Observation of primary scintillations in the visible range in liquid argon doped with methane

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1. Introduction

Neutron veto detector based on liquid scintillator containing hydrogen atoms is an integral part of any underground experiment for dark matter search. So far, a flammable mixture of liquid hydrocarbons was used as a liquid scintillator. A safe alternative would be a liquid scintillator based on liquid Ar doped with CH_4.

However there is a problem: as the CH_4 concentration in Ar increases, the VUV excimer emission decreases due to the quenching of excited atoms Ar* by CH_4 molecules.

VUV emission of excimers

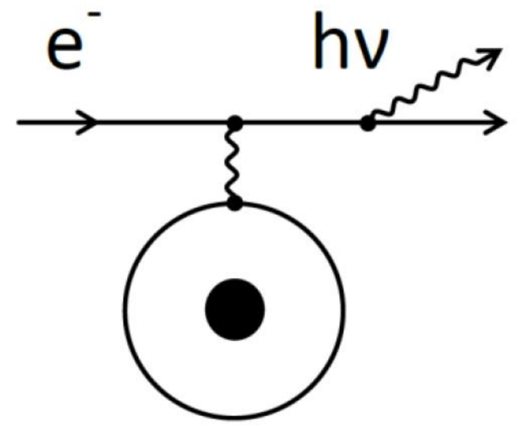
$$e^- + Ar \to e^- + Ar^* ,$$
$$Ar^* + 2Ar \to Ar_2^* + Ar ,$$
$$Ar_2^* \to 2Ar + h\nu .$$

