Testing a Twisted Nematic Liquid Crystal Optical Readout for use in a low pressure Dark Matter Time Projection Chambers (DMTPC)

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Abstract

This paper describes a method for producing a liquid crystal optical readout for a Dark Matter TPC. The liquid crystal cell is produced by replacing one of the homogenous conductors of a p type twisted nematic liquid crystal cell with a membrane filter with conductor filled holes. The 5 micron holes of the polycarbonate membrane filter were filled by a process of electroless plating followed by electroplating. Once the modified liquid crystal cell was built the optical behavior was tested in several manners. The locality of the color changes were established in the new LC cell sample by touching the conductive pads and applying a small AC voltage. Additionally, color change discharges were observed as a result of corona discharges in air from a high voltage wire. Finally, the paper describes a method for further testing the liquid crystal cell in a gas chamber which simulates the amplification region of a DMTPC.

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Cottage hospital ICU without whom, I would not have been able to complete my role in this experiment.
Introduction

Astrophysical evidence for dark matter

Figure 1: Here is a plot of the rotation curves of NGC 3198. As one can see the velocity rotation curve flattens at 150km/s at larger radii. To compensate for the $1/\sqrt{r}$ fall it velocities it has been implied that a dark matter halo must exist to exist for the apparent disparity in velocities. Image courtesy of [http://ag-physics.org/gravity/pic_gravity/img305.png](http://ag-physics.org/gravity/pic_gravity/img305.png)

The dark matter problem is fundamentally underpinned by the discrepant behavior that galactic objects have exhibited at large galactic radii which, seemingly contradict the laws of gravitation. Zwicky’s observation and application of the virial theorem to the Coma cluster in 1935 implied that not all mass of the Coma cluster was accounted for [5]. Zwicky’s conclusion was also later corroborated by Rubin et al when they observed the rotation curves of objects far away from the galactic centers in 21 galaxies [11]. The general conclusion from their study and other subsequent surveys was that contrary to the expectation of classical Newtonian dynamics. The rotational velocity $v(r)$ was not given by $v(r) = \sqrt{G \cdot M(r)/r}$ where $M(r)$ is the galactic mass distribution
and $r$ is the distance to the galactic center. Instead it was noted that the velocity rotation curves plateaued implying that the mass $M(r) \propto r$. More recent observations of astrophysical objects such as IE0657-56 have implied additional information regarding the nature of dark matter. The gravitational lensing of object IE0657-56 gave an interesting example for how dark matter may interact (if only weakly) with itself implying an agreement with CDM theories about the nature of dark matter.

Main Explanations

The major explanations for the problem are that Newtonian gravity must be modified or that there is excess mass due to unseen matter. So, why cannot we just have a modified definition of gravity? Based on data from SDSS (Solan Digital Sky Survey) the density distribution of the peripheral parts of the galaxy imply that the distribution varies with the galactic radius by $\rho_{DM}(r) \propto r^{-3}$ [10]. This contradicts the major proposition of the modified Newtonian gravity because most theoretical models for modified gravity require that this density relation to not hold true.

So, how about the suggestion of unseen matter? With regards to unseen matter, the issue can be separated into two subfields for which matter is baryonic and non-baryonic. The baryonic solution generally assumes that the dark halo is made up of MAssive Compact Halo ObjectS (MACHOS). Gravitational microlensing experiments have largely discounted the MACHO suggestion because according to microlensing sky searches less than 8% of the "dark" matter was solely due to massive baryonic objects
Neutrinos are hot non baryonic candidates which until recently were seen as an excellent dark matter candidate. However the mass eigenvalues of neutrino mass give $m_\nu \leq 2.05eV$. This implies that neutrino’s have a relic density of $\Omega_\nu h^2 = 0.07$ which make neutrinos not adequate to account for all of the missing mass [3].

