Design of the microchannel plate photomultiplier Tube for applications in strong magnetic fields

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Motivation

There are several possible applications of microchannel plate photomultiplier tube (MCP-PMT) in high energy experiments with magnetic fields higher than 1 T. The strong magnetic fields affect the gain of the MCP-PMT in two ways. Photoelectron trajectories from the photocathode to the MCP can be badly deflected by the magnetic fields resulting that photoelectrons fail to hit the MCP. In the MCP channels, magnetic fields can decrease the electron transit length and energy, and therefore lead to a low gain. Several publications concluded that smaller channels yield higher immunity against strong magnetic field, and less than 10 μm diameter is necessary to work in magnetic fields higher than 1 T. In this work, strong magnetic fields up to 5 T effects on the photoelectrons from the photocathode to the MCP are studied.

Simulation details

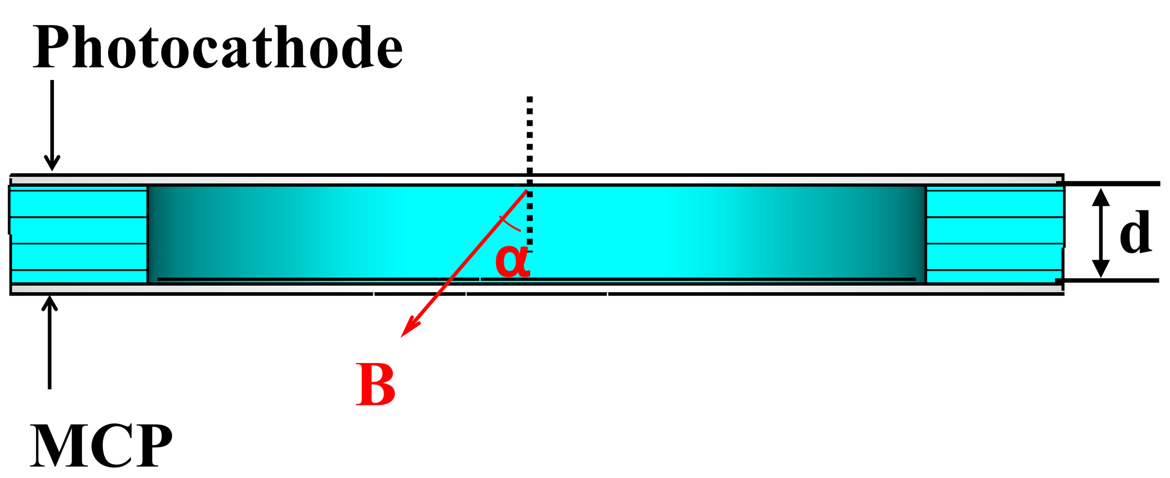

Fig. 1 3D model of the MCP-PMT and definition of parameters.

A 3D simulation model is built in CST program to trace photoelectron trajectories from the photocathode to the MCP in strong magnetic fields up to 5 T. The outer diameter of the photocathode and the MCP is ϕ25 mm with an effective diameter of ϕ18 mm. The initial energy of photoelectrons emitted from the photocathode obeys a beta distribution in the range of 0-1 eV. The initial angular distribution is approximately a cosine distribution. The probability of photoelectrons hitting the MCP CEm is simulated as functions of distance between photocathode and MCP d, as well as the bias voltage U for different magnetic field angles α.

