**Team Avalanche Final Report**

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The goal of Team Avalanche this summer was to better understand Townsend Avalanches and proportional gain in various liquefied noble gases. One part of this was to get the Nevis Laboratories/eBubble LAr cryostat functioning and begin to test various detector components within the cryostat. The primary component that was to be tested was the pin detector which uses the process of Townsend Avalanching to amplify the signal of charge deposited in a detecting region. Various geometries, pins, and setups were placed in the cyrostat to be tested. As well as actually testing the pin structure Team Avalanche also strived to try to understand avalanching more thoroughly. The theory of Townsend Avalanching was researched as well a simple model used to predict if and when avalanching/proportional gain would occur in the eBubble pin structure.

**Detection and Ionization**

The principle behind an electron bubble drift chamber is that an incoming particle will enter the detecting mass and within a certain probability undergo an inelastic collision with an electron in an atom giving it enough energy to free it. With neutrinos this collision rate is determined through analysis of the cross-section due to the weak interaction between the electron and neutrino. After the electron is released with a certain kinetic energy it creates a trail of ionization along its path. With each ionization the electron loses energy, and continues ionizing until its kinetic energy is lower than the energy required to free an electron. If this path of free electrons is placed in a linear, constant electric field, as in a parallel plate capacitor, one can drift the electrons towards a detection plane, keeping the structure of the path intact. On the detection plane the electrons that make up the path can be detected.

In order to read out these electrons as a signal, and because the number of electrons deposited for a low energy rare event is not great, one must amplify the signal by some technique within the detecting medium. The technique most commonly used exploits the phenomena of the Townsend Avalanche. The Townsend Avalanche works by accelerating the electrons in a high electric field so that they gain enough kinetic energy to begin ionizing the atoms of the medium that they hit. In this ionization another electron is created which can then also accelerate and subsequently cause another ionization. This process can continue until the electric field ceases to be sufficiently high or the whole medium is ionized. Since the complete ionization of the detection medium would want to be avoided, it would destroy any information in the original electrons beyond there existence, the electric field must be controlled. This is achieved by using different geometries of electrode structures so that the field is not constant. Traditionally wires are

used so that the field changes with distance away from the wire. In an LHe eBubble detector we propose to use a pin structure so that the field approaches the geometry of a point where the field would vary with the square of the distance from the point.

The limits on how fast you can get the electrons to go, and hence the rate of ionization, is determined by the strength of the electric field and the distance an electron can travel before hitting an atom. This distance can be understood as the mean free path or the average distance between two atoms within the detecting substance. The mean free path itself is dictated by the properties of the detecting medium. The voltages used and the geometry of the anode structure determine the strength of the field. The rate of ionization can be expressed as the First Townsend Coefficient which is the expression for the ionizations per distance traveled. The Townsend Coefficient is therefore an expression of both the mean free path and the geometry of the avalanche detector.

**Pin Structure**

As stated, it has been determined that the a proportional pin detector would be necessary in a future LHe detector as to opposed to the traditional well understood proportional wire chamber. This choice is a consequence of the liquid noble gases that we would hope to use in the final detector. Unfortunately, as proposed, a proportional pin structure that works in cryogenic liquids has not yet been developed. One development that hints at the possibility of the possible success of this structure is the development of the micro-fabricated MIPA detector at Brookhaven that uses a similar geometry to achieve proportional gain in gases. Likewise last summer Phil Harris tested similar geometries in non-quenched noble gases and was able to effectively achieve stable gain. Therefore it was upon the eBubble group to test the possibility of seeing proportional gain on a pin in a liquid. To this end both a LAr and a LHe cryostat were commissioned to test the pin structure.

In order to test the possibility of avalanche on a pin it was also necessary to build a testing structure that would test the pins that could easily be used in a cryostat. A pin structure was designed which had four parts: a source/anode, a pin/cathode, an anode guard ring and a cathode guard ring. The source was plated with a radioactive substance that emits alpha particles, which ionizes creating the electrons that will be detected by the pin. The source that finally went into our LAr cryostat was a sewing needle that was plated on the eye with Americium. It was hoped that the radioactive plating would be place on the needle tip so as to avoid problems with recombination of electrons and ions in the ionization of the alpha particles, but this was not possible due to the restrictions placed on radioactive substances. At first it was proposed to use a small radius wire (~5 μm) that would jut out beyond a capillary to replicate the pin structure. Instead probing electrode pins were purchased that were machined to have a tips on the order of microns. The pins would be a better choice, as they would not undergo effects of bending or breaking.

Placing the necessary voltage on the anode and cathode creates the electric field needed for avalanche. Guard rings are put in so as to shape the field and direct the incoming particles towards the pin tip where the electric field is large enough to induce avalanching. Voltage is also placed on these guard rings as is appropriate. To determine the ideal geometrical and voltage configuration within the testing structure simulations were done in a program known as Simion. Simion was also able to produce a measurement for the electric field within a couple microns of the pin tip, which is where we expected to see avalanching.