Therefore the remaining candidates should ideally be cold and non luminous. This leaves a zoo of particles which includes the axion and most of the SUSY particles such as the gluino, neutralino, wino etc. Current theories imply that the neutralino may be a preferred candidate because its weakly interacting behavior would give the correct density fractions for dark matter. For a detailed discussion of CDM candidates see Particle Dark Matter: Evidence, Candidates and Constraints by Bertone et al which gives a detailed description of the theory candidates. [3].

**Detection of WIMPs**

The detector which this particular optical readout is designed for is a Dark Matter Time Projection Chamber (DMTPC). How does a DMTPC detect a Weakly Interacting Massive Particle (WIMP)? This is done by having a scintillation gas immersed in a high potential gradient. The high voltage potential ionizes the scintillation gas so therefore a high energy interacting particle (such as a photon or WIMP) can scatter elastically and create a positive ion and a free electron. The high electric field then separates these high energy particles preventing recombination. The energetic elections now collide with further ions and creates a avalanche of electrons.
These cascade of electrons are directed towards the ground plate by an array of wire meshes at which they can be detected. In addition to the production of electrons, high energy photons are produced via each scattering interaction. The ratio of detectable photons to electrons is 1:3 [1]. This enables for the positional imaging of interactions via detection of the liberated photons and/or electrons. A major advantage of a TPC is that a large number of scintillating gases can be chosen. For example $CF_4$ produces a spin dependent interaction due to the unpaired proton (and it has large gas gains of order $10^5$) which is advantageous because it would enable the WIMP spin to be easily determined.

Previous experimental setups such as those used by Ahlen et al imaged the cascade induced by a scattering neutron $CF_4$ scintillator collision[1]. They imaged the particle track by setting up a copper clad anode separated by the ground grid using a resistive spacer. The scintillation light in this region is imaged using a charge multiplier and viewed by a CCD camera which is outside the detector. The method described by this paper utilizes the amplified electrons since they are produced with more abundance than the scintillation light. This would involve a conductive mesh held at a high voltage separated by a ground plate with a thin fishing wire. This would enable for pulse discharges between the conductive mesh and the ground plate. The pulse discharges would be imaged by a liquid crystal optical readout with a large number of conductive sites at which the electron cascade could deposit. Once the liquid crystal undergoes phase color changes the tracks can then be analyzed by an external optics system.
Figure 2: Here is the gas gain and amplification region of a previously made gas TPC by Ahlen et al. The WIMP particle (or test particle) creates free ions in the gas gain region which then drift toward the ground plate and then the gas amplification region. Image courtesy Ahlen et al. [1]

The liquid crystal optical readout would be able to provide a number of details about singular tracks. The intensity of the color change would enable the energy of the nuclear recoil to be calculated with relative ease. Moreover, the length of the recoil track and the energy gradient $dE/dx$ would enable for easy discrimination of background tracks such as those produced by $\alpha$ particles. The astrometric information about WIMP directions can also depicted relatively easily since WIMP winds are expected to change with respect to the time and position of the detector. This way the WIMP backgrounds also easily be discriminated. Additionally since the DMTPC will be run at high pressures typically between 50 to 500 torr the track sizes to possibly extend to orders of 1mm; tracks which can easily be imaged by the liquid crystal...
Liquid Crystal Theory

Figure 3: Here is a typical setup of a liquid crystal cell. LEFT Here with no external electric field the molecules retain their natural helical twist relative leaving the molecules to remain parallel to the rubbing direction. Applying an electric field results in the molecules twisting and aligning themselves in the direction of that electric field. Image courtesy of Cristaldi et al. [4]

Liquid crystals by their nature are anisotropic materials which correspondingly lead to them to have their physical properties described by tensors. Additionally, liquid crystals such as 4-Cyano-4′-pentylbiphenyl(5CB) and 4-Cyano-4′-hexylbiphenyl(6CB) have a strong permanent dipoles [9] [6] (5CB and 6CB will be used in this experiment). This is due to the positioning of various functional groups which result in the molecular electron density to be distributed towards one end of the molecule which induces a permanent dipole type structure. Since this experiment aims to manipulate the electrical behavior of liquid crystals the applied electric field can be generalized in
terms of the perpendicular and parallel components. Therefore the displacement field can be represented by (indicating that the external field E is applied parallel to the \( \hat{z} \) direction and the normal vector \( n \parallel z \)).