Results and analysis

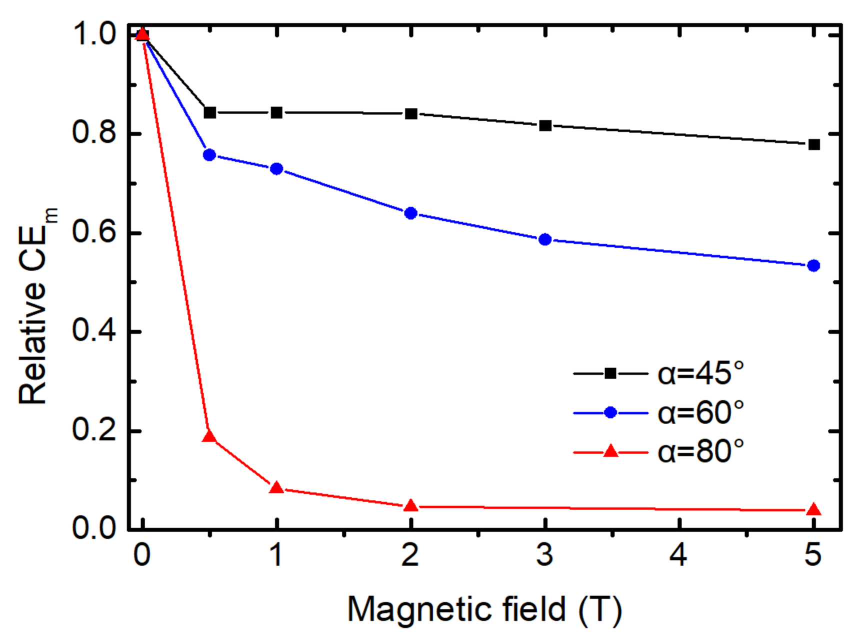

Fig. 2 Relative CEm as a function of magnetic field at d=2 mm and U=500 V.

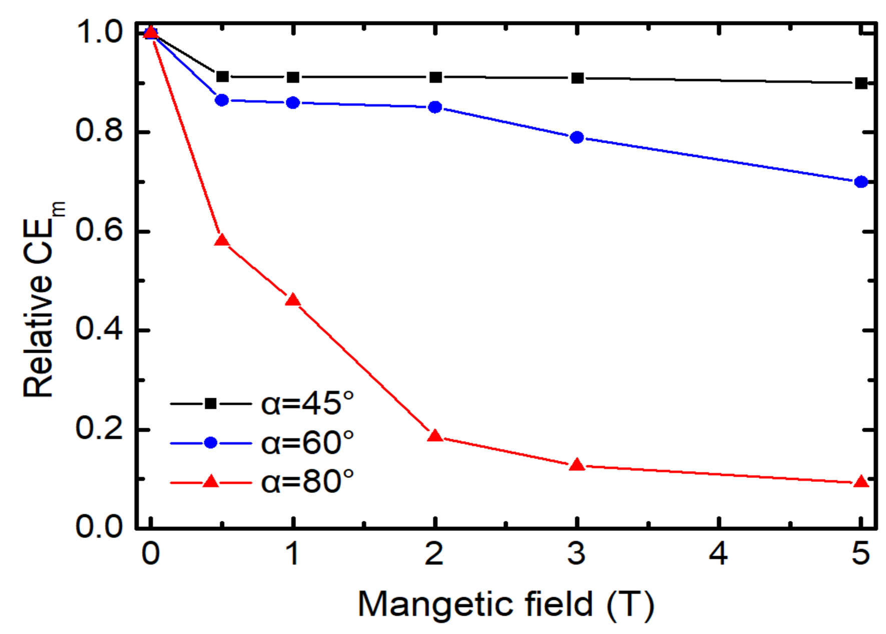

Fig. 3 Relative CEm as a function of magnetic field at d=1mm and U=500 V.

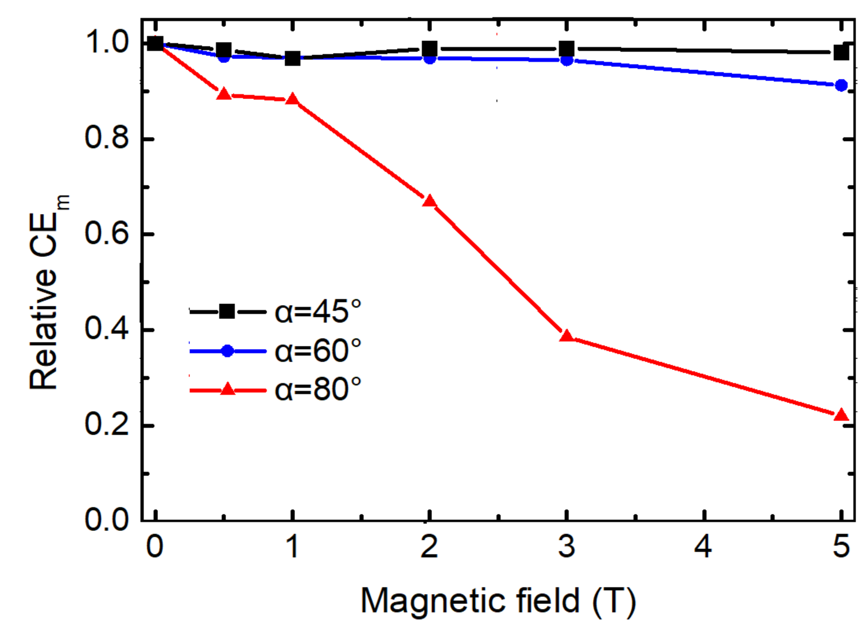

Fig. 4 Relative CEm as a function of magnetic field at d=0.3 mm and U=300 V.

