Recent Developments in Ultra-High Speed and Large Area Photomultiplier Tubes

Dr James Milnes

Outline

- Introduction to Photek and the use of our PMTs in fusion research
- Gating ability
- Accurate pulse measurements
- Pulse response dependence on:
  - Area of illumination
  - Electron gain
- PMT saturation
- Large area PMT developments

Introduction

- Photek is a small company of ~ 50 people on the south coast of the UK
- We produce the fastest MCP-PMTs and photodiodes available
- We are continuing a ten year collaboration with AWE to improve PMT performance
- Also worked with US National Labs:
  - Los Alamos
  - LLE Rochester
  - Lawrence Livermore
- We have many detectors currently in operation at NIF and Omega

Application of Photek PMTs

- The Use of our PMTs in inertial confinement fusion research can be divided into two main sections:
  - Slower, large area (40 mm diameter) PMTs and photodiodes used in nTOF, detecting scintillator light
  - Faster, small area (10 mm diameter) PMTs and photodiodes used in gamma diagnostics, detecting Cherenkov light

Important Parameters

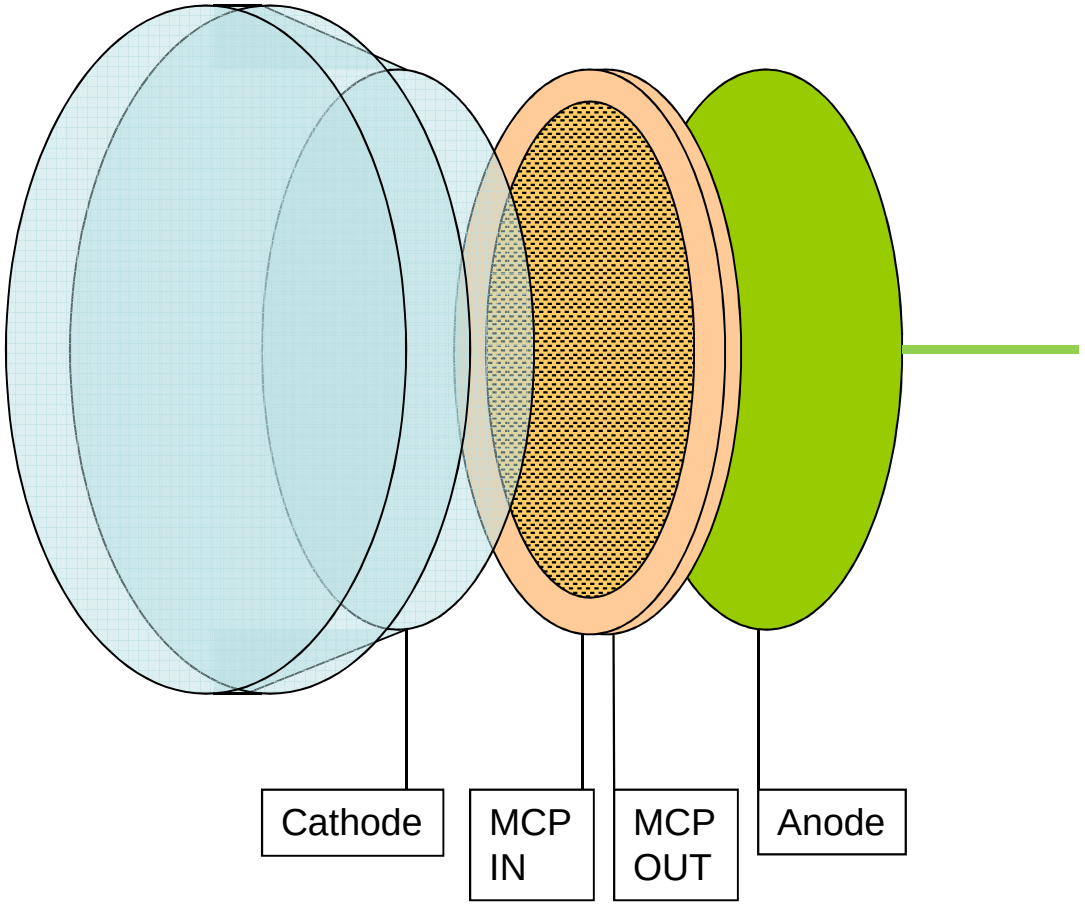
- What matters?
  - Analogue speed, particularly for the small area devices
  - Gating ability
  - Dynamic range
  - Sensitivity and electron gain

PMT Gating

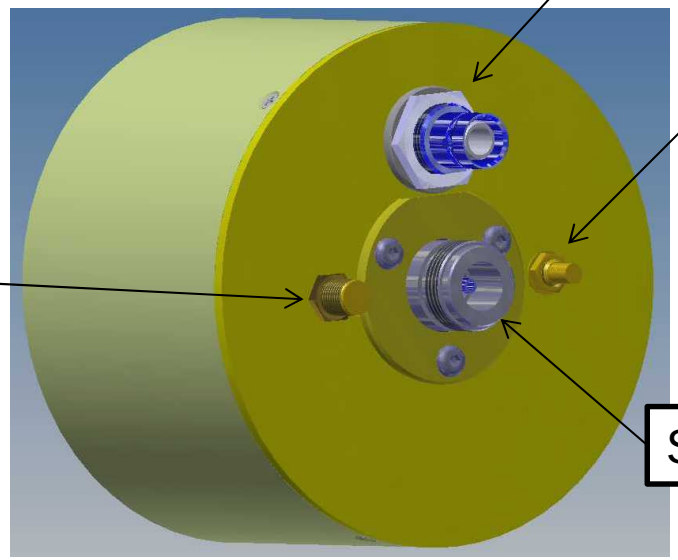
- Photek has introduced significant improvements to the gated operation of their PMTs:
  - Faster transition times
  - Improved stability after an OFF to ON transition
  - Reduced gate pulse pick-up on the anode signal
  - Improved functionality: choice of normally ON or OFF by the operator

PMT Gating

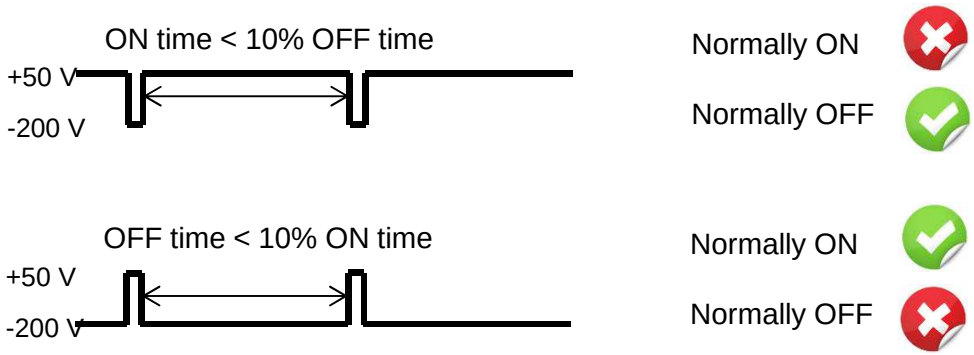
	ON	OFF
Cathode	- 4200 V	- 3950 V
MCP IN	-4000 V	-4000 V
MCP OUT	-3000 V	-3000 V
Anode	0 V	0 V