\[
D = \varepsilon_x E_x \hat{x} + \varepsilon_y E_y \hat{y} + \varepsilon_z E_z \hat{z} = \\
\varepsilon_\perp (E_x \hat{x} + E_y \hat{y}) + \varepsilon_\parallel E_z \hat{n} (\varepsilon_\perp E_z \hat{n} - \varepsilon_\parallel E_z \hat{n}) = \varepsilon_\perp (E_x \hat{x} + E_y \hat{y}) + (\varepsilon_\parallel - \varepsilon_\perp) E_z \hat{n}.
\]

The quantity \( \varepsilon_\parallel - \varepsilon_\perp \) is of interest because it dictates the alignment direction (parallel or perpendicular) of the liquid crystal molecules when an external electric field is applied. If \( \varepsilon_\parallel - \varepsilon_\perp < 0 \) the liquid crystal is characterized as a n type and if \( \varepsilon_\parallel - \varepsilon_\perp > 0 \) it is characterized a p type[4]. For this particular experiment a p type liquid crystal is used because one wishes for the liquid crystal molecules to align with the externally applied field rather than remain perpendicular to it. The critical value of the electric field required to induce a color change is given by \( E_{\text{threshold}} = (\pi/d) \sqrt{k_{ii}/|\Delta\varepsilon \cdot \varepsilon_0|} \) where \( k_{ii} \) is the elastic constant tensor, \( d \) is the plate separation distance and \( \Delta\varepsilon = \varepsilon_\parallel - \varepsilon_\perp \).

Since in this model the liquid crystal is placed inside a parallel plate capacitor the corresponding potential \( V_{\text{threshold}} = E_{\text{threshold}} \cdot d \approx \pi \sqrt{k_{ii}/|\Delta\varepsilon \cdot \varepsilon_0|} \) [4].

The optical readout is based on a model of a translucent capacitor with a optically responsive liquid crystal dielectric. Once the electrons have cascaded through the amplification region they would deposit on a conductive site and then induce a small voltage difference to which the liquid crystal can optically respond (See Figure 3).

Liquid crystals have a number of optically responsive behaviors depending on the temperature as well as the magnitude and direction of external electric, magnetic and contact forces. There are a number of intermediary transitional phases before a liquid
crystal becomes purely isotropic. For this particular application a nematic liquid crystal will be used because the liquid crystal molecules are able to have sufficient degrees of freedom to maintain a helical shape. The helical shape is necessary because it enables for the polarization of an external light source can be phase delayed of 90° hence creating a birefringent effect.

The optical behavior of twisted nematic liquid crystals results from the birefringence of light passing through the liquid crystal. Birefringence also occurs in liquid crystals when induced by an external force such as a contact or electric force. In order to induce a uniform birefringent color change as a result of an externally applied electric field, the liquid crystal is sandwiched between two unidirectionally rubbed layers to induce a permanent molecular helix. Applying an electric field results in the the liquid crystal molecules breaking from their helical layer ranks and aligning with the external electric field (due to their dipole like structure of the p type molecules). Therefore, when viewing the liquid crystal cell through crossed polarizers incoming light should be transmitted because the polarization vector is delayed by 90°. When the helical layer ranks are broken, external light is not transmitted so there is no phase shift inside the liquid crystal cell.