Ar* quenching

$$Ar^* + CH_4 \to Ar + CH_4^*$$

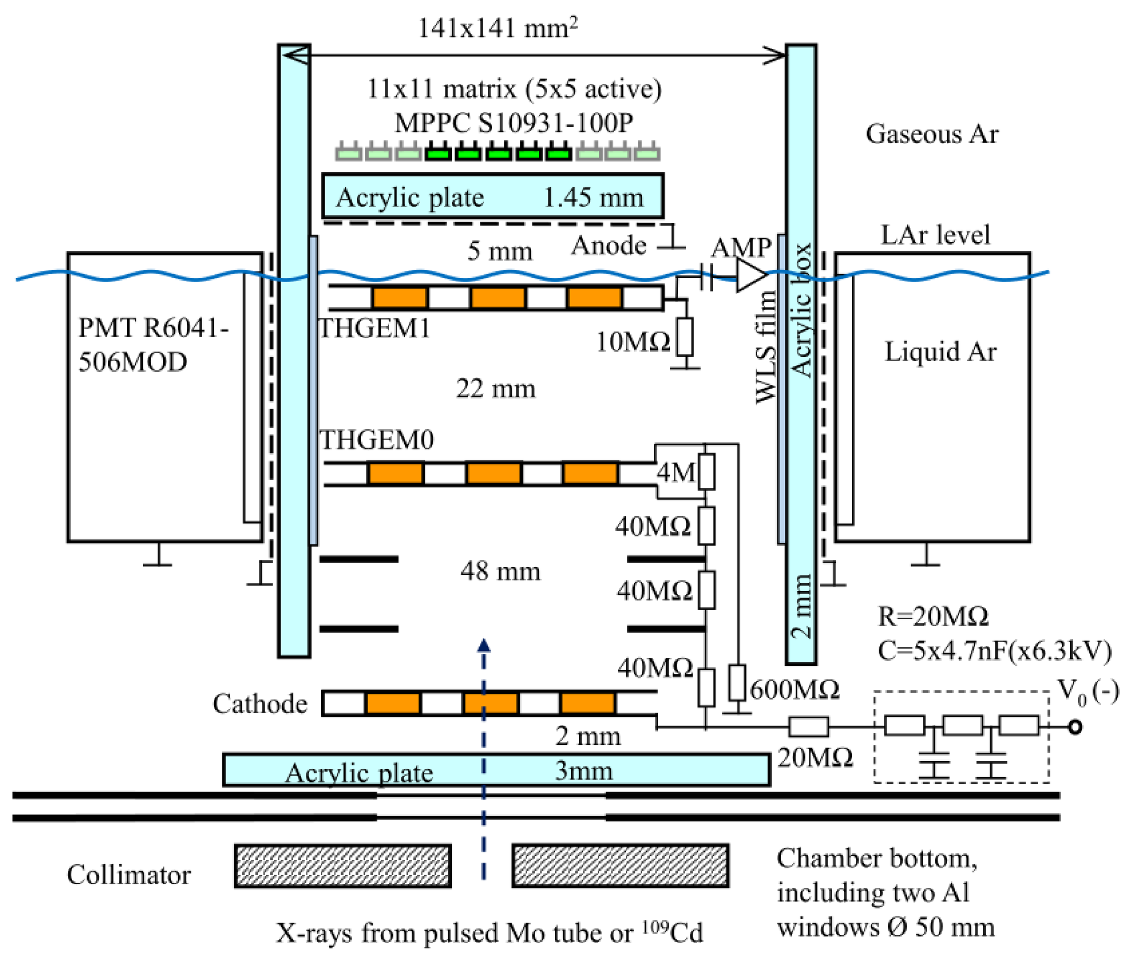
Neutral bremsstrahlung

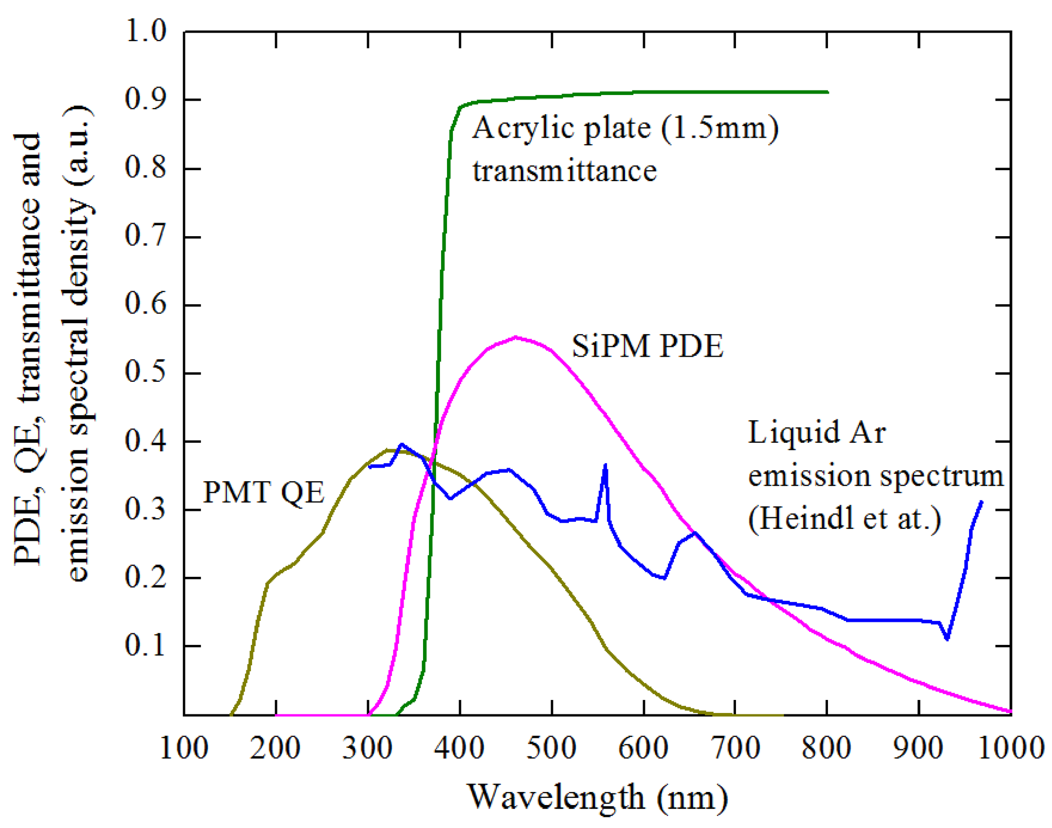
$$e^- + A \to e^- + A + h\nu$$



Neutral bremsstrahlung (NBrS) mechanism produces scintillation directly during electron elastic scattering on atoms [1]. Since the formation of excited states does not play an important role for this mechanism, NBrS scintillation perhaps will not be quenched by CH_4.