**Model for Mean Free Path**

In order to get a better handle on the avalanching that we would expect in the pin structure we attempted to calculate the Townsend Coefficient in liquid argon near the tip of the pin. The first step was to calculate the mean free path ($\lambda$) in LAr.

$$\sigma\lambda = \Omega/N = A/(N_A\rho)\ , \qquad (1)$$

We used equation (1) to do calculate the mean free path ($\lambda$) by inputting the cross-sectional area of the Argon atom ($\sigma$), a standard volume element ($\Omega$), the atomic weight (A) of argon, Avagadro's Number $N_A$, and the density of LAr ($\rho$). We then calculated the velocity achieved by an electron accelerated from rest traveling the mean free path in the electric field near the pin tip. That velocity was then used to calculate the kinetic energy of the electron that was compared to the ionization energy needed to free an electron from argon. To our surprise from this rudimentary calculation we found that there was not sufficient field in order to achieve avalanching.

The holes in our calculation came from some of the assumptions that we made. We assumed that the electrons would be starting from zero velocity after one collision and would therefore need to achieve the necessary kinetic energy in one mean free path. This is not necessarily the case. Electrons do not always deposit all of their kinetic energy in a collision; it is possible that they deflect off of an atom with minimal effect on their velocity. This possibility would have to be dealt with in order to get a better grasp on the first Townsend Coefficient in our pin structure. To do this it would be necessary to simulate the avalanche rigorously. A simulation of that complexity was beyond the scope of the Team Avalanche and eBubble collaboration for this summer.

Hence it was proposed that we calculate the First Townsend Coefficient by scaling from the well-known Townsend Coefficient in gaseous argon. This involves taking the known Townsend Coefficient in gas and using the ratio of their densities to calculate the change to liquid. Unfortunately after cursory calculations showed that we would have enough field to generate Townsend Avalanches in our pin structure research discovered that this method has been shown to be unsuccessful when used to calculate

the Townsend Coefficient for liquid Xenon in a proportional wire chamber. Therefore this calculation was not pursued further.

**Testing, Results and Preliminary Analysis**

To expedite the testing of our pins, and as a first step before testing the final pin structure (with guard rings), a preliminary pin structure was constructed which contained a pin and anode separated by 1 mm but did not have the guard rings. The pins that we finally purchased had tip radii ranging from .7 micron to 3.5 micron. As soon as all the components were gathered, the preliminary pin structure constructed and the LAr cryostat brought online testing began. The first tests were done using the pins of .7 microns. The pin structure that was submerged in LAr was connected to a high voltage source and the cathode was fed out through a preamp to be read on the oscilloscope. The electronics and oscilloscope were calibrated and tested using a test pulse sent sent through the preamp, which simulated a signal seen in the pin structure.

The pin structure was then submerged in LAr and signals were recorded on the oscilloscope using the Vmax and histogram functions of the scope. The Vmax function records the max peak voltage for any signal as well as calculating the mean of the voltage peaks in a given time. The histogram function generated a histogram of points generated by a signal within a arbitrary range. The histogram function unfortunately could not generate a histogram of voltage peaks, which was information that could only be generated by programming the scope. Unfortunately we did not have enough time this summer to commit to learning how to program the oscilloscope.

The pin structure with the .7 radius micron pin was tested over a range of voltages. The pin was then replaced with a 3.5 radius micron pin and likewise tested over a range of voltages. Preliminary visual analysis of the scope would say that we did end up seeing avalanching on our preliminary pin structure. The histograms generated by the scope did not create a nice proportional peak correlating to the alpha particle energy at any voltage with either pin. This would reflect the fact that the vast majority of electrons were not landing on the tip of the pin where the fields were strong enough to create avalanches but where landing on the shank. Likewise the mean generated by the Vmax function would reach 1.7 mV at reasonable voltage but would then not change at higher voltages. This mean would reflect the total collection without gain of the charge saved from recombination deposited by the alpha particle. These problems will be avoided in the final pin structure because the guard rings will focus the electrons on to the tip of the pin where avalanche is more likely. Despite this downfall of our geometry we did see significantly higher pulses at a higher rate when the voltage was run up. At 2 kV on the anode with the .7

micron pin we saw several pulses that peaked well above 8 mV, which would reflect a proportional gain of a factor three.

**Future**

Assuming that we had learned as much as we could from our preliminary pin structure we moved on to submerging and testing the final pin structure. Unfortunately the fabrication of the final pin structure was not completed until the final week of the summer and no data was able to be retrieved.

Before moving on to the liquid helium cryostat, which will be completed in the fall, the eBubble group must rigorously test our pin structure in the LAr cryostat that is already functioning. Hopefully our hints of avalanches with the preliminary pin structure will reveal more convincing evidence of avalanches in the final pin structure. This information will be then be helpful in later testing in the liquid helium cryostat and the possible development of a large scale liquid helium detector.