There are other optically responsive nematic optical behavior exhibited by n type liquid crystals. For example n type liquid crystals such as N-(4-Methoxybenzylidene)-4-butylaniline (MBBA) react optically to large electric
fields. If an electric field exceeds a certain bifurcation point, the n-type molecules oscillate about their dipole moment due to an induced torque and therefore scatter light at oblique angles. While this may hypothetically be useful in liquid crystal optical readouts, it has two distinct disadvantages to the p-type twisted nematic. N-type typically require a higher response voltage than p-types and more fundamentally, their optical responses are induced by nonlinear effects, thereby resulting in their optical behavior to not have a smooth transition. It is due to this that n-type liquid crystals cannot be very effective at producing a uniform $dE/dx$ particle track, thereby making TN liquid crystals ideal for use in this particular experiment.

**Experimental**

**Overview**

Making the liquid crystal cell involved several major stages. The first stage was to have produced a working twisted nematic liquid crystal cell which exhibits distinct a on/off...
phase. The second stage was to produce a layer which the electrons amplified by the TPC could be deposited on. Thus what was produced in the second stage is in essence the high resolution pixel readout. The third stage was to test the high voltage optical readout by observing if the readout can detect the deposition of electrons from a high voltage corona discharges in air. The final stage of the experiment was to build a pseudo TPC and test if the optical readout responds to pulse discharges simulating the actual TPC signals.

A single pixel liquid crystal cell

![Figure 5: These are images of a (5mm)$^2$ liquid crystal cell containing 6CB. LEFT: this displays the liquid crystal displaying the dark color phase RIGHT light color phase. Taken under a microscope with a 10/4 objective lens.](image)

To produce a single twisted nematic liquid crystal cell, we used standard p type nematic liquid crystals 5CB and 6CB which were acquired from Sigma Aldrich. 5CB was dropped in a $1cm^2$ 20 micron thick mylar separator and sandwiched between two unidirectionally rubbed Indium Tin Oxide (ITO) coated Polyethylene terephthalate(PET) (again acquired from Sigma Aldrich). Two polarizers are then placed on both sides of the cell sandwich (the polarizers should be perpendicularly
aligned). A 5V 1Hz signal gave a distinct light/dark color fluctuation as depicted by Figure 5. Due to birefringent effects of ITO and PET a quarter wave plate was used to correct for this phase shift.

**Creation of membrane filter**

To create a high resolution detector the next stage was to replace one of the ITO layers with a insulator containing a large number of conducting sites. This was made by filling the holes of a membrane filter (which is typically used in microfiltration) with a conductor (membrane filter acquired from 2spi). The membrane filter contained a large number of small holes which had an average diameter of 5 microns and the filter had a thickness of 10 microns. The holes were filled by firstly using weak electroless plating to make the entire membrane filter surface conductive.

The filter was initially treated with a diluted mixture of 100ml DI water and a single drop of chromic acid/33% assay hydrochloric acid mixture and then dipped in clean DI water. This created a number of nanoscopic holes in the plastic membrane filter which should render the film hydrophilic. The second stage of electroless plating was to deposit catalysts on to the hydrophilic surface of the membrane filter. The filter was then dipped in a dilute solution of Tin(II)Chloride/HCl and then a Palladium (II) Chloride solution. This caused a palladium catalyst to be deposited onto the membrane filter via the reduction of palladium according to the half reaction

\[ Sn^{2+}(aq) + Pd^{2+}(aq) \rightarrow Pd(s) + Sn^{4+}(aq). \]

The electroless process can now be
completed by immersing the membrane filter into a mixture of hydrated sodium hypophosphite \((NaPO_2H_2 \cdot H_2O)\), aluminum hydroxide \((Al(OH)_3)\) and hydrated nickel sulfate \((NiSO_4 \cdot 6H_2O)\). Stewing the membrane filter in this produced a faint coat of nickel on the surface. The advantage of this technique was that the inside of the holes were coated with a conductor.\[12\] \[7\] \[2\]

![Figure 6: Here is a membrane filter image of the rubbed layer. The black regions are the Cu/Ni conductor filling the membrane filter holes. Taken under a microscope with a 10/4 objective lens](image)