Operation



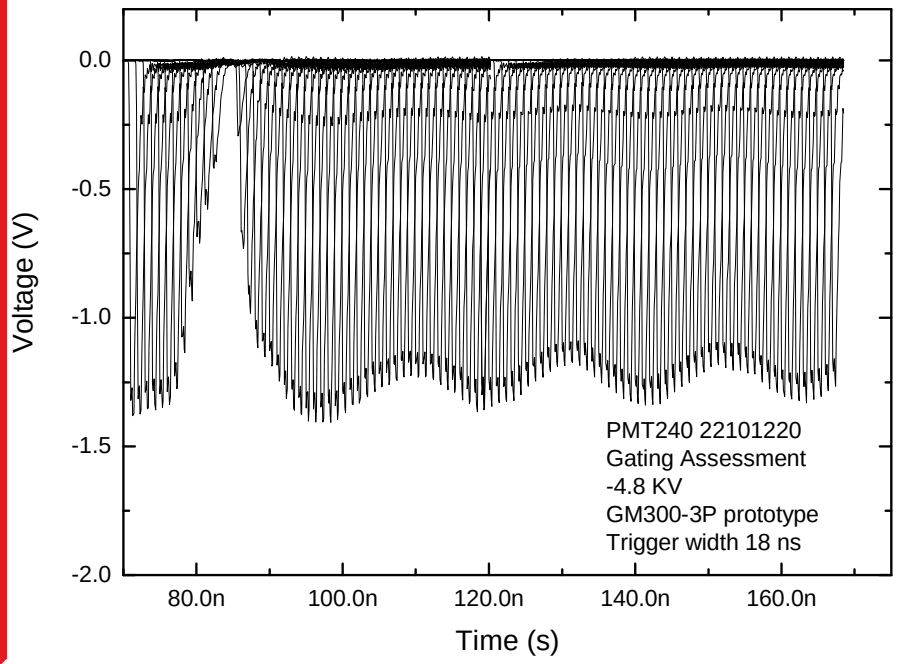
- The gate pulse is A.C. coupled, so there are duty cycle restrictions to the gating pulse

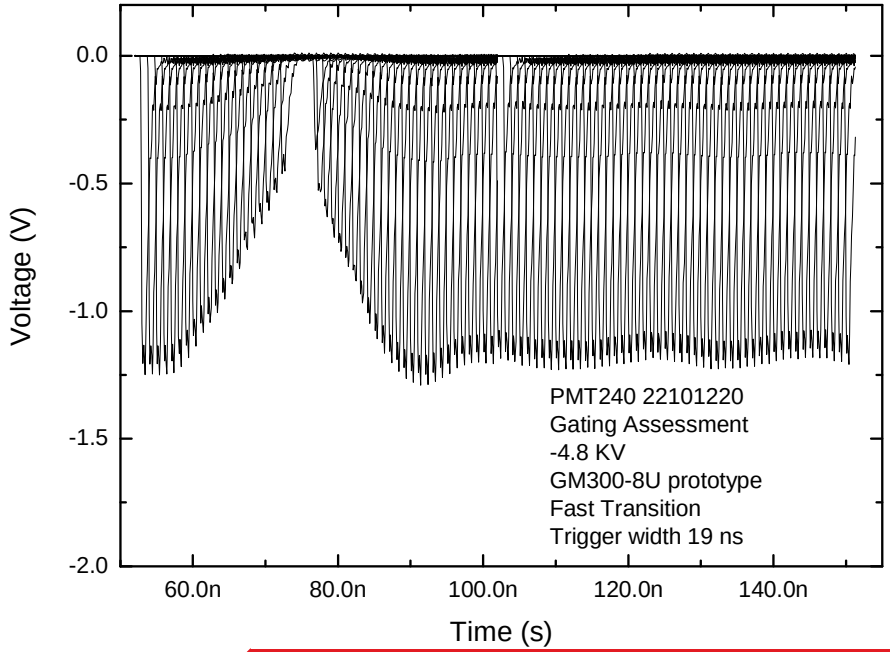


*Some early models have this control polarity reversed

Transition time and post gate stability

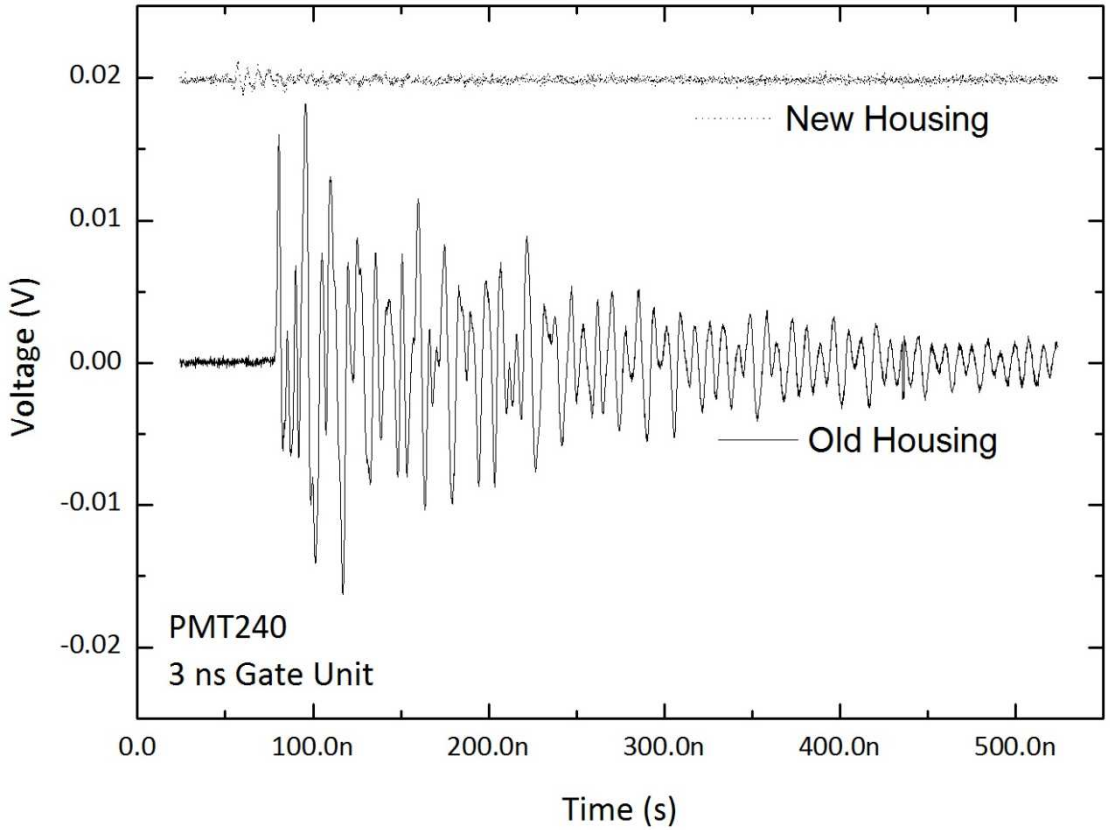
- These two parameters have a compromise
  - For this PMT240, using the fastest GM300-3P gate unit produced a transition time of ~ 6 ns but also introduced a ~ 13% pk – pk ripple on the post gate output
  - Using the slower GM300-8U gate unit lengthened the transition to ~15 ns but also reduced the ripple to ~ 6%
  - The adjustment on the GM300-8U allows the operator to set their own compromise position





