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Simulating Performance of Microchannel Plate Photomultipliers in Magnetic Fields

E J Baldwin, J S Lapington, S A Leach – Space Research Centre, University of Leicester, UK
Contact: ejb71@le.ac.uk

ABSTRACT

Photon counting detectors are utilised for applications in medical imaging, nuclear and particle physics where a strong magnetic field is present, requiring a detector that can operate in these circumstances. An extremely important characteristic of photon counting detectors is the method of electron multiplication used. In vacuum tubes such as photomultiplier tubes (PMTs) and microchannel plates (MCPs), secondary electron emission (SEE) provides electron multiplication through an accelerating field across the dynode. MCPs are high gain, fast timing electron multipliers and our research seeks to model their operation in magnetic fields.

We illustrate how a PMT can be simulated using a model generated using Computer Simulation Technology (CST) Studio Suite software. The model consists of a photocathode, an MCP structure including electrodes, resistive and secondary electron emitting dynode surfaces, and a readout anode, with appropriate potentials applied to the components of the model. Magnetic fields can be applied to the model with different directions and amplitudes. Using this simulation it is possible to produce the gain and timing characteristics of the PMT. We present simulation results from the modelled PMT, demonstrating electron multiplication performance and timing performance as a function of external magnetic field strength and direction.

SIMULATION GEOMETRY

A PMT has been simulated in CST software. A small photon source is placed above a photocathode with 25 photons being emitted for each iteration of the simulation. Multiple photons are used to account for probabilistic effects and different trajectories that can be taken by electrons. Future simulations will be performed with single photons as well. An MCP model with 919 hexagonally arranged pores has been created with an L/D of 40:1 and a bias angle of 12°. A simple cylindrical representation of the anode is simulated, which allows space, time and energy analysis of the colliding particles. The tracking solver is used in CST as this allows simulation of photoemission.

The Vaughan secondary electron emission (SEE) model [1] was used and the secondary electron yield (SEY) characteristics for the MgO dynode material and NiChrome were input manually. All parameters are assigned variables that can be changed by the user. The photocathode properties were also input manually and a work function of 1.0 eV was used, with a constant radiant sensitivity of 45 mA/W. One electron is emitted for each incident photon. This is a simplistic representation of a photocathode. The photons that are emitted from the photon source have a wavelength of 450 nm and a power of 1 x 10^{-7} W.

