University of Virginia Endcap Photodetector Studies and Photodector Upgrade Plans for the SLHC

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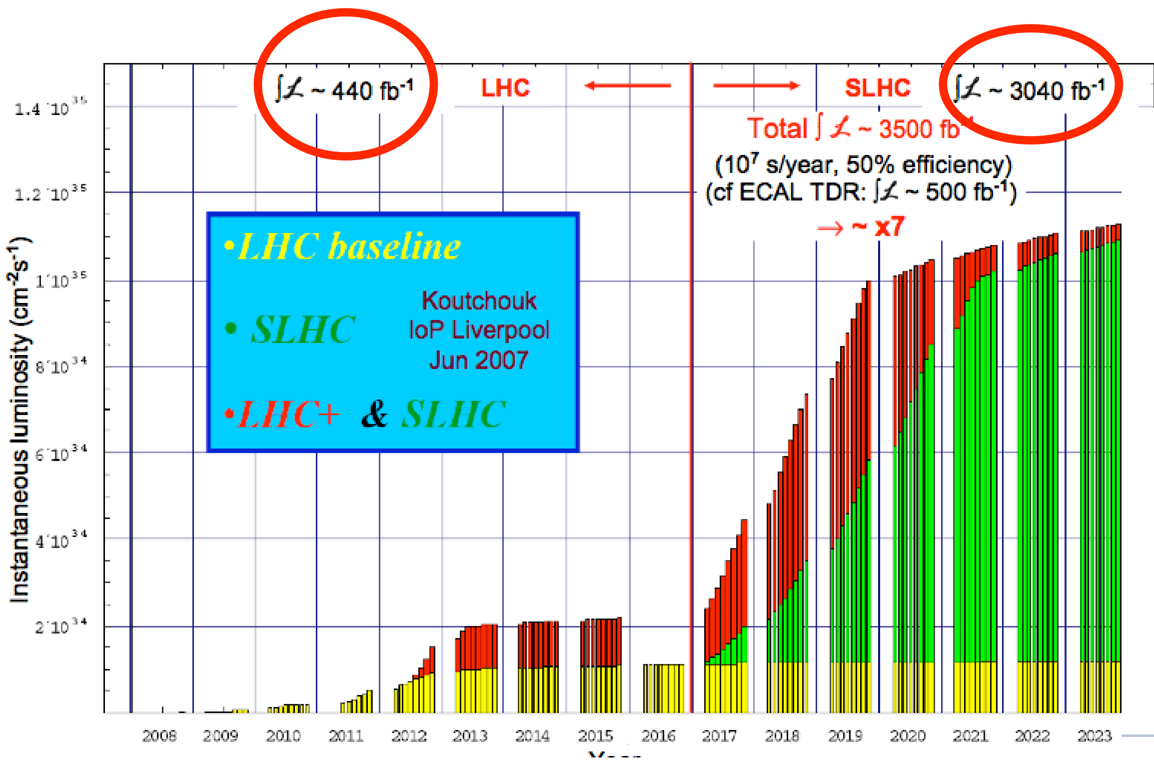
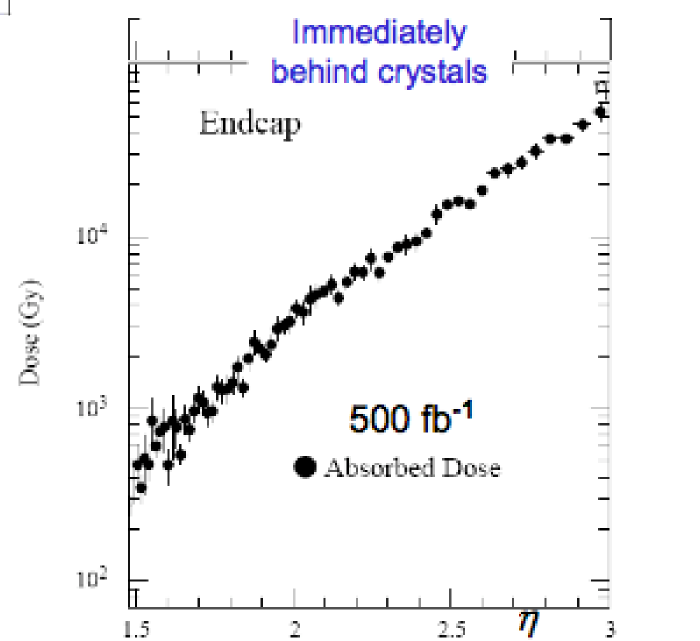
Early Days in the discussions between Rutherford, Brunel, Caltech, UVa

Expected Integrated Luminosity for 10^{34} Era ~ 500 fb^{-1}





Will the VPT's survive to the 10^{35} era and what do we do for photodetectors at the SLHC at L~10^{35}?

We have begun to think about replacements for the Vacuum Phototriodes (VPT's) presently used in the CMS endcaps but will the performance of the VPTs in the 10^{34} era (integrated luminosity of 400 fb^{-1} is still under study as a guide to behavior in the early 10^{35} era (integrated luminosity >3000 fb^{-1}).

