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Position Reconstruction in a Liquid Xenon Scintillation Chamber for Measuring Detection of Low Energy Nuclear Recoils and Gamma-Rays

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Liquid xenon has been recognised as a promising medium for direct detection of hypothetical
Weakly Interactive Massive Particles. Therefore, investigation of the response of liquid xenon to
nuclear recoils and g-rays is of primary importance.
In particular, we have recently measured the relative scintillation efficiencies of liquid xenon for
these two particles by irradiating a liquid xenon chamber with monoenergetic neutrons and detecting
the scintillation due to xenon recoils from elastic scattering of the neutrons. The liquid xenon chamber
used in these measurements was equipped with 7 two-inch photomultipliers (PMTs) in the top of a
cylindrical volume ø17×5.5 cm3 surrounded by PTFE reflectors, which define the active volume of
the liquid. The scintillation efficiency of liquid xenon for nuclear recoils with the energy from
140 keV down to 5 keV has been measured. The experimental uncertainties, among other factors,
include the variation of the signal amplitude with the event position and some contribution from
multiple scattering in the liquid.
Thus, measurement of the interaction position and rejection of the events involving two or more
scintillation points would allow the uncertainties to be reduced. For that, we adopted the maximum
likelihood (ML) method previously employed with success for scintillation detectors of similar
configuration [1], [2]. Two main difficulties are normally associated with this method: (i) exact
knowledge of the light collection function throughout the detector volume is essential, but this
function is difficult to measure or model; (ii) search for the maximum of the likelihood function is a
heavy computational task.
In the case of our detector, the rather simple configuration of the device allows to simulate the
light collection using a model with just three free parameters

(reflection coefficient of PTFE, absorption and scattering lengths in liquid xenon) easily adjustable to experimental data obtained with gamma-ray source of 122 keV at various positions. The light collection template with 2 mm step in 3D has been obtained in this way. The search for the ML was performed using conventional techniques such as simplex method, which has been proved to be efficient for this purpose.

In the case when the scintillation signals are of very low amplitude, resulting in emission of just a few photoelectrons from the PMT photocathodes, the single photoelectron response of the PMTs has to be taken into account. Therefore, instead of using the Poisson distribution, as it is normally done, we implemented ML with Polya distribution.

The developed algorithm was tested with 122 keV g-rays from a 57Co source placed under the chamber bottom. An (x,y)-position resolution of s=6.7 mm was obtained in the xenon layer of a few mm next to the chamber bottom. In order to assess the resolution in the whole volume, a number of fake data sets were produced by Monte Carlo simulation and reconstruction algorithm has been applied to them. The results indicate that at 122 keV the resolution is better than 4-5 mm for the central region of the chamber (ø80 mm and 40 mm high) and better than 7 mm in approximately 80% of the total volume of the chamber. For lower energies, the results indicate a slow worsening of the resolution. For example, for 10 keV energy depositions by g-rays, the position resolution is expected to become worse by a factor of about 2.

Applying of the developed reconstruction algorithm to the data obtained with nuclear recoils will allow the necessary corrections to be introduced and thus to improve the precision in determining the scintillation efficiency of liquid xenon to this particles. This method can potentially be useful for other liquid xenon purely scintillation detectors that are being developed for other applications.

[1] W.R. Cook et al., IEEE Trans. Nucl. Sci., NS-32, No. 1, pp. 129-133 (1985)

[2] D. Gagnon et al., IEEE Trans. Med. Imag., v. 12, No. 1, pp. 101-107 (1993)

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