Absolute experimental primary scintillation yield in Xe for electrons and alpha particles

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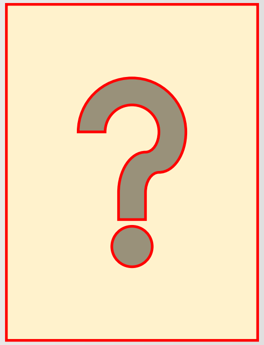
Outline

1. Motivation
2. Experimental Setup: GPSC
3. Methodology & analysis
4. Experimental Results: w_{sc}
5. Conclusions
6. References

Motivation

- GXe Scintillation → widely used in particle physics experiments (XENON, LZ, NEXT,…);
- w_{sc} - mean energy required to produce a scintillation photon → important parameter;
- Primary Scintillation Yield (no recombination) → data **scarce**, **dispersed** and **inconsistent;**
  - (w_{sc} for α–particles < w_{sc} for e$^-$)
- Literature: w_{sc}-value in GXe → [30-120] eV
  - **Nature** of the incident particle (x-rays; γ-rays; α-particles);
  - **Energy** of the interacting particle ;
  - **Electric field** intensity;



- → Systematic study of **absolute primary scintillation yield in Xe** for **x-rays, α-particles**
  using a Gas Proportional Scintillation Counter (GPSC)

Former results for - w_{sc}

M. Mimura *et al.* Jpn. J. Appl. Phys. **48** (2009) 076501

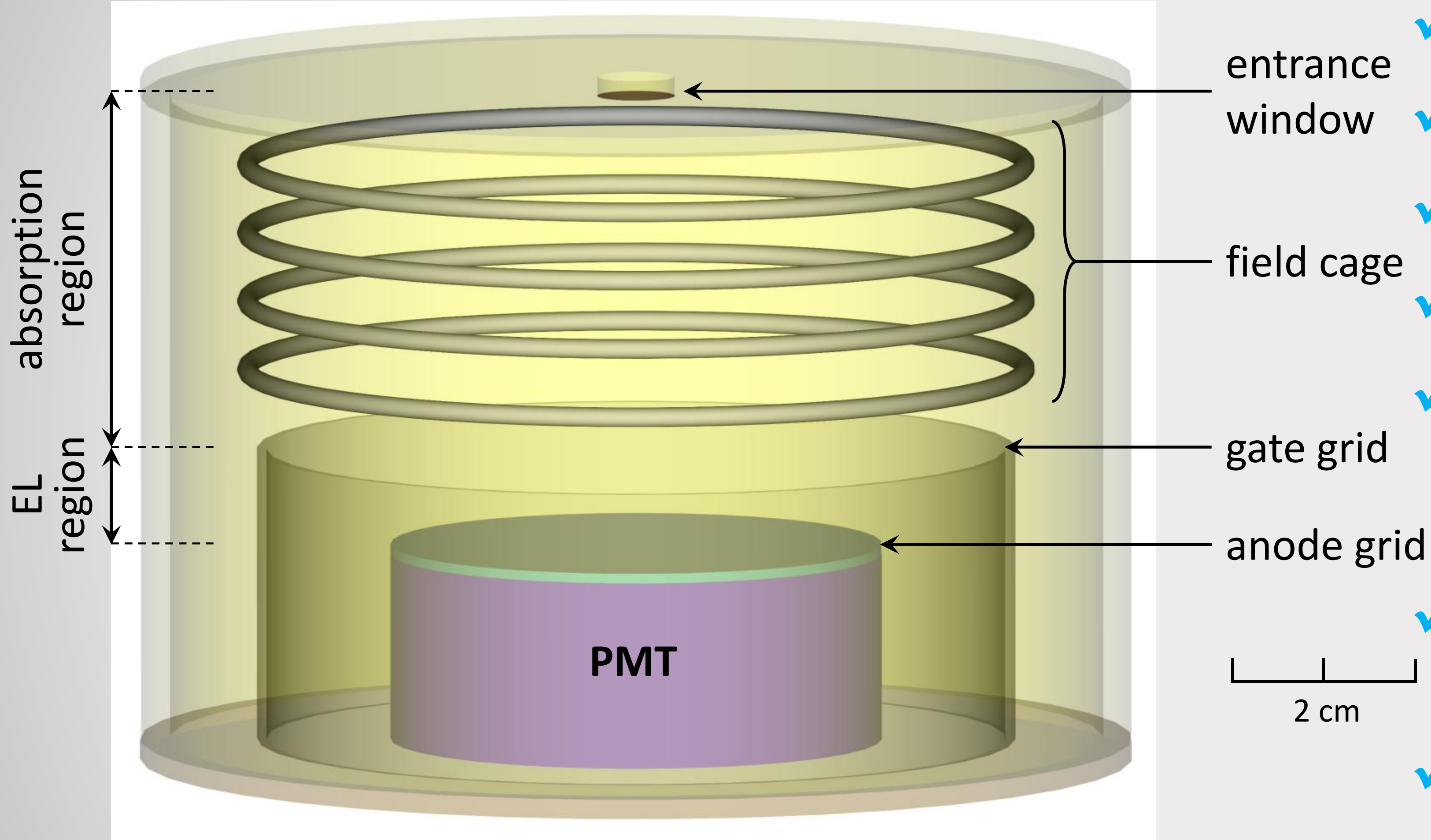
Table I. Comparison with previous studies in terms of W-value, W_{ex}-value, and N_{ex}/N_i.