Issues with VPT's

- short term stability under high light load
- long term stability under high light load
- stability under changing light loads

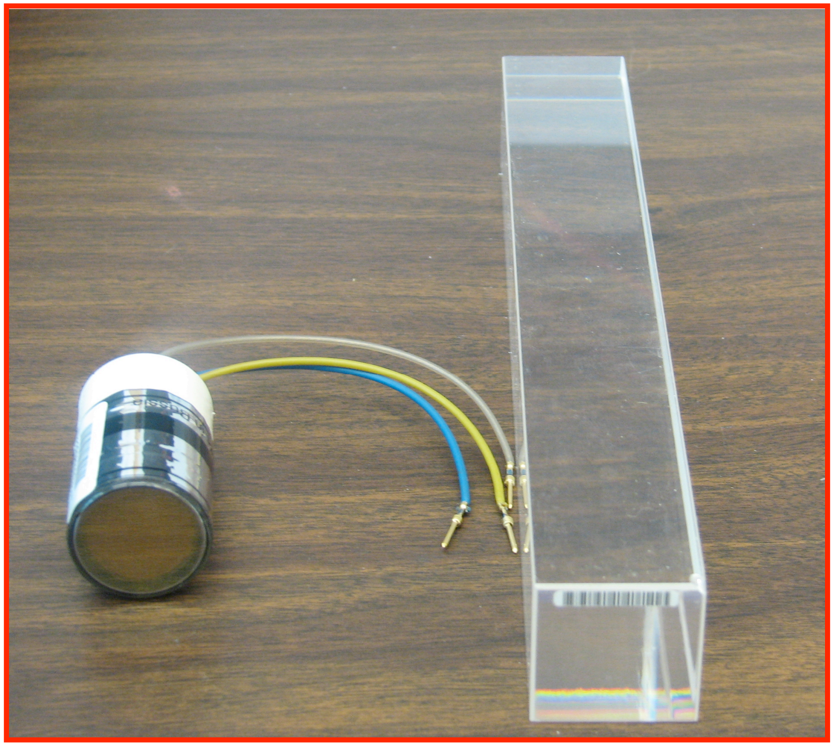
} **Much more stable in a high magnetic field (~3,8T)**

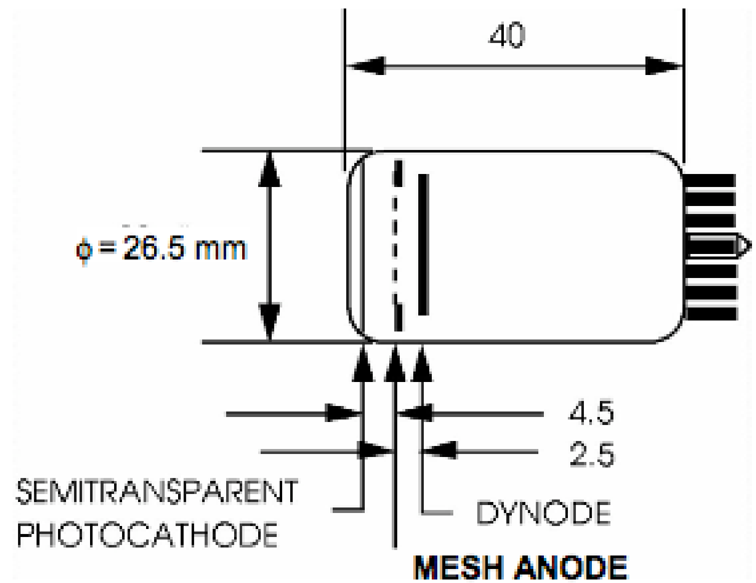
- sensitivity to magnetic field
- vulnerability to radiation damage

We have set up at UVa to do full field tests (3.8T) of VPTs **or any upgrade photodetector replacement** (possibly photodiodes) for SLHC

The Present Endcap Vacuum Phototriodes

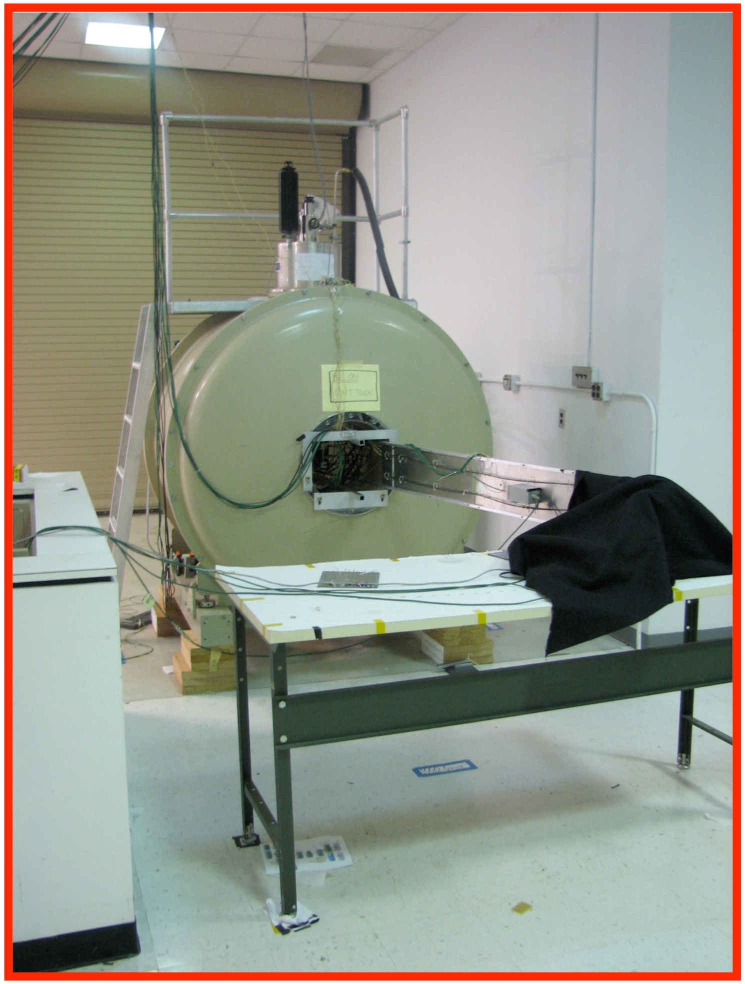
Bialkali (CsK_2Sb) photocathode and dynode coating (QE ~20% at 420 nm)





