MESHING CHALLENGES IN SIMULATING THE INDUCED CURRENTS IN A VACUUM PHOTOTRIODE

PARTICLE TRACING IN ELECTROMAGNETIC FIELDS

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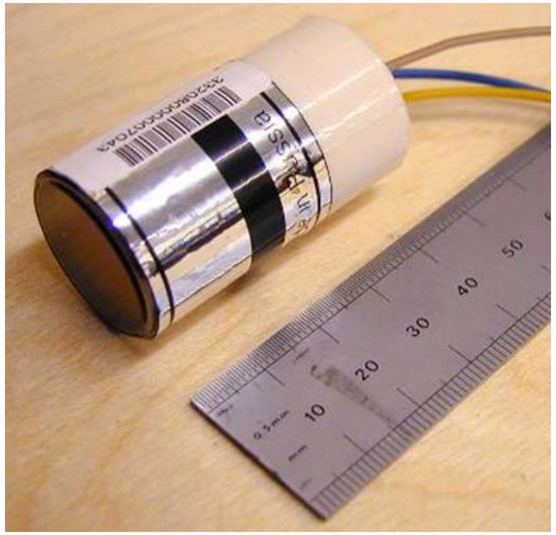
INTRODUCTION

- The aim of these simulations is to understand and visualise the activity that occurs within the vacuum phototriode (VPT).
- Particle trajectories and movement within the VPT.
- Simulations to produce gain vs. magnetic field strength and angle.



BACKGROUND

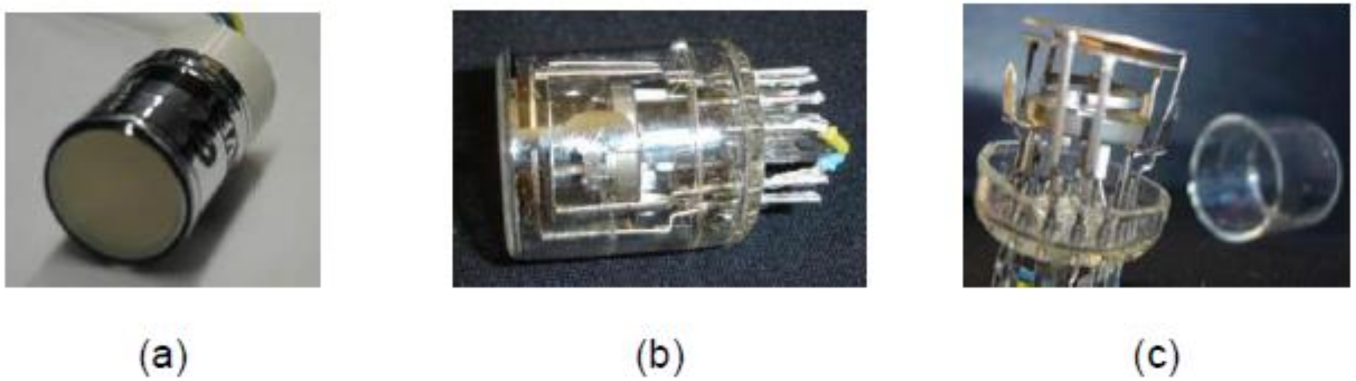

(a) (b) (c)

Figure 2-3: Real Production RIE VPT. (a) Standard VPT before opening. (b) Cut VPT, anode and dynode are now visible through the glass. (c) Cut and opened VPT in display.

- Used in OPAL, DELPHI, CMS and many more experiments.
- Within CMS:
  - - Avalanche photodiode (APD) for barrel
  - - Vacuum phototriode (VPT) for end caps
- Vacuum phototriodes (VPT) are single gain-stage photomultipliers.
- VPT is attached a lead tungstate crystal.
- Timing response of the VPT is vital.

WHAT ARE VPTS

- Convert a light source into a signal of amplified electrons that is proportional to the light magnitude.
- VPTs contains three main electrodes:
  - Photocathode – light into photoelectrons.
  - Anode - collection of signal.
  - Dynode – multiplication of electrons.
- VPTs are able to operate within a magnetic field and high radiation tolerance.