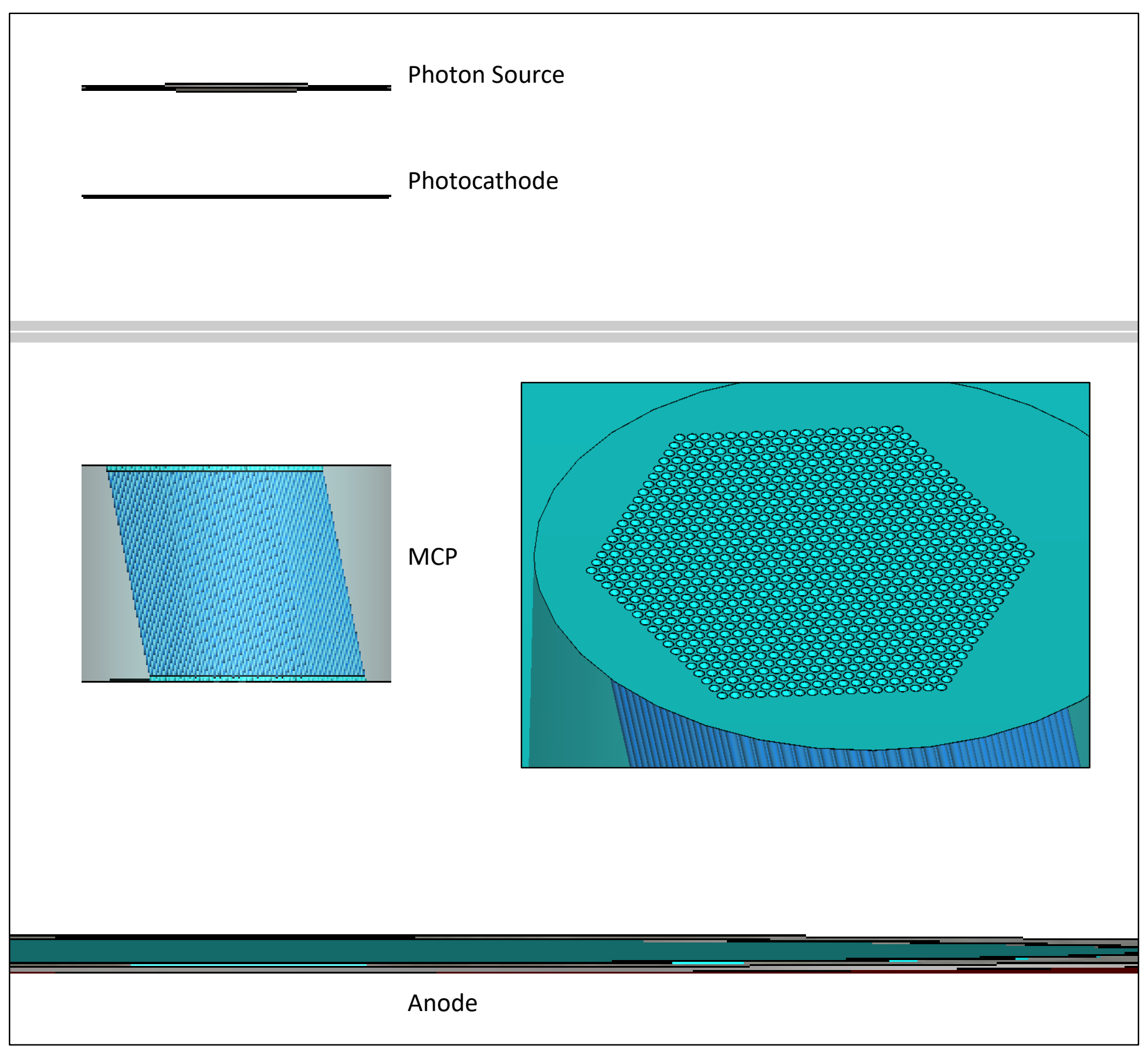

Figure 1. MCP-PMT simulation structure. Right image shows the hexagonal MCP pore structure

