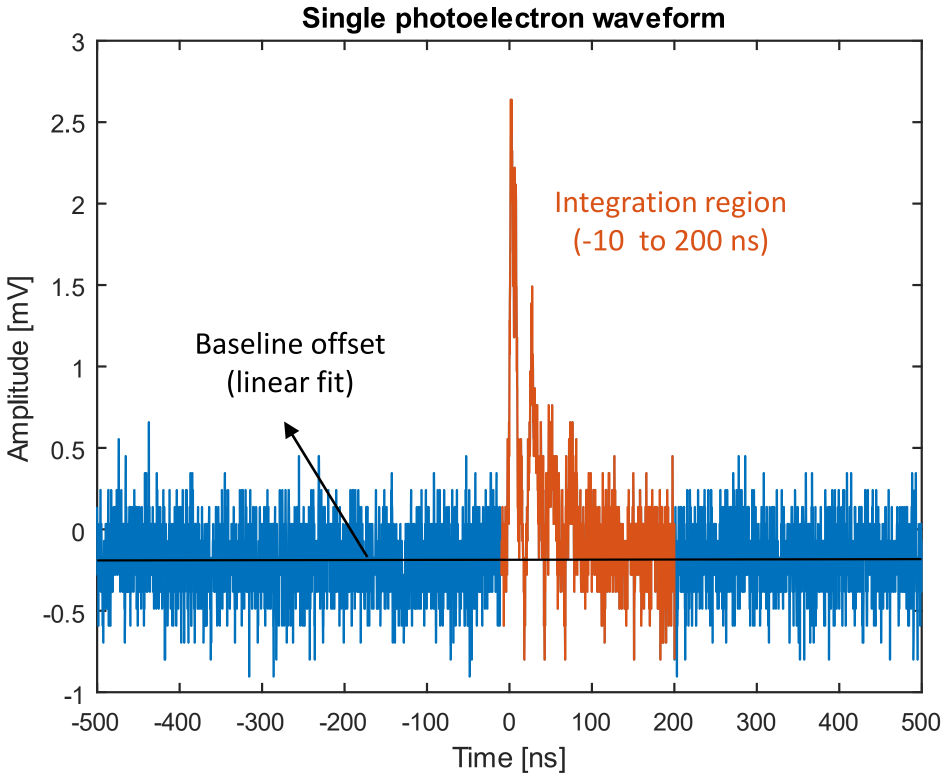
- Typical average waveform obtained for **5.9 keV X-rays** (average of ~ 120k events)

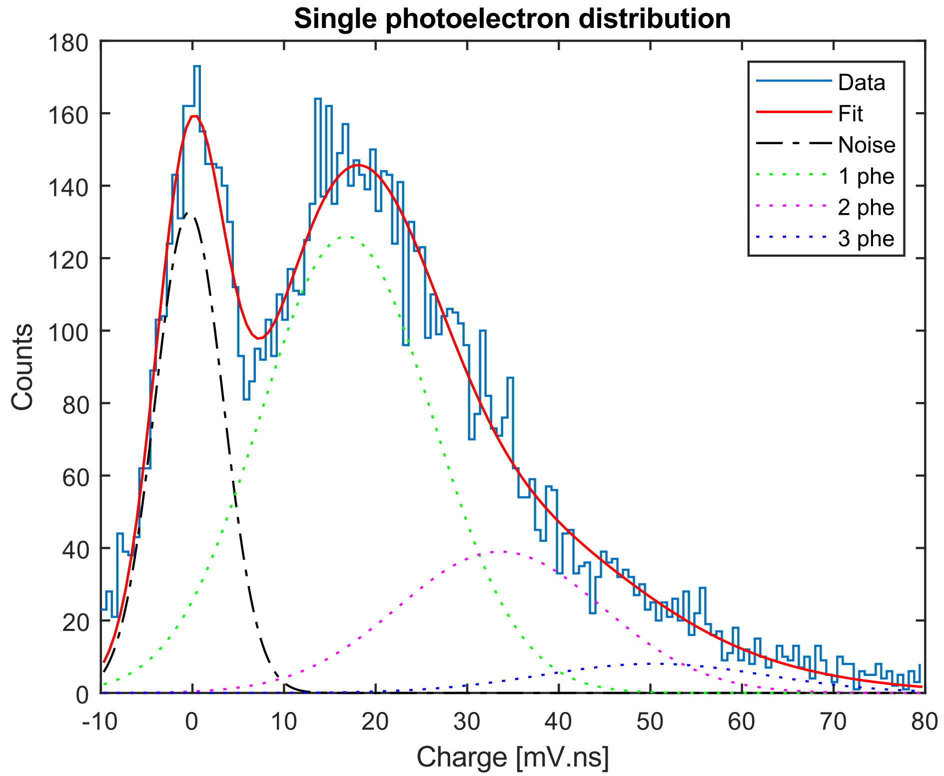


- Primary scintillation signal is now visible
- The tail on the right of S1 results from the interaction of X-rays at different depths in the absorption region