Gate Pulse Pick-Up

- In the past using fast gate units with PMTs was restricted due to the gate pulse coupling onto the anode signal
- The improved housing has significantly reduced this effect

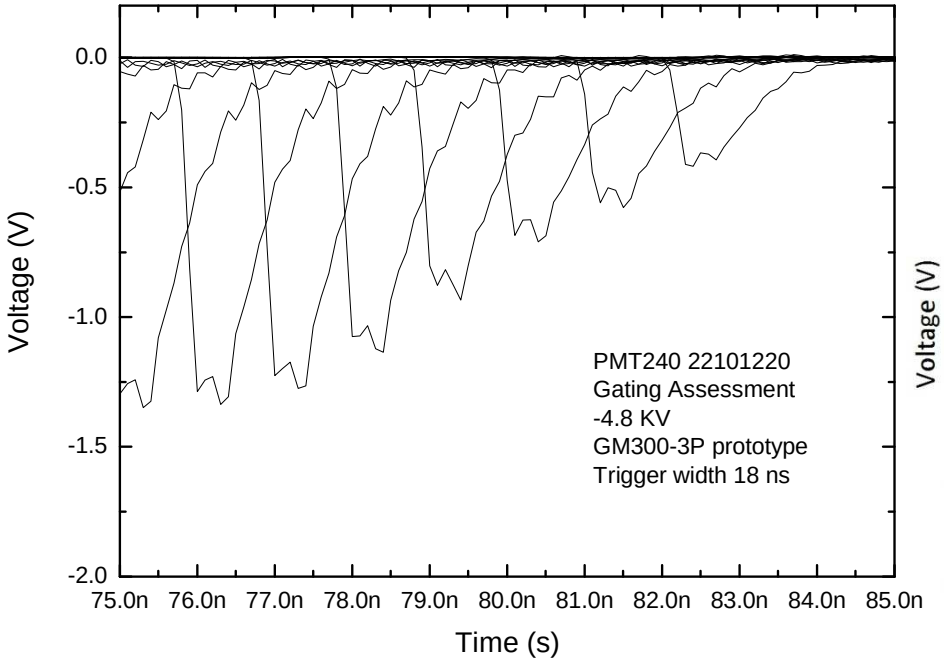


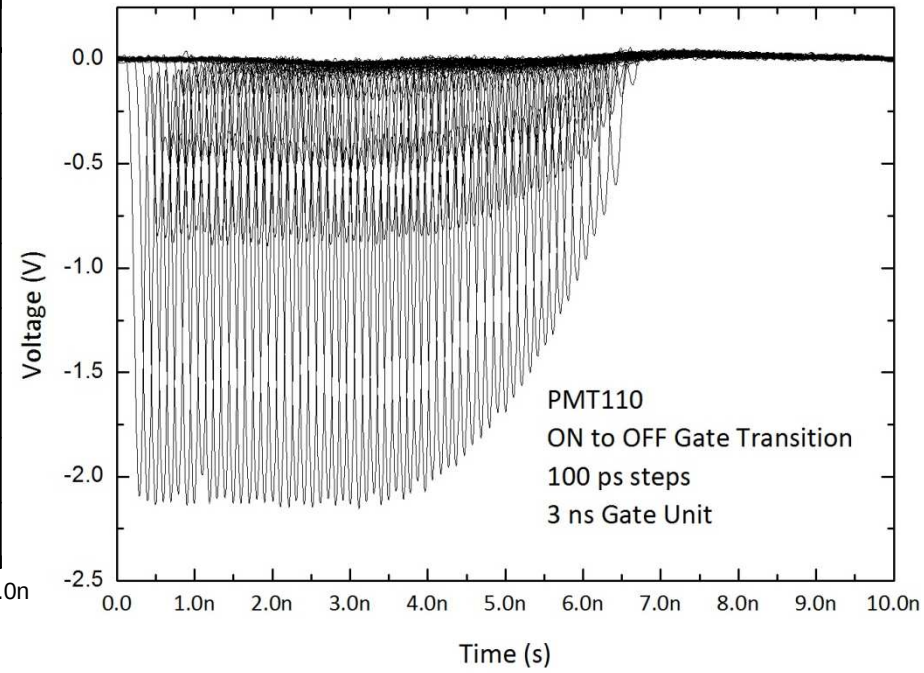
PMT Gating Performance Notes

- Large area PMTs present a larger capacitance load to the gate unit, this means:
  - Slower gate transition time
  - Larger gate-pulse pick-up
- The ultimate transition speed is always a combination of the gate unit and the PMT. Each PMT will have a time constant defined by it's capacitance and the conduction of the photocathode
  - Meshed photocathodes have the fastest gating transition
  - However, they also perform worse in terms of post- gate stability and gate-pulse pick-up

PMT Gating Performance Notes

- Large area PMTs will never gate as well as their small area equivalents:
  - These results both use meshed photocathodes and the fastest gate unit:





PMT Pulse Response – Accurate Measurement

- Obtaining a clean, accurate measurement of a sub 100 ps PMT pulse is not straight-forward
- The pulse width of the optical source (laser pulse) and the bandwidth of the measuring oscilloscope can limit the accuracy
- Traditionally, high bandwidth scopes used random sampling technique:
  - Needs very low jitter triggering signal
  - Often difficult to get such a reference from a very short pulse laser
- Recent developments in very high bandwidth / real time oscilloscopes have changed the picture