To complete the top conductive plate the holes of the now rendered conductive membrane were filled via electroplating. The electroplating was completed by using a \(HCl/H_2SO_4/CuSO_4\) electrolyte with a copper anode and the conductive nickel plated membrane filter as a cathode. Copper was deposited by applying a 3V DC signal through the electrolytic cell for an hour. The electrolyte was sufficiently acidic to act as an etchant so a kimwipe tissue removes the excess copper leaving the pore holes filled. The dried and completed membrane filter is pictured in Figure 6.
Setup of LC cell

The liquid crystal cell was completed in a setup reminiscent of the single pixel cell. One side of the conductor sandwich was again a unidirectionally rubbed piece of ITO with a 20 micron mylar enclosure cut as demonstrated in Figure 7. To minimize any anomalous color changes due to the birefringence created due to the attraction of the flexible conductor filled membrane filter and the ITO layer, 22 micron ultra spherical soda glass beads were used as spacers in the liquid crystal enclosure cut in the mylar. The membrane filter is unidirectionally rubbed and glued to complete the liquid crystal sandwich. To complete the process the liquid crystal was injected into a capillary (cut into the mylar) in the cell to prevent liquid crystal leakage. A completed cell without the polarizers is depicted in figure 7.

Figure 7: Image of liquid crystal cell on a microscope slide.
Testing Experiments

As a LC cell

To test whether each pixel is optically responsive a 50 micron wire was moved to carefully touch a number of conductive pads on the membrane filter cover LC cell. The optical color change was then recorded. The charge deposited on the one of the conductive pads on the membrane filter determined the rate and magnitude of the color change. The charge deposited on the conductive pad was given by the standard solution to the resistor capacitor differential equation $Q(t) = Q_0 e^{-t/RC}$ where $Q$ is the charge, $R$ is the circuit resistance and $C$ is the capacitance of the liquid crystal (Naturally this is a component of the liquid crystal tensor capacitance). Therefore, it is necessary to measure the characteristic relaxation time and the total charge decay time to give a good indicator of how quickly the liquid crystal cell should respond to the deposition of electrical charge. This was done by applying a $100Hz$ 50% duty cycle square signal varied between 0V to 14V and measuring the response time and relaxation time of the cell. In addition to the RC response time, the time which each liquid crystal pixel stays ”on” after the initial charge is deposited. The general behavior of this was given by integrating the standard solution to the resistor-capacitance differential equation $\int_{Q_{threshold}}^{Q_0} dQ/Q = RC \cdot \int_{0}^{T_{Q(0)}}$ which gives a general solution as $T_{Q(0)} = RC \cdot log(Q_0/Q_{threshold})$ where $Q$ is the respective capacitance, $R$ is the circuit resistance and $T$ gives the maximal charge time [?]. Therefore, the on lifetime was measured by applying a $200mHz$ 50% duty cycle square signal.
**High Voltage probe test**

This part of the experiment was aimed at observing whether the liquid crystal cell responded optically to a discharge from a high voltage wire. The setup involved a 50 micron wire held approximately two millimeters away from the liquid crystal cell. The high voltage wire was run of order of 1kV which created a sufficiently high potential so as to ionize the air molecules surrounding the wire, simulating the amplification region and thereby enabling for a corona discharge onto the conductive pads of the membrane filter of the liquid crystal cell. The voltage was incrementally increased until a there was a major visible change in current which is significantly larger than the background, implying a corona discharge. This enabled for the discrimination between any color changes induced by electrons from the corona discharge and from the fringing field of the wire. While this doesn’t produce a iron clad discrimination between color changes between these two countering effects however due to Peeks Law the electron discharge voltage varies as $\epsilon V \propto \log_e(r)$ where $r$ is a separation of the two conductors, implying that there should be a large corona voltage jump at the correct threshold voltage. So, by incrementally increasing the input voltage; careful observation of sudden color changes over small voltage changes enabled adequate discrimination between color changes due to the fringing field and the corona current discharge. [?]
Spark test in argon