Method – PMT calibration

- A PMT calibration is needed to obtain the absolute values of S1 and S2



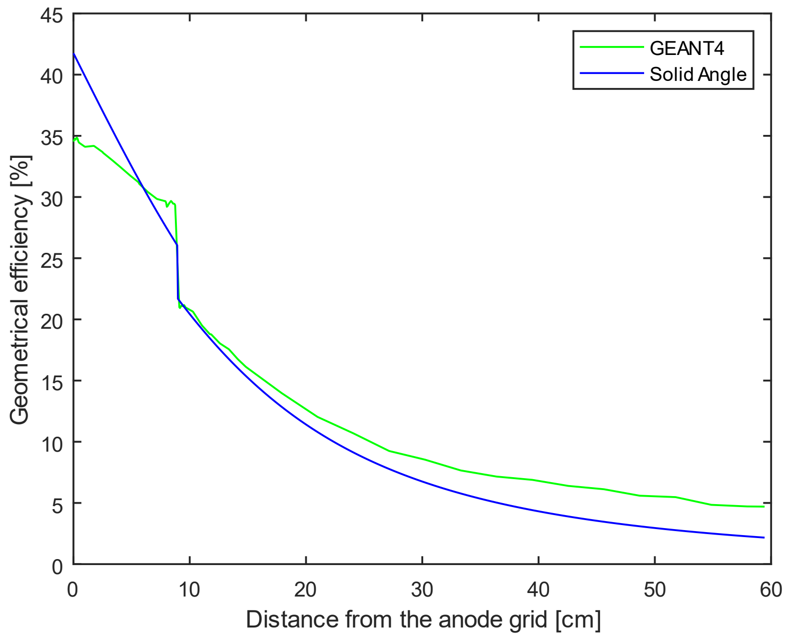


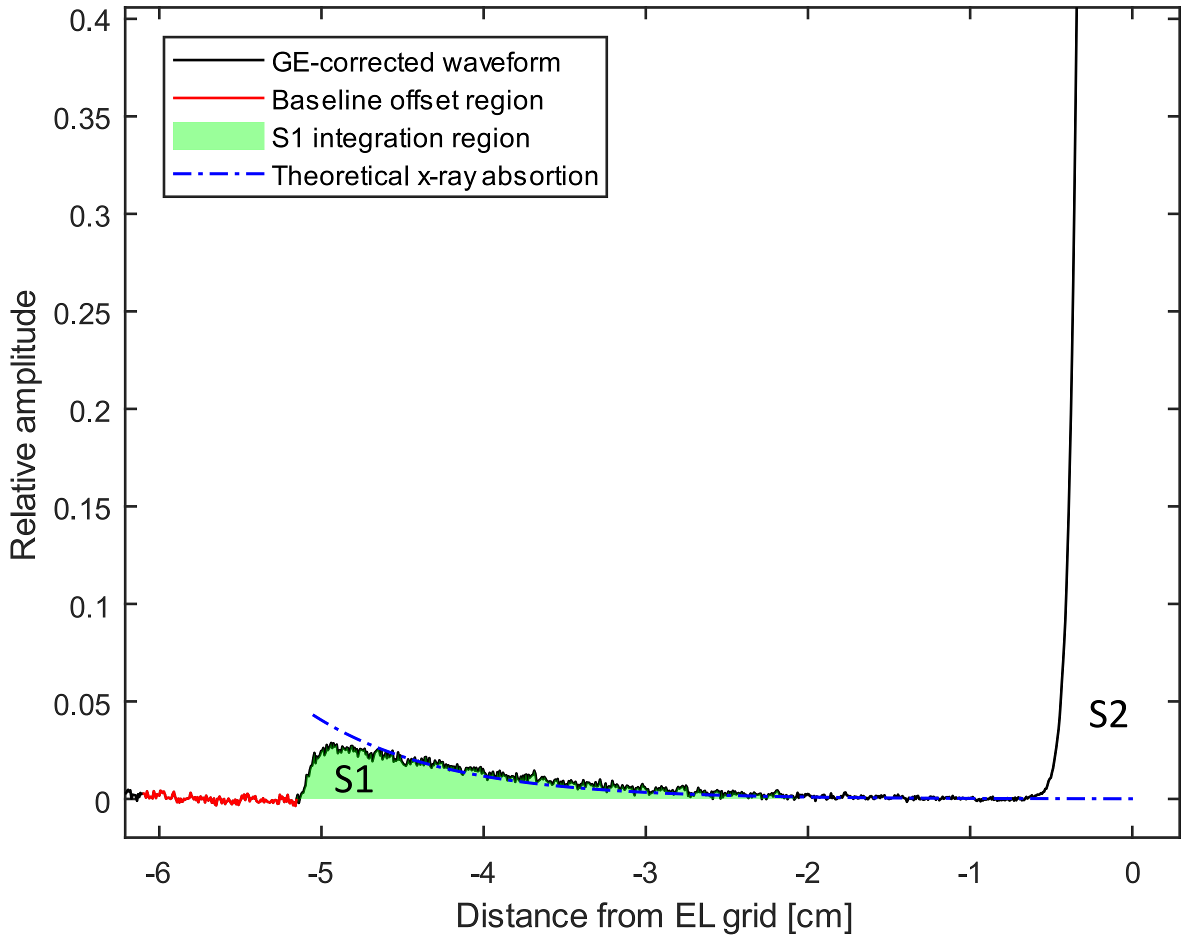
- Single photoelectron waveform obtained using a LED
- Linear fit to correct baseline offset
- Long integration region to include wave reflections