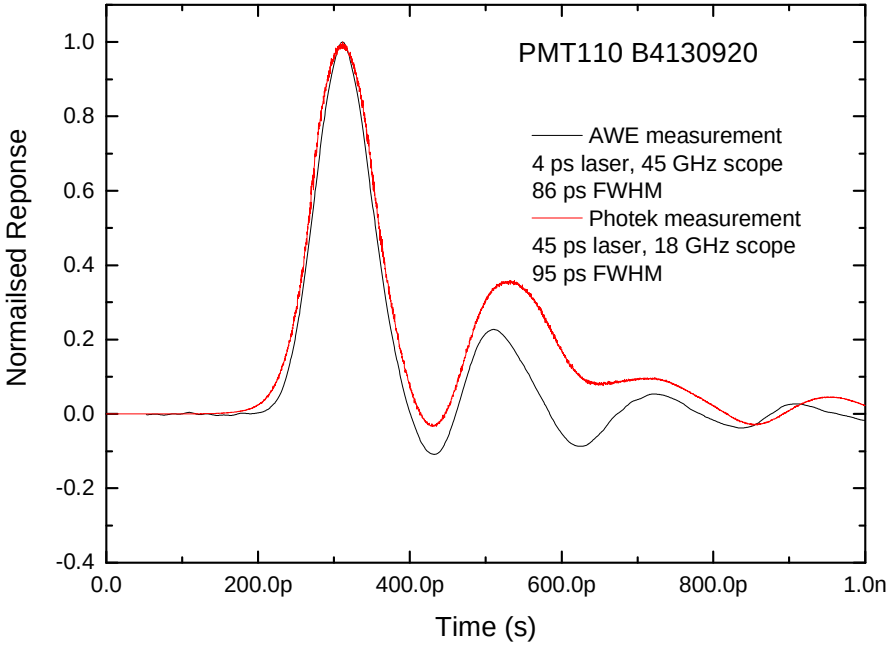
PMT Pulse Response – Accurate Measurement

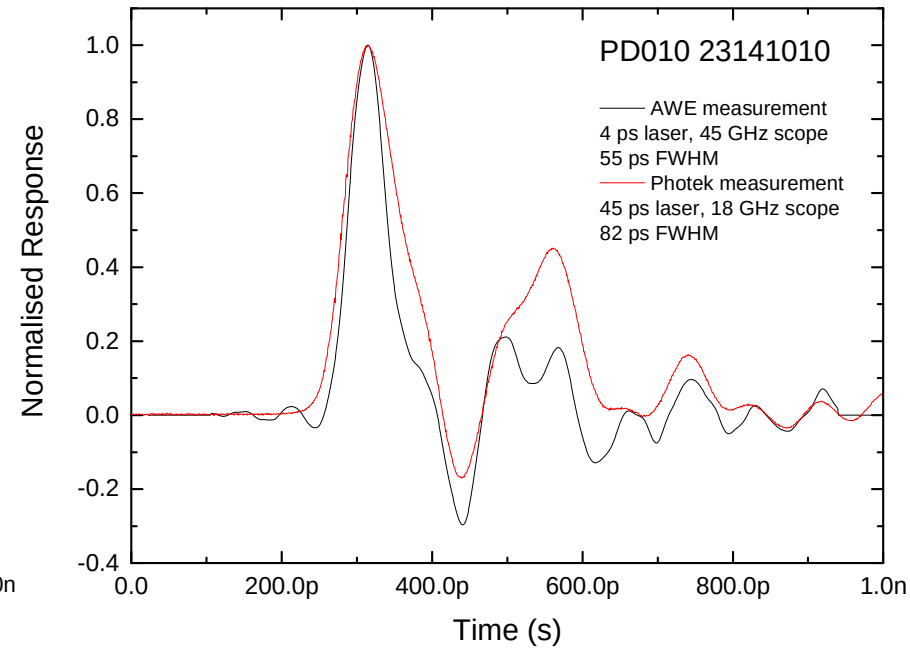
- Photek's test facility is limited to a 45 ps laser and 18 GHz sampling oscilloscope
- Our collaboration with AWE provided access to a 45 GHz real time oscilloscope and a 4 ps laser source at the Orion Laser Facility

LeCroy Wavemaster 845Zi-A

PMT Pulse Response – Accurate Measurement

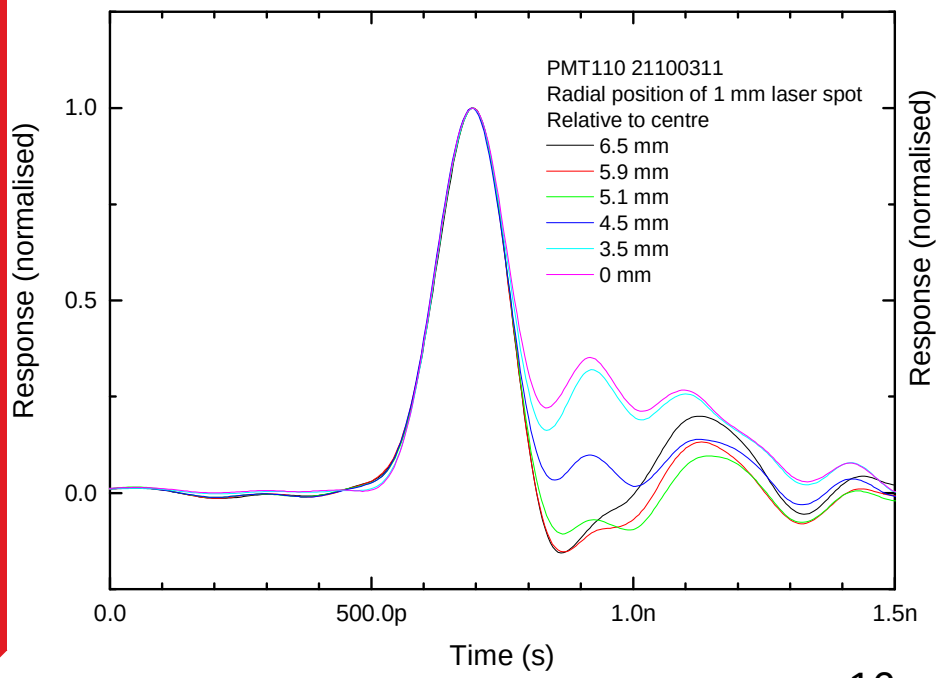
- The difference in measurements is clear, particularly in the faster photodiode - true response is shown to be 55 ps FWHM
- Comparing the PMT and PD indicate the temporal broadening of the MCP

