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Simulation of a vacuum phototriode with SIMION 3D

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Abstract

An electron-optic model of a 26 mm diameter vacuum phototriode (VPT) photodetector was developed using SIMION 3D software extended by additional code to simulate secondary emission at the dynode. The predictions of the variation of gain with magnetic field for mesh anodes with 100, 40 and 7 lines per mm and fields from 0 and 4 T are presented. The predicted time development of the signal at 0 T is presented and compared with experimental data obtained by illuminating a production VPT for the electromagnetic endcap calorimeter of CMS with 60 ps laser pulses at a wavelength of 435 nm.

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1. Introduction

The vacuum phototriode (VPT) is a single gain stage photomultiplier, which is very insensitive to high magnetic fields compared to a multi-stage device. It has been chosen as the photodetector for the homogeneous lead tungstate endcap electromagnetic calorimeter of the Compact Muon Solenoid (CMS) experiment [1] which is currently under construction at CERN, Geneva, Switzerland. In the endcap region the VPT is located in the full 4 T magnetic field of the CMS solenoid. Other VPT have been used in a previous generation of particle detectors, for example the endcap calorimeter of OPAL [2] and the STIC of DELPHI [3]. A VPT for CMS is shown schematically in Fig. 1.

Photoelectrons from the cathode are accelerated towards the anode by the high electric field. The anode is a partially transmitting metal mesh and the primary electrons that are not directly captured are slightly decelerated before hitting a solid dynode with a high secondary emission coefficient. The secondary electrons produced at the dynode are accelerated back towards the anode where a fraction is collected; these produce the bulk of the signal flowing in the external circuit. Those transmitted are decelerated in the anode–cathode gap, return to the anode, where a further fraction are collected, and then back to the dynode where a further generation of secondary electrons can occur.

The simple planar geometry, coupled with small inter-electrode gaps, suggests that such a VPT structure should be fast and have good timing resolution. In this preliminary study we discuss a simulation of a model of a CMS production VPT [4] using an extended version of the SIMION 3D electron optic simulation software and present our predictions for gain at fields from 0 to 4 T. We have also made an initial measurement of the relative time delay as a function of operating potential of a VPT illuminated by 60 ps laser pulses at a wavelength of 435 nm.

2. Simulation of gain and time response

To simulate the VPT we used version 7.0 of the commercial ion/electron optic simulation program SIMION 3D™ [5]. This enables the tracking of electrons or ions through static electric and magnetic fields defined by a three-dimensional geometric electrode model. SIMION tracks the path and calculates the time-of-flight of each particle, but once a particle hits an electrode the data relating to the particle is stored and the particle is lost. In order to simulate the secondary emission from a VPT

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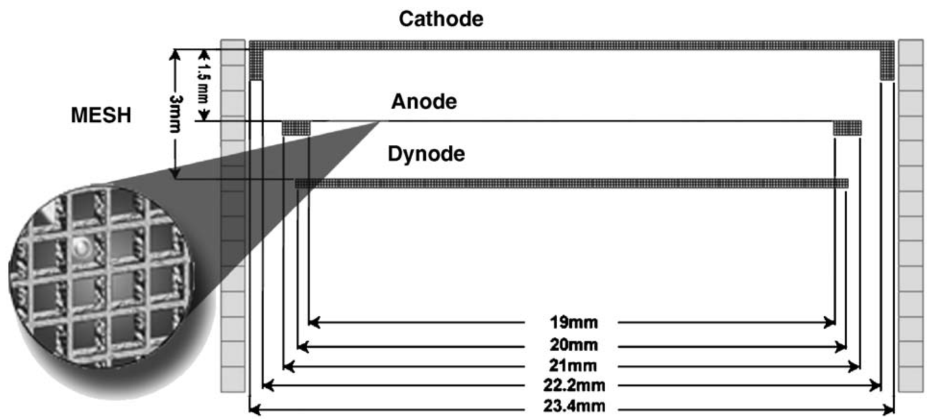

Fig. 1. Schematic of a CMS production VPT. The outside diameter of the tube is 26 mm. Only the parts modelled in the SIMION 3D simulation are illustrated. The anode is made up of a metal ring supporting a thin mesh with a transparency of approximately 50% over a diameter of 19 mm.

dynode we have integrated SIMION with our own code, which uses the hit position of the primary electrons on the dynode as the source of secondary electrons whose time origin is now equal to the flight time of the primary. This process is repeated until the incident energy of an electron hitting the dynode has fallen below a user-defined threshold.

The detailed simulation of the mesh anode is a critical element in our studies. SIMION allows for an "ideal mesh" which is fully transparent and exists just to define a surface at a constant potential through which ions or electrons can pass unhindered. In our VPT we have two different length scales at which we must simulate a potential array and track electrons. The basic size of the VPT, and its inter-electrode gaps, is on the scale of millimetres; however, the anode mesh in production tubes has 100 lines per millimetre in two orthogonal directions. In order to avoid splitting the macroscopic dimensions of the VPT into millions of fundamental cubes whose side ("grid-unit", gu) would be of order 5 μm, we used the concept of multiple instances. The large-scale structures are simulated at a resolution of 0.083 mm per gu with an ideal (100% transmission) anode mesh in order to generate the correct electrostatic potentials. Superposed on top of the ideal mesh is a very thin cylindrical volume in which a real (i.e. capable of absorbing particles) mesh is simulated at a spatial resolution appropriate to the mesh being modelled. We simulated three different meshes each with 50% optical transmission. One mesh had 7 lines per mm (0.032 mm per-gu), one had 40 per mm (0.006 mm per gu) and a third with 100 lines per mm (0.005 mm per gu). The 100 lines per mm mesh simulates the anode mesh fitted to production VPT.

The modelling of the dynode secondary emission is currently very simple. This is deliberate as we wish to understand exactly what contributes to different experimentally observed aspects of VPT performance, and with a simple model one level of complexity is removed. We used a multiplicative factor, which only depends on the incident energy of the primary electron incident on the dynode. At any given energy a constant number of secondary electrons are produced, each with an initial energy of 5 eV. The emitted angle is randomly varied by up to 5° from the surface normal.

2.1. Gain at 0T

The gain of the VPT depends on the secondary emission of the dynode and the transparency of the mesh. A simple model [6] predicts that a transparency of around 50% is optimum. The planar geometry with small inter-electrode gaps should also result in a very fast pulse with short transit time. Although it is already known from beam tests that the speed of response of the VPT for CMS is fast (<10 ns) it has not yet been directly measured.

The predicted and measured gain, as a function of dynode voltage, at 0T field for a production VPT with a 100 lp m mesh are shown in Fig. 2. In order to obtain reasonable agreement for absolute maximum gain the secondary emission gain G was modelled as

$$G(V_{K-D}) = \frac{V_{K-D}}{40},$$

where V_{K-D} is the potential difference between the cathode and the dynode and the units are Volts.

The simulated arrival times of electrons on the anode is shown in Fig. 3. There is an increasing transit time with increasing dynode potential as the accelerating potential between the anode and dynode decreases and thus the average velocity of the secondary electrons decreases too. A preliminary measurement of relative delay has been made and is described in the next section.

2.2. Response to fast laser pulsed illumination at 0T

A preliminary experimental verification of the predicted variation of the time delay of the anode signal with dynode potential when illuminated by a fast light pulse has been made. The centre of the photocathode of a production VPT, at 0T, was illuminated by fast pulses (60 ps FWHM at 435 nm) from a PicoQuant SEPIA 808 diode laser. The