Gain ~10

UVa
3.8 T Superconducting Solenoid Test Bed



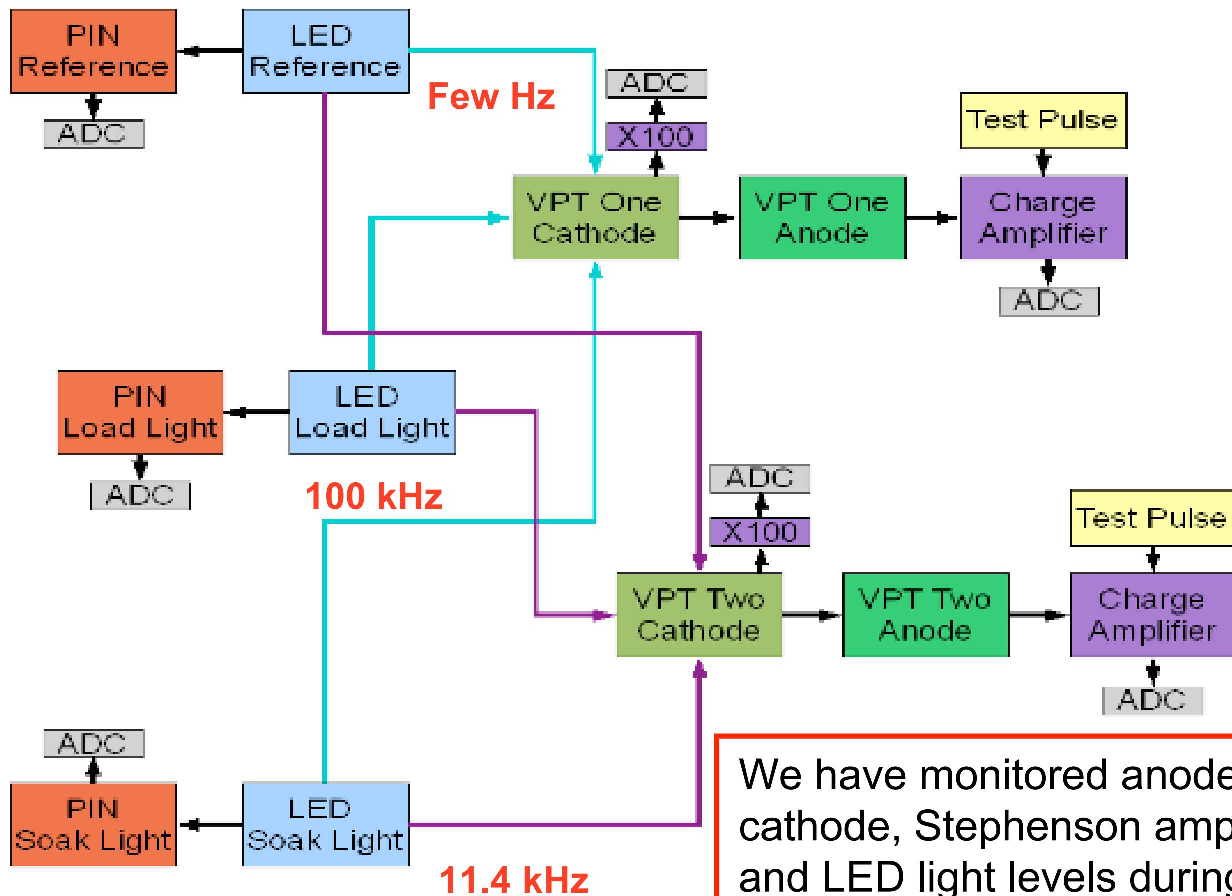
This setup has been used to measure a few hundred VPTs over a ±27° range in one degree intervals.