- Sum of 4 Gaussians (electronic noise, 1phe, 2phe and 3phe) to fit the single photoelectron distribution

Method – Corrected waveform

- ❑ Geometrical efficiency (GE) computed along the detector central axis using GEANT4





- ❑ Longitudinal position of X-ray interactions was determined using the electron drift velocity calculated

- ❑ Average waveform corrected using the computed GE

- ❑ Acceptable agreement between the corrected waveform and the theoretical X-ray absorption

Preliminary Results

Electron Drift Velocity

Drift Electric Field [kV cm^{-1} bar^{-1}]	Experimental [mm/us]	Literature [1] [mm/us]
0.22	1.865	1.841
0.19	1.791	1.784
0.15	1.720	1.683
0.11	1.634	1.607

- **Electron drift velocities** obtained are in good agreement with the results found in the literature [1]

Primary Scintillation

Preliminary

X-ray energy [keV]	W_{sc}-value [eV]
5.9	106.6 ± 5% (sta.) ± 24% (sys.)
14.3	113.9 ± 5% (sta.) ± 24% (sys.)

- **W_{sc}**-values of **106.6 eV and 113.9 eV** were obtained, for 5.9 and 14.3 keV X-rays, respectively.

[1] J. L. Pack, et al, "Longitudinal electron diffusion coefficients in gases: Noble gases", Journal of Applied Physics 71, 5363-5371 (1992)

Conclusions

- **Secondary Scintillation Yield**

❑ Absolute measurements of the secondary scintillation yield obtained in a Kr GPSC were reported.

❑ The obtained experimental results are compatible with results from simulation available in the literature.

❑ The scintillation amplification parameter obtained in **Kr**, **113 photons/kV,** is about 15% lower than the one obtained in **Xe, 137 photons/kV** [1], and 40% higher than the one obtained in **Ar**, **81 photons/kV** [2].

- **Primary Scintillation**

❑ Absolute values of 106.6 eV and 113.9eV were obtained for the w_{sc}-value in Kr, for 5.9 keV and 14.3 keV X-rays, respectively.

❑ S1 will be determined for alpha-particles and different X-rays energies, in runs with more events.

[1] C.M.B. Monteiro, et al., Secondary Scintillation Yield in Pure Xenon, J. Instrum. 2 (2007) P05001.
[2] C.M.B. Monteiro et al., Secondary scintillation yield in pure argon, Physics Letters B, Volume 668, Issue 3, 2008, Pages 167-170.
[3] C.M.B. Monteiro et al., An argon gas proportional scintillation counter with UV avalanche photodiode scintillation readout, IEEE Trans. Nucl. Sci. 48 (2001) 1081-1086.

Thank you for your attention

Acknowledgements

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COMPETE 2020

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