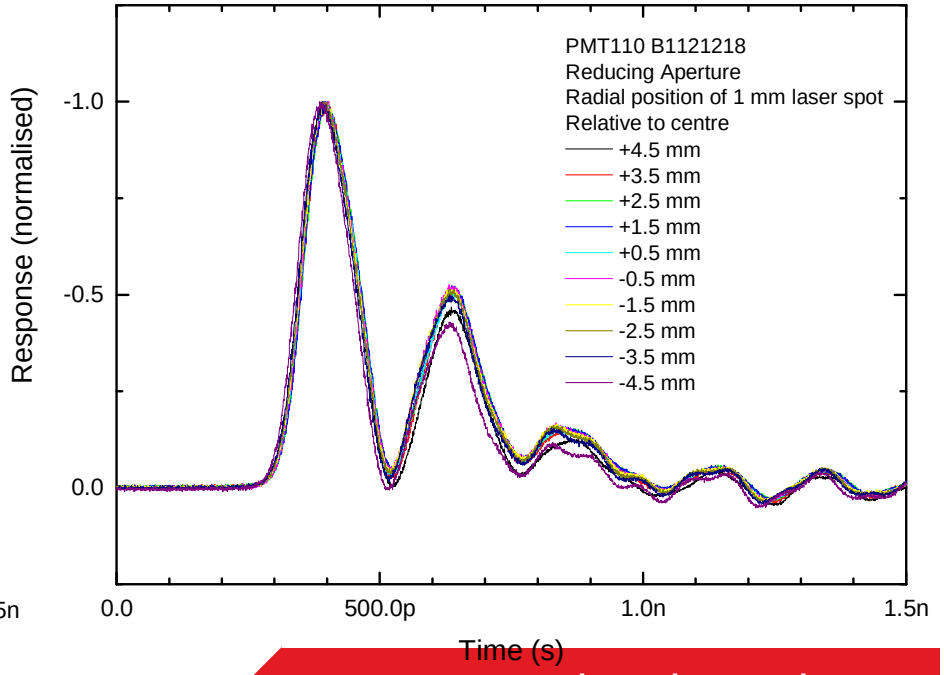




Pulse Shape as a Function of Area

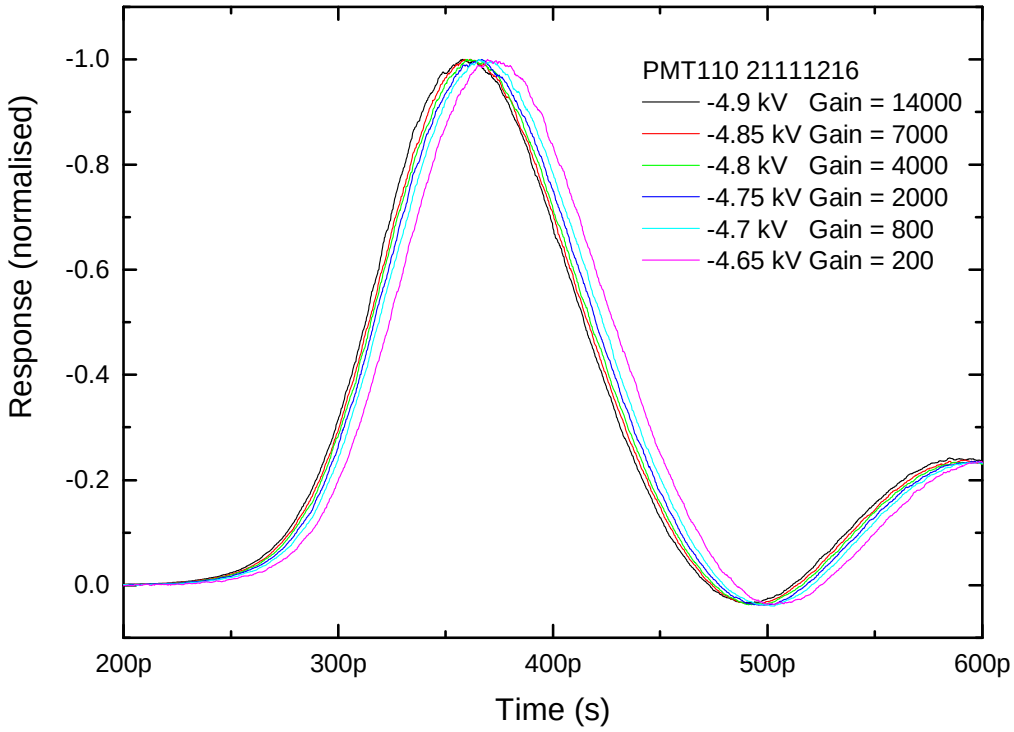
- Older models the PMT110 showed some area dependence on the pulse shape
  - This was attributed to edge effects as photocathode and MCP were both > 10 mm
- Masking the anode resolved the issue