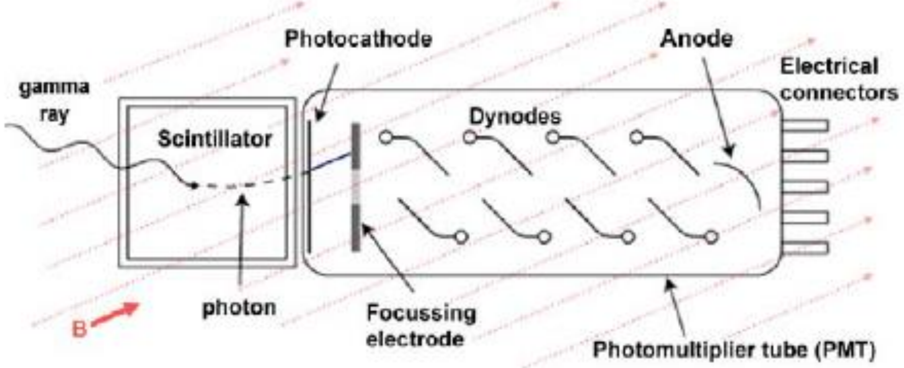
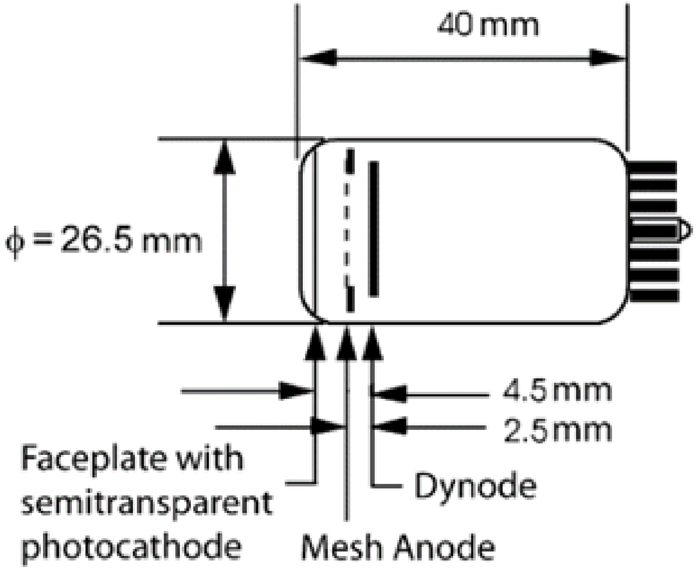


Figure 1-8 a photomultiplier in a strong uniform magnetic field.
Magnetic field forces electrons to a trajectory parallel to the field lines. Because of t
the avalanche of electrons in the photomultiplier tube can not reach consecutive
dynodes, and therefore can not make progress