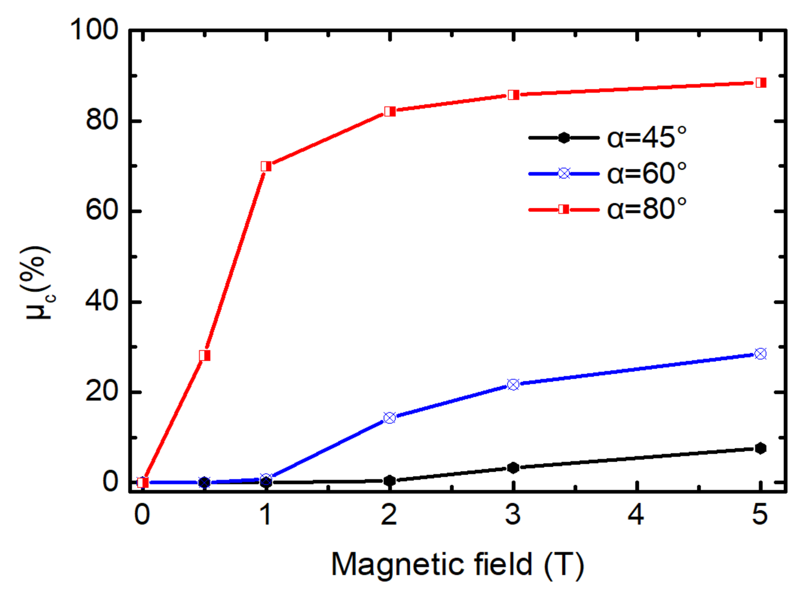

Fig. 5 Probability of photoelectrons striking photocathode as a function of magnetic field at d=2 mm and U=500 V.

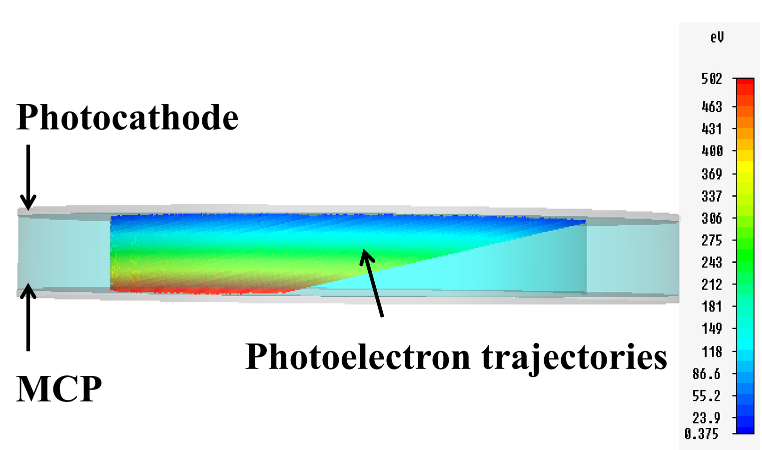

Fig. 6 Photoelectron trajectories for magnetic field of 3 T at d=2 mm and U=500 V.

It's showed that CEm drops as the magnetic field increases and the angle between the magnetic field and the photoelectron motion increases. Low electric field strength between photocathode and MCP also leads to weak immunity against magnetic fields. CEm decreases less than 50% when α is smaller than 45° and the electric field is stronger than 250V/mm. While it can drops 90% as α larger than 80°. To have more than of CEm in magnetic field up to 5 T, electric field stronger than and α less than 45° should be guaranteed.

It should be noted that a growing number of photoelectrons tend to strike photocathode as magnetic field increases, which may reduce the cathode lifetime.

Conclusions and prospects

Several examples of MCP-PMTs with different photocathode and MCP spaces and bias voltages are simulated in magnetic fields up to 5 T. It's found that photoelectrons strike back to photocathode with enhancing magnetic fields, which not only reduces gain but also decreases the photocathode lifetime. To have more than 60% CEm in magnetic field up to 5 T, electric field stronger than 500 V/mm and α less than 45° should be guaranteed.

It's planed to study the electron motions in the MCP channels.