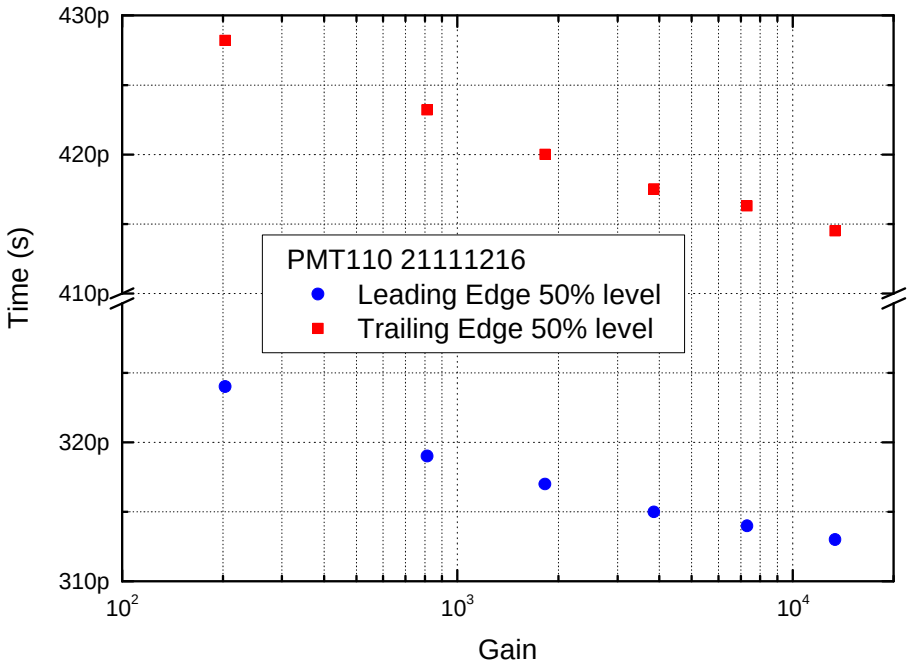
Pulse Shape as a Function of Gain

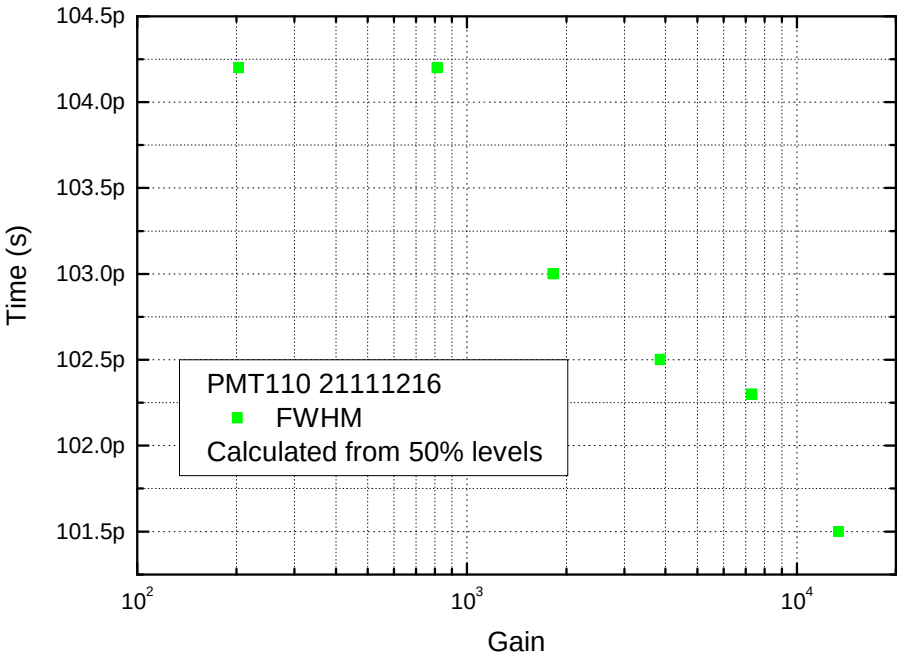
- In fusion diagnostics PMTs often have to deal with a large variation in signal levels
- The ability to adjust the electron gain over several orders of magnitude is very useful
- Need to verify that the pulse output is consistent throughout the working range of gain available



Pulse Shape as a Function of Gain

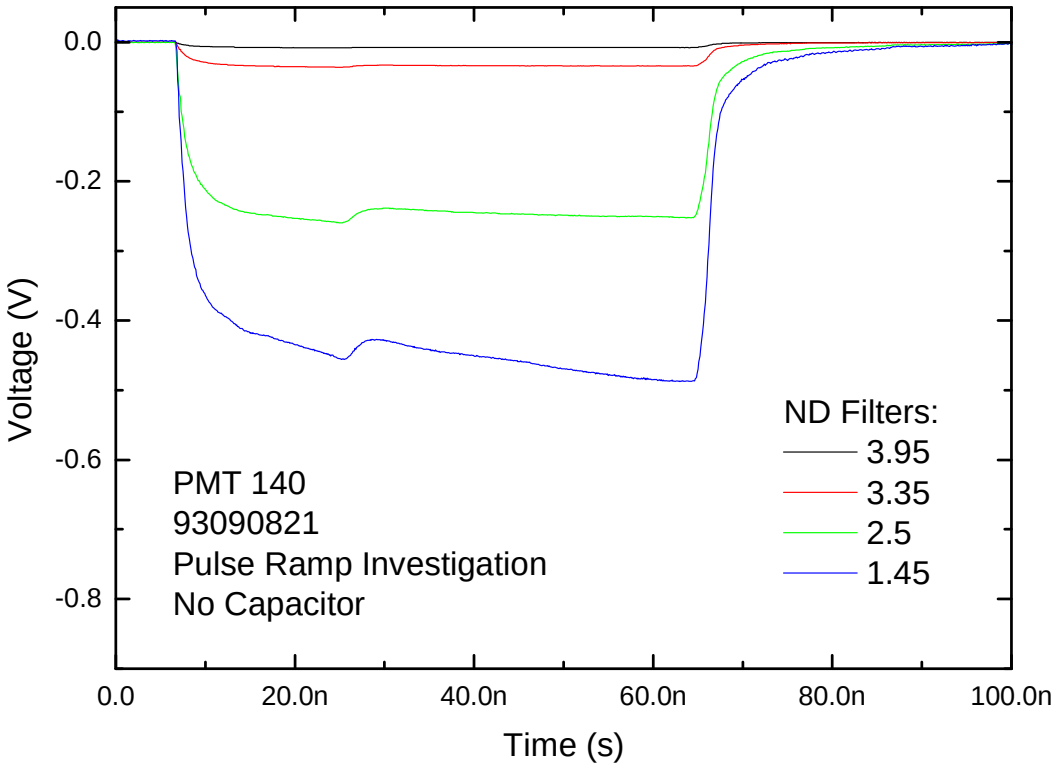
- A closer look at the leading and trailing edges shows the arrival time drifts by ~ 10 ps over 2 orders of magnitude of gain, but the width only changes by ~ 3 ps





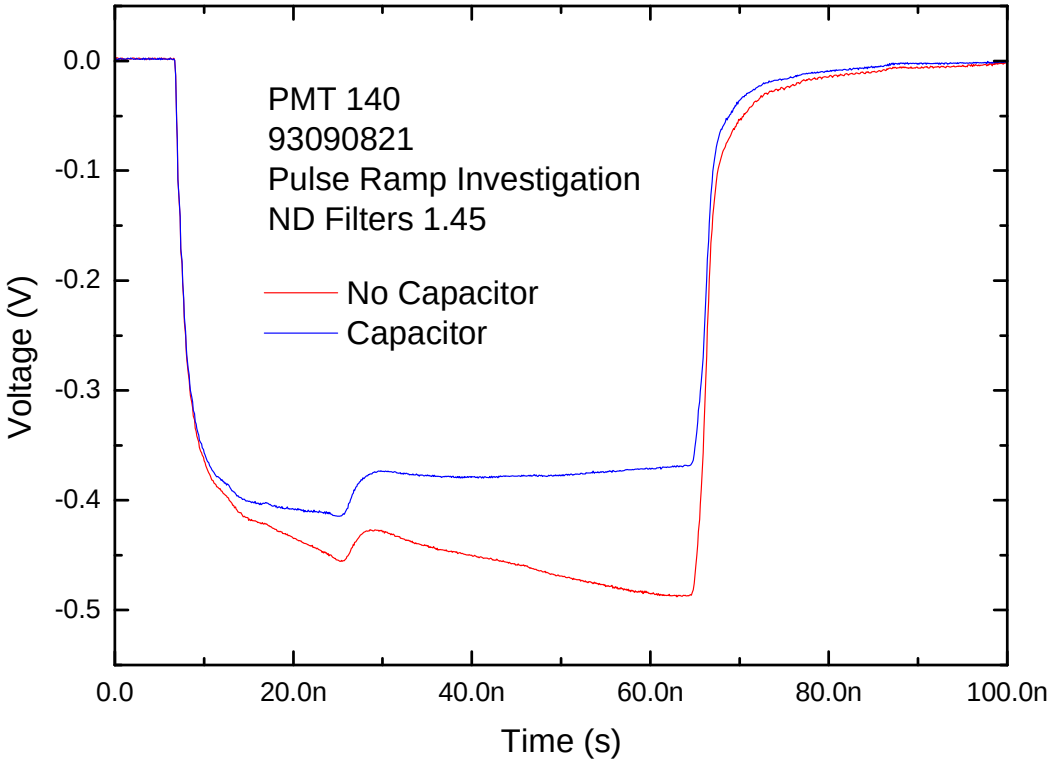
PMT Saturation

- Older models exhibited a peculiar saturation effect known as “ramped output”
- This was due to a voltage transient on the MCP output face temporarily increasing the gain