The final part of the experiment was to produce a spark test in argon/$CH_4$ gas, which would simulate the charge amplification region of the TPC. There were several stages to this particular setup, firstly to design the gas chamber which holds the liquid crystal cell slide, secondly the electrical setup which inputs a offset pulse and finally the imaging component to detect whether a pulse discharge had occurred. The chamber body was made from a conductive aluminum body which has two see through lids as depicted by figure 8. The transparent lids have a layer of ITO on each side to create a faraday cage which would decrease any output noise. There are three openings into the chamber, a gas inlet and outlet and a electrical BNC input. The liquid crystal cell slide is suspended inside the chamber and is arranged in a particular manner. The uniform
ITO conductor inside the liquid crystal is connected to the grounded chamber body and the membrane filter side is separated from uniform ITO sheet by a fishing wire. The purpose of the upper ITO layer is to simulate the wire mesh amplification gap inside the DMTPC. This system is suspended inside the chamber so that an external camera or photodiode viewer can regulate color changes. Argon/$CH_4$ gas is pumped in and the chamber is kept 1atm.

The discharge pulses are regulated by a square wave AC output riding high voltage DC offset. A signal generator outputs a pulse to a ORTEC preamplifier/amplifier and then to the chamber. The pulse discharges are plotted on an external oscilloscope and then used as a reference for observation of color change events. The final part of the argon spark test experiment is to produce a sensitive photodiode system to view for optical events. The photodiode itself is housed in a modified eyepiece made to hinder any background readings due to external light.

**Observations**

**LC cell**

The LC membrane cell behavior and the color response was tested with a 1Hz 3V offset square wave input. Figure 9 depicts a screenshot of a on off event and a zoomed in image of the wire tip. What this demonstrates is the localization of color changes among the membrane layer. The localized effect demonstrated that the membrane
pads can indeed act as individual pixels and therefore act as electron deposition sites inside the TPC. There were a number of possible contributions which may have created a false positive color change in this scenario. The first is that color changes could have been induced by the wire being incrementally pulled toward the ground plate. This incremental pull could have imparted a momentum on the liquid crystal which could have induced a color change. This effect was minimized in several ways, firstly the test probe was held down in a controlled manner so as to prevent it being pulled toward the ground plate. Additionally, this effect would have been clearly visible to the viewer because the color changes due to these external effects would have occurred outside the focus of the microscope.

Now that the color changes had been viewed to be localized, it was then necessary to test the relaxation and fall times of the cell. Figure 10 depicts the relative relaxation time of a (9mm)$^2$ and (3mm)$^2$ cell. The figures were plotted on Mathematica software and fitted with a $a + bx + cx^2 + dx^3$ curve. As expected there was a increase in the RC times above 2V for both cell areas because this is the typical threshold switching voltage for a liquid crystal. The (9mm)$^2$ cell approaches a local maximum RC time around 12V in contrast with the (3mm)$^2$ whose inflection point occurs at approximately 14V. The (3mm)$^2$ cell has a greater RC response variation than its 9mm)$^2$ counterpart implying that the (3mm)$^2$ cell has greater sensitivity because its corresponding cutoff frequency would be lower. The errors were calculated by using the standard multiplication law for error propagation since the measured time constant is
by definition a product of the circuit resistance and capacitance. Therefore, the circuit capacitance, error in component capacitance, error in circuit resistor were all potential sources of error in the final measurement and were thereby calculated according to

$$\delta \tau = |\tau_{measured}| \sqrt{\frac{\delta x_i}{x_i}}$$

where $x_i$ were the individual components which contributed to the error.

Figure 11 gives the peak voltage to 0V fall time for the two tested cells. The fall time behavior is relatively constant over all voltages for both cells but there is a relative offset between the two graphs. The constant behavior implies that that the total fall time is independent of the input voltage over the regions which the liquid crystal is active and therefore must have been offset as a result of the only other independent variable, the area of the LC cells.