The magnet is capable of 4.7 T and has an aperture diameter of 40 cm

VPT LED Light Pulser Setup

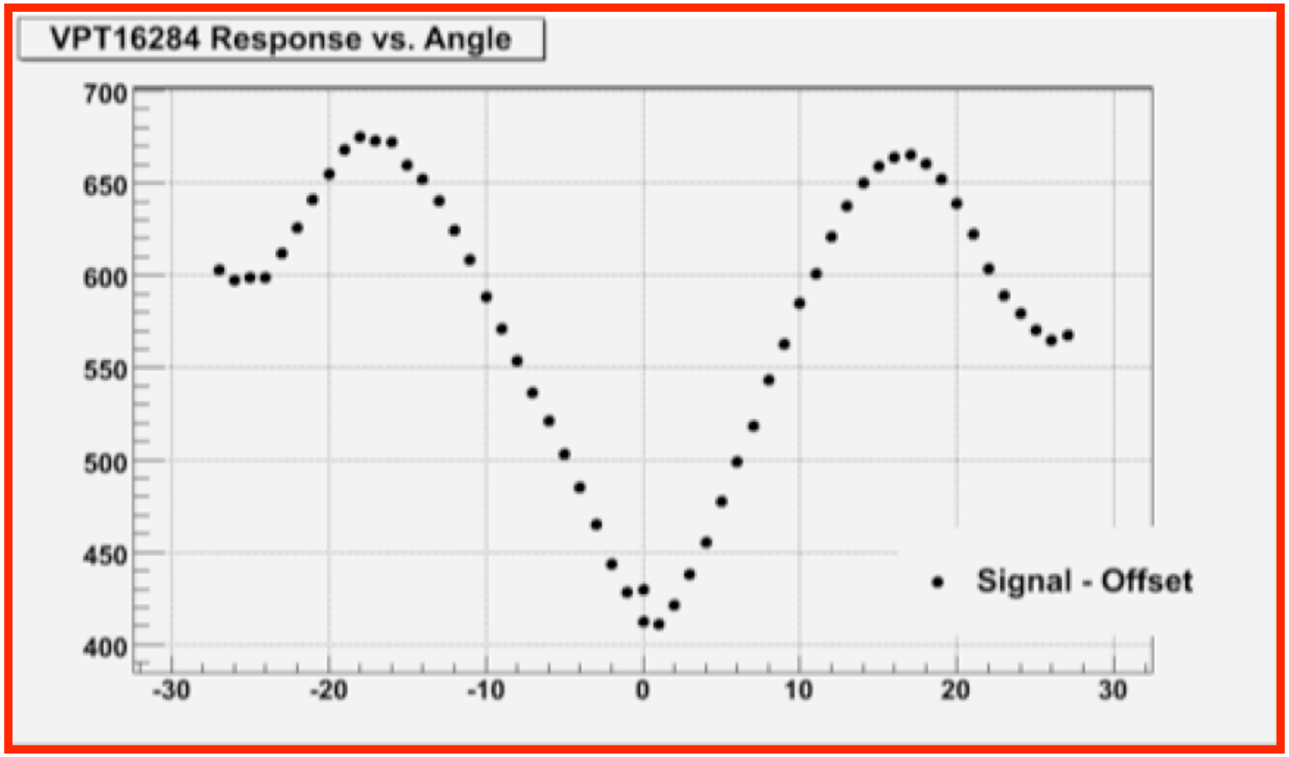
We have set up three blue LED light sources to feed to each VPT to be tested in the 3.8T field. The **load light** emulate the light produced by at a luminosity of 10^{34} at various η of the endcaps. The **soak light** provides A stabilizing light source that bridges the periods when the luminosity changes. Finally a **reference light** source measures the changes in cathode and anode response with time

VPT Testing System Layout



We have monitored anode, cathode, Stephenson amplifier, and LED light levels during tests

Typical Variation of VPT anode signal with Angle of Tube Axis wrst to 3.8T Field



More pronounced and longer period than the variations at 1.6T done by Rutherford Lab

Long term variation studies for VPTs. Necessary for any new photodetector candidates

- Photocathode current vs. time: corrected by the PIN diodes for LED light variation and Stephenson amplifier changes
- Anode current vs time: corrected only for LED light variation and for amplifier gain changes
- Anode current vs. time: corrected for LED light variation, amplifier changes, and photocathode changes

Each point in these distribution is produced by averaging 1500 measurements in a time interval of 20 minutes. The means of these measurements and the error on the mean are fit over 600 hours to

$$e^{-\alpha t}$$

in twenty four hour periods. The variation of α is then plotted as a measure of the flattening or "plateauing" of exponential decrease in the cathode and anode currents

Expected VPT photocathode currents at various endcap η

Estimates by D.C. Imrie

Table 1

η	Energy deposit [J]
2.9	1.63×10^5
2.5	5.34×10^4
2.0	1.21×10^4
1.6	2.77×10^3

Table 2

η	Power at peak luminosity [mW]
2.9	3.26
2.5	1.07
2.0	0.242
1.6	0.055

Table 3

η	VPT photocurrent / nA
2.9	8
2.5	2.5
2.0	0.6
1.6	0.1

$*$These estimates are based on the dose rate at 1 cm intervals in ECAL endcaps as shown in Fig. A5 of the ECAL TDR for an integrated luminosity of 5×10^5 pb^{-1} equivalent to operation at a luminosity of 10^{34} $cm^{-2}s^{-1}$ for 5×10^7s. Converting the doses in table A5 to the energy deposit in a 3x3 cm^2 x 22 cm $PbWO_4$ crystal using ρ=8.28 gm cm^{-3}, the integrated energy deposits per crystal at various η's shown in Table 1 were determined. Dividing by 5×10^7s gives the power deposited per crystal shown in Table 2 and using a VPT photocathode r esponse of 2.3 nA per mW gives the expected VPT photo currents in Table 3.