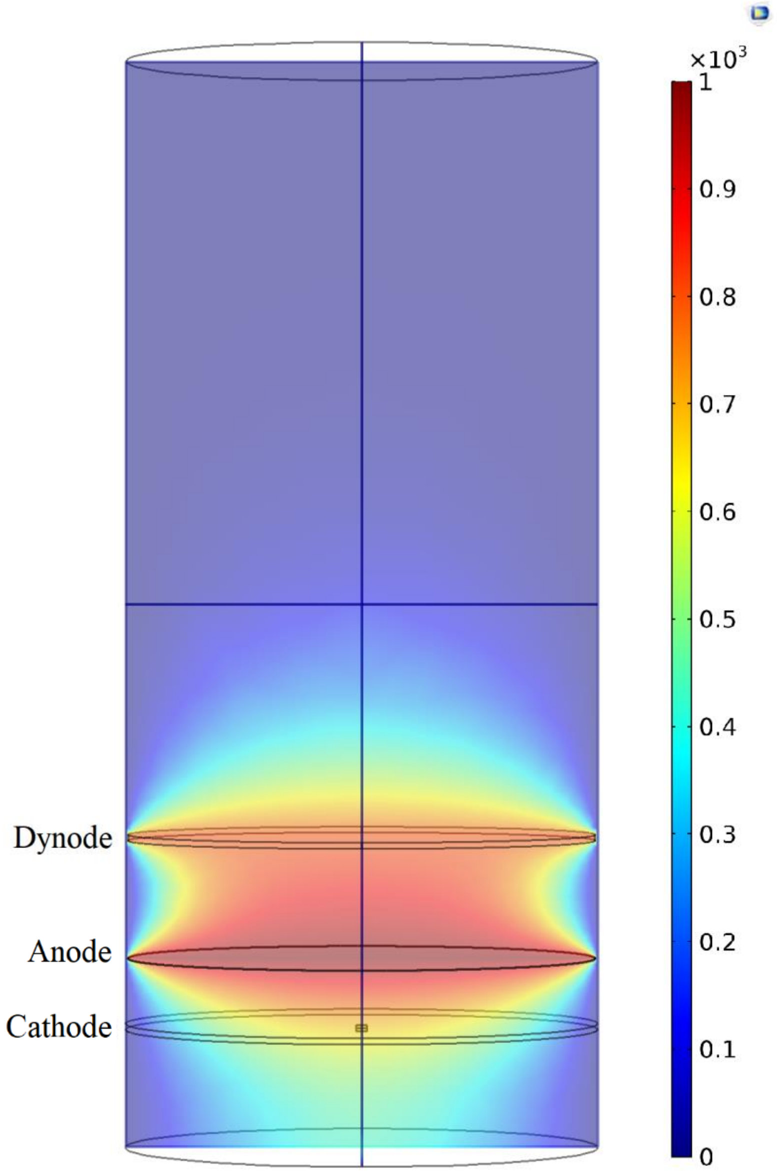
SIMULATION SETUP

- Simulated using COMSOL V5.3.
- Exact replica of the VPT, simulated within a vacuum.
- Fine thin anode mesh with a 10 µm pitch with 50 % transparency.
  - This allows for 50% of the particles travel through anode.
- Workstation used a four-core (plus hyperthreading) Intel i7 processor @3.7 GHz and 48 GB of RAM



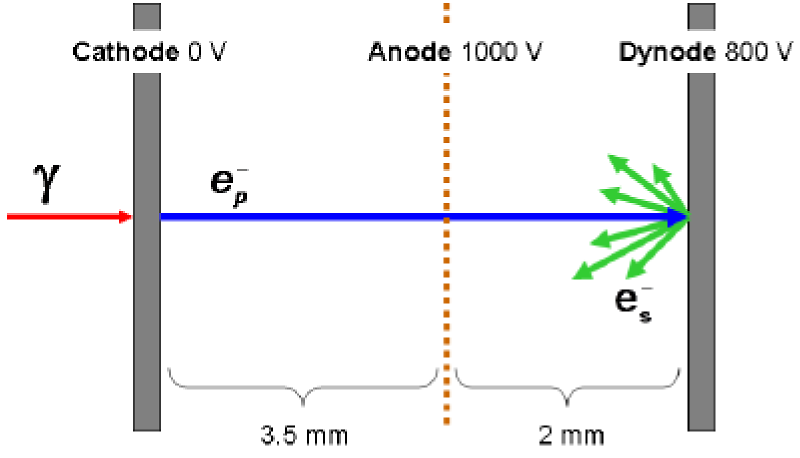
ELECTROSTATICS MODULE

- Geometry is set up to match the real dimensions of the manufactured by RIE St Petersburg tube used within CMS.
- Cathode 0 V, anode 1000 V and dynode 800 V.



PARTICLE TRACING MODULE

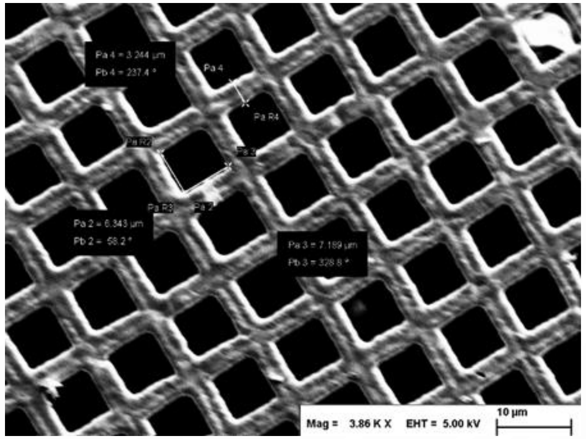
- Setting up magnetic force and the electric forces within the Multiphysics module.
- Secondary emission and particle release set-up.