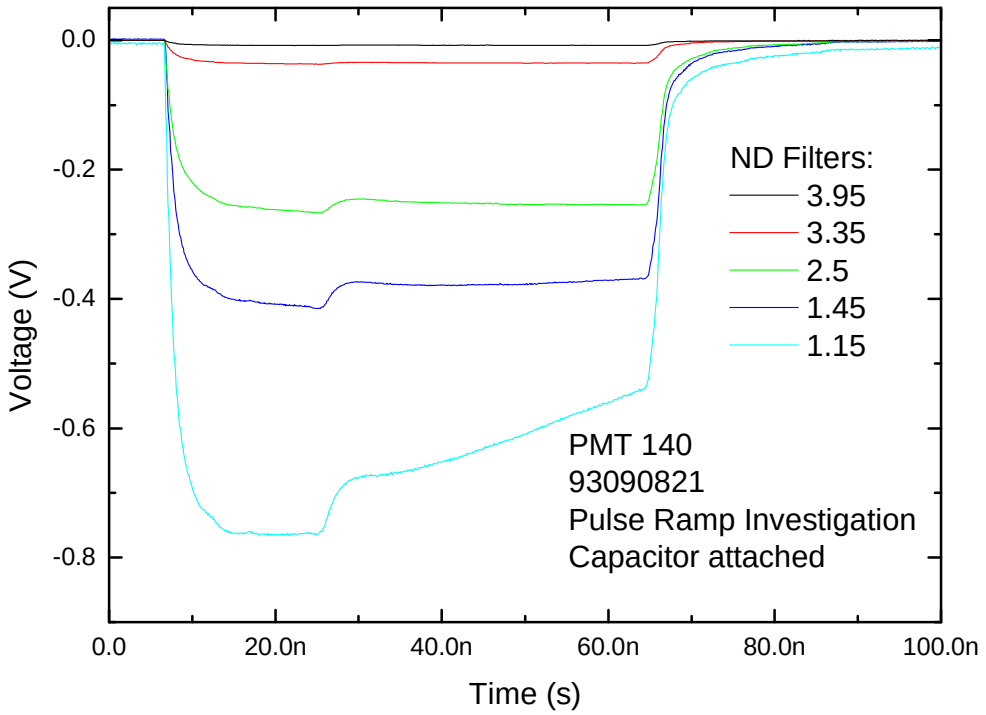
PMT Saturation

- This effect was removed by placing a capacitor from the MCP output face to 0 V to remove the voltage transient



PMT Saturation

- The saturation now displays a more intuitive behaviour
- Capacitor is standard on all new models
- It was added to some older models on request

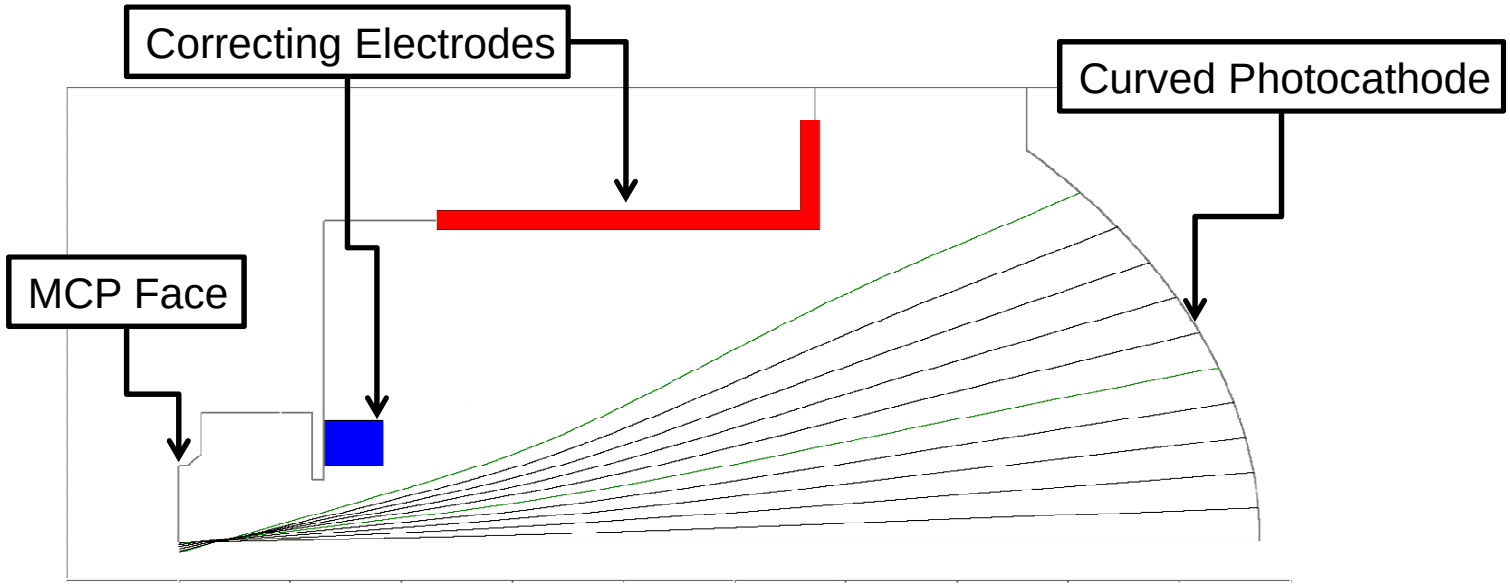


Large Area PMT Development

- Depending on the signal available, distance from the source and focusing geometry – sometimes PMTs need to have a large active area
- The pulse shape of standard large area (25 or 40 mm diameter) MCP-PMTs is noticeably inferior to their small area (10 mm) equivalents
- The large anode capacitance gives a slow and often oscillating trailing edge
- Small pore (3 µm) MCPs that provide the best speed are only available with 18 mm working diameter