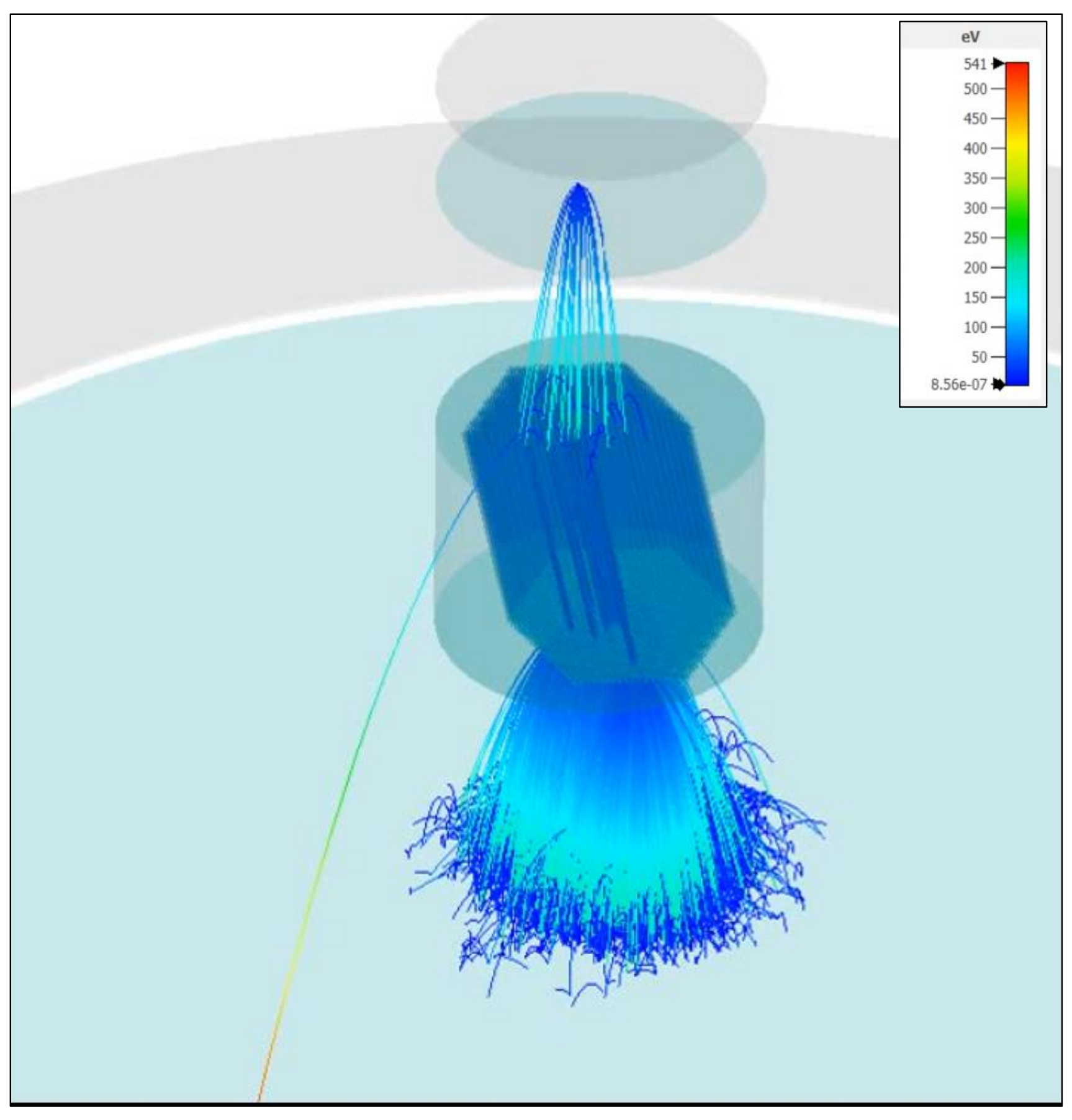

Figure 2. Electron trajectories of the MCP=PMT simulation and their corresponding energies.