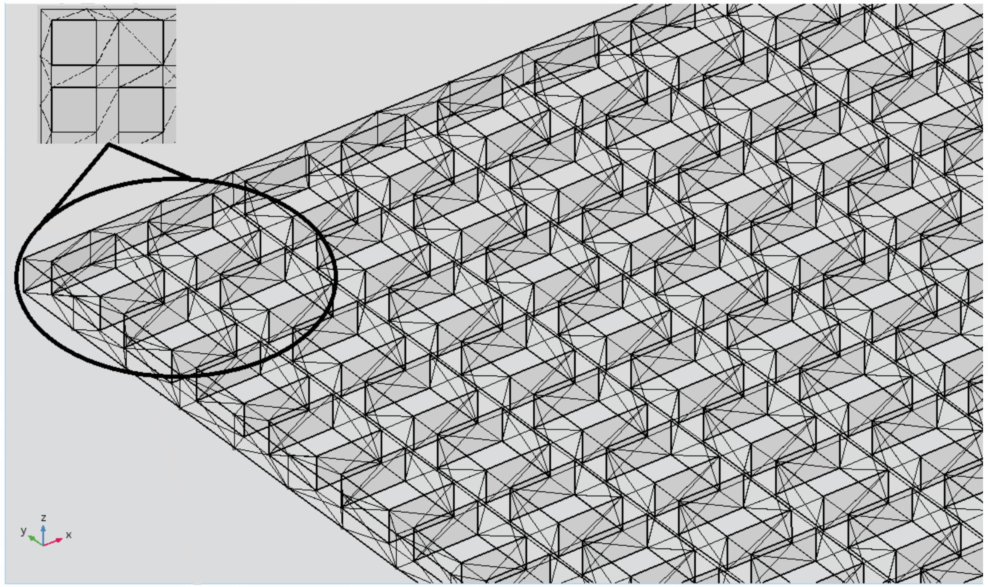


- The Shockley-Ramo Theorem is used to calculate the induced current.
  - The current i on an electrode induced by a moving point is given by:
  - $i = -q \cdot \vec{v} \cdot \vec{F}_k$
- The induced current on the anode provides the output signal.

MESHING THE ANODE GRID

- An estimated 5 million+ square holes are required to match the real dimensions.
- Meshing the anode grid is a challenging task.
- Anode mesh depth 1.6 µm, to simplify uses 2.5 µm.
- To simplify the problem an array of 150 x 150 is used.

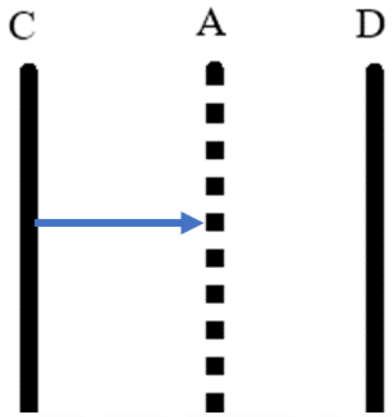




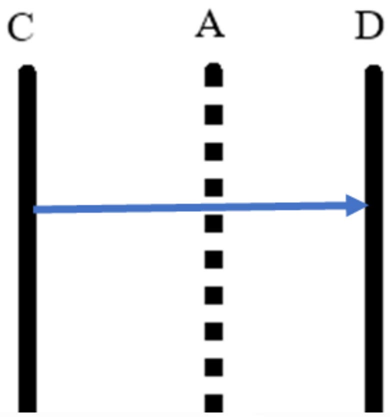
MESHING DIFFICULTY

- The FEM for the whole VPT consists of 8534251 domain elements, 1485338 boundary elements, and 495636 edge elements.
- The computation time is approximately 14 hours.
- Issues generally to do with:
  - Running out of memory whilst computing the geometry or the COMSOL mesh.
  - Error converging on a single edge or point.
- New version of COMSOL has new features which has helped the time computation and difficulty of this task (avoid small elements).