Author	Density (g/cm^3)	Type[a]	W_{ex} (eV)	W (eV)	N_{ex}/N_i
This work	0.028–0.111 (gas)	m	34.1 ± 2.4	20.9 ± 0.4	0.61 ± 0.04
Saito *et al.*[6]	0.005–0.056 (gas)	m	34.5[b]	20.9 ± 0.4	0.60
Saito *et al.*[7]	0.005–0.011 (gas)	m	59.4 ± 2.4	(22.1)[32]	0.38 ± 0.02
Carmo *et al.*[8]	0.006 (gas)	m	111 ± 16	$(21.61^{+0.14}_{-0.10})$[33]	0.19[d]
Date *et al.*[24]	0.001 (gas)	c	31.6[c]	21.7	0.69[d]
Doke *et al.*[31]	3.06 (liquid)	m	120[d]	(15.6 ± 0.3)[34]	0.13

a) "m" and "c" represent measurement and calculation, respectively.
b) This value was determined from the average scintillation yield of 1.59×10^5 for 5.49 MeV α-particles.
c) This value was estimated from the average number of excitation collision events of 317 for 10 keV electrons. The average number was determined from the distribution of the frequency of excitation collisions shown in Fig. 7 in ref. 24.
d) These values are estimated by us from refs. 8, 24 and 31.

Serra et al., (NEXT)	alpha	10 bar	39.2 +- 3.2 eV
Parsons et al.,	60 keV	15 bar	76 + - 12 eV
Fernandes et al.,	5.9 keV	1-3 bar	72 +- 6 eV
Renner et al., (NEXT)	662 keV	10 bar	61.4 +- 18 eV