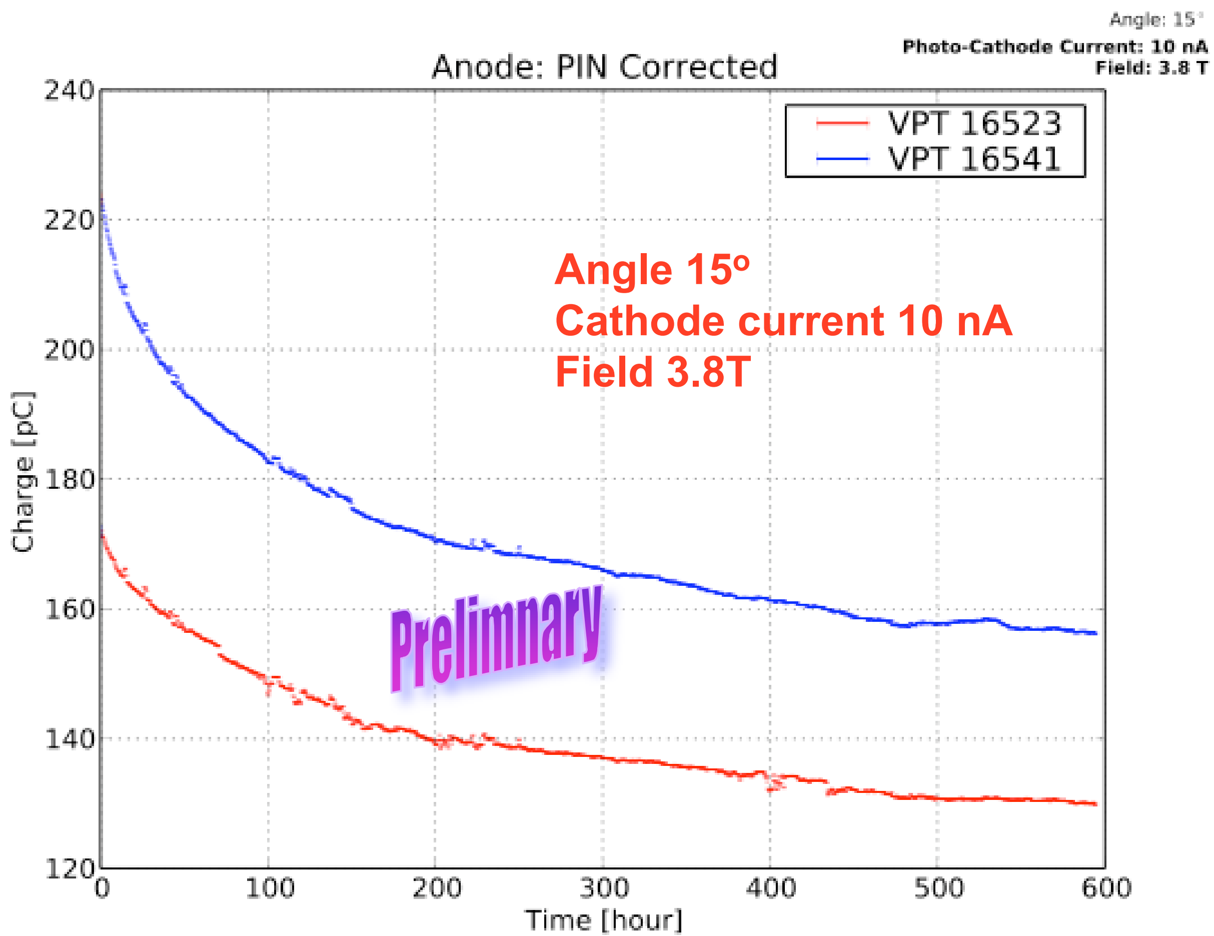
VPT Burn-in Test Conditions

The photocathode, anode currents as a function of time have been measured for three VPTs under the following conditions:

VPT	Duration Of Test	Angle wrst Magnetic Field (3.8 T)	Average Photocathode Current
VPT 16523	25 days	15 degrees	~10 na
VPT 16541	25 days	15 degrees	~10 na

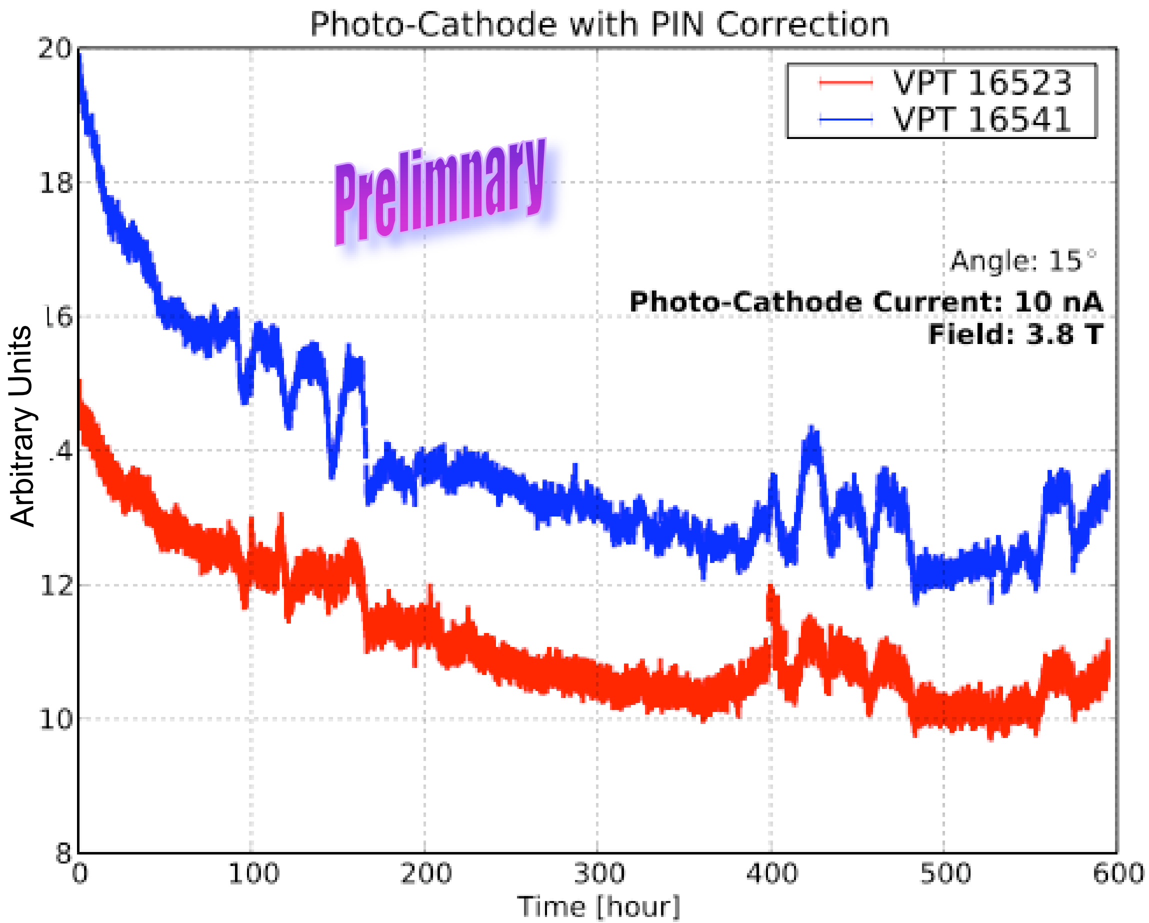
The test were performed using a load light intensity provided by 100 kHz of pulses with amplitudes large to produce a cathode current of ~10 na. The changes in cathode and anode currents were measured using a reference pulse of frequency 1.25 Hz. The soak light was not employed during these tests