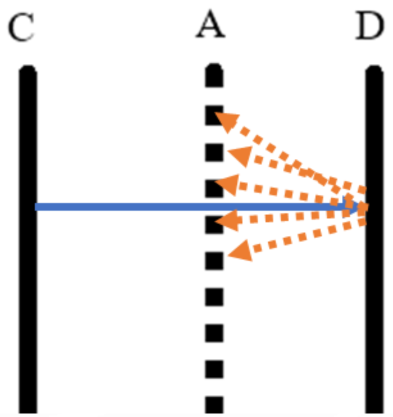
PARTICLE TRAJECTORIES SCENARIOS



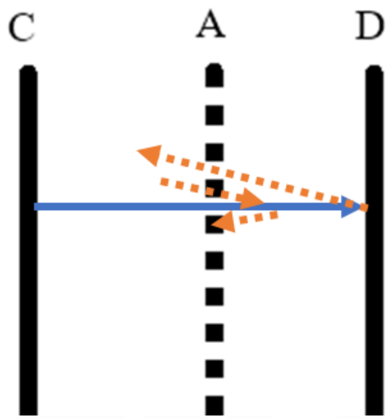
1) Photoelectron hits anode



2) Photoelectron hits dynode



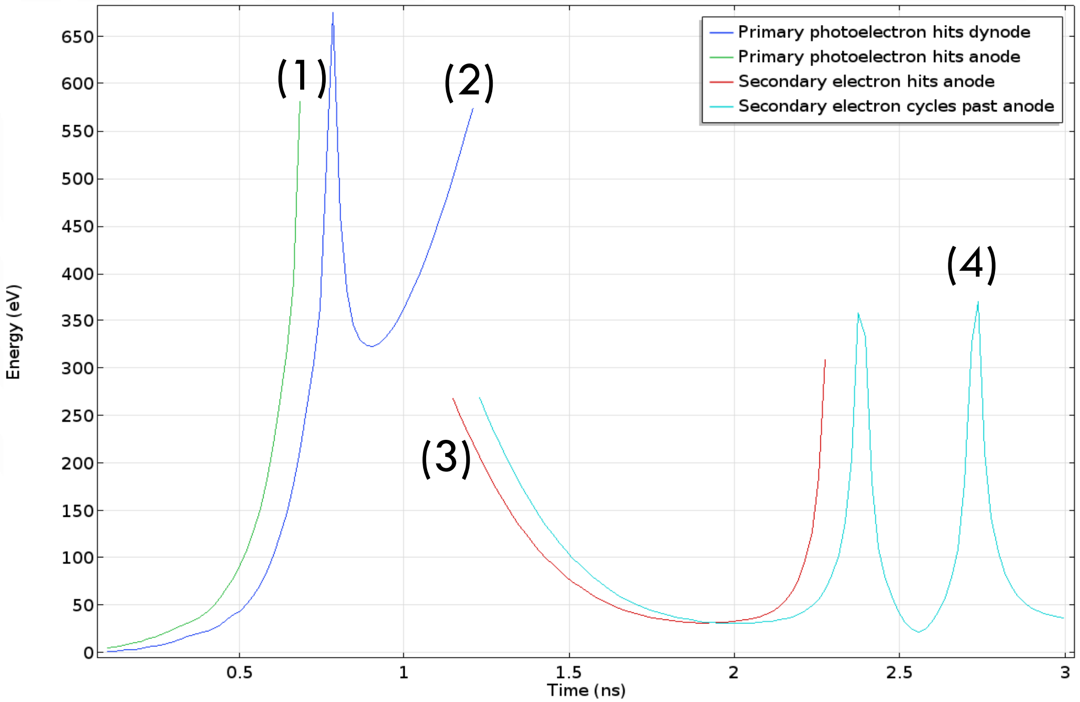
3) Secondary electron hits anode

