Effect of electron space-charge on the gain of a two-dimensional photomultiplier tube model

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Abstract

Photomultiplier tubes (PMTs) [1] are widely used as photodetectors in military, industrial and medical applications since almost one century. When faced with high-intensity light pulses, PMTs exhibit a non-linear response due to extrinsic factors like voltage supply electronics [2] as well as intrinsic ones, such as electron space-charge: a cloud of densely packed electron trajectories perturbing the electrostatic field in the vacuum of the PMT. To quantify the effect of space charge on the amplification factor (gain) of the PMT, we perform a Monte Carlo simulation of a two-dimensional model of a PMT. Based on an X-ray image of it, we manually contour the dynodes, anode, cathode and glass envelope. The electrostatic field is solved using a two-dimensional mesh after setting the boundary conditions in the faces of the contoured geometries, namely the voltages recommended by the manufacturer on each of the electrodes. The electron trajectories are then calculated by using the Boris leap-frog method [3] and the amplification is based on Vaughan's model [4]. The effect of space-charge is estimated iteratively and without time dependence, by incorporating a charge density into the solution of the electrostatic field and retracing the trajectories. In each step, the charge density is determined by the distribution of electron trajectories found out in the previous iteration. Finally, the effect of the space charge on the PMT gain is studied in terms of the stationary photocathode current for a fixed supply voltage. In the future, the extension of this study to 3D geometry and comparison with experimental measurements are planned.

References

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