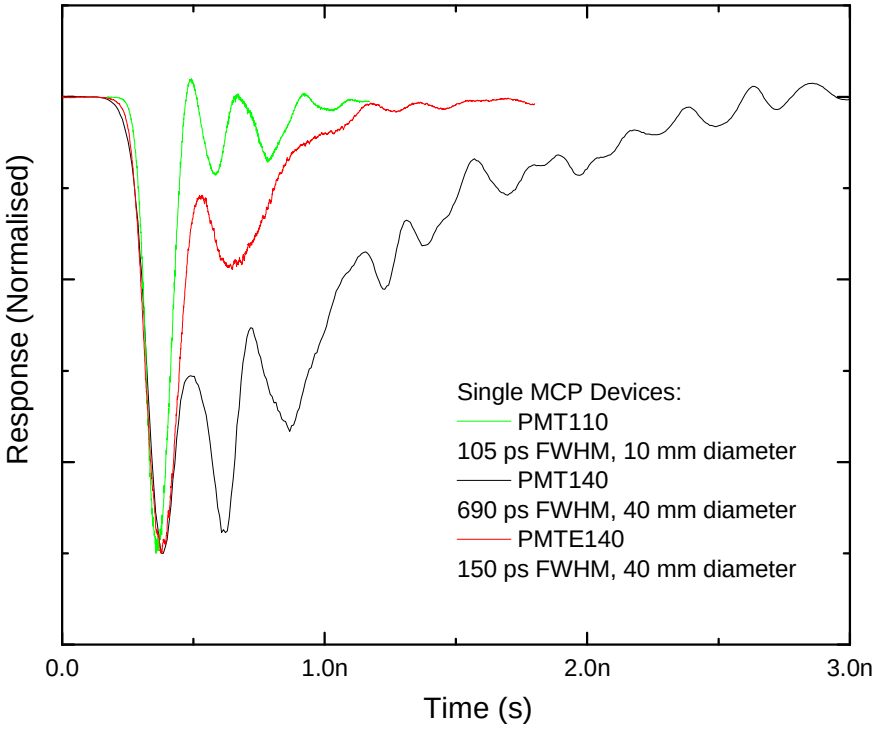
Large Area PMT Development

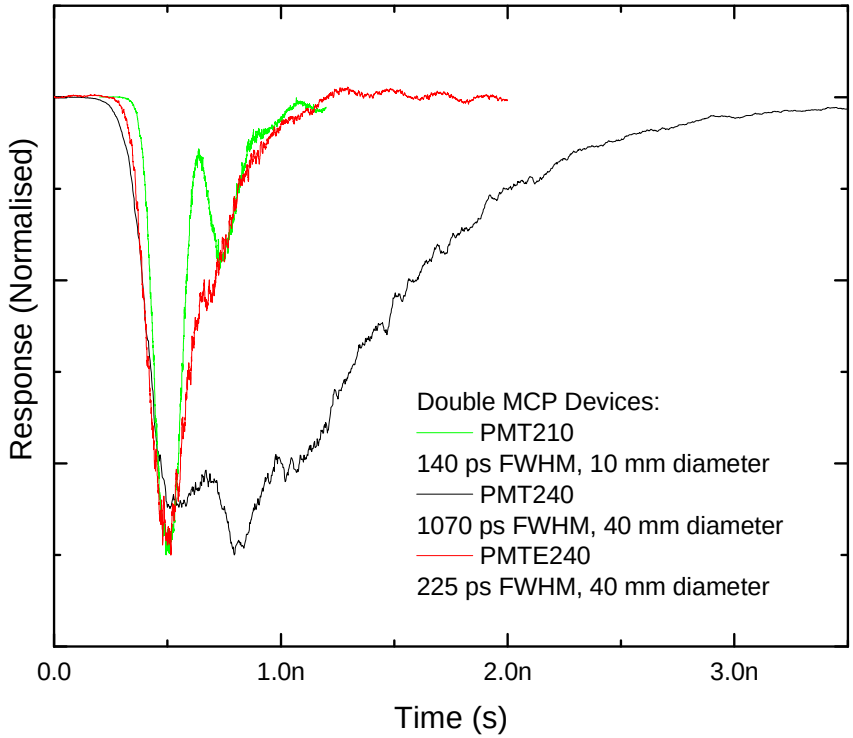
- Proposed solution is to replace the proximity gap between photocathode and MCP with an electro-static focusing section
- Able to combine anode & MCP assembly of a small PMT with the working area of a large PMT



Large Area PMT Development - Results

- Single and double MCP 40 mm prototypes perform very well
- Nearly match the speed of 10 mm equivalents

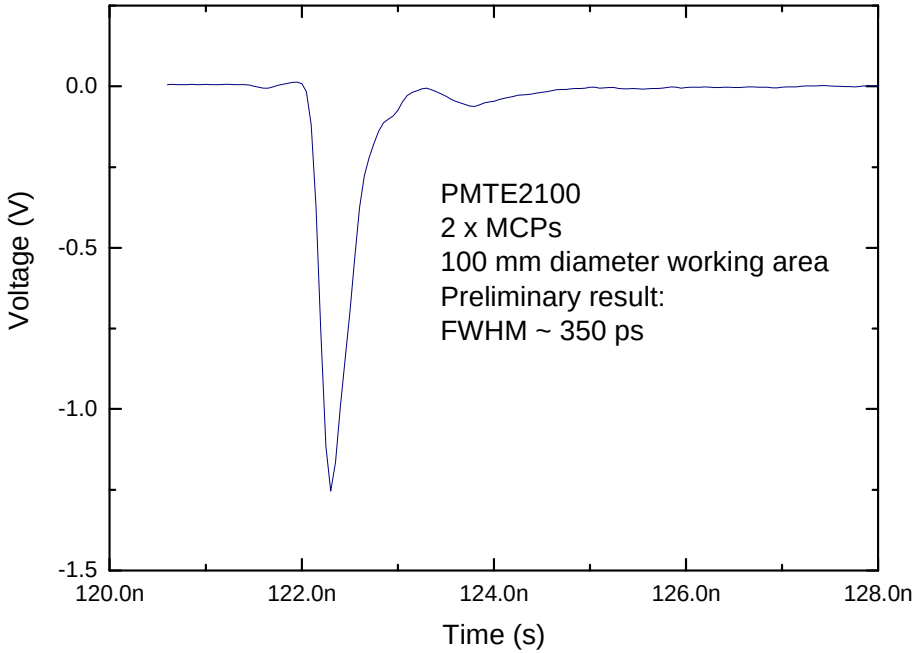




Large Area PMT Development - Results

- Issues still to be resolved:
  - Gating is possible, but not trivial
  - Concerns about the effect of external EM fields on the focussing section

- Currently analysing latest prototype – 100 mm diameter PMT designed for a diagnostic on Orion (AWE)



Summary

- Photek are a well established provider of PMTs to major ICF facilities for neutron and gamma diagnostics
- We have recently improved:
  - Gating capability
  - Measurement accuracy of the true impulse response
  - Pulse response uniformity
  - Saturation effects
- Currently developing novel large area PMTs with improved pulse response

PHOTEK
ENVISAGE THE FUTURE

Thank you for listening