2. Experimental setup

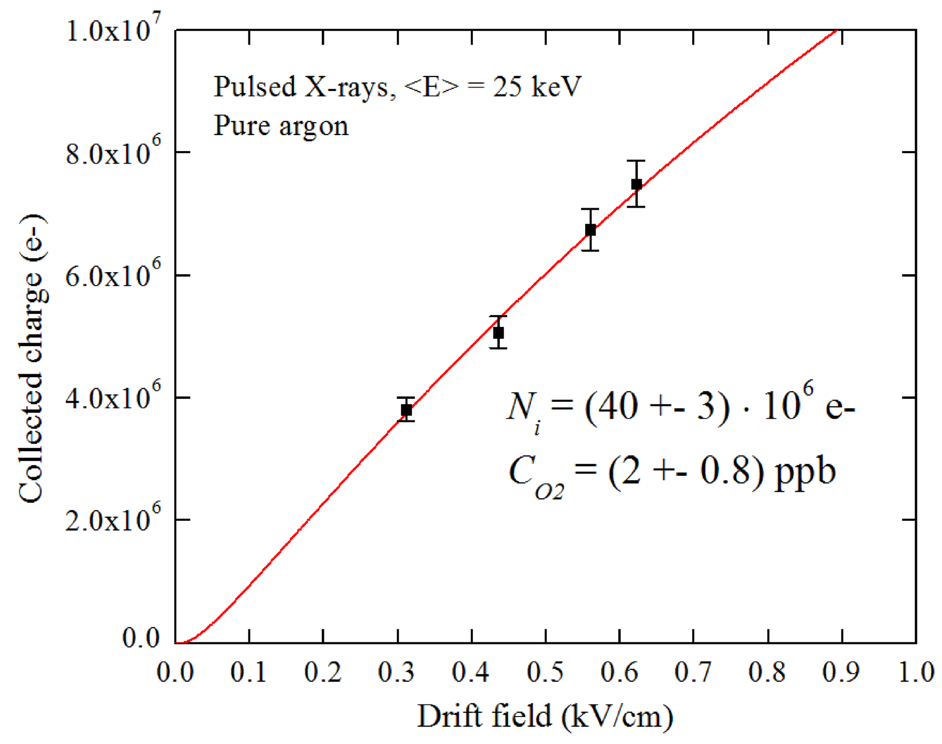




Single-phase liquid Ar detector:

- 9 liters cryogenic chamber filled with 3.5 liter of liquid Ar
- Pulsed X-ray source (<E> in LAr = 25 keV)
- High field gap, formed by THGEM0 and THGEM1 (anode), is used for charge recording
- 4 cryogenic PMTs R6041-506MOD: 3 PMTs with WLS (3PMT+WLS), and 1 bare PMT (1PMT)
- 5x5 matrix of SiPMs (of S10931-100P type, 6x6 mm² active area) with 1 cm channel pitch.