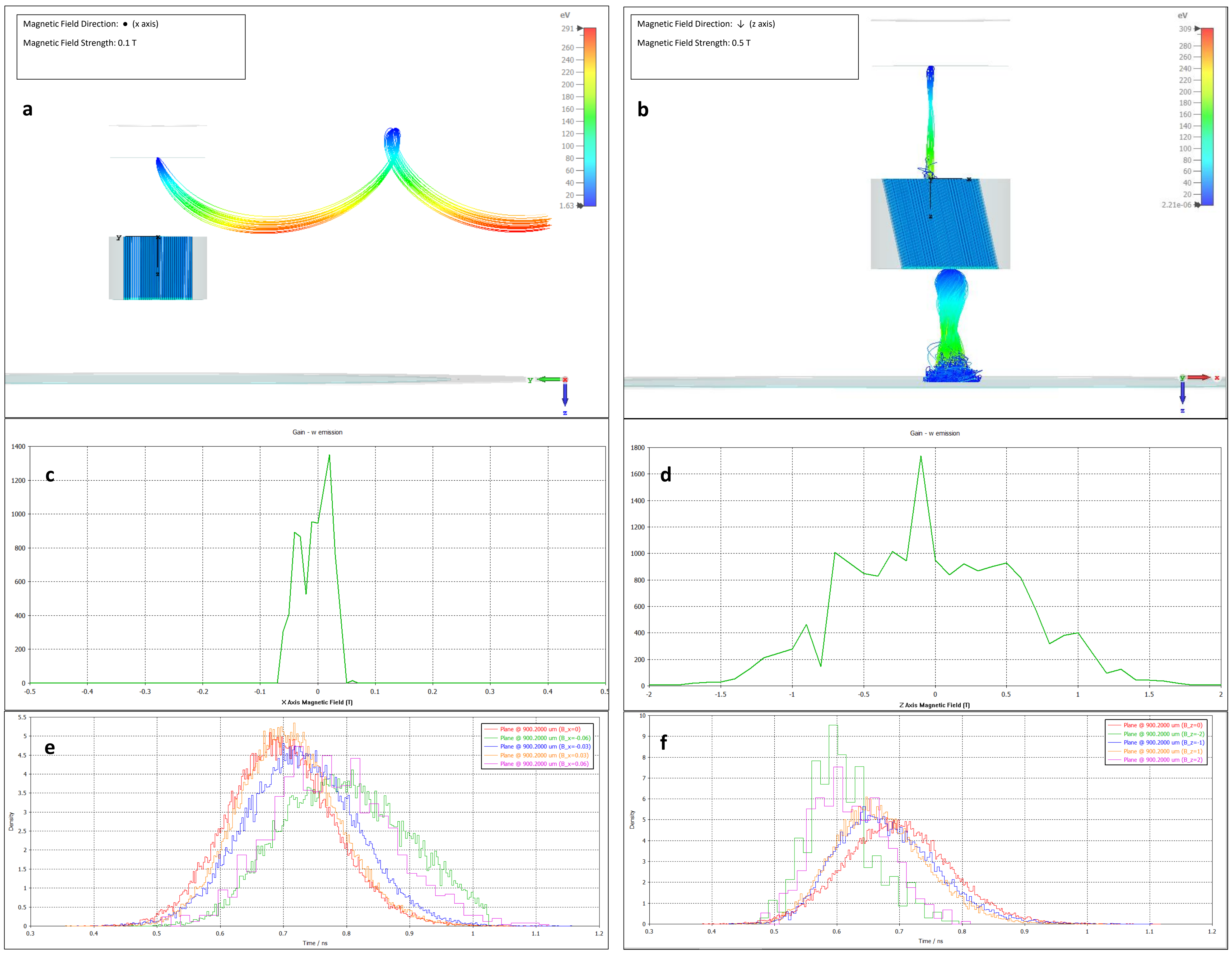

Figure 3. (Left) X axis magnetic field simulation results. (Right) Z axis magnetic field simulation results. The top images show the electron trajectories that are calculated in the presence of a magnetic field for a single iteration. The middle plots show the gain variation with magnetic field strength and the bottom plots show the time distribution of electrons colliding with the anode for different magnetic field strengths.

RESULTS

Tracking solver simulations were performed with magnetic fields in the x, y and z directions of varying magnetic field strengths. The results from the x and y magnetic fields were similar so only the results of the x direction magnetic field are discussed in detail.

Trajectory plots (Figure 3a) show that the magnetic field in the x direction has a significant impact on the performance of an MCP. The circular nature of magnetic field induced motion results in electrons being unable to enter the MCP itself at relatively low field strengths. This results in the narrow gain peak between values of 0.1 T in the –x direction and 0.1 T in the +x direction (Figure 3c). The magnetic field applied in the z direction also shows a circular trajectory of electrons, with overall motion in the z direction as seen in figure 3b. This allows the electrons to still enter the MCP and consequently a wider gain peak can be seen. At increasingly high magnetic field strengths the electric field is unable to overcome the magnetic field affects and electrons lose too much energy in their collisions with the MCP pores. Reasonable MCP performance is measured between 1.5 T in the –z direction and 1.5 T in the +z direction (Figure 3d).

The time distribution plots (Figures 3e & 3f) show that the direction of the magnetic field in each axis doesn't largely vary the timing characteristics of the MCP-PMT, however the field strength does. Further simulation results for high gain outputs are required to see the true effect of magnetic field on the timing characteristics of MCP-PMTs. A particle-in-cell (PIC) solver is available in CST which performs transient analysis of charged particle motion, allowing more complex time characteristics such as rise time and FWHM to be calculated, and further simulations will be performed using this solver.

CONCLUSION

There are several complex relationships to consider when simulating MCPs, particularly in relation to magnetic fields and more complex MCP and MCP-PMT arrangements.

- We have shown it's possible to simulate an MCP-PMT with 919 pores simulated in the MCP.
- We have simulated a magnetic field across the MCP-PMT model and analysed how the direction and magnetic field strength affect gain and timing performance.
- We have established the effect of the magnetic fields on the electron trajectories and how this varies for different field directions.

Future Work:

- Analyse the effect of magnetic fields applied at different angles and see how changing the potentials applied across the model affects the simulation results.
- Simulate the MCP-PMT using the PIC solver, allowing more detailed transient analysis and more realistic gain calculations.
- Repeat simulations with single incident photons.

[1] Vaughan, 1989, A new formula for secondary emission yield.