VPT Anode Current
Long Term Tests



25 days at the equivalent of $L = 10^{34}$

VPT Cathode Variation
Long Term Tests

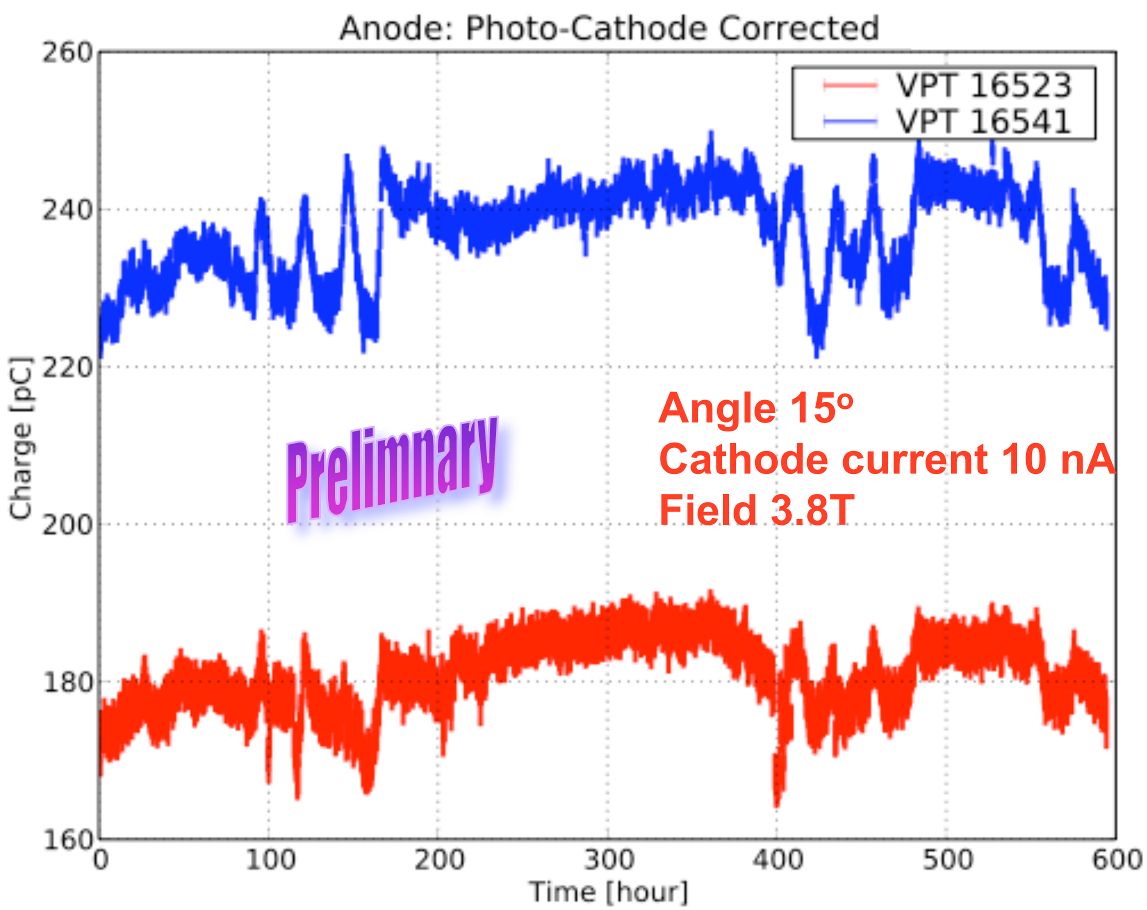


Voltage produced by the cathode current drawn through a 1 mΩ resistor from ground.