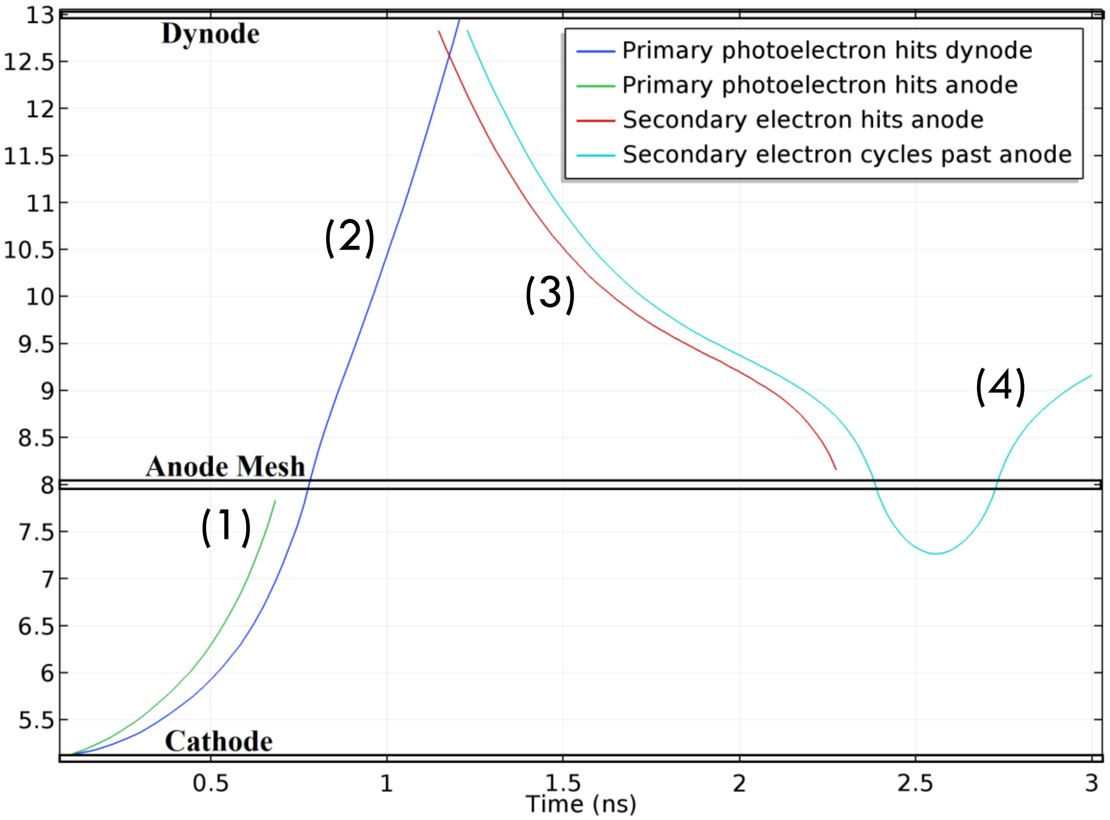


4) Secondary electron cycles past anode

SECONDARY EMISSION

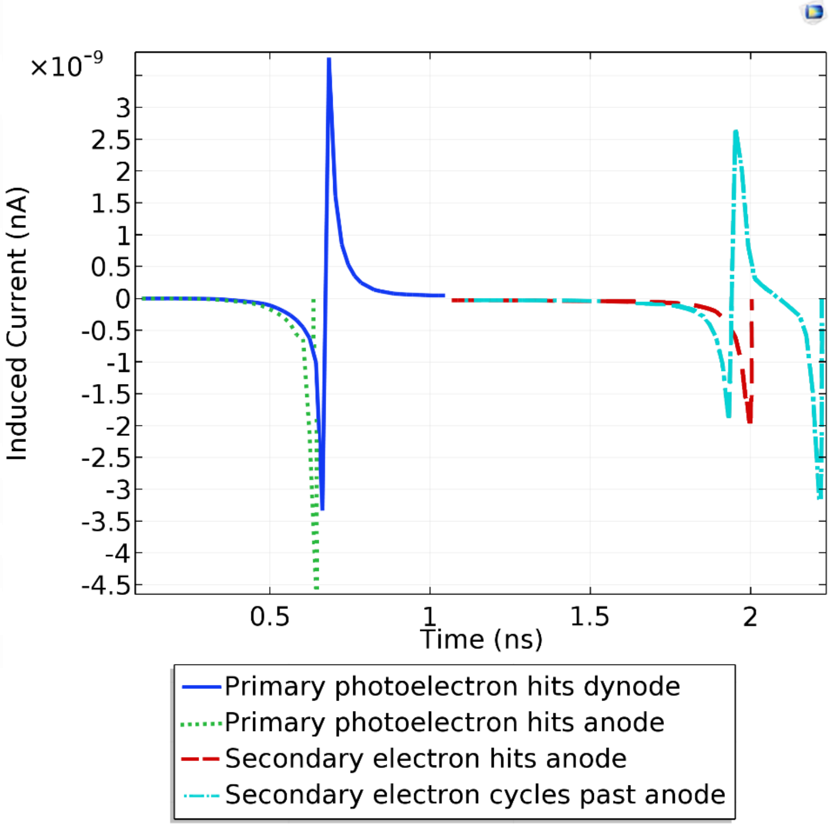
- Photoelectrons are accelerated towards the anode due to the potential difference between the cathode, dynode and the anode.