3. Light and charge measurements

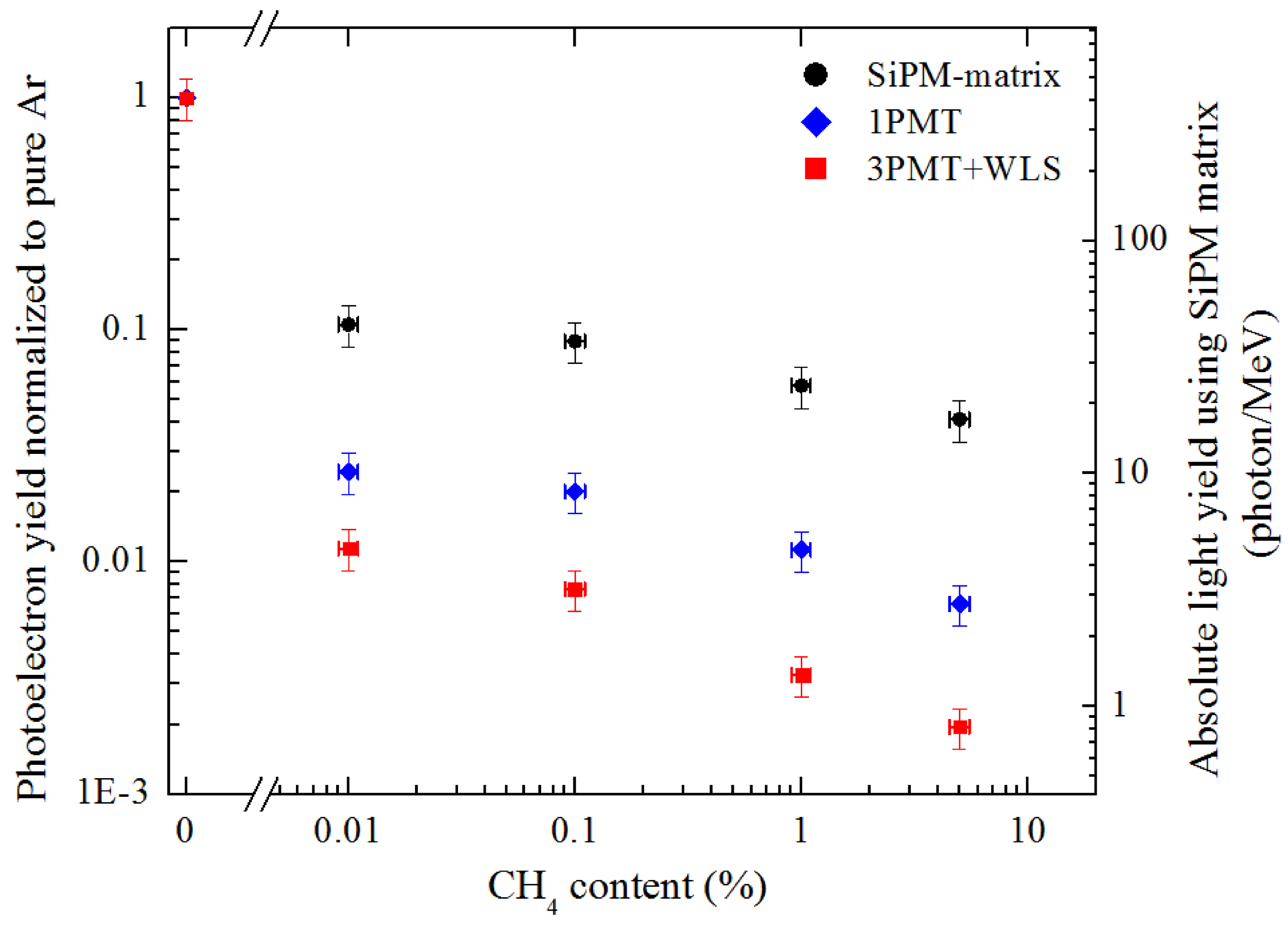


Photoelectron yield (Y_{PE}) was measured for a given spectral device (3PMT+WLS, 1PMT or SiPM matrix) as the ratio of recorded number of photoelectrons (N_{PE}) and the primary ionization charge (N_i):

$$Y_{PE} = N_{PE}/N_i .$$

The primary ionization charge was found from the dependence of the collected charge on the drift field in pure argon [2,3].

4. Light yield results



Relative (left scale) and absolute (right scale) scintillation yield as a function of CH_4 content in liquid Ar. The absolute yield in the range of 400-1000 nm was estimated using SiPM matrix and photon emission spectrum for LAr reported in [4]. One can see that primary scintillations are still observed in LAr + CH_4 even at CH_4 content reaching 5%. This might be interpreted by neutral bremsstrahlung mechanism.

5. Conclusions

1. The relative light yield of primary scintillations in the visible range, of 400–1000 nm, has for the first time been measured in liquid Ar doped with CH_4, with CH_4 content reaching 5%.
2. In pure argon, the absolute light yield was estimated to be 420±60 photon/MeV, which is consistent with previous study [5].
3. At CH_4 content of 5%, needed for effective operation of the neutron veto detector, the primary scintillation is still substantial, its light yield being assessed as 20±5 photon/MeV. This corresponds to the emission of 130±31 photons for 6.2 MeV gammas from neutron capture on argon.

6. References

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3. A. Bondar et al., 2016 NIM A 816 119
4. T. Heindl et al., 2011 JINST 6 P02011
5. A. Bondar et al., 2012 JINST 7 P06014