Low level common mode noise oscillation at this low signal level is experience but the overall behavior is a decrease of cathode output with time.

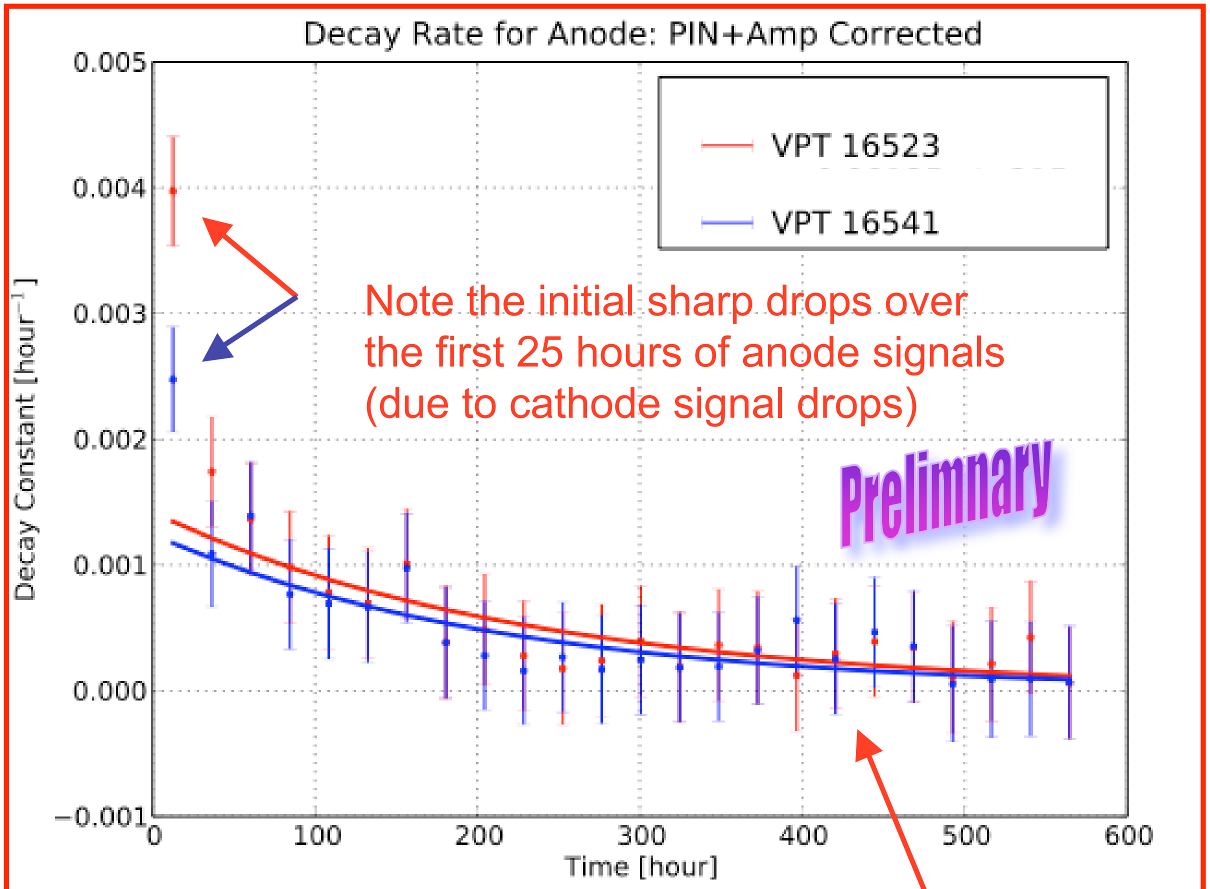
The majority of the decrease of anode response is due to the cathode behavior

Anode signal corrected for LED light changes amplifier gain variations and cathode variations



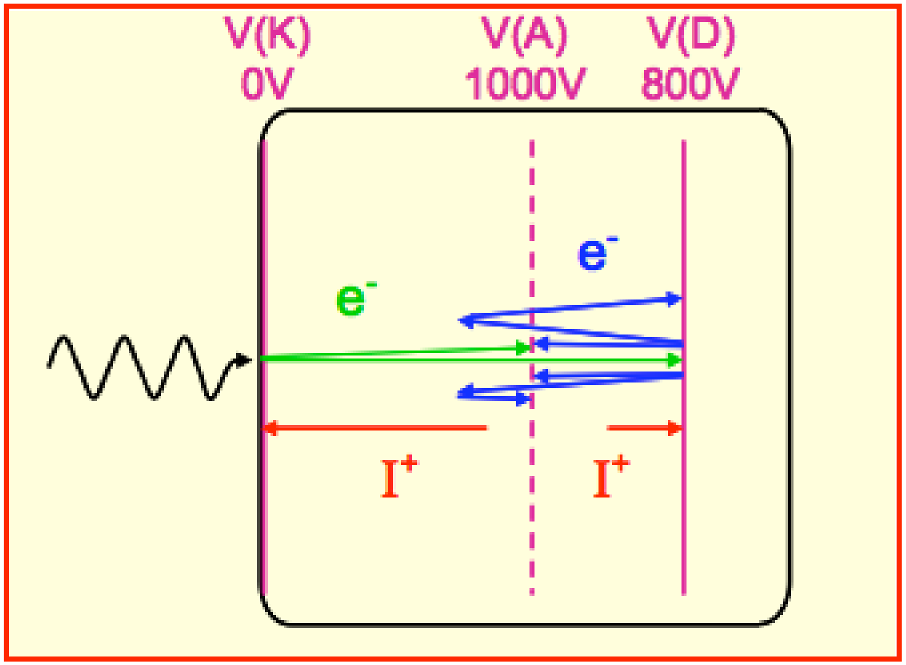
The anode signal may be showing a slight tendency to increase with time.