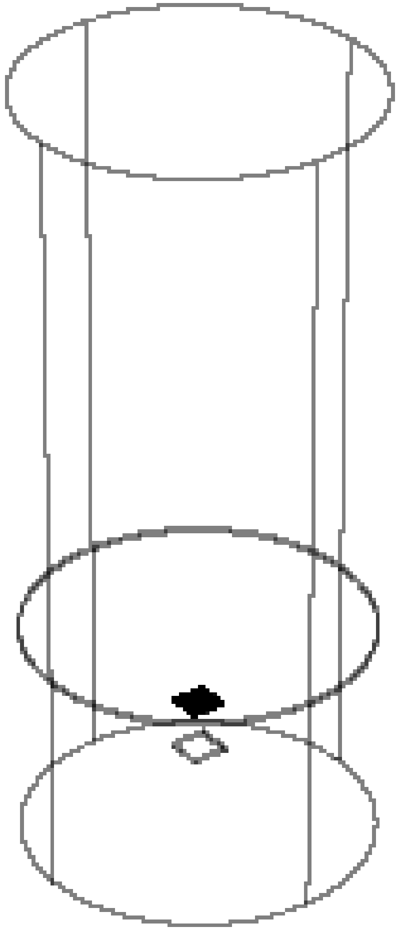




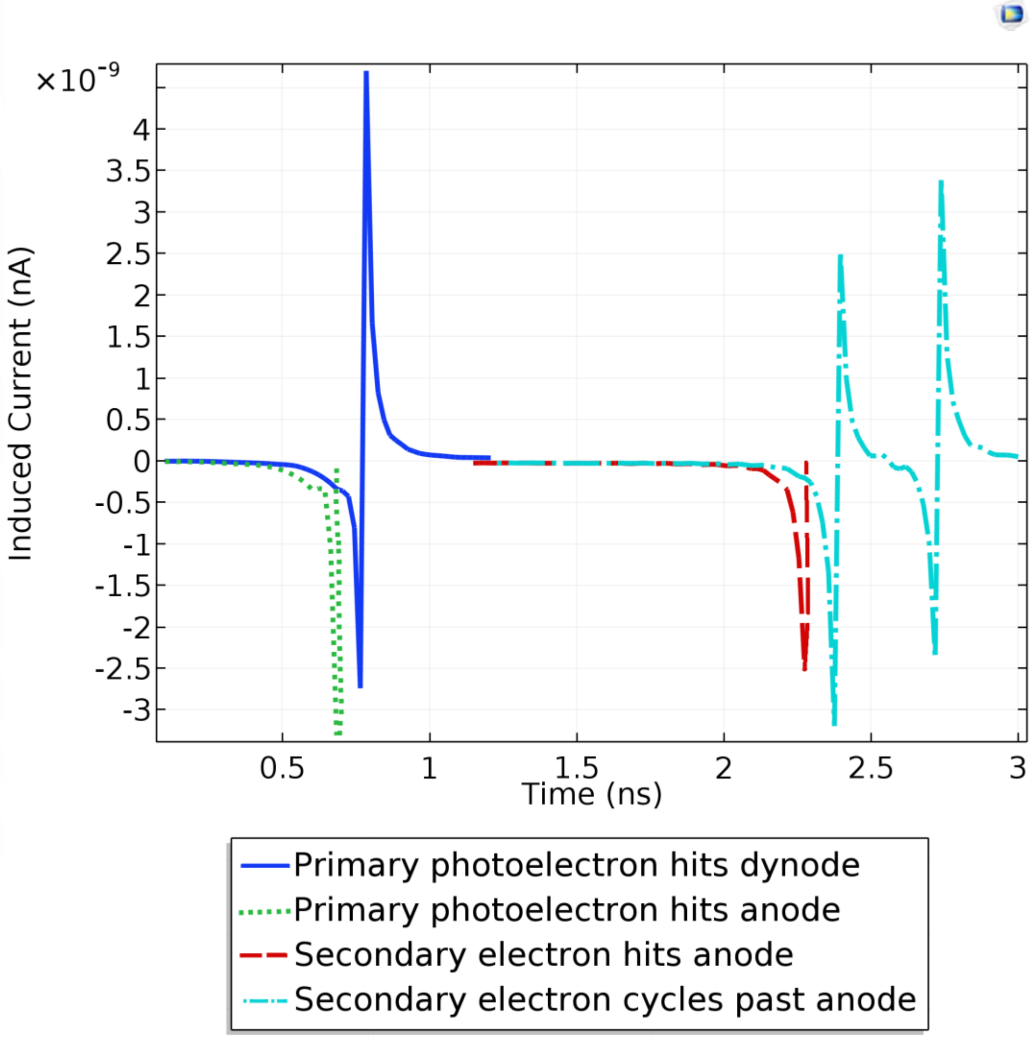
INDUCED CURRENT AT 0T

Induced current for a single electron.

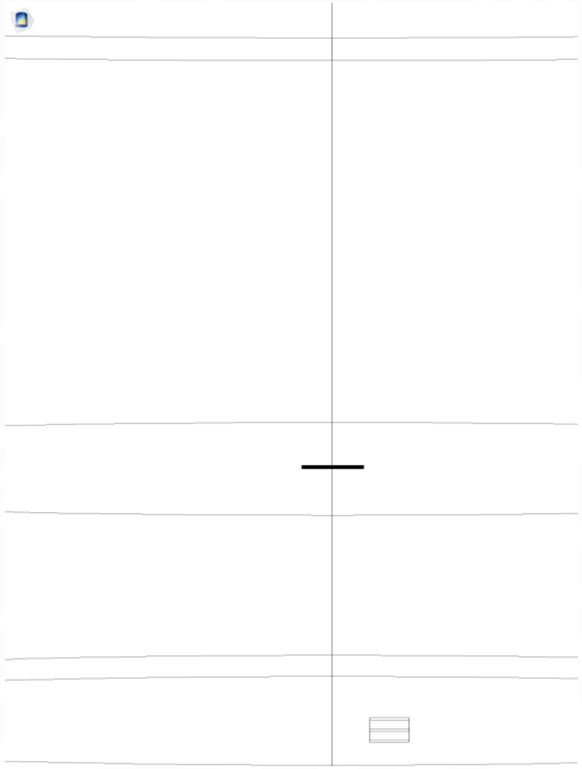




INDUCED CURRENT AT 4T 15 DEGREE



- Configuration used in CMS Endcap calorimeter.