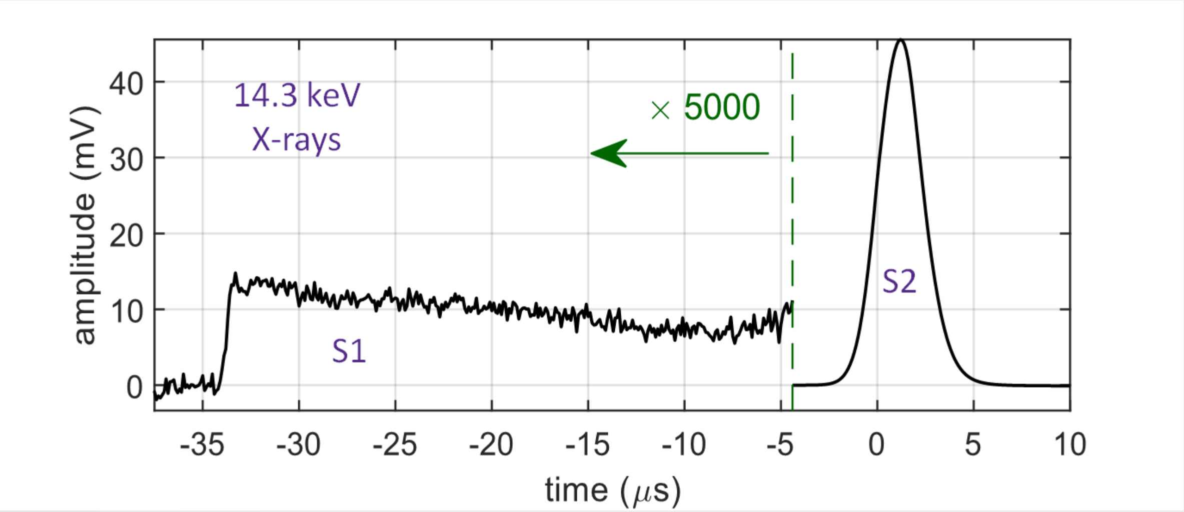
Experimental Setup: GPSC



- absorption region: **3.6 cm**;
- scintillation (EL) region: **1 cm**;
- Photosensor: 2′′ PMT;
- GXe @ 1.2 bar;
- **x-rays** (5.9-25 keV) & **α-particles** (2.3 MeV) from ^{244}Cm, ^{55}Fe, ^{109}Cd and ^{141}Am;
- GXe in closed circuit purified by hot getters (SAES-ST707);
- Signal amplification: Electroluminescence (EL);

Methodology – Data acquisition

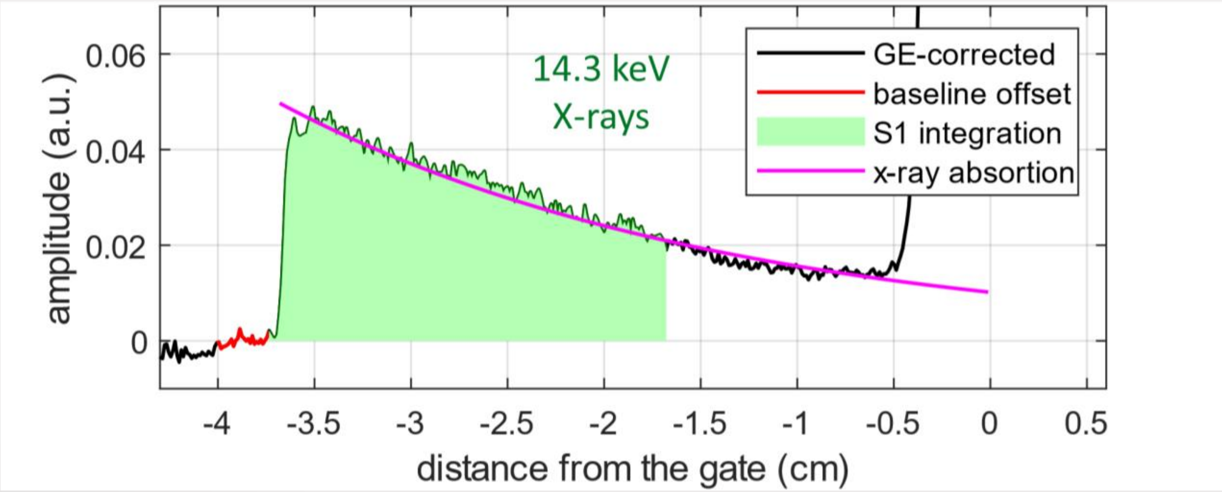
- The primary scintillation signal (S1) is more than 3 orders of magnitude lower than the secondary scintillation signal (S2); S1 is hardly distinguishable from the electronic noise;
- Therefore, for x-rays we rely on the average waveform computed from a high number events to cancel out the baseline fluctuations;
- For alpha particles, the stronger S1 enables the w_{sc} measurement on a per-event basis;
- This allows to crosscheck the average waveform method;
- Example of the average waveform from 1 million of 14.3-keV x-ray events:



Methodology – data analysis

1. X-ray energies are selected triggering on S2 and carefully aligned using the 50-% S2-rising-edge as t=0 s.
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 1.5-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.

S1 integration of the GE-corrected waveform



Experimental Results - w_{sc}

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

Conclusions

- the w_{sc}-value was found to be within **40-50 eV;**
- the w_{sc}-value does **not depend** on the **nature** of the interacting particle (**x-rays** or **α-particle**);
- the w_{sc}-value does **not depend** on the **energy** of the interacting particle;
- the w_{sc}-value does **not depend** on the **electric field** (> 0.1 kV/cm/bar) applied to the drift region;
- The S2 yields estimated using the same methodology agree with simulations within 5%;
- This result together with the **good agreement** between **average method** and **per-event method** observed for alpha particles demonstrate the **reliability** of our **analysis** and **GE simulation model**.

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.
- [5] M. Mimura *et al.*, Japan. J. Appl. Phys. **48** (2009), 076501
- [6] S. J. C. do Carmo *et al.*, J. Instrum. **3** (2008), P07004.
- [7] L. M. P. Fernandes *et al.*, J. Instrum. **5** (2010), P09006.
- [8] L. Serra *et al.* (NEXT), J. Instrum. **10** (2015), P03025.

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