$e^{-\alpha t}$ Decay constant for anode signal



Nicely plateauing anode current with α (the time constant) tending to zero

Possible Cause of Anode and Cathode Decrease due to High Currents



Speculation

Positive ion deposition on cathode and dynode surfaces thereby decreasing the currents until the +ion deposit saturates

"Long Term Behavior of Three Prototype Vacuum Phototriodes operated With High Photocurrents" D. Imrie, Brunel Univ. and Rutherford Lab

Conclusions
About VPT Behavior

- The behavior of VPTs is much improved at 3.8T - No discharges
- Variation of Stephenson amplifier operated for 25 days in a 3.8T field shows stability at < 0.5% level.
- The overall anode signal shows a slow approach to a plateau after 25 days of operation at cathode currents of 10 na appropriate for $\eta \sim 2.7$.
- Almost all of the anode signal decrease is due to changes in the cathode response.
- The typical behavior is to to have a sharp initial decrease followed by a gradual plateauing. A decrease in anode current of 30% is typical.
- After adjusting anode signal output for cathode variation, a residual slow rise with time in the anode response independent of cathode variation.
- A strong dependence of anode signal on angle of the VPT wrst to the field direction is observed.

More tests to do on Phototriodes at 3.8T (and on any replacement)

Not Inclusive!

- Effect of absence of light minutes or hours (beam off periods)
- Effect of HV off periods (maintenance or otherwise) (for minutes, for hours?)
- Effect of different angles of tubes wrst to field direction
- Ability of soak light (different frequencies and amplitudes) to compensate for different loads
- Effect of large bursts (times 10 for 30 seconds)
- Try red LED’s to see if effects are wavelength sensitive
- Increase light load to 10^{35} equivalent and repeat studies

What will an endcap upgrade consist of? Questions

The end cap will be highly radioactive at the point by the time of the increase of luminosity to $10^{35}cm^{-2}s^{-1}$. Will it be possible to work on it?

Will the VPT's still function at least in the large angular region of the endcap?

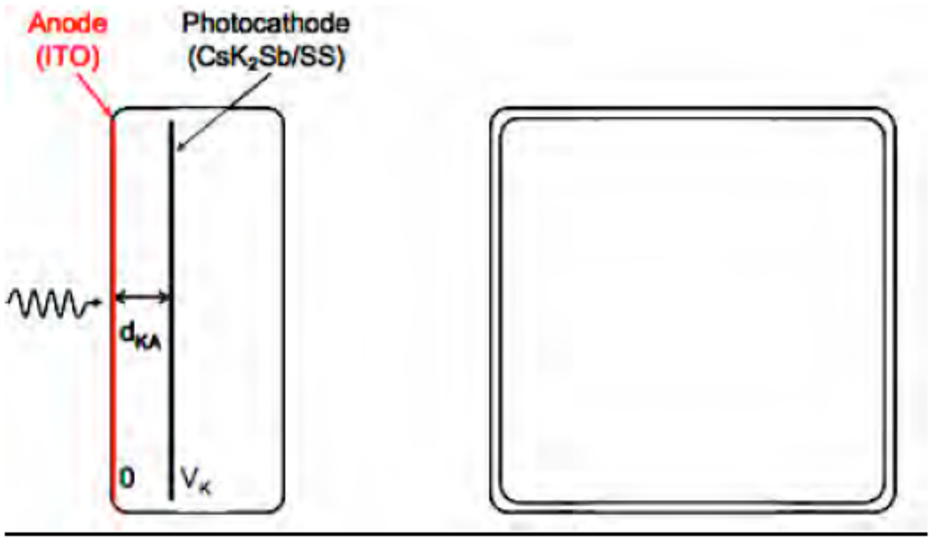
Will the $PbWO_4$ be viable at least in the large angular region of the endcap?

Will a replacement of the $PbWO_4$ with LYSO (200 x the light yield of PbWO4) be necessary or economically feasible?

Can we do a partial replacement of the center of the endcaps even though they were built from the inside out and it is not easy to see how to disassemble them from the inside out?

Possible Replacement Devices

Reflective photocathode



Square Photocathode?

Quantum efficiency?

More robust against radiation damage
but transparent photocathode is still in play

UVa Plans
For the Future

We plan to examine several different new photodetector options in short and long term tests similar to the VPT tests that are now in progress. We will also including radiation tests to measure rad damage properties as well as vulnerability to high currents. Photocathode material and reflective vs. transparent photocathode??

Possible candidates

Hamamatsu R6356
- multi-alkali SbK2Cs photocathode used in reflective mode
- BNL studies for SbK2Cs photocathode: QE 2-6% depending on substrate;
- good from low UV through visible; peak wavelength = 400nm
- window is UV glass
- geometry would need to be redefined for actual CMS use

Hamamatsu R6352
- bi-alkali SbCs reflective photocathode
- similar wavelength sensitivity as above..
- no info at hand on QE for bi-alkali photocathodes

Hamamatsu R6351
- similar to R6352 but with a fused silica window