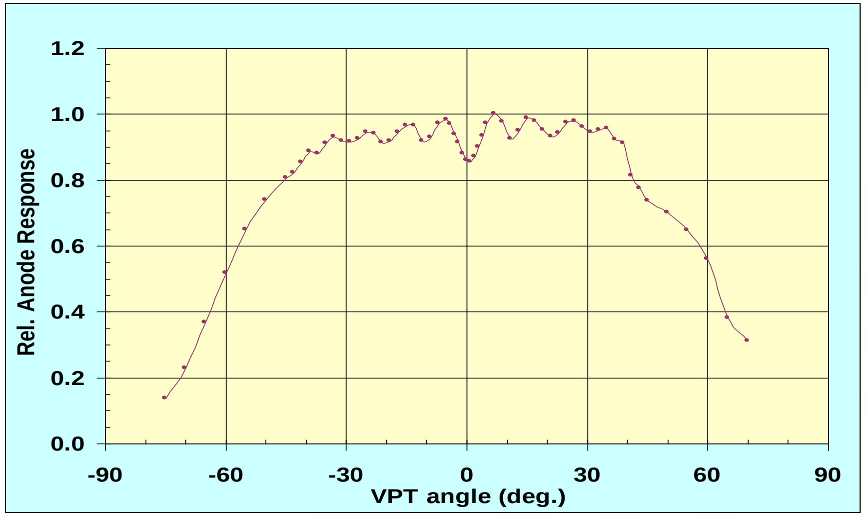


GAIN VS MAGNETIC FIELD AT 15°

- Variation between the magnetic field and gain is vital to understand.
- Understanding this behaviour allows for the devices to be used to their full potential.

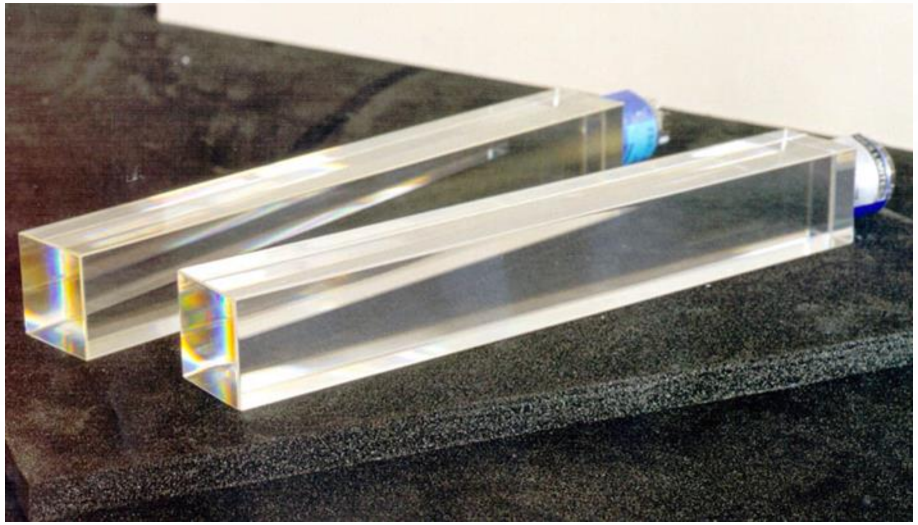
Magnetic Field (T)	Gain
0	6
1	6
2	4
3	5
4	5

Previous known data on the response vs. angle at 1.8 T



NEXT STAGE

- Simulating the wiring of the VPT – impedances and capacitances.
- Is there a solution to increase the anode grid size?
- RF module could be used to model the crystals attached to the VPT.



SUMMARY

- Produced results for the induced currents within the VPT.
- Magnetic field strength and angle variation against the output gain of the VPT.
- Challenges in developing a COMSOL model of a vacuum phototriode where the critical dimensions of the fine anode mesh are ~ 1000 times smaller than the typical areas of the mesh and the other two electrodes.

BACKUP SLIDES