Finally the liquid crystal color change response time is plotted. This gives the time which it took for the liquid crystal color change to fully change from one color to another. Both (3mm)$^2$ and (9mm)$^2$ cells seem to display almost identical behavior in this case where for voltages below 8V the two curves overlap within a standard deviation. Above 8V the two fit curves begin to deviate slightly but still fall within 2$\sigma$ within each other. The reason for this behavior is that the color phase change is an intrinsic property of the liquid crystal and therefore at low voltage ranges not disturbed by the changing active areas of the liquid crystal cell.
**High voltage probe test**

A single discharge was determined when the input voltage was increased until there was a noticeable current discharge which was greater than background. The voltage was slowly turned up in increments of 10V between 1kV and 1.3kV. The turning voltage of the optical change was observed via a Canon EOS 25mm camera and focusing lens system in addition to a microscope with a 10/4 objective lens. The individual color changes are displayed by Figure 13. The active LC cell area was 5mm$^2$. The color threshold voltage was between 1.2kV and 1.3kV. For voltages above 1.3kV breakdown was noted in which the liquid crystal cell began disintegrating as a result of the high current generation. It was noted that there were no major observable color change offset due to the increasing background fringing field implying that the color changes were due to a electron transfer from the high voltage wire to the membrane layer.

**Spark test in argon**

At the time of submission this part of the experiment is pending to be completed. The experiment has been test run and no visible color changes were observable with the naked eye. To complete the experiment itself a microscope with a photodiode eyepiece has to be made sensitive enough to detect small enough color changes within the liquid crystal. The faraday cage setup has resulted in relatively little noise when observing the pulse discharges. The pulse discharges had a width of approximately a few µs which is definitely detectable by the liquid crystal.
Conclusions

During the course of this experiment a number of interesting observations have been made. The first effect is the optical behavior of a standard twisted nematic liquid crystal in a sandwich with transparent conducting plates. Additionally by the development of filling the holes of a polycarbonate membrane filter, the progression of a liquid crystal cell for use in the amplification region of a DMTPC has been initiated. The locality of the color changes were established in the new LC cell sample by touching the conductive pads and applying a small AC voltage. Finally color change discharges were observed as a result of a corona discharge from a high voltage wire. This implies that the liquid crystal cell responds optically to corona discharges brought on by high voltage ionization of air near the conductive sites of the membrane layer.

Now that these behaviors have been established the experiment will be continued with the testing of the LC cell in a region simulating the amplification region of the DMTPC. The liquid crystal cell amplification section could be tested in a low pressure dark matter TPC to see if the signatures of test α particles could be imaged. To do this an optics system would have to be implemented that is capable of detecting the color changes over large regions of the LC cell 1cm². This would mark the beginning of the progression towards building a high resolution liquid crystal optical readout for DMTPC’s.
Figure 9: TOP LEFT: Image of 50 micron probe in contact with the top membrane filter with pixel color on. Note the most intense pixel color change is at the very bottom of the probe receptor. BOTTOM LEFT: Zoomed image of bottom of probe. TOP RIGHT: Color response when voltage is off. BOTTOM RIGHT: Zoomed image of bottom of probe with input voltage turned off. Taken under a microscope with a 10/4 objective lens.
Figure 10: RC time in $\mu$s VS Input peak voltage. Fitted with third order polynomial to mimic liquid crystal on/off phase. Red line is data for (3mm)$^2$ and blue line is data for (9mm)$^2$.

Figure 11: Peak voltage to 0V fall time. Red line is data for (3mm)$^2$ and blue line is data for (9mm)$^2$. 
Figure 12: Plot of color change phase time VS $V_{\text{peak}>0}$ pulse drop. Red line is data for $(3\text{mm})^2$ and blue line is data for $(9\text{mm})^2$.

Figure 13: TOP: Pixel color change at 1.2kV. Cell area $(3\text{mm})^2$. Images taken with a Canon 25mm lens and a focusing lens. BOTTOM: Color phase change taken under similar conditions under a microscope with a 10/4 objective lens.
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